WORLD DATA CENTER A
for
Solid Earth Geophysics

Global Change Data Base

Pilot (Diskette) Project for Africa

Data Base Documentation
Version 1.1

World Data Center A for Solid Earth Geophysics Publication SE-47
June 1992

NATIONAL GEOPHYSICAL DATA CENTER

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JUNE 1992

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL ENVIRONMENTAL SATELLITE, DATA, AND INFORMATION SERVICE
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The user must be cautious when using these data and computer programs. Because this is an experimental database constructed from existing sources, errors and omissions can be expected. The user is referred to peer evaluations of this product and subsequent revisions for determination of suitability for any given purpose.

PREFACE

Version 0.2 of this documentation and associated data base was distributed to beta-test facilities for evaluation and further development in July 1990. Version 1.0 of the documentation was a special edition for limited use associated with the United Nations Environment Program and United Nations Institute of Training and Research, and the International Geosphere-Biosphere Programme's workshop held in Dakar, Senegal, in 1990. This Version 1.1 is a slight revision of Version 1.0, and intended for a general audience.

We anticipate that most users of this documentation will be educators, or people learning about the global environment with the data and the Training Exercise Manual distributed by NGDC. If you do not know about the data or the Training Exercise Manual, please contact NGDC for more information.

It is likely that the documentation for the full Global Change Data Base will be updated more frequently than this set of documentation for Africa. If you wish to keep current with the development of global environmental (or global change) data, please contact NGDC to be placed on the mailing list for the full Global Change Data Base series.

Any comments, suggestions, or possible contributions of data are welcome. Please contact:

Global Change Database Program
World Data Center-A for Solid Earth Geophysics
NOAA National Geophysical Data Center, Code E/GC1
325 Broadway
Boulder, Colorado 80303

Telephone: 303-497-6125
Fax: 303-497-6513
Telex: 592811 NOAA MASC BDR
Internet: info@mail.ngdc.noaa.gov

This documentation contains separate chapters of material edited about separate data sets of the overall Global Change Data Base, Pilot (Diskette) Project for Africa. Descriptions of data formats, authors, and contributors are accompanied by documentation of the development/use of the data. These materials have been suggested and contributed directly by the authors of the individual data sets. To avoid confusion, some information contained in this documentation that is not directly relevant to this data base has been either omitted, crossed out, or blanked out.

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Innumerable people have contributed to the development of this documentation. In addition to the authors and contributors of data, we would like to especially note the efforts of John Kineman, Jeff Colby, Mark Ohrenschall, David Schoolcraft, David Hastings, Susan Boyle, Andra Mealey, Silvanna Della Mana, and David Mellon.

Note on the Quality of Reproduction of This Volume

This volume is a collection of overview materials prepared at NGDC, and copies of documents produced by many publishers, laboratories, and individual scientists.

Each section begins with a summary in a common format developed at NGDC. After the summary, each section contains materials provided (or recommended) by the creator of the data set concerned. The materials are considered the most useful, concise discussion of the creation and/or use of the data.

As these materials come from diverse sources, they have a variety of formats. This shows the diversity of approaches (and implementations) of documentation currently used. **We apologize for the lack of uniformity of these materials, and for the imperfect reproduction of some material.**

This document should be referenced as:

WDC-A, 1992. *Global Change Data Base Pilot (Diskette) Project for Africa; Data Base Documentation, Version 1.1.* Publication SE-47. World Data Center-A for Solid Earth Geophysics, NOAA National Geophysical Data Center, Boulder, Colorado. 337 pp.

TABLE OF CONTENTS

Preface iii

Introduction 1
- Background 1
- Getting Started 3
- The Database 5
- Data Set Documentation 9
- Directory of Data Files on the Floppy Diskettes 13
- Integrated Global Environmental (Global Change) Data Activities Support Researchers and Educators: Review Paper 19
- Software Guide: Browse and Visualization Modules 23

Appendices

A. NOAA Monthly 10-Minute Normalized Difference Vegetation Index (April 1985 - December 1988) A-1

B. Olson World Ecosystems (WE 1.4) B-1

C. Holdridge Life Zones C-1

D. Matthews Vegetation, Land Use, and Seasonal Albedo D-1

E. Wilson and Henderson-Sellers Land Cover and Soils for Global Circulation Modeling E-1

F. Zobler Soil Type, Soil Texture, Surface Slope, and Other Properties F-1

G. FAO Soil Units G-1

H. UNEP/FAO GRID Africa GIS Data Base H-1

I. Legates and Willmott Average Monthly Air Temperature and Precipitation I-1

J. Revised FNOC Elevation, Terrain, and Surface Characteristics J-1

K. Integrated Elevation and Bathymetry K-1

L. Micro World Data Bank II: Coastlines, Country Boundaries, Islands, Lakes, and Rivers L-1

M. World Data Bank II: Country Regions and Rivers M-1

N. The World Data Center System N-1

GLOBAL CHANGE DATA BASE

Pilot (Diskette) Project for Africa

Data Set Documentation

INTRODUCTION

I. BACKGROUND

The Data Management & Information Systems Working Group of the International Geosphere-Biosphere Program (IGBP) in concert with the ICSU Panel on World Data Centres developed an action plan that was approved by the IGBP Scientific Advisory Council at its October 1988 meeting in Stockholm, Sweden. A key element of this plan was the creation of a Pilot Data Assembly Project for land surface data. The first phase of this project was the assembly on floppy diskettes of a monthly vegetation index for a recent three and a half year period and other thematic data for the continent of Africa. Vegetation indices, produced by NOAA from its Polar Orbiting satellites, have been composited and re-sampled to create monthly values on a 10 arc-minute geographic grid (approximately 18km at the equator). Complementary thematic data have been included on compatible grids, as available, and all data sets are registered to a common origin and projection (latitude-longitude). The database was structured to be compatible with an existing Geographic Information System (GIS), so that a complete analytical package could be provided for experimentation, evaluation, and further development.

The World Data Center-A (WDC-A) for Solid Earth Geophysics, operated by the U.S. National Geophysical Data Center (NGDC) in Boulder, Colorado, produced this database and is leading its implementation in cooperation with the IGBP and ICSU Panel on World Data Centers. The software (known as Idrisi) was developed and adapted for this project at Clark University. The National Center for Geographic Information and Analysis (NCGIA) in Santa Barbara, California, has recently joined the project to assist with training and evaluation. The data diskettes and GIS package are being used in a series of workshops as part of GIS training sessions organized by the United Nations Environment Program (UNEP) Global Resource Information Database (GRID) and United Nations Institute for Training and Research (UNITAR). The first workshop was held in 1989 in Accra, Ghana, the second in 1990 in Dakar, Senegal. These UN training sessions will serve as the means to distribute the database and establish operational capabilities within African countries. The database is also being distributed, together with analysis software, to various research and test facilities worldwide to establish a network of scientists that will serve to guide applications, enhancements, and communication among users. The data are provided by NGDC/WDC-A on ten diskettes in a compressed data format (with extraction software included). The GIS package is distributed and maintained separately by Clark University. The complete integrated global and regional databases are also available from NGDC, although individual archive data sets should be obtained from sources indicated in this

documentation. This Pilot Project for Africa is a prototype for other regional and global projects.

Beta Test and Research Development facilities have been selected to initiate a process of peer review and testing for this and subsequent updates. The test network may expand with subsequent releases; hopefully stimulating experimentation, new applications, and the development of methodological conventions. Meanwhile, selected sites will evaluate the first releases of this database for scientific usefulness, technical accuracy, and usability with commonly available software. A long-range goal of this effort is to support various kinds of model building, including predictive and diagnostic indicies, hypotheses testing, risk models, classifications, and interfaces to process modeling. It is extremely important to determine specifications for future releases. Equally necessary are preliminary results which can be obtained from the data in their present form that can serve for training purposes, and which can be used to test the mechanism for establishing local validation studies.

Selection criteria:

The choice of data sets was determined mostly by availability, within a range of resolutions which seemed suitable for questions of environmental and ecological change at the continental to global level; and on time scales from years to decades or centuries. Consideration of spatial and temporal scale and associated resolutions is essential because patterns that can be represented at one scale may not be directly relatable to another; and furthermore resolution of phenomena and patterns of interest must be matched with appropriate sampling (in both time and space).

The project has been based on the idea that the resolutions afforded by global AVHRR data would be well-suited for studying a particular class of phenomena and patterns that falls in a "medium resolution" between global modeling (typically on 2-5 degree grids), and resource studies (typically at 1-km to 10-meter resolutions). A nominal 10 arc-minute scale was chosen to provide compatibility with other scales and because this corresponds closely with the resolution of global AVHRR coverage. Other data sets, however, were not available at this resolution, so in order to include these additional variables, and to provide some experimentation with combining scales, it was decided to incorporate source data from three spatial resolutions--10 arc-minute (raster grid), 1/2 to 1 degree (raster grid), and country units (vector polygons and rasterized units). The latter may provide some links to existing country databases and international statistics.

It is also worth noting that linkage between the resolutions indicated here and other projects dealing with higher resolutions is an important research area. Direct comparison of data at different scales can be useful for quality control and developing classification hierarchies. Furthermore, interaction at the level of analysis or modeling at different scales can have great scientific value by allowing intercomparison of predictions and studies of different kinds of phenomena. Future developments may allow resolutions down to 1 km to be included, depending on the availability of data with global or regional coverage. The volumes of data at this scale would naturally imply different distribution media, such as CD-ROM. On the other

hand, grids of up to 5-degree resolution may be desired for global modeling. One of the goals of this project is to experiment with linking studies at different scales.

Normalized vegetation indices (NDVI) were selected as the basic data because they are sensitive indicators of green vegetation health and have been related to significant processes of climate variability and human activity. The period from April 1985 to December 1988 was selected because it corresponds to a consistent period in NOAA's image compositing procedures. The period also covers a well-documented El Nino event which occurred between 1986 and 1987 and which produced major global climatic perturbations. By focusing on this time frame, it might be possible to identify the nature and extent of the changes which resulted from El Nino.

The Idrisi GIS/Analytical software package was chosen for this project because of its functionality, availability, adaptability, and relative low cost to developing countries. The software requires IBM or MS DOS PC machines, which are widely available and have a well established user base.

II. GETTING STARTED

System compatibility:

The diskettes which accompany this documentation are written in IBM DOS compatible format, as either 5 1/4, 1.2 megabyte, or 3 1/2, 1.44 megabyte high-density diskettes. The data files are written in a compressed "archive" format (PKZIP) to conserve space. The un-compression software, PKUNZIP, is compiled for IBM DOS compatible machines. The database is also available un-compressed, on standard 9-track 1600 BPI ASCII tape.

Data diskettes:

Ten data diskettes are provided with this documentation. Before doing anything else, use the DOS DISKCOPY command (or some other method) to make a backup copy of each diskette. Refer to your DOS manual for usage of the DISKCOPY command. As an extra margin of security, write-protect your backup diskettes.

The entire database, when completely extracted from the archive, occupies 41,390,874 bytes of disk space. The vegetation data alone occupies 9,488,571 bytes, the climate data occupies 21,900,854 bytes, and the other thematic data sets occupy 10,001,449 bytes. A standard IBM DOS disk volume of 32 megabytes will, therefore, not contain the entire database. In such cases the user will have to select portions of the data to load and work with at any given time. The following archives are provided on the floppy disks as indicated:

Disk #1:	AFDISK1.ZIP	Monthly Vegetation Index; April 1985 through January 1985
Disk #2:	AFDISK2.ZIP	Monthly Vegetation Index; February 1985 through October 1986
Disk #3:	AFDISK3.ZIP	Monthly Vegetation Index; November 1986 through June 1987
Disk #4:	AFDISK4.ZIP	Monthly Vegetation Index; July 1987 through January 1988
Disk #5:	AFDISK5.ZIP	Monthly Vegetation Index; February 1988 through September 1988
Disk #6:	AFDISK6.ZIP	Monthly Vegetation Index; October 1988 through December 1988 and Decadal Average Monthly Climate Errors; 12 months
Disk #7:	AFDISK7.ZIP	Decadal Average Monthly Temperature; 12 months
Disk #8:	AFDISK8.ZIP	Decadal Average Monthly Measured Precipitation; 12 months
Disk #9:	AFDISK9.ZIP	Decadal Average Monthly Corrected Precipitation; 12 months
Disk #10:	AFDISK10.ZIP	Thematic and Vector (linework) Reference Data

Each diskette contains a single data file (two in the case of diskette #6) in an archive (ZIP) format. This archive can only be accessed using the PKUNZIP.EXE program provided on the diskette. The PKUNZIP program is self-documenting (simply make the floppy drive your default drive, and type 'PKUNZIP' at the DOS prompt to obtain instructions). However, the following examples may be helpful:

(1) **To set up the default floppy drive,** insert the floppy disk into one of the floppy disk drives, close the door, and type 'A:' or 'B:' depending on which disk drive you have inserted the floppy. You may type 'DIR' to list the archive filenames on your computer screen (or simply note the archive name from the diskette label).

(2) **To view the list of files in the archive,** type 'PKUNZIP -V' followed by a space, then the archive name (with or without the .ZIP extension), for example: 'PKUNZIP -V AFDISK1'.

(3) **To extract all files from the archive to a fixed (hard) disk,** type 'PKUNZIP' followed by a space, then archive name followed by a space, then the destination data path, for example: 'PKUNZIP AFDISK1 D:\Diskette\Africa'. You must first create your destination directory using the DOS 'MD' command (refer to your DOS manual).

(4) **To extract a specified data set from the archive to a fixed (hard) disk,** type 'PKUNZIP' followed by a space, then the archive name followed by a space, then the destination data path followed by a space, then the data set name followed by a period and asterisk; for example: 'PKUNZIP AFDISK1 D:\DISKETTE\AFRICA AFAPR85.*'. This will extract two files, the data file and its text (ASCII) documentation file.

As you become more familiar with PKUNZIP, you will be able to do more sophisticated search and/or retrievals. The ability to retrieve less than the entire archive may be important to you if your computer does not have a large disk.

III. THE DATABASE

Africa Window and Projection:

The database consists of a collection of raster (cell) and vector (point, line or polygon) data files which have been "windowed" from global files specifically for the IGBP Pilot Project for Africa. All but the UNEP/GRID Africa data sets have archive versions that are global in coverage. The original UNEP/GRID Africa data are available only for Africa. All data are provided in a geographic (Longitude/Latitude) projection (i.e., "unprojected"). The geographic window that was choosen contains the entire African mainland and has the following edge coordinates:

Western Edge: 20-deg. West Longitude
Eastern Edge: 60-deg. East Longitude
Northern Edge: 38-deg. North Latitude
Southern Edge: 35-deg. South Latitude

Raster Grid (Image) Files:

The raster data are on a uniform and commonly registered grid with 10 arc-minute spacing (i.e., 1/6 degree grid). Where source data were provided on coarser grids (up to 1 degree) they have been expanded to the standard 10 minute grid for uniformity. This allows the database to be used in overlay operations without resampling in systems that are unable to mix variable grid spacings. There is a direct correlation, however, between the source data and the 10 minute "expanded" version supplied with this database (the original data set can be reproduced by contracting the 10 minute data set to its original grid spacing). Where source data were of finer resolution than 10-minutes, or in the case of fractional grid dimensions (such as the NDVI, which was supplied on an 8.6 minute grid), resampling to 10 minutes was performed by simple averaging (considering the percentage of overlap of 10 minute cells with the originals), or grid sampling (in the case of classed data).

The geographic window for Africa is exactly fitted with an array of 10 minute cells that has its edges coinciding with the window coordinates. The cell sequencing and registration is shown below:

Western Edge: 20-deg. West Longitude
Eastern Edge: 60-deg. East Longitude
Northern Edge: 38-deg. North Latitude
Southern Edge: 35-deg. South Latitude

```
        Pixel sequenceing
        - (480 columns) -
       -----------------------
      | 0 | 1 | 2 | 3 |...|479|
  |   |---+---+---+---+---+---|
(438  |480|481|482|...|...|...|
rows) |---+---+---+---+---+---|
  |   |   |   |   |   |   |   |
      |---+---+---+---+---+---|
      |   |   |   |   |   |   |
       -----------------------
                 total        =
210,240
```

Since the common pixel size is 10-minutes in latitude and longitude, the resulting Africa grid size is:

480 Columns
438 Rows

In the archived global grids, which have their left-hand-edge at the International Date Line (i.e. 180 deg. West Longitude, or -180 degrees longitude) the row/column windowing coordinates (numbering pixels beginning from zero!) to obtain the Africa Pilot Project window are:

Start column: 960
Start row: 312
End column: 1439
End row: 749

All of the Africa grid data files conform to the above registration and grid dimensions. Each raster data file is identified with an 8-letter name followed by a ".img" file extension.

Raster Documentation Files:

Each data set is accompanied by an ASCII documentation file which contains information necessary for use of the data set in a Geographic Information System or other software. The following shows an example of a documentation file, with explanations in brackets.

image title : UNESCO/FAO Soil Classes	{Name of the data set}
data type : byte	{byte, integer, or real}
file type : binary	{ascii, binary, or packed binary}
rows : 438	{number of rows}
columns : 480	{number of columns}
minimum : 0.0000000000E+00	{minimum data value in the dataset}
maximum : 1.3300000000E+02	{maximum data value in the dataset}
cell x : 0.1666666667E+00	{cell size = 1/6 degree}
cell y : 0.1666666667E+00	{cell size = 1/6 degree}
legend : 133	{number of legend categories}
category 1 : A Acrisols	{legends ....
category 2 : Af Ferric Acrisols	
category 3 : Ag Gleyic Acrisols	
..... etc.	

NOTES:

(1) The grid (image) data and documentation files are compatible with the Idrisi GIS format.

(2) The current version of the ASCII documentation file does not allow the specification of category 0 in the legends. Legend information for category 0 is, however, included in this documentation manual.

Vector Data Files:

Vector data are provided in the following format:

```
ID#   #Points
xxxx  yyyy
xxxx  yyyy
...etc.
0     0
```

where ID# is a feature identification number, #Points is the number of coordinate pairs that follow to define the feature, xxxx is the longitude (X) coordinate and yyyy is the latitude (Y) coordinate. The last line of each vector file consists of two zeros, separated by one or more spaces. Coordinates are all referenced to the Greenwich meridian with positive values indicating East and

negative values indicating West; and to the equator with positive values indicating North and negative values indicating South. In this format, point data files would have only one coordinate pair defining each feature (point), line data files can have up to 999 coordinate pairs for each feature (unlimitted number of features), and are open ended, and polygons; and polygon data files are similar to line data files except that each feature is closed (i.e., the starting point and ending point are identical). The units for coordinate values used in the vector files are defined in their corresponding documentation files.

Vector Documentation Files:

title : Africa Coastlines	{Name of the data set}
data type : integer	{byte, integer, or real}
file type : ascii	{ascii or binary}
object type : line	{point, line or polygon}
coord. span : 1.6667000000E-02	{coordinate span = 1/60 degree}
coord. unit : deg	{units of measure = degrees}
min X : -1.2000000000E+03	{minimum x value}
max X : 3.6000000000E+03	{maximum x value}
min Y : -2.1000000000E+03	{minimum y value}
max Y : 2.2800000000E+03	{maximum y value}

NOTES:

(1) The minimum bounding rectangle (MBR, indicated by the last four fields) has been set to values which correspond to the Africa Pilot Project window described above (not the actual range of values in the file). Therefore, by matching the MBR of the vector files with the edges of the raster files, a correctly registered overlay can be obtained, regardless of the units used in the vector file.

(2) The vector data and documentation files are compatible with the Idrisi GIS.

Data storage formats:

Raster data files are stored using either byte binary or integer binary numbers. Byte data are coded in 8 binary bits, thus allowing numbers from 0 to 255 (decimal) to be stored. Integer data are coded as 16 binary bits (or two bytes). Since one bit is used for the algebraic sign, numbers from -32,768 to +32,768 (decimal) can be stored as integer data. The order of the the two bits used for integer data conforms to conventions used by IBM and DEC. (Note that some other computer systems may require integers to be "byte-swapped," i.e. the order of the two bytes must

be reversed with a specially written program). Binary real data types are not used in this database. The data type for each data file in indicated in its associated documentation file.

Vector data files and both vector and raster documentation files are stored using ASCII characters, requiring one byte for each character. The ASCII format uses the IBM DOS convention for terminating a line with two bytes, a carriage return (hexidecimal 0D) followed by a line feed (hexidecimal 0A). ASCII files may or may not be ended with an end-of-file mark (hexidecimal 1F).

IV. DATA SET DOCUMENTATION

Summary Information:
Each data set has its own section in the documentation. These sections include all relevant information provided by the contributor or other sources. At the begining of each section there is a brief summary of information about the origin of the data set.

The following information categories refer to the original and complete version of the data set (i.e. the archived version before creating regional sub-sets or processing into a uniform grid and projection). This information may be critical when considering the reliability and potential application of the data set.

NAME of the archive (i.e., referenced) version of the data set (at top of each page).

CITATION: Recommended way of citing the data set in official references (when referring to the present or other regional sub-set of the data, it is recommended to use the same citation, with appropriate descriptions of the geographic area extracted).

DATE: Date of production or most recent update of the data set content (not format).

SOURCE: Development and processing history of the data set.

CONTRIBUTOR: Person (or institution) who contributed the data for this project.

CENTER: Data center(s) with official responsibility for distribution of the individual data set. A list (below) provides information for each of the centers referenced in this field.

GEOGRAPHIC SAMPLING: The original spatial interval or scale of the data and the type of statistic (i.e. vector point, line, or polygon: grid sample, average, mode, etc.). Since all data sets in this database are provided on uniform 10-minute grids (or in vector form), this field indicates whether or not re-gridding was necessary, and from what source.

COVERAGE: The full geographical area covered by the data set.

PROJECTION: The original geographic projection of the source data set. Since all data sets in this database are provided in geographic (longitude/latitude) projection, this field indicates whether or not re-projection was necessary, and from which source projection.

TIME SAMPLING: The original time interval or resolution of data set and the type of statistic (i.e. "snapshot," running average, typical or average period, etc.).

REFERENCES: Literature references for any publications that are relevant to the use of the data set.

The following category refers only to the current Africa continental sub-set of the database, and is for reference to the diskettes which accompany this documentation:

FILE NAMES: The actual names of the digital files included within the .ZIP archive files provided with this version of the database.

Data Center Codes:

In the summary pages described above, abreviations are used to identify centers from which source data may be obtained. These abreviations are defined below, with their addresses:

CDIAC Carbon Dioxide Information Analysis Center
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, TN 37831-6335, USA

EDC EROS Data Center

US Geological Survey
Sioux Falls, South Dakota 57198, USA

GRID/Geneva Global Resource Information Database
Global Environment Monitoring System
United Nations Environment Program
6 Reu del la Gabell
CH-1227 Carouge
Geneva, Switzerland

GRID/Nairobi Global Resource Information Database
Global Environment Monitoring System
United Nations Environment Program
P.O. Box 30552
Nairobi, Kenya

IIASA International Institute for Applied Systems Analysis
A-2361 Laxenburg, Austria

NCAR National Center for Atmospheric Research
P.O. Box 3000
Boulder, Colorado 80307, USA

NCDC National Climatic Data Center
NOAA, NESDIS
Federal Building
Ashville, NC 28801, USA

NGDC National Geophysical Data Center
National Oceanic and Atmospheric Administration
325 Broadway E/GC
Boulder, Colorado 80303, USA

SDSD Satellite Data Services Division,
NCDC
NOAA, NESDIS
World Weather Building, Room 100
Washington, DC 20233, USA

WDC	World Data Centers International Council of Scientific Unions (see associated national data centers) For information, contact: Chairman, ICSU Panel on World Data Centers University Corporation for Atmospheric Research P.O. Box 3000 Boulder, CO 80307-3000, USA

Other organization acronyms:

CIA	Central Intelligence Agency, USA
DMA	Defense Mapping Agency, USA
ESRI	Environmental Systems Research Institute, Inc., Redlands, California, USA
FAO	United Nations Food and Agriculture Organization
NESDIS	National Environmental Satellite Data and Information Service, USA
NOAA	National Oceanic and Atmospheric Administration, USA
UNEP	United Nations Environment Programme
UNESCO	United Nations Education Scientific and Cultural Organization
USAF	United States Air Force
USN/FNOC	United States Navy, Fleet Numeric Oceanographic Center
USNOO	United States Naval Oceanographic Office, USA

DIRECTORY OF DATA FILES ON THE FLOPPY DISKETTES

Inventory of Data Files on Each Diskette

Disk 1 file: **AFDISK1**

Volume in drive A is GCDBAFRICA1
Directory of A:\

AFDISK1 ZIP	1185878	05-04-92	11:38a
PKUNZIP EXE	21440	11-15-89	3:24p
LOAD BAT	29	05-09-92	4:51p
3 file(s)	1207347 bytes		
	5632 bytes free		

Listing of uncompressed files contained in *AFDISK1.ZIP:*

name		size
AFAPR85	IMG	210240
AFAPR85	DOC	616
AFMAY85	IMG	210240
AFMAY85	DOC	614
AFJUN85	DOC	615
AFJUN85	IMG	210240
AFJUL85	IMG	210240
AFJUL85	DOC	615
AFAUG85	IMG	210240
AFAUG85	DOC	617
AFSEP85	IMG	210240
AFSEP85	DOC	620
AFOCT85	IMG	210240
AFOCT85	DOC	618
AFNOV85	IMG	210240
AFNOV85	DOC	619
AFDEC85	IMG	210240
AFDEC85	DOC	619
AFJAN86	IMG	210240
AFJAN86	DOC	618
20 file(s)		2108571 bytes

++++++++++++++++++++++++

DISK 2 file: **AFDISK2**

Volume in drive A is GCDBAFRICA2
Directory of A:\

AFDISK2 ZIP	1137445	07-02-90	10:50p
PKUNZIP EXE	21440	11-15-89	3:24p
LOAD BAT	29	05-09-92	4:51p
3 file(s)	1158914 bytes		
	54272 bytes free		

Listing of uncompressed files contained in *AFDISK2.*

name		size
AFFEB86	IMG	210240
AFFEB86	DOC	619
AFMAR86	IMG	210240
AFMAR86	DOC	616
AFAPR86	IMG	210240
AFAPR86	DOC	616
AFMAY86	IMG	210240
AFMAY86	DOC	614
AFJUN86	IMG	210240
AFJUN86	DOC	615
AFJUL86	IMG	210240
AFJUL86	DOC	615
AFAUG86	IMG	210240
AFAUG86	DOC	617
AFSEP86	IMG	210240
AFSEP86	DOC	620
18 file(s)		1897710 bytes

++++++++++++++++++++++++

DISK 3 file: **AFDISK3**

Volume in drive A is GCDBAFRICA3
Directory of A:\

AFDISK3 ZIP	1173285	05-09-92 5:09p
PKUNZIP EXE	21440	11-15-89 3:24p
LOAD BAT	29	05-09-92 4:51p
3 file(s)	1194754 bytes	
	18432 bytes free	

Listing of uncompressed files contained in *AFDISK3.ZIP*

name		size
AFNOV86	IMG	210240
AFNOV86	DOC	619
AFDEC86	IMG	210240
AFDEC86	DOC	619
AFJAN87	IMG	210240
AFJAN87	DOC	618
AFFEB87	IMG	210240
AFFEB87	DOC	619
AFMAR87	IMG	210240
AFMAR87	DOC	616
AFAPR87	IMG	210240
AFAPR87	DOC	616
AFMAY87	IMG	210240
AFMAY87	DOC	614
AFJUN87	IMG	210240
AFJUN87	DOC	615
16 file(s)	1686856 bytes	

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Disk 4 File: **AFDISK4**

Volume in drive A is GCDBAFRICA4
Directory of A:\

AFDISK4 ZIP	1051823	07-02-90 10:53p
PKUNZIP EXE	21440	11-15-89 3:24p
LOAD BAT	29	05-09-92 4:51p
3 file(s)	1073292 bytes	
	139776 bytes free	

Listing of uncompressed files contained in *AFDISK4.ZIP*

name		size
AFJUL87	IMG	210240
AFJUL87	DOC	615
AFAUG87	IMG	210240
AFAUG87	DOC	617
AFSEP87	IMG	210240
AFSEP87	DOC	620
AFOCT87	IMG	210240
AFOCT87	DOC	618
AFNOV87	IMG	210240
AFNOV87	DOC	619
AFDEC87	IMG	210240
AFDEC87	DOC	619
AFJAN88	IMG	210240
AFJAN88	DOC	618
14 file(s)	1476006 bytes	

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Disk 5 File:**AFDISK5**

Volume in drive A is GCDBAFRICA5
Directory of A:\

AFDISK5 ZIP	1162050	07-02-90 10:55p
PKUNZIP EXE	21440	11-15-89 3:24p
LOAD BAT	29	05-09-92 4:51p
3 file(s)	1183519 bytes	
	29696 bytes free	

Listing of uncompressed files contained in *AFDISK5.ZIP*

name		size
AFFEB88	IMG	210240
AFFEB88	DOC	619
AFMAR88	IMG	210240
AFMAR88	DOC	616
AFAPR88	IMG	210240
AFAPR88	DOC	616
AFMAY88	IMG	210240
AFMAY88	DOC	614
AFJUN88	IMG	210240
AFJUN88	DOC	615
AFJUL88	IMG	210240
AFJUL88	DOC	615
AFAUG88	IMG	210240
AFAUG88	DOC	617
AFSEP88	IMG	210240
AFSEP88	DOC	620
16 file(s)	1686852 bytes	

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Disk 6 File : **AFDISK6**

Volume in drive A is GCDBAFRICA6
Directory of A:\

AFDISK6 ZIP	1089646	04-25-92	5:43p
PKUNZIP EXE	21440	11-15-89	3:24p
LOAD BAT	29	05-09-92	4:51p
3 file(s)	1111115 bytes		
	101888 bytes free		

Listing of uncompressed files contained in *AFDISK6.ZIP*

name		size
AFOCT88	IMG	210240
AFOCT88	DOC	618
AFNOV88	IMG	210240
AFNOV88	DOC	619
AFDEC88	IMG	210240
AFDEC88	DOC	619
AFERRJAN	IMG	420480
AFERRJAN	DOC	678
AFERRFEB	IMG	420480
AFERRFEB	DOC	679
AFERRMAR	IMG	420480
AFERRMAR	DOC	676
AFERRAPR	IMG	420480
AFERRAPR	DOC	676
AFERRMAY	IMG	420480
AFERRMAY	DOC	674
AFERRJUN	IMG	420480
AFERRJUN	DOC	675
AFERRJUL	IMG	420480
AFERRJUL	DOC	675
AFERRAUG	IMG	420480
AFERRAUG	DOC	677
AFERRSEP	IMG	420480
AFERRSEP	DOC	680
AFERROCT	IMG	420480
AFERROCT	DOC	678
AFERRNOV	IMG	420480
AFERRNOV	DOC	679
AFERRDEC	DOC	679
AFERRDEC	IMG	420480
30 file(s)		5686462 bytes

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Disk 7 file: **AFDISK7**

Volume in drive A is GCDPAFRICA7
Directory of A:\

AFDISK ZIP	999392	07-02-90	6:43p
PKUNZIP EXE	21440	11-15-89	3:24p
LOAD BAT	29	05-09-92	4:51p
3 file(s)	1020861 bytes		
	192512 bytes free		

Listing of uncompressed files contained in *AFDISK7.ZIP*

name		size
AFTMPJAN	IMG	420480
AFTMPJAN	DOC	684
AFTMPFEB	IMG	420480
AFTMPFEB	DOC	686
AFTMPMAR	IMG	420480
AFTMPMAR	DOC	683
AFTMPAPR	IMG	420480
AFTMPAPR	DOC	683
AFTMPMAY	IMG	420480
AFTMPMAY	DOC	681
AFTMPJUN	IMG	420480
AFTMPJUN	DOC	682
AFTMPJUL	IMG	420480
AFTMPJUL	DOC	682
AFTMPAUG	IMG	420480
AFTMPAUG	DOC	684
AFTMPSEP	IMG	420480
AFTMPSEP	DOC	687
AFTMPOCT	DOC	685
AFTMPOCT	IMG	420480
AFTMPNOV	IMG	420480
AFTMPNOV	DOC	686
AFTMPDEC	IMG	420480
AFTMPDEC	DOC	686
24 file(s)		5053969 bytes

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Disk 8 file: **AFDISK8**

Volume in drive A is GCDBAFRICA8
Directory of A:\

AFDISK8 ZIP	1085965	07-02-90	6:45p
PKUNZIP EXE	21440	11-15-89	3:24p
LOAD BAT	29	05-09-92	4:51p
3 file(s)	1107434 bytes		
	105472 bytes free		

Listing of uncompressed files contained in *AFDISK8.ZIP*

name	size
AFMPRJAN IMG	420480
AFMPRJAN DOC	698
AFMPRFEB IMG	420480
AFMPRFEB DOC	699
AFMPRMAR IMG	420480
AFMPRMAR DOC	696
AFMPRAPR IMG	420480
AFMPRAPR DOC	696
AFMPRMAY IMG	420480
AFMPRMAY DOC	694
AFMPRJUN IMG	420480
AFMPRJUN DOC	695
AFMPRJUL IMG	420480
AFMPRJUL DOC	695
AFMPRAUG IMG	420480
AFMPRAUG DOC	697
AFMPRSEP IMG	420480
AFMPRSEP DOC	700
AFMPROCT IMG	420480
AFMPROCT DOC	698
AFMPRNOV IMG	420480
AFMPRNOV DOC	699
AFMPRDEC IMG	420480
AFMPRDEC DOC	699
24 file(s)	5054126 bytes

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Disk 9 file: **AFDISK9**

Volume in drive A is GCDBAFRICA9
Directory of A:\

AFDISK9 ZIP	1118177	07-02-90	6:46p
PKUNZIP EXE	21440	11-15-89	3:24p
LOAD BAT	29	05-09-92	4:51p
3 file(s)	1139646 bytes		
	73728 bytes free		

Listing of uncompressed files contained in *AFDISK9.ZIP*

name	size
AFCPRJAN IMG	420480
AFCPRJAN DOC	699
AFCPRFEB IMG	420480
AFCPRFEB DOC	700
AFCPRMAR IMG	420480
AFCPRMAR DOC	697
AFCPRAPR IMG	420480
AFCPRAPR DOC	697
AFCPRMAY IMG	420480
AFCPRMAY DOC	695
AFCPRJUN IMG	420480
AFCPRJUN DOC	696
AFCPRJUL IMG	420480
AFCPRJUL DOC	696
AFCPRAUG IMG	420480
AFCPRAUG DOC	698
AFCPRSEP IMG	420480
AFCPRSEP DOC	701
AFCPROCT IMG	420480
AFCPROCT DOC	699
AFCPRNOV IMG	420480
AFCPRNOV DOC	700
AFCPRDEC IMG	420480
AFCPRDEC DOC	700
24 file(s)	5054138 bytes

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Disk 10 file: **AFDISK10**

Volume in drive A is GCDPAFRIC10
Directory of A:\

AFDISK10 ZIP	1083102	05-09-92	4:23p
PKUNZIP EXE	21440	11-15-89	3:24p
LOAD BAT	27	05-09-92	4:15p
3 file(s)	1104569 bytes		
	108544 bytes free		

Listing of uncompressed files contained in *AFDISK10.ZIP*

name		size
AFWE14	IMG	210240
AFWSOILR	DOC	410
AFWSOILR	IMG	210240
AFWE14	DOC	4600
AFHOLD	DOC	2103
AFHOLD	IMG	210240
AFMVEG	DOC	2565
AFMVEG	IMG	210240
AFMCULT	DOC	405
AFMCULT	IMG	210240
AFMALBFA	DOC	694
AFMALBFA	IMG	420480
AFMALBSM	DOC	696
AFMALBSM	IMG	420480
AFMALBSP	DOC	696
AFMALBSP	IMG	420480
AFMALBWN	DOC	696
AFMALBWN	IMG	420480
AFZSOILS	DOC	3103
AFZSOILS	IMG	210240
AFZTEX	DOC	605
AFZTEX	IMG	210240
AFZSLOPE	DOC	514
AFZSLOPE	IMG	210240
AFZPHS	IMG	210240
AFZPHS	DOC	2423
AFZSUBSD	IMG	210240
AFZSUBSD	DOC	3949
AFZAREA	DOC	595
AFZAREA	IMG	210240
AFZSP3	IMG	210240
AFZSP3	DOC	1174
AFFAOSOL	DOC	5986
AFFAOSOL	IMG	210240
AFCROPX	IMG	210240
AFCROPX	DOC	491
AFRAINX	DOC	1334
AFRAINX	IMG	210240
AFSOILX	DOC	1366
AFSOILX	IMG	210240
AFVEGX	IMG	210240
AFVEGX	DOC	1097
AFWINDX	DOC	709
AFWINDX	IMG	210240
AFDESRTX	DOC	803
AFDESRTX	IMG	210240
AFTEMPX	DOC	697
AFTEMPX	IMG	210240
AFMAX	DOC	709
AFMAX	IMG	420480
AFMIN	DOC	704
AFMIN	IMG	420480
AFMODE	IMG	420480
AFMODE	DOC	703
AFURBAN	DOC	1483
AFURBAN	IMG	210240
AFWATER	DOC	2390
AFWATER	IMG	420480
AFOCEAN	IMG	210240
AFOCEAN	DOC	314
AFELBA	DOC	716
AFELBA	IMG	420480
COASTS	DVC	299
COASTS	VEC	95202
COUNTRY	DVC	302
COUNTRY	VEC	82120
ISLANDS	DVC	300
ISLANDS	VEC	4467
LAKES	DVC	298
LAKES	VEC	32350
RIVERS	DVC	299
RIVERS	VEC	57579
AFNATION	DOC	3142
AFNATION	IMG	210240
AFRIVERS	IMG	210240
AFRIVERS	DOC	294
AFWLAND	DOC	1606
AFWLAND	IMG	210240
AFWLAND1	DOC	3735
AFWLAND1	IMG	210240
AFWLAND2	DOC	3736
AFWLAND2	IMG	210240
AFWLANDR	DOC	390
AFWLANDR	IMG	210240
84 file(s)	10001889 bytes	

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Disk 11 file: **AFDISK11**

Volume in drive A Supplemental
Directory of A:\

AFDISK11 ZIP	204970	05-08-92
LOAD BAT	29	05-09-92
PKUNZIP EXE	21440	11-15-89
3 file(s)	226439 bytes	
	986624 bytes free	

Listing of uncompressed files contained in *AFDISK11.ZIP*

name		size
AFFALL	DOC	295
AFFALL	IMG	92108
AFJANTMP	DOC	567
AFJANTMP	IMG	210240
AFSPRG	DOC	297
AFSPRG	IMG	97046
AFSUMM	DOC	297
AFSUMM	IMG	86196
AFVEGX2	DOC	700
AFVEGX2	IMG	210240
AFWINT	DOC	297
AFWINT	IMG	91984
NDVI	PAL	223
NWZ	DVC	281
NWZ	VEC	15683
SEASONS	TS	37
VEG	PAL	224
VIFILES	TS	133
18 file(s)		806848 bytes

(This paper is in press: Proceedings of the European Conference on the International Space Year, 1992)

INTEGRATED GLOBAL ENVIRONMENTAL (GLOBAL CHANGE) DATA ACTIVITIES SUPPORT RESEARCHERS AND EDUCATORS

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ABSTRACT/RESUME

The Global Change Data Base results from a cooperatively developed method of publishing peer-reviewed data designed for integrated multivariate spatial analysis. The GCDB with accompanying documentation and access software lie entirely within the public domain. They are designed (1) to further research, education, and overall awareness of the global environment; (2) to provide beneficial feedback to enable the authors to enhance their own research and data development, and (3) to provide a mechanism for scientists to share and receive credit for the intellectual content and expression of their experimental designs, analyses, interpretations, and models of the global environment. The prime medium for distribution is CD-ROM, though educational data sets are being prepared for distribution on floppy diskette, accompanied by a manual of exercises.

Keywords: global change, data, integration, research, education, outreach.

1. INTRODUCTION

An increasing number of laboratories and individual scientists have been developing digital spatial data sets to describe various aspects of the global environment. A cooperative effort to integrate many of these data has been progressing for several years, and is about to reach fruition in the first public release of NGDC's Global Change Data Base (GCDB; Ref. 1)

The integration effort has involved careful inspection of data for spatial registration, consistency between documentation and data content, and appropriateness for multivariate analysis and modeling in image processing, spatial statistics, and geographic information systems.

To reduce the hugeness of the task of data integration, the GCDB is starting with only global data sets. However, as it advances, interest is increasing for continental- and regional-scale data bases. Selected continental-scale data sets may soon be added to the GCDB.

This task may appear menial and boring. Indeed, there is much tedious inspection of data and documentation. However, the Global Change Data Base is also an experiment in integrating and improving access to individual data sets. When combined, these data constitute a fascinating view of (1) the Earth as a system, and (2) how we conduct science.

2. OBJECTIVES

Why the need for an integrated data base? Many people currently concentrating on one or two parameters that attempt to describe certain aspects of the global environment would like access to more data to work with. However, assembling such data is tedious. Even without rigorously assuring cartographic fidelity and scientific accountability, simply finding and acquiring such data can be time consuming. A single reference data set can thus be acquired more easily, can be used as a focal point for comparisons, etc. In addition, resources needed to improve the geographic fit and scientific usefulness of such data can be expended once to a certain level, leaving the scientist or educator to move beyond this point in whatever way s/he chooses.

2.1 Integration of Data for Multivariate Analysis

Many existing environmental data sets are produced individually by specialists in a particular field. These data are often designed for a special application, with compromises that may not be optimal for other users. The data may also have characteristics (cartographic projection, legend categories, simplifications) that may make them difficult to use as part of an integrated multivariate study.

For the past few years, the USA's National Oceanic and Atmospheric Administration has placed emphasis on "Earth Systems" approaches to science. NOAA's National Geophysical Data Center, and its co-located World Data Center - A, Boulder (Colorado) Centers, is emphasizing the development of integrated data sets for studying the Earth as a system.

Many studies of the global environment emphasize only one or two types of data. For example, detailed studies are sometimes made of several weeks or years of Global Vegetation Index (GVI) from NOAA's Advanced Very High Resolution Radiometer (AVHRR), perhaps comparing such data with past and predicted crop yields in the African Sahel. Such data can be internally consistent but slightly misregistered to the globe (as one can still identify the West African coastline, for example, in the imagery) without significantly affecting some studies. However, (1) attempts to relate the GVI to vegetation type, soils, or topography (Ref. 2), or (2) attempts to "validate" production and processing of satellite imagery by comparisons with ground-based data can be greatly assisted if the separate data sets are integrated into an overall data base designed for multivariate application.

The Global Change Data Base is an attempt to address this issue of integration and quality assessment. Hastings and others (Ref. 3), Clark and others (Ref. 4) and Kineman and others (Ref. 5), discuss some aspects of this activity in greater detail than the present review.

2.2 Peer-Reviewed "Publication" of Data

Fundamental analytical scientific data are often more widely

used, with hundreds of users, than are typical scientific research papers, which may typically be cited by a few other authors. Yet financial/logistical/moral support for sharing data is often low. Why this problem, and how to solve it?

The design and execution of experiments that collect data have frequently been recognized as intellectual contributions only if the scientists involved produced publishable findings from the data. As such, sufficient acknowledgement may not have previously been made for the development of certain pioneering attempts to characterize the global environment.

Faced with such a reception, scientists have sometimes preferred to publish findings from data, rather than to thoroughly document the data and share them with the public.

On the other hand, there has been considerable discussion on what constitutes scientifically valid data on the environment. How are such data certified? Should committees be formed to validate such data?

One alternative is to adapt certain existing traditions of peer review and hardcopy publication to digital data. The Global Change Data Base is an attempt to support such thinking.

In the GCDB, individual data sets are considered as authored chapters in a symposium volume. Each chapter consists of data, basic documentation on file format and data development, written discussion of scientific applications of the data (often with technical writings on research findings), guidelines on characteristics of the data that might affect new applications, and a bibliography of other writings on the data.

The data are reviewed in-house at NOAA/NGDC for geographic registration, accuracy and appropriateness of categorization, completeness of documentation, and ability to be used with other data in the GCDB. Many data sets have initial problems in these areas that may not have affected their original applications but which, if not corrected, would cause trouble when used in the multivariate spatial GCDB. Data and documentation are corrected and/or enhanced for some data sets, to improve their integration into the GCDB.

The data are then sent to several experts for their comments. These comments are used to further edit the data and documentation, for increased value to users of the data base.

The Global Change Data Base has had two forms of peer review to date: (1) The first prototype, an integrated collection of data for Africa, was reviewed by scientists on six continents, as part of the International Geosphere-Biosphere Programme's (IGBP's) Global Change Database Project, Pilot Project for Africa. (2) A CD-ROM containing about 500 megabytes of integrated global data was reviewed by about 150 Beta testers as part of a cooperative Global Ecosystems Database project with the USA's Environmental Protection Agency. Both of these data sets are described in more detail below.

Peer-reviewed data should not be considered as perfect, especially in these early stages of describing the global environment. However, they have been determined by reviewers to be appropriate for cautious study by scientists who will read the documentation and use care and judgment in their use of the data. As in hardcopy information, we can expect people to find enhancements, alternatives, or additions to the GCDB. We invite anyone to contact us with comments, suggestions, or data for subsequent releases of the data base.

2.3 Public-Domain, Accessible

The Global Change Data Base, as is the case for all data distributed by NOAA/NGDC, is completely in the public domain. There is no restriction on the distribution or use of the GCDB, other than common courtesy that the authors and publisher be referenced in any subsequent use.

NOAA/NGDC distributes its data in all appropriate media. Magnetic tape, floppy diskette, and Compact Disc Read-Only Memory (CD-ROM) have been used for data contained in the GCDB. Because of the large volumes of data already in the GCDB, CD-ROM is considered the most practical (and most economical) form of distribution for the data.

On-line distribution of scientific data has been attractive to many scientists. With such systems, a person can collect large quantities of data for the cost of a connection to a communications network, or for telephone hookup via modem to the source of the data. Currently, there are no plans for such distribution for the Global Change Data Base other than during the review process. NOAA/NGDC must recover its costs of managing the data, which places a nominal charge on data (with numerous exceptions, such as for contributors of data, researchers or cooperators in various programs, who get the data at no charge). Also, the size of the Global Change Data Base (over a gigabyte and growing rapidly) makes even high speed network transmission nontrivial. Also, networks are not yet fully accountable for data quality, which makes them inappropriate media for operationally transmitting the reviewed GCDB.

The data are accompanied by software that helps the user to browse through and visualize the GCDB and select appropriate data for use. The current version of the software is being enhanced and implemented for multiple platforms, such as IBM-compatible computers, Apple Macintosh computers, and UNIX workstations. The data are immediately compatible with several spatial analysis systems including GRASS-GIS (for UNIX; Ref. 6) and IDRISI (for DOS; Ref. 7). The data have been easily imported into several more spatial analysis systems.

2.4 Support Research, Education, Awareness

The previous paragraph notes that one can view several aspects of the global environment with the data and accompanying software. However, the main purposes of the data base are better served by using software of the user's choice for research, education, or public awareness. For this purpose, the data are stored in a latitude-longitude unheaded grid format (with associated vector data) compatible with ingest into many software systems.

In-house analysis at NOAA/NGDC has already begun to produce some research results (Ref. 2). Several Beta testers have commented on their research activities with the data.

The IGBP's Global Change Database Project has been conducted with the United Nations Environment Programme (UNEP) the United Nations Institute for Training and Research (UNITAR), la Sociedad de Especialistas Latinoamericanos en Percepcion Remota (SELPER, the Society of Latin American Remote Sensing Specialists) and other organizations to conduct training and awareness workshops in Africa and Latin America. One result of this activity is a training manual designed for self-instruction and exploration of the global environment, focusing on Africa as an example. NOAA/NGDC has enhanced the IGBP training workbook for publication in 1992. There are plans for additional educational materials, such as narrated 35mm slide sets, and perhaps a video. We invite commercial publishers to produce value-added products from these materials, after the GCDB materials are publicly released.

2.5 Provide Feedback to Authors of Data Sets

The integration, in-house and external testing, and development of educational materials is done in consultation with the authors of the data, even if the data have already been placed into the public domain. No data set enters the GCDB without explicit approval of its author(s) for its unrestricted distribution.

We want the GCDB to be as useful to the authors of the data as to customers of the data base. The authors are the ultimate authorities on their work. The authors are also pioneers in attempting to describe the environment. However, the GCDB offers feedback on attempts to integrate and use these with other data, and in documenting the data for users outside the authors' own specialties. Our analysis of spatial and thematic representations, intercomparison, and other research on the integration of the data offers back to the original authors information that might stimulate improvements in (and new applications of) the data.

2.6 A Is this a Prototype for Future Distribution Of Digital Data?

Are there elements of the GCDB that can be useful to others in the business of distributing data?

We hope so. Indeed, interchange of ideas between NOAA/-NGDC and the Canada Centre for Remote Sensing has been fruitful for the GCDB, as well as helping in the development of CCRS' *Global Change Encyclopedia* for the International Space Year.

Just as the hardcopy publishing industry has many producers of a wide variety of publications, we can predict many different sources of digital data in the future. We hope that some of these sources will improve the technology of data quality, integration, review/certification, documentation, and accessibility.

3. CURRENT STATUS OF THE GCDB

3.1 Current Contents

The current version of the GCDB includes the following data:

topography (Ref. 8)
distribution of population (Ref. 8)
surface water coverage (Ref. 8)
terrain characteristics (Ref. 8)
topography/bathymetry (Ref. 9)
vegetation (Ref. 10)
land use (Ref. 10)
seasonal albedo (Ref. 10)
ecosystems (Refs. 11, 12)
soils (Refs. 13, 14)
life zones (Ref. 15)
temperature & precipitation (Refs. 16-18)
vector base map linework (Ref. 19)
vegetation index from AVHRR (Refs 20-22)

Many other data sets are at various stages of incorporation into the data base. Such data will be added to the GCDB as they proceed through acquisition, discussion with authors, ingest, quality control, integration, Beta Test peer review, and documentation. Although all of these data sets are global, we plan to incorporate significant regional data sets at a later date: for example, where such data might help stimulate demand for (and later supply of) global versions of such data.

3.2 Availability

The Beta Test of the IGBP Pilot (Diskette) Project for Africa was conducted in 1990-1991. The Beta Test of the NOAA/EPA Global Ecosystems Database was conducted, in conjunction with the USA's Environmental Protection Agency, in 1991-1992.

The revised GCDB Pilot Project for Africa is slated for distribution on floppy diskette, with documentation and training workbook, sometime in 1992. Annotated slide sets may follow later in 1992. We invite anyone interested in producing educational materials for schools (or any other audience) to contact NGDC in Boulder or NOAA's Educational Affairs Division in Washington, DC.

The full Global Change Data Base is slated for publication on a series of CD-ROMs, also in 1992. A new Beta Test of proposed additions to the GCDB will also be conducted in 1992.

We invite anyone interested in the data to contact NOAA/NGDC for an information packet, and to be placed on the mailing list for the data.

We also encourage authors of global or regional data sets to contact us if they are interested in the concept of peer-reviewed publication of such data.

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SOFTWARE GUIDE

Browse and Visualization Modules for the
Global Change Data Base, Pilot (Diskette) Project for Africa

WELCOME!

The enclosed floppy diskette contains a subset of the IDRISI Geographic Analysis System that has been specially prepared by Clark University and NOAA/NGDC for use with the Global Change Data Base. Almost any 8000-, 80286-, 80386-, 80486 or compatible personal computer running IBM-DOS or compatible operating system, with EGA, VGA, or 8514Z compatible graphics should be able to run these modules.

In the future, NGDC plans to have browse and visualization software that runs on IBM-PC/MS-Windows, Macintosh, and UNIX/Windows environments. This software will be a generalized version of NGDC's GeoVu software (which had its debut in NGDC's CD-ROM on Geophysics of North America).

The software can be run from the floppy diskette, but more practically should be copied to a separate AFRICAVU (or other) program directory. You can then run the program named MENU. The MENU lists modules contained on this diskette, which can then be run interactively by typing in the appropriate command name.

To get the MENU, type MENU or HELP.

INTRODUCTORY NOTES:

1. These modules were developed especially for NGDC's Global Change Data Base, and for a cooperative project called the "Global Ecosystems Database Project" between NOAA/NGDC and the U. S. Environmental Protection Agency. Some parts of the software refer specifically to this cooperative project, which, within NGDC, is a part of the overall Global Change Database Program.

2. This disk contains two versions of the COLOR program -- one simply called COLOR for EGA and VGA systems and a second called COLOR85 for 8514/A or XGA systems (the EGA/VGA version can also be used with 8514/A and XGA systems). If you are working with an 8514/A or XGA or compatible graphics adaptor, please be sure that your applications interface (AI) driver has been loaded. If the module fails to produce a graphic image, it indicates that the AI driver is not memory resident or that it is not compatible.

3. You can run this software from a floppy diskette drive. Your data can also be on floppy diskettes. However, you will have an easier time with the software and data installed on a hard disk drive. We will assume that your data are in hard disk drive D: If your data are on a drive with a different designation, pay attention to installation step 3 below.

4. If you already own a copy of IDRISI, these modules may be copied to your IDRISI directory. However, since many of these modules are revisions that have been specially prepared for this project, you should keep these separate from the general-release versions. This is why we suggest a separate AFRICAVU subdirectory.

SOFTWARE INSTALLATION:

1. The software can be fun from floppy diskette, but is better run from a hard disk. If you have a hard disk, copy the entire contents of the floppy diskette containing software to a new directory on your hard disk. The software is set up to run in a \AFRICAVU directory on your C: hard disk.

2. If you install the software in a different environment, you should run the ENVIRON command (just go to the directory containing the software and type ENVIRON and hit the ENTER key). Follow the instructions on the screen to interactively change the drive and directory settings appropriately.

3. The programs are set up to run successfully if your data are on your "D:" drive, in your \AFRICA subdirectory. If your data are stored differently, you will need to perform a simple editing of these programs. To do so:

--Go to the drive and directory that contain the software modules.

--Type ENVIRON and hit the ENTER key.

--If your data are in a drive other than D: do the following

Type 1, and press the ENTER key
Type the drive letter followed by a colon (such as D:), press ENTER

--If your data are in a directory other than \AFRICA do the following

Type 2, and press the ENTER key
Type the directory path (such as \AFRICA), press ENTER

--Press ENTER again, to exit ENVIRON and save these settings.

FURTHER NOTES:

1. Note that we are including several .pal files. These are alternate color palettes for displaying images with COLOR or COLOR85. You may want to experiment with these, especially those with GVI in their names. To use such a palette, note when COLOR or COLOR85 ask you for your choice of palette. Answer with the number for "user-defined palette." Then, when prompted, give the name of the palette (which you must know beforehand by using DOS commands).

2. All IDRISI modules belong to Clark University and are protected by International Copyright Law. The modules distributed here have been made available to the EPA and NOAA/NGDC through a special Memorandum of Understanding with Clark University. They may not be distributed independently of the Global Change Data Base. For further information about the Global Change Data Base, please contact :

NOAA/NGDC
325 Broadway
Boulder, CO 80303
USA

Tel : (303) 497-6125
FAX : (303) 497-6513
Attn: David Schoolcraft

For further information about the IDRISI Geographic Analysis System please contact :

IDRISI Project
Clark University
950 Main St.
Worcester MA 01610
USA

Tel : (508) 793-7526
FAX : (508) 793-8881

-A-

NOAA MONTHLY 10-MIN. NORMALIZED DIFFERENCE VEGETATION INDEX

(APRIL 1985 - DECEMBER 1988)

CITATION: NOAA/NGDC, 1989. Global Monthly 10-min Normalized Difference Vegetation Index (April 1985 - December 1988). Digital Data. NOAA/NESDIS/National Geophysical Data Center, Boulder, Colorado. 105 Megabytes.

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A. NOAA MONTHLY 10-MIN NORMALIZED VEGETATION INDEX (APRIL 1985 - DECEMBER 1988)

DATE: 1989

SOURCE:

(1) AVHRR (Global Plate Carree)
NOAA/NESDIS/SDSD
NCDC, World Weather Building, Rm. 100
Washington, DC 20233
(301) 763-8111

(2) Reprocessed by:
John Kineman
NOAA/NGDC
Boulder, CO

CONTRIBUTOR: NOAA/NESDIS (SDSD AND NGDC)

DATA CENTER:

(1) SDSD (primary distribution)

(2) NGDC/WDC-A (monthly 10-min composites)

GEOGRAPHIC SAMPLING:

10-min grid, resampled from 8.6 min grid, averaged from weekly samples.

COVERAGE: Global

PROJECTION: Lat/lon

TIME SAMPLING: Monthly averages

REFERENCES:

Katherine B. Kidwell (ed.), 1990. "Global Vegetation Index User's Guide." NOAA/NESDIS/SDSD. (Excerpts included.)
For additional references, see pp. A1-A3 in Kidwell, 1990. (Also included)

FILE NAMES: AFAPR85 - AFDEC88 NVI (month/year) (45 files)

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NOAA MONTHLY 10-MIN NORMALIZED VEGETATION INDEX
(APRIL 1985 - DECEMBER 1988)
EXAMPLE DOCUMENTATION FILE

File Names: AFAPR85.DOC - AFDEC88.DOC (45 files)

```
image title : (April 1985 through December 1988) Vegetation Index
data type   : byte
file type   : binary
rows        : 438
columns     : 480
minimum     :   0.0000000000E+00
maximum     :   1.7500000000E+02
cell x      :   1.6666000000E-01
cell y      :   1.6666000000E-01
legend      : 15
category  1 : 11-21
category  2 : 22-32
category  3 : 33-43
category  4 : 44-54
category  5 : 55-65
category  6 : 66-76
category  7 : 77-87
category  8 : 88-98
category  9 : 99-109
category 10 : 110-120
category 11 : 121-131
category 12 : 132-142
category 13 : 143-153
category 14 : 154-164
category 15 : 165-175

{category 0 : 0-10}
```

[This legend is only appropriate for displays which reclass (contrast stretch) the continuous values into 16 classes.]

Note: The maximum indicated in the documentation file has been standardized to 175 so that automatic scaling during display will show comparable results between monthly images.

Units are scaled NDVI values from 0 to 255. Note that these values are inverted from the NOAA scaled NDVI values (255 - original NOAA scaled value), so that high values indicate greater vegetation response.

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NOAA MONTHLY 10-MIN NORMALIZED VEGETATION INDEX (APRIL 1985 - DECEMBER 1988)

PROCESSING

Advanced Very High Resolution Radiometer (AVHRR) data from NOAA Polar Orbiting Environmental Satellites were obtained from the National Environmental Satellite, Data and Information's (NESDIS) Satellite Data Services Division. The data were acquired in NOAA's operational Normalized Difference Vegetation Index (NDVI) "Plate Carree" (latitude/longitude) weekly image format, and were subsequently converted at the National Geophysical Data Center into 10-minute grids, composited monthly.

The AVHRR spectral bands used for vegetation monitoring are Channel 1, a visible band (0.58 to 0.68 m) and Channel 2, a near infrared band (0.73 to 1.10 m). Since the spectral reflectance of chlorophyll is more than three times greater in the reflected infrared than in the visible portion of the spectrum, the difference between the value for Channel 2 and Channel 1 is an indication of the degree to which the scene viewed includes green vegetation. Various mathematical combinations of Channel 1 and 2 data have been found to be sensitive indicators of the presence of green vegetation and are referred to as vegetation indices.

The basic index used by NOAA is the Unscaled Normalized Difference Vegetation Index (XVI), defined by the equation:

$$XVI = (Ch2 - Ch1) / (Ch2 + Ch1)$$

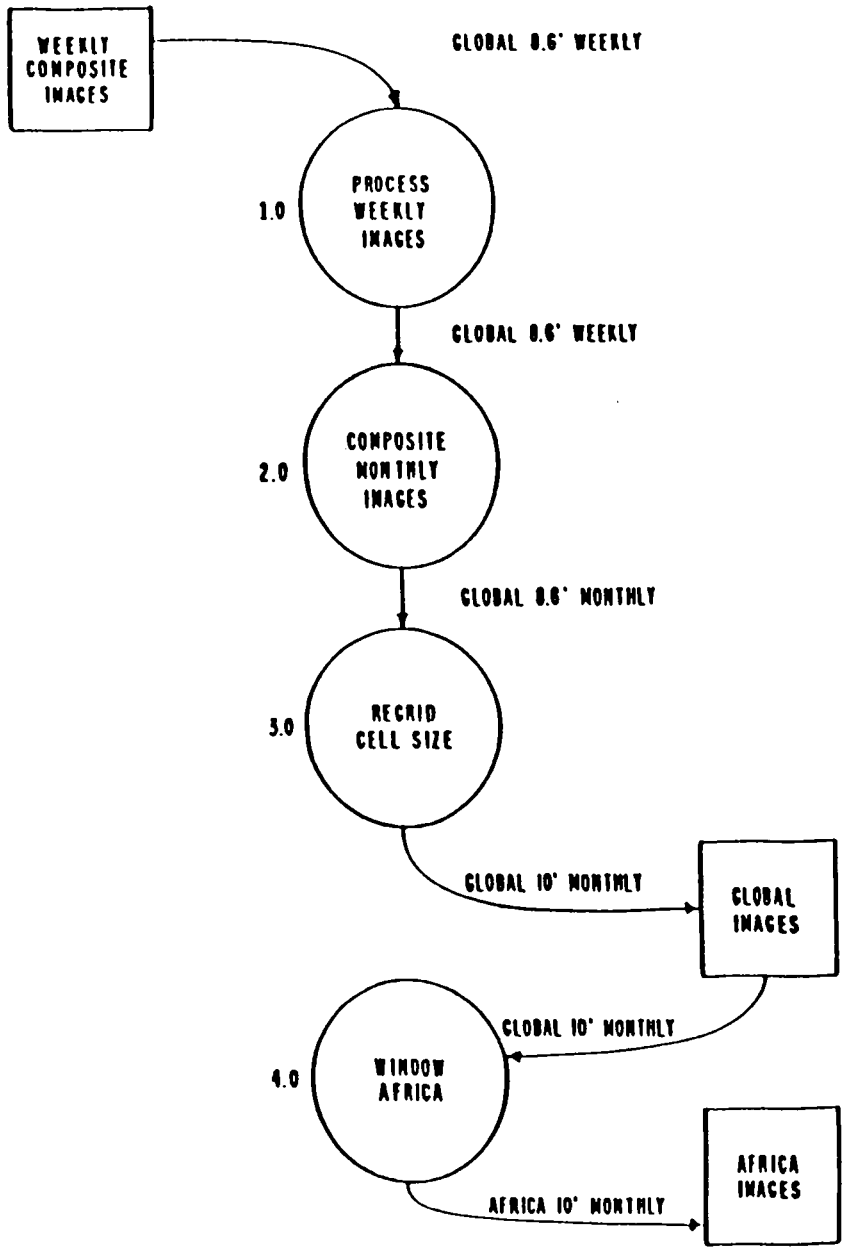
In images with vegetation, the NDVIs range from 0.1 m to 0.6 m, the higher values being associated with greater density and greenness of the plant canopy. Atmospheric effects, such a scattering and sub-pixel-sized clouds, all act to increase the value of Ch1 with respect to Ch2 and reduce the values of the computed vegetation indices. The normalized index has another advantage for global vegetation monitoring, for it partially compensates for changing illumination conditions, surface slope, and viewing aspect. Clouds, water, and snow have greater reflectance in the visible than in the near infrared, so for these features NDVI values are negative. Rock and bare soil have similar reflectances in the visible and near infrared and this results in vegetation indices near zero.

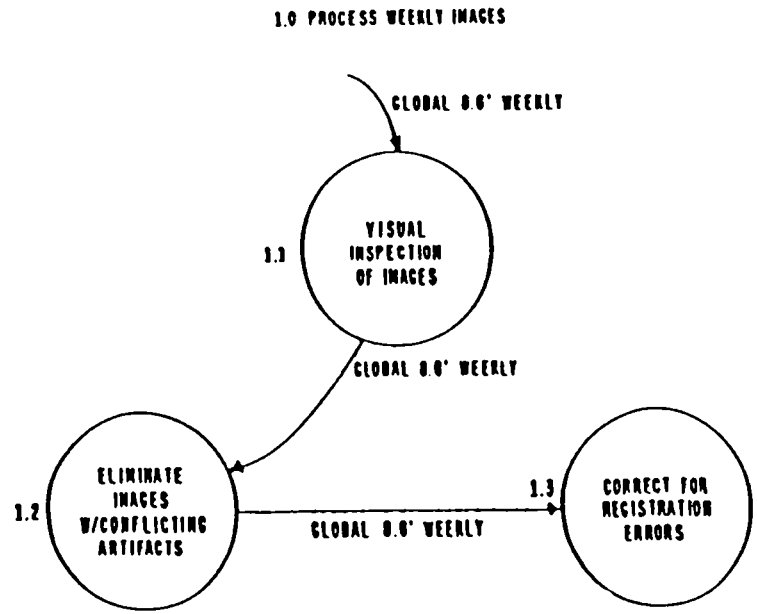
The data provided by NOAA were scaled as integer values from 0 to 255 according to the formula NDVI = 240-(XVI+0.05)*350 (see Global Vegetation Index User's Guide). In processing, however, the scale was inverted by subtraction from 255, so that high values in the data correspond to high vegetation signals. Thus the values used in compositing and re-gridding are described by the formula:

$$NDVI = (XVI+0.05)*350 + 15$$

The satellite images were re-sampled from weekly to monthly averages in a series of steps. Two procedures were used to control the quality of these composite images. First, registration accuracy was ensured by alignment of recognizable geographic locations. Second, each weekly composite image was visually inspected for artifacts (i.e., scan lines, image swaths, and other system noise). If an artifact occurred at the same location in two or more images, only one of those images was used. The remaining artifacts were removed during the monthly composite procedure, which combined all weeks which overlapped the calendar month (thus providing up to one week overlap between months). In this procedure, the high and low weekly values for each cell were eliminated and a root-mean-square average of the remaining weekly values was calculated. This technique eliminated random artifacts and biased the result toward higher (and presumably more reliable) values, without forcing the monthly value to its maximum. The result is therefore a statistic that is presumed to be representative of the month's vegetation activity; however, as with any such index, it must be calibrated or classified using additional information. Also, these values are uncorrected for orbital parameters or sensor drift.

PROCEDURE FOR DEVELOPING NVI MONTHLY COMPOSITE IMAGES FOR AFRICA





FLOW CHART FOR NDVI PROCESSING

Weekly composites in global Platte Carre projection (NOAA/SDSD).

1.0 Process weekly images.

1.1 Visually inspect images for artifacts and registration errors.

1.2 Eliminate images with conflicting artifacts (i.e. where artifacts overlap the same area).

1.3 Correct for registration errors.

2.0 Composite each month using an "Root-mean square (RMS) average of the median values (eliminating the high and low values for each pixel) and correcting for registration errors.

3.0 Re-grid from original 8.6-minute image cell to 10-minute cell size.

4.0 Produce both global and Africa windows.

Notes:

1. Averaging only the median values for a given month eliminates random errors evident in the original images. A "clean" image is guaranteed for the African continent by the visual inspection and selection process, which insures that no two artifacts overlap in Africa. An RMS average was chosen as a more meaningful statistic given the greater likelihood for high NDVI values to be representative of the vegetation (due to cloud effects). This was considered superior to choosing only the highest values because of the goal of producing a statistic representing a time-average of the month's vegetation "signal," rathern than selecting peak times.

2. The re-gridding procedure employs an averaging process weighted by the percentage of cell overlap in converting from the 8.6-minute grid to a 10-minute grid. This fairly robust procedure provides a statistic that is as representative as possible for a given 10-minute cell. Since a given pixel from each source image, of the original Plate Carree grid has an uncertainty in position on the order of one pixel, the final average is of a somewhat random sample within a definable region, roughly the size of a 10-minute cell.

3. The greatest remaining bias in the resulting images is due to cloud obscuration, for which no correction was attempted other than the NOAA compositing procedure of choosing the highest NDVI when producing the weekly composites. Various cloud corrections may be attempted using other data sets in conjunction with this set of monthly NDVI images.

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GLOBAL VEGETATION INDEX
USER'S GUIDE

MAY 1990

Compiled and edited by:

Katherine B. Kidwell

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(Only Excerpts Included)

TABLE OF CONTENTS

1.0 Introduction 1

2.0 Computation of Global Vegetation Index (GVI) . . . 3
2.1 Background 3
2.2 Processing Overview 4
2.3 Changes in the First Generation (Experimental) GVI Product 6

3.0 Second Generation GVI Product 7
3.1 Introduction 7
3.2 Plate Carreé Projection 9
3.3 Daily Processing 9
3.3.1 Processing of AVHRR GAC Data Sets . . 10
3.3.1.1 Processing of GAC Scan Lines . 10
3.3.1.2 Scan Angle Processing 11
3.3.1.3 IR Temperature Look-up Table Generation 11
3.3.2 Updating the Basic Composite Arrays . 12
3.3.3 Weekly Composite Arrays 13

1.0 Introduction

This User's Guide describes the Global Vegetation Index (GVI) Product that is archived by the Satellite Data Services Division (SDSD) of NOAA's National Climatic Data Center (NCDC) under the National Environmental Satellite, Data, and Information Service (NESDIS). It includes the current Second Generation version of the product produced from April 1985 to the present, in addition to the earlier First Generation version produced from May 1982 through March 1985.

This guide contains a section describing the vegetation index itself, descriptions of the two generations of GVI products, and information on how they may be ordered from SDSD.

2.0 Computation of Global Vegetation Index (GVI)

This section provides technical background on the Global Vegetation Index (GVI) and an overview of how the product is produced and changes that were made in the production of the First Generation experimental product.

2.1 Background

The spectral reflectance of chlorophyll pigment in the visible and near infrared part of the spectrum provides a means of monitoring density and vigor of green vegetation. Green leaves have a reflectance of less than 20 percent in the 0.5 to 0.7 μm spectral interval, but about 60 percent in the 0.7 to 1.3 μm range. Differential reflectance in these bands has been widely used with LANDSAT multispectral data to classify land cover, estimate crop acreage, and detect plant stress.

NOAA series operational meteorological satellites provide data that can be used for vegetation monitoring. The Advanced Very High Resolution Radiometer (AVHRR) flown currently on NOAA-11 and previously on NOAA-7 and NOAA-9 is a 5-channel instrument which scans continuously at a ground resolution of 1 km. The 1 km data is sampled and averaged to a nominal 4 km resolution and recorded on board the satellite for subsequent transmission. AVHRR Global Area Coverage (GAC) at 4 km resolution is thus available. This coverage is supplemented by 1 km resolution coverage of selected areas using AVHRR LAC (Local Area Coverage) data. The sampling done on board the satellite to produce the GAC data consists of selecting every third 1 km LAC data line, and selecting four of every five samples along the line and averaging these to yield one GAC sample. Thus the nominal "footprint" of a GAC sample is 1 km by 4 km, with (near nadir) gaps between GAC lines and small gaps between GAC samples. LAC and GAC samples are 10 bit binary "count" values (digitized voltages).

The spectral response of the five AVHRR channels is as follows:

Channel 1	0.58	to	0.68	μm
Channel 2	0.725	to	1.10	μm
Channel 3	3.55	to	3.93	μm
Channel 4	10.30	to	11.30	μm
Channel 5	11.50	to	12.50	μm

The spectral bands used currently for vegetation monitoring are the Channel 1 visible band (0.58 to 0.68 μm) and Channel 2 in the near infrared band (0.73 to 1.10 μm). The spectral response curves for these channels are similar to those of bands 5 and 7 on the LANDSAT multispectral scanner. Various mathematical combinations of Channel 1 and 2 data have been found to be sensitive indicators of the presence of green vegetation and are referred to as vegetation indices. This effect is due to the differential reflectance of vegetation in these bands. Thus, the difference in the Channel 2 and Channel 1 data values (which are proportional to the reflectance of the scene viewed) computed as *Ch2-Ch1* is a measure of the degree to which the scene viewed includes green vegetation.

The basic index is the Normalized Difference Vegetation Index, (*NDVI*). It is the main GVI product produced between May 1982 and the present. The *NDVI* is defined by the equation:

$$NDVI = \frac{(Ch2 - Ch1)}{(Ch2 + Ch1)}$$

where *Ch1* and *Ch2* are count values from Channel 1 and Channel 2, respectively of the AVHRR instrument. The *NDVI* is preferred for global vegetation monitoring because it partially compensates for changing illumination conditions, surface slope, and viewing aspect. Clouds, water, and snow have larger reflectances in the visible than in the near infrared, so for these features *NDVI* is negative. Rock and bare soil have similar reflectances in these two bands and result in vegetation indices near zero. In scenes with vegetation, the *NDVI* ranges from 0.1 to 0.6; the higher values are associated with greater density and greenness of the plant canopy. Atmospheric effects such as scattering by dust and aerosols, Rayleigh scattering, and subpixel-sized clouds all act to increase *Ch1* with respect to *Ch2* and reduce the computed vegetation indices.

Research performed with the First Generation GVI product, which included only *Ch1*, *Ch2*, *Ch2-Ch1*, and *NDVI* values mapped on a Polar-Stereographic grid, suggested that additional information would be of help in mitigating the effects of cloud contamination and facilitating year to year comparisons of *NDVI* values over the same areas. (Appendix A is a bibliography of significant research reports selected to be of most value to the users of the GVI products.) Thus, the Second Generation GVI product also includes Channel 4 and Channel 5 IR data values, which may be of use in cloud screening, and Solar Zenith and Scan angles, which should assist in normalizing *NDVI* values for year to year comparisons.

2.2 Processing Overview

Daily GVI maps are produced by processing AVHRR data orbit by orbit and mapping it to a standard base projection. Briefly, this process consists of truncating the original 10 bit GAC data to 8 bit data and scaling. When the IR channels were added (for the Second Generation product), they were calibrated, tuned to temperature and scaled. The standard base projection was Polar-Stereographic from May 1982 through March 1985 (First Generation version), and is currently Plate Carreé (or latitude/longitude) for the Second Generation version of the product, April 1985 through the present. On a weekly basis, Polar-Stereographic composites were produced from May 1982 to the present, with Mercator composites also produced for data from April 1985 to the present. The NOAA-11 satellite (and previously the NOAA-7 and NOAA-9 satellites) is in a sun-synchronous near-polar orbit with equator crossings at about 0230 and 1430 local time. A single day's map consists of a mosaic of the daytime portion of 14 orbital swaths. The Polar-Stereographic maps are on a one-sixteenth sub-mesh grid of the standard 65x65 Polar-Stereographic projection used by the National Meteorological Center and the Air Force Global Weather Center. Resolution in the mapped data ranges from 13 km at the equator to 26 km at the poles. The data are sampled in the mapping process so that the GVI in an array location consists of a value computed from a single AVHRR pixel; there is no averaging.

On any single day, about half the Earth is obscured by clouds. To remove clouds, seven-day maximum vegetation index composites are produced from the daily arrays. For each composite period of seven days, the pixel from the daily data having the greatest *Ch2-Ch1* difference (computed from counts, i.e., uncalibrated) is retained at each array location (i.e. the "greenest" of the seven daily values for each array location is retained in the composite). This eliminates clouds from the composite except for areas which were cloudy at the time of satellite overpass for all seven days. When several cloud-free views of an area are obtained over the compositing period, *NDVI* values computed on days with haze and subpixel clouds are eliminated. The values of *Ch1*, *Ch2*, *Ch4*, *Ch5*, *Solar Zenith* and *Scan Angles* that are also present on the composite products are for the same day's data as the *NDVI* value selected for the composite.

The weekly cycle for the First Generation GVI product began with Monday and ended on the following Sunday. Beginning with the Second Generation GVI product in April 1985, the weekly cycle was synchronized by Julian day (i.e., Julian days 1 through 7 were always the first week, Julian days 8 through 14 were the second week, etc.). This scheme causes the weekly cycle to vary from year to year depending on what day of the

week January 1 falls on (e.g., the weekly cycle for 1985 runs from Tuesday through the following Monday, while 1986 runs from Wednesday through the following Tuesday).

When DPSS took over the GVI processing on April 11, 1988, the weekly cycle was changed again to Monday through the following Sunday. This cycle does not change from year to year.

2.3 Changes in the First Generation (Experimental) GVI Product

Because the First Generation *NDVI* was an experimental product, users are cautioned that changes in the computation of the daily arrays were made as more was learned about the cloud contamination problem. This trial and error process went through the following steps:

1. From May 10, 1982 (Julian day 100) through August 7, 1982 (Julian day 219), the daily *NDVI* was computed from the last value mapped to each location on the Polar-Stereographic output grid. This was regarded as a random sampling.

2. From August 8, 1982 (Julian day 220) through September 12, 1982 (Julian day 255), the daily *NDVI* was computed from the *Channel 1* and *Channel 2* values with the greatest difference mapped to each location on the Polar-Stereographic output grid. This resulted in an apparent marked improvement in the removal of cloud contamination, but was not a random sampling, in that it selected the "greenest" pixel for each map location on a daily basis.

3. From September 13, 1982 (Julian day 256) to March 27, 1983 (Julian day 86), the "greenest" pixel from only every other AVHRR scan line was mapped, to save computer time and restore a degree of "randomness" to the sampling.

4. From March 28, 1983 (Julian day 87) to the present, the sampling was changed back to the random method (using the last sample mapped to each grid cell in use from May 10 to August 7, 1982). Data from only every other scan line is being used to save computer time. This method is used in the current Second Generation *NDVI* product.

3.0 Second Generation GVI Products (April 1985 - Present)

This section describes the enhanced, Second Generation GVI product currently being produced operationally by the Data Processing and Services Subsystem's (DPSS) IBM 4381 which is managed by the Information Processing Division (IPD), Office of Satellite Data Processing and Distribution (OSDPD) of NOAA/NESDIS. SDSD produced the Second Generation GVI product operationally until April 1988 when DPSS took over this function.

3.1 Introduction

The process by which the GVI products are produced takes place in two phases. The first phase involves production of a set of daily master arrays from each day's AVHRR GAC data sets and the updating of the basic set of composite arrays. The second phase consists of the production of a set of final weekly composite products from the composite arrays.

The Plate Carreé projection, or latitude/longitude, was selected as the map projection to be used for the daily master arrays and the basic composite arrays, and is discussed in section 3.2 below.

Each AVHRR GAC Level 1b data set contains data from one orbit of the satellite (currently NOAA-11). The orbital period is 102 minutes, so there are approximately 14.1 orbits every 24 hours. Thus, there will be 14 and occasionally 15 data sets to be processed each day for global coverage. Each GAC data set contains approximately 6,600 records, each consisting of two scan lines with 409 data points (i.e. 409 sets of data values from the five AVHRR channels) per scan line. The total volume of one day's worth of GAC data (15 orbits) would be 637.56 megabytes. Only one quarter of this data volume is actually processed, since only daytime data and only data from every other scan line are used.

The six daily master arrays, each 2500 X 904 elements in size, consist of the following data:

1. Channel 1 (*Ch 1*)
2. Channel 2 (*Ch 2*)
3. Channel 4 (*Ch 4*)
4. Channel 5 (*Ch 5*)
5. Solar Zenith Angle (*SZ*)

6. Scan Angle (*SA*)

The *Channel 1* and *Channel 2* values are original count values truncated to 8 bit precision. The *Channel 4* and *Channel 5* values are then converted to "GOES counts" (intended originally for use with geostaticnary satellites). The GOES counts are 8 bit binary numbers corresponding to temperature values according to a standard look-up table (Appendix B). The *solar zenith angle* and the *scan angle* values are scaled binary values to the nearest half of a degree. As noted, the *Channel 4* and *Channel 5* binary counts are converted to "GOES" counts before they are mapped. This involves using the channel calibration coefficients to convert the binary counts to energy values, then using the inverse of Planck's radiation formula, convert the energy values to absolute temperatures, and finally scaling the temperature values to 8 bit binary values to be placed in one byte as GOES counts. In practice, the computation is performed once for each possible data value, for each of the two IR channels, to create a set of look-up tables which will be used for the actual data processing.

The basic composite arrays, each of which have 2500 by 904 elements, include the six items listed above plus a Normalized Difference Vegetation Index array (*NDVI*).

Each week, these seven basic composite arrays are used to produce the Mercator maps and the Polar-Stereographic arrays.

The resolution selected for the Plate Carreé arrays is 16 km at the equator, which results in the 2500 X 904 element size array to map the region between 75° North and 55° South.

All seven weekly composite Plate Carreé arrays are converted to the corresponding Mercator arrays; each Mercator array consisting of 2048 X 1038 elements corresponding to a resolution of 19.5 km at the equator.

All seven weekly composite Plate Carreé arrays are converted to Polar-Stereographic arrays. Each hemisphere is a 1024 by 1024 element array, consistent with the Polar-Stereographic First Generation GVI product. The Polar-Stereographic arrays have a better resolution of 13 km at the equator compared to the corresponding resolution of 16 km for the master Plate Carreé arrays. To avoid "holes" in the Polar-Stereographic arrays near the equator (within 15° latitude north or south), the mapping process fetches a pixel from the Plate Carreé arrays for each cell in the Polar-Stereographic array, which results in repetition of some pixels (where otherwise holes would have occurred). As a result of the latitude limits (75° North to 55°.South) selected to include significant land areas but also to minimize processing, Polar-Stereographic arrays

produced from the Plate Carreé arrays have conspicuous "holes" around the poles.

3.2 Plate Carreé Projection

Several map projections were considered for the daily master arrays: Mercator, Equal Area, and Plate Carreé. Plate Carreé was selected because it is the simplest for data processing, and it provides a reasonable representation of the problematic polar regions, where both the Mercator and the Equal Area projections would be more distorted.

The Plate Carreé projection is not conformal, but has the following simple form:

$$X = \frac{IN}{360} \times (\lambda - \lambda_0)$$

$$Y = \frac{IN}{360} \times \phi$$

where λ and ϕ are respectively the longitude and the latitude, measured in degrees, while λ_0 is the central longitude. The value for λ_0 is 0°, corresponding to the Greenwich Meridian, which will be at the center of the array, and with the edges of the array being 180° of longitude East and West. IN is the number of non-duplicated pixels in the array in the East-West direction. IN is set to 2500, corresponding to a resolution of 16 km at the equator. The I and J values on the map are given by:

$$I = X + 1250$$

$$J = -Y + 522$$

where I ranges from 1 to 2500, while J ranges from 1 to 904, covering the latitude range of 75° North to -55° South.

Longitudes are measured from 0° to +180° eastward and from 0° to -180° westward, which is the convention used to store the values within the GAC data sets.

3.3 Daily Processing

This section describes the daily processing of GAC data sets and updating of the basic composite arrays.

3.3.1 Processing of AVHRR GAC Data Sets

A given GAC data set is read record by record, and for each record of daytime data one scan line is processed. The *Ch1*, *Ch2*, and *Ch4* data are extracted and mapped to the corresponding master daily arrays and held in computer memory. The *Ch5*, *SZ*, and *SA* data are held in a temporary disk file. Once the entire master arrays are written to disk, the *Ch5*, *SZ*, and *SA* arrays are read in, and updated from the temporary file. When this process is completed for a GAC data set, another is processed, until the full day's worth of GAC data sets have been processed.

3.3.1.1 Processing of GAC Scan Lines

The first of two scan lines packed in each GAC record is examined. If the scan line contains night time data, or if earth location or calibration information is missing, the scan line is skipped. If the latitudes are outside the range of 75° North through 55° South, the scan line is skipped. For a good scan line, first latitude and longitude values for each of the 409 data points are interpolated from the 51 benchmark latitude/longitude pairs. These earth locations are converted into 409 pairs of (*I,J*) values on the Plate Carreé array, indexing the positions to which each GAC pixel will be mapped. Then the Solar Zenith (*SZ*) angles are interpolated for the 409 data points from the 51 benchmark values.

The five channel count values for each data point are then unpacked from the video data and truncated to 8 bit precision. The *Ch4* and *Ch5* count values are converted to GOES counts using a pre-computed look-up table (refer to Appendix B). This processing yields 10 bytes of information to be mapped for each GAC data point:

a. *I, J* location for this data point on the daily master array, 4 bytes;

b. *Ch1, Ch2* count values, 1 byte each;

c. *Ch4, Ch5* GOES count values, 1 byte each;

d. *SZ* and *SA* values, 1 byte each.

These data are then used to update the daily master arrays as outlined above. Since the resolution of the GAC data (4 km) is much finer than the resolution of the Plate Carreé arrays, a number of GAC pixels will be mapped to each location in the Plate Carreé array. Each value will replace the one previously written. Thus, a selection of one GAC sample is

made to represent the population of GAC samples to be mapped to that location. Because the selection does not depend upon the value of the sample, this selection process is regarded as random (as opposed to basing the selection on the value of the *Ch2-Ch1* difference, as was experimented with for a time while the First Generation GVI product was being produced).

3.3.1.2 Scan Angle Processing

The scan angle for one orbital swath range from -55.4° to +55.4° relative to nadir, a total span of 110.8°. Scan angles to the nearest half-degree corresponding to the 409 sample positions on a scan line are calculated as a binary count of half-degree steps from 0, for sample 1; to 222, for sample 409. The nadir point will therefore correspond to 110.8 half-degree steps, rounded to 111.

The scan angle *SA* in half-degree steps for the Nth sample position is given by:

$$SA = \frac{221.6}{2047} \times (5N-1)$$

where $1 \leq N \leq 409$. The scan angle values are stored in one byte as binary integers.

3.3.1.3 IR Temperature Look-up Table Generation

Look-up tables are used to convert *Ch4* and *Ch5* values to GOES counts. The first step is the conversion of the possible range of count values to radiances, using the *Channel 4* and *Channel 5* calibration coefficients present in the GAC scan line:

$$E = M \times N + S$$

where N is the raw channel count; M is the slope parameter for the channel; S is the intercept parameter for the channel; and E is the channel radiance (energy) in milliwatts/m^2-steradian-cm^{-1}.

The radiances in turn are converted to the absolute temperatures, by the following:

$$TA = \frac{A \times \nu}{\ln\left[1 + \frac{(B \times \nu^3)}{E}\right]}$$

where *TA* is the absolute temperature in °K; $A = 1.438833$ cm-°K; $B = 1.1910659 \times 10^{-5}$ milliwatts/m^2-steradian-cm^{-4}; ν is the central wave number where $\nu = 929.46$ cm^{-1} for Channel 4 of NOAA-9, and $\nu = 845.19$ cm^{-1} for Channel 5 of NOAA-9.

The temperatures are then rescaled to GOES count values (so they will fall in the range from 0 to 255) using the following equation:

$$GOES = C \times TA + D$$

where *GOES* is the GOES count value, and *TA* the absolute temperature. Constants *C* and *D* have the values $C = -1.006412$ and $D = 419.05128$ for temperatures in the range $164°K \leq TA \leq 242°K$; and $C = -2.0057142$ and $D = 661.88571$ for temperatures in the range $242°K < TA \leq 330°K$.

The result are two look-up tables of 255 GOES count values, a Channel 4 table and a Channel 5 table. Appendix B contains a single GOES count to absolute temperature conversion table that may be used to recover the absolute temperature values.

3.3.2 Updating the Basic Composite Arrays

Each day the seven basic composite Plate Carreé arrays are updated from the six new daily master arrays. Updating of the composites is performed cell by cell. The difference of the Channel 2 and Channel 1 values (*Ch2-Ch1*) for the new data is computed, and compared to the *Ch2-Ch1* value for the corresponding element of the basic composite array. If the new difference is greater (i.e., if the cell is "greener" or clearer) then the *NDVI* value for the new data point is computed and replaces the *NDVI* value in the basic composite array, and the values in the other six basic composite arrays for that cell location are replaced by the corresponding six values from the new daily master arrays. Thus, compositing is bypassed if the new cell is less "green" than the corresponding cell in the basic composite arrays. Compositing is also bypassed if the difference value for the new cell is 255. If compositing is bypassed, the cell values in all seven basic composite arrays are left unchanged.

When a new data point is to be composited (i.e. when its value replaces the previous cell value in the basic composite

arrays), its *NDVI* value is computed from the data point's *Ch1* and *Ch2* values from the new daily master array, as follows:

$$XVI = \frac{(Ch2 - Ch1)}{(Ch2 + Ch1)}$$

where *XVI* is an unscaled *NDVI* value, and *Ch1* and *Ch2* are the Channel 1 and Channel 2 count values, respectively. Thus, NDVI is computed as follows:

$$NDVI = 240 - (XVI + 0.05) \times 350$$

The values of *XVI* range from -.05 (no green) to +.60 (greenest). These values are then scaled to an eight bit binary integer, so that the greenest areas appear the darkest when an image is produced. Thus, a *scaled NDVI* value of 240 (white) corresponds to an unscaled *XVI* value of -.05, and a *scaled NDVI* value of 12 (black) corresponds to an unscaled value of +.60.

The process described above is performed for every data point (cell) in the daily master arrays.

3.3.3 Weekly Composite Arrays

Once a week, the seven basic composite arrays (which are in the Plate Carreé projection) are used to produce a set of Polar-Stereographic and Mercator arrays. The mapping is done by sequentially filling each cell location in the Polar-Stereographic or Mercator arrays with a value from a location on the Plate Carreé arrays to ensure that there are no "holes" (i.e. cell locations that do not receive values) resulting from the difference in resolution of the new arrays compared to the Plate Carreé arrays.

3.4.2 Weekly Composite GVI Products

The weekly composite GVI product tapes contain the seven files listed above for the daily master array tape with the addition of an eighth file containing *scaled NDVI* data. Three types of weekly tapes are produced: a Plate Carreé tape, a Polar-Stereographic tape, and a Mercator tape. In each case, the contents of File 1 is a single Documentation Record. The number of days worth of data used to produce the composite, and identification of their Julian dates, is also included.

The Documentation Record contains the following information:

Bytes	# Bytes	Contents
1	1	Number of days of compositing;
2	1	Unused, blank filled;
3 - 8	6	First date processed (YYDDDb);
9 - 14	6	Second date processed (YYDDDb);
.	.	.
.	.	.
39 - 44	6	Seventh date processed (YYDDDb);
45 - 5000		Blank filled.

where YYDDDb indicates the date as the last two digits of the year (YY), Julian day (DDD), and one blank character (b).

Files 2 through 8 of each type of tape contain data arrays (in the same order as the daily master array tape with the addition of the *NDVI* file as file #8) formatted as follows.

3.4.2.1 Plate Carreé Tape

The format of files 2 through 8 of the Plate Carreé weekly composite product tape is the same as the daily master array tape format described in Section 3.4.1, except for the addition of the *NDVI* file as file #8.

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- B -

OLSON WORLD ECOSYSTEMS (WE1.4)

CITATION: Olson. J. S.. 1989. World Ecosystems (WE1.4) Digital Data. NOAA/NGDC/WDC-A, Boulder, Colorado. 2.3 MB.

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B. OLSON WORLD ECOSYSTEMS (WE1.4)

DATE: 1989

SOURCE:

(1) From available maps and observations.
Jerry S. Olson
Global Patterns Company
Box 361A, Rt. 2
Lenoir City, TN 37771

(2) Reprocessed by:
Jerry Olson, Lee Stanley, Jeff Colby, Mark Ohrenschall
NOAA/NGDC
Boulder, CO

CONTRIBUTOR:

Jerry S. Olson
Global Patterns Company
Lenoir City, TN 37771

DATA CENTER: NGDC/WDC-A

GEOGRAPHIC SAMPLING:

.5 degree grid (with 10-min updates for Africa), characteristic classes

COVERAGE: Global

PROJECTION: Lat/lon

TIME SAMPLING: Decadal composites

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FILE NAME: AFWE 14 Olson Ecosystem Classes Version 1.4

OLSON WORLD ECOSYSTEMS (WE 1.4)
DOCUMENTATION FILE

File Name: AFWE 14.DOC

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maximum     :   7.2000000000E+01
cell x      :   1.6666666667E-01
cell y      :   1.6666666667E-01
legend      : 72
category  1 :  1   CCX       City complexes--being added for MM4 type cat.1
category  2 :  2   SPV       Shortgrass prairie variant of 40 or 41
category  3 :  3   Not used
category  4 :  4   Not used
category  5 :  5   Not used
category  6 :  6   TMT       Temperate to montane tropical (major forest
                             and woodland)
category  7 :  7   Not used
category  8 :  8   DMB       Desert, mostly bare
category  9 :  9   Not used
category 10 : 10   Not used
category 11 : 11   Not used
category 12 : 12   Not used
category 13 : 13   Not used
category 14 : 14   Not used
category 15 : 15   Not used
category 16 : 16   Not used
category 17 : 17   ICE       Antarctic ice, land or grounded shore ice
category 18 : 18   Not used
category 19 : 19   Not used
category 20 : 20   SRC       Snowy, rainy coastal conifer (with alder etc.)
category 21 : 21   MBC       Main Boreal conifers
category 22 : 22   SNB       Snowy non-Boreal conifer forest
category 23 : 23   CDS       Conifer/deciduous, snow persisting in winter
category 24 : 24   SED       (semi) Evergreen deciduous, little/no snow
category 25 : 25   SDF       Similar to 26, snow persisting in winter
category 26 : 26   TDF       Temperate ~deciduous forest, little or no snow
category 27 : 27   NSC       Non-snowy conifer forest
category 28 : 28   TMC       Tropical montane complexes (tree & other)
category 29 : 29   TSF       Tropical seasonal forest (~evergreen...)
                             (major forest/woodland)
category 30 : 30   CFS       Cool farmland & settlements (~snowy)
category 31 : 31   MFS       Mild/hot farmland & settlements
category 32 : 32   RGD       Rain-green (drought-deciduous) (major forest
                             and woodland)
category 33 : 33   TRM       Tropical rainforest (major forest and
                             woodland)
category 34 : 34   Not used
category 35 : 35   Not used
```

category 36 :	36	PRA	Paddy rice and associated lands (part anaerobic)
category 37 :	37	WCI	Warm/hot crops with extensive irrigation
category 38 :	38	CCI	Cool crops with irrigation (variable extent)
category 39 :	39	CCP	Cold crops, pasture, irrigation ~local
category 40 :	40	CGS	Cool (snowy) grass/shrub (including much 2)
category 41 :	41	MGS	Mild/warm/hot grass/shrub
category 42 :	42	CSM	Cold steppe/meadow +/- larch, scrub
category 43 :	43	STB	Savanna, mostly tallgrass + bush fallow/woods
category 44 :	44	MAG	Mire (acid bog &/or groundwater-fed fen) ~cold peatland (or muck): sphagnum, grass-like, and/or dwarf shrub or mire tree vegetation
category 45 :	45	MOS	Marsh or other swamp (warm-hot) salty/ freshwater marsh, thicket, ~flooded woods
category 46 :	46	MET	Mediterranean evergreen tree/scrub (winter rain)
category 47 :	47	ODH	Other dry or highland scrub/tree (juniper, etc.)
category 48 :	48	EAQ	Eucalyptus or Acacia, quebracho, saxaul
category 49 :	49	HVI	Hot-mild volcanic "islands"(variable vegetation)
category 50 :	50	SDB	Sand desert, partly blowing
category 51 :	51	ODS	Other desert and semidesert
category 52 :	52	CSS	Cool/cold shrub semidesert/steppe (sagebrush...)
category 53 :	53	TUN	Tundra (polar, alpine)
category 54 :	54	TRC	Temperate rainforest (+/- conifer) (major forest and woodland)
category 55 :	55	SCW	Similar to 58: cool-cold (~persistent snow)
category 56 :	56	RWC	Regrowing woods + crop/grass
category 57 :	57	SWC	Similar to 56: cool-cold (~persistent snow)
category 58 :	58	GCW	Grass/crop + <40% woods: warm, hot
category 59 :	59	STW	Succulent and thorn woods
category 60 :	60	SDT	Southern dry taiga (and other aspen/birch, etc.)
category 61 :	61	SLT	Siberian larch taiga [partly other taiga 21]
category 62 :	62	NMT	Northern or maritime taiga/tundra
category 63 :	63	WTM	~Wooded tundra margin (or mt. scrub, meadow)
category 64 :	64	HMW	Heath and moorland, wild or artificial (~grazed)
category 65 :	65	NW	NW quadrant near most land (...mainland, large island, ...)
category 66 :	66	NE	NE quadrant near most land (...peninsula, small islands, ...)
category 67 :	67	SE	SE quadrant near most land (...or isthmus)
category 68 :	68	SW	SW quadrant near most land
category 69 :	69	PDL	Polar desert (rock lichens)
category 70 :	70	GLA	Glaciers (other polar and alpine)
category 71 :	71	SSF	Salt/soda flats (playas, lake flats rarely ~wet)
category 72 :	72	MSM	Mangrove swamp/mudflat [Africa only]

{category 0 : unclassed}

[This legend is appropriate for display of the individual classes (i.e. without rescaling).]

OLSON WORLD ECOSYSTEMS (WE1.4)

DATA UPDATING PROCEDURES

Jerry Olson, Lee Stanley, Jeff Colby and

Mark Ohrenschall

National Geophysical Data Center

Boulder, Colorado

During the summer of 1989 Dr. Jerry Olson, Lee Stanley and research assistants from the National Geophysical Data Center updated the data set, "Major World Ecosystem Complexes Ranked by Carbon in Live Vegetation: A Database." The results of this update have been incorporated into Olson World Ecosystem WE1.4.

Data were revised at both 30 and 10 minute-resolution. Changes were first made for the 30 minute data between 20 degrees West and 70 degrees East. In addition modifications were made to limited portions of the United States data. Revisions were made in the following ecological classes--tropical forest (type 33), polar deserts (type 69), ice (type 70), and a few areas of mangrove/tropical swamp forest (type 72). Updates for the United States were quite limited and affected mostly the islands and coastlines of Alaska. To a lesser extent changes were made along the western and eastern coastlines of the lower 48 states.

Modifications at 10 minute-resolution were numerous, but were confined to the African continent and some coastlines. They included changes in tropical montane complexes (type 28), broadleaved evergreen forest types at high altitudes with cool climates despite tropical latitudes (type 6) (for example in Cameroon, Ethiopia, other areas of East Africa and some in the Atlas Mountains), mangrove tropical swamp forests (type 72), and coastlines. Salt/soda flats (type 71) were not systematically reviewed but received sample editing.

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(legwe2.0, Aug. 17, Revised DEC. 7, 1989; edit Jan. 21, 1990) FREE copying.
Questions: 615/376 2250)

LEGEND/CAPTIONS FOR WORLD ECOSYSTEM MAP/DATABASE version 2.0 (or 3.0)

Jerry S. Olson, Global Patterns Company, Box 361A, Rt. 2, Lenoir City TN 37771

Broad Groups (and symbols for printer character output) on the left are here related to the Biosphere Atmosphere Transfer Scheme (BATS) codes of Dickinson et al. (1986) at the National Center for Atmospheric Research (NCAR), box 3000, Boulder, Colorado, 80307-3000. The middle list and numbers under the WE2.0 heading match improved versions of the Map of Major World Ecosystem Complexes (Olson and Watts 1982) with half degree (30') cells. Additional or alternative numbers are being tested for 10' sub-cell database for the International Council of Scientific Unions (ICSU) and World Data Center A, National Geophysical Data Center of U.S. National Oceano graphic and Atmospheric Administration (NOAA).

****

Table 1. Groupings of World Ecosystem Complexes and Dominant Vegetation

Printer Group symbol	Landscape/Life Form b BATS #/GROUP	Major World Ecosystems (WE) a Vegetation/climate	WE2.0	provisional colors or other variables
	WETLANDS, COASTS, AND WATER			
	Waters, including--		0	Pale
	15 Ocean		(15)	BLUE
	14 Inland Waters (dominating 30' cells)		(14)	
	Coast, Island			- - -
,		Shore & hinterland complexes	65-68	
		65...68 mean NW, NE, SE, or SW quadrant, respectively, near most land (mainland, large island, peninsula, small islands, or isthmus)		BLACK
*		Hot-mild volcanic "islands" (variable vegetation)	49	
,		[Other small islands/atolls--for 10' resolution	73]	_ _ _
!		[Rivers/small lakes + land, partly wooded	74]	(p. blue)
	Wetlands: major or intermittent methane sources			
	13 Swamp, Marsh, Bog, or Fen			
!		Mangrove swamp/mudflat [Africa only, Aug. 1989]	72	dark
		~saline forests, thickets, tideland, estuaries		RED
=		Marsh or other swamp (warm-hot)	45	
		salty/freshwater marsh, thicket, ~flooded woods		- - -
_		Mire (acid bog &/or groundwater-fed fen), ~cold	44	
		peatland (or muck): sphagnum, grass-like, and/or dwarf shrub or mire tree vegetation		light CYAN
	10 Irrigated Crops--ONLY the following grouped here:			
#		Paddy rice and associated lands (part anaerobic)	36	
		(See below for other cropland types.)		
	TUNDRA-LIKE AND/OR DESERT			
	Deserts and Semideserts (nonpolar)			
~		Salt/soda flats (playas, lake flats rarely ~wet)	71	
:	8 Desert: mostly bare		8	
.		Sand desert, partly blowing	50	BROWN
;		Other desert and semidesert	51	- - -
;	11 Cool/cold shrub semidesert/steppe (sagebrush...)		52	
				GRAY

```
      Polar and Alpine                                                  black
:          Polar desert (rock lichens)                        69        ____
.      12  Glaciers
            Antarctic ice, land or grounded shore ice  <17-->12>        WHITE
            Glaciers (other polar and alpine)                 70
           ---------------------------------------------------------   - - -
       9   Tundra & Marginal Cold
^           Tundra (polar, alpine)                            53
!   16,17   ~Wooded tundra margin (or mt. scrub, meadow)      63        GRAY
+           Cold steppe/meadow +/-larch, scrub                42        black
             (Siberian to Himalayas or maritime No. Pacific)
```

```
  GRASSY &/OR CROP, SETTLEMENT LAND
.    Main Grass- &/or Shrub land
'           Cool (snowy) grass/shrub (including much 2)       40
-       2   Shortgrass prairie variant of above or following   2        pink
"           Mild/warm/hot grass/shrub                         41        - - -
=           Heath and moorland, wild or artificial (~grazed)  64
7       7   Savanna, mostly Tallgrass +bush fallow/ woods     43        RED
             Parts have seasonal waterlogging &/or ungulates;
             these parts and termites are methane sources.
     ---------------------------------------------------------------   -----
     Cropped, Residential, Commercial, Park, Marginal Lands
      10    Irrigated Drylands (besides paddy rice), +/- trees
(           Warm/hot crops with extensive irrigation          37        light
[           Cool crops with irrigation (variable extent)      38        GREEN
{           Cold crops, pasture, irrigation ~local            39
     ---------------------------------------------------------------   -----
       1    Other Crop/mixed Farming, Towns, Industrial complex
)           Mild/hot farmland & settlements                   31
s          [CITY COMPLEXES--being ADDED for MM4 type cat.1)    1        YELLOW
]           Cool farmland & settlements (~snowy)             .30
```

```
 "WOODS"--from forests to tall or dense scrub, frequently patchy:
   INTERRUPTED WOODS, artificial or natural mosaics with other cover
     [19] Second-growth Woods and Field Mosaics +/- Towns
/          Field/woods
G           Grass/crop + <40% woods: warm, hot                58
g           similar: cool-cold (~persistent snow)             55        light
%          Forest/field                                                 GREEN
F           Regrowing woods + crop/grass                      56
f           similar: cool-cold (~persistent snow)             57
          ---------------------------------------------------------   -----
           Narrow Conifers; gradients to scrub/meadow
&    [19]   Northern or maritime taiga/tundra                 62        light
           <Subalpine forest/meadow/thicket                   62a       CYAN
           Semiarid Woodland or Low Forest/Scrub + fields               -----
E    [19]   Eucalyptus or Acacia, quebracho, saxaul           48
     ---------------------------------------------------------
     Other Dry Woods Mosaics (+/- fields ~locally)                      BROWN
?   16/17  Other Dry or Highland Scrub/Tree (Juniper etc.)    47
m     16    Mediterranean evergreen tree/scrub (winter rain)  46
e    <16    other (mostly) evergreen scrub                    16>
d    <17    (mostly) deciduous scrub                     NEW  17>      ____________
           Tropical Succulent/thorn Woods or Montane
x   17/16   Succulent and thorn woods                         59
@    6+7    Tropical montane complexes (tree & other)         28
                                                                       VIOLET
```

```
      MAJOR FOREST AND WOODLAND, with cut/burn openings
       ~Tropical Dry Woodland/Forest
 s       5   Rain-green (drought-deciduous)                    32
       ~Broadleaved evergreen
 6       6   Temperate to montane tropical                      6
 T           Temperate rainforest (+/- conifer)                54
 R           Tropical rainforest                               33    PURPLE
 S           Tropical seasonal forest (~evergreen--            29
              OR ~semideciduous, or deciduous in monsoon area)
      ------------------------------------------------------------
      Other Deciduous and Mixed Forest and Woodland
       18  Mixed deciduous and conifer/evergreen
 M           (semi) Evergreen/deciduous, little/no snow        24    CYAN
 N           Conifer/deciduous, snow persisting in winter      23
             See also: southern and Siberian taiga below (60-61)

            Summergreen (~cold-deciduous, temperate) forests
 H           Temperate ~deciduous forest, little or no snow    26
 J           similar, snow persisting in winter                25    GREEN
 i          (Low deciduous woods of cold and/or dry areas       5)
      ------------------------------------------------------------
      Conifer (with some mixed and local broadleaved) Forest
        3  Evergreen needle-leaved forests (See also taiga)
 Q           Non-snowy conifer forest                          27
 P           Snowy non-Boreal conifer forest                   22    BLUE
 C           Snowy, rainy coastal conifer (with alder etc.)    20

            Taiga (Boreal Forest) +/- deciduous trees
 B       3   Main Boreal conifers                              21
      ------------------------------------------------------------
 A    18/4   Southern dry taiga (and other aspen/birch, etc.) 60
                                                               CYAN
        4  Deciduous Conifer
 L           Siberian larch taiga [partly other taiga 21]      61 (4)
 W          (Coming additions: Cypress swamp, Metasequoia  83-84)

==================================================================
```

a Numbers in middle columns from Olson et al. (1983) or Numerical Data Set 17 (= WE1.2) of Olson et al. (1985), refined for wetlands and other methane, isoprene or terpene sources. () not yet used; [] unevenly applied in 1989.

b Numbers on left are already in wide use for BATS (Biosphere-Atmosphere Transfer Scheme) of Dickinson et al. 1986, for better defining vegetation-soil boundary conditions of the global climate system, for global climate models (GCMs) at NCAR (National Center for Atmospheric Research).

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[Excerpts from original reference]

NDP-017

MAJOR WORLD ECOSYSTEM COMPLEXES RANKED BY CARBON IN LIVE VEGETATION: A DATABASE

Contributed by
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September, 1985

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Oak Ridge, Tennessee 37831
operated by
Martin Marietta Energy Systems, Inc.
for the
U. S. Department of Energy
under contract No. DE-AC05-84OR21400

CDIC NUMERIC DATA PACKAGE-017
ABSTRACT

1. NUMERIC DATA PACKAGE NAME

Major World Ecosystem Complexes Ranked by Carbon in Live Vegetation: A Database

2. CONTRIBUTORS

Jerry S. Olson, Julia A. Watts, and Linda J. Allison
Environmental Sciences Division
Oak Ridge National Laboratory
Oak Ridge, TN 37831

3. CITATION OF THE PACKAGE

The Carbon Dioxide Information Center (CDIC) recommends the following citation for those citing or referencing this package:

Olson, J.S., J.A. Watts, and L.J. Allison. 1985. Major world ecosystem complexes ranked by carbon in live vegetation: A Database. NDP-017, Carbon Dioxide Information Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

4. BACKGROUND INFORMATION

Available vegetation maps and resource inventories are not sufficiently detailed, accurate, and current to answer major questions about the biological "source or sink" of atmospheric CO_2. A number of carbon estimates were summarized and discussed in Bolin et al. (1979) and Bolin (1981), along with applications for modeling the global carbon cycle. Other inventories, however, use different methods and classification systems for estimating terrestrial carbon and are therefore difficult to compare. Regional studies, which concentrate on one area with little attention to the others, can furnish useful but limited data on types and trends. Changes in one vegetation group are sometimes offset by changes in the opposite direction in other areas. Deforestation or other landscape modifications in one region may be balanced by reversion to forests in others. But the carbon cycle must be evaluated on a global scale. While detailed, localized studies proceed, the map and data base documented in this package provide a unifying format for the continuing evaluation of changes in estimated carbon in plant mass, and eventually other components, of the whole terrestrial ecosystem.

5. SOURCE AND SCOPE OF THE DATA

The global ecology map ~~(inside back cover)~~ shows the spatial distribution of major world ecosystem complexes estimated for 1980. However, because some information sources documented here are older some of this information may not be current. Except for more drastic changes caused by humans, it also reflects the map of broad "Continental Ecosystem Patterns and Reconstructed Living Carbon Prior to the Iron Age" prepared earlier by Olson (1970), after Bazilevich and Rodin (1967). Both maps were developed after more than 20 years of field investigation and consultations, and analyses of maps and published literature. The latter are cited mainly in chapters 2 and 3 and the ~~Appendices of the report by Olson et al. (1983), which is included in this package.~~ The map printing was an experiment, using computer-generated color separation plates derived from a file of land-cover types.

Counting the cells of each type in each 0.5° latitude band and adding their areas over latitude bands gave total area estimates for these ecosystem complexes. Some independent area estimates are brought together in Sect. 4.1 of Olson et al. (1983) and confirm the thesis that some earlier estimates of forest area and forest contribution to global carbon inventories were apparently overestimated. Current estimates of the range in density of carbon per unit area (Table 1) are discussed in Sect. 4.2 and the Appendices of Olson et al. (1983). Multiplying the low medium, and high density estimates by ecosystem area gives corresponding estimates of the global total carbon by ecosystem complexes (Sect. 4.3 of Olson et al., 1983).

Only the mass of green plants is considered here, since the amounts of animal biomass are small in comparison. The mass of fungi and bacteria is not necessarily negligible, but evaluating it was beyond the scope of the 1983 report. This mass of decomposers varies greatly with time and space. It is important for controlling flux or recycling rates rather than for its own inventory. The recycling rate of CO_2 by respiration is usually expressed relative to the substrates of standing, fallen, and incorporated soil residues. The range of uncertainty about total plant carbon and its component parts reveals where more attention could reduce the uncertainty. Implications of these data are discussed briefly by Olson et al. (1983).

Estimation of the inventory of carbon in major world ecosystems and of the exchanges with the atmosphere and other major reservoirs has thus been approached in two ways. In the first approach, development of broad global patterns uses potential vegetation maps, or associates vegetation types with climatic or other environmental factors independent of local disturbance. The distributions described by Bazilevich and Rodin (1967), Lieth (1975), Kuchler (1978), and Bailey (1978) are examples of this approach. In the second approach, development of modern regional or stand-type estimates is based on analyses of current vegetation and land-use practices. This method uses updated resource maps of natural vegetation, forestry surveys, agricultural yields, and human and economic as well as

geopolitical considerations. Both approaches were applied in the development of the ecosystem map. The personal judgment of experts about ecosystem types, their locations and extent, and likely biomass or carbon in landscape complexes representative of different parts of the world is crucial in either approach.

6. APPLICATIONS OF THE DATA

The rates of CO_2 release to the atmosphere and its removal are controlled differently by factors affecting photosynthesis, respiration, and burning as well as by shifts in land use and climate. Understanding these relations together with increased knowledge of the plant pools undergoing change will enhance our ability to integrate information from biology and geography into geophysical modeling of element cycles and climate.

1. The map of Major World Ecosystem Complexes provides a current reference base for interpreting the role of vegetation in the global cycling of CO_2 and other gases. It combines improvement in available ecological data and techniques for computer generation of maps.

2. The data provide a basis for improved estimates of vegetation and soil carbon, of natural exchanges of CO_2, and of net historic shifts of carbon between the biosphere and the atmosphere.

3. Landscape areas inferred from the map and other sources and weighted averages of carbon in various kinds of vegetation suggest significantly lower carbon in global vegetation than has been sometimes used in recent analyses of global geochemical cycles.

4. Tabulations still show tree formations holding most of the plant carbon. Yet decreases in area and mass of closed forest have already been so extensive that hundreds of petagrams (billion metric tons) of carbon were probably released over centuries or millenia before recent industrialization and human population growth.

5. The remaining plant pool is still large enough to contribute a few petagrams of carbon per year to atmospheric CO_2, if conversion as well as harvesting of massive tropical forests continues (a significant fraction of recent releases of 5 petagrams of carbon per year is from burning of fossil fuels). The problem remains, however, to infer how much of that release is offset by renewed storage in untilled areas of the tropics. In temperate or Boreal zones, even more forests are regrowing after earlier harvesting and clearing and because of recent fire protection.

7. RESTRICTIONS AND LIMITATIONS

The broad ranges given on the map legend for the carbon content in the major groups probably span all the type means in each ecosystem group and most of the stand averages for each mapping cell within an ecosystem group. At the present stage of

development of this methodology, a carbon density based on the ranges and means as given cannot be assigned to each cell. Such an effort requires local assessments of vegetative cover, land use, soils, topography, and climatic factors.

Uncertainties for regions known poorly or inferred indirectly (by analogy) will remain for additional refinements. The digitized map offers a systematic way of locating future revisions of boundaries and ecosystem areas. As amounts of carbon per unit area or their transfer rates are analyzed in more locations, then the mean estimates, which are currently applied as "default" values for each place a given type occurs, can be suitably adjusted for variations among nations, among climatic or soil regions of a given ecosystem type, or for particular map cells. Remote sensing on a continental or world-wide basis (e.g., with Advanced Very High Resolution Radiometry) is one approach to this next stage of analysis. If the climate itself changes significantly, whether due to CO_2 or to other possible interacting causes (Manabe and Wetherald 1967, 1975, 1980; WMO 1979; Clark 1982), then the relation of the present patterns of vegetation and climate can be used in helping to project the impacts on change of vegetation and related resources.

Because forests, open woodlands, and complexes in which these ecosystems alternate with nonwooded communities (so-called "Interrupted Woods"), constitute most of the carbon in live vegetation, present uncertainties (about 20 percent) still center on these types. Where investigated most recently, tropical woods have been identified with even lower biomass and carbon estimates than were expected in 1982.

Some coniferous forests of moist regions like the northwestern coast of North America are identified with even higher biomass than the tropical rain forests.

A major uncertainty exists in the "nonwoods" ecosystem concerning the amount of carbon that should be added for scattered trees or woody inclusions not counted in the "woods" ecosystems. There is considerable allowance from judgment and experience in using the sampled averages differently.

As closer refinements are made, the future estimates for carbon density in ecosystems will more likely be revised downward from the medium estimate of 560 $\pm$ 100 petagrams (Pg).

The database in this package may not duplicate exactly the world ecosystems complexes map that is part of this package. Revisions to about 200 cells (0.8% of all cells) were made to the plates used to print the map. Some of these revisions were not recorded and may not have been incorporated into the database.

- C -

HOLDRIDGE LIFE ZONES

CITATION: Leemans, R., 1990. Global Holdridge Life Zones. Digital Data. IIASA, Laxenberg, Austria. .26 MB.

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C. HOLDRIDGE LIFE ZONES

DATE: 1990

SOURCE:
R. Leemans
International Institute for Applied Systems Analysis (IIASA)
Laxenberg, Austria

CONTRIBUTOR:
Peter Schlesinger
Woods Hole Research Center
Woods Hole, MA

DATA CENTER: IIASA

GEOGRAPHIC SAMPLING: .5 degree grid, characteristic classes

COVERAGE: Global

PROJECTION: Lat/lon

TIME SAMPLING: Decadal composites

REFERENCES:
Leemans, R., 1990. "Global data sets collected and compiled by the Biosphere Project." Working paper, IIASA, A-2361. (Excerpts included)

FILE NAMES: AFHOLD Holdridge Life Zones

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HOLDRIDGE LIFE ZONES
DOCUMENTATION FILE

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maximum     :   3.7000000000E+01
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cell y      :   1.6666666667E-01
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category  2 :  2 SpDT     SUBPOLAR DRY TUNDRA
category  3 :  3 SpMT     SUBPOLAR MOIST TUNDRA
category  4 :  4 SpWT     SUBPOLAR WET TUNDRA
category  5 :  5 SpRT     SUBPOLAR RAIN TUNDRA
category  6 :  6 BD       BOREAL DESERT
category  7 :  7 BDS      BOREAL DRY SCRUB
category  8 :  8 BMF      BOREAL MOIST FOREST
category  9 :  9 BWF      BOREAL WET FOREST
category 10 : 10 BRF      BOREAL RAIN FOREST
category 11 : 11 CTD      COOL TEMPERATE DESERT
category 12 : 12 CTDS     COOL TEMPERATE DESERT SCRUB
category 13 : 13 CTS      COOL TEMPERATE STEPPE
category 14 : 14 CTMF     COOL TEMPERATE MOIST FOREST
category 15 : 15 CTWF     COOL TEMPERATE WET FOREST
category 16 : 16 CTR      COOL TEMPERATE RAINFOREST
category 17 : 17 WTD      WARM TEMPERATE DESERT
category 18 : 18 WTDS     WARM TEMPERATE DESERT SCRUB
category 19 : 19 WTTS     WARM TEMPERATE THORN STEPPE
category 20 : 20 WTDF     WARM TEMPERATE DRY FOREST
category 21 : 21 WTMF     WARM TEMPERATE MOIST FOREST
category 22 : 22 WTWF     WARM TEMPERATE WET FOREST
category 23 : 23 WTR      WARM TEMPERATE RAINFOREST
category 24 : 24 StD      SUBTROPICAL DESERT
category 25 : 25 StDS     SUBTROPICAL DESERT SCRUB
category 26 : 26 StTW     SUBTROPICAL THORN WOODLAND
category 27 : 27 StDF     SUBTROPICAL DRY FOREST
category 28 : 28 StMF     SUBTROPICAL MOIST FOREST
category 29 : 29 StWF     SUBTROPICAL WET FOREST
category 30 : 30 StR      SUBTROPICAL RAINFOREST
category 31 : 31 TD       TROPICAL DESERT
category 32 : 32 TDS      TROPICAL DESERT SCRUB
category 33 : 33 TTW      TROPICAL THORN WOODLAND
category 34 : 34 TVDF     TROPICAL VERY DRY FOREST
category 35 : 35 TDF      TROPICAL DRY FOREST
category 36 : 36 TMF      TROPICAL MOIST FOREST
category 37 : 37 TWF      TROPICAL WET FOREST

{category 0 : unclassed}

[This legend is appropriate for display of the individual classes
 (i.e. without rescaling).
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HOLDRIDGE LIFE ZONES
DOCUMENTATION FILE

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maximum     :   3.7000000000E+01
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cell y      :   1.6666666667E-01
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category  2 :  2 SpDT     SUBPOLAR DRY TUNDRA
category  3 :  3 SpMT     SUBPOLAR MOIST TUNDRA
category  4 :  4 SpWT     SUBPOLAR WET TUNDRA
category  5 :  5 SpRT     SUBPOLAR RAIN TUNDRA
category  6 :  6 BD       BOREAL DESERT
category  7 :  7 BDS      BOREAL DRY SCRUB
category  8 :  8 BMF      BOREAL MOIST FOREST
category  9 :  9 BWF      BOREAL WET FOREST
category 10 : 10 BRF      BOREAL RAIN FOREST
category 11 : 11 CTD      COOL TEMPERATE DESERT
category 12 : 12 CTDS     COOL TEMPERATE DESERT SCRUB
category 13 : 13 CTS      COOL TEMPERATE STEPPE
category 14 : 14 CTMF     COOL TEMPERATE MOIST FOREST
category 15 : 15 CTWF     COOL TEMPERATE WET FOREST
category 16 : 16 CTR      COOL TEMPERATE RAINFOREST
category 17 : 17 WTD      WARM TEMPERATE DESERT
category 18 : 18 WTDS     WARM TEMPERATE DESERT SCRUB
category 19 : 19 WTTS     WARM TEMPERATE THORN STEPPE
category 20 : 20 WTDF     WARM TEMPERATE DRY FOREST
category 21 : 21 WTMF     WARM TEMPERATE MOIST FOREST
category 22 : 22 WTWF     WARM TEMPERATE WET FOREST
category 23 : 23 WTR      WARM TEMPERATE RAINFOREST
category 24 : 24 StD      SUBTROPICAL DESERT
category 25 : 25 StDS     SUBTROPICAL DESERT SCRUB
category 26 : 26 StTW     SUBTROPICAL THORN WOODLAND
category 27 : 27 StDF     SUBTROPICAL DRY FOREST
category 28 : 28 StMF     SUBTROPICAL MOIST FOREST
category 29 : 29 StWF     SUBTROPICAL WET FOREST
category 30 : 30 StR      SUBTROPICAL RAINFOREST
category 31 : 31 TD       TROPICAL DESERT
category 32 : 32 TDS      TROPICAL DESERT SCRUB
category 33 : 33 TTW      TROPICAL THORN WOODLAND
category 34 : 34 TVDF     TROPICAL VERY DRY FOREST
category 35 : 35 TDF      TROPICAL DRY FOREST
category 36 : 36 TMF      TROPICAL MOIST FOREST
category 37 : 37 TWF      TROPICAL WET FOREST

{category 0 : unclassed}

[This legend is appropriate for display of the individual classes
 (i.e. without rescaling).
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WORKING PAPER

POSSIBLE CHANGES IN NATURAL VEGETATION PATTERNS DUE TO A GLOBAL WARMING

Rik Leemans

February 1990
WP-90-08

PUBLICATION NUMBER 108 of the Biosphere Dynamics Project

IIASA
International Institute
for Applied Systems Analysis

POSSIBLE CHANGES IN NATURAL VEGETATION PATTERNS DUE TO A GLOBAL WARMING

Rik Leemans

February 1990
WP-90-08

PUBLICATION NUMBER 108 of the Biosphere Dynamics Project

Working Papers are interim reports on work of the International Institute for Applied Systems Analysis and have received only limited review. Views or opinions expressed herein do not necessarily represent those of the Institute or of its National Member Organizations.

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
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FOREWORD

IIASA's projects within the Environment Program are devoted to investigating the interaction of human development activities and the environment, particularly in terms of the sustainable development of the biosphere. The research is policy-oriented, interdisciplinary, international in scope and heavily dependent on collaboration with a network of research scientists and institutes in many countries. The importance of IIASA's Environment Program stems from the fact that the many components of the planetary life-support systems are being threatened by increasing human activity, and that these problems are not susceptible to solution by singular governments or even, international agencies. Instead, resolution of the difficulties will demand concerted and cooperative actions by many governments and agencies, based on valid understanding of the earth's environmental systems. Establishment of a basis for international cooperation, and production of accurate global environmental perceptions are both hallmarks of IIASA's Environment Program.

Foremost among the global environmental issues of concern are those involving increasing concentrations of greenhouse gases and changing climate. Problem solutions will only become apparent after collection and analysis of pertinent data, testing of relevant hypotheses, genesis of mitigation strategies and investigation of the efficacy of the strategies which are developed. All of these activities can support development of, or be supported by, the appropriate mathematical models of the biosphere. Therefore, the Biosphere Dynamics Project has been focused on the creation of models which can describe the processes in the biosphere which result in vegetation dynamics. The models are being designed to define the biotic and ecological results of measures suggested to slow or stop increases in greenhouse gases. The models must be capable of documenting whether, and if so by how much, vegetational communities would benefit from mitigation actions, as well as describing how the terrestrial biosphere will respond in its role as carbon source and sink.

One such study is aimed at examining the potential future geographic configurations of the world's vegetation biomes under specified, steady-state distributions of global climate variables. The first step we have chosen is to document the data sets and classification systems available for modification to fit our needs, exemplified by the content of this working paper. This paper appeared as pages 105 to 122 in *Der Treibhauseffekt. Das Problem - Mögliche Folgen - Erforderliche Massnahmen*, edited by A. Hackl and published in 1989 by the Akademie für Umwelt und Energie, A-2361 Laxenburg, Austria. The progress in modifying the models and data sets to fit the peculiar characteristics of global environmental change, supported by the present work, will be examined in subsequent working papers.

B.R. Döös
Leader
Environment Program

ABSTRACT

The distribution of global vegetation patterns is strongly related to climate patterns. Local differences in soil characteristics and water availability, which are in turn also partly determined by climate, force the global vegetation patterns to become even more pronounced and the local patterns more diverse. The predicted global climate change, due to the increased levels of greenhouse gases, will thus have large impacts on broad-scale vegetation patterns. The Holdridge life zone classification is based on biotemperature (a heat sum), annual mean precipitation and a potential evapotranspiration ratio; it was used in the current paper to create an objective global vegetation (life zone) map. The map was created by interpolation of a large data base of weather stations to a grid of land cells with a resolution of 0.5°. The climate scenario for future climate under double CO_2 concentrations is based on results of the U.K. Meteorological Office general circulation model. Large changes in vegetation patterns are observed between the life zone classifications of present and future climate. The polar regions decrease most in their extent, and all boundaries between the different latitudinal regions move toward their poles. Most sensitive to climatic warming are the borders between the latitudinal regions. Changes are most clearly observable at the southern and northern edges of the boreal forest region. Limitations of the Holdridge classification to study impacts of climate change are discussed and improved approaches are proposed.

POSSIBLE CHANGES IN NATURAL VEGETATION PATTERNS DUE TO A GLOBAL WARMING

Rik Leemans

INTRODUCTION

Regional vegetation is the result of a close network of interrelations between the characteristics of the local environment, natural vegetation succession, and several other factors with human management/influence being one of the most important. On a global scale, climate is the leading factor in differentiating vegetation. The broad-scale distribution of major vegetation types or biomes is roughly in equilibrium with the present climate. The notion that the physical environment largely determines the observed vegetation patterns, can be found in many textbooks on ecology and geography. Although human societies have used local flora and fauna intensively, limitations on the choice of crops and maximum limits to productivity are heavily determined by the local environment. Climate maps of the world are often based on continental and regional vegetation patterns, which were much easier to observe, locate and measure than climatic parameters. And reliable networks of meteorological measurement stations were, until recently, not available in large parts of the world.

Vegetation and soil have large effects on microclimate and local climates. Climate operates on vegetation in an indirect way, namely through competition between neighboring individuals, probably of different species. This means that a plant will appear only as close to its absolute climatic limit when it can overcome the competition with individuals of other species, which are often better adapted to the local environment. Any direct effect of climate on vegetation or species distribution should be regarded as an exceptional phenomenon, such as those during critical parts of a species life-cycle, like germination and establishment.

In this paper, I use a static equilibrium model, a climate classification, which objectively links climate to vegetation and may provide plausible projections of changes in global vegetation patterns. I will visualize these changes in the distributions as a result of climate change by using a climate scenario based on a Global Circulation Model (GCM). By studying the extent of these patterns, areas with potential large vegetation changes can be recognized.

I will not take into account any other impacts of climate change, like sea-level rise, the thawing of permafrost in high latitude soils, and changes in local soil characteristics like increased decomposition rates, increased leaching and an accelerated degradation, when vegetation cannot take up the extra amount of released nutrients. These impacts can, of course, locally be of major importance. An impressive compilation of such local impacts on agriculture and forestry is given by Parry et al. (1988).

HOLDRIDGE LIFE ZONE CLASSIFICATION

Climate consists of a complex mixture of many elements, like temperature, moisture, precipitation, wind, etc. Practically any climatic element or combinations of those elements could influence a single plant's life. Climate can be quantified in terms of various parameters, like means, extreme values, durations. Many simple and complex ways have been proposed to relate vegetation to climate and vice versa. Tuhkanen (1980) gives a historical review of the different methods used, their data requirements, and advantages and disadvantages. For this study, I use a combined system of climatic parameters, namely the Holdridge life zone classification (Holdridge 1947, 1967).

This system was used in a climate change impact study by Emanuel et al. (1985a, 1985b). Holdridge's underlying assumption is that the differentiation and physiognomy of vegetation under relatively undisturbed conditions reflect the effects of climatic factors on vegetation. This means that any climax vegetation in an area can be defined objectively by its climate. Topographic, biotic and edaphic factors also depend to a certain extent upon climate, and

these lead only to a secondary differentiation (Holdridge 1967). Tests of the Holdridge life zones have revealed that the system can fit tropical vegetation zones (e.g. Holdridge 1967), mediterranean zones (Steila 1966), as well as the boreal zones, but that it is less applicable to cold oceanic or cold arid climates (Hämet-Ahti et al. 1974) where moisture becomes the determining factor. The ease at which the Holdridge classification can be used in determining the life zones objectively from frequent available climate data (monthly temperature and precipitation) makes this system more suitable for climate change impact studies at a global scale than other well known systems, like the Köppen (19[illegible]), Thornthwaite (1948) and Box (1981) classifications which are far more data demanding and dependent or are more difficult to relate to actual vegetation patterns.

The Holdridge life zone classification is based on three climate parameters: biotemperature, mean annual precipitation and a potential evapotranspiration (PET) ratio. The biotemperature is a temperature sum, related to growing degree days, and is here defined as the sum of daily mean temperatures between 0° and 30° C divided by 365. Biotemperature defines the latitudinal or altitudinal belts of life zones. Mean annual precipitation is the sum of the mean monthly values. PET is a simple empirical linear function of biotemperature, and adds no extra information to the model. The PET-ratio is defined as PET divided by annual precipitation. The PET ratio defines different humidity provinces. The three climatic indices are displayed graphically in a logarithmical system, so that each separate life zone becomes equivalent in significance (Figure 1). Each life zone is named to suggest a vegetation association.

I have made use of the Holdridge classification to create a global life zone map by using monthly temperature and precipitation values of weather stations scattered around the world. The data base was compiled at the International Institute for Applied Systems Analysis (IIASA), based on published (Weather Bureau 1959; Walter and Lieth 1960-67; Meteorological Office 1972; Müller 1982) and unpublished (China, USSR) sources. The different source data sets were separately screened for errors, outliers and unreliable stations, and for doublets. An observation record of between 10 and 40 years (if possible 1931-60) was required for the computation of mean monthly temperature and precipitation values. The final data set contained ca. 5500 stations worldwide, characterized by longitude, latitude and altitude.

This array of selected stations was then used to create a global monthly temperature and precipitation data base for land areas on a grid with a resolution of 0.5° (grid cell of about 55 x 55 km at the equator). The interpolation scheme used for each variable is a smooth surface fitting on a triangulation network, based on all stations (Akima 1978). Temperature values were corrected for changes in altitudes between the stations by applying a moist adiabatic lapse-rate of 0.6° C/100 m. Before the interpolation, the altitudes of all stations values were calculated as sea-level temperatures and after the interpolation all grid cell values were calculated as the modal height of that cell, using a topography data set (National Geophysical Data Center 1988). Mean annual precipitation was computed as the sum of all monthly values. The biotemperature was computed by using daily values and generated by fitting a quadratic spline function through the monthly values. The specific PET-ratio was computed from the biotemperature and total annual precipitation. These three climate indices in each land cell (total 62,483 without Antarctica) generated a world life zone map (Figure 2).

The life zone patterns (Figure 2) roughly compare with existing vegetation patterns when compared with, for example, the digitized vegetation map of Olson et al. (1982). Precise comparison is difficult, however, because of differences in the number and definition of vegetation classes. However, the overall global pattern is clearly visible in both schemes. In Northern areas, where temperature is much more important than precipitation, spurious classes appear in life zones in comparison with natural vegetation. In addition, in areas where soil and soil-moisture characteristics strongly determine vegetation, differences between life zones and actual vegetation are encountered, e.g. the extended pampa-grasslands in Argentina (G. Rush, personal communication). Such discrepancies can only be overcome if more soil parameters are taken into account, which leads to a more complex approach and many other problems, like defining the most important factor. Due to the use of a moist adiabatic lapse rate, this map reflects the life zones of mountainous

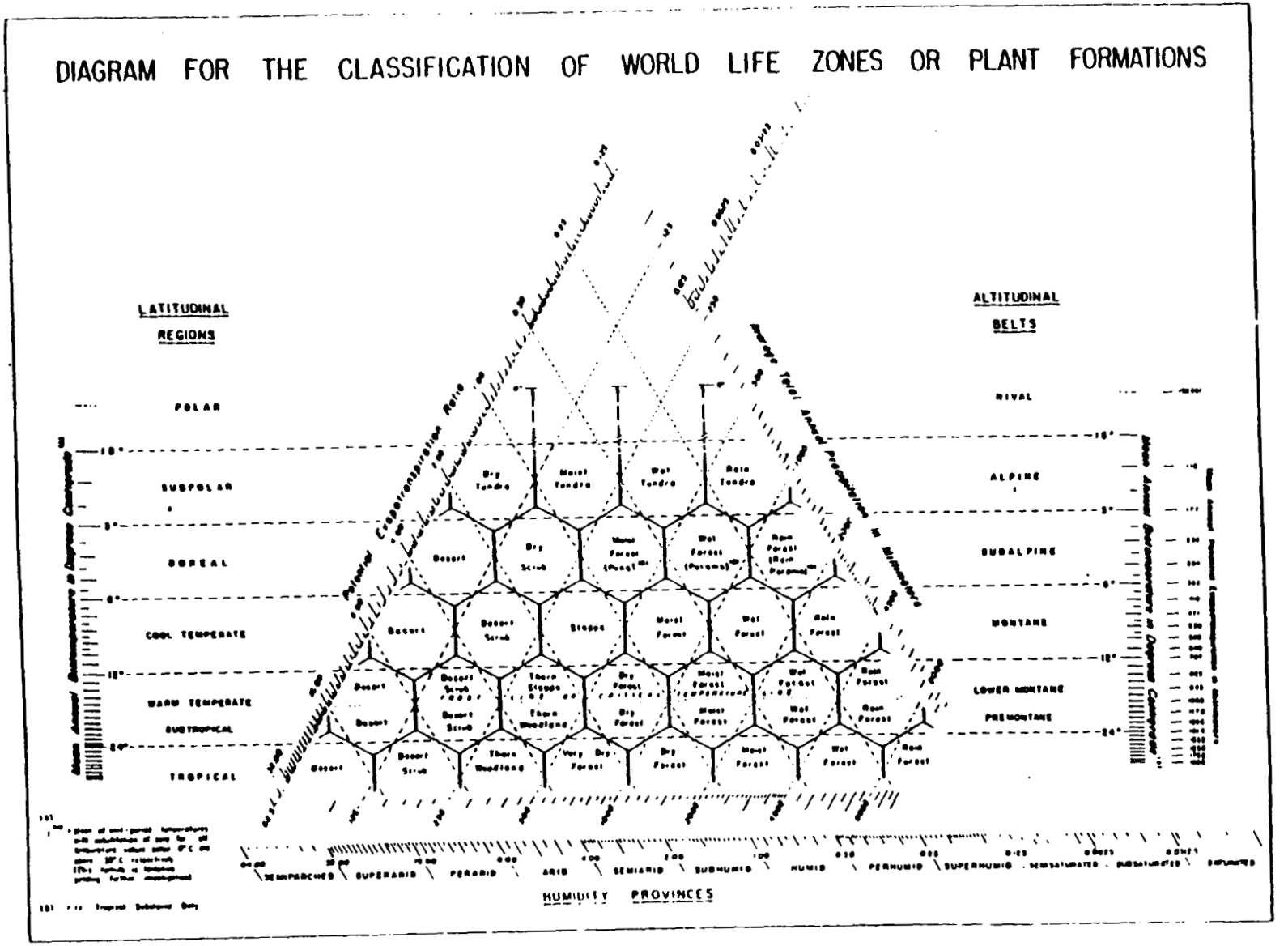

Figure 1. The Holdridge classification of world life zones (Holdridge 1967).

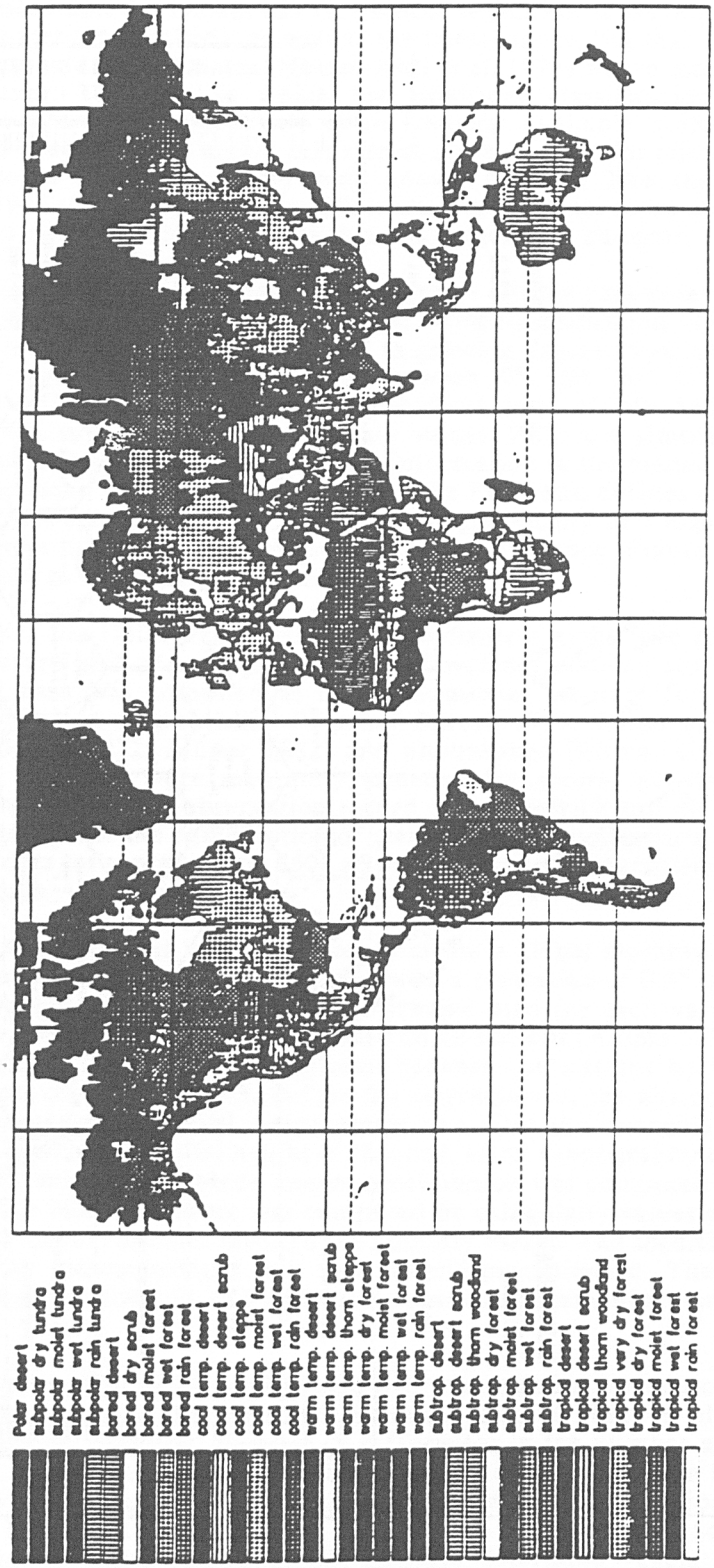

Figure 2. A world map with the Holdridge life zone classification based on a 0.5° gridded temperature and precipitation data base.

areas much better than does the life zone map published by Emanuel et al. (1985a).

The impact of climate change was determined by using results of simulated climate by a general circulation model of the atmosphere (GCM). At present there are several scenarios of climate change available. Most available GCMs indicate similar climate change trends, although major differences may occur in the magnitude of change and in local patterns. I used the output of the model developed by the U.K. Meteorological Office (UKMO), and for a present climate and a doubled CO_2 (Mitchell 1983). This model was chosen because it has a higher horizontal spatial resolution than most other models. This leads to more reliable regional patterns (Mitchell, personal communication) needed to give a realistic scenario of vegetation change.

The differences in monthly mean temperature and monthly mean precipitation between the two different model runs were used to define the amount of climate change. This quantity was then added to the present climate data base to give a doubled CO_2 future climate. The combination of the change, simulated by the UKMO GCM-model, and an authentic climate data base has the advantage that existing regional differences in the climate parameters are included, and that imperfections in the GCM-model are reduced. The simulated global climate change scenario thus becomes more realistic.

The "climate change" data base was used to determine a Holdridge life zone classification for the future climate under a doubled CO_2. The maps shown here mark only the areas undergoing a change; the portions of present life zones which would change (Figure 3) and portions of future life zones which vegetation could potentially change into (Figure 4). Changes are apparent between the two maps: only little more than 50% of the world's vegetation does not change from one life zone to another between present and future climate (Table 1 and Table 2). The climatic warming is obvious in the pattern of life zone changes. The latitudinal belts are markedly replaced polewards. This results in the largest vegetation change being in the polar regions. This vegetation decreases in area by 33%. Given that Greenland remains as a large polar desert (land ice), the largest part of the change occurs in the tundra ecosystems. There boreal life zones largely replace the tundra which is limited at its northern border by the polar ice-sea, and thus cannot expand poleward. The boreal forest, in turn, is replaced at its southern edge by temperate forests, but its total area remains almost equal, due to its northward extension. This result contrasts that of Emanuel et al. (1985a, 1985b), who found a larger decrease in the area of the boreal forest. A complex pattern of changes occurs at the borders between the temperate and subtropical regions. The range of most tropic life zones increases. In Africa, the Sahara desert expands toward the south and the transitions toward the tropical life zone becomes much less gradual than in the present climate.

DISCUSSION

Vegetation Change

The changes in potential life zones as shown here are large, and affect directly or indirectly the whole globe with all its ecosystems. For example, the tundra systems are important for many migrating birds, like geese, for their reproduction and summer foraging. If these grounds disappear or even largely decrease, this will have a catastrophic effect on the populations of these birds, and probably many other ecological impacts along their migratory path. During the creation of large biosphere reserves, possible effects of climate change should be considered; these reserves should not be created in areas with a high probability of change. Unfortunately, the most diverse systems are located in the transitions between ecosystems or biomes.

The actual impacts of climate change on vegetation will probably not be observed immediately after the climate change has occurred. There will be a time lag, ranging from decades to decennia. Species and their propagules are not available immediately if the circumstances become appropriate. Especially plants are rather immobile and have slow migration rates. Boreal species, for example, have an estimated natural migration capacity of 1 to 40 kilometers per century (Davis 1981). Massive, practically impossible, new

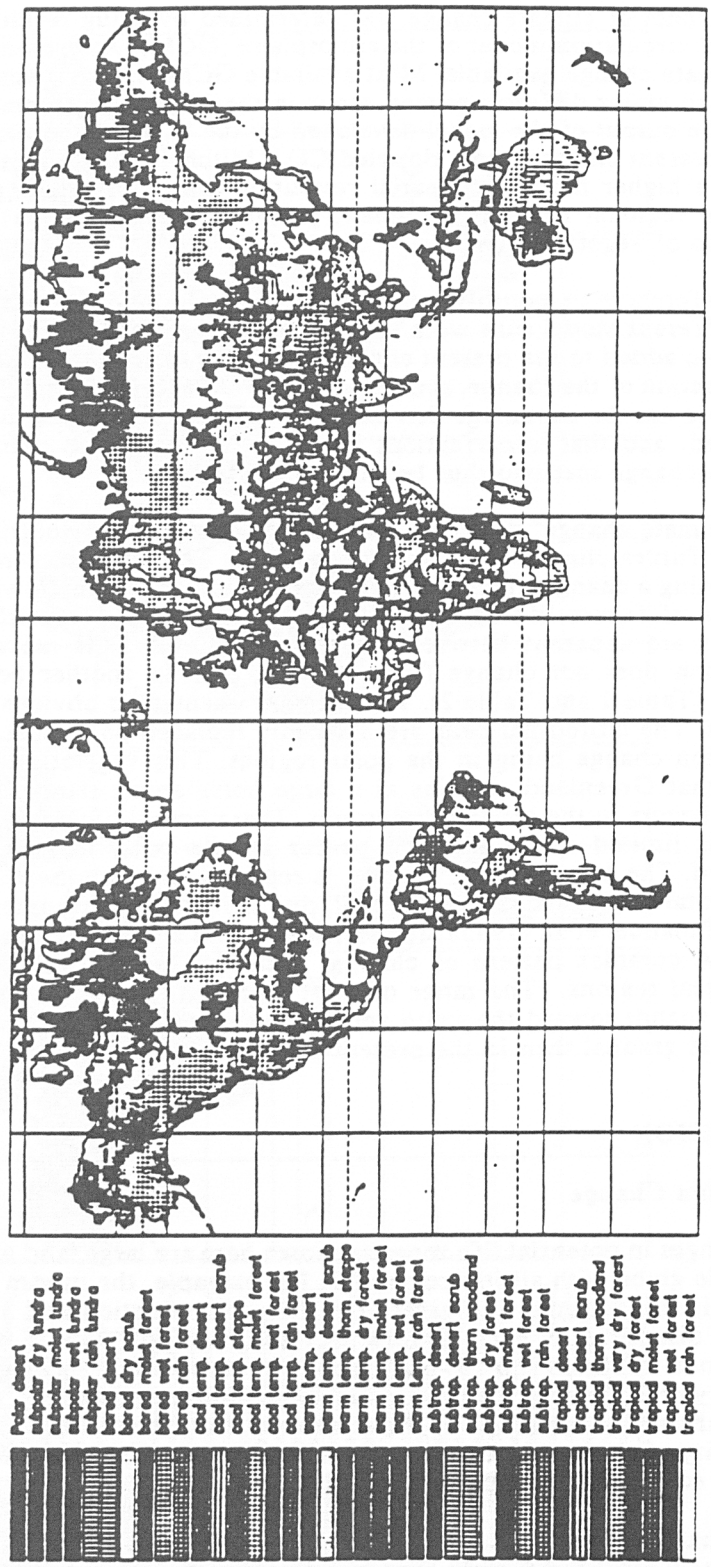

Figure 3. A Holdridge life zone world map with the differences between present climate and a double CO_2 future climate. The marked areas are the original life zones, determined on the basis of present climate.

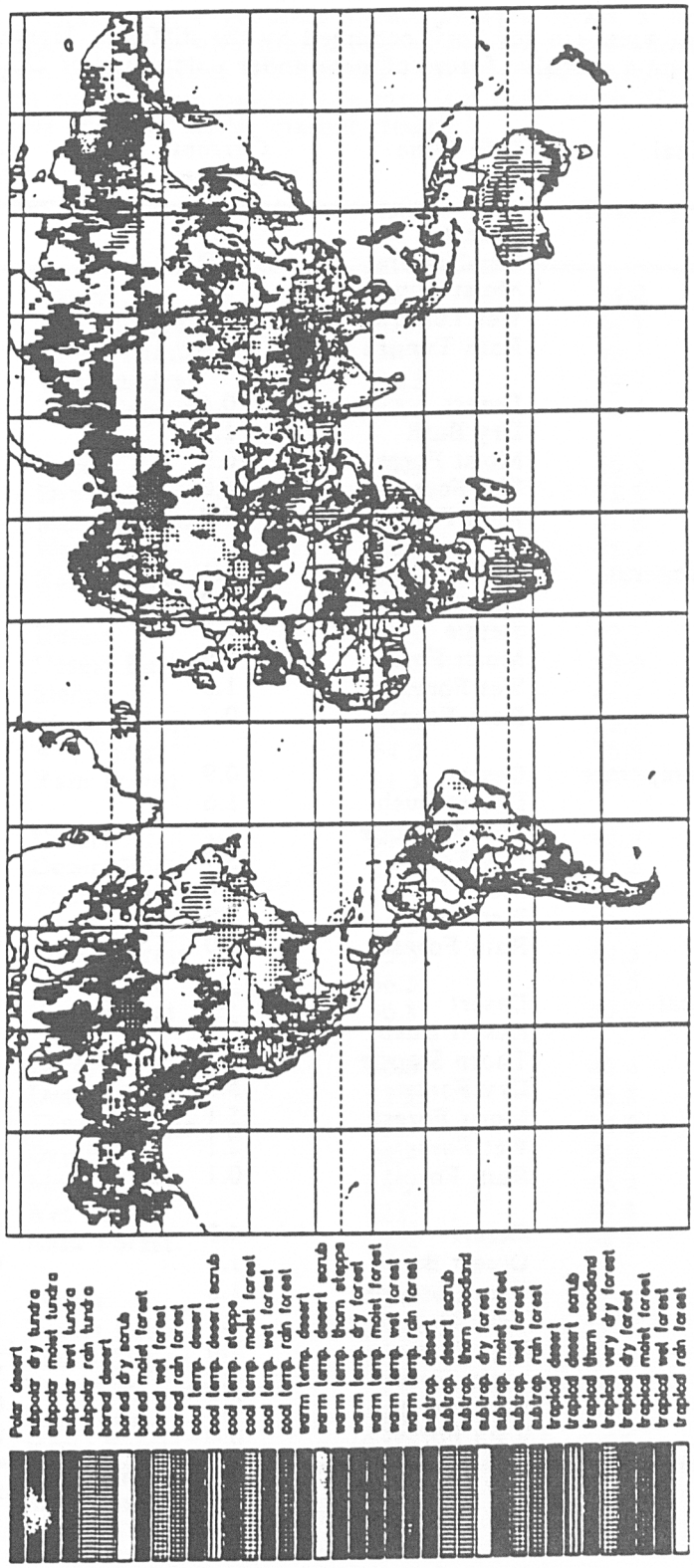

Figure 4. A Holdridge life zone world map with the differences between present climate and double CO_2 future climate. The marked areas are the future life zones determined on the basis of simulated climate.

Table 1. Areas (in 10^6 km^2) occupied by the different Holdridge life zones for present climate and a probable future climate under a doubling of CO_2.

Latitudinal Region	Life Zone	Current Climate	Future Climate	Difference
Polar	Desert	8.3	4.6	- 3.6
	Dry Tundra	0.9	1.0	+ 0.1
	Moist Tundra	3.3	2.4	- 0.9
	Wet Tundra	3.5	2.4	- 1.1
	Rain Tundra	2.1	1.6	- 0.5
Boreal	Desert	0.4	0.4	+ 0.0
	Dry Bush	1.8	1.9	+ 0.1
	Moist Forest	10.9	8.3	- 2.5
	Wet Forest	4.6	6.0	+ 1.3
	Rain Forest	0.9	1.0	+ 0.2
Cool Temperate	Desert	1.1	0.8	- 0.1
	Desert Bush	2.0	1.8	+ 0.2
	Steppe	7.5	7.7	+ 0.2
	Moist Forest	8.9	10.4	+ 1.6
	Wet Forest	1.3	1.9	+ 0.6
	Rain Forest	0.2	0.4	+ 0.2
Warm Temperate	Desert	0.9	1.0	+ 0.2
	Desert Bush	1.6	1.2	- 0.5
	Thorn Steppe	2.2	1.7	- 0.4
	Dry Forest	3.7	2.7	- 1.0
	Moist Forest	3.0	2.6	- 0.3
	Wet Forest	0.2	0.3	+ 0.1
	Rain Forest	0.0	0.1	- 0.0
Subtropical	Desert	7.2	6.3	- 0.8
	Desert Bush	5.1	2.8	- 2.2
	Thorn Steppe	4.8	4.3	- 0.5
	Dry Forest	8.9	8.0	- 0.8
	Moist Forest	15.1	11.7	- 3.3
	Wet Forest	2.1	1.3	- 0.8
	Rain Forest	0.1	0.1	+ 0.0
Tropical	Desert	4.2	8.6	+ 4.4
	Desert Bush	1.1	0.9	- 0.2
	Thorn Steppe	1.8	1.6	- 0.2
	Very Dry Forest	3.1	5.6	+ 2.4
	Dry Forest	7.6	13.1	+ 5.5
	Moist Forest	4.8	7.6	+ 2.9
	Wet Forest	0.2	0.7	+ 0.6
	Rain Forest	0.0	0.0	+ 0.0
Total:		135.2	135.2	

Table 2. Summary of percentage change in areal extent of the different Holdridge life zones for present climate and a probable future climate under a doubling of CO_2. "STABILITY" indicates the area with similar life zones under both climates. "CHANGE" indicates those which change from the current life zone into another. "EXPANSION" indicates those which change from another life zone into the current life zone. (All values are relative to the area occupied under present climate.)

Latitudinal Region	Life Zone	Change	Stability	Expansion
Polar	Desert	56.0	44.0	0.0
	Dry Tundra	45.9	54.1	63.8
	Moist Tundra	36.9	63.1	35.6
	Wet Tundra	25.3	74.7	44.2
	Rain Tundra	27.6	72.4	48.7
Boreal	Desert	19.6	80.4	87.8
	Dry Bush	41.7	58.3	64.3
	Moist Forest	52.2	47.8	24.2
	Wet Forest	54.6	45.4	73.9
	Rain Forest	43.1	56.9	74.6
Cool Temperate	Desert	47.3	52.7	27.4
	Desert Bush	37.1	62.9	57.3
	Steppe	58.7	41.3	44.6
	Moist Forest	64.3	35.7	53.4
	Wet Forest	64.0	36.0	89.7
	Rain Forest	61.3	38.7	111.3
Warm Temperate	Desert	51.1	48.9	66.6
	Desert Bush	22.2	77.8	48.5
	Thorn Steppe	16.9	83.1	62.7
	Dry Forest	26.5	73.5	47.4
	Moist Forest	35.5	64.5	52.9
	Wet Forest	56.5	43.5	82.3
	Rain Forest	36.8	63.2	18.9
Subtropical	Desert	50.6	49.4	38.3
	Desert Bush	23.2	76.8	33.1
	Thorn Steppe	26.0	74.0	63.6
	Dry Forest	40.4	59.6	50.4
	Moist Forest	54.6	45.4	23.3
	Wet Forest	52.2	47.8	10.4
	Rain Forest	65.9	34.1	34.8
Tropical	Desert	94.7	5.3	100.2
	Desert Bush	18.5	81.5	62.7
	Thorn Steppe	38.4	61.6	49.9
	Very Dry Forest	63.4	36.6	112.3
	Dry Forest	85.1	14.9	86.2
	Moist Forest	95.4	4.6	61.9
	Wet Forest	100.0	0.0	245.4
	Rain Forest	-	-	-

plantings would be required to sustain its distribution northwards.

As plant distributions are an outcome of competition between individuals and new, better adapted species are not yet available, the species present could remain due to lower competitive pressure. If individuals are surviving in an unappropriated environment, higher mortality rates will be observed as a result of an increased environmental stress at a species environmental limit. The world could then be faced with a vegetation decline on a large spatial scale (up to 50% according to the above analysis). This change, occurring during a short time-scale (up to one century), has no equivalent in history and as a result, many species may become extinct. Such a decrease in biodiversity is irreversible. For example, after the sudden crash in species number at the end of the Permian period (some 240 years ago), it took more than 5 million years to recover (Erwin 1989). After this crash the evolutionary path had changed in a direction leading to the dominance of mammals.

Improvements of Static Equilibrium Models

The above-described example of a static equilibrium model has some severe disadvantages, like many other models of this type. These models do not include rates of changes, only amplitudes of change, and present only the possible distributions of potential vegetation types under a specified climate. Transient responses cannot be studied with such models. As global climatic warming spreads northwards (locally several hundreds of kilometers), the time-scale will be important. Single plant species often lack migration potential fast enough to keep up with expected climate changes. Models, which do not take into account competition and possibly migration rates, cannot predict the actual vegetation transients under a climatic change.

Dynamic models for vegetation succession have been developed. The most successful group has been developed for forests and is based on the gap-models developed by Botkin et al. (1972), Shugart (1984), and Prentice and Leemans (1990). At IIASA, we have combined one of these models (FORSKA, Leemans and Prentice 1989) with specific environmental driver routines (Bonan 1989) to simulate the global dynamics of boreal forests, because they are one of the ecosystems where the largest changes will occur (see above). The boreal forest is also a relatively simple system, with few well known species, located in a few countries (Canada, Alaska, Norway, Sweden, Finland, and the USSR), which makes the collection of data, impact monitoring networks, and exchange of knowledge much easier.

The boreal model incorporates the growth of single trees, not in an empirical, but in a mechanistic way, and incorporates competition between these trees, resulting in a realistic forest structure. The environmental driver includes permafrost dynamics, moisture and temperature effects, fire and other ecological disturbances, which all have their specific effect on the growth of trees. The model soon will be used to simulate the impacts of climatic change on the boreal forest and along its borders.

The boreal forest covers ca. 10% of the world's land surface. By modeling this part only, we can examine no impacts elsewhere. The development of a dynamic global vegetation model, including all ecosystems and species, becomes necessary. In cooperation with the International Geosphere-Biosphere Program (IGBP), we have started to develop such a model. Difficulties which arise here are the different characteristics of terrestrial ecosystems, like grasslands, forests and their transients. The present approach taken at IIASA is illustrated in Figure 5 (Prentice et al. 1989). This approach can include a wide range of environment-vegetation interactions and plant-plant interactions. Single species will not be represented; they will be classified into "functional groups" according to their ecological functions. The first, initial results of this model may be ready in mid-1990.

Environmental Data Bases

All these model exercises need huge amounts of data. At IIASA we are compiling a set of environmental data bases of geographical information, such as vegetation, soil, topography and climate. All our data bases are linked to a gridded map of the world on a 5° resolution,

and are model independent. The Holdridge life zone classification was one of the first applications to use these data bases. The data bases are updated and improved continuously, and new subjects are added.

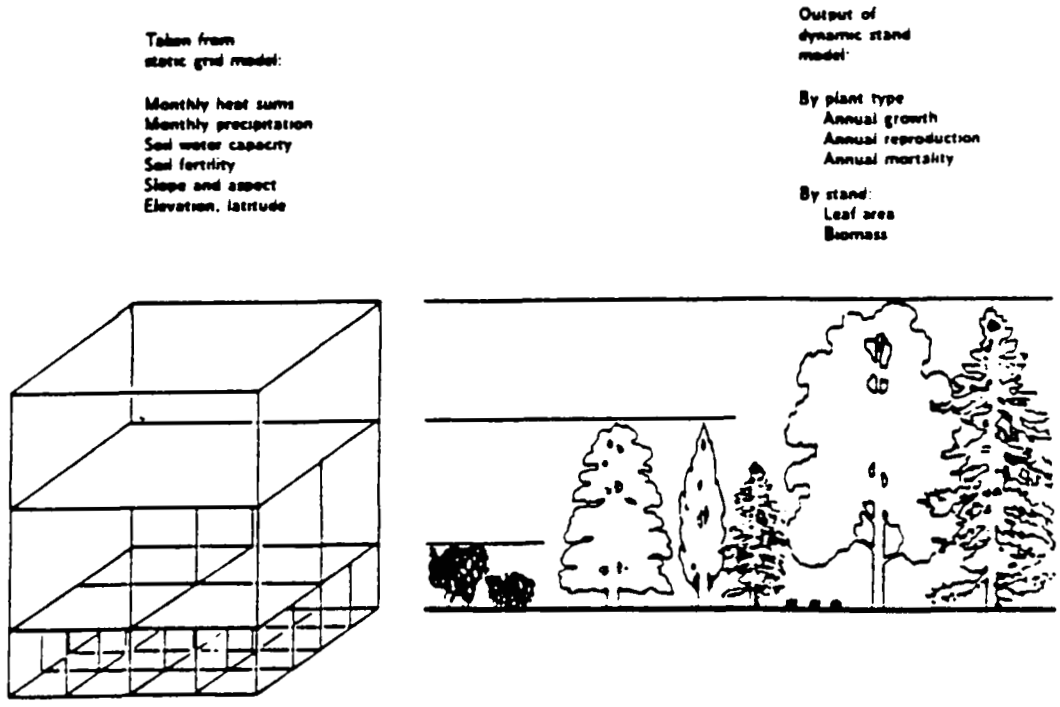

Figure 5. A conceptual form of a dynamic vegetation model. The tallest plants shade out shorter ones; the number of simulations required for smaller-stature plants is greater than for tall plants. Each vertical layer of vegetation is subdivided into separate layers in which different sized individuals of one species can grow (Prentice et al. 1989).

CONCLUSIONS

Climate and vegetation are closely related. Although we have much knowledge about the spatial distribution of vegetation patterns, we hardly know how the different spatial and temporal patterns of vegetation are generated in a mechanistic way. The understanding of such dynamics are of increasing importance for accessing the possible impacts of any climate change.

I perceive the near future as a composite of many exciting scientific challenges in which scientists from different fields, traditions, approaches and countries collaborate seriously to unravel the dynamic links within the biosphere. This will be the only way to make available the information necessary for policy-makers and the public to decide about a sustainable development of mankind within the biosphere.

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Weather Bureau. 1959. *World Weather Records 1941-1950*. U.S. Department of Commerce, Washington, D.C.

- D -

MATTHEWS VEGETATION, LAND-USE, AND SEASONAL ALBEDO

CITATION: Matthews, E., 1984. Global Vegetation, Land-Use, and Seasonal Albedo. Digital Data. NCAR, Boulder, Colorado. .65 MB.

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D. MATTHEWS VEGETATION, LAND-USE, AND SEASONAL ALBEDO

DATE: 1984

SOURCE:

Digitized from available sources.
Elaine Matthews
Goddard Institute of Space Science
Columbia University
New York, NY

CONTRIBUTOR:

Roy Jenne
NCAR
P.O. Box 3000
Boulder, CO 80307-3000

DATA CENTER: NCAR

GEOGRAPHIC SAMPLING: 1 degree grid, characteristic classes

COVERAGE: Global

PROJECTION: Lat/lon

TIME SAMPLING: Decadal composites

REFERENCES:

Matthews, E., 1984. "Vegetation, Land-Use and Seasonal Albedo Data Sets: Documentation of Archived Data Tape." NASA Technical Memorandum #86107.

Matthews, E., 1983. "Global vegetation and land use: New high resolution data bases for climate studies." *J. Clim. Appl. Meteor.*, vol. 22, pp. 474-487.

Zobler, L., 1986. "A World Soil File for Global Climate Modeling." NASA Technical Memorandum #87802.

FILE NAMES:

AFMVEG	Matthews Vegetation Type
AFMCULT	Matthews Cultivation Intensity
AFMALBFA	Matthews Fall Albedo (x 100)
AFMALBSM	Matthews Summer Albedo (x 100)
AFMALBSP	Matthews Spring Albedo (x 100)
AFMALBWN	Matthews Winter Albedo (x 100)

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MATTHEWS VEGETATION TYPE
DOCUMENTATION FILE

File Name: AFMVEG.DOC

```
image title : Matthews Vegetation Types
data type   : byte
file type   : binary
rows        : 438
columns     : 480
minimum     : 0.0000000000E+00
maximum     : 3.0000000000E+01
cell x      : 1.6666666667E-01
cell y      : 1.6666666667E-01
legend      : 32
category  1 :  1 TER        Tropical evergreen rainforest, mangrove forest
category  2 :  2 TES        Tropical/subtropical evergreen seasonal
                            broadleaved forest
category  3 :  3 SER        Subtropical evergreen rainforest
category  4 :  4 TSP        Temperate/subpolar evergreen rainforest
category  5 :  5 TSB        Temperate evergreen seasonal broadleaved
                            forest, summer rain
category  6 :  6 EBS        Evergreen broadleaved sclerophyllous forest,
                            winter rain
category  7 :  7 TEN        Tropical/subtropical evergreen needleleaved
                            forest
category  8 :  8 TSE        Temperate/subpolar evergreen needleleaved
                            forest
category  9:  9 TSD         Tropical/subtropical drought-deciduous forest
category 10 : 10 CDE        Cold-deciduous forest, with evergreens
category 11 : 11 CDF        Cold-deciduous forest, without evergreens
category 12 : 12 XFW        Xeromorphic forest/woodland
category 13 : 13 ESW        Evergreen broadleaved sclerophyllous woodland
category 14 : 14 ENW        Evergreen needleleaved woodland
category 15 : 15 TDD        Tropical/subtropical drought-deciduous
                            woodland
category 16 : 16 CDW        Cold-deciduous woodland
category 17 : 17 EBT        Evergreen broadleaved shrubland/thicket,
                            evergreen dwarf-shrubland
category 18 : 18 ENM        Evergreen needleleaved or microphyllous
                            shrubland/thicket
category 19 : 19 DDS        Drought-deciduous shrubland/thicket
category 20 : 20 CDS        Cold-deciduous subalpine/subpolar shrubland,
                            cold-deciduous dwarf shrubland
category 21 : 21 XSD        Xeromorphic shrubland/dwarf shrubland
category 22 : 22 ATM        Arctic/alpine tundra, mossy bog
category 23 : 23 TGW        Tall/medium/short grassland with 10-40% woody
                            tree cover
category 24 : 24 TGV        Tall/medium/short grassland with <10% woody
                            tree cover or tuft-plant cover
category 25 : 25 TGS        Tall/medium/short grassland with shrub cover
category 26 : 26 TGN        Tall grassland, no woody cover
category 27 : 27 MGN        Medium grassland, no woody cover
category 28 : 28 MSG        Meadow, short grassland, no woody cover
category 29 : 29 FFO        Forb formations
category 30 : 30 DES        Desert
category 31 : 31 ICE        Ice
category 32 : 32 CUL        Cultivation
{category 0 : unclassed}
[This legend is appropriate for display of the individual classes
 (i.e. without rescaling).]
```

MATTHEWS CULTIVATION INTENSITY
DOCUMENTATION FILE

File Name: AFMCULT.DOC

```
image title : Matthews Cultivation Intensity
data type   : byte
file type   : binary
rows        : 438
columns     : 480
minimum     :   0.0000000000E+00
maximum     :   5.0000000000E+00
cell x      :   1.6666666667E-01
cell y      :   1.6666666667E-01
legend      : 5
category  1 : 1   0 %
category  2 : 2  20 %
category  3 : 3  50 %
category  4 : 4  75 %
category  5 : 5 100 %

{category 0 : unclassed}



[This legend is appropriate for display of the individual classes
 (i.e. without rescaling).]
```

MATTHEWS SEASONAL ALBEDO
EXAMPLE DOCUMENTATION FILE

File Names: **AFMALBFA.DOC, AFMALBSM.DOC, AFMALBSP.DOC, AFMALBWN.DOC**

```
image title : Matthews (Seasonal) Albedo (X 100)
data type   : integer
file type   : binary
rows        : 438
columns     : 480
minimum     :   0.0000000000E+00
maximum     :   3.2000000000E+03
cell x      :   1.6666666667E-01
cell y      :   1.6666666667E-01
legend      : 15
category  1 : 200 to 399
category  2 : 400 to 599
category  3 : 600 to 799
category  4 : 800 to 999
category  5 : 1000 to 1199
category  6 : 1200 to 1399
category  7 : 1400 to 1599
category  8 : 1600 to 1799
category  9 : 1800 to 1999
category 10 : 2000 to 2199
category 11 : 2200 to 2399
category 12 : 2400 to 2599
category 13 : 2600 to 2799
category 14 : 2800 to 2999
category 15 : 3000 to 3199

{category 0 : 0 to 199}
```

[This legend is only appropriate for displays which reclass (contrast stretch) the continuous values into 16 classes.]

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VEGETATION, LAND-USE AND SEASONAL ALBEDO

DATA SETS:

DOCUMENTATION OF ARCHIVED DATA TAPE

MAY 1984

E. MATTHEWS
Sigma Data Services
NASA-Goddard Space Flight Center
Institute for Space Studies
2880 Broadway
New York, New York
10025

*NOTE: This is a revised version of the documentation provided to NCAR in July 1983.

GENERAL DESCRIPTION

Global data bases of vegetation, land use, and land cover have been compiled for use in climate studies at a 1° latitude x 1° longitude resolution, drawing on approximately 100 published sources complemented by a large collection of satellite imagery. A series of 6 datasets has been prepared and archived at NCAR. The first is a vegetation data set (VEGTYPE) representing natural (pre-agricultural) vegetation based on the UNESCO classification system. The second, derived from the land-use compilation is a cultivation intensity data set (CULTINT) defining the areal extent of presently cultivated land in the 1° cells. The last four are present integrated surface-albedo data sets (January, April, July, October) for snow-free conditions except for permanently snow-covered continental ice, incorporating natural vegetation and cultivation characteristics from the vegetation and cultivation-intensity data sets. These 6 data sets include non-zero data for permanent land only, including continental ice; water, including oceans and lakes, is zero.

This paper includes ~~documentation of the data tape format,~~ brief descriptions of the individual data sets, ~~and a regional map of several of the data sets as examples.~~

For complete discussion of the vegetation and land-use data sets see E. Matthews, 1983, Global vegetation and land use: new high-resolution data bases for climate studies, J. Clim. Appl. Meteor., 22, 474-487. Tape prepared by E. Matthews, NASA-Goddard Space Flight Center, Institute for Space Studies, 2880 Broadway, New York, N.Y. 10025, (212) 678-5500, FTS 664-5500.

Acknowledgments. I would like to thank the following people for helpful suggestions and support during the preparation of this report: R.E. Dickinson, I.Y. Fung, J.E. Hansen, R. Jenne, L.C. Tsang, and M. Verstraete.

FILE #	FILE NAME*	ARRAY SIZE	TYPE	DESCRIPTION
1	VEGTYPE	(360,180)	I*2	land points: 1-32 include continental ice water points: 0 include lake & ocean see Table 1, Fig. 1
2	CULTINT	(360,180)	I*2	land points: 1-5 include continental ice water points: 0 include lake & ocean see Table 2, Fig. 2
3	ALBEDO	(360,180)x4	R*4	land points: 1.-100. include continental ice water points: 0. include lake & ocean albedo arrays for 4 months: January,April,July,October snow-free conditions except for permanently snow-covered continental ice See Table 3, Fig. 3

* File names are not on the tape

Table 1. VEGTYPE: The thirty two vegetation types described in Col. 3 are identified in VEGTYPE as 1 to 32, as shown in Col. 1. Col. 2 lists the 32 associated map symbols used to map VEGTYPE in Fig. 1

1	2	3
Vegetation Type	Map Symbol	Description
1	1	tropical evergreen rainforest, mangrove forest
2	2	tropical/subtropical evergreen seasonal broadleaved forest
3	3	subtropical evergreen rainforest
4	4	temperate/subpolar evergreen rainforest
5	5	temperate evergreen seasonal broadleaved forest, summer rain
6	6	evergreen broadleaved sclerophyllous forest, winter rain
7	7	tropical/subtropical evergreen needleleaved forest
8	8	temperate/subpolar evergreen needleleaved forest
9	9	tropical/subtropical drought-deciduous forest
10	A	cold-deciduous forest, with evergreens
11	B	cold-deciduous forest, without evergreens
12	C	xeromorphic forest/woodland
13	D	evergreen broadleaved sclerophyllous woodland
14	E	evergreen needleleaved woodland
15	F	tropical/subtropical drought-deciduous woodland
16	G	cold-deciduous woodland
17	H	evergreen broadleaved shrubland/thicket, evergreen dwarf-shrubland
18	I	evergreen needleleaved or microphyllous shrubland/thicket
19	J	drought-deciduous shrubland/thicket

Table 1. (continued)

1	2	3
Vegetation Type	Map Symbol	Description
20	K	cold-deciduous subalpine/subpolar shrubland, cold-deciduous dwarf shrubland
21	L	xeromorphic shrubland/dwarf shrubland
22	M	arctic/alpine tundra, mossy bog
23	N	tall/medium/short grassland with 10-40% woody tree cover
24	O	tall/medium/short grassland with <10% woody tree cover or tuft-plant cover
25	P	tall/medium/short grassland with shrub cover
26	Q	tall grassland, no woody cover
27	R	medium grassland, no woody cover
28	S	meadow, short grassland, no woody cover,
29	T	forb formations
30	U	desert
31	V	ice
32	W	cultivation

Table 2. CULTINT: Cultivation intensities, ranging from 0 to 5 in CULTINT translate into % cultivated and % natural vegetation as shown.

Cultivation Intensity	Description		
	land/water	% cultivated	% natural vegetation
0	water	-	-
1	land	0	100
2	land	20	80
3	land	50	50
4	land	75	25
5	land	100	0

TABLE 3A. Seasonal snow-free, integrated albedos for 32 vegetation types listed in Table 1. The winter, spring, summer and fall values correspond to January, April, July and October in the northern hemisphere and to July, October, January and April in the southern hemisphere. The appropriate seasonal values were used, in conjunction with the VEGTYPE and CULTINT data bases, to produce albedo data sets for January, April, July and October.

VEGETATION	WINTER	SPRING	SUMMER	FALL
1	11	11	11	11
2	11	11	11	11
3	11	11	11	11
4	12	12	12	12
5	12	13	14	13
6	17	14	13	14
7	13	14	16	13
8	11	12	15	12
9	18	16	15	16
10	12	15	18	13
11	12	15	18	13
12	28	32	28	28
13	15	13	12	13
14	14	14	16	14
15	20	18	17	18
16	14	14	17	14
17	15	15	18	15
18	15	15	18	15
19	17	20	20	17
20	17	20	20	17
21	28	32	28	28
22	12	12	17	15
23	14	15	17	15

TABLE 3A. (continued)

VEGETATION	WINTER	SPRING	SUMMER	FALL
24	14	15	16	14
25	16	18	25	20
26	17	17	20	17
27	16	20	20	18
28	16	20	20	18
29	16	20	20	18
30	30	30	30	30
31	75	75	75	75
32	16	18	20	18

-E-

WILSON AND HENDERSON-SELLERS LAND COVER AND SOILS FOR GLOBAL CIRCULATION MODELING

CITATION: Wilson, M. F., and A. Henderson-Sellers, 1985. Global Land Cover and Soils data: digital data. National Center for Atmospheric Research, Boulder, Colorado. .32 Megabytes.

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E. WILSON AND HENDERSON-SELLERS LAND COVER AND SOILS FOR GCMs

DATE: 1985

SOURCE:

Digitized from available sources.
M. F. Wilson and A. Henderson-Sellers
University of Liverpool
Department of Geography
P.O. Box 147
Liverpool, U. K.

CONTRIBUTOR:

Roy Jenne
NCAR
P.O. Box 3000
Boulder, CO 80307-3000

DATA CENTER: NCAR

GEOGRAPHIC SAMPLING: 1 degree grid, characteristic classes

COVERAGE: Global

PROJECTION: Lat/lon

TIME SAMPLING: Decadal composites

REFERENCES:

Wilson, M. F. and A. Henderson-Sellers, 1985. "A global archive of land cover and soils data for use in general circulation climate models." *Journal of Climatology*, vol. 5, pp. 119-143. (Included)

FILE NAMES:

AFWSOILS	Wilson/Henderson-Sellers Soil Classes
AFWSOILR	Wilson/Henderson-Sellers Soil Class Reliability
AFWLAND1	Wilson/Henderson-Sellers Primary Land Cover Classes
AFWLAND2	Wilson/Henderson-Sellers Secondary Land Cover Classes
AFWLANDR	Wilson/Henderson-Sellers Land Cover Class Reliability

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WILSON/HENDERSON-SELLERS SOIL CLASSES DOCUMENTATION FILE

File Name: AFWSOILS.DOC

```
image title : Wilson & Henderson-Sellers Soil Classes
data type   : byte
file type   : binary
rows        : 438
columns     : 480
minimum     :  0.0000000000E+00
maximum     :  3.1000000000E+01
cell x      :  1.6666666667E-01
cell y      :  1.6666666667E-01
legend      : 31
category  1 :  1 not used
category  2 :  2 not used
category  3 :  3 not used
category  4 :  4 not used
category  5 :  5 not used
category  6 :  6 not used
category  7 :  7 not used
category  8 :  8 not used
category  9 :  9 not used
category 10 : 10 not used
category 11 : 11 LCF      LIGHT, COARSE, FREE
category 12 : 12 LIF      LIGHT, INTERMEDIATE, FREE
category 13 : 13 LFF      LIGHT, FINE, FREE
category 14 : 14 LCI      LIGHT, COARSE, IMPEDED
category 15 : 15 LII      LIGHT, INTERMEDIATE, IMPEDED
category 16 : 16 LFI      LIGHT, FINE, IMPEDED
category 17 : 17 MCF      MEDIUM, COARSE, FREE
category 18 : 18 MIF      MEDIUM, INTERMEDIATE, FREE
category 19 : 19 MFF      MEDIUM, FINE, FREE
category 20 : 20 MCI      MEDIUM, COARSE, IMPEDED
category 21 : 21 MII      MEDIUM, INTERMEDIATE, IMPEDED
category 22 : 22 MFI      MEDIUM, FINE, IMPEDED
category 23 : 23 DCF      DARK, COARSE, FREE
category 24 : 24 DIF      DARK, INTERMEDIATE, FREE
category 25 : 25 DFF      DARK, FINE, FREE
category 26 : 26 DCI      DARK, COARSE, IMPEDED
category 27 : 27 DII      DARK, INTERMEDIATE, IMPEDED
category 28 : 28 DFI      DARK, FINE, IMPEDED
category 29 : 29 L-P      LIGHT, --, POOR
category 30 : 30 M-P      MEDIUM, --, POOR
category 31 : 31 D-P      DARK, --, POOR
category 34 : 34 ICE      ICE

{category 0 : unclassed}
```

WILSON/HENDERSON-SELLERS SOIL CLASS RELIABILITY DOCUMENTATION FILE

File Name: AFWSOILR.DOC

```
image title : Wilson/Henderson-Sellers Soil Class Reliability
data type   : byte
file type   : binary
rows        : 438
columns     : 480
minimum     :   0.0000000000E+00
maximum     :   5.0000000000E+00
cell x      :   1.6666666667E-01
cell y      :   1.6666666667E-01
legend      : 5
category  1 : 1 High
category  2 : 2 Good
category  3 : 3 Moderate
category  4 : 4 Fair
category  5 : 5 Poor

{category 0 : unclassed}


[This legend is appropriate for display of the individual classes
 (i.e. without rescaling).
```

```
category 39 : 39 PAS          Pasture + shrub
category 40 : 40 ARC          Arable cropland
category 41 : 41 DFA          Dry farm arable
category 42 : 42 NMG          Nursery and market gardening
category 43 : 43 CAS          Cane sugar
category 44 : 44 MAI          Maize
category 45 : 45 COT          Cotton
category 46 : 46 COF          Coffee
category 47 : 47 VIN          Vineyard
category 48 : 48 IRG          Irrigated cropland
category 49 : 49 TEA          Tea
category 50 : 50 ERF          Equatorial rain forest
category 51 : 51 ETC          Equatorial tree crop
category 52 : 52 TBF          Tropical broadleaf forest (slight seasonality)
category 53 : 53 Not used
category 54 : 54 Not used
category 55 : 55 Not used
category 56 : 56 Not used
category 57 : 57 Not used
category 58 : 58 Not used
category 59 : 59 Not used
category 60 : 60 Not used
category 61 : 61 TUN          Tundra
category 62 : 62 DWS          Dwarf shrub (tundra transition and high
                              altitude wasteland)
category 63 : 63 Not used
category 64 : 64 Not used
category 65 : 65 Not used
category 66 : 66 Not used
category 67 : 67 Not used
category 68 : 68 Not used
category 69 : 69 Not used
category 70 : 70 SDB          Sand desert and barren land
category 71 : 71 SDS          Scrub desert and semi desert
category 72 : 72 Not used
category 73 : 73 SDT          Semi desert + scattered trees

{category 0 : Open Water}
{category 80: Not Occurring}
```

[This legend is appropriate for display of the individual classes (i.e. without rescaling).]

WILSON/HENDERSON-SELLERS PRIMARY LAND COVER CLASSES DOCUMENTATION FILE

File Name: AFWLAND1.DOC

```
image title : Wilson/Henderson-Sellers Primary Land Cover Classes
data type   : byte
file type   : binary
rows        : 438
columns     : 480
minimum     :   0.0000000000E+00
maximum     :   7.3000000000E+01
cell x      :   1.6666666667E-01
cell y      :   1.6666666667E-01
legend      : 73
category  1 :  1 INW          Inland water
category  2 :  2 BOM          Bog or marsh
category  3 :  3 ICE          Ice
category  4 :  4 PAR          Paddy rice
category  5 :  5 MAN          Mangrove (tree swamp)
category  6 :  6 Not used
category  7 :  7 Not used
category  8 :  8 Not used
category  9 :  9 Not used
category 10 : 10 DNE          Dense needleleaf evergreen forest
category 11 : 11 ONE          Open needleleaf evergreen woodland
category 12 : 12 DMN          Dense mixed needleleaf and broadleaf evergreen
                              and deciduous forest
category 13 : 13 OMN          Open mixed needleleaf and broadleaf, evergreen
                              and deciduous woodland
category 14 : 14 EBW          Evergreen broadleaf woodland
category 15 : 15 EBC          Evergreen broadleaf cropland
category 16 : 16 EBS          Evergreen broadleaf shrub
category 17 : 17 ODN          Open deciduous needleleaf woodland
category 18 : 18 DDN          Dense deciduous needleleaf forest
category 19 : 19 DEB          Dense evergreen broadleaf forest
category 20 : 20 DDB          Dense deciduous broadleaf forest
category 21 : 21 ODB          Open deciduous broadleaf woodland
category 22 : 22 DTC          Deciduous tree crops (temperate)
category 23 : 23 OTW          Open tropical woodland
category 24 : 24 WOS          Woodland + shrub
category 25 : 25 DDD          Dense drought deciduous forest
category 26 : 26 ODD          Open drought deciduous woodland
category 27 : 27 DES          Deciduous shrub
category 28 : 28 THS          Thorn shrub
category 29 : 29 Not used
category 30 : 30 TMP          Temperate meadow and permanent pasture
category 31 : 31 TRG          Temperate rough grazing
category 32 : 32 TGS          Tropical grassland + shrub
category 33 : 33 TRP          Tropical pasture
category 34 : 34 RGS          Rough grazing + shrub
category 35 : 35 PAT          Pasture + tree
category 36 : 36 SAR          Semi arid rough grazing
category 37 : 37 TSG          Tropical Savanna (grassland + tree)
category 38 : 38 Not used
```

WILSON/HENDERSON-SELLERS SECONDARY LAND COVER CLASSES DOCUMENTATION FILE

File Name: AFWLAND2.DOC

```
image title : Wilson/Henderson-Sellers Secondary Land Cover Classes
data type   : byte
file type   : binary
rows        : 438
columns     : 480
minimum     :   0.0000000000E+00
maximum     :   7.3000000000E+01
cell x      :   1.6666666667E-01
cell y      :   1.6666666667E-01
legend      : 73
category  1 :  1 INW          Inland water
category  2 :  2 BOM          Bog or marsh
category  3 :  3 ICE          Ice
category  4 :  4 PAR          Paddy rice
category  5 :  5 MAN          Mangrove (tree swamp)
category  6 :  6 Not used
category  7 :  7 Not used
category  8 :  8 Not used
category  9 :  9 Not used
category 10 : 10 DNE          Dense needleleaf evergreen forest
category 11 : 11 ONE          Open needleleaf evergreen woodland
category 12 : 12 DMN          Dense mixed needleleaf and broadleaf evergreen
                              and deciduous forest
category 13 : 13 OMN          Open mixed needleleaf and broadleaf, evergreen
                              and deciduous woodland
category 14 : 14 EBW          Evergreen broadleaf woodland
category 15 : 15 EBC          Evergreen broadleaf cropland
category 16 : 16 EBS          Evergreen broadleaf shrub
category 17 : 17 ODN          Open deciduous needleleaf woodland
category 18 : 18 DDN          Dense deciduous needleleaf forest
category 19 : 19 DEB          Dense evergreen broadleaf forest
category 20 : 20 DDB          Dense deciduous broadleaf forest
category 21 : 21 ODB          Open deciduous broadleaf woodland
category 22 : 22 DTC          Deciduous tree crops (temperate)
category 23 : 23 OTW          Open tropical woodland
category 24 : 24 WOS          Woodland + shrub
category 25 : 25 DDD          Dense drought deciduous forest
category 26 : 26 ODD          Open drought deciduous woodland
category 27 : 27 DES          Deciduous shrub
category 28 : 28 THS          Thorn shrub
category 29 : 29 Not used
category 30 : 30 TMP          Temperate meadow and permanent pasture
category 31 : 31 TRG          Temperate rough grazing
category 32 : 32 TGS          Tropical grassland + shrub
category 33 : 33 TRP          Tropical pasture
category 34 : 34 RGS          Rough grazing + shrub
category 35 : 35 PAT          Pasture + tree
category 36 : 36 SAR          Semi arid rough grazing
category 37 : 37 TSG          Tropical Savanna (grassland + tree)
category 38 : 38 Not used
```

category 39 :	39 PAS	Pasture + shrub
category 40 :	40 ARC	Arable cropland
category 41 :	41 DFA	Dry farm arable
category 42 :	42 NMG	Nursery and market gardening
category 43 :	43 CAS	Cane sugar
category 44 :	44 MAI	Maize
category 45 :	45 COT	Cotton
category 46 :	46 COF	Coffee
category 47 :	47 VIN	Vineyard
category 48 :	48 IRG	Irrigated cropland
category 49 :	49 TEA	Tea
category 50 :	50 ERF	Equatorial rain forest
category 51 :	51 ETC	Equatorial tree crop
category 52 :	52 TBF	Tropical broadleaf forest (slight seasonality)
category 53 :	53 Not used	
category 54 :	54 Not used	
category 55 :	55 Not used	
category 56 :	56 Not used	
category 57 :	57 Not used	
category 58 :	58 Not used	
category 59 :	59 Not used	
category 60 :	60 Not used	
category 61 :	61 TUN	Tundra
category 62 :	62 DWS	Dwarf shrub (tundra transition and high altitude wasteland)
category 63 :	63 Not used	
category 64 :	64 Not used	
category 65 :	65 Not used	
category 66 :	66 Not used	
category 67 :	67 Not used	
category 68 :	68 Not used	
category 69 :	69 Not used	
category 70 :	70 SDB	Sand desert and barren land
category 71 :	71 SDS	Scrub desert and semi desert
category 72 :	72 Not used	
category 73 :	73 SDT	Semi desert + scattered trees

{category 0 : Open Water}
{category 10: Not Occurring}

[This legend is appropriate for display of the individual classes (i.e. without rescaling).]

WILSON/HENDERSON-SELLERS LAND COVER CLASS RELIABILITY DOCUMENTATION FILE

File Name: **AFWLANDR.DOC**

```
image title : Wilson/Henderson-Sellers Land Cover Class Reliability
data type   : byte
file type   : binary
rows        : 438
columns     : 480
minimum     :   0.0000000000E+00
maximum     :   5.0000000000E+00
cell x      :   1.6666666667E-01
cell y      :   1.6666666667E-01
legend      : 5
category  1 : 1 High
category  2 : 2
category  3 : 3
category  4 : 4
category  5 : 5 Low

{category 0 : unclassed}


[This legend is appropriate for display of the individual classes
 (i.e. without rescaling).]
```

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FORMAT & BRIEF DESCRIPTION OF SOIL AND VEGETATION DATA

(University of Liverpool)

1) The 3 basic data arrays, 1° x 1° soil data, 1° x 1° primary vegetation data, and 1° x 1° secondary vegetation have been merged consecutively and stored as one file (called soilveg data) on the tape.

   Each data type was originally stored as an integer array (32 bits), dimensions 360 x 180, (output) in FORTRAN integer format, 40I2 i.e., 1620 lines per data type, 4860 lines in total.

2) The 2 reliablility data arrays, 1° x 1° soil reliability, and 1° x 1° land cover reliability have been merged consecutively and stored as one file (called rel data) on the tape.

   Each data type is stored as an integer array dimensions 360 x 180 in FORTRAN integer format 40I1 i.e., 1620 lines per data type, 3240 lines in total.

File soilveg data

1) 1° x 1° soil data - 360 x 180 array - lines 0 - 1620

2) 1° x 1° primary veg. data - 360 x 180 array - lines 1621 - 3240

3) 1° x 1° secondary veg. data - 360 x 180 array, lines 3241 - 4860

File rel data

1) 1° x 1° soil reliability - 360 x 180 array - lines 0 - 1620

2) 1° x 1° land cover reliability - 360 x 180 array - lines 1621 - 3240

The tape has been written by an IBM 4341 under VM/CMS using the move-file command.

JCL to write tape

The data are output as 80 character logical records, blocked 10 to a physical record (800 by tens).

```
Fi inmove soilveg data.
Fi outmove tapl (lrecl 80 block 800 recfm fb den 1600 9track)
movefile

Fi inmove rel data A
Fi outmove tap (lrecl 80 block 800 recfm fb den 1600 9track)
movefile
```

Table 1. Land cover classes used in new data archive

Code	Land Cover Description
00	Open water
01	Inland water
02	Bog or marsh
03	Ice
04	Paddy rice
05	Mangrove (tree swamp)
10	Dense needleleaf evergreen forest
11	Open needleleaf evergreen woodland
12	Dense mixed needleleaf and broadleaf, evergreen and deciduous forest
13	Open mixed needleleaf & broadleaf, evergreen & deciduous woodland
14	Evergreen broadleaf woodland
15	Evergreen broadleaf cropland
16	Evergreen broadleaf shrub
17	Open deciduous needleleaf woodland
18	Dense deciduous needleleaf forest
19	Dense evergreen broadleaf forest
20	Dense deciduous broadleaf forest
21	Open deciduous broadleaf woodland
22	Deciduous tree crops (temperate)
23	Open tropical woodland
24	Woodland + shrub
25	Dense drought deciduous forest
26	Open drought deciduous woodland
27	Deciduous shrub
28	Thorn shrub
30	Temperate meadow and permanent pasture
31	Temperate rough grazing
32	Tropical grassland + shrub
33	Tropical pasture
34	Rough grazing + shrub
35	Pasture + tree
36	Semi arid rough grazing
37	Tropical savanna (grassland + tree)
39	Pasture + shrub
40	Arable cropland
41	Dry farm arable
42	Nursery and market gardening
43	Cane sugar
44	Maize
45	Cotton
46	Coffee
47	Vineyard
48	Irrigated cropland
49	Tea
50	Equatorial rain forest
51	Equatorial tree crop
52	Tropical broadleaf forest (slight seasonality)
61	Tundra
62	Dwarf shrub (tundra transition and high altitude wasteland)
70	Sand desert and barren land
71	Scrub desert and semi desert
73	Semi desert + scattered trees
80	Urban

Table 2. Code and properties of soil classes used in the soil data archive

Code	Colour	Texture	Drainage
11	light	coarse	free
12	"	intermediate	free
13	"	fine	free
14	"	coarse	impeded
15	"	intermediate	impeded
16	"	fine	impeded
17	medium	coarse	free
18	"	intermediate	free
19	"	fine	free
20	"	coarse	impeded
21	"	intermediate	impeded
22	"	fine	impeded
23	dark	coarse	free
24	"	intermediate	free
25	"	fine	free
32	"	coarse	impeded
27	"	intermediate	impeded
28	"	fine	impeded
29	light	--	poor
30	medium	--	poor
31	dark	--	poor
34	ice		

Reliability Scores:

Land cover		Soils	
1	high	1	high
2		2	good
3		3	moderate
4		4	fair
5	low	5	Poor

First row is northernmost; 180° = left-hand margin of row

JOURNAL OF CLIMATOLOGY, VOL. 5, 119–143 (1985) 551.513:551.588.3:581.524.44:631.4

A GLOBAL ARCHIVE OF LAND COVER AND SOILS DATA FOR USE IN GENERAL CIRCULATION CLIMATE MODELS

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Received 15 March 1984
Revised 1 June 1984

ABSTRACT

A new global archive of soil type and land cover data derived for use in GCM climate models is described. The data are archived at a resolution of 1° latitude × 1° longitude. The method of construction of the component data sets is given together with 'reliability estimates'. The soils data form the only published data set designed specifically for use in climate studies. The land cover data are compatible with the soils data, forming a coherent and complete data set and seem to be comparable with other land cover information. Recommendations are made about combining and coarsening the data to the grid of any general circulation climate model. Methods of parameterizing surface radiative and hydrological properties in climate models are proposed.

KEY WORDS Land surface Climate models Soils Vegetation Albedo Hydrology

1. INTRODUCTION

There is increasing awareness of and concern about the possible causes and consequences of climate fluctuations. Major international and interdisciplinary efforts are currently being made to improve our understanding of the climate system. The main objectives of the World Climate Research Programme (WCRP) are to determine: (i) to what extent climate can be predicted and (ii) the extent of man's influence on climate (Houghton, 1982). The most sophisticated tool with which to study global scale climate is the 3-D general circulation model (GCM).

The physical properties of the soil and the presence and nature of a vegetation cover influence the surface energy and moisture balance and the exchange of moisture, heat and momentum between the atmosphere and the land surface. Until very recently climate modellers have concentrated upon producing successful simulations of the large scale dynamics of the atmosphere and the associated transports of energy and moisture. Surface–atmosphere interactions have been represented in climate models by using only simple parameterizations. There is, however, an increasing awareness of the importance of the interaction of the components of the climate system on various temporal and spatial scales. The need for an interdisciplinary approach to climate model development has been recognized recently (Dickinson, 1983).

Development of land surface parameterization and examination of the possible impact of man on climate through surface modification are important and currently active fields of research within the WCRP. To develop land surface parameterization schemes the global distribution of climatically important parameters must be prescribed as input data for the models. An early attempt was made by Posey and Clapp (1964) to provide information about global vegetation for use in albedo studies although these data were produced only in map form and the mislabelling of their Figures 2–5 must be

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0196–1748/85/020119–25$02.50
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corrected if comparisons are to be drawn. The only global vegetation data known to the authors to be currently available* in digital format are the land cover classifications of Hummel and Reck (1979) and Matthews (1983a). We know of no global soils data in digital form.

Sensitivity experiments show that many climate models are sensitive to surface albedo changes (e.g. Charney, 1975; Charney *et al.*, 1977; Washington and Chervin, 1979; Sud and Fennessy, 1982). More recently the sensitivity of climate models to surface moisture and evapotranspiration has been clearly demonstrated in the global irrigation experiment undertaken by Shukla and Mintz (1982) using the Goddard Laboratory for Atmospheric Science (GLAS) general circulation model and in similar experiments undertaken at the U.K. Meteorological Office (UKMO) (Carson and Sangster, 1982). At the regional scale, Walker and Rowntree (1977) and Rowntree and Bolton (1983) have shown that persistent response to soil moisture anomalies occurs. It is clear that there are many links between properties of the energy and moisture budgets. As models are sensitive to soil and land cover properties, climate modellers require information about the surface upon which to base parameterization schemes.

A new global data set of type of land cover and soil designed specifically for use in climate models (specifically for the U.K. Meteorological Office 11 layer GCM) has been constructed. The data were collated from natural vegetation, forestry, agriculture, land use and soils maps with reference to the accompanying descriptive legends. The final data archive is stored in digital format at a 1° latitude×1° longitude resolution. The soils data have been averaged from digitized dominant type of soil at a finer resolution (1/2° latitude ×1/2° longitude). The land cover data also provide information at a finer resolution than 1° × 1° as dominant primary and secondary land cover types are archived as separate arrays (see Section 3). The identification of secondary land type may be important for cover types such as urban development which have a fragmented distribution. The incorporation of both primary and secondary land uses results in a finer effective resolution than any data previously incorporated into a GCM. The soils data are the only existing global soils data set known to the authors in which soil type is classified according to climatically important properties for use in GCMs, although other land cover data sets are available and additional data sets of both types are currently being prepared (B. Moore, 1984, p.c.). The most important feature of the archive described here is that it contains *both* soil and land cover information. Thus, for the first time, parameterization of the hydrological cycle, especially evaporation, runoff and soil moisture dependence of albedo, can be incorporated consistently with vegetation parameterization schemes. Recommendations concerning the use of the new data in both climate modelling and monitoring programmes are made at the end of this paper.

2. SOILS DATA SET

The digital soils data described here are presented as a 180 × 360 element array. Each row starts with the Greenwich meridian as the western boundary of the first element and progresses eastwards. Twenty-one categories of soil based on a combination of colour, texture and drainage classes are identified.

2.1. Criteria for soil category selection

The four major components of soil are inorganic material, organic material, water and air. There are many factors which influence the development of soil. These factors vary in time and space such that the integral of all soil forming processes produces a multiplicity of soil profile types. The GCM modeller needs information about the large scale distribution of thermal, hydraulic and radiative soil properties to determine surface and subsurface temperature and moisture state in a model integration. A simple soils data set with relatively few classes is required.

Surface reflectivity, soil thermal conductivity, specific heat and heat capacity are the most important soil parameters influencing the surface thermal regime. Thermal response depends on the conductivity

* CLIMAP (1981) produced a land surface data file at 2° × 2° which we believe is also available (R. T. Wetherald, 1984, p.c.)

and bulk average heat capacity of the soil particles, soil porosity and soil moisture content. In general, heat capacity increases and conductivity decreases as texture varies from coarse to fine in dry soils whereas both increase with increasing soil moisture content.

Of the numerous factors which contribute to the moisture regime of the soil, surface texture and information relating to the presence of an impermeable layer impeding vertical drainage are the only parameters available at a global scale. The soil classification used here is based on a combination of 3 colour, 3 texture and 3 drainage categories. Surface colour (light, medium or dark) influences the surface albedo. Surface texture (fine, intermediate or coarse) may be used to parameterize rates of infiltration of moisture into the soil and soil water movement and to assign appropriate thermal and moisture capacities for the upper soil layers. Drainage (free, impeded or poor) may be used as an indicator of the likelihood of waterlogging and the depth to which moisture can penetrate.

2.2. *Description of data sources*

The main data source used was the FAO/UNESCO Soil Map of the World (S.M.W.). It was necessary to use the Oxford Regional Economic Atlas of U.S.S.R. and Eastern Europe in conjunction with the Central Asia and East European map sheets to classify the soils of N.E. Asia, as the relevant map sheet was not available. The internationally agreed legend of the S.M.W. is not a pedological classification system in itself. It was designed to provide a more general framework into which soil classes of the many existing systems could be fitted. A general legend and 10 regional legends accompany the map sheets. Each legend contains details of the environmental conditions, the sources of data used and their reliability. Details of morphological, chemical and physical properties of soils from selected profiles are presented. Colours are given according to the Munsell colour scheme. One hundred and six major soil units are identified in the S.M.W. In the S.M.W. the term soil unit is used to identify soil profile types. 'These units do not correspond to equivalent categories in different classification systems' (FAO/UNESCO, 1974, p. 10). It is not possible to assess quantitatively the amount of organic matter typical of each of these units. However, from the profile descriptions it is possible to distinguish qualitatively soil units in S.M.W. expected to have low or high organic matter content (Table I). High organic matter content is associated with dark soils. It can occur either as a result of waterlogging and low decay rates or it can promote aggregation and a structure which improves drainage.

2.3. *Derivation of colour classes*

For climate modelling the colour of the surface layer is required to determine the surface albedo. The colour of the surface 'A' or 'O' horizon is a function of the mineral material, organic matter content and soil moisture content. The S.M.W. units were grouped into 3 colour classes: dark, medium and light. The colour class was determined primarily from the description of major soil units given in the general legend. Soil colour is given according to the Munsell colour scale. The Munsell colour scale defines colour according to three parameters: hue (which is an indication of the tone of a soil colour), chroma (which is dependent on the intensity of the colour) and value (which is a measure of the lightness of the colour). Soil units characterized by mollic or umbric 'A' horizons or dark organic rich 'O' or 'A' horizons as a diagnostic feature have been classed as dark. Mollic or umbric 'A' horizons are defined in the S.M.W. legend as those in which 'both broken and crushed samples have colours (Munsell) with a chroma of less than 3·5 when moist, and a value darker than 3·5 when moist'. The remaining soil units of S.M.W. either

(i) have an ochric 'A' horizon or

(ii) the 'A' horizon characteristics are not a diagnostic feature of the unit.

An ochric 'A' horizon is defined in the S.M.W. general legend as one that is either 'too light in colour, has too high a chroma or too little organic matter, or, is too thin (<10 cm if underlain by rock, 18 cm or 25 cm where the column is less than and greater than 75 cm respectively) to be classified as mollic or umbric or, is both hard and massive when dry'. Therefore it is not possible to assume that all ochric soils

Table I. Soil units having high organic matter content

gelic histosols
dystric histosols
eutric histosols
mollic solonchaks
mollic gleysols
humic gleysols
mollic andosols
humic andosols
humic ferralsols
mollic planosols
humic planosols
mollic solonetz
gleyic greyzems
orthic greyzems
luvic chernozems
glossic chernozems
calcic chernozems
haplic chernozems
luvic kastanozems
calcic kastanozems
haplic kastanozems
luvic phaeozems
gleyic phaeozems
calcic phaeozems
haplic phaeozems
humic cambisols
humic acrisols
humic nitosols
rankers
rendizinas

will be lighter in colour than umbric or mollic soils, as a criterion other than colour may have been used in distinguishing the unit. To re-classify the remaining soil units of the S.M.W. therefore, the descriptions of organic matter content and colour given for individual sample profiles of the units presented in the regional legends were considered. The colour of the surface horizon in individual profile descriptions is given in terms of hue, value and chroma in accordance with notation used in the Munsell soil colour charts. These colours were subjectively classified as light, medium and dark by reference to a colour chart. The indices of hue, value and chroma chosen as the limits of each class are shown in Table II. Where information was available in the profile description about the moisture status of the soil, the effect on soil colour was also considered. Problems associated with this technique include the limited number of sample profiles described for each of the S.M.W. soil units and lack of information about the moisture status of the sample profile at the time of observation. The dark, medium and light categories are designed to distinguish soil units that

(i) range in colour from dark when wet to medium or dark when dry; these soil units were placed in the dark category
(ii) show medium colour characteristics for all moisture states; these soil units were assigned to the medium category
(iii) have a range of colour that is light when dry and either light or medium when wet; these soil units were placed in the light category.

Soil units which were found to have variable colour characteristics in different sample profiles were assigned to the medium colour class. If only one or no sample profile was available for a soil unit it was placed in the medium category except where all other soil units within the soil order (group of soil units, e.g. fluvisols) show a specific dark or light colouration.

Table II. Hue, value and chroma limits used in classifying soil colour

Hue	Value	Chroma	Assigned colour class
10 R	<4	<6	dark
	4	all	medium
	5	>8	medium
	5	<8	light
	6	all	light
2·5 YR	<4	<6	dark
	4	all	medium
	5	>6	medium
	5	<6	light
	6	all	light
5 YR	<4	<4	dark
	4	all	medium
	5	>6	medium
	5	<6	light
	6	all	light
7·5 YR	<4	all	dark
	4	all	medium
	5	>6	medium
	5	<6	light
	6	all	light
10 YR	≤3	<6	dark
	4	all	medium
	5	>4	medium
	5	<4	light
	6	all	light
2·5 Y	<4	all	dark
	4	all	medium
	5	all	medium
	6	>6	medium
	6	<6	light

2.4. *Derivation of texture classes*

Three texture classes are given in the S.M.W. Texture is defined (FAO/UNESCO, 1974) by the percentage of sand, silt and clay in the top 30 cm of the soil profile (Figure 1). The texture class in the new data set was classified as in the S.M.W. except in 3 cases:

(i) If a soil unit is noted in the legend to drain very quickly then in order to prevent excessively slow drainage in a model simulation, if fine texture was shown, the texture was recorded as intermediate.

(ii) If a slope of <8 per cent was coincident with fine texture and low organic matter the soil was classified as poorly drained.

(iii) If fine texture was coincident with high organic matter and good drainage it was assumed that the organic matter would improve structure and promote good drainage and therefore the texture was recorded as intermediate.

2.5. *Derivation of drainage classes*

Three drainage categories are identified in the new data set: free, poor and impeded. The descriptions of drainage characteristics in the S.M.W. legend were reviewed. Soil units which were frequently noted to have rapid, poor or impeded drainage were identified. These soil units are given in Table III. For characteristically poorly drained soil units, or where fine texture, low organic matter and

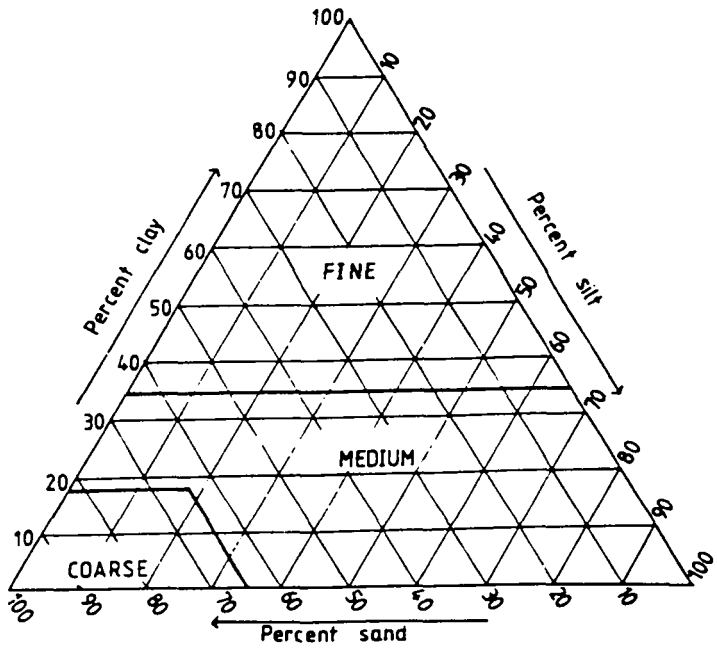


Figure 1. Texture triangle used in FAO/UNESCO Soil Map of the World classification

slope <8 per cent were coincident, or where a marsh overprint symbol occurred, the soil category was recorded as poorly drained in this data archive. For the remaining areas, division into free or impeded drainage classes was made according to the location relative to the permafrost boundary and information pertaining to the soil phase. Soil phase is indicated by overprint symbols in the S.M.W. and defined as subdivisions of soil units based on characteristics which are significant to the use or management of the land but are not diagnostic of separation of units themselves. Impeded soils are either (i) located within the boundary of a permafrost zone and/or (ii) lithosols and/or (iii) soils having lithic, petrocalcic, petrogypsic, petroferric, phreatic, fragipan or duripan phase.

2.6. *Construction of the soils data archive*

The soil category recorded in the new archive was identified according to the soil unit, slope and drainage class which occupied the greatest area in a 1/2° latitude × 1/2° longitude grid area. If no soil unit was dominant in a grid area a subjective appraisal was made of the individual colour, texture and drainage characteristics of soil units present. The element was then recorded as the category which best summarized the mixed properties. The 1° × 1° soils data are shown in Plate I. Plate I(a) is the global distribution of the 3 colour classes. In Plates I(b) and I(c) the texture and drainage classes are presented.

From Plate I(a) it is evident that the majority of grid boxes have medium coloured soils. Dark soils occur in central North America, eastern Europe and throughout much of central and north-east U.S.S.R, north-east India and parts of east Africa and South America. Light soils are identified as dominant throughout the desert areas of north and south-west Africa, the Middle East and Mongolia. Light coloured soils are also found along the southern and western coasts of Australia and much of eastern Canada and most of Scandinavia.

The soil texture and drainage categories are shown in Plates I(b) and I(c). The three texture categories of the freely draining soils are shown in Plate I(b) and of the impeded and poorly draining soils are shown in Plate I(c). The most common soil category is the intermediate texture, freely draining soil. This occurs throughout most of the U.S.A., Europe and western Asia and is common in Africa and eastern Asia. The high northern latitudes have impeded drainage. In many such areas the impermeable

Table III. Soil units dominated by rapid, poor and impeded drainage characteristics (free, i.e. normal, drainage is associated with all the remaining units)

Rapid	chromic luvisols
	cambric arenosols
	luvic arenosols
	ferralic arenosols
	albic arenosols
	eutric regosols
	calcaric regosols
	dystric regosols
Poor	eutric gleysols
	calcaric gleysols
	dystric gleysols
	mollic gleysols
	humic gleysols
	plinthic gleysols
	gelic gleysols
	gleyic solonchaks
	gleyic podzoluvisols
	gleyic acrisols
	gleyic cambisols
	gleyic luvisols
	gleyic podzols
	gleyic phaeozems
	gleyic greyzems
	eutric histosols
	dystric histosols
	gelic histosols
	orthic solonetz
	mollic solonetz
	gleyic solonetz
	pellic vertisols
	chromic vertisols
Impeded	lithosols

(All other soil units have *free* drainage).

nature of the soil is due to the presence of continuous permafrost. Most desert regions have coarse textured soils. Fine textured soils are confined mostly to north-west Alaska, the southern coast of Hudson Bay, the northern coast of central U.S.S.R, south-east China and parts of Brazil.

For each map sheet of the S.M.W., a small scale inset map is included showing whether the information used in constructing the map was derived from (i) systematic soil surveys, (ii) soil reconnaissance techniques or (iii) from general information based mainly on the interpretation of land forms, geology, vegetation and climate. The maps of source data have been used to show the reliability estimate for the data (Plate II). Only in the Eastern U.S.A. and Eurasia are there large areas where information has been derived entirely from systematic survey. These regions are shown as having a high level of reliability. General information has been used in most of the sparsely vegetated regions, India and the rain-forest regions. The greatest uncertainty in the soil archive is therefore in Canada, N.W. Brazil, Africa, the Middle East and southern Asia. New survey information should be incorporated in these areas as soon as possible.

3. LAND COVER DATA SET

The land cover data are presented as two 180 × 360 1° latitude × 1° longitude resolution arrays. Each type is represented by a two digit code. The 53 possible land cover types used are listed in Table IV. The first array contains primary land types. The second array contains secondary land types. The

Plate I(a). Global distribution of dark, medium and light coloured soils

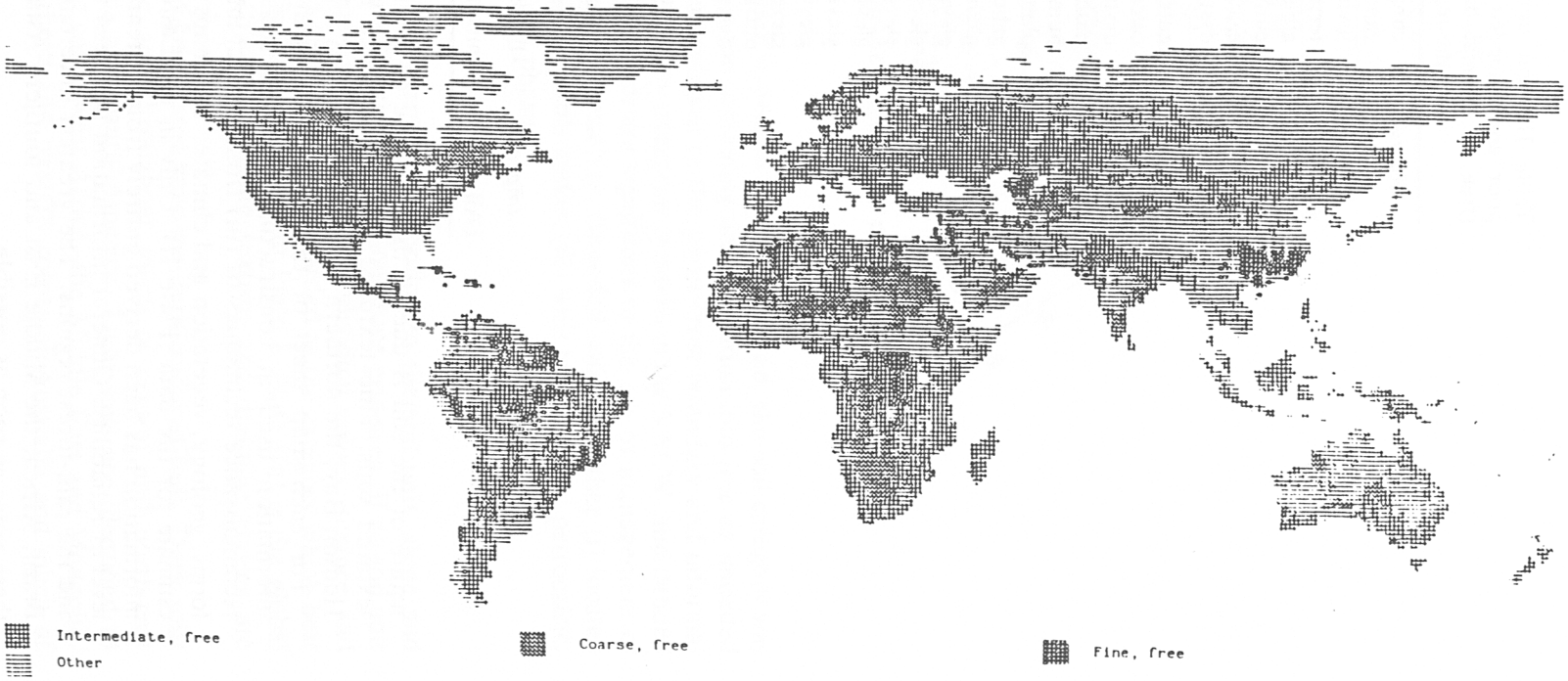


Plate I(b). Global distribution of soil texture classes

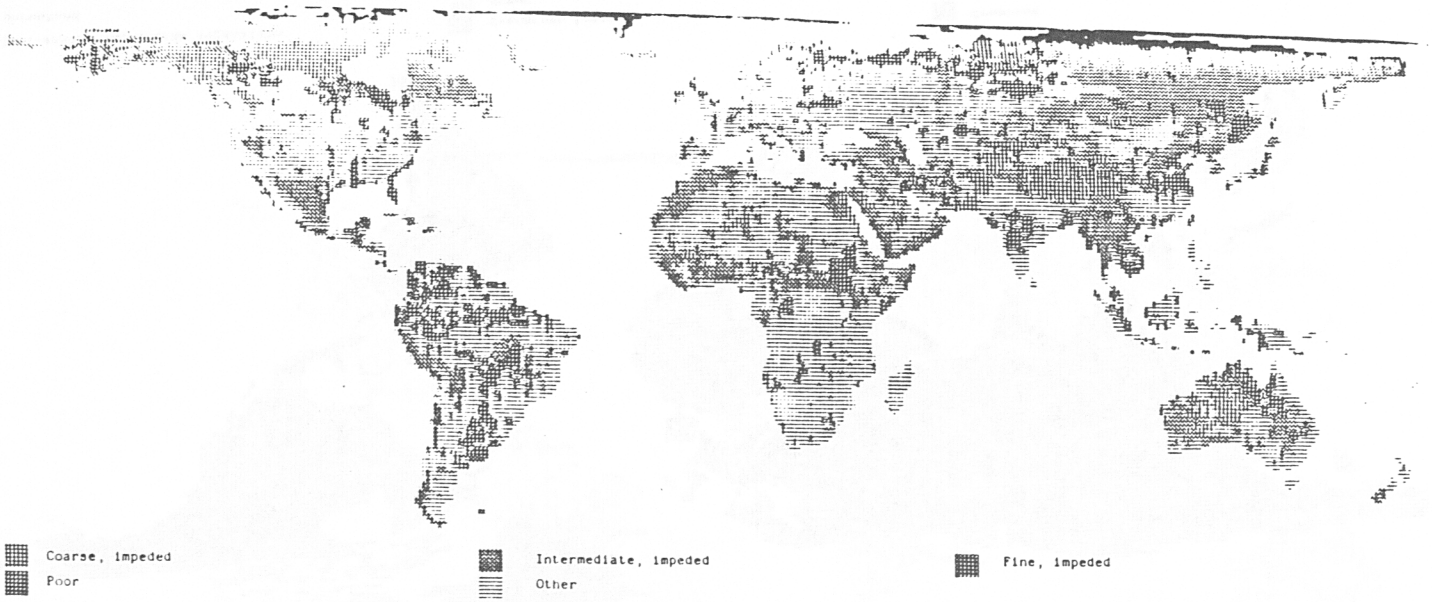


Plate I(c). Global distribution of soil drainage classes

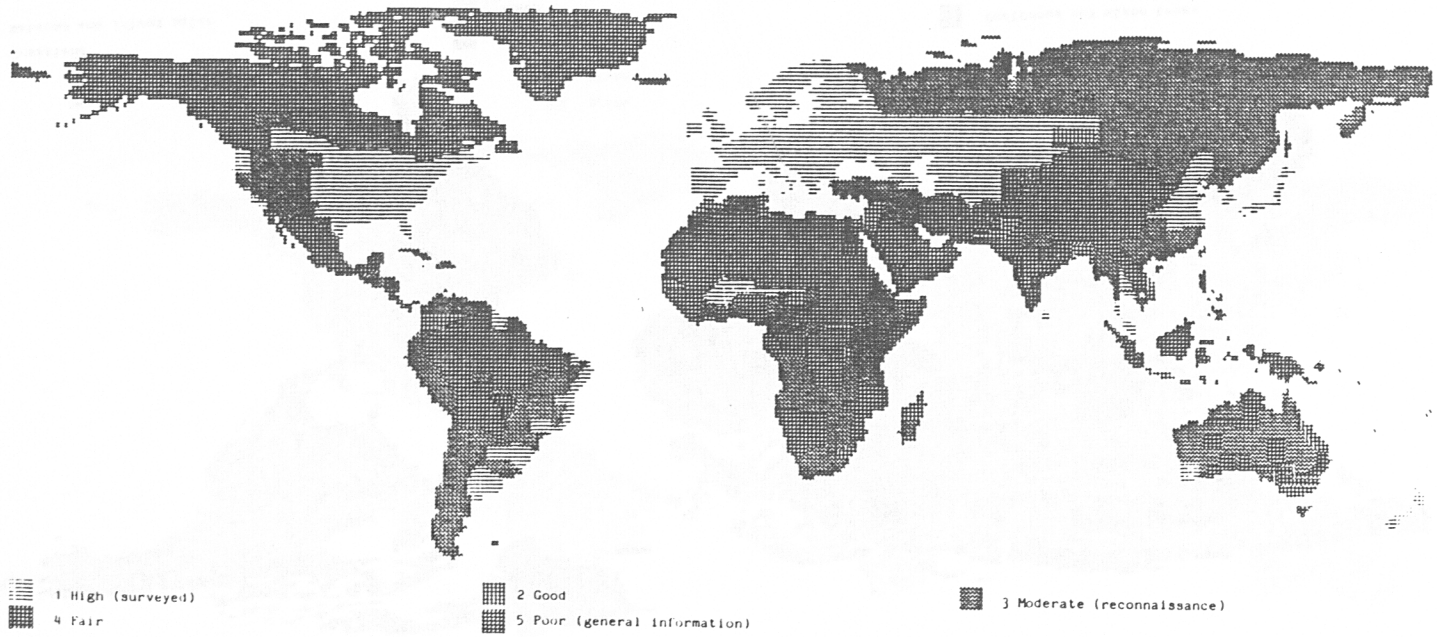
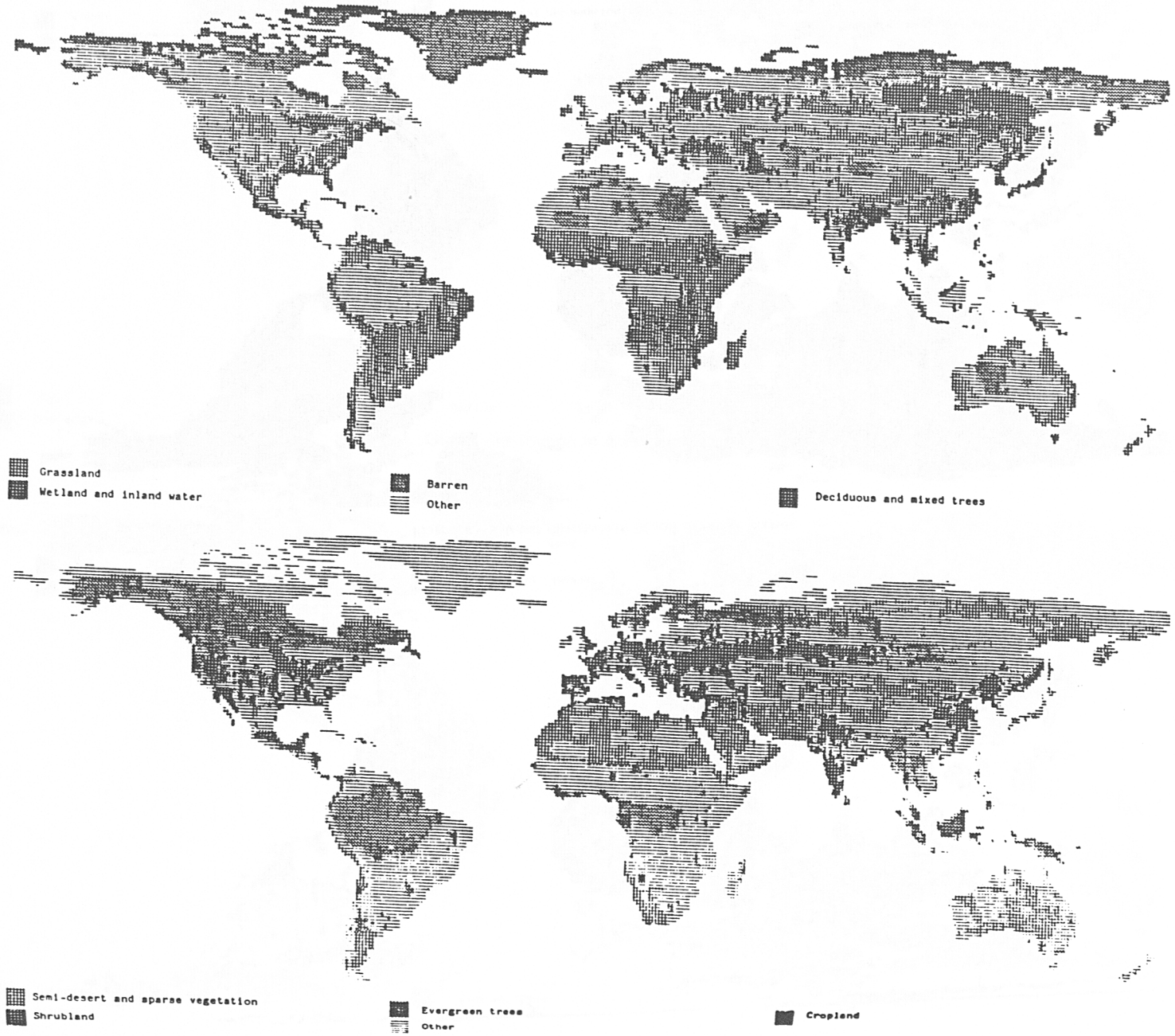
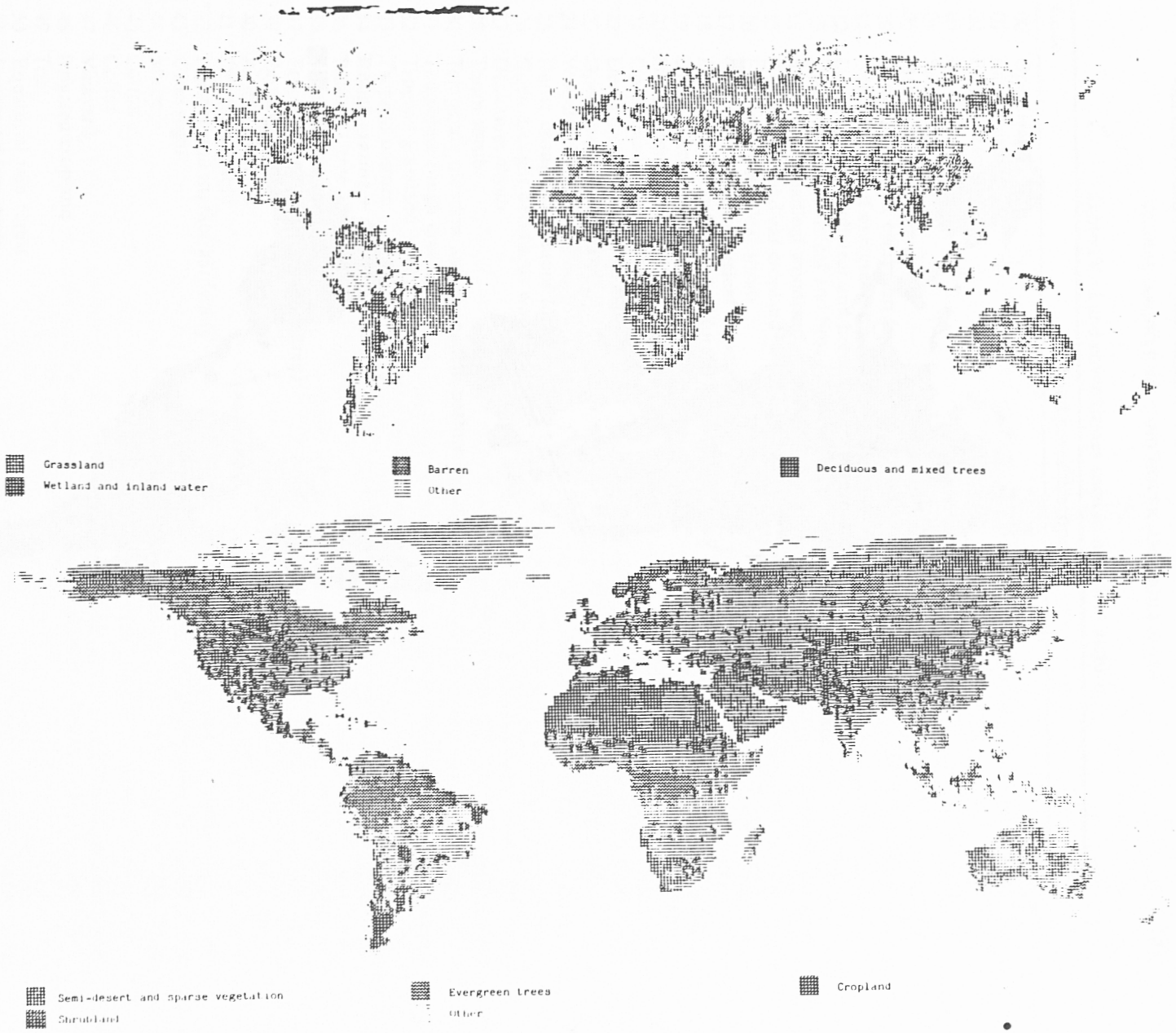


Plate II. Reliability estimates for the source data used in compiling the soils data file



Plates IV(a) and IV(b). Distribution of secondary land cover groups



Plates IV(a) and IV(b). Distribution of secondary land cover groups

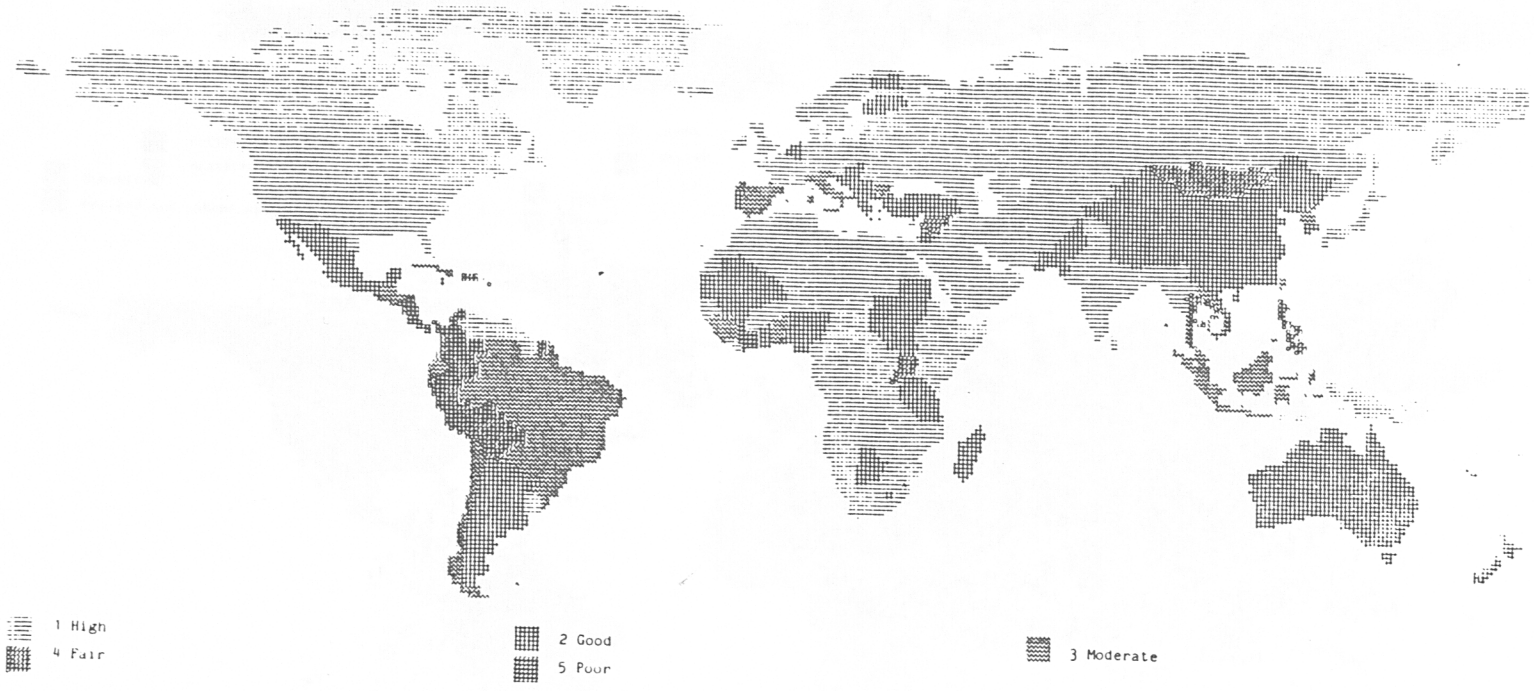


Plate V. Reliability estimates for the source data used in compiling the land cover file

Table IV. Land cover classes used in new data archive

Code	Land cover description
00	Open water
01	Inland water
02	Bog or marsh
03	Ice
04	Paddy rice
05	Mangrove (tree swamp)
10	Dense needleleaf evergreen forest
11	Open needleleaf evergreen woodland
12	Dense mixed needleleaf and broadleaf, evergreen and deciduous forest
13	Open mixed needleleaf and broadleaf, evergreen and deciduous woodland
14	Evergreen broadleaf woodland
15	Evergreen broadleaf cropland
16	Evergreen broadleaf shrub
17	Open deciduous needleleaf woodland
18	Dense deciduous needleleaf forest
19	Dense evergreen broadleaf forest
20	Dense deciduous broadleaf forest
21	Open deciduous broadleaf woodland
*22	Deciduous tree crops (temperate)
23	Open tropical woodland
24	Woodland + shrub
25	Dense drought deciduous forest
26	Open drought deciduous woodland
27	Deciduous shrub
28	Thorn shrub
30	Temperate meadow and permanent pasture
31	Temperate rough grazing
32	Tropical grassland + shrub
33	Tropical pasture
34	Rough grazing + shrub
35	Pasture + tree
36	Semi arid rough grazing
37	Tropical savanna (grassland + tree)
39	Pasture + shrub
40	Arable cropland
41	Dry farm arable
*42	Nursery and market gardening
43	Cane sugar
44	Maize
45	Cotton
46	Coffee
47	Vineyard
48	Irrigated cropland
49	Tea
50	Equatorial rain forest
51	Equatorial tree crop
52	Tropical broadleaf forest (slight seasonality)
61	Tundra
62	Dwarf shrub (tundra transition and high altitude wasteland)
70	Sand desert and barren land
71	Scrub desert and semi desert
73	Semi desert + scattered trees
80	Urban

* not identified at 1° × 1° resolution

primary land type is one which best represents the land cover type which occupies ≥50 per cent of the grid area. The secondary land type occupies <50 per cent and ≥25 per cent of the grid area. If no secondary land type could be distinguished the primary code was repeated for the secondary land type. For grid areas with mixed vegetation or where no single type was clearly dominant, primary and secondary types were chosen which most accurately summarized all the component land types. A number of mixed categories are incorporated in the classification.

3.1. Choice of land type categories

Parameterization of the influence of land cover on surface energy and moisture exchange with the atmosphere requires estimates of vegetation height, structure, density, seasonality, ground cover and rooting depth at a scale appropriate to the model resolution.

Four height categories are incorporated in the classification scheme: tall (trees), intermediate (shrub and tall grasses and maize), short (grasses and most crops) and very short (tundra and barren land). Needleleaf and broadleaf trees have been separated because they differ in structure, interception and evapotranspiration characteristics. Density classes range from dense forest, through open woodland, shrubland, tree crops, grass or crop with tree shrub, open grassland and cropland to semi-desert, dwarf shrub tundra transition, tundra and finally to bare soil. Seasonality is incorporated by distinguishing between evergreen and deciduous, temperate and drought shrub and tree formations, temperate and tropical ecosystems and between cultivated arable land, permanent pasture and natural grazing. Irrigated and dry farm crop systems are distinguished from other arable land due to their different cover characteristics and artifically imposed surface hydrology. The combination of both primary and secondary land types permits representation of transition zones between dominant land cover types and increases the number of types that can be included.

Fifty-three possible classes divide global vegetation on the basis of parameters important in climate modelling studies. Of these 53 classes only 51 were identified at the 1° × 1° resolution (see Table IV). Although an agreed international classification for vegetation mapping (UNESCO, 1973) has now been published and may be employed in future mapping, existing maps have used diverse classification schemes. In this archive the classification is designed specifically to provide information about the gross surface features from existing ground based surveys with critical consideration of as many of the available data sources as possible. Only a few classes were used for each parameter (e.g. tall, intermediate, short and very short/barren in the height classes), so that it was possible to infer these distinctions from most of the data sources available in spite of the disparate classification schemes used. The classes have, additionally, been chosen on the basis of expected requirements of land surface parameterization schemes in climate models. The data represent a simple classification of major vegetation types according to qualitative categorization of gross features of the vegetation cover. In classifying vegetation at the large scale appropriate to the climate modelling community it is not possible, and probably also not necessary, to identify more than a few broad classes for each of the climatically important parameters. Despite the simplified system we have used we are pleased to note the similarity between our classification scheme (Table IV) and the subdivisions of major ecosystems listed by Matthews (1983a) (her table 4) which were based on the UNESCO (1973) classes.

3.2. Description of main data sources

A large number of data sources were used in constructing the land cover data set. The main sources were:

(1) The World Atlas of Agriculture (1969–1976), UNESCO)
(2) The World Forestry Atlas (1961 and continuing)
(3) Heinemann, Times and Oxford World atlases
(4) Oxford regional economic atlases
(5) National and regional atlases (Table V)
(6) A global vegetation map produced for use in carbon budget studies (Olson and Watts, 1982)
(7) Northern Hemisphere snow covered albedo map (Robinson, 1982).

Table V. Atlases and map books used in constructing the land cover data file

World

Atlas of Economic Geography. 1975. Humlum, J., 7th edition, Gyldendal, Copenhagen.
Meyer's Grosser physischer Weltatlas 3. 1976. Schmithüsen, J. (ed), Atlas zur Biogeographie, Bibliographisches Institut, Mannheim.
Oxford Economic Atlas of the World. 1972. Jones, D. B. (ed.), 4th edition, Oxford University Press, London.
Oxford World Atlas. 1973. Cohen, S. B. (ed.), Oxford University Press, London.
The Heinemann World Atlas. 1979. Rand McNally (ed.), Heinemann, London.
The University Atlas. 1977. Fullard, H. and Darby, H. C. (eds), 18th edition, Philip, London.
The Times Atlas of the World. 1968. Comprehensive edition, Times Newspaper, London.
The Times Concise Atlas of the World. 1972. Times Newspaper, London.
Weltforstatlas. 1961 (continuing). Verlag Paul Parey, Hamburg.
World Atlas of Agriculture. 1969. Committee for the World Atlas Agriculture, Instituto Geografico de Agostini, Novara.

Europe

Agro-ecological Atlas of Cereal Growing in Europe, Vol. 1 Agroclimatic Atlas of Europe. 1965. Thran, P. and Broekhuizen, S., Elsevier, London.
Atlas of Europe: a profile of Western Europe. 1974. Browne, G. S. (ed.), Bartholomew and Warne, London.
Oxford Regional Economic Atlas of U.S.S.R. and Eastern Europe. 1963. Oxford University Press, London.
Oxford Regional Economic Atlas of Western Europe. 1971. Clayton, K. M. and Kormoss, I. B. F., (eds) Oxford University Press, London.
Atlas de Belgique. 1951. Comité National de Géographie Commision d l'Atlas, Brussels.
A Map Book of the Benelux Countries. 1979. Tussler, A. J. B. and Alden, A. J. L., Macmillan Education, London.
Atlas Ceskoslovenskej Socialistickej Republiky. 1962. Svoboda, J. Ústreda správa geodézie a kartografie, Prague.
Atlas Republiky Ceskoslovenské. 1935. Pantofliček, J. (ed.), Editions Orbis S. A., Prague.
Atlas of Denmark. 1961. Nielson, N. (ed.), Royal Danish Geographic Society, Copenhagen.
Danmark Atlas. 1976. Humlum, J. and Nygård, K., 2nd edition, Gyldendal, Copenhagen.
Deutscher Planungsatlas. 1970–1975. Kuhn, A., Haubner, K., Kraus, H. and Witt, W. (eds), Schroedel, Hanover.
Atlas Deutsche Demokratische Republik. 1981. Akademie der Wissenchaftten der D.D.R., Haack, Gotha.
An Agricultural Atlas of England and Wales. 1976. Coppock, J. T. (ed.), Faber and Faber, London.
Atlas of Britain and Northern Ireland. 1963. Blackman, G. E., Caesar, A. A. L., Gullick, C. F. W. R., Steers, J. A. and Worswick, G. D. N., Clarendon Press, Oxford.
Ordnance Survey Atlas of Great Britain. 1982. Ordnance Survey, Hamlyn, London.
Atlas of Ireland. 1979. Irish National Committee for Geography, Royal Irish Academy, Dublin.
Atlas Nacional de Espana. 1965. Instituto Geografico y Catastral, Madrid.
Atlas of Finland. 1960. Aario, L., (ed.), The Geographical Society of Finland, Kustannusosakeyhtiö Otava, Helsinki.
Atlas de France (Metropole). 1953–1959. Comité Nationale de Géographie, Paris.
A Map Book of France. 1980. Tussler, A. J. B. and Alden, A. J. L., 4th edition, Macmillan Education, London.
A Map Book of West Germany. 1979. Tussler, A. J. B. and Alden, A. J. L., Macmillan Education, London.
Economic and Social Atlas of Greece. 1964. Kayser, B. and Thompson, K., Center of Economic Research and National Statistical Service of Greece, and Social Sciences Centre, Athens.
National Atlas of Hungary. 1967. Sándor, R., (ed.), Cartographia, Budapest.
Atlas of Luxembourg. 1971. Ministère de l'Éducation Nationale, Luxembourg.
Atlas van Nederland. 1963–1977. Government Printing and Publishing Office, The Hague.
Netherlands in One Hundred Maps. 1977. Tamsma, R., Royal Dutch Geographical Society, Amsterdam.
Atlas von Niederösterreich. 1951–1958. Hassinger, H. and Becker, A., Freytag-Berndt und Artaria, Vienna.
Atlas der Republik Österreich. 1980. Bobek, H. (ed.), Freytag-Berndt und Artaria, Vienna.
Atlas Polski. 1952–1961. Centralny Urząd Geodezji i Kartografii, Warsaw.
Narodowy Atlas Polski. 1973–1978. Leszozycki, S. (ed.), Polska Akademia Nauk, Instytut Geografii, Warsaw.
Atlas Geografic Republica Socialistă România. 1965. Eustatiu, G. and Victor, T., (eds), Bucharest.
Atlas de la Suisse. 1981. Imhof, E. (ed.), L'Office Fédéral de Topographie, Wabern, Berne.
A Map Book of Scandinavia. 1979. Tussler, A. J. B. and Buckby, P. R., Macmillan Education, London.
Agricultural Atlas of Scotland. 1976. Coppock, J. T. (ed.), John Donald, Edinburgh.
Economic Atlas of the Soviet Union. 1960. Kish, G., University of Michigan Press, Ann Arbor.
U.S.S.R. in Maps. 1982. Dewdney, J. C., Hodder and Stoughton, London.
Atlas over Sverige. 1953–1971. Anrick, C. J., Hogbom, I., Enebbquist, G. and Lundquist, M., Kartografiska Institutet, Stockholm.
Geografski Atlas Jugoslavje. 1961. Mardešić, P. and Dugački, Z., Zagreb, Znanje.

Asia

Atlas of the Arab World and the Middle East. 1960. Macmillan, London.
Atlas of South-East Asia. 1964. Macmillan, Amsterdam.
Oxford Regional Economic Atlas of Middle East and North Africa. 1960. Oxford University Press, London.
South Asia in Maps. 1974. Kingsbury, R. C., 2nd edition, Donoyer Geppert, Chicago.
General Atlas of Afghanistan. 1970 (continuing). Sahab Geographic and Drafting Institute, Tehran.
Atlas of Land Utilization in China. 1950. Chen, C-S., National Taiwan University, Taipei.

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Atlas of China. 1973. Hsieh, C.-M. and Salter, C. (eds), McGraw-Hill, New York.
Census Atlas of India. 1970. Mitra, A., Census Commission of India, New Delhi.
National Atlas of India. 1980. National Atlas and Thematic Mapping Organisation, Department of Science and Technology, Government of India, Calcutta.
Atlas of Israel. 1956–1964. Department of Surveys, Jerusalem.
Atlas of Japan. 1974. International Society for Educational Information, Tokyo.
Oxford Economic Atlas of Pakistan. 1955. Gullick, C. F. W. R. (ed.), Oxford University Press, London.
An Atlas of Papua and New Guinea. 1970. Ward, R. G. and Lea, D. A. M. (eds), University of Papua New Guinea and Collins-Longman, Glasgow.
Geographical Atlas of Taiwan. 1959. Chen, C.-S., National Taiwan Univeristy, Taipei.
Thailand National Resources Atlas. 1972. Royal Thai Survey Department, Bangkok.
Soviet Union In Maps. 1972. Fullard, H. (ed.), Phillip, London.

Africa

Jeune Atlas Afrique. 1974. Chi-Bonnardel, R. V., Editions Jeune Afrique, Paris.
Oxford Atlas for East Africa. 1966. Oxford University Press, London.
Oxford Regional Economic Atlas of Africa. 1965. Oxford University Press, London.
Geography of African Affairs. 1972. Fordham, P., 3rd edition, Penguin, Harmondsworth.
Atlas du Burundi. 1979. L'Université de Bordeaux III, Association Atlas Burundi, Gradignan.
Atlas du Cameroun. 1960. Institute de Récherches Scientifiques du Cameroun, Yaoundé.
Atlas de la République Unie du Cameroun. 1979. Laclavère, G., (ed.), Editions Jeune Afrique, Paris.
Atlas de la République Populaire du Congo. 1977. Vennetier, P., (ed.), Editions Jeune Afrique, Paris.
Atlas de Côte d'Ivoire. 1979. l'Association de L'Atlas de Côte d'Ivoire, Abidjan.
Atlas de la Côte d'Ivoire. 1980. Vennetier, P., (ed.), Editions Jeune Afrique, Paris.
National Atlas of the Ivory Coast. 1971/1972. Office de la Récherche Scientifique et Technique, Abidjan.
Ghana National Atlas. 1972. Boateng, E. A., (ed.), Council of Scientific and Industrial Research, Accra.
Atlas de la Haute-Volta. 1975. Péron, Y. and Zalacain, V., Editions Jeune Afrique, Paris.
National Atlas of Kenya. 1970. 3rd edition, Survey of Kenya, Nairobi.
Liberia in Maps. 1972. Gnielinski, S., (ed.), University of London Press, London.
Atlas du Maroc. 1954 (continuing). Comité National de Géographie du Maroc, Rabat.
Malawi in Maps. 1972. Agnew, S. and Stubbs, M. (eds), University of London Press, London.
Atlas de la République Islamique de Mauritanie. 1977. Toupet, C. and Laclavère, G. (eds), Editions Jeune Afrique, Paris.
Atlas du Niger. 1980. Bernus, E. and Hamidou, S. A., Editions Jeune Afrique, Paris.
An Agricultural Atlas of Nigeria. 1979. Agboola, S. A. (ed.), Oxford University Press, London.
Nigeria in Maps. 1982. Barbour, K. M., Oguntoyinbo, J. S., Onyemelukwe, J. O. C. and Nwafor, J. C., Hodder and Stoughton, London.
Federal Atlas of Rhodesia and Nyasaland. 1960–1966. Federal Department of Trigonometrical and Topographic Surveys, Government Printer, Salisbury.
Atlas of Sierra Leone. 1966. Surveys and Land Division, 2nd edition, Stanford, London.
Sierra Leone in Maps. 1969. Clarke, J. I., Hodder and Stoughton, London.
Atlas of Tanzania. 1967. Surveys and Mapping Division, Ministry of Lands, Settlement and Water Development, Dar-es-Salaam.
Tanzania in Maps. 1971. Berry, L. (ed.), University of London Press, London.
Atlas Pratique du Tchad. 1972. Cabot, J., Bouquet, C. and Dresch, J. (eds), Institut National Tchadien pour les Sciences Humaines, Institut Géographique National, Paris.
Atlas of Uganda. 1967. Dawner, E. R. (ed.), Lands and Surveys Department, Government Printer, Entebbe.
Atlas de la République du Zaïre. 1978. Laclavère, G. (ed.), Editions Jeune Afrique, Paris.
Zambia in Maps. 1971. Davies, D. H. (ed.), University of London Press, London.

Australasia

Atlas of Australian Resources. 1966–1982. Plumb, T. (ed.), 2nd Series, Department of National Development, Canberra.
Reader's Digest Atlas of Australia. 1977. Reader's Digest (ed.), Reader's Digest, Sydney.
New Zealand Atlas. 1976. Wards, I. (ed.), Shearer, Wellington.
New Zealand in Maps. 1977. Anderson, A. G., Hodder and Stoughton, London.

North America

Atlas of North American Affairs. 1969. Adam, D. E. and Rodgers, H. B., Methuen, London.
Oxford Regional Economic Atlas of United States and Canada. 1967. Chapman, J. D. and Sherman, J. C. (eds), Oxford University Press, London.
National Atlas of Canada. 1974. Surveys and Mapping Branch, Department of Energy, Mines and Resources, Macmillan of Canada, Ottawa.
National Atlas of the United States. 1970. U.S. Department of the Interior, Geological Survey, Washington, D.C.

Central and South America

Atlas of Central America. 1979. Arbingast, S. A., Holz, R. K., Gill, C. C., Ryan, R. M. and Hezlep, W. L., Bureau of Business Research, University of Texas, Austin.

Table V. (*Contd.*)

Atlas de la República Argentina. 1970. 4th edition, Instituto Geográfico Militar, Buenos Aires.
Atlas for the Bahamas. 1971. Collins and Son, Glasgow.
Atlas for Barbados, Windwards and Leewards. 1974. Looby, A., Arthur, J., Harris, F., Glean, C., Browne, I., Woodley, S., Braithwaite, M. and Kirby, E., Macmillan Education, London.
Atlas de Bolivia. 1958. René, R., Instituto Geográfico de Agostini, Novara.
Atlas National do Brasil. 1966. Conselho Nacional de Geografia, Rio de Janeiro.
Atlas de Columbia. 1969. Diaz, A. 2nd edition. Instituto Geográfico Agustín Codazzí, Litografía Arco, Bogota.
Atlas de Cuba. 1978. Instituto Cubano de Geodesia y Cartografía, La Habana.
Atlas Nacional de Cuba. 1970. Instituto de Geografía de la Academia de Ciencias de Cuba y Instituto de Geografía de la Academia de Ciencias de la U.R.S.S. La Habana.
Atlas Geográfico del Ecuador. 1975. Jaramillo de Dávila, V., Instituto Geográfico Militar, Bogota.
Atlas National de Guatemala. 1972. Instituto Geográfico Nacional, Guatemala.
Atlas for Guyana, Trinidad and Tobago. 1978. Akai, A. and Matadeen, J., Macmillan Education, London.
Atlas for Jamaica and the Western Caribbean. 1971. Eyre, L. A., (ed.), Colins-Longman, Glasgow.
Jamaica in Maps. 1974. Clarke, C. G. and Hodgkiss, A. G., University of London Press, London.
Atlas of Mexico. 1975. Arbingast, S. A., Gill, C. C., Blair, C. D., Holz, R. K., Buchanan, J. R., Marin, C. A., Ryan, R. M., Bonine, M. E. and Weiler, J. P., 2nd edition, Bureau of Business Research, University of Texas, Austin.
Atlas of Peru. 1971. López Dominovich, A., Guía, Lascano.
Atlas of Venezuela. 1979. Ministerio del Ambiente y de los Recursos Naturales Renovables, Caracas.

3.2.1. World Atlas of Agriculture (W.A.A.). This contains land-use maps at a scale of 1:5,000,000 or larger for all land areas (except northern Canada which is mapped at a scale of 1:12,500,000). Sources used in its construction are listed in the atlas. It is therefore possible to assess to some extent the accuracy of these data. Monographs contain selected bibliographies, descriptions of the physical environment (climate, geomorphology and natural vegetation) and details of exploitation of natural resources and land use for each country. Sixteen fundamental land use categories are used in this atlas. In areas of mixed land use extra classes are used with the land-use categories given in order of dominance.

3.2.2. World Forestry Atlas (1961 and continuing) (W.F.A.). This source contains maps of major forest types at a scale of 1:5,000,000. Coarser resolution maps are presented of the distribution of major species in individual countries. These data were used to augment data presented in the W.A.A. and national atlases to determine the distribution of deciduous, evergreen, broadleaf and needleleaf species.

3.2.3. Heinemann World Atlas (1979), Times Atlas of the World (1968), Oxford Economic World (1972) and Oxford Regional (1959–1971) Atlases. Small scale maps of the natural climax vegetation and land use presented in these atlases were used to validate data contained in the W.A.A. and to provide supplementary information in areas of non-cultivated land.

3.2.4. National atlases. Many national atlases were consulted in compiling the new land cover data file. Wherever national atlas data were available at a higher resolution or more recent date than the source for the W.A.A. the data sources were compared. If disagreement between these sources occurred, the most recently compiled of the two data sources was used.

3.2.5. Olson and Watts (1982). This is a map of global vegetation types at a scale of 1:30,000,000 designed for use in global carbon budget studies, based on a previous study by Hummel and Reck (1979). Major ecosystems (forest, grassland, shrubland, desert and cropland) are shown on the map with further subdivisions made according to species, density and climatic region. Unfortunately it has not been possible to establish the exact sources used to compile this map. Thus although it is a useful verification tool, little direct assessment was made from this source.

3.2.6. Snow covered albedo map (Robinson, 1982). This source contains clear sky surface albedo estimated for snow covered land derived in 1° × 1° segments from image processed analyses of Defense Meteorological Satellite Program brightness. The brightness data were converted to albedo values by linear interpolation between 0·8 for bright tundra and 0·18 for dense coniferous forest. Six albedo

classes are given in this source. Highest snow covered albedo exists for low and sparse vegetation or a bare surface which is completely buried by snow. Areas with tall vegetation have a greater number of dark protrusions above the snow surface and therefore have a low snow covered albedo. These data were used to distinguish dense forest, open woodland, grassland, tundra transition and tundra, in high latitude regions of the northern hemisphere. Although used to add detail to classes already identified from other sources these data were not used to delimit the location of major vegetation types if disagreement occurred between these data and atlas sources.

Before it is possible to derive land cover classes suitable for climate modelling from satellite data there are many difficulties to overcome (Henderson-Sellers and Wilson, 1983b). No satellite data have been directly incorporated in this data set although reference has been made to albedo data pertaining to high latitude forests as described above. The data set described represents a land based survey of surface cover roughly appropriate to the period 1950–1970. As such it represents a base (i.e. historic) data set useful in developing surface monitoring programmes, e.g. within the framework of the International Satellite Land Surface Climatology Project (ISLSCP, 1984).

3.3. Data compilation

A 1° × 1° grid was superimposed on data from each of the sources. Land use was determined primarily from the World Atlas of Agriculture and national atlases. The other sources were used only to add detail, including classification of dominant crop type, tree type and density class and the nature of non-agricultural land use.

To permit illustration of the newly archived data here, the primary and secondary land classes were grouped into the 7 categories as listed in Table VI. The grouped data are displayed in Plate III (primary) and Plate IV (secondary). It is important to note that the incorporation of a secondary land type also permits identification of, for example, areas of scattered woodland in north-west Europe which would be classed as cultivated if a base resolution of 1° × 1° (i.e. the primary data only) were employed. Differences are bound to occur between this and other data sets; for example, in eastern Australia the new data set shows semi desert where Hummel and Reck (1979) indicate the presence of

Table VI. Grouped land cover classes used in displaying the new data archive

Group	Classes incorporated in groups
Open water and bog	Inland water, bog or marsh, paddy rice, mangrove tree swamp.
Evergreen wood and forest	Dense needleleaf evergreen forest, open needleleaf evergreen woodland, evergreen broadleaf woodland, evergreen broadleaf cropland, dense evergreen broadleaf forest, equatorial rain forest, equatorial tree crop, tropical broadleaf forest.
Mixed and deciduous wood and forest	Dense deciduous needleleaf forest, open deciduous needlefeaf woodland, dense (mixed) needleleaf and broadleaf, evergreen and deciduous woodland. open mixed needleleaf and broadleaf evergreen and deciduous woodland, dense deciduous broadleaf forest, open deciduous broadleaf woodland, deciduous tree crops, open tropical woodland, woodland and shrub, dense drought deciduous forest, open drought deciduous woodland.
Grassland	Temperate meadow and permanent pasture, temperate rough grazing, savanna, tropical grassland and shrub, tropical pasture, rough grazing and shrub, pasture and tree, pasture and shrub
Cropland	Arable cropland, dry farm arable, nursery and market gardening, cane sugar, maize, irrigated cropland.
Semi-arid	Dwarf shrub, scrub desert and semi-desert, semi-desert and scattered trees, semi-arid rough grazing, urban.
Barren	Ice, sand desert and barren land, tundra.
Shrub	Evergreen broadleaf shrub, deciduous shrub, thorn shrub, cotton, coffee, vineyard, tea.

grazing land. This difference is due to the incorporation in the new data archive of a semi-arid rough grazing category in an attempt to distinguish different levels of grazing cover type. Other similar differences, both real and apparent, would certainly be revealed by a detailed comparison of the available vegetation data sets (B. Moore, 1984, p.c.). We believe that our land cover information, shown in simplified form in Plates III and IV, provides a satisfactory and useful adjunct to our soils data described above. We believe that the most appropriate way to compare global land surface archives is to perform GCM integrations using the same model, initial conditions etc. The results from such a comparison would also identify the level of information resolution to which GCMs are sensitive. Such a comparison forms the basis of our current research programme.

Problems associated with construction of the new data set occur due to different scales and classification schemes used in the various sources, lack of documentation of the date and scale of source data used in construction of atlas data and lack of recent surveys in areas of rapid anthropogenic change and in remote areas.

Throughout the mapping procedure difficulties in assigning a land cover category discussed in the W.A.A. were noted. For example, in the monograph for South Korea it is stated that difficulty was encountered in classifying the land cover into one of the fundamental categories due to the patchy nature of forest clearance for permanent and shifting cultivation. In many semi-arid areas, it is noted that much of the land classified as arable is fallow for long periods. Where disagreement occurred between the different data sources reviewed, the nature of the discrepancy was recorded. FAO land use statistics for each country for the years 1961–1965, 1970, 1969–1971 and 1980 were compared. The percentage of change in each ten year period was calculated. This information in conjunction with the date of the source data and the recorded discrepancies between data sources and difficulties in applying W.A.A. classification were used to derive a reliability score between 1 and 5 for each country. These reliability values are shown in Plate V.

A high reliability score is found throughout North America, most of Europe, the Middle East, U.S.S.R and much of the African continent. This high reliability is indicative of either a very recent source of data or a change of <2·5 per cent at the national scale since the date of publication of the map source data. The areas of lowest data reliability occur in Central and South America, along the south-west coast of northern Africa, Uganda, Rwanda-Burundi, the Phillipines, Thailand, Mongolia and Syria. The sensitivity of any climate model simulations to surface forcing in these areas should be investigated in order to determine the possible effects of the lack of satisfactory data on model results.

4. PROPOSED APPLICATION OF THESE DATA IN SPECIFIC CLIMATE MODELLING AND MONITORING STUDIES

In deriving and archiving these new data sets it was intended that as much information (spatial and classification) as possible should be retained. It is almost inevitable that users will require a coarser spatial resolution than the 1° × 1° archived data. The applications are likely to be in parameterization of surface albedo (e.g. Dickinson, 1983; Henderson-Sellers and Wilson, 1983a) and surface hydrology (e.g. Carson and Sangster, 1982; Rowntree and Bolton, 1983). The methods of use proposed here could be modified to suit user requirements. In using the data sets, the data must be corrected to the land/sea distribution of the model.

4.1. Coarsening the resolution of the archived data

The resolution of the data (1° × 1°) is fine enough to permit summary of features of the data for use at the coarser resolution of most GCMs. It is suggested that to derive vegetation files at the resolution required by a specific model, percentage amounts of a restricted range of vegetation components should be averaged. To undertake this, each vegetation type is broken down into percentage of different preselected components. For example, arable land may be broken down into 60 per cent crop, 20 per cent grass and 20 per cent bare soil; open mixed woodland into 30 per cent coniferous tree, 30 per cent

Table VII(a). Annual mean percentage of 24 vegetation components and their associated land types

Code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
00	100																							
1			100																					
2																							100	
3		100																						
4			25													75								
5	25							40		25														10
10				85																				15
11				55									30											15
12				45			45																	10
13				30			30						30											10
14					60								30											10
15					70								20											10
16										60			25											15
17						60							25											15
18						85																		15
19					90																			10
20							85						10											5
21							60				5		30											5
22							60						30											10
23								55						35										10
24							50				25		15											10
25									75					5										20
26									55			5		15										25
27											60		30											10
28												50		20										30
30													90											10
31											10		70	5										15
32								5			20			60										15
33													20	65										15
34											20		65											15
35							15				5		75											5
36										15		15		25										45
37								20						75										5
39											15		75											10
40													20		60									20
41													10		55									35
42															90									10
43														10			70							20
44															30			50						20
45															10				70					20
46								60							20									20
47											60				20									20
48													10							75				15
49											60			20										20
50				85				10																5
51				70										10	10									10
52				30			50							10										10
61																						100		
62										30	20											40		10
70																								100
71										10		20		10										60
73								40						20										40
80											20										70			10

Table VII(b). Twenty-four land types and descriptions

Type	*Description*
1	Water
2	Ice
3	Inland lake
4	Evergreen needleleaf tree
5	Evergreen broadleaf tree
6	Deciduous needleleaf tree
7	Deciduous broadleaf tree
8	Tropical broadleaf tree
9	Drought deciduous tree
10	Evergreen broadleaf shrub
11	Deciduous shrub
12	Thorn shrub
13	Short grass and forbs
14	Long grass
15	Arable
16	Rice
17	Sugar
18	Maize
19	Cotton
20	Irrigated crop
21	Urban
22	Tundra
23	Swamp
24	Soil

deciduous tree, 30 per cent grass and forbs and 10 per cent soil etc. Examples of this type of division are given in Table VII. Primary and secondary land types may be divided into their respective components and then weighted ($\times$75 per cent of each of the primary type components) + ($\times$25 per cent for each of the secondary type components). Thus percentage cover of the 24 components is determined. The averaged values may then either be assigned back into one of the original land type categories or, more usefully, the parameterization scheme could use the 24 more general classes listed in Table VII.

The resolution of the soils data may be changed by averaging separately the colour, texture and drainage characteristics for the area. The averaged properties are then re-assigned to one of the original classes. The colour and texture classes are averaged by assigning values of 3, 2 and 1 to light, medium and dark colour classes and coarse, intermediate and fine texture classes, respectively, and averaging the values over the required grid area. The colour class at the new resolution is light if the average colour, x, is $>2{\cdot}5$, medium, if $1{\cdot}5 \leqslant x \leqslant 2{\cdot}5$ and dark if $x < 1{\cdot}5$. The drainage properties are most accurately summarized by determining the dominant drainage category: free, impeded or poor. An example of the major steps in the conversion to a 2° $\times$ 2° resolution is shown schematically in Figure 2.

In the following subsection suggestions about the specific application of these new data are made. Potential users are warned, however, that although we are confident about the archived data there is a considerable range of opinion pertaining to albedo (and hydrological) values and their methods of inclusion in climate models.

4.2. *Application to albedo and other parameters*

Once the soils and land type data have been averaged to the required GCM grid size (in this case it is assumed that the primary and secondary vegetation types have been combined in the proportions of 75 to 25 per cent into one of the 24 land type classes) a grid box albedo can be calculated using the proposed albedos for vegetation (Table VIII) and soil colour (Table IX). It is likely that soil albedos may be made a function of model-determined soil moisture. Therefore both wet and dry soil albedo

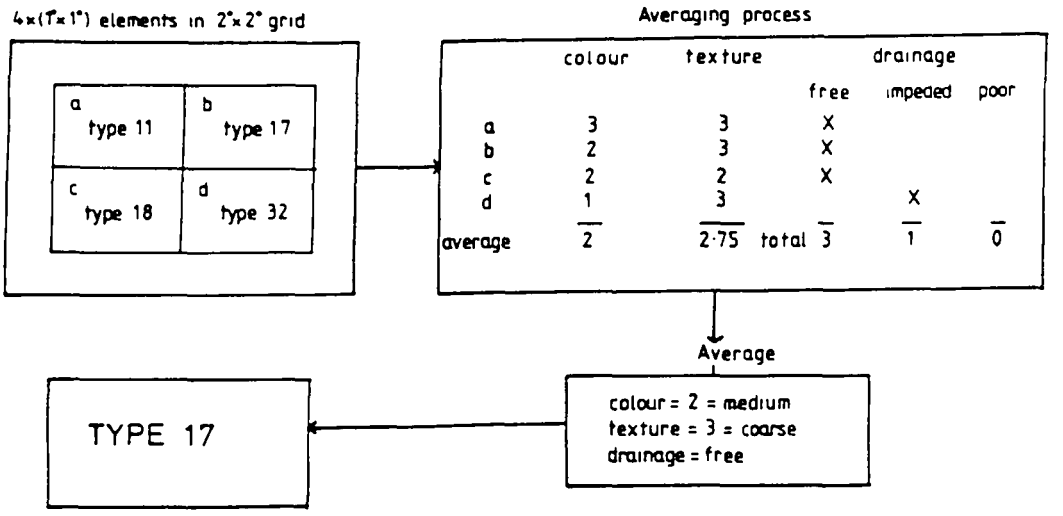

Figure 2. Major steps involved in converting the soils data from a 1° × 1° to a 2° × 2° resolution

Table VIII. Proposed albedo values for use in equation (1)

	Land type component	Annual	Summer	Winter
1	Water	0·07	0·07	0·07
2	Ice	0·75	0·60	0·80
3	Inland lake	0·06	0·06	0·06
4	Evergreen needleleaf tree	0·14	0·14	0·15
5	Evergreen broadleaf tree	0·14	0·14	0·14
6	Deciduous needleleaf tree	0·13	0·14	0·12
7	Deciduous broadleaf tree	0·13	0·14	0·12
8	Tropical broadleaf tree	0·13	0·13	0·13
9	Drought deciduous tree	0·13	0·13	0·12
10	Evergreen broadleaf shrub	0·17	0·17	0·17
11	Deciduous shrub	0·16	0·17	0·15
12	Thorn shrub	0·16	0·16	0·16
13	Short grass and forbs	0·19	0·20	0·18
14	Tall grass	0·20	0·17	0·22
15	Arable	0·20	0·25	0·16
16	Rice	0·12	0·12	0·12
17	Sugar	0·17	0·17	0·17
18	Maize	0·19	0·22	0·16
19	Cotton	0·19	0·22	0·17
20	Irrigated crop	0·25	0·25	0·25
21	Urban	0·18	0·18	0·18
22	Tundra	0·15	0·17	0·12
23	Swamp	0·12	0·12	0·12
24	Soil	See Table IX—colour and moisture		

Table IX. Typical soil albedos, A_s

Colour class	Light	Medium	Dark
Moisture state	wet dry	wet dry	wet dry
Albedos	0·18 0·35	0·10 0·20	0·07 0·15
Average	(0·26)	(0·15)	0·11)

values are proposed here. It may also be desirable to include seasonality. This can be done either using the seasonal albedos given in Table VIII (or others) and/or by modifying the types and percentages of the basic 24 land type classes specified for the finer archive classes (Table VII). A single grid box albedo, A, will be given by

$$A = \sum_{i=1}^{23} (P_{vi} A_{vi}) + A_s P_s \tag{1}$$

where P_{vi} and A_{vi} are the percentages of the 23 vegetation components and their associated albedos; A_s is the soil albedo for the dominant soil colour type for the grid box (with a prespecified functional dependence on soil moisture if desired) and P_s is the percentage amount of soil (i.e. P_s is identically equal to P_{v24}). Sensitivity experiments using the described soil and land cover data using a parameterization of this nature are currently being undertaken with the U.K. Meteorological Office 11 layer GCM.

Additionally it may be considered desirable to incorporate latitudinal dependence for the specified vegetation albedos in order to accommodate reduced seasonality at low latitudes and the effect of solar zenith angle variations in different latitude zones. However, it is considered that the uncertainty in the proposed vegetation albedos, A_v, listed in Table VIII, is greater than either of these effects. Rather, it is recommended that detailed sensitivity studies be carried out (i) to assess the best method of incorporating soil moisture dependence and (ii) that this be done *before* second order terms in the albedo calculation are included. For a full review of sources used in compiling Tables VIII and IX see Henderson-Sellers and Wilson (1983b).

It is also desirable to use data such as the archive described here to improve the parameterization of surface hydrology in GCMs. The amount of water which can be held in a soil is greatly influenced by soil texture. The runoff from each model grid square will be critically dependent upon the way in which water which reaches the ground surface as either precipitation or snow-melt occurs and will be a function of vegetation cover, soil moisture and surface texture. Similarly the amount of moisture available for evapotranspiration is a function both of the capacity of the soil and also the extent of the vegetation root system (i.e. the effective depth of moisture available to plants). Finally, soil thermal properties are influenced by the texture, organic matter content and moisture content of the soil. Using the texture classes given in the soils data set and model-predicted moisture content it may be possible to improve parameterization of storage and fluxes of heat in the soil surface layers. However it is important to note that while the thermal capacity and rate of temperature change could be calculated for each texture type as a function of the soil moisture content at a chosen interval in a GCM integration the results may depend upon the selected interval and will depend upon the precipitation predicted. Similarly, with respect to the parameterization of evapotranspiration it must be noted that the specific effective root depths will differ from real root depths and will be a function of other modelled surface properties such as the number of ground layers. Climate sensitivities are as likely to be the result of other model features as of the land surface data used.

5. SUMMARY

The increasing awareness of the importance of land surface–atmosphere interaction to successful climate simulation has prompted a search for improved land surface information. Climate models are

sensitive to surface radiative and hydrological properties (Mintz, 1982). Modellers require relatively simple data archives with which to parameterize surface atmosphere moisture, energy and momentum exchange. A complete data archive of soil and land cover information has been presented and the criteria for category selection have been discussed. The soils and land cover data sets have been established at base resolutions finer than 1° × 1°. In the case of the land cover classification both primary and secondary cover types for each 1° × 1° grid element were recorded, and the soils data were archived in the first instance at a resolution of 1/2° × 1/2°. This was to ensure that confidence could be placed in the 1° latitude by 1° longitude classification presented here. Additionally the higher base resolution permits a more accurate procedure for averaging the data to the coarse grid resolutions typical of GCMs. The soil classes have been derived by combining three colour, three texture and three drainage classes. The land cover classes were chosen on the basis of height, structure, seasonality and density criteria. The data described here were designed specifically for inclusion in the U.K. Meteorological Office GCM. It was considered essential that both soil and land cover information were available in the same archive and at similar resolutions. Individual features of the archive may be questionable since interpolation and subjective assessment was, unfortunately, necessary. The land surface data are not directly comparable with the much more detailed data set of Matthews (1983a, b) although an assessment of the response of a GCM to an integrated data set containing both her vegetation and some other soils data as compared to the response caused by using our data would be most interesting.

Reliability estimates on an ordinal scale (1–5) are presented for the soils data according to the nature of the source data. Similar estimates of reliability are also presented for the land cover data derived from information about the rate of change of land use indicated by FAO statistics, the date of publication of the source and difficulties encountered in assigning the chosen categories. A method of averaging the data to the coarser resolution of a GCM has been proposed. It is suggested that these data be used to derive albedo by weighting the soil and vegetation albedo for each grid box according to an annual average or seasonal vegetation cover value. The soil albedo could be made a function of both the soil colour class and also the model predicted soil moisture content although parameterization of hydrological features is likely to be more complex than inclusion of appropriate radiative terms.

The new archive described here has the advantage of including soil information as well as land cover data information. This combination will permit consistent incorporation of *both* hydrological and albedo parameterizations into climate models. Earlier data archives unfortunately neglected the description of soil colour, texture and drainage. Henderson-Sellers and Wilson (1983a) emphasize the importance of both these aspects of the land surface for climate models. It is vital that data sets of a type similar to this new archive be incorporated into GCMs in order to assess the sensitivity of the models to land surface changes. The data described here are now an integral part of the U.K. Meteorological Office 11 layer GCM. Experiments have already been undertaken to compare the effect of establishing surface albedos using (i) the Hummel and Reck (1979) data and (ii) the data described here. The results will be described in a subsequent publication. Preliminary investigations of the importance of the surface hydrological parameterization are also being undertaken. The recommendation (Dickinson, 1983) that a single, coherent data archive be used by many climate modelling groups to permit intercomparison of GCM sensitivity to land surface parameterization schemes can now be fulfilled.

ACKNOWLEDGEMENTS

M.F.W. holds an NERC Studentship. Dr. J. Hummel is thanked for providing quantitative data for archive comparisons. We are grateful to Dr. P. Rowntree and P. James who commented constructively on the development of the data sets and to Dr. R. Dickinson and Dr. B. Moore who read an earlier version of this paper. We wish to acknowledge the considerable assistance and co-operation of the dynamical climatology branch of the U.K. Meteorological Office. Finally thanks must be given to the large number of scientists who commented constructively upon preliminary versions of this archive throughout 1982 and to Dr. N. A. Hughes who performed most of the computer cartography.

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- F -

ZOBLER SOIL TYPE, SOIL TEXTURE, SURFACE SLOPE, AND OTHER PROPERTIES

CITATION: Staub, B. and C. Rosenweig, 1987. Global Zobler Soil Type, Soil Texture, Surface Slope, and Other Properties. Digital Data. NCAR, Boulder, Colorado. .45 MB.

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F. ZOBLER SOIL TYPE, SOIL TEXTURE, SURFACE SLOPE, AND OTHER PROPERTIES

DATE: 1987

SOURCE:

(1) Leonard Zobler
Goddard Institute of Space Science
Columbia University
New York, N. Y.

(2) Reprocessed by:
Brad Staub and Cynthia Rosenweig
NASA Goddard Space Flight Center
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CONTRIBUTOR:

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NCAR
P.O. Box 3000
Boulder, CO 80307-3000

DATA CENTER: NCAR

GEOGRAPHIC SAMPLING: 1 degree grid, characteristic classses

COVERAGE: Global

PROJECTION: Lat/lon

TIME SAMPLING: Decadal composites

REFERENCES:

Staub, Brad and Cynthia Rosenzweig. "Global Digital Data Sets of Soil Type, Soil Texture, Surface Slope, and Other Properties: Documentation of Archived Tape Data." NASA Technical Memorandum #100685.

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FILE NAMES:

AFZSOILS	Zobler Soil Types
AFZTEX	Zobler Soil Texture
AFZSLOPE	Zobler Surface Slope
AFZPHS	Zobler Phase Codes
AFZSUBSD	Zobler Subsidiary Soil Units
AFZAREA	Zobler Area Codes
AFZSP3	Zobler Special Codes

ZOBLER SOIL CLASSES
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[This legend is appropriate for display of the individual classes (i.e. without rescaling).]

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category  9 :  9 LI       Land-Ice

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category  7 : 7 0-8%; 8-30%; >30%
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[This legend is appropriate for display of the individual classes (i.e. without rescaling).]

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DOCUMENTATION FILE

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category  5 :  5 St/R      stony, rock debris (1 26)
category  6 :  6 St/?      stony, undocumented (1 27)
category  7 :  7 St/Du     stony, dunes/sands (1 25)
category  8 :  8 St/L/Pc   stony, lithic, petrocalcic (1 2 5)
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category 24 : 24 R         rock debris (26)
category 25 : 25 R/Du      rock debris, dunes/sands (26 25)
category 26 : 26 R/St/?    rock debris, stony, undocumented (26 1 27)
category 27 : 27 R/Du/St   rock debris, dunes/sands, stony (26 25 1)
category 28 : 28 ?         undocumented (27)
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[This legend is appropriate for display of the individual classes (i.e. without rescaling).]

Note: The various permutations of the phase codes (in parentheses) in the original data have been reassigned to the above categorical values.

ZOBLER SUBSIDIARY SOIL UNITS
DOCUMENTATION FILE

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category 13 :  13 BV
category 14 :  14 BVLC
category 15 :  15 E
category 16 :  16 FO
category 17 :  17 FOFX
category 18 :  18 FP
category 19 :  19 JCXK
category 20 :  20 L
category 21 :  21 L RE
category 22 :  22 L Q
category 23 :  23 LCE
category 24 :  24 LCRE
category 25 :  25 LCX
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category 27 :  27 LFNE
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category 40 :  40 RE
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category 44 :  44 XH
category 45 :  45 XK
category 46 :  46 Y
category 47 :  47 YH
category 48 :  48 YHYK
category 49 :  49 YK
category 50 :  50 YY
category 51 :  51 ZO
category 52 :  52 (1)
category 53 :  53 (10)
category 54 :  54 (104)
category 55 :  55 (11)
category 56 :  56 (117)
category 57 :  57 (12)
category 58 :  58 (120)
category 59 :  59 (122)
category 60 :  60 (13)
category 61 :  61 (14)
category 62 :  62 (15)
category 63 :  63 (16)
category 64 :  64 (17)
category 65 :  65 (18)
category 66 :  66 (19)
category 67 :  67 (2)
category 68 :  68 (20)
category 69 :  69 (21)
category 70 :  70 (22)
category 71 :  71 (23)
category 72 :  72 (24)
category 73 :  73 (25)
category 74 :  74 (26)
category 75 :  75 (27)
category 76 :  76 (28)
category 77 :  77 (29)
category 78 :  78 (3)
category 79 :  79 (30)
category 80 :  80 (31)
category 81 :  81 (32)
category 82 :  82 (33)
category 83 :  83 (34)
category 84 :  84 (35)
category 85 :  85 (36)
category 86 :  86 (37)
category 87 :  87 (38)
category 88 :  88 (39)
category 89 :  89 (4)
category 90 :  90 (40)
category 91 :  91 (41)
category 92 :  92 (42)
category 93 :  93 (43)
category 94 :  94 (44)
category 95 :  95 (45)
category 96 :  96 (46)
category 97 :  97 (47)
category 98 :  98 (48)
category 99 :  99 (49)
```

```
category100 : 100 (5)
category101 : 101 (50)
category102 : 102 (51)
category103 : 103 (52)
category104 : 104 (53)
category105 : 105 (54)
category106 : 106 (55)
category107 : 107 (56)
category108 : 108 (59)
category109 : 109 (6)
category110 : 110 (60)
category111 : 111 (61)
category112 : 112 (62)
category113 : 113 (63)
category114 : 114 (64)
category115 : 115 (65)
category116 : 116 (66)
category117 : 117 (67)
category118 : 118 (68)
category119 : 119 (69)
category120 : 120 (7)
category121 : 121 (70)
category122 : 122 (75)
category123 : 123 (76)
category124 : 124 (77)
category125 : 125 (78)
category126 : 126 (79)
category127 : 127 (8)
category128 : 128 (80)
category129 : 129 (81)
category130 : 130 (82)
category131 : 131 (83)
category132 : 132 (85)
category133 : 133 (86)
category134 : 134 (87)
category135 : 135 (88)
category136 : 136 (89)
category137 : 137 (9)
category138 : 138 (90)
category139 : 139 (91)
category140 : 140 (92)
category141 : 141 (93)
category142 : 142 (94)
category143 : 143 (97)

{category 0 : water}
```

[This legend is appropriate for display of the individual classes (i.e. without rescaling).]

Note: The original subsidiary codes have been reassigned to the above categorical values. For further explanation of these codes see individual FAO map sheets.

ZOBLER AREA CODES
DOCUMENTATION FILE

File Name: AFZAREA.DOC

```
image title : Zobler Area Codes
data type   : byte
file type   : binary
rows        : 438
columns     : 480
minimum     :  0.0000000000E+00
maximum     :  7.0000000000E+00
cell x      :  1.6666666667E-01
cell y      :  1.6666666667E-01
legend      : 8
category  1 : 1 AFR       Africa
category  2 : 2 AUS       Australia, South Pacific
category  3 : 3 EUR       Europe
category  4 : 4 NAM       North America
category  5 : 5 NCA       North Central Asia
category  6 : 6 SAM       South America
category  7 : 7 SAS       Southern Asia
category  8 : 8 SEA       South East Asia

{category 0 : water}
```

[This legend is appropriate for display of the individual classes (i.e. without rescaling).]

Note: The area codes that appear in the documentation have been reassigned to the above categorical values.

ZOBLER SPECIAL CODES
DOCUMENTATION FILE

File Name: AFZSP3.DOC

```
image title : Zobler Special Codes
data type   : byte
file type   : binary
rows        : 438
columns     : 480
minimum     :  0.0000000000E+00
maximum     :  1.1000000000E+01
cell x      :  1.6666666667E-01
cell y      :  1.6666666667E-01
legend      : 11
category  1 :  1 No Data Blank
category  2 :  2 (33)     Land cell not present on FAO map; classified
                          as soil; SU, TEX, and SLP fields filled in
category  3 :  3 (44)     Land cell not present on FAO map; classified
                          as land-ice
category  4 :  4 (55 88) (See explanations for codes 55 and 88)
category  5 :  5 (55)     Cell classified as soil by Zobler, and as
                          land-ice by Matthews
category  6 :  6 (66)     Cell classified as land-ice by Zobler, and as
                          vegetation (soil implied) by Matthews
category  7 :  7 (77 88) (See explanations for codes 77 and 88)
category  8 :  8 (77)     Slope information missing; SLP field filled in
category  9 :  9 (88)     Texture information missing; TEX field filled in
category 10 : 10 (88 77) (See explanations for codes 88 and 77)
category 11 : 11 (99)     No soil information present on the map; SU,
                          TEX, and SLP fields filled in

{category 0 : water}
```

[This legend is appropriate for display of the individual classes (i.e. without rescaling).]

Note: The various permutations of the special codes (in parentheses) in the original data have been reclassed to the above categorical values.

NASA TECHNICAL MEMORANDUM #100685

GLOBAL DIGITAL DATA SETS OF SOIL TYPE, SOIL TEXTURE, SURFACE SLOPE, AND OTHER PROPERTIES DOCUMENTATION OF ARCHIVED DATA TAPE

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October, 1987
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ABSTRACT

This documentation describes the file structure and coding of four soils data sets derived from the Zobler (1986) world soil file. These data were digitized on a one-degree square grid, a design especially useful for large-area studies such as climate research with general circulation models. They are also suitable for studies in forestry, agriculture, soils, hydrology, and other research areas that can utilize soils information on this scale. All four data sets are based on the Food and Agriculture Organization (FAO, 1974) Soil May of the World and on the Mathews (1983; 1984) vegetation data set. Data characteristics, coding scheme, and collection methodology are fully described by Zobler (1986).

The advantages of the Zobler world soil file are: 1) Missing data have been filled in; 2) Subsidiary soils of the designated FAO soil association for each map unit are included; and 3) the data set may be easily converted to compatibility in nominal classification of land, land-ice and water cells with either the Mathews vegetation file or the FAO Soil Map of the World. Dot grid overlay was used to determine the largest map unit of each one-degree cell.

The Zobler world soil file differs from the Wilson (described in Wilson and Henderson-Sellers 1985) soil data set in that more complete information on texture (9 classes), and phase (18) is included for each map unit (106 FAO soil types) comprising the largest area of each one-degree square land cell. This encoding provides more detailed information at each cell than the Wilson soil data set which has a classification scheme (21 types) based on combinations of three colors, three textures, and three drainage classes.

The Zobler world soil file also provides more detailed information about each map unit than the Gildea and Moore (described in Henderson-Sellers et al., 1986) FAOSOL global soil archive because it includes the soil types designated by FAO as "associated" and "included." "Associated" soils occupy at least 20% of the soil association and "included" soils occupy less than 20% of the soil association of each map unit. The Gildea and Moore global soil archive is at 0.5° x 0.5° resolution, while the Zobler world soil file is at 1° x 1° resolution.

The fourth file on the tape is the SOILWRLD data set. It contains information on soil properties of land cells of both Mathews' and FAO sources, reconciles land-classification differences between the two, and has missing dat filled in. The first thorough third files on this tape are subsets of the SOILWRLD data set that have been ordered in a standard 360 x 180 data matrix geometry, have been partially recoded for ease of use, have missing data filled in, and agree with Mathews' (1984) nominal classification of land type (land, land-ice, water). The first file is a data set of codes for soil unit, land-ice, or water, for all the one-degree square cells of the earth. the second file is a data set of codes for texture, land-ice, or water, for these same soil units. The third file is a data set of codes for slope, land-ice, or water for these same soil unites. When used together, these three data sets conveniently define a soil type, texture, and slope, for the one-degree square cells of the earth.

The Navy Fleet Numerical Oceanography Center/(NFNOC) began creating the original 10-minute terrain data set in the mid 1960's. Work extended into the early 1970's. The main sources for the data were the U.S. Department of Defense Operational Navigation Charts (ONC), scale 1:1,000,000. For certain regions ONC charts were not available; for such areas selected charts from the Jet Navigation charts and World Aeronautical Charts were used. The charts were hand read out to forms by employees, and then read by optical character reader to tape. The values were estimates from contour lines. Isometric graphs were made for quality control, checking terrain features. Later, other errors were corrected by the National Center for Atmospheric Research in Boulder, Colorado.

NFNOC hopes in the future to update the data set using satellite data. This update will not be available to the general public for several years, as much of the new information will be defense-classified. For further information on the history and original sources of the data, you are welcome to contact Leo Clark, NFNOC, Code 42, Monterey, California, 93943.

SECTION 1: Description of SOIL UNIT file. ~~Data Set Name: SOIL.USER~~

This file consists of a (360, 180) matrix of character*2 SOIL UNIT data based on the FAO Soil Map of the World, and compiled into digital form by Zobler. Each matrix element represents the dominant soil unit in a one-degree square cell of the earth's surface. This file was prepared from the SOILWRLD data set (the fourth file on this tape), with the addition of the land-ice cells of Antarctica. This file conforms exactly in number, location, and nominal classification (land, land-ice, water) to Matthews' vegetation data set.

SECTION 1.A: ~~File Format and~~ Coding. ~~lrecl: 720 blksize: 3600 recfm: fb~~

~~This data set is read with the following FORTRAN statements, and with 'unit' set as a tape:~~

```
~~CHARACTER*2 SU(360, 180)~~

~~DO 20 J=1,180~~
~~20 READ(unit, 101)(SU(I,J), I=1,360)~~
~~101 FORMAT(250A2,110A2)~~
```

The SOIL UNIT codes in this file are identical with the soil unit codes of the SOILWRLD file and the FAO map (see Appendix 1 for a list of the 106 soil unit names and their two-character codes). WATER cells are included in this file and are coded as ' ' (double blank). LAND-ICE cells are coded as '99' (ninety-nine).

SECTION 1.B: Notes

(1) The latitude and longitude of the northwest corner of any one-degree square cell are determined by:

```
LAT = J - 90
LON = I - 181
```

Cell latitudes are 0 at the equator, increase positively northward to +90, and increase negatively southward to -89. Cell longitudes are 0 at the prime meridian, increase positively eastward to +179, and increase negatively westward to -180. This convention holds for all four data sets on this tape. See Appendix 2 for a discussion of map coordinates and matrix indices.

(2) See Appendix 3 for a discussion of simple printer-mapping routines for this data set.

SECTION 2: Description of TEXTURE file. ~~Data Set Name: TEX.USER~~

This file consists of a (360,180) matrix of character*1 TEXTURE data based on the FAO Soil Map of the World, and compiled into digital form by Zobler. Each matrix element represents the near-surface texture (upper 30 cm) of the dominant soil unit in a one-degree square cell of the earth's surface. This file was prepared from the SOILWRLD data set ~~(the fourth file on this tape)~~, with the addition of the land-ice cells of Antarctica. This file conforms exactly in number, location, and nominal classification (land, land-ice, water) to Matthews' vegetation data set.

SECTION 2.A: ~~File Format and~~ Coding. ~~lrecl: 360 blksize:3600 recfm: fb~~

~~These data are read with the following FORTRAN statements, and with 'unit' set as a~~ tape:

```
CHARACTER*1 TEX(360,180)

DO 20 J=1,180
20 READ(unit,105)(TEX(I,J), I=1,360)
105 FORMAT(250A1,110A1)
```

The TEXTURE codes in this data set are shown in Table 2.1.

Table 2.1. Texture codes and class in TEX data set.

texture code	texture class
'1'	coarse
'2'	medium
'3'	fine
'4'	coarse-medium
'5'	coarse-fine
'6'	medium-fine
'7'	coarse-medium-fine
'8'	organic
'9'	land-ice
' '	water

SECTION 2.B: Notes

(1) The 'organic' texture class is applied to those soil units, primarily Histosols, that have no

texture symbol on the FAO map, and that are organic soils (i.e., possessing an H or O master horizon). This texture class is not an FAO specification.

(2) The longitude and latitude convention is identical to the Soil Unit data set, as described in Section 1.B.(1), and Appendix 2.

(3) These data can be mapped, as shown in Appendix 3.

SECTION 3: Description of the SLOPE file. ~~Data Set Name: SLP.USER~~

This file consists of a (360,180) matrix of character*1 SLOPE data based on the FAO Soil Map of the World, and compiled into digital form by Zobler. Each matrix element represents the surface slope of the dominant soil unit in a one-degree square cell of the earth's surface. This file was prepared from the SOILWRLD data set (~~the fourth file on this tape~~), with the addition of the land-ice cells of Antarctica. This file conforms exactly in number, location, and nominal classification (land, land-ice, water) to the Matthews vegetation data set.

SECTION 3.A: ~~File Format and~~ Coding. ~~lrecl: 360 blksize: 3600 recfm: fb.~~

~~These data are read with the following FORTRAN statements, and with 'unit' set as a tape:~~

```
      CHARACTER*1 SLP(360,180)
      DO 20 J=1,180
   20 READ(unit,105)(SLP(I,J),I=1,360)
  105 FORMAT(250A1,110A1)
```

The slope codes in this data set are shown in Table 3.1.

Table 3.1 Slope codes and class in the SLP data set.

slope code	percent slope class
'1'	0-8
'2'	8-30
'3'	greater than 30
'4'	0-30
'5'	0-8; greater than 30
'6'	8-30; greater than 30
'7'	0-8; 8-30; greater than 30
'9'	land-ice
' '	water

SECTION 3.B: Notes

(1) The longitude and latitude convention is identical to the Soil Unit data set, as described in Section 1.B.(1), and Appendix 2.

(2) These data may be easily plotted as shown in Appendix 3.

SECTION 4: Description of a WORLD SOIL FILE. ~~Data Set Name: SOILWRLD.USER~~

This file is the SOILWRLD data set compiled by Zobler. It consists of 15413 card image records of soils information obtained from the FAO Soil Map of the World. Each record contains information on soil type, near-surface texture, slope, and phase for the map unit comprising the largest area of a one-degree square land cell. The largest map unit was determined by dot grid overlay. Missing data have been filled in. Conflicting nominal classification of some land cells between FAO and Matthews' data sets are identified, and coded to permit reconciliation according to either source. Water cells and Antarctica are excluded from this file; other non-soil land cells, such as debris fields, dunes, and land-ice, are included.

SECTION 4.A: File Format and Coding. ~~lrecl:80 blksize:6160 recfm: fb~~

Each record consists of 9 fields in the order shown in Table 4.1.

Table 4.1 Data fields of a SOILWRLD data set record.

mnemonic	data type	field description
LAT	I5	LATITUDE of northwest corner of cell.
LON	I5	LONGITUDE of northwest corner of cell.
SU	A2	Two-letter SOIL UNIT code (see Appendix 1) and also a ' ' (double blank) for land-ice; (see note (1), below).
SUBSID	A6	Associated and included SUBSIDIARY soil units (see note (2), below).
TEX	A3	TEXTURE codes (see note (3), below).
SLP	A3	SLOPE codes (see note (4), below).
PHS	A15	A string of one- and two-digit PHASE symbols, if any (see note (5), below).
SP(3)	A2	A three-element array of two-digit SPECIAL codes (see note (6), below) used to mask record attributes.
AREA	A3	A three-letter code that nominally identifies a broad regional location of the cell (see note (7), below).

~~Including the imbedded blanks between fields, the following FORTRAN statements (with 'unit' set as a tape) may be used to read one record:~~

```
INTEGER *4        LAT, LON
CHARACTER *2  SU, SP(3)
CHARACTER *3  TEX, SLP, AREA
CHARACTER *6  SUBSID
CHARACTER *15 PHS

10 READ (unit,101) LAT, LON, SU, SUBSID, TEX, SLP, PHS, SP, AREA
101 FORMAT (2I5, 3X, A2, 1X, A6, 2X, A3, 2X, A3, 1X, A15, 3(1X,A2),
  *1X, A3)
```

~~To read all the records, place this READ statement within a DO loop of 1 to 15413, or under some other program control.~~

Section 4.B: Notes

(1) The SU (soil unit) codes are the two-letter symbols for the FAO soil unit names of the dominant soil type of the map unit comprising the largest area within a one-degree land cell. These codes are identical with the codes in the first file on this tape (see Appendix 1). In addition, land-ice is coded as ' ' (double blank); recall that water cells are not included.

(2) The SUBSID (subsidiary) codes are the FAO symbols for 'associated' and 'included' soil types of a soil association. The dominant soil type of the association is indicated in the SU field (note (1), above). 'Associated' soils occupy at least 20% of the area of the soil association, and 'included' soils occupy less than 20%. These codes are explained on individual FAO map sheets.

(3) The TEX (texture) codes are for the upper 30 cm of the dominant soil unit of a cell (note (1), above). The codes are identical to the FAO symbols, with the addition of a ' ' (triple blank) for land-ice, and a '9 ' (nine; double blank) for organic type soils having no texture symbol on the FAO map (see 2.B.1). Recall that water cells are not included. The texture classes and the codes are shown in Table 4.2.

Table 4.2. Texture codes and class in SOILWRLD data set.

texture code	texture class
'1 '	coarse
'2 '	medium
'3 '	fine
'12 '	coarse-medium
'13 '	coarse-fine
'23 '	medium-fine
'123'	coarse-medium-fine
'9 '	organic
' '	land-ice

(4) The SLP (slope) codes are for the dominant soil unit of a cell (see note (1), above). The codes are identical to the FAO symbols with the addition of a ' ' (triple blank) for land-ice. Recall that water cells are not included. The slope classes and codes are shown in Table 4.3

Table 4.3. Slope codes and classes in SOILWRLD data set.

slope code	percent slope class
'A '	0-8
'B '	8-30
'C '	greater than 30
'AB '	0-30
'AC '	0-8; greater than 30
'BC '	8-30; greater than 30
'ABC'	0-8; 8-30; greater than 30
' '	land-ice

(5) Soil phases are properties of a soil that influence its use and management, but are not used to classify the soil. Soils may have none, one, or more phases. The PHS (phase) codes in this data set are one- and two-digit symbols, if any, separated by one or more blanks, not in ordinal sequence. The phase codes are shown in Table 4.4.

Table 4.4. Phase codes and meaning in SOILWRLD data set.

phase code	meaning	phase code	meaning
'1'	stony	'11'	phreactic
'2'	lithic	'12'	cerrado

Table 4.4. (Cont.)

phase code	meaning	phase code	meaning
'3'	petric	'13'	sodic
'4'	petroferric	'21'	permafrost
'5'	petrocalcic	'22'	intermittent permafrost
'6'	petrogypsic	'23'	glacier (i.e., land-ice)
'7'	fragipan	'24'	ponded
'8'	duripan	'25'	dunes, sands
'9'	saline	'26'	rock debris

(6) The SP (special) codes serve two purposes: to identify land cells that have missing data in some of the fields, and to identify cells that have a conflicting nominal classification (land, land-ice, water) between Zobler and Matthews.

(6.1) Missing data. When soil unit, texture, or slope information for the map unit chosen to represent a land cell was missing on the FAO map, this information was added by Zobler and was used to fill in the SU, TEX, or SLP fields for such a record in the file. In addition, a code was placed in the SP field to indicate which fields were filled in (Table 4.5).

Table 4.5. SP codes for missing data in the SOILWRLD data set.

'99'	No soil information present on the map; SU, TEX, and SLP fields filled in.
'88'	Texture information missing; TEX field filled in.
'77'	Slope information missing; SLP field filled in.

These codes allow a user of this data set to reproduce the actual FAO map unit chosen to characterize a cell by checking for these codes in the SP field and masking the appropriate filled in field(s). Note that a '99' indicates that a non-soil land cell (such as debris field or dunes) was present on the FAO map. In this instance, in addition to the filled in missing data, the phase field contains a code for the type of non-soil land unit that is indicated on the map.

(6.2) Nominal classification conflicts. The nominal classification conflicts between Zobler and

Matthews are of two kinds: land/water classification, and land-ice/land classification.

A land/water conflict occurred whenever Zobler found a cell to be absent on the FAO map and present in Matthews. In this instance the cell was added to the SOILWRLD data set as either land-ice or an interpreted soil, in conformity with the Matthews nominal classification of the cell. In addition, a code was placed in the SP field to indicate this condition (Table 4.6).

Table 4.6. SP codes for land/water conflicts.

'44'	Land cell not present on FAO map; classified as land-ice.
'33'	Land cell not present on FAO map; classified as soil; SU, TEX, and SLP fields filled-in.

A land-ice/land conflict occurred whenever Matthews and FAO disagreed on the land-ice classification of a cell. Records of this kind are not uniquely classified in this file, and so have attributes of both a soil cell and a land-ice (i.e., glacier) cell: the SU, TEX, and SLP fields have appropriate codes in them, and the PHS field also contains a glacier code. In addition, a code was placed in the SP field to indicate this condition (Table 4.7).

Table 4.7. SP codes for land-ice/land conflicts.

'66'	Cell classified as land-ice by Zobler, and as vegetation (soil implied) by Matthews.
'55'	Cell classified as soil by Zobler, and as land-ice by Matthews.

The user of this data set may choose how these records should be classified, either as Zobler-compatible, or as Matthews-compatible, or as some other union of the two. According to the table below (Table 4.8), this decision amounts to either a row collapse, a column collapse, or other masking, respectively. (Note that as an aid to users already using the Matthews data sets, the first three data sets on this tape have been made Matthews-compatible).

Table 4.8. Zobler and Matthews compatibility.

		ZOBLER	
		Soil	Glacier
MATTHEWS	Soil	true soil	'66'
	Glacier	'55'	true ice

When these cells are resolved according to Matthews, a '66'-type cell becomes a soil cell (delete the glacier code from the PHS field; retain all other fields), and a '55'-type cell becomes a land-ice cell (retain the glacier code in the PHS field; delete the SU, SUBSID, TEX, and SLP fields, and other non-glacier PHS codes). To reconcile these type cells according to Zobler, perform the same masking operations of the opposing cell types: a '66'-type cell becoming a land-ice cell, and a '55'-type cell a soil cell.

(7) The AREA codes indicate territorial regions and are used as broad guides to a cell location on FAO map sheets. These codes are shown in Table 4.9.

Table 4.9. AREA codes and meaning in SOILWRLD data set.

AREA code	meaning	AREA code	meaning
'AUS'	Australia, South Pacific	'SAM'	South America
'AFR'	Africa	'NCA'	North Central Asia
'EUR'	Europe	'SAS'	Southern Asia
'NAM'	North America	'SEA'	South East Asia

(8) The latitude and longitude conventions are the same as those discussed in section 1.B.(1), and Appendix 2.

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Acknowledgments

We thank Elaine Matthews for her help in preparing this report, Tina Cary for coding advice, and Leonard Zobler for his encouragement on soils parameterization in hydrology. Christopher Shashkin typed the report. This work was supported by the NASA Climate Program and EPA Contract R812962-010.

APPENDIX 1 (cont'd.)

L LUVISOLS

LO Orthic Luvisols
LC Chromic Luvisols
LK Calcic Luvisols
LV Vertic Luvisols
LF Ferric Luvisols
LA Albic Luvisols
LP Plinthic Luvisols
LG Gleyic Luvisols

W PLANOSOLS

WE Eutric Planosols
WD Dystric Planosols
WM Mollic Planosols
WH Humic Planosols
WS Solodic Planosols
WX Gelic Planosols

O HISTOSOLS

OE Eutric Histosols
OD Dysiric Histosols
OX Gelic Histosols

D PODZOLUVISOLS

DE Eutric Podzoluvisols
DD Dystric Podzoluvisols
DG Gleyic Podzoluvisols

P PODZOLS

PO Orthic Podzols
PL Leptiv Podzols
PF Ferric Podzols
PH Humic Podzols
PP Placic Podzols
PG Gleyic Podzols

F FERRALSOLS

FO Orthic Ferralsols
FX Xanthic Ferralsols
FR Rhodic Ferralsols
FH Humic Ferralsols
FA Acric Ferralsols
FP Plinthic Ferralsols

A ACRISOLS

AO Orthic Acrisols
AF Ferric Acrisols
AH Humic Acrisols
AP Plinthic Acrisols
AG Gleyic Acrisols

N NITOSOLS

NE Eutric Nitosols
ND Dystric Nitosols
NH Humic Nitosols

- G -

FAO SOIL UNITS

CITATION: Witt, R. (ed.), 1984. Global FAO Soil Units (10-min grid). Digital Data. UNEP/GRID, Geneva, Switzerland. 2.3 MB.

Blank page retained for pagination

G. FAO SOIL UNITS

DATE: 1974

SOURCE:

(1) UNESCO/FAO

(2) ESRI (FAO contract)
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Geneva, Switzerland

DATA CENTER: GRID (Geneva)

GEOGRAPHIC SAMPLING: 2-min grid, resampled to 10-min, characteristic classes.

COVERAGE: Global

PROJECTION: Lat/lon

TIME SAMPLING: Decadal composites

REFERENCES:

FILE NAMES: AFFAOSOL FAO Soil Units

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FAO SOIL UNITS
DOCUMENTATION FILE

File Name: AFFAOSOL.DOC

```
image title : UNESCO/FAO Soil Units
data type   : byte
file type   : binary
rows        : 438
columns     : 480
minimum     :   0.0000000000E+00
maximum     :   1.3300000000E+02
cell x      :   1.6666666667E-01
cell y      :   1.6666666667E-01
legend      : 133
category  1 :  1    A     Acrisols
category  2 :  2    Af    Ferric Acrisols
category  3 :  3    Ag    Gleyic Acrisols
category  4 :  4    Ah    Humic Acrisols
category  5 :  5    Ao    Orthic Acrisols
category  6 :  6    Ap    Plinthic Acrisols
category  7 :  7    B     Cambisols
category  8 :  8    Bc    Chromic Cambisols
category  9 :  9    Bd    Dystric Cambisols
category 10 : 10    Be    Eutric Cambisols
category 11 : 11    Bf    Ferralic Cambisols
category 12 : 12    Bg    Gleyic Cambisols
category 13 : 13    Bh    Humic Cambisols
category 14 : 14    Bk    Calcic Cambisols
category 15 : 15    Bv    Vertic Cambisols
category 16 : 16    Bx    Gelic Cambisols
category 17 : 17    C     Chernozems
category 18 : 18    Cg    Glossic Chernozems
category 19 : 19    Ch    Haplic Chernozems
category 20 : 20    Ck    Calcic Chernozems
category 21 : 21    Cl    Luvic Chernozems
category 22 : 22    D     Podzoluvisols
category 23 : 23    Dd    Dystric Podzoluvisols
category 24 : 24    De    Eutric Podzoluvisols
category 25 : 25    Dg    Gleyic Podzoluvisols
category 26 : 26    E     Rendzinas
category 27 : 27    F     Ferralsols
category 28 : 28    Fa    Acric Ferralsols
category 29 : 29    Fh    Humic Ferralsols
category 30 : 30    Fo    Orthic Ferralsols
category 31 : 31    Fp    Plinthic Ferralsols
category 32 : 32    Fr    Rhodic Ferralsols
category 33 : 33    Fx    Xanthic Ferralsols
category 34 : 34    G     Gleysols
category 35 : 35    Gc    Calcaric Gleysols
category 36 : 36    Gd    Dystric Gleysols
category 37 : 37    Ge    Eutric Gleysols
category 38 : 38    Gh    Humic Gleysols
category 39 : 39    Gm    Mollic Gleysols
category 40 : 40    Gp    Plinthic Gleysols
```

category 41 :	41	Gx	Gelic Gleysols
category 42 :	42	H	Phaeozems
category 43 :	43	Hc	Calcaric Phaeozems
category 44 :	44	Hg	Gleyic Phaeozems
category 45 :	45	Hh	Haplic Phaeozems
category 46 :	46	Hl	Luvic Phaeozems
category 47 :	47	I	Lithosols
category 48 :	48	J	Fluvisols
category 49 :	49	Jc	Calcaric Fluvisols
category 50 :	50	Jd	Dystric Fluvisols
category 51 :	51	Je	Eutric Fluvisols
category 52 :	52	Jt	Thionic Fluvisols
category 53 :	53	K	Kastanozems
category 54 :	54	Kh	Haplic Kastanozems
category 55 :	55	Kk	Calcic Kastanozems
category 56 :	56	Kl	Luvic Kastanozems
category 57 :	57	L	Luvisols
category 58 :	58	La	Albic Luvisols
category 59 :	59	Lc	Chromic Luvisols
category 60 :	60	Lf	Ferric Luvisols
category 61 :	61	Lg	Gleyic Luvisols
category 62 :	62	Lk	Calcic Luvisols
category 63 :	63	Lo	Orthic Luvisols
category 64 :	64	Lp	Plinthic Luvisols
category 65 :	65	Lv	Vertic Luvisols
category 66 :	66	M	Greyzems
category 67 :	67	Mg	Gleyic Greyzems
category 68 :	68	Mo	Orthic Gleyzems
category 69 :	69	N	Nitosols
category 70 :	70	Nd	Dystric Nitosols
category 71 :	71	Ne	Eutric Nitosols
category 72 :	72	Nh	Humic Nitosols
category 73 :	73	O	Histosols
category 74 :	74	Od	Dystric Histosols
category 75 :	75	Oe	Eutric Histosols
category 76 :	76	Ox	Gelic Histosols
category 77 :	77	P	Podzols
category 78 :	78	Pf	Ferric Podzols
category 79 :	79	Pg	Gleyic Podzols
category 80 :	80	Ph	Humic Podzols
category 81 :	81	Pl	Leptic Podzols
category 82 :	82	Po	Orthic Podzols
category 83 :	83	Pp	Placic Podzols
category 84 :	84	Q	Arenosols
category 85 :	85	Aq	Albic Arenosols
category 86 :	86	Qc	Cambic Arenosols
category 87 :	87	Qf	Ferralic Arenosols
category 88 :	88	Ql	Luvic Arenosols
category 89 :	89	R	Regosols
category 90 :	90	Rc	Calcaric Regosols
category 91 :	91	Rd	Dystric Regosols
category 92 :	92	Re	Eutric Regosols
category 93 :	93	Rx	Gelic Regosols
category 94 :	94	S	Solonetz
category 95 :	95	Sg	Gleyic Solonetz
category 96 :	96	Sm	Mollic Solonetz
category 97 :	97	So	Orthic Solonetz
category 98 :	98	T	Andosols
category 99 :	99	Th	Humic Andosols
category100 :	100	Tm	Mollic Andosols

```
category101 : 101   To    Ochric Andosols
category102 : 102   Tv    Vitric Andosols
category103 : 103   U     Rankers
category104 : 104   V     Vertisols
category105 : 105   Vc    Chromic Vertisols
category106 : 106   Vp    Pellic Vertisols
category107 :  107   W    Planosols
category108 :  108   Wd   Dystric Planosols
category109 :  109   We   Eutric Planosols
category110 :  110   Wh   Humic Planosols
category111 :  111   Wm   Mollic Planosols
category112 :  112   Ws   Solodic Planosols
category113 :  113   Wx   Gelic Planosols
category114 :  114   X    Xerosols
category115 :  115   Xh   Haplic Xerosols
category116 :  116   Xk   Calcic Xerosols
category117 :  117   Xl   Luvic Xerosols
category118 :  118   Xy   Gypsic Xerosols
category119 :  119   Y    Yermosols
category120 :  120   Yh   Haplic Yermosols
category121 :  121   Yk   Calcic Yermosols
category122 :  122   Yl   Luvic Yermosols
category123 :  123   Yt   Takyric Yermosols
category124 :  124   Yy   Gypsic Yermosols
category125 :  125   Z    Solonchaks
category126 :  126   Zg   Gleyic Solonchaks
category127 :  127   Zm   Mollic Solonchaks
category128 :  128   Zo   Orthic Solonchaks
category129 :  129   Zt   Takyric Solonchaks
category130 :  130   RO   Rock
category131 :  131   SA   Salt
category132 :  132   WA   Water
category133 :  133   --   no name

{category 0 : unclassed}
```

[This legend is appropriate for display of the individual classes (i.e. without rescaling).]

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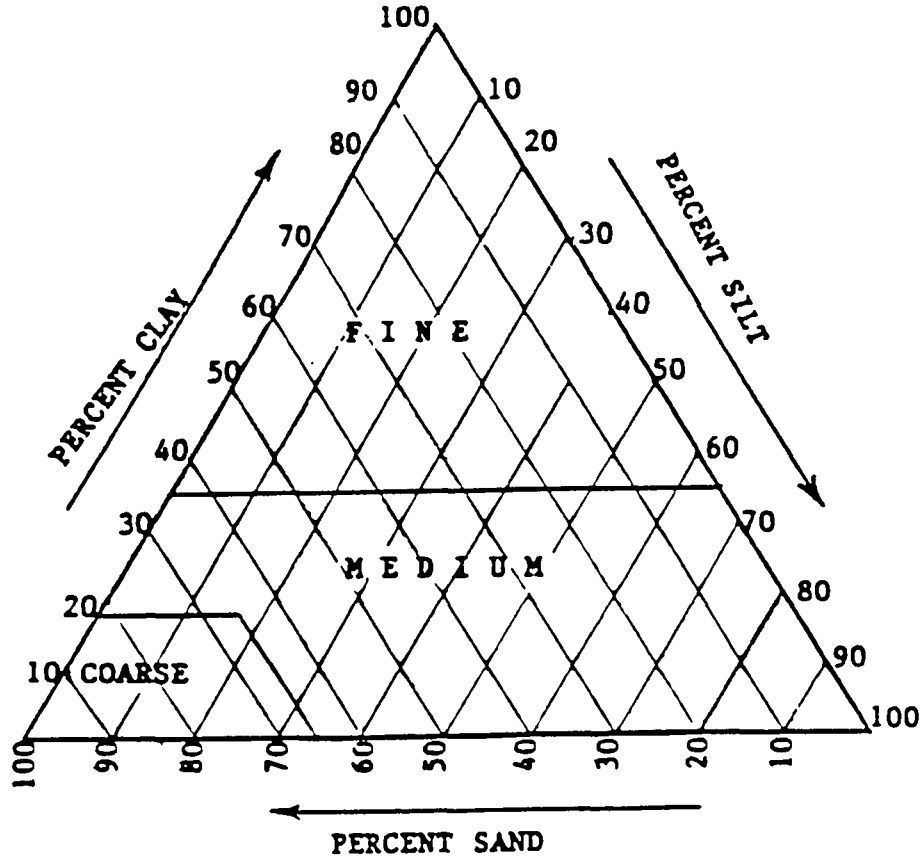
The African soils database resident at UNEP/GRID in Geneva was digitized by ESRI in Redlands, California from the 1973 UNESCO/FAO Soil Map of the World at 1:5000000 scale. The legend of the Soil Map of the World comprises an estimated 5000 different map units, which consist of soil units or associations of soil units occuring with in the limits of a mapable physiographic entity. At the time of compilation of maps for the 1973 map there were 1509 map units for Africa (Sheets VI 1-2-3). The number of soil units which compose the legend of the Soil Map of the World is 106. This number has been increased to 133 at UNEP/GRID to allow the identification of soils with insufficient information to specify the dominant soil unit to be that of the dominant soil group (i.e. A for Acrisols when dominant Acrisol unit is not known). When a map unit is not homogeneous, it is composed of a dominant soil and of associated soils, the latter covering at least 20 percent of the area; important soils which cover less than 20 percent of the area are added as inclusions.

Textural classes reflect the relative proportions of clay (fraction less than 2 microns), silt (2-50 microns), and sand (50-2000 microns). There are three textural classes recognized as shown figuratively below, they are coarse, medium, and fine and are given for the dominant soil in each association and refers to texture in the upper 30 cm of the soil. The texture of a soil horizon is one of its most permanent characteristics and in conjunction with other properties is directly related to soil structure, consistence, porosity and cation exchange capacity.



Slope is an integral part of the land surface as it influences drainage, run-off, erosion, exposure, and accessibility. Three slope classes are distinguished on the Soil Map of the World. Marked by the symbols a,b,c they are:

a. level to gently undulating: dominant slopes ranging between 0 and 8 percent;

b. rolling to hilly: dominant slopes ranging between 8 and 30 percent;

c. steeply dissected to mountainous: dominant slopes are over 30 percent.

Phases are subdivisions of soil units based on characteristics which are significant to the use or management of the land but not diagnostic for the separation of soil units themselves. The phases on the Soil Map of the World are: stony, lithic, petric, petrocalcic, petrogypsic, petroferric, phreatic, fragipan, duripan, saline, sodic and cerrado. These phasis are shown as overprints on the map.

Consideration was given to the insertion of "climatic variants" in the Soil Map of the World. However, the separation of such variants would have required a general agreement on a climatological classification which was beyond the scope of the publication. Hence, only the boundaries of permafrost and intermittent permafrost have been shown on the map.

The soil associations have been noted on the map and in Earth Resource Laboratory Software (ELAS) polygon manipulation routines by symbols reflecting the dominant soil unit, texture of the upper 30 cm of the dominant soil, and slope classes where available. Each of the symbols are fully explained on the reverse of the maps as a composition of the association. The soil dataplane available from UNEP/GRID was derived using the 133 dominant soil types. Dataplanes depicting associated soils, texture, or slope may be developed but currently do not exist at UNEP/GRID. The basic soil units for Africa were digitized by Environmental Systems Research Institute (ESRI) in Redlands, California under contract from UNEP from the Soil Map of the World which was in the Miller oblated stereographic projection. Polygon vertices in digitizer table coordinates were processed through ELAS software and georeferenced to latitude and longitude raster database having an equal area projection of 0.86 square kilometers per picture-element (pixel) or cell with a cell size resolution of 927 meters or 30 seconds of

latitude (+North) and longitude (+East of Greenwich Meridian). The offset pixel (located at scan line zero and element zero) has a longitude of -72030 seconds (or 72030 seconds West of GM) and latitude of 136830 seconds North of Equator. The data tape contains one file of data with 8762 records. The first record is a header record composed of 1024 bytes of information about the data file. The remaining 8761 records (8761 scan lines) are all 8704 bytes each (8641 picture elements modulated by 256). There are 133 soil types as noted in the accompanying type table each of which has a class number with an associated colour. The enclosed colour table depicts colour components (blue, red, green) ranging in value from zero (darkest) to fifteen (brightest).

UNEP/FAO SOIL TYPES

CLASS	SYMBOL	NAME
1	A	Acrisols
2	Af	Ferric Acrisols
3	Ag	Gleyic Acrisols
4	Ah	Humic Acrisols
5	Ao	Orthic Acrisols
6	Ap	Plintic Acrisols
7	B	Cambisols
8	Bc	Chromic Cambisols
9	Bd	Dystric Cambisols
10	Be	Eutric Cambisols
11	Bf	Ferralic Cambisols
12	Bg	Gleyic Cambisols
13	Bh	Humic Cambisols
14	Bk	Calcic Cambisols
15	Bv	Vertic Cambisols
16	Bx	Gelic Cambisols
17	C	Chernozems
18	Cg	Glossic Chernozems
19	Ch	Haplic Chernozems
20	Ck	Calcic Chernozems
21	Cl	Luvic Chernozems
22	D	Podzoluvisols
23	Dd	Dystric Podzoluvisols
24	De	Eutric Podzoluvisols
25	Dg	Gleyic Podzoluvisols
26	E	Rendzinas
27	F	Ferralsols
28	Fa	Acric Ferralsols
29	Fh	Humic Ferralsols
30	Fo	Orthic Ferralsols
31	Fp	Plinthic Ferralsols
32	Fr	Rhodic Ferralsols
33	Fx	Xanthic Ferralsols

34	G	Gleysols
35	Gc	Calcaric Gleysols
36	Gd	Dystric Gleysols
37	Ge	Eutric Gleysols
38	Gh	Humic Gleysols
39	Gm	Mollic Gleysols
40	Gp	Plinthic Gleysols
41	Gx	Gelic Gleysols
42	H	Phaeozems
43	Hc	Calcaric Phaeozems
44	Hg	Gleyic Phaeozems
45	Hh	Haplic Phaeozems
46	Hl	Luvic Phaeozems
47	I	Lithosols
48	J	Fluvisols
49	Jc	Calcaric Fluvisols
50	Jd	Dystric Fluvisols
51	Je	Eutric Fluvisols
52	Jt	Thionic Fluvisols
53	K	Kastanozems
54	Kh	Haplic Kastanozems
55	Kk	Calcic Kastanozems
56	Kl	Luvic Kastanozems
57	L	Luvisols
58	La	Albic Luvisols
59	Lc	Chromic Luvisols
60	Lf	Ferric Luvisols
61	Lg	Gleyic Luvisols
62	Lk	Calcic Luvisols
63	Lo	Orthic Luvisols
64	Lp	Plinthic Luvisols
65	Lv	Vertic Luvisols
66	M	Greyzems
67	Mg	Gleyic Greyzems
68	Mo	Orthic Greyzems
69	N	Nitosols
70	Nd	Dystric Nitosols
71	Ne	Eutric Nitosols
72	Nh	Humic Nitosols

73	O	Histosols
74	Od	Dystric Histosols
75	Oe	Eutric Histosols
76	Ox	Gelic Histosols
77	P	Podzols
78	Pf	Ferric Podzols
79	Pg	Gleyic Podzols
80	Ph	Humic Podzols
81	Pl	Leptic Podzols
82	Po	Orthic Podzols
83	Pp	Placic Podzols
84	Q	Arenosols
85	Qa	Albic Arenosols
86	Qc	Cambic Arenosols
87	Qf	Ferralic Arenosols
88	Ql	Luvic Arenosols
89	R	Regosols
90	Rc	Calcaric Regosols
91	Rd	Dystric Regosols
92	Re	Eutric Regosols
93	Rx	Gelic Regosols
94	S	Solonetz
95	Sg	Gleyic Solonetz
96	Sm	Mollic Solonetz
97	So	Orthic Solonetz
98	T	Andosols
99	Th	Humic Andosols
100	Tm	Mollic Andosols
101	To	Ochric Andosols
102	Tv	Vitric Andosols
103	U	Rankers
104	V	Vertisols
105	Vc	Chromic Vertisols
106	Vp	Pellic Vertisols
107	W	Planosols
108	Wd	Dystric Planosols
109	We	Eutric Planosols
110	Wh	Humic Planosols

111	Wm	Mollic Planosols
112	Ws	Solodic Planosols
113	Wx	Gelic Planosols
114	X	Xerosols
115	Xh	Haplic Xerosols
116	Xk	Calcic Xerosols
117	Xl	Luvic Xerosols
118	Xy	Gypsic Xerosols
119	Y	Yermosols
120	Yh	Haplic Yermosols
121	Yk	Calcic Yermosols
122	Yl	Luvic Yermosols
123	Yt	Takyric Yermosols
124	Yy	Gypsic Yermosols
125	Z	Solonchaks
126	Zg	Gleyic Solonchaks
127	Zm	Mollic Solonchaks
128	Zo	Orthic Solonchaks
129	Zt	Takyric Solonchaks
130	RO	Rock
131	SA	Salt
132	WA	Water
133	—	no name

- H -

UNEP/FAO GRID AFRICA GIS DATA BASE

CITATION: Witt, R. (ed.), 1984. Africa GIS Data Base. Digital Data. UNEP/GRID, Nairobi, Kenya. 150 MB.

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H. UNEP/FAO GRID AFRICA GIS DATA BASE

DATE: 1984

SOURCE:

(1) UNEP/FAO

(2) Environmental Systems Research Institute
380 New York Street
Redlands, CA 92373

CONTRIBUTOR:

UNEP/GRID
P.O. Box 30552
Nairobi, Kenya

DATA CENTER: GRID (Nairobi)

GEOGRAPHIC SAMPLING:

1:5,000,000 scale vector points, lines, and polygons with attributes. Rasterized to a 10-min grid.

COVERAGE: Africa

PROJECTION: Miller Oblate Stereographic for Africa, resampled to lat/lon.

TIME SAMPLING: Varies by data set.

REFERENCES:

UNEP/FAO, 1983. "Provisional Methodology for the Assessment and Mapping of Desertification."

ESRI, 1984. "UNEP/FAO World and Africa GIS Data Base." (Excerpts included.)

FILE NAMES:

AFCROPX	Cropland (Experimental)
AFRAINX	Rainfall (mm) (Experimental)
AFSOILX	Soils (Experimental)
AFVEGX	Vegetation (Experimental)
AFWINDX	Wind speed (m/s) (Experimental)
AFDESRTX	Desertification hazard (Experimental)
AFTEMPX	January temperatures (deg K-100) (Experimental)

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UNEP/FAO GRID CROPLAND
DOCUMENTATION FILE

File Name: AFCROPX.DOC

```
image title : UNEP/FAO GRID Africa Database--Cropland (Experimental)
data type   : byte
file type   : binary
rows        : 438
columns     : 480
minimum     :   0.0000000000E+00
maximum     :   9.0000000000E+00
cell x      :   1.6666600000E-01
cell y      :   1.6666600000E-01
legend      : 4
category  1 : 1 Water     Water
category  2 : 2 No Crop/N Not Cropland or Cropland/Natural Mosaic
category  3 : 3 Crop/N Mo Cropland/Natural Mosaic
category  4 : 4 Cropland  Cropland

{category 0 : unclassed}



[This legend is appropriate for display of the individual classes
 (i.e. without rescaling).]
```

UNEP/FAO GRID RAINFALL
DOCUMENTATION FILE

File Name: AFRAINX.DOC

```
image title : UNEP/FAO GRID Africa Database--Rainfall (mm) (Experimental)
data type   : byte
file type   : binary
rows        : 438
columns     : 480
minimum     :   0.0000000000E+00
maximum     :   3.2000000000E+01
cell x      :   1.6666600000E-01
cell y      :   1.6666600000E-01
legend      : 32
category  1 :  1   0 to  50
category  2 :  2  50 to 100
category  3 :  3 100 to 150
category  4 :  4 100 to 200
category  5 :  5 150 to 200
category  6 :  6 200 to 250
category  7 :  7 200 to 300
category  8 :  8 200 to 400
category  9 :  9 250 to 300
category 10 : 10 250 to 400
category 11 : 11 300 to 350
category 12 : 12 300 to 400
category 13 : 13 350 to 400
category 14 : 14 400 to 450
category 15 : 15 400 to 500
category 16 : 16 400 to 600
category 17 : 17 450 to 500
category 18 : 18 450 to 550
category 19 : 19 500 to 550
category 20 : 20 500 to 600
category 21 : 21 550 to 600
category 22 : 22 600 to 700
category 23 : 23 600 to 800
category 24 : 24 600 to 1000
category 25 : 25 700 to 800
category 26 : 26 800 to 900
category 27 : 27 800 to 1000
category 28 : 28 900 to 1000
category 29 : 29 1000 to 1500
category 30 : 30 1500 to 2000
category 31 : 31 2000 to 3000
category 32 : 32 > 3000

{category 0 : unclassed}
```

[This legend is appropriate for display of the individual classes (i.e. without rescaling).]

UNEP/FAO GRID SOILS
DOCUMENTATION FILE

File Name: AFSOILX.DOC

```
image title : UNEP/FAO GRID Africa Database--Major Soil Classes (Exp)
data type   : byte
file type   : binary
rows        : 438
columns     : 480
minimum     :   0.0000000000E+00
maximum     :   3.3000000000E+01
cell x      :   1.6666666667E-01
cell y      :   1.6666666667E-01
legend      : 32
category  1 :  1 A Acrisols
category  2 :  2 B Cambisols
category  3 :  3 C Chernozems
category  4 :  4 D Podzoluvisols
category  5 :  5 E Rendzinas
category  6 :  6 F Ferralsols
category  7 :  7 G Gleysols
category  8 :  8 H Phaeozems
category  9 :  9 I Lithosols
category 10 : 10 J Fluvisols
category 11 : 11 K Kastanozems
category 12 : 12 L Luvisols
category 13 : 13 M Greyzems
category 14 : 14 N Nitosols
category 15 : 15 O Histosols
category 16 : 16 P Podzols
category 17 : 17 Q Arenosols
category 18 : 18 R Regosols
category 19 : 19 S Solonetz
category 20 : 20 T Andosols
category 21 : 21 U Rankers
category 22 : 22 V Vertisols
category 23 : 23 W Planosols
category 24 : 24 X Xerosols
category 25 : 25 Y Yermosols
category 26 : 26 Z Solonchaks
category 27 : 27 Not used
category 28 : 28 Not used
category 29 : 29 Not used
category 30 : 30 Rock
category 31 : 31 Salt
category 32 : 32 Water

{category 0 : unclassed}
```

[This legend is appropriate for display of the individual classes (i.e. without rescaling).]

UNEP/FAO GRID VEGETATION DOCUMENTATION FILE

File Name: AFVEGX.DOC

```
image title : UNEP/FAO GRID Africa Database--Vegetation (Experimental)
data type   : byte
file type   : binary
rows        : 438
columns     : 480
minimum     :   0.0000000000E+00
maximum     :   1.6000000000E+01
cell x      :   1.6666666667E-01
cell y      :   1.6666666667E-01
legend      :  16
category  1 :  1 IFOR     Inundated Forest (11)
category  2 :  2 ITRE     Inundated Tree Savanna (21)
category  3 :  3 IGRS     Inundated Grassland (31)
category  4 :  4 IMAN     Inundated Mangroves (41)
category  5 :  5 IMAR     Inundated Marsh/Swamps (51)
category  6 :  6 IOAS     Inundated Oasis (61)
category  7 :  7 IOTH     Inundated Other (91)
category  8 :  8  FOR     Forest (19)
category  9 :  9  TRE     Tree Savanna (29)
category 10 : 10  GRS     Grassland (39)
category 11 : 11  MAN     Mangroves (49)
category 12 : 12  MAR     Marsh/Swamp (59)
category 13 : 13  OAS     Oasis (69)
category 14 : 14  OTH     Other (99)
category 15 : 15 OTHR     Other-Rice (92)
category 16 : 16  WAT     Water (88)

{category 0 : unclassed}
```

[This legend is appropriate for display of the individual classes (i.e. without rescaling).]

Note: The original values that appear in the documentation (in parentheses) have been reassigned to the above categorical values.

UNEP/FAO GRID WIND SPEED
DOCUMENTATION FILE

File Name: AFWINDX.DOC

```
image title : UNEP/FAO GRID Africa Database--Wind speed (m/s) (Exp)
data type   : byte
file type   : binary
rows        : 438
columns     : 480
minimum     :   0.0000000000E+00
maximum     :   1.3000000000E+01
cell x      :   1.6666666667E-01
cell y      :   1.6666666667E-01
legend      : 13
category  1 :  1  0.0 to 0.5
category  2 :  2  0.5 to 1.0
category  3 :  3  1.0 to 1.5
category  4 :  4  1.5 to 2.0
category  5 :  5  2.0 to 2.5
category  6 :  6  2.5 to 3.0
category  7 :  7  3.0 to 3.5
category  8 :  8  3.5 to 4.0
category  9 :  9  4.0 to 4.5
category 10 : 10  4.5 to 5.0
category 11 : 11  5.0 to 5.5
category 12 : 12  5.5 to 6.0
category 13 : 13  > 6.0

{category 0 : unclassed}
```

[This legend is appropriate for display of the individual classes (i.e. without rescaling).]

UNEP/FAO GRID DESERTIFICATION HAZARD DOCUMENTATION FILE

File Name: AFDESRTX.DOC

```
image title : UNEP/FAO GRID Africa Database--Desertification Hazard (Exp)
data type   : byte
file type   : binary
rows        : 438
columns     : 480
minimum     :   0.0000000000E+00
maximum     :   2.5500000000E+02
cell x      :   1.6666666667E-01
cell y      :   1.6666666667E-01
legend      : 15
category  1 :  16-31  slight
category  2 :  32-47  slight
category  3 :  48-63  moderate
category  4 :  64-79  moderate
category  5 :  80-95  severe
category  6 :  96-111 severe
category  7 : 112-127 severe
category  8 : 128-143 very severe
category  9 : 144-159 very severe
category 10 : 160-175 very severe
category 11 : 176-191 very severe
category 12 : 192-207 very severe
category 13 : 208-223 very severe
category 14 : 224-239 very severe
category 15 : 240-255 very severe

{category 0 : 0-15  slight}
```

[This legend is only appropriate for displays which reclass (contrast stretch) the continuous values into 16 classes.]

UNEP/FAO GRID JANUARY TEMPERATURES
DOCUMENTATION FILE

File Name: AFTEMPX.DOC

```
image title : UNEP/GRID Nairobi January Temperatures (degrees K - 100)
data type   : byte
file type   : binary
rows        : 438
columns     : 480
minimum     :   1.8000000000E+02
maximum     :   2.1100000000E+02
cell x      :   1.6666666667E-01
cell y      :   1.6666666667E-01
legend      : 15
category  1 : 182 to 183
category  2 : 184 to 185
category  3 : 186 to 187
category  4 : 188 to 189
category  5 : 190 to 191
category  6 : 192 to 193
category  7 : 194 to 195
category  8 : 196 to 197
category  9 : 198 to 199
category 10 : 200 to 201
category 11 : 202 to 203
category 12 : 204 to 205
category 13 : 206 to 207
category 14 : 208 to 209
category 15 : 210 to 211

{category 0 : 180 to 181}
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[This legend is only appropriate for displays which reclass (contrast stretch) the continuous values into 16 classes.]

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[Excerpt from Original Documentation]

FINAL REPORT
UNEP/FAO WORLD AND AFRICA GIS DATA BASE
December 1984

This Report was Prepared as Part of
Phase II of the FAO/UNEP Desertification
and Mapping Project

Prepared under UNEP Contracts 83/0012 and 84/0001

for
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PREFACE

A Geographic Information System (GIS) data base comprised of cartographic and attribute information was developed at varying intensities for the World, Developing World, and Africa as part of Phase II of the UNEP/FAO Desertification Assessment and Mapping Project. Most data for the data base were provided by FAO and were automated at a scale of 1:5,000,000 using the same basemap that was used for the FAO Soil Map of the World. The data base was used to conduct desertification assessments for the World and Africa and to produce the following draft maps for presentation at the Governing Council of UNEP in May 1984:

> Map of Desertification Hazards Africa. Component Analyses 1:25 Million. Final Hazards Analyses 1.5 Million Scale.
>
> Soil Elements used in Assessing Desertification and Degradation. World. 1:10 Million Scale.

The data base and maps were prepared by ESRI under contract to UNEP. The process and products are generally described in the Map of Desertification Hazards: Explanatory Note prepared for the conference. The methodology for the assessment of desertification hazard was prepared and the maps edited by Dr. Todor Boyadgiev of the Soil Resources, Management and Conservation Service, Land and Water Development Division, FAO, Rome. The methodology is described in the FAO/UNEP document, prepared in 1983, entitled, Provisional Methodology for the Assessment and Mapping of Desertification.

The data base, built upon an intelligent data structure, was designed to support the ongoing assessment of desertification and to serve a broad range of land analysis, planning, and management interests. It was provided in digital form to UNEP and FAO. This report primarily describes the processes and sources used to create it, and documents its format and content. The report, originally submitted in June 1984, was revised in December 1984 to accomodate ESRI and FAO experiences with the installation and use of the data base at FAO Headquarters.

Introduction

This report was prepared for the United Nations Environment Programme (UNEP) by Environmental Systems Research Institute (ESRI) under Contracts 83-0012 and 84-0001. It describes and documents the process whereby a Geographic Information System (GIS) resource data base was developed at varying intensities for the World, Developing World, and Africa and was applied in a multi-scale and multi-level assessment of the patterns and processes of desertification. A full analysis of desertification hazards was carried out only for Africa. This report is principally intended to provide documentation for the automated resource data base in order to facilitate on-going assessment of desertification, as well as spatial and tabular analyses related to a much wider range of land planning, evaluation and management interests of UNEP, Food and Agricultural Organization of the United Nations (FAO) and governmental and scientific institutions which might acquire it in a digital form.

The automated data base which was produced as part of the contracted effort is composed primarily of data originally developed by FAO. As indicated, it was produced at three levels of intensity. For the world, the data base contains the coordinates and codes for all of the topical information illustrated on the eighteen sheets of the FAO Soil Map of the World at 1:5 million scale. This is supplemented by tabular files of descriptive and interpretive information which were developed by FAO and ESRI as part of this project. For the developing world, the soils information is supplemented by coordinate information illustrated on the five sheets of the 1:10 million scale map of agro-ecological zones represented in the FAO study entitled, Potential Population Supporting Capacities of lands in the Developing World. For Africa, attribute codes for the agro-ecological units were developed by FAO and were automated and associated with the cartographic files automated by ESRI. Other data, including FAO climatic and census data as well as physiographic, geologic, detailed soil, vegetation, land use and infrastructure data drawn from standard source documents, were also included in the automated files for Africa. In addition, several elements including land surface form, landforms, and surface modifiers were interpreted and mapped from imagery and topographic maps by ESRI staff scientists. A process of data standardization was employed to insure that all of the data for Africa were image-verified, spatially rectified and cross-compared with related components in order to insure appropriate cartographic boundary match. In effect, the source data for Africa were cross-compared and checked against topographic basemaps and imagery for accuracy and consistency prior to automation.

The automation procedures which were employed were designed to accurately and efficiently capture the coordinates and attributes of all of the mapped data. High resolution manual digitizing stations were used to automate all of the coordinate data except that contained on the composite/integrated maps of terrain information in Africa. Given high data density, the terrain maps were automated on an automatic laser scanning device. All data were processed

in a vector format using ESRI's ARC/INFO software. Interface programs allowed conversion of scan-entered raster data to a vector format and the conversion of vector files to raster for laser film display. True coordinate match among and between related data sets on each map sheet and along sheet boundaries was effected. The coordinates of features which were represented on more than one map were entered once, thereafter being joined automatically to other pertinent overlays. A template containing the polygonal land/water features and outer sheet boundary was developed and automated for each map sheet. This was automatically superimposed on all pertinent data in processing. In Africa, a true coordinate match was effected along national boundaries which followed the stream courses delineated on the surface hydrology maps. And, the national boundaries developed as part of a representation of administrative/statistical areas at a scale of 1:5 million were used to replace the national boundaries represented as part of the agro-ecological units maps at 1:10 million. For the world soils data and the African data used in the analyses, coordinate match was effected between cartographic features on adjoining map sheets. The pertinent map coverages were transformed from inch references to true latitude/longitude references using computerized algorithms. Adjacent sheets were joined and the coordinates for the adjoining features were matched by interactive machine processing. The automated files for the world and Africa which were edge-matched were subsequently overlaid for use in the final analyses. The overlay files for Africa contain soils, agro-ecological, climatic, vegetation and land use data. The final processing step for Africa involved the overlay of the template water features. The overlay for the world outside of Africa involved the imposition of the water template on the polygon structures which resulted from the modeled assessment of soil elements.

Chapter IV: Model Development and Iteration

Introduction

Conceptual models were developed by FAO staff to assess global soils in relation to the processes of desertification and to conduct a full desertification hazards evaluation in Africa. The map sheet for NE Africa was established as a test base for applying both the World and Africa models. Preliminary versions of the models were presented to ESRI in October 1983. Todor Boyadgiev provided direction for model iteration and review over a period of three months, being present at ESRI for four weeks in January - February and two weeks in April 1984. Models were programmed using INFO software and involved both logical and arithmetic operations. All coordinate and attribute manipulations were effected by means of INFO and ARC software respectively.

The World models were programmed by ESRI staff to operate on the expansion file of FAO soils for Africa. Thus, with each run, all of the soils on the continent were evaluated. The results, however, were initially presented in a map form only for the NE sheet. Elsewhere, the results were represented by computer listings only. Following iteration and review, the World models were also run on the expansion file of FAO soils for the World outside of Africa. The resulting model values were added to the expansion files and served as the basis for the spatial patterning and values displayed on the final maps. The Africa models were programmed to operate in the expansion files wherever possible. Final results were resolved to the attribute components of the overlay files which were created for each of the three Africa sheets.

As part of the modeling effort, interpretive values for each of the FAO soil unit components were developed by FAO staff. These values, involving ratings for grassland productivity, soil constraints and agricultural productivity, soil K-values and wind erodibility ratings, were automated and were used in the modeling process through a relational data base operation which tied them to the pertinent soil type. Some of these values were modified during the process of model iteration. The soil interpretive values used in the final models for Africa are included in the code listings accompanying the final data files. The program statements used to produce the final models for Africa and the World are included in Appendix D of this report. The concepts and definitions concerning desertification analysis are detailed in the FAO report entitled, Provisional Methodology for Assessment and Mapping of Desertification. The definitions, criteria, and class values employed for both the Africa models and the World models are outlined in the Map of Desertification Hazards: Explanatory Note, which accompanied the maps prepared for presentation in May 1984.

Africa Models

A seven-stage evaluation of desertification hazards in Africa was conducted. Six component analyses were programmed and iterated, each iteration involving

a review of the maps and statistical outputs from the computer analysis. The full results of each of the component analyses were used in the final analysis. Thus, it was necessary to resolve all of the component analyses prior to generating a final hazards map for iteration and review. Based upon a review of the resulting spatial and statistical distributions from each of the analyses, summation criteria for each of the models were specified and iterated. The results of each of the component analyses were classed in four levels: slight, moderate, severe, and very severe. The class limits were based upon percentages of the highest numeric value for each model. The following values and percentages were used:

	Soil Constraint		Wind Action		Water Action	
	Values	%	Values	%	Values	%
Slight	≤ 4.0	10	≤ 3.000	10	≤ 1.900	10
Moderate	4.1-12.0	30	3.001-9.000	30	1.901-5.700	30
Severe	12.1-20.0	50	9.001-15.000	50	5.701-9.500	50
Very Severe	>20.0		>15.000		>9.500	
	40 (40=100)		29.689 (30.0=100)		18.794 (19.0=100)	

	Salinization		Population Pressure		Animal Pressure	
	Values	%	Values	%	Values	%
Slight	≤3.250	2.5	≤1.000	2.5	<0.40	2.5
Moderate	3.251-13.000	10	1.001-4.000	10	0.41-1.60	10
Severe	13.001-39.000	30	4.001-12.000	30	1.61-4.80	30
Very Severe	>39.000		>12.000		>4.80	
	129.594 (130.0=100)		40 (40=100)		25 (16=100)	

The final summary values were built using the raw numeric values from each of the component analyses. These were normalized by use of the factors listed below. Each component analysis contributed a maximum value of 100 to the summary.

Soil Constraints	2.5
Wind Action	3.368
Water Action	5.321
Salinization	0.772
Population	2.5
Animal	6.25

The class limits for the summary model were established as follows:

Summary	
None to Slight	≤ 42.50
Moderate	42.51-85.00
Severe	85.01-127.50
Very Severe	> 127.50

The final model was programmed to track the relative contribution of each component of the summary value. The two most significant components were identified in the summary statement for the model and were displayed on the resulting map. For final presentation, the hazard ratings and factors were eliminated in areas with greater than 180 days growing period or with cold temperatures, and were discriminated in areas with zero and with 0-180 growing periods.

The results of the modeling program for Africa, including the World models run on the African sheets, were stored in the overlay file. These results, documented in Appendix N, include both raw numeric values and final aggregate ratings. These served as the basis for developing the final presentation files outlined in Chapter V and documented in Appendix O.

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UNEP/FAO World and Africa Data Base
Mapping Procedures and Data Sources
Integrated Terrain Units
(Africa 1:5,000,000)

This manuscript synthesizes and organizes a variety of natural resource information and constitutes the basis for the assessment of desertification hazards for the African continent. Data sources were either supplied by FAO, collected by ESRI, or interpreted from satellite imagery and collateral information by ESRI. The data sources for each data item are described below. The data were prepared at a scale of 1.5 million for the African sheets and contain polygon coordinate information, first level attribute codes, and second level attribute codes for selected variables. The maps were prepared by first creating a set of thematic map sheets for each of the components and then integrating these maps to form a single map manuscript containing all of the map unit boundaries for each module. The method for preparing each of the thematic sheets and description of the integration sequence and process is provided in the following sections.

Physiographic Divisions

Physiographic divisions were derived from the Lobeck Physiographic Diagram of Africa. The original which existed at a scale of approximately 1:35 million, was rescaled manually and rectified to the FAO basemap. The physiographic units were assigned a three-digit descriptive code which was recorded directly on the thematic map. Text which accompanied the original diagram was reviewed to verify that the rescaled and rectified unit boundaries were properly located.

Geomorphological Regions

Geomorphological regions were derived from those illustrated in Volume VI of the FAO Soil Map of the World. While largely corollary to the physiographic divisions, the geomorphological regions emphasize those regional patterns which correspond most directly to changes in pedology. The physiographic divisions included tectonic and geologic considerations. The original geomorphological data was treated in the same manner as the physiographic divisions, being rescaled, rectified and verified. The resulting data was reformatted at a scale of 1:5 million and were comprised of polygons with descriptive numeric codes. The code system was based on major regions with areas of special interest separately identified and delineated. The text descriptions and comparison of the delineations to the DMA topographic sheets and the Landsat images served as a base for the verification of this thematic map component.

Land Surface Form

Land surface form was interpreted from the topographic film separate of the FAO Soil Map of the World. The DMA Topographic Maps of Africa were used for comparison and to add further precision to the ratings of slope and profile type. The system for rating land surface form was based on the method developed by Edwin Hammond for small-scale continental landform maps. To prepare the thematic maps, a matte drafting film was affixed to the FAO basemap. A grid composed of two-centimeter-square cells was drawn on this overlay. The map interpreters then evaluated the area of the basemap which fell within each cell. A numeric code was written in each cell. It recorded the following: the relative local relief in meters; the percent of the land surface within the cell which fell into different slope classes; and the profile type indicating the percent of the area characterized by gently sloping land and the percent of the area in a lowland versus upland position. The gridded information was then overlaid on the Landsat images, and "natural landscape units" were interpreted. These units were polygonal and conformed to major landscape features such as mountain chains, plains, and plateaus. The attribute values were recorded on the manuscript. A final review of the polygon data against the DMA topographic sheets verified the attribute values.

Landforms

Landforms/Waterforms were interpreted using numerous sources of collateral information. Principal sources included the Landsat mosaics, the USSCS World Soil Map of Africa, the Raize Landform Map of North Africa, and the UNESCO Geological World Atlas. The classification system was developed in consultation with the FAO desertification analyst and was built around pedogenic considerations. The system divides the landscape into mountains, piedmont and plain, and then subdivides each according to those gross features which are most pertinent to soil development. Mountains and hills were divided by rock type and pH. Piedmonts were divided into lithic and regolic areas as were plateaus. Plains were divided by mode of formation. Floodplains and deltaic plains were further divided into age groups. The landform classification which was employed is outlined later in this Appendix. Definitions of the interpreted units are provided below:

> Mountains. This type consists of portions of the earth's crust elevated more than 500 meters above the immediate surrounding surface. These features generally have moderate to steep slopes, and are often found either in long chains or ranges, or as single, isolated eminences. These forms were interpreted using the Landsat images and the topographic basemap primarily.
>
> Hills. This landform type is comprised of a mass of material elevated less than 500 meters above the surrounding terrain and culminating in a well-developed crest or summit. These features may have slopes ranging from slight to steep, and range in height from hillocks, a few hundred

meters high, to large hills up to five hundred. These forms were interpreted largely using the topographic basemap and Landsat images.

Lithic piedmont. A piedmont is an area lying at or formed at the base of the lower slopes of mountains or hills. The lithic piedmont signifies a region in which the rock fragments comprise proportionally more of the overlying soil layer than any other constituent, and for which this mantle is generally fifty centimeters or less in depth over the bedrock. Separation of lithic versus regolic piedmonts was performed in conjunction with the USDA, SCS soil data and the satellite imagery. This class includes "pediment" areas, which are planar erosion surfaces carved into bedrock and generally veneered with fluvial gravels. These features usually occur near piedmont areas, and generally constitute extensive bedrock surfaces over which the erosion products of the retreating mountain fronts are transported to sedimentary basins or plains.

Regolic Piedmont. The regolic piedmont indicates a region at the lower slopes of mountains or hills with a thickened layer or mantle of unconsolidated, incoherent rock detritus and soil materials. These sediments are at least fifty centimeters thick over the bedrock. This class includes areas comprised of coalescing alluvial fans in similar geographic positions as the "pediment" surfaces described under lithic piedmonts.

Lithic Plateau. A plateau is comprised of relatively elevated areas of comparatively flat lands which are terminated on at least one margin by a steep escarpment. The elevation of a plateau may range widely. The lithic plateau retains a mantle fifty centimeters or less in thickness over the bedrock. Extensive dissection of plateaus may produce hills at some localities. The distinction between lithic and regolic plateaus is determined through use of the SCS soil data, the Landsat imagery, and DMA maps.

Regolic Plateau. A regolic plateau retains a thickened layer or mantle of materials which are unconsolidated, including rock detritus of numerous origins and soil. This mantle is at least fifty centimeters thick overlying the bedrock.

Plains undivided. A plain is comprised of a region of generally uniform, comparatively flat slope of considerable extent which is not broken by any marked elevations and/or depressions. This class was utilized where the origin of the plain (example: coastal or lacustrine, flood or deltaic) is either unknown, or not readily apparent. This class was interpreted using the basemaps and Landsat images as primary data.

Coastal Plain. This type of plain generally has one margin on the oceanic shoreline, and usually represents an area of emerged sea floor sediments. These sediments include beach, bar and spit detritus, coastal eolian dunes, and lagoonal, estuarine, bay, tidal marsh and flat

deposits. These units were identified primarily using the geologic maps, Landsat and the topographic base map.

Lacustrine Plain. This type of plain results from the infilling of lake basins of former perennial lakes, or by the development of clay or salt flats in areas of intermittent lakes. Lacustrine deposits of present or former perennial lakes are generally coarsest along the margins of the relict lakes (beach and shoreline deposits) and tend to become finer as the distance from shore increases, becoming finest in texture in the central part of the basin. Intermittent lake bottoms are generally fine-grained and/or transitional to evaporitic deposition. Eolian sand deposition is common in and around lacustrine plains. This class was also used to designate lacustrine areas of very large size which are now preserved primarily as terraces in a larger, undifferentiated plain (Congo Basin). Landsat images and the base map served as primary data for these forms.

Recent Floodplain. The floodplain consists of that portion of a river valley adjacent to the river channel which is composed of detritus deposited by the stream during flood stages when it overflows its banks. As used in this project, this class includes all active, inactive and abandoned floodplain areas and most terraces associated with the major perennial rivers. This class is also used to designate the larger wash or wadi areas of intermittent floodplain activity. Interpretation was based primarily on the Landsat imagery.

Relict Floodplain. This class was used to designate floodplain areas which are now entirely abandoned due to stream piracy, and in a few limited cases, for some areas of relatively high terraces which were of sufficient size to be mappable at the project scale. The abandoned floodplain areas generally retain the full development of the lateal structure of active floodplains (i.e., active, inactive, abandoned floodplains, and low and high terraces) despite the general lack of flooding activity in the area. Other characteristics of the relict floodplain remain the same as that of the active floodplain. Interpretation was based on Landsat images within the help of the field experience of the FAO project coordinator.

Recent Deltaic Plain. This class is a specialized type of plain caused by the active deposition of fluvial sediments at the mouth of a river into a comparatively still body of water. The delta may develop into lakes, or into the ocean, and to be mappable at the project mapping scale, the deltas must be unusually large. This designation is reserved for currently active deltas. Deltaic deposits may include some minor lacustrine deposits, and generally form the transition from continental to marine influences; salt marshes may occur on the outer flanks of deltas extending into ocean waters. Interpretation was based on Landsat images and geologic maps.

Relict Deltaic Plain. This class is used to represent areas of old, inactive deltas which otherwise retain the characteristics of recent, active deltaic plains. Relict deltaic plains are generally isolated, and are the result of oceanward advancement of the shoreline such as by uplift of the coastal plain, by drainage of the lacustrine area, or by stream piracy which transfers the source materials to another locality. Interpretation was based on field experience of the FAO coordinate and Landsat imagery.

Rift Valley. This feature is a active, tectonically-produced valley or graben originated through subsidence of a longitudinal strip of land bounded by two subparallel faults. These valleys are generally steep-sided, are frequently filled with water to form lakes in some places. These valleys represent areas of separation between crustal plates. These areas may have hills occurring within the rift zone itself, and are commonly bounded by plateaus on either margin of the valley. Interpretation is based primarily on the topographic basemap.

The landform maps were made by drafting interpretations onto drafting film registered to the basemap and overlaid on the Landsat images, soil maps, or other collateral information. Each interpretation was verified using as many supporting documents as possible. Attribute codes were written directly on the thematic map.

Surface Modifiers

Using the same thematic map sheets on which landforms were delineated, the interpreters proceeded to further differentiate the landforms according to modifying surface conditions including salt cover, sand cover, sand orientation, stone cover, degree of dissection and poor drainage areas. Salt cover was delineated using the USSCS World Soil Map, FAO Soil Map of the World, DMA Topographic Maps of Africa, Raize Landform Map of North Africa, and Landsat mosaics. Salt areas were mapped if they were at least 600 sq. km. in extent and observed on more than one data source. Sand cover was interpreted primarily on the basis of Landsat imagery with assistance from the USSCS maps, Raize map, and the DMA topographic maps for areas where dune formations were evident. The direction of prevailing alignment of dual structures was interpreted using the Landsat imagery. It should be noted that dune orientation interpreted for this effort is on a general scale, local observation at a detailed scale could show significant departures from the values recorded. Stone cover was interpreted primarily from the FAO and SCC soil maps. In North Africa the Erwin Raize map was very helpful. Delineations were verified using the Landsat images where practical.

Degree of dissection was interpreted based on interpretation of surface texture as displayed on the Landsat mosaics. The interpretations are intended to be suggestive rather than definitive because no measure of the depth of dissection or of minor surface dissection is possible using Landsat imagery. Drainage was taken directly from the DMA topographic sheets by photo reducing

the originals to project scale and then delineating those areas which were shaded using the inundation symbol. The Landsat images did not allow verification of the poor drainage areas.

Geology

Geology was derived entirely from the UNESCO Geological World Atlas. The original was published at 1:10 million so photographic rescaling was used to produce map sheets at 1:5 million. No rectification was required because the data was printed on exactly the same map projection as the FAO basemap. To the extent possible major rock units were verfied using the Landsat images. The thematic map was prepared by overlaying the rescaled originals with the FAO basemaps to which a matte drafting film was registered. Rock unit boundaries were then traced and subsequently compared to the Landsat images. Attribute codes were written on the manuscript for each rock unit. The codes include Geologic age, Origin, pH, Types of intrusive, extrusive, or metamorphic rock and rock facies for appropriate units.

Vegetation

Vegetation was originally to be derived from the UNESCO vegetation maps for the Mediterranean and the area south of the Sahara as well as the NOAA chlorophyl index imagery. However, careful inspection of the data indicated that the classifications, based largely on potential vegetation conditions, did not provide an adequate estimate of actual vegetative structure or crown cover. The vegetation patterning shown on the DMA Topographic Maps of Africa shows vegetation structure and average density for forest, tree savanna, and bunch grass. It was decided in conjunction with the FAO desertification coordinator to include the DMA vegetation information in the data base.

The DMA sheets originally at 1:2 million were photo reduced as color film transparencies and overlaid by the FAO basemaps with attached matte film overlays. The vegetation patterns were traced and given a two digit code number. The first digit described the vegetation type and the second digit indicated drainage condition.

General Land Use

General Land use was taken from the World Atlas of Agriculture. These data exist at a scale of 1:5 million and show general zones of cultivation. The cartographic display on the original maps included both closed polygons showing areas with high density of cultivated land and scattered open dot patterns indicating a mosaic of cultivated and non-cultivated lands. The latter required reformatting into polygon coverages. This was accomplished by drawing lines around clusters of dots and clusters of extremely small polygons with equal amounts of intervening-natural land. These polygons were classed as cultivated/natural mosaic. The resulting polygon coverage was drawn on a

matte drafting film affixed to the basemap on a light table. The land use patterns were not verified against imagery or the vegetation delineations.

FAO Soils

FAO soils were incorporated into the terrain unit directly from the film originals from the FAO Soil Map of the World. Rescaling and rectification were not required. The first level attribute information was converted into an alphanumeric code list. During a later step secondary attribute codes for the Africa soils were prepared. This process is described under the FAO Soil Manuscript. The structure for first and second level codes is outlined later in this Appendix.

USDA-SCS Soils

USSCS Soils were obtained at a scale of 1:1 million in a rough manuscript form. These constitute part of the unpublished USSCS World Soil Map. The originals were photographically reduced to 1:5 million. Following the rescaling step, it was necessary to rectify the data to the FAO basemap by carefully registering each map sheet to the hydrologic and topographic features and re-drawing the soil patterns. During this reformatting step, it was desirable to drop out some of the smallest units and to slightly generalize the boundary line crenulation. Edgematch discrepencies were identified and corrected by image interpretation and verified through discussions with the SCS staff soil scientists. SCS code symbols were inscribed on the thematic map. The completed map was compared to the Landsat imagery and the topographic basemap to verify the location and extent of map units. Secondary attribute code sheets were developed which included soil types, components, dominance, modifiers, landforms, parent material and documentation. These basic and expanded codes are outlined later in this Appendix.

Integration

After all of the thematic map sheets were complete, they were integrated onto a single sheet. The order of map sheet integration was:

1. FAO Soils
2. Geology
3. USDA Soils
4. Landforms and Surface Modifiers
5. Land Surface Forms
6. Vegetation
7. Land Use
8. Physiographic Divisions
9. Geomorphological Regions

As described earlier, the thematic maps were compared two at a time and slight differences were resolved by comparing to the Landsat images and the

topographic basemaps. Each thematic map was redrawn incorporating the revisions and the attribute codes transferred onto the sheets containing the new delineations. The boundaries from all nine data maps were then composited onto a single sheet. Sequential identification numbers and label placement centroids were drawn on a separate matte film overlay registered to the composite polygon map.

The polygon boundary sheet was automated by laser scanning and the polygon centroids were manually digitized. The two separate files were later appended together during the automation step to form a single spatial file. Attribute code forms were filled out by placing the numbered polygons atop the data maps each-in-turn and recording the appropriate attribute code in its assigned code column. The attributes were then key entered. The maps were edited by producing a computer plot of each data category which included boundaries and code values. Additional automated editing steps were carried out to identify code errors or inconsistencies. These are described in Chapter III.

UNEP/FAO World and Africa Data Base
Mapping Procedures and Data Sources
Mean Annual Rainfall
Mean Annual Wind Velocity
Number of Wet Days per Year
(Africa 1:5,000,000)

Three separate climate manuscripts were prepared directly from original hand drawn climate maps provided by FAO. The source climate maps were prepared on the FAO/AGS base at a scale of 1:5 million. These were provided by FAO on a relatively stable copy base for each of the Africa sheets.

The data were prepared for automation by highlighting and numbering the longitude/latitude tic marks. A matte drafting film was affixed to each map sheet on which a sequential identification number and centroid was drawn for each map polygon. Polygons which intercepted the coastline were extended into the water to facilitate use of the template. The map sheets were mounted on the digitizer tablet and manually digitized. The attribute values for the lines were key entered as a part of their arc identification during digitizing. Polygon attributes were encoded as first level codes by completing and key entering attribute code lists. Editing was done by producing computer generated plots of the lines with attributes displayed using various line symbols and colors and units with polygon values written as numeric codes plotted at the polygon centroids.

UNEP/FAO AFRICA GIS DATABASE

1. VEGETATION MAP

	INUNDATED CLASS		NOT INUNDATED OR RICE CLASS	
	11	FOREST	19	
	21	TREE SAVANNA	29	
	31	GRASSLAND	39	
	41	MANGROVES	49	(NONE)
	51	MARSH/SWAMP	59	
(NONE)	61	OASIS	69	(NONE)
	91	OTHER	99	
	92	OTHER - RICE		
	88	WATER		

2. RAINFALL (MILLIMETERS)

1	0 - 50	18	450 - 550
2	50 - 100	19	500 - 550
3	100 - 150	20	500 - 600
4	100 - 200	21	550 - 600
5	150 - 200	22	600 - 700
6	200 - 250	23	600 - 800
7	200 - 300	24	600 - 1000
8	200 - 400	25	700 - 800
9	250 - 300	26	800 - 900
10	250 - 400	27	800 - 1000
11	300 - 350	28	900 - 1000
12	300 - 400	29	1000 - 1500
13	350 - 400	30	1500 - 2000
14	400 - 450	31	2000 - 3000
15	400 - 500	32	>3000
16	400 - 600		
17	450 - 500		

3. WIND (METERS/SECOND)

CLASS	WIND SPEED	CLASS	WIND SPEED
1	0.0 - 0.5	7	3.0 - 3.5
2	0.5 - 1.0	8	3.5 - 4.0
3	1.0 - 1.5	9	4.0 - 4.5
4	1.5 - 2.0	10	4.5 - 5.0
5	2.0 - 2.5	11	5.0 - 5.5
6	2.5 - 3.0	12	5.5 - 6.0
		13	>6.0

4. SOILS - 90 SOILS GROUPED TO 24 GREAT GROUP (USA)

GREAT GROUP (USA)			ERODIBILITY	PRODUCTIVITY
1	A.	ACRISOLS	6	3
2	B.	CAMBISOLS	7	5
4	D.	PODZOLUVISOLS	7	6
5	E.	RENDZINAS	9	4
6	F.	FERRALSOLS	9	2
7	G.	GLEYSOLS	2	4
8	H.	PHAEDZEMS	7	7
9	I.	LITHOSOLS	8	1
10	J.	FLUVISOLS	3	4
11	K.	KASTANOZEMS	8	8
12	L.	LUVISOLS	6	5
14	N.	NITOSOLS	7	5
15	O.	HISTOSOLS	1	3
16	P.	PODZOLS	8	3
17	Q.	ARENOSOLS	5	1
18	R.X	REGOSOLS	8	2
19	S.	SOLONETZ	2	3
20	T.X	ANDOSOLS	5	7
21	U.	RANKERS	*	
22	V.X	VERTISOLS	4	9
23	W.	PLANOSOLS	3	2

* NO SOILS OF THIS TYPE IN DATA

- I -

LEGATES AND WILLMOTT AVERAGE MONTHLY AIR TEMPERATURE AND PRECIPITATION

CITATION: Legates, D. R. and C. J. Willmott, 1989. Global Air Temperature and Precipitation. Digital Data. NCAR, Boulder, Colorado. 13.5 MB.

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I. LEGATES AND WILLMOTT AVERAGE MONTHLY AIR TEMPERATURE AND PRECIPITATION

DATE: 1989

SOURCE:

Compiled from multiple sources by
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Boulder, CO 80307-3000

DATA CENTER: NCAR

GEOGRAPHIC SAMPLING: .5 degree grid

COVERAGE: Global

PROJECTION: Lat/lon

TIME SAMPLING: Monthly

REFERENCES:

Legates, David R. and Cort J. Willmott, 1990. "Mean Seasonal and and Spatial Variability in Gauge-Corrected Global Precipitation," *International Journal of Climatology*, vol. 10, pp. 111-127. (Included)

FILE NAMES:

AFCPRJAN - AFCPRDEC	Monthly corrected precipitation
AFMPRJAN - AFMPRDEC	Monthly measured precipitation
AFTMPJAN - AFTMPDEC	Monthly mean surface air temperature
AFERRJAN - AFERRDEC	Monthly standard error for corrected precipitation

(Total of 48 files)

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LEGATES AND WILLMOTT MONTHLY CORRECTED PRECIPITATION EXAMPLE DOCUMENTATION FILE

File Names: *AFCPRJAN.DOC - AFCPRDEC.DOC, (12 files)*

```
image title : Legates & Willmott, (Monthly) Corrected Precipitation (mm/month)
data type   : integer
file type   : binary
rows        : 438
columns     : 480
minimum     :   0.0000000000E+00
maximum     :   6.2800000000E+02
cell x      :   1.6666666667E-01
cell y      :   1.6666666667E-01
legend      : 15
category  1 : 55 to 109
category  2 : 110 to 164
category  3 : 165 to 219
category  4 : 220 to 274
category  5 : 275 to 329
category  6 : 330 to 384
category  7 : 385 to 439
category  8 : 440 to 494
category  9 : 495 to 549
category 10 : 550 to 604
category 11 : 605 to 659
category 12 : 660 to 714
category 13 : 715 to 769
category 14 : 770 to 824
category 15 : > 824

{category 0 : 0 to 54}
```

[This legend is only appropriate for displays which reclass (contrast stretch) the continuous values into 16 classes.]

Note: The minimum and maximum values indicated in the documentation files have been standardized to 0 and 628 respectively so that automatic scaling during display will show comparable results between monthly images.

LEGATES AND WILLMOTT ANNUAL CORRECTED PRECIPITATION DOCUMENTATION FILE

File Name: AFCPRANN.DOC

```
image title : Legates & Willmott, Annual Corrected Precipitation (mm/year)
data type   : integer
file type   : binary
rows        : 438
columns     : 480
minimum     :   0.0000000000E+00
maximum     :   5.4690000000E+03
cell x      :   1.6666666667E-01
cell y      :   1.6666666667E-01
legend      : 15
category  1 : 341 to 682
category  2 : 683 to 1024
category  3 : 1025 to 1366
category  4 : 1367 to 1708
category  5 : 1709 to 2050
category  6 : 2051 to 2392
category  7 : 2393 to 2734
category  8 : 2735 to 3075
category  9 : 3076 to 3417
category 10 : 3418 to 3759
category 11 : 3760 to 4101
category 12 : 4102 to 4443
category 13 : 4444 to 4785
category 14 : 4786 to 5127
category 15 : 5128 to 5469

{category 0 : 0 to 340}
```

[This legend is only appropriate for displays which reclass (contrast stretch) the continuous values into 16 classes.]

LEGATES AND WILLMOTT MONTHLY MEASURED PRECIPITATION
EXAMPLE DOCUMENTATION FILE

File Names: AFMPRJAN.DOC - AFMPRDEC.DOC (12 files)

```
image title : Legates & Willmott, (Monthly) Measured Precipitation (mm/month)
data type   : integer
file type   : binary
rows        : 438
columns     : 480
minimum     :   0.0000000000E+00
maximum     :   8.4700000000E+02
cell x      :   1.6666666667E-01
cell y      :   1.6666666667E-01
legend      : 15
category  1 : 53 to 105
category  2 : 106 to 158
category  3 : 159 to 211
category  4 : 212 to 264
category  5 : 265 to 317
category  6 : 318 to 370
category  7 : 371 to 423
category  8 : 424 to 476
category  9 : 477 to 529
category 10 : 530 to 582
category 11 : 583 to 635
category 12 : 636 to 688
category 13 : 689 to 741
category 14 : 742 to 794
category 15 : > 794

{category 0 : 0 to 52}
```

[This legend is only appropriate for displays which reclass (contrast stretch) the continuous values into 16 classes.]

Note: The minimum and maximum values indicated in the documentation files have been standardized to 0 and 847 respectively so that automatic scaling during display will show comparable results between monthly images.

LEGATES AND WILLMOTT ANNUAL MEASURED PRECIPITATION DOCUMENTATION FILE

File Name: AFMPRANN.DOC

```
image title : Legates & Willmott, Annual Measured Precipitation (mm/year)
data type   : integer
file type   : binary
rows        : 438
columns     : 480
minimum     :   0.0000000000E+00
maximum     :   5.2910000000E+03
cell x      :   1.6666666667E-01
cell y      :   1.6666666667E-01
legend      : 15
category  1 : 330 to 660
category  2 : 661 to 991
category  3 : 992 to 1322
category  4 : 1323 to 1652
category  5 : 1653 to 1983
category  6 : 1984 to 2314
category  7 : 2315 to 2645
category  8 : 2646 to 2975
category  9 : 2976 to 3306
category 10 : 3307 to 3637
category 11 : 3638 to 3968
category 12 : 3969 to 4298
category 13 : 4299 to 4629
category 14 : 4630 to 4961
category 15 : 4961 to 5291

{category 0 : 0 to 329}
```

[This legend is only appropriate for displays which reclass (contrast stretch) the continuous values into 16 classes.]

LEGATES AND WILLMOTT MONTHLY STANDARD ERROR
EXAMPLE DOCUMENTATION FILE

File Names: AFERRJAN.DOC - AFERRDEC.DOC (12 files)

```
image title : Legates & Willmott, (Monthly) Standard Error (mm/month)
data type   : integer
file type   : binary
rows        : 438
columns     : 480
minimum     :   0.0000000000E+00
maximum     :   2.0700000000E+02
cell x      :   1.6666666667E-01
cell y      :   1.6666666667E-01
legend      : 15
category  1 : 13 to 25
category  2 : 26 to 38
category  3 : 39 to 51
category  4 : 52 to 64
category  5 : 65 to 77
category  6 : 78 to 90
category  7 : 91 to 103
category  8 : 104 to 116
category  9 : 117 to 129
category 10 : 130 to 142
category 11 : 143 to 155
category 12 : 156 to 168
category 13 : 169 to 181
category 14 : 182 to 194
category 15 : > 194

{category 0 : 0 to 12}
```

[This legend is only appropriate for displays which reclass (contrast stretch) the continuous values into 16 classes.]

Note: The minimum and maximum values indicated in the documentation files have been standardized to 0 and 207 respectively so that automatic scaling during display will show comparable results between monthly images.

LEGATES AND WILLMOTT ANNUAL STANDARD ERROR DOCUMENTATION FILE

File Name: AFERRANN.DOC

```
image title : Legates & Willmott, Annual Standard Error (mm/month)
data type   : integer
file type   : binary
rows        : 438
columns     : 480
minimum     :   1.0000000000E+00
maximum     :   1.0200000000E+02
cell x      :   1.6666666667E-01
cell y      :   1.6666666667E-01
legend      : 15
category  1 : 7 to 12
category  2 : 13 to 19
category  3 : 20 to 25
category  4 : 26 to 31
category  5 : 32 to 38
category  6 : 39 to 44
category  7 : 45 to 51
category  8 : 52 to 57
category  9 : 58 to 63
category 10 : 64 to 70
category 11 : 71 to 76
category 12 : 77 to 82
category 13 : 83 to 89
category 14 : 90 to 95
category 15 : 96 to 102

{category 0 : 1 to 6}
```

[This legend is only appropriate for displays which reclass (contrast stretch) the continuous values into 16 classes.]

LEGATES AND WILLMOTT MONTHLY AIR TEMPERATURE
EXAMPLE DOCUMENTATION FILE

File Names: AFTMPJAN.DOC - AFTMPDEC.DOC (12 files)

```
image title : Legates & Willmott, (Monthly) Air Temperature (0.1 C)
data type   : integer
file type   : binary
rows        : 438
columns     : 480
minimum     :   1.5000000000E+01
maximum     :   3.8600000000E+02
cell x      :   1.6666666667E-01
cell y      :   1.6666666667E-01
legend      : 15
category  1 : 38 to 60
category  2 : 61 to 83
category  3 : 84 to 107
category  4 : 108 to 130
category  5 : 131 to 153
category  6 : 154 to 176
category  7 : 177 to 200
category  8 : 201 to 223
category  9 : 224 to 246
category 10 : 247 to 269
category 11 : 270 to 293
category 12 : 294 to 316
category 13 : 317 to 339
category 14 : 340 to 362
category 15 : > 362

{category 0 : < 37}
```

[This legend is only appropriate for displays which reclass (contrast stretch) the continuous values into 16 classes.]

Note: The minimum and maximum values indicated in the documentation files have been standardized to 15 and 386 respectively so that automatic scaling during display will show comparable results between monthly images.

LEGATES AND WILLMOTT ANNUAL AIR TEMPERATURE DOCUMENTATION FILE

File Name: AFTMPANN.DOC

```
image title : Legates & Willmott, Annual Air Temperature (0.1 C)
data type   : integer
file type   : binary
rows        : 438
columns     : 480
minimum     :   9.7000000000E+01
maximum     :   3.1000000000E+02
cell x      :   1.6666666667E-01
cell y      :   1.6666666667E-01
legend      : 15
category  1 : 110 to 122
category  2 : 123 to 136
category  3 : 137 to 149
category  4 : 150 to 162
category  5 : 163 to 176
category  6 : 177 to 189
category  7 : 190 to 203
category  8 : 204 to 216
category  9 : 217 to 229
category 10 : 230 to 243
category 11 : 244 to 256
category 12 : 257 to 269
category 13 : 270 to 283
category 14 : 284 to 296
category 15 : 297 to 310

{category 0 :  97 to 109}
```

[This legend is only appropriate for displays which reclass (contrast stretch) the continuous values into 16 classes.]

April 1989

GLOBAL AIR TEMPERATURE AND PRECIPITATION DATA ARCHIVE

by

D.R. Legates and C.J. Willmott

Data Support Section
NCAR
PO Box 3000
Boulder, CO 80307

This tape is a 9-track, ~~1600~~ 6250 bpi, unlabelled tape that was created on an IBM3090 at the University of Delaware on ~~May 1, 1988~~ Feb 1, 1989. It contains the following four files:

File 1 Corrected monthly and annual precipitation interpolated to a 0.5' × 0.5' resolution. Estimated biases in the gage-measurements have been removed from these observations. This file has a logical record length (LRECL) of 80 bytes, a blocksize (BLOCK) of 8000 bytes and contains 260,281 records. The format of each record is:

VARIABLE	FORMAT	COLS.
Latitude (decimal degrees)	(F7.2)	1-7
Longitude (decimal degrees)	(F7.2)	8-14
Corrected Precipitation (mm month^{-1}) (Jan. - Dec.)	(12I5)	15-74
Annual Corrected Precipitation (mm year^{-1})	(I6)	75-80

File 2 Measured monthly and annual precipitation interpolated to a 0.5' × 0.5' resolution. This file has a logical record length (LRECL) of 80 bytes, a blocksize (BLOCK) of 8000 bytes and contains 260,281 records. The format of each record is:

VARIABLE	FORMAT	COLS.
Latitude (decimal degrees)	(F7.2)	1-7
Longitude (decimal degrees)	(F7.2)	8-14
Measured Precipitation (mm month^{-1}) (Jan. - Dec.)	(12I5)	15-74
Annual Measured Precipitation (mm year^{-1})	(I6)	75-80

File 3 Monthly and annual air temperature interpolated to a 0.5° × 0.5° resolution. This file has a logical record length (LRECL) of 80 bytes, a blocksize (BLOCK) of 8000 bytes and contains 260,281 records. The format of each record is:

VARIABLE	FORMAT	COLS.
Latitude (decimal degrees)	(F7.2)	1-7
Longitude (decimal degrees)	(F7.2)	8-14
Air Temperature (0.1°C) (Jan. - Dec.)	(12I5)	15-74
Annual Average Air Temperature (0.1°C)	(I6)	75-80

File 4 Standard errors for the precipitation corrections interpolated to a 0.5° × 0.5° resolution. This file has a logical record length (LRECL) of 80 bytes, a blocksize (BLOCK) of 8000 bytes and contains 260,281 records. The format of each record is:

VARIABLE	FORMAT	COLS.
Latitude (decimal degrees)	(F7.2)	1-7
Longitude (decimal degrees)	(F7.2)	8-14
Standard Error (mm month^{-1}) (Jan. - Dec.)	(12I5)	15-74
Annual Standard Error (mm month^{-1})	(I6)	75-80

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MEAN SEASONAL AND SPATIAL VARIABILITY IN GAUGE-CORRECTED, GLOBAL PRECIPITATION

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Received 24 August 1988
Revised 31 January 1989

ABSTRACT

Using traditional land-based gauge measurements and shipboard estimates, a global climatology of mean monthly precipitation has been developed. Data were obtained from ten existing sources, screened for coding errors, and redundant station records were removed. The edited data base contains 24,635 spatially independent terrestrial station records and 2223 oceanic grid-point records. A procedure for correcting gauge-induced biases is presented and used to remove systematic errors caused by wind, wetting on the interior walls of the gauge, and evaporation from the gauge. These 'corrected' monthly precipitation observations were then interpolated to a 0·5° of latitude by 0·5° of longitude grid using a spherically based interpolation procedure. Bias-corrected spatial distributions of the annual mean and intra-annual variance are presented along with a harmonic decomposition of the intra-annual variance.

KEY WORDS Global precipitation Harmonic analysis Raingauge errors

INTRODUCTION

Precipitation is probably the longest observed and most widely recorded hydrological phenomenon' (Strangeways, 1985, p. 41) and is an essential component of the hydrological cycle. A completely reliable spatial and temporal representation of global precipitation, however, remains unavailable (cf. Mintz, 1981; Baumgartner, 1982; Jaeger, 1983; Willmott *et al.*, 1985a), even though the demand for such data is increasing (National Aeronautics and Space Administration Advisory Council, 1988). Accurate estimates of global precipitation are needed, for example, to help verify general circulation model (GCM) prognostications of the seasonal precipitation cycle. Ground truth for evaluating and calibrating precipitation estimates obtained from radars and satellites also is needed. Additionally, precipitation data can be used in diagnosing GCM dynamics, inasmuch as precipitation is a measure of the vertically integrated diabatic heating field. Moreover, global precipitation climatologies are necessary for large-scale hydrological and ecological studies and may be used as standards for evaluating climate change.

Deficiencies in existing precipitation climatologies are related to inadequate raingauge networks (highly uneven spatial and temporal coverage), a paucity of oceanic measurements, and the translation of station data to overly coarse grids. Most existing climatologies of global precipitation have also used standard raingauge measurements that have long been recognized as underestimates of the actual precipitation (cf. Kurtyka, 1953; Larson, 1971). Only one existing climatology, in fact, is based on 'corrected' precipitation data (Unesco, 1978), although it was developed from very few stations (1042) outside of the Soviet Union. (Prior to 1980, only Finland and the Soviet Union corrected precipitation measurements for gauge-induced biases. Recent

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cooperative and individual efforts to remove gauge biases in Europe, however, have been initiated (Sevruk, 1986a).)

It is reasonable to conclude that our knowledge of large-scale precipitation patterns is incomplete and that improved climatologies are needed. One such new climatology is presented here and is based upon (1) a spatially dense network of terrestrial stations, (2) relatively accurate estimates of oceanic precipitation, and (3) corrections for the major biases inherent in the gauge collection procedure. Radar and satellite estimates of precipitation were not used since the technology is relatively new and long-term means are not yet available. As this climatology is independent from remotely sensed precipitation, it may also serve as ground truth for evaluating remotely sensed precipitation estimates.

MERGED AND EDITED DATA

Terrestrial precipitation measurements

Global archives of monthly precipitation have been compiled by Wernstedt (1972), Willmott *et al.* (1981), and the National Center for Atmospheric Research (Spangler and Jenne, 1984), and they provided most of the data for this climatology. The Wernstedt and Willmott *et al.* data sets contain monthly averages for 17,347 and 13,659 stations, respectively. Spangler and Jenne, however, give monthly time-series for 3679 stations, from which monthly averages had to be computed. Wernstedt's Canadian data were not used since snowfall was excluded from the averaging. Using only these three archives, adequate spatial coverage is achieved for much of the terrestrial surface; however, Australia, New Guinea, China, parts of the Far East, and Antarctica are underrepresented.

To improve the spatial resolution in the above-mentioned regions, monthly averages were obtained from an additional 208 stations in Australia, New Guinea, and Indonesia (Commonwealth Scientific and Industrial Research Organization, 1962–1971; Australian Department of National Development, 1965), 584 stations in China and the Far East (Nuttonson, 1947; Terjung *et al.*, 1985; G. Tan, pers. comm., 1986), and ten stations in Antarctica (van Rooy, 1957). A more dense coverage is not currently possible for Antarctica because these data comprise nearly all of the gauge records that exist. Ramage (1971) also provided monthly precipitation averages for five stations in the Sahara.

Temporal comparability was compromised to achieve a dense spatial resolution; that is, virtually all station records were used even though they are based on differing time-periods. Most of the data, however, were observed between 1920 and 1980, and so this climatology is largely representative of that 60-year period; with greater weight given to the more recent (data-rich) years.

Potential coding errors were identified and, where appropriate, corrected using the procedure outlined by Legates (1987) and Legates and Willmott (1989). These 35,492 station records then were merged into a single data base. Many stations, however, were represented in more than one archive and, therefore, it was necessary to combine these 'redundant' records to a single record. Once again, a procedure described by Legates (1987) and Legates and Willmott (1989) was used.

After editing and merging the data, 24,635 independent station records were realized (Figure 1). A relatively dense station network exists in the industrialized countries of North America, Europe, and East Asia. Station distributions in arid, mountainous, and polar regions, however, are less dense.

Oceanic precipitation estimates

Shipboard gauges are adversely influenced by 'the aerodynamic effect due to the superstructure of the ship, the influence of roll and pitch, the capture of spray and the movement of the ship' (World Meteorological Organization, 1971, XVII, pp. 11), as well as by the same biases that affect land-based gauges. Averaged shipboard estimates also have a 'fair-weather bias'; that is, ships tend to avoid storms and other severe weather (Quayle, 1974). As a consequence, a serious deficiency exists of reliable precipitation measurements over the oceans, and alternative estimates are needed (Jacobs, 1968; Reed and Elliott, 1973).

Several methods have been developed to extrapolate oceanic precipitation from coastal and island observations (Reed and Elliott (1973) and Dorman and Bourke (1979) list seven of these studies). In this study,

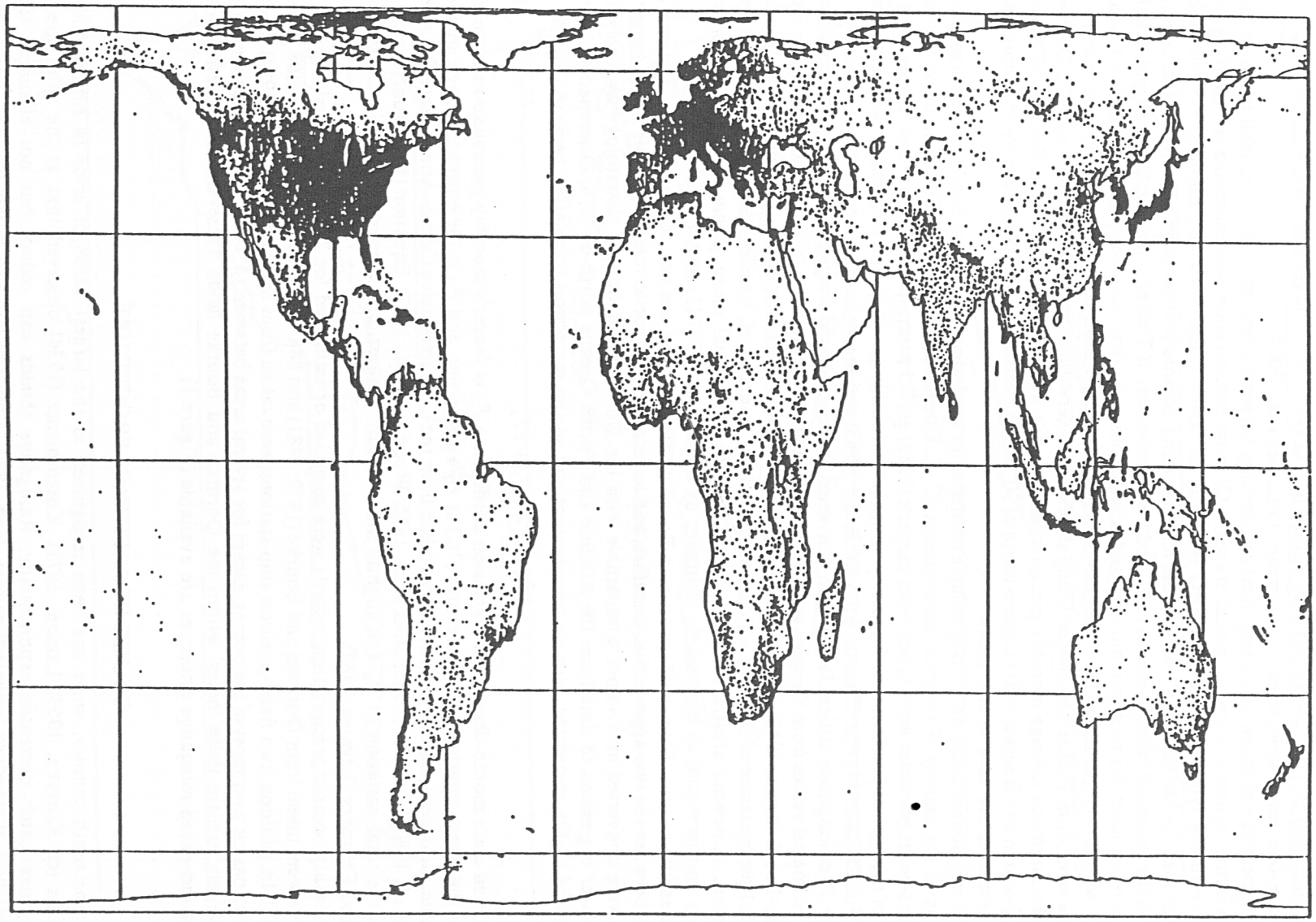

Figure 1. Locations of the 24,635 independent terrestrial precipitation stations contained in the edited and merged data set. Twelve mean monthly precipitation measurements are available for each station

oceanic precipitation is estimated according to Dorman and Bourke (1978). Their method was derived from a technique proposed by J. S. Sawyer and later refined by Tucker (1961). It is generally more accurate than the precipitation-frequency approaches (cf. Dorman, 1982; Legates, 1987).

Tucker's method was based on an empirical relationship between observed monthly rainfall totals and the 'current weather' synoptic code at coastal stations. Oceanic precipitation was estimated by applying this relationship to the synoptic weather reports recorded on board ships. Reed and Elliott (1977), however, determined that Tucker's method was suitable for estimating oceanic precipitation only in mid-latitudes. In the tropics, the increased rainfall intensity reduced the effectiveness of Tucker's method. Dorman and Bourke (1978) also recognized this problem, but they additionally observed that the error was systematic and highly correlated with air temperature. They then developed a set of regression equations (one for each month) to remove the error from Tucker's estimates. Using shipboard observations from 1950 through to 1972, Dorman and Bourke estimated average monthly precipitation for both the Pacific (Dorman and Bourke, 1979) and Atlantic (Dorman and Bourke, 1981) Oceans north of 30°S at the vertices of a 2° of latitude by 5° of longitude lattice. These data are used in this study.

Dorman and Bourke could not obtain reliable estimates for the Indian Ocean and Southern Ocean south of 30°S owing to the paucity of synoptic observations (C. E. Dorman, pers. comm., 1986). For these regions, oceanic grid-point estimates were taken from Jaeger's (1983) global precipitation climatology. Jaeger used a variation of the typical precipitation-frequency approach. Monthly precipitation frequencies were extracted from the United States Marine Climatic Atlas (cf. Jaeger, 1983) and Jaeger interpolated these values to a 4° of latitude by 5° of longitude lattice. Jaeger then converted the interpolated frequencies to annual percentages and used estimated values from Geiger's map of mean annual precipitation to translate the percentages into rainfall depths (cf. Jaeger, 1983). When integrated, Jaeger's global precipitation climatology gave an annual mean global precipitation of 966 mm which, based on other evidence (cf. Kessler, 1985), Jaeger felt was too low. He then, somewhat arbitrarily, selected 1000 mm as the annual mean global precipitation for his climatology and increased all his oceanic estimates by a factor of 1·062 (Jaeger, 1983).

Jaeger's estimates and those of Dorman and Bourke, unfortunately, are not commensurate. Systematic differences between the two approaches, therefore, had to be resolved prior to their use in this study. Jaeger's estimates were converted into values comparable with the Dorman and Bourke climatology by applying multiple linear regression to data from the Atlantic and Pacific Oceans north of 30°S. Discrepancies were assumed to be highly correlated with air temperature and so the regression translation became,

$$\hat{P}_D = a + bP_J + cT_a \qquad (1)$$

where a, b, and c are month-dependent regression coefficients, P_J is Jaeger's monthly precipitation estimate (mm), T_a is the mean monthly air temperature (°C) at P_J's grid point, and $\hat{P}_D$ is the estimated Dorman and Bourke value. Grid-point air temperatures were taken from the Comprehensive Ocean–Atmosphere Data Set (Fletcher *et al.*, 1983; Woodruff, 1985; Slutz *et al.*, 1985; Woodruff *et al.*, 1987). Equation (1) accounts for 58·7 per cent of the total variation in P_D and slightly more in July, August, and September than in December, January, and February (Legates, 1987).

Mean monthly oceanic precipitation records were compiled or estimated for 2223 grid points (Figure 2): 1335 records were taken from Dorman and Bourke (1979; 1981) and 888 were derived from Jaeger (1983) and Equation (1). In addition, two fixed-position ship stations were taken from Spangler and Jenne (1984). Even coverage is apparent over most of the oceans, except for several areas between 15°N and 30°S. Infrequent ship traverses largely explain these 'holes' within the Dorman and Bourke fields. In several of these regions, however, island-based raingauge estimates are available (Figure 1).

GAUGE CORRECTION PROCEDURE

Since the nineteenth century, wind has been recognized as the largest cause of error in precipitation measurements (cf. Kurtyka, 1953; Larson, 1971). Koschmieder (1934) observed that as the wind speed increases, gauge catch decreases exponentially. Raingauge shields can reduce but not eliminate the measurement bias of standard (elevated) gauges (Neff, 1977). Research has also shown (cf. Neff, 1977) that

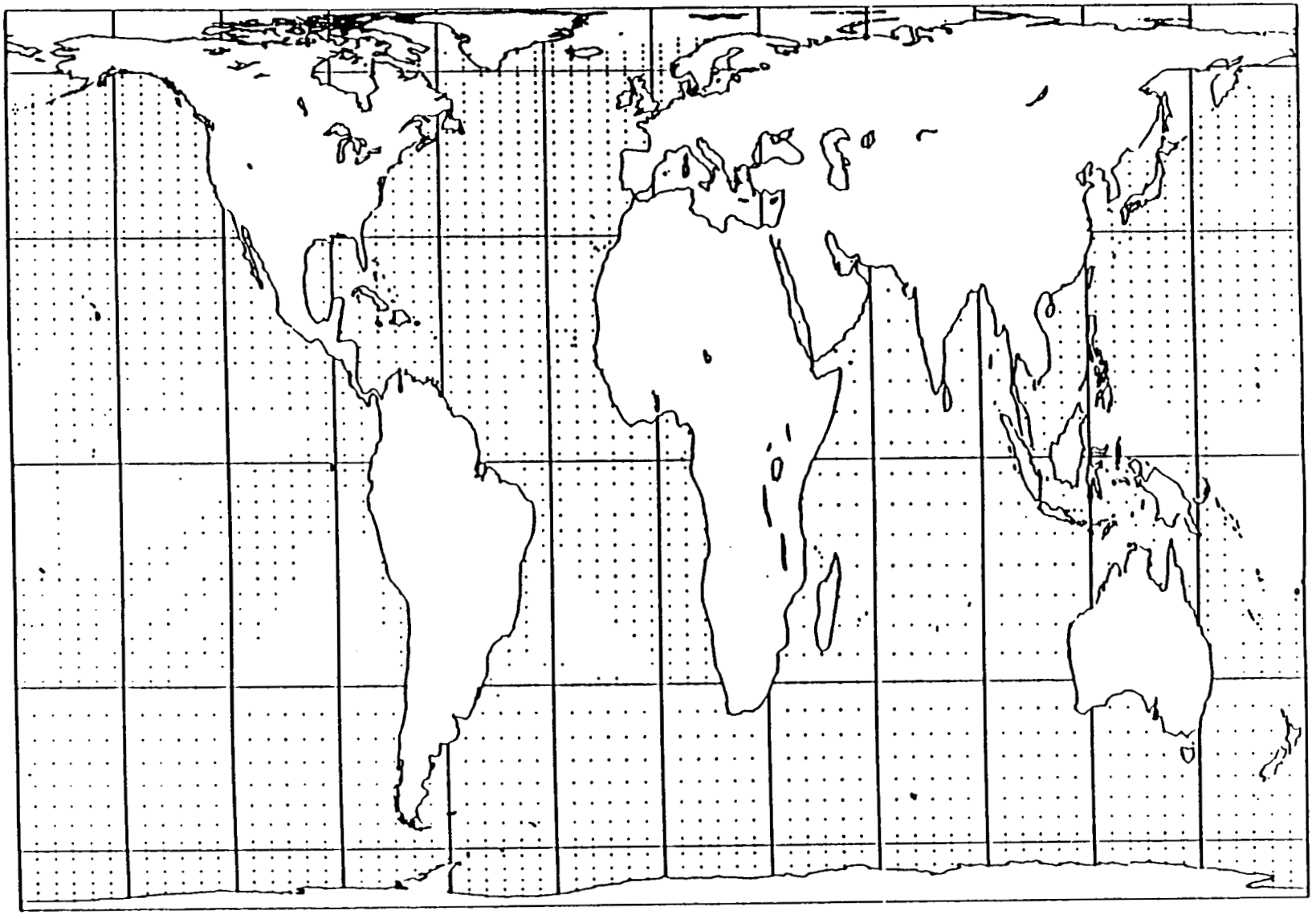

Figure 2. Locations of the 2,223 oceanic grid points for which mean monthly precipitation estimates are available

'accurate' precipitation measurements can be obtained by pit gauges (buried gauges with their orifices at ground level); that is, by gauges sited where the wind speed is at a minimum. Pit gauges, however, have been used infrequently and, even today, precipitation usually is measured by an elevated gauge without a shield (Sevruk, 1975, 1979, 1987).

Systematic errors in raingauge measurements can also arise from (1) wetting on the internal walls of the gauge, (2) evaporation from the gauge, (3) splashing into or out of the gauge, and (4) blowing snow (Sevruk, 1979; Sevruk and Hamon, 1984). Such systematic gauge errors should be identified and removed from existing records. Considering five potential sources of errors, Sevruk proposed a general model for precipitation correction,

$$P_c = \kappa(P_g + \Delta P_w + \Delta P_e) \pm \Delta P_s \pm \Delta P_b \pm \Delta P_r \tag{2}$$

where P_c is the corrected precipitation estimate, P_g is the precipitation measured by the gauge, κ is the wind correction factor ($\kappa \geqslant 1$), ΔP_w is the correction for the wetting loss, ΔP_e is the correction for evaporation, ΔP_s is the correction for splashing, ΔP_b is the correction for blowing snow, and ΔP_r is the correction for unsystematic (random) errors.

While ΔP_r may be as large as 10 per cent of the actual catch, its expected value is zero when integrated over long time periods (Sevruk, 1979). It, therefore, is assumed to be zero here. Furthermore, ΔP_s approaches zero for nearly all elevated gauges since 'splashing in' is negligible (due to the elevated orifice) and 'splashing out' is minimized by the depth of the container. Snow blown into the gauge from the adjacent snow cover ($+\Delta P_b$) and, to a lesser extent, snow blown out of the gauge ($-\Delta P_b$) also are considered to be negligible for every gauge except the Tretyakov gauge. Struzer and Bryazgin (1971) and Unesco (1978) observed that 'it is significant only for the precipitation gauge used in the USSR [i.e. the Tretyakov gauge] and mainly in high latitudes' (Unesco, 1978, p. 121). Since the specification of κ_s for the Tretyakov gauge (discussed below) takes ΔP_b into account, there is no need to explicitly consider it.

Gauge losses also are affected by the form of precipitation (i.e. liquid or solid). Error sources in Equation (2), therefore, should be partitioned into liquid (rain) and solid (snow) components. In view of this, Equation (2) can be rewritten as

$$P_c = (1-R)\kappa_r(P_g + \Delta P_{wr} + \Delta P_{er}) + R\kappa_s(P_g + \Delta P_{ws} + \Delta P_{es}) \tag{3}$$

where the subscripts r and s are used for rain and snow, respectively, and R denotes the proportion of monthly precipitation that falls in solid form.

With the exception of R, the remaining unknowns (κ_r, κ_s, ΔP_{wr}, ΔP_{ws}, ΔP_{er}, and ΔP_{es}) must be separately estimated for each gauge type due to non-trivial differences among gauge designs. Legates (1987) categorized gauges on the basis of three bias-influencing criteria: the orifice area, whether the gauge was equipped with a shield, and the height of the orifice above the ground. He then compiled these parameters for most of the world's standard precipitation gauges. His compilation of gauge-type parameters is used here.

When a standard gauge could not be identified for a country, gauge characteristics had to be inferred (Legates, 1987). Kurtyka (1953) indicated that the R.M.O. Mk I raingauge (elevated at 30 cm) is most frequently used in British protectorates and countries that formerly were part of the British Commonwealth. Unesco (1978) similarly concluded that the R.M.O. Mk I was the primary gauge in the Far East, Indonesia, New Guinea, Libya, and Near Eastern countries. Sevruk (1982) identified the Hellmann gauge (elevated at an average height of 1 m) as dominant in South America and Africa. In the absence of more reliable information, the gauge types suggested by Kurtyka, Unesco, and Sevruk were assigned.

Wind

As mentioned above, wind is the single largest cause of error in measuring precipitation and, therefore, its influence (κ_r and κ_s) must be estimated. To accomplish this, both wind data and reliable relationships between the wind data and the wind correction factors are required.

Long-term mean monthly wind-speed data were obtained for 733 terrestrial stations and 6972 oceanic grid boxes. The boxes have dimensions of 2° of latitude by 2° of longitude (Legates, 1987). Averaged wind data,

however, underrepresent the wind speed during precipitation and, thus, average wind speeds during precipitation events must be estimated. Sevruk (1979, 1982, 1986b) suggests that

$$w_p = L\,w \tag{4}$$

where w_p is the estimate of the wind speed during precipitation at anemometer height and w is the mean monthly wind speed. The empirical coefficient, L, depends on the form of precipitation and the number of days in a month with precipitation greater than 1 mm, M. Equations for estimating L were specified by Legates (1987) from tabulated values given by Sevruk (1979, 1982, 1986b) and they are used here:

While M is available for many stations, it was not encoded for most of the records evaluated here and, therefore, it had to be estimated. Using data from Spangler and Jenne (1984), Legates (1987) fit

$$M = 1{\cdot}09\,D_M\,[1{\cdot}0 - (1{\cdot}00425)^{P_a(T_a - 50{\cdot}94)/D_M}] \tag{5}$$

where D_M is the number of days in the month and T_a is the mean monthly air temperature in °C. This equation was more accurate than several other equations inasmuch as the mean absolute error in estimating M was less than 2 days. Equation (5), therefore, is used to estimate M.

With an estimate of w_p, wind speed during precipitation at the gauge orifice, w_{hp}, can be estimated from

$$w_{hp} = K_L\,m\,w_p \tag{6}$$

where K_L is the logarithmic coefficient of the wind speed profile and m is an exposure coefficient. Site-specific estimates of K_L are not available for most precipitation gauges. Legates (1987), therefore, estimated these two coefficients using Sevruk's (1979, 1982) guidelines and obtained

$$K_L = \frac{\ln(h_o/z)}{\ln(h_a/z)} \tag{7}$$

where h_o is the height of the gauge orifice, h_a is the height of the anemometer, and z is the roughness length. Sevruk (1979, 1982) determined that z (for most gauge sites) ranges from 0·005 to 0·03 m. Estimates of z were obtained by scaling roughness lengths of natural vegetation (Wilson and Henderson-Sellers, 1985; Henderson-Sellers *et al.*, 1986) to match this range (Legates, 1987). Although gauges are usually placed in clearings, the roughness length at the gauge site should be influenced by the roughness length of the surrounding vegetation.

Sevruk (1979, 1982) indicates that m should range from 0·6 for well-sheltered sites to 1·0 for unsheltered sites. Site-specific estimates of m were not available for most precipitation gauges, therefore, the natural vegetation was assumed to be the most significant gauge obstruction. Vegetation heights and coverage parameters were obtained from Willmott and Klink (1986) and an equation developed by Legates (1987) was used to estimate the exposure coefficient from these parameters.

It was necessary to select an equation for κ_r and κ_s that was applicable to a wide range of gauge types. One such equation is

$$\kappa = 1{\cdot}0 + A\,\mu^2 w_{hp}^2 \tag{8}$$

where the coefficient, A, depends on both the form of precipitation (r or s) and gauge type, and μ is the 'coefficient of transfer from the standard atmosphere to its actual condition' (Golubev, 1986, p. 138). Average values of A for both rain and snow have been tabulated for several different gauge types (Legates, 1987). For the Tretyakov gauge, A takes into account the effect of blowing snow (Sevruk, 1982). Here, estimates of κ_r and κ_s are based upon equation (8).

Other parameterizations of κ_r and κ_s were used when A had not been evaluated. Separate equations, all of which are functions of w_{hp}, were used for the Canadian snowgauge, the United States National Weather Service gauge, and the Swedish SHMI gauge (cf. Legates, 1987). Errors associated with estimating κ_r by these methods were generally small. Legates (1987), for instance, examined both standard and pit gauge data at 54 stations (Sevruk and Hamon, 1984) and reported a mean absolute error of less than 0·027. No systematic biases were observed.

Wetting losses

Wetting losses (ΔP_w and ΔP_{ws}) are comprised of moisture that adheres to the internal walls of the gauge during precipitation and during emptying. Sevruk (1973) estimates that wetting losses cause an underestimate in globally averaged precipitation of about 2·6 per cent. Wetting losses depend on (1) the design (material and geometry) of the collector, (2) the frequency of precipitation measurements, and (3) the form and frequency of precipitation. Gauge differences as well as the different forms of precipitation, therefore, should influence the estimation of wetting loss.

Following Sevruk (1979), wetting loss is estimated from

$$\Delta P_w = \bar{a} M \tag{9}$$

where the average wetting loss per precipitation event, $\bar{a}$, depends on both the form of precipitation and gauge type. As before, M is the number of precipitation days in the month. Values of $\bar{a}$ are taken from Sevruk (1979, 1982, 1985) whose compilation included most national precipitation gauges. In general, $\bar{a}$ varies little among gauges with the same orifice area and ranges from 0·02 to 0·30 mm per precipitation event.

Evaporation

Evaporation from the gauge (ΔP_{ev} and ΔP_{es}) typically accounts for a decrease in the measured precipitation of about 0·5 per cent (Sevruk and Hamon, 1984). Consistent with Sevruk (1984), evaporative loss is estimated by

$$\Delta P_e = i_e \tau_e M \tag{10}$$

where i_e is the intensity and τ_e is the duration of evaporation (the elaspsed time between the end of precipitation and its measurement). On average, τ_e is 0·5 or 0·25 when precipitation is measured once or twice daily, respectively. Standard observing practices for many countries are unknown (S. Unninayar, pers. comm., 1986), however, and so the average of these two values, 0·375, is used.

Procedures to estimate i_e are also not well known. It varies with the gauge type and form of precipitation. It has also been related to mean monthly wind speed, air temperature, and more frequently to the average monthly vapour pressure deficit. Estimates of i_e are obtained from a procedure that makes use of derived vapour pressure deficits (Legates, 1987). His estimates of average monthly vapour pressure deficit, using mean monthly air temperature and precipitation, are within 2 mbar of measurements. These data then can be used with equations to estimate i_e for eight different gauge types. Precision associated with these equations, fit coefficients of determination (r^2), ranges from 0·288 to 0·887.

Form of precipitation

It is relatively easy to determine the form of precipitation for daily or hourly totals, but not for long-term averages. Lauscher (1954), nevertheless, suggested that the proportion of monthly precipitation falling as snow (solid) may be estimated from

$$R = 0{\cdot}5 - 0{\cdot}05\, T_a \tag{11}$$

where T_a is the average monthly air temperature (°C). Legates (1987), however, found that a logistic curve gave a better fit to Lauscher's data, and he gives

$$R = \frac{1}{1 + 1{\cdot}61(1{\cdot}35)^{T_a}} \tag{12}$$

Equation (12) estimates R with a fit mean absolute error of less than 0·06. It is used here to partition mean monthly precipitation into solid and liquid components.

INTERPOLATION TO A HIGH-RESOLUTION GRID

Corrected station data and oceanic grid-point estimates were interpolated to a 0.5° of latitude by 0.5° of longitude lattice. An appropriate interpolation algorithm first had to be selected. It is especially important to

account for the sphericity of the earth when the spatial domain is the entire globe (Willmott *et al.*, 1985b). Legates (1987) evaluated several procedures and concluded that a spherical adaptation of Shepard's (1968, 1984) numerical approximation method (Willmott *et al.*, 1985b) was reliable. Several modifications were made to this algorithm and they are outlined in Legates and Willmott (1989). A more complete discussion is presented by Willmott *et al.* (1985b) and Legates (1987). Interpolations here are based on this procedure.

Numerical approximation methods give weighted averages as point estimates on a field. Legates and Willmott (1989) write Shepard's (1968) weight as

$$W_i = S_i^{\gamma}(1 + D_i) \tag{13}$$

where S_i is the distance component for station i and D_i is the directional component. Shepard (1968, 1984) and Willmott *et al.* (1985b) used a value of 2·0 for the exponent, γ. Legates (1987), however, estimated an optimal exponent of 0·75 for these precipitation data. Here, then, 0·75 is used.

GLOBAL PRECIPITATION

Annual mean

Mean annual precipitation is heaviest along the Inter-Tropical Convergence Zone (Figure 3). Intense surface heating and the confluence of the tropical easterlies result in annual precipitation rates that often exceed 8 mm day^{-1}. Heavy annual rainfall is especially apparent over large areas of the equatorial Pacific as well as over the rain forests of South America, Africa, and Asia. High precipitation rates also occur over the western sides of the continents in the upper mid-latitudes (marine West Coast climates) and over warm ocean currents. Warm currents increase both the buoyancy and moisture content of the air, as evidenced by increased precipitation rates over the Gulf Stream and Kuroshio currents, for instance. Monsoonal circulation substantially increases the annual means as well.

Descending air and clear skies associated with the poleward arm of the Hadley Cell help minimize precipitation in the hot desert regions. Archetypical desert regions include the Sahara, Gobi, Kalahari, Atacama, American south-west, and Australian Outback which, on average, receive less than 1 mm day^{-1} (Figure 3). Coastal upwelling reduces sea-surface temperatures, which tends to extend these deserts over adjacent oceans. Precipitation is also light in polar regions (cold deserts), largely owing to the diminished moisture capacity of cold air.

Mountainous regions (e.g. the Rockies and the Alps) exhibit average precipitation rates that vary dramatically over small spatial scales (Figure 3), while average precipitation is relatively homogeneous over level terrain (e.g. over the Australian Outback, the Tibetan Plateau, and central North America). The leeward sides of mountains, of course, are much drier than windward sides owing to the rain-shadow effect. These patterns are evident especially in the Rockies, the Andes, and the Himalayas.

Average precipitation patterns associated with the Walker Cell circulation can be seen in the South Pacific Ocean between the Equator and 30°S (Figure 3). Heavy precipitation is apparent in the western South Pacific, while light rainfall can be seen off the western coast of South America. Heavier precipitation occurs over eastern Australia and the western South Pacific than over Peru and the eastern South Pacific.

Average intra-annual variation

Intra-annual variation in precipitation was evaluated by computing the temporal standard deviation of the 12 mean monthly values associated with each grid point. Standard deviation is, in general, directly correlated with annual mean precipitation (Figures 3 and 4). Temporal standard deviations, for instance, are less than 0·6 mm day^{-1} for most areas receiving an average of less than 2·0 mm day^{-1}. Areas of heavy precipitation, by contrast, often have standard deviations that exceed 2·4 mm day^{-1}. High variability also characterizes the monsoon regions of the Far East, northern Australia, and equatorial Africa.

Moderating influences that the oceans exert on precipitation are evident particularly in the Southern Hemisphere. Precipitation variability is especially damped over the extensive southern ocean. Intermittent

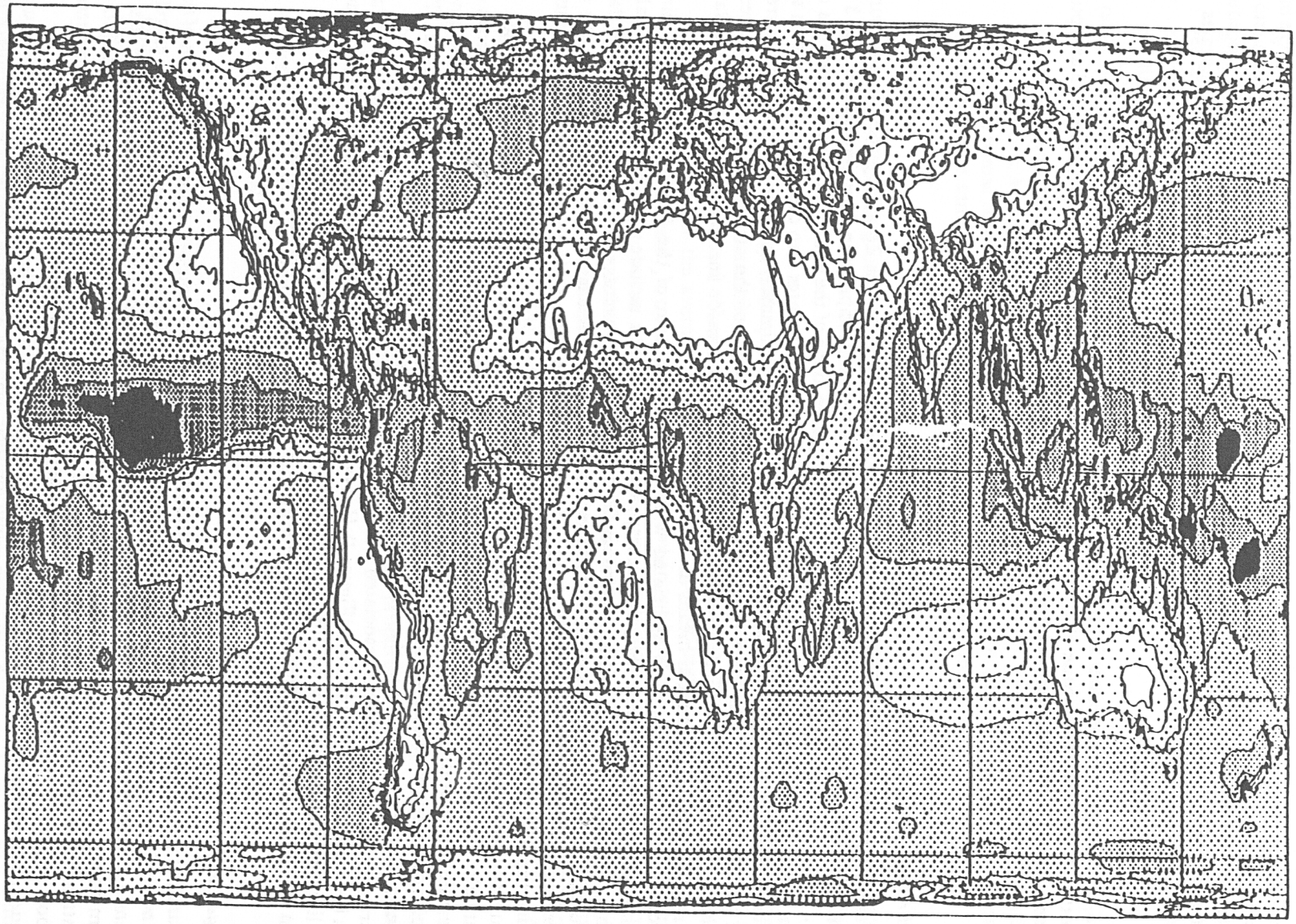

Figure 3. Mean annual precipitation. Isohyets are 0·5, 1·0, 2·0, 4·0, 8·0, and 12·0 mm day^{-1}. Areas receiving less than 0·5 mm day^{-1} are unshaded while areas receiving more than 12·0 mm day^{-1} are completely blackened

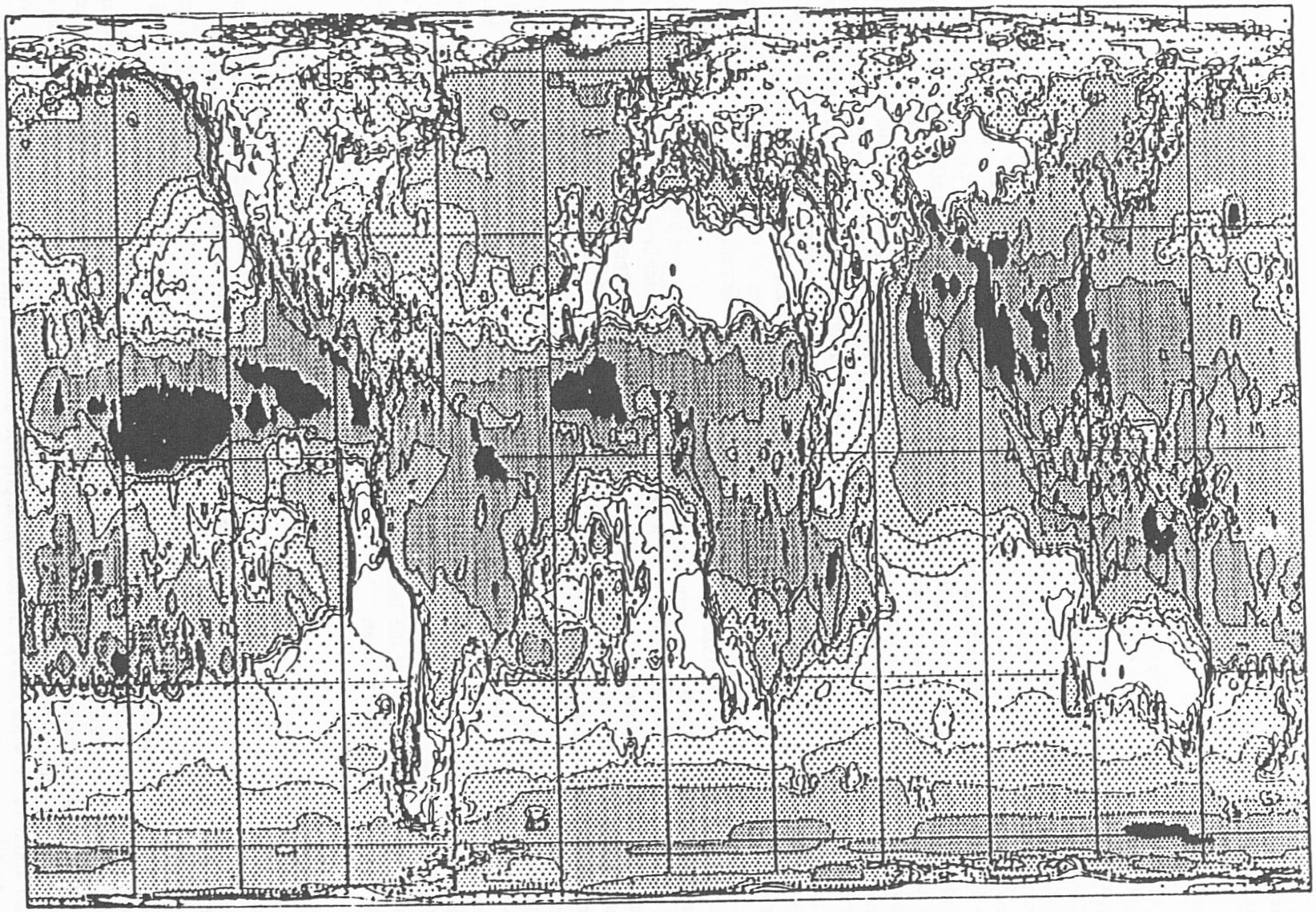

Figure 4. Temporal standard deviation of mean monthly precipitation. Isohyets are 0·3, 0·6, 0·9, 1·2, 2·4, and 4·8 mm day^{-1}. Areas with standard deviations less than 0·3 mm day^{-1} are unshaded while areas with standard deviations greater than 4·8 mm day^{-1} are completely blackened

land areas, even small islands, typically increase the seasonal variation and they stand out (e.g. the Falkland Islands).

Seasonality

Using the same 4° of latitude by 5° of longitude lattice (in projected coordinates) discussed by Legates and Willmott (1989), precipitation was decomposed into the annual mean (Figure 3) and the first two annual harmonics (see Figures 6 and 7). The length of a mapped arrow indicates the amplitude of the harmonic (note the logarithmic scale) while the direction locates (approximately) the occurrence in time of the maximum (or maxima). A complete discussion of harmonic analysis is given by Rayner (1971).

More than 85 per cent of the variation in mean monthly precipitation is accounted for by the first two harmonics. Explanation of the seasonal variation (r^2) over the continents is greater than over the oceans (Figure 5). Nevertheless, the unexplained variation is not more than 1.0 mm day^{-1} for any grid point.

Maximum precipitation occurs during the mid- to late high-sun season over much of the subtropics (Figure 6). Very heavy rain occurs in July and August just north of the Equator and in January and February south of the Equator. Monsoonal rains reach their peak between late July and early September (in the Far East) while, in northern Australia, the height of the wet season occurs about February. Precipitation between 5°N and 5°S, particularly in the Atlantic Ocean, has a March or April maximum, which coincides with the maximum surface air temperature for this region (Legates and Willmott, 1989). Equatorial precipitation in the Indian Ocean is nearly 6 months out of phase with the Atlantic: the maximum occurs in September and early October. Low-latitude oceanic precipitation, especially in the subtropics of the Northern Hemisphere, is delayed for one or two months relative to terrestrial precipitation and this is coincident with the occurrence of the maximum surface air temperature.

First-harmonic amplitudes are much smaller in mid-latitudes owing to lower precipitation rates. Oceanic maxima occur in December and January, in both hemispheres, and their amplitudes tend to be greater than terrestrial amplitudes (at comparable latitudes). Continental interiors generally exhibit a wet-summer/dry-winter cycle while dry-summer climates are clearly distinguishable (e.g. the California coast, the Mediterranean region, coastal western Australia, and the Chilean coast).

Second harmonics explained only about one-third as much variance as the first (Figure 7). Large amplitudes are evident in the equatorial Atlantic and Pacific Oceans where double-maxima occur owing to the semi-annual passage of the Inter-Tropical Convergence Zone. Over the Atlantic, the maximum phase corresponds well with low solar zenith angles but it is delayed in the Pacific. Oceanic phases in the tropics, once again, are correlated with the surface air temperature cycle (Legates and Willmott, 1989). Large amplitudes also are observed over northern India and they are nearly in phase with the first harmonic. This attests to the marked seasonality of the Indian monsoon. Amplitudes in mid-latitudes are generally much smaller, except over the southern ocean.

CONCLUDING REMARKS

A relatively dense global network of long-term average monthly precipitation records has been compiled from existing sources. Gauge measurement errors, owing to the effects of the wind, wetting on the internal walls of the gauge, and evaporation from the gauge, have been estimated and removed from the records. These irregularly distributed records were then interpolated to a 0.5° of latitude by 0.5° of longitude grid using a spherically based interpolation algorithm.

Precipitation is heaviest in the low latitudes and generally decreases toward the poles. Average intra-annual variability is positively correlated with average annual precipitation. Harmonic analysis depicted the marked effect that the seasonal migration of the Inter-Tropical Convergence Zone has on the timing of precipitation in equatorial regions. A double-maxima regime characterizes the seasonal precipitation cycle between the Equator and about 10°N, while heavy unimodal precipitation dominates the subtropics north and south of this region. Mid-latitude precipitation is generally less than in the tropics and is usually heavier over the oceans than over land.

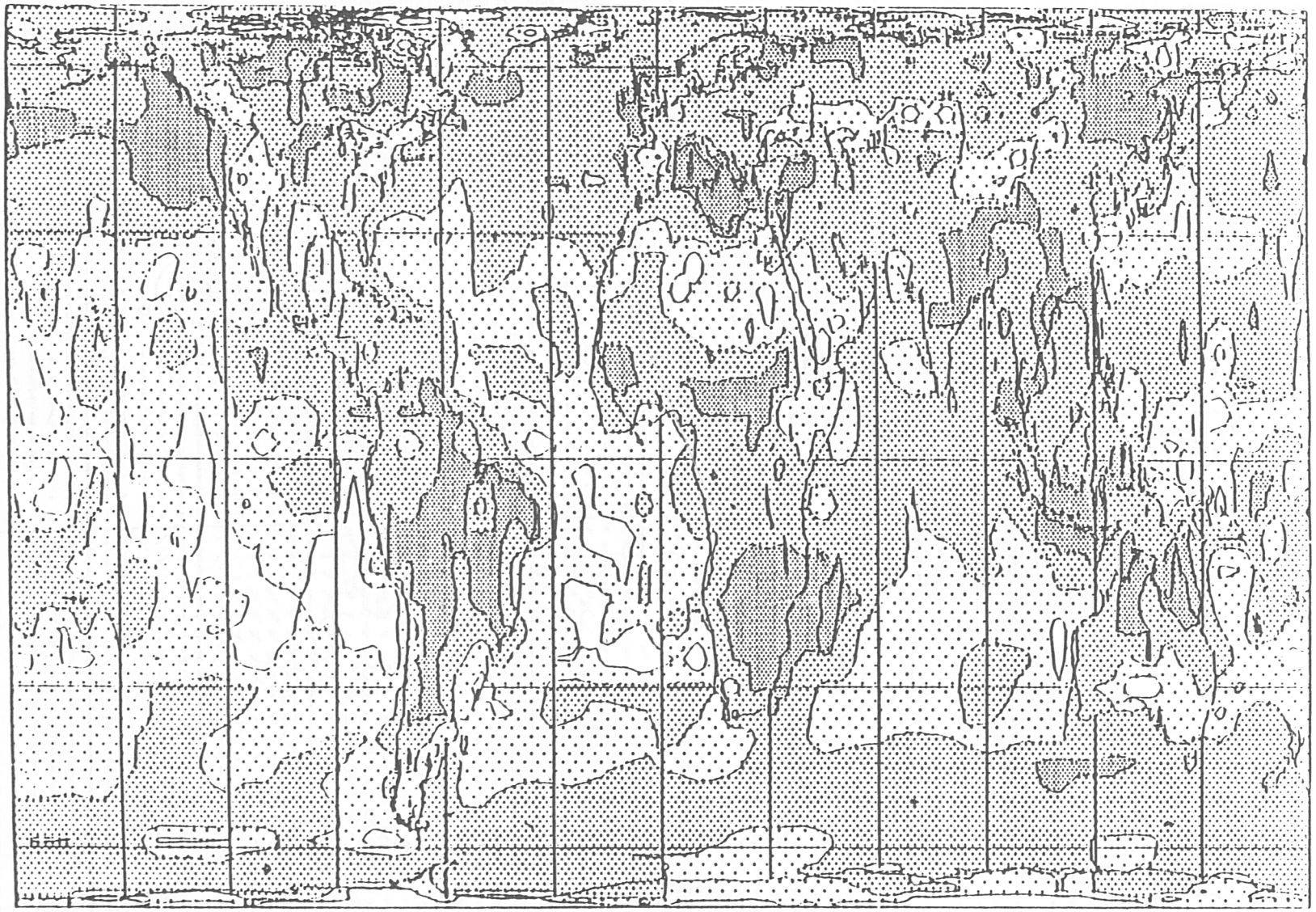

Figure 5. Percentage of the temporal variance explained in mean monthly precipitation (r^2) by the first two harmonics. Isolines are 50·0, 80·0, and 95·0 per cent. Areas where r^2 is le than 50·0 per cent are unshaded while areas where r^2 is greater than 95·0 per cent are dark grey (e.g. south-eastern Africa)

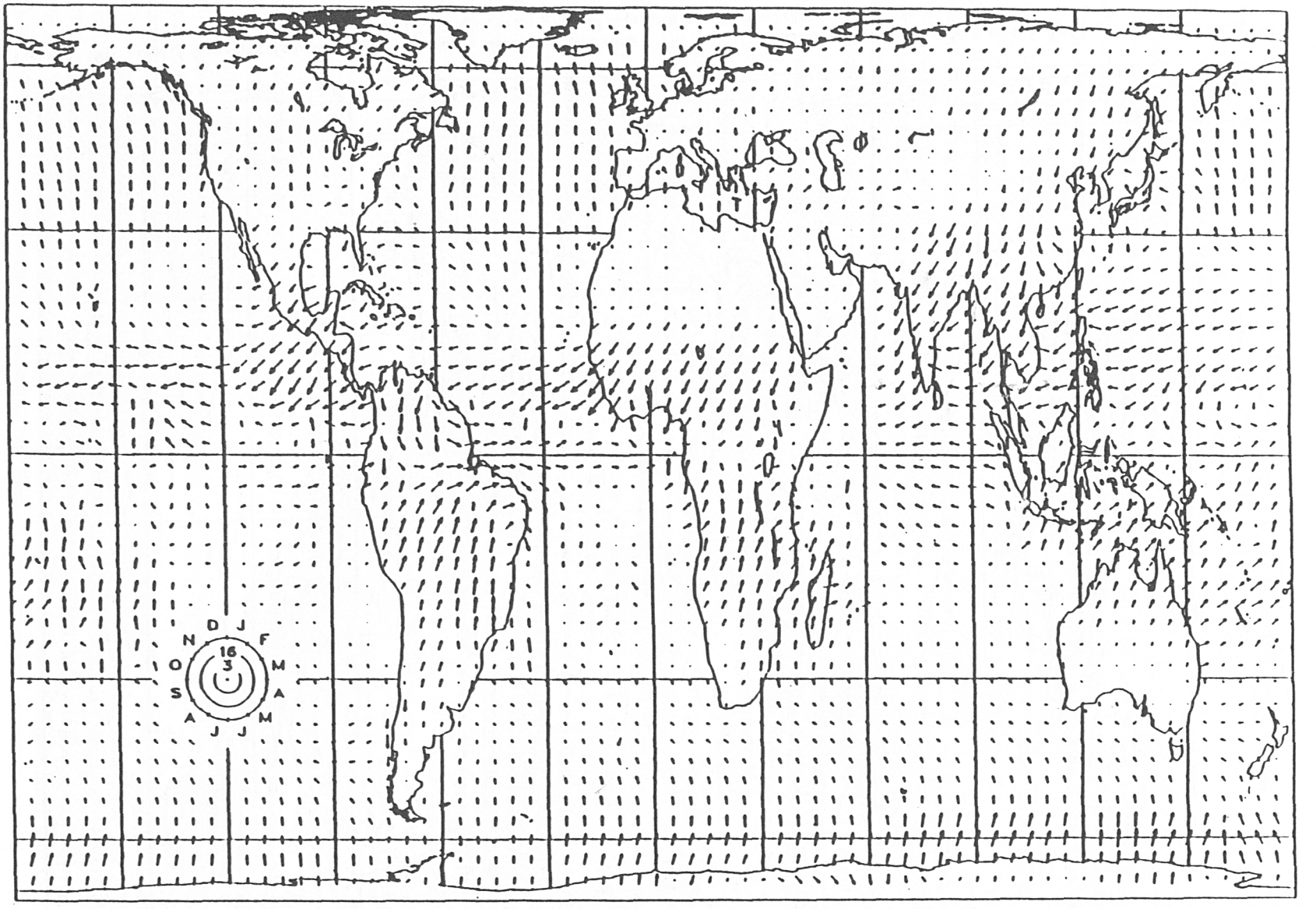

Figure 6. First temporal harmonic of average monthly precipitation (mm day^{-1}). Amplitude is proportional to the length of the arrow (measured from the centre of the scale/dial) while the occurrence of the maximum in time is given by its direction (edge of the scale/dial)

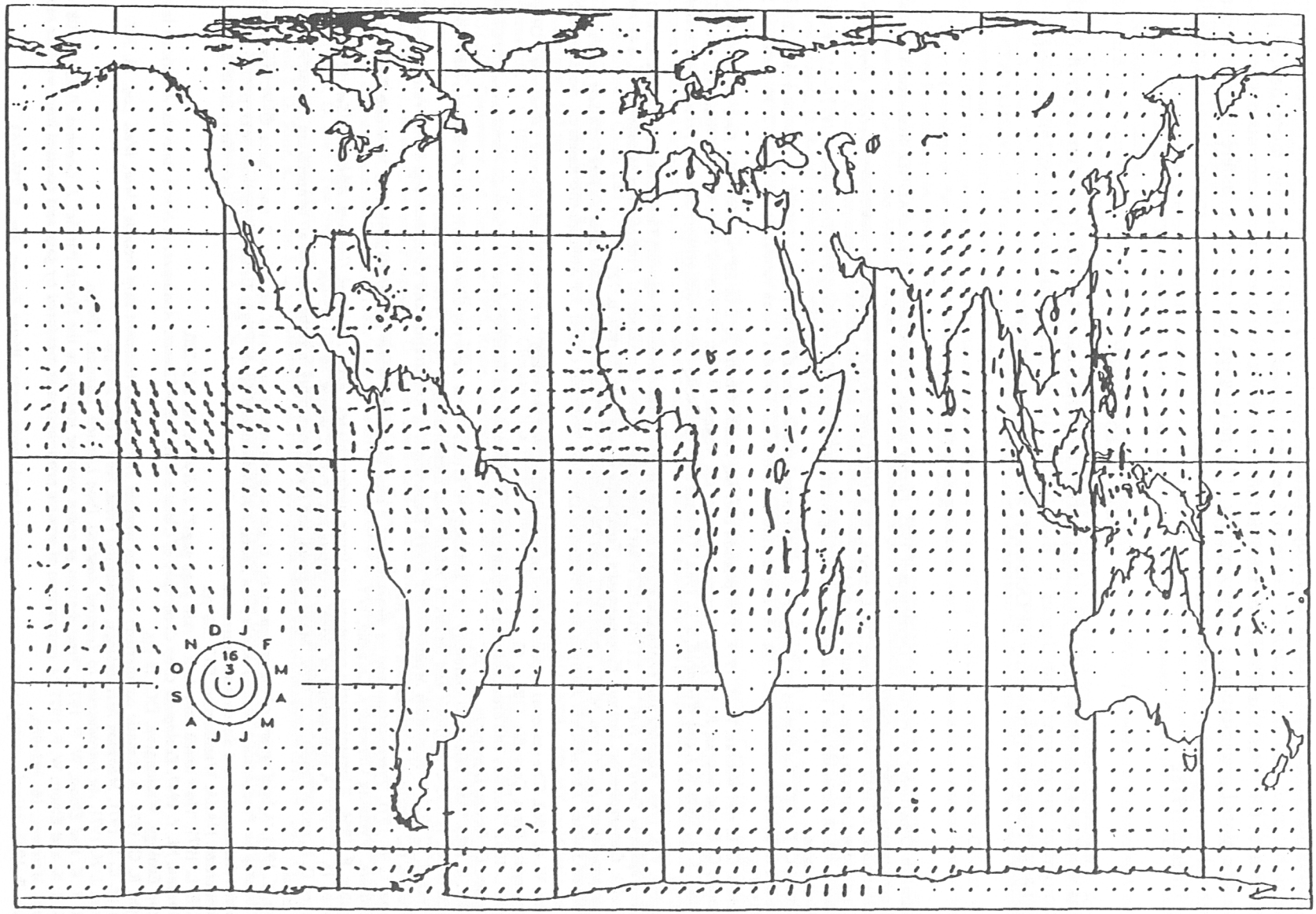

Figure 7. Second temporal harmonic of average monthly precipitation (mm day^{-1}). Amplitude is proportional to the length of the arrow (measured from the centre of the scale/dial) while the occurrence of the maxima in time is given by its orientations (edge of the scale/dial)

Raingauge errors tend to be directly proportional to total precipitation and amount to nearly 11 per cent of the global catch. An undercatch of less than 5 per cent occurs in the tropics, while more than 40 per cent is common at the poles: illustrating the sizeable influence of wind on gauge measurements of snowfall. Annual average global precipitation is approximately 1123 mm (gauge corrections considered), which is consistent with values suggested by Kessler (1985). It is also within 7 mm of the gauge-corrected global estimate obtained by Unesco (1978).

ACKNOWLEDGEMENTS

This work was supported by the National Aeronautics and Space Administration under grant NAG 5-853. Thoughtful suggestions from James E. Burt (University of Wisconsin) and cartographic assistance from Johannes Feddema (University of Delaware) are greatly appreciated.

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Woodruff, S. D., Slutz, R. J., Jenne, R. L. and Steurer, P. M. 1987. 'A comprehensive ocean–atmosphere data set', *Bull. Am. Meteorol. Soc.*, 68, 1239–1250.

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- J -

REVISED FNOC ELEVATION, TERRAIN, AND SURFACE CHARACTERISTICS

CITATION: Kineman, J. (ed.), 1985. Revised FNOC Global Elevation, Terrain, and Surface Characteristics. Digital Data. NOAA/NGDC/WDC-A, Boulder, Colorado. 28 MB.

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J. REVISED FNOC ELEVATION, TERRAIN, AND SURFACE CHARACTERISTICS

DATE: 1985

SOURCES:

Digitized from available maps and reprocessed.

(1) Leo Clark
USN FNOC
Code 42
Monterey, CA 93943

(2) Dennis Joeseph
NCAR
P.O. Box 3000
Boulder, CO 80303-3000

(3) John Kineman
NOAA/NGDC
Boulder, CO

CONTRIBUTOR:

NOAA/NESDIS/NGDC
Boulder, CO

DATA CENTER: NGDC/WDC-A

GEOGRAPHIC SAMPLING:

10-min grid

(1) Mode, maximum, minimum within cell (Elevation)
(2) Percent cover within cell (Urban and Water Cover)
(3) Characteristic class (Ocean Mask)

COVERAGE: Global

PROJECTION: Lat/lon

TIME SAMPLING: Multiple year composite before 1980

REFERENCES:

Cuming, Michael J. and Barbara A. Hawkins, 1981. "TERDAT: The FNOC System for Terrain Data Extraction and Processing." Technical Report MII Project M-254 (Second Edition). Prepared for Fleet Numerical Oceanography Center (Monterey, CA). Published by Meteorology International Incorporated.

(continued on the next page)

FILE NAMES:

AFMAX	Maximum elevation (meters)
AFMIN	Minimum elevation (meters)
AFMODE	Modal elevation (meters)
AFURBAN	Percent urban cover
AFWATER	Percent water
AFOCEAN	Ocean mask

REVISED FNOC MAXIMUM ELEVATION DOCUMENTATION FILE

File Name: AFMAX.DOC

```
image title : Revised FNOC Maximum Elevation (meters)
data type   : integer
file type   : binary
rows        : 438
columns     : 480
minimum     :  -1.2000000000E+02
maximum     :   5.8800000000E+03
cell x      :   1.6666600000E-01
cell y      :   1.6666600000E-01
legend      : 15
category  1 :  255 to  629
category  2 :  630 to 1004
category  3 : 1005 to 1379
category  4 : 1380 to 1754
category  5 : 1755 to 2129
category  6 : 2130 to 2504
category  7 : 2505 to 2879
category  8 : 2880 to 3254
category  9 : 3255 to 3629
category 10 : 3630 to 4004
category 11 : 4005 to 4379
category 12 : 4380 to 4754
category 13 : 4755 to 5129
category 14 : 5130 to 5504
category 15 : 5505 to 5880

{category 0 : -120 to 254}
```

[This legend is only appropriate for displays which reclass (contrast stretch) the continuous values into 16 classes.]

REVISED FNOC MINIMUM ELEVATION DOCUMENTATION FILE

File Name: AFMIN.DOC

```
image title : Revised FNOC Minimum Elevation (meters)
data type   : integer
file type   : binary
rows        : 438
columns     : 480
minimum     :  -1.5000000000E+02
maximum     :   3.6600000000E+03
cell x      :   1.6666600000E-01
cell y      :   1.6666600000E-01
legend      : 15
category  1 :   88 to  325
category  2 :  326 to  563
category  3 :  564 to  801
category  4 :  802 to 1039
category  5 : 1040 to 1278
category  6 : 1279 to 1516
category  7 : 1517 to 1754
category  8 : 1755 to 1992
category  9 : 1993 to 2230
category 10 : 2231 to 2469
category 11 : 2470 to 2707
category 12 : 2708 to 2945
category 13 : 2946 to 3183
category 14 : 3184 to 3421
category 15 : 3422 to 3660

{category 0 : -150 to 87}
```

[This legend is only appropriate for displays which reclass (contrast stretch) the continuous values into 16 classes.]

REVISED FNOC MODAL ELEVATION DOCUMENTATION FILE

File Name: AFMODE.DOC

```
image title : Revised FNOC Modal Elevation (meters)
data type   : integer
file type   : binary
rows        : 438
columns     : 480
minimum     :  -1.2000000000E+02
maximum     :   3.9600000000E+03
cell x      :   1.6666666000E-01
cell y      :   1.6666666000E-01
legend      : 15
category  1 : 135 to 389
category  2 : 390 to 644
category  3 : 645 to 899
category  4 : 900 to 1154
category  5 : 1155 to 1409
category  6 : 1410 to 1664
category  7 : 1665 to 1919
category  8 : 1920 to 2174
category  9 : 2175 to 2429
category 10 : 2430 to 2684
category 11 : 2685 to 2939
category 12 : 2940 to 3194
category 13 : 3195 to 3449
category 14 : 3450 to 3704
category 15 : 3705 to 3960

{category 0 : -120 to 134}
```

[This legend is only appropriate for displays which reclass (contrast stretch) the continuous values into 16 classes.]

REVISED FNOC PERCENT URBAN COVER DOCUMENTATION FILE

File Name: AFURBAN.DOC

```
image title : Revised FNOC Percent Urban Cover
data type   : byte
file type   : binary
rows        : 438
columns     : 480
minimum     :   0.0000000000E+00
maximum     :   6.0000000000E+01
cell x      :   1.6666600000E-01
cell y      :   1.6666600000E-01
legend      :  60
category  1 :  1 %
category  2 :  2 %
category  3 :  3 %
category  4 :  4 %
category  5 :  5 %
category  6 :  6 %
category  7 :  7 %
category  8 :  8 %
category  9 :  9 %
category 10 : 10 %
category 11 : 11 %
category 12 : 12 %
category 13 : 13 %
category 14 : 14 %
category 15 : 15 %
category 16 : 16 %
category 17 : 17 %
category 18 : 18 %
category 19 : 19 %
category 20 : 20 %
category 21 : 21 %
category 22 : 22 %
category 23 : 23 %
category 24 : 24 %
category 25 : 25 %
category 26 : 26 %
category 27 : 27 %
category 28 : 28 %
category 29 : 29 %
category 30 : 30 %
category 31 : 31 %
category 32 : 32 %
category 33 : 33 %
category 34 : 34 %
category 35 : 35 %
category 36 : 36 %
category 37 : 37 %
category 38 : 38 %
category 39 : 39 %
category 40 : 40 %
```

```
category 41 : 41 %
category 42 : 42 %
category 43 : 43 %
category 44 : 44 %
category 45 : 45 %
category 46 : 46 %
category 47 : 47 %
category 48 : 48 %
category 49 : 49 %
category 50 : 50 %
category 51 : 51 %
category 52 : 52 %
category 53 : 53 %
category 54 : 54 %
category 55 : 55 %
category 56 : 56 %
category 57 : 57 %
category 58 : 58 %
category 59 : 59 %
category 60 : 60 %

{category 0 : 0 %}
```

[This legend is appropriate for display of the individual classes (i.e. without rescaling).]

REVISED FNOC PERCENT WATER DOCUMENTATION FILE

File Name: AFWATER.DOC

```
image title : Revised FNOC Percent Water Cover
data type   : integer
file type   : binary
rows        : 438
columns     : 480
minimum     :   0.0000000000E+00
maximum     :   1.0000000000E+02
cell x      :   1.6666600000E-01
cell y      :   1.6666600000E-01
legend      : 100
category  1 :   1 %
category  2 :   2 %
category  3 :   3 %
category  4 :   4 %
category  5 :   5 %
category  6 :   6 %
category  7 :   7 %
category  8 :   8 %
category  9 :   9 %
category 10 :  10 %
category 11 :  11 %
category 12 :  12 %
category 13 :  13 %
category 14 :  14 %
category 15 :  15 %
category 16 :  16 %
category 17 :  17 %
category 18 :  18 %
category 19 :  19 %
category 20 :  20 %
category 21 :  21 %
category 22 :  22 %
category 23 :  23 %
category 24 :  24 %
category 25 :  25 %
category 26 :  26 %
category 27 :  27 %
category 28 :  28 %
category 29 :  29 %
category 30 :  30 %
category 31 :  31 %
category 32 :  32 %
category 33 :  33 %
category 34 :  34 %
category 35 :  35 %
category 36 :  36 %
category 37 :  37 %
category 38 :  38 %
category 39 :  39 %
category 40 :  40 %
category 41 :  41 %
category 42 :  42 %
category 43 :  43 %
category 44 :  44 %
category 45 :  45 %
```

```
category 46 :  46 %

category 47 :  47 %
category 48 :  48 %
category 49 :  49 %
category 50 :  50 %
category 51 :  51 %
category 52 :  52 %
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category 54 :  54 %
category 55 :  55 %
category 56 :  56 %
category 57 :  57 %
category 58 :  58 %
category 59 :  59 %
category 60 :  60 %
category 61 :  61 %
category 62 :  62 %
category 63 :  63 %
category 64 :  64 %
category 65 :  65 %
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category 67 :  67 %
category 68 :  68 %
category 69 :  69 %
category 70 :  70 %
category 71 :  71 %
category 72 :  72 %
category 73 :  73 %
category 74 :  74 %
category 75 :  75 %
category 76 :  76 %
category 77 :  77 %
category 78 :  78 %
category 79 :  79 %
category 80 :  80 %
category 81 :  81 %
category 82 :  82 %
category 83 :  83 %
category 84 :  84 %
category 85 :  85 %
category 86 :  86 %
category 87 :  87 %
category 88 :  88 %
category 89 :  89 %
category 90 :  90 %
category 91 :  91 %
category 92 :  92 %
category 93 :  93 %
category 94 :  94 %
category 95 :  95 %
category 96 :  96 %
category 97 :  97 %
category 98 :  98 %
category 99 :  99 %
category100 : 100 %

{category 0 : 0 %}

[This legend is appropriate for display of the individual classes
 (i.e. without rescaling).]
```

OCEAN MASK
DOCUMENTATION FILE

File Name: AFOCEAN.DOC

```
image title : Ocean mask (produced from Revised FNOC data)
data type   : byte
file type   : binary
rows        : 438
columns     : 480
minimum     :  0.0000000000E+00
maximum     :  1.0000000000E+00
cell x      :  1.6666600000E-01
cell y      :  1.6666600000E-01
legend      : 1
category  1 : Land

{category 0 : Ocean/Water}


[This legend is appropriate for display of the individual classes
 (i.e. without rescaling).]
```

The Navy Fleet Numerical Oceanography Center/(NFNOC) began creating the original 10-minute terrain data set in the mid 1960's. Work extended into the early 1970's. The main sources for the data were the U.S. Department of Defense Operational Navigation Charts (ONC), scale 1:1,000,000. For certain regions ONC charts were not available; for such areas selected charts from the Jet Navigation charts and World Aeronautical Charts were used. The charts were hand read out to forms by employees, and then read by optical character reader to tape. The values were estimates from contour lines. Isometric graphs were made for quality control, checking terrain features. Later, other errors were corrected by the National Center for Atmospheric Research in Boulder, Colorado.

NFNOC hopes in the future to update the data set using satellite data. This update will not be available to the general public for several years, as much of the new information will be defense-classified. For further information on the history and original sources of the data, you are welcome to contact Leo Clark, NFNOC, Code 42, Monterey, California, 93943.

3/7/85

SOLID EARTH DIVISION
NOAA/NGDC E/GC-1
325 Broadway
Boulder, CO 80303

Documentation of the SED/NGDC format of the Navy 10-minute topographic data

The Navy 10-minute topography data was reformatted at NOAA into a 40 character/record ASCII format. All data fields were retained, and all data fields were quality checked for reasonable values (ie., within documented limits, etc.). The checks that were performed, and the resulting errors are listed in the data documentation files ("SUMMARY" and "CHKERRS"). Below is a listing of the error check definitions:

```
MSG  (1) = 'RANGE EXCLUDES MODE'
MSG  (2) = 'SEA HEIGHT AND TYPE MISMATCH'
MSG  (3) = 'RIDGE AZIMUTH OUT OF LIMIT'
MSG  (4) = 'NUMBER OF RIDGES OUT OF LIMIT'
MSG  (5) = 'SECONDARY TYPE UNDEFINED'
MSG  (6) = 'PRIMARY TYPE UNDEFINED'
MSG  (7) = '%WATER OUT OF LIMIT'
MSG  (8) = '%URBAN OUT OF LIMIT'
MSG  (9) = 'MAX/MIN OUT OF LIMIT'
MSG (10) = 'SEA TYPE-CODE DISCREPANCY
```

The NOAA/NGDC/SEGD ASCII format, in Fortran, is:

```
(F7.2,1X,F6.2,1X,I3,1X,2I3,1X,4I2,2I3)
```

The field elements are:

Format	Field contents
F7.2	Longitude (+/- 180)
X	
F6.2	Latitude (+/- 90)
X	
I3	Modal heights in hundreds of feet
X	
I3	Maximum height in hundreds of feet
I3	Minimum hight in hundreds of feet
X	
I2	Number of significant ridges
I2	Direction of ridges in 10's of degrees (0-18)
I2	Primary surface type code
I2	Secondary surface type code
I3	Percentage of surface covered by water
I3	Percentage of surface covered by urban development

Refer to the original binary NCAR/NAVY documentation for details about the data fields, and the data itself.

Note: Documentation of data contents and original format:

Data Format for
Global 10 Minute Elevation Data
from the U.S. Navy
Dennis Joseph
NCAR, Data Support Section
April 1992, update Dec. 1984

Global elevation data at a resolution of 10 minutes was prepared by the Navy Fleet Numerical Oceanography Center at Monterey. For each 10 x 10 minute area, the set includes modal elevation, minimum elevation, maximum elevation. orientation of ridges, terrain characteristics, and urban development. This is archived by the NCAR Data Support Section (DSS) in a packed binary format. Parameters available are identifical to those described in documents by Meteorological International, Inc. and the Fleet Numerical Oceanography Center, but the DSS has made some changes to the set. The data is now organized somewhat differently with each tape block containing all data for a 5 x 5 degree area. The data format has been changed and a few coding changes were made for consistency with the format. The information content of the original set has been preserved entirely.

The tape contains 2592 tape blocks, each 962 60-bit words in length. A single block contains all data within a 5 x 5 degree square. Each block is labelled with the latitude and longitude of its southwest corner. The tape is ordered beginning with the block for 90s,0 and moving eastward for 72 blocks then the next 72 blocks beginning at 85s,0 etc. Within a tape block there are data values for 900 10'x10' squares. These values apply to a 30x30 array where the data points are ordered beginning in the southwest corner of the box and scanning eastward then the next row 10 minutes north, and ends with the data point for the northeast corner of the box (see figures below).

Each tape block has the following format:

Bits	Meaning
1-9	Latitude of SW corner of box where (0=90s,5=85s,90=equator,175=85n,180=90n,etc.)
10-18	Longitude of SW corner of box in degrees east.
19-57618	900 64-bit groups containing data for each point (see below)
57619-57660	Unused.
57661-57720	60-bit chucksum of previous 961 60-bit words (can be ignored bymost users).

Each 64 bit group has the following format:

Bits	Code	Description
1-6	RR	Estimate of the number of significant ridges
7-12	DD	General direction of ridges
13-21	HMO	Terrain elevation - Modal height

22-30	HHI	Terrain elevation - Maximum height
31-39	NLO	Terrain elevation - Minimum height
40-45	C1	Primary characteristics of terrain
46-50	C2	Secondary characteristics of the terrain
51-57	WWW	Percentage of water surface
58-64	URB	Percentage of urban development

Significant Ridges -

Subjective estimate of number of ridges and their orientation in tens of degrees (00-18)

Terrain Elevation -

Elevation in feet = (packed value - 100)*100.
Note that zero values do not necessarily indicate ocean surface. Use primary terrain characteristic to identify ocean.
Inland water bodies are coded with the elevation of the water surface (except in minimum field where it is always zero).

Characteristics of the terrain -

0- salt or lake bed
1- flat or relatively flat
2- desert (or, for high latitudes, glaciers or permanent ice)
3- marsh
4- lake country or atoll
5- major valleys or river beds
6- isolated mountains, ridge or peak
7- low mountains or hills
8- average mountains
9- extremely rugged mountains

62- ocean (identified in primary only).

Percentage of water -

For ocean areas at sea level the value is 100, for all other areas the range is 00 to 99 (large lakes or inland seas will not be coded as 100).

Percentage of Urban Development -

Not updated (reflects highly subjective judgments from the maps used).

General Information

The model terrain height has been contoured at NCAR, and major problems identified in these plots have been corrected by the Navy. Distribution summaries of all parameters indicate that there are still some invalid elevation values and unexplained code values, especially in the terrain characteristics field. As of this date no further information is available on

these problems. Occasional occurrences of full range values (all bits on) are assumed to indicate missing data.

The data distribution summaries showed a strong tendency for elevation values of cluster around multiples of 500 feet. This is probably due to the contour intervals in the original maps or to some other characteristics in the method of reading map values.

The true resolution of the data is reduced to 20 minutes poleward of 70 degrees latitude, but data values are still present for each 10 minute square. More information on the original data format, the sources of the data, the methods of reading the data, and the routines designed for the Navy to read the original format is available in documentation by the Fleet Numerical Oceanography Center and Meteorology International, Inc. (refer to address mentioned previously on page 4.)

General Information Update - Dec. 1984

Various users have noted a large number of bad data points in the minimum elevations. A few bad points in the modal and maximum elevations have also been identified. An attempt has been made to remove these bad points and replace them with estimated values. The minimum values from a previous edition of the data were found to have many fewer problems and these values were used for all minimum elevations north of 30 South. Checks for unreasonable values and gradients were run and comparisons of min, mode, and max were made. The results of these tests were manually inspected and where estimates seemed better than the original values, they were inserted in the set. checks were run on the minimum, modal, and maximum elevation only. No checks were run on the other parameters.

There are most likely still some erroneous values in the set, but most of the totally unreasonable values have been removed. Note that the minimum elevations are coded as zero for all water surfaces regardless of the true elevation of the water surface (even when this surface is below sea level). In some areas the elevation values are constant over one degree areas indicating that the resolution is not truly 10 minute in those areas. In general, the modal elevations seem to be more reliable than the minimum or maximum.

This corrected set will be a=the primary archive set, but the uncorrected earlier versions are available on request.

Roughness Computations

Stephano Tibaldi, European Center for Medium range Weather Forecasting, has used those elevations to compute estimates of surface roughness. His method for computing roughness length (Z) over a suer-defined area containing multiple 10′ squares is given on the following page. Note that his relative maximum are determined by examining the 8 surrounding squares. When looking at data which is poleward of 70 degrees, use every other point to compensate for the true resolution of 20′.

Formula to compute the roughness length Z_o:

$$Z_o = \sqrt{\frac{N}{F}\left(\sum p_i \bar{h}_i^{\,2} - \left(\sum p_i h_i\right)^2\right)} + \sum \sqrt{\frac{n_i}{f_i}}\, p_i \frac{(\bar{h}_i - h_i^{\min})(h_i^{\max} - \bar{h}_i)}{4}$$

where:

N	= number of relative $\bar{h}_i$ maximum in the user-defined grid square
F	= surface area of the user-defined grid square
n_i	= number of significant ridges in the 10' grid square
$\bar{h}_i$	= mean height in the 10' grid square
$h_i^{\max}$	= maximum height in the 10' grid Square
$h_i^{\min}$	= minimum height in the 10' grid square
f_i	= surface area of the 10' grid square
p_i	= proportion of the user-defined grid square occupied by the ith 10' grid square

Notes on the FNWC Terrain Data Set
Navy 10′ Global Elevation Values
27 January 1981
Dennis Joseph
NCAR

Documentation by Meteorology Internationa, Inc. and Fleet Numerical Weather central describes in detail the format and content of the elevation data tape. The actual layout of tape blocks was not described in these documents, and this note explains this layout and make a few other observations about the data. On the FNWC system, long logical tape records are segmented into shorter tape blocks. Since each block contains an integral number of the 96-bit segments, this format has been maintained as a simple way of avoiding excessively long tape blocks. The only change made at NCAR is that type labels have been removed so that the tape contains only one file.

Each 10 degree square of data consists of one 96-bit identifier segment followed by 3600 96-bit data point segments. Each square is recorded in 12 consecutive tape blocks. The first 11 bolocks are 512 60-bit words in length and each contains 320 96-bit segments. The 12th block is 130 60-bit words in length and contains 81 96-bit segments. There are 24 unused bits at the end of the 12th block. There is one 12-block group for each 10 degree square of the globe. Thus, the tape contains 648 groups for a total of 7776 blocks.

Users should note carefully the order of the elevation values. The 10 degree squares are organized with longitude varying fastest and sequential squares moving westward. The hemispheres are separate, NH first, and each is organized equator to pole. The labelling conventions have resulted in some confusion as to where values apply, especially in the Southern Hemisphere. data is labelled with one degree labels, but it is not really organized by one degree squares. The one degree box has no effect on the organization in hte NH, but does result in unusual ordering or the data in the SH.

In the Northern Hemisphere, ten degree squares and one degree squares are labelled with the lat-lon of the SW corner. Within 10 degree squars, the 10′ data values are organized with longitude varying fastest, but sequential values move eastward. Latitude values move poleward. The Meteology International document has diagrams showing this organization on pages 7 and 9.

In the Southern Hemisphere, ten degree squares are labelled with the lat-lon of the NW corner and the one degree squares are labelled with the lat-lon of the NE corner. This results in a column of one degree points which are not within the ten degree square in which they appear on the tape. While one degree values scan eastward, the ten minute values within each one degree segment actually scan westward. The following diagrams show the data layout within ten degree squares for each hemisphere.

We hope to be able to reorganize the data in the near future so that all data will scan in the same sense.

****

THE FNWC TERRAIN DATA SET

1. Terrain elevations and other parameters have been extracted from certain U.S. aeronautical charts in 10 minute latitude/longitude scale over the globe. Data points are contained on magnetic tape in 96 bit segments. The parameter details are:

LAT latitude - 0 through 89 degrees, N/S; SHemi Lat expressed 777 complement

LON longitude - 1 through 360 degrees west (e.g. 110 deg E=250 deg W)

NN 10 minute square number within a 1 degree L/L square

Northern Hemisphere

05	15	25	35	45	55
04	14	24	34	44	54
03	13	23	33	43	53
02	12	22	32	42	52
01	11	21	31	41	51
00	10	20	30	40	50

Southern Hemisphere

50	40	30	20	10	00
51	41	31	21	11	01
52	42	32	22	12	02
53	43	33	23	13	03
54	44	34	24	14	04
55	45	35	25	15	05

ref. coordinate

1 deg. latitude

ref. coordinate 1 degree longitude

RR ridges - estimated number of significant ridges

DD direction/general orientation of the ridges - 0 to 18 deg.. range

HMO terrain elevation - modal height as read from contour lines
HHI " " maximum height
HLO " " minimum
coded as positive numbers in hundreds of feet (e.g. 005=500 ft elev.)
below sea level is coded 4XX (401=100 ft below sea level)

C1 primary terrain characteristic - judged from relative topography
C2 secondary " " and map symbols
CODE:
0 - salt or lake bed
1 - flat or relatively flat
2 - desert (70+ N - glaciers or permanent ice)
3 - marsh
4 - lake country or atoll
5 - major valleys or river beds
6 - isolated mountains, ridge or peak
7 - low mountains or hills
8 - average mountains
9 - extremely rugged mountains

WWW percentage of water surface - estimated from chart details; minimum land recorded is 2%; water is 98% or less.

URB percentage of urban development - estimated from map w/populated areas

- K -

INTEGRATED ELEVATION AND BATHYMETRY

CITATION: Kineman, J. (ed.), 1989. Integrated Global Elevation and Bathymetry. Digital Data. NOAA/NGDC/WDC-A, Boulder, Colorado. 4.7 MB.

Blank page retained for pagination

K. INTEGRATED ELEVATION AND BATHYMETRY

DATE: 1985

SOURCE:

Integrated from best available 5- and 10-min digital sources.

(1) US Navy Fleet Numeric Oceanographic Center
Monterey, CA

(2) US Defense Mapping Agency

(3) US Naval Oceanographci Observatory

(4) Bureau of Mineral Resources of Australia, and
Department of Scientific and Industrial Research of New Zealand

(5) Integration of (1) - (4) above:
Margaret Edwards (5-min compilation)
Washington University
Earth and Planetary Remote Sensing Laboratory
St. Louis, MO

(6) 10-min resampling: John Kineman
NOAA/NGDC
Boulder, CO

CONTRIBUTOR:

Peter Sloss
NOAA/NGDC
Boulder, CO

DATA CENTER: NGDC

GEOGRAPHIC SAMPLING: 10-min grid (averaged from 5-min grid)

COVERAGE: Global

PROJECTION: Lat/lon

TIME SAMPLING: Most recent information

REFERENCES:

Edwards, Margaret Helen, 1986. "Digital Image Processing of Local and Global Bathymetric Data." Master's Thesis. Washington University, Department of Earth and Planetary Sciences, St. Louis, Missouri, 106 p. (Excerpt included.)

(continued on the next page)

Haxby, W. F., et al, 1983. "Digital Images of Combined Oceanic and Continental Data Sets and Their Use in Tectonic Studies." *EOS Transactions of the American Geophysical Union*, vol. 64, no. 52, pp. 995-1004. (Excerpt included)

FILE NAMES: AFELBA Integrated elevation and bathymetry (feet)

INTEGRATED ELEVATION AND BATHYMETRY DOCUMENTATION FILE

File Name: AFELBA.DOC

```
image title : Integrated Elevation and Bathymetry (feet)
data type   : integer
file type   : binary
rows        : 438
columns     : 480
minimum     :  -5.9530000000E+03
maximum     :   3.5240000000E+03
cell x      :   1.6666666666E-01
cell y      :   1.6666666667E-01
legend      : 15
category  1 : -5360  -4769
category  2 : -4768  -4176
category  3 : -4175  -3584
category  4 : -3583  -2992
category  5 : -2991  -2399
category  6 : -2398  -1807
category  7 : -1806  -1215
category  8 : -1214   -622
category  9 :  -621    -30
category 10 :  -29 to  562
category 11 :  563 to 1154
category 12 : 1155 to 1746
category 13 : 1747 to 2339
category 14 : 2340 to 2931
category 15 : 2932 to 3524

{category 0 : -5953 to -5361}
```

[This legend is only appropriate for displays which reclass (contrast stretch) the continuous values into 16 classes.]

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WASHINGTON UNIVERSITY

Department of Earth and Planetary Sciences

DIGITAL IMAGE PROCESSING AND INTERPRETATION OF LOCAL AND GLOBAL BATHYMETRIC DATA

by

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A thesis presented to the
Graduate School of Arts and Sciences
of Washington University in
partial fulfillment of the
requirements for the
degree of Master of Arts

December, 1986

Saint Louis, Missouri

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5. DBDB5 STUDY

5.1. INTRODUCTION

The second study involves digital manipulation and interpretation of the global bathymetric database, DBDB5. The first step in this study was to generate a global topographic dataset using the global bathymetry and three continental datasets, all with 10° by 10° resolution or better. The global topographic dataset was used to generate a series of three map sheets of Earth topography in shaded relief and color-coded shaded relief form that have been published by N.O.A.A.'s National Geophysical Data Center [1985]. Subsequently, a subset of the bathymetric dataset was used to examine the flexure that occurs along fracture zones in the East Pacific. Figure 5.1 is a flow diagram depicting the image processing techniques that were used to generate the global topographic dataset.

5.2. GENERATION OF THE GLOBAL ELEVATION DATASET

The first portion of this study involves the generation of a global, digital elevation dataset. Four separate datasets with resolutions of 10° by 10° or better were used to generate the global map. The datasets were merged in such a way that the best spatial resolution data were retained for any given location. In addition, the data were merged using a priority scheme that selected data on the basis of data reliability. For example, all of the oceanic data were taken from the bathymetric database even though all three of the continental datasets contained oceanic data for areas adjacent to the coastlines, because the bathymetric dataset was assumed to have more reliable oceanic data. The data were displayed in different map projections with depth/elevation represented as colors, gray values, and shaded relief maps. The resulting images depict many terrestrial and marine landforms such as mountains, plains, ridges, trenches, seamounts, and continental margins. In this section the various datasets and techniques used to generate the global dataset are discussed.

DBDB5 IMAGE PROCESSING

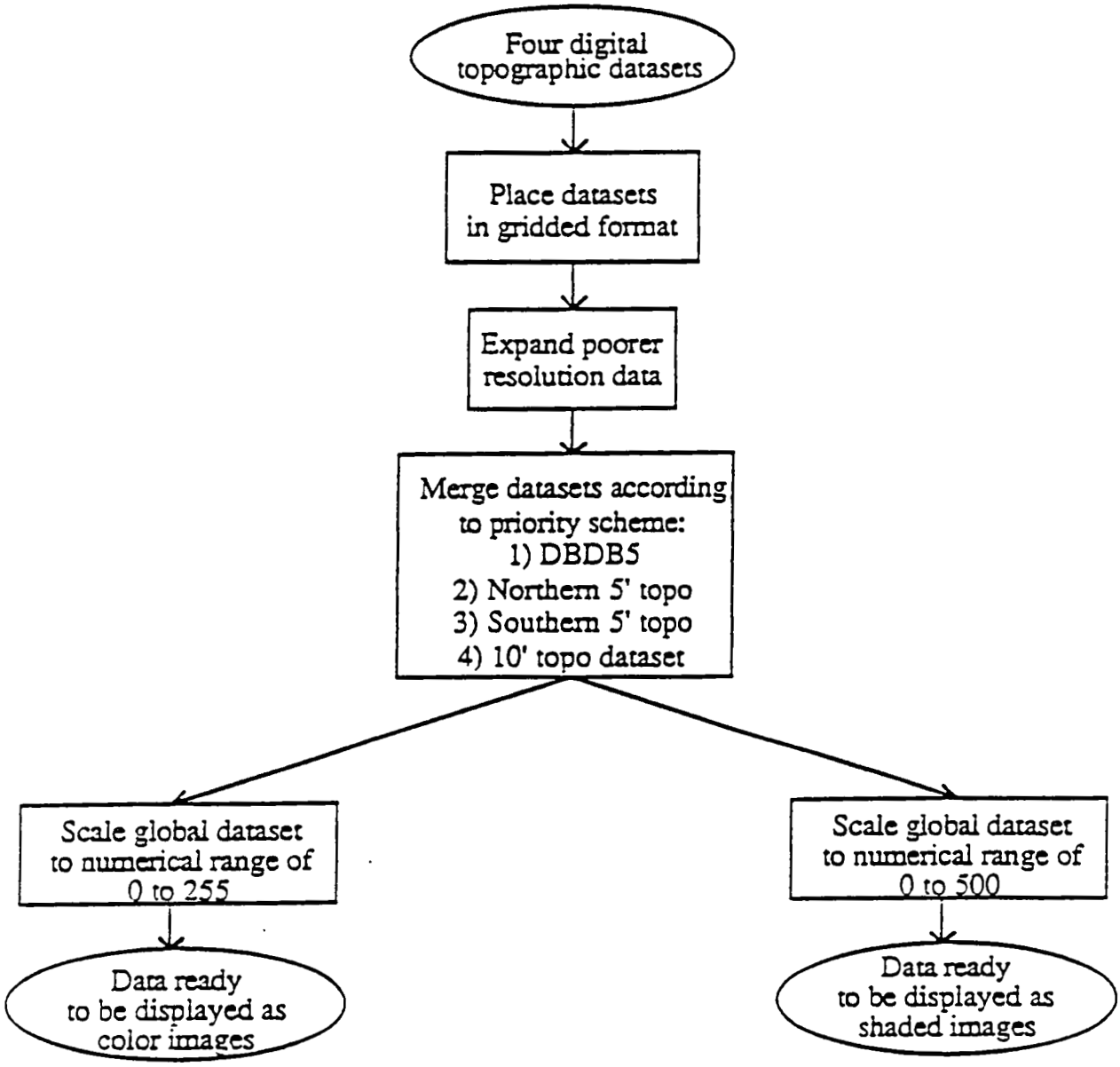


Figure 5.1 - This diagram represents the image processing techniques that were used to generate the global dataset. In this figure, input and output are represented as ovals and processes are represented as boxes. The flow of processing is represented by the arrows.

The global elevation dataset was compiled from four separate datasets (Table 1). T dataset used as the base map is Digital Bathymetric Database 5 (DBDB5; formerly known SYNBAPS) available from N.O.A.A.'s National Geophysical Data Center. This databas composed of 5' bathymetric averages and was compiled using bathymetric contour charts (see Section 2 for a detailed description of the compilation techniques). The bathymetric dataset was used as the base map because it has the most coverage at the best resolution. second and third datasets in the priority scheme have comparable resolution to the bathymetric dataset but cover smaller land areas. The second dataset contains 5' average elevations for parts of North America and Europe and is also available at the National Geophysical Data Center. The third dataset covers Australia, Tasmania, and New Zealand is composed of 5' average elevations, and was obtained from William Haxby and Jeffrey Weissel at Lamont-Doherty Geological Observatory. The Australian dataset was compiled by the Bureau of Mineral Resources, Canberra, and the New Zealand Department of Scientific and Industrial Research [Haxby *et al.*, 1983]. The fourth and final dataset was prepared by the U.S. Navy Fleet Numerical Oceanography Center using 100 foot contour charts. This dataset has the poorest resolution but covers the rest of the remaining land areas. Data in the fourth dataset have 10' resolution and are composed of modal elevations rather than average elevations (*e.g.* rather than averaging the values within an area, this dataset contains the elevation most frequently encountered within the area). Areal coverage of the four datasets is illustrated in the simple cylindrical map of the Earth shown in Figure 5.2. The formats on digital tape of each of the four datasets varied considerably and hence separate programs were developed to convert the data to a gridded image format (Appendix D).

TABLE 5.1 Datasets used to generate global digital elevation dataset

Name/Coverage	Resolution	Type of Measurement	Availability/Compilation
DBDB5 - Major bodies of water	5' by 5'	average elevations	Available from NOAA's NGDC; Compiled by U.S. Naval Oceanographic Office
Central and North America, and Europe	5' by 5'	average elevations	Available from NOAA's NGDC; Prepared by the Defense Mapping Agency
Australia, Tasmania, and New Zealand	5' by 5'	average elevations	Compiled by the Bureau of Mineral Resources, Canberra, and the New Zealand Department of Scientific and Industrial Research; Gridded by Wm. Haxby and colleagues, Lamont-Doherty Geological Observatory
Africa, Asia, South America, Northern Canada, etc.	10' by 10'	modal elevations	Compiled by the U.S. Fleet Numerical Oceanography Center; Available from NOAA's NGDC

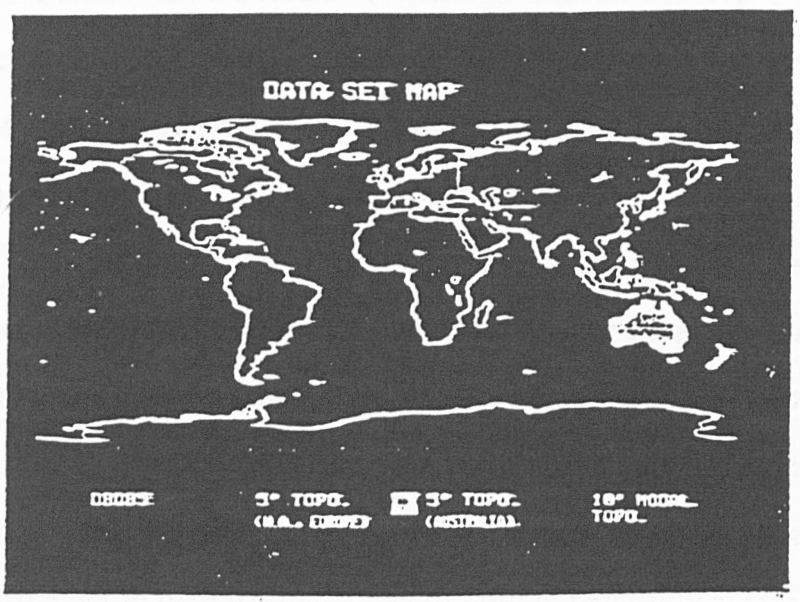


Figure 5.2 - Map of the four datasets used to generate the global topographic dataset. The data shown as blue represent the global bathymetric dataset; the data in yellow cover Australia, New Zealand, and Tasmania; green areas represent the data used for most of North America and Western Europe; the dataset shown as red was used to fill in all remaining areas. The character and availability of each of these datasets is described in Table 5.1.

The first step after converting the data to image format was to expand the 10' data by a factor of two using the bilinear interpolation expansion algorithm described in Section 3.3. The poorer resolution data were expanded rather than decreasing the resolution of the other datasets to preserve the maximum information content. Data values in the combined dataset ranged from a minimum value of approximately -10800 meters to a maximum value of +8750 meters. For processing purposes it was convenient to scale the data to fit into smaller numerical ranges. The data were scaled in two ways; to a range from 0 to 255 and to a range between 0 and 500. The reason for the two different scales was that it was more convenient for the processing system hardware to display the data with the smaller numerical range while the data that ranged from 0 to 500 were used for computational purposes. The data were merged to make two global topographic maps of the Earth, one map containing byte information (range 0 to 255) for each gridded location, and another containing data ranging from 0 to 500 for each location. These two maps were then combined to produce the global elevation dataset shown in Figure 5.3.

The merged data were displayed in a variety of map projections with elevation data represented as gray values, colors, or shaded relief maps (Figures 5.4 and 5.5). The shaded relief maps were generated using the algorithm described in Section 3.3 and Appendix C. In this instance the simulated sun was assumed to be 20 degrees above the western horizon. The shaded relief maps in Figures 5.4b and 5.5a were generated using the data that were scaled from 0 to 500. Attempts to create shaded relief maps from the data with the smaller numeric range resulted in subdued expression of many topographic features. For example, the Mid-Atlantic Ridge is much more discernible in Figure 5.5a than it is in Figure 5.5b. The reason for the subdued appearance of the data in Figure 5.5b is that almost twenty kilometers of relief have been compressed to a range two orders of magnitude smaller than the range of the original data. Using the data that had been scaled from 0 to 500 increased the value of the apparent slope of the data, thereby depicting greater detail in the shaded relief map in Figure 5.5a. Trial and error experimentation determined that a range of relief much greater than 0 to 500 led to distortion in the images due to too high slopes during computation.

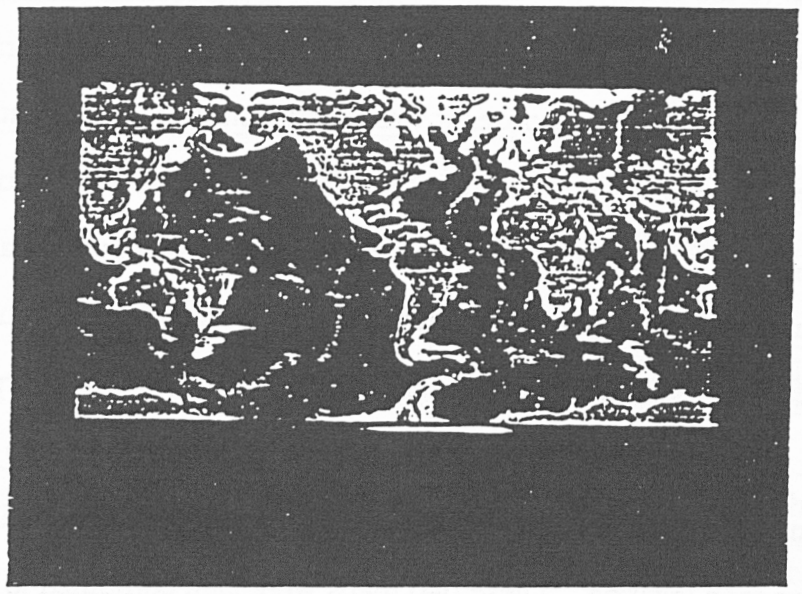
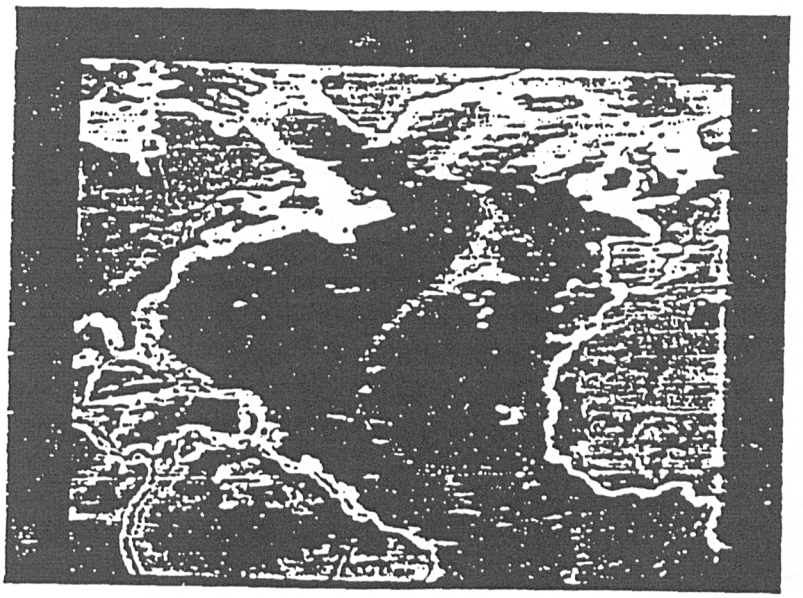


Figure 5.3 - Mercator map projection of the global topography of the Earth. The resolution of the data has been decreased by a factor of 4 so that the entire dataset could be photographed in one image. Latitude limits are 72° S to 72° N; longitude limits are 90° W to 120° W. Continental outlines and 10° grid marks are shown in black. Colors in the bar at the bottom of the image have been assigned to represent approximately equal area under the hypsometric curve for the Earth.



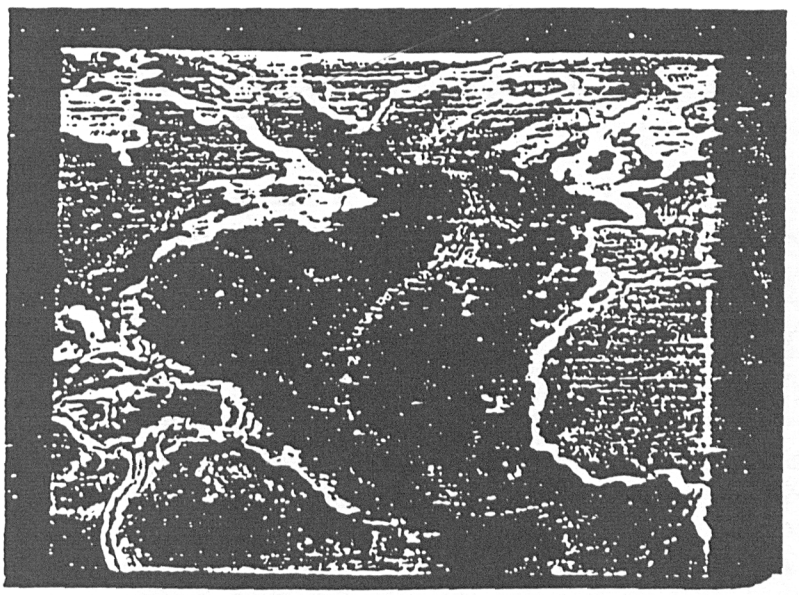
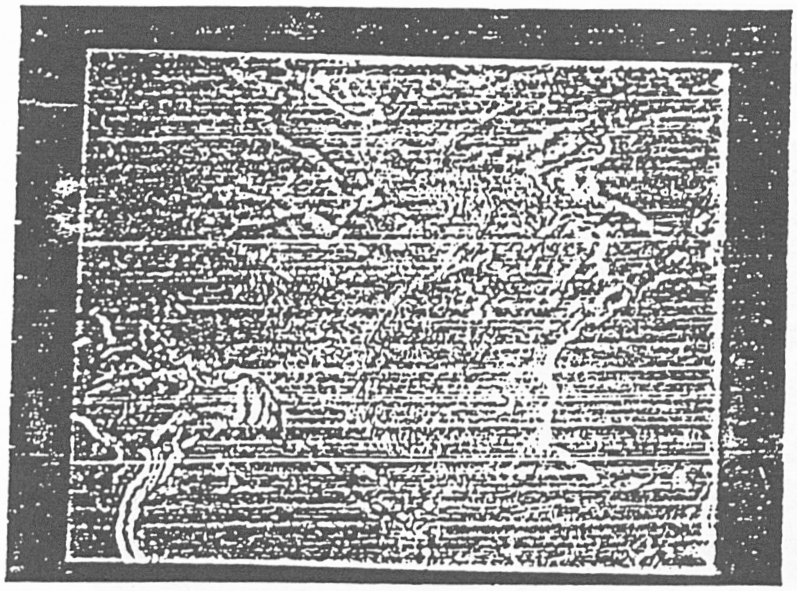


Figure 5.4 - In Figure 5.4a gray values have been converted to colors using one of the color look-up tables given in Appendix D. The colors are the same as those shown in the color bar in Figure 5.3. The data range from latitude 10° S to 70° N and from longitude 90° W to 10° E. Figure 5.4b is a color-coded shaded relief map of the same area. In this image the colors from Figure 5.4a have been overlaid onto the shaded relief map shown in Figure 5.5a. The advantage of combining color contours with a shaded relief map (both of which actually depict the same information) is that the combined form is a pseudo-three-dimensional image.



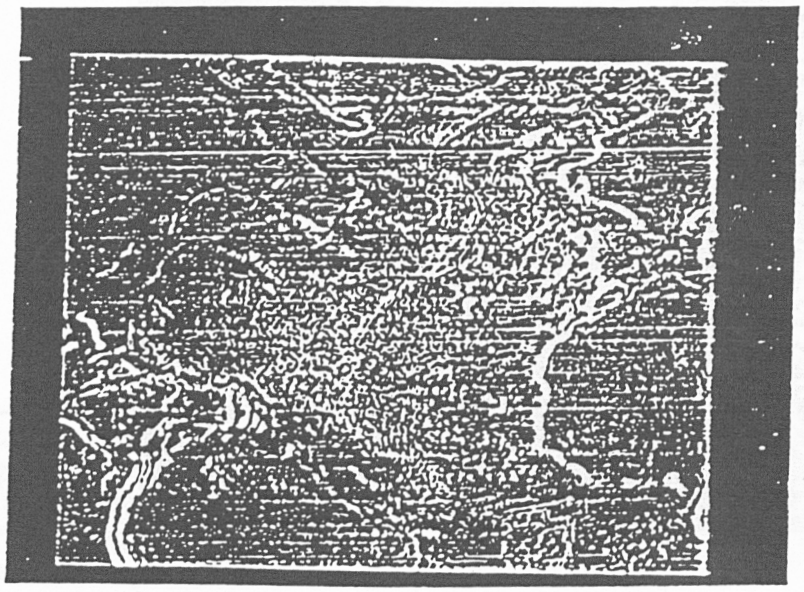


Figure 5.5 - Figure 5.5a is a shaded relief map of the northern Atlantic Ocean generated using data which had been compressed to a numeric range of 0 to 500. Figure 5.5b is a shaded relief map of the same area generated using byte data with a range of 0 to 255. Note that the topography in this image is subdued compared to the shaded relief map in Figure 5.5a.

As in the Seabeam study, images of the global topography were generated with color contours overlaid on top of a shaded relief map. Several experiments with color were performed before the final color scale was chosen (Appendix E). The final color scale shown in Figures 5.3 and 5.4 was patterned after "The World," Series 1145, Edition 1-DMATC, which was prepared and published under the direction of the Department of Defense by the Defense Mapping Agency and the Topographic and Hydrographic Centers. The color scale was determined using a data distribution curve (approximately the equivalent of a hypsometric curve) for the elevation dataset. Colors were assigned to represent approximately equal areas under the curve. The colors were chosen so that oceanic data were represented as various shades of blue, the deepest blues occurring at trench locations and the lightest blues occurring at depths close to sea level. The continental data were represented by multiple hues ranging from green at sea level through yellow, red, and finally to white at the highest elevations. A color bar of the final color scale is shown in Figure 5.3. In total, thirty-eight colors were used to generate the final color scale. A color could represent an elevation range as small as 75 meters or as large as 2 kilometers based on where the color fell along the "hypsometric" color curve. The color-coded data were displayed as a simple color map or as color modulated by a shaded relief map. The gray tone and color-coded maps were then displayed in a variety of map projections including Mercator projections, polar stereographic projections, and projections that simulate spacecraft views of the Earth (Figure 5.6). The resultant images depict a variety of interesting morphological features including seamounts, ridges, trenches, and continental margins.

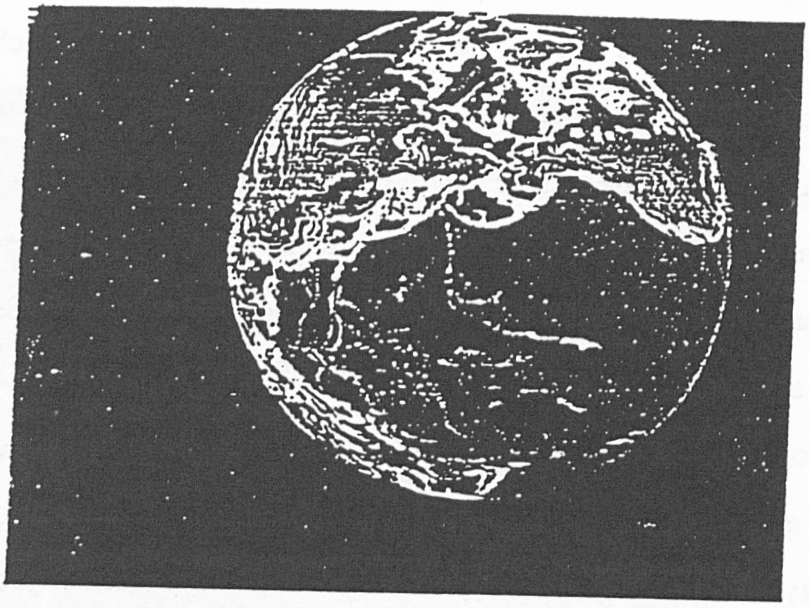


Figure 5.6 - Figure 5.6a is a polar stereographic map of the North Pole. The formulas for converting from a simple cylindrical to a polar stereographic projection are given in Appendix A. Continental outlines are shown in black. The data in this image range to a latitude of 55°. Figure 5.6b is a simulated spacecraft view of the Earth centered over 135 °E and 30°N. The distance from the center of the planet to the hypothetical focal plane is 580,000 kilometers. The theory used to generate these images is discussed in Appendix B. Continental outlines are shown in white.

- L -

MICRO WORLD DATA BANK II (MWDB-II): COASTLINES, COUNTRY BOUNDARIES, ISLANDS, LAKES, AND RIVERS

CITATION: Pospeschill, F., 1988. Micro World Data Bank II (MWDB-II): Coastlines, Country Boundaries, Islands, Lakes, and Rivers. Digital Data. NOAA/NGDC/WDC-A, Boulder, Colorado. 2.5 MB.

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L. MICRO WORLD DATA BANK II (MWDB-II): COASTLINES, COUNTRY BOUNDARIES, ISLANDS, LAKES, AND RIVERS

DATE: 1988

SOURCE:

Digitized from available sources.

(1) CIA WDB-II

(2) USAF (Generalized to 1-min.)

(3) Fred Pospeschil
Micro Doc
3108 Jackson Street
Bellevue, Nebraska 68005

CONTRIBUTOR:

Fred Pospeschil
Micro Doc
3108 Jackson Street
Bellevue, Nebraska 68005

DATA CENTER: NGDC/WDC-A

GEOGRAPHIC SAMPLING: 1:3,000,000 scale vector lines, unlabeled

COVERAGE: Global

PROJECTION: Lat/lon

TIME SAMPLING: Most recent information

REFERENCES:

FILE NAMES:

COASTS	African Coastlines
COUNTRY	African Country Boundaries
ISLANDS	African Islands
LAKES	African Lakes
RIVERS	African Rivers

MICRO WORLD DATA BANK II: COASTLINES DOCUMENTATION FILE

File Name: COASTS.DVC

```
title       : MWDB-II Coasts, Detail Level 1
data type   : integer
file type   : ascii
object type : line
coord. span :   1.6666666660E-02
coord. unit : deg
min X       :  -1.2000000000E+03
max X       :   3.6000000000E+03
min Y       :  -2.1000000000E+03
max Y       :   2.2800000000E+03
```

MICRO WORLD DATA BANK II: COUNTRIES
DOCUMENTATION FILE

File Name: COUNTRY.DVC

```
title        : MWDB-II Countries, Detail Level 1
data type    : integer
file type    : ascii
object type  : line
coord. span  :   1.6666666660E-02
coord. unit  : deg
min X        :  -1.2000000000E+03
max X        :   3.6000000000E+03
min Y        :  -2.1000000000E+03
max Y        :   2.2800000000E+03
```

MICRO WORLD DATA BANK II: ISLANDS
DOCUMENTATION FILE

File Name: ISLANDS.DVC

```
title       : MWDB-II Islands, Detail Level 1
data type   : integer
file type   : ascii
object type : line
coord. span :   1.6666666666E-02
coord. unit : deg
min X       :  -1.2000000000E+03
max X       :   3.6000000000E+03
min Y       :  -2.1000000000E+03
max Y       :   2.2800000000E+03
```

MICRO WORLD DATA BANK II: LAKES
DOCUMENTATION FILE

File Name: LAKES.DVC

```
title       : MWDB-II Lakes, Detail Level 1
data type   : integer
file type   : ascii
object type : line
coord. span :   1.6666666600E-02
coord. unit : deg
min X       :  -1.2000000000E+03
max X       :   3.6000000000E+03
min Y       :  -2.1000000000E+03
max Y       :   2.2800000000E+03
```

MICRO WORLD DATA BANK II: RIVERS
DOCUMENTATION FILE

File Name: RIVERS.DVC

```
title       : MWDB-II Rivers, Detail Level 1
data type   : integer
file type   : ascii
object type : line
coord. span :   1.6666666666E-02
coord. unit : deg
min X       :  -1.2000000000E+03
max X       :   3.6000000000E+03
min Y       :  -2.1000000000E+03
max Y       :   2.2800000000E+03
```

Micro World Data Bank II (MWDB-II)

Introduction

The full WDB-II is a digitial map data base produced by the Central Intelligence Agency (CIA) and distributed by the National Technical Information Service (NTIS), U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA, 22161. Micro WDB-II is a highly compressed version which is suitable for use on micro computers and was put in this configuration by Micro Doc. Before describing Micro WDB-II a few words should be said about the source file - WDB-II. The following paragraphs are paraphrased from the NTIS overview of WDB-II.

> WDB-II is a digitial representation of the world coastlines and boundries suitable for use in automated mapping systems. It contains approximately six million discrete geographic points and was digitized using all available sources of information. Map scales used range from 1:750,000 to 1:4,000,000 with a nominal scale of 1:3,000,000. These points are grouped by and identified as describing (1) coast lines, (2) country boundries, (3) state boundries (USA only), (4) islands, (5) lakes, and (6) rivers. Each of these groupings is further broken down into features and subordinate classifications/ranks. These ranks are hierarchically structured, and are also used for plotting symbol definition.
>
> ~~WDB-II, as provided by NTIS, is in a 20-character format on five 9-track EBCDIC one-half inch magnetic tapes. This data base consists of two types of records, one for the line segment identifier data, and the other for the latitude and longitude values of each discrete point making up the line segment. In this format latitude and longitude values are recorded only as integers in degrees, minutes, and seconds. WDB-II is available for $660.00 (Order Number PB-271 874 SET/HBG).~~

Clearly, WDB-II is an excellent data source when making large (4 x 6 foot) plots on a mainframe or minicomputer. It is, however, somewhat large (150 - 200 megabytes) for use on microcomputers. Even on the larger commercial online graphics systems, many points have to be filtered out before generating displays. For this reason many people have spent considerable time over the past to filter and compress this data into a form which could be used in desktop computers. To these people we wish to express our appreciation - particularly Antonio Riveria who provided us with a copy of the latest download of the file.

Background

The present version began as a three megabyte ASCII text file which contained some 179,000 points selected from all six of the line types described above. This file was then converted into a sixteen bit integer format which reduced the size to just over one megabyte. Since this was still a little large for most five inch disk formats the file was divided into six files - one for each of the six line types. The coast line file was further divided into two files as it was over 400 KB. With this processing completed the file was

configured such that it could be readily moved to most desk top microcomputers using the MSDOS disk format. The following table provides a brief statistical overview of the six line types which are contained in the data base.

Micro WDB-II File Composition

Detail Level	COAST .PNT	COUNTRY .PNT	STATE .PNT	ISLAND .PNT	LAKE .PNT	RIVER .PNT	Total
1	29150	8573	798	13781	5886	11146	69339
2	35077	10172	959	16077	7080	13217	82599
3	5470	1496	153	2524	1023	1817	12526
4	4000	1249	101	1945	820	1254	9502
5	1478	869	248	844	309	760	5365
Total	75175	22359	2259	35171	15118	28194	179331
Lines	208	301	111	344	103	196	1263
Size (KB)	449	134	14	211	90	169	1067

The above table shows the number of points which are in each file and for each level of detail. It also shows the number of line segments in each file and the file sizes in kilobytes.

Detail level 5 contains the fewest points and produces the least detailed graphics image. The points at each level of detail are additive to the points at all lower levels. For example, when using detail level 4 the points from both levels 4 and 5 must be used / retrieved. Therefore, if one were drawing coast lines at detail level 4, a total of 5478 (4000 + 1478) points would be processed. These 5487 points will describe 208 line segments of various lengths.

Note that the same number of line segments exist at all levels of detail. For example, regardless of which level of detail is selected, there will always be 208 line segments described by the coast line data file. In some cases, mostly in the islands file, line segments degenerate to single points at the lower levels of detail. Therefore, programs which process this data must check to see whether each line segment header record is followed by a point record or another line segment record. More will be said about this later.

Actual use of the data in these files has shown that most displays which cover a reasonably large area do not need all of the detail provided at level 1. A large area would be a major portion of the U.S. For large area plots level 3 or 4 is normally sufficient and greatly reduces the number of points which must be processed. To support generation of large area displays, four composite files were created. These are WDB3.ALL, WDB4.ALL, WDB5.ALL, and WDB5.CCI. The first three contain all line types for the indicated detail level (WDB3.ALL is level 3, etc.). WDB5.CCI contains only country, coast line, and island line segments and is intended for 'quick and dirty' testing work.

Micro WDB-II Composite Files

Detail Level	WDB3 .ALL	WDB4 .ALL	WDB5 .ALL	WDB5 .CCI
3	12480	0	0	0
4	9365	9502	0	0
5	4315	5365	4315	3664
Total	26160	14867	4315	3664
Lines	1263	1263	1263	853
Size (KB)	157	82	25	17

Micro WDB-II File and Record Structures

All Micro WDB-II files are sequential files composed of fixed length six byte records which can be accessed randomly. Each record is composed of three 16-bit signed integer fields which can be read by all microcomputer languages. There are no record seperators used in these files. The record layout is :

| Code | Latitude | Longitude |

In Pascal, the record definition is :

```
POINT = RECORD
          CODE      : INTEGER;
          LATITUDE  : INTEGER;
          LONGITUDE : INTEGER;
        END;
```

Within the MWDBII files the records are stored as shown below. In some cases there may be hundreds of points in a single line segment. In other cases there may be consecutive header records which locate individual points to be plotted.

|Header|Point1|Point2|PointN|Header|Point1|Point2|PointN|Header
|Point1|Point2|Header|Header|Header|Point1|Point2|PointN|

The same format is used for both the line header records and point records. The usage of each field is as follows :

Field Definitions

CODE - Line Header Records.

The CODE field is used to :

1. Identify the type of line segment which is described by the point records which follow it,

2. Identify the line or point within the line type, and

3. Provide the coordinates if the record describes a point.

In header records the CODE field is always a positive four digit number in the form of : ABBB where

A =	BBB =	CODE =
1 = Coast lines	001 -> 208	1001 -> 1208
2 = Country boundries	001 -> 301	2001 -> 2301
4 = State boundries	001 -> 111	4001 -> 4111
5 = Islands	001 -> 344	5001 -> 5344
6 = Lakes	001 -> 103	6001 -> 6103
7 = Rivers	001 -> 196	7001 -> 7196

CODE - Point records.

In point records the CODE field contains the detail level. The detail level is a value in the range of 1 through 5. To properly retrieve points at any detail level use the following comparison :

```
IF CODE >= DESIRED_DETAIL_LEVEL THEN ...
```

LATITUDE and LONGITUDE - In both header and point records.

The latitude and longitude fields contain the coordinate values expressed in signed minutes. The values in these fields are computed with the formula COORD_VALUE := (Degrees * 60) + Minutes. Thus, the ranges of coordinate values in MWDBII are :

```
 90 00N =    5400
 90 00S =   -5400
180 00E =   10800
180 00W =  -10800
```

MWDBII uses the standard four quadrant cartesian coordinate system in which north, south, east, and west are referenced to the equator and the Greenwich meridian.

When a header record is followed by point records the coordinates in the header record are the beginning of the line. When a header record is followed by another header record then the coordinates in the header record should be plotted as a single point. When working at low levels of detail it is common to find multiple consecutive header records which locate isolated points. There may also be gaps between some of the lines.

This documentation and the associated files are placed in the public domain and may be incorporated into other products without fee so long as appropriate credits are included. An appropriate credit line would be - "This product contains/uses data and/or code placed in the public domain by Fred Pospeschil and Antonio Riveria. Original coordinate data was created by the Central Intelligence Agency."

All programs were compiled with MS Pascal Version 3.20. Graphics support was from Flexi-Graph, New Orleans General Data Services, 7230 Chadbourne Drive, New Orleans, LA 70126 and Micro Doc, 3108 Jackson St., Bellevue, NE 68005.

ALL USERS OF THESE MATERIALS ARE TOTALLY RESPONSIBLE FOR THEIR USE AS THESE MATERIALS ARE PROVIDED WITHOUT EITHER EXPRESS OR IMPLIED WARRANTIES OF ANY KIND.

- M -

WORLD DATA BANK II (WBDII): COUNTRY REGIONS AND RIVERS

CITATION: EROS Data Center, 1990. African Nations and Rivers. Digital Data. EDC, Sioux Falls, S.D. .42 MB.

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M. WORLD DATA BANK II: COUNTRY REGIONS AND RIVERS

DATE: 1990

SOURCE:

(1) CIA-World Data Bank II

(2) Reprocessed by:
EROS Data Center
Sioux Falls, SD

CONTRIBUTOR:

EROS Data Center
Sioux Falls, SD

DATA CENTER: EDC

GEOGRAPHIC SAMPLING: 1:1,000,000 vector lines and polygons with labels

COVERAGE: Africa

PROJECTION: Lat/lon

TIME SAMPLING: Most recent information

REFERENCES:

FILE NAMES:

AFNATION	African countries
AFRIVERS	African rivers

WDB-II AFRICAN RIVERS
DOCUMENTATION FILES

File Name: AFRIVERS.DOC

```
image title : WDB-II African Rivers
data type   : byte
file type   : binary
rows        : 438
columns     : 480
minimum     :   0.0000000000E+00
maximum     :   1.0000000000E+00
cell x      :   1.6666666667E-01
cell y      :   1.6666666667E-01
legend      : 1
category  1 : 1 Rivers

{category 0 : unclassed}
```

[This legend is appropriate for display of the individual classes (i.e. without rescaling).]

File Name: AFNATION.DOC

```
image title : WDB-II African Countries
data type   : byte
file type   : binary
rows        : 438
columns     : 480
minimum     :   0.0000000000E+00
maximum     :   6.8000000000E+01
cell x      :   1.6666700000E-01
cell y      :   1.6666700000E-01
legend      : 68
category  1 : TUNISIA        Tunisia (TS)
category  2 : ALGERIA        Algeria (AG)
category  3 : MOROCCO        Morocco (MO)
category  4 : JERBA IS       Jerba Island
category  5 : LIBYA          Libya (LY)
category  6 : MADEIRA IS     Madeira Island
category  7 : EGYPT          Egypt (EG)
category  8 : CANARY IS      Canary Island
category  9 : CANARY IS      Canary Island
category 10 : CANARY IS      Canary Island
category 11 : CANARY IS      Canary Island
category 12 : CANARY IS      Canary Island
category 13 : CANARY IS      Canary Island
category 14 : W SAHARA       Western Sahara (WI)
category 15 : MAURITANIA     Mauritania (MR)
category 16 : MALI           Mali (ML)
category 17 : NIGER          Niger (NG)
category 18 : CHAD           Chad (CD)
category 19 : SUDAN          Sudan (SU)
category 20 : ETHIOPIA       Ethiopia (ET)
category 21 : SENEGAL        Senegal (SG)
category 22 : BURKINA FASO   Burkina Faso (Dahlak Arch)
category 23 : UPPER VOLTA    Upper Volta (UV)
category 24 : NIGERIA        Nigeria (NI)
category 25 : THE GAMBIA     The Gambia (GA)
category 26 : CAMEROON       Cameroon (CM)
category 27 : DJIBOUTI       Djibouti (DJ)
category 28 : GUI-BISSAU     Guinea-Bissau (PU)
category 29 : GUINEA         Guinea (GV)
category 30 : BENIN          Benin (BN)
category 31 : SOMALIA        Somalia (SO)
category 32 : AR BIJAGOS     Arquipelago dos Bijagos
category 33 : GHANA          Ghana (GH)
category 34 : TOGO           Togo (TO)
category 35 : CEN AFR REP    Central African Republic (CT)
category 36 : IVORY COAST    Ivory Coast (IV)
category 37 : SIERRA LEONE   Sierra Leone (SL)
category 38 : LIBERIA        Liberia (LI)
category 39 : SHERBRO IS     Sherbro Island
category 40 : ZAIRE          Zaire (CG)
category 41 : KENYA          Kenya (KE)
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category 42 : UGANDA          Uganda (UG)
category 43 : EQ GUINEA       Equatorial Guinea (EK)
category 44 : CONGO           Congo (CF)
category 45 : RIO MUNI        Rio Muni
category 46 : GABON           Gabon (GB)
category 47 : S TOME PRINC    Sao Tome & Principe (TP)
category 48 : TANZANIA        Tanzania (TZ)
category 49 : RWANDA          Rwanda (RW)
category 50 : BURUNDI         Burundi (BY)
category 51 : CABINDA         Cabinda
category 52 : PEMBA IS        Pemba Island
category 53 : ZANZIBAR        Zanzibar
category 54 : ANGOLA          Angola (AO)
category 55 : MAFIA IS        Mafia Island
category 56 : ZAMBIA          Zambia (ZA)
category 57 : MALAWI          Malawi (MI)
category 58 : COMOROS IS      Comoros Island
category 59 : MADAGASCAR      Madagascar (MA)
category 60 : COMOROS IS      Comoros Island
category 61 : NAMIBIA         Namibia (WA)
category 62 : BOTSWANA        Botswana (BC)
category 63 : SOUTH AFRICA    South Africa (SF)
category 64 : WALVIS BAY      Walvis Bay
category 65 : SWAZILAND       Swaziland (WZ)
category 66 : LESOTHO         Lesotho (LT)
category 67 : MOZAMBIQUE      Mozambique (MZ)
category 68 : ZIMBABWE        Zimbabwe (ZI)

{category 0 : OCEAN}
```

[This legend is appropriate for display of the individual classes (i.e. without rescaling).]

The Description OF WDBII

WDBII contains five geographic areas such as North America, South America including Central America, Europe, AFrica and Asia including Australia. Each area is further subdivided into separate files for coastlines, islands and lakes (CIL), rivers (RIV), and international boundaries (BDY). In the case of North America, additional file PBY) further delineates the individual states of the USA and the provinces of Canada. WDBII uses map scales ranged from 1:1 million in the case of the Middle East, to 1:4 million for the USSR. Nominally, a scale of 1:3 million is used to achieve the amount of detail desired.

The following is the subordinate classification/ranks used by CIL, RIV, BDY and PBY files.

CIL file: - Coastlines, islands and lakes

Code No	Ranks
01	Coastlines, islands and lakes on all maps
02	Additional major islands and lakes
03	Intermediate island and likes
04	Minor islands and lakes
06	Intermittent major lakes
07	Intermittent minor lakes
08	Reefs
09	Salt pans - major
10	Salt pans - minor
13	Ice shelves - major
14	Ice shelves - minor
15	Glaciers

RIV file: - Rivers

Code No	Ranks
01	Permanent major rivers
02	Additional major rivers
03	Additional rivers
04	Minor rivers
05	Double-lined rivers
06	Intermittent rivers - major
07	Intermittent rivers - additional
08	Intermittent rivers - minor
10	Major canals
11	Canals of lesser importance
12	Canals - irrigation type

BDY file: - International boundaries or limits of sovereignty

Code No	Ranks
01	Demarcated or delimited
02	Indefinite or in dispute

03	Other line of separation or sovereignty on land

PBY file: - Internal boundaries

Code No	Ranks
01	First order administration

Each WDBII file contains two different types of records. The formats of these two types of records are shown below:

Line Identifier Record (Line Record)

Field	Description	Position	Length	Format
1	Line identifier	1 - 7	7	I7
2	Rank code no.	8 - 9	2	I2
3	No. of points in the line (NP	10 - 15	5	I6
4	Zeros	15 - 20	5	I5

Latitude/Longitude Record (Point Record)

Field	Description	Position	Length	Format
1	Latitude (DDMMSSH)	1 - 7	7	3I3,A1
2	Longitude (DDDMMSSH)	5 - 15	8	I3,2I2,A1
3	Sequence Count	15 - 20	5	I5

As can be surmised from the above formats, there exists a single record for each line identifier, with NP subsequent latitude/longitude records, one for each point contained in the line. The record size of both formats is 20 bytes.

THE DESCRIPTION OF THE REFORMATTED WDBII DATA BASE

RFWBII incorporates the input files into one large file. The record size of the file is 16 bytes. RFWBII converts the input data from ASCII format into binary format.

The following shows the file numbers and the code numbers assigned by RFWBII to the 16 files presently included in the WDBII::

File No.	Code No.	Area File Type
1	11	North America - CIL
2	12	North America - RIV
3	13	North America - BDY
4	14	North America - PBY
5	21	South America - CIL
6	22	South America - RIV
7	23	South America - BDY
8	24	Vacant
9	31	Europe - CIL

10	32	Europe - RIV
11	33	Europe - BDY
12	34	Vacant
13	41	Africa - CIL
14	42	Africa - RIV
15	43	Africa - BDY
16	44	Vacant
17	51	Asia - CIL
18	52	Asia - RIV
19	53	Asia - BDY
20	54	Vacant

In addition to the line and point records, RFWBII contains 13 header records. The formats of these records are shown below:

Rec. No.	Word No.	Type	Description
1	1	INT*4	World boundary data base identifier (-555)
"	2	"	Maximum no. of input files (20)
"	3	"	No. of actual input lines
"	4	"	Total no. of records
2	1		Total no. of segments
"	2	"	Not used
"	3		Not used
"	4	Real	Approximation threshold

- N -

THE WORLD DATA CENTER SYSTEM

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APPENDIX N. THE WORLD DATA CENTER SYSTEM

Description of World Data Centers

The World Data Centers (WDCs) were created in 1957 to provide archiving for the observational data resulting from the International Geophysical Year (IGY). In the years following the IGY, the International Council of Scientific Unions (ICSU) recommended that the WDCs continue to collect, archive, and redistribute data. This new system for exchanging geophysical data was found to be very effective, and the operations of the WDCs were extended by ICSU on a continuing basis to other international programs. The WDCs were under the supervision of the Comite International de Geophysique for the period 1960 through 1967 and are now supervised by the ICSU Panel on World Data Centres.

World Data Centers have been established in a variety of countries: WDC-A is located in the USA; WDC-B in the USSR; WDC-C in western Europe, Australia, and Japan; and WDC-D in the People's Republic of China. The Centers collect and distribute data for a number of disciplines:

- meteorology
- oceanography
- astronomy
- rockets and satellites
- solar-terrestrial physics: solar and interplanetary phenomena, ionospheric phenomena, flare-associated events, geomagnetic phenomena, aurora, cosmic rays, airglow
- nuclear radiation
- glaciology (snow and ice) and geocryology
- marine geology and geophysics: gravity, magnetics, bathymetry, seismic profiles, marine sediment, rock analyses
- solid earth geology and geophysics: seismology, tsunamis, gravimetry, Earth tides, recent movements of Earth's crust, Earth's rotation, magnetic measurements, paleomagnetism and archeomagnetism, volcanology, geothermics
- renewable resources and environment

In each discipline, the scientific community determines the nature and form of data exchange, based on research needs. Thus, the type and amount of data in the WDCs differ from discipline to discipline. However, each WDC is responsible for:

- collecting data in the field or discipline for which it is responsible
- protecting the incoming data

- copying and reproducing data, maintaining adequate standards of clarity and durability
- supplying copies of data to other WDCs
- preparing catalogs of data
- making data available to the scientific community.

All the Centers are staffed, funded, and maintained exclusively by the countries in which they are located. The WDCs catalog the data and make them available to scientists in all countries upon written request or personal visit. Minimal charges may be requested to cover costs of processing the requested data.

World Data Center A

World Data Center A was established in the United States under the auspices of the National Academy of Sciences. WDC-A is operated with national resources, but follows ICSU guidelines. The National Academy of Sciences has overall responsibility through the Geophysics Research Forum and its Committee on Geophysical Data. WDC-A consists of a Coordination Office and nine subcenters at scientific institutions in various parts of the United States. Most WDC-A subcenters are at corresponding national data centers, whose large national collections are available through the WDC-A subcenters.

Organizations wishing to contribute data or establish exchange agreements should contact the appropriate World Data Center A.

WORLD DATA CENTER A
COORDINATION OFFICE
National Academy of Sciences
2101 Constitution Avenue, NW
Washington, DC 20418, USA
Telephone: 202-334-3368

WORLD DATA CENTER A: GLACIOLOGY (SNOW AND ICE)
Cooperative Institute for Research in Environmental Sciences
University of Colorado
Boulder, Colorado 80309, U.S.A.
Telephone: 303-492-5171

WORLD DATA CENTER A FOR MARINE GEOLOGY AND GEOPHYSICS
National Geophysical Data Center
NOAA, E/GC3
325 Broadway
Boulder, Colorado 80303-3328, U.S.A.
Telephone: 303-497-6487

WORLD DATA CENTER A: METEOROLOGY
National Climatic Data Center
NOAA, E/CC
Federal Building
Asheville, North Carolina 28801, U.S.A.
Telephone: 704-259-0682

WORLD DATA CENTER A: OCEANOGRAPHY
National Oceanographic Data Center
NOAA, E/OC
1825 Connecticut Avenue, NW
Universal Building, Room 406
Washington, DC 20235, U.S.A.
Telephone: 202-673-5594

WORLD DATA CENTER A: ROCKETS AND SATELLITES
NASA/Goddard Space Flight Center
Code 630.2
Greenbelt, Maryland 20771, U.S.A.
Telephone: 301-286-7354

WORLD DATA CENTER A: ROTATION OF THE EARTH
U.S. Naval Observatory
Washington, DC 20392-5100, U.S.A.
Telephone: 202-653-1529 or 1527

WORLD DATA CENTER A: SEISMOLOGY
U.S. Geological Survey
Branch of Global Seismology and Geomagnetism
Box 250436, Mail Stop 967
Denver Federal Center
Denver, Colorado 80225, U.S.A.
Telephone: 303-236-1500

WORLD DATA CENTER A FOR SOLAR-TERRESTRIAL PHYSICS
National Geophysical Data Center
NOAA, E/GC2
325 Broadway
Boulder, Colorado 80303-3328, U.S.A.
Telephone: 303-497-6324

WORLD DATA CENTER A FOR SOLID EARTH GEOPHYSICS
National Geophysical Data Center
NOAA, E/GC1
325 Broadway
Boulder, Colorado 80303-3328, U.S.A.
Telephone: 303-497-6521

WDC-A for Solid Earth Geophysics Reports

World Data Center A for Solid Earth Geophysics has a variety of reports related to its activities. This publication, SE-47, is one in a series. To obtain ordering information about the other publications (listed below), call 303-497-6277, fax 303-497-6513, telex 592811 NOAA MASC BDR, or write to:

WORLD DATA CENTER-A FOR SOLID EARTH GEOPHYSICS
NATIONAL GEOPHYSICAL DATA CENTER
NOAA, CODE E/GC1
325 BROADWAY
BOULDER, COLORADO 80303-3328, U.S.A.

SE-1 Catalog of Tsunamis in Alaska
SE-2 Geodynamics International-9
SE-3 Summary of Earthquake Focal Mechanisms for the Western Pacific-Indonesian Region, 1929-1973
SE-4 Catalog of Tsunamis in Hawaii
SE-5 Geodynamics International-10

SE-6 Catalog of Seismograms and Strong-Motion Records
SE-7 Directory of Seismograph Stations
SE-8 Survey of Practice in Determining Magnitudes of Near Earthquakes, Part 2: Europe, Asia, Africa, Australia, the Pacific
SE-9 Survey of Practice in Determining Magnitudes of Near Earthquakes, Part 1: North, Central, and South America
SE-10 Geodynamics International-11

SE-11 The Information Explosion and Its Consequences for Data Acquisition, Documentation, and Processing: An Additional Aspect of the Limits to Growth
SE-12 Geodynamics International-12
SE-13 Bibliography of Statistical Aspects of Seismicity
SE-14 Directory of U.S. Data Repositories Supporting the International Geodynamics Project
SE-15 Geodynamics International-13

SE-16 Geodynamics International-14
SE-17 Annual Mean Values of Geomagnetic Components for Selected Observatories, 1940-1973
SE-18 Homogenous Magnitude System of the Eurasian Continent: P-Waves
SE-19 Geodynamics International-15
SE-20 Manual of Seismological Practice

SE-21 Geomagnetic Observatories, 1978
SE-22 Historical Seismogram Filming Project: First Progress Report
SE-23 Geodynamics International-16
SE-24 Historical Seismogram Filming Project: Second Progress Report
SE-25 Directory of World Seismograph Stations, Volume 1. The Americas—Part 1. United States, Canada, Bermuda

SE-26 Geodynamics International-17: Final Report
SE-27 Catalog of Significant Earthquakes, 2000 B.C.-1979
SE-28 Historical Seismogram Filming Project: Third Progress Report
SE-29 Strong-Motion Data from Japanese Earthquakes
SE-30 Progress Report on Selected Geophysical Activities of the United States, 1977-1981

SE-31 New Catalog of Strong Earthquakes in the U.S.S.R. from Ancient Times Through 1977
SE-32 Directory of World Digital Seismic Stations
SE-33 Historical Seismogram Filming Project: Fourth Progress Report
SE-34 Homogeneous Magnitude System of the Eurasian Continent: S and L Waves
SE-35 Documentation of Earthquake Algorithms

SE-36 Catalog of Submarine Volcanoes and Hydrological Phenomena Associated with Volcanic Events: 1500 B.C. to December 31, 1899
SE-37 Inventory of Filmed Historical Seismograms and Station Bulletins at World Data Center A
SE-38 Catalog of Strong-Motion Accelerograph Records
SE-39 Tsunamis in Peru-Chile
SE-40 Earthquake Catalog for the Middle East Countries 1900-1983

SE-41 Directory of World Seismograph Stations, Volume II. East Asia—China, Japan, Korea, and Mongolia

SE-42 Catalog of Submarine Volcanoes and Hydrological Phenomena Associated with Volcanic Events: January 1, 1900 to December 31, 1959

SE-43 A Directory of Geomagnetic Observatories with Digital Recording Magnetometers, 1987

SE-44 Directory of Data Sources for Lithospheric Investigations, Volume 1

SE-45 A Report on Geomagnetic Observatory Operations, 1990

SE-46 Enhancement of Earth Science Research and Educational Capabilities in the Developing Nations Through the Use of Compact Disc Technology; Report on the Pilot Project

SE-47 Global Change Data Base: Pilot (Diskette) Project for Africa; Data Base Documentation, Version 1.1

SE-48 Global Change Data Base: Training Exercise Manual; Exploring Earth's Environment, Africa as an Example

*U.S. GOVERNMENT PRINTING OFFICE:1992-673-025/69016