NASA/CR-2004-213249

Effects of Meteorological Conditions on Reactions to Noise Exposure

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November 2004

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Prepared for Langley Research Center
under Contract NAS1-98100

November 2004

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ABBREVIATIONS AND SYMBOLS

Exact definitions of noise indices and scales for acoustical measurements can be found in general acoustical reference publications (Bennett and Pearsons 1981). The units in which quantities are expressed are enclosed in square brackets.

a	Intercept in a regression equation
dB	Decibel
B_L	Annoyance associated with a 1-decibel difference in steady-state noise exposure (positive values indicate that annoyance increases with noise level) [Annoyance scale units]
B_x	Annoyance associated with a 1-unit change in variable x, calculated in a regression analysis [Annoyance scale units]
dBEAU	Decibel Equivalent Units. This expresses annoyance effects in terms of the number of decibels that would create an equivalent effect by dividing an effect (expressed in annoyance units) by the amount of increase in annoyance (expressed in annoyance units) that is associated with a one-decibel increase in steady-state noise exposure.
DNL	Day-night Average Sound Level, [dB(A)]
GDCN	Global Daily Climatology Network
KNMI	Royal Netherlands Meteorological Institute

EXECUTIVE SUMMARY

This report analyzes three sets of data to determine whether meteorological conditions, including temperature, amount of precipitation and wind speed affect residents' reactions to environmental noise. The first data set is based on seven years of continuous surveys of the population of the Netherlands. The second and third data sets are based on 41previous community surveys from 14 countries that contain measures of noise exposure and social survey data for more than 53,000 responses to that noise. The continuous Netherlands survey shows a clear seasonal pattern in residents' annoyance with road traffic, aircraft and railway noise in which the greatest annoyance is expressed around the summer months and the least in the winter months. Five of seven previously published studies have also found evidence of seasonal effects.

All three data sets analyzed in this report find a pattern of increasing noise annoyance with increasing temperature but this pattern is not statistically significant. Other mixed evidence suggests that annoyance is also increased by more hours of sunshine, decreasing precipitation, and decreasing wind speeds. One explanation for such meteorological factors' effects is that they encourage opening windows and more outdoor activities and thus could lead to higher noise exposure to environmental noise such as aircraft and road traffic.

The analyses of these data sets provide some weak evidence on other issues. The analyses find some evidence that noise annoyance is affected by the average temperature conditions in the months preceding residents' interviews, but find no evidence that noise annoyance is particularly strongly affected by meteorological conditions in the days immediately preceding residents' interviews. The best estimate from these data is that a 15° (C) difference in temperature has about the same effect on noise annoyance as does a one to three-decibel difference in noise exposure. Estimates from the DLO Netherlands data are relatively precise, but are based on only the particular set of correlated climatic conditions found in the Netherlands. All estimates of meteorological effects from the combined data from the 41 season-linked studies are imprecise and significance tests indicate that these analyses cannot exclude either the possibility that temperature has little or no effect or that temperature has an important effect, with a 15° difference in temperature having the same effect as a five to ten decibel difference in noise exposure.

Each of the data sets used in these analyses has different weaknesses that limit the accuracy of the results it could provide. Stronger results could be expected in the future if these and other data sets were developed that include noise exposure data and date of interview for all interviews; closely link the respondent's location with permanent weather stations; include a wide range of meteorological conditions that are not highly correlated; and use uniform social survey methods and noise annoyance measures.

1.0 INTRODUCTION

Residents' reactions to the noise environments at their residences have been widely studied. Several hundred studies have been conducted in which residents' reactions, measured in social surveys, have been related to the long-term noise environments, as measured in acoustical surveys and noise estimation programs (Fields 2001). Estimates of reactions to different types of noise sources have been published based on the mean estimates from diverse surveys and are widely available for environmental noise planning purposes (Fidell *et al.* 1991;Miedema and Vos 1998;Schultz 1978). Considerable attention has been directed at ways in which residents' characteristics and the acoustical environment can affect residents' reactions to noise. Relatively little attention has been devoted to other types of factors that are normally relatively uniform within any one social survey such as meteorological and cultural conditions.

This report examines the effects of two types of meteorological conditions on residents' annoyance with environmental noise. Short-term, meteorological effects (weather effects) are generally referred to as "seasonal" effects in this report. Long-term meteorological conditions are generally referred to as "climate" effects in the report. Either type of meteorological effect, if present, could have important implications for both noise research and noise policy. For noise-annoyance survey design purposes, seasonal effects are a potentially confounding factor for any comparisons between studies or, for longitudinal studies, within a study if different waves of surveys are conducted during periods with different meteorological conditions. For example, longitudinal studies of reactions to changes in noise environments could easily confound the effects of a change in noise conditions with differences in meteorological conditions at the time of the survey. Such meteorological and climatic differences become especially important if attempts are made to set uniform noise policies for different countries or regions that vary greatly in their meteorological conditions. For example, if colder temperatures are associated with reduced reactions to noise, policy issues arise about whether the same noise annoyance thresholds are appropriate for different countries in the European Union.

Although meteorological effects, primarily temperature, have been considered in at least seven noise response surveys, these surveys have been limited to a small number of communities and a limited range of climatic conditions. Each survey has compared reactions at only a few points in time (for example between one winter survey and one summer survey). Most of these surveys have found some evidence for seasonal differences in response, but due to study designs that make observations under only two conditions, they have not attempted to assess the independent effects of different aspects of the meteorological conditions or attempted to model seasonal responses for an entire year.

The present report analyzes existing data from social surveys to study reactions under different meteorological conditions. Two distinct analytic approaches are taken to overcome the previous studies' limitations. The first approach is to study a single population over a long period of time. This approach is pursued with an analysis of seven years of data from the Netherlands Continuous Life Information Survey (DLO). The second approach is to study a set of diverse, independently-designed studies that are available from a single archive but which were conducted under very different meteorological conditions. This approach is pursued through the analysis of two data sets that were obtained in cooperation with the Netherlands TNO noise data archive. One of the data sets, the day-linked data set, consists of 12 surveys in which individuals' responses can be related to the meteorological conditions on the date of their interview. The second data set, the season-linked data set, adds additional surveys from the data archive to construct a data base of 41 surveys where the individuals' responses are linked to only the season of the interview (identified by month) and to a thirty-year average of the meteorological conditions for a month in that season. In analyses of this season-linked data set, the day and the year of the interview are not considered in the analyses.

1.1 Basis for expecting meteorological effects on noise reactions

This report does not attempt to provide a formal model for meteorological effects. This section presents, however, a few of the factors that might be considered for such a model. A previous publication contains an attempt to describe some of these factors and to present them in a graphical format (Fields *et al.* 2000).

A simple acoustical basis for the effect of meteorological conditions is provided by the observation that residents' exposure to exterior transportation noises will vary depending upon the amount of time they spend out of doors and the amount of time their windows are open. As a result the noise exposure would be expected to increase as temperature increases, the extent of precipitation decreases, and the wind speed decreases. Of course there could be regional and national variations in outdoor activity patterns and window opening practices that could affect these exposure patterns. For example, the residential air conditioning in some countries may result in a high level of acoustical insulation in warm seasons, some cultures value open windows for "fresh air" in the nighttime in almost any season, and particular seasons may have accompanying outdoor activities that are likely to occur with little regard to the meteorological conditions. None-the-less the concept of individual acoustical exposure provides a possible basis for combining the effects of a variety of meteorological conditions.

This simple acoustical model may need to be supplemented by other considerations. There may be some adaptation of populations with different long term climatic conditions. For example, populations in warmer countries may be less affected by warm weather noise exposure because they experience such exposure for a longer period of the year. A similar pattern of warm/cold climate differences would be generated if residents in colder climates attach special importance to outdoor activities during their relative short periods of outdoor exposure. In addition, there could be cultural factors that would attach more or less importance to noise-related disturbances regardless of season. The possibility of general seasonal variations in people's moods and sensitivity to environmental nuisances could also be considered.

Of course the possibility of variations in differences in acoustical source emissions for particular local areas should also be considered. These can be substantial for specific, communities with major seasonal variations in population or for short periods of time (for example, resort communities). It is possible, but unlikely, that such differences have an important effect on much of the residential population. Pavements are not usually wet enough, even during wet seasons, to substantially effect noise exposures that are averaged over month-long periods. Variations in numbers of aircraft or road traffic vehicles are not usually of substantial acoustical importance in residential areas for noise indices such as DNL for which a doubling of numbers of events generates only a three-decibel increase in noise exposure. Perhaps the main possibility for such variations might be for local road traffic and neighborhood noise in European countries where a large proportion of the population takes vacations within the same small number of weeks in the summer.

1.2 Overview of data available for analyses

The strongest data sets for analyses of meteorological effects on noise annoyance consist of three linked components. Those components and a few of the characteristics that distinguish strong from weak components for meteorological effect surveys are :

* *Social survey data with each resident's reaction to specified noise sources.*
  Strong social surveys will: 1) contain identical noise-annoyance questions, 2) be designed with interviews spread over a broad range of noise levels, 3) be conducted under a wide range of meteorological conditions, 4) be designed so that meteorological conditions are not correlated with noise levels, methodological procedures, or other variables.
* *Acoustical data on the exposure of residents' dwelling to the noise sources.*
  Acoustical data should: 1) be expressed in the same unit for all respondents, 2) characterize a standard position at all respondents' dwellings, and 3) be of a known level of accuracy for the estimation of the exposure at the respondents' dwelling
* *Meteorological data about the conditions for the area on dates preceding each resident's interview.*
  Meteorological data should: 1) be available on a daily basis during the days and months preceding the interview, 2) be available on a daily or monthly aggregated basis for several years before the interview, and 3) be representative of the meteorological conditions present at the individuals' residences.

Since the meteorological data come from weather stations that may be unfamiliar to the investigator, correctly linking the meteorological data and the interview data may be difficult. In preparing the data sets for the analyses in this report, the two parts of this linking that were found to be most difficult or impossible were:

* Determining the exact date or, in many cases, even the year of the interview

* Determining which, if any, meteorological station should be linked to a specific study area

The three data sets used in this report differed in the sources of the social survey, acoustical, and meteorological data. Table 1 summarizes some of these differences. More details about the meteorological data are available in Table 12.

1.2.1 The Netherlands Continuous Life Information Survey (DLO)

The Central Bureau of Statistics of the Netherlands has conducted the Continuous Life Information Survey (DLO) for more than a decade. The present analysis is based on seven years of data, the 84 months from January 1990 through December 1996. The DLO survey is conducted on a continuous basis throughout the year with a nationally-representative sample (18 years of age and older) that is redrawn every four weeks. In the seven-year period over 35,000 residents were interviewed with an average of about 400 a month. The response rates were less than 50%.

The individual data were not available for the DLO data set. Instead, the Netherlands Statistical Agency (CSB) provided the mean annoyance reaction for each month. This mean reaction was based on weighted data that adjusted for non-response. The approximate number of respondents for each month were indicated on the dataset for each month. All of the statistical tests for the DLO data are conducted with monthly values (n = 84 = 7 years x 12 months) as the unit of analysis and simple random sampling assumptions as it is not possible with the existing data to take into account the details of the within-month sample design.

This general-purpose survey has included questions about noise annoyance since at least April 1989. For the seven-year study period in this report, the questions remained similar with revisions being made at only one point, in January of 1994. The basic annoyance questions are reproduced in full in Appendix A in English (Table 15) and in Dutch (Table 16).

This survey provides the only source of information about the same population's reaction to noise in every month of the year. Since the survey methodology has remained the same over the seven years and the only question wording change was made in January of 1994, there are no methodological differences to be confounded with meteorological conditions. The nationwide sample design means that there should only be random differences in noise exposure between the respondents in different time periods.

While the survey is valuable for examining seasonal differences, the information in Table 1 shows that its value is limited by three major aspects of the design: 1) the respondents' noise exposures are not known, 2) the location of the respondents within the Netherlands is not known, and 3) only the month (not the day) of the interview is known. These limitations mean that the data cannot be used to test for the effect of the weather in the days immediately preceding the interview and that the data cannot clearly test the relative importance of seasonal effects and noise exposure effects. The absence of information about interview locations is less important for the Netherlands than it would be for larger, more geographically diverse countries. All respondents were assumed to have experienced the same meteorological conditions as were measured at a central location in the Netherlands (De Bilt). An analysis of the variation in monthly meteorological indices over the 84 months at 6 locations in the Netherlands determined that there was not a statistically significant difference between the temperature and precipitation indices at the six sites, but that here were distinct differences in the wind speed and sunshine indices with the two coastal stations having distinctly higher wind speeds and numbers of hours of sunlight. As a result, the effects of these variables may be somewhat underestimated in the analyses or may be confounded with the effects of correlated variables. The averaging of reactions across different noise exposures and inability to link interviews to particular day-linked meteorological data, may have also attenuated the observed relationships for this survey.

Table 1: Characteristics of noise, meteorological and social survey data in three data sets

Characteristic	Data set		
	Day-linked data set	Season-linked data set	Netherlands Continuous Life Information survey (DLO)
Social survey characteristics			
Number of responses[a]	15,107 (7,713 with precipitation data)	53,130 (47,825 with wind speed data)	35,000 (approximate)
Number of respondents	13,100 (approximate)	49,400 (approximate)	35,000 (approximate)
Number of studies	12 (16 noise sources evaluated)	41 (48 noise sources evaluated)	1 (4 noise sources evaluated)
Number of sample PSUs	28 (cities or other areas within the 12 studies)	41 (studies)	84 (months)
Settings	7 countries (5 languages)	14 countries (9 languages)	Netherlands (one language)
Reaction question	Intensity of annoyance (Diverse wordings)	Intensity of annoyance (Diverse wordings)	Frequency of annoyance[e] (1990-93 & 1994-96 versions)
Study methods	Methods differ between studies	Methods differ between studies	Uniform for data set
Noise sources studied	Road traffic Aircraft	Road traffic Aircraft Railway	Road traffic Aircraft Railway (Neighbors)
Aggregation	Individual interviews	Individual interviews	Group averages of each month's interviews
Within-study variation in weather	Small	Small	Large
Acoustical data			
Acoustical index	DNL	DNL	(No noise data)
Estimation & measurement methods	Methods differ between studies	Methods differ between studies	(No noise data, but same population for all years.)
Meteorological data			
Aggregation in base data	Daily data	30-year averages for each month (total of 12 values)	Monthly data

Characteristic	Data set		
	Day-linked data set	Season-linked data set	Netherlands Continuous Life Information survey (DLO)
Integration time (default)[b]	91 days up to and including the interview day	3 months up to and including the interview month	2 months preceding the interview month
Meteorological data (means of daily values)	Temperature (C)[c] Precipitation *(total - mm per24 hours)*	Temperature(C)[c] Precipitation *(total (mm) & number of days with precipitation)* Sunshine *(minutes per 24 hours)* Wind speed *(mean - meter/s)*	Temperature(C)[c] Precipitation *(total (mm) & number of hours with precipitation)* Sunshine *(minutes & % of daylight hours with sunshine)* Wind speed *(mean & average of hourly maximums)*
Sources[d]	UK Met office, for British sites, GDCN Version 1.0 for all other sites	Wereld Klimaat Informatie (WKI) data base from KNMI	KNMI (Web site)
Information for linking meteorological and social survey data			
Location[f]	City of survey or nearby city	City of survey or nearest location in the same country within the same climate zone	One central location in the Netherlands (De Bilt)
Data on date of survey interviews	Day Month Year	Month (Within 3- month period)	Month Year

a. If respondents are asked about two noise sources for which noise data are available, a single interview usually provides two responses in the day-linked and season-linked data sets
b. This "default" integration period is used in the analyses in this article unless otherwise noted. The interview month is excluded from the DLO data because respondents interviewed early in a month would not have experienced the entire month's conditions. The nominal "interview" month is included for the season-linked data set because this "nominal" month is sometimes in the middle of a two or three-month interviewing period.
c. Three measures of temperature (in Celsius) are available for all three data sets:average of the 24 hourly values, and the maximum and minimum daily values. The algorithm for combining the 24 hourly values may vary between studies.
d. The sources of the meteorological data for the three data sets are:
- Day-linked data set: Data for most studies come from the Global Daily Climatology Network (GDCN) Version 1.0 data set that was produced in July 2002 by the Climate Analysis Branch of the National Climate Data Center of the National Oceanic and Atmospheric Administration (NOAA) (www.ncdc.noaa.gov/gden.html). Daily weather data for the UK were ordered from the UK MET Office (www.meto.gov.uk).
- Season-linked data set: In 2003 the Wereld Klimaat Informatie (WKI) data base from KNMI (Royal Netherlands Meteorological Institute at http://www.knmi.nl) provided 30-year averages (1961-1990) for each month of the year for a large number of sites around the world in a graphic product (in Dutch).
- Continuous DLO survey: The KNMI data set (De Bilt) includs data on mean air pressure (hPa), maximum wind gusts, wind direction, and cloud cover (octants of sky visible) that were not examined in any analyses. In January 2003 the definitions appear on http://www.knmi.nl/voor/kd/lijsten/daggem/uitleg_dagklim_en_html.
e. The annoyance questions for the DLO survey are shown in Dutch and an English translation in Appendix A.
f. For two UK surveys (UKD-072, UKD-116) and all of The Netherlands' surveys a single central meteorological station's data were used to represent the meteorological conditions for the entire country.

1.2.2 The day-linked data set

A search of the TNO archived noise annoyance surveys identified 13 studies for which the exact date of each interview was known. The twelve of these data sets (listed in Table 3) that permitted a close match between survey locations and meteorological station data constitute the date-specific data set with 15,107 responses. In some cases some interviews from a selected study were excluded from the day-linked data set. Interviews were excluded, for example, if they were conducted in periods after a recent change in noise conditions.

Although this data set shares many of its strengths and weakness with that of the season-linked data set that also comes from the TNO data archive, it has one major strength: temperature indices are merged on the social survey data set for each of the 15,107 responses for the date of interview and for every day preceding the interview for the previous 11 years (i.e. approximately 4,000 days of temperature data per respondent). Precipitation data are available on a similar basis for a lesser 7,713 responses because precipitation data were not available for some meteorological stations. This day-linked meteorological data set provides the data to examine the effects of meteorological conditions in the days, weeks, and months immediately preceding the interview. The meteorological data for Great Britain were purchased from the United Kingdom Met office. Meteorological data for all other countries for the day-linked analysis were purchased from the National Climate Data Center of the National Oceanic and Atmospheric Administration (NOAA) of the United States. In each case, the longitude, latitude, and altitude of the meteorological stations were examined before linking the station to the study sites for the survey respondents.

1.2.3 The season-linked data set

The search of the TNO data archive identified a total of 41 surveys, listed in Table 3 that contain 53,130 responses for which the months of the study field period can be determined and the study location could be linked to a meteorological station's data. These 41 surveys include reactions to 48 noise sources. These 41 surveys include the 12 surveys and 15,107 responses from the day-linked data set. These 41 surveys provide social survey and acoustical data with most of the same types of strengths and weaknesses as were described in the previous section for the day-linked data set. The primary difference between the two data sets is in the specificity of the interview date information and the accompanying types of meteorological indices that are available for analyses.

Table 3 displays the range in climatic and meteorological conditions found in the study sites. Reactions are studied in areas that extend over approximately a 15 degree range in temperature (Celsius), 5 millimeter range in daily precipitation and 5 meter/sec range in wind velocity. The combination of seasonal temperature and precipitation patterns are captured by the codes of the Köppen Climate Classification System in Table 2, the most widely used system for classifying the world's climates.(Critchfield 1983). In Table 3 it is seen that about two-thirds of the studies come from moist mid latitude climates (C -__) while such sites with warm summers and no dry period (Code Cfa) account for about half of the study sites.

Table 2: Codes for climates in the Köppen Climate Classification System

Character in Köppen climate classification system (1st, 2nd and 3rd character codes)		
1st	2nd	3rd
A=tropical moist (all months>18° Celsius)		
B=dry climates	w =dry winter	h=hot (mean>18°C) k =cool (<18°C)
C=moist mid-latitude with mild winter	s = dry summer	a = hot summer b = warm summers c = cool summers
D=moist mid-latitude with cold winter	f = no dry period	
E=polar - extremely cold winter and summer		

For most of the season-linked studies, the date-of-survey information comes from publications or personal communications with researchers that more-or-less precisely define the social survey field period. To link these data to the meteorological data a nominal "interview" month is assigned to each respondent. When the interviews with groups of respondents were spread over two or three months, a month in which most interviews were concentrated or the month in the middle of the interviewing period was chosen. No studies or interviews were included if the interview could not be placed within a three-month period. In some cases, the precise year of the study's field work was also uncertain. At least one study was conducted at the same season in two years but interviews were not identified by the year of interview in the data set. These uncertainties and the ready availability of long-term meteorological data lead to the decision to use thirty-year averages (1961 - 1990) to characterize the meteorological conditions for each month of the year. The primary meteorological index for each response to this survey is the average of three of these 30-year averaged months, the month of the survey and the two preceding months. The data were obtained from the Wereld Klimaat Informatie (WKI) data base, an electronic publication that includes a graphical presentation format (in Dutch) that is available from the Royal Netherlands Meteorological Institute (KNMI).

The primary weakness of the season-linked data set, relative to the day-linked data set, is the less precise linkage between the interview date and the meteorological conditions. The primary strength is the larger number of interviews, studies, and climatic conditions. This advantage provides data to attempt to determine whether there is both a climatic effect (i.e. differences between reactions in different locations even under similar acoustical and short-term meteorological conditions.) as well as a seasonal effect (i.e. variations in reactions at different times of year in a single location).

Table 3: Noise annoyance surveys used in the day-linked and season-linked analyses

Description of study				Climate (Köppen classification)	Conditions for survey period - avr. over sites (N of int's)				Yearly range over site(s) (N of interviews)			Response scale points & type[a]
Type	Study [Catalog number (Fields 2001)]	Noise source	Study year		Temperature (90 days before)	Temperature (3-month, 30-year avr.)	Precipitation (3-month, 30-yr avr.)	Wind speed (3-month, 30-yr avr.)	Temperature (Coldest month)	Temperature (Warmest month)	Temperature (range)	
Day-linked studies (also in Season-linked data set)	1967 USA Four-Airport (Phase I Tracor) (USA-022)	Aircraft	1967	Cfa, Csa, Dfa	13.5 (3499)	15.4 (3499)	3.2 (3499)	5.3 (3499)	2.8 (3499)	24.2 (3499)	21.4 (3499)	5-Annoy: Unipolar
	1973 Los Angeles Airport Night (USA-082)	Aircraft	1973	Csa	14.2 (702)	14.7 (702)	4.5 (702)	4.1 (702)	13.8 (702)	20.6 (702)	6.8 (702)	5-Annoy: Unipolar
	1974 Dordrecht Home Sound Insulation (NET-106)	Road	1974	Cfb	6.1 (420)	5.6 (420)	1.7 (420)	5.6 (420)	2.8 (420)	16.8 (420)	14.0 (420)	6>5Annoy :Unipolar[b]
	1975-76 Southern Ontario Community (CAN-121)	Road	1975-76	Dfb	11.1 (1303)	15.1 (1303)	2.2 (1303)	4.1 (1303)	-4.5 (1304)	22.1 (1304)	26.6 (1304)	9>5Annoy : Bipolar
	1979 Burbank Aircraft Noise Change (USA-203)	Aircraft	1979	Csa	20.9 (924)	20.6 (924)	6.6 (924)	4.0 (924)	13.8 (924)	20.6 (924)	6.8 (924)	5-Annoy: Unipolar
	1984 Glasgow Combined Aircraft/Road Traffic (UKD-238)	Aircraft	1984	Cfb	8.2 (588)	9.6 (597)	2.1 (597)	. (0)	2.8 (598)	14.4 (598)	11.6 (598)	10-Annoy: Unipolar
		Road	1984	Cfb	8.2 (527)	9.6 (535)	2.1 (535)	. (0)	2.8 (536)	14.4 (536)	11.6 (536)	10-Annoy: Unipolar
	1984-1986 French Combined Aircraft/Road Traffic (FRA-239)	Aircraft	1984	Cfb	14.4 (564)	15.4 (565)	1.9 (565)	3.7 (565)	3.4 (565)	18.4 (565)	15.0 (565)	10-Annoy: Unipolar
		Road	1984	Cfb	14.5 (523)	15.4 (524)	1.9 (524)	3.7 (524)	3.4 (524)	18.4 (524)	15.0 (524)	10-Annoy: Unipolar
	1984 Schiphol Combined Aircraft/Road Traffic (NET-240)	Aircraft	1984	Cfb	14.9 (569)	12.9 (573)	2.3 (573)	4.5 (573)	2.4 (573)	16.6 (573)	14.2 (573)	10-Annoy: Unipolar
		Road	1984	Cfb	14.7 (471)	12.7 (473)	2.3 (473)	4.6 (473)	2.4 (473)	16.6 (473)	14.2 (473)	10-Annoy: Unipolar
	1982 United Kingdom Aircraft Noise Index (UKD-242)	Aircraft	1980, 1982	Cfb	15.1 (1993)	14.4 (1993)	1.7 (1993)	3.6 (1993)	3.5 (1993)	16.5 (1993)	13.0 (1993)	4-Annoy: Unipolar

Description of study				Climate (Köppen classification)	Conditions for survey period - avr. over sites (N of int's)				Yearly range over site(s) (N of interviews)			Response scale points & type[a]
Type	Study [Catalog number (Fields 2001)]	Noise source	Study year		Temperature (90 days before)	Temperature (3-month, 30-year avr.)	Precipitation (3-month, 30-yr avr.)	Wind speed (3-month, 30-yr avr.)	Temperature (Coldest month)	Temperature (Warmest month)	Temperature (range)	
		Road	1982	Cfb	14.8 (410)	14.1 (410)	1.7 (410)	3.6 (410)	3.5 (410)	16.5 (410)	13.0 (410)	4-Annoy: Unipolar
	1975 Amsterdam Home Sound Insulation (NET-258)	Road	1975	Cfb	4.9 (364)	4.5 (364)	1.6 (364)	5.8 (364)	2.4 (365)	16.6 (365)	14.2 (365)	6>5Annoy :Unipolar[b]
	1989 Oslo Airport (NOR-311)	Aircraft	1989	Dfb	3.8 (1548)	.1 (1548)	1.4 (1548)	2.1 (1548)	-4.3 (1548)	16.4 (1548)	20.7 (1548)	2 Questions[b]#31
	1992-93 Bodoe Aircraft Military Exercise (NOR-328)	Aircraft	1992	Cfc	1.1 (702)	-1.5 (702)	2.8 (702)	. (0)	-2.2 (702)	12.5 (702)	14.7 (702)	4-Annoy: Unipolar
	Subtotal				11.8 (15107)	12.0 (15132)	2.6 (15132)	4.2 (13298)	2.5 (15136)	19.0 (15136)	16.5 (15136)	
Season-(only)-linked studies	1967 Heathrow Aircraft (2nd Heathrow) (UKD-024)	Aircraft	1967	Cfb	. (0)	15.5 (4515)	1.8 (4515)	3.3 (4515)	3.5 (4515)	16.5 (4515)	13.0 (4515)	4-Annoy: Unipolar
	1969 USA Three-Airport (Phase II Tracor) (USA-032)	Aircraft	1969	Aw, Cfa, Dfb	. (0)	21.7 (1166)	2.5 (1166)	5.7 (1166)	-1.8 (1166)	23.1 (1166)	24.9 (1166)	5-Annoy: Unipolar
	1970 USA Small City Airports (USA-044)	Aircraft	1970-71	Bsk, Cfa	. (0)	7.9 (1954)	2.5 (1954)	2.7 (1954)	1.9 (1954)	24.2 (1954)	22.3 (1954)	5-Annoy: Unipolar
	1971 Swiss Three-City (SWI-053)	Aircraft	1971-72	Cfb	. (0)	8.8 (3934)	3.1 (3934)	3.1 (3934)	-1.0 (3934)	16.7 (3934)	17.7 (3934)	11-Annoy: Unipolar
		Road	1972	Cfb	. (0)	11.6 (945)	3.7 (945)	3.0 (945)	-1.0 (945)	16.7 (945)	17.7 (945)	11-Annoy: Unipolar[b]
	1972 Paris Area Railway (FRA-063)	Railway	1972	Cfb	. (0)	6.8 (344)	1.6 (344)	4.3 (344)	3.4 (344)	18.4 (344)	15.0 (344)	7-Annoy: Unipolar[b]
	1972 B.R.S. London Traffic (UKD-071)	Road	1972	Cfb	. (0)	11.2 (2903)	1.8 (2903)	3.8 (2903)	3.5 (2903)	16.5 (2903)	13.0 (2903)	7>6Annoy :Bipolar
	1972 English Road Traffic (UKD-072)	Road	1972	Cfb	. (0)	12.7 (1031)	1.7 (1031)	4.1 (1031)	3.1 (1040)	15.8 (1040)	12.7 (1040)	7>6Annoy :Bipolar

Description of study				Climate (Köppen classification)	Conditions for survey period - avr. over sites (N of int's)				Yearly range over site(s) (N of interviews)			Response scale points & type[a]
Type	Study [Catalog number (Fields 2001)]	Noise source	Study year		Temperature (90 days before)	Temperature (3-month, 30-year avr.)	Precipitation (3-month, 30-yr avr.)	Wind speed (3-month, 30-yr avr.)	Temperature (Coldest month)	Temperature (Warmest month)	Temperature (range)	
	1973 French Ten-City Traffic (FRA-092)	Road	1973-74	Cfb, Csa	. (0)	17.1 (975)	1.9 (975)	3.1 (897)	3.1 (975)	20.1 (975)	17.0 (975)	4-Annoy: Unipolar
	1975 British National Railway (UKD-116)	Railway	1975-76	Cfb	. (0)	8.5 (1382)	1.9 (1382)	4.3 (1382)	3.1 (1385)	15.8 (1385)	12.7 (1385)	4-Annoy: Unipolar
	1975 Western Ontario University Traffic (CAN-120)	Road	1976	Dfb	. (0)	-.4 (1149)	2.3 (1149)	5.9 (1149)	-4.5 (1149)	22.1 (1149)	26.6 (1149)	7-Annoy: Unipolar
	1977 Netherlands Railway (NET-153)	Railway	1977	Cfb	. (0)	13.7 (671)	2.3 (671)	3.0 (671)	2.2 (671)	16.8 (671)	14.6 (671)	2 Questions[b]
	1977 London Area Panel (UKD-157)	Road	1977-78	Cfb	. (0)	6.2 (364)	2.4 (364)	3.9 (364)	3.5 (364)	16.5 (364)	13.0 (364)	4-Annoy: Unipolar
	1978 Canadian Four-Airport (CAN-168)	Aircraft	1978	Dfb	. (0)	15.0 (630)	2.2 (630)	4.1 (630)	-4.5 (631)	22.1 (631)	26.6 (631)	11-Annoy: Unipolar
		Road	1978	Dfb	. (0)	15.0 (567)	2.2 (567)	4.1 (567)	-4.5 (568)	22.1 (568)	26.6 (568)	
	1981 John Wayne Airport Operation Change (USA-204)	Aircraft	1981	Csa	. (0)	21.0 (601)	6.5 (601)	4.0 (601)	13.8 (601)	20.6 (601)	6.8 (601)	2 Questions[b]
	1980 Australian Five-Airport (AUL-210)	Aircraft	1980	Bsh, Cfb, Csa	. (0)	18.7 (3288)	3.2 (3288)	4.1 (3288)	11.7 (3288)	22.3 (3288)	-10.6 (3288)	5-Annoy: Unipolar
	1983 Netherlands Tram/Road Traffic (NET-276)	Road	1983	Cfb	. (0)	14.7 (697)	2.1 (697)	5.0 (697)	2.8 (697)	16.8 (697)	14.0 (697)	2 Questions[b]
		Railway	1983	Cfb	. (0)	14.7 (265)	2.1 (265)	5.0 (265)	2.8 (265)	16.8 (265)	14.0 (265)	
	1989 Austrian Alps Road Traffic (AUS-329)	Road	1989	Cfb	. (0)	10.0 (826)	2.0 (826)	1.2 (826)	-1.1 (826)	18.7 (826)	19.8 (826)	4-Annoy: Unipolar
	1990 Modena Traffic (ITL-350)	Road	1990	Cfa	. (0)	17.6 (908)	2.0 (908)	. (0)	2.4 (908)	24.6 (908)	22.2 (908)	2 Questions[b]

Description of study				Climate (Köppen classification)	Conditions for survey period - avr. over sites (N of int's)				Yearly range over site(s) (N of interviews)			Response scale points & type[a]
Type	Study [Catalog number (Fields 2001)]	Noise source	Study year		Temperature (90 days before)	Temperature (3-month, 30-year avr.)	Precipitation (3-month, 30-yr avr.)	Wind speed (3-month, 30-yr avr.)	Temperature (Coldest month)	Temperature (Warmest month)	Temperature (range)	
	1993 Netherlands National Environmental (NET-361)	Road	1993	Cfb	. (0)	15.5 (880)	2.3 (880)	3.0 (880)	2.2 (880)	16.8 (880)	14.6 (880)	10-Annoy: Unipolar
	1984-85 Arnhem Trolley Bus Introduction (NET-362)	Road	1984	Cfb	. (0)	8.2 (293)	2.1 (293)	4.7 (293)	1.6 (293)	16.6 (293)	15.0 (293)	2 Questions[b]
	1993-94 French 18-Site Time-Of-Day (FRA-364)	Road	1993-94	Cfb, Csa	. (0)	11.2 (895)	2.2 (895)	3.2 (573)	2.7 (895)	19.0 (895)	16.3 (895)	11Annoy: Unipolar
	1989-93 Swedish Railway (SWE-365)	Railway	1989-93	Cfb	. (0)	6.0 (2532)	1.5 (2532)	4.2 (1540)	-2.4 (2532)	15.9 (2532)	18.3 (2532)	4-Annoy: Unipolar
	1990-91 Vaernes Aircraft Military Exercise (NOR-366)	Aircraft	1990	Cfc	. (0)	13.3 (391)	2.7 (391)	2.4 (391)	-3.2 (391)	13.9 (391)	17.1 (391)	4-Annoy: Unipolar
	Istanbul Trans-European Motorway (TRK-367)	Road	1996	Csa	. (0)	22.0 (154)	.9 (154)	. (0)	5.6 (154)	23.2 (154)	17.6 (154)	5-Annoy: Unipolar
	1996 Gothenburg Road Traffic (SWE-368)	Road	1996	Cfb	. (0)	-1.0 (1316)	2.0 (1316)	4.5 (1316)	-1.6 (1316)	16.2 (1316)	17.8 (1316)	4-Annoy: Unipolar
	1996 Kumamoto Road Traffic (JPN-369)	Road	1996	Dfa	. (0)	18.6 (823)	5.8 (823)	2.9 (823)	5.8 (823)	26.9 (823)	21.1 (823)	4-Annoy: Unipolar
	1985-86 Ratingen Dusseldorf Aircraft/Road (GER-372)	Road	1986	Cfb	. (0)	3.9 (559)	2.1 (559)	. (0)	2.2 (559)	18.1 (559)	15.9 (559)	11-Annoy: Unipolar
	1987 Dusseldorf/Ratingen Aircraft/ Road (GER-373)	Road	1987	Cfb	. (0)	6.9 (440)	2.0 (440)	. (0)	2.2 (440)	18.1 (440)	15.9 (440)	11-Annoy: Unipolar

Description of study				Climate (Köppen classification)	Conditions for survey period - avr. over sites (N of int's)				Yearly range over site(s) (N of interviews)			Response scale points & type[a]
Type	Study [Catalog number (Fields 2001)]	Noise source	Study year		Temperature (90 days before)	Temperature (3-month, 30-year avr.)	Precipitation (3-month, 30-yr avr.)	Wind speed (3-month, 30-yr avr.)	Temperature (Coldest month)	Temperature (Warmest month)	Tempera-ture (range)	
	1993 Greifswald Traffic (GER-374)	Road	1993	Cfb	. (0)	15.5 (582)	1.8 (582)	4.9 (582)	-1.0 (582)	18.1 (582)	19.1 (582)	5-Annoy: Unipolar
	Subtotal				. (0)	11.9 (37980)	2.4 (37980)	3.7 (34527)	2.1 (37994)	18.7 (37994)	14.7 (37994)	
Total					11.8 (15107)	11.9 (53112)	2.5 (53112)	3.9 (47825)	2.2 (53130)	18.8 (53130)	15.2 (53130)	

[a] Unless otherwise noted all scales ask about general, not specific annoyance or disturbance, and assign numeric scores that are separated by equal intervals with the end points of each scale being at the center of the first and last category (see text). The ">" in an expression "A>B" indicates that the original "A" points in the question were collapsed into "B" points when the points are scored. Unless otherwise noted in footnote "b" the "Unipolar" scales in the questionnaire were anchored with equally extreme positive and negative end positions and included a neutral word (e.g. "Not annoyed") in the center of the scale. The scoring of many of these studies' scales is available in a TNO report (Miedema 1992).

[b] The scoring for the annoyance scales on the following studies departed from the general description given in footnote "a".

SWI-053 The only available data collapses the 11-point, unipolar numeric scale into four categories that are assigned the mid-point of their combined categories resulting in the following scores being assigned: point 1=4.55, points 2,3,4=22.73, points 5,6,7,8=54.55, points 9,10,11=86.36.

ITL-350 - Two 11-point numeric scales asking about weekday and weekend annoyance are averaged to create a 21-point scale with equal intervals

NOR-311-Two 4-point verbal scales asking about indoor and outdoor annoyance are expanded into a 7-point scale with equal intervals

USA-204 - An answer of "not" on a screening annoyance question is scored 11.25. Other respondents were scored on a unipolar 5-point scale without equal intervals (11.25, 21.25, 43.75, 66.25, 88.75).

NET-106, NET-258 A 6-point verbal scale is collapsed to form five equally-spaced categories by collapsing the two lowest points ("definitely not annoying" and "not annoying").

NET-153 - An answer of "never" or "seldom" on a 4-point frequency of annoyance screening question was scored 10. Other respondents were scored on their answers to a 7-point verbal scale. The 7-point scale is collapsed into five equally spaced categories by scoring 10 for the lowest two categories ("definitely not annoying", "not annoying") and scoring 20 for either of the next two points ("just not annoying" "neutral") .

NET-362 and NET-376 - An answer of "never" or "seldom" on a 4-point frequency of annoyance screening question was scored 10. Other respondents were scored on answers to a 5-point verbal scale that was scored with five equal intervals

UKD-071, UKD-072 - A two lowest points of a bipolar 7-point numeric scale with ends labeled as "definitely satisfactory" and "definitely unsatisfactory" are collapsed to form 6 equally-spaced points..

FRA-063 A 7-point numeric scale is considered to be a unipolar scale on the assumption that the lowest point ("Trés supportable" - Quite acceptable) is not a positive rating.

1.2.4 Features of both the day-linked and season-linked data sets

Important strengths that the day-linked data set shares with the season-linked data set include:

1) Environmental noise data expressed in a common index (Day Night Noise Level - DNL) that have been normalized to the noisiest facade of each respondent's dwelling (after removing reflection effects)
2) Response scales that measure the intensity of annoyance
3) A large number of responses
4) A wide range of meteorological conditions (e.g. The maximum temperatures in the warmest month range from 12.5 degrees for a survey in Norway to 26.9 for one Japan in Table 3)
5) Relatively low correlations between the two different meteorological conditions (temperature and precipitation) because the studies come from different climates.

The primary weaknesses for both the day-linked and season-linked data sets are that:

1) The estimates of meteorological effects are almost entirely dependent upon comparisons between studies (not within studies) because there is relatively little variation in meteorological conditions within any of the 41 component studies, largely because interviews tend to be conducted within a short time period
2) There are considerable between-survey differences in language (9 languages), cultures (14 countries), annoyance question wording, questionnaire design, noise sources (road traffic, aircraft, and railway), and other aspects of the survey methods.
3) The effective sample size is very much smaller than the number of responses (53,130 for the season-linked data set) would seem to indicate because; 1] more than one response is sometimes given by a single individual (e.g. when a survey includes separate responses - and noise data- for more than one noise source), and 2] the errors in measurements within the twelve surveys are not independent.

The noise annoyance questions and response scales differ in wording and numbers of scale points. For the comparative analysis in this report each answer scale is expressed as a numeric quantity within a range of scores that are greater than zero and less than one-hundred by assuming that each of the response scale points is the mid-point of an interval along the same 0 - 100 point scale.

A single simple rule is used for creating the scores when the survey response scale is unipolar scale. At unipolar scale only measures negative reactions and extends from a low point of "no annoyance" to a high point (i.e. "extremely annoyed"). A bipolar scale includes responses for both positive and negative reactions to the sound. For the simple unipolar scale, the definition of the scale points is expressed as $score_i = 100\ (i\text{-}1/2)/m$ where "i" is the rank order of the scale point in the questionnaire and "m" is the number of points on the scale. As a result, the three points for the continuous DLO survey question are assigned scores of 16.7, 50.0, and 84.3. The rationale for this procedure is provided in (Miedema and Vos 1998).

When a balanced bipolar scale with "r" points is used with the middle point labeled with a neutral label (i.e. "no annoyance") then the positive responses are merged into a single category with the "no annoyance" responses and the resulting scale is scored just as for a unipolar scale that has (r+1)/2 points. For example the 11-point bipolar scale becomes a 6-point scale with the six points assumed to be the midpoints of six equal-sized intervals. The words that are used to describe the scale points for the unipolar scales and the negative end of the bipolar scales differ between studies. The simple rule presented in the previous paragraph is based on the assumptions that the variations between the wordings will not affect respondents' answers and thus that respondents react to the position of the points on the scale and that those points are spaced at equal intervals on some underlying, unobserved annoyance scale.

More complex rules that involve investigator judgment are required for other instances when, for example, screening questions are used, separate questions are used for annoyance experienced indoors and outdoors, separate questions were used for weekday and weekend, or the bipolar scale does not have a clearly labeled neutral point. Studies in which these types of judgments were required are listed in footnote b of Table 3. The investigator's judgement is occasionally invoked to decide when the scale point words create a bipolar scale or the words are so unusual as to violate the equal interval assumption. For example, for studies UKD-071 and UKD-072 respondents are asked to chose one of seven points on a numeric scale upon which the endpoints are labeled "definitely satisfactory" and "definitely unsatisfactory" and the mid point is not labeled. To recognize the bi-polar nature of the words, the lowest two points are collapsed and, with the remaining five points, are assumed to, as for other scales, be the midpoints of six equal sized intervals. For other scales it is assumed that differences in wordings of two scales should not alter the scoring. For example scores of 10, 30, 50, 70, 90 are assigned to both the 5-point scale for USA-203 with the five points being labeled "not at all, a little, moderately, very, extremely" annoying and for the 5-point scale from NET-362 with the labels "not annoying, just not annoying, just annoying, annoying, and very annoying". More details on the scoring and the rationale for scoring many questions are given in a TNO report (Miedema 1992).

Since the individual interviews are clustered within countries, studies, and cities, the interview observations are not statistically independent. As a result sampling errors have been assessed using a technique, jackknife repeated replication (Model JK1), that recognizes the dependence between observations in the sample (Brick *et al.* 2000;Frankel 1983). For the purposes of these sampling error calculations, the day-linked sample of 15,107 responses from 12 studies, are assumed to be clustered into 28 independent primary sampling units (PSU). The jackknife model used here does not assume that the sample of PSU's is stratified. A single study was divided into several PSU's when, for example, the study had been conducted in several cities. For the season-linked analysis the PSU's are assumed to be the 41 studies. Sampling errors using these techniques indicate that inferential statistics such as confidence intervals, are several times larger than would be estimated using incorrect simple random sampling assumptions.

2.0 SEASONAL DIFFERENCES IN NOISE REACTIONS: THE NETHERLANDS CONTINUOUS LIFE INFORMATION STUDY (DLO)

The strongest evidence about seasonal effects comes from the year-round Continuous Life Information Survey (DLO) in the Netherlands. Interviews that are available from seven years for every season give a firm basis for averaging over idiosyncratic aspects of particular years or months and, as a result, provide a more stable estimate of the reactions at different times of year.

2.1 Annoyance and meteorological variables for the DLO analysis

The analyses in this report are based on noise annoyance questions about four noise sources. Respondents were asked about being bothered at home by three transportation noise sources; aircraft noise; noise from trains, trams or subways; and noise from cars, lorries, motorcycles, or mopeds. The noise from these three sources comes from outside the home and, as a result, the levels experienced by residents could vary with the time of year as window opening or outside activity patterns differ. The noise from the fourth source, neighbors, could include interior noise from adjacent neighbors in multi-unit dwellings as well as noise from outdoors. The noise annoyance answer scale has three points and, unlike other noise annoyance surveys, has a middle point "sometimes" that refers to the frequency of annoyance. The scales are given in Appendix A in English (Table 15) and Dutch (Table 16).

In the analyses the respondents' answers are presented as the percentage annoyed (i.e. giving any answer other than the lowest point) and as three-point annoyance scores with the three points being scored 16.7, 50.0, or 83.3 (the midpoints of three intervals that extend from 0 to 100), as was explained earlier. In several analyses the three transportation noise sources are combined into a single index by averaging each individual's scores for the three transportation noise sources.

The meteorological variables that appear in the tables and figures in the DLO analyses are defined similarly and all are constrained by the fact that the month, but not the day, of the interview is known. Each respondent is assigned the average of the daily values for the two months preceding the interviewing month. This is consistent with the finding reported in the section on the day-linked analysis that reactions appear to be linked as closely to conditions over the preceding 90 days as they are to the conditions in the month of the survey. The meteorological conditions for the month of the interview are not included since respondents interviewed at the beginning of the month would not have experienced the conditions from the remainder of the month. Other analyses examined the effects of meteorological conditions when indices were formed using periods defined as the previous three months, the interview month, the two months including the interview month, the three months including the interview month, and the 90 days extending back from the middle of the interview month. Although values of regression and correlation coefficients changed somewhat, none of these indices was consistently more closely related to noise annoyance than was the two-preceding-month index used here. The meteorological conditions for the DLO analyses are monthly averages of the following daily indices:

Temperature Mean	= Mean of 24 hourly temperature values (degrees Celsius)
Temperature Max	= Maximum temperature reading in the day.
Temperature Min	= Minimum temperature reading in the day.
Wind speed	= Mean of wind speed during 24 hours (meters per second)
Sunshine	= Percent of the possible daylight hours with sunlight
Precipitation (mm.)	= Total of the precipitation during the 24 hours (millimeters)
Precipitation (hrs.)	= Number of hours during which there is precipitation.

2.2 Noise annoyance reactions

The average values for each month for both annoyance and meteorological indices from the survey appear in Table 4 and Figures 1 and 2. The first panel in Table 4 gives the percentage of the respondents who express annoyance by selecting either of the top two points on the three point scale. The middle panel averages the scores on the three-point annoyance scale where the three points are scored 16.67, 50.00, and 83.33 respectively. Annoyance with road traffic, aircraft, and railway noise all follow a general seasonal pattern with annoyance being highest in the summer and early autumn and lowest in the winter. Annoyance with neighbors does not follow the same pattern and is not clearly linked to season. The transportation noise annoyance patterns can be clearly discerned in Figure 1 if each of the four sets of annoyance reactions' data points is compared to their respective reference lines (dotted straight lines) at the yearly mean annoyance score. For example, road traffic annoyance, the most frequent source of annoyance, has reactions that are above the yearly average in June, July, August, September, and October and reactions that are below the yearly average in December, January, February, and March. The corresponding change in mean temperature is seen in Figure 1 to range between about 18 degrees (C) in the summer to about 3 in the winter.

Figure 2 graphs the six meteorological indices that are presented in the bottom panel of Table 4. To more clearly show the patterns, all the scales except temperature are shown as 10 times their actual value (e.g. the maximum precipitation of about 3 mm/day in January is plotted as 30 in the figure).

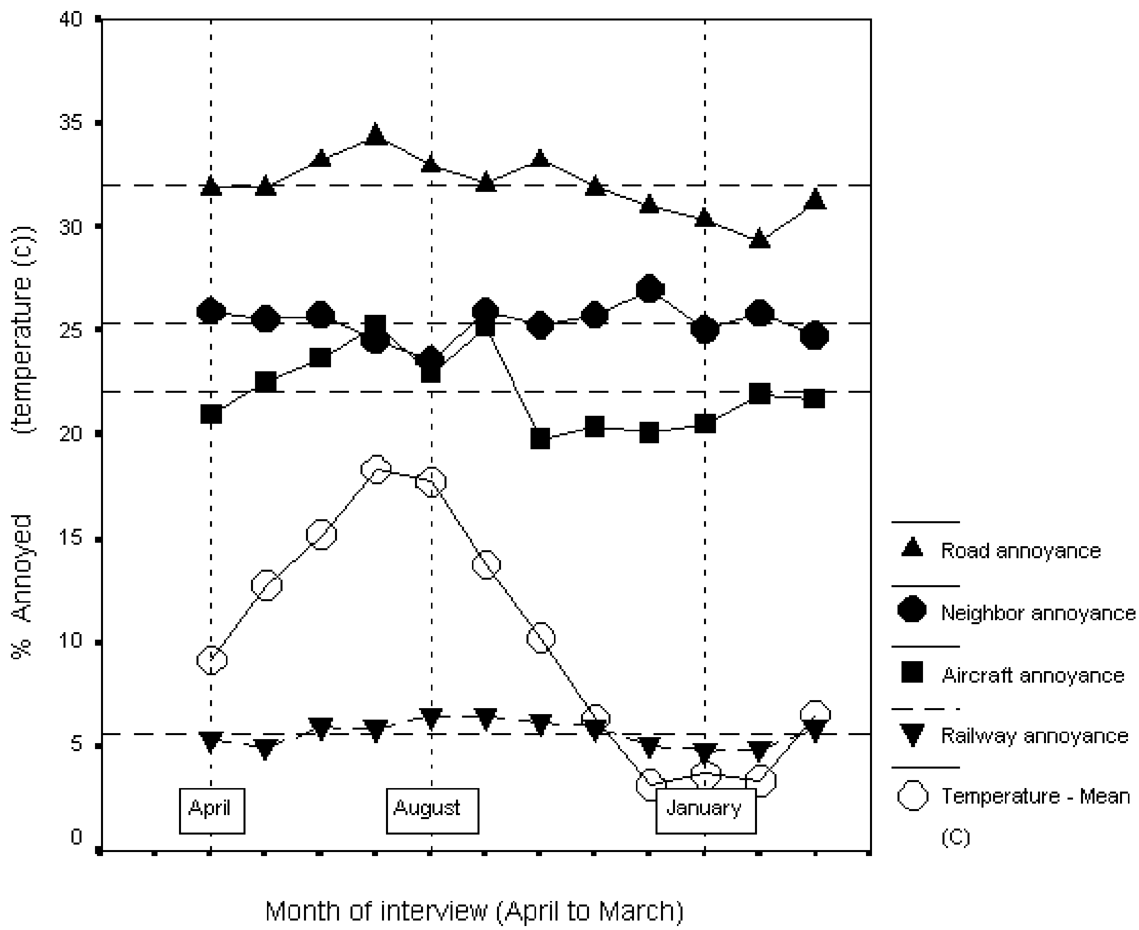

Figure 1 Annoyance reactions by month (DLO survey)

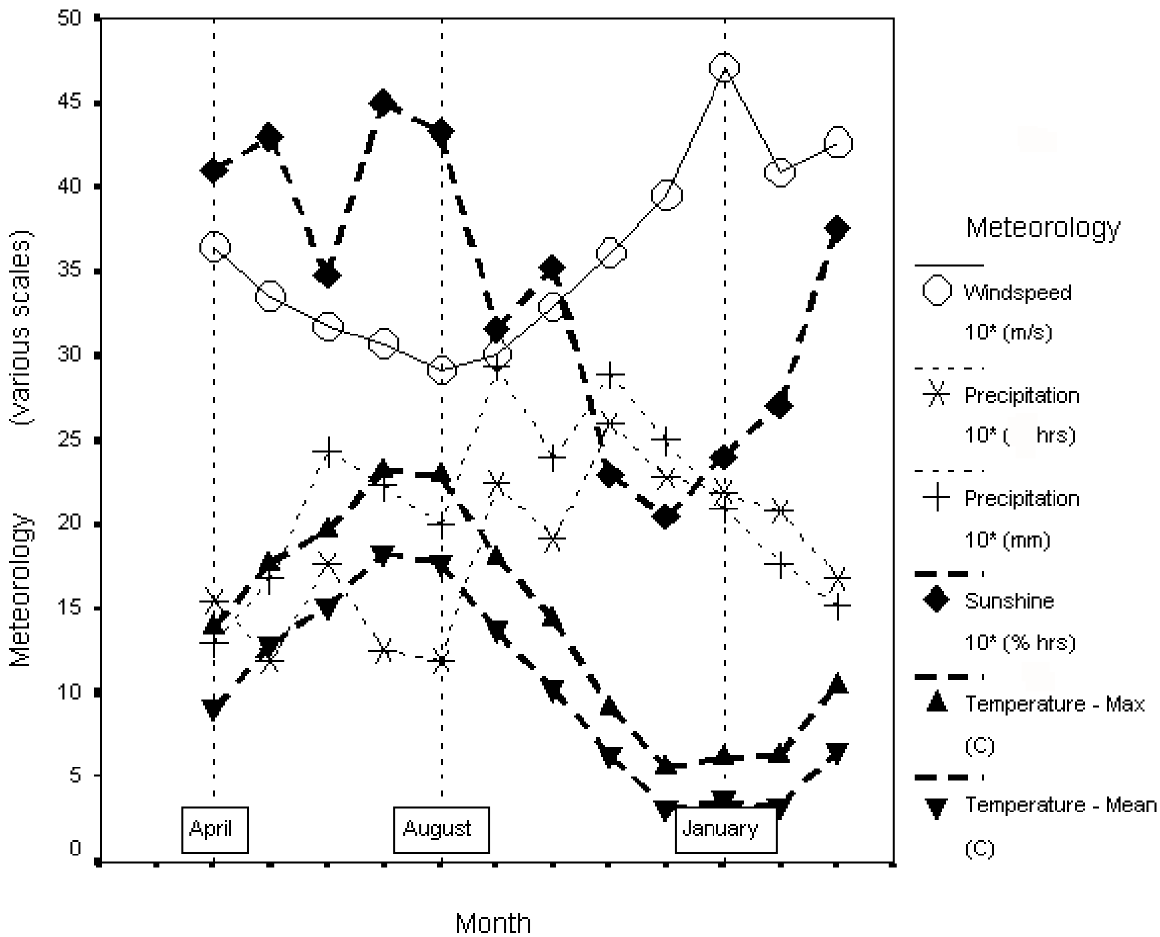

Figure 2 Meteorological conditions by month (continuous DLO survey)

Table 4: Seven-year average of noise reactions and meteorological conditions for the DLO survey (by month)

Variable[a]	Month of interview												Average (12 months)
	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	
Annoyance (% with any degree of annoyance)													
Road-Annoyed (%)	31.9%	31.9%	33.3%	34.4%	33.0%	32.1%	33.3%	31.9%	31.0%	30.3%	29.4%	31.3%	32.0%
Air -Annoyed (%)	21.0%	22.5%	23.7%	25.3%	22.9%	25.1%	19.8%	20.4%	20.1%	20.5%	22.0%	21.7%	22.1%
Rail-Annoyed (%)	5.4%	5.0%	5.9%	5.9%	6.5%	6.5%	6.2%	5.9%	5.1%	4.8%	4.9%	5.9%	5.7%
Neighbors-Annoyed (%)	25.9%	25.5%	25.8%	24.6%	23.6%	25.9%	25.3%	25.7%	27.0%	25.1%	25.8%	24.8%	25.4%
Annoyance score (3-point scale)													
Road-Annoyance (Score)	31.43	31.49	32.42	33.02	32.09	32.08	32.66	31.78	31.36	30.53	30.12	30.91	31.66
Air -Annoyance (Score)	25.36	26.20	26.71	27.11	25.83	27.00	25.04	25.15	24.84	25.13	25.81	25.50	25.81
Rail-Annoyance (Score)	19.06	18.89	19.39	19.48	19.60	19.58	19.62	19.36	19.01	18.88	18.79	19.25	19.24
Neighbors-Annoyance (Score)	28.53	28.01	28.06	27.67	27.18	28.46	28.13	28.36	28.70	28.04	28.25	27.51	28.08
Meteorological variables													
Temperature (Max C)	13.93	17.74	19.59	23.17	22.88	18.11	14.42	9.13	5.59	6.17	6.34	10.44	13.96
Temperature (Mean C)	9.15	12.82	15.18	18.29	17.73	13.74	10.29	6.36	3.13	3.65	3.28	6.56	10.02
Wind speed (Avr. m/s)	3.65	3.36	3.17	3.07	2.92	3.02	3.29	3.61	3.95	4.70	4.09	4.26	3.59
Sunshine (%/day)	41.0%	43.1%	34.7%	45.0%	43.3%	31.6%	35.2%	23.0%	20.5%	24.0%	27.1%	37.5%	33.8%
Precipitation (mm.)	1.30	1.68	2.44	2.23	2.00	2.93	2.40	2.89	2.49	2.10	1.77	1.52	2.15
Precipitation (hrs.)	1.6	1.2	1.8	1.3	1.2	2.2	1.9	2.6	2.3	2.2	2.1	1.7	1.8

[a] Variables for the continuous DLO study are defined in the Annoyance and Meteorological section in the beginning of this chapter and in Table 12.

2.3 Model for the seasonal reaction pattern

The seasonal variation can be summarized with a function that assumes that the variation over the seven-year period is represented by a continuous 12-month curve in which the growth and decay curves are symmetrical, but exactly reversed. The sine function defines one such curve as:

$$\text{annoyance score} = a + b \sin[(\text{month}-c)*(2\pi/12)]$$

where:

- Month= Month of year (1=Jan., 2=Feb., 3=Mar., ... 12=Dec)
- a = is the mean yearly reaction
- b = a multiplier determining the size of the most extreme deviations from the mean reaction
- c = a locational parameter that gives the month identification number for one of two months at which the function predicts the mean yearly reaction
- $2\pi/12 = 0.5236$

The parameters of the function are estimated with a Marquardt procedure (Draper 1981). This function has been estimated for each of the four noise sources and for a combined index for the three transportation noise sources, all of which display the seasonal variation. The analysis is based on 84 observations, one for each month in each of the seven years. The values of the parameters are given for each noise source in Table 5. Each function is plotted as a solid line and compared to the monthly annoyance scores in Figure 3.

The analysis based on the sine function supports the conclusion that there is a statistically significant effect of season on transportation noise annoyance, but that there is not a statistically significant effect of season on annoyance with neighbors. The fact that the amplitude parameter is significantly different than zero for all the transportation noise sources in Table 5 shows that there is a significant relationship with season for all the transportation noise sources. The maximum annoyance for these transportation noise functions is reached at the month with the value of c + 3. With values of c ranging from c=3 to c=5 in Table 5, the point of maximum annoyance for the transportation noise sources is thus in the interval from June (Month 6) to August.

The reactions to neighbors are strikingly different and do not show a seasonal effect: the amplitude parameter (b) is not significantly different than zero. The explanation for the lack of a seasonal pattern for neighbor noise has not been explored. It is hypothesized that any reduction in neighbor noise that is achieved in the winter by closing windows is counterbalanced in multiple unit dwellings when an apartment neighbor's noise becomes more noticeable in the winter when noise from exterior sources are reduced by the closed windows. The low point for neighbor noise is in August. It is possible that this may be related to the fact that many residents are away from their homes for vacations during the period of the summer school holidays with the likely result that the neighborhood is quieter for other residents.

Table 5: Parameters of sine functions for the continuous DLO survey

Reaction measure	Parameters of sine function (Standard errors given in parentheses) Mean reaction (a)	Amplitude (b)	Average month (c)	R^2	Predict maximum annoyance in:
Road traffic	31.658 (0.168)	1.049 (0.238)	4.932 (0.434)	0.19	July
Aircraft	25.808 (0.153)	0.826 (0.216)	3.666 (0.499)	0.15	June
Rail	19.243 (0.068)	0.356 (0.096)	5.446 (0.513)	0.15	August
Index(Road, Air, Rail)	25.570 (0.088)	0.695 (0.124)	4.550 (0.342)	0.28	July
Neighbors	28.077 (0.132)	-0.273 (0.187)	3.372 (1.310)	0.03	December

Although there is a seasonal pattern for the transportation noise sources, the patterns vary and are not precisely explained by the time of year. The point of maximum annoyance is estimated to be almost two months earlier for aircraft than for railway noise. The 95 percent confidence intervals for the point of maximum annoyance [(c + 3) x ±1.96(standard error of c)] for each of the noise sources extends over more than a three-week period. The variation in predicted points of maximum annoyance would be expected to be a function of random variations in respondents' sensitivity to noise, random differences in the noise exposures of the samples each year and to genuine differences in meteorological conditions each year. The variations in the timing of maximum annoyance between sources might reflect genuine differences or may indicate that the actual sampling errors are being underestimated.

2.4 Explaining seasonal differences

Definitive explanations for the seasonal differences in reactions to transportation noise sources are not obvious from an examination of Figures 1 and 2 or the associated meteorological data in Table 4. Although it is seen that the reactions roughly parallel the mean temperature curve in Figure 1, the display of other meteorological data for the same period in Figure 2 shows that the amount of sunshine is closely correlated with temperature and that the wind speed follows a correlated seasonal pattern (negative correlation) in the Netherlands. Both temperature and wind conditions are such that they would both encourage the least window opening and outside activity levels in the winter months. The correlations in Table 6 show that there are significant relationships of most of the noise annoyance measures with most of the meteorological indices.

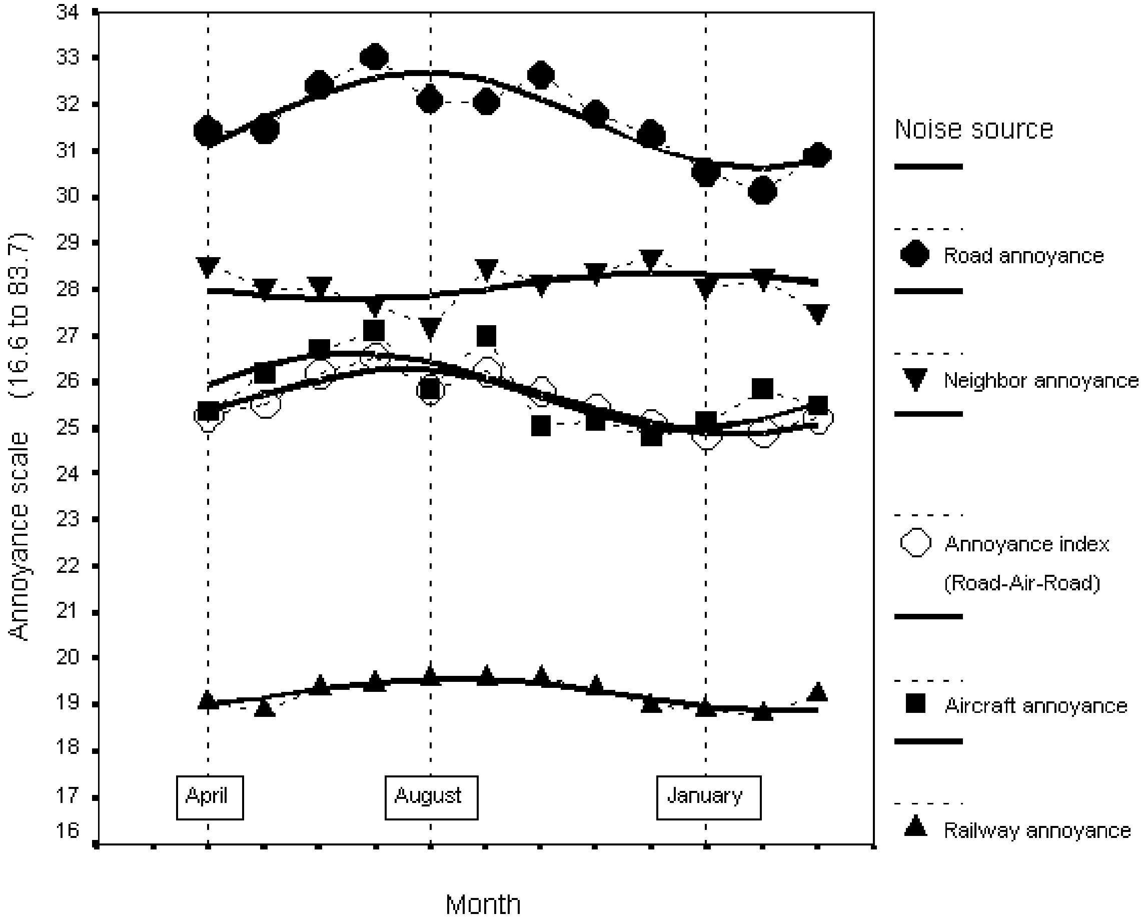

Figure 3 Comparison of sine model and reactions (DLO survey)

The analysis of the relationship of these variables with reactions is presented in the regression analysis in Table 7 and discussed in more detail in a later section of this report .

The contrast between the reaction to neighbors' noise and to the transportation noise sources does, however, eliminate one possible explanation for the seasonal variation in noise annoyance reactions. The absence of a similar seasonal response pattern for neighbor noise suggests that the seasonal response pattern to transportation noise is not due to an overall, undifferentiated response bias that might apply to all types of feelings or judgments during the summer or winter months.

Table 6: Correlation coefficients for the continuous DLO survey

	Annoy-Road	Annoy-Aircraft	Annoy-Railway	Annoy-Neighbors	Temperature-mean	Sunshine (% day)	Precipitation-(mm)	Precipitation (hrs.)	Wind speed
Annoy-Road	1.000	.294 (.007)	.370 (.001)	.225 (.040)	.459 (.000)	.393 (.000)	-.050 (.654)	-.246 (.024)	-.344 (.001)
Annoy-Aircraft	.294 (.007)	1.000	.001 (.996)	.209 (.056)	.262 (.016)	.297 (.006)	-.160 (.145)	-.288 (.008)	-.218 (.046)
Annoy-Railway	.370 (.001)	.001 (.996)	1.000	.131 (.233)	.358 (.001)	.171 (.119)	.099 (.371)	-.118 (.285)	-.330 (.002)
Annoy-Neighbors	.225 (.040)	.209 (.056)	.131 (.233)	1.000	-.035 (.751)	-.065 (.558)	-.062 (.573)	-.090 (.413)	-.266 (.015)
Temperature-mean	.459 (.000)	.262 (.016)	.358 (.001)	-.035 (.751)	1.000	.661 (.000)	.108 (.328)	-.300 (.006)	-.576 (.000)
Sunshine % day	.393 (.000)	.297 (.006)	.171 (.119)	-.065 (.558)	.661 (.000)	1.000	-.375 (.000)	-.576 (.000)	-.386 (.000)
Precipitation (mm.)	-.050 (.654)	-.160 (.145)	.099 (.371)	-.062 (.573)	.108 (.328)	-.375 (.000)	1.000	.833 (.000)	.310 (.004)
Precipitation -(hrs.)	-.246 (.024)	-.288 (.008)	-.118 (.285)	-.090 (.413)	-.300 (.006)	-.576 (.000)	.833 (.000)	1.000	.645 (.000)
Wind speed	-.344 (.001)	-.218 (.046)	-.330 (.002)	-.266 (.015)	-.576 (.000)	-.386 (.000)	.310 (.004)	.645 (.000)	1.000

Notes to table: The statistical significance is given in parentheses.
Variables for the continuous DLO study are defined in the Annoyance and Meteorological section in the beginning of this chapter. The meteorological variables are thus defined as two-month averages.

Table 7: Regression coefficients for four meteorological variables from regressions of noise annoyance [three noise sources and combined annoyance index] (DLO survey)

Type of analysis	Intercept	Independent variables in the regression equation[b]: Mean temperature (C)		Sunshine (% of daylight hours)		Precipitation (mm)		Wind speed (m/s)	
		B	Std Err (B)	B	Std Err (B)	B	Std Err (B)	B	Std Err (B)
Road traffic noise annoyance									
Univariate [a]	[a]	0.148*	0.032	0.072*	0.018	-0.519*	0.226	-0.824*	0.248
Multivariate analyses (two to four meteor-ological variables in the equation)	30.765	0.088	0.057	0.032	0.032	0.052	0.363	-0.326	0.408
	31.192	0.129*	0.039			-0.188	0.274	-0.137	0.362
	29.525	0.114*	0.042	0.029	0.024				
	30.737	0.137*	0.033			-0.251	0.217		
	31.419	0.126*	0.039					-0.288	0.287
	29.447			0.069*	0.023	-0.060	0.264		
	31.711			0.056*	0.020			-0.542*	0.258
	34.537					-0.085	0.288	-0.762*	0.327
Aircraft noise annoyance									
Univariate [a]	[a]	0.076*	0.030	0.048*	0.017	-0.539*	0.198	-0.462*	0.228
Multivariate analyses (two to four meteor-ological variables in the equation)	25.219	0.055	0.054	0.009	0.030	-0.456	0.344	0.154	0.386
	25.342	0.067	0.370			-0.526*	0.258	0.208	0.341
	24.271	0.033	0.040	0.035	0.023				
	26.033	0.055	0.031			-0.43*	0.205		
	25.977	0.059	0.037					-0.212	0.277
	25.328			0.032	0.021	-0.327	0.240		
	25.360			0.040	0.018			-0.257	0.242
	27.083					-0.472	0.260	-0.117	0.295

Type of analysis	Intercept	Independent variables in the regression equation[b]:							
		Mean temperature (C)		Sunshine (% of daylight hours)		Precipitation (mm)		Wind speed (m/s)	
		B	Std Err (B)	B	Std Err (B)	B	Std Err (B)	B	Std Err (B)
Railway noise annoyance									
Univariate [a]	[a]	0.046*	0.013	0.012	0.008	-0.097	0.090	-0.308*	0.097
Multivariate analyses (two to four meteor-ological variables in the equation)	19.724	0.035	0.023	-0.004	0.013	0.083	0.148	-0.240	0.167
	19.675	0.030	0.016			0.110	0.111	-0.261	0.147
	18.969	0.055*	0.017	-0.008	0.010				
	18.811	0.045*	0.014			-0.010	0.090		
	19.543	0.031*	0.016					-0.173	0.117
	18.914			0.011	0.010	-0.024	0.110		
	20.153			0.004	0.008			-0.289	0.106
	20.451					0.134	0.112	-0.406	0.127
Mean of three annoyance scores (Road-Air-Rail)									
Univariate [a]	[a]	0.090*	0.017	0.044*	0.010	-0.385*	0.122	-0.531*	0.134
Multivariate analyses (2 to 4 meteor-ological variables in the equation)	25.236	0.059	0.030	0.013	0.017	-0.107	0.193	-0.137	0.216
	25.403	0.075*	0.021			-0.201	0.145	-0.063	0.192
	24.255	0.067*	0.023	0.019	0.013				
	25.194	0.078*	0.018			-0.23*	0.115		
	25.646	0.072*	0.021					-0.224	0.153
	24.563			0.037*	0.012	-0.137	0.142		

* An asterisk indicates that the regression coefficient is statistically significantly different from zero ($p<0.05$)

a The "Univariate" rows contain the results from four univariate regressions of noise annoyance on each meteorological condition. The intercept for each of the regression equations is not shown here but is, of course, different for each of the four regressions.

b Variables for the continuous DLO study are defined in the Annoyance and Meteorological section in the beginning of this chapter. The period of integration for the meteorological variables is the two months preceding the interview. The parameters for each independent variable are: B = The unstandardized regression coefficient, Std Err(B) = Standard Error of B. (The 95% confidence interval for B is 1.96 * Std Err(B).)

3.0 METEOROLOGICAL EFFECTS: PERIOD OF IMPACT

The analysis of the continuous DLO population study of the Netherlands in the previous section clearly demonstrates that reactions to similar noise environments differ by season with residents being more annoyed during warmer times of year. The data from the DLO study are not, however, suitable for closely examining the length of the period that should be considered for understanding noise reactions. The only noise reaction data available in the DLO study are for the average of the noise reactions over entire months of 28 to 31 days. As a result the exposure on the date of an interview could not be determined and analyses could not examine the relationship between meteorological conditions and reactions on particular dates. Other data are analyzed in this section to obtain information about the period during which the temperature could affect reactions.

3.1 Data: day-linked data set

The day-linked data set consists of 15,107 respondents' reactions to aircraft and road traffic noise from 12 studies conducted in 7 countries (see Table 3). The meteorological data have been individualized to each respondent's interview date by integrating the meteorological data over nine proximate periods of increasing lengths ranging from one day (the date of the interview) to 91 days (the average over the date of the interview and the 90 days leading up to the interview). The long-term meteorological conditions for the site have been calculated by averaging the data for the previous ten calendar years (not including the year of the interview). Although many complex models might be posited for the relative importance of immediate and remote meteorological conditions, the analyses in this report are based on a simple model in which all days during a period are given the same weight. Other, more theoretically satisfying models (for example: an exponential decay model) have not been tested because, as will be seen, the evidence does not support a model that weights recent events more heavily.

3.2 Analysis of reactions

Table 8 compares the strength of the effect of meteorological conditions on annoyance as the number of days integrated increases from the single day of the interview to all 90 days before the interview. This comparison is first made for a base analysis in the first column (Column A) and then for variations on that base analysis in the other columns. The effect of temperature is examined for the base analysis (Column A in Table 8) by regressing noise level and the average daily mean temperature on annoyance in the first data column (A). The analyses that provide evidence about the period of integration for the meteorological effect are in the lowest panel of the table but the earlier rows provide the context for understanding that panel.

Table 8: Regression analyses for varying lengths of aggregated meteorological data (Day-linked data set)

Information in row	Temperature analyses							Precipitation	
Model >>>	Base (DNL & 90-day met) (A)	Base & Source of noise [a] (B)	Base & 10-year average temperature[a] (C)	Subset (DNL from 45 to 75) (D)	Base analysis - but maximum temp. (E)	Base analysis - but minimum temp (F)	Discrete periods (not cumulative) (G)	Precipitation (Total daily -- in mm.) (H)	Precipitation (% of days precipitate) (I)
Meteorological descriptor (avr. of daily values)	Temperature - mean				Temperature - high	Temperature - minimum	Temperature - mean	Precipitation - total	Precipitation - % of days
N of reactions>>	15,107	15,107	15,107	12,770	15,107	15,107	15,107	7,713	7,713
First regression analysis (Regression with 90-day meteorological variable)									
Regression coefficients (not standardized) (B_{DNL} is statistically significant p<.05)	a= -36.618 B_{DNL}= 1.200 B_{M-90}= .312	a= -44.784 B_{DNL}=1.215 B_{Air}=11.497 B_{M-90}= .204	a= -35.926 B_{DNL}= 1.137 B_{T10-Yr}= .778 B_{M-90}= -.115	a= -56.657 B_{DNL}=1.533 B_{M-90}= .299	a= -36.054 B_{DNL}= 1.228 B_{M-90}= 0.079	a= -35.808 B_{DNL}= 1.179 B_{M-90}= .581	a= -38.565 B_{DNL}= 1.202 B_{M-90}= .564	a= -17.375 B_{DNL}= 1.166 B_{M-90}= -7.855	a= -43.482 B_{DNL}= 1.257 B_{M-90}= 0.070
Std. error for B_{M-90} Significance	0.340 (NS)	0.364 (NS)	0.573 (NS)	0.278 (NS)	0.292 (NS)	0.355 (NS)	0.331 (NS)	2.288 p<0.05	0.341 NS
Multiple R^2=	R^2=0.152	R^2=0.179	R^2=0.155	R^2=0.132	R^2=0.149	R^2=0.158	R^2=0.159	R^2=0.169	R^2=0.114
Second regression analysis (Regression without 90-day meteorological variable)									
Regression coefficients (not standardized) (B_{DNL} is always significant p<.05)	a= -35.545 B_{DNL}= 1.240	a= -44.282 B_{DNL}=1.242 B_{Air}=11.768	a= -36.177 B_{DNL}= 1.141 B_{T10-Yr}= 0.650	a= -54.307 B_{DNL}=1.550	a= -35.545 B_{DNL}= 1.240	a= -35.545 B_{DNL}= 1.240	a= -35.545 B_{DNL}= 1.240	a= -39.369 B_{DNL}= 1.234	a= -39.369 B_{DNL}= 1.234
	Addendum to 2nd analysis: Beta (standardized regression)coefficient for each period (other periods are not in the equation)								
Earliest day from which daily meteorological data are averaged									
0	-.025	-.024	-.104	-.036	-.051	.011	-.025	-.007	-.025
1	-.021	-.016	-.096	-.025	-.048	.015	-.021	-.047	-.037
2	-.015	-.013	-.091	-.021	-.045	.022	-.010	-.056	-.049
3	-.010	-.008	-.084	-.014	-.039	.027	.002	-.054	-.055
7	.001	.002	-.076	-.003	-.030	.039	.009	-.082	-.064
14	.000	.000	-.090	-.005	-.034	.039	-.002	-.097	-.056
30	.002	-.002	-.104	-.003	-.032	.041	.004	-.089	-.048
60	.025	.014	-.077	.019	-.013	.066	.044	-.136	.009
90	.055	.036	-.022	.053	.015	.097	.104	-.172	.028

a. The DNL-only regression equation for columns B and C is a=-35.545, B_{DNL}=1.240.

The results from two regression equations are shown in each column. In all cases the dependent variable is the annoyance scale. The first three rows are based on the regression of annoyance on DNL, a meteorological variable (the 90-day mean value for that variable) and, in Columns B and C, one other variable (a dummy variable representing aircraft surveys in Column B, a 10-year mean temperature variable in Column C.) The coefficients in the rows in the first panel are unstandardized regression coefficients. The second panel gives the standard error for the 90-day meteorological variable. The coefficients in the first panel of the first column show that each increase of 1 degree centigrade (mean temperature averaged over the date of the interview and the previous 90 days) is estimated to increase noise annoyance by approximately 0.312 (B_{M90}=0.312) annoyance score points. This would indicate that, as expected, annoyance increases as temperature increases. However, the standard error of 0.340 in the next panel shows that the 0.312 effect is surrounded by a confidence interval of +/- 0.666 (0.666= 0.340 * 1.96) and thus is not significantly different than zero. The third panel containing the multiple R^2, gives the proportion of the variance in annoyance explained by the equation.

The second regression in each column more directly addresses the period-of-integration issue. The coefficients are given in the first row for an equation that does not include the 90-day temperature variable. The primary finding with respect to the period of integration is presented in the lowest panel of the table where the Beta coefficient is given for each of nine time periods. Each of these is the beta coefficient that would apply to each meteorological variable if it were included in the regression analysis presented immediately above. These beta coefficients are standardized regression coefficients (standardized to the variances in the annoyance scores and meteorological scores) and can be expressed as a transformation of partial correlation coefficients and the unstandardized regression coefficients. The value of beta = 0.055 for the 90 period (last line in the first column) is the transformation of the unstandardized regression coefficient that appeared in the first regression in the column (B_{M90}=0.312) that indicates that a one standard deviation change in temperature (90-day mean temperature index) generates a 0.055 standard deviation change in annoyance. Thus the beta values given in the lowest panel are a measure of the effect of each of nine noise periods when only one of them is included in a regression equation as the sole index for the meteorological condition (temperature, in the first seven columns; precipitation in the last two columns).

The analyses based on temperature data are all consistent (Columns A through G) with higher temperatures increasing noise annoyance (the coefficients for the 90-day temperature variable are positive), but the "NS" in each column shows that the 95% confidence for the estimates of the 90-day regression coefficient are so large that the effect of temperature is not statistically significant. For precipitation, the measure of total daily precipitation is statistically significant (Column H), but not the measure of the percent of days that have any precipitation (Column I). The large standard errors for the meteorological variables mean that these data will not, therefore, give definitive estimates of the effect of these two meteorological variables. Some of the trends in the data do, however, give the best information available. Seven of the nine columns in the table provide this information in a similar format. The two columns with shaded Beta coefficients are less relevant; Column C is included for a different purpose (examining the effect of the year-around average temperature) and Column G contains a different definition of the meteorological variables in the Beta coefficient panel at the bottom of the table.

The values of the Beta coefficients in Column G give some insight into the pattern that is displayed in the other columns that assess the effect of temperature (Columns A, B, D, E, F). Column G is the only column in which the temperature variables in the lowest panel are based on mutually-exclusive, discrete periods. Thus the 90-day variable (beta=0.104) is an average for 30 days (days 61 to 90) not for 90 days. The Beta coefficients in this column (Column G) show that the coefficients are positive (i.e. consistent with the seasonal effect found in the continuous Netherlands DLO data) from the third day backward (except for day 8-14), but that they are negative for the first three days (the interview day, and day 1 and day 2). The beta coefficients, negative or positive, are very small for the day 2 to day 30 time periods, but become stronger in the expected direction for the 60-day (i.e. 31-60 day period) and 90-day period (i.e. 61-90 day). None of these coefficients are statistically significant. There is certainly no indication that the temperature on the day of the interview or on the immediately preceding days has an especially strong effect; the coefficients are small, the relationships are not statistically significant and the relationships are in the wrong direction relative to the strong evidence from the Netherlands DLO survey. With all of the uncertainties it is concluded that an integration over a period that is more than a month is most likely to be correct.

The same conclusion is consistent with the variety of patterns of the Beta coefficients for six of the seven remaining columns all of which are based on cumulative meteorological data. The three columns based on mean daily temperatures (Columns A, B, D) show the same tendency for weak negative relationships in the first days, but increasing positive relationships as additional days of meteorological information are integrated into the index with the 90 day meteorological variable showing the strongest relationship. These three columns include the base case with only a DNL predictor (Column A), an equation that adds a dummy variable for type of noise source (Column B), or an analysis that is restricted to the 45-75 DNL exposure range (Column D). The two other temperature analyses show slight variations on the same pattern. For the maximum temperature column (E) all beta coefficients are negative except for the 90-day coefficient that is finally in the expected direction. For the minimum temperature (Column F) all beta coefficients are positive with the value steadily increasing as more days are cumulated. The total precipitation variable shows the same pattern (Column H): the longer the integration period the stronger the relationship. This is the only column in which the meteorological variables have statistically significant relationships. The only column that does not support the general pattern of stronger relations with longer time periods is the last column in which the coefficients for the days-of-precipitation variable do not follow a clear pattern. There is some evidence that this days-of-precipitation index is so weak that the pattern is of relative little importance. An examination of the standard errors shows that the standard error for the 90-day coefficient is almost five times the size of the estimate (5=0.341/0.0700), greater than for any other column.

Table 9: Partial regression coefficients from linear and logistic regressions of noise annoyance on DNL, noise source and nine alternative integration periods for temperature and precipitation (Day-linked data set)

Meteorological variable (mean of daily values)[a]	Controls (DNL, noise source)	Earliest day from which daily meteorological data are averaged [b]								
		0	1	2	3	7	14	30	60	90
Linear regression										
Temperature (C)	DNL	-0.12	-0.10	-0.08	-0.05	0.01	0.00	0.01	0.13	0.31
	DNL& source	-0.11	-0.08	-0.06	-0.04	0.01	0.00	-0.01	0.07	0.20
Precipitation (mm)	DNL	-0.04	-0.05	-0.08	-0.09	-0.12	-0.12	-0.14	-0.19	-0.19
	DNL & source	-0.04	-0.04	-0.06	-0.07	-0.09	-0.09	-0.10	-0.09	-0.03
Logistic regression with moderate annoyance (50% or more of scale = 1, under 50%= 0)										
Temperature (C)	DNL	0.000	0.001	0.004	0.006	0.010	0.009	0.009	0.016	0.026
	DNL & source	-0.001	0.002	0.004	0.005	0.009	0.008	0.006	0.010	0.017
Precipitation (mm)	DNL	-0.003	-0.003	-0.005	-0.006	-0.008	-0.009	-0.011	-0.017	-0.017
	DNL & source	-0.003	-0.003	-0.004	-0.005	-0.007	-0.007	-0.007	-0.010	-0.007
Logistic regression with high annoyance (72% or more of scale = 1 ("High annoyance"), 71% or less =0)[c]										
Temperature (C)	DNL	-0.014	-0.014	-0.013	-0.012	-0.009	-0.010	-0.011	-0.003	0.007
	DNL & source	-0.016	-0.015	-0.014	-0.014	-0.011	-0.012	-0.014	-0.010	-0.003
Precipitation (mm)	DNL	-0.002	-0.003	-0.004	-0.004	-0.005	-0.005	-0.006	-0.006	-0.006
	DNL & source	-0.001	-0.002	-0.003	-0.003	-0.003	-0.002	-0.003	0.000	0.003

Notes for Table 9: None of the coefficients for the meteorological variables in this table are statistically significant at p<0.05]. Coefficients are not shown for DNL but are statistically significant for all analyses. The dummy variable coefficients for noise source (aircraft or road) are not statistically significant for any regressions including the precipitation variable or for any of the regressions for moderate annoyance. The dummy variable coefficients for noise source are statistically significant for all linear regressions in the second line of the table (temperature, line) and for about half the logistic regression analyses for the high annoyance equations that include temperature.

[a] In this table temperature is the average daily temperature. Precipitation is the total daily amount.
[b] The meteorological data for day "0" are for the interview day. The data for day 3, for example include the interview day (0) and the 3 prior days of meteorological data.
[c] Since the response scales have been transformed as explained in the text, high annoyance is the top point on a 4 or 5-point scale, the top 2 points on a 6 or 7-point scale, and top 3 on a 10 or 11-point scale.

The regression coefficients (unadjusted) for different length-of-integration metrics are provided in Table 9. (The other regression equation parameters from the regression equations are not presented.) The first three lines of Table 9, repeat the analyses in columns A, B and H of the lowest panel of Table 8. For example, the beta=0.055 for the 90 day period at the bottom of column A (Table 8) is shown in Table 9 to be the standardized value of the unadjusted partial regression coefficient of B=0.31 (last column of the first row). The analyses in Table 9 all draw on the same data for one linear and two logistic regression analyses. The temperature variable coefficients in five of the six analyses in Table 9 show the same tendency for stronger relations with annoyance as the meteorological information is integrated over the longer period. Only the high annoyance logistic regression analysis with controls for noise source does not find the expected positive relationship between annoyance and temperature. For the precipitation analyses based on either linear regression or logistic regression (for moderate annoyance), all relationships are in the expected direction (noise annoyance increases when there is less precipitation) and the strongest relationship is found for coefficients for the 7, 30, 60 or 90-day aggregation period. The relationships are not consistent for the logistic regression using the high annoyance measure. None of the meteorological variables for any of the day-linked analyses in Table 9 are statistically significant ($p<0.05$).

3.3 Conclusions about the period of impact

The best available evidence about the period of impact, weak though it is, comes from the analyses in this section. There is no evidence for noise annoyance being strongly impacted by the temperature or precipitation in the days immediately preceding the interview. The available evidence suggests that the impact comes from a longer period, possibly including the 90 days before the interview. This is the evidence that supports the decision to cumulate the meteorological data for 90 days for the analyses presented in the remainder of this report. Given the tentative nature of the conclusion, however, most of other analyses were repeated for other integration periods as well even though they are not reported here.

The DLO data that seem to indicate that annoyance is highest in the warmest months does not provide a good basis for conclusions about the period of integration because the exact interview dates are unknown and because the meteorological conditions in the DLO survey are highly correlated. For example, the noise reaction data in Figure 3 closely follow the sine curves that show the highest annoyance is in the warmest months (June, July, August) rather than in the early Autumn as would be expected from a 90-day cumulation period. However the seasonal meteorological patterns in Figure 2 show that both precipitation and wind speed increase in the Autumn and may thus counterbalance the residual effect of temperature from the summer months.

4.0 ASSESSING METEOROLOGICAL EFFECTS WITH THE SEASON-LINKED DATA SET

The continuous DLO study showed that season is related to noise annoyance reactions in the Netherlands and that the pattern of reactions is consistent with an effect of temperature. However, the high correlations between the major meteorological variables, especially wind speed and temperature (r= -0.68) within the Netherlands limits the precision of the estimates and the conclusions drawn about the independent effects of the correlated variables. Data from a wider range of climatic conditions in a season-linked data set are used in this section to evaluate the independent effects of these meteorological variables. This data set relates noise reactions to the meteorological conditions that normally occur at the time of year at the site where the study interviews were conducted as well as to the average yearly meteorological conditions at the site.

4.1 Data: Season-linked data set

The season-linked data set includes 53,130 responses from 41 studies in 14 countries (Table 3). These include all of the 15,107 responses from the day-linked analysis for which the exact date of interview is known as well as about 38,000 additional responses for which the exact date of the interview is not known.

Three months of meteorological data were averaged to characterize the weather for each interview, the nominal interview month and the two preceding months. The meteorological conditions for each month are, as was explained earlier, based on the average of thirty years of meteorological data (from 1961 to 1990) for the specified months.

4.2 Analysis of reactions

Four meteorological conditions are considered in the season-linked analysis. Correlations between some of the indices representing these conditions and annoyance and noise level are presented in Table 10. Sunshine is the average of the hours of sunshine per day. This is, as a result, a function of both the amount of cloud cover and the number of hours of day-light that are possible at the particular time of year. As a result, it is seen that there is a rather high correlation between sunshine and the five temperature indices in Table 10 (from r=0.577 to r=0.826). Precipitation ("Precip." in Table 10) is represented by the average of the daily total amount of precipitation (millimeters). Wind speed is the average of the daily mean wind speed expressed in meters/second. The primary temperature variable used in these analyses (T-3MoMn = Temperature-3 Month Mean)is the average of the daily mean temperatures for three months that include the nominal interview month and two previous months (just as for the other variables).

Table 10: Correlations between noise annoyance and meteorological variables in the season-linked data set

Variables	Annoyance	DNL	Aircraft	Railway	T-3MoMn	T-3MoMx	T-3MoMi	T-2MoMn	T-2-4Mo	Precip.	Sunshine	Wind
Annoyance (100-Point Scale)	1.000	.382	.122	-.191	.128	.125	.132	.136	.095	.102	.161	.031
DNL Noise level (DNL)	.382	1.000	-.041	-.039	.092	.096	.088	.129	.011	.138	.212	.222
Aircraft noise source (Aircraft=1, others=0)	.122	-.041	1.000	-.342	.233	.269	.211	.231	.198	.269	.360	-.110
Railway noise source (Railway=1, others = 0)	-.191	-.039	-.342	1.000	-.205	-.222	-.195	-.237	-.114	-.194	-.274	.075
T-3MoMnv= Temperature 3-Month Daily means(Avr)	.128	.092	.233	-.205	1.000	.988	.983	.969	.881	.358	.787	.057
T-3MoMx = Temperature 3-Month Maximum(Avr.)	.125	.096	.269	-.222	.988	1.000	.946	.962	.863	.297	.821	.026
T-3MoMi v=Temperature 3-Month Minimum (Avr.)	.132	.088	.211	-.195	.983	.946	1.000	.953	.866	.438	.724	.073
T-2MoMn = Temperature 2-Month Mean	.136	.129	.231	-.237	.969	.962	.953	1.000	.738	.353	.826	.085
T-2-4Mo = Temperature 2-4 Months before Mean	.095	.011	.198	-.114	.881	.863	.866	.738	1.000	.315	.577	-.004
Precipitation 3-Month Mean Daily	.102	.138	.269	-.194	.358	.297	.438	.353	.315	1.000	.329	.008
Sunshine hours 3-Month Mean daily hours	.161	.212	.360	-.274	.787	.821	.724	.826	.577	.329	1.000	.096
Wind Speed 3-Month Mean	.031	.222	-.110	.075	.057	.026	.073	.085	-.004	.008	.096	1.000

In Table 10 it is seen that this mean temperature index is highly correlated with three other temperature indices: 3-month average of the daily maximum temperatures (T-3MoMx) at r=0.988, 3-month average of the daily minimum temperature (T-3MoMi) at r=0.983, two-month average (interview month and preceding month) of the daily mean temperature (T-2MoMn) at r=0.969, and a 3-month index that excludes the interview month (i.e. includes the last three months before the interview month) for the daily mean temperature (T-2-4Mo) at r=0.881. Since the maximum, minimum and mean temperature indices are so highly correlated, only the mean temperature indices are included in the remaining analyses.

The correlations in Table 10, also show that noise level happens to be correlated with many of the meteorological indices across these data sets, presumably because some of the studies that were designed with especially high noise exposure zones happened to have been conducted in seasons and countries where there were warmer, sunnier, windier and higher precipitation conditions. As a result all further analyses control for noise level in assessing the impact of meteorological conditions on noise annoyance.

Information on precipitation and wind speed does not help to reveal the relative role of seasonal conditions and long-term climatic conditions because the correlations are too high between annual and the 3-month indices for precipitation (r=0.93) and annual and 3-month indices for wind speed (r=0.91). The two remaining variables, temperature and sunshine, provide only a moderately stronger basis for these analyses due to the high correlations between the 3-month average conditions and the year-long average conditions (r=0.62 for temperature, r=0.67 for sunshine).

The effects of meteorological conditions on noise annoyance are examined in regression analyses of noise annoyance on the six meteorological indices, each of which is represented by a column in Table 11. All regressions contain DNL and at least one meteorological variable. The regressions in the second analysis section (Section #2), also contain dummy variables to represent type of noise source (aircraft and rail traffic are set to the value of one). The coefficients for the aircraft and rail traffic dummy variables represent the deviations from the road traffic condition.

4.3 Discussion of climatic effects

The season-linked data set has been used to explore the possibility of climate effects; that is, whether reactions are affected by only the transitory conditions in the months preceding the interview or whether reactions are somewhat moderated by the base, average climatic conditions in a location. Do residents in all climates find, for example, that summer is more annoying but adjust to the average climatic conditions so that average of the reactions over the entire year is the same in all climates? In Part E of Table 11 a measure of the yearly average for the meteorological condition at each site [Met. Var.(Year)] is included in each of the regression equations. The analyses do not provide clear answers to the question. When both the seasonal meteorological measure (Met. Var) and the yearly average [Met. Var.(Year)] are included in the same equations in Sections #13 and #14, the coefficients for the yearly average are never statistically significant and the coefficient for the seasonal measure is statistically significant in only two instances. The expected correlations between seasonal and yearly meteorological conditions clearly introduce imprecision in the estimates.

There is, however, some indication that reactions to similar meteorological conditions in different climates in different countries may not be as different as would be expected from the differences between the meteorological conditions in the countries imply. The correlations with the seasonal meteorological conditions (Sections #1 and 2) are about the same as the correlations with only the yearly meteorological variables (Sections #15 and 16). Similarly when both the seasonal and yearly average meteorological variables are included in the same equations (Sections #13 and #14) the seasonal variable and yearly variable have opposite signs and thus suggest that seasonal differences may be partially compensated for by a tendency for a similar average yearly reaction. Thus, for example, if there is a 10 degree difference in the average annual temperature at two locations, the regression equation for temperature in the second column of Section #13 predicts that those in the warmer location will be less annoyed at the same temperature by 0.6 points (-0.6 = -0.06*10) on the annoyance scale. However, if the seasonal temperature in a particular month is 8 degrees higher in the warmer climate then the annoyance scores in the warmer climate that month will actually be 3.1 annoyance score points higher than the colder climate because the 0.6 point annoyance score reduction due to the climate is more than offset by a 3.7 annoyance score increase due to the differences in temperature (3.7 = 0.46 * 8). These results are subject to such high standard errors, however, that the results actually provide little useful information about the true relationship. This is due to the high correlations between the yearly and seasonal values; r=0.93 for precipitation, 0.91 for wind speed, 0.67 for sunshine, and 0.62 for temperature.

In general, the relationships of noise annoyance with meteorological conditions are not accurately estimated in Table 11, as demonstrated by the standard errors that are large relative to the sizes of the regression coefficients for the meteorological conditions. It is unlikely that any other analyses of these data would yield more definitive results about the relative impact of seasonal and mean-year conditions. The standard errors of the partial regression coefficients for seasonal variables do not show increased precision over the regressions shown in Section # 2 that introduce noise source type as a control. Relationships are similar or weaker for the regressions in Sections #3 and 4 that are based on interviews in the 45 to 75 DNL range where there is a more nearly linear relationship between noise annoyance and noise level. The relations are not systematically more likely to be statistically significant in Sections #5 to 8 where the logistic regression allows for non-linear relationships and does not rely on the assumption of a linear reaction scale. In addition to characterizing a climate by the yearly average temperature, the temperature in the warmest month (July in the Northern Hemisphere, January in the Southern Hemisphere) as well as the coldest month, was also examined. Neither of these variables has a statistically significant correlation with noise annoyance.Although the estimates of all the parameters are too imprecise to draw conclusions from these data, they do indicate that some caution should be exercised in extrapolating observed differences in seasonal reactions to presumed differences in reactions to yearly climatic differences.

Table 11: Regressions for the season-linked data set

Variables in equation	Meteorological variable examined																	
(The "Met. Var" is defined in the column heading.)	Temperature 3-Month Daily Means (Average) [T-3MoMnv]			Temperature 2,3,4 Prior Months Daily Mean (Avr.) [T-2-4Mo]			Sunshine 3-Month Mean daily hours			Precipitation 3-Month Mean Daily			Precipitation 2-Month Mean Daily			Wind speed[a] 3-Month Mean		
Statistics>	B	Std.Er.	Sig.	B	Std.Er.	Sig.	B	Std.Er.	Sig.	B	Std.Er.	Sig.	B	Std.Er.	Sig.	B	Std.Er.	Sig.
Part A: Examination of monthly meteorological variables - linear regression																		
#1: [Intercept]	-37.39			-38.21			-37.00			-35.37			-35.33			-25.77		
Met. Var.	0.46*	0.228	0.05	0.44*	0.220	0.05	1.16	0.638	0.08	1.26	0.964	0.20	1.17	0.884	0.19	-1.56	1.268	0.22
DNL	1.19*	0.169	0.00	1.21*	0.166	0.00	1.16*	0.175	0.00	1.20*	0.179	0.00	1.20*	0.180	0.00	1.20*	0.173	0.00
R^2=	R^2=0.155			R^2=0.155			R^2=0.153			R^2=0.149			R^2= 0.149			R^2=0.139		
#2: [Intercept]	-36.14			-37.14			-34.86			-34.48			-34.35			-28.81		
Met. Var.	0.23	0.166	0.18	0.29	0.153	0.07	0.15	0.618	0.80	-0.05	0.879	0.96	-0.17	0.773	0.83	-0.99	1.686	0.56
DNL	1.20*	0.146	0.00	1.21*	0.142	0.00	1.20*	0.142	0.00	1.21*	0.147	0.00	1.21*	0.146	0.00	1.18*	0.147	0.00
Aircraft	4.70	3.173	0.15	4.59	3.065	0.14	5.03	3.383	0.14	5.26	3.284	0.12	5.35	3.269	0.11	5.06	3.516	0.16
Railway	-13.97*	2.843	0.00	-14.30*	2.634	0.00	-14.44*	3.118	0.00	-14.63*	3.219	0.00	-14.69*	3.233	0.00	-13.49*	2.845	0.00
R^2=	R^2=0.186			R^2=0.187			R^2=0.184			R^2=0.184			R^2=0.184			R^2=0.169		
#3: [Intercept]	-48.99			-49.94			-49.15			-47.93			-47.86			-36.16		
Met. Var.	0.40	0.215	0.07	0.40	0.205	0.06	1.01	0.574	0.08	1.24	0.981	0.21	1.15	0.902	0.21	-1.71	1.222	0.17
DNL(45-75)	1.38*	0.157	0.00	1.40*	0.153	0.00	1.37*	0.160	0.00	1.39*	0.164	0.00	1.39*	0.164	0.00	1.36*	0.163	0.00
R^2=	R^2=0.124			R^2=0.124			R^2=0.122			R^2=0.119			R^2=0.119			R^2=0.107		
#4: [Intercept]	-47.76			-48.67			-46.75			-46.61			-46.46			-39.56		
Met. Var.	0.18	0.156	0.26	0.25	0.145	0.10	0.04	0.591	0.94	-0.04	0.723	0.96	-0.16	0.640	0.81	-1.01	1.548	0.52
DNL(45-75)	1.38*	0.136	0.00	1.39*	0.132	0.00	1.40*	0.132	0.00	1.40*	0.135	0.00	1.40*	0.134	0.00	1.35*	0.143	0.00
Aircraft	5.25	2.912	0.08	5.09	2.798	0.08	5.61	3.126	0.08	5.68*	2.876	0.05	5.75*	2.861	0.05	5.41	3.146	0.09
Railway	-13.87*	2.779	0.00	-14.10*	2.476	0.00	-14.31*	3.055	0.00	-14.37*	3.185	0.00	-14.44*	3.210	0.00	-13.23*	2.715	0.00
R^2=	R^2=0.158			R^2=0.160			R^2=0.157			R^2=0.157			R^2=0.157			R^2=0.139		

Variables in equation	Meteorological variable examined																	
(The "Met. Var" is defined in the column heading.)	Temperature 3-Month Daily Means (Average) [T-3MoMnv]			Temperature 2,3,4 Prior Months Daily Mean (Avr.) [T-2-4Mo]			Sunshine 3-Month Mean daily hours			Precipitation 3-Month Mean Daily			Precipitation 2-Month Mean Daily			Wind speed[a] 3-Month Mean		
Statistics>	B	Std.Er.	Sig.	B	Std.Er.	Sig.	B	Std.Er.	Sig.	B	Std.Er.	Sig.	B	Std.Er.	Sig.	B	Std.Er.	Sig.
Part B: Examination of monthly meteorological variables - Logistic regression with a Moderate annoyance division (50% or more of scale = 1, under 50%= 0)																		
#5: [Intercept]	-5.98			-6.03			-5.99			-5.85			-5.86			-5.15		
Met. Var.	0.03*	0.016	0.05	0.03*	0.015	0.05	0.10*	0.043	0.03	0.11	0.071	0.13	0.11	0.069	0.12	-0.06	0.082	0.49
DNL	0.09*	0.012	0.00	0.09*	0.011	0.00	0.08*	0.012	0.00	0.08*	0.013	0.00	0.08*	0.013	0.00	0.08*	0.012	0.00
R^2 analog	0.101			0.101			0.102			0.098			0.099			0.088		
#6: [Intercept]	-6.11			-6.18			-6.05			-6.02			-6.02			-5.64		
Met. Var.	0.01	0.012	0.24	0.02*	0.008	0.04	0.02	0.042	0.60	0.01	0.048	0.79	0.01	0.042	0.80	-0.01	0.107	0.90
DNL	0.09*	0.010	0.00	0.09*	0.010	0.00	0.09*	0.010	0.00	0.09*	0.011	0.00	0.09*	0.011	0.00	0.09*	0.010	0.00
Aircraft	0.38*	0.177	0.04	0.37*	0.172	0.04	0.39*	0.192	0.05	0.41*	0.178	0.03	0.41*	0.178	0.03	0.42*	0.194	0.03
Railway	-1.32*	0.369	0.00	-1.35*	0.355	0.00	-1.34*	0.394	0.00	-1.36*	0.381	0.00	-1.36*	0.381	0.00	-1.21*	0.291	0.00
R^2 analog	0.129			0.130			0.128			0.128			0.128			0.115		
Part C: Examination of monthly meteorological variables - Logistic regression with a High annoyance division (72% or more of scale = "High" annoyance)[b]																		
#7: [Intercept]	-7.45			-7.43			-7.39			-7.33			-7.31			-6.87		
Met. Var.	0.02	0.015	0.22	0.01	0.014	0.34	0.04	0.044	0.31	0.04	0.067	0.59	0.02	0.062	0.70	-0.05	0.114	0.66
DNL	0.09*	0.010	0.00	0.09*	0.010	0.00	0.09*	0.010	0.00	0.09*	0.010	0.00	0.09*	0.010	0.00	0.09*	0.009	0.00
R^2 analog	0.98			0.097			0.098			0.097			0.096			0.091		
#8: [Intercept]	-7.39			-7.39			-7.32			-7.30			-7.29			-7.00		
Met. Var.	0.01	0.014	0.64	0.01	0.012	0.65	-0.01	0.041	0.80	-0.03	0.070	0.67	-0.04	0.065	0.49	-0.03	0.132	0.83
DNL	0.09*	0.010	0.00	0.09*	0.010	0.00	0.09*	0.009	0.00	0.09*	0.010	0.00	0.09*	0.010	0.00	0.09*	0.009	0.00
Aircraft	0.14	0.254	0.58	0.14	0.245	0.57	0.17	0.259	0.51	0.18	0.247	0.48	0.19	0.246	0.44	0.12	0.285	0.68
Railway	-1.38*	0.269	0.00	-1.40*	0.271	0.00	-1.42*	0.261	0.00	-1.42*	0.277	0.00	-1.43*	0.277	0.00	-1.29*	0.280	0.00
R^2 analog	0.113			0.113			0.113			0.113			0.114			0.105		

Variables in equation	Meteorological variable examined					
(The "Met. Var" is defined in the column heading.)	Temperature 3-Month Daily Means (Average) [T-3MoMnv]	Temperature 2,3,4 Prior Months Daily Mean (Avr.) [T-2-4Mo]	Sunshine 3-Month Mean daily hours	Precipitation 3-Month Mean Daily	Precipitation 2-Month Mean Daily	Wind speed[a] 3-Month Mean
Statistics>	B Std.Er. Sig.	B Std.Er. Sig.	B Std.Er. Sig.	B Std.Er. Sig.	B Std.Er. Sig.	B Std.Er. Sig.
Part D: Examination of the combined effect of three meteorological variables - linear regression (Each of the two sections of cells represents a single regression equation)						
#9: [Intercept]	-30.28					
Met. Var.	0.46 0.320 0.16			0.30 1.065 0.78		-1.68 1.488 0.27
DNL	1.17* 0.162 0.00					
R^2=	R^2=0.148					
#10: [Intercept]	-30.14					
Met. Var.	0.24 0.247 0.34			-0.27 1.018 0.79		-1.11 1.709 0.52
DNL	1.18* 0.143 0.00					
Aircraft	4.51 3.726 0.23					
Railway	-12.67* 2.898 0.00					
R^2=	R^2=0.171					
#11: [Intercept]	-35.87					
Met. Var.	0.25 0.192 0.20			-0.43 0.973 0.66		
DNL	1.20* 0.143 0.00					
Aircraft	4.89 3.264 0.14					
Railway	-14.09* 2.907 0.00					
R^2=	R^2=0.186					
#12: [Intercept]	-30.28					
Met. Var.	0.22 0.206 0.29					-1.10 1.705 0.52
DNL	1.18* 0.145 0.00					
Aircraft	4.41 3.675 0.24					
Railway	-12.61* 2.822 0.00					
R^2=	R^2=0.171					

Variables in equation	Meteorological variable examined																	
(The "Met. Var" is defined in the column heading.)	Temperature 3-Month Daily Means (Average) [T-3MoMnv]			Temperature 2,3,4 Prior Months Daily Mean (Avr.) [T-2-4Mo]			Sunshine 3-Month Mean daily hours			Precipitation 3-Month Mean Daily			Precipitation 2-Month Mean Daily			Wind speed[a] 3-Month Mean		
Statistics>	B	Std.Er.	Sig.	B	Std.Er.	Sig.	B	Std.Er.	Sig.	B	Std.Er.	Sig.	B	Std.Er.	Sig.	B	Std.Er.	Sig.
Part E: Examination of the both seasonal and year-round indicators for meteorological variables - linear regression																		
#13: [Intercept]	-37.41			-38.07			-35.57			-38.25			-37.89			-25.45		
Met. Var.	0.45	0.311	0.15	0.46	0.333	0.17	1.77*	0.811	0.03	-2.31	2.703	0.40	-1.49	1.870	0.43	-1.23	3.891	0.75
DNL	1.19*	0.167	0.00	1.22*	0.158	0.00	1.18*	0.162	0.00	1.18*	0.176	0.00	1.18*	0.177	0.00	1.19*	0.177	0.00
Met. Var.(Year)	0.01	0.491	0.99	-0.06	0.573	0.91	-1.23	1.016	0.23	5.17	3.805	0.18	4.25	2.903	0.15	-0.37	4.613	0.94
R^2=	R^2=0.155			R^2=0.155			R^2=0.155			R^2=0.152			R^2=0.152			R^2= 0.139		
#14: [Intercept]	-35.02			-35.75			-33.21			-36.27			-36.40			-28.33		
Met. Var.	0.34	0.270	0.21	0.51*	0.226	0.03	1.02	0.731	0.17	-2.27	3.108	0.47	-2.26	2.180	0.31	-0.50	4.376	0.91
DNL	1.22*	0.136	0.00	1.25*	0.123	0.00	1.25*	0.119	0.00	1.20*	0.148	0.00	1.20*	0.147	0.00	1.18*	0.151	0.00
Aircraft	5.00	3.048	0.11	5.09	2.847	0.08	6.44*	3.160	0.05	5.06	3.325	0.13	5.29	3.264	0.11	5.07	3.745	0.18
Railway	-14.26*	3.157	0.00	-15.13*	2.893	0.00	-14.06*	2.931	0.00	-14.39*	3.351	0.00	-14.48*	3.380	0.00	-13.49*	2.935	0.00
Met. Var.(Year)	-0.37	0.421	0.39	-0.65	0.373	0.09	-1.98*	0.994	0.05	3.28	4.771	0.50	3.36	3.761	0.38	-0.55	4.579	0.90
R^2=	R^2=0.187			R^2=0.190			R^2=0.190			R^2=0.185			R^2=0.186			R^2=0.169		
#15: [Intercept]	-36.78			-36.78			-34.47			-37.09			-37.09			-24.94		
- - - -																		
DNL	1.18*	0.179	0.00	1.18*	0.179	0.00	1.20*	0.172	0.00	1.18*	0.178	0.00	1.18*	0.178	0.00	1.18*	0.181	0.00
Met. Var.(Year)	0.52	0.382	0.18	0.52	0.382	0.18	0.31	0.864	0.72	2.29	1.277	0.08	2.29	1.277	0.08	-1.52	1.678	0.37
R^2=	R^2=0.150			R^2=0.150			R^2=0.146			R^2=0.151			R^2=0.151			R^2=0.138		
#16: [Intercept]	-34.53			-34.53			-32.43			-35.09			-35.09			-28.15		
- - - - -																		
DNL	1.21*	0.145	0.00	1.21*	0.145	0.00	1.26*	0.124	0.00	1.20*	0.151	0.00	1.20*	0.151	0.00	1.18*	0.152	0.00
Aircraft	5.24	3.075	0.10	5.24	3.075	0.10	6.77*	3.124	0.04	5.03	3.408	0.15	5.03	3.408	0.15	5.09	3.473	0.15
Railway	-14.62*	3.236	0.00	-14.62*	3.236	0.00	-14.97*	2.846	0.00	-14.45*	3.192	0.00	-14.45*	3.192	0.00	-13.51*	2.863	0.00
Met. Var.(Year)	0.00	0.245	1.00	0.00	0.245	1.00	-1.18	0.884	0.19	0.45	1.365	0.74	0.45	1.365	0.74	-1.01	1.829	0.58
R^2=	R^2=0.184			R^2=0.184			R^2=0.187			R^2=0.184			R^2=0.184			R^2=0.169		

* A single asterisk ("*") indicates that a partial regression coefficient is significant at $p<0.05$.
* Analyses are based on 53,130 reactions except for those including wind speed analyses for which 47,825 reactions are available. which 47,825 reactions are available.
[b] Since the scale has been transformed (see text) high annoyance is the top point on a 4 or 5-point scale, top 2 on a 6 or 7-point scale and top 3 on a 10 or 11-point scale.

5.0 RELATIONSHIP BETWEEN TEMPERATURE AND OTHER METEOROLOGICAL CONDITIONS AND NOISE ANNOYANCE REACTIONS

The Netherlands Continuous Life Information Survey (DLO) clearly finds a seasonal effect in the Netherlands with annoyance being higher around the summer months and lower around the winter months. The analysis of the day-linked annoyance/meteorological data found no evidence that the meteorological conditions in the few days immediately preceding an interview has an especially strong effect on annoyance. In fact, it appears that the best predictor is the average of the meteorological conditions over several months preceding the interview. As a result, the analyses in this section proceed with the assumption that there can be a seasonal effect and that the average of the meteorological conditions in the three months preceding the interview will be the most effective predictor of reactions for the existing data sets.

5.1 Available meteorological data

This section attempts to determine which meteorological characteristics of the weather impact noise annoyance and how large those effects are. All three of the data sets provide some evidence on these issues. The meteorological data that are available from each data set are summarized in Table 12. It should be recalled that there are other potentially important differences between the data sets that were previously summarized in Table 1. The sources of the meteorological data are also given in Table 1. The day-linked and season-linked meteorological data come from many measurement stations located in different countries. Although the latitude, longitude and elevations of all measurement stations are known, the precise methods used to measure and summarize meteorological observations at these stations are not known, but are presumed to introduce only minor variations between stations.

All of the meteorological indices used in this report are simple averages of daily values. The single maximum value for a month or longer period for temperature and wind speed were examined in some analyses of the DLO data, but did not reveal stronger relationships. The possibility of weighting the days immediately prior to the interview with a more complex scheme to define multi-month meteorological indices was examined in the earlier analysis of the day-linked data set. However the lack of evidence for a strong relationship with proximate interviewing days, suggests that a more complex weighting of daily meteorological data would not provide stronger relationships than those observed with the simple averages used in this report.

Table 12: Numbers of responses available for analysis for each type of meteorological data

Indicator[a]		Data set (Each cell contains the number of interview reactions with data)		
Condition	Description	Day-linked data set *[Means of meteorological data for interview day and 1,2,3,7,14,30,60 or 90 previous days]*	Season-linked set *[Mean for 3 months (interview & preceding 2 months) for 30 year avr. (1961 to 1990)]*	Continuous (DLO) Survey *[Mean for 2 months before the month of the interview]*
Temperature[b] (degrees Celsius)	Daily mean (average of 24 hourly values or mean of highest and lowest hours)	15,107	53,130	35,000
	Maximum in 24 hours	15,107	53,130	35,000
	Minimum in 24 hours	15,107	53,130	35,000
Precipitation	Daily total (millimeters)	7,713	53,130	35,000
	Number of hours with precipitation (hrs)	0	0	35,000
	Percent of days with any precipitation (%)	7,713	0	0
Sunshine	Percent of time in daylight hours with sunshine (%)	0	0	35,000
	Number of hours with sunshine (hours)	0	53,130	35,000
Wind speed (meters per second)	Average over day	0	47,825	35,000
	Average of hourly maximums	0	0	35,000

a. The height of measurement is not specified for all measurement stations. KNMI temperature data for De Bilt were taken at 1.5 meters. KNMI wind data are measured at 10 meters above the surface.
b. Temperature: The precise method for averaging temperatures over the 24 hours could vary between different weather stations.

The effects of alternative meteorological indices are analyzed with slightly different techniques for the continuous Netherlands DLO study and the day-linked and season-linked data sets. The DLO study does not include noise data. As a result of consistently surveying a single national study population, it is assumed that noise emissions effects should not be confounded with seasonal conditions. As a result, these DLO data are analyzed with simple bivariate correlation or regression coefficients. However, for the particular combination of studies examined in the day-linked and season-linked data sets, noise levels are correlated with some meteorological conditions. To control for these correlations, regression analyses are performed that include a noise exposure index (DNL) to remove the effects of correlated noise levels from the analyses. For the season-linked analyses, correlations between DNL and meteorological conditions in Table

10 are r=0.092 for 3-month mean temperature and r=0.222 for 3-month mean wind speed. For the day-linked analysis, correlations are r=0.231 with 90-day mean temperature and r=-0.218 for precipitation (percent of time with precipitation).

5.2 Relationships with temperature

Analyses of all three data sets have found more consistent evidence for an effect of temperature than for the effect of precipitation or wind speed. Although the effects of temperature are not usually statistically significant, it is possible to estimate the range of a possible temperature effect from various analyses in the three data sets.

Table 13 presents the estimated effect of a 15° (C) change in temperature from 17 analyses performed on the three data sets in this report. Fifteen degrees is approximately the average difference between the coldest and warmest months of the year for these survey sites and about the same as the difference between the various sites' summer temperatures observed in Table 3. About 3/4's of the 48 evaluations in Table 3 are with a fifteen degree range in mean temperatures from 7.9 ° (C) to 22.7 ° (C) during the survey period. Each part of Table 13 presents the results for a different data set. The first three columns of results provide the basic regression coefficients for noise level and temperature and the standard error of the temperature regression coefficient. The decibel equivalent of the one degree increase in the next column is the ratio of the temperature to the noise exposure regression coefficients. The last three columns indicate the number of decibels of change in noise exposure that are estimated to create the same increase in annoyance as a 15° (C) increase in temperature. The estimates in the "best estimate" column thus indicate this 15° difference in temperature is estimated to produce a change in annoyance that is equivalent to that produced by a zero to seven decibel increase in noise exposure An approximate estimate of the 95 percent confidence intervals of the "best" estimates is formed in the last two columns where only the variability in the temperature regression coefficient has been considered. The findings in these columns suggest that the results from the DLO survey are very exact: the 15° (C) increase in temperature is equivalent to a 1 decibel increase in noise level. However, this confidence interval does not take into account other non-sampling errors such as the fact that the estimate of the effect of noise level (B_{DNL}= 1.15)comes from other studies that used a different type of noise annoyance scale (a degree-of-annoyance rather than frequency-of-annoyance scale) and the fact that the temperature effects in the Netherlands climatic setting may be confounded with other effects that are not present in other countries. When the results from the wider range of conditions are examined with the day-linked or season-linked data sets, the confidence intervals for the estimates are very large. The lower 95% confidence interval is negative or zero for all estimates. The upper 95% confidence interval is from 6 to 16 decibels. If the analyses are restricted to those using the mean temperature (not maximum or minimum) and the those including controls for type of noise source, the range of estimates is considerably reduced. The best estimates range from the equivalent of 1 to 3 decibels and the upper 95% confidence interval ranges from 1 to 11 decibels

Table 13: Estimates of the impact of temperature on noise annoyance

Unique features of analysis (The standard, base analysis is a linear regression with temperature represented by the daily means using all interviews.)	Regression equation			Decibel equivalent of 1° (C) increase	Decibel equivalent of 15° (C) increase		
	B_{DNL}	B_{Temp}	Std. Error (B_{Temp})		Best est.	Lower (95%)	Upper (95%)
Part A: Day-linked data set (Temperature is average of previous 90 days)							
Base analysis (DNL, daily mean termperatures)	1.200*	0.312	0.340	0.26	4	-4	12
Noise source	1.215*	0.204	0.364	0.17	3	-6	11
(45-75 dB, DNL)	1.533*	0.299	0.209	0.20	3	-1	7
Noise source (45-75 dB, DNL)	1.660*	0.209	0.317	0.13	2	-4	8
(temperature=daily maixmums)	1.228*	0.079	0.291	0.06	1	-6	8
Noise source (temperature=daily maximums)	1.241*	0.004	0.340	0.00	0	-8	8
(temperature=daily minimums)	1.179*	0.581	0.355	0.49	7	-1	16
Noise source (temperature=daily minimums)	1.194*	0.447	0.376	0.37	6	-4	15
Part B: Season-linked (Temperature is averaged over 30 years for three months)							
Base analysis (DNL, daily mean termperatures)	1.337*	0.468*	0.223	0.35	5	0	10
Noise source	1.281*	0.241	0.191	0.19	3	-2	7
(45-75 dB, DNL)	1.474*	0.431	0.221	0.29	4	0	9
Noise source (45-75 dB, DNL)	1.386*	0.193	0.189	0.14	2	-2	6
Logistic: Moderate annoyance[a]	0.092*	0.033	0.019	0.36	5	-1	11
Logistic: Moderate annoyance[a], Noise source	0.092*	0.009	0.015	0.10	2	-3	6
Logistic: High annoyance[a]	0.097*	0.025	0.018	0.26	4	-2	9
Logistic: High annoyance[a], Noise source	0.097*	0.014	0.017	0.14	2	-3	7
Part C: Continuous DLO survey (Temperature is mean of previous two months)							
Noise source [No noise data]	1.150	0.090*	0.011	0.08	1	1	1

a See footnotes in previous table for definitions of moderate and high annoyance.
b The estimate of the regression coefficient for noise exposure for the DLO survey comes from analyses of other surveys what, unlike the DLO survey, use intensity-of-annoyance not frequency-of-annoyance questions.

Several alternative approaches to assessing temperature effects were considered but it was concluded that none would change the conclusions provided here. Maximum or minimum daily temperatures were evaluated, but the correlations between maximum, minimum, and mean daily temperatures are so high that any differences are likely to be of no consequence. The correlation in the day-linked data set between the mean and maximum 90-day temperatures is r=0.98 and between the mean and minimum temperatures is r=0.97. In the season-linked data set the comparable correlations are r=0.99 and r=0.98. The possibility that there might be strong non-linear relationships was explored by plotting the residuals from regressions of annoyance on noise exposure. These residuals were visually inspected and found to be approximately linear with no strong, consistent non-linear components. Logistic regression models were considered in the season-linked analyses in Table 11, but the temperature coefficients were found to be significant statistically even less often than were the coefficients from linear regression analyses.

When precipitation and wind speed and temperature are simultaneously included as predictors in an equation with temperature in Sections #10 to #12 of Table 11 and each of the variable's regression coefficients are compared with earlier single meteorological variable analyses in the table, it is seen that the relationships are not weakened. The regression coefficient for temperature of $B_{Met.Var}$=0.23 (Section #2) that is controlled for only DNL and noise source is almost the same as the value of $B_{Met.Var}$=0.24 (Section #10) when both precipitation and wind speed are simultaneously considered. The continuous DLO survey displays a similar pattern for temperature for the analyses that do not include sunshine in Table 7. As a result it appears the effects of temperature, wind speed, and precipitation are not being confounded. However, the effects of sunshine and temperature may still be partially confounded in these analyses due to their high correlations The number of hours of sunshine is highly correlated with temperature in both data sets (r=0.661 for the continuous DLO data and r=0.787 for the season-linked data set).   No attempt has been made to separate the effects of hours of sunshine and temperature in this report.

5.3 Relationships with precipitation

One precipitation index is included in all three data sets: the amount of precipitation (millimeters). Two other indices of the duration of precipitation are each used in a data set; the percent of a 24-hour day with precipitation (continuous DLO data set) and the percent of days with any precipitation (day-linked data set). The findings, while mixed, suggest that precipitation may have some effect.

The season-linked data set provides only weak evidence that precipitation reduces annoyance (Table 11). The precipitation is not estimated to reduce annoyance unless the control for noise source is introduced. Even with this control in Table 11, the probability that the relationship could arise from chance is very high ($p>0.96$).

The analysis for the day-linked data set in Table 8 (Column H), however, provides stronger evidence of a precipitation effect (statistically significant, $p<0.05$) with the multiple correlation coefficient being about the same for the precipitation and the temperature variables. If the comparison is restricted to only those 7,713 interviews with precipitation data, the multiple correlation coefficient of R^2=0.17 (next-to-last column in Table 8) for precipitation and DNL is again greater than the correlation of R^2=0.14 for an equation with DNL and mean temperature (not shown in Table 8). The same pattern is present when a control for noise source is also included: R^2=0.17 for DNL, noise source, and 90 day total precipitation; R^2=0.16 for DNL, noise source, and 90 day mean temperature.

The DLO data set (Table 6) shows a similar relationship in the expected direction for the index of the amount of precipitation that is statistically significant ($p<0.05$) for road traffic and aircraft noise but not rail traffic. When controlled for temperature, the relation remains statistically significant for road traffic, but is substantially reduce for aircraft and even changes direction for railway noise.

The mean daily precipitation levels during the survey period in Table 3 cover a 5.7 mm range (0.9 mm to 6.6 mm. About 3/4 of the sites are included with in a narrow 1.2 mm range (1.6 mm to 2.8 mm). The coefficients for the precipitation variables are so small, that the analyses presented in Tables 7 and 11 estimate that even a 5 mm difference in precipitation implies no more than the equivalent of a 2-decibel reduction in annoyance. The estimates are so imprecise, however, that the season-linked data cannot reject the possibility of as much as the equivalent of a 7-decibel reduction.

5.4 Relationships with sunshine

Sunshine is measured as the number of hours a day during which the sun appears in both the season-linked data-set and the continuous DLO survey data set. The hours a day the sun could be visible varies, of course, with the latitude and time of year. A second index in the DLO survey accounts for this with an index of the percent of the daylight hours during which the sun is visible. Although this variable is not used in the analysis in Table 6, the correlation with the number-of-hours-of-sunshine variable is so high (r=0.94) that the relative strengths of the two variables could not be evaluated.

Sunshine is, like temperature, positively correlated with noise annoyance. The relationship is slightly weaker than the relationship with temperature for the season-linked analysis in Table 11 (the multiple correlation coefficient is almost identical or slightly lower for most analyses) and is weaker for two of the three noise annoyance sources in the continuous DLO analyses (Table 6). The number of hours of sunshine is highly correlated with temperature in both data sets (r=0.661 for the continuous DLO data and r=0.787 for the season-linked data set). No attempt has been made to separate the effects of hours of sunshine and temperature in this report.

5.5 Relationships with wind speed

The daily average wind speed (meters/sec) is available for two data sets, the season-linked and DLO data sets. The DLO data set also includes indices of the highest mean wind speed measured in any hourly period and the highest wind gust measured during each day but these variables have not been analyzed here. In the DLO survey, the relationship between seasonal patterns for temperature and wind conditions seen in Figure 2 create a correlation of r= -0.58 between the temperature and wind speed (Table 6). In the season-linked data set, however, a wider variety of climatic conditions results in a correlation of only r=0.06 (Table 10). Average wind speeds for the study periods examined in this report included one site at 1.2 m/s with the rest contained within a 3.8 m/s range from 2.1 m/s to 5.9 m/s (see Table 3). About 3/4 of the locations fell within about a 2.7 m/s range.

In both data sets, wind speed is consistently negatively related to noise annoyance (as would be expected) with the impact of wind speed on annoyance being about the same or somewhat weaker than is that of temperature (Tables 6, 11). The relationship is generally modest and not statistically significant. In Sections #2 and #4 of the last column of Table 11 it is seen that each 1 m/s increase in wind speed reduces annoyance by approximately one annoyance score point in analyses that include controls for noise source A 4 m/s increase in wind speed is estimated to have about the same effect as a 3-decibel decrease in noise exposure for the linear analyses with controls for noise level and noise source in Table 11. Similar logistic regression analyses provide estimates of no effect or 1 decibel effect. Analyses that do not control for noise source, provide somewhat higher estimates with as much as a 5-decibel impact for linear regression analyses. Using the same methods as were used in Table 13, the DLO data provide estimates that a 4 m/s change in wind speed would reduce annoyance by the equivalent of a one or two decibel increase in noise exposure. The estimates are subject to considerable sampling error for the season-linked data set. In the season-linked data set, the correlations are not statistically significant ($p>0.05$). As a result the 95% confidence interval for the effect of a 4 m/s increase in wind speed extends over a range from the equivalent of more than a 10-decibel increase in annoyance to nearly a 10-decibel decrease in annoyance. The simple bivariate correlations between wind speed and annoyance are statistically significant in the DLO data set, but are considerably reduced and not statistically significant when controlled for temperature. The confidence intervals based on sampling error are small for the DLO data with estimates that, for example, the 4 m/s wind speed range could generate no greater reduction in annoyance than would a three decibel change in annoyance. However, unmeasured non-sampling errors introduce uncertainty in the evaluation of the DLO results. For example, the single, centrally-located meteorological station at de Bilt is used to characterize the wind conditions for all of the Netherlands DLO survey when in fact the wind speeds tend to vary by location and be, for example, systematically higher in costal areas. Also, as for temperature, the possible effect of other correlated seasonal factors introduce uncertainty as to whether the estimate of the effect of wind speed is being affected by other factors. In Table 7, for example, it is seen that introducing the control for temperature reduces the estimated effect of wind speed by more than 50 percent for road traffic, aircraft and the combined annoyance indices.

6.0 FINDINGS ABOUT SEASONAL DIFFERENCES FROM PREVIOUS SURVEYS

Although meteorological effects, primarily temperature, have been considered in at least seven noise response surveys, these surveys have been limited to a small number of communities and a limited range of climatic conditions. Most of these surveys have found some evidence for seasonal differences in response. The surveys and their findings are listed in Table 14. Additional background information about each survey can be located through their catalog identification number (first Column of Table 14) in a noise survey catalog (Fields 2001).

The seven noise annoyance studies have evaluated the effects of season by comparing their respondents' answers at two times of year, usually at the same location. The first five of these seven studies in Table 14 found that respondents who were interviewed in warm months were more annoyed than respondents who were interviewed in colder months. The remaining two studies report no difference. The results in the fourth column of Table 14 show seasonal effects for the five studies that are the equivalent of at least a five-percentage point difference in annoyance responses or a three-decibel difference in noise level. The narrative descriptions in the next-to-last column of the table document differences as large as 15 percentage points (catalog ID=USA-143) or the equivalent of five decibels (USA-022/USA-032/USA-044). Most of the surveys include information about dose/response relationships that could, theoretically, be used to more closely estimate the decibel equivalence of the differences in annoyance reactions in different seasons. This has not been done due to concerns about the effects of correlated variables and biases introduced by publication practices. These concerns are related to the conclusions drawn about seasonal effects, a minor goal for most surveys, and not for conclusions about the surveys' other, usually more important, goals.

Seasonal differences may be correlated with other factors in several studies. Two of the studies did not explicitly control for differences in noise exposure and did not make efforts to ensure that such differences were controlled or randomly distributed in the two seasons (UKD-008, CAN-078). For one of the remaining studies, the difference between seasons is confounded with study sites, since the two winter surveys were at different airports than the summer surveys (USA-022/USA-032/USA-044). In this particular case the two winter airports had been selected for study because they were smaller than the previously studied airports. In the analysis phase, however, it was realized that the observed response difference could not be interpreted because these two small airports were also the only ones surveyed in the winter. None of the seven studies were designed to average the seasonal effects for both seasons over several years. Five of the studies base at least one of the seasonal observations on interviews from a single month with the result that the effect of season is confounded with any other unique events at that time.

Publication practices could introduced biases if investigators reported findings when seasonal effects were found but failed to report their findings when no seasonal effects were found. Although this is a commonly recognized problem in meta-analysis(Wolf 1986), it could be an especially serious problem for these surveys that were not designed to test for seasonal effects. The two surveys that were designed to test for seasonal effects (UKD-157, SPA-313) were the only two that did not find seasonal effects. When the list of 282 surveys that had yielded six tests of seasonal effects was reexamined, it was found that an additional 12 surveys in the list had interviews from different seasons that encompassed more than a six-month period, but that the publications had not reported any tests for seasonal effects (Fields 2001); survey numbers: AUL-210, AUL-227, FRA-239, GER-192, GER-278, SWE-021, UKD-268, USA-059, USA-088, USA-127, USA-129, USA-156). It is not known whether these surveys examined the possibility of seasonal differences.

Table 14: Findings on seasonal differences from seven studies

Study (Catalog ID)	Seasonal comparison [Sample size]	Variables controlled in analysis	Annoyance is highest in: (basis)	Narrative description of finding	References
1975 Schiphol/ Marssum and 1975 Leeuwarden NIPO [Aircraft]] (NET-115, NET-844)	September compared to November of 1975 [N=143]	Noise level, study area	Hot, dry summer (>3dB)	Annoyance is reduced by the equivalent of 3 dB(A) from September after a hot summer, until November after a wet, cool autumn.	de Jong, 1981:8, Fig. 15
USA Airport [9 Cities] (USA-022, USA-032, USA-044)	Summer of 1967 (May/ August) & 1969(July/ Nov.) compared to Oct. 1970 to Jan. 1971 [N≈8500]	Noise level (different airports)	Summer (>3dB)	Mean annoyance at 7 large city airports in summers (1967-69) is the equivalent of 5 dB greater than winter surveys at 2 small airports 1 to 4 years later. However annoyance in 4 of the 7 summer surveys is similar to the winter surveys.	Connor, Patterson, 1972:31-33; Fields, 1983: 966
1961 Heathrow Aircraft (UKD-008)	September [n=1731] compared to Oct. & Nov. [N=114]of 1961	Airport (uncertain if Oct/Nov sample is of same population)	Summer (>5%) (Statistically significant, Simple random sampling assumption)	2% more "Very" and 10% more "Moderately /Very" annoyed in early Sept. than in Oct./Nov. (Barely significant, p<.05 simple random sampling assumptions)	McKennell, 1963: Appendix R
1977 3-Phase JFK Concorde (USA-143)	Summer to winter (1971) [N=5404]	Distance from airport	Summer (>5%)	At least 15% less "high" annoyance during the winter interviews.	Borsky, 1978: 20
1972 Calgary Community Noise (CAN-078)	February compared to Summer of 1972 [N≈720]	None (Uncertain if same population)	Summer (>5%)	At least 10% more are annoyed in summer than in February. Self-completion questionnaires were used.	Dunn, Posey, 1974:26,27 47,48
1977 London Area Panel [ROAD TRAFFIC] (UKD-157)	Dec. 1977 to spring & Sept. 1978 (4 waves, n=888 inter-views by N=222 respondents)	Noise level, study site, respondents	No difference (p<.05)	No significant difference between noise annoyance in different seasons though reports of window opening do differ. (Panel survey with the same respondents)	Griffiths, Langdon, Swan, 1980:236
1984-85 Gandía Three-Site Traffic Noise Survey (SPA-313)	Summers of 1984 & 1985 compared to Winter 1984-85, N=543	Noise level, study site	No difference (<5%)	It would have been expected that the additional traffic in the summer could have accentuated a seasonal effect.	García, Romero-Faus,1987, 175

7.0 SUMMARY AND CONCLUSIONS

The data analyzed in this report find that there are seasonal differences in noise annoyance reactions to similar noise levels, but that the size of these seasonal differences cannot be accurately estimated and the effect of temperature and other meteorological conditions cannot be accurately estimated. Seasonal differences can be important for some policy and methodological purposes. Several different types of research could improve knowledge about seasonal effects.

7.1 Summary of findings

This report analyzes three sets of data to determine whether meteorological conditions, including temperature, amount of precipitation, and wind speed affect residents' reactions to environmental noise. Seven years of continuous surveys of the population of the Netherlands generated the first data set, one that shows a clear seasonal pattern in residents' annoyance with road traffic, aircraft and railway noise in which the greatest annoyance is expressed around the summer months and the least around the winter months. Five of seven previously published studies have found evidence of similar seasonal effects. Analyses of two multi-national data sets containing more than 53,000 responses in 41 noise-reaction surveys also provide some evidence that reactions to noise increase with increasing temperature. The analyses find some evidence that noise annoyance is affected by the average temperature conditions in the preceding months, but find no evidence that noise annoyance is particularly strongly affected by the current temperature conditions (for example, the temperatures in the days immediately preceding an interview) Other mixed evidence suggests that annoyance is also increased by more hours of sunshine, less precipitation, and lower wind speeds. One explanation for these meteorological factors' effects is that they lead to higher noise exposure to exterior noise sources because they encourage the opening of windows and the greater usage of outdoor living areas around residences.

The analyses of these data sets provide some weak evidence on other issues. While the evidence suggests that higher temperatures are associated with greater annoyance at the same noise levels in warmer climates, there is some weak, but not statistically significant evidence that noise annoyance reactions in such climates may be less than reactions in colder climates at the identical noise levels and temperatures. The evidence is also imprecise on the importance of any meteorological effects. For example, the three data sets analyzed for this study give different estimates of the extent to which a 15-degree (Celsius) temperature increase would in turn increase annoyance. The lowest estimate is that a 15-degree increase in temperature is equivalent to less than a one-decibel (DNL) increase in noise level while the highest is that a 15-degree temperature difference is equivalent to almost a 7-decibel increase in noise level. The 95 percent confidence intervals for these estimates include effects that are equivalent to more than a 10 decibel difference.

7.2 The role of seasonal and climate effects in research and noise policy

Seasonal and climate effects have received relatively little attention in previous research; probably because they are not important for many traditional environmental noise research studies or local environmental noise policy issues. The effects are, however, of considerable potential importance for other issues.

Meteorological effects are likely to be of little importance for the findings from most community noise studies because the variables being studied are not correlated with meteorological conditions. Most community noise reaction surveys are conducted in a single city or other small area over a period of a few days or weeks. Even when interview studies are spread over several months, most interviews are often conducted in a short time at the beginning of the period. The objectives of most community noise reaction studies are to estimate the effects of personal or environmental conditions that vary between the different locations within a city or other small region that, coincidentally, has uniform meteorological conditions during the study period As a result, meteorological effects are probably of minor importance for the goals of most community noise surveys. One minor caveat is needed if, contrary to the indications in the present report, noise reactions were to be affected by short-term conditions on the day of the interview. If there were such day-of-interview effects, then even these traditional studies could be affected if interviews in different areas were clustered on different days.

Meteorological effects are of considerable importance for any types of studies that compare reactions at different times and are of potential importance for investigations that are based on comparisons of different studies. Studies of reactions to change in environmental noise conditions are often designed with study waves before a change in noise exposure and at several points after a change in noise exposure. The social surveys are timed to follow the noise exposure changes and thus may occur under quite different meteorological conditions. Seasonal effects could therefore generate misleading findings in such studies. Considerable attention needs to be given to strategies that will control for or detect any meteorological effects in such studies. The simple strategy of conducting the before and after studies at the same time of year may not be sufficient if the temperature or precipitation patterns are quite different in different years.

Seasonal or climatic effects could also have a serious effect on research that calculates effects by examining contrasts between surveys rather than contrasts between conditions within a single survey. If, for example, reactions to different noise sources are evaluated by comparing a road traffic survey conducted in the winter with an aircraft survey conducted in the summer, it is possible that any differences in reactions could be caused by weather differences rather than noise source differences. The data reviewed in this report do not provide a basis for adjusting for seasonal differences. Meteorological conditions, thus provide another source of variance for between-survey comparisons as well as another reason for designing surveys so that important variables' effects can be estimated using within-survey contrasts. If reactions are heightened under certain meteorological conditions, then survey planners would need to conduct their field work in the warmest months or shortly after the warmest times of year to measure the maximum impact of a noise source on the population.

Seasonal and climatic effects may well have little effect on local noise policy. The seasonal effects are not subject to manipulation. In addition it is not clear that major transportation sources, the source of most environmental noise, could be operated in different ways at different times of year.

The major implications of seasonal and climatic effects would seem to be on international policy. If there are genuine differences in reactions under different climatic conditions then, policy makers may need to vary the standards with the climatic conditions. The weak pattern observed in the present data was for temperature to affect annoyance, but for the effect between climate areas to be less than would be expected from the seasonal differences within a single climate. This implies that regulations that are set on equivalent annoyance criteria would impose stricter criteria in a warm than a cold climate, but that under the identical acoustical and temperature conditions (for example winter in a warm country and summer in a cold country) the criteria would be stricter in the cold country. The strong evidence for some types of seasonal effects that are correlated with meteorological conditions, coupled with the mixed evidence on between-climate effects, would seem to make climate effects a potentially important issue for international noise regulations.

7.3 Strategies for acquiring information through future research

Each of the data sets used in these analyses has different weaknesses that limit the accuracy of the results it could provide. Stronger results in the future could be expected if these and other data sets were developed that include noise exposure data and date of interview for all respondents; closely link each respondent's location with permanent weather stations; include a wide range of meteorological conditions that are not highly correlated; and use uniform social survey methods and noise annoyance measures.

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ACKNOWLEDGMENTS

This report is part of a joint project with researchers at TNO in the Netherlands. Henk M.E. Miedema provided the impetus, critical comments, and most of the data for the project. Henk Vos provided several data sets and the computer code that formed the bases of much of the initial data manipulation. The contents of this report are solely the responsibility of the author.

APPENDIX A: METHODS FOR THE NETHERLANDS CONTINUOUS LIFE INFORMATION SURVEY (DLO)

The two tables in this appendix provide the wording of the noise annoyance questions from the Netherlands Continuous Life Information Survey(DLO).

A.1 Wording of questions in English

Table 15: The Netherlands continuous DLO survey questions about noise (English translation)

Part of question	Survey period*	
	April 1998 to December 1993	January 1994 to December 1996
Stem of question	Now I am going to mention a number of issues to you, which *could bother people at home.* I would like to know whether *you are bothered by them, here.* *Could you answer according to this card?* Are you here, at home, bothered by:	Now I am going to mention a number of issues to you, of which I would like to know whether *they bother you in your living environment.* Are you, in your living environment, bothered by:
Alternative answers	*[on show card:]* YES, *OFTEN* *YES,* SOMETIMES *SELDOM OR NEVER*	*[No show card]* YES SOMETIMES *NO* REFUSES/DOESN'T KNOW
Noise sources	c) aircraft noise?	1. aircraft noise?
	d) noise from trains, trams or subways?	2. noise from trains, trams, subways?
	e) noise from cars, motorcycles or mopeds?	3. noise from cars, *lorries,* motorcycles or mopeds?
	f) street noise, from loading and unloading, or from playing children?	*4. street noise, from loading and unloading?*
		5. street noise, from playing children or young people?
	g) noise from industry or businesses?	6. noise from industry or businesses?
	h) noise from neighbors?	7. noise from neighbors?

* *Italics* indicate wording that was changed in January 1994.

A.2 Wording of questions in Dutch

Table 16: The DLO survey questions about noise (in Dutch)

Part of question	Wording for two survey periods (NOTE: Wording changes appear in italics.)	
	April 1998 to December 1993	January 1994 to December 1996
Stem of question	1) INT.: Card 1 Ik ga u nu een aantal zaken noemen waar mensen in huis last van kunnen hebben. Ik zou graag van u willen weten of u er hier last van heeft. Wilt u antwoorden aan de hand van de kaart. Heeft u hier in huis last van	1. Ik ga u nu een aantal zaken noemen waarvan ik zou willen weten of u daar in uw woonomgeving last van heeft. Heeft u in uw woonomgeving last van:
Alternative answers	[card:] - JA, VAAK JA, SOMS ZELDEN OF NOOIT	JA SOMS NEE WEIGERT/WEET NIET
Noise sources	c) lawaai van vliegtuigen	1. lawaai van vliegtuigen/
	d) lawaai van treinen, trams of metro's	2. lawaai van treinen, trams of metro's/
	e) lawaai van auto's, motoren of brommers	3. lawaai van auto's, vrachtauto's, motoren of brommers/
	f) straatlawaai van laden of lossen, of van spelende kinderen	4. straatlawaai van laden of lossen?
		5. straatlawaai van spelende kinderen of jongeren?
	g) lawaii van industrie of bedrijven	6. lawaii van industrie of bedrijven?
	h) geluiden van buren	7. geluiden van buren?

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*
01- 11 - 2004

2. REPORT TYPE
Contractor Report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Effects of Meteorological Conditions on Reactions to Noise Exposure

5a. CONTRACT NUMBER
NAS1-98100

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Fields, James M.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
23-781-10-13

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, VA 23681-2199

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSOR/MONITOR'S ACRONYM(S)
NASA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
NASA/CR-2004-213249

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 71
Availability: NASA CASI (301) 621-0390 Distribution: Standard

13. SUPPLEMENTARY NOTES
Langley Technical Monitor: Kevin P. Shepherd
An electronic version can be found at http://techreports.larc.nasa.gov/ltrs/ or http://ntrs.nasa.gov

14. ABSTRACT
More than 80,000 residents' responses to transportation noise at different times of year provide the best, but imprecise, statistical estimates of the effects of season and meteorological conditions on community response to noise. Annoyance with noise is found to be slightly statistically significantly higher in the summer than in the winter in a seven-year study in the Netherlands. Analyses of 41 other surveys drawn from diverse countries, climates, and times of year find noise annoyance is increased by temperature, and may be increased by more sunshine, less precipitation, and reduced wind speeds. Meteorological conditions on the day of the interview or the immediately preceding days do not appear to have any more effect on reactions than do the conditions over the immediately preceding weeks or months.

15. SUBJECT TERMS
Aircraft noise; Environmental noise; Social surveys

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			STI Help Desk (email: help@sti.nasa.gov)
					19b. TELEPHONE NUMBER ***(Include area code)***
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