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FINAL TECHNICAL REPORT

for

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Participation in the Mars Data Analysis Program: Analysis of Cloud Forms in Viking and Mariner 9 Images

(National Aeronautics and Space Administration)

Principal Investigator: Professor Peter Gierasch
Co-Investigator: Dr. Ralph A. Kahn

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Ithaca, New York 14853-0355

Final Report for NASA Grant NSG 7612 to Cornell University, March 1, 1983 to February 28, 1985.

Title: "Participation in the Mars Data Analysis Program: Analysis of Cloud Forms in Viking and Mariner 9 Images"

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Co-Investigator: Dr. Ralph A. Kahn

Peter J. Gierasch — date: 1 April 85 — Ralph A. Kahn — date: March 27, 1985

All the major tasks funded under this grant were completed within the granting period. The full cloud catalog for Mars, including all imaging data from the Mariner 9 and Viking Missions, is complete. It currently exists as a research tool in digital form at Cornell and at Washington University, St. Louis.

Analysis of the global-scale behavior of cloud forms has been performed and the primary results appear as two studies, published in the Journal of Geophysical Research (Kahn, 1983; 1984; reprints attached). Spinoffs from this task include investigation of regional and local cloud behavior (e.g., Kahn and Gierasch, 1982, reprint attached, and work currently in progress), the effects of clouds on deductions about surface features and surface processes (Arvidson, Guinness, and Kahn, in preparation), and examination of global and local cloud behavior using vis and infrared data simultaneously (work currently in progress).

This project produced the first systematic account of the climate of Mars, based upon observations. Cloud data were used to determine spatially and temporally varying near-surface wind direction, relative wind speed, static stability, and humidity conditions on a global scale. Existing models of meteorological processes were critically reexamined in light of the new data, and more stringent constraints were set on global processes. Several discoveries were made, including the large extent and seasonal variability of the Mars equatorial Hadley cell, the failure of high latitude winds to reverse direction in early northern spring, the change in meridional wind component in southern midautumn, and the almost constant cloud cover in the northern hemisphere, during spring and summer primarily by condensate clouds and in fall and winter by condensates and dust. The implications of these observations have been discussed in our publications. In addition, support was found for theoretical predictions about seasonal variability in static stability, slope winds occurrence, and relative wind speeds, and considerable detail that had previously been lacking was obtained.

This work, and the continuing studies which it has generated, are providing a better understanding of the processes governing Martian climate, and are generating information critical for the planning of the next mission to Mars.

ABSTRACTS OF ARTICLES PUBLISHED UNDER THIS GRANT

JOURNAL OF GEOPHYSICAL RESEARCH. VOL. 87. NO. A2. PAGES 867–880. FEBRUARY 1. 1982

Long Cloud Observations on Mars and Implications for Boundary Layer Characteristics Over Slopes

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Viking orbiter images of Mars show several instances of long continuous cloud formations on the slopes of Arsia and Pavonis Mons. We have searched all the images of the planet for occurrences of such formations. Only in the Tharsis region were long clouds unambiguously identified. We have measured the times and locations of occurrence. the wavelengths and when possible. the apparent velocity of motion of these clouds. We have also tabulated the wavelengths of patches of ripple clouds that are often found with the long formations. The long clouds are observed only in the early morning hours. suggesting that they are associated with drainage winds due to a cold planetary boundary layer. We develop simple mathematical models to examine various aspects of such boundary layer winds: these allow us to construct a complete and self-consistent explanation of all the observed features of the cloud formations. We use the results to characterize some physical properties of the Mars boundary layer. There is strong downslope flow in the boundary layer on the high slopes of both volcanos. In the saddle region between the peaks the flow slows and undergoes a hydraulic jump. producing the long clouds. Downstream of the jump. standing internal gravity waves can exist and are excited by flow over surface irregularities. Small variations in their observed wavelengths behind the jump may be attributed to variation in the flow speed and depth. Finally. we can account for the location of the jumps by the variation of relative strength of the boundary layer flows on the two volcanos.

JOURNAL OF GEOPHYSICAL RESEARCH. VOL. 88. NO. A12. PAGES 10.189–10.209. DECEMBER 1. 1983

Some Observational Constraints on the Global-Scale Wind Systems of Mars

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Wind direction measurements from a variety of indicators. taken over several Mars years and covering the entire planet. have been collected. These include observations of lee wave clouds not previously studied. The data exhibit a high degree of consistency and seasonal reproducibility. making it possible to interpret most of the observations in terms of the zonally symmetric circulation of Mars. We examine these data in the context of the constraints the observed wind directions place upon the thermal and polar cap mass flux fields which force the flows. Within the limitations of the data set. mid- and high-latitude winds appear to be controlled by the thermal field during mid and late summer and winter. and in the northern hemisphere. during early spring and early summer. At other times. the cap flows dominate. At high latitudes. the strongest yearly winds are probably generated by cap formation in the north and cap recession in the south. The hemispheric asymmetry seems to result primarily from the effects of global dust storms on the north polar cap. Turning of the prograde wind from poleward to equatorward in midautumn is observed. consistent with reduced poleward mass flux and increased meridional temperature gradient at that time. The latitudinal extent of the equatorial Hadley cell. when observed. is probably larger than that predicted by nearly inviscid models of low-latitude circulation. The cross-equatorial Hadley cell. and high-latitude poleward flows which occur in both hemispheres during the summer seasons. may set additional constraints on the thermal forcing mechanisms at these times.

JOURNAL OF GEOPHYSICAL RESEARCH. VOL. 89. NO. A6. PAGES 6671–6688. AUGUST 1. 1984

The Spatial and Seasonal Distribution of Martian Clouds and Some Meteorological Implications

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The spatial and seasonal distributions of Martian atmospheric clouds. organized according to simple morphologic criteria. exhibit distinct patterns. When interpreted self-consistently using analogies to terrestrial cloud forms and Martian temperature. wind direction. and water vapor measurements. patterns of cloud occurrence provide some loose constraints on global-scale near-surface wind speed. static stability. and humidity. We have examined all Mariner 9 and Viking Orbiter images for this study; we concentrate primarily on the larger Viking data set. Whenever observations are possible. relatively high near-surface winds appear to follow the seasonal cap edges during early fall. late winter. and spring. Moderate to high winds are also inferred in mid-latitudes for mid southern winter and in low latitudes. mainly in the steeply sloping areas of Tharsis. near the solstices. At other times. lower winds are suspected. Hemispheric asymmetries are traced to differences in atmospheric hydration state and to global dust storm related effects on the atmospheric temperature structure and the north polar cap recession schedule. Cloud occurrence data suggest that the near-surface daytime static stability is low in the northern hemisphere during summer and at low latitudes during mid northern spring. Relatively high static stability is deduced near the winter poles and globally during the dust storm season. In spite of low atmospheric temperatures. the correspondingly low absolute humidity apparently precludes the formation of thick water ice clouds at high latitudes in mid to late autumn and winter in both hemispheres and in southern mid-latitudes during early winter. During northern spring and summer. saturation conditions seem to be easily achieved at mid-latitudes. and condensate clouds are abundant; the situation is complicated by atmospheric dust in southern spring and summer. Low latitudes generally appear to be farther from saturation than mid-latitudes. and clouds generally form more easily in the northern hemisphere than in the south during corresponding seasons.