consistent with the view that the atmosphere is composed mainly of CO_2.

Temperatures in the middle atmosphere, at altitudes Z from 25 to 90 km (Fig. 4), ranged from 120° to 165°K, with local peaks at 64 and 30 km, and would appear to join smoothly with the mass spectrometer temperatures above 140 km. At the time of entry, the CO_2 condensation boundary was about 20°K below atmospheric temperatures.

The atmospheric pressure profile to 90 km is shown in Fig. 5. The middle atmosphere data extend smoothly into the directly sensed data below 3.5 km. Ambient densities (not shown) were likewise defined over five decades, and at altitudes above 35 km were 2 to 5 times greater than the mean model to which the Viking lander was designed. At touchdown, however, density was near the pre-Viking expectation.

The pressure data indicate that the landing site is about 2.9 km below the mean martian surface, if we take an average surface pressure for the martian atmosphere equal to 6.1 mbar. The accelerometer data, however, indicate an acceleration due to gravity at the landing site of 3.7189 ± 0.0006 m sec^{-2}, which implies a planetocentric distance at touchdown of 3389.8 ± 0.03 km (*11*), while the radio science data (*12*) indicate a radius of 3389.5 ± 0.3 km. These results may be compared to the value predicted from the mean ellipsoid equation given by Standish (*13*), 3391.51 km, and would imply a terrain elevation at the landing site of -1.7 to -2.0 km, and a mean surface pressure of 6.6 to 6.7 mbar.

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14. A.O.N. is indebted to J. L. Hayden for assistance in the design of the UAMS and to Ward Johnson and Stephen Richter for help in analyzing data. W.B.H. expresses his appreciation to colleagues S. Sanatani and D. Zuccaro for help with hardware and software design of the RPA. A.S. acknowledges helpful contributions by D. Kirk, P. Intrieri, R. Blanchard, R. Corridan, and S. C. Sommer. We are indebted to personnel at Bendix Systems Division, particularly Don Bianco, Steve Smith, and James Rice, for their efforts in constructing the UAMS and RPA flight instruments. Work at the University of Minnesota, the University of Texas, and Harvard University was supported by NASA under contract numbers NAS-1-9697, NAS-1-9699, and NAS-1-10492, respectively.

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Preliminary Meteorological Results on Mars from the Viking 1 Lander

Abstract. *The results from the meteorology instruments on the Viking 1 lander are presented for the first 4 sols of operation. The instruments are working satisfactorily. Temperatures fluctuated from a low of 188°K to an estimated maximum of 244°K. The mean pressure is 7.65 millibars with a diurnal variation of amplitude 0.1 millibar. Wind speeds averaged over several minutes have ranged from essentially calm to 9 meters per second. Wind directions have exhibited a remarkable regularity which may be associated with nocturnal downslope winds and gravitational oscillations, or to tidal effects of the diurnal pressure wave, or to both.*

The meteorology instruments and system on the Viking lander have been described (*1*), and only a brief description suffices here. Two hot film sensors orthogonally oriented in the horizontal plane are used to determine wind speed and direction by measuring the power required to maintain constant overheating with respect to an identical unheated reference sensor. A fourfold ambiguity in wind direction as sensed by this array is resolved by means of a quadrant sensor, which utilizes four thermocouples to sense temperature differences on four sides of a heated vertical rod. This is an application of the classical "wet finger" method of wind determination. This sensor also provides information and wind speed in the Reynolds-number range, in which it is now operating on Mars, and data from both the hot film and quadrant sensors are reduced together to provide best measures of wind speed and direction in the least squares sense. The reference temperature sensor is subject to radiation and conduction errors at the low pressure prevailing on Mars. Accurate temperature measurements are made by means of a set of thermocouples, which are referenced to an internal temperature measured by means of a platinum resistance thermometer. The entire array is mounted on a boom deployed 1.6 m above the surface, and 0.61 m from the nearest part of the lander body. Wind tunnel tests indicate measurement accuracies of at least ± 15 percent for wind speed in excess of 2 m/sec, ± 10° in wind direction and ± 1.5°C in temperature. Tests also indicate that effects of lander interference should not be large, but may have a small effect on flow at azimuths between about 260° and 340° (*2*). In addition, pressure is measured by means of a sensor within the lander body whose accuracy and stability are comparable with the digital resolution, about 0.07 mbar.

Table 1. Average variances for 11-minute modules during the first 5 sols. Night includes the period from 1.5 hours before sunset to 1.5 hours after sunrise; day includes the remainder of the sol.

Time	Variance		
	Temperature (°C)	Wind direction (deg)	Wind speed (m/sec)
Night	0.57	7.6	0.74
Day	2.63	24.5	2.07

All indications are that the entire system is performing nominally. Our confidence in the temperature measurements is based on the comparison between the reference and thermocouple sensors; the differences between them are those expected from radiation and conduction effects. Wind directions and speeds determined independently by the quadrant and hot film sensors are in satisfactory agreement, and the standard deviations obtained in the least-squares minimization procedure used to obtain wind speed and direction are agreeably low.

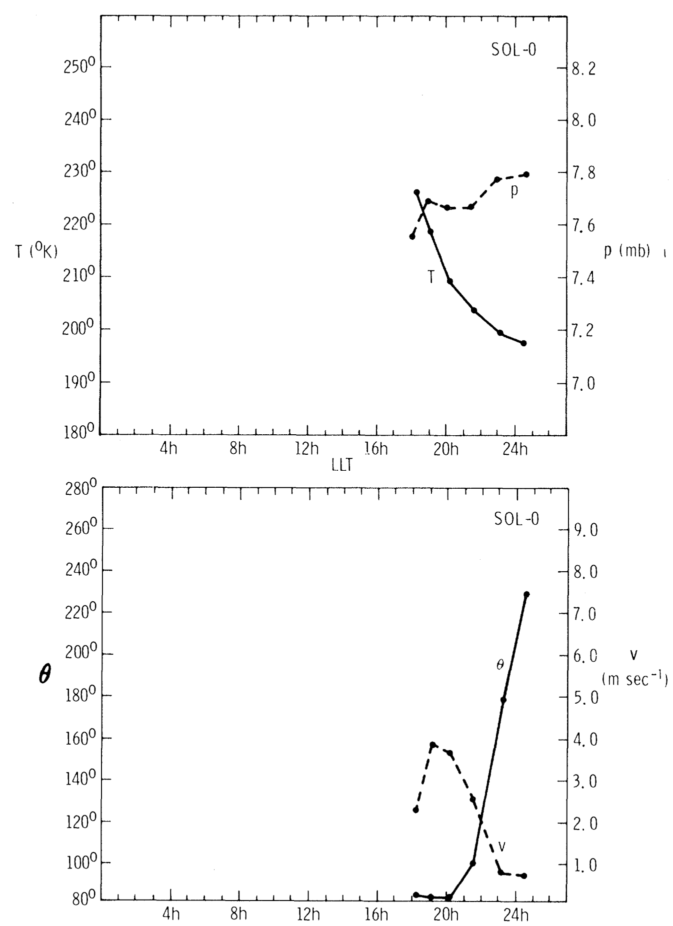
Measurements at the Chryse site (*3*) began about 2 hours after landing, and results of the first few sols are reported here. Data were obtained in modules spaced 1 hour and 27 minutes apart, with some gaps during periods of lander-orbiter and lander-Earth communication. The modules were 11 minutes in length, except for two somewhat longer modules each sol (*4*). Samples within modules were obtained at either 4-second or 8-second intervals.

Figures 1 to 4 display module-averaged data from the first four sols. The outstanding characteristic of these data is their repeatability from sol to sol. This is not completely unexpected, since this is summer in the subtropics where, in the thin, dry martian atmosphere, processes should be dominated by the very regular rates of incoming solar radiation and outgoing infrared radiation as compared to Earth. Thus, temperatures at the same time of day differ from sol to sol by only a very few Kelvins. Nevertheless, the repeatability of the wind data is striking. Despite some differences, the general nature of the wind regime is light easterly winds in the late afternoon with wind speeds decreasing to near zero as midnight is approached. Thereafter, during the night the winds blow from the southwest with regular oscillations in direction and speed.

This behavior can be plausibly understood in terms of the large-scale topography of the site. Elevation contours constructed from Mariner 9 observations (*5*) indicate that the lander is southwest of the center of a broad depression in the surface. This bowl is some 300 km in diameter and about 3 km deep. At the lander location, the ground slopes gently downward toward the northeast. It seems likely that the average southwest winds at night are caused by radiatively cooled air, sliding downslope, a process well known on Earth. Particularly striking are the oscillations in wind direction with periods of roughly 4 hours which repeatedly occur after midnight. These are suggestive of a large-scale gravity wave oscillation, and may be associated with drainage over the entire Chryse basin.

An alternative interpretation of the diurnal oscillations in wind and pressure is that they are manifestations of a planetary scale diurnal traveling wave driven by the traveling daily heating cycle, a diurnal tide (*6*). A very simple model of such a planetary oscillation in which latitudinal variations of pressure are neglected suggests that the observed diurnal pressure amplitude (0.1 mbar) would be coupled with a wind speed amplitude of the order of 5 m/sec, with westerly winds coinciding with the late afternoon pressure minimum, and clockwise wind rotation. Undoubtedly both planetary scale tides and local drainage effects contribute to the repeated diurnal pattern.

Figure 5 presents evidence for diurnal variations in boundary layer characteristics. The gas temperature at 1.6 m



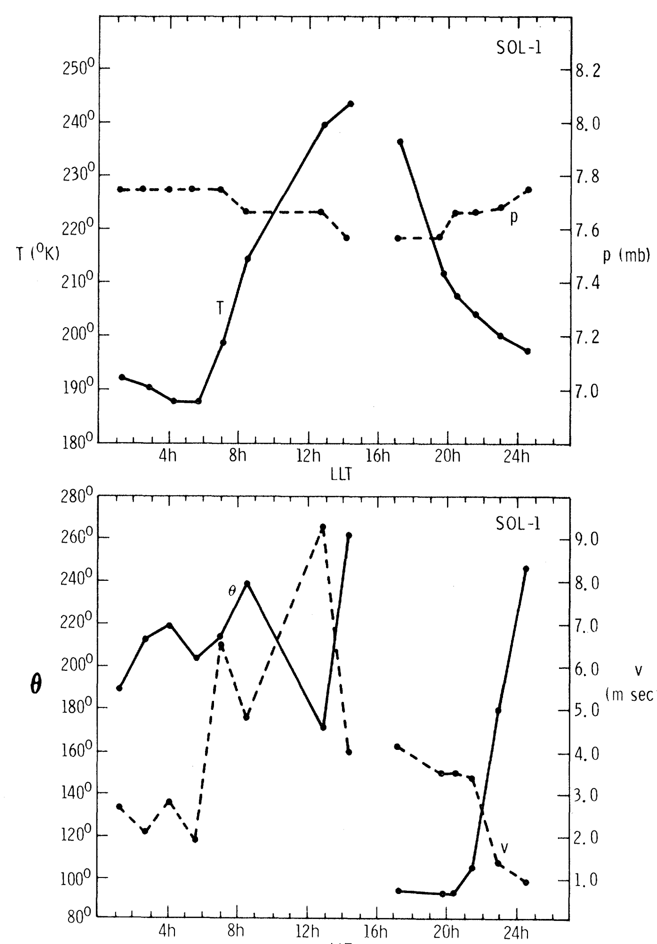
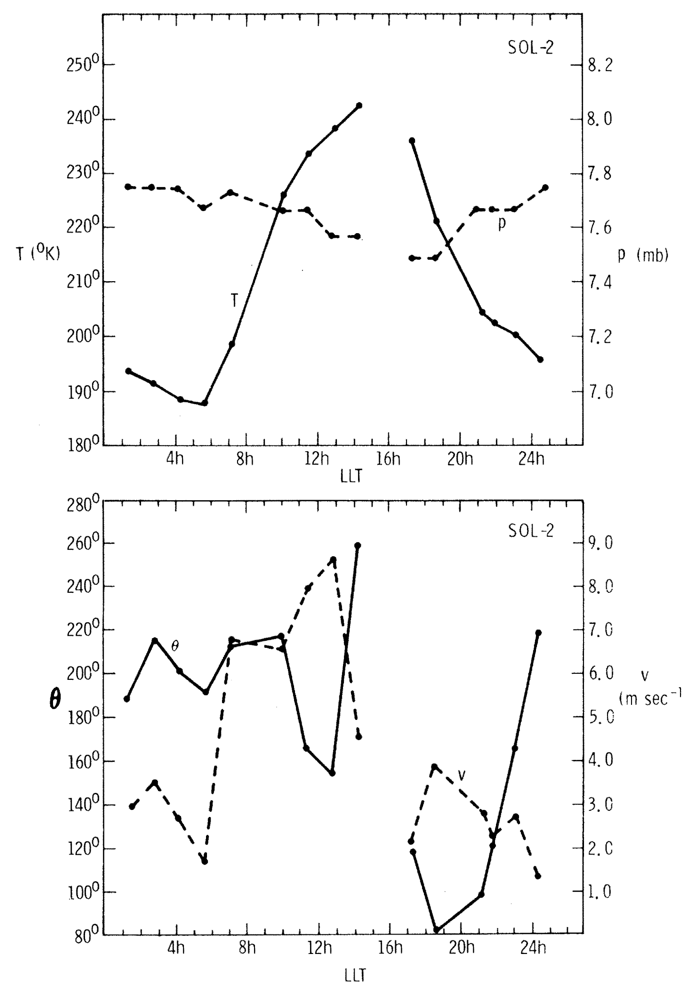


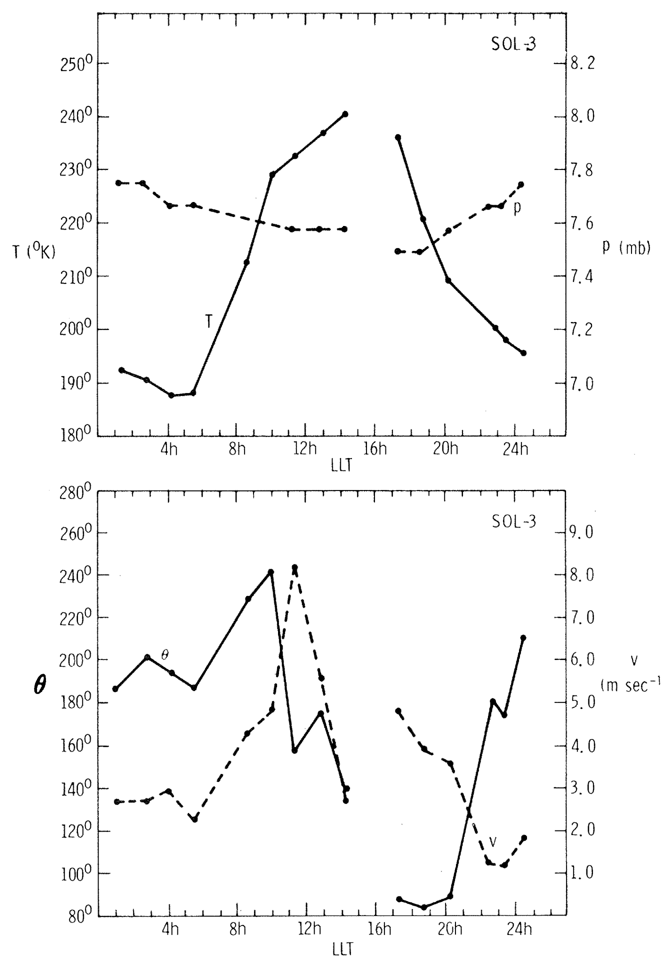
Fig. 1 (left). Module mean data for sol 0. Temperature (T), pressure (P), wind direction measured clockwise from north (θ), and wind speed (V) plotted as functions of local lander time beginning with zero at midnight (L.L.T.). Gaps in the curves are at the time of operation of the relay transmitter when the meteorology system is shut off. Pressure is plotted on an expanded scale in which the digitization increments are visible. The first module of meteorology data was initiated 1 hour and 47 minutes after touchdown of the lander on 20 July 1976. Fig. 2 (right). Module mean data for sol 1; see description of Fig. 1.

agrees well with the ground temperature inferred by the Viking orbiter infrared temperature mapping experiment (7) in the landing site region during the predawn period, but is up to 25°C colder during the day. This is analogous to the behavior of the air and ground temperatures in terrestrial deserts, and is indicative of intense convection. Further evidence of convection appears in the behavior of wind and temperature statistics within individual modules. Both wind and temperature are much more viable during the day than during the night (Table 1), indicating relatively gusty daytime conditions.

As is clear from Figs. 1 to 4, the minimum temperatures occur just after dawn, which is at 5 : 24 L.L.T. From the three cases available, the average minimum temperature is 188°K. Unfortunately, the gap for relay link transmission includes the time of maximum temperature. The last module of data recorded before the gap is centered at 14 : 21 L.L.T. and the first module after the gap is centered at 17 : 15 L.L.T. Thus, the maximum occurs between 2.3 and 5.2 hours after noon. A least-squares harmonic analysis of the data for sols 0 to 3 places the maximum at about 15 : 30 L.L.T. with a value of 244°K.

The pressure data show a diurnal varia-





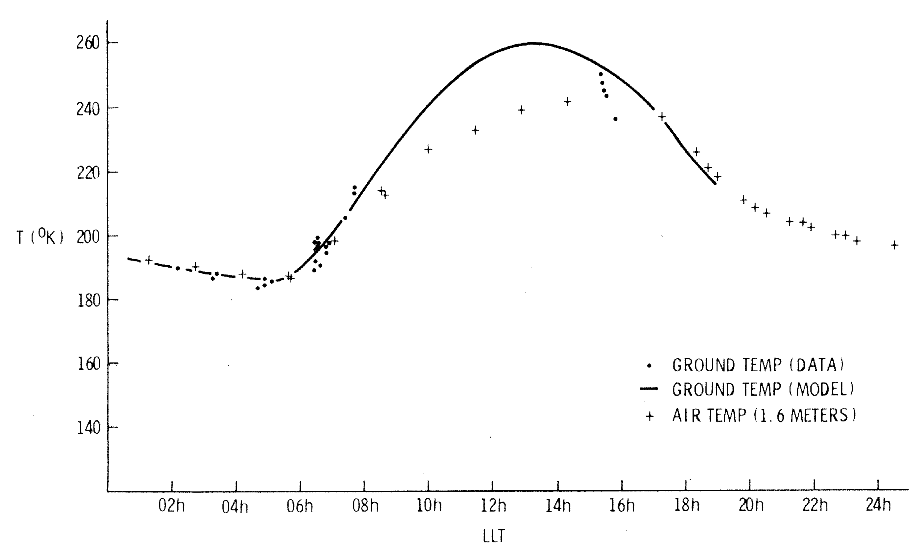


Fig. 3 (top left). Module mean data for sol 2; see description of Fig. 1. Fig. 4 (top right). Module mean data for sol 3; see description of Fig. 1. Fig. 5 (bottom). Comparison of ground temperatures by infrared from orbit with directly measured air temperatures. The air temperatures are a composite of all observations on sols 0 to 3.

tion with a difference between extremes of about 0.2 mbar. The minimum occurs about 4 hours after noon and the maximum at about 4 hours after midnight. Figures 1 to 4 exhibit this diurnal behavior even though the digitization increment of the data is a substantial fraction of the amplitude detected. The mean pressure for sols 1 to 3 is 7.65 mbar. It is worthy of note that an amplitude of 0.1 mbar is in excess of 1 percent of the mean. On Earth, that would be a diurnal amplitude greater than 10 mbar, very much larger than what is observed (about 1.5 mbar).

Finally, we note that neither the magnitude nor the direction of the measured winds is consistent with the aeolian (wind-formed) features identified in lander images (*8*). We conclude that these features were produced during another martian season, or another epoch.

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The Surface of Mars: The View from the Viking 1 Lander

Abstract. *The first photographs ever returned from the surface of Mars were obtained by two facsimile cameras aboard the Viking 1 lander, including black-and-white and color, 0.12° and 0.04° resolution, and monoscopic and stereoscopic images. The surface, on the western slopes of Chryse Planitia, is a boulder-strewn deeply reddish desert, with distant eminences—some of which may be the rims of impact craters—surmounted by a pink sky. Both impact and aeolian processes are evident. After dissipation of a small dust cloud stirred by the landing maneuvers, no subsequent signs of movement were detected on the landscape, and nothing has been observed that is indicative of macroscopic biology at this time and place.*

On 20 July 1976, at 1613 after local Mars midnight, the Viking 1 spacecraft touched down on the surface of Mars and immediately began transmission of photographs to Earth. Camera 2 on the Viking 1 lander obtained the first photographs ever returned from the surface of Mars—a high-resolution view of the vicinity of Viking lander footpad 3 in the near field (Fig. 1) and a low-resolution panoramic view of the middle to far field, including the sky of Mars (Fig. 2).

The Viking lander camera (*1*, *2*) is basically a multispectral radiometer with an optical-mechanical scanning mechanism that determines both the image raster and the field of view. It features an array of 12 silicon photodiodes consisting of four broadband channels with selectable focus for high-resolution imaging, one broadband channel for rapid surveys, six narrowband (about 0.1 μm) channels for multispectral imaging (color and near-infrared), and one narrowband channel for scanning the sun. The instantaneous fields of view are 0.04° for the four high-resolution channels and 0.12° for the other channels. The field of view ranges in elevation from 40° above to 60° below the horizon, and in azimuth from 0° to 342.5°. The camera scanning rates are synchronized to the lander data transmission rates of 16,000 bit/sec to the two orbiters as relay stations and 250 bit/sec directly to Earth. Image data can also be secured at preferred times and stored on a lander tape recorder for later transmission to take advantage of favorable imaging periods (for example, sun elevation angles).

High sensitivity is obtained over a wide dynamic range with only 6-bit encoding by the use of six commandable linear gains and 32 offsets. This approach was expected to require some initial trials in selecting optimum dynamic ranges after landing (*3*). However, once the atmosphere and surface brightness was approximately characterized from initial image data, it was possible to select optimum dynamic ranges for subsequent imagery and radiometry experiments.

General geological setting. The Viking 1 landing site (22.47° ± 0.15°N, 48.0° ± 0.5°W, areographic coordinates) is located about 130 km to the east of Lunae Planum, on the western slopes of the large depression, Chryse Planitia (*4*). The Chryse basin is about 5 km deep and the landing site lies about 2 km higher than the floor. Lunae Planum is separated from the more sparsely cratered Chryse Planitia by an irregular, scarplike boundary. Viking orbiter imagery shows a num-

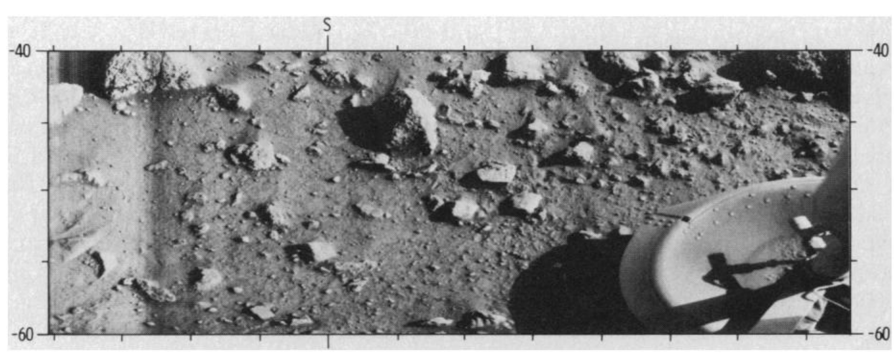

Fig. 1. This high-resolution picture of footpad number 3 and the adjacent surface is the first image ever returned from the surface of Mars. The large rock near the center is about 10 cm across. Some of the rocks have a vesicular appearance; one in the upper right has a horizontally banded texture. Some of the texture in the smooth parts of the surface was probably produced during landing; in particular a few elongate pits near the center appear to have been produced by the impact of small pebbles thrown out by the rocket exhaust. Sediment, including small pebbles or clods, has been deposited in the concave footpad. At left are angular rocks with adjacent sediment piles. At right center is a rock which seems to have been moved about its own length to the right. It is just conceivable that the retrorocket exhaust during landing produced this offset. Refer to Fig. 3 for an orthographic sketch map of this terrain.