Morning Martian Atmospheric Temperature Gradients and Fluctuations Observed by Mars Pathfinder

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Summary

We have studied the most prominent atmospheric temperature fluctuations observed during Martian mornings by Mars Pathfinder and have concluded, based on comparisons with wind directions, that they appear to be a result of atmospheric heating associated with the Lander spacecraft. Also, we have examined the morning surface layer temperature lapse rates, which are found to decrease as autumn approaches at the Pathfinder location, and which have mean (and median) values as large as 7.3 K/m in the earlier portions of the Pathfinder landed mission. It is plausible that brief isolated periods with gradients twice as steep are associated with atmospheric heating adjacent to Lander air bag material. In addition, we have calculated the gradient with height of the structure function obtained with Mars Pathfinder, for Mars' atmospheric temperatures measured within about 1.3 m from the surface, assuming a power law dependence, and have found that these gradients superficially resemble those reported for the upper region of the terrestrial stable boundary layer [Caughey et al., 1979].

Introduction

Prominent atmospheric thermal fluctuations (15 - 20 K amplitude) were observed in the morning by the Mars Pathfinder (Sagan Memorial Station), which landed on Mars on July 4, 1997. Figure 1, an example published as 120 s running means [Schofield et al., 1997] of the diurnal temperature cycle observed with Pathfinder, shows such morning fluctuations, from 0730 to about 1300 LST (Local Solar Time), measured with thin wire thermocouples mounted at 0.25, 0.5 and 1.0 m heights on a 1.1 m mast surmounted with a wind sensor [Seiff et al., 1997]. The base of the mast was about 0.27 m above the planetary surface [Haberle et al., 1999]. A mean diurnal

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temperature record from the thermocouple data is given in Haberle et al. [1999]. Pathfinder Lander imagery ["Mars Pathfinder," 1997; Golombek et al., 1999] together with consideration of the implementation of the Lander camera, deployed on its own mast [Smith et al., 1997a; Golombek, 1997] suggest that substantial near-surface atmospheric flow disturbances may be expected from a fairly wide range of directions owing to the presence of spacecraft structure, the camera mast, air bags, etc. The potential for such flow disturbances is also indicated by virtual reality representations [Stoker et al., 1999] of the environs of the landed Station. An example of the terrestrial diurnal temperature cycle with somewhat more placid fluctuations is shown in figure 2. Here we classify some seemingly intermittent disturbances in the temperature records and show correspondences of some classes of these with specific wind directions. It is suggested that some effects of atmospheric heating associated with wind blowing over the warm Lander and air bags are detected. Also we calculate structure functions for the temperature data in order to characterize the nature of the turbulent thermal fluctuations. Detailed assessment of possible atmospheric flow perturbations in the vicinity of the Pathfinder Lander is not done here, nor have we made an analytic determination if effects of likely flow disturbances could be detected. We have also obtained probability distributions for the morning temperature gradients.

Results

Martian meteorology data were acquired nearly every sol (Martian day) for 83 sols, by the Mars Pathfinder, but there are only five cases of continuous sampling during complete one sol periods. For each of these five cases the probability distribution of surface layer temperature lapse rates observed during periods approximately 9 hours long that encompassed the entire intervals with prominent daytime temperature fluctuations is shown in figure 3. These gradients were obtained from linear least squares fits to the samples from the three thermocouples described above and are useful for calculations of atmospheric stability and of gradient and bulk Richardson numbers

[Kaimal and Finnigan, 1994]. The median and mean values of these distributions decreased with time as the Martian summer ended at the Pathfinder location, the days became shorter and the maximum sun elevation angles decreased [Allison, 1997; the autumnal equinox was on sol 69]. The values of the medians (means) are 7.2 (7.2) K/m for sol 25 and 7.3 (7.3) K/m for sol 32-3, but only 5.7 (6.1) K/m for sol 68-9.

In figure 3 the distributions of temperature lapse rates extend to negative values which would be characteristic of nighttime rather than daytime conditions, but the fraction of negative values is observed to decrease with time, from 3.5% for sol 25, to less than 0.33% for sols 38-9, 55-6, and 68-9. The negative values seem to be associated with distinct atmospheric parcels that passed over the Lander and were heated at least at the 1.0 m level, as discussed subsequently.

Also, the probability distributions in figure 3 have tails that extend to values twice as steep as the most likely cases. The fractions of cases with lapse rates more negative than twice the mean value are roughly the same, 3%, for all five distributions. We found that cases with particularly steep lapse rates seem to be associated with another family of distinct atmospheric parcels that, moreover, were associated with wind from a particular direction, one from which, based on Lander images ["Mars Pathfinder," 1997; Smith et al., 1997a, b; Golombek et al., 1997, 1999; Stoker et al., 1999], atmospheric wind motion toward the lowest of the three thermocouples would tend to be partially obscured by piled up Lander air bag material heated by morning sunlight; this is discussed subsequently also.

It may be that morning surface layer lapse rate distributions characteristic of the Martian atmosphere unperturbed by foreign disturbances, such as the Lander, could be approximated by the cases of figure 3 with the extreme values (the negative values and those more positive than twice the mean) omitted.

Discussion

Here two phenomena mentioned above are discussed in more detail. The first is the negative lapse rates observed in the morning; the second is the particularly steep lapse rates also observed in the morning. Following discussion of these, a third phenomenon, cooling at all three levels simultaneously, observed in the early afternoon, is described and discussed briefly.

First, in figure 4, a 5000 s duration sample of thermocouple temperature differences (1.0 m level - 0.5 m level), wind directions and atmospheric temperatures

measured with the top thermocouple (1.0 m level), from sol 25, is shown. The largest fluctuations appear to be isolated episodes with substantial positive temperature differences that appear correlated with wind passing over the Lander and that evidently are a consequence of atmospheric heating by the Lander. In figure 4 such episodes occur near 0745, 0756:15, 0801:40, 0811:40, 0818:20, and 0823:20 LST. Some of these episodes are bounded by particularly large difference values that must be due to relative cooling at the 0.5 m height. In general, negative temperature differences should be indicative of daytime atmospheric temperature lapse rates, with the atmosphere being heated by Mars' warm surface, while positive differences would be expected at night when the Martian surface should be cooler than the atmosphere. The atmospheric heating at the 1.0 m level that produces these fluctuating temperature differences makes up a significant portion of all the morning temperature variations that have been published and that are shown on Figure 1. However, by around 1030 LST increased temperature excursions at these heights are generally found to no longer correspond with flow over the Lander.

In figure 4, between the isolated periods with larger temperature differences are intervals that exhibit a lower, but significant level of fluctuation that presumably is less contaminated. This lower level of fluctuation should be more representative of ambient morning convective turbulent mixing, rather than the 15 to 20 K fluctuations noted by Schofield et al. [1997], although outlying portions of the Lander (e.g., petals with solar panels) represent modifications of the preexisting terrain and, together with the main body of the Lander, could generate eddies when wind is present as well as enhance turbulent transport and mixing effects. As mentioned above, the later sols of those with a complete diurnal record do not show as much of the behavior shown in figure 4. It could be that this is due to decreased Lander electric power dissipation at these later times. However, during those later sols the wind appears to be steadier during the earlier parts of the morning, with directions that first pass over the Lander only later in the morning.

Second, in figure 5 is shown a 3000 s duration sample of temperature differences (0.5 m level - 0.25 m level) later in the morning, as well as wind directions, all from sol 25. During this time interval the most prominent amplitude fluctuations appear to be five isolated excursions of this temperature difference down to values of -14 K and lower, indicative of steeper than usual thermal gradients with height. These excursions appear correlated with times when the wind arrives from around 165 deg azimuth. From Lander images ["Mars Pathfinder," 1997; Golombek et al., 1997; 1999], it appears that Lander air bag material is piled up in that direction, relatively near

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the mast on which the thermocouples are mounted. From the virtual reality representation of the landed Mars Pathfinder and its environs [Stoker et al.; 1999], in that direction air bag material protrudes by as much as 18 cm above the Lander petal (C. R. Stoker, personal communication, 1999). The morning sun undoubtedly heats the eastern exposure of this air bag material; this could enhance the observed warming of the atmosphere at the lowest level, near the air bag material, which would make the temperature differences plotted in figure 6 more negative, as well as increase the measured lapse rates. This same behavior is observed in data from other sols.

Finally, in figure 1, after noon a different type of perturbation appears in the temperature records in addition to those discussed above: these are isolated temperature decreases (e.g., at 25.608 and 25.622) that can approach 10 K in magnitude and that appear coincidentally in the data from all three thermocouples but do not change much the temperature lapse rate. It may be that these decreases represent the cooling effect of atmospheric cloud patches but we do not study them further here. However, it may be noted that these times are not far from those at which (at least for sol 25; see also Haberle et al. [1999]) the mean diurnal variation of wind direction is from the direction that first passes over the Lander electronics enclosure where atmospheric parcels could be heated, and additionally, in the afternoon the temperature of the atmosphere should approach that of the Lander enclosure.

Structure Function

The spatial structure function for parameters of a turbulent medium is given, for example, by Monin [1990]; we use the conventional scalar simplification (for temperature, T)

$$D_T(h) = <[T(z) - T(z + h)]^2>$$

The angle brackets here denote the mean value. For unstable conditions in the surface layer of the terrestrial atmosphere, $D_T(h) \propto h^{2/3}$ (cf. Stull [1988], Kaimal and Finnigan [1994]; strictly speaking, h is scaled by the value of the turbulent heat flux at the surface). For more stable conditions (evening), more negative exponents than -2/3 would be characteristic of part of the height profile of the structure function for temperature (cf. Caughey et al. [1979]). Assuming $D_T(h) \propto h^{-n}$, a time series of power law exponents n is obtained from the ratios of the logarithms of the heights and of the individual temperature differences. The time series is then smoothed by locally weighted least squares. Figure 6 shows an example for

sol 25. During daytime the power law exponent is about -4. There are perturbations of the value of the exponent at sunset, and either side of sunrise. The early morning (post sunrise) deviations from a constant value may be a reflection of local effects due to the presence of the Lander; the significance of the constant values during part of the night, and of pre-sunset and pre-sunrise perturbations is not discussed here. These results are representative of those from other daytime data periods obtained with Mars Pathfinder.

The power law exponent of -4 appears similar to that for the uppermost region of the stable terrestrial boundary layer as deduced by Caughey et al. [1979] and discussed in Stull [1988]. The more common -2/3 power law can also be deduced from similarity relationships (cf. Stull [1988]).

Concluding Remarks

Morning atmospheric temperature fluctuations observed with Mars Pathfinder appear to be strongly influenced by atmospheric heating associated with wind blowing over the warm main body of the Lander spacecraft and/or heating induced by wind blowing over warm extended components of the Lander. Data segments that contain significant effects due to the proximity of the Lander have to be accounted for when interpretations are made.

The observed distributions of atmospheric surface layer temperature lapse rates shift toward lower values as autumn approaches at the Lander location. The gradient with height of the structure function for atmospheric temperatures, assuming a power law dependence, superficially resembles that of the upper portion of the terrestrial stable boundary layer.

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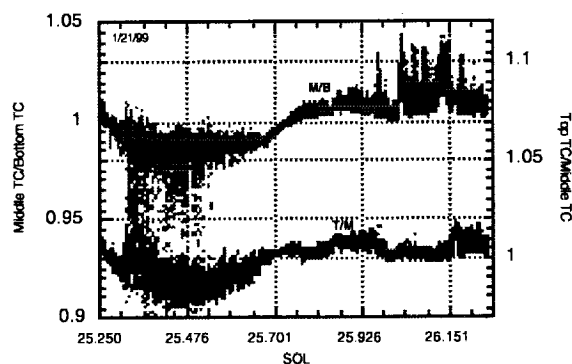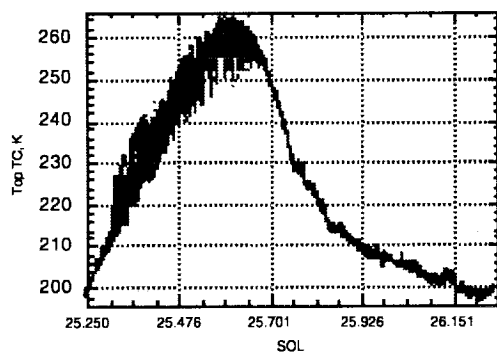
Figure 1. Diurnal variation of temperatures measured at three heights along the Mars Pathfinder meteorology mast (sols 25-6); sampling interval was 4 s. The left panel gives the temperatures reported from the top thermocouple and the right panel gives the top/middle ("T/M," lower plot, right-hand scale) and middle/bottom ("M/B," top plot, left-hand scale) thermocouple temperature ratios. Ratios are employed to display better the small systematic variations between the three measurements. Sunrise was at about 0545 (sol 25) and sunset was at about 1814 [Allison, 1997].
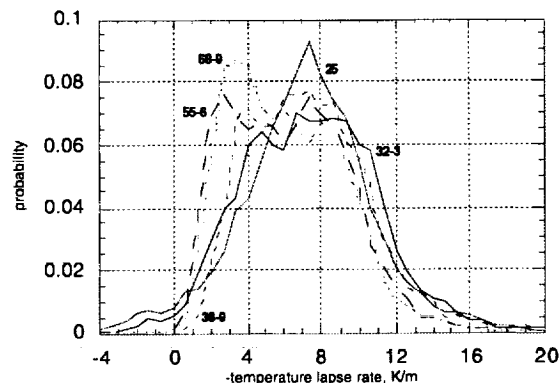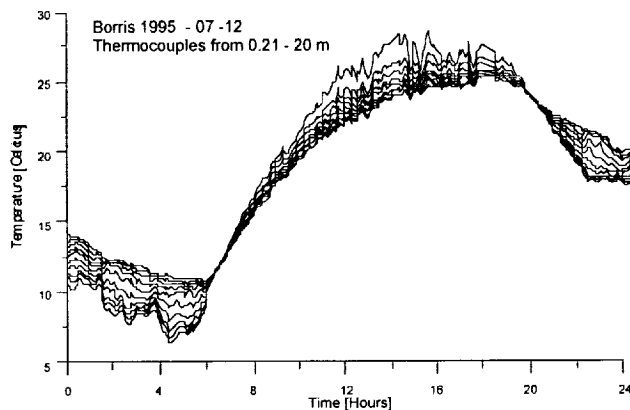
Figure 2. Diurnal variation of terrestrial summer atmospheric temperatures measured in Denmark at various heights (courtesy of H. E. Jorgensen and S. E. Larsen, Risoe National Laboratory, Roskilde, Denmark).

Figure 3. Probability distributions (2/3 K/m bins) of near-surface Martian atmospheric temperature lapse rates for the five complete diurnal cycles obtained by Mars Pathfinder. The distributions are labeled with their respective sol numbers.
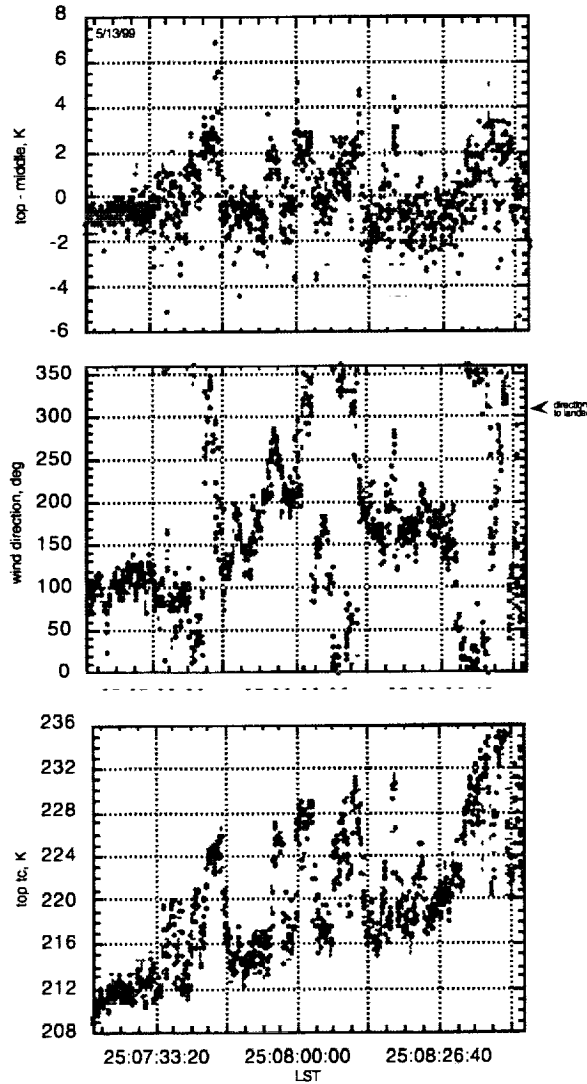
Figure 4. Thermocouple temperature differences (top - middle), wind directions and atmospheric temperatures measured by the top thermocouple, from sol 25, 0721:30 to 0842:40 LST.
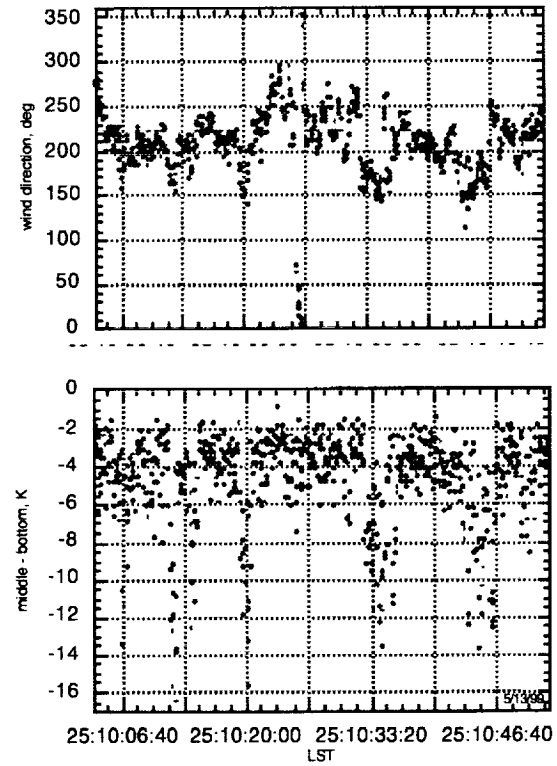

Figure 5. Thermocouple temperature differences (middle - bottom) and wind directions from sol 25, 1003:49 to 1052:25 LST.
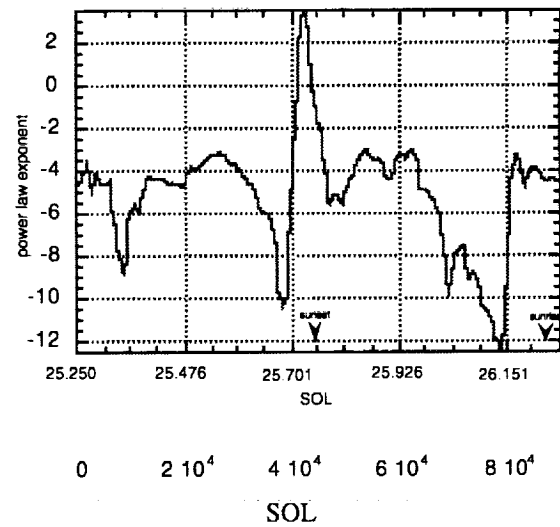

Figure 6. Smoothed diurnal cycle of power law exponents of gradient with height of structure function for temperature from Mars Pathfinder sols 25-6. The smoothing was done with locally weighted least squares applied to all segments that contain 2% of the total record. The times of sunrise and sunset as estimated by Allison [1997] are indicated.

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13. ABSTRACT (Maximum 200 words)

We have studied the most prominent atmospheric temperature fluctuations observed during Martian mornings by Mars Pathfinder and have concluded, based on comparisons with wind directions, that they appear to be a result of atmospheric heating associated with the Lander spacecraft. Also, we have examined the morning surface layer temperature lapse rates, which are found to decrease as autumn approaches at the Pathfinder location, and which have mean (and median) values as large as 7.3 K/m in the earlier portions of the Pathfinder landed mission. It is plausible that brief isolated periods with gradients twice as steep are associated with atmospheric heating adjacent to Lander air bag material. In addition, we have calculated the gradient with height of the structure function obtained with Mars Pathfinder, for Mars' atmospheric temperatures measured within about 1.3 m from the surface, assuming a power law dependence, and have found that these gradients superficially resemble those reported for the upper region of the terrestrial stable boundary layer.

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