DUST DEVILS AND VORTICES AT THE PHOENIX LANDING SITE ON MARS.

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Introduction: Near continuous measurements of pressure and temperature by the MET instrumentation on the Phoenix Mars Lander [1] are used to identify the passage of vertically oriented vortex structures at the Phoenix landing site (126W, 68N) on Mars.

Dust devils are thermally driven vortices. Convective vortices form in the lower part of the boundary layer when the atmosphere exhibits a superadiabatic lapse rate and the surface is strongly heated, generating convective plumes of rising air parcels that interact with the ambient vorticity. The rising hot plumes induce a radial inflow of air near the surface due to mass conservation and since this air will attempt to conserve its angular momentum, it becomes accelerated and creates a converging, circulatory flow around the low pressure core of the vortex. Some of these vortices obtain horizontal wind speeds large enough for dust particles to be lifted off the surface and into the vortex and thus become "Dust Devils". Dust Devils are a common feature in dry regions on Earth, such as hot desert regions [2] and in the subarctic [3] and has been observed in pressure data and in images on several Mars missions, such as Viking [4], Pathfinder [5] and Mars Exploration Rovers [6]. Furthermore, Dust Devil tracks have been observed by several orbiters, e.g. Mars Global Surveyor Mars Orbiter Camera [7].

Convective vortices and hence the dust devils have a characteristic pressure and temperature signature due to the low pressure core and the inflow of warm surface air towards the center of the vortex. [8]

From a ground based sensor, e.g. on the Phoenix Mars Lander, this signature will be a distinct pressure dip of the order of ~20 seconds when the dust devil passes by. The temperature will correspondingly increase during the passage of the dust devil (see Fig 1).

In this work we try to characterize the convective vortices and dust devils at the Phoenix landing site from pressure signatures in the Phoenix MET pressure and temperature data. Similar work was done on Mars Pathfinder pressure data by Murphy and Nelli (2002) [9] and to some extent Ferri et al. (2003) [10].

Method: To find the significant pressure events in the raw pressure data, we use a running average algorithm with 3 intervals of each 20 seconds: a, b and c. The algorithm calculates the average pressure difference Δp_av =((a+c)/2 – b) between intervals a, c and b. If Δp_av is larger than a preset cut-off value, we record the event. For every found pressure event, we record the surrounding pressure and temperature values and the "real" Δp = (a+c)/2 – min(b). We remove the recorded non-significant and false events by hand.

Results: During the Phoenix mission the pressure and temperature sensors frequently detected features passing over or close to the lander. Short duration (order 20 s) pressure drops of order 1-3 Pa, and often less, were observed frequently, accompanied by increases in temperature. Dust Devils were observed several times at the Phoenix landing site by other instruments. The Surface Stereo Imager (SSI) captured many images of Dust Devils [11] and the Telltale wind measuring device also shows evidence of Dust Devils [12].

Figure 1 shows a typical pressure event with a short pressure dip and a corresponding temperature increase during ~20 seconds, captured on Sol 13.

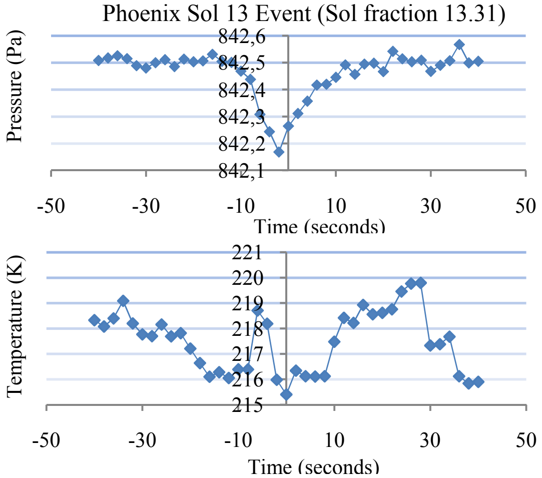

Figure 1: A typical pressure event from Sol 13

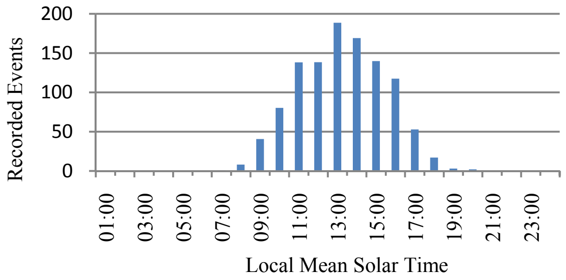

Figure 2: Frequency of events during the Martian sol

Many of the smaller recorded events do not look this smooth and symmetrical but in general, all our major recorded events (>1 Pa) have this distinct signature. The filter of course captures most events close to the cut-off value and we see an exponentially decaying trend towards larger pressure events. With a cut-off value of 0.2 Pa, the algorithm finds more than 1000 significant events from Sol 0-151 and roughly 30 of these are larger than 1 Pa. The largest recorded event is 2.89 Pa and was captured on Sol 95. Figure 2 shows the frequency of events through the Martian day. The distribution is somewhat bell shaped and most events occur in the early afternoon, but we also see some events in the surrounding hours.

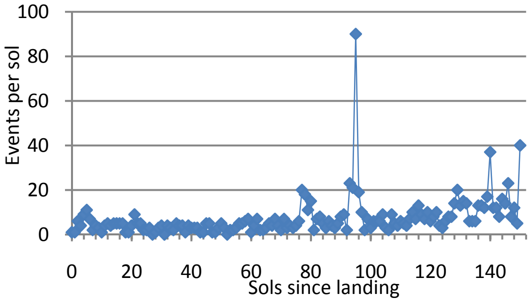

Figure 3: Events per sol as a function of time

Figure 3 shows recorded events per sol as a function of time since landing. Besides from the major peak around Sol 95, an increasing trend can be seen, especially from Sol 80 to Sol 151. This agrees well with the change in seasons and the atmosphere being more active with regards to boundary layer convection towards autumn. The Sol 95 peak happened when a low pressure system passed by the landing site, causing the atmosphere to become more active. This can be seen on Figure 4 that shows a clear drop in pressure during Sol 92-97 which clearly can be correlated with the amount of recorded pressure events at that time. MARCI images show diffuse water ice clouds at the Phoenix landing site those Sols [13].

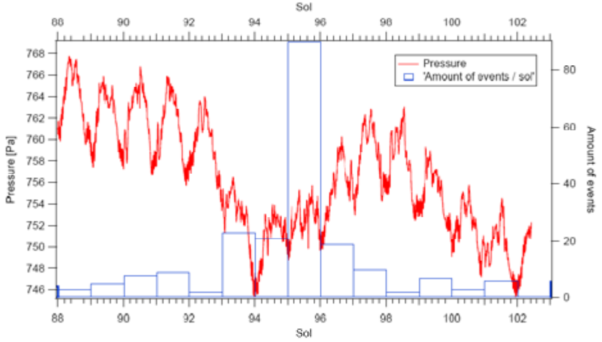

Figure 4: Pressure and recorded pressure events as a function of time since landing.

Compared to Mars Pathfinder results [9] we see the same patterns in magnitude, duration and temperature correlation with all our major pressure events (>1 Pa) having the same signature as the Pathfinder events. We also see the same patterns in the diurnal distribution of the pressure events with most events occurring between noon and 3pm LMST, the hottest part of the sol.

By assuming the concept of a vortex in cyclostrophic flow as well as various assumptions about the atmosphere and surface, we obtain a pressure drop of 1.9 - 3.2 Pa if dust is to be raised. We only saw a few pressure drops this large in Sols 0-151, but SSI images did show several Dust Devils. This emphasizes that the features do not need to pass directly over the lander and the pressures could be lower than the minima we measure. Furthermore, the response time of the pressure sensor is of order 3-5 s so it may not capture peak pressure perturbations. Thus, more dust devils may have occurred near the Phoenix site than indicated here.

Using a Large Eddy Simulation model, we can simulate highly convective boundary layers on Mars [14]. The typical vortex has a diameter of 150 m, and extends up to 1 km. Vortex wind speeds are order of 6 m/s, the core pressure drops are of order 1 Pa and the temperature rises are up to 10 K. Further calculations give an incidence of 11 vortex events per day that could be compatible with the LES simulations. Deeper investigation of this is planned -but the numbers are roughly compatible. If the significant pressure signatures are limited to the center of the vortex then 5 per sol might be appropriate.

Conclusion: The Phoenix mission has collected a unique set of in situ meteorological data from the Arctic regions on Mars and this can be used to characterize the convective vortices and Dust Devils at the landing site. Our results agree well with theory as well as with Mars Pathfinder results.

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