PHOENIX: Dustless Devils at the Lander Site: Mads Dam Ellehøj[1], Peter A. Taylor[2], Haraldur P. Gunnlaugsson[3], Babak Tavakoli Gheynani[2], Christina Holstein-Rathlou[3], Line Drube[1] and James Whiteway[2]; [1]Niels Bohr Institute, University of Copenhagen, Juliane Maries Vej 30, #337, DK-2100 Copenhagen, Denmark, [2] Centre for Research in Earth and Space Science, York University, 4700 Keele St., Toronto, Ontario, Canada M3J 1P3, [3]Department of Physics and Astronomy, University of Aarhus, Ny Munkegade, DK-8000 Århus C, Denmark,

Introduction: Near continuous measurements of temperatures and pressure on the Phoenix Lander are used to identify the passage of vertically oriented vortex structures at the Phoenix site (126W, 68N) during mid summer on Mars. LES modelling work [1] of highly convective boundary layers on both Earth and Mars shows that intense, vertically oriented vortices with low pressure, warm cores, can develop on internal boundaries, such as those associated with cellular convection. The measurements are consistent with the results of Large Eddy Simulations. Simple cyclostrophic estimates of wind speeds in the vortices suggest that very few will be capable of lifting dust from the surface – hence "dustless devils".

Observations: During the Phoenix mission the pressure and temperature sensors frequently detected such features passing over or close to the lander. Figure 1 below shows a fairly typical example.

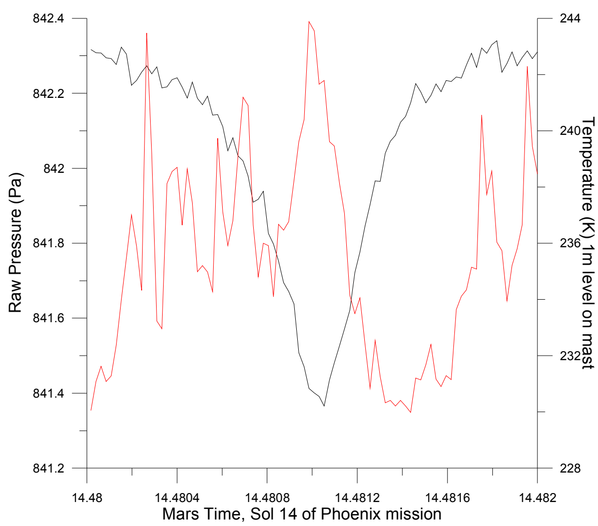

Figure 1 Typical signature of a vortex passing near the lander. Unadjusted pressure data in black, temperatures in red.

Short duration (order 20 s) pressure drops of order 1 Pa, and often less, were observed relatively frequently, accompanied by increases in temperature. The temperature increases arise because warm air from close to the surface is being drawn into the vortex and lifted to the levels of the temperature sensors on the mast. The 1m sensor is approximately 2m above ground level. Similar features were observed from the Pathfinder mission, although in that case the reported pressure drops were often larger [2].

Statistics of the pressure drop features over the first 60 sols of the Phoenix mission are shown in Figures 2 and 3 below. Most of the events occur between noon and 1500 LMST – the hottest part of the sol.

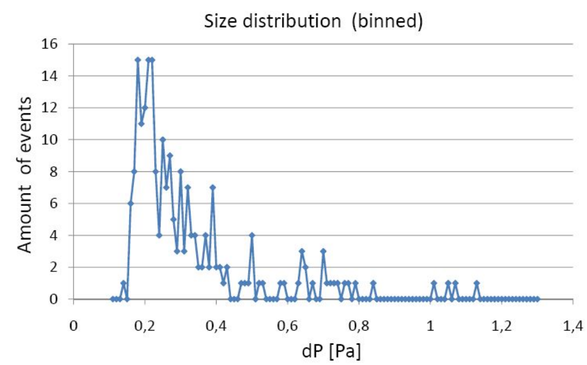

Figure 2. Magnitudes of the pressure events, Sols 0-60 of the Phoenix mission

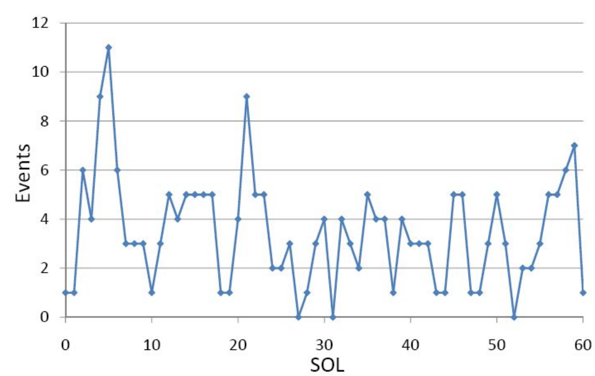

Figure 3. Numbers of events with $\Delta p > 0.2$ Pa during Sols 0-60 of the Phoenix mission.

Dust Lifting: We use the concept of a vortex in cyclostrophic flow of radius R, with $V^2/R = (1/\rho)\delta p/\delta r$. Approximating $\delta p/\delta r$ by $\Delta p/R$, if the velocity in the vortex were V and air density ρ then the pressure drop would be simply ρV^2. Whether or not dust is picked up can be related to a threshold friction velocity, u_{*t}. Our best estimate of the threshold friction velocity for Mars dust is 1 to 1.3 ms^{-1}. The fine dust is hard to lift without an initial saltation process involving larger sand grains. We can relate winds at the telltale level, 2m, to the surface friction velocity. Assuming a roughness length of

0.02m - a reasonable guess from looking at the surface, we have V(2m) = 11.5 u_*, so a threshold 2m wind speed would be from 11.5 - 15 ms^{-1}. However, pressures are measured at 1m above the surface so we can use V(1m) = 9.8 u_*, with thresholds of 9.8 - 12.7 ms^{-1}. Corresponding to this vortex velocity would be a pressure drop of 1.9 - 3.2 Pa (taking $\rho = 2x10^{-2}$ kgm^{-3}) if dust is to be raised. We did not see pressure drops this large in Sols 0-60 but may do later in the mission. Also bear in mind that the features need not pass directly over the lander and the centrap pressures could be lower than the minima we measure. We can also note that the response time of the pressure sensor is of order 3-5s so it may not capture peak pressure perturbations.

So a few dust devils may have occurred near the Phoenix lander site, but most of our vortices would be ghostly, dustless devils.

Modelling Studies: Using a Large Eddy Simulation model based on that developed at NCAR by Peter Sullivan, we can simulate highly convective boundary layers on Mars [1]. Figure 4 below shows how these develop along the boundaries of convection cells and gives an indication of their frequency of occurrence.

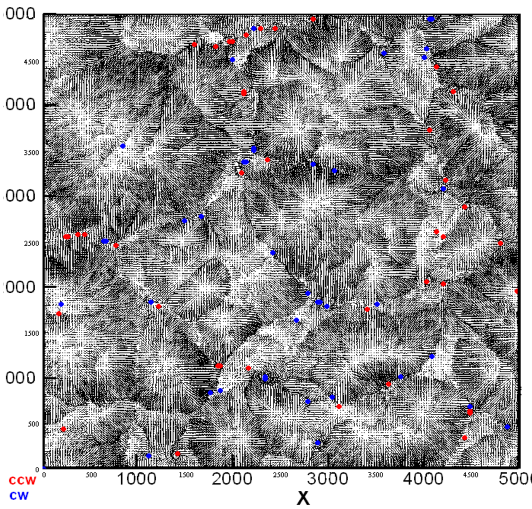

Figure 4: Vortices (84) found in the 25 km^2 domain of a large eddy simulation of the Martian boundary layer. z=20m, zero geostrophic wind and surface heat flux 25 Wm^{-2}.

The typical vortex has a diameter of 150m, and extends up to 1 km. Wind speeds in the vortex are of order 6 ms^{-1} (not enough to pick up dust) while the core pressure drops are of order 1 Pa and the temperature rises are up to 10 K.

We assume 50 vortices in 25 km2 at any given time – rather than 86 since the estimated heat flux turns out to be a little lower than the 25 Wm^{-2} used in the LES. With diameter 100m this represents 0.0314% of the area lying within a vortex. This situation may last 4 hours per day. If the vortices are travelling at 4 ms^{-1} and have diameter 100m the lander's pressure sensor could be affected by vortices within an area 4 x 3600 x 4 x 100 = 5.76 x 106 m^2 on each day. This area could include 50 x 5.76/25 = 11.5 vortices, so an incidence of 11 vortex events per day could be compatible with these LES simulations. Matching of the overall conditions is not exact and further investigation is planned - but the numbers are roughly compatible. If we argued that the significant pressure signatures would be limited to the central core of the vortex then 5 per sol might be appropriate.

Conclusions: The Phoenix mission has collected a unique set of in situ meteorological data from northern Arctic regions on Mars. Vortex signatures can be detected in the data but few have strong enough wind speeds to pick up local dust, so, at least in the first 60 sols, most of the Phoenix devils are dustless.

References

[1] Gheynani, B.T. and Taylor, P.A., (2008), Large Eddy Simulation of vertical vortices in highly convective Martian boundary layer, Paper 10 B.6, 18th Symposium on Boundary Layers and Turbulence, June 2008, Stockholm, Sweden

[2] F Ferri, PH Smith, M Lemmon, NO Renno; (2003) Dust devils as observed by Mars Pathfinder. JGR,108, NO. E12, 5133, doi:10.1029/2000JE001421.