VIKING LANDER 1 AND 2 REVISITED: THE CHARACTERISATION AND DETECTION OF MARTIAN DUST DEVILS.

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Introduction: During the summer of 1976 Viking Lander 1 and 2 touched down at Chryse Planitia and Utopia Planitia, Mars respectively. The primary aim of both Viking Landers was to look for the presence of organic life on the surface of Mars, however each Lander also had a comprehensive meteorological package to monitor the martian atmospheric conditions [1]. The meteorological package consisted of pressure, temperature and wind sensors, enabling the landers to perform the first detailed in-situ investigation of martian weather. Data was logged for the full mission at a variety of sampling rates. High data rates were used early on in the mission (one sample every 8 seconds), but this moved to a lower rate (one sample per minute) after sol 60 for Viking Lander 2. The meteorological results from the Viking Landers highlighted diurnal variations in pressure and temperature. The ambient wind speeds were generally below 10ms^{-1}. The biggest pressure variation was between the two landing sites; explained by the difference in latitude and altitude. Apart from this variation the long-term pressure was relatively constant at approximately 6 mbar. Large temperature variations were seen to be commonplace on Mars, with a diurnal range of approximately 50K. This diurnal temperature variation is essentially a consequence of the low thermal inertia of the surface and the atmosphere.

Dust devils form at the base of convective plumes. These convective plumes are created by surface heating from the Sun. Dust devils, when detected, will produce changes in all of the key meteorological parameters measured by the Viking Landers, namely pressure, temperature, and wind. These vortices may also leave tracks or marks on the surface where they have lofted the surface regolith; these were first seen and identified from Viking orbital photography [2]. The two Viking Lander meteorological instruments did indeed detect possible convective vortices, first reported by Ryan and Lucich, (1983), who gave an indication of annual occurrence statistics. Mars Pathfinder also detected 79 convective vortices inferred from pressure variations [3]. Dust devils have also been detected in some of the Mars Pathfinder wide angle camera images [4]. It is clear therefore that dust devils occur on Mars, and their relevance to the martian global dust cycle is currently a topic of scientific interest [4-6].

Vortex Detection: Convective vortices can be detected by a characteristic behaviour in their meteorological parameters. This signature or change in meteorological parameters could include a change in wind speed and direction, a rise in temperature, or a drop in pressure. The last two parameters will only be truly characteristic if the sensor suite encounters the vortex core.

Modelling exists to approximate empirically the wind speed and direction changes characteristic of atmospheric vortices. Wind speed is modelled using the Rankine vortex method [7], where the tangential wind speed decreases with a $1/r$ relationship from the edge of the core boundary outwards to the edge of the zone of influence (approximately 10 x visible core radius) and also decreases linearly inwards to zero at the centre of the vortex. Apparent wind direction (as seen by a stationary observer) is calculated using simple trigonometry. The modelled vortex signature can then be used to identify vortices in meteorological data.

To identify convective vortices from the Viking Lander meteorological data, the detection technique used is to compare a time-averaged mean to a threshold value, commonly known as a phase picker. For each variable under consideration, this method calculates a short term mean, STA (a running average of the last few readings), and a long term mean, LTA (a running average covering a longer period of time). The difference between the STA and LTA is compared to a specified threshold value. (values of 6ms^{-1} for wind speed and 40 degrees for wind direction in this study).

$$|STA - LTA| > threshold \qquad (1)$$

The STA uses for example the most recent 3 samples and the LTA uses the most recent 50 samples (dependent on sample rate). This approach is widely used in seismology for time series data to detect events of interest [8]. Possible convective vortex events are then highlighted and examined manually. The technique not only picks out possible convective vortices but will trigger on other anomalies in the data such as gradients in the wind data which are also of interest. This method has been used successfully to detect terrestrial dust devils during a recent field investigation, as part of the MATADOR 2001 programme [9].

Classification of Convective Vortex Events: Once the dust devil is detected a Rankine fit can be used to estimate miss distance and diameter to give a better picture of the vortex. In addition the meteorological phenomena seen by The Viking Landers convective vortices have been classified, allowing for easy identification of convective vortices. This classification gives a clear indication of what to look for in a possible dust devil event. This clasification is not intended to be specific to Viking and could be used to classify convective vortices from any field study, including future missions. Convective vortices are divided into three groups, core (1), near miss (2), and possible (3). The first two categories are then subdivided to differentiate between convective vortices and dust devil events. Category 3 is reserved for 'possible events', which pass a considerable distance from the sensors and may or may not fit the empirical Rankine vortex model. Two further categories 4 and 5 describe sustained gusts, and other transient events that do not fit into other categories.

Results: Ryan and Lucich (1983) analysed a total of 129 (Viking Lander 1) and 151 sols (Viking Lander 2) of which 43% and 39% contained vortices respectively. They also provided seasonal statistics on the formation of vortices. The analysis contained in this paper does not cover the seasonal variation which was analysed by Ryan and Lucich, but provides a more in depth analysis of diurnal statistics for the Viking landers, which will complement the findings of Ryan and Lucich.

The threshold values used produced 38 possible vortices in the first 60 sols of Viking Lander 2 [with STA = 3, LTA=50, and a sample rate of 0.5 to 0.0625 Hz]. These candidates were then manually confirmed by looking at the pressure and temperature variations. This number of vortex events is consistent with the statistics from previous martian dust devil studies of the Viking Landers [10]. 34 other events were detected for Viking Lander 2 ranging from direct passes over the meteorological sensors to gusts or unidentifiable events. The entire data set was also scanned by eye to confirm the efficiency of the phase picker algorithm used. Events were then classified according to the scheme described previously.

It is believed that some true dust devils have been detected, defined as a convective vortex with wind speeds above the threshold wind speed able to loft sand particles, (25-30ms^{-1}, [11]). However there is no way to be sure if these did in fact loft surface particles. Recent work is tending to indicate that dust devils may not follow traditional saltation rules [5]. During the martian summer of 1976 the wind speeds were in general below 10ms^{-1}, which would be insufficient to loft surface particles by traditional methods.

Of the 38 possible vortices, an initial analysis indicated no preference between clockwise and counterclockwise rotation, in agreement with Ryan and Lucich(1983).

Diurnal Statistics: Considering the diurnal occurrence and properties of the martian wind dominated phenomena detected, Fig. 1 summarises the diurnal statistics for categories 1, 2, and 3, (possible convective vortices for Viking Lander 2 sols 1-60) and shows a maximum at between 13:00 and 13:30, with the majority of activity happening before this time. This is similar, but not exactly the same behaviour, to that seen on Earth, where the maximum generally comes in the afternoon, with little activity in the morning.

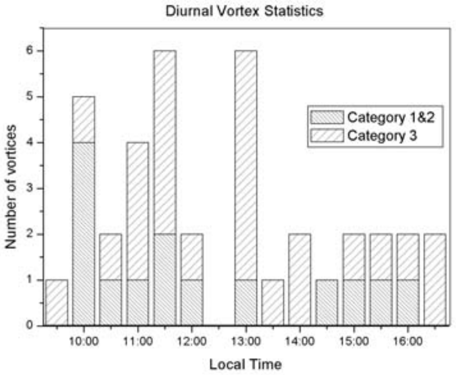

Figure 1 Diurnal statistics for vortices seen by VL2

Classification Example: Figure 2 a convective vortex (category 1b) from sol 4 (Viking Lander 2), which has a distinctive vortex signature. There is an abrupt shift and return to ambient in wind direction, a peak in wind speed and temperature, all in a time scale of about 90 seconds. This is a good example, showing the vortex core, and the convective vortex must have passed almost directly over the lander.

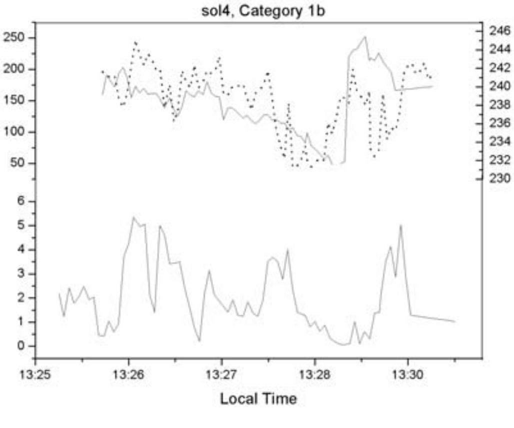

Figure 2 The upper solid line and upper left axis represents wind direction in degrees, from the local north, the lower solid line and lower left axis is wind speed (ms^{-1}), the short dashed line is temperature (K), upper right axis.

Implications: At the Mars Pathfinder landing site the dust deposition rate was estimated to be 5-15 μmyr^{-1}. This would result in a surface particulate layer metres thick accumulating over a geologically short period of time, suggesting that large amounts of surface material is constantly redistributed around the surface [12]. Applying the estimates of dust loading of appropriate dust devils seen by the Mars Pathfinder [4] to the Viking data, one can estimate the total amount of surface material lofted by dust devil events around Viking Lander 2 over the first 60 sols to be at least $3.4x10^4$ kg, equivalent to 800±10 $kgsol^{-1}km^{-2}$. This assumes a dust loading of $7x10^{-5}$ kgm^{-3}, an average vertical velocity of 7 ms^{-1} and a dust free core of 50% [13, 14]. This strongly implies that dust devils are responsible for redistributing large amounts of martian surface material over a geologically short time period.

Conclusions: Convective vortices and dust devils have been seen on Mars both in orbital data and meteorological data, as well as lander images. Previous estimates of dust devil activity [10] at the Viking Lander sites have provided information about the seasonal behaviour. To add to this data set, Viking Lander 2 meteorological data has been analysed for the sols 1-60, which have a sufficiently high sampling rate for reliable detection of short-term meteorological phenomena. Convective vortices have been identified from their distinctive meteorological signature, using a phase picker algorithm [8] and categorized by a rating scheme, which considers intensity and confidence of detection. Wherever possible, estimates are made of the core miss distance from the Lander and the predicted diameter of the vortex, assuming a response for the vertical sensitivity of the wind sensor, and estimating a vertical wind profile within a convective vortex based on previous studies. An estimate of maximum wind speed within the vortex is also made and compared to the estimated dust saltation threshold at the landing site [15] to infer if the vortex was dust laden. In total, over the 60 sols of Viking Lander 2, 38 vortices have been detected. It is thought that a few of these vortices are false signals due to lander body interference [1] but 6 of the 38 have sufficient wind speeds to entrain local surface material from the landing site. Diurnal activity is similar to terrestrial behaviour, but with increased early morning activity, which it is inferred is probably due to a lower adiabatic lapse on Mars. Total number statistics seen here give a detection rate of 0.6 vortices per sol, compared to recent results of 2 per sol seen by Mars Pathfinder [3]. These results illustrate how common convective vortices are on Mars and potentially how important dust devils are in shaping the martian surface. As a broad estimate, applying the Mars Pathfinder estimates of dust devil dust loading, the total amount of material lofted in the area of the Viking Lander 2 is of the order of 800 $kgsol^{-1}km^{-2}$. This analysis is in agreement with the earlier study by Ryan and Lucich and adds to the published data by providing data on the diurnal behaviour of convective vortices at the Viking 2 landing site. Further analysis is currently ongoing characterizing convective vortex events from the Viking Lander 1 data.

References: [1] Hess, S., et al., *Meteorological results from the surface of Mars: Viking 1 & 2.* JGR., 1977. **82**: p. 4559-4574. [2] Thomas, P. and P. Gierasch, *Dust Devils On Mars.* Science, 1985. **230**: p. 175-177. [3] Murphy, J.R. and S. Nelli, *Mars Pathfinder convective vortices: Frequency of occurrence.* GRL, 2002. **29**(23). [4] Metzger, S. and M. Carr, *Dust devil Vortices seen by the Mars Pathfinder Camera. GRL*, 1999. **26**: p. 2781-2784. [5] Balme, M., et al. *Dust devils on Mars: results from threshold test using a vortex generator*. in *LPSC*. 2002. [6] Tratt, D., et al. *In Situ Measurements of Dust Devil Dynamics*. in *American Geophysical Union*. 2001. [7] Faber, T.E., *Fluid Dynamics for Physicists*. 1995: Cambridge University Press. [8] Allen, R., *Automatic Phase Pickers: Their Present Use and Future Prospects.* Bulletin of the Seismological Society of America, 1982. **72**(6): p. 225-242. [9] Hecht, M., et al., *MATADOR Dust Devil Campaign*. 2001. [10] Ryan, J. and R. Lucich, *Possible Dust Devils, Vortices on Mars.* JGR., 1983. **88**: p. 11005-11011. [11] Greeley, R. and J.D. Iversen, *Wind as a geological process on Earth, Mars, Venus, and Titan*. 1985: Cambridge University Press. [12]Golombek, M.P. and N.T. Bridges, *Erosion rates on Mars and implications for climate change: constraints from the Mars Pathfinder Landing site.* JGR., 2000. **105**: p. 1841-1853. [13] Metzger, S., *Dust Devils as Aeolian Transport Mechanisms in Southern Nevada and the Mars Pathfinder Landing Site*, in *Department of Geology*. 1999, Ph.D., University of Nevada: Reno. p. 208. [14] Sinclair, P., *A Quantitative Analysis of The Dust Devil*, in *Geology*. 1966, Arizona State. [15] Greeley, R., et al., *Threshold Windspeeds for Sand on Mars: Wind Tunnel Simulations, GRL*, 1980. **7**: p. 121-124.

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