EPSC Abstracts
Vol. 13, EPSC-DPS2019-550-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Wind and pressure measurements of Dust Devils by Mars Science Laboratory

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Abstract

NASA's Mars Science Laboratory lander (MSL) has measured simultaneous fluctuations in wind and atmospheric pressure, caused by passing convective vortices. We present a method for fitting a theoretical vortex model to these pressure and wind measurements. Our first results show that the model is in good agreement with the data.

1. Introduction

It has been suggested that dust devils, i.e. dust lifting convective cortices, maintain the background dust haze of the Martian atmosphere [3]. Dust devils have been imaged by several Mars orbiters and landers [1, 5]. Also, wind and pressure fluctuations caused by convective vortices have been measured by landers [5]. However, all previous meteorological surveys on Martian convective vortices have been based on either pressure or wind data, not both of them. The first coincident pressure and wind measurements of Martian convective cortices are presented in this study.

In 2016, Lorenz presented a method for fitting a vortex model to pressure and wind measurements [4]. We have developed that method further and utilize it to the data measured by MSL.

2. Data

We use air pressure and wind data measured by the REMS instrument (Rover Environmental Monitoring Station) onboard MSL [2]. As the REMS wind data may be significantly biased, particularly after the sensor damage during MSL's landing [2], and high frequency data could be less accurate, only 5 minute averaged values of wind speed and direction are available in NASA's Planetary Data System (PDS).

However, a new wind retrieval algorithm was developed that allows relatively good wind measurements to be extracted from the raw dataset obtained with the damaged sensor [6]. Thus, we use the high frequency (1 Hz) wind data within high quality periods in order to fit the vortex model with enough temporal resolution. Measurement points considered unreliable are discarded. Because the wind velocity readings are still noisy, we use only the wind direction and pressure measurements as inputs when fitting the vortex model to the data.

3. Vortex model fitting method

The pressure field P of a passing vortex is modelled with a Lorentzian function

$$P(d) = P_\infty - \frac{\Delta P_0}{1+(2d/D)^2} \qquad (1)$$

where d is the distance from vortex center, D is the half-maximum diameter of the pressure depression of the vortex, ΔP_0 is its central pressure drop, and P_∞ is background pressure. The modelled wind vector $\overline{\boldsymbol{W}}$ at the measurement station is a sum of the ambient wind $\overline{\boldsymbol{U}}$ and the tangential wind around the vortex center $\overline{\boldsymbol{V}}_{\boldsymbol{T}}$. Assuming that the vortex is in cyclostrophic balance, the velocity of the tangential wind V_T is given by

$$V_T(d) = \sqrt{\frac{d}{\rho}\frac{\partial P}{\partial d}} = \sqrt{\frac{2\Delta P_0}{\rho}\frac{2d/D}{1+(2d/D)^2}} \qquad (2)$$

where ρ is air density.

The vortex is assumed to move along a straight line with velocity S, passing by the measurement station at miss distance d_{min} on time point t_0. Hence, the distance d between the vortex center and the measurement station as a function of time t is given by $d(t) = \sqrt{d_{min}^2 + S^2(t-t_0)^2}$. The modelled pressure at the measurement station is got by substituting this into eq. 1:

$$P(t) = P_\infty - \frac{\Delta P_{obs}}{1+\left(2(t-t_0)/t_{1/2}\right)^2}. \quad (3)$$

In eq. 3, $t_{1/2}$ is the Full Width at Half Maximum duration of the observed pressure drop

$$t_{1/2} = \sqrt{(2d_{min}/S)^2 + (D/S)^2} \quad (4)$$

and ΔP_{obs} is the depth of the observed pressure drop

$$\Delta P_{obs} = \frac{{t_{1/2}}^2 - (2d_{min}/S)^2}{{t_{1/2}}^2} \Delta P_0. \quad (5)$$

The values of the parameters $t_{1/2}$, ΔP_{obs}, t_0 and P_∞ are determined by fitting a function with the form of eq. 3 into the pressure data.

By solving D and ΔP_0 from equations 4 and 5 and substituting them into eq. 2 we get a model for the tangential wind velocity at the measurement station:

$$V_T(t) = \sqrt{\frac{\Delta P_{obs}}{2\rho} \frac{t_{1/2}\sqrt{(d_{min}/S)^2 + (t-t_0)^2}}{\left(t_{1/2}/2\right)^2 + (t-t_0)^2}} \quad (6)$$

The azimuth θ of vortex as seen from the station is got from geometry:

$$\theta(t) = \theta_M + \tan^{-1}\left(\frac{t-t_0}{d_{min}/S}\right) \quad (7)$$

where θ_M is the azimuth of vortex on the moment of closest approach. The direction of the tangential vortex wind at the measurement station is $\theta \pm 90°$, the sign depending on the rotation direction of the vortex. Note that the magnitude and the direction of the tangential vortex wind at the measurement station depend on the ratio d_{min}/S, however, the tangential wind does not depend directly on d_{min} nor S (eqs. 6 and 7).

The direction and velocity of the ambient wind $\bar{\boldsymbol{U}}$ and the values of the parameters d_{min}/S and θ_M are determined by fitting the model of the wind direction ($\bar{\boldsymbol{U}} + \bar{\boldsymbol{V}}_{\boldsymbol{T}}$) to the measured wind direction data. The central pressure drop ΔP_0 can then be solved from equation 5 by using the value of the d_{min}/S parameter.

4. First results

We have applied the fitting method described above to three vortex events on MSL sols 72, 123 and 150. The model fits the data well in all of these cases. The modelled wind velocity also fits the data rather well even if the wind velocity measurements were not used in the fitting.

5. Conclusions and further work

The assumption that Martian dust devils are in cyclostrophic balance seems to be a good presumption based on our first results. We aim to analyze more vortex events in the near future. Events with simultaneous drops in the UV flux measured by REMS [2] will be prioritized as these events are apparently caused by dust lifting vortices shadowing the incoming solar radiation [3, 5]. Applying the vortex model fitting method to these events would thus give information about the depth of the central pressure drops and tangential wind velocities of Martian dust devils.

Acknowledgements

The contribution of H. Kahanpää in this study was funded by The Finnish Cultural Foundation (grant number 00180446).

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