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The impact of dust storms on the near-surface meteorology of Mars

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1. Introduction

Regional and global dust storms on Mars cause major changes to the atmospheric state due to the impact of changes to the spatio-temporal distribution of dust abundance and particle size on heating rates and hence circulation [1]. Quantifying the near-surface meteorological impact of storms is important because: (i) it impacts future dust lifting via wind stress and dust devils, hence provides insight into the dust storm growth feedbacks; (ii) the circulation during storms may be important to understand aeolian observations; (iii) the success of robotic and manned missions may rely on accounting for the near-surface weather that occurs during such events; and (iv) unusual conditions test the performance of numerical models designed to simulate Martian weather, in particular their physical parameterization schemes.

Two major dust events occurred in MY34: a global dust storm (GDS) that was observed on the surface from Ls~182° by the Mars Science Laboratory (MSL) Curiosity Rover, and a regional dust storm, observed on the surface from Ls~320° by both MSL and the InSight Lander. Both storms were also observed from orbit by the Mars Climate Sounder (MCS) on Mars Reconnaissance Orbiter and Thermal Emission Imaging System (THEMIS) on Mars Odyssey. Using column dust opacities retrieved from MCS and THEMIS data [2] we prescribe the dust distribution inside the MarsWRF atmospheric model [3] and use it to simulate both storms. We compare the observed and modelled atmospheric response and use the model to investigate causes of the observed changes in pressure, temperature and winds during storms.

2. Methodology

The MarsWRF multi-scale atmospheric model is run with higher-resolution domains ‘nested’ inside its global domain with a three-fold increase in resolution from nest to nest. Four domains are used to model the circulation at InSight’s landing site, with a resolution of ~4.4km in the innermost nest. For modeling the circulation seen by MSL, domain 4 is moved to sit over Gale Crater and another nest is added inside it, in order to resolve the internal crater topography.

3. Surface meteorological datasets

MSL carries the Rover Environmental Monitoring Station (REMS) which returned surface pressure, air and ground temperature, UV flux, and water vapor relative humidity for the period covering both storms. Wind data were not returned due to MSL’s already-damaged wind sensor failing completely in MY33. InSight carries the Auxiliary Payload Sensor Suite (APSS), consisting of a surface pressure sensor plus two booms with an air temperature and wind sensor each, and also carries an infrared radiometer to provide ground temperature. InSight landed after the global storm but returned data for the regional storm.

4. Impact of a global dust storm in Gale Crater

Figure 1 shows (in color) the observed diurnal cycles of pressure, ground temperature and air temperature, both prior to and during onset of the MY34 global dust storm which began at Ls~182°. Also shown is the modeled atmospheric response to the evolving dust distribution using the MarsWRF model (in black). The key signature of the global storm is an additional maximum in pressure signaling a stronger semi-diurnal tide, which is largely captured by the model. There is also an increase in the diurnal pressure range, which is over-predicted by the model. MarsWRF also captures the observed decrease in the ground temperature diurnal range due to the amount of atmospheric dust present. The impact on temperatures is greater, in both the model and data, as the storm develops further (not shown).

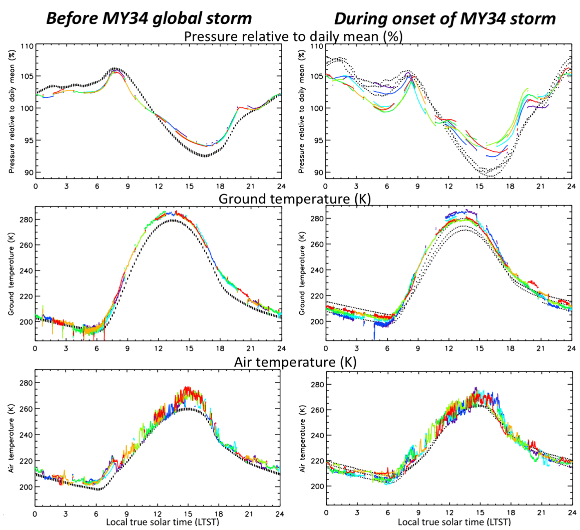

Figure 1: Diurnal cycles at MSL's location, (left) prior to [Ls~176°] and (right) during [Ls~189°] the global storm. Colors = REMS, black = MarsWRF.

5. Impact of a regional dust storm in Elysium Planitia

Figure 2 shows diurnal cycles of surface pressure, wind speed and wind direction observed by InSight and simulated by MarsWRF before and during the regional storm. During the storm the diurnal pressure amplitude is increased by ~80%, which is very well captured by MarsWRF. The relative strength of the semi-diurnal tide is also much increased causing a larger secondary peak, also as largely captured by the model. MarsWRF captures most diurnal variations in wind speed and direction, but misses the strongest daytime turbulent wind gusts, which cannot be simulated at the resolution of the innermost nest. Both gustiness and the minimum wind speed appear to decline during the storm, also as predicted. The wind direction prior to the regional storm is captured very well by MarsWRF, although predicted winds are too northerly from ~3pm-3am. However, the model nicely captures the change to a ~westerly wind direction pre-dawn due to strengthening downslope winds on the dichotomy boundary. By contrast, during the storm the wind direction turns through 360° over the course of most sols, which is captured very well by MarsWRF. Investigation shows that this is due to the stronger influence of tidal circulation components than slope winds during the storm.

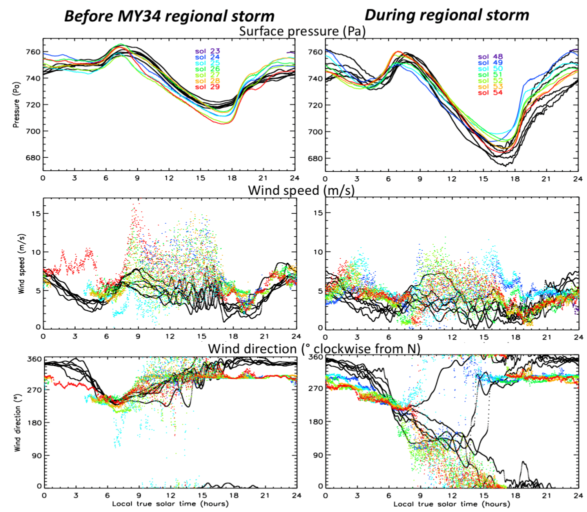

Figure 2: Diurnal cycles at InSight's location, prior to [Ls~312°] and during [Ls~322°] the late MY34 regional storm. Colors=APSS, black = MarsWRF.

6. Conclusions

The MarsWRF multi-scale model, driven by observed dust distributions, reproduces much of the observed atmospheric response to global or regional dust storms. This model output may then be investigated to indicate the likeliest processes and feedbacks that are present in the real atmosphere.

References

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