Convective vortex and dust devil predictions in Gale Crater using a thermodynamic theory, and comparison with observations
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Background and motivation

- Atmospheric dust is the main driver of variability in Martian weather/climate
- Dust devils (dust-filled vortices) are likely a primary mechanism for raising dust into Mars’ atmosphere outside of major dust storms
- Understanding the spatio-temporal variation of vortices and the amount of dust lifted may be key to predicting Mars weather and climate
- Dust devils are also important for cleaning dust off solar panels, sensor optics, and other surfaces on landed missions
- Rovers/landers and orbiters have been imaging Mars dust devils and tracks since the 1970s
- Rover/lander meteorological sensors have also been used to measure rapid pressure drops and other changes associated with passing vortices
- Curiosity has used its cameras and the Rover Environmental Monitoring System (REMS) to monitor dust devils and vortices since 2012

Dust devils imaged by Navcam in Gale Crater, sol 1597

REM5 pressure drops associated with vortex passage

Rennó et al. theory of dust devil activity

- Rennó et al. [1998] proposed a thermodynamic theory for convective vortices and dust devils
- It defines a ‘dust devil activity,’ DDA ≈ max(0, η F_s) where F_s is surface sensible heat flux (heat input to the vortex base) and η is the vertical thermodynamic efficiency (the fraction of this heat turned into work)
- η = 1 - b where b ≈ \left( \frac{\rho_u^*}{\rho_u} \right) \left( \frac{\rho_a}{\rho_u} + \frac{\rho_0}{\rho_a} \right) and where \rho_u is the ambient surface pressure, \rho_a is the ambient pressure at the top of the convective boundary layer, and η = R'/(c_p c_u)
- => η (and hence DDA) increases with the depth of the planetary boundary layer (PBL)
- F_s = C_p u_*^4 (T_{surf} - T_{air}) where C_p is a drag coefficient that depends on the stability of the near-surface atmosphere, \rho is air density, u_\ast is drag velocity, and T_{surf} and T_{air} are the surface and lowest layer air temperatures, respectively
- This lets macroscale meteorological fields (e.g. from models) be used to predict DDA, e.g. as a proxy for dust devil lifting in dust cycle modeling [e.g. Newman et al., JGR, 2002a,b]

Predicting DDA using MarsWRF output

- 5 increasingly (3-fold per domain) high-resolution domains are ‘nested’ inside a global 2nd-simulation
- Domain 6 MarsWRF output is used to predict DDA

Noon DDA, F_s and η at 4 times of year

- The rover traverse is contained inside the yellow box
- Predicted DDA in all seasons is larger as we look higher on the slopes of Aeolis Mons within that box
- However, η (varies as ~PBL depth) is not predicted to increase over the slopes in most seasons, and is smaller over Aeolis Mons at summer solstice
- ⇒ The predicted increase is mostly due to spatial variations in sensible heat flux, F_s

What causes the predicted spatial variation in F_s?

- Maximum DDA is predicted around summer solstice, minimum DDA around winter solstice
- Peak DDA is predicted ~12-3pm around summer solstice and ~12-2pm around winter solstice
- A double peak in DDA is predicted around spring/fall equinoxes (maxima at ~11am and 2pm), due to a double peak / big early peak in sensible heat flux and large late peak in PBL depth F_s peaks earlier around fall and (more so) spring equinox than summer/winter solstice around spring equinox
- For all seasons and LTST, DDA is predicted to increase from year to year, mostly due to F_s

Predicting DDA vs. inferred # of observed vortex pressure drops per hr

- Predicted DDA captures the main seasonal, LTST, and year-to-year variation in observed vortex pressure drops
- However, MSL did not see the double peak predicted around spring equinox, whereas one is suggested (but not predicted) around summer solstice
- Also, far fewer pressure drops are observed than predicted over much of year 1 and around winter solstice of year 2; could this be due to errors in (or low resolution of) the thermal inertia map used in domain 6?

Summary and conclusions

- Rennó et al.’s ‘dust devil activity’ predicted using output from modeling of the near-surface atmosphere captures most of the seasonal, LTST, and year-to-year variation in vortex pressure drops observed by MSL
- Spatial (hence year-to-year) variations are predicted to be mainly due to sensible heat flux variations, which are due primarily to variations in thermal inertia and u_\ast