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Original deep convection in the atmosphere of Mars driven by the radiative impact of dust and water-ice particles

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Background and motivation Recent spacecraft observations have shed a new light on "mesoscale" meteorological phenomena in planetary atmospheres, developing at spatial scales smaller than the Rossby radius of deformation: Mars' regional dust storms[1], Venus' cloud layer plumes[2], Titan's methane storms[3], gas giants' convective storms[4,5]. Not only those processes have a crucial influence on the whole climate, but they also unveil key characteristics of planetary environments, and fundamental atmospheric fluid dynamics. Some of the above-mentioned mesoscale phenomena (e.g. convective storms on Titan and gas giants) share similarities with moist convective motions on the Earth: convective instability is triggered by the release of latent heat by condensing species such as water, methane, ammonia. By contrast, Mars was thought to be devoid of deep convection: water-ice clouds do form because the atmosphere is close to saturation, but the associated release of latent heat is negligible given the low quantity of water involved[6]. Here, using dedicated mesoscale modeling and Large-Eddy Simulations[7], using an interactive dust scheme[8] and a complete radiative + scavenging model for water-ice clouds[9,10], we unveil two examples of deep convection on Mars – in dust storms[11] and water-ice clouds[12] – to demonstrate that the radiative effect of aerosols and clouds can lead to powerful convective motions just as much as the release of latent heat in moist convection.

Convection in dust storms Dust storms are often considered as indicative of regional and global winds, and having an impact on global circulation. Mesoscale modeling could draw a slightly different picture[13]. Our simulations with a dust transport scheme showed that deep convective motions, implying a fast and efficient upward transport of dust particles, occur in Martian local and regional dust storms, a phenomena we named "rocket dust storms"[11]. The supply of convective energy is provided by the absorption of incoming sunlight by dust particles (positive buoyancy, Fig 1), rather than by latent heating as in moist convection on Earth and other environments. A potentially strong implication is the formation of detached layers of aerosols[14], which needs to be parameterized in Global Climate Models. This new view on local dust storms might also help to understand how a large regional storms becomes a planet-encircling dust storm, with mechanisms possibly analogous to Mesoscale Convective Systems[15] and convective self-aggregation on the Earth.

Convection in water-ice clouds Nighttime mixing layers were unveiled in the troposphere of Mars by radio-occultations on board Mars Global Surveyor and Mars Reconnaissance Orbiter[16] (they went unnoticed for about a decade because the existing temperature data were never displayed as potential temperature which clearly emphasizes the presence of mixed layers as zero-slope signatures along the vertical axis). We were able to show with mesoscale simulations that the observed deep mixing layers can be reproduced by modeling, and that the radiative effect in nighttime water-ice clouds cause those layers to occur through convective destabilization by the radiative cooling (negative buoyancy, Fig 2) exerted by water-ice particles within the cloud[12]. It was shown that water ice clouds play a key role through their radiative effect in the large-scale thermal structure and dynamics of the Martian atmosphere[9], but their impact on the mesoscale dimensions have not been addressed until now. Large-Eddy Simulations of the atmospheric flow within and below water-ice clouds demonstrate that this deep mixing result from powerful convective plumes, which also cause virga-like phenomena to occur when water-ice particles are transported in a downward plume. We proposed to name those phenomena Martian "convective snowstorms" or "ice microbursts"; they provide explanation for not only the observed nighttime mixing layers, but also the precipitating signatures identified by the Phoenix LIDAR in polar regions on Mars.

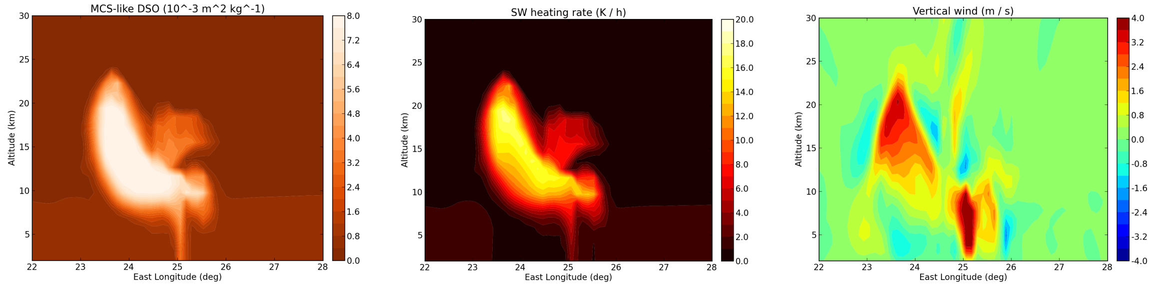

Figure 1: *Mesoscale simulation of a Martian rocket dust storm*[11]*. Longitude-altitude sections obtained at local time* 1500 *and latitude* $2.5°$*S. From left to right: (a) density-scaled optical depth at* 21.6 μm *in* 10^{-3} m^2 kg^{-1}*; (b) vertical wind in m* s^{-1} *(maximum is about* 10 *m* s^{-1}*); (c) shortwave heating rate in K per Martian hour (maximum is about* 24 *K/h).*

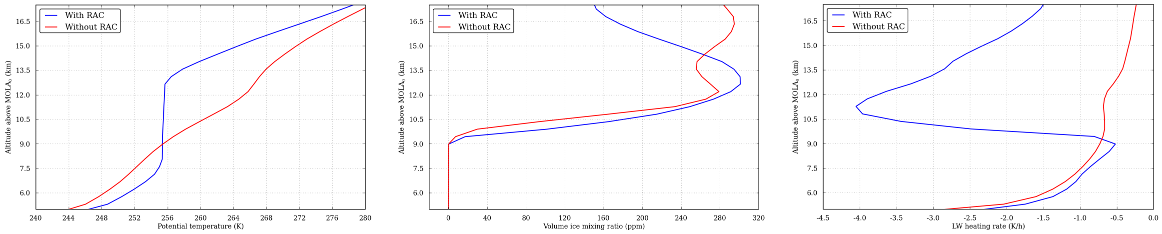

Figure 2: *Mesoscale simulation of a Martian convective snowstorm. Typical vertical profiles of (from top to bottom) potential temperature, water ice mixing ratio, total longwave radiative net heating rate, extracted from mesoscale simulations with (blue curves) and without (red curves) the radiative effects of water-ice clouds included. Profiles were extracted at longitude* $-120°$*E, latitude* $8°$*N, local time* 1000 *PM.*

Perspectives Those two original examples of aerosol-induced deep convection in the Martian atmosphere broaden the knowledge of both aerosols-atmosphere interactions and mechanisms underlying convection in planetary atmospheres, as well as the impact of convection in the regional and global scale (e.g. emission of gravity waves), with possible comparative planetology approaches where the convective dynamics of Martian water-ice clouds could be compared to Venusian sulfuric-acid clouds[17].

Bibliography

[1] A. Määttänen, T. Fouchet, et al. A study of the properties of a local dust storm with Mars Express OMEGA and PFS data. *Icarus*, 201(2):504–516, 2009.

[2] D. V. Markiewicz, W. J. andTitov, S. S. Limaye, et al. Morphology and dynamics of the upper cloud layer of Venus. *Nature*, 450:633–636, 2007.

[3] E.L. Barth and S.C.R. Rafkin. TRAMS: A new dynamic cloud model for Titan's methane clouds. *Geophys. Res. Lett.*, 34:L03203, 2007.

[4] U. A. Dyudina, A. P. Ingersoll, et al. Lightning storms on Saturn observed by Cassini ISS and RPWS during 2004 2006. *Icarus*, 190:545–555, 2007.

[5] A. Sánchez-Lavega, T. del Río-Gaztelurrutia, et al. Deep winds beneath Saturn's upper clouds from a seasonal long-lived planetary-scale storm. *Nature*, 475:71–74, 2011.

[6] H. Savijärvi and A. Määttänen. Boundary-layer simulations for the Mars Phoenix lander site. *Quarterly Journal of the Royal Meteorological Society*, 136:1497–1505, 2010.

[7] A. Spiga and F. Forget. A new model to simulate the Martian mesoscale and microscale atmospheric circulation: Validation and first results. *Journal of Geophysical Research (Planets)*, 114:E02009, 2009.

[8] J.-B. Madeleine, F. Forget, et al. Revisiting the radiative impact of dust on Mars using the LMD Global Climate Model. *Journal of Geophysical Research (Planets)*, 116:11010, November 2011.

[9] J.-B. Madeleine, F. Forget, et al. The influence of radiatively active water ice clouds on the Martian climate. *Geophys. Res. Lett.*, 39:23202, 2012.

[10] T. Navarro, J.-B. Madeleine, et al. Global Climate Modeling of the Martian water cycle with improved microphysics and radiatively active water ice clouds. *Journal of Geophysical Research (Planets)*, 2014.

[11] A. Spiga, J. Faure, et al. Rocket dust storms and detached dust layers in the Martian atmosphere. *Journal of Geophysical Research (Planets)*, 118:746–767, April 2013.

[12] A. Spiga, D.P. Hinson, et al. Snow precipitation on Mars driven by cloud-induced nighttime convection. *Nature Geoscience* (in revision), 2017.

[13] S. C. R. Rafkin. A positive radiative-dynamic feedback mechanism for the maintenance and growth of Martian dust storms. *Journal of Geophysical Research (Planets)*, 114(E13):1009–+, 2009.

[14] N. G. Heavens, M. I. Richardson, et al. Vertical distribution of dust in the Martian atmosphere during northern spring and summer: High-altitude tropical dust maximum at northern summer solstice. *Journal of Geophysical Research (Planets)*, 116(E15):E01007, 2011.

[15] S. E. Yuter and R. A. Houze. Three-Dimensional Kinematic and Microphysical Evolution of Florida Cumulonimbus. Part III: Vertical Mass Transport, Maw Divergence, and Synthesis. *Monthly Weather Review*, 123:1964–+, 1995.

[16] D. P. Hinson, S. W. Asmar, et al. Initial results from radio occultation measurements with the Mars Reconnaissance Orbiter: A nocturnal mixed layer in the tropics and comparisons with polar profiles from the Mars Climate Sounder. *Icarus*, 243:91–103, 2014.

[17] M. Lefèvre, A. Spiga, and S. Lebonnois. Three-dimensional turbulence-resolving modeling of the venusian cloud layer and induced gravity waves. *Journal of Geophysical Research: Planets*, page 2016JE005146, 2017.