MARS ATMOSPHERE SIMULATIONS WITH THE ROCKE-3D GCM: SENSITIVITY TO INTERACTIVE H_2O SNOW AND RADIATIVELY ACTIVE DUST CYCLE

I. Aleinov[1,2,3], [1]*Center for Climate Systems Research, Columbia University, New York, NY, USA (igor.aleinov@columbia.edu),* [2]*NASA Goddard Institute for Space Studies, New York, NY, USA,* [3]*Sellers Exoplanet Environments Collaboration, NASA Goddard Space Flight Center, Greenbelt, MD, USA*, **J. P. Perlwitz**[2,3,4], [4]*Climate, Aerosol, and Pollution Research, LLC, Bronx, NY, USA*, **K. Tsigaridis**[1,2,3], **S. D. Guzewich**[3,5], [5]*NASA Goddard Space Flight Center, Greenbelt, MD, USA* , **M. J. Way**[2,3,6], [6]*Theoretical Astrophysics, Department of Physics & Astronomy, Uppsala University, Uppsala SE-75120, Sweden,* **E. T. Wolf**[3,7]**,** [7]*University of Colorado, Boulder, USA.*

Introduction:

One of the capabilities of the Resolving Orbital and Climate Keys of Earth and Extraterrestrial Environments with Dynamics (ROCKE-3D) [1] planetary General Circulation Model (GCM) is the ability to model the atmosphere of modern Mars. Recent developments include implementation of separate H_2O and CO_2 snow packs and of a radiatively active dust cycle. Here we investigate the effect of their treatment on a simulated Mars climatology.

The model:

ROCKE-3D is a three-dimensional GCM developed at NASA Goddard Institute for Space Studies (GISS) as a generalization of its parent Earth GCM, GISS ModelE [2,3] for general planetary applications.

The atmospheric part of ROCKE-3D uses a Cartesian grid for all quantities. The horizontal resolution is 4^ox5^o with the Arakawa B-type discretization [4] for the velocity. Vertically, the model has 40 layers and employs a hybrid sigma/constant pressure coordinate system [4]. In our Mars simulations, the upper atmospheric boundary was set at ~0.7 microbar. The advection of tracers (including aerosols) is performed by a 9-moment algorithm [5], which effectively accounts for their subgrid variability.

The model includes all elements of a complete hydrological cycle, with the formation of H_2O clouds, precipitation and ground hydrology. Currently the model does not include CO_2 clouds, so all CO_2 condensation happens only at the surface in the form of CO_2 frost. The ground is represented by 6 layers of soil up to a depth of 3.5 meters. The soil layers can contain frozen and liquid water, with liquid water being exchanged between the layers according to gravitational and capillary forces. The hydraulic and thermal properties of the soil layers are defined by their textures. The bottom boundary of the soil is assumed to be impermeable to heat and water, although it is possible to specify a geothermal heating flux. On top of the soil the model can accumulate snow.

The snowpack consists of three layers of snow which accumulate due to precipitation and condensation and lose their mass due to sublimation and melting. The liquid phase can drain to the lower layers, where it can refreeze or leave the snowpack as a melt water. The density of the layers is computed prognostically according to a gravitational compaction algorithm [6].

The model simulates the aerosols as radiatively active tracers. Dust aerosols are represented by a sectional scheme that partitions the simulated dust into five transport size classes, covering a total size range from 0.1 to 32 μm particle diameter. The model simulates the emission from sources, advection, and turbulent, gravitational, and wet deposition of dust. The strength of the dust cycle can be calibrated with a global factor for the dust emission.

For the radiative transfer we employ the Suite of Community Radiative Transfer codes based on Edwards and Slingo (SOCRATES) [7,8], which provides us the flexibility to simulate a planet with virtually any atmospheric composition. In this work we assume a pure CO_2 atmosphere with a trace amount of water (as computed by the model). The scattering and absorption of aerosols (such as clouds and dust) is computed according to Mie theory. The smallest transport size bin of dust, 0.1 to 2 μm particle diameter, is additionally partitioned into four sub sizes for the radiative calculations.

For the boundary conditions at the surface we use MOLA topography, TES dataset for the ground albedo and an Earth-like sand texture for the soil.

Experiments:

We investigate the effect of surface snow on Mars' climate. We considered several configurations with H_2O snow in the polar caps. In particular, we considered a snow-free case and a case of a 4 m snow water equivalent H_2O snow cap ~1000 km in diameter located at the North pole. Figure 1 shows the resulting atmospheric surface pressure in such experiments at the Viking 2 landing site compared to observations. The experiment with the H_2O snow cap produces lower pressures which better fits the observations. This is most likely due to the lower surface temperature caused by the presence of the H_2O snow.

In our dust experiments we investigate the effect of the interaction of the dust cycle with the radiation. In dust cycle models, the emission factor is typically tuned to the conditions on a particular planet. Since for non-Earth applications it is poorly constrained, we performed experiments for a range of plausible emission factors. Figure 2 shows the aerosol optical depth (AOD) for simulations with radiatively active and inactive dust, compared to the observed values averaged over 11 years [9,10]. In general, within the limits on tuning parameters, the simulated AOD fits the observations. Compared to inactive dust, the radiative effect of dust tends to weaken the dust cycle when the dust AOD is low (negative feedback). However, the dust cycle responds nonlinearly to an increase in dust emission with radiatively active dust, indicating the emergence of a positive feedback between dust emission and radiative effect, when radiative heating by dust is sufficiently large. Figure 3 shows the effect of atmospheric dust on the surface air temperature. The radiatively active dust leads to a 2^o-3^o K warmer surface temperature, most likely due to increased greenhouse effect.

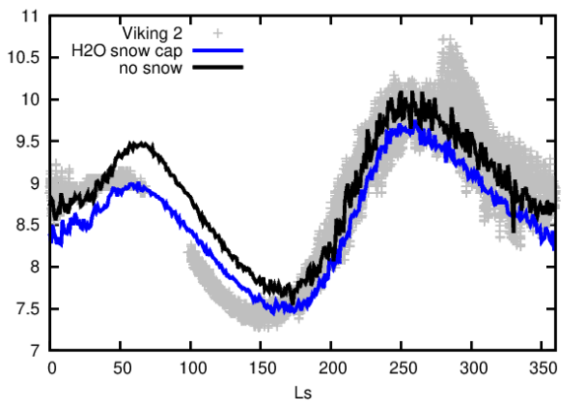

Figure 1. Surface pressure (mb) at Viking 2 landing site. Black line - simulations without the H_2O snow cap. Blue line - simulations with the H_2O snow at the North pole.

Conclusions:

The Mars version of ROCKE-3D was recently updated with a more flexible treatment of surface snow and radiatively active dust. Our experiments show that inclusion of a permanent deposit of H_2O snow around the North pole improves the seasonal cycle of surface pressure. Radiatively active dust can cause both negative and positive feedback on the dust cycle (as compared to a radiatively passive dust). The dust cycle simulated by ROCKE-3D is in qualitative agreement with the observations.

Acknowledgments:

We acknowledge support from the GSFC Sellers Exoplanet Environments Collaboration (SEEC), which is funded by the NASA Planetary ScienceDivision's Internal Scientist Funding Model. This research was also supported by NASA Solar System Workings program award 80NSSC21K0163. Resources supporting this work were provided by the NASA High-End Computing (HEC) Program through the NASA Center for Climate Simulation (NCCS) at Goddard Space Flight Center.

References:

[1]Way M. J. et al. (2017) ApJS, 231, 12. [2] Schmidt, G.A.et al. (2014) Adv. Model. Earth Syst., 6, no. 1, 141-184. [3] Kelley, M. et al. (2020) J. Adv. Model. Earth Syst., 12, no. 8, e2019MS002025. [4] Hansen, J. et al. (1983) Mon. Weather Rev., 111, 609–662[5] Prather, M. J. (1986) J. Geophys. Res., 91, 6671–6680. [6] Lynch-Stieglitz, M. (1994) J. Climate 7, 1842–1855. [7] Edwards, J. M. (1996), JAtS, 53, 1921. [8] Edwards, J. M., & Slingo, A. (1996), QJRMS, 122, 689. [9] Montabone, L. et al. (2015) Icarus, 251, 65. [10] Montabone, L. et al. (2020) JGR Planets, 2019JE006111.

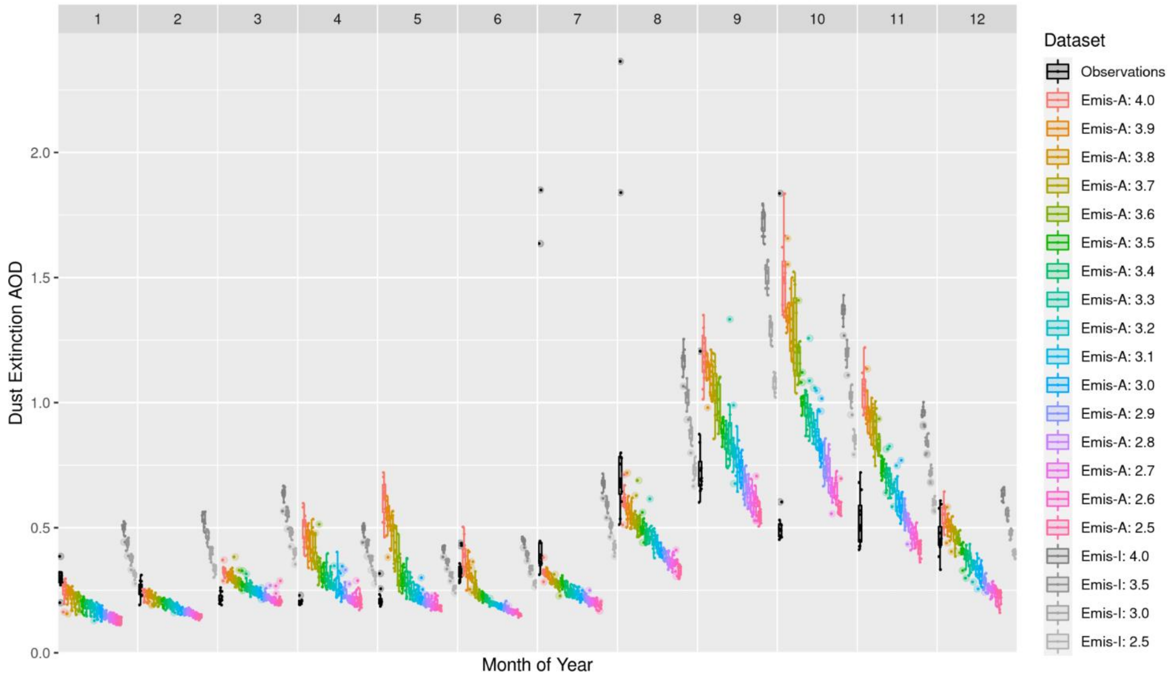

Figure 2. Global mean dust aerosol optical depth as a function of the emission factor: radiatively active dust (Emis-A) vs inactive dust (Emis-I).

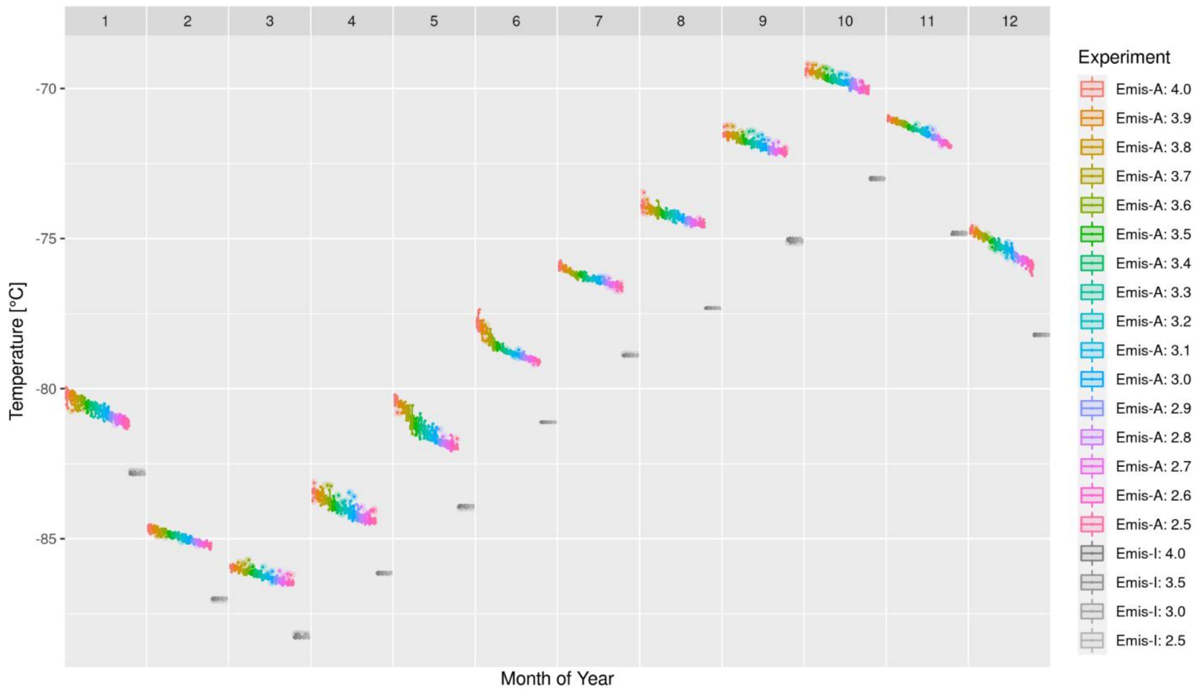

Figure 3. Global mean surface temperature as a function of the emission factor: radiatively active dust (Emis-A) vs inactive dust (Emis-I).