Improved Treatment of Martian Polar Processes in ROCKE-3D GCM: the Exotic Ices Model

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Introduction:

It is typical for atmospheres of rocky planets to contain volatiles which can condense and form a deposit on the surface. Proper treatment of such processes is important for accurate simulation of climate. While modern Earth has only one condensable (H_2O), this is not always the case for other planets. In particular, Mars' atmosphere has two condensable species: H_2O and CO_2. Most Mars GCMs treat deposition of these volatiles at the surface independently, often as simple bucket models. This may lead to an inaccurate representation of snow insulation properties and introduce uncertainty when computing snow albedo. Also, the presence of species of one ice on top of another can provide a protective layer and delay its sublimation thus changing the response of the whole snowpack to the climatic forcings.

Here we present a newly developed Exotic Ices snow model which was coupled to the ROCKE-3D Mars General Circulation Model (GCM) for a more accurate treatment of condensable species at the surface. The Exotic Ices snow model was specially developed for planetary applications which involve multiple condensable species, and it treats such species on equal footing in a single snowpack. For this particular project, the model was configured to include H_2O and CO_2 ices. We tune and test this model in simulations of the modern Mars climate. We then speculate on its application to paleo-Mars studies which involve a more active H_2O cycle, thus making interaction of H_2O and CO_2 ices more dynamic.

ROCKE-3D Mars model:

The Resolving Orbital and Climate Keys of Earth and Extraterrestrial Environments with Dynamics (ROCKE-3D) [1,2] planetary GCM was developed from the NASA Goddard Institute for Space Studies ModelE Earth GCM [3] by coupling it to an extremely flexible SOCRATES radiative transfer model [4] and implementing a configurable framework for setting orbital and calendar parameters. For the purpose of modern Mars applications, the model algorithms were tuned for robust behavior for thin atmospheres (down to microbar scale). The radiatively active dust algorithm was inherited from the Earth version of the model, but it was properly re-tuned for the modern Mars conditions based on Montabone dataset [5]. Thermal inertia of regular Earth soil textures is too high for modern Mars applications, so we introduced a special Mars regolith texture with the thermal inertia 284 J $m^{-2}K^{-1}s^{-1/2}$ which we use uniformly. The model has H_2O clouds and can generate corresponding precipitation, though no CO_2 clouds were implemented yet.

In our simulations, we use MOLA topography and TES dataset for dry regolith albedo. The roughness length was set uniformly to a typical desert value on Earth. The atmospheric composition was 100% CO_2. Modern Mars experiments were initialized with dry regolith and an H_2O snow slab (4 m of water equivalent) north of 80º N.

Exotic Ices model:

The volatile processes (including the CO_2 condensation and sublimation) at the surface are simulated by the Exotic Ices snow model. The Exotic Ices model can be configured to handle any number of condensable species, though for this project we use only H_2O and CO_2. The snowpack is represented by a number of snow layers (up to 15 layers in this research) with the upper layer maintained ~0.1 m deep and lower layers added and removed dynamically as necessary. Smart layering algorithm is employed to reduce numerical diffusion. Each layer contains a mixture of supported ice species with their own physical properties (such as heat capacity and phase curve). The ice is allowed to condense and sublimate in any layer, though typically it happens only in the upper layer. All species are treated equally, but only H_2O is allowed to turn into liquid form (when surface pressure is above the triple point) in which case it can drain to lower layers and refreeze there. The density of layers is controlled by a densification algorithm which takes into account the planet's gravity.

The albedo is computed for 6 radiation bands. We use modern Earth formulation for H_2O and data from [6] for CO_2. The total albedo is a weighted average of H_2O and CO_2 contributions according to their concentrations in the upper snow layer.

Discussion:

Figure 1 shows simulated vertical profiles of atmospheric temperature for four seasons compared to Mars Climate Sounder (MCS) observations. The model exhibits a good fit for lower atmosphere, though it is slightly colder in upper atmosphere, most likely due to insufficient uplifting of the dust. In our tests, these temperatures were mainly controlled by the dust cycle and surface albedo. Changes in the surface snow treatment had little effect on these results.

Figure 2 presents a comparison of the simulated surface pressure at the Viking 2 landing site to the Viking 2 lander observations. The snow albedo and emissivity were mildly tuned to get a better fit. Mainly the snow aging algorithm (inherited from the Earth model) was tuned. The tuning was agnostic to the position on the planet, i.e., no distinction was made between Northern and Southern polar ice caps. The northern ice cap freezes a little faster than in observations. We argue that this may be due to the lack of an explicit treatment of the dust effect on snow albedo. We plan to address this in future development. For modern Mars, the CO_2 deposition mainly happens on top of the H_2O ice, but we expect more interactive behavior of ice species in paleo-Mars experiments.

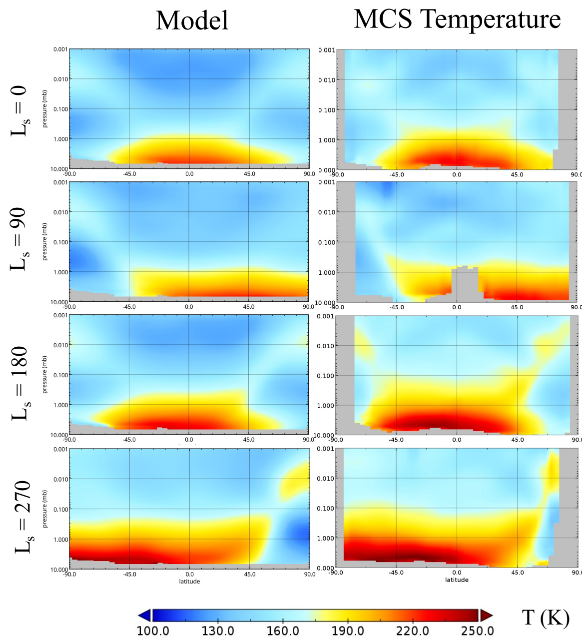

Figure 1. Vertical profiles (zonal means) of simulated (left) and observed (right) atmospheric temperature for four seasons.

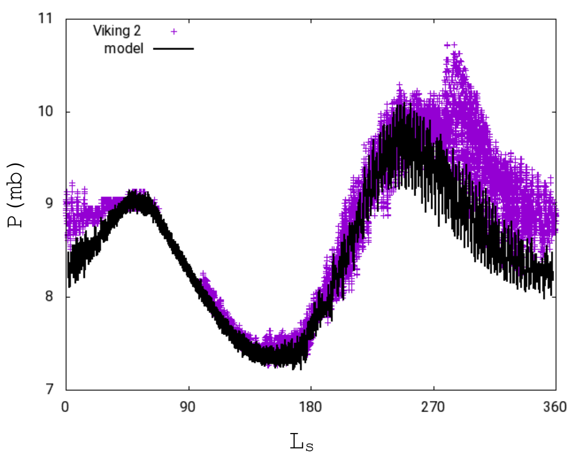

Figure 2. Seasonal cycle of simulated (black lines) vs observed (purple crosses) surface pressure at the Viking 2 landing site.

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