AN IMPROVED MODEL OF REGOLITH-ATMOSPHERE EXCHANGE OF WATER VAPOR IN THE LMD GLOBAL CLIMATE MODEL. P.-Y. Meslin[1], F. Forget[2], and E. Millour[3], [1]Laboratoire de Météorologie Dynamique, IPSL, Université Paris 6, France (pierre-yves.meslin@lmd.jussieu.fr).

Introduction: The importance of regolith-atmosphere exchange in the diurnal, seasonal and inter-annual variability of the water cycle remains an open question, although there is a consensus on its fundamental (but not well understood) role over geological timescales. A broad literature exists now on the subject, aimed at understanding several aspects of the exchange between the different water reservoirs: theoretical/numerical studies on the subsurface ice stability over geological timescales [1-4] and over the seasonal cycle [4,5]; theories or simplified static models to explain the current distribution of water-equivalent hydrogen measured by *Mars Odyssey* in terms of topographic control [6], transient ground ice [7], exchange with hydrous minerals [8]; 1D or simplified 3D models of the 'breathing' of the regolith caused by adsorption of water vapor on the soil matrix aimed at explaining still hypothetical diurnal variations of the water column density [9], or at explaining the spatial inhomogeneity of the martian subsurface water distribution [10]; *etc*. Recent observations of the hydration state of the martian surface and its seasonal variations by *OMEGA* on board *Mars Express* have brought new constraints to modelers [11,12]. A growing number of studies is also filling the need for experimental data on the adsorption or hydration properties of martian regolith simulants [13-18] and on the diffusion of water vapor through such porous media under martian conditions [19,20]. These studies have enabled us to gain much insight into the dynamics of sublimation of a subsurface ice table.

To get a full and integrated picture of all the processes that are at stake, it is necessary to use a Global Circulation Model that describes well the exchange of water with the perennial and seasonal polar caps, and its inter-hemispheric transport. Other GCMs interacting with an active regolith have been developed in the past [21,22], but their model of regolith was rather crude (2-layers model and no formation of subsurface ice in [22]) and gave conflicting results on its importance on the current water cycle. Böttger et al. [5] have implemented a more complex regolith scheme in the LMD Global Climate Model [23] and their results, although dependent upon initial conditions, demonstrated the potential importance of regolith-atmosphere exchange on the seasonal and inter-annual water cycle. For instance, they found that the regolith can act as a buffer for water vapor leaving the northern high mid-latitudes during northern summer, preventing some of the water from reaching the southern hemisphere via the Hadley circulation and thus enabling to maintain the observed North-South atmospheric water vapor asymmetry. This water, trapped in the soil during winter, is then released into the northern spring time atmosphere and returns to the residual water ice cap through eddie transport. An active regolith had therefore a stabilizing effect on the simulated water cycle and was necessary to match TES observations [24]. Another important result pertained to the southern hemisphere subsurface ice, which was found to sublimate and be a net source for atmospheric water over the years. However, they were unable to explain the purported diurnal variations of the water column abundance by exchange with the regolith. The latter result is nonetheless dependent upon the experimental isotherm used in the model.

Since these simulations, modeling of the atmospheric water cycle with the LMD GCM has been improved with a better cloud microphysics model [25] and the equivalent ice particle size has been finely tuned to reproduce the revised TES data [26]. Hence, there is now a good match with TES data without the need for an active regolith. However, some discrepancies remain that need to be resolved : for example, the atmosphere is too wet in the model compared to TES data at high latitudes at the end of the southern summer [26,27], and the model predicts frost formation equatorward of the CO_2 cap edge later in autumn, which is not observed by OMEGA [26]. The GCM simulations are also unable to reproduce the correlation between the normalized water column density and the surface pressure found by Mars Express PFS/LW [28], which is incompatible with a vertically homogeneous mixing ratio and which points towards a short term exchange of 3-4 pr-μm between the surface and the atmosphere [28,29].

In an attempt to resolve these discrepancies, we have undertaken new simulations with an active regolith and an improved version of the model used by Böttger et al. [5]. This improved model will also allow us to study the stability of ice, the diurnal, seasonal and obliquity cycles, and possibly to put constraints on the adsorption capacity of the regolith, which is related to its mineral composition.

General description of the regolith model: The regolith model implemented by Böttger et al. [5] uses 10 subsurface layers, whose depths are expressed in units of thermal skin depths and which are also used in the soil thermal model. Its time marching scheme is based on an implicit Backward Euler method with a ~30 minutes timestep.

The physics of the model follows the one described by Zent et al. [9], and also used by [4]. It models the diffusion, adsorption and condensation of the water molecules within the soil. It is a purely diffusive model, meaning that it does not take into account advection. It also neglects surface diffusion, barodiffusion and thermal transpiration. Mixing ratio gradients (which are present in the expression of the fluxes according to Fick's law) are replaced by number density gradients, for computational convenience (otherwise the levels of the soil layers would have to be calculated at each timestep and correction terms would be necessary to ensure mass conservation).

The model uses Neumann boundary conditions, unless water or CO_2 ice is present on the surface, in which case the upper boundary condition becomes a Dirichlet one (the mixing ratio at the surface is equal to the saturation value).

It uses the same adsorption isotherm as Zent et al. [9], which is similar to a Langmuir isotherm in its shape and also in the fact that it is a function of the partial pressure of water and not of the relative humidity. This makes it quite convenient to use in an implicit time marching scheme, as developed by [30], but its use assumes low surface coverage of adsorbed molecules (less than a monolayer). The use of an equilibrium isotherm assumes that the kinetics of adsorption and desorption is fast with respect to diffusion, and thus precludes the study of soil materials characterized by slow adsorption kinetics constants.

Improvements: The new regolith scheme contains 18 layers (down to ~18 m) of fixed thickness. This new grid is also used in the soil thermal model.

The physics of the improved model is based on the same conservation equations as the original one, but there are a few new features:

- the diffusion coefficient takes into account the obstruction of the pores (reduced porosity and increased tortuosity) when ice is present, while porosity was constant in the previous version ;
- the diffusion coefficient can either have a fixed value (as before), or be calculated as a fonction of temperature, pressure and grains size, in a transition regime between Knudsen and molecular diffusion. This second order feature is only intended to take into account differences in surface pressure (with altitude or season), as the grain size distribution is unknown;
- a somewhat new implementation of the diffusion equation, which could lead to different results regarding ice stability (previously, diffusion was applied to the whole water content of a cell, including ice – see [5] and [30] for details – while it is only applied to the {water vapor + adsorbed water} system in the present version).

The treatment of the adsorption remains based on the use of Langmuir-type isotherms, because it can be implemented in an implicit model. This may underestimate the amount of adsorbed water as the partial pressure approaches the saturation pressure, and thus have a lower retardation effect on the formation of ice, but the total amount of water in each cell should not be affected much. We will investigate new isotherms [13,14,17,18], some of them being characterized by a larger adsorption capacity [17,18]. As the specific surface area of the soil appears to be a fundamental parameter [13], it is used as a tunable parameter. It could be related to the presence of clays in the soil [10].

As the possible role of the regolith in the diurnal/seasonal cycle of atmospheric water depends on the diffusion rate of water vapor in the soil, on whether the soil is capable of adsorbing and releasing sufficient water vapor (over the thickness affected by diurnal/seasonal temperature changes) to account for the amount of water involved, but also on the kinetics of adsorption and desorption [17], we will explore the sensitivity of the model to adsorption/desorption rates as well. This requires to solve a coupled system of partial differential equations (one for the vapor phase, one for the adsorbed phase), which can be treated in our implicit model if one assumes a linear adsorption isotherm (which is only valid for low surface coverage).

We will report on new simulations with the latest 3D version of the GCM including coupling with this improved regolith model.

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