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South polar permanent CO_2 ice cap presentation in the Global Mars Multiscale Model

Farahnaz Fazel-Rastgar

Department of Geography and the Centre for Research in Earth and Space Science, York University, Toronto, Canada

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Abstract

The atmospheric influence caused by the Martian permanent south CO_2 ice cap is examined to improve the Global Mars Multiscale Model (GM3) to see if it can significantly improve the representation of south polar meteorology. However, the seasonal carbon dioxide ice in the polar regions is presented in the surface ice simulation by the Global Mars Multiscale Model but the model does not produce a permanent south CO_2 ice cap, and the physics code must modify to capture the realistic physical such as ice process detail; probably makes a bias in terms of total CO_2 ice and meteorological processes in the model aside from ice formation. The permanent south CO_2 ice cap in the model can significantly improve the representation of south polar meteorology for example in predicted surface temperatures, surface pressures, horizontal and zonal winds over the south cap and possible initiation of dust storms at south polar region during the southern summer period.

Keywords: Mars; Permanent south CO_2 ice cap

1. Introduction

The residual CO_2 cap simulation remains more challenging because the simple energy balance models (with time-invariant albedo and emissivity values chosen to fit the Viking Landers pressures) used by all published General Circulation Model results do not predict the residual CO_2 ice cap (Guo et al., 2010). After southern summer solstice (Ls = 270°), observations indicate that the south polar cap ice shrinks rapidly and by mid-summer (320–340° Ls) it remains a relatively small residual ice cap. So, the seasonal deposit sublimates entirely each summer (e.g., Kieffer, 1979; Hess et al., 1979; James et al., 1992; Tokar et al., 2002). The annual spatial pattern of CO_2 deposition/sublimation shows that the existence of the strong correlation with the residual south polar cap deposits but lesser in north one which likely could be due to the persistent colder temperatures of CO_2 ice and higher albedo on that unit of the south residual cap (Aharonson et al., 2004). Also, it appears that the Residual South Polar Cap as a whole is quasi-stable on decadal timescales (Buhler et al., 2017) and the extent of the southern permanent ice cap seems to be stable (Byrne et al., 2008). In fact, most Mars General Circulation Models are able to fit the atmospheric budget and the seasonal caps reasonably well by tuning the seasonal cap albedos, emissivities, total CO_2 inventory in the system, and the subsurface thermal properties (Forget et al., 1999; Guo et al., 2010; Haberle et al., 2008; Kelly et al., 2006; Pollack et al., 1993). However, the residual CO_2 cap simulation remains more challenging because the simple energy balance models (with time-invariant albedo and emissivity values chosen to fit the Viking Landers pressures) used by all published General Circulation Model results do not predict the residual CO_2 ice cap (Guo et al., 2010). The GM3 simulation also does not produce a permanent south CO_2 ice cap, and the physics code must be modified in order to capture

E-mail address: farahnaz@yorku.ca

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the realistic physical and meteorological processes in the model.

Here, it was investigated the atmospheric influence caused by the permanent south CO_2 ice cap in the model in order to see if it can significantly improve the representation of south polar meteorology. For example, what is the impact on predicted surface temperatures, surface pressures or cloud occurrence and possible initiation of dust storms in the south polar region during the southern summer period.

2. Description of the Global Mars Multiscale Model

The Global Mars Multiscale Model (GM3) is a three dimensional global climate model for the Martian atmosphere, which was developed at York University (Moudden et al., 2005; Moudden and McConnell, 2005; Akingunola, 2009). The model includes both physics and chemistry modules built onto the dynamical core.

2.1. Dynamical core

The dynamical core of GM3 is based on the GEM (Global Environmental Multiscale Model) which was developed at the Meteorological Service of Canada for operational weather forecasting (Côté et al., 1998). GEM is a grid-point model with both global uniform and global variable resolutions (i.e. the GEM 15 is a global variable GEM at 15 km in horizontal resolution) with the capacity to resolve the small scale disturbances within a high resolution sub-domain. The dynamical core of GEM can therefore provide the dual run-time capability of global scale with a uniform resolution latitude/longitude grid system and can be run in the mesoscale meteorology mode within a limited area over any portion of the globe using the global variable resolution configuration. In addition, the model can be run at very high resolution over a small domain in limited area mode (LAM). For example, GEM 2.5 is GEM-LAM at 2.5 km resolution (Mailhot et al., 2006). GM3 retains the GEM dynamical core except for fixed parameters such as gravity, composition, mean molecular weight, specific heat, radius and rotational rate which have to be redefined for Mars. The fundamental equations, conservation of mass, energy and momentum are solved in the dynamical core. The governing primitive equations can be solved in either hydrostatic or non-hydrostatic mode. It uses a hybrid vertical coordinate and the top boundary condition can be either rigid or elastic (Laprise and Girard, 1990). The second version of Global Mars Multiscale Model is based on version 3.3.0 of the GEM dynamical core. The time-stepping is semi-implicit and the advection scheme is semi-Lagrangian.

2.2. Model physics

The Martian processes represented in the physics module include atmospheric heating, involving scattering and absorption of solar and thermal radiation, surface and sub-surface processes, orographic gravity wave drag, planetary boundary-layer parameterizations, atmospheric water processes and condensation and sublimation of atmospheric constituents (Akingunola, 2009).

2.2.1. Heating

Dust scattering and absorption of solar and infrared radiation, CO_2 absorption in the 15 μm band and solar heating by CO_2, are calculated in this module (Akingunola, 2009). The two-stream formulation has also been extended to permit the treatment of radiation by water ice particles in the thermal infrared (Akingunola, 2009). The non-LTE (Local Thermodynamic Equilibrium) formulation of López-Valverde et al. (1998) is used to calculate cooling at altitudes above ~70 km where departure from local thermodynamic equilibrium becomes important. A wide-band emittance is used in calculating the radiative fluxes due to the absorption of radiation in 15 μm band of CO_2 according to Liou (1992). The generalized two-stream method with the quadrature approximation (Liou, 1992; Toon et al., 1989) is used to solve the set of two-stream (upwards and downward fluxes) equations (Akingunola, 2009). The fluxes are summed up, and the temperature tendency due to radiation is calculated. A comparison of the GM3 predicted air temperatures at 0.5 mb and MY26 TES observation shows nearly good agreement between model and TES measurements (Akingunola, 2009). However, there are two exceptions between the model prediction and TES observation. First the model has a low bias against TES measurements during early summer in the southern hemisphere for the equatorial region, and secondly TES shows a nearly global increase in temperature around Ls = 320° due to a global dust storm which was not predicted by the GM3 (Akingunola, 2009).

2.2.2. Surface and sub-surface layers

The soil scheme, surface fluxes and the calculation of the surface temperature are performed in the physics core. The surface layer properties including the Monin-Obukhov length, the homogenous surface flux for heat and momentum and surface friction velocity use the Monin-Obukhov similarity theory (Monin and Obukhov, 1954). This theory was confirmed for Mars's boundary layer by retrieving Mars Pathfinder temperatures in the lowest level of the Mars atmosphere (e.g. Maattanen and Savijarvi, 2004). This theory describes the relationships between temperature, near surface wind profile, and specific humidity and the surface fluxes including heat, momentum and water vapour in the surface layer. Assuming constant Monin-Obukhov length and friction velocity through the surface layer, the wind, temperature and specific humidity profile are calculated from Eqs. (2.16)–(2.21) in Akingunola (2009) and based on those according to Pielke (1990). Heat diffusion within the sub-soil and resulting soil temperatures are calculated too. This information is used to balance the

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