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Simulation of the coupled atmosphere and hydrosphere on early Mars using a GCM

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Abstract

We have adopted a Mars Global Climate Model (MGCM) for the early Martian climate (Paleo-Mars GCM, hereafter PMGCM) with the surface pressures of up to 2 bars, introducing the water cycle scheme with the liquid phase, liquid ocean/lakes on surface and their freezing/thermodynamic processes, and surface fluvial activities. We reproduced the warm surface condition to allow the fluvial activities except during winter, and the comparison of the simulated distributions of fluvial and sediment discharges with the observed valley networks was made.

1. Introduction

Martian valley networks are considered the evidence of a climate warm enough to allow the existence of long-term fluvial systems on early Mars during the Noachian and Hesperian boundary (3.85-3.6 Ga). The isotopic ratios detected from Martian meteorites showed the evidence of surface pressure of >0.5 bars in ~4.1 Ga [1] and surface water abundance of ~550 m global equivalent layer around that time [2], which should indicate that the surface liquid water made the observed fluvial traces.

However, 3-dimensional numerical studies using MGCMs had shown that the reproduction of surface temperature of above 273K (melting point of water) assuming the Martian environment of 3.8 Ga (with 25% weaker solar luminosity than the present value) would be difficult with only the radiative effects of thick (up to 7 bars) CO_2 atmosphere, water vapor and clouds [3,4]. To solve this contradiction, some studies has shown that higher surface temperature may be achieved by adding the radiative effects of SO_2[5] or H_2[6,7], but no 3-dimensional simulation study of early Martian climate had been done including the effects of the spatial changes of surface parameters such as thermal inertia of liquid water surface (ocean/lake) and estimating the fluvial features on surface for the accurate understanding of the environment.

2. Model Description

The PMGCM used in this study has been developed based on DRAMATIC (Dynamics, RAdiation, MAterial Transport and their mutual InteraCtions) MGCM, with the dynamical core of CCSR/NIES/ FRCGC MIROC [8], which has reproduced various dynamical and physical processes for the current Martian atmosphere [9-11]. Here we simulated the possible early Martian climate assuming a pure CO_2 atmosphere with surface pressures of up to 2 bars, decreased solar flux to be 75% of the present value, a radiative scheme with the coupling of CO_2/H_2O gases and clouds, and water cycle including the large scale condensation and cumulus convection. We also implemented the ocean/land thermodynamics and land hydrology with the ocean mixed layer of 20 m and formation of sea ice, variable thermal inertia and surface albedo, and water penetration/fluvial transport/sediment transport processes.

Figure 1 shows the surface condition of the PMGCM assuming an ocean and lakes with the sea level of -2.54 km altitude on the topography of current Mars.

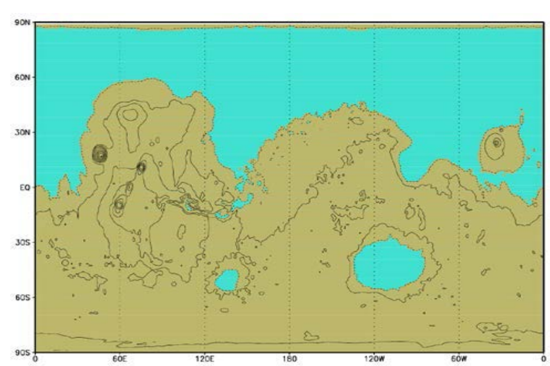

Figure 1: Surface condition of the PMGCM. Aqua regions represent the ocean/lakes.

3. Results

Figures 2 and 3 show the annual mean surface temperature and annual precipitation (sum of rain and snow), respectively. Due to the assumption of high thermal inertia of the ocean, we reproduced the warm surface temperature exceeding 273K from spring to autumn allowing seasonal melting of snow-ice deposits, while cold surface (< 273 K) during winter to produce considerable snow precipitation and accumulation, with the surface pressures of higher than 1.5 bars.

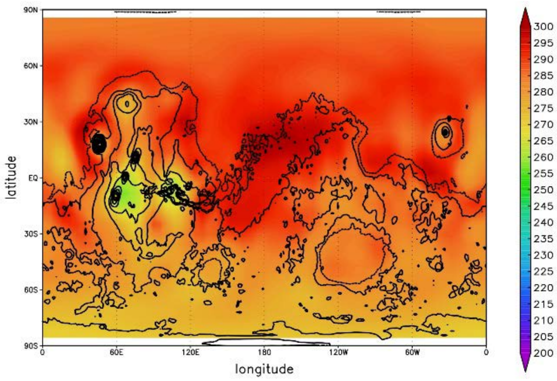

Figure 2: Simulated annual mean surface temperature [K] in our PMGCM with surface pressure of 2 bars.

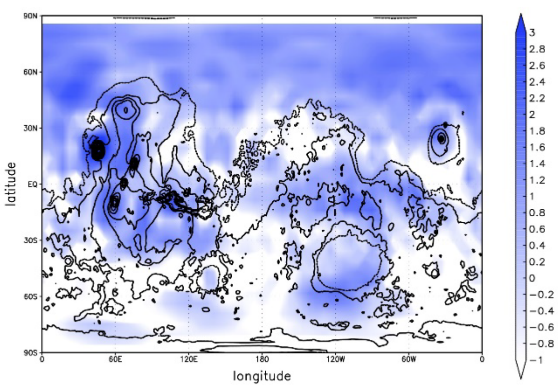

Figure 3: Same as Figure 2 except the annual precipitation [$\log_{10}$ of mm/Martian year].

Figures 4 and 5 show the annual mean fluvial and sediment discharges, respectively, simulated with the surface pressure of 2 bars. The results indicate the existence of fluvial sediment transport in the southern low- and mid-latitudes enough to reproduce Martian valley networks within a relatively short time (less than 10 million years) in the early Martian climate. However, there are some differences between the distributions of simulated discharges and observed valley networks which should be discussed.

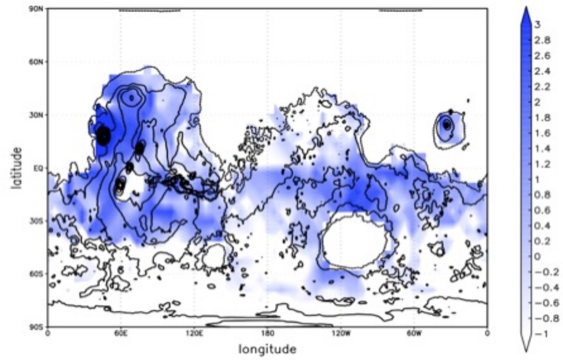

Figure 4: Same as Figure 2 except the annual mean fluvial discharge [$\log_{10}$ of m^3/Martian year].

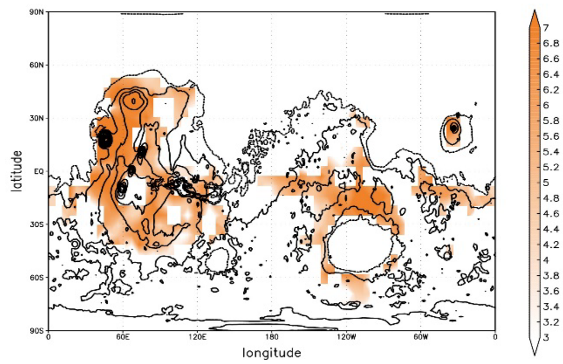

Figure 5: Same as Figure 2 except the annual mean sediment discharge [$\log_{10}$ of m^3/Martian year].

Our study first showed the possibilities of the clement and aqueous early Martian environment using a coupled atmospheric–hydrospheric MGCM in a 3-dimensional manner [12].

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