COLD LATE HESPERIAN CLIMATE F. Schmidt[1], M. Way[2,3,4], F. Costard[1], S. Bouley[1], A. Séjourné[1], [1]Université Paris-Saclay, CNRS, GEOPS, 91405, Orsay, France, [2]NASA/Goddard Institute for Space Studies, 2880 Broadway, NY, NY 10025, USA [3]GSFC Sellers Exoplanet Environments Collaboration, Greenbelt, MD, USA, [4]TheoreticalAstrophysics, Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden

Summary: How was the Martian climate 3Gy ago ? Warm and wet or cold and dry? Formulated this way the question leads to an apparent paradox since both options seem implausible [1]. A warm and wet climate would have produced extensive fluvial erosion but few valley networks have been observed. A cold and dry climate would have frozen the ocean rapidly, without enough time for large impacts to occur and tsunami to form. Here, we provide new insights from numerical climate simulations for a both cold and wet scenario. Using an advanced General Circulation Model (GCM), we demonstrate that an ocean can be stable, even if the Martian mean surface temperature is lower than 0°C, thanks to ocean circulation. Rainfall is very limited near the shorelines and in the ocean. The southern plateau is mostly covered by ice with a mean temperature below 0°C.

Introduction: The possibility of a Martian ocean is a topic of debate with strong implications on the habitability of the Red Planet. Geomorphological arguments in favor and against an ocean has been recently reviewed [2]. There is evidence of Martian paleo-shorelines [3] in Deuteronilus (sometimes noted contact No 2) in a geometry close to the current equipotential height [4]. Deuteronilus shoreline seems to be the latest in the last stage of Tharsis induced true polar wander [5].

Recent interpretation of tsunami deposits near the shorelines [6,7] has provided news clues on the debate. In addition, the potential impact crater, at the origin of the tsunami wave has been possibly identified [8]. These new investigations suggest a long-term stable water body 3 Gy ago in the Northern lowland of Mars.

Various scenarios have been investigated to maintain an ocean [1]. If the climate is cold, the ocean should have been entirely frozen shortly after its formation. If warm, the ice-free ocean should have produced intense fluvial erosion of Hesperian terrains. But there is a lack of observation of such extensive valley network [1]. A cold and wet Mars scenario has been theoretically proposed [9] but the long term stability of an ocean in such a scenario has never been achieved by a 3D-GCM.

Model: We propose here a fully coupled ocean/atmosphere 3-D General Circulation Model simulations based on ROCKE-3D [10], which is based upon a parent Earth Climate Model known as ModelE2 [11]. This model allows us to estimate the interaction between atmosphere/ocean circulation but also encompasses a surface hydrological scheme.

We assume the solar luminosity to be ∼79% of its current value (1360.67W m^{-2}) [12], hence at 3 Gy, the flux at Mars would be 452.8 $W.m^{-2}$. The ocean shoreline is set to –3900 meters in all runs. This gives an ocean surface fraction of ∼16% which is small in comparison to Earth at ∼71%. The ocean is also shallower than the mean depth for Earth. For this reason the time to bring our ancient Mars model ocean and atmosphere into equilibrium is much shorter (∼100s of years) than would be the case for an Earth like ocean (∼1000s of years). We assume this equilibrium has been reached when the net radiative balance (the difference between incoming and outgoing fluxes) is less than 0.2 $W.m^{-2}$.

H_2 provide a powerful greenhouse component in combination with CO_2 as a background gas, but other gas combinations involving CH_4 or H_2S may have an equivalent radiative effect even if the motivation for their use is lacking. We run simulation with 10% and 20% H_2 in a CO_2 dominated atmosphere with 0°, 20°, 40°, 60° obliquity, since this orbital parameter can have large excursions from the mean value in the past [13, 14].

Results: Figures 1, 2, 3 show the simulated fields averaged over 10 Martian years for H2=10% and total pressure of 1 bar. Despite an average temperature below 0°C, the ocean is stable due to its low altitude, low albedo and circulation. On land, there is a clear boundary at an altitude of -2000 meters which corresponds to the dichotomy boundary. In the high altitude domain, the surface is mostly frozen and snow precipitation is observed. The extensive accumulation of snow in the highlands can lead to the formation of significant ice sheets that may flow down to the ocean. In the lowest altitude domain, liquid water rain is observed and surface runoff is possible. The rain mainly occurs over the ocean, meaning that annually ocean evaporation is almost fully compensated by rain.

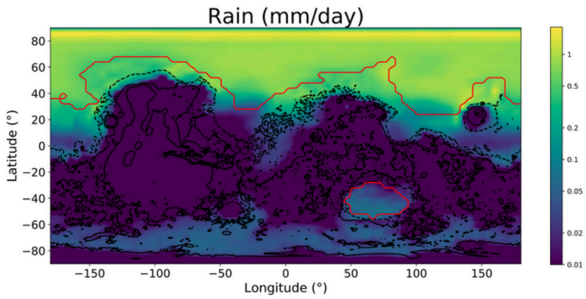

Figure 1: 3D GCM output at 40° obliquity for the rain precipitation. Black contour lines represent altitude level and the red contour line is the paleo-shoreline

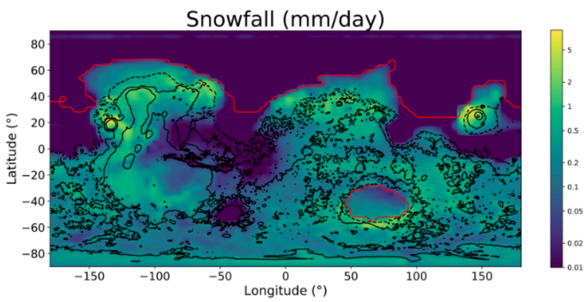

Figure 2: same as Fig. 1 for snowfall

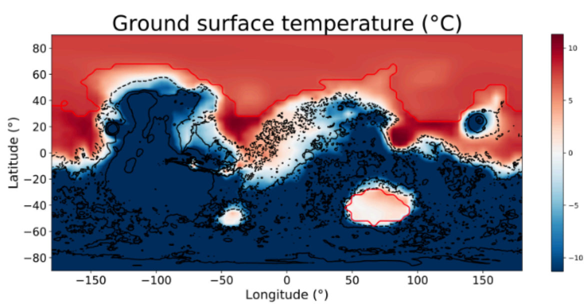

Figure 3: same as Fig. 1 for sea/ground surface temperature

Discussion and conclusion: We propose here a fully coupled ocean/atmosphere to investigate the Martian climate 3 Gy ago. It seems that this coupling significantly increases the stability of the ocean due to its circulation [15]. Comparison with observed geological features of the same epoch shall be done in order to validate or invalidate this scenario.

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