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Constraints on Atmospheric Precipitation during the Noachian-Hesperian Boundary on Early Mars from Valley Network Discharge and Runoff

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Abstract

Dendritic valley networks are linear erosion features on modern Mars formed by fluvial processes (3.6-3.8) Gyrs ago. By analysing these geomorphological features assuming that their inner channel was completely filled with water, we derive mean flow discharge and runoff rates for Early Mars' surface. Then, we apply a 1D global mean atmospheric column model where we vary atmospheric mass (assuming a CO_2, H_2O composition) from a 20mb CO_2 surface pressure up to 3 bar and evaluate the atmospheric temperature profile and the water column. Finally, we make a straightforward assumption to estimate the precipitation rates. We present some initial results comparing the geomorphological runoff data with the modelled atmospheric precipitation rates and discuss the uncertainties of the approach.

1. Introduction

An improved understanding the evolution of the early Martian atmosphere will play a central role in the emerging science of planetary habitability and will contribute to the ongoing discussion on the conditions necessary for the emergence of life. This work adopts an interdisciplinary approach combining expertise from the geomorphological and atmospheric sciences. We present a geomorphological analysis of the valleys networks on Mars with atmospheric modeling studies of the early Martian atmosphere with the aim of constraining atmospheric precipitation rates.

1.1 Methods and Tools

(1) Valley Network Analysis - we deduced peak discharge rates of more than 50 valley networks located in the southern Martian highlands by measuring or deriving widths of interior channels [1]. The discharge rates were deduced by the width of each channel calculated by $Q = 1.4W^{1.22}$ [2] and range between 50 m³/s for small and 5200 m³/s for larger catchment areas. This empirical equation includes parameters of the unit balanced continuity, Manning equation and the relative gravitation (=0.38). Potential errors of about a factor of 2 to 3 likely arise due to the unknown cohesion of channel banks, variability in the width of the channel and successive degradation. After the determination of catchment areas we calculated runoff production rates (i.e. the discharge rate in relation to the catchment) ranging from 0.78 cm/d up to more than 153.6 cm/d.

(2) Atmospheric Model and Scenarios - we employed a 1-dimensional radiative-convective global mean atmospheric model based on [3]. Precipitation was estimated in a straightforward manner by assuming 13% daily rainout of the gas-phase water content calculated in the model to be precipitating as liquid water – this assumes a similar hydrology of early Mars as for the modern Earth.

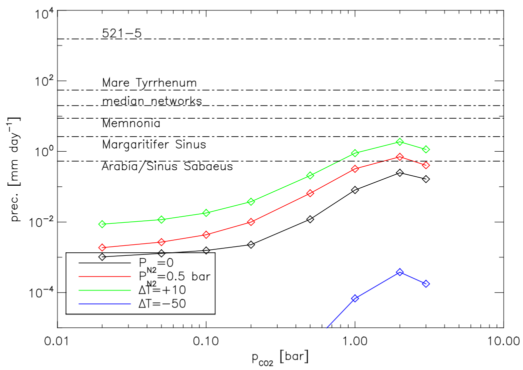
Scenarios - we performed eight runs with reduced total solar intensity of 75% modern day (corresponding to 3.8 Ga), constant surface albedo=0.21, and surface CO_2 varying from 20mb to 3 bar.

2. Initial Results

Initial results from our on-going analysis suggest that the atmospheric precipitation rates derived from the atmospheric model may be significantly lower than the values obtained by the geomorphological analysis. However, we are currently engaged in a discussion of the uncertainties involved and possible ways to refine the approach.

3. Figure

The Figure shows results from the geomorphological valley network analysis (horizontal lines where individual Valleys are indicated). Curved lines indicate results derived from the atmospheric model. Also shown is the influence of clouds, and of including N_2 in the atmosphere (see also [4]). Shown in the Figure is a simple estimate of the effect of CO_2 clouds. These are very challenging to include interactively in a 1D stationary model. They can lead to cooling or warming depending on e.g. their altitude, size distribution and cloud thickness, hence optical depth. Initial estimates of the temperature effects due to clouds however have been performed. Assuming CO_2 cloud particles at ambient temperature of 160-180K, surface temperature perturbations of -50 to +10K could be expected, assuming particle sizes of around 5 and 300 microns, respectively. The upper and lower curves in the Figure correspond to the effect of this cloud-uncertainty on the modelled precipitation rates. Future work will investigate clouds effects in more depth.



4. Summary and Conclusions

Initial results provide a hint that atmospheric models may under-estimate precipitation derived from geomorphological features on Early Mars. On the one hand there is an overestimation of the geomorphological analysis since the hydrograph is considered to be homogeneous (i.e., always in peak discharge). On the other hand, there is an underestimation due to the neglect of infiltration and evaporation. We may safely assume that the former (overestimation) is much larger (orders of magnitude) than the latter (underestimation). The net effect is likely therefore to result in a decrease of the offset between both methods (geomorphology and 1D model). However, the methods applied here are rather straightforward for this initial analysis – future work will focus on a more sophisticated approach and a discussion of the uncertainties involved.

Acknowledgements

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