WHY ARE MOUNTAIN-TOPS COLD? — THE DECORRELATION OF SURFACE TEMPERATURE AND TOPOGRAPHY DUE TO THE DECLINE OF THE GREENHOUSE EFFECT ON EARLY MARS.

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Introduction: Mars lost its CO_2-dominated atmosphere over time, from < 2 bar around 4 Ga to 6 mbar today [1-2]. The atmospheric evolution of Mars was accompanied by climate change, which was recorded by shifts in the spatial distribution of rivers and lakes [3]. Consistently, climate models predict shifts in surface temperature pattern with decreasing atmospheric CO_2 [4]. When the CO_2 atmosphere is thick, surface temperature T_s decreases with height (correlated with topography); when the atmosphere is thin, T_s only depends on insolation (decorrelated with topography). Yet the mechanism for this decorrelation remains unknown.

Methods: We use the MarsWRF GCM [5-6] to explore the transition of river-forming climates. We assume the atmosphere is CO_2-only, but allow additional greenhouse warming using a gray gas scheme. To simplify the relation between elevation and surface temperature, we set obliquity to 0° and include simulations with both idealized topography (Fig. 1) and present-day Mars topography. The range of mean surface pressure that we consider is between 0.01 bar and 2 bar.

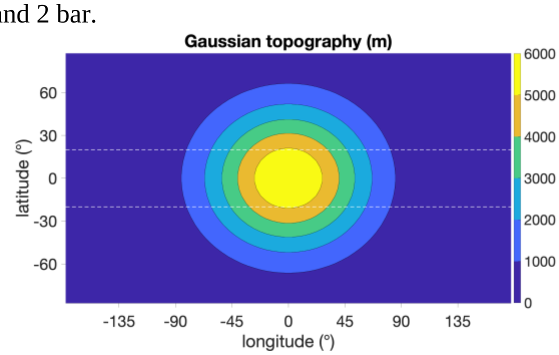

Fig. 1. *The idealized Gaussian topography. A 6000-meter-high mountain is placed at the equator (comparable to Tharsis on Mars). The white dash lines are the boundary for tropical averaging in Fig. 2.*

Results: We use a surface energy budget framework to analyze outputs (Fig. 2):

$$SW + LW_a = LW_s + SH$$

where SW is the net shortwave heating from the sun, LW_a is the longwave heating from the atmospheric greenhouse effect, LW_s is the surface cooling by longwave emission, and SH is the surface cooling by sensible heat flux, respectively. We find greenhouse heating LW_a is the main term balancing the variable surface radiation LW_s (associated with the elevation-dependent temperature) under high P_{CO_2}, in contrast to predictions from the previous literature that sensible heat SH was the cause of the regime transition [3-4] (SH is always small, and is not correlated with topography). This conclusion does not change with switching to realistic topography or switching CO_2 radiation to a gray gas scheme. Under low surface pressure P_s but strong gray gas greenhouse effect (high longwave absorption coefficient κ), the surface temperature still varies with elevation following the adiabatic lapse rate, so the regime transition can be attributed to the evolution of greenhouse gases other than CO_2.

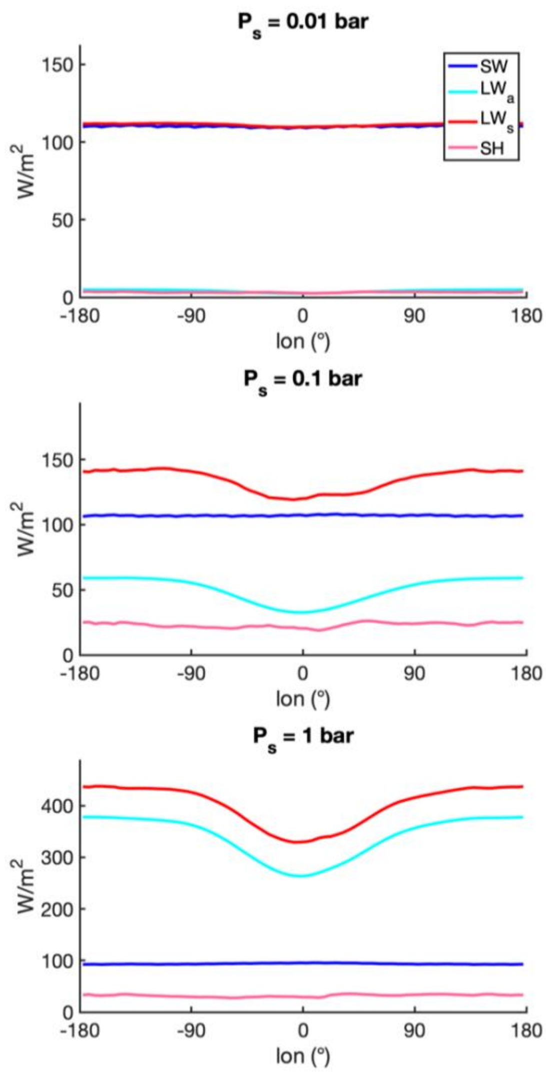

Fig. 2. *Time-averaged surface energy budgets. Each term is averaged within the tropics (20°N - 20°S). The red curve with a dip shows a correlation between* T_s *and topography (lower* T_s*, thus lower emission over the mountain), which is controlled by the decrease of greenhouse heating. These examples are performed with Gaussian topography, correlated-k* CO_2 *scheme, and diurnal-mean insolation, but changing topography, changing radiation scheme, or adding a diurnal cycle do not change our conclusion.*

Interpretation: Why does high greenhouse effect lead to elevation-dependent temperature while low greenhouse effect leads to uniform temperatures? With low atmospheric greenhouse effect (i.e., low atmospheric emissivity), atmospheric radiation back to the surface LW_a is negligible. As a result, the surface energy balance becomes dominated by a balance between surface insolation *SW* and surface emission LW_s, such that surface temperature (which regulates LW_s) is purely set by incoming solar radiation and independent of elevation. With high atmospheric greenhouse effect, atmospheric radiation LW_a becomes important in the surface energy balance, with the leading balance eventually being surface emission LW_s and LW_a. The surface temperature hence is controlled by the atmospheric temperature, whose vertical structure in turn is tied to the adiabatic lapse rate.

Conclusion: On Earth, mountain-tops are cold and the temperature follows the atmospheric lapse rate, while Mars's surface temperature decorrelates with topography through its climate change. If wet episodes on early Mars were cold, surface temperature can tell us where the water sources from ice/snowmelt would have been during warming episodes (Rainfall is an alternative scenario when water sources are indirectly connected with surface temperature [7]). Since the surface temperature decorrelation comes from the decline of the greenhouse effect only, changes in Mars' fluvial patterns may arise from non-CO_2 greenhouse gases (e.g., H_2) only, rather than the loss of a CO2 dominated atmosphere [8].

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