Time-variable gravity signatures of the Mars annual atmospheric mass transport cycle.

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Introduction: An improved understanding of the Mars climate cycle is a high priority in planetary science [1]. We have a reasonably good understanding of how the spin and orbit parameters have varied with time in the recent past [2,3,4], and how those variations influence the diurnal and annual insolation patterns [5,6].

However, detailed reconstruction of past climate states also depends upon having accurate and robust parameterizations of the physical and chemical processes acting in the present day. Some of the key parameters are still not adequately constrained.

It has long been known that there is a large scale annual cycle of mass transport on Mars, involving condensation of solid carbon dioxide on the winter polar cap, and sublimation from the summer cap [7,8]. This process yields spatial and temporal variations in the distribution of CO_2 mass density (kg/m^2), both in terms of material condensed on the surface, and in the atmospheric column, at all locations on Mars.

Though the surface condensation and sublimation is mainly confined to the polar caps, the atmospheric column mass change is global in extent. It is clearly seen in temporal variation of surface atmospheric pressure variations, and has been measured by several lander instruments [9,10].

The questions we address here involve simulations of this mass transport cycle, and conversion of the resulting spatial and temporal pattern of surface and atmospheric column mass into estimates of change in the Mars gravity field. ***How accurate do Mars gravity field measurements need to be, in order to constrain the climate dynamics?***

While current generation Mars gravity models do detect some aspects of the seasonal mass transport cycle [11,12], the current measurement accuracy is not sufficient to provide significant numerical constraints on relevant climate parameters. Our focus here is an attempt to understand the level of accuracy required for future Mars gravity measurements, so that they will provide important new constraints on the climate system.

Simulation targets: In a previous analysis of the annual cycle of Viking lander measurements of surface atmospheric pressure variations [13], it was found that a very good fit could be obtained by adjusting surface ice parameters in the MarsWRF [14] atmospheric general circulation model. The adjustable parameters include albedo and emissivity for each polar cap, and the total mass of transportable CO_2.

In our gravity analysis, we used the same atmospheric dynamics model [13], and adjusted the same 5 parameters. In particular, we performed 11 simulations of the annual mass transport cycle. One case used nominal values for the parameters, and each of the other cases had one of the parameters perturbed, either upward or downward, by a few percent from the nominal. That allows determination of both a nominal response, and partial derivatives of the mass transport pattern with respect to each parameter. Using both positive and negative perturbations allows for possible non-linear behavior.

In the present context, we are mainly interested in the annual cycle. As such, we have used output sampled at one sol (Mars mean solar day) time steps, on a 2x2 degree spatial grid. Each grid cell provides separate accounting of the mass density (kg/m^2) of CO_2 condensed on the surface, and in the atmospheric column. We also record the height above the local topographic surface of the center-of-mass of the atmospheric column..

At each time step, we sum the surface and atmospheric column mass density values, within each grid cell, and compute from that a spherical harmonic series representation of the gravitational potential associated with that mass distribution.

Results: Figure 1 shows how the diurnal average insolation pattern varies with latitude and orbital position. The solid black line shows the sub-solar latitude, and dashed lines show inflection points in the pattern. These variations ultimately drive the changes in temperature and pressure within the atmosphere.

Figure 2 shows how the RMS amplitude of spherical harmonic coefficients varies with harmonic degree and time of year. Rather as expected, the higher degree harmonics tend to have smaller amplitude variations over the seasonal cycle.

What is new here is that we now have numerical estimates of the nominal values, and of the partial derivatives. Future gravity measurement programs can be designed to meet these templates, and then, by measuring the actual values, help constrain the climate parameters.

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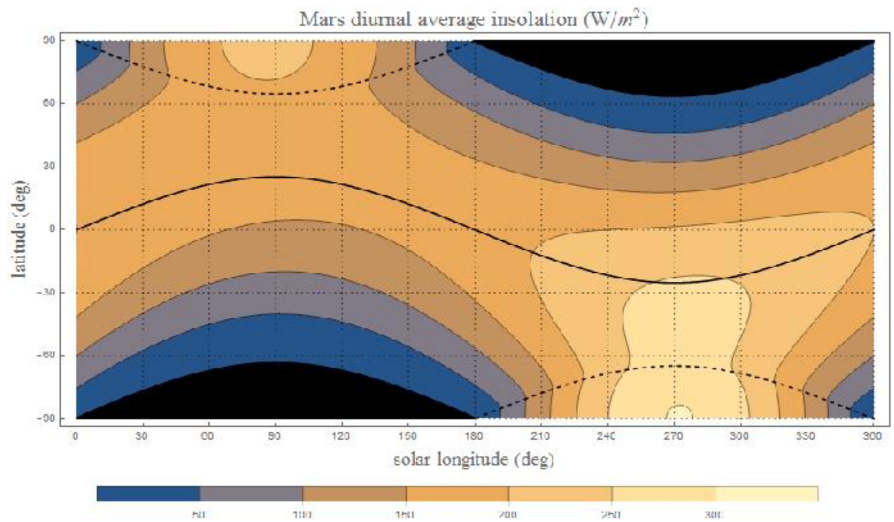

Figure 1. Annual cycle of diurnal average insolation

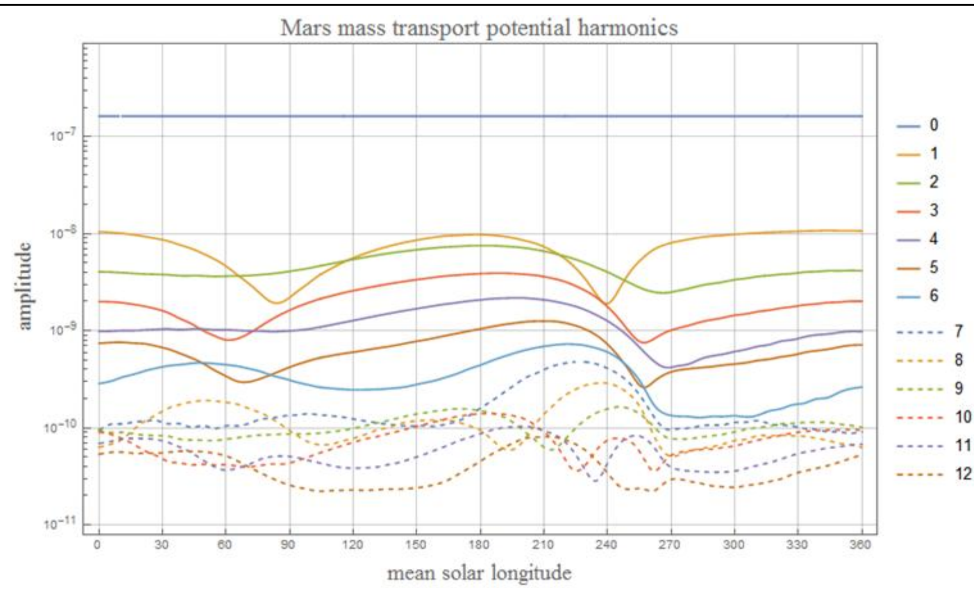

Figure 2. Annual cycle of gravitational potential variations