INTERNAL DYNAMICAL VARIABILITY IN THE NASA AMES MARS GENERAL CIRCULATION MODELS

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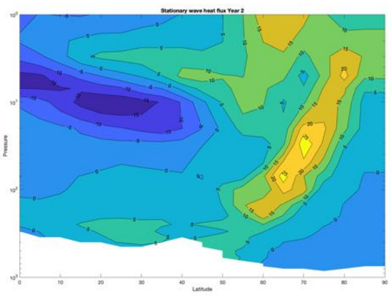
Introduction: General Circulation Models (GCMs) have been used for decades in order to understand and predict how the larger-scale motions and associated structures and phenomena develop and behave. One use of GCMs involves varying external forcings in order to understand the atmosphere's sensitivity to forcings. This can include (Earth) sea-surface temperatures or CO_2 levels, and (Mars) dust storms or the surface albedo field. Interpretation of results depends on an understanding of the internal variability of the GCM.

We seek here to extend an earlier study [1] to characterize the internal variability of the NASA-AMES MGCM. There are two incarnations of this model: (a) the Legacy model; and (b) the new FV3-based version. The Legacy model has been under development for decades and is now "frozen". It was recently released for general use [3], [2]. The newer FV3-based version is built around the finite-volume dynamical core developed at NOAA/GFDL. The two models share common physics packages but have different dynamical cores. Our earlier study utilized an earlier version of the Legacy model. Our first step in the current study is to repeat those earlier experiments using the most recent Legacy code. After that, we will conduct parallel experiments with the new model, and thus determine whether variability we find is characteristic of both models.

Both the terrestrial and Martian atmospheres have structures which accomplish poleward heat transfer. From a zonal- and time-average perspective, these include the Hadley cell, and both stationary and transient eddies. The net poleward heat transfer is required (i.e., forced by) the pole-to-equator net radiative heating gradient on each planet. The breakdown amongst the various components is less well understood. For example, is there any *a priori* expectation that the Hadley cell should be responsible for the bulk of the heat transport (on either Earth or Mars)? We established earlier [1] that this breakdown can vary from year-to-year (Y2Y) in multi-year simulations: this can be viewed as one characterization of internal variability in an MGCM.

Procedure: Our first task is to repeat the earlier analysis but with the final/frozen form of the Legacy code. The chief difference between this and the earlier code used is in the updated physics packages, many of which were informed by new observations. Assuming we find year-to-year variability in the core dynamic behavior (which we do), the physics codes give us the opportunity to see whether variability is suppressed/enhanced when we add e.g., clouds or a water cycle. The model is run for several years under these conditions, assuming MY31 dust opacity which is allowed to repeat every year. For now, we choose to examine the Ls 270 season, since this is characterized by strong transient and stationary wave activity (e.g., as observed since Viking and via modeling). For each year of the simulation, we extract 30 sols of data centered around Ls 270. We extract meridional winds and temperatures, and use them to construct the various poleward heat flux fields outlined in [4] (their Eq 4.10). Specifically, the total heat flux can be broken down to show that the contributions of: (i) the Hadley cell (time- and zonally-averaged circulations); (ii) stationary eddies; (iii) transient eddies; and (iv) transience in the Hadley circulation. Not included in this formulation are contributions (if any) from the condensation flow associated with cap formation/sublimation.

Results: Each quantity discussed above is computed for the 30 sols of data. Stationary eddy heat fluxes are plotted for years two and three in Fig. 1. Although the same general patten exists, there are significant differences in amplitude [O(10-20%) below 10 Pa].



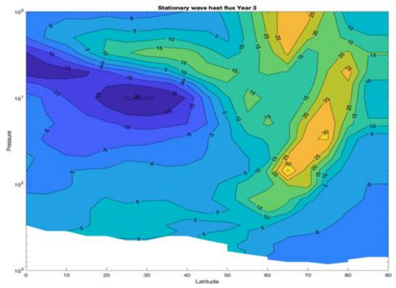


Figure 1. Latitude-height distribution of poleward heat fluxes due to stationary waves in years 2 (upper) and 3 of a Legacy MGCM simulation. Warmer shades indicate higher values.

Transient eddy heat fluxes are plotted for years two and three in Fig. 2. Differences here are as pronounced as above. Note that this includes activity at very low levels around 60°N.

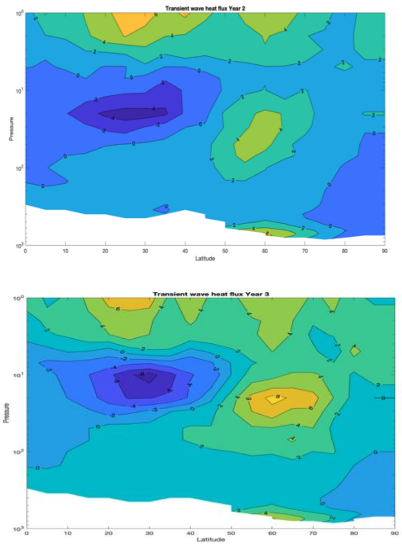


Figure 2. As Figure 1 but for transient eddies.

These early results confirm the presence of Y2Y variability in the Legacy MGCM. Meanwhile, the zonally- and time-averaged circulations are essentially the same Y2Y (not shown). The differences in eddy heat fluxes (stationary and transient) exist despite this. Our results could mean that there are more/fewer storms Y2Y, or that they have weaker/stronger amplitudes, or that their vertical and/or horizontal structures vary Y2Y, allowing more/less efficient heat flux (all of which will be examined).

We are continuing to examine Y2Y variability in the Legacy code via longer simulations. We plan next to conduct similar experiments with the new FV3-based model. Provided both models show similar degrees of internal variability, we plan to then conduct studies of: (i) the total heat flux Y2Y; (ii) heat fluxes before/after the solstitial pause; (iii) fluxes in the southern winter; and (iv) whether Y2Y variations respond to (strengthen? diminish?) conditions such as the presence/absence of a water cycle, the dust cycle, and surface conditions such as albedo. These studies will inform the overall importance of the internal variability (which is important in terrestrial models but might not be for Mars).

Summary: Simulations of the Martian atmosphere over multiple years show interesting Y2Y variability in one field examined – poleward heat flux (we have earlier shown Y2Y variations in surface stress/dust deflation [1]). Whether these variations have any practical importance – e.g., in understanding the generation of planetary dust storms or in mission planning – remains to be established. However, an understanding of the dynamical variability in a GCM is necessary in order to fully understand a model's response to an imposed forcing (on Earth for example, the response to enhanced greenhouse gases; on Mars, for better understanding Y2Y variations in the dust cycle).

References:

[1] Bridger & Haberle, 2004: Intrinsic variability in dust deflation potential in multi-annual MGCM simulations. Division of Planetary Sciences Annual Meeting, Louisville, KY.

[2] Haberle et al, 2019: Documentation of the NASA/Ames Legacy Mars Global Climate Model: Simulations of the present seasonal water cycle. Icarus, 333, pp 130-164.

[3] NASA Ames Legacy Mars GCM Virtual Workshop Tutorial, November 2-4, 2021. https://www.nasa.gov/mars-climate-modeling-center-ames/MarsGlobalClimateModelTutorial: Mt. View, CA.

[4] Peixoto & Oort, 1992: Physics of Climate. American Institute of Physics.