DATA ASSIMILATION OF THE GLOBALLY TELECONNECTED MARTIAN ATMOSPHERE

D. M. Kass[1]
[1]*Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA (david.m.kass@jpl.nasa.gov)*

Introduction: The Martian atmosphere is significantly thinner than the terrestrial atmosphere. This results in a very rapid radiative and thermal response, especially since there are no identified large, long-term thermal reservoirs that are well connected to the atmosphere. The rapid radiative/thermal response creates a number of well-known implications for the Martian climate and climate response [1].

The thin atmosphere and rapid thermal response also introduce a type of weather not seen in the terrestrial atmosphere: global weather. Weather is used in the sense of a coherent perturbation on the climatological mean state [2]. The best-known examples of the phenomena are the global dust storms where the weather of the entire planet is modified in a very short duration. In the case of global dust storms, the dust driving the change in weather is lifted or advected globally, however in many cases, the extended change in the weather is through dynamical teleconnection.

The closest the terrestrial atmosphere comes are oscillations such as El Niño or SAO. However, these are long period phenomena and not weather in the usual sense of the term. Many of the other phenomena (e.g. thermal tides) affecting Mars are also present on the earth, but they are of modest or insignificant amplitudes, at least in the tropopause. Some are also sufficiently regular to be instead part of the climatology.

Global Weather/Teleconnection Phenomena: There are multiple phenomena in the Martian atmosphere that act as weather with a global or at least hemispheric impact. In this context, the phenomena of interest are both global and exhibit the type of short-term variability associated with traditional "weather." These are just a sample and there are others that also need to be considered.

Large Scale Dust Events: Most large-scale dust events result in significant dynamical forcing of the global atmosphere [3]. In addition, these storms usually transport dust over very broad regions of the planet. "Thin" veils or hazes of dust in the lower atmosphere (~20 km to 50 km altitudes) will affect all longitudes in broad latitudinal bands. The widespread dust haze results in significant daytime heating of the atmosphere.

When the dust haze is essentially global (as in a global dust storm), the weather response is obviously global. However, even before the dust is widespread, there are often nearly global dynamical responses to the heating. Based on observations, once moderate amounts of dust are transported vertically beyond the boundary layer (or maybe 2 scale heights above the surface), dynamical responses can be very rapid. The most noticeable one is the northern heating response in the "A" and "C" type large-scale regional dust events (and global storms) [3].

The northern dynamical response is a combination of a tidal enhancement (see next section) and a strengthening of the single cross-equatorial (solsticial) overturning circulation. Initially, the response is longitudinally connected to the direct dust heating in the southern hemisphere and often manifests within a sol—at the limit of the data sampling frequency—implying information propagation speeds exceeding half the speed of sound. The northern heating is generally focused in the descending branch of the Hadley circulation at the edge of the northern winter polar vortex. The increased temperature gradient across the boundary implies an intensification of the winter polar jet.

In addition to the northern dynamical warming, the polar vortex is also strongly (and equally rapidly influenced). The size, shape and location are influenced as part of the dynamical response. When the forcing is asymmetric (during the growth phases of the dust storm), the vortex tends to be significantly displaced, sometimes to the point where the pole is no longer in the vortex. As the dust haze is spread longitudinally the vortex tends to instead be latitudinally compressed, often to a quarter (or less) of its original/climatological area.

Thermal Tides and Planetary Scale Waves: The thermal tides and other planetary scale traveling and stationary waves are a global or near global phenomena. The magnitude of some of them, especially the diurnal sun-synchronous thermal tide, means they are a major controlling factor of the atmospheric structure. The tides are driven and "shaped," to a large extent, by aerosol heating. Thus as the heating changes they change. Given the short radiative time constant, the changes can be fast and will have a global effect. The rapid change and global nature means that they are effectively weather and thus should be "corrected" by data assimilation.

Baroclinic Waves: The baroclinic waves on Mars can be of large amplitude and regionally dominant at certain seasons. They occur in both polar regions, especially during the winter in the hemisphere. Recent work has identified the signature of the northern baroclinic waves in the MSL pressure measurements at Gale crater in the southern tropics [4]. This indicates the waves have at least a hemispheric impact. The phase and amplitude of the individual waves measured near the edge of the polar vortex are also influencing the weather into the tropics. Likewise, the routine dominance of a single wave mode for the baroclinic waves [5, 6] means that once the phase and amplitude at one location is measured, the pattern over the rest of the polar region (and even the hemisphere) can be deduced through correlation patterns [7, 8]. The overall pattern is generally modified by topography, so the actual longitude of the measurement needs to be considered. However, even ignoring this, there are clear circum-polar correlation patterns.

Implications for Data Assimilation: The existence on Mars of global weather has significant implications for data assimilation. The global nature of the weather and the hemispheric to global teleconnections are a challenge for current data assimilation schemes [9].

Dust storms are regularly captured, even in data assimilation reanalysis products by prescribing the dust field. This is often done using dust column measurements, which are insensitive to the dust at critical altitudes for teleconnection responses. The contribution to the dust column from dust at 20 km to 50 km is very small (usually a few percent), but that dust is driving the global dynamical response. This is especially the case when the only dust enhancement in a given region is advected from the top of the storm elsewhere (a 5% increase in the dust column spread through the column has little effect). See other abstracts and [9, 10] for some work on assimilating dust and some of the limitations of attempting to do so.

For the baroclinic waves and especially the thermal tides, the hemispheric or global response of the atmosphere to changes may be important to capture. Currently, the active assimilation schemes use localized assimilation. Thus they are deliberately discarding the global information available in the observations. Furthermore, as discussed in Navarro et al. [2017], if the MGCM is not consistent with the global weather, the short radiative time constant of the atmosphere will allow the state to rapidly revert back to the MGCM's preference. Under these conditions, the assimilated observations are unable to update or correct the global atmosphere as it responds to the weather.

Conclusions: Many of the global weather phenomena are poorly observed at Mars. Likewise, the MGCM models often do not accurately represent them. Thus, there is the possibility of significant advances in our understanding of these global weather phenomena through successful data assimilation. However, to extract all the available information from the observations and to keep the model forecasts accurate, it may be necessary to globally update some aspects of the atmospheric state based on the observations.

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