THE CASE FOR ASSIMILATING SURFACE PRESSURE OBSERVATIONS

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Introduction: The evolving distribution of radiatively active dust and water ice clouds plays a major role in modulating the seasonal and interannual variation in the thermal forcing of the Martian atmosphere, and thus the resulting intensity of the circulation. Thermal tides are the global-scale atmospheric response to the diurnally varying thermal forcing, due to aerosol heating within the atmosphere and radiative and convective heat transfer from the surface. The global tide includes westward propagating (sun-synchronous) waves driven in response to solar heating, as well as nonmigrating waves that result from zonal variations in the thermotidal forcing that are caused by variations in the surface (the topography and surface thermal properties) and the distribution of aerosols (dust and water ice clouds). The migrating tides are of particular interest, since they tend to be directly responsive to the aerosol distribution. However, distinguishing these particular tides from the mix of additional nonmigrating tides is difficult with only a limited number of surface observations. It is argued that the compact set of dominant tide modes suggests that a small number of surface lander sites may be sufficient to yield significant constraints on global-scale thermal forcing. Current data assimilation techniques consider local adjustments to temperature and/or aerosol to compensate for prediction errors. I propose that a recognition of the planetary-scale correlations in the atmospheric response to thermal forcing could be used to isolate key tide modes. This then could be used to introduce adjustments to the model aerosol field to reduce model biases. Such a bias seems to be present in the current MACDA Reanalysis. While time-mean atmospheric temperatures are well constrained by TES temperature observations, the surface pressure tide amplitudes are too weak, implying insufficient diurnally-varying forcing in the assimilation model.

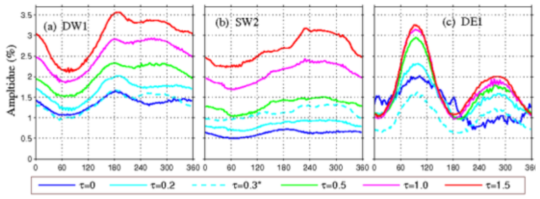

Figure 1. (a) Simulated seasonal variation of equatorial DW1 for 5 values of uniformly mixed dust with specified column dust opacity (τ = 0.0, 0.2, 0.5, 1.0, 1.5). An additional case (τ =0.3*, dashed curve) includes a detached dust layer that contributes an additional 0.1 unit of column opacity. (b) SW2. (c) DE1.

Thermal tides and aerosol: An observed tide harmonic, S_n, at a lander site represents contributions from the corresponding migrating component and additional eastward and westward propagating nonmigrating components. Migrating tides include DW1 and SW2, respectively for the westward propagating diurnal and semidiurnal, migrating tides. The most prominent nonmigrating tides are the resonantly enhanced, eastward propagating diurnal and semidiurnal Kelvin waves (DE1 and SE2). Model simulations suggest that the spatial distributions of diurnal and semidiurnal variability are dominated by the corresponding migrating tides and two resonantly enhanced eastward propagating Kelvin waves [*Wilson and Hamilton*, 1996; *Guzewich et al.*, 2016; Wilson et al., 2017]. This is illustrated in Fig. 1, where the seasonal variation of the equatorial amplitude of selected tide modes in MGCM simulations is shown for a specified uniform visible dust column opacity varying from zero to 1.5. The modes shown are the dominant contributions to pressure variability in their respective frequencies. The migrating tides (DW1, SW2) are particularly responsive to changes in aerosol forcing. There is a roughly linear relationship between the SW2 amplitude and the dust column optical depth, which makes this mode an effective proxy for globally integrated thermal forcing. The seasonal variation of the resonantly-enhanced Kelvin waves (DE1 and SE2) show a strong preference for the two solstice seasons, with a clear emphasis on the $L_s = 90°$ season. These two modes contribute to significant zonal modulation of the S_1 and S_2, respectively [*Wilson and Hamilton*, 1996; *Guzewich et al*., 2016], which suggests that an ability to isolate key migrating

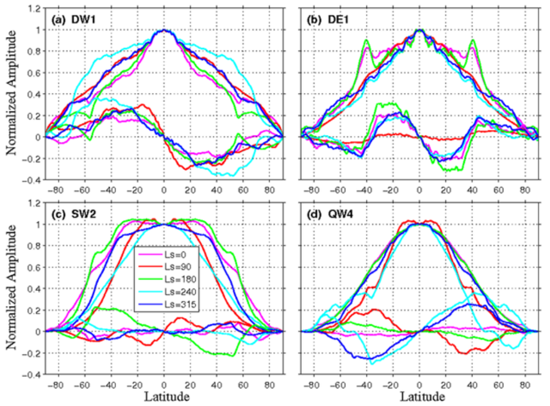

Figure 2 (a) Latitude variation of the amplitude of DW1 in an annual cycle simulation. Both the symmetric and antisymmetric components are shown. The curves have been normalized by the seasonally varying amplitude of equatorial DW1 to emphasize changes in latitude structure with season and are color coded by Ls. (b) As for (a) but for DE1. (c) As for (a) but for SW2. (d) As for (a) but for QW4.

tides would offer an important opportunity to constrain boundary layer and aerosol thermal forcing. There now exists an extended record of surface pressure observations at two locations in the Martian tropics, as provided by REMS aboard the MSL rover Curiosity in Gale crater (4.5°S, 137°E) and from VL1 (22.5°N, 312°E). The surface pressure records from MSL and VL1 are currently the only surface-based observations available for evaluating and validating atmospheric models. The high degree of reproducibility of the Viking tide record over 4 Mars years (MY12-15) in the aphelion season (L_s=0-135°), the reproducibility of ~3 years of MSL observations, and the same reproducibility in TES and MCS atmospheric temperatures in this season, all suggest that the atmospheric state observed by Viking during the aphelion season is likely the same as that seen by MSL. To the extent that this holds true, the two surface pressure records can be used as the basis for a two-station network.

MGCMs include parameterizations that yield a thermal forcing field from distributions of dust and water ice clouds. Simulated atmospheric temperature and surface pressure are then obtained consistently as the atmosphere responds to the thermal forcing. The extent to which the simulated fields correspond to observations provides insight into how well the thermal forcing field is represented. It has become evident that radiative forcing by water ice clouds contributes significantly to the thermal balance particularly in the aphelion season [*Wilson et al*., 2008; *Madeleine et al*., 2012; *Wilson et al*., 2014], although details are still poorly constrained. Another poorly constrained issue is the effect of vertical variation of dust (detached dust layers) on thermal forcing.

Very High Resolution Simulations:

I speculating how inclusion of observed tidal surface pressures (which are a global response to aerosol forcing) could be used with data assimilation. An important theme is that the westward propagating sun-synchronous semidiurnal tide (SW2) has a surface pressure variation related to global aerosol forcing. It has a well-defined latitude response and it, along with the semidiurnal Kelvin wave (SE2), dominates the semidiurnal tide at different lander sites. It would be very interesting to see how DA could take advantage of this. Figure 2 shows the meridionally broad character of the dominant tide modes. It suggests that the response at one latitude is highly correlated with other latitudes: something that DA could potentially take advantage of. How can we use these observations to improve the data assimilation? Increasing SW2 could be achieved by adding more dust

In principle, S_2 = SW2 + SE2. We can roughly relate SW2 (or SE2) at one lander latitude with another. Each tide component has an amplitude and phase: $SX2 = A_{w/e}\cos(2t \pm 2x + \delta_{w/e})$ so that there are 4 observations of 4 unknowns so that SW2 and SE2 can, in principal, be isolated. The relationship between global opacity (dust , water ice) could then be exploited to make adjustments to the simulated aerosol in order to get a better prediction.

MACDA Reanalysis vs MSL and VL1:

Figure 3 shows the comparison of simulated S_2 amplitude and phase at VL1 and MSL from the MACDA MY26 reanalysis with the corresponding observations. Although this simulation is in general agreement with observations, there are notable differences that are likely diagnostic of deficiencies in the formulation of thermal forcing in the models. The resynthesized lander tide variation (not shown) based only on SW2 and SE2 accounts for much of the variability in the simulated S_2. The synchronized decline in S_2 at VL1 and MSL is due to the combined impact of SW2 and SE2. This simplification, that closer agreement between simulations and observations may be achieved by changes to a very small number of tide modes, which are particularly responsive to planetary scale aerosol distributions, also suggests the possibility that a relatively small network of surface observation sites may be sufficient to gain a level of success in relating the observed tide response to thermal forcing. It appears that simulated SW2 and SE2 are underpredicted. If SW2 is too weak, then the overall aerosol heating in the model is likely underpredicted, even though the diurnal mean temperatures in the Reanalysis are in good agreement with the TES observations.

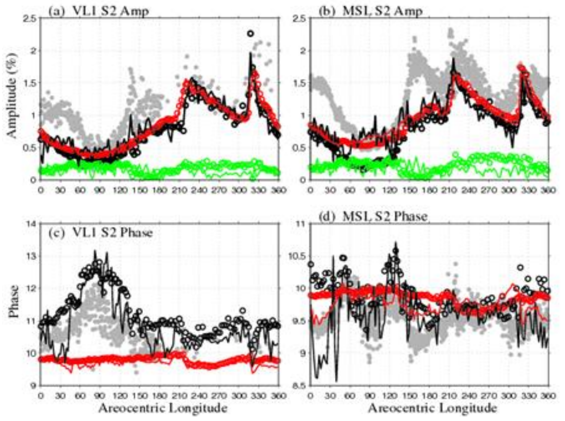

Figure 3. Black curves show the simulated amplitude (top row) and phase (bottom row) of S_2 at VL1 and MSL using the MACDA MY26 reanalysis. The VL1 and MSL observations are shown in grey. Red curves show SW2 while green curves show SE2. There combination of the two tide components depends on their relative phasing. SW2 generally has a very well defined phase of ~0945 LT.

References

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