RECONCILING DUST OPACITY DATASETS AND BUILDING MULTI-ANNUAL DUST SCENARIOS FOR MARS ATMOSPHERIC MODELS.

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Introduction:

In Meridiani Planum (about 354.47° E longitude, −14.57° latitude), several instruments observed dust optical depth at approximately the same time for three Martian years. These include Mars Global Surveyor/TES (at least for the beginning of MY27), Mars Odyssey/THEMIS, Mars Reconnaissance Orbiter/CRISM from space, mini-TES and Pancam camera from MER-B "Opportunity" on the ground. The same applies for Gusev crater, where MER-A "Spirit" landed and operated (around 175.48° E longitude, −14.57° latitude).

There is a very good opportunity, therefore, to carry out an inter-comparison of total dust opacities retrieved at different wavelengths using different instruments and different retrieval algorithms.

Systematic differences among the datasets can be discovered and analysed in detail. The aim is to reconcile different measurements by producing *ad-hoc* "calibrations" at least at two locations on Mars (Meridiani and Gusev), if the physical reasons for such discrepancies cannot ultimately be found.

Another possible application of "calibrated" dust opacities lies in the use of multiple datasets to build time-evolving 2D maps of column-integrated dust optical depth. These maps can then be used by numerical atmospheric models (such as global circulation and mesoscale models) as realistic dust scenarios for different Martian years, when a proper inter-annual variability is requested (e.g. in the production of the Mars Climate Database statistics, see Millour et al., 2008).

Dust Opacity Datasets:

We compared so far five different datasets of column-integrated dust opacities, from five different instruments:

- Mars Global Surveyor / Thermal Emission Spectrometer (TES). See details in Smith (2004). Dust opacities are retrieved from observations in the absorption-only infrared (wavelength around 1075 cm^{-1}, or 9.3 μm), and we multiply by a factor of 1.3 to pass to extinction IR opacities (Wolff and Clancy , 2003)
- Mars Odyssey / Thermal Emission Imaging System (THEMIS). See details in Smith (2009). The same consideration as above applies to dust opacities retrieved from THEMIS.
- Mars Exploration Rovers A "Spirit" and B "Opportunity" / Mini-TES. See details in Christensen et al. (2003). Opacities for this instrument are retrieved from the infrared wavelengths around 1075 cm^{-1} (9.3 μm), same wavelengths as TES and THEMIS, but in extinction rather than absorption-only (they include scattering)
- Mars Exploration Rovers A "Spirit" and B "Opportunity" / Pancam camera. See details in Lemmon et al. (2004). Dust opacities for Pancam cameras are given at the near-IR wavelength of 880 nm
- Mars Reconnaissance Orbiter / Compact Reconnaissance Imaging Spectrometer (CRISM). See details in Murchie et al. (2007). MRO/CRISM dust opacities are retrieved around the near-IR wavelength of 900 nm, which compares directly to Pancam 880 nm wavelength.

The datasets are not homogeneous, neither in the frequency of observations in Meridiani or Gusev nor in their spatial distribution. Observations are mostly not simultaneous and not strictly at the same location, therefore data have to be compared as temporal-spatial averages rather than single observations.

Preliminary Results of the Comparison:

The inter-comparison carried out at Gusev crater, the site where Spirit operates, shows a good agreement among the five datasets.

Less so is the agreement among the five datasets in Meridiani Planum, Opportunity's site. In particular:

- two IR spectrometers from space (TES and THEMIS) observe values of dust opacity as low as 0.1 (in equivalent extinction) at the summer solstice, on average.
- An IR spectrometer (mini-TES) that measures opacities from the ground observes values mostly larger than 0.25 in spring/summer (on average).
- A near-IR spectrometer from space (CRISM) and a near-IR camera (Pancam) on the ground agree quite well (on average) throughout the seasons and years.
- When IR (extinction) opacities are converted into equivalent visible by multiplying by a factor 1.7 (Clancy et al., 1995, 2003, for a r_{eff} around 1.5), and all five instruments are directly compared, it seems clear that mini-TES, Pancam and CRISM mostly agree, whereas

TES and THEMIS underestimate opacities by a factor 2 in Northern summer (starting to diverge from the spring equinox).

The precise reason for this systematic disagreement in summer between THEMIS/TES and the other instruments in Meridiani Planum is not well understood. Dedicated retrievals of TES, THEMIS and CRISM dust opacities for the sites of Spirit and Opportunity should be carried out, before proper conclusions can be drawn. This would assure, for instance, that the surface properties used during the retrievals are consistently the same. Errors bars and proper statistical analysis need also to be applied, in order to understand whether what appears to be a systematic disagreement in summer is indeed so.

At the moment, it seems unlikely, for instance, that the differences at Meridiani are due to the anomalous presence of dust very close to the ground, which is not seen by nadir-looking instruments, because 1) Spirit observed many more dust devils at Gusev than Opportunity at Meridiani, which is not consistent with the hypothesis that dust devils could put more dust aloft in spring/summer at Meridiani, and 2) if there was more dust on the optics of Pancam and mini-TES at Meridiani, CRISM should not agree so well with their measurements, at least in principle.

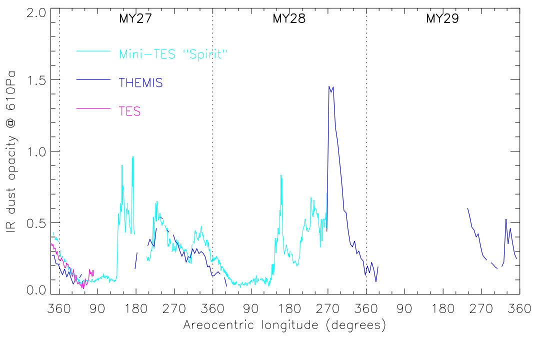

Figure 1: Comparison of retrieved total dust opacities among Spirit mini-TES, TES and THEMIS in MY27, 28, 29 at Gusev crater. Mini-TES observations are averaged in the local time range 9h-14h and within 1° areocentric longitude, THEMIS observations are averaged in a box 28°x28° in longitude, latitude and 5° areocentric longitude, TES observations are averaged in a box 12°x4° in longitude, latitude and 2° areocentric longitude. TES and THEMIS absorption-only IR observations are converted to equivalent extinction by multiplying by a factor of 1.3. Dust opacities are normalised at the reference pressure of 610 Pa.

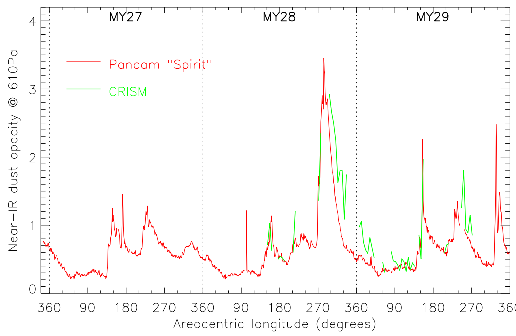

Figure 2: Comparison of retrieved total dust opacities among Spirit Pancam and MRO/CRISM in MY27, 28, 29 at Gusev crater. Pancam observations are averaged within 1° areocentric longitude, and CRISM observations are averaged in a box 10°x10° in longitude, latitude, and 5° in areocentric longitude. Dust opacities are normalised at the reference pressure of 610 Pa.

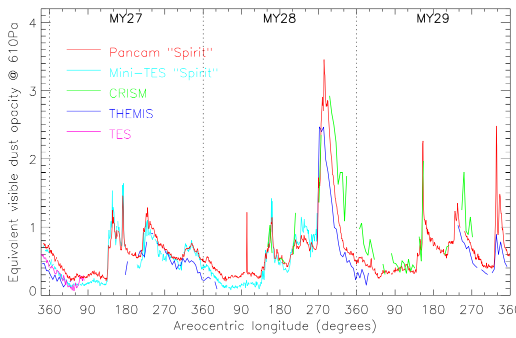

Figure 3: Comparison of all the five datasets at Gusev crater. TES, THEMIS equivalent extinction and mini-TES extinction IR observations are converted to equivalent visible by multiplying by a factor of 1.7. Pancam and CRISM opacities in the near-IR are already close to mean visible opacities, so no multiplicative factor is used. Dust opacities are normalised at the reference pressure of 610 Pa.

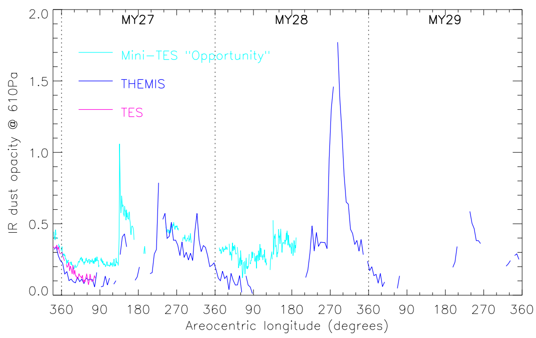

Figure 4: Same as Fig. 1, but using Opportunity mini-TES, TES and THEMIS at Meridiani Planum.

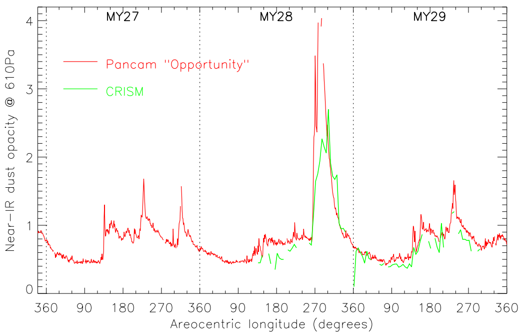

Figure 5: Same as Fig. 2, but using Opportunity Pancam and CRISM at Meridiani Planum.

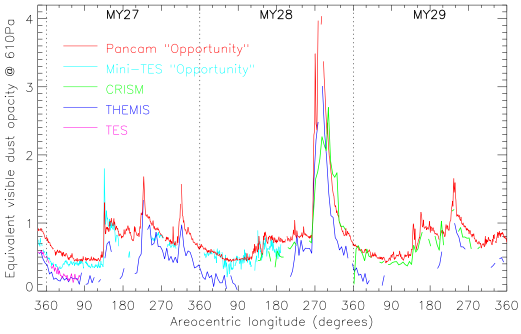

Figure 6: Same as Fig. 3, but using all the datasets at Meridiani Planum.

Building Dust Scenarios for Models:

The first step to build time-evolving 2D maps of column-integrated dust opacities to be used as dust scenarios in atmospheric models is to characterize the level of agreement (or disagreement) among all the datasets that are going to be used. This is the main reason why reconciling disagreements among the datasets at Meridiani and Gusev is of primary importance.

Once different datasets (e.g. those mentioned in this paper) have been "calibrated", 2D maps of time-varying dust opacity are built according to the following steps:

- MGS/TES dust opacity observations in MY24 (from L_s=141) and MY25 (until L_s=141) are averaged using a 15° L_s running window. Missing data in the polar night regions are replaced by an opportune constant value.
- Using kriging interpolation, we produce maps of equivalent background dust opacity for MY27, 28 and 29, based on re-normalised MGS/TES data in MY24/25 (we use Spirit and Opportunity time series for opportune re-normalisation).
- We "assimilate" all available dust opacity observations in MY27, 28 and 29, using the maps described before as background. We use a simplified formula to weight the information produced by each observation in space and time.

Future Work:

Apart understanding the origin of the systematic disagreement showed in this paper at Meridiani, future work might include in the inter-comparison other two dust opacity datasets, namely Mars Express/Planetary Fourier Spectrometer (PFS) and MRO/Mars Climate Sounder (MCS). PFS retrievals have very recently become publicly available. At the moment, there are issues about saturation of dust opacity values above a certain threshold, but if there are available observations at Meridiani and Gusev that can be used in the comparison, they will be included. The same applies to MCS column-integrated opacities, although there are only few observations in the day side at Equatorial latitudes.

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