AN INTERCOMPARISON OF PFS AND MCS TEMPERATURE PROFILES IN SUPPORT OF MARS PHOENIX EDL.

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Introduction: The Mars Phoenix Lander successfully touched down on the Northern Plains of Mars on May 25th, 2008 after a cruise of more than nine months. A substantial effort was made by the Phoenix team to ensure that the martian atmosphere was well characterized at the projected landing site (68.3° N, 233.0° E) for the time of year (L_s=76°) and time of day (1630h) of landing. Contributions from an array of numerical modeling groups and instrument science teams were assimilated into a series of atmospheric products used during the weeks leading up to Phoenix entry, descent and landing (EDL).

Primary atmospheric support for Phoenix EDL was provided by the Mars Reconnaissance Orbiter (MRO) Mars Climate Sounder (MCS), a limb-staring array infrared radiometer capable of providing both nadir and limb measurements of atmospheric temperature and both dust and water ice opacity [1]. Throughout EDL, only limb-sounding measurements were obtained. In its limb-viewing orientation, MCS is capable of providing vertical temperature profiles from ~10-80 km with 5 km vertical resolution. The polar orbit of MRO is sun-synchronous, with equator crossings at 3AM and 3PM, providing two daily temperature measurements of the landing site.

As a protection against unforeseen circumstances that could disable either MRO in general, or MCS in particular, the Phoenix team solicited and received the help of the Mars Express (MEX) Planetary Fourier Spectrometer (PFS) team to provide temperature profiles over the Phoenix landing site in the weeks leading up to EDL. The PFS-LW (longwave) instrument is a nadir-pointing spectrometer with high spectral resolution (nominally 1 cm^{-1}) capable of returning temperatures in the ~0-50 km range [2,3].

Data Sets: MCS data was piped through pre-processing routines and made available to Phoenix on a daily basis. Because of the ~27° spacing between MRO passes and a ~5° daily precession of the spacecraft orbit, direct overflights of the landing ellipse occurred approximately every five days, however the nearest orbital track was never more than 15° from the landing site. The relatively benign nature of the Northern Plains during this season assured that even the least optimal orbital configuration provided measurements that were still representative of the weather over the landing ellipse.

Due to the limited opportunities of MRO to view the PHX landing site with HiRISE during the EDL period, MCS data acquisition over the landing site was sparse throughout April and given priority beginning only in the first week of May. Regular coverage was obtained through May 25, including the orbits immediately preceding and immediately following EDL. (Telecom-imposed restrictions prevented the acquisition of MCS data on the direct EDL overflight.) Within each orbit, as many as ten of the nearest individual profiles were retrieved within a box 10° latitude x 30° longitude around the landing target. These profiles were subsequently averaged to produce a single, mean profile, representative of the local atmospheric conditions around the landing site.

Concurrently, a total of 14 profiles were periodically provided to Phoenix by the PFS team between April 2 and May 24, with the final profile arriving only hours before EDL. Due to the highly elliptical shape of the MEX orbit, local time coverage was somewhat more variable, differing from the regular 3AM-3PM passes of MRO by as much as nine hours, although most were within three hours. For each orbit, a series of profiles within a few degrees of the landing site was averaged, and a mean profile delivered to Phoenix by the PFS team. Table 1 lists the MEX orbit number, PFS observation lat/lon and time, and corresponding MCS mean observation lat/lon and time for the 14 orbits used in this study. For 13 of the 14 PFS profiles, a 'matching' MCS profile was processed, post-landing, that encompassed the same general atmosphere within ±9 hours. Only for profile #8 (April 22) was there no comparable MCS profile obtained.

Procedure: Prior to EDL, the PFS data were evaluated alongside MCS data in a qualitative sense, with the expectation that it would act as a general validation of MCS results, and to ensure no false or spurious profiles were being delivered to Phoenix. In some instances, the two profiles matched well within the 10-50 km range, however in many cases, the two profiles showed significant differences. Because of the time pressure introduced by EDL activities, no effort was made to resolve these discrepancies prior to landing.

Post-landing, this issue was readdressed, under the auspices of the Phoenix project, in order to understand the root causes of the profile differences. Data was shared directly between the PFS and MCS teams for analysis. Mean profiles from the PFS team were sent to the MCS team in text format as T(z). Similar profiles from MCS were likewise provided to the PFS team. The intent of this 'data swap' was to ensure that both MCS and PFS teams were 'cross-pollinated' with each other's profiles as a way of performing internal validation and ensuring that there were no errors in calibration or data reduction.

Discussion: Figure 1 shows a typical comparison, for results from MEX Orbit 5459, and the corresponding MCS temperature profiles. Below ~20 km, both profiles match well, despite an approximately two hour local time difference between the observations. Above 20 km, the profiles diverge, with the PFS profile reaching a minimum in temperature some 10-15 K lower than MCS at ~40 km altitude. Because it is a nadir-pointing instrument, PFS cannot reliably return radiances at altitudes above this level, so the PFS profile >40 km is of reduced value.

This discrepancy between 20-40 km is seen in most of the comparisons we have made, and suggests one or more issues may be present that require further analysis.

1. Differences in local time and position may result in differences in atmospheric temperature.
2. The radiative transfer calculations between the two instruments are sufficiently different to cause discrepancies in the retrieved profiles.
3. Poor fits to the measured radiances result in incorrect temperature profiles.
4. There are calibration issues with one or both instruments.

Each of these issues will be addressed in turn.

To understand the effect of time/position differences (issue #1), the teams are presently correlating spectra and retrieval errors with the time and location errors in order to evaluate the potential magnitude of this contribution. Similar differences are seen regardless of the local time difference, including both cases when the PFS observations are made earlier than MCS and cases when it is later. Preliminary findings suggest that this issue likely contributes, at most, only a small portion of overall profile differences.

There are notable distinctions in the radiative transfer calculations for the retrievals by both instruments, which is the focus of issue #2. Notably, MCS does not consider scattering by atmospheric aerosols, while PFS incorporates a multiple scattering approximation. There are a number of reasons this is likely not a significant source of error, however. First, at the altitudes of maximum difference between MCS and PFS, aerosol abundances are quite low, and not likely to result in significant temperature adjustments. At the altitudes where aerosol opacity and scattering become significant (<20 km), the profiles generally align quite well. Second, tests performed by the PFS team generating synthetic spectra with various model assumptions (Figure 2) show that the influence of multiple scattering in the 15μm band is generally small. However, because of the limb view geometry, the observation path of MCS can contain as much as 50x more aerosol opacity than in the nadir view. Additional tests need to be performed to evaluate the overall role of dust and aerosol scattering on the results.

To address issue #3, both teams have been asked to perform a cross-comparison of their respective retrieval models. Both PFS and MCS have good agreement between their respective measured and calculated radiances, which suggests internal consistency for both models. Tests attempting to derive a spectrum from one of the other team's profiles show inconsistencies between models that may suggest a heretofore unforeseen bias. Figure 3 illustrates the result when an MCS temperature profile is fit to the observed PFS spectrum. In the core of the 15μm band there is a large difference between the spectrum corresponding to the MCS profile ('MCS temperature profile') and that of PFS ('BDM temperature profile'). Future tests have been designed to retrieve temperature profiles back from these derived spectra (making a circular loop from profile → derived spectra → profile). Ideally, the model should return a final profile identical to the original input. Any inability to reproduce the input profile would reflect an internal bias that must be addressed.

Issue #4 may present the most promising solution to these discrepancies, and requires verification of the respective radiometric calibration of the two instruments. A preliminary plan to do this has been designed and will be performed. During late 2006/early 2007, MCS was making nadir radiance measurements, which provide the closest comparison to the PFS measurement configuration. The objective is to produce radiances from versions of both radiometric codes that rely on the spectral response of the other instrument. For example, the MCS team will provide the PFS team with the spectral response of the MCS A3 channel (635-662 cm^{-1}). By substituting this weighting function for the PFS instrument weighting function, one will obtain an A3 channel radiance from the measured PFS spectrum. Comparing this to a similar radiance derived purely by the MCS radiance model should yield comparable results so long as the relative calibrations of the two instruments are equivalent. Finding observations that are close in both time and space will provide the best comparison, although selecting observations in more quiescent portions of the