THEMIS INSTRUMENT DESCRIPTION AND ATMOSPHERIC OBSERVATIONS

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Introduction: The Mars Odyssey spacecraft entered into Martian orbit in October 2001 and after successful aerobraking began mapping in February 2002 (approximately Ls=330°). Images taken by the Thermal Emission Imaging System (THEMIS) on-board the Odyssey spacecraft allow the quantitative retrieval of atmospheric temperature, and dust and water-ice aerosol optical depth. Atmospheric quantities retrieved from THEMIS build upon existing datasets returned by Mariner 9, Viking, and Mars Global Surveyor (MGS). Data from THEMIS complements the concurrent MGS Thermal Emission Spectrometer (TES) data by offering a later local time (~2:00 for TES vs. ~4:00-5:30 for THEMIS) and much higher spatial resolution.

THEMIS Instrument Characteristics: The THEMIS instrument contains a thermal infrared wavelength focal plane with 10 spectral filters ranging from 6.6 to 15 µm, and a visible wavelength focal plane with 5 spectral filters ranging from 423 to 870 nm. Although atmospheric observations using the visible light filters can be used to identify water ice and dust clouds, we concern ourselves here with data from the thermal infrared only.

THEMIS infrared images are 320 pixels wide with a spatial resolution of 100 m/pixel, so the images are 32 km wide. Images are of variable length, often stretching for several thousand pixels along the orbit track (which runs in a roughly north-south direction). At each pixel, data is returned in up to 10 spectral bands. THEMIS bands # 1 and 2 have the same spectral response, so there are 9 distinct spectral bands with centers at 6.62, 7.88, 8.56, 9.30, 10.11, 11.03, 11.78, 12.58, and 14.96 µm, respectively for bands # 1/2 through 10. Each spectral band has a bandwidth of about 1.0 µm. The top panel of Fig. 1 shows the THEMIS bands (Recall that wavenumber = 10,000 / wavelength in microns). The bottom panel of Fig. 1 shows the spectral dependence of absorption features caused by dust, water ice, and a non-unit surface emissivity basaltic surface at THEMIS spectral resolution [*Smith et al.,* 2000b; *Bandfield and Smith* 2002]. Notice that the dust and water-ice spectral features are resolved and well-described even at the relatively low spectral resolution of THEMIS. However, notice also that the spectral dependence of dust and the basaltic surface are very similar over this spectral range. This makes it difficult to separate their contributions using THEMIS data alone. This point will be discussed in more detail in the "Retrieval Methods" section that follows. THEMIS band # 10 lies within the 15-µm (667 cm^{-1}) CO_2 band complex and is used to give an indication of atmospheric temperature.

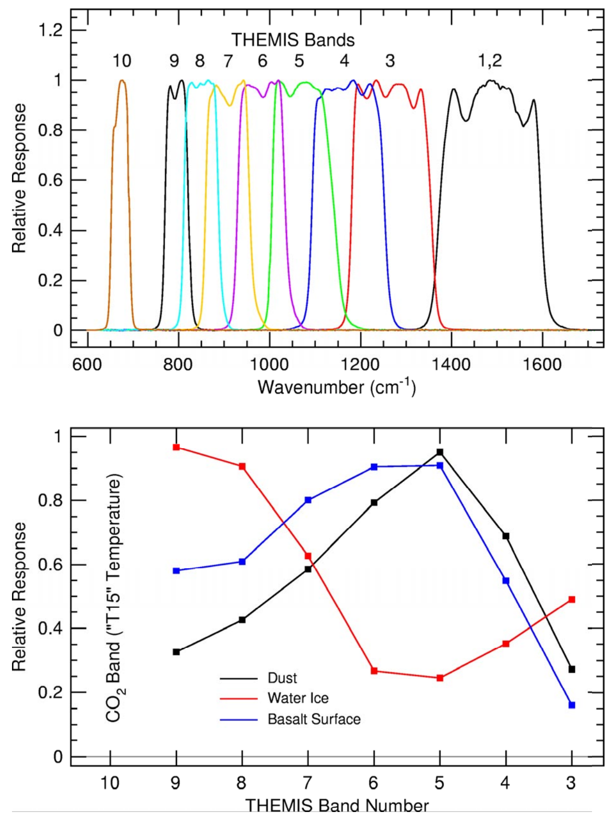

Figure 1. (top) The spectral response of the 10 THEMIS bands. Note that bands # 1 and 2 have the same spectral response. (bottom) The spectral dependence of absorption features caused by dust, water ice, and a non-unit surface emissivity basaltic surface at THEMIS spectral resolution. Note that the "x-axis" quantity is similar but not the same for these two plots.

The primary goals of the THEMIS instrument are to determine surface mineralogy and to study small-scale geologic processes and thermophysical properties. Much of the imaging time during the first part of the mission has been used to intensely study identified potential landing sites for the Mars Exploration Rovers to be launched in 2003. Because of this, THEMIS imaging does not have the systematic pole-to-pole coverage that MGS TES usually has. However, wherever full

10-band infrared images are taken, atmospheric properties can be retrieved regardless of the primary purpose for taking the image at a certain location. In practice, there are enough geologically interesting regions throughout the globe that reasonably good global coverage is achieved. Atmospheric science is a recognized goal of the THEMIS team, and roughly 5% of the THEMIS imaging time is devoted to atmospheric observations. This time has been used to maximize latitudinal coverage in at attempt to fill in the gaps that might be left behind in the geologic imaging.

Retrieval Methods: The THEMIS infrared images allow for the retrieval of atmospheric temperature, dust, and water ice optical depth. Here we briefly describe the retrieval algorithms used to derive atmospheric quantities.

Because there is just one THEMIS band (#10) in the CO_2 absorption band, a temperature profile (temperature as a function of height) cannot be retrieved as done using MGS TES spectra. Instead, one temperature that is representative of the atmosphere can be determined. We call this temperature "T15" because of its similarity to the "T15" temperatures measured by the Viking IRTM instrument [*Martin and Kieffer* 1979].

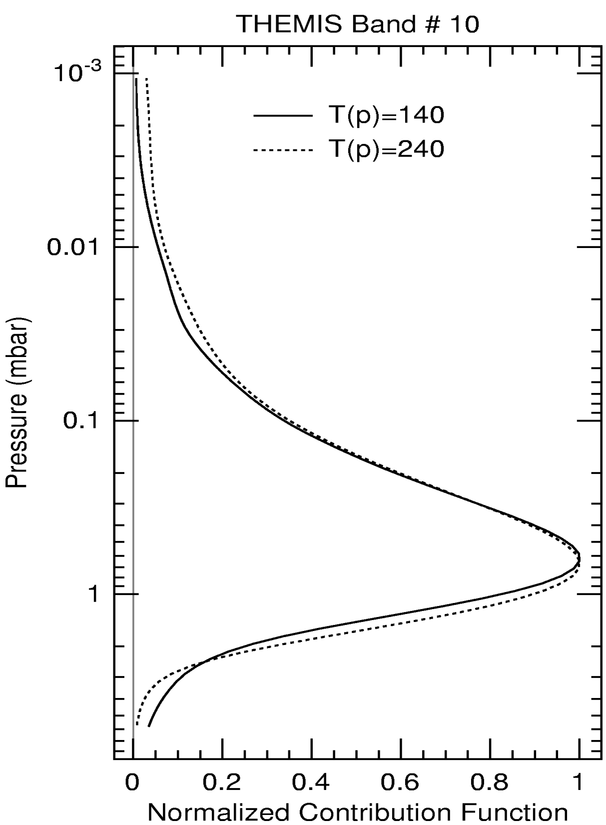

Figure 2. The contribution functions for THEMIS band # 10, showing the relative contribution of different vertical levels of the atmosphere to the observed radiance. The contribution is not very sensitive to temperature and has a broad peak at 0.6 mbar.

Because band # 10 covers a relatively wide spectral range, a look-up table is used to convert observed radiance into a temperature (instead of simply inverting the Planck function). The look-up table is computed by convolving the Planck function for a particular temperature with the band # 10 spectral response.

To aid in the interpretation of T15 temperature, a very useful quantity to compute is the contribution function. It describes the amount that each vertical layer of the atmosphere contributes to the observed radiance. Contribution functions for THEMIS band # 10 are shown in Fig. 2 for two extreme bracketing cases of atmospheric temperature. The T15 temperature represents an average over a large portion of the atmosphere but is weighted most heavily near 0.6 mbar. If the surface pressure is less than about 3.0 mbar, then the contribution function is not zero at the surface, which means that there is a contribution in band # 10 from the surface. Figure 3 shows the total atmospheric transmittance as a function of surface pressure for the two cases. The contribution from the surface to the observed radiance in band # 10 cannot be neglected when surface pressure is low.

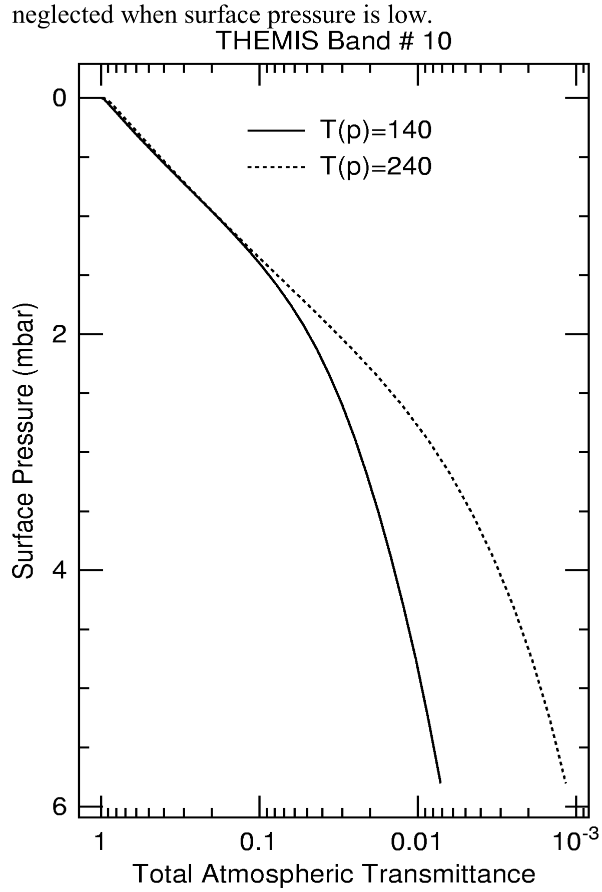

Figure 3. The total atmospheric transmittance as a function of surface pressure. The contribution to observed THEMIS band # 10 radiance from the surface becomes significant at high altitudes (low surface pressure), especially when the atmosphere is cold.

To make an accurate retrieval of aerosol optical depth, it is necessary to make an estimate of the pressure dependence of temperature. The temperature profile can be modeling using T15 and the surface temperature as a tie point [*Martin and Richardson* 1993], but while MGS is still operational it is most accurate to use the temperature profiles retrieved using concurrent observations by TES.

Following the algorithms used for TES, dust and water ice optical depth are retrieved simultaneously [*Smith et al.* 2000a]. The basic idea is to find the values of dust and water ice optical depth that provide the best fit between computed and observed radiance. The observations used are THEMIS bands # 3 through 8.

Although the above retrieval takes only a small fraction of a second, it is still not practical to perform on a pixel-by-pixel basis because of the large number of pixels in THEMIS infrared images. Instead, we perform the retrieval on blocks of data called "framelets" that are 320 pixels wide (the width of the image) by 256 pixels long (along track). This translates to 32 x 26 km, or roughly one-third of a degree square. This spatial resolution is sufficient to resolve most atmospheric variations of interest, and the capability for spatial averaging of any size (including pixel-by-pixel) has been retained for special investigations involving small-scale processes.

Because the spectral dependence of surface emissivity is often very similar to that of atmospheric dust (see the "dust" and "basalt surface" lines in the bottom panel of Fig. 1), we do not attempt to independently retrieve surface and atmospheric components on the framelet scale. The surface emissivity at this scale has already been very well determined using TES spectra [*Bandfield et al.* 2000; *Bandfield* 2002], so we account for non-unit surface emissivity by simply using the maps created by TES. TES can easily distinguish between dust and a basaltic surface because the spectral shape of dust and basalt are much more different in the 20-40 μm wavelength range that is observed by TES but not by THEMIS.

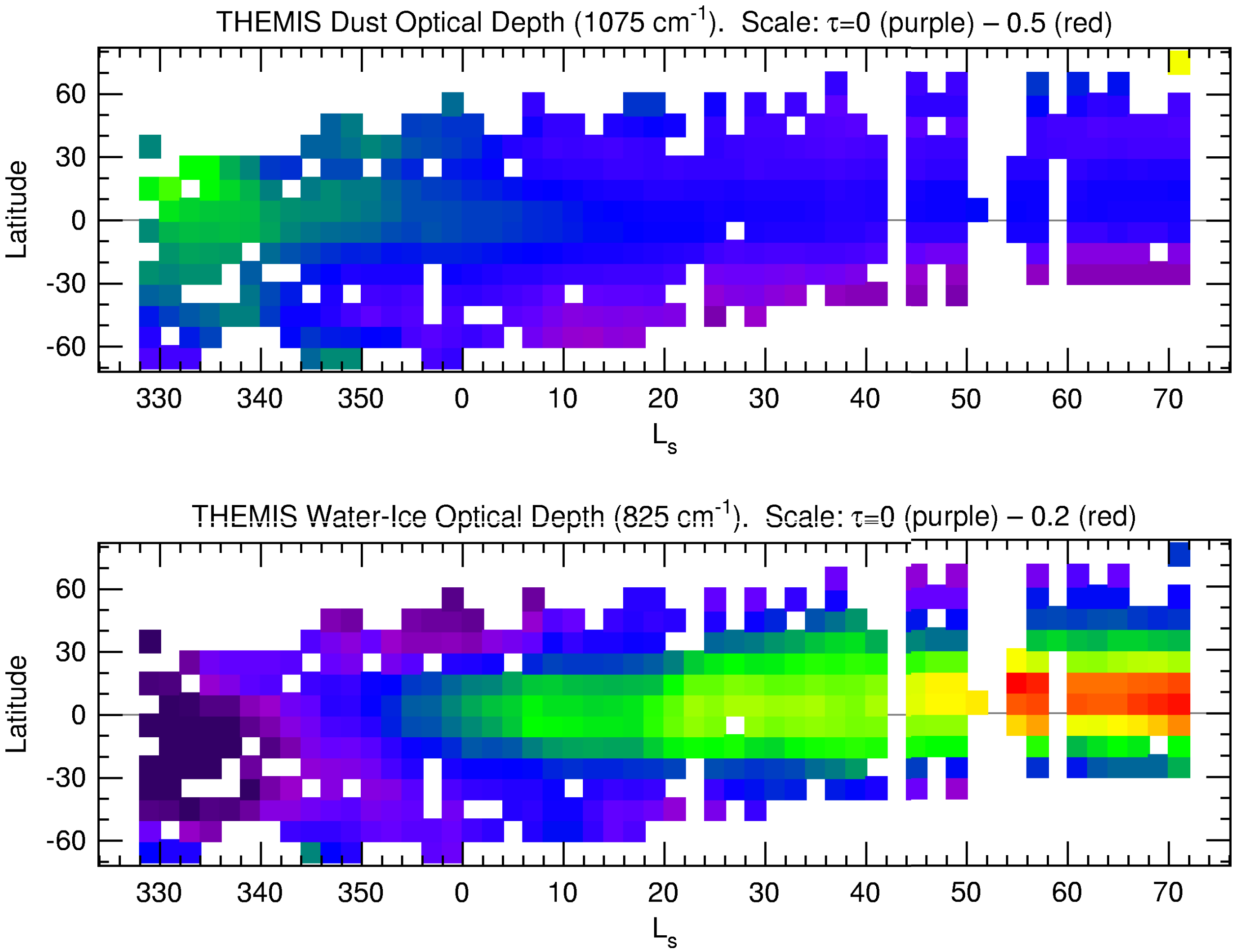

Figure 4. An overview of daytime THEMIS aerosol observations is shown as zonal averages as a function of latitude and season (Ls). (top) dust optical depth at 1075 cm^{-1} scaled to an equivalent 6.1 mbar pressure surface, (bottom) water-ice optical depth at 825 cm^{-1}.

The surface temperature is initially estimated as the equivalent brightness temperature of band # 3, but is varied in a self-consistent way along with aerosol optical depth to account for the non-negligible opacity of dust and water ice in band # 3 (see bottom panel of Fig. 1).

Overview of THEMIS Atmospheric Observations: The results presented below were derived using data from the beginning of Mars Odyssey mapping at Ls=330° (20 February 2002) to Ls=71° (21 September 2002). In Fig. 4 we show the seasonal and latitudinal variation of dust and water-ice aerosol optical depth over that period. Zonal means of dayside data are presented. Local time for the observations varies from roughly 1500 hours in the beginning to 1630 hours at the end. The retrieval of aerosol optical depth is restricted to those spectra with a surface temperature >220 K to ensure adequate thermal contrast between the surface and the atmosphere. Because dust optical depth is usually nearly well-mixed with CO_2, it has been scaled to a 6.1-mbar equivalent pressure surface to remove the effect of topography. Water-ice optical depth is not as closely well-mixed as dust and so are not scaled. Estimated uncertainties in Fig. 4 are 0.03 for aerosol optical depth.

Apparent in the top panel of Fig. 4 is the decay of a moderate regional dust storm. The dust storm was observed by TES to have begun at Ls~315°. Very low dust optical depth is observed in the southern hemisphere after Ls=0°. There is a single relatively high opacity point (optical depth of 0.37) at high northern latitudes at Ls=71° which may represent activity along the edge of the retreating northern seasonal polar ice cap.

The bottom panel of Fig. 4 clearly shows the return of the aphelion season cloud belt. The amplitude and latitudinal extent of the cloud is consistent with TES observations (see accompanying abstract "TES Observations of Aerosol Optical Depth and Water Vapor Abundance"). Maps of the latitude-longitude distribution of THEMIS water ice optical depth (figure not shown here) are very similar to those derived from TES data [e.g. *Pearl et al.* 2001].

We do not show THEMIS T15 temperatures here. Although the observed radiance data for THEMIS bands # 1 through 9 have now been relatively well calibrated, there are still significant outstanding issues to be resolved for the proper calibration of band # 10. Because band # 10 views a significantly different temperature than the other filters (T15 can be as much as 100 K lower than the surface temperature) the calibration procedure for band # 10 can not be performed in the same way as with the other bands. Work to resolve the calibration issues for band # 10 is ongoing.

Summary: Infrared data from the Thermal Emission Imaging System (THEMIS) can provide information about atmospheric temperature, dust and water ice aerosol optical depth. Observations taken during late northern winter and spring show the decay of a regional dust storm and the formation of the aphelion season water-ice cloud belt in good agreement with TES observations.

Atmospheric observations by THEMIS provide the potential to complement the extensive atmospheric data concurrently being returned by MGS TES. Throughout the remainder of the nominal Odyssey mission, the local solar time for THEMIS observations will be between 4:00 and 5:30 AM/PM. The difference of up to 3 hours between TES and THEMIS observations will allow some measure of the diurnal variation of aerosols (especially water-ice clouds) to be determined and will greatly aid in the identification of the amplitude and phase of solar tides (especially during large dust storms). Furthermore, the small spatial scale that can be resolved by THEMIS allows the study of phenomena not visible from TES such as dust devils.

References:

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