THEMIS OBSERVATIONS OF ATMOSPHERIC AEROSOL OPTICAL DETPH. Michael D. Smith[1], Joshua L. Bandfield[2], Philip R. Christensen[2], and Mark I. Richardson[3], [1]NASA Goddard Space Flight Center, Greenbelt, MD 20771 USA (Michael.D.Smith@nasa.gov), [2]Arizona State University, Tempe, AZ 85287 USA, [3]California Institute of Technology, Pasadena, CA 91125 USA.

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 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 [*1*, *2*]. 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.

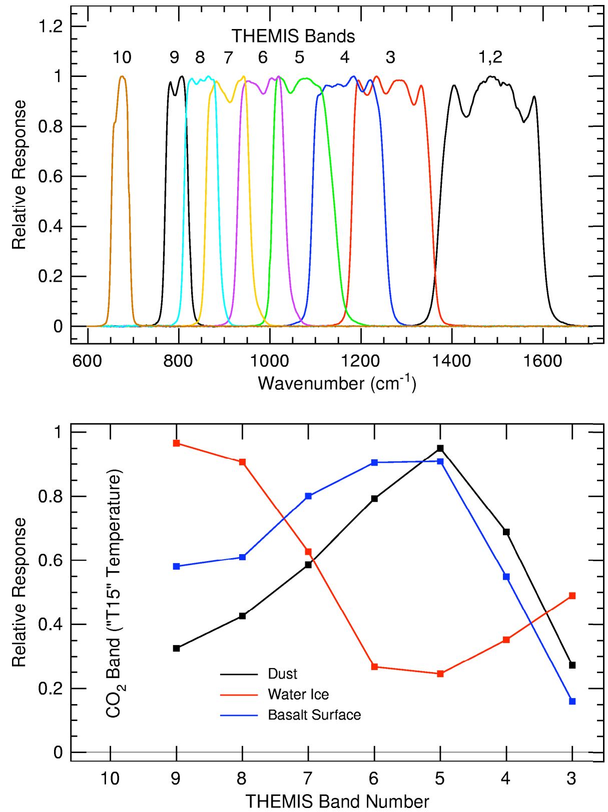

Figure 1. (top) The spectral response of the 10 THEMIS bands. Note that bands # 1 and 2 have the same spectral response. (bottom) The spectral dependence of absorption features caused by dust, water ice, and a non-unit surface emissivity basaltic surface at THEMIS spectral resolution. Note that the "x-axis"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

Although the primary goals of the THEMIS instrument are to determine surface mineralogy and to study small-scale geologic processes and thermophysical properties, atmospheric science is also a priority of the THEMIS science team. The spectral range covered by THEMIS contains strong signatures of atmospheric dust and water-ice aerosols and is well-suited for the quantitative retrieval of aerosol optical depth.

Retrieval Mehods: Following the algorithms used for TES [*3,4*], dust and water ice optical depth are retrieved simultaneously in a separate step after the atmospheric temperature profile T(p) has been estimated. 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 we use are THEMIS bands 3 through 8. Bands 1 and 2 are not used because of contributions from water vapor and surface emissivity effects, and because of uncertainties in the aerosol spectral dependence in that spectral region. Band 9 is not used because of contributions from the wings of the 15-μm CO_2 band.

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 [*5,6*], 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.

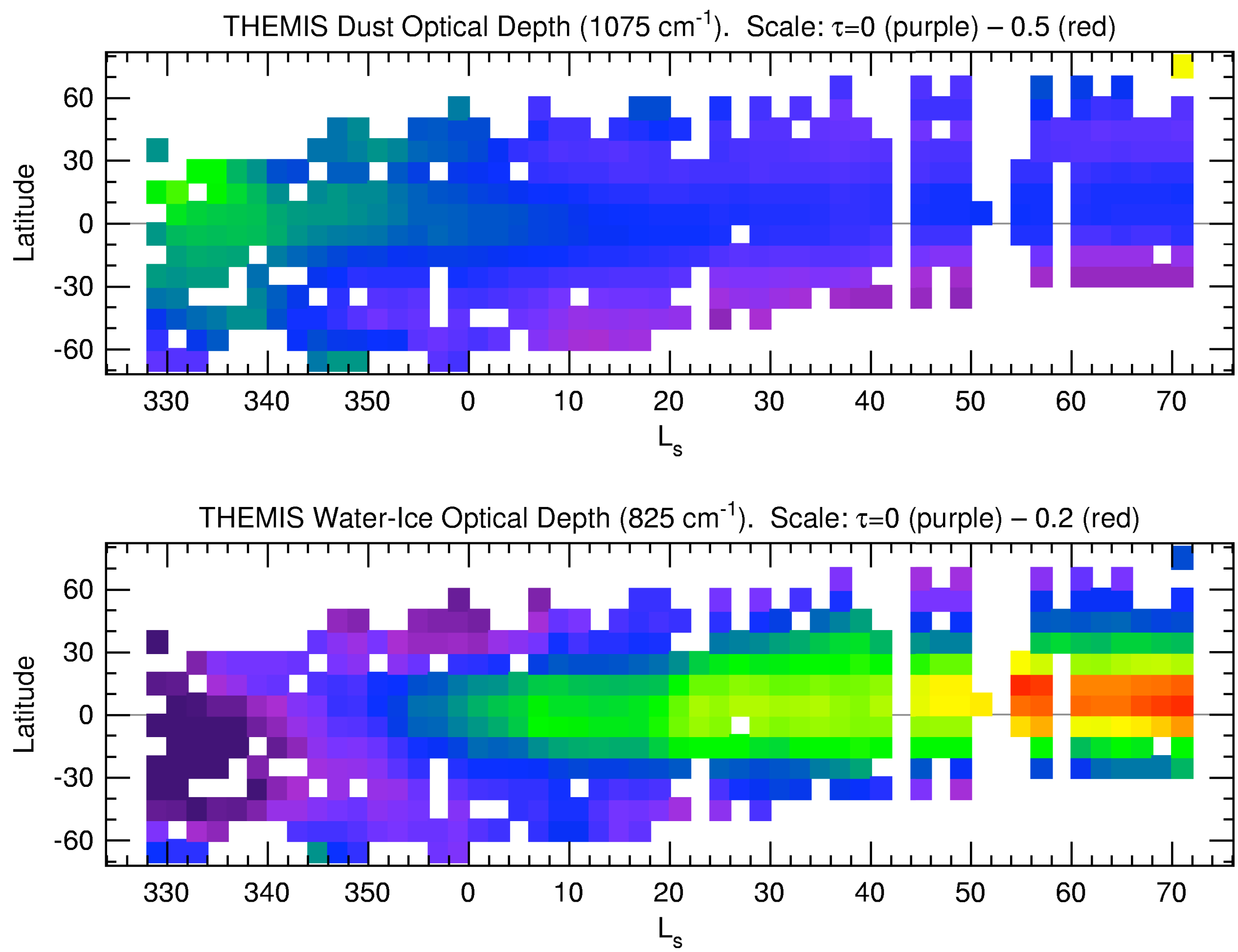

Figure 2. An overview of daytime THEMIS aerosol observations is shown as zonal averages as a function of latitude and season (Ls). (top) dust optical depth at 1075 cm^{-1} scaled to an equivalent 6.1 mbar pressure surface, (bottom) water-ice optical depth at 825 cm^{-1}.

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. 2 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 3:00 PM in the beginning to 4:30 PM 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 for aerosol optical depth in Fig. 2 are 0.03.

Apparent in the top panel of Fig. 2 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. 2 clearly shows the return of the aphelion season cloud belt. The amplitude and latitudinal extent of the cloud is consistent with TES observations [*7*]. 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 [*4*].

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. 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:

[1] Smith et al., (2000b), *J. Geophys. Res. 105*, 9589. [2] Bandfield and Smith (2002), *Icarus*, *161*, 47. [3] Smith et al., (2000a), *J. Geophys. Res. 105.* [4] Pearl et al., (2001), *J. Geophys. Res. 106*, 12,325. [5] Bandfield et al., (2000); *J. Geophys. Res. 105*, 9573. [6] Bandfield (2002), *J. Geophys. Res. 107*, 10.1029/2001JE001510. [7] Smith et al. (2001) *J. Geophys. Res. 106*, 23,929.