

ISIS Processing Tools for Thermal Emission Spectrometer Data. K. Becker<sup>1</sup>, J.R. Johnson<sup>1</sup>, and L. Gaddis<sup>1</sup>, <sup>1</sup>U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001, kbecker@usgs.gov.

*Introduction:* The Integrated Software for Imagers and Spectrometers (ISIS) package is a widely used planetary data processing and cartography software system produced by the Astrogeology program of the USGS in Flagstaff, AZ [1-4]. Recent additions to the ISIS system provide useful tools for extracting and projecting Thermal Emission Spectrometer (TES) data for use with other ISIS programs to process, analyze, and visualize these data, particularly in comparison with other Mars data sets.

*Overview of new tools.* The following programs and tools can be used for extracting and processing TES data and are available in ISIS:

- *vanna* - An ISIS interface to the "vanilla" command-line software from the TES team at Arizona State University (ASU). This allows the user to create an ascii or binary database of TES data for a given region on Mars. The *vanna* program can be used alone or via *tesemiss*.
- *tesemiss* - Uses *vanna* to retrieve TES emissivity and related data from a "vanilla" database. Allows extraction of TES data such as emissivity, lambert albedo, or target temperature for a given region on Mars. Searches can be restricted on the basis of albedo, dust, clouds,  $L_s$ , and other parameters associated with the TES data.
- *lev2raster* - Rasterizes ascii or binary data generated from *vanna* or *tesemiss* using specified latitude and longitude coordinates. This is a generalized program that creates an ISIS image cube of TES data, using square representations of TES pixels (defaulting to 3.15 km resolution). It can be used to create TES cubes that are coregistered to MOC, MOLA, and/or MDIM data.
- *tesmap* - An ISIS implementation of the *DMAP* software provided by the ASU team, but refined to use the specific SPICE data for a given set of observations. *tesemiss* is mainly intended for use in accurately projecting and registering TES mosaics or emission phase function observations onto existing MDIM 2.1, MOC, MOLA, or THEMIS images or mosaics. Like *lev2raster*, *tesmap* can be used to produce images of any TES parameter value, but *tesmap* accounts for variations in footprint size depending on viewing angle and spacecraft trajectory, and has been modified to permit projection of both TES 5 cm<sup>-1</sup> and 10 cm<sup>-1</sup> data. It processes ascii data extracted using the *vanna* application.

*Discussion:* Processing of TES data in ISIS is a two step process. The first step is to extract the TES data from the *vanilla* database. Fundamental to this process is the ISIS *vanna* application. *vanna* was created to make interfacing with ASU's *vanilla* application more in line with ISIS processing philosophy. *vanna* provides the familiar TAE interface and scripting capabilities within the ISIS system. It maintains consistency with *vanilla*'s "-select" and "-fields" parameters. The resulting text output file is a slightly modified version of the *vanilla* output file in which a '#' symbol is added to all comments along with an additional comment line that contains the *vanilla* command used to generate the dataset.

The second step is the projection of TES data in the ISIS system. The *lev2raster* and *tesmap* ISIS applications take the output files generated by *vanna* and project them to any projection supported by the ISIS system. Both applications have the ability to: (1) project multiband TES datasets such as emissivity; (2) construct new output products from user specified projection properties (e.g., latitudinal ranges, projection type, coordinate system (e.g., 0 to 360 or -180 to 180 and positive east or west longitude, planetocentric and planetographic latitudes); (3) inherit projection properties from an existing projected ISIS product; and (4) provide support for both 5 cm<sup>-1</sup> and 10 cm<sup>-1</sup> TES data. However, these two applications differ in how they map the data into the projection space.

### **LEV2RASTER**

*lev2raster* utilizes the latitude and longitude values directly from the TES *vanilla* database to determine where each detector observation is mapped in the output projected ISIS product. These values were precomputed and stored in the database by the ASU TES team using the planetary radii and prime meridian values from Mars 1994 IAU specification and planetary, spacecraft and instrument ephemerides (i.e., NAIF SPICE PCK, SPK and CK data). Any Mars data sets that are not geometrically projected using precisely the same IAU and ephemerides data will be spatially misaligned. *lev2raster* addresses this problem with input parameters that allow users to specify which IAU values to use in the creation of new projected products (via the parameter value TARGDEF), make adjustments to longitude values to align prime meridians (parameter PMEROFF) and

specify a configuration file (parameter CONFIG) that along with the *vanna* output file completely describes the TES viewing geometry.

Because *lev2raster* plots individual detector observations, data must be projected at a fixed resolution that best represents TES observing conditions. For  $10\text{ cm}^{-1}$  data, this is approximately 3.15 km per pixel resolution. To directly compare these data to existing data sets of different resolutions requires a reprojection using the *lev2tolev2* ISIS application. For multiple TES values that map into the same pixel location, data can be averaged, replaced by subsequent data, or the initial value can be preserved. Although *lev2raster* is mainly intended for use with data sets covering large regions [5], in Figure 1 we show for comparison to *tesmap* the results of the *lev2raster* application for a partial TES mosaic acquired at  $10\text{ cm}^{-1}$  resolution and a full mosaic at  $5\text{ cm}^{-1}$  resolution [6].

### **TESMAP**

The ISIS *tesmap* application is similar in its approach to projecting TES data to the *DMAP* tool produced by the ASU TES team. *DMAP* provides an instrument model for the TES 3-by-2 detector array. Using data that is stored in the *vanilla* database, *DMAP* constructs a latitude/longitude grid from data selected by the user using the *vanilla* application. *DMAP* can optionally project TES data onto a background map such as an MDIM subscene [cf. 7].

Using image motion compensation (IMC), TES has the ability to compensate for spacecraft orbit motion, stepping the mirror to maintain pointing at a specific location on the surface of Mars. However, because the Mars Global Surveyor (MGS) spacecraft had its downtrack orientation reversed prior to the mapping phase (causing MGS to orbit Mars backwards from its originally intended direction), the IMC mode was not used [7]. Without IMC, the TES field of view (FOV) is better described as a “smear.” The mirror motion remains fixed and spacecraft motion governs observation conditions during the 1.8 sec data collection duration for TES  $10\text{ cm}^{-1}$  mode (3.6 sec for  $5\text{ cm}^{-1}$  mode). *DMAP* compensates for non-IMC mode by providing a model that simulates the resulting smear effect during observations under these viewing conditions. Essentially, this model represents each individual TES detector as an elongated detector (rectangular in appearance as opposed to square) in the downtrack direction of the MGS orbital path. This approach assumes the downtrack speed and altitude of MGS are constant for all observations. According to

the ASU TES team, the *vanilla* database stores the ephemeris time of TES observations corresponding to the exact middle of the exposure duration. Under these conditions, TES observations are modeled as an instantaneous FOV (IFOV) at the middle of the exposure duration.

An additional characteristic of the TES instrument is the ability to collect data off-nadir. The TES stepping mirror can be commanded to different angles from nadir along track. Off-nadir TES observations are used to collect mosaics. This technique utilizes the rotational motion of Mars and careful planning of systematic changes in mirror angles to collect off-nadir looking data resulting in a mosaic of TES observations. One side-effect of off-nadir mirror angles is that the TES detector array is also rotated by the same angle. Figure 2 shows the result of a  $10\text{ cm}^{-1}$  mosaic as mapped by the *DMAP* application. Data that is off-nadir is mapped at increasing angles counter-clockwise to the nadir looking data. Note that *DMAP* does not provide a FOV model for  $5\text{ cm}^{-1}$  TES data collected using non-IMC mode.

The ISIS *tesmap* application derives new geometric coordinates for each detector FOV directly from the ephemeris time stored in the *vanilla* database for each observation. As mentioned previously, this time corresponds to the middle of the exposure duration for all TES observations. *tesmap* incorporates the use of the TES IMC-mode detector model from *DMAP* to represent the specifications of each detector in the TES instrument array. *tesmap* maps non-IMC observations by direct computation using SPICE data of the IFOV at the start and the end of the exposure duration for each detector. The start time of the observation is determined by subtracting half the exposure duration from the ephemeris time as stored in (and retrieved from) the *vanilla* database. The end time is half the exposure duration added to the ephemeris time. The smear effect is achieved by combining the detector's endpoint IFOVs and the downtrack motion resulting in the elongated detector footprint FOV. Figure 3 shows the results of *tesmap* for the same data used to create Figures 1 and 2.

*Discussion.* The computation of the *DMAP* detector FOVs differs from that in *tesmap*. *DMAP* generates a single IFOV assuming fixed spacecraft velocity and altitude using SPICE ephemerides to determine viewing conditions at mid-exposure time. *tesmap* relies upon SPICE ephemerides to determine exact spacecraft position and instrument platform pointing at the start and end of every observation for each detector

in the array. The combination of the two endpoint IFOVs for detectors naturally create the smear effect for each observation. Off-nadir observations for both *DMAP* and *tesmap* are handled by rotating the detector footprints by the same angle. However, *DMAP*'s off-nadir representations are an IFOV of a model that simulates detector smear whereas *tesmap* is a combination of actual rotated detector IFOVs at the endpoints of the exposure duration. In summary, the computed footprint in *tesmap* is different than *DMAP* because it is created from endpoint IFOVs using SPICE ephemerides. This takes into account relative spacecraft position, downtrack velocity, and instrument pointing computed at the endpoints of the exposure duration.

*DMAP* and *tesmap* have options for managing overlapping data. Overlapping data occurs because of the organization of the detector array in a 3-by-2 pattern. With this configuration, the downtrack detector row for a given observation will have portions of the same region observed by the uptrack row during the same observation. Both applications have average, minimum, maximum, first and last options to process common areas of overlap. *tesmap* has the additional option that merges (averages) the data from all six detectors and then replicates the average value for each detector.

Inherent in the implementation of *tesmap* is the ability to use different Mars IAU specifications. Geometric data in the TES *vanilla* database were computed using 1994 IAU Mars specifications, whereas the design of *tesmap* allows the users to explicitly select the desired IAU specifications of Mars. Within the ISIS system, it defaults to the most current IAU specification and ensures that products from other missions or instruments processed in ISIS are consistent for direct comparison.

*tesmap* can convert between planetocentric and planetographic latitude representations and variations in longitude systems. Geometric data in the *vanilla* database are stored in planetocentric latitudes and 0 to 360 degree WEST longitudes. Usage of these data in other cartographic representations must work in that environment or explicitly handle the conversion. *tesmap* avoids this because it computes new geometry strictly from the time of the observation using SPICE data contained within the ISIS system.

In summary, *tesmap* most accurately represents the nadir and off-nadir TES footprint because it is based upon IFOVs at the start and end of the exposure

duration computed from SPICE ephemeris. It supports both 5 and 10 cm<sup>-1</sup> TES observation data. It is compatible with ISIS and products derived using the ISIS software system, but is sufficiently flexible to allow the user to modify many aspects of the resulting map projected product to match other non-ISIS image products. For comparison, *lev2raster* provides the flexibility to control the projected resolution of a specific TES observation, and is more suitable for generating image products of large regions.

Future work will provide the ability to map TES data using the MOLA DEM instead of the IAU spheroid description for the Martian surface. Additional refinements to *tesmap* will increase computational efficiency, thereby making *tesmap* more suitable for mapping large regions.

*Availability.* The functionality and usage of the *vanna*, *lev2raster*, and *tesemiss* tools is described more completely in "cookbook" form under "TES Emissivity Data Processing with ISIS" at:  
<http://www.flag.wr.usgs.gov/isis-bin/documentation.cgi>

Use of these TES programs in ISIS requires the *vanilla* software and access to the TES data. *vanilla* can be acquired from any PDS TES cdrom and also from the ASU *vanilla* site below. Although TES data can be acquired by downloading contents of the widely distributed PDS TES cdroms, it is highly recommended that they be downloaded from an online database (see below) and that a structured TES "DATASET" be created according to the instructions found at the TES team site at ASU:

<http://software.la.asu.edu/vanilla/vanilla2.html>

Questions on the use of *vanilla* and the DATASET format can be directed to [vanilla@tes.asu.edu](mailto:vanilla@tes.asu.edu). The TES data and special products are available online at:  
<http://wufs.wustl.edu/missions/mgs/tes/index.html>  
[http://tes.asu.edu/data\\_archive](http://tes.asu.edu/data_archive)

To read more about ISIS and get a copy of the ISIS software, see these Web sites:

<http://www.flag.wr.usgs.gov/isis-bin/isis.cgi>

<http://www.flag.wr.usgs.gov/isis-bin/acquireisis2.cgi>

Questions about ISIS and the use of these programs can be addressed to:

<http://isisdist.wr.usgs.gov/>

**References:** [1] Eliason et al., LPSC XXXVIII, pp. 331-332, 1997. [2] Gaddis et al., LPSC XXVIII, pp. 387-388, 1997. [3] Torson and Becker, LPS XXVIII, pp. 1443-1444, 1997. [4] Eliason et al., LPSC XXXII, abstract 2081, 2001; [5] Gaddis et al., LPSC XXXIV, abstract #1956, 2003. [6] Johnson et al., LPSC XXXIV, abstract #2041, 2003; [7] Christensen et al., *J. Geophys. Res.*, 106, 23823-23871, 2001.

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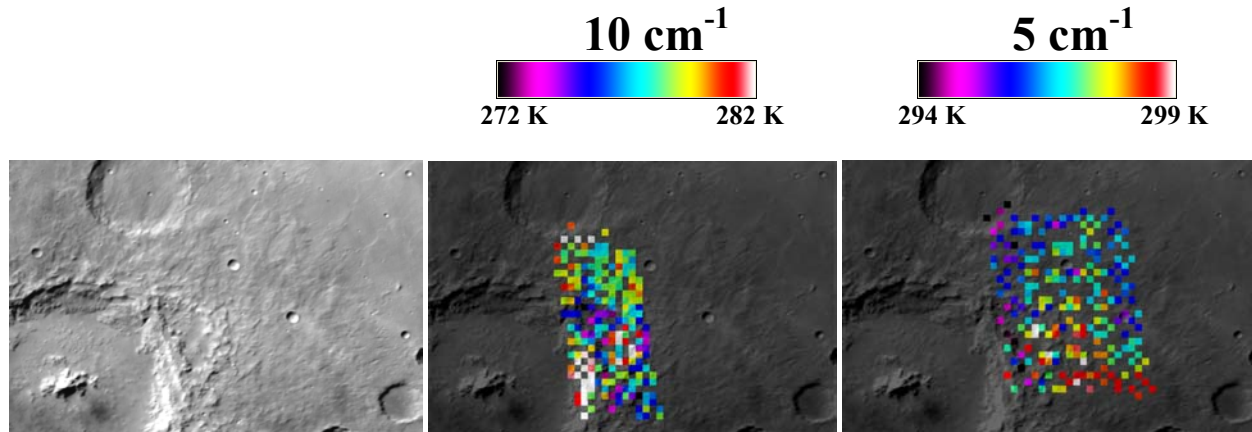


Figure 1. (*left*) Moc WA mosaic centered on  $-24^\circ$ ,  $167.5^\circ\text{E}$ ; (*middle*) *lev2raster* temperature image of  $10\text{ cm}^{-1}$  mosaic (only partial coverage obtained, incidence angle  $48^\circ$ , local time 14:45), (*right*) *lev2raster* temperature image of  $5\text{ cm}^{-1}$  mosaic (full coverage, incidence angle  $25^\circ$ , local time 13:48).

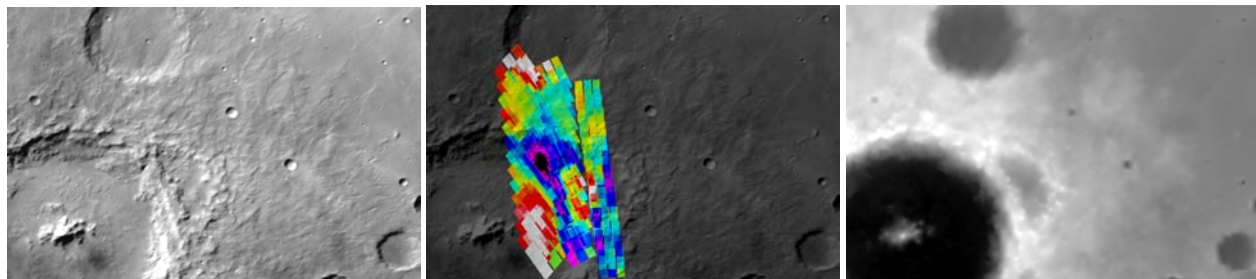


Figure 2. (*left*) Moc WA mosaic centered on  $-24^\circ$ ,  $167.5^\circ\text{E}$ ; (*middle*) *DMAP* temperature image of  $10\text{ cm}^{-1}$  mosaic. An additional manual image shift corresponding to  $0.271^\circ$  longitude is required to align the TES image with the MOC basemap as a result of prime meridian differences; (*right*) *MOLA* image of region.

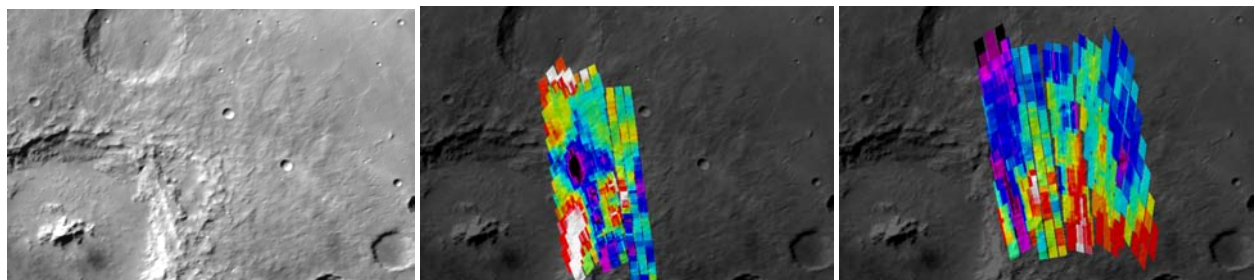


Figure 3. (*left*) Moc WA mosaic centered on  $-24^\circ$ ,  $167.5^\circ\text{E}$ ; (*middle*) *tesmap* temperature image of  $10\text{ cm}^{-1}$  mosaic (*right*) *tesmap* temperature image of  $5\text{ cm}^{-1}$  mosaic (full coverage).