2001 Mars Odyssey
Thermal Emission Imaging System
(THEMIS)

Data Processing User's Guide
Part 1 - Infrared

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1. OVERVIEW

1.1 INSTRUMENT OVERVIEW

The Thermal Emission Imaging System (THEMIS) instrument consists of separate infrared and visible focal plane assemblies that share the telescope through a beamsplitter but have independent power and data interfaces to the spacecraft to provide system redundancy. The instrument was developed by Arizona State University (ASU) with Santa Barbara Remote Sensing (SBRS). The infrared focal plane and electronics were provided by the Santa Barbara Research Center (SBRS). The visible imager focal plane and electronics were provided by Malin Space Science Systems (MSSS). The telescope is a three-mirror anastigmat telescope with a 12-cm effective aperture and a speed of f/1.6. The IR and visible imagers have independent power and data interfaces to the spacecraft . The IR focal plane is an uncooled microbolometer with 320 cross-track pixels and 240 down-track pixels with an instantaneous field of view (IFOV) of 0.25 milli-radians (100 m from 400 km altitude). The focal plane is temperature stabilized to ~0.001 K using a temperature controller driving a thermo-electric heater/cooler. Ten stripe filters are placed over the microbolometer array to produce ten ~1-μm wide spectral bands at nine separate wavelengths centered from 6.8 to 14.9 μm. Two filters (Bands 1 and 2) cover the same spectral region centered at 6.8 μm. The nine THEMIS IR wavelengths include eight surface-sensing wavelengths (Bands 1-9) and one atmospheric wavelength (Band 10). Time delay integration (TDI) of 16 consecutive rows is performed by firmware in the THEMIS IR imager. The THEMIS visible imager contains 1,024 cross-track pixels with an IFOV of 0.045 milli-radians (18 m from 400 km altitude) covering a 18.4 km swath bore-sighted with the IR imager. The visible imager has five stripe filters**,** each covering 192 rows on the detector. These 192-line framelets are collected every 1 second, producing 26 rows of downtrack overlap in successive framelets at an orbital velocity of 3.0 km/sec. An internal calibration flag, the only moving part in the instrument, provides thermal calibration and IR flat-fielding, and is used to protect the detectors from unintentional direct illumination from the Sun. The instrument weighs 11.2 kg, is 29 cm by 37 cm by 55 cm in size, and consumes an orbital-average power of 14 W.

THEMIS images are calibrated in flight using periodic views of the internal calibration flag. The calibration shutter flag is stored against a sidewall that maintains the flag at a known temperature. The flag is closed, imaged, and reopened at selectable intervals throughout each orbit. This process produces gores in the surface observations lasting approximately 50 seconds for each calibration. Calibration data are acquired every ~3-10 minutes as necessary. The optimum spacing of these observations is chosen to meet the calibration accuracy requirements, while minimizing the loss of surface observations.

The THEMIS IR imager internal analog-to-digital converter (ADC) produces a 12-bit signal (DN values of 0-4095). The digital output signal from the ADC is digitally adjusted by gain and offset terms and the result is converted to an 8-bit output value that is returned to Earth. The gain term determines how the dynamic range of the 12-bit signal from the ADC is converted to the 8-bit output. At a gain of 1, the full 4096 DN input range is used and is converted to an 8-bit number by dividing by 16. At a gain of two the input dynamic range is 2048, etc, up to a gain of 16 that uses a dynamic range of 256. Thus, a gain of 1 uses the full input dynamic range, but with a factor of 16 loss in precision; a gain of 16 preserves the full precision from the ADC with a factor of 16 reduction in dynamic range. Gains higher than 16 are not appropriate as they result in a lower input dynamic range than is available in the 8-bit output. The position of the selected dynamic range relative to the full 4096 input values is determined by the offset term. The offset term is measured relative to the mid-point (2048) of the input signal. The input to output conversion is given by:

$$\text{output} = (\text{gain} / 16) * \text{input} - (256 * (\text{offset} + 8))$$

The analog gain of the THEMIS IR imager was adjusted during assembly to provide a 1-sigma variance of approximately 0.5 DN at the maximum useful digital gain of 16.

The data returned from the instrument in flight are converted to scene spectral radiance (W cm^{-2} str^{-1} μm^{-1}) by: (1) adjusting for the gain and offset that were applied in the instrument to optimize the dynamic range and signal resolution for each scene; (2) correcting for any signal drift or offset that occur between observations of the calibration flag; and (3) converting signal to radiance using the measured signal and temperature of the calibration flag, together with the instrument response function determined prior to launch.

1.2 PRE-LAUNCH CALIBRATION OVERVIEW

The calibration, test, and characterization of the THEMIS was performed at SBRS prior to instrument installation on the Mars 2001 Odyssey spacecraft at Lockheed Martin in Denver. The THEMIS calibration was performed by personnel from SBRS and ASU.

The primary objectives of these tests were to determine:

1) the geometric performance of the infrared and visible imagers, including the point-spread function, out-of-field response, camera model, and the focus performance over temperature;

2) the relative spectral response of the infrared and visible imagers; and

3) the radiometric performance of the infrared and visible imagers, including the instrument response function, the absolute radiometric calibration, the radiometric precision (noise equivalent spectral radiance), the performance metrics, and the analysis of systematic errors.

In addition to these calibrations, an extensive set of tests were performed under ambient and vacuum conditions to verify the instrument functional performance, including the command and signal processors, the command and data links, and the calibration flag actuator.

1.3 INFRARED SPATIAL SUMMING OVERVIEW

In Spring 2006, a software patch was loaded into the spacecraft memory to apply spatial summing to IR images before downlink; available summing modes (N) are 2, 4, 8, 16, 32, 80, 160, and 320. The software patch was implemented in such a manner that image collection proceeds as originally designed. Spatial summing is applied just prior to downlink by simple averaging of N x N pixels, and stored with the resultant data value truncated. The only complication is that the first line in a summed image is often calculated from less than N collected lines, due to the complexity of onboard TDI processing; this makes expanding a summed image out to 320 pixels wide a deterministic, but non-trivial process. Raw (EDR) and calibrated (RDR) standard IR image products will be provided in the summed format (i.e. image width = 320/N pixels), while all brightness temperature (BTR) image products will be provided in the expanded format (320 pixels wide).

2. INFRARED IMAGER CALIBRATION

2.1 INFRARED IMAGER CALIBRATION OVERVIEW

The THEMIS infrared imager is calibrated in flight using periodic observations of an internal calibration flag mounted in the THEMIS optical path immediately in front of the IR/visible beamsplitter. Observations of this flag are used to automatically flat field the IR detectors prior to data acquisition, and to radiometrically calibrate the THEMIS data at the end of each data acquisition.

Figure 2-1 shows the Mars data calibration flow for the IR imager. The basic process steps are outlined below; the details of the measurements and/or processes are discussed in subsequent sections.

1) Acquire raw Mars image and flag-closing image.

2) Adjust Mars and flag-closing images for applied gain and offset – convert to signal level (Gain=1; offset=0).
   Integer values of gain and offset (DN at a gain of 1) are available. In flight only gains of 1, 2, 4, 8, or 16 will be used. The DN offset will be adjusted to prevent saturation at either the high or low end depending on scene temperature.

3) Remove image offset due to focal plane thermal equilibration using the measured calibration flag signal at end of image sequence.

   The instrument firmware automatically sets the signal level when viewing the internal calibration flag to 128 DN for a gain of 1, offset of 0. During observations of external targets the THEMIS focal plane and internal temperatures drift slightly as these components attempt to equilibrate with the radiance of the observed scene (**Figure 2-2**). In flight this image offset component is removed by observing the calibration flag at the end of each observing sequence and finding the maximum or minimum calibration flag signal value as appropriate.

4) Compute the delta signal (scene minus calibration flag)

5) Correct for residual image signal drift.

The time constant of the thermal equilibration is approximately 30 seconds under typical observing conditions. Thus, the majority of the signal drift occurs within the first two minutes after the calibration flag is opened, and the effect of signal drift is minimized by waiting two minutes following a calibration before acquiring Mars images. Any minor signal drift that occurs during the image sequence can removed if necessary.

6) Compute the delta spectral radiance using the instrument response function.

7) Compute the calibration flag spectral radiance using the measured calibration flag temperature, the calibration flag emissivity, and the spectral-radiance-versus-temperature function determined pre-launch.

8) Compute the initial scene spectral radiance using the calibration flag spectral radiance and the delta spectral radiance.

9) Remove systematic noise.

a) Remove column- and row-correlated systematic noise.

Column-correlated noise occurs due to minor time-variable changes in detector response relative to the pre-launch response function. Row-correlated noise occurs due to minor fluctuations in the detector read-out bias voltage.

b) Remove time-domain signal variations.

Minor (~0.001 °C) fluctuations in the focal-plane temperature over in time scales of ~10-60 seconds produce minor (~1 DN; gain – 16) signal variations in the time domain. These signal variations are constant across a row in each band and are correlated in time between bands. Because each band is viewing a different point on Mars at a given time, these correlations in time are offset in space.

10) Remove optical stray light. The calibrated spectral radiance produced from this step is archived in the THEMIS IR Reduced Data Record (RDR).

11) Compute brightness temperature in Band 9 and archive in the THEMIS IR Brightness Temperature Record (BTR).

2.2 INFRARED IMAGER CALIBRATION ALGORITHM

2.2.1 Acquire raw image.

THEMIS IR images are acquired using a single global gain and offset that applies to all bands over the entire image. A calibration reset is performed prior to Mars data acquisition. The calibration reset consists of closing the calibration flag, observing the flag, and setting the DN of each pixel to 128 at a gain of 1, offset of 0 (**Figure 2-2**). This reset produces a uniform flat field for all detectors. The THEMIS flight software requires that an image be acquired when a calibration reset is performed. This image is referred to as the Reset Image. Closing the calibration flag introduces a thermal perturbation to the focal plane assembly, and it is observed at SBRS and in flight that the instrument experiences a temperature reequilibration following this perturbation (**Figure 2-2**; see the THEMIS Calibration Report for details). The thermal reequilibration after the calibration flag is opened produces a drift in the output signal that stabilizes with a time constant of approximately 30 seconds.

The Reset Image occurs during the period of highest signal drift and is the least well calibrated. It is typically limited to the minimum length possible (256 lines; 1 band), except for images acquired specifically to monitor and assess the degree of signal drift following a calibration reset. Typically, Mars imaging does not begin within 2 minutes of the Reset Image to allow the signal drift to stabilize; however, if the Reset Image is embedded into a full length surface image, the data collected within the first few seconds (lines 1-512, all bands) is set to null following calibration.

2.2.2 Adjust Mars and flag-closing images for applied gain and offset

All THEMIS IR image data are converted to a floating point "signal" value, corresponding to a gain of 1, offset of 0 prior to radiance calibration.

2.2.3 Remove image offset due to focal plane thermal equilibration

A flag-closing image is acquired at the end of each THEMIS IR observing sequence. The davinci function "get_flag_dn" (author: P. Christensen) finds the DN value in this image that best corresponds to the flag DN in each band. All 320 columns are averaged to improve the signal-to-noise for this determination. The average of Band 3 lines 1 through 5 and 20 through 25 in flag-closing image are compared to determine if the scene was warmer than the flag (flag-closing DN decreasing with time) or colder (flag-closing DN increasing with time). If scene was warmer, the algorithm finds the minimum in the flag-closing image. If scene was colder, the algorithm uses the maximum in the flag-closing image. The function returns the calibration flag signal value (Gain = 1; offset = 0).

The maximum (or minimum) flag-closing DN cannot be observed in Bands 6-10 because of the time delay built into the THEMS firmware to account for the fact that each successive band observes the same point on Mars at a later time. The firmware acts to align the images from each band in space, resulting in an offset in time. As a result, the flag has closed and the signal has begun to reequilibrate before data from Bands 6-10 are collected.

flag_option 1. This option returns the measured maximum (or minimum) DN values for Bands 1-5. The average DN of Bands 1-5 is used for the flag DN for Bands 6-10.

flag_option 2: Same as option 1 for Bands 1-5. The flag DN for Bands 6-10 is calculated using the DN offset between Band 5 and Bands 6-10 for the lines in Bands 6-10 that correspond to the identical time in Band 5. The DN offsets at this time are added to the flag DN for Band 5 to determine the flag DN in Bands 6-10. This option also filters the flag-closing image (flag_filter_option = 1; filter size = 3) in time before finding maximum (or minimum) value.

The "flag_option" and "flag_filter_option" used in each version of the calibration are given in Section 2.3.

2.2.4 Compute the delta signal (scene minus calibration flag)

The delta signal is computed by subtracting the calibration flag signal value from the Mars image signal for each band.

2.2.5 Correct for residual image signal drift

The davinci function "drift" (author: P. Christensen) removes residual signal image drift. This function includes a "no drift" option in which no correction is applied. The "no-drift" option is the default.

2.2.6 Compute the delta spectral radiance using the instrument response function

The pre-launch instrument response function is used to convert delta signal to delta spectral radiance. The SBRS pre-launch data were processed using the davinci function "make_response" (author: P. Christensen) and fit using a linear least-squares fit using davinci function "fit_response_full" (author: P. Christensen). The slope and offset terms for this linear fit are computed and stored for each of the 320 cross-track "pixels" in each band. These pixels correspond to the average of the 16 downtrack pixels that are merged using time-delay-integration (TDI) in the THEMIS firmware. When TDI is not used, the signals from a single row in each filter are used. A separate response function was not determined for these rows; if TDI is not used at Mars, the TDI-averaged response function will still be used and the resulting calculated radiance will be slightly (< 5%) in error.

The versions of "make_response" and the versions of the instrument response data files derived from "make_response" are described in Section 2.3. The versions of the davinci function "fit_response_full" and the versions of the instrument response function coefficient files derived from "fit_response_full" are described in Section 2.3. Section 2.3 also lists the instrument response function used in each version of the instrument calibration.

2.2.7 Compute the calibration flag spectral radiance.

The calibration flag spectral radiance is computed using the derived temperature of the flag and the radiance-to-temperature look-up table calculated from the relative spectral response of each THEMIS band. The temperature of the flag is determined from the average of the two values of the "flag_temp" telemetry point returned at the beginning of the flag-closing image. If this telemetry point is not available, then the values from the end of the flag-closing image are used. If these values are also not available, then the calibration_quality_flag (TBD) for all images that use this flag-closing image are set to "TBD (not available)".

The radiance-to-temperature look-up table is computed using davinci function "make_temp_rad" (author: P. Christensen). The versions of the file produced by "make_temp_rad" and the file used in each version of the calibration are given in Section 2.3.

2.2.8 Compute the initial spectral radiance using the calibration flag spectral radiance and the delta spectral radiance.

The calibrated spectral radiance for each pixel in the image is computed by adding the calibration flag spectral radiance to the delta spectral radiance.

2.2.9 Remove systematic noise

a) Remove column- and row-correlated systematic noise.

The davinci function "destripe" (author: P. Christensen) is used to remove column- and row-correlated noise. Column-correlated noise is due to minor variations in the instrument response in one or more of the detectors that are combined in each pixel by time-delay-integration. If these variations are constant throughout an image, then an entire column has a slightly high or low signal relative to the neighboring columns along the entire length of the image. This correlation along the image is used to remove this noise effect. This effect produces column-to-column variations of up to approximately 0.25 DN at a gain of 16.

Row-correlated noise is produced by fluctuations in the detector read-out bias voltage on time scales that are short compared with the read-out time for a row in the focal plane array, but long compared with the time between reading out a given row in the following frame (30 Hz). Thus, all pixels in a row have a similar bias, but the following row can have a slightly different bias. This variation produces average line-to-line variations of up to ~ 0.5 DN at a gain of 16.

Row-correlated noise is removed by first transposing the image in x and y, and then applying the identical algorithm described below. The resulting image and the computed difference vectors are transposed back within the "destripe" algorithm.

The first step in the algorithm takes the image average in the y direction for each band. The resulting average line vector is filtered using a unity weight filter of user-specified length (parameters "destripe_filter_x; destripe_filter_y"). The default filter size is 9 samples in both x and y. The average vector and filtered average vector are differenced to create a difference vector.

Option 1: Subtract the difference vector from each line in the image to create a new calibratrated radiance with noise removed. The line and column difference vectors (diff_line; diff_column) are returned from the "destripe" function and stored in the image history structure.

Option 2: Same as Option 1 except the values of the difference vector less than a threshold value (parameter thresh_size) are set to 0. prior to subtracting the difference vector from image.

Option 3: Same as Option 1 except: Where the value of the difference vector is greater than a threshold value (thresh_size), the value of the average vector at this location is set to the average of nearest neighbors that are not themselves above the threshold values. This modified average vector is then filtered with a unity-weight filter of size "destripe_filter_x or destripe_filter_y". The difference between the original average vector and the filtered modified average vector is used to create a new difference vector (diff_line; diff_column) that is subtracted from each line or column in the image. The effect of removing the "spikes" before filtering is to reduce the erroneous propagation of these spikes into neighboring values when the filtering is applied.

The "destripe" parameters (destripe_option_x; destripe_option_y; destripe_filter_x; destripe_filter_y) used in each version of the calibration are given in Section 2.3.

b) Remove focal-plane-correlated signal oscillations.

The process to correct this noise is non-reversible and will only be applied to higher level products.

2.2.10 Remove optical stray light.

The THEMIS beamsplitter bracket has a surface that is out of the image ray bundle, but can produce a reflection of stray light that can reach the focal plane in IR

Bands 3 through 8 and produce a “ghost” image. This ghost image is defocused slightly due to its longer path length through the optics, and moves through the focal plane in the opposite direction as the primary image. This opposite motion acts to blur the image in the downtrack direction when TDI is applied. The ghost image is removed in the standard processing in a three-step process using davinci function “fix_ghost” (author P. Christensen). The first step is to compute the ghost image. This is done by convolving the primary image with a two-dimensional, unity-weight “defocus_filter” that simulates the defocus blur of the ghost image, and a one-dimensional, variable-weight along-track “tdi_smear_filter” that simulates the blurring effect of TDI (davinci function “convolve_ghost”; author P. Christensen). This function has two parameters; “defocus_filter” that sets the size of the defocus filter, and “tdi_smear_filter” that sets the size and characteristics of the TDI smear filter. The second step is to offset the ghost image to simulate the downtrack optical offset and the resulting crosstrack motion due to planetary rotation (davinci function “geom._ghost”; authors N. Gorelick and M. Weiss-Malik). This function has a single parameter “yoffset” that determines the offset of the ghost image in each band in the time dimension. The third step is to subtract the compute ghost image from the radiance image (davinci function “subtract_ghost2”; author P. Christensen). This function uses removes the appropriate amount (“percent”) of the primary image that makes up the ghost image. This value is related to the reflectivity of the beamsplitter bracket surface in each band. The computed ghost image is further offset in the cross-track direction by “xdelta” to account for the fact that the beamsplitter bracket is not exactly aligned with the focal plane. The values of “defocus_filter”, tdi_smear_filter”, “yoffset”, “percent”, and “xdelta” used in the calibration are given in Section 2.3.

Because the stray light correction relies on a complicated model assuming non-summed image dimensions, summed images are expanded (davinci function “expand_ir”, author K. Murray) to the nominal 320 pixels wide before the “fix_ghost” function is applied. The expansion is reversed (davinci function “degrade_ir”, author K. Murray) after the “geom._ghost” function is complete. The final product is calibrated spectral radiance, the IR-RDR standard product, which has the width dimension of (320/summing_mode) pixels.

2.2.11 Compute Brightness Temperature.

The brightness temperature is computed from the calibrated spectral radiance for Band 9 assuming a surface emissivity of 1.0 and an atmospheric opacity of 0.0. Several steps are required to generate the brightness temperature product (BTR). First, if spatial summing was applied during data collection, the image is expanded out to the equivalent non-summed dimensions. The final BTR will maintain these nominal dimensions (320 pixels wide) and differ in size compared with the original calibrated radiance product (RDR). Next, a “signal drift correction” is applied to the calibrated spectral radiance of all images. This correction (davinici function “uddw”; author J. Bandfield) removes data value fluctuations caused by the oscillations in the temperature of the IR detector array. Then, the brightness temperature is determined using the radiance-to-temperature look-up table with davinci function “make_temp_rad” (author: P. Christensen). The versions of the translation table produced by "make_temp_rad" and the table used in each version of the calibration are given in Section 2.3. Finally, the data is prepared for storage in the PDS Image file format using the davinci function "rad2tbimage" (author: P. Christensen) which truncates the highest and lowest ends of the image histogram (assumed to be noise) and translates the floating point temperature values to scaled integers. The linear offset and scaling factor values are retained in the data labels to allow the translation to be reversed.

2.3 IR CALIBRATION ALGORITHM AND PARAMETER HISTORY

Version **ir_image_cal_qube**	**Date**	**Description** **bold = change from previous version**
ir_image_cal_qube_v5.2	04/01/16	All set parameters and calibration functions are same as previous version; **rounding to nearest integer before storing scaled calibrated radiance in PDS Spectral Qube**
ir_image_cal_qube_v5.1	11/01/07	All set parameters are same as previous version **Spatially summed images are expanded and degraded using the same logic as the onboard summation algorithm**
ir_image_cal_qube_v5.0	6/01/06	**Set lines 1:512 to null if image contains embedded Reset Image** **Modifications to calibrate spatially summed images: expand & degrade image data, resample IRF, destripe applied only to summing modes 1, 2, & 4** geom_ghost inst. response = irf_fit_all_v3.0_tv6_1_2_3.0 temp_rad = temp_rad_v4 calib. script = cal_image_v1 flag_option = 2 flag_filtter_option = 1 destripe_option_x = 3 destripe_option_y = 3 **filt_size_x = 9 (adjusted by summing)** **filt_size_y = 9 (adjusted by summing)** drift_option = 0 radiance_offset = radiance_offset_v1 defocus_option = 13 tdi_smear_option = 1 yoffset = 0, 0, 349, 299, 249, 202, 152, 103, 0, 0, xdel_option = 8 ydel = 0. percent_option = 5
ir_image_cal_qube_v4.9	12/01/05	All set parameters are same as previous version **Destripe modified to handle data dropouts**

ir_image_cal_qube_v4.8	9/22/05	**geom_ghost** inst. response = irf_fit_all_v3.0_tv6_1_2_3.0 temp_rad = temp_rad_v4 calib. script = cal_image_v1 flag_option = 2 flag_filtter_option = 1 destripe_option_x = 3 destripe_option_y = 3 filt_size_x = 9 filt_size_y = 9 drift_option = 0 radiance_offset = radiance_offset_v1 defocus_option = 13 tdi_smear_option = 1 yoffset = 0, 0, 349, 299, 249, 202, 152, 103, 0, 0, xdel_option = 8 ydel = 0. percent_option = 5
ir_image_cal_qube_v4.7	----	(never used for processing)
ir_image_cal_qube_v4.6	9/6/02	inst. response = irf_fit_all_v3.0_tv6_1_2_3.0 temp_rad = temp_rad_v4 calib. script = cal_image_v1 flag_option = 2 flag_filtter_option = 1 destripe_option_x = 3 destripe_option_y = 3 filt_size_x = 9 filt_size_y = 9 drift_option = 0 radiance_offset = radiance_offset_v1 **defocus_option = 13** **tdi_smear_option = 1** **yoffset = 0, 0, 349, 299, 249, 202, 152, 103, 0, 0,** **xdel_option = 8** **ydel = 0.** **percent_option = 5**

ir_image_cal_qube_v4.5	6/27/02	inst. response = irf_fit_all_v3.0_tv6_1_2_3.0 temp_rad = temp_rad_v4 calib. script = cal_image_v1 flag_option = 2 flag_filtter_option = 1 destripe_option_x = 3 destripe_option_y = 3 filt_size_x = 9 filt_size_y = 9 drift_option = 0 **radiance_offset = radiance_offset_v1**
ir_image_cal_qube_v4.4	5/25/02	inst. response = irf_fit_all_v3.0_tv6_1_2_3.0 temp_rad = temp_rad_v4 calib. script = cal_image_v1 flag_option = 2 flag_filtter_option = 1 **destripe_option_x = 3** **destripe_option_y = 3** filt_size_x = 9 filt_size_y = 9 drift_option = 0 deghost_option = 0
ir_image_cal_qube_v4.3	5/21/02	**inst. response = irf_fit_all_v3.0_tv6_1_2_3.0** temp_rad = temp_rad_v4 calib. script = cal_image_v1 flag_option = 2 flag_filtter_option = 1 destripe_option_x = 1 destripe_option_y = 1 filt_size_x = 9 filt_size_y = 9 drift_option = 0 deghost_option = 0

ir_image_cal_qube_v4.2	5/20/02	**inst. response = irf_fit_all_v2.0_tv6_1_2_3.0** temp_rad = temp_rad_v4 calib. script = cal_image_v1 flag_option = 2 flag_filtter_option = 1 destripe_option_x = 1 destripe_option_y = 1 filt_size_x = 9 filt_size_y = 9 drift_option = 0 deghost_option = 0
ir_image_cal_qube_v4.1	5/19/02	inst. response = irf_fit_all_v2.0_tv6_1_1_3.0 temp_rad = temp_rad_v4 calib. script = cal_image_v1 **flag_option = 2** **flag_filtter_option = 1** **destripe_option_x = 1** **destripe_option_y = 1** **filt_size_x = 9** **filt_size_y = 9** drift_option = 0
ir_image_cal_qube_v3	5/18/02	Same as unversioned ir_image_cal_qube. Gave identical results as unversioned version. inst. response = irf_fit_all_v2.0_tv6_1_1_3.0 temp_rad = temp_rad_v4 cal_image_v1 flag_option = 1 flag_filtter_option = 0 destripe_option_x = 0 destripe_option_y = 0 drift_option = 0
ir_image_cal_qube	2/02	Used from start of mapping to ~5/18/02 when version '_v3' was implemented

bold = change from previous version

Script	Version	Date	Description
cal_image	cal_image_v1	5/17/02	Identical to unversioned version
	cal_image	10/2/01	Used from start of mapping to _ when '_v1' was implemented
get_flag_dn		5/15/02	Flag_option 2: Same as option 1 for Bands 1-5. The flag DN for Bands 6-10 is calculated using the DN offset between Band 5 and Bands 6-10 determined using the lines in Bands 6-10 that correspond to the identical time in Band 5. The DN offsets at this time are added to the flag DN for Band 5 to determine the flag DN in Bands 6-10. This option also filters the flag-closing image (flag_filter_option = 1; filter size = 3) in time before finding maximum (or minimum)..
		6/00	Flag_0ption 1: Use two early points in flag-closing image to determine if scene was warmer or colder than flag. If scene was warmer, find minimum in flag-closing image. If scene was colder, find maximum in flag-closing image. The maximum (or minimum) DN cannot be observed in Bands 6-10 because of the time delay built into the THEMS firmware to account for the fact that each successive band observes the same point on Mars at a later time. The firmware acts to align the images from each band in space, resulting in an offset in time. As a result, the flag has closed and the signal has begun to reequilibrate before data from Bands 6-10 are collected. Flag_option 1 returns the measured maximum (or minimum) DN values for Bands 1-5. The average DN of Bands 1-5 is used to approximate the flag DN for Bands 6-10. Flag_filter_option = 1 Filter flag-closing image by 3 samples in time prior to determining flag DN.

destripe		5/25/02	Option 3: Same as Option 1 except: Set difference vector values greater than threshold value (thresh_size) to average of nearest neighbors that are not themselves above the threshold values. Filter this modified vector with boxcar filter of size "destripe_filter_x; destripe_filter_y". Take difference between modified vector and filtered modified vector to create a difference vector (diff_line; diff_column). Subtract this difference vector from each line or (column) in image. The effect of removing the "spikes" before filtering is to reduce the erroneous propagation of the spikes into neighboring values when the filtering is applied. Create and remove row vector (column noise) first, then create and remove column vector (row noise). Row and column vectors corresponding to the noise removed are stored in RDR header and can be reapplied (column vector first, then row vector).
		11/8/01	Option 2: Same as Option 1 except: Set difference vector values less than threshold value (thresh_size) to 0., then difference from image.
		11/8/01	Option 1: Take average in direction 1 (x or y) to create a vector in direction 2 (y or x). Filter this vector with boxcar filter of size "filter_size". Take difference between vector and filtered vector to create a difference vector (diff_used). Subtract this difference vector from each line or (column) in image.
make_response	3.0	3/29/02	used temp_rad_v4 (spectral radiance)
	2.0	1/4/02	used temp_rad_v2 (integrated radiance)
	1.1	11/12/01	used temp_rad_v1.1 (0.5 C intervals; integrated radiance)
	1.0	7/00	used temp_rad_1 (0.1 C intervals; integrated radiance)

fit_response_full	3.0	5/21/02	Exclude 2 bad calibration test sets (Tinst=0 C, Target = 170 K; and Tinst = 35 C, Target = 307 K)
	2.1	4/26/02	Instrument temp groups 1-4 (-30, -15, 0, 15 C)
	2.2	4/26/02	Instrument temp groups 2-4 (-15, 0, 15 C)
	2.3	4/26/02	Instrument temp group 3 (0 C)
	2.4	4/26/02	Instrument temp groups 2-3 (-15, 0 C)
	2.0	3/29/02	Changed to use spectral radiance; all 5 instrument temperature groups (-30, -15, 0, 15, 30 C)
	1.0	1/29/00	Integrated radiance – early version

File	Version	Date	Description
temp_rad			(file generated by make_temp_rad)
	temp_rad_v4	**3/29/02**	**Changed to use spectral radiance**
	temp_rad_v3	3/14/02	Changed temperature range to 100-380 C (from 120-360 C)
	temp_rad_v2	1/4/02	Used better relative spectral response – filter* window* beamsplitter
	temp_rad_v1.1	1/12/01	Temperature interval changed to 0.5 C
	temp_rad_1	10/3/01	Temperature interval of 0.1 C
tv			
	tv_6_1_2_v3.0	**5/20/02**	**from make_response v3.0 cycle = 6; mirror_flag = 1; dn_flag = 2 (new get_flag_dn method; filter by 3); spectral radiance**
	tv_636_1_1_v3.0	5/16/02	from make_reponse v3.0; cycle = 636; used image 36 (gain =4; offset=0); mirror_flag = 1; dn_flag = 1; spectral radiance. (test case – did not make significant improvement)
	tv_6_1_1_v3.0	3/29/02	from make_response v3.0 cycle = 6; mirror_flag = 1; dn_flag = 1; spectral radiance
	tv_6_1_1_v2.0	2/14/02	from make_response v2.0 cycle = 6; mirror_flag = 1; dn_flag = 1
	tv_6_1_1_v1.1	11/12/01	from make_response v1.1 cycle = 6; mirror_flag = 1; dn_flag = 1
	tv_6_1_1_v1.0	??	from make_response v1.0; cycle = 6; mirror_flag = 1; dn_flag = 1
irf_fit_all			
	irf_fit_all_v3.0_tv6_1_2_3.0	**5/21/02**	**fit of tv6_1_2_3.0 using fit_response_full v3.0 (new get_flag_dn; exclude 2 bad test sets in fit)**
	irf_fit_all_v2.0_tv6_1_2_3.0	5/20/02	fit of tv6_1_2_3.0 using fit_response_full v2.0 (new get_flag_dn; all 35 test sets)
	irf_fit_all_v2.0_tv636_1_1_3.0	5/16/02	fit of tv636_1_1_3.0 using fit_response_full v2.0

irf_fit_all_v2.1_tv6_1_1_3.0	4/26/02	fit of tv6_1_1_3.0 using fit_response_full v2.1
irf_fit_all_v2.2_tv6_1_1_3.0	4/26/02	fit of tv6_1_1_3.0 using fit_response_full v2.2
irf_fit_all_v2.3_tv6_1_1_3.0	4/26/02	fit of tv6_1_1_3.0 using fit_response_full v2.3
irf_fit_all_v2.4_tv6_1_1_3.0	4/26/02	fit of tv6_1_1_3.0 using fit_response_full v2.4
irf_fit_all_v2.0_tv6_1_1_3.0	3/29/02	fit of tv6_1_1_3.0 using fit_response_full v2.0
irf_fit_all_v_1.0_tv6_1_1_2.0	2/18/02	fit of tv6_1_1_2.0 using fit_response_full v1.0

radiance_offset

radiance_offset_v1	**6/27/02**	**3.09400e-7; 6.81523e-7; 9.26852e-6; 1.54012e-5; 1.42841e-5; 1.25434e-5; 1.19725e-5; 5.46783e-6; -1.98854e-6; -4.36478e-6 W cm-2 str-1 μm-1.**

defocus_option

13	**9/6/02**	**defocus_filter = ((29, 25, 19, 15, 9, 5) x 3) for bands 3 through 8**

tdi_smear_option

1	**9/6/02**	**tdi_smear_filter = ((1,0,1,0,1,0,1,0,1,0, 1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0) x 3) filter**

xdel_option

8	**9/6/02**	**xdelta = (0, 0, 3, 3, 3, 3, 1, 1, 0, 0) pixel offset for bands 1 through 10**

percent_option

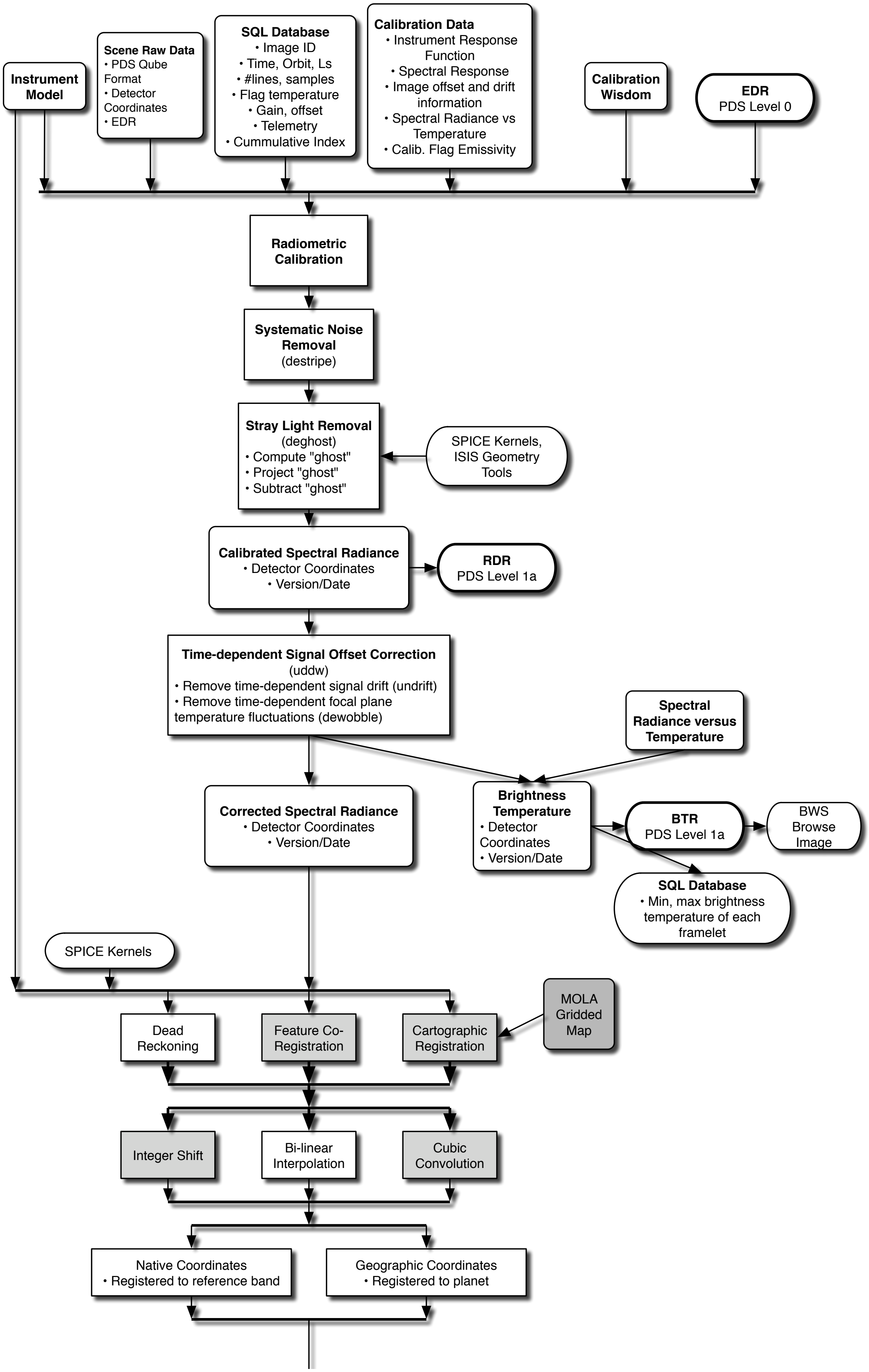
5	**9/6/02**	**percent = (0., 0., 2.0, 4.5, 6.0, 5.5, 5.0, 5.0., 0., 0.) for bands 1 through 10**

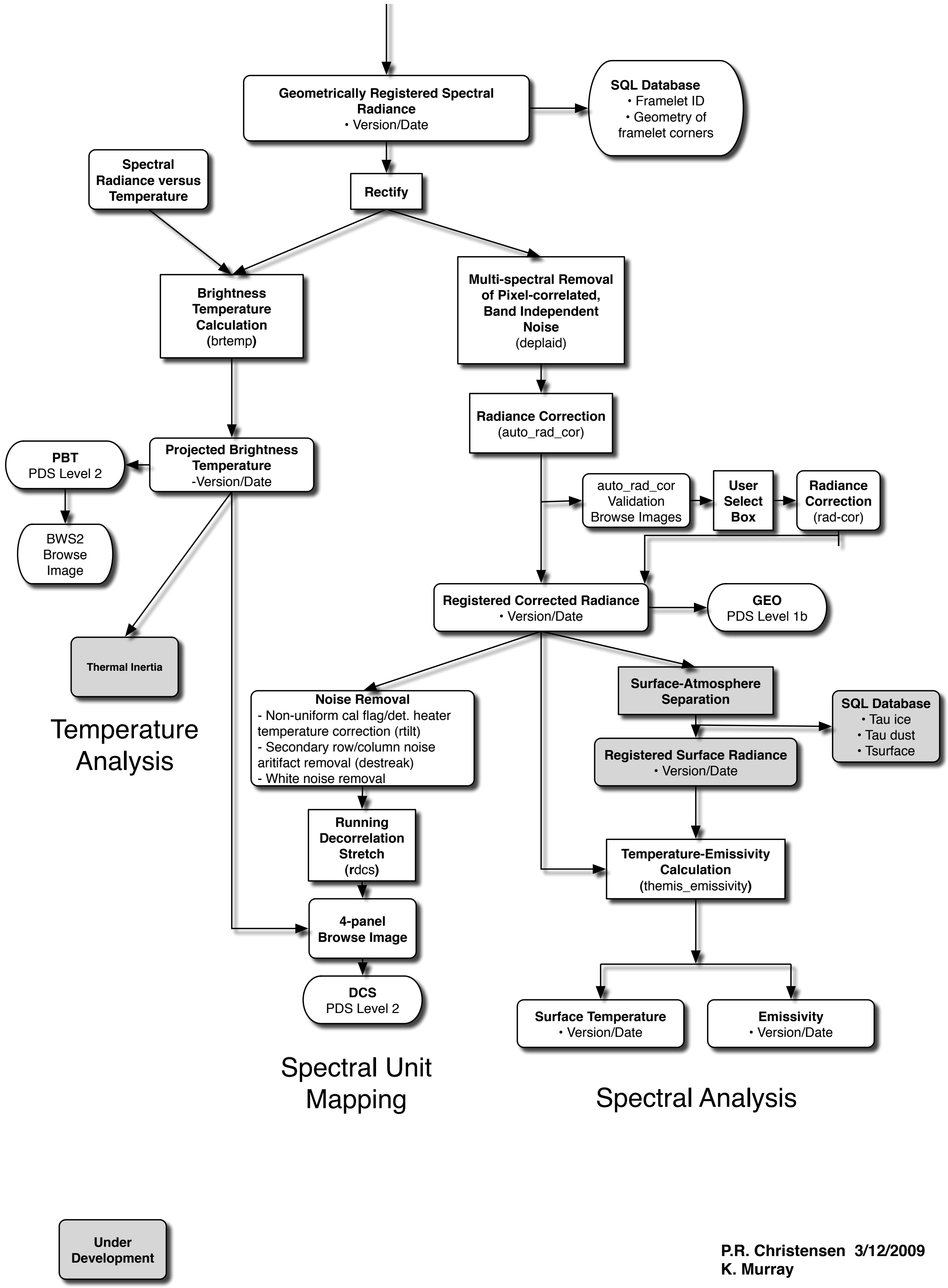
bold = currently used in standard calibration

3. VISIBLE IMAGER CALIBRATION

This section is available in Part 2 of this document.

THEMIS Data Processing Flow





Geometrically Registered Spectral Radiance
• Version/Date
SQL Database
• Framelet ID
• Geometry of framelet corners
Spectral Radiance versus Temperature
Rectify
Brightness Temperature Calculation (brtemp)
Multi-spectral Removal of Pixel-correlated, Band Independent Noise (deplaid)
Radiance Correction (auto_rad_cor)
PBT PDS Level 2
Projected Brightness Temperature -Version/Date
BWS2 Browse Image
auto_rad_cor Validation Browse Images
User Select Box
Radiance Correction (rad-cor)
Registered Corrected Radiance
• Version/Date
GEO PDS Level 1b
Thermal Inertia
Noise Removal
- Non-uniform cal flag/det. heater temperature correction (rtilt)
- Secondary row/column noise aritifact removal (destreak)
- White noise removal
Surface-Atmosphere Separation
SQL Database
• Tau ice
• Tau dust
• Tsurface
Registered Surface Radiance
• Version/Date
Temperature Analysis
Running Decorrelation Stretch (rdcs)
Temperature-Emissivity Calculation (themis_emissivity)
4-panel Browse Image
DCS PDS Level 2
Surface Temperature
• Version/Date
Emissivity
• Version/Date
Spectral Unit Mapping
Spectral Analysis
Under Development
P.R. Christensen 3/12/2009
K. Murray

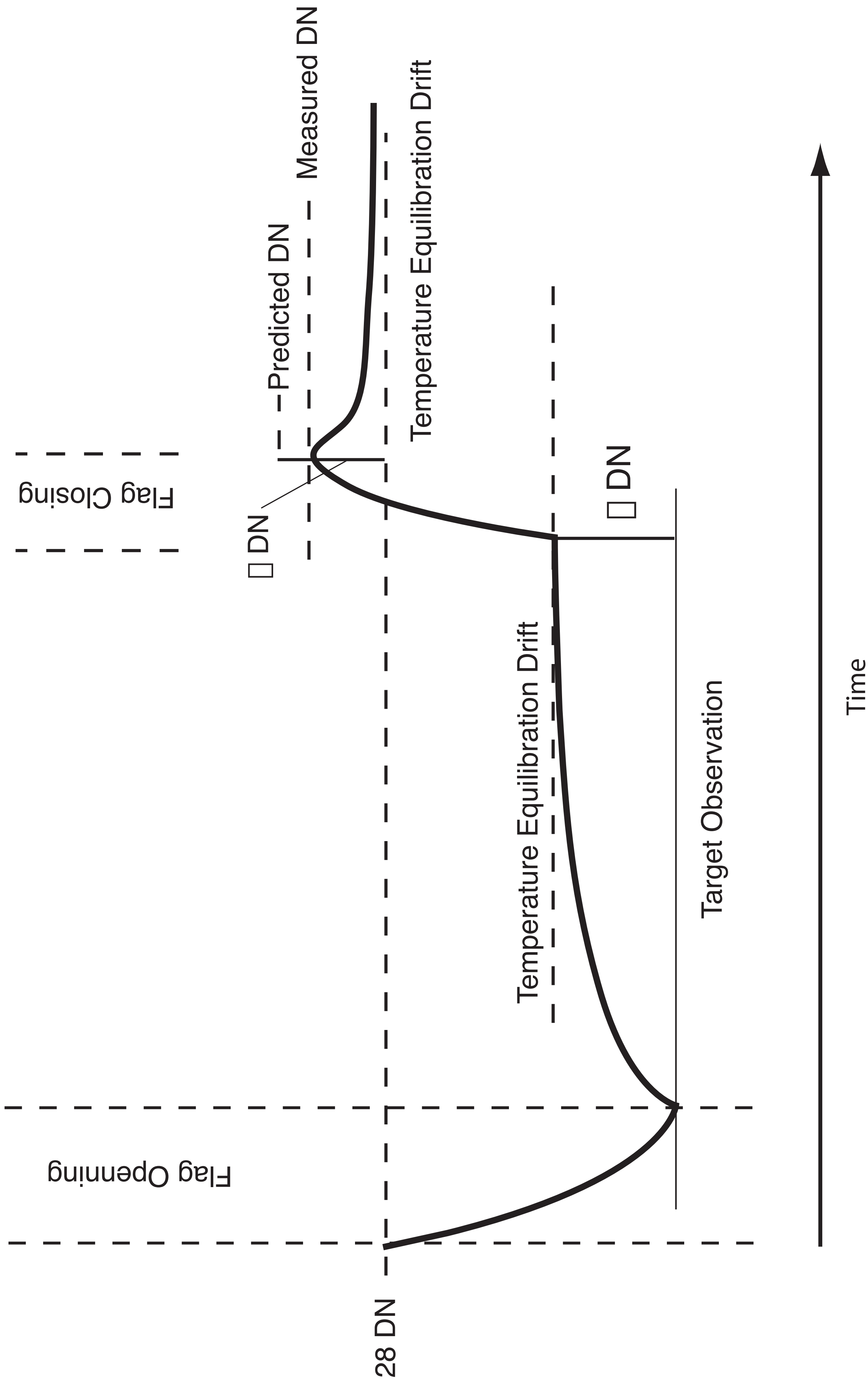

Measured DN
Predicted DN
Temperature Equilibration Drift
Flag Closing
□ DN
□ DN
Temperature Equilibration Drift
Target Observation
Time
Flag Openning
128 DN

Figure 2-2