**THEMIS Calibration Algorithm Document**

**Introduction**

This document contains brief descriptions of the calibration software used for THEMIS data. For each THEMIS data type, the name of the SPEDAS IDL program used for calibration is given, with links to the documentation header, and also links to other calibration information. The procedures described here are not typically called by the user, and are instead called when loading Level 1 data for the given instrument.

If calibration files are used in processing, their location in the local database is specified. Note that all calibration processing will auto-download any necessary files, including the raw data, calibration data, and other ancillary data, such as spacecraft position and attitude, or magnetic field data.

Each calibration routine has a number of different keyword options that can be specified. All options are not discussed here; only the default calibrations are described, with a few exceptions. An interested user can check out the documentation headers, or the source code, for details. Links are provided to online documentation or source code for the programs used in data processing, in addition to any other applicable documents. Variables discussed in the text are TPLOT variables. For more information regarding the SPEDAS software package used for THEMIS data load and calibration, please see <http://themis.ssl.berkeley.edu/software.shtml> .

**Spacecraft**

**Fields**

**EFI**

**EFI** data files contain Electric Field Instrument (EFI) Electric field measurements.

PROCEDURE NAME:

THM\_CAL\_EFI

LINKS:

Instrument information: [http://themis.ssl.berkeley.edu/instrument\_efi.shtml](about:blank)

Cal procedure:

[http://themis.ssl.berkeley.edu/socware/spedas\_5\_0/idl/projects/themis/spacecraft/fields\_spd\_doc\_list.html#THM\_CAL\_EFI[3](about:blank)]

Other programs used:

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spacecraft/fields_spd_doc_list.html#THM_EFI_DESPIN>

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/state/cotrans_spd_doc_list.html#THM_COTRANS>

Other applicable documents:

[http://themis.ssl.berkeley.edu/themisftp/3%20Ground%20Systems/3.2%20Science%20Operations/Science%20Operations%20Documents/thm\_soc\_130\_efi\_calibration.pdf](about:blank)

CALIBRATION FILES:

The EFI calibration file for each probe is located in $ROOT\_DATA\_DIR/th(probe)/l1/eff/0000, where ROOT\_DATA\_DIR is the default data directory for THEMIS data. (See ROOT\_DATA\_DIR.pro, <http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/general/misc_spd_doc_list.html#ROOT_DATA_DIR> .)

PROCESS DESCRIPTION:

Inputs: From Level 1 files,

1) Voltages: vaf, vbf, vap, vbp, vaw, vbw and fields: eff, efp and efw. Level 1 voltages have 6 components, one per boom, v1 to v6. Level 1 fields have 6 components, eac12, eac34, eac56, edc12, edc34, edc56, for the three different boom pairs, for AC and DC coupling.

(For probe data the last letter in a variable datatype is an indication of the observing mode, ‘f’ for fast survey or full mode, ‘p’ for particle burst mode, and ‘w’ for wave burst mode. For variable name information, see <http://themis.ssl.berkeley.edu/var_desc.shtml> .)

Datatypes are calibrated separately. For fields, additional variables are created; ef(mode)\_0 (where the (mode) refers to ‘f’, ‘p’ or ‘w’) is the field with the Z component (in DSL coordinates) set to zero; ef(mode)\_dot0 contains the field with the Z component calculated under the assumption E dot B = 0. The X and Y components are unchanged.

For information regarding THEMIS coordinate systems, see <http://themis.ssl.berkeley.edu/themisftp/3%20Ground%20Systems/3.2%20Science%20Operations/Science%20Operations%20Documents/thm_soc_110_COORDINATES_20100729.pdf> .

For each datatype:

2) Gains and offsets are input from calibration files. Currently these are not time-dependent, but may vary from probe to probe, thus there is a different file for each probe. The calibration structure for voltage variables contains a calibration time, gain, offset and units.

For Electric field variables, the calibration structure contains a calibration time, gain values for EAC and EDC data, offsets for each axis (in ADC units, 70, 113, 0 for E12, E34 ,E56), boom length (meters, 49.6 for boom 12, 40.4 for boom 34, 5.63 for boom 56), boom shorting (0.714 for booms12 and 34, 0.50 for boom 56) and a despun field offset (2.5, 0, 0 for E12, E34 ,E56, respectively, subtracted from calibrated data after despin).

3) For voltage variables, v1 through v6 are voltage values for booms 1 to 6. The offset is subtracted from raw data, and the result is multiplied by the gain factor.

4) For electric field data, a number of extra steps are needed. First the header information is accessed to determine AC or DC coupling. If both AC and DC coupled modes are present (only possible with efw (wave burst) data), then the appropriate gain is used to convert the raw ADC value.

The offsets input from the calibration files are not used for the spin-plane field components in the default case. Instead, offset values are calculated from the raw data smoothed over a number of spacecraft spin periods (20 by default, but due to the presence of data gaps, may be as short as one spin period). This option may be turned off using keywords, which are summarized below.

Once the offsets are found, the variables are adjusted for gain and offset. For each field component:

calibrated\_data = -1000\*gain\*(raw\_data - offset)/(boom\_length\*boom\_shorting\_factor).

5) The data variables are now in physically meaningful units of mV/m, but in a coordinate system spinning with the spacecraft (SPG, space probe geometric coordinates). The default is to return the calibrated data in DSL (despun spacecraft) coordinates. This is done in the program THM\_EFI\_DESPIN.

The despin procedure is slightly different from a typical THEMIS coordinate change in that the dsc\_offset parameter is subtracted from the field after despinning. Thus, if a user simply loads calibrated data in SPG coordinates and then despins using THM\_COTRANS, the result will be different from data which are despun in the calibration procedure.

6) Once despun, the ‘\_0’ and ‘\_dot0’ fields are calculated. The ‘\_0’ variables are the DSL fields with the spin-axis component (the Z component) set to zero. The ‘\_dot0’ variables are more complicated. FGM data (by default FGL-low time resolution for EFF and FGH- high time resolution for EFP and EFW), interpolated to the appropriate EFI time array are used for the local magnetic field. For the ‘\_dot0’ variables, the Z component is a linear combination of the X and Y components calculated so that E dot B is zero (E is perpendicular to the local magnetic field).

**FBK:**

**FBK** data files contain data from the Electric Field Instrument (EFI) and Search Coil Magnetometer (SCM) Digital Fields Board. Files contain on-board, digitally computed filter bank spectra and E12 (electric field for 1-2 boom pair) peak and average in the HF band.

PROCEDURE NAME:

THM\_CAL\_FBK

LINKS:

Instrument information:

[http://themis.ssl.berkeley.edu/instrument\_fbk.shtml](about:blank)

Cal procedure:

[http://themis.ssl.berkeley.edu/socware/spedas\_5\_0/idl/projects/themis/spacecraft/fields\_spd\_doc\_list.html#THM\_CAL\_FBK](about:blank)

Other programs used:

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spacecraft/fields_spd_doc_list.html#THM_GET_FBK_CAL_PARS>

CALIBRATION FILES:

There is no calibration file input. Calibration parameters are defined in the procedure, THM\_GET\_FBK\_CAL\_PARS.

PROCESS DESCRIPTION:

Inputs: From Level 1 files

1) There are a number of possible different datatypes, but not all are included in the Level 1 files. Typically one SCM datatype and one EFI datatype are stored in variables ‘th(probe)\_fb1’ and ‘th(probe)\_fb2’. (For example, a common configuration would have EDC34 data contained in the ‘\_fb1’ variable, and SCM1 data contained in the ‘\_fb2’ variable). The ‘th(probe)\_fbh’ variable contains high frequency field data. The first step for each variable is to determine the data source (SCM or EFI).

2) Once the data source is determined, the calibration gain and frequency response are input via a call to THM\_GET\_FBK\_CAL\_PARS.

3) Data values are decompressed, and then multiplied by the gain and frequency response factor for the appropriate source.

4) Data times are adjusted for each sample. The header time for a given sample corresponds to the sample from roughly half a sample period earlier. This is accounted for in the same code block as the calibration.

5) Data points are collated and sorted. Only data points with finite values are retained.

**FFT**

**FFT** data files contain on-board Fast Fourier Transform (FFT) power spectra of Electric (EFI) and Magnetic (SCM) field data.

PROCEDURE NAME:

THM\_CAL\_FFT

LINKS:

Instrument information:

[http://themis.ssl.berkeley.edu/instrument\_fft.shtml](about:blank)

Cal procedure:

[http://themis.ssl.berkeley.edu/socware/spedas\_5\_0/idl/projects/themis/spacecraft/fields\_spd\_doc\_list.html#THM\_CAL\_FFT](about:blank)

Other programs used:

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spacecraft/fields_spd_doc_list.html#THM_GET_FFT_CAL_PARS>

CALIBRATION FILES:

There is no calibration file input. Calibration parameters are defined in the procedure, THM\_GET\_FFT\_CAL\_PARS.pro.

PROCESS DESCRIPTION:

Inputs: From Level 1 files

1) Level 1 input for each mode (full, particle burst, and wave burst mode) and number of frequency channels (16, 32 and 64) are contained in individual files. Possible datatypes include EAC (AC coupled) and EDC (DC coupled) data for boom pairs 12, 34 and 56 from EFI, and SCM data from axes 1 2 and 3. All of the possible mode/N channel combinations and datatypes are not necessarily included in the files.

2) Level 1 data variables contain four FFT spectra from 4 different sources; a flag for the identity of each source is provided in a separate variable with the suffix ‘\_src’; header information is provided in a variable with suffix ‘\_hed’, and information regarding the ADC settings is held in a variable with suffix ‘\_adc’. (For example, the L1 variable ‘tha\_fft\_32’ is associated with variables ‘tha\_fft\_32\_src’, ‘tha\_fft\_32\_hed’ and ‘tha\_fft\_adc\_32’. Only the ‘\_src’ and data variables are used in the calibration process). The first step in calibration for each of the four sets of spectra is to determine the source, from the ‘\_src’ variable.

3) The calibration gain, frequencies for each channel, frequency response and units for the appropriate source are calculated in the subroutine THM\_GET\_FFT\_CAL\_PARS.

4) Data values are decompressed, and then multiplied by the gain and frequency response factor for the appropriate source.

5) Data points are collated and sorted, and output.

**FGM**

**FGM** data files contain Fluxgate Magnetometer data, including FGE (engineering) magnetic field, FGH (high-resolution) magnetic field, FGL (low-resolution) magnetic field.

PROCEDURE NAME:

THM\_CAL\_FGM

LINKS:

Instrument information:

[http://themis.ssl.berkeley.edu/instrument\_fgm.shtml](about:blank)

Cal procedure:

[http://themis.ssl.berkeley.edu/socware/spedas\_5\_0/idl/projects/themis/spacecraft/fields\_spd\_doc\_list.html#THM\_CAL\_FGM](about:blank)

Other programs used:

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spacecraft/fields_spd_doc_list.html#THM_CAL_FGM_SPIN_HARMONICS>

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spin_spd_doc_list.html#SPINMODEL_GET_PTR.PRO>

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spin_spd_doc_list.html#SPINMODEL_INTERP_T.PRO[1>]

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spin_spd_doc_list.html#SPINMODEL_GET_INFO.PRO>

Other applicable documents: [http://themis.ssl.berkeley.edu/themisftp/3%20Ground%20Systems/3.2%20Science%20Operations/Science%20Operations%20Documents/thm\_soc\_113\_FGM\_CALPROC\_20061018.pdf](about:blank)

CALIBRATION FILES:

The file ‘th(probe)\_fgmcal.txt’ with offsets and calibration matrix values for each probe is located in $ROOT\_DATA\_DIR/th(probe)/ll1/fgm/0000, where ROOT\_DATA\_DIR is the default data directory for THEMIS data. Spin calibration files, used for solar array current harmonic removal, are located in the directory $ROOT\_DATA\_DIR/th(probe)/ll1/fgm/0000/spin\_cal.

PROCESS DESCRIPTION:

Inputs: From Level 1 files

1) For each value of probe and datatype combination (fge, fgh, fgl) THM\_CAL\_FGM calls itself recursively. (‘fge’ variables contain engineering data, ‘fgh’ variables contain high resolution data, and ‘fgl’ variables contain low resolution data.)

2) The spin period is obtained from the spin model, via the programs SPINMODEL\_GET\_PTR, SPINMODEL\_INTERP\_T and SPINMODEL\_GET\_INFO.

3) The data values are multiplied by a scale constant (25000/2^23).

4) Harmonics created by the solar array current are removed using the program THM\_CAL\_FGM\_SPIN\_HARMONICS, provided that the probe is not in shadow.

5) The calibration matrix is formed from values in the appropriate calibration file, ‘th(probe)\_fgmcal.txt’. The file contains 3 offsets, and 9 values for the calibration matrix, measured for the full mission. If the interpolate\_cal keyword is not set (this is the default), then the calibration values for the most recent measurement are used.

6) The data values are multiplied by the calibration matrix, and offsets are subtracted.

7) Filter correction is performed if necessary. If the filter mode flag is present and equal to 2, then the data has been calculated by averaging over 128 Hz raw data. Since this is done before de-spinning, there are amplitude and spin phase errors, which are corrected as a last step.

**FIT**

**FIT** data files contain on-board spin fits of Electric Field Instrument (EFI) and Fluxgate Magnetometer (FGM) field data.

PROCEDURE NAME:

THM\_CAL\_FIT

LINKS:

Instrument information:

[http://themis.ssl.berkeley.edu/instrument\_fit.shtml](about:blank)

Cal procedure:

[http://themis.ssl.berkeley.edu/socware/spedas\_5\_0/idl/projects/themis/spacecraft/fields\_spd\_doc\_list.html#THM\_CAL\_FIT](about:blank)

CALIBRATION FILES:

The FGM calibration file ‘th(probe)\_fgmcal.txt’ with offsets and calibration matrix values for each probe is located in $ROOT\_DATA\_DIR/th(probe)/ll1/fgm/0000, where ROOT\_DATA\_DIR is the default data directory for THEMIS data. The EFI calibration file for each probe is located in $ROOT\_DATA\_DIR/th(probe)/l1/eff/0000. Other calibration values are defined in the routine THM\_CAL\_FIT.

PROCESS DESCRIPTION:

Inputs: From Level 1 files

1) Level 1 FIT data variables (‘th(probe)\_fit’)have 10 values for each time interval, so that the data array has dimensions (ntimes, 5, 2), with both electric and magnetic field data. The last index of the data array has value 0 for EFI, and 1 for FGM. Information about the contents of the data variable is contained in other variables with suffixes ‘\_code’, ‘\_npts’ and ‘\_hed’. Only the ‘\_code’ variable is used in the calibration process.

2) The spin period is obtained from the spin model, via the programs SPINMODEL\_GET\_PTR and SPINMODEL\_INTERP\_T.

3) The FIT B-field data variable is calibrated. The first step is to read the calibration file, and to calculate rotation constants, which are used to rotate the data on the spin plane to match output DSL (despun spacecraft) coordinates. (See

[http://themis.ssl.berkeley.edu/themisftp/3%20Ground%20Systems/3.2%20Science%20Operations/Science%20Operations%20Documents/thm\_soc\_110\_COORDINATES\_20100729.pdf](about:blank)

for coordinate definitions.)

4) The B-field values are multiplied by constants to convert to units of nanoTesla.

5) X and Y components of the B field are rotated to the DSL coordinate system.

6) An offset value from the calibration file is subtracted from the Z component of the B field.

7) NaN values are removed, and the data array values (\*, 0:2, 1) are stored in the variable named ‘th(probe)\_fgs’.

8) If there are good data values after NaN removal, the uncertainty variable ‘th(probe)\_fgs\_sigma’ is filled from the data array values (\*, 3, 1).

9) The FIT E-field data are calibrated. The first step is to determine which boom pair (e12 or e34) was used for the measurement. This information is found in the variable ‘th(probe)\_fit\_code’. If e34 data was used, then the field data are rotated by 90 degrees in the spin plane.

10) The E-field data are stored in indices 1, 2, and 4 of the fit data array, (as opposed to 0, 1 and 3 for B-field data.) The Z component of the field data may contain spacecraft potential (depending on the ‘\_code’ variable contents), so this is saved in a separate variable.

11) Data are multiplied by scale constants, to result in units of EFI level-1 data, the rest of the process for the E-field is similar, but not identical to that for Level-1 EFI.

12) First, the header data is checked to see if the E-filed data variable is AC or DC coupled, so that the appropriate calibration constants are applied. Then once the offsets are found, the variables are adjusted for gain and offset. For the X and Y field components:

calibrated\_data = -1000\*gain\*(raw\_data - offset)/(boom\_length\*boom\_shorting\_factor).

There is a ‘no\_cal’ keyword option included. If ‘/no\_cal’ is set, then offsets are not subtracted and the boom shorting factor is not included.

13) If the fit code indicates that the Z component of the variable contains the spacecraft potential, then the Z component of the calibrated data just calculated is set to NaN. (The original raw data for Z has been saved in a separate array.)

14) Non-NaN data values are stored in a variable ‘th(probe)\_efs’

15) Values from index (\*, 3, 0) contain estimated uncertainty and are stored in the variable ‘th(probe)\_efs\_sigma’.

16) If the original Z-component contains the SC potential, then a separate variable named ‘th(probe)\_efs\_potl’ is created. The time values are offset by (spin\_period\*169.0/360.0) and the data values are scaled by 0.00401937 to set units to Volts, consistent with values of the potential obtained from MOM (on-board moment) data files.

17) Variables named ‘th(probe)\_efs \_0’ and ‘th(probe)\_efs\_dot0’ fields are calculated, as in the THM\_CAL\_EFI process. The ‘\_0’ variables are simply the DSL fields with the spin-axis component (the Z component) set to zero. For the ‘\_dot0’ variables, the Z component is a linear combination of the X and Y components calculated so that E dot B is zero (E is perpendicular to the local magnetic field).

**SCM**

**SCM** data files include Search Coil Magnetometer (SCM) Magnetic Field Measurements, including FAST SURVEY (scf), PARTICLE BURST (scb) and WAVE BURST (scw) data.

PROCEDURE NAME:

THM\_CAL\_SCM

LINKS:

Instrument information:

[http://themis.ssl.berkeley.edu/instrument\_scm.shtml](about:blank)

Cal procedure:

[http://themis.ssl.berkeley.edu/socware/spedas\_5\_0/idl/projects/themis/spacecraft/fields\_spd\_doc\_list.html#THM\_CAL\_SCM](about:blank#THM_CAL_SCM)

Other programs used:

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spacecraft/fields/thm_scm_gainant_vec.pro>

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spacecraft/fields/thm_scm_modpha.pro>

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spacecraft/fields/thm_scm_deconvo_vec.pro>

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spacecraft/fields/thm_scm_casinus_vec.pro>

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spacecraft/fields/spin_tones_cleaning_vector_v5.pro>

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spacecraft/fields/scm_cleanup_ccc.pro>

Other applicable documents:

[http://themis.ssl.berkeley.edu/themisftp/3%20Ground%20Systems/3.2%20Science%20Operations/Science%20Operations%20Documents/thm\_soc\_129\_scm\_calibration.pdf](about:blank)

CALIBRATION FILES:

The SCM calibration file for each probe is located in $ROOT\_DATA\_DIR/th(probe)/l1/scm/0000, where ROOT\_DATA\_DIR is the default data directory for THEMIS data. Each file contains the Gap angle (degrees) between the reference axis and the radiance diagram axis of the antenna. Following these parameters are the real and imaginary parts for the X, Y, and Z sensors for the full frequency range of each sensor.

PROCESS DESCRIPTION:

Processing is done in steps individually for each datatype, scf, scp, and scw. (**scf**: fast survey 1/8 second time resolution; **scp**: particle burst 1/128 second time resolution burst mode; **scw**: wave burst 1/8192 second time resolution.) By default, processing stops after step 5.

**NOTE** that for SCM, the calibration parameters used when creating Level2 data files are different from the default for L1 load. For L2 data calibration parameters differ for the different modes; for SCF and SCP data, the following are used: mk = 8 (the convolution kernel used is 8 times the sample frequency), despin = 1 (use despin), n\_spinfit = 2 (2 spins used to fit for misalignment, dc field calculation and despin, cleanup = 0 (no spin tone or 8/32 Hz tones), fdet = 0 (no detrend performed), fcut = 0.4 (low frequency cut-off for calibration), fmin = 0.8 (min frequency for filtering), fmax = 0 (use nyquist frequency for max frequency for filtering). For SCW data, the calibration parameters are: mk = 1, n\_spinfit = 2, cleanup = 0, fdet = 0, fcut = 0.4, fmin = 2.0 , fmax = 0. A full explanation of the SCM calibration parameters can be found in the SCM calibration document referenced above.

Processing is done in separate batches which require different kernel sizes, based on sample rate and spin rate

Step 0a) Find sample rate changes; the convolution kernel size is rate dependent.

0b) Find data gaps, working with one sample rate at a time.

Batches are defined by the different discontinuities. Steps 1 to 6 are done batch by batch, and NaN values are inserted between batches.

For each batch, the process is as follows:

1) Convert to Volts, The value of the field is multiplied by a calibration factor of: 10.04/2.^16.

2a) Get antenna response at spin frequency; this process calls routines THM\_SCM\_GAINANT\_VEC (returns the gain of the antenna for a given frequency), and THM\_SCM\_MODPHA (returns the amplitude and phase of the response).

2b) Check for abnormally incrementing spin phase; looks for a decrease in spin phase, adds 360.0 to make the negative values positive.

2c) Initial centering of the waveforms: The average value of the field is subtracted from the field values.

2d) Calculate sine fit for calculation of misalignment angle and classic\_despin. Calls the routine THM\_SCM\_CASINUS\_VEC, that computes a pure sine wave from an input signal. The sine wave is then subtracted to get the ‘useful’ signal.

2e) Cleanup (if requested) If cleanup = 'spin', then only spin tones are removed, If cleanup = 'full' then spin tones and 8/32 Hz 1s phase locked noise is cleaned up. Calls routine SPIN\_TONES\_CLEANING\_VECTOR\_V5, if the parameter clnup\_author is 'ole' (default). If clunp\_author is 'ccc' then SCM\_CLEANUP\_CCC is called. The default for cleanup is 'none'.

2f) Determine antenna misalignment. First take the spin sine wave (calculated above via THM\_SCM\_CASINUS\_VEC), and divide by the antenna response to get into units of nT. Next the ‘misalignment angle’ is arcsin(Bz\*sqrt(2.0)/B), where Bz and B represent the z-component and total value of the sine wave B field. (Note that this sine-wave field eventually forms the basis of the DC field.)

2g) If the detrend frequency is not set to zero (which is the default), then a high-pass filter is applied, the field is smoothed over a number of points corresponding to (fe/fdet), where fe is the sampling frequency and fdet is the dtrend frequency, and the smoothed field is subtracted from the overall field.

2h) Final centering of the waveform -- the average value of the field is subtracted from the field.

2i) The DC field is put into DSL (despun) coordinates: the X,Y amplitude and phase are computed in the scm sensor system. The transformation to SSL is a rotation of about 45 + 12.4 degrees, and must be consistent with the Sensor to SSL matrix. The transformation from SSL to DSL is then a rotation of sun pulse phase. These two DC field components in DSL at the spin period resolution (3s) can be used for comparison with the same components of FGM data.

2j) Finally, the values of the dc field (only for Bx and By) are saved along with the misalignment angles. NaN values are inserted at the batch edges.

3) Calibrated data in sensor spinning system [nT] without DC. This first checks to be sure that there are more data points than the number of points in a convolution kernel, then calls the routine THM\_SCM\_DECONVO\_VEC for each component, using the sine-wave subtracted, average subtracted field. THM\_SCM\_DECONVO\_VEC performs a continuous calibration accomplished by convolving a signal with a kernel. The kernel is derived by taking the fft of the inverse of the frequency response. The kernel is also constructed to account for any sample delay.

4) Calibrated data in SSL spinning system [nT] without DC. Rotates the calibrated data in sensor spinning system to SSL coordinates, using the function THM\_SCM\_SENSOR\_TO\_SSL, which applies an approximate 57.4 degree rotation:

5) Calibrated data in DSL system [nT] without DC. Applies rotation of spin phase angle, as in the SSL2DSL routine. This is the end of the default SCM calibration.

6) Calibrated data in DSL system [nT] with DC. Adds the DC component of B (calculated at the end of step 2) back into the X,Y components.

As for the other data, rotation from DSL to science frames (GSE or GSM) can be performed by the spedas coordinate transformation routines.

**Particles**

**ESA**

**ESA** files contain electron and ion particle distribution data in the energy range from a few eV to above 20 keV.

PROCEDURE NAME:

THM\_LOAD\_ESA­\_PKT

LINKS:

Instrument information:

[http://themis.ssl.berkeley.edu/instrument\_esa.shtml](about:blank)

Load/Cal procedures:

[http://themis.ssl.berkeley.edu/socware/spedas\_5\_0/idl/projects/themis/spacecraft/particles/ESA/packet\_spd\_doc\_list.html#THM\_LOAD\_ESA\_PKT](about:blank)

Other programs used:

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spacecraft/particles/ESA/packet_spd_doc_list.html>

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spacecraft/particles/ESA/packet_spd_doc_list.html#GET_THM_ESA_CAL>

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/state_spd_doc_list.html#THM_LOAD_STATE>

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spacecraft/particles/ESA/packet_spd_doc_list.html#GET_THA_PEIF>

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spacecraft/particles/ESA/packet_spd_doc_list.html#THM_READ_ESA_ANGLE_FULL_MODE>

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spacecraft/particles/ESA/packet_spd_doc_list.html#THM_READ_ESA_ANGLE_BURST_MODE>

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spacecraft/particles/ESA/packet_spd_doc_list.html#THM_READ_IESA_ANGLE_REDUCED_MODE>

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spacecraft/particles/ESA/packet_spd_doc_list.html#THM_READ_EESA_ANGLE_REDUCED_MODE>

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spacecraft/particles/ESA/packet_spd_doc_list.html#THM_READ_ESA_SWEEP_FULL_MODE>

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spacecraft/particles/ESA/packet_spd_doc_list.html#THM_READ_ESA_SWEEP_REDUCED_MODE>

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spacecraft/particles/ESA/packet_spd_doc_list.html#THM_READ_ESA_SWEEP_REDUCED_MODE>

CALIBRATION FILES:

The ESA calibration file ‘tha\_l1\_esa\_cal.txt’ with time-dependent gain factors is located in $ROOT\_DATA\_DIR/tha/ll1/esa/0000, where ROOT\_DATA\_DIR is the default data directory for THEMIS data. This file is used for all probes. Other calibration values, efficiency, deadtime and geometric factors are coded in the program GET\_THM\_ESA\_CAL.

PROCESS DESCRIPTION:

Inputs: From Level 0 files (this is the only instrument process that accesses level 0 data.)

1) Data for individual modes for each datatype are held in separate files, for the individual app\_ids, (454 for full mode ion, peif data, 455 for reduced mode ion, peir data, 456 for burst mode ion, peib data, 457 for full mode electron, peef data, 458 for reduced mode electron, peer data, 459 for burst mode electron, peeb data). Internally, the data for a given datatype are held in a common block, exclusive for that apid and probe. (For example PEIF data for THEMIS A are kept in structures in a common block called ‘tha\_454’.)

For each datatype:

1) Support data is loaded; calibration gain values are input from the calibration file, position, velocity and spin period data are input using THM\_LOAD\_STATE.

2) Level 0 data are loaded using THM\_LOAD\_(datatype), for the appropriate datatype. (For example, peif data are loaded using THM\_LOAD\_PEIF.)

In this program for each datatype,

2a) The common block for the given probe and datatype is initialized.

2b) Various arrays are defined, for data decompression, decoding of different modes from the mode variable, also arrays for the number of spins, energies and angles for the different modes. (In this case a ‘mode’ defines the number of energy values and angular bins for the given data interval.)

2c) Packet data is input from the Level 0 file.

2d) Spin model is loaded using SPINMODEL\_GET\_PTR. Spin period can also be obtained from packet headers, to be used if there is no spin model available

2e) Data decomuation loops over packets: sample start and end times, angle and energy binning are decoded from the packet headers and raw data is saved from packets to arrays

2f) After packet loop, packet time is shifted to unix time (i.e., time in seconds from, 1-jan-1970).

2g) Calibration data, energy efficiency, geometric factor and deadtime factors are input via GET\_THM\_ESA\_CAL. For electron data, a factor for electron energy efficiency is calculated.

2h) Values for angular binning are input using the programs THM\_READ\_ESA\_ANGLE\_FULL\_MODE, THM\_READ\_IESA\_ANGLE\_REDUCED\_MODE, THM\_READ\_EESA\_ANGLE\_REDUCED\_MODE, or THM\_READ\_ANGLE\_BURST\_MODE. Values for energy binning are input using the programs THM\_READ\_ESA\_SWEEP\_FULL\_MODE, THM\_READ\_ESA\_SWEEP\_REDUCED\_MODE, or THM\_READ\_ESA\_SWEEP\_BURST\_MODE.

2i) ‘3D’ data structures, containing raw data and all information about modes, angles, energies, etc.. are filled with data. These are stored in the appropriate common blocks.

2j) TPLOT count rate spectrogram variables, (e.g., ‘tha\_peif\_en\_counts’ for full mode ion data) are created using decompressed raw data.

3) Calibration of the data in the 3D data structure is accomplished in the appropriate function GET\_TH(probe)\_(datatype). For example, for probe A and PEIF data, the function is GET\_THA\_PEIF.pro This function decompresses the data, converts units from counts to flux, energy flux or distribution functions as needed, and assigns an individual 3D data structure with the appropriate units for each time interval chosen.

**SST**

**SST** files contain electron and ion particle distribution data in the energy range from above 20 keV to a few MeV.

PROCEDURE NAME:

THM\_LOAD\_SST2

THM\_PART\_DIST

As for ESA, there is no separate program for calibration. Data are loaded via THM\_PART\_LOAD, which calls THM\_LOAD\_SST2, or can be loaded using THM\_LOAD\_SST2 directly. Calibration happens in the program THM\_PART\_DIST, during processing for moments and angular and energy distributions.

LINKS:

Instrument information:

[http://themis.ssl.berkeley.edu/instrument\_sst.shtml](about:blank)

Load/Cal procedures:

[http://themis.ssl.berkeley.edu/socware/spedas\_5\_0/idl/projects/themis/spacecraft/particles/SST/SST\_cal\_workdir\_spd\_doc\_list.html#THM\_LOAD\_SST2](about:blank#THM_LOAD_SST2)

[http://themis.ssl.berkeley.edu/socware/spedas\_5\_0/idl/projects/themis/spacecraft/particles/thm\_part\_products\_spd\_doc\_list.html#THM\_PART\_DIST](about:blank#THM_PART_DIST)

Other programs used:

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spacecraft/particles/SST/SST_cal_workdir_spd_doc_list.html#THM_SST_BUILD_CAL_FILES>

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spacecraft/particles/thm_part_products_spd_doc_list.html#THM_PART_PRODUCTS>

Other applicable documents:

[http://themis.ssl.berkeley.edu/themisftp/3%20Ground%20Systems/3.2%20Science%20Operations/Science%20Operations%20Documents/thm\_sst\_davin\_larson\_June2009.pdf](about:blank)

[http://themis.ssl.berkeley.edu/socware/spedas\_5\_0/idl/projects/themis/spacecraft/particles/SST/SST\_cal\_workdir/thm\_sst\_calibration\_description\_DLTedits.txt](about:blank)

CALIBRATION FILES:

SST calibration files for each probe are located in $ROOT\_DATA\_DIR/th(probe)/l1/sst/0000, where ROOT\_DATA\_DIR is the default data directory for THEMIS data. Detailed descriptions of the calibration parameters are given in the program THM\_SST\_BUILD\_CAL\_FILES.pro.

PROCESS DESCRIPTION:

Input: from Level 1 files

1) In THM\_LOAD\_SST2, SST data are loaded into data structures stored in pointer arrays, which are held in TPLOT variables. Each data structure stores a time series of 16 by 64 (16 energy channels and 64 angular bins) of raw counts data.

3) Calibration is done when the data is accessed by THM\_PART\_PRODUCTS which calls THM\_PART\_DIST2 and returns calibrated data in a structure for the input time.

3a) Calibration data are loaded into the data structures in the routine THM\_SST\_CALIB\_PARAMS2 called from THM\_PART\_DIST2. Values are added to the data structure for: high and low energy limits for each channel; deadtime correction factors; geometric factor for each angular bin and energy; dead layer offset for each look direction (there are four of these, corresponding to each value of polar angle); attenuator scaling factors (nominally 1/64); energy efficiency for each energy channel.

3b) Units for energy bands are converted to eV in the routine THM\_SST\_ENERGY\_CAL2 called from THM\_PART\_DIST2, using the input values from the previous step. Dead layer offsets are added to the energy band high and low values here.

4) Sun pulse contamination is removed using the routine THM\_PGS\_CLEAN\_SST (called from THM\_PART\_PRODUCTS). This process can only be done for full mode data, angular bins to be removed can be optionally input by the user, but use of the default angular bins is recommended. See [http://sprg.ssl.berkeley.edu/~jimm/themis/SST/thm\_soc\_XXX\_sst\_cotaminated\_bins.pdf](about:blank)

5) Calibrated moments and particle distributions are returned from THM\_PART\_PRODUCTS.

**MOM**

**MOM** files include moments for the Electrostatic Analyzer (ESA) and Solid State Telescope (SST) calculated on-board: (density, velocity, pressure, and temperature). Also a measurement of the spacecraft potential is included.

PROCEDURE NAME:

THM\_LOAD\_MOM

There is no separate program for calibration (THM\_CAL\_MOM was deprecated in 2010). Calibration is handled in the load routine.

LINKS:

Instrument information:

[http://themis.ssl.berkeley.edu/instrument\_esa.shtml](about:blank)

[http://themis.ssl.berkeley.edu/instrument\_sst.shtml](about:blank)

Load/Cal procedures:

[http://themis.ssl.berkeley.edu/socware/spedas\_5\_0/idl/projects/themis/spacecraft/particles/moments\_spd\_doc\_list.html#THM\_LOAD\_MOM](about:blank#THM_LOAD_MOM)

<http://themis.ssl.berkeley.edu/socware/spedas_5_0/idl/projects/themis/spacecraft/particles/moments_spd_doc_list.html#THM_READ_MOM_CAL_FILE>

CALIBRATION FILES:

The MOM calibration file ‘tha\_l1\_mom\_cal\_v02.txt’ is located in $ROOT\_DATA\_DIR/tha/l1/mom/0000, where ROOT\_DATA\_DIR is the default data directory for THEMIS data. This file is used for all probes. The ESA calibration file ($ROOT\_DATA\_DIR/tha/l1/esa/0000/tha\_l1\_esa\_cal.txt) is also accessed, for values of the geometrical factor used for ESA moments.

PORCESS DESCRIPTION:

Input: from level 1 files

1) Calibration data are input using the routine THM\_READ\_MOM\_CAL\_FILE. The file contains scaling factors for on-board moments and spacecraft potential. The outputs in a structure are a 4X13 array of scaling for the moments, then another 4X13 array, used for solar wind mode, then a single number for scaling of SC potential.

2) Appropriate factors are chosen for solar wind mode, or normal observing. Scale factors for ESA were determined by comparing data to ground processed moments when not in solar wind mode. Efficiency, dead time, and energy sweep variation corrections are only performed on ground, and a different spacecraft potential is often used, depending on the availability of spacecraft potential measurements from the Electric Field Instrument. This means that there may be some discrepancy between on-board and ground based moments. To determine calibration factors, ground corrections that are not done on-board were turned off, and on-board SC potential was used for the ground-calculated moments.

Scale factors for ESA in the solar wind were determined by comparing data to ground processed moments when in solar wind mode.

Note that appropriate parameters for solar wind/non-solar wind are used if correct inputs are available, the default is to use only non-solar wind parameters.

3) Scale factors are multiplied by the raw data values, and the results are saved as tplot variables.

**Ground**

**All-Sky Image**

**ASI**

ASI Level 1 data are contained in 3 different file types. Level 1ASF files contain full-resolution (256x256) images from each of 25 stations. AST files contain thumbnail images for each station. ASK files contain keograms, which are summary images from all stations. Unlike the probe data, for which Level 1 files are uncalibrated, THEMIS ASI data are calibrated with respect to intensity and released as Level 1 files. The only user application for calibration in the SPEDAS distribution is for the creation of mosaics, which apply positional information contained in the calibration files to locate images on a map.

PROCEDURE NAME:

THM\_LOAD\_ASI\_CAL

LINKS:

Instrument information:

[http://themis.ssl.berkeley.edu/instrument\_asi.shtml](about:blank)

Cal procedure:

[http://themis.ssl.berkeley.edu/socware/spedas\_5\_0/idl/projects/themis/ground\_spd\_doc\_list.html#THM\_LOAD\_ASI\_CAL](http://themis.ssl.berkeley.edu/socware/spedas_4_1/idl/projects/themis/ground_spd_doc_list.html#THM_LOAD_ASI_CAL)

Applicable documents:

<http://themis.ssl.berkeley.edu/themisftp/3%20Ground%20Systems/3.2%20Science%20Operations/Science%20Operations%20Documents/thm_soc_119_ASI_CALPROC_20061108.pdf>

CALIBRATION FILES:

Calibration files for each ASI ground station are in the directory $ROOT\_DATA\_DIR/thg/l2/asi/cal, where $ROOT\_DATA\_DIR is the default data directory for THEMIS data. The CDF filenames are ‘thg\_l2\_asc\_(station)\_19700101\_v02.cdf’. ASI ground stations are referred to by a 4 character string. For example, ‘atha’ refers to Athabasca, Alberta.

PROCESS DESCRIPTION:

1) Calibration parameters are loaded for each ground station using the program THM\_ASI\_LOAD\_CAL. The parameters may be different for each station, but generally include the following, for different types of ASI data, ASF, AST and ASK: ‘azim’ = azimuth, ‘elev’ = elevation, ‘glon’ = longitude, ‘glat’ = latitude, ‘mlon’ = magnetic longitude, ‘mlat’ = magnetic latitude, ‘alti’ = altitude used for glon, glat calculation. Variables for mask, for bad pixels and offsets are included. Note that the quantity names here are different than in the calibration document ‘ASI\_CALPROC’ referenced above. Also values for the image centers ‘ASC’ are given.

2) If the user is creating a mosaic, the cal parameters are applied to the data from each station to locate it on a map to complete the mosaic.

3) Some of the stations were moved during servicing and new calibration parameters were determined. The software automatically checks for the number of calibration data sets within a particular file, determined the valid time range, and selects the correct set for the requested time.

**GMAG**

**GMAG** files include magnetic field data from 106 different sites across the northern hemisphere and two stations in Antarctica. There are 22 official THEMIS GMAG stations in the Northern United States and Canada. These GMAGs measure the magnetic field with 0.01 nT resolution at 2 samples/second. Units are nanotesla.

PROCEDURE NAME:

THM\_LOAD\_GMAG

LINKS:

Instrument information:

<http://themis.ssl.berkeley.edu/gmag_desc.shtml>

Load procedure:

[http://themis.ssl.berkeley.edu/socware/spedas\_5\_0/idl/projects/themis/ground\_spd\_doc\_list.html#THM\_LOAD\_GMAG](http://themis.ssl.berkeley.edu/socware/spedas_4_1/idl/projects/themis/ground_spd_doc_list.html#THM_LOAD_GMAG)

CALIBRATION FILES:

The calibration files for the GMAG data are not distributed. Calibration is done in Level 1 to Level 2 processing, for THEMIS EPO and GBO data. Unlike the probe data, where calibrated L1 data is the default input, for GMAG L2 data are the default input.

PROCESS DESCRIPTION:

1) There are a number of different processes for different GMAG sources. There are 22 official THEMIS GMAG stations in the Northern United States and Canada. Ten of these systems are installed with the Ground-Based Observatory (GBO) systems for THEMIS. Twelve are installed in schools and are part of the THEMIS Education and Public Outreach (E/PO) program. Also included in the L2 distribution are stations from the University of Alaska, the University of Alberta, the MACCS project at Augsburg College, the University of Athabasca, the Technical University of Denmark, the Tromsø Geophysical University in Norway, the US Geological Survey, the Geological Survey of Canada, the Geological Survey of Sweden (SGU), the Leirvogur Magnetic Observatory in Iceland, AARI in Russia, and the PENGUIn network in Antarctica.

2) Here we describe the process for the 22 THEMIS GBO and EPO, which is done during L2 processing. GMAG calibration files for the different station include the following: station\_id = a 4 character string for each station, station\_name= the full station name, serial number, start date, cal = a calibration scale, to convert to nanoTesla, dac = another (digital analog?) conversion value, and offs = an offset.

2a) In the calibration process, the first step is to subtract a constant offset of 524288 from the raw data value.

2b) Next the dac value from the calibration file is multiplied by a scaling factor from the input data file.

2c) The data value (from step 2a) is divided by the scaling factor (‘cal’) from the calibration file to give units of nanoTesla.

2d) The adjusted dac value (step 2b) is then subtracted.

2e) The offset from the calibration file is then added.

2f) The rotation matrix from the calibration file is applied to put the data in HDZ\* coordinates. (See, e.g., <http://www.nerc-bas.ac.uk/public/uasd/instrums/magnet/hdz.html> for coordinate system information.)

3) Final values are output into Level 2 CDF files.