THEMIS
Project Data Management Plan

THM-SYS-012

12/03/2003

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Document Revision Record

Rev.	Date	Description of Change	Approved By
-	12/03/03	Preliminary Draft	-

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TBD List

Identifier	Description
TBD-PDMP-01 -> TBD-PDMP-04	Official Doc name needed
TBD-PDMP-05	Data Flow Diagram
TBD-PDMP-06	LZP File Format
TBD-PDMP-07	SCID for filename field
TBD-PDMP-08	CDF content description
TBD-PDMP-09	UCalgary GBO Data retrieval rate
TBD-PDMP-10	Website URL
TBD-PDMP-11	Data Availability figure

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1. Introduction.

1.1 Purpose and Scope.

This document provides the Project Data Management Plan (PDMP) for the Time History of Events and Macro scale Interactions during Sub storms (THEMIS) Explorer Mission. The PDMP describes all of the activities associated with the flow of THEMIS scientific data from collection on the spacecraft through production, distribution and access, and archiving of data and data products. This also includes extensive ground based imager and magnetometer measurements taken by 20 Ground Based Observatories (GBO's) spread across Alaska and Canada, and 10 Education and Public Outreach (E/PO) magnetometers spread across the northern continental United States.

1.2 Applicable Documents.

1. THM-SYS-102 THEMIS Command Format Specification
2. THM-SYS-115 THEMIS Telemetry Data Format Specification
3. THM-SYS-116 THEMIS Telemetry Data Packet Format Specification
4. TBD-PDMP-01 UC GBO ICD (Details UCalgary data collection, distribution, and formats)
5. TBD-PDMP-02 UCLA S/W ICD (Details GBO GMAG data formats)
6. TBD-PDMP-03 UA Canopus GMAG Data ICD (Details GMAG data collected from Canopus GMAGS)
7. THM-SYS-114 Space to Ground ICD
8. THM-SYS-(TBD-PDMP-04) Launch and Early Orbit Operations Plan

2. Project Overview.

2.1 Science Objectives.

The primary objective for the THEMIS project is to understand the onset and macro scale evolution of magnetospheric substorms. A substorm is an instability in the circulation of magnetic flux and plasma through the solar wind magnetospheric system ultimately linked to the familiar auroral eruptions on the Earth's polar ionosphere. Understanding the substorm instability is crucial for space science, basic plasma physics, and space weather, and has been identified by the National Research Council as one of the main strategic questions in space physics. THEMIS will determine for the first time when and where in the magnetosphere substorms start, and how they evolve macroscopically. It will do so by timing well-known plasma particle and field signatures at several locations in the Earth's magnetotail while simultaneously determining the time and location of substorm onset at Earth using a dense network of ground observatories.

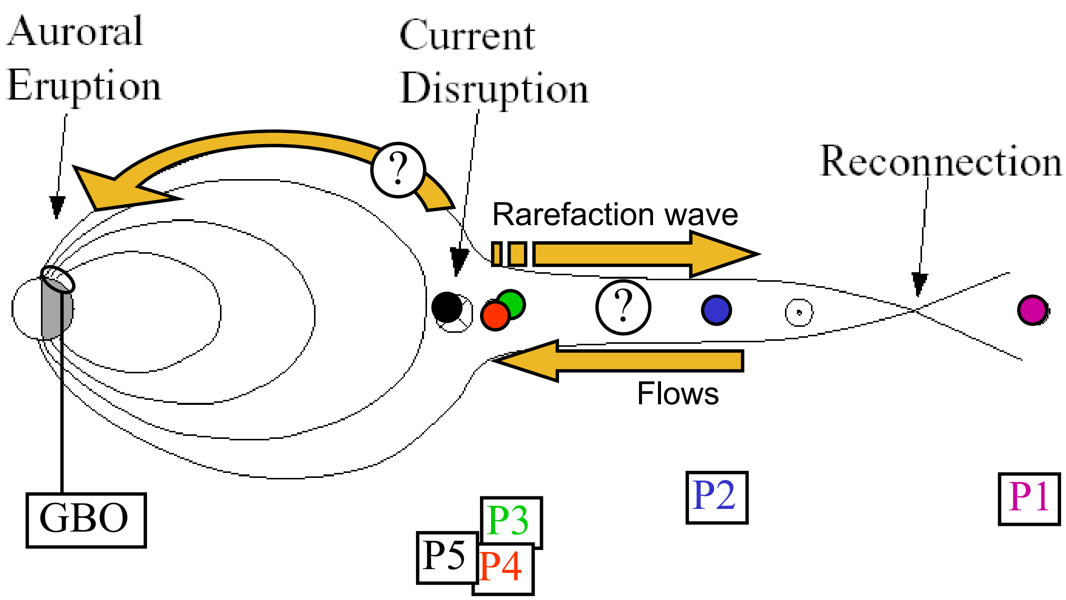


Figure 1 Science Objectives

2.2 Mission Summary.

The THEMIS science objectives are achieved by five space probes in High Earth Orbits (HEO) with similar perigee altitudes (1.16 to 1.5 earth radii, Re) and varying apogee altitudes. Probe 1 has a apogee of ~30 Re, P2 at ~20 Re, and P3 - P5 at ~12 Re, with corresponding orbital periods of ~4, 2, and 1 days, respectively. This choice of periods results in multi-point conjunctions at apogee, allowing the probes to simultaneously measure sub storm signatures over long distances along the magneto tail, while simplifying ground communications and scheduling. The probe conjunctions are tightly coordinated with the ground-based observatories within a 4-month primary data phase per year, centered on mid-February and carried out each year during a 2-year baseline mission. A store-and-forward data flow scheme retrieves prime conjunction plasma and fields data during substorm events with simple, automated science operations.

The ground observations will be carried out by 20 Ground Based Observatories (GBO) spread across Alaska and Canada. Each GBO will use an All Sky Imager (ASI - camera) and ground magnetometer (GMAG) to monitor the auroral light and ionospheric currents in order to localize the time, location, and evolution of the auroral manifestation of the substorm. A second ground network will include 10 Education and Public Outreach (E/PO) Ground Magnetometers located in schools at sub-auroral latitudes in the U.S.

Launch	**Vehicle: Delta II Eastern Range** **Injection: 1.1x12Re, 9 degrees inclination** **Date: August, 2006**
Space Segment	**Spacecraft: 5 spinning probes with fuel for orbit/attitude adjust** **Instruments: 3-Axis E-Field and B-Field, 3-D Ion and Electron Particle Detectors** **Orbit Periods: 1, 2, and 4 days** **Orientation: Ecliptic normal**
Ground Segment	**Ground Based Observatories (GBO): 20 sites in Alaska (4) and Canada(16) containing All Sky Imagers (ASI) and Ground Magnetometers (GMAG)** **E/PO GMAGS: 10 GMAGS placed in schools located in Northern Latitude U.S.**
Operations	**Phases: I&T, L&EO (2 mo), Campaigns (Dec-Mar), De-orbit** **Lifetime: 2 years**

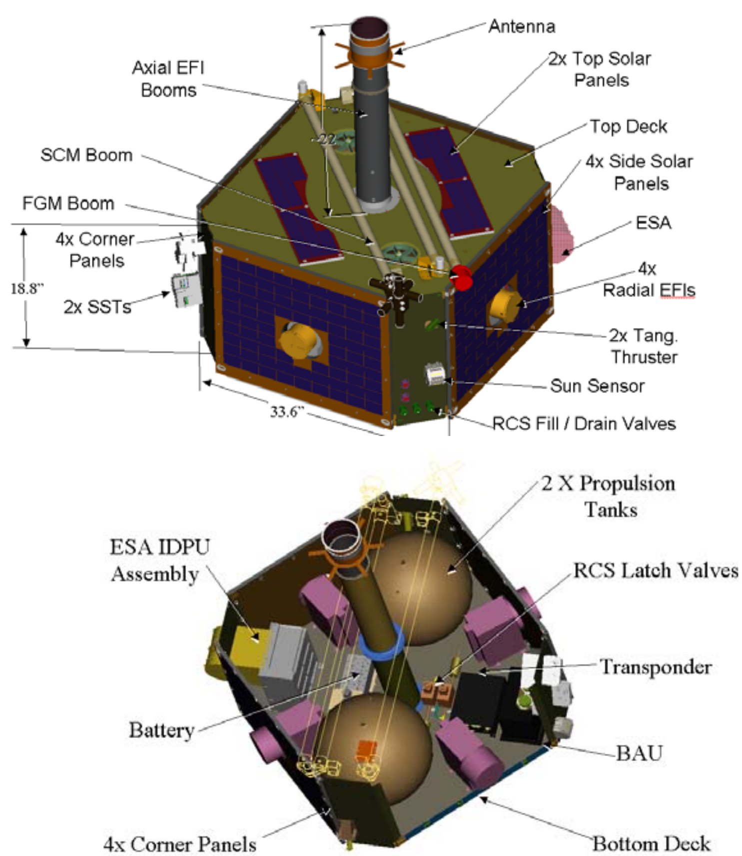
Table 1 THEMIS Mission Summary

3. Probe Description.

3.1 Overview

THEMIS employs 5 simple, identical, high heritage space probes (P1, P2, P3, P4, & P5) in coordinated orbits. Each probe consists of the probe bus (probe) and the instrument suite. The probe bus subsystems include Structural/Mechanical, Thermal, Power, RF and Communications Subsystem (RFCS), Command and Data Handling Subsystem (CDHS), and Guidance Navigation & Control (GN&C). The GN&C consists of the Attitude Control Subsystem (ACS) and the Reactions Control (propulsion) Subsystem (RCS). The electronics associated with the Power, CDHS, ACS, and RCS reside in the Bus Avionics Unit (BAU). The probe bus has a simple, low-rate S-band communication system with a store-and-downlink (near perigee) strategy. It is supported by the General Dynamics ColdFire processor, hosting heritage software to perform data handling and minor fault detection activities. The power system is comprised of simple body-mounted solar panels and a small battery controlled by a direct energy transfer controller. The probes are spin-stabilized and the Attitude Control Subsystem (ACS) uses a fault-tolerant cross-strapped monopropellant hydrazine blow-down system to control orbit, spin rate, and spin axis attitude. ACS is simplified by ground based attitude and orbit determination performed at UCB by the Flight Dynamics Center (FDC). All maneuver sequences are formed, checked (via a spacecraft simulator), uploaded, and executed during real-time ground communications.

Figure 2 THEMIS Probe



3.2 Subsystem Descriptions.

3.2.1 RF and Communications Subsystem (RFCS).

The RFCS utilizes a NASA standard 5-Watt S-Band transponder for Command and Telemetry communications with a single cylindrical FAST-like, torodal gain pattern, omni directional antenna. This transponder allows two-way Doppler ranging for accurate orbit determination. All probes use the same frequency pair for telemetry and commanding. Communications are established with one probe at a time. Command and telemetry protocols for the probes follow standard CCSDS procedures [1]. Downlink telemetry rates are selectable at 1, 4, 8, 16, 32, 64, 128, 512, and 1024 kbps. The command uplink rate is fixed at 1 kbps.

3.2.2 Guidance Navigation and Control (GN&C)

The GN&C subsystem includes the Attitude Control Subsystem (ACS) and the Reaction Control Subsystem (RCS).

The ACS utilizes a manual thruster interface driven by ground-processed estimation and command algorithms with on-board limit and time-out protection. Attitude data collected from a Miniature Spinning Sun Sensor (MSSS) and the science Fluxgate Magnetometer (FGM) are sampled at 10Hz and telemetered to the ground for standard, 3-axis, post-processing estimation. Ground generated thruster command sequences are tested in a hi-fidelity probe simulator (I&T test bed migrated to MOC) prior to any upload. Also, two single-axis gyros, transverse to the spin plane, provide short-term attitude verification (prior to orbit maneuvers). The on-board protection logic monitors real-time sun aspect and the spin period, comparing them to a ground commanded reference uploaded for each maneuver. If thresholds are exceeded, the maneuver is terminated.

The RCS is a two-tank system with two banks of paired thrusters. The RCS utilizes 4 1-N Thrusters: 2 oriented axially, (Both along +Z) for primary In Orbit Checkout (IOC) ΔV; and 2 oriented tangentially for spin up/down control and minor ΔV side thrusting for science operations. The minimum thruster pulse width duration is 1-second.

3.2.3 Command and Data Handling Subsystem (CDHS).

The CDHS provides real-time and stored command capability for the bus subsystems and instruments, collects, formats, and transmits to the ground data from the bus subsystems and instruments, provides engineering data storage, distributes time to the IDPU, and implements autonomous fault protection features to ensure the health and safety of the probe. The CDHS functions are implemented in flight software and hardware that reside in the BAU.

CDHS receives uplink commands from RFCS at a fixed rate of 100 bps using CCSDS telecommand protocols that guarantee correct, in-sequence delivery of variable-length command packets (embedded in command transfer frames) to the probe. Command transfer frames are authenticated. The CDHS is capable of accepting hardware commands (commands that do not require processor involvement) to perform critical operations such as hardware reconfiguration from the ground. Stored command capability in the form of Absolute Time Sequence (ATS) and Relative Time Sequence (RTS) commands is available for controlling the probe and instruments outside of a ground station contact.

CDHS data may involve real-time engineering, playback engineering, or playback science (from the IDPU). The CDHS collects and packetizes engineering data from the bus subsystem and instruments and either delivers this data to the RFCS in real-time for downlink (VC0), or stores the data locally in the BAU for playback at a later time (VC1).The CDHS will also route real-time (VC2) and stored (VC3) science data to the RFCS for downlink.

3.2.4 Power.

The Power Subsystem is a Direct Energy Transfer (DET) system with the battery and solar array connected directly to the power bus. The solar array consists of eight panels, four on each side, and two on each deck. At nominal attitudes, approximately 59 Watts EOL are provided by the side panels and 21 Watts EOL for the top and bottom. Accounting for battery recharging, increased eclipse heater power, and power control efficiencies, the minimum load power available is 41.7 Watts, easily achieving energy balance for the required load power of 29.2 Watts. Eclipse and peak transient loads (i.e., Transmitter operation) are balanced with a 10.5 A-hr, 28V Lithium-Ion battery (TBR). Thermal management using heaters and thermistors keeps the battery at -5 to +25 degrees C.

3.2.5 Structural/Mechanical & Thermal.

The probe consists of a lower deck, an upper deck, and four corner and side panels. The lower deck is the primary mounting surface for most of the instruments and probe components. The upper deck, corner, and side panels close out the probe internal cavity. The FGM and SCM mount to the upper deck; solar cells utilize the exterior surface of the probe side panels as their substrate. The ESA and SST instruments, the fine sun sensor, and thruster brackets mount to two of the corner panels for clear a clear Field of View (FOV). The mechanical and thermal designs provide a low conductance composite structure for isolation of the body-mounted solar panels, minimizing thermal energy effects between full-sun and shadow operations.

3.2.6 Bus Avionics Unit (BAU).

The BAU includes a SMEX-Lite heritage uplink/downlink communications card, a processor card (identical to the IDPU processor card), and a Direct Energy Transfer (DET) power control card with SMEX-Lite and EO-1 heritage. The flight software is derived from prior SMEX mission modules (in C-language) and is hosted by the heritage CMX-RTX Real-Time Operating System (RTOS). Instrument and bus housekeeping data are stored in the local bus memory, while science data are stored in the IDPU. During a ground station contact the housekeeping data is transmitted directly by the bus with the IDPU science data flowing through the bus (bent pipe flow), similar to the FAST implementation.

3.2.7 Probe Carrier Configuration and Launch.

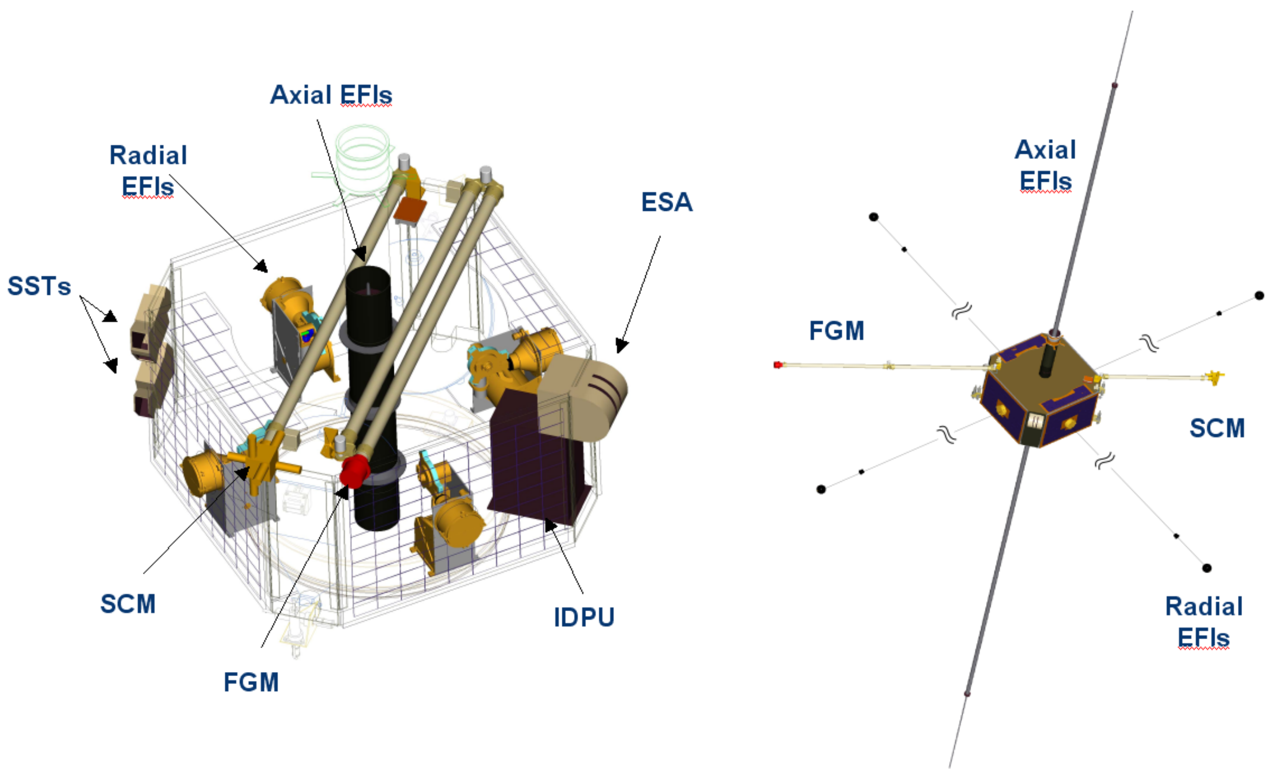
THEMIS will use a standard Delta sequence to directly inject the Probe Carrier Assembly (PCA) into the target parking orbit. The PC does not separate from the third stage. The probes separate from the probe carrier immediately after third stage burnout and yo-yo despin. The probes are electrically independent; each imitates separation based on built-in sequence timers and ELV separation signals, thereby eliminating any credible single point failure. Multiple timers (hardware and software) are provided to protect against premature probe separation. Ground command scan also be used to initiate separation.

4. Instrument Descriptions.

4.1 Overview

Each probe contains an instrument complement that will measure DC and AC electric and magnetic fields as well as electron and ion energies and distributions. A detailed list of the instrument data quantities, data rates, and data volume is given in appendix A, B, and C respectively. The instruments and their probe placement and configuration are detailed in figure 3 below.

Figure 3 Instrument/Probe Configuration



4.2 Fluxgate Magnetometer

A tri-axial fluxgate magnetometer will measure the 3D ambient magnetic field in the frequency bandwidth from DC to 64 Hz (Nyquist).

4.2.1 Science Requirements

1) Measure DC and low frequency perturbations of the magnetic field
2) Time wave and structure propagation between probes
3) Provide information on plasma currents based on instantaneous magnetic field differences on two or more probes, separated by >0.2 Re.

4.2.2 Specification

The unit consists of two orthogonal ring core elements of different diameter, fixed with a bobbin. The unit is mounted on a 2-meter double-hinge carbon epoxy boom. The electronics consist of the driver and control circuits on a board within the IDPU. The controller controls digital excitation, data acquisition, feedback, and compensation, making the device low power. It's low noise permits east inter-calibration with the search-coil magnetometer at frequencies of approximately 10 Hz.

Figure 4 Fluxgate Magnetometer

4.2.3 Calibration

Although a 1 nT absolute accuracy requirement is achievable with independent sensor calibration, it is important to ascertain that two separate probes provide identical values when properties of the medium are steady. As required (near each apogee, perigee or both), calibration data will be collected at 32 Hz to determine (on individual probes) zero levels, gains, and sensor orientation. The magnetometers on all 5 probes will also be inter-calibrated during the early part of the mission (L&EO) using traversals of current-free (or low current density) regions of the magnetosphere. Also, as required during the second year of the mission, magnetometer data from probes P3, P4 and P5 will be collected at high rates outside of burst-mode triggers, in order to perform inter-calibration of their relative orientation and offsets in current-free regions. The validity of a divergence-free assumption (a theoretical necessity) will be used to ascertain the validity of the current-free approximation. If the divergence-free approximation cannot be easily met then time-tagged data from the probes traversing the same region will be compared for trend-recognition after long-term averaging.

4.2.4 Boom Deployment

During L&EO, once the FGM and SCM are operating, the magnetometer booms will be deployed by ground command. This begins by enabling 32 Hz FGM data in the real-time telemetry stream (VC2). The prime and secondary boom release mechanisms are then commanded in succession. The FGM axis rotation is verified during deployment.

4.3 Electrostatic Analyzers (ESA).

The Electrostatic Analyzers will measure thermal ions and electrons in the range 5eV - 30 keV.

4.3.1 Science Requirements

1) Plasma moments to within 10%, at high time resolution (10s or better) for inter-probe timing studies.
2) Instantaneous differences in velocity and ion pressure between probes, to estimate the scale size of transport, the size and strength of flow vortices and the pressure gradient.
3) Distribution functions of ions and electrons, to ascertain the presence of free energy sources.

4.3.2 Specifications

Both the ion and electron ESA have a look direction of 180 degrees in elevation, split in eight 22.5-degree bins (one per anode). Measurements over a 4π steridian are made once per spin. The particles are selected in E/q (where q is the charge) by a sweeping potential applied in 32 steps, 32 times/spin (32 azimuths) between the outer (0 kV and the inner (~3 kV) concentric spheres in a Chevron configuration. On-board moment, pitch angle, and averaging computations are implemented at the IDPU. These operations routinely utilize FGM and SST data (to ensure correct values when the peak flux extends beyond the plasma instrument energy range). Even with onboard averaging, the ESAs generate nearly 3kbytes of data each spin and thus require onboard moment calculations to obtain spin period data. 3-D distributions will be transmitted at a much lower cadence except during event bursts that will contain spin period distributions.

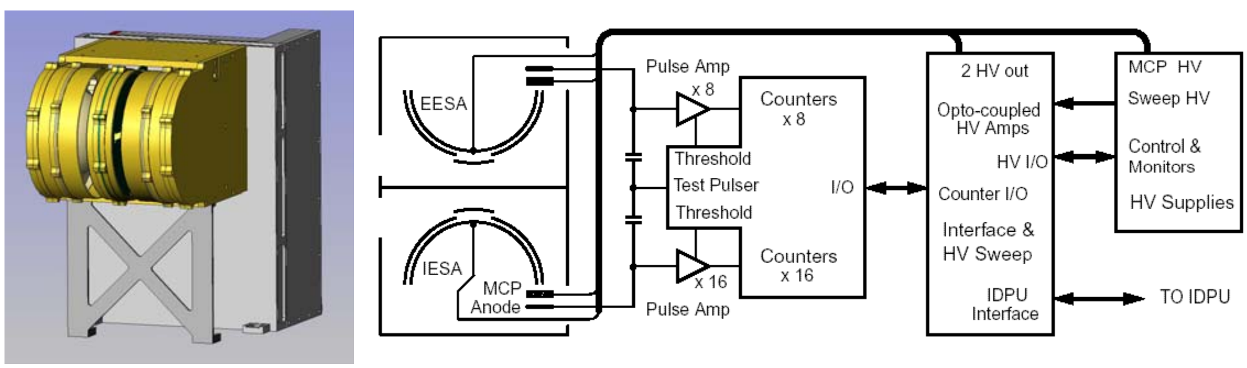


Figure 5 ESA

4.3.3 Calibration

The science requirement of 10% accuracy on moment computation can be met by independent calibration of the ESAs. However, by inter-calibrating hour-long averages of routinely collected particle distributions during quiet-time probe-conjunctions it is expected to surpass the accuracy obtained from independent ESA calibration.

An automated calibration procedure performs a complete angle/energy calibration of an instrument stack in less than 1 day. Calibration determines:

1) analyzer constant, uniformity of energy/angle response
2) Hemisphere concentricity
3) Optimum MCP voltage
4) sweep voltage verification
5) relative geometric factors
6) flight mode validation

Absolute geometric factor values are determined from computer simulations and calibrations with a Ni63 beta source.

4.3.4 Aperture Cover Release

During L&EO the ESA entrance aperture covers will be removed. This process will be commanded from the ground and the cover release is performed using a Shaped Metal Alloy (SMA) device.

4.4 Solid State Telescope (SST).

The Solid State Telescope (SST) measures the angular distribution (~3π steridian coverage) of super thermal ions and electrons. The detectors are identical to the SST pairs flown on the WIND spacecraft. Each probe carries two pairs.

4.4.1 Science Requirements.

1) Perform remote sensing of the tail ward-moving current distribution boundary (at P3, P4, P5)
2) Measure the time-of-arrival of super thermal ions and electrons (30-300 keV, at 10s resolution or better) during injections, and ascertain the Rx onset time (P1, P2).

4.4.2 Specifications

Each probe has two sensor heads. Each head is composed of two double-ended telescopes. Each telescope is equipped with three stacked, fully depleted, passivated, ion-implanted, 1.5 cm2 silicon detectors. The center (T) detector is 600 microns thick, while the outside (O & F) detectors are 300 u thick. The two detector pairs are mounted such that two telescope units point on the spin-plane (~ecliptic). One points above and the other below the spin-plane.

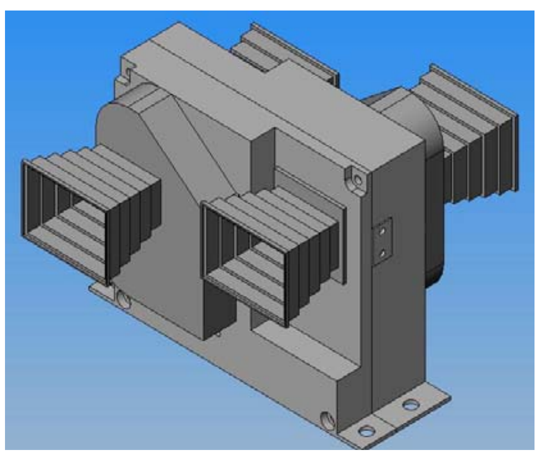


Figure 6 SST

4.4.3 Calibrations

Absolute calibration points are determined by monitoring the highest energy of protons stopped and by placing the pairs (or triplets) of detectors in coincidence and monitoring the minimum ionizing energy for penetrating particles. Such practices have led to superb agreement between SST and ESA fluxes on WIND, and result to <10% absolute flux uncertainty. Inter-probe calibration will also be performed at times of low plasma sheet activity, when the flux anisotropy is low.

4.4.4 Attenuator Operation

The SST attenuator is controlled by the IDPU. It will be operated when the probes get near the radiation belts based on the flux levels measured and ensuring sufficient (~10min) hysterisis built into the design.

4.5 Search Coil Magnetometer

The SCM measures the 3D magnetic field in the frequency bandwidth from 1Hz to 4kHz. It will extend with appropriate sensitivity the measurements of the FGM beyond the 1 Hz range.

4.5.1 Science Requirements

The science requirements derive from the need to measure with appropriate sensitivity (<1pT/sqrtHz @ 10Hz): the cross-field current disruption waves (~0.1 fLH) at least as close to Earth as 8Re (fLH-60Hz).

4.5.2 Specifications

The SCM measures the variation of the magnetic flux threading three orthogonal high permeability μ–metal rods. The unit sensitivity is 0.5pT/sqrtHz @ 10 Hz. A flux feedback loop is employed to ensure phase stability.

The signals from the three sensors are pre-amplified and then processed together with the EFI data at the IDPU.

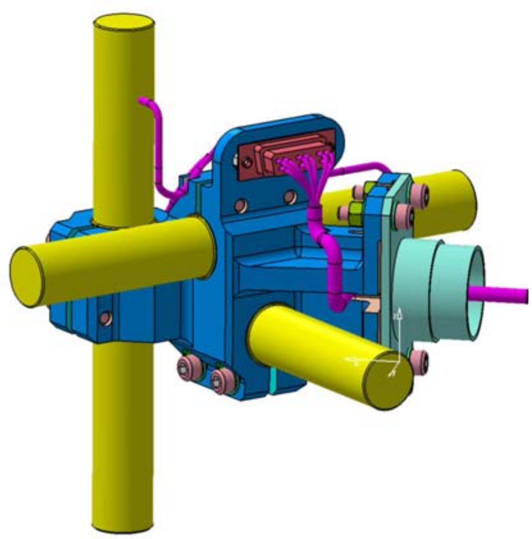


Figure 7 SCM

4.5.3 Calibration

Absolute amplitude and phase calibration takes place with calibration coils that create a known AC pseudo-random noise consisting of a series of discrete frequencies covering most of the bandwidth (10Hz-4kHz). Calibration switch-on is commanded by the IDPU according to a pre-scheduled sequence.

4.5.4 Boom Deployment

See FGM boom deployment.

4.6 Electric Field Instrument (EFI)

The EFI measures the 3D electric field in the frequency range from DC to 300KHz. The three dimensional EFI experiment consists of 4 spin-plane spherical sensors each suspended on it's own 20mm deployable cable 20 meters away from the probe center. Also, 2 axial tubular sensors, each 1m-long and mounted on a 4m-long stacer element.

4.6.1 Science Requirements

Determine at the time of onset at 8-10Re:

1) The plasma pure convection motion, i.e., without the effects of diamagnetic drifts that ESA measurements are subject to.
2) The low frequency (T~1min) wave mode and Pointing flux.

Even under extremely thin plasma sheet conditions the inner probes will determine the axial component independently from the axial boom measurement and provide both a method for calibration of the axial measurement and a backup solution.

4.6.2 Specifications

Boom electronics located at the EFI housing perform stub and guard voltage control and sphere-biasing. Signal processing takes place in the IDPU, together with the SCM. Routine waveforms (32 samples/s) or burst waveforms (128-8192 samples/s) are captured and processed just as for the SCM data. Spectral processing of the low frequency (< 8 kHz) data occurs in the DSP in a fashion identical to the SCM. The wire booms will be deployed with near real-time monitoring of a release and spin-up sequence, each lasting 1-2 hours/probe. Alternating between different THEMIS probes in science and sphere-release phase, mission-total EFI deployment lasts < 10 days.

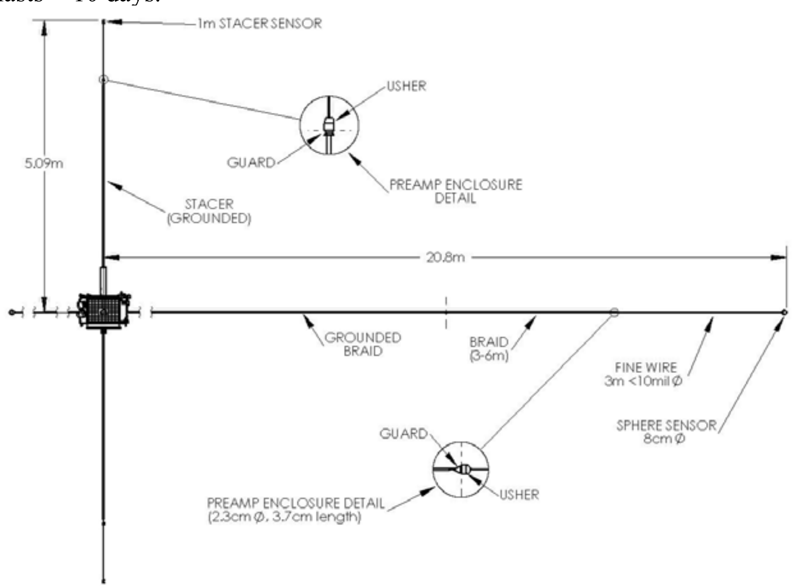


Figure 8 EFI

4.6.3 Calibration

The aforementioned individual probes calibration results in absolute DC measurement accuracy of 0.1 mV/m, i.e. <10% of the field value anticipated during fast flows. Increased confidence in the measurements will be obtained from inter-spacecraft calibration at quiet times.

4.6.4 Deployment Operations

The EFI requires operational commands to govern boom deployment and adjustment as well as science commands to control sensor bias voltages, data sample rates, filter settings, and spectral resolution control. As in previous missions, a typical mode can be specified with ~200 commands valid over a typical operational period of ~1 month once deployment and checkout phases have completed.

Three phases:

1) Deployment alternatively extending the wire boom pair in predetermined increments. During radial wire boom deployment and at each stop, sphere potentials are monitored in order to characterize probe charging affects, plasma environment, and EFI status. After the radial boom deployment, the axial booms are each deployed to their final lengths using one initiator event per boom
2) Checkout: Assuming nominal potential measurements and probe spin rate, the checkout phase begins with final adjustments in wire boom lengths to verify that each pair deployed symmetrically relative to the probe body. These occur in near real-time sessions, monitoring the release and spin-up sequence, each lasting 1-2 hours/probe. Alternating between different THEMIS probes in science data collection and sphere-release phase, mission-total EFI deployment lasts < 10 days. After boom deployment, an EFI early-checkout phase begins in which the photo-currents are characterized and the guards, stubs, and bias adjusted accordingly, requiring a new command load roughly once per week, per probe. Science quality data are returned during this phase which lasts ~1 month
3) During the nominal science phase, the EFI is configured roughly once each month through a command sequence

4.7 Instrument Data Processing Unit (IDPU)

This unit is the heart of the instrument package: it provides instrument power, controls instrument functions, receives instrument commands and obtains housekeeping and science data, stores and processes the data and transmits data to the probe bus electronics. It is the interface between the instrument sensors and the probe BAU. THE IDPU uses an 8085 processor and 256 Mbytes of memory to store science data.

The IDPU collects, compresses, and stores instrument data and transmits the data to the ground upon command with a nominal downlink rate of 512 kbps or 1,024 kbps. The command uplink protocol is a 1 kbps, COP-1 compliant system, with commands relayed by the bus processor. Instrument data is yielded to the IDPU at continuous rates governed by the overall system mode (survey, particle burst, wave burst I or II). The data format is 24-bits consisting of an 8-bit application identifier (AppID) followed by 16 bits of data. Data compression and complete packetization is performed by the processor, prior to storage in the IDPU memory. The IDPU-to-bus C&DH telemetry requirement is a 1 Mbps serial data stream. The IDPU can mix and prioritize engineering and science frames according to operational preferences at downlink time.

During nominal operation, the IDPU provides instrument housekeeping packets to the probe-BAU, which is combined with its data into CCSDS frames for downlink. Stored science data is transmitted separately after engineering data over the high-speed link to the BAU when commanded from the ground.

The IDPU is responsible for monitoring instrument science data and using pre-defined measurement quantities as criteria for the overall instrument data rates. Using a command upload table, the processor steers instrument quantities into a trigger buffer section of memory based on a trigger AppID list. A real-time evaluation of a single measurement level or weighted linear combinations of several measurements are compared to pre-set thresholds as criteria for survey, particle burst, or wave burst instrument rates.

Mode definition tables are large macros used by the IDPU to configure instruments appropriate to the region of space being examined. The IDPU will be programmed with a number of mode definitions that are selected by an ATS command or on-board triggering logic. Assuming 32 macros of 512 bytes each, a full reload would require 16K. ESA and SST Moment Tables are calculated by IDPU FSW at system startup and loaded into the ESA and SST Moment circuitry. For contingency operations, these tables are also directly loadable from the ground. EFI biasing, FGM and SCM parameter modes are expected to be small and included in the mode definitions.

4.8 Ground Observations

Ground observations and measurements will be made of the aurora and earth's magnetic field by two networks of instruments. The first will be 20 Ground Based Observatories (GBO's) spread across Alaska (4) and Canada (16). The GBO's will contain All Sky Imagers (ASI - camera's) and magnetometers. The second network will be 10 Education and Public Outreach (EPO) Ground Magnetometers located in schools at sub-auroral latitudes in the U.S.

4.8.1 Ground Based Observatories (GBO)

The THEMIS mission times substorm signatures on the ground and in space with a time resolution of better than 30 seconds. The comprehensive THEMIS approach to solving the substorm problem calls for monitoring the night side auroral oval with fast (<1s exposures), low cost, and robust white-light All Sky Imagers (ASI) and high-time resolution (1s) Ground Magnetometers (GMAGS). These instrument will produce auroral images and Earth magnetic field measurements. In addition to the ASI and GMAG data, the GBO will produce health and safety data for evaluating the status of the site. The ASI's are provided by UCBerkeley and the GMAGS are supplied by UCLA. Each site will contain a 80 Gbytes harddrive for collecting and storing ASI and GMAD data. The University of Calgary (UC) is responsible for the deployment, maintenance of the GBO's, as well as data retrieval. UC will serve as the prime data hub for collection of the data from the image sites. The University of Alberta will be responsible for ingesting the magnetometer data from the image sites and posting those, along with existing CANOPUS magnetometer as a combined THEMIS ground magnetometer dataset. UCLA will receive the ground magnetometer data. UCB will receive both the image and the magnetometer data.

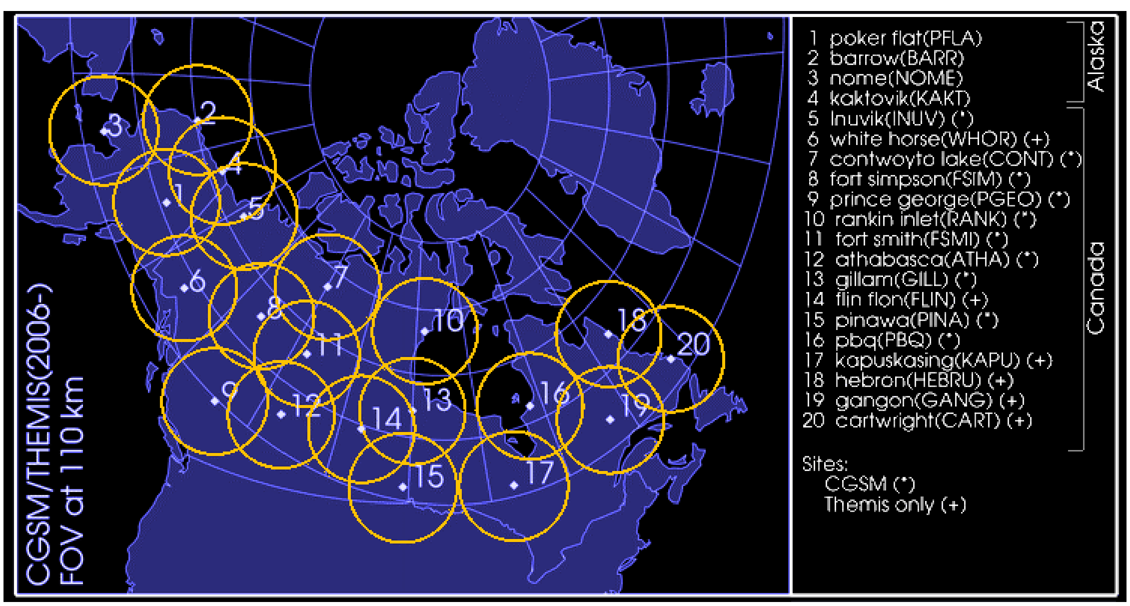


Figure 9 GBO Sites

4.8.1.1 All Sky Imagers (ASI)

Ground substorm onset is determined by sensing the optical (white light) signatures of erupting aurora with the UCB-built ASIs at integration time <1s and time resolution <10s (nominally 3-5 sec). Each GBO will include an auroral All Ski Imager (ASI) developed at UCB based on commercially available components. The camera environmental design is based on the heritage of AGO sites in Alaska. It also includes a GPS receiver, a magnetometer laptop, a ASI laptop in protective foam-cored fiberglass, ruggadized casing, a heater which thaws ice on the dome ensuring good optical measurements, and controlled air flow for spring/summer higher temps. The ASI camera looks through a heated Plexiglas dome that ensures evaporation of precipitation.

Two image data streams will be produced:

- Stream 1 - Thumbnail frames: Will be comprised of low resolution "Thumbnail" frames in compressed binary PGM format. Data is routed from the GBO to UC via the internet using the commercial provider Telesat HIs. This data stream could also contain up to 10% of the raw image frames (Stream2). Each thumbnail is comprised of 20x20 8-bit values (pixels) plus header information (roughly 50 bytes) for a total of ~450bytes. GZIP compression reduces this to 270 bytes/frame (60%). A 5-second frame rate will produce 430 bps or 190 Kbytes/hour.

- Stream 2 - Raw Image Frames: Will consist of high resolution raw image frames stored in PNG format. A fraction of the high resolution data will be recovered with stream 1 (<10%). The remainder is stored redundantly on site and data is recovered by physically swapping out the local disk drive and returning it to UC for download. Each image frame is made up of 256x256 16-bit values (pixels). PNG compression reduces this to 90 Kbytes/frame (70%). A 5-second frame rate will produce 150 kbps or 60 Mbytes/hour

Full images are produced on site and from these the thumbnails are produced. Both are stored locally. At a 5-second cadence there will be 720 images/hour. For stream 2, the expected data volume is **~62 Gbytes annually per station.**

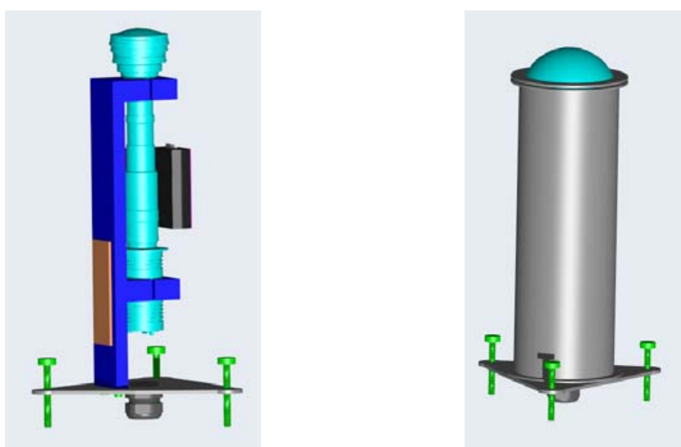


Figure 10 ASI with Outdoor Mounting and Installation

4.8.1.2 Ground Magnetometers (GBO-GMAGS)

There are 8 GBO's (2 in Alaska, 6 in Canada) that will house Ground Magnetometers (GMAGS) developed by UCLA. These units are also referred to as Fluxgate Magnetometers, have a +/-72KnT dynamic range @ 0.03nT resolution, and will produce 2 vectors per second. Each vector consists of three quantities: Bx, By, and Bz, which are measurements of the magnetic field strength along each axis. The data output is expected to be 86.4 Kbytes/hour with approximately 100 bytes/hour for housekeeping and log data. The raw magnetometer data is recorded and calibration is applied when products are compiled for distribution. The GMAGs are small, low power, and have a ruggedized all weather sensor design. These magnetometers complement existing units at CANOPUS all sky stations.

Figure 11 Ground Magnetometer Fluxgate Sensor

4.8.1.3 Health & Safety - System Status

The GBO will log approximately 10 Kbytes of health and safety data every 5 minutes, or 100 Kbytes/hour. Essential information is much lower, roughly 10 Kbytes/hour or 20 bps.

4.8.2 E/PO Ground Magnetometers (E/PO-GMAGS)

UCLA will also build and install 10 additional GMAGS to K-12 schools located in sub-auroral latitudes in the U.S. The UCB Education and Public Outreach group will manage this effort in order to promote inquiry-based and theme-based instruction as well as allow hands-on student participation.

ASCII conversion routines will process the raw magnetometer data at the sites. Working with E/PO personnel, students and teachers will use standard Windows software packages (Excel import of ASCII data) to view and analyze data. Web-based download functions will make the data accessible to other schools and the general public. Data will also be copied to UCLA and UCB. At UCB, the data will be integrated into the data access and retrieval system as well as folded into the summary plot production system.

5. Ground Data System (GDS) Description

5.1 Overview

The THEMIS GDS consists of several functional segments: The Ground Stations (GS) to communicate with the probes on-orbit, the Mission Operations Center (MOC) for probe telemetry and command control, the Flight Dynamics Center (FDC) for probe orbit and attitude determination, and the Science Operations Center (SOC) for instrument data collection, processing, archiving, and distribution functions as well as planning and generating commands for instrument operations. The Berkeley Ground Station (BGS), MOC, FDC, and SOC are all co-located at the Space Sciences Laboratory on the UCB campus. A general description of each GDS segment is given below as well as their operational responsibility.

5.2 Ground Stations

5.2.1 Berkeley Ground Station (BGS)

The primary ground station for THEMIS is the Berkeley Ground Station (BGS). The BGS employs front-end processors for bit synchronization, Viterbi decoding, frame synchronization, Reed-Solomon decoding, and CCSDS channel routing. Data streams that carry real-time engineering and science data are routed directly into the MOC for real-time state-of-health monitoring and control functions. In addition all received telemetry data are stored locally on the ground station in separate files for each virtual channel and are automatically transferred to the MOC and SOC via FTP once the support is complete.

Commanding of the probes is initiated from the ITOS workstations in the MOC and follows standard CCSDS procedures [1]. Individual commands or entire command loads are divided up into CLTUs and are forwarded to the front-end processors via secure TCP/IP network socket connections. The command data stream is then transmitted in real-time at a rate of 1 kbps and BPSK modulated onto a 16-kHz subcarrier. The subcarrier is in turn PM modulated onto the RF carrier with a modulation index of 1.0-1.3 rad. The COP_1 protocol is used to verify command reception on the probe. Once a command is transmitted to the probe, ITOS monitors the Command Link Control Word (CLCW) that is attached to each telemetry frame and indicated the command verification status on-board the probe. ITOS automatically initiates retransmission of commands that are not verified.

Each probe contains a coherent STDN compatible transponder, thus allowing two-way Doppler ranging for accurate orbit determination. All probes use the same frequency pair for telemetry and commanding. Communications are established with one probe at a time.

5.2.2 Secondary and Backup Ground Stations

Secondary ground station support will be provided by NASA/GN stations WGS 11-m, AGO 9-m and HBK 10-m. TDRSS support is baselined for the Launch and Early Orbit (L&EO) phase of the mission to aid in maneuver operations and recovery from anomalous conditions.

Real-time telemetry and command data are carried between the ground station and MOC via a T1 line. Telemetry data stored on the ground are transferred to the MOC and SOC via the open internet. During Launch and Early Orbit (L&EO) operations, TDRSS Single Access mode allows communications with each of the probes after deployment at a low data rate at times when the individual probes are within communications range of a TDRSS spacecraft.

Pass schedule requests generated by the MOC are submitted to the respective scheduling office associated with each ground station network. Confirmed pass schedules are used to perform mission planning and build command loads. All real-time command and telemetry connections between the MOC and ground stations are carried over secure network links. Tracking data are transferred from all ground stations to the FDC to perform orbit determination in order to generate updated ephemeris products. Attitude sensor data received from the probes through the MOC are routed to the FDC to obtain ground based attitude solutions. Once verified, ephemeris products and attitude solutions are used to plan orbit maneuvers.

5.3 Mission Operations Center (MOC)

The THEMIS Mission Operations Center (MOC), located at the Space Science Lab (SSL) on the campus of the University of California Berkeley, will perform mission planning functions, flight dynamics, orbit and attitude determination, maneuver planning, commanding and state of health monitoring of the 5 probes, recovery of science and engineering data, data trending and anomaly resolution. The UCB Flight Operations Team (FOT) will carry out these activities.

5.3.1 Mission Operations

5.3.1.1 Overview

The main operational modes or phases include Pre-Launch, Launch and Early Orbit (L&EO), Nominal Science Operations, Maneuvers, and End-of-Mission. The probes are powered with the receiver on during Pre-Launch and L&EO modes with all deployable appendages stowed during the Probe Carrier (PC) dispense operation. The probes are passively spin-stabilized upon release (even under dispense fault conditions) and full command and telemetry operations commence, initiated by ground command, to each probe using unique identification codes. Deployment of all booms, checkout, and power-up of each instrument is accomplished at the appropriate stages of the In Orbit Checkout (IOC) phase (part of L&EO) to verify key instrument functions and extract body (FGM), sheath (EFI), and field (SCM) calibration data for each unique configuration during these deployments. This allows for independent decoupling and characterization of the probe body effects for use in subsequent science data analysis. While all probes are self-sufficient the MOC/FDC will carry out orbit and attitude determination using the Berkeley Flight Dynamics System (BFDS) and all maneuvers will take place during a ground station contact. A passively spin-stabilized control scheme, 4π steradian power positive body-mounted solar panels and a near omni directional communication coverage allow any probe to fail-safe with no required maneuvers.

5.3.1.2 Pre-launch, Launch and Early Orbit (L&EO) Operations

Pre-launch operations include end-to-end data flow tests, rehearsals, and full mission simulations, integrating and operating all of the GDS elements. During the launch sequence the Delta II injects the PCA into the target parking orbit, initiating the release of the probes from the PCA. At this time operational command and control authority transitions from the L/V controllers to the MOC at UCB. Subsequently each probe is polled via ground station and TDRSS contacts in a round-robin scheme to evaluate state-of-health and to obtain telemetry and tracking data for initial orbit and attitude determination. Once the orbits are well established, the MOC generates the first set of command loads that are uplinked to each probe. Further on-orbit checkout commences with deployment of the SCM/FGM magnetometer booms, which undergo a simultaneous deploy, and the power up sequence of all science instruments. As soon as all probes are checked out, the final designation of probes 1 and 2 is performed based on functional test results and magnetic signature levels. This scheme allows for implementation of mission redundancy and a probe replacement strategy that minimizes impact from off-nominal science instrument performance.

Final orbit injection begins after all probes are re-spun to a spin rate of 15 rpm. Calibration of the tangential thrusters occurs as part of a re-orientation and re-spin sequence. The orbits of each probe are then adjusted in one (P3-P5) or two (P1-P2) discrete pairs of apogee and perigee maneuvers, using the axial thrusters. Each individual maneuver is followed by careful orbit and attitude determination, allowing for a calibration of the axial thrusters. Proper thruster firing is verified in real-time by monitoring telemetry data from the RCS temperature sensors, tank pressure gauges, and attitude sensors. Once placed in their final mission orbits, the probes are commanded to deploy the radial EFI wire booms and subsequently the axial EFI booms. The EFI radial wire-boom pair #1 is deployed first, followed by EFI radial wire boom pair #2. One the radial wire booms have been deployed, the and EFI axial-boom pair undergo a simultaneous deploy.

5.3.1.3 Normal Operations

Normal operations begin with preparation for the conjunction season. During normal operations, communications with each probe are established at least once per day via the primary ground station (BGS) to monitor the probe health and safety, to recover stored engineering data, and to collect tracking data for precise orbit determination.

Data are stored on-board and are dumped over a several-hour-long window at perigee. The stations will transfer health and safety data in real-time (VC0) as well as a subset of science data (VC2) for monitoring instrument performance. The ground station will accumulate all other VC's into files and will deliver these to the MOC (VC1 - stored state of health) and the SOC (VC1-VC3).

Stored science data are downloaded once per orbit near perigee via the primary and secondary ground stations. Data transmissions are initiated by time sequence commands stored on-board each probe. These commands are part of an Absolute Time Sequence (ATS) load generated individually for each probe using the Mission Planning System (MPS). ATS loads are uploaded several times per week and cover at least 8 days for probe 1, 4 days for probe 2, and 2 days for probes 3, 4, and 5.

During normal operations, the orbits of P1, P2, and P5 are adjusted in a few (2-4/year depending on probe) intervals to optimize conjunctions. These short duration adjustments are nominally performed with side thrusting. Additionally, orbit maneuvers are performed once per year with P1 and P2 to the lunar affects on inclination, thus avoiding long shadow periods while optimizing science conjunction time. These longer duration burns for P1 and P2 take place outside the main science season and are performed with axial thrusting.

The Spacecraft Emergency Response System (SERS) is used to contact FOT members if probe/instrument telemetry out-of-limits conditions are detected or other GDS conditions arise that require immediate attention. The SERS will parse through log files generated by ITOS during real-time passes and playback of stored engineering data, and automatically checks for yellow and red telemetry limit violations. The SERS will also act on email warning messages sent to it from other GDS elements. If a limit violation or other GDS anomaly is detected, on-call FOT members are alerted via 2-way email pagers in order to access and resolve the problem.

5.3.1.4 **End of Mission**

After the second year of operations the probes will be positioned for re-entry course.

5.4 Flight Dynamics Center (FDC)

5.4.1 Overview

The FDC is responsible for supporting all orbit dynamics and maneuver functions, such as generation of ephemeris and mission planning products, orbit determination, ACS sensor calibration, attitude determination, maneuver planning, and analysis and calibration of thruster performance.

5.4.2 Software Tools

Four major software tools are used to generate all ephemeris and mission planning products, perform orbit and attitude determination, and carry out maneuver planning functions. These tools are the Goddard Trajectory Determination System (GTDS), the General Maneuver Program (GMAN), and the Multi-mission Spin Axis Stabilized Spacecraft attitude analysis systems were all developed at GSFC. SatTrack is a Commercial Off The Shelf (COTS) program. Probe conjunction analysis is accomplished with a combination of GTDS and an Interactive Data Language (IDL) based software library that was developed in-house at SSL.

5.4.3 Operations

The four major functions of these software tools are described below:

5.4.3.1 Orbit determination

GTDS performs high-precision orbit propagation and orbit determination functions for THEMIS. For orbit-determination, GTDS ingests angle and two-way Doppler tracking data collected from the ground stations in UTDF, DSN, and TDRSS format. These tracking data are obtained during regular science data transmissions at ranges of 20,000 km or less, and during additional passes at other parts of the orbit at each probe. GTDS estimates new state vectors for the five probes and generates an updated ephemeris. . Once state vectors have been updated, new mission planning products are generated, and the updated vectors are distributed to the ground stations to generate new acquisition angles for upcoming pass supports. Routine NORAD orbit determination using radar tracking data provides a back-up for the primary orbit determination.

5.4.3.2 Mission Planning Products

Mission planning products are generated by SatTrack based on GTDS ephemeris output. These include ground station view periods, link access periods, eclipse entry and exit times, and other orbit events required as input to MPS. Other tools in the SatTrack software suite distribute real-time event messages to various ground system elements such as ITOS and the BGS in a fully autonomous client/server network environment

5.4.3.3 Attitude Determination

Ground based attitude determination of the probes utilizes MSASS to ingest raw sensor data from the telemetry stream that are converted into vectors expressed in spacecraft body coordinates. The suite of attitude sensors on each probes comprises a V-slit sun sensor, two mini-gyros, and the dual use three-axis FGM three axis magnetometer. FGM data are utilized during the near-Earth portion of the probe orbits to cross-calibrate the other sensors. Reference vectors for conversion from the body frame to the inertial frame are obtained from the spacecraft, solar, lunar, and planetary ephemeris, and from the most current International Geophysical Reference Model (IGRF) of Earth's magnetic field. Based on these inputs, the MSASS estimator determines the inertial attitude vector at any given time for each probe.

5.4.3.4 Maneuver Planning

The GMAN tool performs all maneuver planning functions. Based on probe propulsion plus current and target state vectors, GMAN generates an optimized mission profile that includes spin-axis reorientation and orbit adjustment maneuvers with coast periods between thruster firings. A typical maneuver scenario includes a reorientation of the probe from its mission attitude to the orbit maneuver attitude, followed by the orbit maneuver itself and the reorientation maneuver returning attitude back to nominal. Attitude reorientation maneuvers are performed near perigee to take advantage of the magnetometer data that allow for independent confirmation of the correct attitude for the subsequent orbit maneuver. Orbit maneuvers are executed near perigee and apogee for operational mission orbit insertion and periodic orbit maintenance. Maneuver planning functions are performed at the FDC in consultation with GSFC/FDAB.

5.5 Flight Operations Team (FOT)

The MOC, FDS, and BGS systems will be controlled and maintained by the UCB Flight Operation Team (FOT). In the MOC, the FOT will use the Integrated Test and Operations System (ITOS) for probe command, control, and Health and Safety (H&S) monitoring. The use of ITOS from I&T through on-orbit operations allows the FOT member to be trained in bus and instrument operations early on, facilitating a smooth transition from I&T to normal operations.

5.6 Science Operations Center (SOC)

5.6.1 Overview

The THEMIS Science Operations Center (SOC), located at the Space Science Lab (SSL) on the campus of the University of California Berkeley, will be responsible for instrument data collection, processing, archiving, and distribution functions as well as planning and generating commands for instrument operations. The SOC works closely with the co-located MOC to guarantee a seamless transfer and processing of telemetry data, and to forward science commands for instrument control and configuration. The MOC will merge instrument commands with other probe Absolute Time Sequence Commands (ATS) and transmit them to the probe.

5.6.2 Science Operations

Data accumulation is expected to be approximately 480 to 640 Mbits per orbit, compressed. Baseline primary science can be accomplished with routine data accumulation. High-time resolution particles and fields datasets are afforded by the Particle and Wave burst modes. Particle bursts collect high resolution distributions and low frequency waveforms. They aim at capturing the components of the global magnetospheric sub storm instability (-5min to +10min from burst trigger). They will be triggered by local plasma conditions. Wave bursts are intended to capture the Electric and Magnetic (E&B) field waveforms of the waves anticipated within the disruption region.

Data are stored on-board and are dumped over a several-hour-long window at perigee. The stations will transfer health and safety data in real-time (VC0) as well as a subset of science data (VC2) for monitoring instrument performance in real-time. The ground station will accumulate all other VC's into files and will deliver these to the MOC (VC1 - stored state of health) and the SOC (VC1 & VC3).

During a probe contact, the ground station will store the VC1 and VC3 data in separate files. When the contact is complete, the files will be forwarded to the SOC server. Reception of the VC files will initiate autonomous processing of the data. Scripts running on the SOC main server will initially strip out the data by Application ID (AppID) and perform and time-sorting if necessary. The AppID data are then mapped to 24 hour data files. Quality checks are performed on the files, determining if data gaps have occurred both within files and between prior data dumps. Once the quality checks have been performed, both the raw VC files, and the 24 hour combined data files will be kept on hard drives and archived to DVD.

The 24 hour data files are converted to Common Data Format (CDF), which are made available to both project science personnel and the general public. The CDF's and instrument calibration files are also used to create overview plots of the instrument data that will allow an operations scientist (Tohban) to check on the status and configuration of the instruments. The data CDFs and calibration files are also used to create summary data CDF's and plots that combine the spacecraft and ground observation data. These are also available to project science personnel and the general public. Access to the data and products will be via the UC Berkeley THEMIS website and via the UC Berkeley THEMIS software package which allows both local and remote access to designated users. The data CDF's will be backed up onto DVD media also.

The data CDFs, calibration files, and overview and summary data products they produce, will be validated daily by the Tohban who is also responsible for daily checks of (i) the overall data quality, (ii) housekeeping data trends (e.g., detector efficiencies and offsets) and (iii)identification and tabulation of geophysical events of special interest.

Interprobe calibration will be performed in the early mission phase to confirm individual probe calibrations but will not be part of the required data validation efforts thereafter so as not to hold up data dissemination.

The probe orbit placements result in highest science returns when the prime tail-season, a four month period, is centered approximately around Feb. 21 of each year. Science operations entail simple instrument command generation and burst trigger table uploads. Probe-probe conjunctions are optimized by two small period trim maneuvers on P1 & P2, at 1 month from the center-tail target date. Dayside science is also optimized by one period trim maneuver of P1 and P2 prior to the dayside observation period (two months after the end of the tail season). P5 also undergoes a period trim maneuver after the first prime science season to accommodate dayside and second year tail season performance. All of these apogee trims. These maneuvers will be carried out at apogee, are short duration, use side-thrusting (tangential thruster pair), and have long post-thrust orbit determination intervals. Prior to the second year tail season a inclination maneuver occurs for P1 and P2 using axial thrusters. This is done to place them in the correct orbit that, considering lunar perturbations, will place them on scientifically optimal inclination and argument of perigee. P3 and P4 nominally remain in the same orbits throughout the mission. In the unlikely event of loss of one probe, the P3 (or P4) fuel budgets are sized so they can replace any other probe.

During maneuvers, the ESA and SST high-voltage will be turned off. Also, the SST will be placed in attenuated mode.

After the second year of operations the probes are positioned for re-entry course. All maneuvers occur while in contact with a ground station with full a priori and a posteriori (near-real-time) attitude and orbit determination.

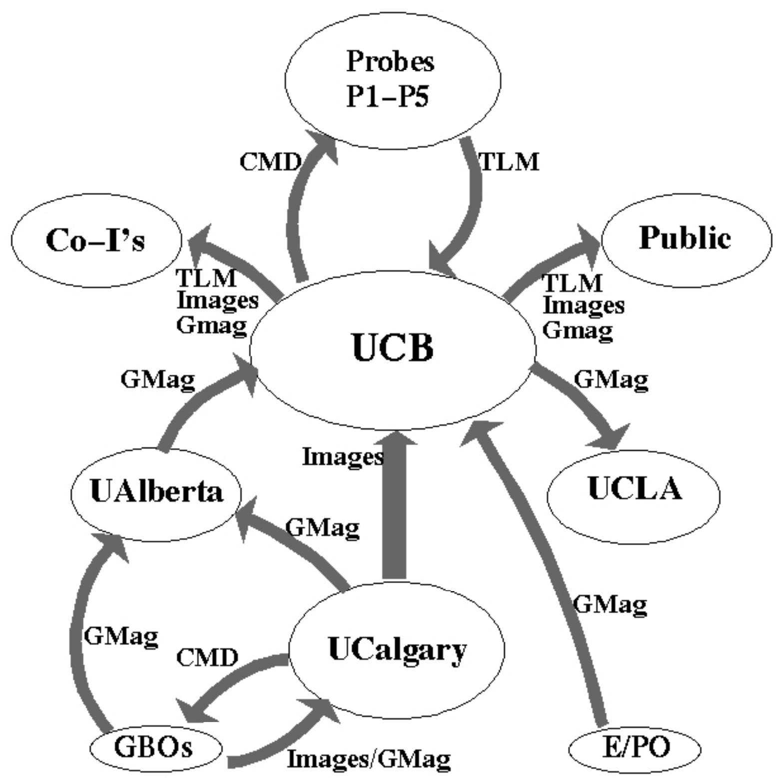


Figure 12 Science Data Flow

6. Project Data Flow

6.1 Probe Telemetry

6.1.1 Overview

A general overview of the timing and flow of the probe telemetry is given in figures TBD-PDMP-05.

6.1.2 Probe to Ground Station

Engineering (VC1) and science data (VC3) are stored on-board and are dumped over a several-hour-long window at perigee. In addition to the stored data, the probe will downlink real-time engineering (VC0) and science (VC2) data. A fill frame (VC7) is also dumped. The dumps are controlled by the stored command loads the UCB FOT had uplinked to the probe.

VC ID	Description
0	Real-time Engineering Data (Probe and Instruments)
1	Stored Engineering Data (Probe and Instruments)
2	Real-time Science Data
3	Stored Science Data
7	Fill

The THEMIS telemetry format is based on CCSDSS standards and data structures. The telemetry link is encoded using concatenated rate-1/2 (K=7) convolutional and Reed-Solomon (223,255,I=5) coding to allow for error correction. Also, the VC3 packet data is compressed [3]. Document [3] fully describes the format compression scheme of the telemetry data the ground stations will receive. The possible telemetry rates are listed below in table 2, with the nominal rate being 512 kbps. The expected data volume during a science dump is 480 Mbits.

The stations will transfer health and safety data in real-time (VC0) as well as a subset of science data (VC2) for monitoring instrument performance in real-time to the MOC. The ground station will accumulate all other VC's into files and will deliver these to the MOC (VC1 - stored state of health) and the SOC (VC1 and VC3) approximately 1 hour after the ground station contact is over.

Bit Rates	1 kbps, 4kbps, 16kbps……512kbps, 1024 kbps
Data Volume per Orbit per probe	480 - 640 Mbits
Virtual Channels	0-3
Encoding	Convolutional and Reed-Solomon
Compression Scheme (VC3 only)	Differencing and truncation or Huffman (TBR)

Table 2 Telemetry Summary

6.1.3 Ground Station to MOC

In real-time, the ground stations will deliver VC0 and VC2 data to an ITOS workstation in the MOC. VC0 will contain health and safety information for the spacecraft and instruments. VC2 will contain a subset of the instrument science data in real-time, which will be useful during Integration and Testing (I&T) and Launch and Early Orbit (L&EO) operations when the instruments will be heavily tested and configured for normal operations. Also, VC2 will give the FOT an additional avenue for checking that instruments are operating properly on a day to day basis. The VC0 and VC2 data will undergo limit checking by ITOS and will be archived to files that will be available for post-pass processing. The results of the limit checking are recorded to a file and passed on to the SERS for error detection and personnel notification.

Following the end of a ground station contact (approximately LOS+1hr), the ground station will deliver a VC1 file to the MOC. This file contains stored health and safety data for the probe and instruments. This file will be processed autonomously by an ITOS workstation in a similar fashion to the real-time support, with the log file passed on to the SERS for error detection and user notification.

6.1.4 Ground Station to SOC

After the contact (approximately LOS+1hr), the ground stations will FTP the VC1 and VC3 files to the SOC server over the open internet. The reception of VC files will initiate the first stage in data processing. Also, these data files will also be immediately available to data analysis tools (SDT and IDL routines) used to thoroughly checkout instrument operation during I&T and the L&EO instrument turn on and commissioning phase. The VC files will remain accessible from hard-drive and be backed up on to DVD.

6.1.5 Telemetry File Formats and Naming Conventions

The ground station telemetry file transfer protocols and file formats are listed in reference document [7]. The file naming convention is listed below:

Telemetry File Naming Conventions:

Format:

- FACILITY.PROBE_BUS_NAME.TLM_VCN.YYYY_DDD_HHMMSS.dat

Examples:

- BGS.THEMIS_0.TLM_VC0.2007_028_060312.dat
- BGS.THEMIS_1.TLM_VC0.2007_028_060312.dat
- BGS.THEMIS_2.TLM_VC0.2007_028_060312.dat
- BGS.THEMIS_3.TLM_VC0.2007_028_060312.dat

6.1.6 SOC Data Processing

6.1.6.1 Level Zero Processing (LZP)

The first major processing step to occur will be to combine and convert the VC1 and VC3 files into 24-hour data files. This step will be referred to as the Level Zero Processing step (LZP) and the files produced referred to as LZP files. In this process the data packets will be stripped out of the VC files, sorted by Application Identifier (AppID), time ordered if necessary, then recombined into 24-hour data files beginning at 0000 GMT. The format of these files is defined below:

TBD-PDMP-06 Figure LZP file format

The file naming convention will be:

scid_yyyymmdd_vv.lzp

where:

scid=Spacecraft Identifier (TBD-PDMP-07)
yyyy=year
mm=month (01-12)
dd=day of month (01-31)
vv=version number (00-99)
lzp=Level Zero Processed

The LZP data files will be stored on local hard-drives and backed up on DVD. The directory structure on the local hard-drive will take the following form:

/data/lzp/yyyy/mm/dd

Every time a 24-hour LZP data file is created or updated, it will initiate the production of Common Data Format (CDF) files. Before the CDF processing step begins, an intermediate process will perform data quality checks and data statistics generation

6.1.6.2 Data Quality Checks and Statistics

After a 24 hour LZP file is created or updated, quality checks and statistics generation operations will occur. These quality check operations look for data gaps and errors as well as generating data statistics. This information is stored in an operational database that will be scanned routinely by autonomous scripts looking for data gaps or errors. When data gaps or errors are discovered, designated operations personnel will be notified via page and/or email.

6.1.6.3 Data CDF's

After each 24 hour LZP file is produced or updated, it will be used to make or update a 24 hour CDF data file. The Level Zero data is processed by a combination of data decommutation software, written in C, and IDL routines, both using standard NSSDC supplied CDF libraries. CDF production will also use orbit and attitude data produced by the FDC. Since orbit and attitude data is essential to the production of the CDF's, any updates to FDC data will also initiate the production or re-production of CDF files. The CDF file naming convention used will be as follows:

scid_yyyymmdd_vv.cdf

Once the CDF files are produced they will be stored on hard-drives and archived to DVD media. The CDF directory structure will take the following form:

/data/cdf/yyyy/mm/dd

The exact content of the CDF files is described in more detail in TBD-PDMP-08.

As the CDF data files are produced, they will be available for download from the UCB website or accessible using the UCB THEMIS software package, which is described in more detail in section 9.

The production or update of a data CDF file will trigger the production of overview and summary data, which is described in the following section.

6.1.6.4 Instrument Overview Plot Production and Instrument Calibration Validation

When a CDF instrument data file has been produced it will trigger the production of instrument overview plots in the form GIF files and CDF files containing the calibrated plot data. These will be produced for the 10 most recent days. The science team associated with each instrument will produce IDL routines that will ingest the 24 hour data CDF file and an associated 24 hour CDF instrument calibration file (1 Cal file per day per instrument per probe) from the previous day to produce the overview plots.

CDF_Instr_Data -> IDL_Overview + CDF_Instr_Cal -> Overview Plots

These plots will be available by **[Ground Reception + 3 Hours]**.

The overview plots will contain detailed instrument science and state of health data, which will allow the operations scientist (TOHBAN) to quickly assess the operation of each instrument as well as validating the instrument calibration files. The TOHBAN reviews the science overview plots and decides on approval or modification of the current days calibration file. Upon approval or modification, the calibration and data CDF files are released for access by the science team and general public. They will be available for download from the UCB website or accessed using the UCB software package. The data CDF remains untouched unless there's an update to orbit data or VC files (more probe/instrument data are received). Initial calibration files (prelaunch) will be developed through instrument and mission I&T.

6.1.6.5 Summary Plot Production

In a similar fashion to the overview plot production, summary plot production will commence following the overview summary plot production step. The summary plots will use the most recent CDF instrument data and validated calibration data as well as the GBO and E/PO GMAG data.

CDF_Instr_Data+GBO_Data+E/PO_Data-> IDL_Summary+CDF_Instr_Cal_Validated -> Summary_Plots

The summary plots will be available in both GIF and CDF format, and are accessible from the UCB website by **[Ground Reception + 24 hours]**.

6.1.6.6 Data Validation

In addition to validating the data and calibrations on a daily basis, the TOHBAN is responsible for daily checks of (i) the overall data quality, (ii) housekeeping data trends (e.g., detector efficiencies and offsets) and (iii)identification and tabulation of geophysical events of special interest.

6.2 GBO Data

In general, the University of Calgary shall serve as the primary data distribution hub for both the ASI image GMAG data, as well as the GBO health and safety data. However, depending on the quality of the internet link to the particular GBO site, other institutions (UA, UCLA) can go directly to the GBO for access to data.

6.2.1 ASI Data -> UCalgary

Stream 1 (thumbnail frames) is transmitted to UC daily and complies with the needs of THEMIS to determine the onset to better than 0.5 hours in MLT. Primary means of stream 1 data retrieval is through the internet provider Telesat HIs using a typical TCP/IP connection, with the expected throughput rate of 50 kbps. Stream 1 should arrive at UC within a few seconds of acquisition and be available for download after review and movement to central storage (~5minutes). An Iridium telephone backup is available for recovery of stream 1 and health and safety data as well as controlling GBO operations. The Iridium phone link operates at 2400 bps.

Once stream 2 is recovered (once or twice a year), the disk integrity/status is checked and data is copied off to central storage (~1 day). The total image data volume (stream 2) amounts to **~62 Gbytes annually per station**.

As soon as ASI data arrives at UC, it will also enter a sophisticated data access and retrieval system developed for NORSTAR's filter camera images and based on keogram summary plots (image North-South slices as a function of time). With this interactive database a user calls up a customized summary of data from one or more stations.

The image data directory tree is:

/data

/imager/<year>/<month>/<day>/<site>_<instrument>/ut<hour>

e.g. /imager/2003/10/17/ATHA_THEMIS00/ut02

Image filename convention:

<date>_<time>_<site>_<instrument>_<mode>_<exposure>.png

e.g. 20031017_024205_ATHA_THEMIS00_VIS_1000ms.png

6.2.2 GMAG Data -> UCalgary

The GBO GMAGs will be producing measurements of the Earth's magnetic field at 2 Hz. These measurements are packetized and sent out every 10 seconds or so to a C++ program which will be generating files which will be pulled (copied) by UCalgary. UCalgary will pull the data at a TBD-PDMP-09 rate.

GMAG Data Directory Structure:

e.g. /imager/2003/10/17/ATHA_THEMIS00/ut02

/data/gbo_gmag/yyyy/mm/dd/ssss

Data Outputs include:

1. **Mag Vector data (ssssdddddd_MAG_hh_cc.RMD)**
2. **Mag housekeeping data (ssssdddddd_MAG_hh_cc.HKD)**
3. **Magnetometer Log Data (ssssdddddd_MAG_hh_cc.LOD)**
4. **Mag Calibration Data (UCLA_GBO_ssss_Vxx_xx.CAL)**

where:
ssss = GBO or E/PO site
dddddd = yymmdd
hh = hr of day (00-23)
cc = hr index if more then 1 file is produced per hour (01-99)

The vector data file format is:

[File Preamble(I32)]
[File Name(string "ssssdddddd_MAG_hh_cc.RMD")]
[Nominal Vector Interval in msec (I32)]
[Time of next data point(string "mmddyyyy-hh:mm:ss-mmm")]
[Number of vectors to follow N (I32)]
[Vector 1 (3xI32)]
[Vector 2 (3xI32)]
....
[Vector N-1 (3xI32)]
[Vector N (3xI32)]
[Time of next data point(string "mmddyyy-hh:mm:ss-mmm")]

Number of vectors to follow N (I32)]
[Vector 1 (3xI32)]
[Vector 2 (3xI32)]
....
[Vector N-1 (3xI32)]
[Vector N (3xI32)]
[File Postamble(I32)]

6.2.3 Health & Safety Data -> UCalgary

Health and safety monitoring of sites will also occur over the Telesat internet link as well as via a back link using a Iridium telephone. The health and safety data will include the following:

- CPU and motherboard temperatures, fan speeds
- hard drive temperature, error rates
- clock status (NTP)
- network status
- power status (UPS)
- free disk space, memory
- web-cam

6.2.4 UCalgary -> UAlberta

The University of Alberta will collect the Canopus GMAG data directly and will pull the GBO UCLA GMAG data from UCalgary as soon as the data is available.

6.2.5 UCalgary -> UCBerkeley

A mirror program operating at UCB will actively monitor the ASI data collection site at UCalgary and pull (copy) any new or updated files to a central repository at UCB. The ASI and GMAG data directory structures and filenames will remain the same.

6.2.6 UAlberta -> UCBerkeley

A mirror program operating at UCB will actively monitor the Canopus and GBO UCLA GMAG data collection site at UAlberta and pull (copy) any new or updated files to a central repository at UCB. The GMAG data directory structure and filename will remain the same.

6.3 E/PO GMAG Data

UCB will collect and distribute the E/PO GMAG data.

6.3.1 E/PO GMAG -> UCB

E/PO GMAG data collection at each site will occur in a similar fashion as that of the GBO GMAGS. The data directory structure and file naming convention remains the same. UCB will pull (copy) the data and store it locally.

6.4 Instrument Command and Control

6.4.1 Overview

The Flight Operation Team (FOT) will carry out instrument command and control from the Mission Operations Center (MOC) under the direction of the operations scientist (TOHBAN), PI, and instrument Co-Is and engineers. Based on planned and observed instrument operation, the TOHBAN will direct the

FOT to send commands to change or update instrument configurations. The TOHBAN will take input from the PI, Co-I's, and instrument engineers. Command and control of the instruments is separated into (4) different operational phases:

1. Instrument Commissioning (L&EO)
2. Normal Operations
3. Conjunction
4. Maneuvers

6.4.2 Instrument Commissioning

Instrument commissioning begins with the IDPU turn-on as soon as the probe power system is stable and temperatures are below maximum operating limits. From there the instruments are powered up and configured based on the THEMIS Launch and Early Orbit Operations Plan [9].

6.4.3 Normal Operations

The instruments will be operated in 4 basic science modes:

- Slow Survey (SS)
- Fast Survey (FS)
- Particle Burst (PB)
- Wave Burst (WB)

Selection of these modes is controlled by either stored commands or on-board triggers.

6.4.3.1 Slow Survey to Fast Survey

The transition between these two modes will be controlled by instrument commands in the probe Absolute Time Sequence (ATS) load. The load is built by the Mission Planning System (MPS) using the ITOS Command Database. The timing of the commands will be taken from a special ephemeris event file supplied by the FDC and ingested by the MPS.

6.4.3.2 Particle & Wave Burst Triggers

For the triggers, the IDPU FSW continuously samples science data in the SSR (e.g., ESA/SST Peak Flux, DFB V1-V6 voltages, FGM Bx-Bz) and evaluates the data at 1 spin resolution against a pre-loaded threshold value. When the threshold is exceeded, it then calculates a Quality value using 8 selectable functions and tags the resulting burst data collected with a value ranging from 0-255. This quality value decides whether the burst is kept or overwritten as subsequent bursts are collected. Also, the quality value determines the memory readout priority. The particle and wave burst trigger setting will be fine tuned early in the mission using ground commands to the IDPU.

6.4.3.3 Conjunction operations

During conjunction season, the FOT will uplink predicted conjunction times to the IDPU. The FSW will increase the Quality evaluation near the conjunction. Also, conjunction duration and bias settings are commandable.

6.4.3.4 Maneuver Operations

During maneuvers the SST and ESA high voltage will be disabled and the SST placed in attenuated mode.

6.5 GBO Control

The current plan is to configure the GPO's, test them thoroughly, then proceed with data recovery once normal operations commence. Changes to the GBO's are not expected. However, if required, software and configuration changes will be carried out by UCalgary via the high speed internet (Telesat) or low speed (Iridium phone) connection. Also, caretakers are available at each site to carry out a limited set of tasks in the operation and maintenance of each unit.

6.6 E/PO GMAG Control

UCLA will be responsible for the overall installation of the E/PO GMAGS. Site control, operation and data retrieval will be the responsibility of local schools under the guidance of UCLA and UCB. Depending on internet access, UCLA will perform configuration and software changes as necessary. The schoolteachers associated with each site will carry out a limited degree of maintenance of the units under the direction of UCB and UCLA E/PO personnel. Data collection will be the responsibility of UCB and a mirror site will be established at UCLA.

7. Science Data Products

UCB will receive and process probe telemetry, GBO data, and E/PO GMAG data, producing a variety of data products that will be available to the projects scientists and the general public. These include:

- Instrument Data CDF Files
- Instrument Calibration CDF Files
- Instrument Overview and Summary Data CDF Files and Plots
- GBO ASI Data and Products
- GBO GMAG Data and Products
- E/PO GMAG Data and Products

7.1 Instrument Data CDF Files

The raw probe engineering and science data that has undergone level zero processing will be used to produce daily data CDF files. These files will contain all of the VC1 and VC3 data collected for a GMT day (00:00 – 23:59:59). These files are stored locally at UCB.

Directory Structure:

/data/cdf/yyyy/mm/dd

File Naming Convention:

scid_yyyymmdd_vv.cdf

where:

scid	**= Spacecraft ID (TBD-PDMP-07)**
yyyy	**= year**
mm	**= month (01-12)**
dd	**= day (01-31)**
vv	**= version (00-99)**
cdf	**= Common Data Format**

A detailed description of the format of these files is described in reference document [TBD-PDMP-08].

7.2 Instrument Data Calibration Files

Calibration files will exist for each instrument and will be used for processing the raw data quantities that are transmitted in VC3. The calibration files will be initially created based on ground based instrument testing and evaluation during I&T.

The following calibration files are planned:

1) **FGM Mounting Orthogonality and gain**
2) **FGM Boom Angles**
3) **SCM Boom Angles**
4) **SCM Gains**
5) **ESA MCP Gains, one per anode for 16 anodes x 2 heads**
6) **SST Gains, 3 per telescope x 4 telescopes x 2 shutter conditions (open/closed**
7) **EFI 1 current and 3 voltages per sensor x 6 sensors**

A file will be produced for each day and will be associated with the data for that day. The calibration file naming convention and directory structure are listed below.

Directory Structure:

/data/cal/yyyy/mm/dd

File naming convention:

scid_type_yyyymmdd_vv.cal

where:

scid = spacecraft ID
type = Calibration type (e.g., SSTG for SST Gains)
vv = version number
cal = calibration

Interprobe calibration will be performed in the early mission phase to confirm individual probe calibrations but will not be part of the data analysis efforts thereafter so as not to hold up data dissemination

7.3 Instrument Data Overview and Summary Data CDF's and Plots

The data CDF's and calibration files will be used to produce overview and summary data CDF's and Plots. These are listed below:

1) **Keograms (GBO Image Data Overview)**
2) **Auroral Electrojet Indices (GBO Magnetometer Data Overview)**
3) **E/PO Ground Magnetometer Data Overview**
4) **P1 data (Probe Overview)**
5) **P2 data "**
6) **P3 data "**
7) **P4 data "**
8) **P5 data "**
9) **Mission Overview Plot**

The overview and summary data and plots will be available at the UCB website.

7.4 GBO Data and Products

UCB will receive the raw image, GMAG, and calibration data and will produce the following data products.

7.4.1 ASI

The ASI data and data products available at UCBerkeley will include the following:

- Image Thumbnail frames: 20x20 8-bit values (pixels) plus header information (roughly 50 bytes) for a total of ~450bytes. File format = PGM.
- Raw Image Frames: 256x256 16-bit values (pixels). Approximately 131 kbytes in size. File format = PNG
- Calibration files
- Keogram summary plots (NORSTAR's keograms - summary's of one or more stations)
- Composite global views providing both quick overview of data availability and a portal to data selection, decommutation, and analysis

UCalgary will also produce it's own ASI data product set which will be available at it's own website. In addition to the raw image and calibration data, this will include:

- Site status info/plots
- Keograms (latitude slice versus time) for each site
- Merged intensity maps of all stream 1 data
- Merged maps of stream 2 data
- Estimates of visibility based on stars
- Estimates of arc location and orientation (when viewing is good)
- CDF for advanced data products
- raw ASCII and PNG/JPEG for availability lists and summary plots

7.4.2 GMAG

The GMAG data will include the following:

- Raw vector data
- Calibration files
- Auroral Electrojet Indices

Auroral Electrojet indices, already developed for Canopus, give similar, synoptic ground magnetometer information (similar to the presentation of NORSTAR data).

Both UA and UCLA will be producing their own GMAG data products that will be available at their own websites.

7.5 E/PO GMAG Data Products

When the E/PO GMAG data is received at UCB it will be used to produce Auroral Electrojet Indices similar to those produced using the GBO GMAG data. The data will also be folded into mission composite summary plots that will display probe, GBO, and E/PO GMAG data. UCLA will also be producing it's own data product set.

- Raw Vector data
- Calibration files

- Auroral Electrojet Indices

8. Data Access

Access to the THEMIS data and products will be through one of the following:

1. THEMIS Data Analysis Software Package File Search Tool
2. THEMIS Website

8.1 THEMIS Data Analysis Software Package File Search Tool

The File Search Tool (FST) is part of the Data Analysis Software Package which will be available for download from the THEMIS website. The FST will allow both internal and external users (with permission from PI) to query for instrument data and calibration CDF files and associated GBO and E/PO data based on probe ID, date, and time. The internal users will copy files over the Local Area Network (LAN) while external users will use secure FTP or COPY.

8.2 Website

The THEMIS website (TBD-PDMP-10) will allow users to query for instrument data and calibration CDF files, GBO ASI and GMAG raw and calibration files, E/PO GMAG raw and calibration files, and all of the associated data products.

TBD-PDMP-11 Figure: Availability of data CDF's, cal files, and summary data

9. Data Analysis Software

9.1 Overview

UCB will produce and make available a software package for accessing and processing the instrument data and calibration CDF files, GBO ASI and GMAG data, and the E/PO GMAG data. For instrument data, science data analysis software exists in the form of an extensive library of IDL programs and the Science Data Tool (SDT) developed at SSL to analyze data from FAST, WIND, CLUSTER, and POLAR. The decommutator functions that allow access to the raw and CDF formatted data are adapted from those developed to for analysis of FAST science data. In general, four IDL-based software suites are planned:

1) Single probe analysis software, is directly transferable to THEMIS from FAST and WIND.
2) Multi-point data analysis software from ISTP and CLUSTERII analysis to compute the flow shear/curl and pressure gradient along with their standard error will be directly implemented or modified for THEMIS
3) Ancillary Data Software. An existing distributed database of such data will be upgraded with IDL decommutators for plotting them seamlessly, relative to THEMIS quantities
4) Event Modeling. IDL codes that fly virtual probes within simulation run results under specific, idealized solar wind external conditions already exist. These will allow comparisons between models and observations.

For ASI and GMAG data, tools already exist for accessing, evaluating, and comparing the ground observatory data with the space-borne measurements. Data will be analyzed using standard IDL-Based routines developed from years of experience with NORSTAR and other AGO's.

The different software for accessing and analyzing the variety of data and data products will be integrated into one complete package that will be distributed to Co-Is and guest investigators throughout the mission as updates are made. Training sessions in the use of this software are planned. The software package will also be freely available from the UCB website.

9.2 File Search Tool

The file search tool will be available in both a command line and GUI form. The user will enter from 1 to 5 probe IDs and the time period of interest. The tool will initially check the users local directory for the data, and if not found will initiate a LAN copy or FTP session to download the data. In addition to requesting probe data, the user can request ASI and GMAG data for the same period. The user can also go down a basic directory path either locally or from the website and download data via local copy, remote copy, http, or ftp.

Once data is downloaded and available on the users workstation they can engage the second layer of data decommutation software and/or data analysis software described below.

9.3 Moments & Fields Tool

This tool will take data from CDF files and covert them into an ASCII file containing Density (N), Velocity (V), Temperature (T), Pressure (P), Mag field (Bxyz), Electric Field (Exyz), and Position (X,Y,Z). For the particle instruments, this tool will ingest the CDF file and produce an ASCII file that includes:

- N = Density
- V = Velocity
- T = Temperature
- P = Pressure

Partial ion density from the ESA: Niesa
Partial electron pressure from SST: Pesst

For the Fluxgate Magnetometer, this tool will produce:

- Bxyz

For the Electric Field Instrument, this tool will produce:

- Exyz

The filter banks from the EFI and SCM will both produce 8 quantities at spin resolution. The 8 quantities represent the electric field power in 8 frequency bins, as well as the magnetic field power in 8 freq bins.

9.4 Reading and Writing Tools

These include:

- Basic read routine
- Basic write routine
- Conversion routines like cdf2flat, cdf2asci, and cdf2cdf
- Processing routines
- Plotting routines like Specplot, dfplot, lineplot, tplot

10. Data Archiving and Distribution

The following data will be available in its entirety on disk drives at UCB as well as being backed up onto DVD media:

1. VC1 and VC3 files from the ground stations
2. 24 hour LZP data files
3. 24 hour instrument CDF data files

4. GBO Data (ASI & GMAG)
5. E/PO GMAG

The DVD's containing the 24-hour instrument CDF data files will be distributed to Co-I's and NSSDC on a monthly basis.

11. Appendix A. Instrument Data Quantities

Chan	Name	Description	Sync	Bytes
0	DFB64	0 Filters 2 x 8 bytes at 1/16 to 8 Hz	1/16 Hz	2048
1	DFB65	1 Fast Survey (A) V1-V6 at 2 to 256 Hz	1 Hz	3072
2	DFB66	2 Fast Survey (B) V1-V6 at 2 to 256 Hz	1 Hz	3072
3	DFB67	3 Fast Survey E12DC, E34DC, E56DC at 2 to 256 Hz	1 Hz	1536
4	DFB68	4 Fast Survey SCM1, SCM2, SCM3 at 2 to 256 Hz	1 Hz	1536
5	DFB69	5 Particle Burst (A) V1-V6 at 2 to 256 Hz	1 Hz	3072
6	DFB70	6 Particle Burst (B) V1-V6 at 2 to 256 Hz	1 Hz	3072
7	DFB71	7 Particle Burst E12DC, E34DC, E56DC at 2 to 256 Hz	1 Hz	1536
8	DFB72	8 Particle Burst SCM1, SCM2, SCM3 at 2 to 256 Hz	1 Hz	1536
9	DFB73	9 Fast Survey Spectra 1 to 4 16-64 pts @1/4-8 Hz	1 Hz	2048
10	DFB74	10 Wave Burst Spectra 1 to 4 16-64 pts @1/4-8 Hz	1 Hz	2048
11	DFB75	11 Wave Burst (A) V1-V6 at 512 to 8192 Hz	32 Hz	3072
12	DFB76	12 Wave Burst (B) V1-V6 at 512 to 8192 Hz	32 Hz	3072
13	DFB77	13 Wave Burst E12DC, E34DC, E56DC at 512 to 16384 Hz	32 Hz	3072
14	DFB78	14 Wave Burst SCM1, SCM2, SCM3 at 512 to 16384 Hz	32 Hz	3072
15	DFB79	15 Trigger (and Engineering Data) 28-32 values at 16Hz	1 Hz	512
16	DFB80	16 Spin Fits (E12, E34, E56, V1, V2, V3, V4 * 128Hz)	1 Hz	1792

Chan	Name	Description	Sync	Bytes
17	ETC_MOM	ESA and SST Moments [13x2x2 + 13x2x2 every spin collected for 16 spins]	Spin/16	1664
18	eESA_FDF	ESA Burst Electron 88x32 Angle*Energies	Spin	2816
19	iESA_FDF	ESA Burst Ion 88x32 Angle*Energies	Spin	2816
20	eSST_FDF	SST Burst Electron 88x32 Angle*Energies	Spin	2816
21	eSST_FDF	SST Burst Ion 88x32 Angle*Energies	Spin	2816
22	eESA_FDF	ESA Survey Electron 88x32 Angle*Energies	Spin/N	2816
23	iESA_FDF	ESA Survey Ion 88x32 Angle*Energies	Spin/N	2816
24	eSST_FDF	SST Survey Electron 88x32 Angle*Energies	Spin/N	2816
25	eSST_FDF	SST Survey Ion 88x32 Angle*Energies	Spin/N	2816
26	eESA_RDF	ESA Survey Electron 8x16 Angle*Energies	Spin/16	2048
27	iESA_RDF	ESA Survey Ion 8x16 Angle*Energies	Spin/16	2048
28	eSST_RDF	SST Survey Electron 8x16 Angle*Energies	Spin/16	2048
29	eSST_RDF	SST Survey Ion 8x16 Angle*Energies	Spin/16	2048
30	FGE_TML	FGM X, Y, Z from 4 to 32 Hz. Prescaled to 16-bits each	1/16 Hz	3072
31	FGE_TMH	FGM X, Y, Z fixed at 128 Hz. Prescaled to 16-bits each	1/4 Hz	3072
32	FGE_TMH	FGM X, Y, Z fixed at 128 Hz. Prescaled to 16-bits each	1 Hz	768

12. Appendix B. Instrument Data Rates

	Survey							
	Slow Survey (Radbelt science)				Fast Survey (baseline science)			
	S/spin	CH/agle-ergies	BW	bits/s	S/spin	CH/agle-ergies	BW [Sps]	bits/s
FGM	1	5	DC-0.333Sps	27	16	3	5.33	256
SCM	1	8	FB: 1Hz-2kSps	21	32	3	10.67	512
EFI	1	14	DC-2kSps	53	32	4	10.67	683
SST	1	525	spin mom	160	1	2560	spin RDF	2816
ESA	1	1422	spin mom	208	1	4224	spin RDF	7627
Totals (bits/second)				469				11893
Data Rates by category (particles and fields)								
Fields				101				1451
Particles				368				10443

Particle Burst (baseline science, all except HF modes)				Wave Burst (HF modes)											
				Wave Burst 1				Wave Burst 2							
S/sec	CH/agle-ergies	BW [Sps]	bits/s	S/sec	CH/agle-ergies	BW	bits/s	S/sec	CH/agle-ergies	BW	bits/s				
32	3	DC-16 Hz	1536	128	3	DC-64 Hz	6144	128	3	DC-64 Hz	6144				
128	35	10Hz-128Sps	6656	1024	67	32-512 Hz	51200	4096	67	32-2048 Hz	198656				
128	36	DC-128Sps	8704	1024	68	32-512 Hz	67584	4096	68	32-2048 Hz	264192				
-	1	spin FDF	10923	-	0	-	0	-	0	-	0				
-	1	spin FDF	15019	-	0	-	0	-	0	-	0				
			42837				124928				468992				
			16896				124928				468992				
			25941				0				0				

13. Appendix C. Instrument Data Volumes

Compression factor = 1.5

Mbits/ 24 hrs

Instrument	Slow Survey	Fast Survey	Particle Burst	Wave Burst	Total	
FGM	2	10	7	3	21	
SCM	2	20	28	22	72	
EFI	5	27	37	29	97	
SST	14	109	47	0	170	
ESA	18	297	64	0	379	
Total	41	462	183	53	740	
Compressed volume					493	Mbits
Rate/day					493	Mbits

S/C Mode durations / orbits

T_orbit = 24 hrs

S/C Mode	Rel. Allocation		Abs. Allocation		Hours	Seconds	Rate (bps)	Data Vol (Mbits)
T slow survey	100%	T_orb	100%	T_orb	24	86400	469	41
T fast survey	45%	T_ss	45%	T_orb	10.8	38880	11893	462
T P-burst	11%	T_fs	5.0%	T_orb	1.19	4277	42837	183
T W-burst1*	10%	T_pb	0.5%	T_orb	0.12	428	124928	53
T W-burst2*	3%	T_pb	0.1%	T_orb	0.03	114	468992	53
								740

Mbits/ 48 hrs

Instrument	Slow Survey	Fast Survey	Particle Burst	Wave Burst	Total	
FGM	5	10	6	2	23	
SCM	4	19	25	19	68	
EFI	9	26	33	26	94	
SST	28	107	42	0	176	
ESA	36	290	57	0	383	
Total	81	452	163	47	744	
Compressed volume					496	Mbits
Rate/day					248	Mbits

S/C Mode durations / orbits

T_orbit = 48 hrs

S/C Mode	Rel. Allocation		Abs. Allocation		Hours	Seconds	Rate (bps)	Data Vol (Mbits)
T slow survey	100%	T_orb	100%	T_orb	48	172800	469	81
T fast survey	22%	T_ss	22%	T_orb	10.6	38016	11893	452
T P-burst	10%	T_fs	2.2%	T_orb	1.06	3802	42837	163
T W-burst1*	10%	T_pb	0.2%	T_orb	0.11	380	124928	47
T W-burst2*	3%	T_pb	0.1%	T_orb	0.03	101	468992	47
								744

Mbits/ 96 hrs

Instrument	Slow Survey	Fast Survey	Particle Burst	Wave Burst	Total	
FGM	9	10	4	1	24	
SCM	7	19	15	12	54	
EFI	18	26	20	15	80	
SST	55	107	25	0	187	
ESA	72	290	34	0	396	
Total	162	452	98	28	741	
Compressed volume					494	Mbits
Rate/day					123	Mbits

S/C Mode durations / orbits

T_orbit = 96 hrs

S/C Mode	Rel. Allocation		Abs. Allocation		Hours	Seconds	Rate (bps)	Data Vol (Mbits)
T slow survey	100%	T_orb	100%	T_orb	96	345600	469	162
T fast survey	11%	T_ss	11%	T_orb	10.6	38016	11893	452
T P-burst	6%	T_fs	0.7%	T_orb	0.63	2281	42837	98
T W-burst1*	10%	T_pb	0.1%	T_orb	0.06	228	124928	28
T W-burst2*	3%	T_pb	0.0%	T_orb	0.02	61	468992	28
								741