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THEMIS Ground Based Observatory System Design

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Abstract The comprehensive THEMIS approach to solving the substorm problem calls for monitoring the nightside auroral oval with low-cost, robust white-light imagers and magnetometers that can deliver high time resolution data (0.33 and 2 Hz, respectively). A network of 20 Ground-Based Observatories (GBOs) are deployed across Canada and Alaska to support the collection of data from these instruments. Here we describe the system design of the observatory, with emphasis on how the design meets the environmental and data-collection requirements. We also review the design of the All Sky Imager (ASI), discuss how it was built to survive Arctic deployments, and summarize the optical characterizations performed to qualify the design to meet THEMIS mission requirements.

Keywords All sky camera · Geophysics · Aurora · Magnetometer · Magnetosphere

PACS 94.80.+g · 94.30.Aa

1 Introduction

In the spring of 2003, the team responsible for developing the THEMIS Ground Based Observatory (GBO) network kicked off the project by deriving a set of engineering and site requirements based upon the science requirements of the THEMIS mission. These top-level requirements are:

> The GBO shall monitor the auroral light and ionospheric currents across North America in order to localize the time, location, and evolution of the auroral manifestation of the substorm.
> Determine substorm onset time and substorm meridian magnetic local time (MLT) using ground All Sky Imagers (one per MLT hr) and Ground Magnetometers (two per MLT hr) with time resolution better than 30 s and MLT resolution better than 6 degrees, across an 8 hr geographic local time sector including the US.

The team advanced GBO goals to satisfy these requirements with a network of 20 GBOs, that would provide time resolution better than 5 s and MLT resolution better than 1°. The network would span more than 10 hours of geographic local time with ASIs, and more than 14 hours of GMAG coverage, when non-THEMIS magnetometers are considered. This level of continental coverage was a primary technical driver for our efforts.

This team, consisting of researchers at the University of California Berkeley (UCB), the University of Calgary and the University of California Los Angeles (UCLA), collectively included a considerable amount of experience in fielding unattended, ground observatories. It became clear from the outset that the practical considerations of deploying GBOs in remote areas of the North American Arctic would constitute the greater challenge to the project than designing the package. For an example, see Fig. 1. Nonetheless, the combined efforts of the team resulted in a concise set of design criteria and an implementation philosophy that successfully carried the project through to completion.

UCB experience with All Sky Cameras and remote observations is derived from years of field development, deployment, and operation of such systems in remote locations, like the Automatic Geophysical Observatory (AGO) sites in Antarctica (Mende et al. 1999). Figure 2 is a photo of one of the AGO sites, from which we borrow many "lessons learned" and heritage for the GBO development. UCalgary experience is derived from developing

Fig. 1 GBO installation at Inuvik, NT, Canada. The GBO site is about 6 km outside the town of Inuvik. It is very remote, as suggested by the image on the *left*, which shows the road out to the site. The shelter is an ISO container that was outfitted by researchers from the University of Saskatchewan, who operate an ionospheric sounder at the site

Fig. 2 AGO site in Antarctica. Lacking a ready source of local power, the AGOs have been a much greater challenge to design and operate than the GBOs. Nonetheless the systems have much in common

and fielding All-Sky Cameras for the CANOPUS and Canadian GeoSpace Monitoring Programs (Donovan et al. 2003). UCLA's experience is derived from many years of development, deployment, and operation of ground magnetometers in remote sites around the world, including the US, China, Central, and South America.

In this paper we describe the details of the GBO system design, and also include some discussion of our integration and test program. Accompanying articles separately cover other aspects of the THEMIS GBO experiment design, mission requirements, and magnetometer design, so that will not be repeated here.

1.1 Implementation Philosophy

From the start, the plan was to "get in the field, early and often." In other words, the real test of our designs would be in the field, experiencing real weather and other real hazards. While normal laboratory testing is important, it is difficult to simulate the environment and hazards that the GBOs would face. We therefore planned to field a prototype GBO during the next winter season (2003–2004), and prepared to follow that up by fielding four additional units

Fig. 3 GBO Prototype at Athabasca University Geophysical Observatory (AUGO). Shown here is the environmental enclosure, designed to house the Observatory Support Electronics, which are inside. On the right side of the enclosure can be seen the shroud covering the solid state air conditioner and the cable access

during the winter of 2004–2005. We were fully aware that these early systems would have to be upgraded in the field once, or if, the design evolved and changed. And, of course, the design most certainly did change.

This approach meant a very quick development to enable us to field a prototype system by the winter of 2003–2004. The prototype testing took place in Calgary, and also at the very accessible Geophysical Observatory, operated by Athabasca University. Figure 3 shows the prototype GBO as installed in April, 2004.

With our Calgary partners spearheading the deployment effort in Canada, three sites were in operation during the winter of 2004–2005. By the following winter of 2005–2006 we had 10 sites operating, and by the fall of 2006, we had completed 19 of the planned 20 deployments. The final, 20th site was deployed in northern Quebec in fall 2007.

With more than 20 systems to build and deploy, other important aspects of our design philosophy included the following:

- Minimize custom design, and use off-the-shelf components to the greatest extent possible, thereby keeping cost low.
- Select sites that meet optical and magnetic requirements, but they must have access to power, and they must be accessible by a qualified local manager, or custodian, who can maintain the GBO.
- Some sites did not require some components, e.g., magnetometers were not required at all of the sites. Regardless of this, minimize design differences between the sites so that operating software could be maintained uniformly. Keep the design simple and modular enough that components could be easily left out.

2 System Overview

Figure 4 provides a pictorial illustration of all the components that comprise a fully deployed GBO. The primary scientific instruments are the All Sky Imager (ASI) and the Ground Magnetometer (GMAG). The remaining elements are there to support data acquisition, control and communication. GPS is used as a time reference. Iridium, a low-speed, satellite-based communication network, is used for backup communication with the site when the Internet connection is down or unavailable. The Observatory Support Equipment (OSE), mounted

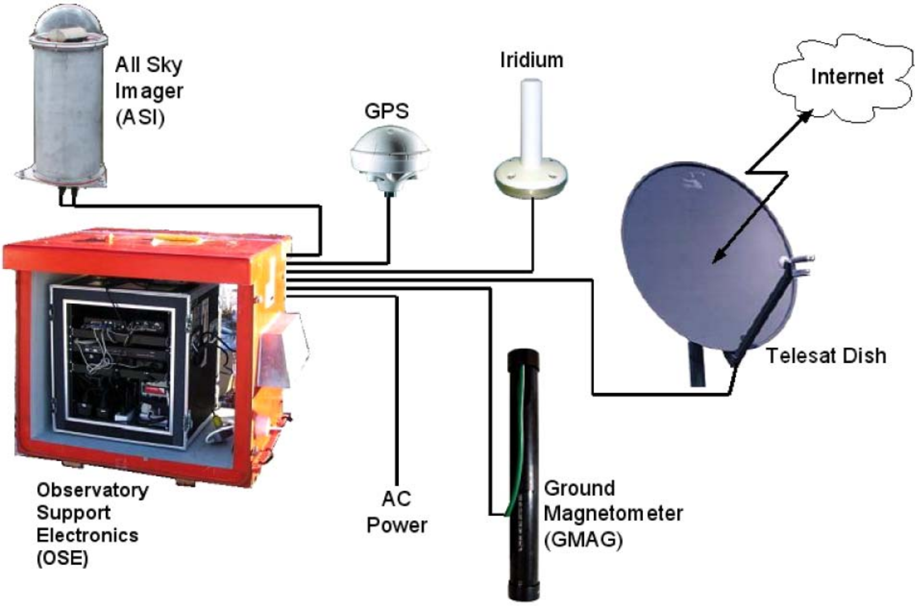

Fig. 4 A depiction of the top-level block diagram for a fully deployed GBO. The Observatory Support Electronics (OSE), assembled in rack-mount shipping case is shown situated inside its custom-built hut. Modular in design, not all components are installed at each site, but the basic design of each system is identical

in a rack, is the assortment of computers, modems, power supplies, and interface hardware needed to operate the station.

An installation is customized according to needs. Only 11 of the sites include the Ground Magnetometer (GMAG) sensor, although all sites include a UCLA-provided GMAG interface, in keeping with our modular design. In those cases, it interfaces only the GPS antenna to the system computer, thereby making the GPS interface identical for all stations.

Other optional installation items include the environmental enclosure (or “hut”) for the OSE. Huts are installed at 7 sites, while the OSE is housed in an existing shelter at all the other sites. These other accommodations range from very comfortable school rooms in McGrath and Kiana, while at Gillam, the OSE is located in a helicopter hangar, and at Prince George it is located in the custodian’s personal garage.

Not all sites require a satellite Internet connection. Many of the sites have wideband Internet service available, either from a local ISP or provided by the custodian’s service.

Beyond these differences in components that make up each site, the logistics requirements for each site are all equally unique and sometimes formidable. By this we mean the requirements for mounting and securing the ASI, the antennas, running cables, and just coping with the logistics of shipping equipment and traveling to these remote locations, where access to hardware stores and other conveniences is not possible. This means that each installation requires a considerable amount of planning, sometimes including prior site visits, to adequately prepare for a deployment. The result is that each site has a unique, and generally different layout.

3 Environmental Requirements and Enclosure Designs

All external components needed at a site are required to operate in the ambient conditions of the far North. This means temperatures ranging from −50°C to +40°C, with all types of weather expected, including blizzards, torrential rain, dust, hot sun, and bitter cold. Fortunately some of the components, and their associated cabling, can be found off-the-shelf and ready for this environment. For example, the GPS antenna and Iridium antenna are commercial units, from Trimble and NAL Research, respectively, that meet our requirements. The same applies to the satellite dish.

The GMAG sensor is buried in the ground. This technique has been employed by our UCLA partners, with great success, for many years. It provides mechanical stability for this very sensitive sensor, and it also allows it to operate at a very constant temperature. The GMAG design is very well suited for operation in just about any terrestrial environment. The ASI and OSE, however, needed special enclosure designs, as described in the following.

3.1 All Sky Imager Enclosure

To help us design the camera enclosure, we enlisted the aid of outside experts, the Allison Park Group, who are located near Pittsburgh, PA. The resulting design is shown in Fig. 5. The ASI CCD camera and lens assembly is put together and tested as a unit, prior to mounting it in the enclosure.

The insulation for the ASI enclosure is foil-faced, polyethylene, air pillow wrap, with three layers used. This flexible insulation, selected for its low out-gassing properties, is wrapped around the internal circumference of the main cylinder. Heat is provided by silicone strip heaters, powered from 120 VAC, i.e. line voltage, which is carried out to the ASI in the multiconductor power cable. The strip heaters on the main camera bracket are rated for 180 W, while the four small heaters located on the dome heater plate are collectively rated

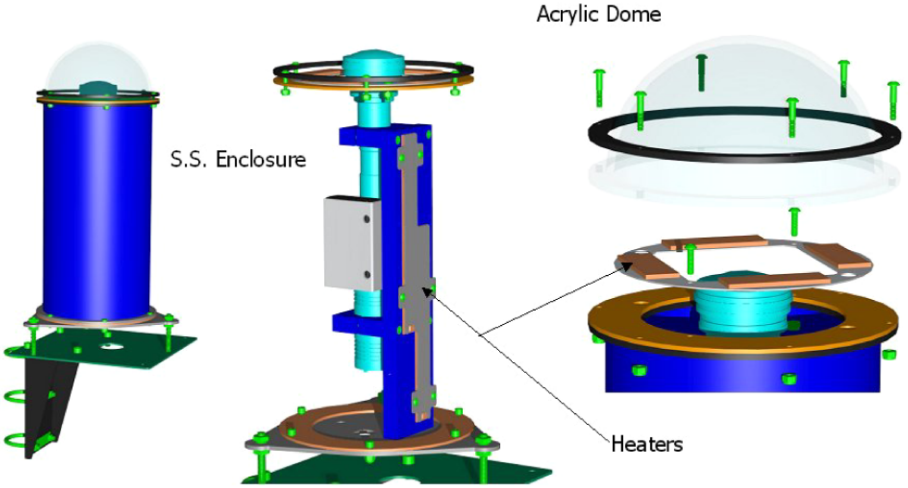

Fig. 5 Details of the ASI enclosure. Mounted inside an insulated, stainless steel case, the internal bracket assembly provides a secure mount for the ASI camera and lens, which is colored in cyan. The assembled housing can be mounted using either of two methods. It can be clamped to a vertical 2″ pipe, or the clamping feature can be removed from the base plate and the housing simply bolted to a flat surface

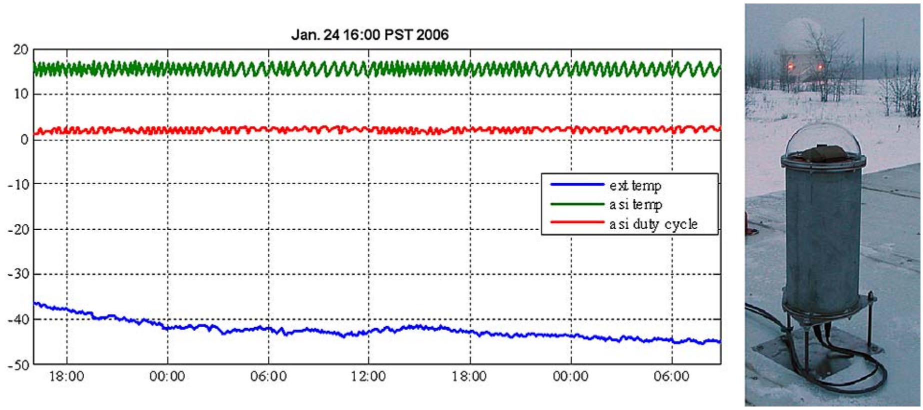

Fig. 6 ASI temperature data from Ft. Yukon. ASI duty cycle is plotted as a temperature 0–10°, corresponding to a percentage of 0–100%. The ASI at Ft. Yukon is shown on the *right*. A routine period of extreme cold at this location demonstrated the adequacy of the ASI enclosure design

for 60 W. The heater circuit is thermostatically protected to prevent a run-away situation. We have shown, referring to Fig. 6, that this level of heating is more than adequate to maintain a ΔT of 60°C, using an average power of 50 W (21% duty cycle), at ambient temperatures near -50°C.

An often-asked question is whether the dome sheds snow easily. Our experience thus far has shown that the dome heaters are effective in quickly removing snow from the dome, but we have seen some ice buildup on the flange surrounding the dome. This has been a minor issue. Generally, no intervention is required to keep the dome clear of snow or rain.

3.1.1 ASI Sun Shade

While not part of the enclosure specifically, the ASI sun shade assembly is intimately associated with it, as seen in Fig. 7. Kept closed during the day, it shields the lens and CCD from daytime sun exposure. This device was found to be necessary after the initial prototype trials in Athabasca demonstrated that:

- the fisheye lens coatings appeared to degrade after periods of sun exposure, and
- the Sony CCD used in the camera features plastic "microlenses" on each pixel, which can become discolored with constant exposure to sunlight, especially UV.

3.2 Observatory Support Electronics (OSE) Enclosure

The OSE is a collection of electronic support equipment that is assembled in a rack-mount shipping case. At most sites, the OSE is housed in an existing shelter, which provides protection from the weather and a room-temperature environment. At six of the sites, a suitable shelter was not available, and for these situations we developed an environmental enclosure referred to as the hut. One of these sites is shown in Fig. 8, and a more detailed look at the hut design is shown in Fig. 9.

The interior space of the hut measures 35″ (w) × 30″ (l) × 32″ (h), and, when empty, it weighs less than 80 lb. The construction material is fiberglass sheets bonded to 2″ thick panels of foam core insulation. This is similar to the construction of the AGO shelters used

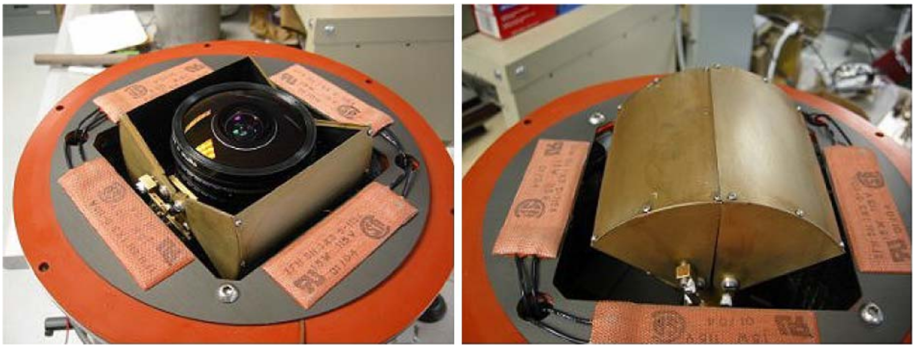

Fig. 7 ASI Sun Shade, shown both open and closed. A clamshell design, it falls open upon removal of power from the solenoid. The inside surface of the clamshell is painted flat black, to enable an ability to take dark images in the field

Fig. 8 The GBO site at Ft. Smith during installation. Our enclosure provides a dry and temperate environment for the OSE. When deployed the hut is typically mounted on cinder blocks, or some sort of platform. Tie points on the side rails provide a method to guy down the hut to prevent movement

in Antarctica. In fact, they were manufactured by the same vendor, an expert in fiberglas manufacturing, Moore Sailboats, located in Watsonville, CA. Both doors use pliable, silicone gaskets, rated for extreme cold, to seal against the main structure. Two latches on each side of the door secure it into place. Two fiberglass "awnings" cover the upper part of each door seal. Their purpose is to keep snow and water from pooling. This prevents a process, through melting and refreezing, that could force open the seal.

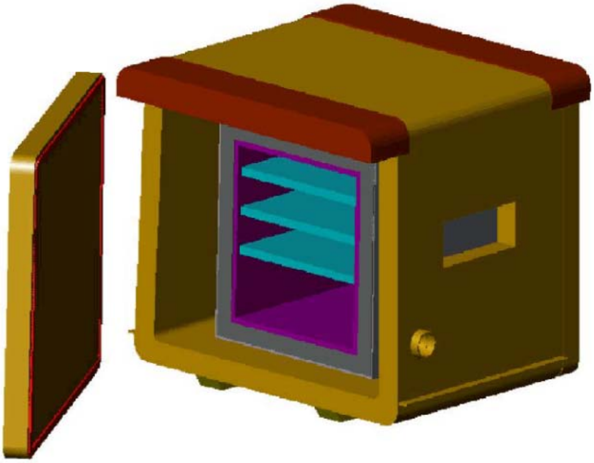

Fig. 9 A solid model of the hut. From this model, the design features are more readily apparent. A model of the rack is shown inside the hut

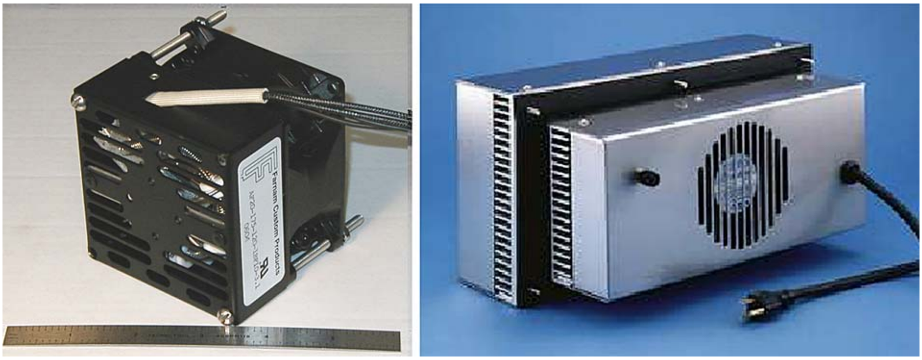

Fig. 10 An OSE heater is shown on the *left*, and the thermoelectric air conditioner is on the *right*. Two heater units are installed in each OSE, mounted to the underside of the lower rack shelf. The space heaters are thermostatically protected from overheating

The only openings in the hut, once the doors are closed, are cut outs for the air conditioner and a 3″ pipe used for cable access. Typically, a pipe elbow is mounted on the external portion of the cable pipe so that moisture is unlikely to travel inside the hut. The pipe is stuffed with insulation once the cables are installed. The air conditioner unit, when mounted on the hut, seals its opening. This makes an enclosure that is not only well insulated, but also dust free.

Active heating and cooling are both necessary, depending on ambient temperatures. Figure 10 shows the devices used for these purposes. Two small, electric space heaters, mounted inside the OSE, are available to add heat inside the hut. Each heater is rated for 175 W, and operates at 120 VAC. The air conditioner is a solid state device, which uses thermoelectric coolers to transfer heat through the wall of the hut. It has a capacity of 163 W.

The performance of the hut has generally been excellent, although the initial design turned out to be a bit too well insulated. With a typical heat load inside the hut reaching 150 W, we found that the OSE heaters were seldom, if ever called on to add heat, even at outside temperatures as low as −40°C. On the other hand, the air conditioner was turning on with external temperatures of 0°C, as seen in Fig. 11. Not only is this rather an unreasonable

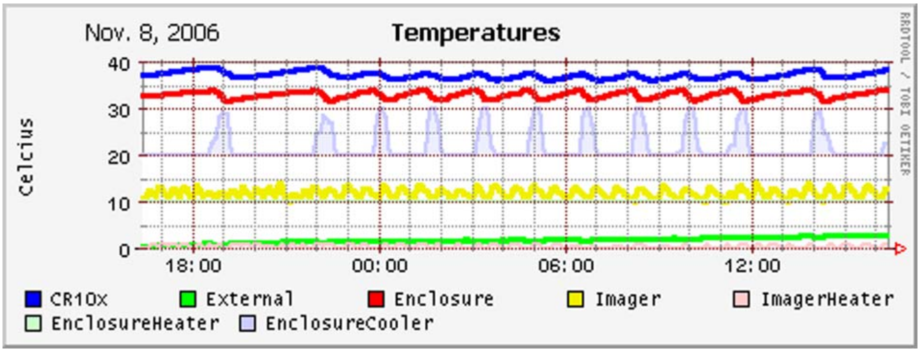

Fig. 11 GBO temperature plot from Chibougamau. This plot shows the temperatures inside the hut, colored *blue* and *red*. The external temperature, colored *green*, is increasing from 0° to 3°C. The duty cycle for the air conditioner is depicted as a temperature ranging between 20° and 30°, corresponding to 0–100%. The duty cycle value is updated every 10 minutes. In this example, the overall "on-time" of the cooler, with ambient temperature just above 0°, is about 30%. The internal temperatures are obviously modulated by the cooler action

situation, but it means that the air conditioner is operating for long periods of the year, which contributed to two failures of the devices during the summer of 2006.

At the time of this writing, we have developed a modification to the hut that involves removing some of the insulation from one of the doors. This has shown to make the hut require less cooling, with the air conditioner turning on at higher ambient temperatures.

4 Observatory Support Electronics

The Observatory Support Electronics (OSE) is based around the System Computer, a small-footprint PC comprised of a VIA Mini-ITX motherboard (model EPIA-CL). This PC is purchased from a vendor, SmallPC, located in Ontario, Canada (ref: http://www.smallpc.com). This computer was selected for two reasons. First, its small size and low power are attractive and, second, it provides a multitude of interface ports needed for the system. A block diagram of the small PC interfaces, and how they are used, is shown in Fig. 12.

Looking at Fig. 12, it is clear that interfaces and connectivity are a prime requirement for the GBO system computer. The Redhat Linux distribution, version 2.4.26, is installed on each system. This operating system is significantly pared down from the standard distribution. Support for Ethernet connections, serial ports, and generic USB is native to this distribution. It also supports the GPS interface using the Network Time Protocol (NTP) that provides accurate time stamps for our data. The "Custodian Laptop" is simply a laptop computer that is supplied with each system and left onsite. It is used as the terminal interface for the System Computer. Software provided by the GBO Team performs data acquisition from the ASI and GMAG, as well as housekeeping data that are acquired via the CR10X Datalogger. The Datalogger is used primarily as the environment monitor and power control device. More will be said about it later.

Also apparent in Fig. 12 is the two ways to communicate with the GBO station, using either the Internet or the Iridium link. The Iridium, acting as our backup mode, is connected via four-port serial switch, such that we can either login to the PC, via port ttyS1, or connect directly to the CR10X. This allows us to control and query the GBO when the Internet is

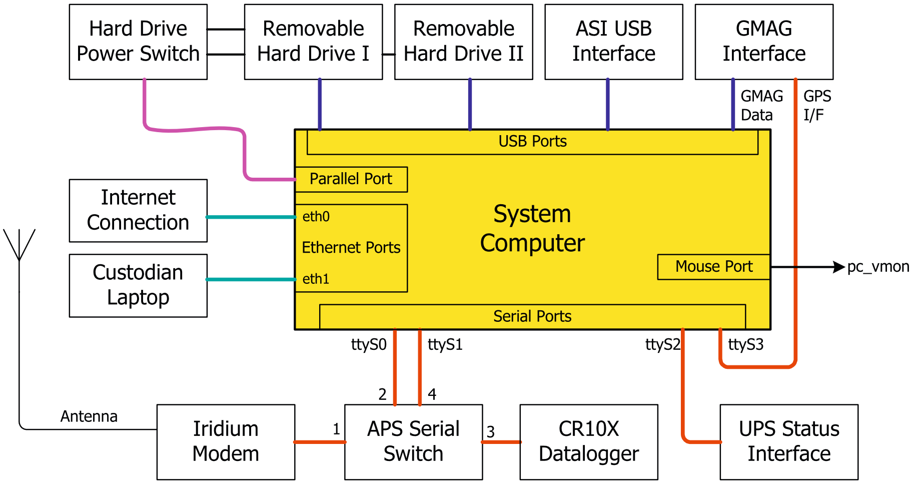

Fig. 12 Block diagram of computer port usage

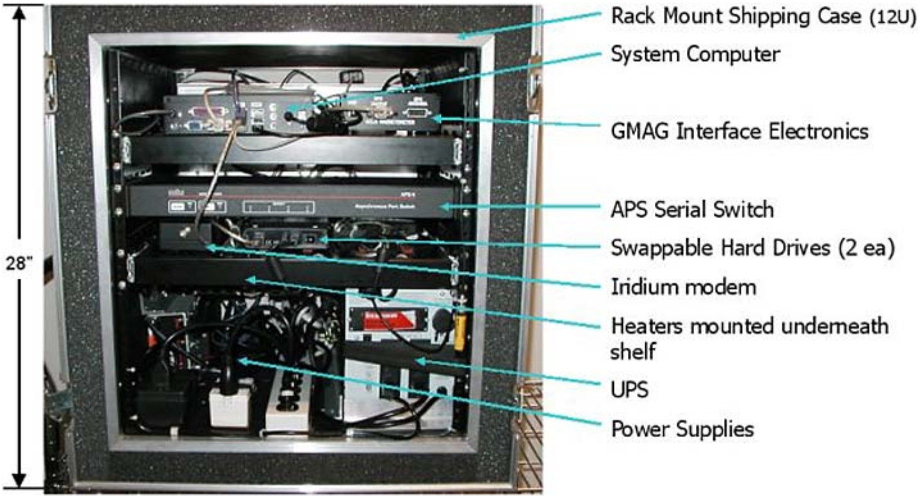

Fig. 13 The OSE, front view. Sliding shelves provide easy access for most components. All items are secured in the rack so that it survives transportation. Most items use high-strength hook-and-loop straps ("Velcro"), to hold them in position, while still allowing easy removal. Twenty systems, assembled in this manner, have been shipped to the field with no problems

down and in times of stress, e.g., station power failure, and we can query the CR10X to learn what is happening.

Views of the physical OSE are shown in Fig. 13 and Fig. 14.

Figure 13 shows the major components of the OSE as seen from the front. The Swappable Hard Drives, as the name implies, are used to both back up data acquired from the ASI and GMAG, and also to create a copy that can be physically transported to the data repository at the University of Calgary. Since the volume of data collected at the station, especially from the ASI, is so great, the only method to retrieve the high-resolution images is via shipment of

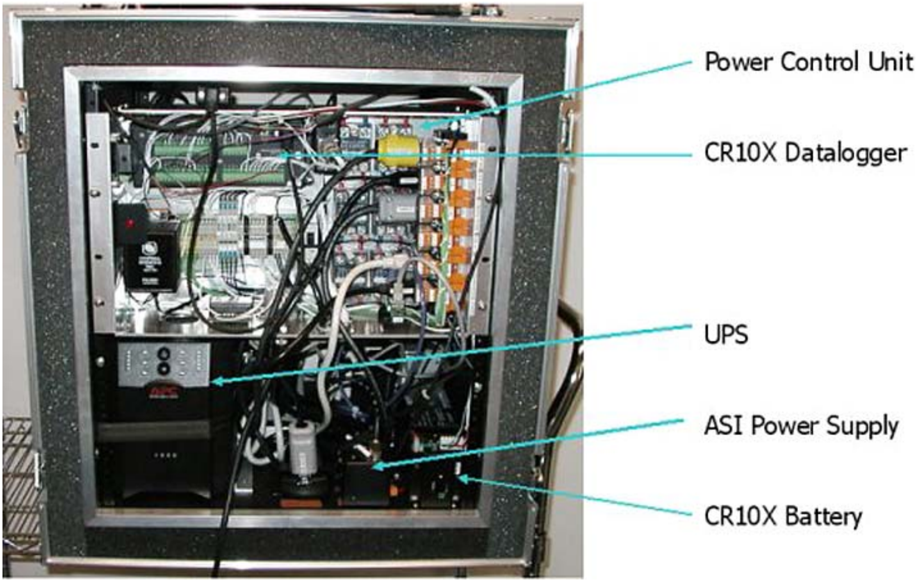

Fig. 14 The OSE rear view. From this side, the Power Control Unit (PCU) is the prominent item. All power switches are accessed from this side of the rack

the external hard drive. With two external drives available, a backup copy of the data always exists until the transfer disk is successfully received at Calgary. The heaters, instrument power, and UPS are controlled from the processor in the Power Control Unit (PCU). In the following sections, we will further describe the functions of the OSE.

4.1 Power and Temperature Control

It was recognized from the outset that power in the remote areas that would be home to the GBOs is often unreliable, and we could experience power outages that last for many hours or days. Also, maintaining a room-temperature environment for the OSE components, being primarily commercial-grade computer equipment, would need some controller that enabled the system computer to be shut down in an orderly fashion in the event of long power failures, or in situations where the system simply gets too cold or too hot. This controller is provided in the Power Control Unit (PCU), a CR10X Datalogger, manufactured by Campbell Scientific. In our application, the CR10X is used not so much as a datalogger, but as a programmable controller. The advantages of using it as the principal device to interface with the environment and control power is as follows:

- It is rated to operate over the entire operating range of the GBO, i.e. −55° to +85°C. As such, it never needs to be turned off. It is always on, monitoring temperatures and power conditions. Operating from its own, dedicated battery pack, it can run without external power for a couple of weeks.
- It implements the graceful shutdown of the computer system, ASI and GMAG in the event of long power failures (those exceeding the capacity of the UPS), and also during loss of temperature control, either too cold or too hot.
- On boot-up, if temperatures and power are within limits, it turns on the UPS and System Power via switched outlets, which allows the System Computer to boot up. After boot-up,

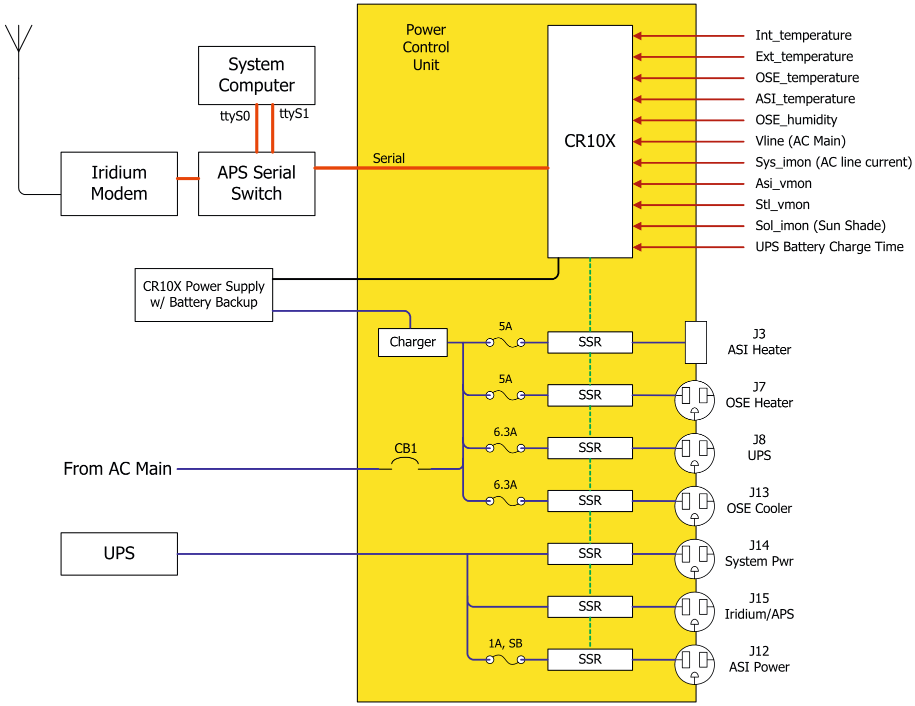

Fig. 15 Block diagram of PCU and discrete sensor interfaces on CR10X. Temperature sensors connect directly to the CR10X via screw terminals. Solid state relays (SSR) are used to control power

the CR10X acts as watchdog to the System Computer, and will reboot the system if the PC does not service the watchdog.

- Since most temperature and voltage sensors in the GBO are interfaced to the CR10X, the System Computer is able to access these data, via the serial interface connection. As such the CR10X acts as a peripheral to the System Computer, and allows us to remotely control the power.
- The CR10X is simple to program, and in the GBO it can be queried remotely via Iridium.

Figure 15 is a block diagram of the Power Control Unit, which illustrates these features.

The CR10X program monitors temperatures and key voltage and current sensors on a cycle that repeats every six seconds. Provided that the line voltage and temperatures are within acceptable limits, it maintains the power on the System Power Bar, which supplies power to the computer, ASI, GMAG, and external hard drives. If power is off for an extended period, exceeding the one-hour capacity of the UPS, then the CR10X flags the System Computer to shutdown. After an appropriate interval, the CR10X turns off power to the Power Bar and waits for the power to be restored. The same process applies to a too hot or too cold situation.

Referring to Fig. 16, ASI power is controlled from a switched outlet which is supplied from the UPS. The ASI CCD camera comes with an AC brick power supply, which after one winter of use was determined to be of marginal design. It had poor regulation with varying levels of AC line voltage and it ran too hot, which in the long term caused internal damage. To circumvent these difficulties, a separate, regulated 12 V supply has been substituted

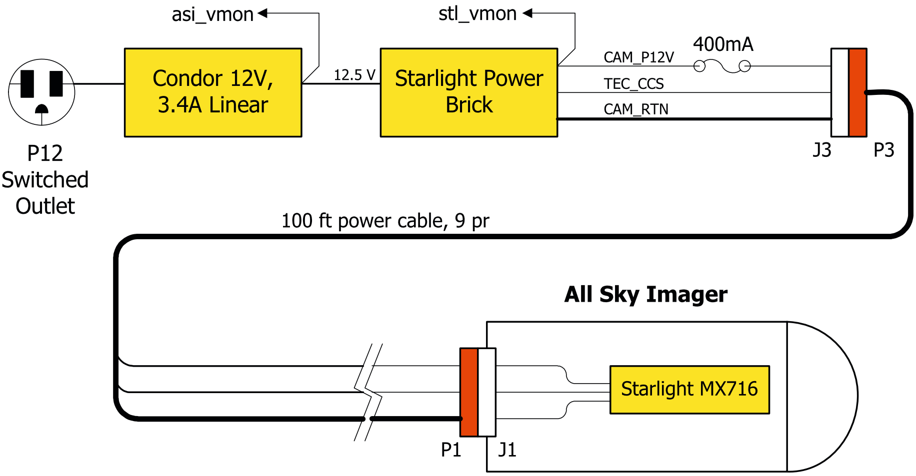

Fig. 16 ASI camera power diagram. The 100' power cable also carries conductors for heaters, sun shade control and temperature sensors in the ASI enclosure

for the camera 12-volt line, and the only function really provided by the "Starlight Power Brick" is the constant current source for the thermoelectric cooler (TEC). The power brick is modified to incorporate a small fan and large heat sink to reduce internal temperature rise to 10°C. The ASI data acquisition application, "imagerd", commands the ASI to power on by setting a flag in the CR10X. The CR10X then turns on the ASI power, provided the temperatures are acceptable.

The temperature inside the ASI is controlled by the CR10X. As the temperature drops below a programmable set point, the heater circuit is activated via SSR. The heaters are turned off when the temperature rises above the set point, plus a suitable amount of hysteresis. An internal thermostat protects against a thermal run-away. The OSE heater and cooler are operated in a similar fashion. In the ASI, the Sun Shade is also controlled by the CR10X. It is closed or opened, as requested by the System Computer, under software control.

4.2 Instrument Interfaces

Referring back to Fig. 12 again, the data interfaces for the ASI and GMAG are implemented with USB. We also collect housekeeping data, referred to as "monitor" data, from the CR10X, the UPS, and from devices and processes in the System Computer. These data are collected, stored, and transmitted back to Calgary via the Internet.

The GMAG subsystem has two interfaces with the System Computer. The USB interface is the GMAG sensor data. This is magnetic vector data, sampled at 2 Hz. Internal to the GMAG Interface Electronics is a processor that interfaces with the GPS antenna, a standard Trimble Accutime 2000. The time stamps for the GMAG data are created directly from the GPS. The GPS serial interface is also made available to the System Computer, where it is serviced by NTP, and it maintains the system clock to within 10 ms rms error. Recorded time stamps for the ASI and monitor data are derived from this system clock.

The ASI data interface is illustrated in Fig. 17. Faced with a USB interface in the Starlight Xpress camera, we were limited to a cable length of five meters, the maximum length supported by USB. This issue was solved with a USB Extender (Iogear model GUCE50), which

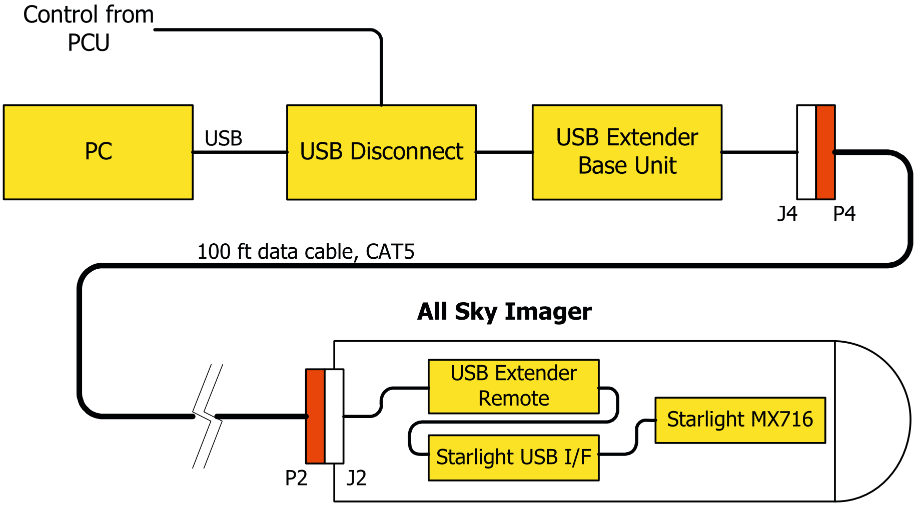

Fig. 17 Block diagram of the ASI data interface. It illustrates the cascade of devices that are used to enable operation of the ASI on long cables. The USB interface to the ASI is only powered on when the main ASI power is On, a function provided by the "USB Disconnect" module

takes the data and power pairs in the standard USB interface and transforms them into four pairs, suitable for transmission on standard CAT-5 cable. This allows USB (v1.1) operation on cable lengths up to 50 m. We also found that the Starlight Xpress USB interface circuitry itself is powered from this USB port. Since this meant we couldn't easily turn off that part of the camera, we developed a computer-controlled USB Disconnect, that allows us to power off the ASI USB interface, effectively disconnecting it from the computer.

4.3 Data Retrieval and Remote Intervention

Data acquired in the System Computer is stored and then backed up on the external hard drives. Real-time data of ASI thumbnails, GMAG, and monitor data are transmitted over the Internet connection. This connection is also used for remote intervention, as shown in Fig. 18. Typically, no intervention is required on a day-to-day basis. Data flow is described in Fig. 19.

5 Integration and Test

Besides construction, the integration and testing of all GBOs was the responsibility of UC Berkeley. An illustration of the integration and test flow is shown in Fig. 20. A brief description of the activities shown is provided in the following sections.

5.1 ASI Testing

ASI testing is done in two steps. First the Starlight Xpress camera and All Sky Lens are mated and characterized. This characterization is done at room temperature on an optical bench using a light source with known spectral radiance, and an optical path that included the acrylic dome. Narrow band filters were used to measure camera responsivity. A sample

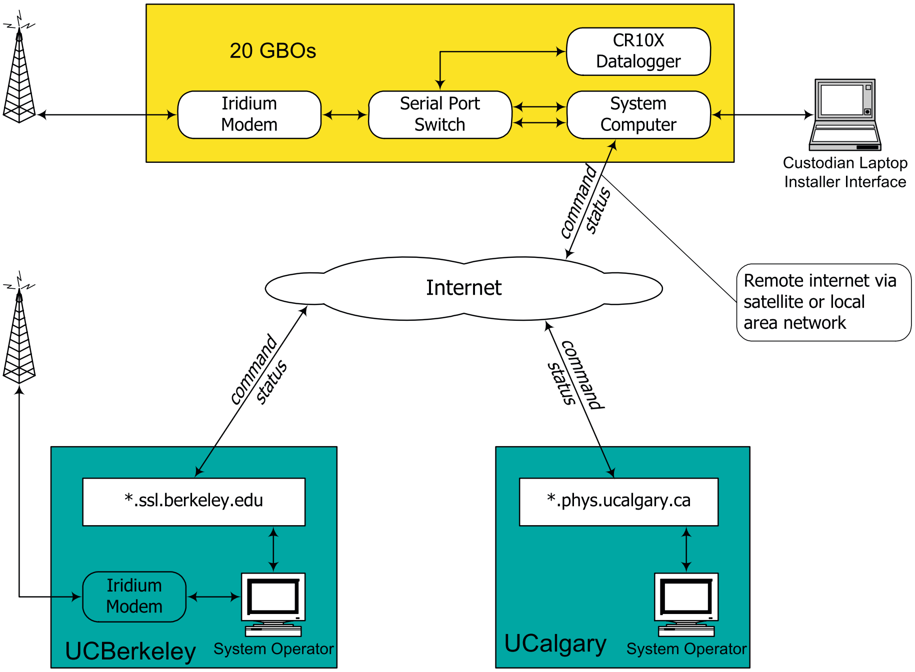

Fig. 18 Remote intervention. Operators at UC Berkeley and University of Calgary can login at any GBO to perform a variety of intervention tasks, such as software updates, troubleshooting, data download, etc. Similar access is afforded by the back-up iridium link

of these data is shown in Fig. 21. In addition, the following parameters were verified during this step in accordance with demonstrating that the ASI met THEMIS mission requirements.

- FOV > 170° (see Fig. 22 for typical data).
- Exposure time duration controllable for 1 ms to 5 s. This verifies the electronic shuttering capability of the Starlight Xpress camera.
- Measure spectral response. Verify minimum responsivity to source radiance is less than 10 kR.
- Spatial resolution >250 pixel across all sky image. Verify focus ability.
- Cadence is better than 1 image every 5 s.
- Record dark and bias images for reference (at room temperature).

Once the optical characterization is complete, the camera/lens is assembled in the ASI enclosure. This completed assembly is tested further to verify:

- Alignment of camera such that top of image is aligned to the "North" datum on housing.
- Final focus adjustment.
- Heater control functional test.
- Sun Shade functional test, which involves a one-year equivalent of open/close cycles.
- Final test and burn-in with completed OSE. This usually lasts several days.

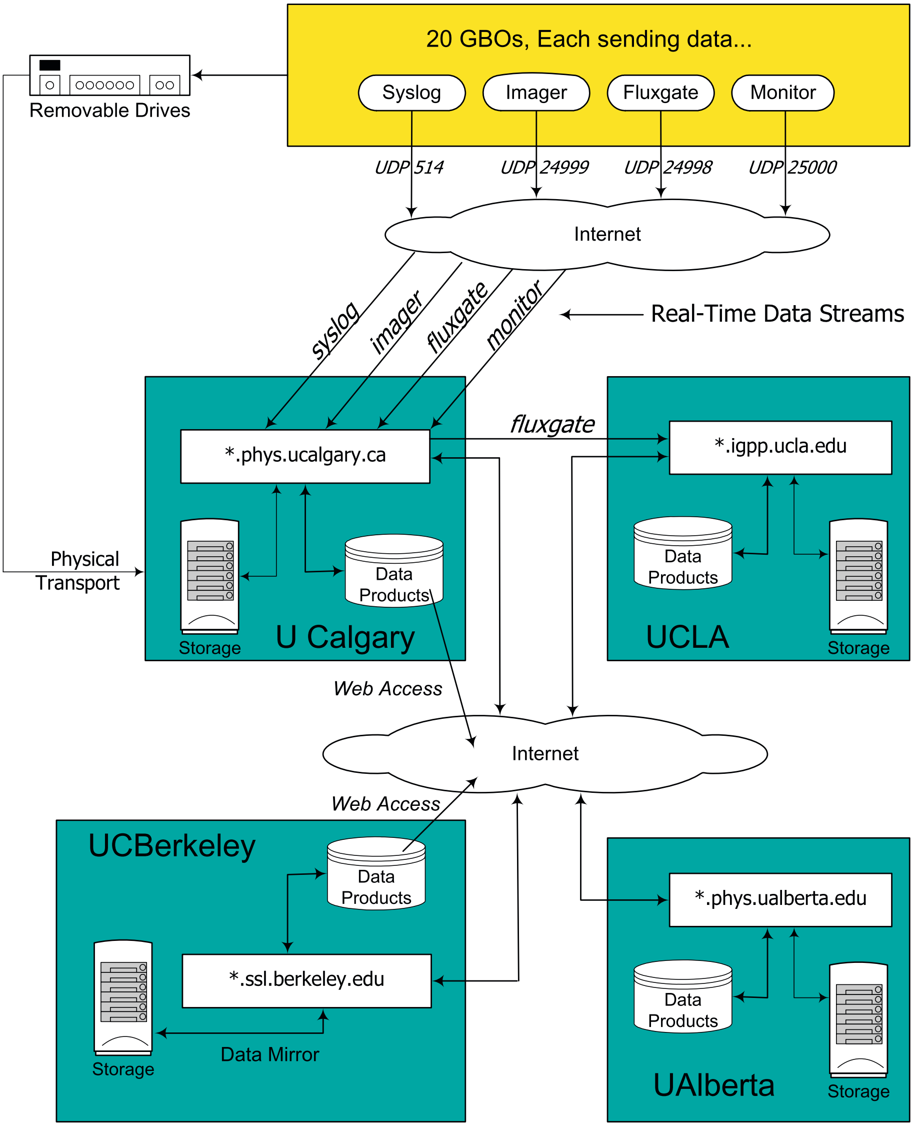

Fig. 19 Block diagram of data flow from GBOs to the Universities. The University of Calgary is the primary collection point for all data. All data are mirrored at UC Berkeley. Real-time data are transmitted as UDP packets to U. Calgary. Magnetometer data from the GBO GMAGs are validated by UCLA and then distributed to the rest of the team. For the GBO sites without magnetometers, we obtain mag data from other sources, such as the University of Alberta and the Geophysical Institute at the University of Alaska

6 Discussion of Operational Hazards

The GBOs have survived many operational hazards in the field. The CR10X embedded in the OSE has proven very reliable in handling situations of too cold (e.g., door to shack left open), too hot (e.g., stuck thermostat in the shack), and long power outages. When we notice these situations, a call to the on-site custodian usually prompts some action to deal

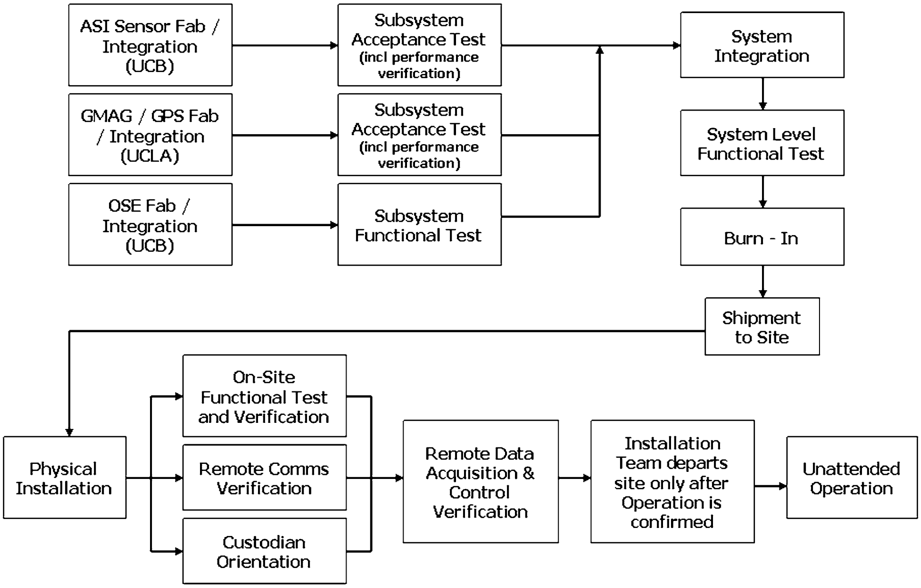

Fig. 20 GBO integration and test flow. Instruments were fabricated and tested individually prior to integration with the OSE

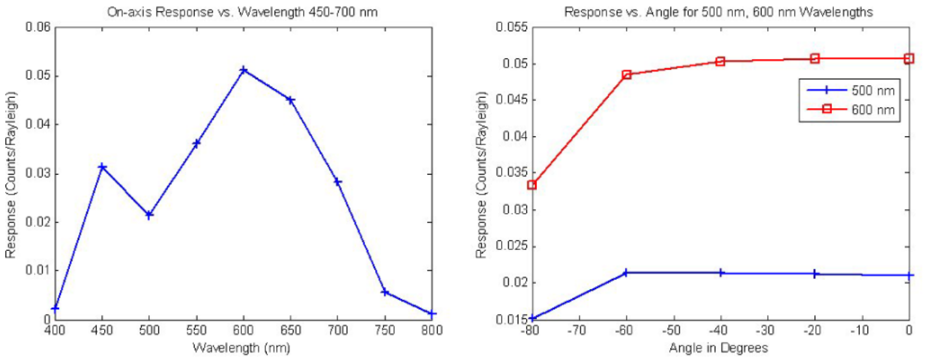

Fig. 21 Typical response curves for the All Sky Imager, one-second exposure. On-axis response is shown on the *left* for all wavelengths tested. On the *right* is response vs field angle. All cameras produced very similar results

with the problem, and the system automatically restarts when conditions are OK. The proof of this statement is backed up by certain sites (e.g., Ekati and Inuvik) that are often fairly inaccessible to the custodian. We have operated these sites, without problem, for two years, and they have needed very little custodian intervention.

During the implementation phase of this project we have had to deal with some difficult problems, some of which are ongoing and some of which have been solved. Here is a short list of such problems including what was done to mitigate the issue where that was possible.

Fig. 22 Typical focus images for the All Sky Imager. A bar test pattern is imaged at various field angles, showing good focus over the entire FOV, although obvious distortion exists off-axis. These are 2X binned images, the normal mode used in the field

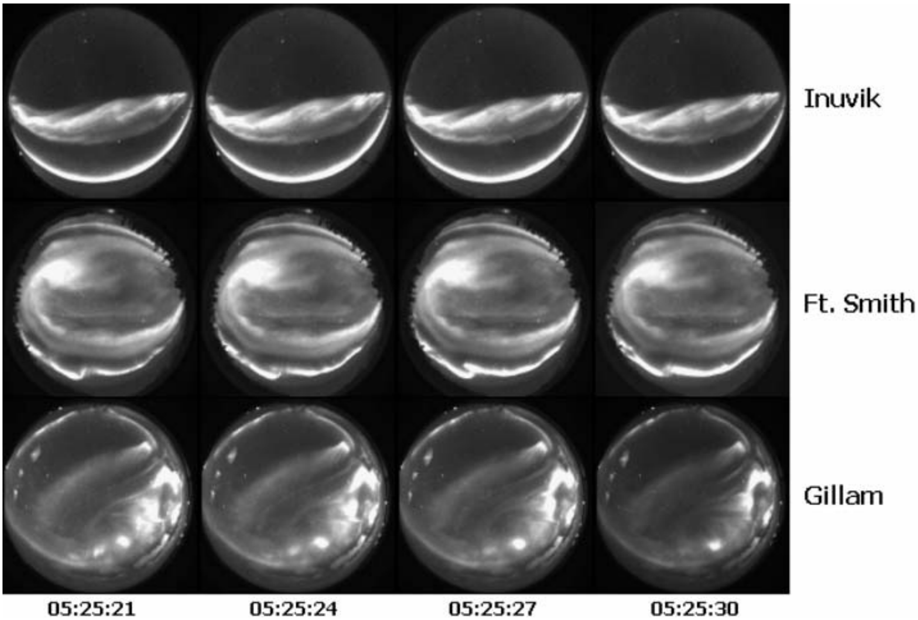

Fig. 23 Sample data from All Sky Imagers acquired on October 5, 2007. The panel shows four consecutive all-sky images taken at three different sites in the GBO network. Image cadence is one image every three seconds. This data sample shows the full-resolution images which are acquired at these sites

- RF Interference. At several sites, the GBO is colocated with existing ionospheric sounding equipment (e.g. CADI, SuperDARN). Unfortunately, RF interference at some sites has occasionally made operation impossible, primarily because it seems to interfere with the commercial implementation of the USB bus. This problem was solved with the addition of common-mode RF filters, added to the ASI data interface.
- Internet connection outages are a fact of life. Our software, however, continues to operate and store data locally, regardless of this connection loss.

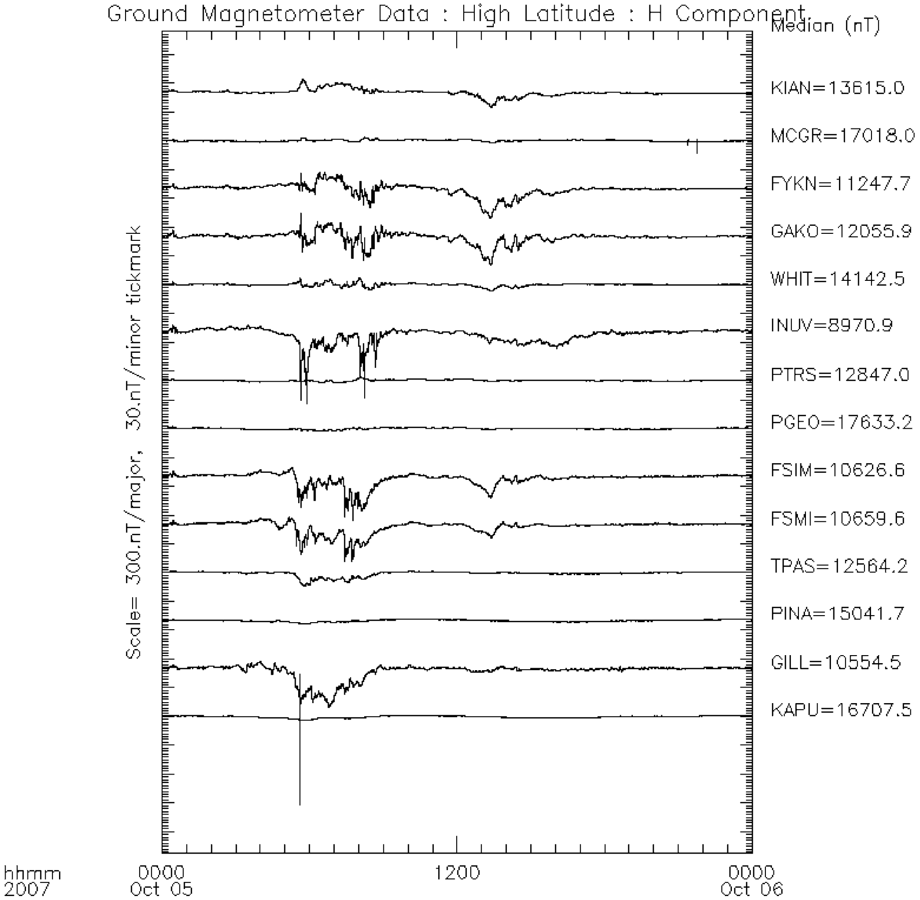

Fig. 24 Sample data from Ground Magnetometers acquired on October 5, 2007. This panel combines magnetometer data from sites outside the GBO network, as they are included in the THEMIS daily summary plot

- Some software issues seem to be not easily solved. For example, USB interfaces can hang inexplicably and some system processes can sometimes go awry (e.g., NTP daemon). These are infrequent occurrences, and they are generally handled by manual intervention.
- Lightning is an occasional occurrence. The ASI is probably the most vulnerable to this, and frankly there is not much that can be done to easily mitigate the problem, other than having spare systems available for unit replacement.
- Finally, we do have the occasional nonresponsive custodian. Fortunately, we can minimize our reliance on these folks but, on the other hand, many of our local helpers have provided outstanding assistance.

7 Summary

In support of the NASA THEMIS program, a network of 20 Ground Based Observatories have been designed, built, and deployed across the active auroral zone of the North American continent. Figures 23 and 24 provide a sample of the data available from the THEMIS network of ground observatories.

The GBO Team now assumes the tasks of data collection, monitoring, and maintenance of the remote sites. This is an ongoing effort that will continue throughout the THEMIS science operations.

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