Autonomous Adaptive Low-Power Instrument Platform (AAL-PIP) Project: Interhemispheric Geomagnetic Field Investigations Along the 40° Magnetic Meridian

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1. Introduction

The main objective of this project is to develop our understanding of the multi-scale global solar wind-magnetosphere-ionosphere coupling dynamics and thus to predict the properties of the complex solar-terrestrial environment (space weather) through high temporal and spatial resolution, magnetically conjugate multi-instrument arrays developed in Eastern Antarctica.

Magnetosphere-Ionosphere Science Team (MIST) at Virginia Tech developed an autonomous adaptive low-power instrument platform (AAL-PIP) to establish a ground instrument network, magnetically conjugate to the Greenland East coast magnetometer chain along the 40° magnetic meridian (PI: Bob Clauer). The new Antarctic array facilitates high-latitude interhemispheric investigations of the magnetosphere and ionosphere.

As of the austral summer 2012-2013, three AAL-PIPs are in operation in the remote field locations in Antarctica. Because Antarctica has a harsh environment and its accessibility is limited, the stations are designed to operate autonomously and to optimize data collection and power management for at least three years. Figure 1 and Table 1 show the locations of the AAL-PIP stations and their conjugate network in Greenland.

Table 1. Geographic and geomagnetic locations of the Greenland and AAL-PIP stations. Magnetic coordinates (Corrected Geomagnetic Coordinates or CGM) are based on the IGRF for Epoch 2013. Unit is in degree (°). Calculations are done using http://omniweb.gsfc.nasa.gov/cgi/vitmo/vitmo_model.cgi. Stations with * will be installed in the field season 2013-2014 and later.

GREENLAND Site	Geog lat	Geog lon (E)	CGM lat	CGM lon	Conj geog lat	Conj geog lon	Antarctic Conj site
Thule (THL)	77.47	290.77	84.40	27.48	-79.72	121.63	Vostok
Savissivik (SVS)	76.02	294.90	82.68	31.23	-81.20	116.23	
Kullorsuaq (KUV)	74.57	302.82	80.36	40.28	-82.25	99.40	AGO4
Upernavik (UPN)	72.78	303.85	78.57	38.71	-83.58	89.26	PG4*
Uunmannaq (UMQ)	70.68	307.87	75.99	41.22	-84.50	77.20	PG1
Qeqertarsuaq (GDH)	69.25	306.47	74.82	38.15	-84.42	57.96	PG2
Attu (ATU)	67.93	306.43	73.54	37.09	-84.81	37.63	PG3
Kangerlussuaq (STF)	67.02	309.28	72.14	39.96	-82.75	28.59	AGO P3
Maniitsoq (SKT)	65.42	307.10	70.93	36.43	-83.32	12.97	PG5*
Nuuk (GHB)	64.17	308.27	69.49	37.12	-81.95	5.67	M82-003
Paamiut (FHB)	62.00	310.32	66.92	38.43	-79.13	358.20	PG6*
Narsarquaq (NAQ)	61.16	314.56	65.23	42.61	-76.25	0.78	

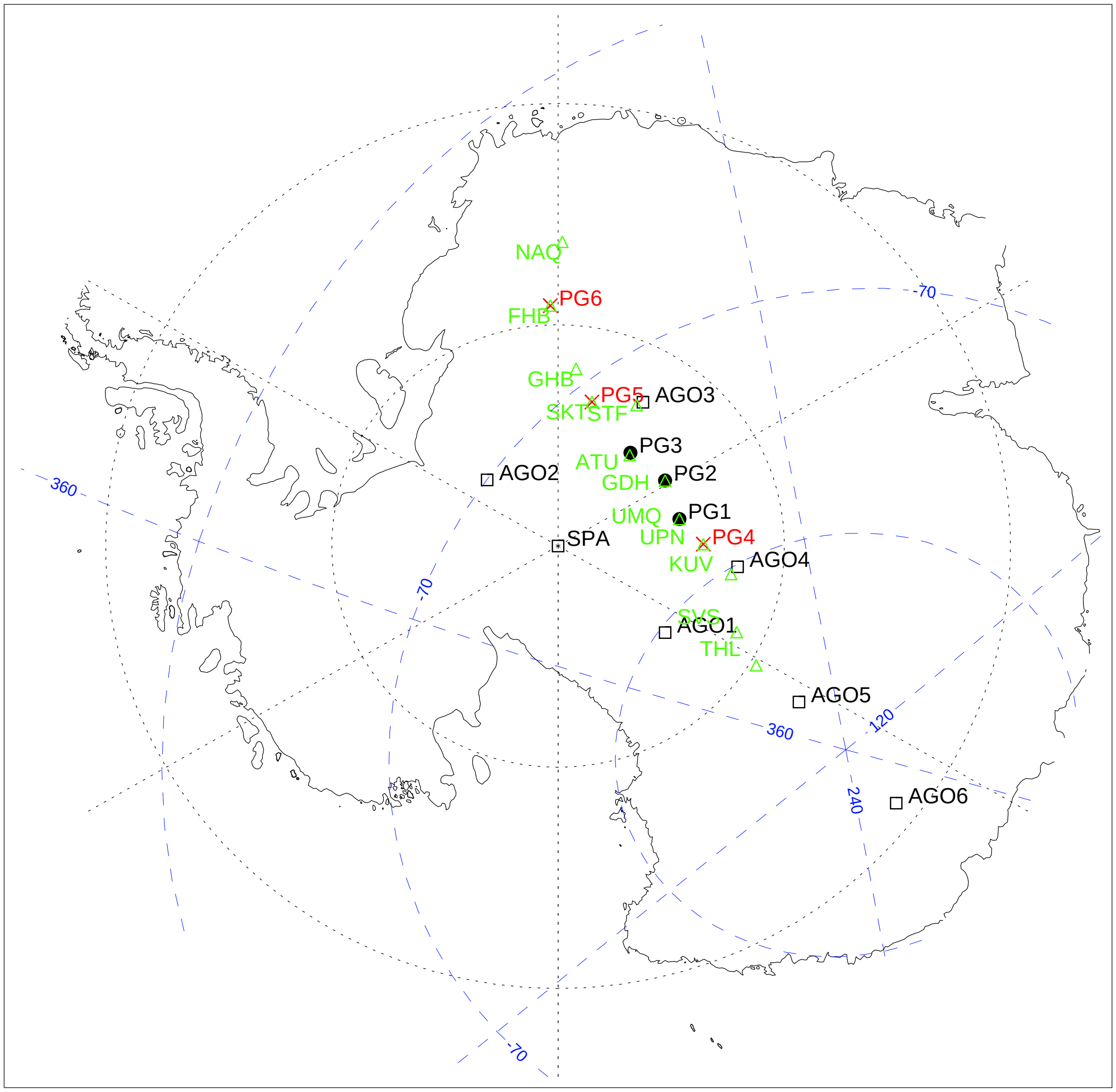

Figure 1. Map of Antarctica showing the locations of the currently operational AAL-PIP stations, PG1, PG2, and PG3 (solid black dots), and planned AAL-PIP stations, PG4, PG5, and PG6 (red × symbols). The green triangles indicate the Greenland magnetometer stations mapped to the Antarctic. The locations of the automatic geophysical observatory (AGO) network are also shown (black open squares).

2. Instrumentation

The AAL-PIP system is designed to support two magnetometers (fluxgate and search-coil type), an HF antenna, and a dual frequency GPS signal receiver, and to operate unattended for at least three years in remote Antarctic regions. The overall system diagram is shown in Figure 2. Data acquired by the instruments are transferred to users via satellite communications to provide near real-time data collection. The data acquisition strategies can be adaptively controlled based on the various conditions of the magnetosphere and the ionosphere, which will maximize the scientific information return within the limits of the available data storage and bandwidth.

The electronics of the system is powered by lead-acid batteries charged by solar panels and designed to consume low power (<~15 W) in association with the adaptive power saving mode. The housings for the electronics and the batteries are temperature-controlled by super-insulated enclosures and a heating plate (only in the battery enclosure) to maximize the operational time. The data acquisition electronics can store at least 1 year of science and engineering data in its internal memory.

The mechanical structure of the system is designed to fit in a small aircraft that is typically used for the US Antarctic missions (Twin Otter). See Figure 3 for the mechanical structure of the AAL-PIP system.

In addition, the system features ease-of-assembly (in most cases, tool-free and glove-friendly), employing components such as quick-snap connectors, and large T-bolts and pins, which accommodates easier and faster construction in the harsh environment. The system installation layout is presented in Figure 4.

Space Physics Research Lab at the University of Michigan has built the systems and is in charge of communication with the systems via the Iridium network and data archive (Lead Engineer: Steve Musko).

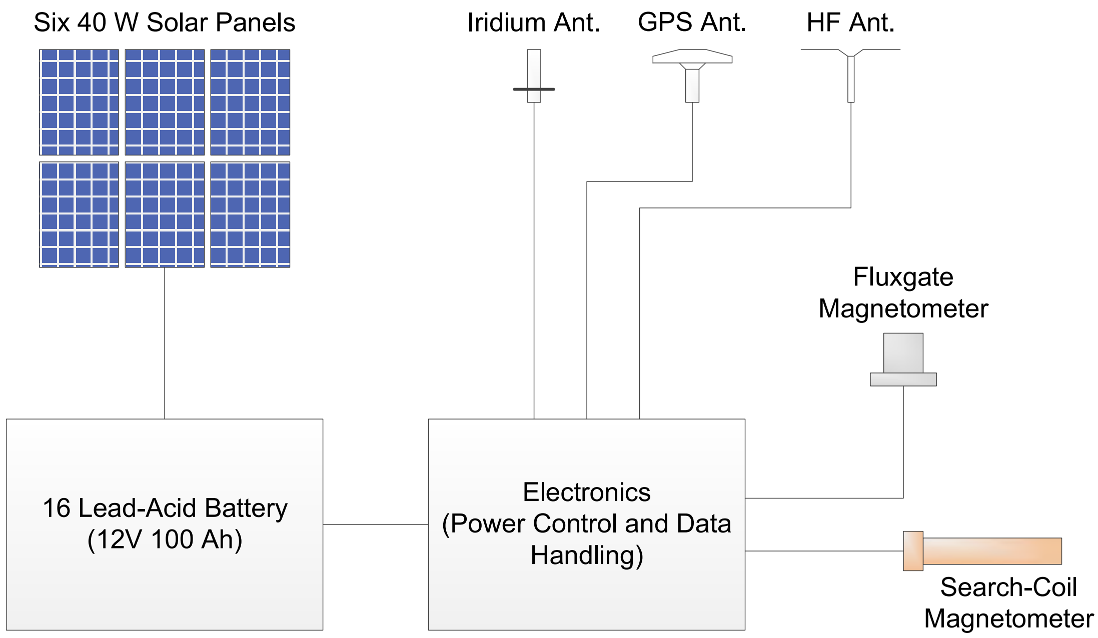

Figure 2. System diagram of the AAL-PIP system.

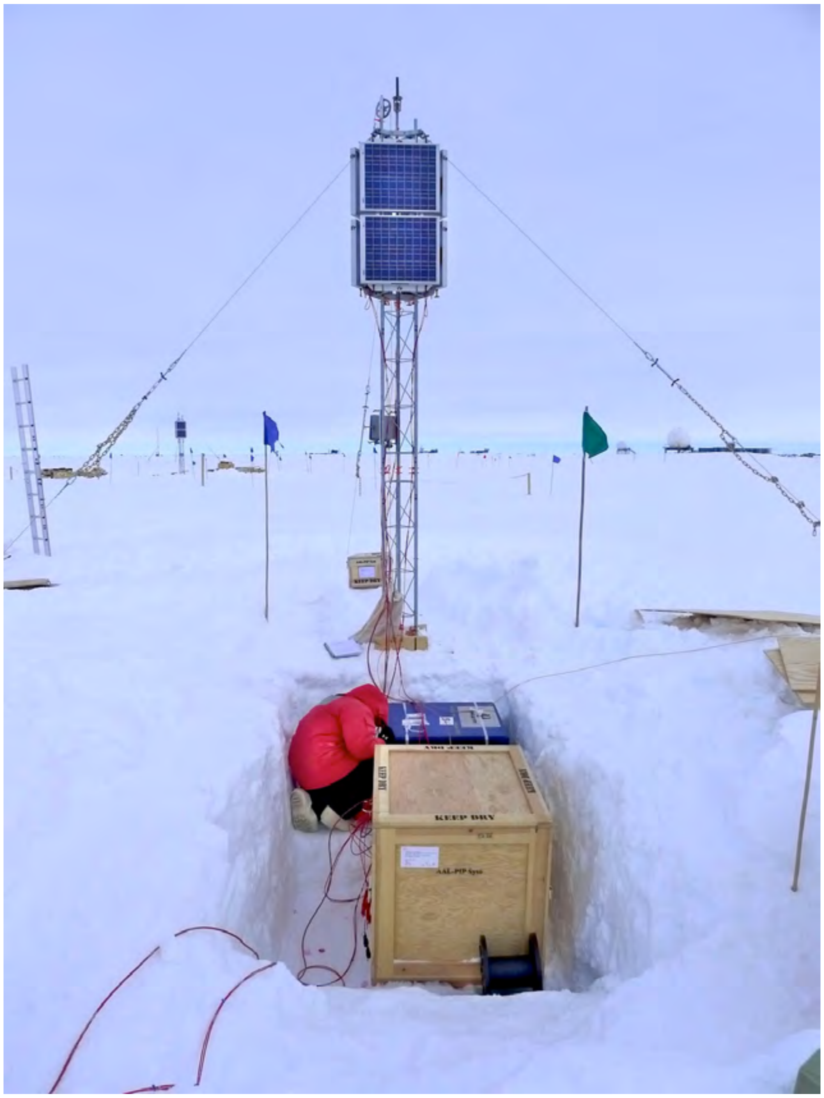

Figure 3. The tower holds six 40 W solar panels and Iridium antenna. Electronics box (blue) and battery box (wooden crate) are be buried at the base of the tower. GPS antenna is mounted on a post (not shown in this picture) located 30 ft away from the tower. The fluxgate and search-coil magnetometers are placed 50 ft and 300 ft away from the tower, respectively (not shown in this picture).

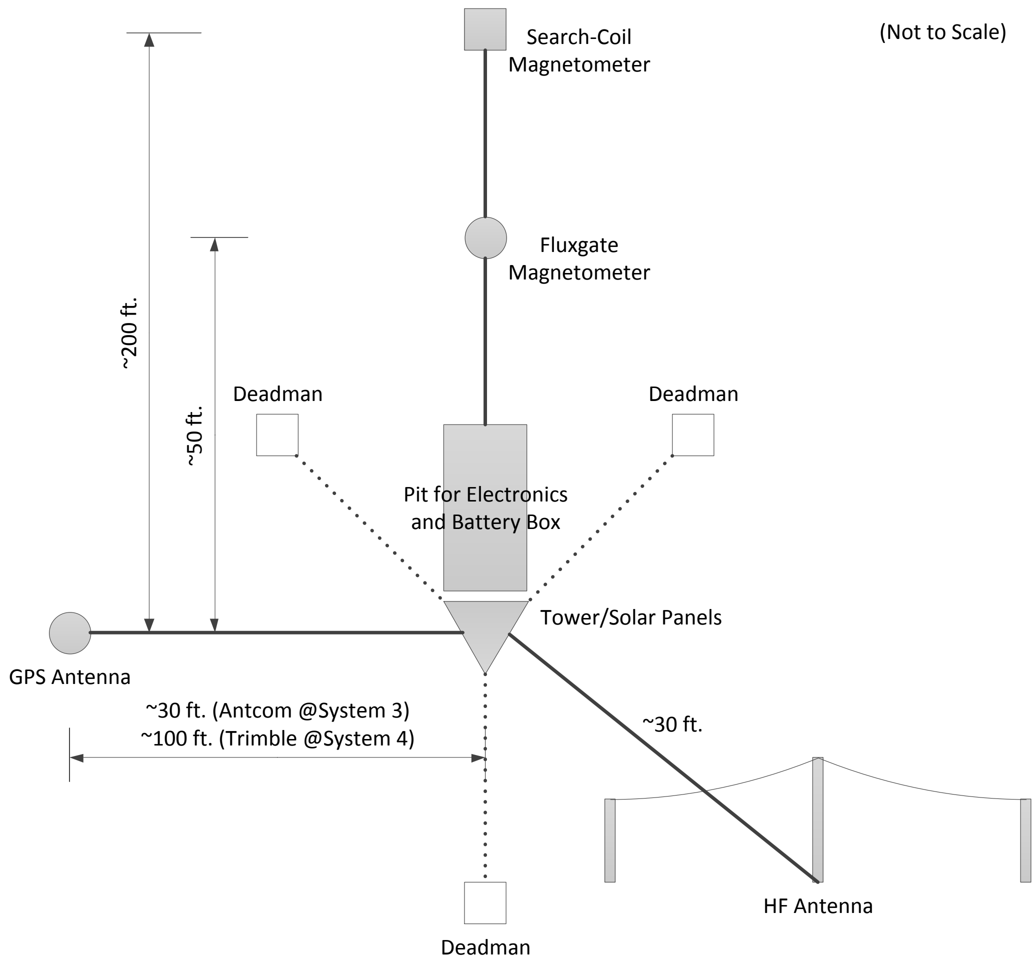

Figure 4. Top view of AAL-PIP installation layout.

Electronics/Power System

The AAL-PIP system employs a single board computer (UNIX-based OS), which is programmable via the Iridium network to support controls of the science instruments, communications, and operation/data acquisition. The interior of the electronics box is self-heated by the electronics placed inside super-insulated vacuum panels and Styrofoam (Figure 5).

The electronics is powered by 16 lead-acid batteries (Figure 6). Charging of the batteries relies only on six solar panels (40W each) attached on the tower. The battery box is insulated with Styrofoam and heated by a thermal plate when necessary. Figure 7 shows the power control electronics located on top of the batteries. The electronics box and the battery box are located in a pit (approximately, 12 ft. L×4 ft. W×4 ft. H) right next to the tower section as shown in Figure 3.

Besides science data from the instruments, the AAL-PIP system produces housekeeping data which contain the temperature of the fluxgate sensor, the battery box, and the electronics (router and fluxgate electronics), the voltage and current of the power electronics, and the information about the operations of various electronic components in order for users to monitor the overall health of the system. Each housekeeping data file consists of 1 hour worth of housekeeping information and a total of 24 hours of housekeeping data are downloaded on a daily basis via the Iridium network. The data produced by the AAL-PIP system are transferred to the server at the University of Michigan via the Iridium network on a daily basis until the AAL-PIP system switches its operation to hibernation mode during the winter times.

Figure 5. AAL-PIP electronic box containing the single board computer, GPS receiver, HF receiver, magnetometer circuits, and Iridium modem. The electronics is insulated by the vacuum panels.

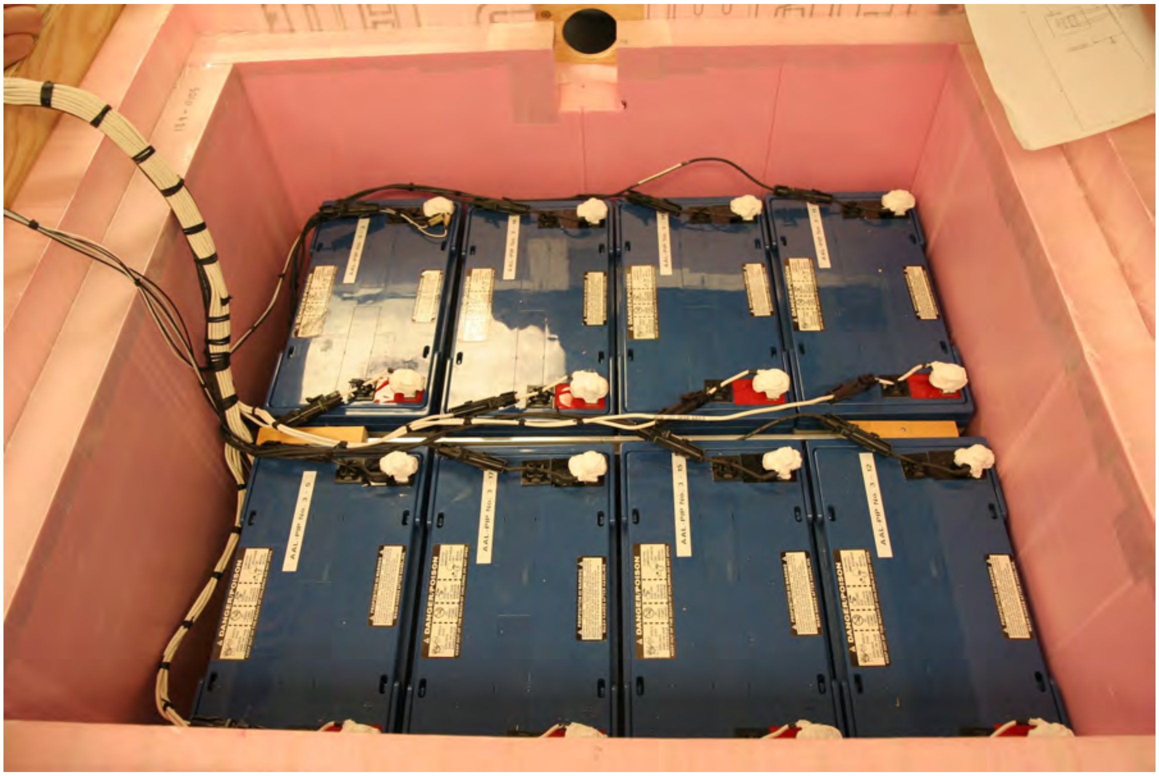

Figure 6. Lead-acid batteries in the battery box.

Figure 7. Power control electronics and fuses on top of the batteries.

Fluxgate Magnetometer
The fluxgate magnetometer (LEMI-022), manufactured by the Lviv Center, Institute of Space Research, National Space Agency of Ukraine (Director Dr. Valery Korepanov), provides three-axis vector magnetic field background information at a rate of 1 vector sample/sec. The sensor consists of two units - sensor unit with adjustable support and electronic unit. The fluxgate sensor is placed in a pit, approximately 50 ft away from the tower (Figure 8). The primary sensor specifications are as follows.

Measuring ranges of total magnetic field at the display of 68000 ±nT
Measured range at analog output of ±1000 nT
Analog output sensitivity of 2.4 mV/nT
Noise level over the frequency response of < 8 pTrms
System (analog + digital) resolution of 0.033 nT
Components initial orthogonality error of < 30 min of arc
Operating temperature range of -40 to +60°C
Operating voltage (battery) of 10-18 V (5 V, digital)
Power consumption of < 0.7 W (< 0.5 W, digital)
Weight of 2.7 kg (sensor with support); 1.8 kg (electronic unit)
Length of connecting cable of 10 m

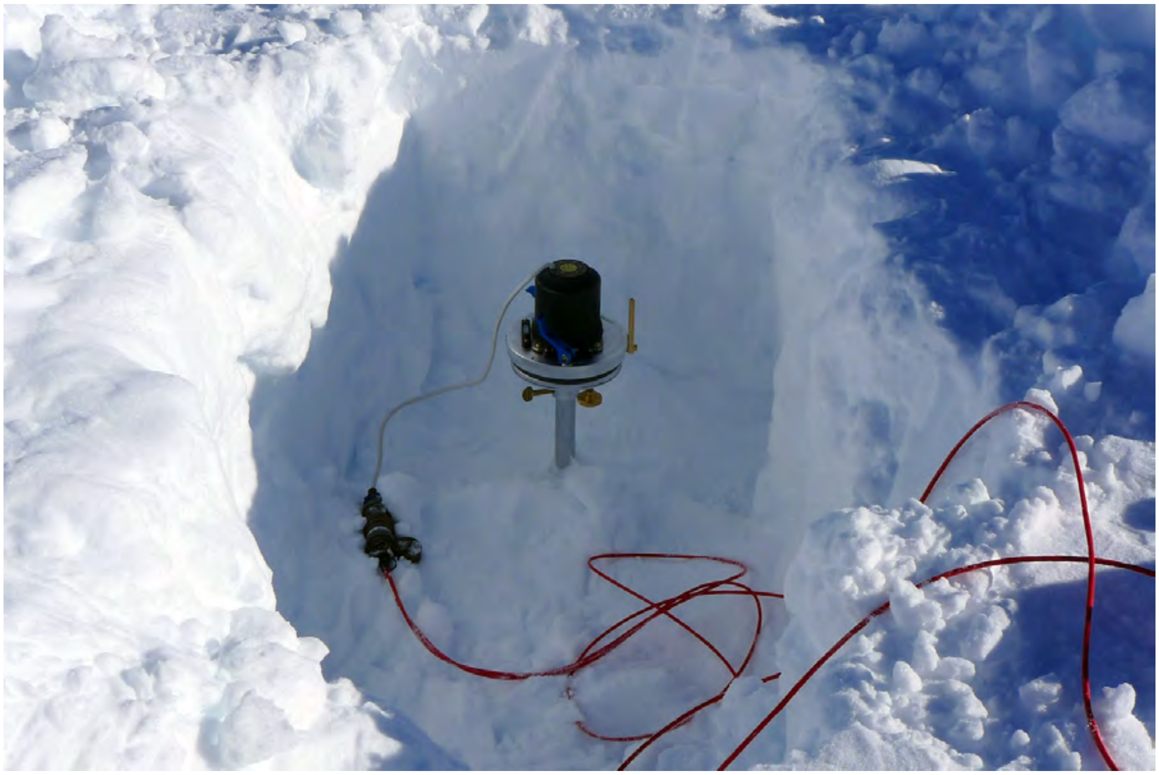

Figure 8. AAL-PIP Fluxgate sensor installed in a snow pit.

Search-Coil Magnetometer

The search-coil magnetometer, developed at the Magnetosphere-Ionosphere Research Lab led by Dr. Marc Lessard at the University of New Hampshire, consists of a 2-axis search-coil magnetic sensor with preamps, a 200 ft. cable, and an analog circuit to observe time-varying magnetic field wave activity (dB/dt) in two directions (N-S and E-W) with a time resolution of 10 samples/sec/axis. The search-coil sensor is shown in Figure 9.

Signals detected by the search-coil magnetic sensor are filtered and amplified by the analog circuit, and digitized and stored in the AAL-PIP data acquisition system. The preamp is equipped in each magnetic sensor so the signals are amplified to a suitable level before being transmitted to the analog electronics via the cable. The main analog electronics include amplifiers and band-pass filters so magnetic field variations in the ULF range (up to 5 Hz) can be detected.

The search-coil magnetic sensors are placed in a pit 200-300 ft. away from the AAL-PIP power and electronics system in order to avoid interference (Figure 10). The primary search-coil magnetometer system specifications are listed as follows.

Operating voltage of ±12 VDC (analog) and ±5 VDC (digital)
Power consumption of 10 mA (preamp/axis) and 36.8 mA (main analog electronics)
Magnetic sensor sensitivity of 150 μV/(nT Hz)
Overall system sensitivity of 4.43 V/(nT Hz)
Frequency response of 0 - 2.5 Hz (-3 dB corner frequency, DC is not measured)
System resolution of ~10 pT/√Hz over the frequency response
Dynamic range of ±2.26 nT over the frequency response
Analog input voltage range of ±10 V
ADC bit resolution of 1 pT Hz (12 bits)
ADC sampling rate of 10 samples/sec

Figure 9. AAL-PIP search-coil magnetic sensor installed in a snow pit.

Figure 10. AAL-PIP search-coil magnetic sensor located in a snow pit. The main structure of the AAL-PIP system is in the background.

CASES GPS

Connected Autonomous Space Environment Sensors (CASES) GPS receiver is a low-cost next generation custom made dual frequency GPS receiver to measure total electron contents (TEC) and ionospheric scintillations, which can be reprogrammed after deployment and operated in various modes to save power or collect mass amounts of data during interesting geophysical conditions in cooperation with optimal signal tracking techniques.

The receiver electronics is developed and built at Cornell University, University of Texas Austin and Atmospheric & Space Technology Research Associates (ASTRA). The

CASES GPS is designed to receive L1 C/A and L2C codes. With a triggering technique, onset of scintillations can be determined and the receiver can be switched from low data rate (1 Hz) to high data rate (50 or 100 Hz) collection mode. A differencing technique (subtracting non-scintillating channel from all channels) is used for eliminating local clock effects or receiver clock bias. The power consumption is 6.5 W and the lowest temperature for reliable operation is -40°C. The GPS antenna is located 30 ft away from the tower (Figure 11).

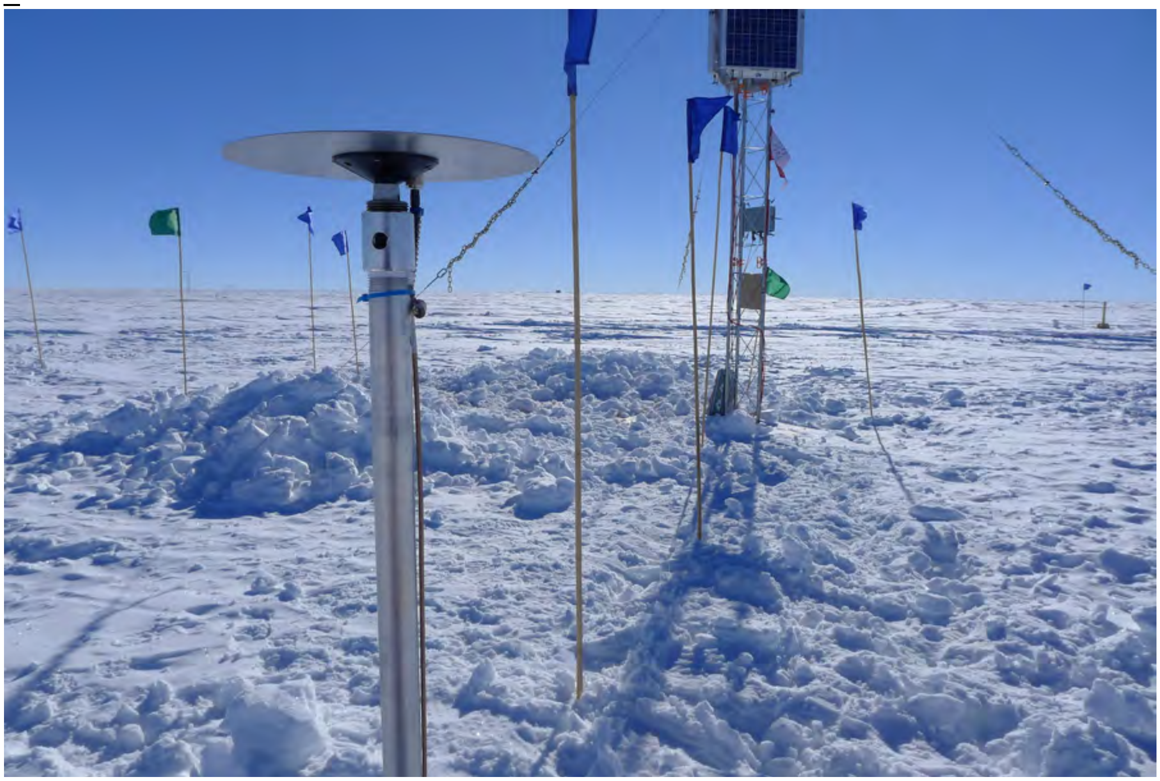

Figure 11. GPS antenna located 50 ft away from the tower.

HF Antenna

The HF antenna is designed for the study of HF communication in Antarctica. The antenna uses a dipole structure located 30 ft away from the tower (Figure 12). The HF dipole antennas are oriented in a way the dipole antennas are perpendicular to the line-of-sight between the two AAL-PIP systems. The HF system requires ~6-10 W during radio transmission.

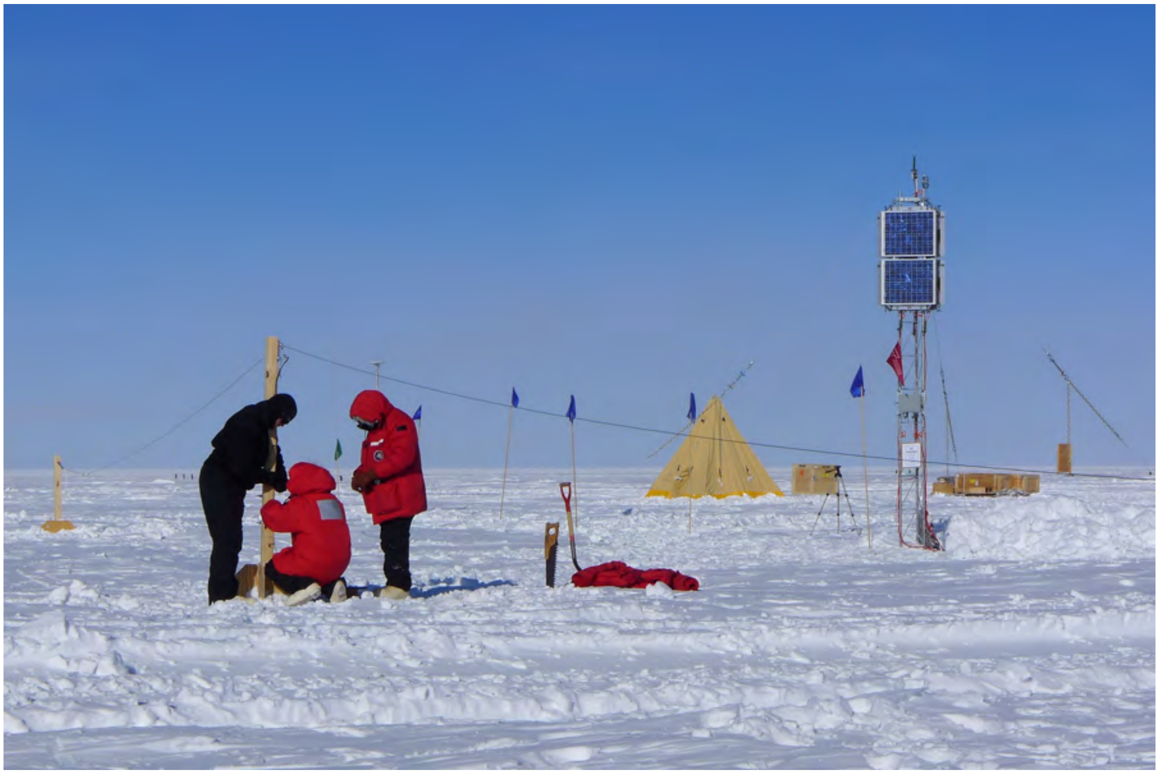

Figure 12. HF dipole antenna installed near the AAL-PIP tower.

Assembly Features
The mechanical structure of the AAL-PIP system features easy and glove-friendly assembly to accommodate to the extreme cold weather. Almost all assembly can be done with gloves on and without hand tools. Large pins and T-bolts, and wing nuts instead of small bolts and nuts are used (Figure 13 and 14). For easy and safe installation, the solar panels are assembled at the bottom of the tower and then winched to top of the tower as shown in Figure 15. The battery box assembly uses harness with quick-snap connectors for easy, safe and unique fit that avoids mistakes (Figure 16).

Figure 13. Pins used for tower assembly.

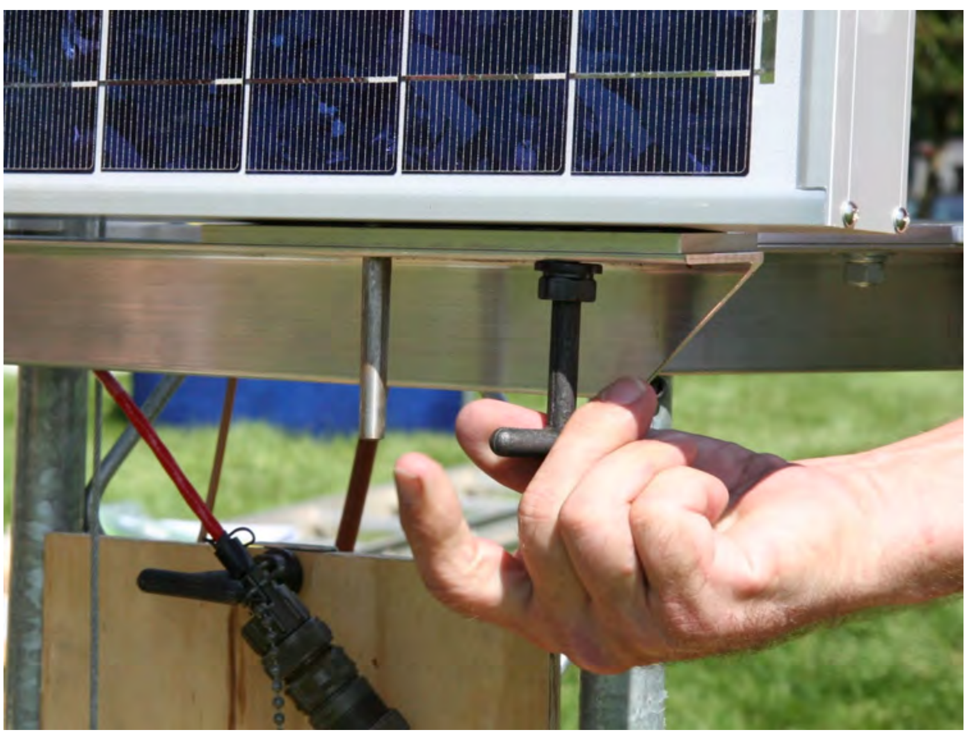

Figure 14. T-bolts used for solar panel assembly.

Figure 15. Winch mechanism for installation of the solar panels on the tower.

Figure 16. Quick-snap connectors used for battery harness.

3. Installation in Antarctica

First-Year Deployment (December 11, 2010 – January 4, 2011)
Four participants from Virginia Tech including the project PI, Dr. Bob Clauer, Research Associate, Dr. Hyomin Kim, and two graduate students, Kshitija Deshpande and Joseph Macon, were deployed to Antarctica. They installed two AAL-PIP systems (Sys3 and Sys4) at the South Pole for 1-year test. Hyomin Kim and Joseph Macon camped for 4 days at PG2 where Sys2 was installed in 2009 and started showing issues with Iridium communication in 2010. PG2 is located on the East Antarctic plateau 600 km away from the South Pole. After several attempts to repair the system on site, the team decided to bring it back to the US for further diagnosis.

Figure 17. AAL-PIP deployment team upon arrival at South Pole Station: Kshitija Deshpande, Bob Clauer, Joseph Macon, and Hyomin Kim (from the left).

Figure 18. Joseph Macon and Hyomin Kim assembling the battery box (Sys3) at South Pole Station.

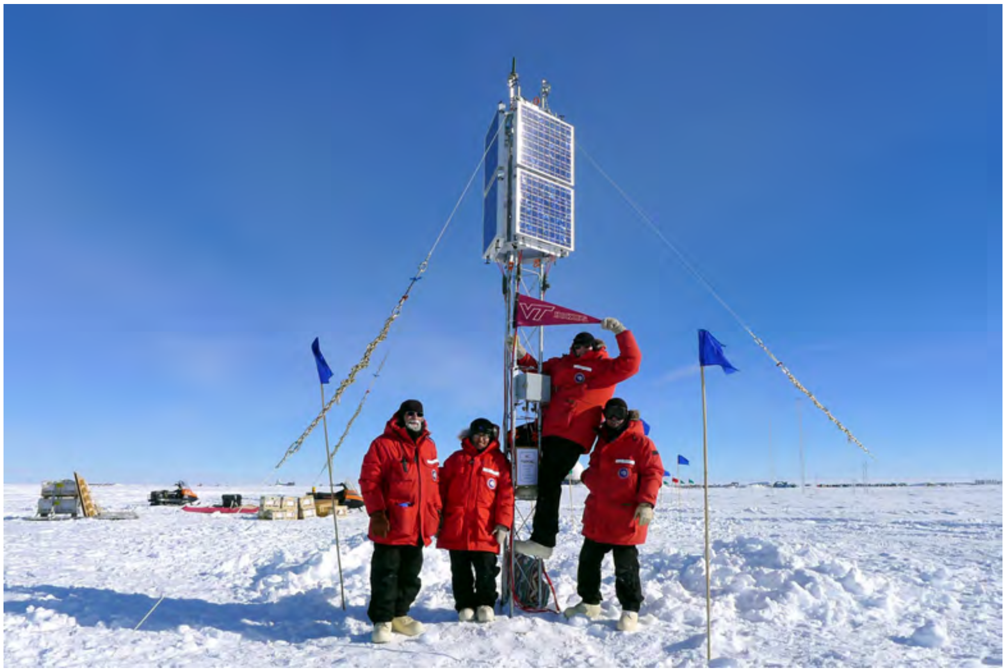

Figure 19. Team members in front of the completed AAL-PIP system at the South Pole.

Figure 20. Twin Otter airplane next to the AAL-PIP system at PG2 which is one of the AAL-PIP remote field stations on the Antarctic plateau.

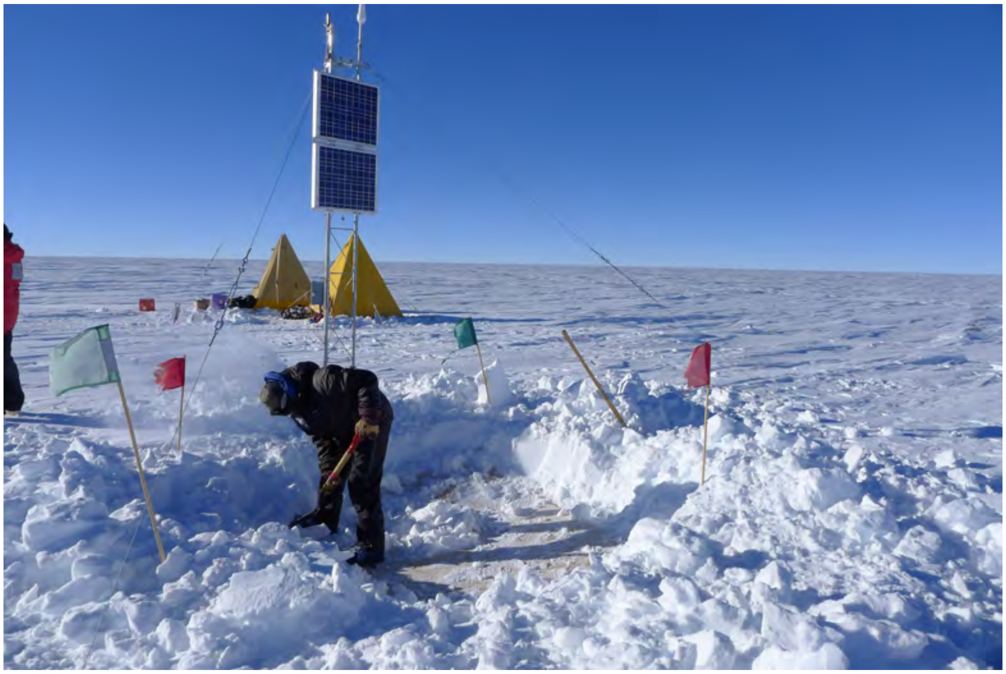

Figure 21. Recovering the PG2 system for repair.

Figure 22. Field camp established at PG2.

Second-Year Deployment (December 13, 2011 – January 16, 2012)
The second year AAL-PIP deployment team includes four participants from Virginia Tech (the project leader Dr. Bob Clauer, Dr. Hyomin Kim, Dr. Majid Manteghi, and Joseph Macon) and one from ULCA (Dr. Bob McPherron). Three AAL-PIP systems (Sys2, 5, and 6) were installed at the South Pole and one system (Sys3), which operated normally at South Pole Station, was moved to the remote field (PG2) where the malfunctioning system was removed in the previous year.

One of the AAL-PIP systems installed at the South Pole in the previous year (Sys4) had a couple of issues with Iridium communication and GPS operation. It was repaired and reinstalled for one more additional year round test at the South Pole. Three team members, Hyomin Kim, Majid Manteghi, and Joseph Macon flew to PG2 and camped there for 4 days to install the AAL-PIP system (Sys3).

Figure 23. AAL-PIP team members arriving at South Pole Station.

Figure 24. Majid Manteghi installing the solar panels on the tower of the AAL-PIP system at South Pole Station.

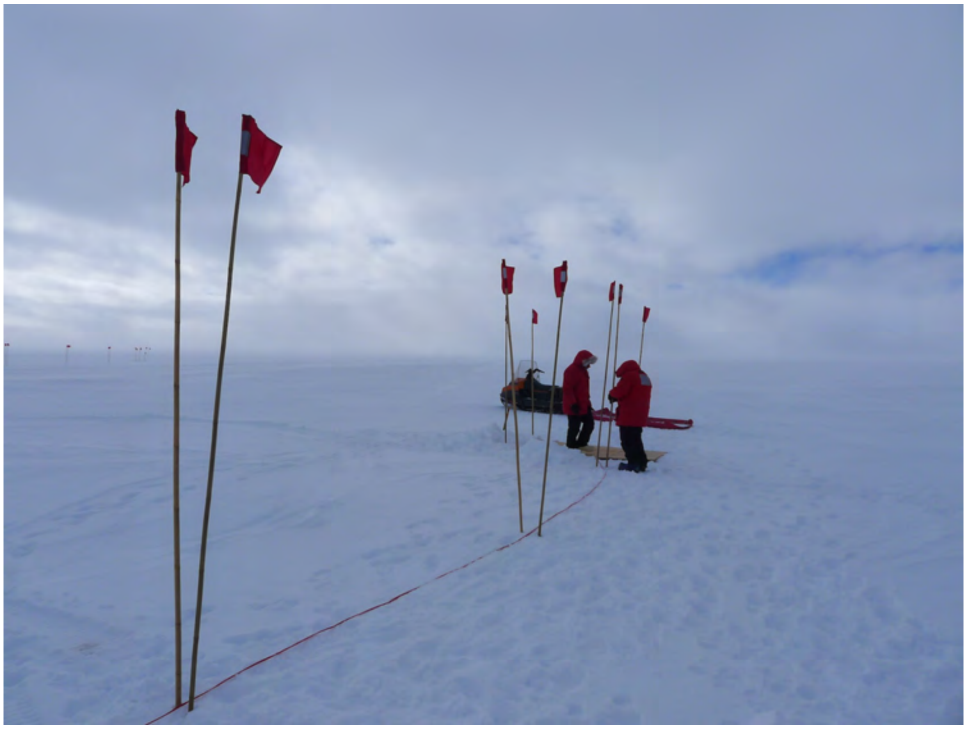

Figure 25. Laying out the search-coil cable at South Pole Station.

Figure 26. AAL-PIP system installed at South Pole Station.

Figure 27. AAL-PIP team members at Sys5 installed at South Pole Station: Majid Manteghi, Bob McPherron, Joseph Macon, Bob Clauer, and Hyomin Kim (from the left).

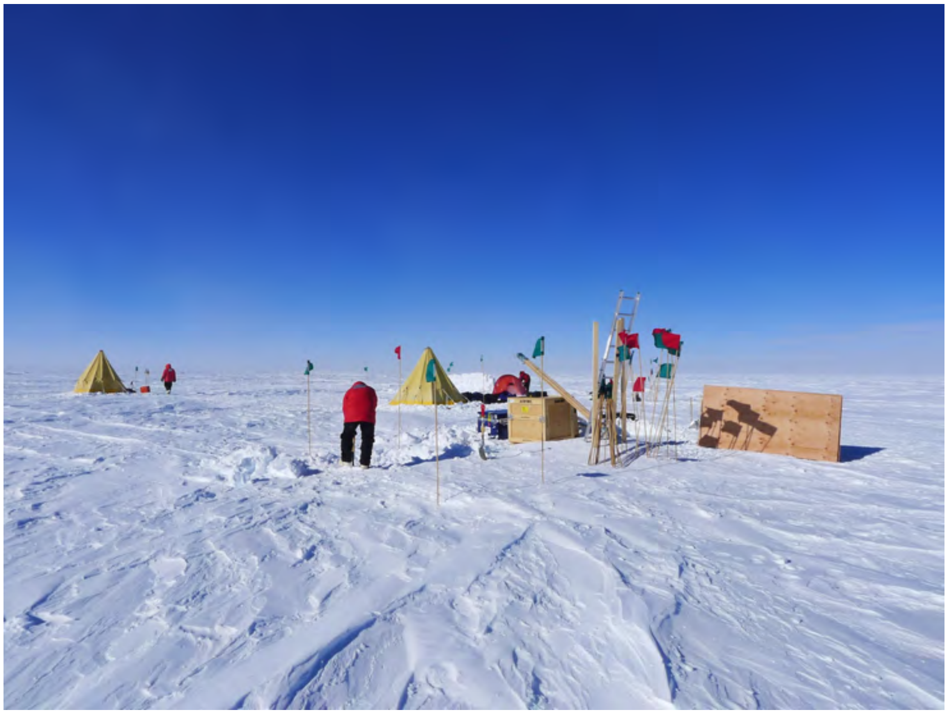

Figure 28. Field camp established at the remote field station, PG2, for the installation of the AAL-PIP system.

Figure 29. Twin Otter airplane at the remote field station, PG2, to transport the second cargo of the AAL-PIP system.

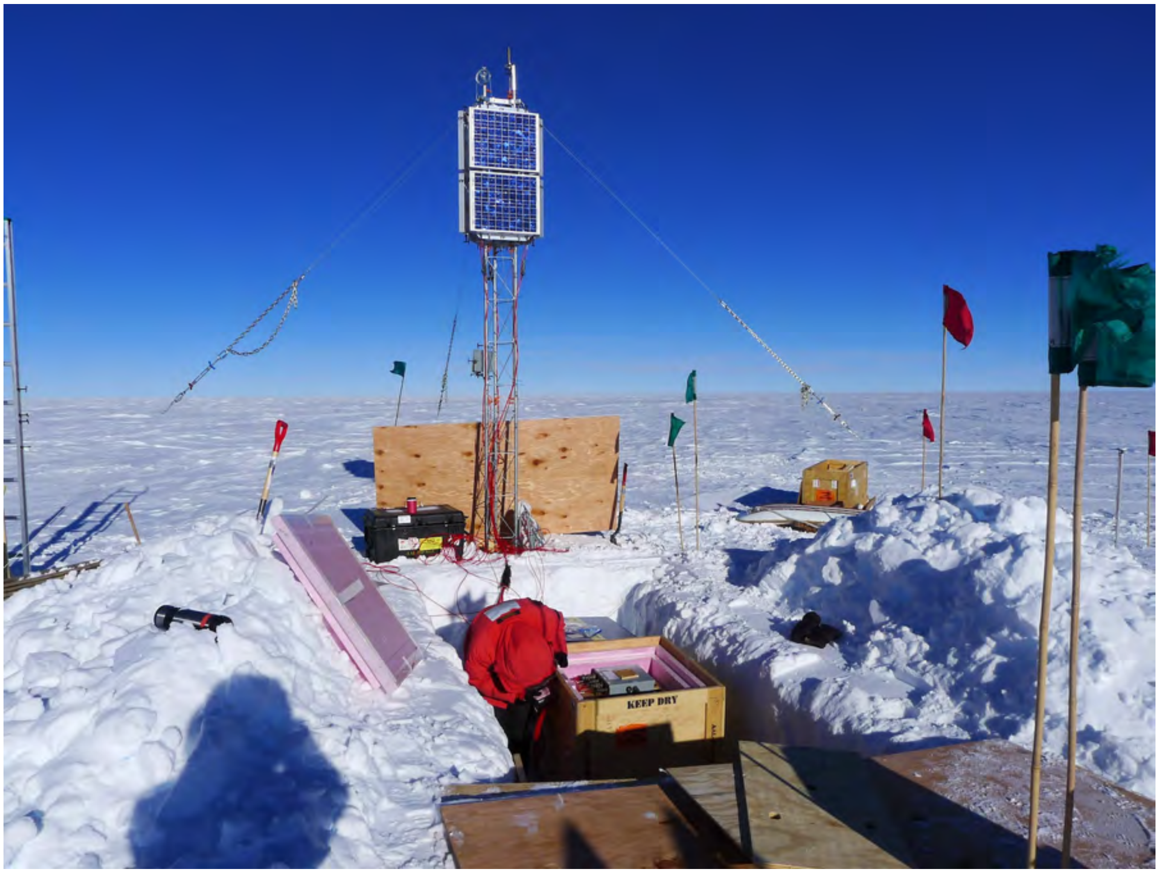

Figure 30. Installation of the AAL-PIP system at the remote field station, PG2.

Third-Year Deployment (December 11, 2012 – January 10, 2013)

Four participants from Virginia Tech (Hyomin Kim, Zhonghua Xu, Chad Fish and Karthik Venkataramani) and one from ASTRA (Adam Reynolds) joined the third year Antarctic deployment for the installation of the AAL-PIP systems. They carried out a repair at PG2 and a new installation at PG3. Since the previous field season (2011-2012), the four AAL-PIP systems (Sys2, 4, 5, and 6) had been operating at the South Pole. Sys2 and Sys6 were removed from the South Pole for repair back in the US as some issues were found from those systems. Sys4, which successfully survived 1 year at the South Pole, was moved to PG2 to replace the existing system (Sys3) which showed issues with the single board computer. Two team members, Zhonghua Xu and Chad Fish, made one-day trip to PG2 for the replacement. A new remote field station, PG3, was established by three team members including Zhonghua Xu, Chad Fish, and Karthik Venkataramani, who camped there for four days.

Figure 31. AAL-PIP deployment team upon arrival at South Pole Station: Adam Reynolds, Chad Fish, Zhonghua Xu, Karthik Venkataramani, and Hyomin Kim (from the left).

Figure 32. Taking down the AAL-PIP system (Sys5) at the South Pole for the preparation of remote field installation.

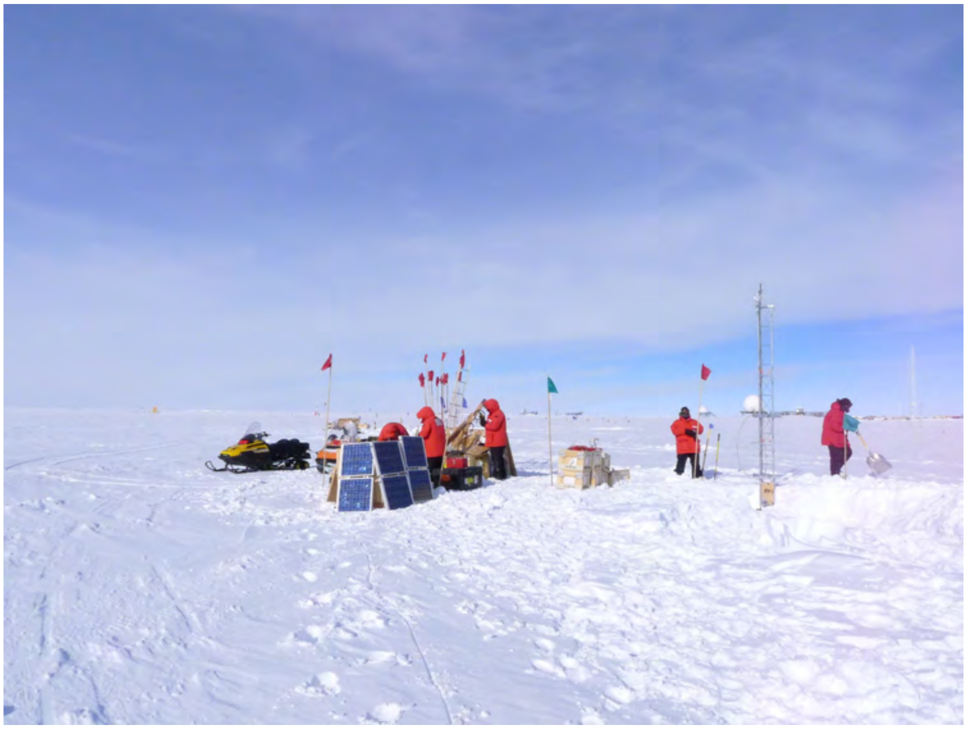

Figure 33. Taking down the AAL-PIP system (Sys6) at the South Pole for the preparation of remote field installation.

Figure 34. AAL-PIP team members in front of the South Pole marker.

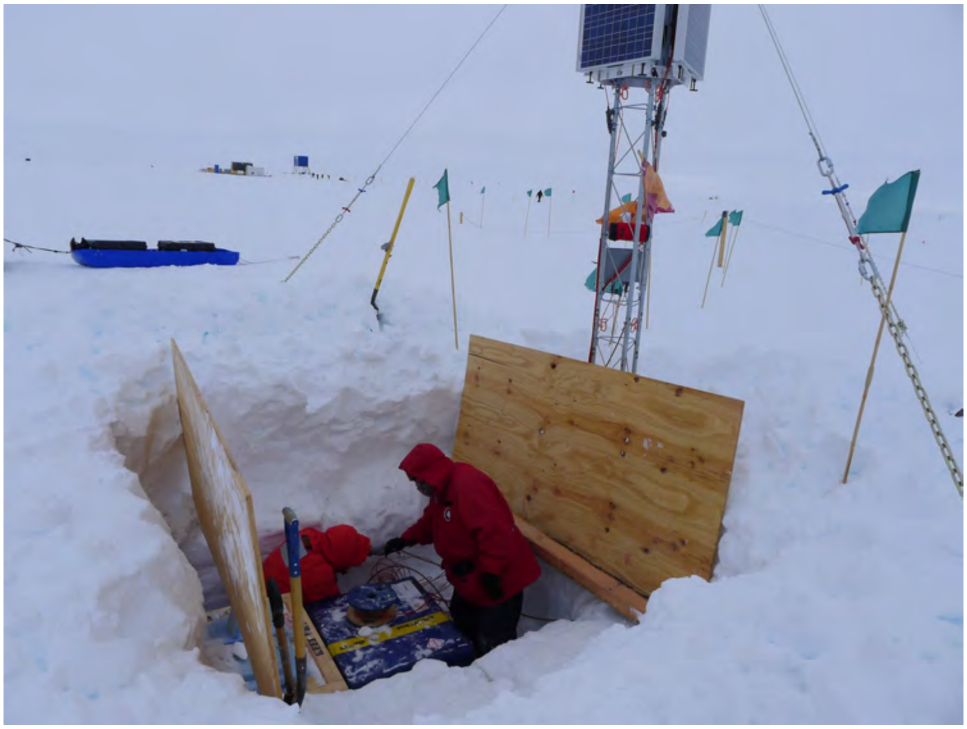

Figure 34. System troubleshooting at South Pole Station.

Figure 35. Unpacking the AAL-PIP shipping boxes at the remote field station, PG3.

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