

Communications systems for remote Polar GNSS station operation

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1. Introduction:

Emerging polar geophysical networks will enable the collection of critical new data sets to address many fundamental questions about the nature and behavior of the crust and mantle beneath Antarctica and Greenland, and their relationship to ice sheet dynamics and climate. It has long been recognized that major advances in addressing many compelling questions in polar geoscience require continuous recording of Global Navigation Satellite System (GNSS) and seismic data at stations that can operate autonomously for a period of two or more years (e.g., Workshop on Antarctic Neotectonics, 2001; Workshop on Structure and Evolution of the Antarctic Plate, 2003). This chapter addresses communication systems for bringing remote polar network GNSS data to the Internet. While the focus is on communications related to GPS systems, the communication strategies are similar for GNSS applications also utilizing GLONASS (and future Galileo) signals.

Up to now, year-round continuous recording of geodetic data in the polar regions has been largely limited to a small number of stations adjacent to permanent settlements and operational bases. To densify networks, the need for truly autonomous station operation is amplified by the logistical constraints under which national science programs operate. Support for remote field deployments is usually restricted by the availability of aircraft flights and fuel. One could argue that some of the important science questions might be answered by gathering data over just the summer months using conventional solar and battery power systems and storing data on-site, but even so revisiting sites annually to retrieve data is logistically impractical in many cases. Robust communication systems are indispensable to minimizing site visits, an essential requirement for long-duration deployment of instruments at very remote sites. Experience has also shown the benefits of quasi-real time data communications in terms of scientific productivity, station maintenance and troubleshooting, overall data availability and quality, and the streamlining of downstream data quality control and processing. In addition, there are some scientific objectives and monitoring functions of remote observatories (such as earthquake and tsunami hazards, GPS-meteorology) that require real-time telemetry of data.

Modern GNSS receiver technology makes it possible to use off-the-shelf units for autonomous recording in the extreme polar environment, and advances in power and communication technologies have now put us on the threshold of deploying large GNSS networks at the polar latitudes. A development effort is underway by UNAVCO and IRIS (Prescott and Simpson, 2006) to capitalize on these advances to build reliable power and communication systems that will enable autonomous station operation in the remotest polar locations for periods of two or more years. These power/communication systems will support the next generation of polar researchers, and will allow the science community to achieve the first long-duration deployment of continuously-recording GNSS and seismic stations across the Antarctic continent as well as in other remote polar regions, proposed to commence during the International Polar Year (IPY 2007-2009). Chapter ??, *Technology Development for Remote GNSS Stations in Extreme Environments*, highlights the technical and environmental challenges of such systems, while this chapter provides a detailed look at the specific challenges and options for communication systems for remote data retrieval.

Full GPS data transfer (30 second logging rate) requires up to 1MB/day of bandwidth and is well within the capabilities of numerous communication services (Stowers and Fisher, 2006). As a result, full data communication solutions are readily obtainable for geodetic GPS deployments anywhere in the world (Figures 1 and 2). The large volume of onboard memory on modern GNSS receivers also allows for backup data storage on the receivers, providing protection from extended communication outages. In the event of a communication failure the data can still be retrieved manually during the next maintenance visit. Since specific services change rapidly and new capabilities evolve, this paper is intended to highlight the options for polar regions communications at the commencement of IPY.

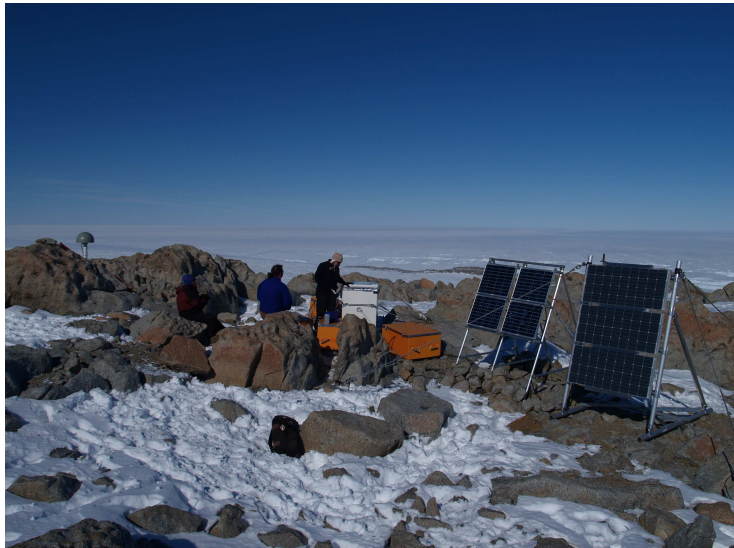


Figure 1 – The remote GPS station Fishtail Point (FTP4) at 79° S is part of the Transantarctic Mountain Deformation Network (TAMDEF).

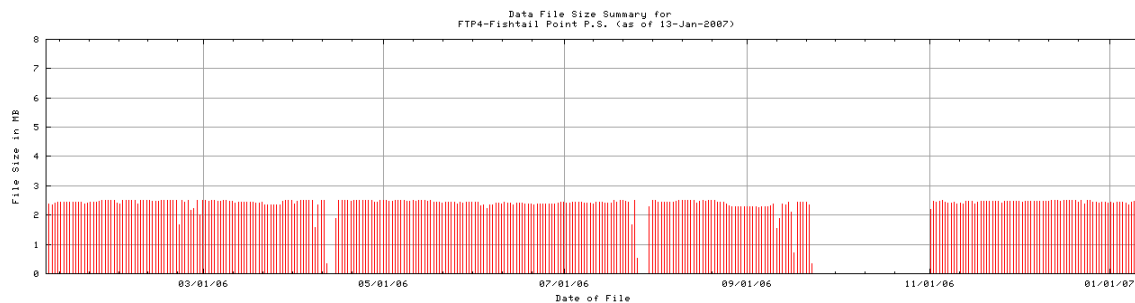


Figure 2 – FTP4 data archive summary shows year-round operation of a remote Antarctic GPS station. Data files are downloaded via Iridium, and the large data gap was the result of a GPS receiver failure.

2. Communication options and considerations:

There are often several communication options available with fundamental differences in terms of functionality, reliability, and cost, and the appropriate solution for any particular site is dependent on site specifics. For networks one must also consider the trade-offs between optimizing the communication solution for each site vs. maintaining a standardized network to simplify operation and maintenance. For example, an Antarctic network may be designed with Iridium communications at all remote stations even if there is a site within the Inmarsat footprint (Figure 3), since the complexity introduced by a one-off solution may negate any service cost savings. Likewise, the use of radio links with no recurring costs is a reasonable choice where a point-to-point link gains access to an Internet hub, but once a repeater is required the added cost and complexity of the repeater needs to be considered vs. adopting a satellite based link. In cases where complete standardization is unrealistic, variations in site designs (GNSS receiver selection, power system, and communication method) should be kept to an absolute minimum to minimize future operational complexity and associated costs.

Inmarsat BGAN coverage

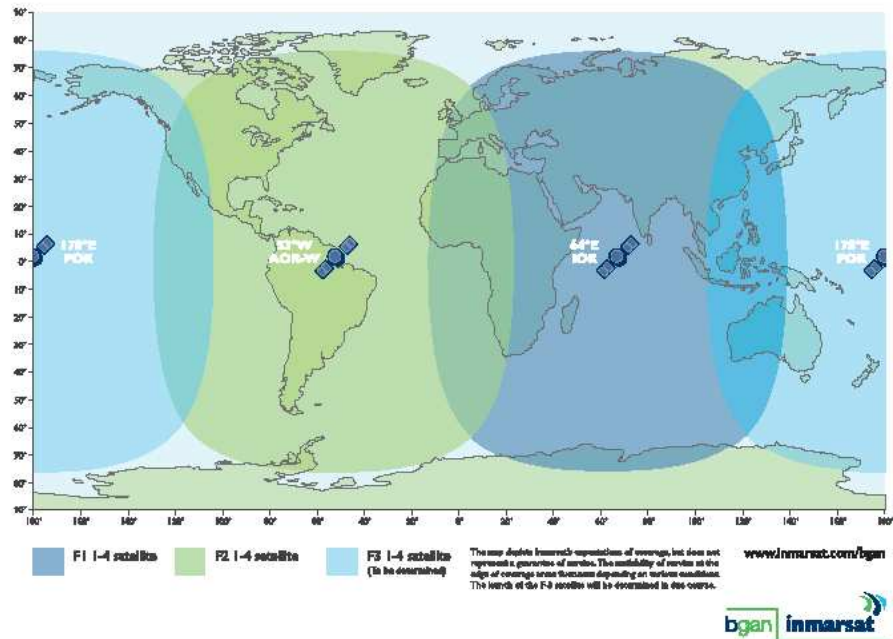


Figure 3 - Inmarsat BGAN coverage (broadband.inmarsat.com). The third satellite over the Pacific is planned for launch in 2007.

In addition to evaluating the various hardware and service options, the particular communication protocols also need to be considered. Standard protocols are preferred over manufacturers' proprietary communication application and allow the data communication center to develop tools and utilities that are not unique to a specific brand of product. When possible, communication protocols should conform to the Transmission Control Protocol/Internet Protocol (TCP/IP) de-facto standard for transmitting data over the Internet. While most communication hardware can be set up for standard TCP/IP and serial communication protocols it is also desirable that the end device, in this case the GNSS receiver, can be operated over standard protocols without having to use a proprietary control software. The added complexity of running a proprietary receiver communication program over third party communication links should be avoided when possible. IP based communications are preferred over serial communications since the goal is to get data to the Internet, and several GNSS receivers now support IP communication for data access and control.

Finally the trade-off between periodic data downloading vs. data streaming should be considered. For most geoscience applications the periodic data download is preferred as a simple and robust method. Latency can be reduced by increasing the download frequency, and retries are straightforward in the event of partial file downloads. Advantages of streaming data include minimal data latency and the opportunity to use short-burst messaging services directly to the Internet, which may reduce operational costs and simplify the overall system. However, a means to communicate with the receiver would still need to be applied, as would a method to catch up on data recovery after eventual system outages. The most stringent latency requirements for data streaming come from real-time network applications such as GNSS virtual reference networks and other real-time differential application, and in such cases the guaranteed delivery specifications from the communications providers need to be considered.

3. Technical characteristics:

Availability, cost, performance, and reliability are the primary concerns when deciding what communication system to use. Table 1 provides a hierarchical overview of preferred communication choices, and GPS data and station performance metrics from the example stations are all available on-line from the UNAVCO data archive (facility.unavco.org). In addition to the individual communications

hardware specifications, the performance of the GNSS receiver and communication hardware as a system must be well understood. System integration and testing are key activities prior to field deployment, and controlling hardware may also be used to optimize the remote operation. Custom solutions may be needed to guarantee access over the Internet when the service provider does not provide static IP addresses. Components may need to be power cycled on a regular basis to ensure robust operation, and power savings can be realized by switching the communications hardware off when not in use.

Table 1 – Preferred choices for GNSS data retrieval.

Situation	Solution	Concerns	Example GPS station
1. The GNSS receiver can be located at an Internet (or telephone) node with available bandwidth.	Simple cable connection.	-Network security and firewall issues.	AMU2, South Pole Station, Antarctica, 90° S
2. The GNSS receiver can be located within line-of-sight (LOS) to an Internet node.	Radio link between the receiver and the Internet.	-Radio and antenna reliability. -Radio power requirements. -Network security and firewall issues.	CONZ, Mt. Erebus, Antarctica, 78° S (Intuicom wireless Ethernet bridge modems)
3. A repeater is required to establish a LOS link to an Internet node.	Radio link to repeater to the Internet.	-Radio and antenna reliability. -Radio power requirements. -Repeater adds complexity of another remote instrument and power system. -Network security and firewall issues.	ROB4, Cape Roberts, Antarctica, 77° S (FreeWave wireless serial modems)
4. The GNSS receiver is in the footprint of a commercial terrestrial wireless communication provider.	Connect via the appropriate network modem.	-Modem system reliability. -Modem power requirements. -Recurring costs for service.	GRNX, Healy, Alaska, 64° N (Proxicast GPRS modem)
5. The GNSS receiver is in the footprint of a commercial geosynchronous satellite wireless communication provider.	Connect via the appropriate network modem.	-Modem system reliability. -Modem power requirements. -Recurring costs for service.	SUMM, Summit Camp, Greenland, 72° N (Harris Maritime Communications Service VSAT)
6. None of the above situations apply.	Connect via the Iridium satellite constellation.	-Limited bandwidth. -Modem system reliability. -Modem power requirements. -Recurring costs for service. -Signal interference.	FTP4, Fishtail Point, Antarctica, 79° S (NAL Research Iridium modem)

a. Private radio link:

Private radio links are commonly used to address the “last mile” problem when the GNSS receiver can be located within line-of-sight to an Internet node or repeater. Many options exist including WiFi links and commercial narrowband and spread spectrum radios. Radios by FreeWave and Intuicom have been used in the Antarctic environment for several years with robust reliable performance over distances up to 100 miles between mountain peaks.

Private radio link

Data rate: 100kbps – 50mbps typical.

Power consumption: 1-5W typical.

Hardware cost: \$500 to \$2000 typical per radio depending on specific system used.

Recurring service cost: None.

Modes of use: Line-of-sight links for point-to-point, point-multipoint communications. Repeaters can be used to mitigate challenging terrain. Can support two way communications, data downloads, and data streaming.

Area of availability: Global – off the shelf hardware is available for all operating environment. Radio frequency control restriction often and use must be coordinated with the local frequency spectrum controlling authority.

Main advantages: Flexible and can be adapted to the specific science instrumentation needs. Owned and fully controlled by the project. No recurring costs.

Main disadvantages: Limited to line-of-sight communications. User must set up infrastructure.

b. Commercial terrestrial wireless:

Wireless terrestrial based third generation mobile communications services (G3) such as General Packet Radio Service (GPRS) are common infrastructure in populated areas. Such services can be of use in the Arctic at sites near villages with wireless Internet service. For example, GPRS service is currently available from Tele-Greenland over the Global System for Mobile Communications (GSM) network that currently covers the larger Greenland villages. The GPRS network is an "always on", private network for data. It uses the existing GSM network to transmit and receive TCP/IP based data to and from GPRS mobile devices.

Commercial terrestrial wireless

Data rate: 15-80 kbps typical.

Power consumption: 2-6W typical.

Hardware cost: \$1000 typical.

Recurring service cost: \$60/month typical.

Modes of use: Provides on-site Internet access for data downloads, data streaming, and system control.

Area of availability: Within commercial telecommunications service areas. Near larger towns and villages in the Arctic. No service in the Antarctic.

Main advantages: Internet access at the site using existing infrastructure.

Main disadvantages: Limited availability in remote areas. Recurring costs.

c. Commercial geosynchronous Earth orbit (GEO) satellite wireless:

Very Small Aperture Terminal (VSAT) networks and the Inmarsat service use GEO satellites to communicate with remote sites. Various VSAT solutions are available depending on the area of interest (Figure 4), while Inmarsat provides a more global service (Figure 3). GEO satellites provide near global coverage, but they do not cover the highest latitudes and service becomes very limited above 70 degrees. Within the satellite footprints, GEO satellite based systems can be used to transfer GNSS data in near real time in areas where no communications infrastructure exists.

i. VSAT satellite wireless:

VSAT satellite space segment providers offer three types of satellite beam: spot, hemisphere, and global. Spot beams are focused on population centers and are generally high power, thus allowing smaller antenna dishes to be used at remote sites. Hemisphere and global beams have a much larger footprint and weaker signal strength and thus requires a larger antenna diameter relative to spot beam systems (Jackson et. al, 2001). VSAT may provide a cost effective solution when shared with other users, but the large power consumption and large dish size makes it less desirable for standalone GNSS applications.



Figure 4 - StarBand VSAT service provided by the IA-7 Telstar-7 satellite Ku band includes the Alaska Arctic (www.satsig.net).

GEO-VSAT

Data rate: 150 kbps typical.

Power consumption: 20W typical.

Hardware cost: \$1000 typical.

Recurring service cost: \$150/month typical.

Modes of use: Provides on-site Internet access for data downloads, data streaming, and system control.

Area of availability: Most populated regions and parts of the high Arctic.

Main advantages: Internet access at the site using existing infrastructure.

Main disadvantages: Limited availability in high latitude polar regions. Large power requirements. Recurring costs. Directional antenna may require set-up expertise. Large antenna dish can be problematic.

ii. Inmarsat:

Inmarsat's Broadband Global Area Network (BGAN) provides broadband data through a single device on a global basis (Figure 5). This new service supports both standard and streaming IP communications, and appears promising for near-global GNSS data telemetry. As with all GEO satellites, coverage is not available at the highest latitude locations (Figure 3) and the planned 3rd F3 satellite is needed to cover the present service gap over the Pacific.

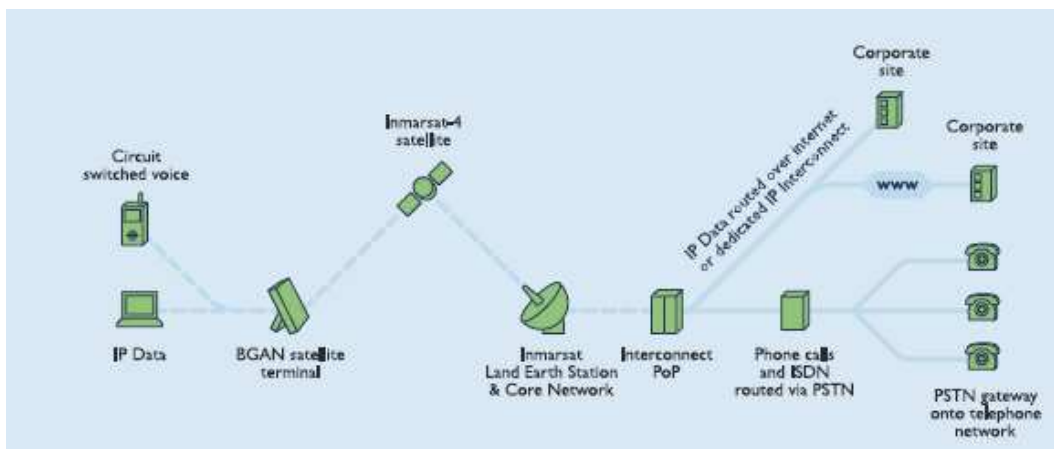


Figure 5 – BGAN communication routing options (broadband.inmarsat.com).

GEO-Inmarsat

Data rate: 60 kbps typical.

Power consumption: 1W typical.

Hardware cost: \$200 to \$2000 per radio depending on specific system used.

Recurring service cost: \$250/month for 1MB/day data retrieval.

Modes of use: Provides on-site Internet access for data downloads, data streaming, and system control.

Area of availability: Global with F3 satellite, except for highest latitudes.

Advantages: Reasonable cost and power consumption for polar application. IP based services.

Disadvantages: New service that has not yet been tested for GNSS data applications. Recurring costs. Does not cover the highest latitudes.

d. Commercial low-Earth orbit (LEO) satellite wireless:**i. Globalstar**

The Globalstar system relies on a LEO satellite constellation to provide global voice and data services. Data are routed from the user to the gateway hub via a commonly visible satellite. As a result, the distribution of coverage is dictated by the hub locations, and the coverage is similar to that of GEO satellite systems and sparse in the polar regions (Figure 6). The system provides single channel data rates of 9.6kbps.

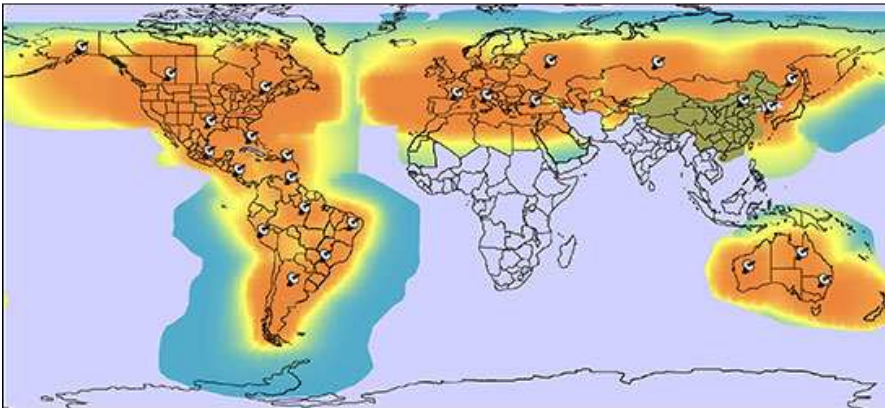


Figure 6 – Globalstar service coverage is dictated by the gateway hub locations (www.globalstar.com).

ii. Iridium

The 66 satellite Iridium constellation is the world's largest satellite network and the only commercial communication system that provides truly global coverage suitable for GNSS data retrieval (Figure 7). Data are routed from satellite to satellite as necessary to reach the gateway hub. Hardware provided by NAL Research provides a traditional serial modem link with AT commands as well as a Short Burst Data service with packets sent directly to an IP address. System enhancements to increase data rates and provide IP based services are underway (Colussi 2006). As a note of caution, both Iridium and GPS operate in the L-band (1616-1626.5MHz for Iridium, 1227.6, 1575.42 MHz for GPS), and interference resulting in GPS cycle slips is possible during Iridium transmission. Antenna separation of at least 10 meters is recommended to mitigate this. Dropped connections are also frequent occurrences with the Iridium system, and the data download system must be set up to handle this.

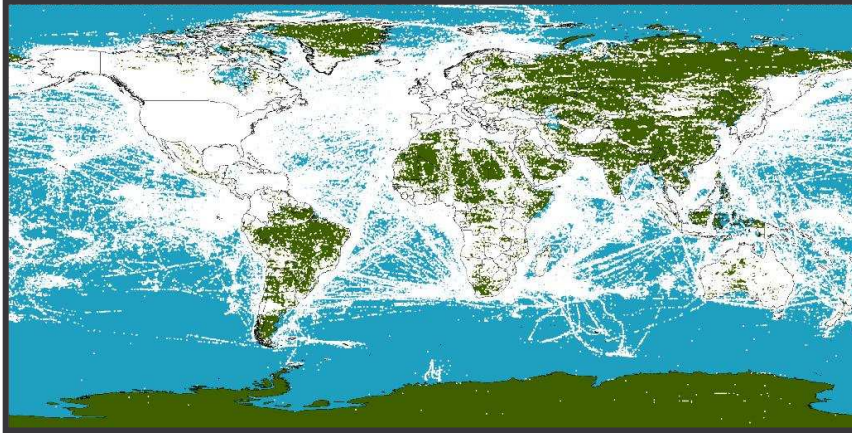


Figure 7 - July 2006 Iridium voice and data activity. Iridium is the only commercial communication system that provides truly global coverage suitable for GNSS data retrieval (Colussi 2006).

LEO - Iridium

Data rate: 2.4 kbps.

Power consumption: 1W typical.

Hardware cost: \$1500 per radio depending on specific system used.

Recurring service cost: \$400 to \$3000 per month.

Modes of use: Global stand-alone system. Support two way communications, data downloads, data streaming, short burst data packaging.

Area of availability: Global – rugged off the shelf hardware is available for all operating environment.

Main advantages: Truly global. Low power consumption. Small omni-directional antenna for easy set-up.

Main disadvantages: Low bandwidth. High recurring cost. Does not support 2-way IP based communications.

Conclusion:

The convergence of reliable remote polar instrumentation, the International Polar Year, and the social relevance of the polar regions to climate change provides an exciting time to take the next “great-leap forward” in the understanding of the nature and behavior of the crust and mantle beneath Antarctica and Greenland and their relationship to ice sheet dynamics and climate. Data communications to the remote instruments promise to optimize and limit the reliance on expensive aircraft logistics, deliver data to users with very little latency, and allow for the almost immediate interpretation. As networks are built and dataflow begins, automated data analysis systems will follow allowing a level of scientific interpretation previously unobtainable. With data routed directly to data archives, they also become accessible to a much larger audience and often benefit diverse science disciplines. One of the anticipated objectives of the IPY is the establishment of enhanced infrastructure to benefit future science needs, and delivering GNSS data from the previously poorly covered remote polar regions will create a lasting legacy.

Web links for global solutions:

FreeWave - www.freewave.com

Globalstar - www.globalstar.com

Inmarsat - broadband.inmarsat.com

Intuicom – www.intuicom.com

Iridium – www.iridium.com

NAL Research – www.nalresearch.com

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References:

Antarctic Neotectonics Workshop, Siena, Italy, 2001. http://www.ingv.it/~roma/cultura/convegni/antec/ANTEC_abstracts/ and <http://www.scar.antec.org/>

Colussi, D. (2006), Communications in the Great North: Alaska, the Arctic and Global Communications, *Commonwealth North workshop proceedings*.

Jackson, M., C. Meertens, O. Ruud, S. Reeder, W. Gallaher, C. Rocken (2001), Real Time GPS Data Transmission Using VSAT Technology, *GPS Solutions*, Vol. 5 No. 4, 10-19.

Prescott, W., K. Anderson, B. Johns, D. Simpson (2006), Collaborative Research: Development of a Power and Communication System for Remote Autonomous GPS and Seismic Stations in Antarctica, *National Science Foundation proposal*.

Stowers, D., S. Fisher (2006), GNSS Stations for Geodetic Applications, *African Geodetic Reference Frame Expert Meeting proceedings*.

Structure and Evolution of the Antarctic Plate Workshop, 2003. <http://www.antarcticarray.org/>