Operating GNSS Equipment in Antarctica
Experiences, Challenges and Solutions

Transition to Continuous Remote GNSS Stations

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Acknowledgements

Dr. Terry Wilson, Principle Investigator, TAMDEF and POLENET Projects

Mr. Mike Willis, PhD candidate, TAMDEF Project

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Ohio State University
• Background
  • IGS Stations: South Pole, Palmer & McMurdo

• Science Objectives

• TAMDEF Project (1996-2007+)
  • GPS Campaign Observation Mode

• Transition to Continuous Remote
  • Challenges
  • Science benefits

• IPY POLENET Project
  • Development of a power & communication system

• Scenes at and enroute to station sites
MCM4 – IGS station in McMurdo
Antenna radome and condensation or ice
AMUNDSEN-SCOTT SOUTH POLE
IGS Station AMU2
PALMER STATION
IGS Station PALM
IGS Station CRAR
McMurdo Station, Antarctica

Installed December 1998 -- GPS and GLONASS Observations
Intraplate deformation:
• Rifting in the Antarctic Interior?
• Glacial Isostatic Adjustment
TransAntarctic Mountains DEFormation Monitoring Network (TAMDEF)
The TransAntarctic Mountains DEFormation Project

The TAMDEF project is a joint OSU and USGS program to measure bedrock motion in the Transantarctic Mountains of Southern Victoria Land.

The bedrock is slowly moving in response to changes in the mass of the Antarctic Ice Sheets. As the weight of the ice sheets changes the Earth's surface bends and the mantle flows to accommodate the new ice configuration.

We are also measuring the tectonic motion over the nearby Terror Rift, an offshore zone of faulting.

We use precision GPS measurements separated by several years to test the predicted rates of motion. The eighth and final seasons of measurement was completed in 2006, in this the most extensive ice-free area on the Antarctic continent.

http://www.geology.ohio-state.edu/TAMDEF/
Transantarctic Mountains Deformation Monitoring Network

- Initiated in 1996
- Use GPS to measure bedrock crustal motions
- Document neotectonic displacements due to:
  - tectonic deformation within the West Antarctic rift (Terror Rift)
  - mass change of the Antarctic ice sheets
- Horizontal displacements related to active neotectonic rifting, strike-slip translations, and volcanism are tightly constrained by monitoring the combined TAMDEF and Italian VLNDEF networks of bedrock GPS stations
The Campaign Network

1996-2000

- 24 sites
- Rock-pins
- Short-duration measurements
Early Campaign Experiences

- Blue board insulated wooden boxes
- 80AH gel cells power Z12 for @15 days
- 60W solar panels extend life of batteries
- Receiver memory limited in capacity
- Choke ring antenna - standard
- Level mounts - fixed height
- Monuments - stainless steel pins
- Pins set in bedrock
- Micro-footprints critical to project
Antenna

Dorne Margolin Choke Ring
Cape Royds (ROY) Local Deformation Micro-footprint

Test for monument stability

Air Photo: TMA-2565-V (12-09-83)
Cape Crozier
Seasonal Campaign GNSS Stations
Esser Hill & Bettle Peak
Seasonal Campaign GNSS Stations
Hidden Valley
Site for fault surveys
Beacon Valley
Site for fault surveys
Challenges
Challenges:

TAMDEF site - Minna Bluff
Rime ice on antenna....effect?
Deverall Island
• Seemingly good bedrock.
• 3.2 cm deformation!
• Eccentric marks still useful.
Network expansion to south – 2003

- Used newer receivers to record up to 100 days of data per season.
- Installed select continuous trackers with robust monuments.

Added:
Remote C-GPS
- 2000/01-present
- 2003-2005

+ 7 sites
IMPROVEMENT:
Long-duration campaign measurements

- Lst. slope: $-12.1 \pm 0.1$ mm/yr; RMS scatter: 5.1
- Long. slope: $9.8 \pm 0.1$ mm/yr; RMS scatter: 4.2

60 to 100 days data/yr

3 to 14 days data/yr.
Longer duration campaign data: SIGNIFICANT BENEFITS

- Weather effects - previously hidden.
- Water vapor studies.
- Captures Ionospheric disturbances.
- Observation overlap – enhances analysis.

MBF Up for 05-06.

Typical Sample Window in 1996
New solar max ~ 2010.
Ionosphere will get noisier.
New frequencies will help.
Two stations were installed on Mount Coates (1996 & 1997 field seasons) and Mount Cocks (1997 field season)
Mount Coats (1)
Mount Coats (2)

MBL AUTONOMOUS GPS STATION

Power (wind generator, solar panels, battery bank)

Station (GPS receiver, data logger, controllers)

Antenna (choke ring antenna, spike, dome)

Electronics and regulators
- Data logger + 3 batteries
- GPS receiver + 3 batteries
Initial Experience

• In the **2000-2001 austral summer**, members of the USGS-LINZ survey field team installed a low-power remote Global Positioning System (GPS) station upon bedrock at the **Cape Roberts** peninsula of southern Victoria Land, Antarctica.

• The station is tied to the nearby tide-gauge operated by Land Information New Zealand (LINZ).

• **ROB1** station is situated upon a TAMDEF project benchmark ROB0.
Installation at Cape Roberts (ROB1)
December 2000
Remote Observatories

Enabling Technologies:

- Solar
- Wind
- Low-power
- High-capacity storage
- Satellite communications

GPS: USGS/TAMDEF

GPS: JPL & UCSB
IMPROVEMENT:
Continuous GPS measurements at remote sites

Fishtail Pt.: USGS/TAMDEF
GNSS Equipment
To Antenna, Second Battery Bank and Solar Panels

Solar charge controller (Sun Selector)

Low Voltage Disconnect (Sun Selector)

Temperature Sensor for top of box (Avatel)

Temperature Sensor for bottom of box (Avatel)

2001-2002 Installations

JNS GPS Receiver

JNS EURO-80 Card

Vacuum Panel R-80 Insulated Enclosure
4 X 40 Watt Solar Panels

1" Tube A-Frame

R-40 Vacuum Insulated Box

"Blu-Board" Insulated Battery Box

12 X 100 AmpHr Batteries
(6 in Insulated Box, 6 in Battery Box)

JNS-EURO-GDA 40-Channel GPS Receiver (1.8W to 2.4W) with 1Gb Flash Card Storage

16-Amp Rated Low-Voltage Disconnect and Charge Controller

Temperature Sensor

TAMDEF CORS at Westhaven Nunatak
Cape Roberts
GNSS CORS Remote
Station ROB4
Success with year round CGPS measurements
Performance of TAMDEF CGPS:
Quite reliable.
Several sites have worked year round.
Challenges remain.
TAMDEF Remote CGPS Stations

**Cape Roberts** (Coastal site)
Co-located with tide gauge.

**Mount Fleming** (Mountain site)
LOS radio system.

**Fishtail Point** (Coastal site)
Iridium Communications system.

**Franklin Island** (Maritime environment)

**Westhaven Nunatak** (Plateau environment)

**Lonewolf Nunatak** (Mountain site)
Extreme conditions
Cape Roberts:
LINZ/USGS funding. Run by OSU.

**CHALLENGES**
low storage capacity initially.
Drifting in winter.
Vibration worries.
Vac-panels broken.

**SOLUTIONS**
New receiver, more storage.
New panels, redundant power.
New monument.
LOS data link, site is monitored.
Cape Roberts
More than 1700 days of data.
Runs to -45°C.
Mount Fleming
Continuous GNSS Remote CORS Station
Mount Fleming:
High Mountain – very cold, windy site.

**CHALLENGES**
High winds.
Difficult access.
Problematic receivers.
Bad wiring.

**SOLUTIONS**
LOS data link – monitoring receiver
Systems integration drive.
Mount Fleming:

>600 days data
Outside temps to at least -40C.
Winds to 140kph (90mph).
Faulty wiring – temperature of system reached 100+ C

Power system replaced in 2005
Fishtail Point
Continuous GNSS remote station
Fishtail Point:
Windy site near Skelton Glacier.

CHALLENGES
Access is difficult.
No LOS to McMurdo.
Problematic receiver.
Wind load on antenna.

SOLUTIONS
New receiver.
Iridium satellite link.
Many many batteries.
New monument.
Fishtail Point:

1250+ days of data. Works to -40C
Winds moved 200 kg enclosure.
2nd attempt at Iridium works well.
Timer resets Iridium modem every 4 days.
No interference between Iridium and GPS seen.
Franklin Island: Marine environment

**CHALLENGES**

Very difficult access.  
1\textsuperscript{st} year, perfect!  
2\textsuperscript{nd} year, failure 😞  
Rime on antenna?

**SOLUTIONS (Future)**

Install late model GNSS  
Data link: LOS to McMurdo  
Multi-year unattended operation?
Westhaven Nunatak
Plateau site, very cold

**Challenges**
Extreme cold
Difficult access
1\(^{st}\) year perfect!
2\(^{nd}\) year failure 😞
Temp sensors failed

**Solutions (future)**
Lightweight station
New logistics plan
Vac-panel box helps
Lonewolf Nunatak
Continuous GNSS remote station
Lonewolf Nunatak: Extremely windy and cold site

**CHALLENGES**
- Temp sensors failed
- Wind destroyed system...Twice.
- Battery charger failed

**SOLUTIONS**
- Strengthened solar panel frame.
- Redundant power.
- Seal system better.
Lonewolf – A development driver.
• Design redundancy needs improvement.
• Systems need strengthened against storms.
• Light weight systems desirable.
• Wind power 😊
Site worked even though the environment was extremely difficult.
MAJOR IMPROVEMENT
Communications systems
Monitoring Data Quality

Archived at UNAVCO

Possible to monitor receiver state of health and basic environmental variables.
TAMDEF Network and Program

- Built upon Campaign experiences.
- Used simple technologies (no moving parts).
- On the whole, highly successful.
CONTINUOUS CHALLENGES

• Long-term autonomous operation
  • Reliable, low-power communications
• Continuous operation through polar night
  • Lightweight power systems
• Effective operation in very remote locations
  • ‘Antarctic-optimized’ system
Diverse environments for deployment. Suggest standardizing systems, but making them customizable.
Average annual Wind speed.

Bromwich, 06
Average annual snow accumulation.
- Coastal sites need taller monuments.

Vaughan et al, 99
Solutions under investigation:

**Data Communications**
- Satellite modems
- Line Of Sight.
- Fly-Over Download.

**Lightweight Power**
- Wind Generators
- Lithium Primary Cells
- Lithium Secondary Cells
- Fuel Cells
- New PV technology

**Environmental Hardening**
- Frame designs.
- System integration
- Hyper-Insulation
- Active heating
Power Generating and Data Communications

Temperature and Power Operating Ranges

**Explanation**
- **To prevent disk drive from running at temperatures below its rating**
- **To prevent batteries from overheating and allow for at least one day of data to be collected before system overheats**
- **To warm Leica, DataBridge, and batteries**
- **Allows enough voltage to obtain at least 1 day of data, taking into account rebound from batteries and system power draws**
- **The overlap with the DataBridge is to possibly save the DataBridge from turning off in the event that power level exceeds turn-on voltage of 13.2 volts.**
In-situ testing is critical.

Testing underway:
- Battery performance
- Insulation benefits
- Power draws

High-R value enclosures work well, if system is running.
Wind Generator Test *in Situ* (Erebus, 3400 m)

- 2 x 400 W 403 Wind Generators
- 80+60 W Solar Panels
- TRC Repeater (NKB, LEH Stations)
- Anemometer/Antenna Mast
- 2000 A-H Gel Cells in Insulated Boxes
- Broadband and Short-period Seismic/Tilt meter Vault
- McIntosh and Aster P-box
Wind Power Generators

These ecological wind turbines, primarily for battery charging, can be used for lighting, water pumping, electric systems in remote area homes and back's, telecommunication, radio, telemetry and data logging.

Durable, aesthetic design, safe around people, constant energy production (in storms and low winds), no gearing system or dripping oil, AC output for low cabling voltage losses.
Tested wind generator performance under Antarctic conditions.

Also tried Windside.

Forgen 500s used by BAS for last three years. No failures. Run to -65C.

Aster-MEVO
Battery testing

- Lithium (non rechargeable cells) to be tested Jan 07, McMurdo and South Pole
- Many manufacturers available
- Weight savings are substantial
- But, large bank of batteries are hard to make & ship
- And, cost is substantial!

HEDB Battery corp.
2400 Amp Hours.
140 Kg.
## Battery comparisons:

<table>
<thead>
<tr>
<th>System Characteristic</th>
<th>Lead Acid</th>
<th>Nickel-Cadmium</th>
<th>Nickel-Hydrogen</th>
<th>Silver-Zinc</th>
<th>Lithium-Ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell Specific Energy (Wh/kg)</td>
<td>30</td>
<td>30</td>
<td>35</td>
<td>~100</td>
<td>130-140</td>
</tr>
<tr>
<td>Cell Energy Density (Wh/lit)</td>
<td>60</td>
<td>100</td>
<td>50</td>
<td>~150</td>
<td>250-300</td>
</tr>
<tr>
<td>Specific Energy (Wh/kg) at Battery</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>75</td>
<td>100</td>
</tr>
<tr>
<td>Energy Density (Wh/lit) at Battery</td>
<td>55</td>
<td>80</td>
<td>40</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>Cycle Life (30-40% DoD)</td>
<td>~1,500</td>
<td>30,000</td>
<td>30000-60000</td>
<td>&lt;100</td>
<td>&gt; 15,000</td>
</tr>
<tr>
<td>Wet life (Storageability)</td>
<td>~7 years</td>
<td>~10 years</td>
<td>&gt; 10 years</td>
<td>2 years</td>
<td>5 years</td>
</tr>
<tr>
<td>Self-Discharge (per month)</td>
<td>5-10 %</td>
<td>15%</td>
<td>30%</td>
<td>15-20%</td>
<td>&lt;5%</td>
</tr>
<tr>
<td>Low temperature Performance (-20°C)</td>
<td>Poor</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Excellent</td>
</tr>
<tr>
<td>Temperature Range, °C</td>
<td>-10- 30</td>
<td>-10- 30</td>
<td>-10- 30</td>
<td>-10- 30</td>
<td>-20 to +40</td>
</tr>
<tr>
<td>Charge Efficiency %</td>
<td>85%</td>
<td>80%</td>
<td>80%</td>
<td>70%</td>
<td>~100%</td>
</tr>
</tbody>
</table>
Pack Performance
Capacity = 6.6 Ah (at 23°C)
Watt-Hours = ~ 95 Wh
Specific Energy = ~ 145 Wh/Kg
Cycle Life = > 80% after 300 cycles
Wet Life = ???
(Life data needs to be verified)

Estimated Battery Performance
(11 x 4s10p Batteries in Parallel)
Voltage = 11 – 16.4 V
Capacity = > 845 Ah (at 23°C)
Watt-Hours = 12,160 Wh (at 23°C)
Specific Energy = ~ 120 Wh/Kg
Battery Weight = ~ 100 Kg

Li Rechargeable.
• Li on Mars rovers. Design for 90 days still running after 950 days.

95 Wh Smart Battery Pack
MP-08 Battery Management Module
Environmental hardening.

Frames must be:
• Quick to build.
• Light.
• Drift proof.
• Strong.
Component Testing.

- System integration
- Cold tolerance
- Receiver performance
- Weight reduction
- Help minimize logistics

Tim Parker

7.5W installation Mike Rose (BAS)

UNAVCO Cold Chamber (Bjorn Johns)
Monument Design

- Quick to install.
- Various heights available.
- Anchored by 4 X 40cm expansion bolts
- Bolts set using epoxy.
- Demonstrated stability.
- Zero offset for antenna.
- Multipath tests needed.
Conclusions

• Continuous stations critical

• Minimize logistical costs by:
  • Light weight strong equipment.
  • Communications.

• Different challenges around Antarctica.

• Good monuments needed.
Suggestions

• Ways to minimize logistical costs further?
• Standardize on monument.
• Open documentation.
• Equipment development dialogue?
• Website equipment development page.

Westhaven Nunatak.
What is POLENET?

• **POLar Earth Observing NETwork** - involving people from 24 nations

• Aims to dramatically improve the coverage of many different kinds of geophysical data across the polar regions of the Earth.

• Core activity of the International Polar Year (IPY) 2007-2008.

• Overcomes scarcity of observational systems in the Earth's polar regions and will provide a legacy in observational infrastructure.

• Technological capabilities in deploying autonomous systems in extreme environments will be developed and extended new datasets will be made available to the global science community.

• Scientists, engineers, field assistants and students are deploying new GPS instruments, seismic stations, magnetometers, tide gauges, ocean-floor sensors and meteorological recorders.

• Enable new research into the interaction between the atmosphere, oceans, polar ice-sheets and the Earth's crust and mantle.

• New insights into the Earth's magnetic field and deep Earth structure will be possible from the important vantage point of high-latitude geophysical observatories.
POLENET SCIENCE

GEODE蒂IC OBSERVATIONS
SEISMOLOGY
GLACIOLOGY
OCEANOGRAPHY
MAGNETOMETERS
GRAVITY
ATMOSPHERIC OBSERVATIONS
METEOROLOGY
Collaborative Research: Development of a Power and Communication System for Remote Autonomous GPS and Seismic Stations in Antarctica

January 2006

Submitted by

UNAVCO and IRIS
on Behalf of the Polar Community

Submitted to

Major Research Infrastructure
and
Office of Polar Programs
Division of Earth Sciences
National Science Foundation
Build on decade of experience with autonomous station technology in Antarctica to achieve reliable, modularized station support systems

<table>
<thead>
<tr>
<th>Technology proven in Antarctica</th>
<th>Advances to be achieved through this MRI effort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quasi-continuous and logistics-intensive GPS and seismic data collection</td>
<td>Reliable year-round data collection, minimizing logistical cost of installation, operation, and maintenance; “plug-and-play” deployment</td>
</tr>
<tr>
<td>Geodetic GPS receivers</td>
<td>Selection of next generation GPS receivers (low power, high memory, remote controllable, robust power management)</td>
</tr>
<tr>
<td>Seismic sensors and datalogger</td>
<td>Develop cold sensor testing and harden data recording system</td>
</tr>
<tr>
<td>Line of sight radio links</td>
<td>Higher bandwidth technology, flyover data retrieval</td>
</tr>
<tr>
<td>Solar power</td>
<td>Standard components, and improve ease of field deployment</td>
</tr>
<tr>
<td>Power control components</td>
<td>Integrated, robust power controller packages</td>
</tr>
<tr>
<td>Iridium satellite data modems, intermittent operation</td>
<td>Robust and efficient Iridium data retrieval, sensor-communications integration</td>
</tr>
<tr>
<td>Wind turbines with highly variable success</td>
<td>Select already proven units, test and optimize for different environmental conditions</td>
</tr>
<tr>
<td>Sealed lead acid batteries</td>
<td>Optimal battery selection, quantified extreme cold performance, lithium battery backup</td>
</tr>
</tbody>
</table>
Technical Requirements – “low” power consumption is a critical design requirement, as well as state-of-the-art in data storage, communications, and system integration.

<table>
<thead>
<tr>
<th>Operating Mode</th>
<th>Allowable power use</th>
<th>Data telemetry requirement</th>
<th>Data storage Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS data collection</td>
<td>2.5W</td>
<td>1Mb/day average</td>
<td>27 months = 830Mb</td>
</tr>
<tr>
<td>Seismic data collection</td>
<td>2W</td>
<td>1Mb/day (SOH and events)</td>
<td>27 months =12Gb</td>
</tr>
<tr>
<td>Satellite data link (NAL Resesarch Iridium)</td>
<td>1W/Mb</td>
<td>&gt;2Mb/day</td>
<td>na</td>
</tr>
<tr>
<td>Radio data link (FreeWave 900MHz)</td>
<td>0.5W/Mb</td>
<td>&gt;16Mb/day</td>
<td>na</td>
</tr>
<tr>
<td>Housekeeping overhead</td>
<td>0.5-1W</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>Lowest power configuration (single sensor, no winter data comms)</td>
<td>2.5W year-round</td>
<td>1Mb/day average, store-and-forward</td>
<td>Up to 12Gb</td>
</tr>
<tr>
<td>Combined GPS and seismic (with low bandwidth link)</td>
<td>7W year-round</td>
<td>2Mb/day average, store-and-forward</td>
<td>830 Mb + 12 Gb</td>
</tr>
<tr>
<td>Highest power configuration (combined sensors, year-round large data volume comms)</td>
<td>10.5W year-round</td>
<td>2Mb/day year-round</td>
<td>830 Mb + 12 Gb</td>
</tr>
</tbody>
</table>
Thanks to: National Science Foundation
         Raytheon Polar Services
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         UNAVCO
         US Coast Guard

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