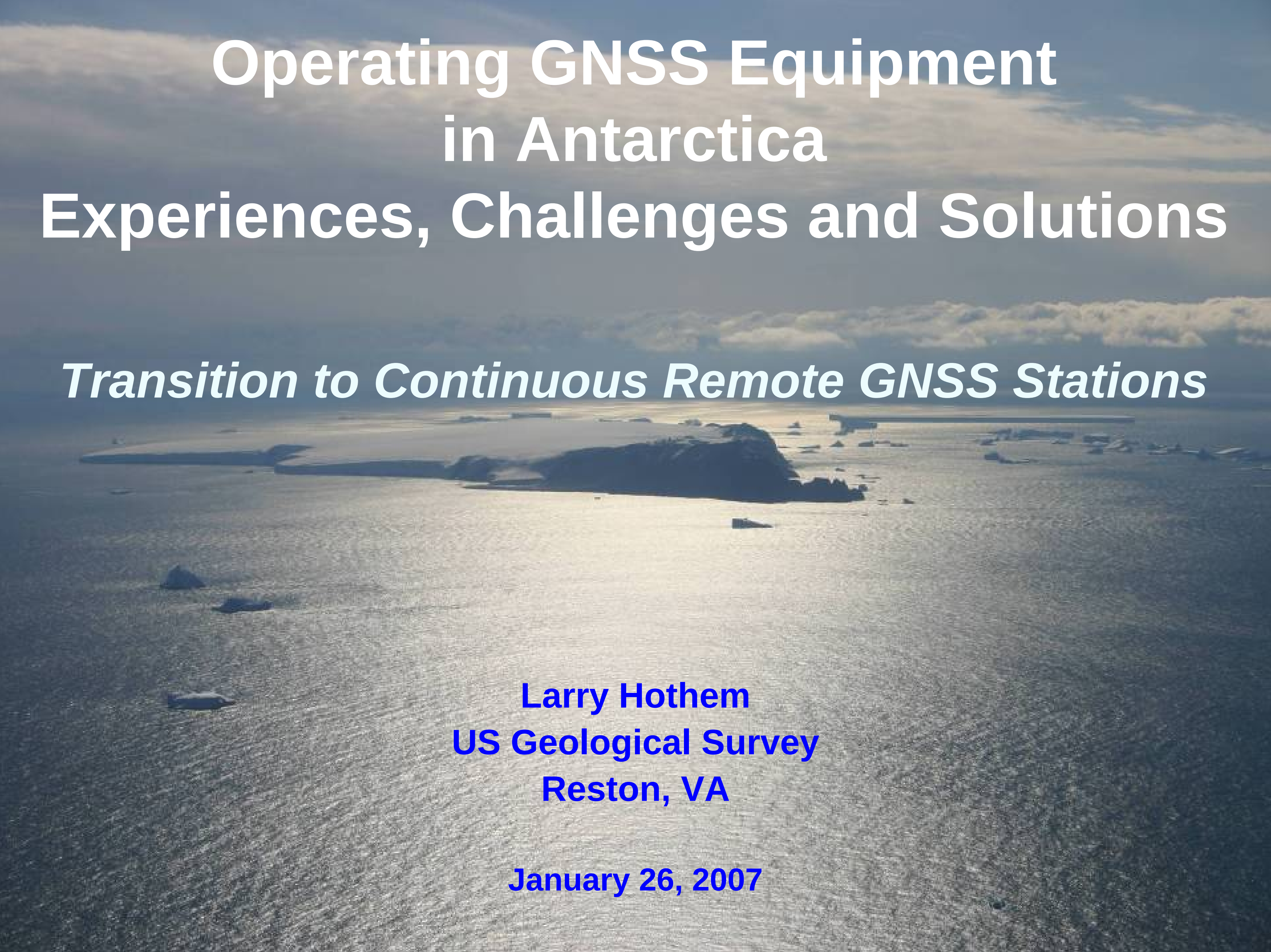


Operating GNSS Equipment in Antarctica Experiences, Challenges and Solutions

Transition to Continuous Remote GNSS Stations

Larry Hothem
US Geological Survey
Reston, VA

January 26, 2007

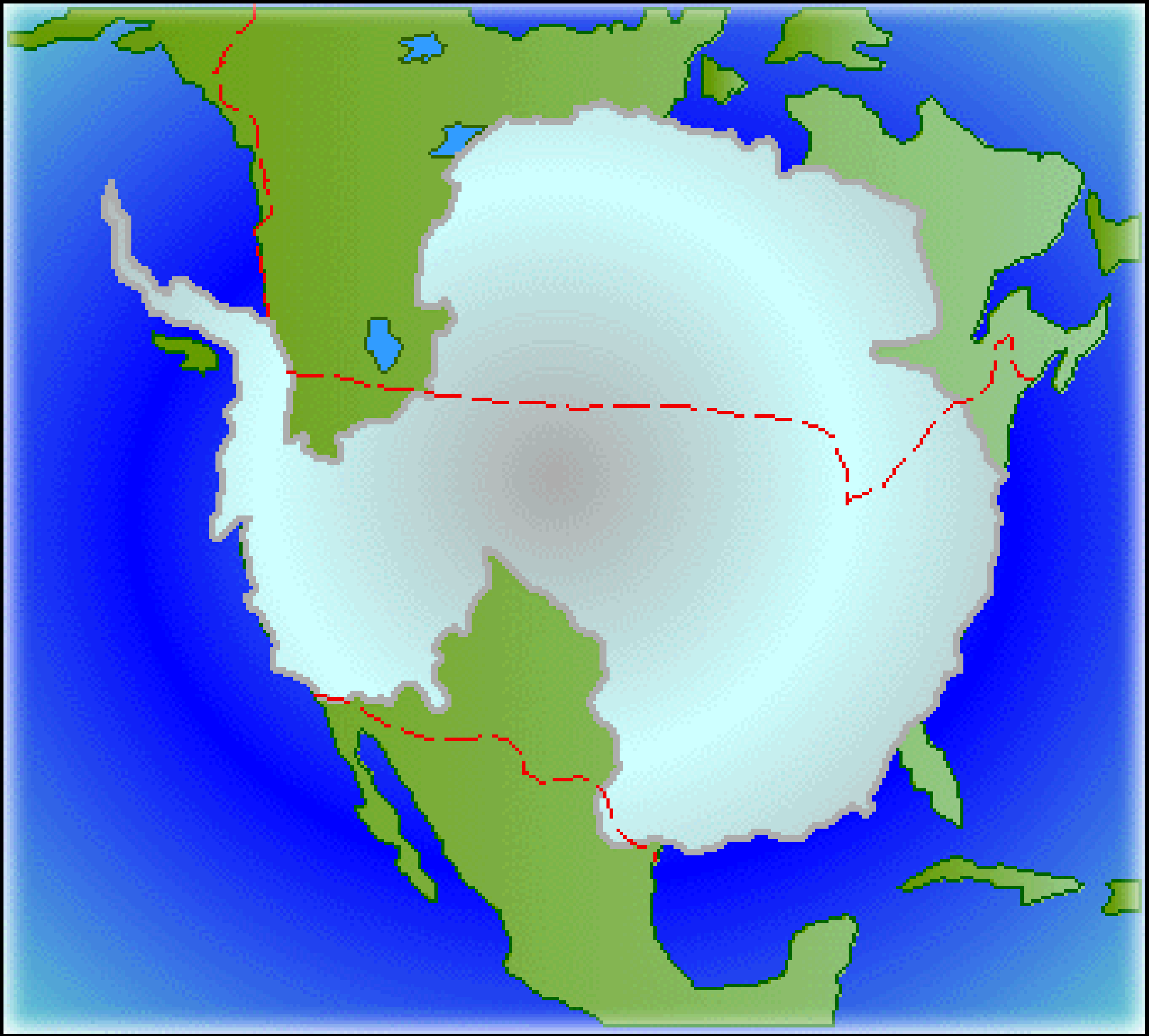
Acknowledgements

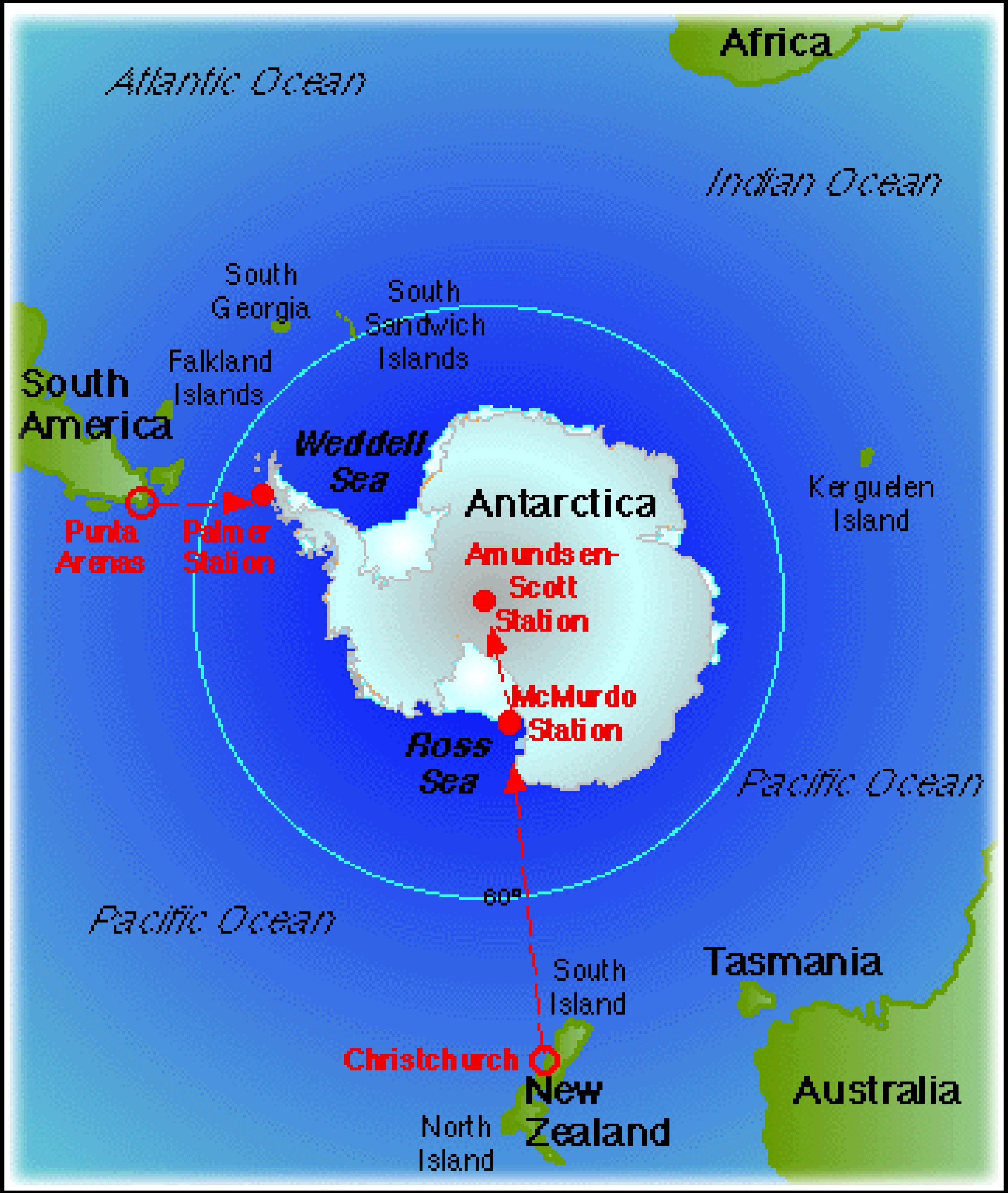
Dr. Terry Wilson, Principle Investigator, TAMDEF and POLENET Projects

Mr. Mike Willis, PhD candidate, TAMDEF Project

School of Earth Sciences, Byrd Polar Research Center
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



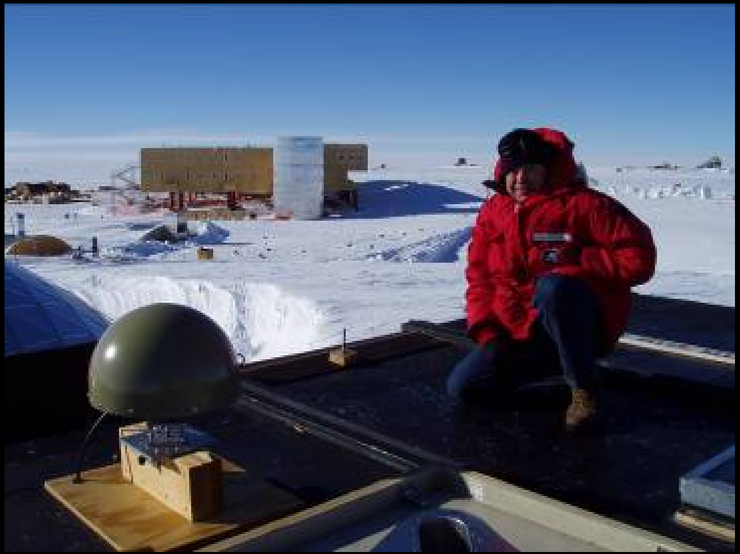


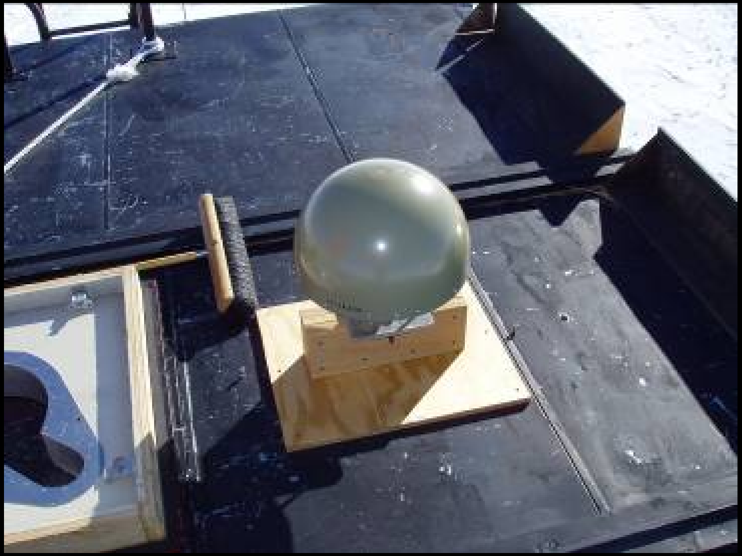
Africa
Atlantic Ocean
Indian Ocean
South Georgia
South Sandwich Islands
Falkland Islands
South America
Weddell Sea
Antarctica
Kerguelen Island
Punta Arenas
Palmer Station
Amundsen-Scott Station
McMurdo Station
Ross Sea
Pacific Ocean
60°
Pacific Ocean
South Island
Tasmania
Christchurch
New Zealand
Australia
North Island

MCM4 – IGS station in McMurdo
Antenna radome and condensation or ice

AMUNDSEN-SCOTT SOUTH POLE

IGS Station AMU2

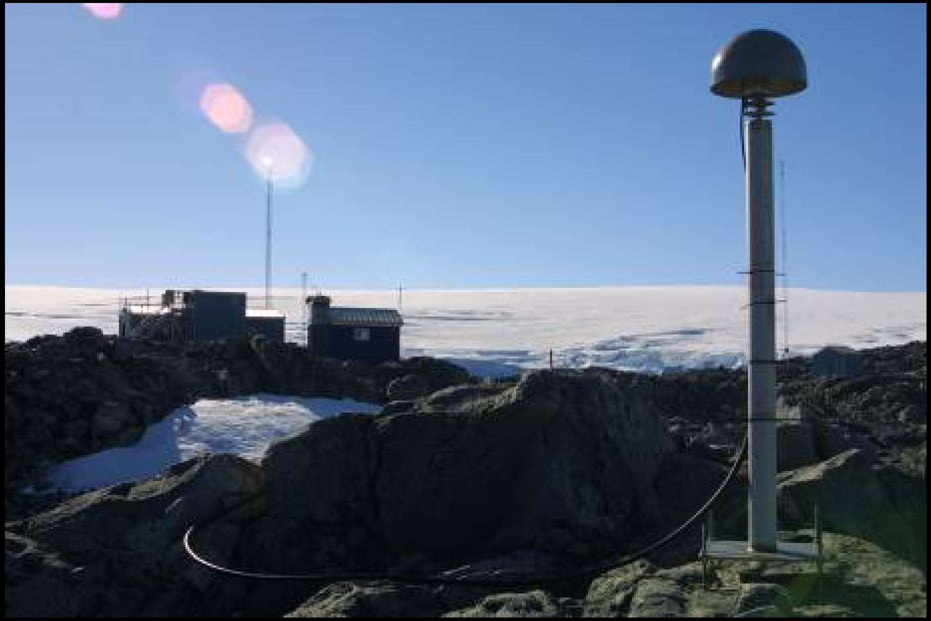




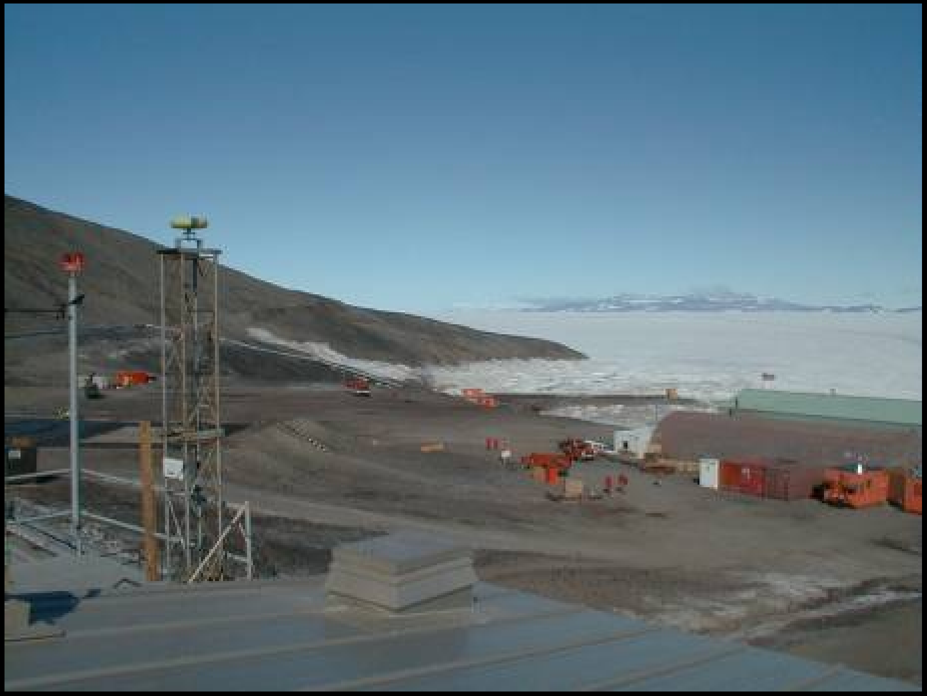

AMUN
Geographic South Pole
(Jan. 1, 2006)
AMU2

PALMER STATION

IGS Station PALM



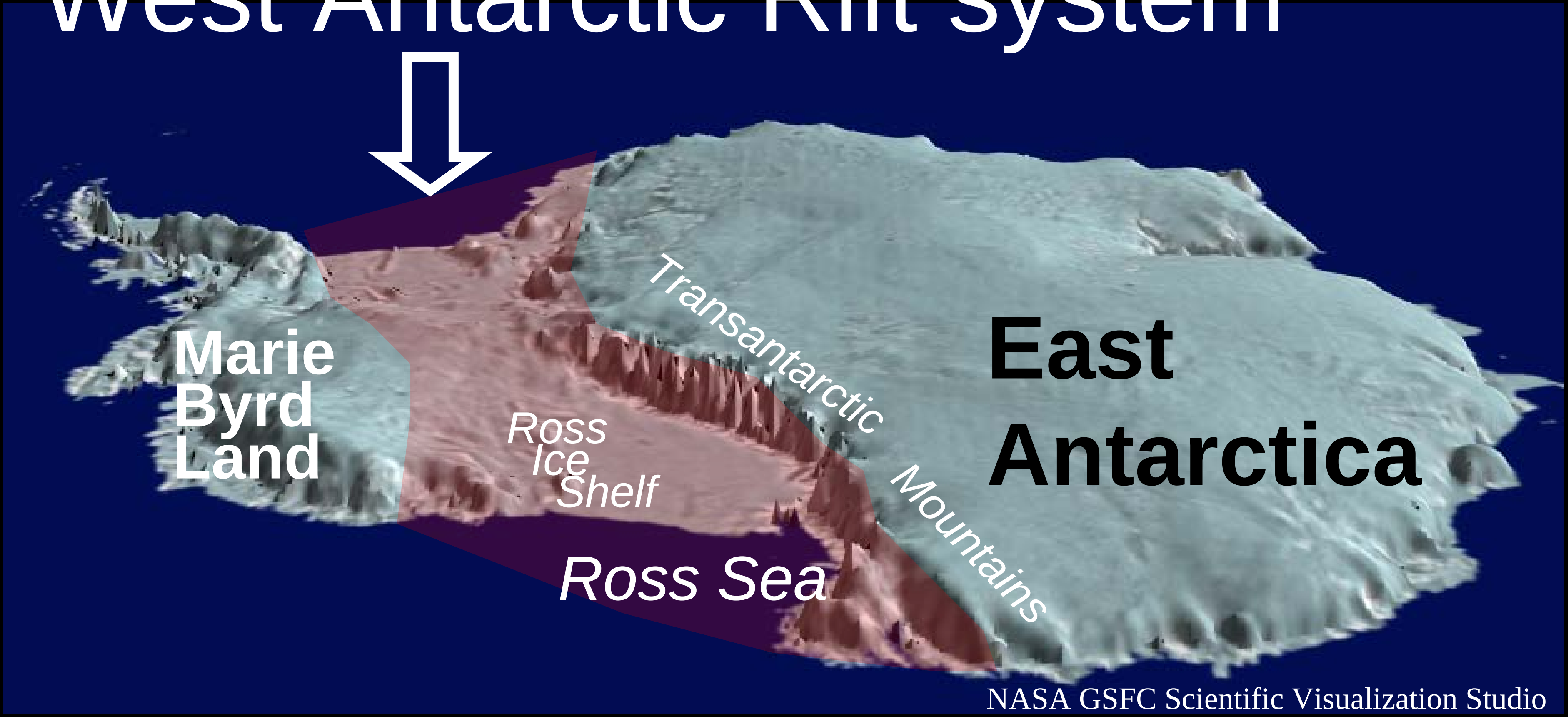
IGS Station CRAR
McMurdo Station, Antarctica



Installed December 1998 -- GPS and GLONASS Observations

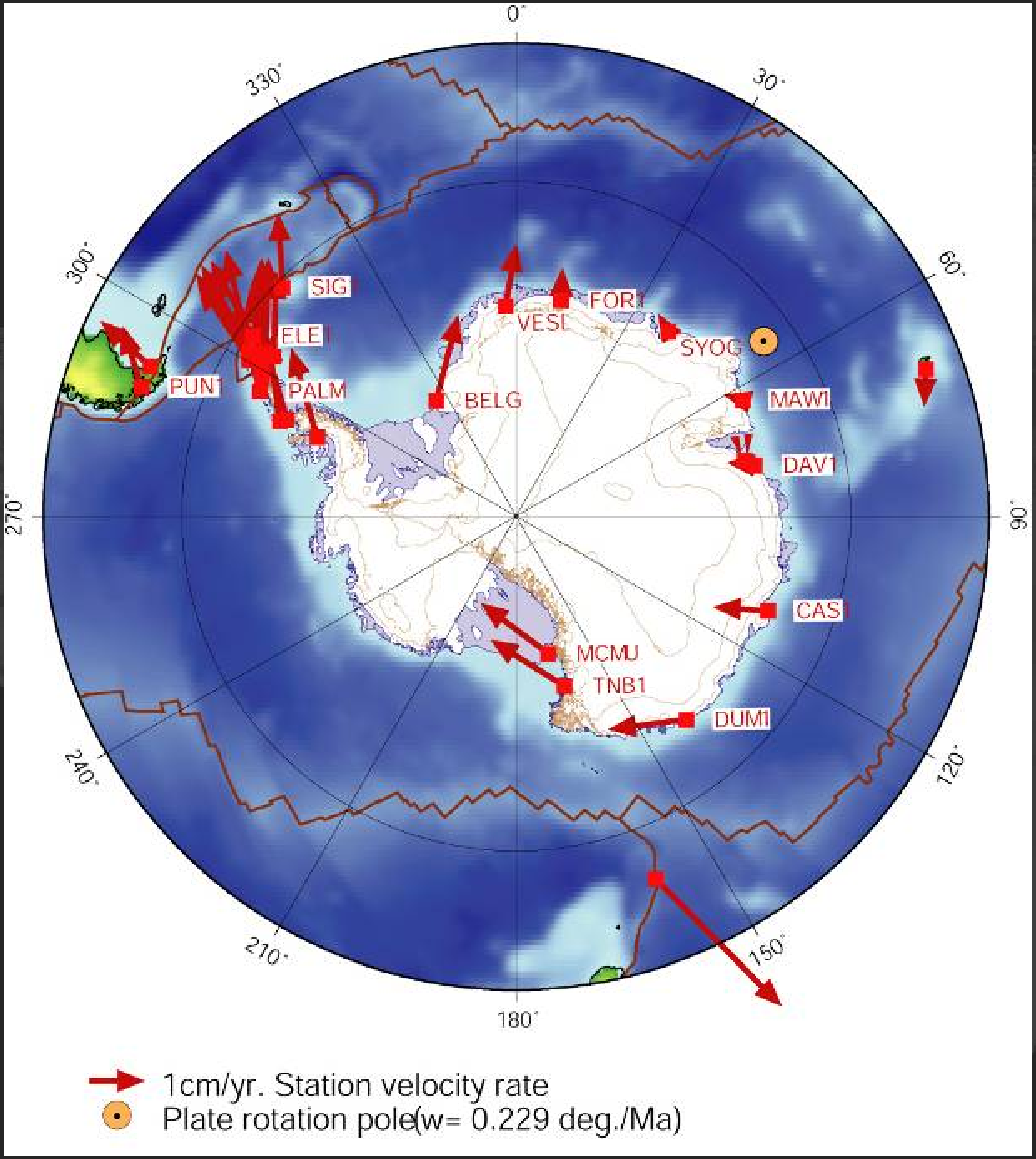
Cutaway view of ice sheet
South Atlantic Ocean
Weddell Sea
Indian Ocean
South Pacific Ocean
Ross Sea
Sanae
Queen Maud Land
Enderby Land
Amery Ice Shelf
Antarctic Peninsula
Ronne Ice Shelf
Anderson Summit
South Pole
Mt. Seelig
Vinson Massif
5140
West Antarctica
East Antarctica
Mt. Kirkpatrick
4528
Transantarctic Mts.
land below sea level
Marie Byrd Land
Ross Ice Shelf
McMurdo
Victoria Land
Wilkes Land
Mirnyy
Dumont d'Urville
2500
0
2800
0
3800
1500
2000
2812
2500
3022
1600
-2500
3600
500
3300
0
3100
-1000
2900
-250
2900
-250
1000
1800
0
2500
-250
1900
blue figures show ice sheet elevation (meters)
black figures show land elevation (meters)
sea ice shown at average minimum extent

West Antarctic Rift system



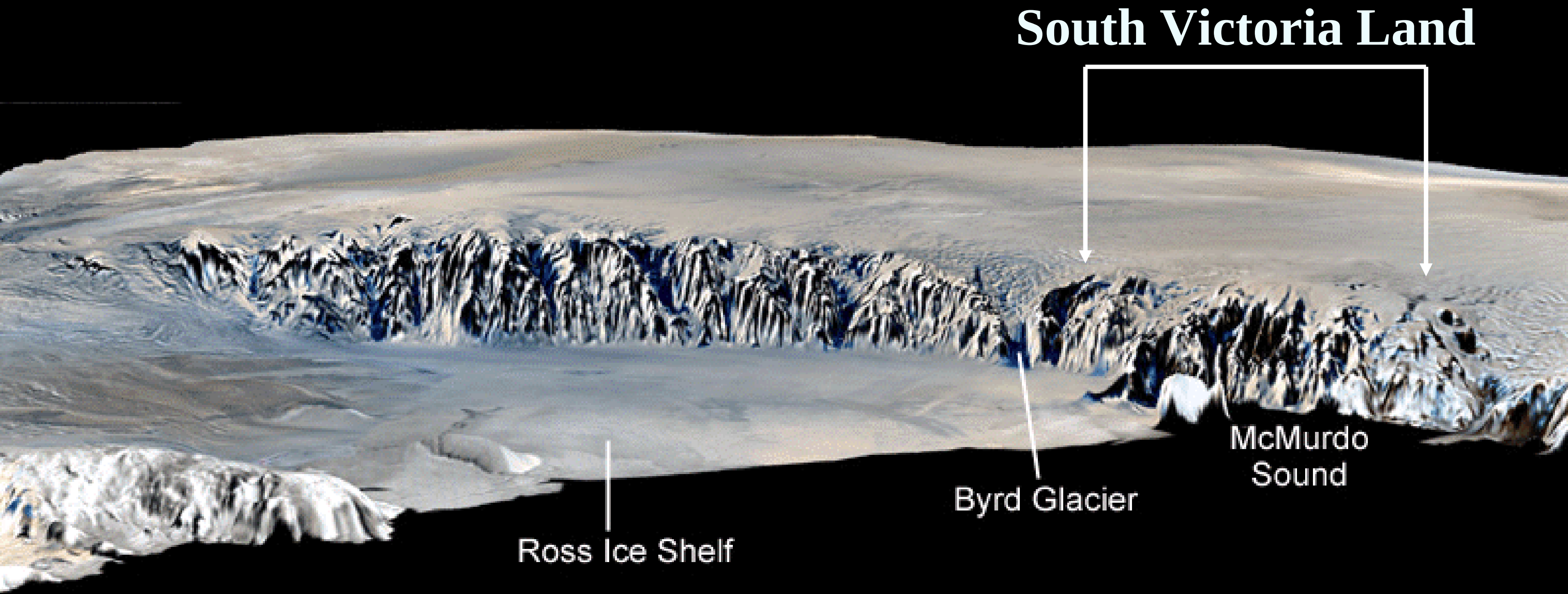
<u>Intraplate deformation:</u>

- Rifting in the Antarctic Interior?
- Glacial Isostatic Adjustment



0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
SIG
ELE
PUN1
PALM
VESL
FOR1
SYOG
BELG
MAW1
DAV1
CAS1
MCMU
TNB1
DUM1
1cm/yr. Station velocity rate
Plate rotation pole(w= 0.229 deg./Ma)

TransAntarctic Mountains DEFormation Monitoring Network (TAMDEF)



THE TAMDEF PROJECT

SITE HOME | | POLENET | ANDRILL | TERROR RIFT

HOME AND NEWS
PROJECT DETAILS
STRATEGY
SITE LOCATIONS
EQUIPMENT USED
2003-2004 PICS
2004-2005 PICS
2005-2006 PICS
PROJECT LINKS

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 Earths surface bends and the mantle flows to accomodate the new ice configuration.

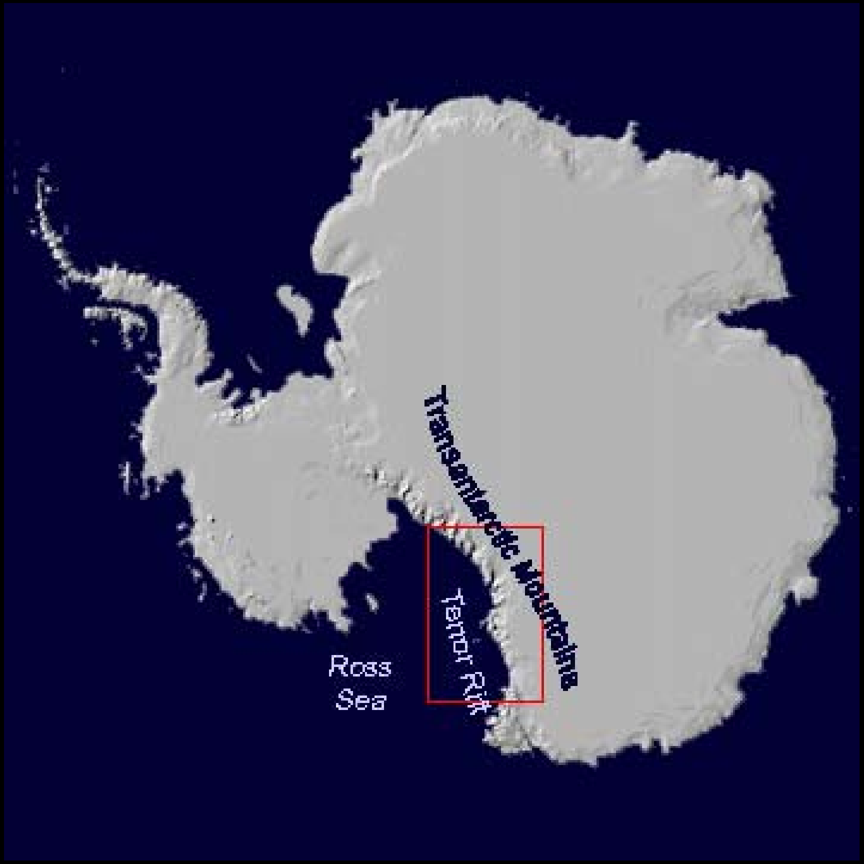
We are also measuring the tectonic motion over the nearby Terror Rift, an offshore zone of faulting.

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.

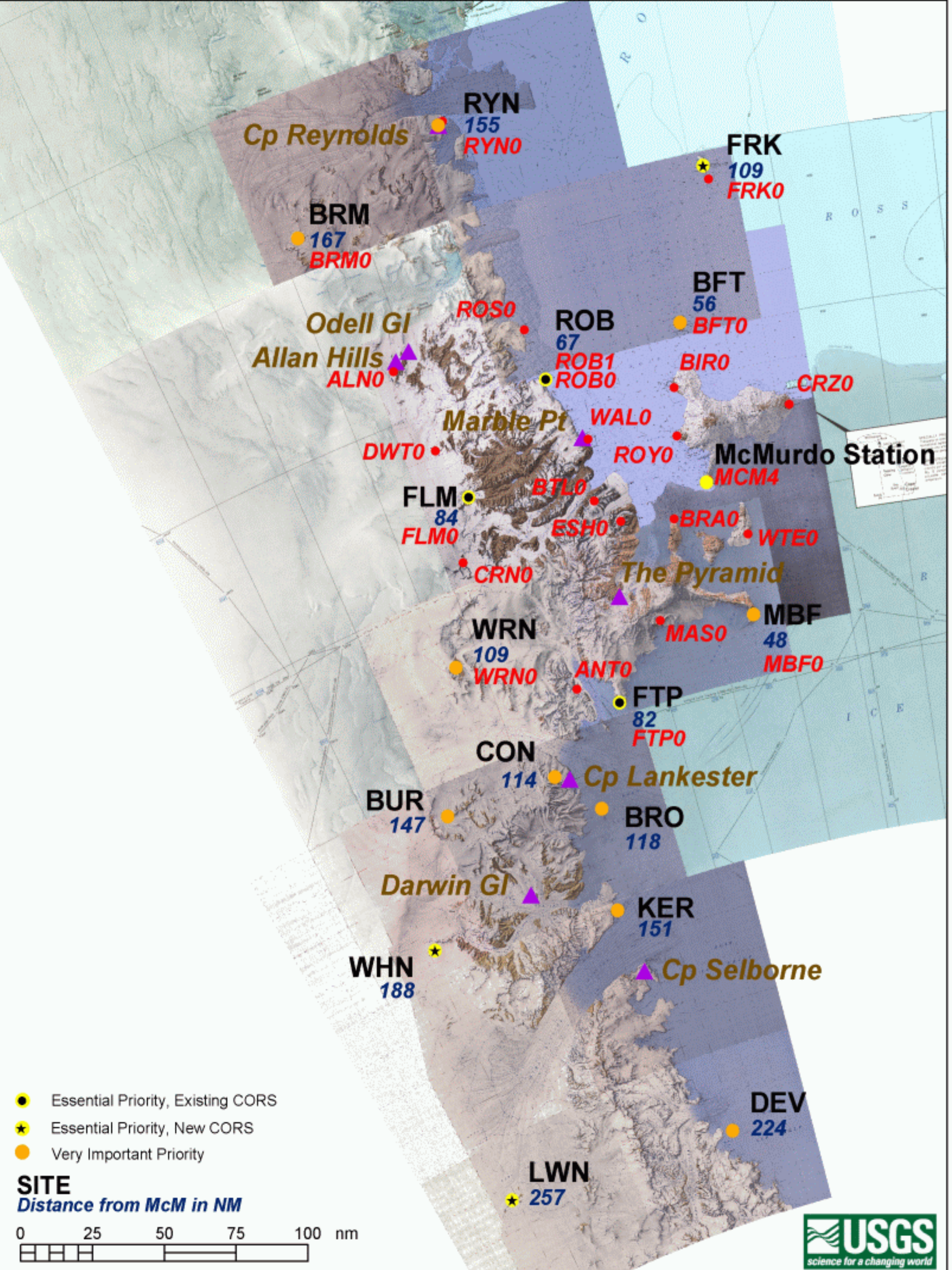
http://www.geology.ohio-state.edu/TAMDEF/

The TAMDEF Project

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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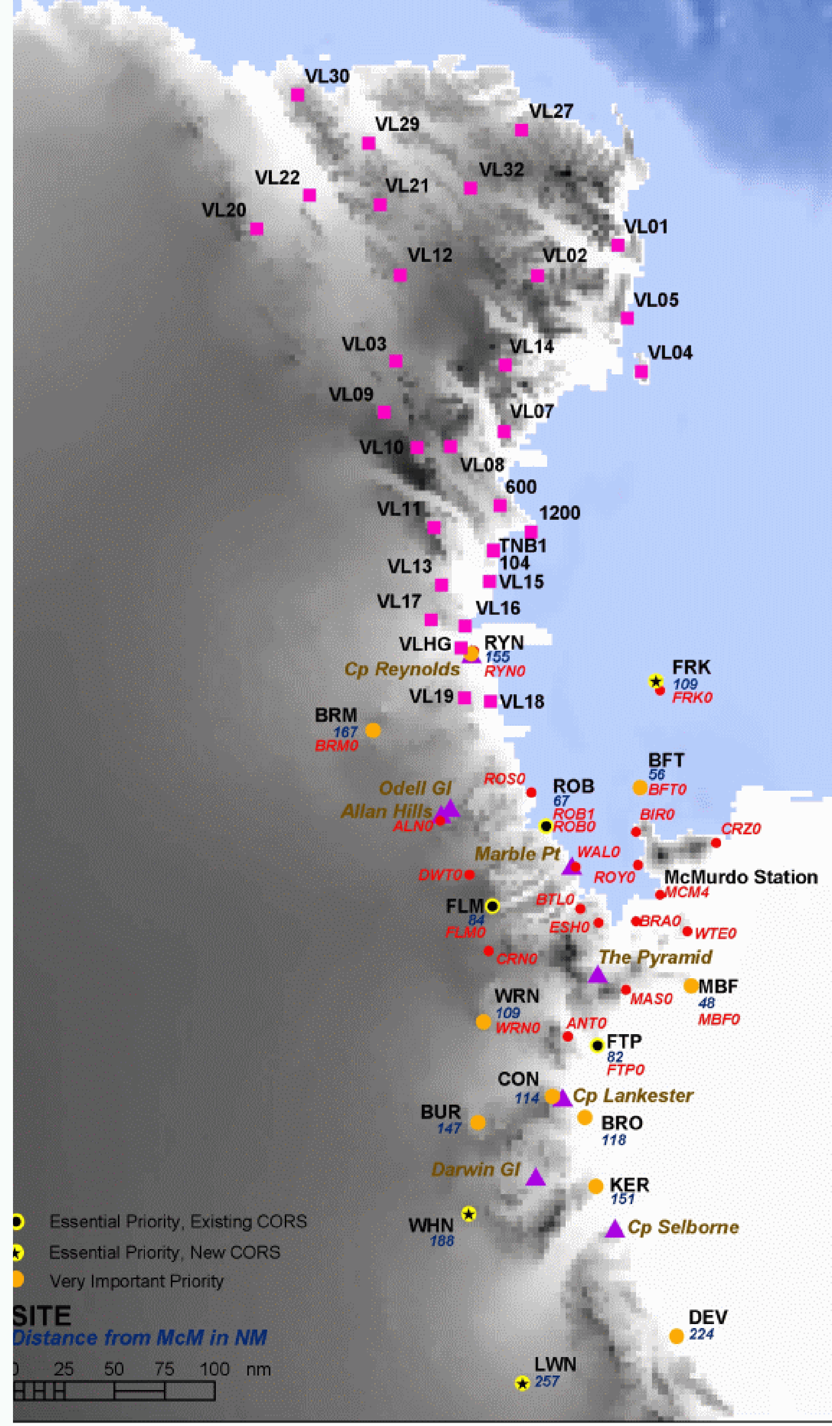
RYN0
Cp Reynolds
FRK
109
FRK0
BRM
167
BRM0
BFT
56
BFT0
ROS0
ROB
67
ROB1
ROB0
Odell Gl
Allan Hills
ALN0
BIR0
CRZ0
Marble Pt
WAL0
DWT0
ROY0
McMurdo Station
MCM4
FLM
84
FLM0
BTL0
ESH0
BRA0
WTE0
CRN0
The Pyramid
MBF
48
MBF0
MAS0
WRN
109
WRN0
ANT0
FTP
82
FTP0
CON
114
Cp Lankester
BUR
147
BRO
118
Darwin Gl
KER
151
WHN
188
Cp Selborne
DEV
224
LWN
257
Essential Priority, Existing CORS
Essential Priority, New CORS
Very Important Priority
SITE
Distance from McM in NM
0
25
50
75
100
nm
USGS
science for a changing world

VL30
VL29
VL27
VL22
VL21
VL32
VL20
VL01
VL12
VL02
VL05
VL03
VL14
VL04
VL09
VL07
VL10
VL08
600
VL11
1200
TNB1
104
VL13
VL15
VL17
VL16
VLHG
RYN
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Cp Reynolds
RYN0
FRK
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FRK0
VL19
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BRM
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BRM0
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BFT0
ROS0
ROB
67
ROB1
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Odell Gl
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ALN0
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Marble Pt
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MBF
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CON
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Darwin Gl
KER
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WHN
188
Cp Selborne
Essential Priority, Existing CORS
Essential Priority, New CORS
Very Important Priority
SITE
Distance from McM in NM
25
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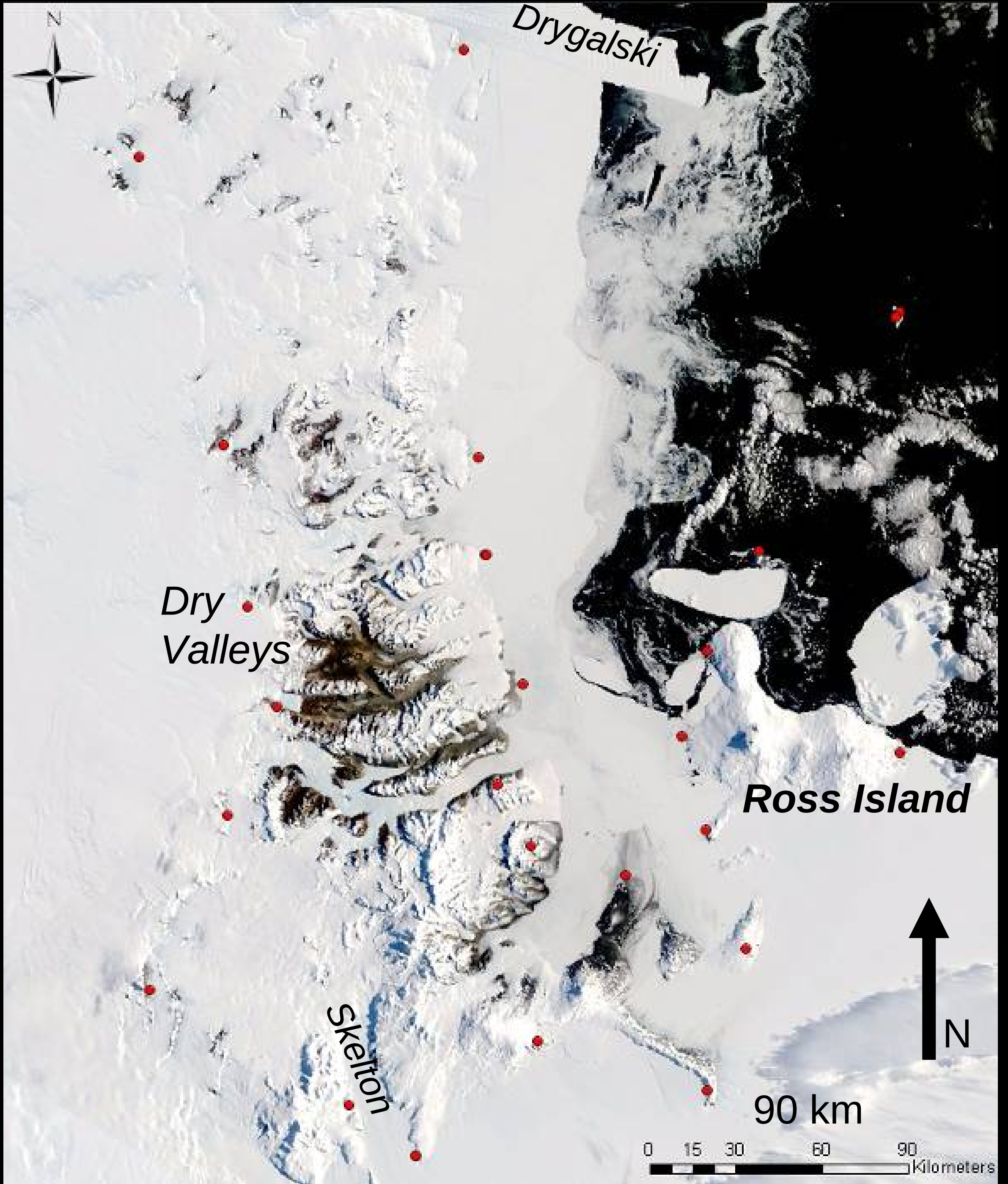
75
100
nm
DEV
224
LWN
257

The Campaign Network

1996-2000

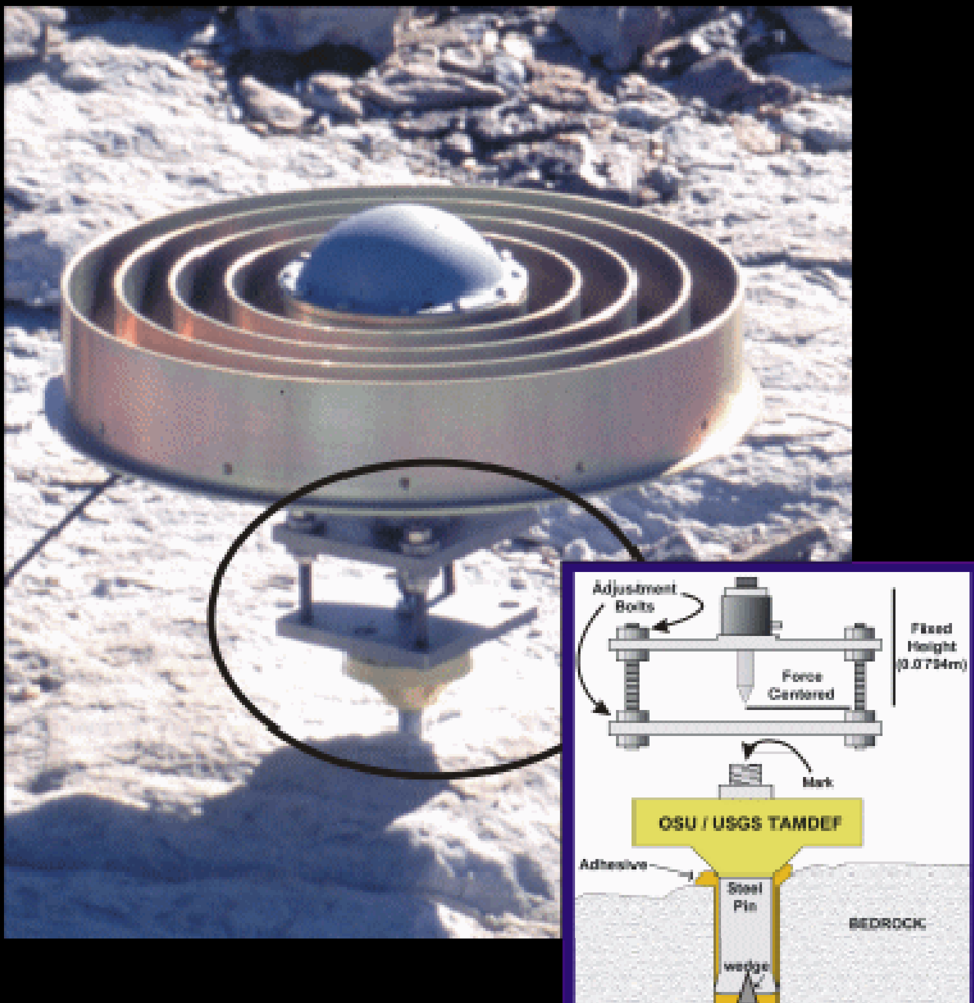
- 24 sites
- Rock-pins
- Short-duration measurements

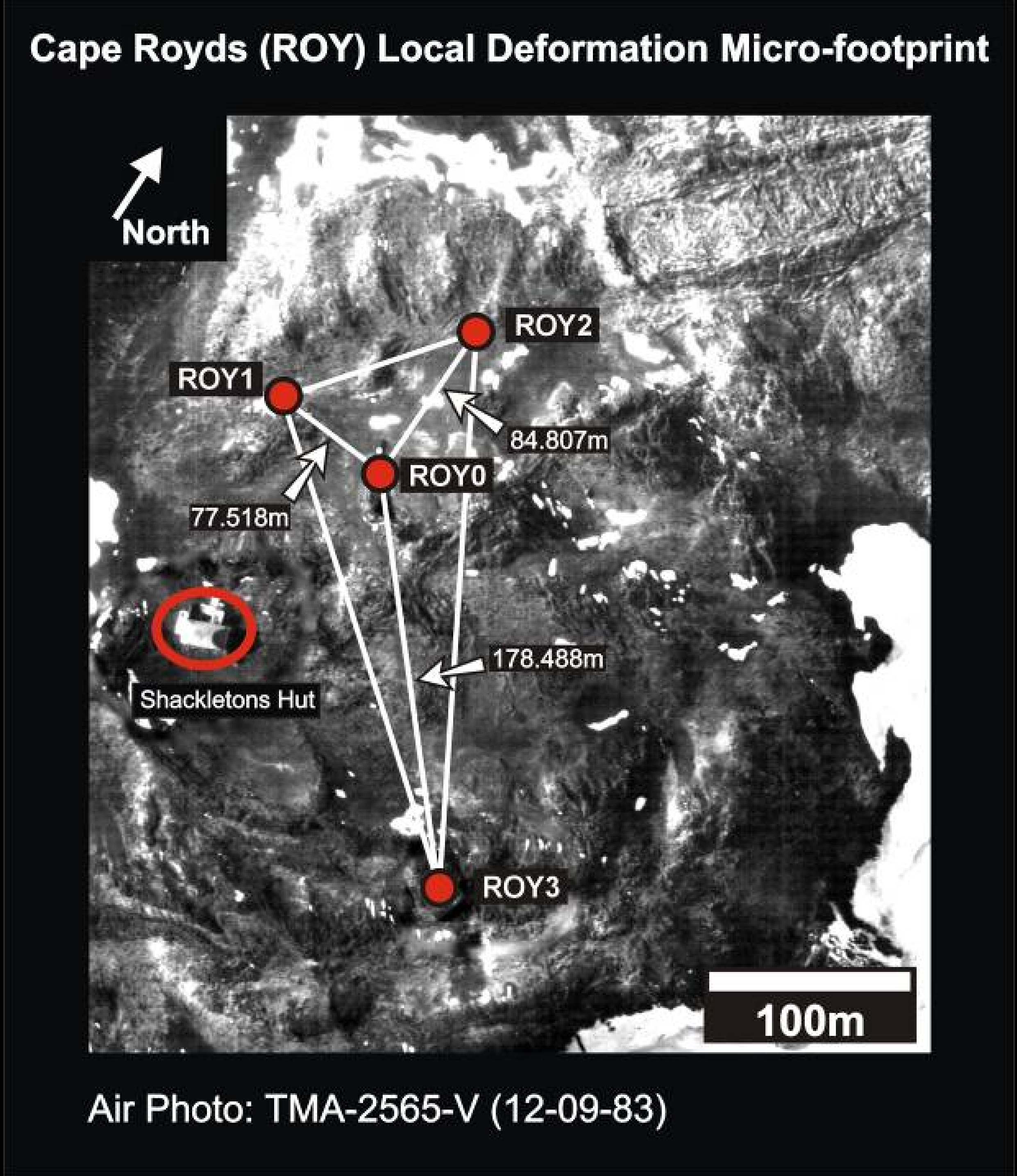


Early Campaign Experiences

- 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





Test for monument stability

Cape Crozier

Seasonal Campaign GNSS Stations


USGS

Esser Hill & Bettle Peak

Seasonal Campaign GNSS Stations

Hidden Valley

Site for fault surveys




Beacon Valley

Site for fault surveys

Challenges

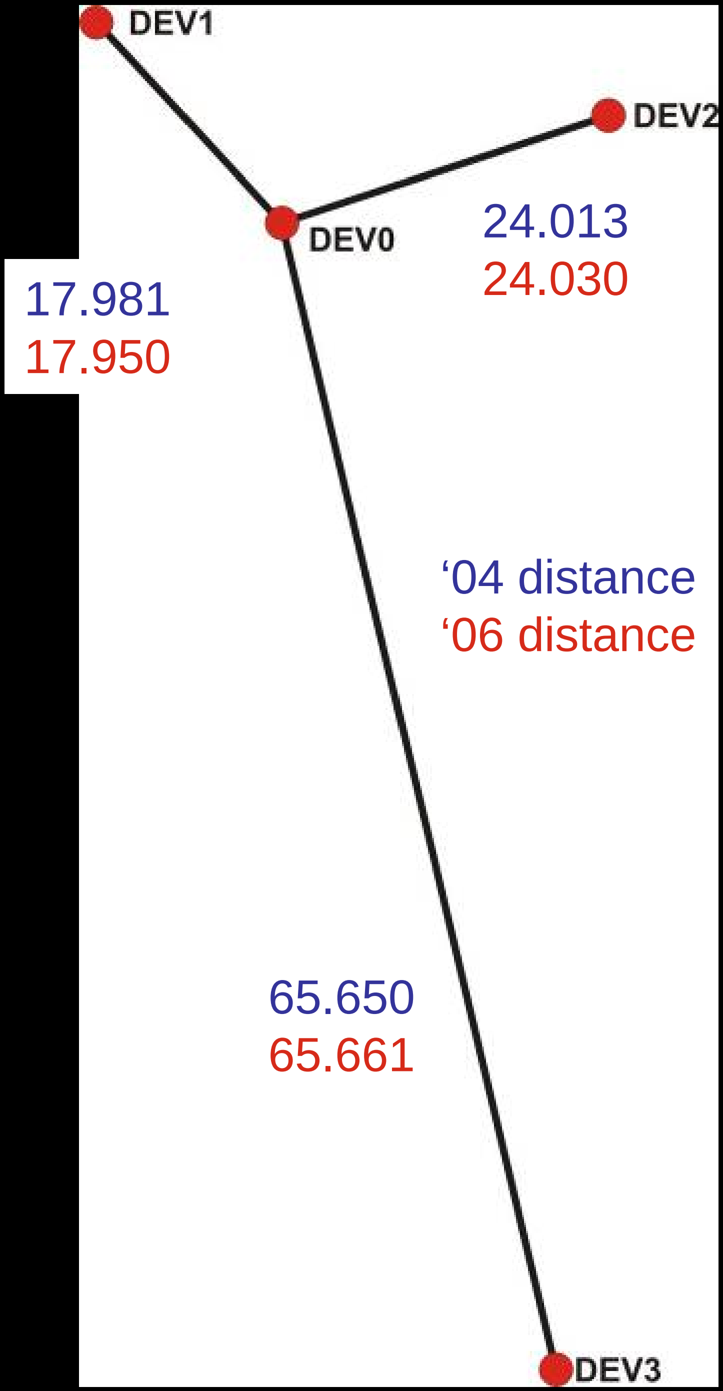
Challenges:

TAMDEF site- Minna Bluff

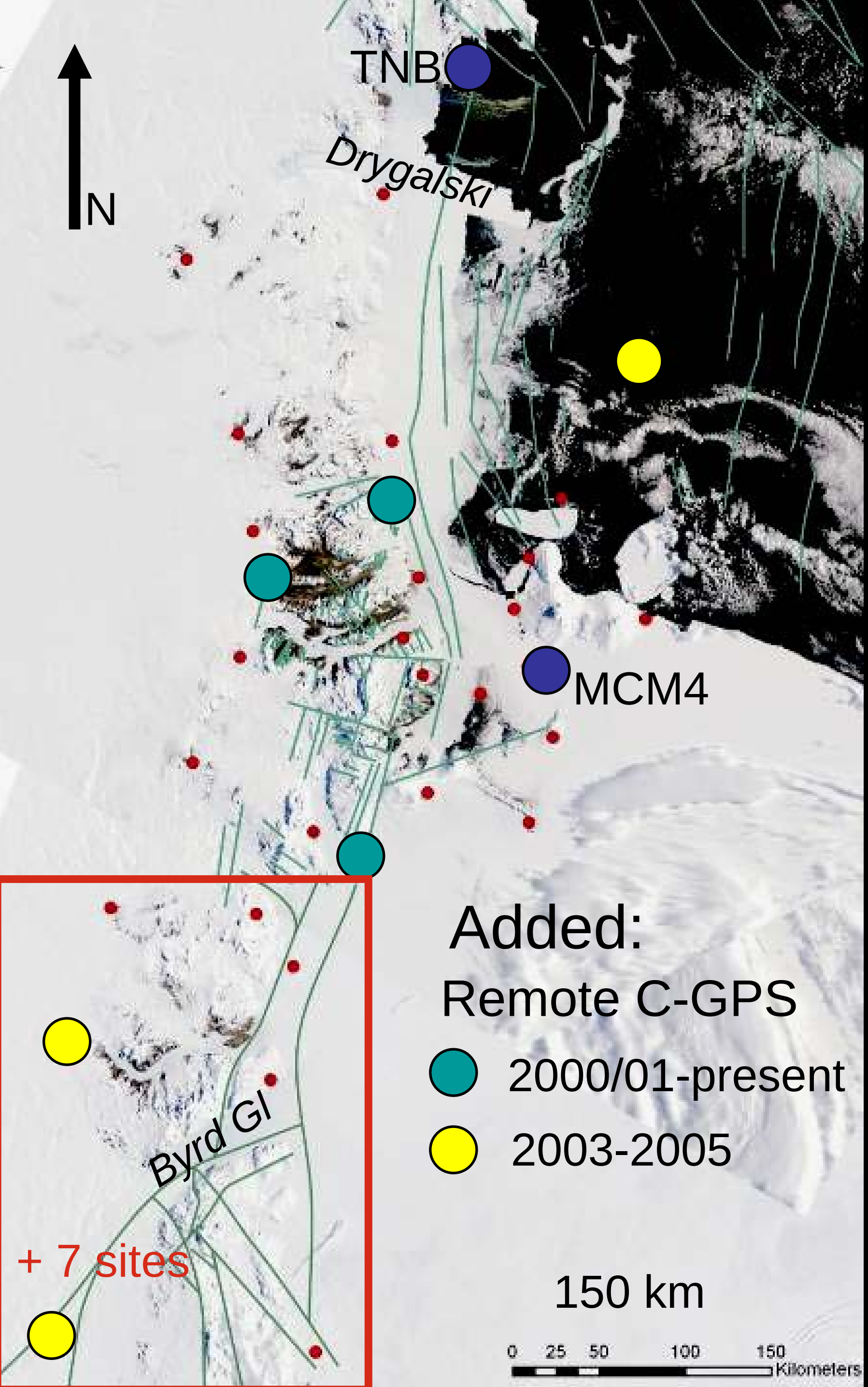
Rime ice on antenna….effect?

Deverall Island

- Seemingly good bedrock.
- 3.2 cm deformation!
- Eccentric marks still useful.



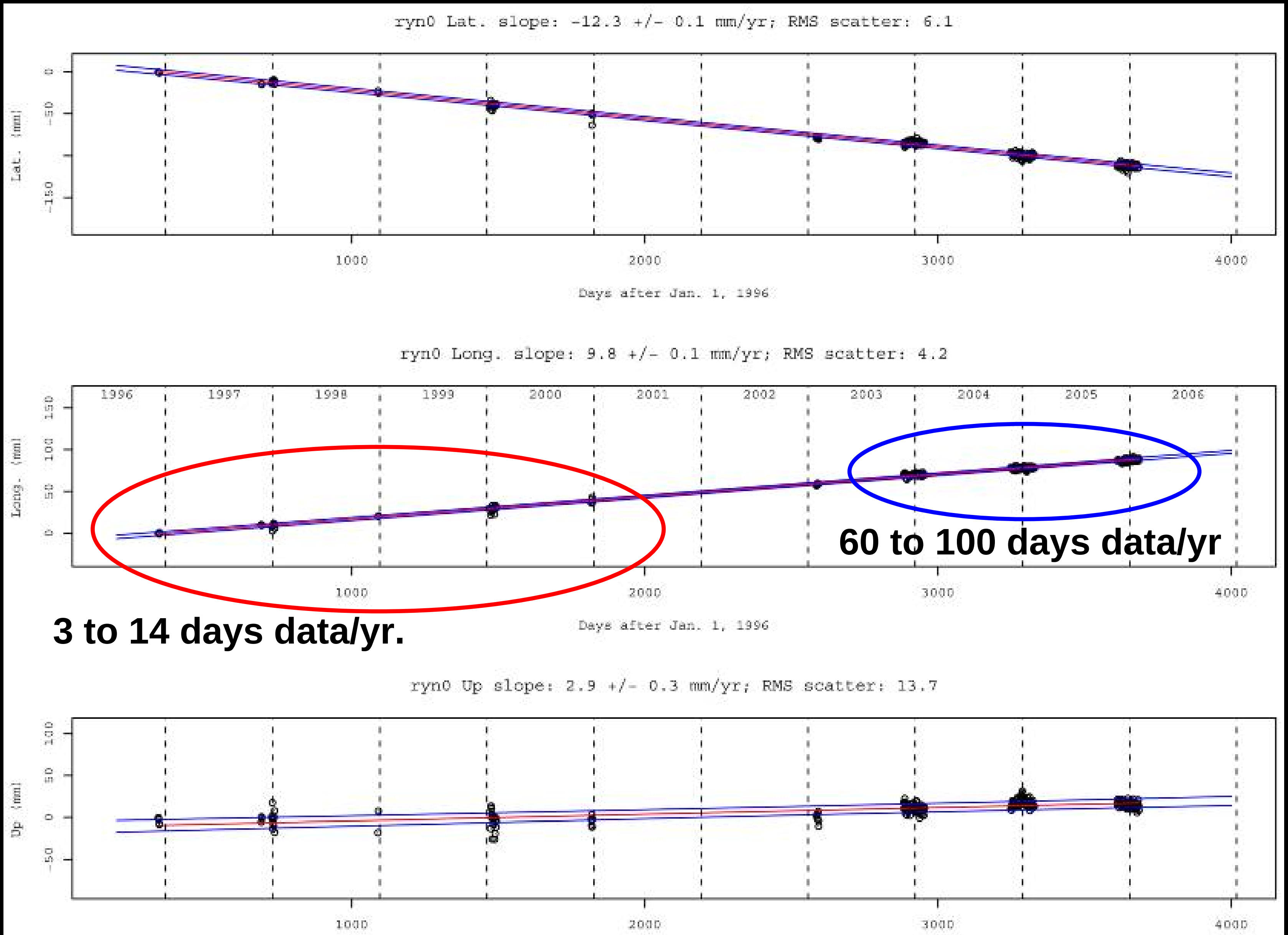
Network expansion to south – 2003



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

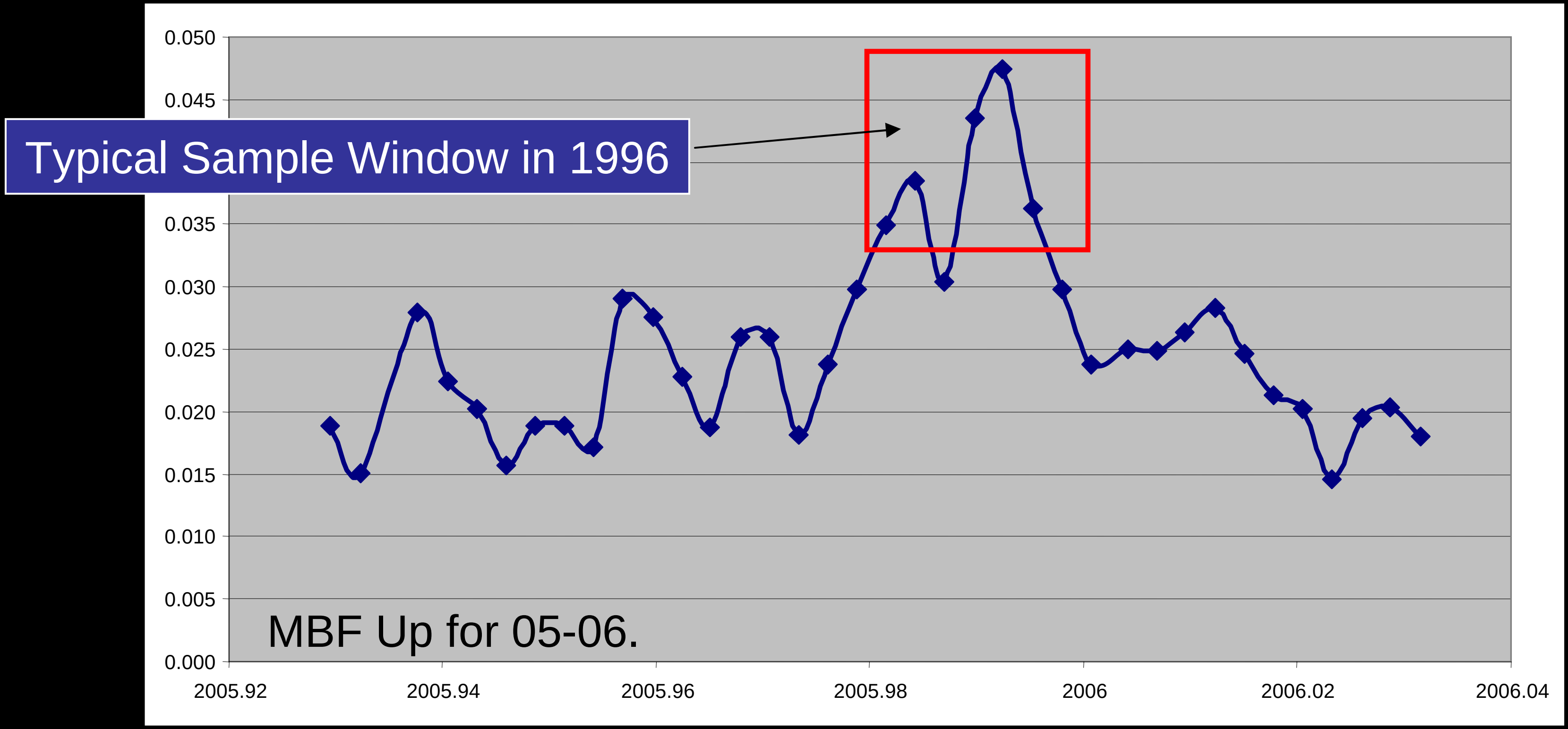
IMPROVEMENT:

Long-duration campaign measurements



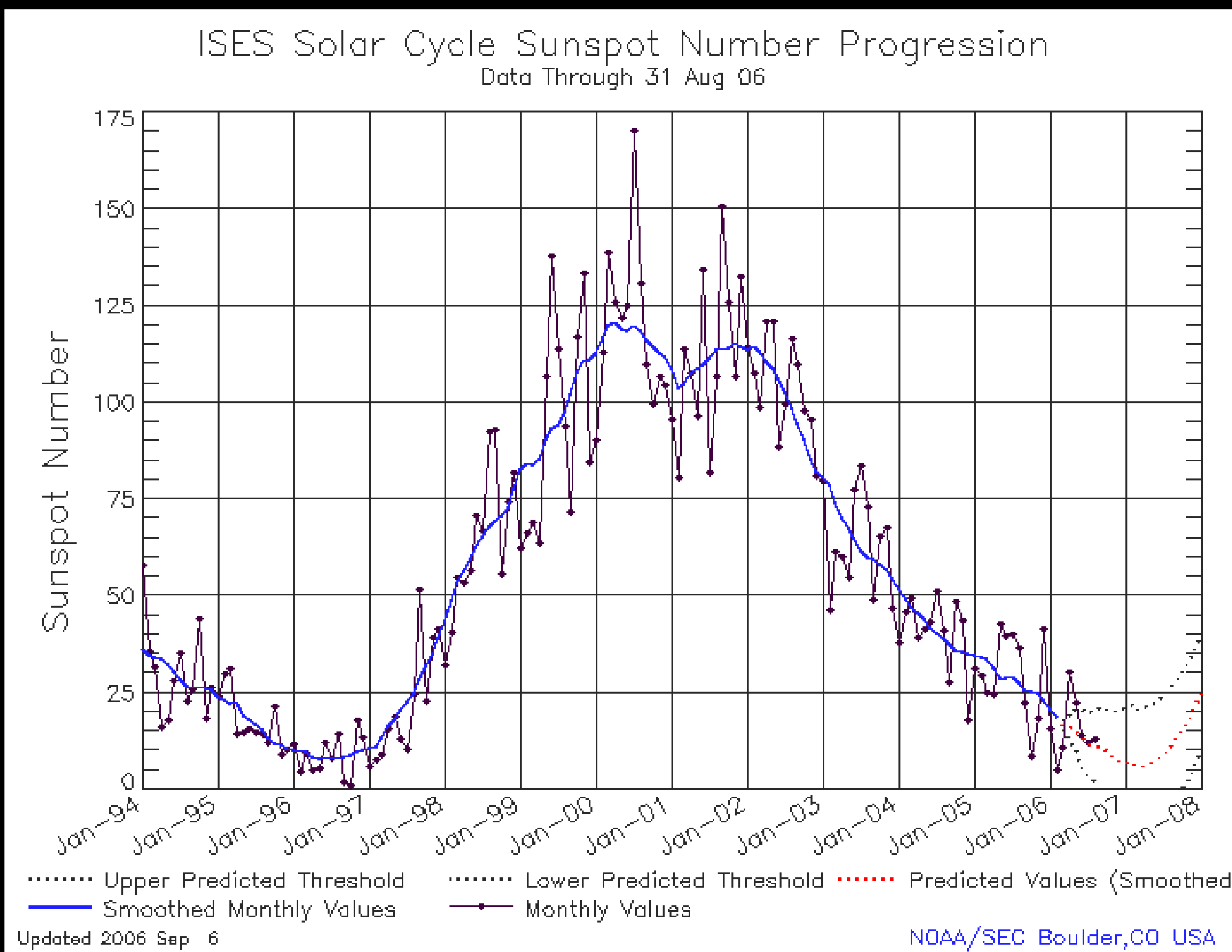
Longer duration campaign data: SIGNIFICANT BENEFITS

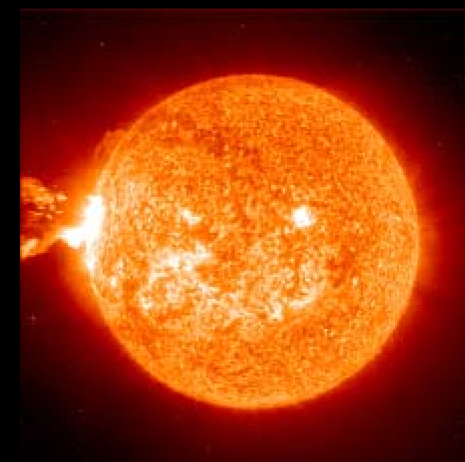
- Weather effects - previously hidden.
- Water vapor studies.
- Captures Ionospheric disturbances.
- Observation overlap – enhances analysis.

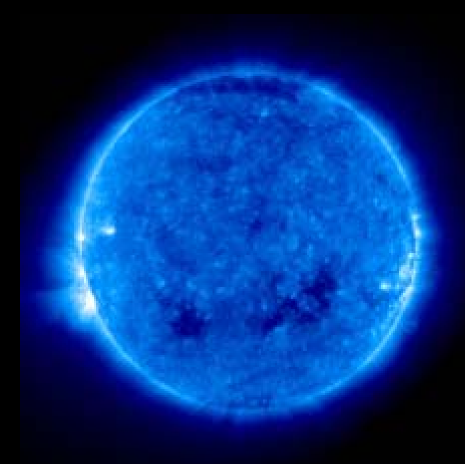


New solar max ~ 2010.

Ionosphere will get noisier.
New frequencies will help.







JPL/NASA GPS Remote Stations

from *Satellite Image Map of Antarctica* (Ferrigno, et al., 1996)

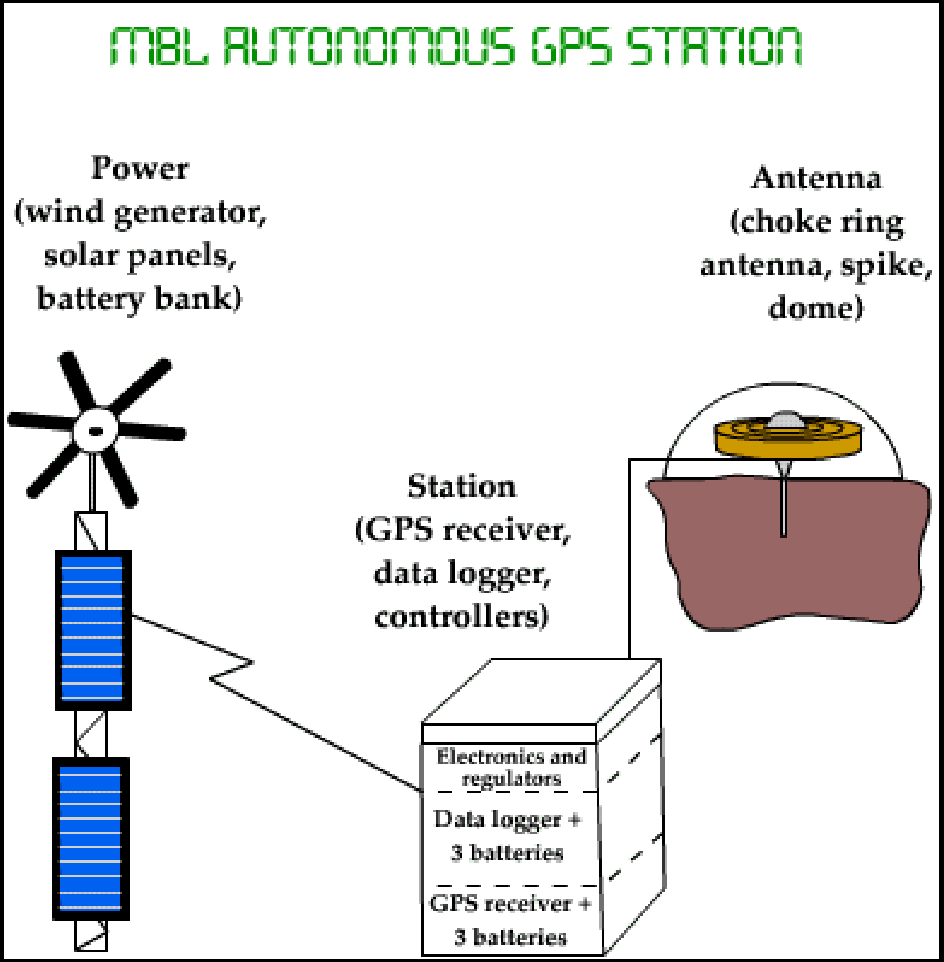
Two stations were installed on Mount Coates (1996 & 1997 field seasons) and Mount Cocks (1997 field season)

Mount Coats (1)

Mount Coats (2)




JPL/NASA Project – 1998-2000



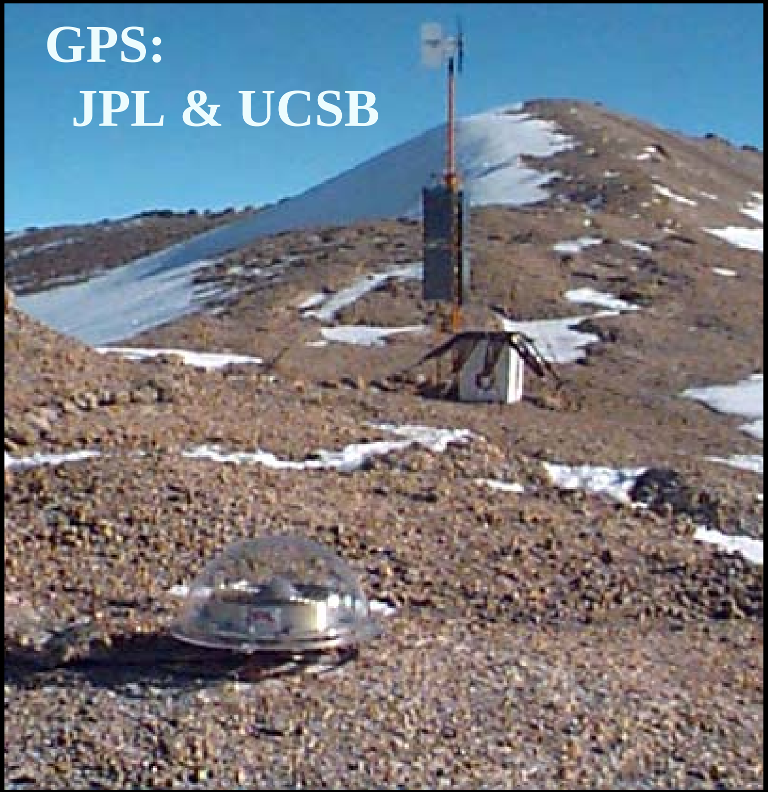
Initial Experience

- 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



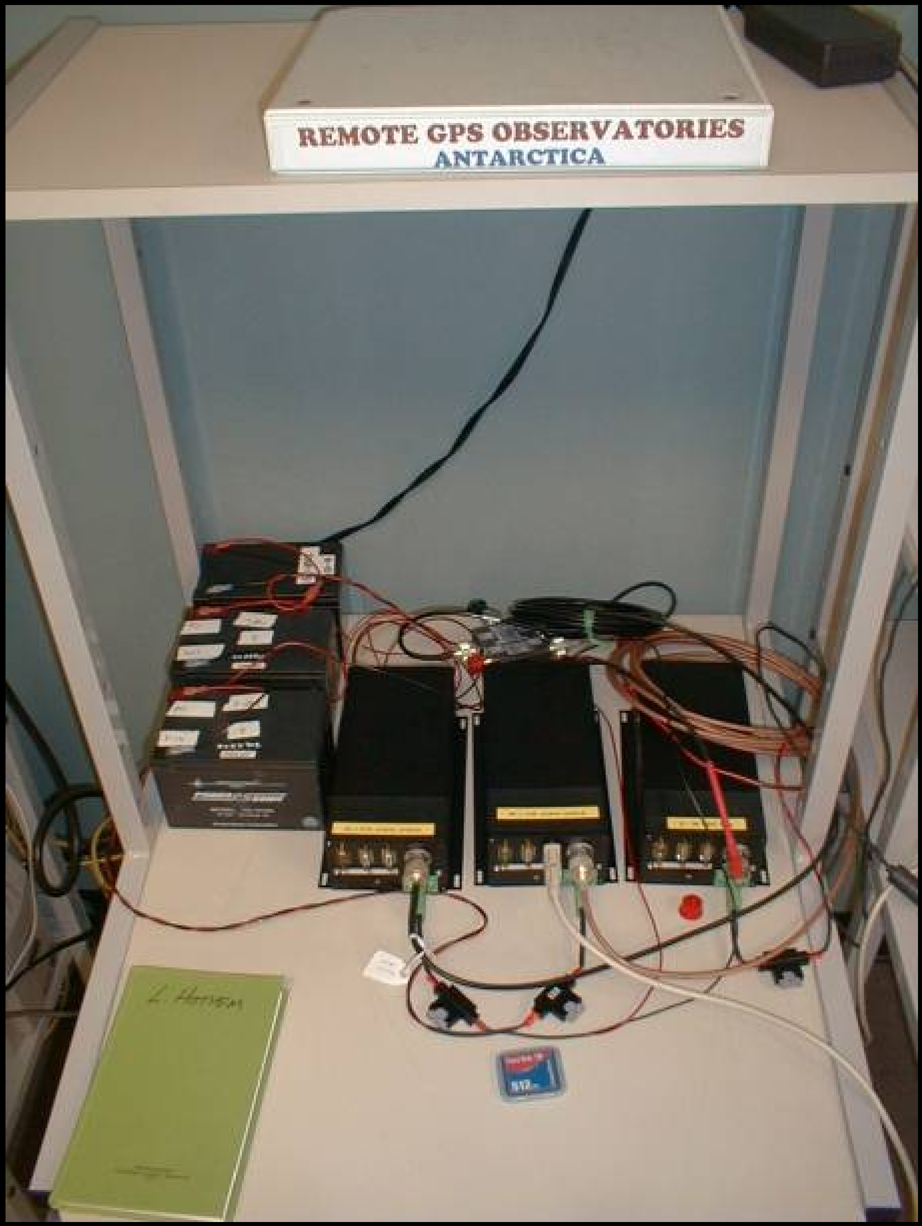
Enabling Technologies:

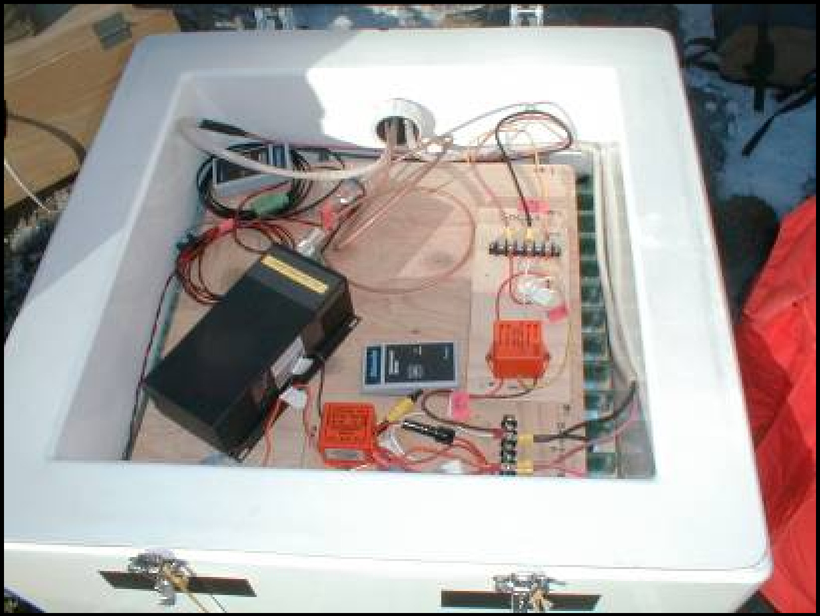
- Solar
- Wind
- Low-power
- High-capacity storage
- Satellite communications

IMPROVEMENT:

Continuous GPS measurements at remote sites

GNSS Equipment



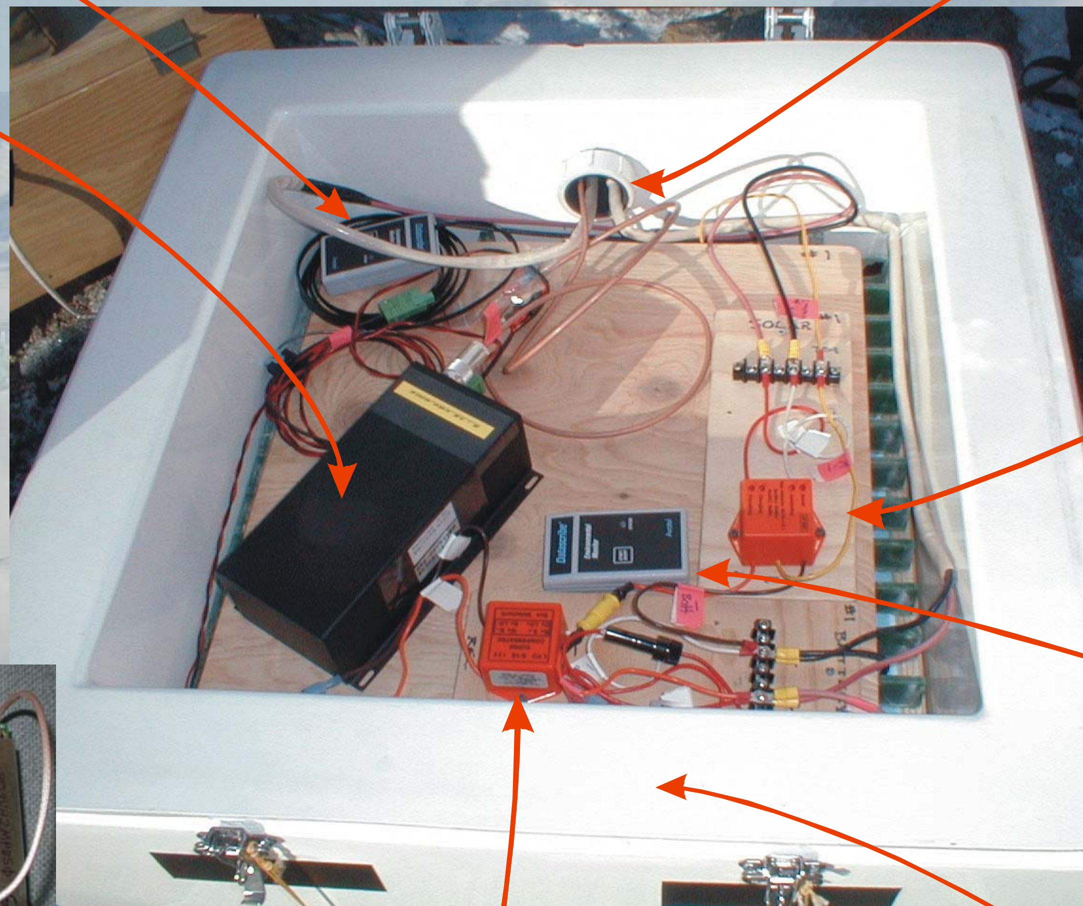


2001-2002 Installations

Temperature Sensor for top of box (Avatel)

To Antenna, Second Battery Bank and Solar Panels

JNS GPS Receiver

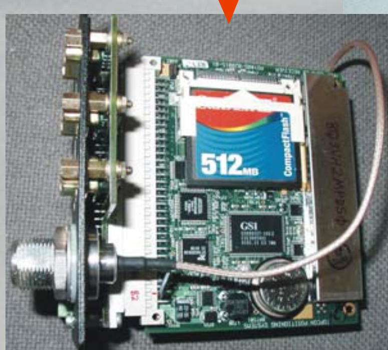


Solar charge controller (Sun Selector)

Temperature Sensor for bottom of box (Avatel)

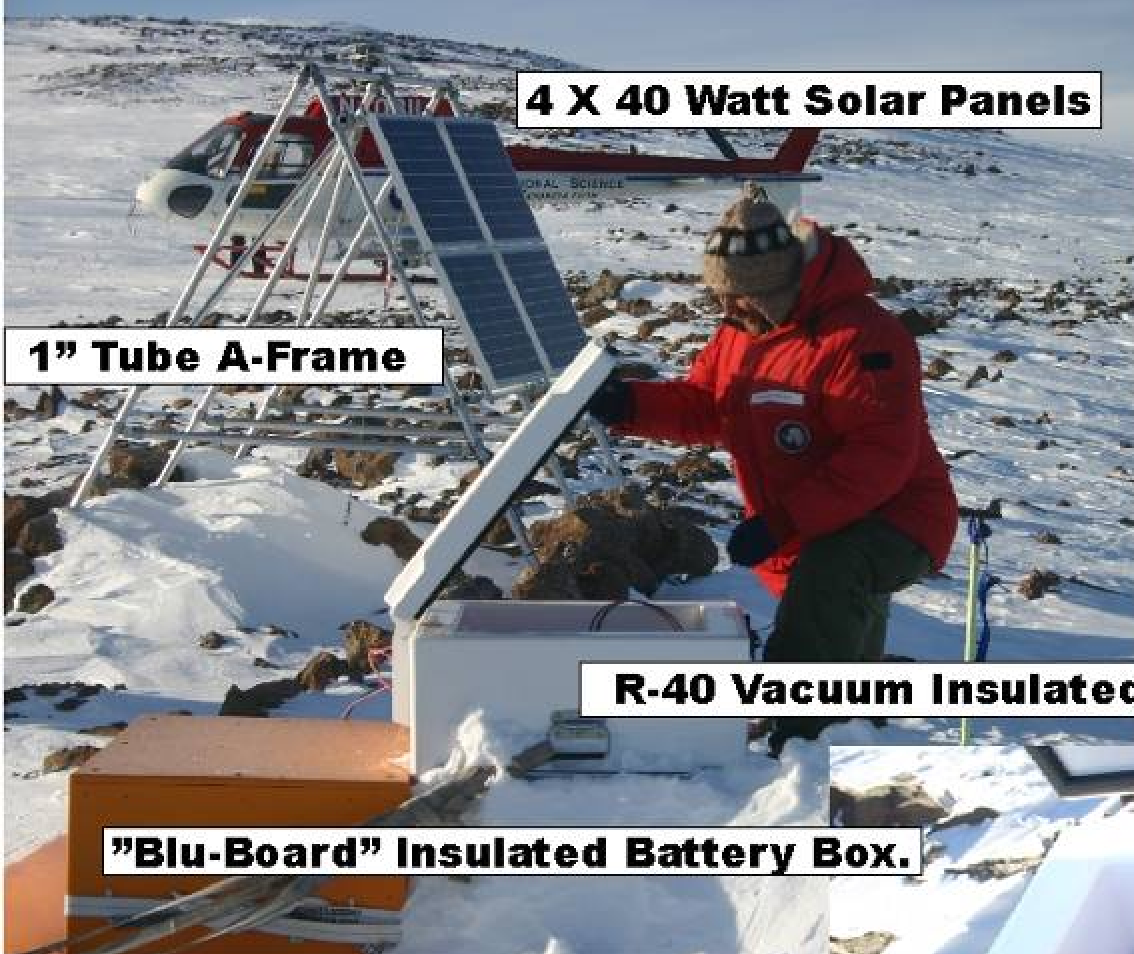
Low Voltage Disconnect (Sun Selector)

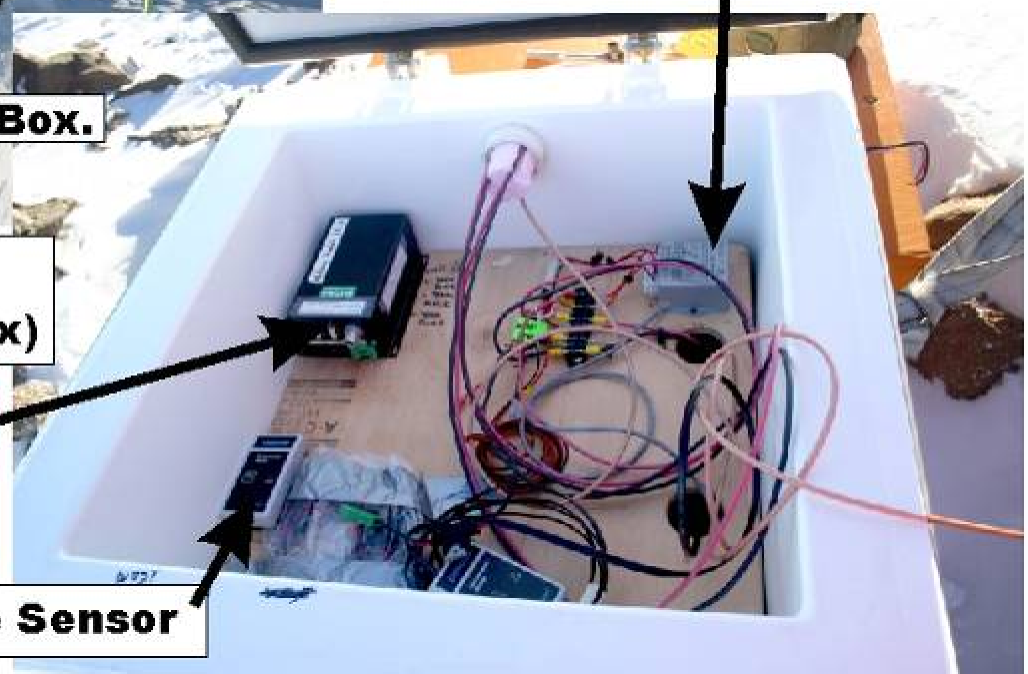
Vacuum Panel R-80 Insulated Enclosure



JNS EURO-80 Card

TAMDEF CORS at Westhaven Nunatak.



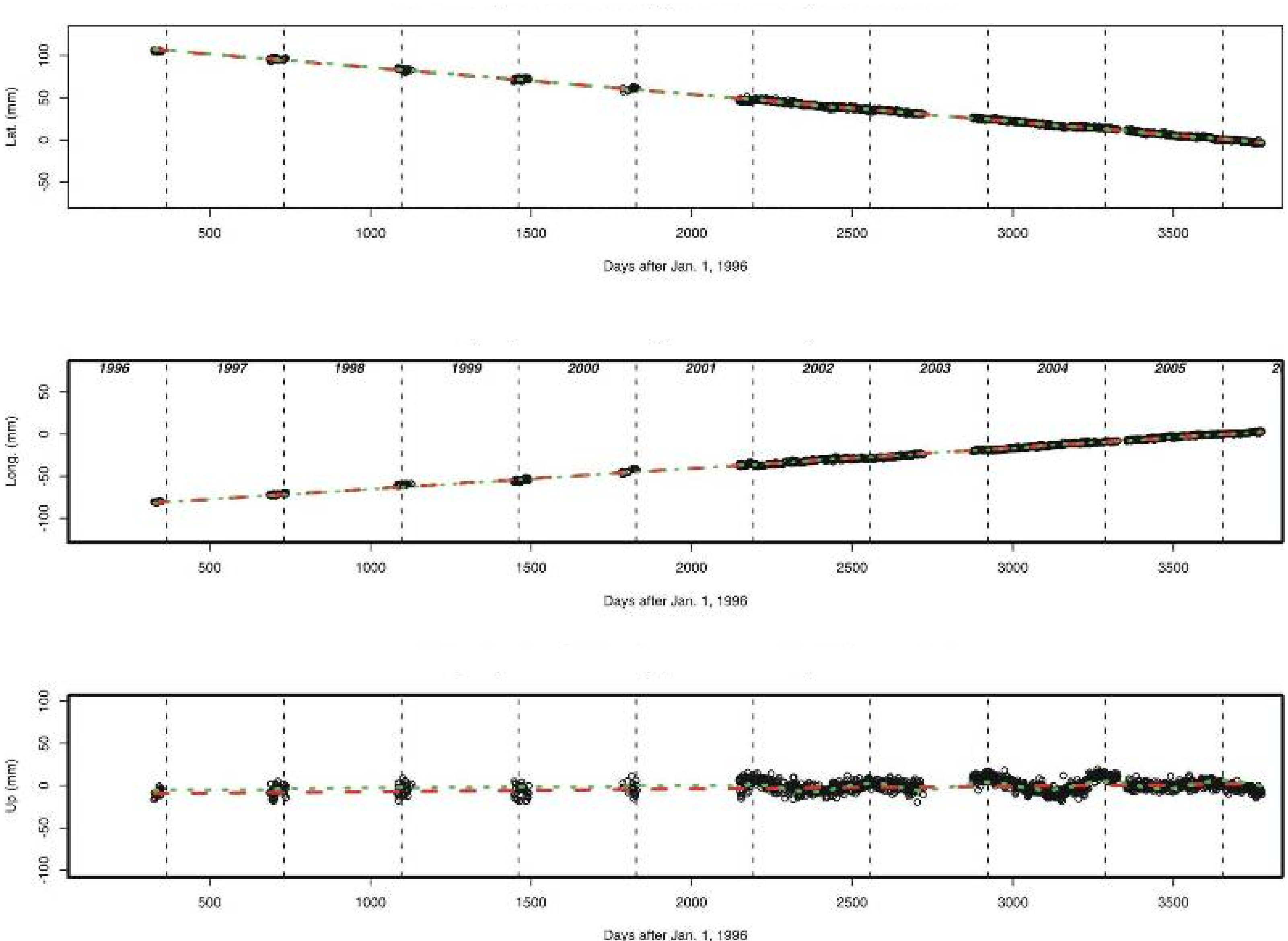


Cape Roberts

GNSS CORS Remote

Station ROB4

Success with year round CGPS measurements

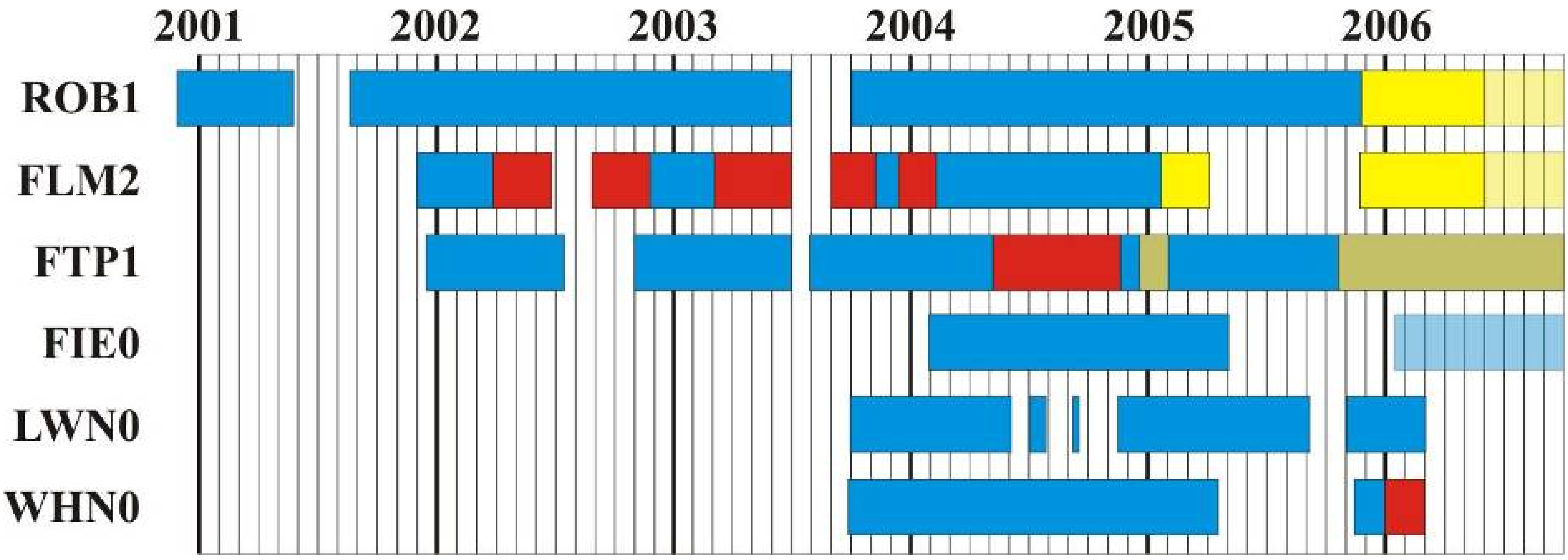


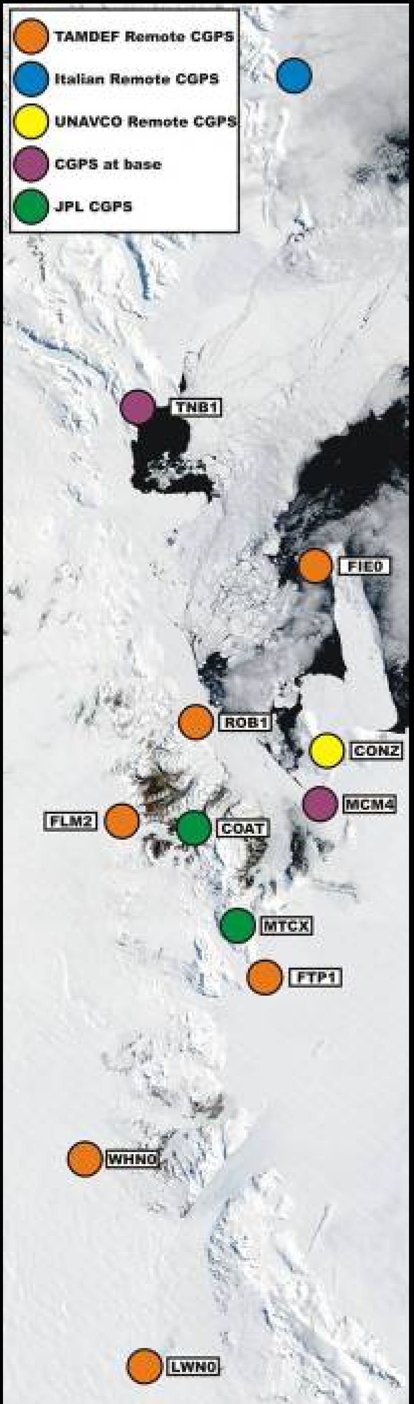
Performance of TAMDEF CGPS:

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.

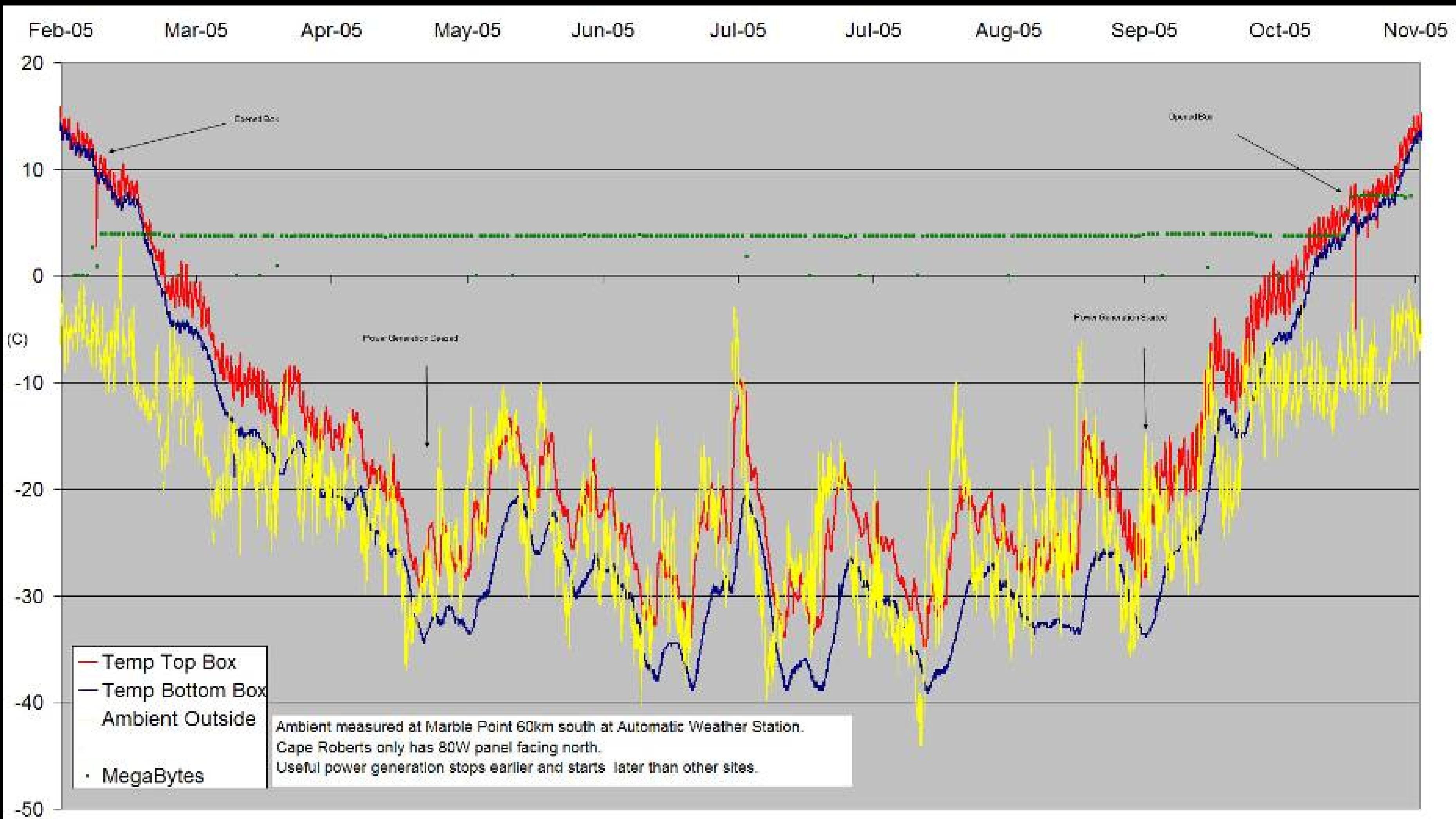
New monument.

LOS data link, site is monitored.

Cape Roberts

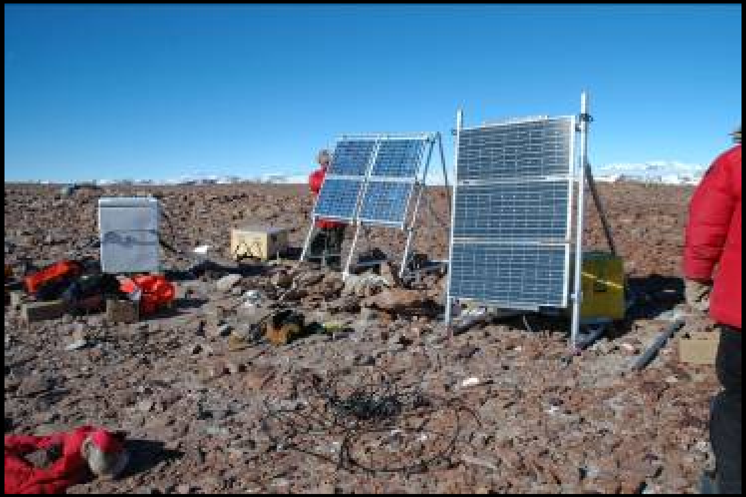
More than 1700 days of data.

Runs to -45C.



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:

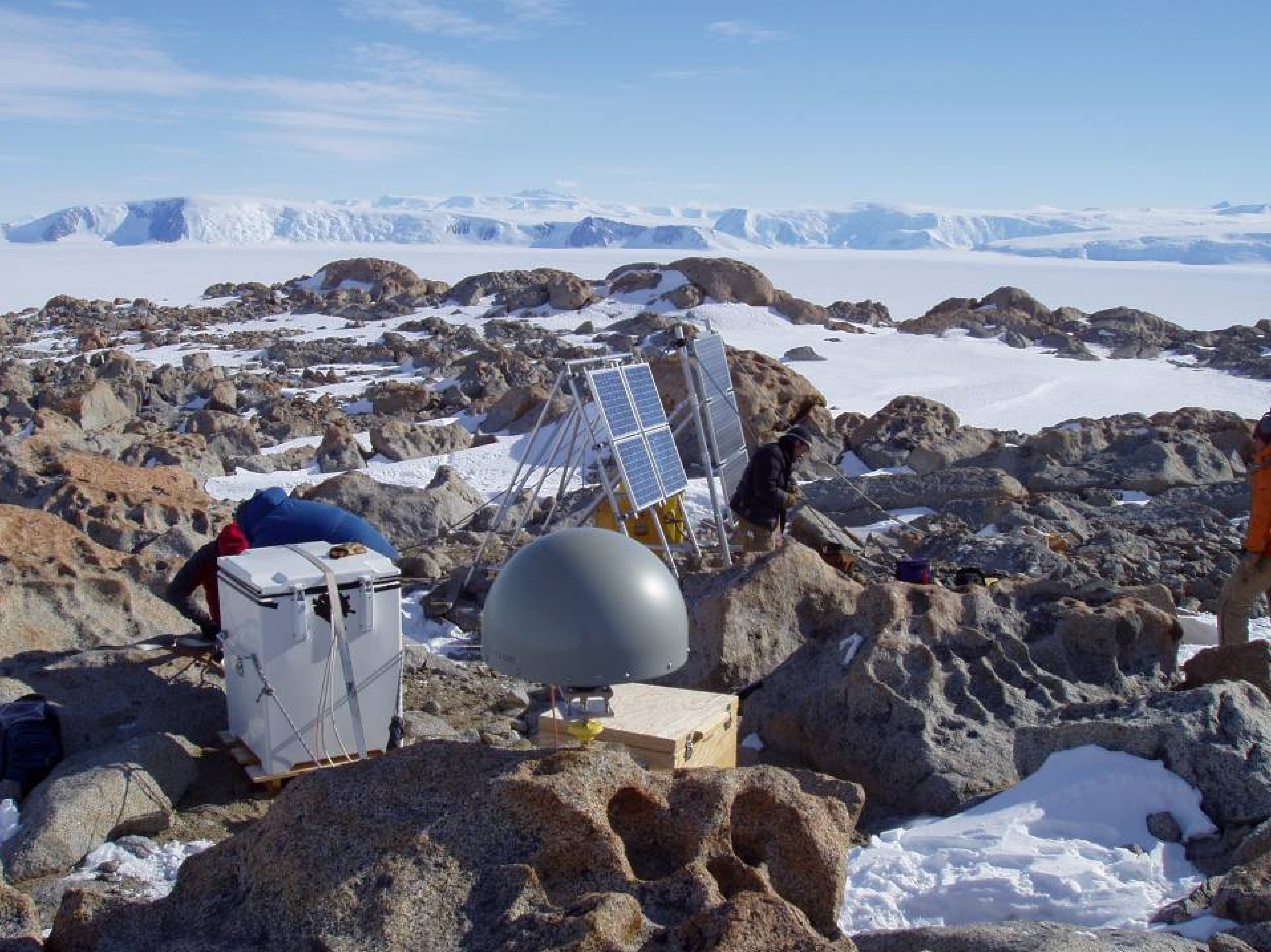
Windy site near Skelton Glacier.

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:

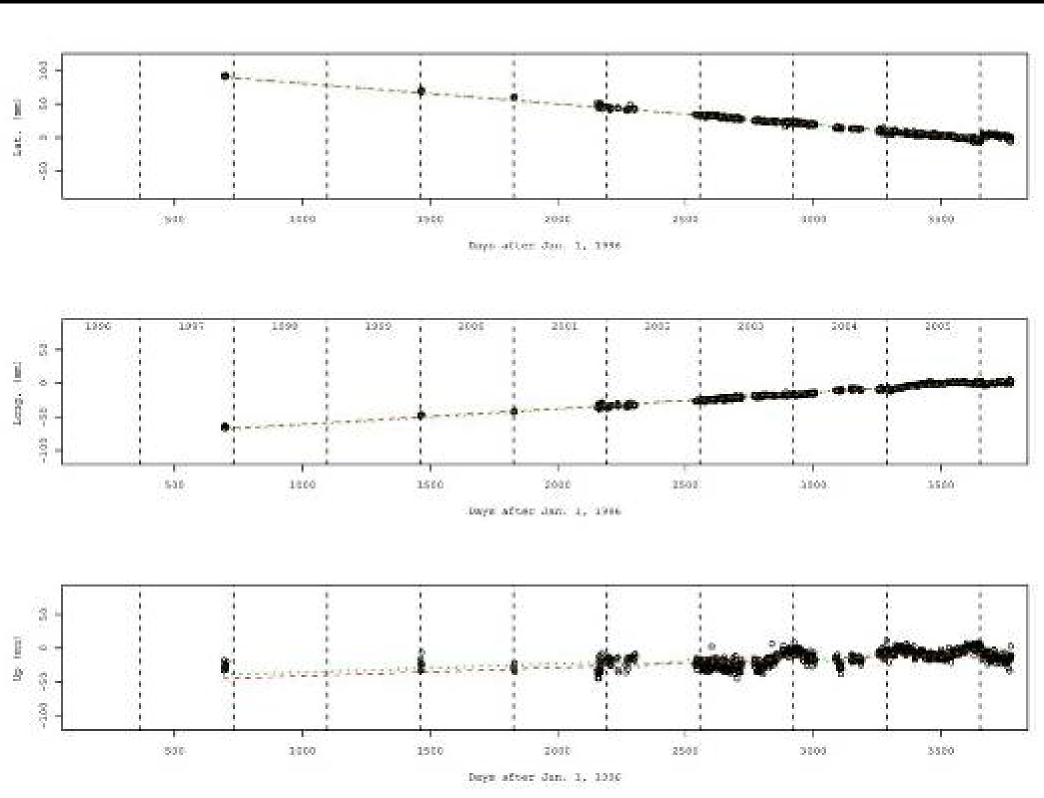
1250+ days of data. Works to -40C

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.

1st year, perfect!

2nd year, failure ☹

Rime on antenna?

SOLUTIONS (Future)

Install late model GNSS

Data link: LOS to McMurdo

Multi-year unattended operation?

Westhaven Nunatak

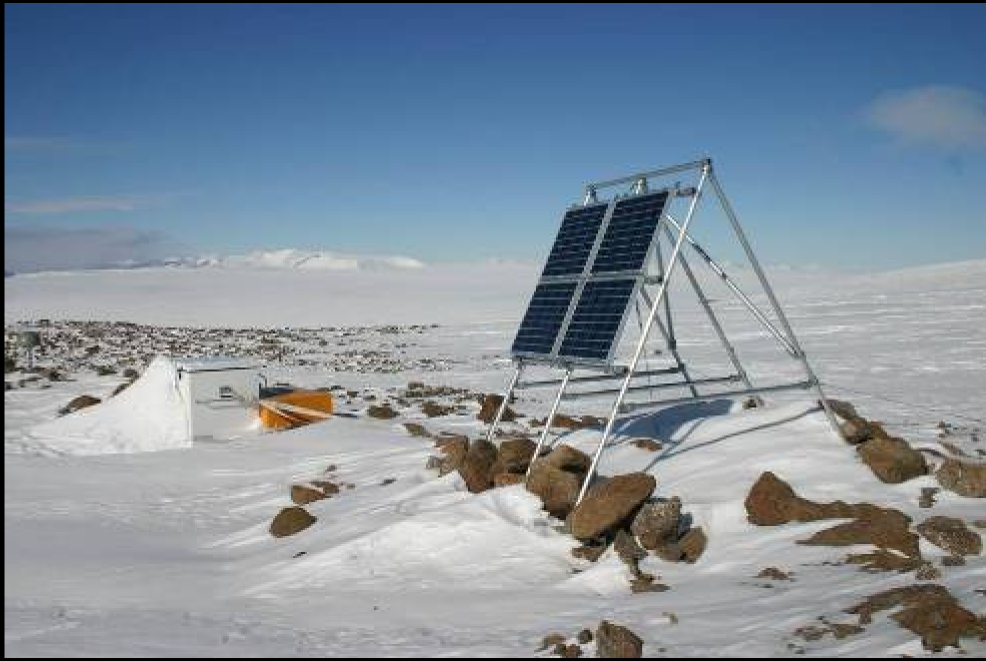
Plateau site, very cold

Challenges

Extreme cold
Difficult access
1st year perfect!
2nd year failure ☹
Temp sensors failed

Solutions (future)

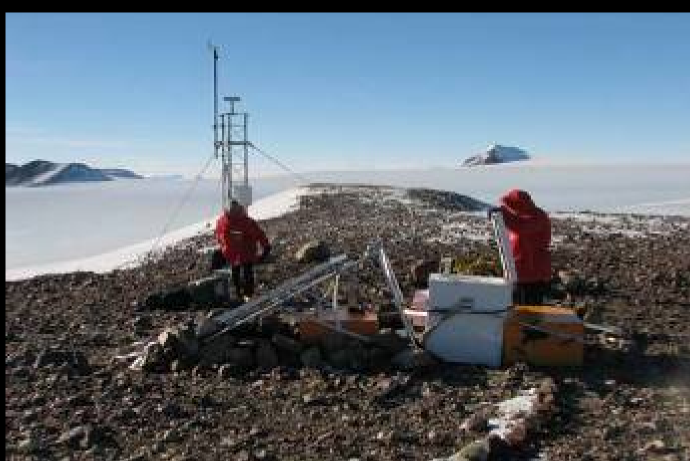
Lightweight station
New logistics plan
Vac-panel box helps



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 ☺

Spindrift in sealed enclosure.

Lower profile – reinforced solar panel frame

Spindrift in sealed enclosure following year.

Panel ripped off again

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.

```
 SV+---------|--------|--------|--------|--------|--------|--------|--------+ SV
 23|L                     L+ooooooooooooo+m_                   mLooooooooo+m| 23
  2|+m                      L+ooooooooo+m_                   L+ooooooooooooo|  2
 13|oo-m                      L+oooooooooooo++_                   mmoooooooo| 13
  6|oo-o+L                    L+ooooooooo+L                      L+ooooooooo|  6
 16|oo-ooo++                   LLoooooooooooo+m                      _L+oooo| 16
 10|oo-ooo+mL                      L+oooooooooo++                   Lmoooooo| 10
 27|oo-ooooo+m                      L+ooooooooooooo++_                   L+o| 27
  7|oo-oooooo+L_                  LL+oooooooooomm                       L+oo|  7
  8|m+-oooooooo+m                     _LooooooooooooooL+                   L|  8
 21|oo-ooooooooL_                     m+ooooooooo+m                     _Loo| 21
 29|L+-oooooooooo+m                       L+ooooooooooo+_                  _| 29
  3|L+-oooooooooo++                   L+ooooooooooo+m                       |  3
 26|LL-ooooooooooo+mL                     LL+ooooooooooo++                  | 26
 18|  _+ooooooooooooo+L                     L+ooooooooo++                   | 18
 19|   L+ooooooooooo++                   L+ooooooooooo+mL                   | 19
 22|     LLooooooooooooo+L_                    m+ooooooooo+m                | 22
 28|      _Looooooooo++                     _Looooooooooooo+m               | 28
  9|        LLooooooooooo+mL                     LL+ooooooooooo+LL          |  9
 11|          _L+ooooooooooo+L                  LL+oooooooooo+mm            | 11
 14|           L+ooooooooooooomm                     LL+ooooooooo++         | 14
 17|             L++ooooooooo++                    L+ooooooooooooo+m        | 17
  1|               L+ooooooooooooo+m                     mLooooooooo+m^     |  1
  5|               Lm+ooooooooo++L                      m+oooooooooooo+L    |  5
 20|                 LLoooooooooooo+L_                  Lm+oooooooooo+L     | 20
 30|                  LL+oooooooooo+m                      LL+oooooooooooo+L| 30
 25|                   _Looooooooooooo+m                      L+ooooooooo+m_| 25
  4|                     L+ooooooooo+++                   Lmoooooooooooo+m  |  4
-dn|                                                                        |-dn
+dn|  c                                                                     |+dn
+10|8bbbbbbbbaaaa888988999aa99aaaa9999aaa9abbbaaaaaaa97789899aaa9aa999998|+10
Pos|oo ooooooo oo             o    oo  o  o oooooooo              o      o  |Pos
Clk|  ^                                                                     |Clk
   +---------|--------|--------|--------|--------|--------|--------|--------+
00:00:00.000                                                        23:59:30.000
2006 Sep 22                                                          2006 Sep 22

********************
QC of RINEX  file(s) : /ap/data/ender/queue/.rinex/.949783/ftp42650.06o
input RnxNAV file(s) : /ap/data/ender/queue/.rinex/.949783/ftp42650.06n
********************

4-character ID          : FTP4 (# = 66062M002)
Receiver type           : TRIMBLE NETRS (# = 4451241729) (fw = 1.1-2)
Antenna type            : ASH700936D_M    SCIS (# = CR13562)
```

TAMDEF Network and Program

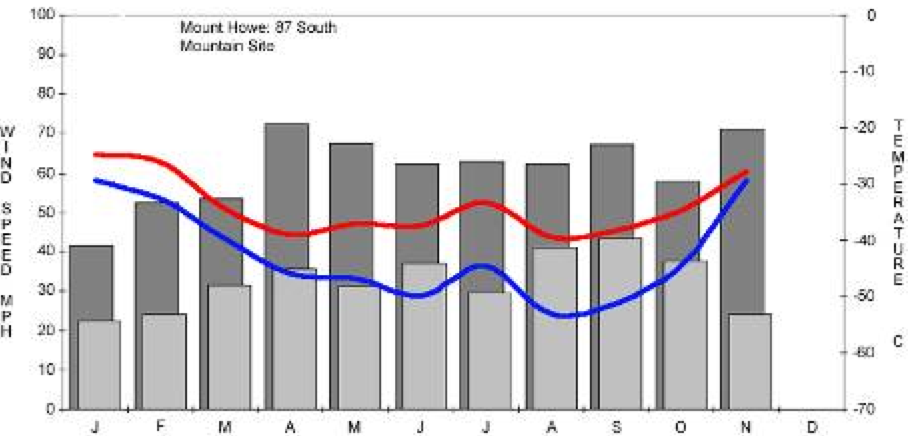
- Built upon Campaign experiences.
- Used simple technologies (no moving parts).
- On the whole, highly successful.

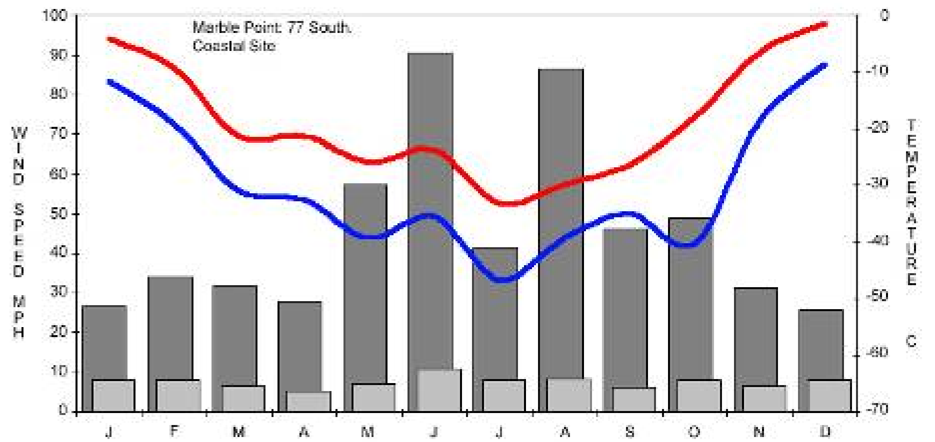
Antarctic realities

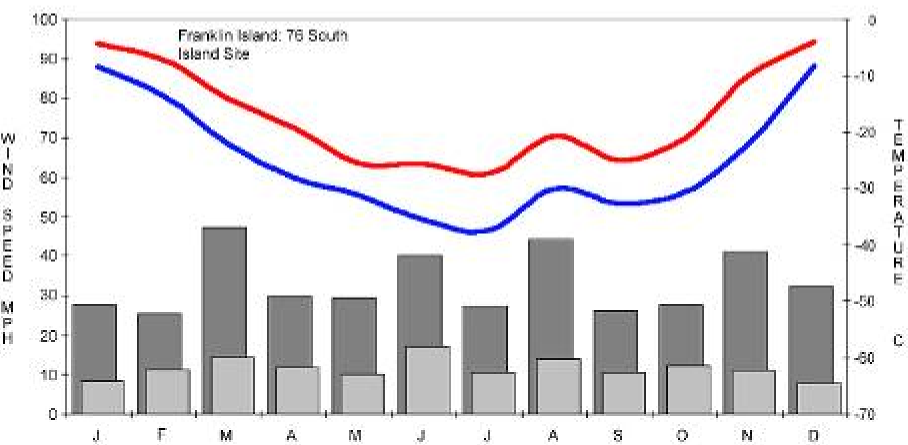
CONTINUOUS CHALLENGES

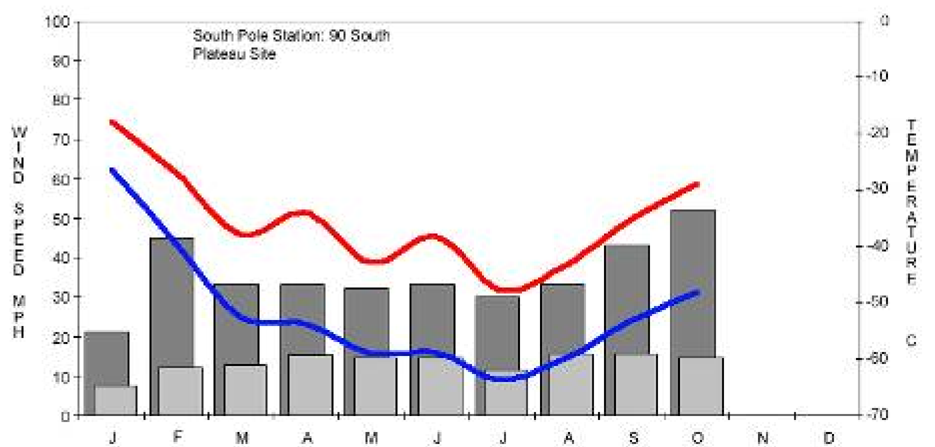
- Long-term autonomous operation
  - *Reliable, low-power communications*
- Continuous operation through polar night
  - *Lightweight power systems*
- Effective operation in very remote locations
  - *'Antarctic-optimized' system*

Diverse environments for deployment. Suggest standardizing systems, but making them customizable.

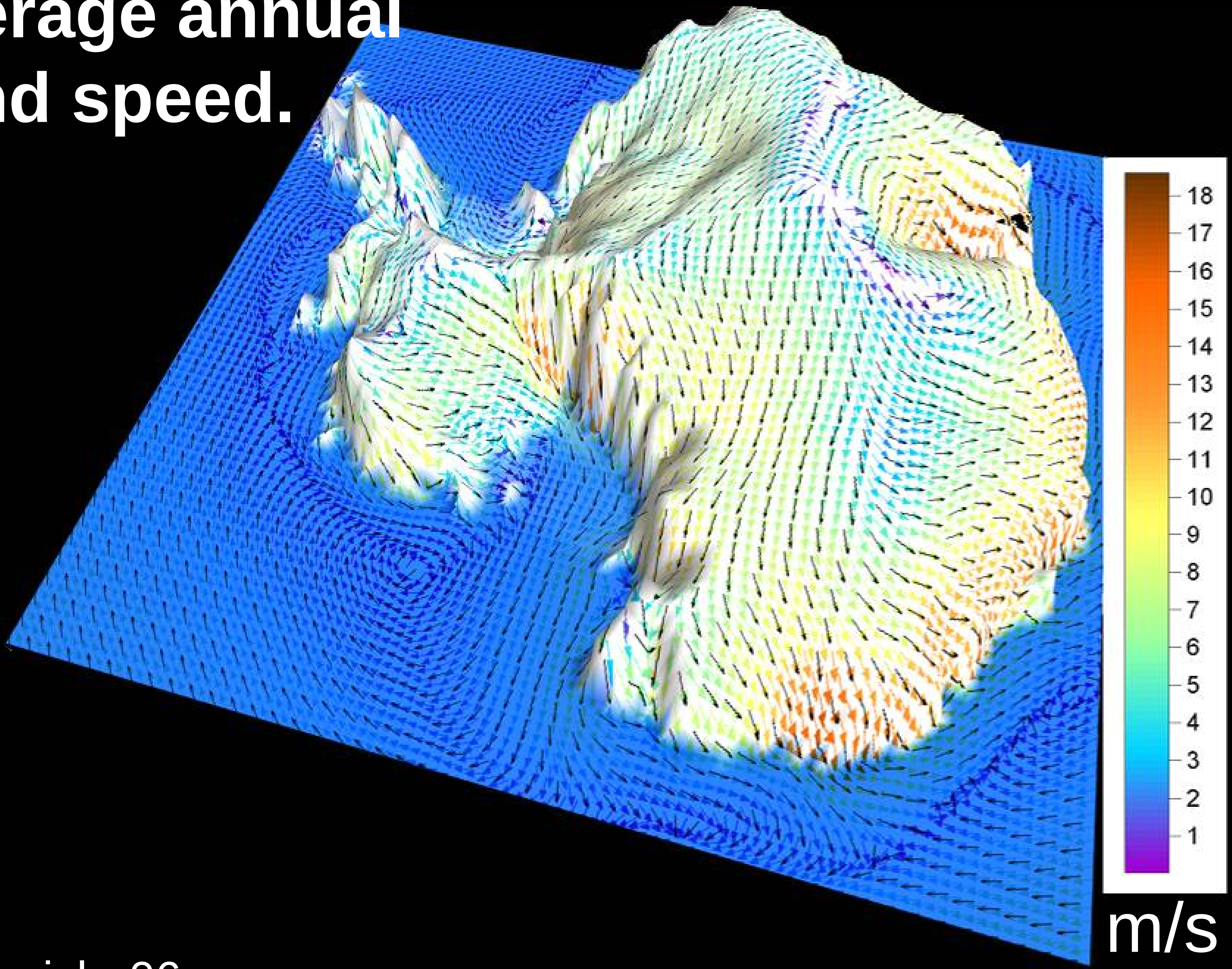








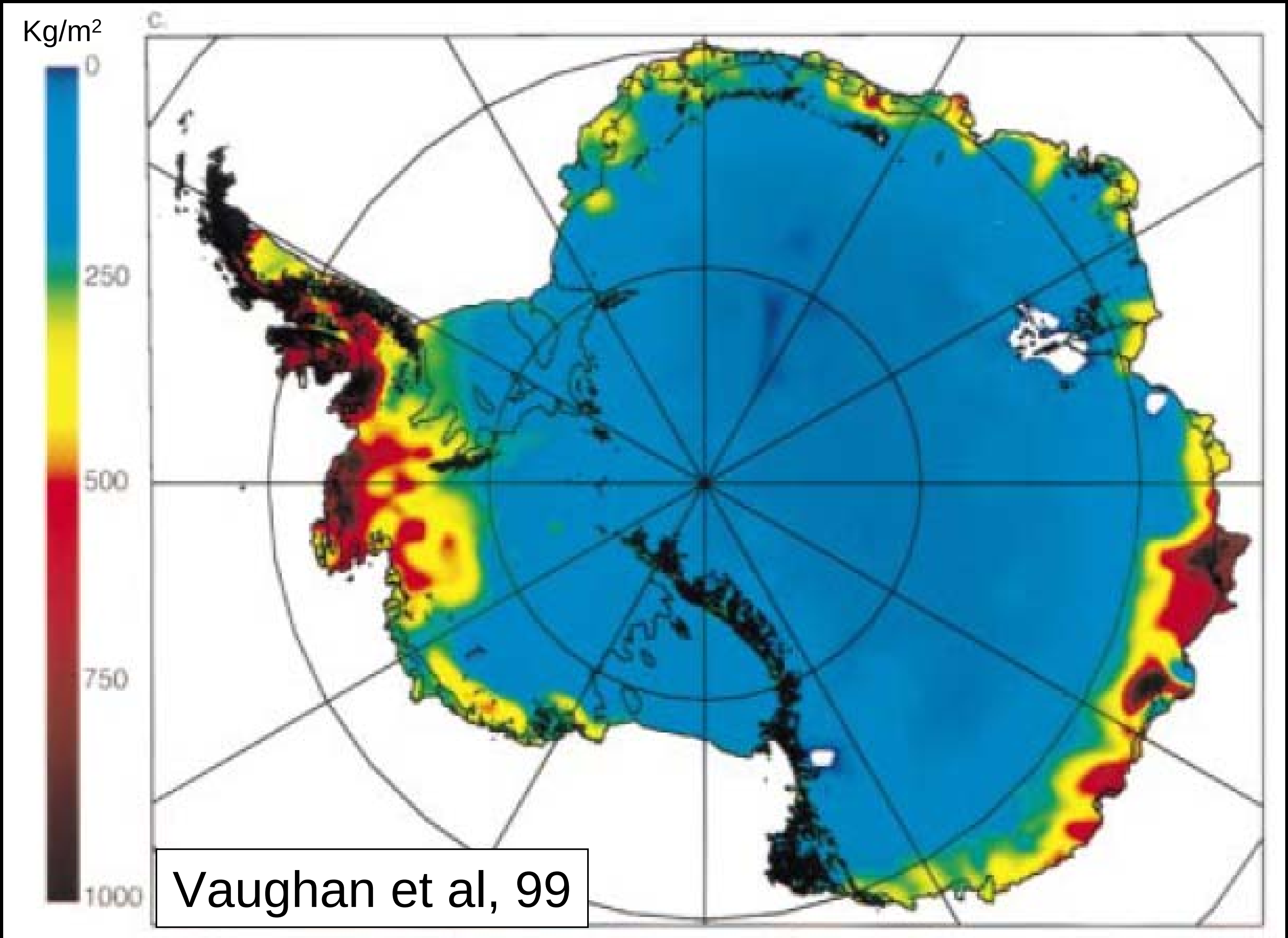
Average annual Wind speed.



Bromwich, 06

Average annual snow accumulation.

- Coastal sites need taller monuments.



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

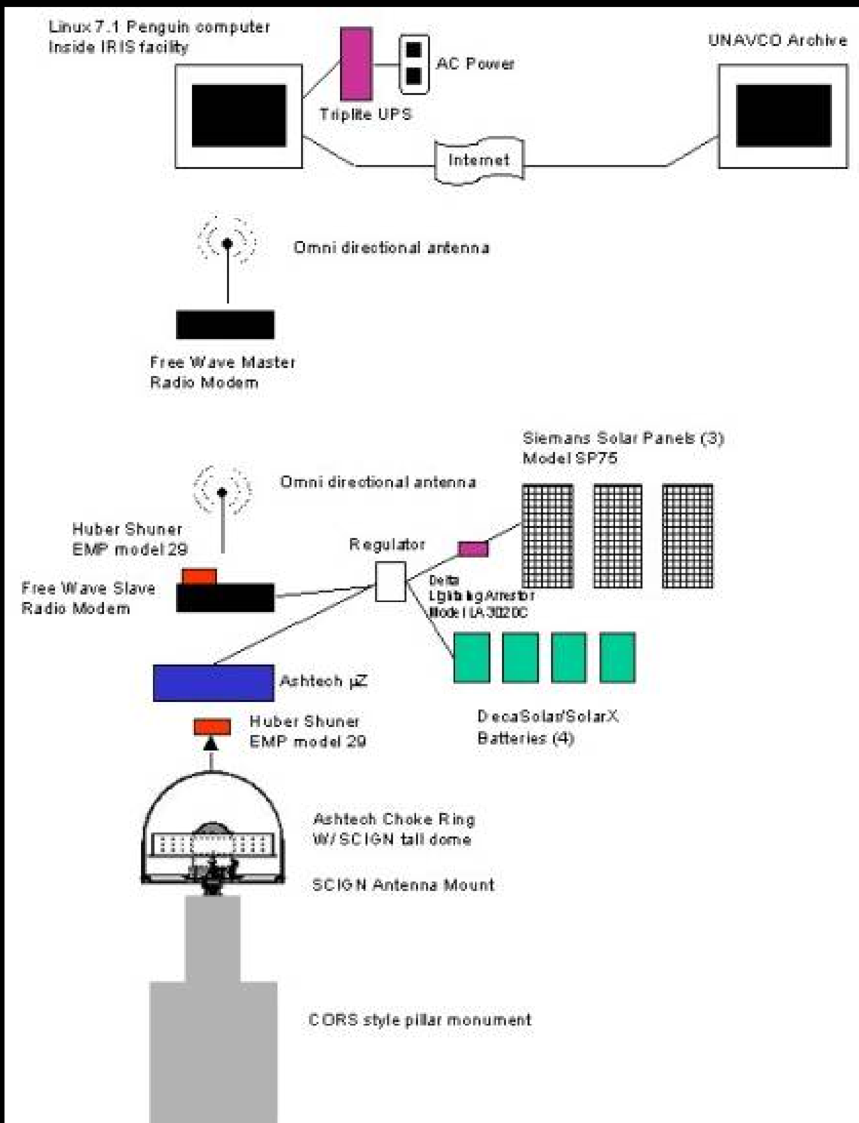
Environmental Hardening

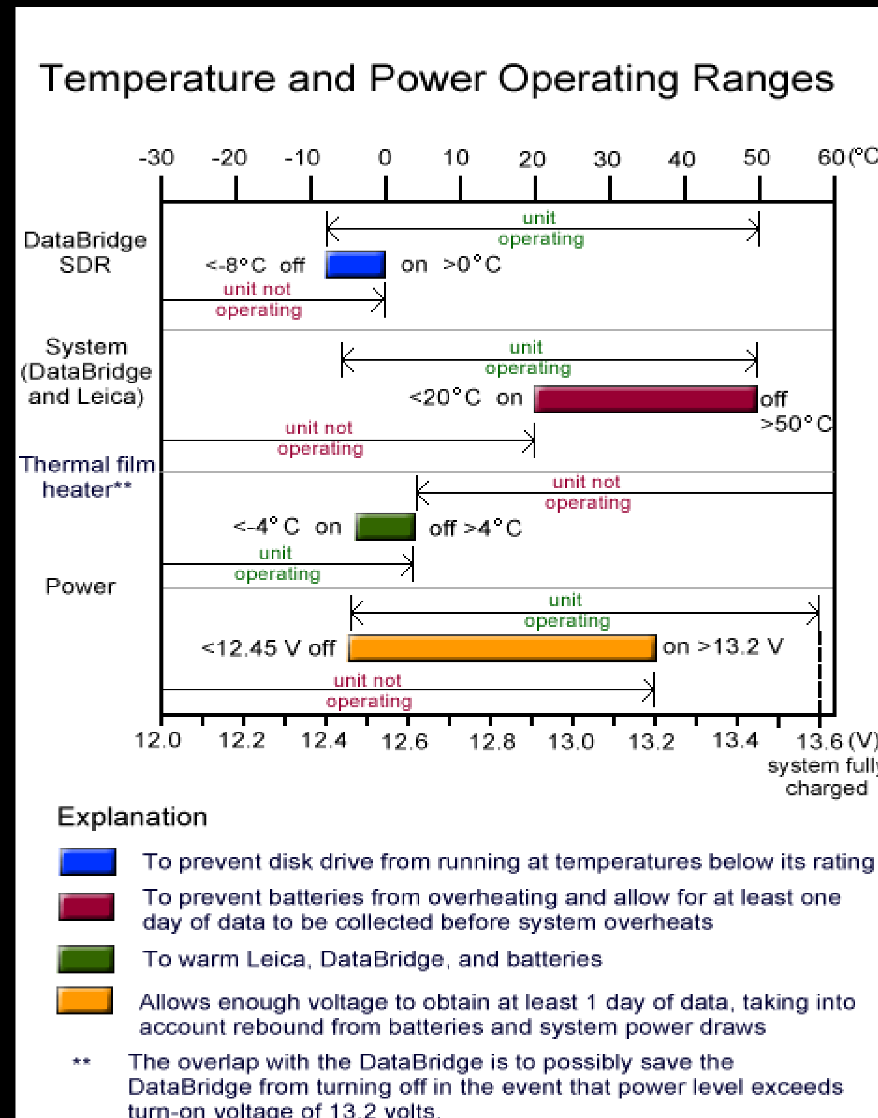
- Frame designs.
- System integration
- Hyper-Insulation
- Active heating

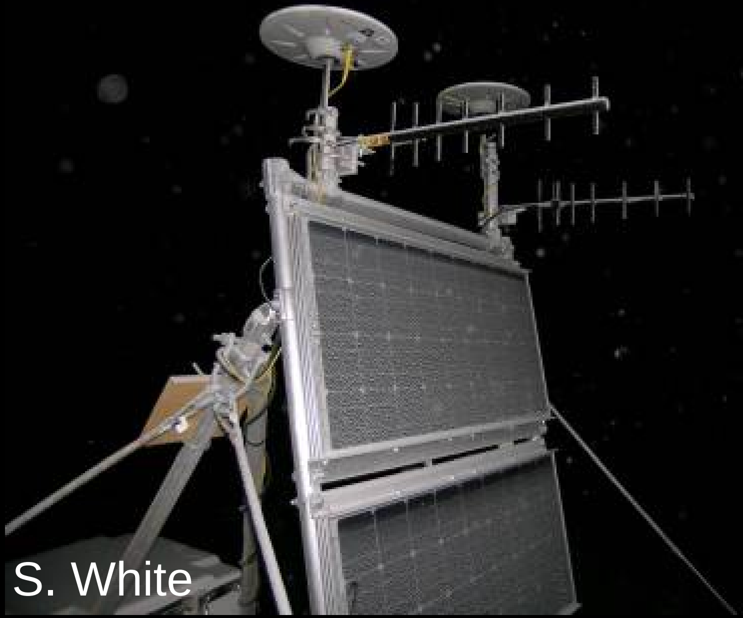
Power Generating

and

Data Communications





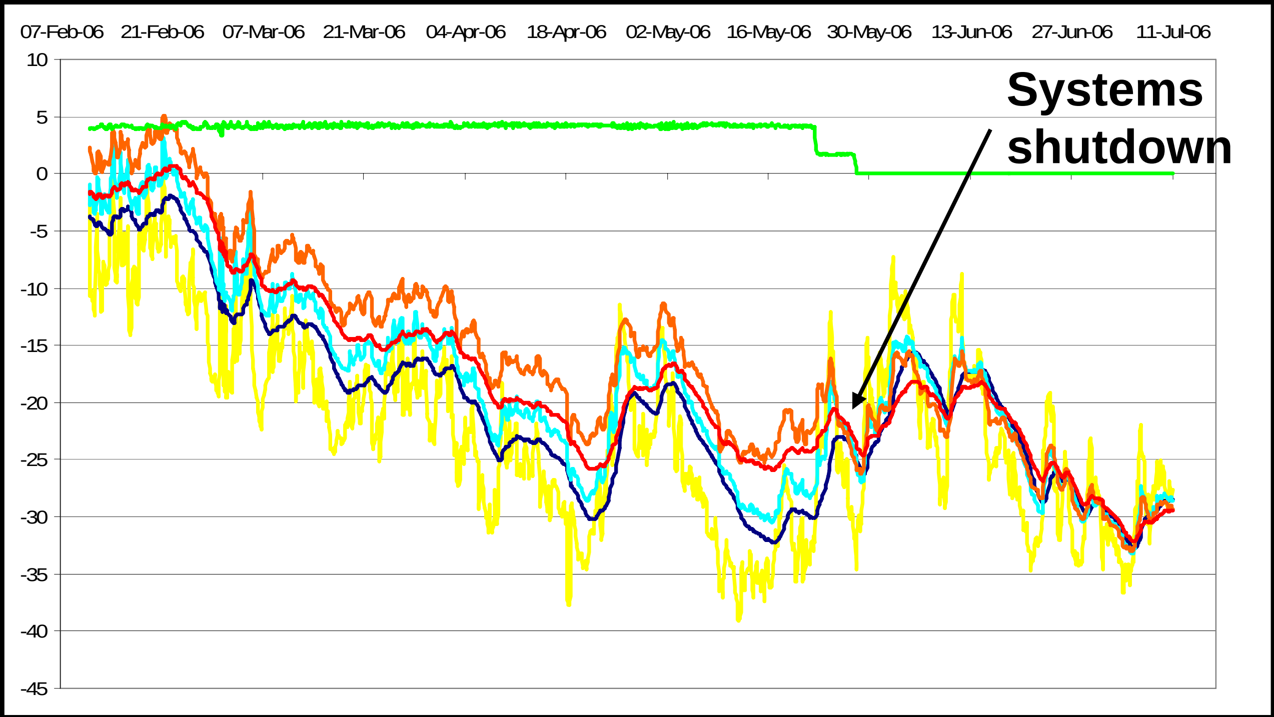


In-situ testing is *critical*.

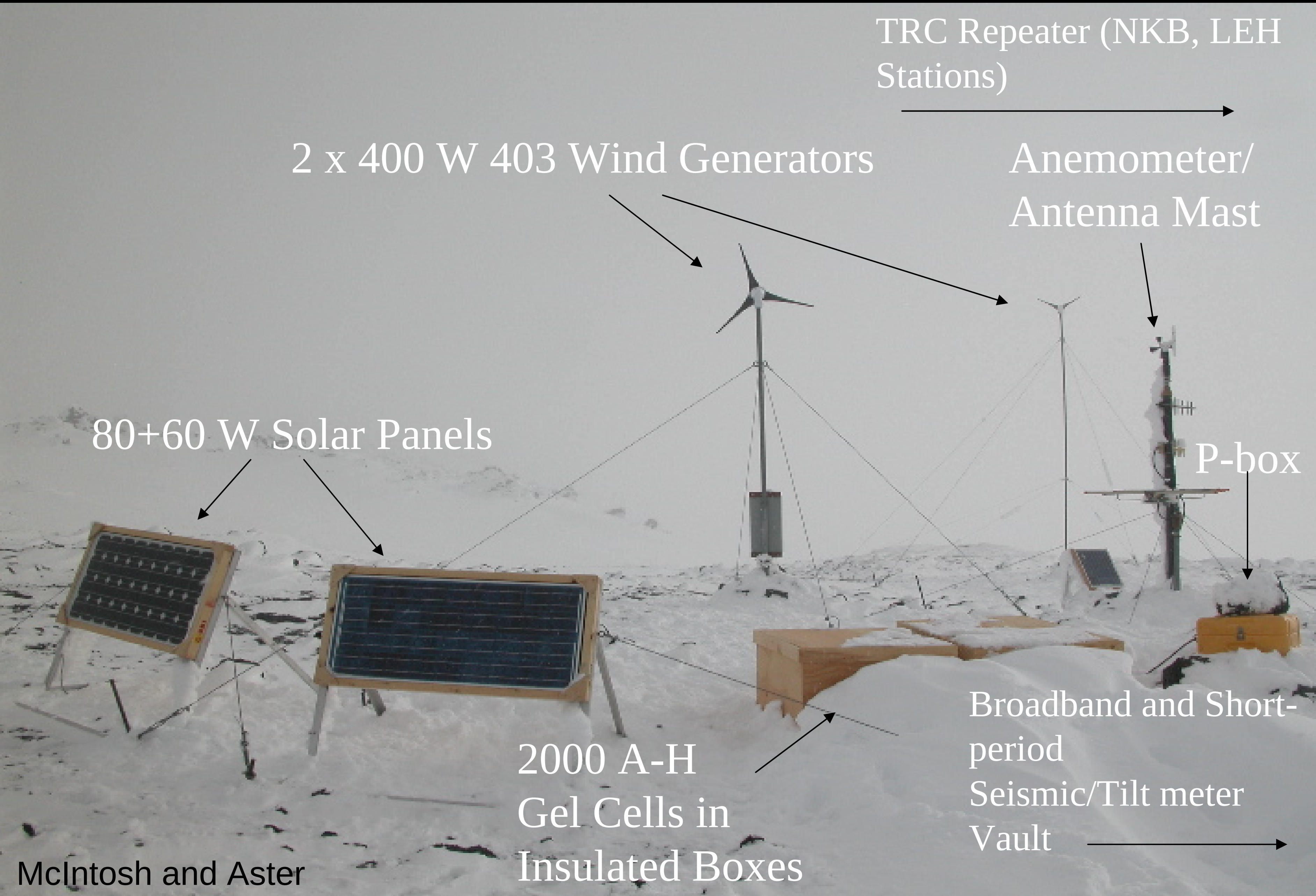
Testing underway:

- **Battery performance**
- **Insulation benefits**
- **Power draws**

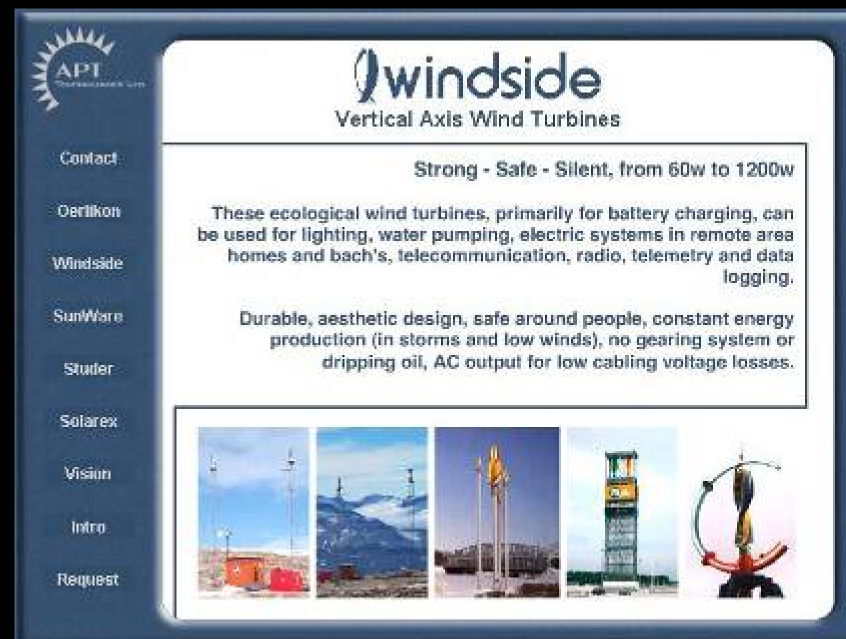
High-R value enclosures work well, *if system is running*.



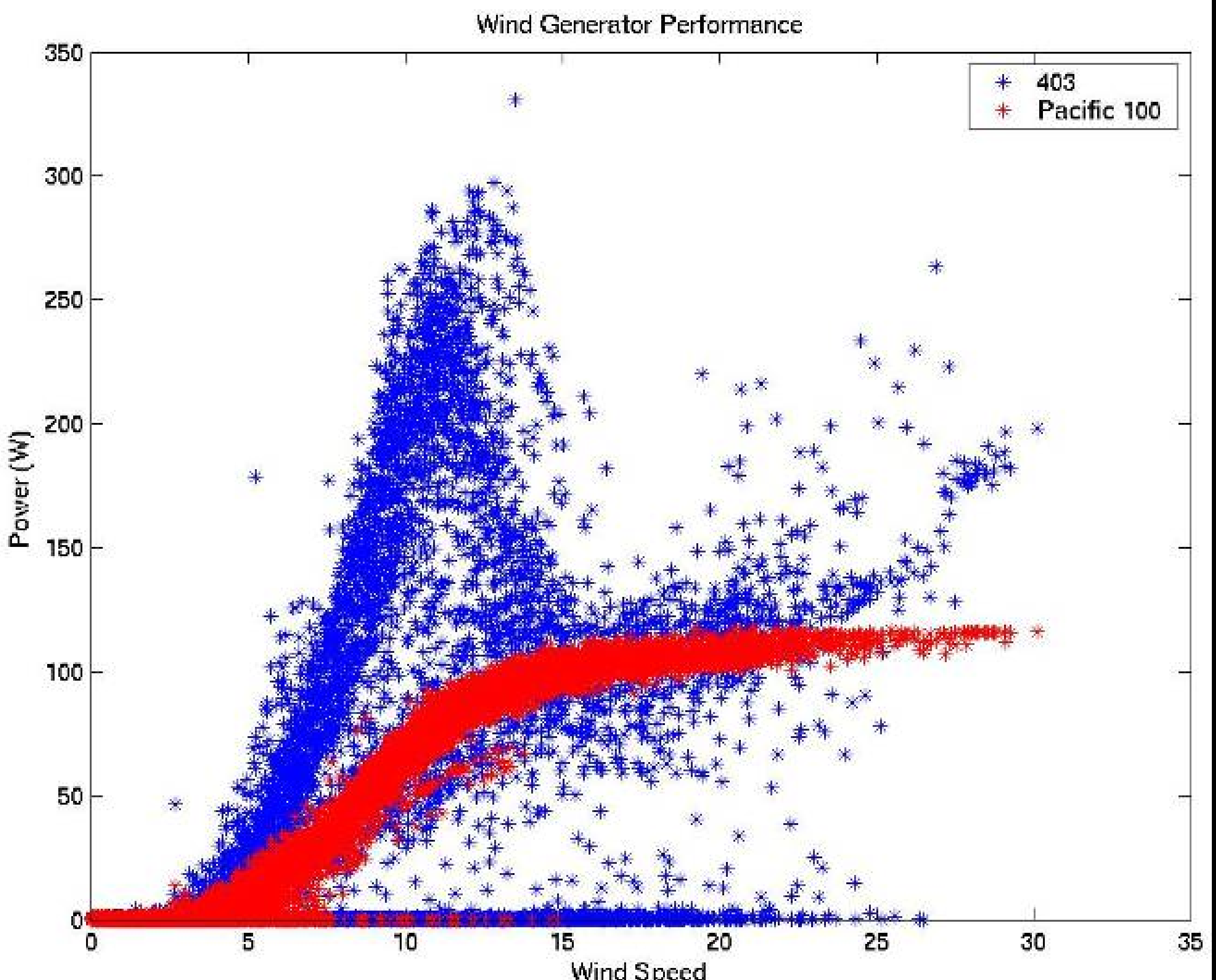
Wind Generator Test *in Situ* (Erebus, 3400 m)



Wind Power Generators



Tested wind generator performance under Antarctic conditions.



Aster-MEVO

Also tried Windside.

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

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:

System Characteristic	Lead Acid	Nickel-Cadmium	Nickel-Hydrogen	Silver-Zinc	Lithium-Ion
Cell Specific Energy (Wh/kg)	30	30	35	~100	130-140
Cell Energy Density (Wh/lit)	60	100	50	~150	250-300
Specific Energy (Wh/kg) at Battery	25	25	25	75	100
Energy Density (Wh/lit) at Battery	55	80	40	100	200
Cycle Life (30-40% DoD)	~ 1,500	30,000	30000-60000	<100	> 15,000
Wet life (Storageability)	~7 years	~10 years	> 10 years	2 years	5 years
Self-Discharge (per month)	5-10 %	15%	30%	15-20%	<5%
Low temperature Performance (-20°C)	Poor	Moderate	Moderate	Moderate	Excellent
Temperature Range, °C	-10- 30	-10- 30	-10- 30	-10- 30	-20 to +40
Charge Efficiency %	85%	80%	80%	70%	~100%

JPL

Li Rechargeable.

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

Pack Performance

Capacity = 6.6 Ah (at 23°C)
Watt-Hours = ~ 95 Wh
Specific Energy = ~ 145 Wh/Kg
Cycle Life = > 80% after 300 cyles
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

95 Wh Smart Battery Pack

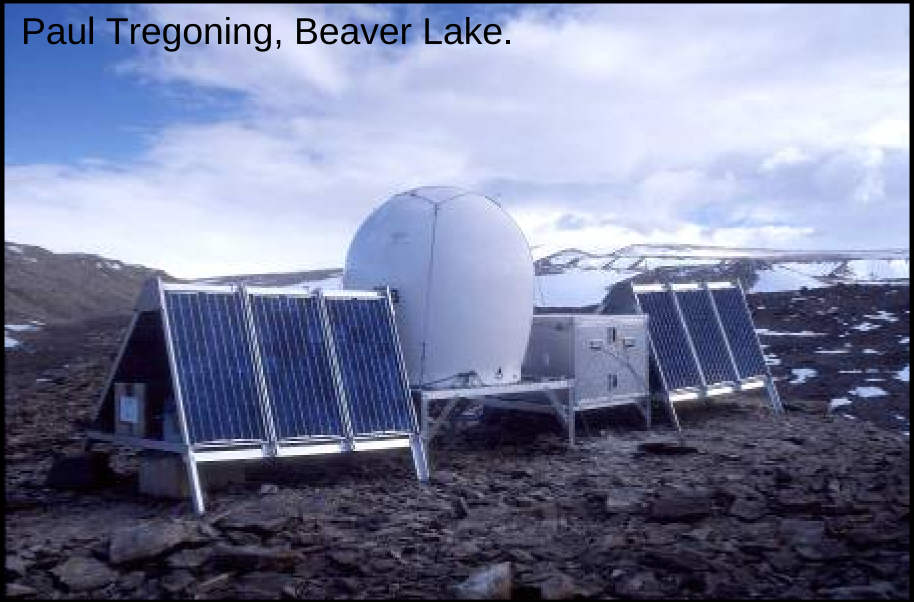
MP-08 Battery Management Module

JPL

Environmental hardening.

Frames must be:

- Quick to build.
- Light.
- Drift proof.
- Strong.



Paul Tregoning, Beaver Lake.

Reinhard Dietrich – Peter I Oye

Franklin Island

Niwot Ridge @ 3500m

Component Testing.

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


7.5W installation Mike Rose (BAS)


Tim Parker


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.**


Jackobshaven, Greenland


Fishtail Point.

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

GEODETIC 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

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

Technical Requirements – "low" power consumption is a critical design requirement, as well as state-of-the-art in data storage, communications, and system integration.

Operating Mode	Allowable power use	Data telemetry requirement	Data storage Requirement
GPS data collection	2.5W	1Mb/day average	27 months = 830Mb
Seismic data collection	2W	1Mb/day (SOH and events) 15Mb/day average (full data retrieval)	27 months =12Gb
Satellite data link (NAL Resesarch Iridium)	1W/Mb	>2Mb/day	na
Radio data link (FreeWave 900MHz)	0.5W/Mb	>16Mb/day	na
Housekeeping overhead	0.5-1W	na	na
Lowest power configuration (single sensor, no winter data comms)	2.5W year-round	1Mb/day average, store-and-forward	Up to 12Gb
Combined GPS and seismic (with low bandwidth link)	7W year-round	2Mb/day average, store-and-forward	830 Mb + 12 Gb
Highest power configuration (combined sensors, year-round large data volume comms)	10.5W year-round	2Mb/day year-round	830 Mb + 12 Gb

Thanks to : National Science Foundation
Raytheon Polar Services
PHI Helicopters
UNAVCO
US Coast Guard

OSU: the late Ian Whillans, Erik Venteris, Jan Wuite, Stephanie Konfal, Jerome Hall, Beth Demyanick, Dorota Brzezinska, Esteban Vazquez

USGS: Bob Glover, Brad Johnson, Jane Turner, Jerry Mullins, Mike Starbuck, Bill Smith.

LINZ: Graeme Blick, Merrin Pearse, Matt Amos, Tony Bevin, John Richie, Sarah Morris, Don Grant, Geoff Linnell, Jeremy Palmer.

PGC: Tom James, Stephane Mazzotti, John He

Geoscience Australia: John Manning, Gary Johnston, Jim Steed

Italy: Alessandro Capra, Francesco Mancini, Luca Vittuari, Stefano Gandolfi, Monia Negusini, Antonio Zanutta, Pieguido Sarti.

Other: Mike Bevis, Mark Schenewerk, Janet Thomson


Thank you