# GPS / SEISMIC REMOTE STATIONS MRI PROJECT
## Status in Year 3

Seth White and Bjorn Johns, UNAVCO

Tim Parker, Brian Bonnett, and Kent Anderson, PASSCAL

April 16, 2009

# Overview

- NSF Major Research Instrumentation (MRI) project
  - "Collaborative Research: Development of a Power and Communication System for Remote Autonomous GPS and Seismic Stations in Antarctica"
  - IRIS/PASSCAL seismic & UNAVCO GPS consortia
  - Unique challenges for GPS versus seismic, but much overlap
  - Broader goal: provide a polar power/comms platform for other disciplines + instruments.
  - Similar goals to ARRO MRI project but different in scale
    - Many more stations; each station less logistically intensive
    - Much lower power and smaller data rates
- GPS station design goals
  - Minimize power draw. Nominal 5W continuous load, modularity for 2.5-10W
  - 1 MB daily data retrieval
  - System weight < 1500 lbs, individual components < 100 lbs
  - Deployable by 3 person team, few hours ground time
  - Maximum two flights with 212 helicopter or Twin Otter (including recon)
  - 2 year service interval
- Two designs for two different operating regimes
  - Continental Margin: moderate cold, extreme winds (includes West Antarctic Ice Sheet)
  - Polar Plateau: extreme cold, moderate winds

# Polar GPS Performance Summary

- Antarctica
  - 29 Margin GPS sites: 24 geodetic (rock surface), 5 West Antarctic Ice Sheet
  - 3 Plateau sites
  - 1 Radio repeater
  - 1 AWS power supply
  - 1 Tide gauge comms system (with Land Information New Zealand)
  - 80% data retrieval (75% near-real time). 8% more still may be retrievable.
- Greenland
  - 29 Margin GPS sites (rock surface)
  - 77% data retrieval (74% near-real time). 17% more still may be retrievable.
- Polar technology website: www.unavco.org/polartechnology
  - System specifications and part drawings
  - Test reports, state of health information for remote sites
- Power/communications systems are available from UNAVCO to support Arctic and Antarctic research projects

# Polar GPS Performance Summary

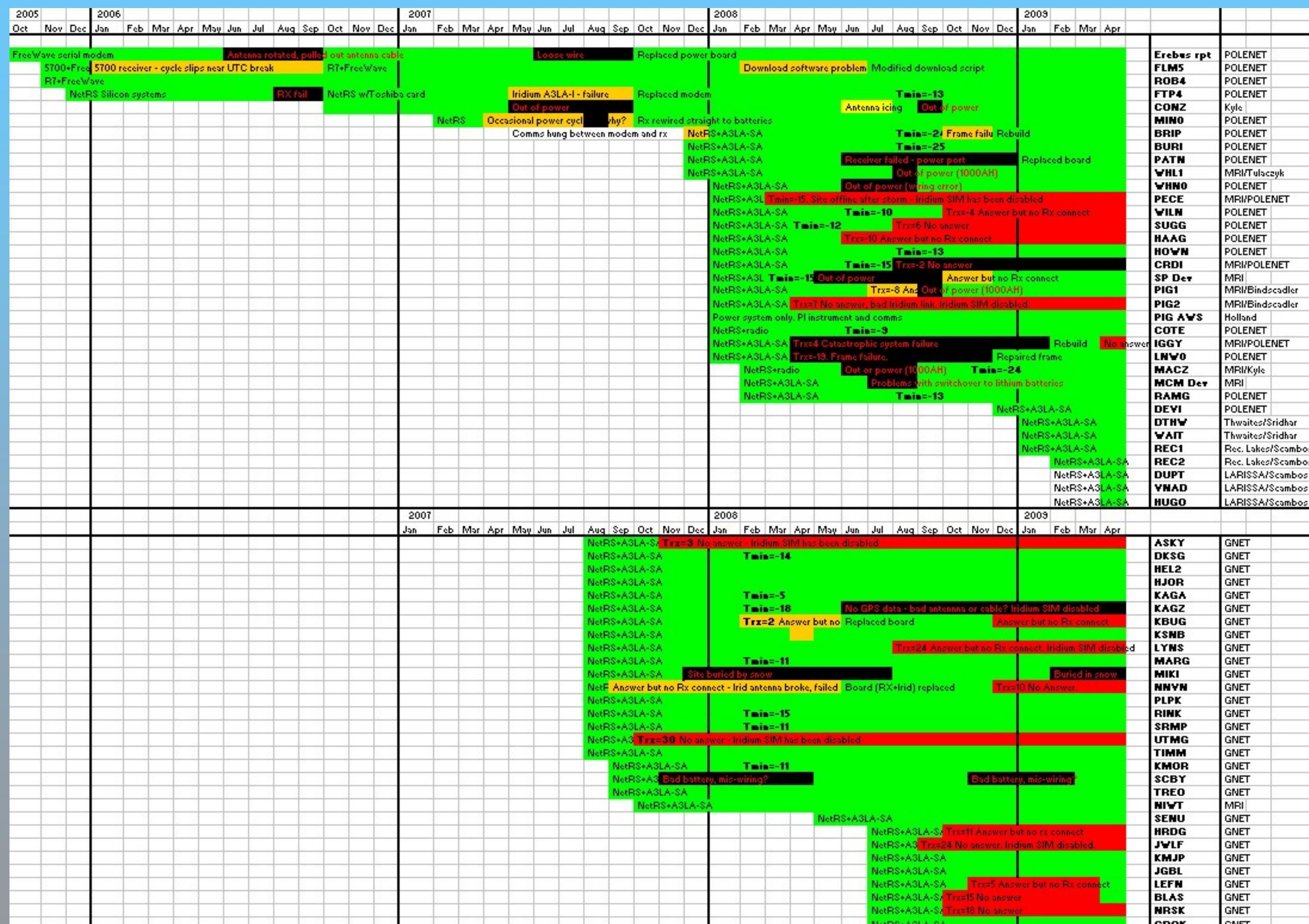
**MRI, POLENET, and PI projects**

GREEN:
Realtime
Data Retrieval

YELLOW:
Delayed
Data Retrieval

BLACK:
No data

RED:
Uncertain
(no comms)






UNAVCO

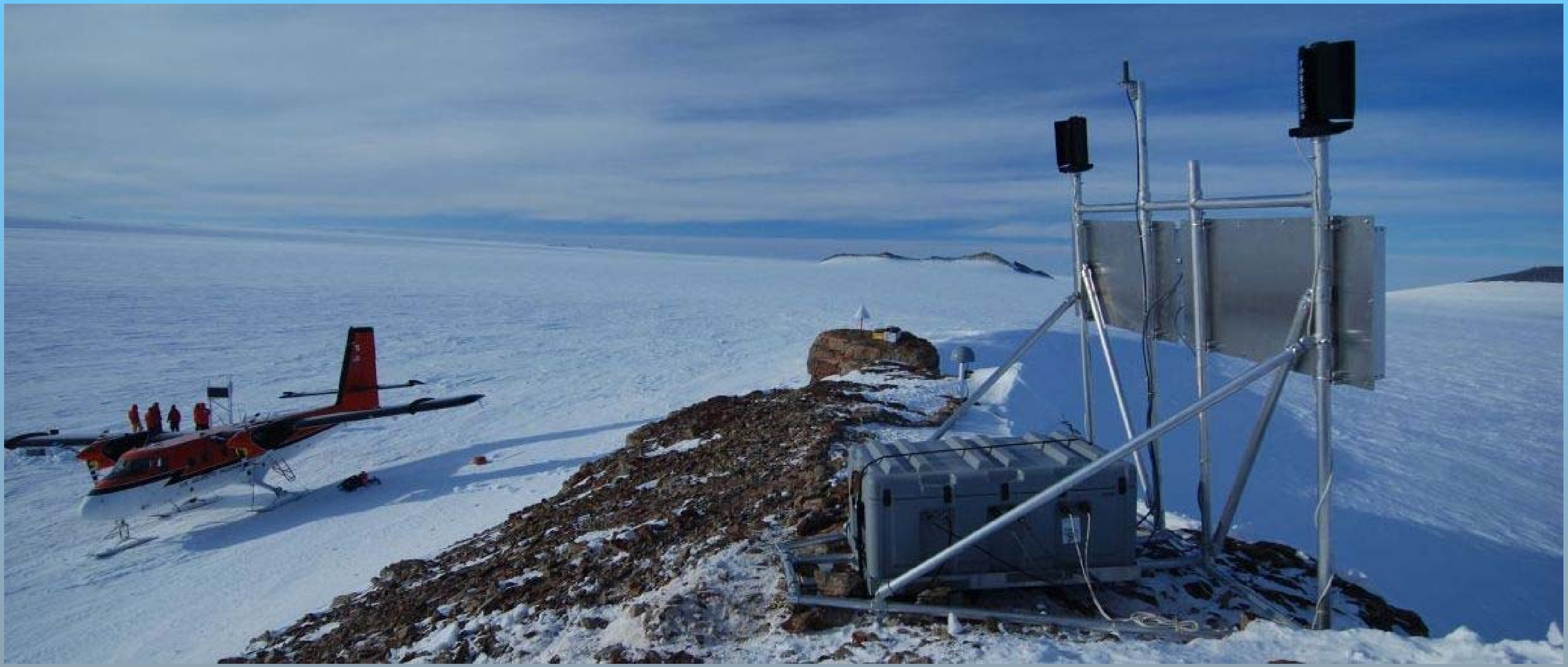
# Margin GPS System: Design

- Power
  - First GPS/Iridium site was 6.25W, now ~4.1W.
  - Low power GPS receiver, regulators, timer switch. Modems cycled on/off to save power.
  - Modularity: one frame holds 1-4 solar panels, 6-24 batteries, 0-2 turbines, 1 comms, 1 met
  - New smaller frame 2009: 1-2 solar panels, 6-10 batteries, 0-2 turbines, 1 comms, 1 met
- Communications
  - Iridium: 70 sites including deep field locations and test stations
    - Modular, scalable Iridium download system: 1 base modem downloads 10 remotes
    - 1 MB is ~2 hrs connect/day, but remote modem ON 12 hours/day (bad comms link or data catchup)
  - Point-to-point radio: 6 sites near research stations
    - Intuicom ethernet and FreeWave serial modems: very reliable in cold
    - Repeater with 120º sector antenna delivers reliable 100 mile link
- Structure
  - Strong frame: 56 frames deployed. 2 failures found; design flaw has been fixed
  - Reinforced solar panels: ~200 deployed, 1 failure found
  - Cables flexible at low temperature. Large, unique connectors.
  - Quick and strong anchoring system. No failures seen.

# Margin GPS System: Design

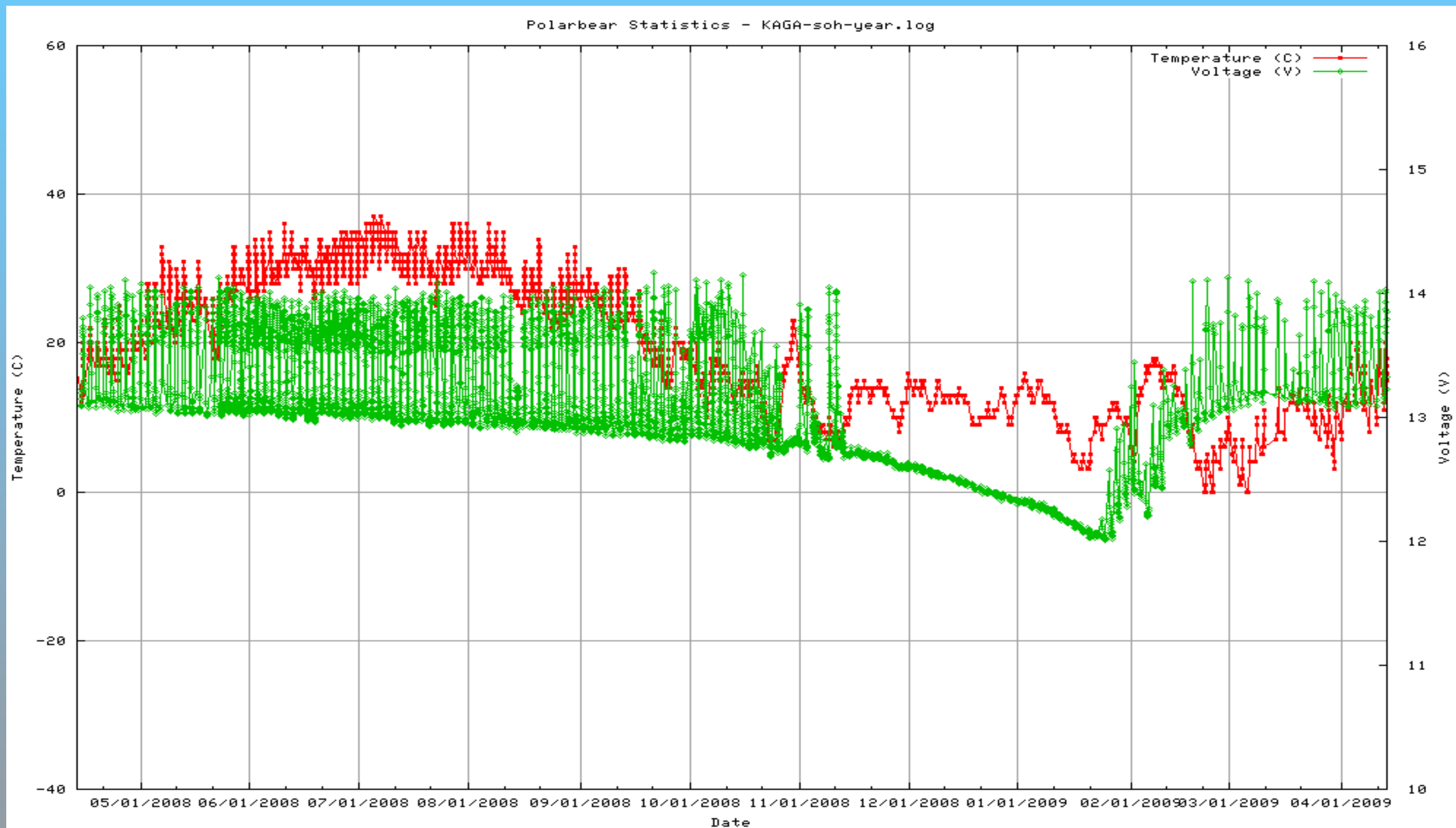
- Install with three people, 1 or 2 flights, 5 hours ground time
  - Optimized design, tools, and installation procedure. ~1300 lbs system weight.
  - Many small increases in efficiency = large time savings. First MRI site = 12 hours, now 5.
  - Thorough field personnel training whenever possible. Manuals and checklists.
- Solar + SLA battery power system
  - Baseline design: 160W solar + 1000 AH battery
  - Year-round operation demonstrated at 69° N, possibly to low 70's
  - Batteries and electronics OK with light insulation at Margin sites (not Plateau)
- Wind power demonstrated
  - Small, vertical axis turbine is optimal for high-wind, low-power polar systems
  - Two small turbines significantly extends range of baseline system
    - Year-round operation demonstrated at 79° S
    - Operation at 85° S with <1 month outage
  - Forgen 500: best available low-power turbine for extreme winds. Mounts directly on frame.
    - Windside has better survivability but very expensive and heavy (separate mast)
    - Primary drawback with Forgen 500 is overall strength.
    - Plan to investigate improvements in design, possibly with manufacturer

# Margin GPS System



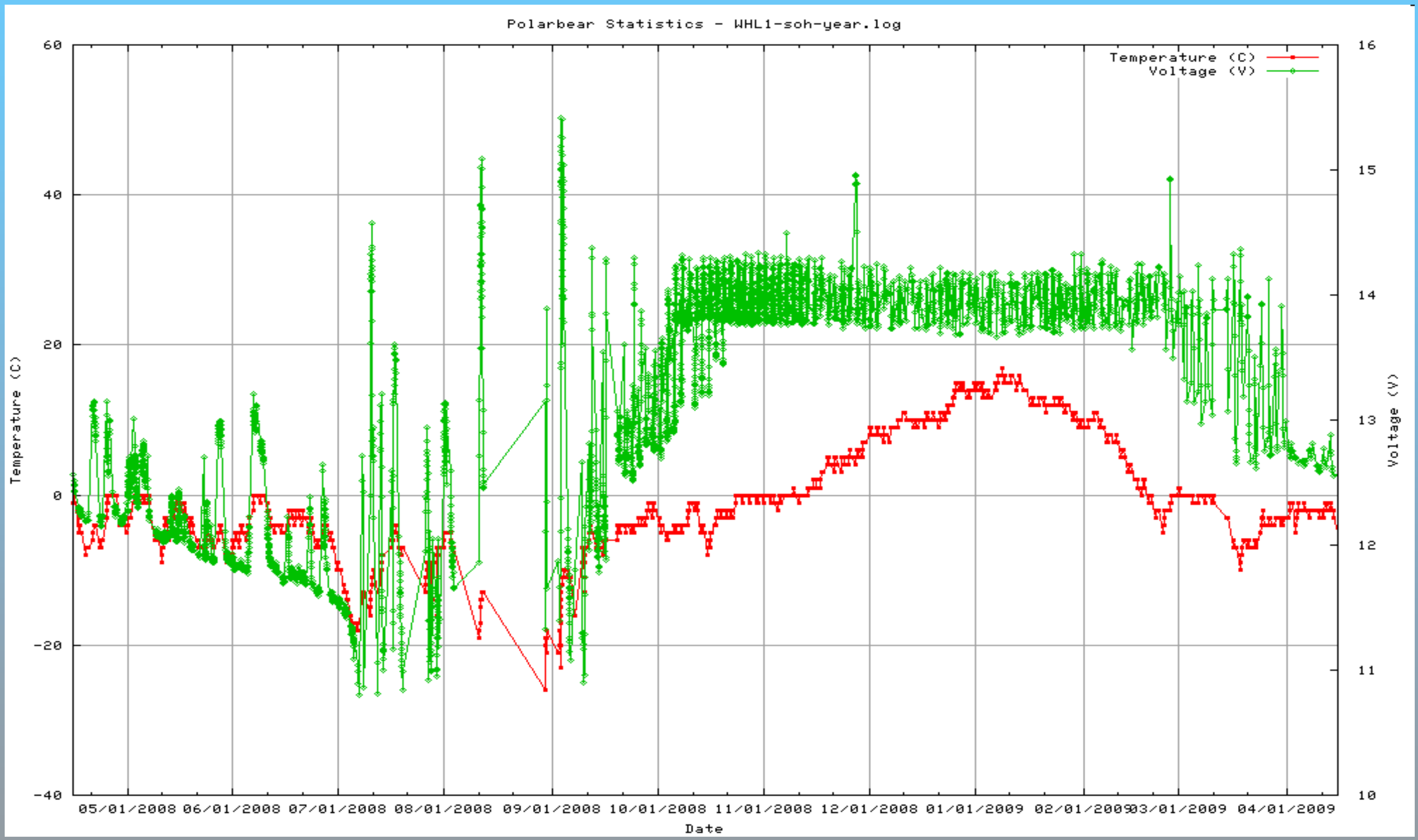
Continental Margin GPS System

# Margin GPS System: Performance




Year-round operation with 1000 AH batteries and 160W solar: Jakobshavn 69° N
Green = SLA battery voltage, Red=instrument temp (~25C above ambient)

# Margin GPS System: Performance




Near year-round operation with 1000 AH batteries, 160W solar, two Forgen 500:
Whillans Ice Stream 85° S

# Margin GPS System: Improvements

- Wind power management
  - 2006-07: wind power unregulated for simplicity
    - Relied upon low power output of Forgen 500 and large battery bank to limit overcharging
    - Initial results OK. No battery damage at Minna Bluff after 2 years.
    - Unlikely that Greenland sites and *most* other and Antarctic sites are overcharged.
  - Summer 2008: Decided to regulate wind based on cold chamber testing and other field data
  - 2008-09 field season: Cracked batteries seen at Butcher Ridge, explosion at Iggy Ridge
    - Much more severe wind conditions than our “extreme” Minna Bluff prototype site
    - Battery offgassing and ignition source = bad news at Iggy Ridge. Site rebuilt early 2009.
  - Flexcharge NC25A12 wind regulator adopted.
    - Used in parallel with Flexcharge NC30L12 regulator
    - Solar+wind charging works seamlessly. Battery voltage stays within normal range.
    - Dump excess power to heating pads: STEP Warmfloor VEP-23-2-22W
- Structural frame
  - Cast-aluminum hinge fittings = design flaw. Redesigned with cast-iron fittings
    - 30 lbs extra weight
    - Much higher fatigue strength
    - Full stress analysis performed

# Margin GPS System: Improvements

- Iridium antenna

  - SAF5350-C
    - Good performance, tested to -70C.
    - Occasionally fragile: one broken in field, three in handling.
  - SAF2020-B

    - stronger than SAF5350-C, performed well in initial testing.
    - Antenna base is grounded to frame. Magnifies static/grounding problems
    - Believe this antenna more subject to icing problems (<u>Preliminary</u> lab tests support this)
    - 5 of 8 sites in NE Greenland with SAF2040-B experienced severe comms problems

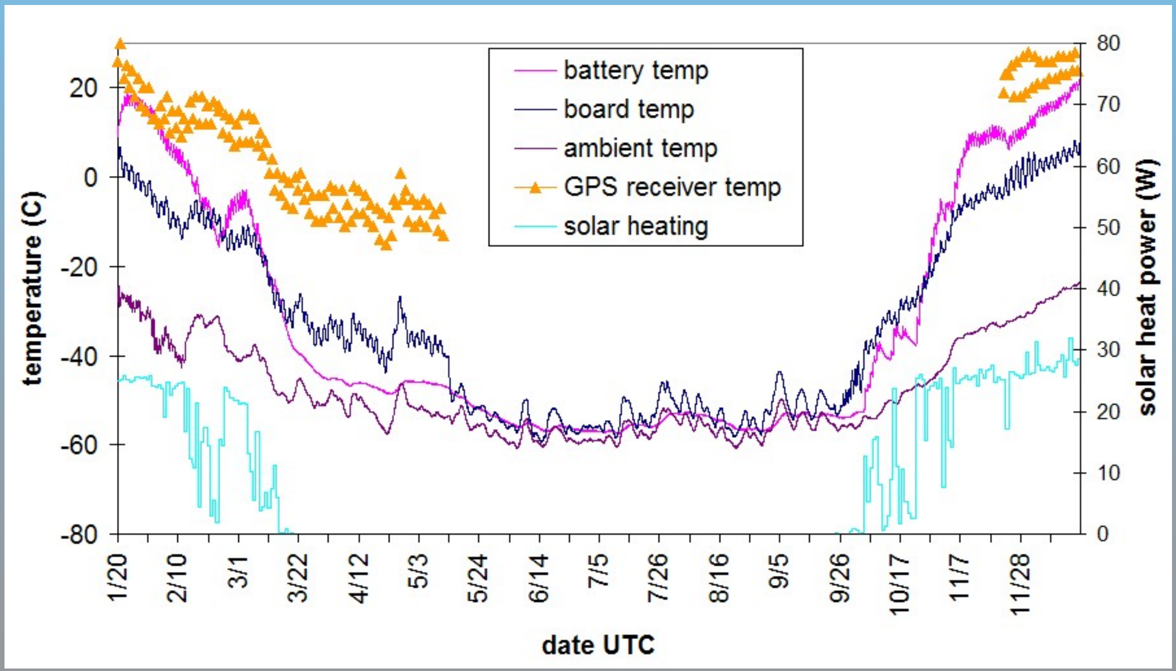
  - SAF5350-A: Currently used by UNAVCO polar.
    - Quad-helix design like SAF5350-C but stronger mechanical design
    - Tested to -70C. <u>Preliminary</u> tests show better performance under icing.
    - Deployed at 4 Antarctic sites, 10 Greenland sites 2009.
  - Eurocom (Sailor) antenna
    - Recommended by RPSC for icing/marine conditions. Not yet tested .
- Microcontroller development
  - Will allow integration of different GPS receivers and other instruments
  - Better system control and more comms options

# Margin GPS System: Improvements

- Comms failures: Ethernet thru Iridium-GPS serial link, via PPP protocol
  - Several serial port failures on Iridium modem and GPS receiver observed
  - GPS receiver bug: requires GPS reboot (not trivial to reboot cleanly)
  - Iridium power cycling: have seen irregular timer switch cycles
- Most likely cause is static and grounding problems
  - Serial configurations and individual pins have been thoroughly examined; believe all OK
  - Significant ground problem was found involving serial line.
    - NAL SYN-DC-936 is a switching power supply. Modem + RF shield not grounded to common.
    - Only path for wind-induced charge buildup is serial ground wire = very likely problem
    - Modem and antenna now grounded, passive serial port surge protectors now used
    - Forcing selected serial pins high may also help
  - Working on robust reboot capability for GPS receiver
- Weather station: Vaisala WXT520
  - Inexpensive, easy to mount and integrate with GPS data
  - Physically fragile under high winds, serial link requires occasional reset, wind sensor does not work below -45C. Disable heater to save power, but allows icing.

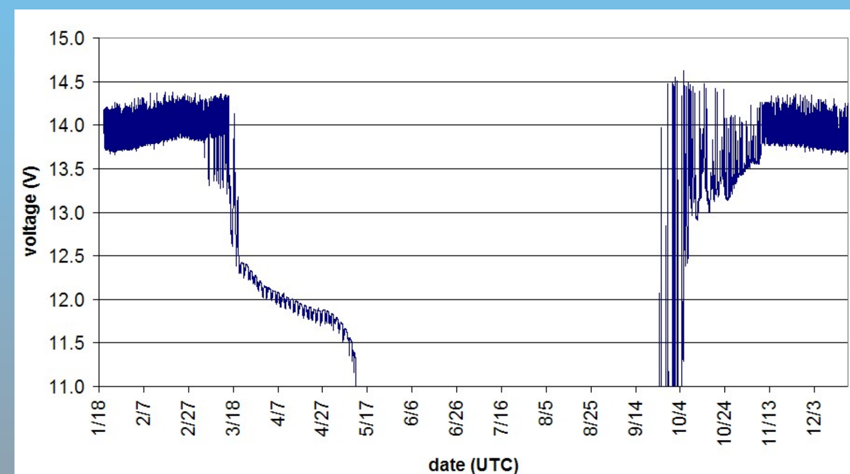
# Plateau GPS System: Version 1

- Installed January 2008
- 3 solar panels + 900 AH SLA batteries + 2 Forgen 1000 wind turbines
- Vacuum-panel insulation, Iridium comms
- 12 channels engineering data recorded: voltage, temperature, current
- System lost power in May, restarted in October
  - Forgen 1000: too little power, bearings not OK for plateau cold
  - Electronics not damaged by cold soak



# Plateau GPS System: Version 1

- Solar heating = improved battery capacity during dark months
  - Batteries fully charged above -20C, discharged at -40C to -50C @ 0.05 amps per battery
  - Overall yield: 47% of room temp capacity (but would still need ~40 batteries at south pole)
- Solar heating = faster recharging and system startup when sun returns
  - System first powered 8 days after sun-up
  - System ON 24/7 14 days after sun-up
- Quick and secure anchoring system
- Omnidirectional tripod solar panel frame
  - Minimal performance decrease on plateau
  - Ensures 2 of 3 panels free of snow





Battery voltage winter 2008

Static snow buildup on leeward panel

# Plateau GPS System: Version 2

- Improved vacuum-panel insulation: ~40% better than Version 1
  - Double layer of 1” panels where possible. Panels from Nanopore.
  - Tighter fit. Edge effects can reduce enclosure’s overall thermal efficiency by ~50%
  - Vacuum panels are very fragile and assembly is extremely labor-intensive. Panels can also fail over time, or during transport.
  - We may prototype a very thick-walled foam box. Same insulation but cheaper, easier, and tougher. Larger volume but still deployable via traverse or Twin Otter.
- Electronics now inside vacuum-panel enclosure with batteries to conserve heat
- New wind turbine
  - Aerogen 4 non-furling
  - Manufactured with custom bearings: C3 clearance and LG68 lubricant
    - Identical bearing specs to turbines used with success on plateau by AGO group with AWP
    - Blade and yaw start torque cold-chamber tested to -70C
  - Aerogen turbine won out in lab tests vs. Ampair 100 and Rutland 910-3
    - Two Plateau sites (Recovery Lakes) have Aerogen 4
    - South Pole runs with Aerogen 4. Also testing modified Ampair 100 (improved yaw bearing)

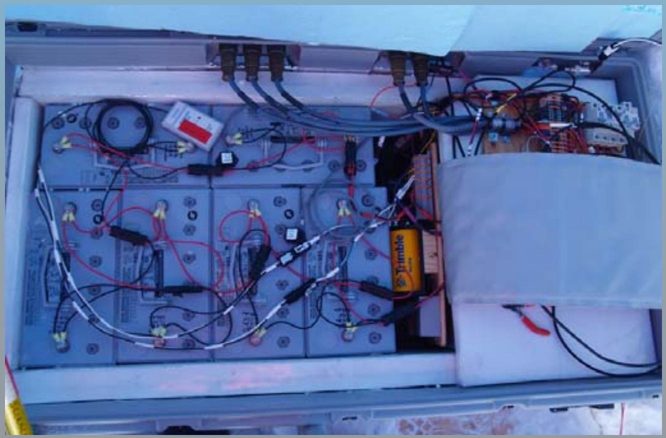
# Plateau GPS System: Version 2

- Power management
  - Solar and wind regulators, identical to Margin design.
  - Two solar panels charge batteries, third panel heats batteries
  - Excess power from wind turbine heats batteries
  - Currently passive thermal regulation, may use thermostats in future
  - STEP Warmfloor VEP-23-2-22W heating pads
    - Self-regulating electro-plastic, resistance increases with temperature
    - Large surface area = no hot spots
    - Deployed at 7 Antarctic GPS sites and many PASSCAL seismic sites
- Lithium-ion battery backup (Tadiran TLP93101/E/L)
  - 12 lbs = 190 amp-hours at room temperature
  - PASSCAL tests: 55% capacity at -50C. Designed for seismic but will run GPS receiver.
  - If SLA batteries run out, GPS switches to lithium batteries and comms turn off
  - Severe bug ID'd with GPS receiver in 2008 McMurdo lithium battery tests
    - Need LVD when using two separate battery banks with GPS receiver
    - Modified design now deployed at 3 Antarctic GPS sites

# Plateau GPS System: Version 2

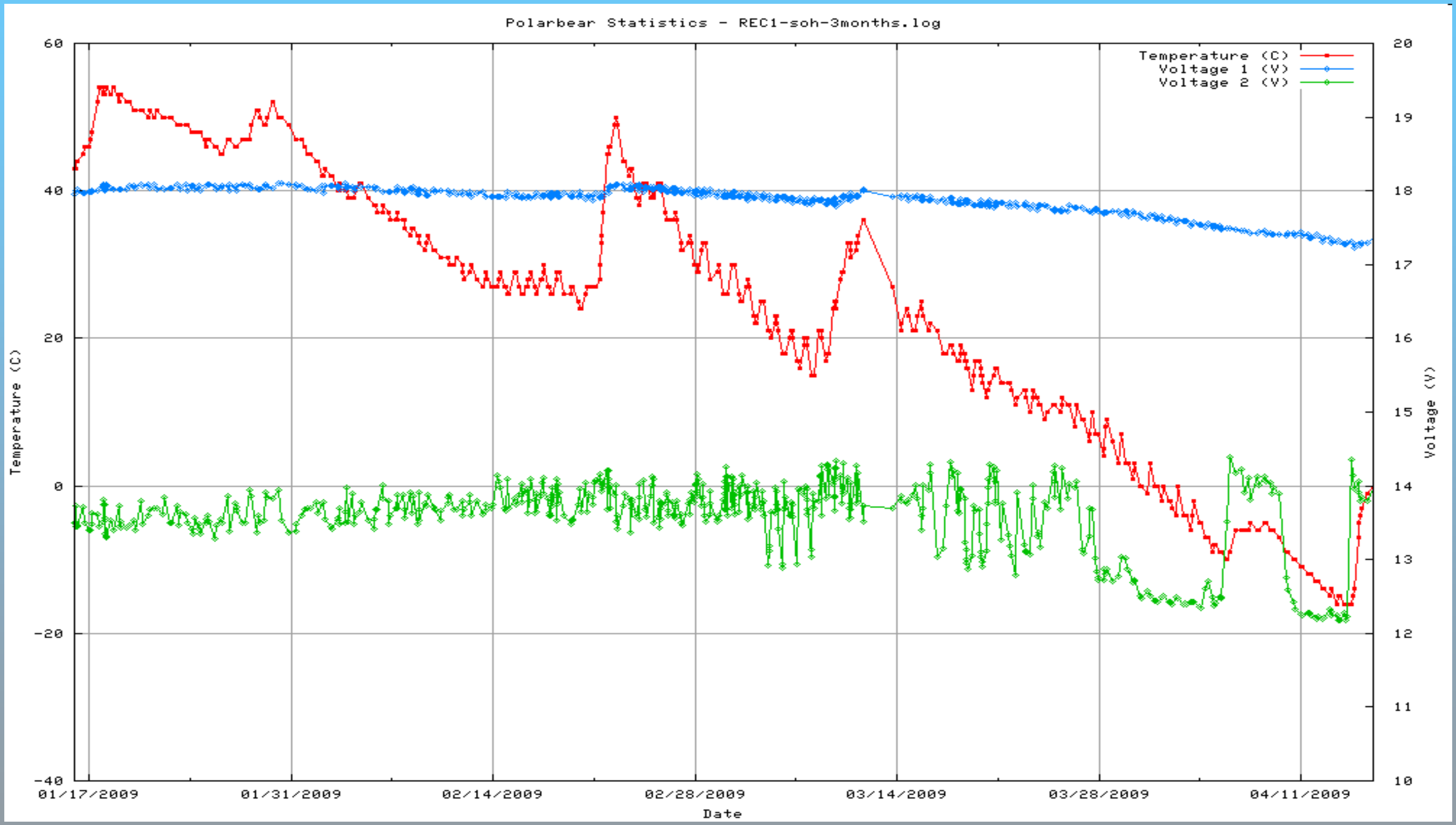

Aerogen 4 turbine

Plateau GPS system at South Pole



Electronics + batteries in vacuum enclosure

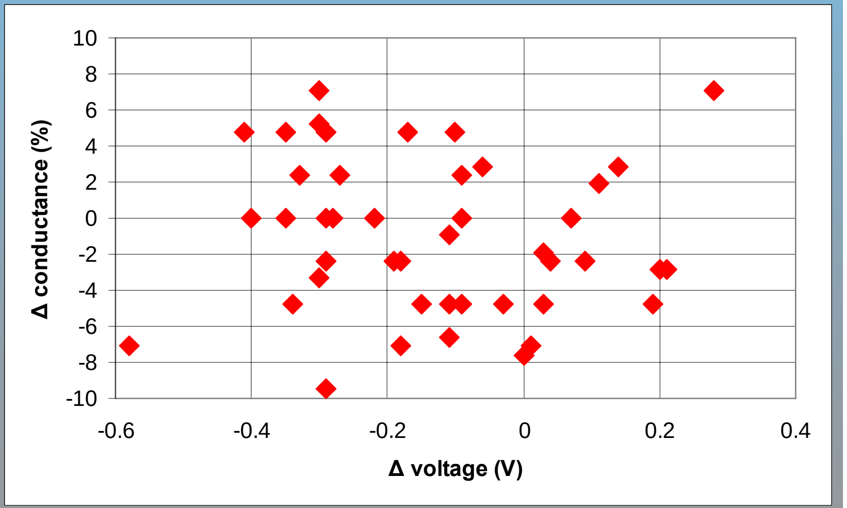
# Plateau GPS System: Version 2




Recovery Lakes (REC2) housekeeping data 2009
red = instrument temp, green = SLA battery voltage, blue = lithium battery voltage

# Lead-Acid Batteries

- Backbone of polar instrumentation systems.
  - No quantitative difference seen between Gel and AGM for low-power polar use
  - UNAVCO uses Deka 8G31-ST 100 amp-hour gel cell
- "Warm" charging at end of summer, cold discharge in winter at low current per cell
  - ~70% capacity observed at continental margin sites
  - ~50% capacity observed on Plateau
- Two batteries retrieved from field site
  - Minna Bluff GPS, 79º S
  - 2-year operation, solar+wind charging
  - Discharge test OK: 99 and 101 amp-hours (!)
- Batteries should be stored cold, fully charged
  - 44 batteries stored over winter at 84º S, charged and tested before and after
  - Very low self-discharge (volts)
  - Negligible drop in conductance (mhos)
- Midtronics conductance testers




Change in battery health after cold-soak at 84º S

# Future Work

- Establishing cold-testing and long duration burn-in standards
  - Essential to weed out "infant mortality" and sub-par components
  - Proper qualification testing not always possible with funding and procurement cycles
    => higher risk of failure must be accepted in this case
- Iridium comms issues
  - Hopeful that better grounding and static mitigation is the answer, but time will tell.
  - Modem-to-modem comms not optimal. RUDICS preferable, now beginning a development effort.
- Plateau system improvements
  - Enclosure fabrication: very thick-wall foam might be preferable to vacuum panels
  - Other modifications possible, based on performance in 2009
- System smarts
  - Microcontroller: allow different GPS receivers and instruments, comms options, and system control
  - Independent watchdog to reset system: essential for any remote instrumentation
- Margin turbine improvements
  - Forgen 500 has proven that the small, vertical axis design is ideal for polar systems at windy sites
  - The uber- high wind turbine is well within reach
- Plateau turbine improvements:
  - So far so good for very cold, low-wind sites. But will problems be found in coming months?