We present here an update of the technology and methodology that allows the year-round-operational PASSCAL-monitored stations of the GLISN (GreenLand Ice Sheet monitoring Network) providing realtime, or higher-latency data. Improvements in station design with an emphasis on telemetry (using satellites for state-of-health snapshots, high-latency realtime, and full realtime) will be discussed along with the trade-offs to be made and the quality and robustness of the recorded data.

Running realtime, year-round seismic stations across the Greenland Ice Sheet

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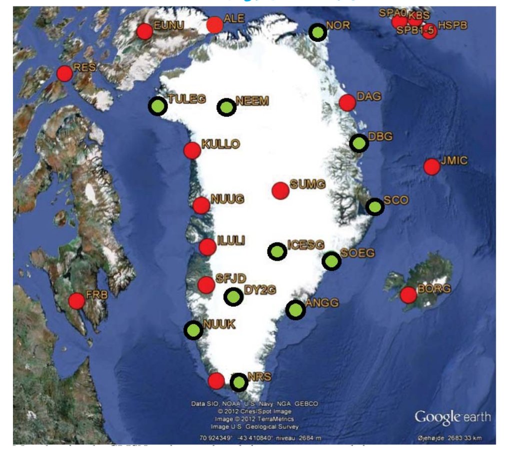
IRIS PASSCAL Instrument Center

Photo of DY2G (Japanese-US cooperative station) taken by Genti Toyokuni

WHAT IS GLISN?



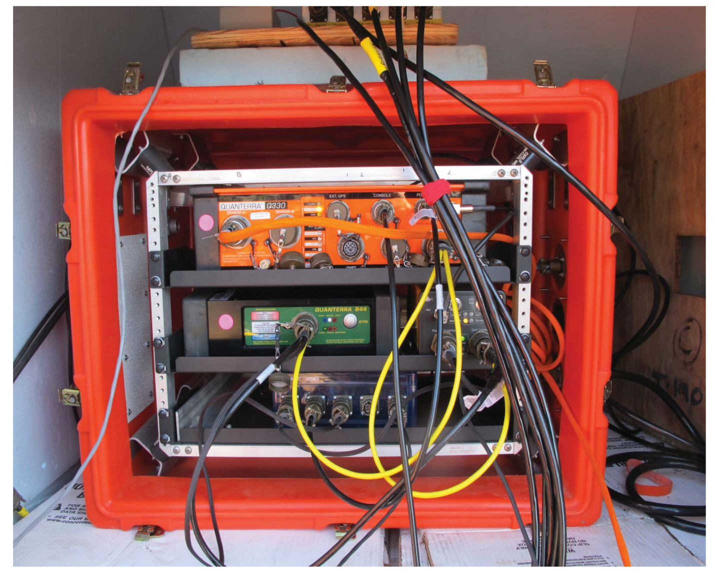
GLISN currently has 32 seismic and 3 GPS stations across Greenland and in the surrounding Arctic region. Most of the stations provide realtime data by taking advantage of existing coastal town infrastructure i.e. shelter, power, and Internet services. PASSCAL contributed to 12 stations, of which 5 are autonomously powered and 6 of them are using the Iridium satellite constellation for station-operational communications and data transfer.

	autonomous power	communications type	sensors installed	install surface
ANGG	N	Internet	surface seismic	bedrock
NRS	N	Internet	surface seismic	bedrock
NUUK	N	Internet	surface seismic	bedrock
SCO	N	Internet	surface seismic	bedrock
TULEG	N	Internet	surface seismic	alluvium
DBG	Y	Phase 2	surface seismic	bedrock
DY2G	Y	Phase 1	GPS, surface & borehole seismic	snow
ICESG	Y	Phase 2	surface & borehole seismic	snow
NEEM	Y	Phase 1	GPS, surface & borehole seismic	snow
NOR	N	Phase 2	surface seismic	alluvium
SOEG	Y	Phase 2	surface seismic	bedrock

WHAT HAS PASSCAL BEEN UP TO?

POLAR STATION DESIGN

Station designs pioneered at PASSCAL in the Polar program have improved the durability and endurance of polar seismic stations.



Instrument Box Layout at East Greenland coastal station SOEG
Top level: Q330 Digitizer (Quanterra)
Middle left: B44 datalogger (Quanterra)
Middle right: XI-100B Iridium Modem (Xeos Technologies)

Photo of coastal station DBG (Danish-US cooperative station) taken in late July 30, 2012

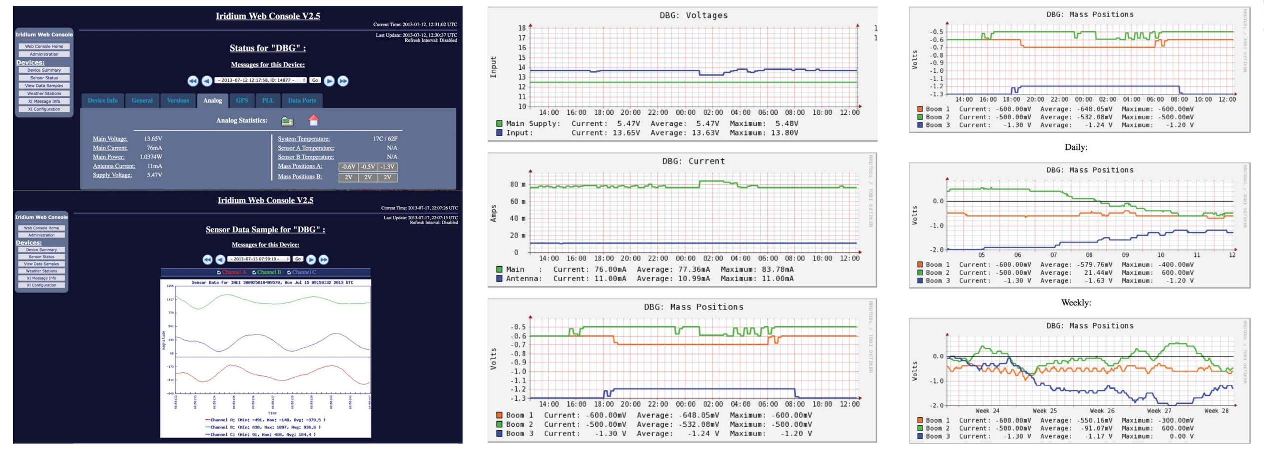
Key design targets are:
- Toughness
- Minimization of station weight
- Minimization of power consumption
- Simplification of install
- Maximization of data recovery and quality

Current projects include:
- External fabrication of fully sealed and insulated instrument boxes that will be more durable and cost less
- Refinements of very low-power internal electronics able to withstand temps to -50°C
- Utilizing new battery technology to minimize battery bank weights while increasing capacity
- Matching solar arrays and charging systems to handle the new technologies
- Improving modularity in design and simplification of installation to reduce confusion when ground time is minimal and environmental conditions are harsh
- Optimization of telemetry uptime for maximum benefit and minimum power consumption
- In-house testing to quantitatively characterize the capabilities and limitations of current and future hardware and designs

STATION TELEMETRY USING IRIDIUM MODEMS

OLD MODEL

In the past 10 years most seismic station telemetry from cold and very remote sites has been utilized only to transmit limited State Of Health (SOH) packages and to allow limited remote command-and-control of the instrumentation. With exception to sites near bases or towns with internet, continuous data transmission was not possible. Data were re-covered by making an on-site visit every 1-2 years.



a) b) c)

Shown above are examples of SOH information delivered via Iridium Short Burst Data (SBD) every 15 mins and then displayed online. (a) Analog tab showing voltage, current, mass posi-tions, etc. above a decimated 10 sec data sample (b) Sample SOH plots for 24 hours (c) Mass positions on day, week, and month time-scales

Check out the PASSCAL Xeos website at: http://xeos.passcal.nmt.edu/

NEW AND IMPROVED: RUDICS

MOVING DATA WITH RUDICS

RUDICS (Router-Based Unrestricted Digital Internet-working Connectivity Solutions) is a new type of Iridium satellite telemetry utilizing the existing pool of XEOS XI-100B modems was introduced to GLISN in the summer of 2012.

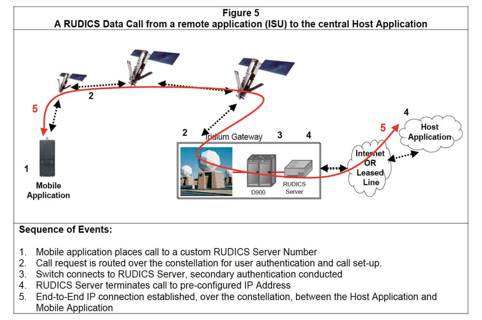


Figure from (Iridium Satellite Data Services White Paper Ver 1.0) © Iridium Communications Inc.

XI-100B Iridium modem (right) manufactured by Xeos Technologies Inc.

- Optimized for polar operation – very low standby current (450uA), integrated heater allows for transmission of data down to -55°C.
- Can interface with datalogger via Ethernet or RS-232
- Current firmware provides power and transmission of data for the Vaisala WX520 weather station
- Hardware can be adapted to other instrumentation packages via modifications to the firmware

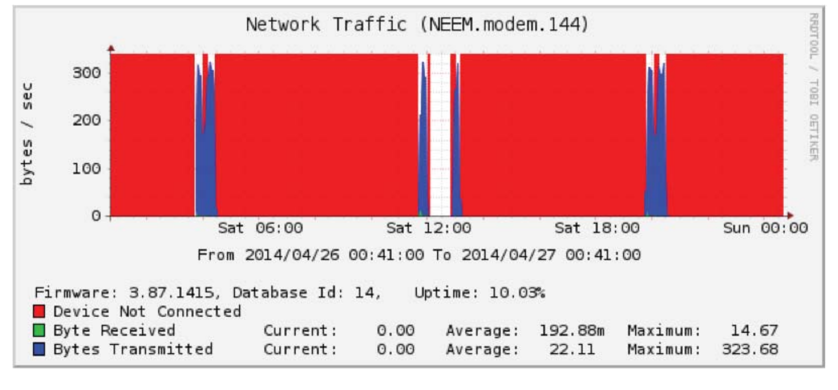
PHASE 1:
Pulling data stored on station-side media

- Established at 6 seismic and 3 GPS stations in 2012
- Automated collection (3 sessions/day) of all continuous SOH and 1 sps seismic waveform data using standard Internet transmission protocols
- Combined XI-100B modem transmission time of 1-3 hrs per day

Advantages:
- Modem can be shutoff during the dark winter months and data from winter can be recovered in the Spring. In this manner, the very heavy battery banks can be reduced considerably
- Limited higher sample rate data can be pulled on-demand to capture events of interest

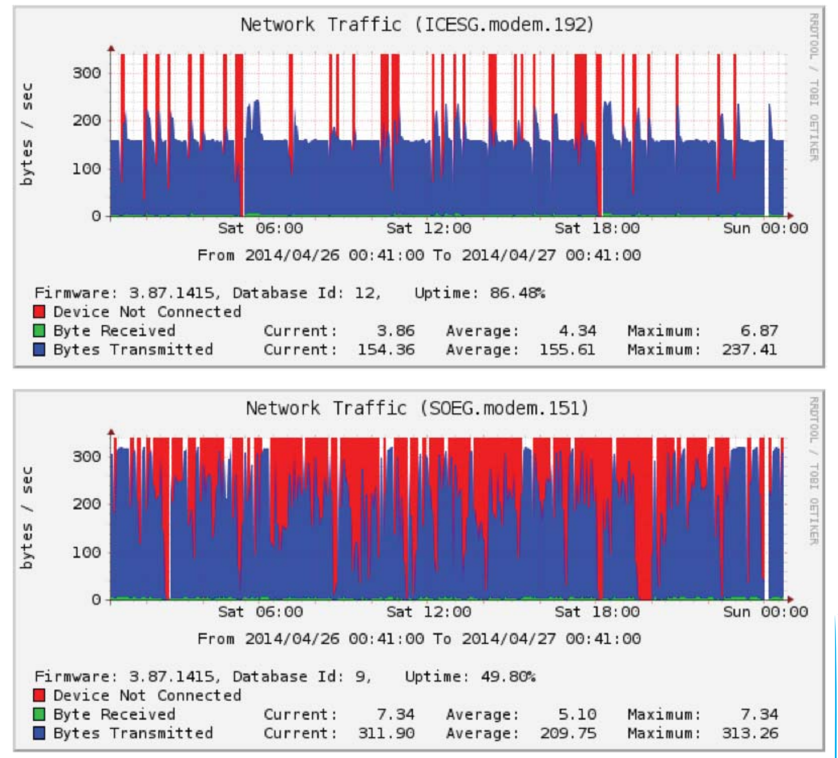
Problems/Disadvantages:
- During a RUDICS transmission session, the B44 datalogger sometimes reboots leading to data loss. Cause of problem is yet to be resolved
- B44 is on full time, which is a considerable drain on power reserves in the dark winter months
- B44 hangs during RUDICS data requests leading to increased telemetry uptime

Example Phase 1 data throughput plot



Above is a 24-hour plot of the 3 scheduled Phase 1 RUDICS sessions at station NEEM.
Blue = data transmitted from the station
Red = the modem is disconnected and in a low-power state
White = modem is connected but the B44 is not responding (an unresolved problem)

Example Phase 2 data throughput plots



Above are plots of network traffic for 2 stations in Phase 2. Colors are the same as in the Phase 1 plot, but here the modem is transmitting fulltime. Note that the station shown in the bottom plot is located in a narrow valley with blocked horizons. This requires more frequent satellite handoffs and thus a higher probability of dropped links. In contrast, the top plot's station has a 360° horizon-to-horizon satellite view.

PHASE 2:
Realtime data recovery utilizing RUDICS and Antelope

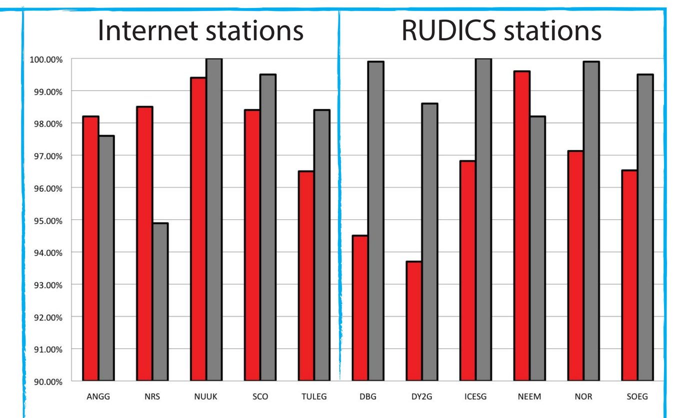
- In Fall of 2013 and Winter of 2014, after extensive in-house and field-prototype testing, 4 of the 6 seismic stations were remotely modified to extract data in realtime at 20 and 1 sps on 3 channels
- Data are pulled by the Antelope Seismic Server software package running over a full-time RUDICS link.
- The data throughput increased by a factor of 10 relative to Phase 1

Advantages:
- Antelope allows easy realtime distribution of data to the IRIS Data Management Center and provides considerable link and network, monitoring and diagnostic tools
- Recovery of higher sample rate data in realtime

Problems/Disadvantages:
- We have had several instances of a total or partial failure of the serial connection between the XI-100B and the Q330 - this issue has yet to be resolved
- Moving more data requires more on-site power; this increases the engineering and logistical challenges for autonomous stations in the cold winter months

DATA RECOVERY

Data recovery since 1 June 2012 using RUDICS compares favorably with data pulled via wired Internet connections. In the chart to the right, red bars indicate realtime data from both telemetry types and gray bars show data recovered from on-site visits. The data return rate for all stations is greater than 93%. Phase I RUDICS was shut off at DBG, ICESG, and SOEG for several months due to spontaneous B44 reboots. This forced outage is not included in the statistics.



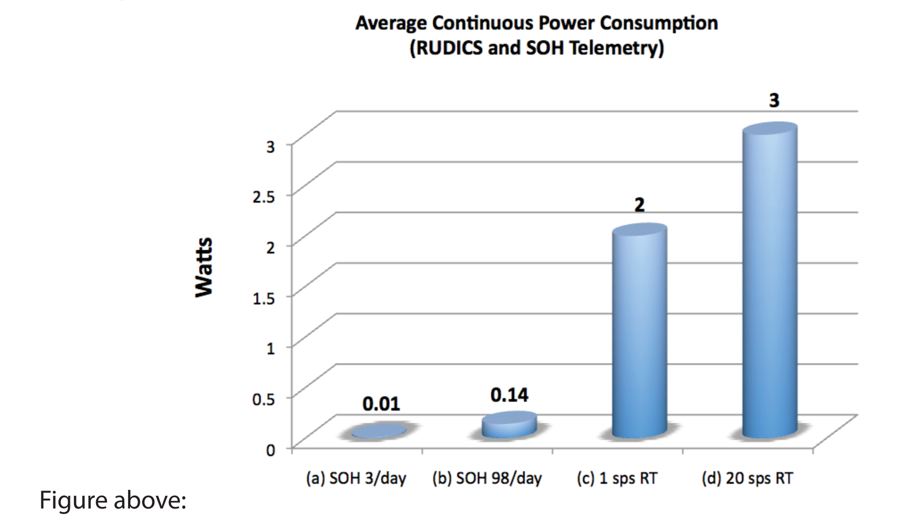


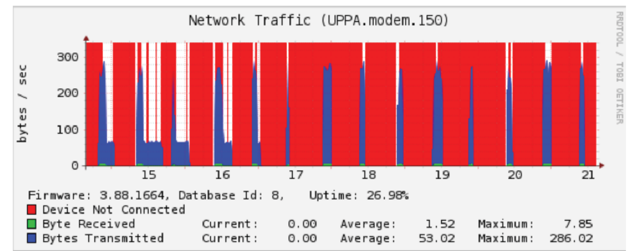
Figure above:
1. SOH only in Winter power-savings mode, NO time series data
2. SOH only, NO time series data
3. Duty-cycled RUDICS, 1 sps and SOH data streaming included
4. Duty-cycled RUDICS, 20 sps and SOH data streaming included

POWER CONSUMPTION AND BANDWIDTH

The current sustainable average bandwidth observed is 240-260 bytes/s. This is suf-ficient to move a peak of 20 MB/day. However, as our existing data loads per station are ~9-10 MB/day, we have sufficient bandwidth to transmit latent data after a telemetry outage or station-side hardware communication failure.

DUTY-CYCLED RUDICS

Below is a data throughput plot from test station UPPA in RUDICS duty-cycle mode. An SBD message is sent to the XI-100B with a "RUDICS-On" timer value. After the timer expires, the modem shuts down the connection and returns to its low-power state until the next timer message. In this mode, a continuous power savings of ~1 W can be realized over a Phase 2 full-time-transmitting RUDICS station.



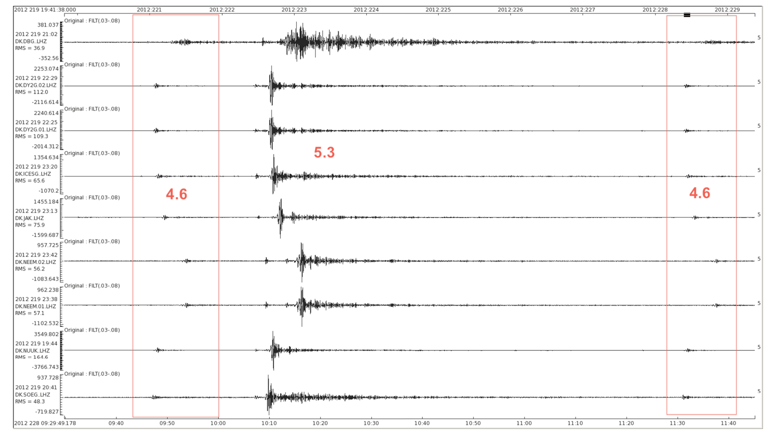
UNDERSTANDING SOME OF THE CHALLENGES

The Iridium network is composed of ~66 Polar orbiting satellites fixed in low Earth orbits. Due to this low orbit, satellite transit times horizon-to-horizon are very short. This requires frequent inter-satellite transmission link handoffs, some of which fail. These telemetry link breaks occur normally 30-80/day and can increase when other problems are present. The high latency of the link can make configuring existing server-side data recovery software diffi-cult as their standard application is for higher-speed and more stable communications.

XI-100B modem SIMS used here are under a Department of Defense (DOD) contract with Iridium. This means all our communications are routed through the DOD gateway, which is strictly off-limits to the public. This inaccessibility to a section of the telemetry link makes troubleshooting of unexplained telemetry outages very difficult for seismic network managers.

LOGISTICAL ADVANTAGES OF RUDICS

- RUDICS connectivity has given network operators a much more extensive suite of remote tools to conduct routine maintenance such as firmware upgrades and complete hardware reconfiguration of the Quanterra Q330 and B44
- With the increased SOH and diagnostic data, station-side problems can be deciphered with greater clarity and confidence and often solved remotely
- The high volume of detailed SOH data gives field personnel a much better chance to be properly prepared to solve the problems that require station visits
- Higher data returns and reduced station visits can offset the initial hardware outlay and operational costs of RUDICS



Above are three submarine Reykjanes Ridge events shown on the Z-component channels of Phase I RUDICS data

Photo of station SOEG

BENEFITS TO SCIENCE

- Phase 1 provides near realtime 1 sps data with the option to retrieve limited windows of higher sample rate data
- Phase 2 delivers realtime 20 and 1 sps data, improving realtime coverage in the North Atlantic
- RUDICS provides the option to remotely adjust short or long-term changes in data collection strategy by reconfiguring the station-side hardware

NEAR-FUTURE PLANS

Outside of GLISN, there are plans to install 7 more autonomous seismic stations in Greenland. Of those, 6 will be deployed on the NE Greenland Icecap and 1 along the SE coast. Two test stations were deployed on the Ross Ice Shelf in Antarctica and another test station is running at Poker Flat in Alaska near Fairbanks. Work is ongoing to minimize total station power consumption, size and weight. Plans are in process to continue the development of the prototype RUDICS tunnel software and to resolve the problems that have been characterized during the RUDICS testing Phases 1 and 2.

Photo of the install team (Japanese, American, Icelandic) at ICESG

Contact us! Dean (dean@passcal.nmt.edu) is the lead engineer of the PASSCAL GLISN stations, while Mouse (mouse@passcal.nmt.edu) looks at wiggles all day and sends the data out all over the world

Acknowledgements: This work couldn't be done with help from a lot of folks. Specifically assistance from the Polar Group at PASSCAL, Air National Guard, Geological Survey of Denmark and Greenland, GFZ-GEOFON (Germany), Istituto Nazionale di Geofisica e Vulcanologia (Italy), Japan Agency for Marine-Earth Science and Technology, Lamont-Doherty Earth Observatory (USA), National Institute of Polar Research (Japan), Norlandair, Polar Field Services, and Tohoku University (Japan)
THANKS!!