Advances in Remote Seismic Station Technology

Polar Technology Conference 2014

Overview

- PASSCAL polar program overview
- Cold temperature performance of $LiFePO_4$ batteries
- Advances in real time data transmission using RUDICS
- Next generation multiyear seismic station design
- Alaska PV study – optimal solar panel mounting for a wide range of latitudes

IRIS PASSCAL POLAR PROGRAM

PASSCAL

Program for Array Seismic Studies of the Continental Lithosphere

- Facility provides instrumentation to NSF, DOE or otherwise funded seismological experiments around the world
- Services include, but are not limited to:
  - Seismic instrumentation
  - Equipment maintenance
  - Software
  - Data archiving
  - Training
  - Logistics and shipping
  - Engineering support
  - Field Support

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Facility

Photo Courtesy of George Slad

Facility

~35 Full Time Employees

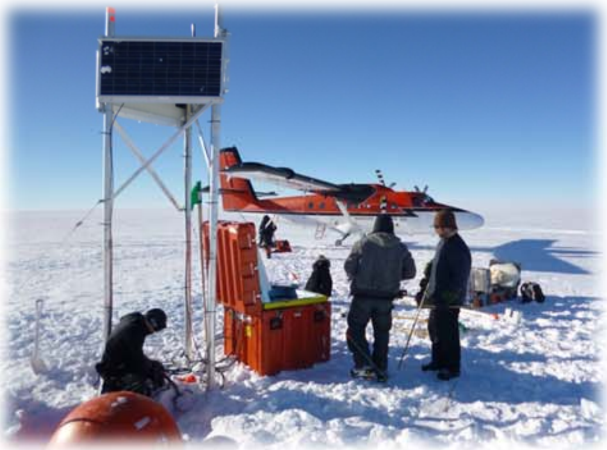
– Polar, Sensors, Hardware, Software, Data, Admin

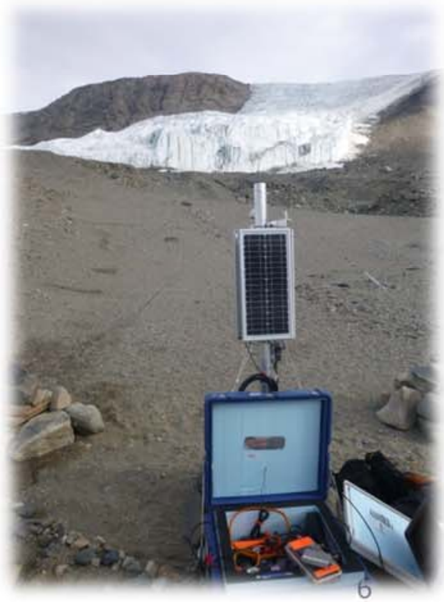
Equipment stored onsite in a warehouse

Lab space for repairing, testing and developing seismic equipment and software

POLAR Group

- Five full time employees support all PASSCAL polar experiments
  - Three mechanical engineer, one electrical engineer, one integration and testing seismologist
  - Rest of facility offers additional support and expertise including equipment testing and repair, shipping and logistics.
- Team spends ~14 months in the field each year, actual man hours spent is much higher
- Heavy focus on engineering and development due to harsh nature of polar environments





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LiFePO$_4$ Testing

LiFePO$_4$ Batteries vs Lead Acid Batteries

- Charging cycles
- **Weight and Volume**
- Charging efficiency
- Charging complexity
- **Cost**
- **Cold temperature performance**

The PASSCAL Engineering group and Genasun have characterized the cold temperature performance of the LiFePO$_4$ batteries sold by Genasun:

- In-house cold temperature discharge testing
- Third part cold charging investigation

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$LiFePO_4$ Testing

Cold Discharge Testing:

- **Test Phase 1** – High current discharge tests to verify batteries' ability to operate at cold temperatures
- **Test Phase 2** – Constant current to constant voltage (CC/CV) discharge tests to characterize low discharge rate performance
- **Test Phase 3** – Long term low current discharge test

Third-party cell characterization:

- Effect of cold charging on $LiFePO_4$ cells, charging efficiency at low temperatures

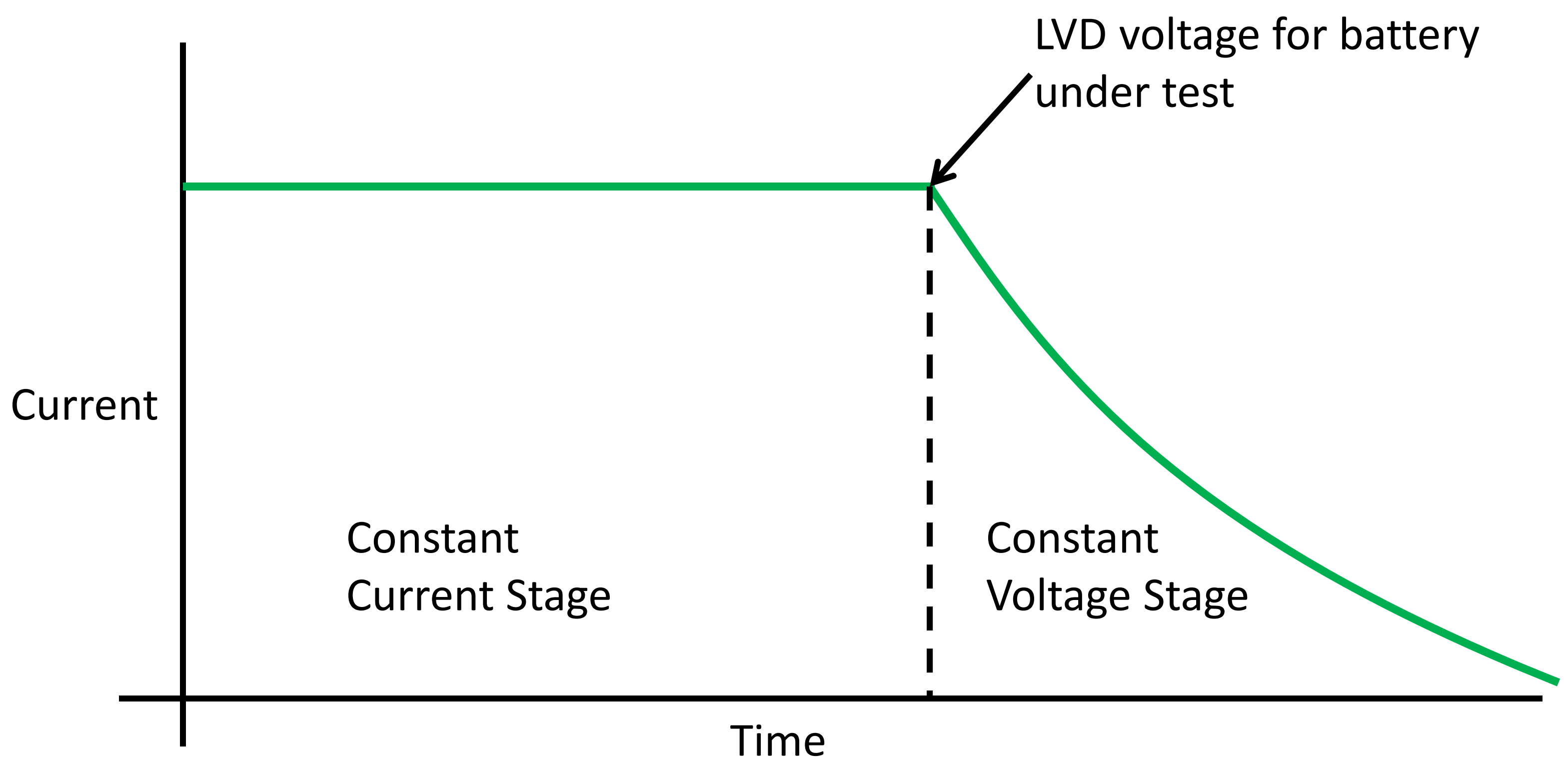
$LiFePO_4$ Test Phase 1

Temp	5A	2A	1A
25C	103Ah	103Ah	104Ah
-20°C	57Ah	69Ah	85Ah
Capacity at -20°C	55%	67%	82%

- Clear loss of capacity at lower temperature
- Capacity loss lessens as discharge rate decreases (beneficial for Polar use)

$LiFePO_4$ Test Phase 2

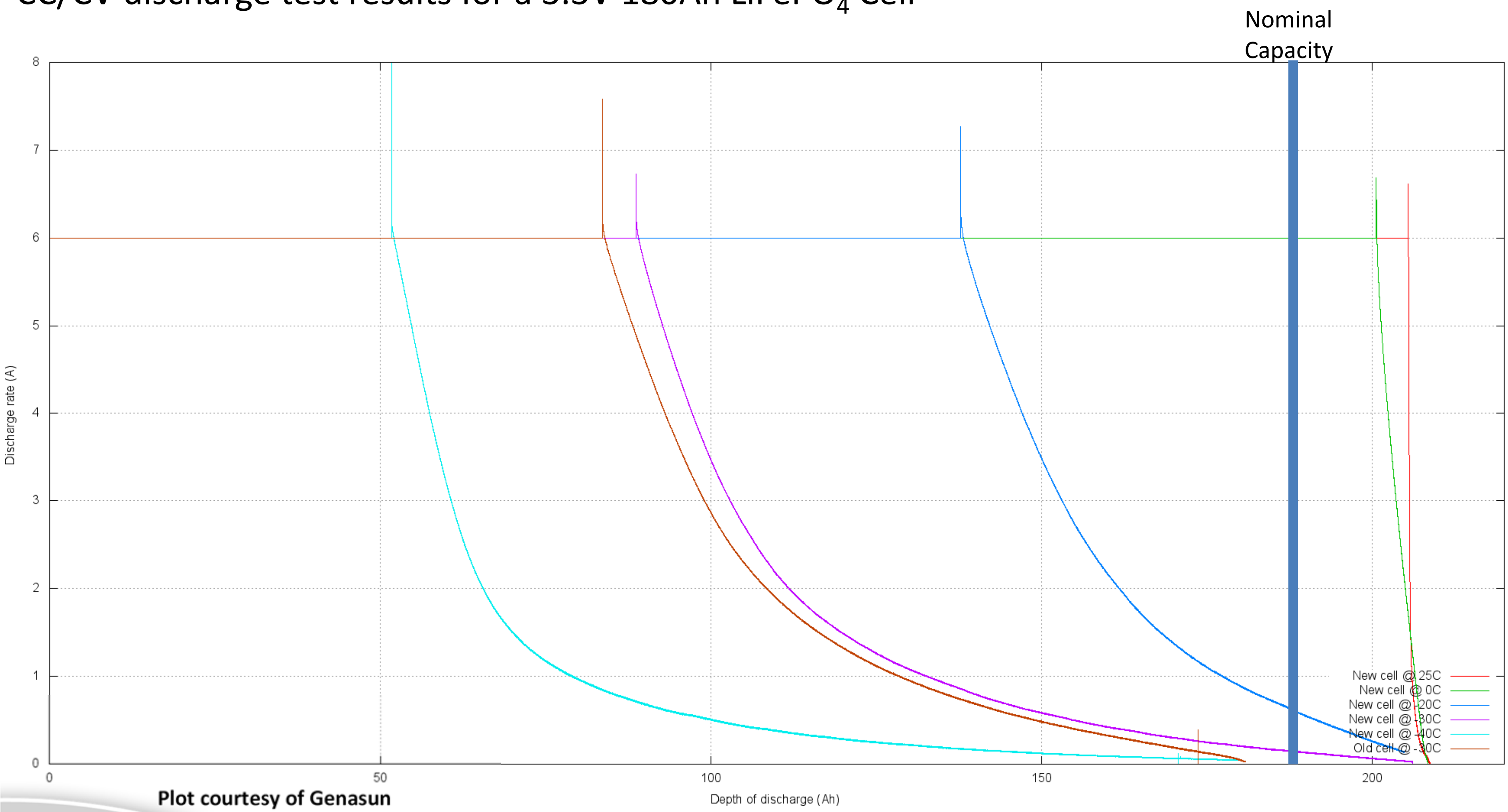
Genasun ran CC/CV discharge tests to rapidly characterize performance at low discharge rates



- Rapidly remove a significant portion of the battery's capacity
- Can obtain a complete capacity vs. discharge rate curve after running a single test
- Run this test at different temperatures to obtain capacity vs temperature relationship

LiFePO$_4$ Test Phase 2

CC/CV discharge test results for a 3.3V 180Ah LiFePO$_4$ Cell



Plot courtesy of Genasun

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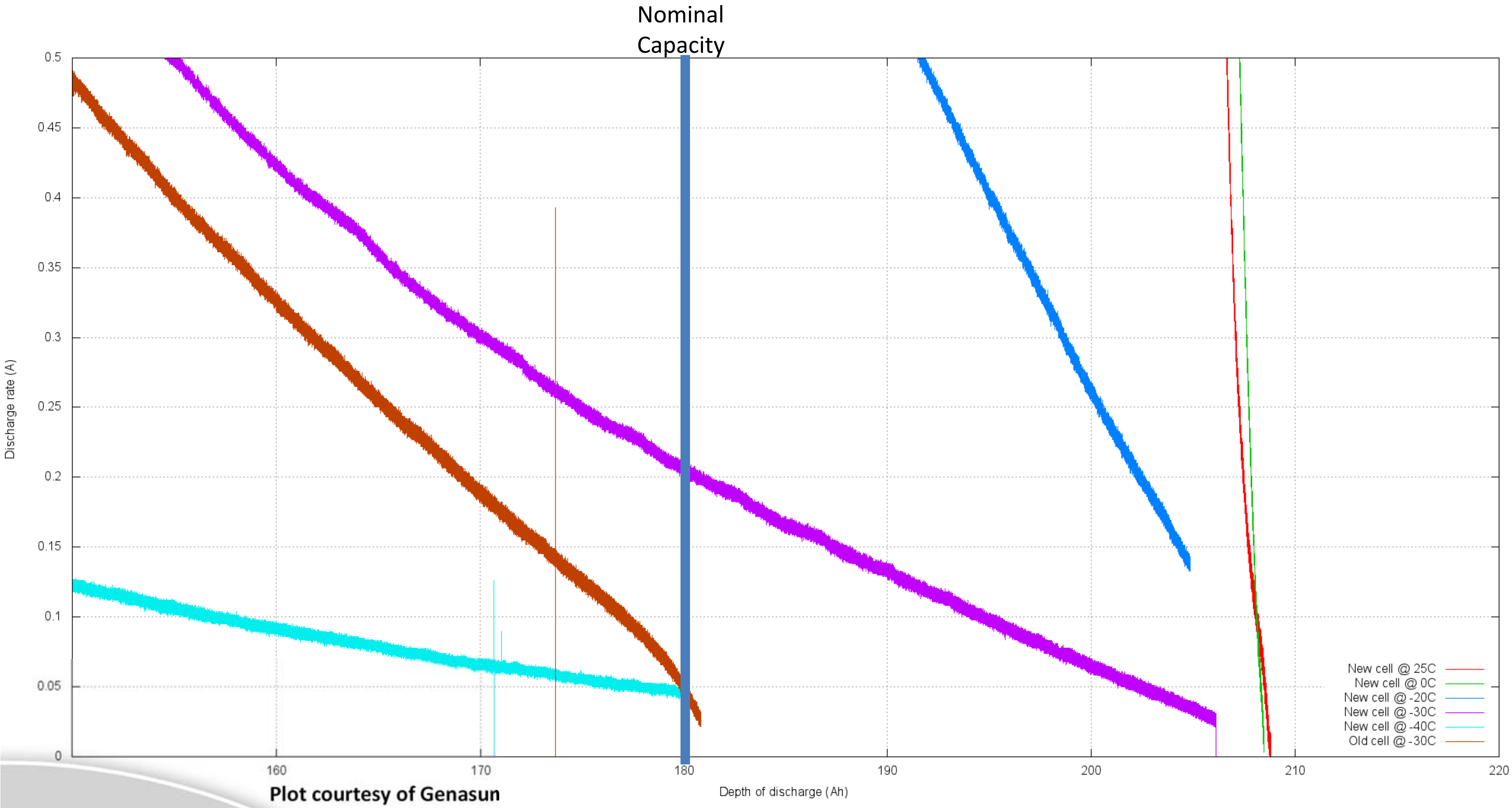
LiFePO$_4$ Test Phase 2

Zoomed in view of results:



Plot courtesy of Genasun

$LiFePO_4$ Test Phase 2

Comparison of constant discharge rate and temperature affects on the 180Ah $LiFePO_4$ Cell:

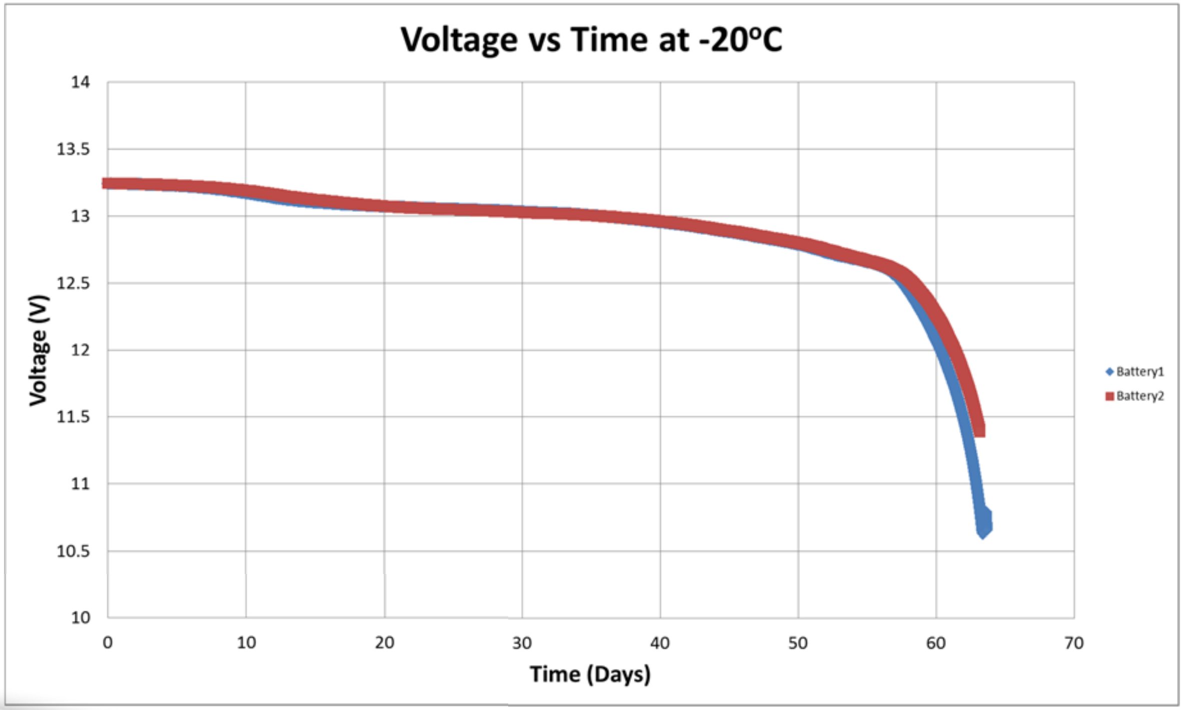
Discharge Rate	-40°C	-30°C	-20°C	0°C
1A	79Ah	132Ah	177Ah	206Ah
0.5A	100Ah	155Ah	192Ah	207Ah
0.25A	125Ah	175Ah	200Ah	207.75Ah
0.1A	157Ah	195Ah	205Ah	208.1Ah
0.05A	180Ah	203Ah	ND	208.3Ah

Low discharge rate allows the battery to deliver nameplate capacity even at very cold temperatures

$LiFePO_4$ Test Phase 3

Two month discharge test to validate cold temperature performance

- Two identical 100Ah $LiFePO_4$ batteries were discharged at -20°C with a load sized to drain the batteries in two months (≈65mA current draw).



Capacity Delivered:

Batt 1 = 97.7Ah

Batt 2 = 97.5Ah

Essentially no de-rate from nameplate capacity!

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LiFePO$_4$ Testing – Third Party

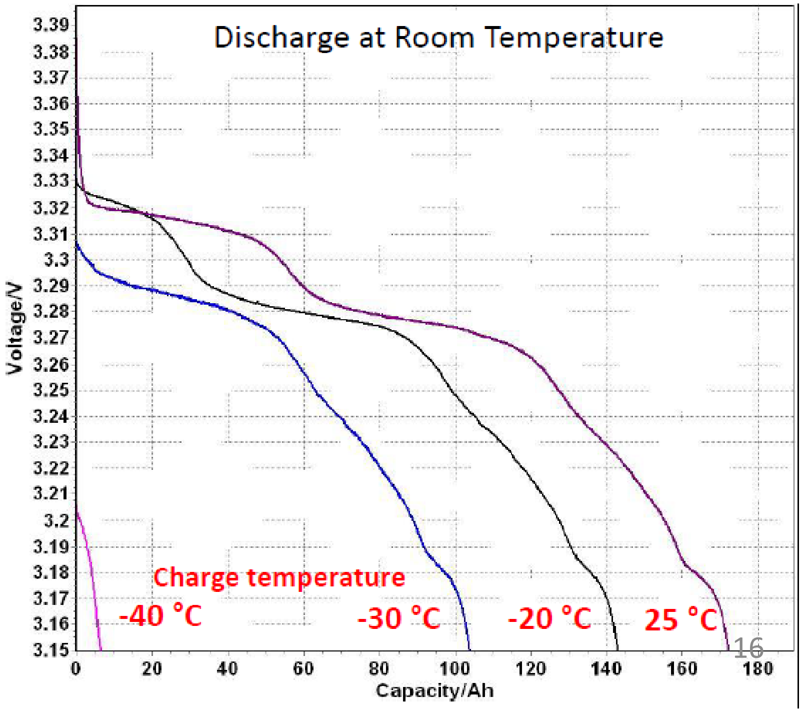
Third party – Exponent Engineering and Scientific Consulting contracted by Genasun

Key Points

- At low temperatures, cell resistance increases significantly which limits charge/discharge capacity
- No evidence of lithium plating in the cells when charged at low temperatures
  - i.e. cells are NOT damaged by cold temperature charging (within bounds)
    - Exponent charged cells with 39.5A at -10°C, -20°C, -30°C and -40°C
- Electrolyte NOT frozen at -40°C, but it is partially frozen at -60°C.

Temperature (°C)	Charge Capacity (Ah)
25	187.7
-20	159.8
-30	104.0
-40	19.0

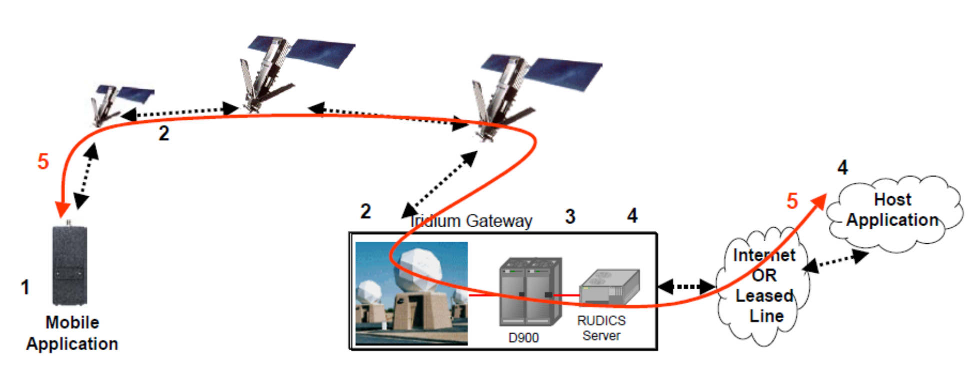
Plot, table courtesy of Genasun



RUDICS

RUDICS – Router-Based Unrestricted Digital Internetworking Connectivity Solutions

Figure 5
A RUDICS Data Call from a remote application (ISU) to the central Host Application



Sequence of Events:

1. Mobile application places call to a custom RUDICS Server Number
2. Call request is routed over the constellation for user authentication and call set-up.
3. Switch connects to RUDICS Server, secondary authentication conducted
4. RUDICS Server terminates call to pre-configured IP Address
5. End-to-End IP connection established, over the constellation, between the Host Application and Mobile Application

From Iridium Satellite Data Services White Paper

Single host application interfacing with many field devices

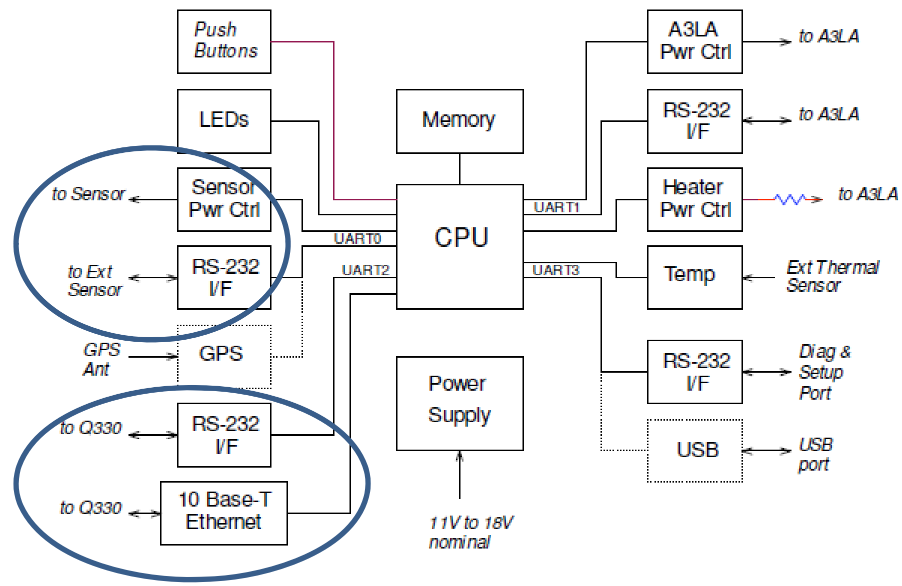
Data calls to and from a specific IP Address

Full two way communications (full duplex)

300 Bytes/s data rate allows for 1MB/hour of real time data

RUDICS - Hardware

XI-100 Iridium terminal manufactured by Xeos Technologies Inc – IRIDIUM VAR



Photo, diagram courtesy of Xeos Technologies

- 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 Serial RS-232
- Can interface with an additional "External Sensor"
    - Provides power and transmission of data, currently supporting WX520 weather station

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RUDICS - Hardware

Xeos tunnel application – provides interface between host application and field devices. Turns a remote, complex network into a LAN. Tunnel can run user scripts allowing automated data acquisition.

rudics.passcal.nmt.edu:8888

Xeos Technologies Inc.

Wed 9 Apr 14 :: 8:36:03 pm

Status | View Logs | Q330 | Shutdown

id	Name	Status		Last Connected	Last Disconnected	Rx/Tx	V/T/RSSI		
8	UPPA.modem.150	Active	Disconnected	09-04-2014 07:14:27 PM	09-04-2014 07:35:10 PM	74 KB / 2431 KB	13.17 V / 32 C / 5	Details	Restart
9	SOEG.modem.151	Active	Connected	09-04-2014 08:32:31 PM	09-04-2014 08:31:30 PM	190 KB / 6711 KB	13.84 V / 19 C / 4	Details	Restart
10	HEL1.modem.181	Active	Disconnected	09-04-2014 07:40:42 PM	09-04-2014 07:42:46 PM	7 KB / 1087 KB	10.71 V / 17 C / 5	Details	Restart
11	NE2.149	Active	Disconnected	n/a	n/a	0 KB / 0 KB	13.52 V / -17 C / 5	Details	Restart
12	ICESG.modem.192	Active	Connected	09-04-2014 07:06:32 PM	09-04-2014 07:01:06 PM	4 KB / 0 KB	14.4 V / -11 C / 5	Details	Restart
13	DY2G.modem.143	Active	Connected	09-04-2014 07:41:43 PM	09-04-2014 07:40:46 PM	6 KB / 1346 KB	14.47 V / -3 C / 5	Details	Restart
14	NEEM.modem.144	Active	Disconnected	09-04-2014 07:40:59 PM	09-04-2014 07:43:01 PM	5 KB / 1179 KB	14.05 V / -18 C / 5	Details	Restart
15	JAK.modem.180	Inactive	Disconnected	n/a	n/a	0 KB / 0 KB	0.0 V / 12 C / 0	Details	Restart
16	RIS3.modem.117	Inactive	Disconnected	n/a	n/a	0 KB / 0 KB	0.0 V / -8 C / 0	Details	Restart
17	PIC1.modem.135.POKER.FLAT	Active	Connected	09-04-2014 08:05:18 PM	09-04-2014 08:03:39 PM	164 KB / 5520 KB	13.84 V / 24 C / 5	Details	Restart
18	RUDI.modem.179	Active	Connected	09-04-2014 08:35:44 PM	09-04-2014 08:34:10 PM	258 KB / 10414 KB	13.2 V / 41 C / 5	Details	Restart
19	ICES2.modem.206	Active	Disconnected	n/a	n/a	0 KB / 0 KB	12.83 V / -21 C / 5	Details	Restart
20	BRRP.modem.145	Active	Disconnected	n/a	n/a	0 KB / 0 KB	12.88 V / 25 C / 5	Details	Restart
21	NOR.modem.178	Active	Connected	09-04-2014 08:03:36 PM	09-04-2014 08:02:11 PM	256 KB / 6755 KB	13.31 V / -5 C / 5	Details	Restart
22	ICES1.modem.205	Active	Disconnected	n/a	n/a	0 KB / 0 KB	12.78 V / -24 C / 5	Details	Restart
23	B44.access.new.rudics.cfg	Inactive	Disconnected	n/a	n/a	0 KB / 0 KB	0.0 V / 28 C / 0	Details	Restart
24	DBG.modem.142	Active	Connected	09-04-2014 08:13:15 PM	09-04-2014 08:11:37 PM	164 KB / 6075 KB	13.44 V / 7 C / 5	Details	Restart
25	NE1.207	Active	Disconnected	n/a	n/a	0 KB / 0 KB	13.39 V / -33 C / 5	Details	Restart
26	modem.208	Inactive	Disconnected	n/a	n/a	0 KB / 0 KB	0.0 V / 25 C / 0	Details	Restart
27	NE3.209	Active	Disconnected	n/a	n/a	0 KB / 0 KB	13.6 V / -19 C / 5	Details	Restart
31	NE4.210	Active	Disconnected	n/a	n/a	0 KB / 0 KB	13.65 V / -18 C / 5	Details	Restart
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33	NE6.212	Active	Disconnected	n/a	n/a	0 KB / 0 KB	12.88 V / -12 C / 5	Details	Restart
34	SE1.213	Active	Disconnected	n/a	n/a	0 KB / 0 KB	13.55 V / -34 C / 5	Details	Restart

Add New Site | Restart All

Modem on and transmitting data
Modem standby

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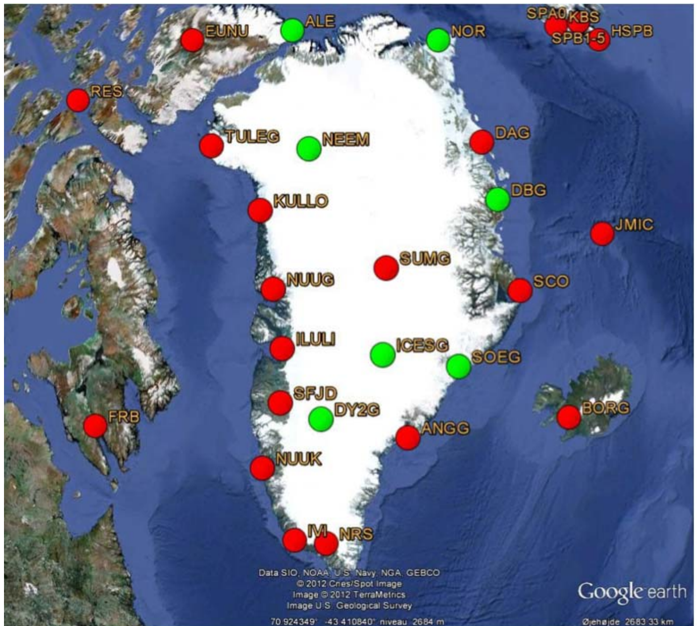
RUDICS – Current Use



GLISN station with RUDICS
GLISN station with other telemetry system

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RUDICS – Current use by PASSCAL

Current Use
1. Poker Flats, Alaska – **9MB/day**
2. Greenland – 8 stations moving up to **20MB/day**
3. Antarctica – 2 stations moving **9MB/day**

Future Deployments
1. Phase into POLENET project – 34 stations in Antarctica
2. Greenland – 7 new stations to be deployed this summer with RUDICS capability

Advantages
1. In depth command and control
2. Real time data acquisition
3. SOH monitoring of devices
4. RUDICS can be turned on/off to conserve power

Current Problems:
1. Complex, inaccessible network makes troubleshooting and bug fixing difficult
    1. DOD black box – networks can be brought down inexplicably.
2. Drop outs, slow link -> difficult to optimize host application

Power Consumption:
1. SOH and 1Hz data on three channels (in the field) – 1.45W
2. SOH and 20Hz on three channels using latest FW (lab testing) – 2W
3. SBD mode (in the field) – 10mW

RUDICS – You can use it!

- Iridium connectivity and real time data transmission need not be complex!
- XI-100 unit currently has great functionality, and much additional functionality that needs more development.
- Unit has been designed to interface with any networked remote device – not specific to seismic or geophysical instrumentation.
  - It is an **Ethernet bridge** of the Iridium Network
  - UNAVCO uses it with GPS receivers

Next Generation Seismic Station

Goals

- Light, small stations
- Rapid installation and removal
- Plug and play design

Solution

- Customized enclosure that reduces footprint and weight
- Primary batteries used in the winter to reduce weight and size
- Solar panel mount that is stable in snow WITHOUT rigging or additional anchoring
- Direct bury sensor with increased tolerance for tilt

Next Generation Seismic Station

Power

Lithium Thionyl Chloride
- 3040Wh in 11lbs
- 276Wh/lb
- Non-rechargeable
- Hazardous
- Low current source
- **Two year station = 113lbs**

Lead Acid AGM
- 1360Wh in 65lbs
- 21Wh/lb
- Rechargeable
- Non-hazardous
- High current source
- **Winter station = 570lbs**

LTC Batteries are ideal for limited length deployments – vastly reduce weight of power system and have excellent cold weather performance

Are combined with a small AGM and solar array for summer time operation

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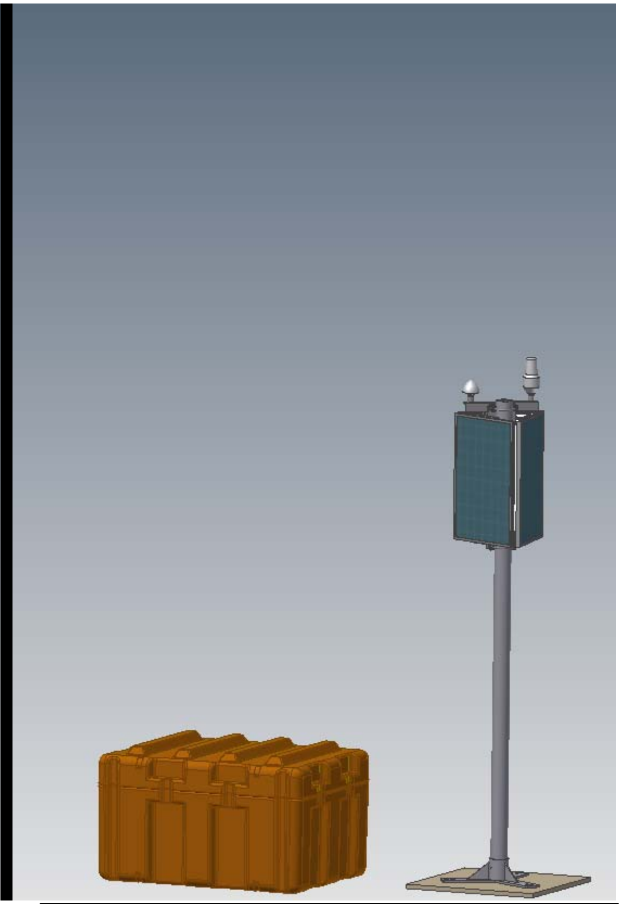
Next Generation Seismic Station

Enclosure and Solar

Weight: 365lbs
Volume: 35ft^3



Weight: 115lbs
Volume: 19ft^3

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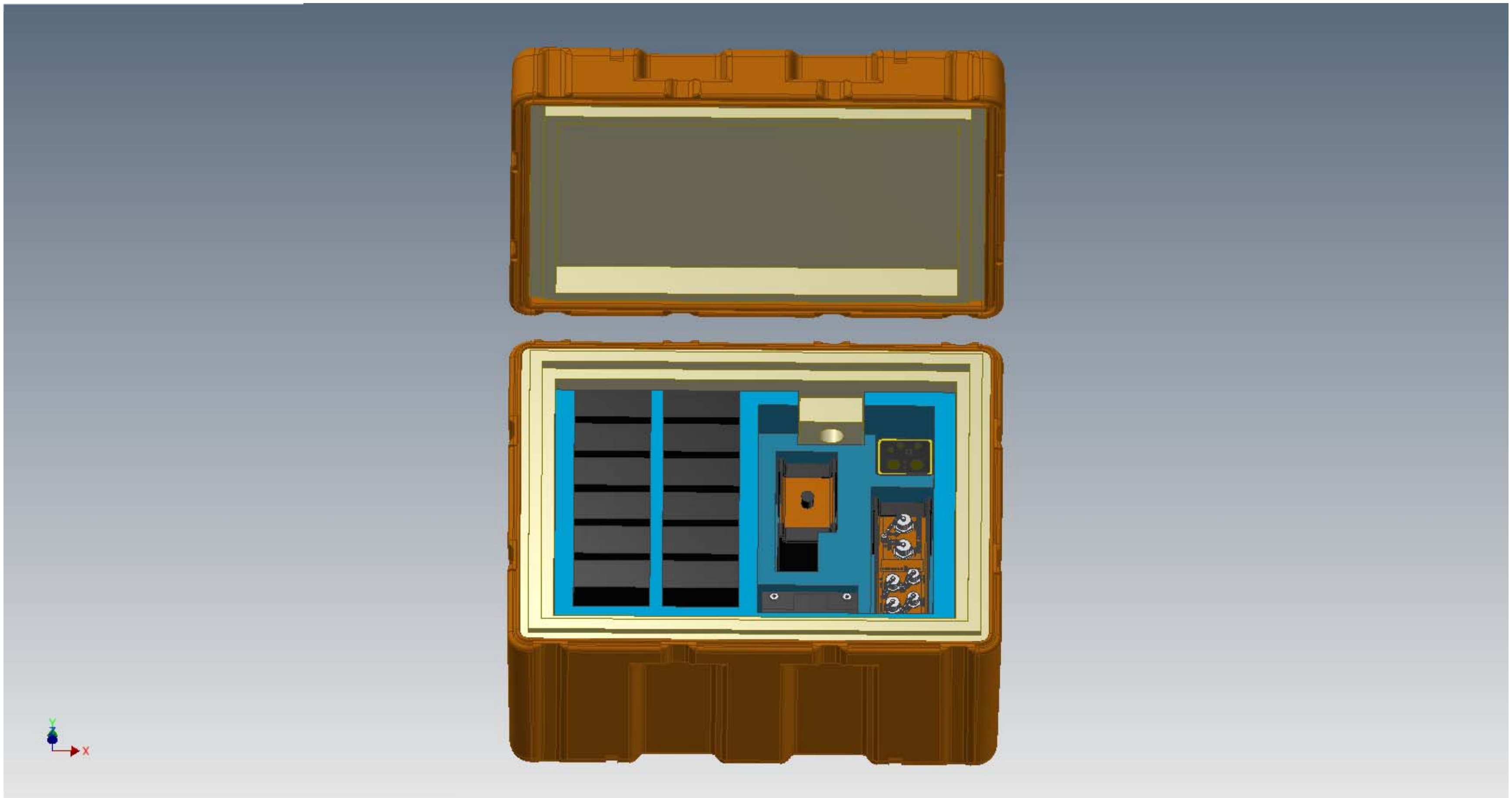
Next Generation Seismic Station



- Injection molded insulation reduces cost, construction time and complexity of the enclosure
- Custom foam liner stabilizes the components during travel

Next Generation Seismic Station

Sensor

Standard Sensor Installation

Weight: 73.5lbs
Volume: 16ft^3

Post Hole Sensor Installation

Weight: 40lbs
Volume: 1ft^3

Next Generation Seismic Station

Year Round AGM Station

Run time = indefinite
Total weight = 1070lbs
Total cube = 51ft^3

Installation:

- Station must be completely built on the ground
- >3 hours with three person team

Rapid Deploy Station

Run time = 2 years
Total weight = 350lbs
Total cube = 20ft^3

Installation:

- Enclosure and solar panel mount preassembled
- <1 hours with three person team

≈35 rapid deploy stations will be installed during 2014-2015 Antarctic season

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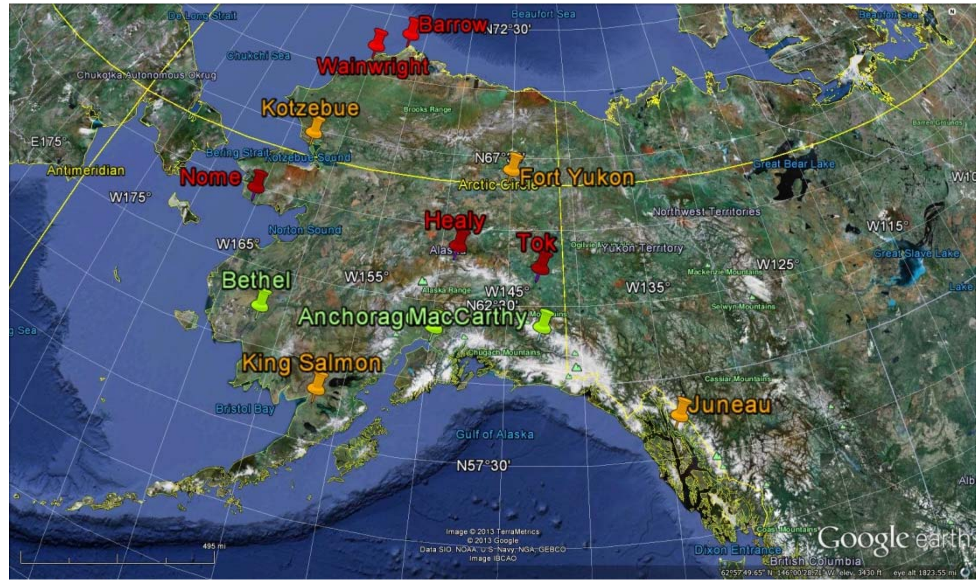
Alaska PV Study



Purpose of the study:

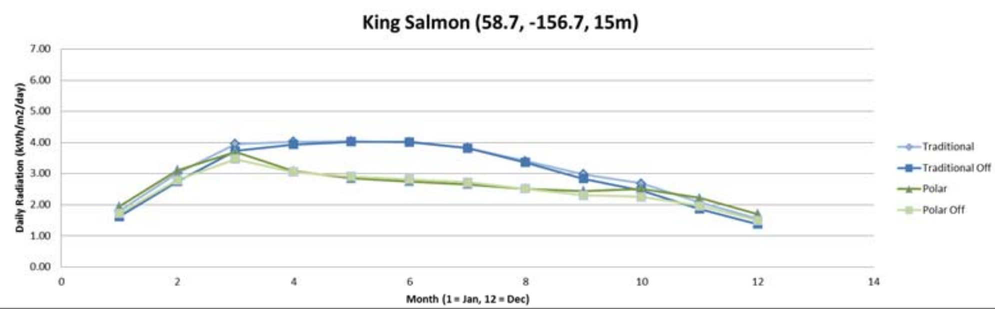
- Determine the optimal solar panel orientation for Alaska

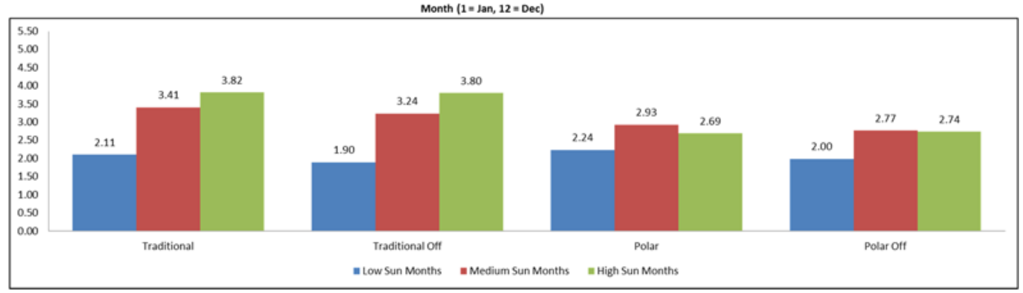
Procedure:

- Use weather and solar radiation data to study available PV power at 5 different latitude bands
- Latitudes ranged from 58°N to 71°N
- Calculate the optimal solar panel orientation
    - Defined as the orientation that minimized the required battery capacity

Results:

- A polar style solar mount (panels mounted vertically and facing due South) is optimal for ALL of Alaska
- Maximizes energy harvesting during low light months
    - Reduces number of batteries needed for the station to run through the winter





Future Developments

GEOICE MRI – Partnership between Central Washington University and IRIS to develop new instrumentation specifically for polar regions. Will include a mixed phase array consisting of broadband and intermediate band seismometers complete with power systems and enclosures.

- Low power, both types integrate a digitizer and post hole seismometer for installation in snow/ice
- Environmentally sealed, built for limited and difficult logistics
- Improved tilt tolerance
- Target is 125 element array
- Initial field testing in 2014?

Air cell batteries – excellent Ah/lb ratio but difficult to work with

- Require oxygen source
- Cannot source large currents
    - Transient currents can cause large voltage drops
- Capacity drops of 0% near -20C
- Use air cells like a solar panel to charge a rechargeable battery?
    - Modify existing solar change controller – GV-5C