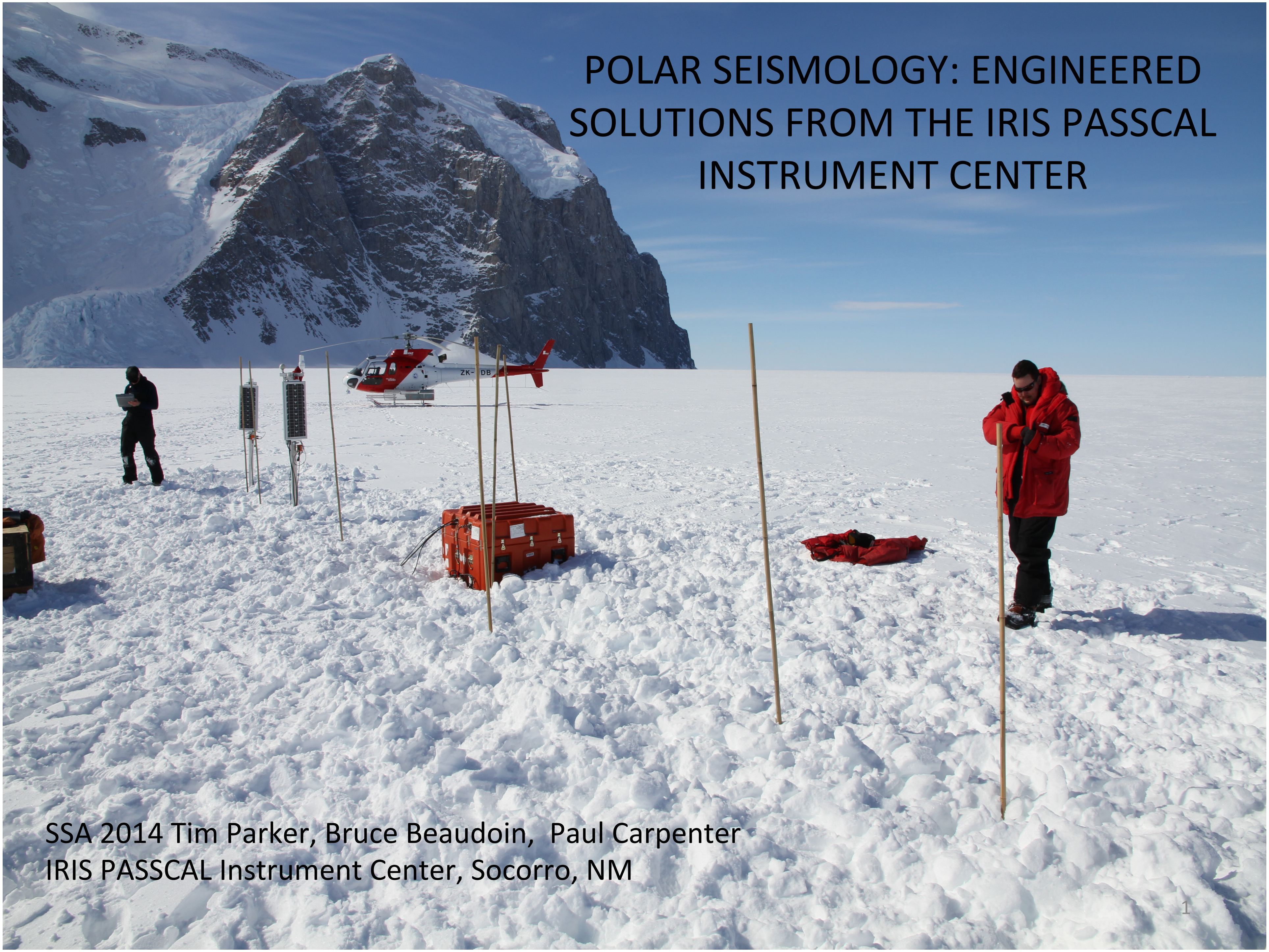
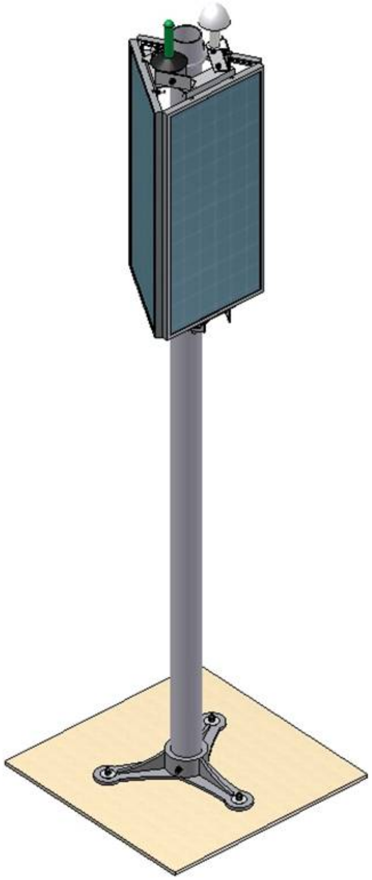


POLAR SEISMOLOGY: ENGINEERED SOLUTIONS FROM THE IRIS PASSCAL INSTRUMENT CENTER

SSA 2014 Tim Parker, Bruce Beaudoin, Paul Carpenter
IRIS PASSCAL Instrument Center, Socorro, NM

Intro and Topics

- Engineering Effort at PIC
- Approach to Polar Station Engineering
- Current and Future Developments

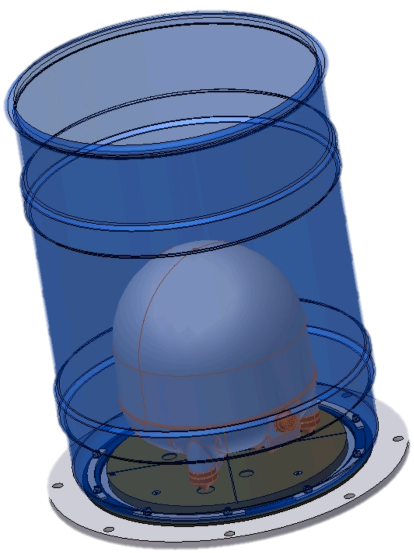


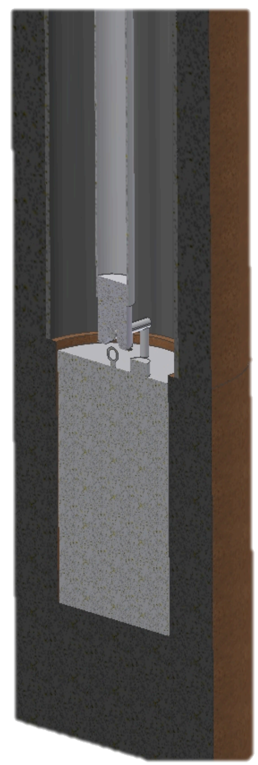
Polar Engineering Effort at PIC

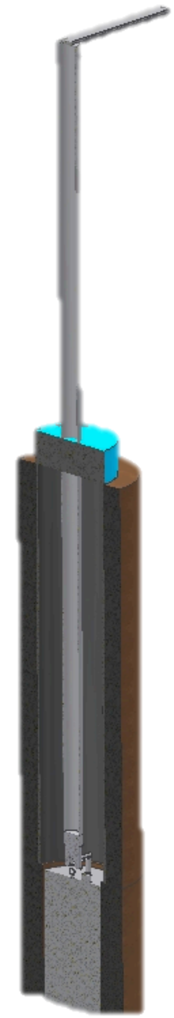
Development Efforts Directed to PI Support…

Work has been episodic and incremental

-Driven by funded experiments and MRIs



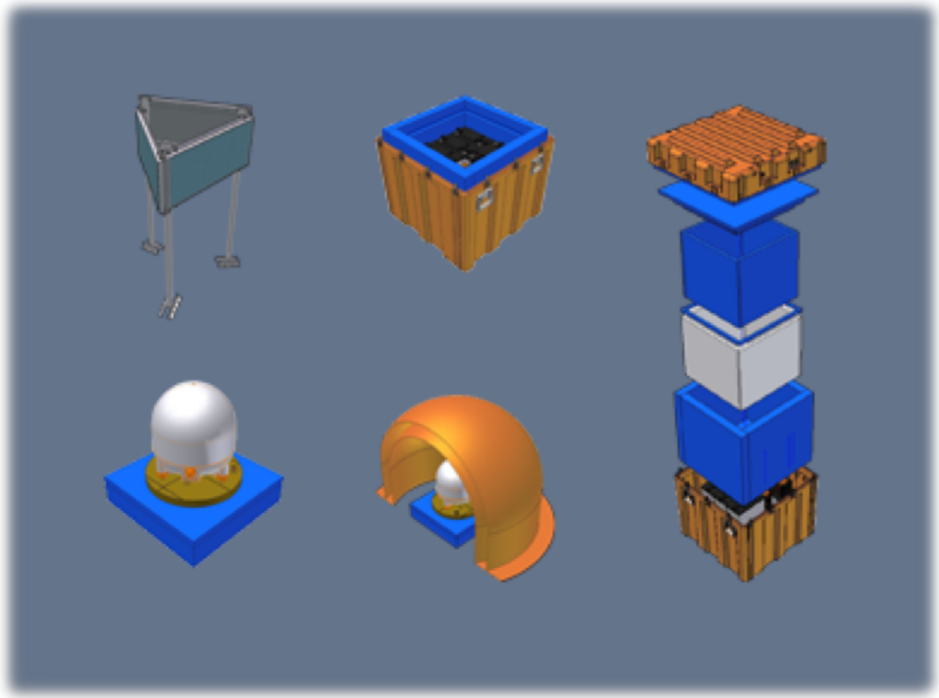




Polar Engineering Effort at PIC

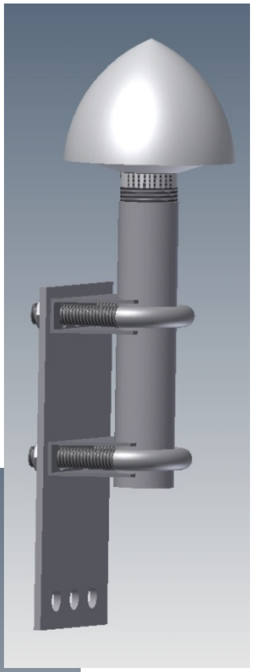
Staff split efforts between:

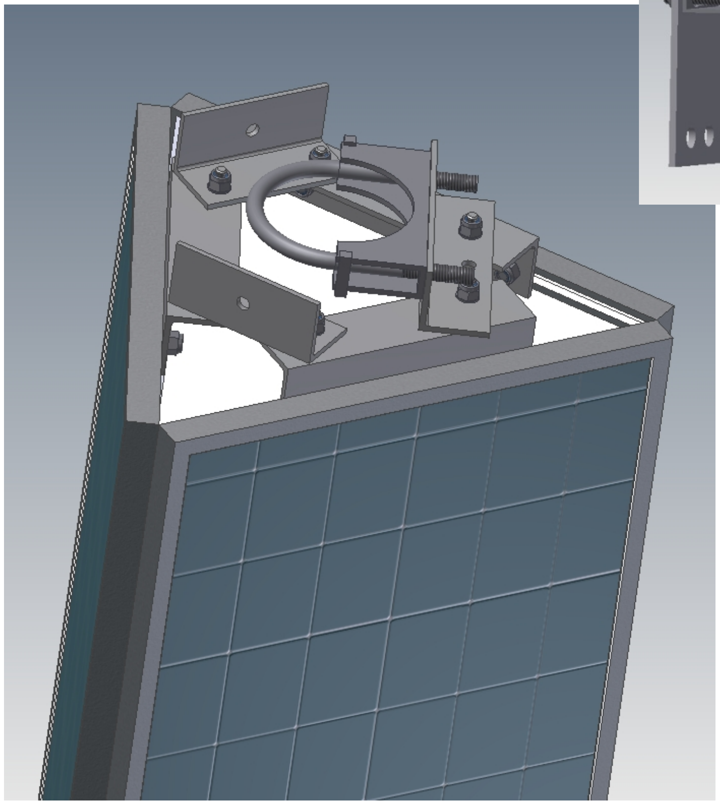
- Development efforts
- Buying, Building and Shipping
- Planning, Field support and Training
- Testing



Example of incremental changes…
Old-Disadvantages

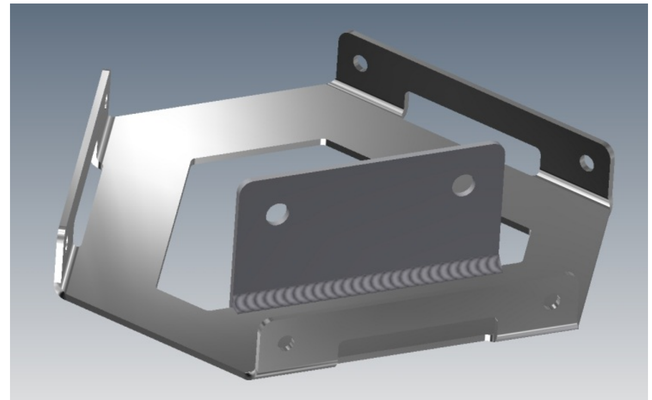
- Lots of hardware
- Long assembly time
- Accommodates only 1 type of panel

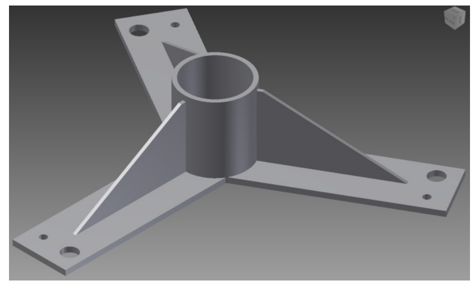


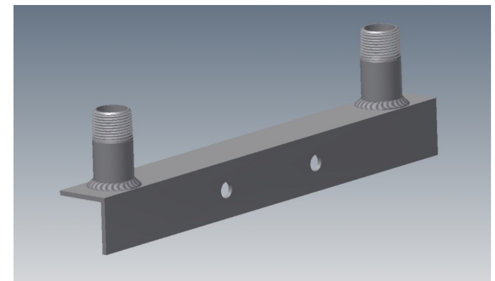


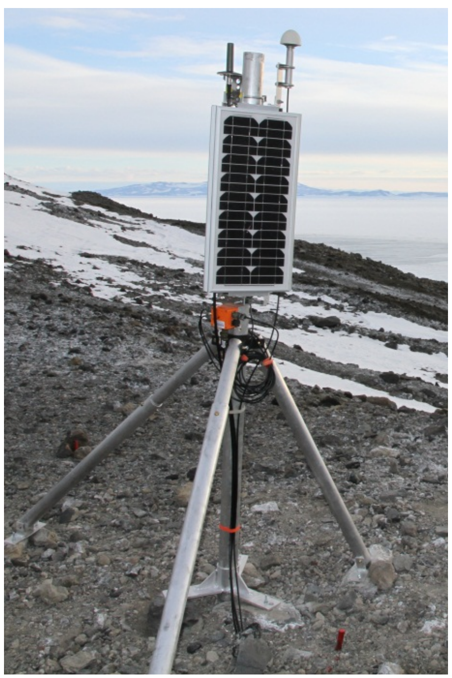
New Design

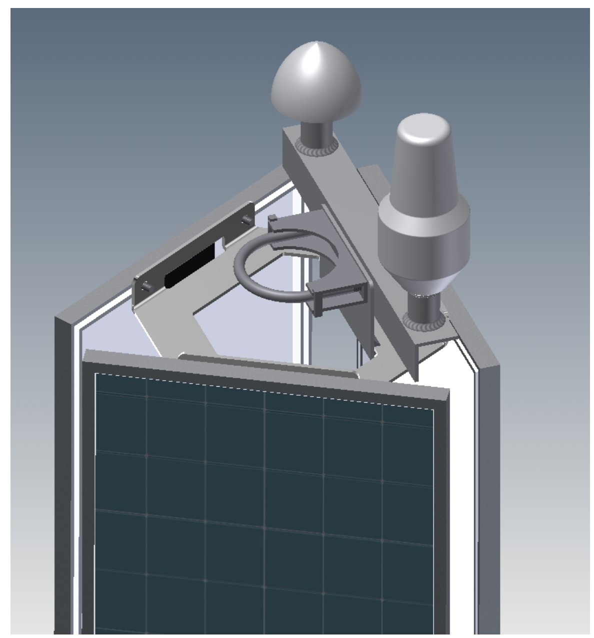
- 1 piece panel mount
- Can accommodate multiple panel models
- Stronger base
- Simpler antenna mount











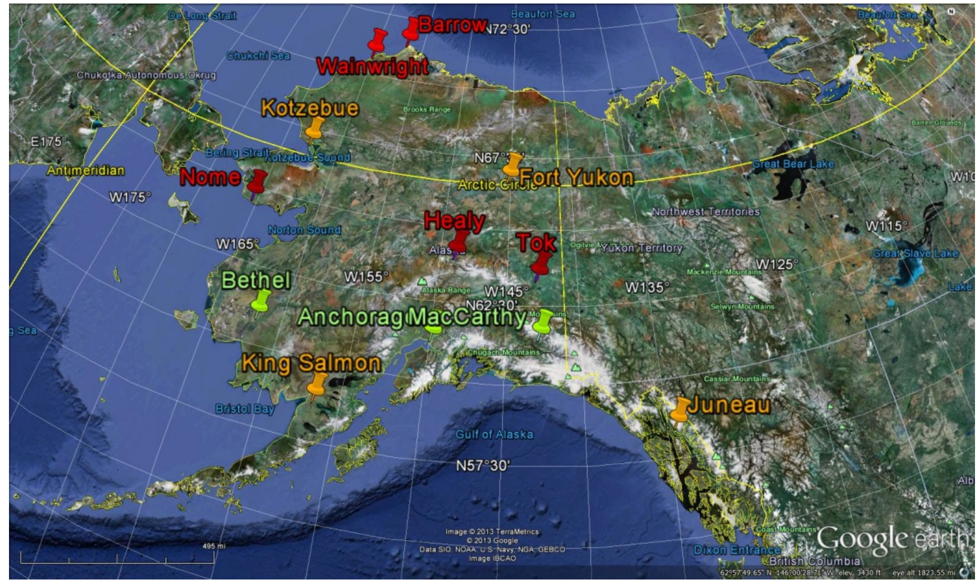
Engineering Process for a Portable Polar Seismic Station

Station is engineered from inside out….

- What are the Seismic experiment requirements?
  - Sample rates, sensor type, telemetry?
- When and where is it located and what is the environment?
- What is the duration of the deployment?
- What are the logistics?
- Is the seismic and ancillary equipment in the PIC pool?
  - If not a budget will have to be proposed after the first engineering review of the project

*Something purpose built and not general will be required for the least logistics

Example Power Analysis: Alaska PV Study



Purpose of the study:

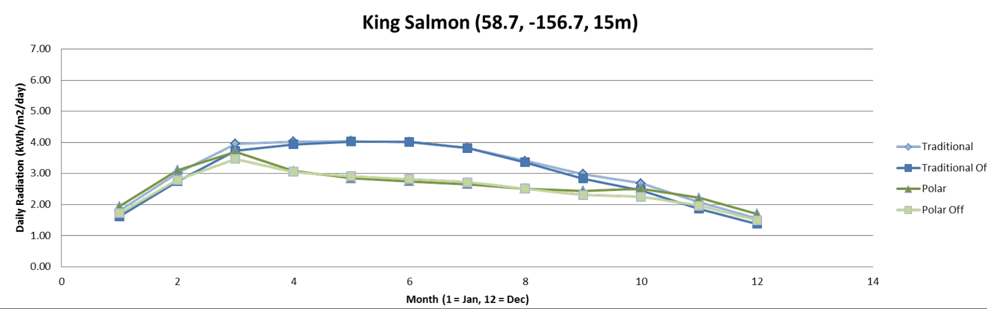
- Determine the optimal solar panel orientation for Alaska

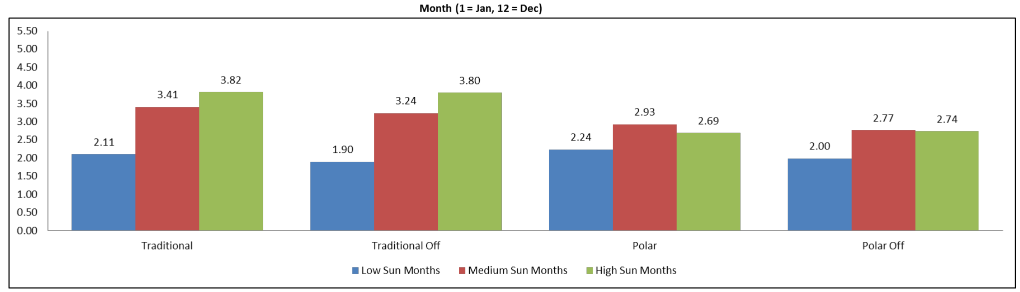
Procedure:

- 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





Power Calcs…

- Once you have all the necessary experiment requirements…the engineering starts!
  - Power calculations based on:
    - Equipment used, do they need telemetry?
    - Weather and latitude, will solar be used?
    - Battery type and derating
    - Primary or secondary batteries with solar or wind charging

POKR Flats Full Time Rudics Power Design

WEATHER, PANEL ORIENTATION DATA

	Horizontal (kWh/m2/day)	South (kWh/m2/day)	North + 30 (kWh/m2/day)	South + 30 (kWh/m2/day)	Earth Temp (degC)
January	0.07	0.62	0.04	0.55	-22.5
February	0.42	1.19	0.27	1.07	-20.6
March	1.59	2.87	1.03	2.67	-16.2
April	3.09	3.00	1.32	2.94	-6.7
May	4.35	3.11	2.20	3.15	5.2
June	NA	NA	NA	NA	NA
July	NA	NA	NA	NA	NA
August	3.00	2.43	1.42	2.41	11.2
September	1.27	1.45	0.55	1.36	3.3
October	0.58	1.33	0.36	1.20	-8.3
November	0.09	0.83	0.05	0.72	-17.9
December	0.01	0.58	0.00	0.50	-20

TWO PANELS DUE SOUTH

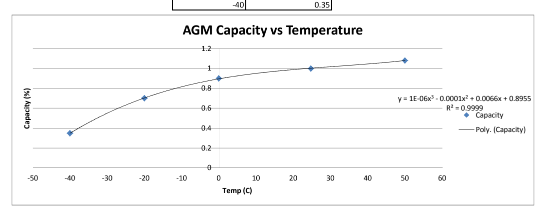
Solar Panels	SPR-90-WHT-U SunPower	
Panel Area each	0.55	m2
Panel Eff each	0.17	%
# Panels South	2.00	EA
#Panels North +30	0.00	EA
Load	7.00	W
System Eff	0.95	%
Charging Eff	0.90	%
Power/day	176.84	Wh
Power/month	5393.68	Wh

ENERGY HARVESTING

	Cold Derate (%)	Harvested/day (Wh)	Harvested/month (Wh)	Net Energy (Wh)	Negative Energy (Wh)	Battery Capcity Needed (Wh)
January	0.68	101.41	3092.93	-2300.76	-2300.76	-3358.85
February	0.71	193.69	5907.58	513.89	0.00	0.00
March	0.76	465.96	14211.83	8818.14	0.00	0.00
April	0.85	488.06	14885.87	9492.19	0.00	0.00
May	0.93	505.59	15420.42	10026.74	0.00	0.00
June	0.00	0.00	0.00	0.00	0.00	0.00
July	0.00	0.00	0.00	0.00	0.00	0.00
August	0.96	394.52	12032.77	6639.09	0.00	0.00
September	0.92	235.90	7195.05	1801.36	0.00	0.00
October	0.83	216.05	6589.52	1195.83	0.00	0.00
November	0.74	134.52	4102.78	-1290.90	-1290.90	-1745.45
December	0.72	94.28	2875.66	-2518.02	-2518.02	-3519.25

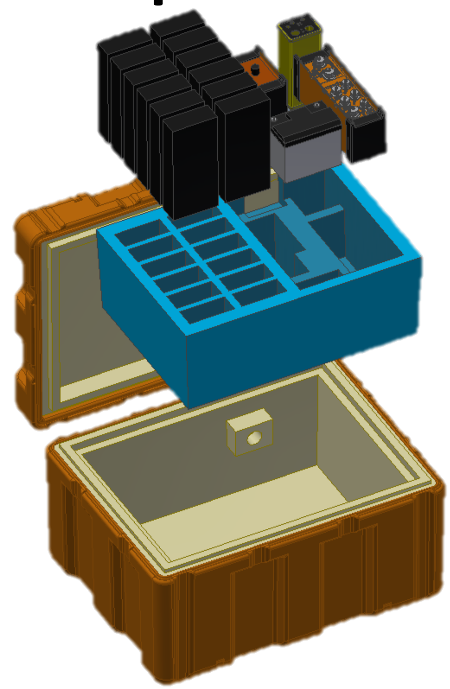
Net Negative Energy (Wh)	-8623.55
Net Negative (Ah)	673.71
Stock Battery (Ah)	108.00
# Batts	**6.24**

Batt Temp (degC)	Capacity (%)
50	1.08
24.7	1
0	0.9
-20	0.7
-40	0.35



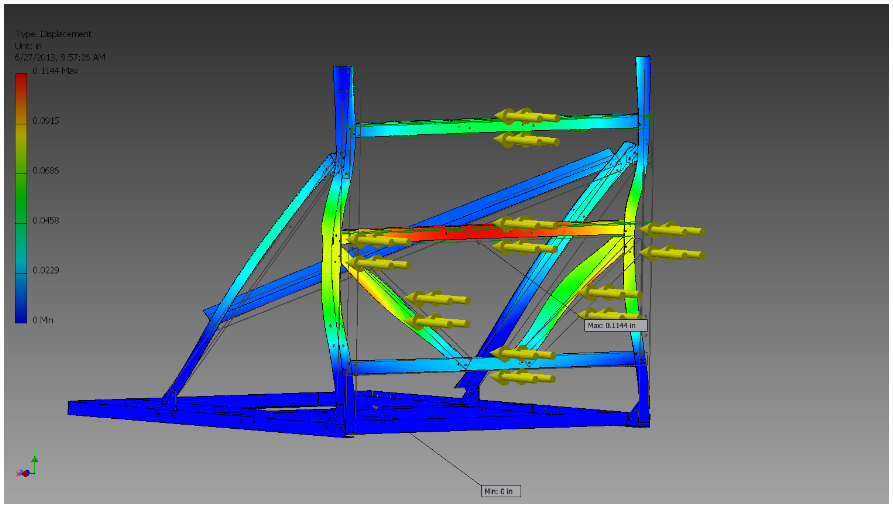
Do we have the enclosures and other ancillary equipment in the pool?

- No? Need to design enclosure based on requirements
  - Very high latitude or high altitude enclosures utilize enclosures with vacuum panel insulation
  - Margins can use less expensive and lighter insulation



Solar panel mounts designed…

- Requirements based on environment
- All are designed for rapid deployment in challenging environments
- One of the last station components to be designed

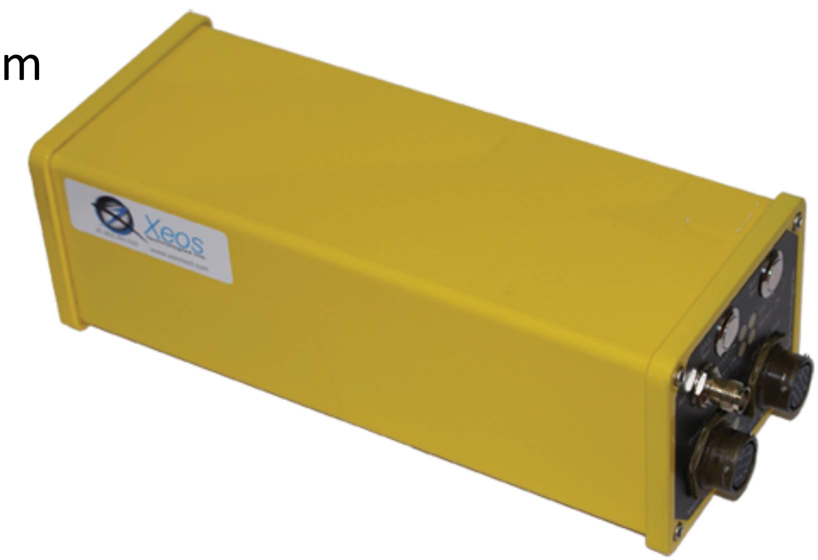


100% Testing Required...Including Cold Testing

Is Telemetry required?

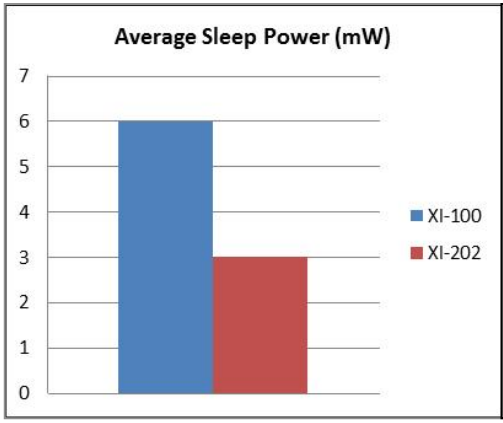
For remote high latitude deployments Iridium based systems is only option....

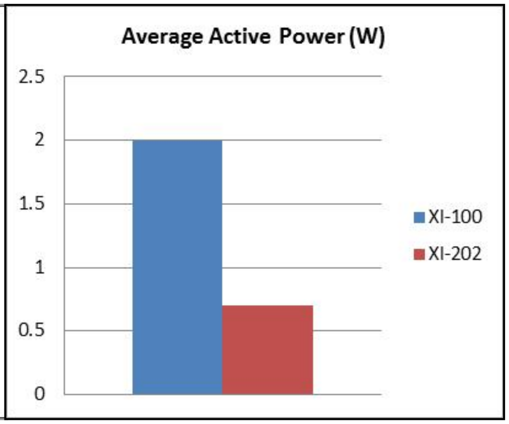
- Rudics is used with an Xeos XI-100B for data transfer, SOH(state of health) and station control
- Short Burst Data (SBD) is used for SOH and control, both XI-100B and XI-202



XI-202
Xeos Technologies Inc.

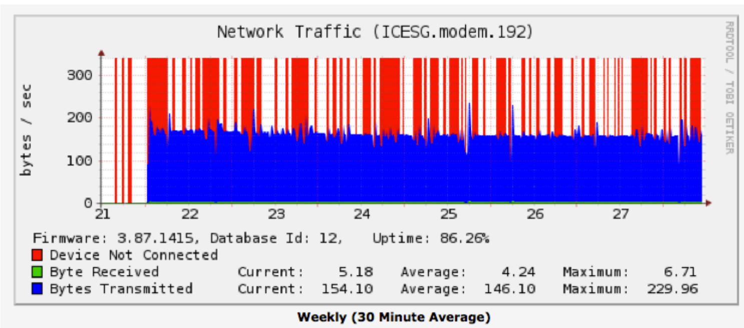
- SIM-less, SBD Only modem
- Low impact, low power solution for reliable state of health (SOH) data.
- Benefits Compared to XI-100:
  - Reduced Size
  - Reduced Power Consumption



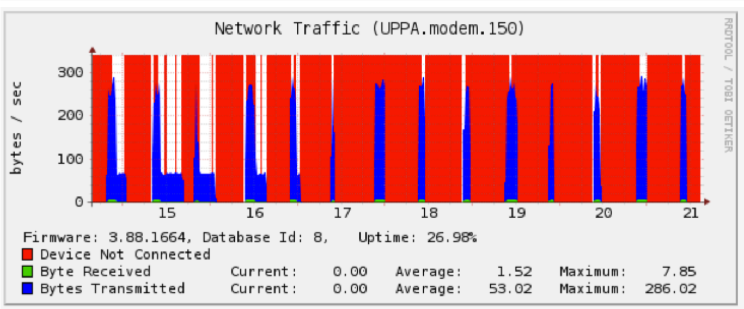


Iridium Rudics Telemetry

- Low power and low bandwidth



4 Watts
20 sps Real time



3 Watts
20 sps 8 hour latency

Next Generation Seismic Station

Goals
- Light, small stations
- Rapid installation and removal
- Plug and play design
- In short, improve on present 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

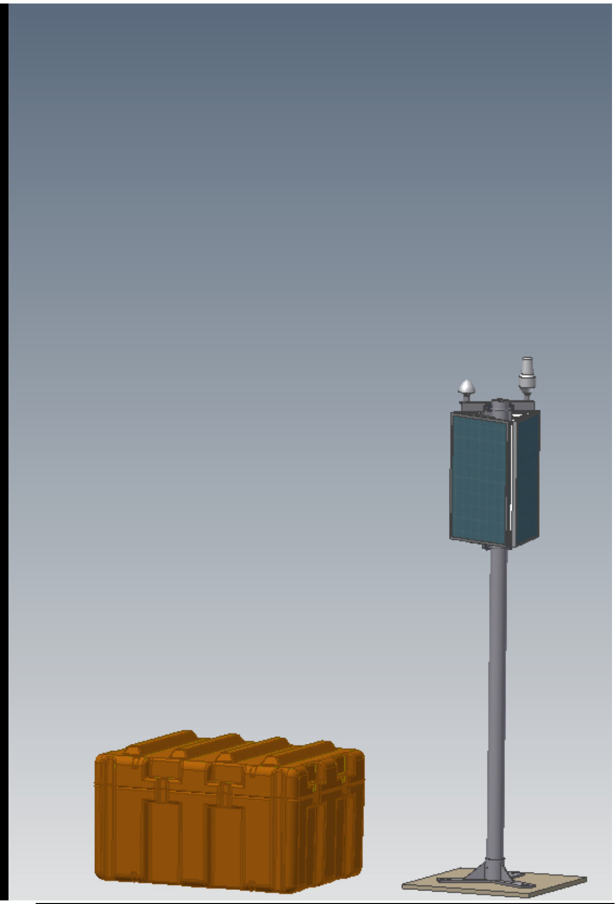
Are combined with a small AGM and solar array for summer time operation

IRIS PASSCAL POLAR PROGRAM

Next Generation Seismic Station

Enclosure and Solar

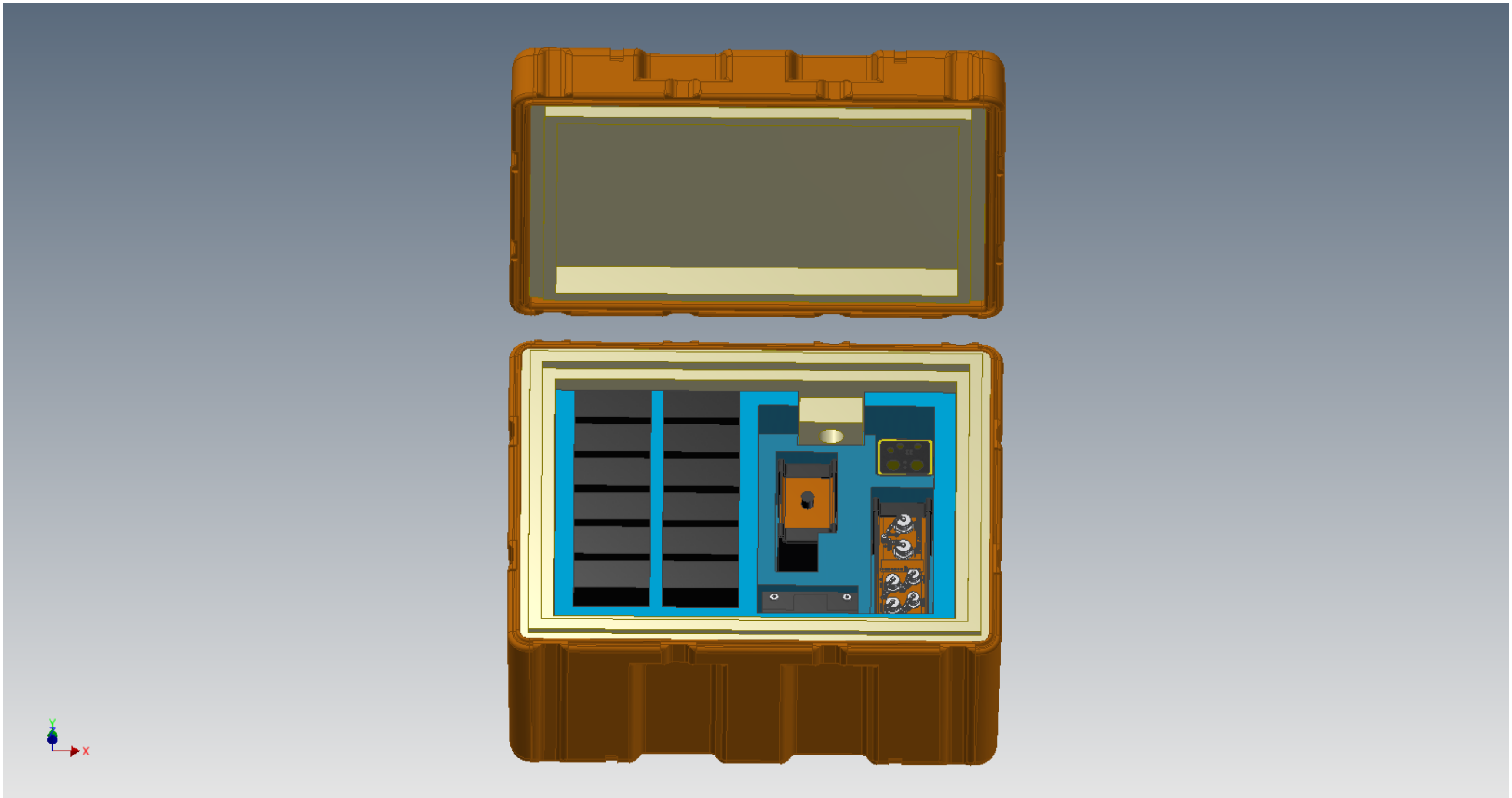
Weight: 365lbs
Volume: 35ft^3



Weight: 115lbs
Volume: 19ft^3

IRIS PASSCAL POLAR PROGRAM

Next Generation Seismic Station



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

IRIS PASSCAL POLAR PROGRAM

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
Average power budget = 2 watts
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
Average power budget = 2 watts
Total weight = 350lbs
Total cube = 20ft^3

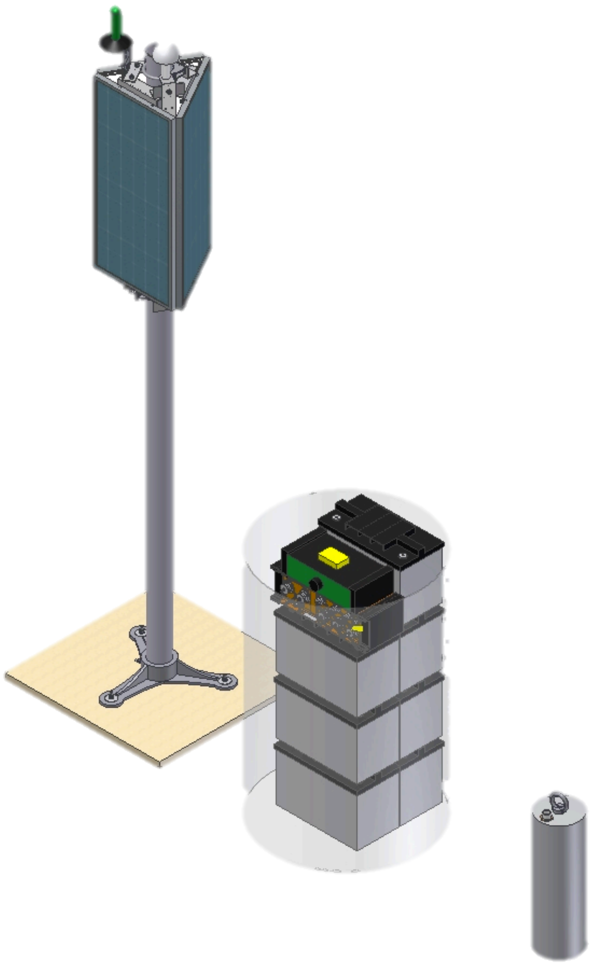
Installation:

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

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

IRIS PASSCAL POLAR PROGRAM

TA Alaska Light Aircraft Deployable Station Concept



Antarctic Station Adapted for TAAK Deployment of 2 Years…..

- Alternate enclosure: steel barrel, water proof, bear proof!?
- Primary and or secondary batteries depending on location.
- Solar panel either strapped to barrel or auger in ground
- Weight still under 300 pounds if primary batteries used
- Direct burial tilt tolerant sensor
- Telemetry limited to power cycled SOH and 1 SPS, quality assessments by file downloads in summer
- Full data recovery by service or at pullout

Future Developments

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.

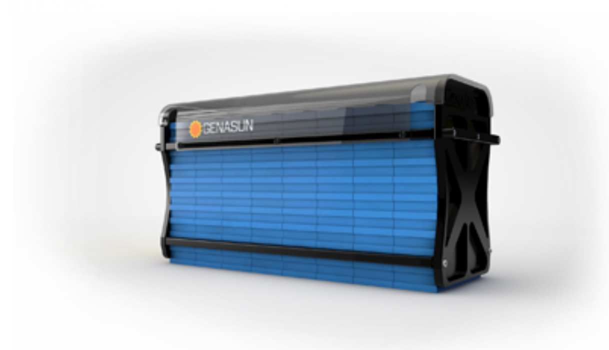
- Low power, both types i**GEOICE** ntegrate a digitizer and post hole seismometer for installation in snow/ice
- Environmentally sealed, built for limited and difficult logistics
- Improved tilt tolerance
- Target is 125 element array
- Initial field testing in 2014?

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

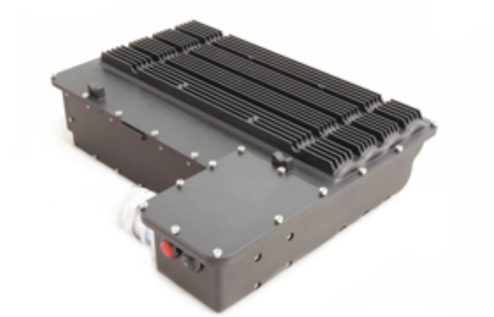
- Require oxygen source
- Cannot source large currents
    - Transient currents can cause large voltage drops
- Capacity drops of 0% near -20C
- Use air cells like a solar panel to charge a rechargeable battery?
    - Modify existing solar change controller – GV-5C

Rechargeable Lithium Batteries

- Characterization Testing on small strings
  - Capacity de-rate at Polar temps
  - Cold temp effect on lifespan
  - BMS functionality at cold temps
- Battery Management System (BMS) Standard
  - Power System Monitoring with data output
  - String Isolation, remove failed cells
  - Heating systems
- More Energy per Weight and Volume
  - 2x Gravimetic Power Density
  - 1.27x Volumetric Power Density



5 kWh Marine Li Battery



240 Wh BDI Battery

$LiFePO_4$ Testing

$LiFePO_4$ Batteries vs Lead Acid Batteries

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

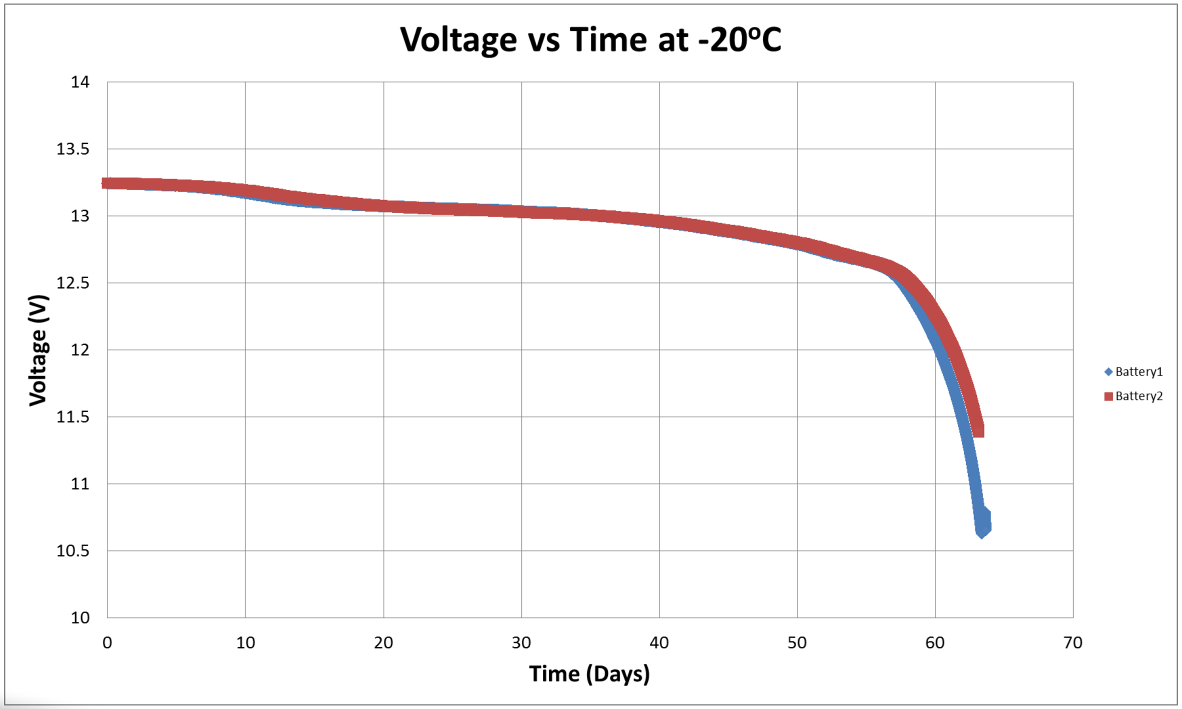
The PASSCAL Engineering group and Genasun have characterized the cold temperature performance of the $LiFePO_4$ batteries sold by Genasun:

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

$LiFePO_4$ 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).

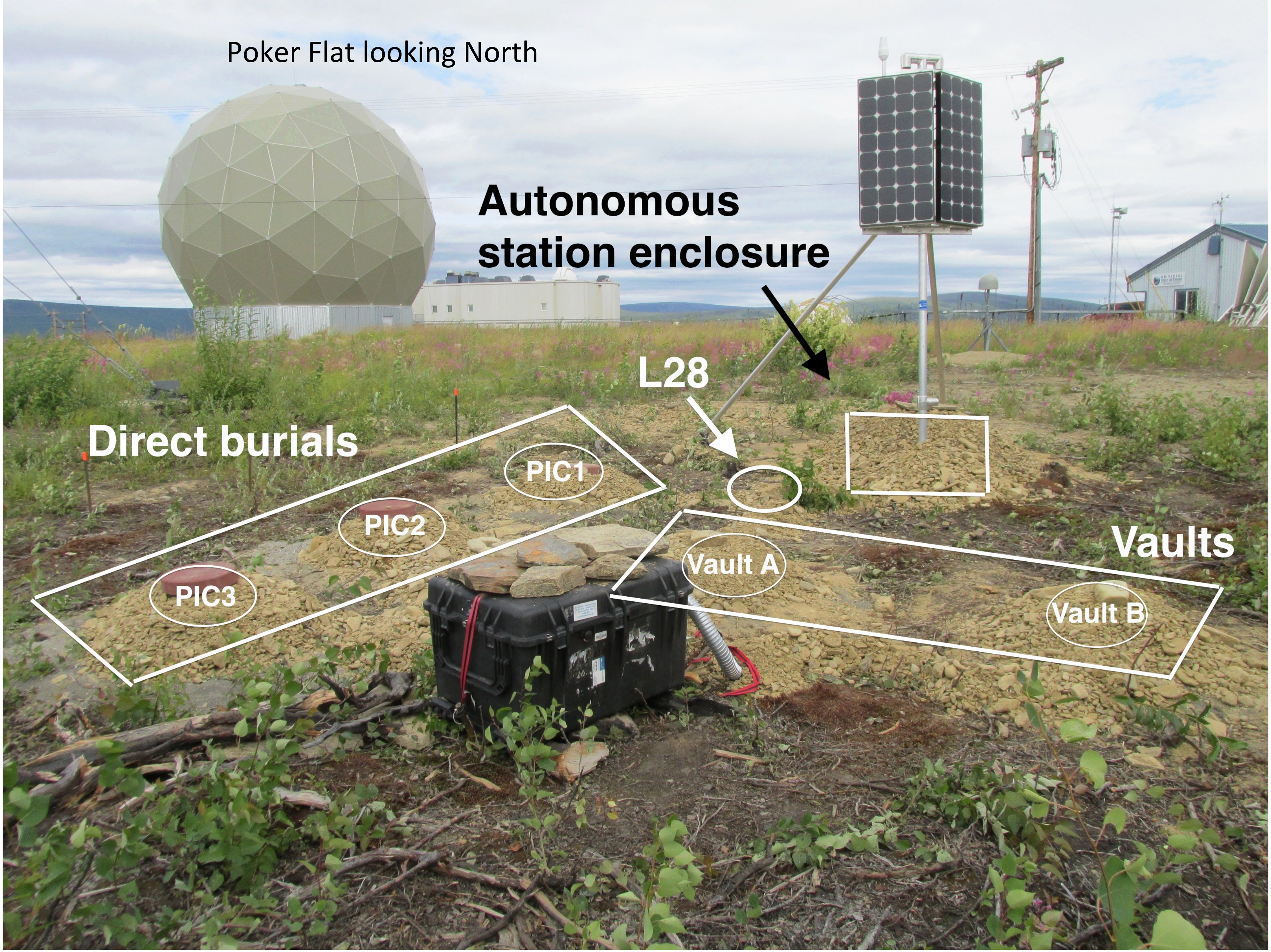


<u>Capacity Delivered:</u>

Batt 1 = 97.7Ah

Batt 2 = 97.5Ah

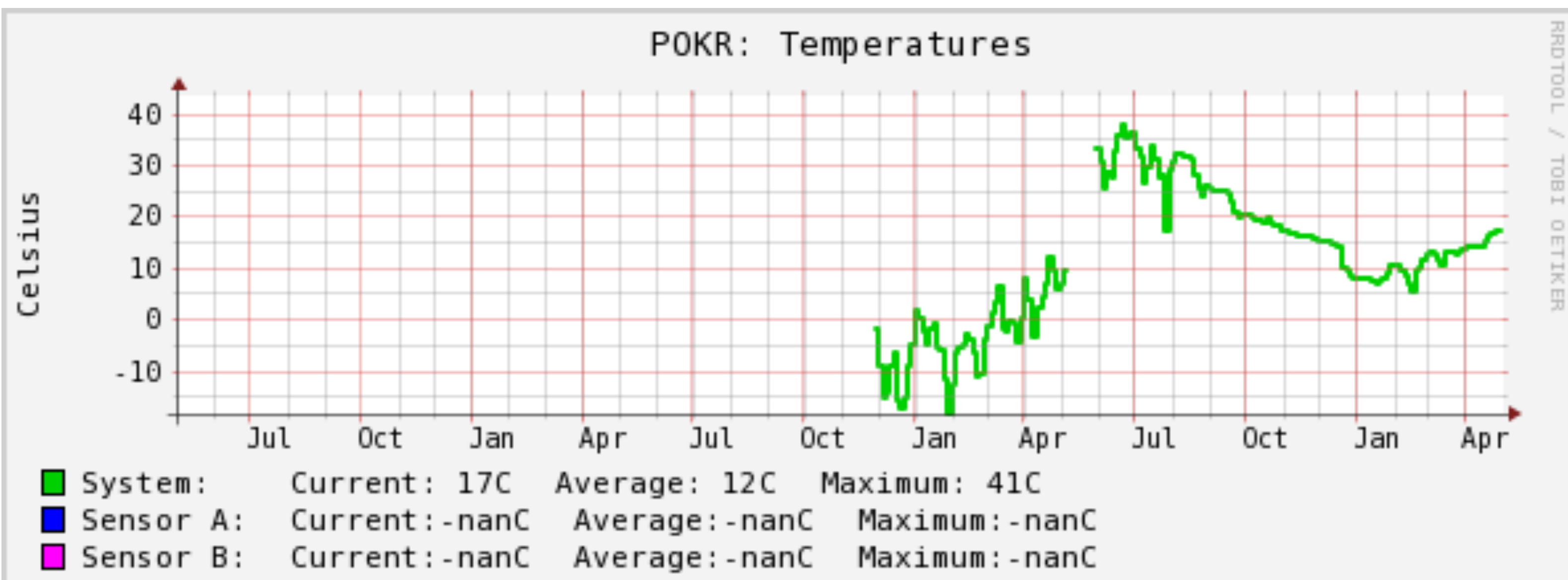
Essentially no de-rate from nameplate capacity!


Poker Flat looking North
Autonomous station enclosure
L28
Direct burials
PIC1
PIC2
PIC3
Vaults
Vault A
Vault B

Direct Burial of Station helps with reducing size of battery pack…

Assuming Polar style discharge rates (less than 100mA per battery cell):

- An AGM will deliver about 65% rated capacity at -20C.
- Lithium rechargeable will deliver 98% capacity at -20C.
- Air cells – 0 capacity at -20C

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