Over-Snow Rovers for Polar Science Campaigns

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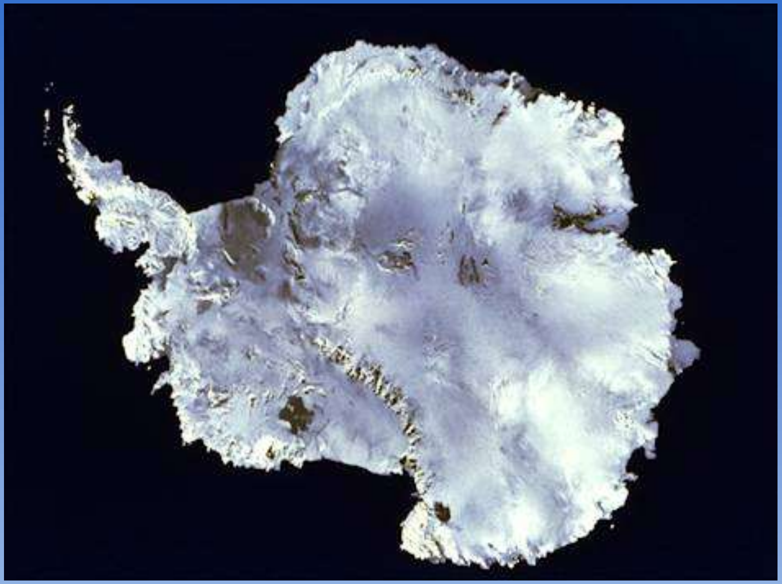
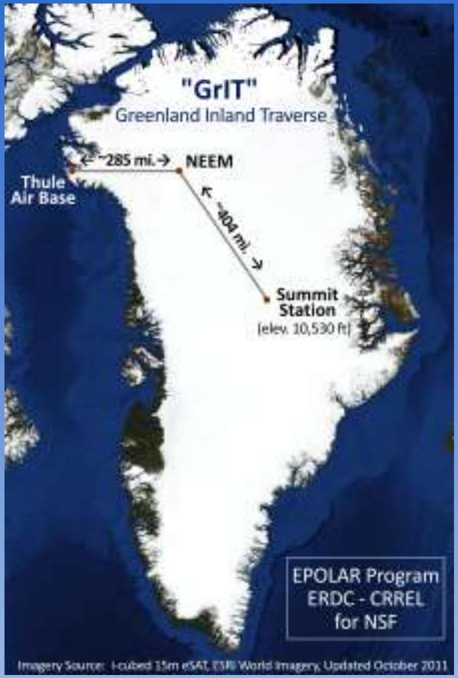
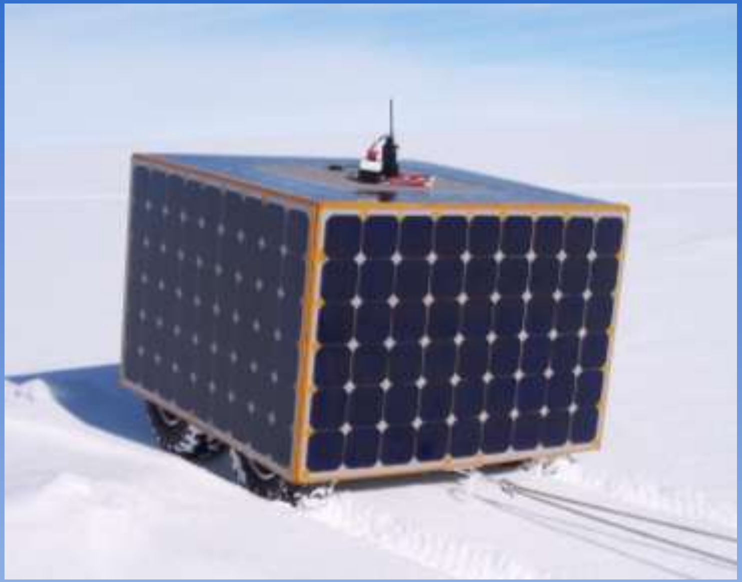
Why Polar Robots?





- Harsh & remote = high cost to conduct field science
- Extend spatial & temporal coverage
  - — Repetitive (boring), systematic surveys
  - — Atmospheric science, glaciology, geology, space weather, extreme biology
- Improve safety of crevasse detection for traverses

Yeti & Cool Robot



Lightweight, reliable, efficient

- 4WD (firm snow) – low drivetrain losses
- GPS waypoint following
- Zero emissions (batteries, solar)
- ~ 160 kg towed-payload capacity
- 3 – 7 km/hr survey speeds

Student design projects

- Mission: to support polar science & operations

Yeti – Autonomous GPR Surveys

- Greenland inland traverse crevasse zone (2008, 2012)
- South Pole traverse crevasse zone (2009, 2010)
- Old Pole station – buried buildings (2011)
- Mt Erebus ice caves (2012)
- McMurdo-Ross Ice Shelf shear zone (2013 – 15)

Yeti Design Parameters

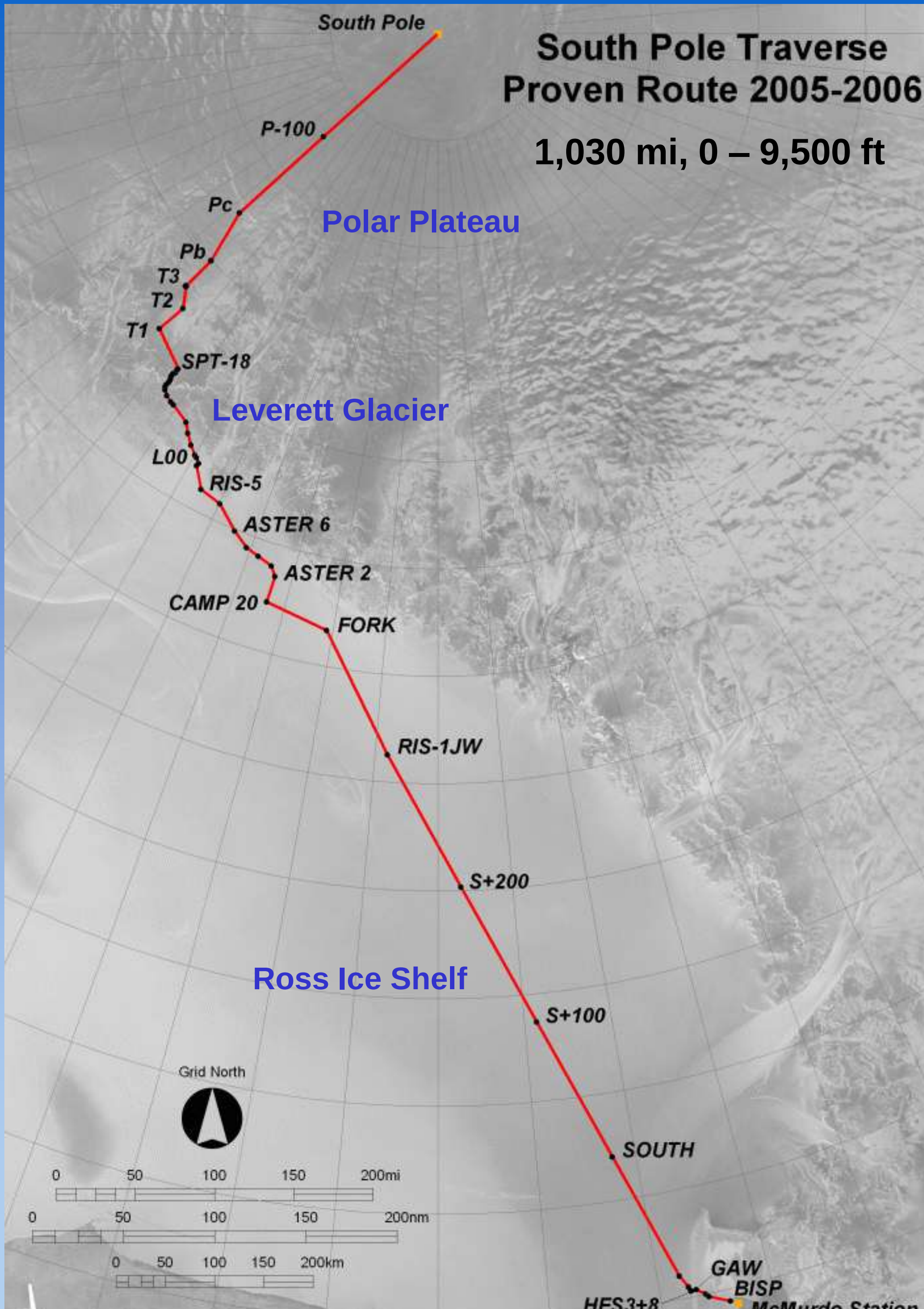
Parameter	Design Target	Measured Result
Rover mass (kg)	70	81
Payload mass, towed (kg)	9	15
Dimensions (m)	1.1 x 1.0 x 0.6	1.1 x 1.1 x 0.9
Speed (m/s): maximum	2.0	2.2
: average	1.5	1.1 – 1.8
Duration (h)	2	2.2 – 9.3
Range (km)	10	12 – 34
Path-following tolerance (m)	± 5	± 3
Minimum temperature (°C)	-30	-32
Wheel diameter (m)	0.51	0.51
Ground clearance	0.30	0.30
Ground pressure (kPa)	< 35	20
Housekeeping power (W)	20	17
Resistance per unit weight, R/W	0.25	0.08 – 0.31

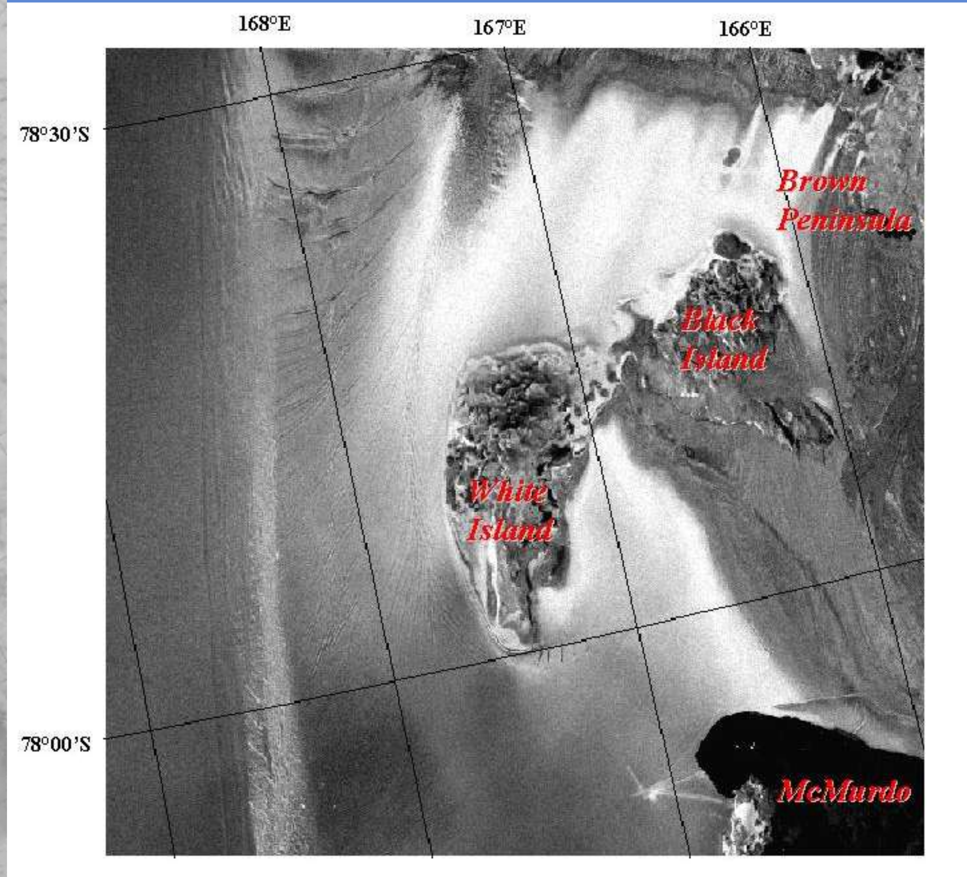
$$P_b = P_h + \frac{W(R/W)V}{\eta_{mg}}$$

~ 500 W, batteries 1,200 Whr

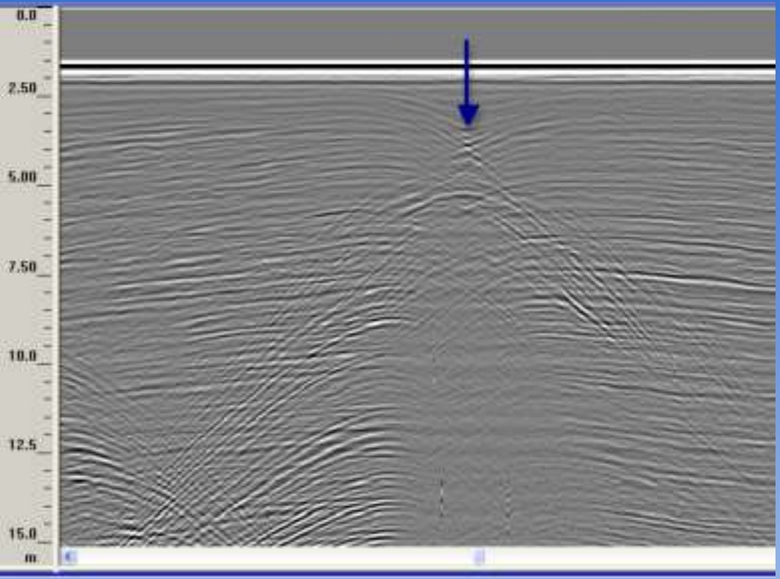
South Pole Traverse Route

- Shear-zone boundary between Ross & McMurdo ice shelves



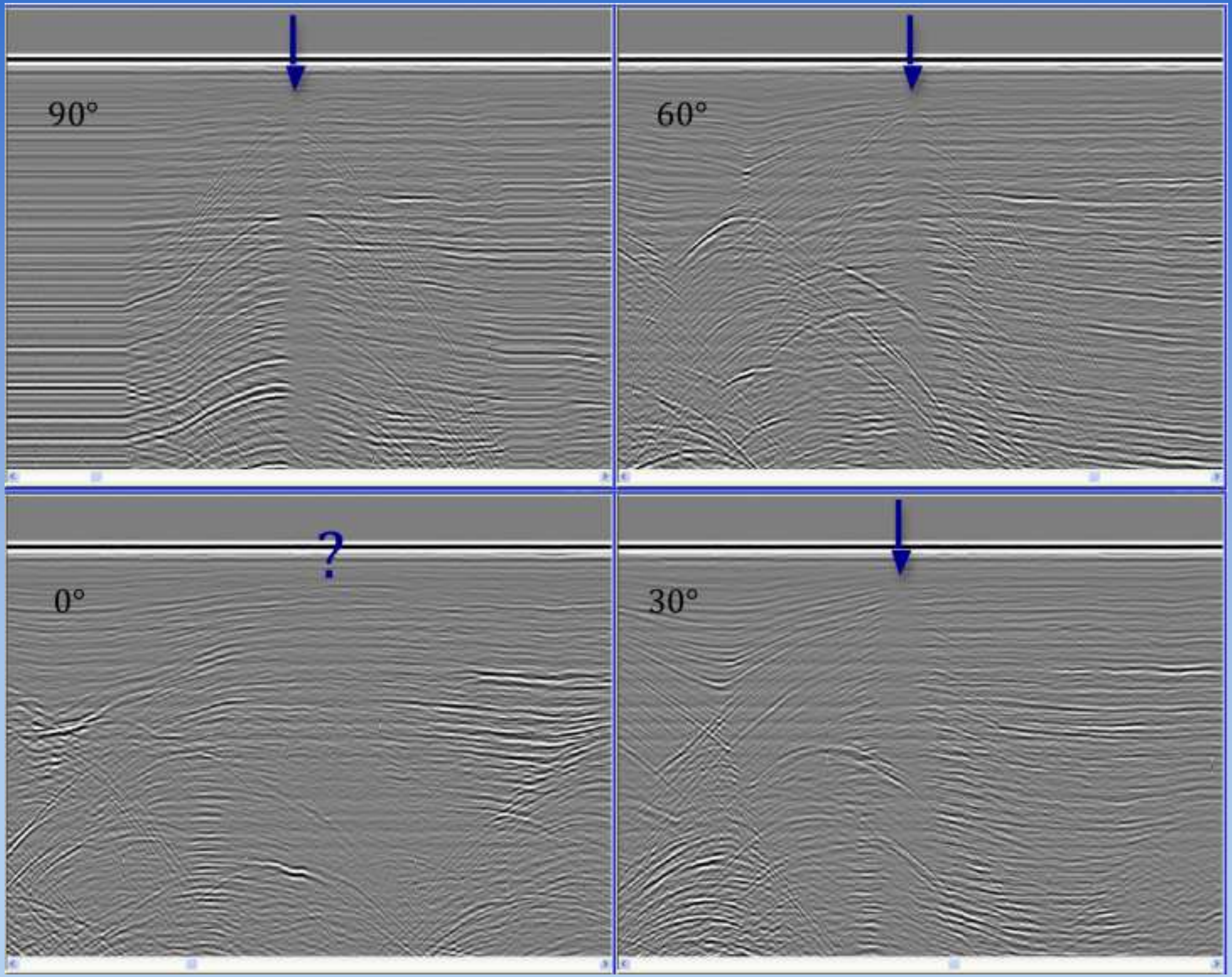


GPR Crevasse Detection

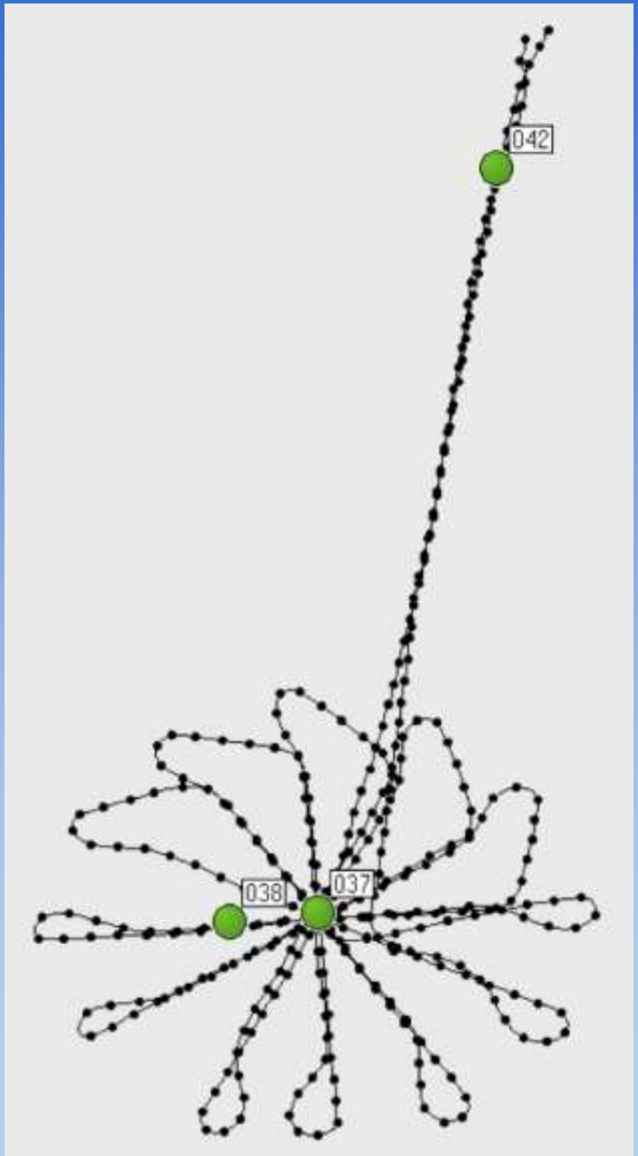


- Radar returns continuously scroll across screen
- Crevasse signature varies with snow conditions & approach angle
- 2 – 4 sec to stop vehicle
- 8 – 12 hr/day focused on GPR screen
- Survey is on critical path for traverse schedule
- High stress & tedious (boring)

Sensitivity to Approach Angle



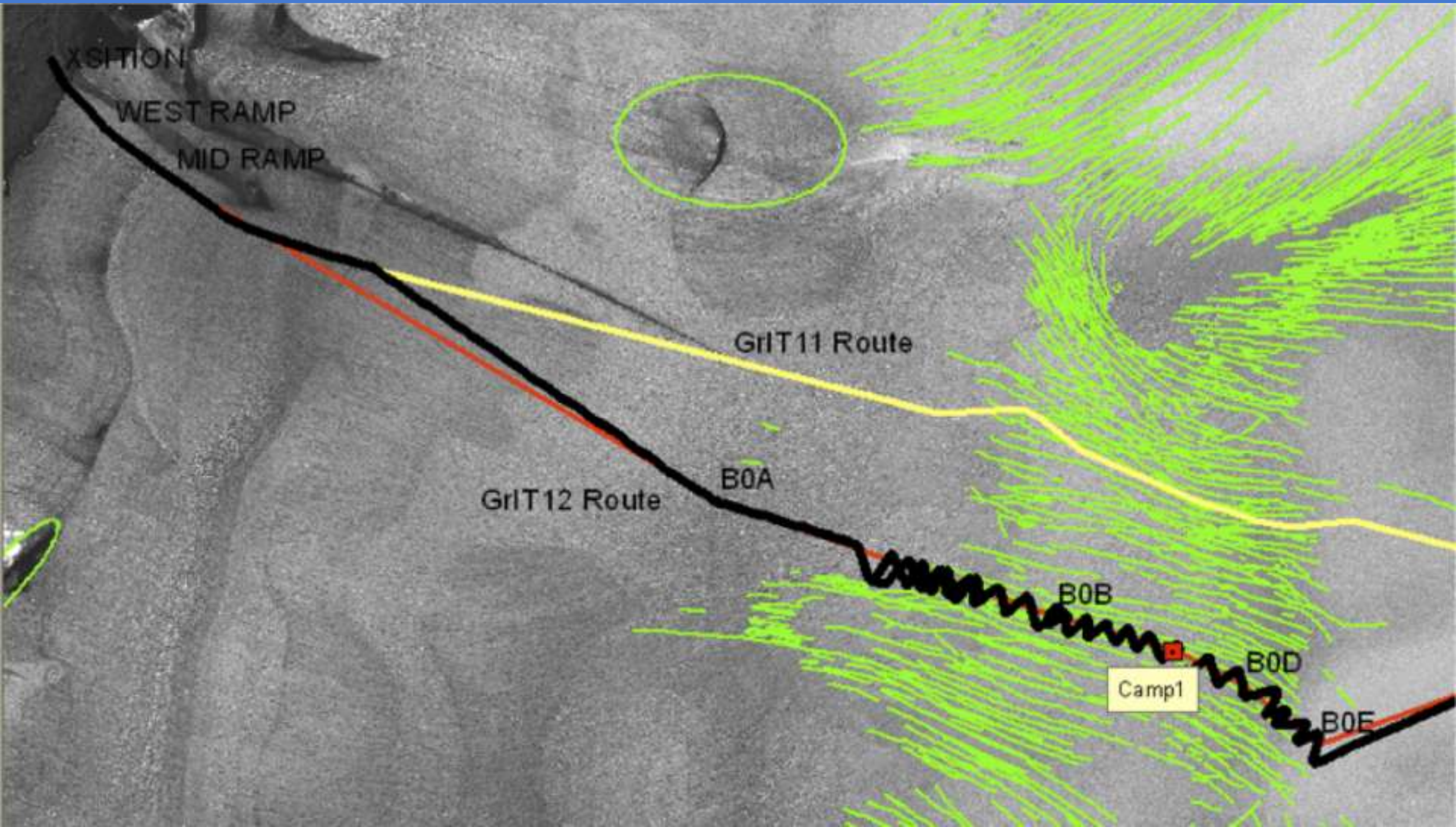
Autonomous vs Manual GPR



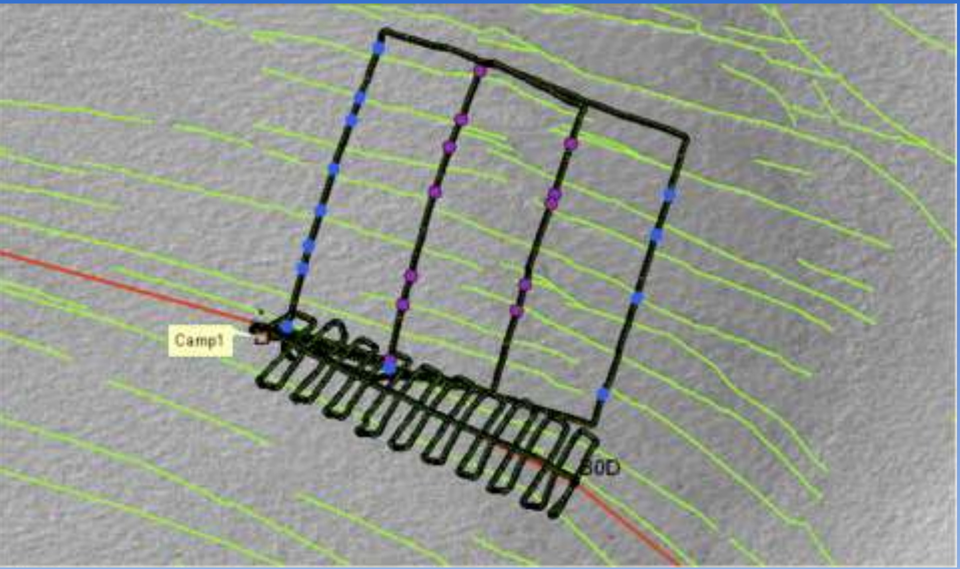
- Increased safety, reduced stress
- Continuous GPR records across hazards
- Adds capability
  - Increased search area
  - Regular, gridded surveys
  - Rosette pattern to investigate “unknowns”
- Developing auto-detection
  - Classify: yes, no, maybe
  - Run auto-rosette if maybe
  - Auto-detect will help manual surveys too

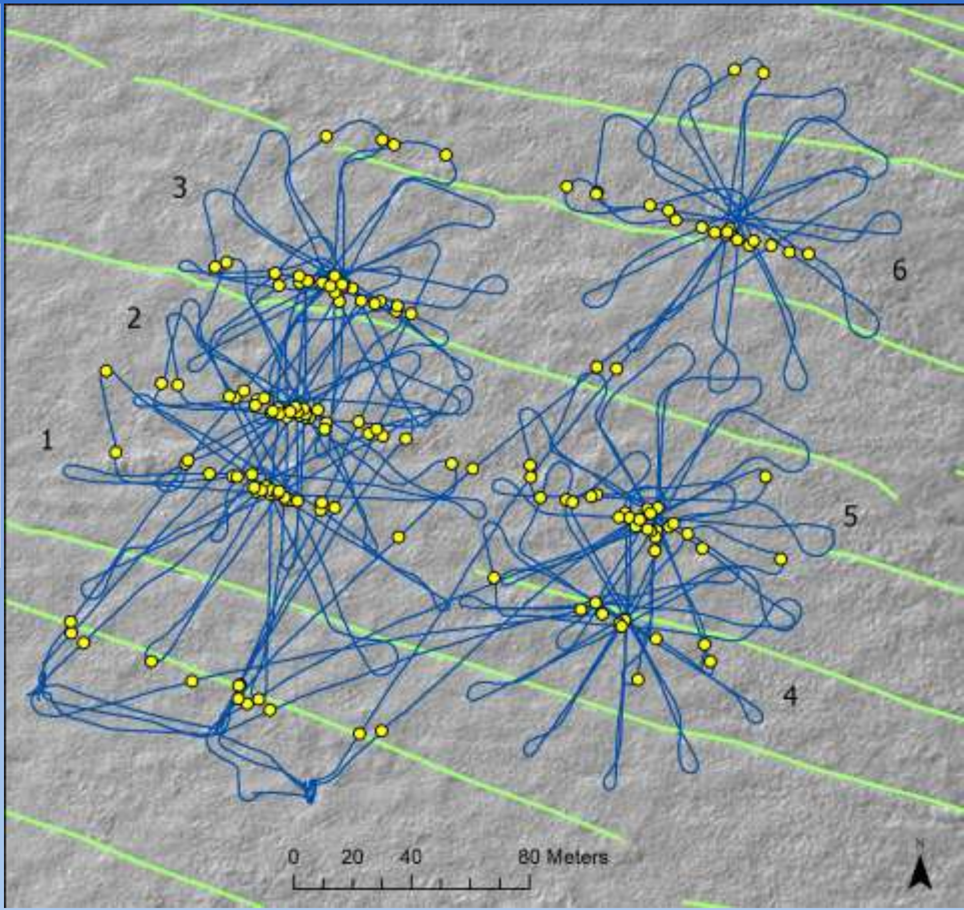
Greenland Inland Traverse Route

- Complex crevasse fields through transition onto ice cap



Yeti 2012 Survey





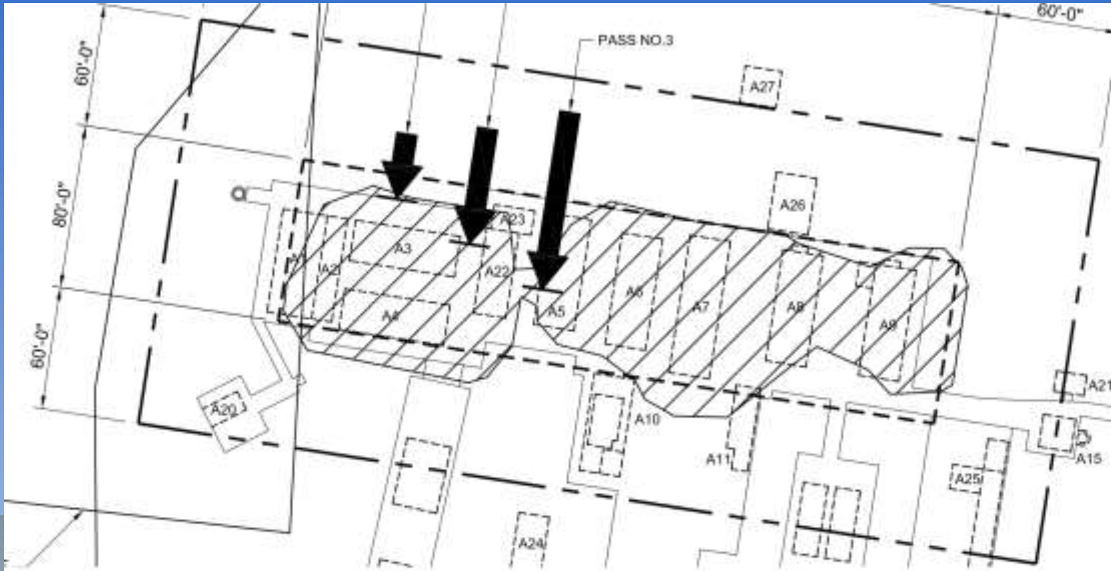
- 34 km of survey lines, 97% auto
- ± 3 m GPS precision
- Demonstrated various survey patterns, including rosettes
- High reliability, good mobility
- Immobilized in basin of soft snow
- Two tip-overs in tractor ruts

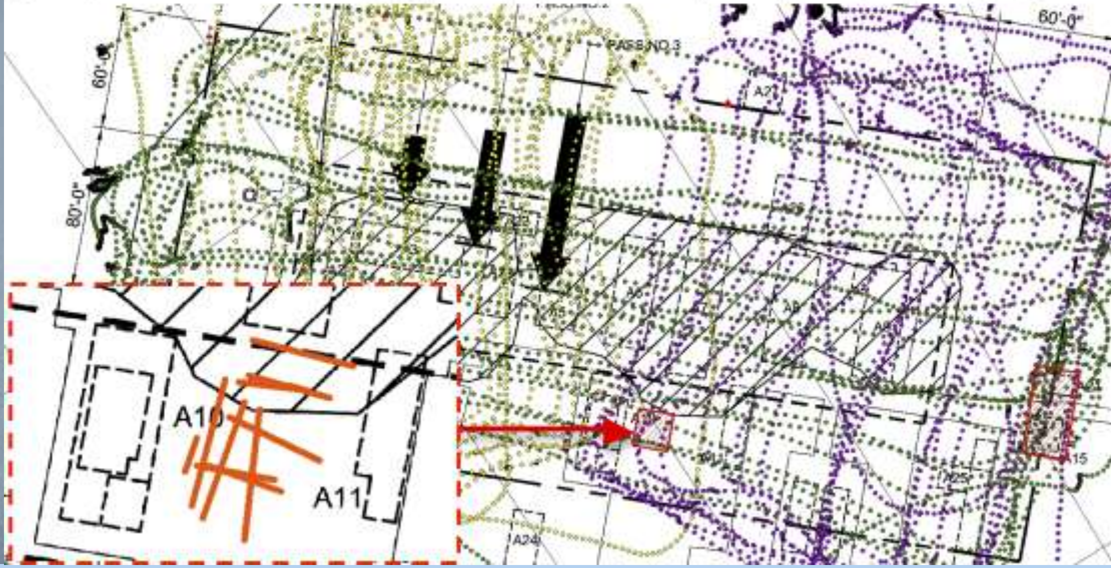
Old Pole Survey

- 1950’s station buried under ~ 30 ft of snow
- Tractor fell into access hatch in 2009
- Manual GPR survey, blasting in 2010
- *Yeti* survey Dec 2011 after winter infilling

Results

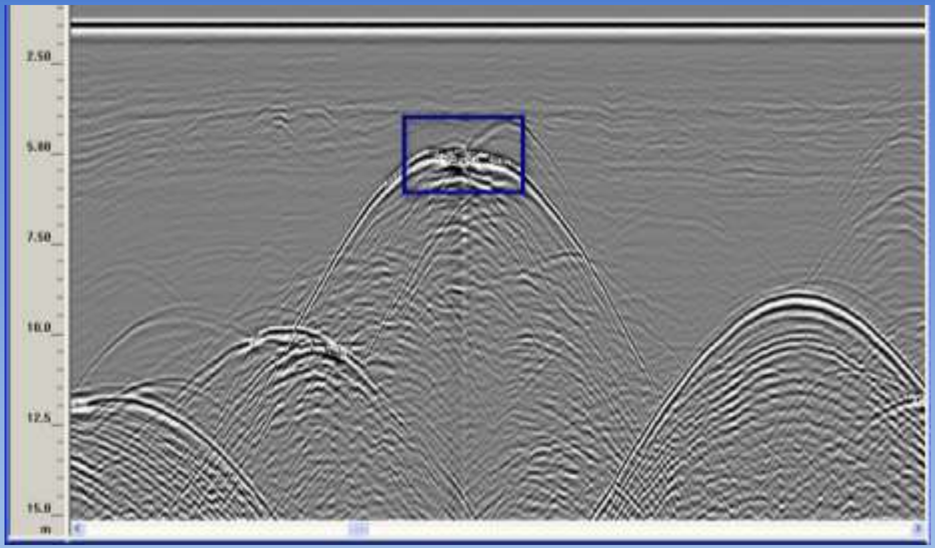
- 10 km of auto surveys
- No immobilizations, -33° C
- Good navigation
  - S 89.987 to 89.988
- Off-continent GPR review
- Found another hazard





Systematic Survey

- 10 crossings in 2 directions, continuous records
- Increased confidence & defined extent
- “Metal-roof building 3 – 4 m below surface”



Future Work

- Tilt limit
- Pre-immobilization detection (M. Eng thesis)
- Autonomous crevasse detection (PhD thesis)
- Auto mapping of crevasse locations

- GPR survey of Ross-McMurdo shear-zone
  - Oct 2013
  - boundary condition on Ross Ice Shelf (stability)
  - 5 km x 5 km grid, 63 m line spacing
  - repeat 2014, 2015

Cool Robot

Summer deployments

- Solar power (24 hrs, renewable, zero emissions)
- Moderate temperatures (-40 C)
- 3 km/hr survey speed = 500 km/week

Simple = Reliable, Efficient & Low Cost

- 4WD, 60 kg, 15 kPa (2 psi) on tires
- GPS navigation (no vision system)

Student design, fabrication & testing

- 6 M.Eng., 4 B.Eng.

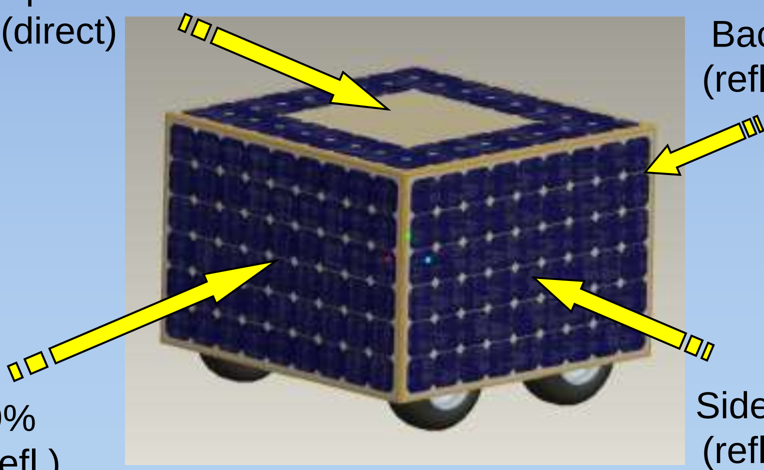
Cool Robot Capabilities

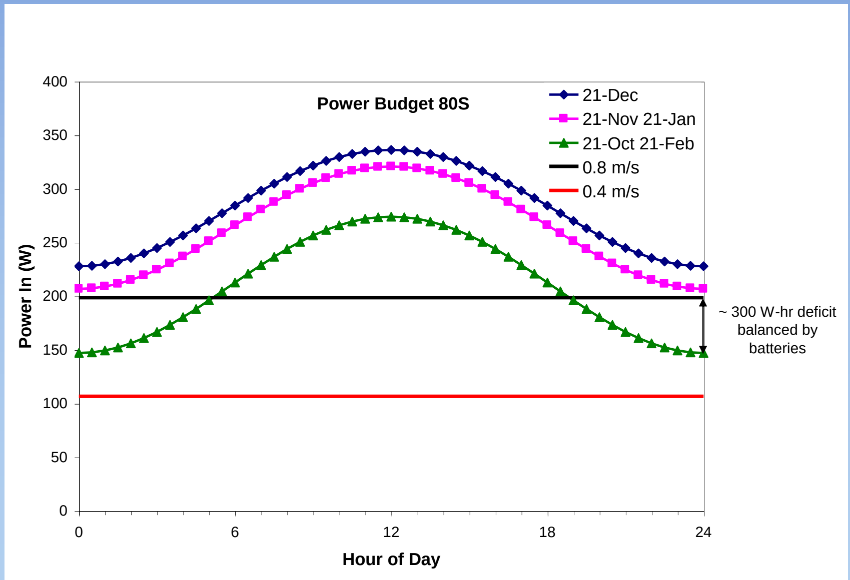
- 60 kg, 1.2 x 1.2 x 1 m
- 20 kg payload (40 kg sled)
- 500 km in 2 weeks (0.4 m/s), max. 1 m/s
- Payload power: 15 W driving, 200 W stationary
- Twin Otter transport without disassembly
- Autonomous GPS navigation
- *Iridium* satellite communications
- Tailor for specific polar science missions

Unique Solar Design

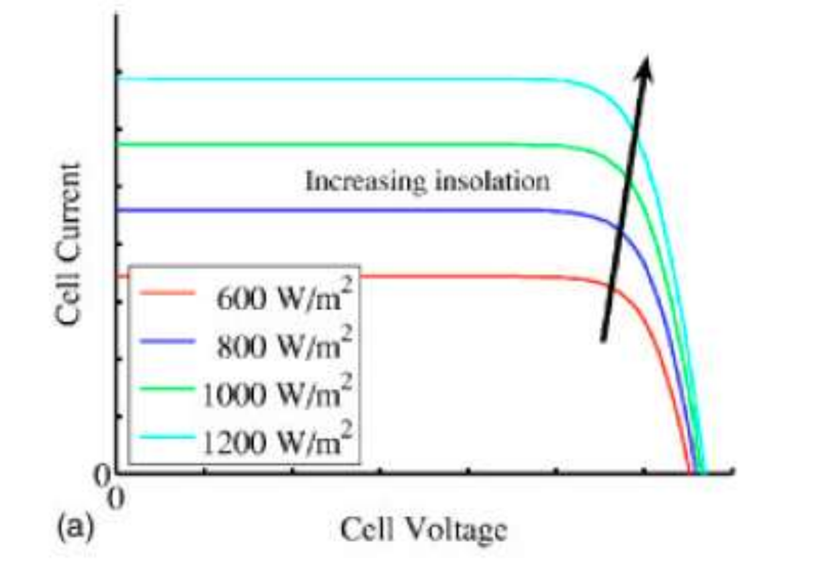
- Passive solar avoids sun tracking
- Vertical panels good at polar elevations
- Brilliant snow reflects sunlight onto panels
- Sufficient power for 500 km/week
- Control system matches power input with demand

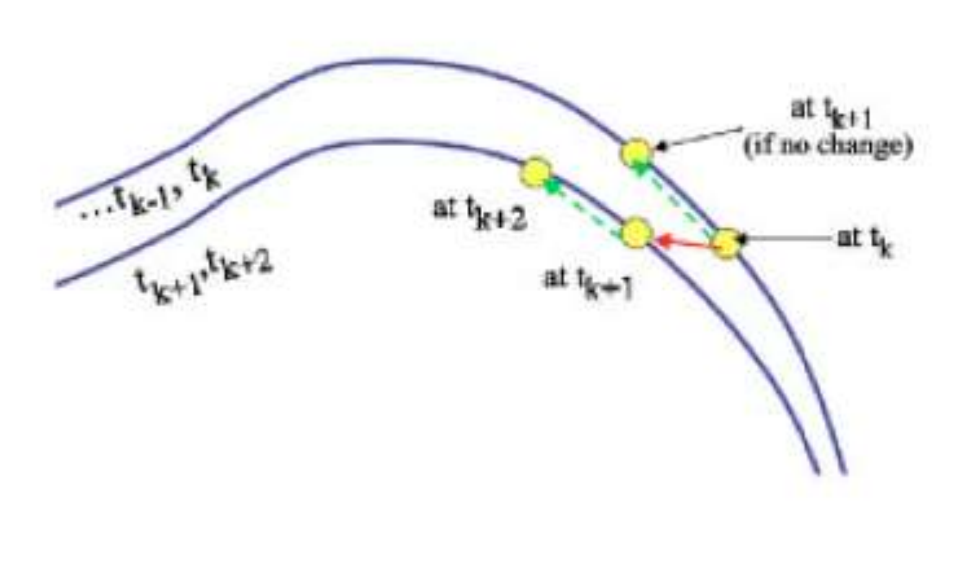
270 W electrical power @ 20˚ sun elev.
35% is reflected power

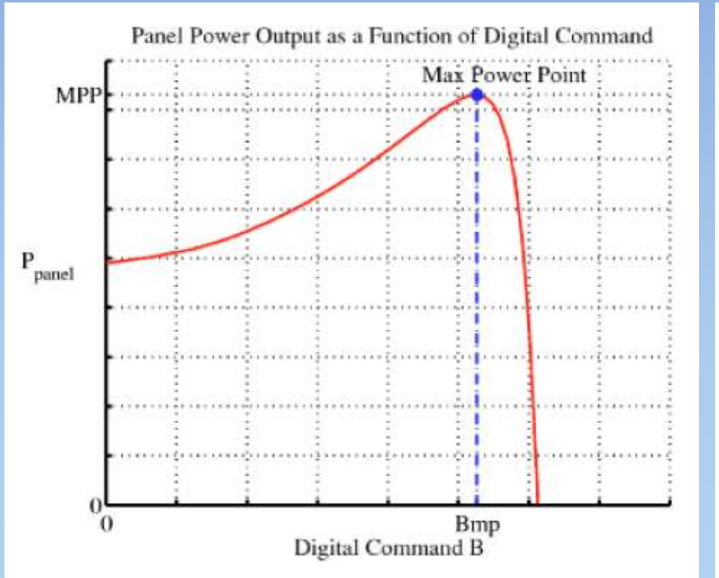


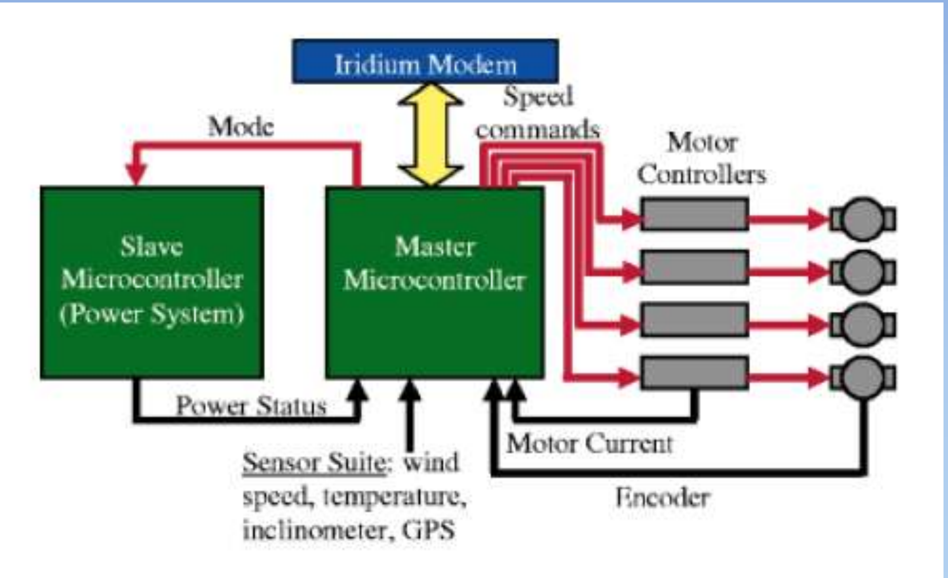


Solar In = Power Needed

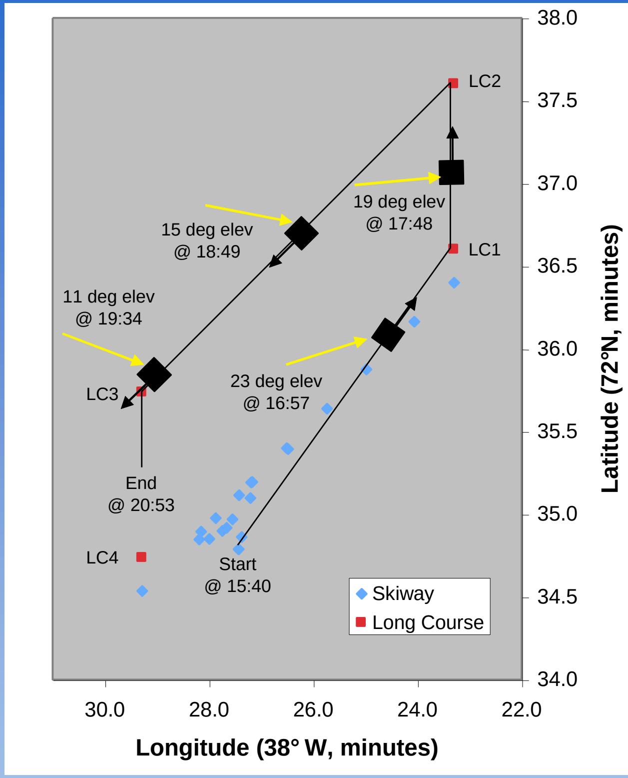


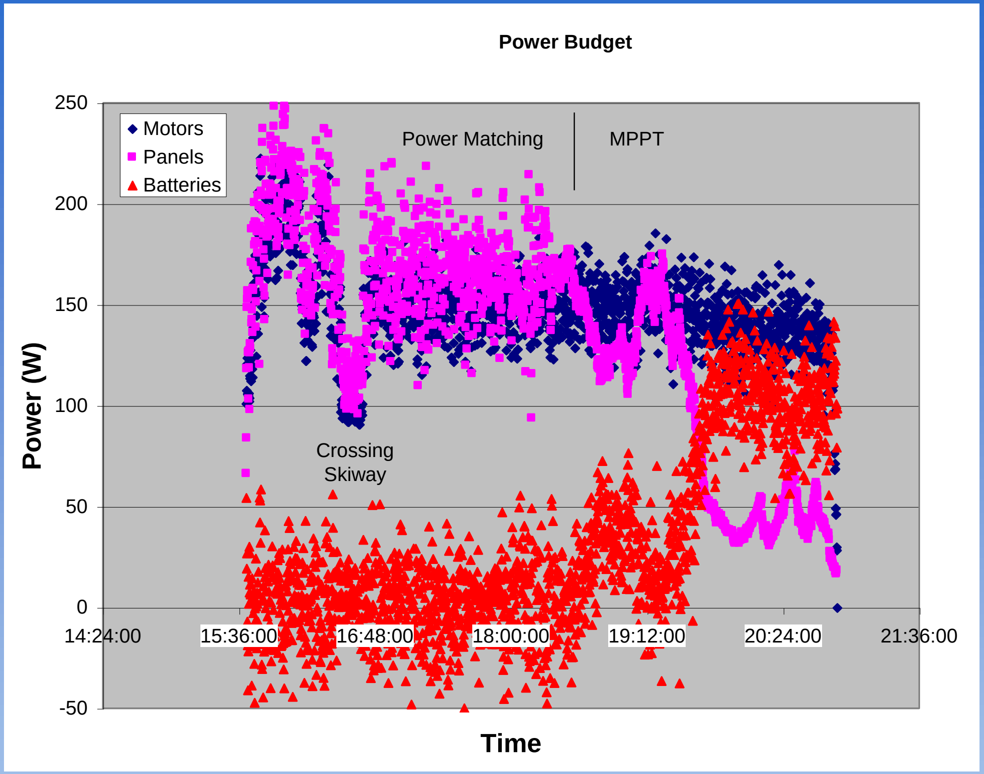






Greenland 2005 Tests





Validated power-budget model, power control & navigation

- Power match to 16° sun elevation (4 panels, low clouds)
- Then max power point tracking
- Successful navigation 5 – 8 hrs (minor algorithm errors)
- Soft snow: R/W = 0.21, Pt = 220 W at 0.8 m/s

Long Mission Concerns

Sastrugi

- Common 10 – 30 cm on 1 – 3 m scales
  - — effect power consumption, control & navigation
- Chart routes around large sastrugi

Winds

- Tip-over > 20 m/s
- Tradeoff solar area for lower profile
- Move every hour during blizzards

Crevasses

- Drive over bridged crevasses
- Chart routes around open crevasses

Future Work

- New solar box (lighter, better access, higher efficiency)
- Microprocessor, GPS same as *Yeti*

- Long-endurance science demo Summit June 2013
  - circumnavigate station for several days, ~ 300 km
  - sample emissions footprint (J. Dibb)
  - radar profile snow stratigraphy (M. Albert)

More Info

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Lever, J.H., A.J. Delaney, L.E Ray, E. Trautmann, L.A. Barna and A.M Burzynski (2013) Autonomous GPR surveys using Polar rover Yeti. *Journal of Field Robotics*, Issue 2, March/April.

R. Williams, J. Lever, and L. Ray (2012) An Autonomous Robotic Platform for Ground Penetrating Radar Surveys. *IEEE International Geoscience and Remote Sensing Symposium*, Munich Germany.

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Ray, L.E., J.H. Lever, A.D. Streeter and A.D. Price (2007) Design and power management of a solar-powered “Cool Robot” for polar instrument networks. *Journal of Field Robotics*, 24(7), 581 – 599.

Questions?