Wireless Network of GPS and Seismic Sensors: geoPebble

S Anandakrishnan, S Bilen, J Urbina
actual work by Tyler Boehmer, Mike Conway, Aaron Fleishmann, Joe Portelli, Bob Capuro, Randall Bock, and Peter Burkett!

Dept. of Geosciences, EESI, EE, SEDTAP
Penn State University

Center for Remote Sensing of Ice Sheets

Motivation

- Eliminate cabling
- Eliminate surveying
- Three component recording
- Open platform for continuous improvement

- Connectors suck!

Motivation

- Seismic
  - –2D seismic lines to 3D images
  - –single component to full wavefield
  - –snapshots in time to “4D” images
- GPS
  - –Glacier speeds are 1-100 cm/day, *with variability at that scale* at timescales of hours to days.
  - –Patterns of strain at the surface encode bed friction.
- Not just cryosphere.

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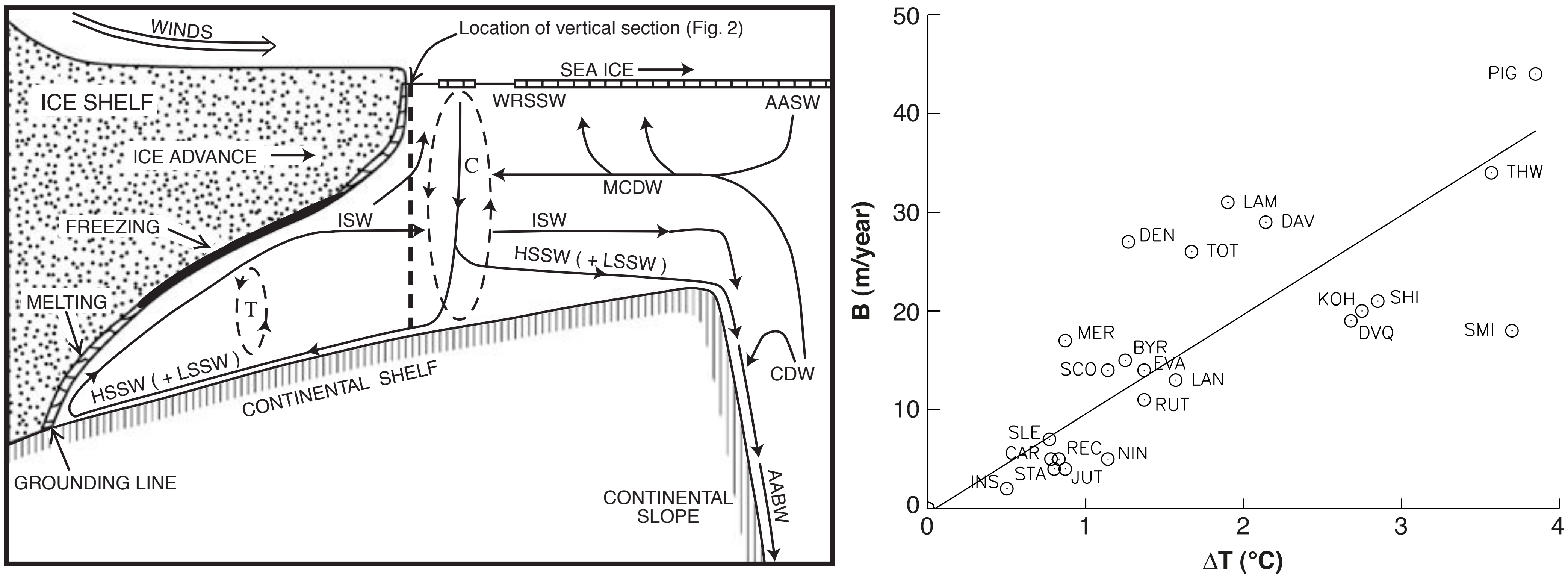
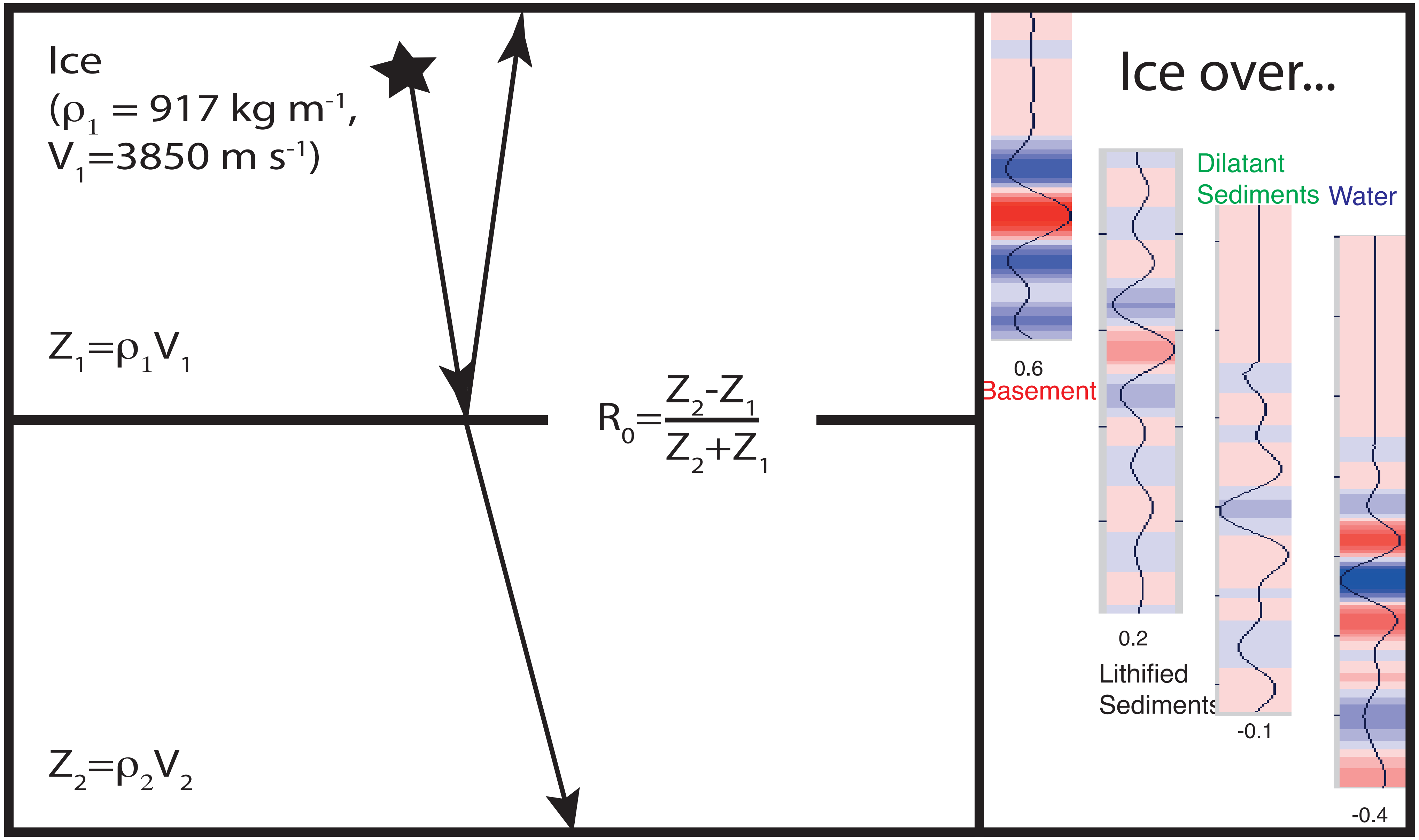
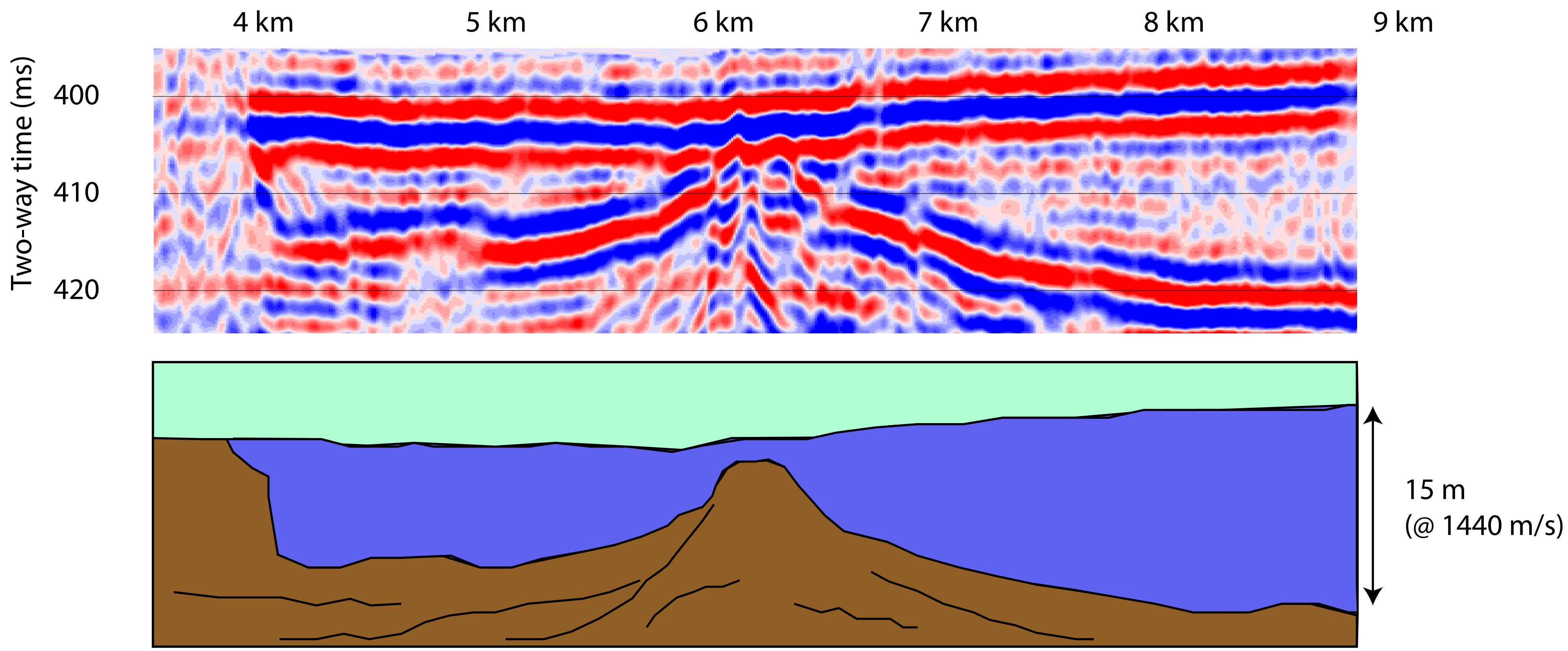


Left: Circulation beneath the Ross Ice Shelf (Smethie and Jacobs, 2005). Right: Grounding line melt rates versus thermal forcing (Rignot and Jacobs, 2002).


Ice
(ρ_1 = 917 kg m^{-1},
V_1=3850 m s^{-1})
$Z_1=\rho_1 V_1$
$R_0=\frac{Z_2-Z_1}{Z_2+Z_1}$
$Z_2=\rho_2 V_2$
Ice over...
0.6
Basement
0.2
Lithified
Sediments
Dilatant
Sediments
-0.1
Water
-0.4


4 km
5 km
6 km
7 km
8 km
9 km
Two-way time (ms)
400
410
420
15 m
(@ 1440 m/s)

Overview

- Motivation for development of geoPebble
  - Mainly for active seismic deployments (2D arrays, problem areas)
  - Short period passive seismic recording
  - decimeter-precision GPS
- Description
- Status of development

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Dynamic Glaciology

- Driving Stress for Glaciers: $\tau = \rho g h \alpha$
- Zero-th Order Measurements
  - Surface slope, α
  - Ice Thickness, h
- First Order Measurements
  - Velocity, bed properties, water, ...
- Critical Measurements
  - Seasonal velocity variability
  - Choose your favorite...

Cryoseismology

- Subglacial structure, sediments, water
- Sub-ice-shelf bathymetry
- Water flow and glacier deformation
  - seismicity for hydro-fracture, water flow; GPS for glacier strain
- Glacial erosion
  - seismicity for subglacial fracture, GPS (?)
- Avalanche precursors, detection

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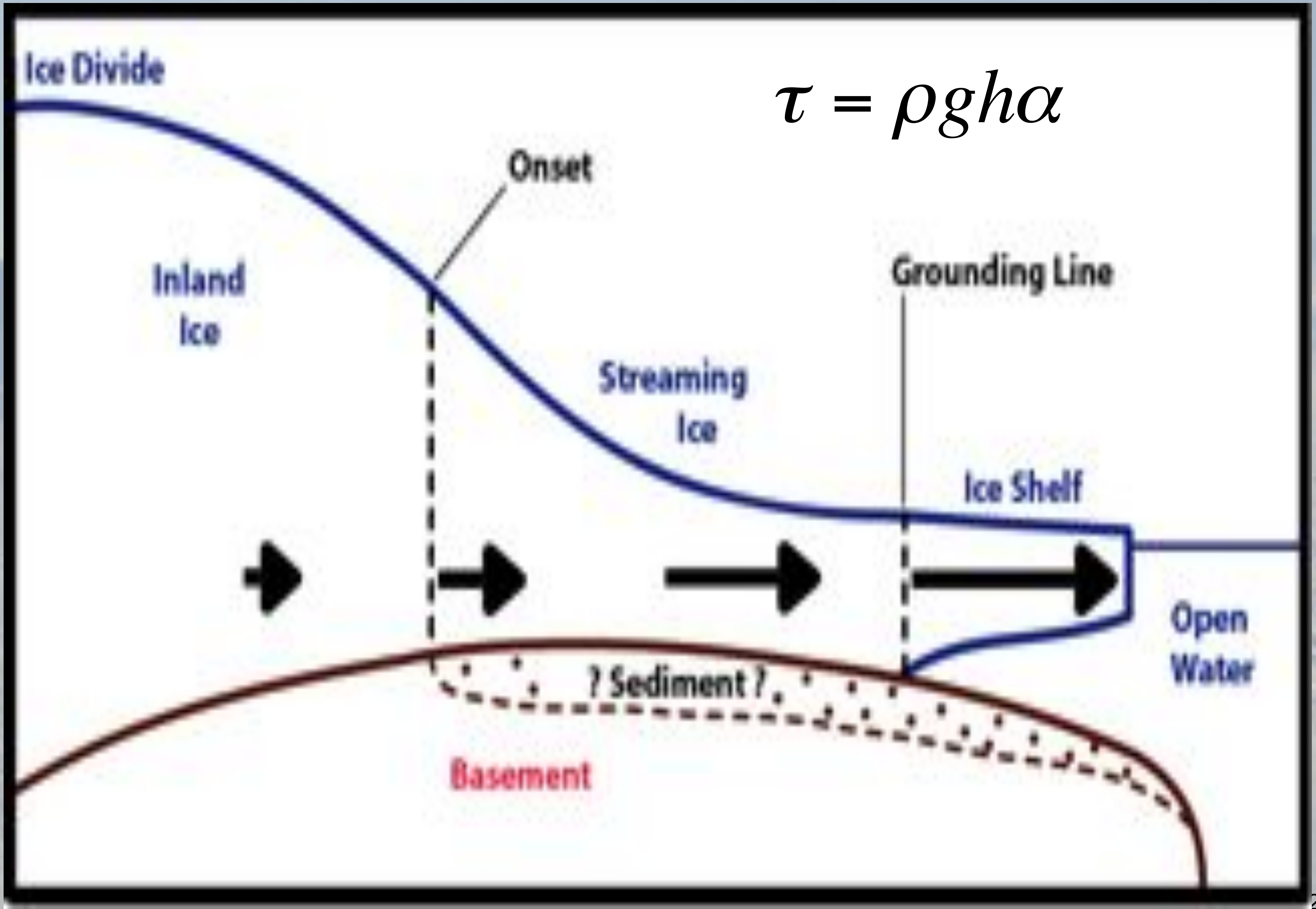
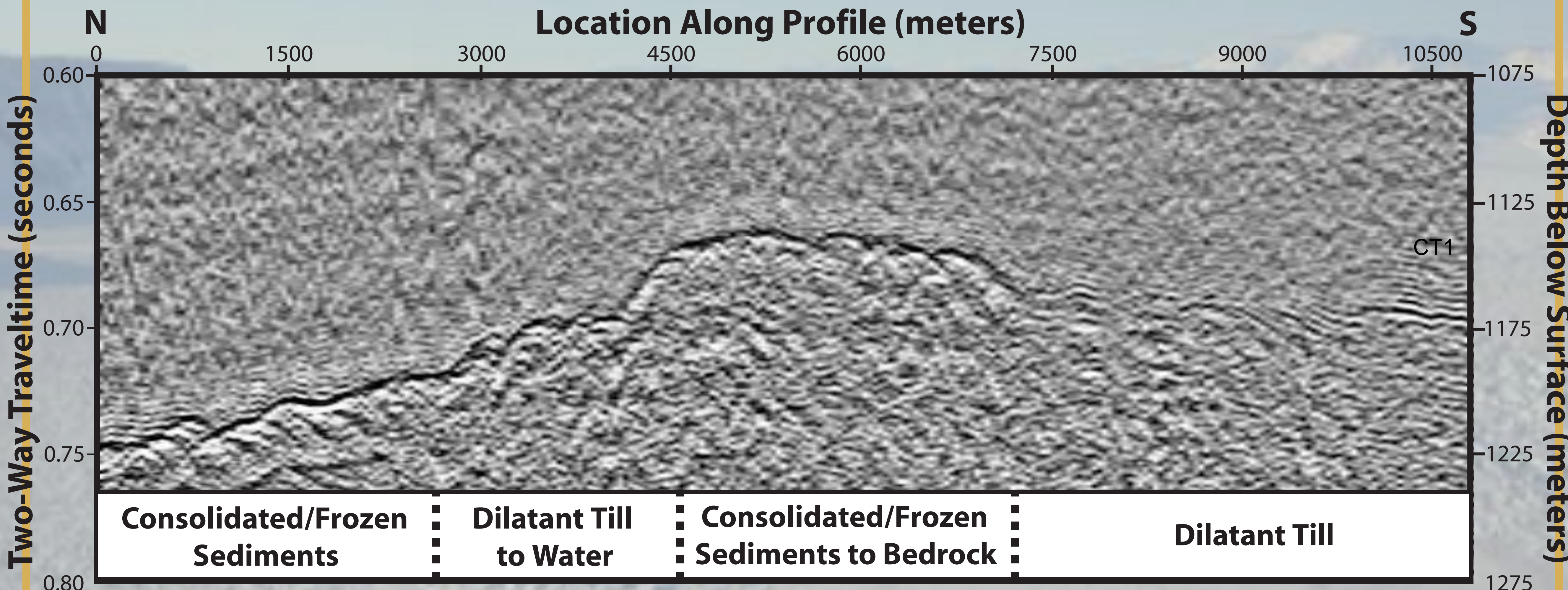


$$\tau = \rho g h \alpha$$

Ice Thickness

- Ground penetrating Radar
  - Excellent for cold, dry glaciers
  - Problematic for warm, wet glaciers
  - Can be used from helicopter or airplane.
- Seismic Reflection Profiling
  - Excellent in all temperatures, wetness
  - Only ground-based

Seismic Stack Section



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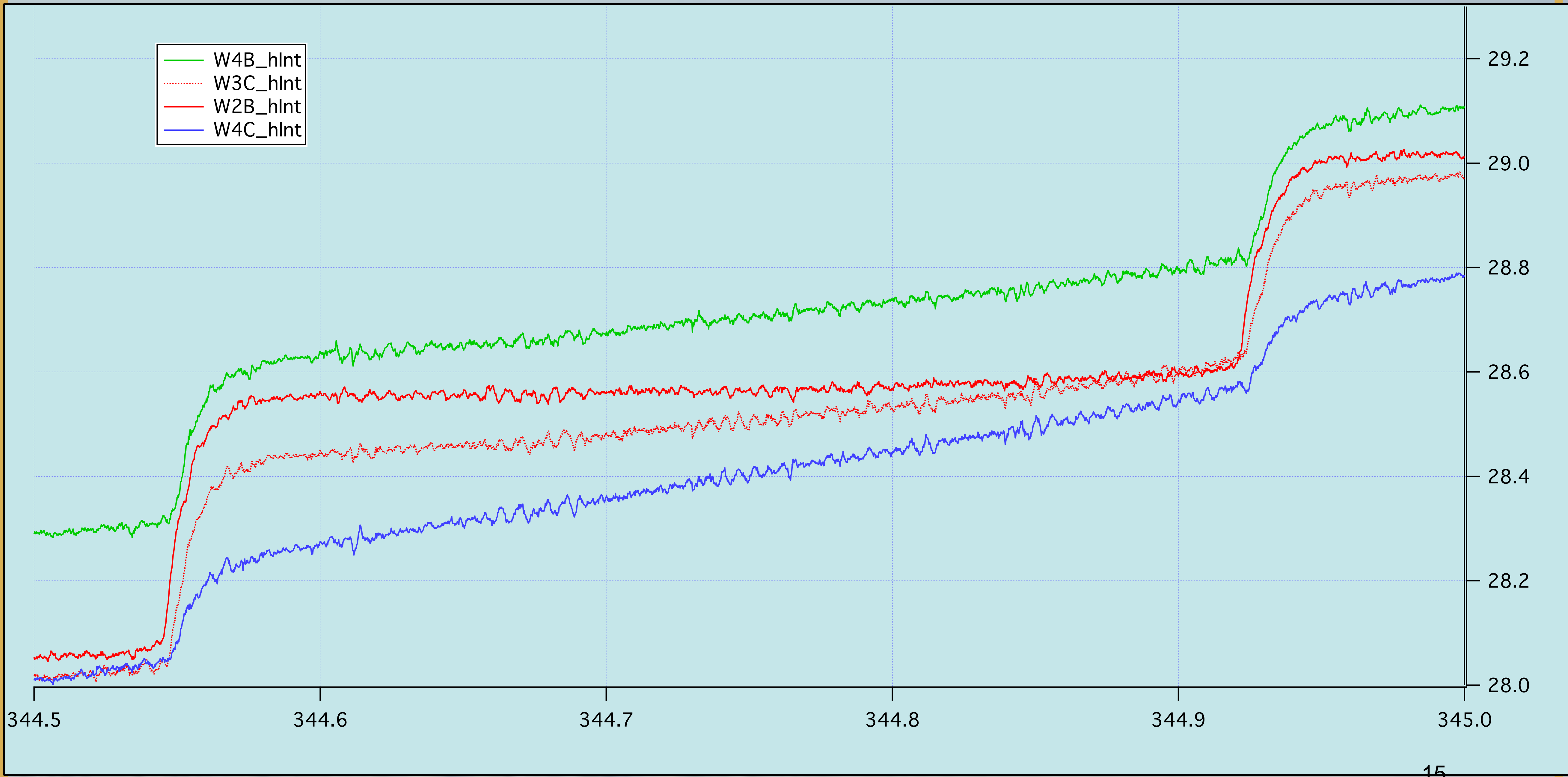
GPS - variability in displacement



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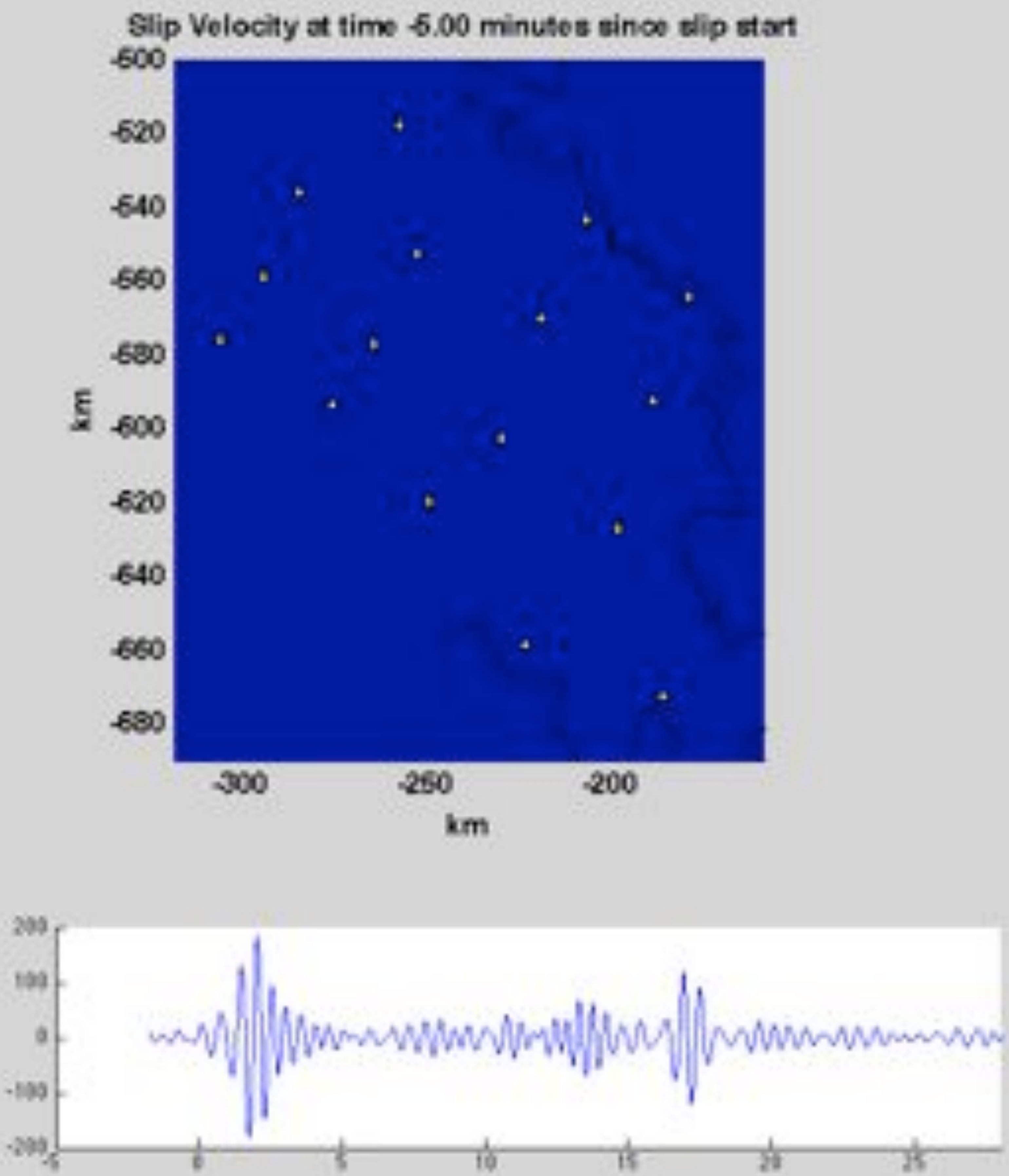
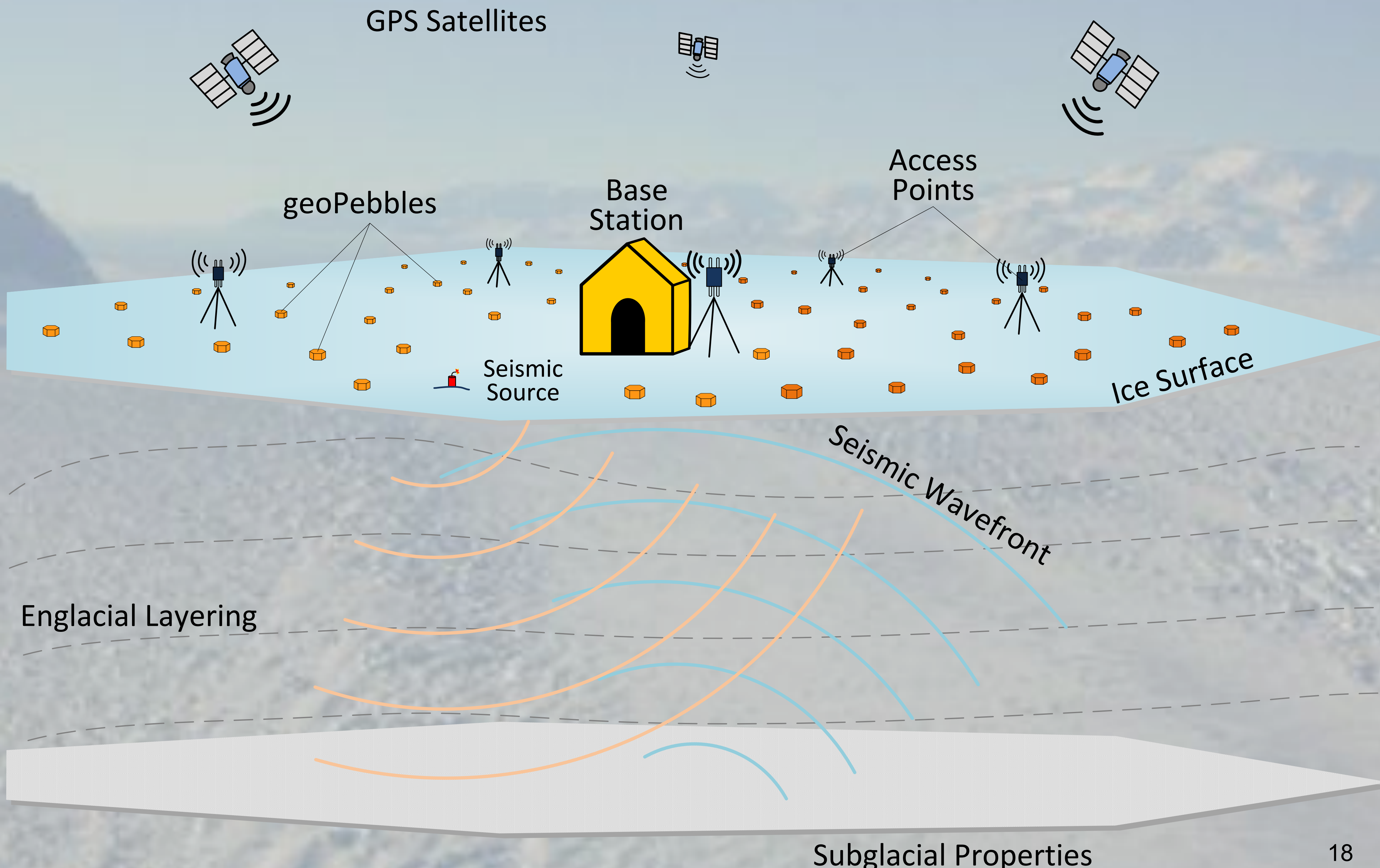

Slip Velocity at time -5.00 minutes since slip start
-600
-620
-640
-660
-680
-600
-620
-640
-660
-680
km
-300
-250
-200
km
200
100
0
-100
-200
-5
0
5
10
15
20
25

Active Seismic Surveys

- Time and labor intensive
- Limited flexibility (linear surveys)

GeoPebble Operations



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GeoPebble Motivation

- No Wires
  - operations in crevassed areas
  - 2D arrays of sensors, rather than straight lines
- GPS position
  - no need to survey
  - velocity measured continuously
- Simplify operations
  - internal geophone, GPS, battery, WiFi

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Specs

- Self-contained (geophones and GPS internal)
- Short-period (10kHz sampling), 3 component
- GPS phase measurements for decimeter posn.
- Wireless
  - Setting parameters, data QC, downloading data, firmware updates.
  - Including charging.
  - And on/off switch (magnetic reed switch)
    - 90% of failures are connectors and cables!

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Specs

- 10 kHz sampling, 30s record length
- 1 kHz sampling, continuous
- QC: “Enough” data download in 30s to evaluate shot quality.
  - Wifi is fast enough to download data.
- All data stored onboard and available for later download

Specs

- All source code available.
- Students can work with verilog code, linux code.
  - mesh networking based on position and time?
  - data QC based on wavelet compression
  - data compression based on near-station data
  - etc
- NSF expects a pedagogical role in projects...

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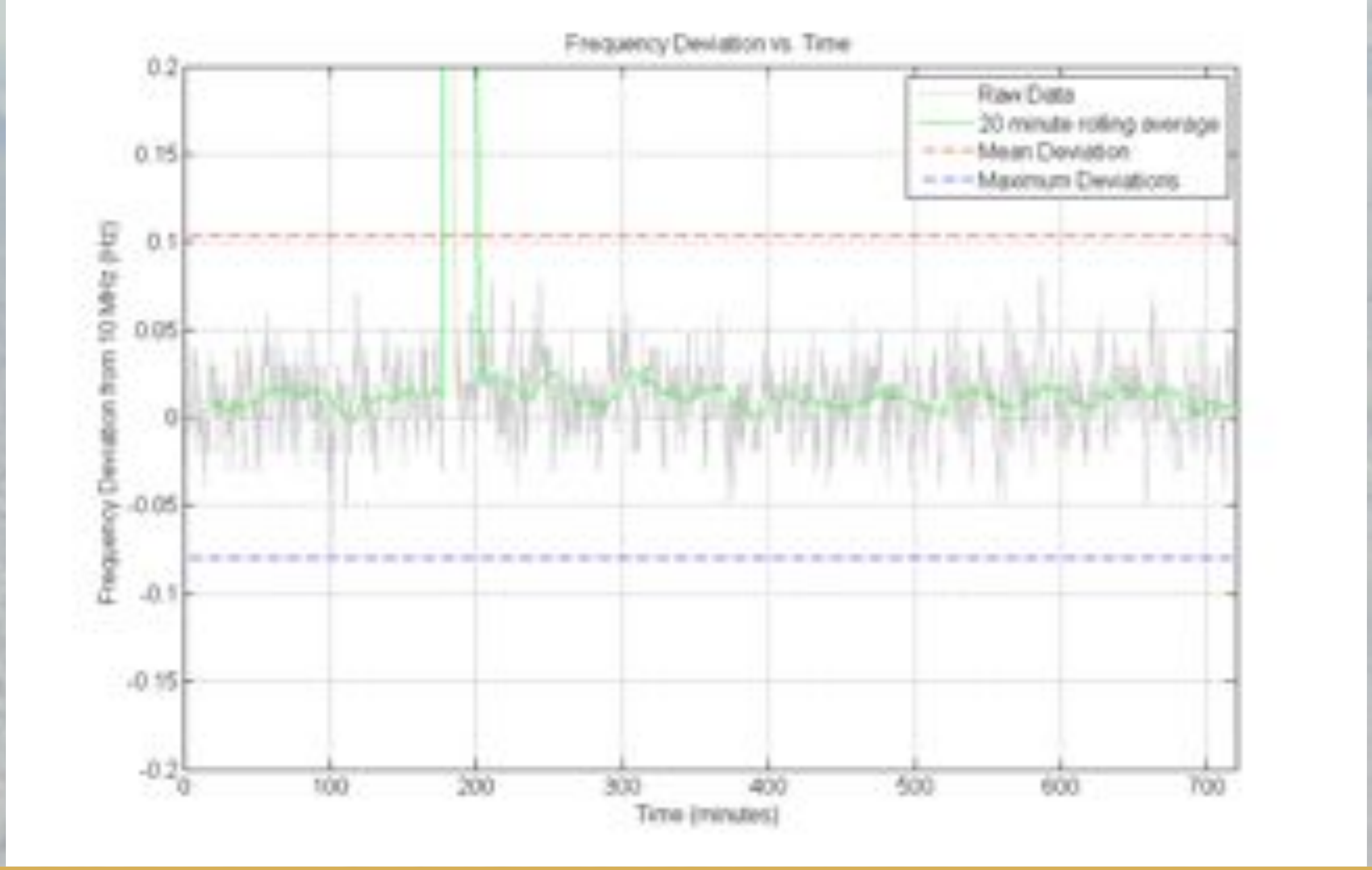
Realization

- GPS disciplined oscillator



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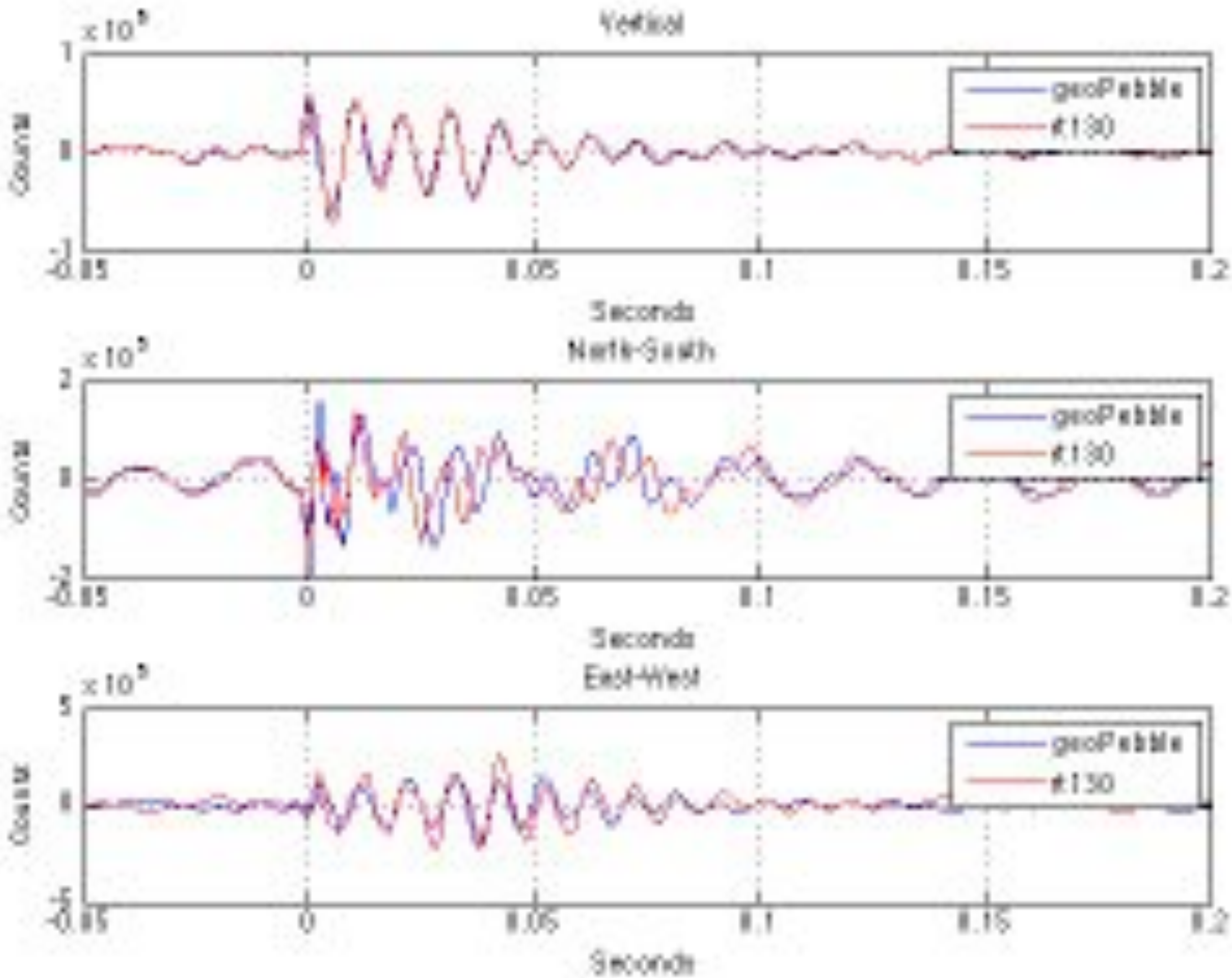
1 8 5 5

Realization

- Maxim 11060 24 bit, 4 channel digitzer.
- Gain control.
- Multiplexer to choose between internal geophones and external inputs.



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Realization

- FPGA soft core
  - Altera 28 nm technology
  - opencores.org (orsoc.se is commercial vendor)
- Linux OS with FPGA hardware (SPI, UART, I2C, timers, etc.)

Realization

- Case designed for our elements.
- Smooth and featureless to avoid snagging or trapping snow
- Internal geophones, battery, GPS antenna
- Wifi (low power, easy integration-802.11abg internal)
- Inductive charging.

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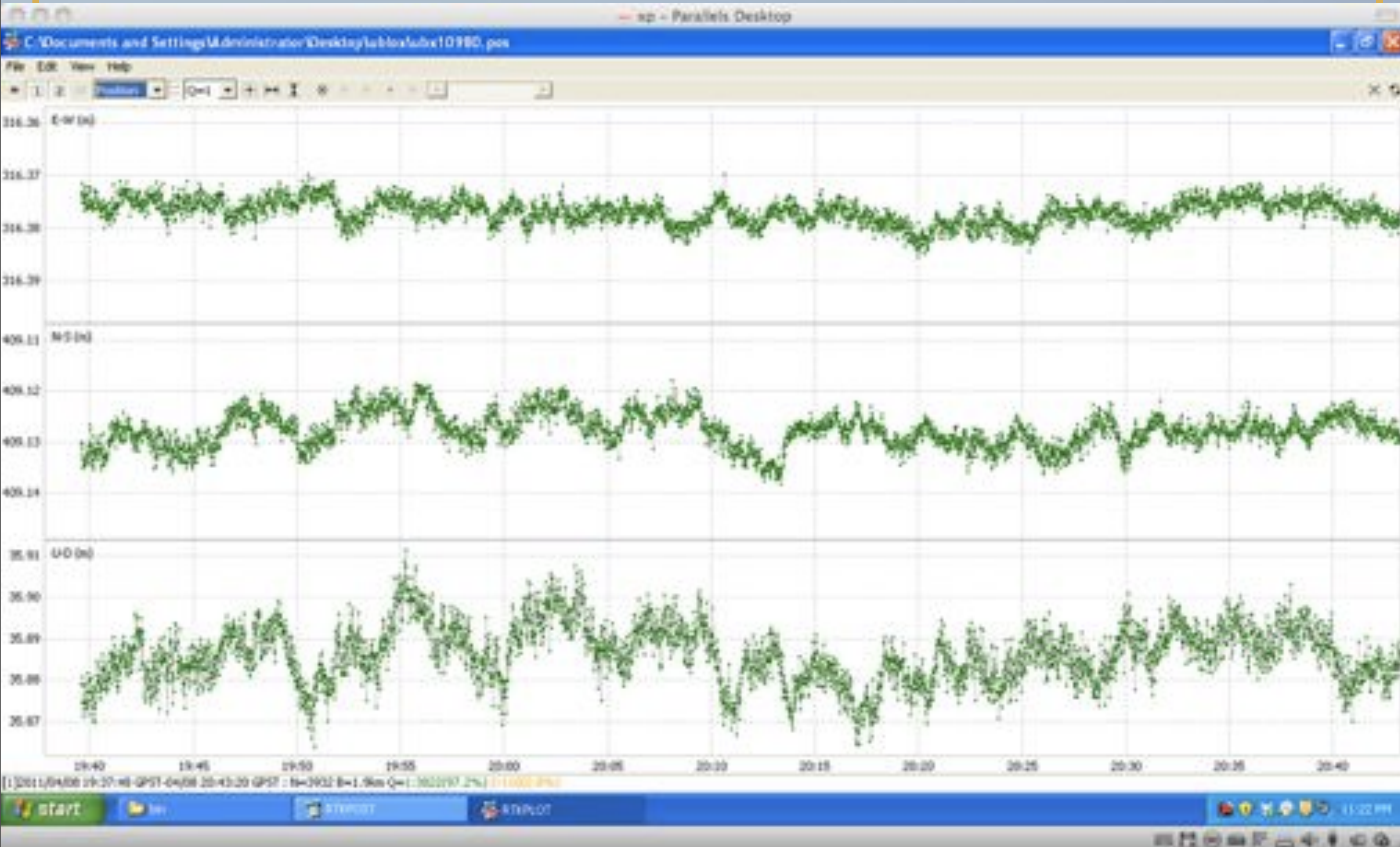

xp - Parallels Desktop
File Edit View Help
E-W (m)
N-S (m)
U-D (m)
19:40
19:45
19:50
19:55
20:00
20:05
20:10
20:15
20:20
20:25
20:30
20:35
20:40
start
RTKPLOT
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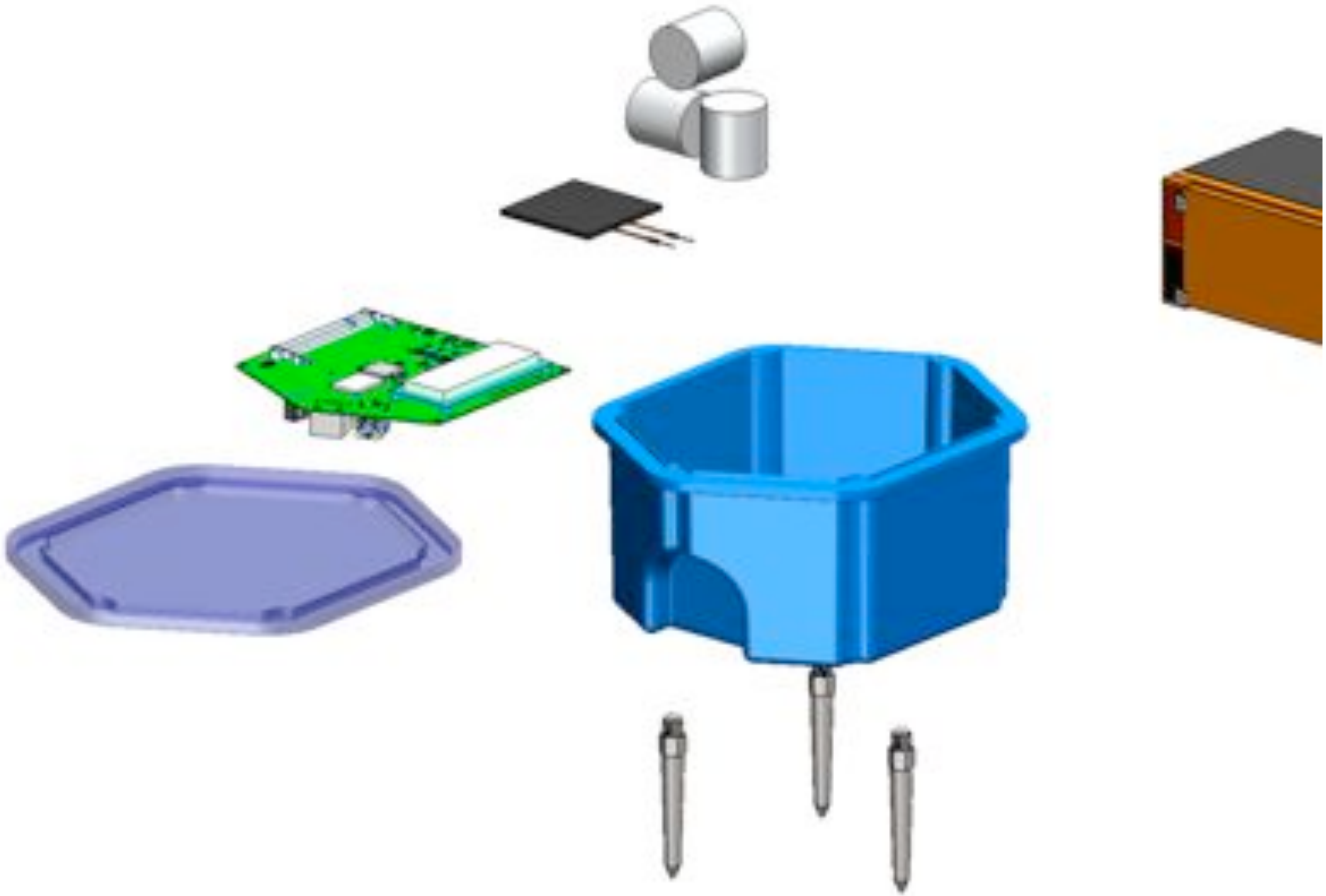

Etc

- Outdoor viewable OLED
- magnetic compass & accelerometer
- temperature, humidity,
- battery fuel gauge and history
  - 94% efficient power supply
- PV input
  - clear cover, so 1W internal possible (wifi/gps testing ongoing)
- $1.5K

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Lessons

- Mechanical
  - –Solidworks rocks, and rapid prototype is cheap.
  - –protomold.com and similar cheap and fast.
- Use a uC to prototype: mbed & propeller
- PCBs cheap and fast - build, test, rebuild.
- Fortunately cubesat, LunarLion on campus
  - –Access to anechoic chamber, env chamber, shake table, etc.

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Lessons

- The best students are immensely productive.
- Computer scientists tend to be theoretical
  - their job ends with a matlab simulation
- Assembly & construction readily available
  - pick and place, ovens, x-ray inspection, almost hobby-grade now.
- Material science is a black art. Injection plastic not yet finalized.

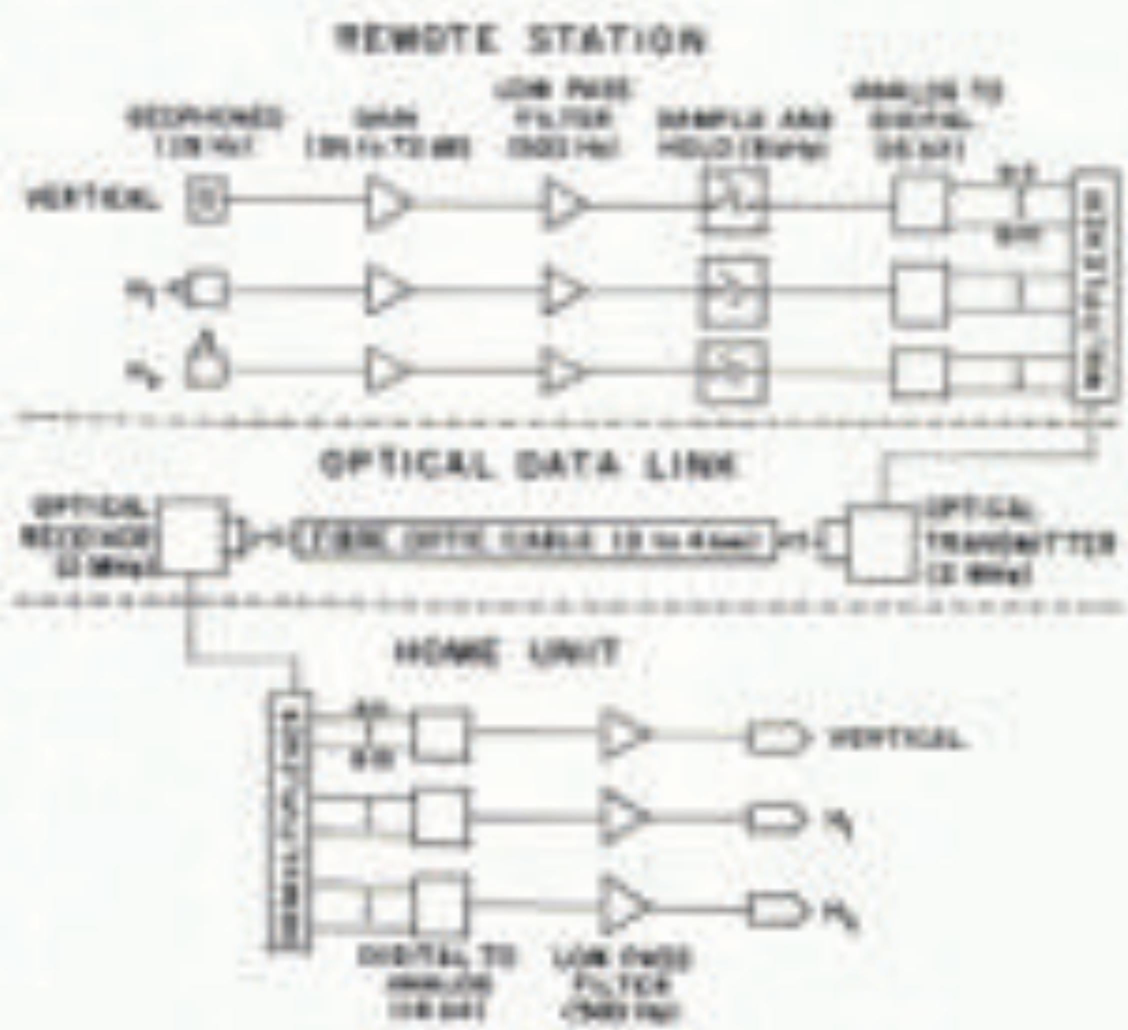

Fig.2. Schematic representation of the three primary elements of the passive seismic array developed by the Geophysical and Polar Research Center. H_1 and H_2 are the horizontal components of ground motion that are parallel and transverse to ice flow, respectively.

Blankenship et al., 1987

- iNova Geophysics
- Fairfield Nodal
- Geospace
- iSeis Sigma