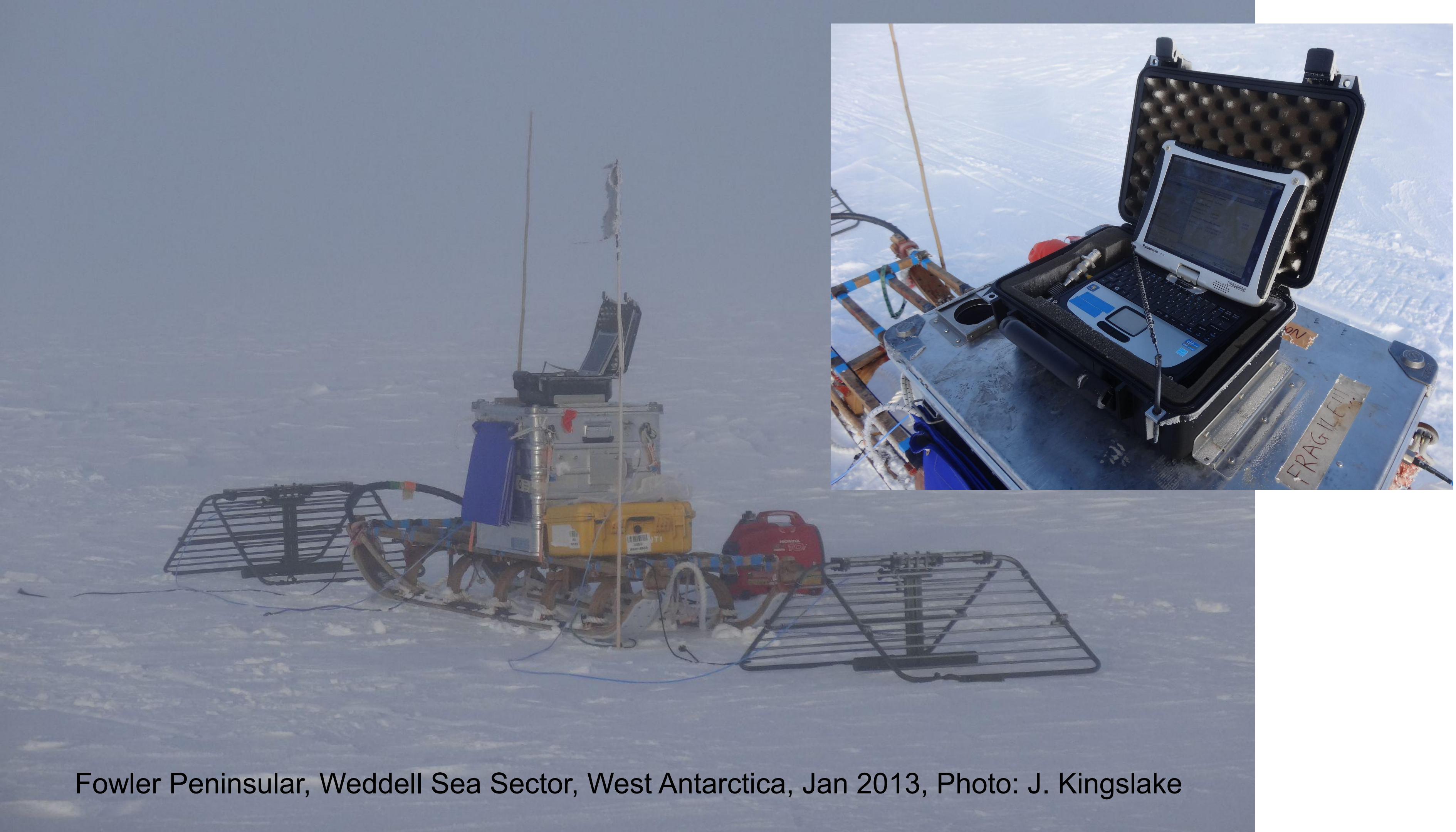
ApRES theory and survey ideas

Jonny Kingslake
July 18th 2024



Fowler Peninsular, Weddell Sea Sector, West Antarctica, Jan 2013, Photo: J. Kingslake


SN-153
SN-154
SN-160
SN-158
SN-159


TX
PLL


TX
PLL
PC
PWR
ON
OFF
IRIDIUM
GPS


S/N 189
PELI
1450 CASE
recyclable
NON-SPILLABLE BATTERY
POWER SONIC
MODEL PS-12180 NB


Sealed Rechargeable Battery
MODEL PS-12180 NB
12 Volt 18.0 Amp. Hr.
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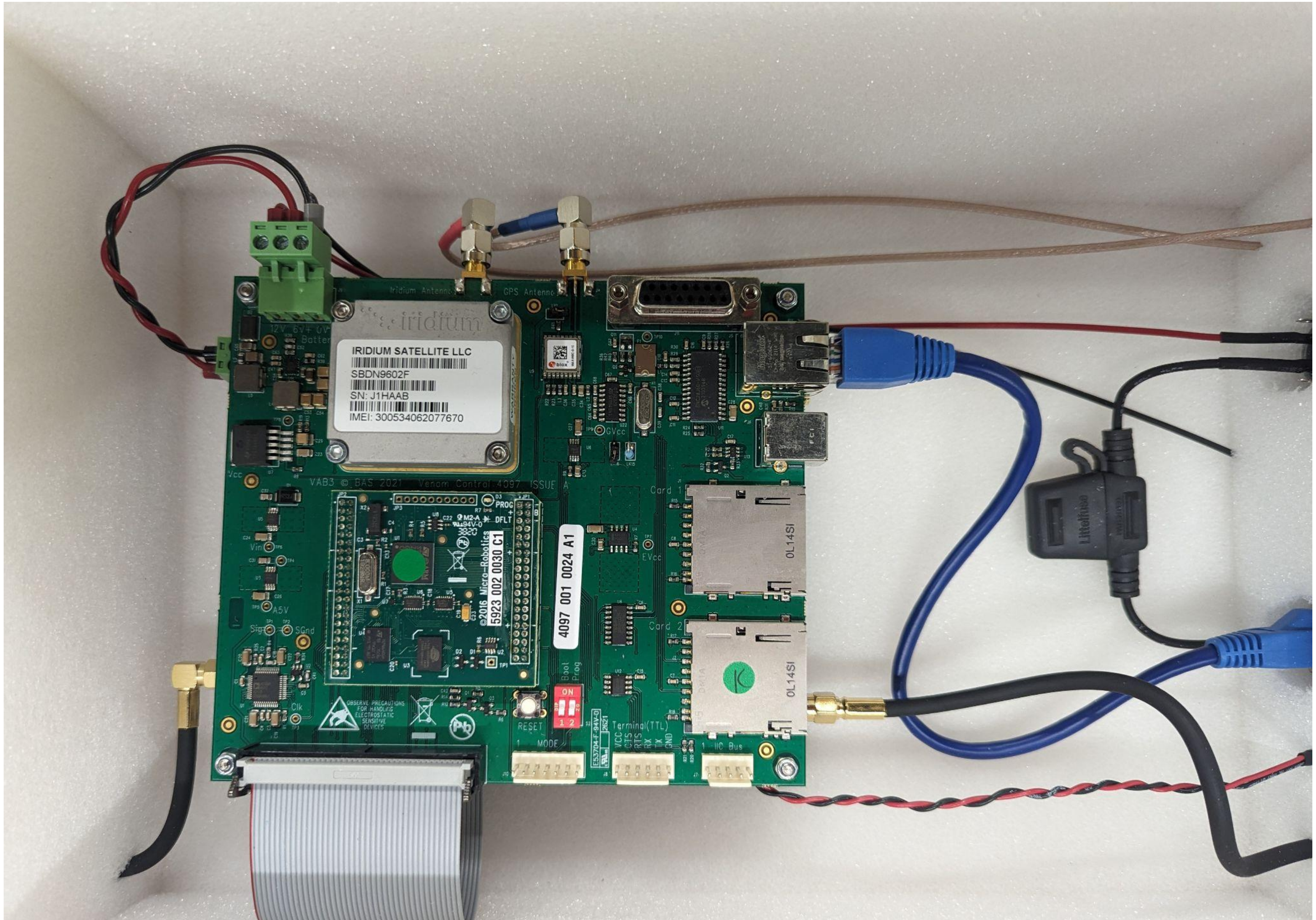
IRIDIUM SATELLITE LLC
SBDN9602F
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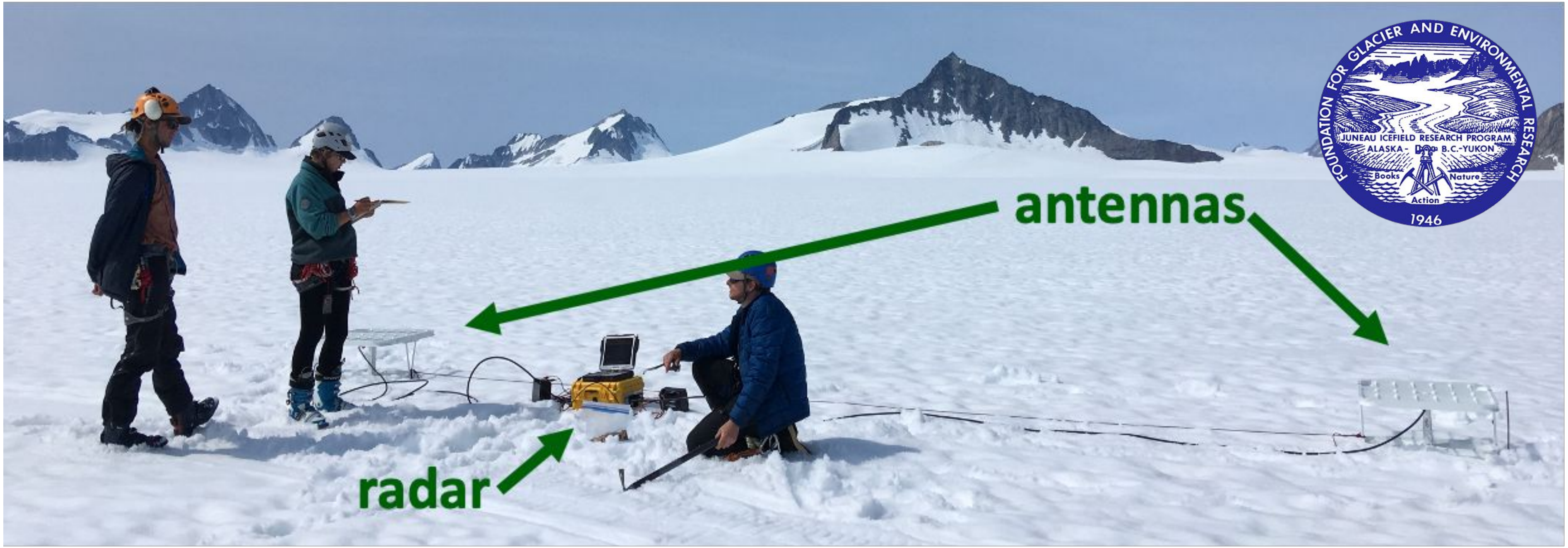
4097 001 0024 A1
5923 002 0030 C1
RESET
MODE
Terminal(TTL)


antennas
radar
FOUNDATION FOR GLACIER AND ENVIRONMENTAL RESEARCH
JUNEAU ICEFIELD RESEARCH PROGRAM
ALASKA - B.C.-YUKON
Books
Nature
Action
1946

History

Previous generation – phase-sensitive radio-echo sounder, pRES

- A step-frequency radar
- Not really a field instrument
- Shown to be very good at measuring change in thickness of ice shelves
  Corr, H.F., Jenkins, A., Nicholls, K.W. and Doake, C.S.M., 2002. Precise measurement of changes in ice-shelf thickness by phase-sensitive radar to determine basal melt rates. *Geophysical Research Letters*, *29*(8), pp.73-1.
- Later used for measuring englacial strain
  Kingslake, J., Hindmarsh, R.C., Aðalgeirsdóttir, G., Conway, H., Corr, H.F., Gillet-Chaulet, F., Martín, C., King, E.C., Mulvaney, R. and Pritchard, H.D., 2014. Full-depth englacial vertical ice sheet velocities measured using phase-sensitive radar. *Journal of Geophysical Research: Earth Surface*, *119*(12), pp.2604-2618.

A newer light-weight, low-power version – Autonomous phase-sensitive radio-echo sounder, ApRES

- A frequency-modulated continuous wave radar
- Has been used widely to measure ice-shelf basal melt rates and changes in englacial water content and changes in basal water content
  Nicholls, K.W., Corr, H.F., Stewart, C.L., Lok, L.B., Brennan, P.V. and Vaughan, D.G., 2015. A ground-based radar for measuring vertical strain rates and time-varying basal melt rates in ice sheets and shelves. *Journal of Glaciology*, *61*(230), pp.1079-1087.

Primarily designed to detect how the separation of reflectors changes in time

Reflectors include

- englacial reflections from internal layering, assumed to be material surface (i.e. they move with the ice as is flows),
- The base of the ice
- Or even the water table (one application was in Oman tracking the water table height over time).

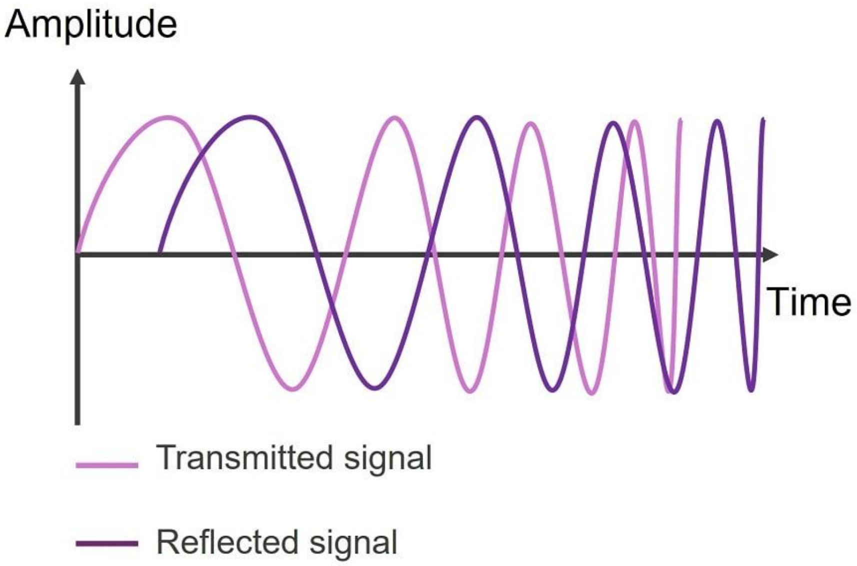
Secondary uses

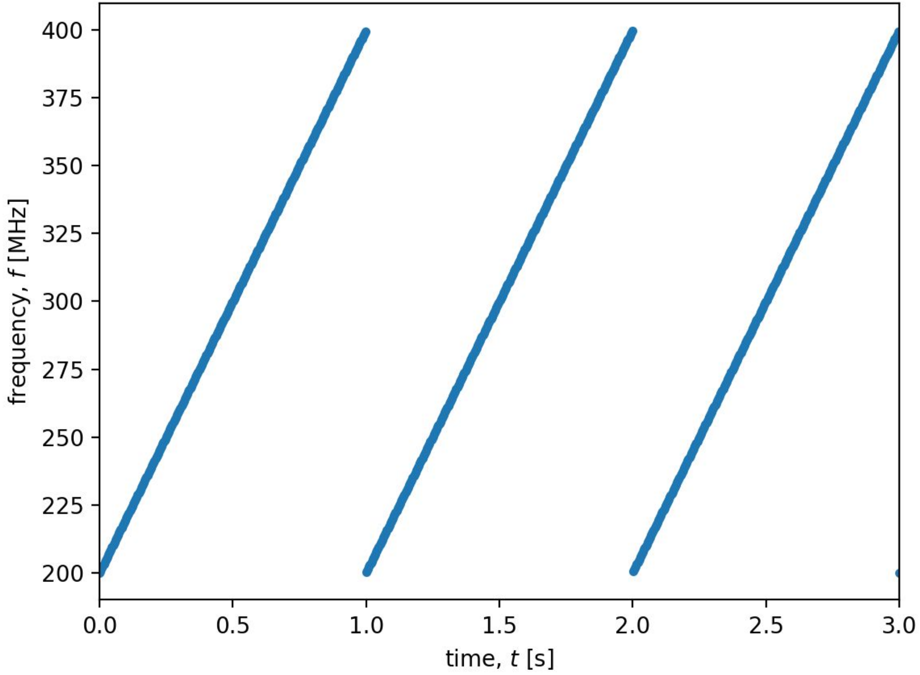
- Detecting how reflectivity changes in time
- Detecting how attenuation changes in time
- Detecting how radio-wave speed changes in time

Theory

The system sends out ‘chirps’:

During each chirp it emits a continuous radio wave with time-varying frequency:





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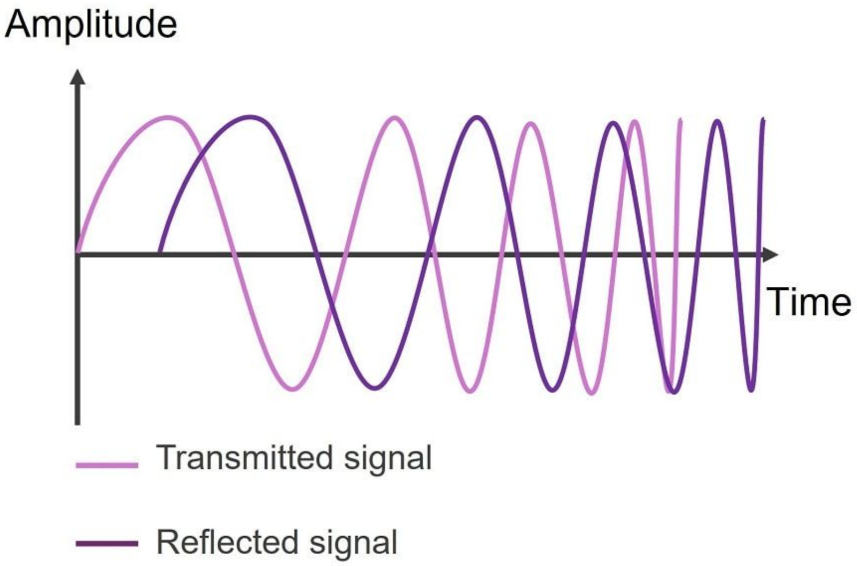
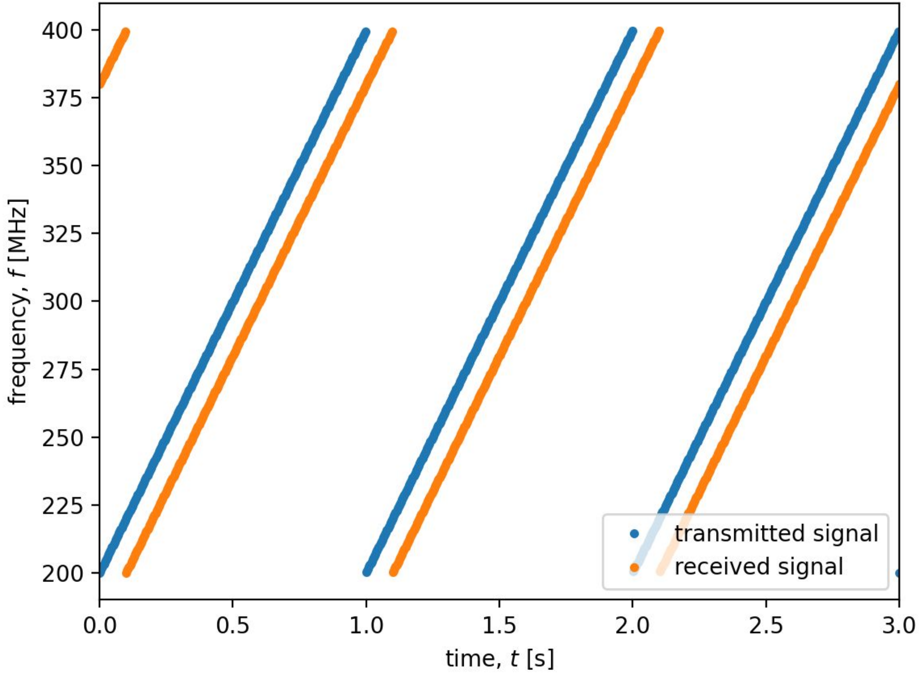
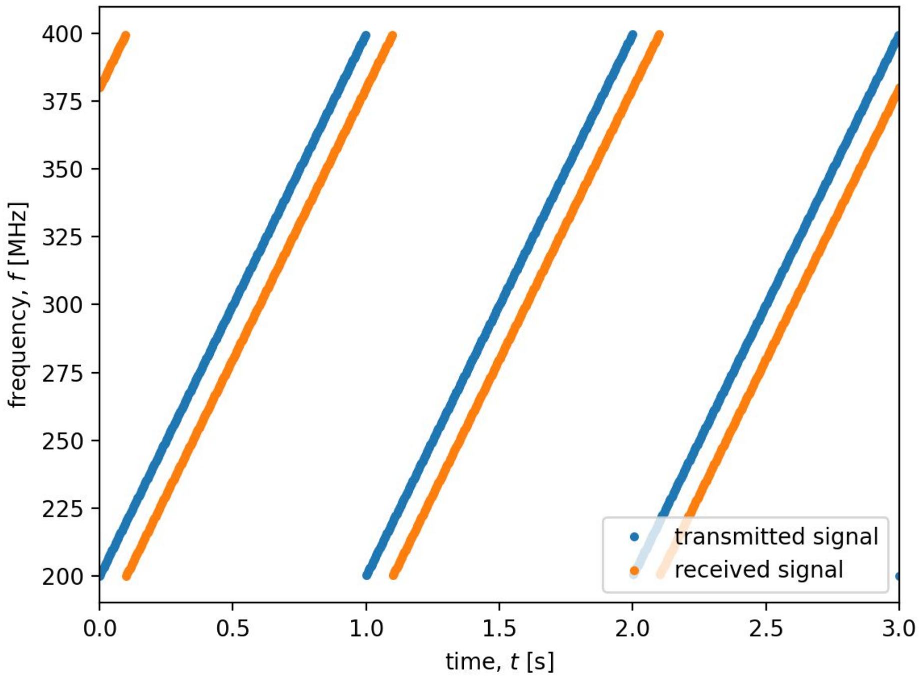




The range to a reflector is proportional to the difference in transmitted and received frequencies.

- At every instant during a chirp, the received signal has travelled to some reflector and back, which takes time.
- so by the time this signal arrives back, the transmitter has shifted to a new frequency
- The transmitted frequency increases linearly with time, so the difference in the frequencies is proportional to the range



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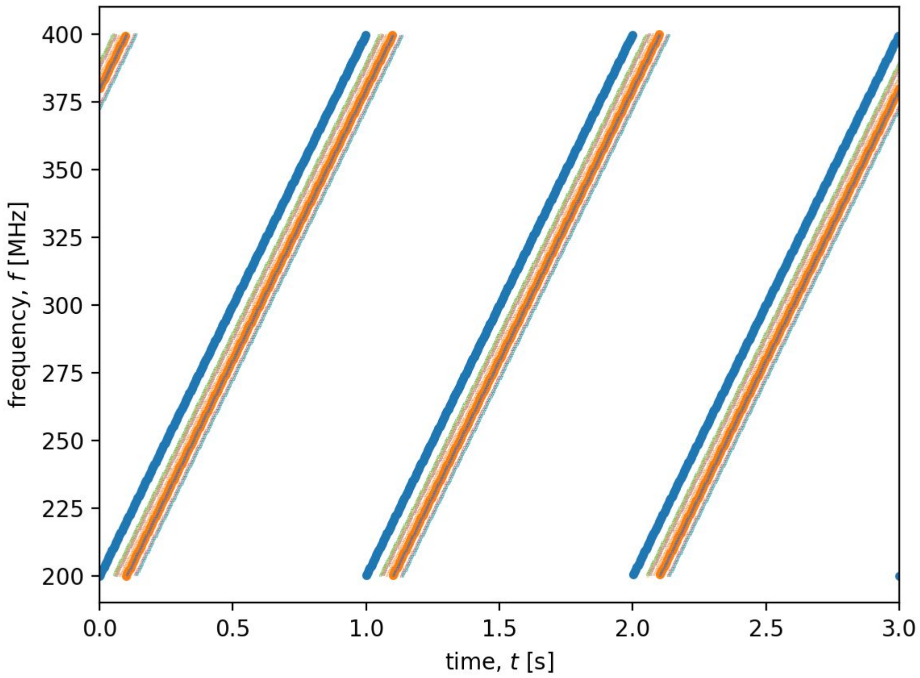
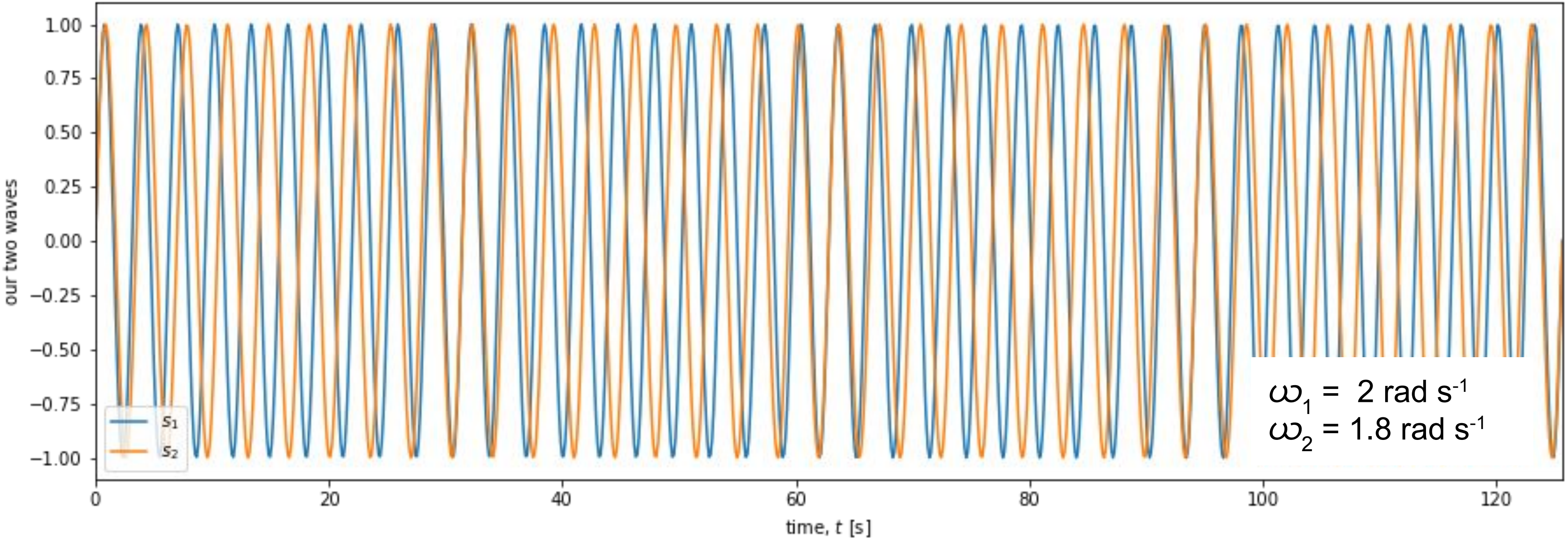


How to compute the frequency difference?

…the ‘beat frequency’

Two signals with different frequencies

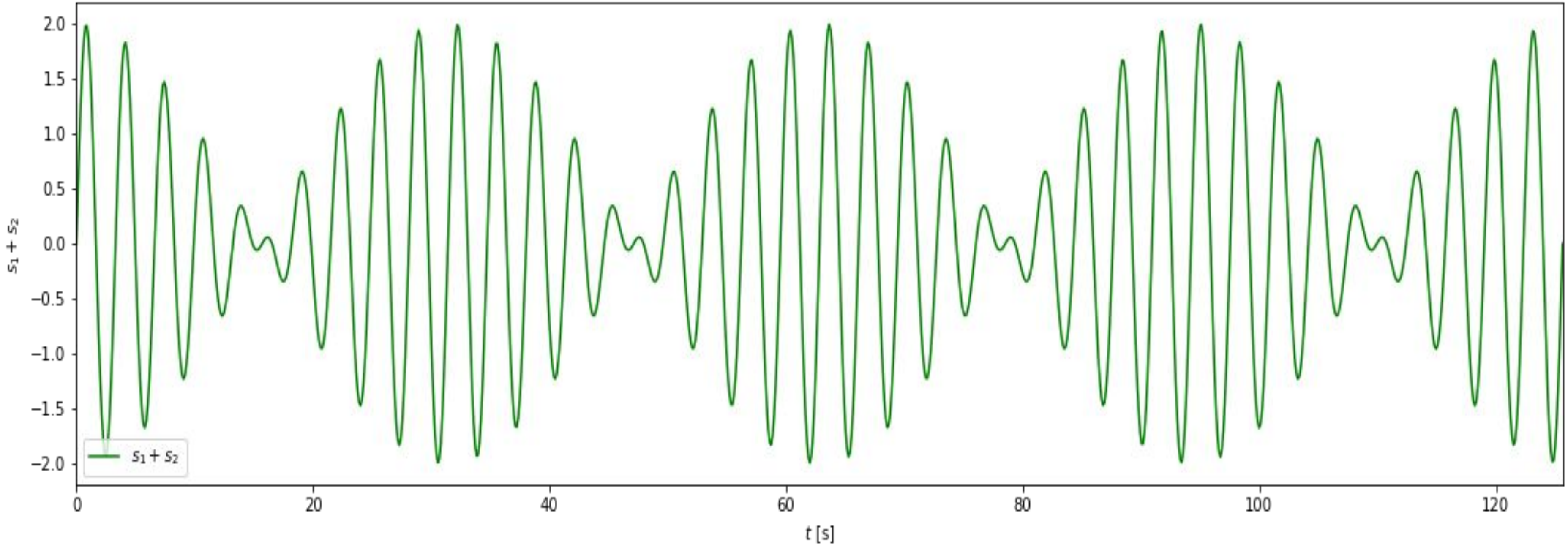


ω_1 = 2 rad s^{-1}
ω_2 = 1.8 rad s^{-1}

How to compute the frequency difference?

…the ‘beat frequency’

The sum of the two signals



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…the ‘beat frequency’

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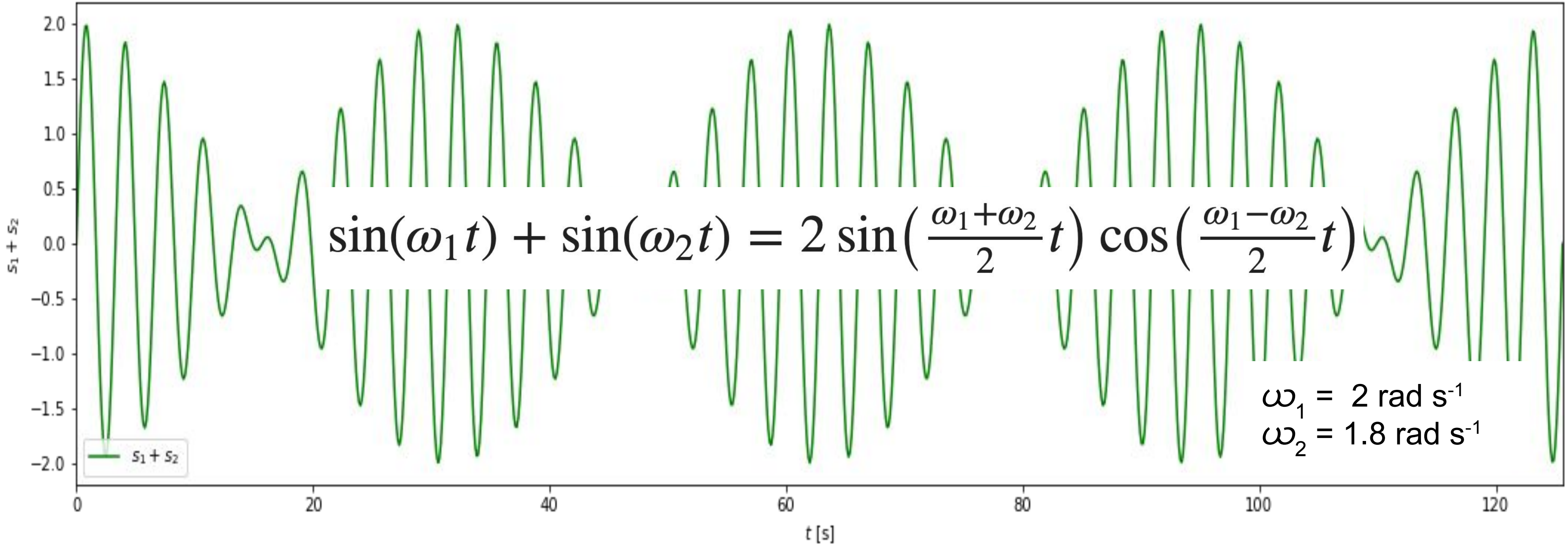


$$\sin(\omega_1 t) + \sin(\omega_2 t) = 2\sin\left(\frac{\omega_1+\omega_2}{2}t\right)\cos\left(\frac{\omega_1-\omega_2}{2}t\right)$$

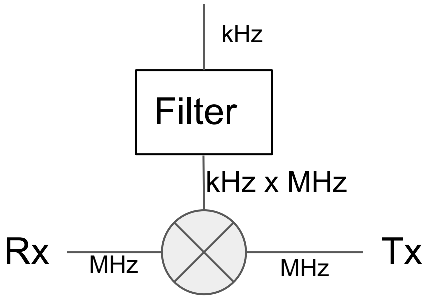
ω_1 = 2 rad s^{-1}
ω_2 = 1.8 rad s^{-1}

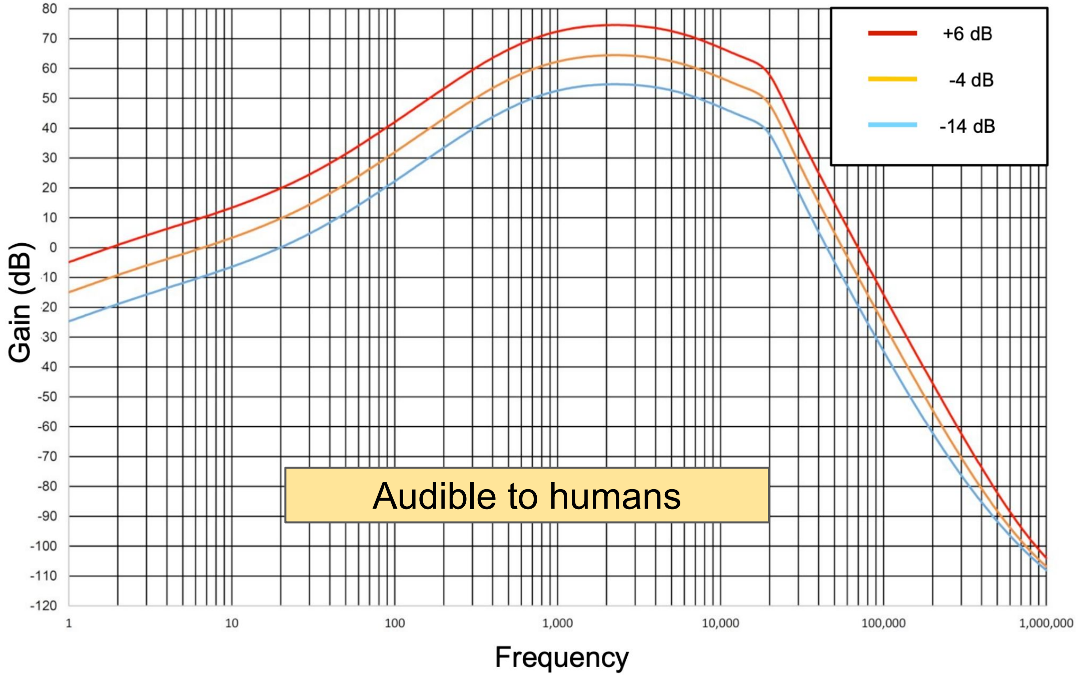
Mixing and filtering

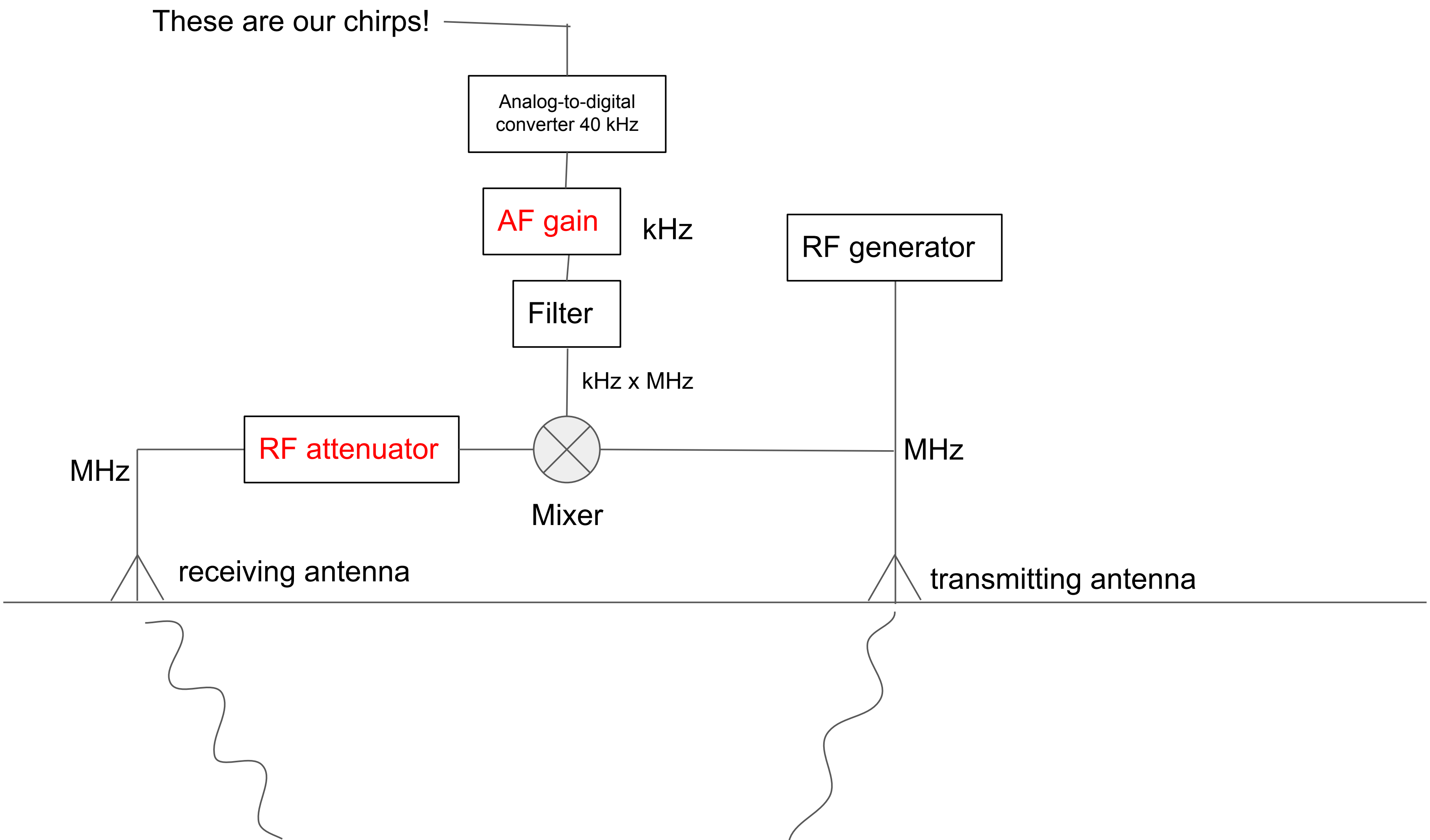
The beat frequency gives us the difference in the frequencies, which can give the range to reflectors.

So. inside ApRES the transmitted signal is continually combined with the received signal to get a curve like the green curve in the previous slide.

To isolate the low frequency part, the signal is passed through a filter.






These are our chirps!
Analog-to-digital converter 40 kHz
AF gain
kHz
RF generator
Filter
kHz x MHz
RF attenuator
MHz
Mixer
MHz
receiving antenna
transmitting antenna

The chirps

Each chirp is made up of many overlaid signals.

Each of these signals has a different frequency.

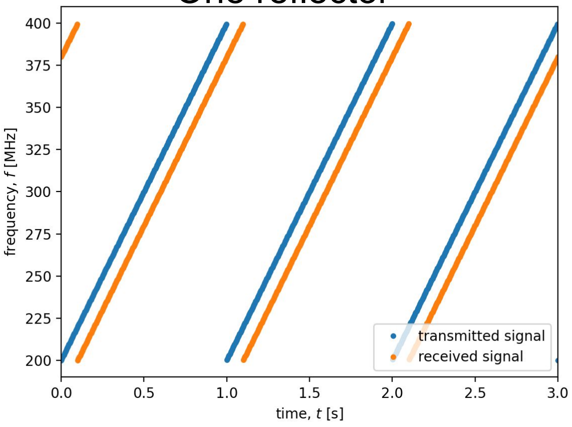
Some of those frequencies are the difference-frequencies generated by combining the transmitted signal with the received signals reflected by different reflectors.

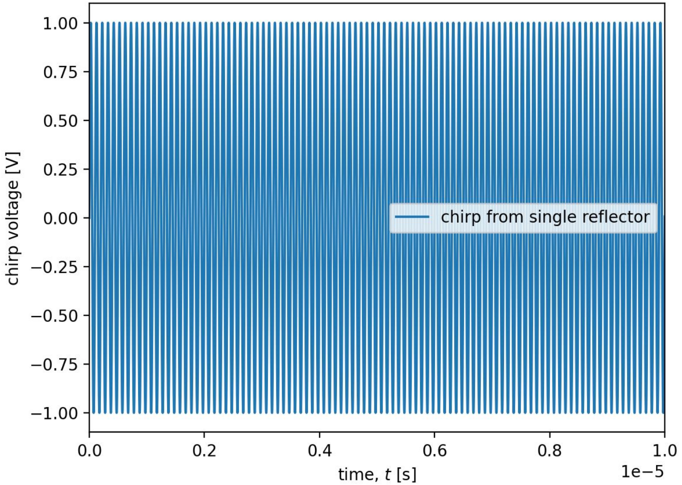
In other words, the frequency content of our chirps corresponds directly to the reflected power coming from a range of different depths.

In other other words, the frequency spectrum of the chirps gives us the ‘normal’ radar representation of the distribution of power with depth.

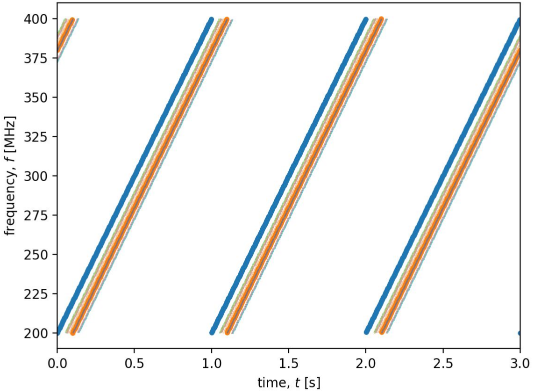
Example chirps from our idealized reflections

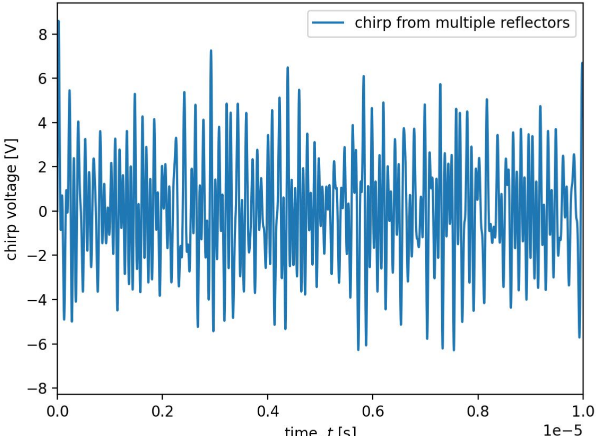
One reflector





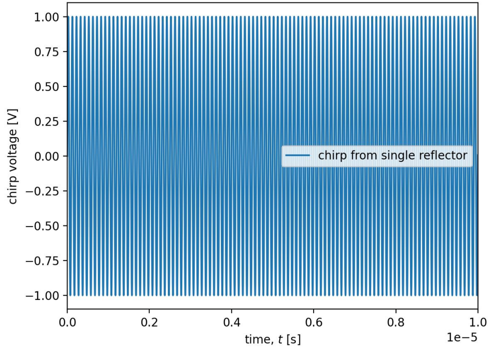
10 reflectors

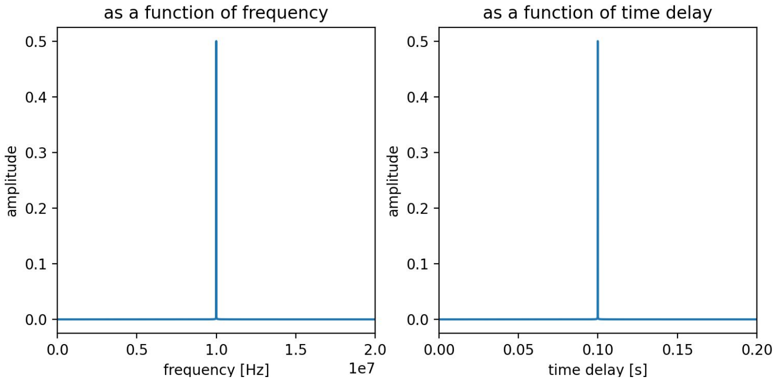


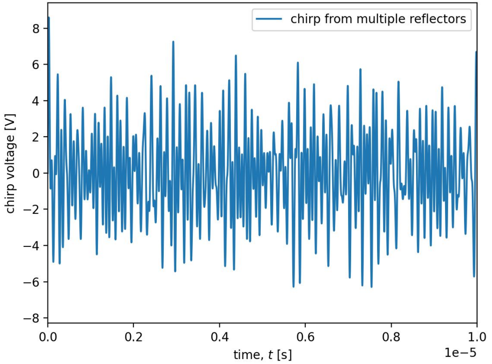


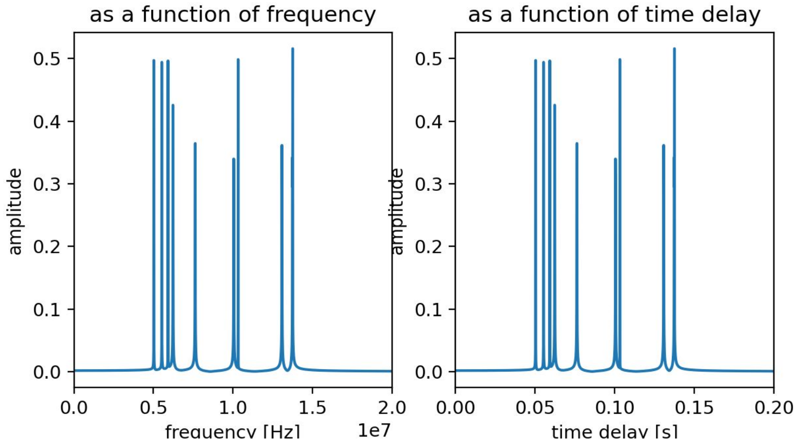
To recover the range to the reflectors we need the frequency content of the chirps

We apply a fourier transform to give us this.

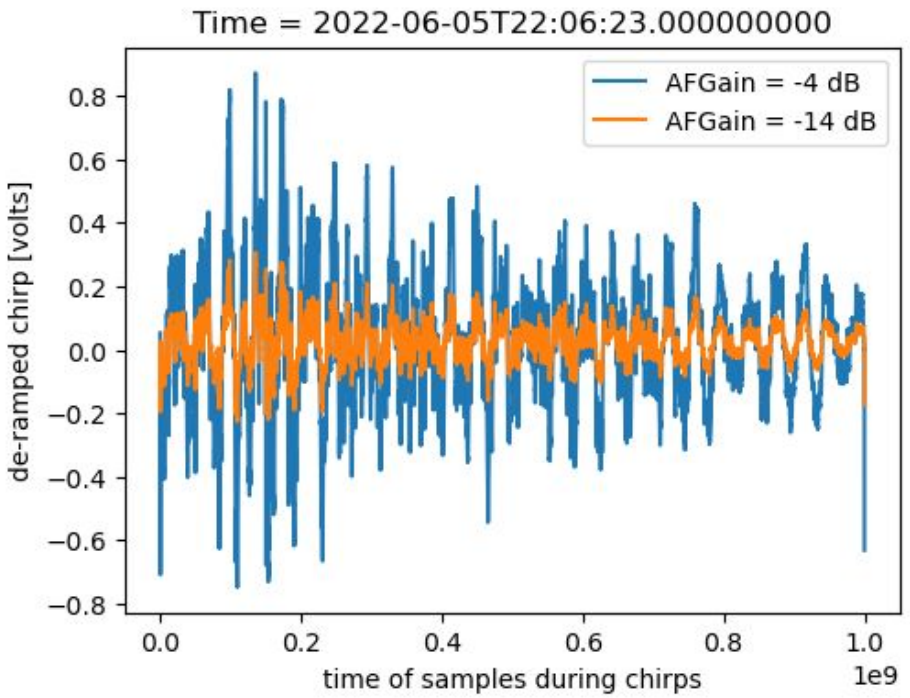


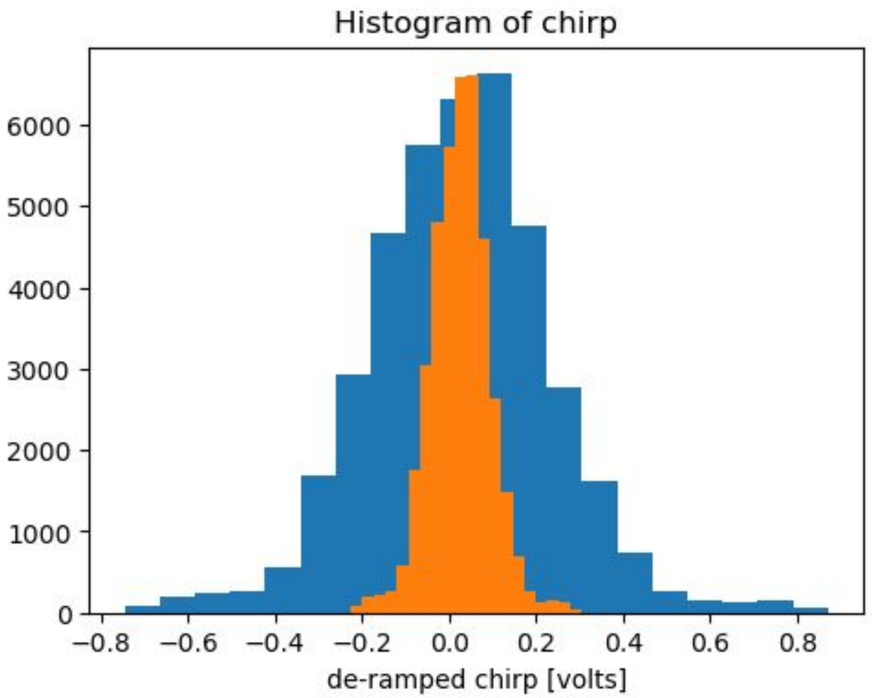






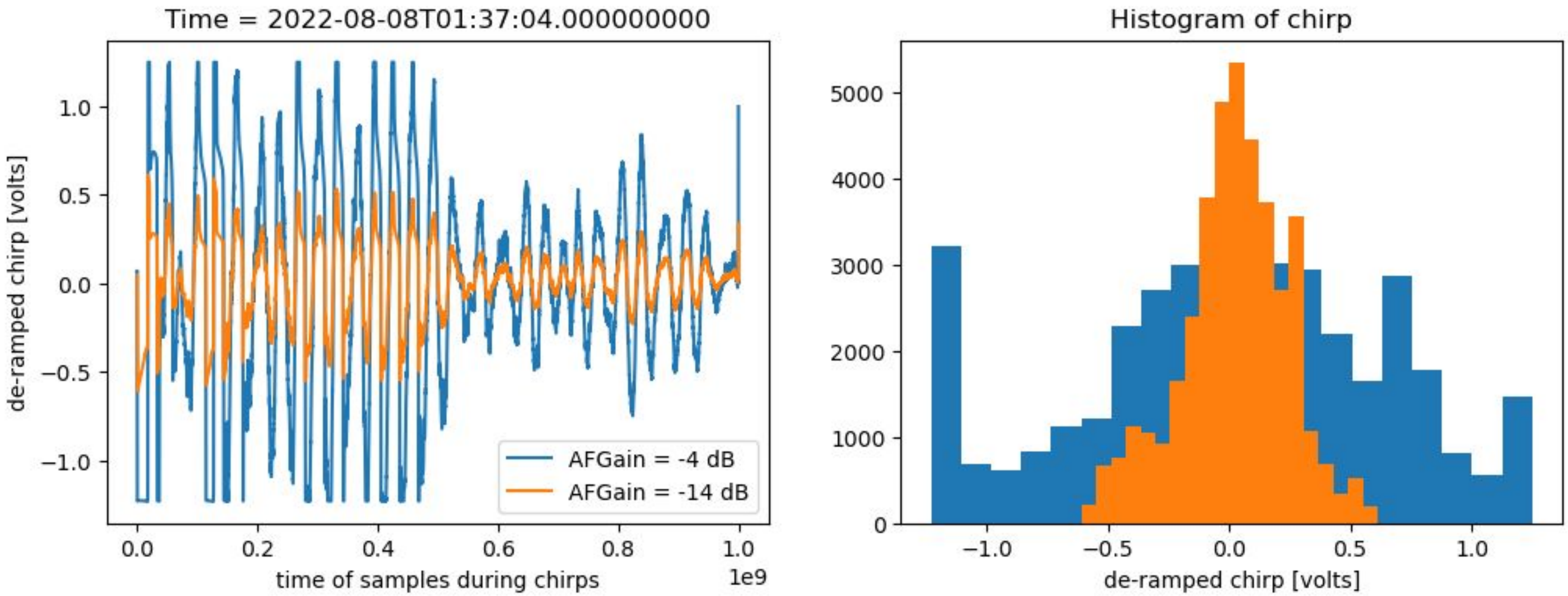
Data from chirps from Greenland: “good” data





slide provided by George Lu

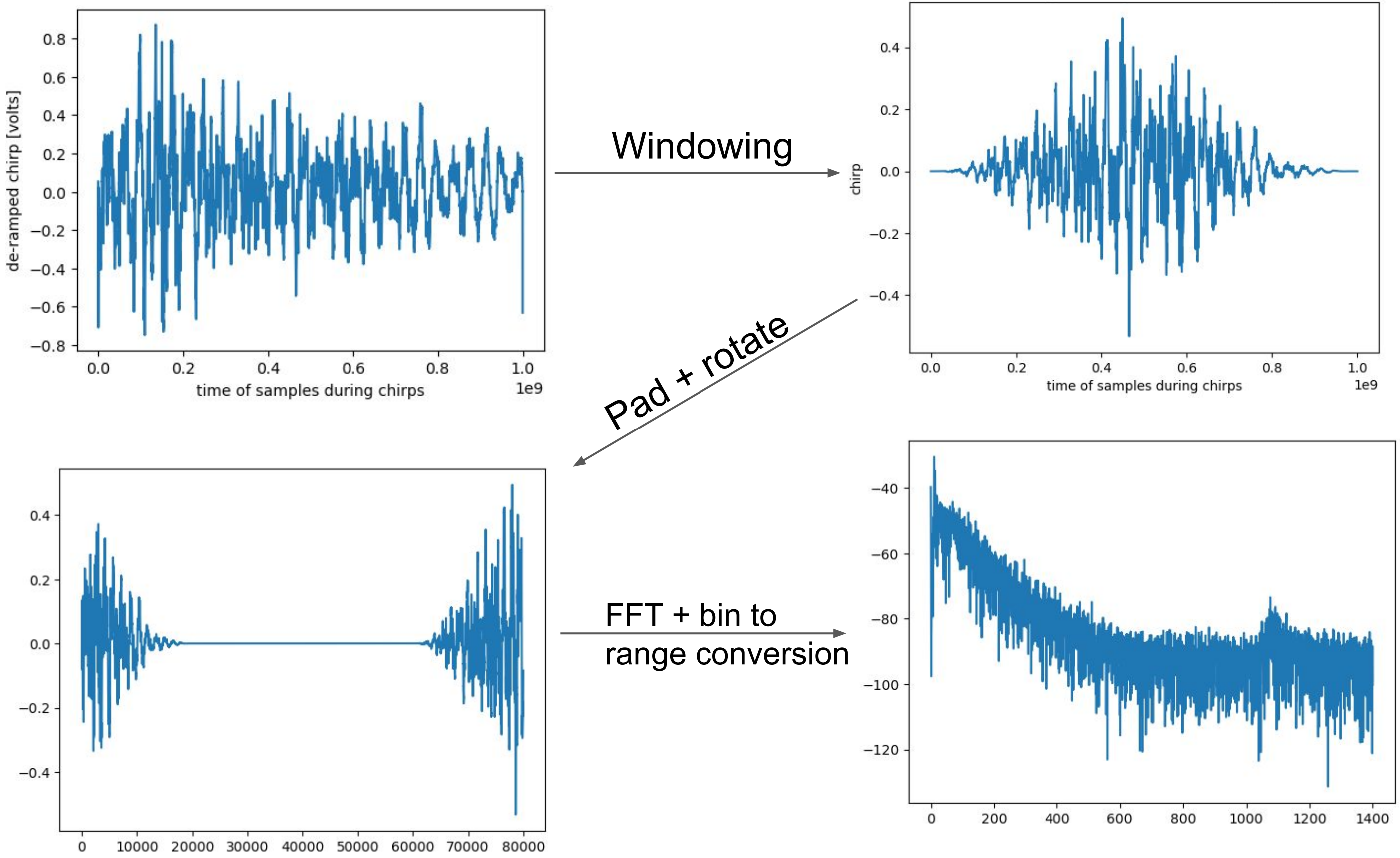
Data from chirps from Greenland: “clipped” data



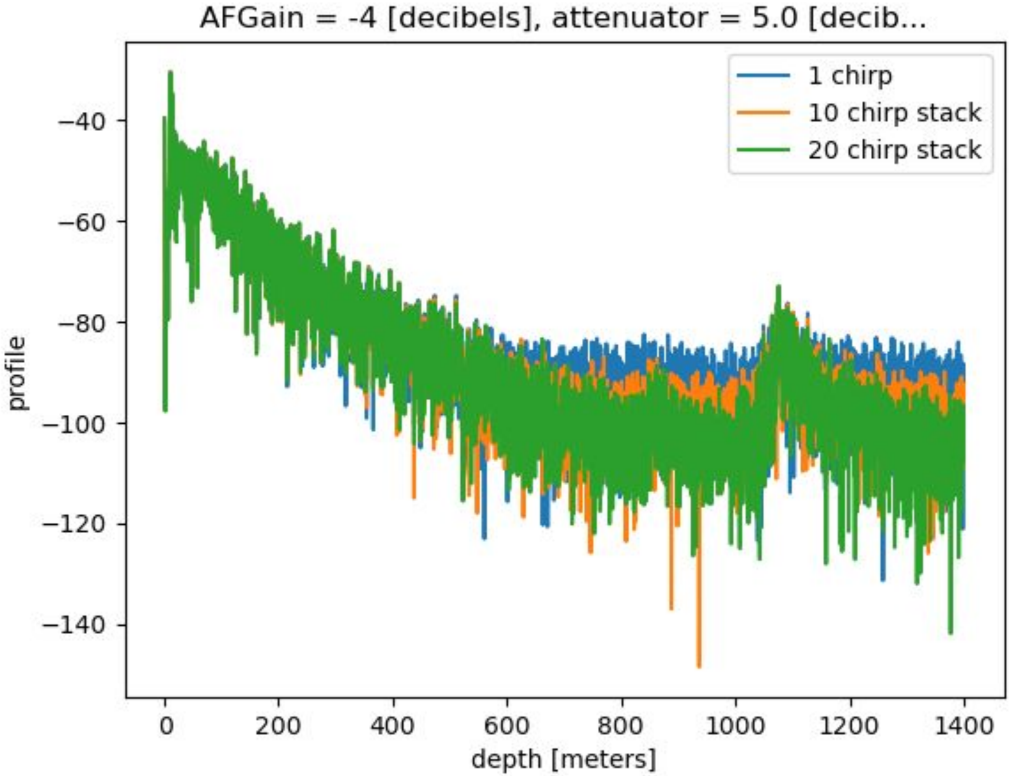
slide provided by George Lu

slide provided by George Lu

Processing Steps



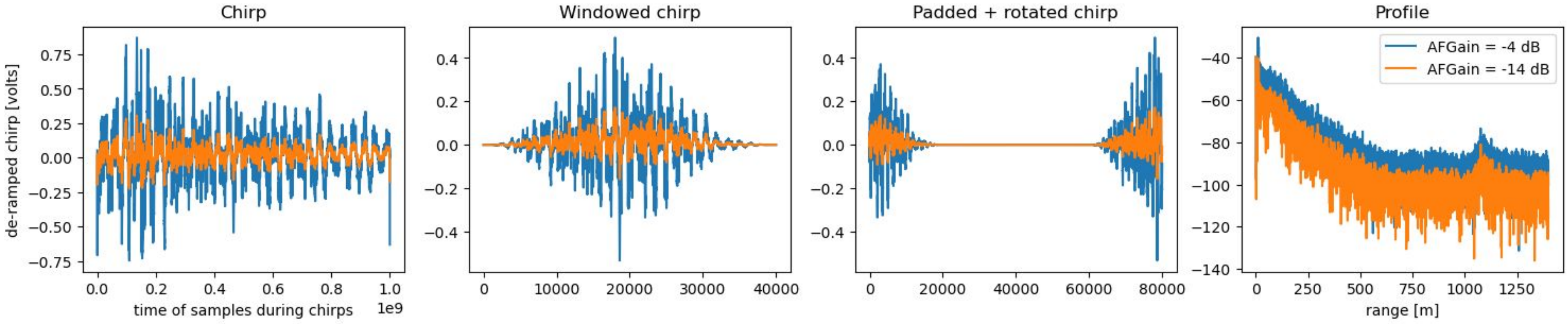
Stacking

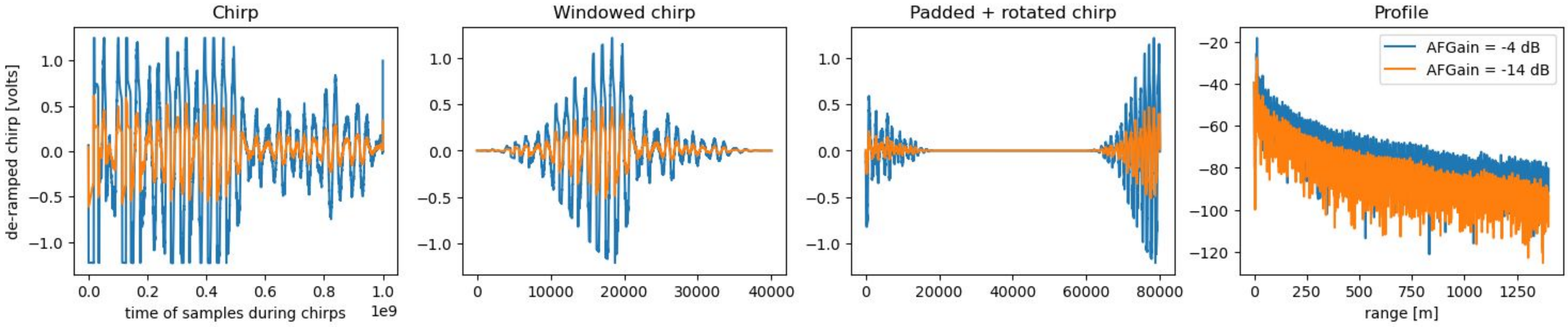


slide provided by George Lu

slide provided by George Lu

Good vs clipped data





Attended vs unattended

Attended:

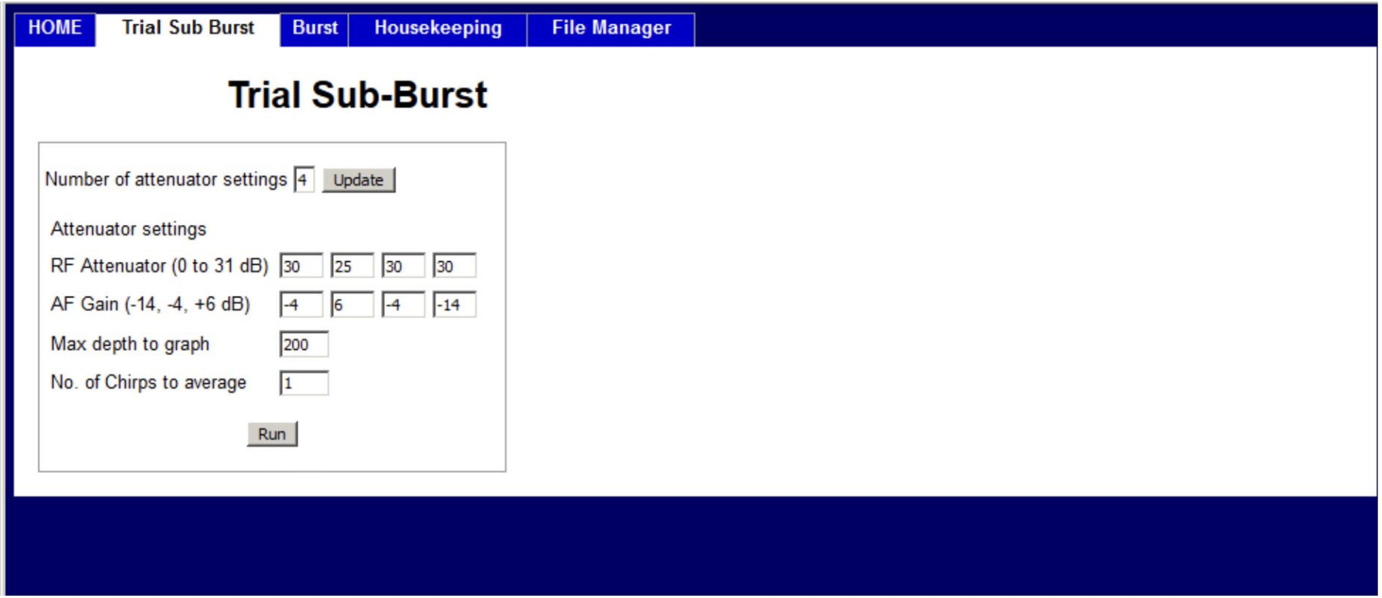
- Interact with the instrument through an ethernet cable and a web interface
- Make individual measurements.
- Typically move the antennas or the whole instrument between measurements

Unattended:

- Systems makes measurements autonomously on a schedule defined in a config file loaded on to the instrument’s SD card.

Avoid clipping by setting attenuator and gain parameters during installation.

This is a page on the ApRES server you can view when in attended mode:



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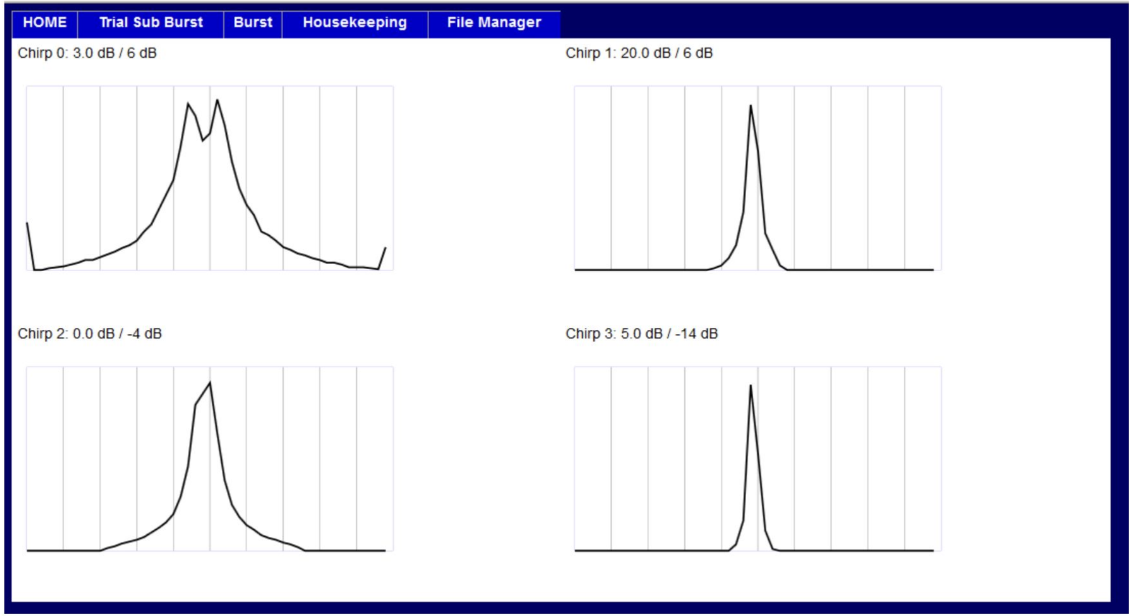

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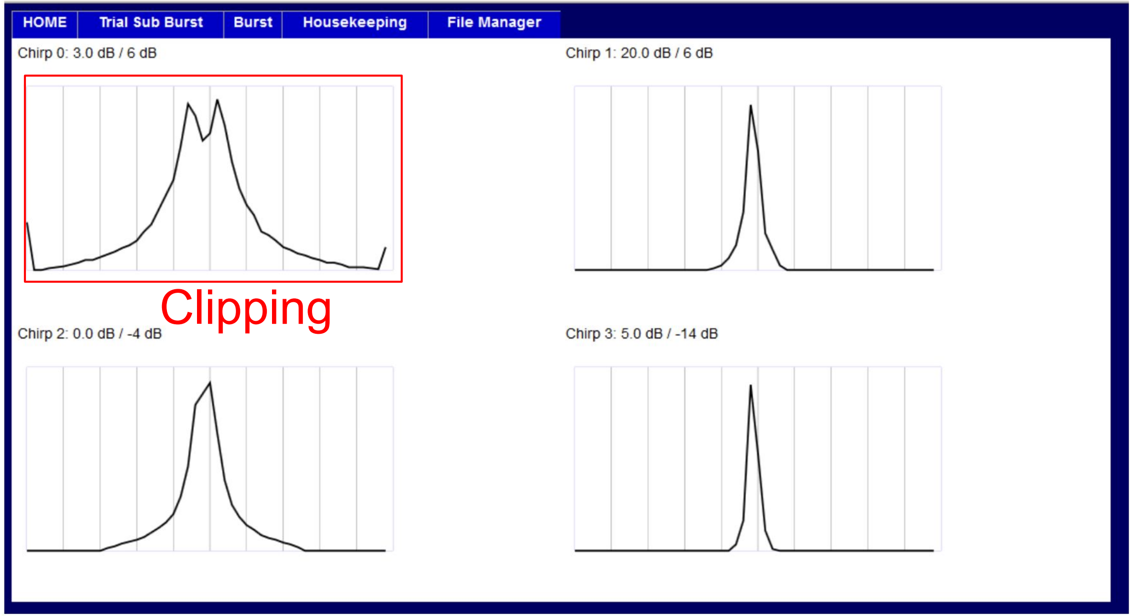


Examples of ApRES deployments:Thwaites Glacier

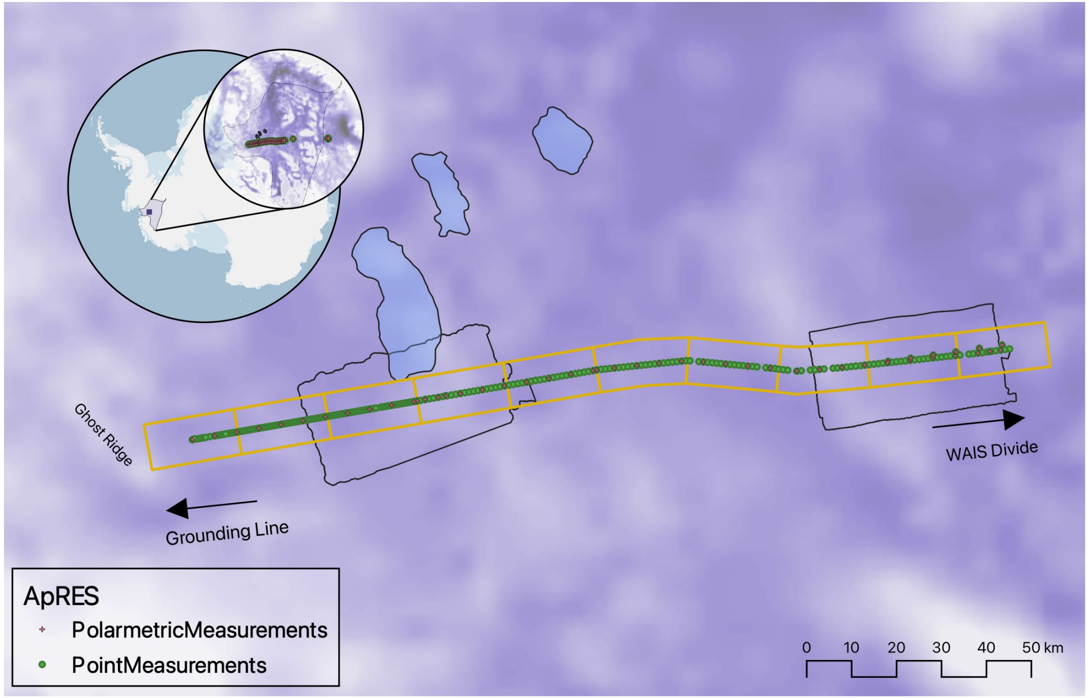
246 measurements along flowline on Thwaites

47 polarmetric measurements

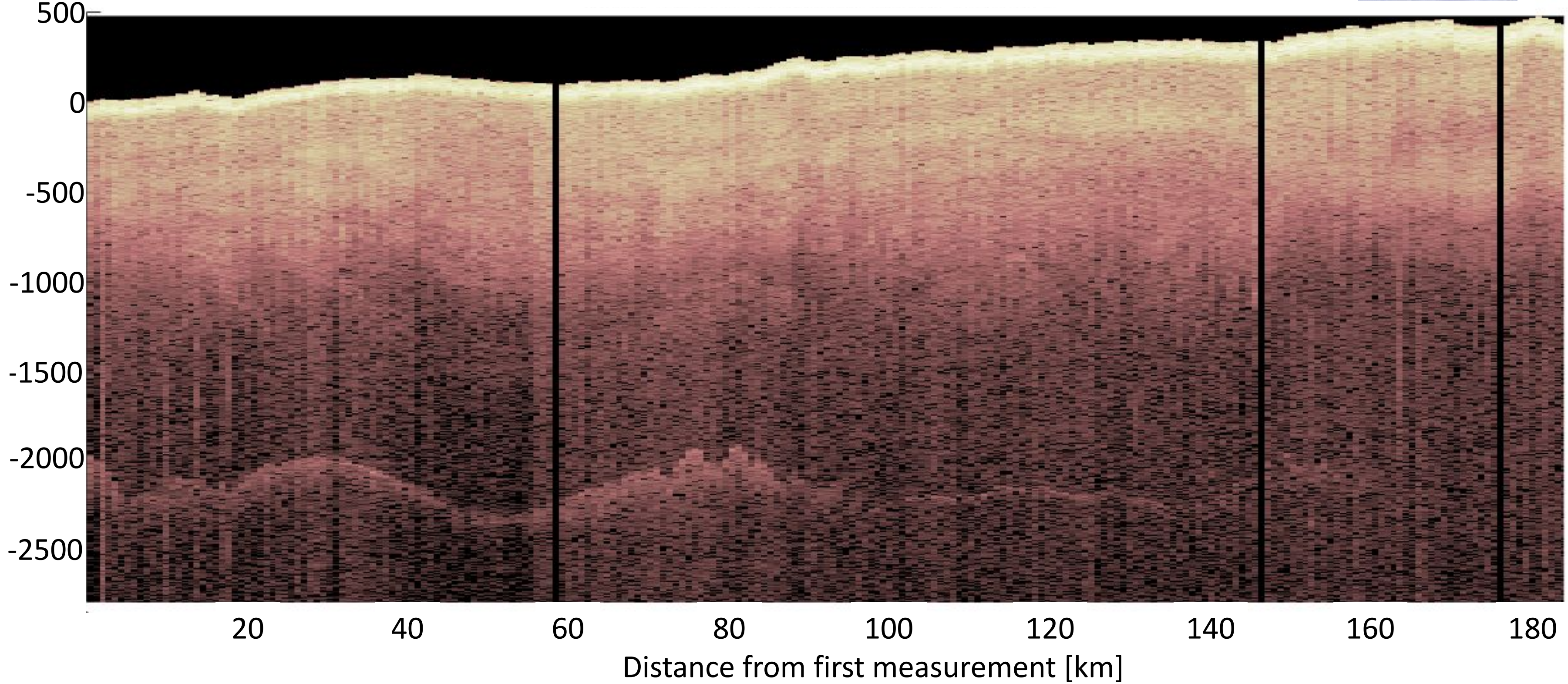
Data collected by Elizabeth Case as part of the GHOST traverse

Elizabeth Case
LDEO, soon Utrecht

INTERNATIONAL THWAITES GLACIER COLLABORATION
GHOST



Attended measurements on Thwaites Glacier



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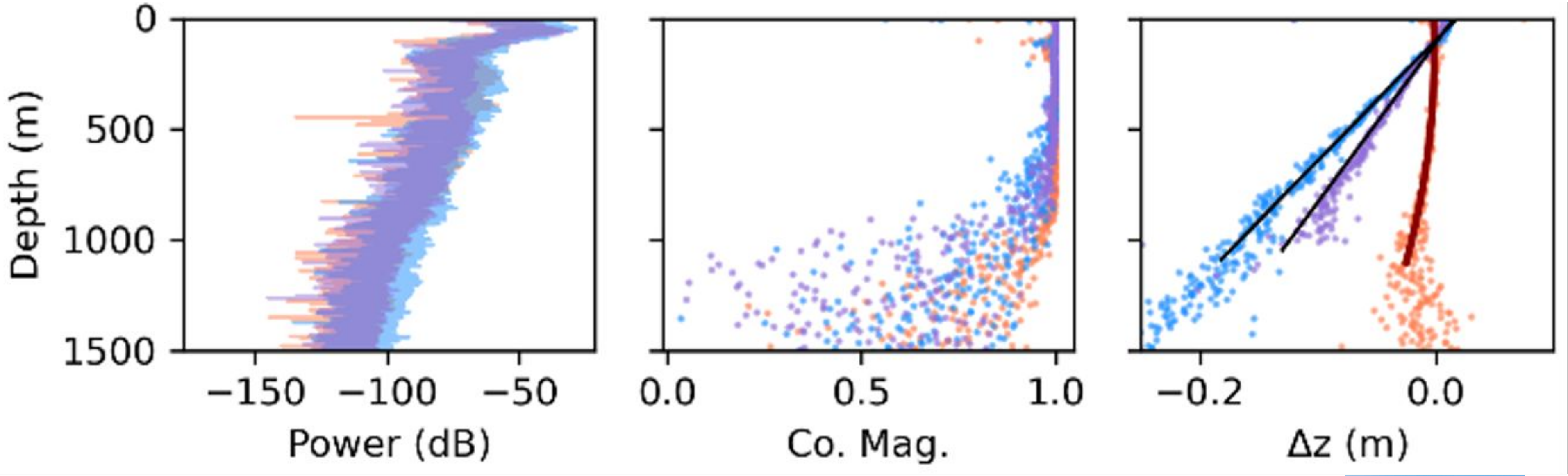
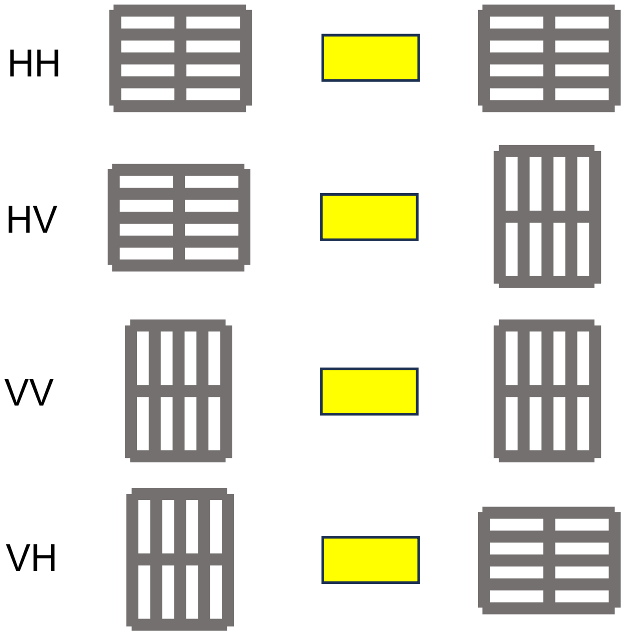
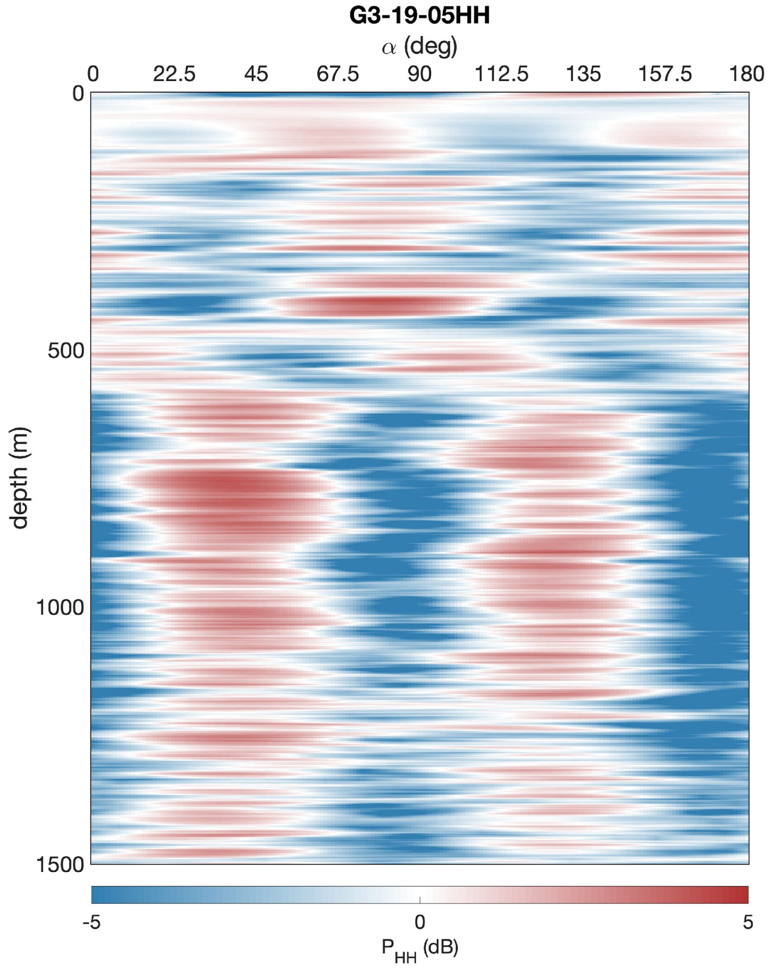


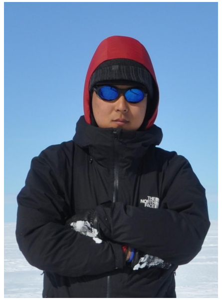
Processed by Andrew Hoffman

Polarimetric surveys → anisotropy





Examples of ApRES deployments: Greenland ablation zone



George Lu, LDEO

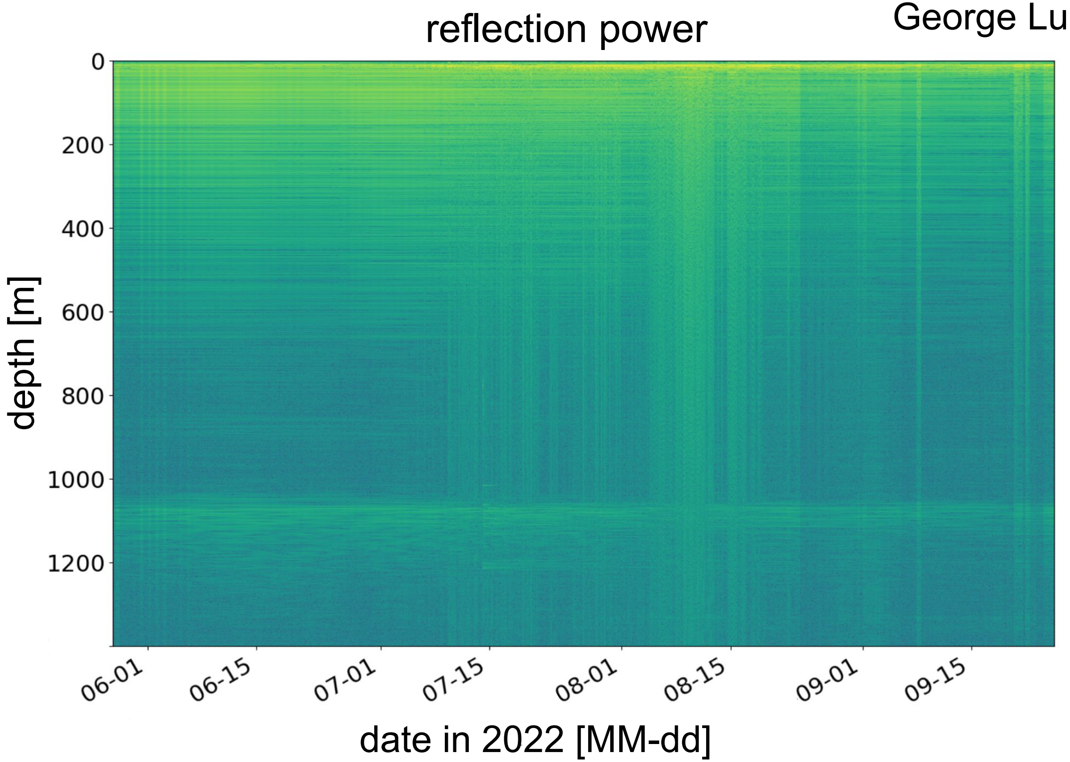
Three ApRES deployed around surface lakes along with GNSS and pressure loggers.

Up to 15 months of measurements at 15-minute intervals.

Field team:
- Meredith Nettles, LDEO
- Laura Stevens, Oxford
- George Lu, LDEO
- Stacy Larochelle, LDEO
- Josh Rines, Stanford
- Marianne Okal, Earthscope
- Kristin Arnold, IRIS mountaineering

Data analysis by George Lu, LDEO

NSF #2003464



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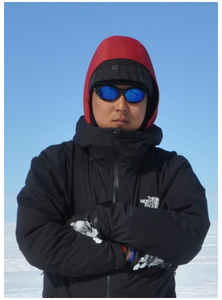
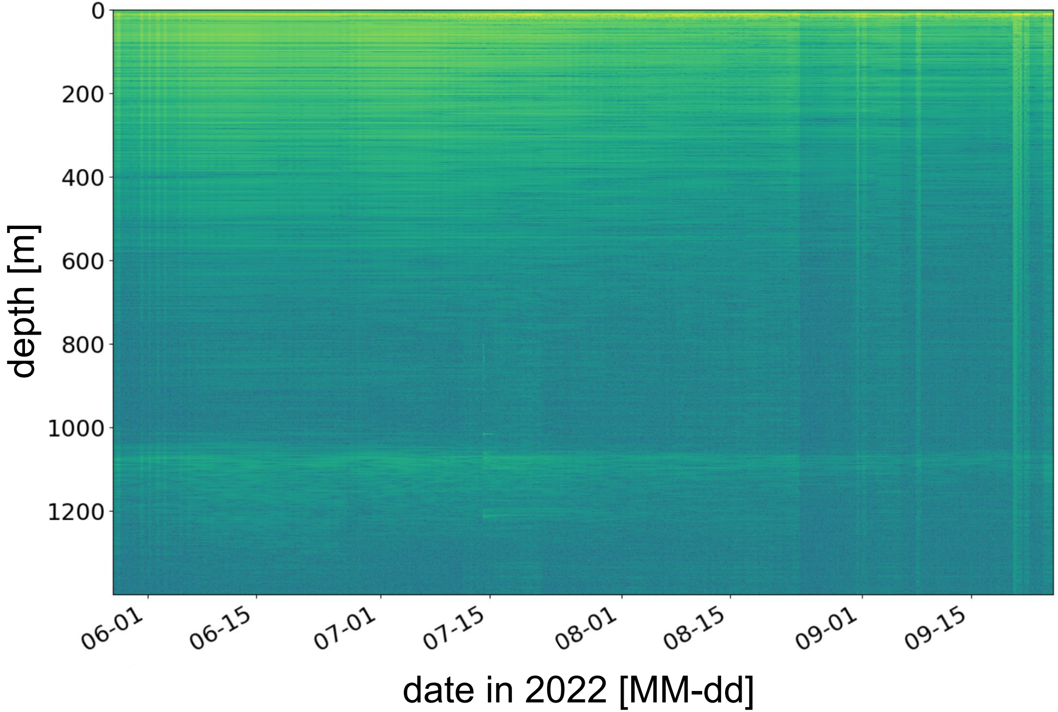


George Lu, LDEO

reflection power
w. clipping artifacts removed



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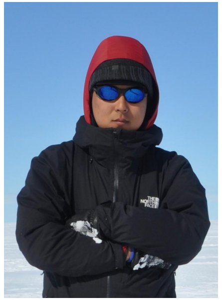

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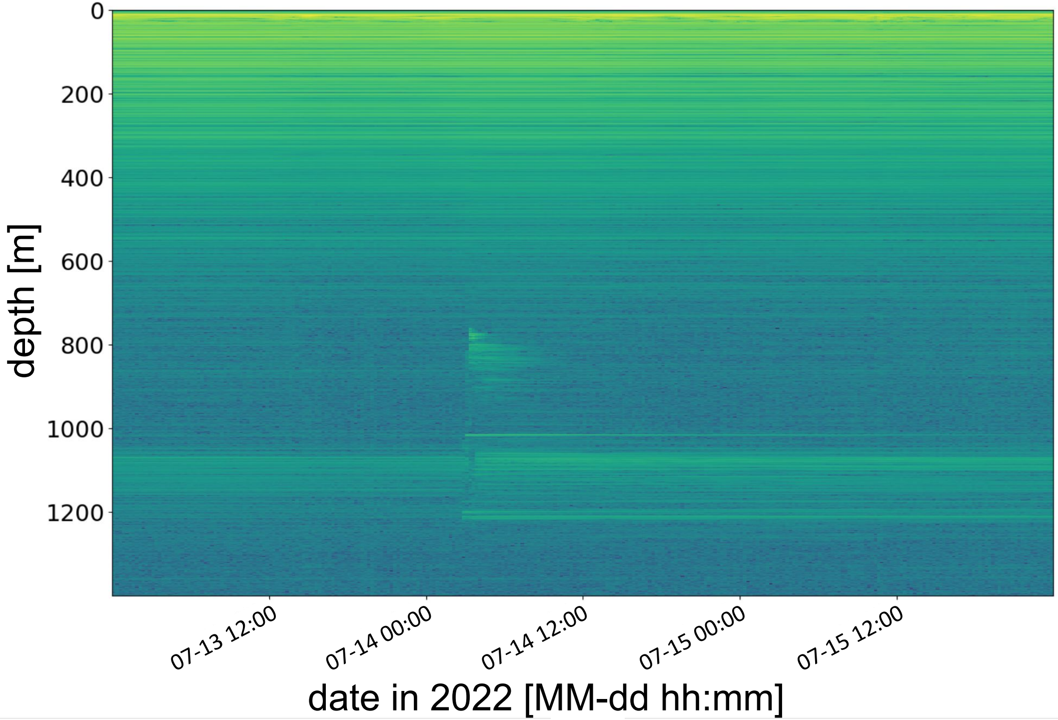
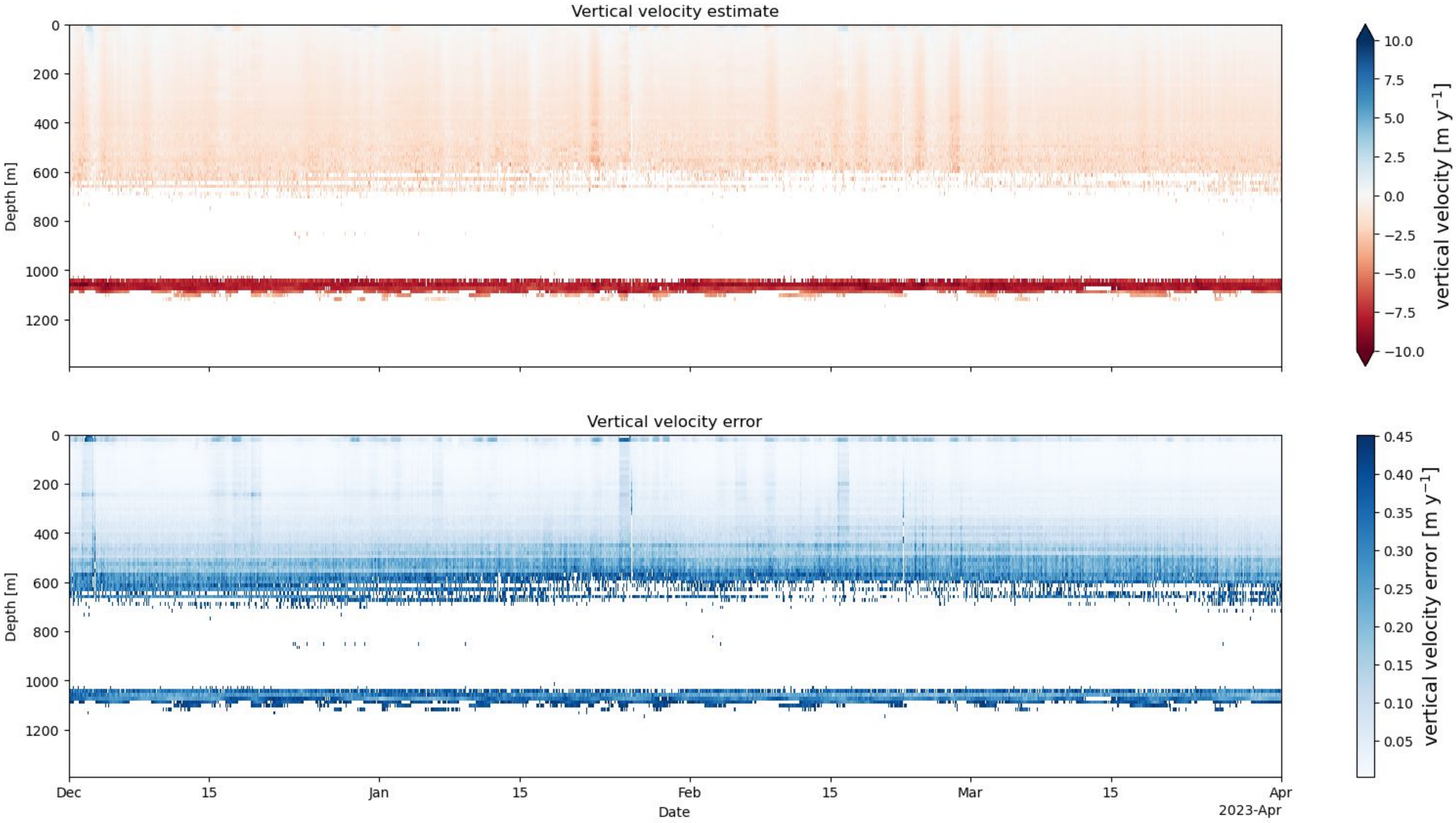
Data analysis by George Lu, LDEO

NSF #2003464

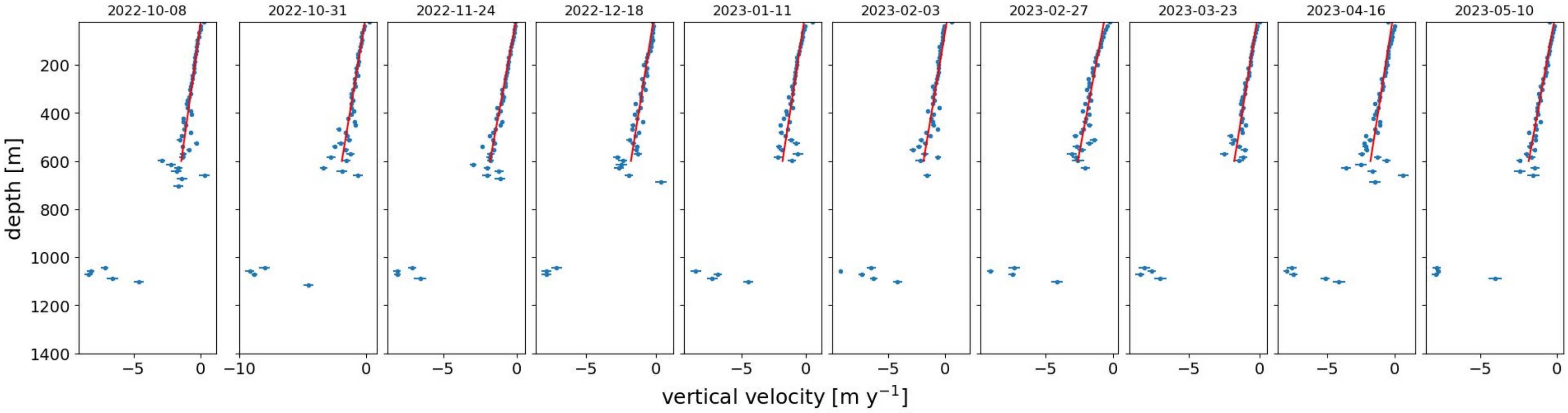
three days of data
around a lake drainage



Preliminary vertical velocity estimates – daily vertical velocities at 15 minute resolution



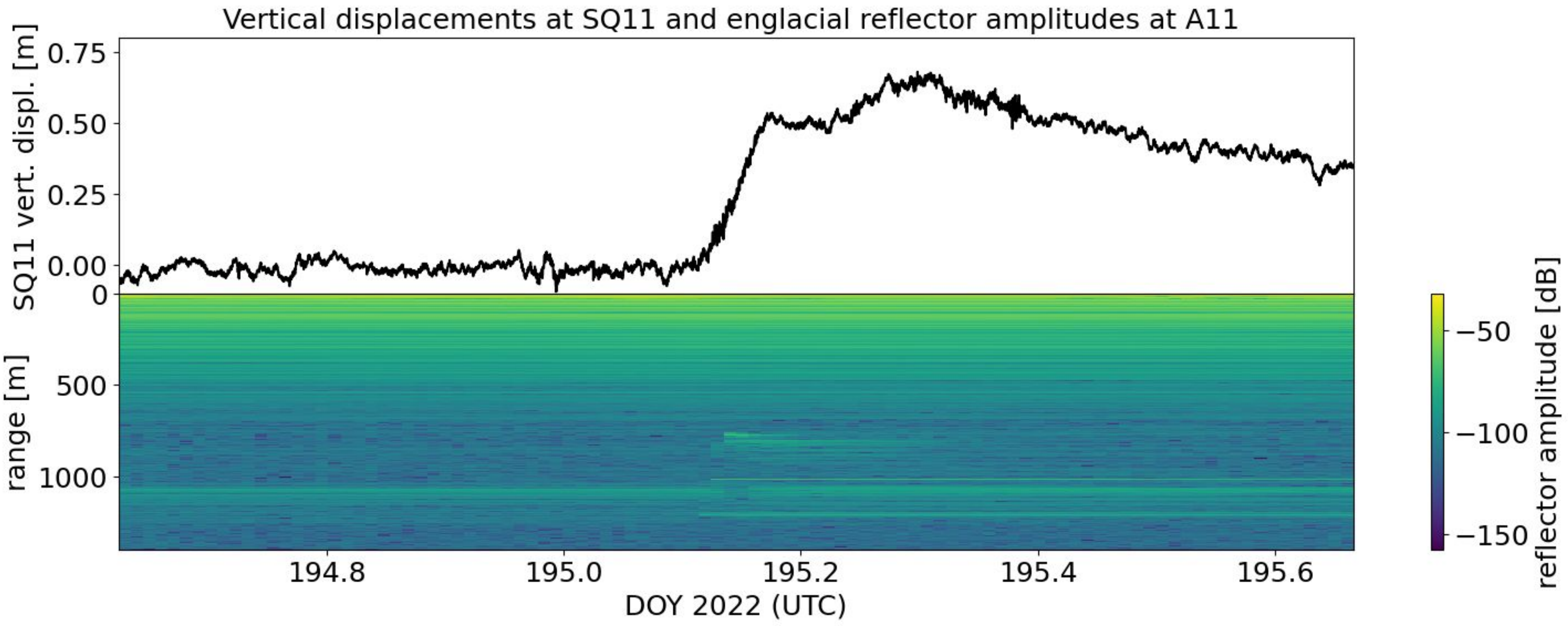
Some daily vertical velocity profiles at selected timestamps



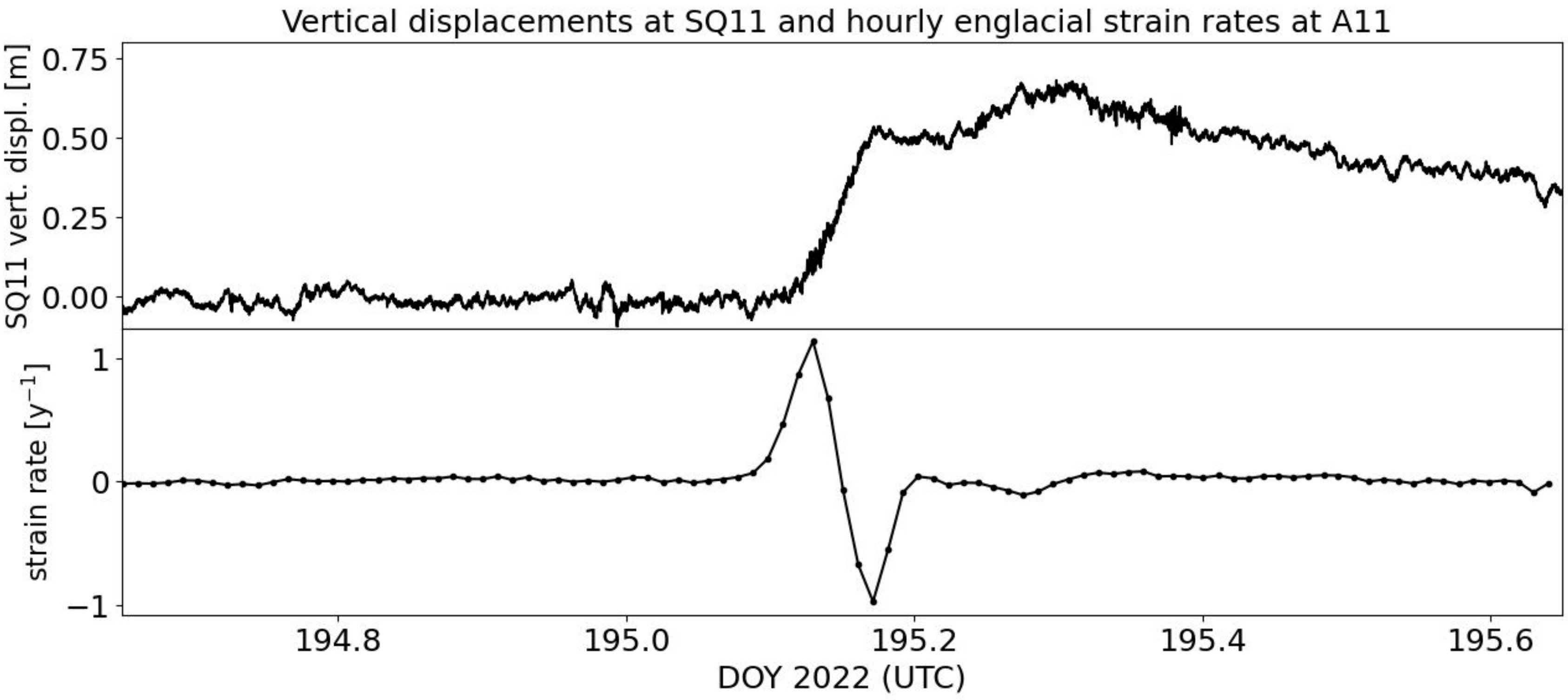
Strain rates (slope of linear fit to velocity) are generally around -0.0025 y^{-1} over the winter at this station,

We discard any result that has a coherence amplitude <0.95

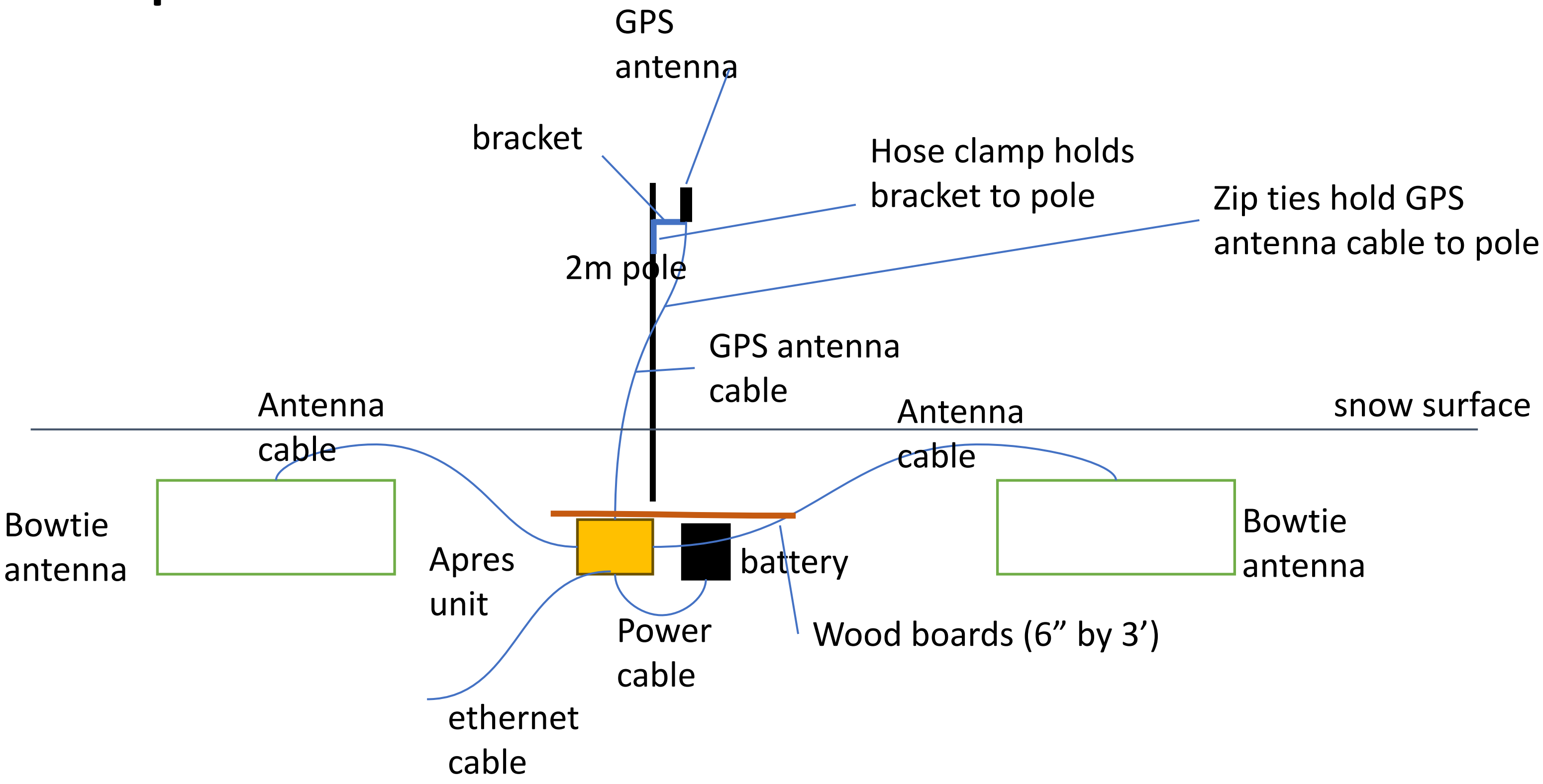
Focusing on lake drainage in summer 2022



New bottom plot is hourly strain rate estimate from top 600 m of ice



Our setup on Flask



Summary

Comparing measurements at different times can provide ice velocities and strain rates (unattended or attended)

Comparing measurements with different antenna orientations can prived ice crystal fabric (with current hardware, only attended).

Survey plans

Three autonomous stations:

- Center line of glacier, colocated with GNSS probably makes the most sense
- install time estimate (assuming 2 people) ~5 hours
- Unattended mode, maybe 15-30 minute intervals

Attended mode measurements (extra):

- 4-5 Polarimetric surveys in places we expect variation in fabric

Maybe run some tests on 1 ApRES then bury 1 or 2 and keep the last 1 for some extra attended measurements?