Passive Sources of Radio Calibration

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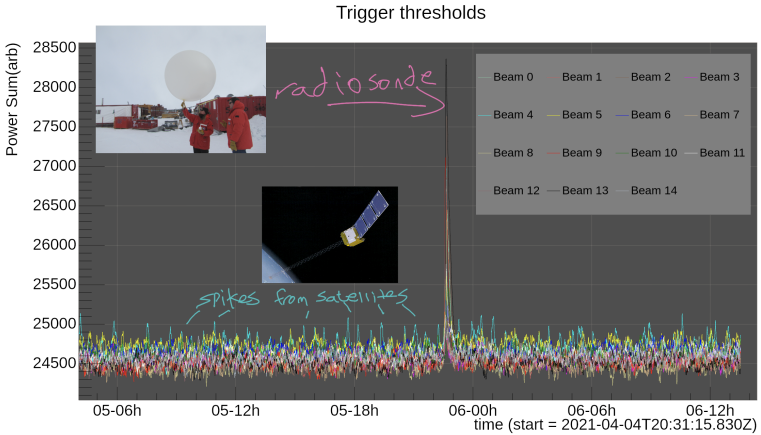
Introduction

- Philosophy: For calibration or validating calibration, can never have too much data!
  - Here, calibration refers to antenna positions / orientation / gain as well as ice properties (refraction index, attenuation, birefringence)
- Ideally, we'd have no RFI in our detectors. This is not the case, so we might as well figure out how to make use of it...
- Any RFI from emitters we don't control, but with position and emission properties we understand, is a potential source of passive radio calibration.
- All of these are outside the ice, so ice model is a big uncertainty in using them
  - Conversely can be used to probe ice model
  - In most cases, ice model affects received zenith angle but not azimuth...
- While we have identified some of the things discussed here as potentially useful in ARA, very little work has been done with them.

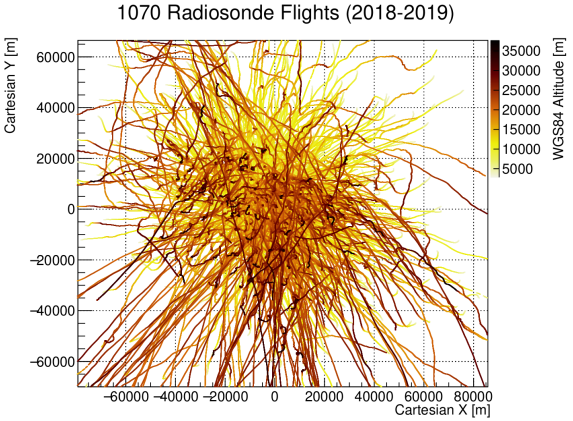
Trigger thresholds from the ARA Phased Array

The phased array trigger adjusts the threshold for each "beam" (set of coherent time delays) to keep the rate approximately constant. Spikes here correspond to non-constant conditions.



Radiosondes

- Weather balloons, with radio transmitter for telemetry. (Vaisala RS41)
- If you ask meteo nicely, they'll give you the raw data transmitted from each radiosonde (includes GPS coordinates)
  - This can probably be systematized...
- 403 MHz narrowband CW signal
  - Amplitude (e.g. surface vs. deep) and relative phase measurements between channels can be done at that frequency to constrain attenuation, ice properties, fine antenna positions
  - $\sim$ 0.5 m wavelength in deep antennas
  - Polarization determined by orientation of whip antenna on radiosonde (not well controlled)



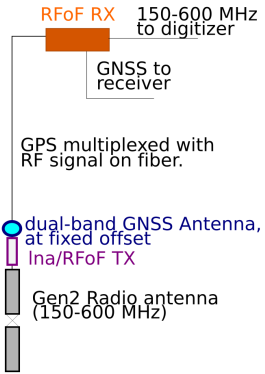
Lots of coverage, many directions! This data is waiting to be analyzed...

Satellites

- The "beam 4" peaks in phased array data were a mystery in the phased array for a long time. Eventually, we (Kaeli) figured out they were correlated with 137 MHz CW.
- 137 CW is a satellite downlink frequency!
  - e.g. ORBCOMM, NOAA
  - A good number of satellites in polar orbit with 137 CW downlink. Satellite ephemeres are readily available, but still have to match the up.
  - Have cursorily looked for other frequencies (260 MHz/380 MHz milsats, 437 amateur band satellites), but nothing super obvious in a brief search. There are certainly satellites in view, but maybe not readily downlinking...
- Positions of satellites, once identified, can be calculated from ephemeres.
- Polarization is always circular, so in principle can probe polarization resolution, birefringence (but since narrowband, can lead to degeneracies).
  - Assuming both HPol and VPol antennas can detect frequency...

Could we use GNSS satellites?

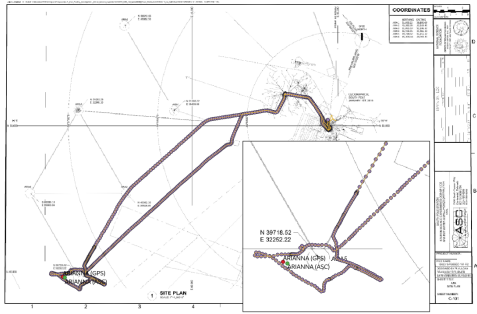
- GNSS sats (GPS, GLONASS, Galileo etc.) are tailor-made for ranging
- But, out of band (1.2/1.6 GHz), require specialized processing.
- However, dual-band receivers now affordable (e.g. u-blox ZED-F9P).
  - Obviously, these will get confused by the ice, but probably can still extract the pseudoranges for each satellite which can be used to fit for antenna positions, ice model.
- Back of the envelope calculation suggests that GNSS signals should be detectable even at -200 m (depending on satellite elevation). Plan to test this summer in Greenland if time available.
  - Typical GNSS power at surface is -120 dBm. Modern receivers sensitive to -145 dBm and better.
- If this works, could multiplex active GPS antenna with RFoF from downhole antennas to GNSS receiver on surface at low cost.
  - Can switch (don't need GNSS receiver per channel).
  - RTK method in principle able to get antenna positions to cm precision.

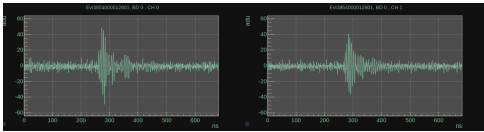


Impulsive RFI?

- CW requires lots of work, impulsive RFI covers all frequencies and has no phase ambiguities.
- Snowmobiles are a good source, but we typically don't know where they are
  - I tracked myself riding a snowmobile last year at Pole and it produced some very nice pulses!
  - Since snowmobile is within a wavelength of surface, can be seen beyond TIR angle (harder to model, but typical of some backgrounds like wind and impacting shower cores).
  - Could theoretically request all snowmobiles in the radio array carry tracking device?
- It's possible that turboprop planes produce pulses. If not, they can certainly reflect them.
  - "Normal" planes transmit GPS coordinates with ADS-B. Not clear if planes at Pole do or not.

2018 map georeferenced to South Pole orthographic projection and propagated false easting/northing to 2020 ice flow, ignore marked scale. Purple dots from phone, yellow line from dedicated GPS tracker during snowmobile. ARIANNA GPS position from Steve Barwick (not propagated from 2019 to 2020).





And wait, there's more!

- Astrophysical sources (galaxy, sun, nebulae)
  - Co-adding enough events all should become visible
  - Evidence of radio flares seen in ARA (`https://arxiv.org/abs/1807.03335`) on an event-by-event basis.
  - We see the sun in individual events in ANITA, but it's easier when you're not below the ice and have high-gain antennas.
- Land Mobile Radio
  - We filter this out on ARA right now, but particularly the rooftop repeaters could potentially be used a calibration source.
- Wireless comms
  - If we use wireless comms, and it's not completely obliterated by filters, it becomse a calibration source!