Phase and Amplitude Calibration of ICEBEAR and SuperDARN Receiver Arrays Using Aircraft Echoes

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Overview

- **ICEBEAR**
- **Interferometry**
- **Airplane Calibration Procedure**
- **Application and Results**
  - ICEBEAR
  - SuperDARN

ICEBEAR

ICEBEAR

Ionospheric

Continuous-wave

E-region

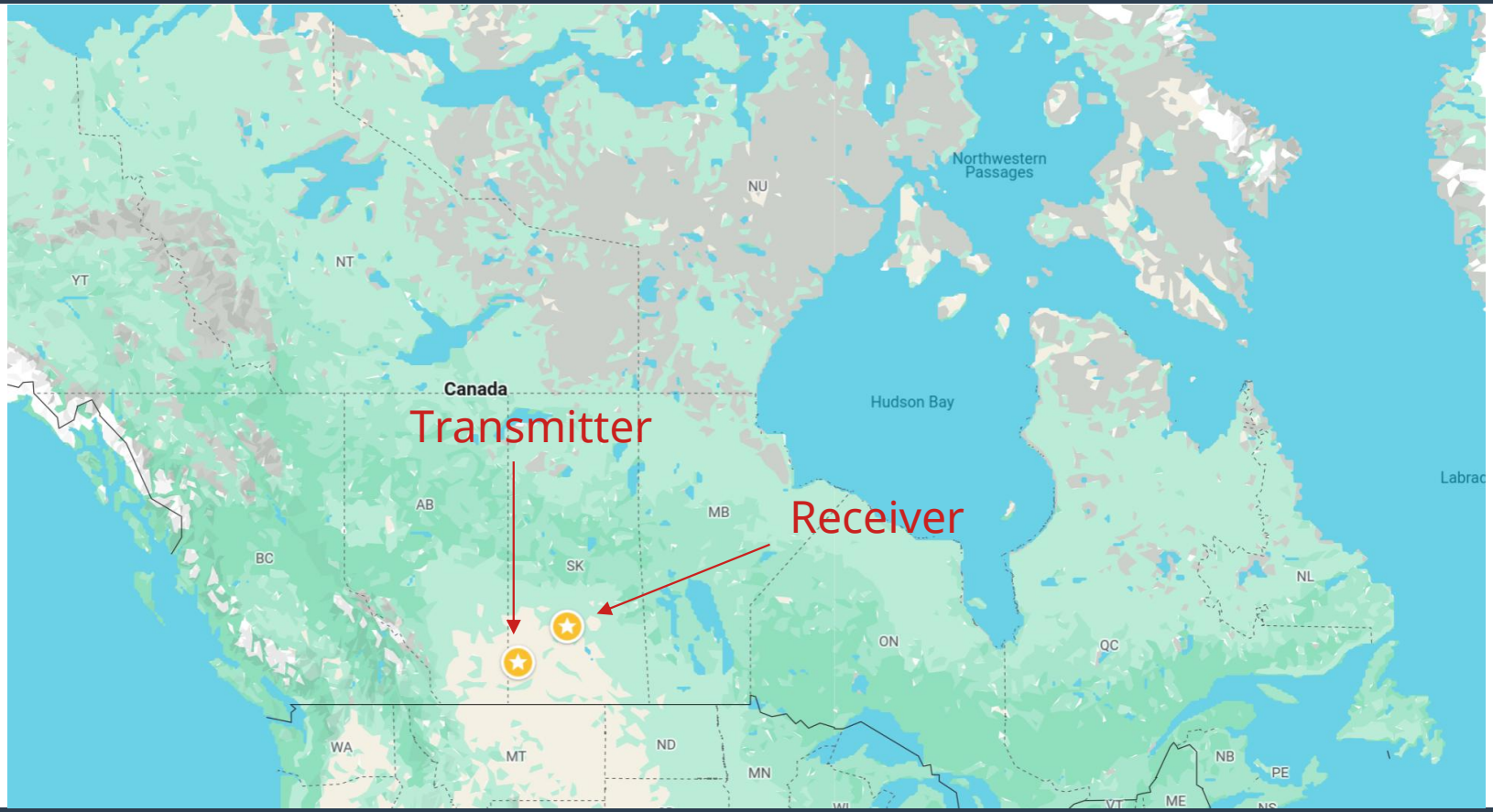
Bistatic

Experimental

Auroral

Radar

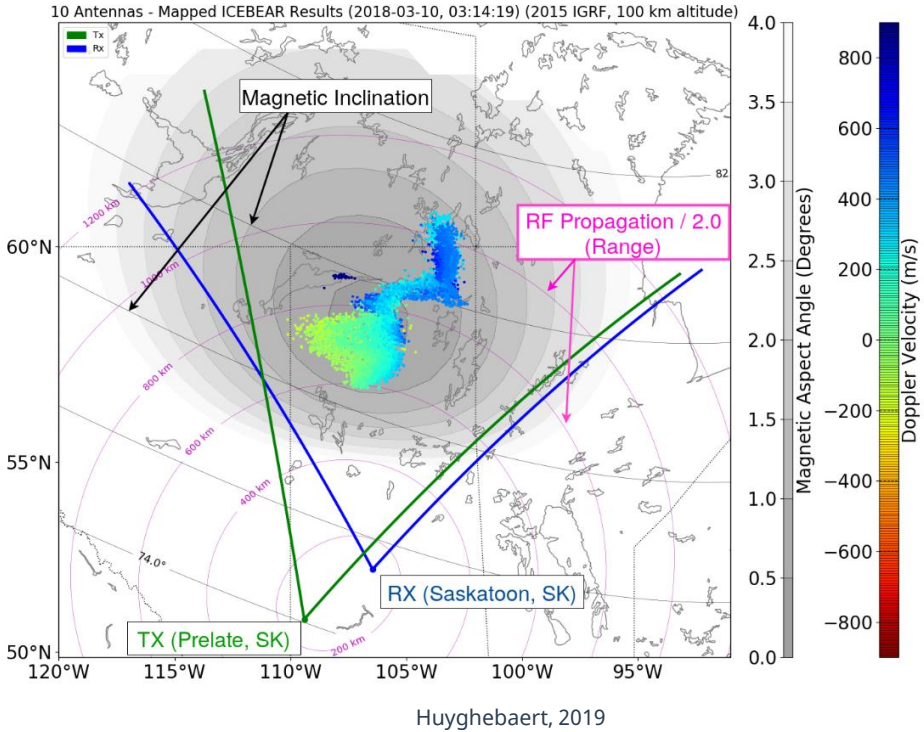
ICEBEAR


Northwestern Passages
NU
NT
YT
Canada
Transmitter
Hudson Bay
Receiver
AB
MB
BC
SK
NL
ON
QC
WA
MT
ND
MN
NB
PE
ME

ICEBEAR

Specifications

- **PI: Dr. Glenn Hussey (glenn.hussey@usask.ca)**
- Coherent scatter radar capable of measuring echoes from E-region, meteor trails **and airplanes**
- Horizon-viewing (up to ~45° elevation)
- **Wide nominal FoV** (~90° azimuth)
- Continuous-wave pseudo random phase modulated signal
- Centre frequency 49.5 MHz, wavelength 6 m
- 100 kHz bandwidth
- **1s temporal resolution**
- **1.5 km range resolution**
- **10 Hz doppler resolution**
- 45 unique Rx baselines
- 10 **fully independent** digitised Rx channels

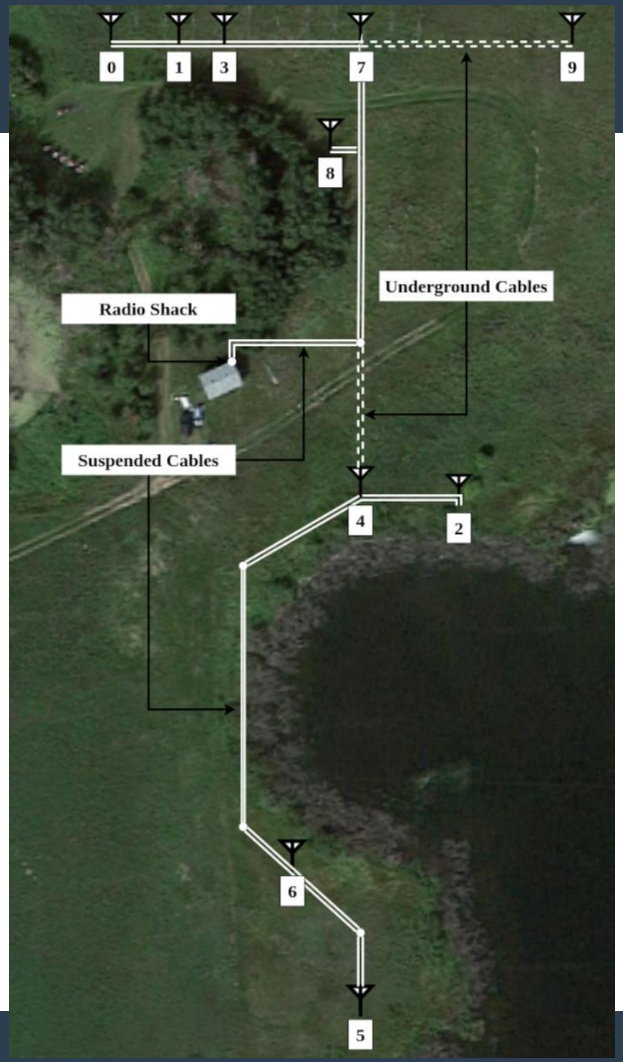


Huyghebaert, 2019

INTERFEROMETRY

ICEBEAR-3D

- Interferometric radar
- 2D irregularly-spaced receiver array
- Unambiguous azimuth and elevation angle of arrival



Interferometry

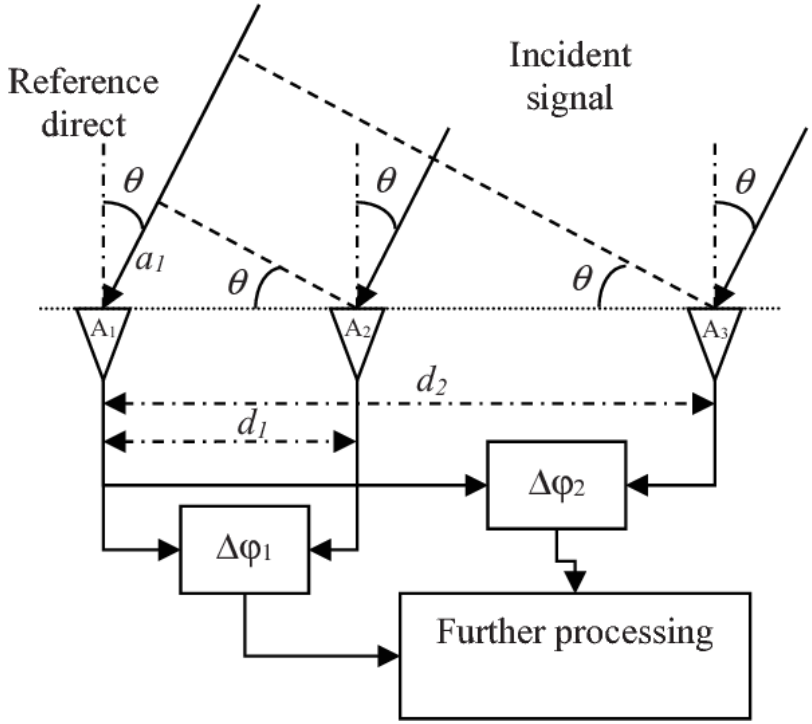
- Use **difference in received signal phase** between two receive antennas

$$V_{ij} = A_i A_j \exp(\phi_i - \phi_j)$$

- Determine **angle of arrival**

$$\Delta\phi = \frac{2\pi d \sin\theta}{\lambda}$$

- Each pair of antennas (baseline) helps reduce ambiguity



https://www.semanticscholar.org/paper/Optimized-algorithm-for-solving-phase-ambiguity-Doan-Vesel%C3%BD/70752aacc0b7966febd0ae87750ec4657ba791e7/figure/0

Spherical Wave Harmonic Transform

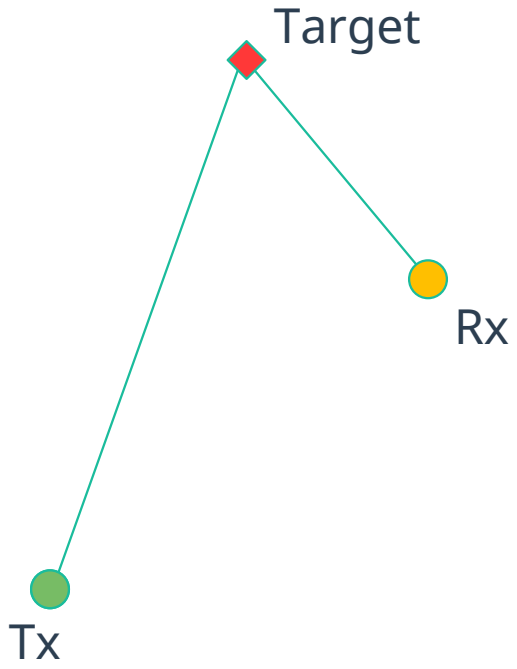
45 baselines

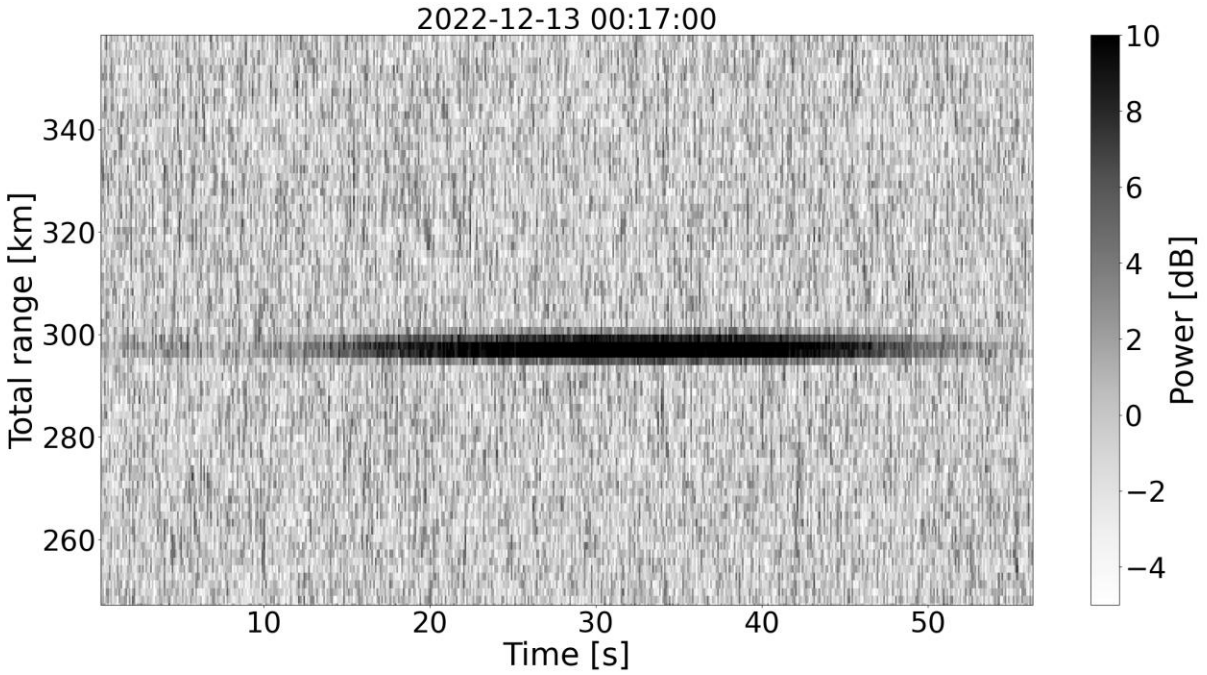
$$B(\Omega_k) = \sum_{l=0}^{\infty} \sum_{m=-l}^{l} Y_{lm}(\Omega_k) \frac{k_0^2}{2\pi^2(-j)^l} \sum_{i=1}^{Q} V_i(k_0) J_l(k_0 r_i) Y_{lm}^*(\Omega_i)$$

1 brightness map

AIRPLANE CALIBRATION PROCEDURE

Airplane Echoes





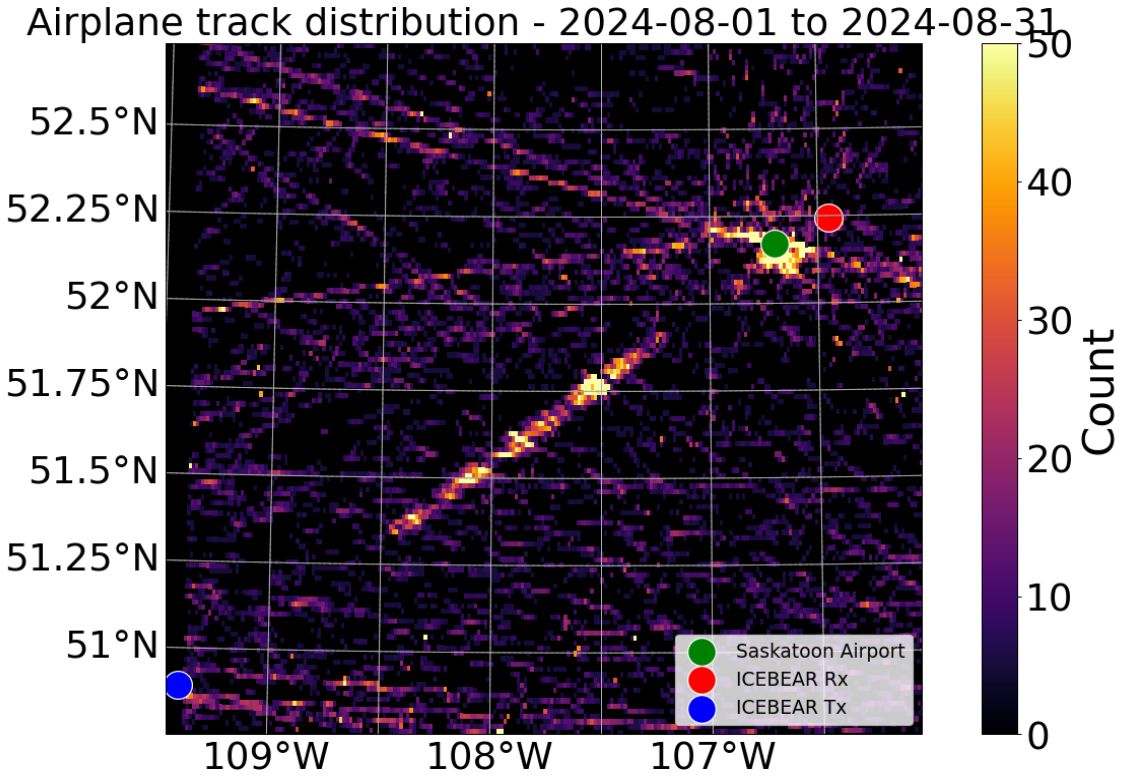
ADS-B and OpenSky Network

Automatic Dependant Surveillance – Broadcast (ADS-B)

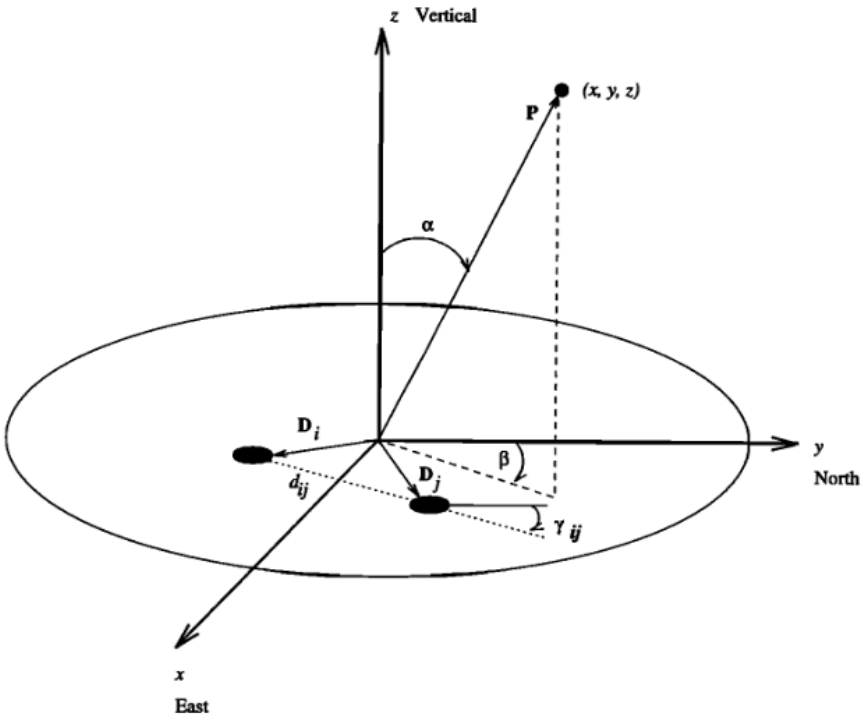
- Used by nearly all aircraft
- Transmits location information

OpenSky Network

- Uses ADS-B receivers to track aircraft
- Provides API to access historical data



Expected and Measured Visibility Phase



$$\phi_{ij} = k(\mathbf{D_i} - \mathbf{D_j}) \cdot \mathbf{n} + \Delta\phi_{ij}$$

ϕ_{ij} : measured visibility phase

$k(\mathbf{D_i} - \mathbf{D_j}) \cdot \mathbf{n}$: expected visibility phase

k : radar wave number

$\mathbf{D}$: vector from origin to antenna

$\mathbf{n}$: unit vector from origin to airplane

$\Delta\phi_{ij}$: error in phase measurement

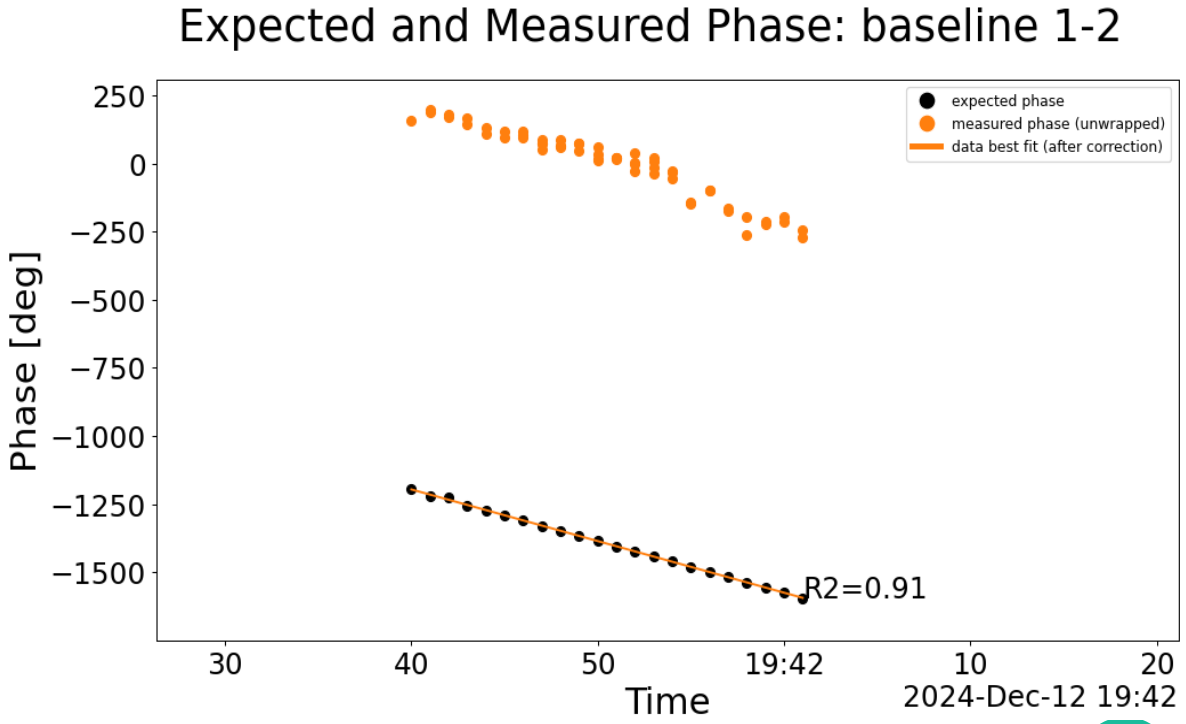
Calculating Calibration

Calculate averaged phase offset for each baseline

$$\Delta\overline{\phi_{ij}} = \frac{1}{N}\sum^{N}\Delta\phi_{ij}$$

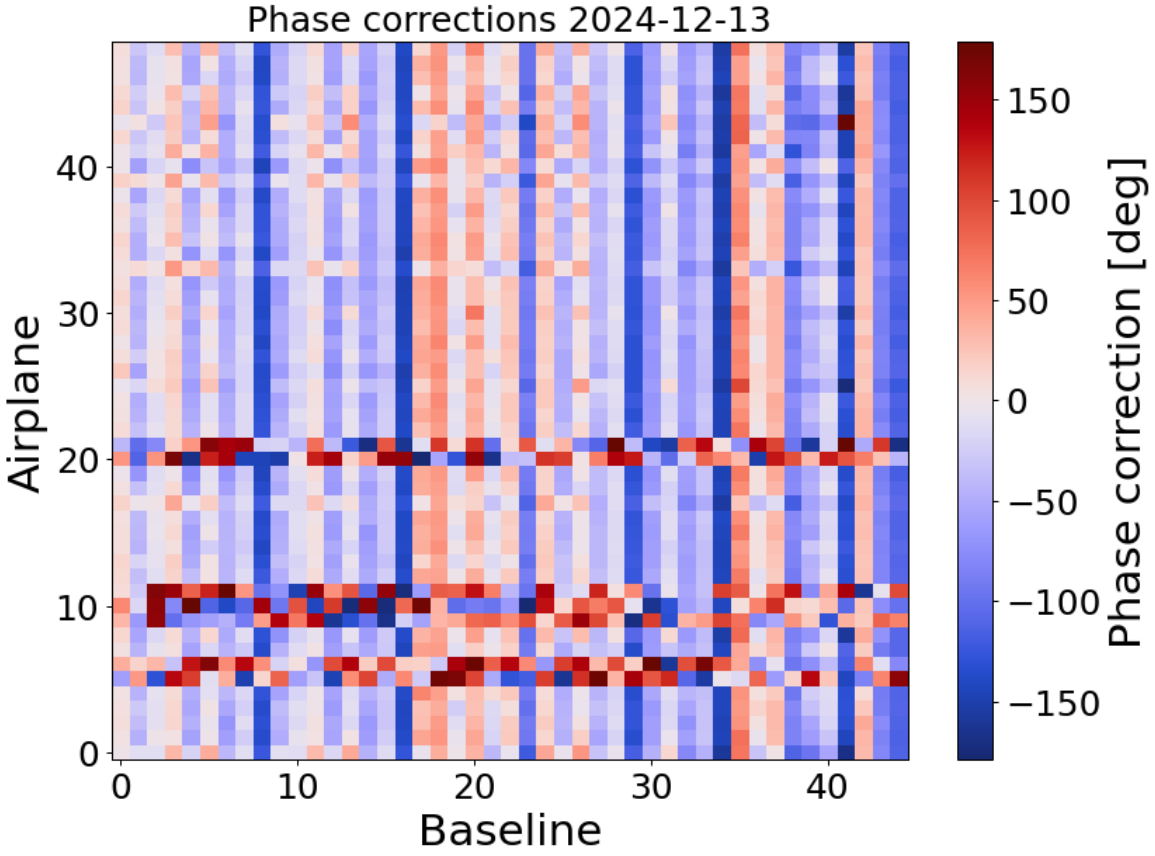
1 airplane
→ **45 averaged offsets** (1 per baseline)

Average over ~20 airplanes / day
→ **45 baseline calibrations / day**

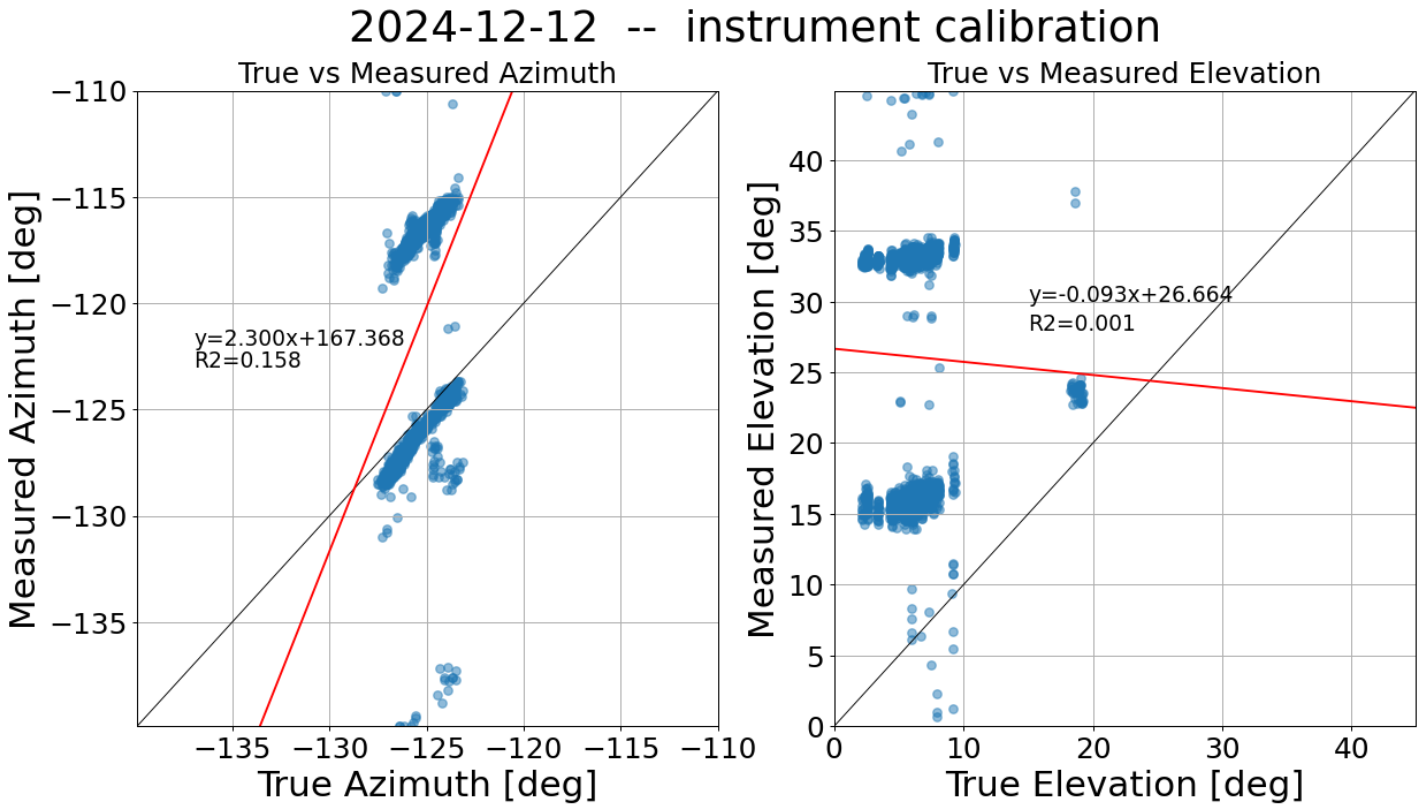


AIRPLANE CALIBRATION RESULTS

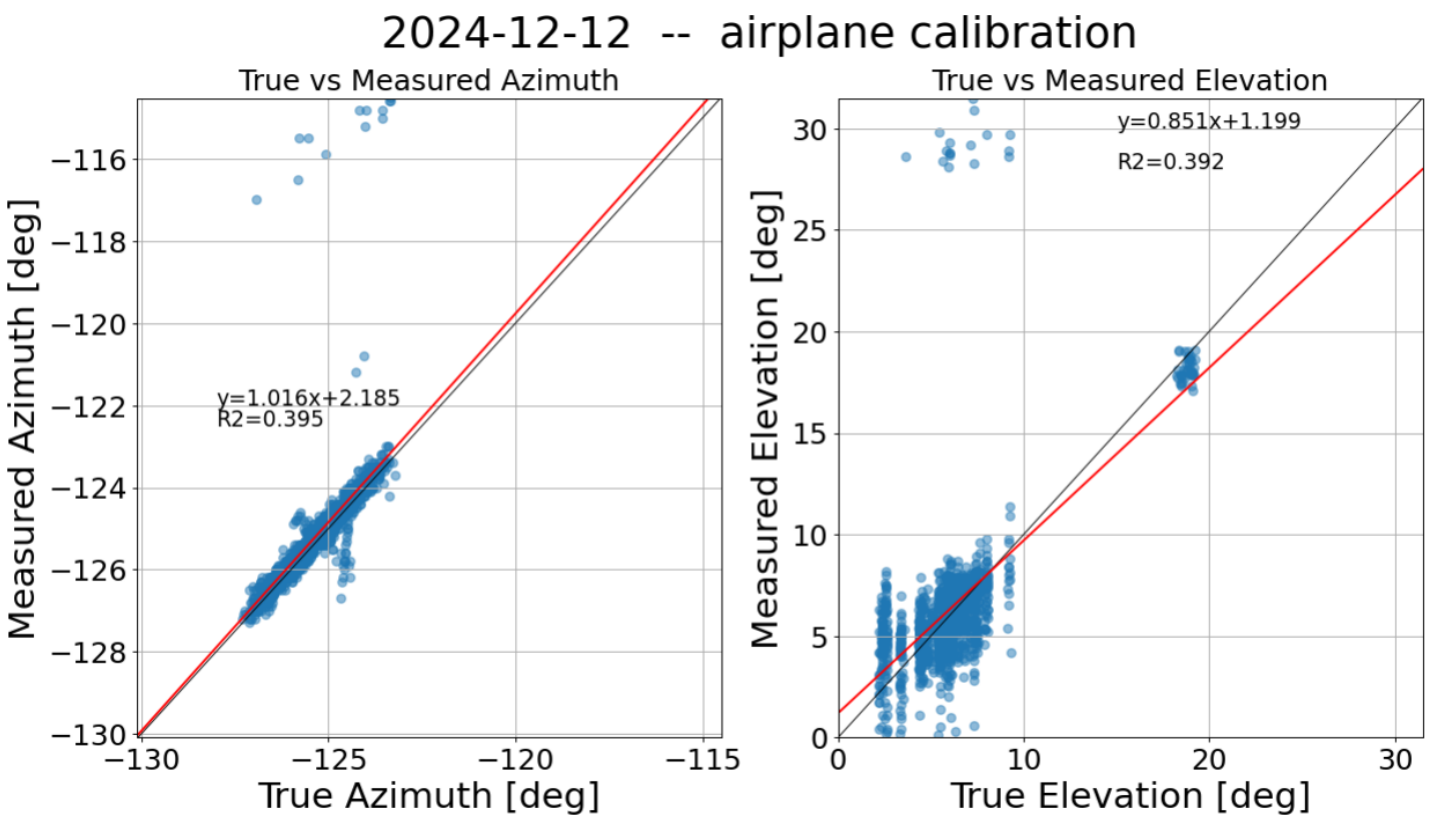
Phase Corrections



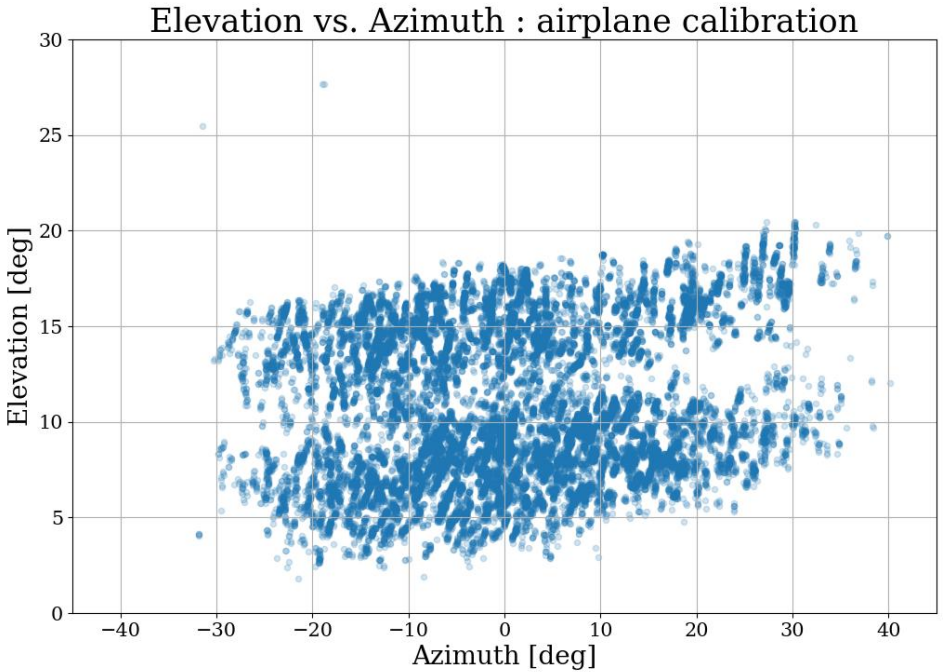
Instrument Calibration

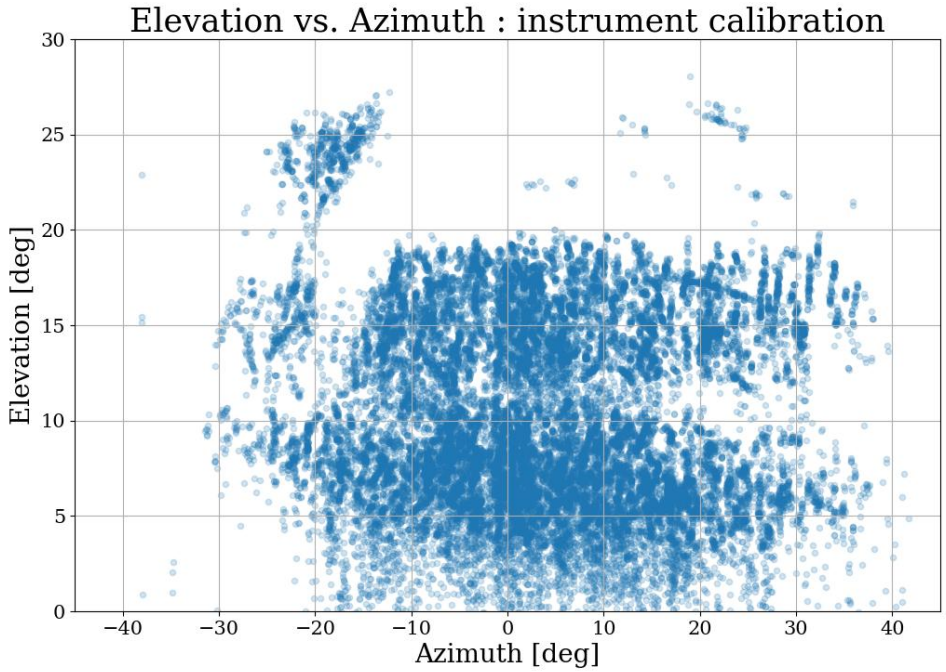


Airplane Calibration



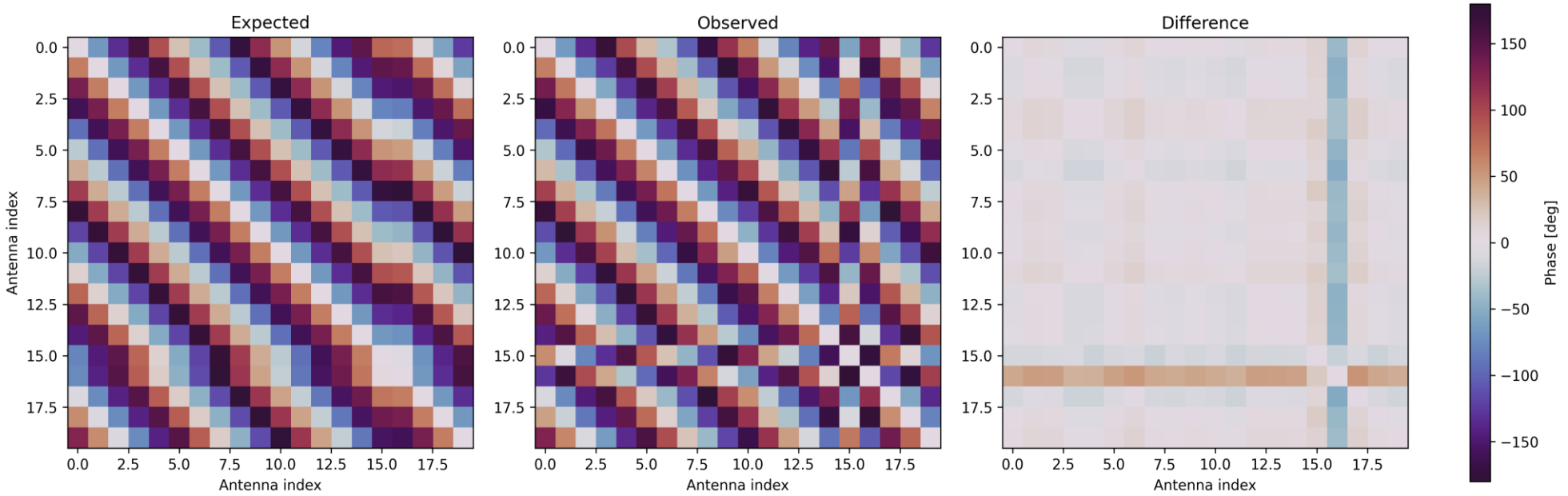
Forward FoV Results



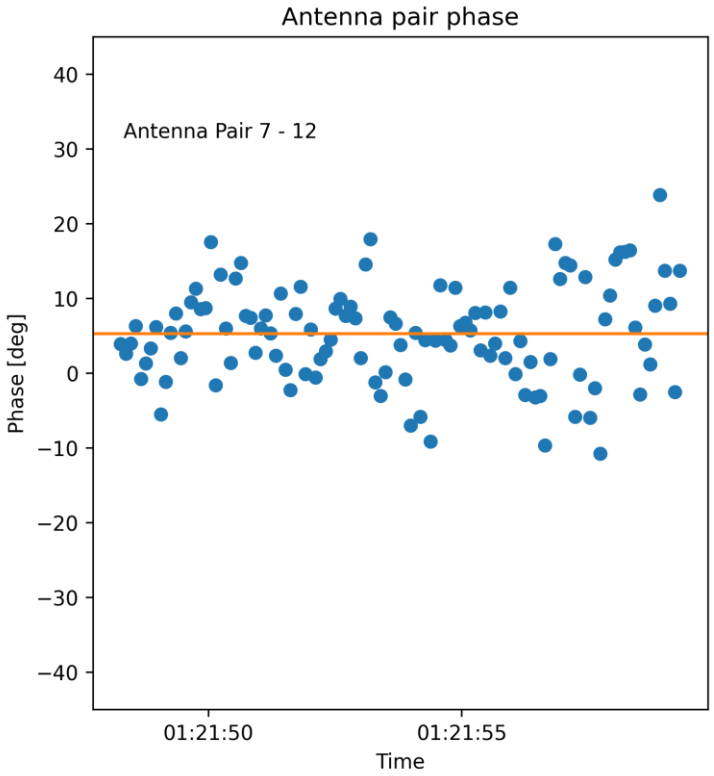


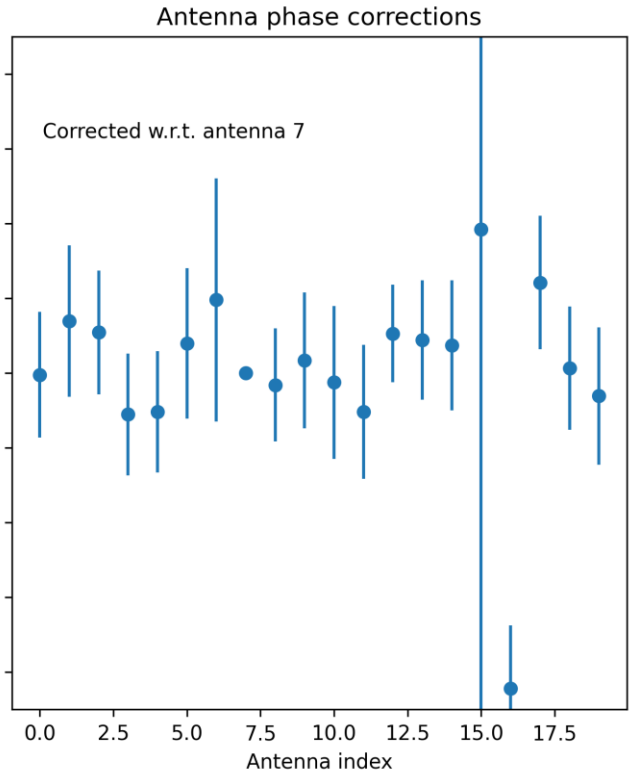
SUPERDARN

SuperDARN (SAS) Airplane Calibration

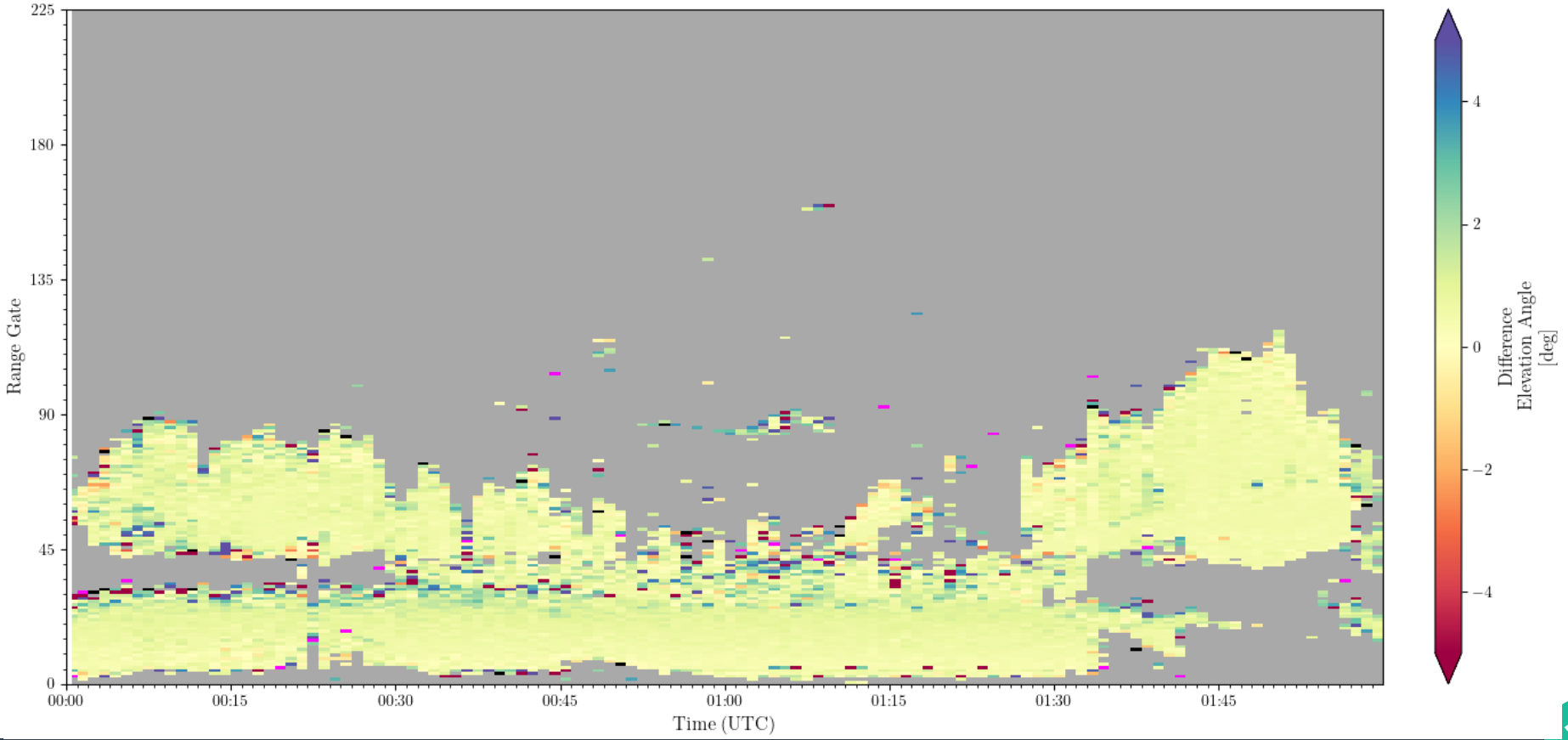


SuperDARN (SAS) Antenna Calibration

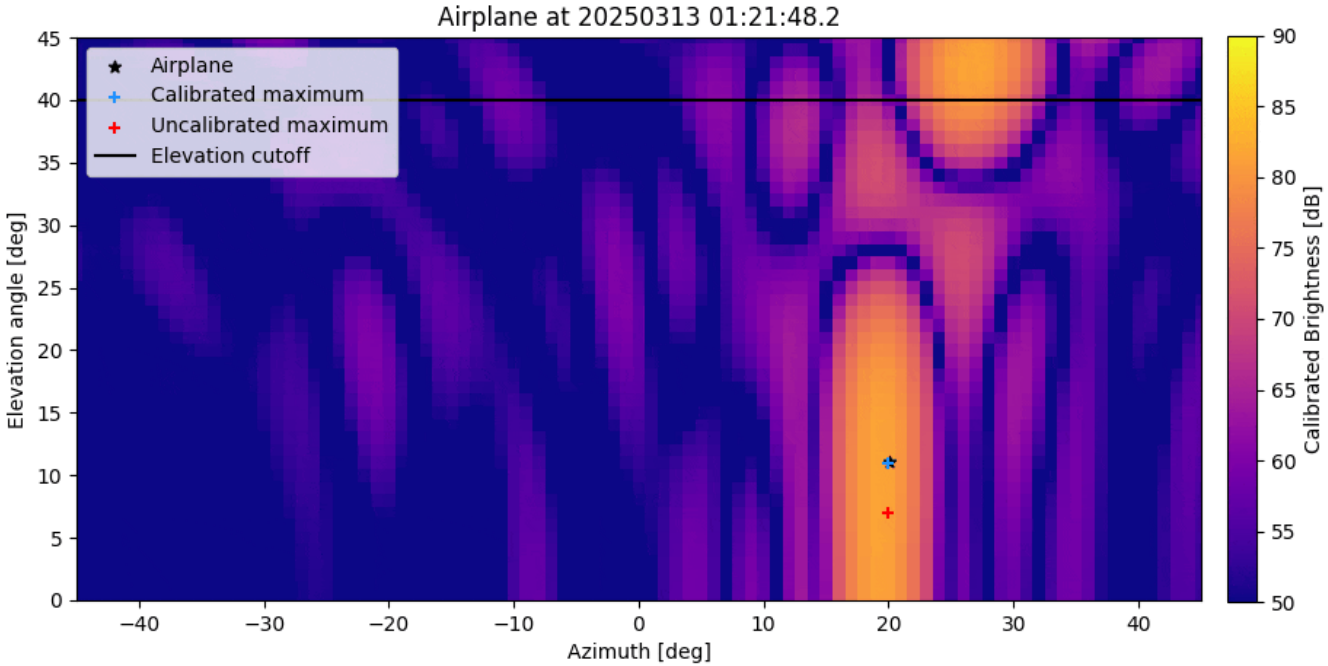




SuperDARN (SAS)
Calibrated Elevation Angles



Imaging with SuperDARN



Summary

- ICEBEAR and SuperDARN see airplanes every day
- Poor channel phase calibration ➡ poor quality beam pattern
- Airplane echoes ➡ baseline AND antenna phase calibrations
- Applying phase calibrations locates airplanes very well
- Part of geolocation solution