HF Signal Geolocation vs. Ionospheric Structure: An Engineering Solution Approach

IES

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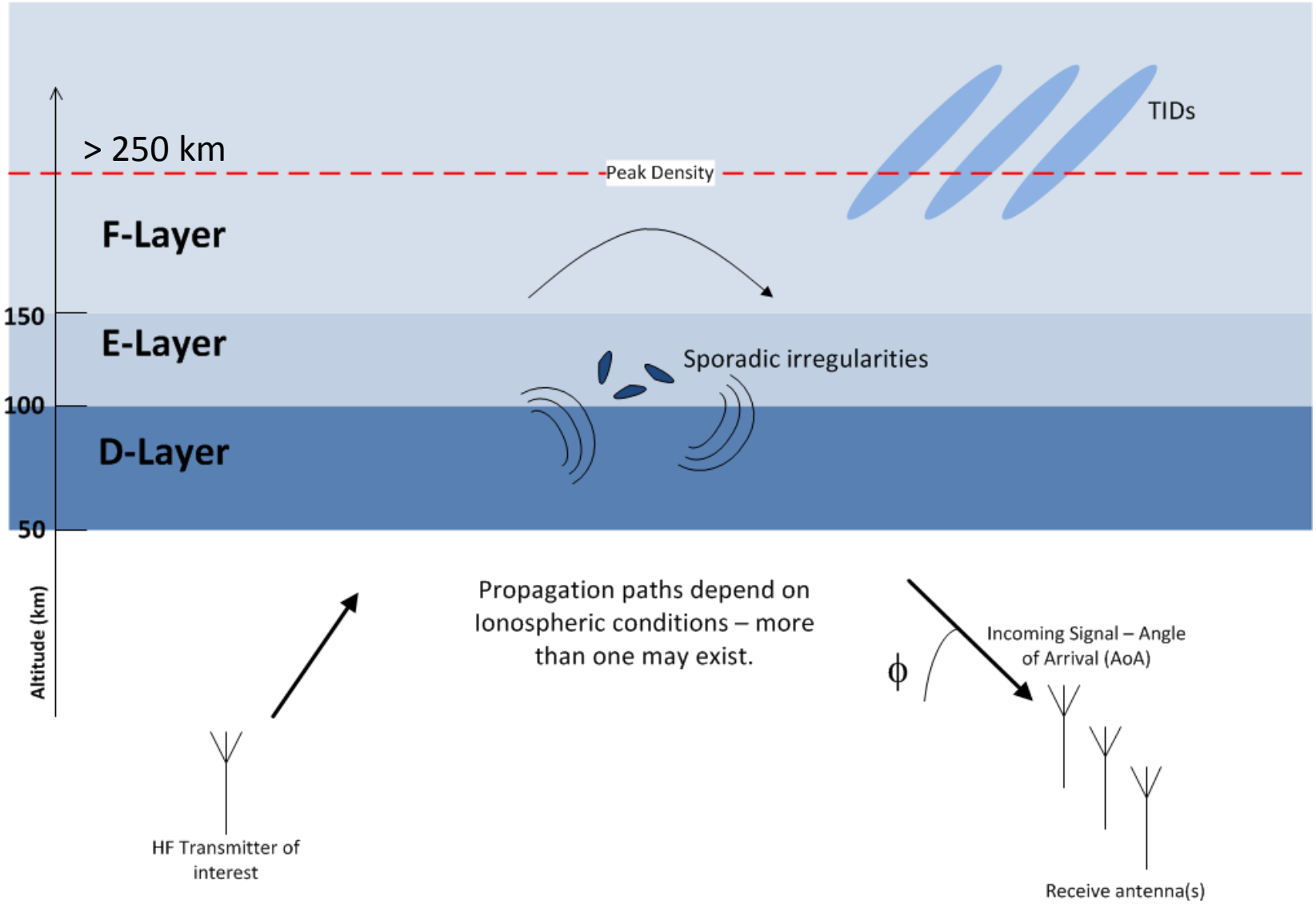
The Skywave Geolocation Problem

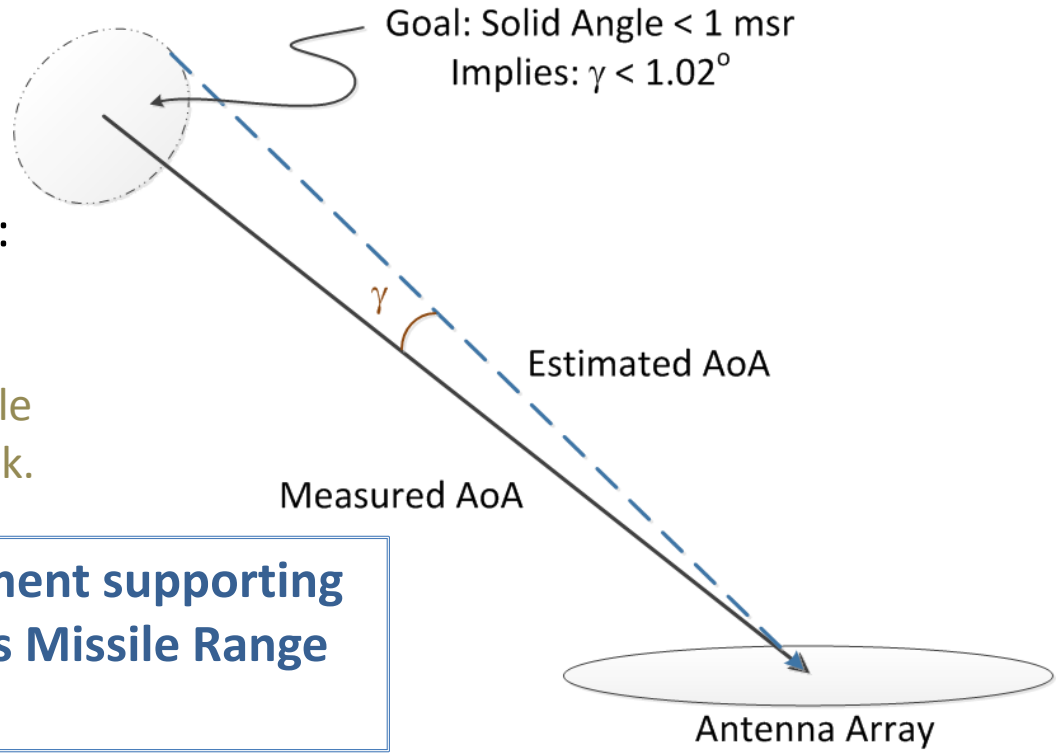


The IARPA HFGeo Phase 1B Program

One Phase 1B Goal

- Measure AoAs of known targets with "truth array" of 19 crossed dipoles
- Estimate AoAs of withheld targets to within 1 msr

How well can an engineering solution based on check targets perform?



- γ measures difference between:
- estimated unknown target AoA
- measured truth target AoA

For convenience, we use 1° cone angle instead of 1 msr solid angle in this talk.

We present results from an experiment supporting Phase 1B conducted at White Sands Missile Range (WSMR) 19-27 January 2014.

Phase 1B Metrics

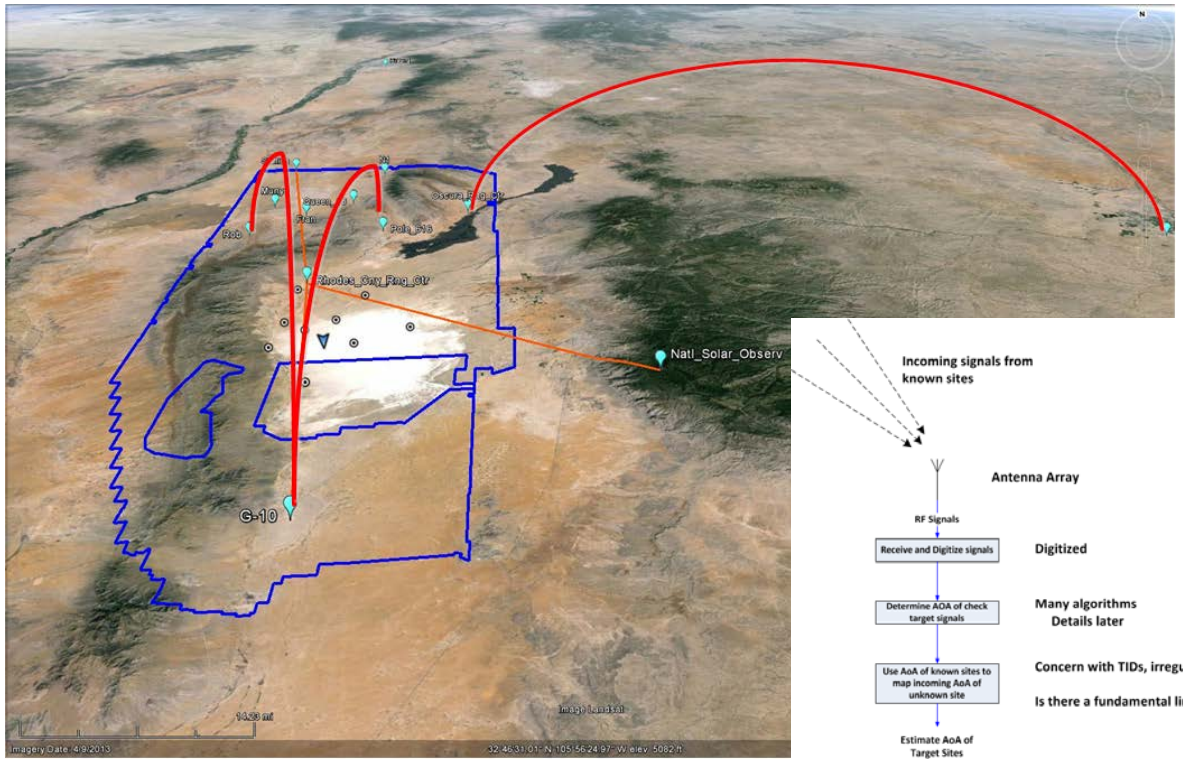
Table 2: Phase 1B Metrics

Figure of Merit	Short range (< 150 Km)	Medium & Long Range (> 150 Km)
Predicted vs. Measured Ionogram		
Time delay error (β)	≤ 20 μsec	
Maximum plasma frequency error (γ)	≤ 50 kHz	
Junction frequency percent error (γ)		≤ 1%
Predicted vs. measured angle-of-arrival difference	≤ 1 mSR (circular error)	≤ 1 deg (cross-range)
Predicted vs. Measured Channel Scattering Function		
Mode amplitude error	≤ 5 dB	
Doppler shift error	≤ 0.05 Hz	
Time delay error (β)	≤ 20 μsec	
Timeliness / latency	≤ 30 seconds (nowcast) to be within a factor of two of the above accuracy ≤ 180 minutes (backcast) with full accuracy	
Availability	> 90% Performer to identify time periods where accuracy goals can be met	

What is “Engineering Solution” Approach?

How well is AoA of a transmitter estimated by those of “nearby” Transmitters (check targets) ?

- **Nearby in space, time, frequency**



Elements:

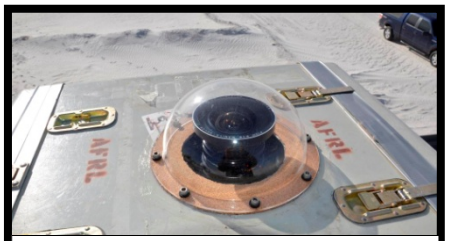
1. Known Tx sites
2. Reasonably dense Tx sites
3. A precise Rx array
4. SNR > 50 dB post-correlation
5. Supporting iono. Measurements
6. Interpolation

Can we meet the 1msr goal?

Phase 1B Experiment Layout

Central Tx Site Equipment

Check Target site with GPS receiver

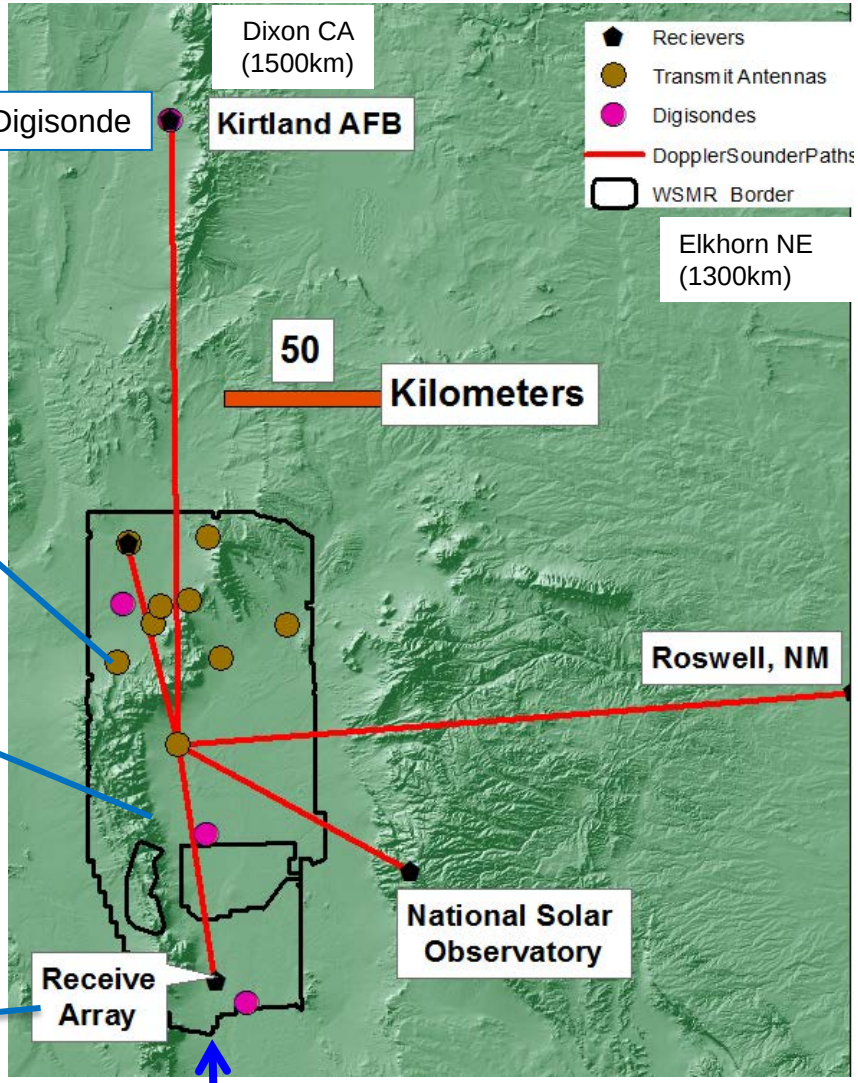


Optical Sensor at Midpoint

Midpoint Digisonde Site

Receive Site Equipment

Main array receive site: G-10

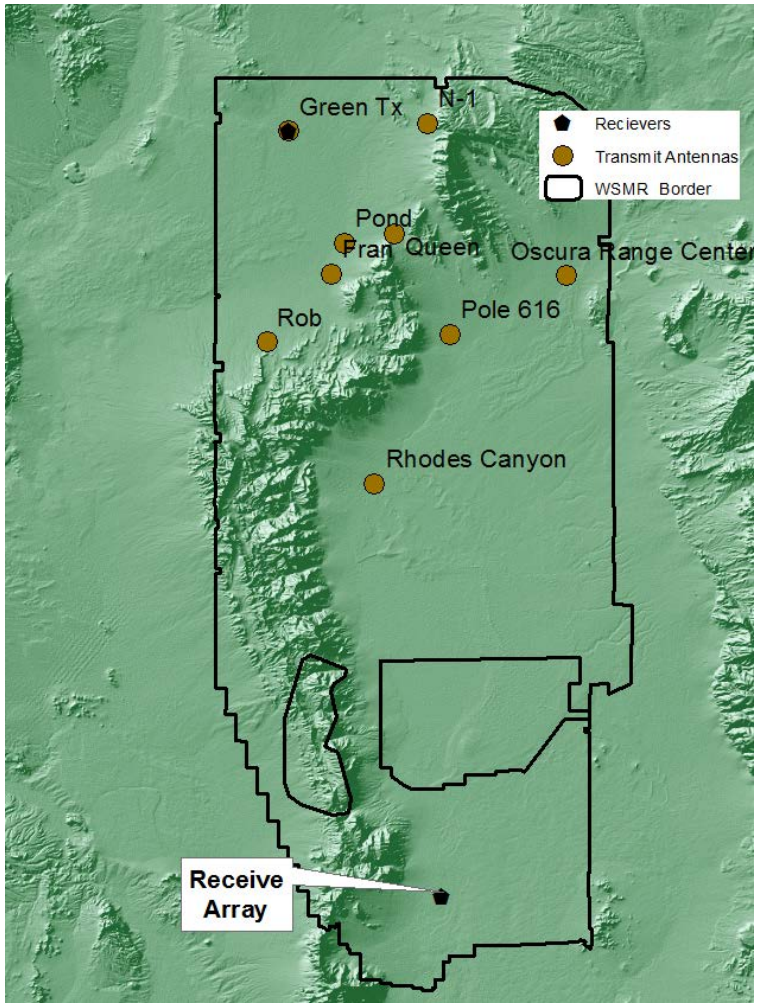


White Sands Missile Range, New Mexico

Transmit Sites

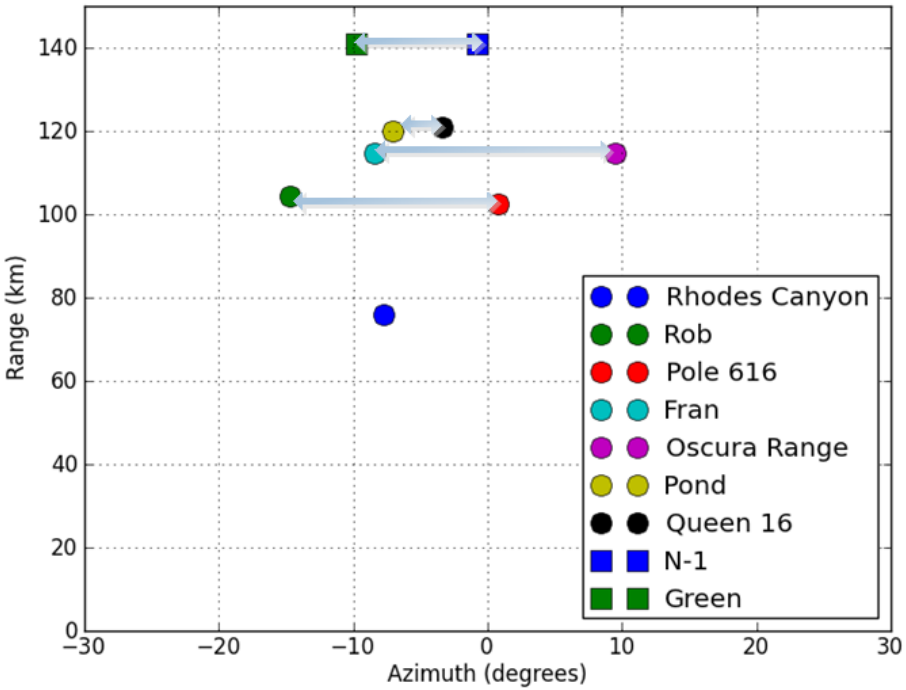
Purpose: transmit signals that can be used to probe ionosphere and permit AoA analysis

- **Transmit from 8 northern sites**
  - **(Rhodes is special)**
- **Single dipole antenna at each site**
- **One of two signals used at each site**
  - Radar
    - LFM 50 kHz at f_{hi} or $f_{lo,}$
    - Freq. offset in multiples of 5 Hz
  - Oblique Sounder
    - 3-12 MHz
    - 100 kHz/sec sweep
    - Freq. offset 2 kHz
- **All transmit sites run concurrently**
  - GPS timing

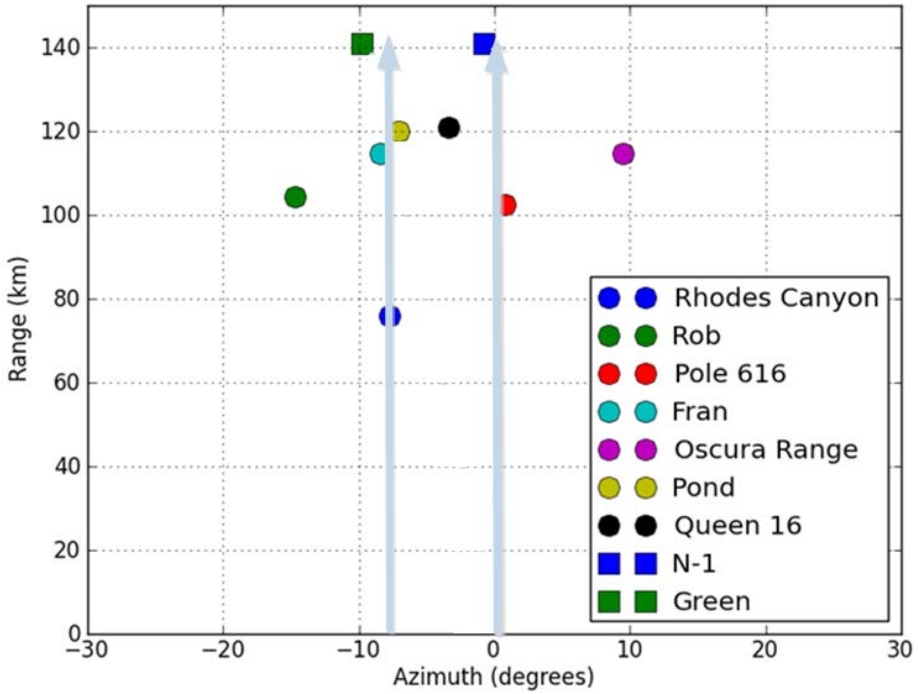


Transmit Site Geometry Relative to G10

Tx site layout designed to allow studies of ionospheric effects on range and azimuth AoA independently.



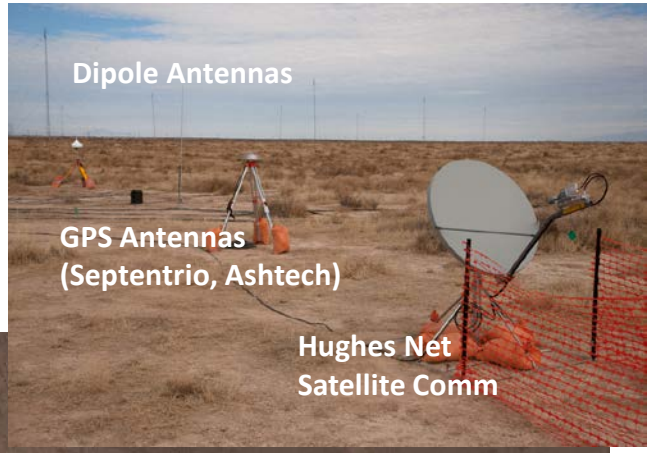
Sites with similar range

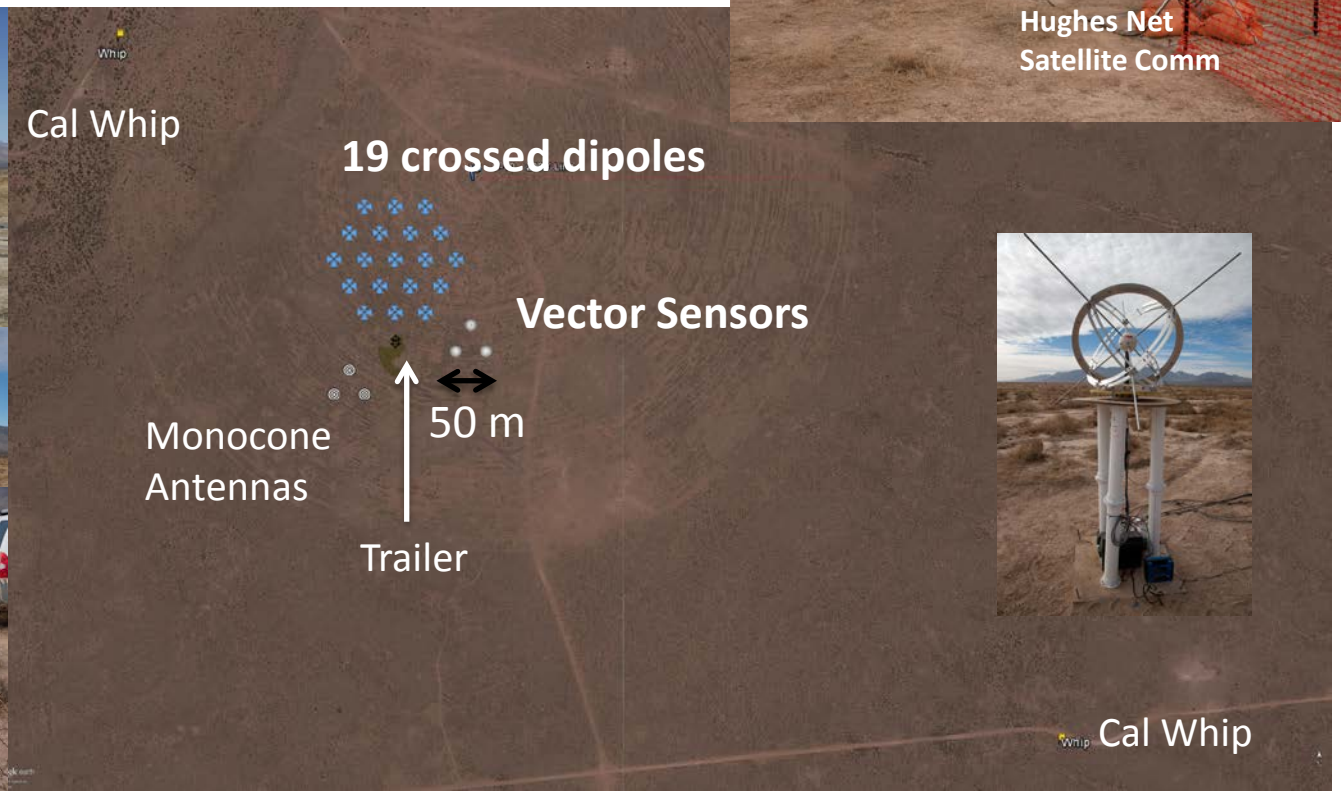


Sites with similar azimuth

G-10: The Truth Array

Purpose: Provide antenna arrays for AoA determination
Dipoles, Vector Sensors
plus
GPS Rx's (2) & Beacon Receiver





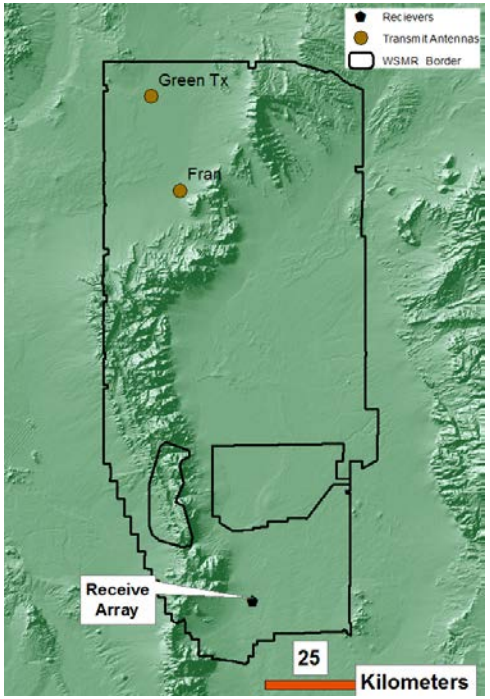
1B Conditions and Target Date for Analysis

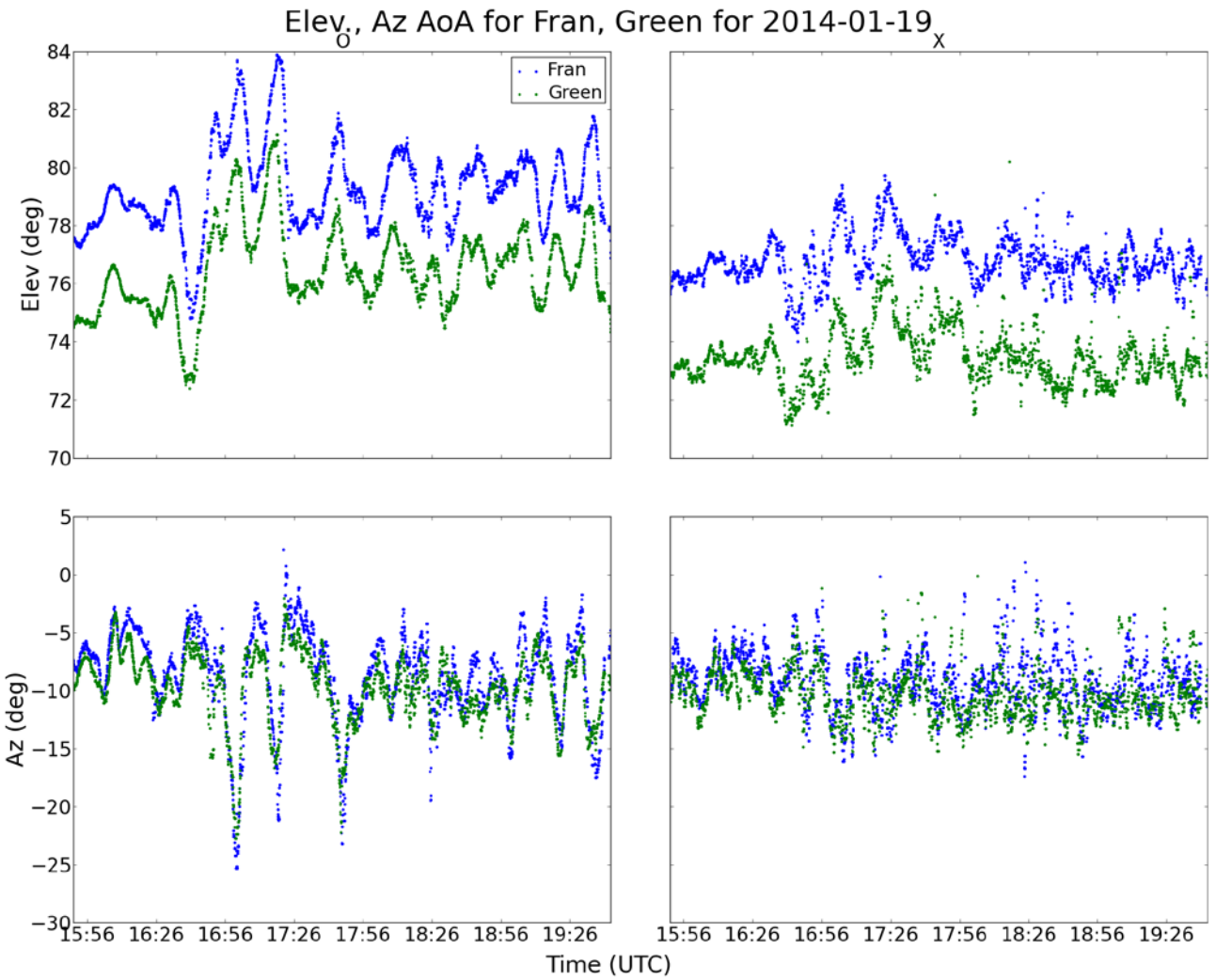
Day	F10.7	SSN	K_p	Observed TID Activity
19	128	91	1	Quiet
20	137	131	1+	Active late
21	146	141	2+	Active
22	143	144	3	Active
23	136	121	2	Active Early
24	136	150	1+	Active
25	133	102	2+	Active
26	138	109	3	Active
27	144	62	1	Active Late

19 Jan had the least-disturbed ionosphere – was an "easy" day

- Experiment Configuration on 19 Jan
  - 7-9 Tx sites using LFM signals
  - One site Linear Swept Sounder
  - f_{hi} = 5.3 MHz, f_{lo} = 4.6 MHz
  - At most two sites at 4.6 MHz
- O & X modes both present
  - Polarization separation as result of crossed dipoles
  - X-mode AoAs are noisier
  - Focus only on O-mode here

Quick-Look, 19 Jan: AoA at Fran & Green Sites



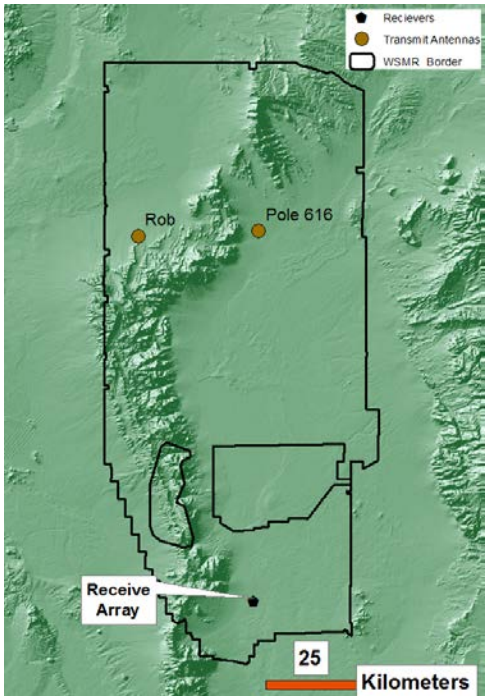


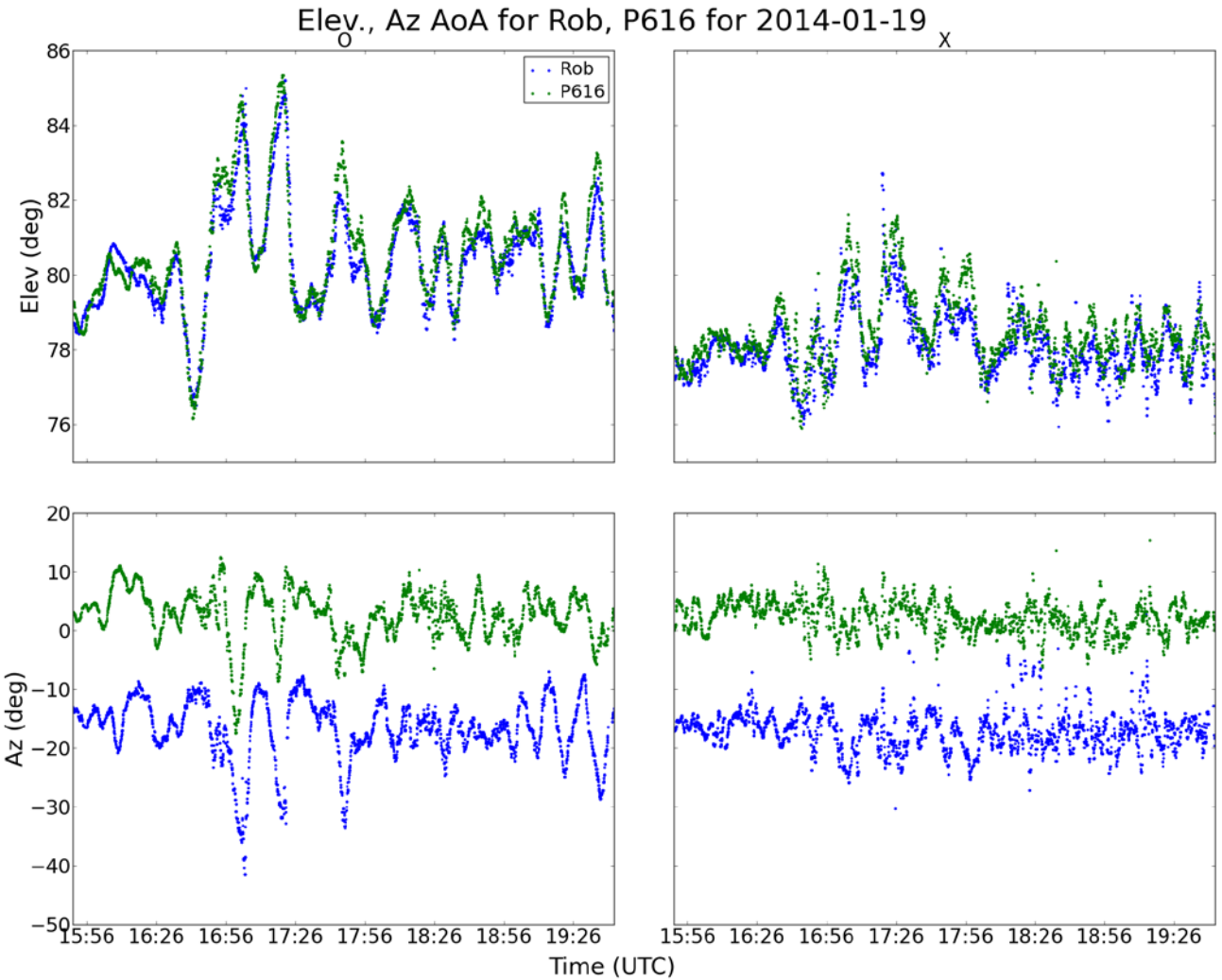
Varying-range pair

Distinct temporal shift visible in elevation plot, less distinct in azimuth

Obvious and strong correlations! Possible MS-TID

Quick-Look, 19 Jan: AoA at Rob & Pole 616 Sites



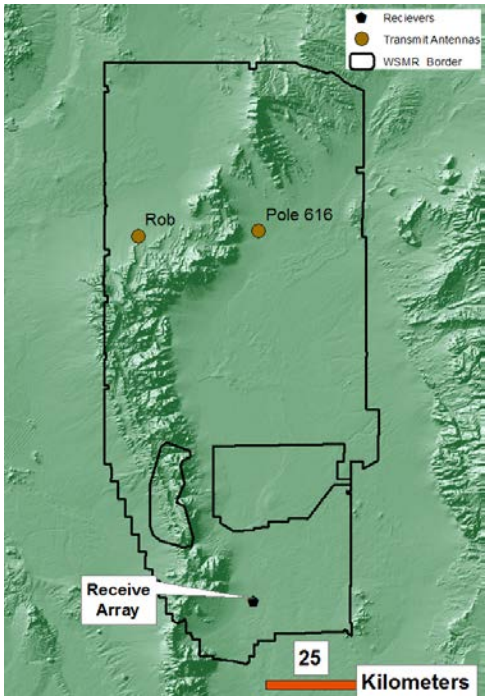


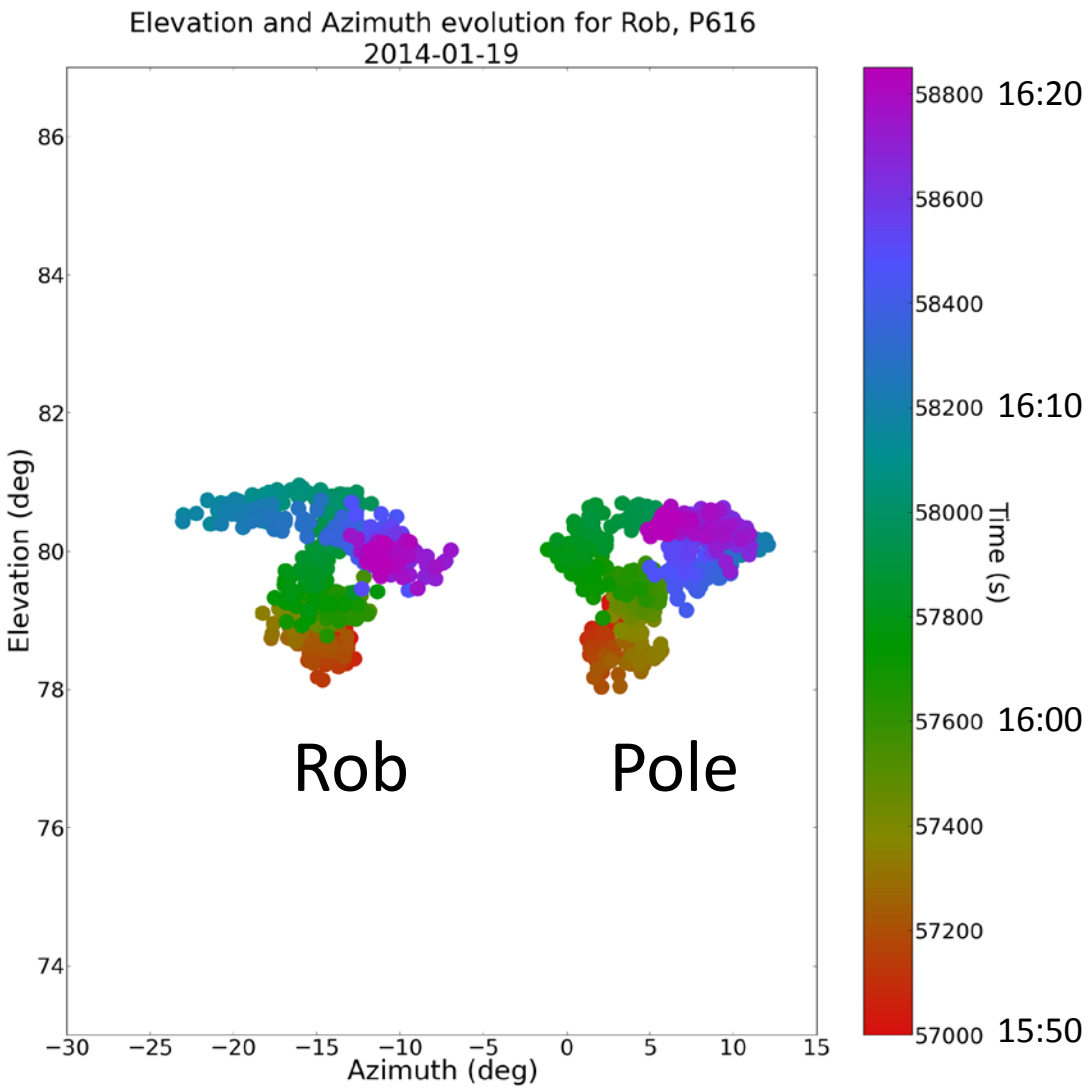
Varying-azimuth pair

Distinct temporal shift visible in azimuth plot, less distinct in range

With Fran/Green plots, hypothesize MS-TID moving southerly

Quick-Look, 19 Jan: 2D Wander, Rob & Pole616





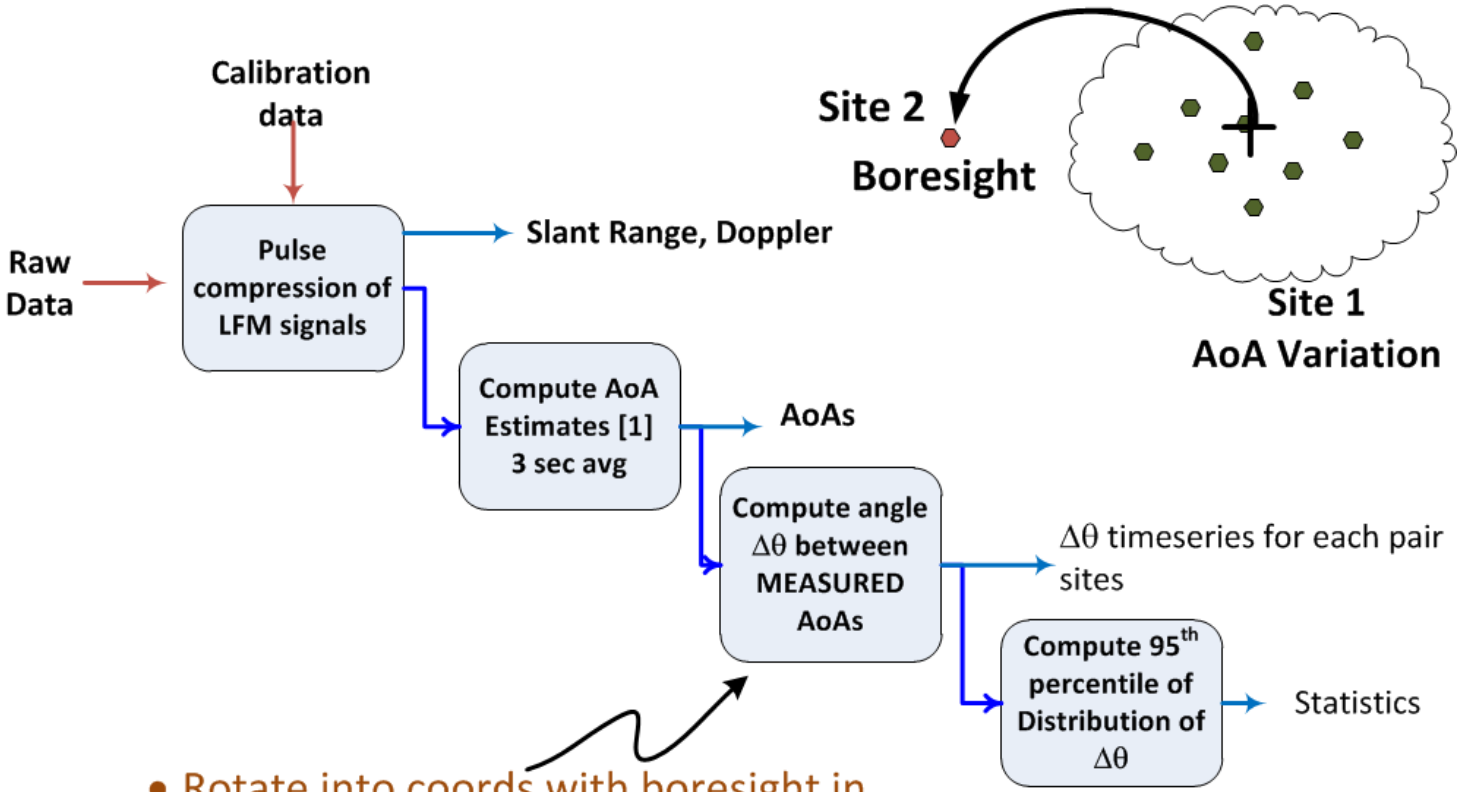
How does the variation look from the receive array?

- A subset of 30 minutes from 15:50 to 16:20 UTC
- Rob & Pole wander progressions are very similar, but not identical

Quick-Look Summary: What does this tell us?

- GPS and Ionosonde data from WSMR corroborate the conclusion that MS-TIDs were present
- AoA truth array data from 19 Jan clearly exhibit:
  - Medium scale dynamics (MS-TIDs)
  - Small scale noise
- Under these benign ionospheric conditions, is the 1B metric achievable without accounting for MS-TIDs?
- Quantitative analysis: compare AoAs between sites
  - Examine $\Delta\theta$ – cone angle between known AoAs
  - Calculate 95th percentile value
  - What does this distribution tell us about the situation?

Methodology



- Rotate into coords with boresight in direction of one AoA
- Compute u,v coordinates of second
- Remove mean of u, v (removes geometry)
- Any common trend is removed

[1] Guldogan, et al Advances Space Research doi:10.1016/j.asr.2009.04.031

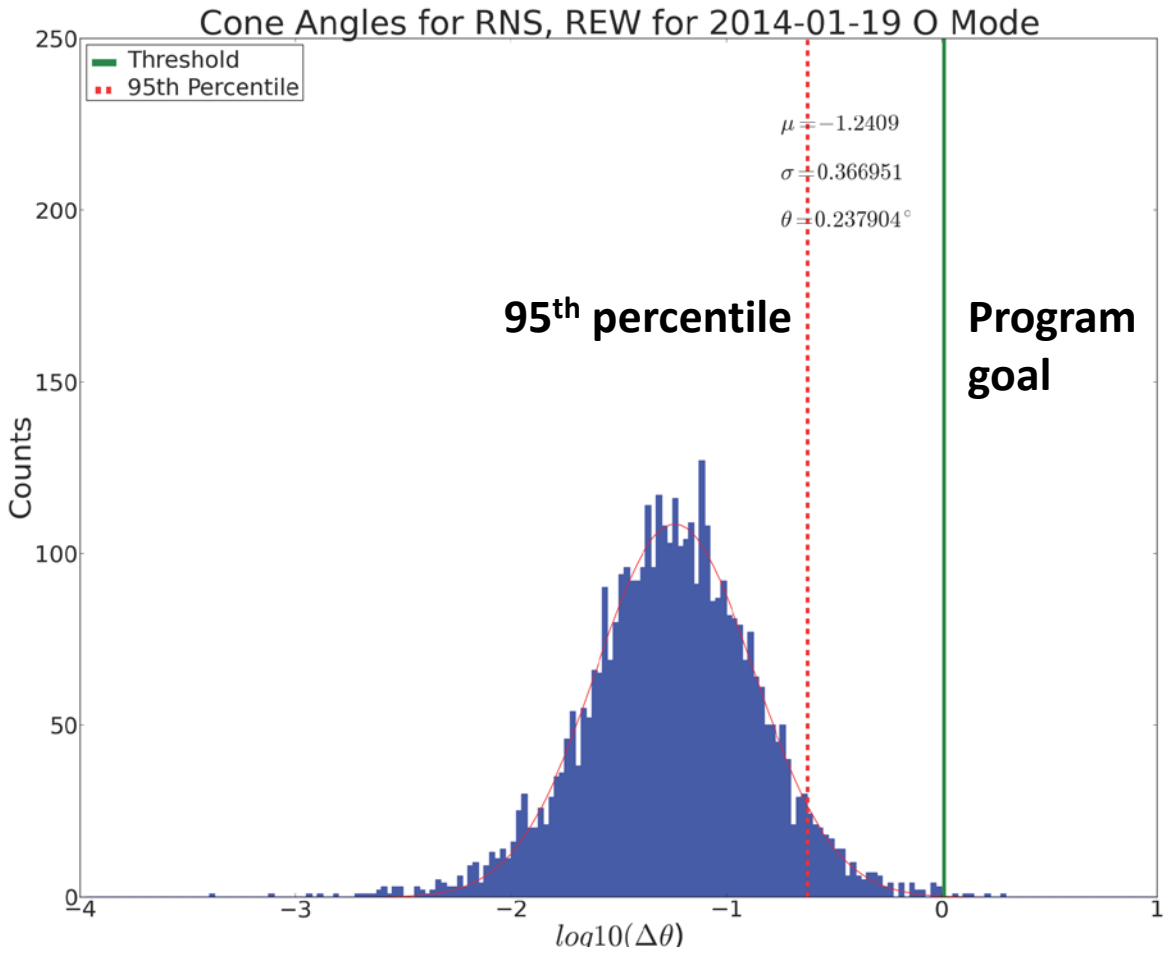
Distribution of Δθ □ Zero Baseline Rhodes Canyon

Two signals from Rhodes (2 antennas ~100 m apart), offset in frequency by 5 Hz

Computed separate AoAs for each of the 2 signals

<u>Ionospheric effects should be identical</u>

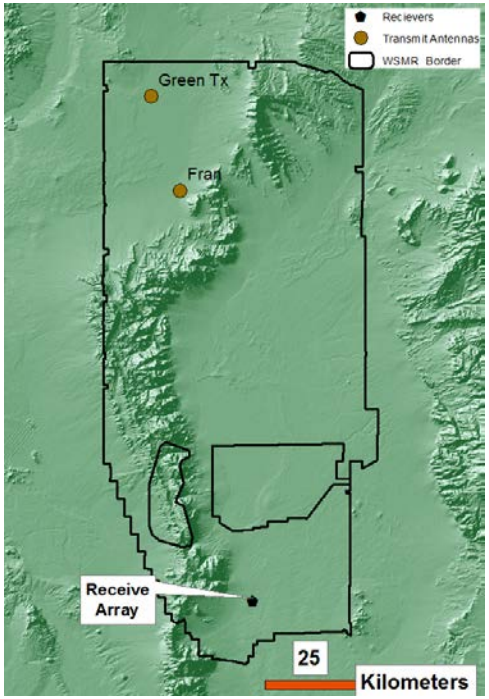
Confirmed: within array resolution, signals have the same AoA

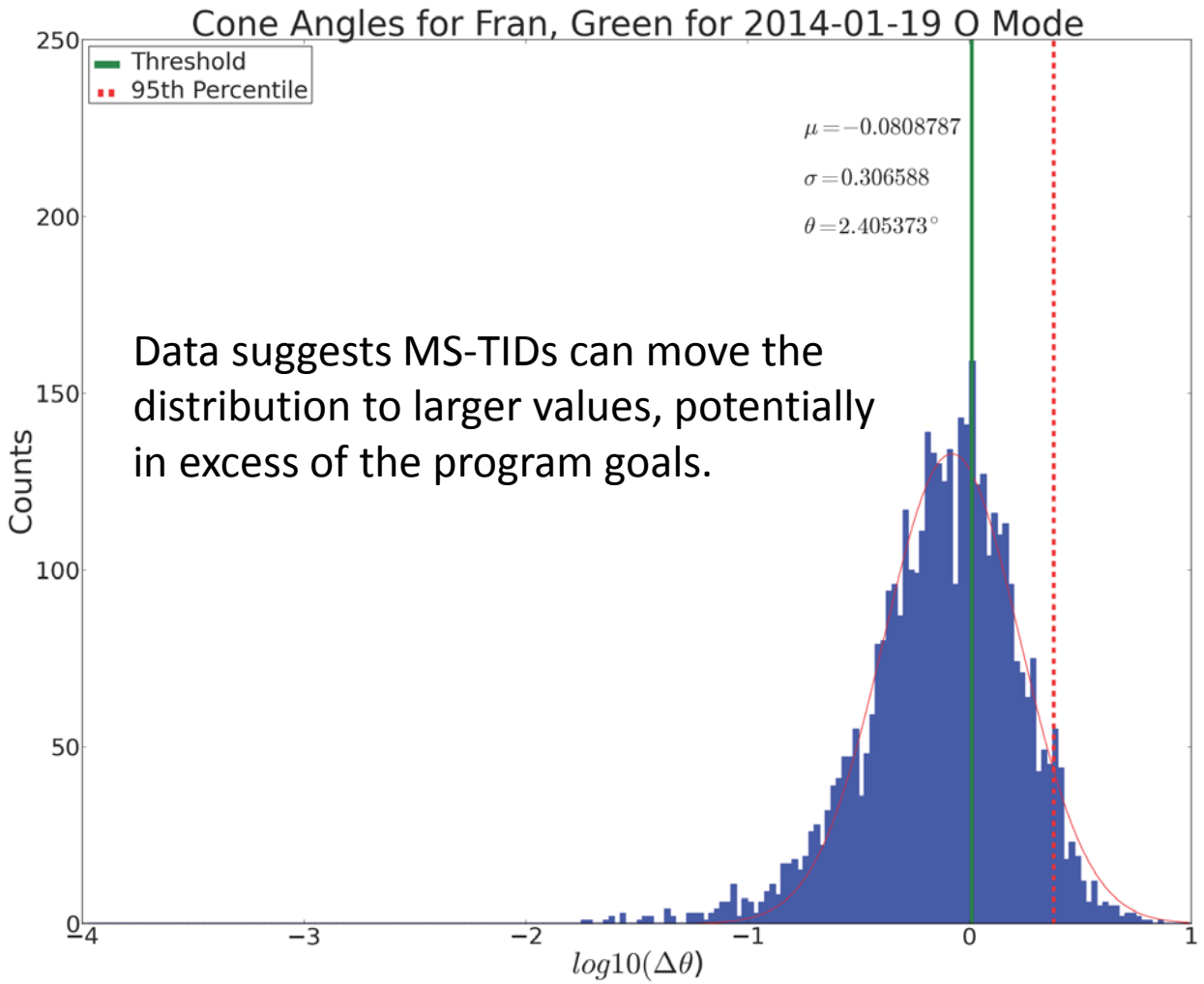


✔ Observation floor is about 0.2° (95th percentile).

We can assess program metric for other sites w/o worrying about the analysis chain!

Δθ Distribution – Non-Zero Baseline Fran-Green



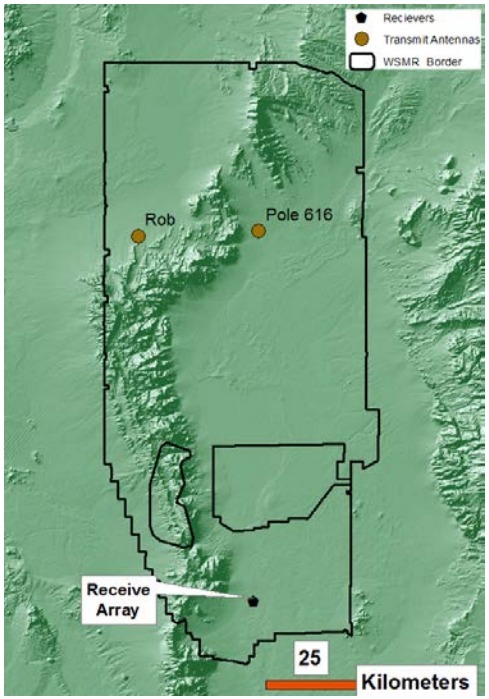


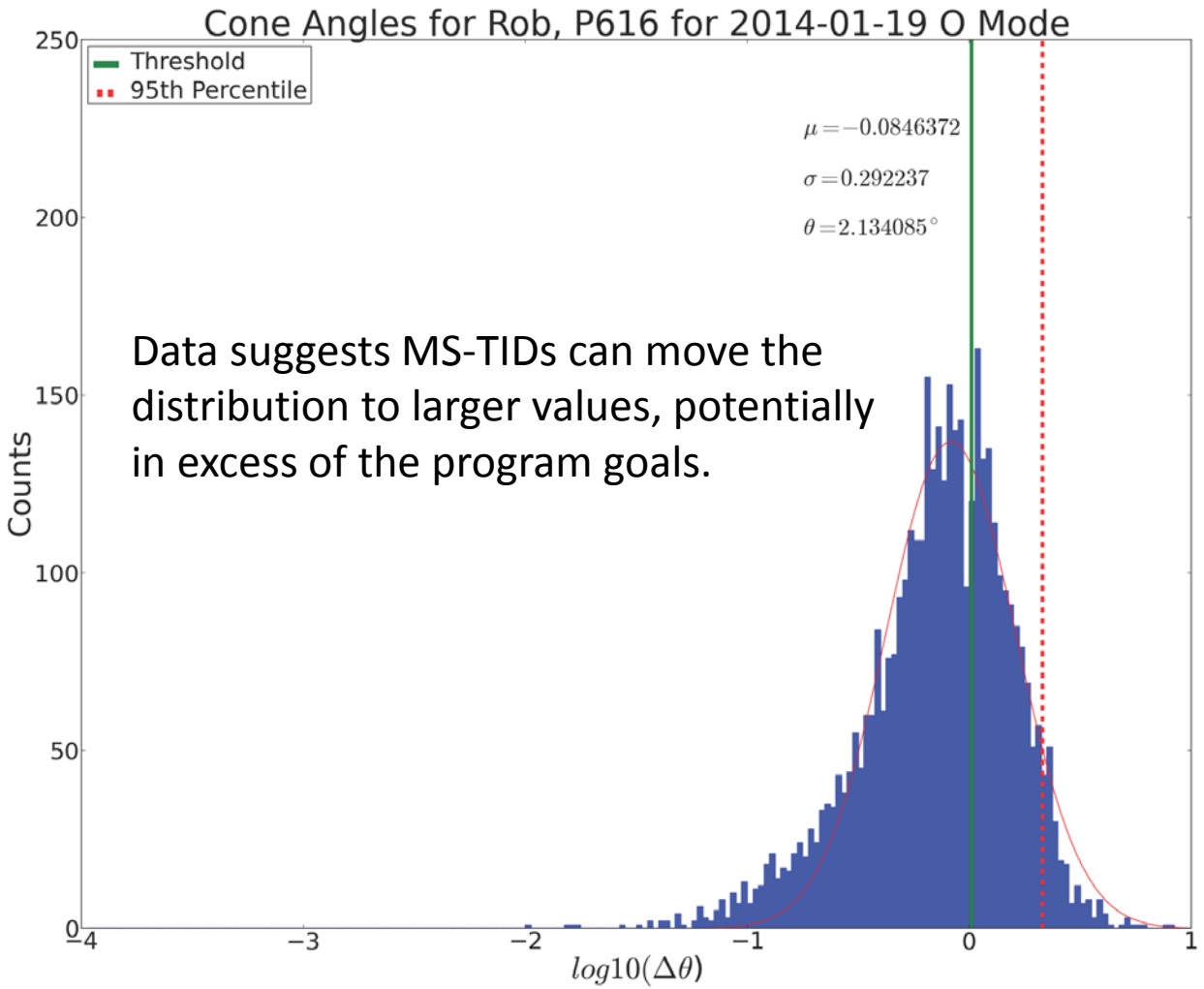
Data suggests MS-TIDs can move the distribution to larger values, potentially in excess of the program goals.

Separation ~ 28 km
Varying-range pair

Program goal not met
(95th percentile >> 1°)

Δθ Distribution – Non-Zero Baseline Rob-Pole 616





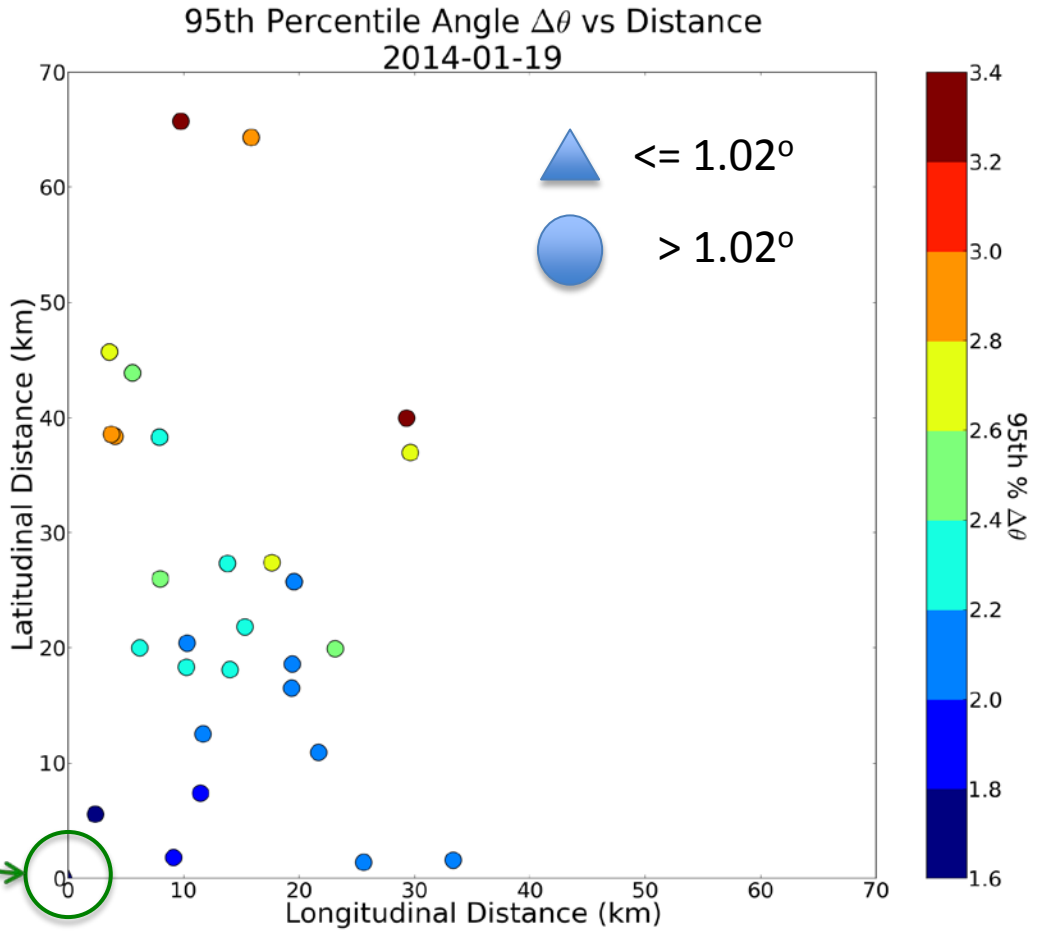
Data suggests MS-TIDs can move the distribution to larger values, potentially in excess of the program goals.

Separation ~ 28 km
Varying-azimuth pair

Program goal not met
(95th percentile >> 1°)

All Site Pairs, Distance Dependence Summary

95th percentile summary for all WSMR site pairs



AoA metric met only for zero-baseline sites (Rhodes 2 antennas).

All other site pairs values are factor 1.6 – 3.4 larger than the metric; they fail at only 5 km site separation

HF geolocation must account for medium-scale ionospheric dynamics!

Assessment: real-world AoA correlations don't satisfy the simple engineering solution assumptions

Thoughts on Results

- Under these benign conditions is the 1B metric achievable without accounting for MS-TIDs?
  - For the one day examined here, MS-TIDs need to be accounted for properly before the program goals are met
    - Despite the benign weather
  - Separation in frequency is likely to increase the challenge

Lesson: A more careful handling of medium scale disturbance is required for the periods we have examined.

Lesson: A simple implementation of the check target approach may work only in limited cases.

Disclaimer

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