Inversion of helicopter characteristics using infrasound data

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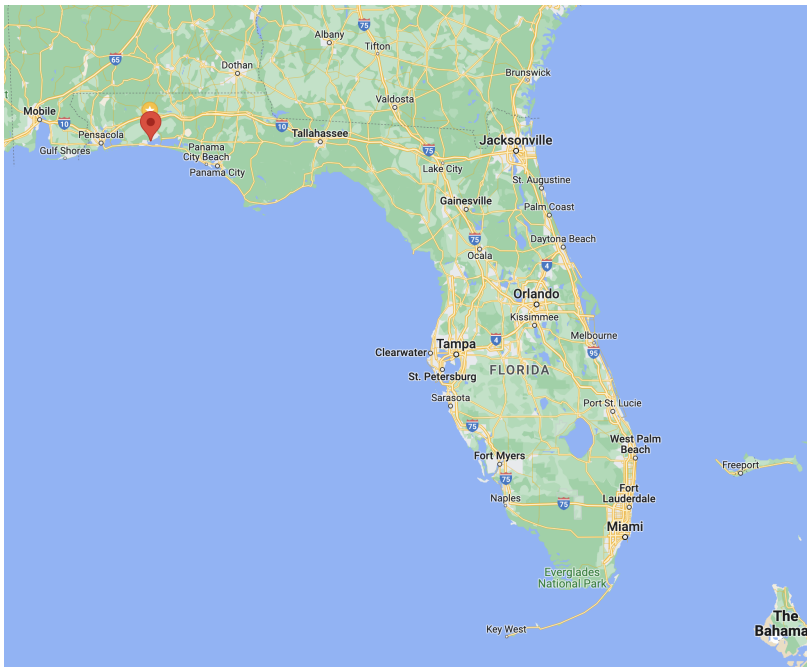
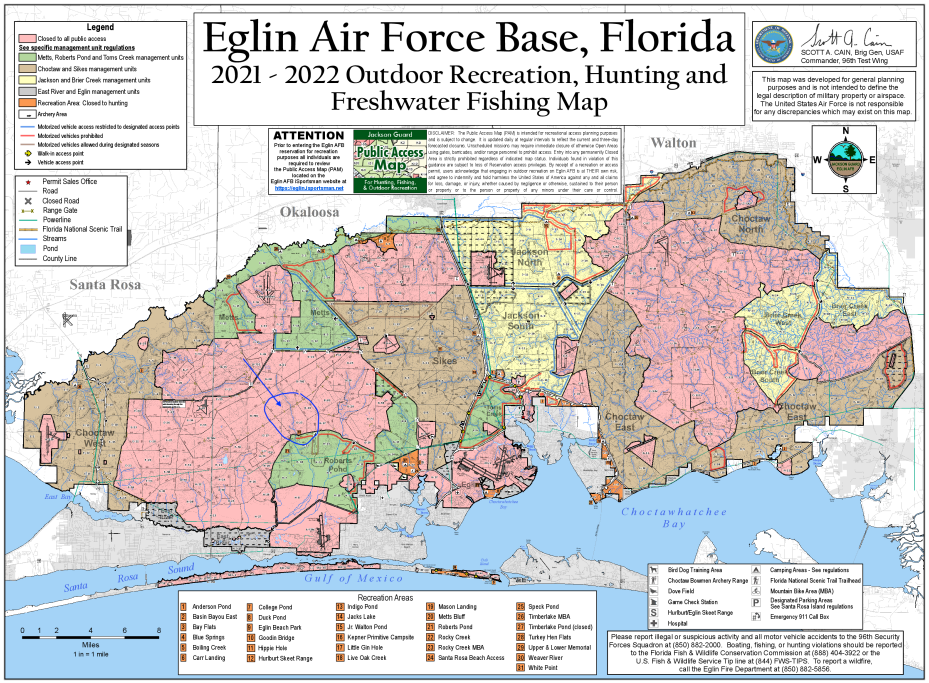
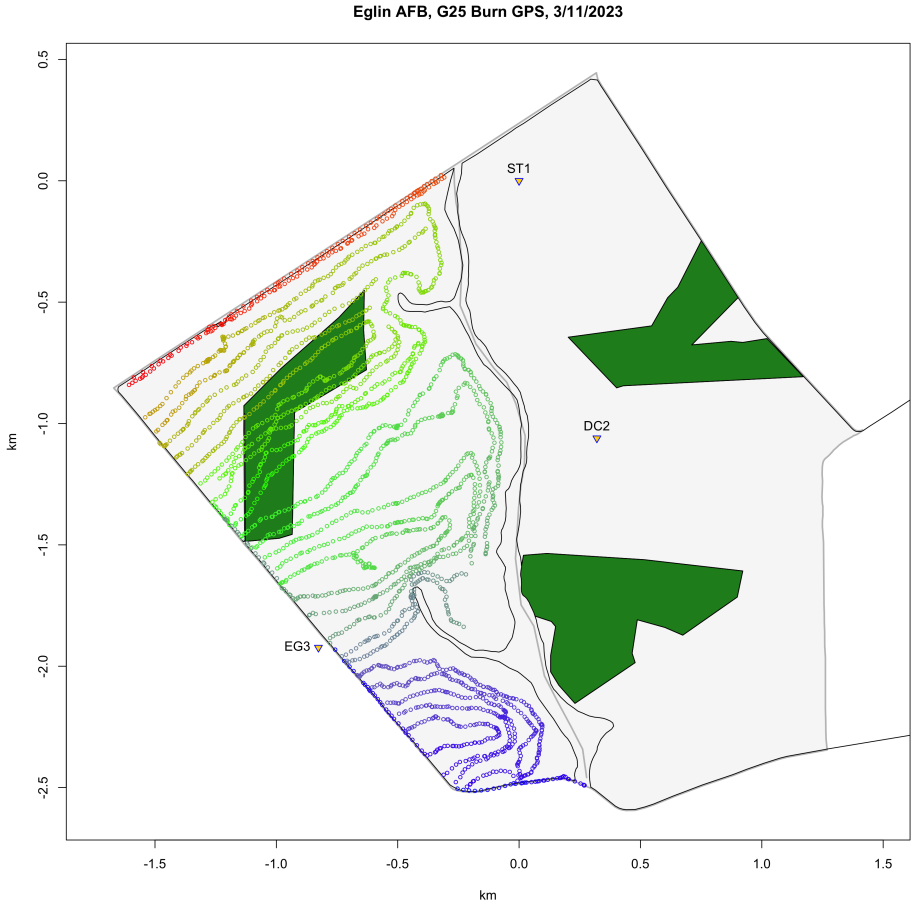


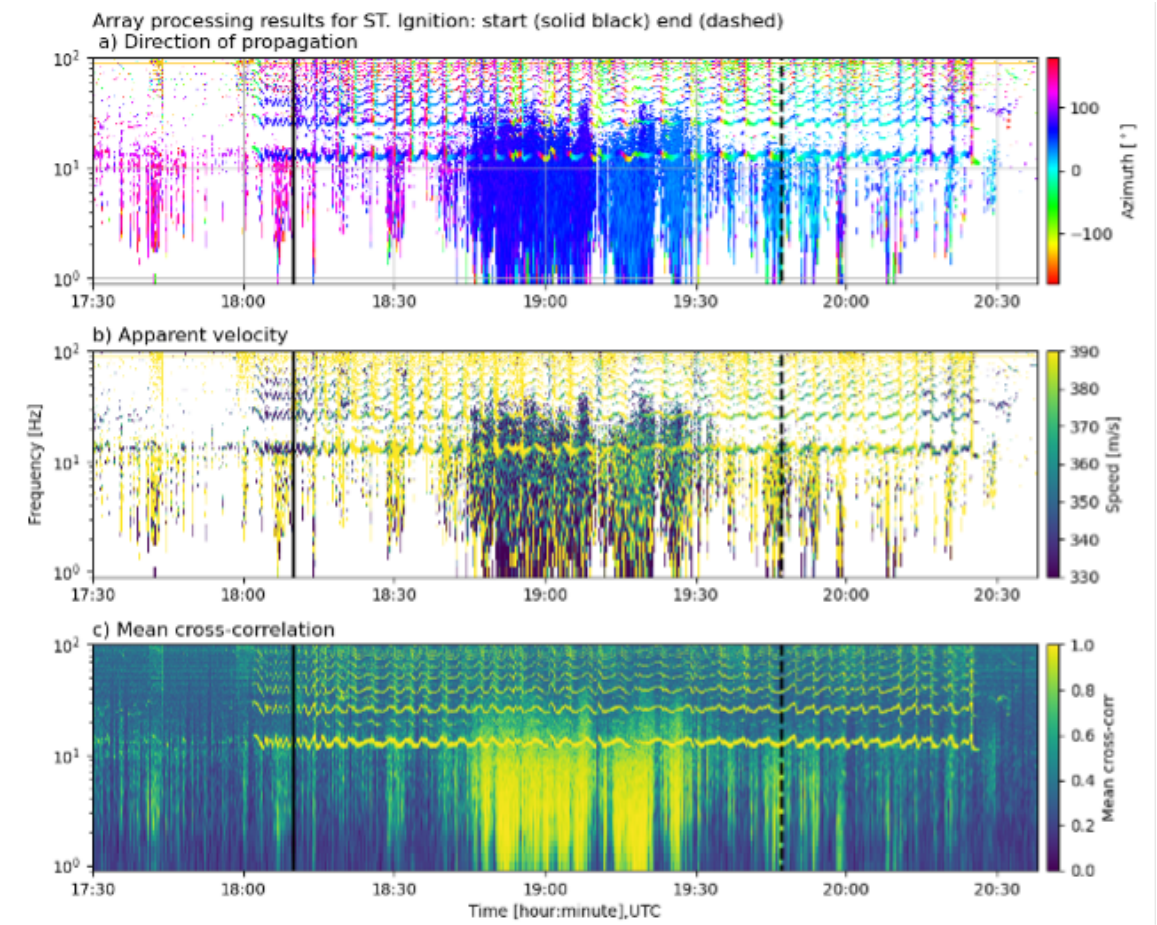
Ground Deployment





Infrasound Station Deployment and Burn Schedule at Eglin AFB, 2023

Marcillo et al., *Applied Acoustics*, 2025



Recent Fire Paper:

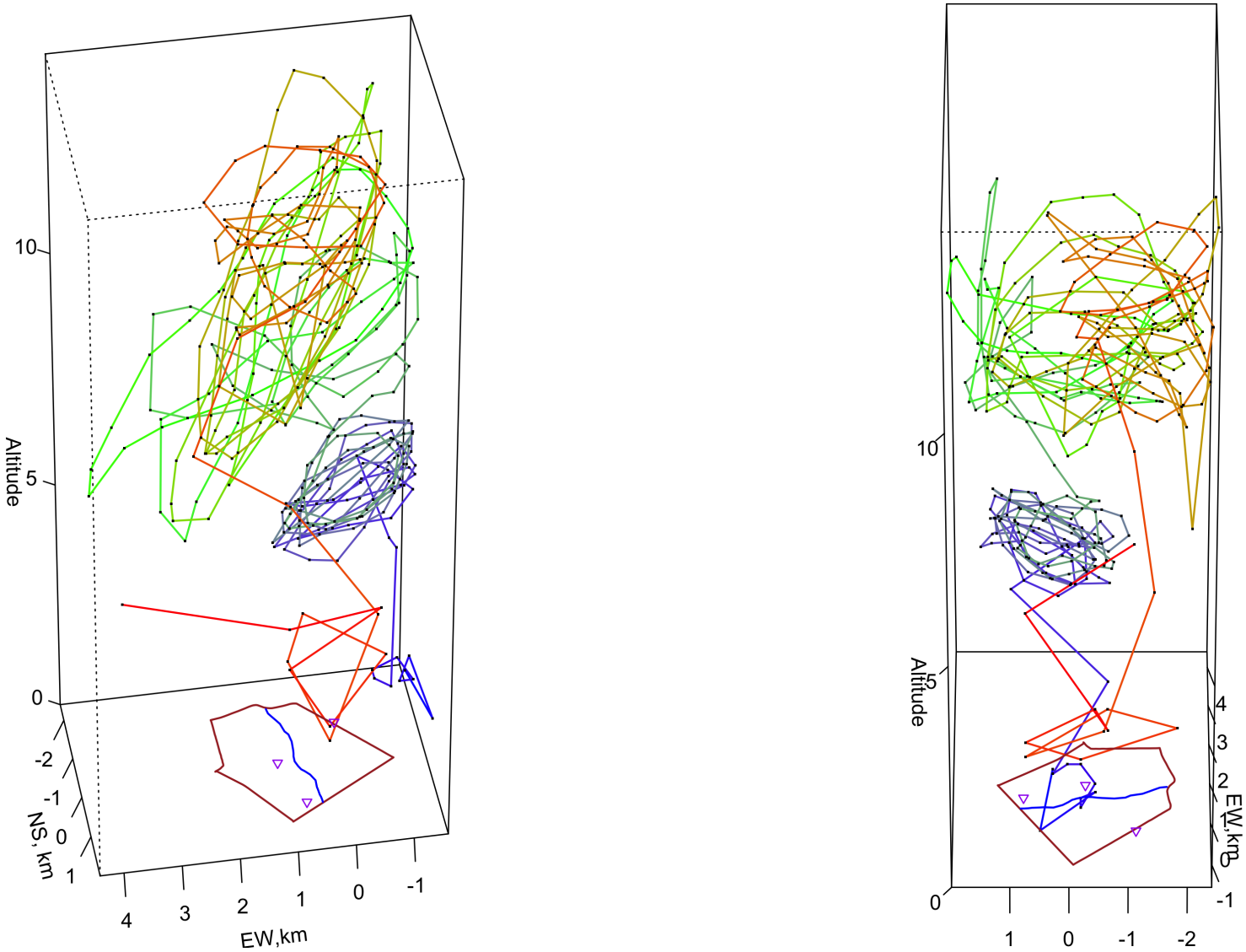
Marcillo, Lees, et al., (2025) Acoustic observations of a prescribed burn, *Appl. Acoust.*, 235,p. 110657, DOI:10.1016/j.apacoust.2025.110657.

Elgin Helicopter Information

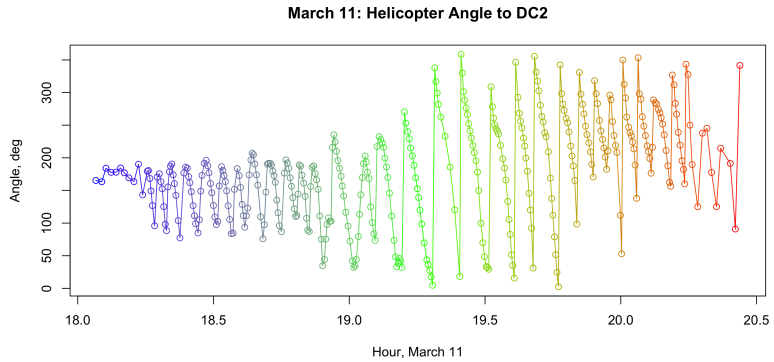
(example from wikipedia)

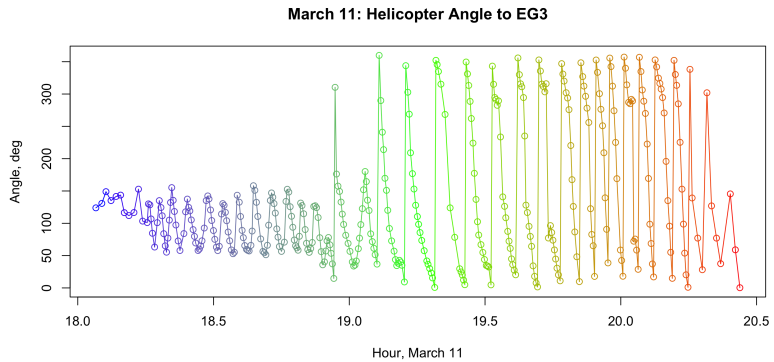
- Two-blade Bell Long-Range
- Constant 400 RPM
- Fundamental Frequency: $2 \times 400/60 = 13.3Hz$
- Two-blade tail rotor with 2500 RPM.

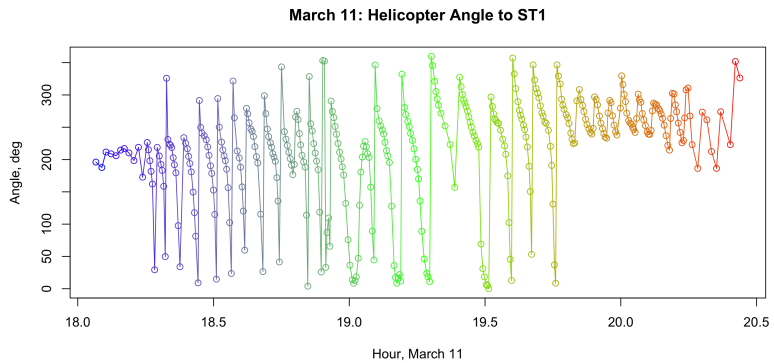
Helicopter 3D

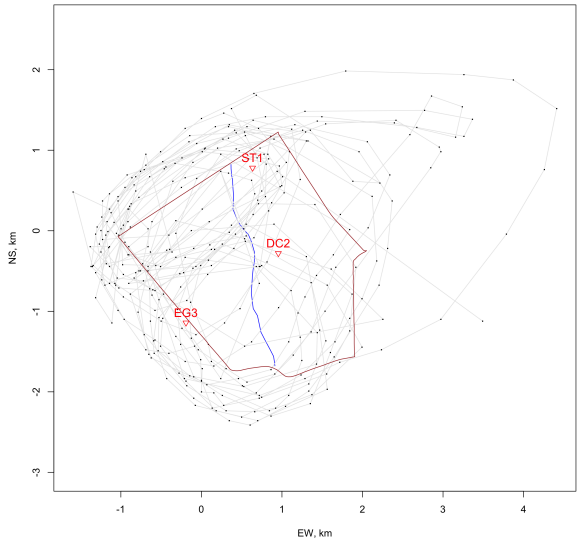


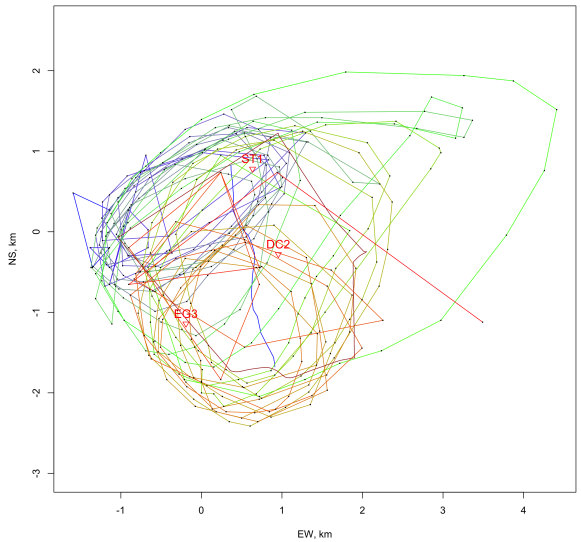
Angle to Helicopter





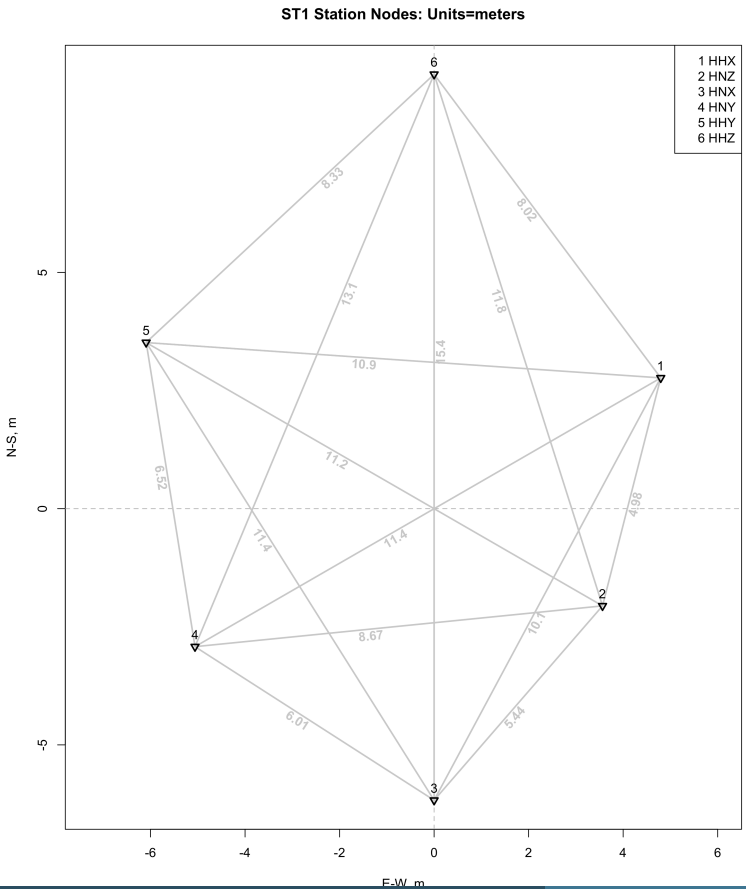


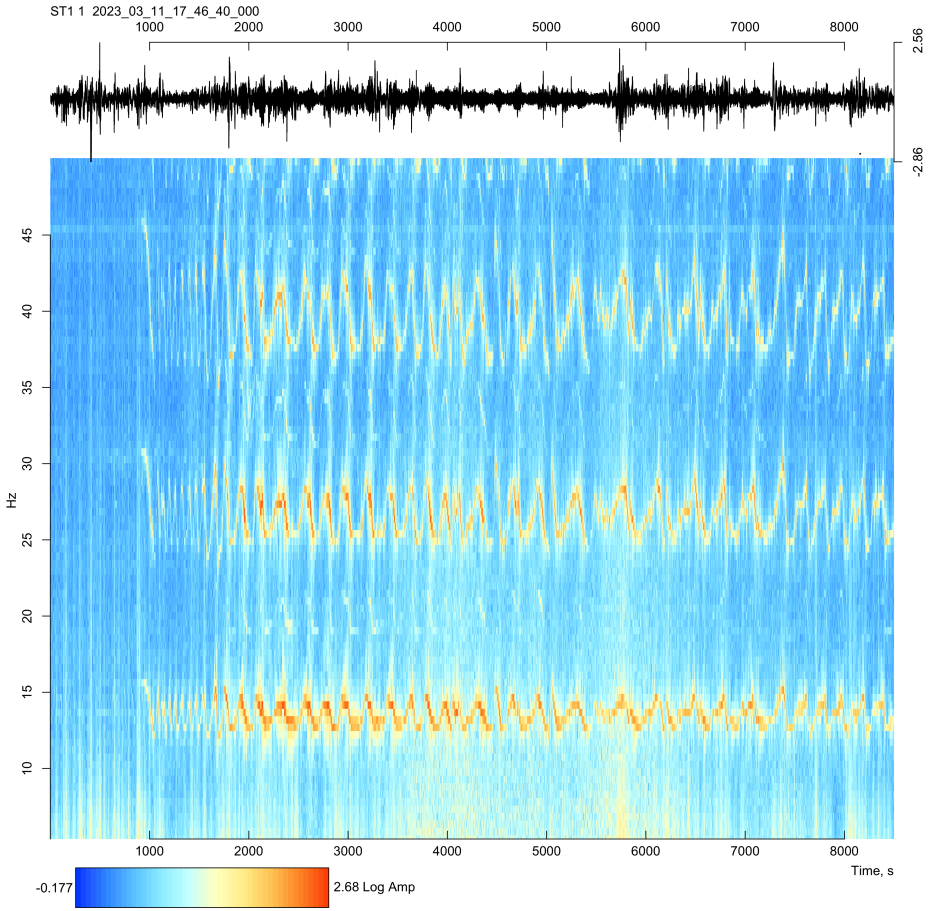




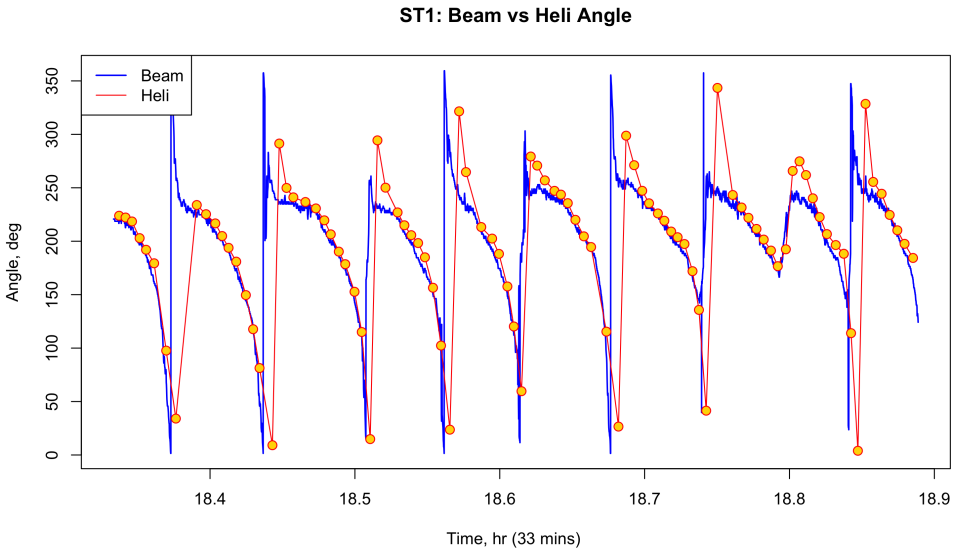
6-node Station ST1

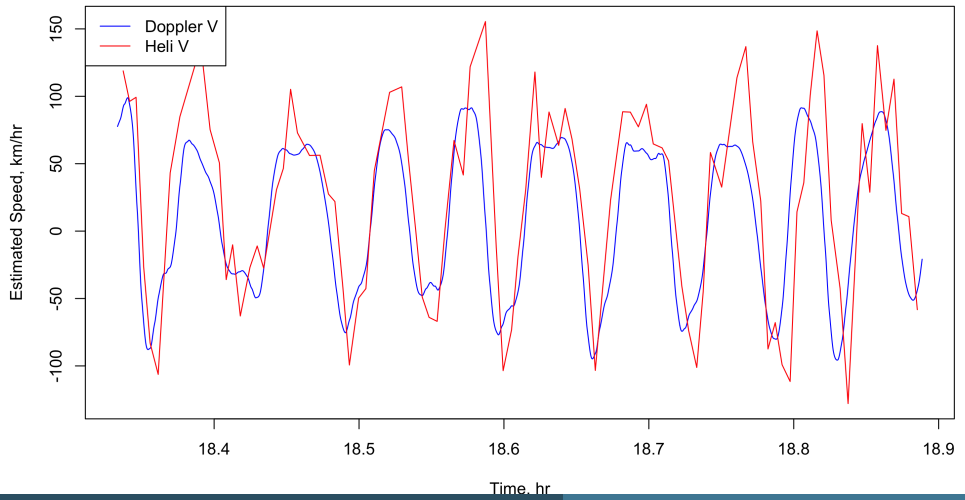
- Six infraBSU sensors in Hex-formation
- Hex-formation, ~ 5m radius
- Centaur digitizer (Nanometrics Inc.)
- 2000 sample/s

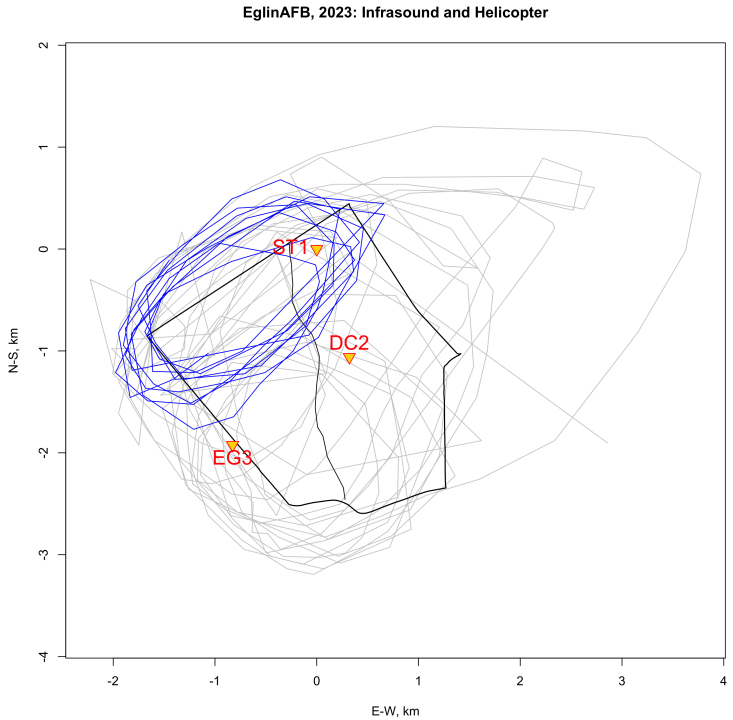




ST1: Beam Angle and Speed V Helicopter

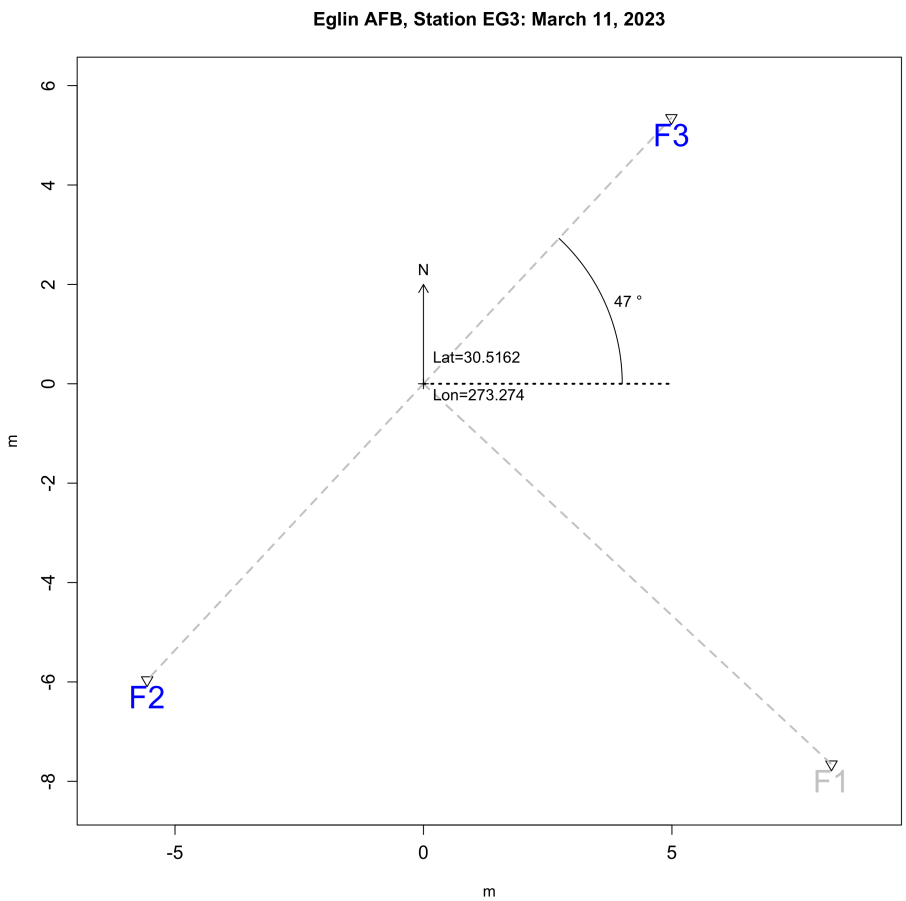


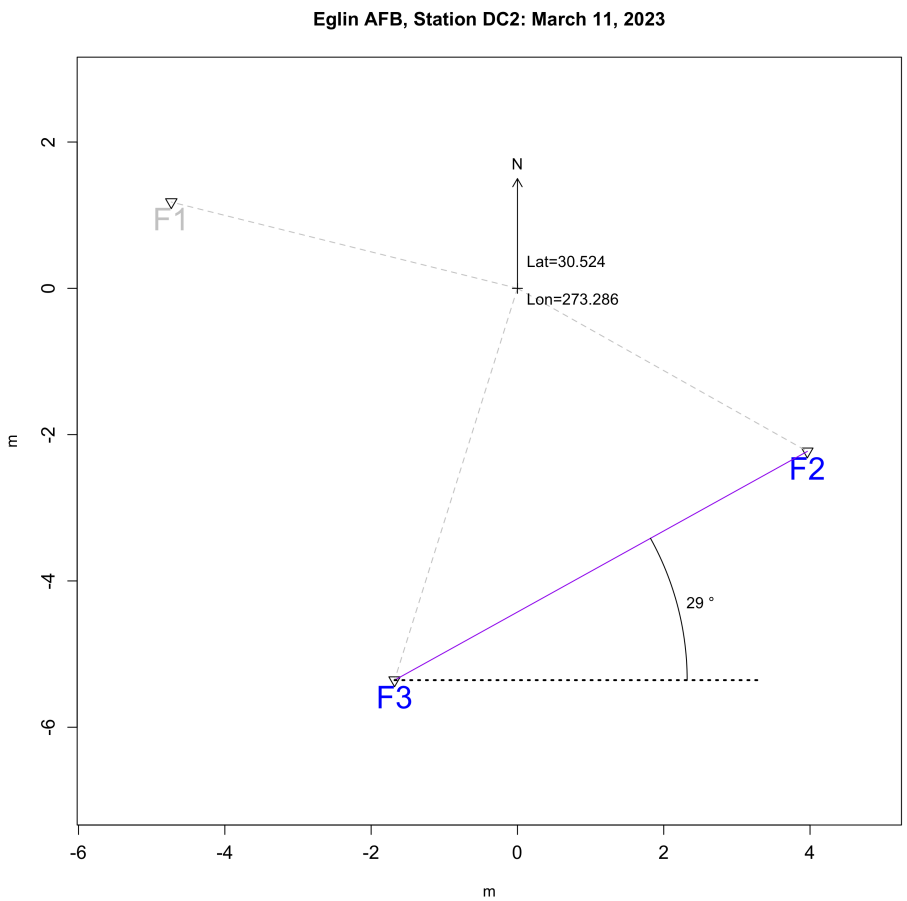




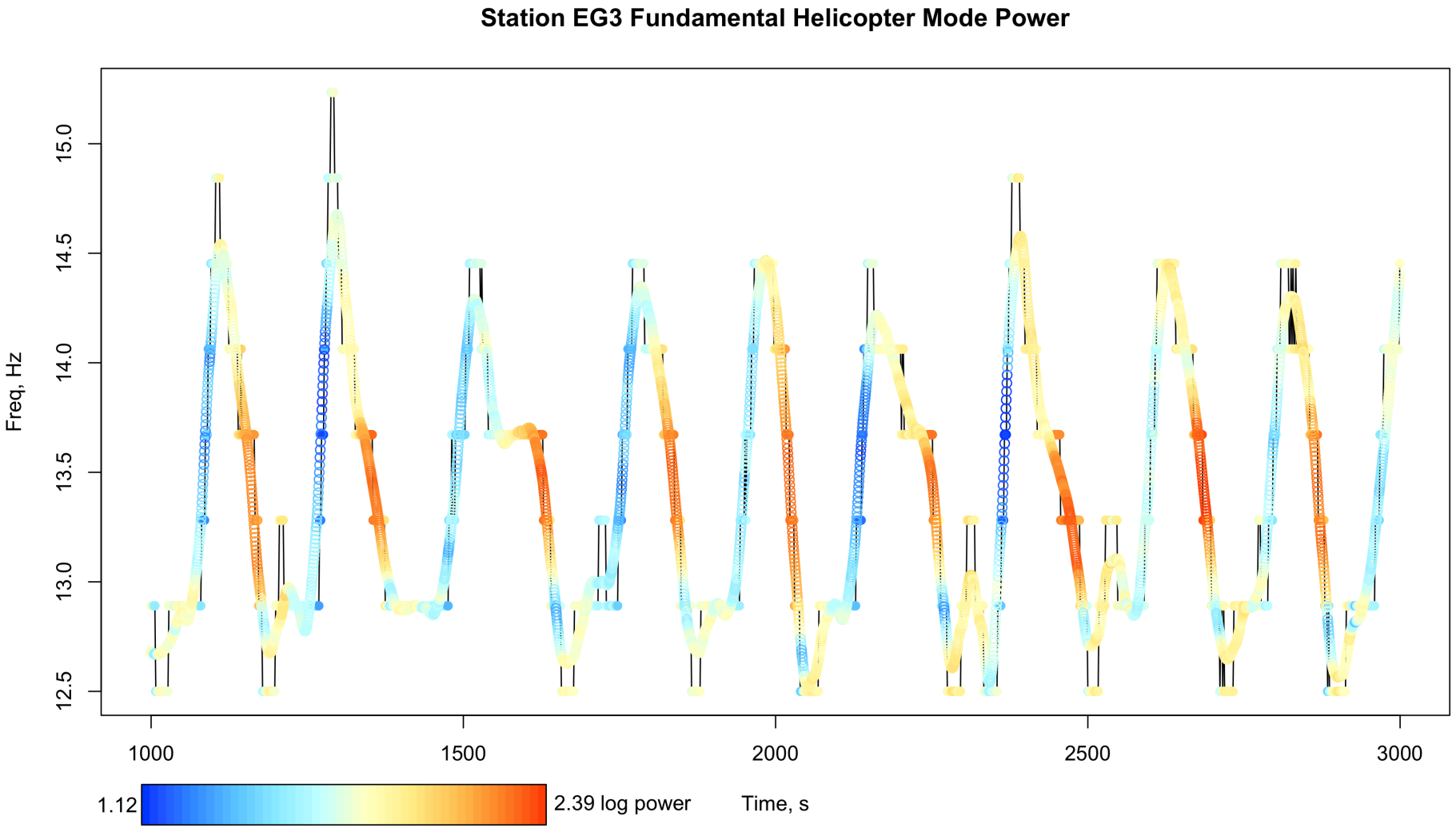
Stations with Two Nodes

Beam-forming with 2-node stations require special handling to adjust for angle ambiguity and noise.

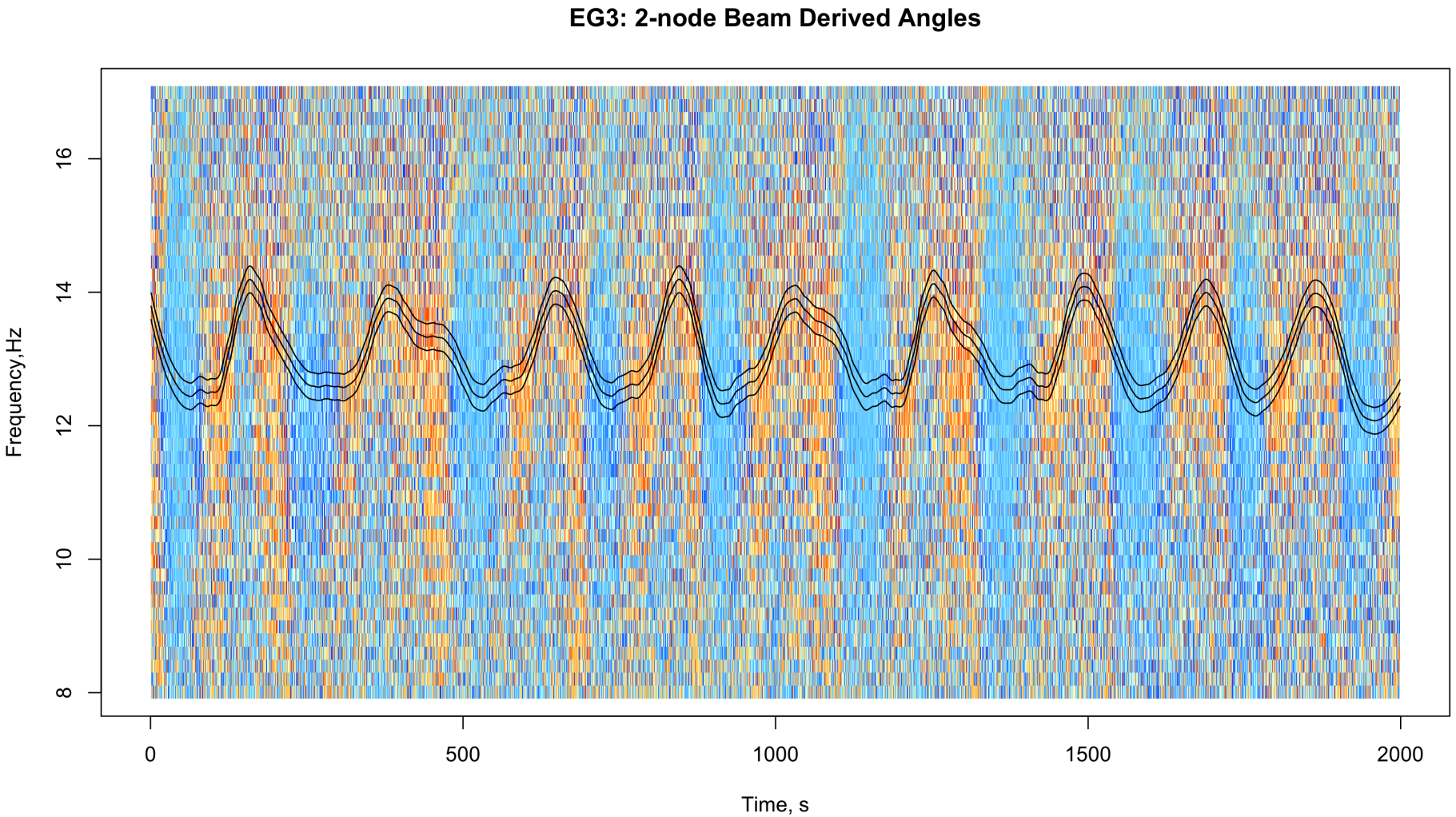




EG3: Fundamental Mode and Power

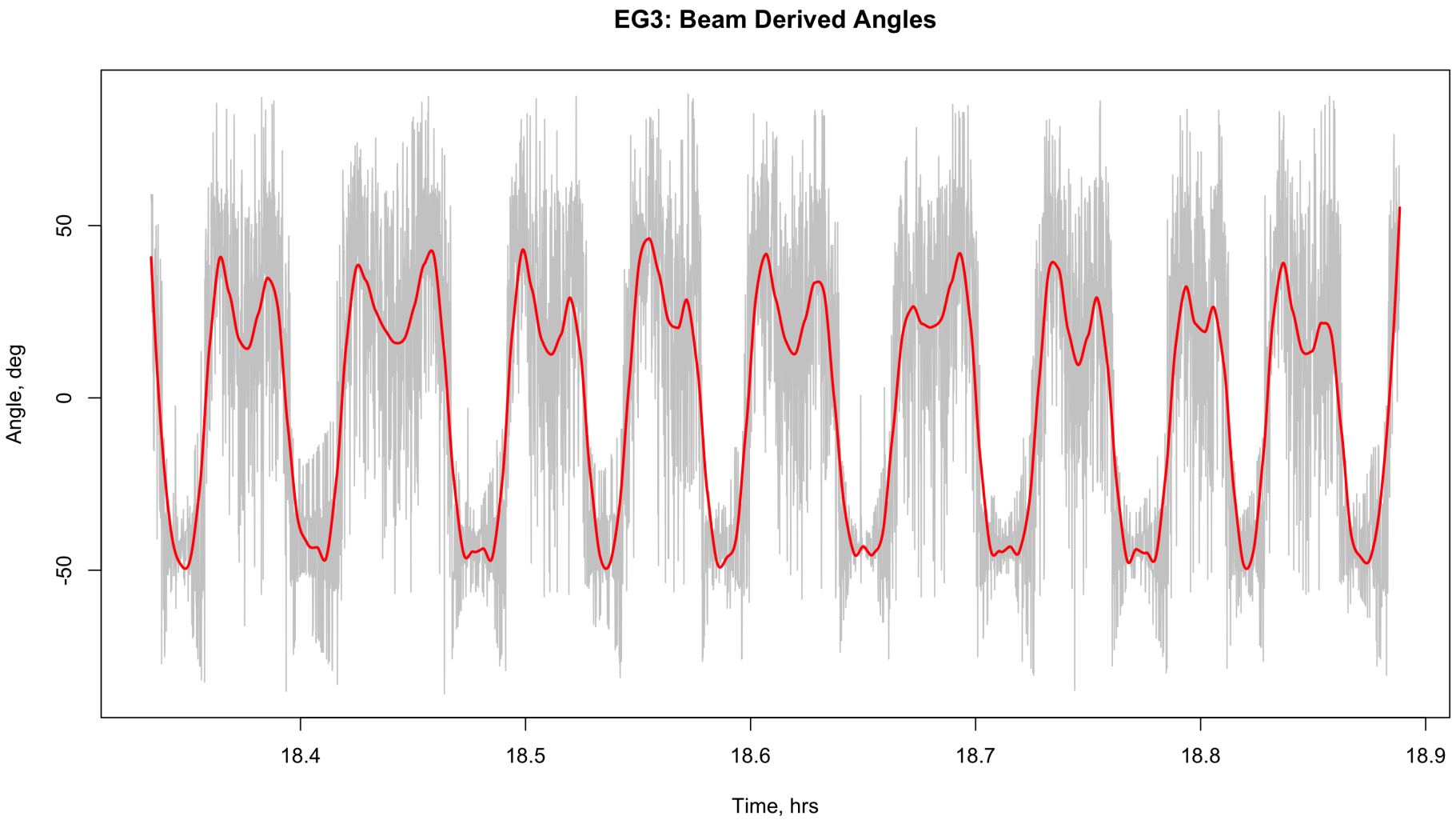


Beam-forming Angle Analysis at EG3



Inspite of noise and ambiguity, there appears to be a reasonable signal.

EG3 Angle extraction



Angles are averaged over the fundamental frequency band. Local estimates are smoothed over time.

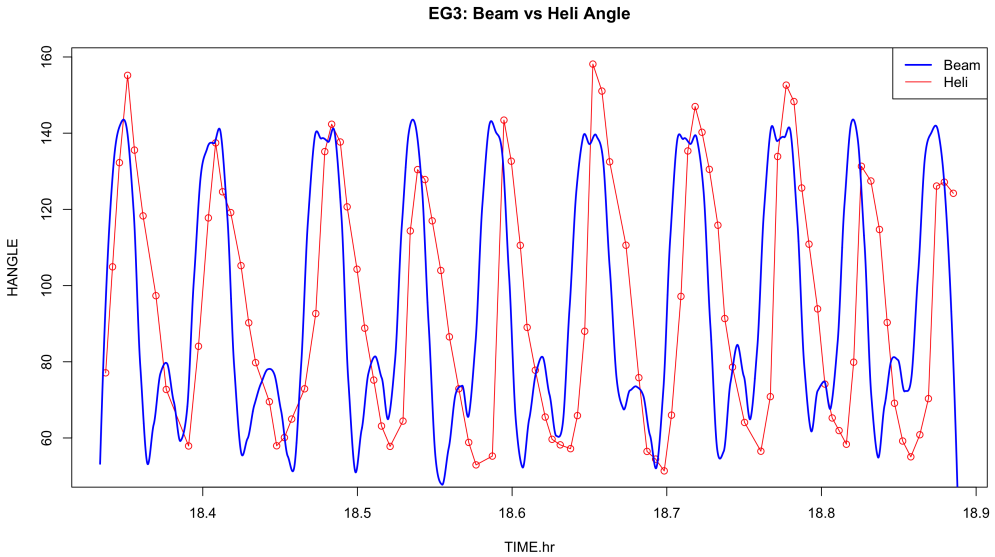
EG3 and DC2 Angle Analysis

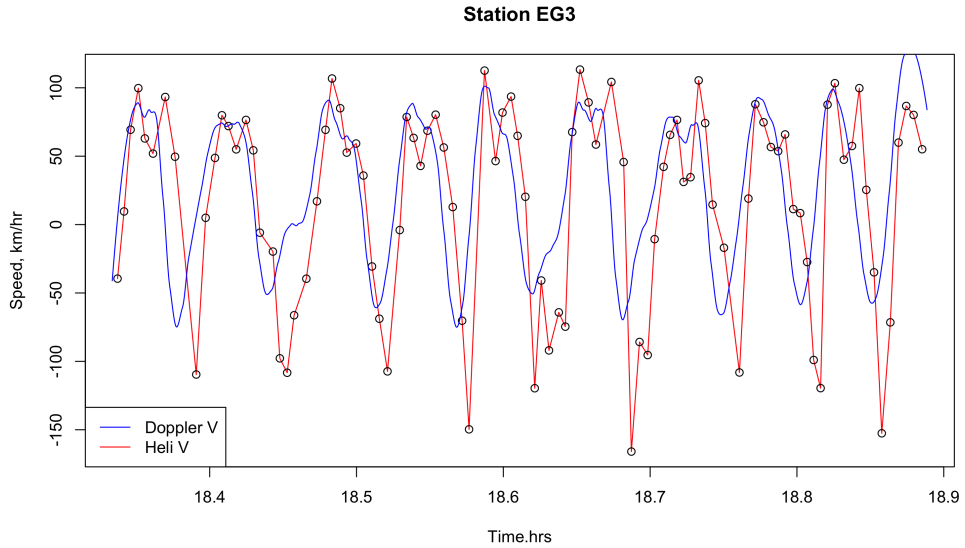
Following Beam forming with 2-node stations:

- Set Frequency range, 8, 17 Hz
- Extract angles from Beamforming at peak power in limited frequency range.
- (Angle at Max peak, might do some averaging)
- Calculate Angle Bias (direction of line connecting 2 nodes)
- Calculate mean angle, should be close to bias
- Smooth time versus angle using loess (span = 0.01)
- Predict new Angle at time values, pp
- Plot Time versus Adjusted Angles
- Add Helocopter angles

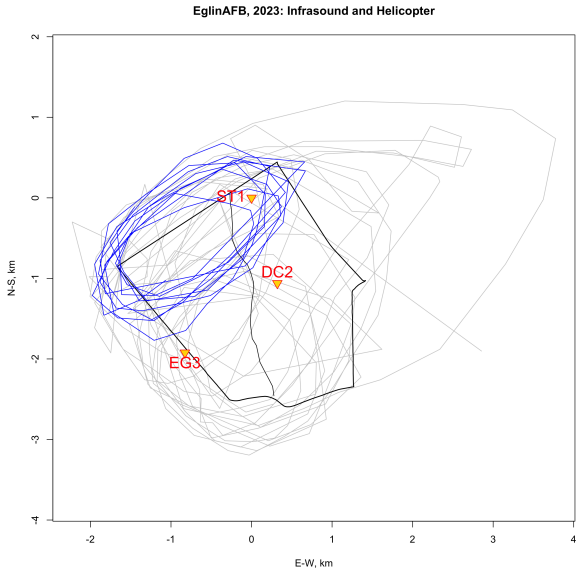
Note: Helicopter angles are in degress clockwise from north. Beam angles are degrees ccw from east

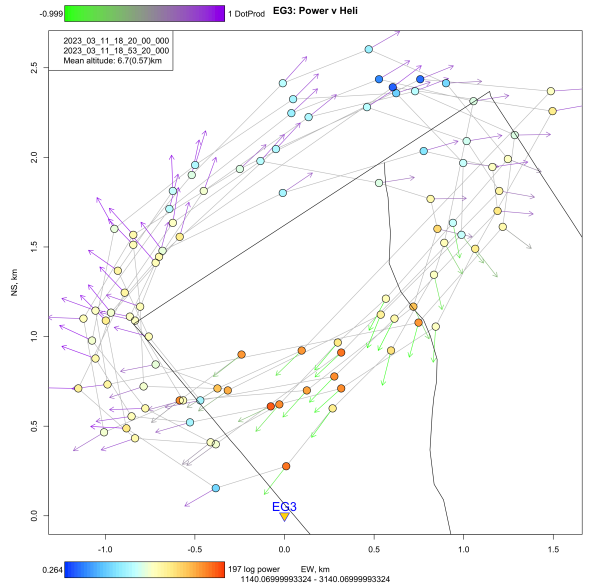
EG3: Angle and Speed vs Heli



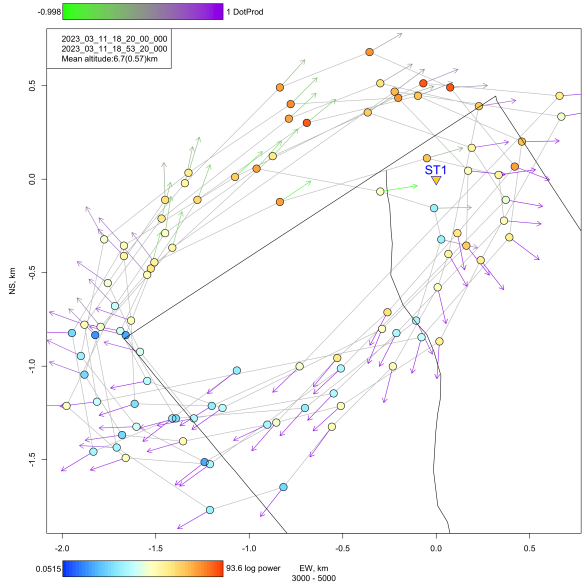


Beam Power and Angles wrt Stations

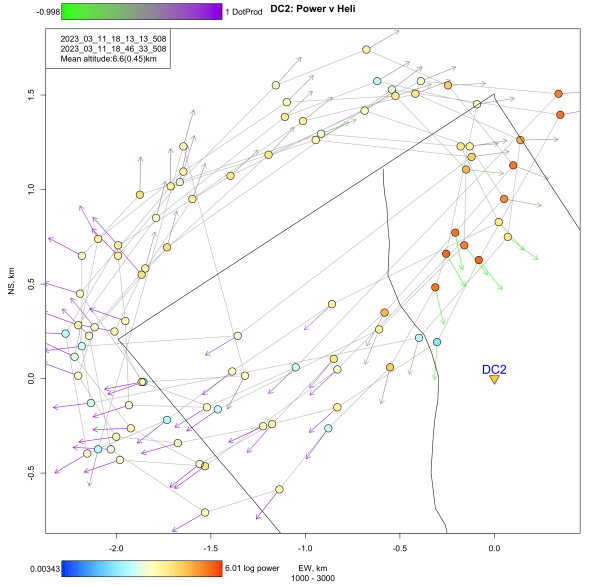




EG3

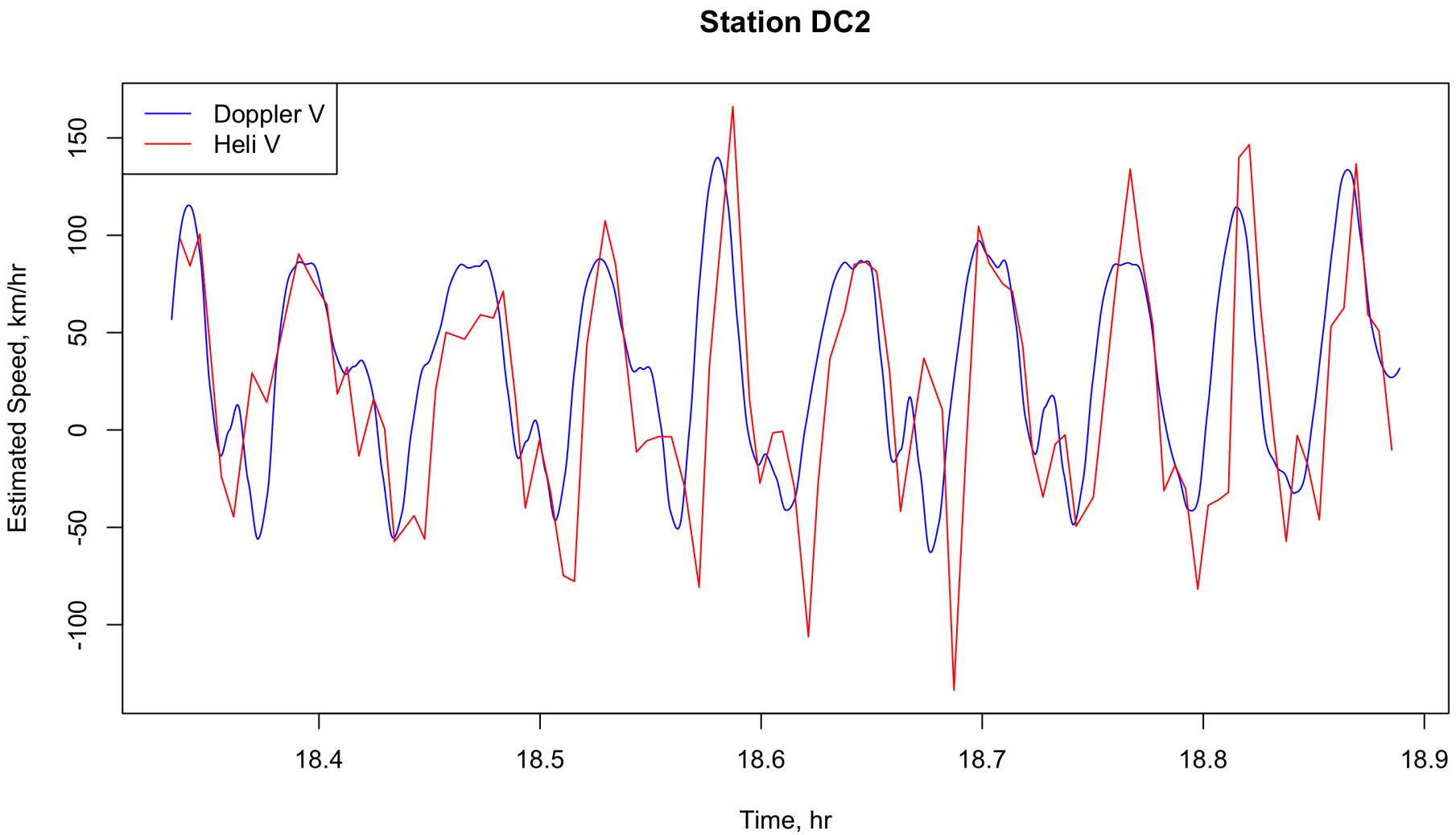


ST1



DC2

DC2 Analysis



DC2: Heli vs 2-Node Beam

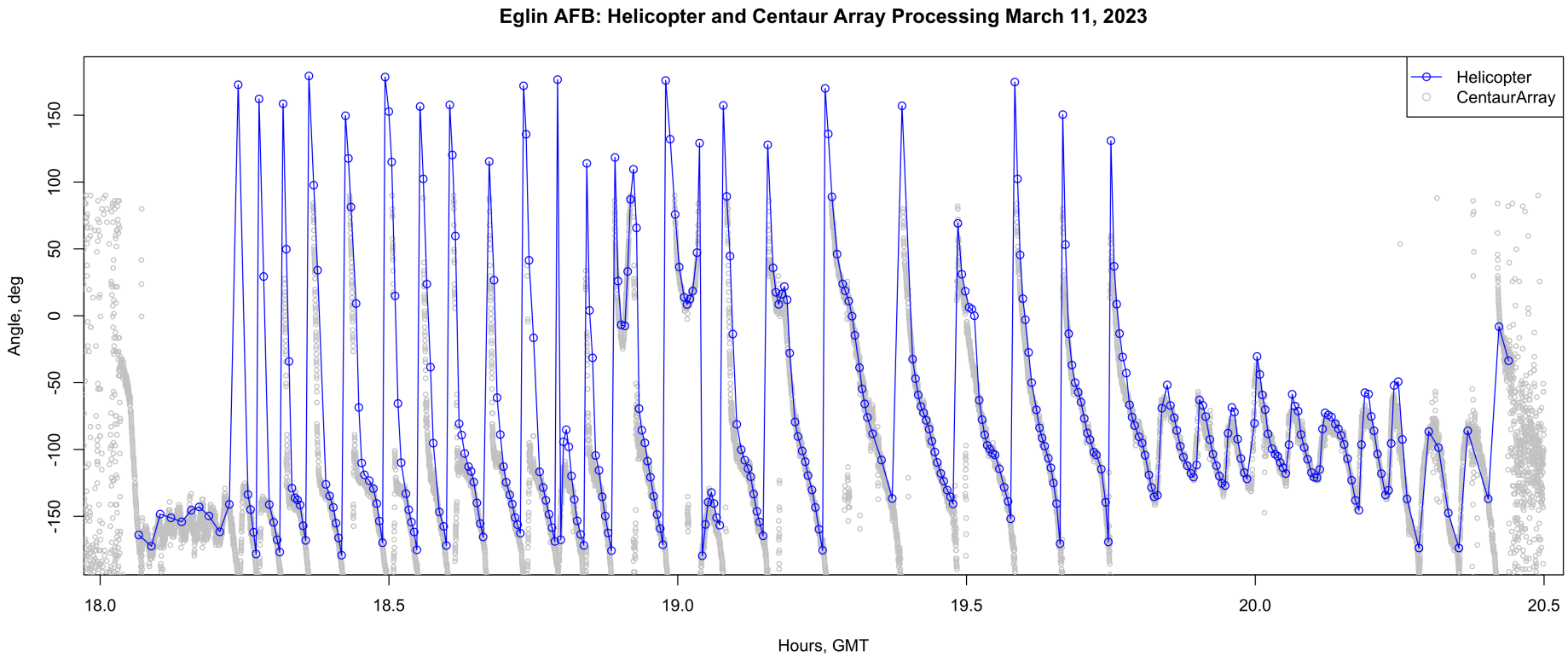
Conclusions

We found that infrasound was effective for estimating various helicopter parameters during overflight at distances of several km.

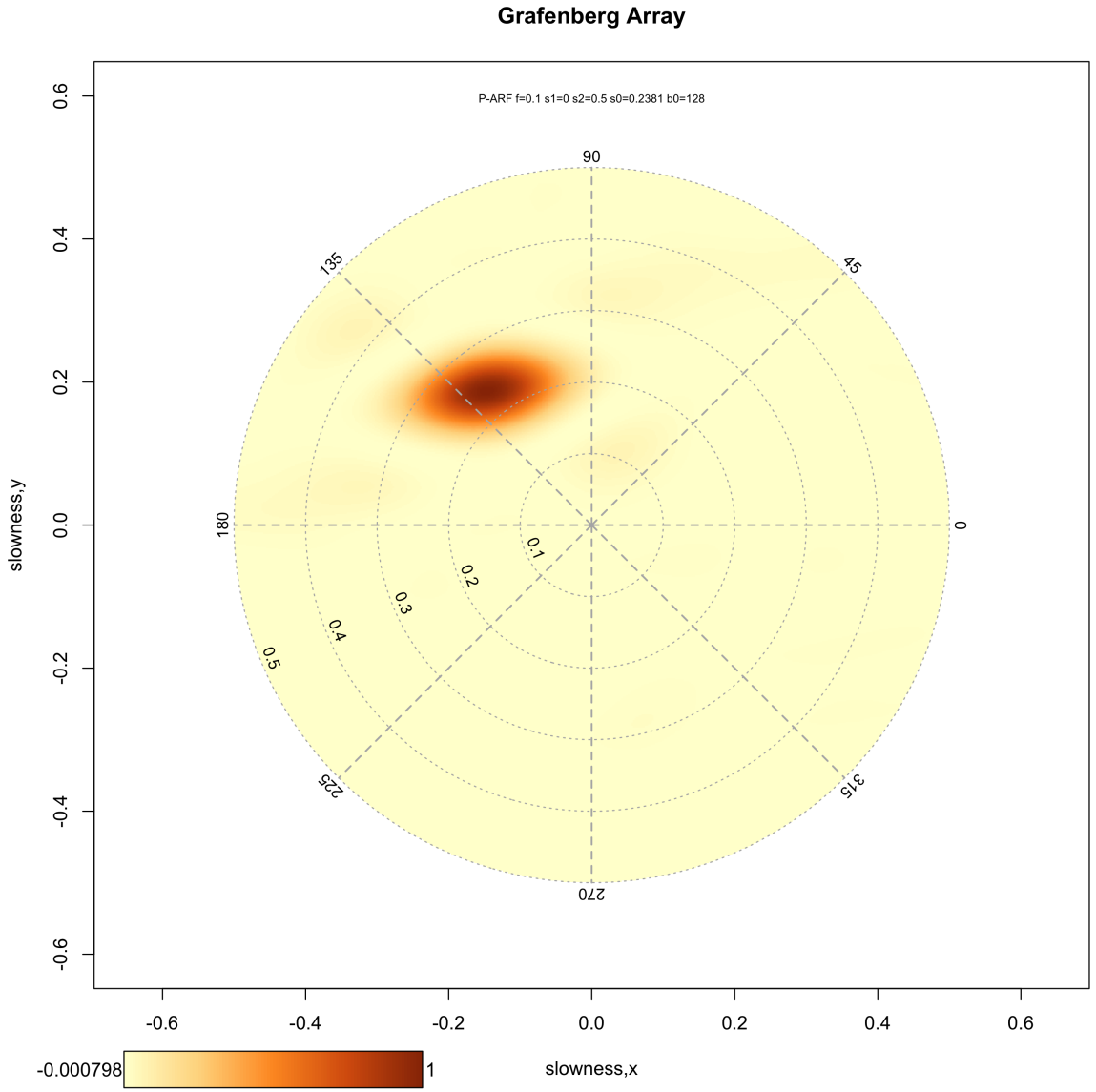
- Estimation of helicopter azimuth (beam-forming)
- Estimation of helicopter relative speed via doppler
- 6-Node (10m aperature) Station Array very effective
- 2000 Hz Sample Rate provides dense sampling of sound waves
- Smaller 2-node 'array', at lower sample rates, may be effective at extracting some helicopter parameters but these have ambiguities and are noisy
- 3-node arrays will improve estimates considerably

The End

Compare BeamForm with Helicopter GPS



Beam Forming Example



DC2: BEAM Angle v Helicopter