An Adaptive Window for Stare Processing of Delay Doppler Maps

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GNSS-R

- Global Navigation Satellite System Reflectometry (GNSS-R)
- Bi-static Radar of opportunity
- Cheap (M,V,P, $)
- Covert
- Over 100 Transmitters
- Spaceborne Scatterometry

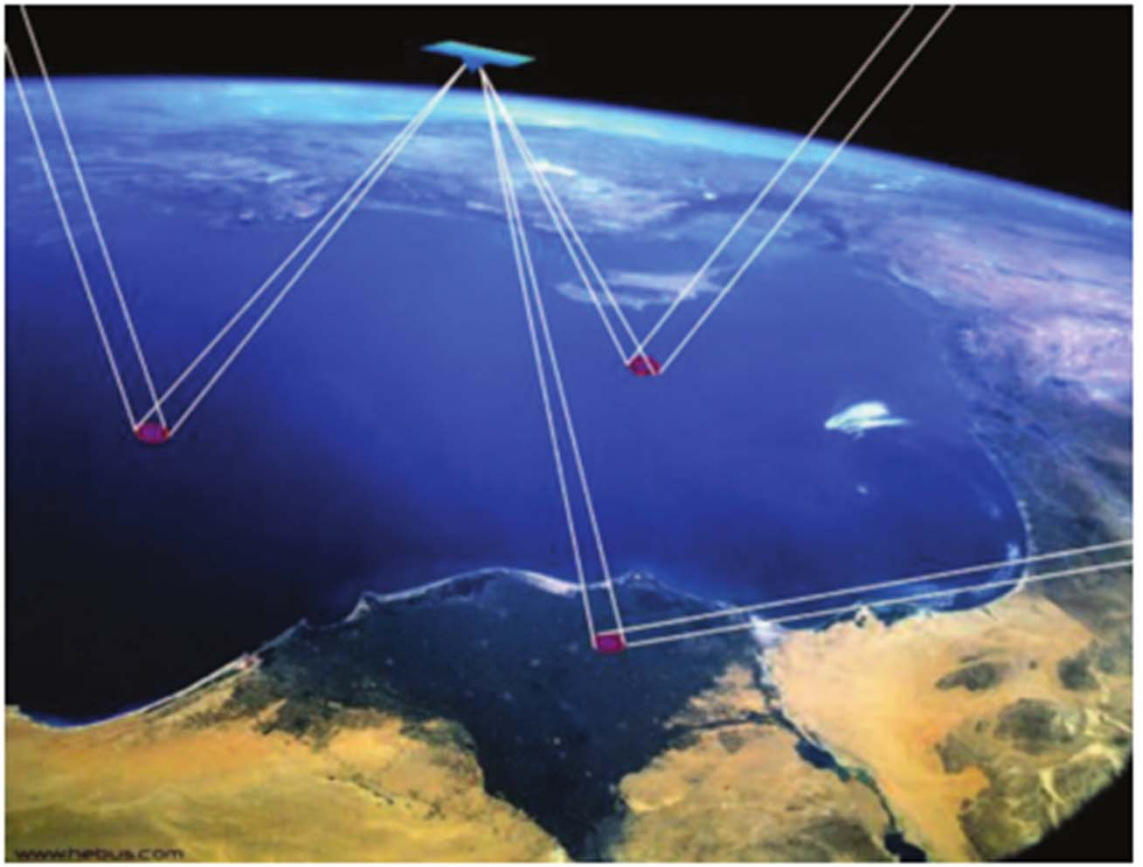
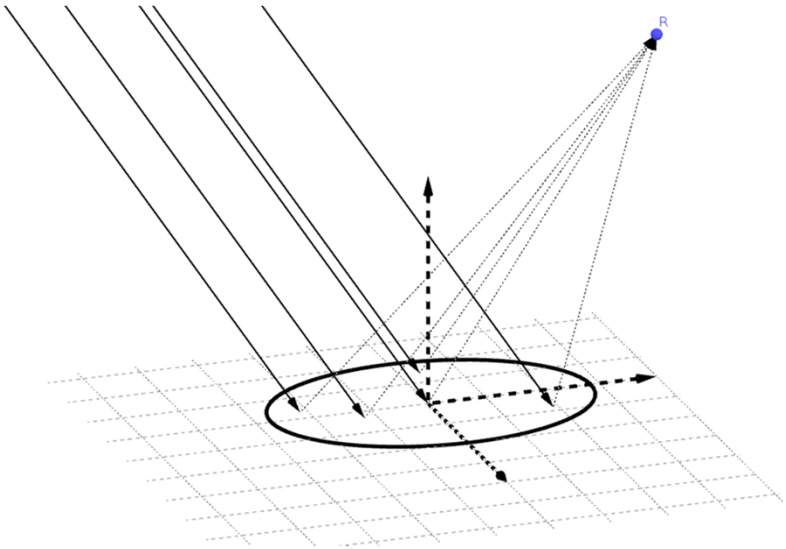


FIGURE 1. Depiction of GNSS bistatic remote sensing concept.

Zavorotny, V. U., Gleason, S., Cardellach, E., & Camps, A. (2014). Tutorial on remote sensing using GNSS bistatic radar of opportunity. *IEEE Geoscience and Remote Sensing Magazine*, *2*(4), 8–45. https://doi.org/10.1109/MGRS.2014.2374220

GNSS-R

The Bistatic Radar Equation



- Assuming a strongly diffuse scattering regime, the received power can be modeled with
  - extended radar cross section
  - system gain
  - receiver effects

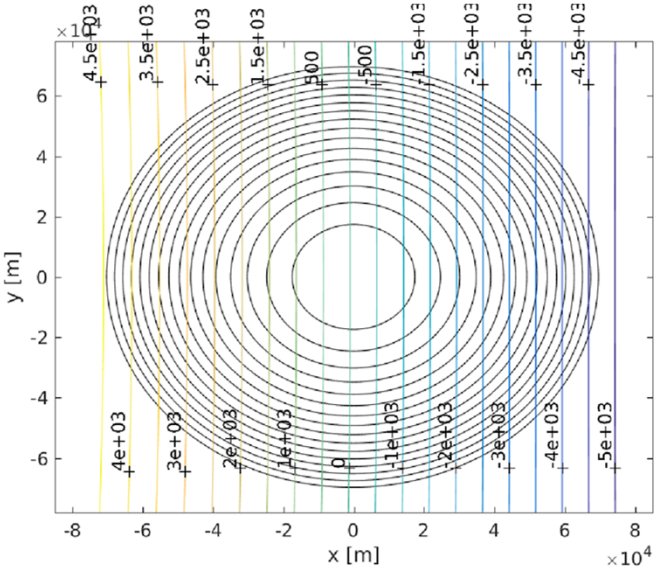
- DDM produced with ~1000 x 1ms integrations
  - limited coherence

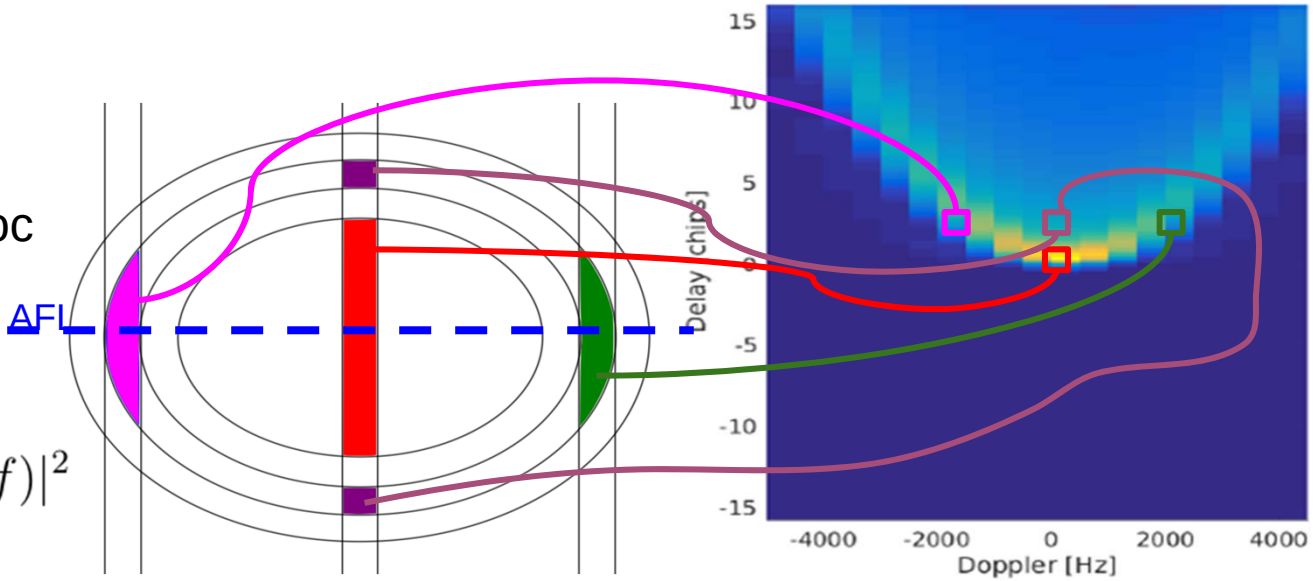
$$\left\langle |Y(\tau, f_D)|^2 \right\rangle = T_i^2 \frac{P_T \lambda^2}{(4\pi)^3} \int\int_A \sigma^0(\boldsymbol{p}) \frac{G_T(\boldsymbol{p}) G_R(\boldsymbol{p})}{R_R^2(\boldsymbol{p}) R_T^2(\boldsymbol{p})} \chi^2(\tau, f_D) \, d^2p$$

Surface Scenario Signal

Mapping to the DDM

- Most points in the spatial domain map ambiguously to delay, doppler domain
- Specular zone is typically processed for wind retrieval
- AFL: $\nabla f = \nabla \tau$
- Signal Space Proc

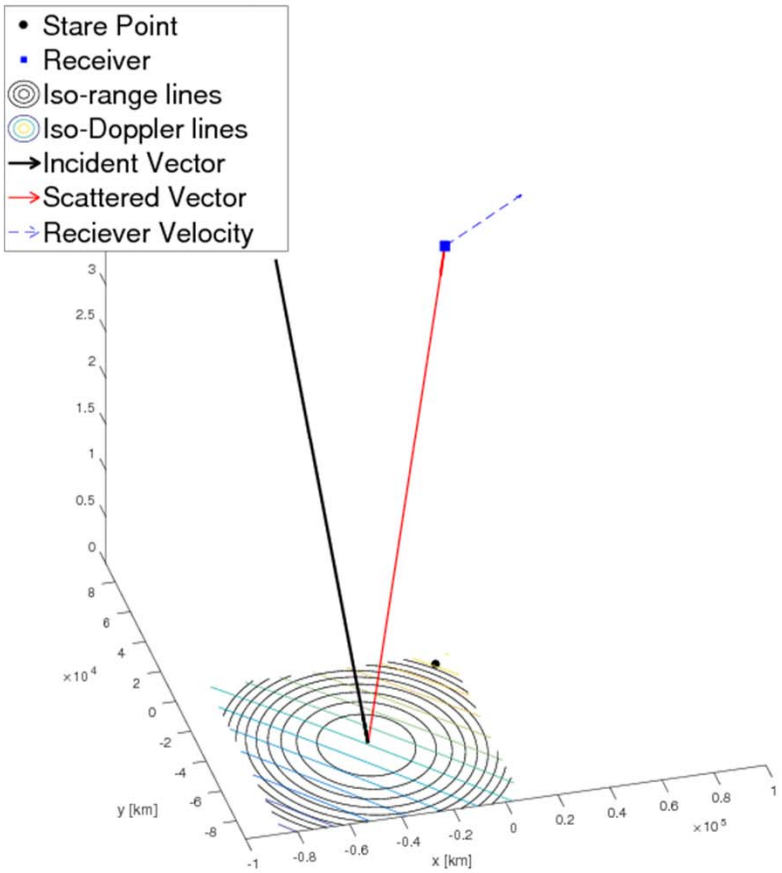


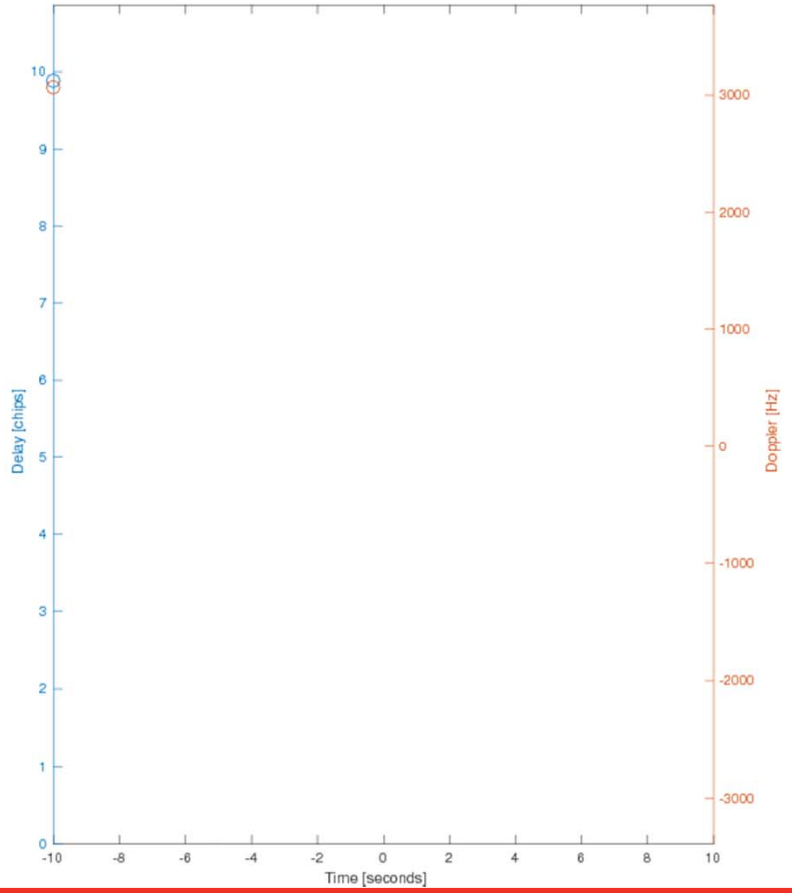


$$\chi^2(\tau, f) \simeq \Lambda^2(\Delta\tau)|S(\Delta f)|^2$$

Stare Processing

Point on AFL



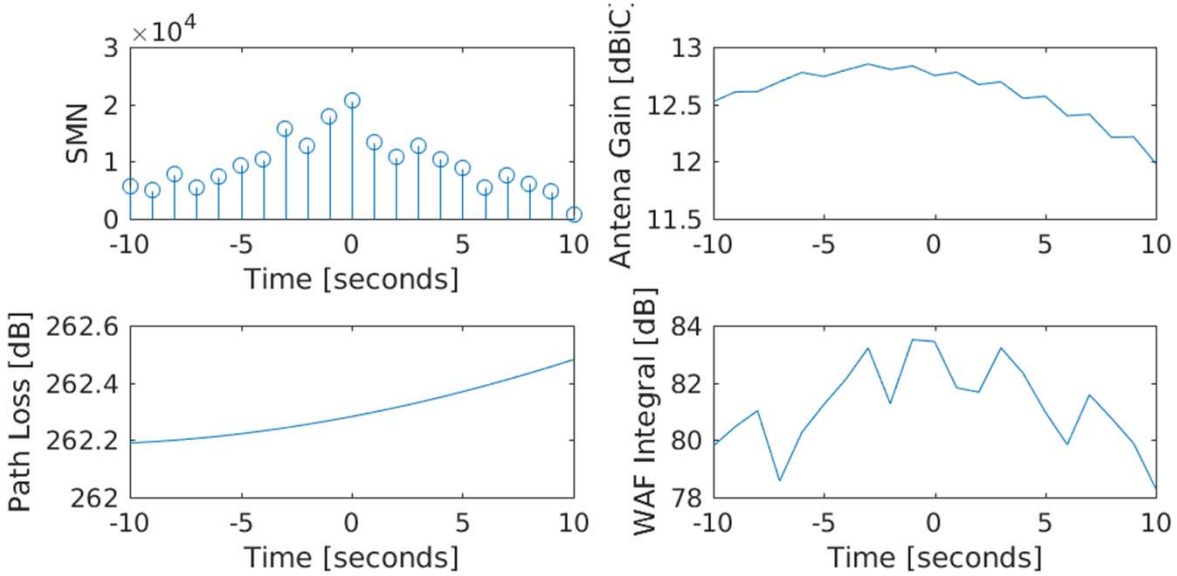


Stare Processing

Example RD35 TD49 PRN 9 Collected by TDS-1

- Similar to traditional scatterometers
- Resolution tradeoff
- Generates a stare profile

$$SMN \propto \sigma^0(\boldsymbol{p})\,\Gamma(\boldsymbol{p})$$



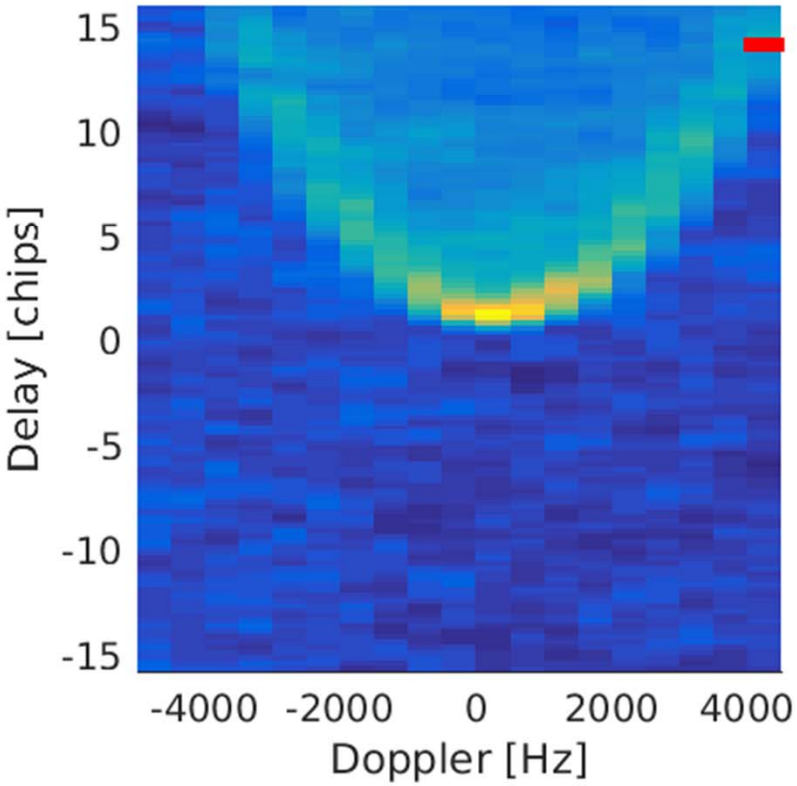
- MSS estimated by fitting simulated profile

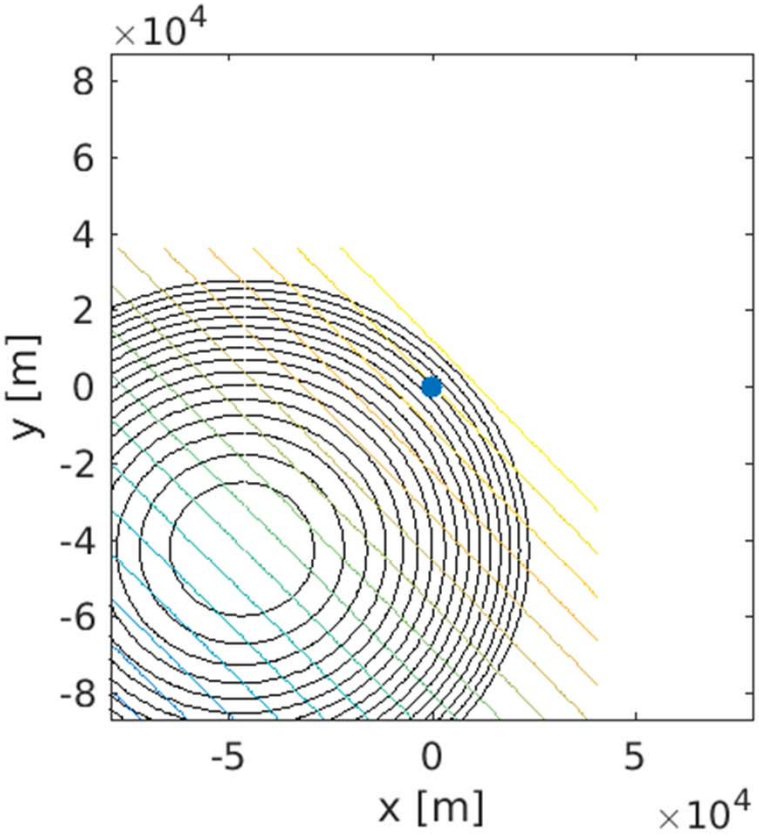
$$\Gamma(\boldsymbol{p}) = \frac{G_R(\boldsymbol{p})\,A_{\chi^2}(\boldsymbol{p})}{R_R^2(\boldsymbol{p})\,R_T^2(\boldsymbol{p})}$$

$$\sigma^0 = \frac{\pi|\Re|^2\boldsymbol{q}^4}{q_z^4} P\left(\frac{\boldsymbol{q}_\perp}{q_z}\right)$$

Stare Processing

Geometric Tracking and DDM sampling

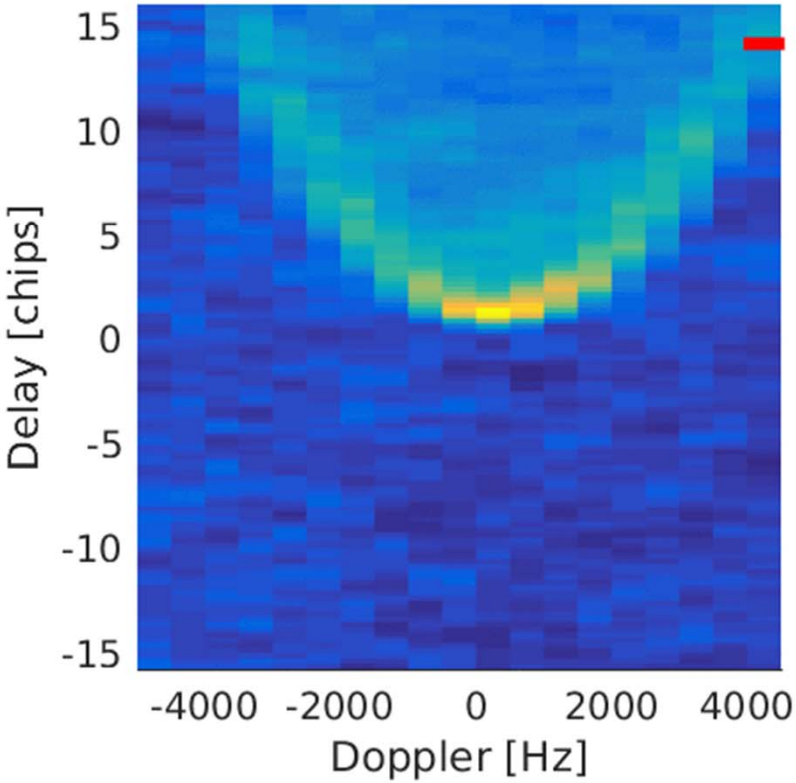


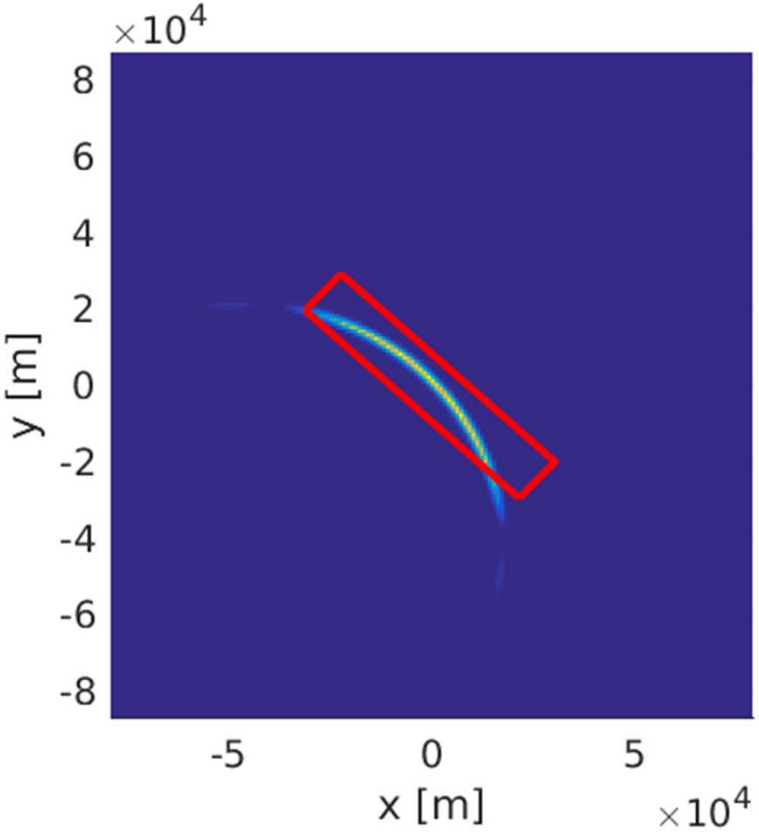


Stare Processing

DDM and WAF Footprint

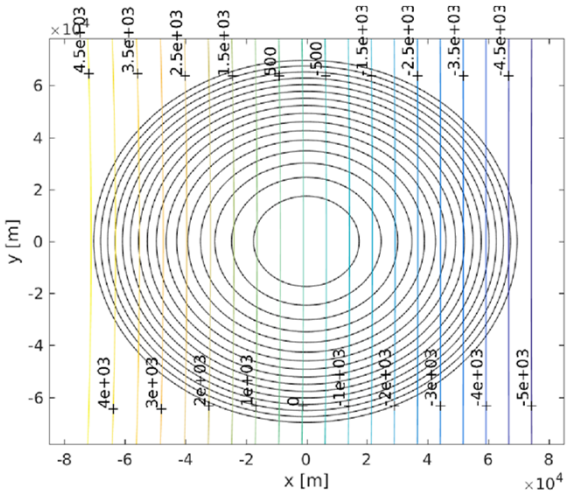
$$\chi^2(\tau, f) \simeq \Lambda^2(\Delta\tau)|S(\Delta f)|^2$$

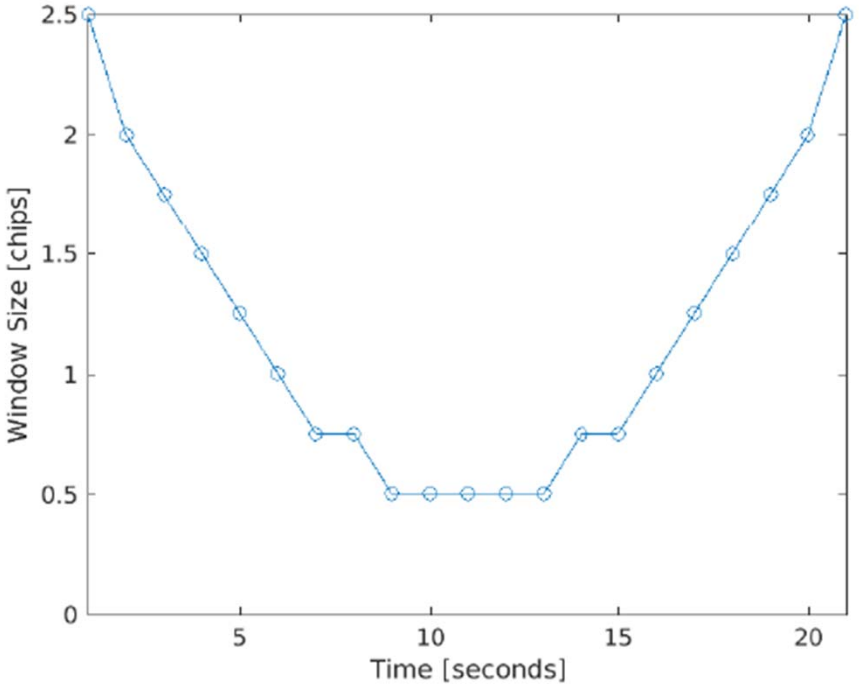




Variable Window Size

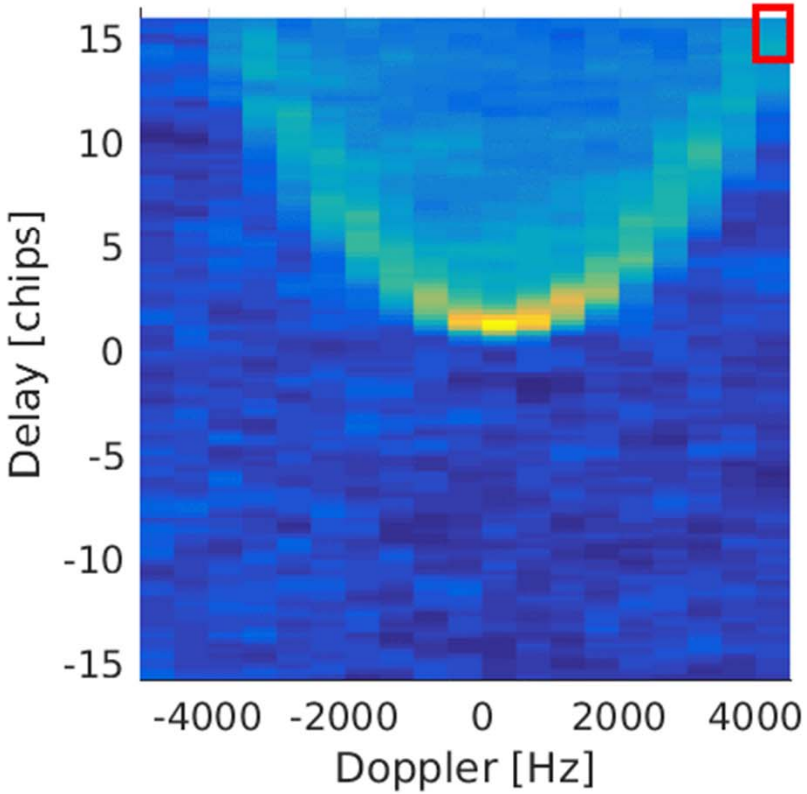
- Iso-range lines becomes closer as delay increases.
- Iso-range gradient -> iso-Dop gradient as delay increases
- Inefficient spatial footprint
  - effective area in BRE << bounding box

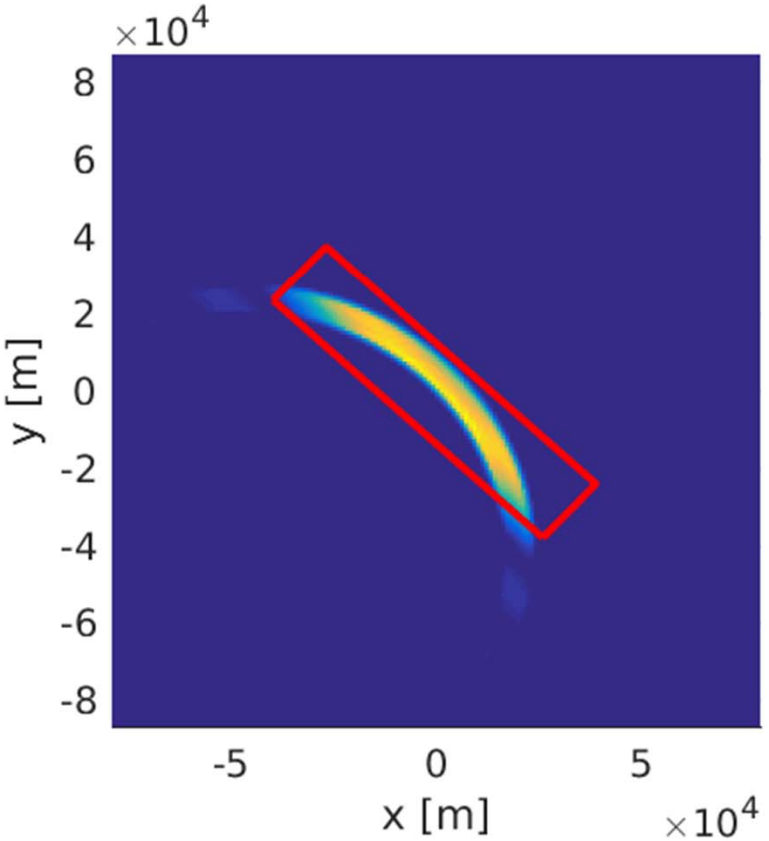




Variable Window Stare Processing

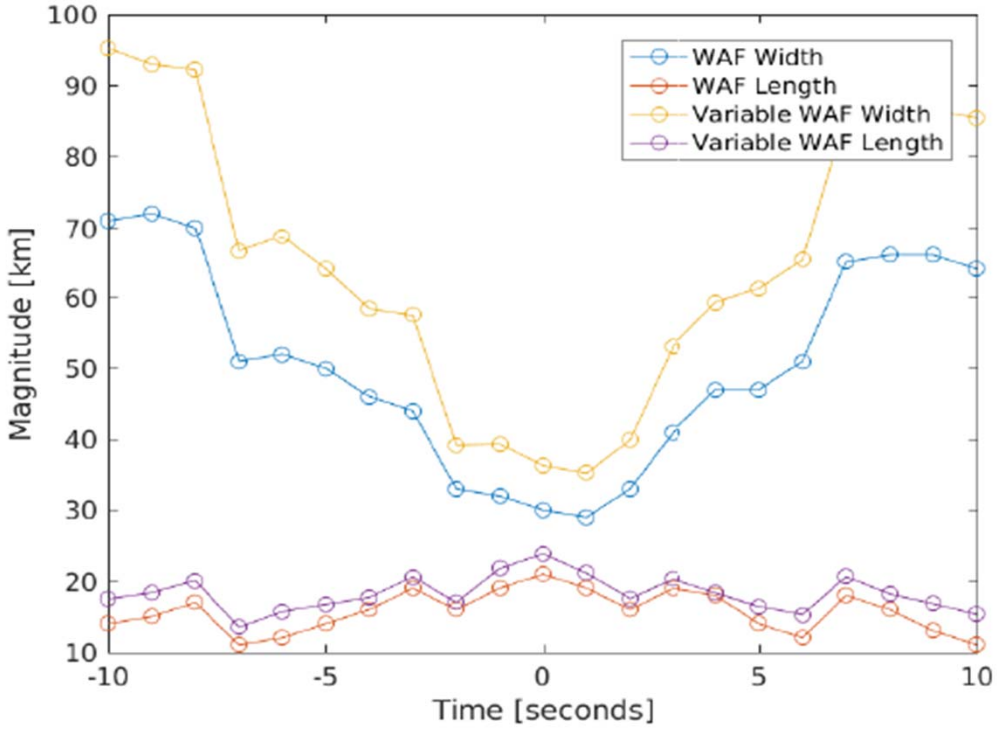
DDM and WAF Footprint





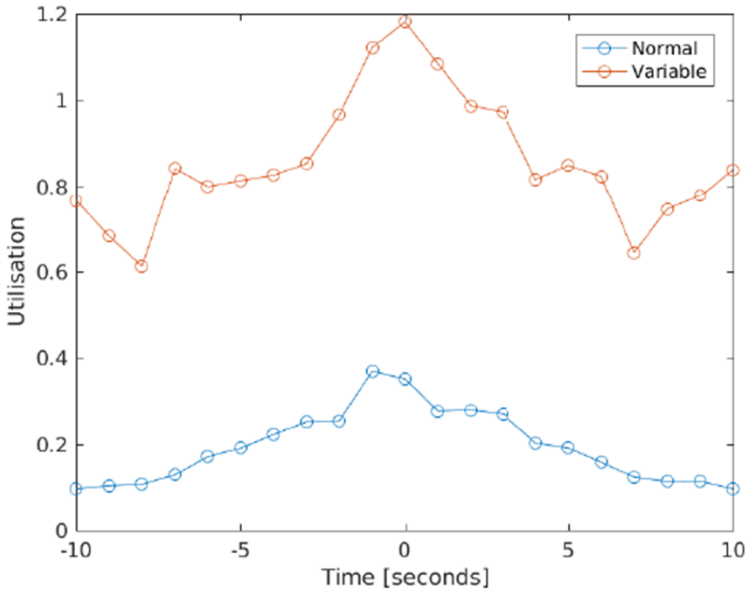
Impact on Resolution

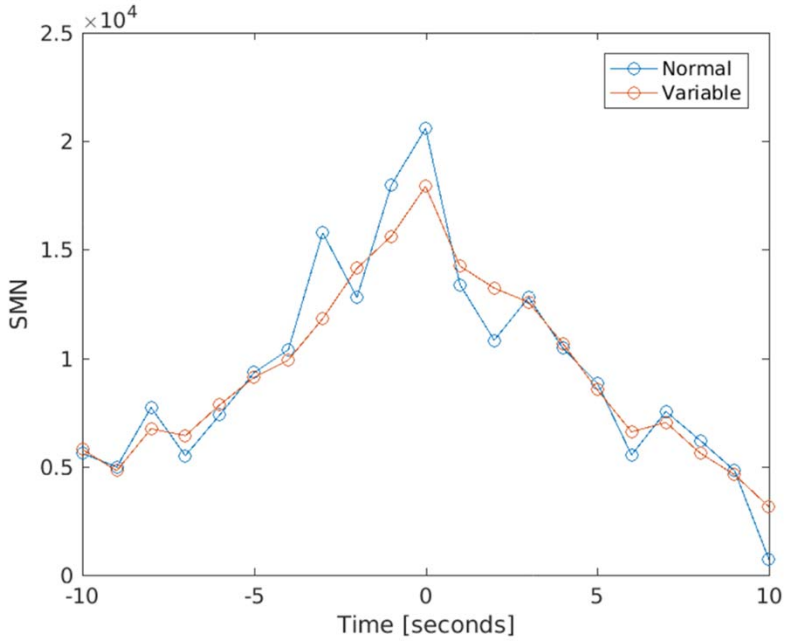
- Poor cross-track resolution regardless of window at high delays as ∇Iso-range -> ∇iso-Doppler. I.e Inherent to the GNSS-r bi-static config
- Cross track not as important as along



SMN

- Averaging Signal Power over multiple d-D cells. More effective use of resolution cell
- More measurements -> less variance in stare profile





Conclusions and Future Work

Stare Processing

- Analogue to multi-look / spotlight SAR
- χ footprint not constant
- SNR is worse at high delays

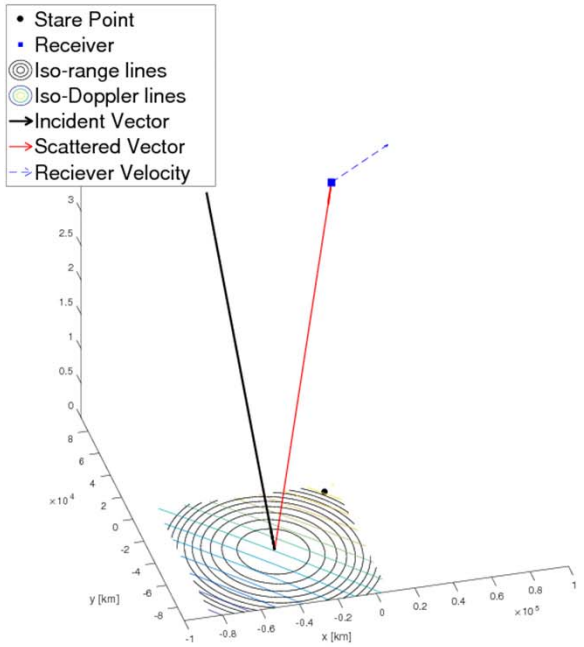
Variable length window

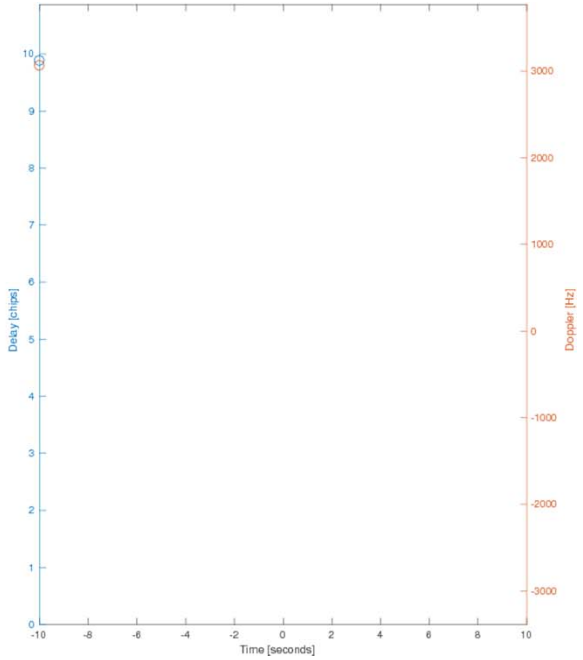
- χ footprint is more consistent
- χ integral / resolution is larger
- SNR improvement at non-zero delays

Future work

- Extension to resolve wind direction
  - Ambiguous Stare Points

Questions?


Stare Point
Receiver
Iso-range lines
Iso-Doppler lines
Incident Vector
Scattered Vector
Reciever Velocity
y [km]
x [km]


Delay [chips]
Doppler [Hz]
Time [seconds]