TOWARDS AN INTERFEROMETRIC AUTOFOCUS FOR IONOSPHERIC PHASE SIGNATURES IN BIOMASS

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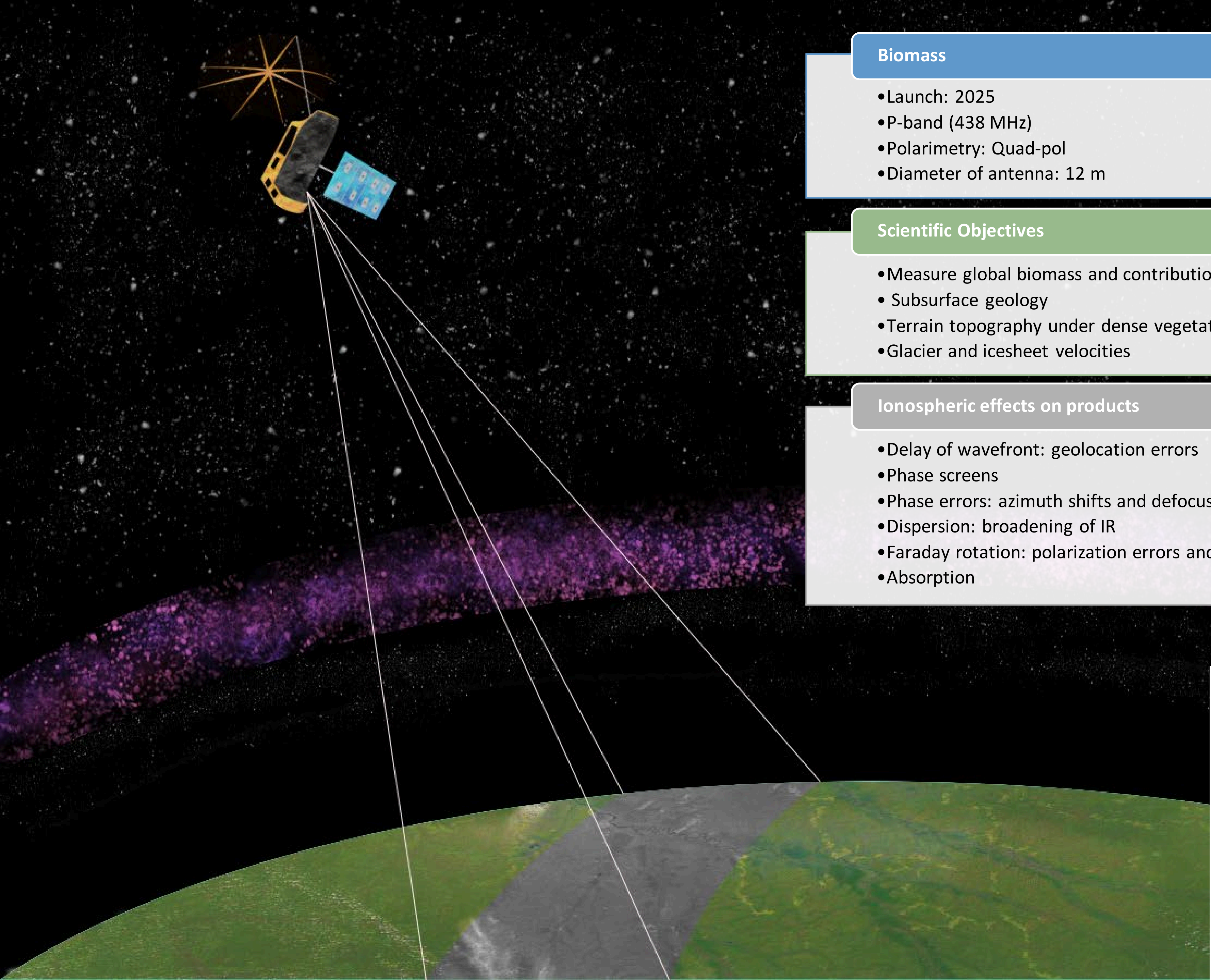


Biomass

- Launch: 2025
- P-band (438 MHz)
- Polarimetry: Quad-pol
- Diameter of antenna: 12 m

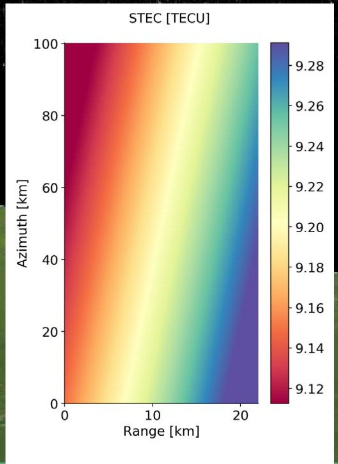
Scientific Objectives

- Measure global biomass and contribution of change in carbon fluxes
- Subsurface geology
- Terrain topography under dense vegetation
- Glacier and icesheet velocities

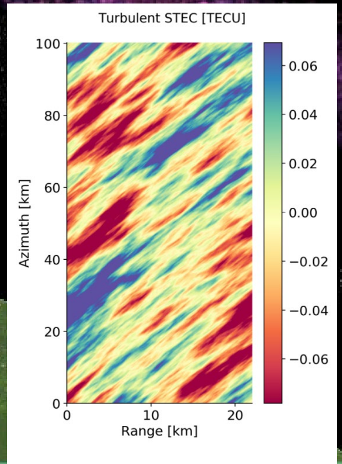
Ionospheric effects on products

- Delay of wavefront: geolocation errors
- Phase screens
- Phase errors: azimuth shifts and defocusing
- Dispersion: broadening of IR
- Faraday rotation: polarization errors and channel imbalance
- Absorption

Background



Turbulent

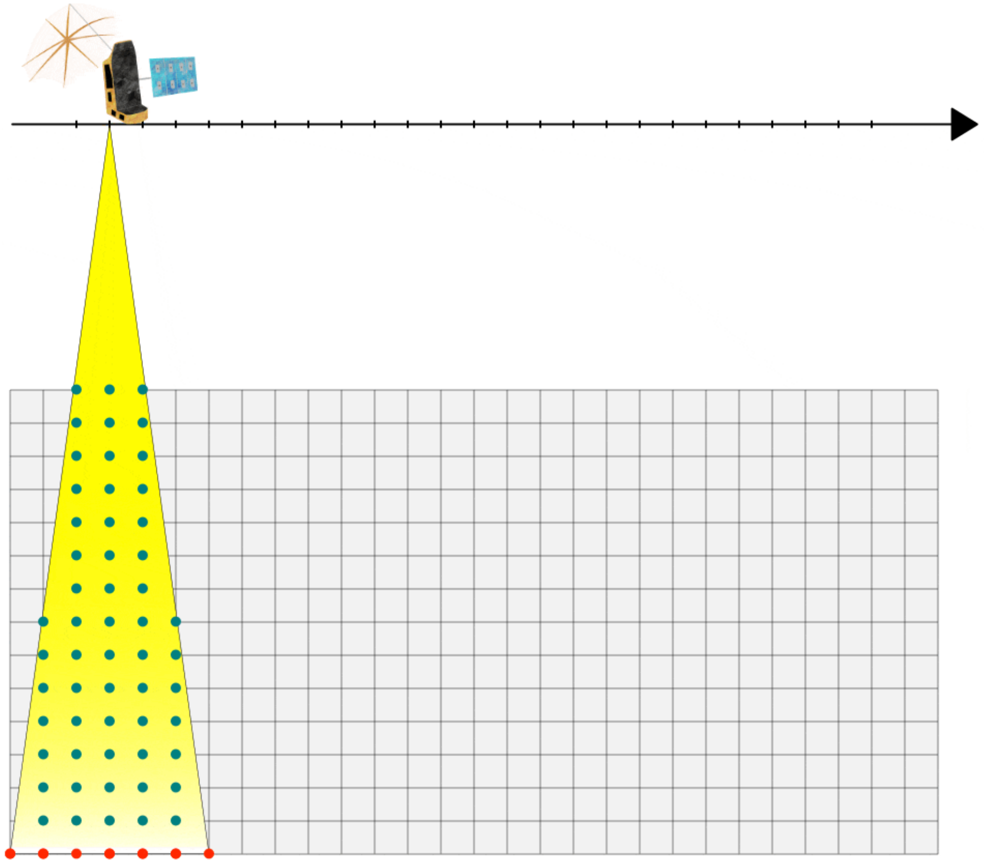


Error Characterization in Ionospheric Calibration of SAR Images

Thin layer approximation

Background component can be removed

Irregularities are stochastic and stationary

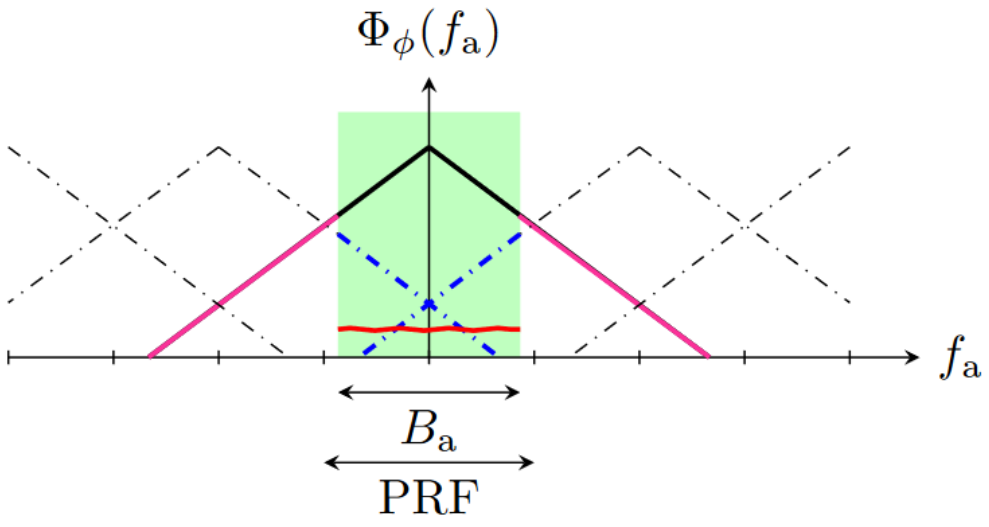


Rino power law

$$\Phi_\phi(\kappa_x, \kappa_y) = \frac{\lambda^2 \cdot \mathrm{r_e^2} \cdot \sec^2\theta_{\mathrm{inc}} \cdot ab \cdot \left(2 \cdot \pi/_{1000}\right)^{p+1} \cdot C_k L}{\left(\kappa_0^2 + A \cdot \kappa_x^2 + B \cdot \kappa_x \cdot \kappa_y + C \cdot \kappa_y^2\right)^{p+1/_2}}$$

$$\Phi_\Omega(\kappa_x, \kappa_y) = \left(\frac{\mathrm{q_e} \cdot \vec{B} \cdot \hat{k}}{\mathrm{m_e} \cdot f \cdot 4 \cdot \pi}\right)^2 \cdot \Phi_\phi(\kappa_x, \kappa_y)$$

Calibration error sources



$$\Phi_{\Delta\phi}(f_a) = \begin{cases} \Phi_\phi(f_a), & f_a > B_a/2 \\ \Phi_N(f_a) + \sum_{i=1}^{+\infty}\Big(\Phi_\phi(f_a + i \cdot \mathrm{PRF}) + \Phi_\phi(f_a - i \cdot \mathrm{PRF})\Big), & f_a \le B_a/2 \end{cases}$$

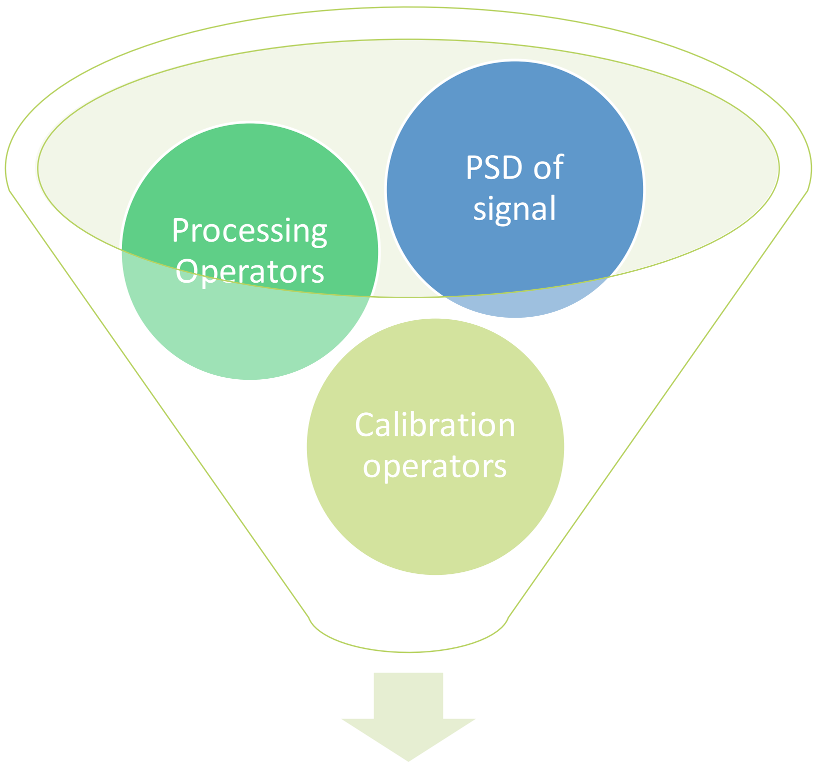
Inside of band

Outside of band

$$\sigma^2_{\Delta\phi} = 2 \cdot \left(\int_0^{B_a/2} \Phi_N(f_a) + \sum_{i=1}^{+\infty}\big(\Phi_\phi(f_a + i \cdot \mathrm{PRF}) + \Phi_\phi(f_a - i \cdot \mathrm{PRF})\big)\, \mathrm{d}f_a + \int_{B_a/2}^{\infty} \Phi_\phi(f_a)\mathrm{d}f_a \right)$$

Noise

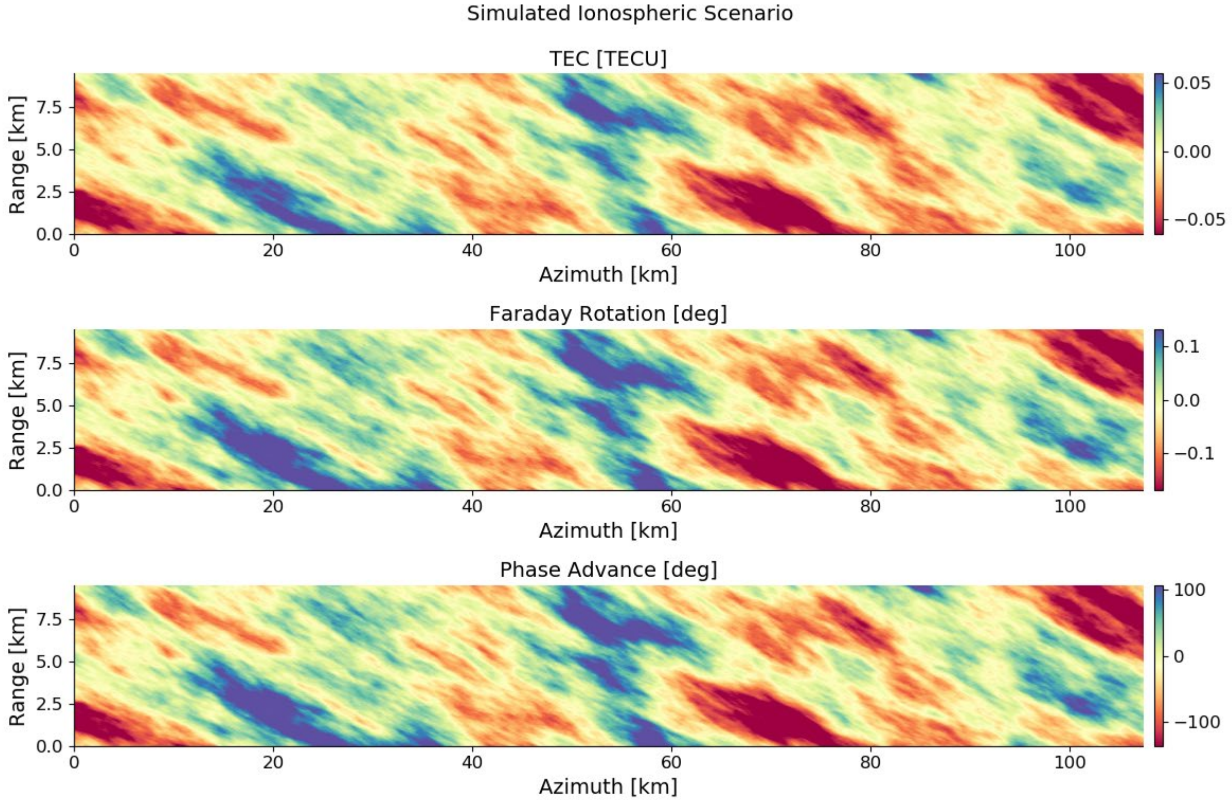
Aliasing

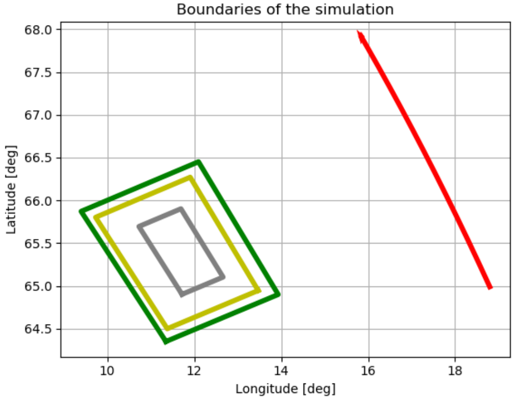


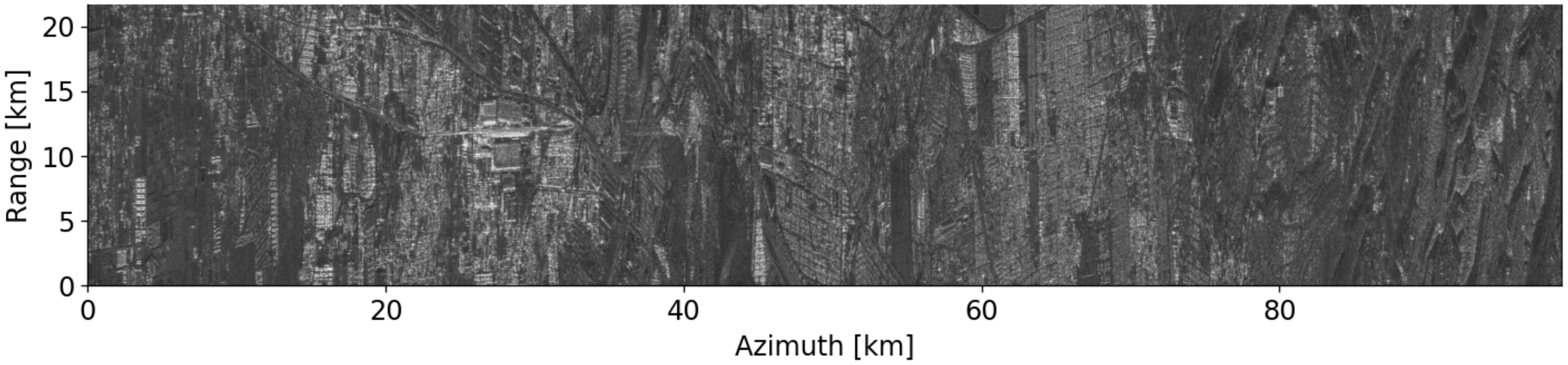
Expected solution and error

Data Simulation

$C_k L$	10^{32}
Outer scale l_o	20 km
Anisotropy $a : b$	5:1
Spectral index p	2.65
Ionospheric height h_{iono}	351 km
Satellite altitude	660 km
Incidence angle	25 deg
Antenna diameter	12 m
Carrier frequency	435 MHz
Pulse Repetition Frequency (PRF)	1475.506 Hz
Azimuth bandwidth (B_a)	1229.588 Hz
Range sampling frequency (RSF)	7565217.4 Hz
Range bandwidth (B_r)	6877470.363 Hz

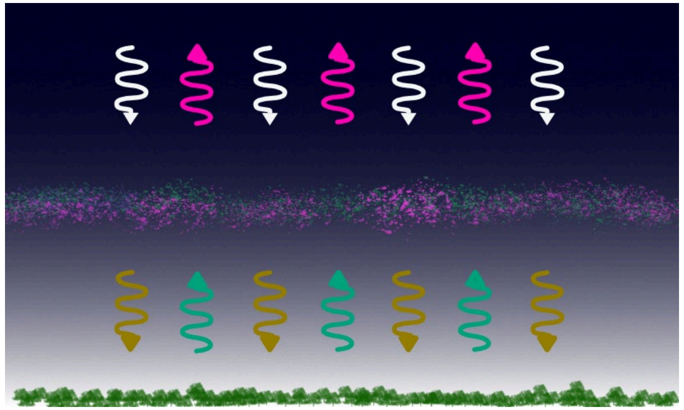


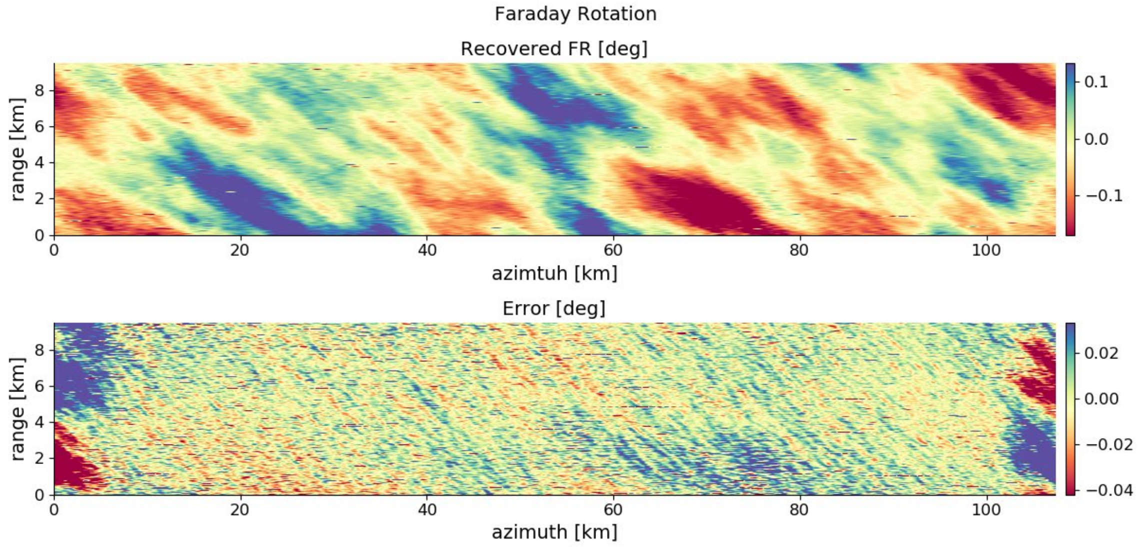




Bickel and Bates Based Estimation

(Tx) H, V → (Rx) HH, HV, VH, VV





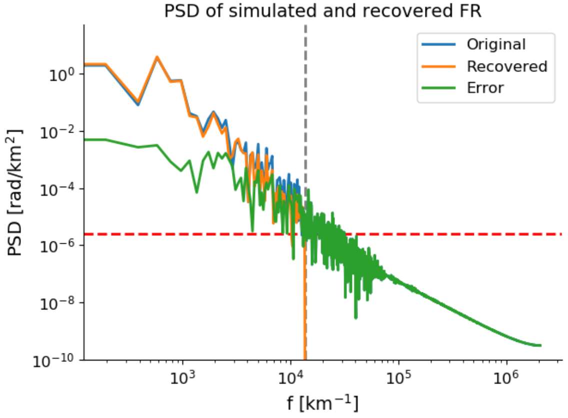
Inside of band

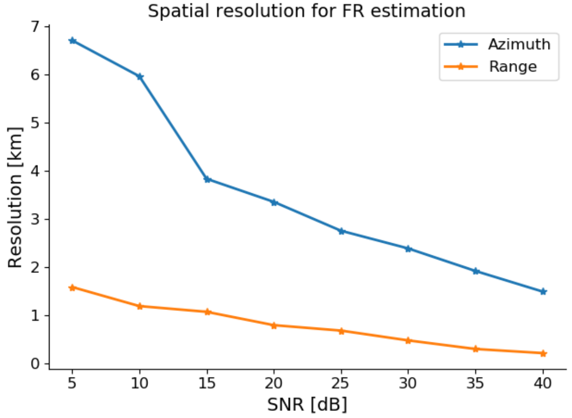
Outside of band

$$\sigma^2_{\Delta\Omega} = \iint_{S_{\mathrm{cbw}}} \underbrace{B^2 \cdot \Phi_{\mathrm{N}}}_{\text{Filtered noise}} + \underbrace{\sum_{i=-\infty}^{+\infty} \sum_{j=-\infty}^{\infty} \Phi_{\Omega}[i,j]}_{\text{Aliasing}} \, \mathrm{d}f_{\mathrm{r}} \cdot \mathrm{d}f_{\mathrm{a}} + \iint_{S^{c}_{\mathrm{cbw}}} \Phi_{\Omega} \, \mathrm{d}f_{\mathrm{a}} \cdot \mathrm{d}f_{\mathrm{a}}$$

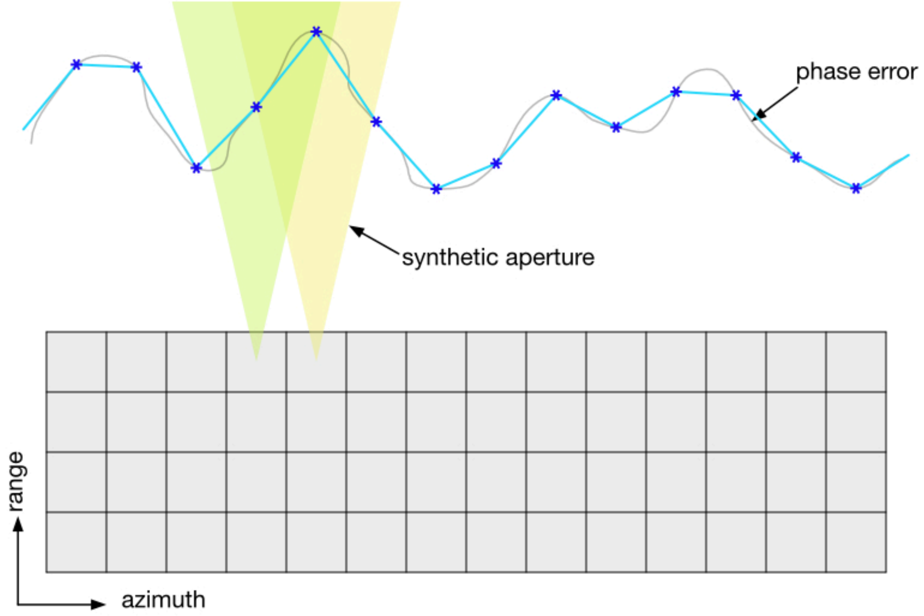
Filtered noise

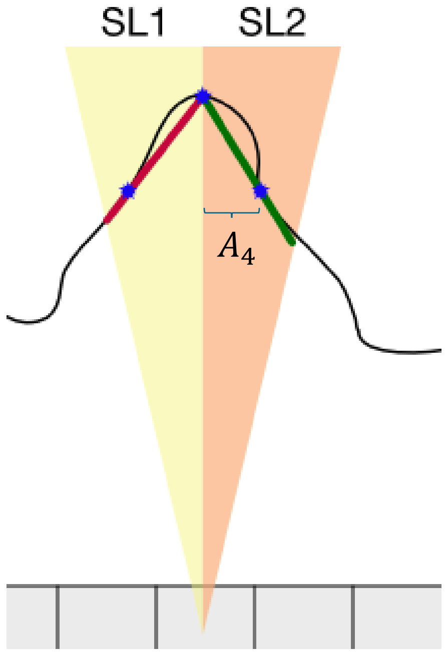
Aliasing

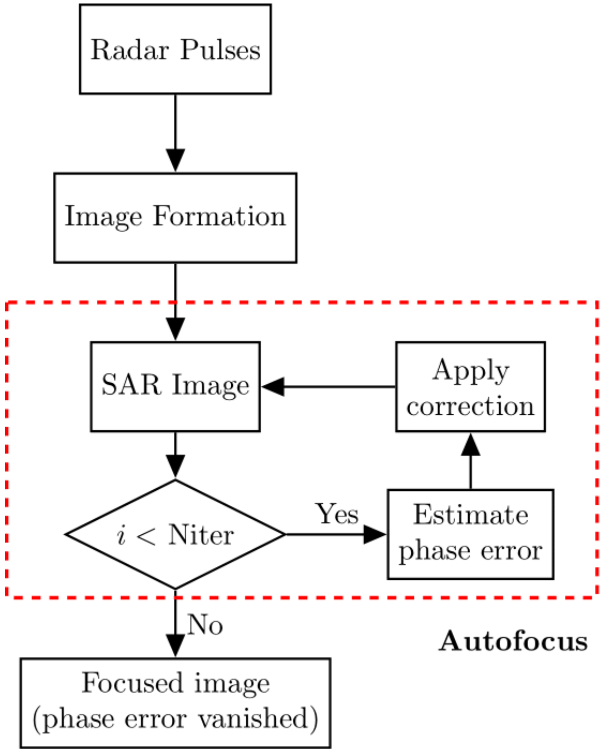




Mapdrift Autofocus







Interpolation

Integration

Sampling

$$\Phi_{\phi,\mathrm{AF}} = L^2 \cdot \frac{1}{(\mathrm{j}\cdot\omega_2)^4}\left(\sum_{i=-\infty}^{+\infty}\sum_{j=-\infty}^{+\infty}\left(B^2\cdot \Phi_{\ddot{\phi}^*}[i,j]\right)\right)$$

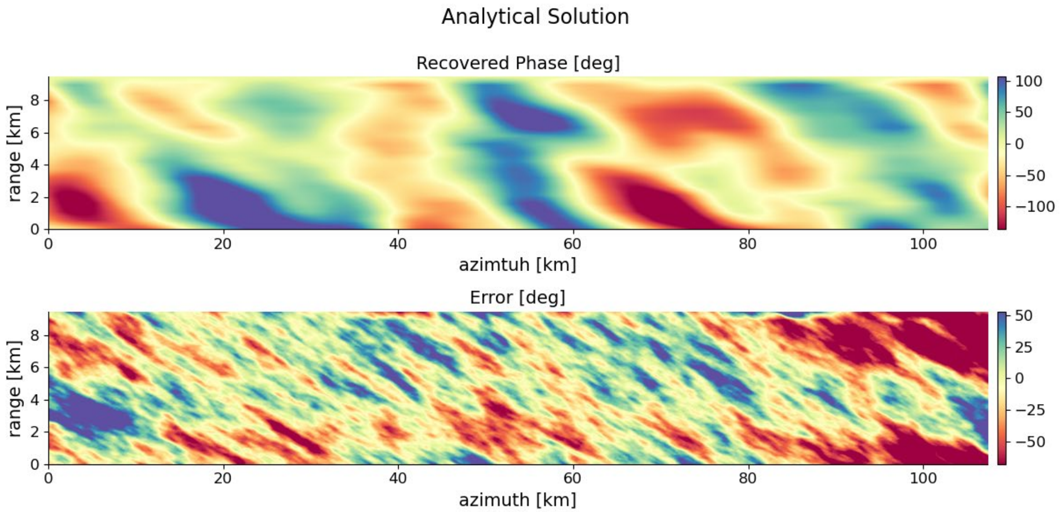
Block averaging

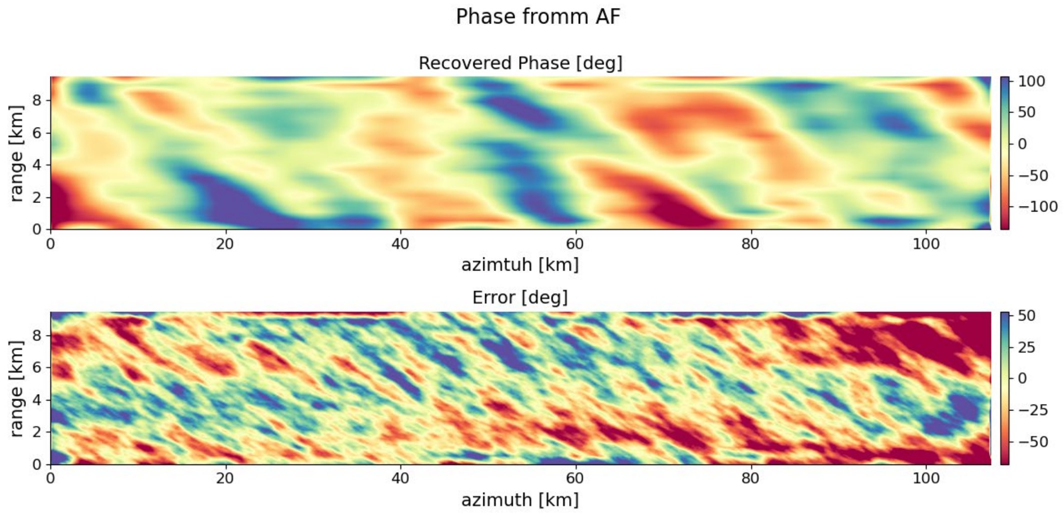
Differentiation + Synthetic Aperture

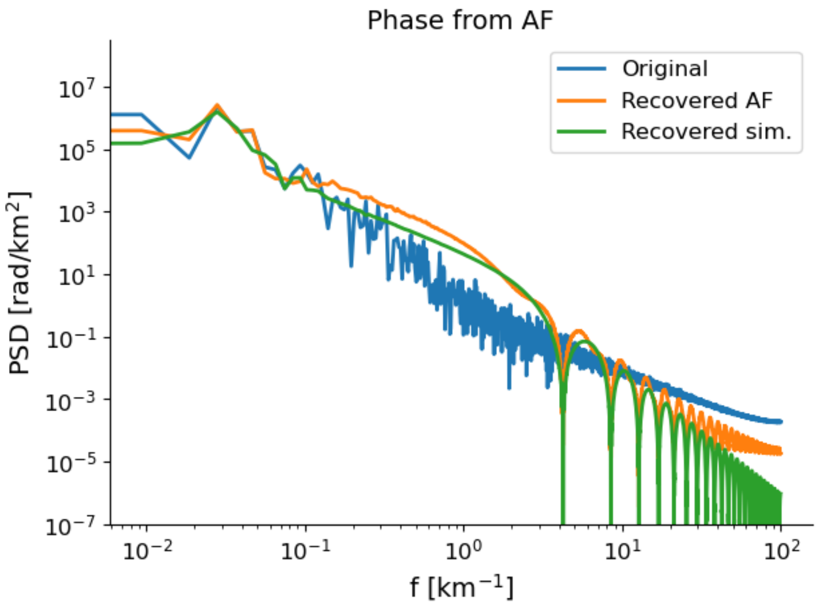
$$\ddot{\phi}^* = \exp(j2\pi f A_4)\,(\exp(j2\pi f A_4)\,\phi - \phi) - (\exp(j2\pi f A_4)\,\phi - \phi)$$

$$\Phi_{\ddot{\phi}^*} = \ddot{\phi}^* \cdot \overline{\ddot{\phi}^*}$$

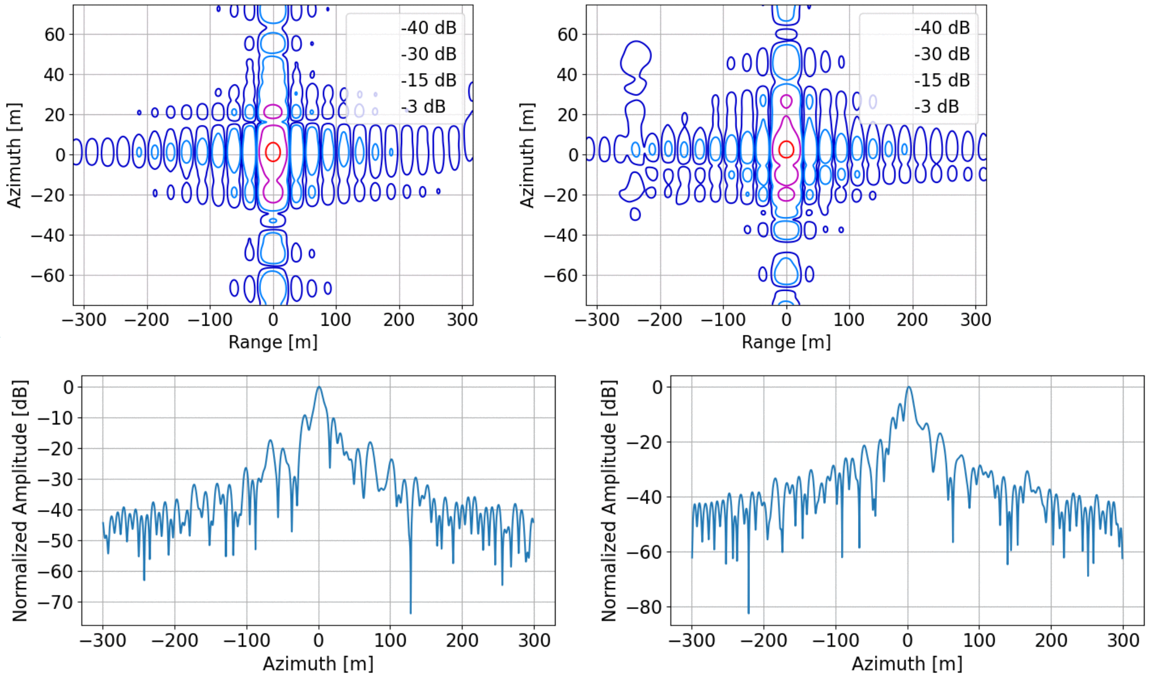
Mapdrift of Autofocus



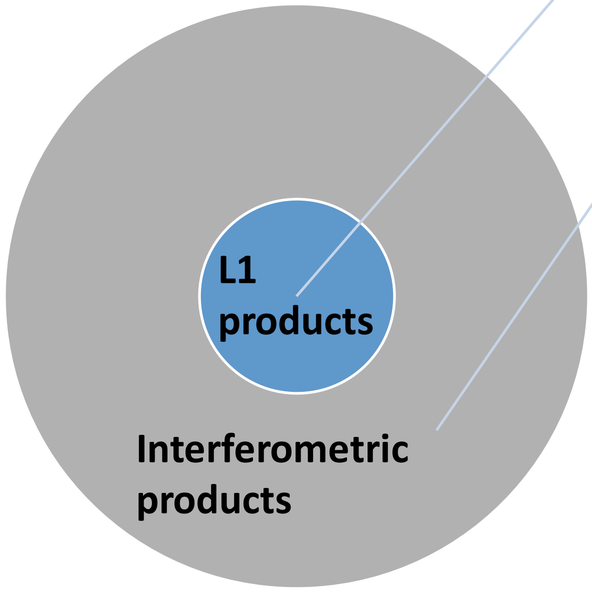




IRF
with/without AF



Methods for Correcting Ionospheric Effects in SAR Products



Single pass calibration

- Polarization angle rotation estimation
- Autofocus

Differential calibration

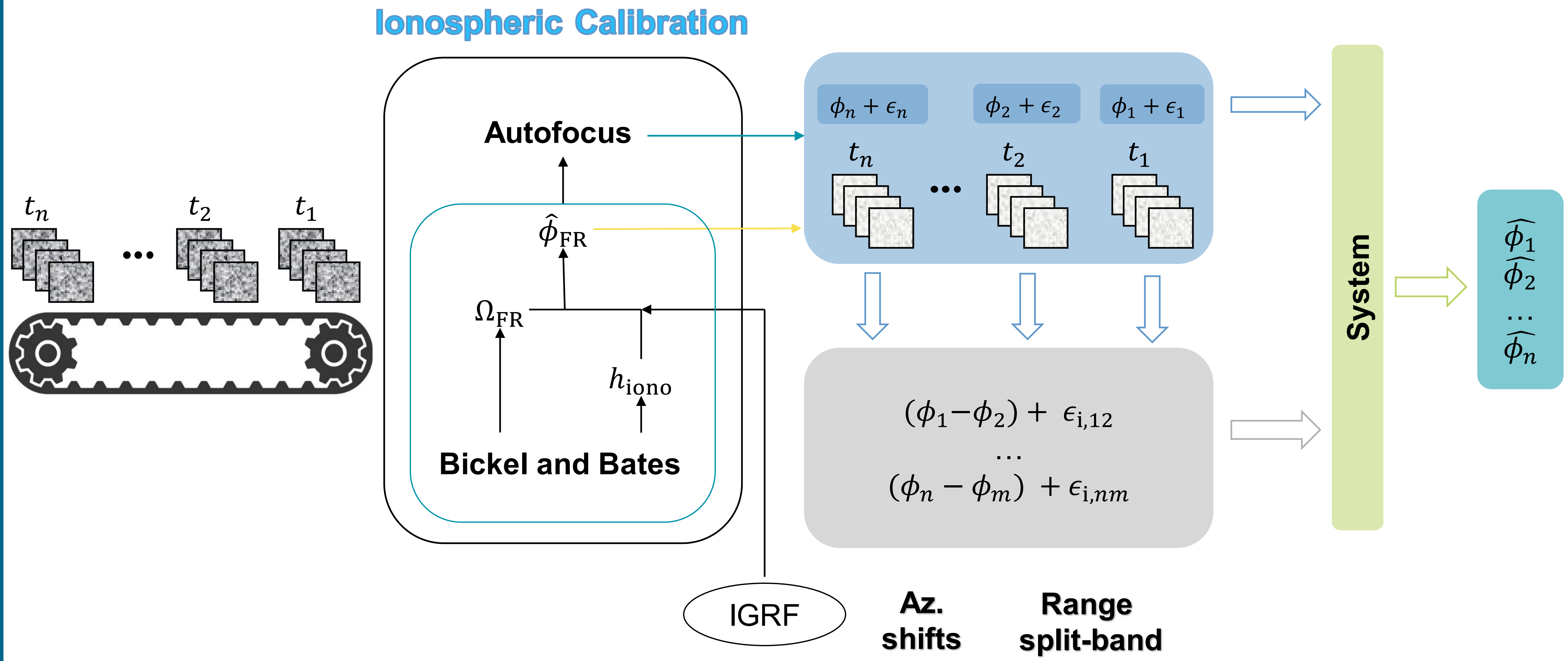
- Split-spectrum
- Azimuth shifts

Interferometric calibration has better resolution but provides only differential ionospheric products

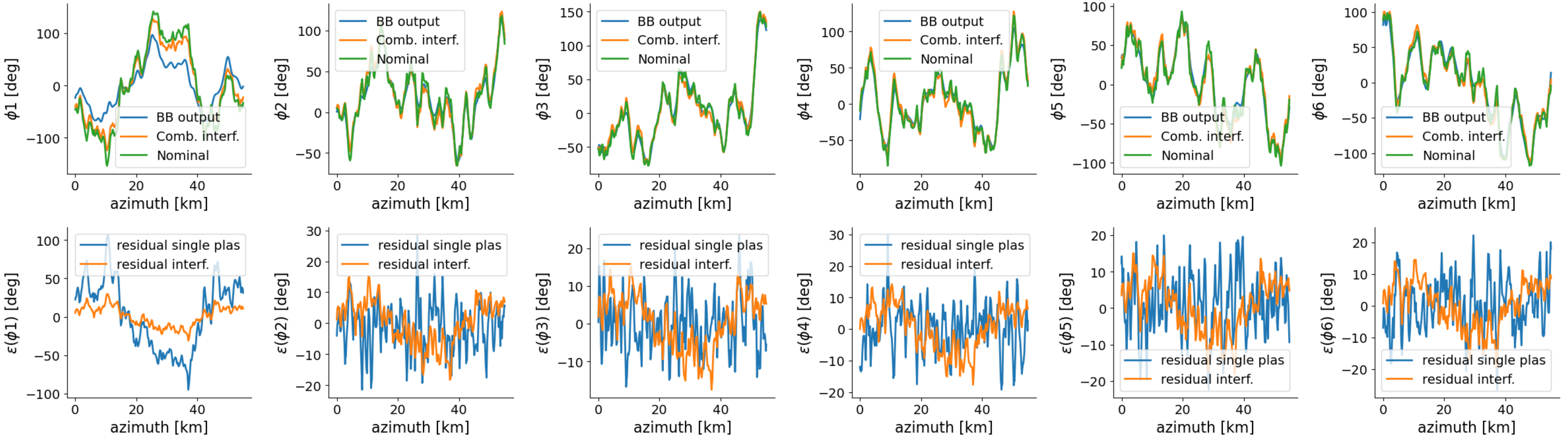
Single pass solutions have worse resolution

Can I profit from the interferometric information to search for better single pass solutions?

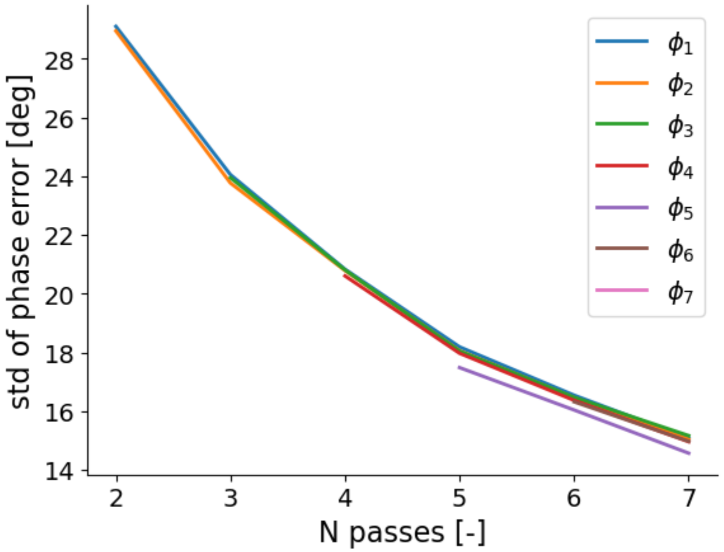
Data combination



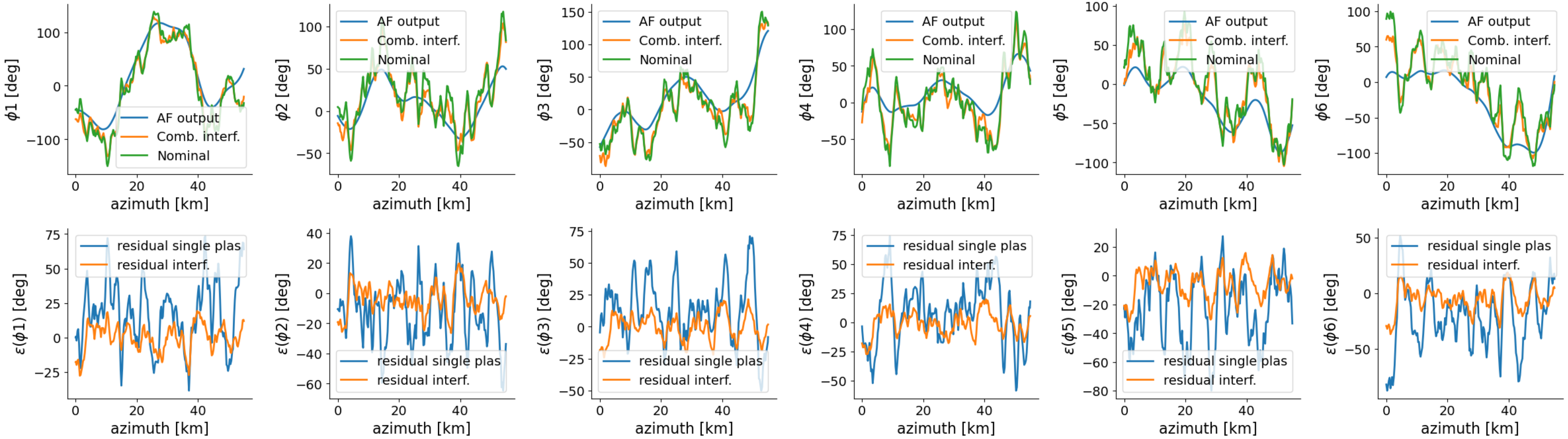
Combination of FR Outputs

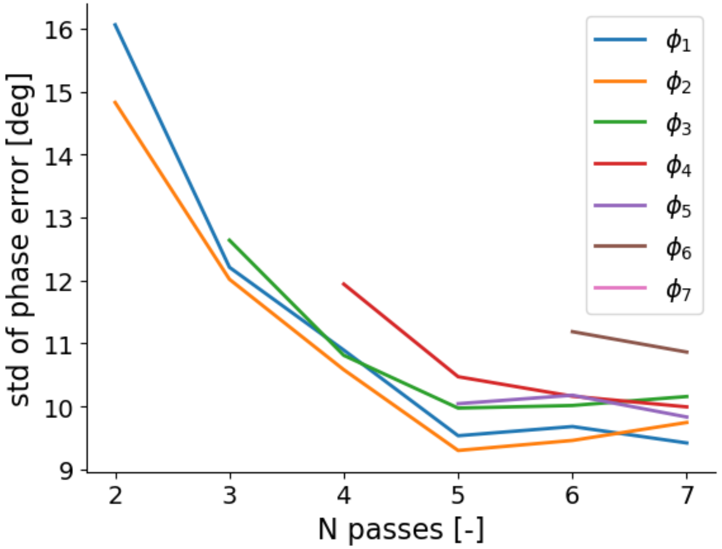


- Combining measurements and forcing the individual solutions to be consistent with the interferograms its is possible to gain resolution in the ionospheric maps
- The more information we have the better
- Remember: only suitable in high latitudes!



Combination of Autofocus Outputs





Conclusions

- Spectral analysis can be used for the characterization of the errors in the calibration algorithms (FR based and Autofocus)
- Residual phase errors after single pass calibrations introduce large errors in the interferograms
- Information obtained by the interferometric processing can be used to gain resolution and reduce uncertainties
- The approach passes by forcing the single pass solutions to be consistent with the interferometric solutions.
- Uncertainty decreases with number of passes

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