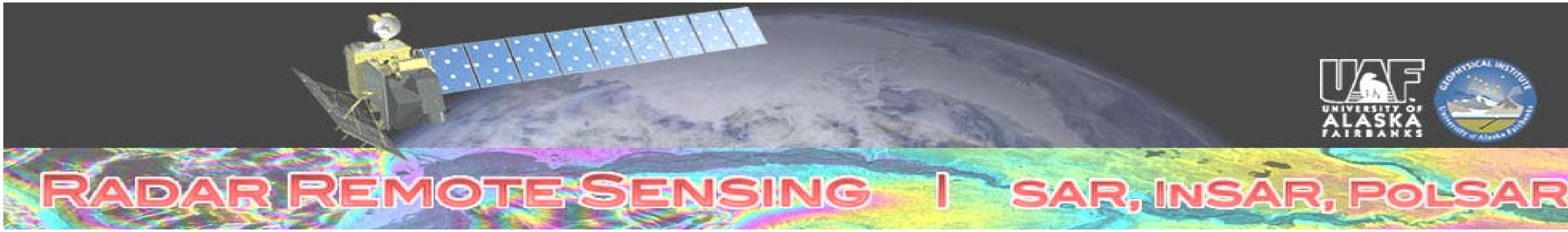

IP-STATS: A SYSTEM FOR DERIVING STATISTICAL MODELS OF IONOSPHERIC SIGNALS IN LOW-FREQUENCY SAR DATA

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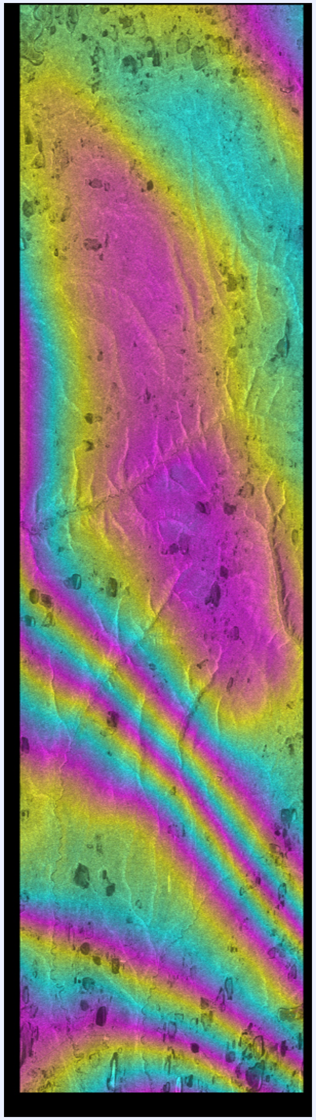
[2)]*Alaska Satellite Facility (ASF)*

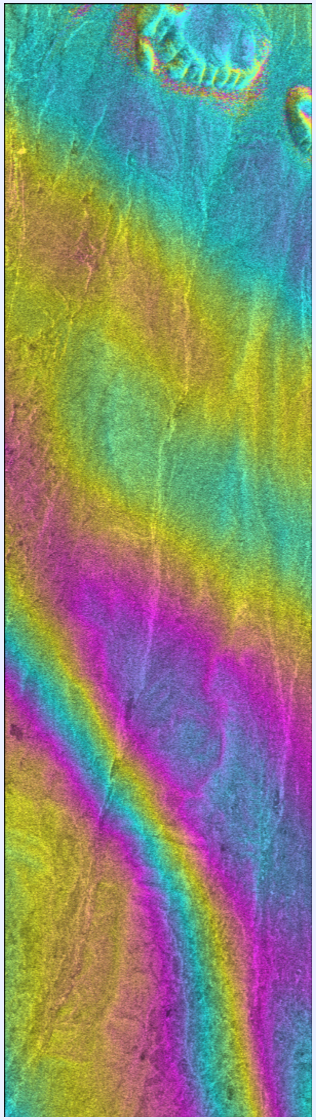
[3)]*Space Physics and Aeronomy, University of Alaska Fairbanks*

Collaborating Organizations:

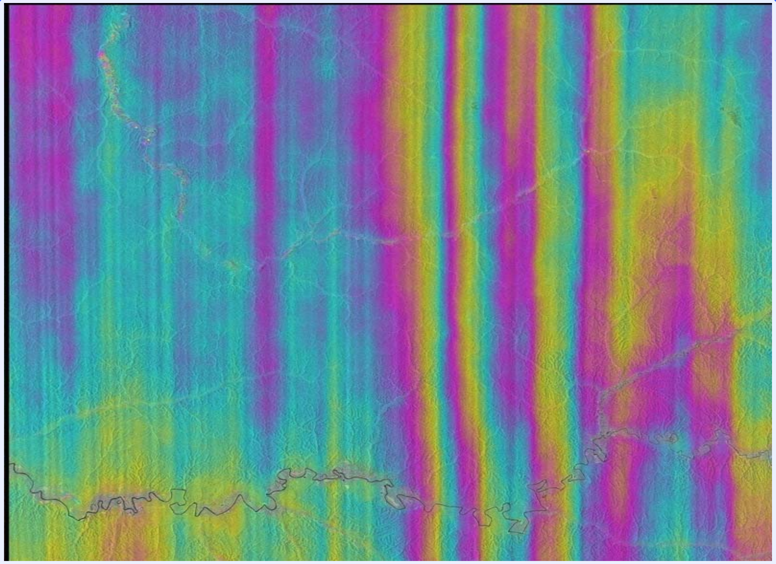
NASA JPL GEOPHYSICAL INSTITUTE UAF ASF DLR

Ionospheric Artifacts in Radar Data



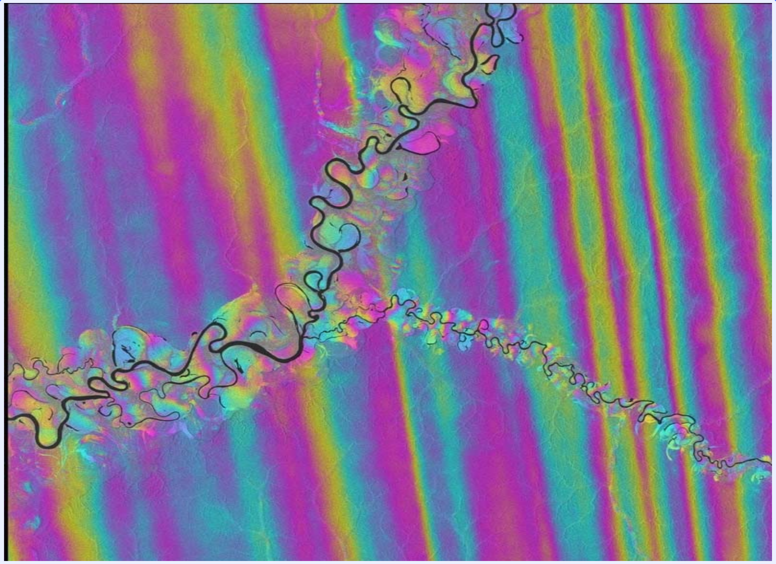


Equatorial Regions



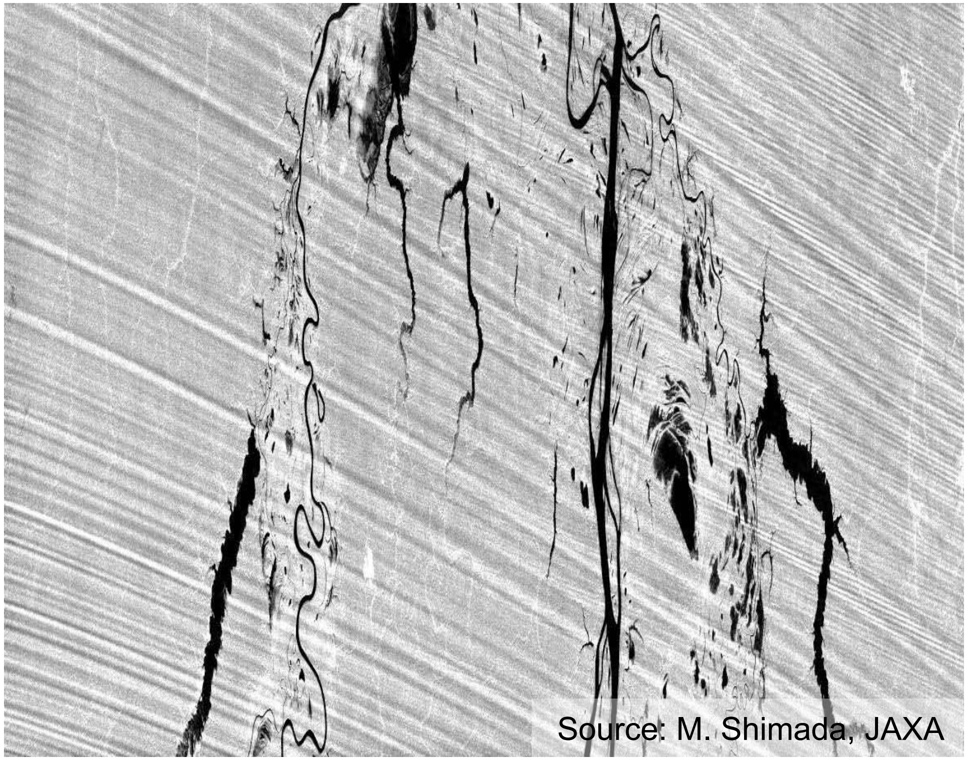
Phase Distortions

Polar Regions



Ionospheric Artifacts in Radar Data

Image Distortions

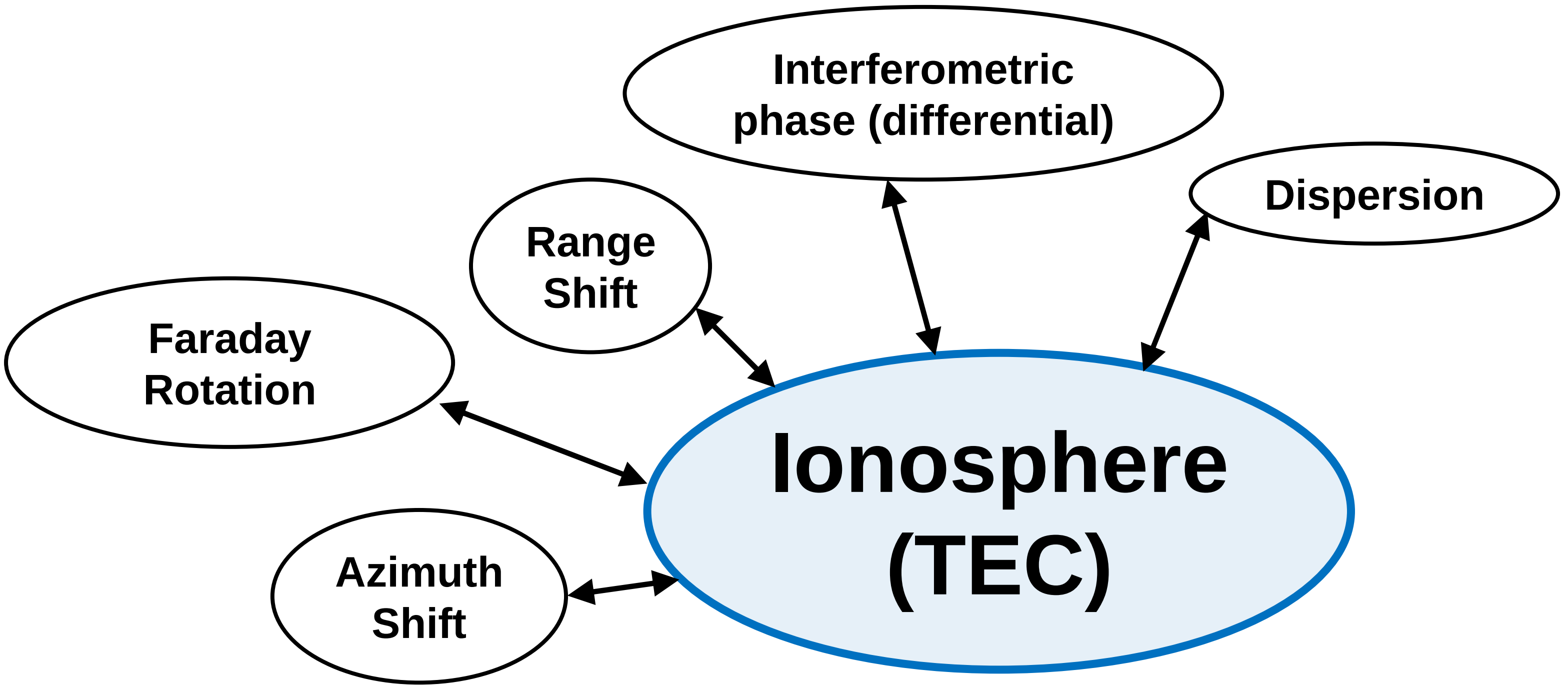


Rainforest, Brazil

South-East Asia

Methods for Ionospheric Correction of SAR

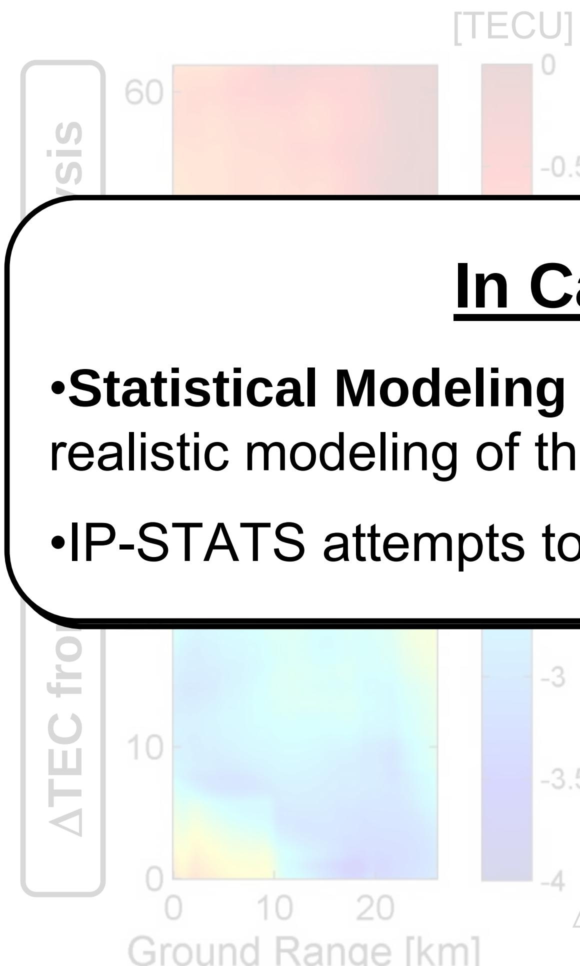
- Ionosphere causes range of effects that can be used for ionospheric mapping

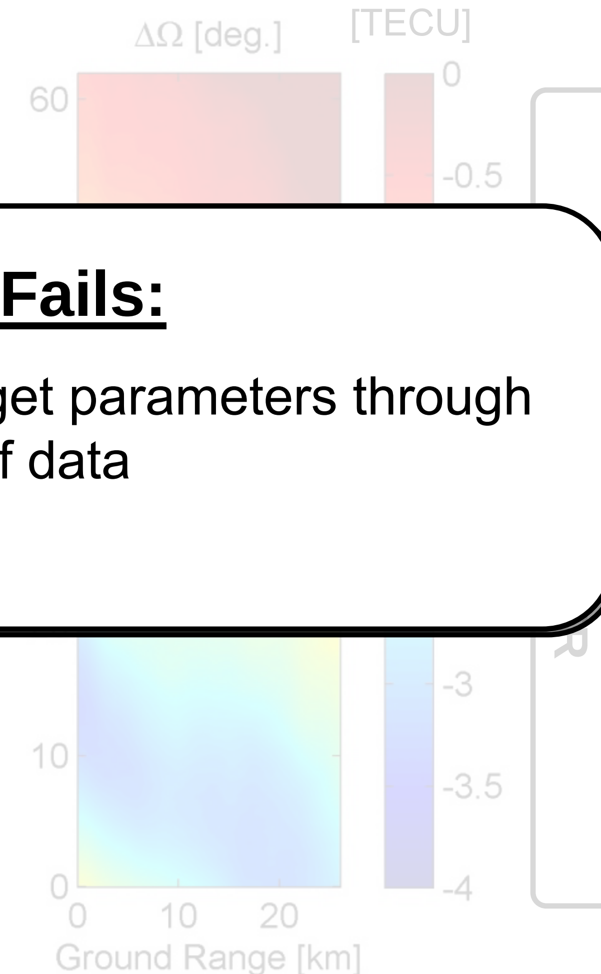


Comparison of Mapping Techniques

Example: Frame 1350 – North Slope, AK

$$\Omega = \frac{K}{f^2} B \cos\theta \sec\chi \cdot TEC$$





<u>In Case Signal Correction Fails:</u>

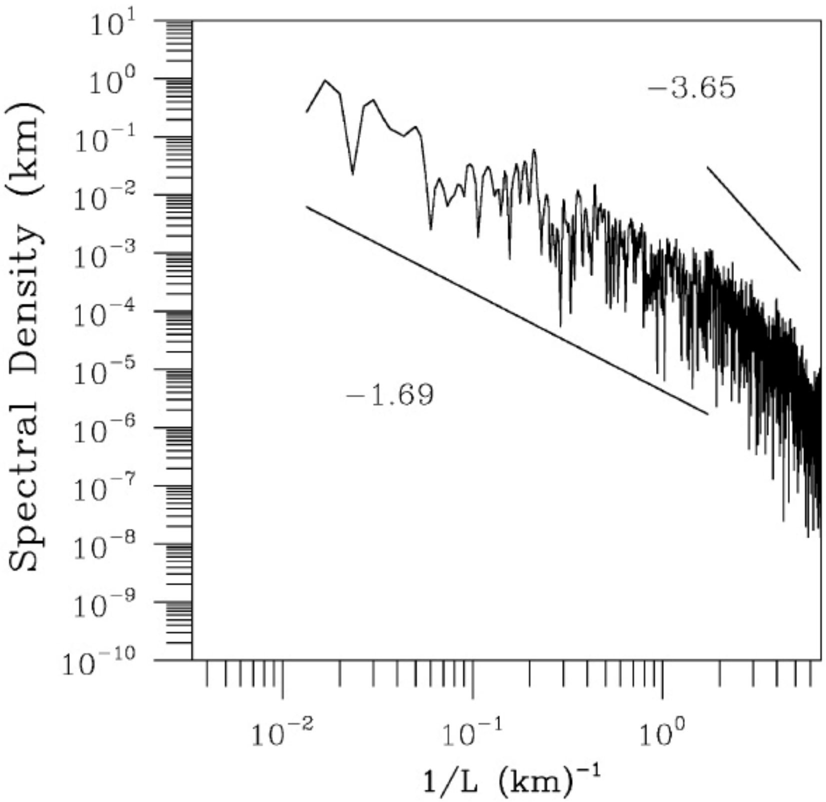
- **Statistical Modeling** mitigates effects on final target parameters through realistic modeling of the accuracy and correlation of data
- IP-STATS attempts to provide such model

$$\Delta TEC = \frac{\frac{1}{f_2}\Delta\phi(f_2) - \frac{1}{f_1}\Delta\phi(f_1)}{\frac{4\pi \cdot K}{c} \cdot \left(\frac{1}{f_1^2} - \frac{1}{f_2^2}\right)}$$

Power Law Model of Small-Scale Ionospheric Signals

- Most small scale variations of ionospheric delay can be described as featureless, scale invariant noise like signals
- Convenient Descriptor: Power Law Functions

$$P_\varphi(k) \propto k^{-v}$$



– Total power of signal
– Distribution of power over spatial scales

– Steep → smooth signal
– Shallow → noisy signal

·5 have been observed

Power Law Model of Small-Scale Ionospheric Signals

- On the convenience of power spectra:
  1. Power Law models can be converted to covariance functions through cosine Fourier Transformation

$$C_\varphi(r) = \int \cos(2\pi f r) P_\varphi(f)\, df$$

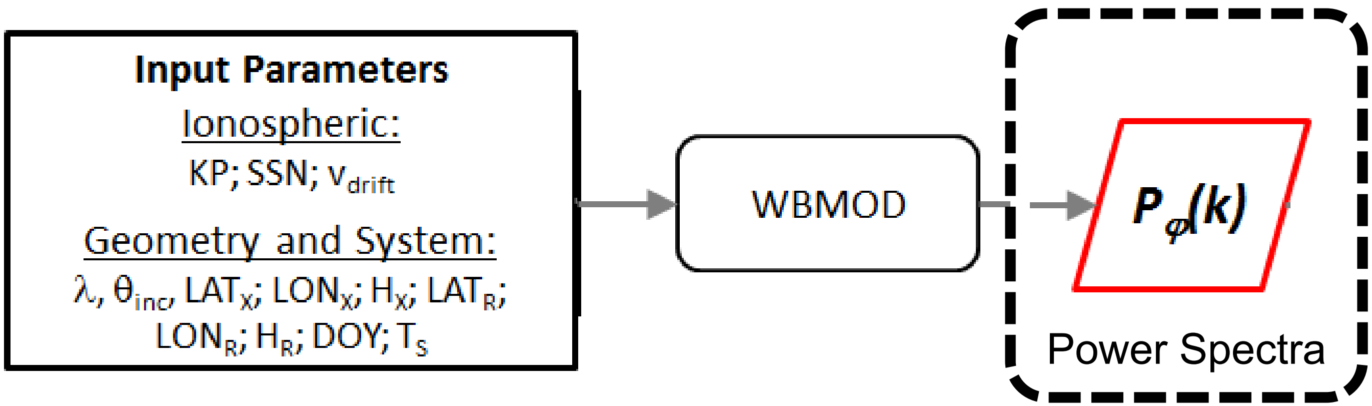
  2. Spectral slopes can be converted to fractal dimensions D

$$v = 7 - 2D$$

→ ***Basis for signal analysis, statistical modeling, signal representation, and simulation***

Predicting Ionospheric Power Spectra

- Representative power spectrum parameters are derived from global ionospheric scintillation model WBMOD (WideBand MODel)
  - WBMOD capable to simulate statistical properties of scintillation effects on user-defined system based on solar activity and system parameters

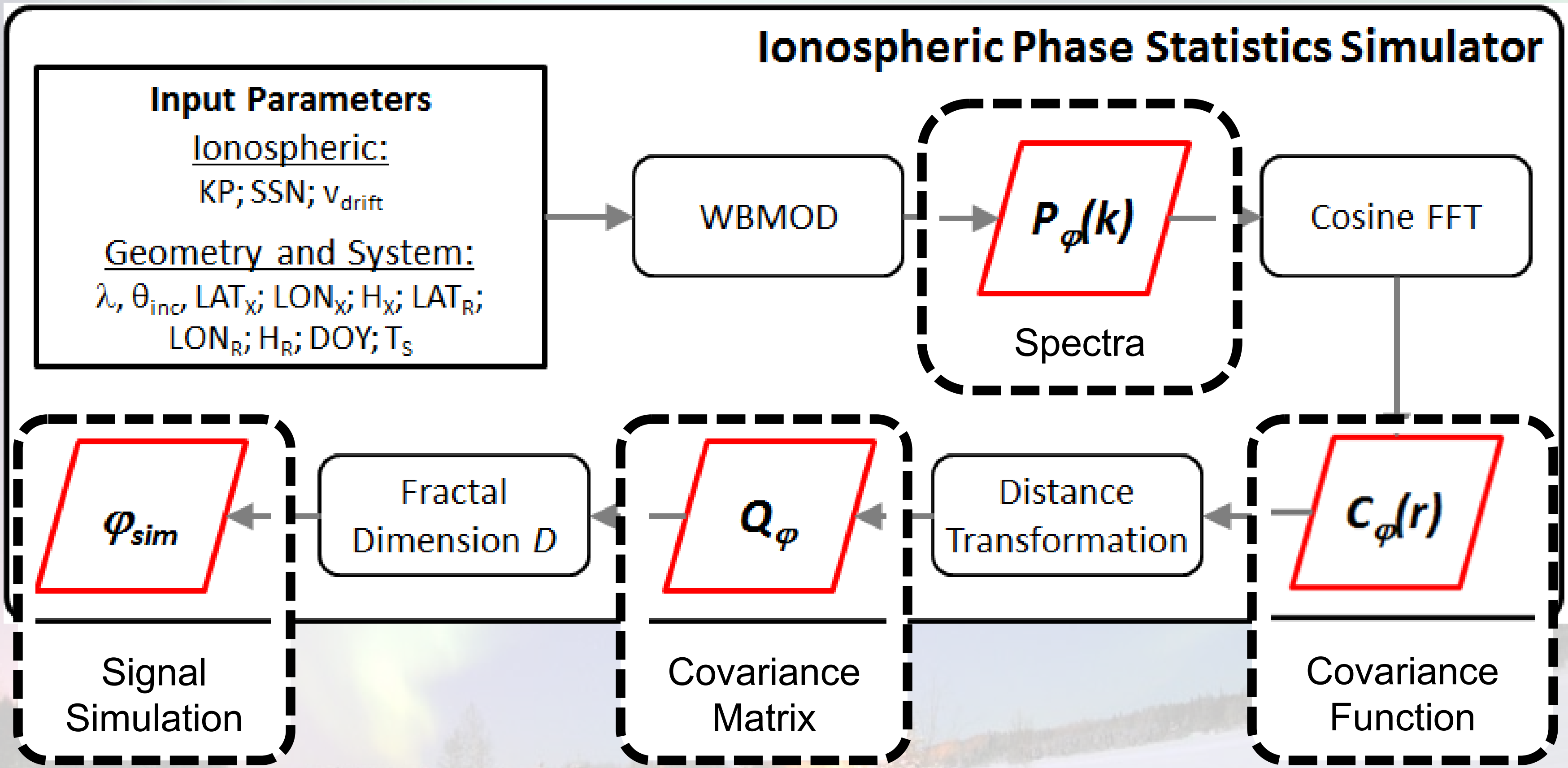


  - Prediction of *single-regime power spectrum parameters* for wide range of systems and ionospheric conditions

E.J. Fremouw & J.A. Secan (1984): Modeling and Scientific Application of Scintillation Results, *Radio Science*, 19(3), pp 687 – 694.

IP-STATS: A System for Describing and Simulating the Ionosphere

- Workflow of the Ionospheric Phase Statistics Simulator (IP-STATS)



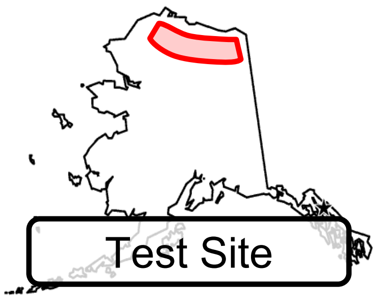
Potential Significance of IP-STATS

- Only dependent on quantifiable ionospheric and system parameters and no requirement for real observations

- Covariance Functions and Matrices:
  - Can support realistic statistical models to be used in parameter estimation

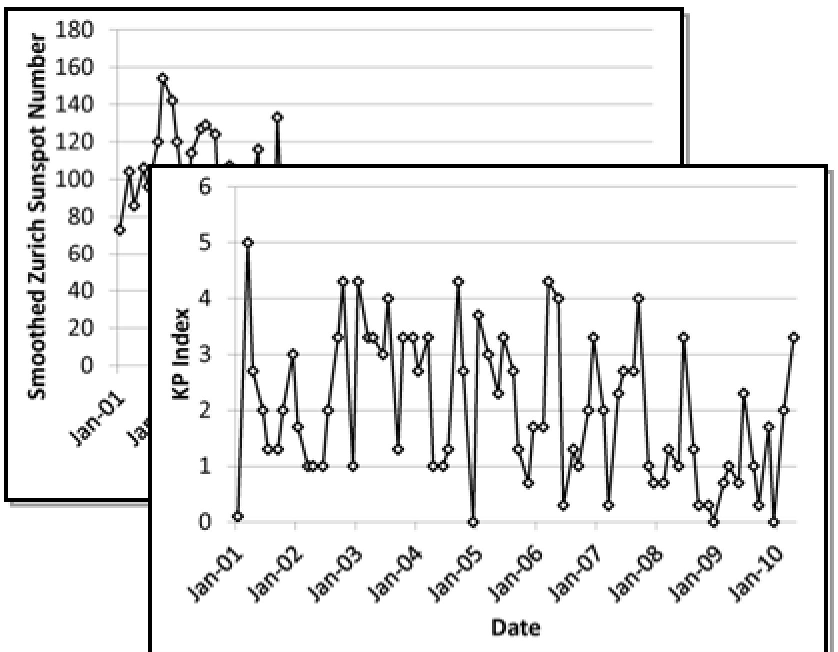
- Phase Simulations:
  - Sensitivity analysis of spaceborne radar systems
  - Useful in System design analysis
  - Selection of best suited radar system for an application

Simulating Ionospheric Conditions for a 10-Year Time Series of SAR Acquisitions over the North Slope of Alaska

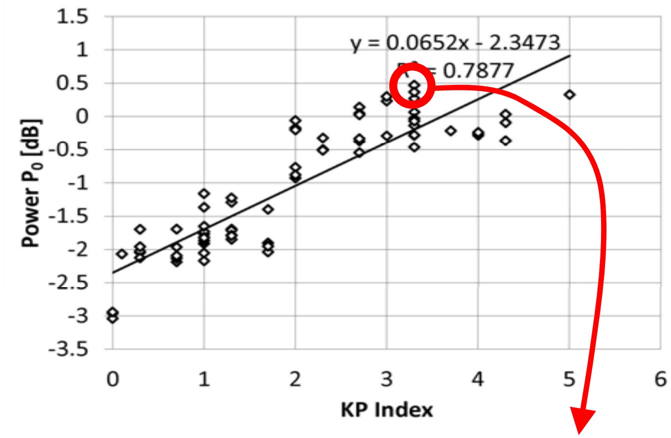


- Data point every 46 days
- Real PALSAR orbit and acquisition parameters

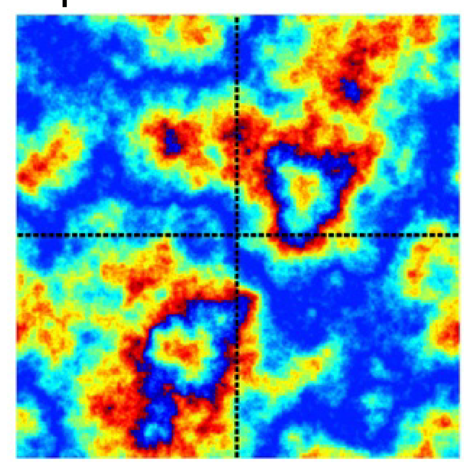
Geophysical Input Parameters



Statistical Ionospheric Descriptors



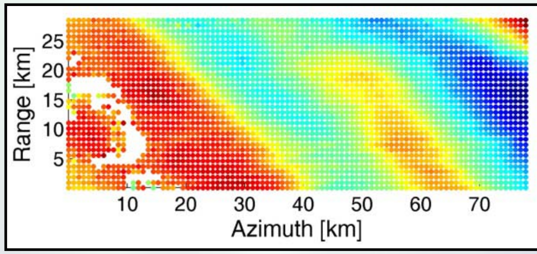
Sample Phase Simulation



Validation of IP-STATS in Polar Regions

- Real data processing:

Faraday Rotation from Quad-Pol SAR



Σ

Signal Variance $\sigma(\phi)$

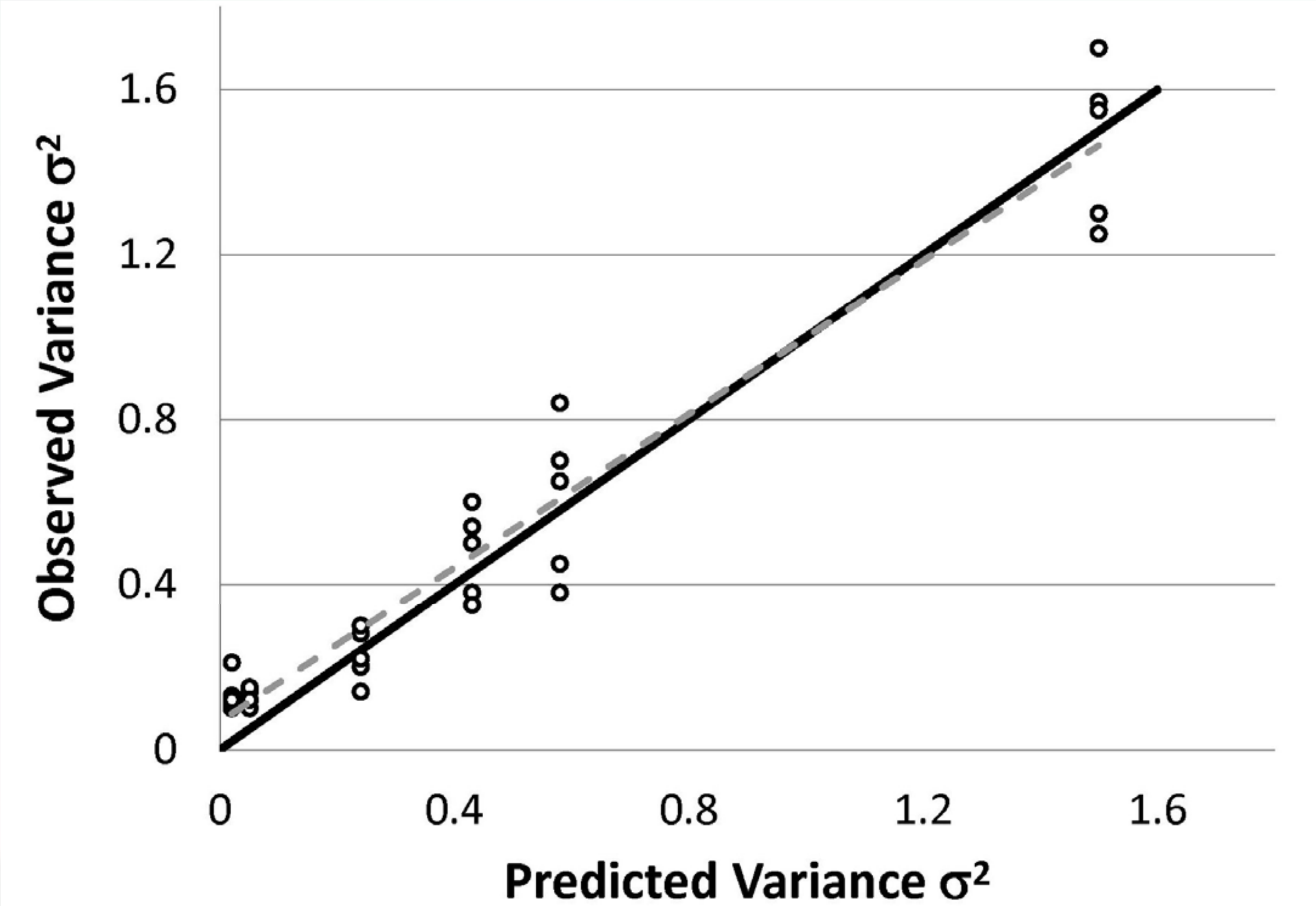
Covariance $C(r)$

- IP-STATS:
  - Ionospheric phase statistics parameter from SAR system parameters, observation geometry, and solar parameters at acquisition time

- COMPARISON:
  - Validation for Auroral Zone conditions

Validation of IP-STATS in Polar Regions

- **Validation of Signal Variance $\sigma(\phi)$:**



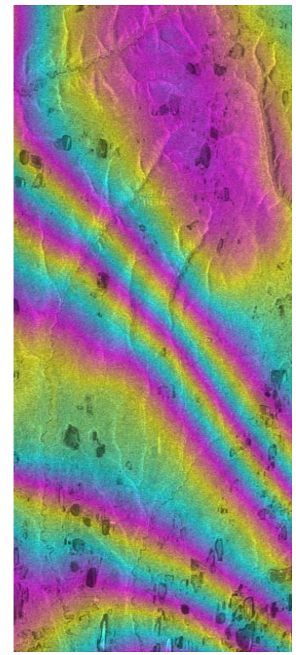
At High Latitudes: Predicted and Measured Signal Variance Matches Well!!

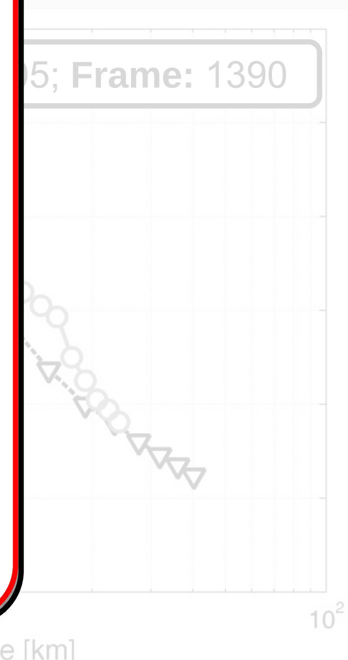
Validation of IP-STATS in Polar Regions

- **Validation of Covariance Function *C(r)* :**
  - **Measured Covariance:** Isotropic signal assumed
  - **Simulated**

Problem: Isotropic signal assumed

Most observed ionospheric signals are NOT isotropic





At High Latitudes: Predicted and Measured Covariance Functions match reasonably well!

Anisotropy Model in IP-STATS

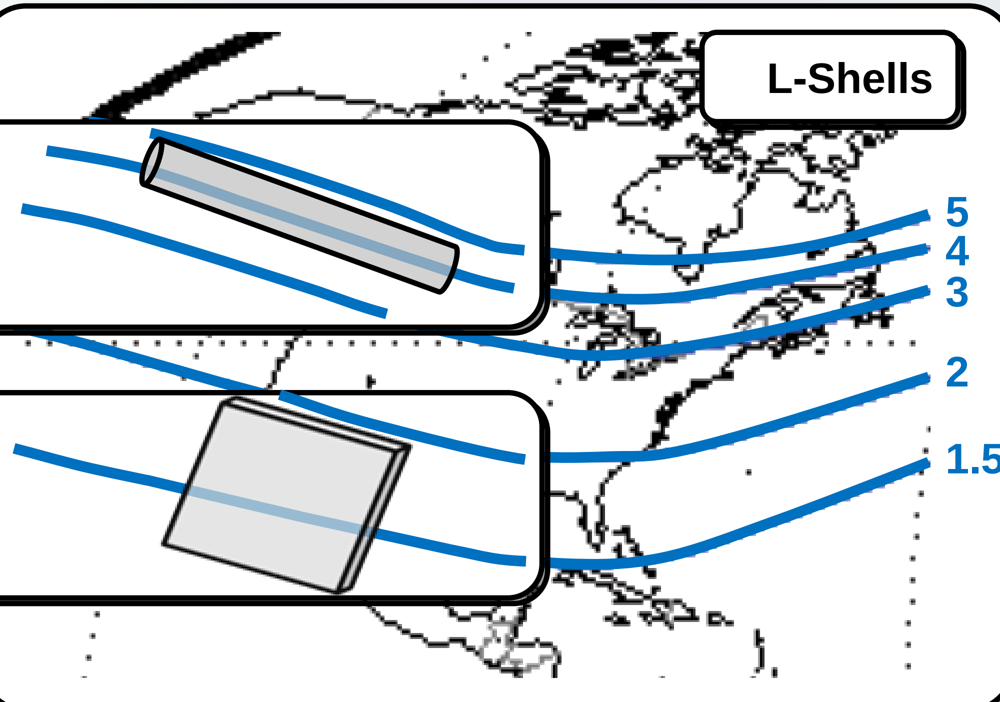
- Current approach – extract information from WBMOD
- Anisotropy approximated by “Correlation Ellipse”:
  - **Shape:** axial ratios a and b (length of axes of correlation ellipse relative to vertical layer thickness thin layer approximation is used)
  - **Orientation:** angle δ relative to local ionospheric L-shell
- Examples:

- **a = 10; b = 1; δ = 0**

Rod-like oriented roughly east-west

- **a = 10; b = 10; δ = 0**

Sheet-like



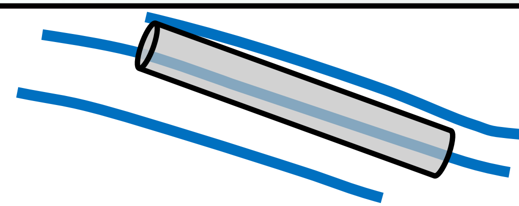
D.G. Singleton (1970): Dependence of Satellite Scintillations on Zenith Angle and Azimuth, *Journal of Atmospheric and Terrestrial Physics*, 32, pp 789 – 803.

Anisotropy Model in IP-STATS

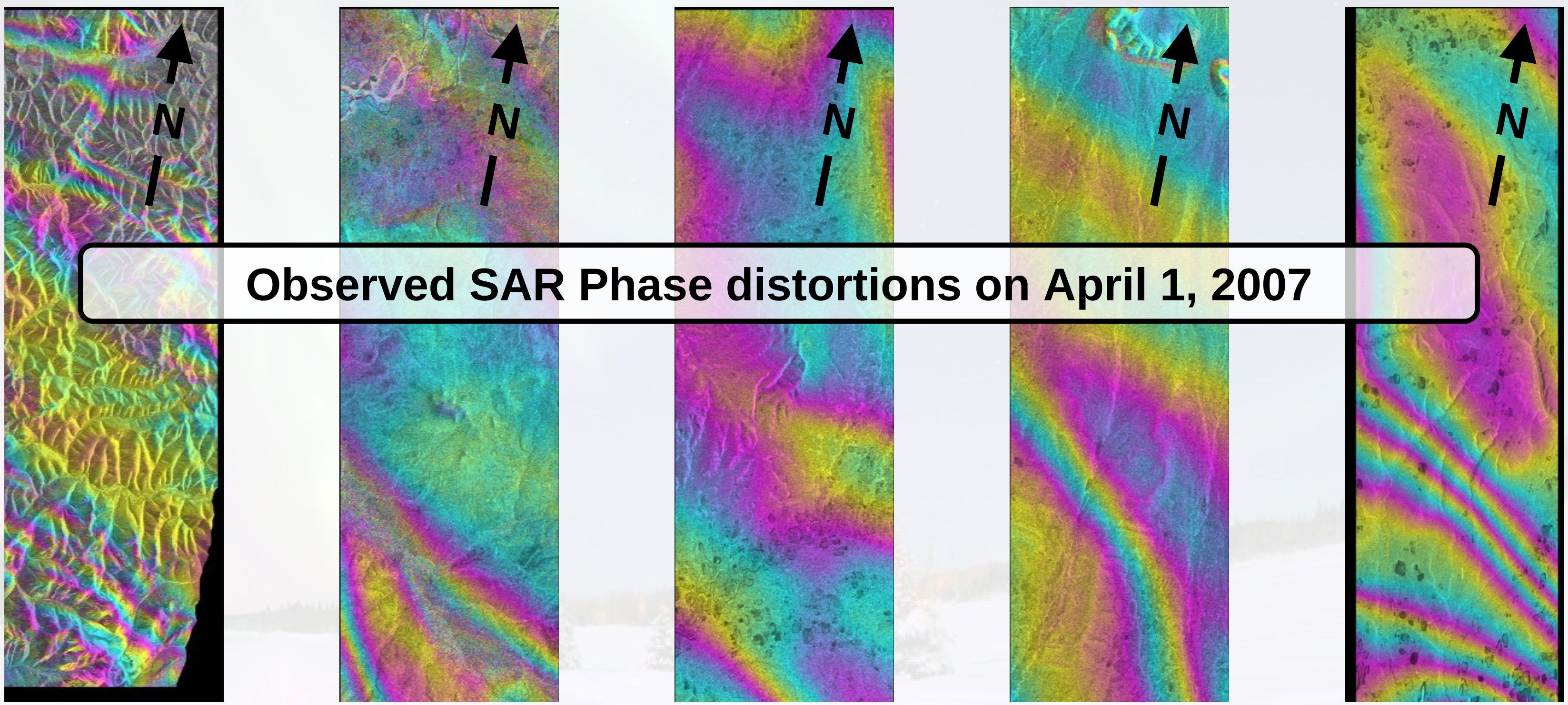
- April 1, 2007:

  - **a = 3; b = 1; δ = 0**

  Rod-like oriented roughly east-west



WBMOD Estimate



Observed SAR Phase distortions on April 1, 2007

Conclusions

- We have shown that:
  - Spaceborne imaging radars are affected by the ionosphere, in particular at times when small scale ionospheric irregularities are likely
  - IP-STATS system models statistical properties of small scale ionospheric irregularities based on power spectra, covariance functions, and fractal dimensions
  - First validations for Polar Regions show good performance of predicting variance and co-variance parameters
- Next steps:
  - Further validation and incorporation of anisotropy are required
  - Investigation of multi-scale power spectra
  - Analysis of ionospheric drift velocities relative to SAR integration time

PALSAR Interferogram Amazon area, Ionospheric Disturbances

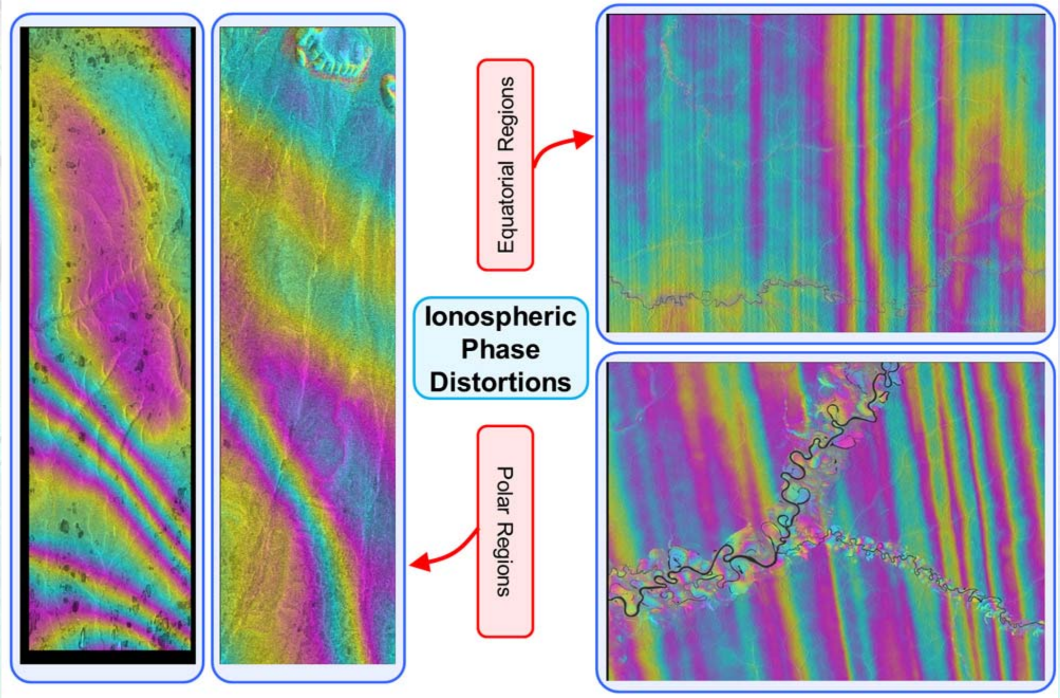
Open Three Year PhD Position

starting fall 2011 / spring 2012 for a radar remote sensing research project at the Geophysical Institute of the University of Alaska Fairbanks on

Theoretical Investigations into the Impact and Mitigation of Ionospheric Effects on Low-Frequency SAR and InSAR Data

Research Focus:

- Investigation of spatial and temporal properties of ionospheric effects in SAR data
- Development of statistical signal models
- Design of optimized methods for ionospheric correction



More information:

Dr. Franz Meyer (fmeyer@gi.alaska.edu) and at: www.insar.alaska.edu

ANNOUNCEMENT:

2011 CEOS SAR Calibration and Validation Workshop

Fairbanks, Alaska

Workshop Dates: **November 7 – 9, 2011**

Abstract Deadline: **October 1, 2011**

More information at:

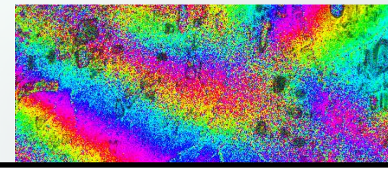
www.asf.alaska.edu/ceos_workshop/

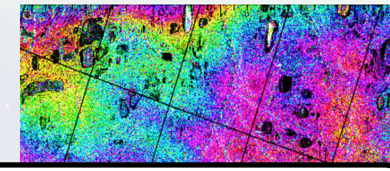
Example of Ionospheric Correction

- Mitigation of ionospheric effects from Faraday Rotation and azimuth-shit estimates

→ reduced phase distortion and

Original phase **Corrected phase**





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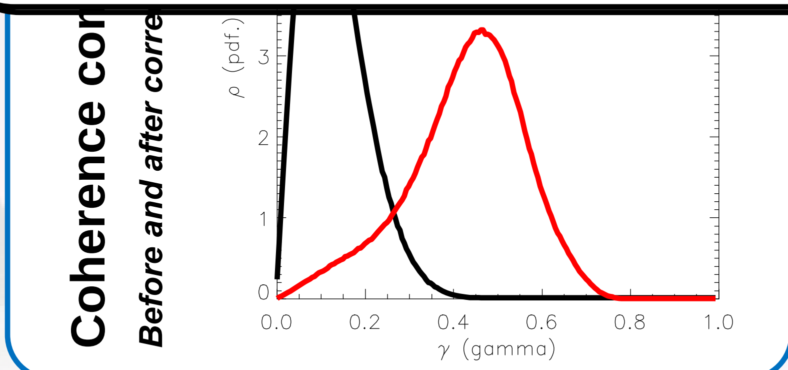

Courtesy of Jun Su Kim, DLR