Developing an Error Model for Ionospheric Phase Distortions in L-Band SAR and InSAR Data

Dr. Franz J. Meyer[1)], Piyush S. Agram[2)]

[1)]*Earth and Planetary Remote Sensing Geophysical Institute, University of Alaska Fairbanks*

[2)]*Jet Propulsion Laboratory (JPL), Pasadena, CA*

UAF Alaska Satellite Facility

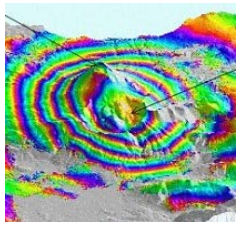
Making remote-sensing data accessible since 1991

JPL

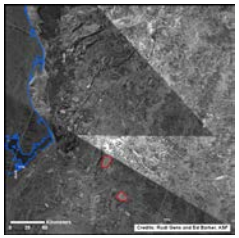
NASA

Geophysical Applications Favor Low-Frequency SAR Systems

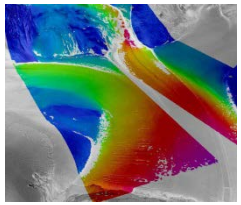
Volcanoes



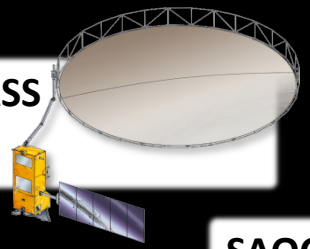
Sea Ice



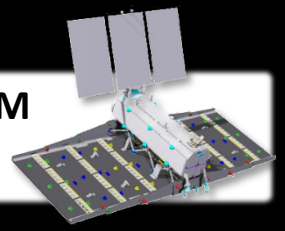
Glaciers & Ice Sheets



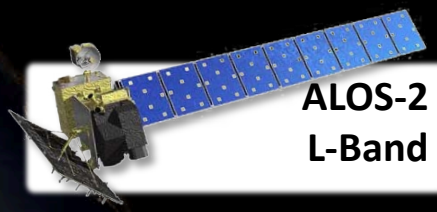
BIOMASS
P-Band



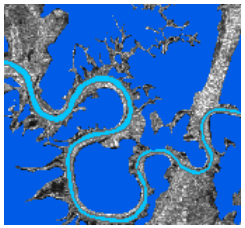
SAOCOM
L-Band



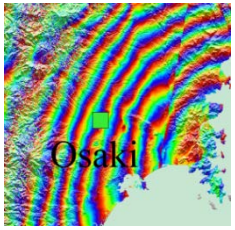
ALOS-2
L-Band



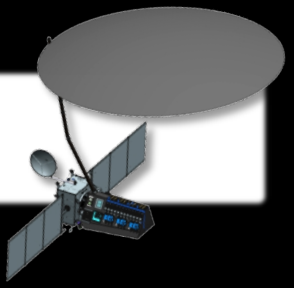
Flooding



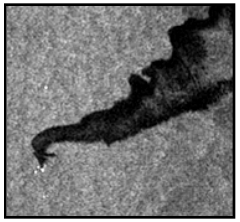
Earthquakes



NISAR
L-Band

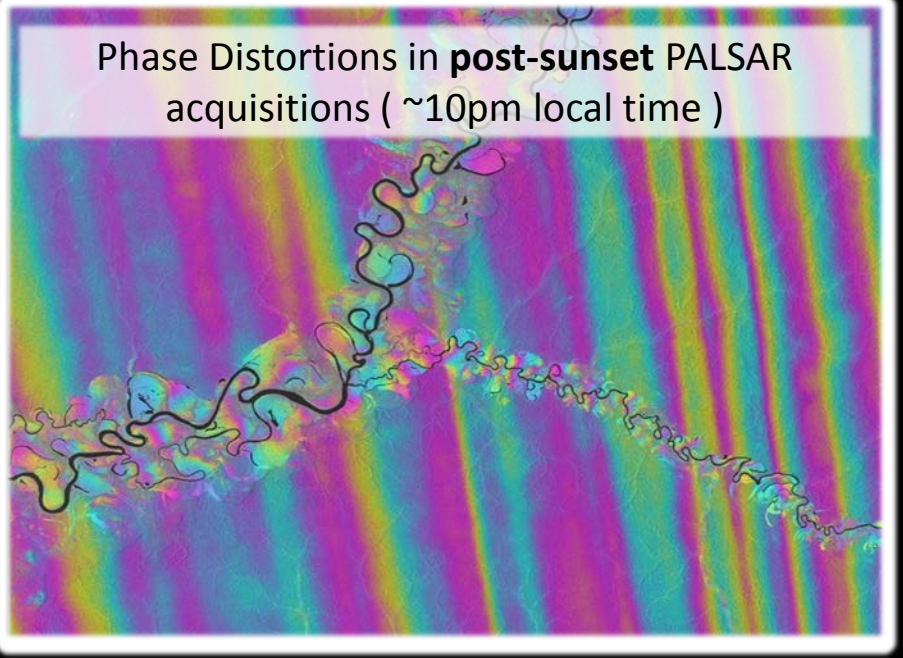


Oil Spills

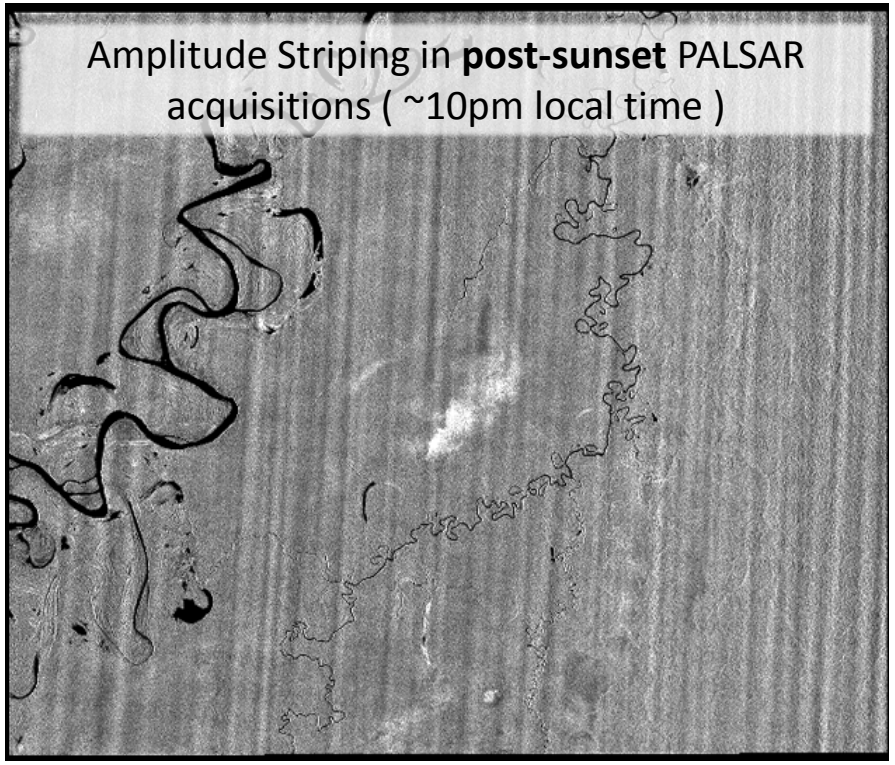


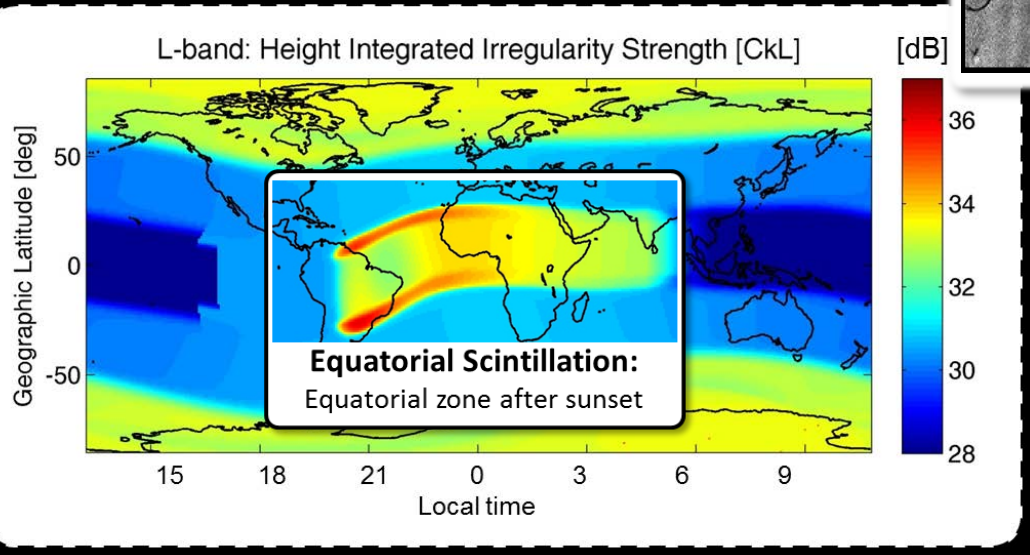
Ionospheric Distortions in Low-Frequency (L-band) SAR

Phase Distortions in **post-sunset** PALSAR acquisitions (~10pm local time)

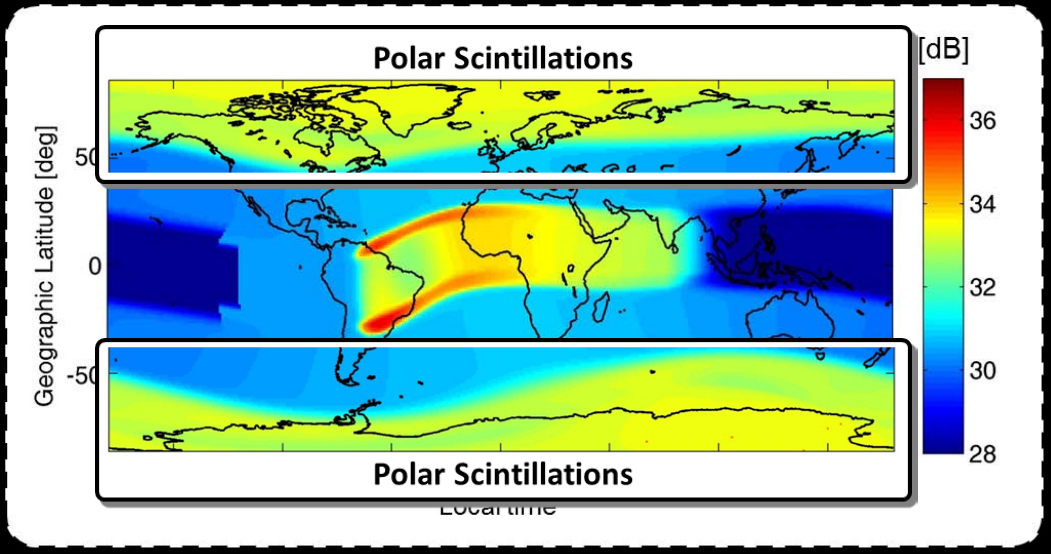


Amplitude Striping in **post-sunset** PALSAR acquisitions (~10pm local time)

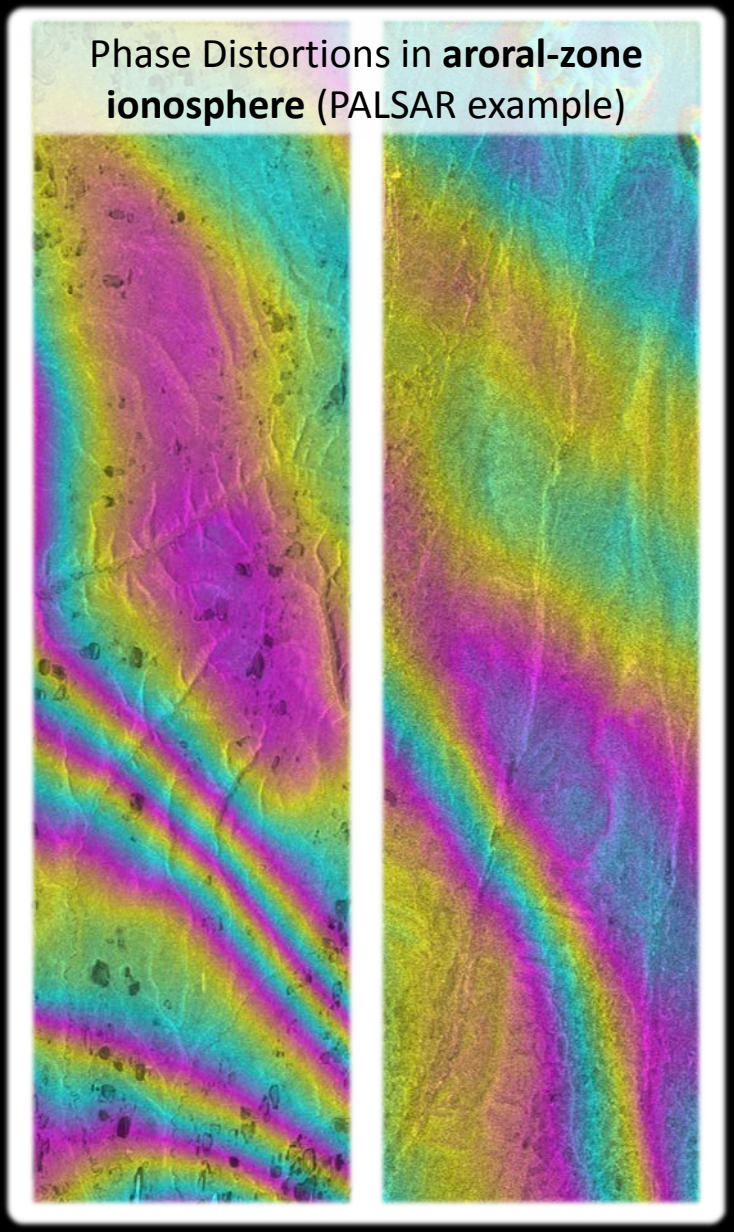




Ionospheric Distortions in Low-Frequency (L-band) SAR



Phase Distortions in **aroral-zone ionosphere** (PALSAR example)



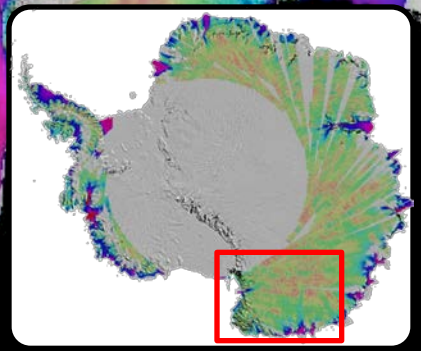
Ionospheric Effects in L-band SAR-based Ice Velocity Measurements

Goal of this work: Develop a global ionospheric error model for

Predicting ionospheric phase noise globally and on image-by-image basis

→Essential for geodetic applications of SAR

→Useful information for mission design



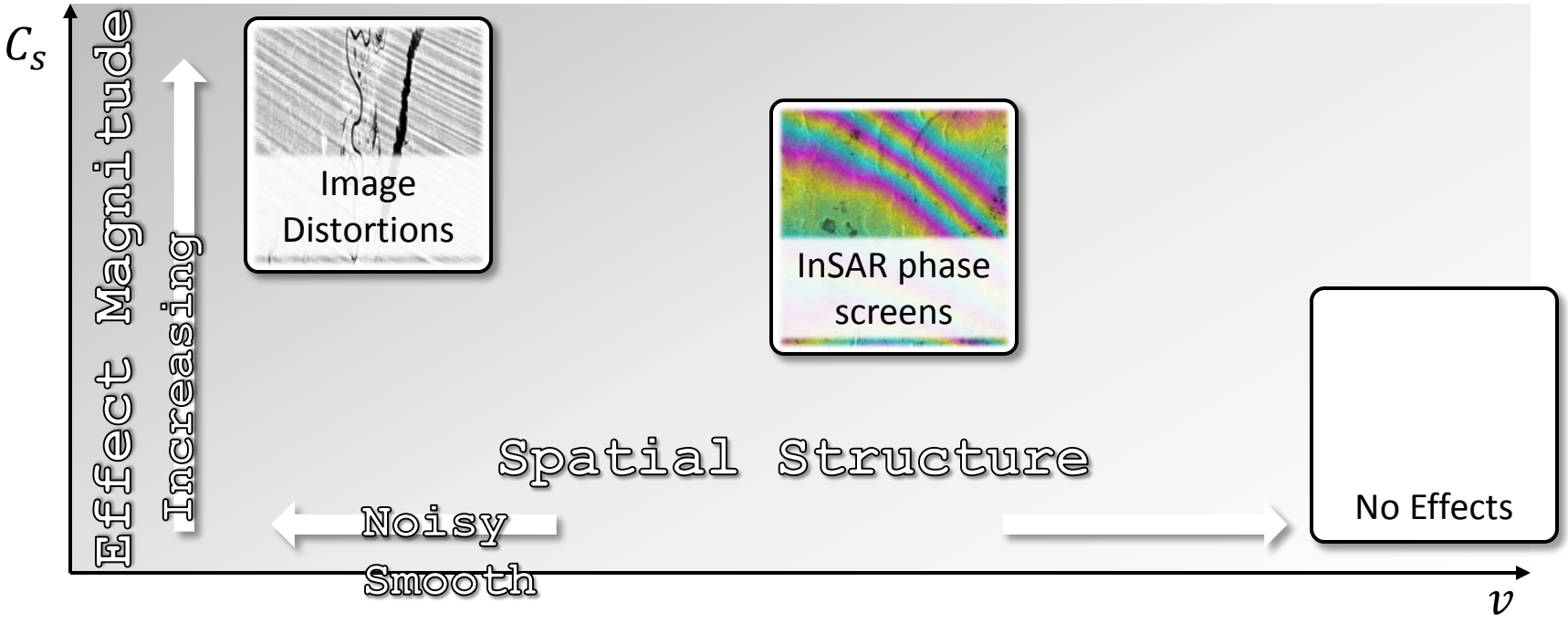
Courtesy: E. Rignot, B. Scheuchl, UCI

Geophysical Origin of Observed Effects

- **Cause:** Ionospheric plasma irregularities due to scintillation
- **Effect:** Scintillation can be modeled using power law considerations

$$Q(k) = \boldsymbol{C_s} \cdot (k_0^2 + k^2)^{-\left(\boldsymbol{v}+\frac{1}{2}\right)}$$

k: spatial wavenumber; C_s: turbulence strength; v: spectral index; k_0: outer scale



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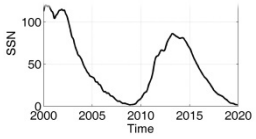
- **<u>Two Step Modeling Concept</u>**:

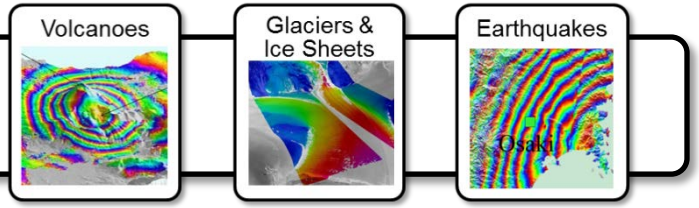
1. **Predict ionospheric structure & calculate SAR phase power spectra**

globally  + time 

= **Full characterization of ionospheric properties**
(1) for each data take and (2) across mission lifetime

2. **Propagate to phase variance & surface deformation errors**

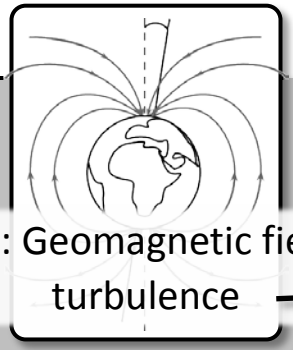
Determine effects on various earth science disciplines:



Deriving Ionospheric Phase Power Spectra

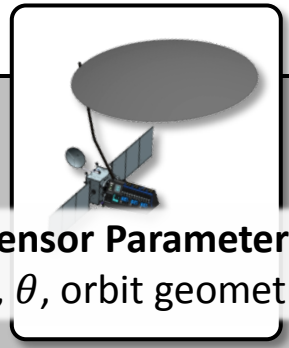
Approach 1: Using Ionospheric Model WBMOD

- **Concept:**

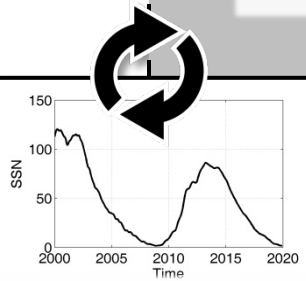


k_p: Geomagnetic field turbulence

SSN: Solar activity



Sensor Parameters: λ, θ, orbit geometry

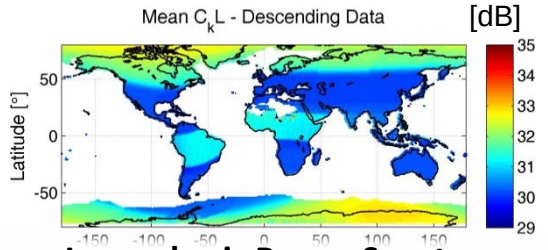


Monte Carlo Simulation
across 1 solar cycle

WBMOD (Wide Beam MODel)

Climatological ionospheric model based on observations and models

Rino & Ishimaru, Radio Science 27, 1992

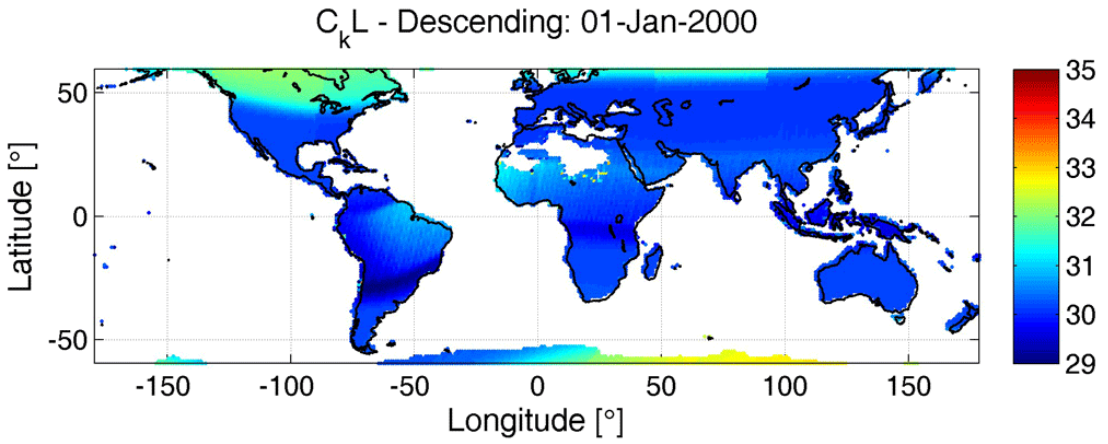


Ionospheric Power Spectra
in magnetic field coordinate system

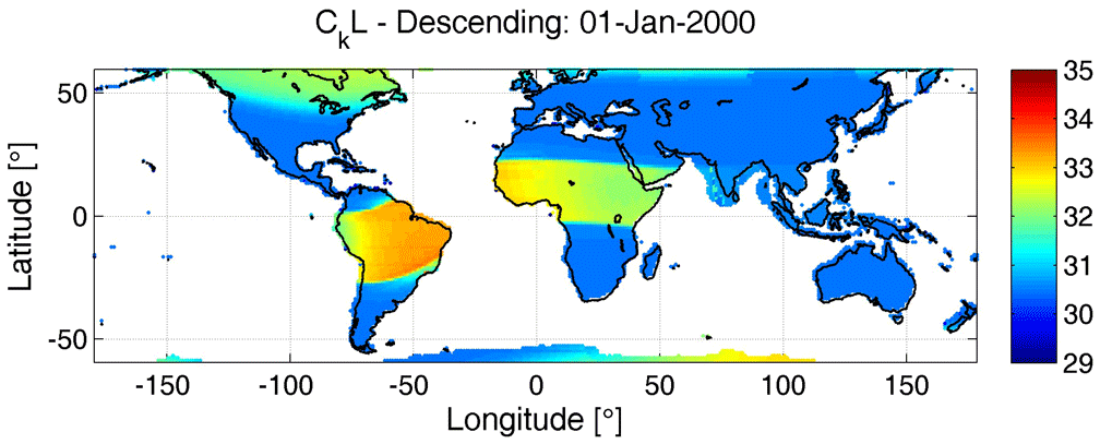
Deriving Ionospheric Phase Power Spectra
Approach 1: Using Ionospheric Model WBMOD

- **Mission-spanning simulations:**
  - Frame-by-frame acquisition simulation every 5th cycle using satellite orbit information.
  - Retrieval of relevant ionospheric parameters per frame and Averaging per $1 \times 1°$ grid cell

NISAR CASE - DESCENDING
acquisition time: 6pm

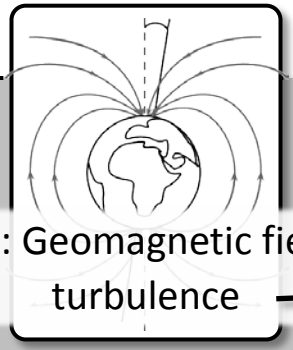


ALOS-2 CASE - DESCENDING
acquisition time: 12am



Deriving Ionospheric Phase Power Spectra
Approach 1: Using Ionospheric Model WBMOD

- **Concept:**



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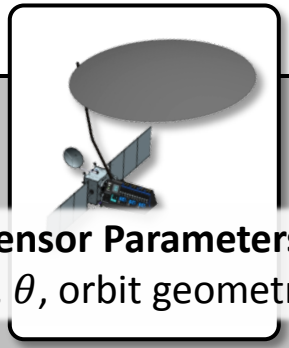

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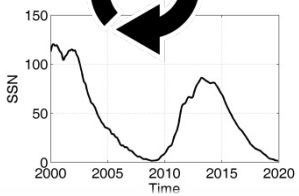

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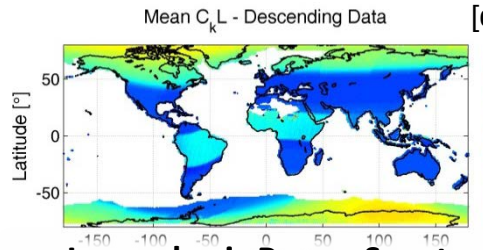
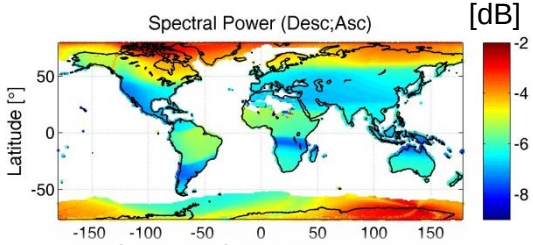


Ionospheric Power Spectra
in magnetic field coordinate system

Projection into SAR Geometry

Meyer et al., 2014; Proceedings of EUSAR

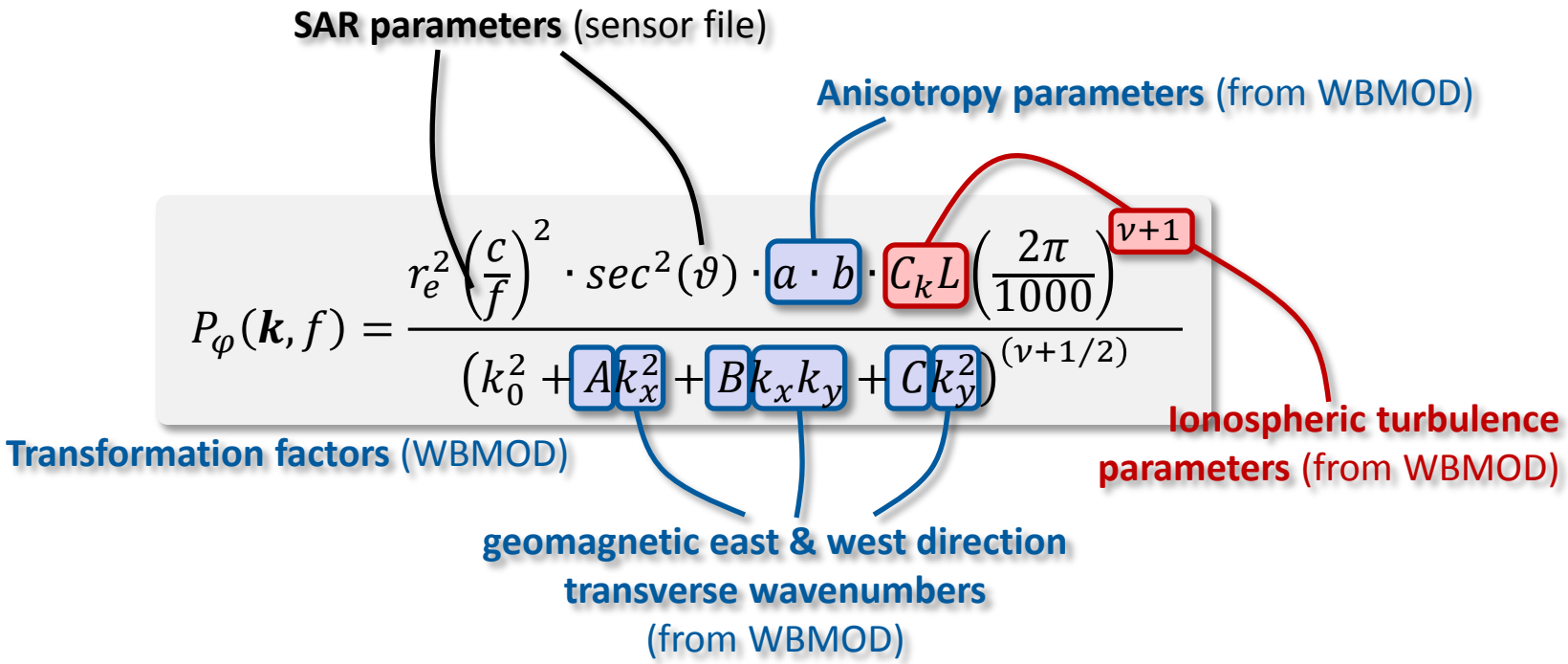


Ionospheric Phase Power Spectra
in SAR image geometry

Deriving Ionospheric Phase Power Spectra

Approach 1: Using Ionospheric Model WBMOD

- **Transformation of ionospheric parameters into SAR phase power spectrum:**



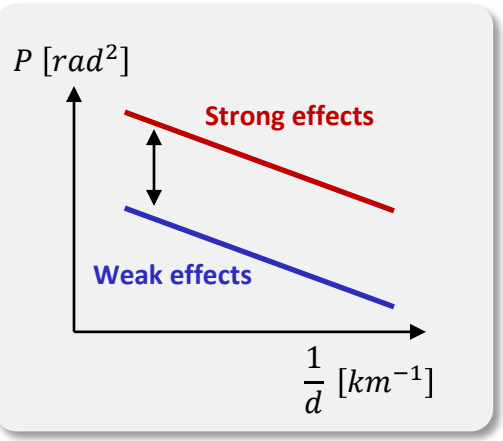
- **Calculate average phase power spectrum parameters for mission lifetime**

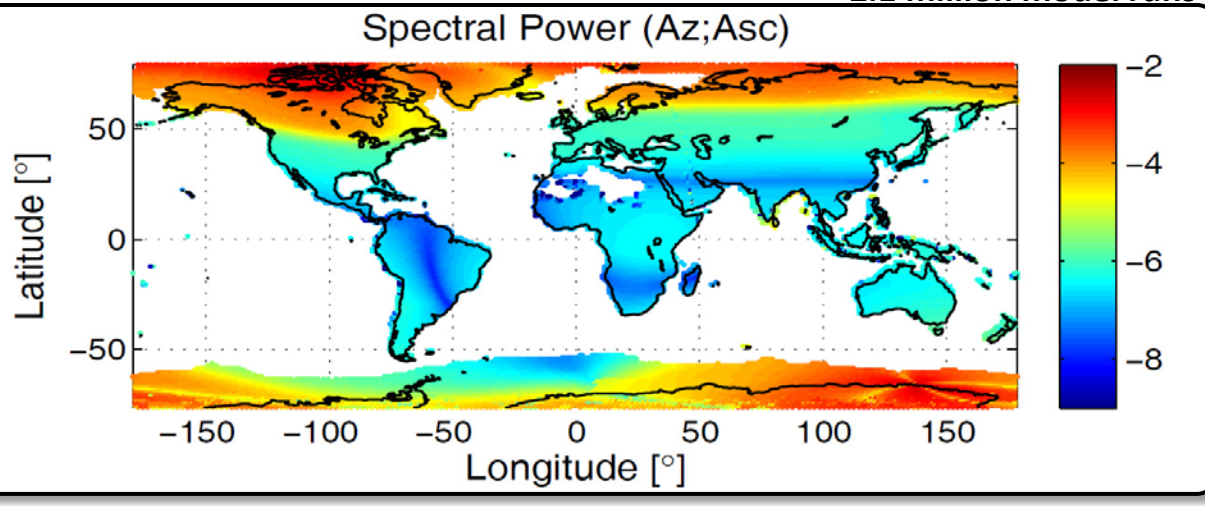
Deriving Ionospheric Phase Power Spectra

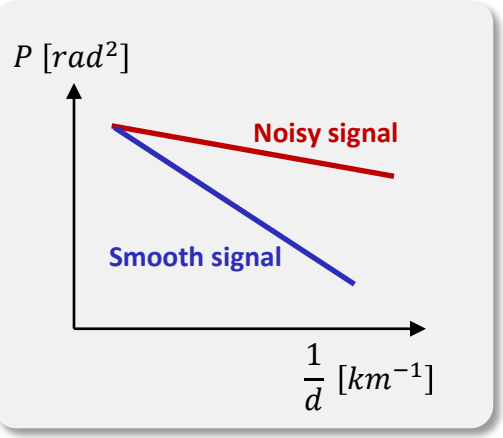
Approach 1: Using Ionospheric Model WBMOD

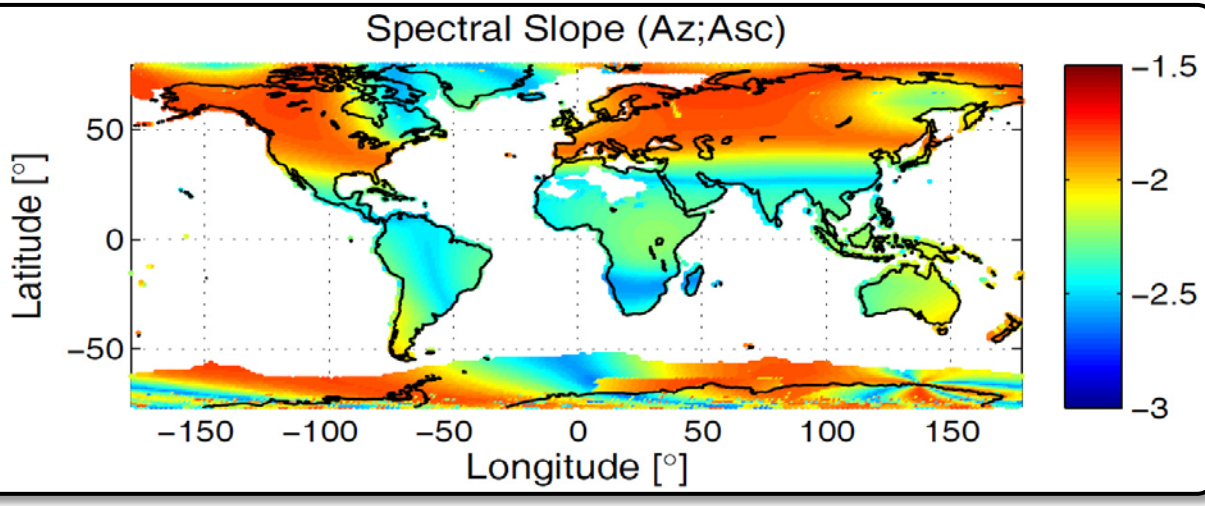
- **Results: Ionospheric Phase Power Spectra in NISAR Data (Azimuth Direction)**

2.1 million model runs





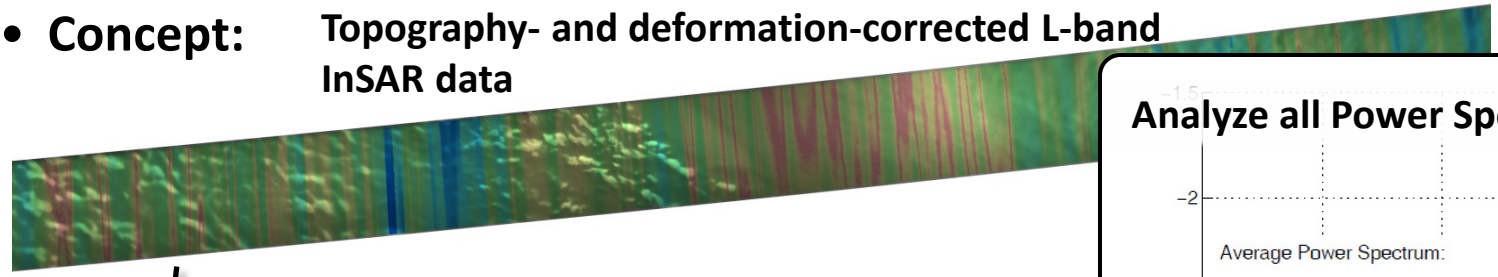




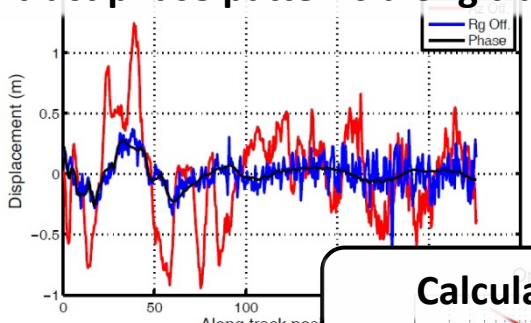
Deriving Ionospheric Phase Power Spectra

Approach 2: Analysis of Available L-band SAR Archives

- **Concept:** Topography- and deformation-corrected L-band InSAR data

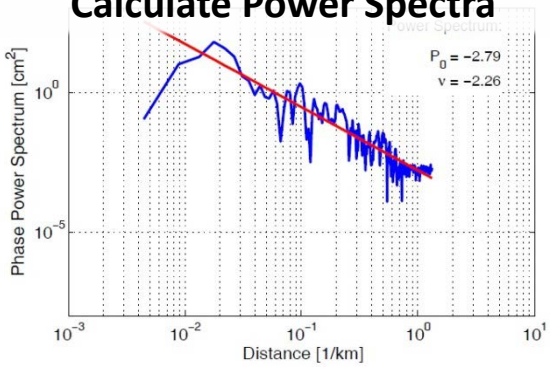


Extract phase patterns along track

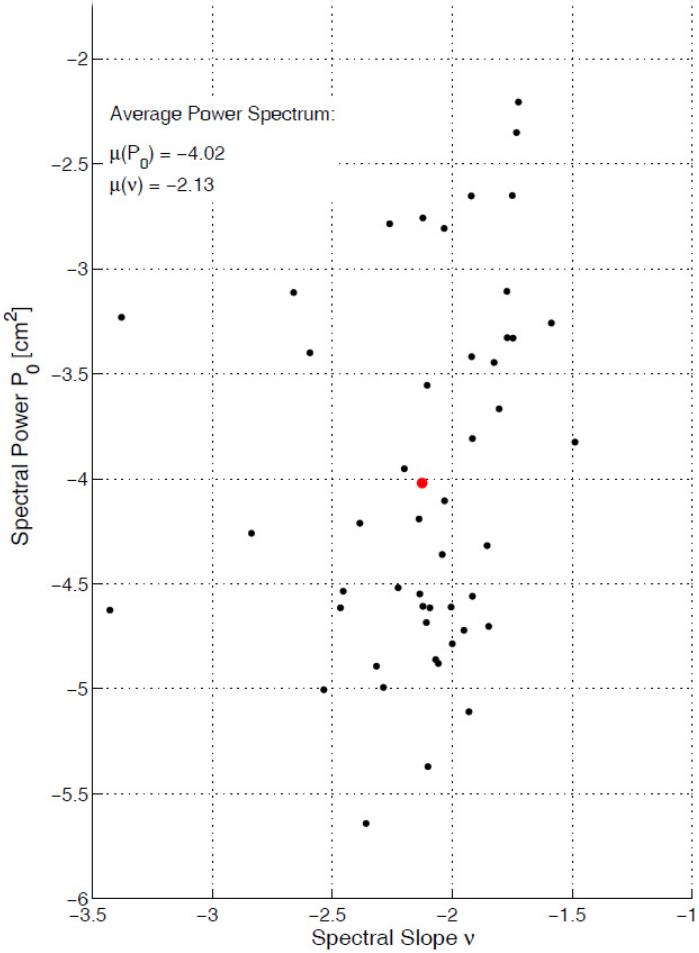


Hundreds of data takes over Greenland & Alaska

Calculate Power Spectra

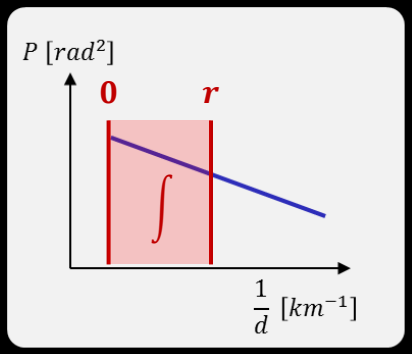


Analyze all Power Spectra Statistically



Calculating Ionosphere-Induced Errors in Deformation Estimates

Single Interferogram Analysis – The NISAR Case



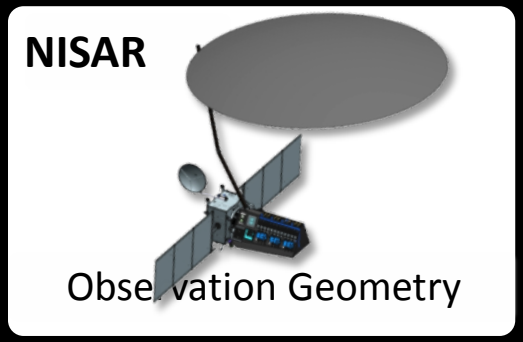
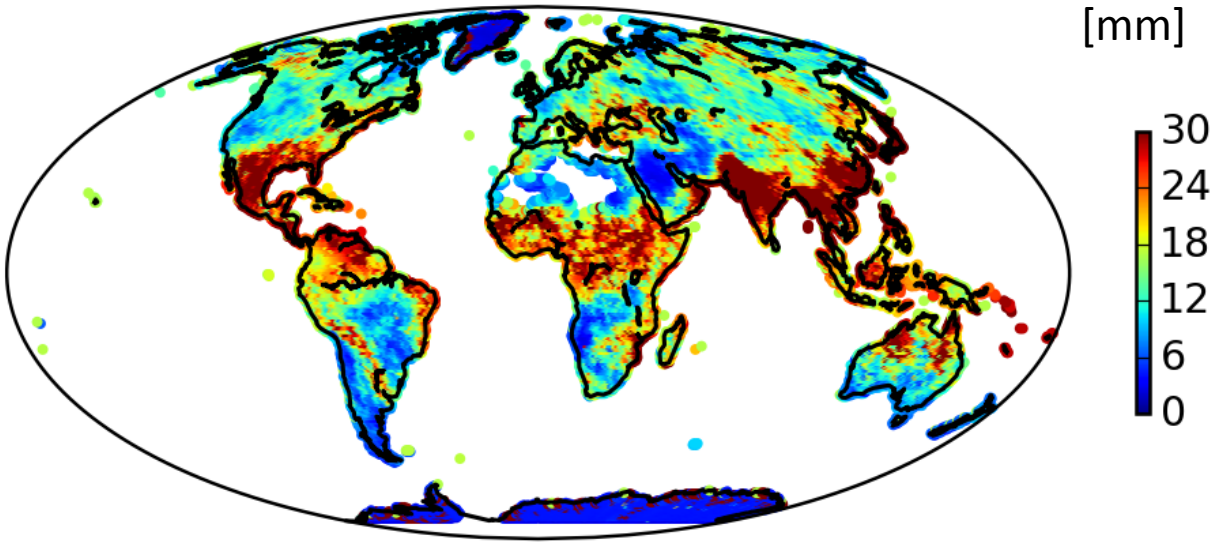


Image-by-Image Error Model ($r = 50km$)

Troposphere-only @ 50km scale



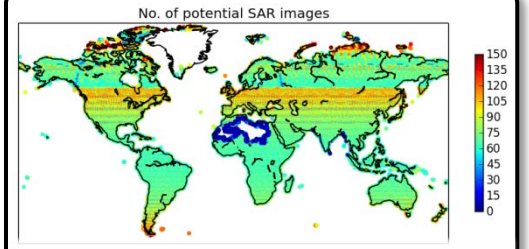
Typical Summer-time conditions

Tropospheric errors from MODIS analysis (Yun et al., AGU abstract G42A-02, 2014)

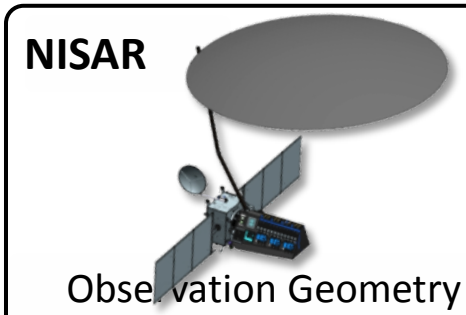
Calculating Ionosphere-Induced Errors in Deformation Estimates

Stack Processing – The NISAR Case

Coherence Model



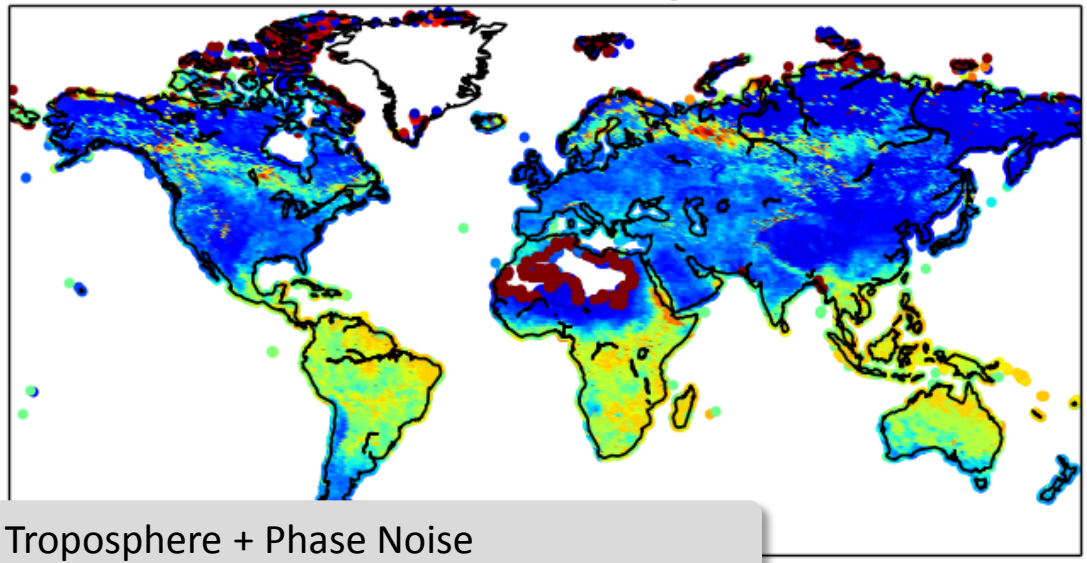
Number of available images



Observation Geometry

SBAS InSAR Model

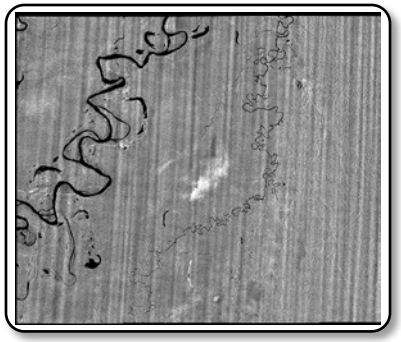
Stack-based Deformation Error



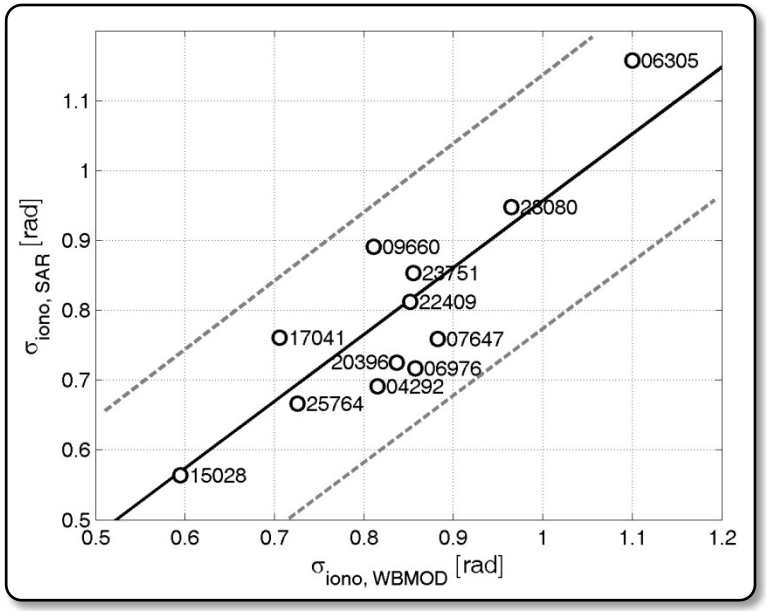
Troposphere + Phase Noise

Output of JPL NISAR Performance Tool (Agram & Simons, JGR, accepted for publication)

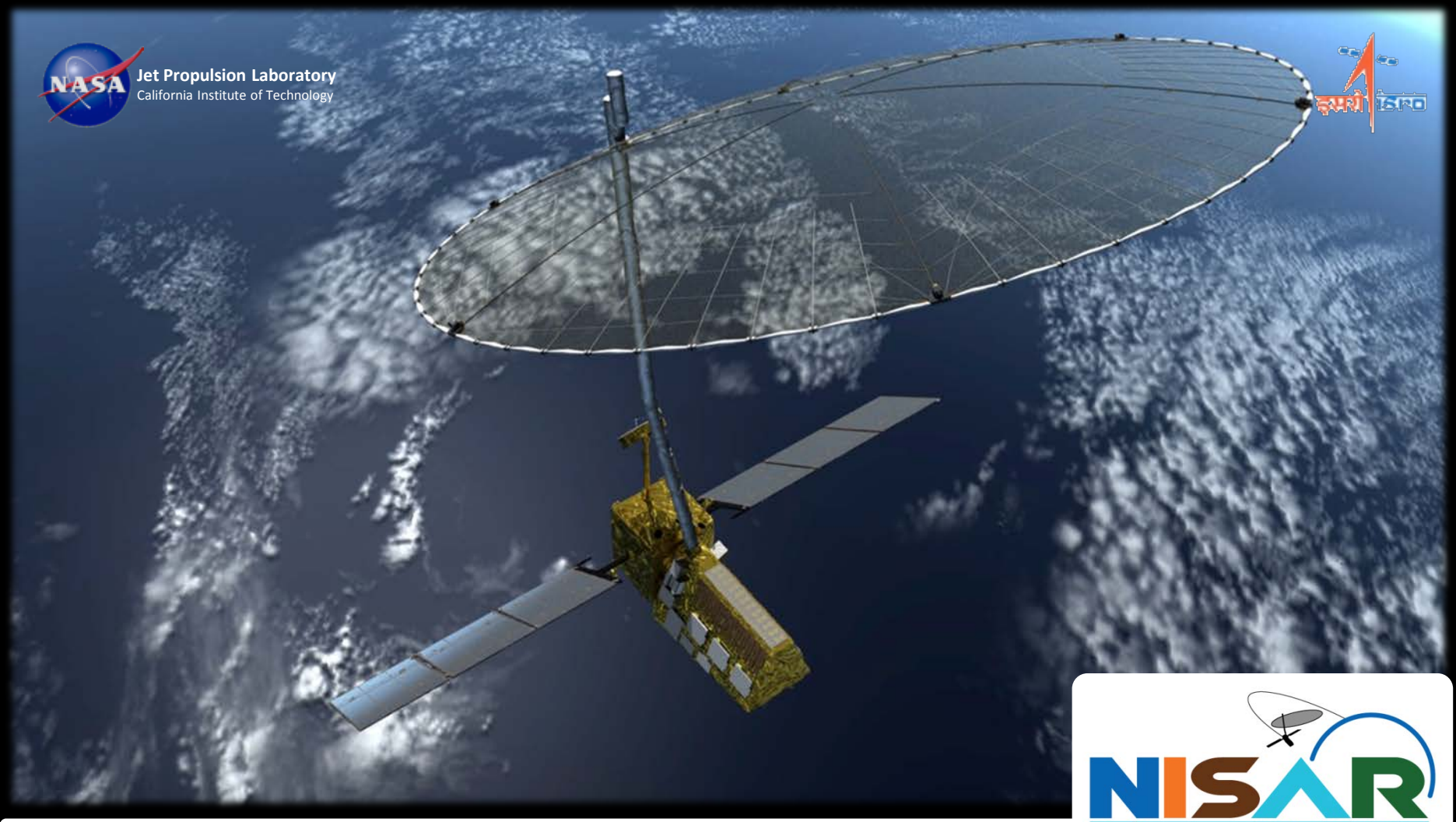
Conclusions



- **Ionospheric effects are an issue in low-frequency SAR data**
- **A global ionospheric error model was developed that can be used in**
  - **Sensor and mission design**
  - **Image-by-image error analysis**
- **First model validation results indicate validity of the model**
- **Model was applied to NISAR mission; largest ionospheric influence in polar regions**



Thank you for your attention!



Funding provided by: NASA ROSES Grant No. NNX12AO29G

Contact: fjmeyer@alaska.edu URL: insar.alaska.edu

NISAR
NASA - ISRO SAR Mission