

# Geolocation of the ionospheric scintillation in the equatorial F-layer from COSMIC-2

- 1) Principles and numerical modeling
- 2) Back propagation of real signals
- 3) Processing of COSMIC-2 data

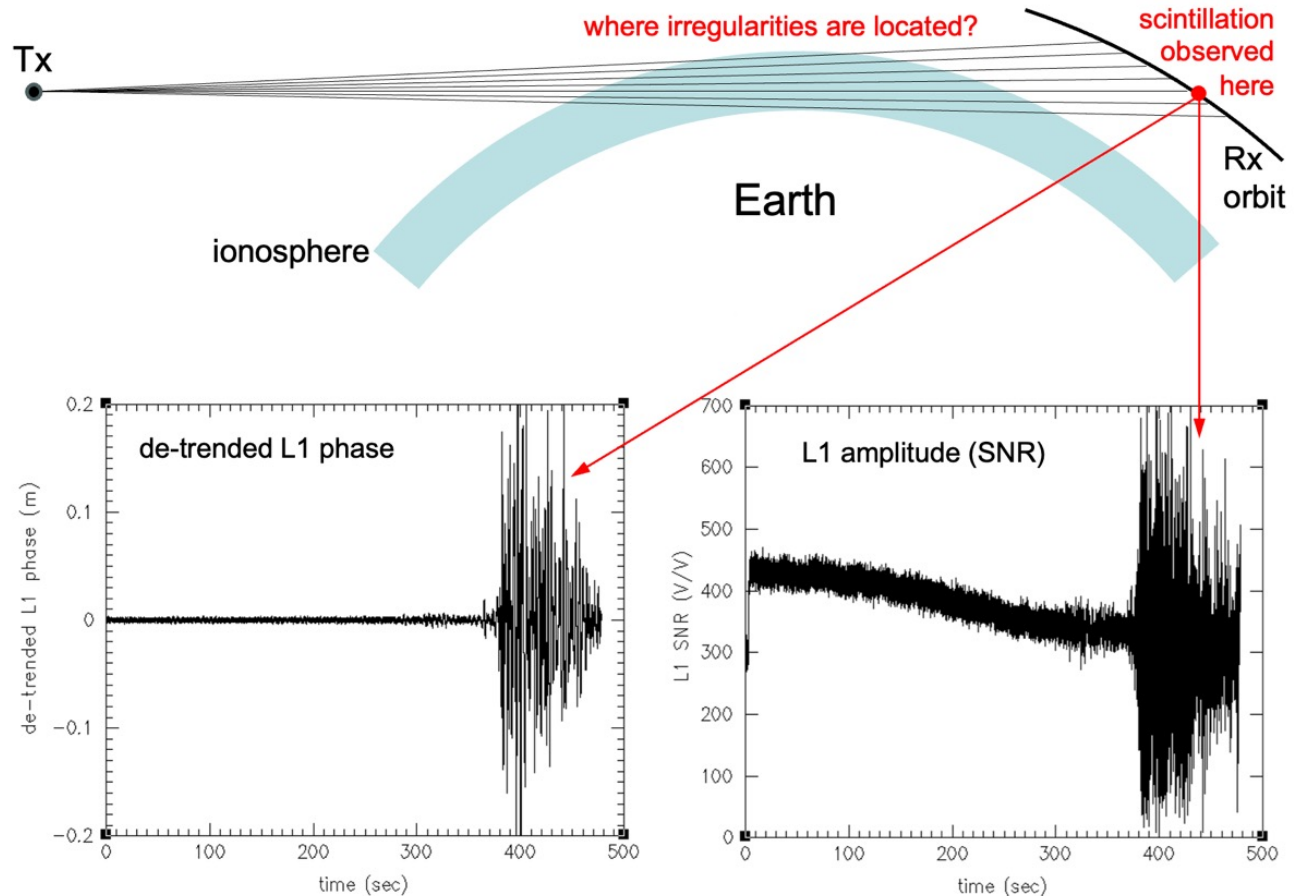
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<sup>1</sup> *University Corporation for Atmospheric Research, Boulder, CO*

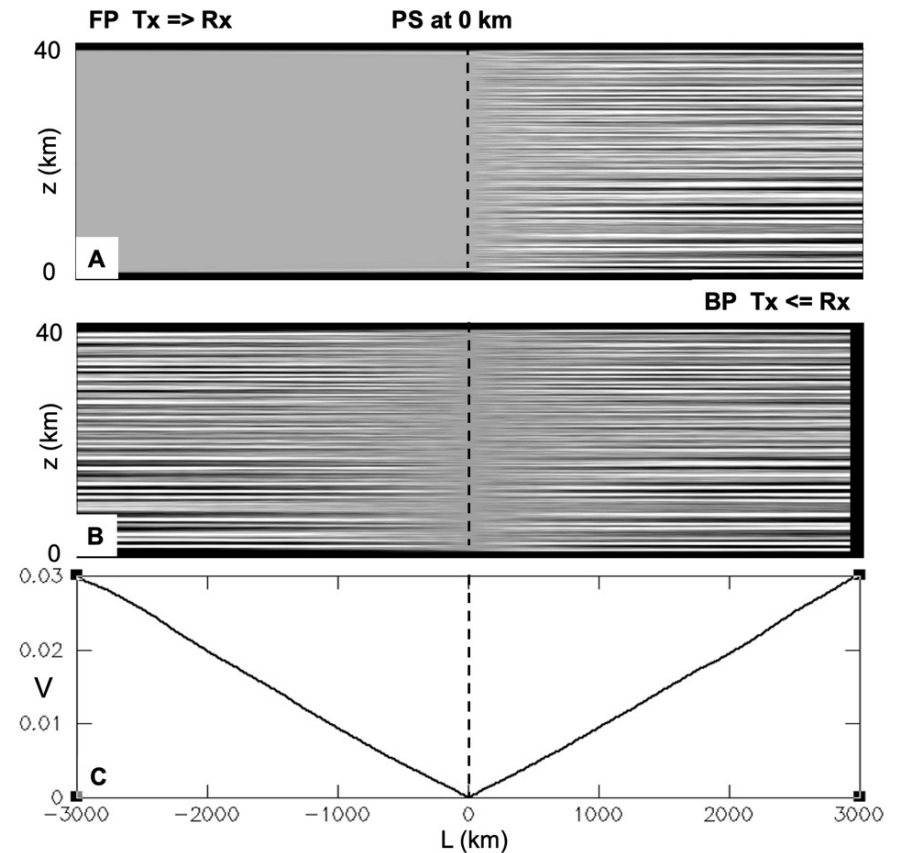
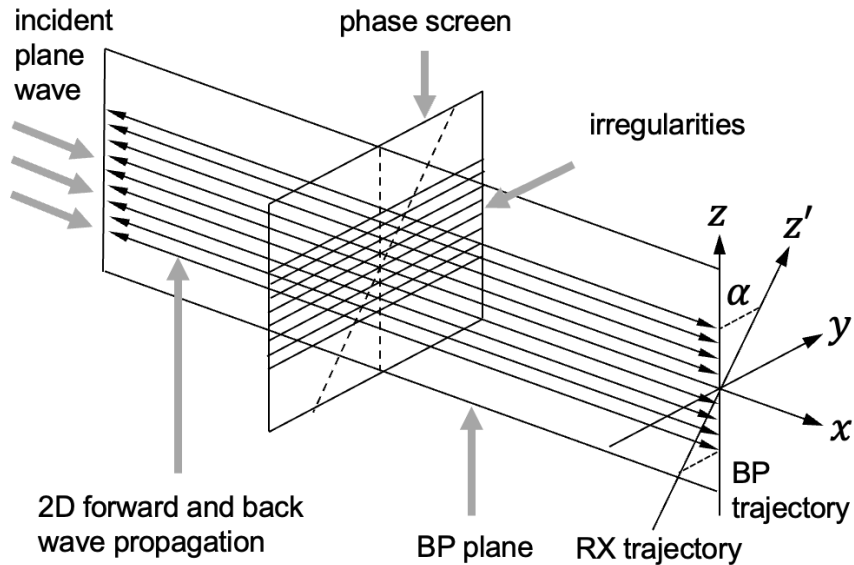
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**COSMIC/JSDA Workshop and IROWG-10 Meeting, Boulder CO, September 12-18, 2024**

- Scintillation is caused by different mechanisms
- Equatorial ionosphere: field-aligned irregularities inside plasma bubbles
- Different methods considered for localization (Carrano et al.)
- Back propagation (BP): solving wave equation in a vacuum by using phase and amplitude at Rx as the boundary condition
- Assumptions & approximations:
  - phase screen approximation
  - anisotropic irregularities
  - known orientation



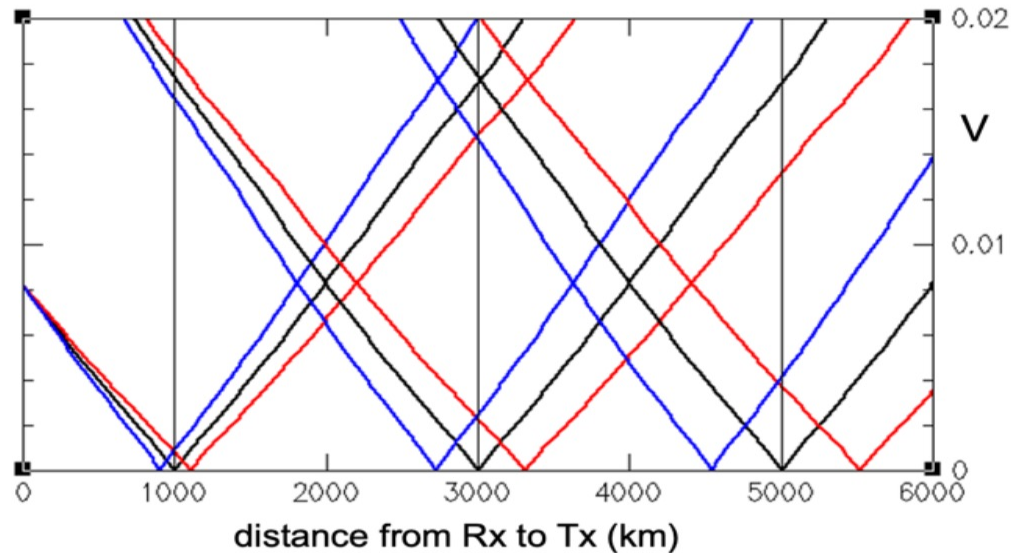
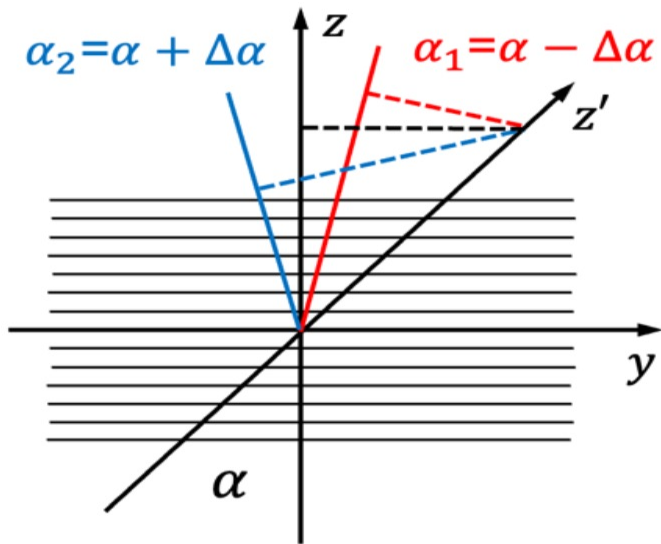
- The signal is observed on 1D Rx trajectory: BP is 2D.
- Thus, the irregularities projected on the phase screen must be 1D.
- This allows projecting signal from any Rx trajectory on the BP plane defined perpendicular to irregularities on the phase screen.



**Important parameters:** Scan angle  $\alpha(L)$ ;  
 Normed amplitude variance  $V(L)$

- Projection of the signal from Rx to BP trajectory is equivalent to scaling  $z$  by a factor  $\cos \alpha$
- Error  $\Delta\alpha$  results in the geolocation error which also depends on  $\alpha$  and distance from Rx to irrerg.
- IGRF model is accurate to  $\sim 1\%$  90% of the time (Matteo and Morton, 2011)

$\Delta\alpha = 0.6^\circ$	$\alpha = 15^\circ$	$\alpha = 45^\circ$	$\alpha = 75^\circ$
L=1000km	6 km	21 km	78 km
L=3000km	17 km	63 km	235 km
L=5000km	28 km	105 km	392 km



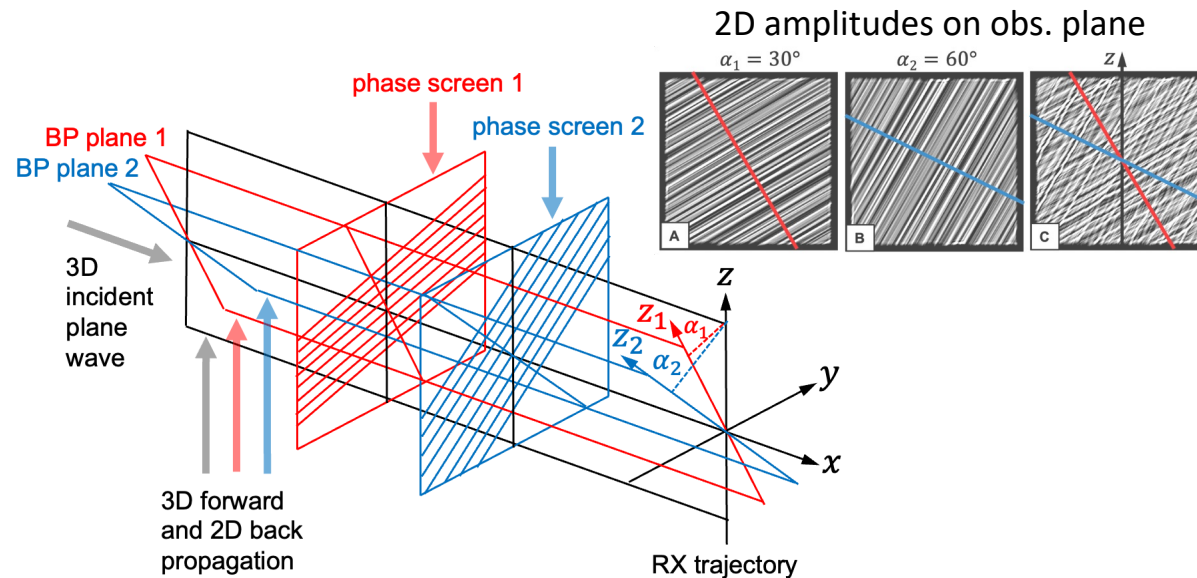
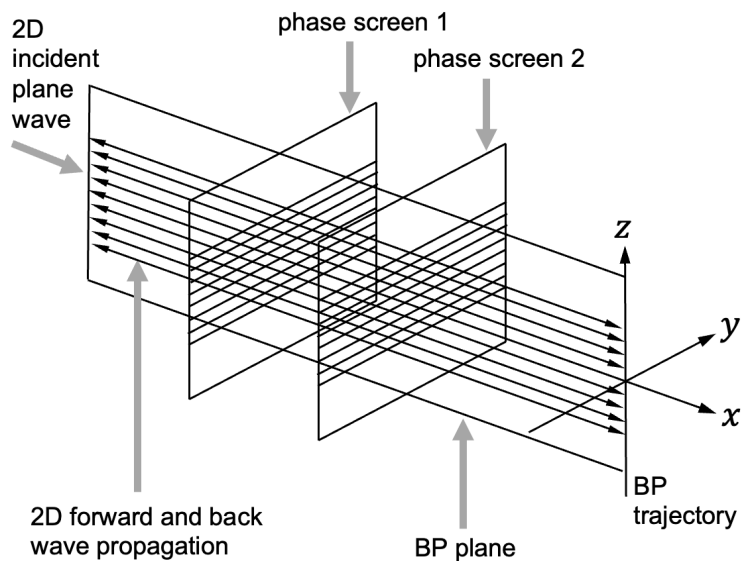
Multiple regions with irregularities along the Tx-Rx LOS are not consistent with the phase screen approximation.

Two regions with the same orientation of irregularities but different  $\sigma_\phi$ , modeled by Ludwig-Barbosa et al., (2023), confirmed in this study.

**Result: two regions cannot be resolved; only the region with larger  $\sigma_\phi$  can be geolocated.**

Two regions with the same  $\sigma_\phi$  but different orientations of irregularities, first time modeled in this study. 2D FP is invalid; 3D FP is used instead; BP is 2D.

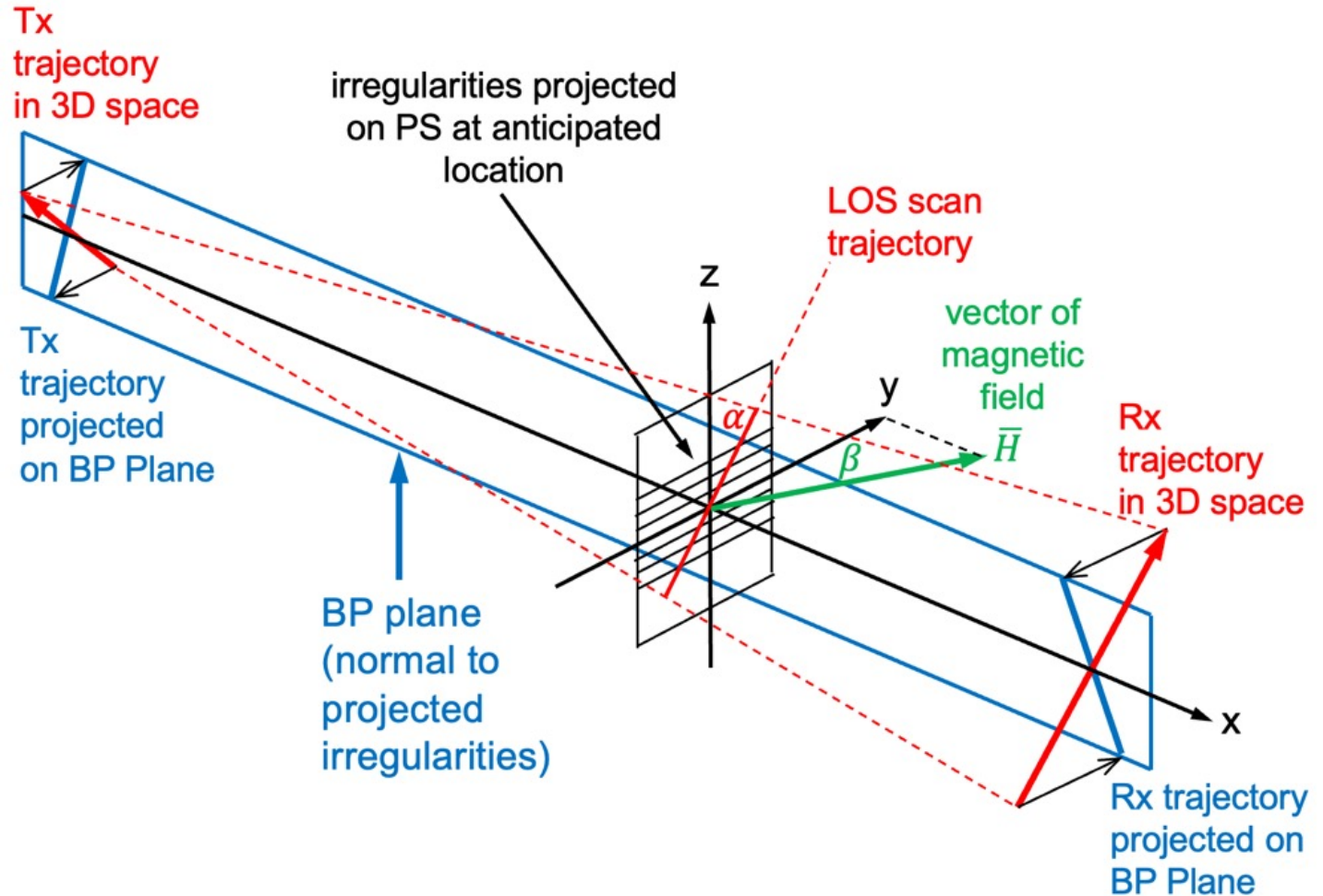
**Result: two regions cannot be resolved; only the region with smaller  $\alpha$  can be geolocated.**



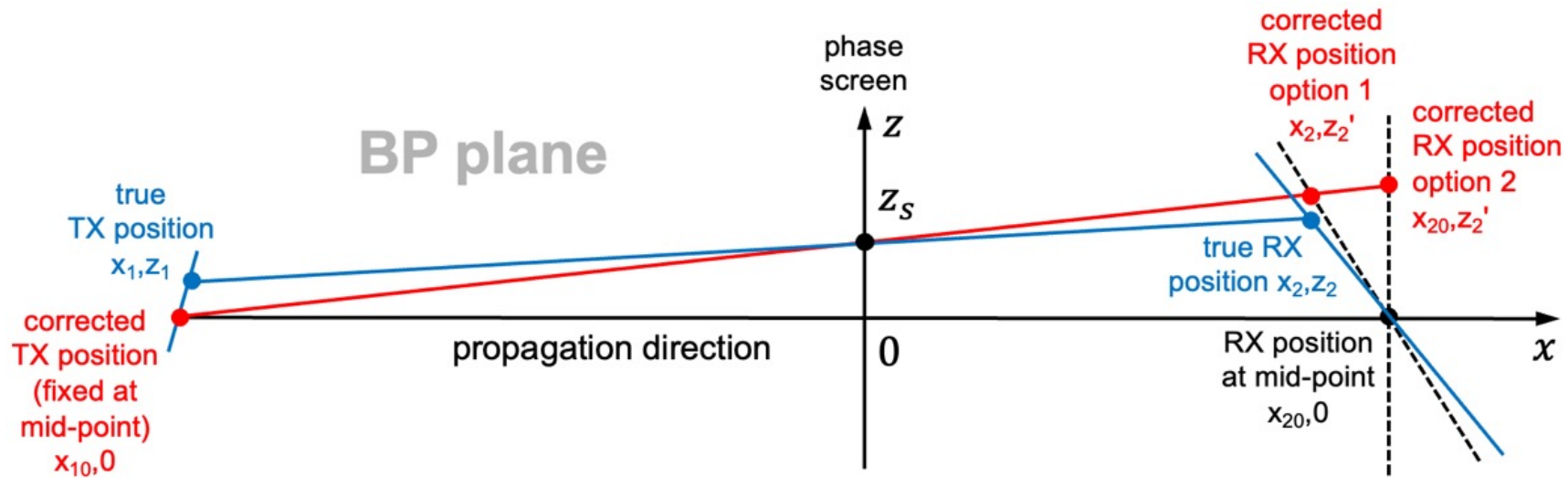
- BP applied in 10-sec intervals

**Step 1.** For each interval:

- BP plane is defined by using direction of magnetic field at anticipated location of irregularities
- Tx and Rx trajectories are projected on BP plane



**Step 2. "Stationarization".** Solving wave equation requires stationary Tx. Fixing Tx at mid-point of 10-sec interval. Correcting Rx positions. Correcting phases.



**Step 3. Correction of the phase front curvature.** Projection of signal on BP plane reduces wavefront curvature radius by a factor  $R \cos^2 \alpha$ . Correction term  $-z^2 \tan^2 \alpha / 2R$  is added to the phase.

An example of COSMIC-2 scintillation

A: amplitude

B: de-trended phase

C: S4 and sigma\_phi

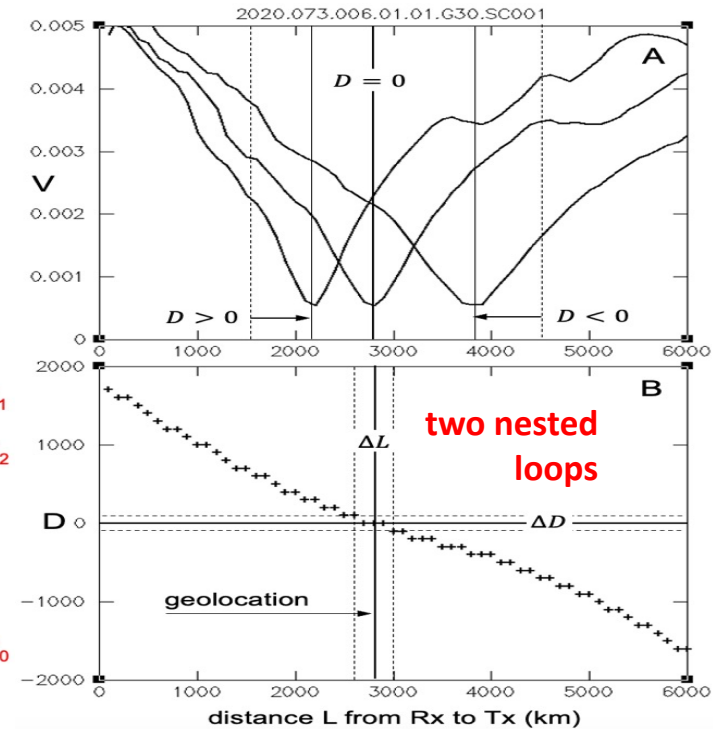
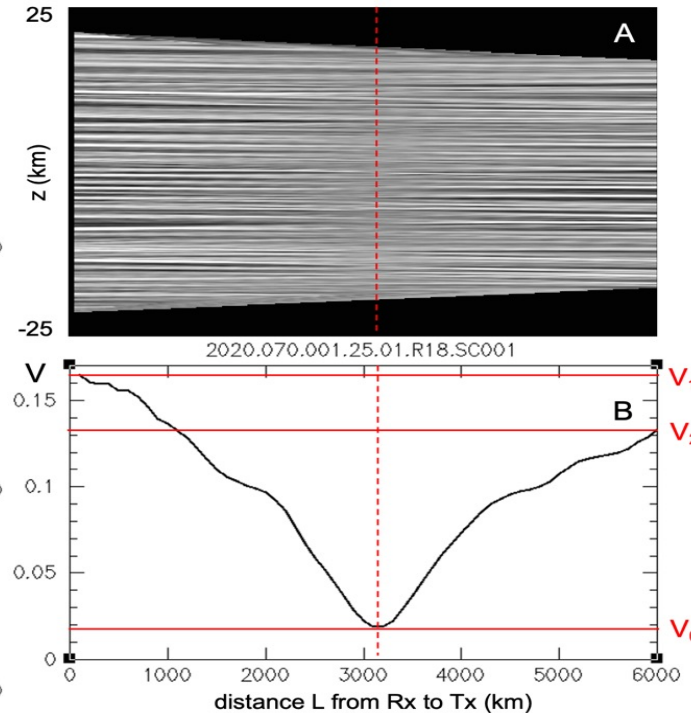
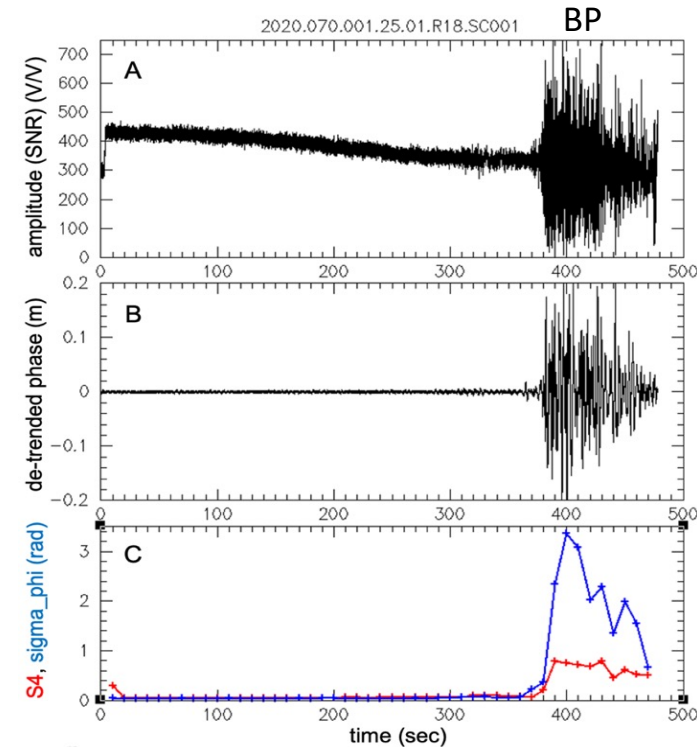
A: BP amplitude

B: normed amplitude variance  $V(L)$

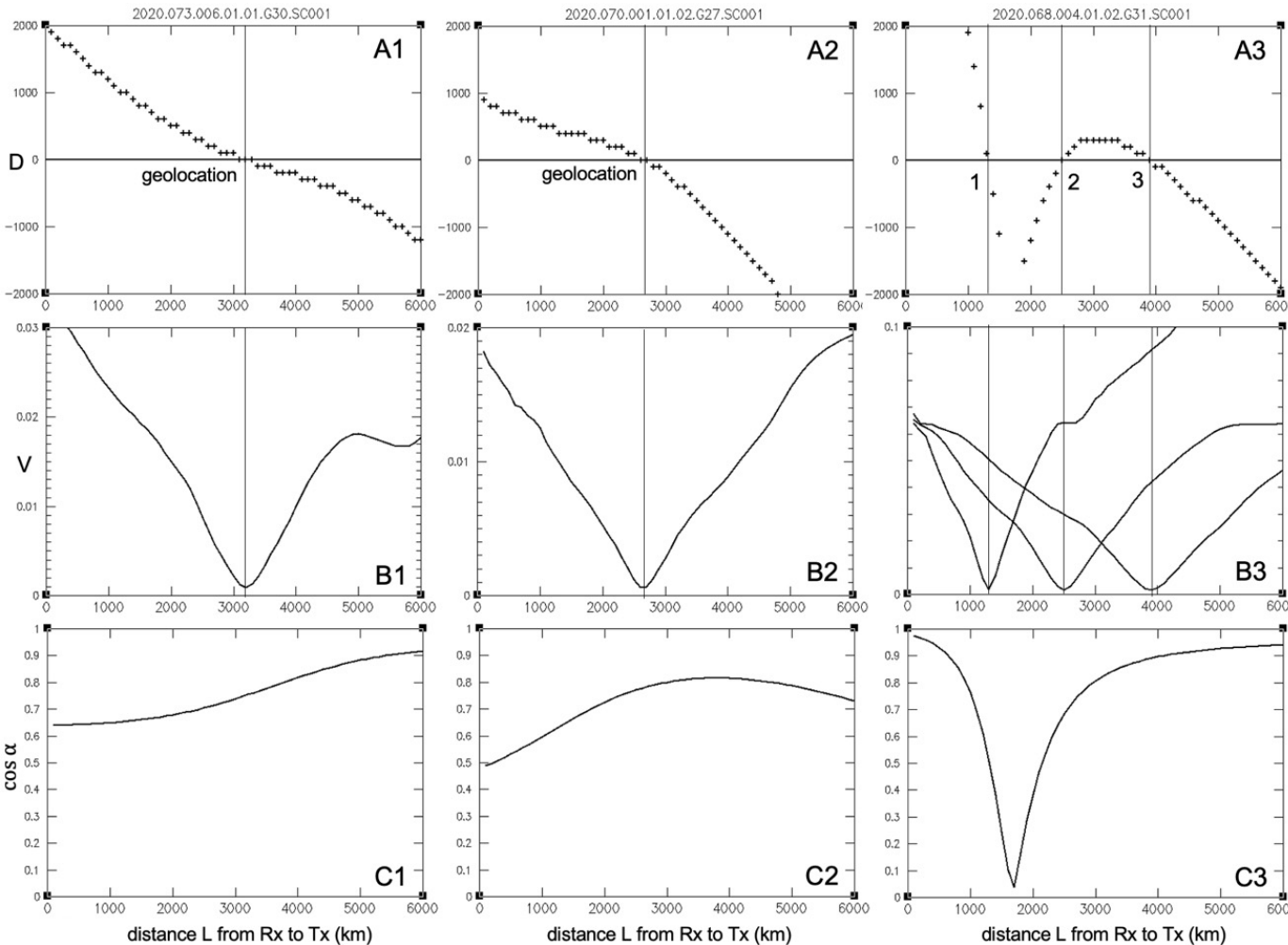
**Important: distance to minimum  $V(L)$  depends on orientation of BP plane defined by angle  $\alpha$**

A: BP applied for 3 orientations of BP plane corresponding to  $\alpha$  defined by magnetic field (MF)

B:  $D(L) = L_{\min} - L_{MF}$  calculated for the set of  $L_{MF}$ ;  **$D(L)=0$  is the geolocation**







- 1) single-valued geolocation
- 2) single-valued geolocation
- 3) **multi-valued geolocation**

Multiple regions with irregularities may not cause multiple geolocations (based on numerical modeling)

**Question:**  
What causes multi-valued geolocations?

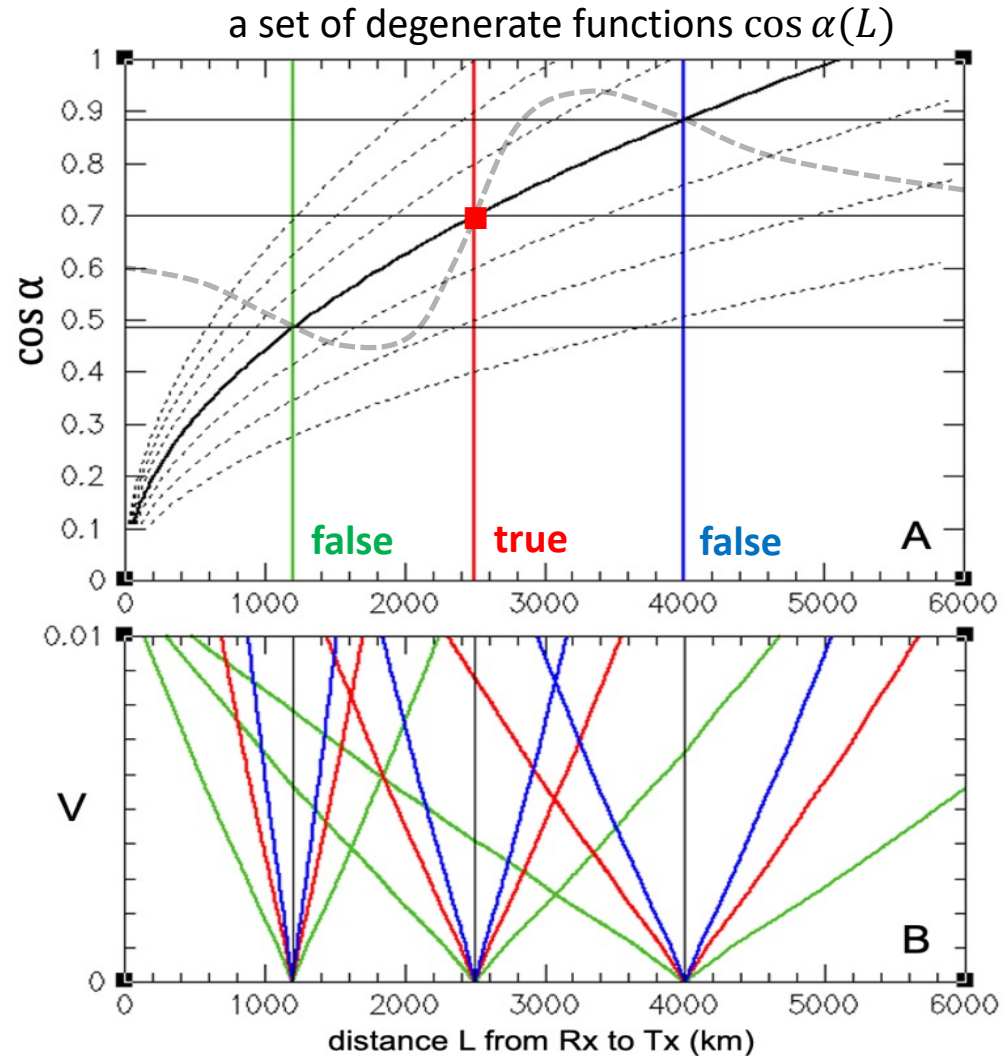
**Answer:**  
Specific structure of the function  $\cos \alpha(L)$  along LOS (next slide)

The "degenerate function"  $\cos \alpha(L)$  is such that **for all L:  $L_{\min} = L_{MF}$**  defined for a given location of the phase screen and a given  $\alpha$  at that location.

**If a real function  $\cos \alpha(L)$  crosses the "degenerate function" multiple times, there are multiple geolocations.**

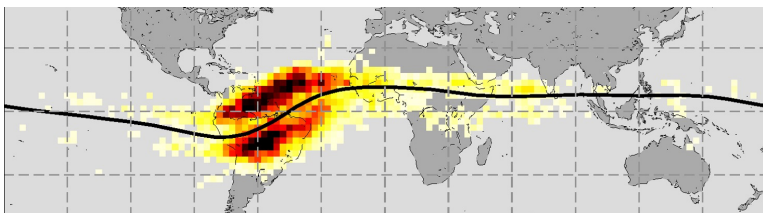
Monotonically decreasing functions  $\cos \alpha(L)$  result in only single-valued geolocations.

It is not possible to distinguish true and false geolocations based on the structures of  $V(L)$ .

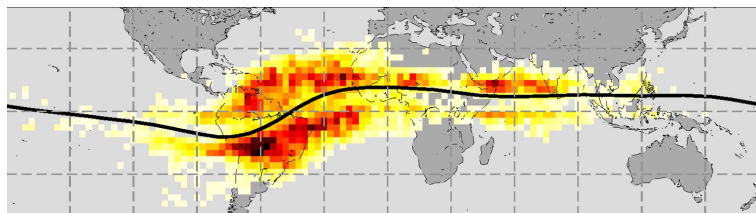


December

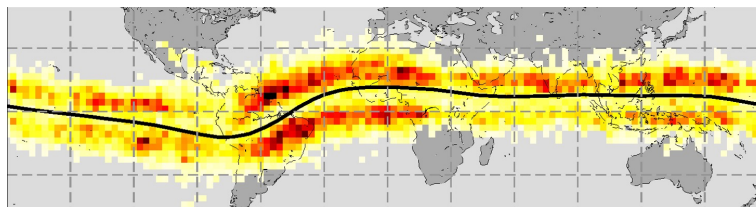
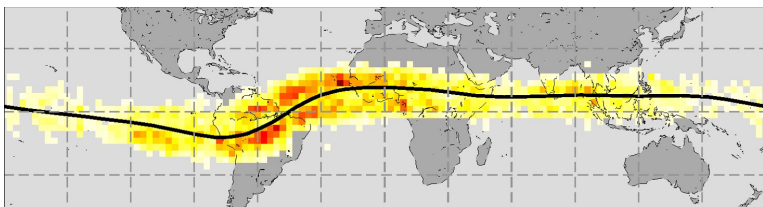
2021



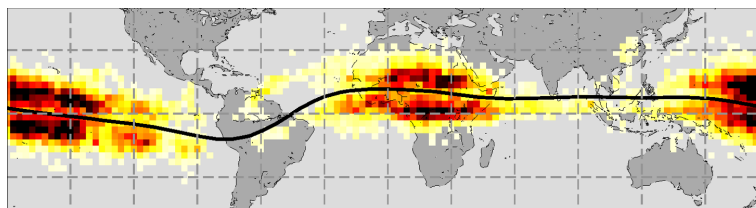
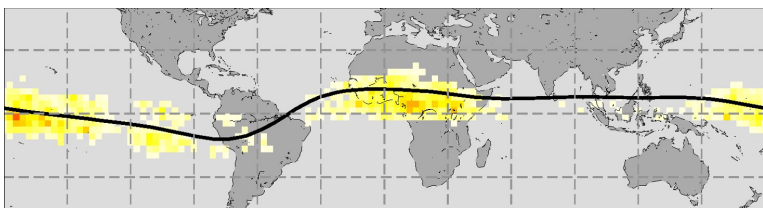
2023



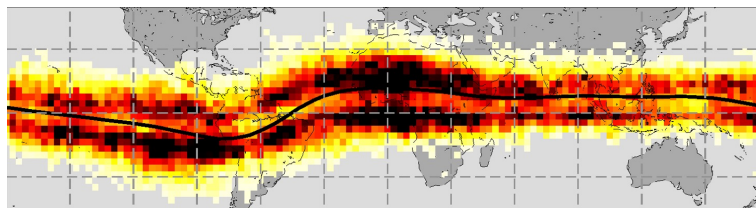
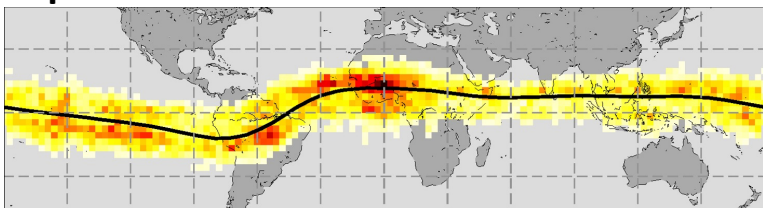
March



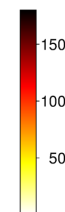
June



September



- Distributions of geolocations obtained from COSMIC-2 POD antenna in different months and years
- Multi-valued geolocations are excluded
- Seasonal variation pattern
- Inter-annual variation (corr. with solar cycle)

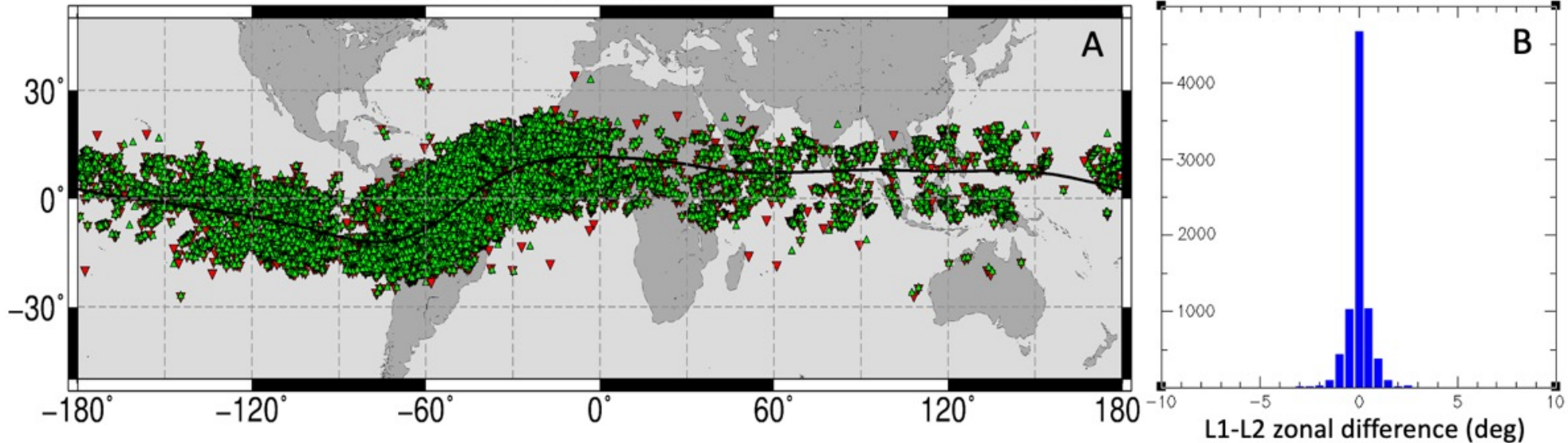


numbers of geolocations in 3x3deg bins

- Commonly, L1 signal is used for geolocations (higher SNR and more reliable tracking)
- During test period 2021.050-060, was also used (L2P occultations were excluded from analysis)
- Generally, L1 and L2 geolocations are in good agreement (longitudinal stand. deviation 1.3deg); this may be considered an internal validation of the method
- However, large differences need further investigation

Year 2021 DOY: 050-060

L1 L2



- Numerical modeling:
  - evaluation of accuracy
  - geolocation of multiple regions (incl. 3D FP)
  - explanation of multi-valued geolocations
- Back propagation of real observational data
- Geolocations from 2 years of COSMIC-2 data
- Comparison of L1 and L2 geolocations

