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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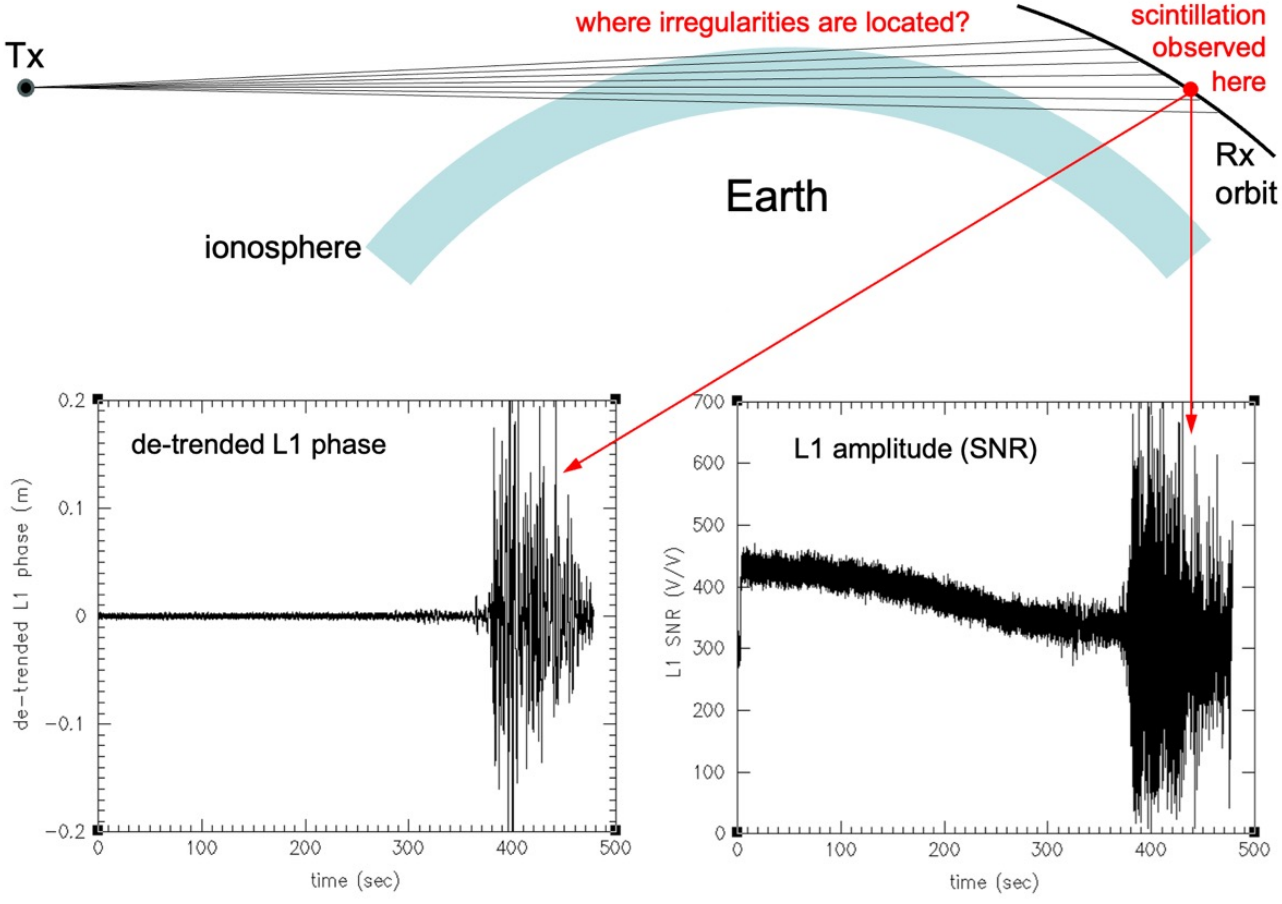
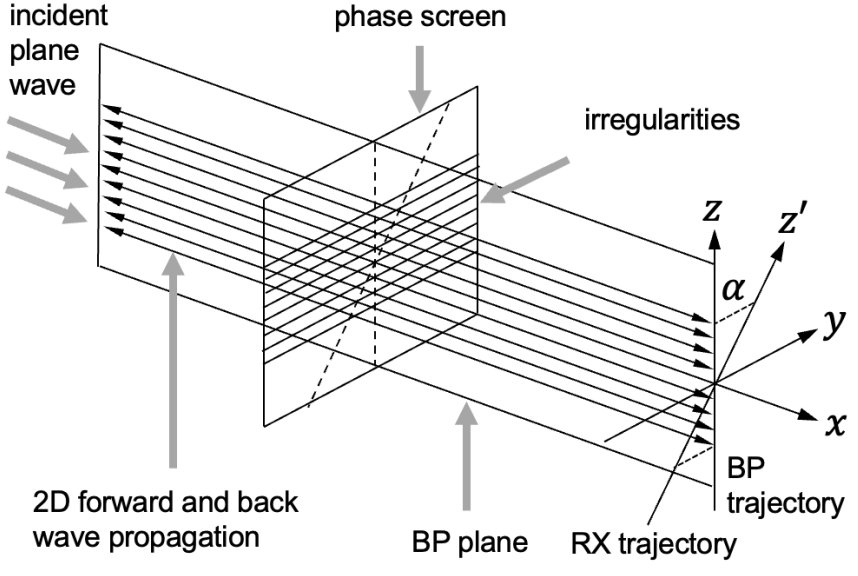
Ionospheric scintillation on orbit

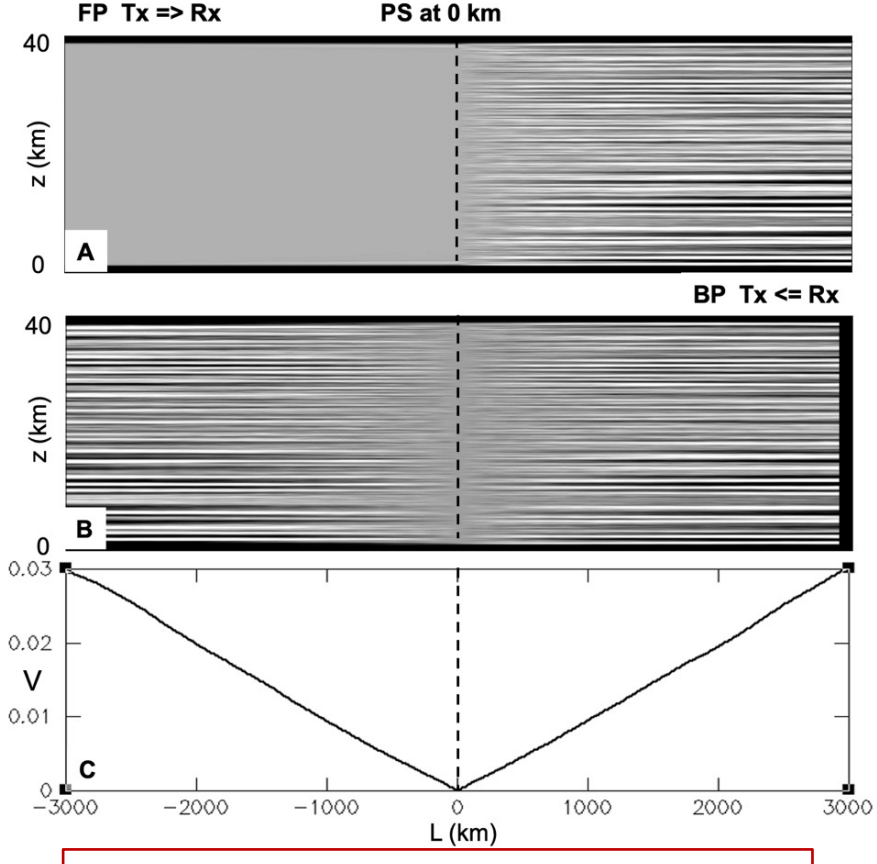
- Scintillation is caused by different mechanisms
- Equatorial ionosphere: field-aligned irregularities inside plasma bubbles
- Different methods considered for localization (Carrano et al.)
- Back propagation (BP): solving wave equation in a vacuum by using phase and amplitude at Rx as the boundary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



Localization of irregularities by 2D back propagation

- 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.



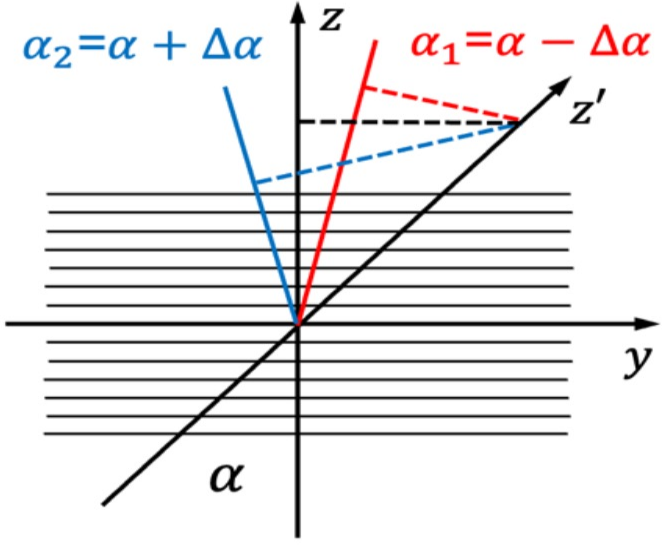


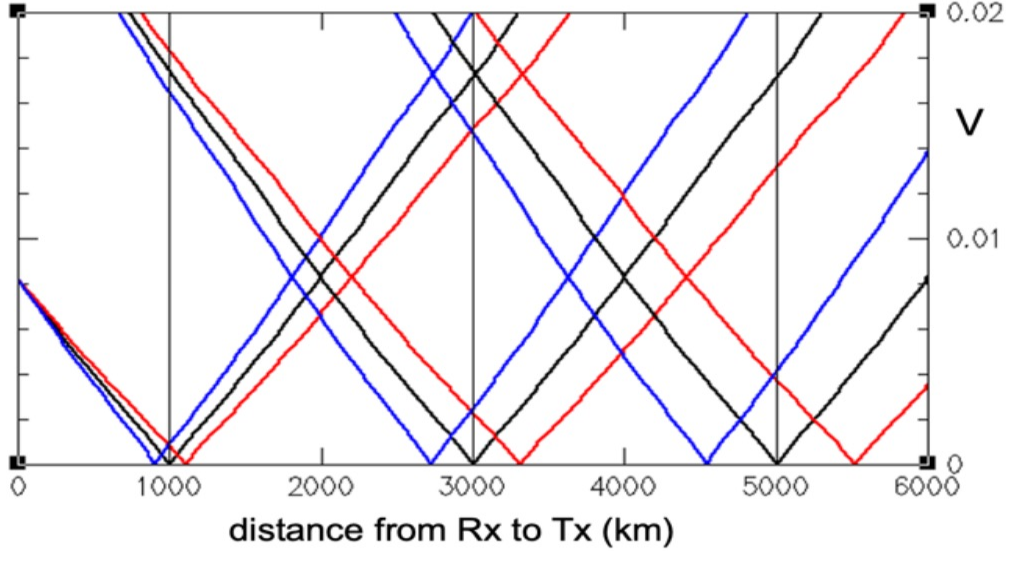
Important parameters: Scan angle $\alpha(L)$; Normed amplitude variance V(L)

Geolocation error: orientation of irregularities

- 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 α and distance from Rx to irrerg.
- IGRF model is accurate to ~1% 90% of the time (Matteo and Morton, 2011)

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



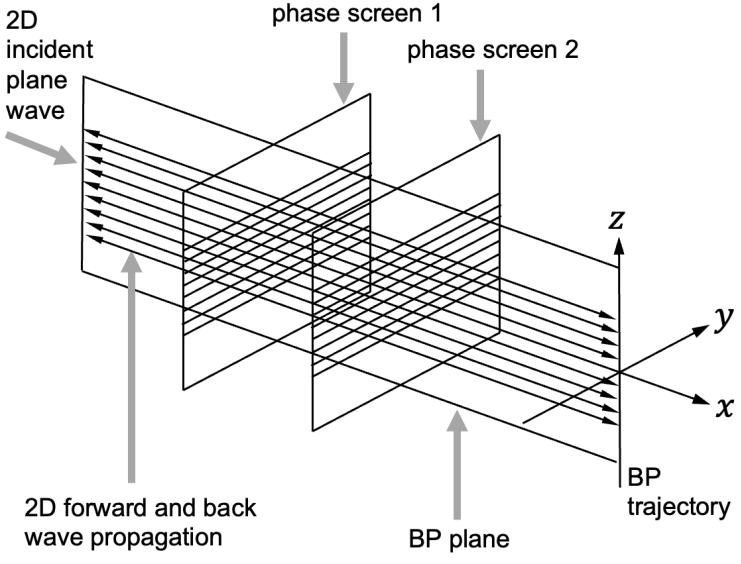


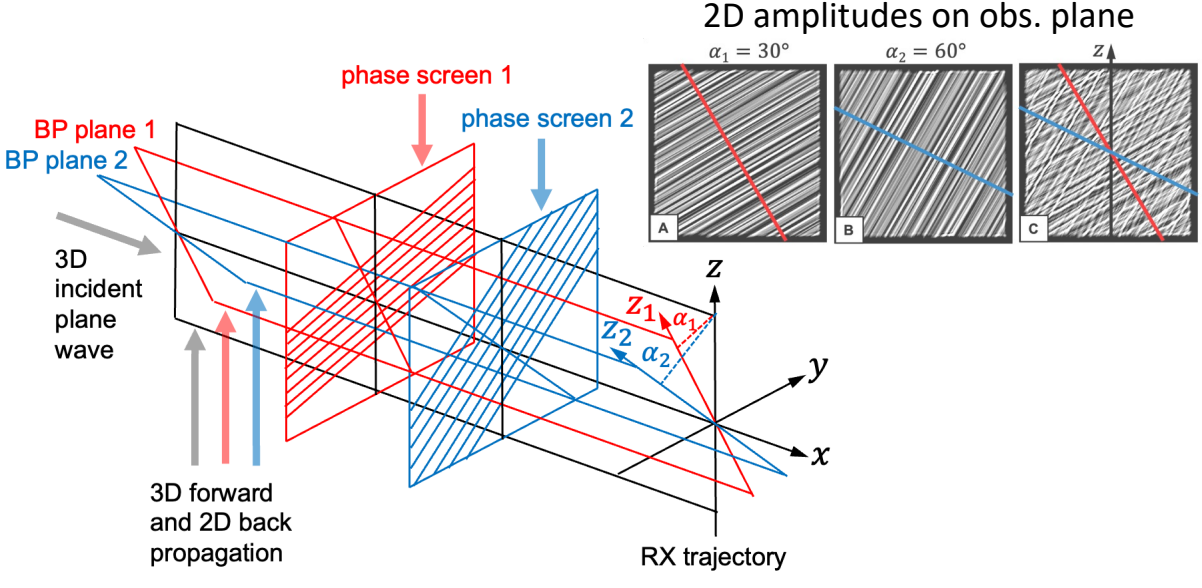
Modeling of geolocation: two regions with irregularities

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 σ_ϕ, modeled by Ludwig-Barbosa et al., (2023), confirmed in this study.
Result: two regions cannot be resolved; only the region with larger σ_ϕ can be geolocated.

Two regions with the same σ_ϕ 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 α can be geolocated.





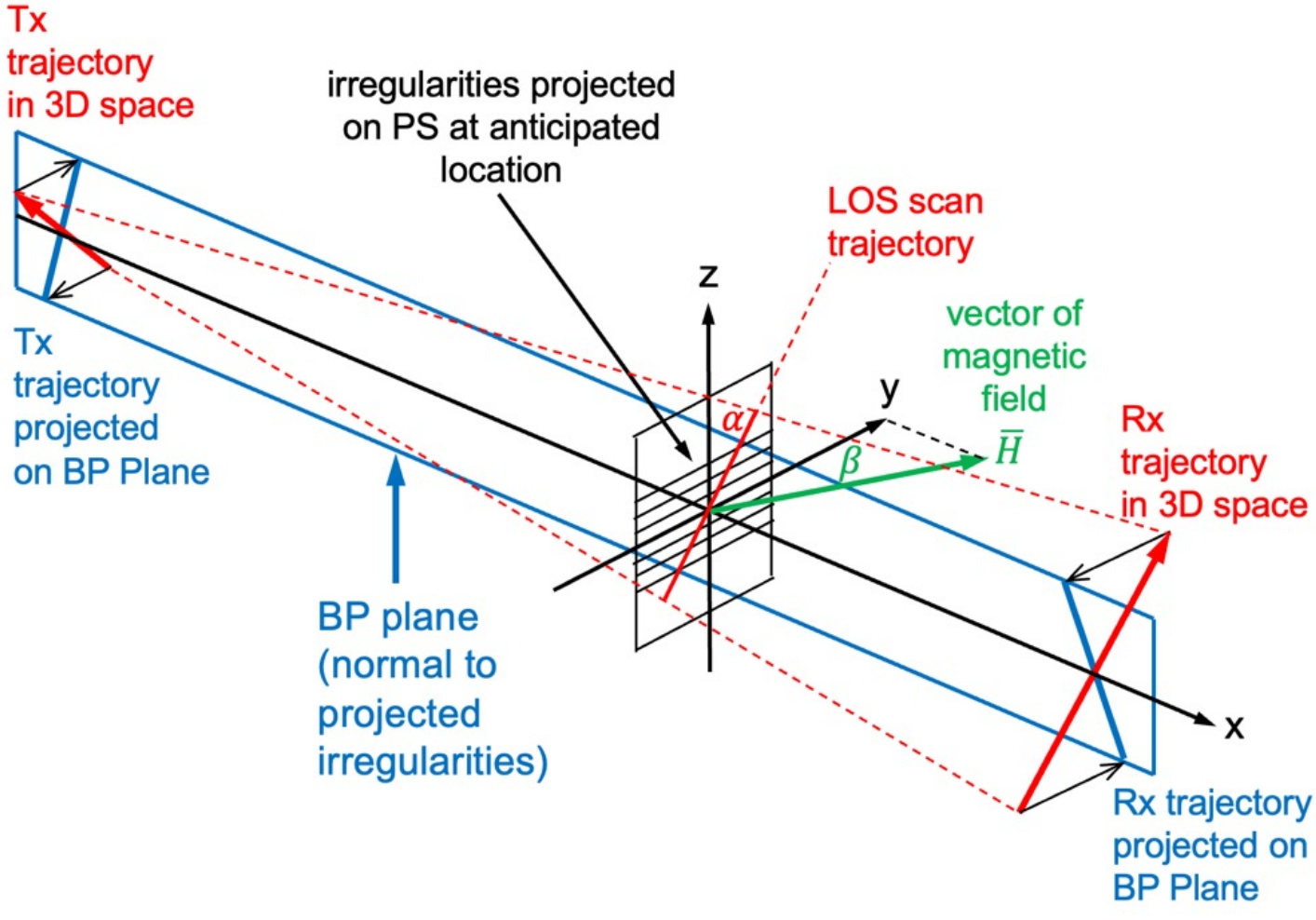
Geolocation using real observational data (step 1)

- BP applied in 10-sec intervals

Step 1. For each interval:

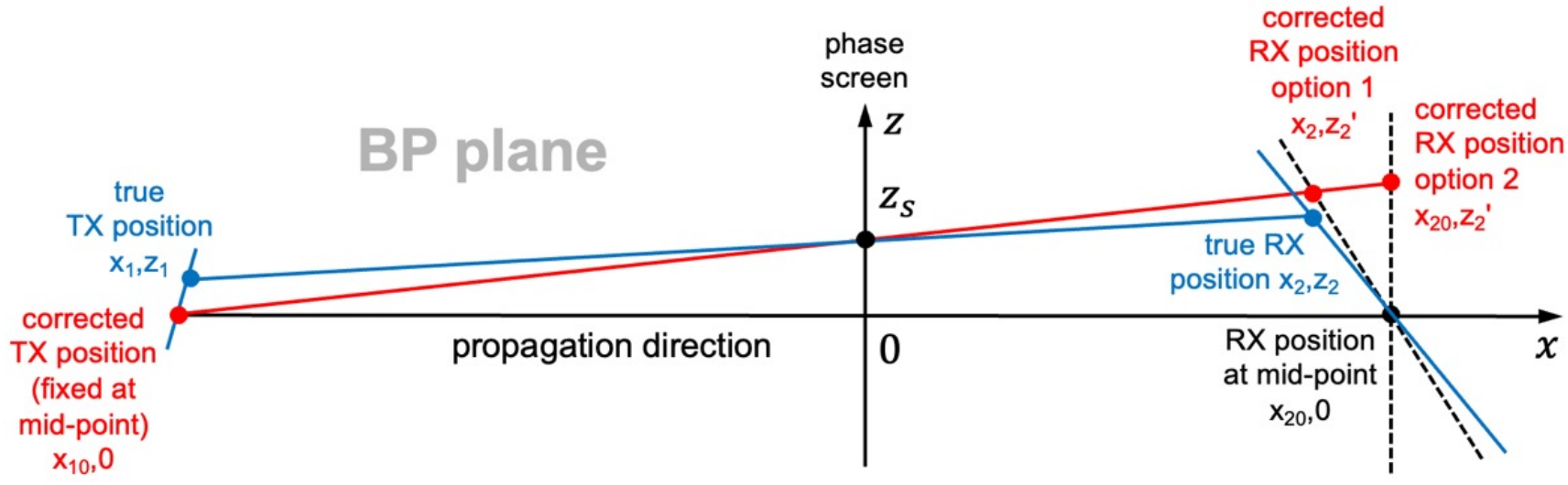
- BP plane is defined by using direction of magnetic field at anticipated location of irregularities

- Tx and Rx trajectories are projected on BP plane



Geolocation using real observational data (steps 2,3)

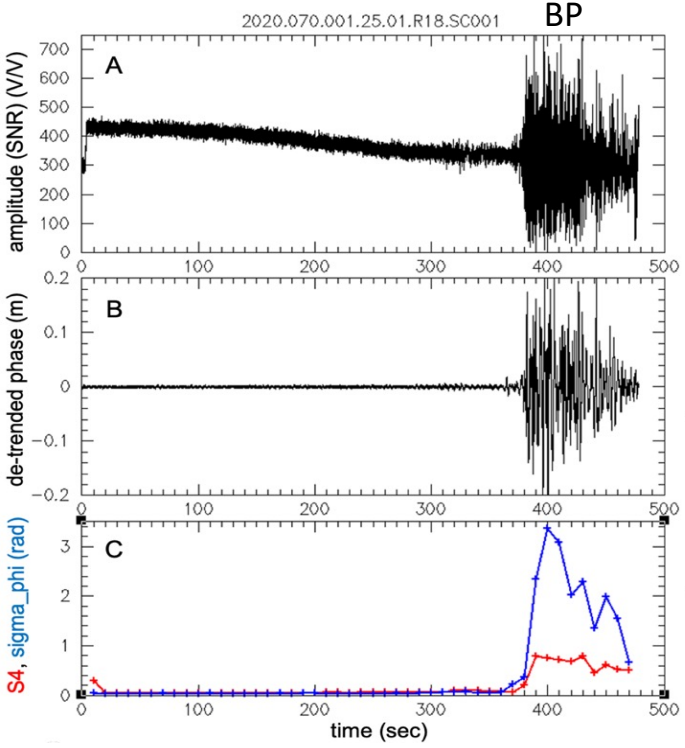
Step 2. "Stationarization". Solving wave equation requires stationary Tx.
Fixing Tx at mid-point of 10-sec interval. Correcting Rx positions. Correcting phases.



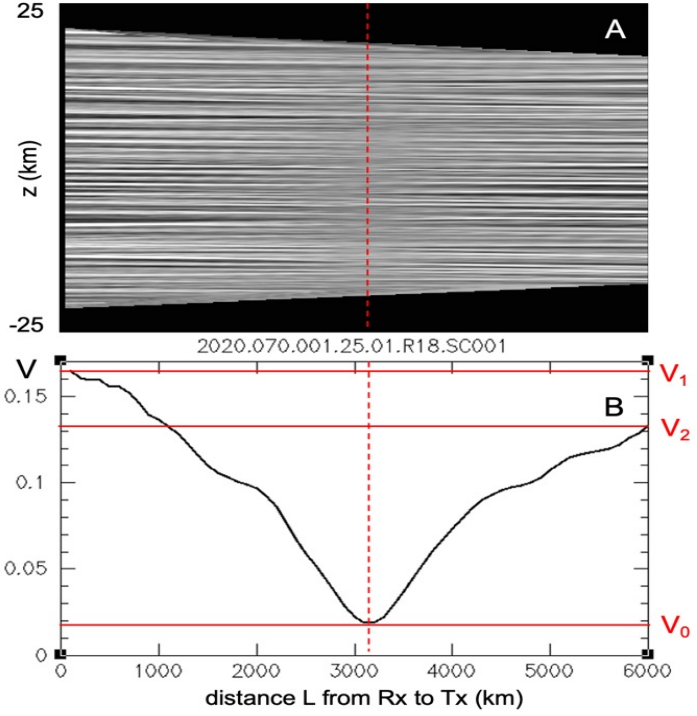
Step 3. Correction of the phase front curvature. Projection of signal on BP plane reduces wavefront curvature radius by a factor $R\ cos^2\alpha$.
Correction term $-z^2 tan^2\alpha/2R$ is added to the phase.

Geolocation, COSMIC-2 observational data

An example of COSMIC-2 scintillation
A: amplitude
B: de-trended phase
C: S4 and sigma_phi

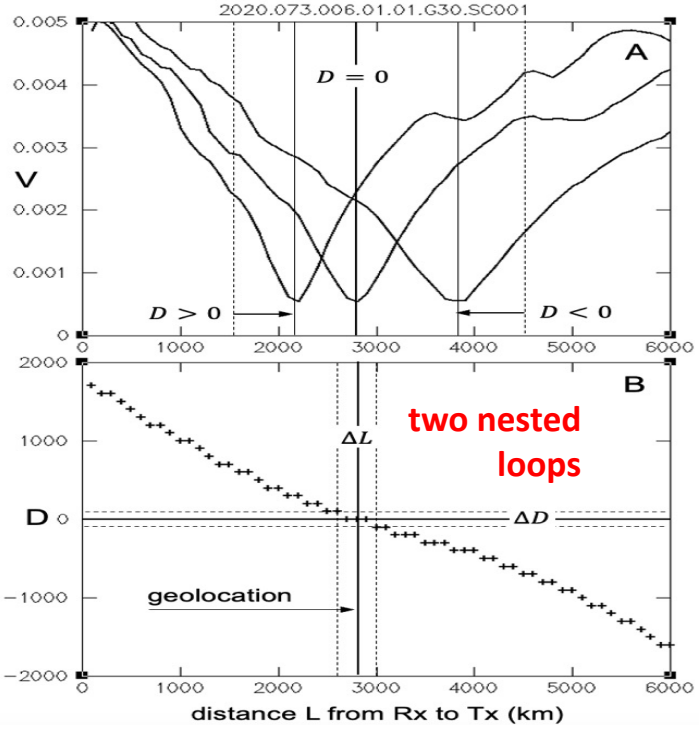


A: BP amplitude
B: normed amplitude variance V(L)
Important: distance to minimum V(L) depends on orientation of BP plane defined by angle α

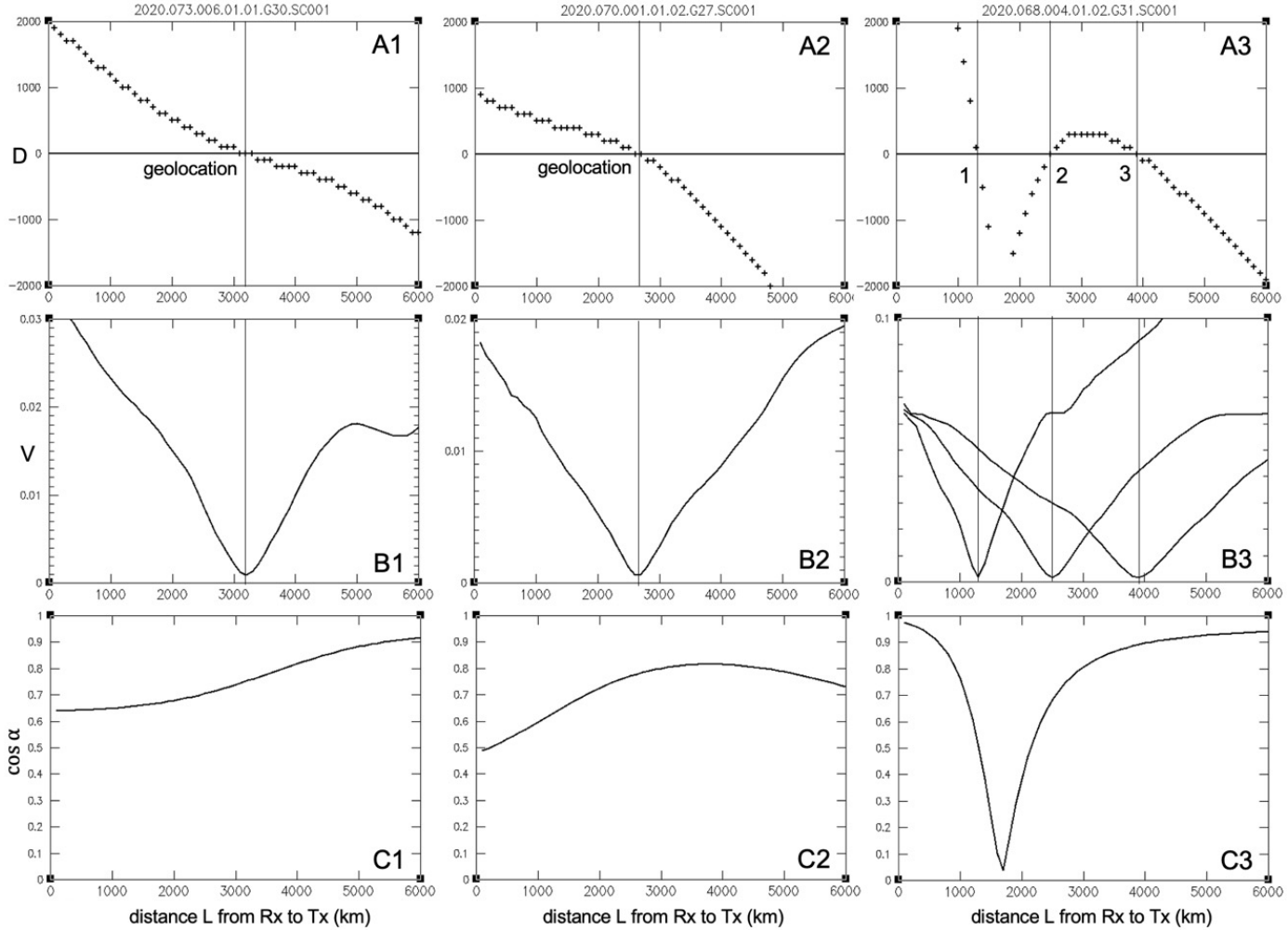


A: BP applied for 3 orientations of BP plane corresponding to α defined by magnetic field (MF)

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



Examples of geolocations, COSMIC-2 observational data



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)

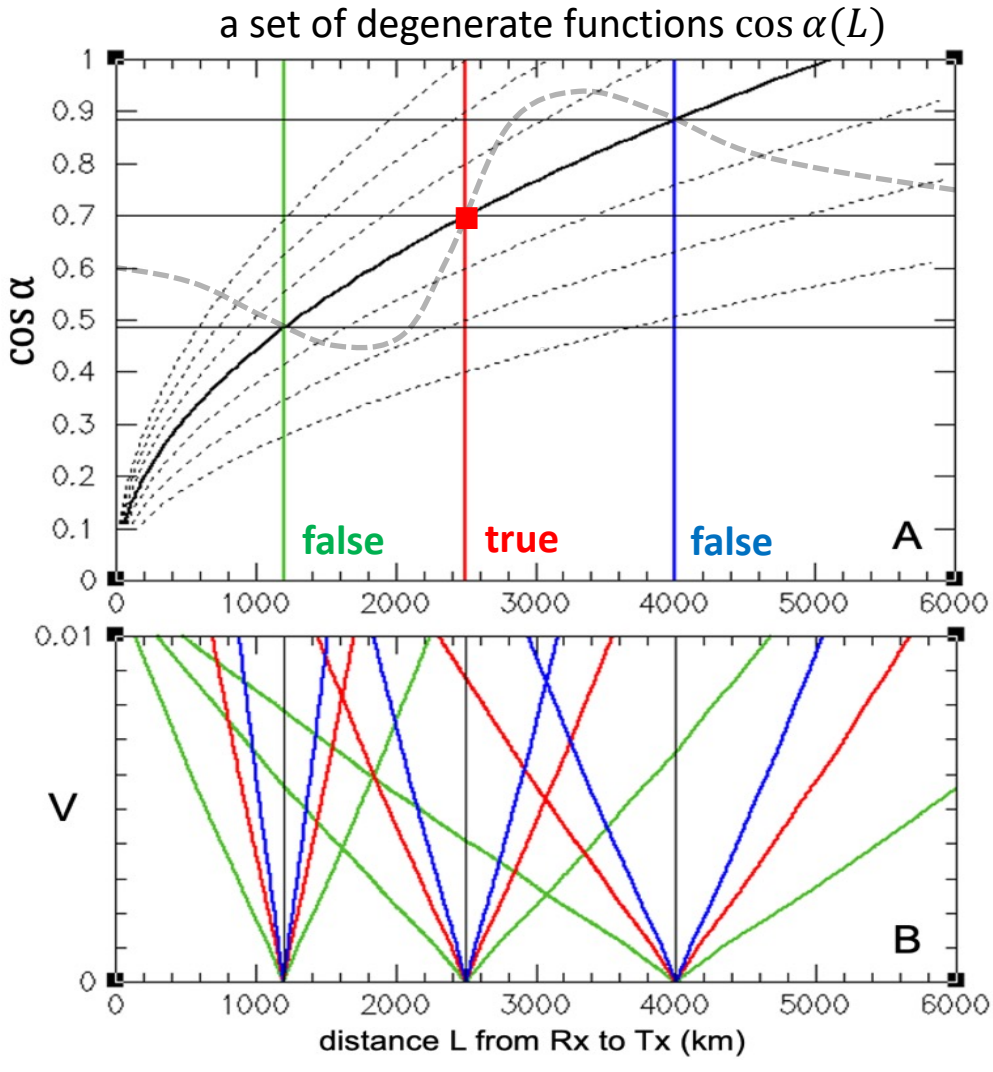
Multi-valued geolocations, degenerate functions $\cos\alpha(L)$

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 α at that location.

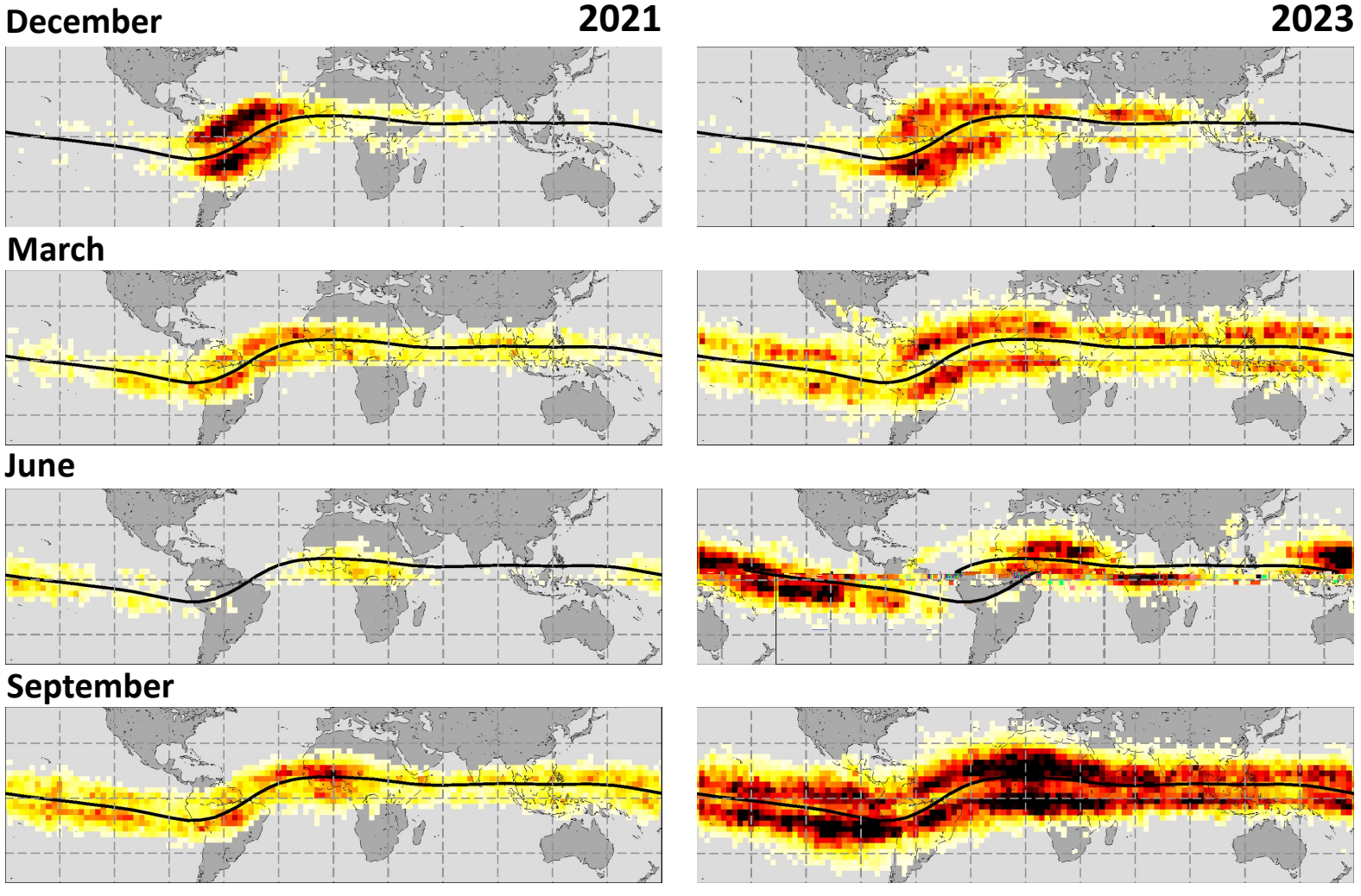
If a real function $\cos\alpha(L)$ crosses the "degenerate function" multiple times, there are multiple geolocations.

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).



Equatorial geolocations from COSMIC-2 for two years

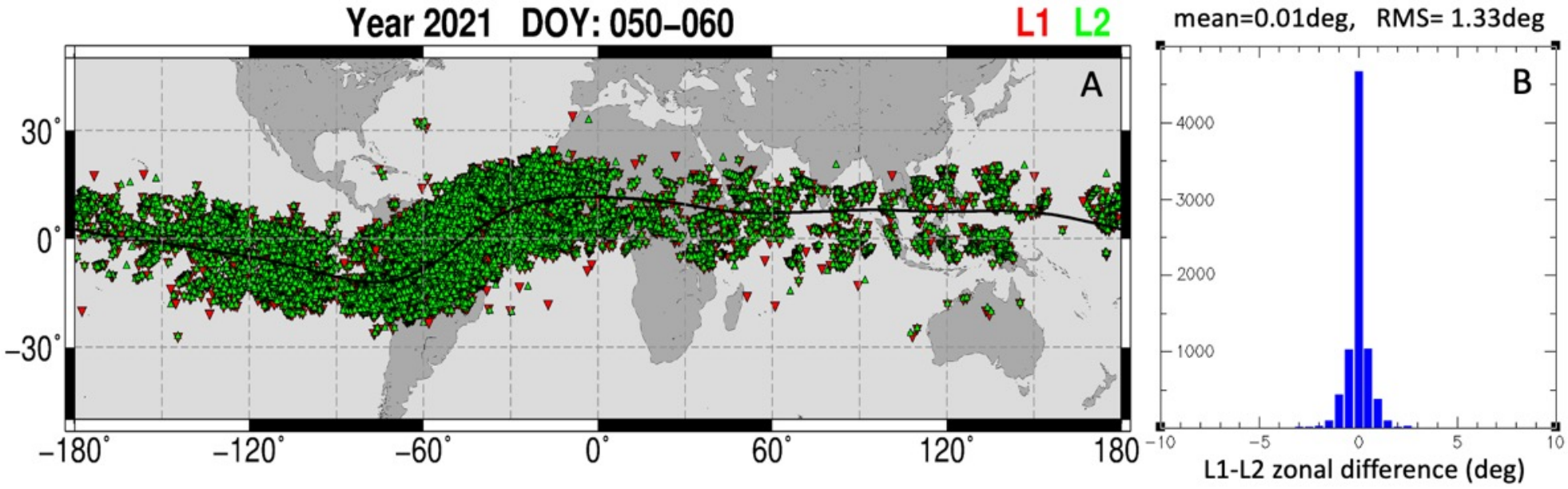


- Distributions of geolocations obtained from COSMIC-2 POD antenna in different months and years
- Multi-valued geolocations are excluded
- Seasonal variation pattern
- Inter-annual variation (corr. with solar cycle)

numbers of geolocations in 3x3deg bins

Geolocations obtained from COSMIC-2 L1 and L2 signals

- 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



Summary

- 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

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