Collaborative observations of the ionosphere by GNSS-R and GNSS-RO on space weather

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Abstract

The Global Navigation Satellite System (GNSS) provides an economic way to monitor the ionosphere changes on a global scale. However, the ground-based GNSS stations are limited to observation coverage above oceanic, polar, and low-population areas. Satellite observations are becoming popular for the rapid revisit that can easily develop global coverage. In this study, the GNSS Reflectometry (GNSS-R) of CYGNSS as well as the GNSS Radio Occultation (GNSS-RO) data of FORMOSAT-7/COSMIC-2 (F7/C2) are used to analyze the ionosphere. The GNSS-R and GNSS-RO observations are used to investigate the space weather in low-latitude regions. The L1-band (1.5GHz) signal-to-noise ratio (SNR) data received by the CYGNSS mission are used to calculate the S4 index and compare to the RO S4 of the F7/C2. The joint scintillation observations of two techniques provide a new aspect monitoring the ionospheric irregularities and Equatorial plasma bubbles (EPBs).

Objectives

From May 10 to 13, 2024, a G5 solar storm occurred during Solar Cycle 25. This event included a series of extreme solar flares, intense solar proton events, and a strong geomagnetic storm component. It was the most powerful geomagnetic storm to affect Earth since 2003, producing auroras at unusually low latitudes in both the Northern and Southern Hemispheres.

This study aims to investigate whether variations associated with this solar storm can be observed using data from three different sources: GNSS ground-based stations, COSMIC-2/FORMOSAT-7 (GNSS-RO data), and CYGNSS(GNSS-R).

Materials and Methods

- **Global Navigation Satellite System (Ground-based stations)**

ROTI and TEC maps during the May 2024 solar storm event

- **CYGNSS (GNSS-R)**

Using DDM (Delay Doppler Map) and SNR (Signal-to-Noise Ratio) data from CYGNSS (Level 1 Science Data Version 3.3), variations in SNR over the ocean from May 9 to May 13, 2024.

- **COSMIC-2/FORMOSAT-7 (GNSS-RO)**

C2/F7 scnLv2 data from TACC (Taiwan Analysis Center for COSMIC) were used in this study to calculate the global S4 probability map based on the S4 index data.

Formula for S4 Probability Calculation:

$$\text{Probability}\ (S4 > T) = \frac{N(S4>T)}{N_{total}}$$, T = 0.5 (threshold).

Where:

- $\text{Probability}\ (S4 > T)$ is the probability of S4 exceeding a given threshold T.
- $N(S4 > T)$ is the number of data points within a given grid cell where S4 exceeds the threshold T.
- N_{total} is the total number of data points within the grid cell.

Results - GNSS TEC Map

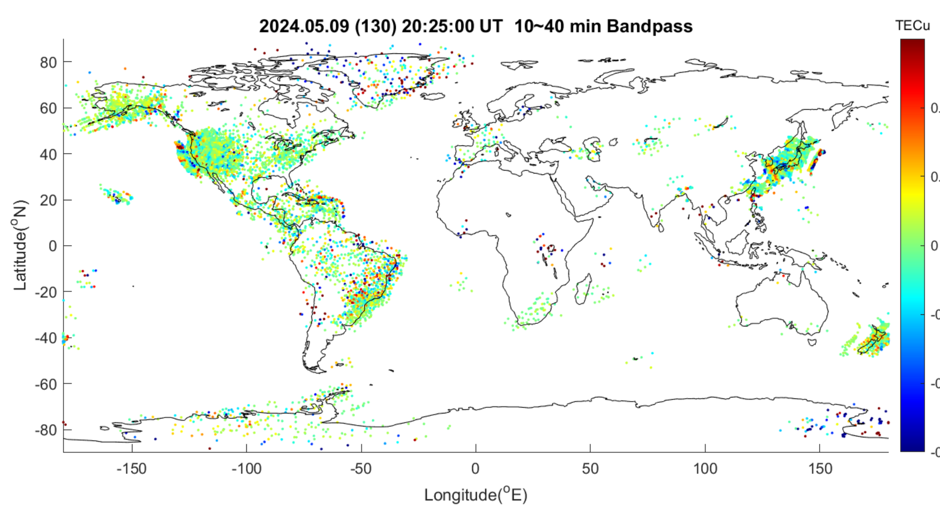


Figure 1.1

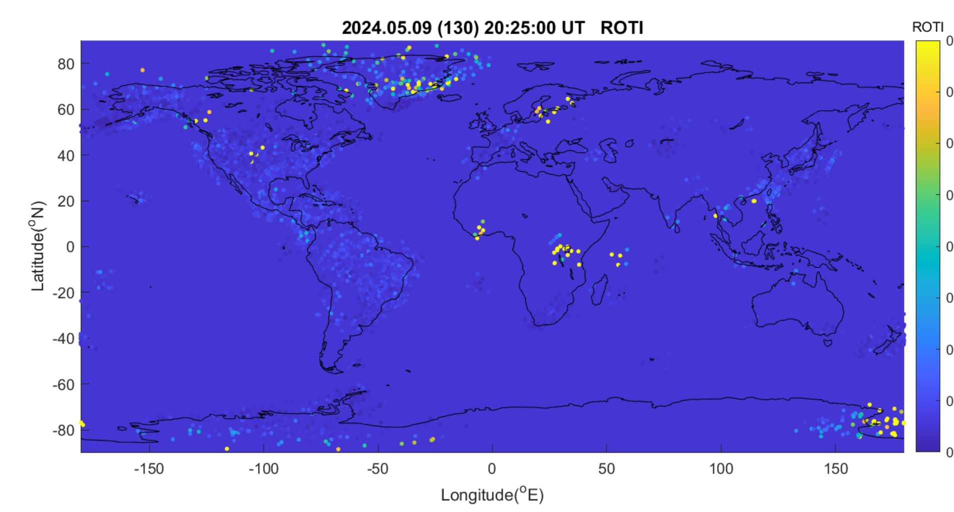
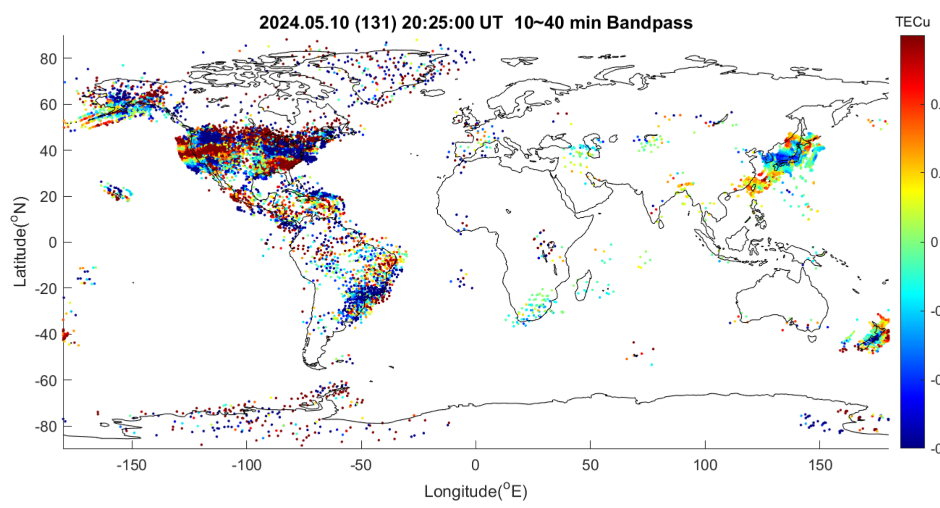


Figure 1.2



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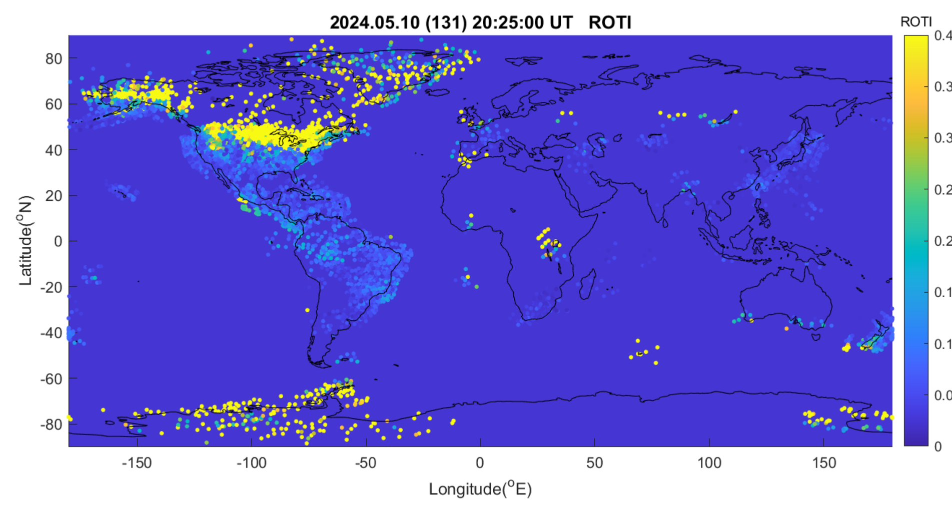


Figure 2.2

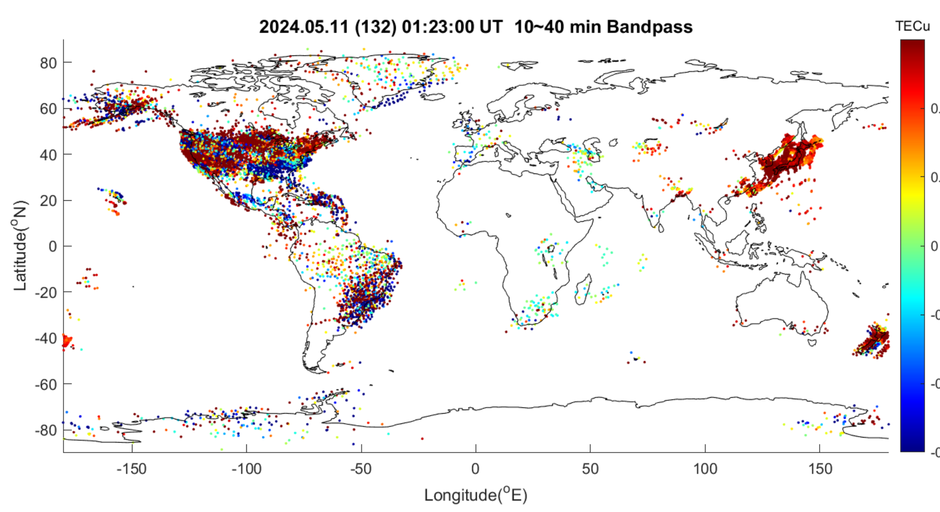


Figure 3.1

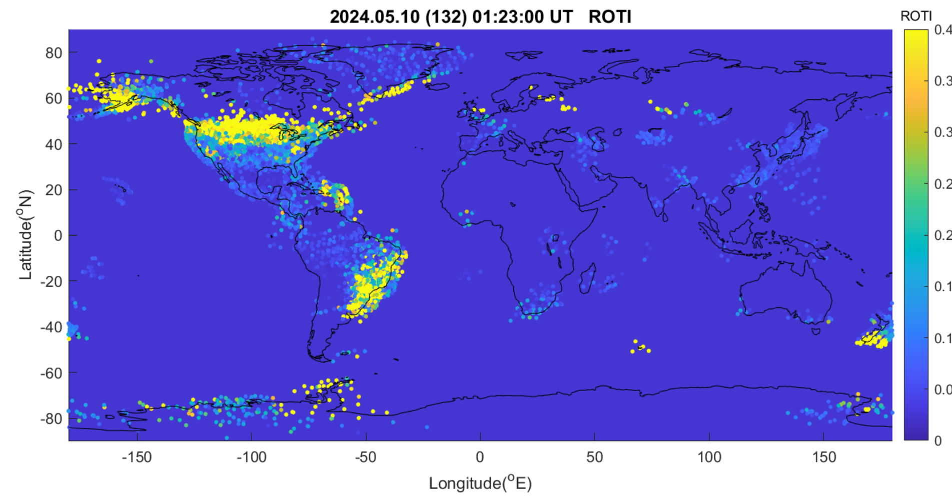


Figure 3.2

Results - CYGNSS SNR

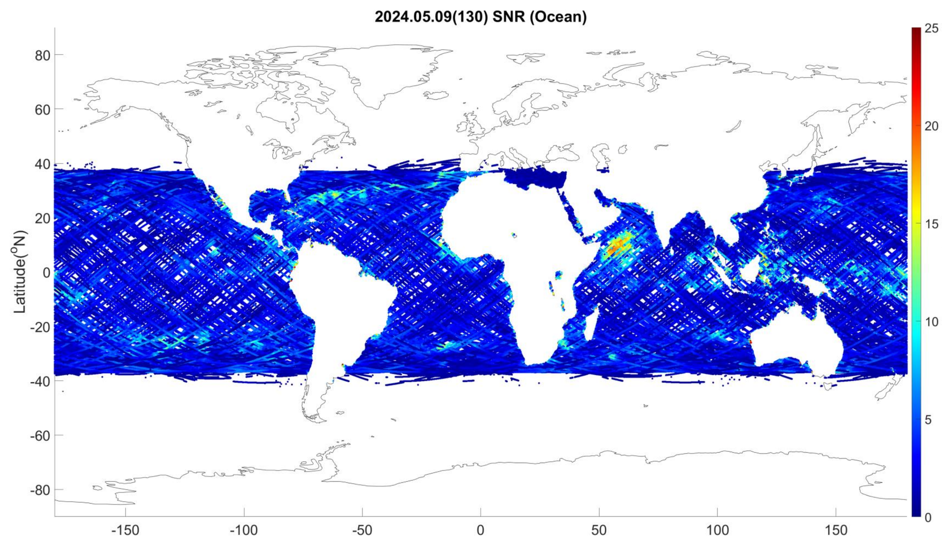
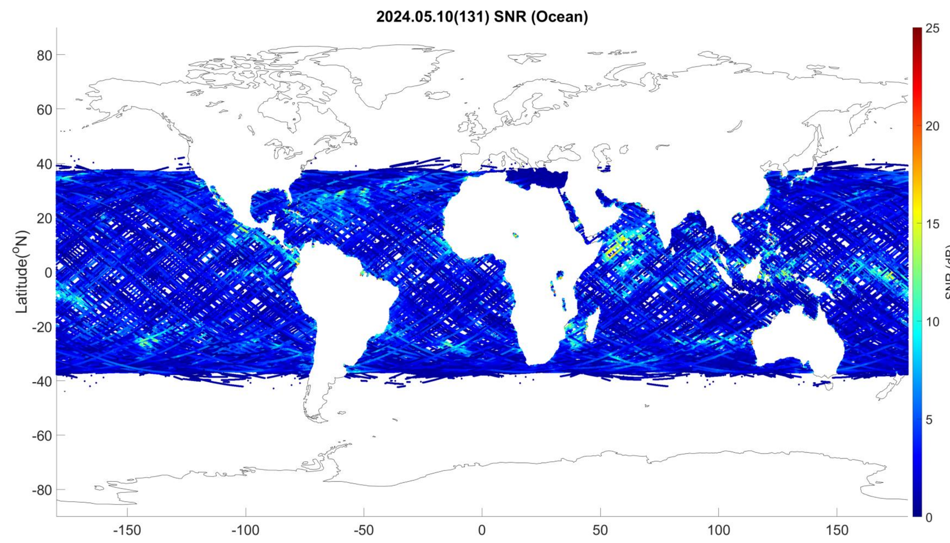


Figure 4.1



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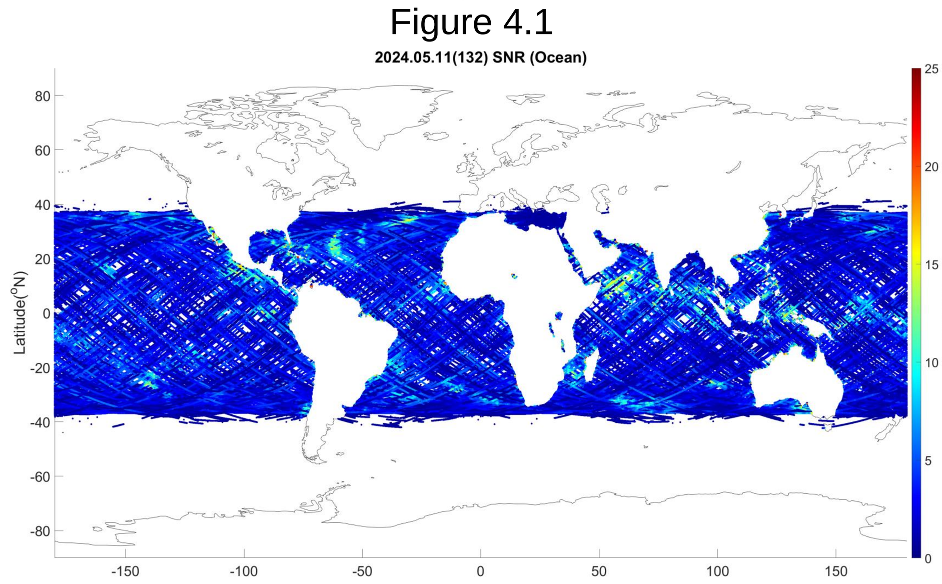


Figure 4.3

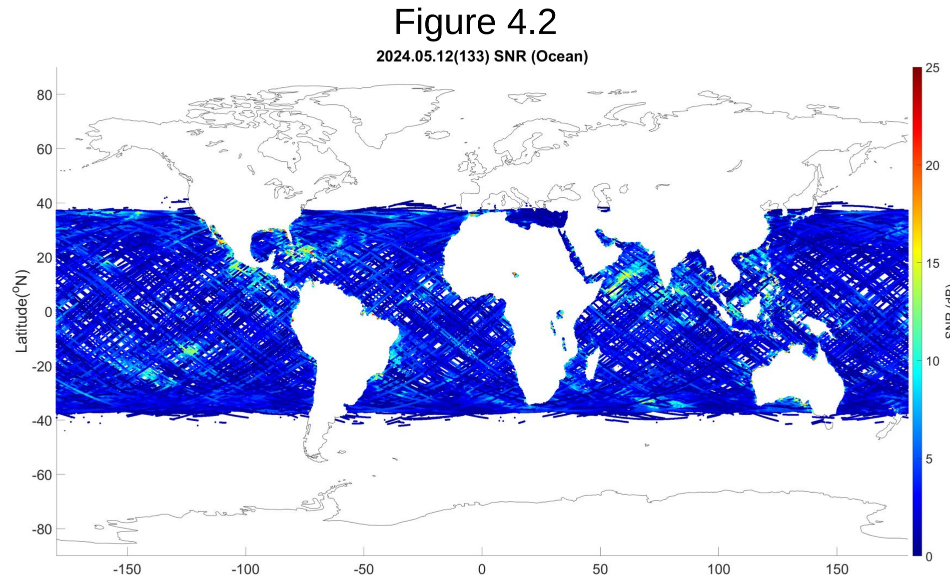


Figure 4.4

Results - C2/F7 Probability of S4 Occurrence

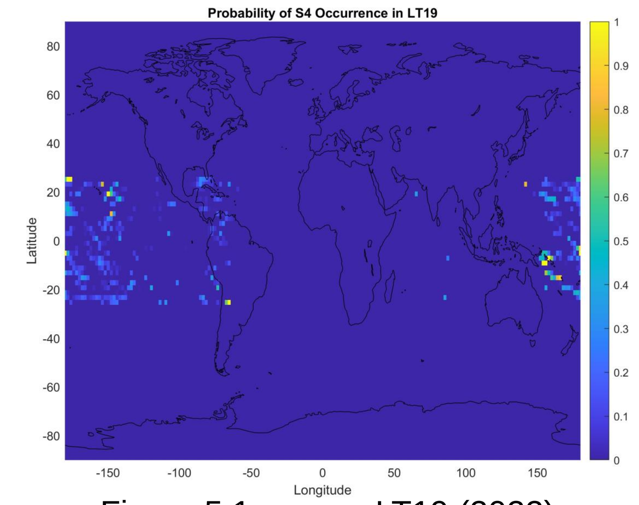


Figure 5.1 、may LT19 (2022)

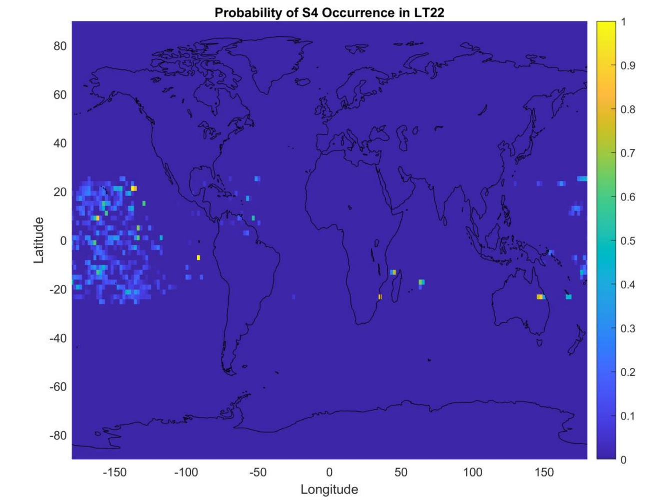
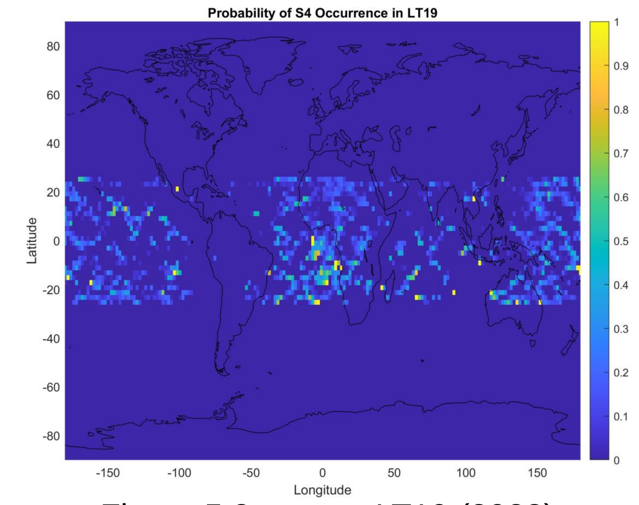


Figure 6.1、may LT22 (2022)



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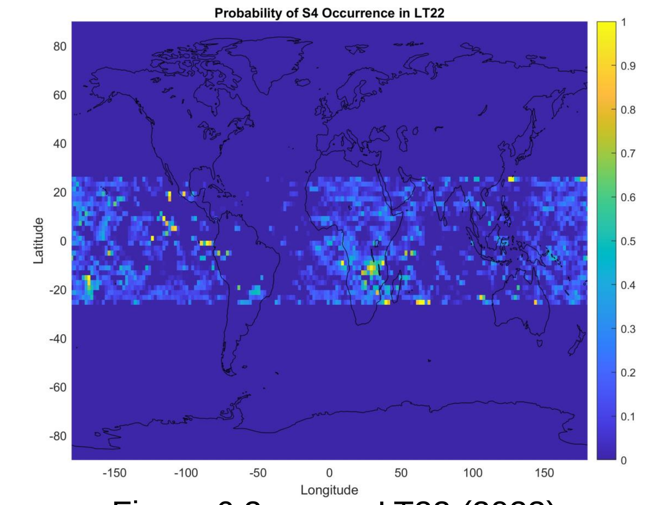

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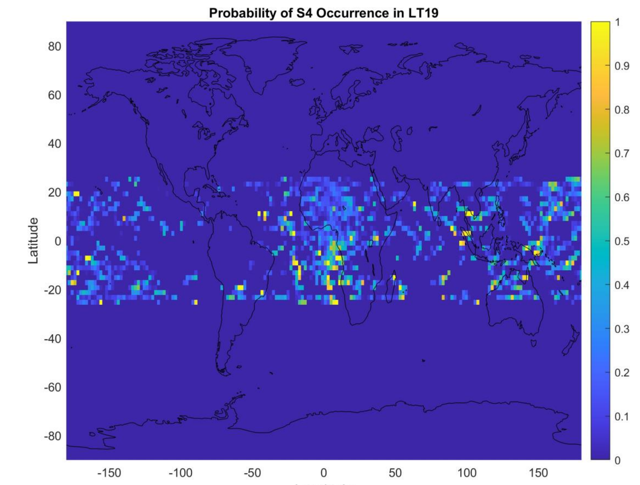

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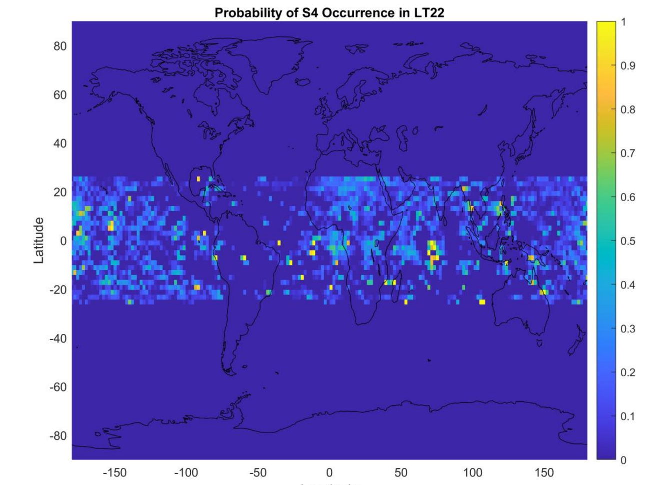

Figure 6.3、may LT22 (2024)

Summary

This study utilized data from CYGNSS (GNSS-R) and COSMIC-2/FORMOSAT-7 (GNSS-RO) to investigate ionospheric disturbances, particularly focusing on the impact of solar activity from 2022 to 2024. By analyzing L1-band SNR data from CYGNSS and radio occultation data from COSMIC-2, the research calculated the global S4 index, which measures ionospheric scintillation.

•2022: During the solar minimum, S4 disturbances were rare and localized.

•2023: As solar activity increased, the probability of S4 disturbances rose, with more widespread effects.

•2024: Solar activity neared its peak, leading to higher and more widespread S4 disturbances, especially in equatorial regions influenced by plasma irregularities.

References

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