IGS 2026 WORKSHOP
SANTIAGO DE CHILE
33°26' S 70°39' O

1-5 June 2026

*João F. Galera Monico (UNESP) – galera.monico@unesp.br
Vinícius A. Stuani Pereira (UTFPR)
Guilherme P. S. Rosa (UNESP)
Ítalo Tsuchiya (UNESP)
Milton H. Shimabukuro (UNESP)
Bruno C. Vani (IFSP)
Felipe Tintino (UNESP)
Lucas G. Ferreira (UNESP)

The legacy of the INCT GNSS NavAer: historic, infrastructure and data set

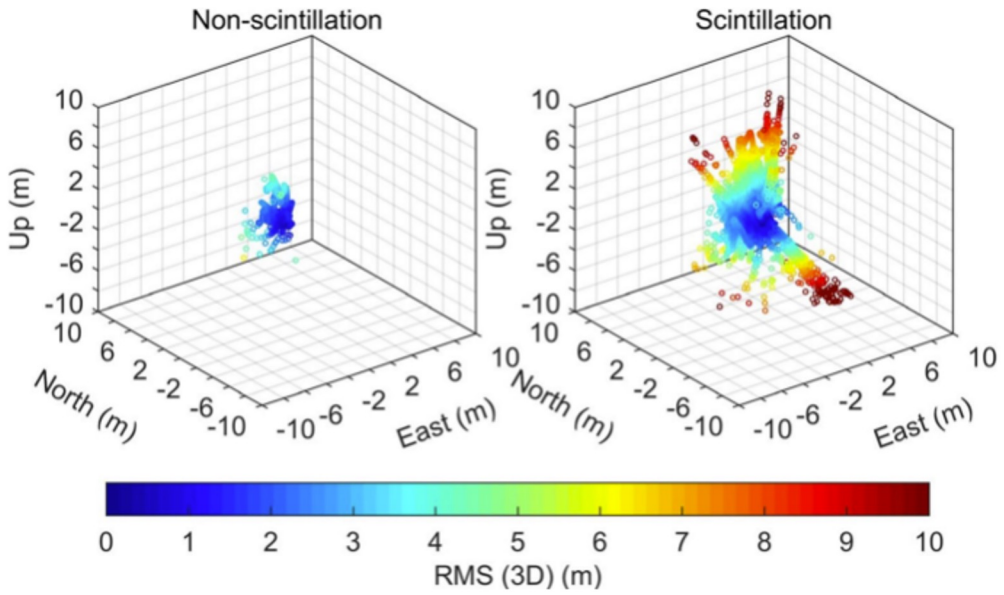
CONTENTS

- Challenge: Ionospheric Scintillation
- INCT GNSS NavAer Network
- ISMR Query Tool
  - Products
- Public GBAS Data Set
- Final Comments

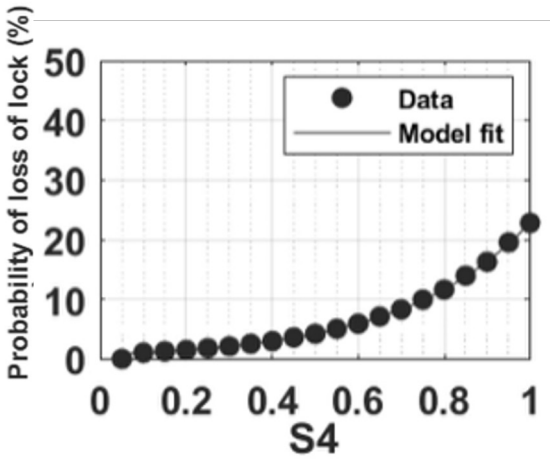
The challenge of the Low-latitude Ionospheric scintillation (IS) for GNSS

IS of GNSS signals at low latitudes is caused by <u>diffraction</u> resulting from small-scale irregularities embedded within Equatorial Plasma Bubbles (EPB).

Scintillation poses a significant threat to the performance of GNSS-dependent services that require real-time, high-precision positioning."



Luo et al., GPS Solutions (2018)
DOI 10.1007/s10291-018-0728-8



Vadakke Veettil, S., & Aquino, M. (2021). *GPS Solutions*, *25*(2), 1-12.

Amplitude scintillation, S4 index:

$$S_4 = \sqrt{\frac{(\langle I^2 \rangle - \langle I \rangle^2)}{\langle I \rangle^2}}$$

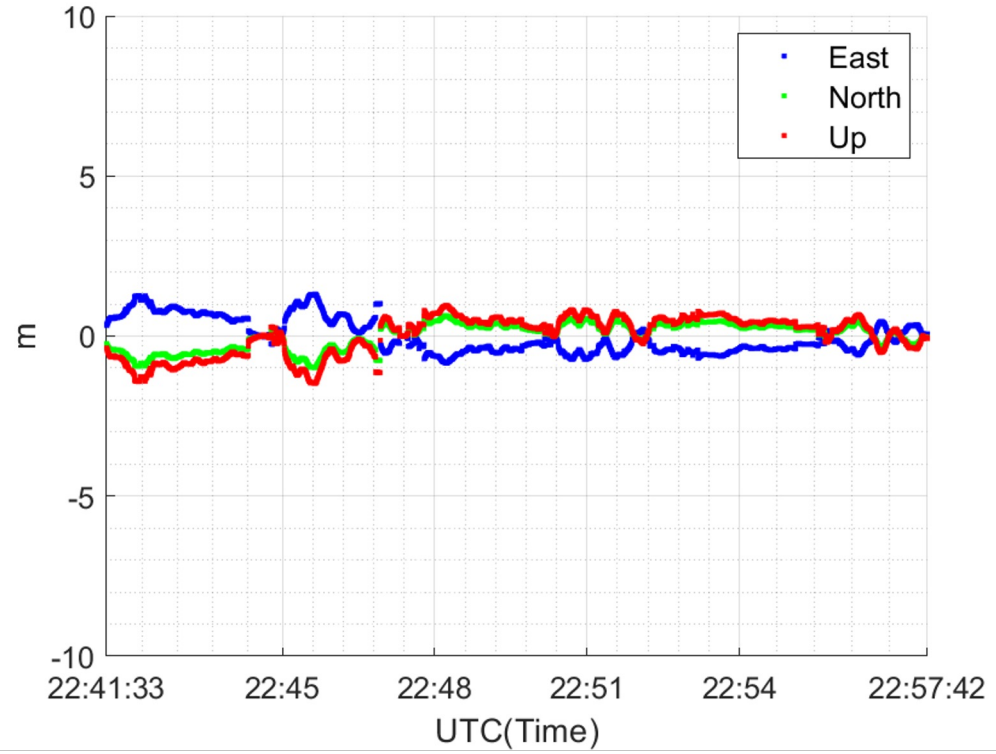
I = Signal Intensity

Phase scintillation, SigmaPhi index:

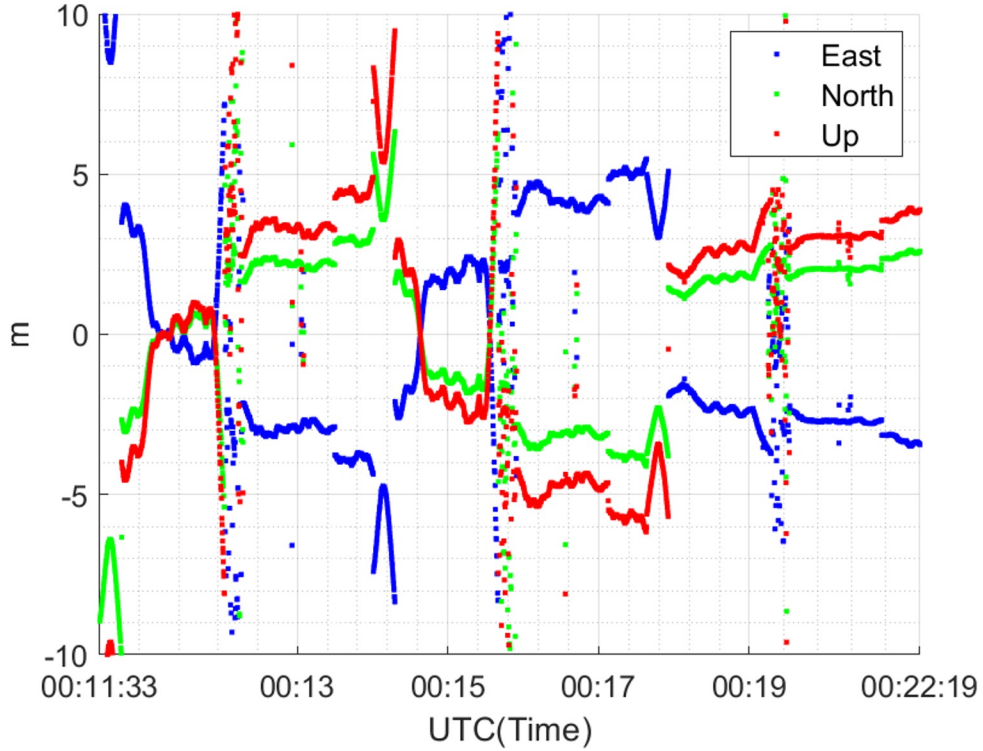
$$\sigma_\varphi = \sqrt{\langle \sigma_e^2 \rangle - \langle \sigma_e \rangle^2}$$

UAV GBAS Experiment: GBAS position errors

145/2023: low scintillation



321/2023: high scintillation



We can observe the great degradation in the position quality due to IS.

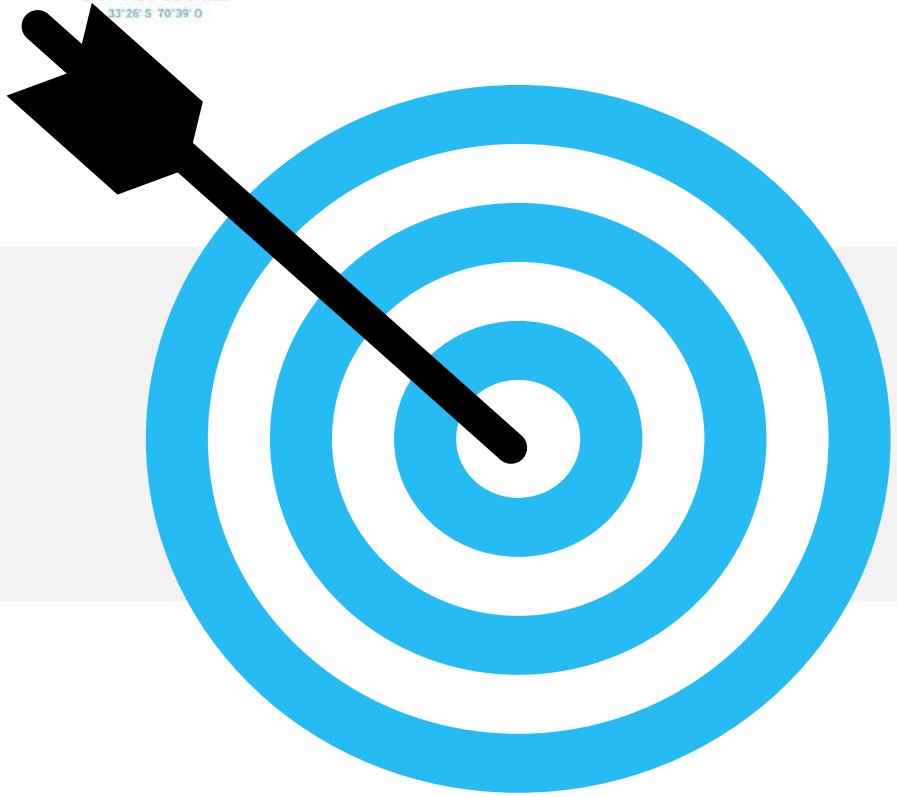
INCT GNSS NavAer

National Institute of Science and Technology: GNSS Technology for Supporting Air Navigation – started Jan 2017 and finished June 2025

- Brazilian institutes

Sponsors

GOALS OF GNSS NAVAER

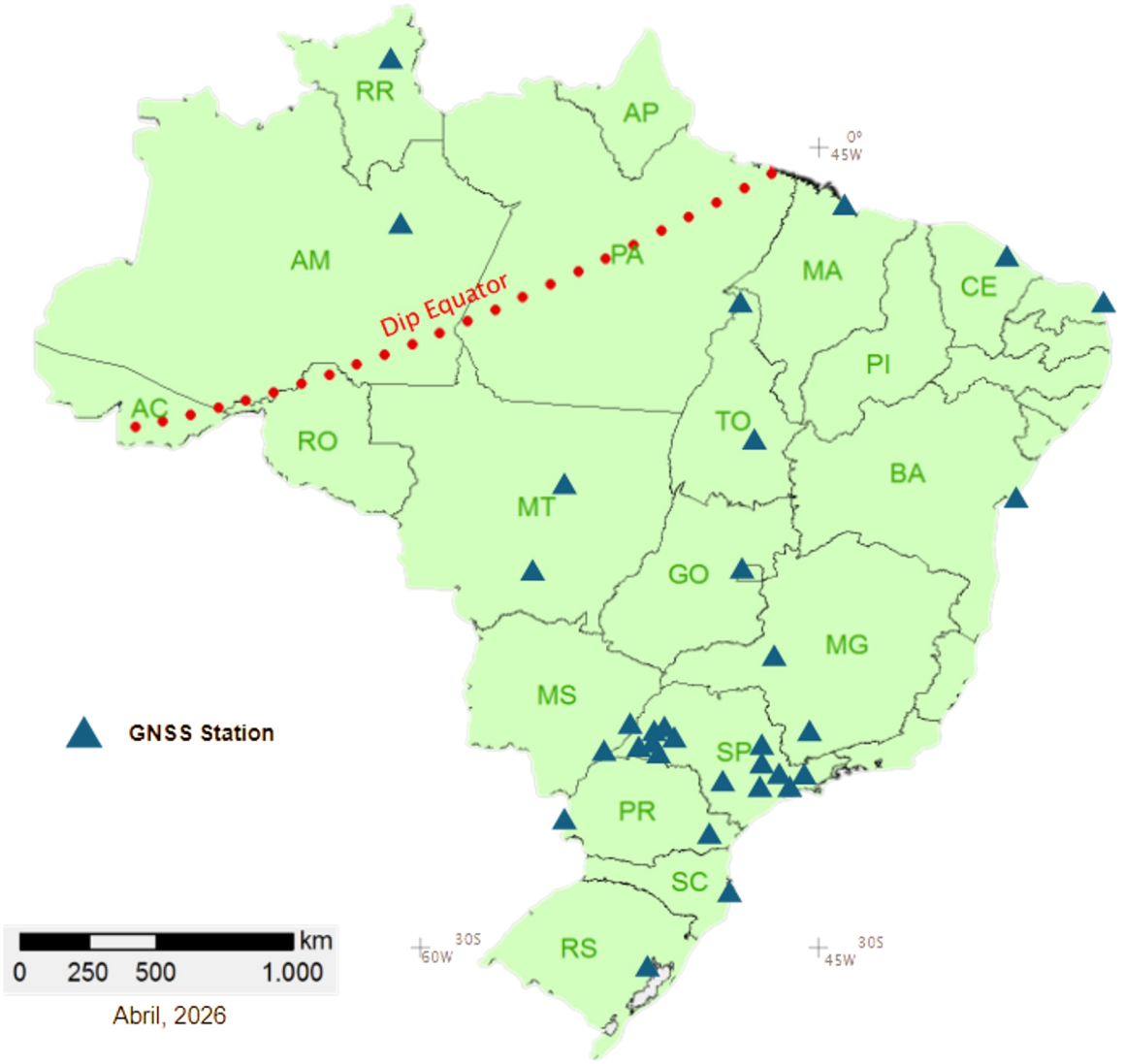


Research	Society	HR	Business
Ionosphere effects on GNSS	Knowledge transfer to society	Developing human resources	Knowledge transfer to industry and public sector

INCT GNSS NavAer (Project) Network

42
Stations

~220
TBytes



Expansion and Modernization of CIGALA & CALIBRA Network, started in 2011

FP7 Program

INCT GNSS NavAer Network

- Strategic placement of new stations, including Boa Vista in the Amazon region.
- Deployment of state-of-the-art PolaRx5 receivers manufactured by Septentrio.
- Advanced capabilities for high-precision data collection up to 100 Hz (we use 50 Hz).

PolaRx5s

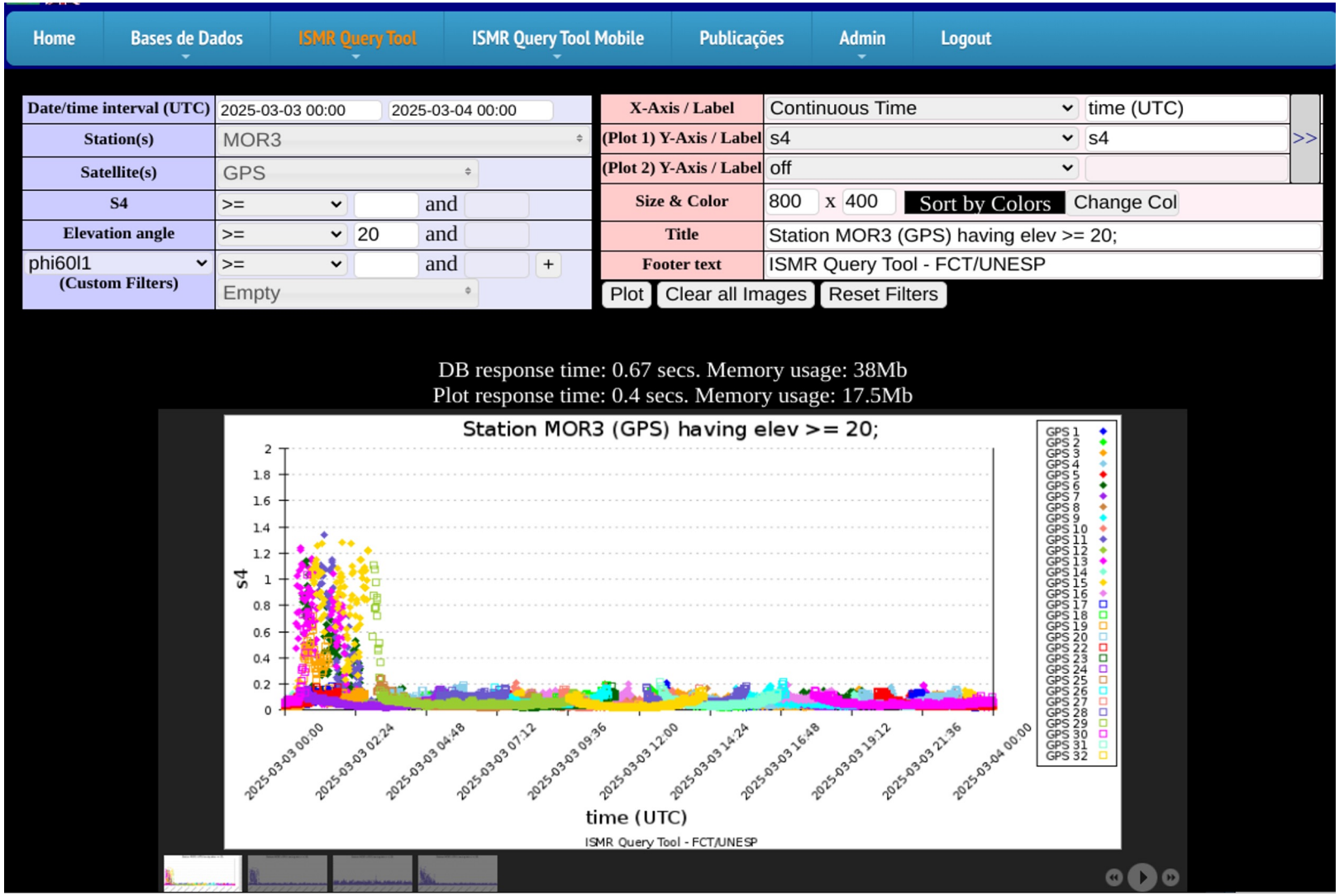
Station Boa Vista in the Amazon Region

ISMR Query Tool - Legacy Version (available since 2011)

Provides IS parameters from the dataset

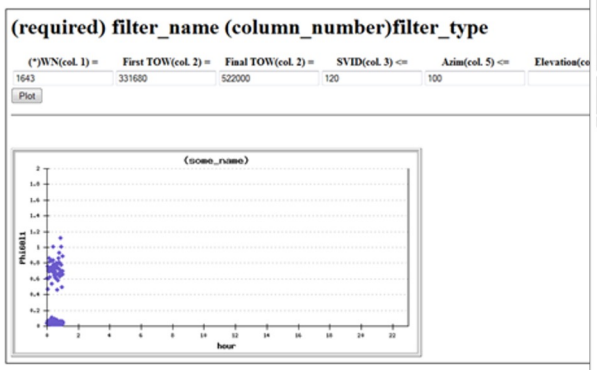
Online service supporting research

~4TB

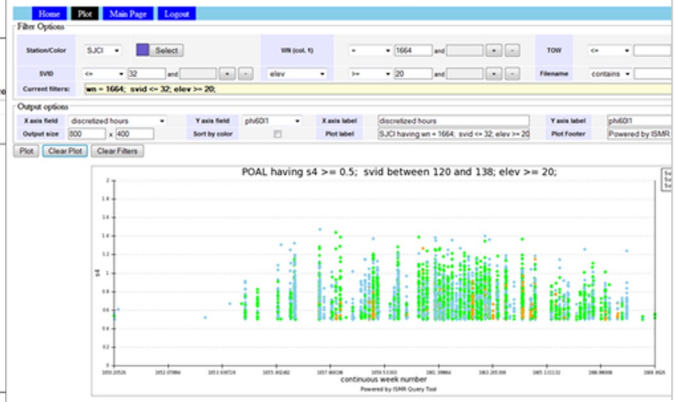


Evolution of the ISMR Query Tool - Legacy version

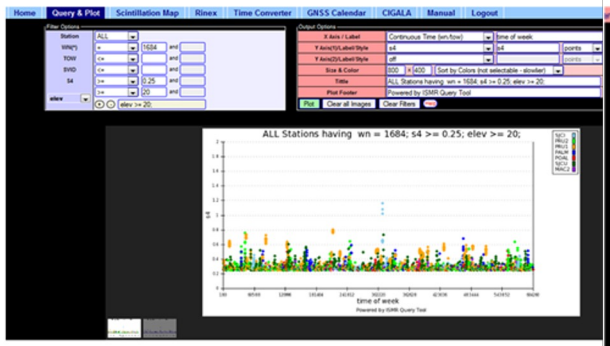
October 2011



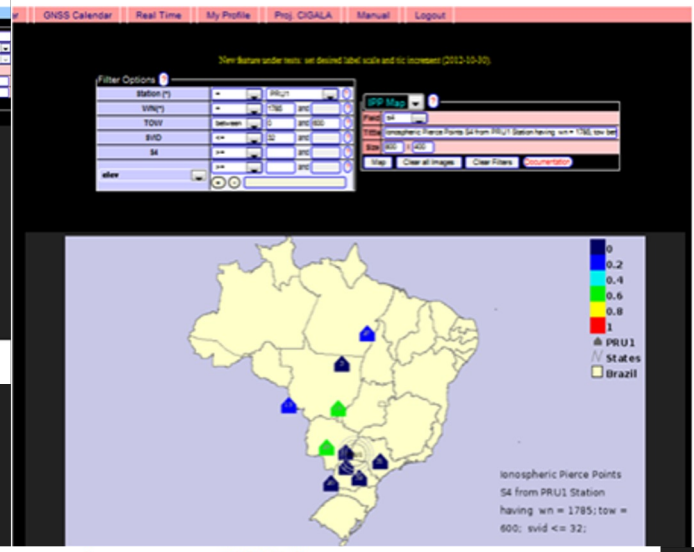
January 2012



April 2012

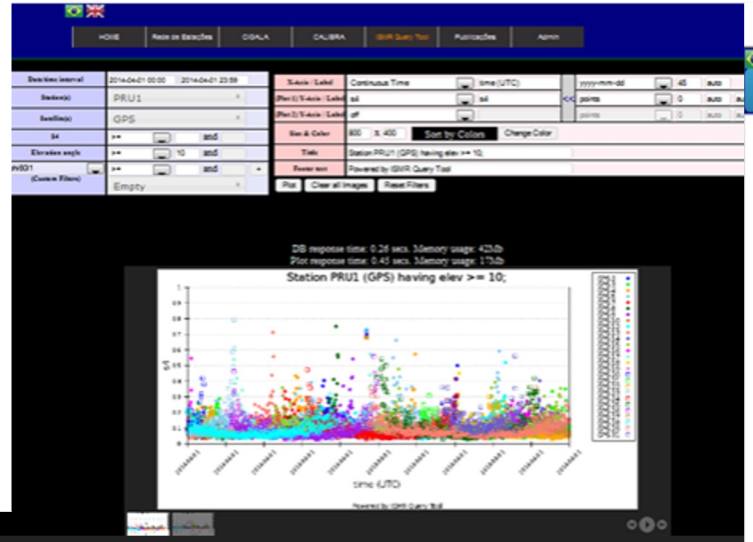


July 2012

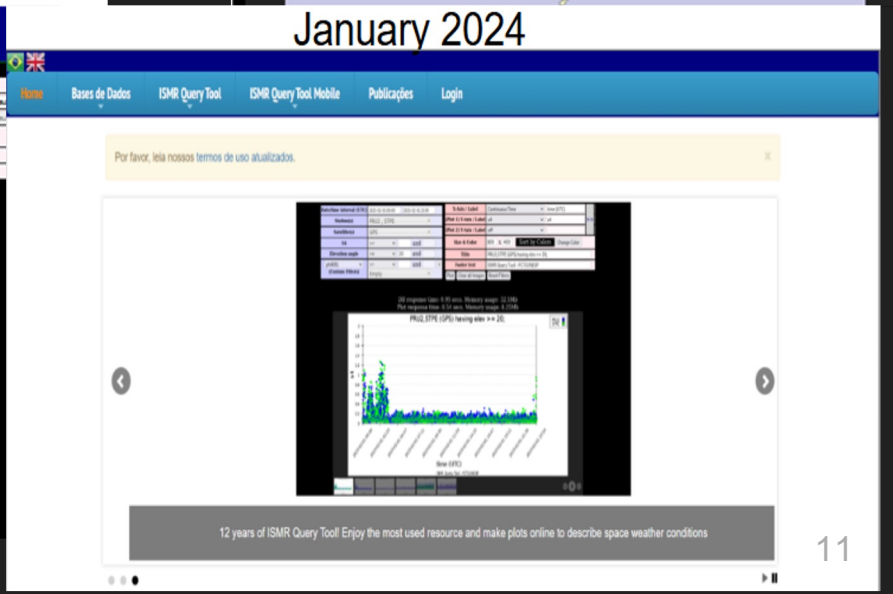


February 2013

May 2013



January 2024



Spatial analysis – scintillation maps

- Data projected on IPP allow the generation of different scintillation maps
- Example show the standard deviation of S4 index for a two-weeks period under strong scintillation occurrence

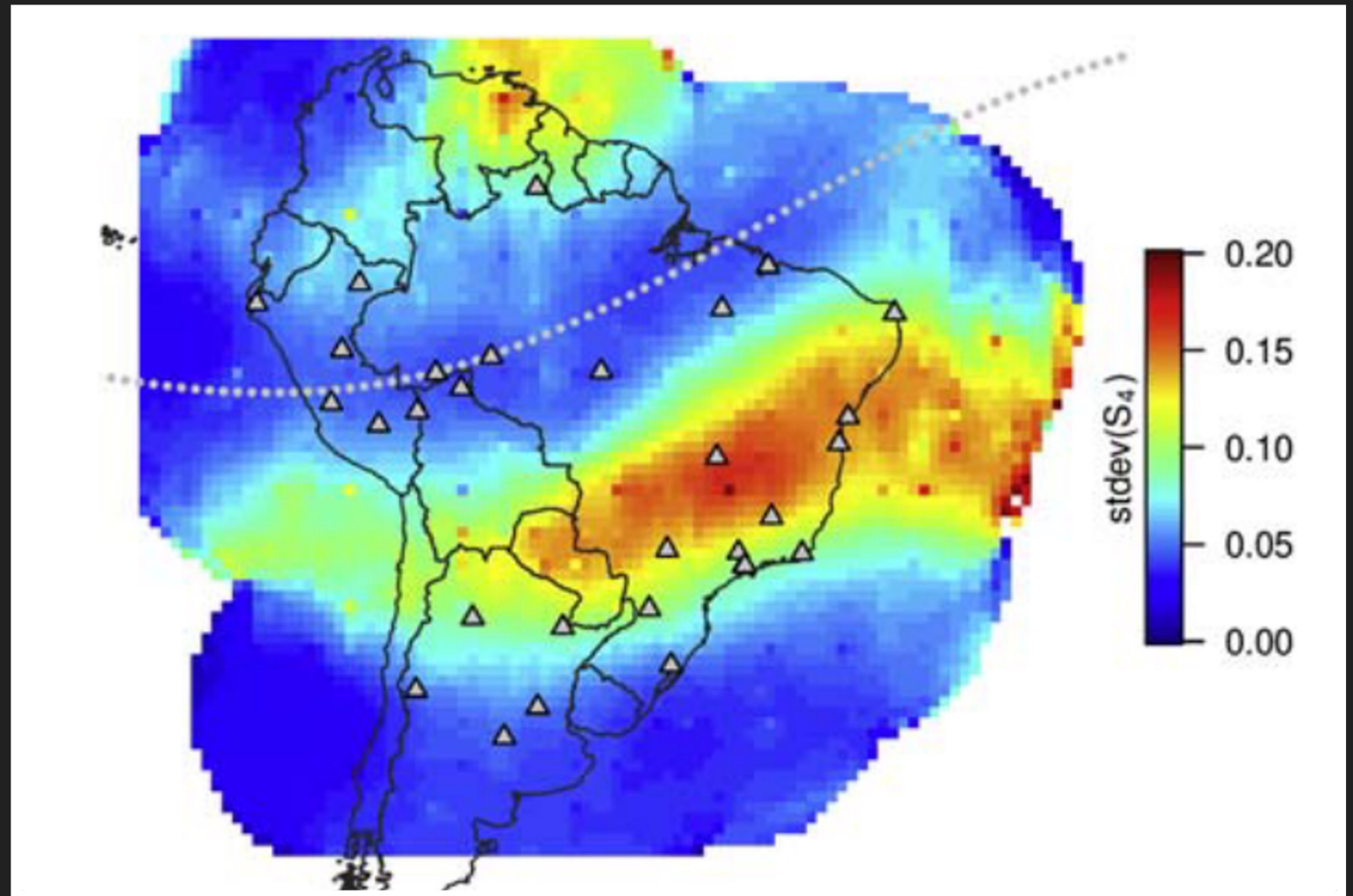


FIGURE 13.4 Standard deviation (stdev) of S_4 index considering the nighttime period (21:00 to 03:00 UT) in the first 2 weeks of November 2014 (multiconstellation case, elevation mask of 10 degrees).

ELSEVIER

GPS and GNSS Technology in Geosciences

2021, Pages 255-280

Chapter 13 - Monitoring ionospheric scintillations with GNSS in South America: scope, results, and challenges

Bruno César Vani [1], Alison de Oliveira Moraes [2], Lucas Alves Salles [3], Victor Hugo Fernandes Breder [3], Moisés José dos Santos Freitas [3], João Francisco Galera Monico [4], Eurico Rodrigues de Paula [5]

Show more

+ Add to Mendeley Share Cite

https://doi.org/10.1016/B978-0-12-818617-6.00012-3

Get rights and content

Inferences on solar cycle progression

- Interactive calendar views allow to:
  - Analyse effects of scintillation associated to solar cycle progression
  - Seasonal variations
  - Quick analysis of data availability by station

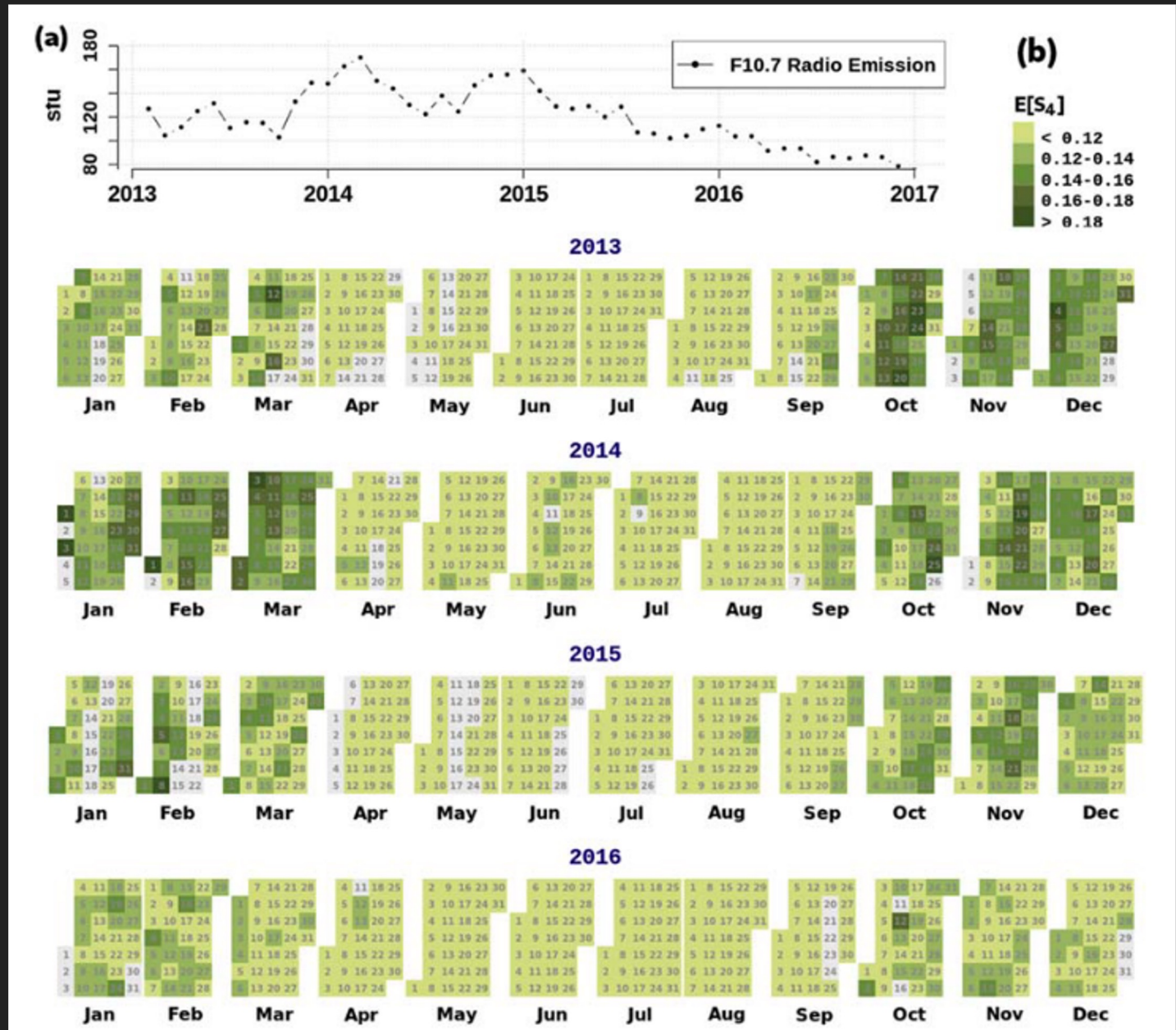
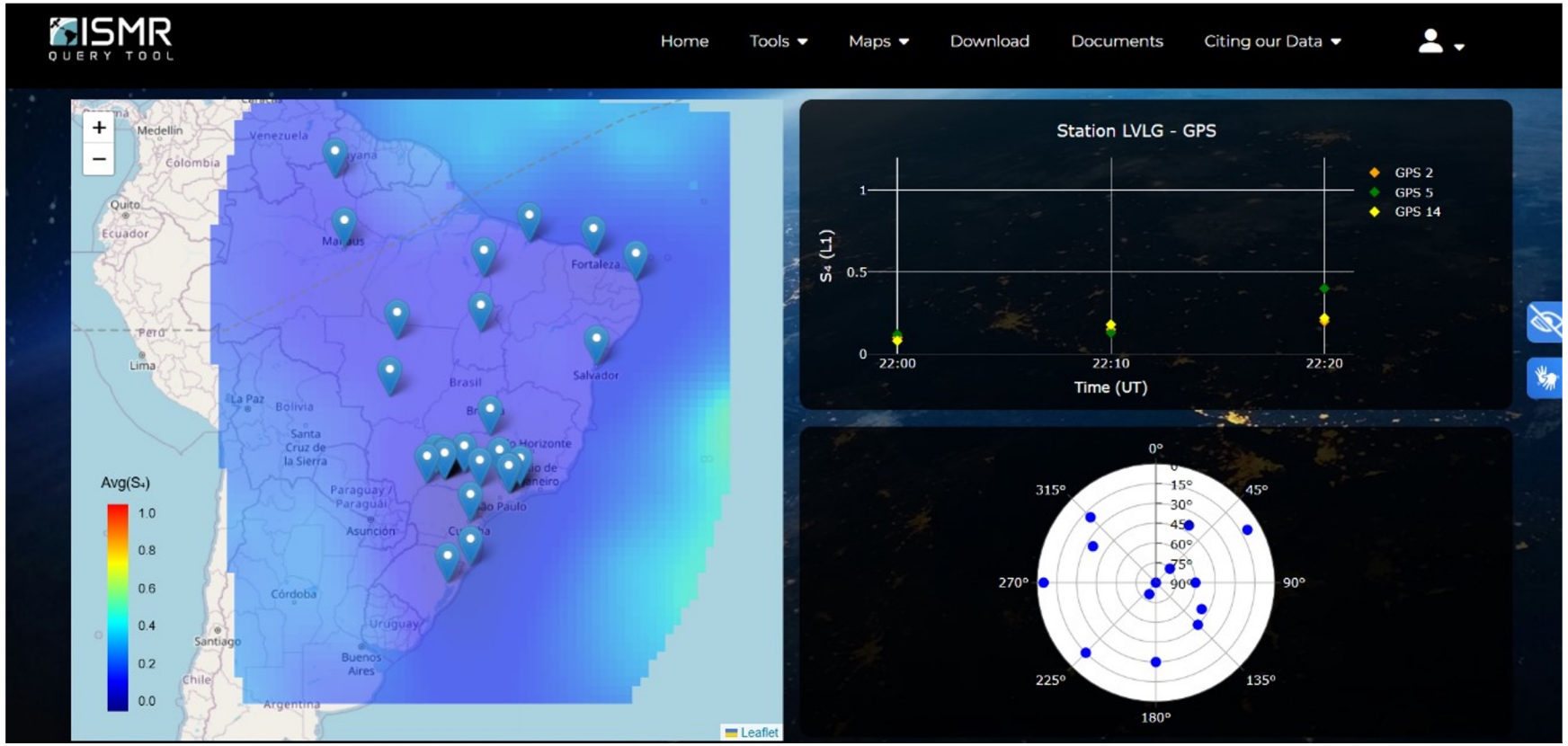


FIGURE 13.2 (A) F10.7 index for the 2013–16 period. (B) Daily averaged S_4 index for PRU2 station in the same period.

Paper available at: https://doi.org/10.1016/B978-0-12-818617-6.00012-3

ISMR Query Tool - New version

Security, performance and accessibility improvements
Updates in the software architecture: front and back ends



- Filtre os dados à esquerda e personalize o gráfico à direita

Início (UTC): 15/12/2025, 18:00:00

Fim (UTC): 16/12/2025, 06:00:00

Estações: CTAS

Satélites: GPS

Sinal: Sig1

S4 (Sig1): >= 0.3

Elevação: >= 10

Outros campos: + Adicionar campo

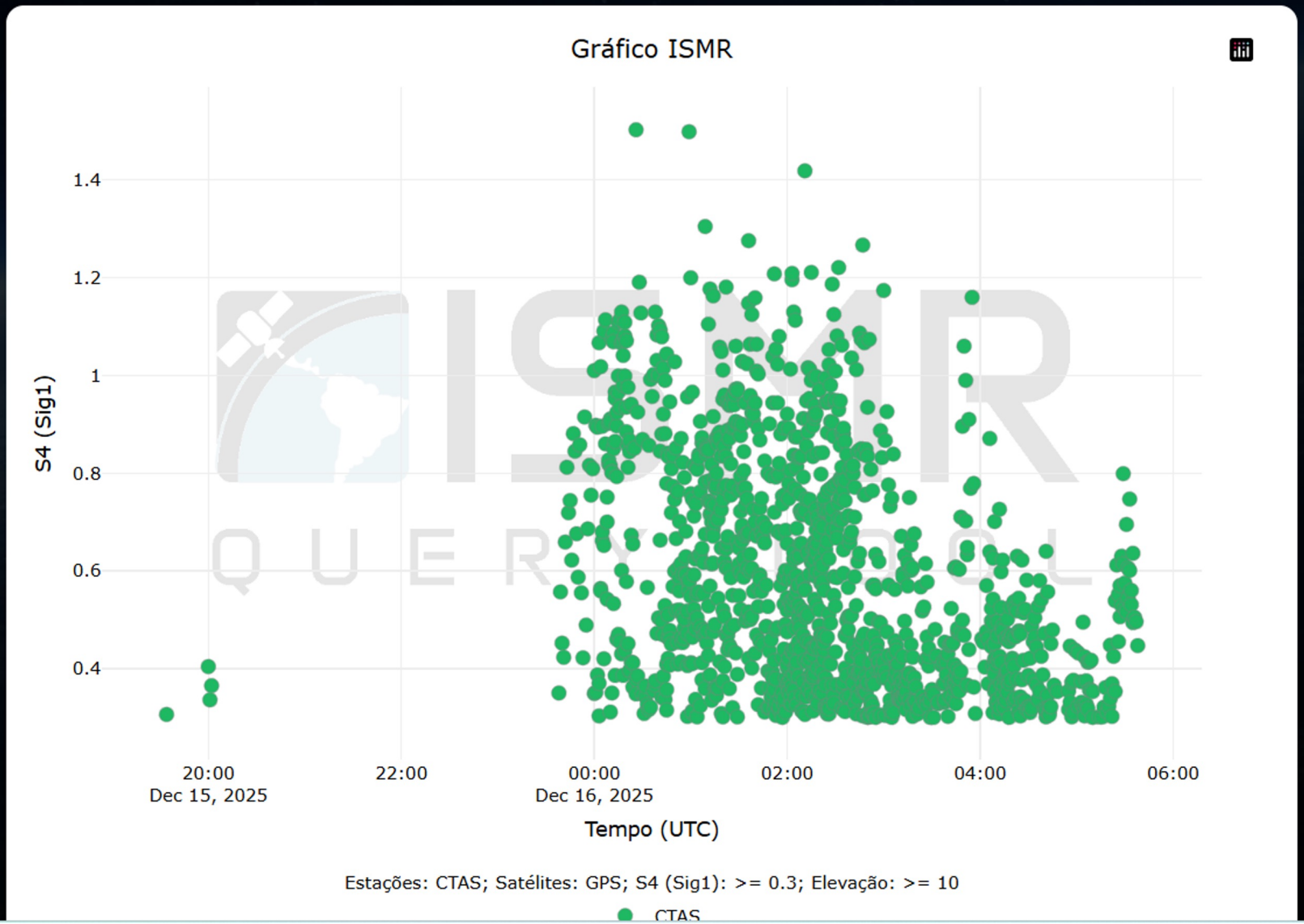
Título: Gráfico ISMR

Eixo X: Tempo (UTC)

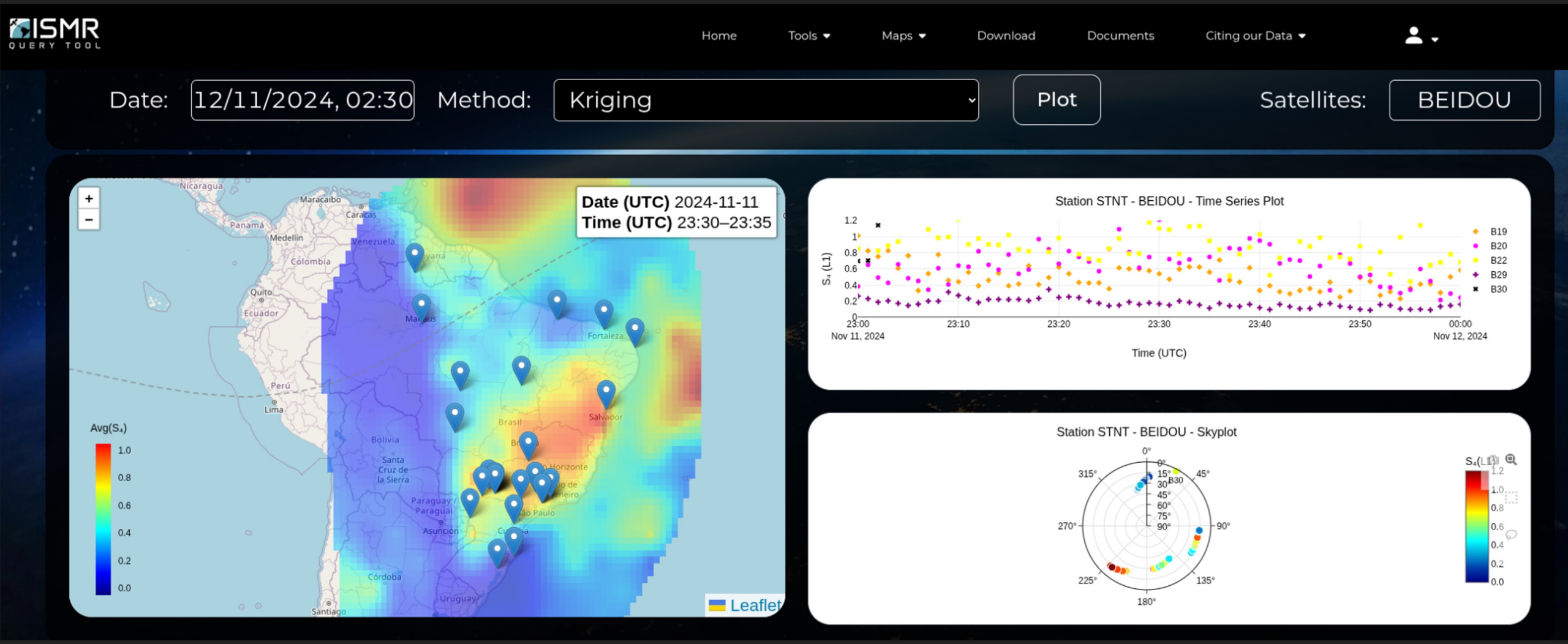
Eixo Y: S4 (Sig1)

Destacar satélites

Plotar



Scintillation Map



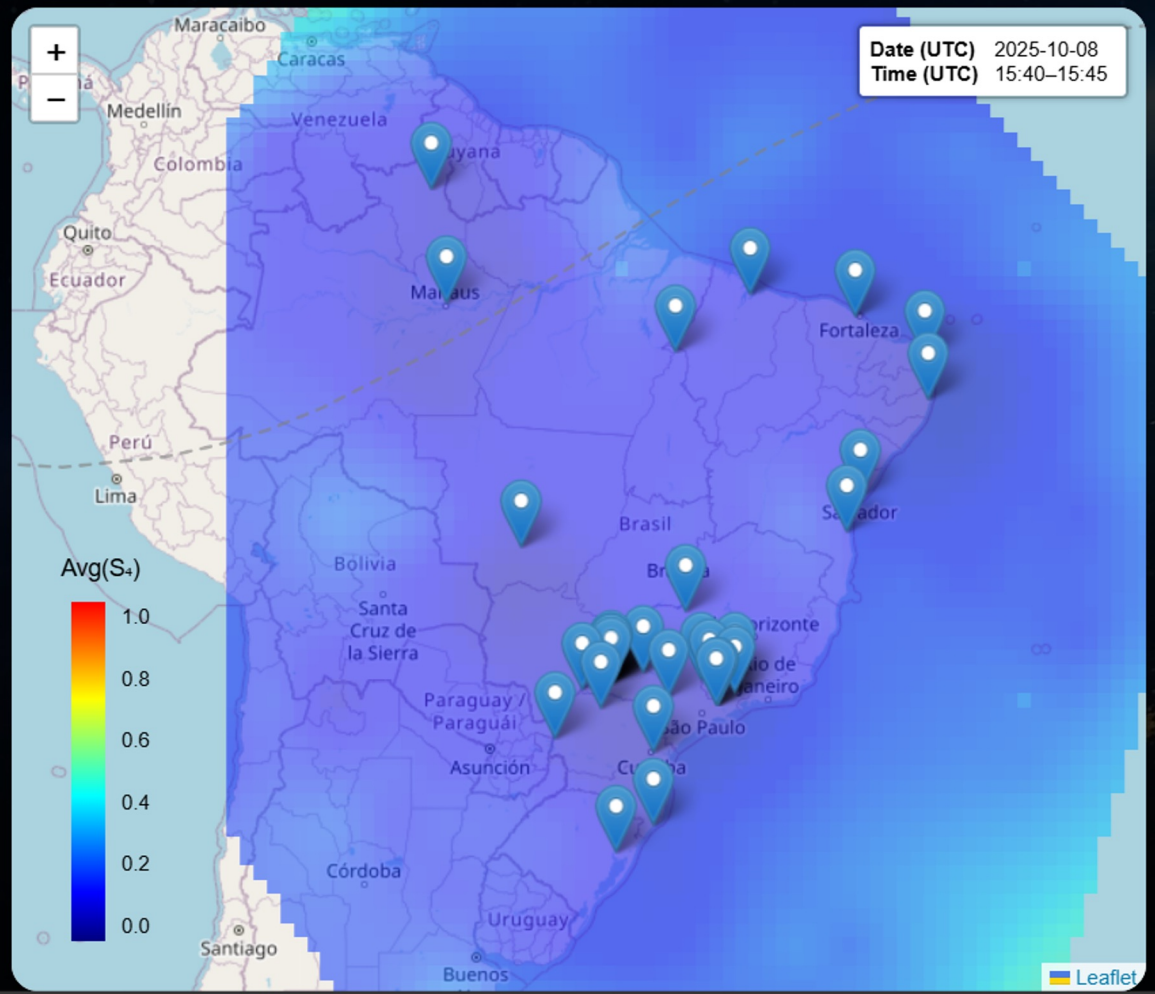
Users can use the interactive viewer by clicking on the station markers

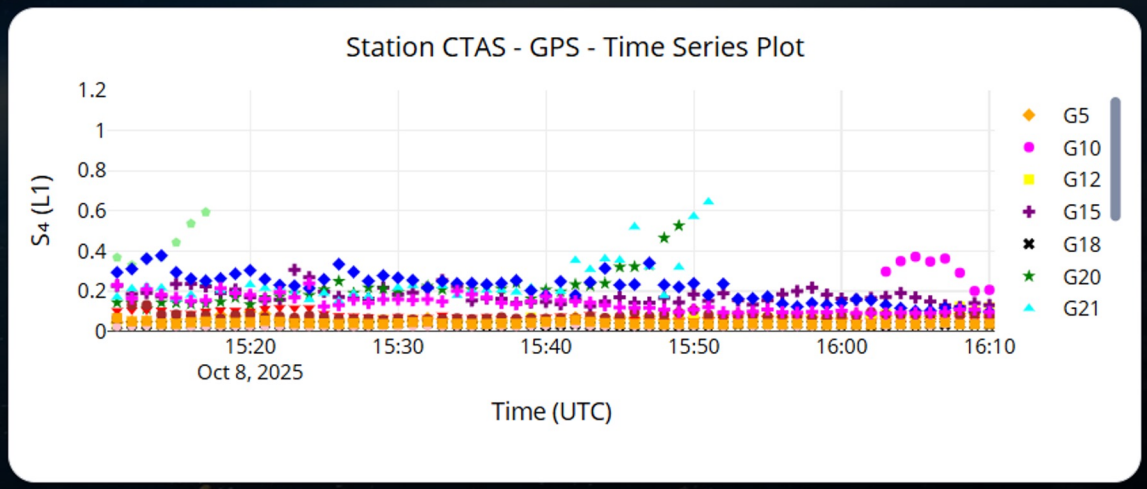
Scintillation Map

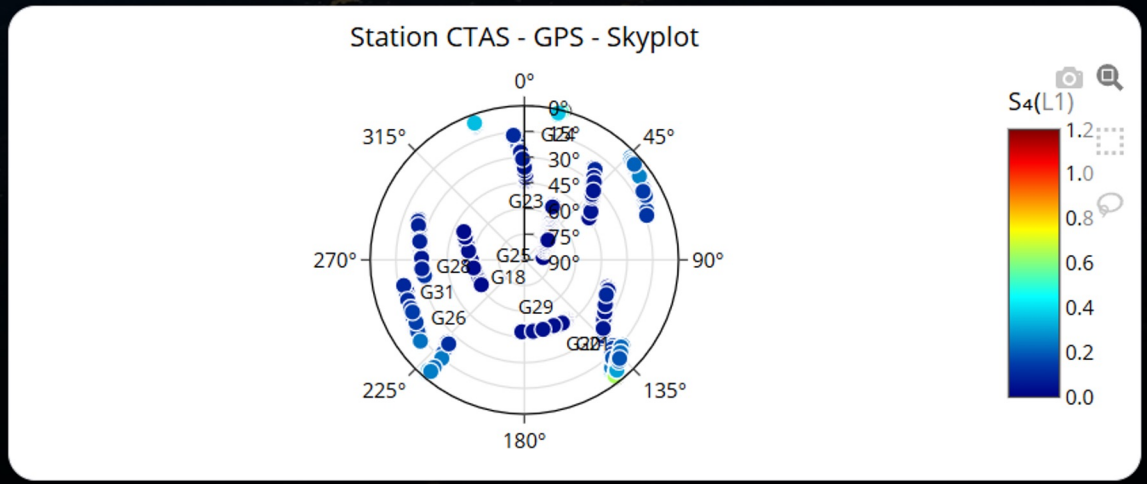
ISMR QUERY TOOL

Home | Tools | Maps | Download | Documents | Citing our Data

Date: 08/10/2025, 18:40 Method: Kriging Plot Satellites: GPS







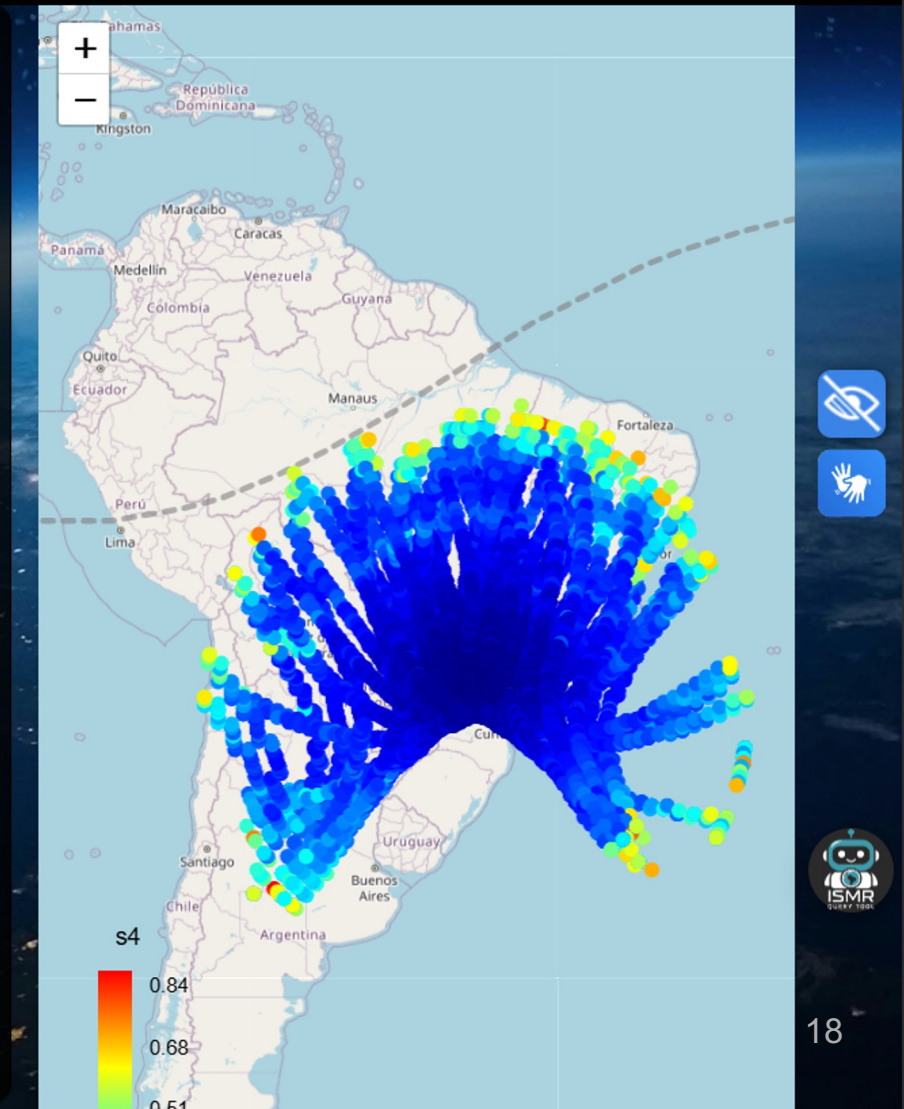
IPP Map

ISMR QUERY TOOL

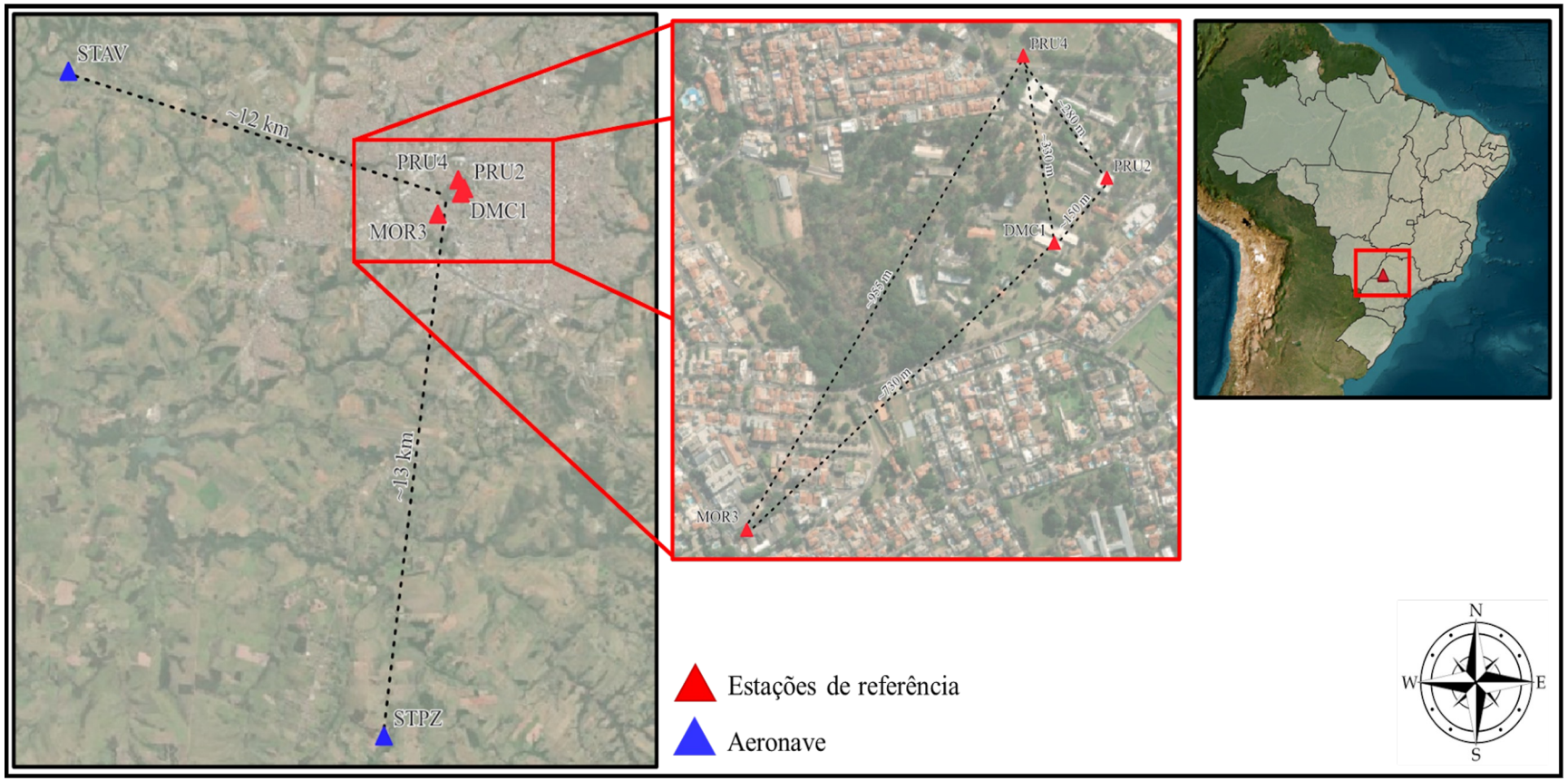
Home | Tools | Maps | Download | Documents | Citing our Data

Start (UTC):	07/10/2025, 18:42:00
End (UTC):	08/10/2025, 18:42:00
Stations:	CTAS
Satellites:	GPS
S4 (L1):	>= 0
Elevation:	>= 0
Other fields:	+ Add field
Field:	s4
Aggregation:	None
Grid Resolution / Threshold:	1 / 0
Mag. Equator Thickness:	3,5
Ionosphere Height (Km):	400 km
Point size:	4
Color Scale Range (Optional):	Min / Max

Plot



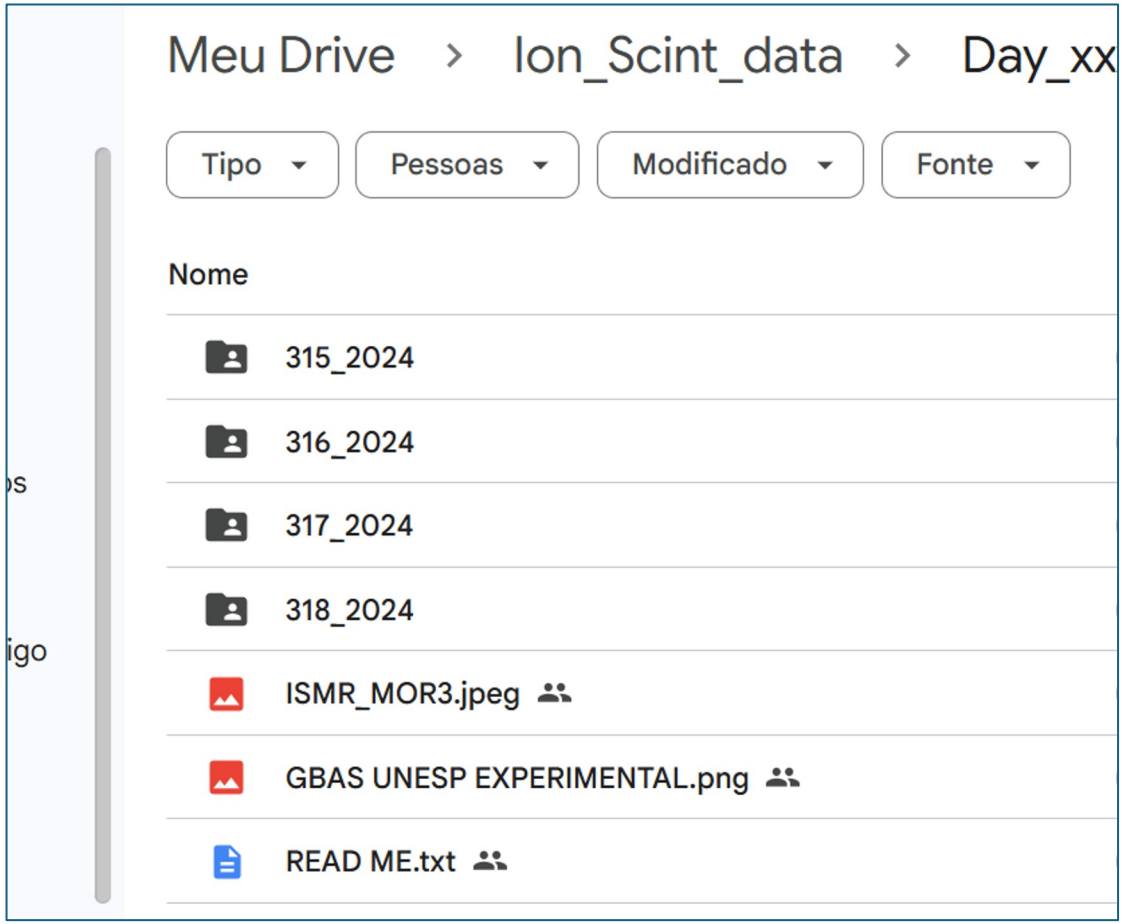
GBAS UNESP EXPERIMENTAL STUDY (ongoing)

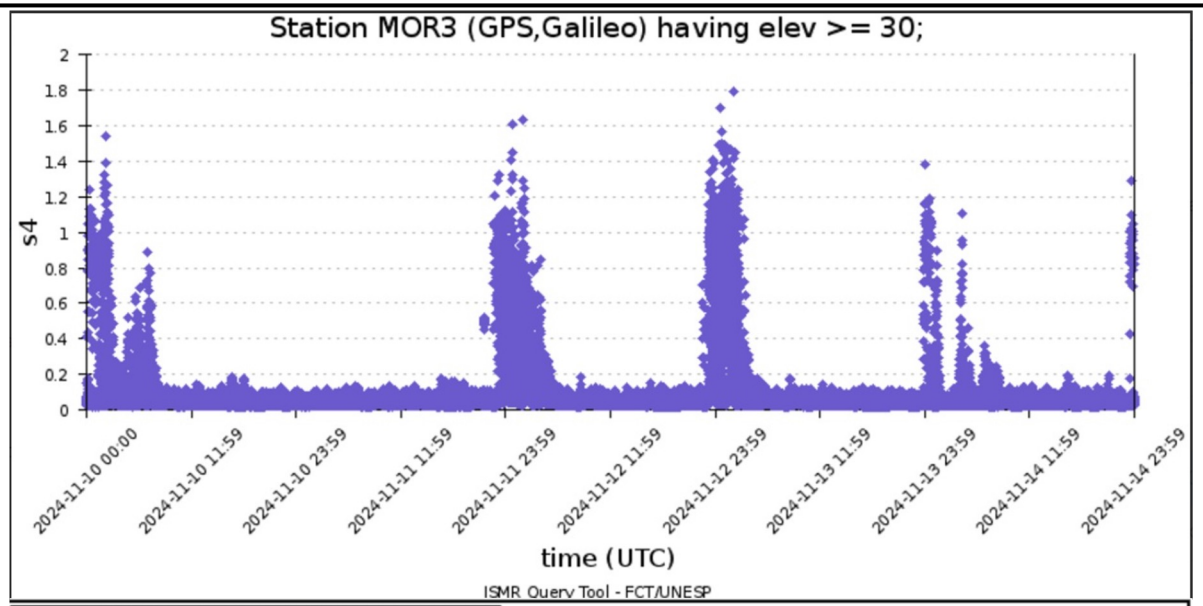


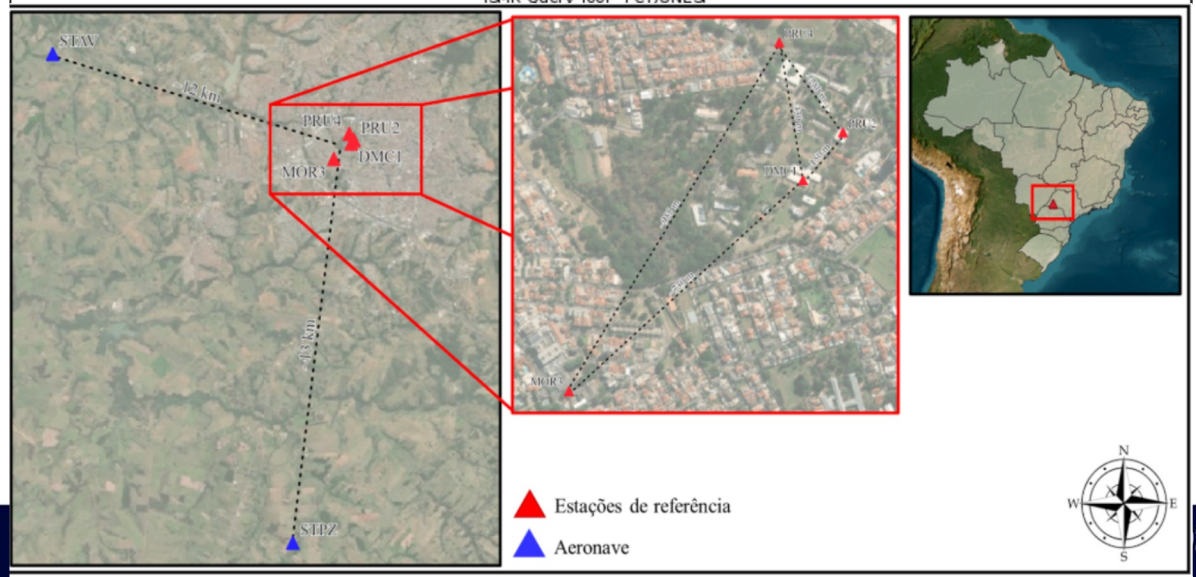
- GBAS monitoring station.
- GBAS DFDC: GPS (L1/L5) and Galileo E1/E5a.
- Simulation of aircraft (in static mode) located around 13 km from the (fictitious) landing point and UAVs flight.

- Purposes: analyzing ionospheric gradients, linear combinations, integrity monitors, adjustment and quality control in positioning, protection levels, etc.

Data set for the community to perform tests of interest

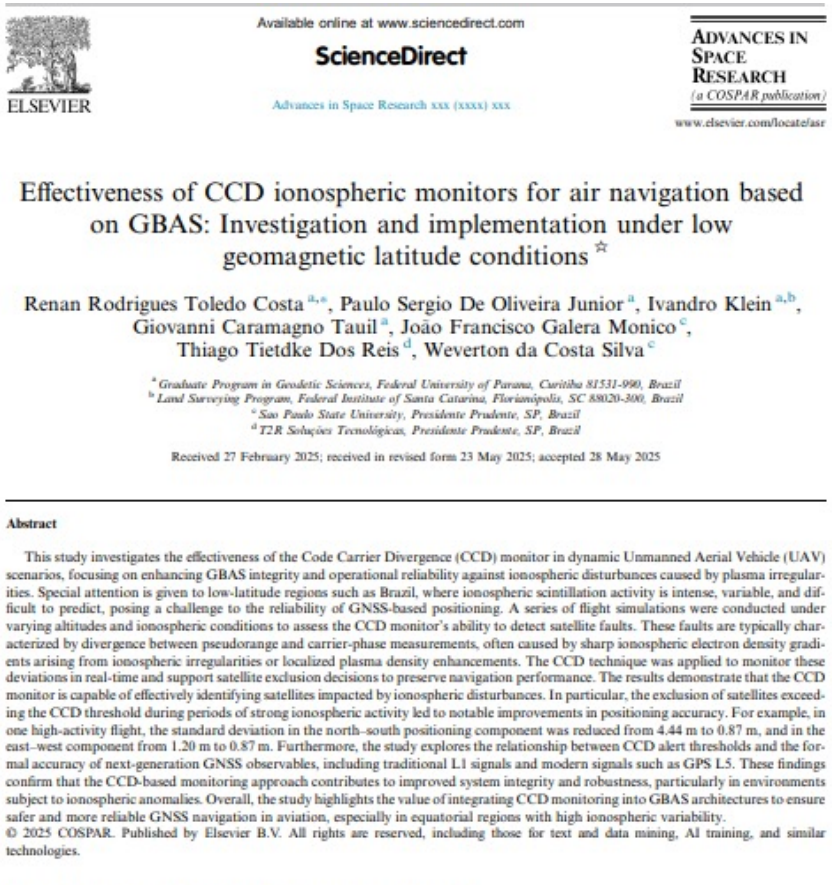






Experiment: GBAS in Kinematic Mode

GBAS performance study for UAV



Available online at www.sciencedirect.com
ScienceDirect
Advances in Space Research xxx (xxxx) xxx
ADVANCES IN SPACE RESEARCH (a COSPAR publication)
www.elsevier.com/locate/asr

Effectiveness of CCD ionospheric monitors for air navigation based on GBAS: Investigation and implementation under low geomagnetic latitude conditions ☆

Renan Rodrigues Toledo Costa [a,*], Paulo Sergio De Oliveira Junior [a], Ivandro Klein [a,b], Giovanni Caramagno Tauil [a], João Francisco Galera Monico [c], Thiago Tietdke Dos Reis [d], Weverton da Costa Silva [c]

[a] Graduate Program in Geodetic Sciences, Federal University of Parana, Curitiba 81531-990, Brazil
[b] Land Surveying Program, Federal Institute of Santa Catarina, Florianópolis, SC 88020-300, Brazil
[c] Sao Paulo State University, Presidente Prudente, SP, Brazil
[d] T2R Soluções Tecnológicas, Presidente Prudente, SP, Brazil

Received 27 February 2025; received in revised form 23 May 2025; accepted 28 May 2025

Abstract

This study investigates the effectiveness of the Code Carrier Divergence (CCD) monitor in dynamic Unmanned Aerial Vehicle (UAV) scenarios, focusing on enhancing GBAS integrity and operational reliability against ionospheric disturbances caused by plasma irregularities. Special attention is given to low-latitude regions such as Brazil, where ionospheric scintillation activity is intense, variable, and difficult to predict, posing a challenge to the reliability of GNSS-based positioning. A series of flight simulations were conducted under varying altitudes and ionospheric conditions to assess the CCD monitor's ability to detect satellite faults. These faults are typically characterized by divergence between pseudorange and carrier-phase measurements, often caused by sharp ionospheric electron density gradients arising from ionospheric irregularities or localized plasma density enhancements. The CCD technique was applied to monitor these deviations in real-time and support satellite exclusion decisions to preserve navigation performance. The results demonstrate that the CCD monitor is capable of effectively identifying satellites impacted by ionospheric disturbances. In particular, the exclusion of satellites exceeding the CCD threshold during periods of strong ionospheric activity led to notable improvements in positioning accuracy. For example, in one high-activity flight, the standard deviation in the north–south positioning component was reduced from 4.44 m to 0.87 m, and in the east–west component from 1.20 m to 0.87 m. Furthermore, the study explores the relationship between CCD alert thresholds and the formal accuracy of next-generation GNSS observables, including traditional L1 signals and modern signals such as GPS L5. These findings confirm that the CCD-based monitoring approach contributes to improved system integrity and robustness, particularly in environments subject to ionospheric anomalies. Overall, the study highlights the value of integrating CCD monitoring into GBAS architectures to ensure safer and more reliable GNSS navigation in aviation, especially in equatorial regions with high ionospheric variability.

Real-time System for Scintillation Monitoring

Real time monitoring of ionospheric scintillation in Brazil

- Real-time system for the generation and online dissemination of amplitude (**S4**) and phase (**σφ**) scintillation maps.
- Data processing are divided into three steps: **remote data acquisition**, **interpolation**, and **image rendering**.
- **Key concept**: establish a **pipeline** for performing data processing asynchronously in the real-time server.

Real-time Amplitude

localhost:8501

INPE Instituto Nacional de Pesquisas Espaciais

Scintillation Monitoring Project

- Home
- Ionospheric Scintillation
- Scintillation Maps
- Probability Maps
- GNSS monitoring stations

Real-Time Scintillation Maps

- **Amplitude (S4)**
- Phase (σφ)

Real-Time Scintillation Probability Maps

- Amplitude (S4)
- Phase (σφ)

Map options

- [ ] Real-time monitoring
- [ ] Show GNSS stations
- [ ] Show DIP latitude

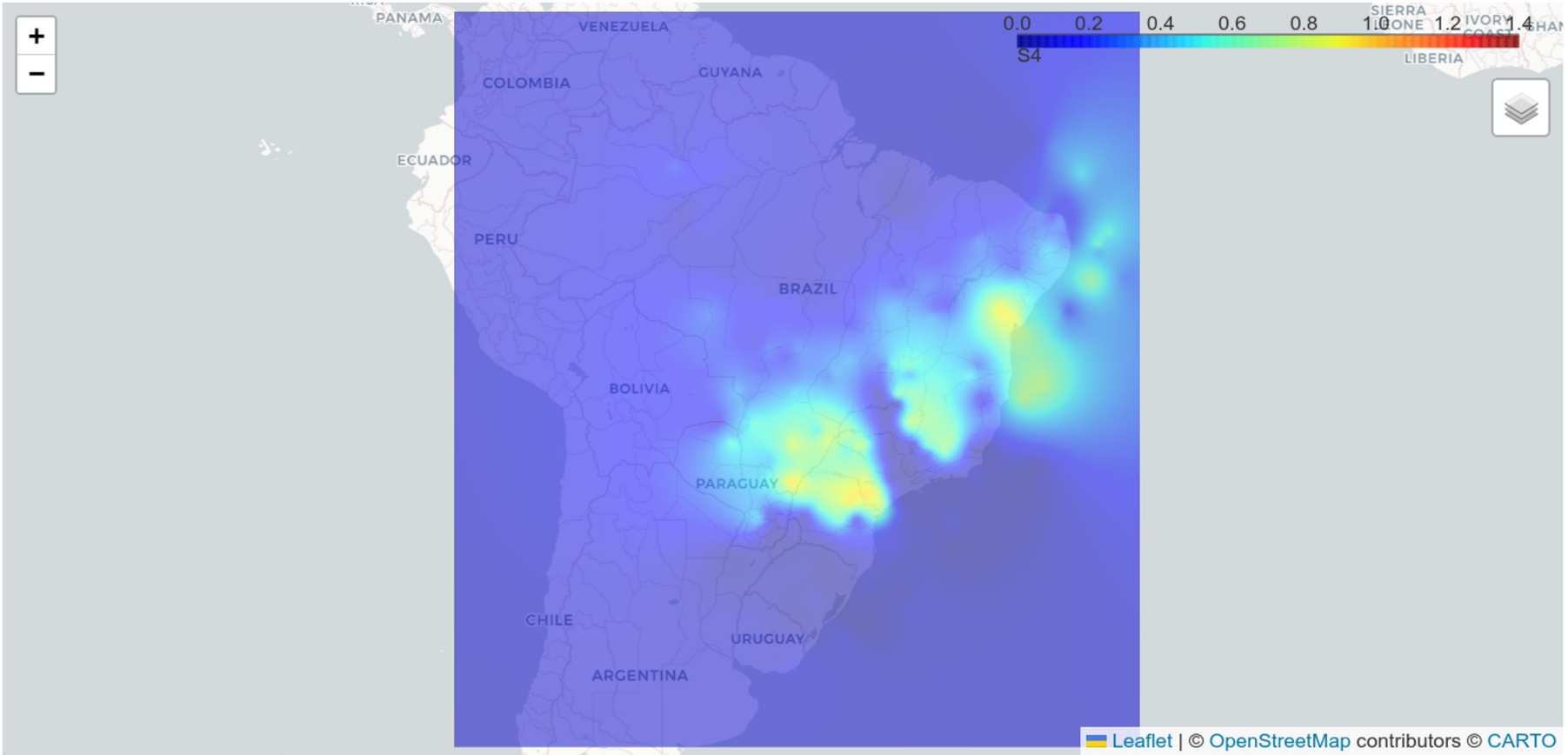
Contact: André R. F. Martinon

andre.martinon@inpe.br

Real-time monitoring - Amplitude Scintillation Map

2023/03/14 - 00:25 UT

2023/03/13 - 20:45 UT — 2023/03/14 - 01:30 UT



INPE Instituto Nacional de Pesquisas Espaciais

Scintillation Monitoring Project

- Home
- Ionospheric Scintillation
- Scintillation Maps
- Probability Maps
- GNSS monitoring stations

Real-Time Scintillation Maps

- Amplitude (S4)
- **Phase (σϕ)**

Real-Time Scintillation Probability Maps

- Amplitude (S4)
- Phase (σϕ)

Map options

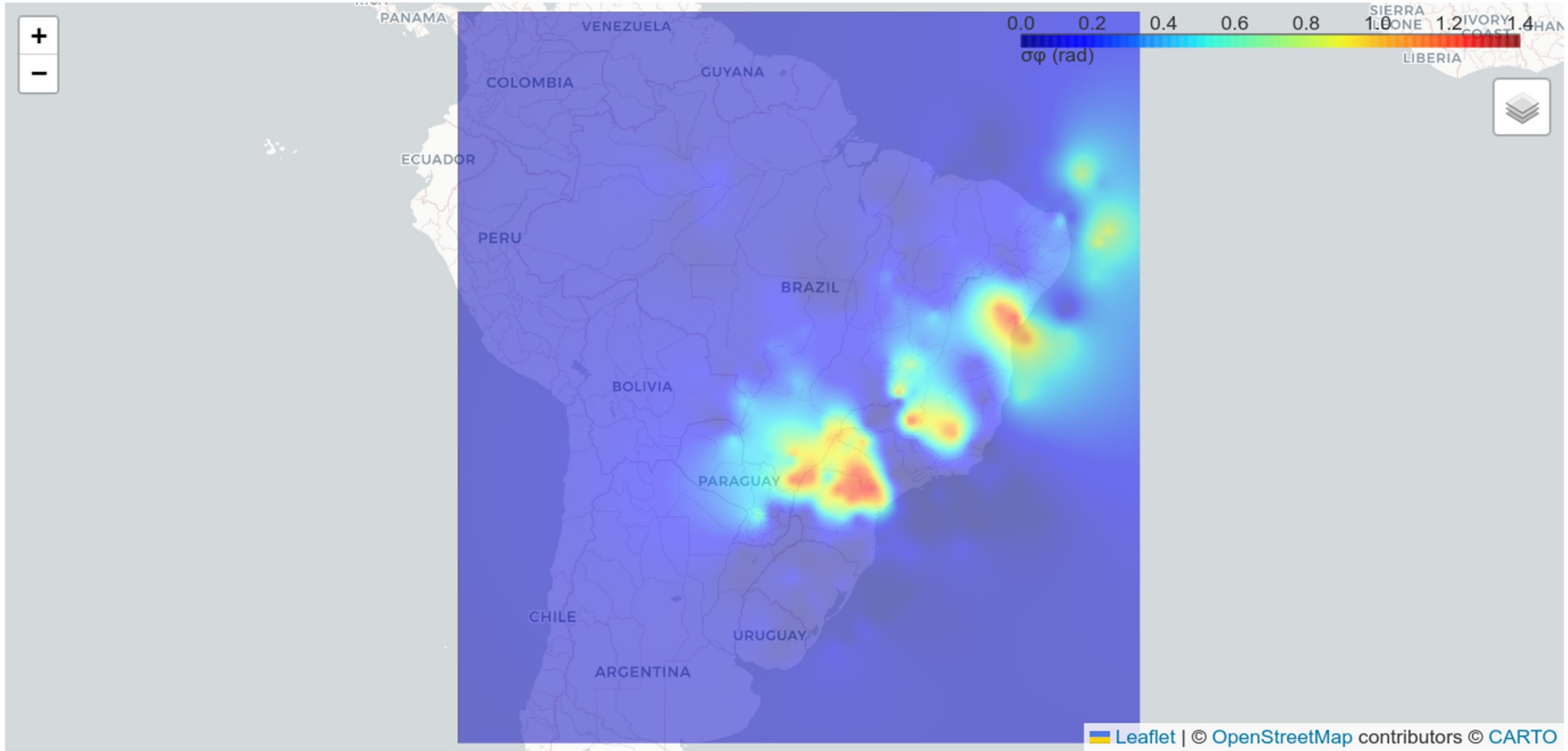
- [ ] Real-time monitoring
- [ ] Show GNSS stations
- [ ] Show DIP latitude

Contact: André R. F. Martinon
andre.martinon@inpe.br

Real-time monitoring - Phase Scintillation Map

2023/03/14 - 00:25 UT

2023/03/13 - 20:45 UT — 2023/03/14 - 01:30 UT



Probability Scintillation Maps

Real time monitoring of ionospheric scintillation that may affect ground or onboard receiver with STRONG scintillation

- Probability maps are generated from the corresponding scintillation maps (**S4** and **σφ**).
- These innovative maps consider elevation and azimuth angles of each GNSS satellite-station link, providing a better awareness of scintillation.
- Three scintillation severity classes (null, weak-moderate and moderate-strong) were defined, but only the moderate-strong matters!

INPE Instituto Nacional de Pesquisas Espaciais

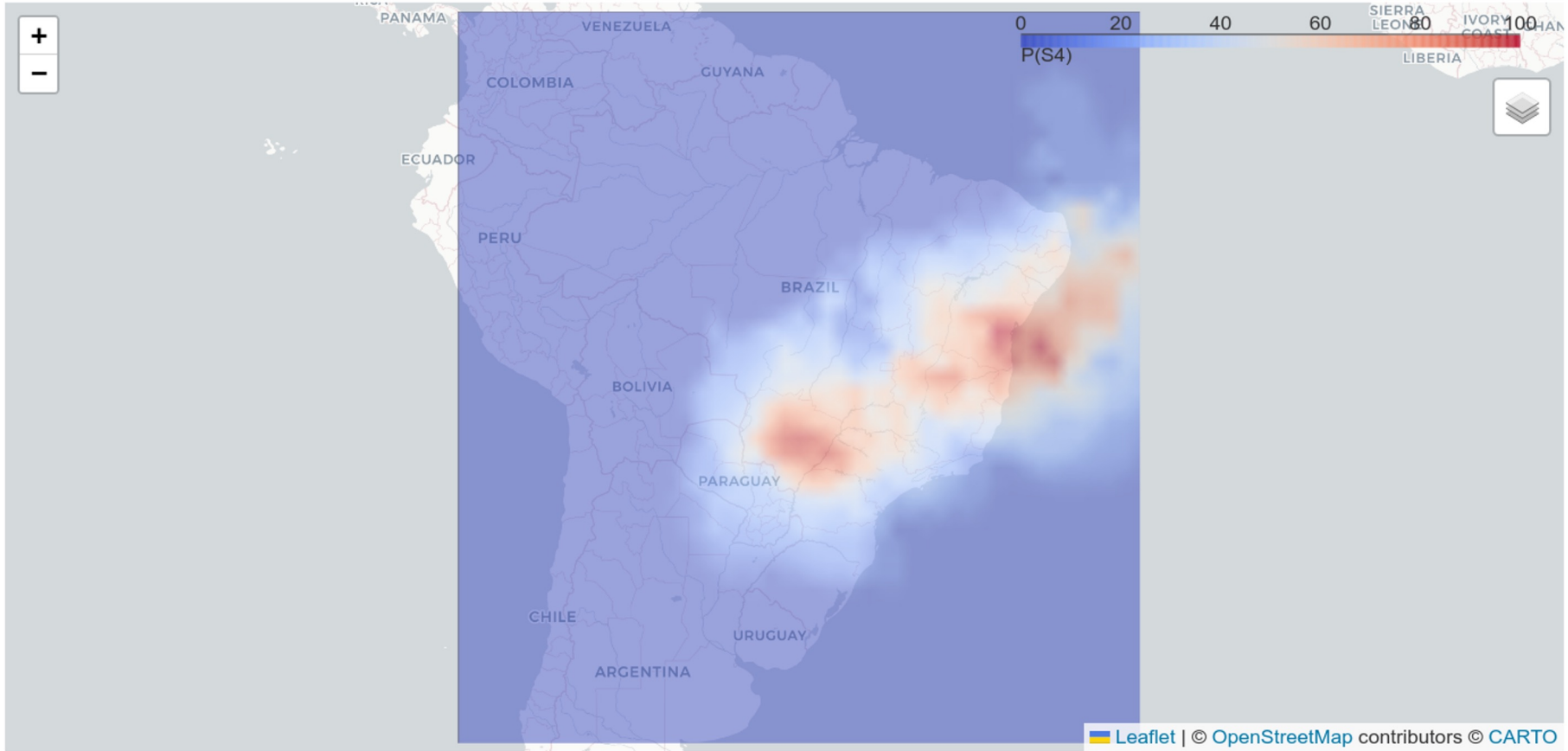
Map options

- [ ] Real-time monitoring
- [ ] Show GNSS stations
- [ ] Show DIP latitude

Real-time monitoring - Amplitude Scintillation Probability Map

2023/03/14 - 00:25 UT

2023/03/13 - 20:45 UT — 2023/03/14 - 01:30 UT



Contact: André R. F. Martinon
andre.martinon@inpe.br

INPE Instituto Nacional de Pesquisas Espaciais

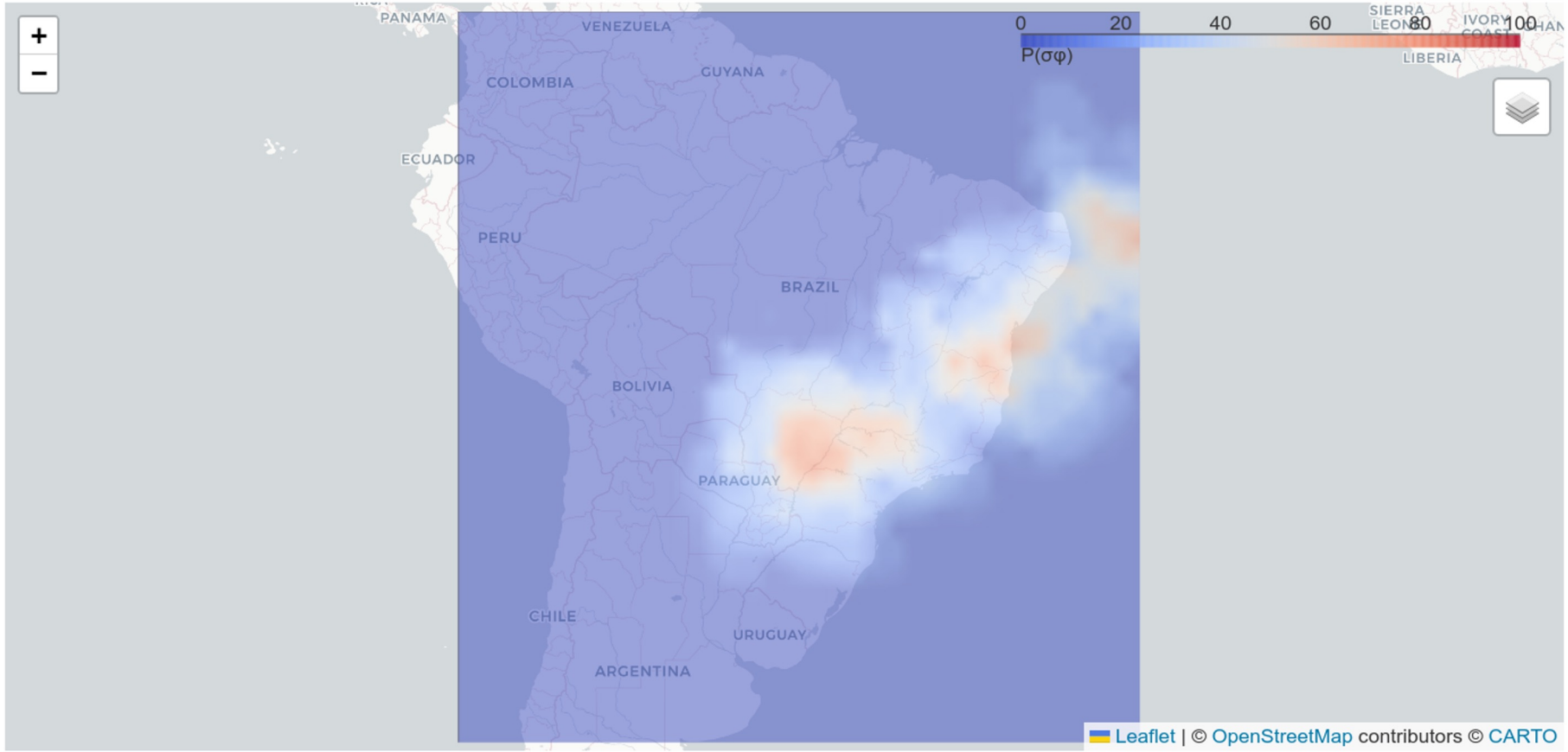
Map options

- [ ] Real-time monitoring
- [ ] Show GNSS stations
- [ ] Show DIP latitude

Real-time monitoring - Phase Scintillation Probability Map

2023/03/14 - 00:25 UT

2023/03/13 - 20:45 UT — 2023/03/14 - 01:30 UT



Contact: André R. F. Martinon
andre.martinon@inpe.br

Final comments

SANTIAGO DE CHILE
33°26' S 70°39' O

The Legacy of INCT GNSS NavAer was presented

- A large infrastructure is available for IS (and other ION-GNSS) studies
- A Data set is available to the community (contact us in case of interest)
- (New) ISMR Query tool available (registration required) - API available for automatization
- Several ION Indices available in real time
- Real time scintillation maps (including probability prediction) are under development

UN Sustainable developments

- 9- Industry, Innovation and Infrastructure
- 13 – Climate Action
- 1 – No poverty

ACKNOWLEDGMENT

CNPq

FAPESP

CAPES

CONTACT US

@GEGE.UNESP