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NAVISP Element 2
Final Presentation OF:
EL2-140 FAIR Project

FAIR

Future Agriculture through Innovative GNSS Robustness

FAIR PROJECT OVERVIEW

FAIR PROJECT MAIN GOALS

- Develop a low cost GNSS based positioning equipment able to fully exploit a mitigation service for scintillation and multipath free precise positioning.
- Develop a Scintillation mitigation service enabled by the patented Short Term Scintillation Forecasting algorithm to provide proper information for Scintillatin mitigation.
- Perform an extended validation and demonstration on the field (in the Brazil country)
- Fully evaluate the market opportunities which can be opened by the mitigation capabilities made available with FAIR.

Proposing TEAM

Contractor

Spacearth Technology (SET) is a SME born as a spin-off company of INGV. It is made of a team of engineers, physicists and geologists with a long involvement in research and business management with a view to creating added value from the results of more than 60 years of experience. SET designs and develops applications, software and hardware products for the Aerospace, Maritime and Environment fields, in cooperation with major European and Italian public and private organizations, universities and research centres. https://www.spacearth.net/

Sub-Contractor

Gter is an SME bors as a spin-off company of the University of Genova main focus is on space tecnologies for precise positioning and monitoring. Gter has skills and expertise in the field of precise positioning with mass market receivers, and in this area has concentrated the main part of its R&D activity in the year, that represents the 50% of the whole turnover. www.gter.it

WORK BREAKDOWN STRUCTURE

- WP100 - Project Management — SET
  - WP200 - Solution Update — SET
    - WP201- Ionopheric forecasting centre Algortithm Update — SET
    - WP202 – Ionospheric error Mititgation Algortithm Update — SET
    - WP203 - Multipath mitigation algorithm update — GTER
  - WP300 - Solution Engineering — GTER
    - WP301 - Set Up Forecasting Centre — SET
    - WP302 - Set Up of the Mitigation Devices — GTER
    - WP303 - System Integration — GTER
  - WP400 - Validatiion and Demonstration — SET
    - WP401- Set up of the experimentation phase — SET
    - WP402 - Validation and Demonstration — SET
  - WP500 - Dissemination and Exploitation — SET
    - WP501 - Project WEB site set up — GTER
    - WP502 - Dissemination and Outreach — SET
    - WP503 - Exploitation — SET

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THE BUSINESS IDEA

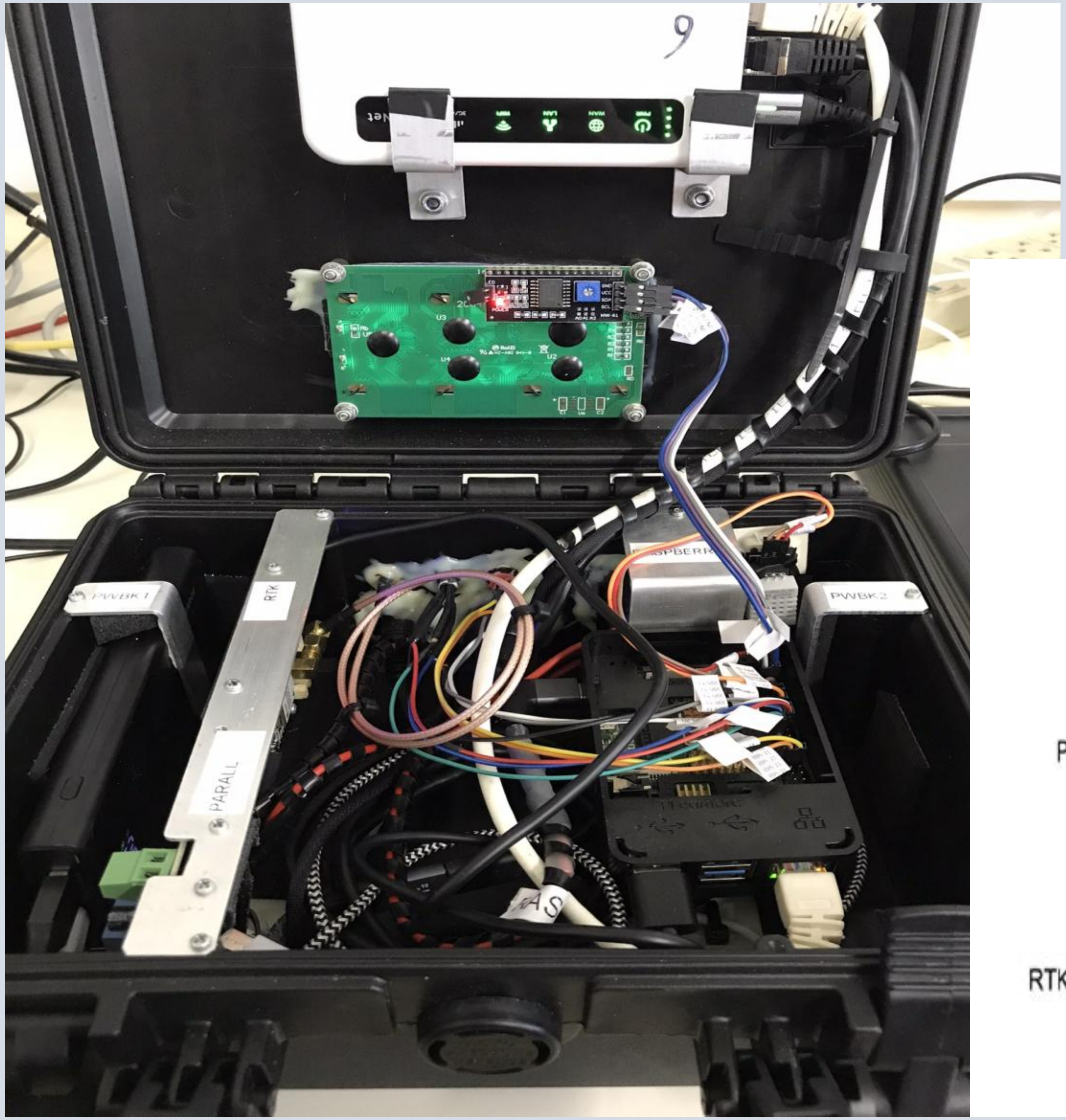
DIGITAL FARMING IN BRAZIL (1)

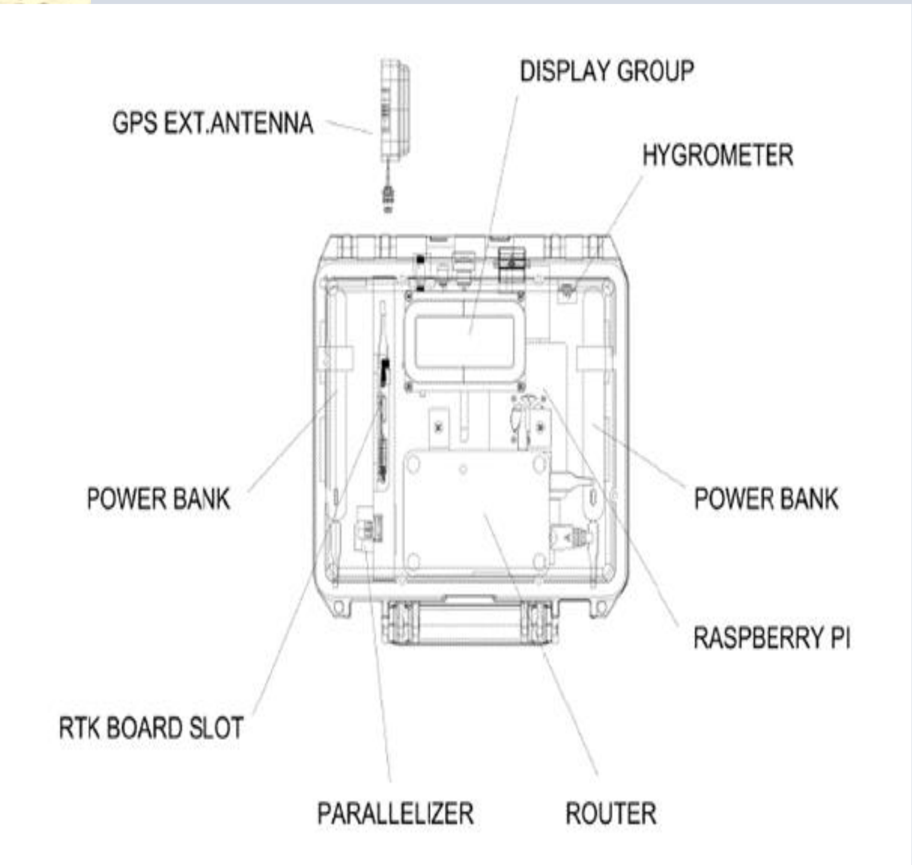
Identified addressable needs /customer benefits
Precise Positioning up to the cm level
Robust Positioning
Continuous cycle efficiency

DIGITAL FARMING IN BRAZIL (2)

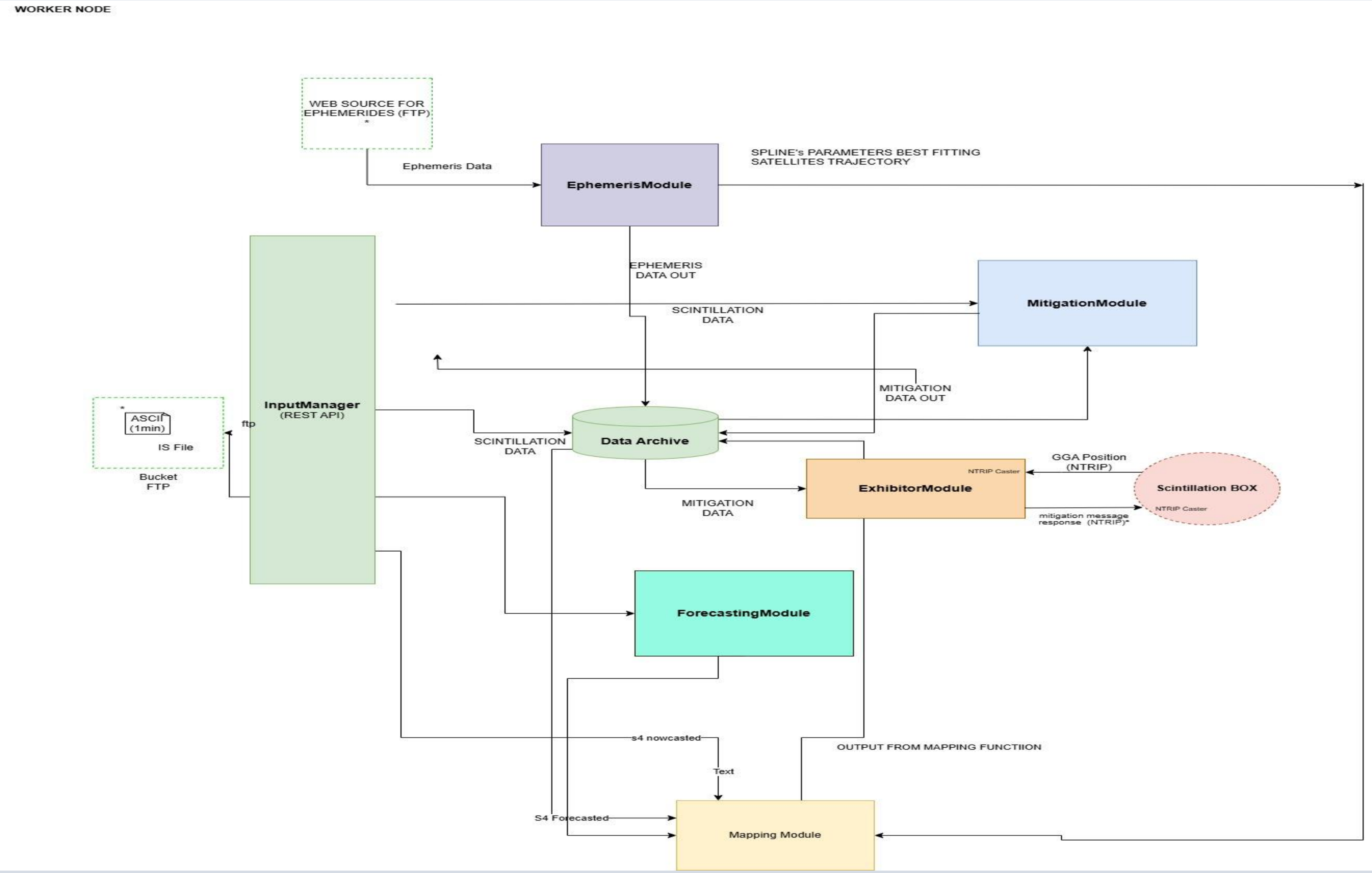
Current Issues	Prototype Innovative Characteristics
The presence of ionospheric scintillations at low latitudes compromises the accuracy of devices using GNSS technology;	Mitigation of positioning error due to scintillation.
In addition to scintillation also multipath can contribute to limit the effectiveness of GNSS in precision farming	Mitigation of multipath effects on positioning
Due to the positioning offset, under scintillation, autonomous and semi-autonomous, 24-hour-guided, machines cannot operate with the needed precision;	Automatic and continuous real time forecasting of scintillation indices to support continuous error mitigation in positioning

PROTOTYPE SET-UP





Low cost GNSS enabled positioning device

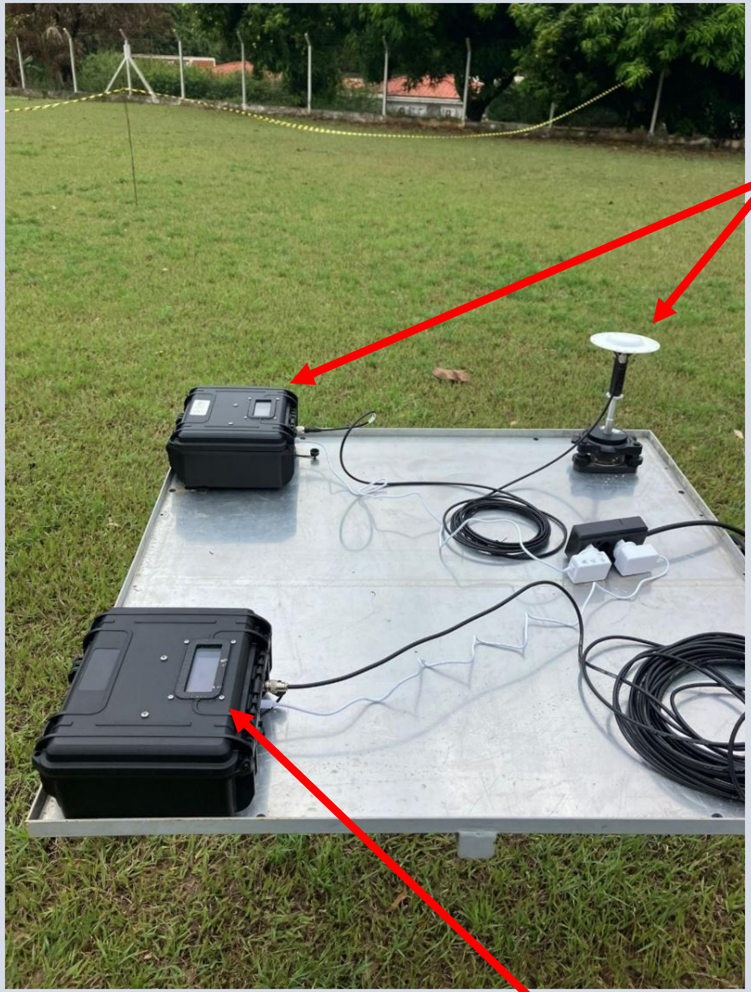


Scintillation forecasting and mitigation Centre

DEMONSTRATION EXPERIMENT SET-UP AND EXECUTION

Two Scintillation Boxes SB1 and SB6 were installed at UNESP in Presidente Prudente as static rovers

One Scintillation Box, SB4, was installed at ESALQ-USP in Piracicaba as static rover



SB5 Kinematic Rover

SB3 Receiver, the antenna is located at the centre of the rotating arm.

The Scintillation Boxes SB3 and SB5 were installed at ESALQ-USP in Piracicaba to support Kinematic experiment

Overall statistics collected during demonstration data set:

STATION	SB1 (static PP)	SB6(static PP)	SB4(static Pir)	SB3 + SB5 (kinematic)
# hours	748	946	924	78

Static SBs collected data all along the day while the data collected in the kinematic experiment where focussed during scintillation hours, few hours (in general three hours) after sunset.

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SCINTILLATION MITIGATION MAIN RESULTS

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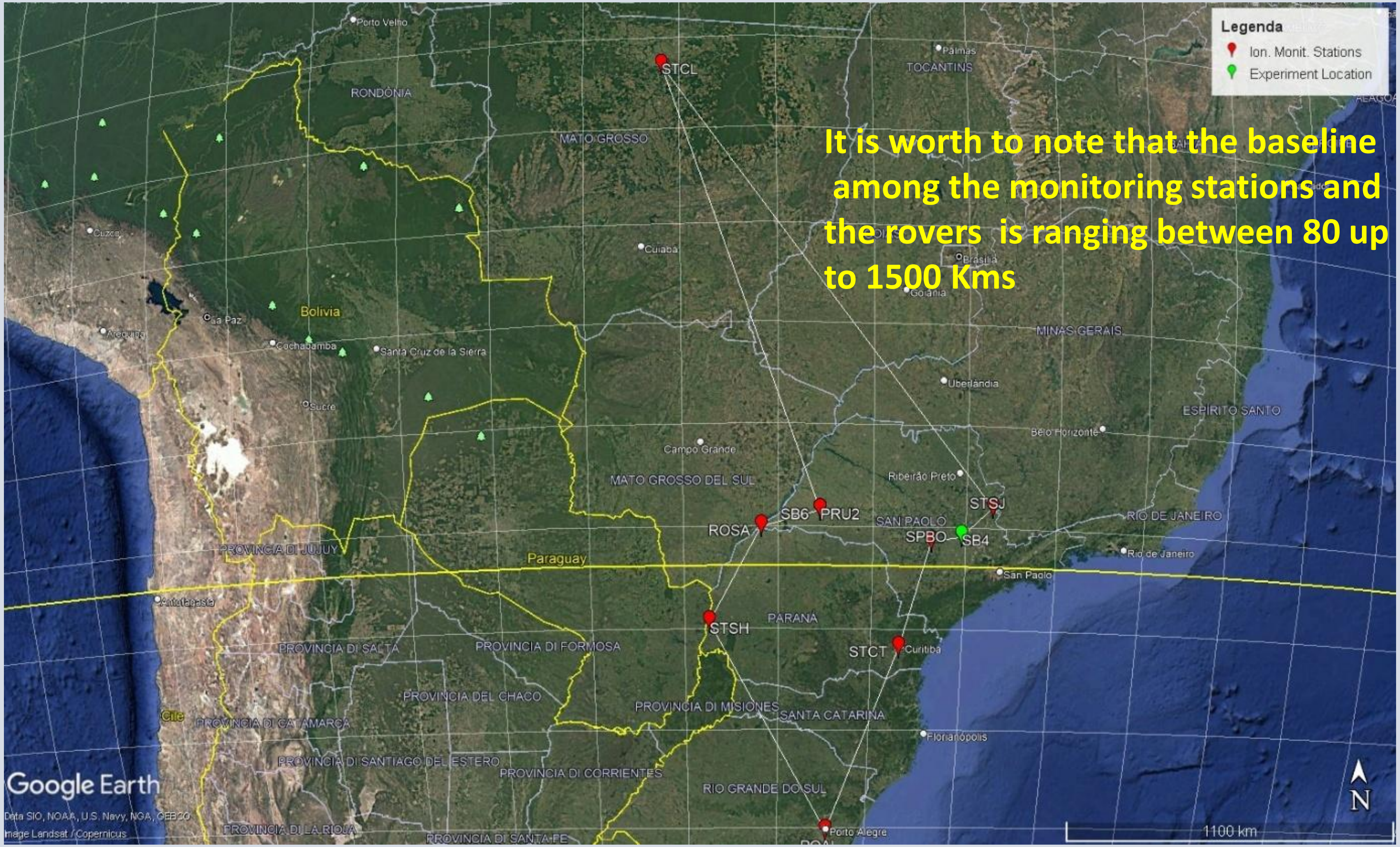
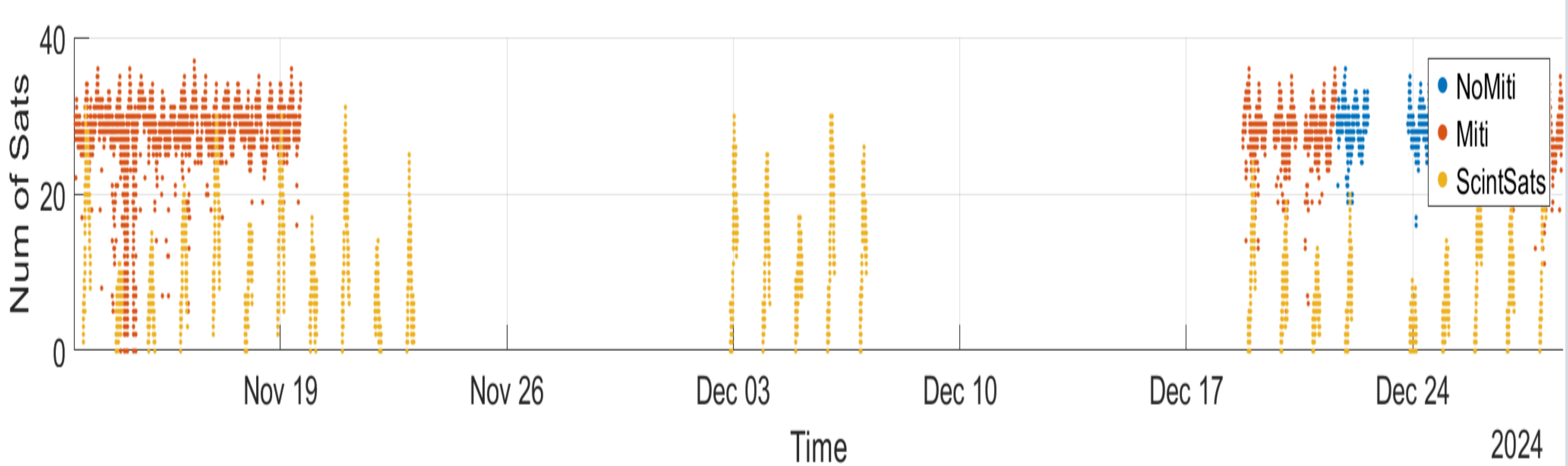
Network of Ionospheric monitoring Stations

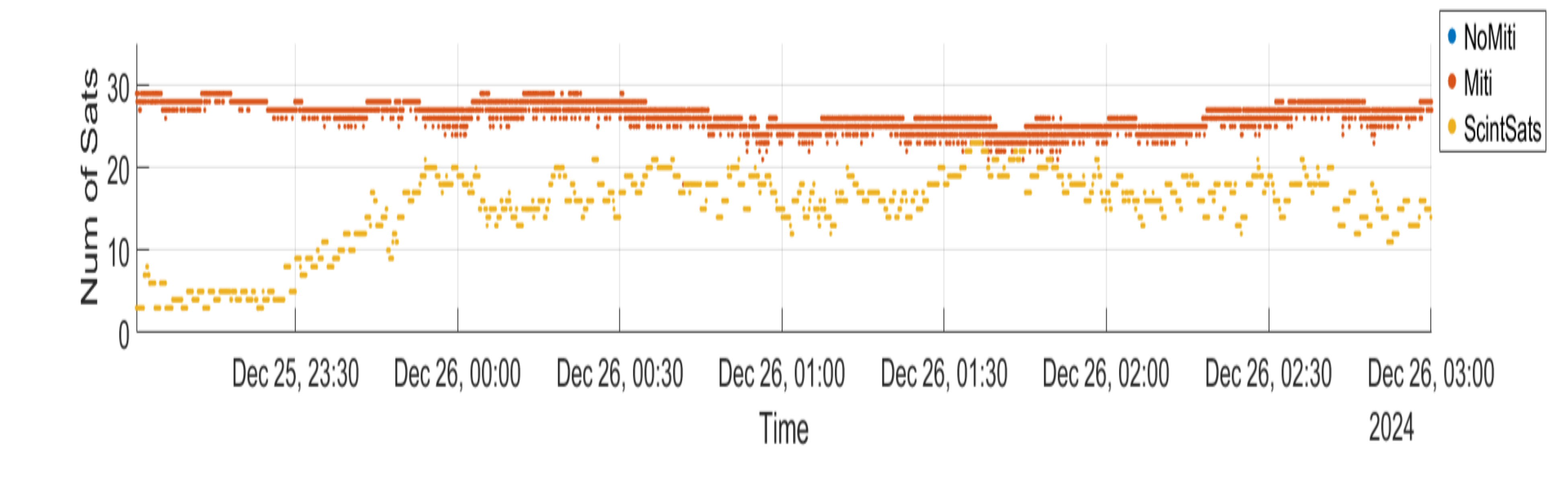


Location of the rovers and the closest ionospheric monitoring station at Presidente Prudente

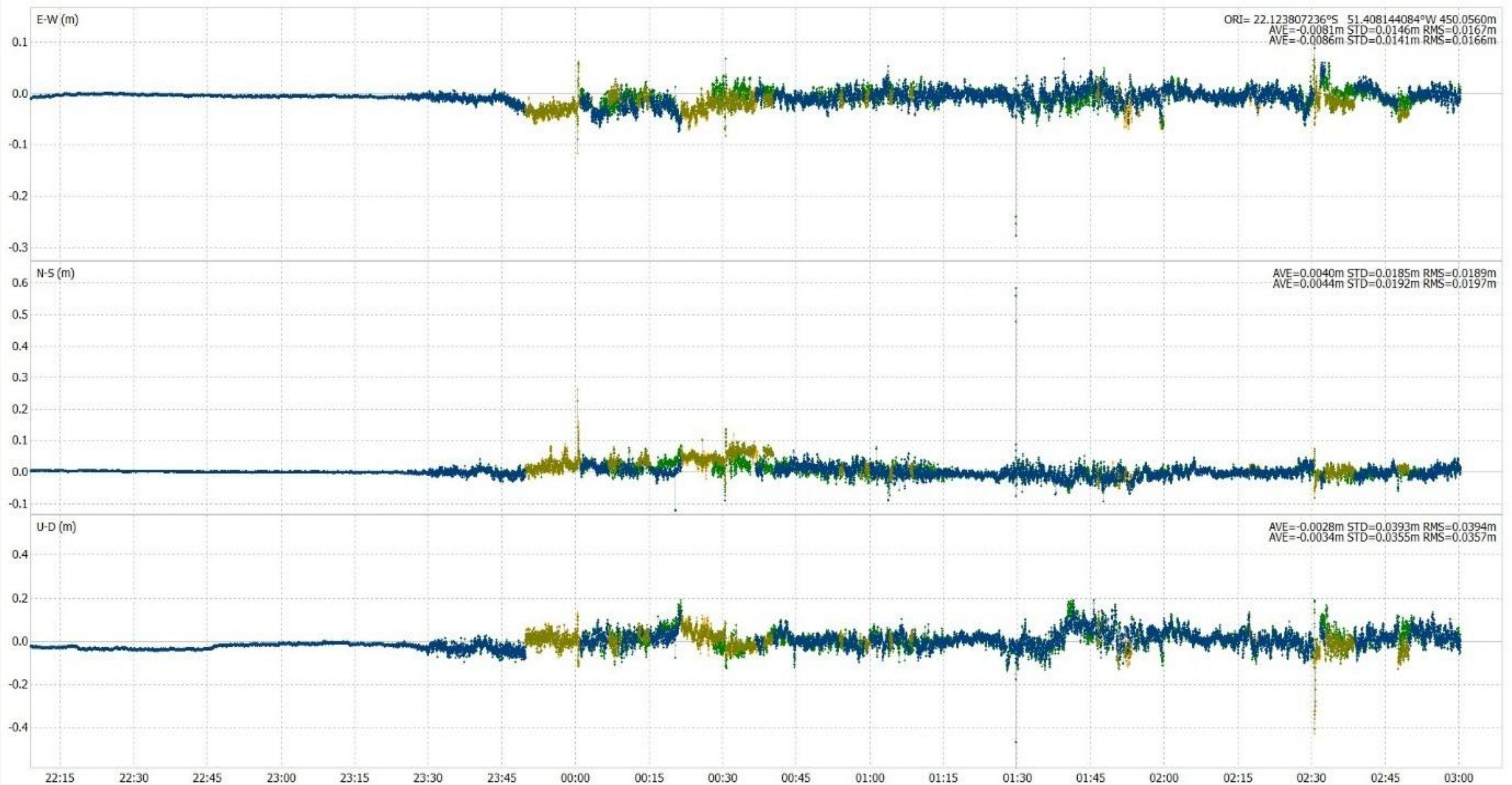


USE CASE	Start epoch	Stop epoch
SB1_UC1	2024/11/12 15:50:20	2024/11/13 15:00:19
SB1_UC2	2024/11/16 15:50:20	2024/11/17 15:00:19
SB1_UC3	2024/11/18 15:50:20	2024/11/19 15:00:19
SB1_UC4	2024/12/18 18:10:41	2024/12/19 10:43:31
SB1_UC5	2024/12/25 15:50:20	2024/12/26 15:00:20

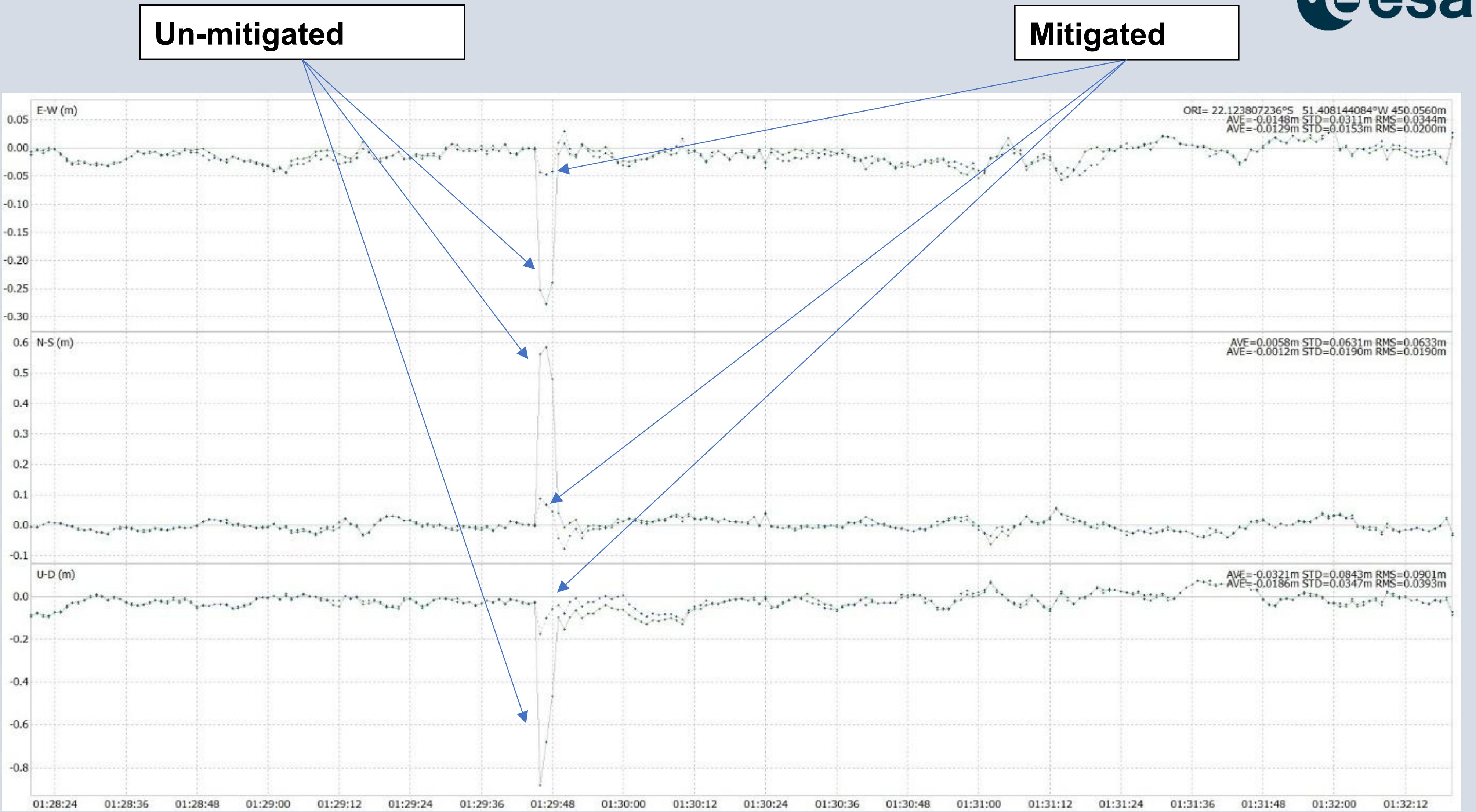
Use case selection for SB1 Static rover

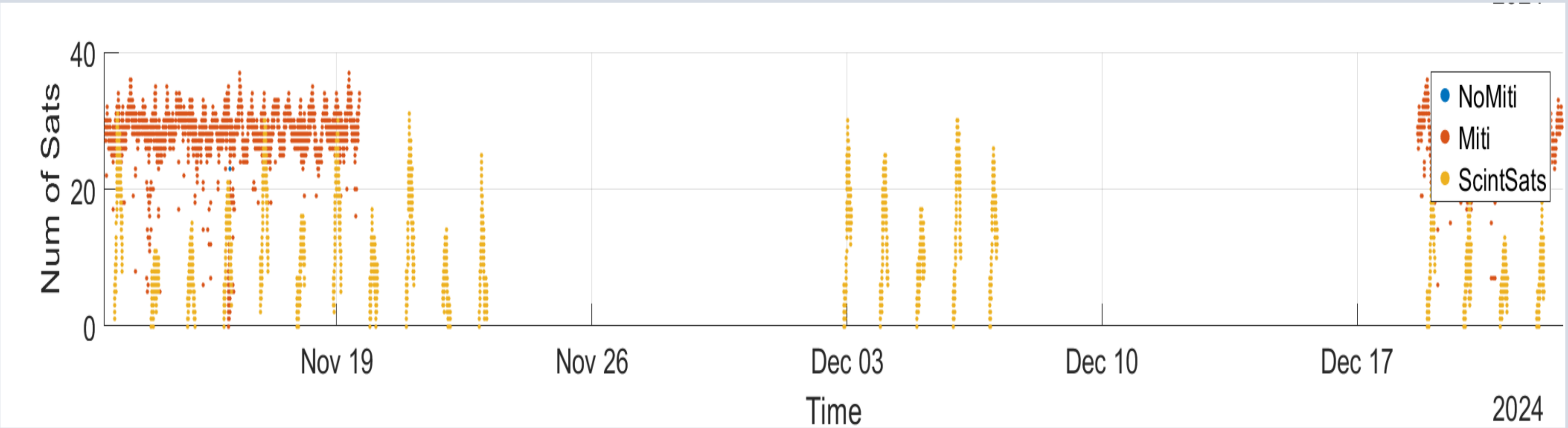


UC5 - Number of scintillating satellites vs satellites in visibility



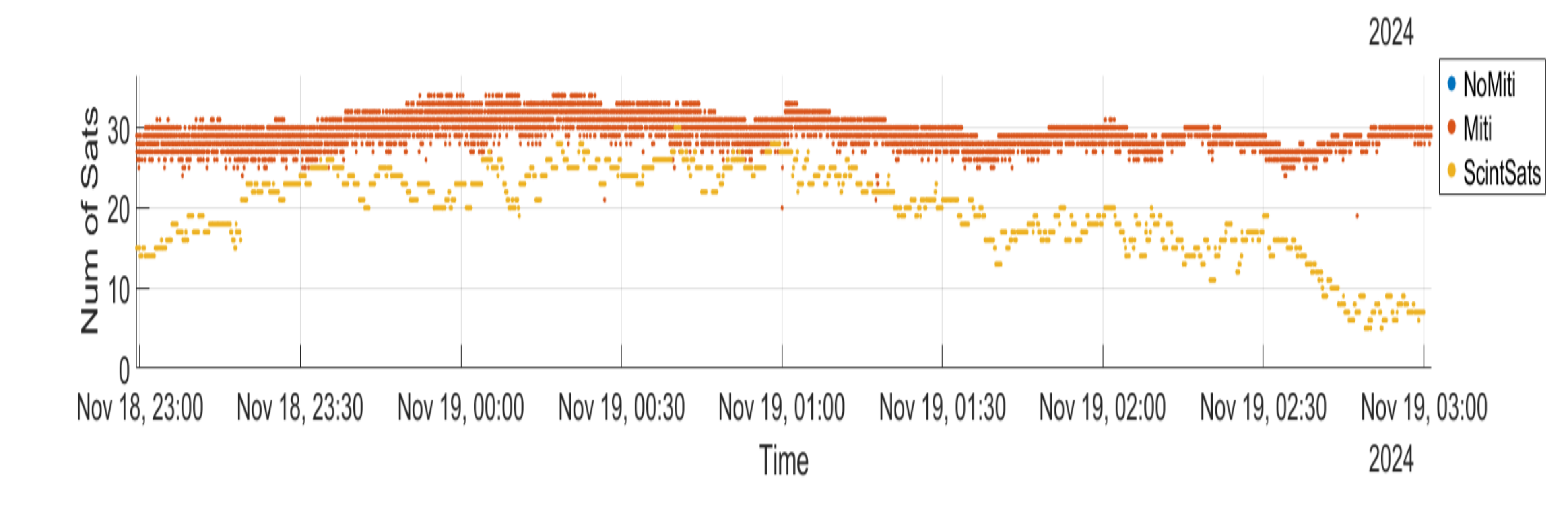
Time series during scintillation hours


Un-mitigated
Mitigated
E-W (m)
ORI= 22.123807236°S 51.408144084°W 450.0560m
AVE=-0.0148m STD=0.0311m RMS=0.0344m
AVE=-0.0129m STD=0.0153m RMS=0.0200m
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
-0.30
N-S (m)
AVE=0.0058m STD=0.0631m RMS=0.0633m
AVE=-0.0012m STD=0.0190m RMS=0.0190m
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
U-D (m)
AVE=-0.0321m STD=0.0843m RMS=0.0901m
AVE=-0.0186m STD=0.0347m RMS=0.0393m
0.0
-0.2
-0.4
-0.6
-0.8
01:28:24
01:28:36
01:28:48
01:29:00
01:29:12
01:29:24
01:29:36
01:29:48
01:30:00
01:30:12
01:30:24
01:30:36
01:30:48
01:31:00
01:31:12
01:31:24
01:31:36
01:31:48
01:32:00
01:32:12



USE CASE	Start epoch	Stop epoch
SB6_UC1	**2024/11/12 15:50:20**	**2024/11/13 15:00:19**
SB6_UC2	**2024/11/16 15:50:20**	**2024/11/17 15:00:19**
SB6_UC3	**2024/11/18 15:50:21**	**2024/11/19 15:00:19**
SB6_UC4	**2024/12/18 15:50:21**	**2024/12/19 15:00:19**
SB6_UC5	**2024/12/21 15:50:20**	**2024/12/22 15:00:20**

Use case selection for SB6 Static rover



UC3 - Number of scintillating satellites vs satellites in visibility

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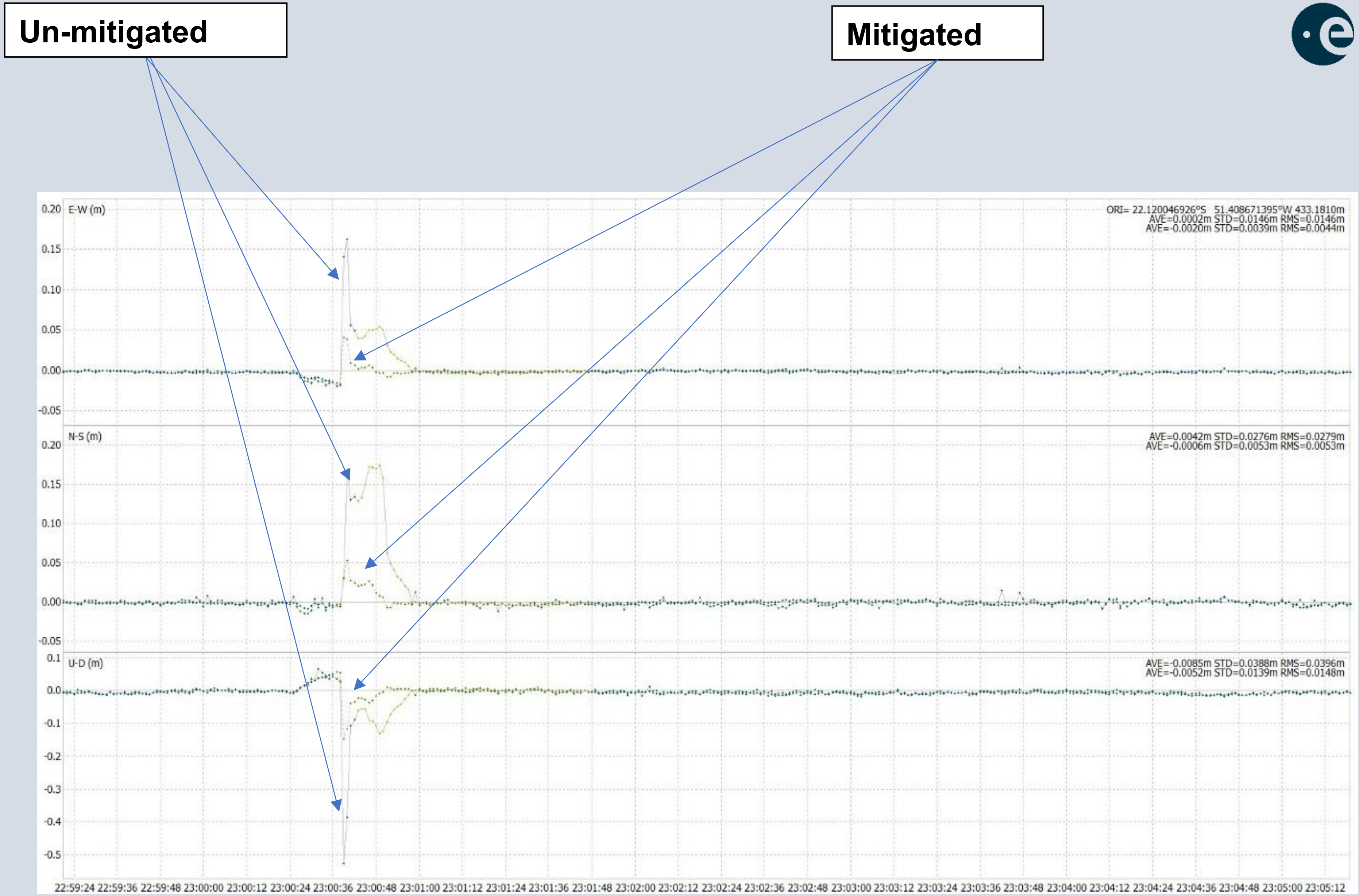
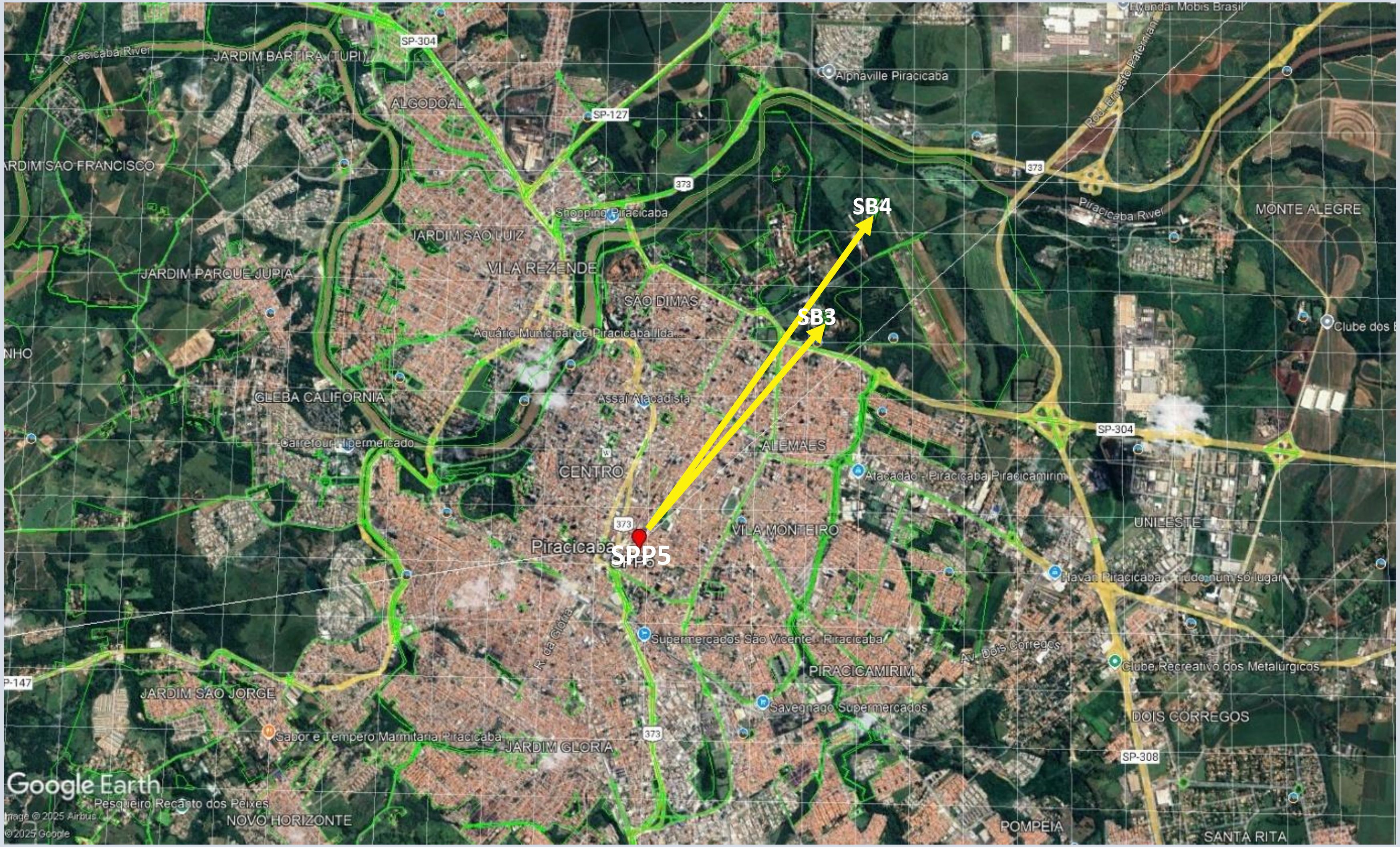
Time series during scintillation hours

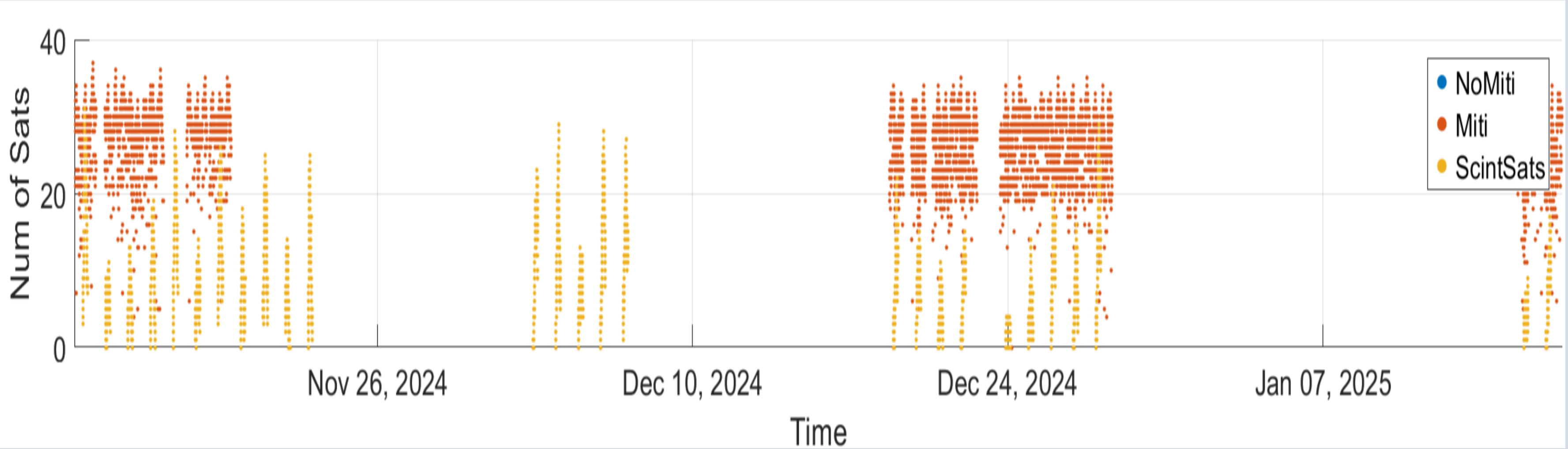

Un-mitigated
Mitigated
E-W (m)
ORI= 22.120046926°S 51.408671395°W 433.1810m
AVE=0.0002m STD=0.0146m RMS=0.0146m
AVE=-0.0020m STD=0.0039m RMS=0.0044m
0.20
0.15
0.10
0.05
0.00
-0.05
N-S (m)
AVE=0.0042m STD=0.0276m RMS=0.0279m
AVE=-0.0006m STD=0.0053m RMS=0.0053m
0.20
0.15
0.10
0.05
0.00
-0.05
U-D (m)
AVE=-0.0085m STD=0.0388m RMS=0.0396m
AVE=-0.0052m STD=0.0139m RMS=0.0148m
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
22:59:24 22:59:36 22:59:48 23:00:00 23:00:12 23:00:24 23:00:36 23:00:48 23:01:00 23:01:12 23:01:24 23:01:36 23:01:48 23:02:00 23:02:12 23:02:24 23:02:36 23:02:48 23:03:00 23:03:12 23:03:24 23:03:36 23:03:48 23:04:00 23:04:12 23:04:24 23:04:36 23:04:48 23:05:00 23:05:12

REMARKS:

The results obtained for the SB1 and SB6 static rovers are good. Despite the presence of **strong scintillation, position accuracy remains unaffected,** even in the non-mitigated solution. This can be attributed to the **proximity of the reference station, PPTE, used for RTK corrections estimation**: approximately tens of meters from SB1 and a less than 3 hundred meters from SB6.

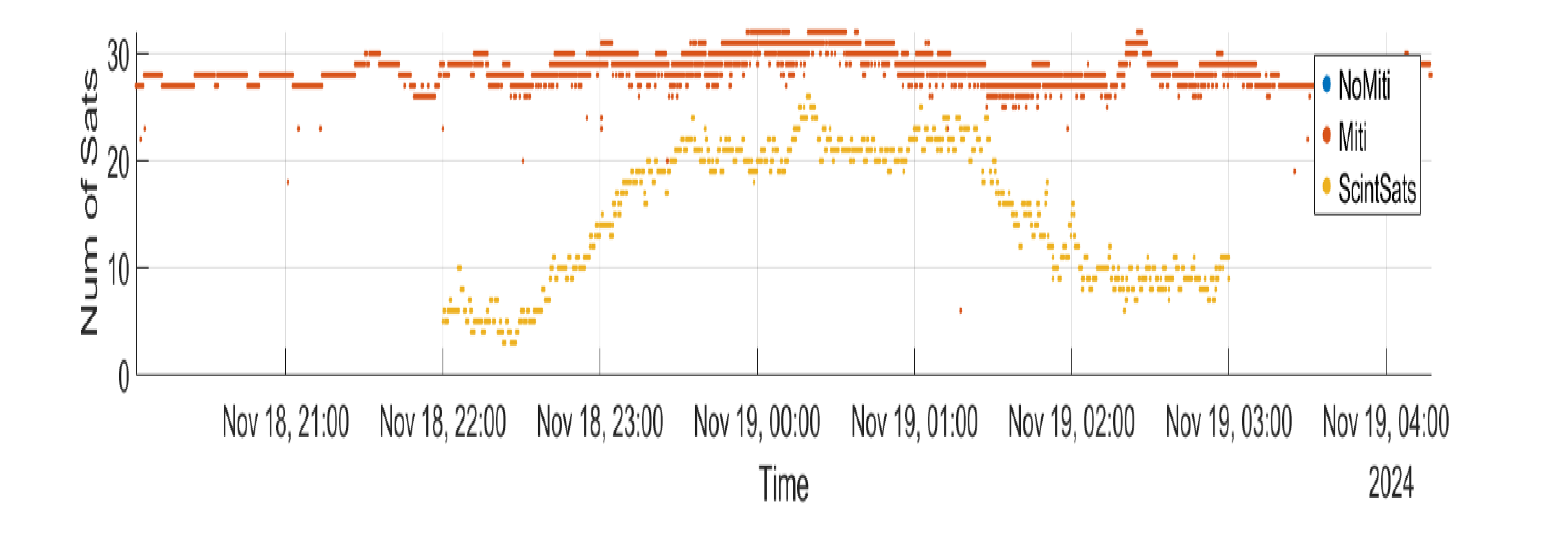


Location of the rovers and the closest ionospheric monitoring station at Piracicaba

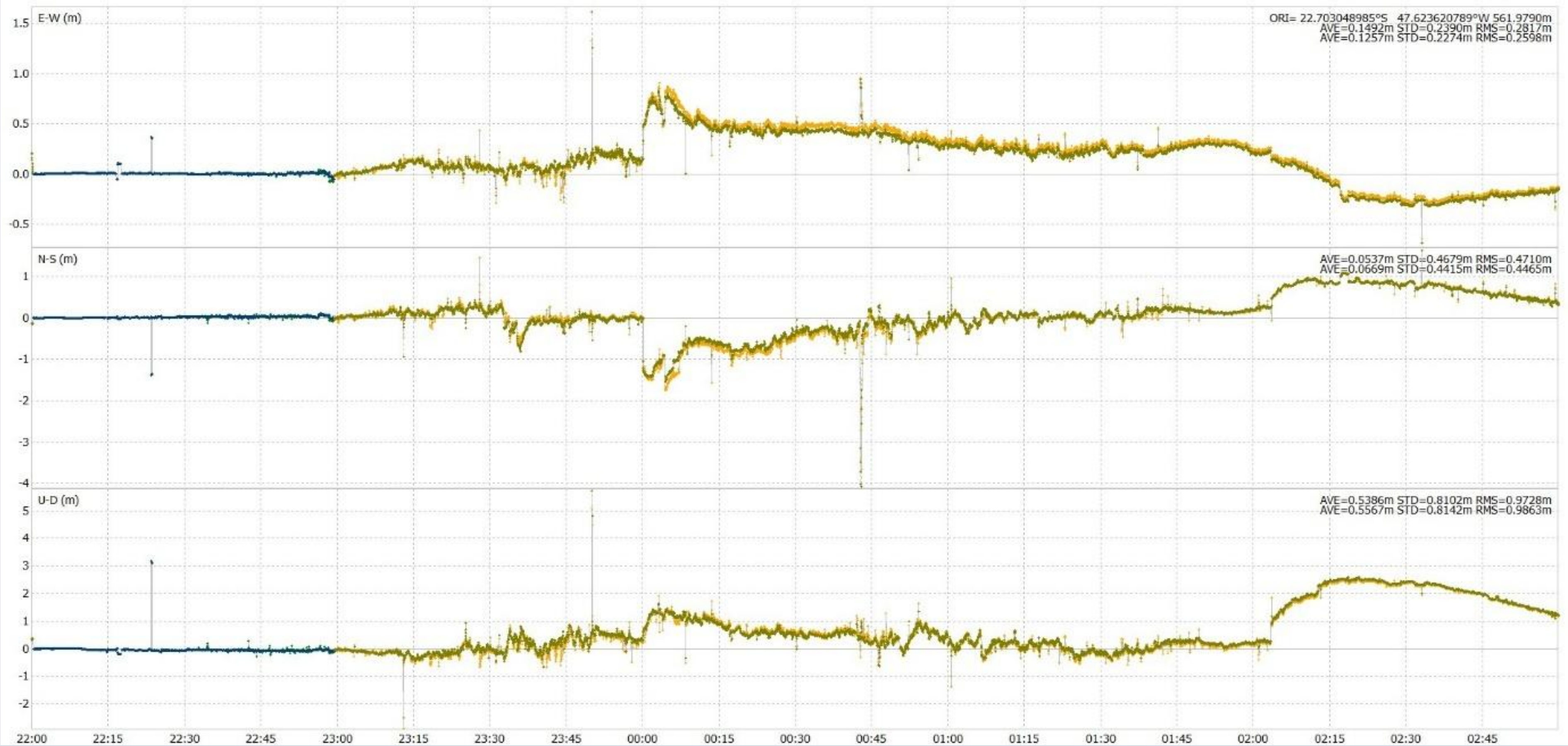


USE CASE	Start epoch	Stop epoch
SB4_UC1	2024/11/12 13:44:00	2024/11/13 12:00:19
SB4_UC2	2024/11/18 12:50:22	2024/11/19 12:00:14
SB4_UC3	2024/12/18 18:05:18	2024/12/19 08:36:20
SB4_UC4	2024/12/25 15:50:20	2024/12/26 15:00:20
SB4_UC5	2024/12/26 15:50:21	2024/12/27 15:00:19
SB4_UC6	2024/12/27 15:50:20	2024/12/28 15:00:20

Use case selection for SB4 Static rover



UC2 - Number of scintillating satellites vs satellites in visibility



Time series during scintillation hours without SPP5

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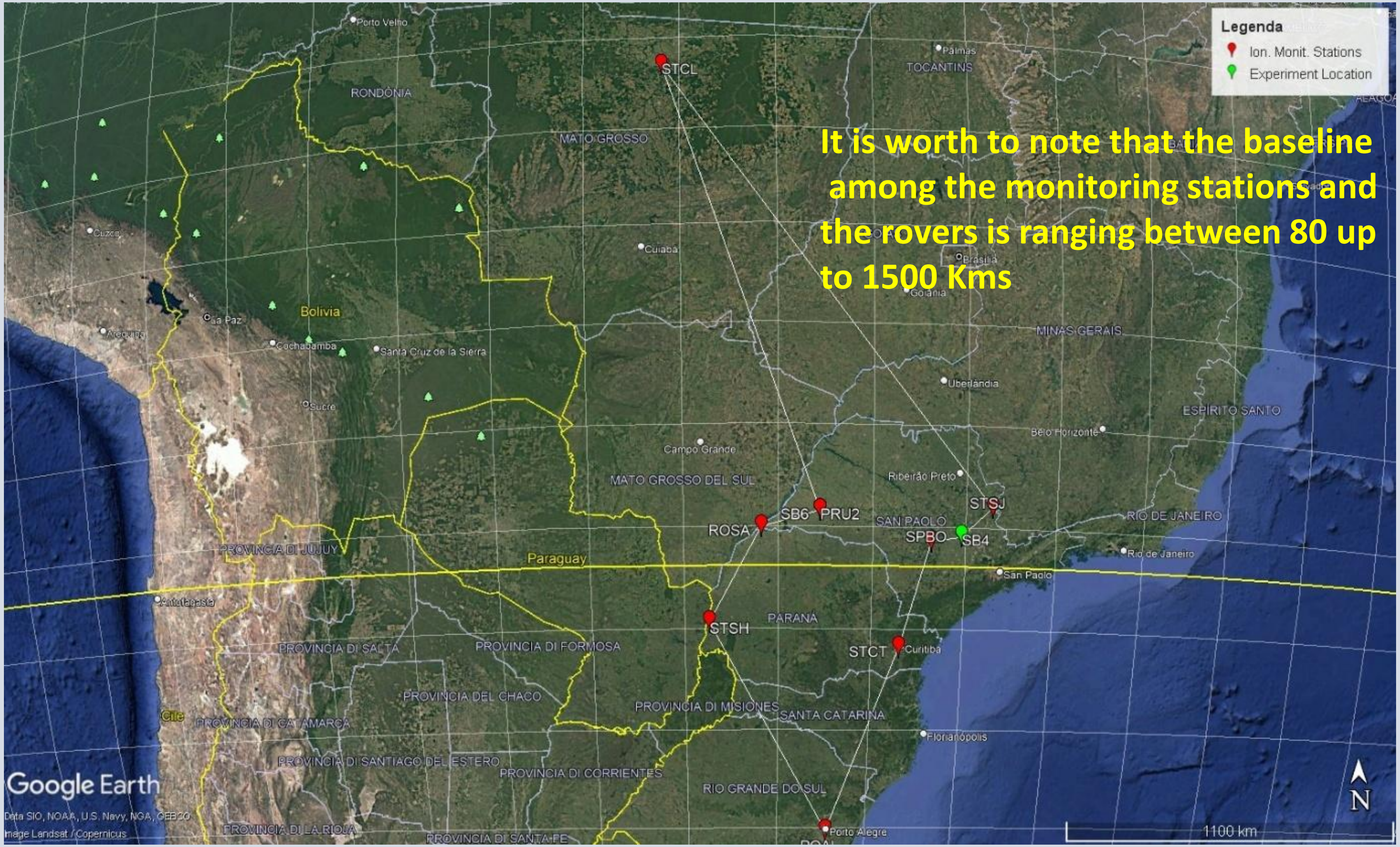
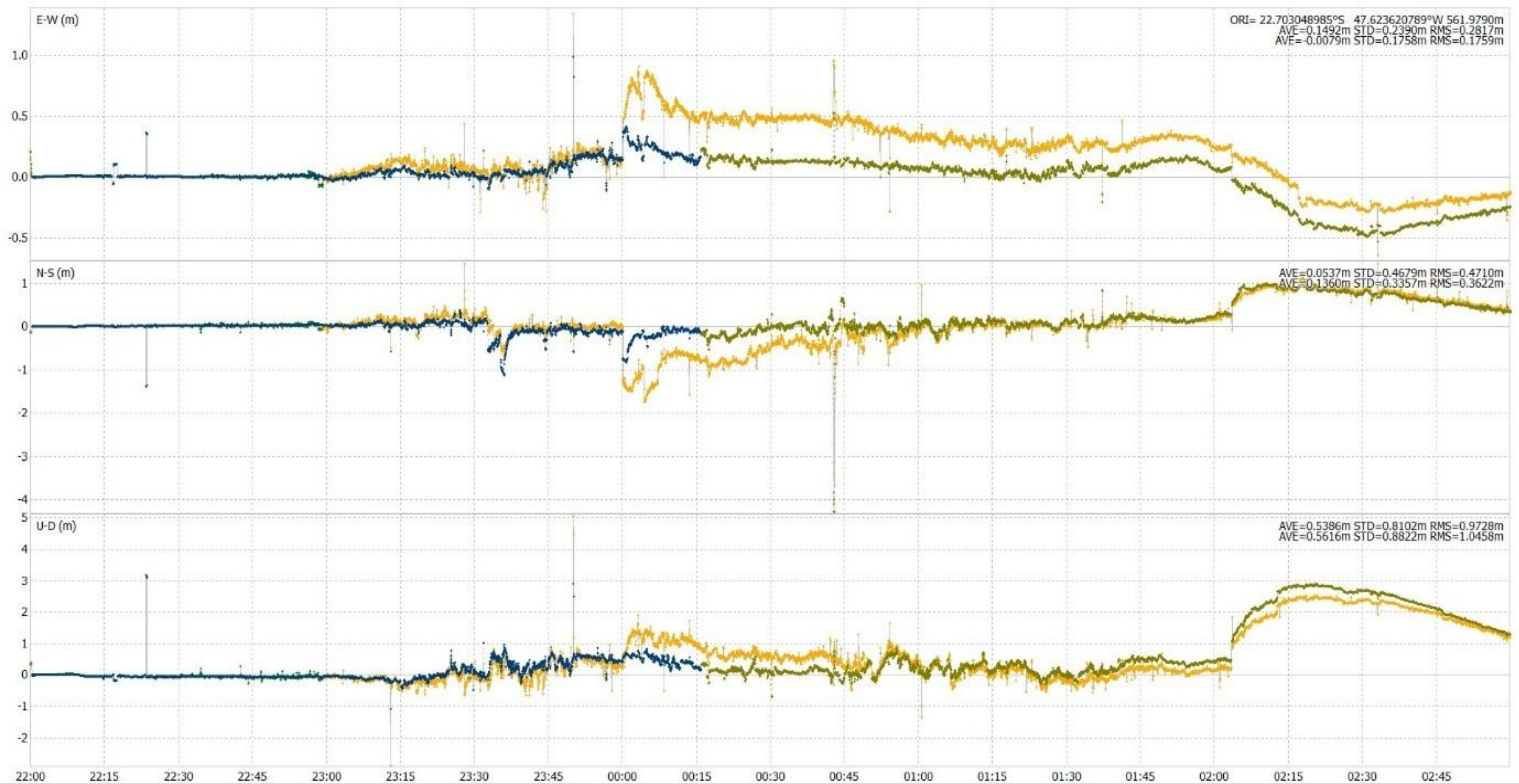
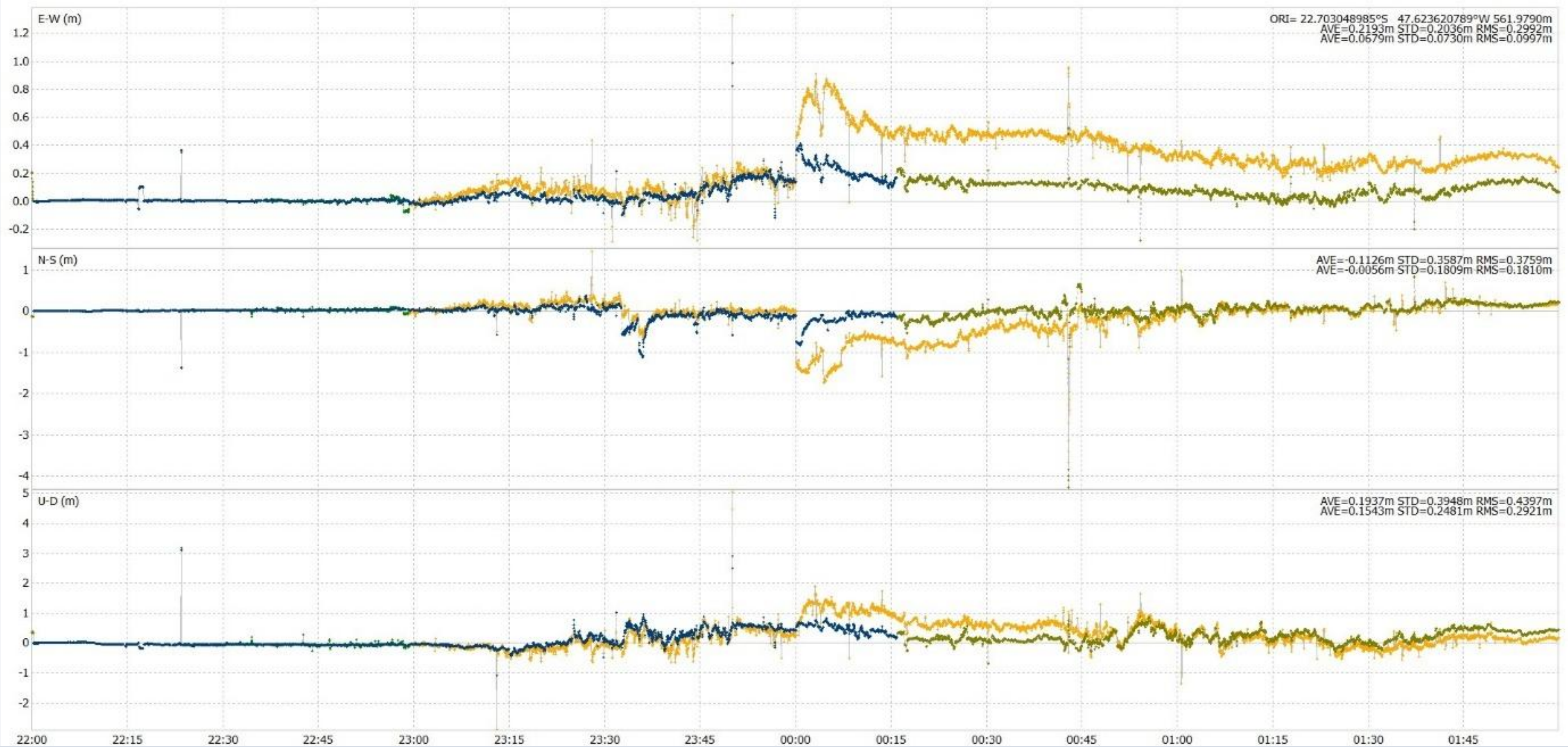
Network of Ionospheric monitoring Stations



It is worth to note that the baseline among the monitoring stations and the rovers is ranging between 80 up to 1500 Kms



Time series during scintillation hours with SPP5

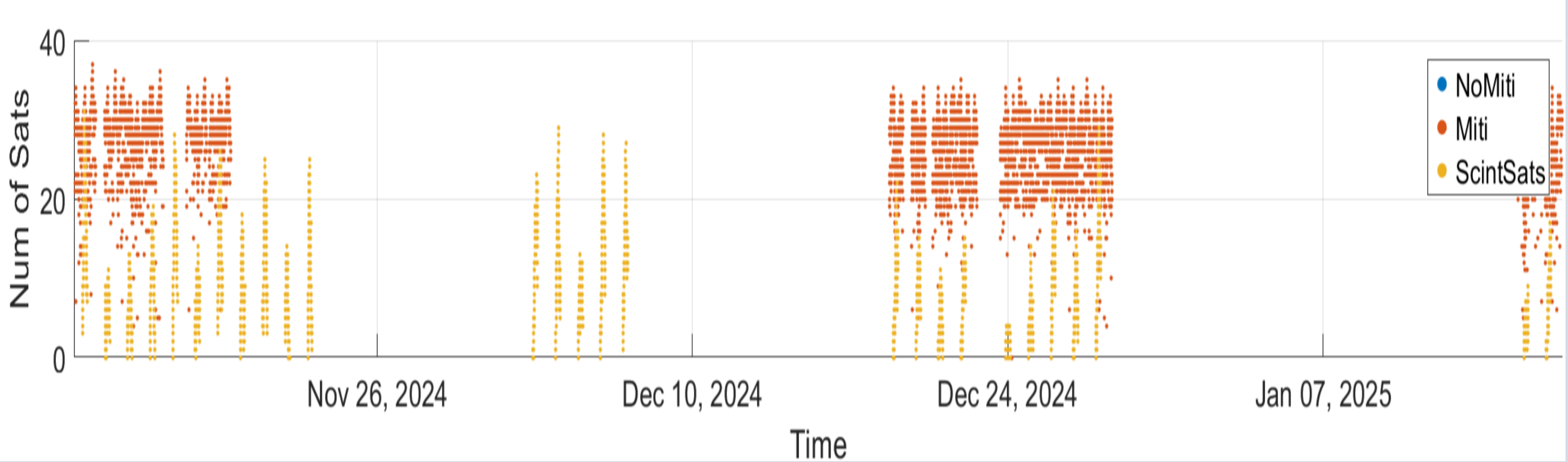


Zooming on the period of highest number of scintillating satellites

REMARKS:

The baseline between the base station, SPP5, and the static rover, SB4, is much longer than the one in Presidente Prudente, almost 4 kilometres compared to a few hundred meters. Given the spatial scale of ionospheric disturbance at low latitudes, it is therefore not surprising to see the high impact of scintillations on position accuracy of the SB4 non-mitigated solutions.

On the other hand, the mitigated solutions, the ones obtained also with SPP5 scintillation indices, represent a tangible improvement, even when not a decisive one. The network of ionospheric monitoring stations at our disposal was too sparse to properly support mitigation of scintillations. This is also confirmed considering that the best results were obtained by including, when available, the SPP5 scintillation indices in the weight calculation. This attempt was only partially successful, but it shows a promising way to test the mitigation algorithm, under an improved Scintillation monitoring network design.

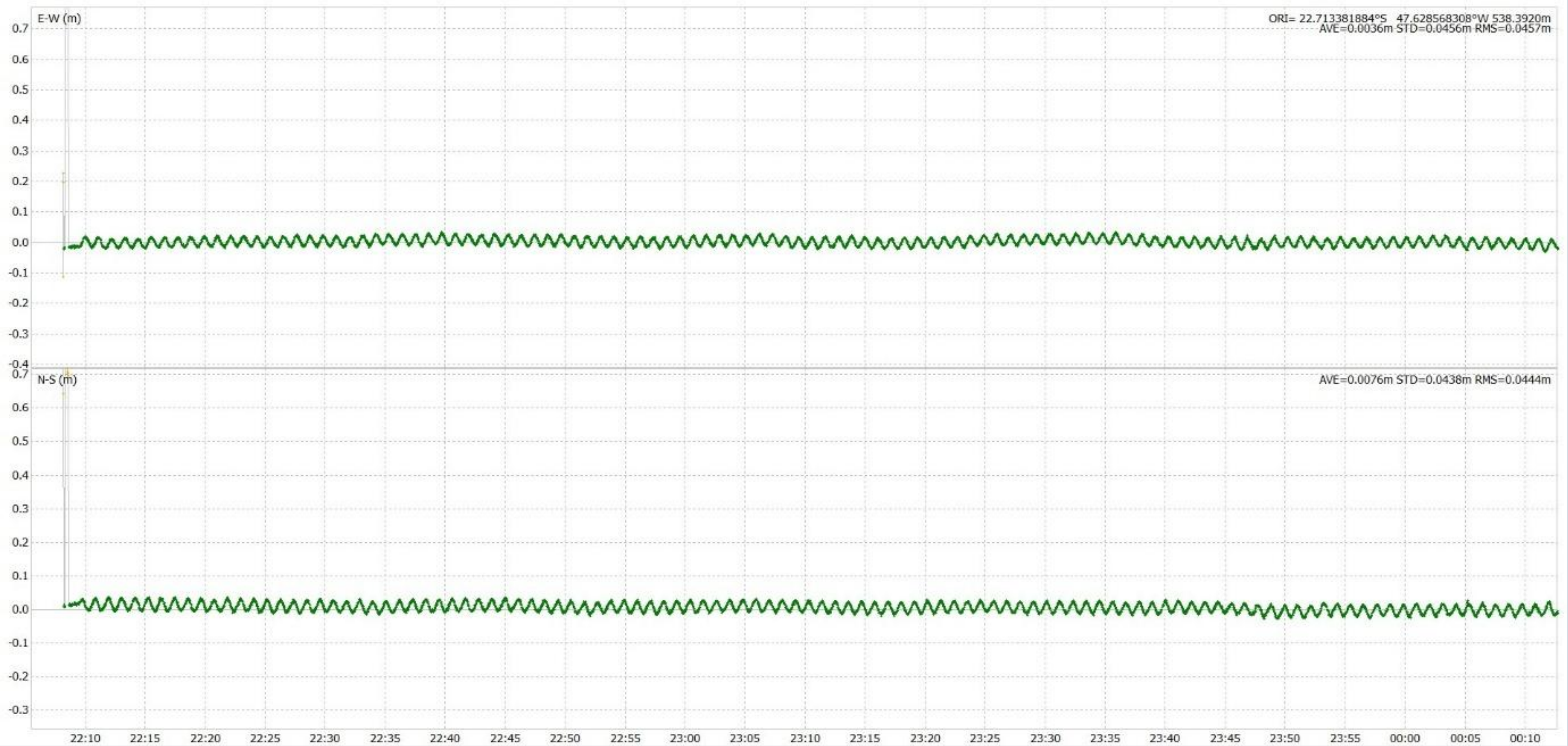


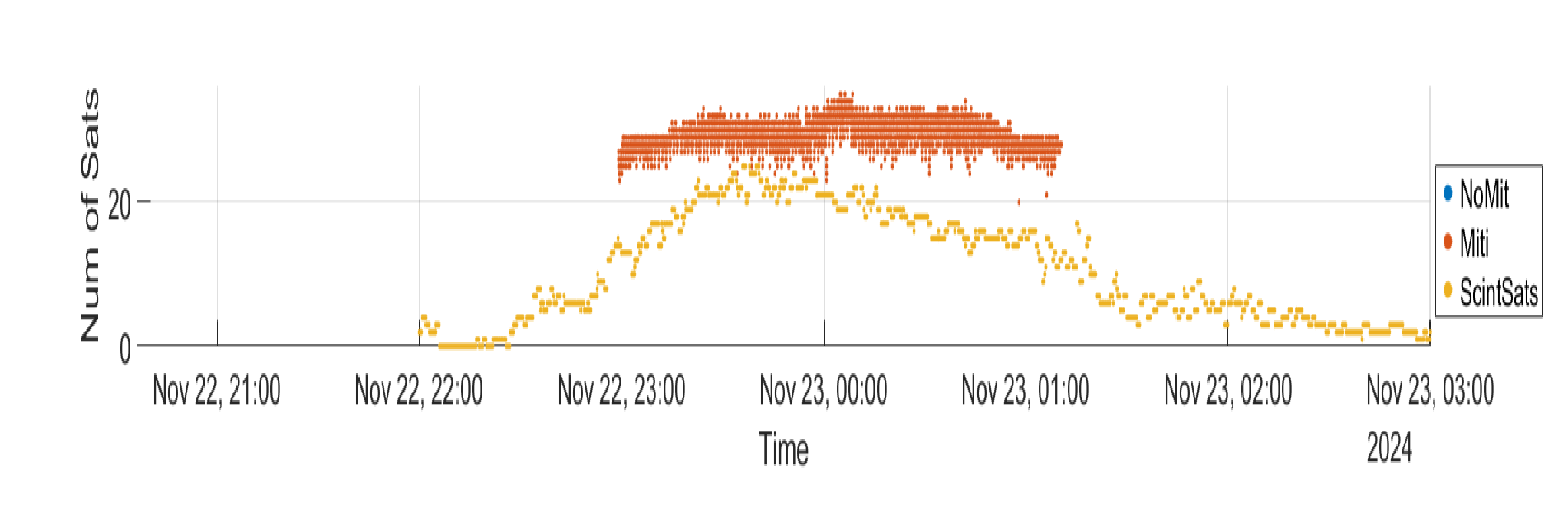
USE CASE	Start epoch	Stop epoch
SB5_UC1	2024/11/14 21:54:50	2024/11/15 02:11:54
SB5_UC2	2024/11/22 22:59:06	2024/11/23 01:10:35
SB5_UC3	2024/12/18 23:28:49	2024/12/19 01:01:40
SB5_UC4	2025/01/16 22:56:54	2025/01/17 01:10:17

Use case selection for Kinematic Experiment

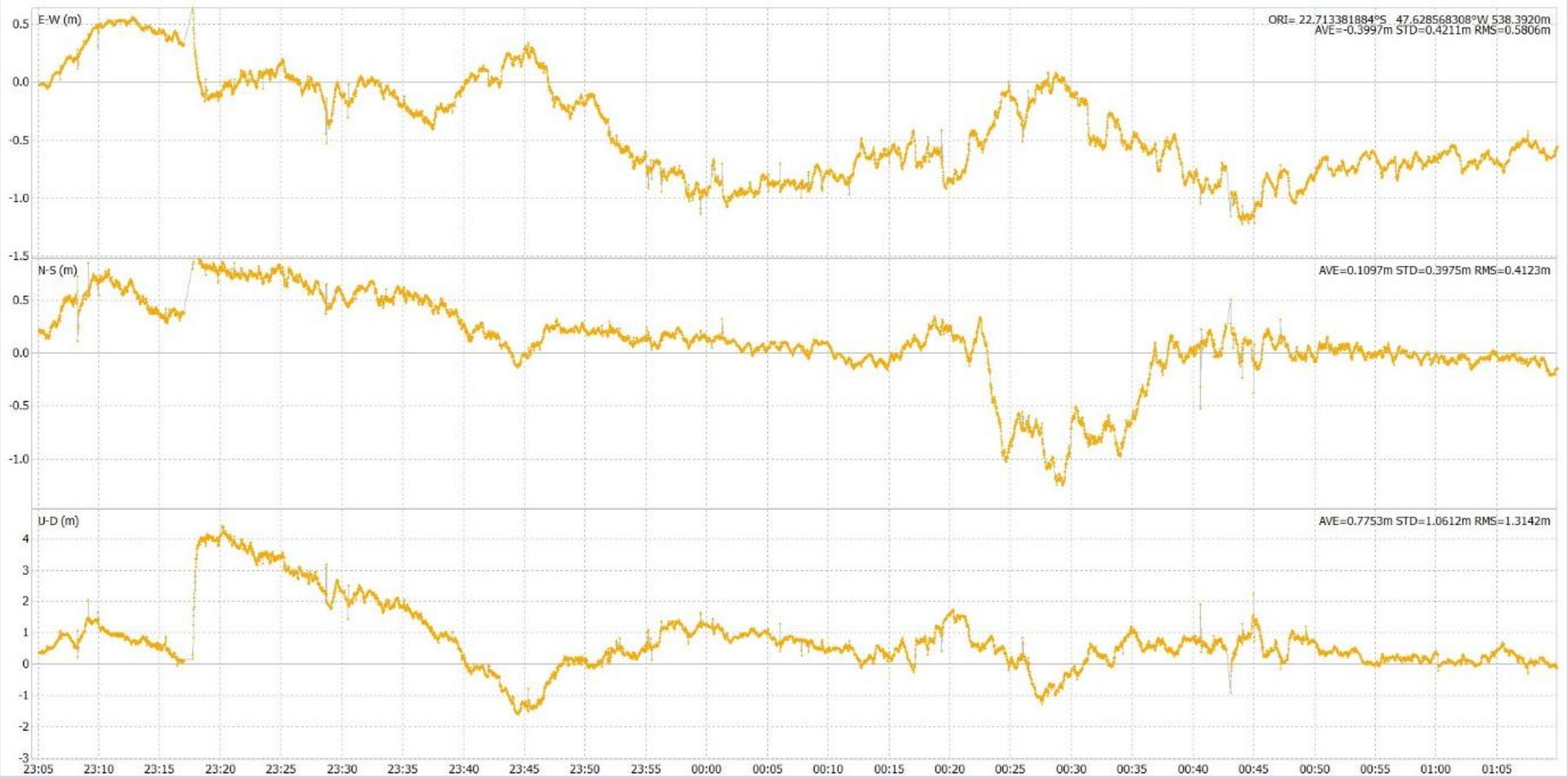
To have the full 3D error with respect to the ground truth we made two independent measurements of the position of the rotating rover: one with respect to the base station and another with respect to the receiver located in the centre of the rotating arm, whose precise coordinates have been precisely estimated independently. The baseline of the rotating rover with respect to the centre of the circle is very short and both the receiver should feel the same errors and they will be eliminated with the double difference approach (as in the case of SB1 and SB6 static rovers at Presidente Prudente). The two kinematic solutions are moreover synchronized because the epoch of solutions is driven by the kinematic rover observations, the SB5.

Unfortunately, during the experiment set-up the SB3 antenna was not put in the centre of the arm but was slightly off of centre.

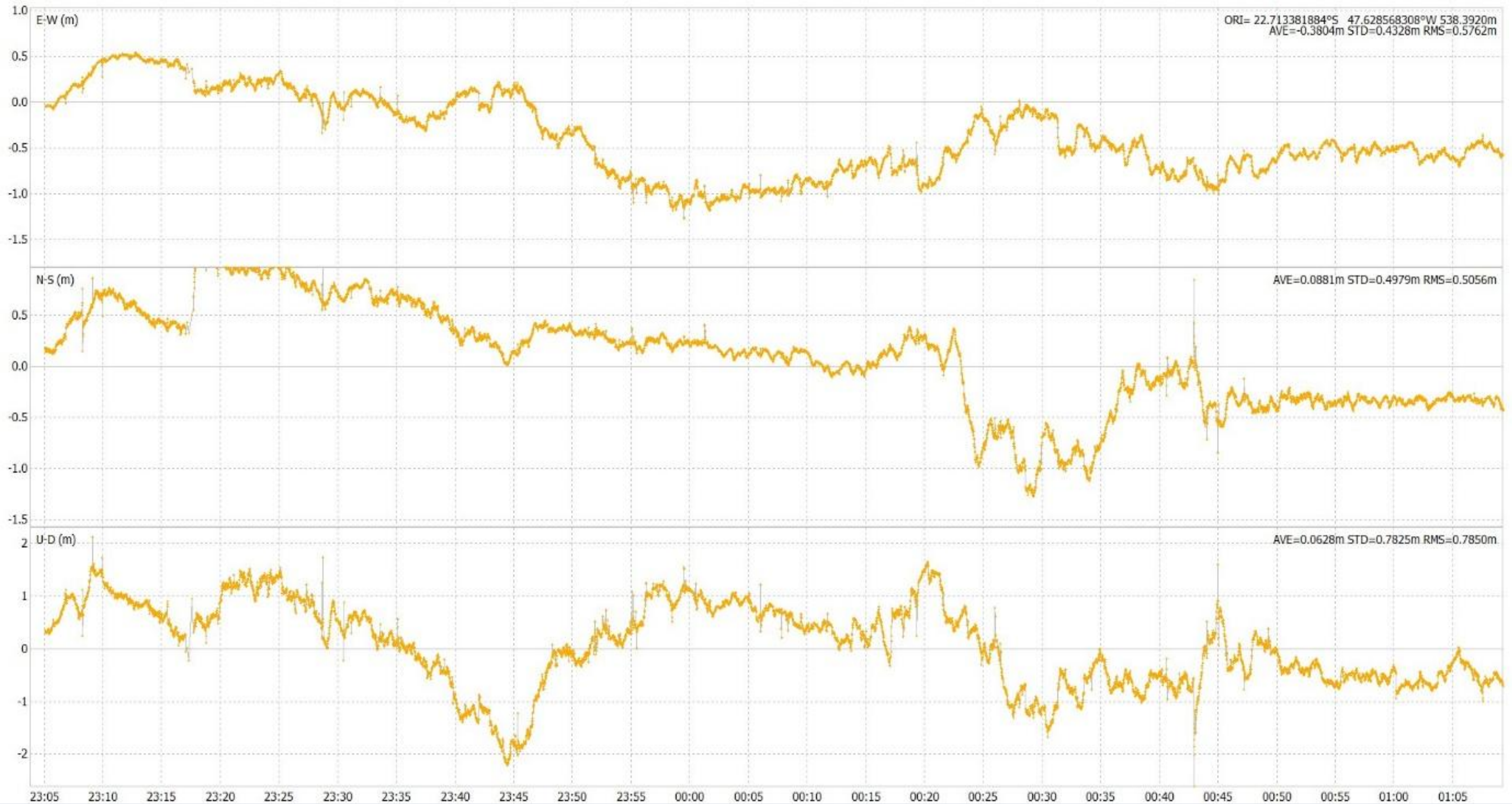




UC2 - Number of scintillating satellites



Time series during scintillation hours Non mitigated solution



Time series during scintillation hours mitigated solution

REMARKS:

We find ourselves in a situation like the one presented for the static rover SB4. Surely, the data exhibit, unfortunately, a low to moderate level of scintillation (sometimes scintillation peaks outside of the data acquisition interval). Nevertheless, the mitigation algorithm doesn't perform quite as expected, as in UC2, the use-case with the highest level of scintillating satellites, that is the highest accuracy error in all components. The improvement in the RMS in the U-D component cannot be thought of as a successful example of mitigation. That said, given the similarity between SB4 and SB5, the considerations outlined in the case od SB4 static rover stay valid. *A local network of ionospheric monitoring stations would agree with the scale of the problem and more effectively describe the fast-changing ionospheric conditions that the algorithm mitigates.*

MULTIPATH MITIGATION MAIN RESULTS

An initial evaluation was performed on static rover data from SB1 and SB6 in Presidente Prudente, and SB4 in Piracicaba. All stations were installed in open-sky environments with minimal nearby reflectors, as already detailed .

To assess potential multipath effects, two methods were used: visual inspection of residuals and multipath diagnostics with Anubis. However, no time windows revealed clear or sustained multipath strong enough to serve as representative test cases.

The clean signal conditions were largely due to the use of choke ring antennas, rooftop installations, and the absence of nearby reflective surfaces.

For completeness, the datasets were processed with and without multipath mitigation. The results showed negligible differences in positioning performance, confirming that these environments were not suitable for robust testing of multipath mitigation algorithms.

To identify the most relevant periods for multipath mitigation analysis, we used Anubis (gnutsoftware.com/anubis) — a GNSS post-processing tool for quality checks on RINEX data. Anubis estimates multipath by combining code and phase observations from multiple frequencies, applying cycle slip detection and correction, and averaging the results using sliding windows. For each dataset, we generated multipath time series and applied a rolling mean to visually highlight trends. This allowed us to pinpoint periods with consistently elevated multipath levels.

USE CASE	Start epoch	Stop epoch
SB5_UC1	21/11/2024 22:57:16	22/11/2024 01:08:10
SB5_UC2	22/11/2024 22:59:06	23/11/2024 01:10:35
SB5_UC3	15/01/2025 21:51:06	16/01/2025 01:07:33
SB5_UC4	14/02/2025 22:17:15	15/02/2025 01:21:58

Use case selection for SB5 Kinematic rover

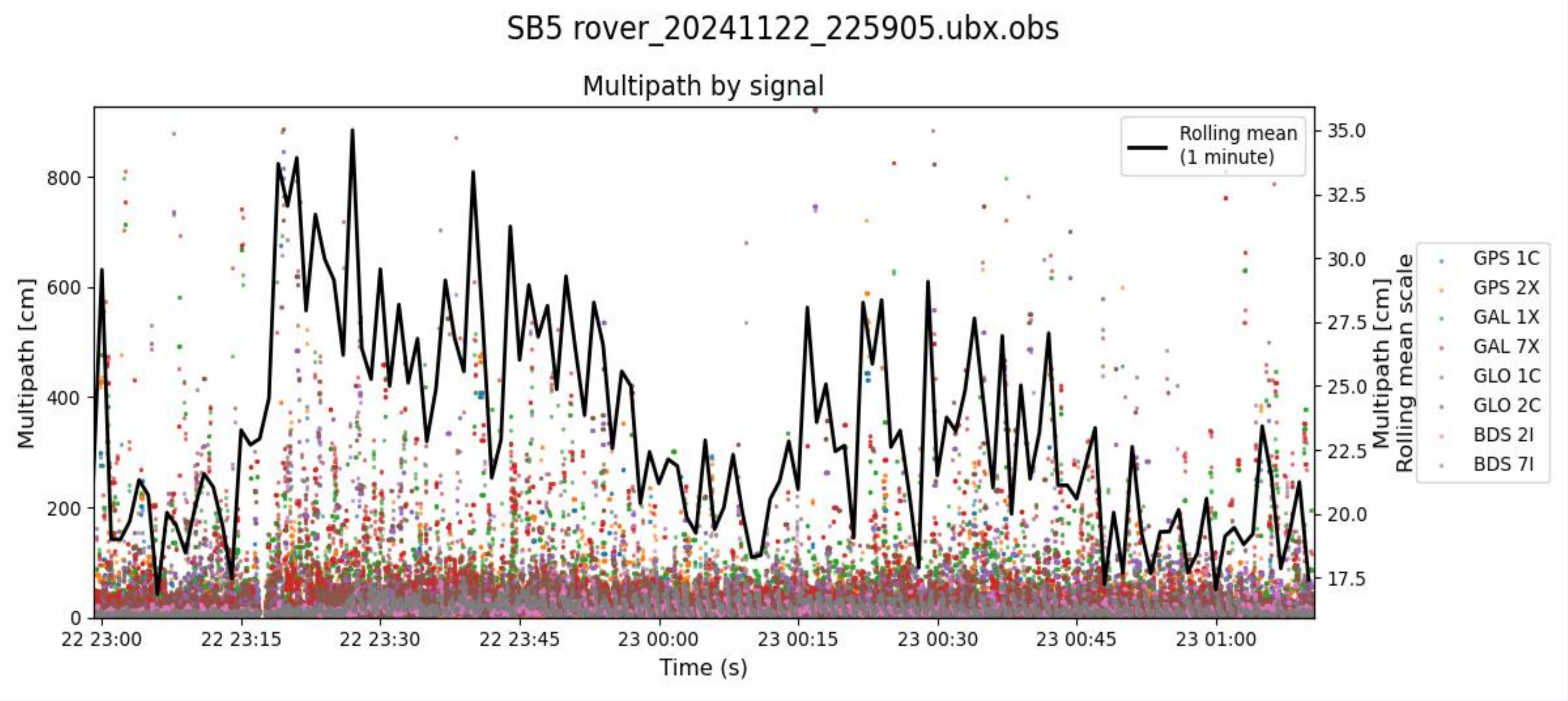
Each use case was analyzed by comparing the ground truth with:

- Non-mitigated solution: standard PPK solution without any multipath correction.
- Multipath-mitigated solution: PPK solution applying GREP mitigation.

For each of them, we will first describe an analysis of the Multipath Detection Parameter (MDP) behavior.This parameter is used by our mitigation algorithm to detect the multipath.

Then we will analyze the positioning results with the following approaches:

- Analisys on Mean error components, and combined
- Analisys on Mean square error components, and combined
- Zoom on Single Revolutions and Trajectory Deviation Analysis
- Frequency Analysis of Positioning Errors Using Fast Fourier Transform



Multipath series for UC2

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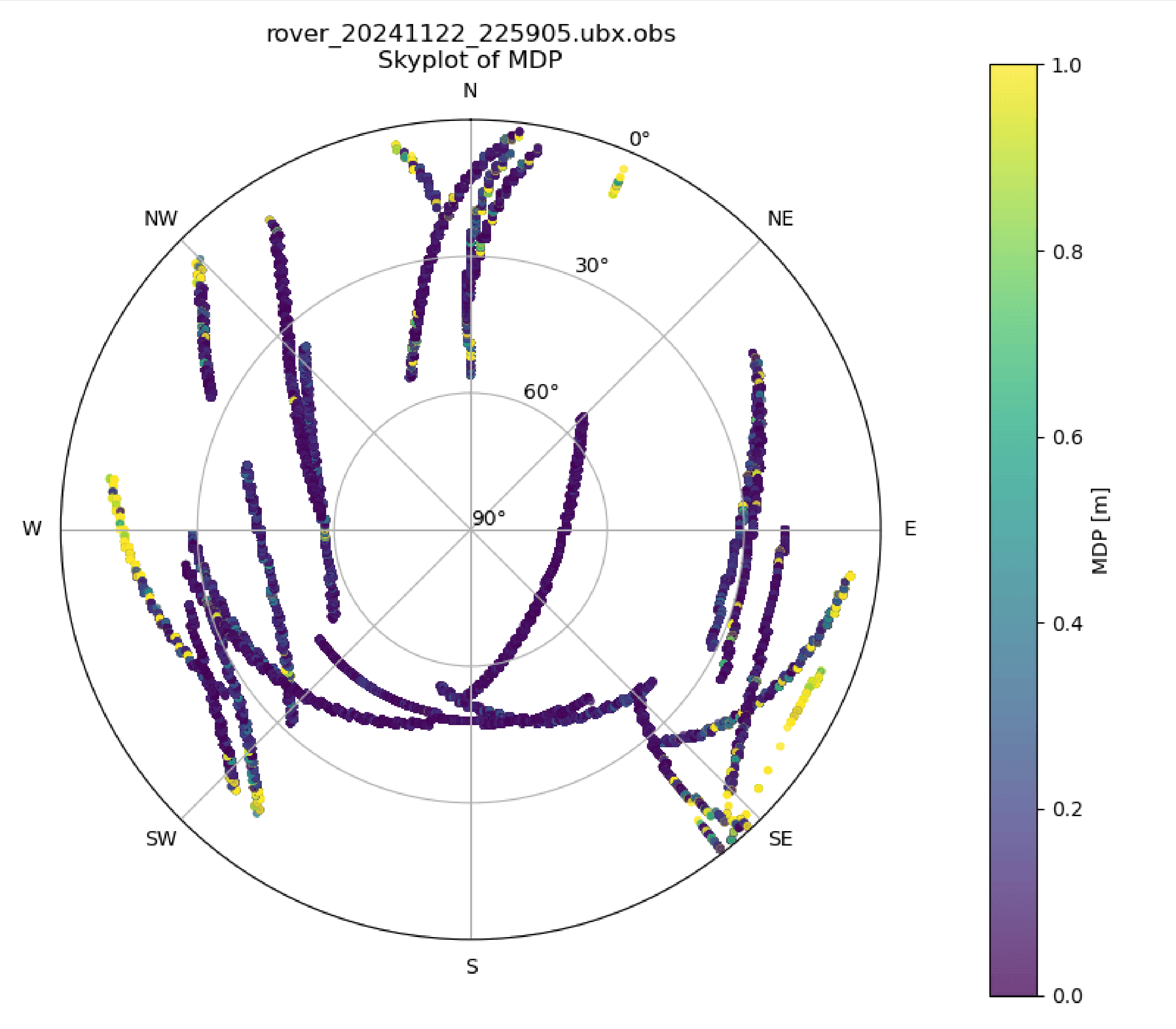

Sky plot and MDP value UC2

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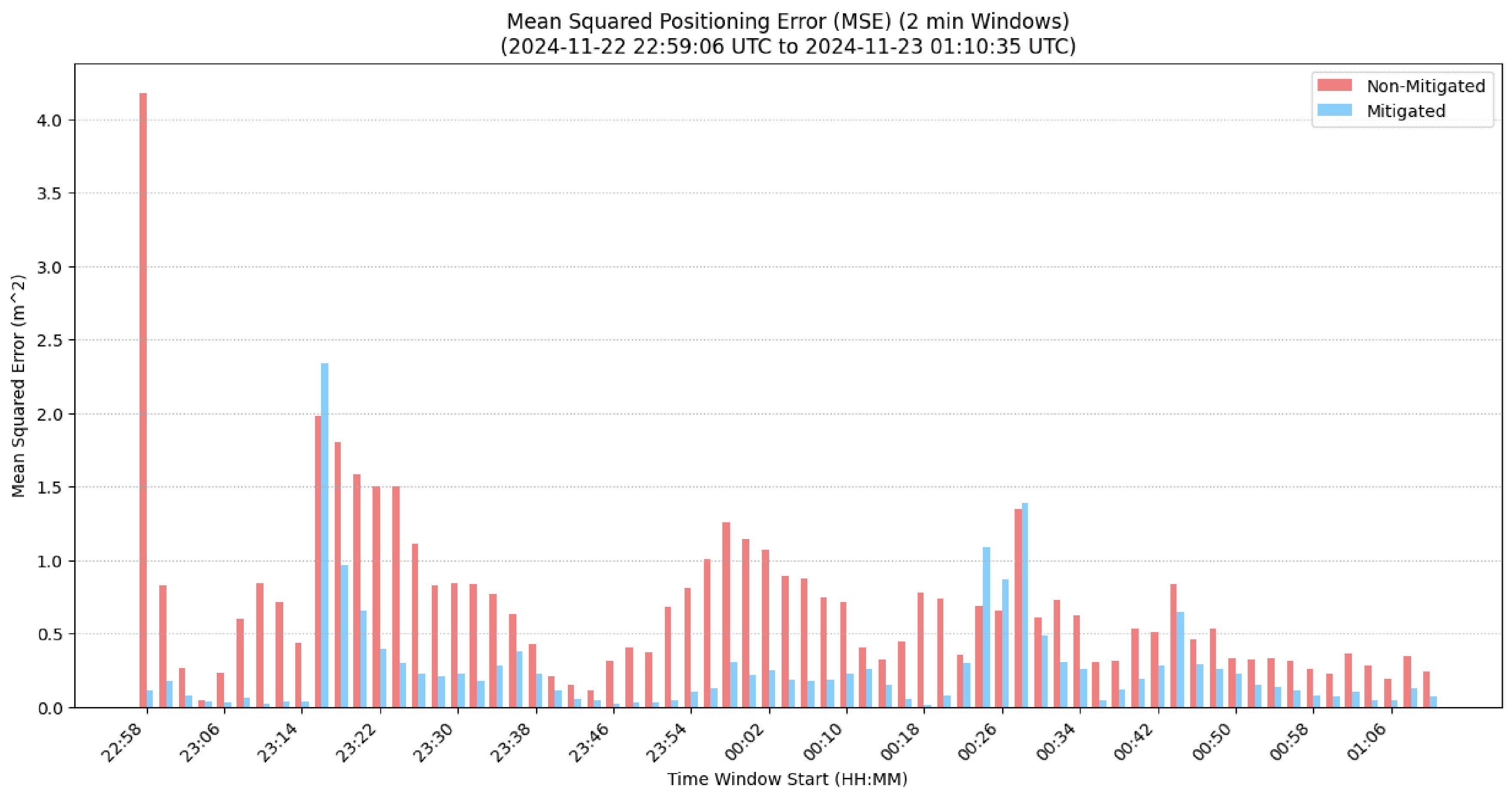
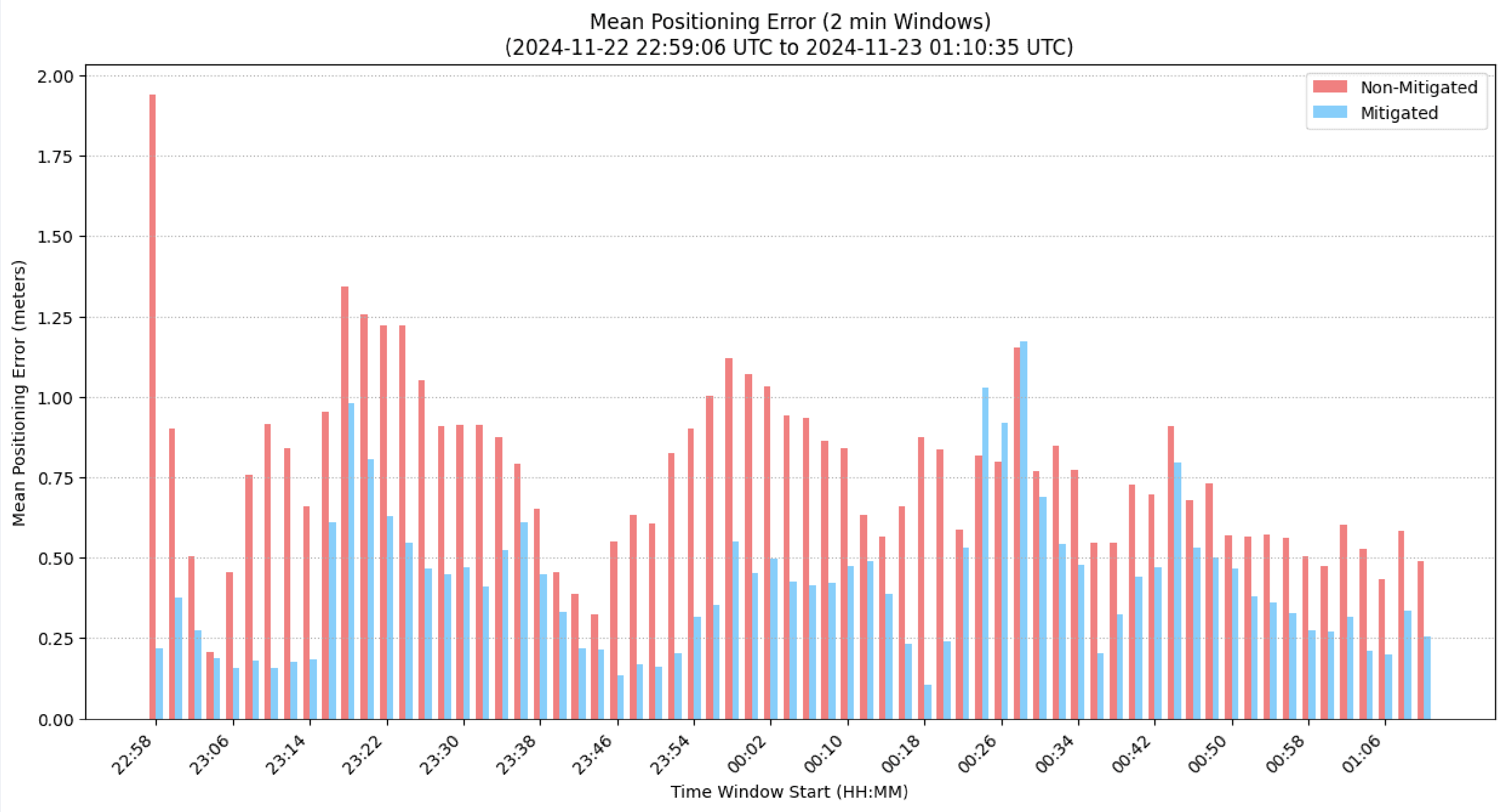
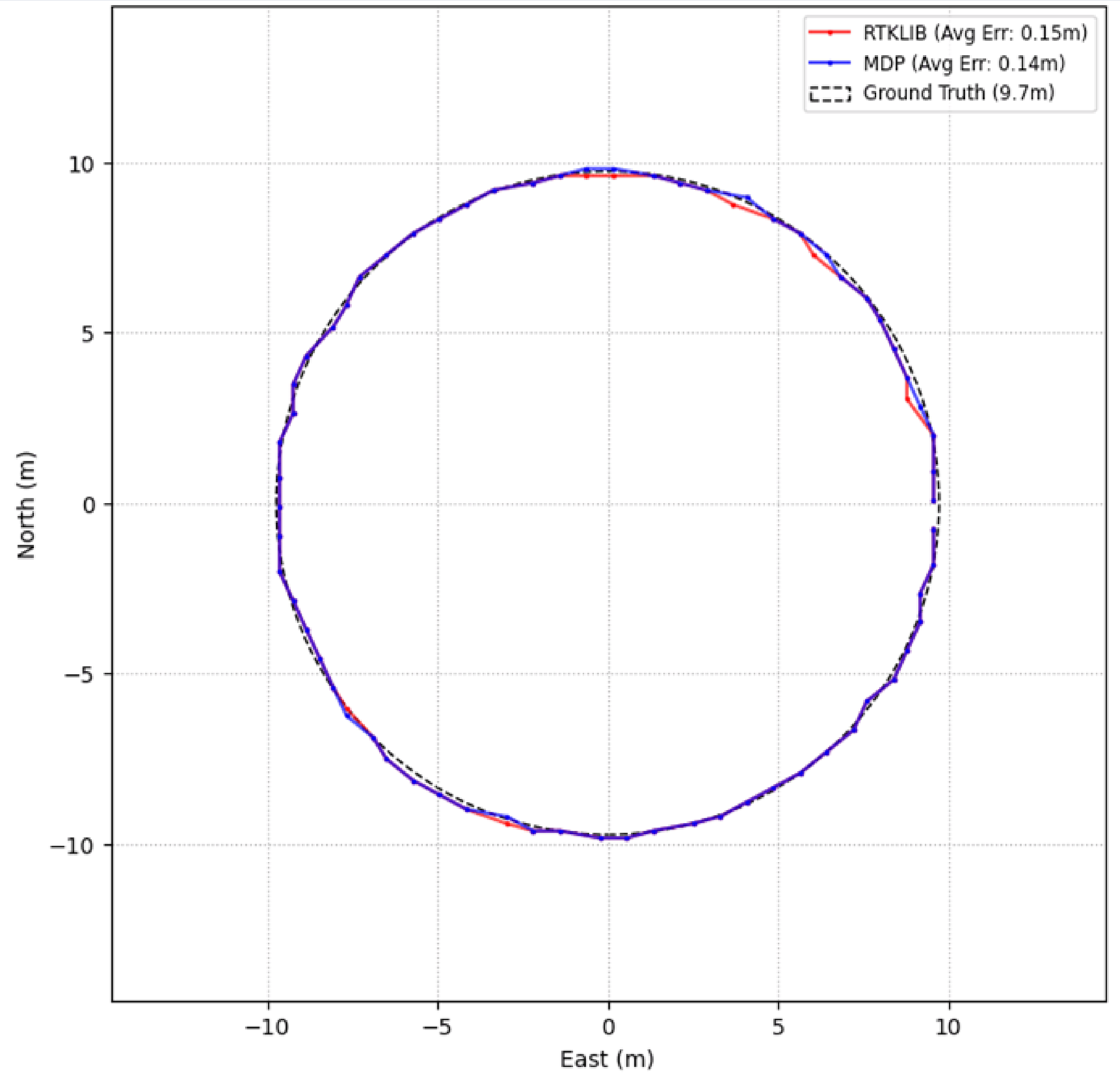


Mean horizontal error comparison for day 22/11/2024 (UC2)



MSE of the total horizontal error comparison for day 22/11/2024 (UC2)



Rotation 53 of UC2

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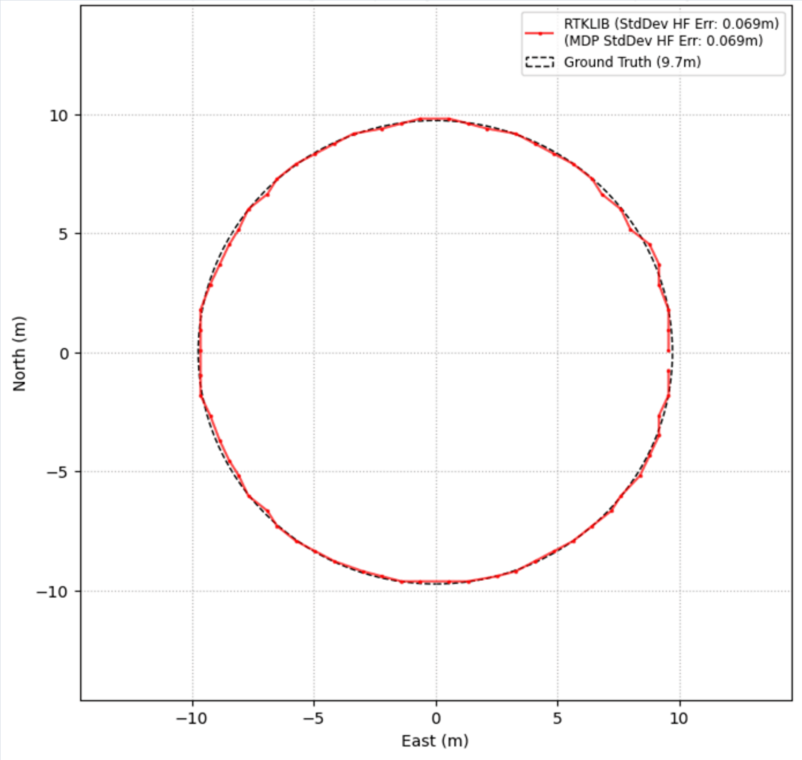
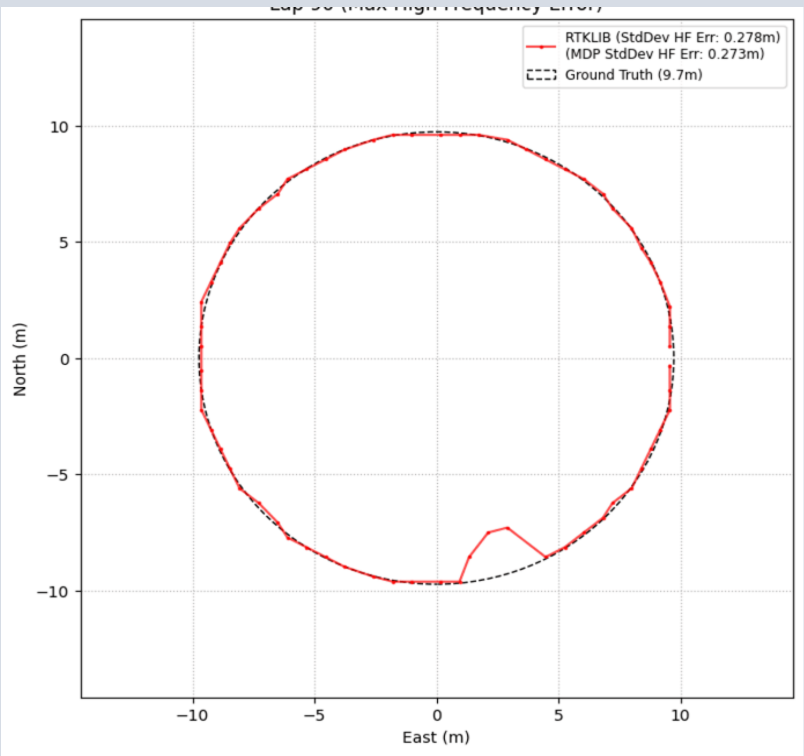
Frequency analysis allows the decomposition of a time series into its constituent frequencies, highlighting dominant oscillatory behaviors that may not be evident in the time domain.

Multipath errors typically manifest at higher frequencies due to their rapid variation over time, especially as the rover moves through environments with varying reflective conditions.





Example of low and high frequency errors

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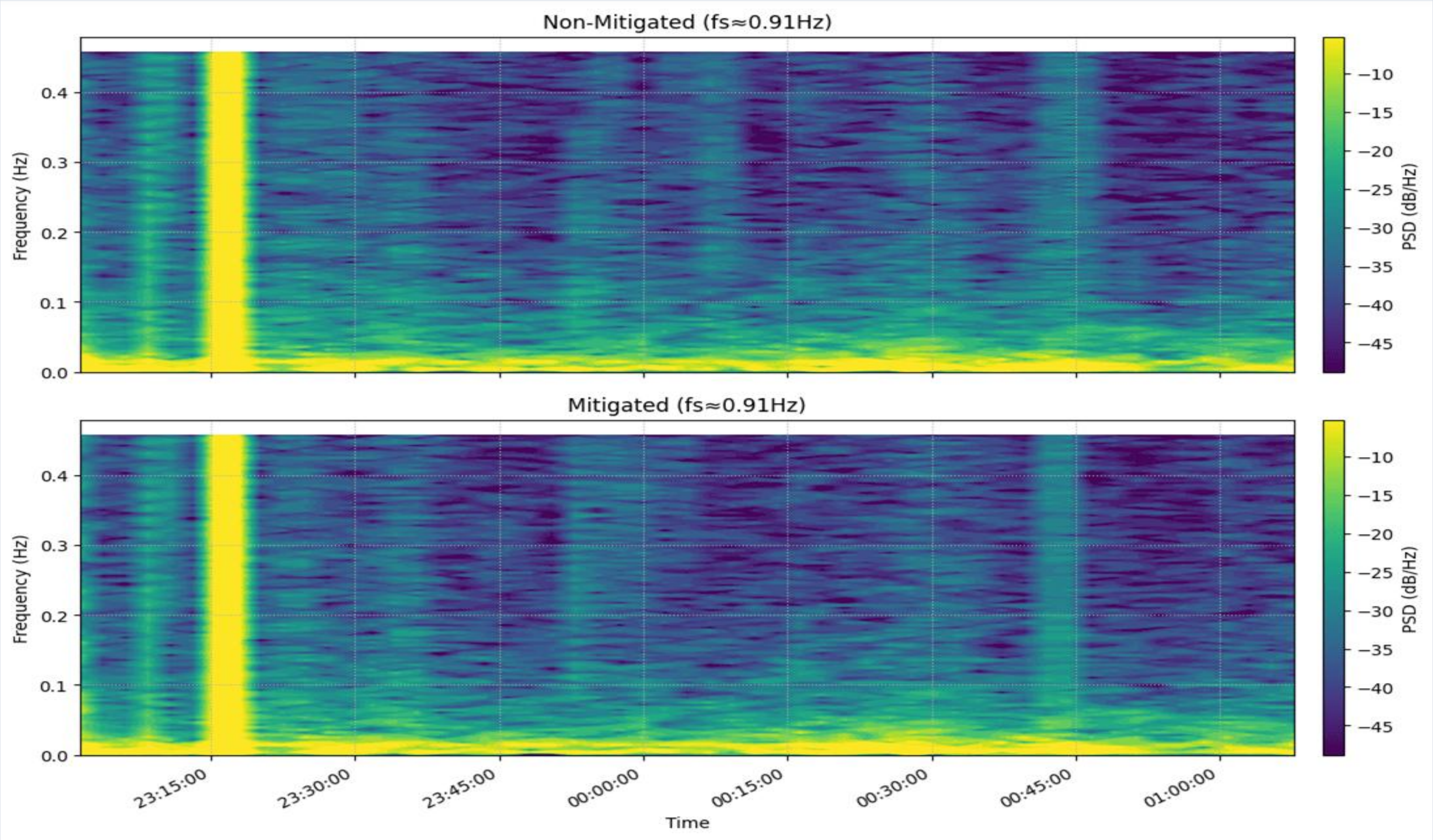
	Power at High Frequency		
	Non Mit. Solution	Mit. Solution	Decrement
SB5_UC2	6.5913e-03 m^2	6.2684e-03 m^2	4.90%



Spectrogram comparison between non-mitigated and mitigated solutions for UC2

Remarks

- **Reduced Mean Error and MSE→ In all 2-minute windows analyzed, mitigated solutions consistently showed lower mean and mean squared errors.**
- **Improved Local Stability→ Per-rotation comparisons revealed that non-mitigated solutions deviated from the circular ground truth, while mitigated paths aligned closely, ensuring better geometric consistency.**
- **Suppression of High-Frequency errors→ Frequency analysis showed a slight reduction in high-frequency signal power after mitigation, matching the expected behavior of multipath-induced errors.**
- **Effective Use of MDP-Based Weighting → The Multipath Detection Parameter (MDP) varied with satellite elevation and, partially, SNR. Sky plots confirmed that observations likely affected by multipath were correctly down-weighted.**

Conclusion (1)

•We developed and operated a prototype service that demonstrated a consistent and measurable improvement in positioning accuracy by mitigating ionospheric scintillation and multipath, proving the effectiveness of our core algorithms.

•By successfully integrating an open-source solution (RTKLIB) with a commercial product, we have laid the groundwork for a competitive and scalable commercial offering.

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Conclusion (2)

IN PARTICULAR FOR SCINTILLATION MITIGATION:

- **The project has generated significant industry interest, evidenced by:**
  - **A successful Proof of Concept with a global leader in the mining sector.**
  - **A licensing agreement negotiation with a major international GNSS manufacturer to commercialize the solution.**
- **This confirms a clear market need for scintillation mitigation not only in agriculture but also in other high-value domains.**
- **Our tests revealed that the primary factor for achieving precision agriculture-grade accuracy is the density of the monitoring network. This project has precisely defined the infrastructure requirements needed to unlock the technology's full potential, moving from a research-oriented network to a purpose-built, commercial-grade network.**
- **The project has significantly elevated SpacEarth Technology's profile as an innovator in the GNSS scintillation mitigation sector, creating a strong foundation for future R&D and commercial leadership.**

Next Steps (1)

To capitalize on our successful results and strong market validation, we have defined a strategic roadmap:

- Transition from leveraging existing academic networks to designing and deploying a network specifically optimized to support high-accuracy, real-time RTK positioning at low latitudes.
- *Integrate the separately validated multipath and scintillation mitigation algorithms into a single, robust solution to address combined error sources simultaneously.*
- Extend the mitigation capabilities from the rover to GNSS base stations, enabling the broadcast of "scintillation-free" RTK corrections.

Next Steps (2)

- ***Adapt and validate the algorithm for high-latitude regions (above 60°), opening up new markets and applications in Arctic and Antarctic environments.***
- **Extend and test the mitigation algorithm's performance with other precise positioning methods like PPP (Precise Point Positioning) and PPP-RTK.**
- ***Broaden the market analysis to fully quantify commercial opportunities in other GNSS-dependent sectors (e.g., maritime, drone logistics, autonomous vehicles).***
- **While initial follow-up activities are underway using internal resources, securing dedicated funding is critical to accelerate these developments. A focused investment will allow us to maintain our competitive edge, meet the accuracy demands of key industries, and rapidly transition this innovative technology into a market-leading commercial service.**

THANK YOU TO ALL

- *To ASI and ESA for their support;*
- *To all the colleagues of SET and GTER for the passion and determination in pursuing the objectives of the project;*
- *To the Brazilian colleagues of UNESP, ESAQL-USP and Guandalini for hosting and supporting the operational activities of the demonstration;*
- *A Special thanks to Raul Orus for his continuous and competent attention and interest in the project;*
- *To the attendant at this presentation for their attention.*