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

1–5 June 2026

Faculdade de Ciências e Tecnologia
Câmpus Presidente Prudente

CAPES

Assessment of Climate Variability and Extreme Events Using GNSS-Based PWV

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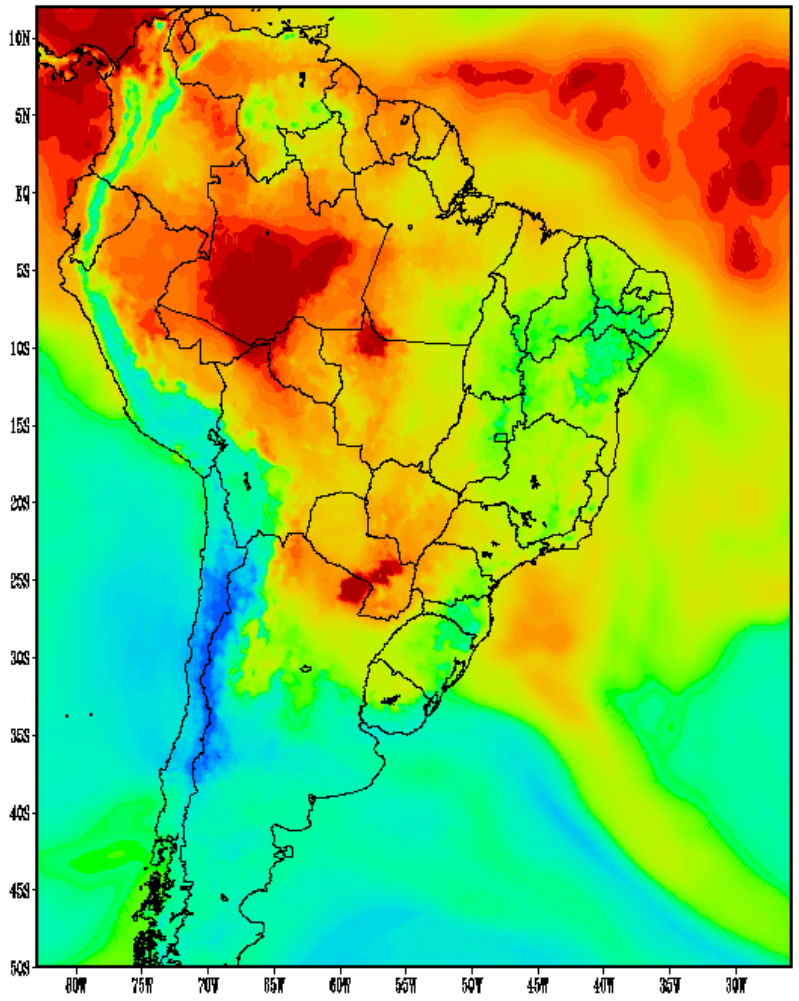
INTRODUCTION

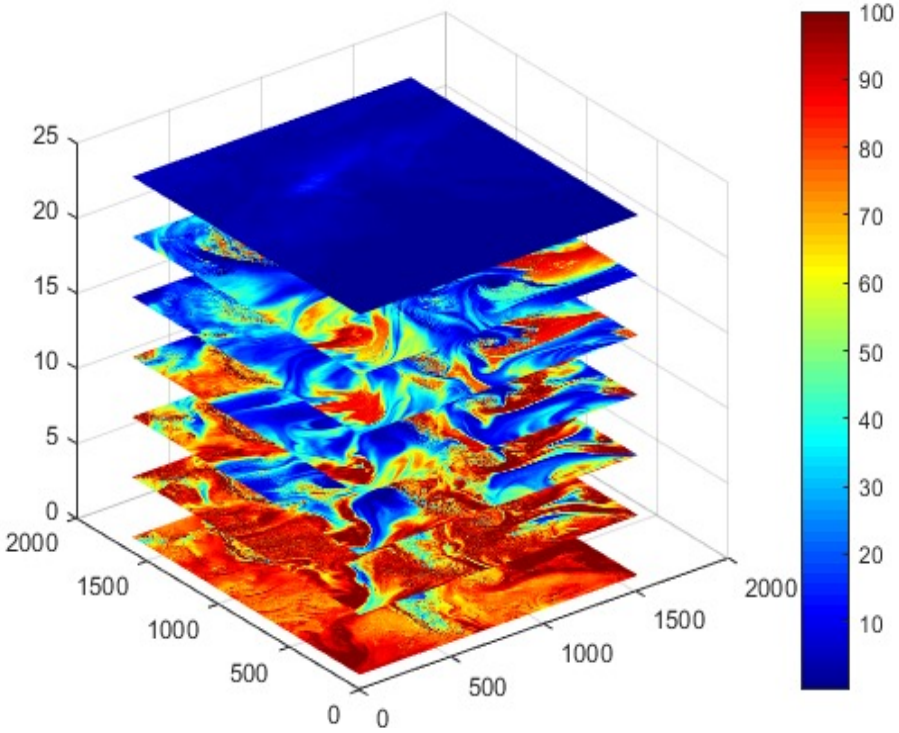
Climate Extremes

- Climate change is increasing the frequency and intensity of extreme weather events worldwide;
- **Tropical regions (Brazil): There is** Intensification of extreme precipitation and catastrophic flooding;
- **“Summer rain”**: Convective rain is rain generated by intense heat and humidity;
- **Challenges:** Increasing pressure on meteorological monitoring, climate modeling, and operational systems that require high-precision atmospheric characterization;

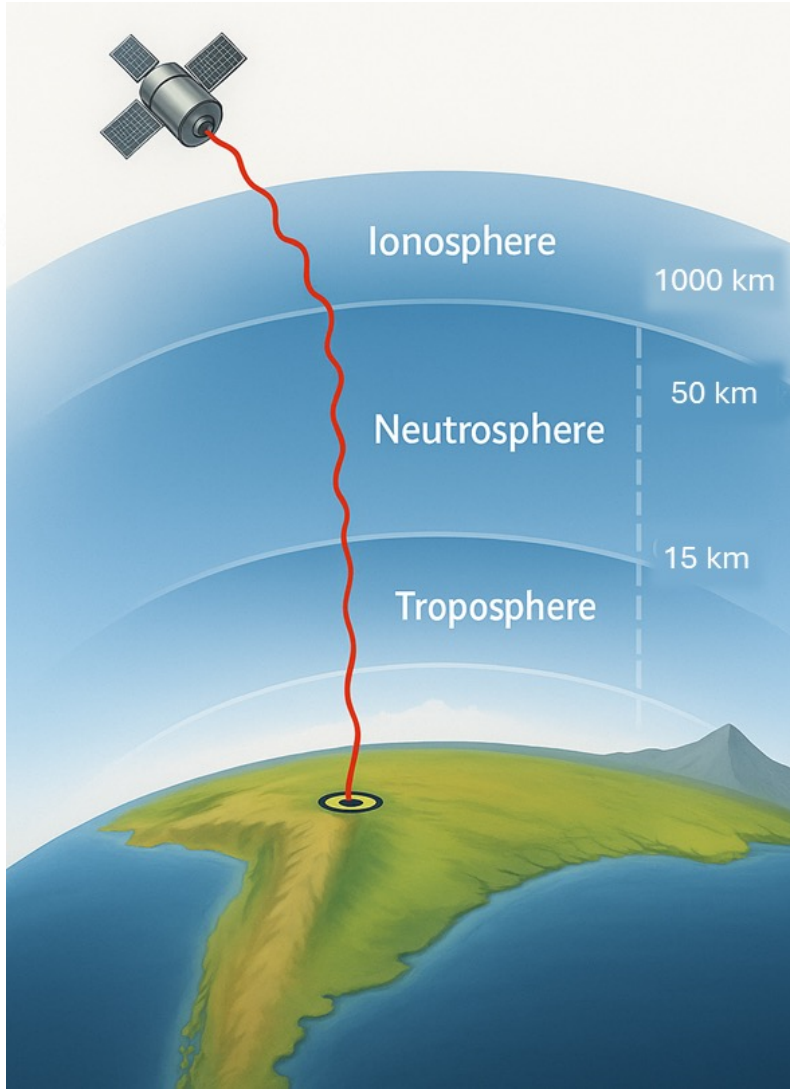
Synergy GNSS Meteorology



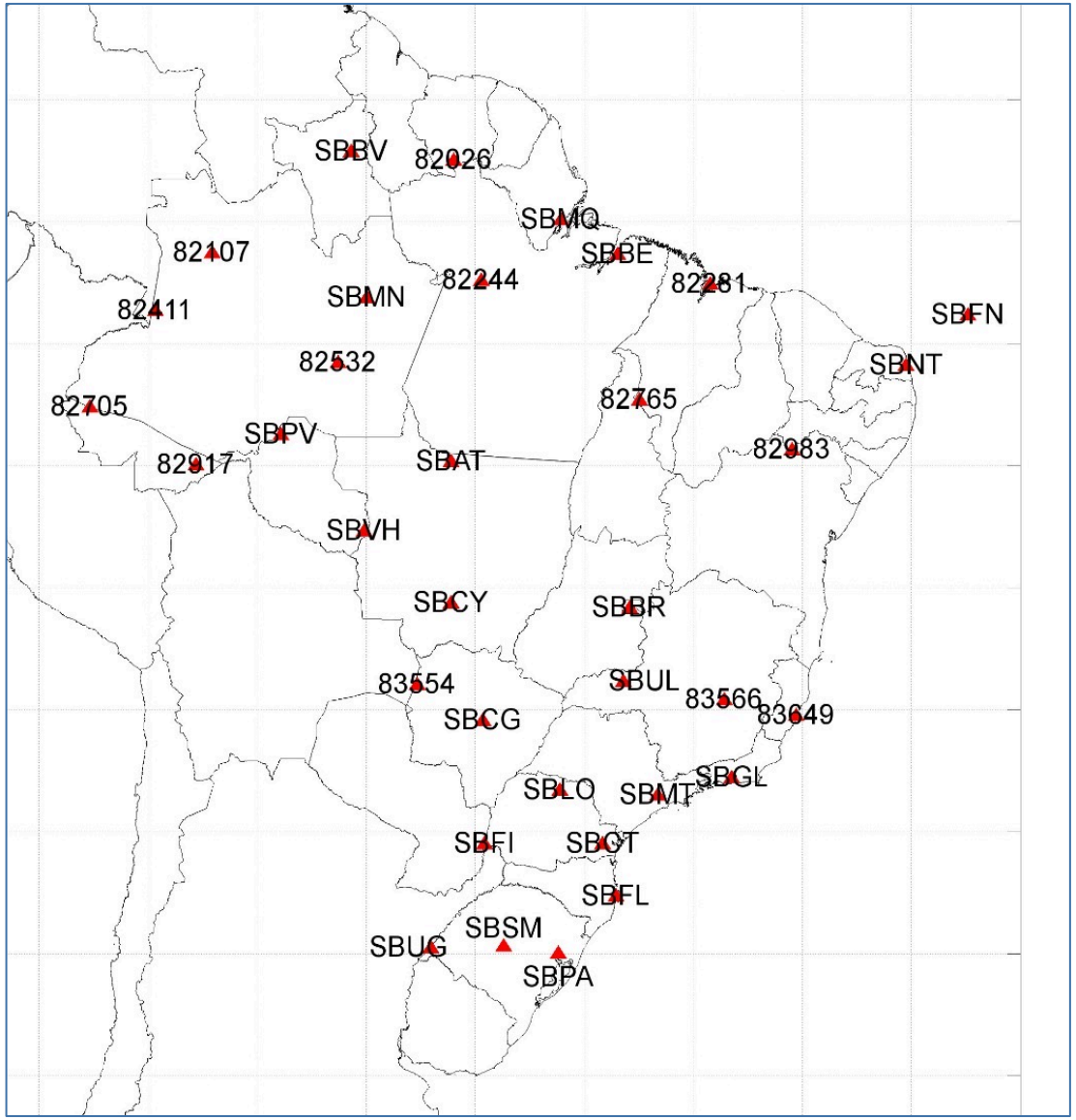
Numerical Weather Prediction
(NWP)



Day 1 – 6-hour forecast
25 layers of the atmosphere



Radiosonde available in Brazil – twice a day

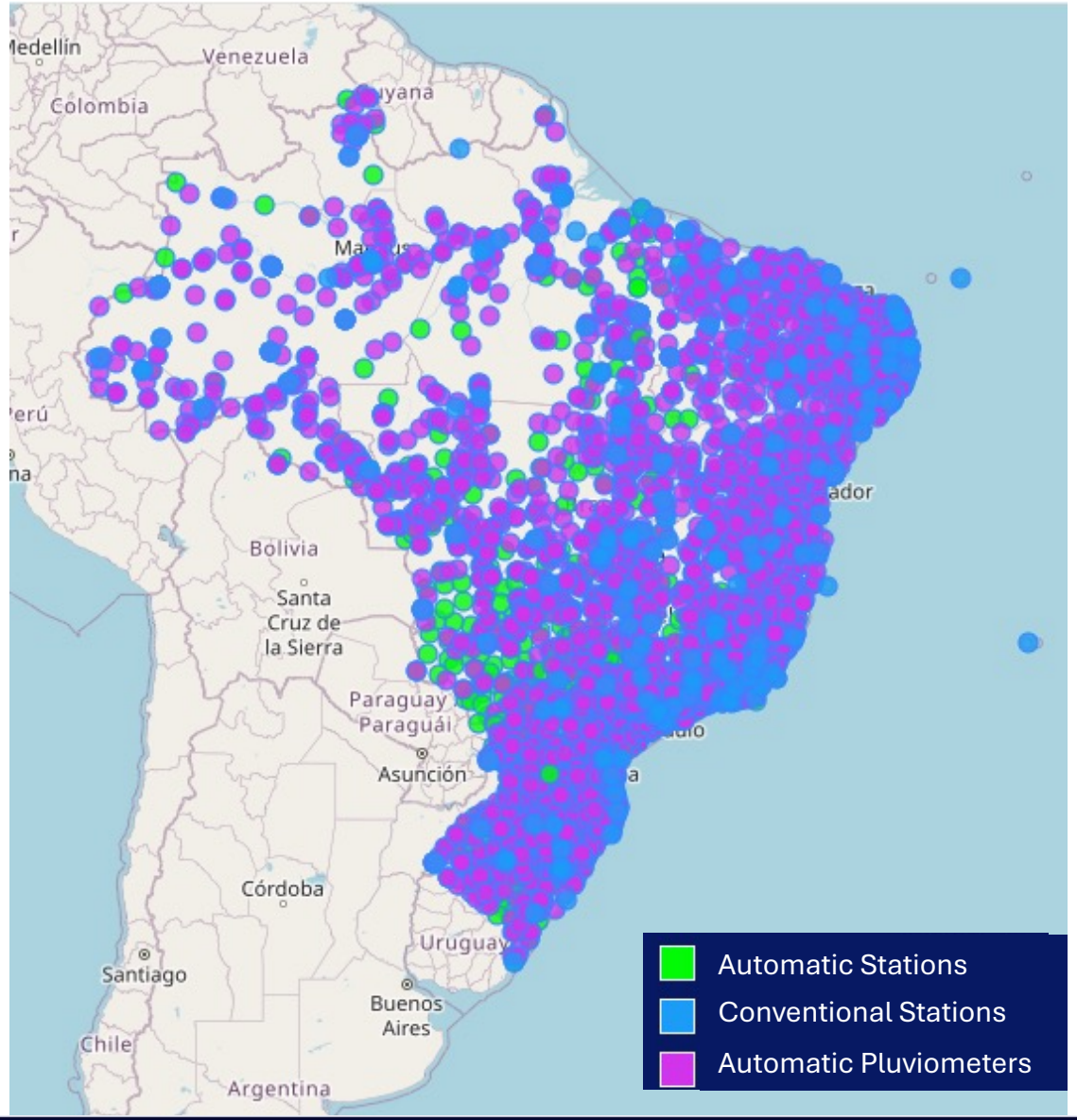


Temporal Resolution:
00h and 12h UTC

Spatial resolution:
~43 Stations

https://weather.uwyo.edu/upperair/sounding.shtml

Brazilian Institute of Meteorology INMET – hourly



Automatic
Temporal Resolution:
01h – 24 per day

Spatial resolution:
603 Stations

Conventional
Temporal Resolution:
08h – 3 per day

Spatial resolution:
97 Stations

https://mapas.inmet.gov.br/

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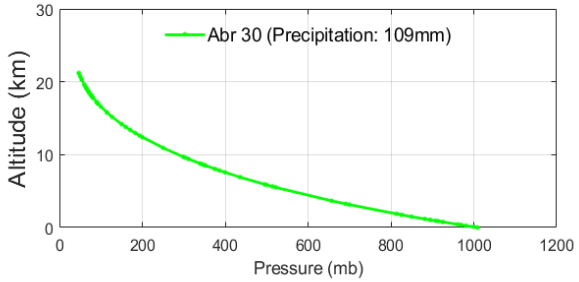
METHODOLOGY

ZTD - GNSS Error X
PWV - Meteorology Information

$$ZTD = 10^{-6} \int_{h_0}^{h_{top}} \underbrace{\left(k_1 \frac{P_d}{T} Z_d^{-1}\right)}_{ZHD} + \underbrace{\left(k_2' \frac{e}{T} Z_w^{-1} + k_3 \frac{e}{T^2} Z_w^{-1}\right)}_{ZWD} dh.$$

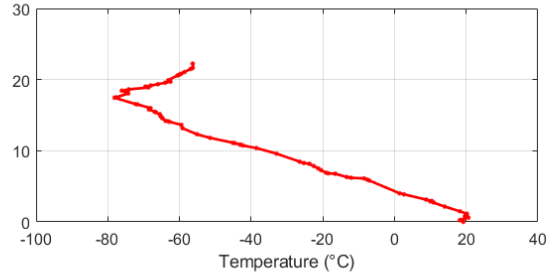
Direct measures
Radiosonde; NWP...

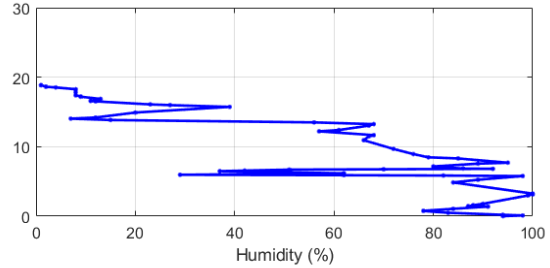
$$\mathrm{ZHD} = 2{,}22765201 \times 10^{-2} \frac{P_0}{9{,}784(1 - 0{,}0026 \cos 2\varphi - 0{,}00028 h_0)}$$



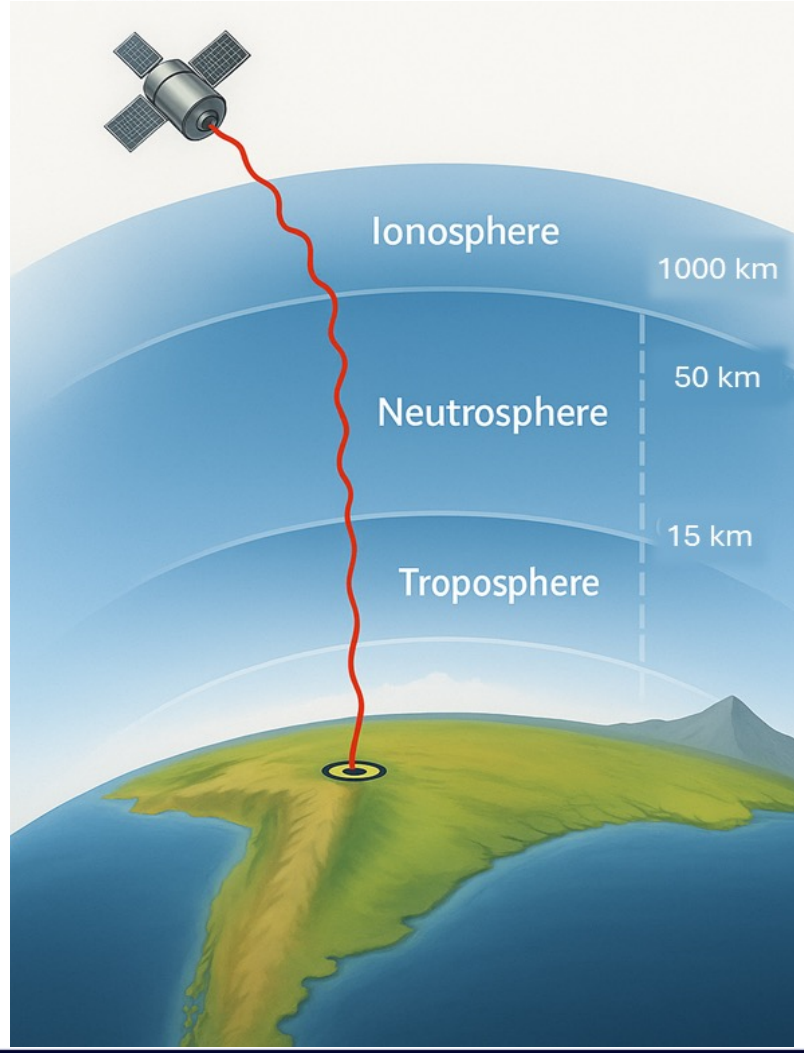
$$\mathrm{ZWD} = 10^{-6} \int \left(\frac{k'_2 e}{T} Z_w^{-1} + k_3 \left(\frac{e}{T^2}\right) Z_w^{-1}\right) dh$$

$$PWV = \frac{ZWD \cdot \dfrac{10^6}{R_w \left[k_2' + \dfrac{k_3}{Tm}\right]}}{\rho_a}.$$





PWV Estimations



Indirect measures – GNSS_SIRGAS (1h)+ INMET (1h)

$$\mathrm{ZHD} = 2{,}22765201\times10^{-2}\,\frac{P_0}{9{,}784(1-0{,}0026\cos 2\varphi - 0{,}00028h_0)}$$

$$\mathrm{ZWD}_{\mathrm{GNSS\_Mod}} = \mathrm{ZTD}_{\mathrm{GNSS}} - \mathrm{ZHDMod}$$

$$PWV = \frac{ZWD \cdot \dfrac{10^6}{R_w\left[k_2' + \dfrac{k_3}{Tm}\right]}}{\rho_a}.$$

$$Tm = \frac{\int \frac{e}{T}\,dh}{\int \frac{e}{T^2}\,dh}$$

Sapucci et al., 2014

What is the best data source?

It depends:

- on the application;
- on the availability of the data.

Radiosonde: direct measurements of pressure, temperature, and humidity – from surface to 28km - 12h - few stations;

Surface stations: direct surface measurements – hourly data - high density coverage;

GNSS estimation: indirect measurements – sec/min or nowcasting - good density coverage;

Precipitable water vapor (PWV) obtained by GNSS, with high temporal resolution (15s, 5min), can be a good strategy.

Neutrospheric Evaluation and Processing Tool

Online service to support research, education and society.

NEPTool
Neutrospheric Evaluation and Processing Tool

https://neptool.fct.unesp.br/

Gouveia et al., 2026

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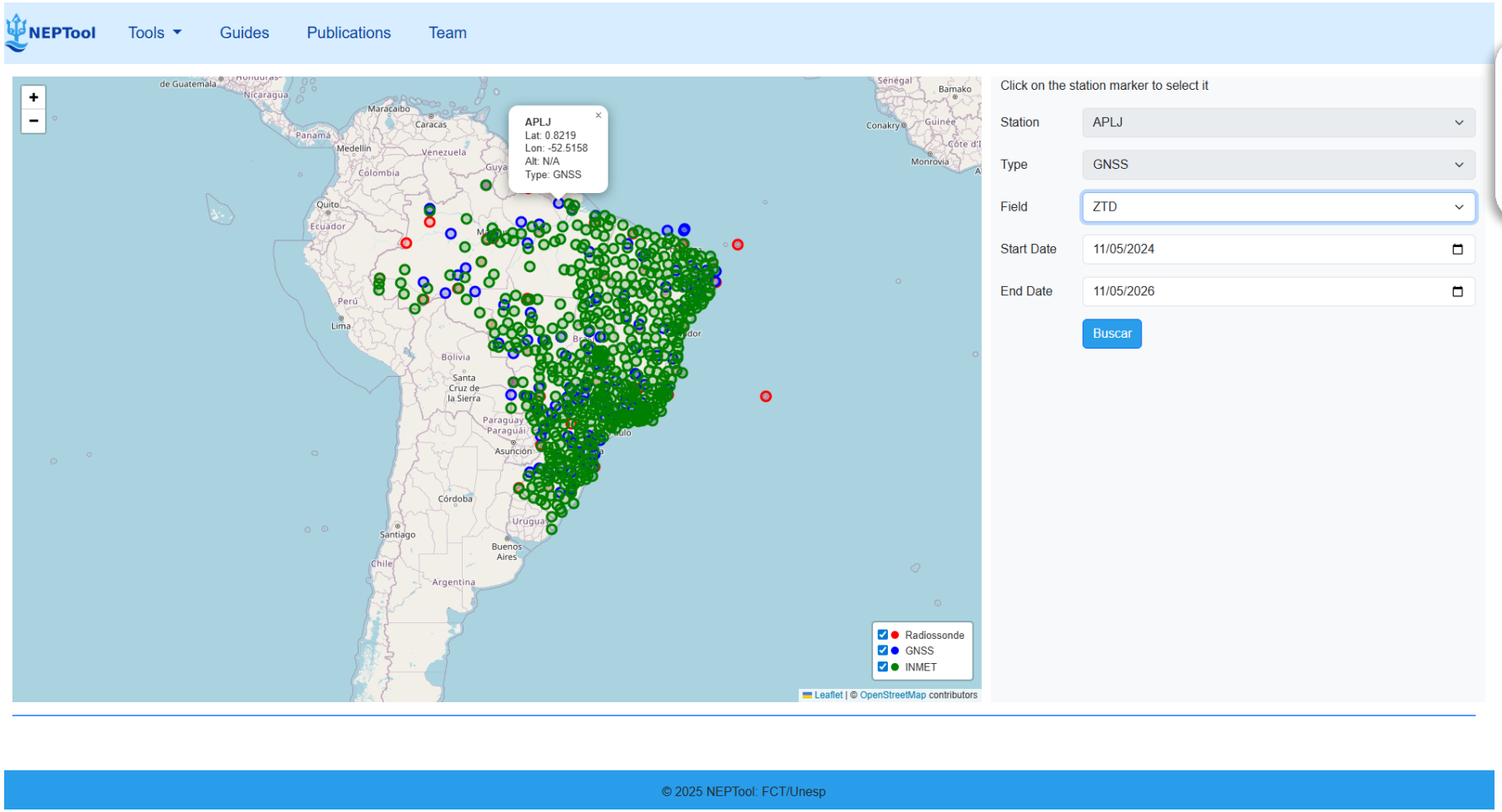
Neutrospheric Evaluation and Processing Tool



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https://neptool.fct.unesp.br/

Challenge

If the weather is changing ...

What are the best and possible strategies to monitor it: blind models, NWP, GNSS data processing?

And is it good for forecasting extreme event alerts?

Case Study of Extreme Precipitation Presidente Prudente - SP

Landslides, Flooding, and Roads Collapsing Under Vehicles as Heavy Rain Pounds Western São Paulo.

- ✓ Presidente Prudente – SP;
- ✓ December 12th to 16th, 2025;
- ✓ An accumulated rainfall of 221.8mm was observed within the urban perimeter in short time interval.

https://g1.globo.com/sp/presidente-prudente-e-regiao/noticia/2025/12/15/fim-de-semana-de-chuva-intensa-deixa-alagamentos-e-prejuizos-no-oeste-paulista.ghtml

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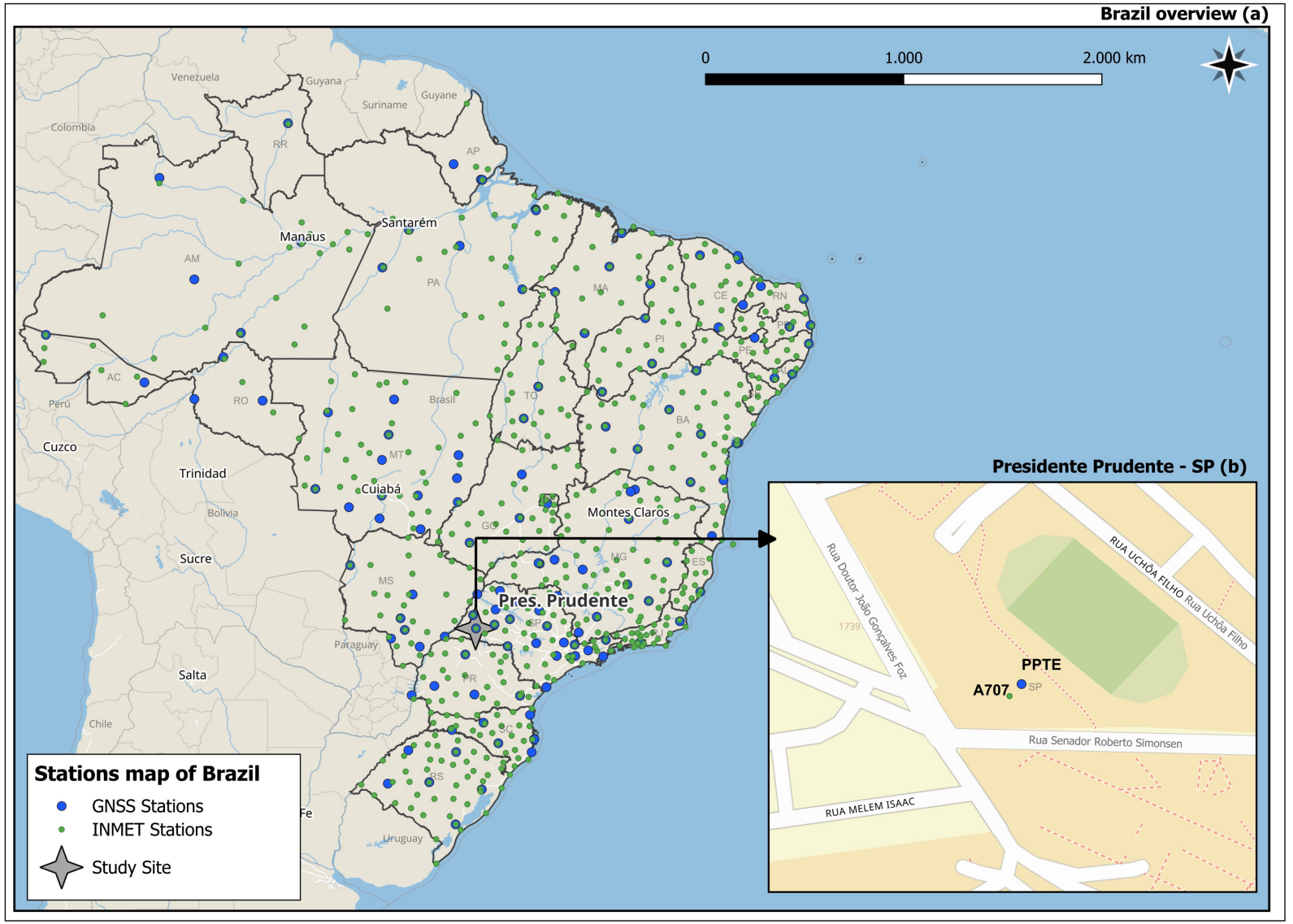
How should we investigate this event?

Presidente Prudente –SP Brazil

- ✓ Brazilian Surface Meteorological Data – INMET;
- ✓ ZTD SIRGAS/IBGE station - PPTE;
- ✓ Period: since 2014;
- ✓ Hourly data from both sources.



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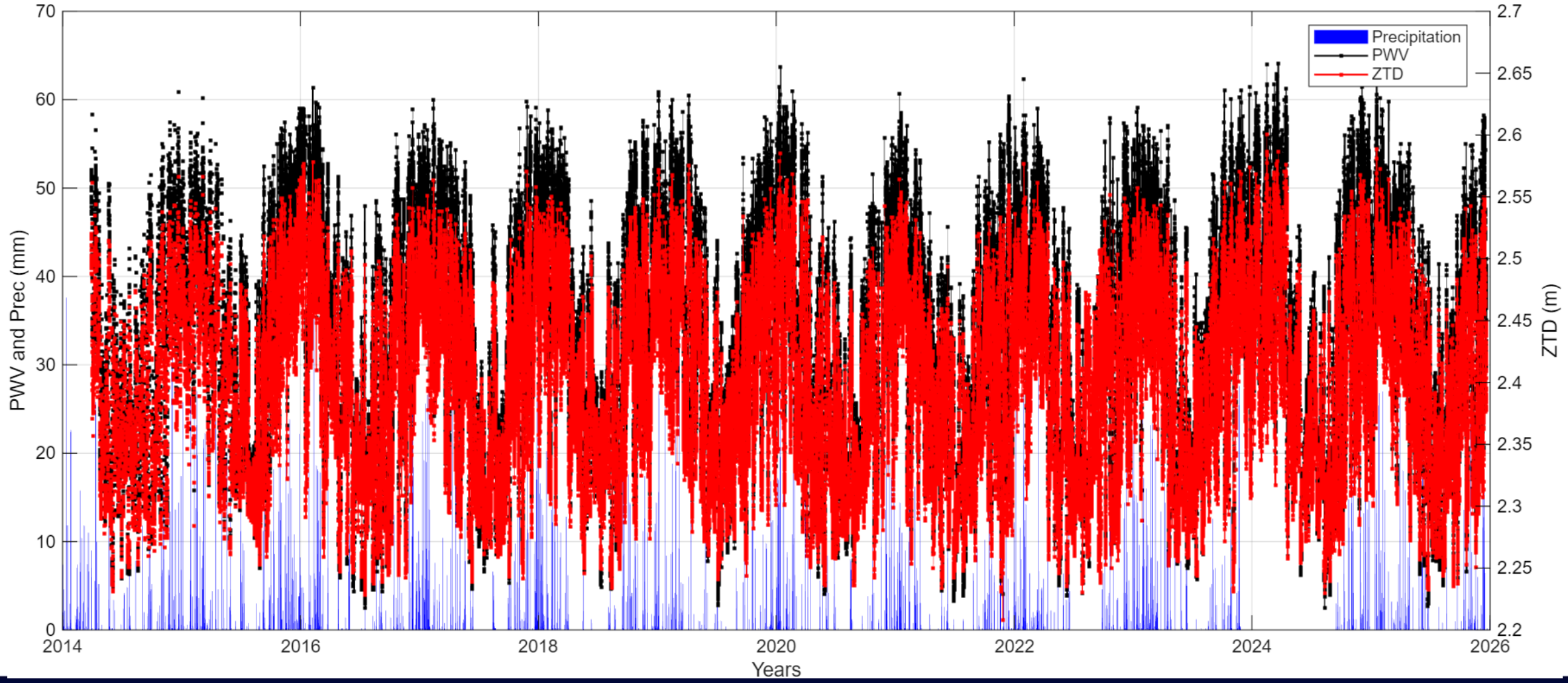
RESULTS AND DISCUSSION

PPTE Temporal Series-11years
ZTD and PWV GNSS +INMET



PPTE Temporal Series-2025
ZTD and PWV GNSS +INMET

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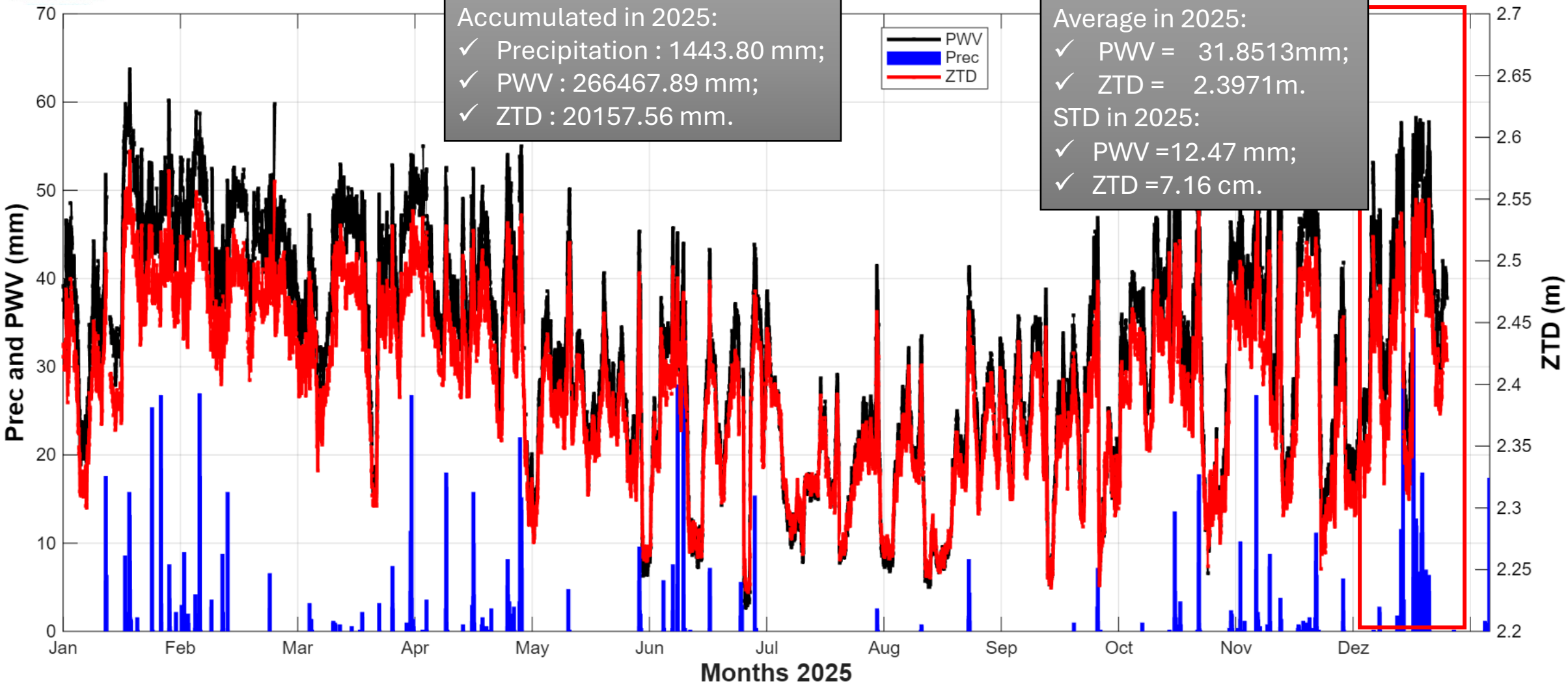
Accumulated in 2025:
- ✓ Precipitation : 1443.80 mm;
- ✓ PWV : 266467.89 mm;
- ✓ ZTD : 20157.56 mm.

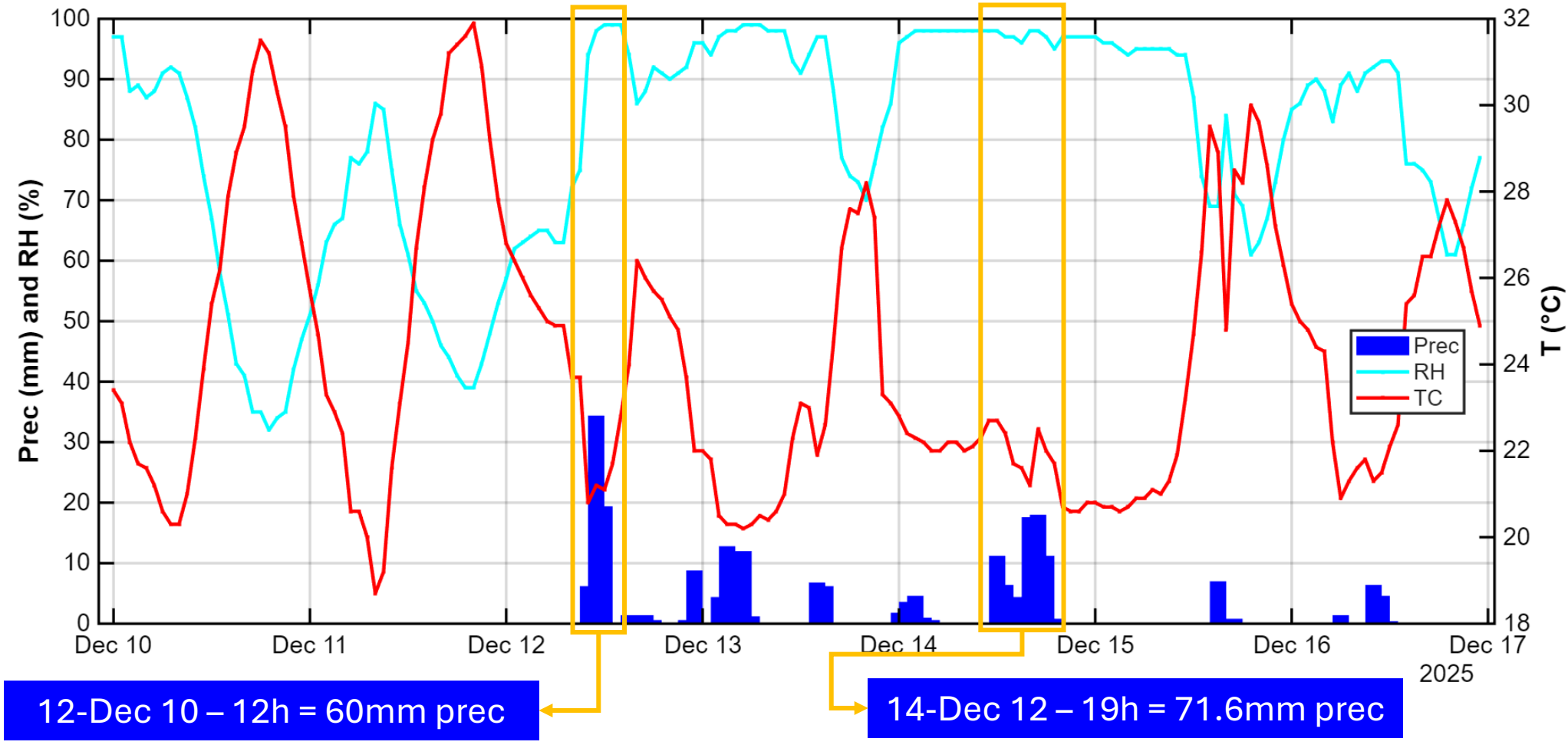
Average in 2025:
- ✓ PWV = 31.8513mm;
- ✓ ZTD = 2.3971m.

STD in 2025:
- ✓ PWV =12.47 mm;
- ✓ ZTD =7.16 cm.

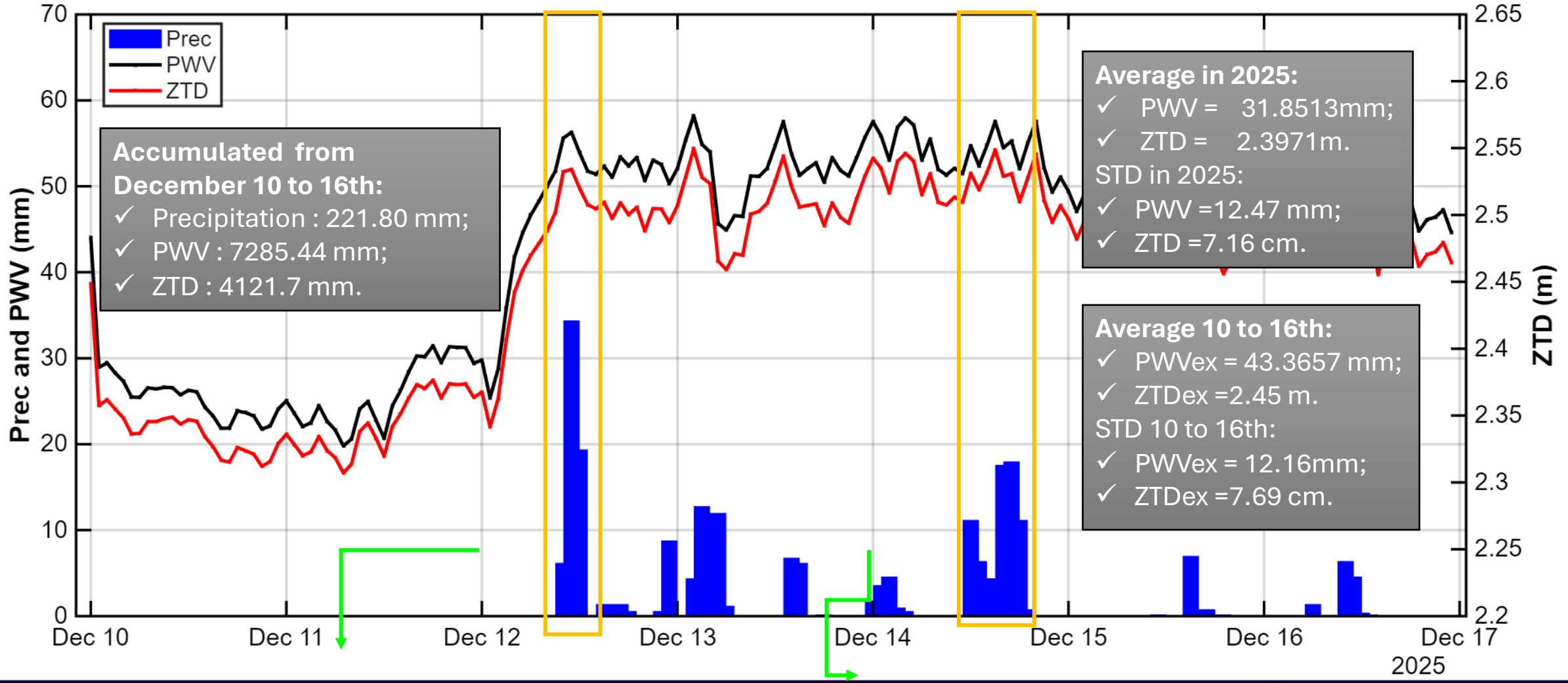


PPTE Temporal Series-2025
ZTD and PWV GNSS+INMET

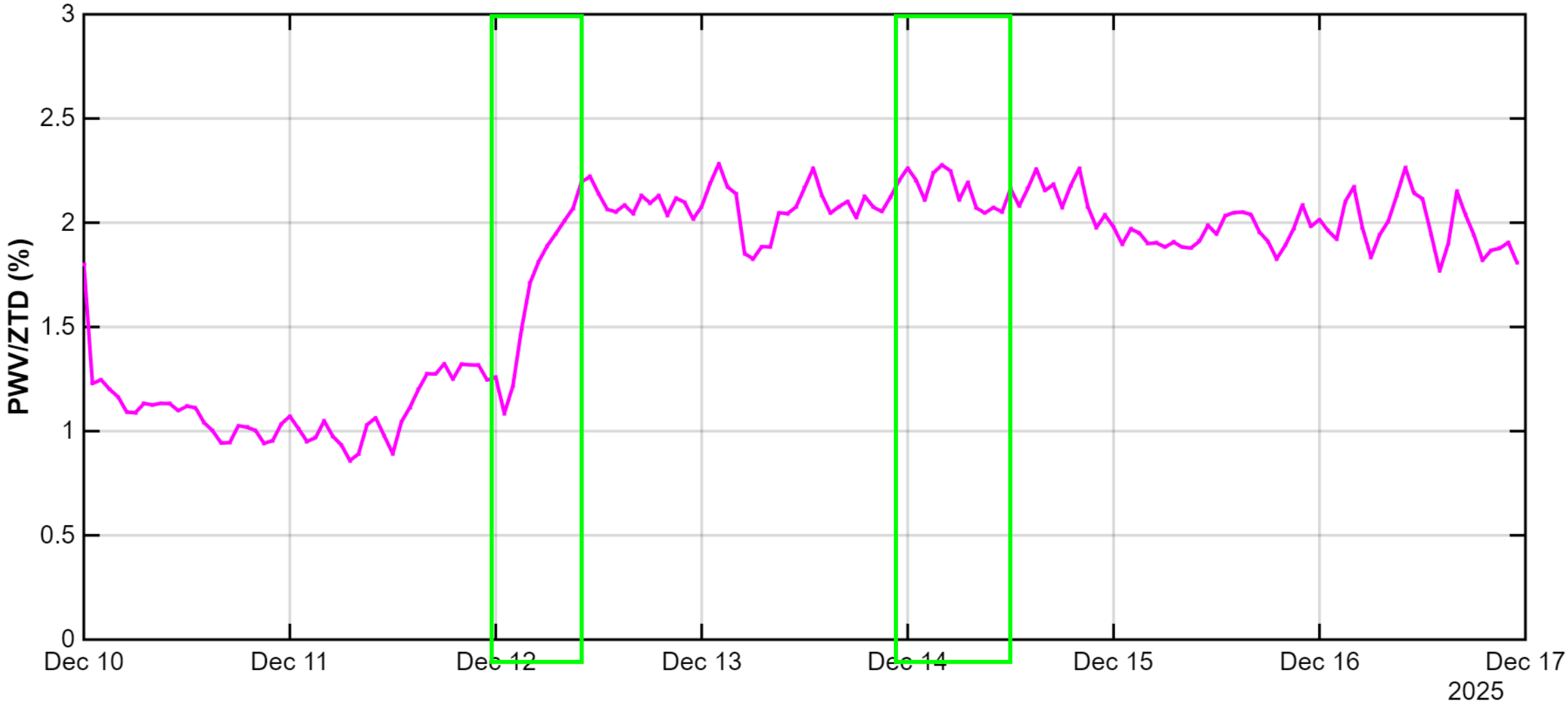
- ✓ Accumulated precipitation in 2025: 1443.80 mm;
- ✓ Total Precipitation for December 10-16: 221.8000 mm;
- ✓ 91% (200 mm) between December 12 to 14.



PPTE – Extreme Precipitation Event
ZTD and PWV GNSS +INMET



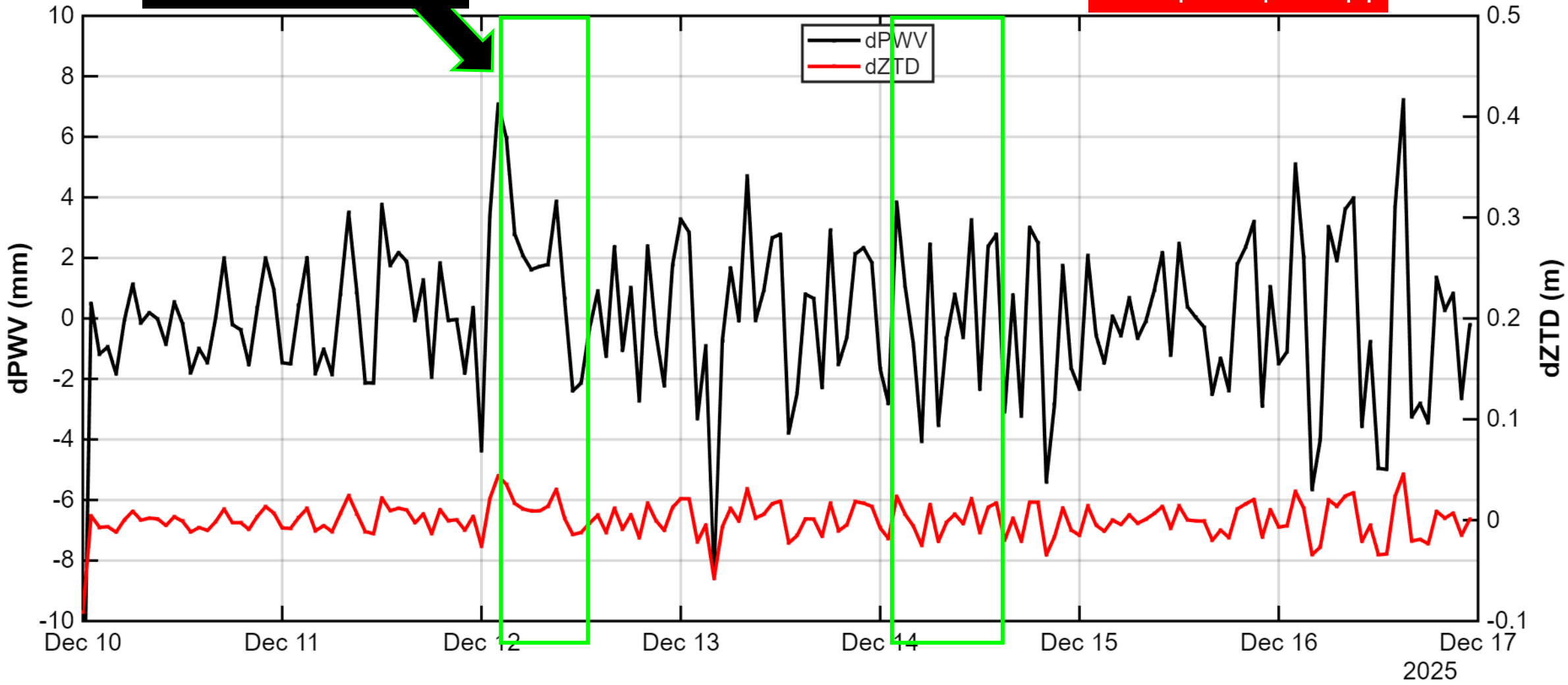
PPTE – Extreme Precipitation Event
Rate of change - PWV/ZTD



PPTE – Extreme Precipitation Event Differential epochs - PWV and ZTD

$\Delta PWV_i = PWV_i - PWV_{i-1}$

$\Delta ZTD_i = ZTD_i - ZTD_{i-1}$



Final Considerations

- The temporal analysis showed that PWV consistently follows the seasonal pattern of precipitation and tends to increase before major rainfall events.
- In contrast, ZTD reflects atmospheric variability associated with changes in pressure, temperature, and humidity.
- The PWV/ZTD ratio exhibited a well-defined seasonal pattern, closely following the annual variability of atmospheric moisture;
- Higher PWV/ZTD values were observed during wetter periods, indicating a greater contribution of water vapor to the total neutrospheirc delay;
- The derivative of PWV appears to better show the occurrence of extreme events;
- Future work: investigate PWV with higher temporal resolution for nowcasting.

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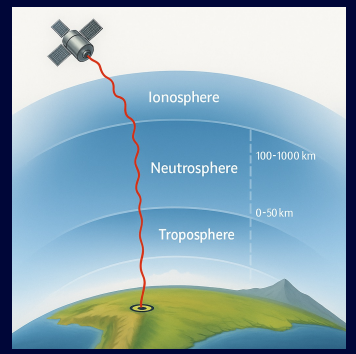
United Nations Global Geodetic Centre of Excellence
UN-GGCE

Data → GNSS Positioning → ZTD Estimation → ZWD meteorological data → Pos-Processing Event Modeling → Nowcasting extreme events alert

IGS Network → **GNSS Signals** → **ZTD GNSS** → **PWV GNSS+ Wet+Tm** → **Extreme Weather Services** → **Precipitable Weather Monitoring**

IGS INTERNATIONAL GNSS SERVICE



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Neutrospheric Evaluation and Processing Tool

References

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- GOUVEIA, T. A. F.; AZEVEDO, H. B. de; ALBUQUERQUE, A. M. et al. Analysis of atmospheric variations using GNSS signal as atmospheric sensor (PWV-GNSS) in extreme rainfall events in Rio Grande do Sul (Brazil) in 2024. *Natural Hazards*, v. 122, p. 212, 2026a. DOI: 10.1007/s11069-025-07748-5.
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Thank you for your attention!

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