

SHIPBORNE GNSS RETRIEVAL OF PWV (PRECIPITABLE WATER VAPOR) AND VALIDATION WITH ERA5 HOURLY DATA ALONG THE AMERIGO VESPUCCI VOYAGE (2023-2025)

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STATE OF THE ART

GNSS is widely used for estimating precipitable water vapor (PWV) on land, but its use at sea is still limited due to the ocean's dynamic environment and lack of fixed stations.

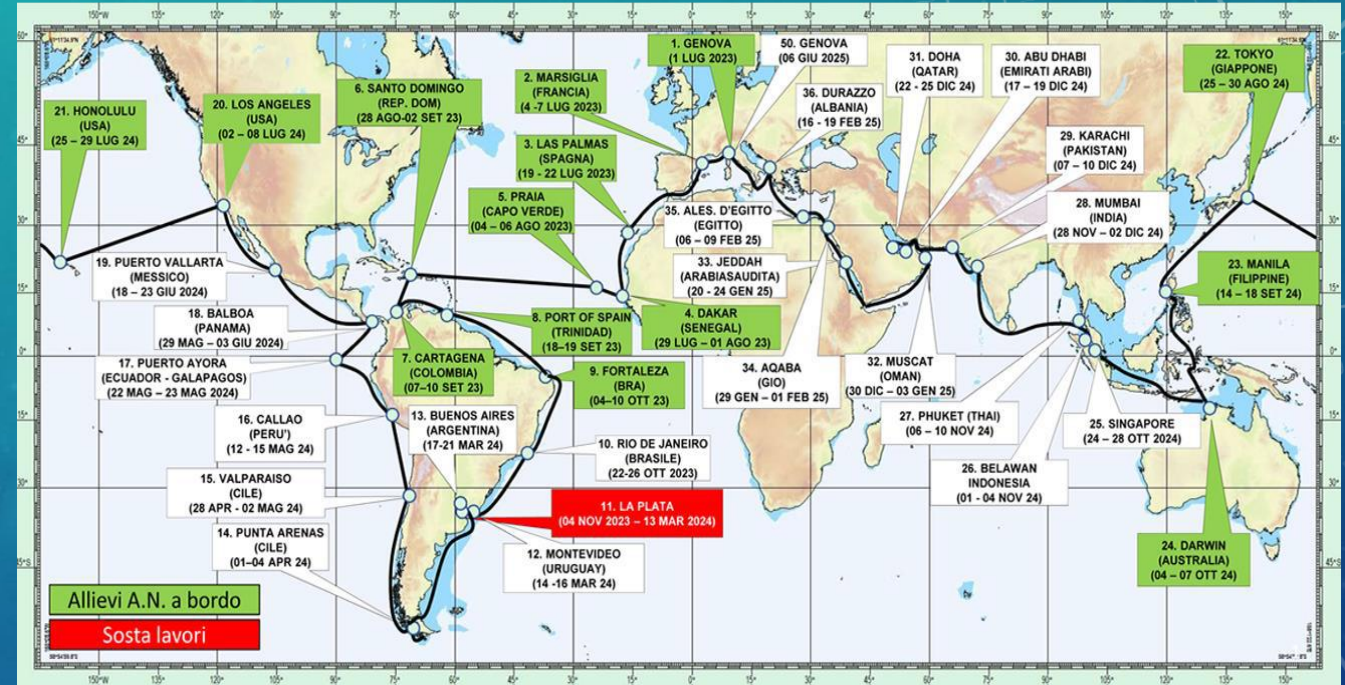
Despite proven reliability, challenges remain in data quality and integration.

OBJECTIVES

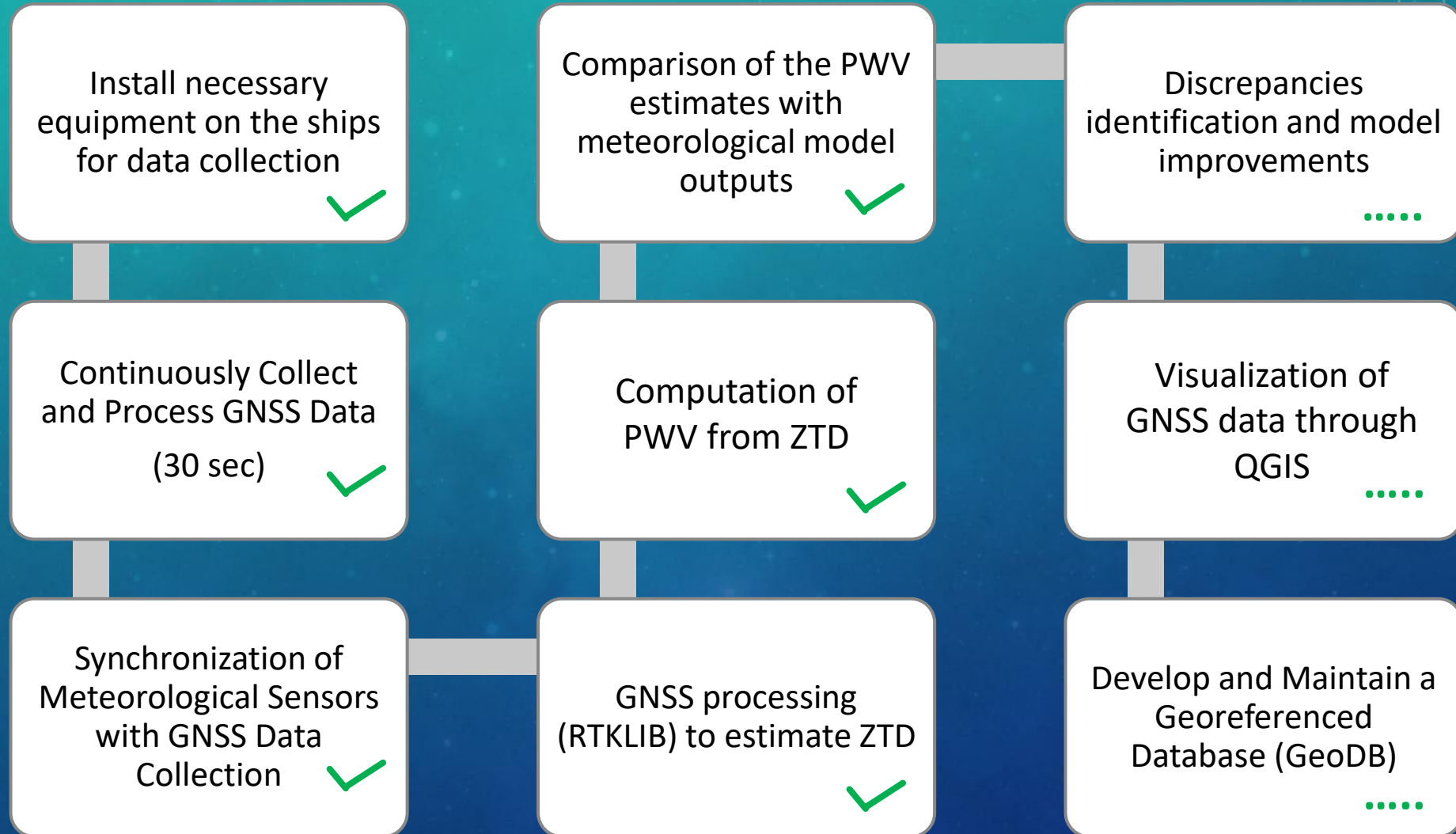
- **Develop** a methodology to process GNSS data onboard ship and convert ZTD to PWV using onboard meteorological inputs.
- **Compare** PWV estimates against remote sensing data, nearby GNSS stations, or numerical weather models.
- **Organize** and geo-reference GNSS and sensor data into a structured/query-able database (GeoDB) for analysis and visualization.
- Use ship-based observations to suggest and explore future marine monitoring applications.

STUDY NOVELTY AND CHALLENGES

- First long-term ship-based GNSS PWV dataset
- Global coverage opportunity
- Continuous monitoring as a **moving atmospheric observatory**
- Historic Italian Navy tall ship used as a mobile scientific observatory
- Exposure of instruments to harsh weather conditions
- Dynamic behavior of the vessel (significant roll and pitch angles)
- Signal obstruction

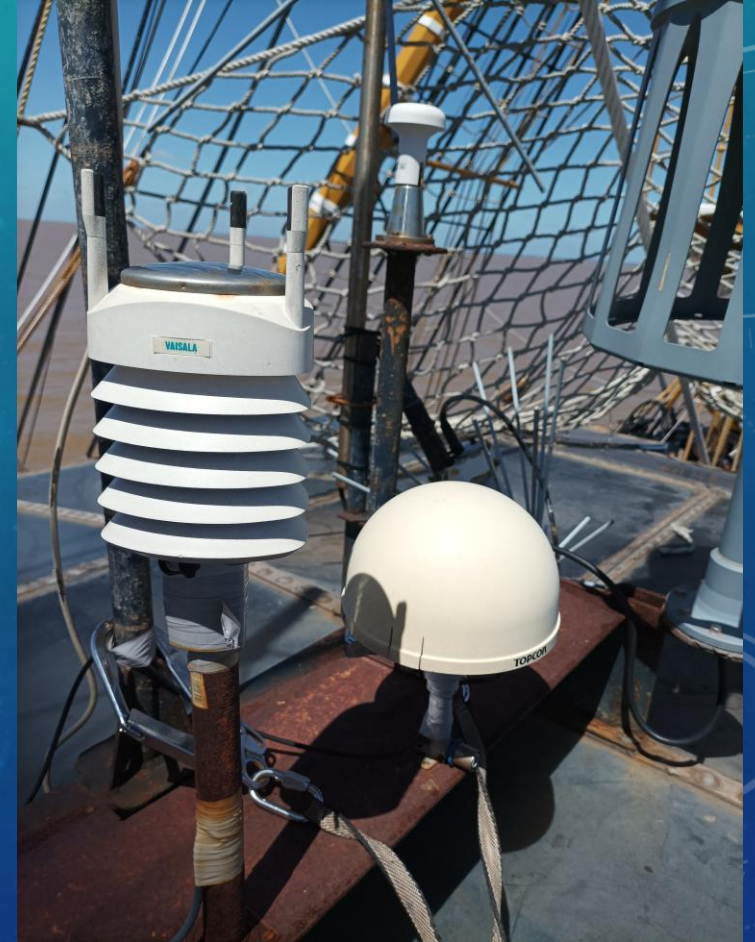


APPROACH:



INSTALLED INSTRUMENTS ONBOARD

- Cover of foredeck bridge
- Topcon NET-G3A GNSS receiver with PG_A1 geodetic antenna
 - Courtesy of Topcon Positioning Italy srl
- Vaisala WXT536 weather station
 - Courtesy of Eurelettronica ICAS srl
- Self-sufficient and autonomous system
- No need for intervention, except for periodic operational checks



DATA ACQUISITION

- Sampling interval: 30 s
- Measurement session duration: 24 hours (UTC time)
- Approximately 5 MB/day file
- Weather observations (wind speed and direction, pressure, temperature, rainfall)

ZTD AND PWV CALCULATION

Step 1	GNSS Processing	Signals from multiple satellites → ZTD estimated
Step 2	Split ZTD	$ZTD = ZHD + ZWD$ ZHD ($\approx 90\%$) → from pressure, latitude, height (Saastamoinen, 1972) $ZWD = ZTD - ZHD$ → linked to water vapor (harder to model, usually obtained by difference of ZTD (estimated) and ZHD (modelled))
Step 3	PWV Estimation	Convert ZWD → PWV using semi-empirical model (Bevis, 1992)
Step 4	Synchronization	Python script aligns: • ZTD (GNSS) • Coordinates (lat long) • Meteorological data (P, T) • Ensures consistent time series (UTC-based)

DATA PROCESSING

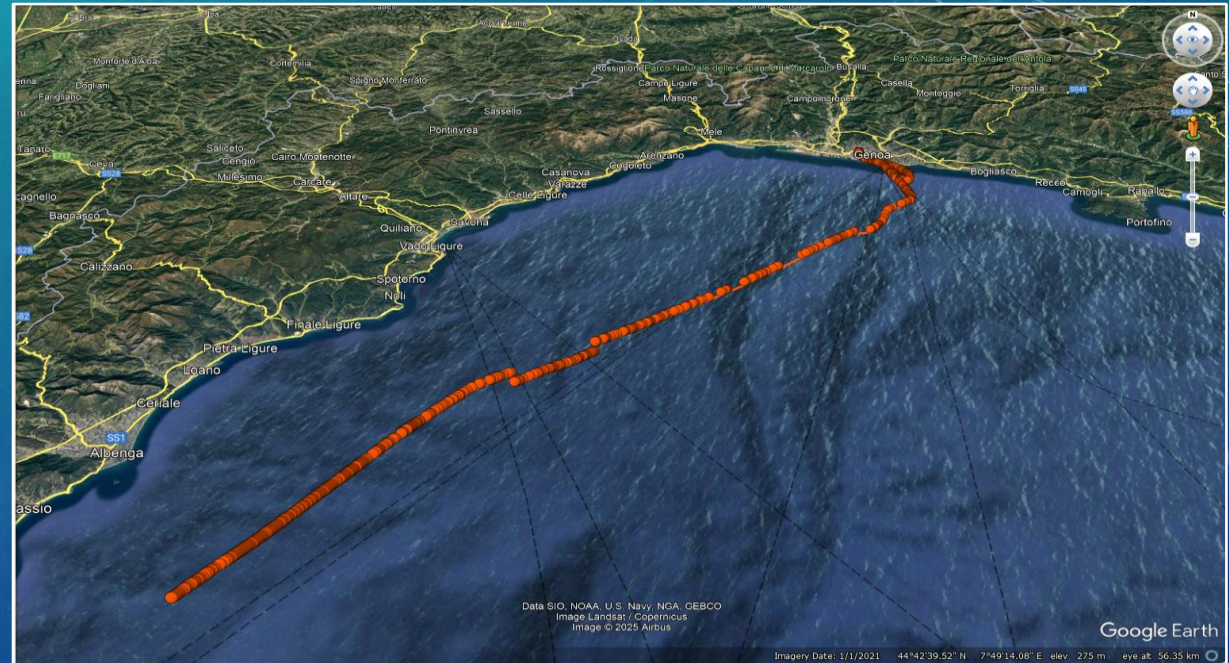
- Conversion from proprietary GNSS file format to RINEX (tps2rin.exe)
- Extraction of meteorological data from proprietary GNSS file (meteoextract.exe)
- GNSS data processing with RTKLIB, PPP mode

SOFTWARE SETTINGS FOR GNSS PROCESSING (RTKLIB)

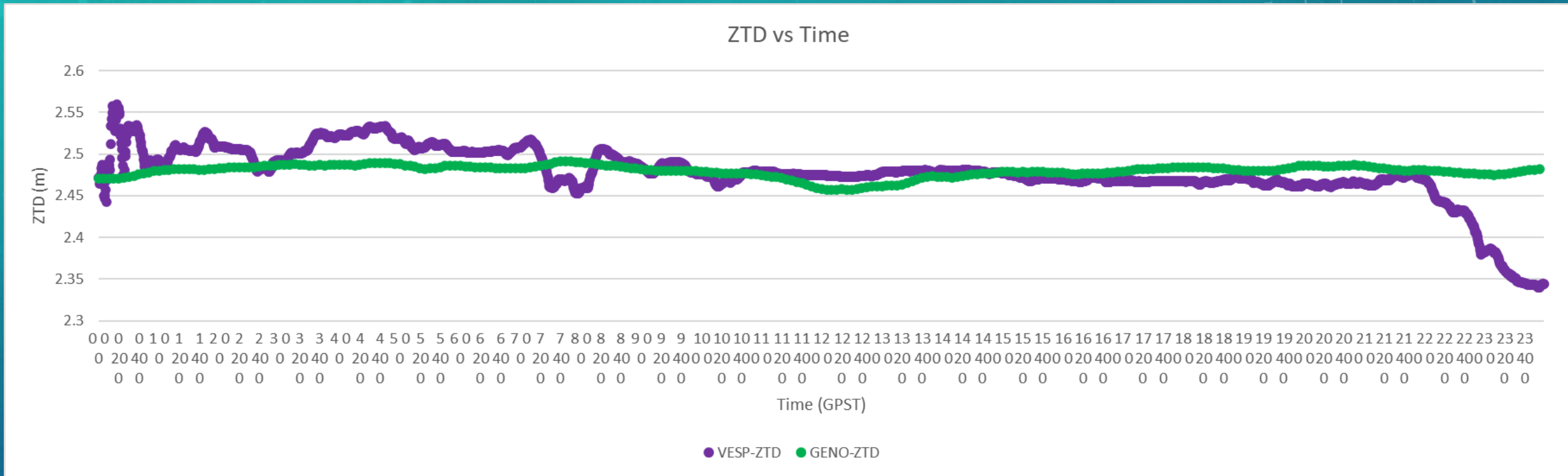
Positioning Mode	PPP Kinematic
Filter Type	Forward
Elevation Mask	10 degrees
Satellite Ephemeris/Clock	Precise (https://cddis.nasa.gov/)
Satellites	GPS & GLONASS
Solution Format	Lat/Long/Height
Time Format	hh:mm:ss GPST
Datum	WGS84 Ellipsoidal
Antenna Type	TPSG3_A1

RESULTS OBTAINED (CASE STUDY DAY-1)

- Finalized the RTKLIB processing strategy by identifying the most suitable parameters, and settings for GNSS data processing of the Amerigo Vespucci dataset.
- Successfully processed 2023 GNSS dataset and derived atmospheric parameters, including ZTD and PWV.
- Performed preliminary comparison for selected periods with ERA5 reanalysis data (hourly), showing overall good agreement and consistency of the GNSS-derived products.
- Additionally, compared GNSS-derived tropospheric parameters with nearby IGS reference stations (GENO, MARS, etc.) during periods when the ship was docked, obtaining encouraging and reliable results.

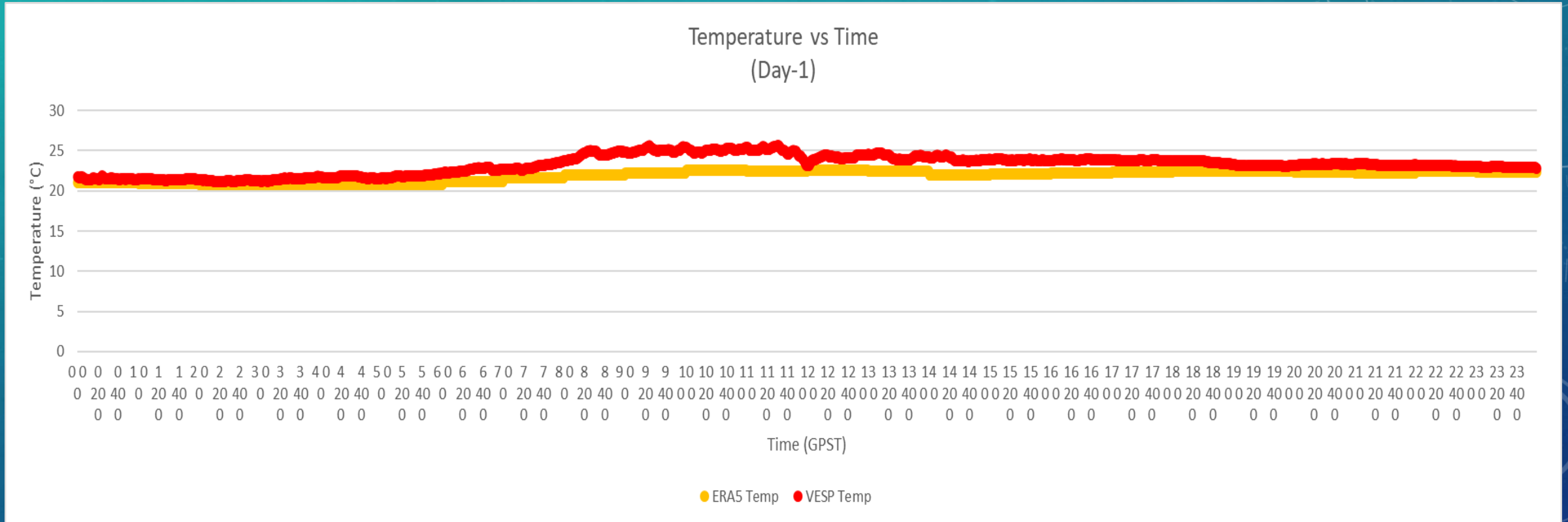


PRELIMINARY RESULTS (SAMPLE DAY-1) COMPARED TO IGS GENO STATION OBTAINED FROM CDDIS-NASA



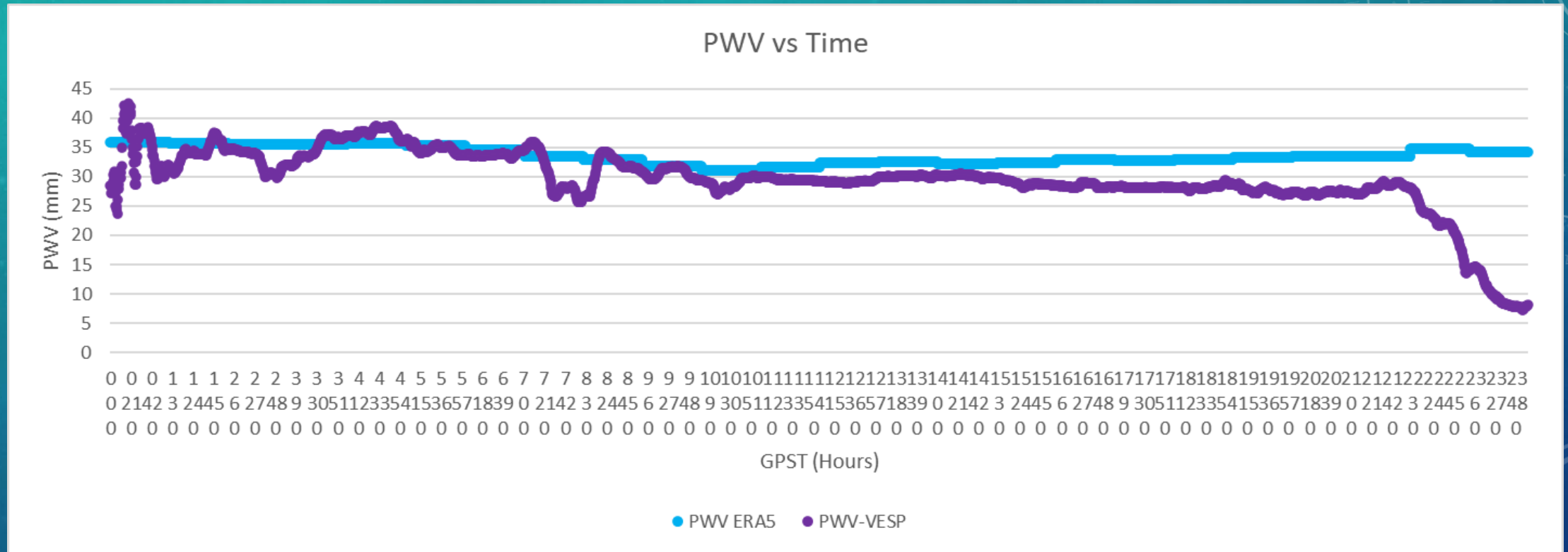
- Stable ZTD (~2.45–2.50 m)
- Good agreement with IGS reference station
- Small fluctuations due to atmosphere/PPP convergence. Average ZTD STD is 15 mm
- Late drop (~22:00) → geometry or signal effects

PRELIMINARY RESULTS (SAMPLE DAY-1) COMPARED TO ERA5 TEMPERATURE DATA OBTAINED FROM CDS COPERNICUS EU



Good agreement; VESP more variable, ERA5 smoother. Avg. Temp. Dif. 1.1 ° C

PRELIMINARY RESULTS (SAMPLE DAY-1) COMPARED TO ERA5 PWV DATA OBTAINED FROM CDS COPERNICUS EU



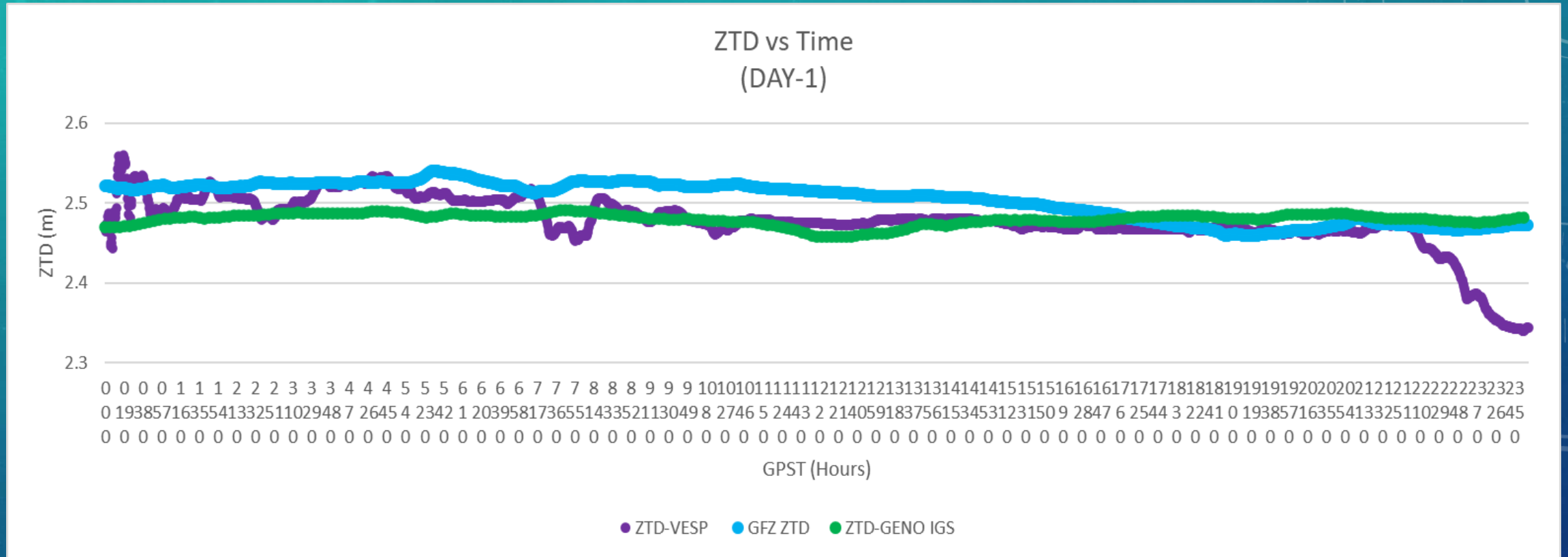
VESP PWV is more variable than ERA5, with overall agreement except for a late-day anomaly.
Avg PWV Dif 4.16 mm & 2.82 mm excluding anomaly hours along with Avg STD 2.1mm

ONGOING RESEARCH PERIOD ABROAD - TU BERLIN



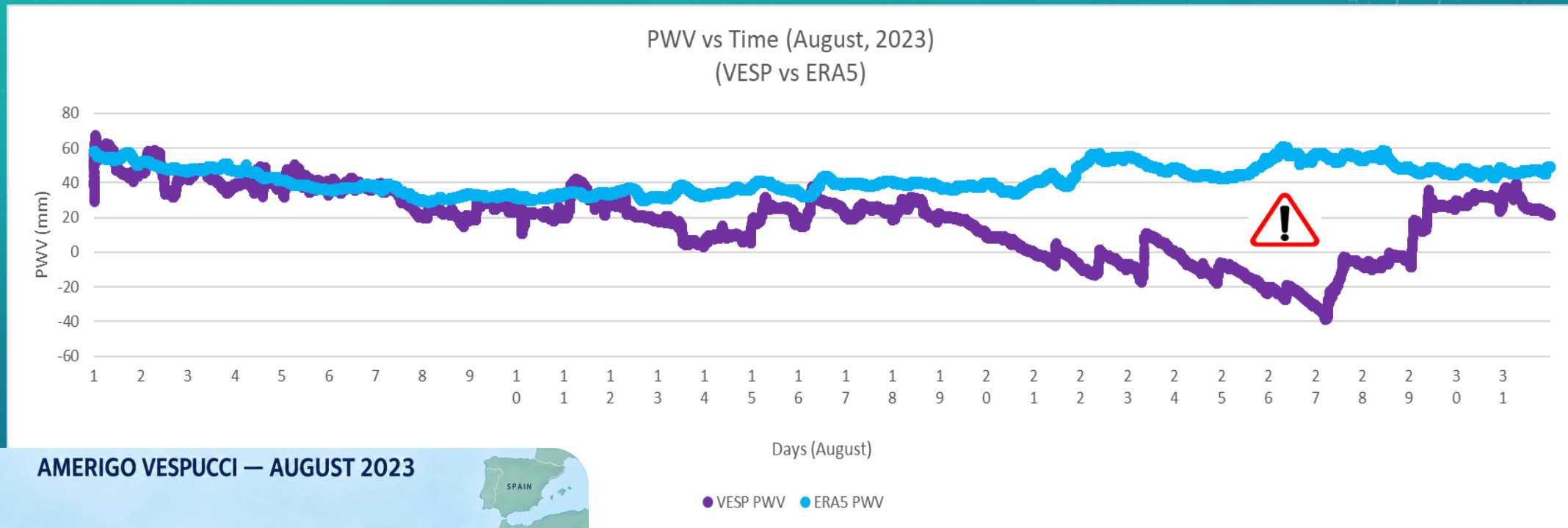
- Currently undertaking my research period abroad at TU Berlin, under the supervision of **Prof. Harald Schuh**.
- Continuing the automation of GNSS processing, ZTD/PWV extraction and comparison workflows ; detailed results are presented in the following slide.
- Comparing the RTKLIB results with those obtained using German Research Centre for Geosciences (GFZ's) EPOS software.
- Preliminary comparisons suggest more reliable results with the EPOS processing workflow.

RED TO



VESP ZTD late-day anomaly vanished in GFZ EPOS result.
More smoother trend of EPOS ZTD.

PRELIMINARY RESULTS FROM AUTOMATED WORKFLOW COMPARED TO ERA5 PWV DATA OBTAINED FROM CDS COPERNICUS EU



VESP PWV captures part of the ERA5 temporal variability ($r = 0.73$), but substantial late month anomalies prevent reliable full-month validation. The negative values and abrupt shifts require investigation before atmospheric interpretation.



RESULTS

- Fine temporal sampling: Good data continuity of the acquisition of data with less data gaps
- High temporal variability captured
- Good consistency with ERA5
- More Quality control is needed
- Anomalies highlight processing sensitivity



CONCLUSION & FUTURE ASPECTS

- Complete and compare the 2-year GNSS dataset using ERA5 reanalysis and nearby IGS stations.
- Build a PWV geo-database linked to ship trajectories and automate GNSS-meteorological data processing using Python.
- Improve processing methodologies (usage of other softwares) and expand toward a global maritime GNSS observation network.
- Probably develop near-real-time PWV estimation to support monitoring of extreme weather events.

REFERENCES

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- Python Software Foundation. Python Language Reference, ver. 3.11. <http://www.python.org>
- RTKLIB user manual. [https://rtkexplorer.com/pdfs/manual demo5.pdf](https://rtkexplorer.com/pdfs/manual%20demo5.pdf)



WORLD TOUR 2023-2025

On July 1, 2023, the Amerigo Vespucci Training Ship set sail from Genoa for the **2023-2025 World Tour**. Over the course of **24 months**, it traveled **49,500 nautical miles**, crossing **five continents** and calling at **33 countries** and **53 ports**. With the Tour, its already established role as a traveling Ambassador of Made in Italy and UNESCO values was further strengthened: alongside the traditional training of Officer Cadets, an extraordinary experience of cultural exchange and international promotion of Italy and its excellence was developed.

For the first time, the ship's journey was accompanied by a **traveling exhibition** dedicated to showcasing Italian traditions and talent: the **Villaggio Italia**.





THANK YOU!
ANY QUESTIONS?