

Assessment of Correlation Length and GNSS-Derived PWV Mapping Across Italy Under Different Meteorological Scenarios

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Introduction

Precipitable Water Vapor (PWV)

Precipitable water vapor (PWV) represents the total amount of water vapor contained in a vertical atmospheric column, expressed as the equivalent depth of liquid water that would result if all of the vapor condensed.

PWV provides an integrated measure of atmospheric moisture and is particularly relevant during extreme weather events, when large moisture availability can contribute to intense precipitation.

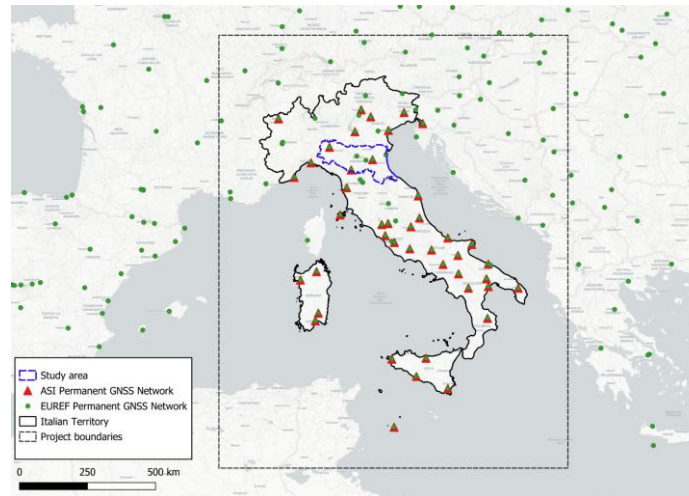
Research Motivation



Italy experiences very different meteorological situations, from homogenous large scale humidity field to very localized patterns.

The Question is:

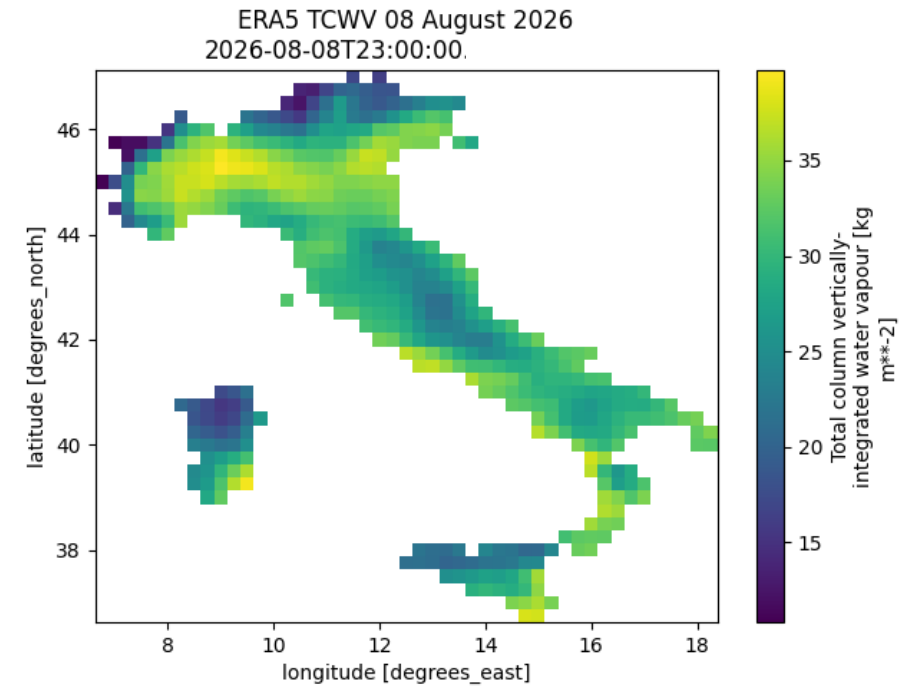
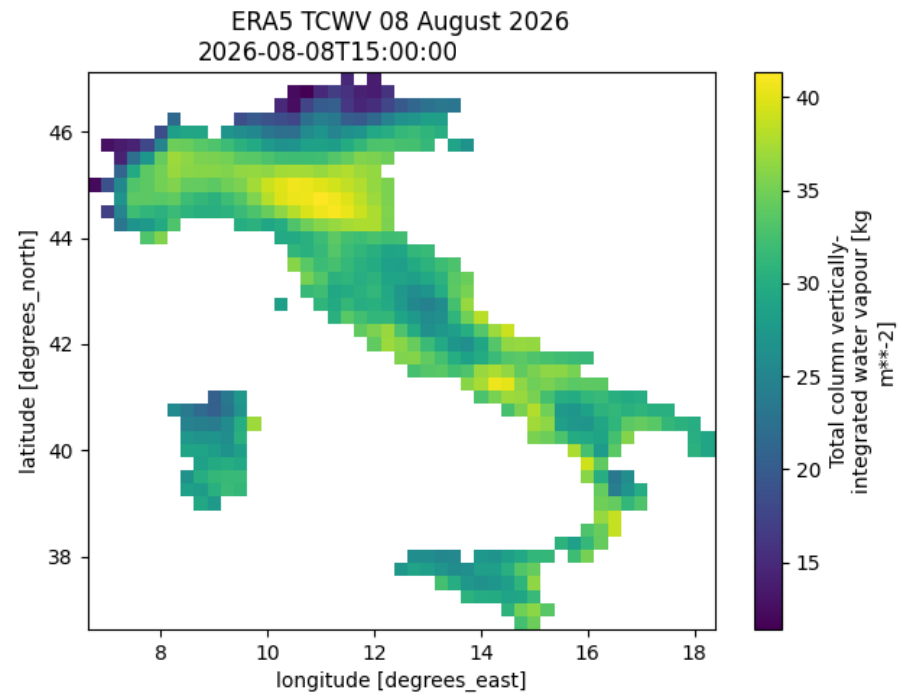
ASI permanent GNSS stations are dense enough to sample PWV distribution across Italy?



STUDY AREA AND DISTRIBUTION OF ASI AND EUREF GNSS STATIONS

Spatial Correlation Length

The correlation length is the characteristic distance over which the variable remains spatially correlated.



The semivariogram describes how the similarity between observations changes with their spatial separation.

Methodology

Semivariogram is used to characterize spatial dependence by measuring the dissimilarity between observations to their separation distance.

PWV values at two locations

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} (z_i - z_{i+h})^2$$

Number of point pairs at distance h

Semivariance for a given separation distance h

Turning back to the research motivation:

The average distance between ASI stations is sufficiently small compared with PWV correlation length?

Methodology

The semivariogram converts the 2-D TCWV field into a spatial scale that can be compared with ASI spacing.

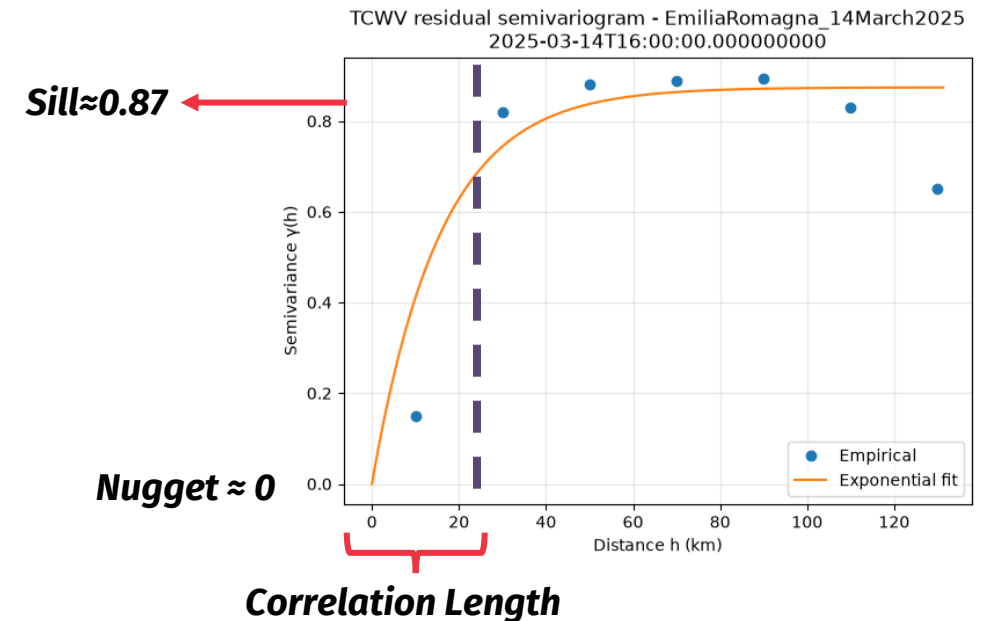
Expected behavior under different scenarios:

Homogeneous

Longer correlation length -> ASI network more likely adequate

Heterogeneous

Shorter correlation length -> ASI network less likely adequate distributed



Methodology

Data preparation



ERA5 TCWV



Select event time
and study area



Clip to region of
interest

Removing large scale
spatial trend

Semivariogram Analysis

Compute pairwise
residual
semivariance

Calculating pairwise
distance

Group pairs into lag
bins

Build empirical
semivariogram

Fit exponential
variogram model

Interpretation

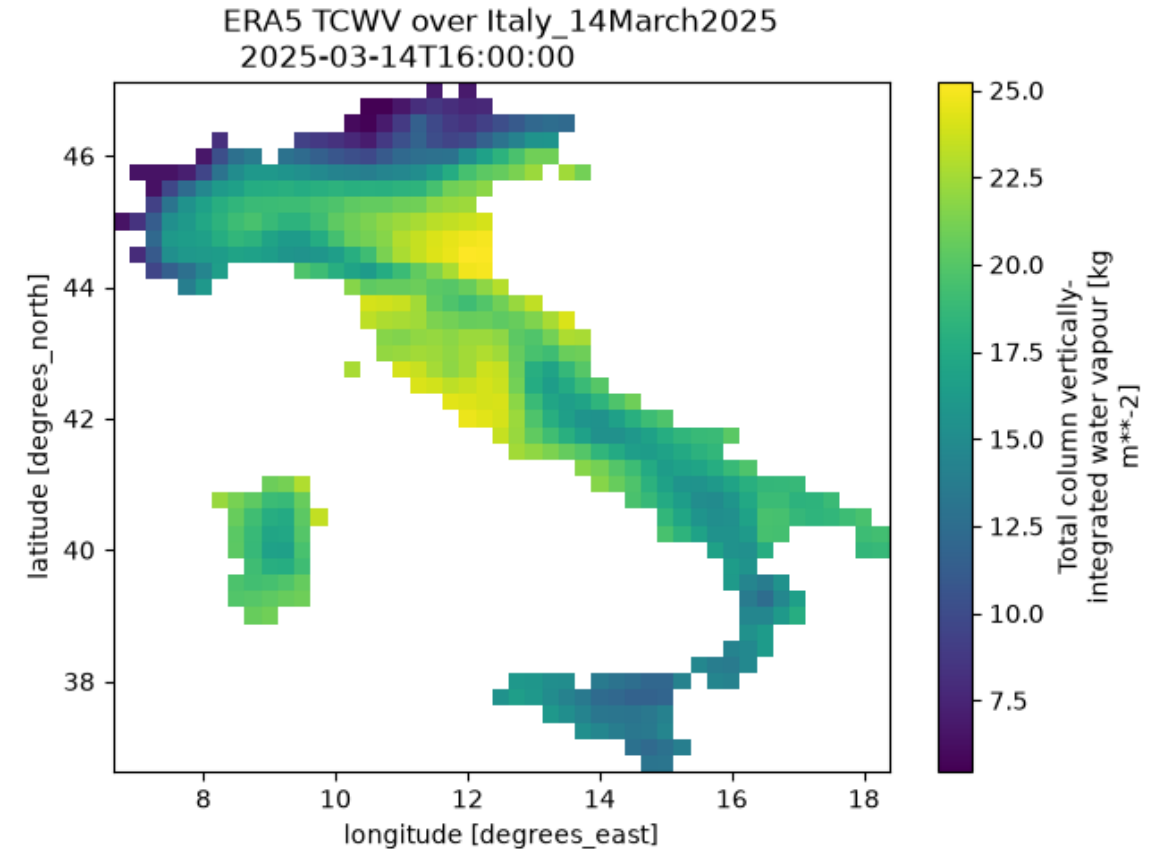
Estimating correlation length and
practical range

Comparing with ASI station
spacing

Is the ASI GNSS network dense
enough?

Data

- **ERA5**: fifth-generation global atmospheric reanalysis dataset produced by **ECMWF**.
- Horizontal spatial resolution: approximately **$0.25^\circ \times 0.25^\circ$** .
- Combines **numerical weather prediction models** with observations from **satellites, ground-based instruments, and other observing systems**.
- Provides **hourly atmospheric data**.



Alert

An official warning issued by Italian civil protection system indicating the expected level of risk from forecast meteorological and Hydrological conditions and their potential impacts on the territory.

- **No Rain**

Stable atmosphere -> smoother PWV field -> Longer correlation length

- **Evenly Distributed Rain**

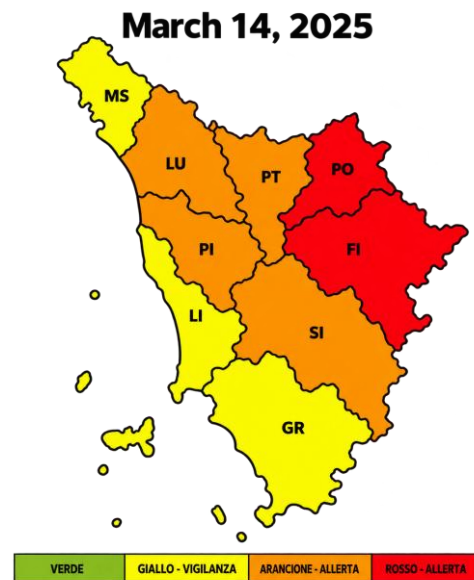
Large scale wet condition -> High PWV but spatially coherent

- **Intense Localized Event**

Strong gradient -> Heterogenous PWV field -> Shorter correlation Length

Case Study

- A **severe storm** affected **Tuscany and Emilia Romagna** on **14 March 2025**, producing intense rainfall and strong winds.
- Several rivers exceeded alert thresholds, with particularly critical conditions in the **Arno and Serchio basins**.
- The event was intensified by a **persistent inflow of moist air driven by strong southwesterly winds**.



Precipitation : 22.4 mm/h

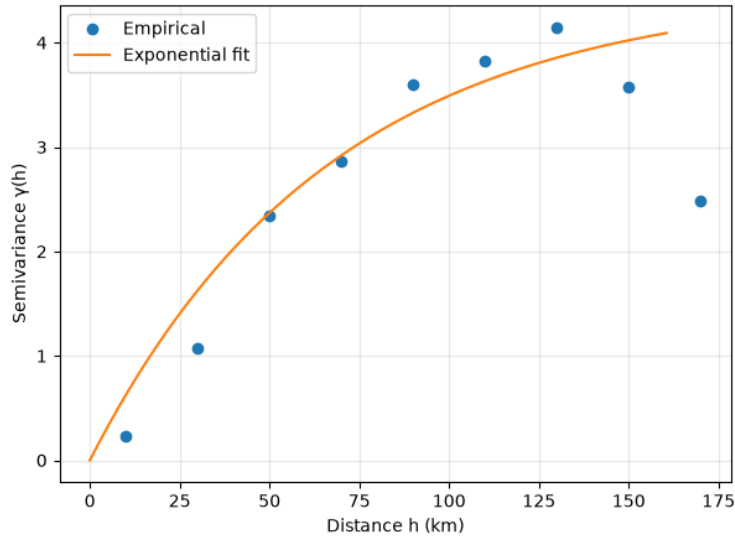


Precipitation : 15.2 mm/h

Tuscany + Emilia Romagna

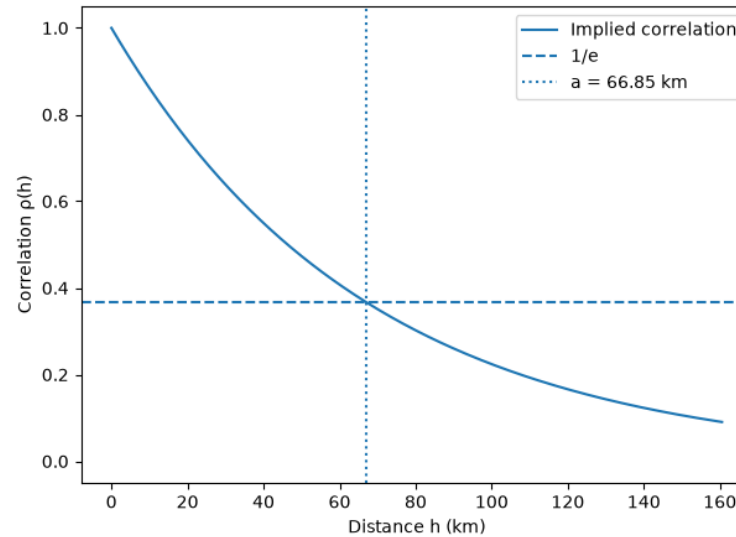
ERA5 TCWV

TCWV residual semivariogram - EmiliaRomagna-Tuscany_14March2025
2025-03-14T09:00:00



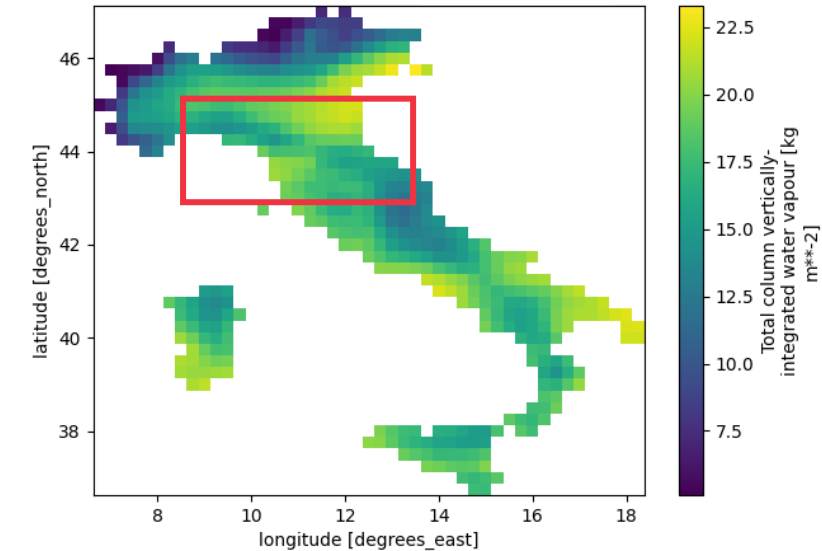
**Blue points represent calculated semivariance
At different separation distance and the orange
Line is the exponential model fitted to these points**

Residual correlation function - EmiliaRomagna-Tuscany_14March2025
2025-03-14T09:00:00



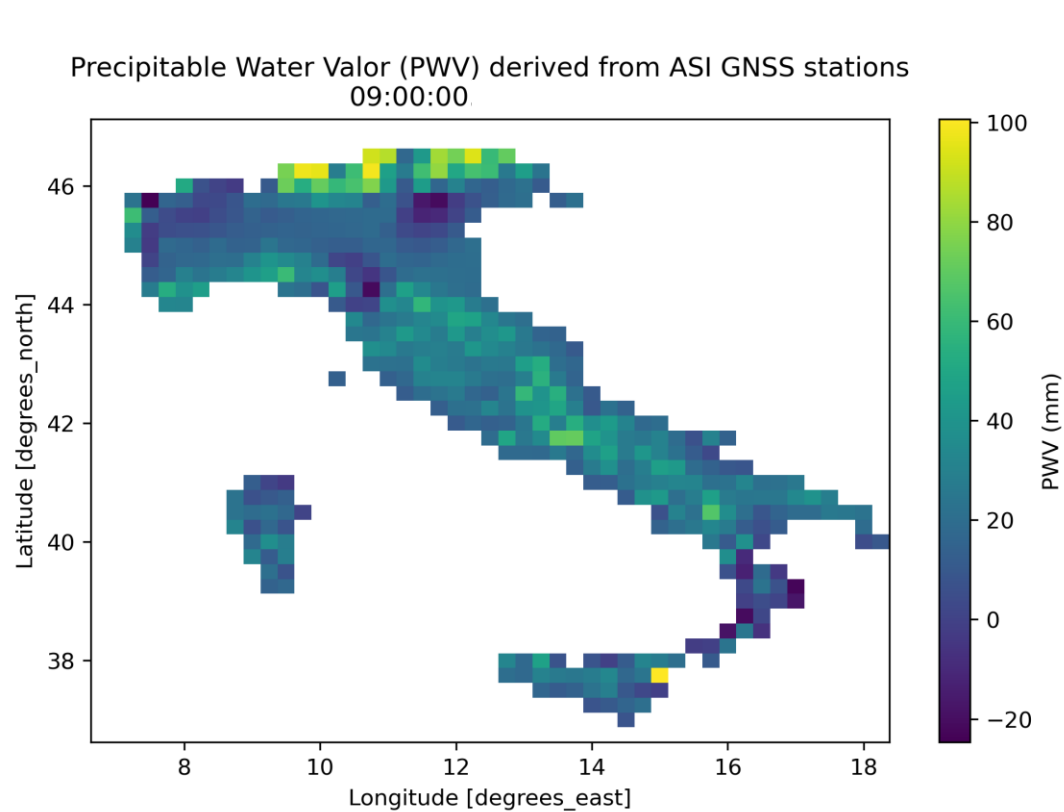
**Estimating spatial correlation length from the fitted
Model. The correlation decreases exponentially with
Distance and reaches 1/e.
(the characteristic PWV correlation length is about 67 km)**

ERA5 TCWV 14 March 2025
2025-03-14T09:00:00

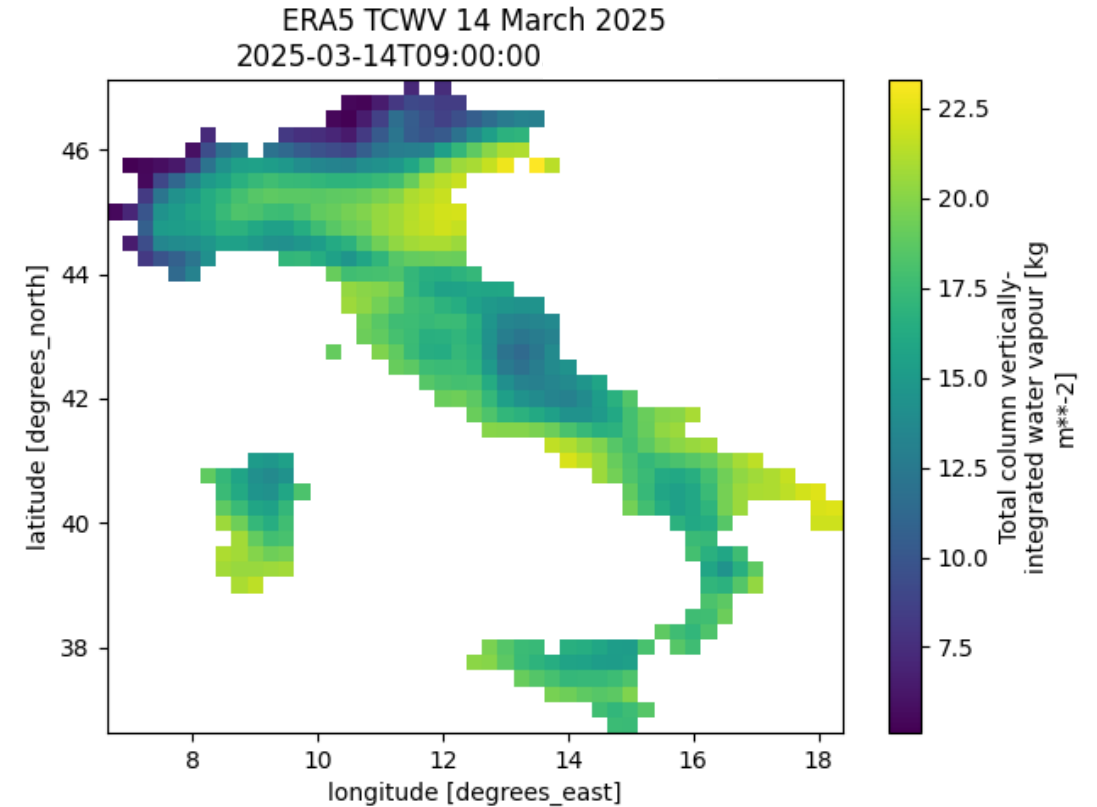


**ERA5 TCWV map over Italy and the
Box identifies the study area covering
Tuscany and Emilia Romagna**

A Comparison between ERA5 TCWV and GNSS derived PWV



Global mean = 23.6 mm
Global standard deviation = 19.0 mm



Global mean = 16.4 kg/m²
Global standard deviation = 3.8 kg/m²

A Comparison between ERA5 TCWV and GNSS derived PWV

- The fitted exponential semivariogram gives a PWV correlation length of ~66.9 km, **(the distance at which spatial correlation decreases to 0.37)** Approximately equal to ASI inter station distance.
- This indicates that, during this spatially **heterogeneous and localized meteorological event**, the ASI network is operating close to the characteristic spatial scale of PWV variability.
- Consequently, the network may **capture the large-scale PWV pattern**, but it can potentially **miss or smooth localized PWV** gradients occurring at scales smaller than the average station spacing.

Thank you for your attention.

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