



Homogenization of integrated water vapour time series using twin GNSS stations and vertical step offsets

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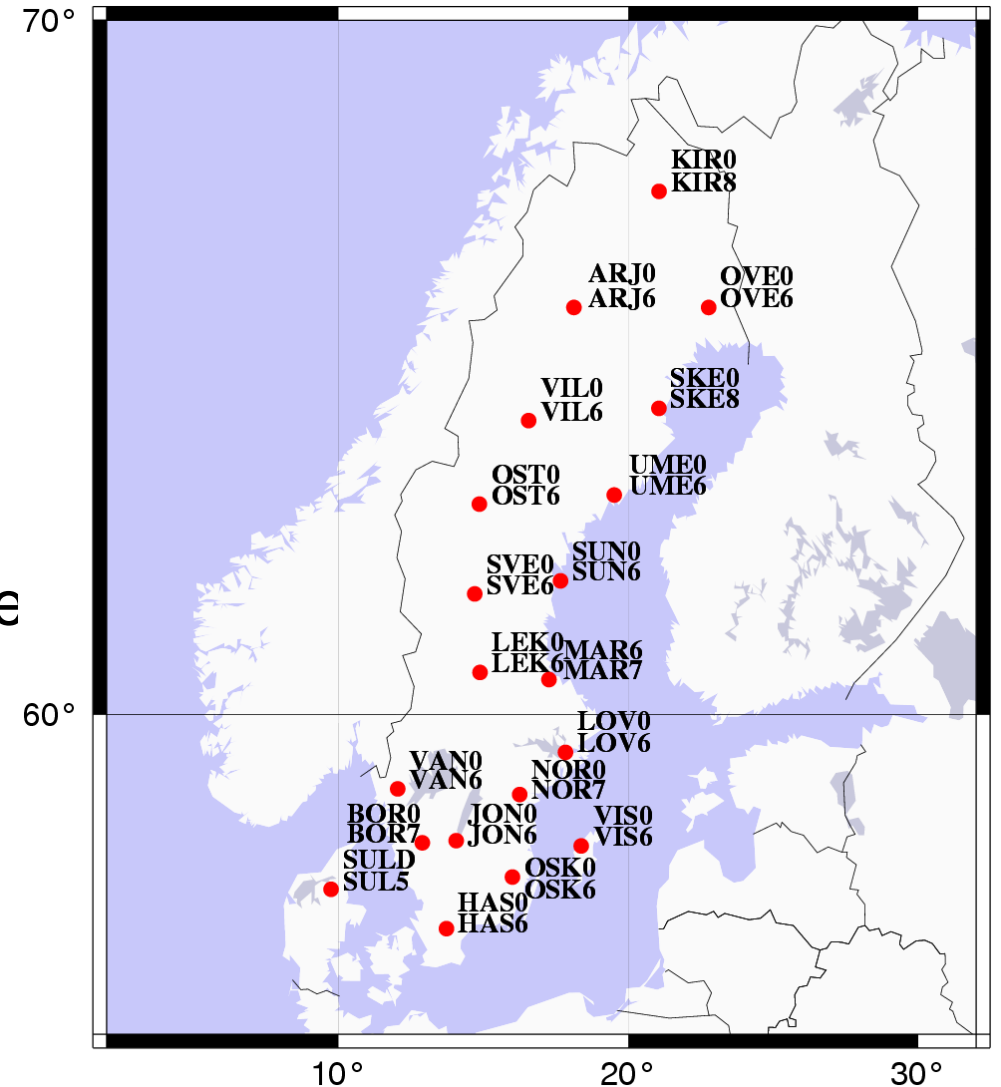


Motivation

- Long-term, realistic, and reliable Integrated Water Vapour (IWV) time series derived from homogeneously reprocessed GNSS observations are essential for climate studies.
- However, changes at GNSS stations, such as antenna, radome, or receiver replacements, can introduce step offsets in the retrieved IWV, obscuring the true long-term climate signal.
- Therefore, a robust and reliable homogenization strategy is required to identify and correct these artificial discontinuities, ensuring consistent IWV time series for climate applications.

GNSS Data

- 20 GNSS sites were selected, each site has two co-located stations.
- During the time period from January 2011 to December 2024.
- We use exclusively GPS data, originating from the processing design of the new BIFROST. In that framework, the decision to utilize GPS data only, was made precisely to maintain a homogeneous, long-term time series.



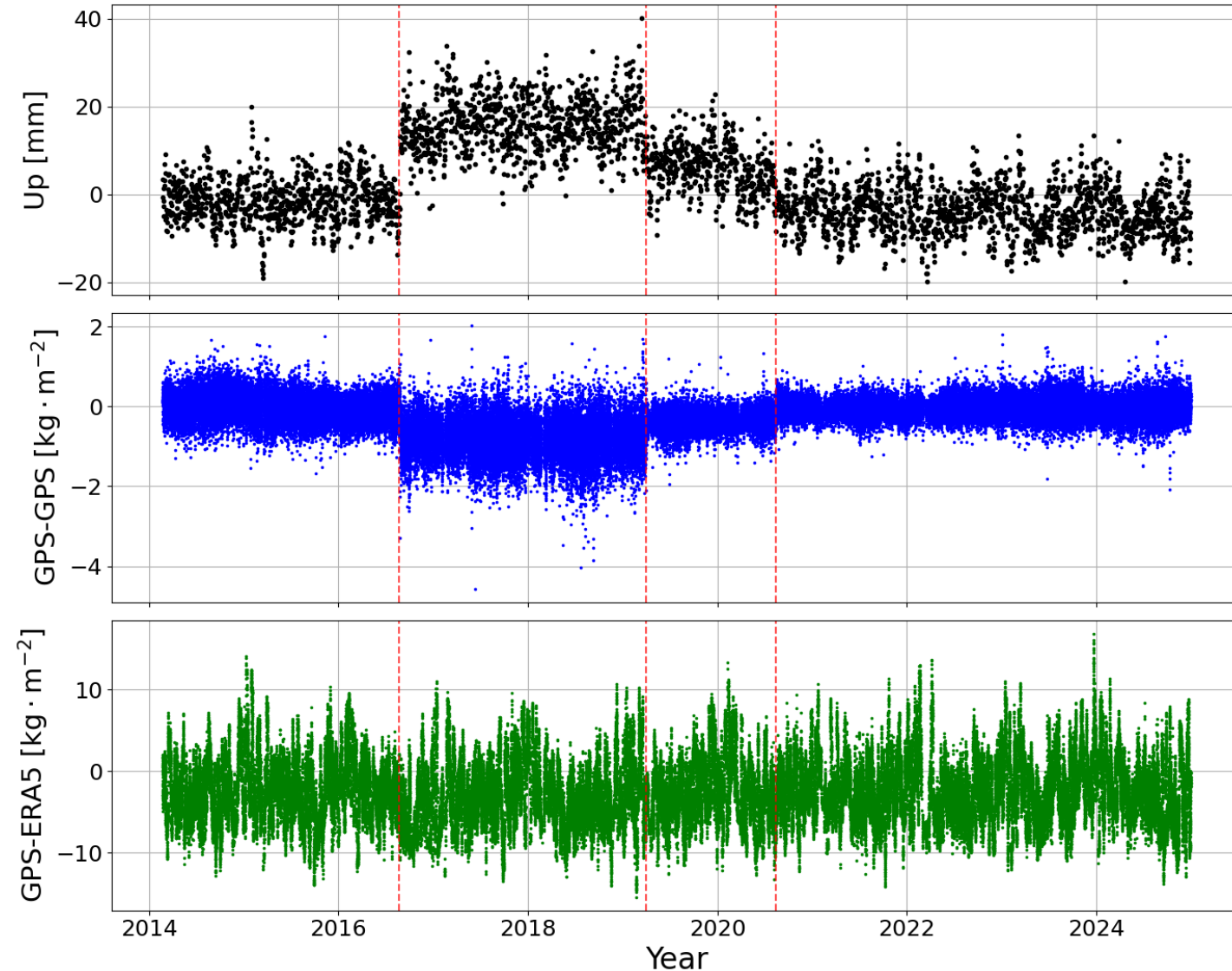
Methods

1. Use ECMWF reanalysis product (ERA5) as the reference
 - Interpolate ERA5 data from the nearby grid points to the GNSS station.
 - Form GPS–ERA5 IWV difference time series.
 - Estimate IWV step offsets by comparing GPS–ERA5 IWV differences before and after the intervention.
2. Use IWV from the co-located GNSS station as the reference
 - Form GPS–GPS IWV difference time series.
 - Estimate IWV step offsets by comparing GPS–GPS IWV differences before and after the intervention.
3. Use height step offsets from the coordinate time series
 - Estimate the height step offset for each intervention.
 - Calculate IWV step offsets using the empirical relationship between height and IWV step offsets.

Step offsets

BOR0, Borås, Sweden

- Time series of the height coordinate and IWV differences for GPS-GPS and GPS-ERA5. Vertical lines indicate the times of the interventions.
- Significant offsets, highly correlated with the height step offsets, are evident in the GPS-GPS IWV difference series.
- Step offsets are difficult to isolate in the GPS-ERA5 IWV differences, as they are dominated by the high natural variability and representation errors inherent in the reanalysis data.



GPS–GPS vs GPS–ERA5

GPS–ERA5:

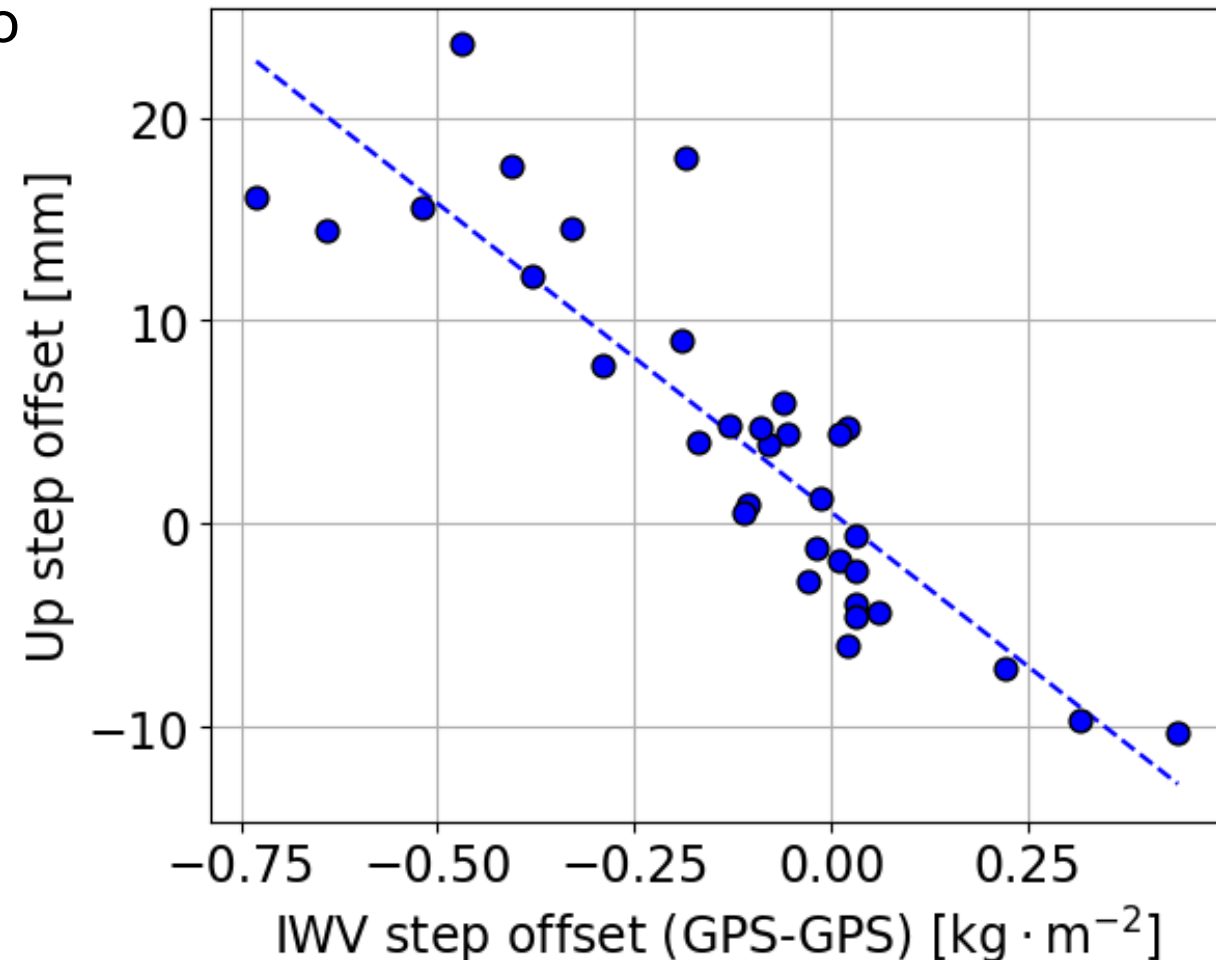
- A method for global homogenization.
- Subject to “representation errors” due to differences in spatial and temporal resolution between the GNSS measurements and gridded reanalysis products.
- Require a minimum data span of approximately one year on both sides of an intervention to average out seasonal noise and representation errors.
- ERA5 reanalysis uncertainty scales with absolute IWV, atmospheric asymmetries around an intervention can create errors that can overwhelm smaller step offsets, making GPS-ERA5 corrections highly unreliable.

GPS–GPS:

- A method for local homogenization.
- The co-located station sense nearly identical atmospheric variations, the GPS-GPS differences effectively cancel out the common atmospheric noise and seasonal signals
- Enable the detection and correction of IWV step offsets with significantly higher precision and shorter data records.

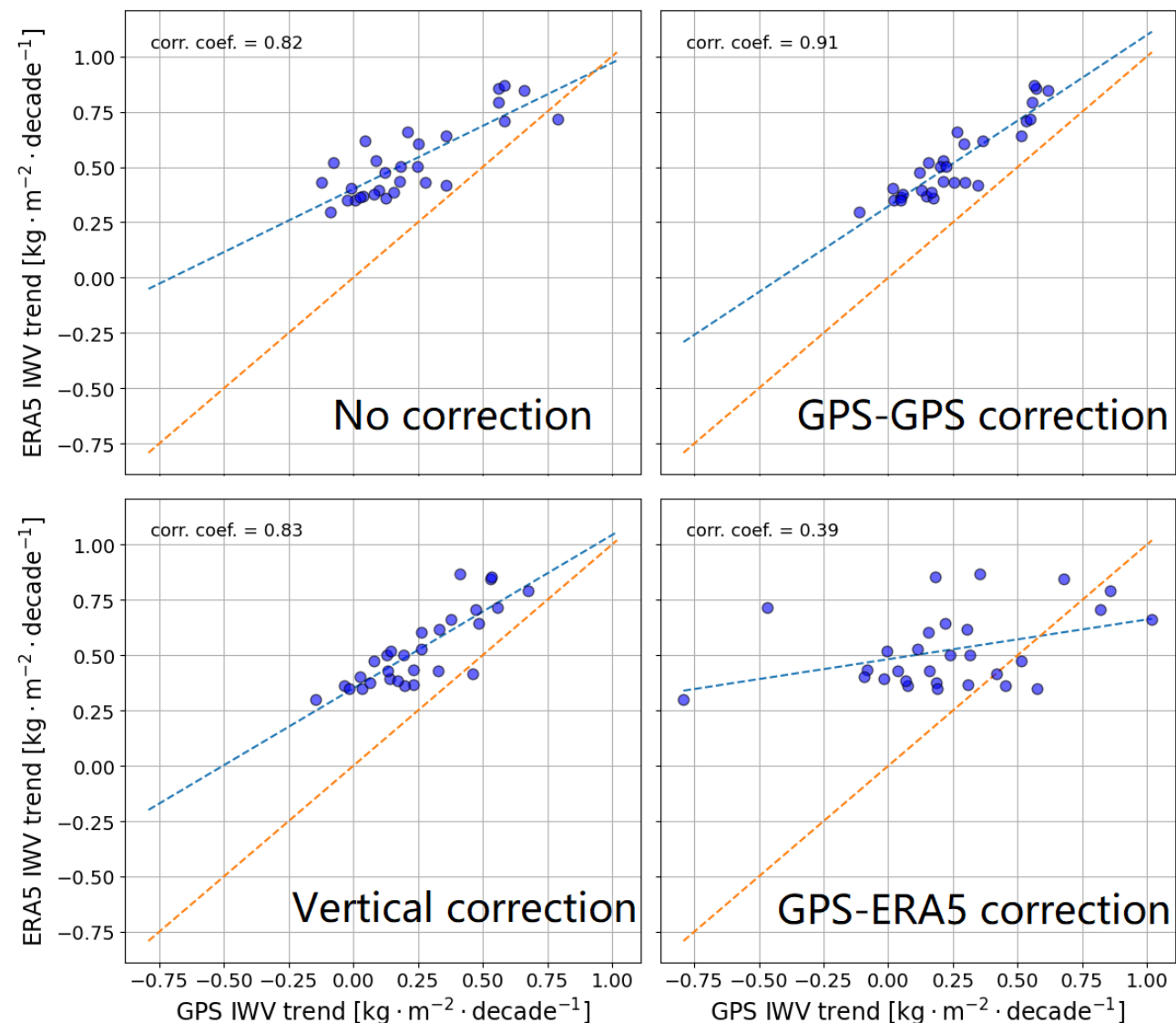
Correlation of step offset in height and the IWV

- Errors in station height and ZTD (and hence also the IWV) are highly correlated because both affect the signal path length in an elevation-dependent way.
- The correlation between the height step offsets and the GPS-GPS derived IWV step offsets reaches -0.88 .
- The resulting regression indicates that a 1 mm height step offset corresponds to an IWV offset of approximately $0.03 \text{ kg} \cdot \text{m}^{-2}$.



Correlation of IWV trends

- To validate the estimated step offsets, we compare the linear trends derived from the different homogenized GPS IWV time series with the corresponding trends from ERA5 reanalysis at each site.
- Best agreement with ERA5 is obtained after the GPS–GPS correction.
- Vertical correction (using height step offsets) provides the second-best agreement.
- GPS–ERA5 correction does not improve the correlation between the GPS-derived and ERA5 trends.



Conclusions

- Twin GNSS stations provide robust local reference to estimate IWV step offsets at the time of the interventions.
- A strong negative correlation found between step offsets in station height and in the retrieved IWV ($1 \text{ mm} - 0.03 \text{ kg}\cdot\text{m}^{-2}$). This conversion factor serves as a valuable, stand-alone tool for single-station GNSS sites where no twin-station reference exists, enabling a direct correction of IWV step offsets using the coordinate time series alone.
- The GPS–ERA5 approach must be treated with caution. In our dataset, most IWV step offsets are small and easily dominated by representation errors and uncertainties in ERA5, making accurate offset estimation difficult.

Questions?

