Atmospheric horizontal gradients estimated from eight co-located GNSS stations

T. Ning[1], and G. Elgered[2]

1. Lantmäteriet (The Swedish Mapping, Cadastral and Land Registration Authority), 80182 Gävle, Sweden
2. Department of Space, Earth and Environment, Chalmers University of Technology, Onsala Space Observatory, 43992 Onsala, Sweden

EUREF Symposium 2024
June 5–7, 2024, Barcelona, Catalonia, Spain

LANTMÄTERIET

Motivation for gradients studies

- In geodetic applications, estimating an equivalent zenith propagation delay along with linear horizontal gradients is recommended

- In meteorological applications, assimilating horizontal gradients is useful to enhance the resolution in numerical forecasting models

- GNSS ground-based stations operate under nearly all-weather conditions and the satellite geometries have been improved through multi-GNSS constellations

GNSS and WVR data

- We have estimated the total horizontal gradients from 8 SWEPOS GNSS stations at the Onsala Space Observatory from March 1, 2022, to December 31, 2023
- The GNSS gradients are validated by available independent estimates of wet gradients from a ground-based water vapour radiometer (WVR)
- The VMF data server provides horizontal hydrostatic gradients which are subtracted from the total gradients to calculate the wet gradients for GNSS data

GNSS data processing

Parameter	Model used in the processing
GNSS processing software	GipsyX 2.0
Strategy	Precise Point Positioning
Clocks and orbits	Final products by CODE for MGEX
Mapping function	Vienna Mapping Functions 1 2006
Elevation cutoff angle	10°
Zenith delay	Estimated every 5 min with the constraint 10 mm/$\sqrt{h}$
Linear horizontal gradient	Estimated every 5 min with the constraints **0.3 or 2.0 mm/$\sqrt{h}$**
Ocean tide loading	FES2004
Antenna PCV	igs14_2196.atx
Ionospheric 2nd order correction	Yes

GNSS gradients vs GNSS gradients

Station	ONSA	ONS1	OTT1	OTT2	OTT3	OTT4	OTT5	OTT6
ONSA	–	0.92	0.93	0.92	0.94	0.92	0.93	0.91
ONS1	0.24	–	0.91	0.90	0.92	0.91	0.93	0.91
OTT1	0.23	0.25	–	0.93	0.93	0.93	0.92	0.91
OTT2	0.24	0.27	0.22	–	0.93	0.93	0.92	0.90
OTT3	0.21	0.25	0.22	0.23	–	0.92	0.94	0.91
OTT4	0.25	0.26	0.23	0.24	0.24	–	0.92	0.91
OTT5	0.22	0.23	0.23	0.25	0.22	0.24	–	0.94
OTT6	0.25	0.25	0.25	0.26	0.25	0.26	0.21	–

- Correlation coefficients (upper right triangle) and standard deviations in mm (lower left triangle) for east gradients from the pairwise comparison of GNSS stations
- A strong agreement is expected given the similarity in the atmospheric sampling across the all stations and the shared presence of various error sources
- On the other hand, such pairwise comparison from the co-located stations can also reveal the errors caused by the installation of the station itself

GNSS gradients vs GNSS gradients

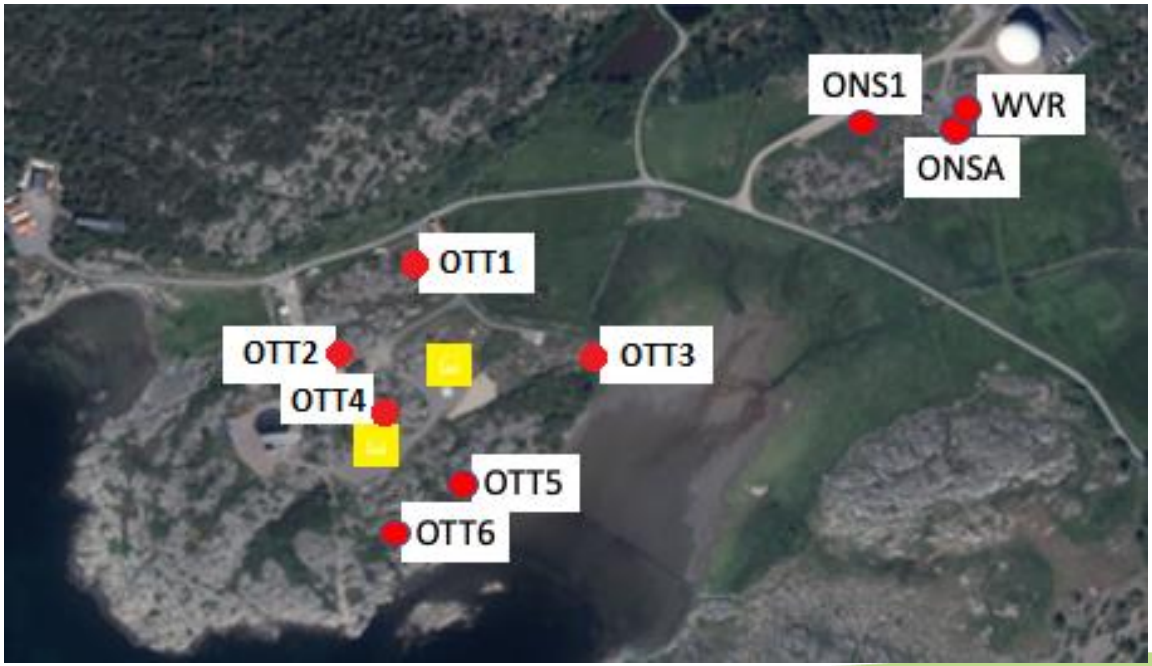
Station	ONSA	ONS1	OTT1	OTT2	OTT3	OTT4	OTT5	OTT6
ONSA	–	0.89	0.89	0.90	0.92	0.86	0.91	0.89
ONS1	0.26	–	0.87	0.88	0.90	0.85	0.90	0.88
OTT1	0.26	0.28	–	0.91	0.91	0.88	0.89	0.88
OTT2	0.25	0.28	0.24	–	0.92	0.89	0.90	0.88
OTT3	0.22	0.25	0.23	0.23	–	0.89	0.92	0.90
OTT4	0.29	0.31	0.28	0.26	0.27	–	0.86	0.85
OTT5	0.23	0.24	0.26	0.25	0.21	0.29	–	0.91
OTT6	0.26	0.27	0.27	0.27	0.25	0.30	0.23	–

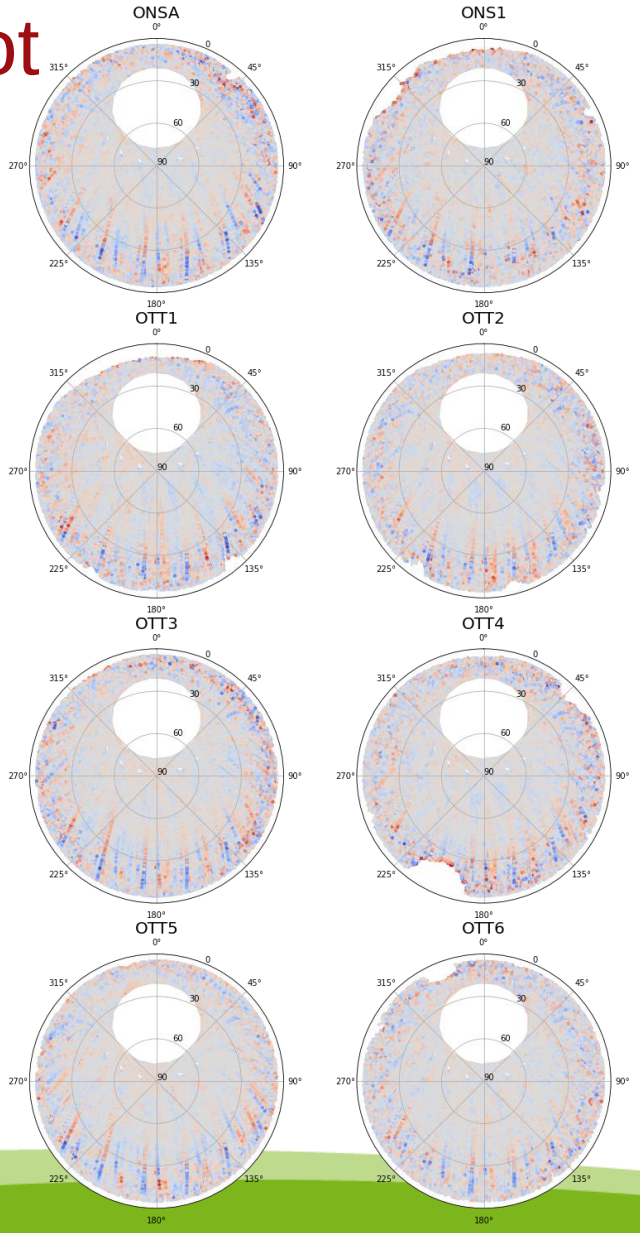
- Correlation coefficients (upper right triangle) and standard deviations in mm (lower left triangle) for north gradients from the pairwise comparison of GNSS stations

- OTT4 shows a slightly worse agreement with the others. This is due to the location of the OTT4 which is very close to one of the VLBI twin telescopes causing data loss from low elevations in the direction of the telescope

GNSS post-fit residuals in skyplot

- No data from low elevations for OTT4 in the south-west direction due to the VLBI telescope
- All GNSS stations show similar residuals

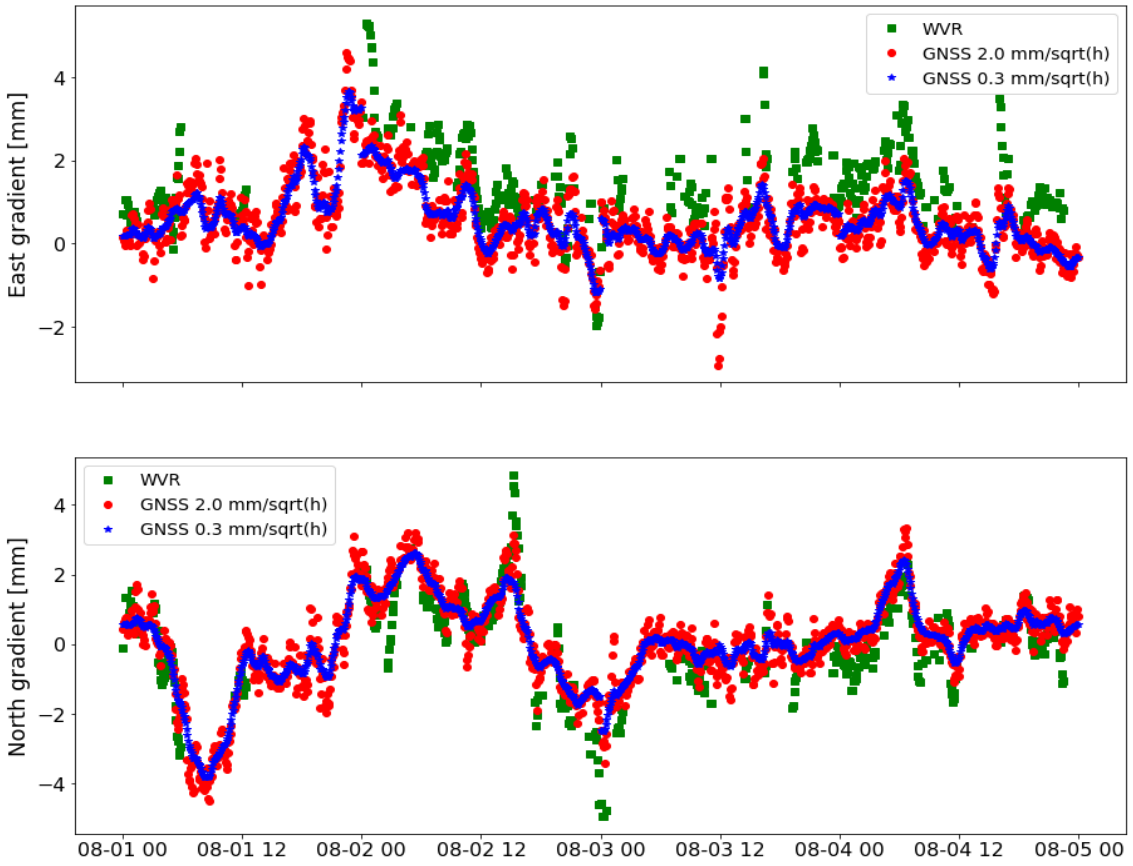




LANTMÄTERIET

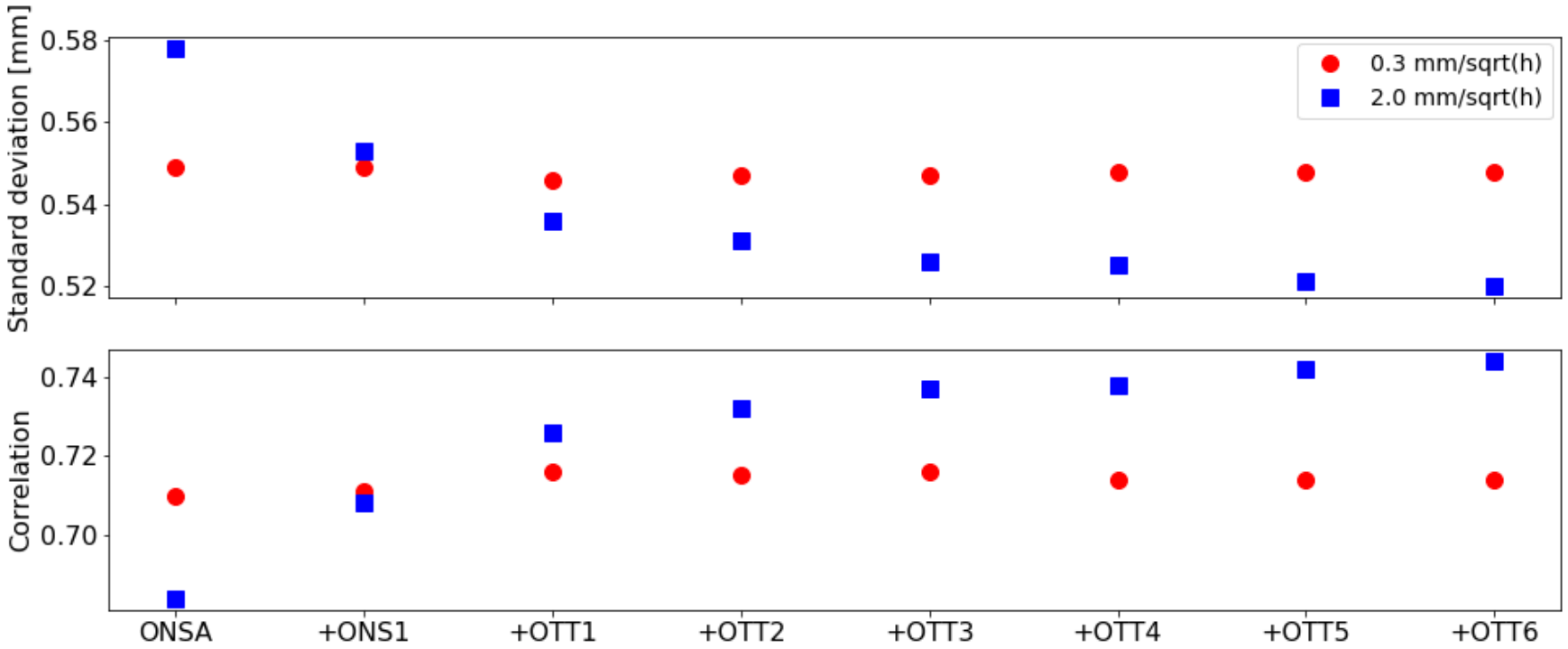
GNSS gradients with different constraints

- Gradients for 5 days from the WVR and the GNSS solutions using two different constraints, 0.3 and 2.0 mm/$\sqrt{h}$, respectively



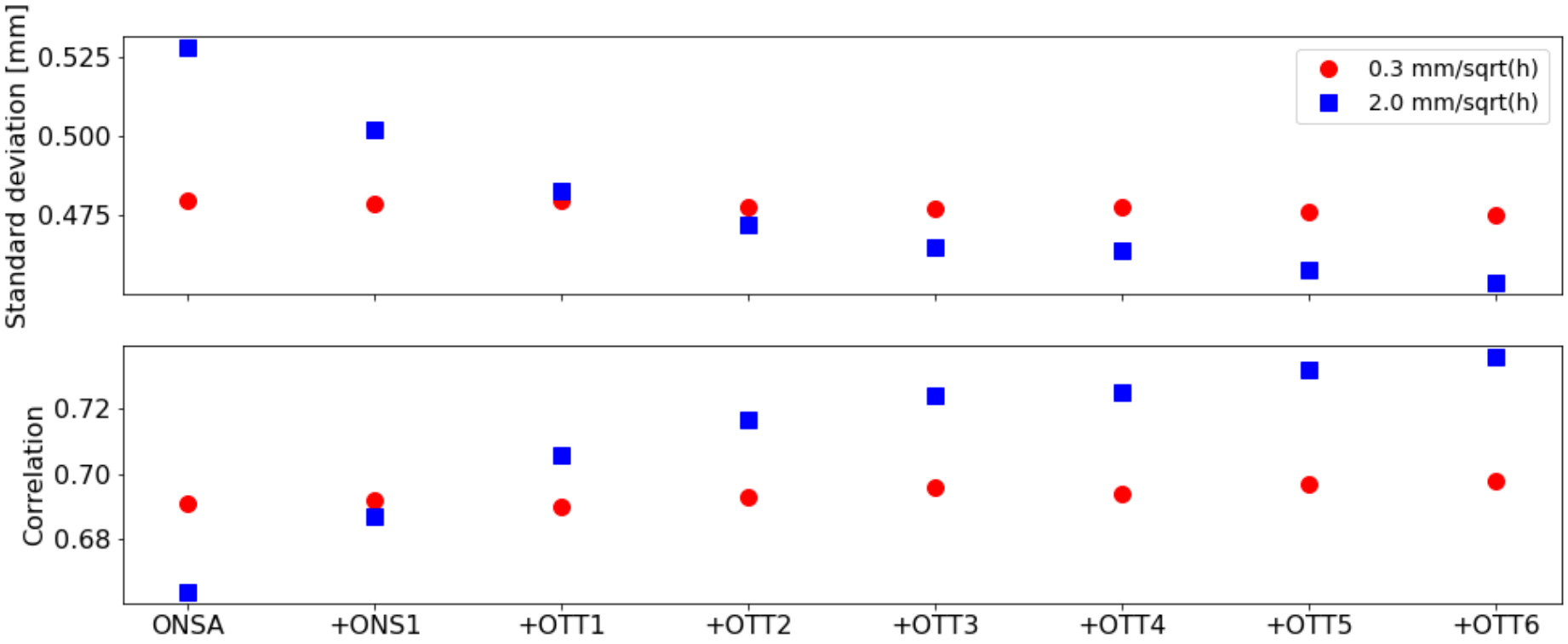
- Applying a weak constraint improved the GNSS data's ability to track large gradients of short duration, however, at the cost of increased formal errors

Averaged GNSS data



- The comparison of east gradients with the WVR data using averaged GNSS data
- The random errors in GNSS measurements, i.e., receiver noise and multipath, are uncorrelated across different stations and therefore can be reduced through averaging
- No clear difference seen for the strong constraint (0.3 mm/ $\sqrt{h}$) while the agreement improves significantly through averaging for the weak constraint (2.0 mm/ $\sqrt{h}$)

Averaged GNSS data



The comparison of north gradeints with the WVR data using the averaged GNSS data

Conclusions

- Overall, consistent gradients obtained from GNSS stations with different installations. OTT4 has a slightly worse agreement for the north gradients. The location of the station is too close to one of the VLBI telescopes

- Applying a weak constraint improved the GNSS data's ability to track large gradients of short duration, however, at the cost of increased formal errors

- The increased formal errors can be reduced by averaging the GNSS gradients acquired from the co-located stations