Multi-technique comparison of troposphere zenith delays and gradients during CONT08

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The aims of our study are

- Quantify agreement of troposphere estimates
- Figure out site and technique specific irregularities

Agreement criteria are

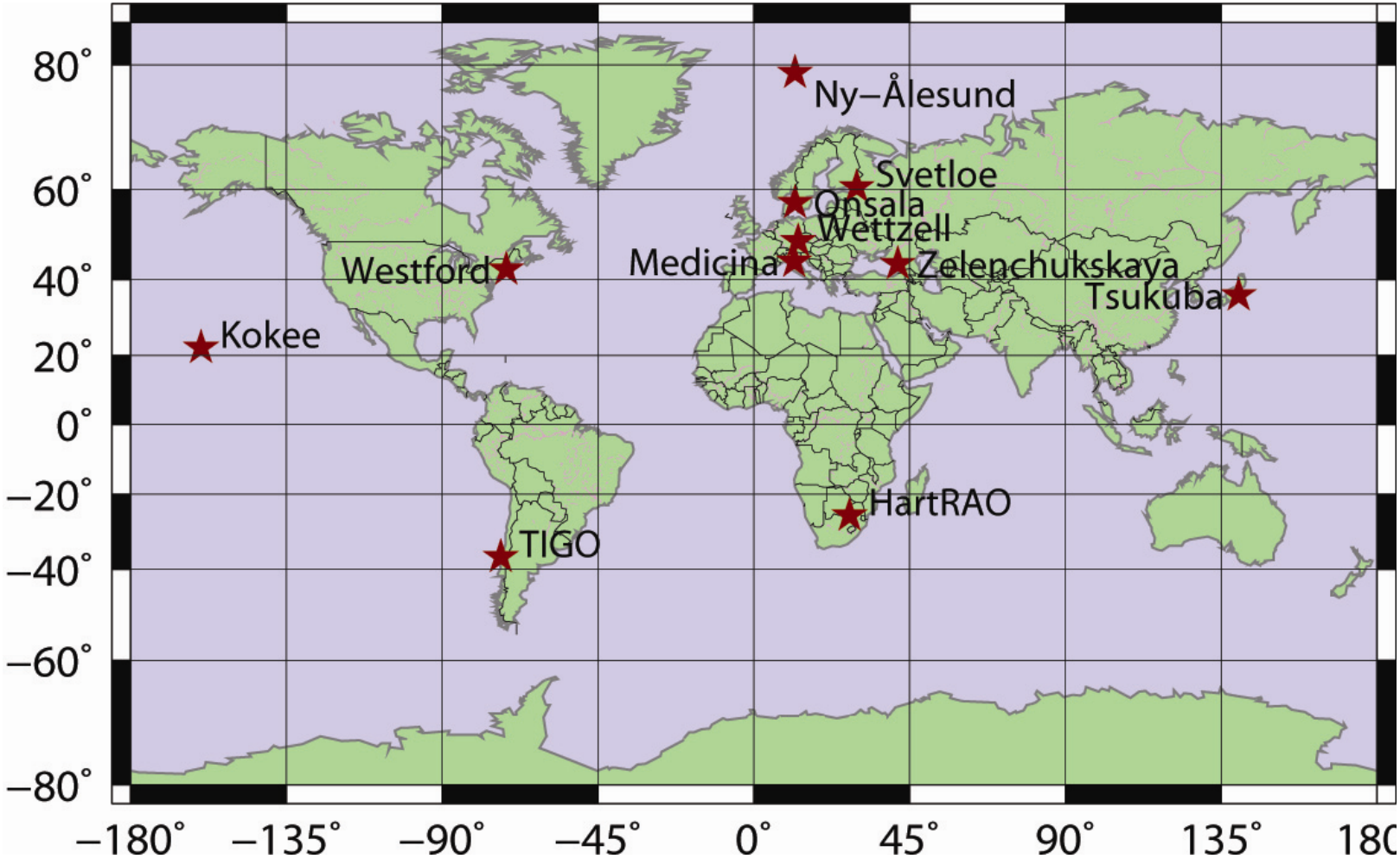
$$e.g. \quad x_i = ZTD_i^{VLBI-VieVS} \quad y_i = ZTD_i^{GPS-CODE} \quad \Delta_i = x_i - y_i$$

$$\bar{\Delta} = \frac{1}{n}\sum_{i=1}^{n}\Delta_i \qquad i = 1, 2, \cdots, n$$

$$Sx = \left[\frac{1}{n-1}\sum_{i=1}^{n}(\Delta_i - \bar{\Delta})^2\right]^{\frac{1}{2}}$$

$$r_{xy} = \frac{Cov(x,y)}{S_x S_y} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\left[\sum_{i=1}^{n}(x_i - \bar{x})^2 \cdot \sum_{i=1}^{n}(y_i - \bar{y})^2\right]^{\frac{1}{2}}} \qquad (p < 0.05)$$

CONT08 co-located sites



first observation: Tuesday August 12, 2008 @ 00:00:00 UT

last observation: Tuesday August 26, 2008 @ 23:59:59 UT

Very Long Baseline Interferometry (VLBI)

- **Vienna VLBI Software (VieVS):**

- NNT/NNR on ITRF2005.
- VMF1, above 5°.
- 0.7 picosec^2/sec for ZTDs (relatively loose).
- 2 mm/day for gradients (relatively loose).
- 30 minutes for ZTDs, and 120 for gradients.
- APL applied a priori (Petrov and Boy, 2004)

- **International VLBI Service for Geodesy and Astrometry (IVS):**

-Intra-technique combined solution for ZTDs and troposphere gradients.
-60 minutes for ZTDs and for gradients

Global Positioning System (GPS)

- **Center for Orbit Determination in Europe (CODE)**

- Bernese GPS software.
- NNR on IGS05.
- 120 minutes interval for ZTDs and 24 h for gradients.
- VMF1, 3° + elevation dependent weighting.
- No constraints for zenith delays and gradients.
- APL applied.

- **International GNSS Service (IGS)**

- GIPSY/Oasis software.
- PPP solution, Kalman filter.
- IGS final combined : orbits, clocks, and EOP.
- NMF, 7°.
- 5 minutes for ZTDs.
- Estimated parameters are: clocks, station position, zenith wet delay, troposphere gradients, phase biases (Byun S.H. and Bar-Sever Y.E., 2009).

Doppler Orbitography and Radio Positioning Integrated by Satellite (DORIS)

- **Institut Géographique National (IGN)**

- Software is GIPSY/Oasis.
- TRF is fixed to ign09d02.
- VMF1, 10°.
- DORIS reset at no regular interval.
- It is reset at start of pass and only if the previous reset is 20 minutes before or earlier.
- ZTD epochs interpolated linearly from the irregular epochs to 120 minutes (epochs at UTC integer hours).
- No interpolation between the data gaps larger than 60 minutes.
- Co-located sites are Ny-Ålesund (spjb), Kokee Park (kolb), Hartebeesthoek (hbmb).

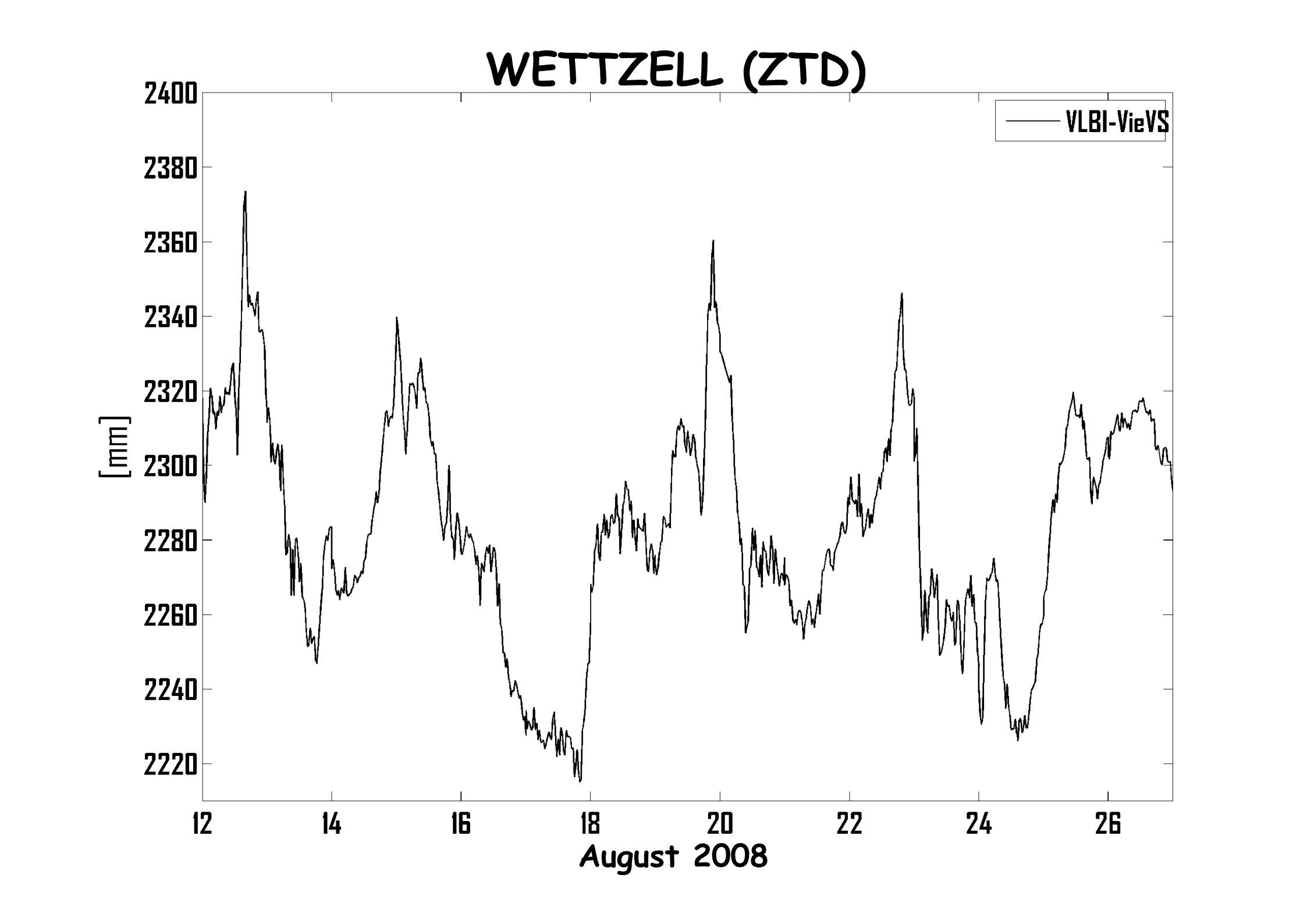
Water Vapor Radiometer (WVR)

- Slant wet delays inferred from measurements of the sky brightness temperature at about 22 GHz and 31 GHz.
- ZWDs and gradients obtained by a least-squares fit. 30 minutes estimation interval for ZWDs and 120 minutes estimation intervals for troposphere gradients.
- ZHDs calculated from surface pressure measurements at the VLBI antenna.
- Cut off 20°.
- Data aquired during rain removed.
- Co-located sites: Wettzell, Tsukuba, and Onsala.

Numerical Weather Models (NWMs)

- Japan Meteorological Agency - Kashima Ray-Tracing Tools (JMA-KARAT).
- High Resolution Limited Area Model (HIRLAM).
- European Centre for Medium-Range Weather Forecasts (ECMWF).

NWM	The regions for which the models provide data	Spatial resolution	Time Resolution (hours)	Number of levels at each profile	Troposphere gradients estimated ?
JMA-KARAT	Japan	0.1°	3	21	YES
HIRLAM	Europe	0.2°	3	40	NO
ECMWF	Global	0.25°	6	21	YES


WETTZELL (ZTD)
VLBI-VieVS
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2380
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[mm]
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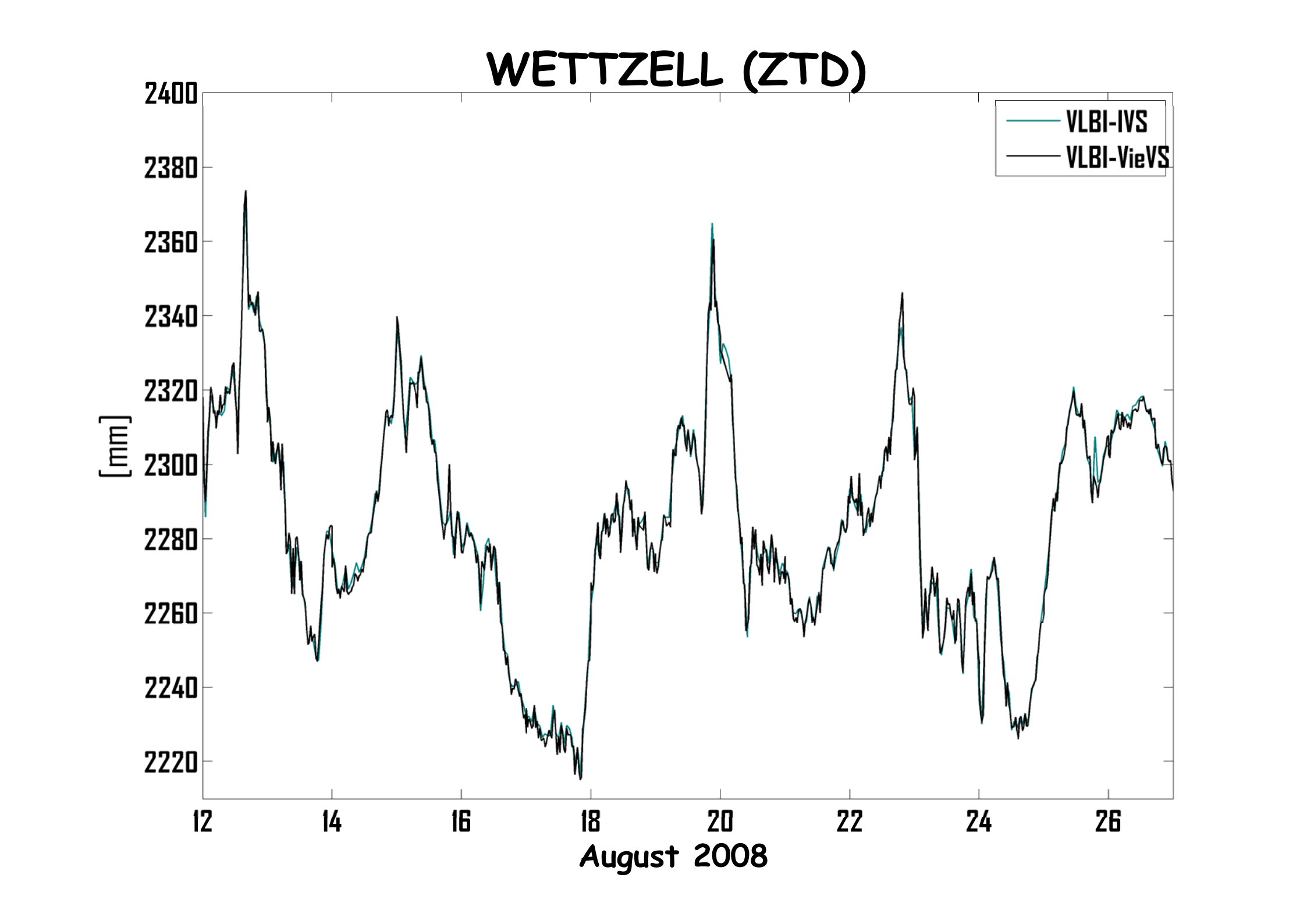
August 2008


WETTZELL (ZTD)
VLBI-IVS
VLBI-VieVS
[mm]
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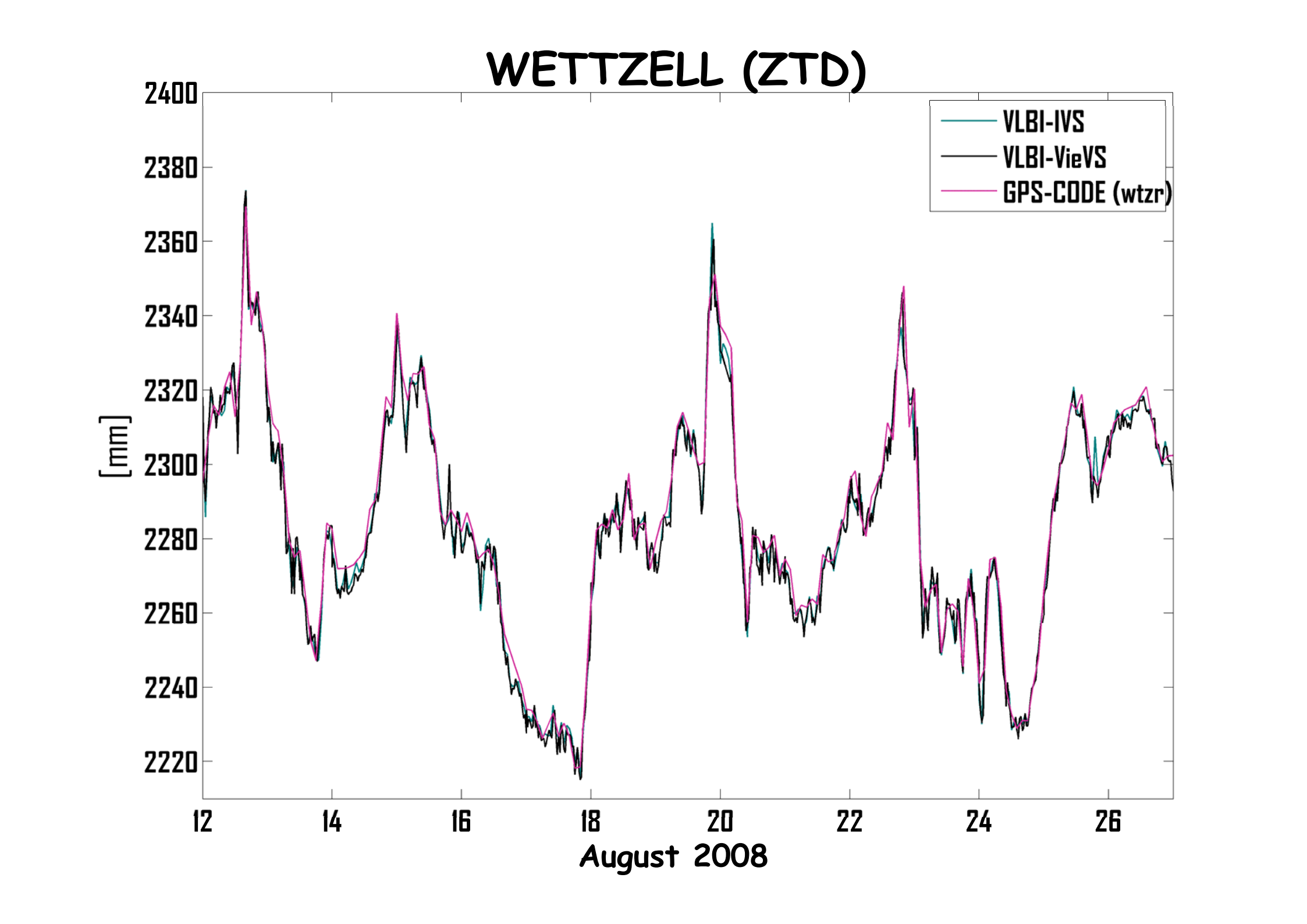
August 2008


WETTZELL (ZTD)
VLBI-IVS
VLBI-VieVS
GPS-CODE (wtzr)
[mm]
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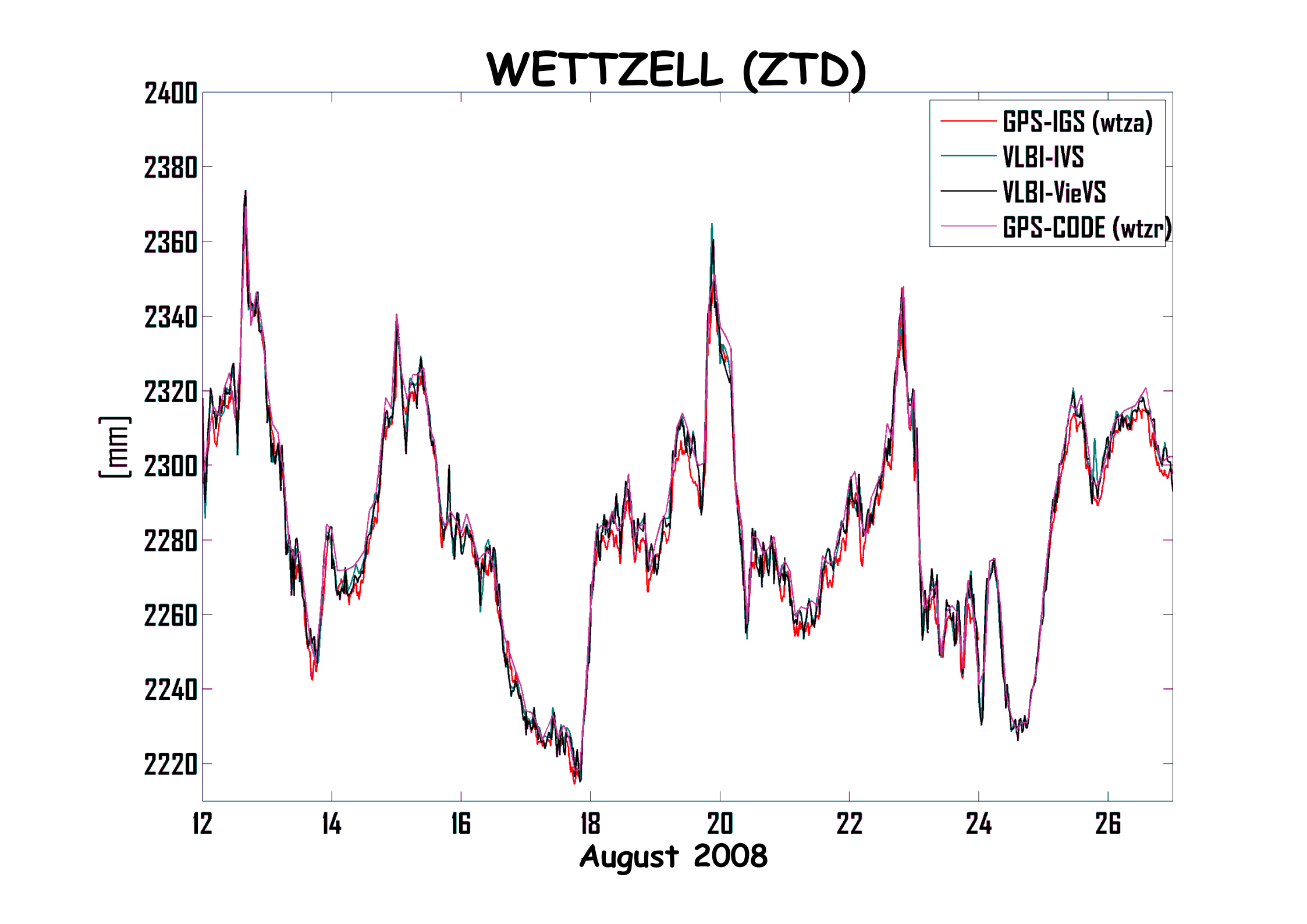
August 2008


WETTZELL (ZTD)
GPS-IGS (wtza)
VLBI-IVS
VLBI-VieVS
GPS-CODE (wtzr)
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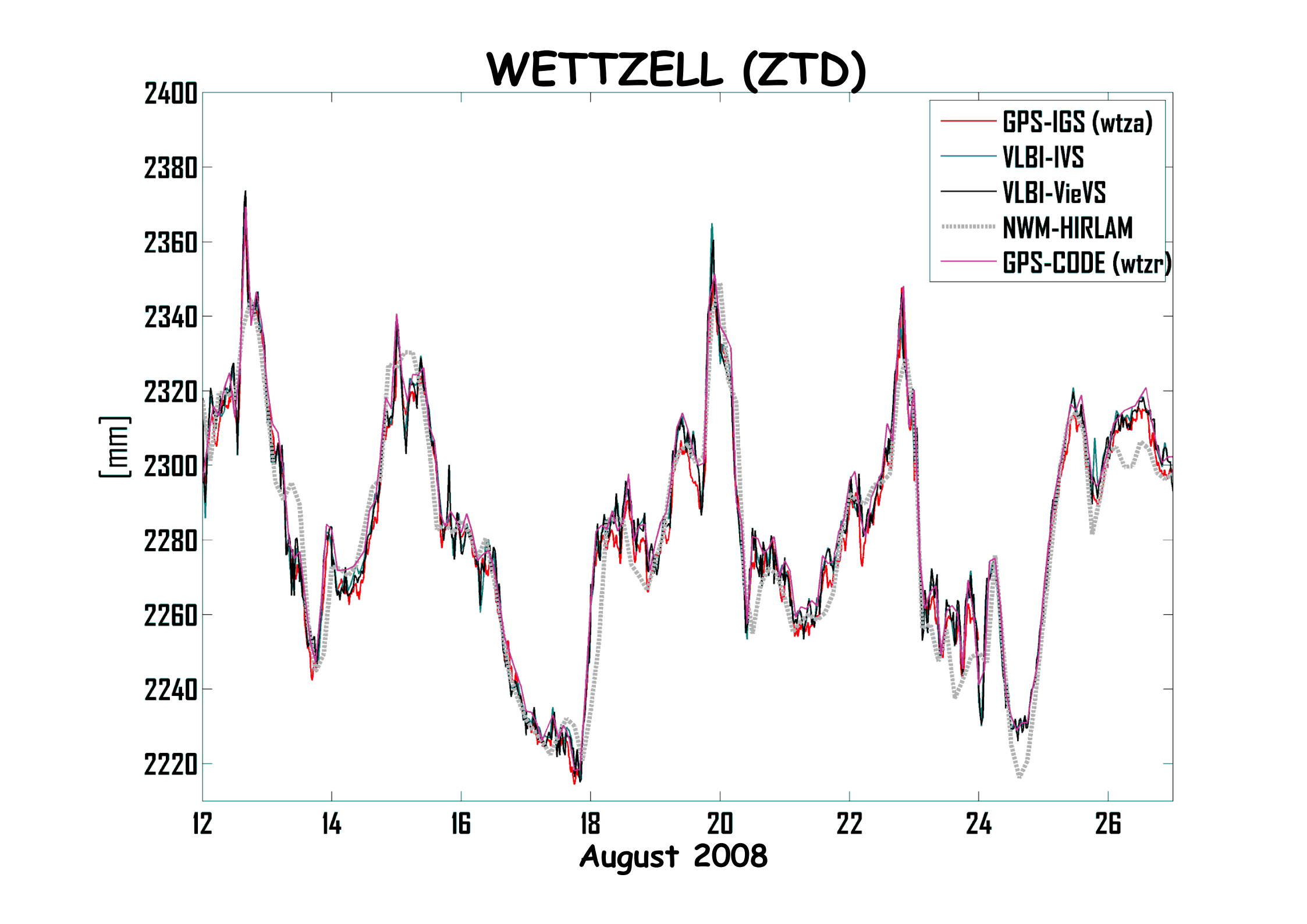
August 2008


WETTZELL (ZTD)
GPS-IGS (wtza)
VLBI-IVS
VLBI-VieVS
NWM-HIRLAM
GPS-CODE (wtzr)
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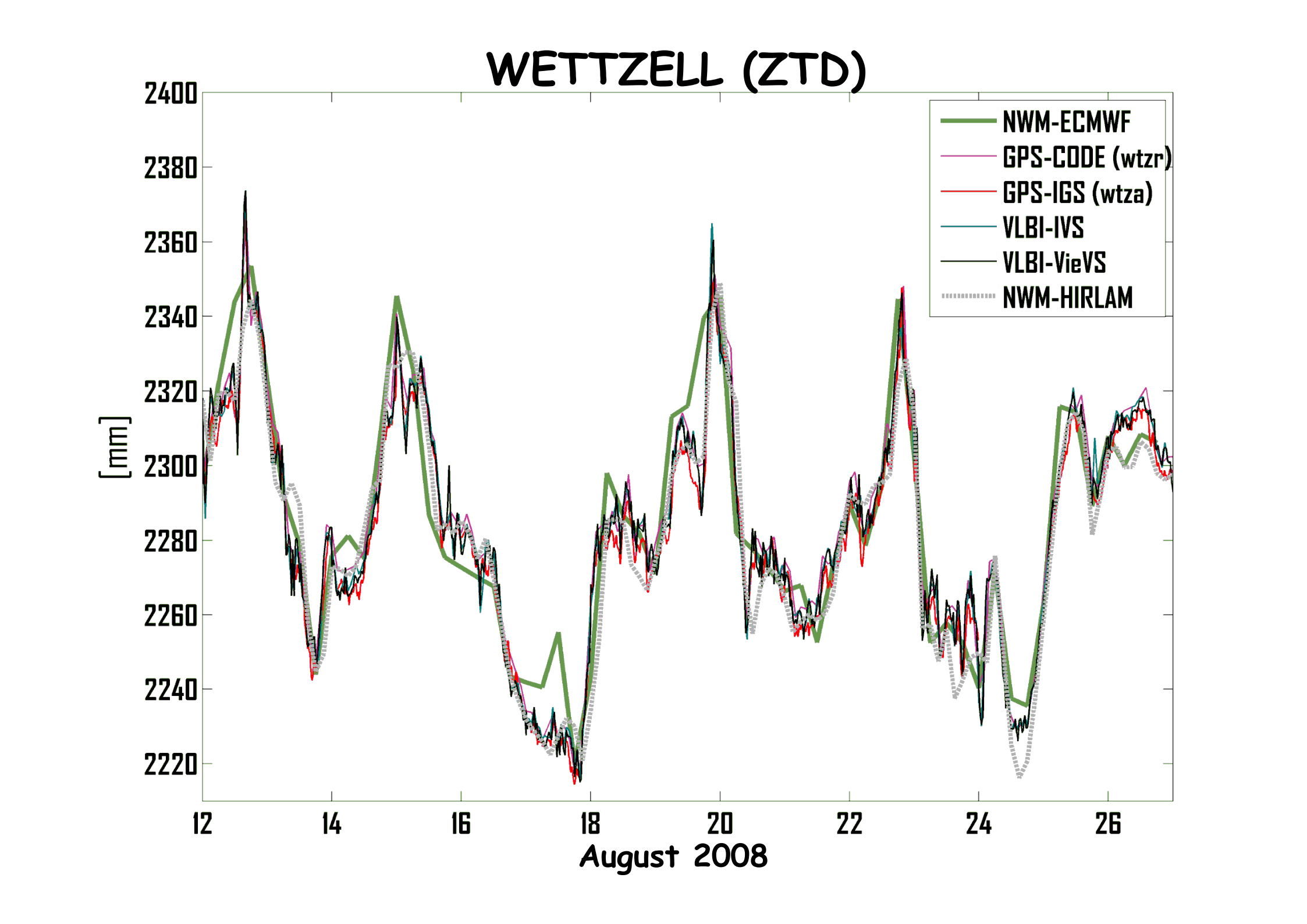
August 2008


WETTZELL (ZTD)
NWM-ECMWF
GPS-CODE (wtzr)
GPS-IGS (wtza)
VLBI-IVS
VLBI-VieVS
NWM-HIRLAM
[mm]
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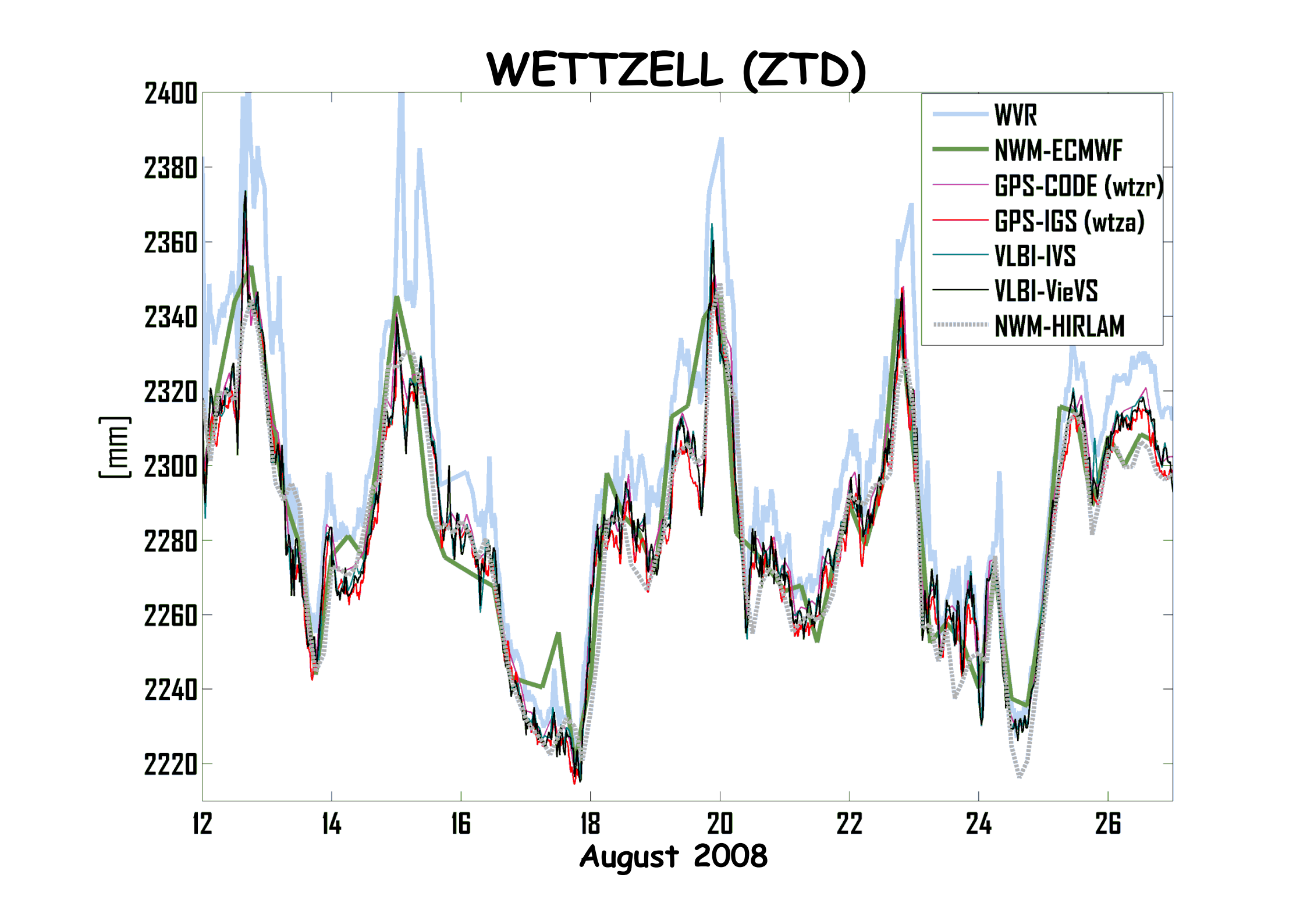
August 2008


WETTZELL (ZTD)
WVR
NWM-ECMWF
GPS-CODE (wtzr)
GPS-IGS (wtza)
VLBI-IVS
VLBI-VieVS
NWM-HIRLAM
[mm]
2400
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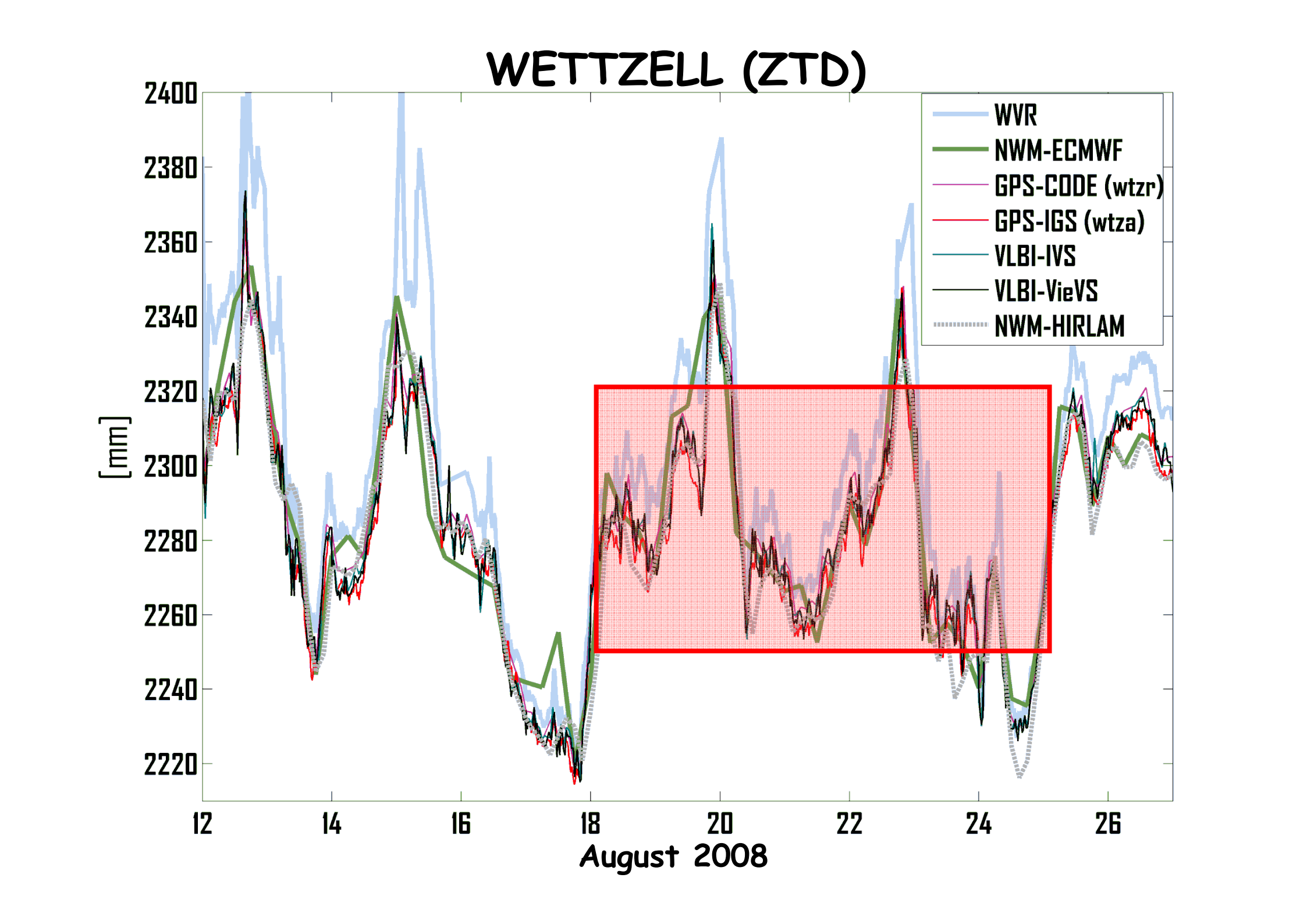
August 2008


WETTZELL (ZTD)
WVR
NWM-ECMWF
GPS-CODE (wtzr)
GPS-IGS (wtza)
VLBI-IVS
VLBI-VieVS
NWM-HIRLAM
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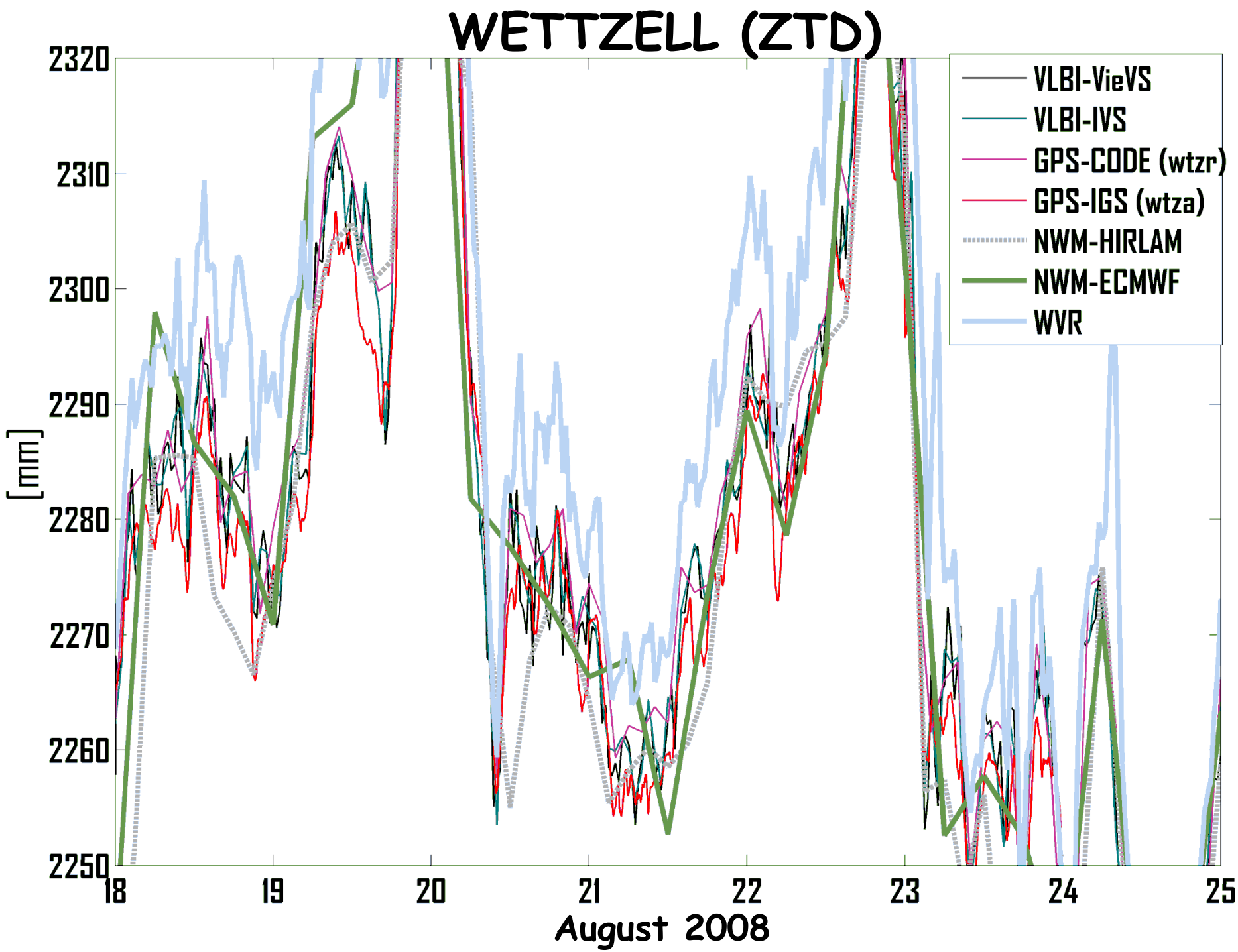
August 2008


WETTZELL (ZTD)
VLBI-VieVS
VLBI-IVS
GPS-CODE (wtzr)
GPS-IGS (wtza)
NWM-HIRLAM
NWM-ECMWF
WVR
[mm]
2320
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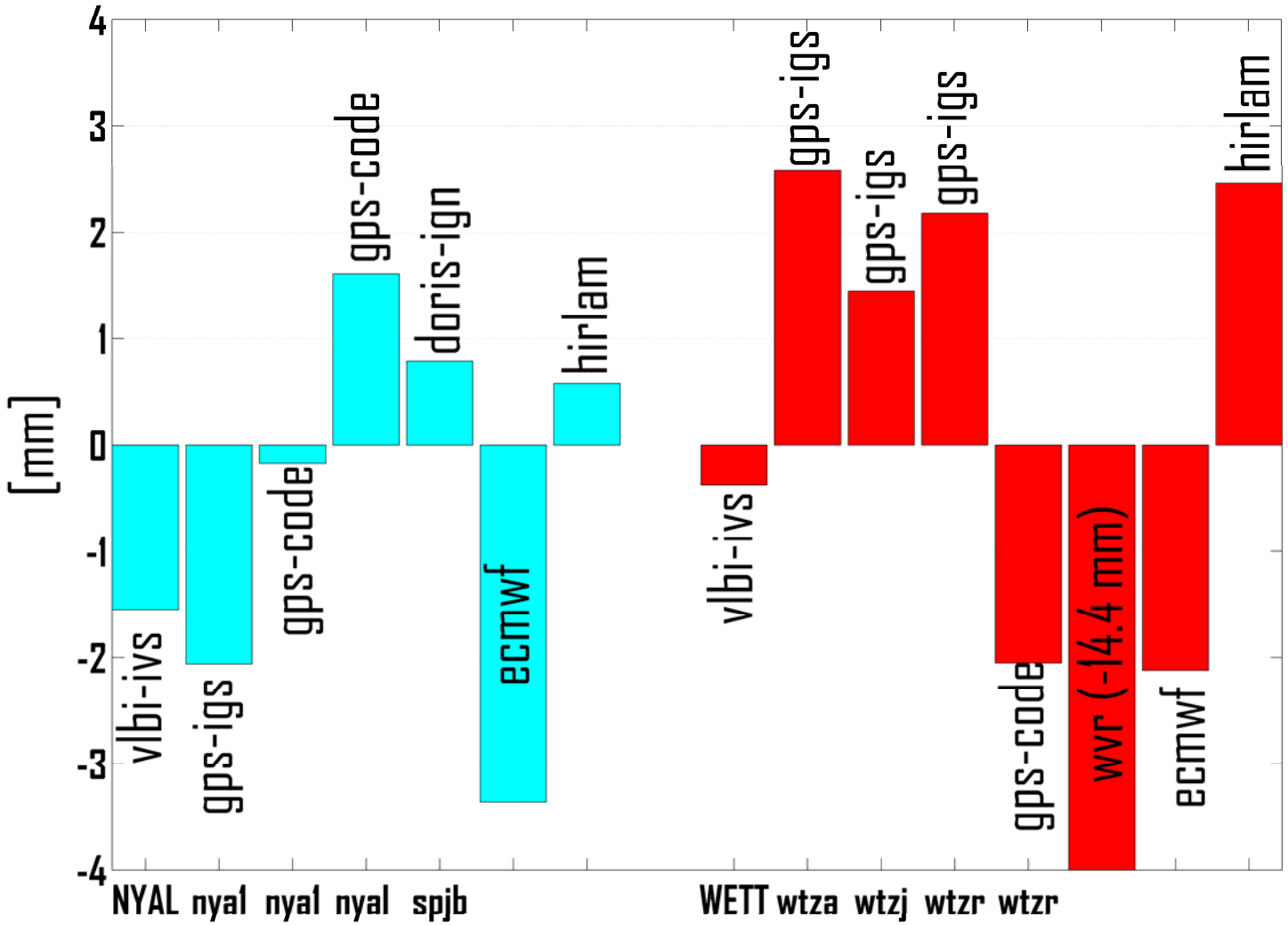
August 2008

Biases of ZTDs between VieVS and other solutions



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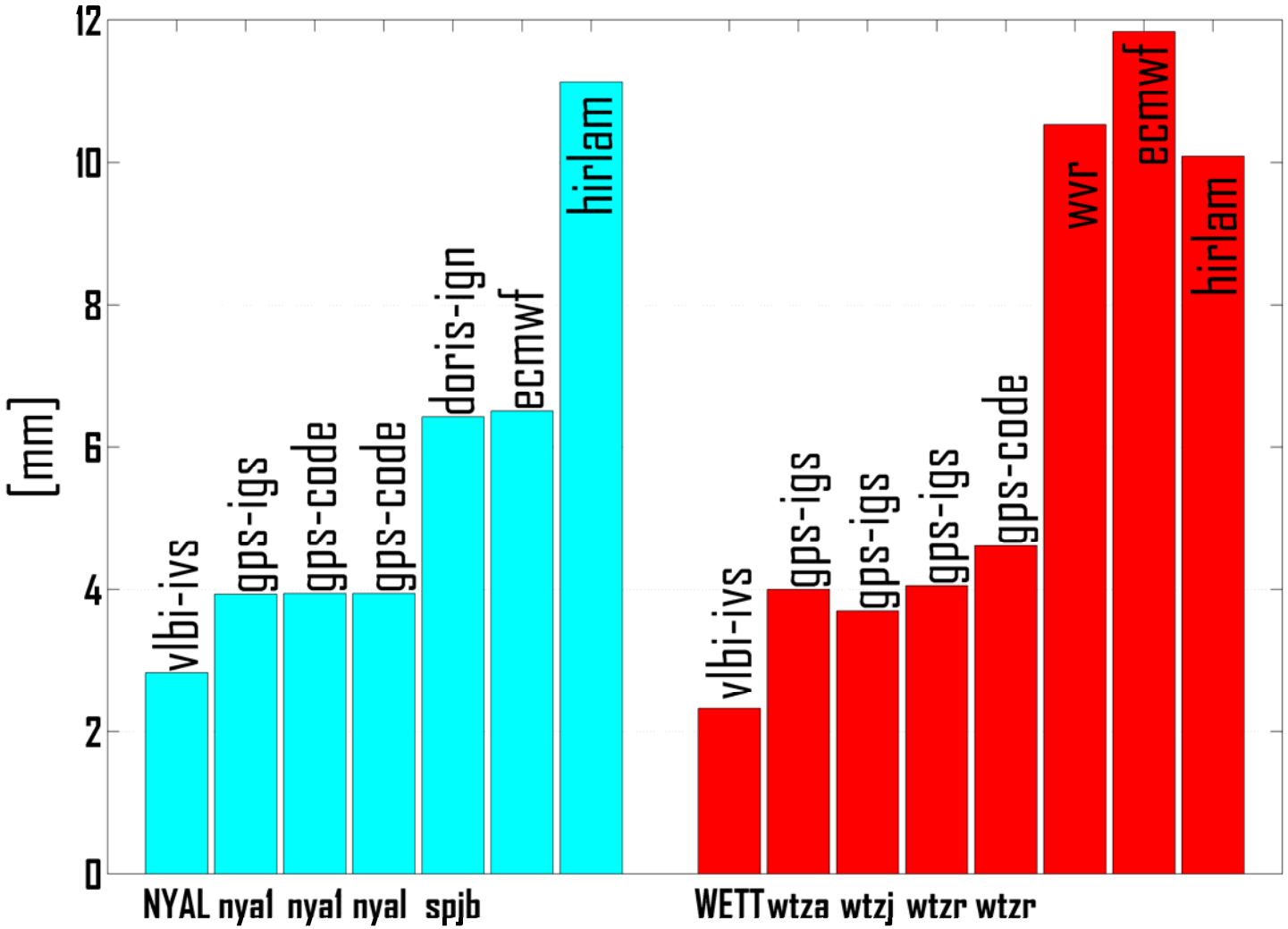
solutions and stations at co-located sites

Std. dev. of ZTDs between VieVS and other solutions



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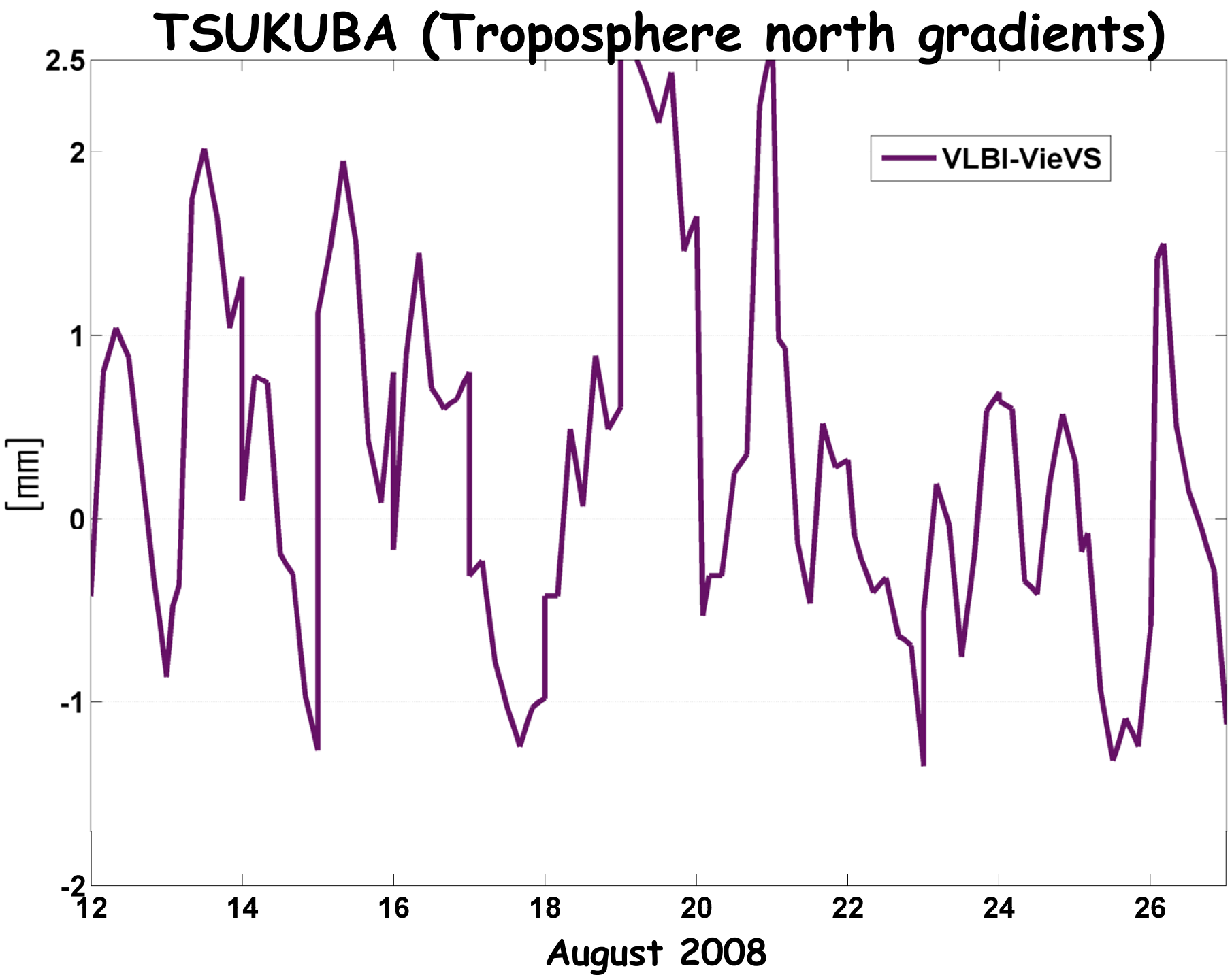
solutions and stations at co-located sites


TSUKUBA (Troposphere north gradients)
VLBI-VieVS
[mm]
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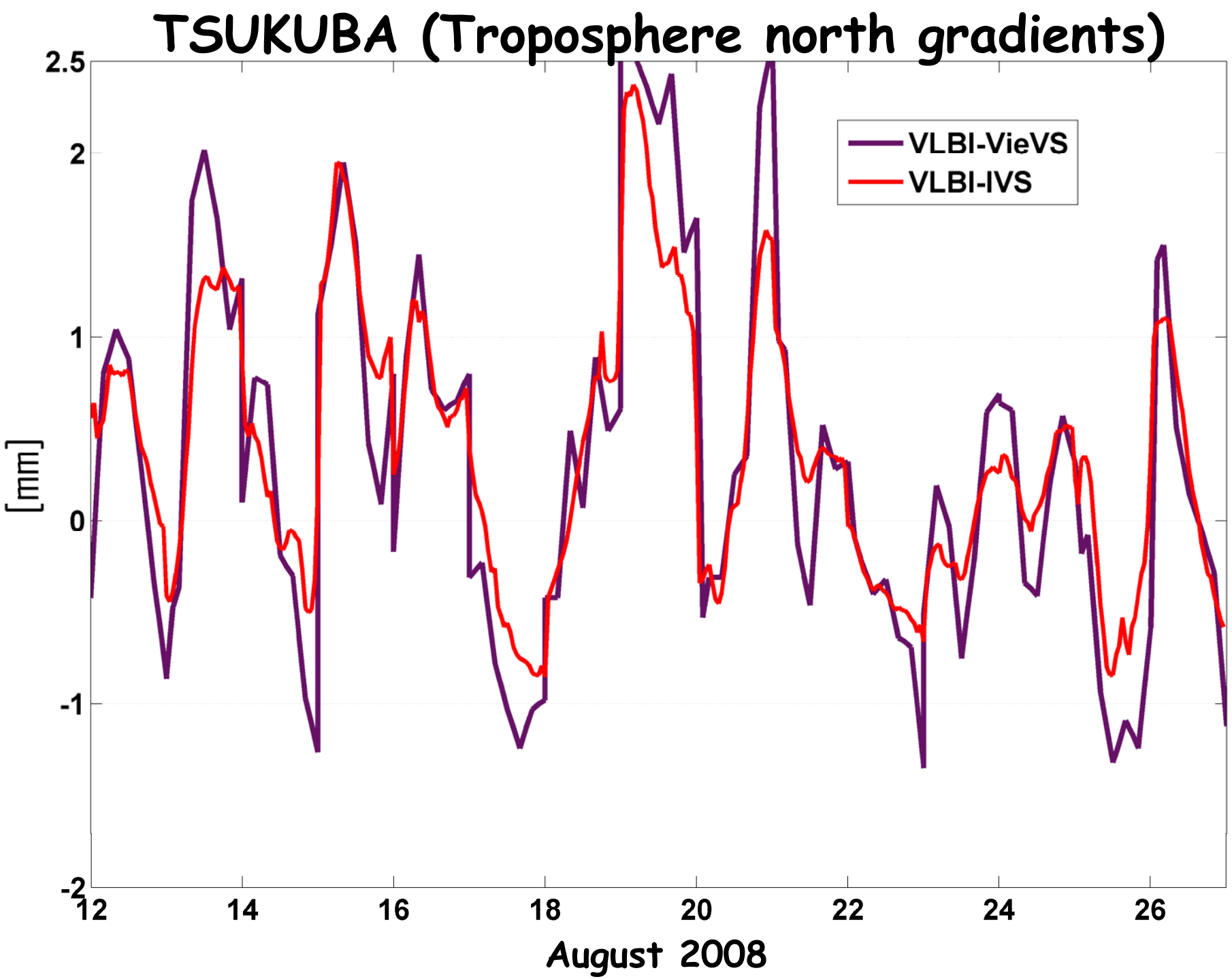
August 2008


TSUKUBA (Troposphere north gradients)
VLBI-VieVS
VLBI-IVS
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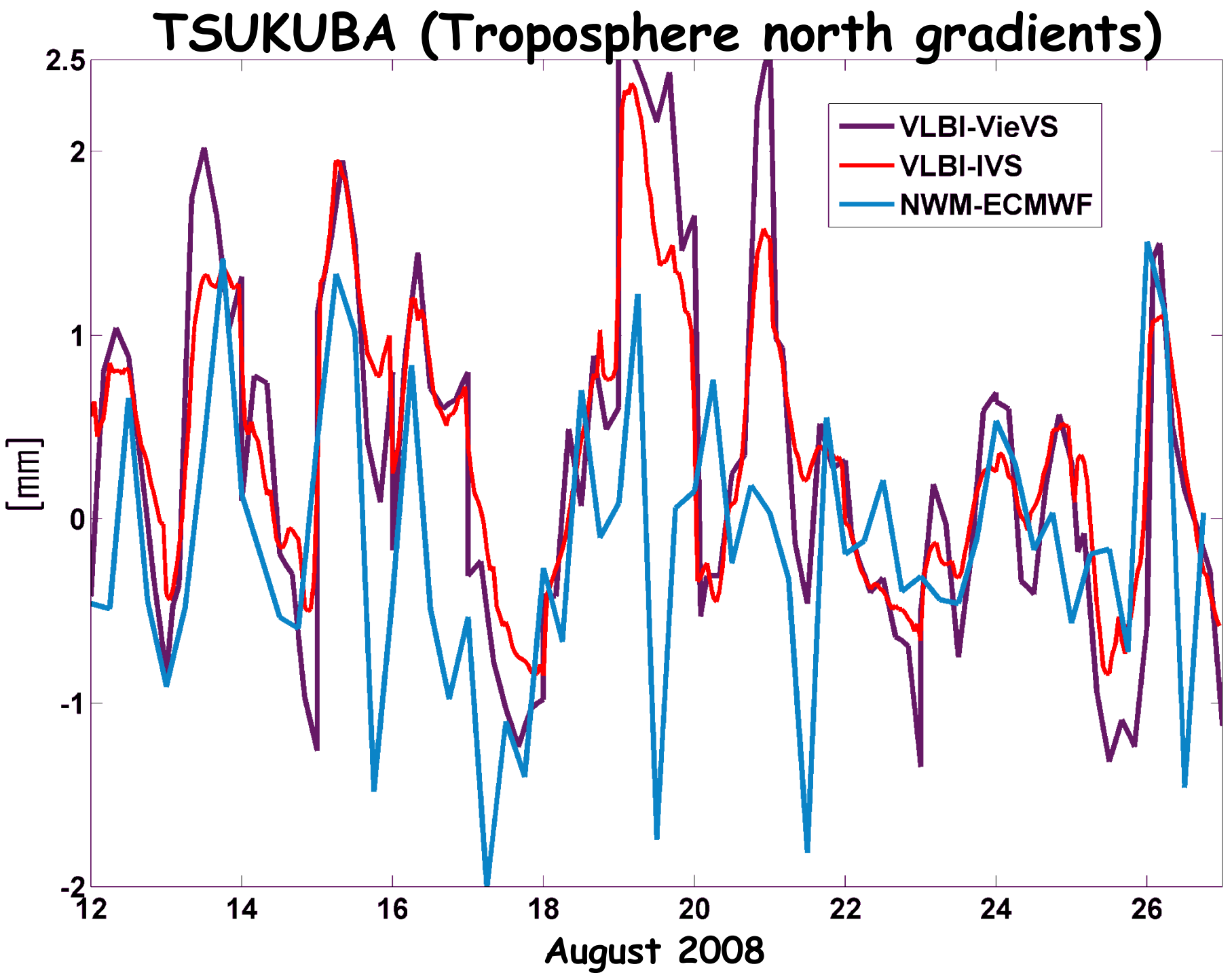
August 2008


TSUKUBA (Troposphere north gradients)
VLBI-VieVS
VLBI-IVS
NWM-ECMWF
[mm]
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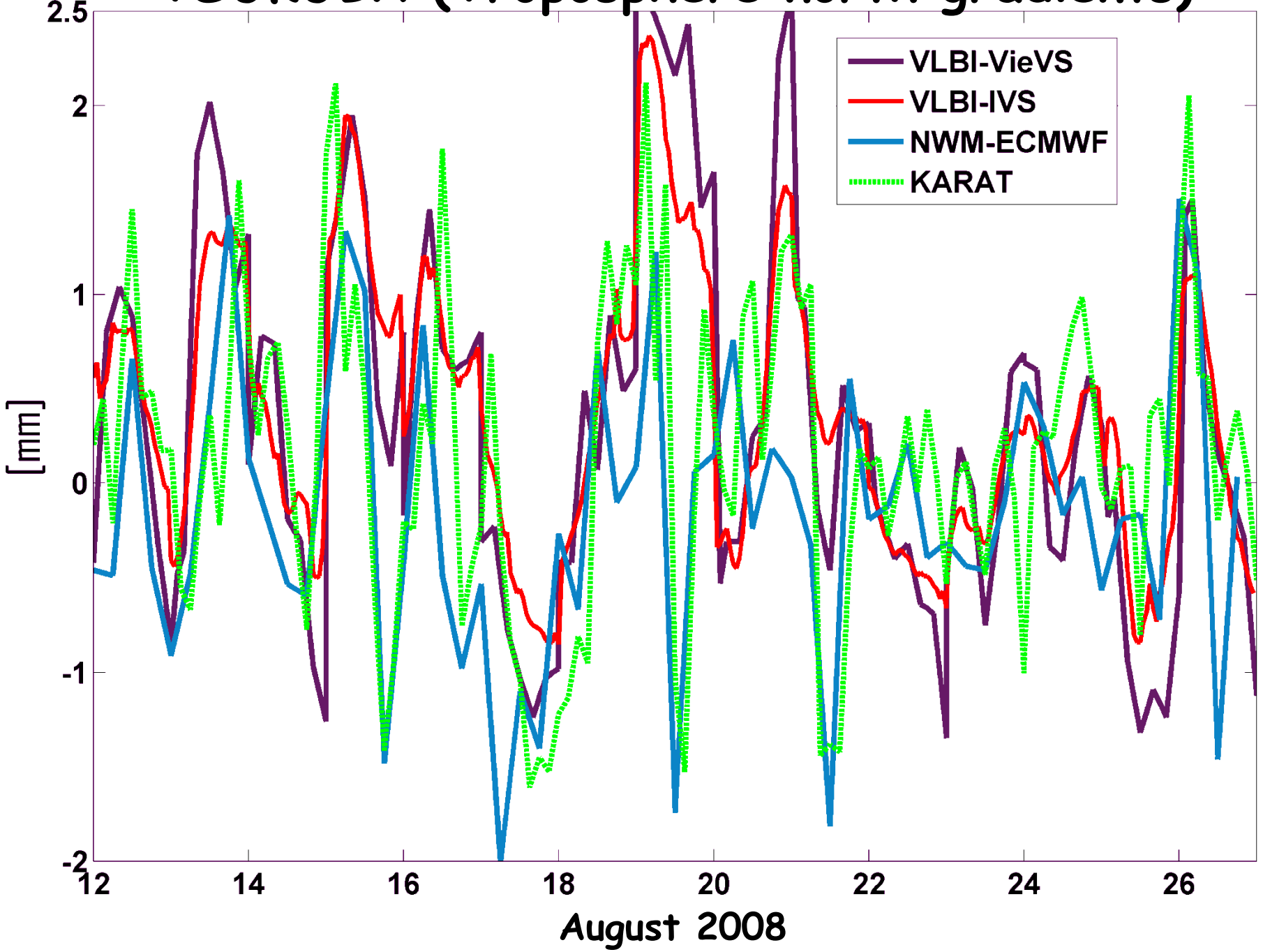
August 2008


TSUKUBA (Troposphere north gradients)
VLBI-VieVS
VLBI-IVS
NWM-ECMWF
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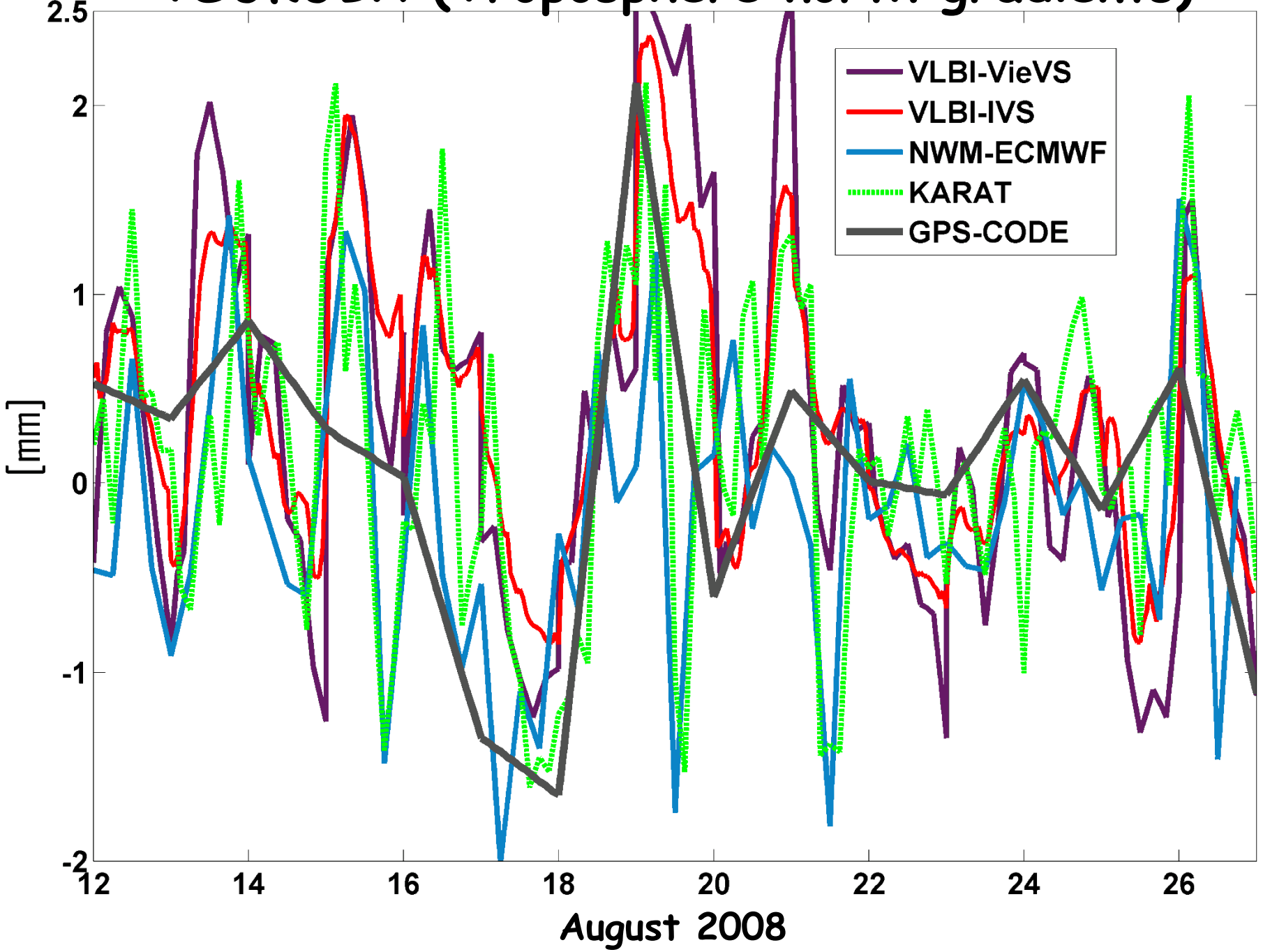
TSUKUBA (Troposphere north gradients)
VLBI-VieVS
VLBI-IVS
NWM-ECMWF
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GPS-CODE
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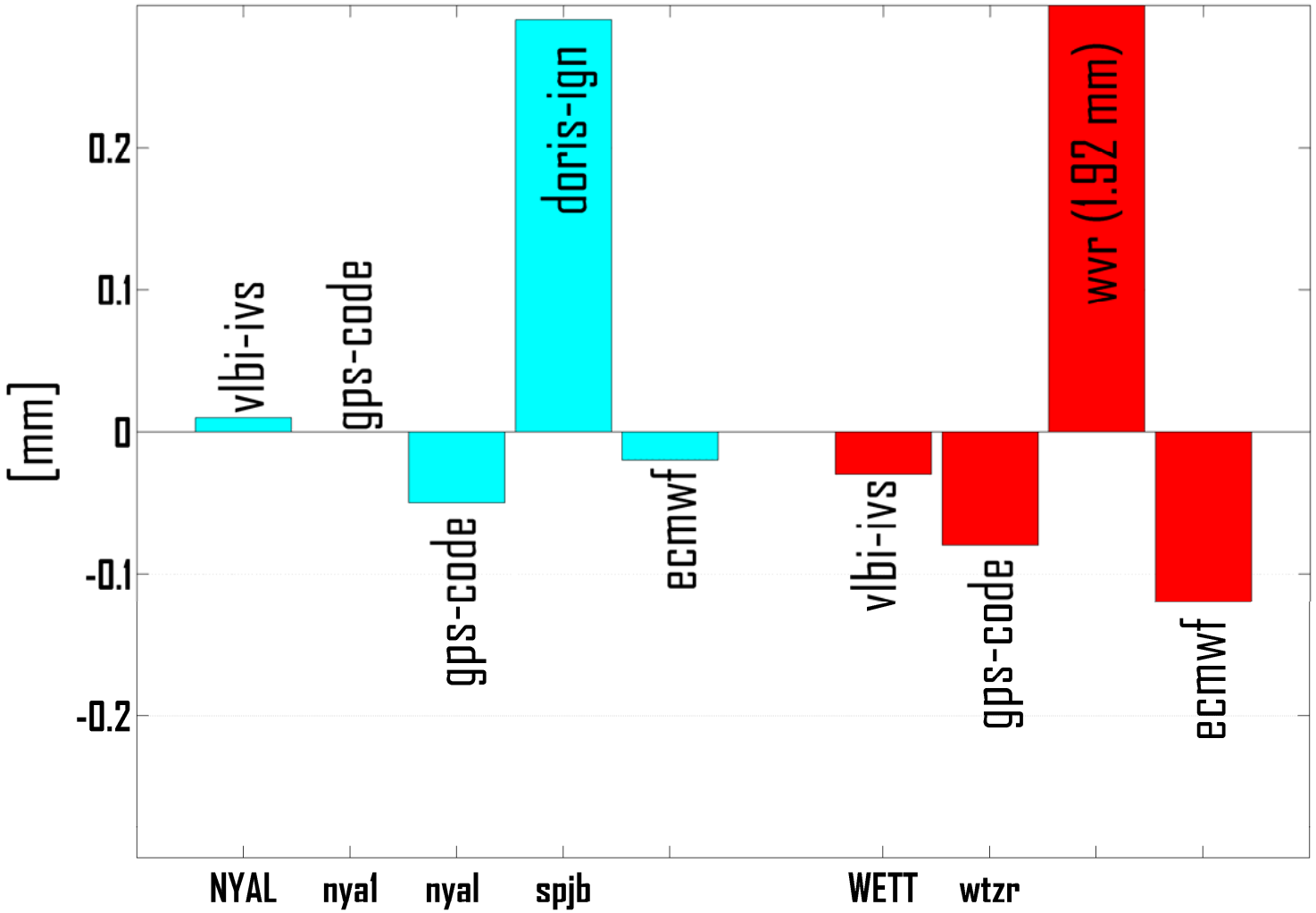
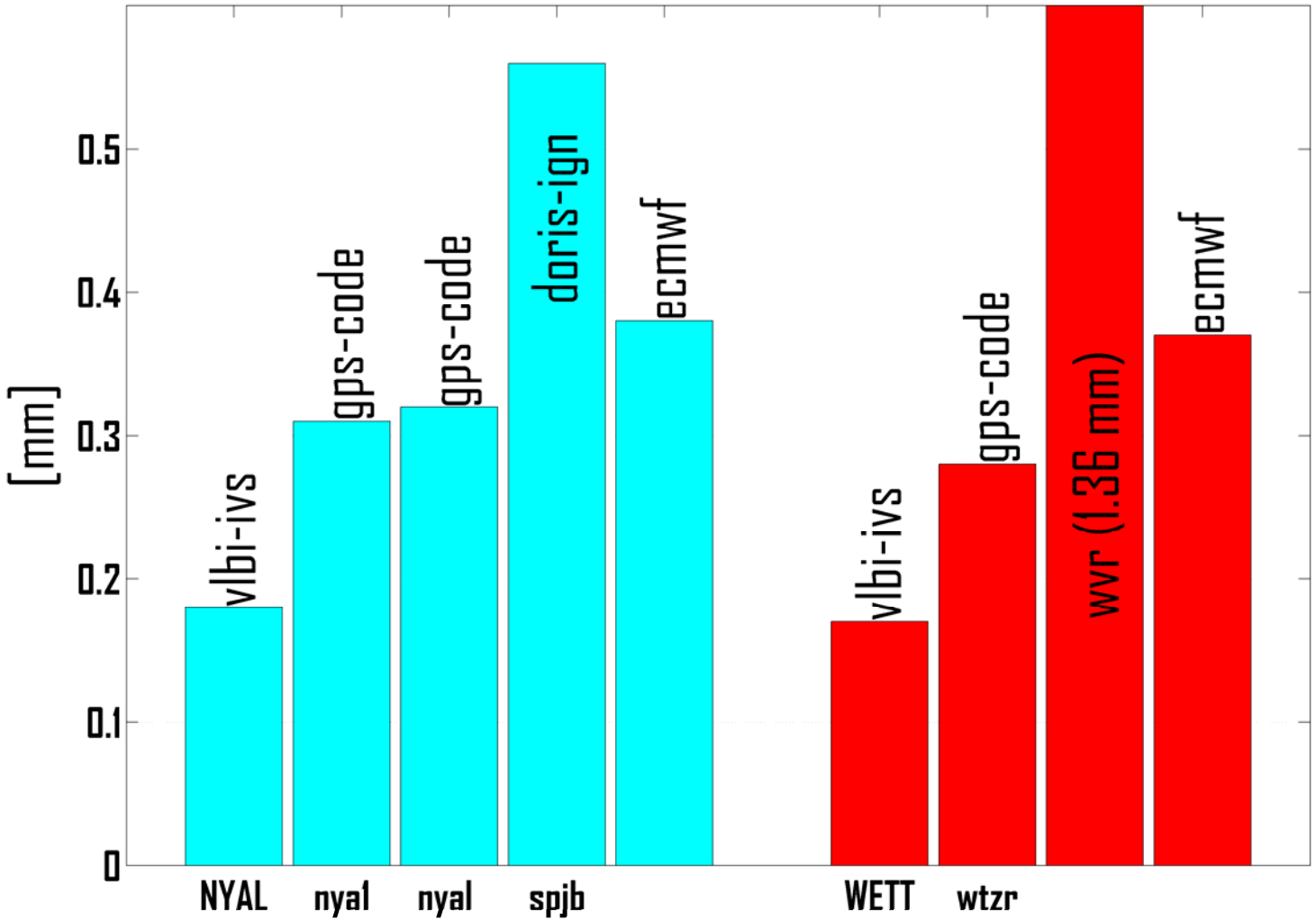
August 2008

Biases of troposphere north gradients between VieVS and other solutions



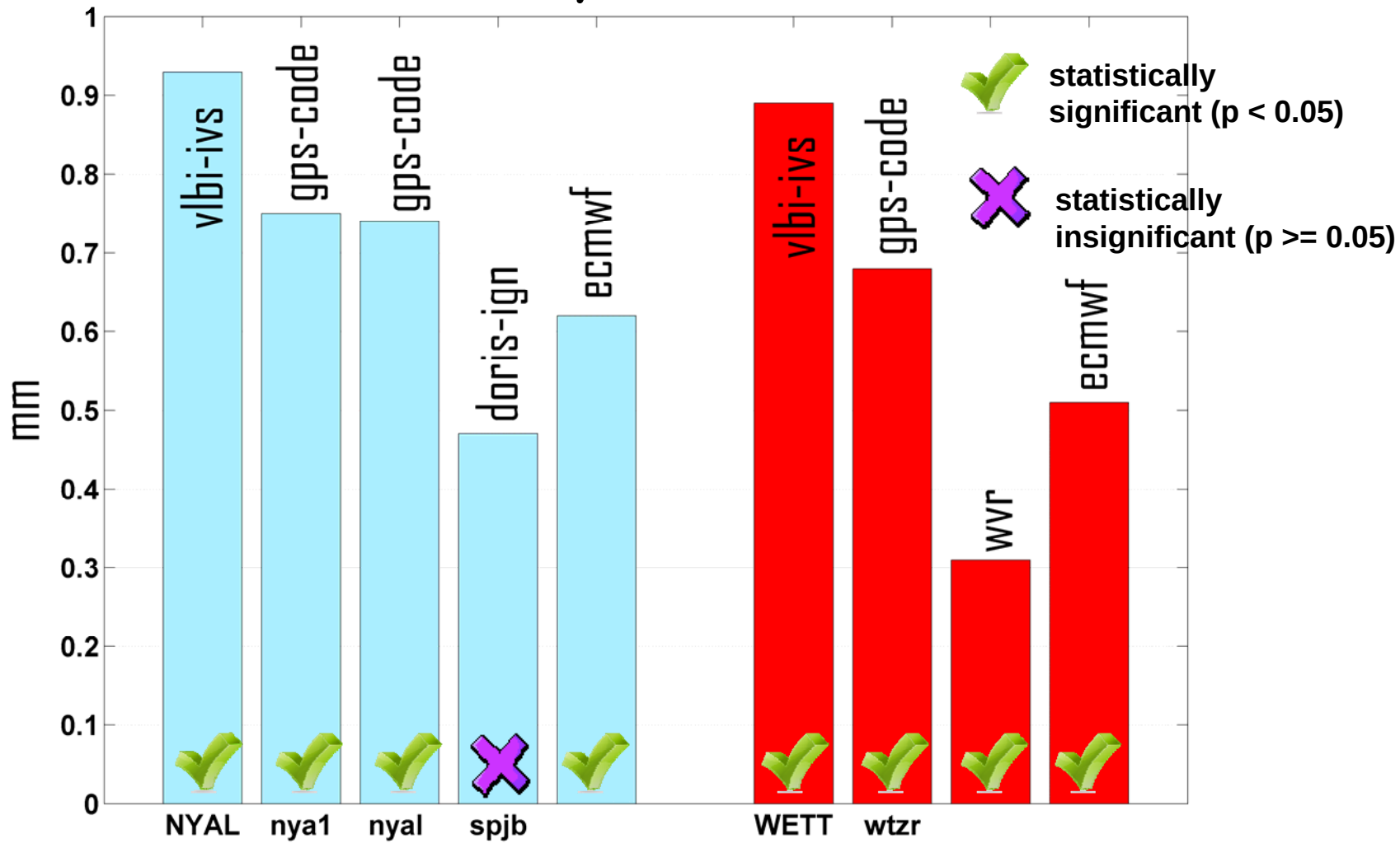
solutions and stations at co-located sites

Standard deviations of troposphere north gradients between VieVS and other solutions



solutions and stations at co-located sites

Correlations of troposphere north gradients between VieVS, and other solutions



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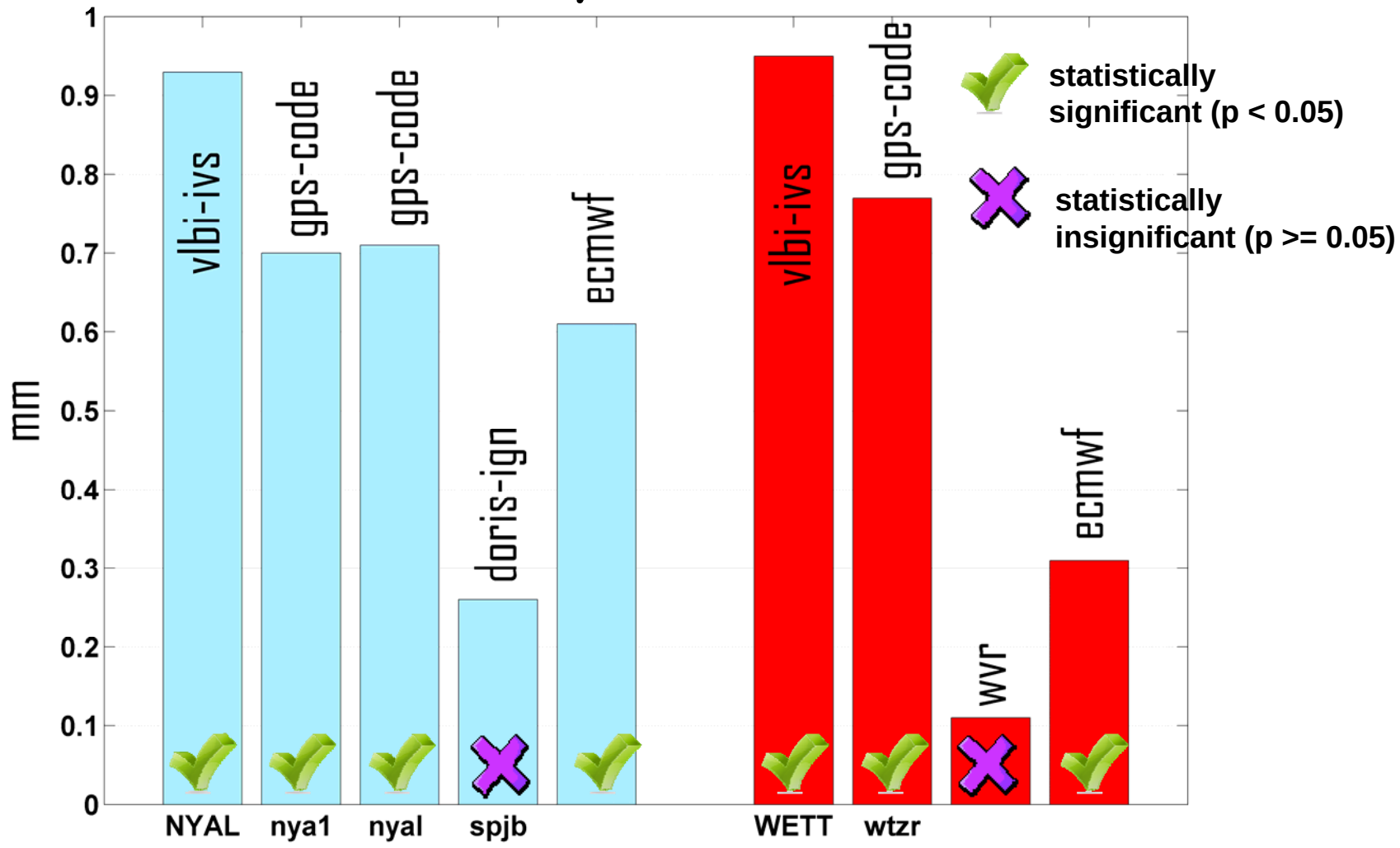
solutions and stations at co-located sites

Correlations of troposphere east gradients between VieVS, and other solutions



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solutions and stations at co-located sites

Conclusions

- ZTD estimates of space geodetic techniques (VLBI, GPS, DORIS) for different solutions (VieVS, IVS, IGN, IGS, CODE) generally agree at the 0.5-1 cm level.
- ZTD estimates of space geodetic techniques and other techniques/models (WVR, ECMWF, HIRLAM, JMA-KARAT) agree with each other better than 2 cm. Correlation coefficients are typically > 0.9 (not shown in the presentation).
- For both ZTDs and gradients the best agreement is found when doing an intra-technique comparison (e.g. VieVS and IVS, CODE and IGS).
- The best inter-technique agreement both for ZTD and gradient estimates is achieved between VLBI and GPS.
- Correlations of gradients between techniques are mostly below 0.6.

Acknowledgements

- We are grateful to the International Services for providing the measurement files we used.

Thank You .