# IVS-CONT08 Oturumları Boyunca Farklı Tekniklerden Elde Edilen Troposfer Zenit Sinyal Gecikmelerinin ve Gradyanların Karşılaştırılması

**Kamil Teke[1], Johannes Böhm[2], Tobias Nilsson[2], Harald Schuh[2], Peter Steigenberger[3], Rolf Dach[4], Robert Heinkelmann[5], Pascal Willis[6, 7], Rüdiger Haas[8], S. Garcia Espada[8, 9], Thomas Hobiger[10], Ryuichi Ichikawa[10], Shingo Shimizu[11]**

(1) Hacettepe University, Türkiye
(2) Vienna University of Technology, Avusturya
(3) Technische Universität München, Almanya
(4) University of Bern, Isvicre
(5) Deutsches Geodätisches Forschungsinstitut, Almanya
(6) Institut Géographique National, Fransa
(7) Institut de Physique du Globe de Paris, Fransa
(8) Chalmers University of Technology, Isvec
(9) Instituto Geografico Nacional, Ispanya
(10) National Institute of Information and Communications Technology, Japonya
(11) National Research Institute for Earth Science and Disaster Prevention, Japonya

# VLBI ölçülerinin analizinde troposfer sinyal gecikme modeli

$$\Delta\tau_{trop} = 10^{-6} \int_{0}^{H_{trop}} \left[ N_h(s) + N_w(s) \right] ds$$

Troposfer gecikmesi lineer model:

$$\Delta\tau_{trop}(\alpha,\varepsilon) = ZHD\, m_h(\varepsilon) + ZWD\, m_w(\varepsilon) + m_w(\varepsilon)\cot(\varepsilon)\left[G_n \cos(\alpha) + G_e \sin(\alpha)\right]$$

Parametre kestirimi öncesi ölcü denklemlerinden indirgenir (Saastamoinen, 1972)

estimated

estimated

estimated

# Troposfer izdüşüm fonksiyonları

$$m_{h,w}(e) = \frac{1 + \cfrac{a_i}{1 + \cfrac{b_i}{1 + \cfrac{c_i}{1 + \cdots}}}}{\sin(e) + \cfrac{a_i}{\sin(e) + \cfrac{b_i}{\sin(e) + \cfrac{c_i}{\sin(e) + \cdots}}}}$$

e : Elevation cut off angle

$a_i$, $b_i$, $c_i$, $\cdots$ = f(φ, H, doy, t, α, ...)

φ : station latitude

H : station orthometric height

doy : day of year

P : surface total pressure

t : surface temperature

α : tempreature lapse rate

Niell Mapping Function (NMF) (Niell, 1996)

Isobaric Mapping Function (IMF) (Niell, 2000)

Vienna Mapping Functions 1 (VMF1) (Boehm, Werl, Schuh, 2006)

Global Mapping Function (Boehm, Niell, Tregoning, Schuh, 2006)

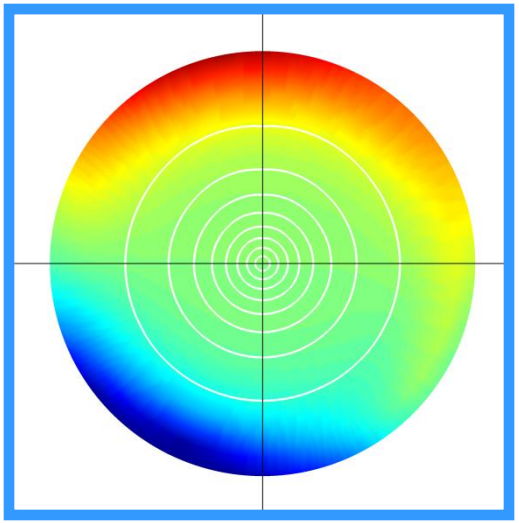
<u>Some other mapping functions:</u>

Chao, Lanyi, CfA, Ifadis, Davis, MTT, B&E, F&K, UNBabc, UNBab

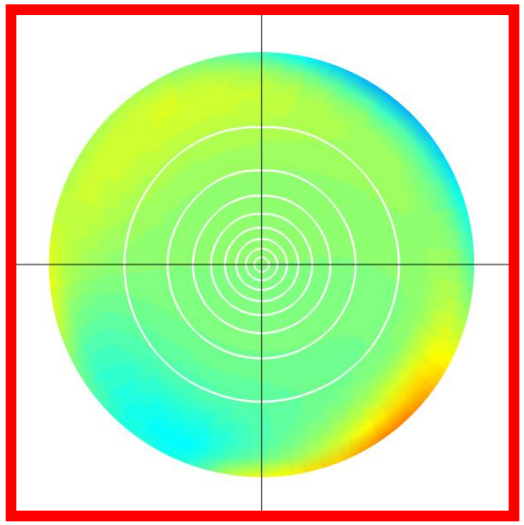
# Modeling azimuthal asymmetries

„classical“ gradients (IERS Conventions 2010)

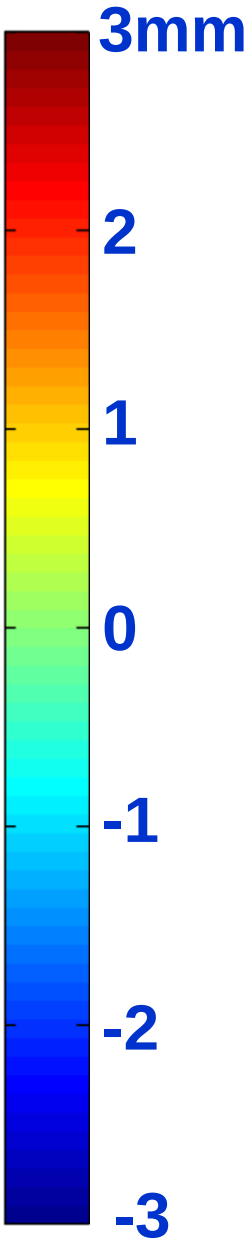
$$\Delta L_{asymm} = m f_g(e) \cdot [G_N \cdot \cos(\alpha) + G_E \cdot \sin(\alpha)]$$



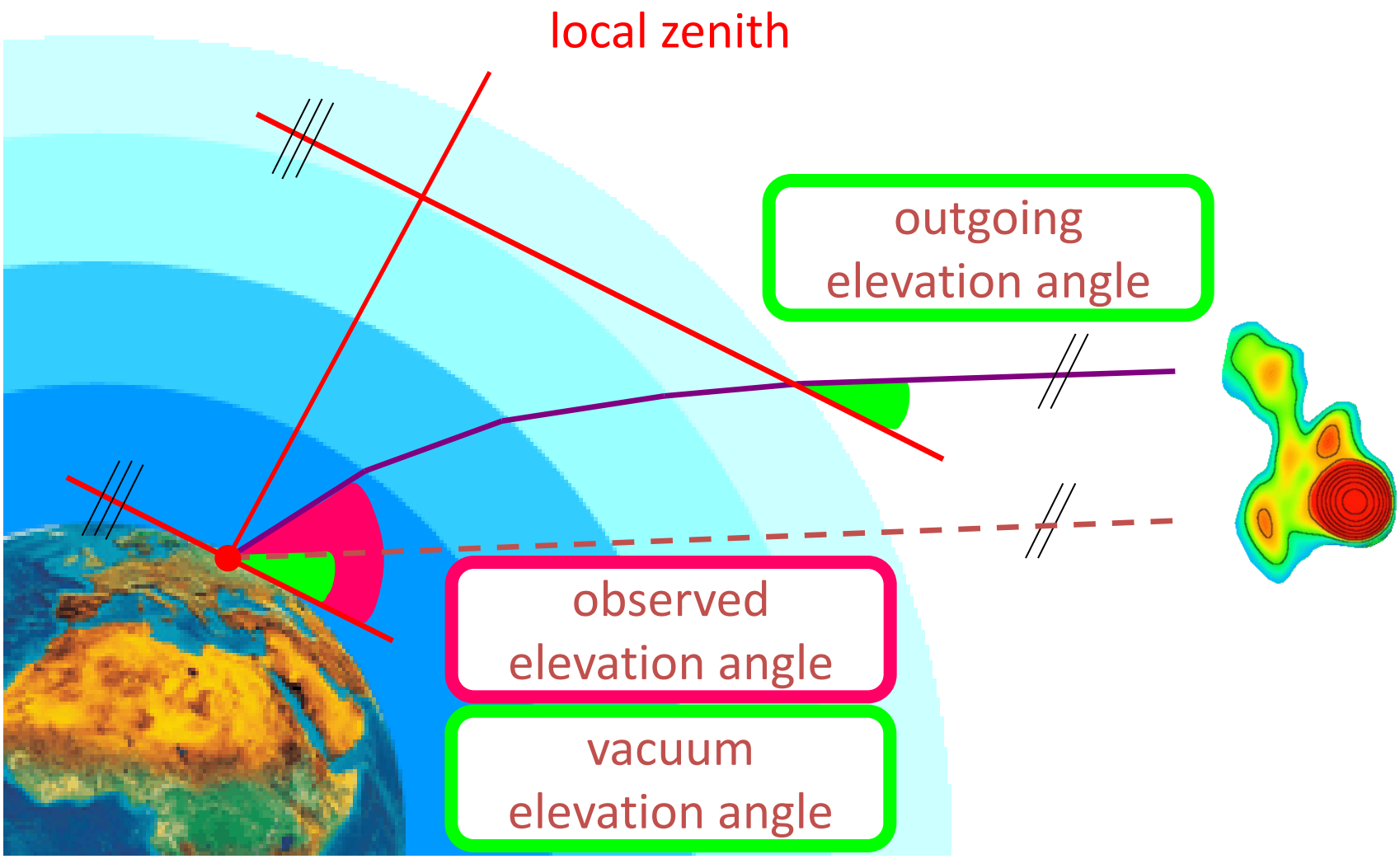
without modeling asymmetries



classical gradients applied



# Troposferin modellenmesinde ray-tracing



# Sayısal Atmosfer Modelleri (NWM)

- JMA-KARAT
- HIRLAM
- ECMWF

| NWM | Modellerin kapsama alanı | Konum çözünürlüğü | Zamansal çözünürlük (saat) | Her profildeki seviye yüzeyleri sayısı |
|---|---|---|---|---|
| JMA-KARAT | Japan | 0.1° | 3 | 21 |
| HIRLAM | Europe | 0.2° | 3 | 40 |
| ECMWF | Global | 0.25° | 6 | 21 |

# Troposferin modellenmesinde ray-tracing (p,e,T)

**inverse compressibility factors by adjustment to thermodynamic data (Owens, 1967)**

$$Z_d^{-1} = 1 + p_d[57.97 \cdot 10^{-8}(1 + \frac{0.52}{T}) - 9.4611 \cdot 10^{-4} \frac{t}{T^2}]$$

$$Z_w^{-1} = 1 + 1650 \frac{e}{T^3}[1 - 0.01317t + 1.75 \cdot 10^{-4} t^2 + 1.44 \cdot 10^{-6} t^3]$$

**Densities of dry air and water vapor**

$$\rho_d = p_d \frac{m_d}{R} \frac{1}{T} Z_d^{-1}$$

$$\rho_w = e \frac{m_w}{R} \frac{1}{T} Z_w^{-1}$$

**Total density**

$$\rho = \rho_d + \rho_w$$

**Hydrostatic and wet refractivities**

$$N_h = k_1 \frac{R}{m_d} \rho$$

$$N_w = (k_2' \frac{e}{T} + k_3 \frac{e}{T^2}) Z_w^{-1}$$

**Troposphere delay along signal path, s**

$$\Delta\tau_{trop} = 10^{-6} \int_0^{H_{trop}} [N_h(s) + N_w(s)] ds$$

$$\Delta\tau_{trop} = 10^{-6} \sum s_i (N_{hi} + N_{wi})$$

R: universal gas constant

$p_d$: partial pressure of dry air

e: water vapor pressure

t, T: temperature in Celsius and Kelvin

$m_{d,w}$: molar masses of dry air and water vapor

$k_1, k_2, k_3, k_2'$: emprical coefficients by Bevis et al., 1994; Rüeger, 2002.

# Troposferin modellenmesinde ray-tracing ($N_{hi}$, $N_{wi}$, $s_i$, $\theta_i$, $\varepsilon_i$)

$$s_i = -r_i \sin\theta_i + \sqrt{r_{i+1}^2 - r_i^2 \cos^2\theta_i} \quad ; \quad r_i = r_0 + h_i$$

$$z_{i+1} = z_i + s_i \sin\varepsilon_i$$

$$y_{i+1} = y_i + s_i \cos\varepsilon_i$$

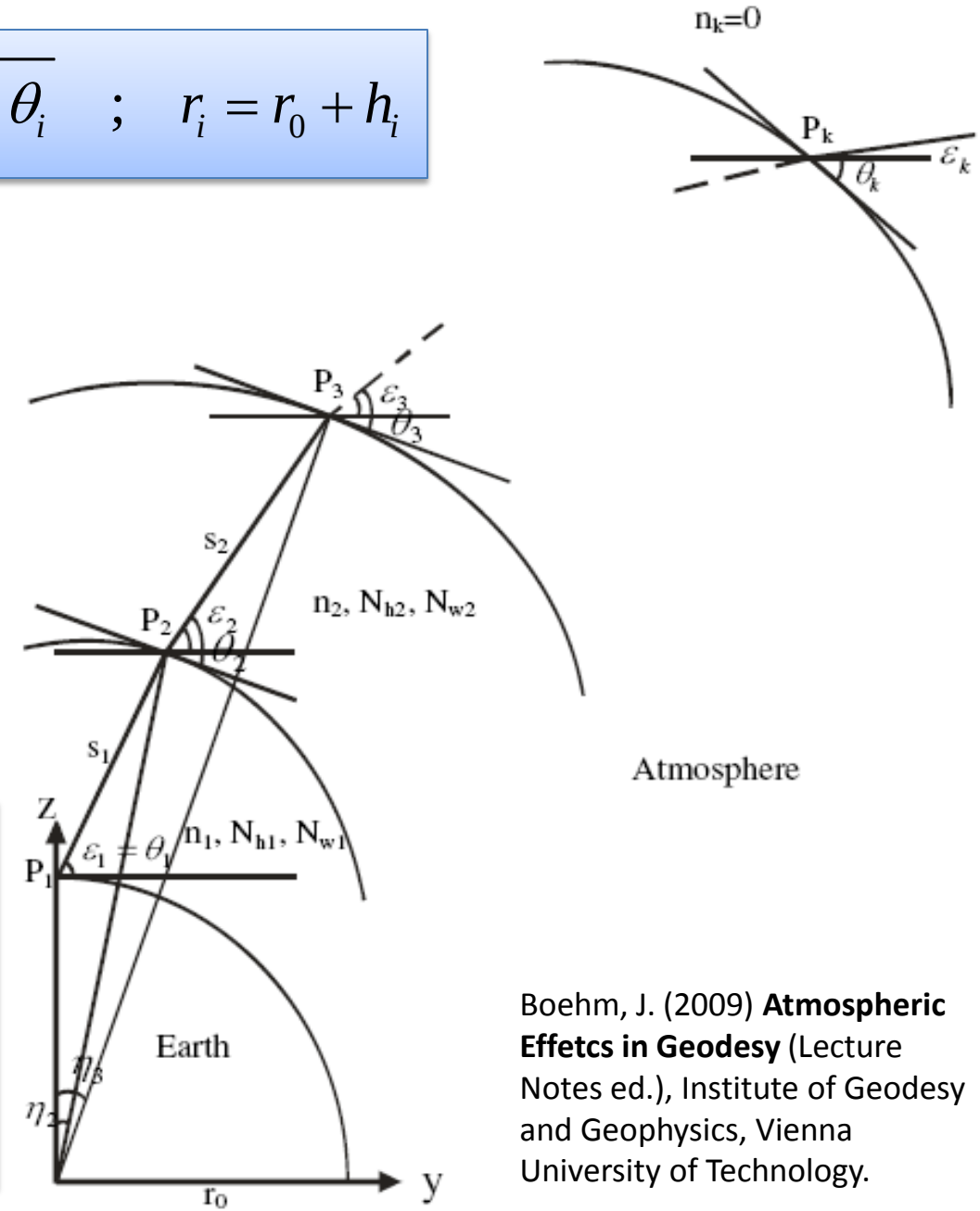
$$\eta_{i+1} = \arctan(y_{i+1} / z_{i+1})$$

$$\delta_{i+1} = \eta_{i+1} - \eta_i$$

$$n_i = 1 + (N_{hi} + N_{wi})10^{-6}$$

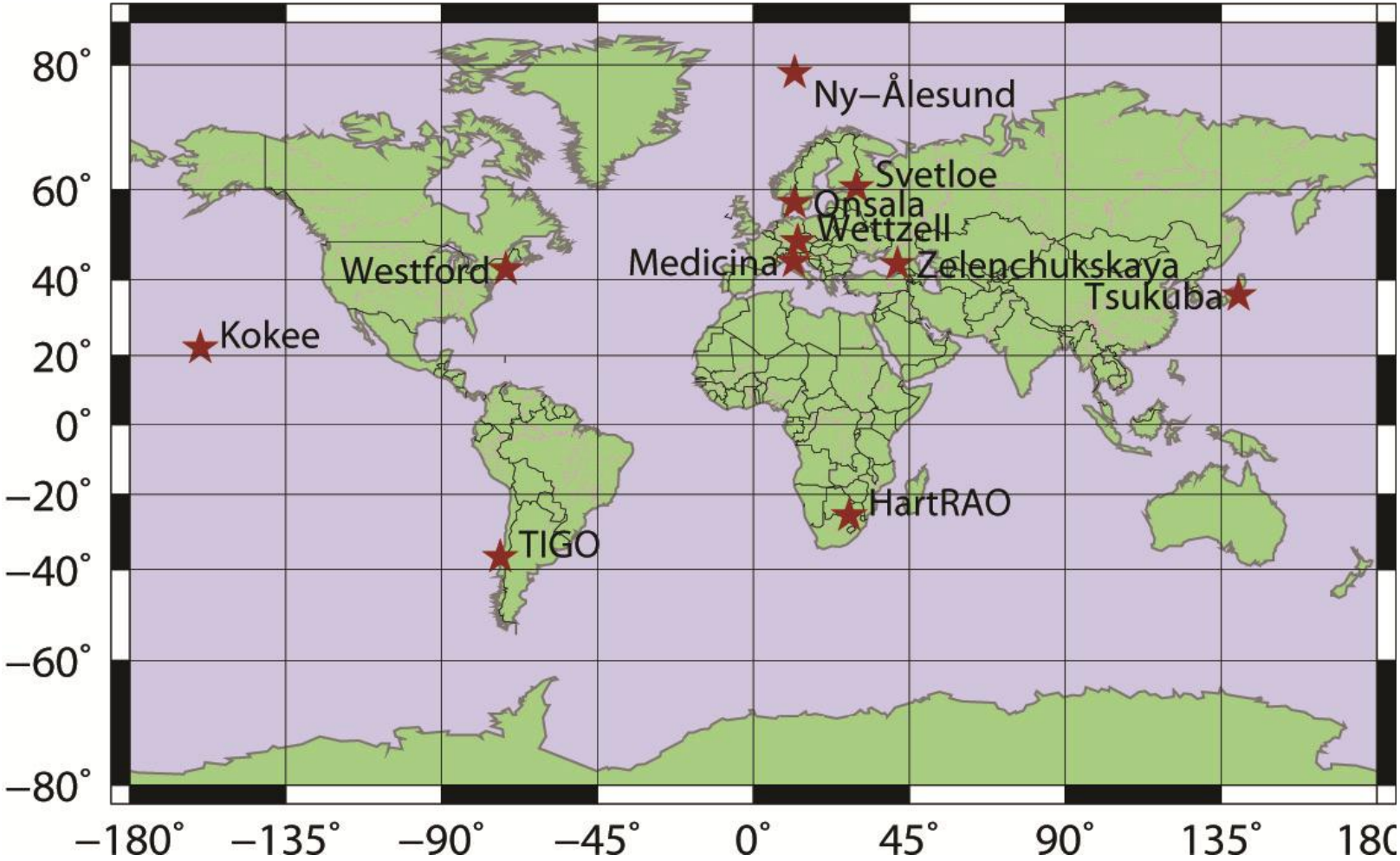
$$\theta_{i+1} = \arccos\left(\frac{n_i}{n_{i+1}} \cos(\theta_i + \delta_{i+1})\right)$$

$$\varepsilon_{i+1} = \theta_{i+1} - \eta_{i+1}$$




Boehm, J. (2009) **Atmospheric Effetcs in Geodesy** (Lecture Notes ed.), Institute of Geodesy and Geophysics, Vienna University of Technology.

# CONT08 ortak yerleşkeleri




**İlk ölcü: Salı Agustos 12, 2008 @ 00:00:00 UT**

**Son ölcü: Salı Agustos 26, 2008 @ 23:59:59 UT**

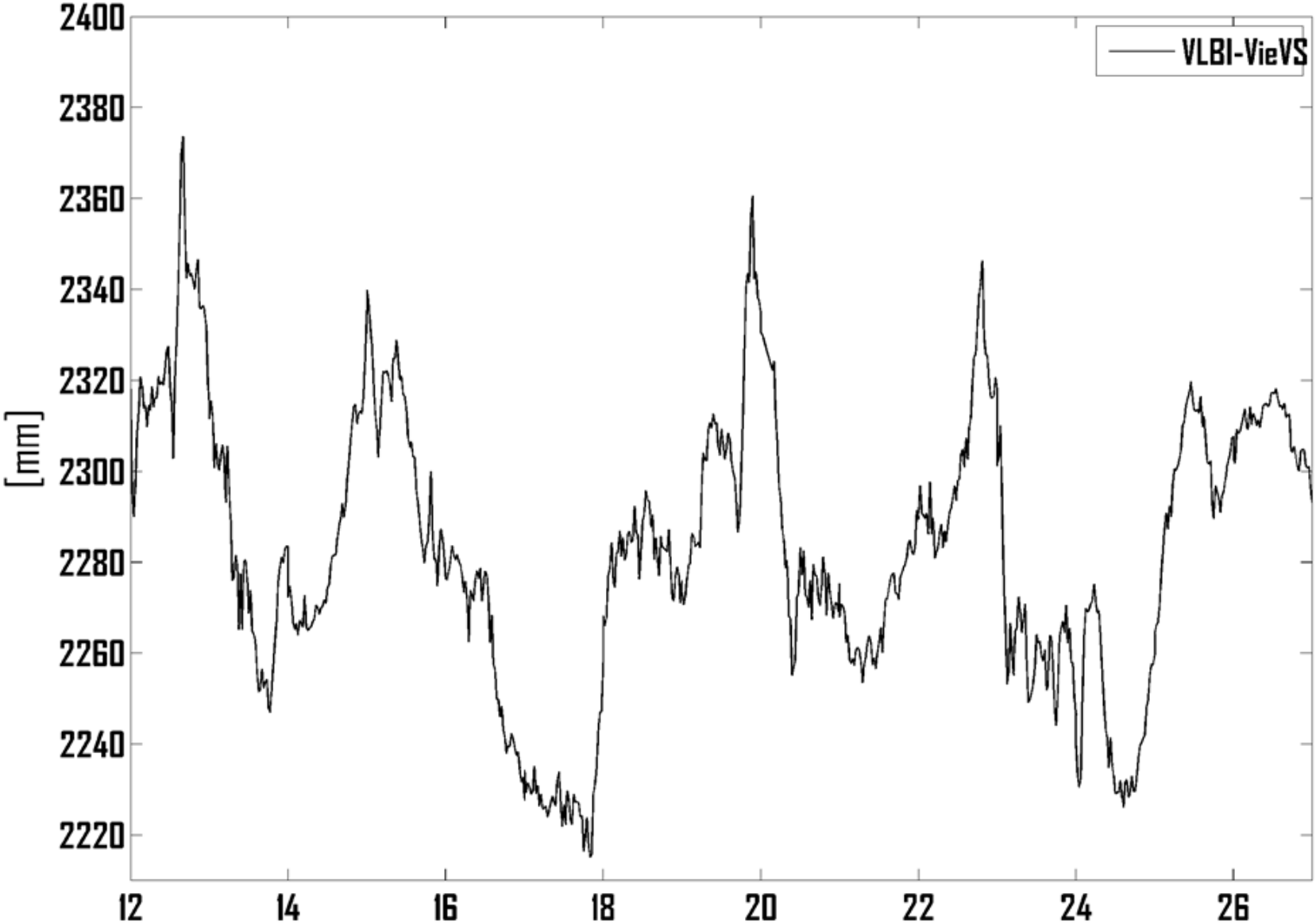
# Uyuşum ölçütleri

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

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

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

# WETTZELL (ZTD)

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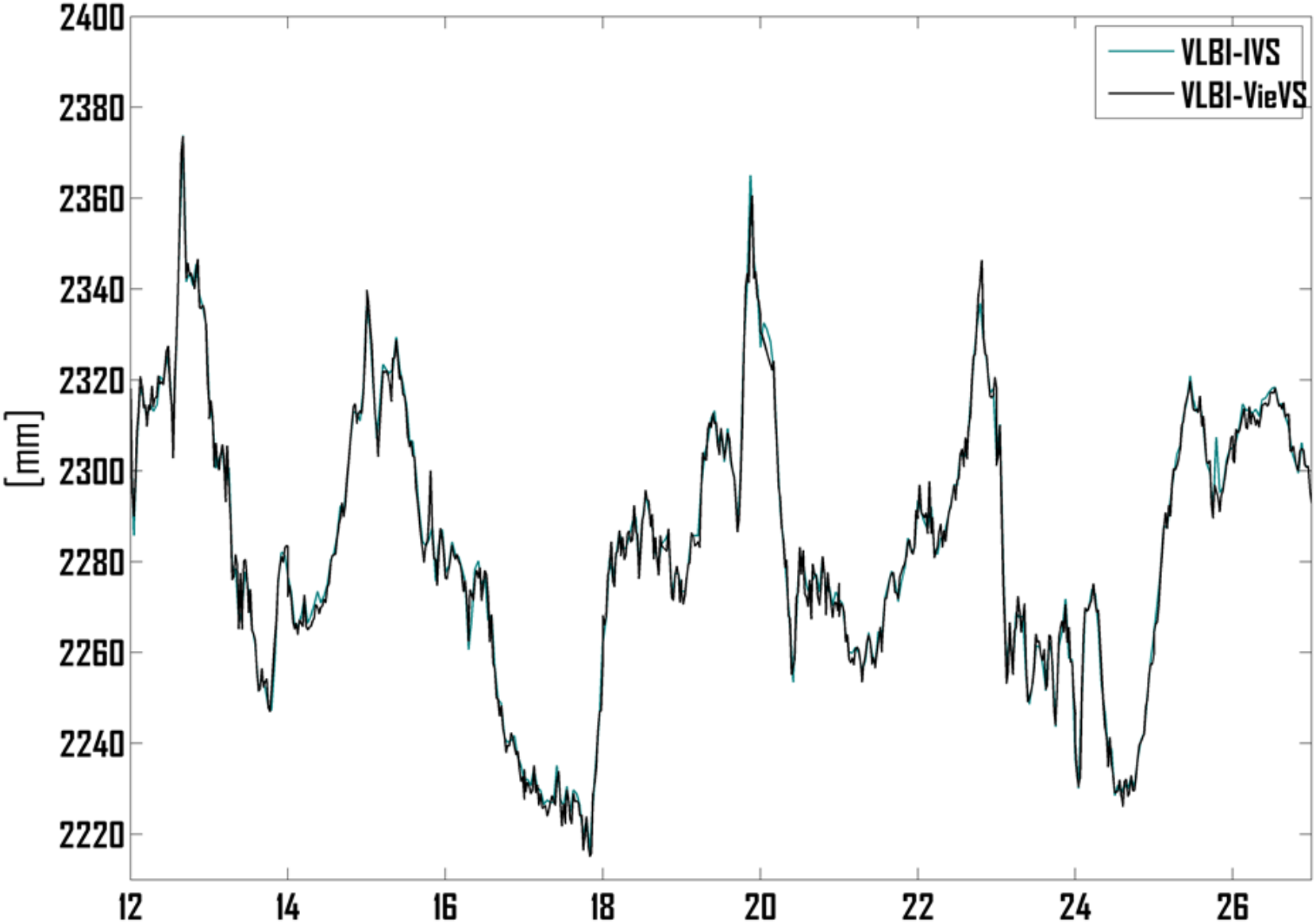


August 2008

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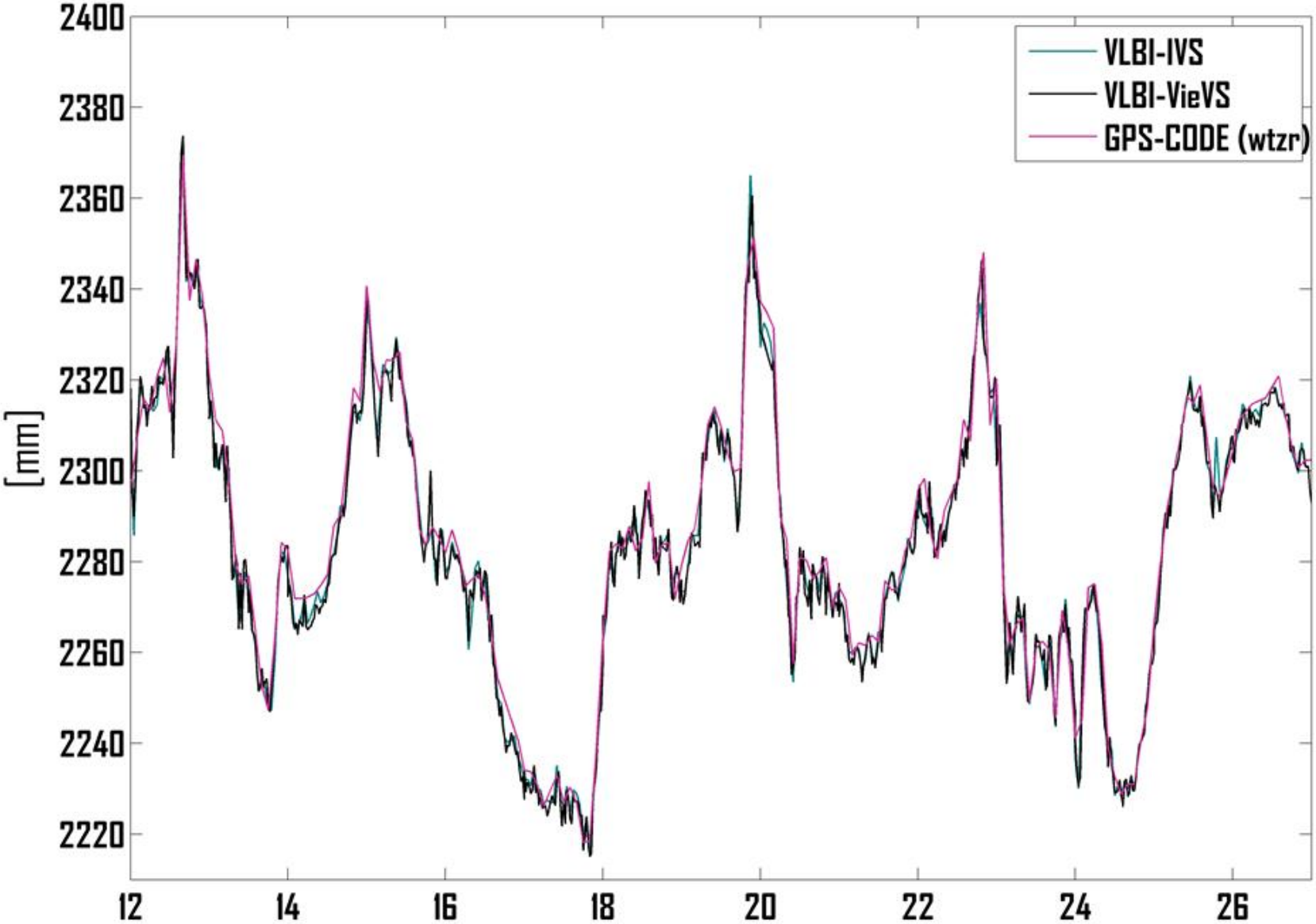


August 2008

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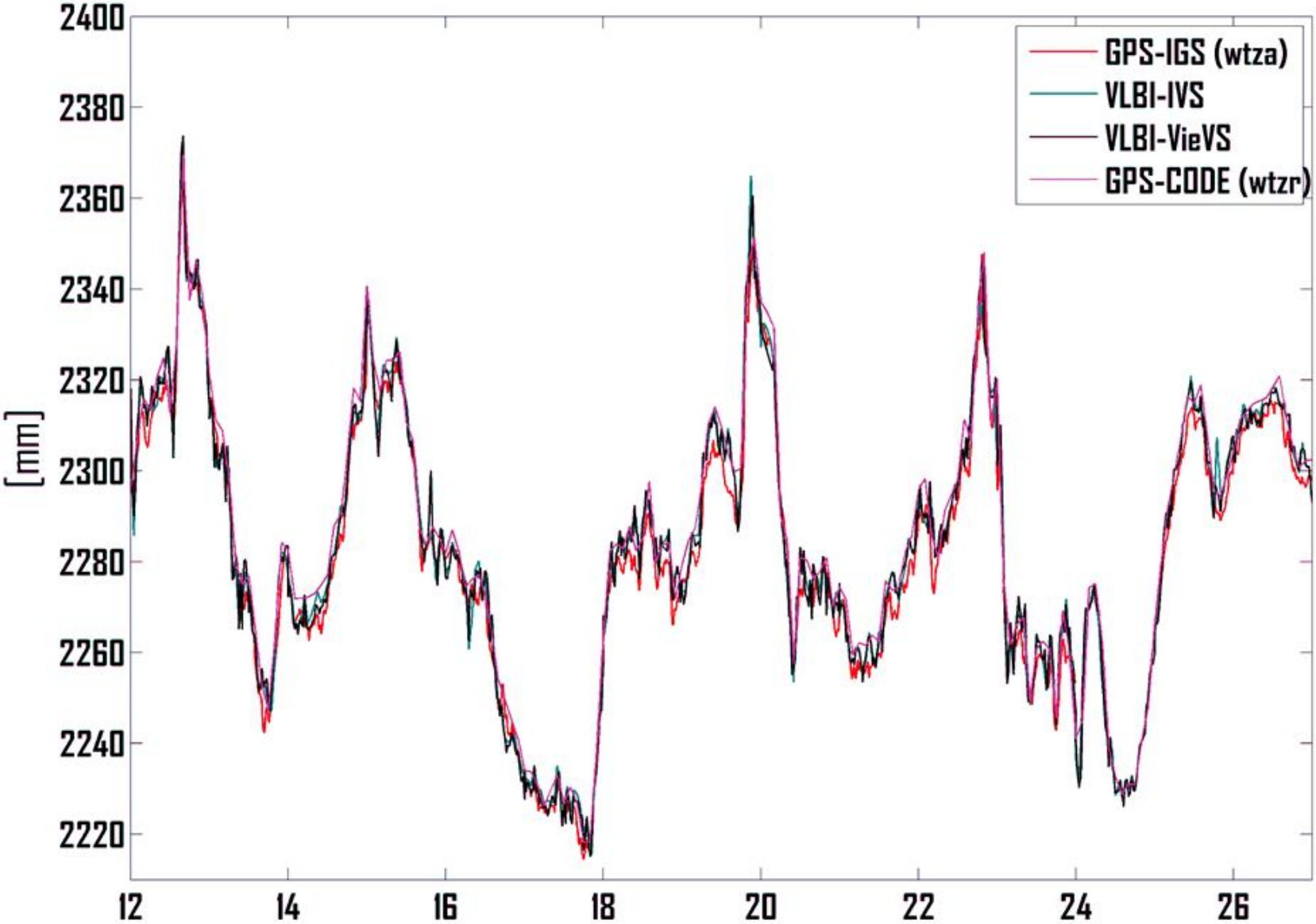


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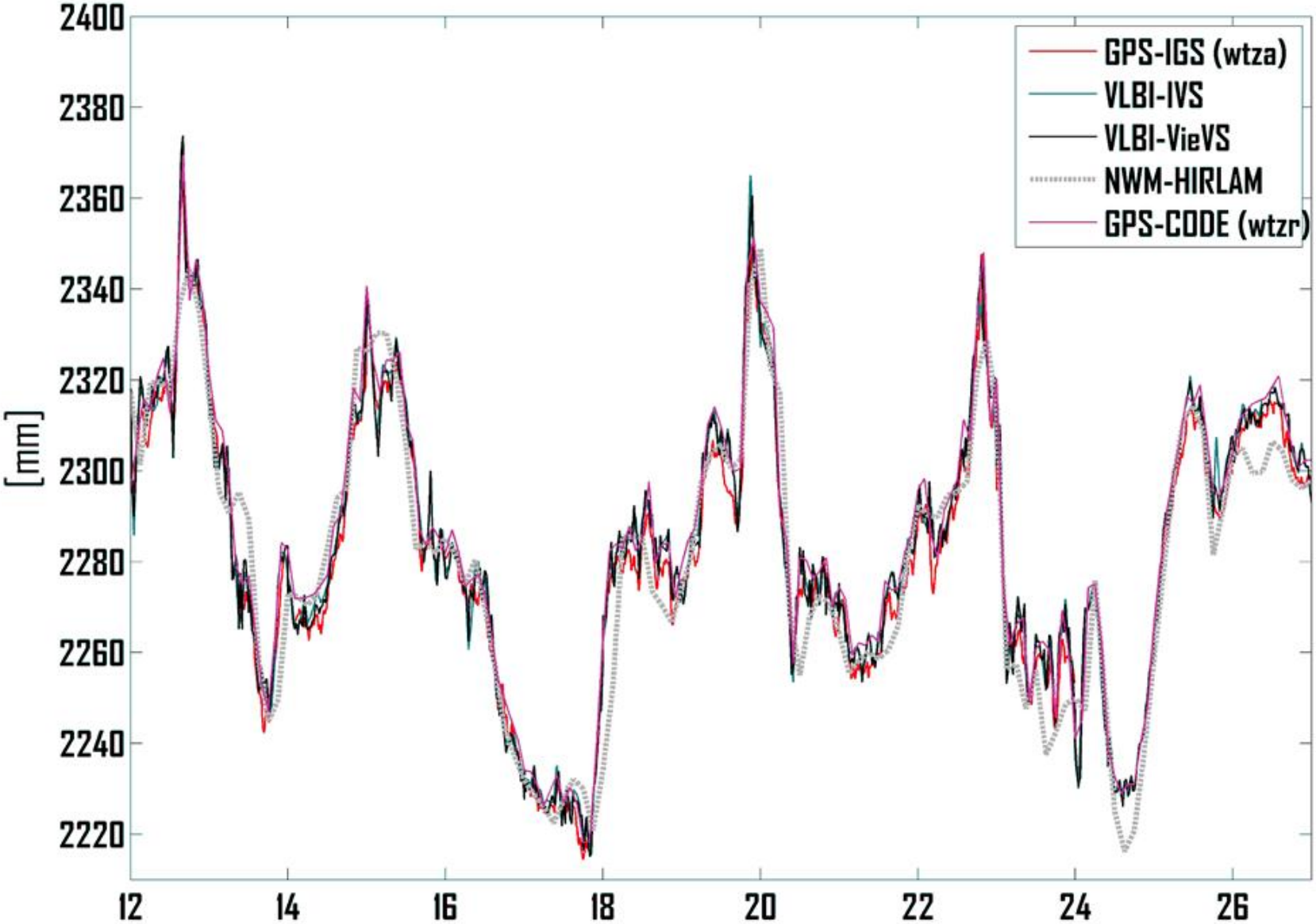


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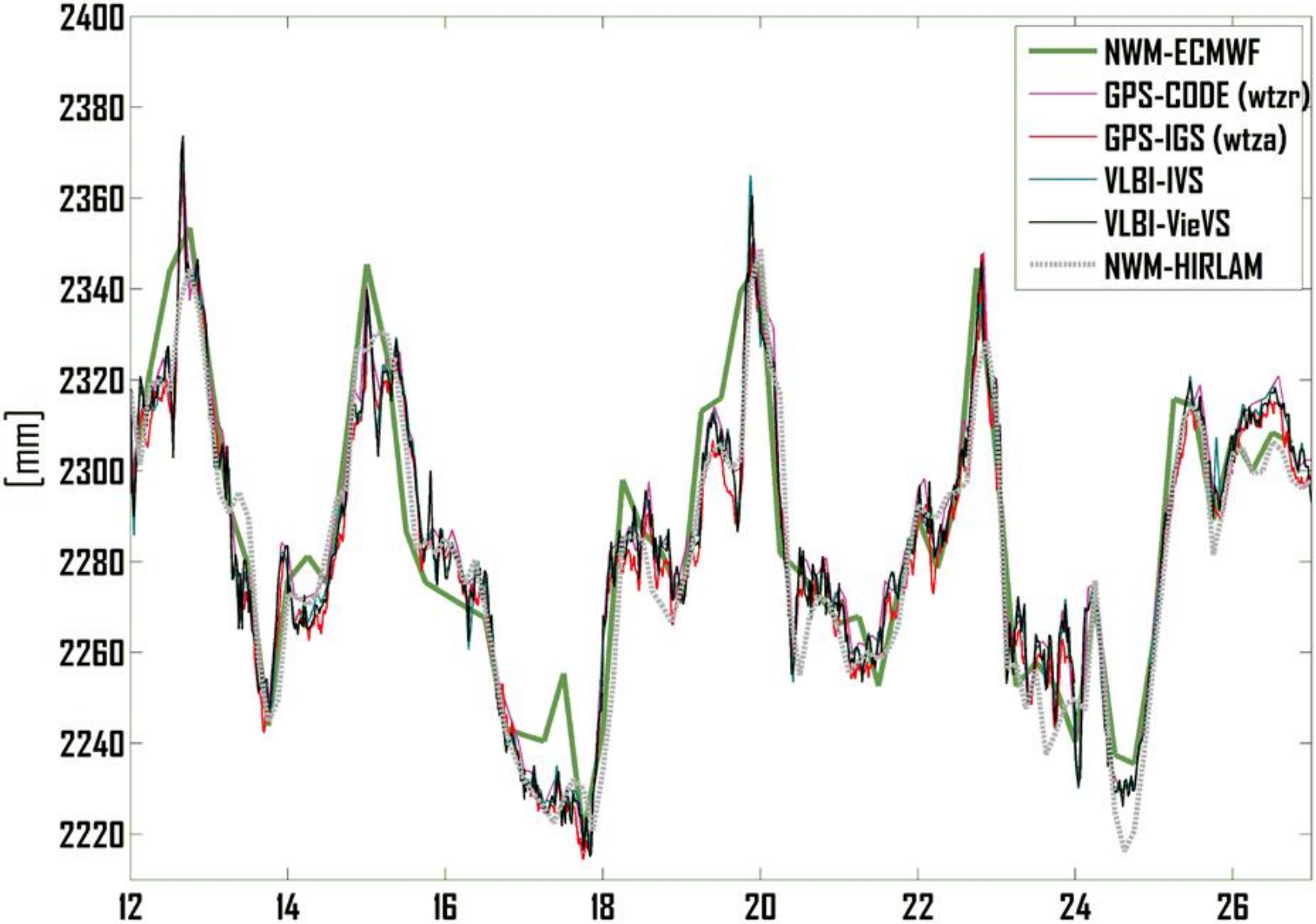


August 2008

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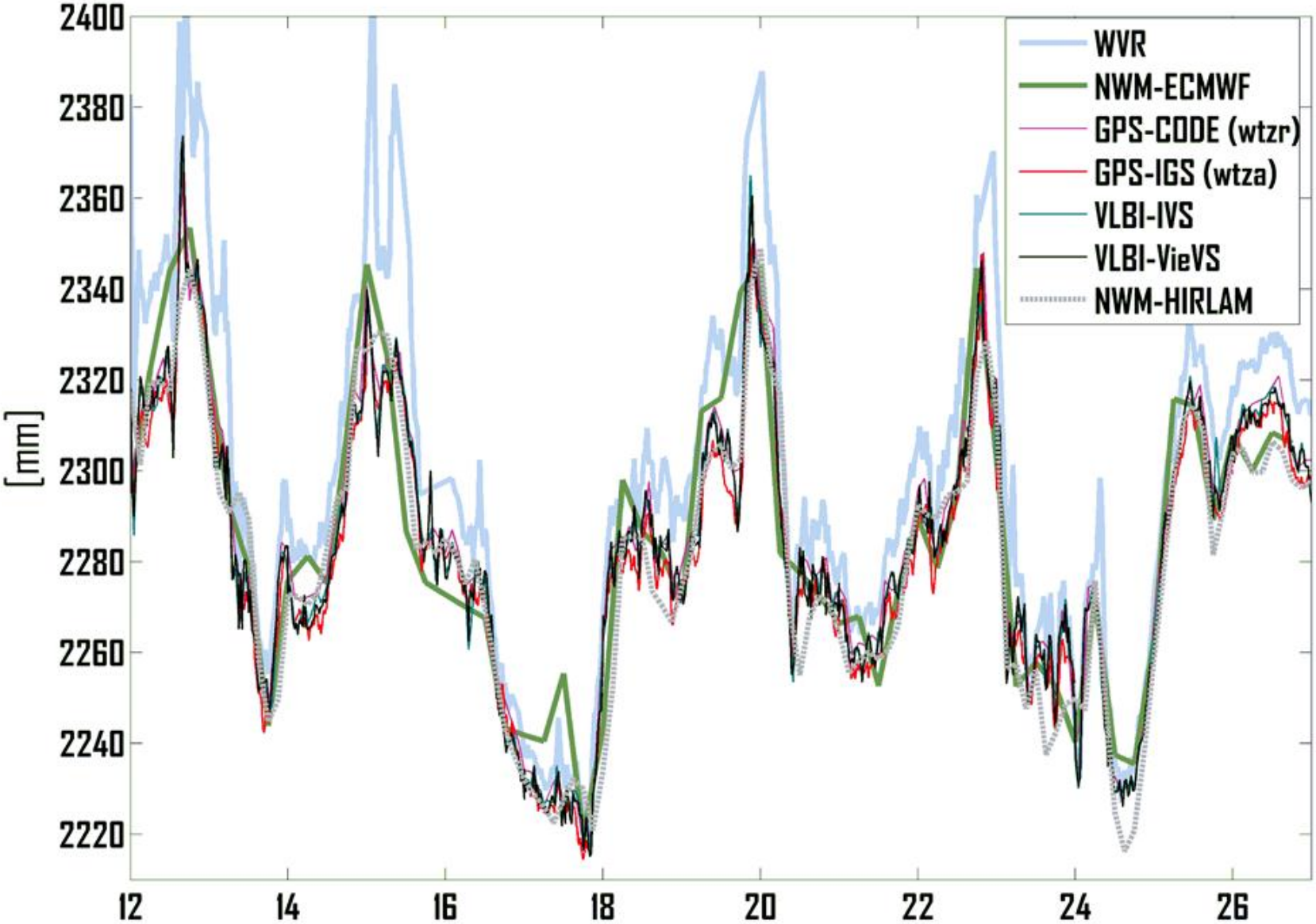


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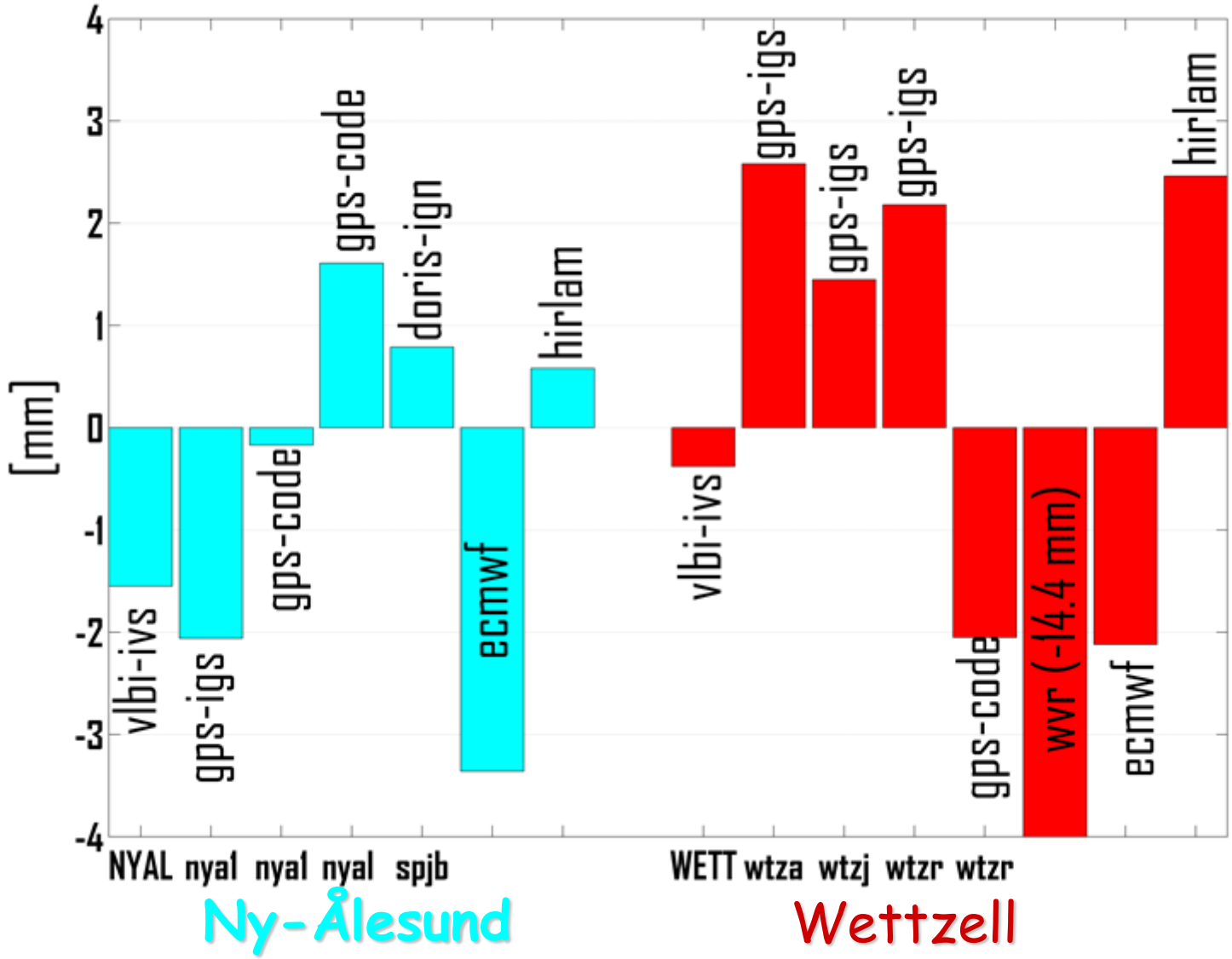
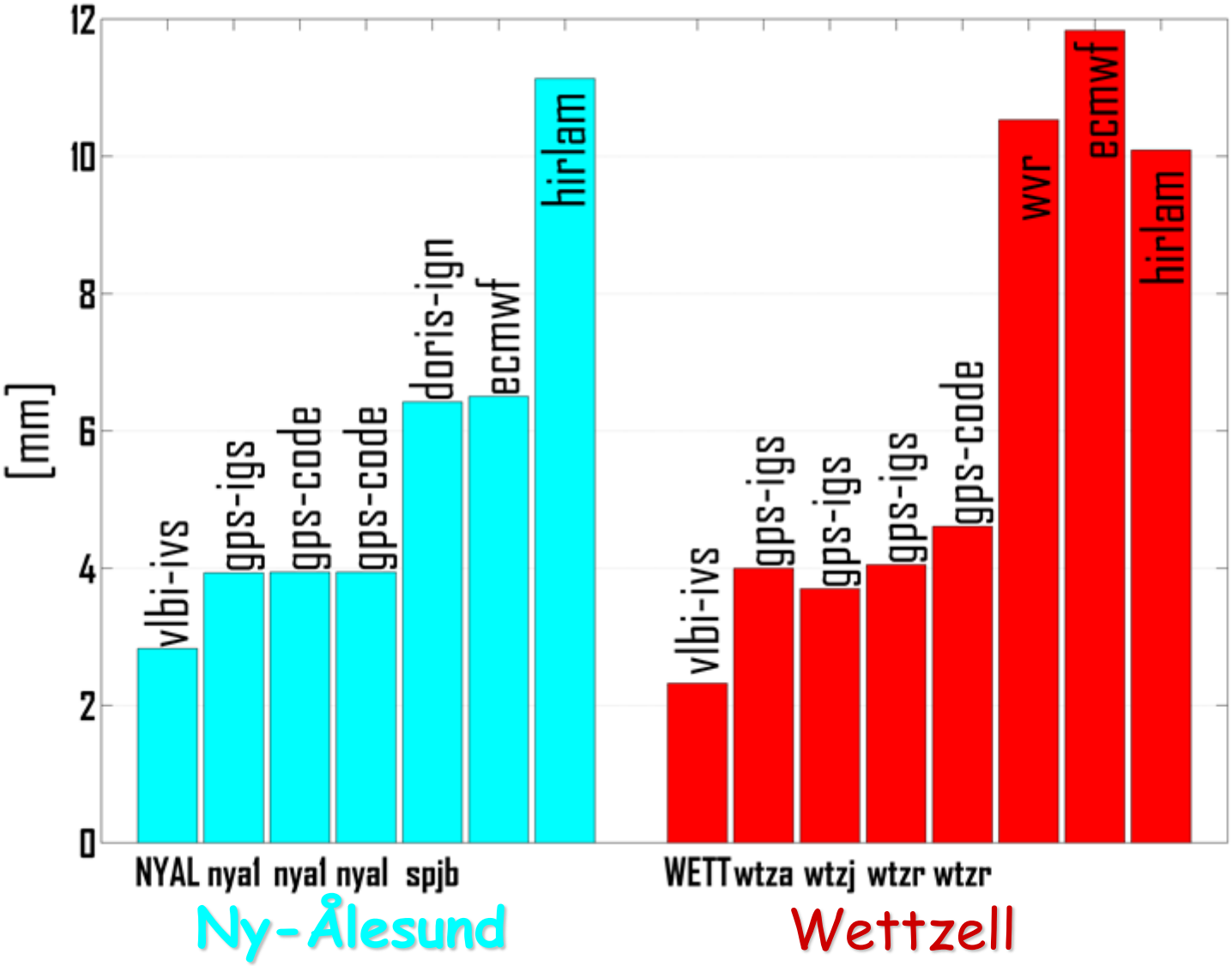
# ZTD - VieVS ve diğer çözümler arasındaki ofsetler



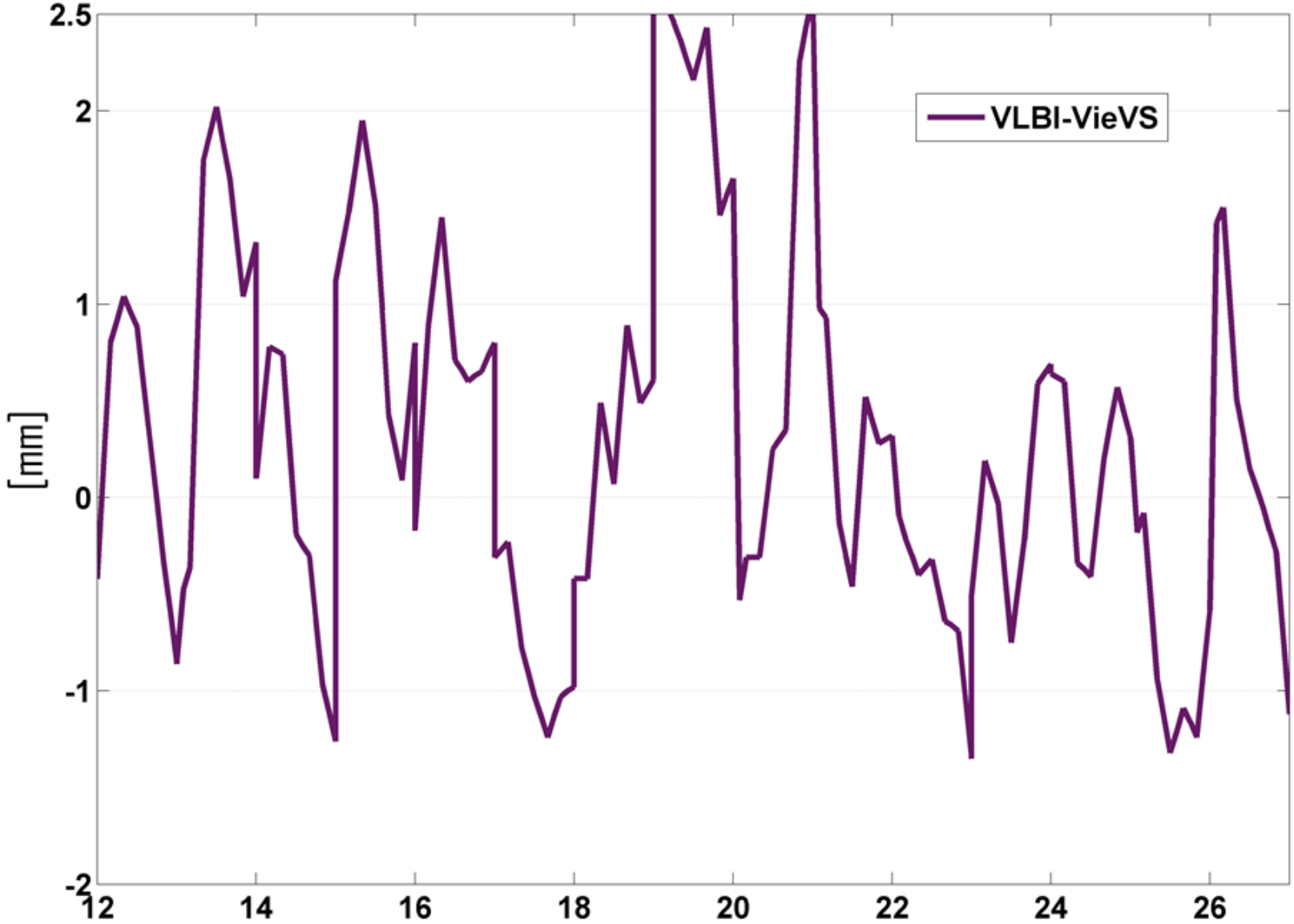

**solutions and stations at co-located sites**

# ZTD - VieVS ve diğer çözümler arasındaki standart sapmalar




**solutions and stations at co-located sites**

# TSUKUBA (Troposphere north gradients)




August 2008

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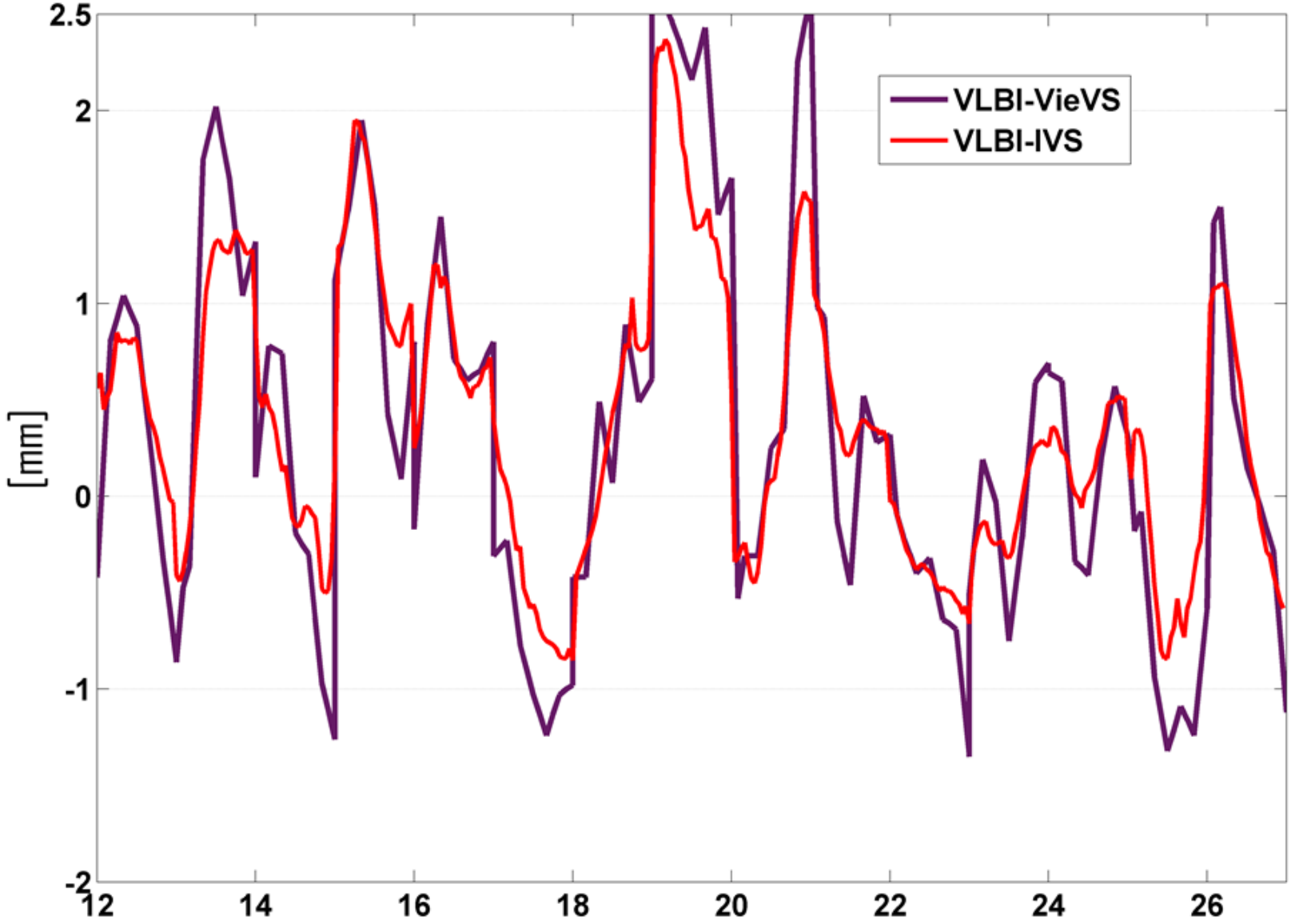


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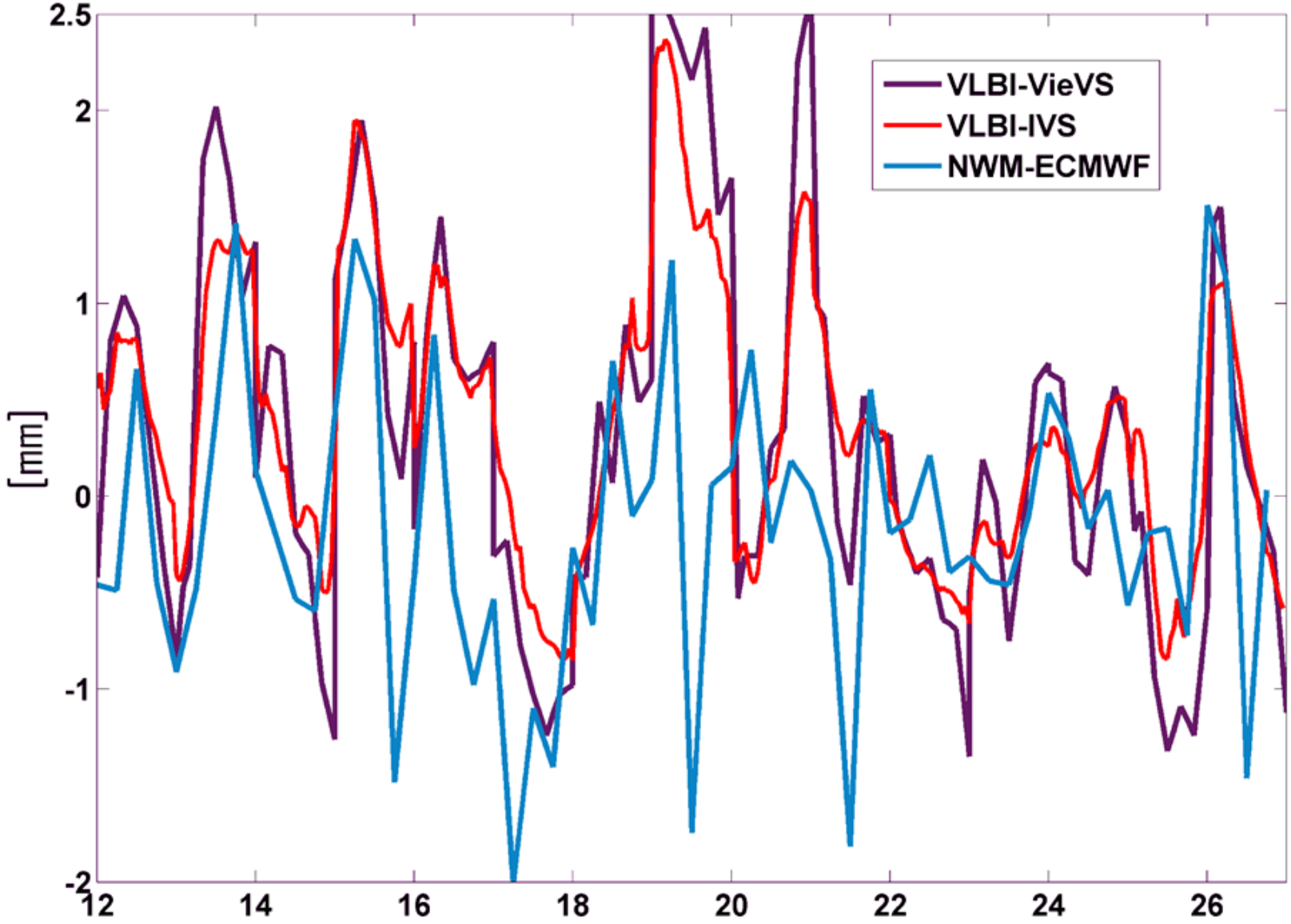


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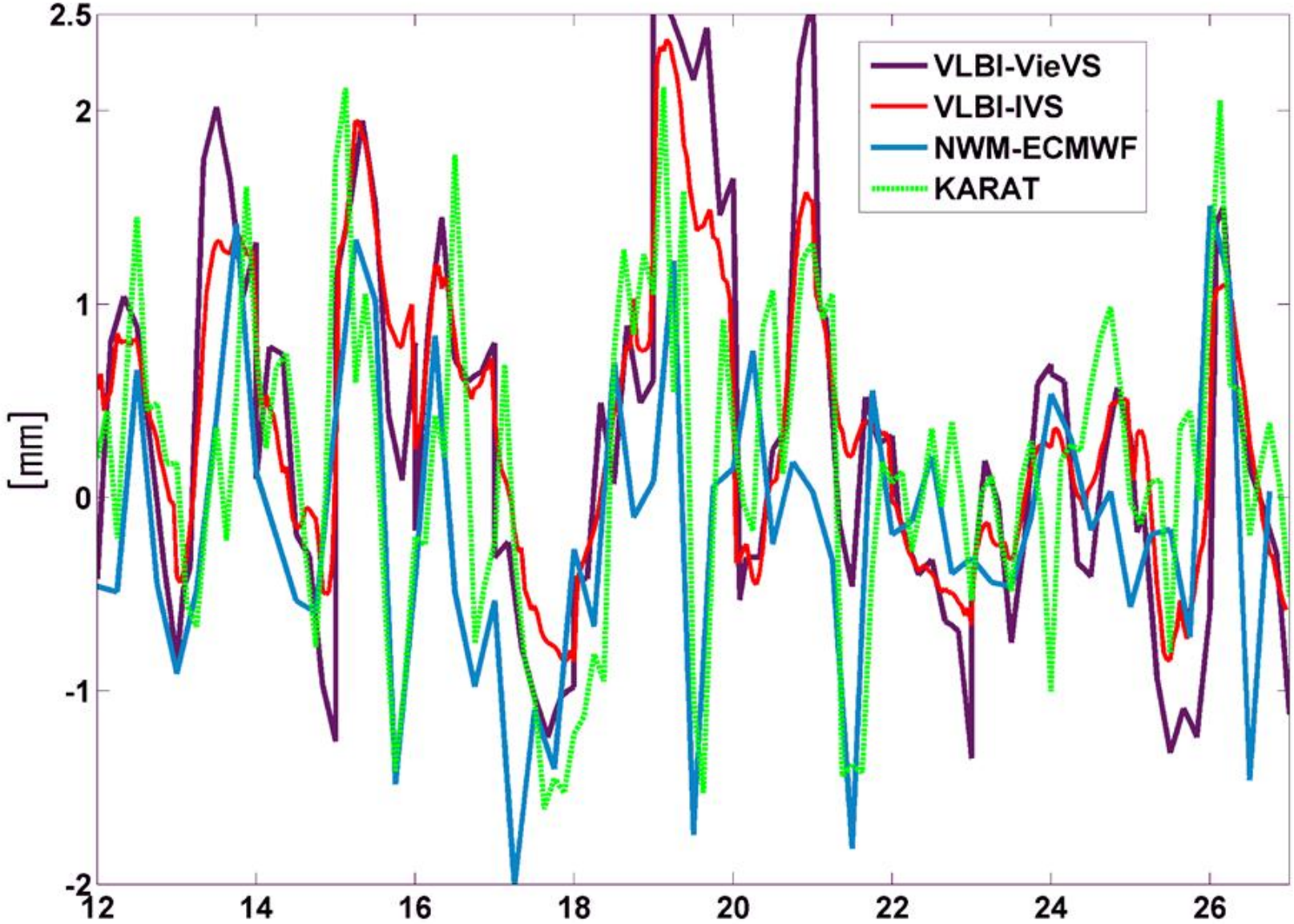


**August 2008**

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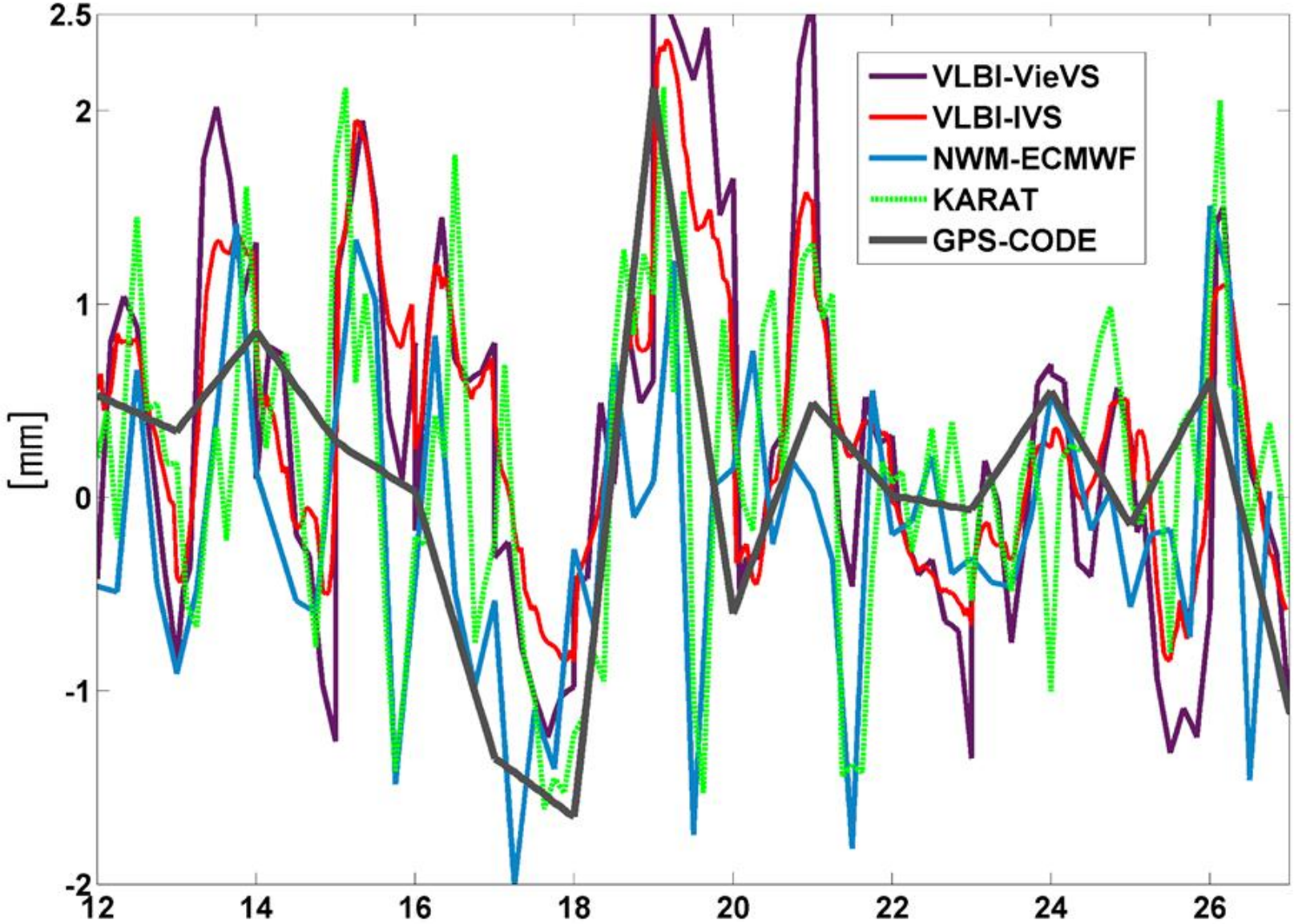
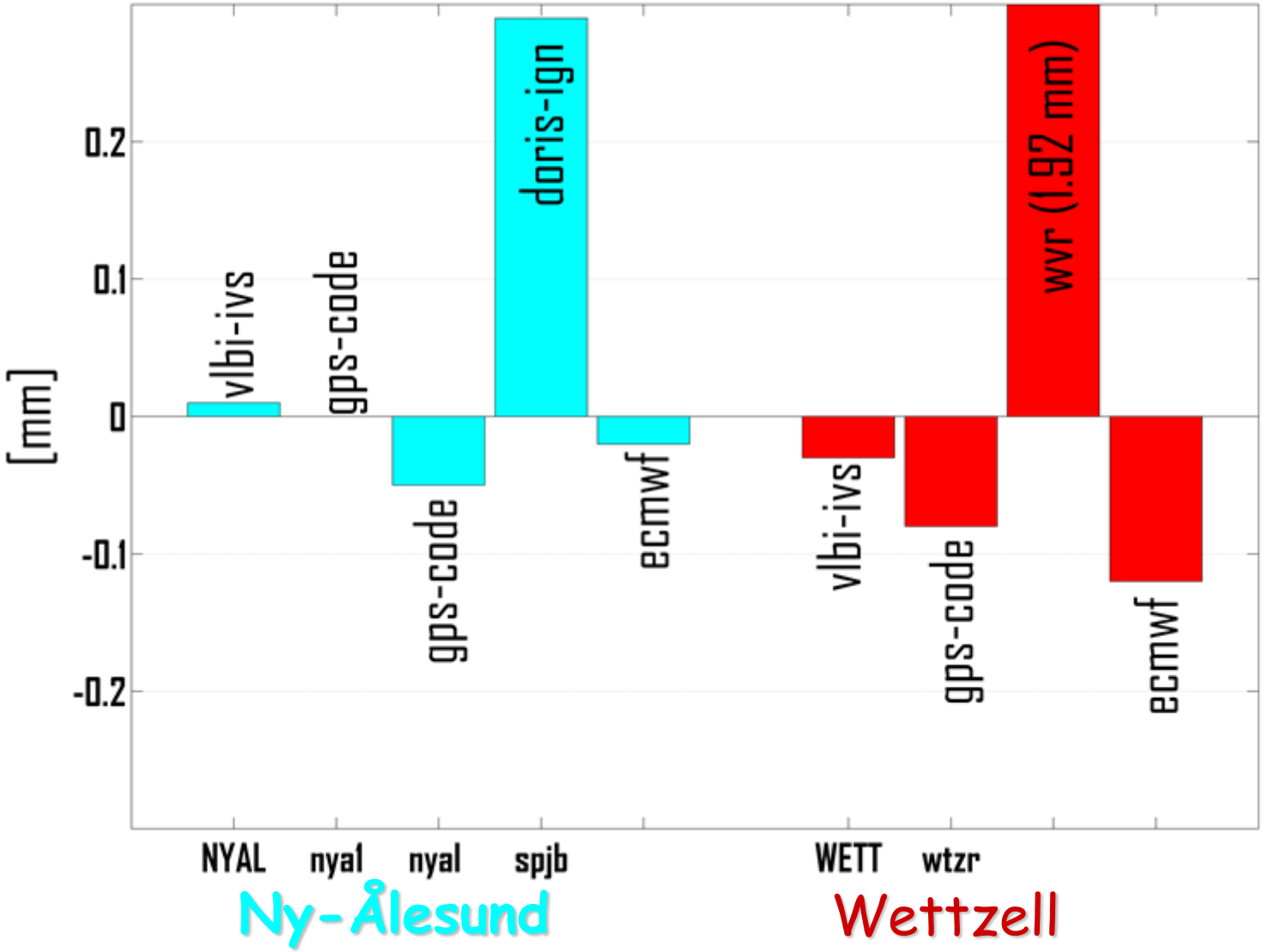



**August 2008**

# Troposfer kuzey gradyanları

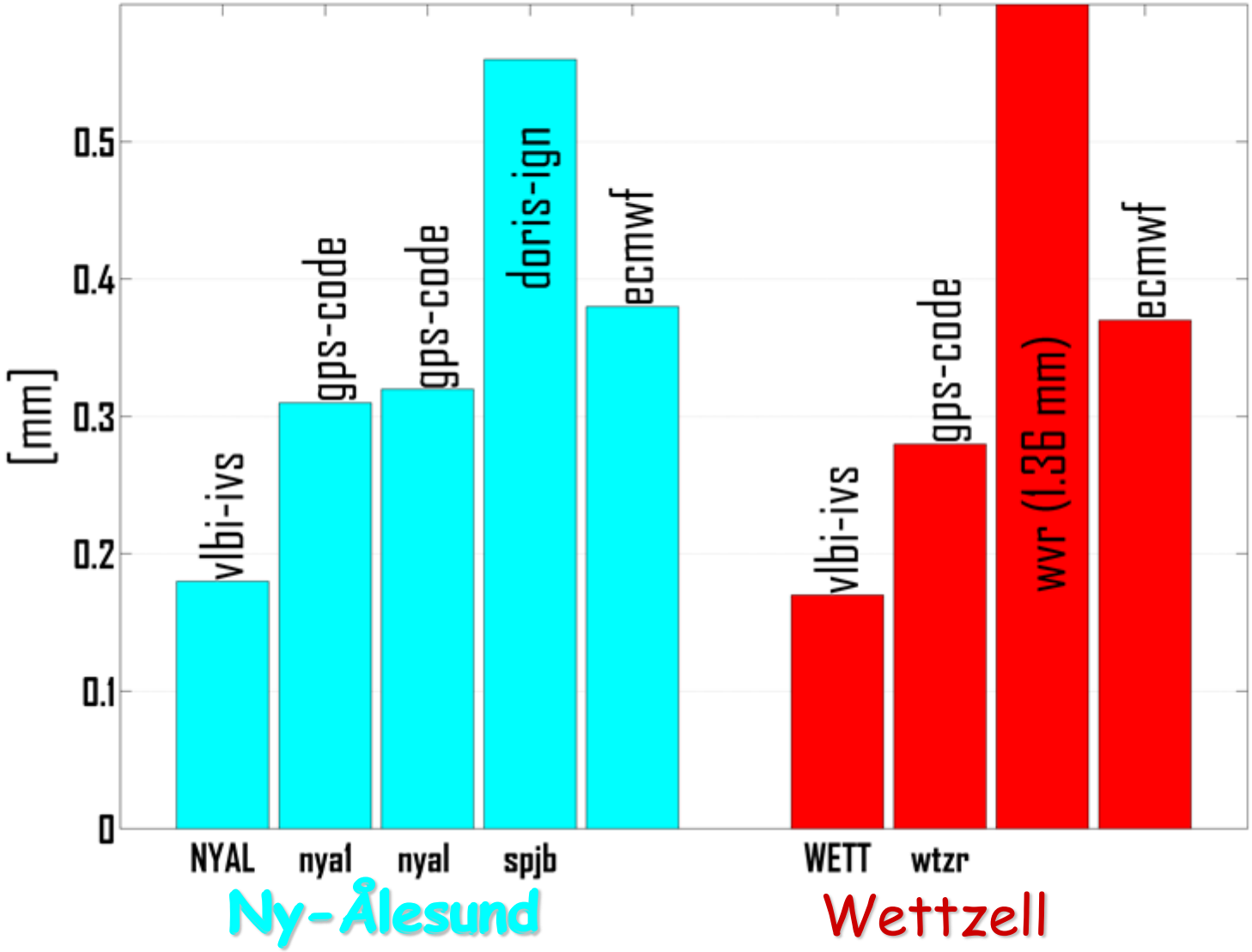
## VieVS ve diğer çözümler arasındaki ofsetler




**solutions and stations at co-located sites**

# Troposfer kuzey gradyanları

## VieVS ve diğer çözümler arasındaki standart sapmalar




**solutions and stations at co-located sites**

# Sonuçlar

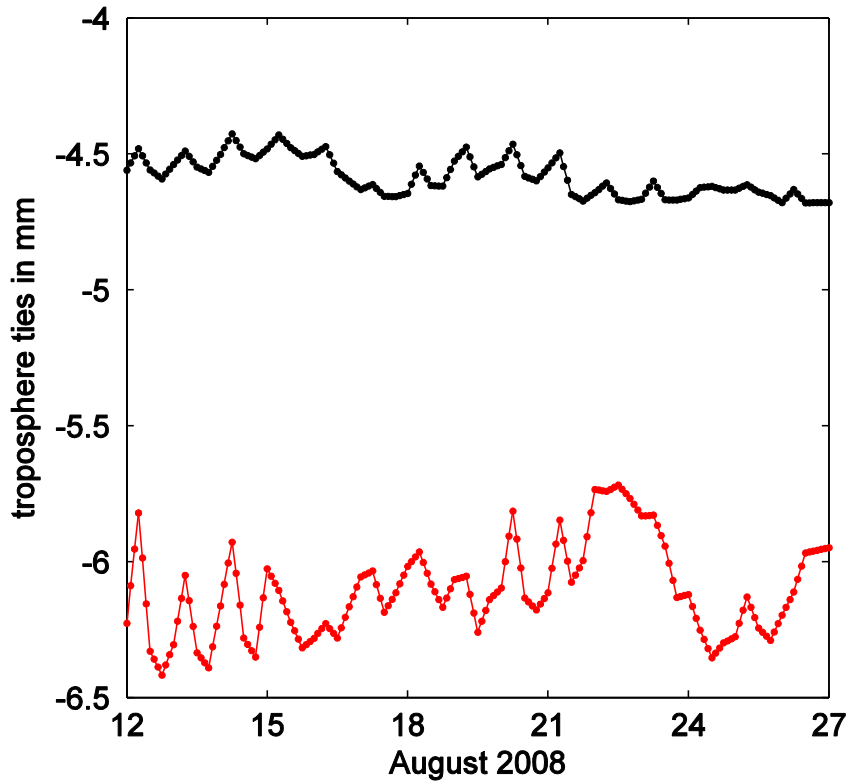
- Uzay Jeodezi teknikleri (VLBI, GPS, DORIS) ölçülerinin analizlerinden (VieVS, IVS, IGN, IGS, CODE) elde edilen zenit sinyal gecikmeleri genellikle 0.5-1 cm aralığında uyuşum göstermektedirler.
- Uzay Jeodezi tekniklerinin zenit sinyal gecikmeleri ile diğer teknikler/modellerden elde edilenler (WVR, ECMWF, HIRLAM, JMA-KARAT) arasındaki farklar 2 cm nin altındadır. Korelasyon katsayıları genellikle > 0.9 (sunumda gösterilmedi).
- Zenit sinyal gecikmelerinde ve gradyanlarda en iyi uyum teknik-içi (intra-teknik) analizlerden elde edilmiştir (VieVS ve IVS, CODE ve IGS).
- Teknikler-arası (inter-teknik) hem zenit sinyal gecikmelerinde hem de gradyanlarda en iyi uyum VLBI ve GPS arasındadır.
- Tekniklerden elde edilen gradyanlar arasındaki korelasyonlar 0.6'nın altında kalmıştır (sunumda gösterilmedi).

**Uluslararası servislere ölçü dosyalarını sagladıkları için teşekkür ederiz !**

Katılımınız ve dinlediğiniz için teşekkür ederiz !

# Troposphere ties

- The reference height were selected as the VLBI reference points heights.
- The troposphere ZTD ties were calculated at each common epoch.




Troposphere ties between the GPS antenna TSKB and the VLBI antenna TSUKUB32 during IVS-CONT08, calculated for all common epochs. Red and black dotted lines illustrate total and hydrostatic ties, respectively.

# Calculation of troposphere ties (Brunner and Rüeger, 1992)

$$p = p_0 (1 - \frac{\gamma (H - H_0)}{T_0})^{\frac{g}{\gamma R_L}}$$

$$\Delta ZHD = \frac{0.0022768 (p - p_0)}{1 - 0.00266 \cos(2\varphi_0) - 0.28 \times 10^{-6} H_0}$$

$$\Delta ZWD = \frac{-2.789 e_0}{T_0^2} (\frac{5383}{T_0} - 0.7803) \gamma (H - H_0)$$

*$H_0$ : Reference height (VLBI reference point height),*
*$e_0$, : Water vapor pressure (hPa) at the reference height,*
*$p_0$, : Total pressure (hPa) at the reference height,*
*$T_0$ : Temperature (Kelvin) at the reference height,*
*H and p : The height and total pressure at the co-located site,*
*$\gamma$ = -0.0065 K $m^{-1}$ (average temperature lapse rate),*
*$R_L$ = 287.058 $m^2$ $s^{-2}$ $K^{-1}$ (specific gas constant),*
*g = the gravity in m $s^{-2}$ ,*
*$\phi_0$ = latitude of the co-located site in degrees.*

# 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.