



EUREF 2018 Symposium
Amsterdam 30 May - 1 June, 2018

Report of the Troposphere Coordinator



R. Pacione

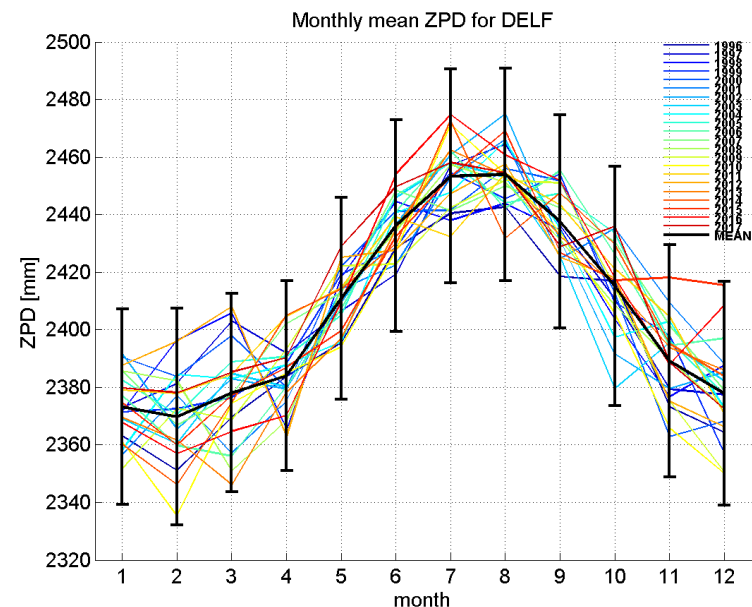
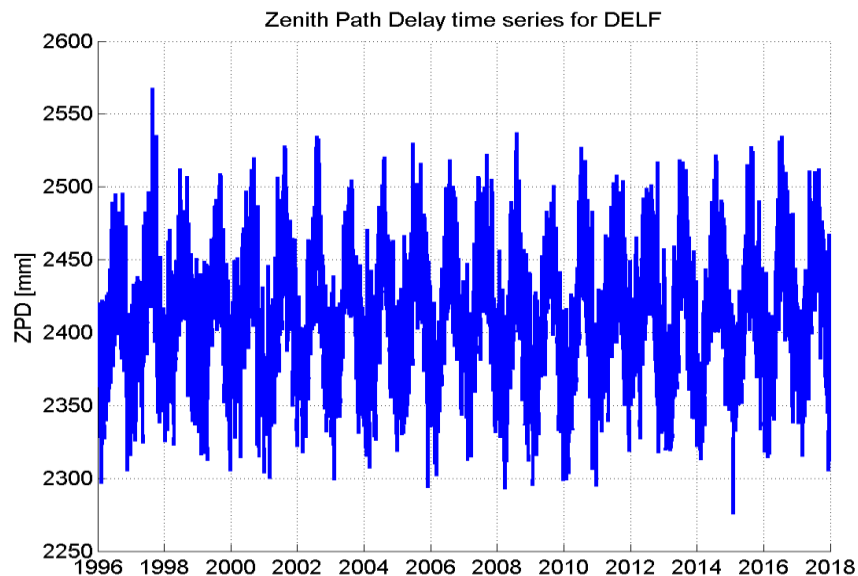
e-GEOS, ASI/CGS-Matera, Italy



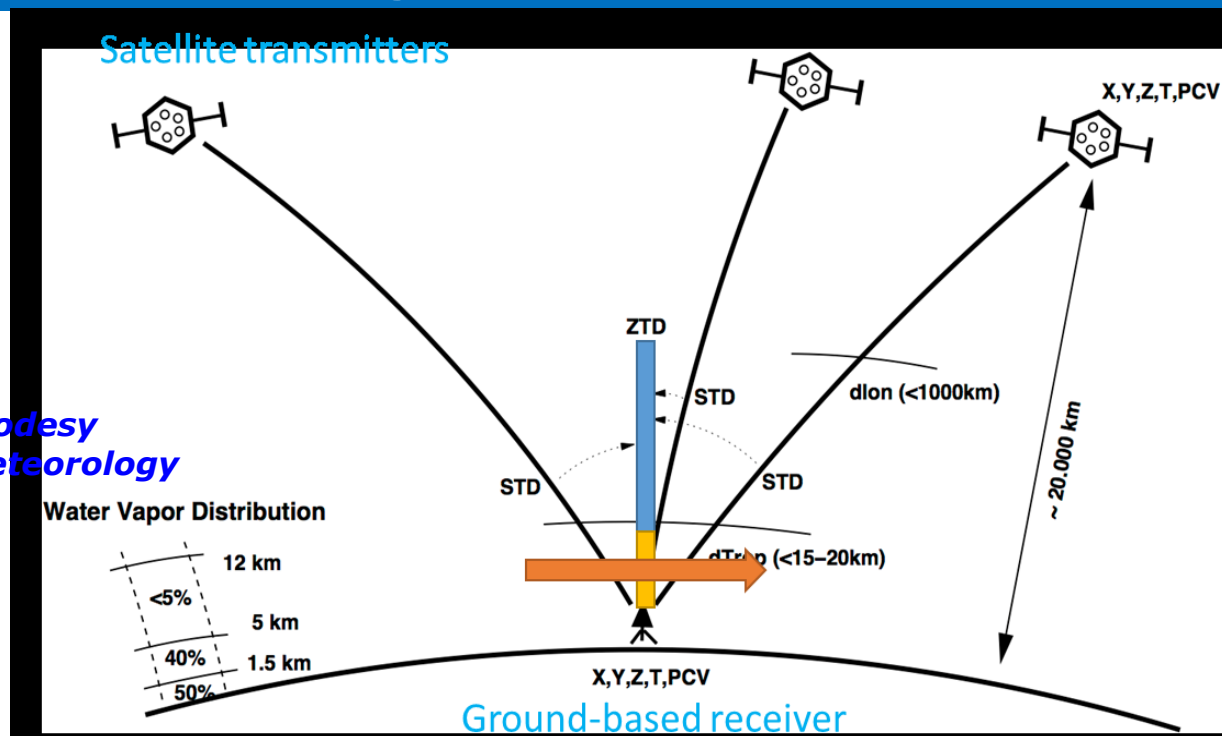
- Key Milestone in the EPN Tropospheric Products
- GNSS-Meteorology Concept
- EPN ZTD Time Series
 - 2nd EPN Reprocessing Campaign: EPN-Repro2 (1996-2014)
 - Operational Solution (2015-today)
- EPN ZTD data exploitation
- Summary and next steps

Key Milestone

- 2001: Special Project
- 2008: Routine Operation
- 2012: EPN-Repro1: 1996-2009
- 2014: Troposphere Analysis Coordinator moved from BKG to ASI/CGS
- 2017: EPN-Repro2: 1996-2014



GNSS-Meteorology Concept



Noise for Geodesy
Signal for Meteorology

Tropospheric delay

$$L_{rec}^{sat} = \rho_{rec}^{sat} + c \cdot (\delta t_{rec} - \delta t^{sat}) + \lambda \cdot N_{rec}^{sat} - d_{iono} + d_{tropo} + \varepsilon_{\phi}$$

$$d_{tropo}(\alpha, e) = \boxed{ZHD} \times m_h(e) + \boxed{ZWD} \times m_w(e) + [\boxed{G_N} \cos \alpha + \boxed{G_E} \sin \alpha] \times m_G(e)$$

Dry delay

Wet delay

gradients

$$N_d = k_1 \cdot \left(\frac{P_d}{T} \right)$$

$$N_w = k_2 \cdot \left(\frac{e}{T} \right) + k_3 \cdot \left(\frac{e}{T^2} \right)$$

Integrated Water Vapour

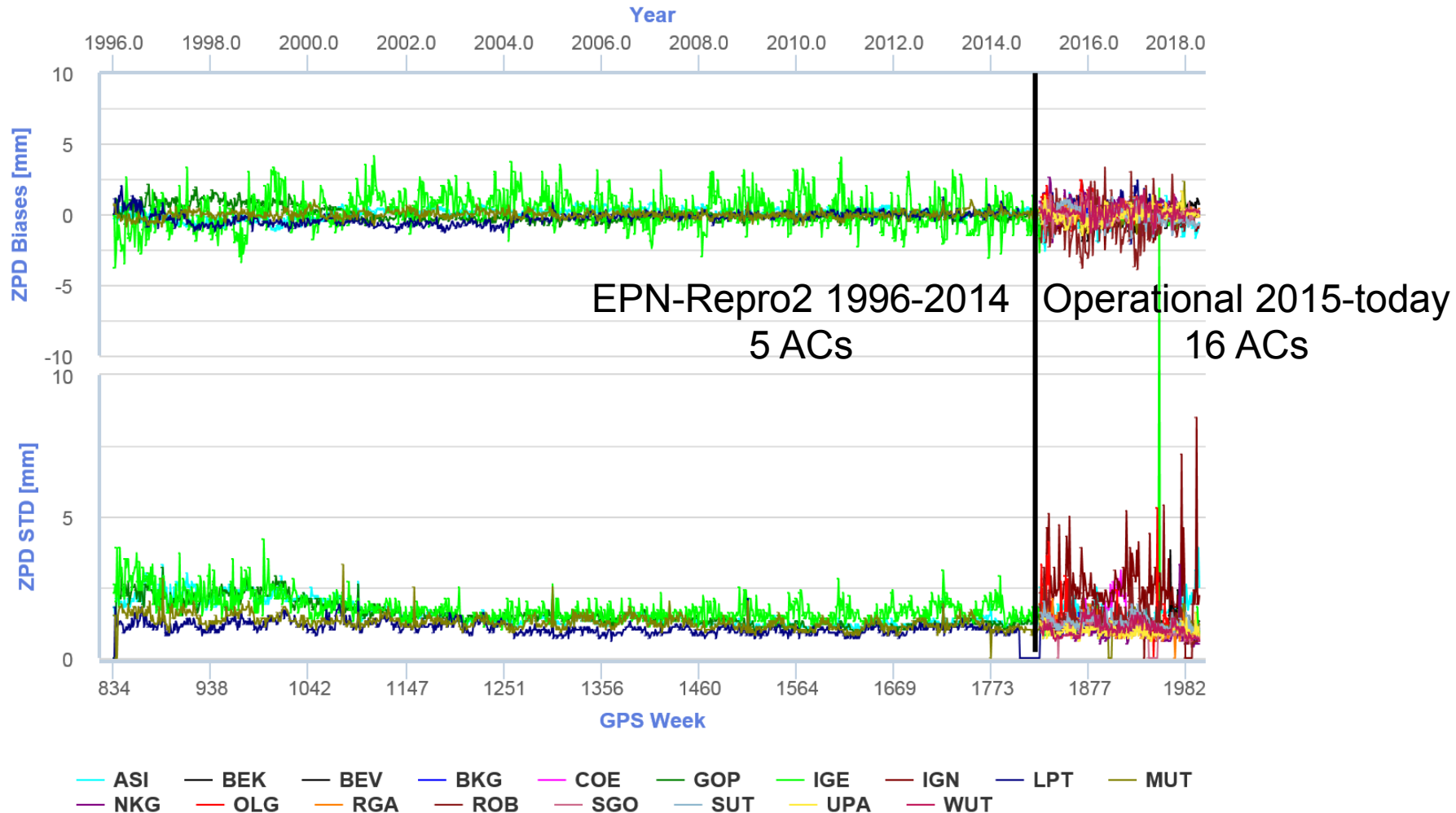
$$IWV = \kappa(T_m) \cdot ZWD$$

Current Status: EPN-Repro2 & Operational

http://www.epncb.oma.be/_productsservices/sitezenithpathdelays/

Mean ZPD biases wrt weekly EPN troposphere solution

(EPN-repro2 + routine)



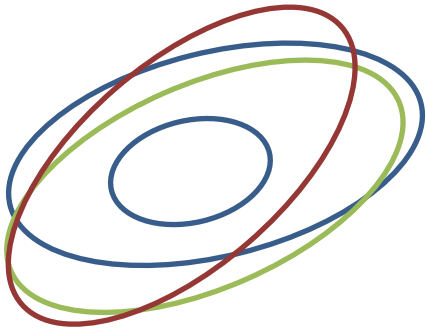
© EPN Central Bureau



EPN-Repro2 – from 1996 to 2014

EPN-Repro2 - From GPS wk 0834 to 1824

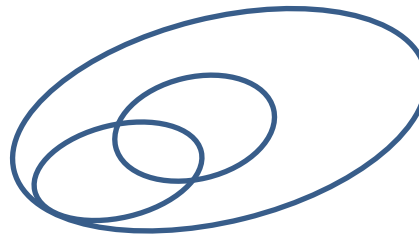
- 5 Input Solutions
- 3 main GNSS SW (Bernese, Gamit, Gipsy)



5 (+3) Solutions

- ASI (GIPSY, Full EPN)
- GOP (Bernese, Full EPN)
- LPT (Bernese, EPN sub-net)
- IGE (Bernese, EPN sub-net)
- MUT (GAMIT, Full EPN)

- **Different software**
- **Different networks**



3 Bernese Solutions

- GOP (Full EPN network)
- LPT (EPN Sub-network)
- IGE (EPN Sub-network)

- **Same software**
- **Different networks**



3 Solutions (Full EPN)

- ASI (GIPSY)
- GOP (Bernese)
- MUT (GAMIT)

- **Different software**
- **Same network**

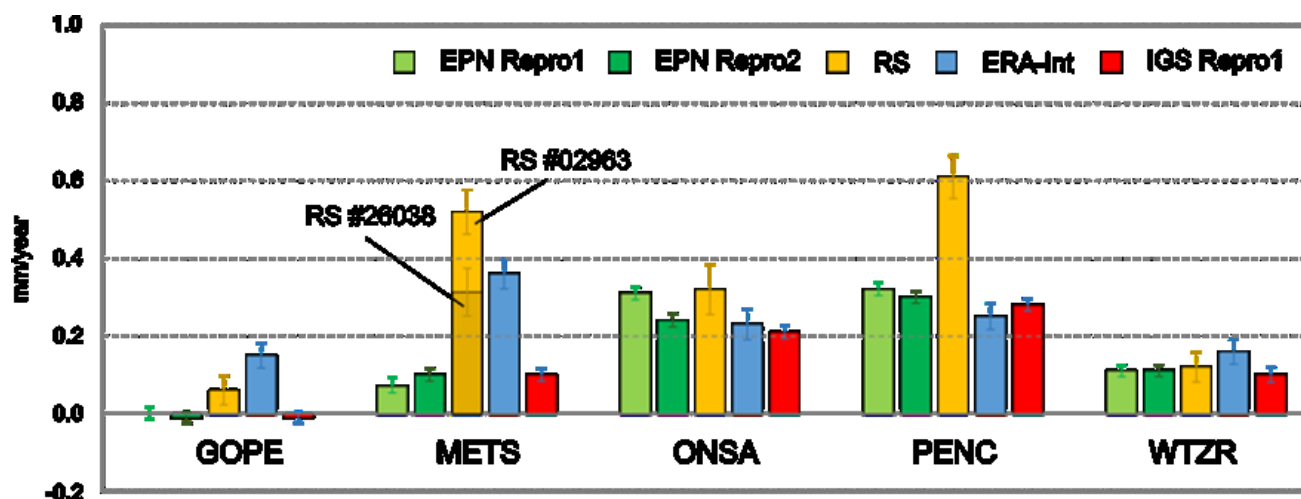
Pacione, R., Araszkiwicz, A., Brockmann, E., and Dousa, J.: EPN Repro2: A reference GNSS tropospheric dataset over Europe, *Atmos. Meas. Tech.*, 10, 1689-1705, <https://doi.org/10.5194/amt-10-1689-2017>, 2017

EPN-Repro2 – from 1996 to 2014 (cont'd)

COST ACTION ES1206 'GNSS4SWEC' Working Group 3:
'Use of GNSS tropospheric products for climate monitoring'



- First Reference data set: IGS Repro1 1995-2010 global
- **Second Reference data set: EPN-Repro2 1996-2014 Europe**



ZTD trends

EPN-Repro2 is a combined product.

Research Question:

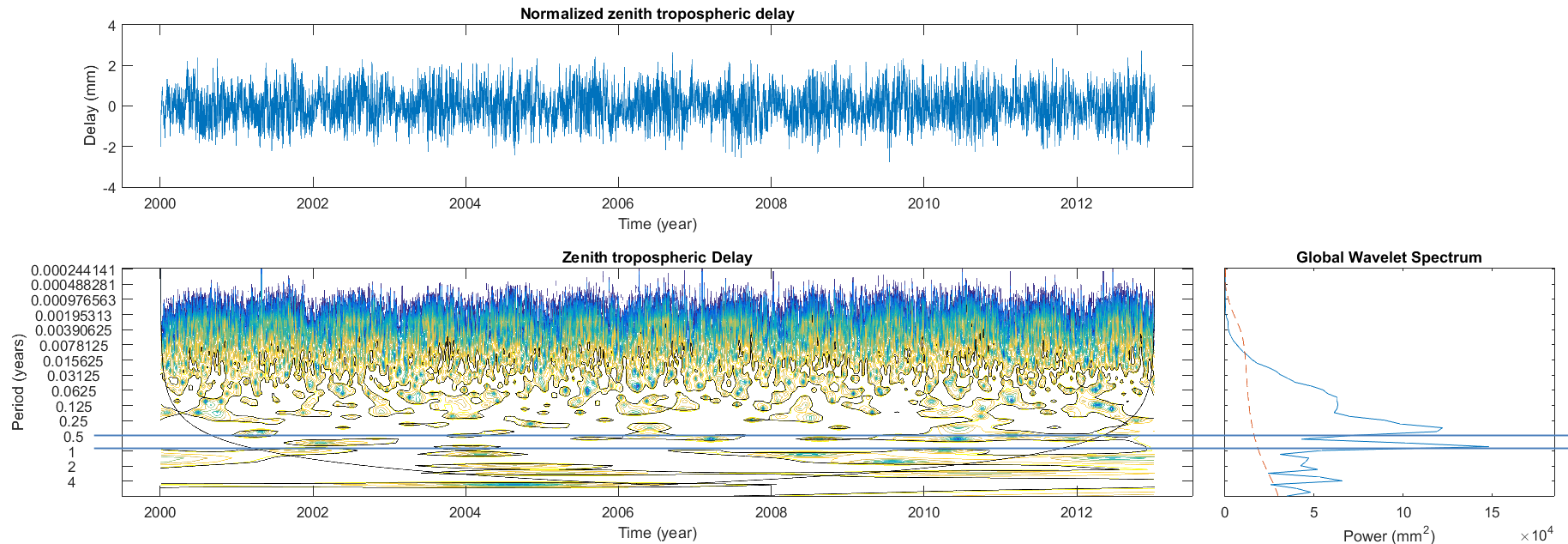
Is there any 'loss of information' in performing the combination?

Wavelet analysis:

1. All 13 year-long time series have a very strong annual component
2. After removing it, finer features become visible
3. EPN spectra are similar

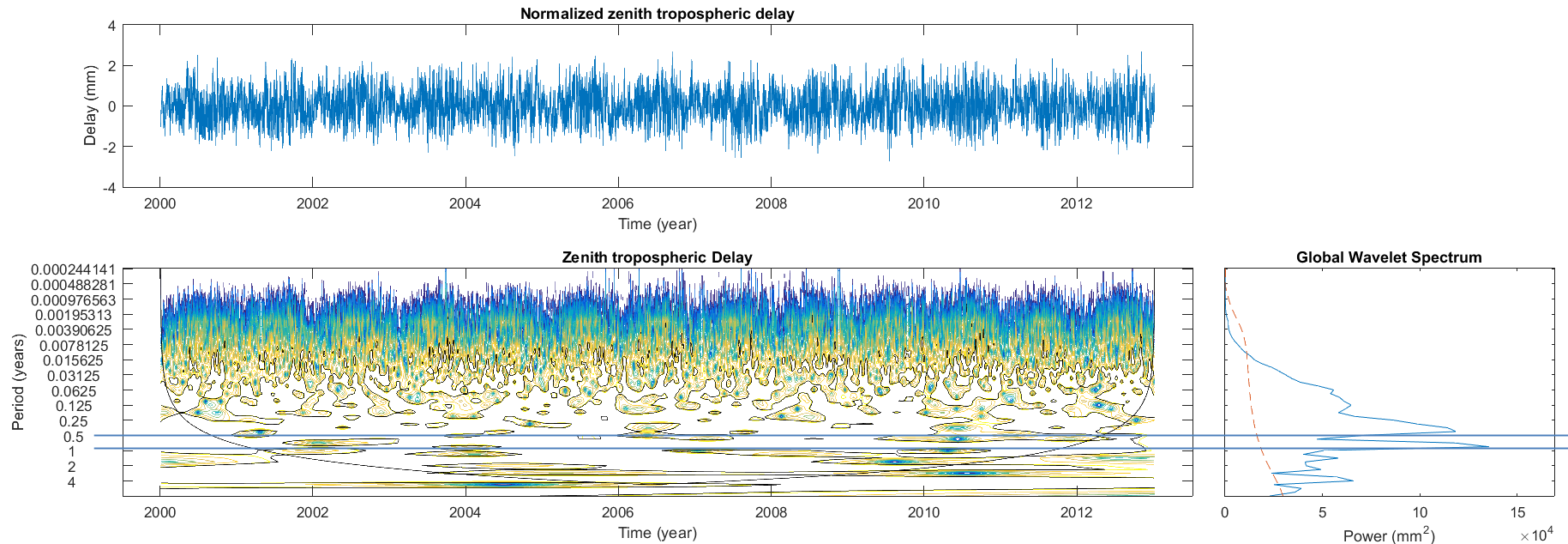
Santos M.C., Pacione R., Balidakis K., Dick G., Wickert J., Heinkelmann R., and Männel B.: On the combination of neutral atmospheric delay estimates from different solutions, EGU GA 2018

Wavelet as0 MATE



Santos M.C., Pacione R., Balidakis K., Dick G., Wickert J., Heinkelmann R., and Männel B.: On the combination of neutral atmospheric delay estimates from different solutions, EGU GA 2018

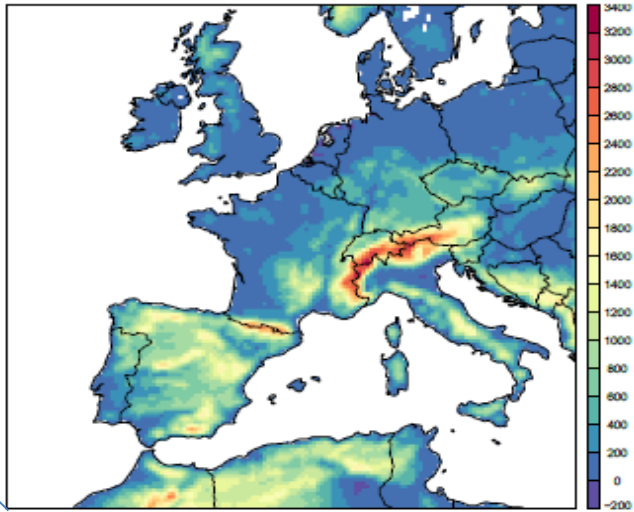
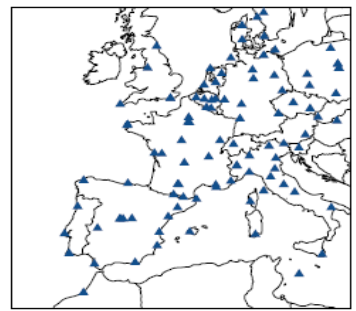
Wavelet eu0 MATE



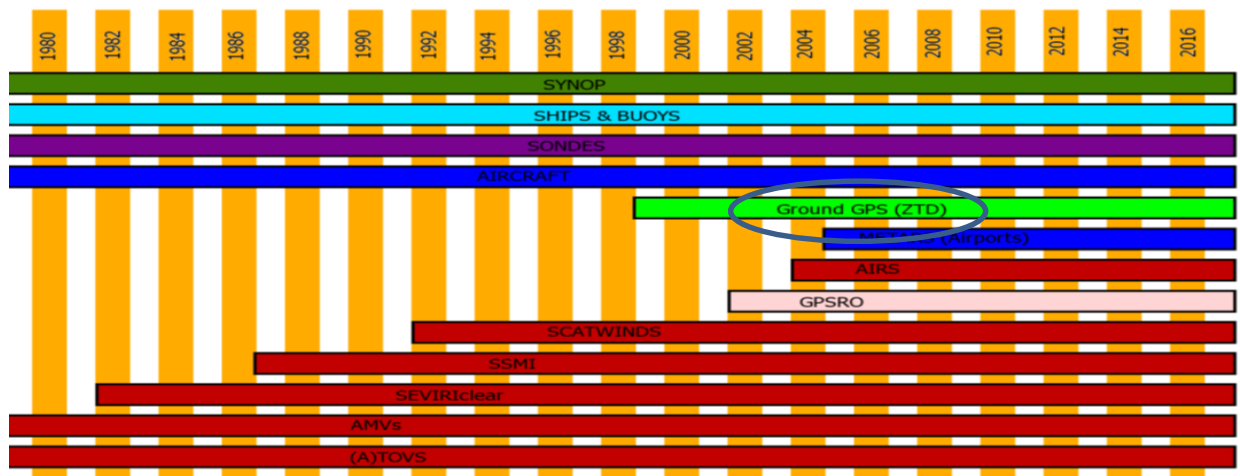
Santos M.C., Pacione R., Balidakis K., Dick G., Wickert J., Heinkelmann R., and Männel B.: On the combination of neutral atmospheric delay estimates from different solutions, EGU GA 2018

Exploitation of EPN-Repro2 dataset

Climate Model Simulation **ALARO Climate Model**



Berckmans J., Van Malderen R., Pottiaux E., and Pacione R.: Evaluation of the atmospheric water vapor content in the regional climate model ALARO-0 using GNSS observations from EPN Repro2, EMS Annual Meeting, 4–8 September 2017, Dublin, Ireland



European ReAnalyses

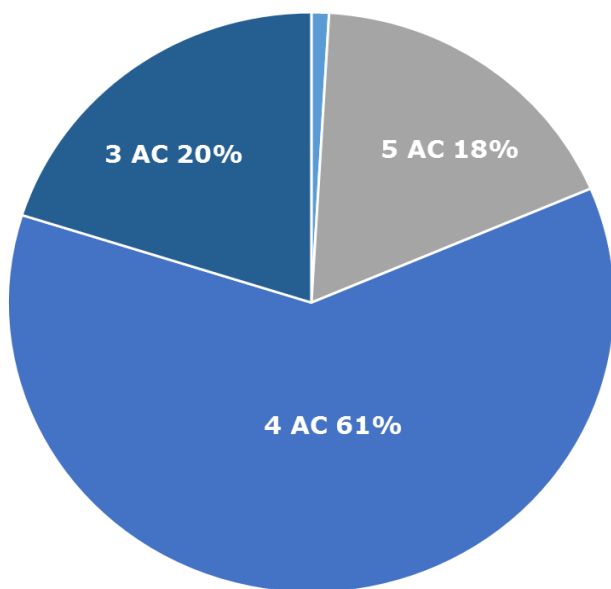
→ Ground-Based GNSS

*Courtesy G.Halloran,
UK MetOffice*



Operational Solutions

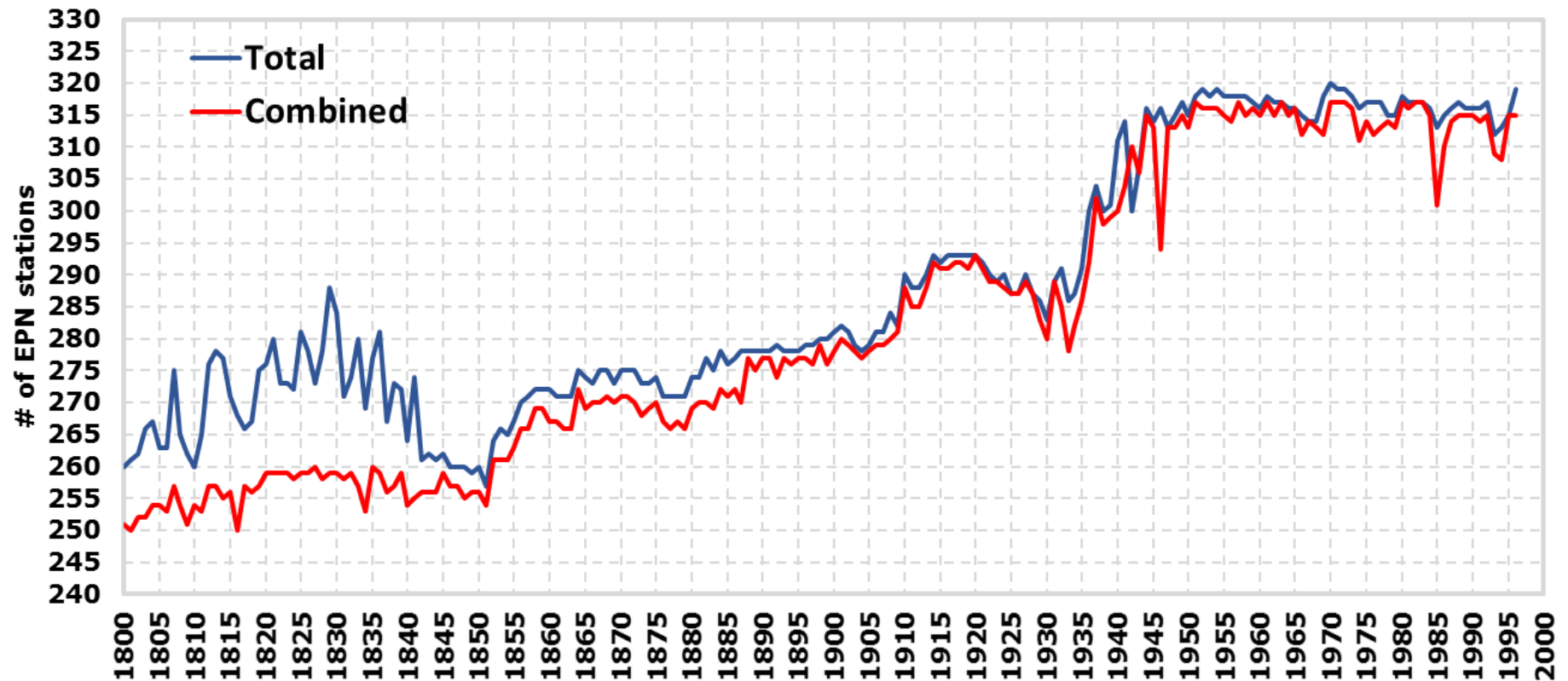
- **Period:** GPS weeks 1825 – 1996
- **16 ACs:** ASI, BEK, BEV, BKG, COE, IGE, IGN, LPT, MUT, NKG, RGA, ROB, SGO, SUT, UPA, WUT
- **Distributed Processing:** The EPN stations are distributed among the AC in such a way that each station is analyzed by at least three AC. This guarantees the reliability of the EPN products
- **GNSS SW:** GIPSY-OASIS (1 AC), GAMIT (1 AC), BERNese (14 ACs)
- **Processing Options:** refer to 'Guidelines for EPN Analysis Centres'



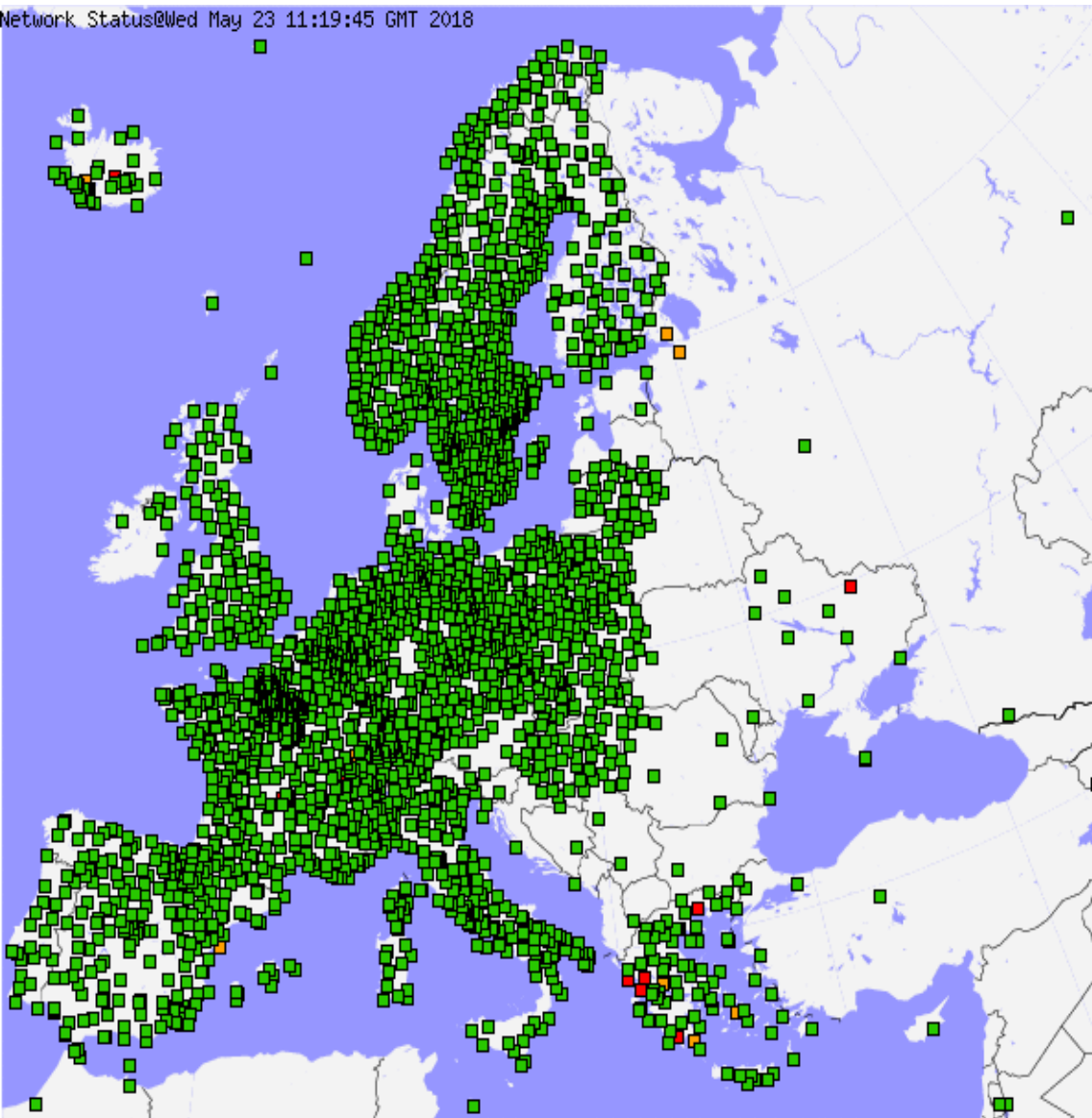
May, 23rd 2018: 323 EPN stations

| | 6 AC | 5 AC | 4 AC | 3 AC |
|-----------|------|------|------|------|
| Station # | 3 | 57 | 198 | 65 |
| % | 1 | 18 | 61 | 20 |

Operational – Total vs Combined Stations



Network Status@Wed May 23 11:19:45 GMT 2018



EUMETNET

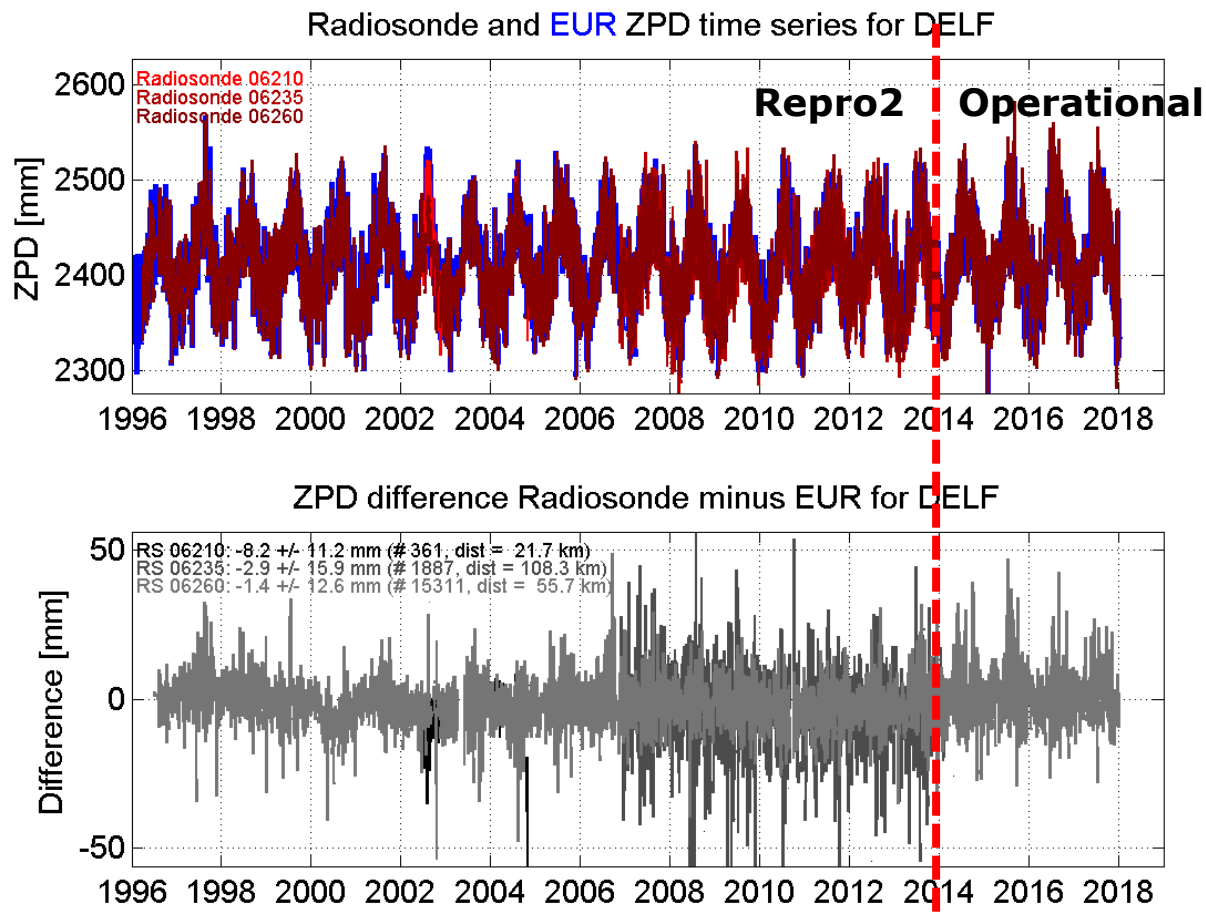
The Network of European Meteorological Services

E-GVAP – The EIG EUMETNET GNSS Water Vapour Programme, Phases I-III (2004-2017)

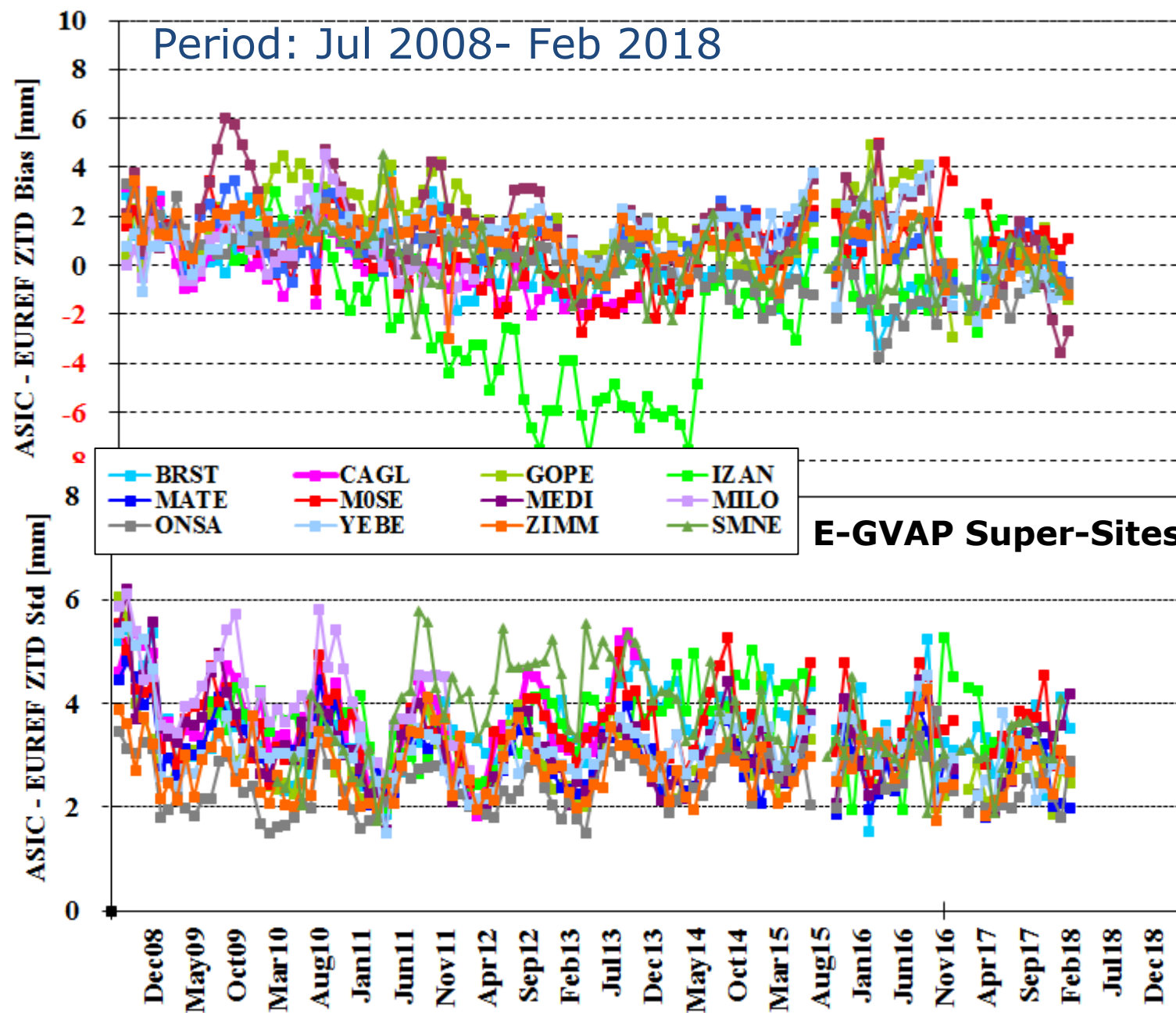
- EIG EUMETNET Project coordinating the **near real-time** delivery of data from ~3000 GPS sites delivering > **14M ZTDs pcm**.
- Focus is on GPS-only **hourly processing**, delivering only ZTD **in 90mins**.
- **Operational assimilation** at a few European National Met Services, many others under testing.
- Use of E-GVAP ZTDs has proven **positive impact** on NWP forecast skill.
- Surface T and P used for conversion to Integrated Water Vapour (**IWV**).
- Active Quality Control (**AQC**) in place.
- **MoUs** in place with **EUREF** and **EUPOS**.

Operational – Cumulative Solution

- Tropospheric cumulative solution T1981, EUREF mail 9326
- Next update: October 2018

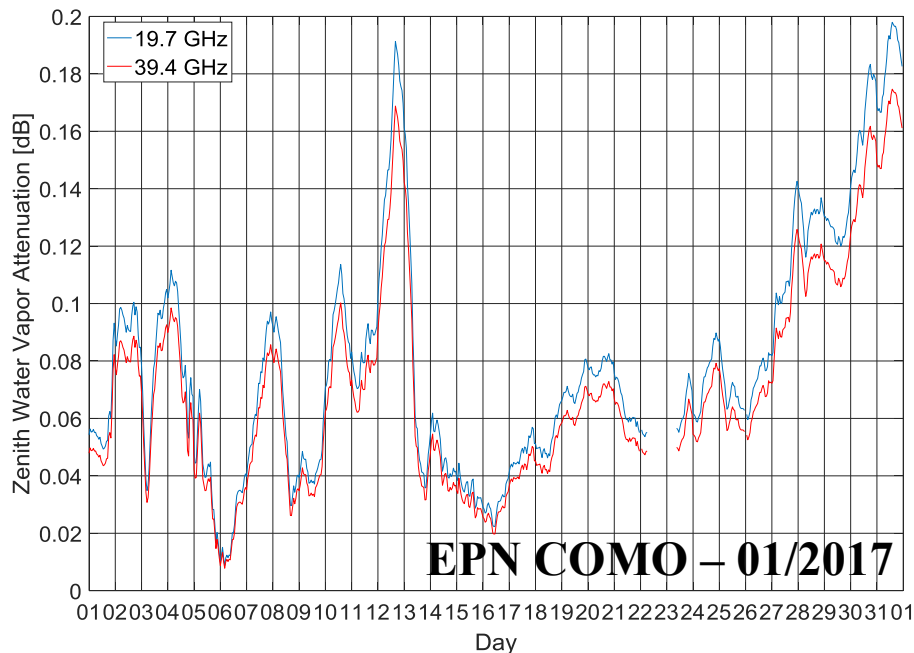


Operational – E-GVAP vs EPN



Earth-Space Propagation Experiment

- GNSS-derived IWV can be used to derive water vapor attenuation, A_{wv} [1]
- A_{wv} , plus dry air attenuation, get “clear sky” or gaseous attenuation
- Gaseous attenuation is used to derive total attenuation from beacon measurements in propagation experiments [2]



Courtesy of G.Siles (UPB)



POLITÉCNICA



- Como EPN IWV data are compared with Milano IWV radiometric measurements
- Distance Como-Milano: ~37,5 km
- Preliminary results satisfactory.

[1] G. Siles, J.M. Riera and P. Garcia-del-Pino, "An Application of IG to Propagation Studies: Validation of Radiometric Atmospheric Attenuation," in *Antennas and Propagation, IEEE Transactions on*, vol.64, no.1, pp.262-270, Jan. 2016S

[2] J. M. Riera, G. A. Siles, P. Garcia-del-Pino and A. Benarroch, "Alphasat propagation experiment in Madrid: Processing of the first year of measurements", *Proc. of 10th European Conference on Antennas and Propagation (EuCAP)*, Davos, Switzerland, April, 2016.



Summary and next steps

- ZTD Products at the EPN stations available since 1996
- EPN-Repro2 selected as the 2° community reference data set by 'GNSS4SWEC' WG3
- Routine monitoring activities of the EPN AC troposphere solutions
- Routine inter-technique evaluation
- Next steps:
 - Horizontal Gradients evaluation
 - EVGA and EPN collocated stations
 - SINEX_TRO v2.0

Acknowledgment: e-GEOS work is carried out under ASI contract N. 2017-21-I.0