Development towards inter-technique tropospheric parameter comparisons and their exploitation

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Motivations & Goals

Tropospheric parameters from space geodetic techniques are **side products** along with estimating geodetic parameters of main interest

However, various **approximations still needed** for tropospheric modeling:

- *Separating hydrostatic/wet parts:* $ZTD = ZHD + ZWD$
- *Mapping to the zenith:* $STD\ (ele) = mf_h\, ZHD + mf_w\, ZWD$
- *Asymmetry modeling:* $STD\ (ele,azi) = STD(ele) + mf_g\ (G_N\ cosA + G_E\ sinA)$

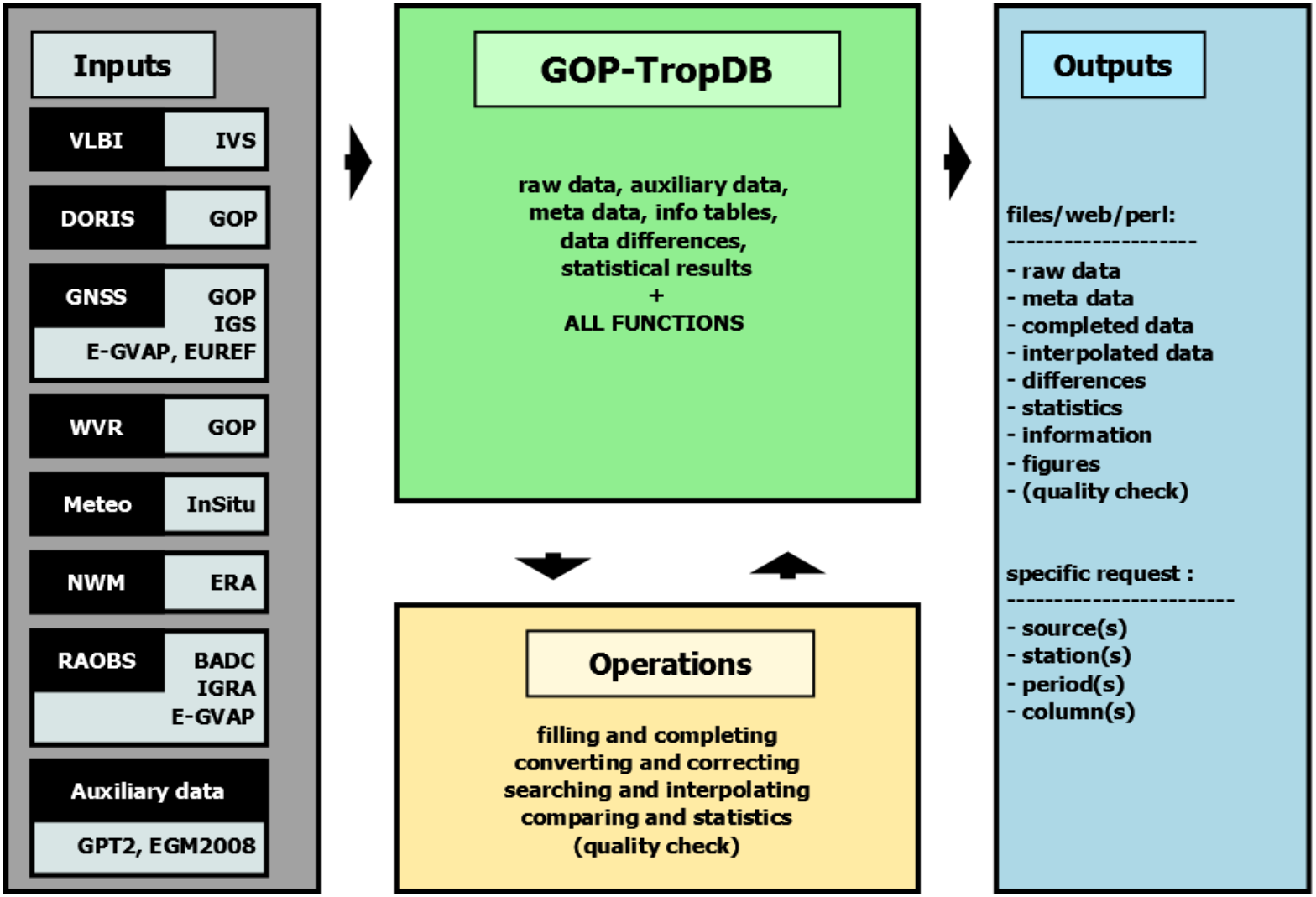
Motivations – complementary benefits for:

- ✓ ***Geodesy:*** ***assessments*** *of tropospheric approximations as well as other models*
- ✓ ***Geodesy:*** ***exploitation*** *of external tropospheric parameters for positioning*
- ✓ ***Meteorology:*** ***assimilation*** *of ZTDs/STDs/gradients into numerical weather models*
- ✓ ***Climatology:*** ***monitoring*** *of long-term trends in integrated water vapor*

Goals:

- ➢ Intra-technique comparisons (GNSS or other space geodetic techniques)
- ➢ Inter-technique comparisons (independent evaluations)
- ➢ Additional functionalities – QC, conversions, TS analyses, archive, user support

IGS TropoWG and GOP-TropDB development



Gyori G, Dousa J (2014) ***GOP-TropDB*** *developments for tropospheric product evaluation and monitoring – design, functionality and initial results, In: IAG Symposia Series, Vol. 143 (accepted)*

Database optimizations

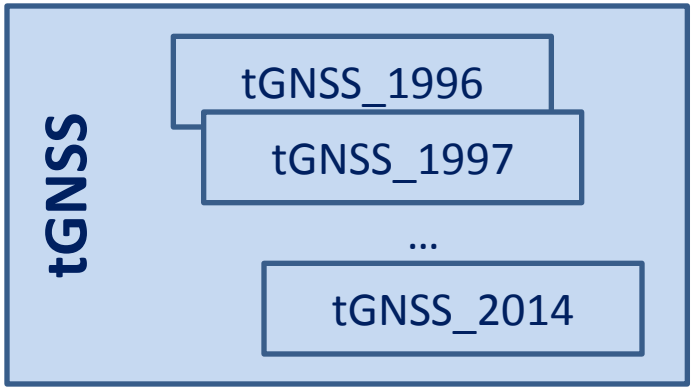
… to deal with billions of records, various sources and data types, …

Data domain (basic design)

Individual tables designed for specific data sources (different content), for example:

Time domain (partitioning)

Table partitioning (on a yearly basis)
Maintained by triggers (automated)
Inherited features (single interface)
Keep reasonable size for physical tables



SQL commands (analysis)

Optimizing command sequences, priorities, sampling, …
Very specific SQL domain

Extensive data processing (vs. running costs)

Optimized data batches for DB insert function (to minimize running costs)
C/C++, perl outside DB or as embedded DB functions
e.g. radiosonde, Numerical Weather Models

Data filling, pre-processing, format issues

Extract-Transform-Load (ETL) input procedures

- to decode (and pre-process) various input data formats
- to prepare and execute SQL command (INSERT / UPDATE)

Many formats !
Official Tro-SINEX could help

Input filter (decoders)	Decoding format (data source)	Insert SQL function	Remarks	Data type
tro-snx-gnss2DB.pl	Tropo-SINEX	fInsertGNSS	ZTDs from IGS/EUREF products	**space geodetic technique**
tro-snx-ivs2DB.pl	Tropo-SINEX (IVS)	fInsertVLBI	ZTDs from IVS combined products	
tro-snx-ids2DB.pl	Tropo-SINEX (GOP)	fInsertDORIS	ZTDs from GOP tropospheric solutions	
rt-flt2DB.pl	G-Nut/Tefnut output	fInsertGNSS	ZTDs from GOP real-time analysis	
cost-trp2DB.pl	COST 716 format	fInsertGNSS	ZTDs from E-GVAP	
met-rnx2DB.pl	Meteo RINEX	fInsertINSIT	In situ meteorological data (GNSS)	**in situe meteorological observations**
cost-met2DB.pl	COST Met format	fInsertSYNOP	COST 716 meteorological data	
wvr2DB.pl	Radiometrics	fInsertWVR	Radiometer data	
raobs2DB.pl	BADC old/new format	fInsertRAOBS	BADC radiosonde integrated data	
raobs2DB.pl	EGVAP format	fInsertRAOBS	EGVAP radiosonde integrated data	
raobs2DB.pl	IGRA format	fInsertRAOBS	IGRA radiosonde integrated data	
cost-trp2DB.pl	COST 716 format	fInsertNWM	ZTDs from NWM	**NWM products**
nwm-shu2DB.pl	G-Nut/Shu (ECMWF,NCEP)	fInsertNWM	NWM integrated data and decay params	
nwm-dns2DB.pl	DNS (ECMWF,NCEP)	fInsertNWM	NWM integrated data, gradients	
gpt2DB.pl	GPT2 model	fInsertGPT2	Global Pressure and Temperature	**Auxiliary models**
geoid2DB.pl	EGM2008 model	fInsertGEOID	EGM2008 geoid grid	
surf2DB.pl	ETOPO1 model	fInsertSURF	ETOPO1 global relief grid	

NEW: Numerical Weather Model field data processing

… to provide background data information for DB functionality …

G-Nut/Shu - developed at GOP for NWM data processing

- Calculate 2D tropospheric correction model or site-specific parameters time-series for DB
- Assess scenarios for vertical approximations, parameter calculations (ZWD, T_m) and others

DNS - Direct Numerical Simulation - developed at GFZ (F. Zus)

- Highly efficient tool for thousands of NWM ray-traces in a second (a single standard CPU)
- NWM-derived mapping function coefficients & horizontal gradients

ERA-Interim (in GOP-TropDB)

- Currently**: 1990 – 2013** and continuously extended
- Full period processed in **1°x 1° grid** for surface & vertical reduction parameters
- Auxiliary background model for GOP-TropDB - **tropospheric ties, converting factors**, …

…. considering to include other NWMs (in E-GVAP and GNSS4SWEC projects)

- Site-specific extractions only (e.g. for IGS/IVS/IDS/EUREF site locations)
- Global and regional high-resolution models and predictions

➢ *Assessment of NWM quality in support of GNSS processing and real-time positioning*

➢ *Providing a feedback for the NWM providers when compared w.r.t. GNSS products as reference*

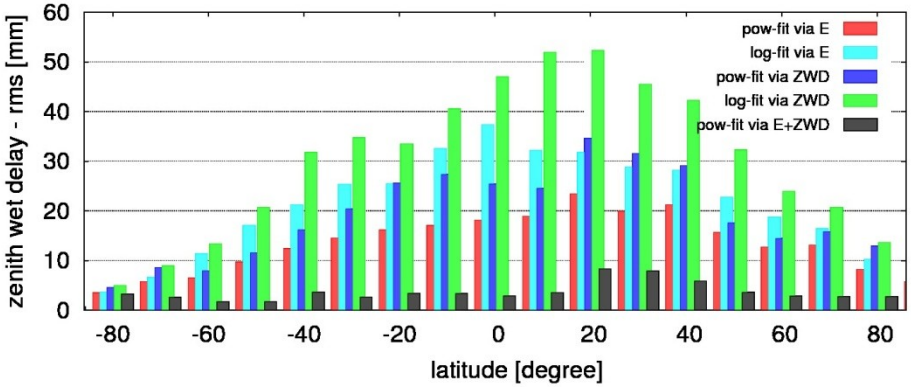
New tropospheric correction model for positioning

… default model for flexible support of GOP-TropDB functionality …

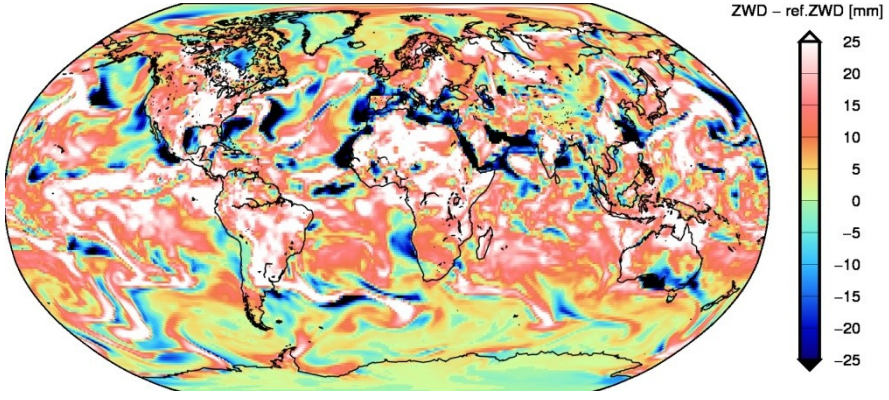
- **Enhanced ZWD vertical approximation** → **applied now in the GOP-TropDB**
- **Improved ZWD physical model** of Askne and Nordius (1987)
- **Requires to assess various NWM models as a potential input for GNSS real-time positioning**

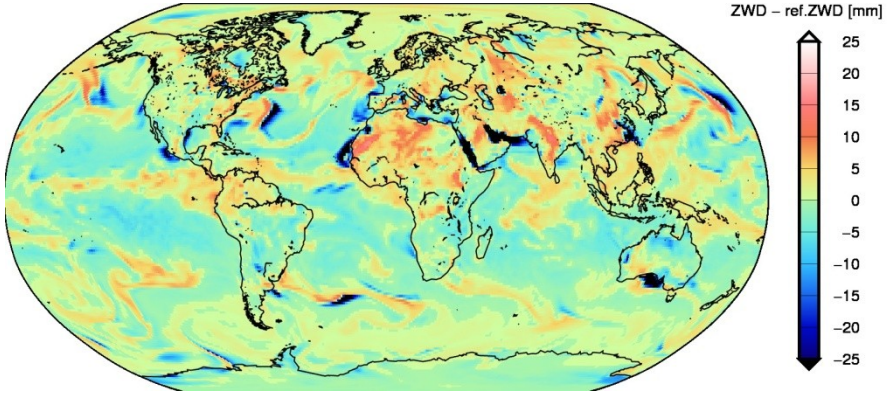
Douša, Eliaš, Václavovic - *Tropospheric correction model in support of Precise Point Positioning*
PS12 – Real-time Service - Poster Session

Douša and Eliaš (2014)
An improved model for tropospheric wet delay, GRL 41



Global ERA-Interim data (2005-06-05:00)





Tropospheric ties – new ZWD vertical reduction

… approximations for correcting altitude differences in ZTD comparisons …

Δ ZHD *(Teke et al., 2011)*

$$\Delta ZHD = \frac{0.0022768\left(p - p_0\right)}{1 - 0.00266 \cdot \cos(2\varphi) - 0.028 \cdot 10^{-6} h_0}$$

Δ ZWD *(Gyori and Dousa, 2014)*

*Vertical decay parameter **β, γ** estimated from ERA-Interim background data set*

$$\Delta ZWD = ZWD_0 \left[\left(1 - \frac{\beta\left(h - h_0\right)}{T_0} \right)^{\frac{(\gamma+1)g_0}{\beta R_d}} - 1 \right]$$

ZWD vertical reduction assessment via global ERA-Interim NWM data

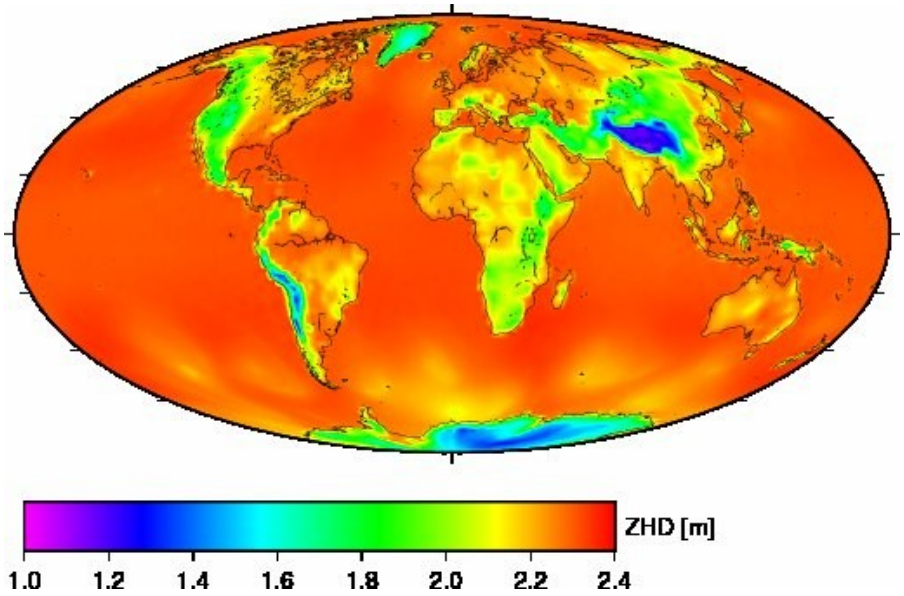
*ZWD vertically approximated at different altitudes compared to **integrated ZWDs***

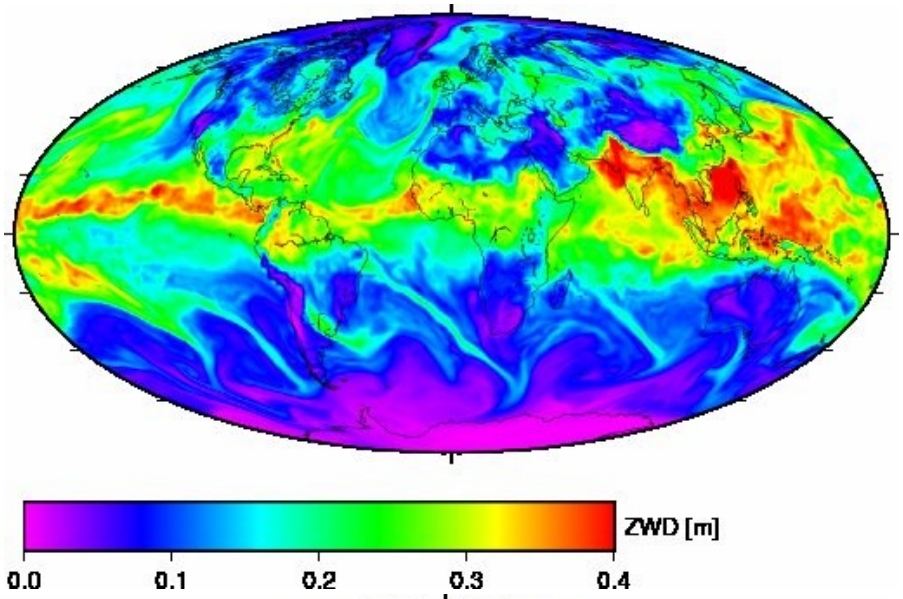
Height	0-1 km	1-2 km	2-3 km	3-4 km	4-5 km	5-6 km	6-7 km	7-8 km
UNB3 orig	11.4	20.7	20.2	19.9	15.3	13.2	10.4	7.9
New f(P)	8.2	7.4	5.5	6.5	5.6	5.6	5.0	3.7
New f(H)	8.3	7.4	5.5	6.5	5.7	5.6	5.0	3.7

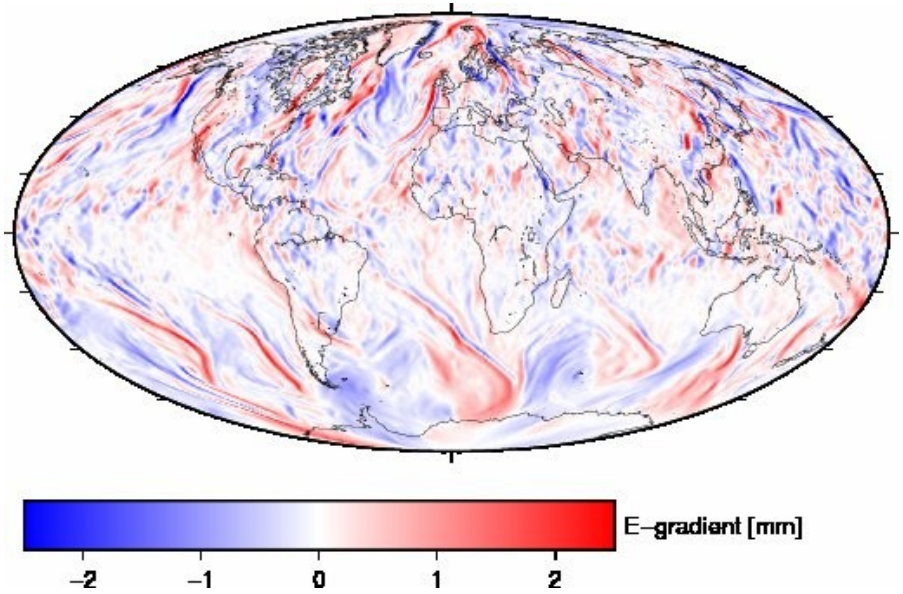
Table shows r.m.s. of ZWD differences [mm] at various altitudes

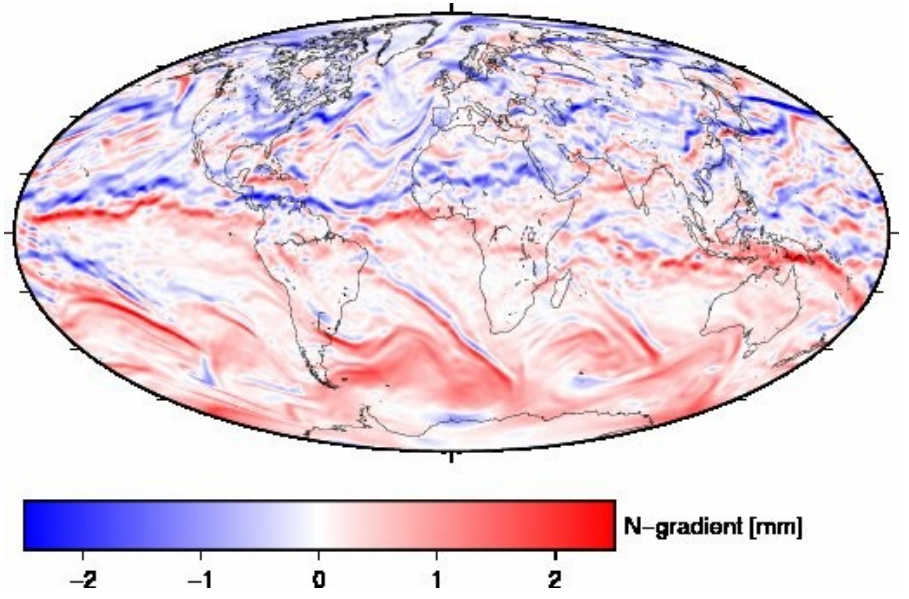
Dousa J, Elias M (2014), An improved model for tropospheric wet delay, GRL 41

Results of NCEP's GFS model (global scope)





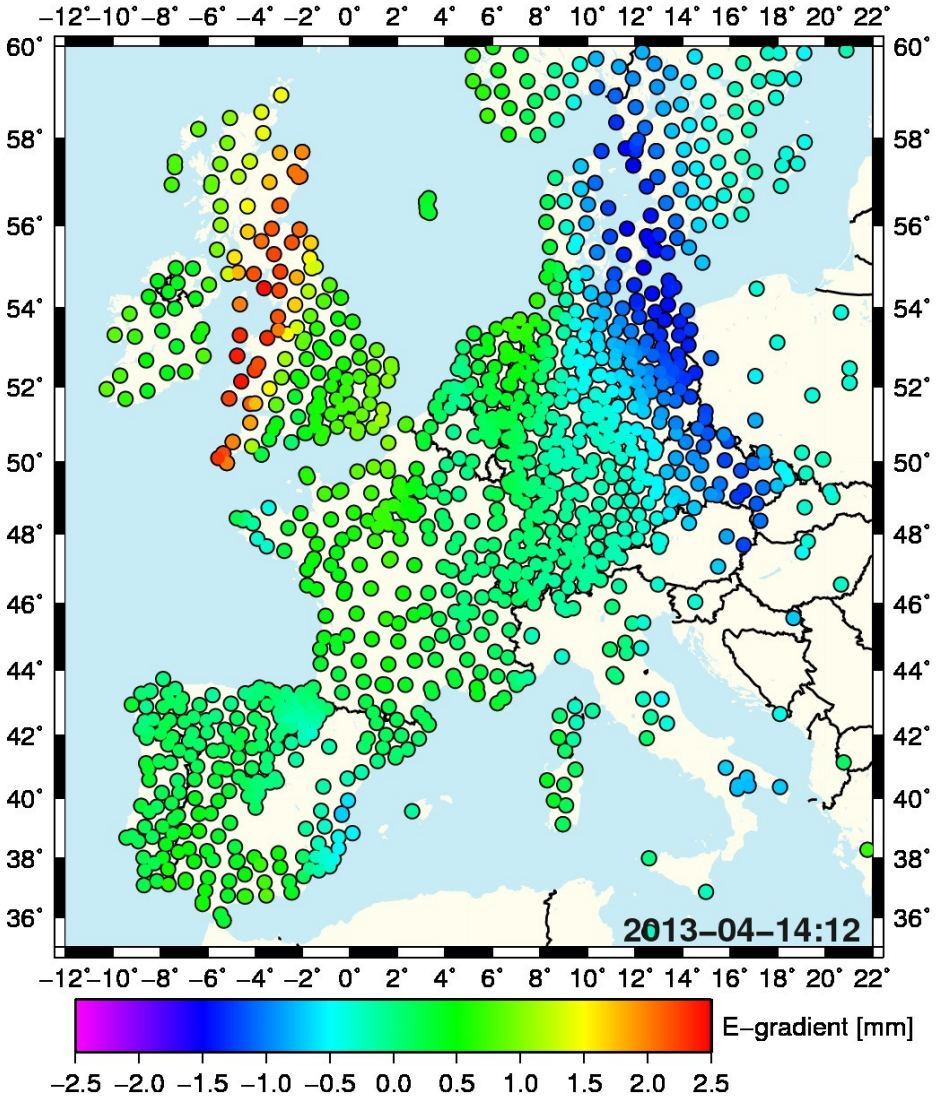


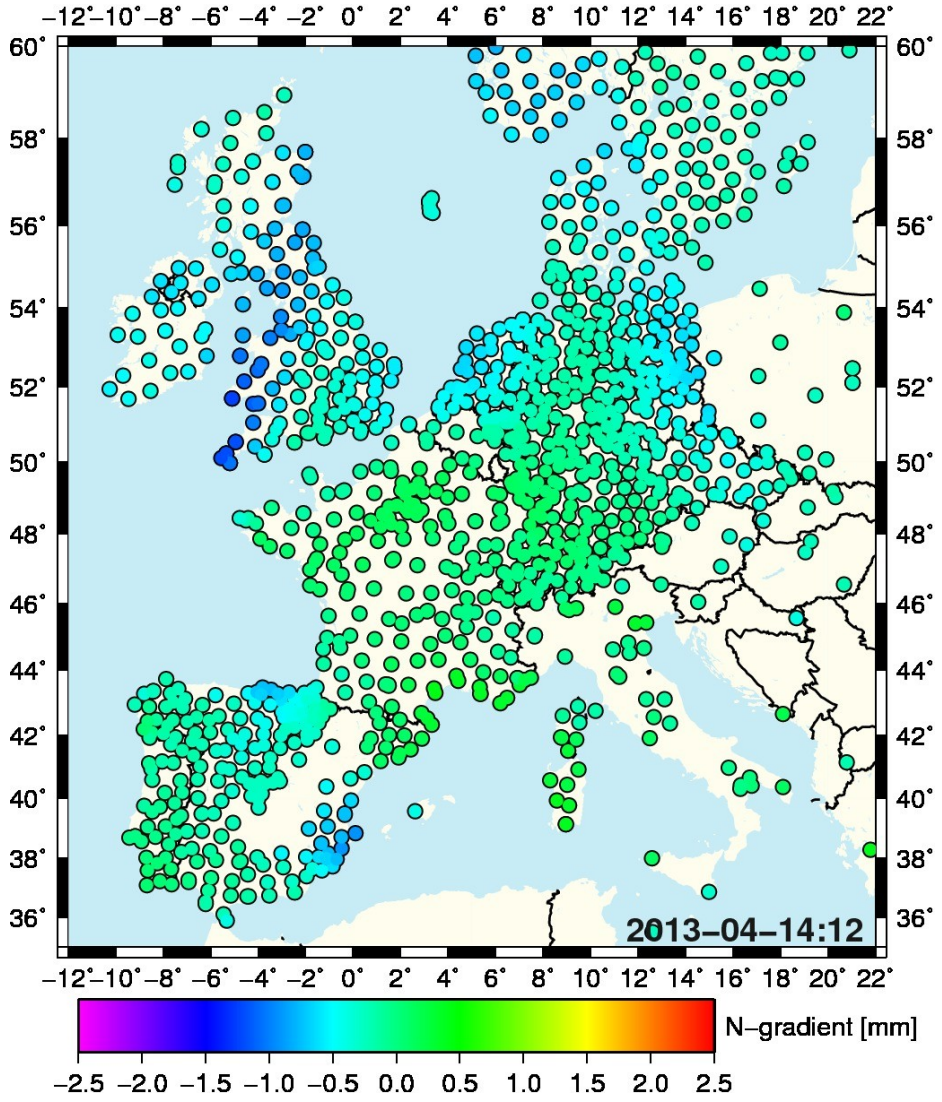


Zus et al. (2014) *The rapid and precise computation of GPS slant delays and mapping factors utilizing a numerical weather model, Radio Science, 49(3) 207-216*

Gradients from ERA-Interim model (in Europe)

… assessment of enhanced NWM data exploitation in positioning …



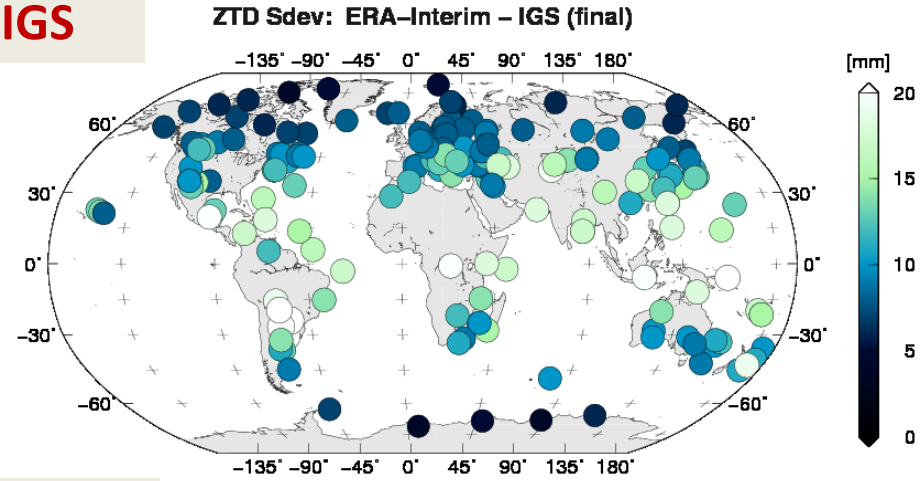


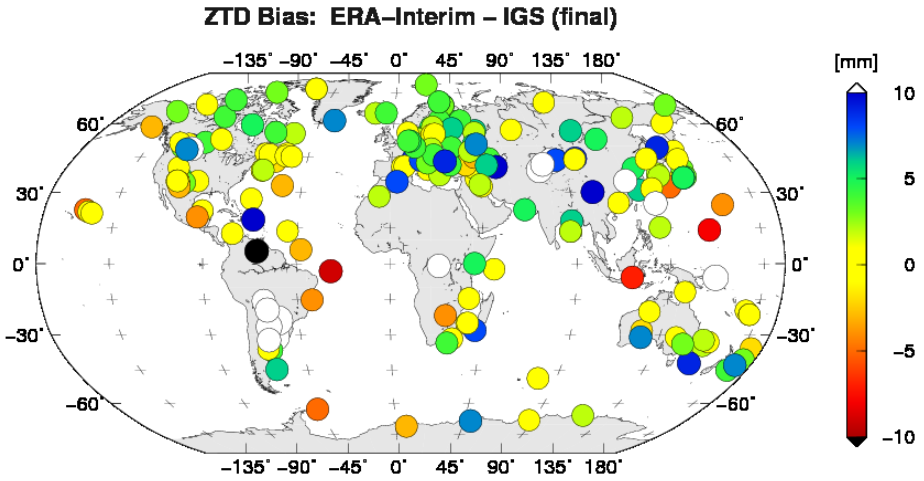
Zus et al (2014) *The information content of GPS slant tropospheric delays* ***@ Tropo Poster session***

ERA-Interim long-term evaluation

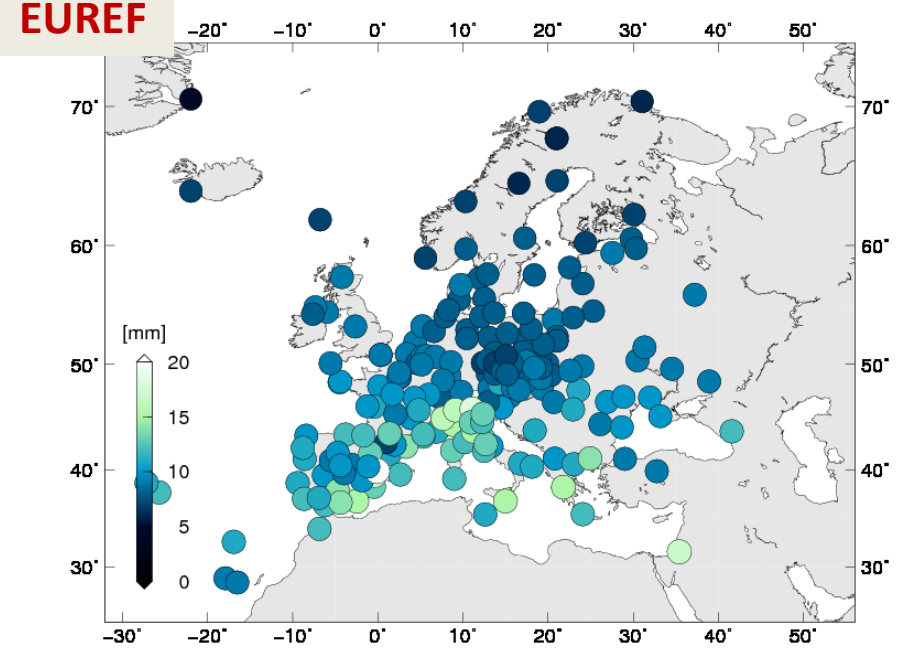
… total statistics of ZTD from ERA-Interim compared to IGS (top) and EUREF (bottom)

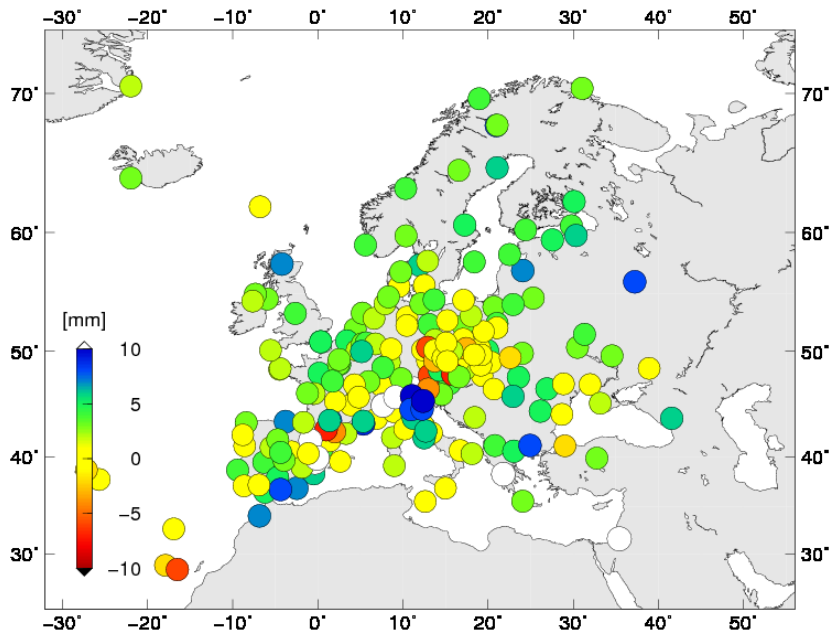
IGS





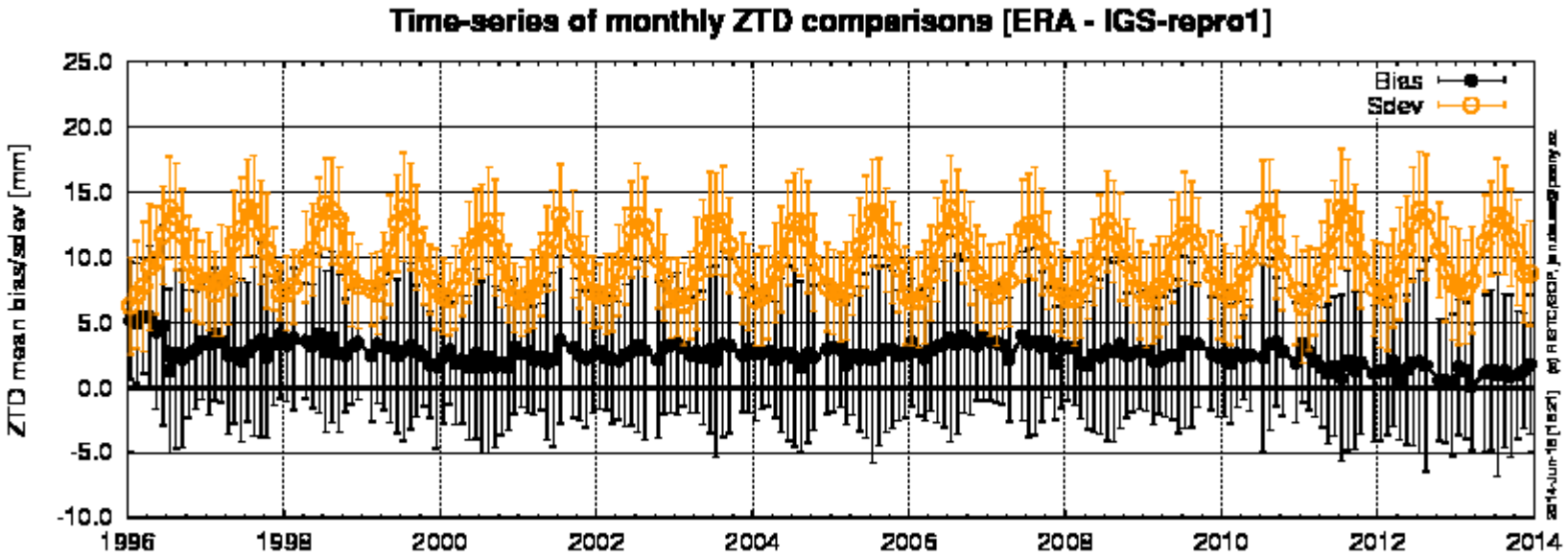
EUREF





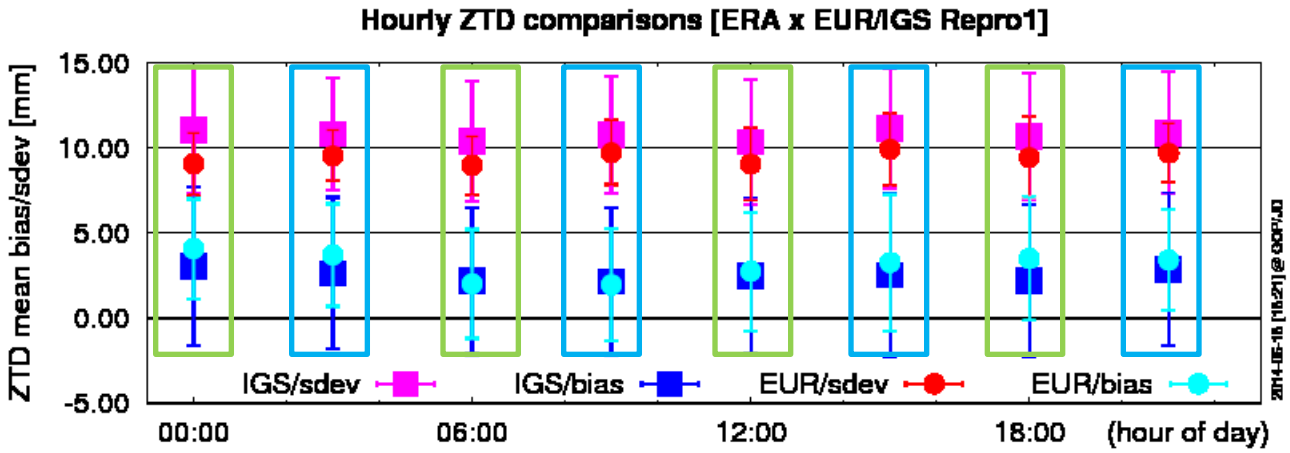
ERA-Interim long-term evaluation

... monthly statistics of ZTD from ERA-Interim compared to IGS (top) and EUREF (bottom)



Estimated

Interpolated

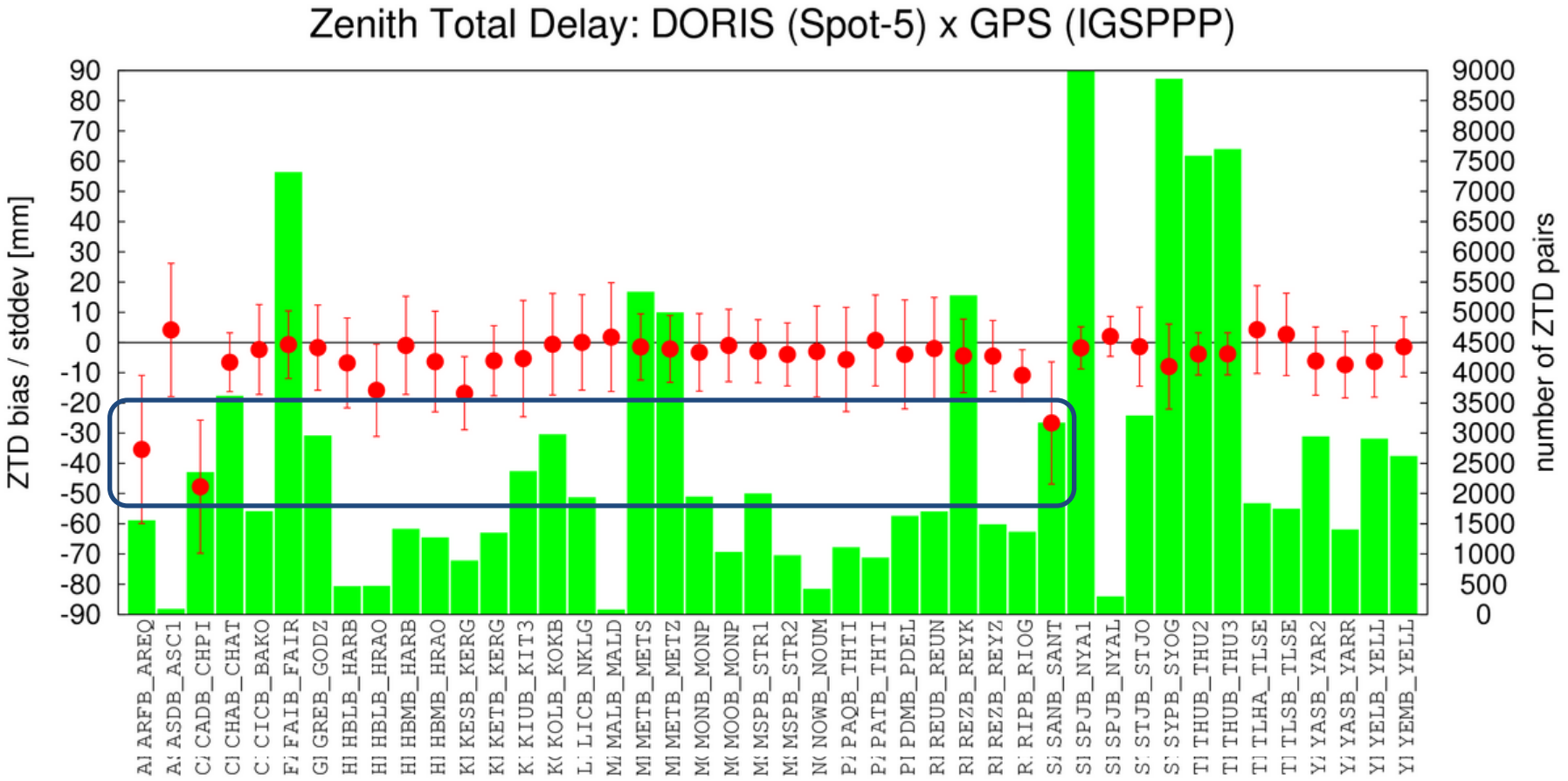


DORIS – GOP tropospheric assessment

GOP DORIS tropospheric parameters compared to IGS finals:

... revealed ZTD of 3 IDS stations significantly biased: AREQ, CHPI, SANT

→ **South Atlantic Anomaly** identified affecting **Spot 5** satellite



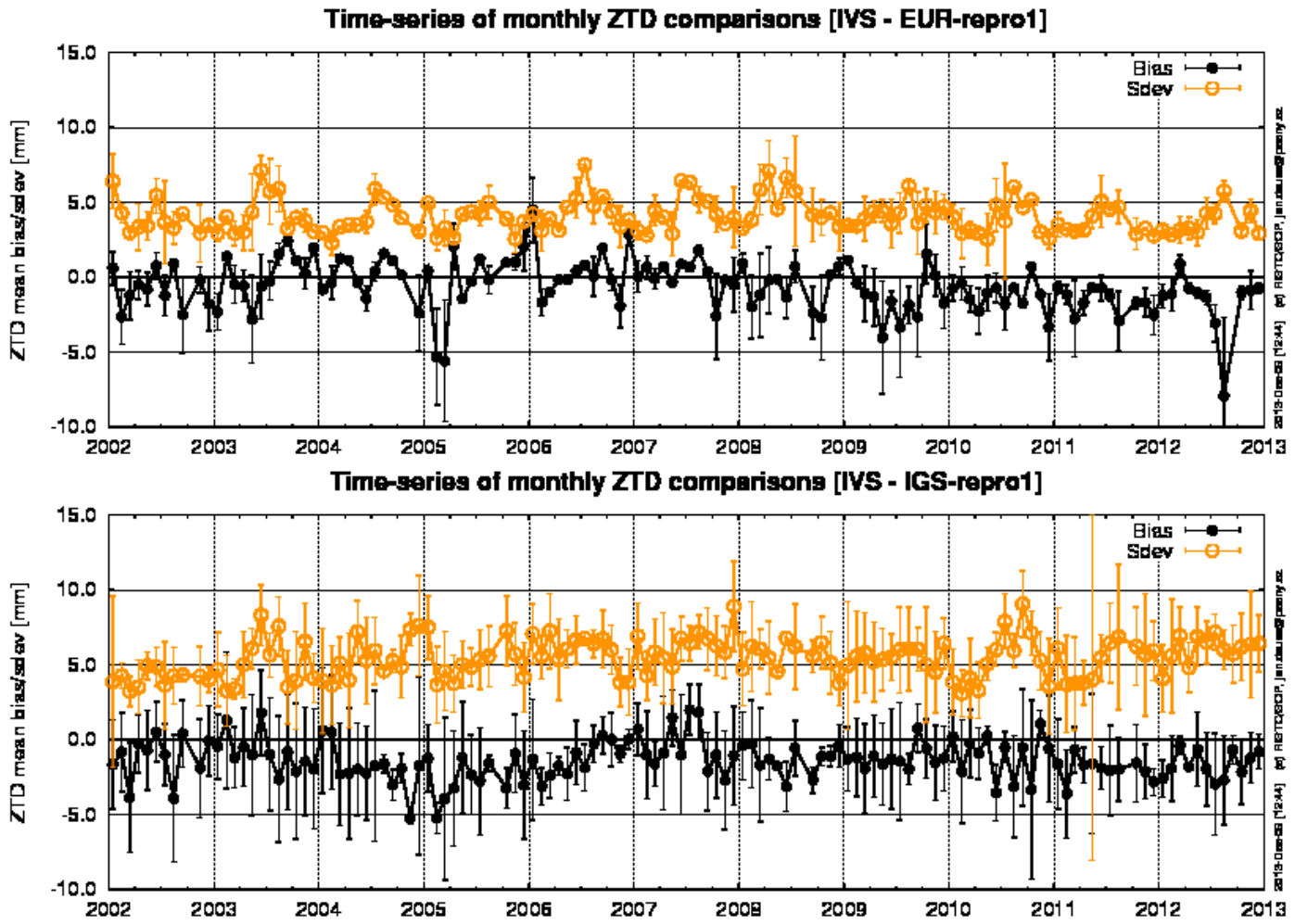
GOP DORIS tropospheric solutions by P. Štěpánek (GOP)

Stepanek P, Dousa J, Filler V (2013), SPOT-5 DORIS oscillator instability due to South Atlantic Anomaly: Mapping the effect and application of data corrective model, Adv. Space Res., 52(7):1355-1365

IVS long-term evaluation (preliminary)

… statistics of ZTD from VLBI compared to IGS (top) and EUREF (bottom)

Note: To compare rigorously, we require to update input format and meta data availability



IVS combined solutions by R. Heinkelman (GFZ)

Individual IGS AC tropo-product comparison

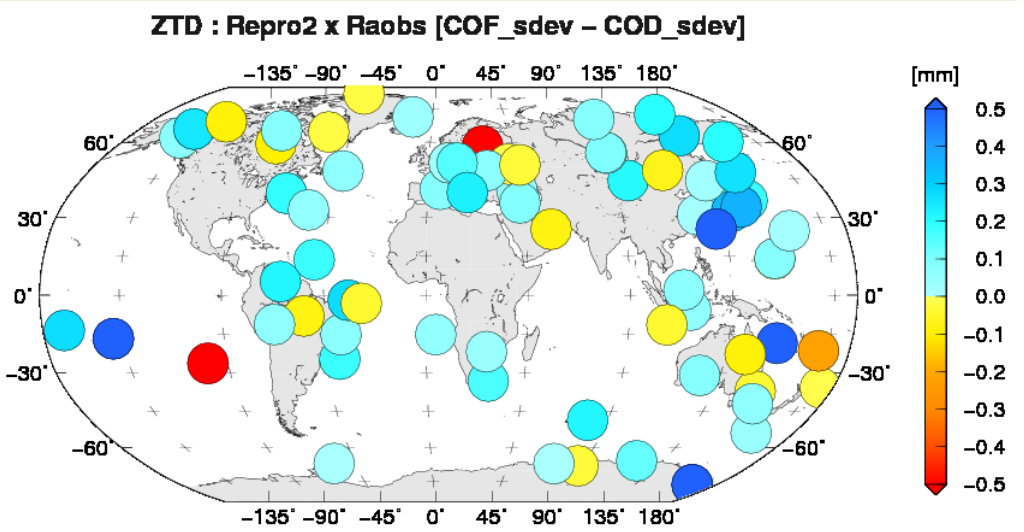
… assessment of processing strategy

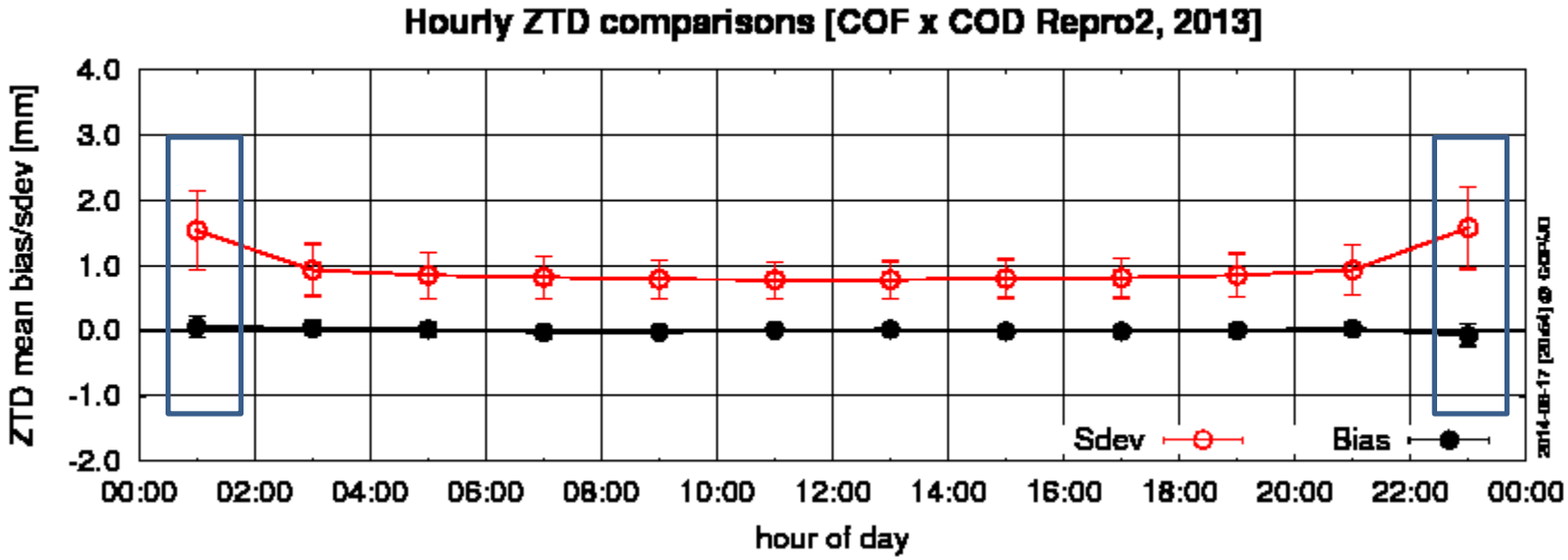
CODE Repro2 ZTD results: **COD × COF**

period 1994-2013

which is more close to external data?

1. Very small differences in midnight
2. Assessment by radiosonde shows:
   positive results for **COD** (blue)
   positive results for **COF** (yellow/red)





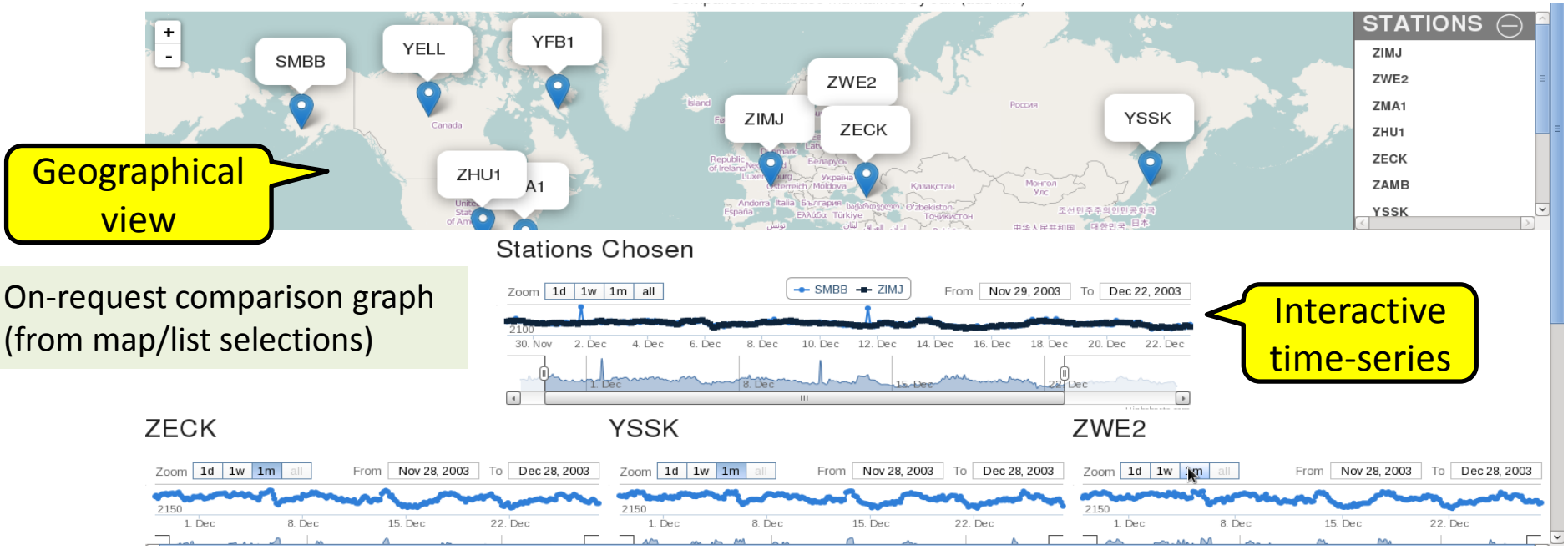
Developing and other potential services

Web-based interface to the GOP-TropDB (in development)

- shared effort between USNO & GOP
- interactive meta data inventory & visualization
- comparison results & statistics visualization (static)
- combination/multi-plots of various raw data outputs (dynamic)
- extraction for raw data, differences, auxiliary parameters

Potential custom comparisons … (or via GOP-TropDB dissemination)

- *user specific data upload*
- *comparisons/visualizations of user-defined stations & time span*



Considering data/functions dissemination

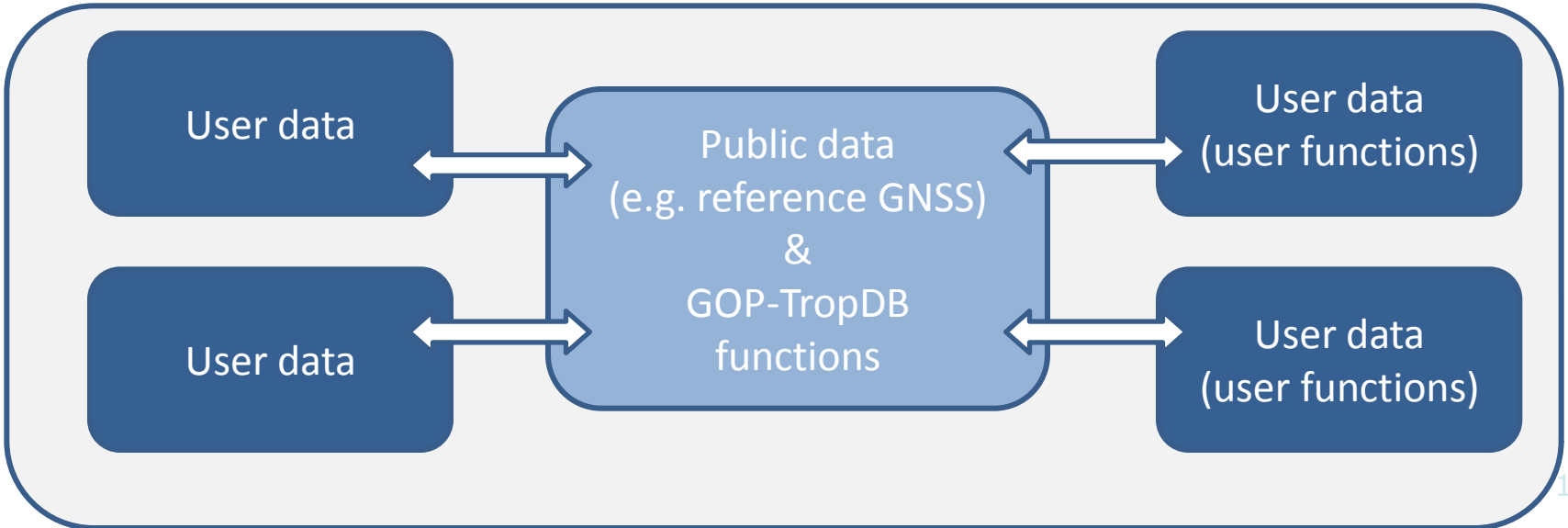
… specific development towards PUBLIC vs. USER area

→ various **dissemination scenarios** for user support

- via login account at GOP (or USNO) or through web-interface
- via a regular DB source update and public data dumps
- (via database replication, web service etc.)

Initial interest in two projects:

- *GOP/USNO bilateral project in support of IGS TropoWG*
- *GNSS4SWEC project for meteorology/climatology applications*



Summary and outlook

Current work

- Focus on the background functionality development
  - New tropospheric ties
  - Sw tools for NWM data processing
  - Background data from ECMWF's ERA-Interim (1990-present)
  - Structure in support of extended goals (public/data, web-interfaces etc.)
- Preliminary functionality testing & visualization
  - Rough comparison results (assess the potential)
  - Static visualization (via time-series, geographical maps, total statistics, …)

Outlook

- Focus on the foreground user-friendly interfaces
  - Web-interfaces with on request functions
  - DB data extractions
  - Dissemination functions etc.
- Focus on detailed results of individual comparison, data souces
  - New data sources (NWM, RAOBS, …)
  - Additional parameters (meteo, gradients, slants)