Tropospheric products of the second GOP European GNSS reprocessing (1996-2014)

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EUREF GNSS 2nd reprocessing (1996-2014)

- **New realization of European Terrestrial Reference System (ETRS)**
  consistent with International Terrestrial Reference System (ITRS)
  with model/products of **International GNSS Service (IGS)**
  International Earth Rotation and Reference Systems Service (IERS)
- Responsibility of International Association of Geodesy (IAG)
  sub-commission for **Reference Frame in Europe (EUREF)**
- Implemented using **EUREF Permanent Network (EPN)**
  consisting of about 300 European GNSS stations
- Based on contributions of homogenously re-processed data (1996-2014)
  - All EPN stations:
    - **ASI/E-GEOS – Italian Space Agency (Gipsy/Oasis)**
    - **GOP – Geodetic Observatory Pecný (Bernese V52)**
    - **MUT – Military University of Technology (GAMIT)**
  - EPN sub-network:
    - **LPT – Swisstopo (Bernese V52)**
    - **IGN – Instituto Geografico National (Bernese V52)**
- Contributions combined by 3 **EUREF coordinators**:

  1) Analysis center, 2) Reference Frame, and 3) Troposphere

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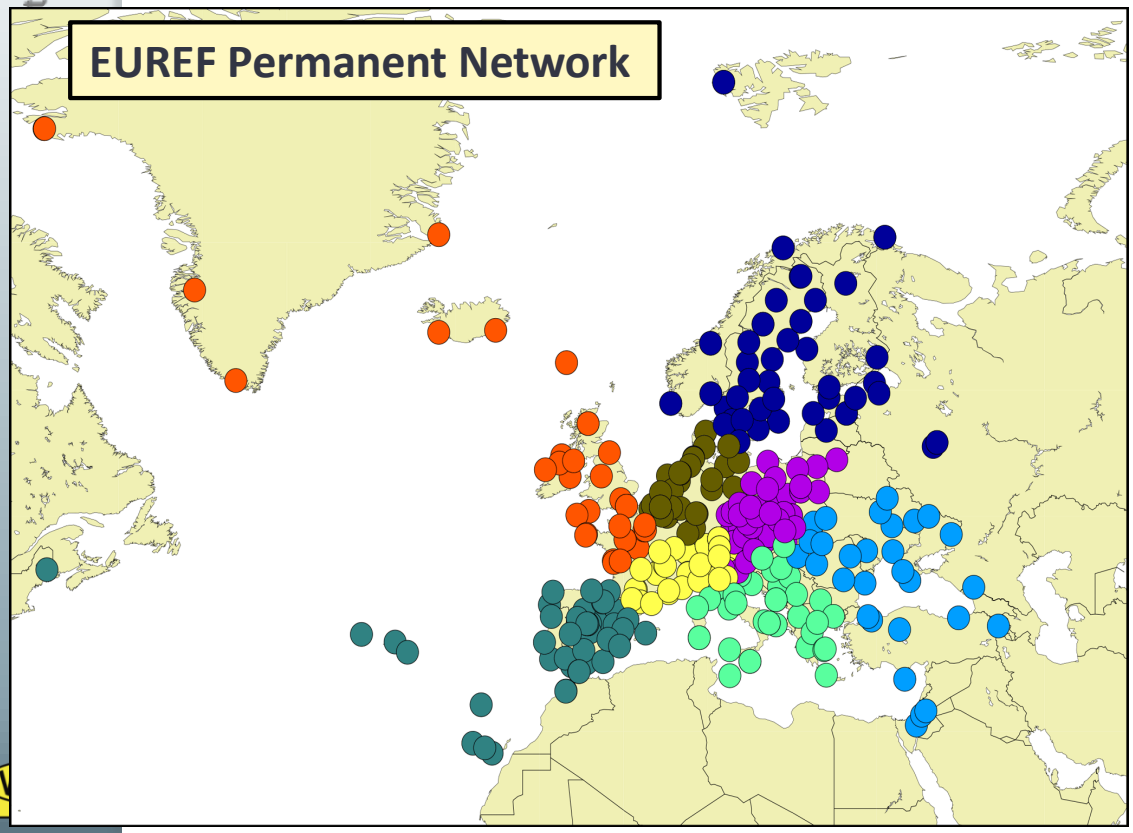
GOP EUREF 2nd GNSS re-processing

- to contribute to new realization of the ETRS **(main goal)**
- to provide a new set of GNSS tropospheric parameter time series (for supporting climate research)

➔ strategy to guarantee a continuity of parameters at midnights

➔ seven variants of GNSS modelling (mainly for troposphere estimates)



GNSS DATA PROCESSING STRATEGY

- Bernese GNSS Software V5.2
- GPS only solution 1996-2014
- E08_1788 absolute antenna model (individual)
- GMF/VMF1 for ZHD + ZWD (1 hour)
- Chen & Herring MF horizontal gradients (6 hours)
- Network: full EPN following predefined intervals
- Reference frame: IGb08 (fiducial stations checked)
- Ambiguity resolution: L5+L6, QIF
- Ionosphere: CODE global product (used in AR, HOI)
- Orbits & EOPs: CODE Repro2 products
- IERS2010 conventions, FES2004 ocean tides

→ data cleaning in historical repository

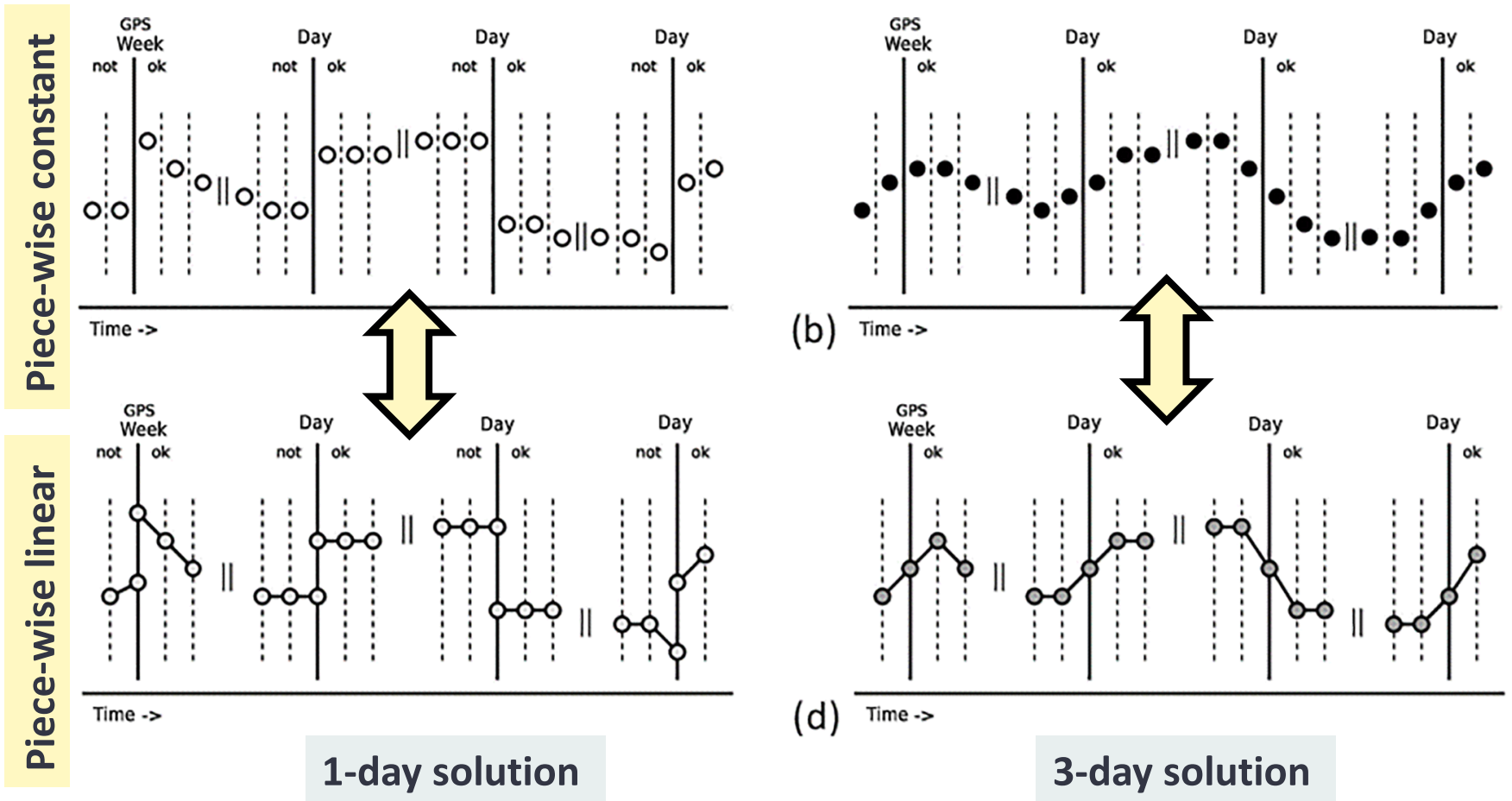
→ product filtering, ZTD homogenization

Troposphere model – old & new strategy

Old: 1-day solution, piece-wise constant troposphere parameter modelling

New: 3-day solution, piece-wise linear troposphere parameter modelling

➔ **to guarantee parameter consistency at day/week midnight boundaries**



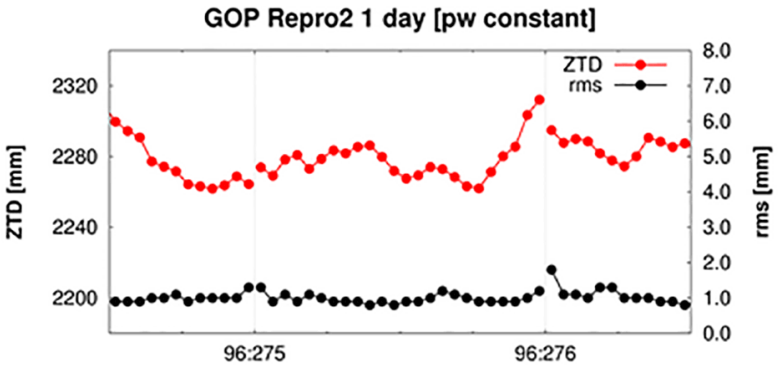
Troposphere model – old & new strategy

Old: 1-day solution, piece-wise constant troposphere parameter modelling

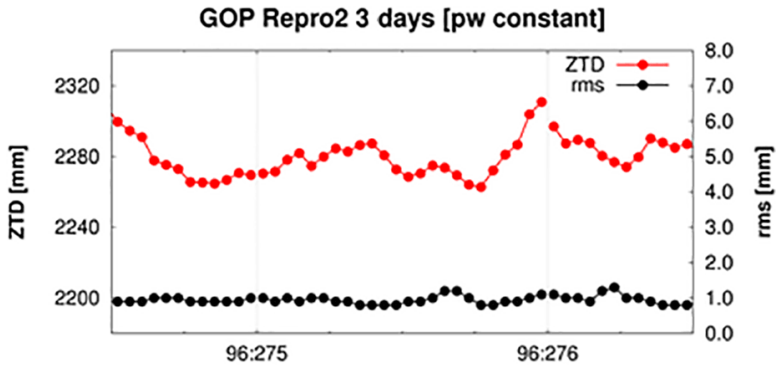
New: 3-day solution, piece-wise linear troposphere parameter modelling

➔ **guarantees consistency during day/week midnight boundaries**

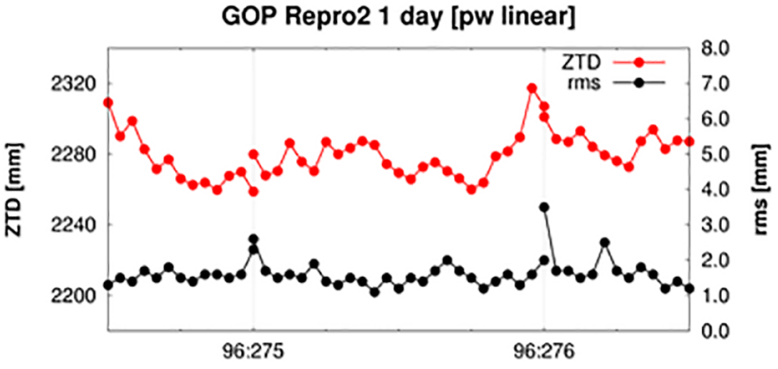
Piece-wise constant



(b)



Piece-wise linear



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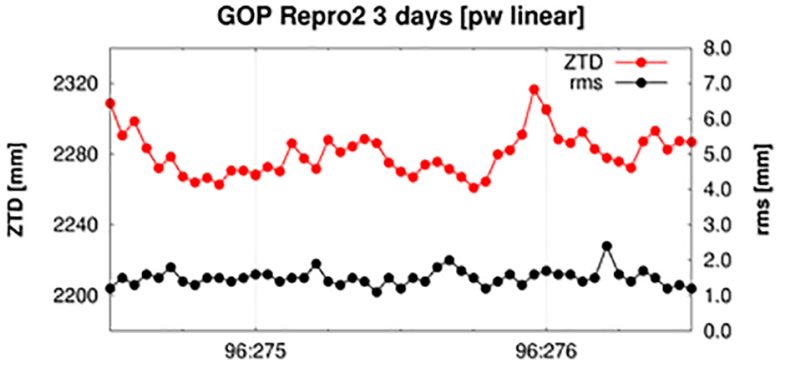

1-day solution

3-day solution

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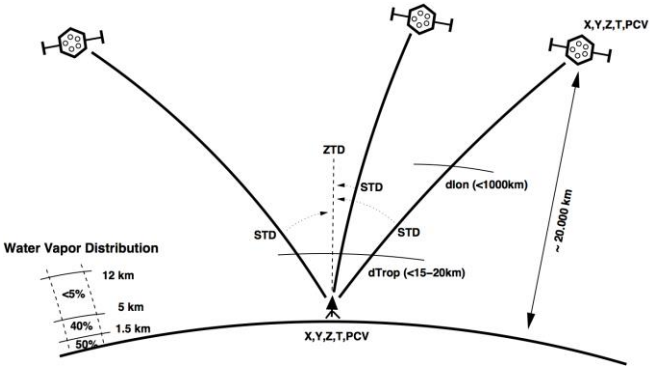
GNSS troposphere model and variants

GNSS model (carrier-phase observations):

$$L_{rec}^{sat} = \sigma_{rec}^{sat} + c \cdot \delta_{rec} - c \cdot \delta^{sat} + \lambda \cdot N_{rec}^{sat} + \Delta_{ion} + \Delta_{tro} + \varepsilon$$



Tropo model: **Symmetric part** **Asymmetric part**

$$\Delta_{tro} = STD = mf_H \cdot ZHD + mf_W \cdot ZWD + mf_G \left[G_N \cos(A) + G_E \sin(A) \right]$$

Strategies used in GOP reprocessing:

Solution ID	Specific settings and differences	Remarks and rationales
GO0	**GMF and 3° cut-off**	**Legacy solution for Repro1**
GO1	VMF1 and 3° cut-off	New candidate for Repro2
GO2	=GO1; 7° cut-off	Impact of elevation cut-off angle
GO3	=GO1; 10° cut-off	Impact of elevation cut-off angle
GO4	**=GO1; atmospheric loading**	**Non-tidal atmospheric loading applied**
GO5	=GO4; higher-order ionosphere	Higher-order ionosphere effect not applied
GO6	**=GO4; 24-hour gradients**	**Tropospheric gradients in 24-hour sampling**

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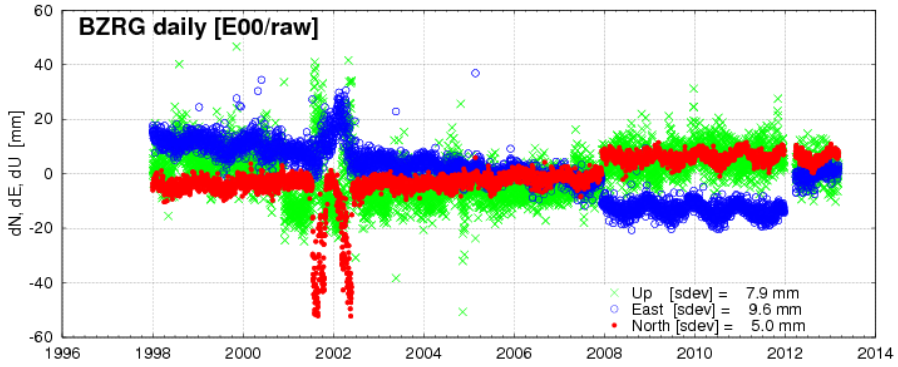
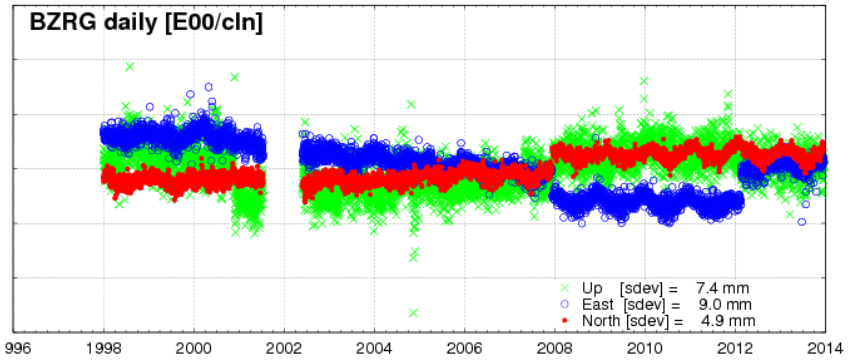
GNSS data quality issues

Coordinates repeatability

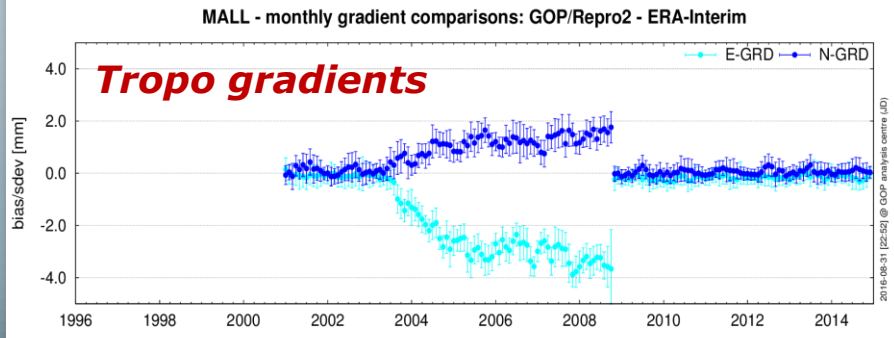
→ various problems observed from daily/weekly coordinates

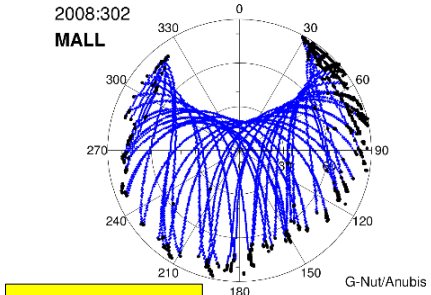




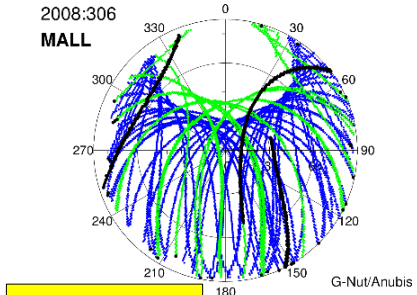
GNSS tropospheric gradients (GRD)

→ sensitive to asymmetry of GNSS data at low-elevation angles





Before replacement



After replacement

Assessment of coordinate repeatability

A. Vertical repeatability was reduced from 4.14 to 3.73 mm with using VMF1 MF, a priori ZHD and non-tidal atmospheric loading corrections

B. Raising the elevation cut-off angle from 3° to 7° and then to 10° increased repeatability of coordinates

C. No improvements: 2nd/3rd ionospheric effects/stacking tropo gradients

Solution	North RMS [mm]	East RMS [mm]	Up RMS [mm]	
GOP-Repro1/IGS05	3.01	2.40	5.08	← Previous analyses
GOP-Repro1/IGS08	2.64	2.21	4.94	
GO0	**1.20**	**1.30**	**4.14**	← Legacy solution
GO1	1.23	1.33	3.97	A
GO2	1.24	1.33	4.01	B
GO3	1.26	1.34	4.07	
GO4	**1.14**	**1.24**	**3.73**	← Official contribution
GO5	1.14	1.24	3.73	C
GO6	**1.14**	**1.24**	**3.73**	← Optimal solution

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ZTD assessment: GNSS vs NWM

➔ *Evaluate troposphere parameters with Numerical Weather Model (NWM)*

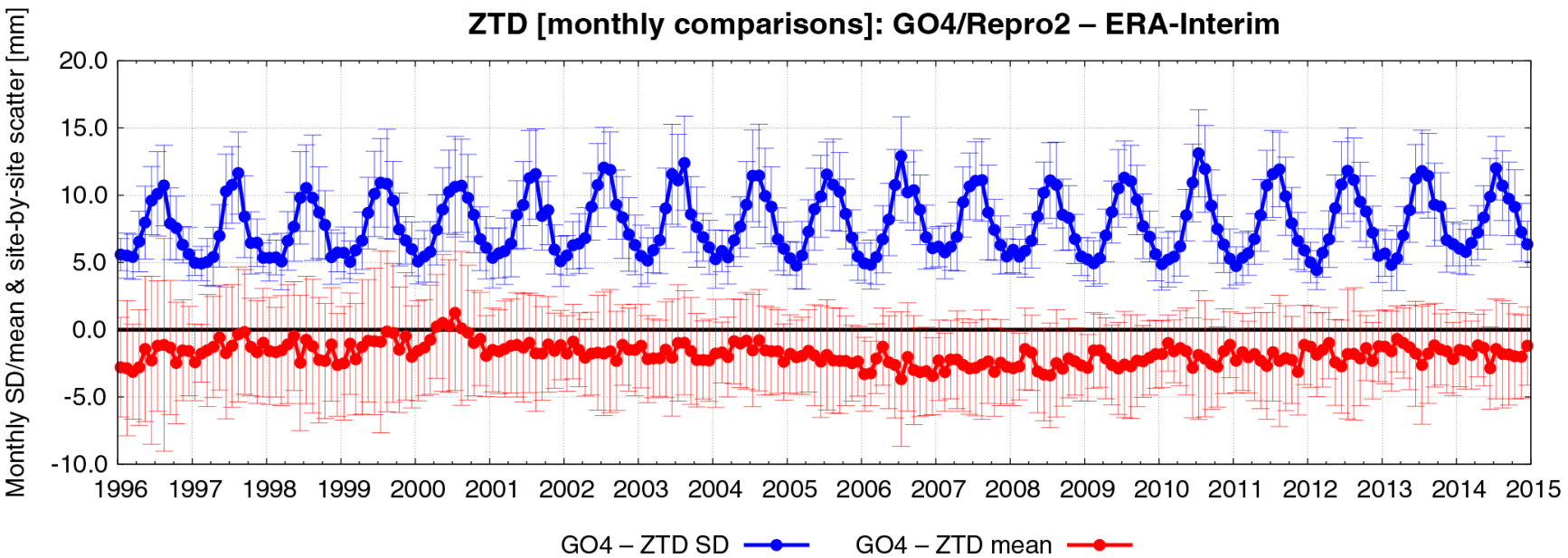
Parameters: ZTD + N/E-gradients

NWM: global 1° × 1° ECMWF's ERA-Interim reanalysis (Dee et al. 2011)

Period: 1996-2014, initially pre-selected 30 EPN stations

Software: using GFZ's ray-tracing software (Zus et al, 2012)

Statistics: mean over all selected stations



ZTD assessment: GNSS vs NWM (2)

➔ *Statistics over all variants w.r.t. to ERA-Interim*

Solution	ZTD bias [mm]	ZTD sdev [mm]	EGRD bias [mm]	EGRD sdev [mm]	NGRD bias [mm]	NGRD sdev [mm]
GO0	-1.5	8.8	-0.04	0.39	+0.01	0.43
GO1	-2.0	8.3	-0.04	0.39	+0.01	0.42
GO2	-1.9	8.4	-0.05	0.41	+0.00	0.45
GO3	-1.8	8.5	-0.08	0.43	-0.01	0.49
GO4	-1.8	8.1	-0.04	0.38	+0.00	0.40
GO5	-1.8	8.1	-0.05	0.38	+0.01	0.40
GO6	-1.8	8.2	-0.04	0.29	+0.01	0.28

- GO1 – positive impact of mapping function using actual NWM (VMF1)
- GO4 – positive impact of non-tidal atmospheric loading on ZTD estimates
- GO6 – positive impact of stacking tropospheric gradients
- GO2,3 – negative impact of increasing elevation angle cut-off on ZTDs
- GO5 – no impact of high-order ionospheric effects modelled

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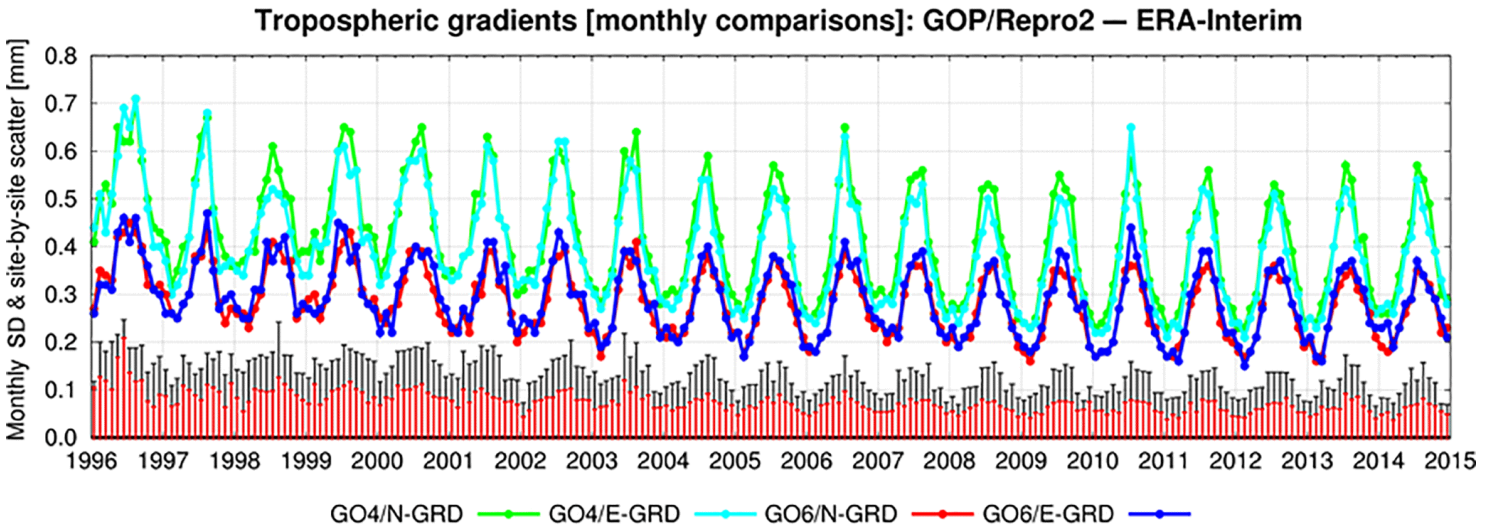
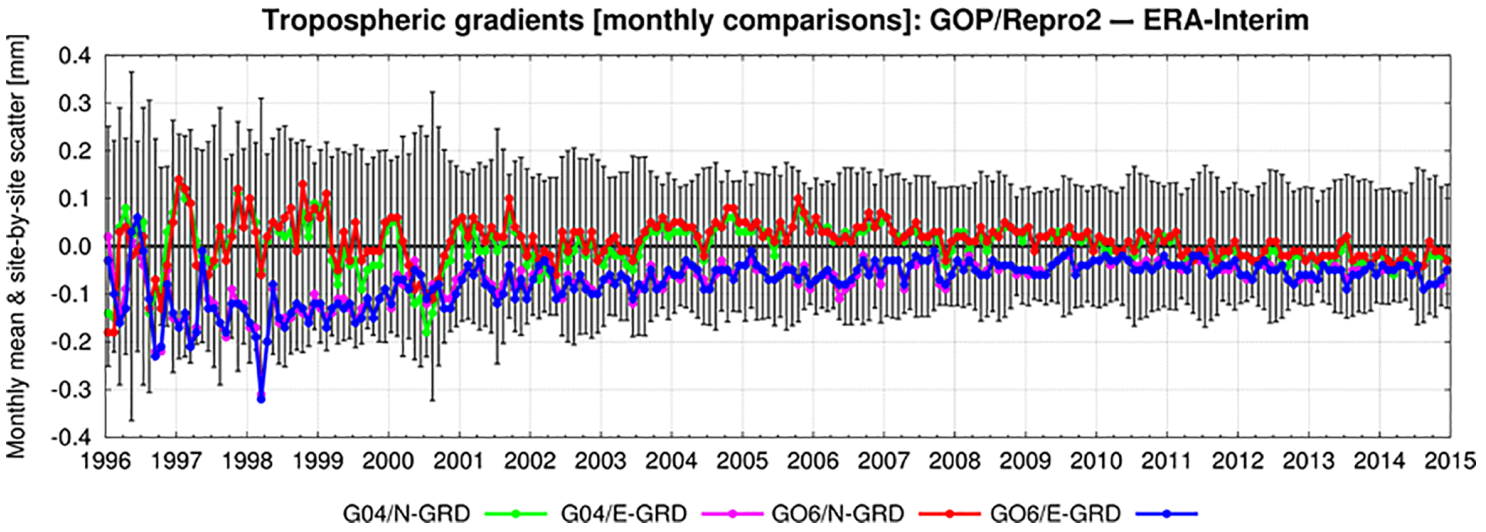
Tropospheric gradients: GNSS vs NWM

➔ *Compared gradients for official (GO4) and optimal (GO6) strategy*

Monthly Std Dev



Monthly Mean



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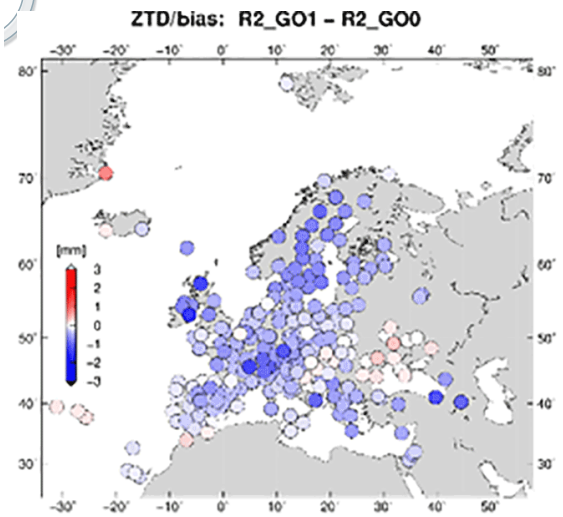
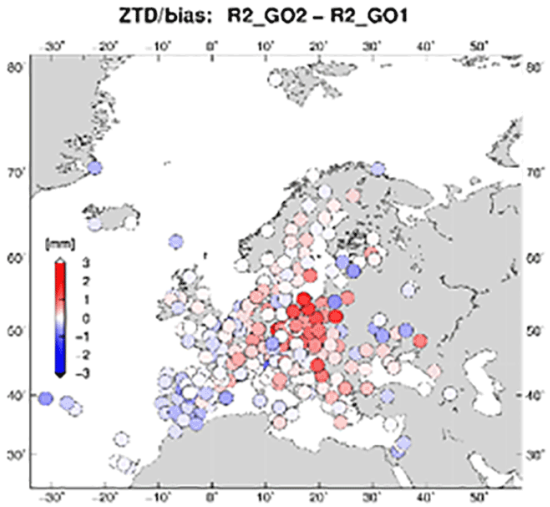
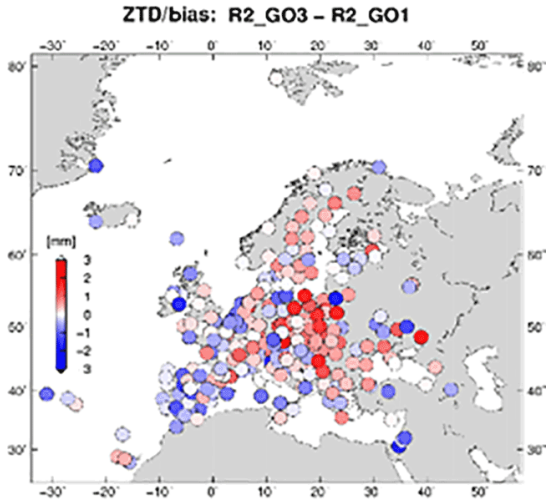
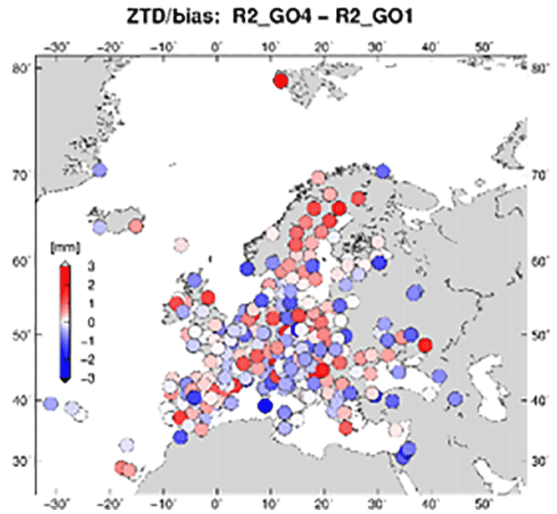
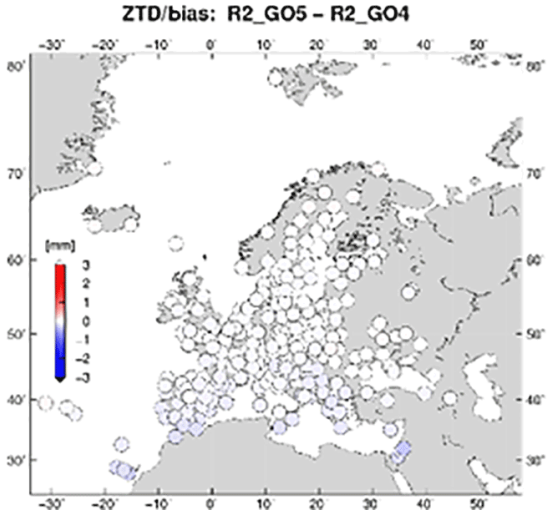
ZTD comparison between variants (BIAS)

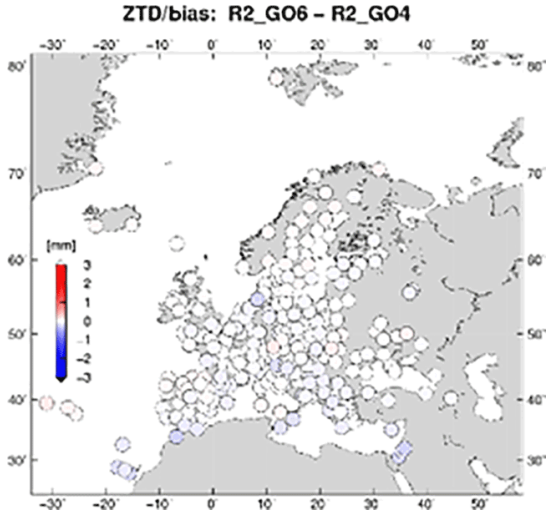












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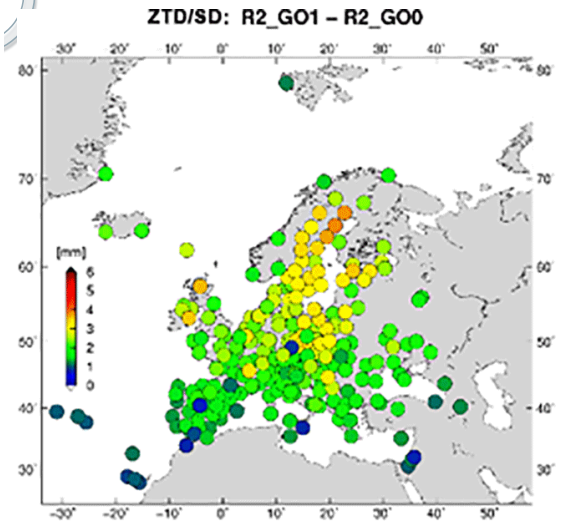
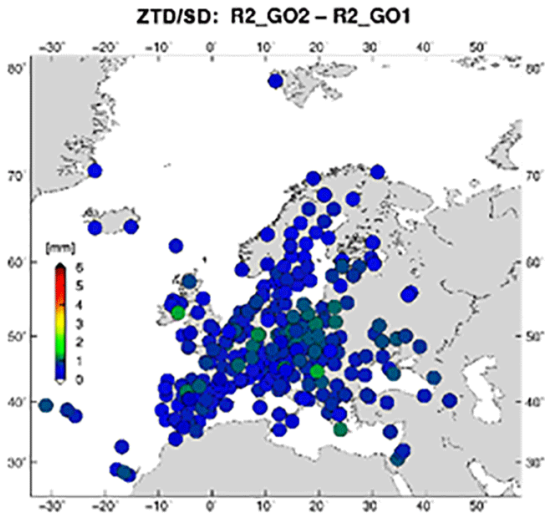
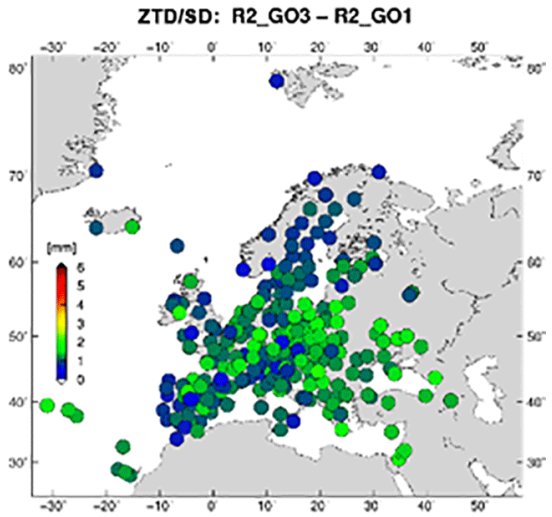
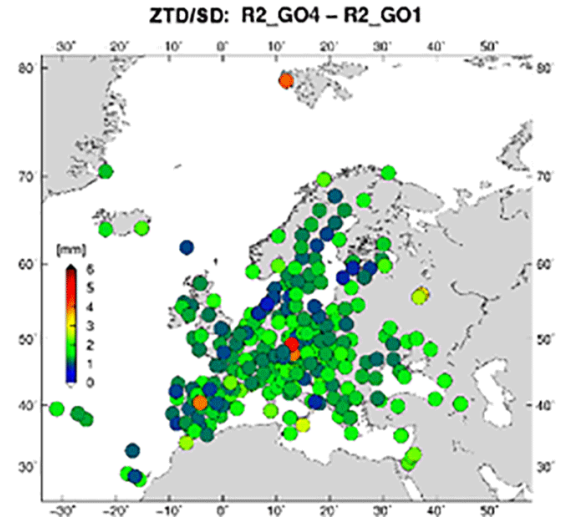
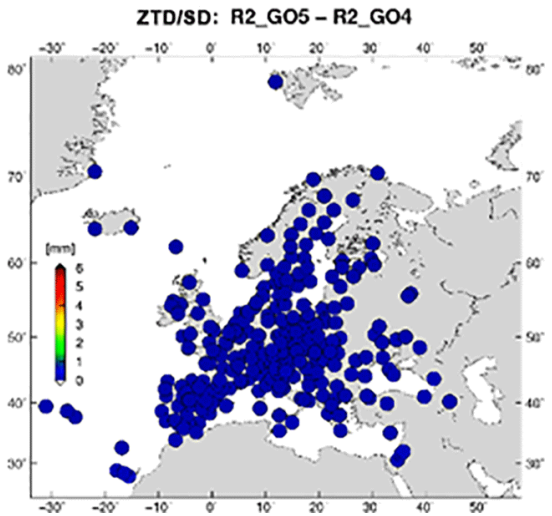
ZTD comparison between variants (SDEV)

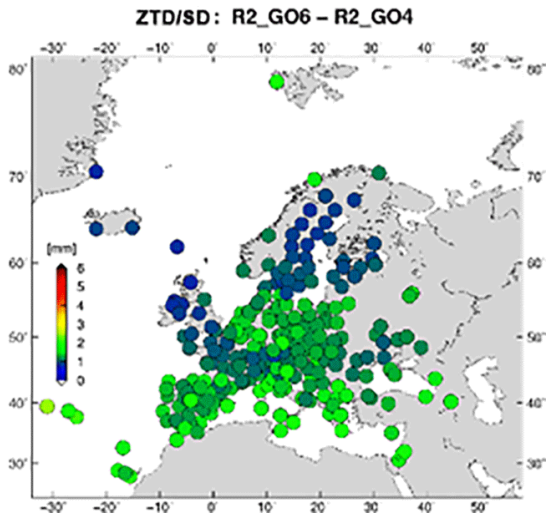












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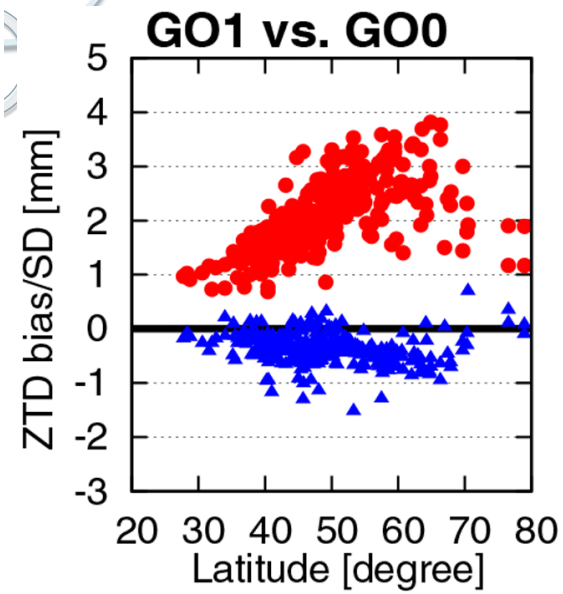
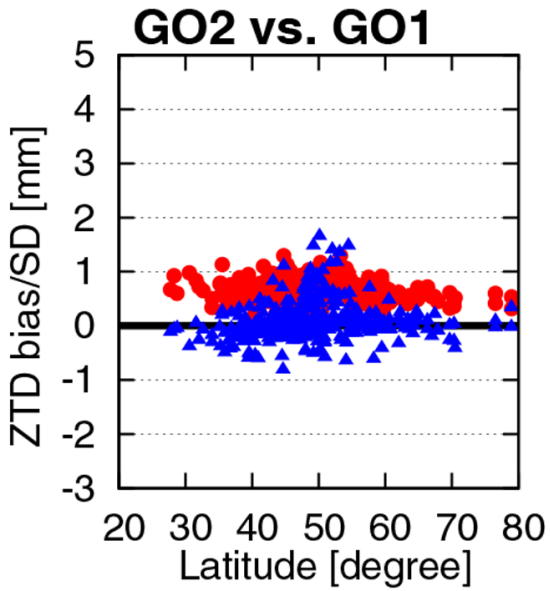
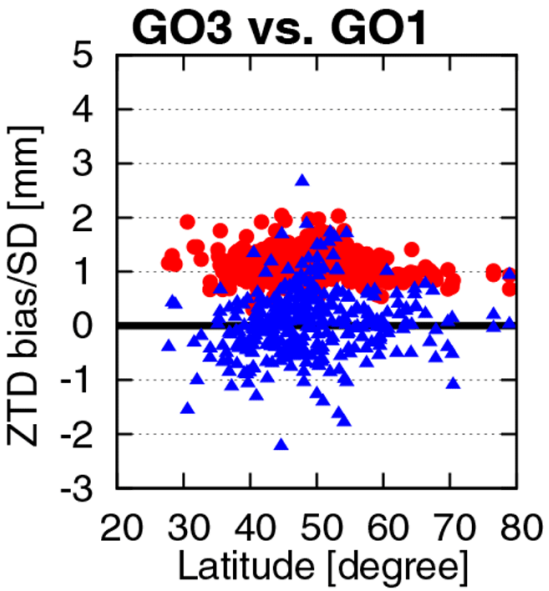
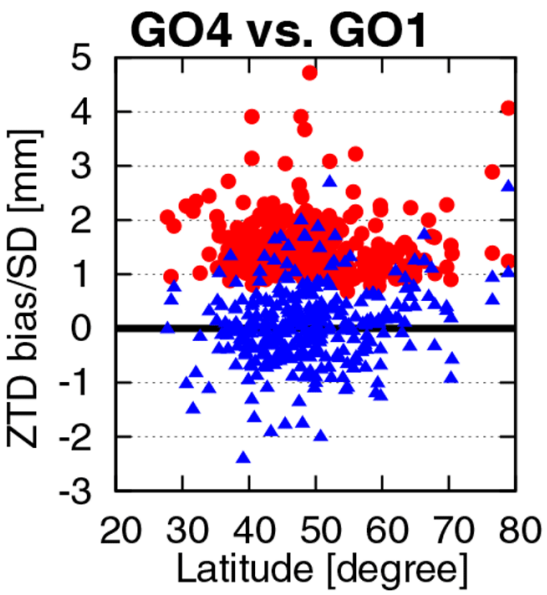
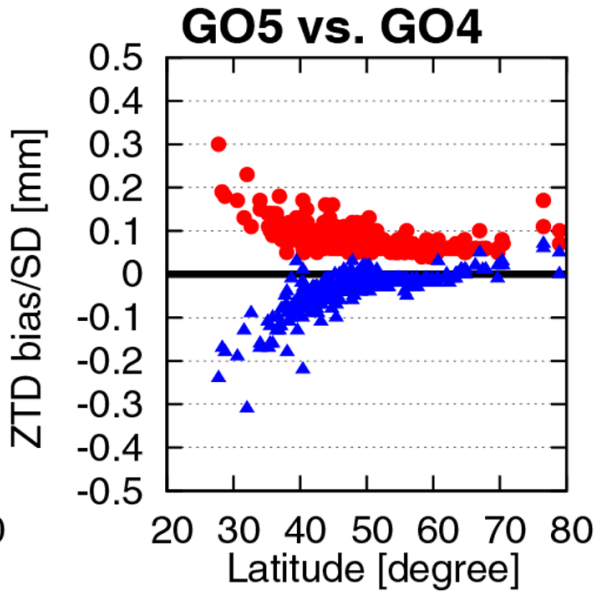
ZTD statistics dependence: LATITUDE

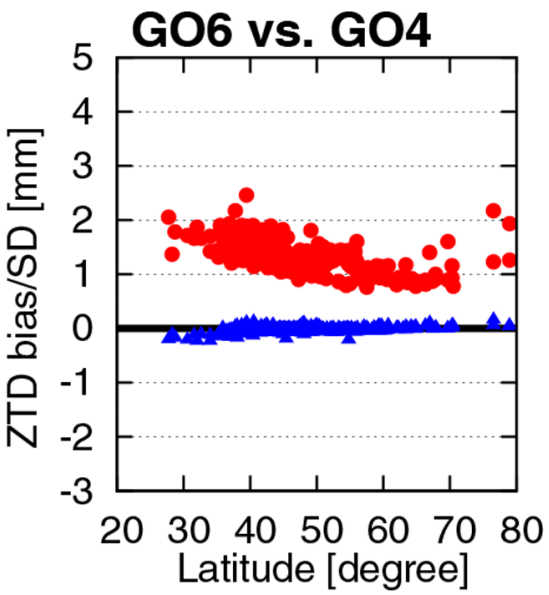












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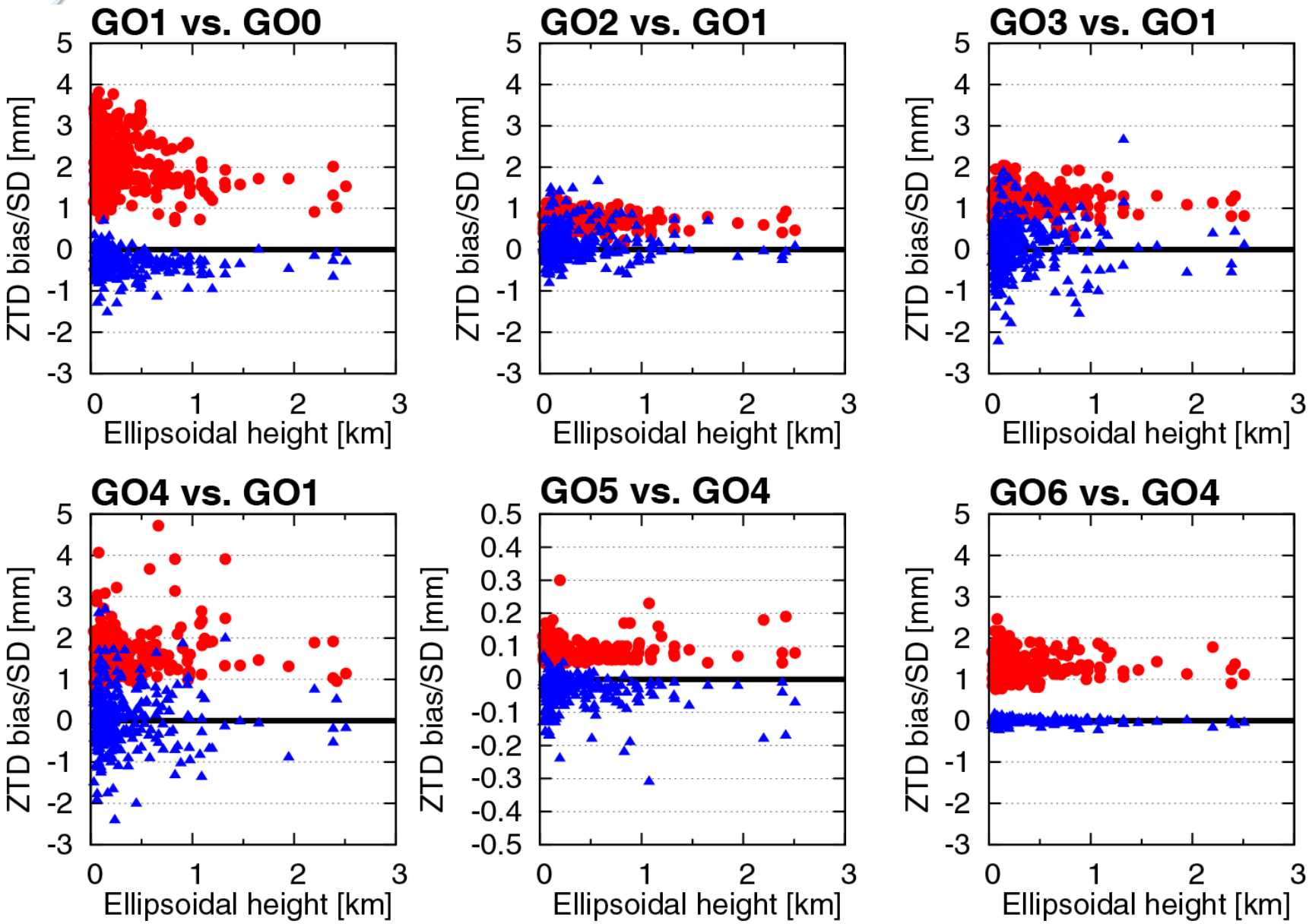
ZTD statistics dependence: HEIGHT



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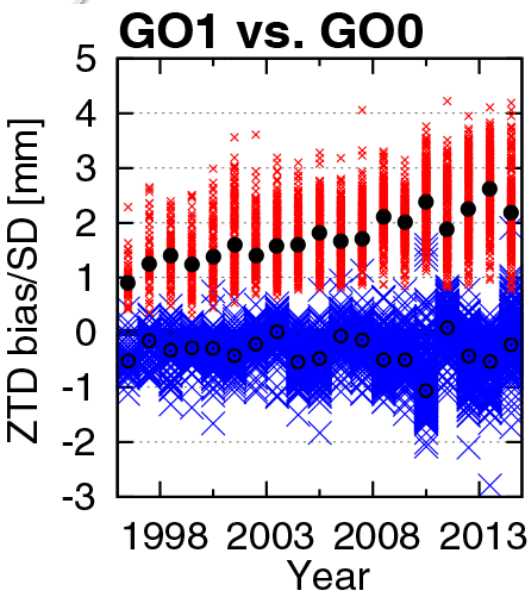
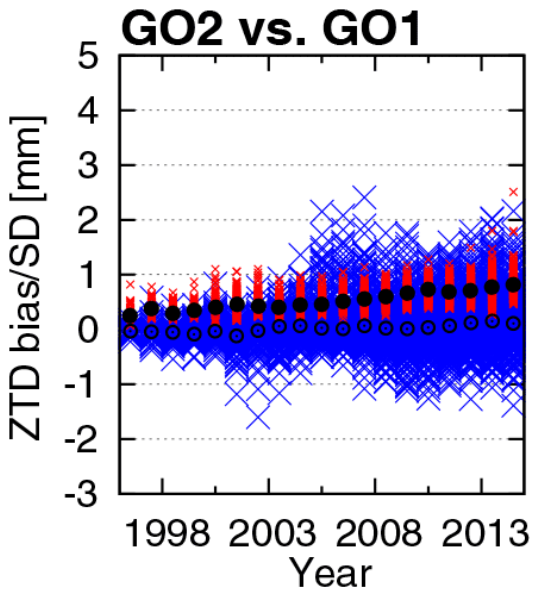
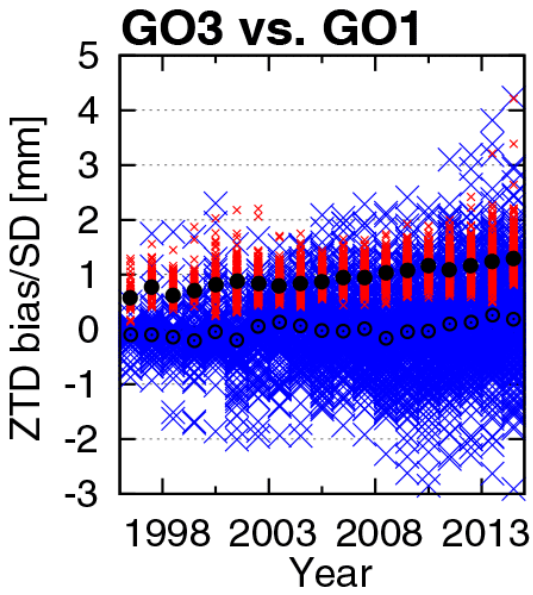
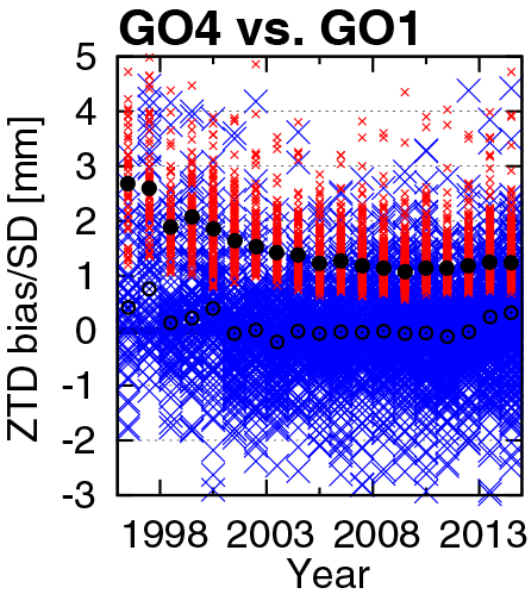
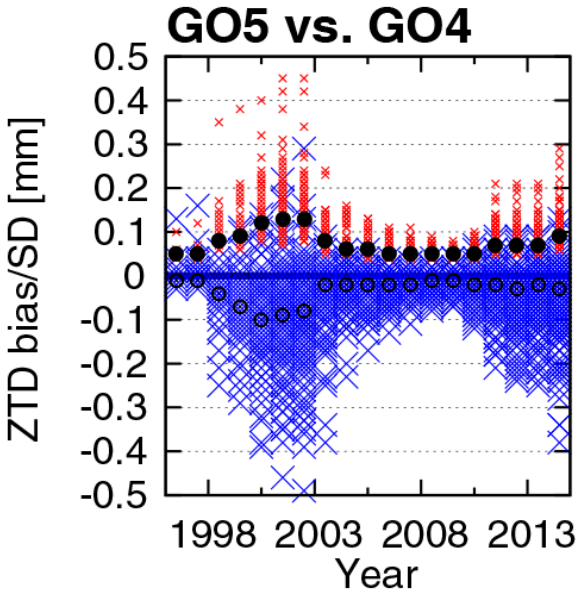
ZTD statistics dependence: TIME

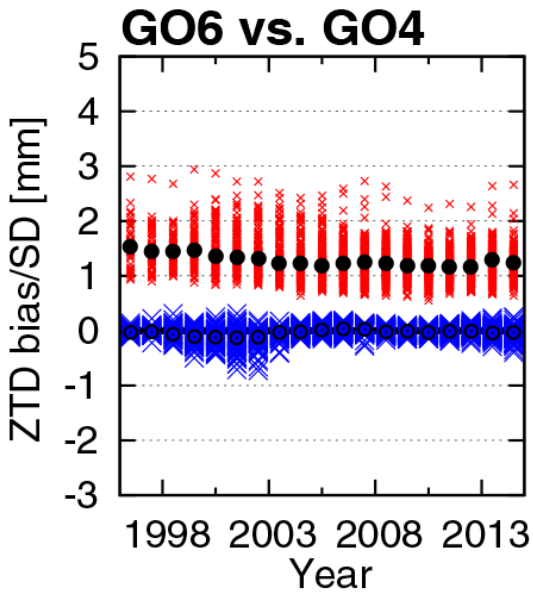












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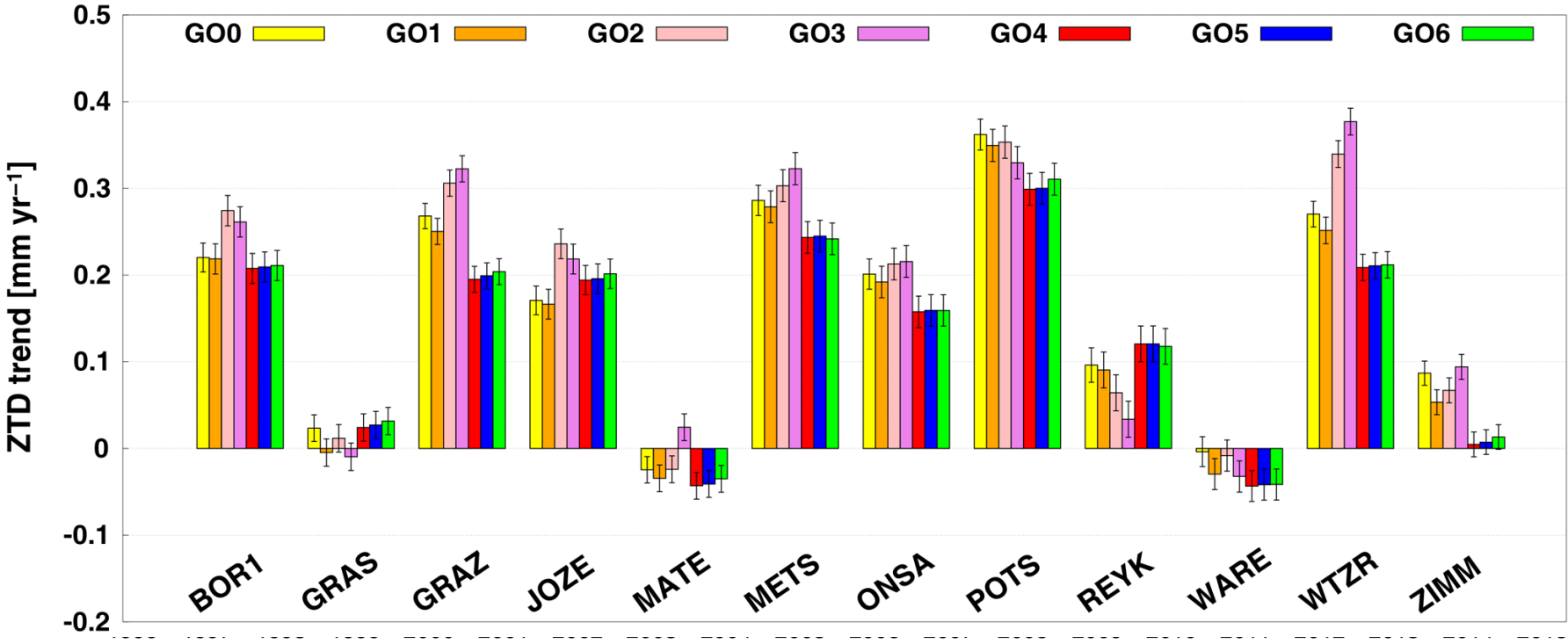
ZTD trends – study impact of strategy

- Tropospheric mapping function (GO1) → rather small
- Elevation angle cut-off (GO2+GO3) → significant (systematic!)
- Non-tidal atm. loading (GO4) → significant (site-specific!)
- Higher-order ionosphere modelling (G05) → fully negligible
- Tropospheric gradients resolution (G06) → almost negligible



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Conclusion

- GOP Repro2 (pan-European) re-analysis contributed to the reference frame maintained by the IAG EUREF sub-commission
- Significant problems of data quality
- New strategy for continuity during day/week boundaries
- Various strategy assessed in terms of coordinate repeatability
- Tropospheric parameters compared to ERA-Interim reanalysis
- Study of impact of strategy on ZTD trends revealed
  - → significant for the station elevation angle cut-off
  - → significant for the non-tidal atmosphere loading modelling
- The product homogenization needed for use in climate study

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Thank you for your attention

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Reference:

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