Comparison of GMF/GPT with VMF1/ECMWF and Implications for Atmospheric Loading

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Introduction

- State-of-the-art troposphere modeling is a prerequisite for the determination of precise station coordinates
- Troposphere modeling of the IGS Final ACs:
  - GMF/GPT: 6 ACs
  - a priori delays from numerical weather models: 2 ACs
  - VMF1: --

- Comparison of **GMF/GPT** with **VMF1/ECMWF**
- Implications of tropospheric mismodeling for **atmospheric loading**

Troposphere Modeling

$$\mathrm{TD}(z) = f_h(z) \cdot \mathrm{ZHD} + f_w(z) \cdot \mathrm{ZWD}$$

TD	Troposphere Total Delay
ZHD	Zenith Hydrostatic Delay (a priori)
ZWD	Zenith Wet Delay (estimated)
z	zenith angle
f_h	hydrostatic mapping function
f_w	wet mapping function

Troposphere Modeling

$$\mathrm{TD}(z) = f_h(z) \cdot \mathrm{ZHD} + f_w(z) \cdot \mathrm{ZWD}$$

Mapping functions:

- Global Mapping Functions (GMF)
- Vienna Mapping Functions 1 (VMF1)

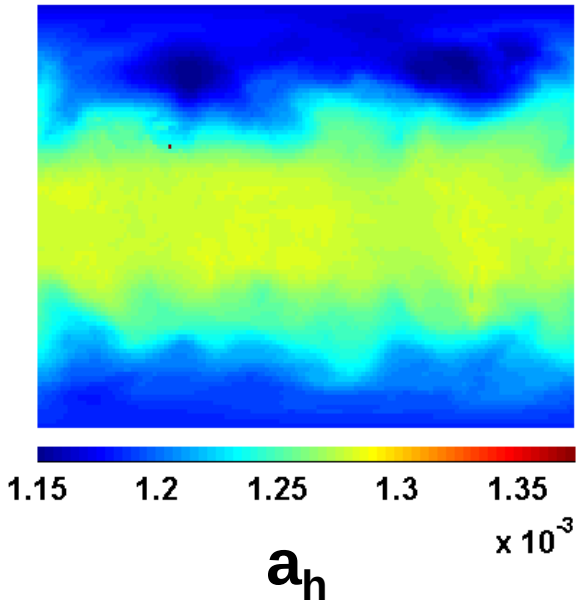
Hydrostatic a priori delays

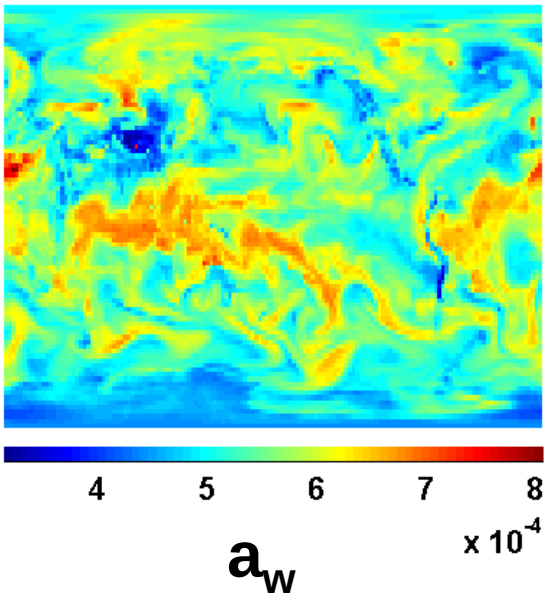
- Global Pressure and Temperature (GPT) model
- Zenith delays from ECMWF weather model data

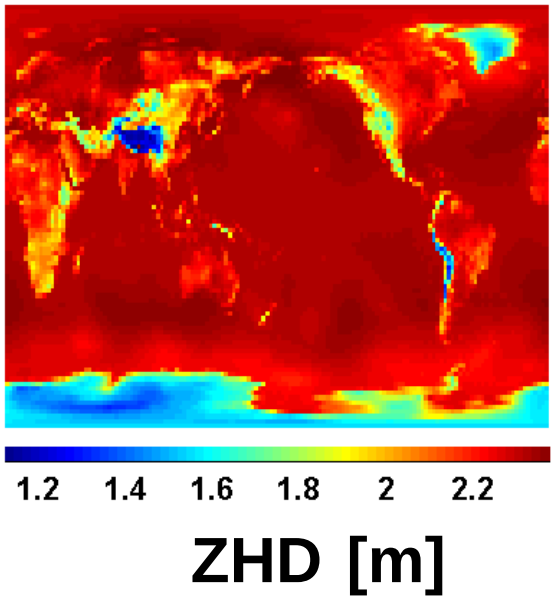
Gridded VMF1/ECMWF ZHD

Mapping Functions: Vienna Mapping Functions 1

A priori zenith delays: ECMWF Zenith Hydrostatic Delays







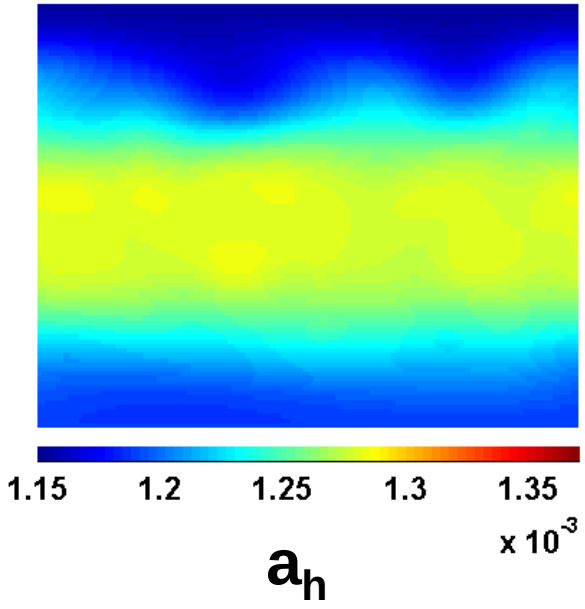
Global grids with 2.0° x 2.5° resolution: a_h a_w ZHD (ZWD)

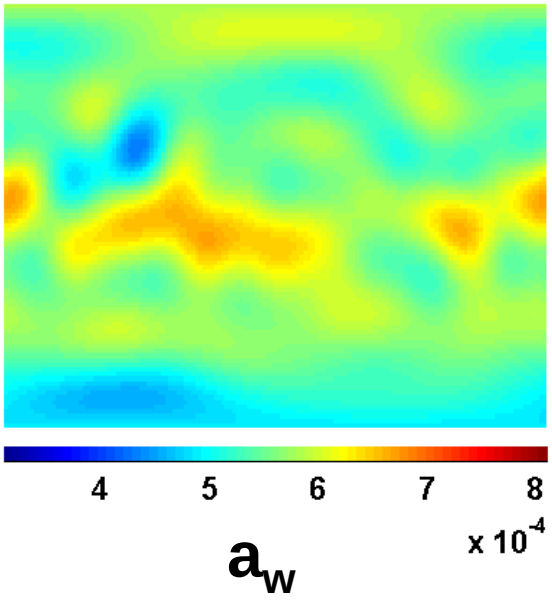
Available since 1992 at 0:00, 6:00, 12:00 and 18:00 UT

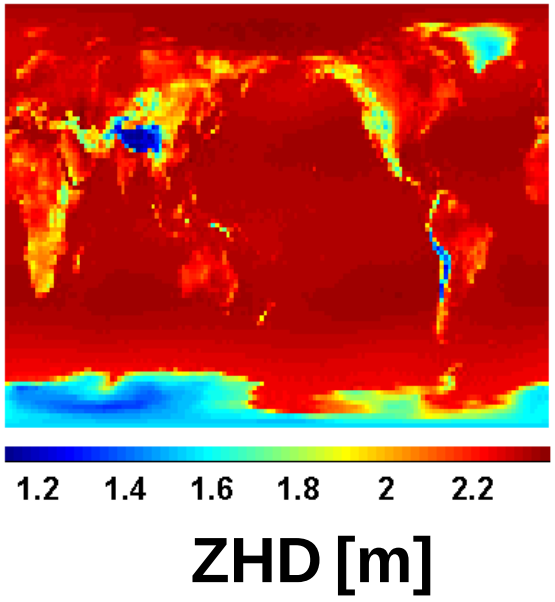
GMF/GPT

Mapping Functions: **G**lobal **M**apping **F**unction

A priori zenith delays: **G**lobal **P**ressure and **T**emperature **M**odel

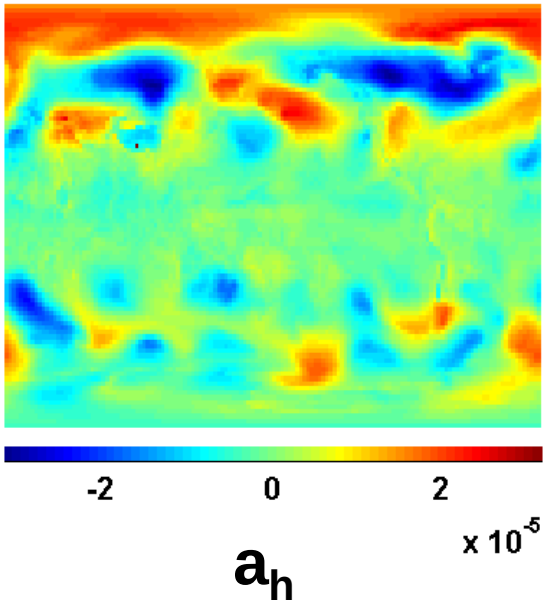




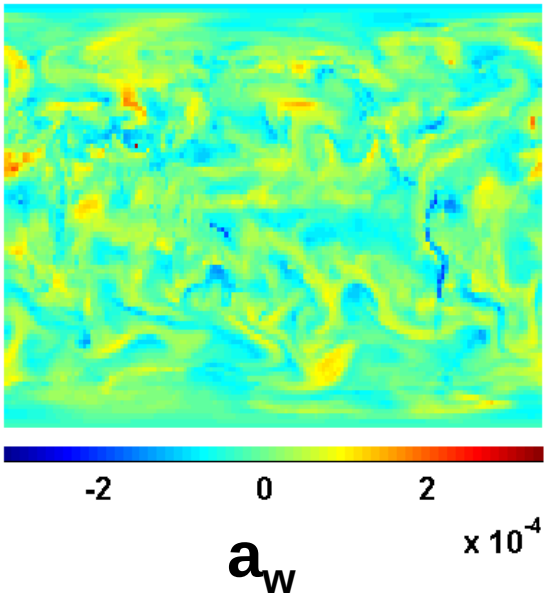


ZHD computed from GPT-pressure with the hydrostatic Saastamoinen equation

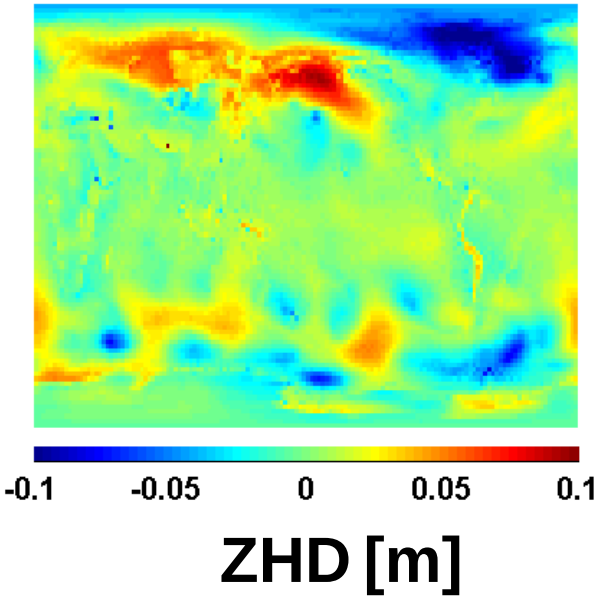
Differences VMF1/ECMWF vs. GMF/GPT



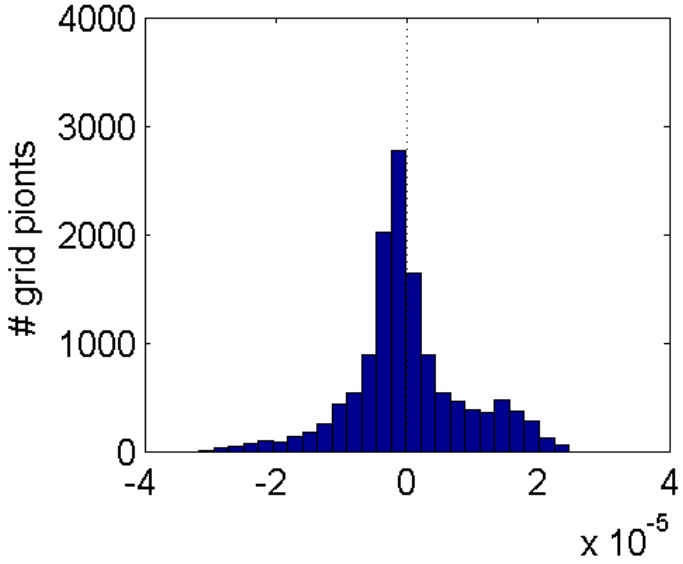
a_h

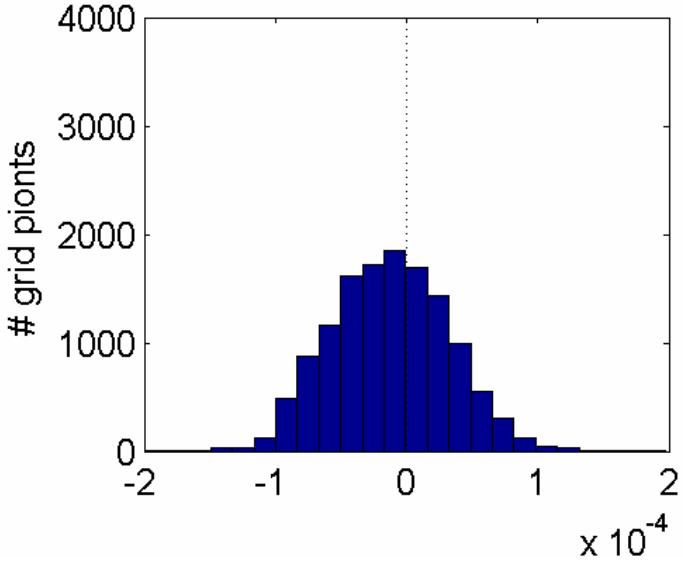


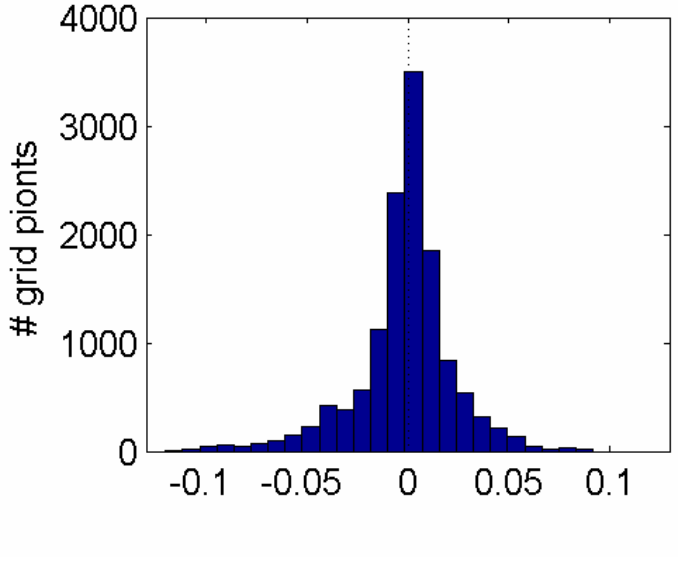
a_w



ZHD [m]







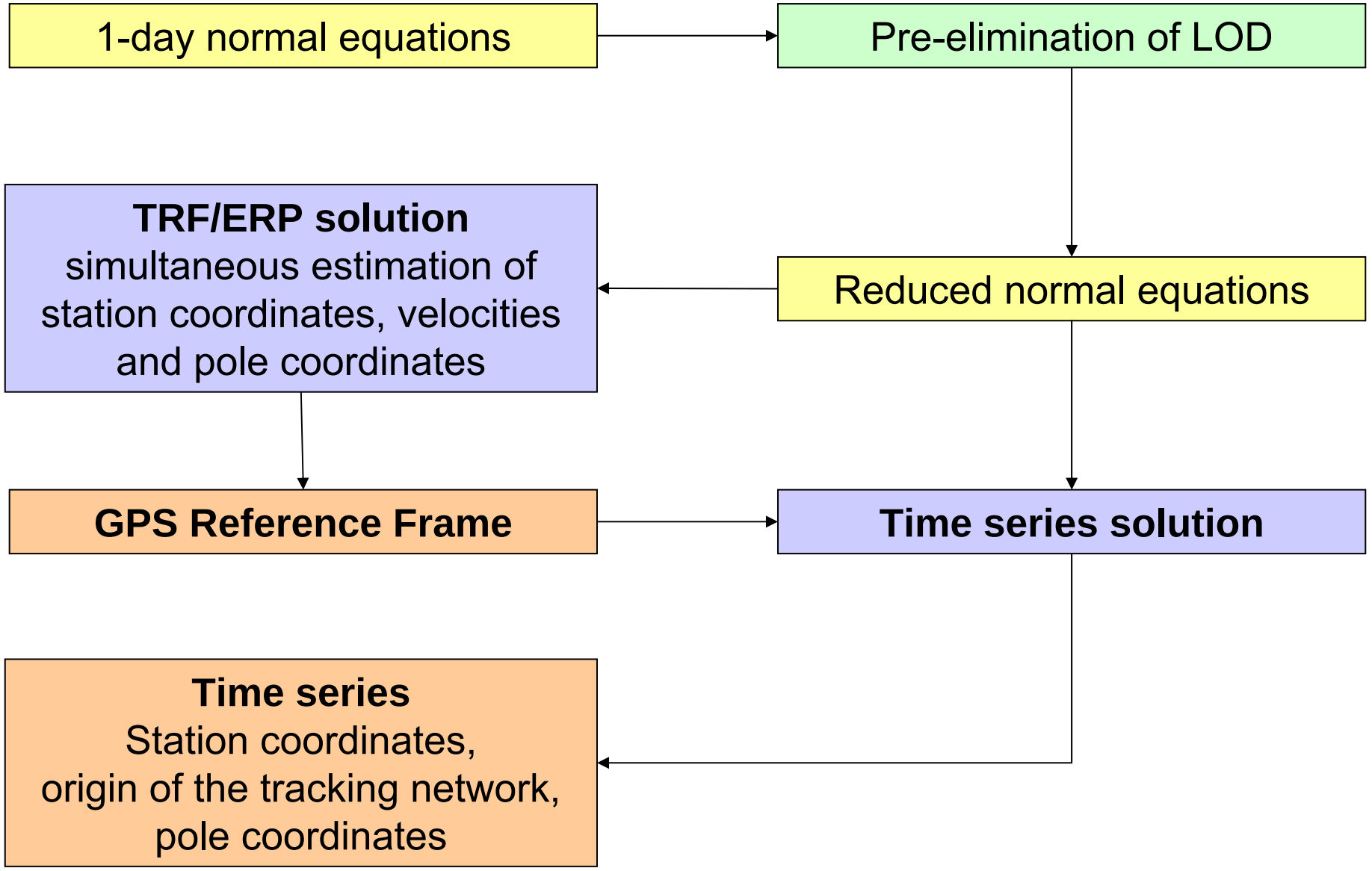
Global GPS Solutions (1)

Complete and homogeneous reprocessing by TU Munich/TU Dresden

- **Altogether 202 stations altogether, up to 160 per day**
- **Datum stations: subset of 66 stable IGb00 stations**
- **Time interval: 1 January 1994 - 31 October 2005 (4322 days)**

Solution	Mapping Function	A priori ZHD
GMF/GPT	GMF	GPT
VMF1/GPT	VMF1	GPT
GMF/ECMWF	GMF	ECMWF
VMF1/ECMWF	VMF1	ECMWF

Global GPS Solutions (2)

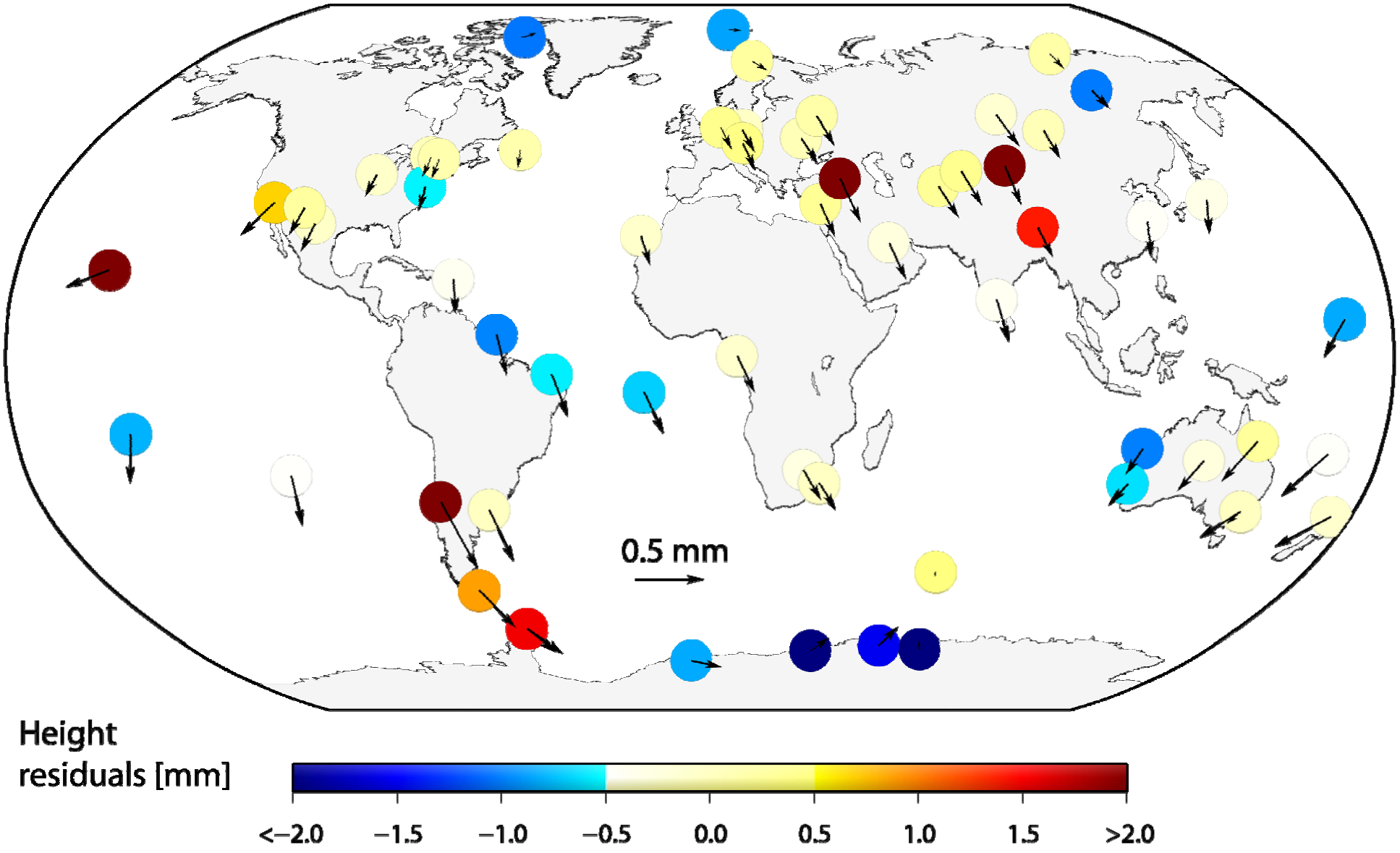


Reference Frame Differences

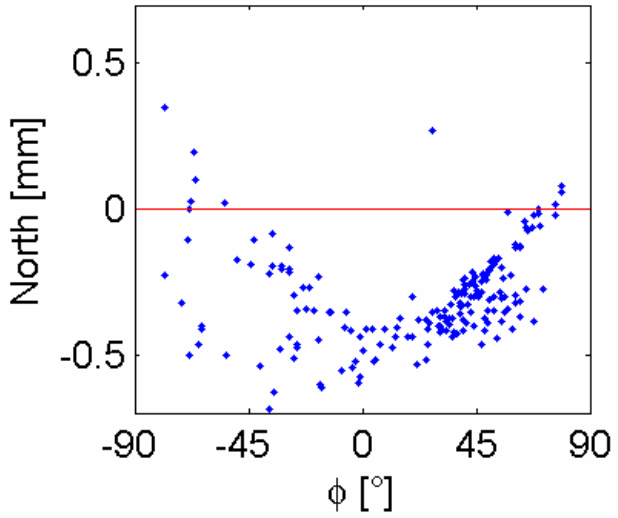
14-parameter similarity transformation between **GMF/GPT TRF** and **VMF1/ECMWF TRF**

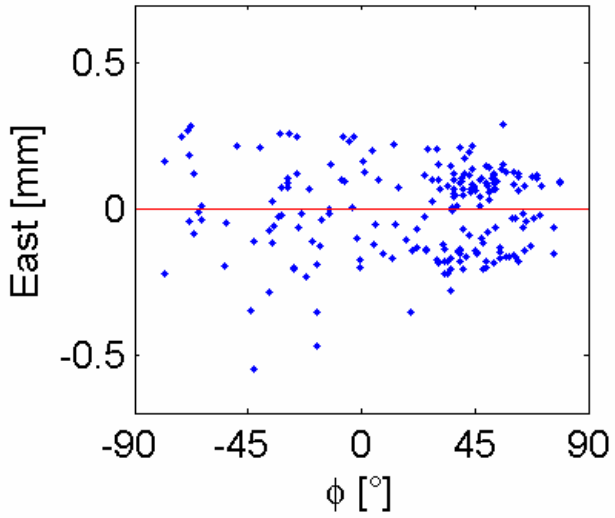
Translation X	0.18	mm	0.02	mm/y
Translation Y	-0.07	mm	0.02	mm/y
Translation Z	0.71	mm	-0.02	mm/y
Rotation X	0.01	mas	0.00	mas/y
Rotation Y	0.00	mas	0.00	mas/y
Rotation Z	0.00	mas	0.00	mas/y
Scale	0.03	ppb	0.00	ppb/y

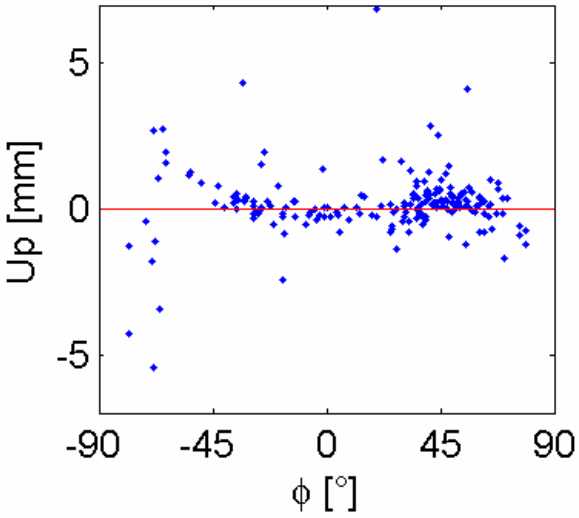
Coordinate residuals

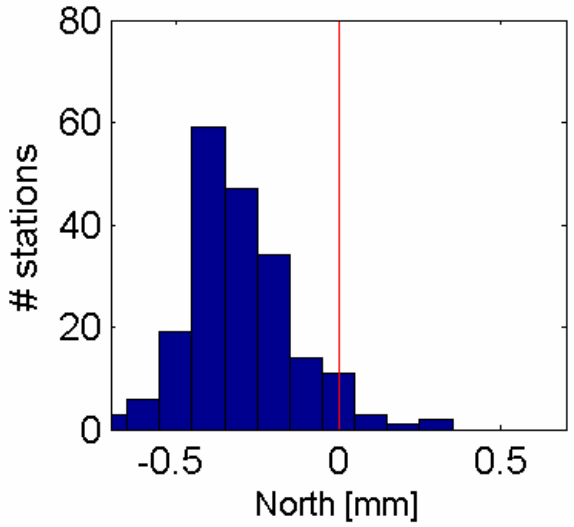


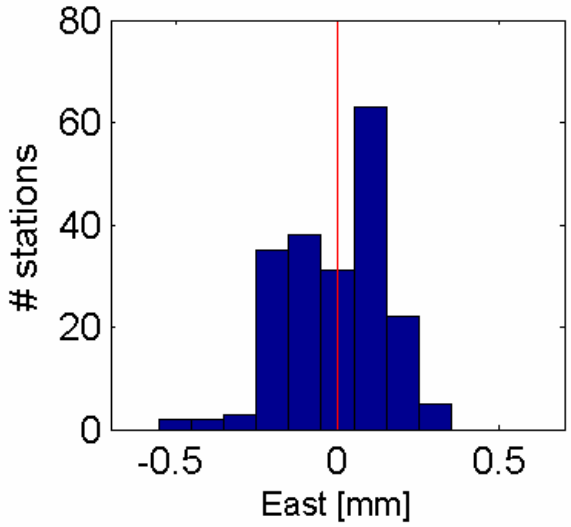
Coordinate residuals

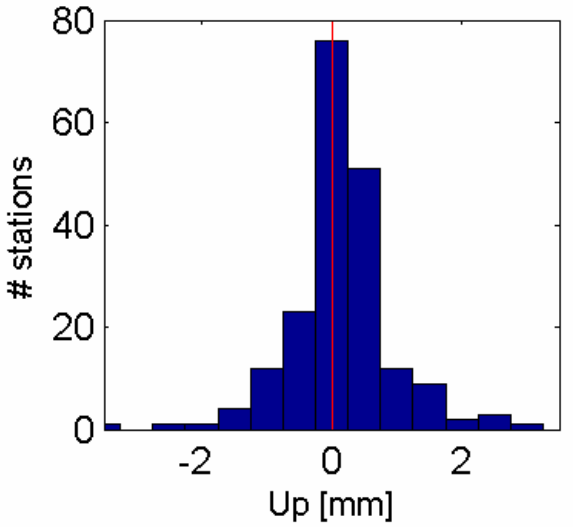










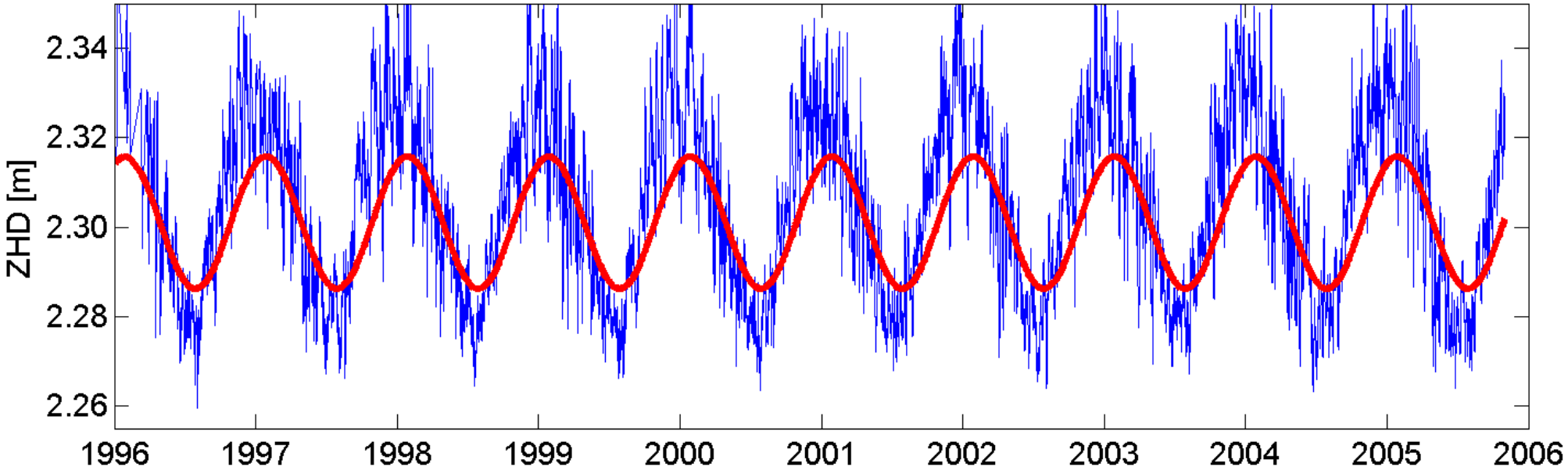


Impact of erroneous ZHD (1)

Differences between the hydrostatic and wet mapping functions introduce a height error if an erroneous ZHD model is applied

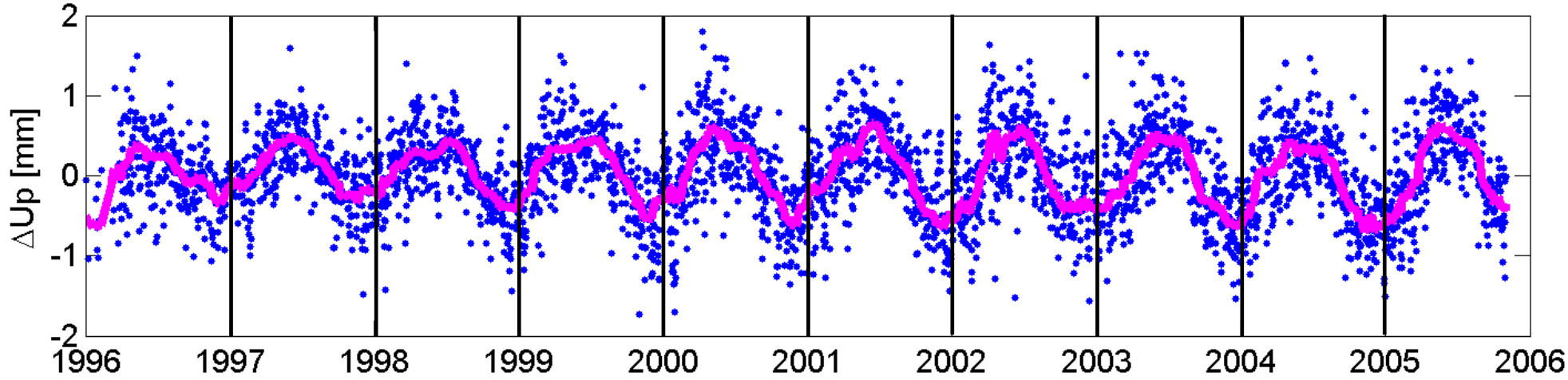
Zenith hydrostatic delay for Wuhan

ECMWF **GPT**

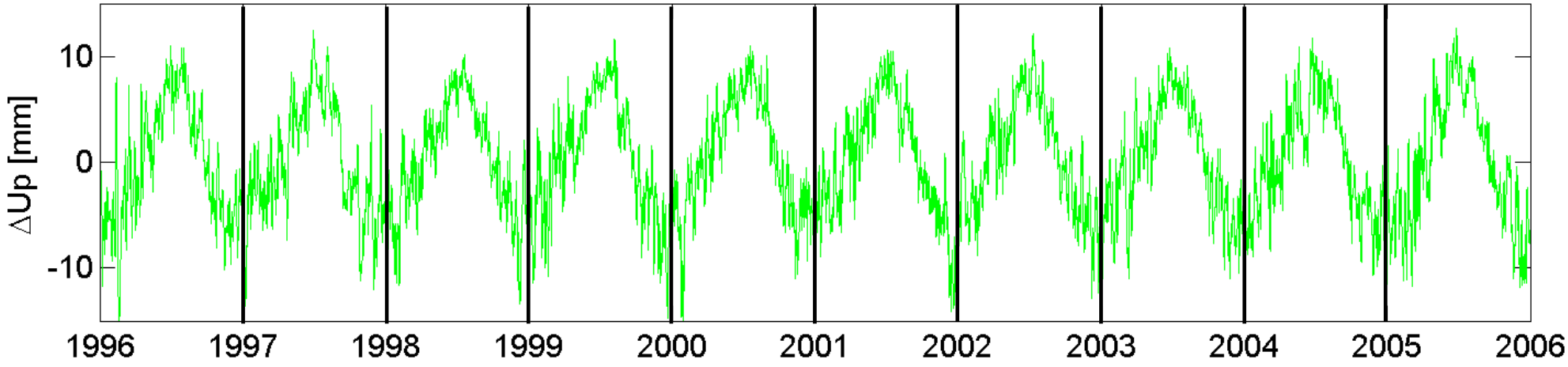


Impact of erroneous ZHD (2)

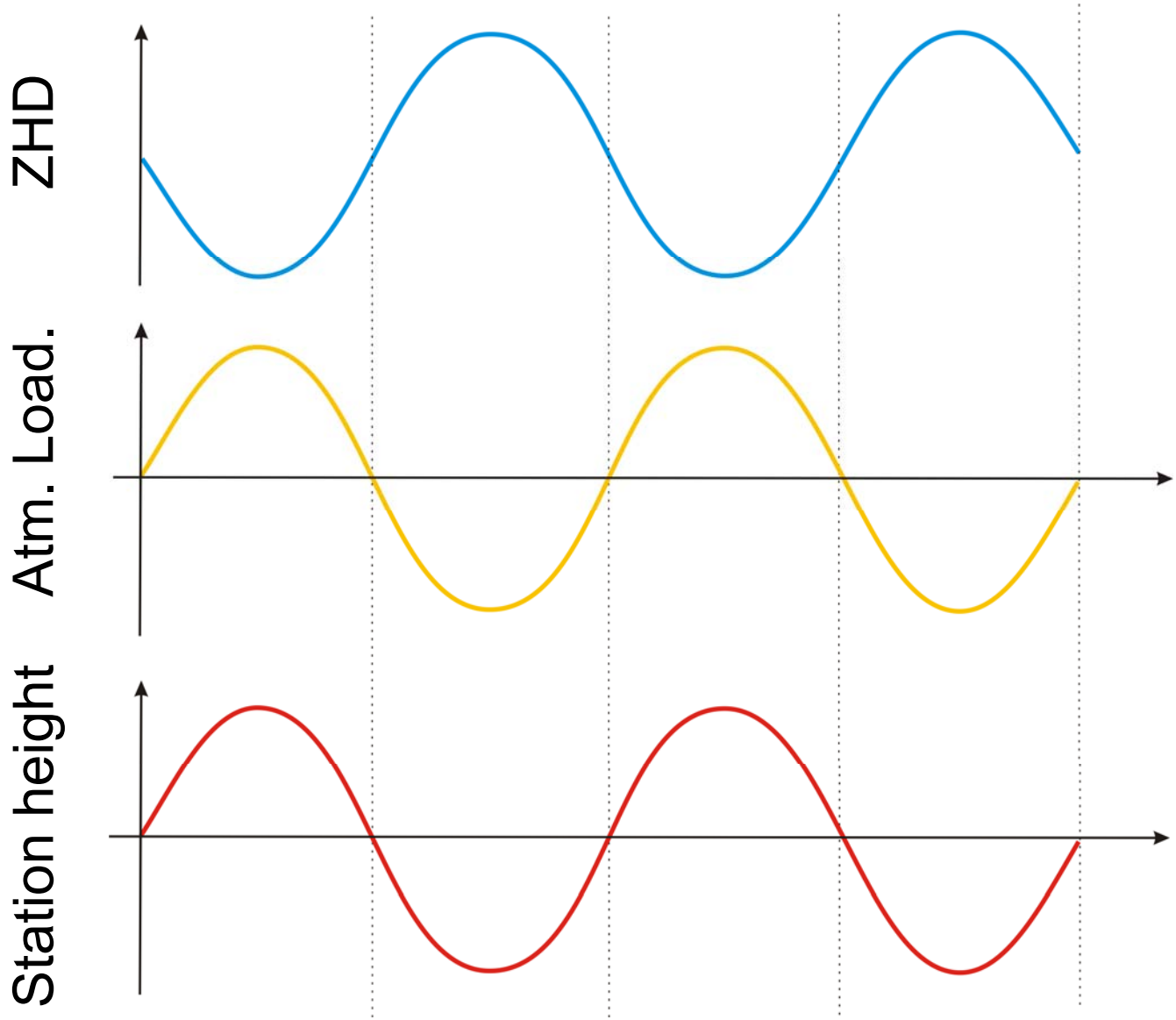
Station height differences ECMWF - GPT



→ **Partial compensation of atmospheric loading**



Ideal Case



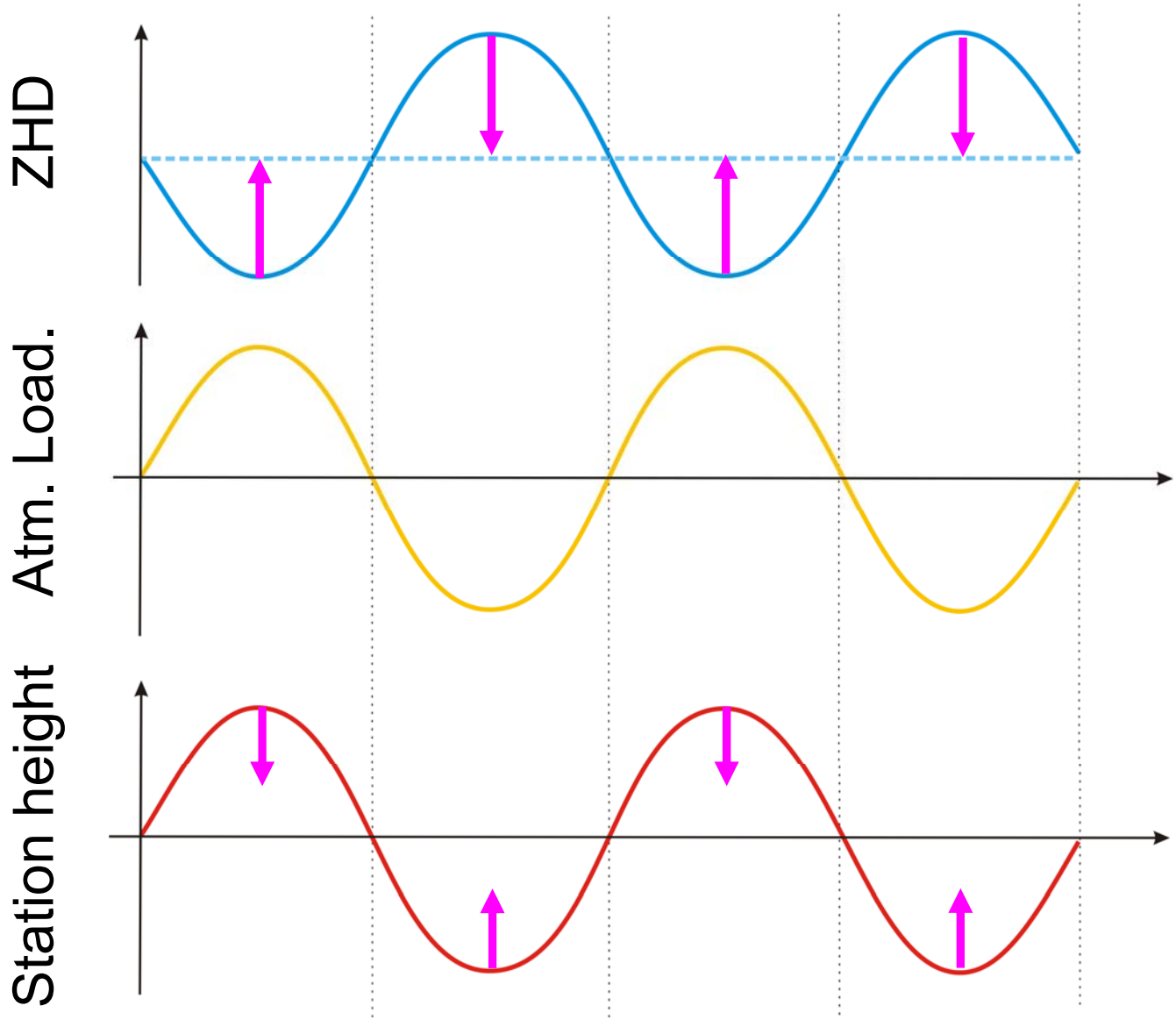
ZHD_{true}

Atmospheric Loading

$H(\mathrm{ZHD}_{true})$

equal to loading signal

Erroneous ZHD



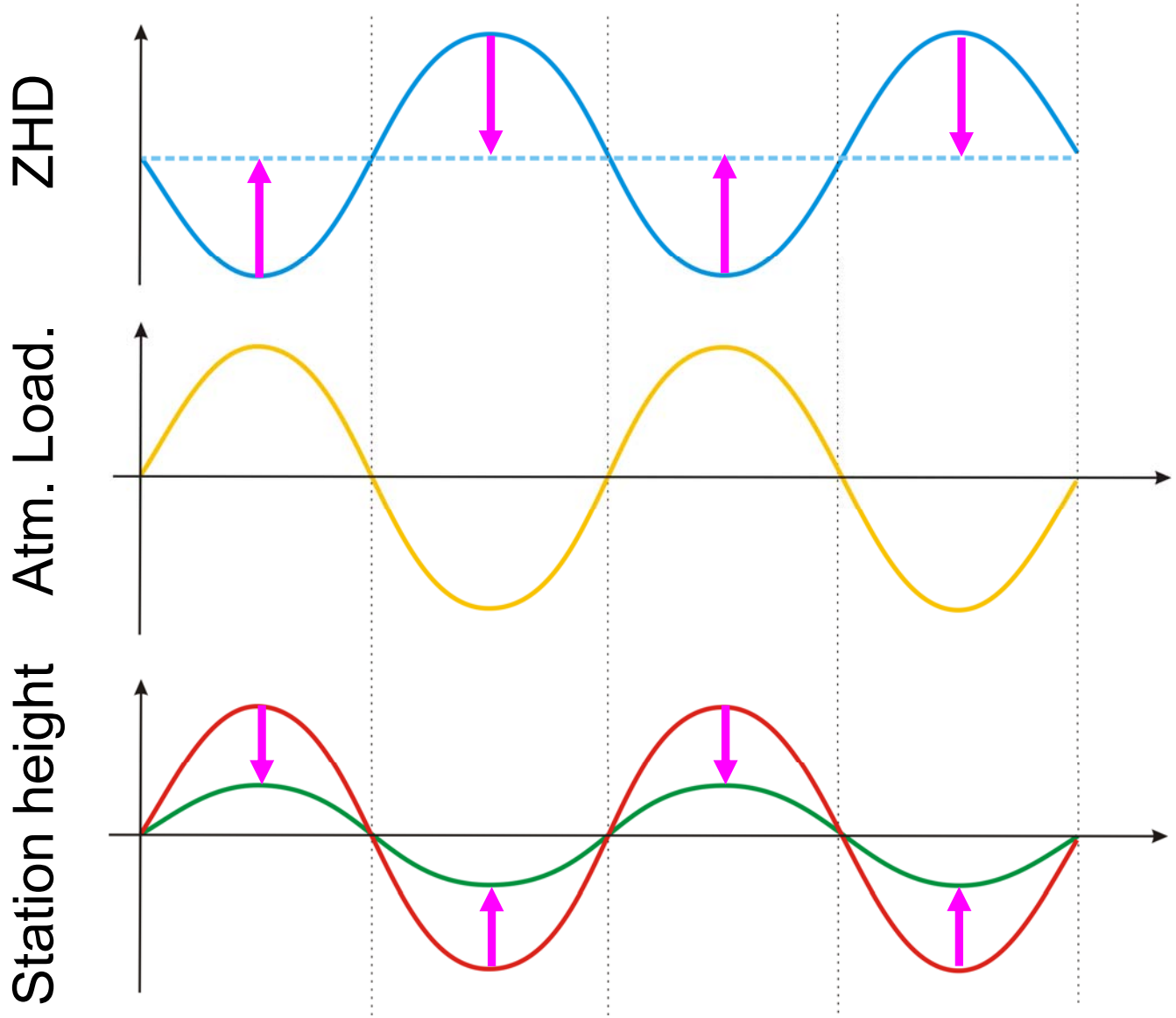
ZHD_{true}

ZHD_{model}

Atmospheric Loading

$H(\mathrm{ZHD}_{true})$

Partial Compensation of Atmospheric Loading (1)



ZHD_{true}

ZHD_{model}

Atmospheric Loading

$H(\mathrm{ZHD}_{true})$

$H(\mathrm{ZHD}_{model})$

Partial Compensation of Atmospheric Loading (2)

- Zenith hydrostatic delay:

$$\mathrm{ZHD} \approx 0.00227768 \cdot P_0$$

- Atmospheric loading effect on station height:

$$\Delta H_{AL} \approx -k \cdot (P_0 - P_{ref})$$

→ **Partial compensation of atmospheric loading**

Without atmospheric **loading correction** we expect:

- **worse** height repeatability for ECMWF ZHDs compared to GPT

With atmospheric **loading correction** we expect:

- **better** height repeatability for ECMWF ZHDs compared to GPT

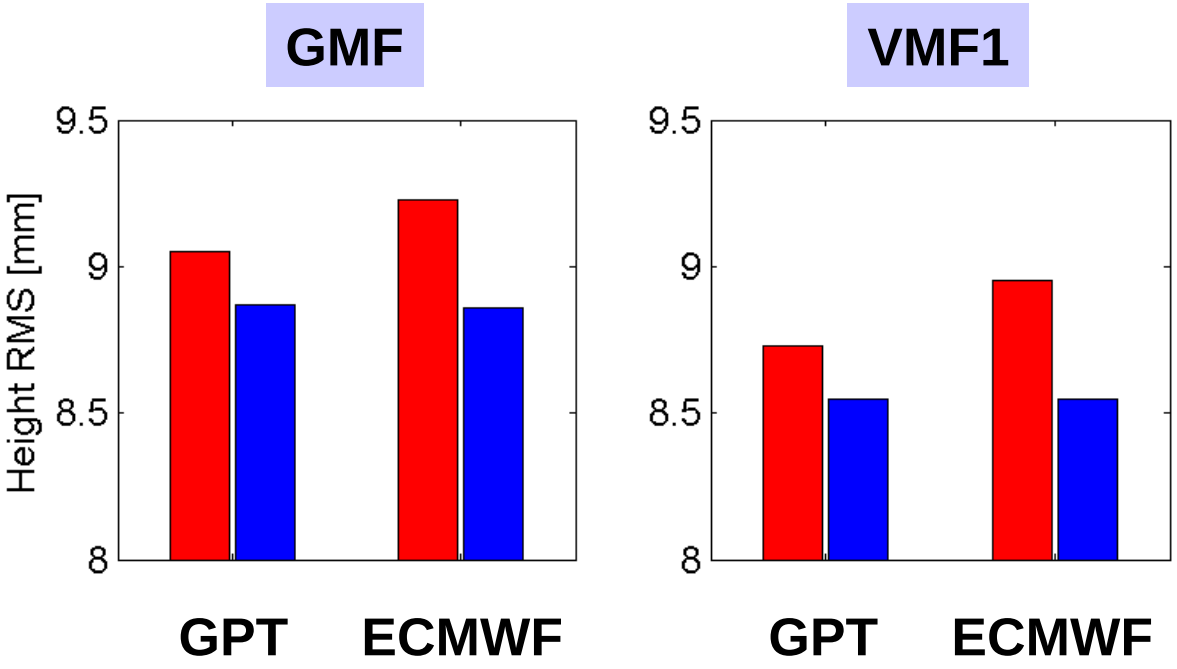
Station Height Repeatabilities

of all stations without applying atmospheric loading corrections

Solution	TRF solution	Weekly sol. 2004
GMF/GPT	9.30 mm	5.35 mm
GMF/ECMWF	9.41 mm	5.46 mm
VMF1/GPT	9.12 mm	5.15 mm
VMF1/ECMWF	9.38 mm	5.28 mm

Mapping Function: VMF1 better than GMF
A priori ZHD: GPT better than ECMWF

Station Height Repeatabilities



reduced set of 12 globally distributed stations **with**/**without** atmospheric loading corrections from Leonid Petrov*

Repeatabilities of solutions with GPT and ECMWF ZHDs are on almost the same level after correcting for atmospheric loading.

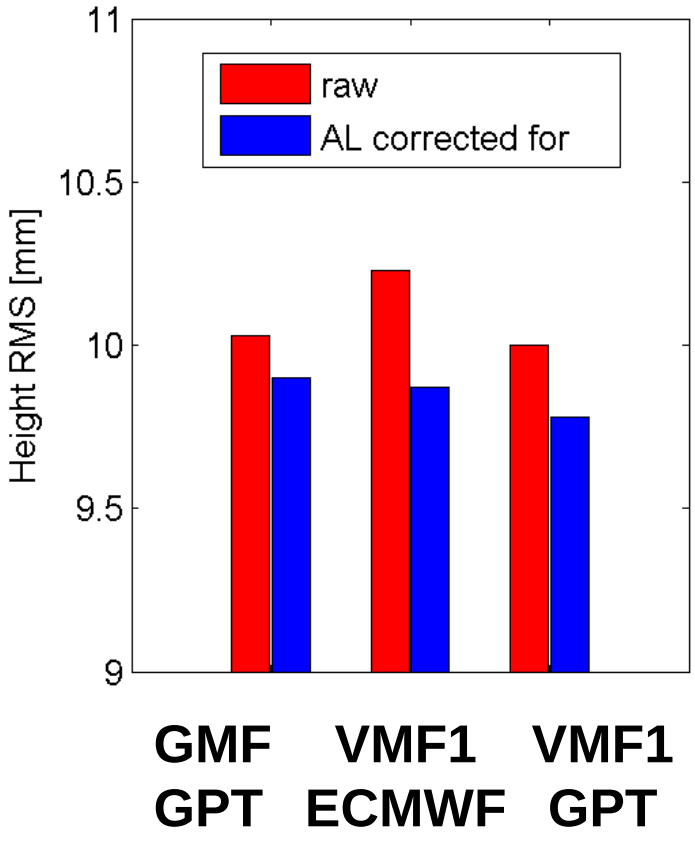
Accuracy/consistency of atmospheric loading corrections?

* http://gemini.gsfc.nasa.gov/aplo/

Comparison of PPP Solutions

Jan Kouba (2008): *Testing of Global Pressure/Temperature (GPT) Model and Global Mapping Function (GMF) in GPS analyses*, Journal of Geodesy, accepted for publication, Tab. 6 augmented by VMF1/GPT

Station	GMF/GPT		VMF1/ECMWF		VMF1/GPT	
	dH	dH_al	dH	dH_al	dH	dH_al
ALGO	6.5	6.3	6.5	5.9	6.1	5.8
HARB	7.3	7.1	7.2	7.0	7.0	6.8
KOKB	10.8	10.7	11.1	11.1	10.7	10.7
KOUR	12.5	12.4	12.5	12.4	12.5	12.4
MCM4	15.1	14.6	15.8	14.9	15.4	14.8
NYAL	6.6	7.1	6.8	6.8	6.6	6.9
OHI2	15.6	15.8	15.6	15.6	15.5	15.6
TSK2	7.9	7.8	8.5	8.3	8.2	8.1
WTZR	6.2	6.3	6.6	6.0	6.5	6.0
YAR2	8.6	8.1	8.5	7.8	8.3	7.7
YELL	6.9	6.2	7.0	5.9	6.5	5.9
Mean	**10.03**	**9.90**	**10.23**	**9.87**	**10.00**	**9.78**



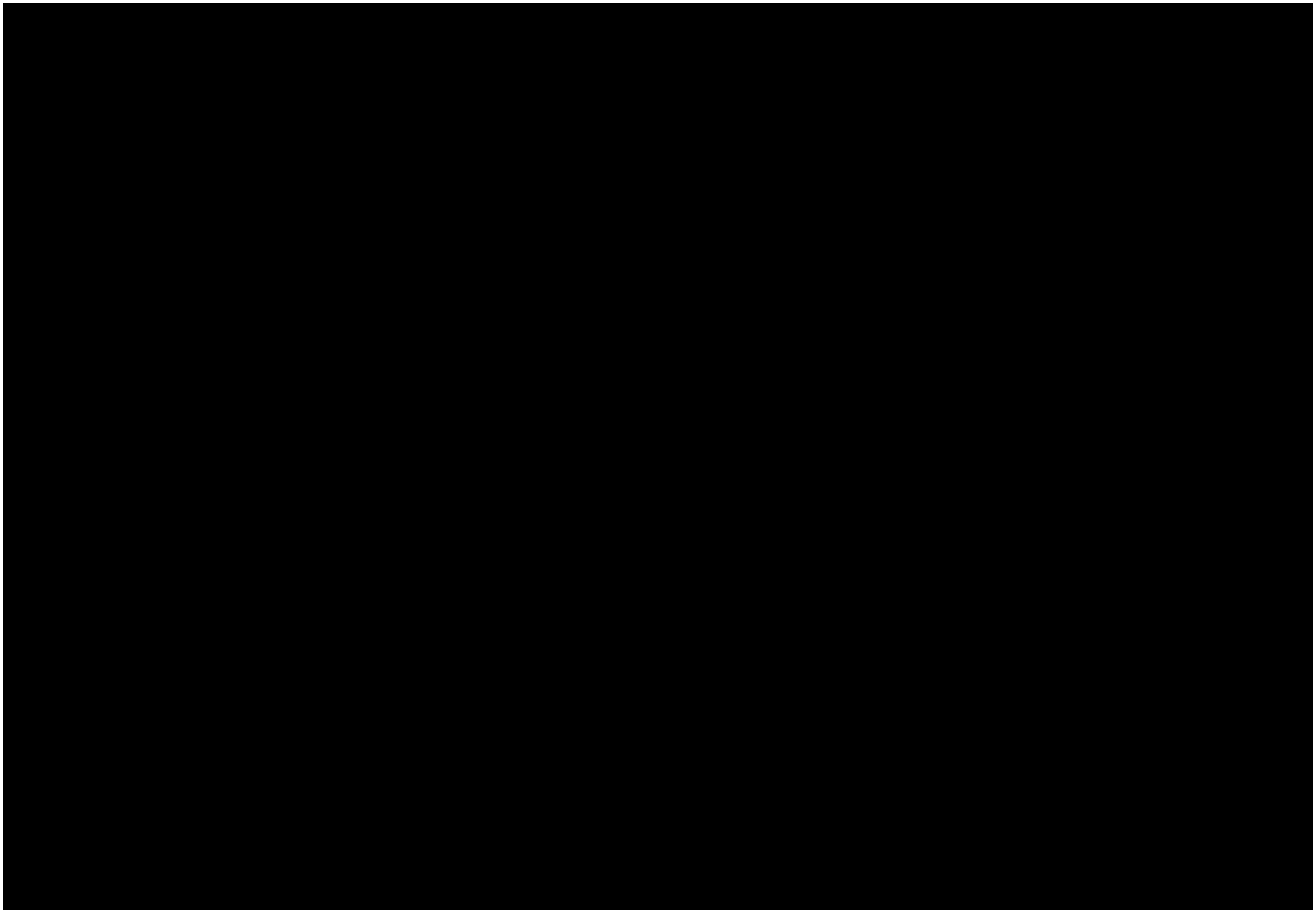
Recommendations

Action Items 12a and 12b of the GGOS Unified Analysis Workshop

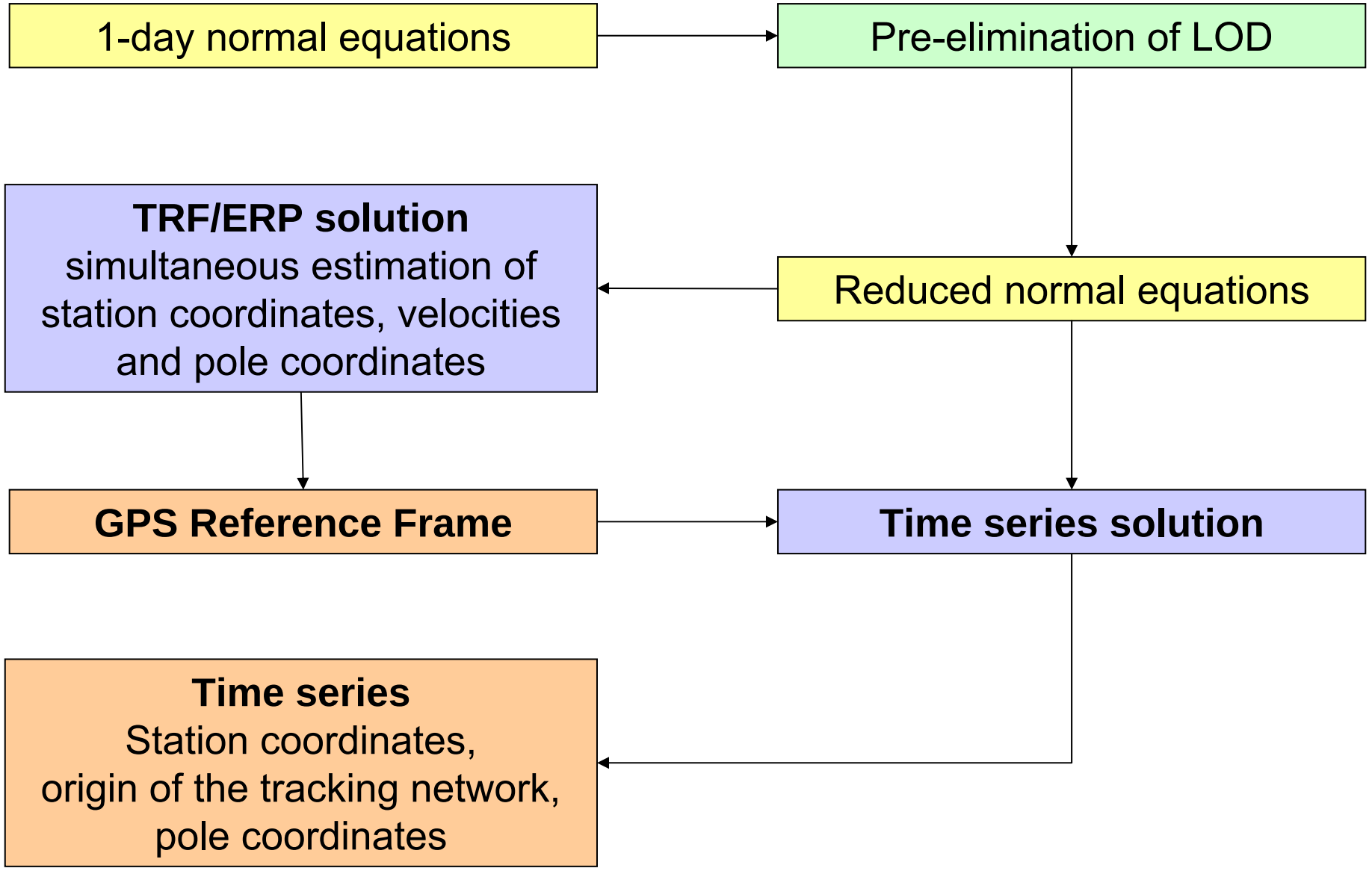
- **Troposphere mapping functions**: Use **at least GMF** (Global Mapping Functions, GMF hyd for the mapping of the a priori hydrostatic zenith delay and GMF wet for the estimation of the residual wet zenith delays), but **preferably VMF1** (Vienna Mapping Functions 1) or any other mapping function based on data from numerical weather models.
- Use **at least GPT** (Global Pressure and Temperature) for the determination of the pressure. The pressure is input for the determination of the **hydrostatic zenith delay** (see Appendix of Davis et al 1985). **Preferable** to GPT would be the use of pressure values recorded at the sites if available or **pressure** values at six hour intervals from **numerical weather models**.

Conclusions

- **Long-term differences** between GMF/GPT and VMF1/ECMWF are in general
  - on the sub-millimeter level for the horizontal component
  - below 1 millimeter for the station heights (up to 2 mm for a few stations)
- There is a clear **connection** between the modeling of **troposphere delays** and **atmospheric loading**
- Therefore, **VMF1** and **a priori hydrostatic zenith delays** with a 6 hours time resolution from **numerical weather models** have to be used to **reveal atmosphere loading signals** in the coordinate time series.



Global GPS Solutions (2)



Station Height Amplitude Differences

Annual signal estimated for GMF/GPT and VMF1/ECMWF