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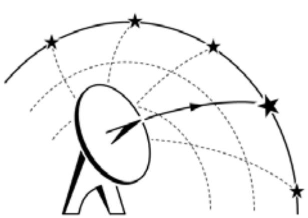
Troposphere delay models in blind mode:
Towards improved predictions of the wet component

Session G5.2: *Atmospheric Remote Sensing with Space Geodetic Techniques*



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Outline:

1. Introduction, overview of existing models (esp. **GPT2**, developed at TU Vienna)

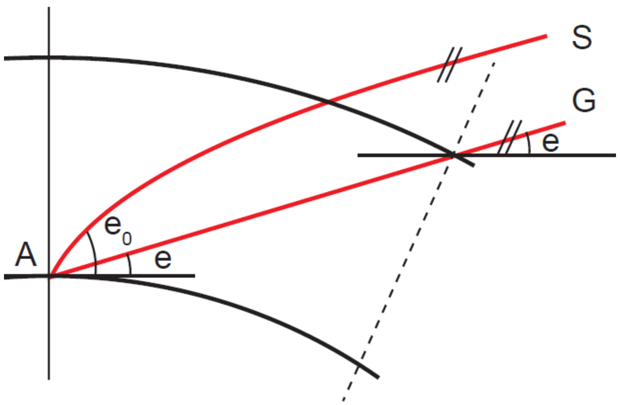
2. Extension for *a priori* zenith wet delays

Tropospheric slant delay modeling:

Hydrostatic part — Wet part

$$\Delta L(e) = \underbrace{\Delta L_h^z \cdot mf_h(e)}_{} + \underbrace{\Delta L_w^z \cdot mf_w(e)}_{}$$

Zenith delay · mapping function



Introduction

Tropospheric slant delay modeling:

$$\Delta L(e) = \Delta L_h^z \cdot mf_h(e) + \Delta L_w^z \cdot mf_w(e)$$

- Zenith wet delay: estimated for high-accuracy applications
- Zenith hydrostatic delay: *a priori* from pressure values at the site (barometer or gridded analysis fields of numerical weather models)
- If available also ray-traced delays or Vienna Mapping Functions 1 (VMF1) coefficients $\{a_h, a_w\}$
- Otherwise empirical (“blind”) models …

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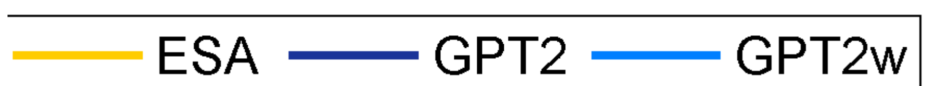


Existing blind models: **RTCA MOPS** (Collins & Langley, 1999)

Variability	Resolution	Parameters	Hydr. Delay	Wet delay
Annual Cycle	15°	p, T, e_s, lapse rates	Saastamoinen (1972)	Askne & Nordius (1987)

- Recommended for SBAS
- Builds on standard atmosphere
- Discretized at five latitude belts

Existing blind models: **ESA model** (proposed in 2007)

Variability	Resolution	Parameters	Hydr. Delay	Wet delay
Annual Cycle	15°	p, T, e_s, lapse rates	Saastamoinen (1972)	Askne & Nordius (1987)
Daily + Annual	1.5°	p, T, e_s, lapse rates	Saastamoinen (1972)	Askne & Nordius (1987)

- GALILEO tropospheric correction model
- Meteorological data: ERA15 re-analysis (1978 – 1994)

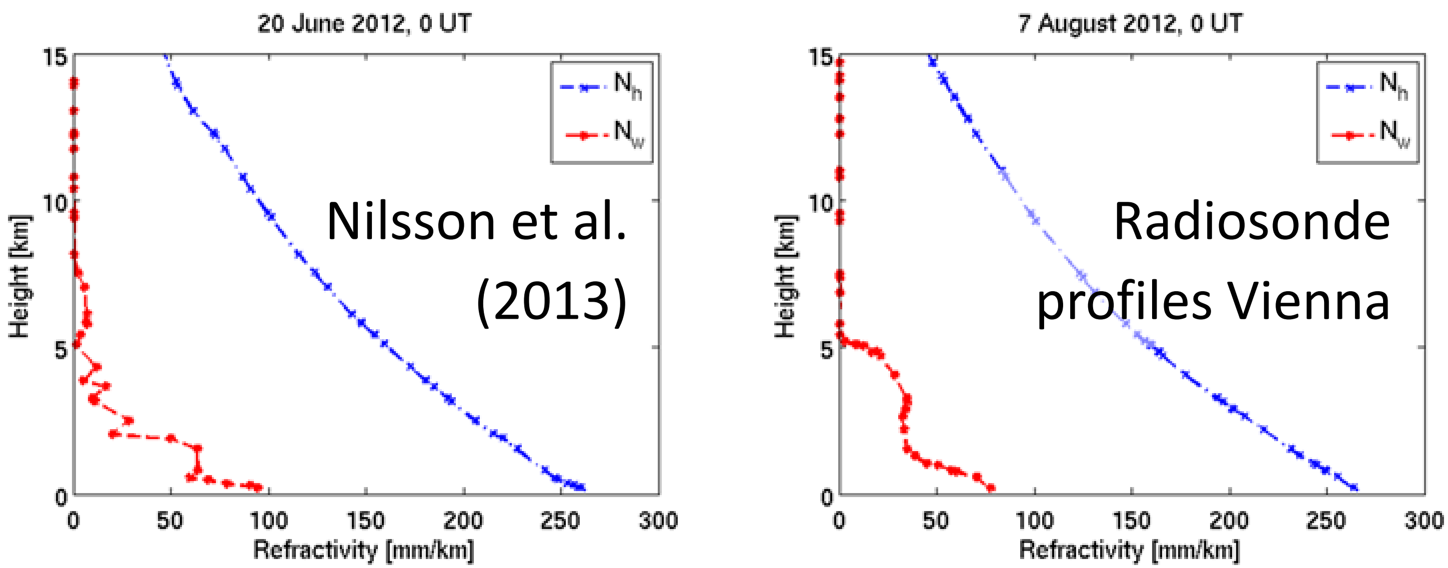
Existing blind models: **GPT2** (Lagler et al., 2013)

Variability	Resolution	Parameters	Hydr. Delay	Wet delay
Annual Cycle	15°	p, T, e_s, lapse rates	Saastamoinen (1972)	Askne & Nordius (1987)
Annual + Daily	1.5°	p, T, e_s, lapse rates	Saastamoinen (1972)	Askne & Nordius (1987)
(Semi-) Annual	5.0°	p, T, Q, dT, a_h, a_w	Saastamoinen (1972)	Saastamoinen* (1972)

- Meteorological data: ERA-Interim re-analysis (2001 – 2010)
- *A priori* zenith wet delays not accurate enough*

GPT2w: auxiliary parameters for better zenith wet delays

- Surface values (like the water vapor pressure e_s) are not representative of the integral wet refractivity as in the case of the hydrostatic part
- Strong spatio-temporal variations of the wet refractivity:



GPT2w specifications & basics:

*Centre of mass of the vertical atmospheric column

- Horizontal resolution of 1°
- New parameters based on *Askne & Nordius* (1987) ...

$$\Delta L_w^z = 10^{-6}\left(k_2' + \frac{k_3}{T_m}\right)\frac{R_d e_s}{(\lambda + 1) g_m}$$

λ ... water vapor pressure decrease factor [ ]

$T_m = \frac{\int_H^\infty e/T \mathrm{d}z}{\int_H^\infty e/T^2 \mathrm{d}z}$ ... mean temperature of water vapor

R_d, k_2', k_3 ... empirical constants

g_m ... gravity acceleration at COM*

GPT2w specifications & basics:

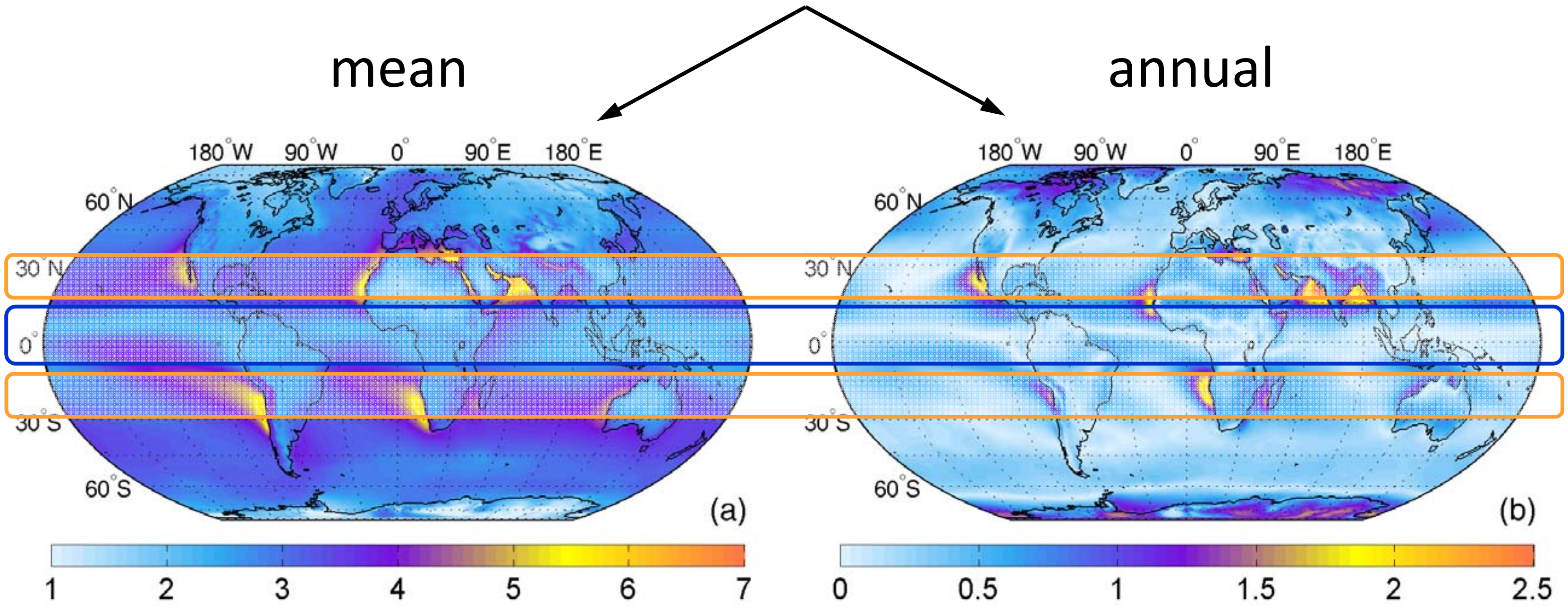
- Horizontal resolution of 1°
- New parameters based on *Askne & Nordius* (1987) ...

$$\Delta L_w^z = 10^{-6}\left(k_2' + \frac{k_3}{T_m}\right)\frac{R_d e_s}{(\lambda + 1) g_m}$$

- ΔL_w^z and T_m computed from ERA-Interim data of GPT2
- Inversion of the equation towards λ
- Fit of functional model: $\lambda(t, lat., lon.) =$ mean + annual + semi-annual terms

A priori zenith wet delays

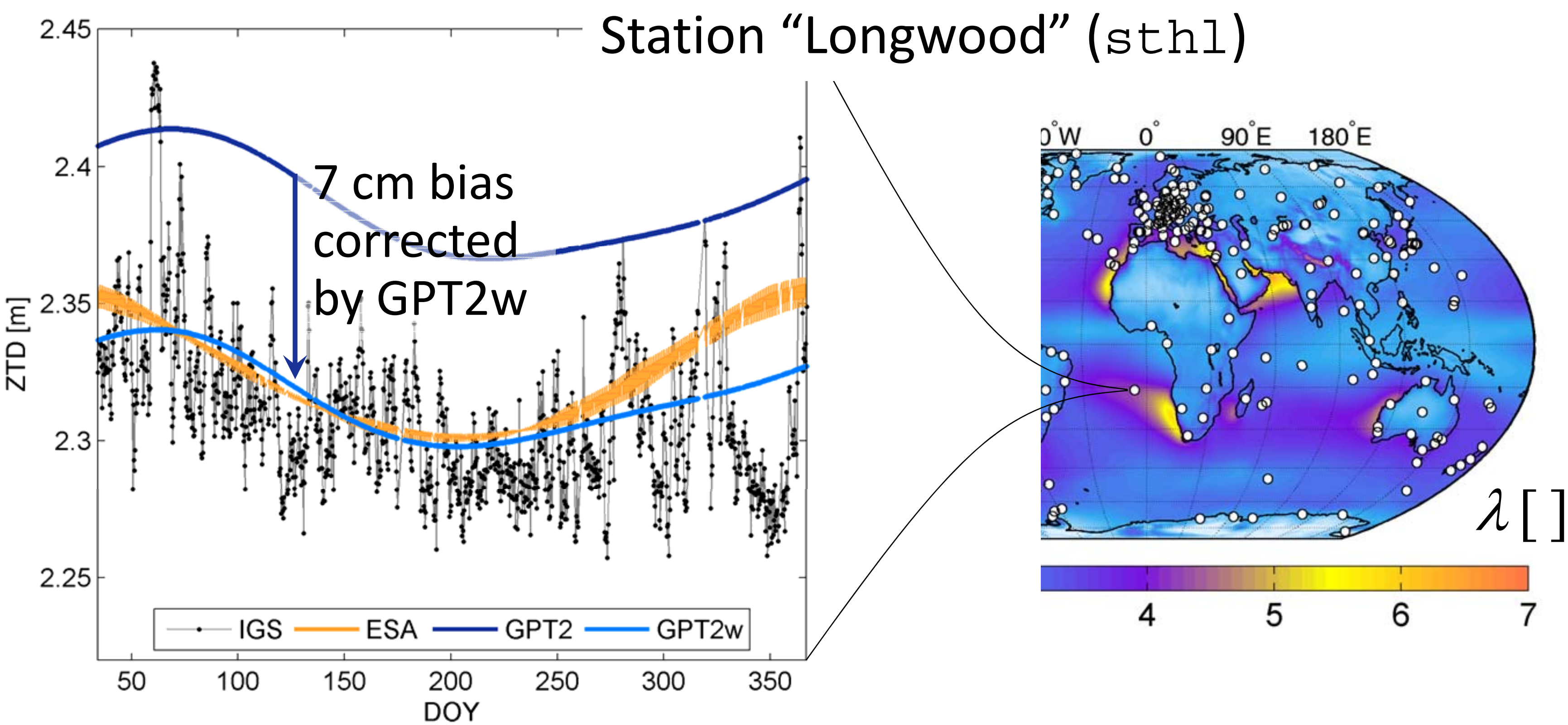
GPT2w: water vapor pressure decrease factor, amplitude



- Intertropical Convergence Zone: ascending moist air $\rightarrow$ small vertical decrease factor λ
- Horse latitudes: descending dry air, in combination with evaporation near the surface $\rightarrow$ large λ

Blind models zenith total delays w.r.t. ~340 IGS sites (year 2012)

Implications of <u>mean terms</u> in GPT2w:

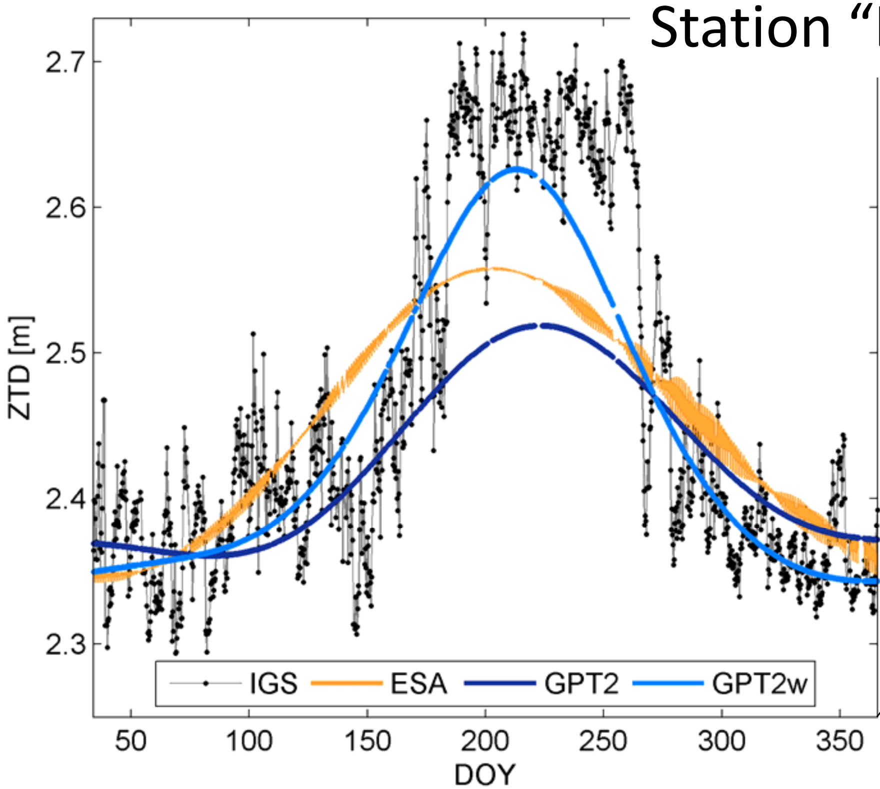


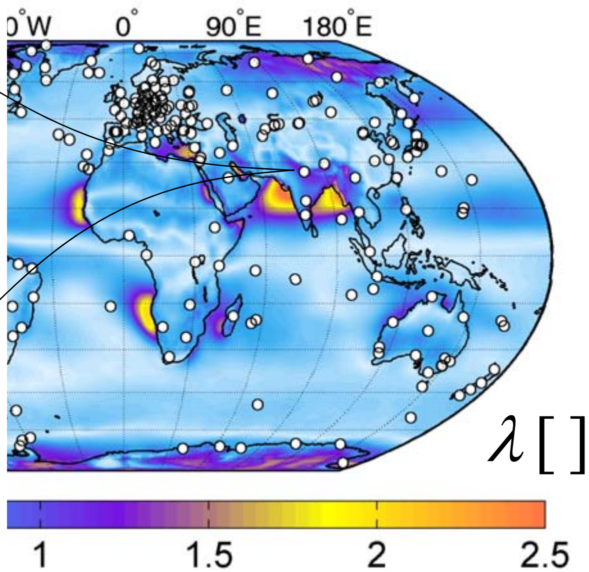
- GPT2 overestimates the zenith wet delay (coasts & islands)

Blind models zenith total delays w.r.t. 340 IGS sites (year 2012)

Implications of <u>annual terms</u> in GPT2w:

Station "Lucknow" (`lcki`)





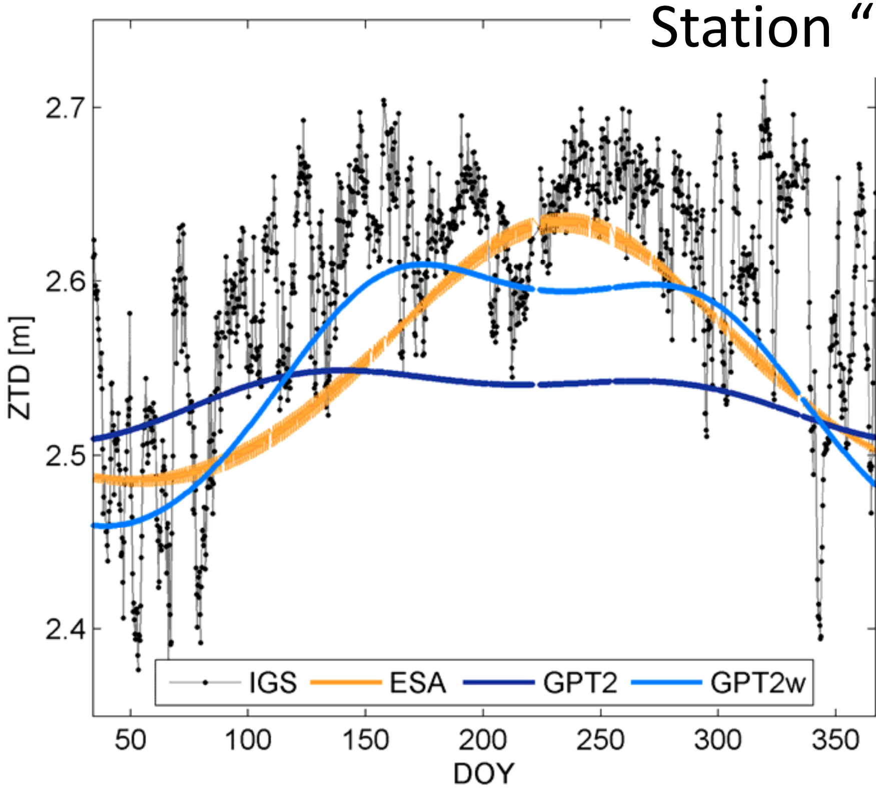
- More a unimodal regime than a perfect annual harmonic

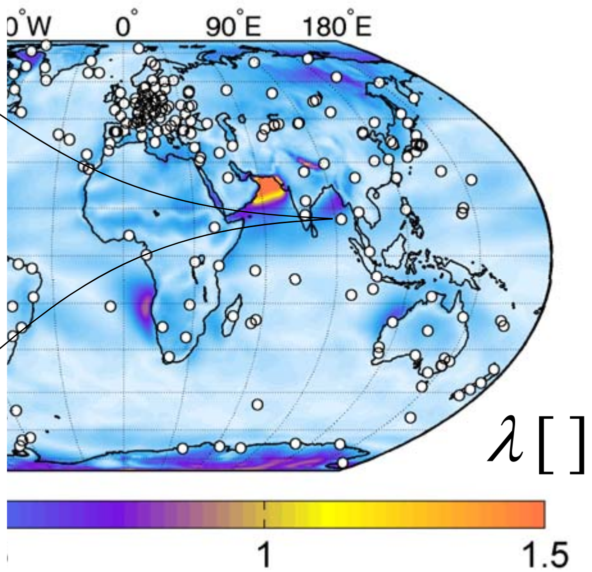
Comparison with IGS zenith total delays

Blind models zenith total delays w.r.t. 340 IGS sites (year 2012)

Implications of <u>semi-annual terms</u> in GPT2w (hard to detect):

Station “Port Blair” (`pbr2`)





- GPT2w with good approximation except for small bias

Comparison with IGS zenith total delays

Substantiate the use of semi-annual (SA) terms:

- Statistical screening of each station, 'IGS – GPT2w' with and without SA terms: **Only 65 instances** (of 340) where SA terms worsened the RMS
- **Almost 100 stations** with RMS improvement at a significance level of $\alpha = 0.05$ (mostly N-Hemisphere)

Bias and RMS of 'IGS – Model' delays (average of 340 stations):

	RTCA MOPS	ESA	GPT2	GPT2w
Bias	-2.5 cm	0.8 cm	-0.3 cm	0.0 cm
RMS	6.0 cm	3.82 cm	3.79 cm	3.61 cm

Troposphere delay models in blind mode

Usability of auxiliary parameters:

- *A priori* ΔL_w^z for navigation and real-time positioning tasks
- T_m for converting measured wet delays to PWV

Concluding remarks:

- GPT2 recommended by the IERS Conventions
- Its mapping functions coefficients to be used with vmf1_ht.f
- In case zenith wet delays are not estimated, GPT2w provides very good (blind) predictions

Routines available: http://ggosatm.hg.tuwien.ac.at/DELAY/SOURCE

The End

Thank you for your attention!

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References

K. Lagler, M. Schindelegger, J. Böhm, H. Krásná, and T. Nilsson, GPT2: Empirical slant delay model for radio space geodetic techniques, *Geophys. Res. Lett., 40(6): 1069-1073*, doi:10.1002/grl.50288, 2013.

J. Böhm, G. Möller, G. Pain, M. Schindelegger, and R. Weber, Development of an improved blind model for slant delays in the troposphere (GPT2w), to be submitted to *GPS Solutions,* 2014.