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Performance Evaluation of the GPT2w and UNB3M Tropospheric Delay correction Models over Africa

By

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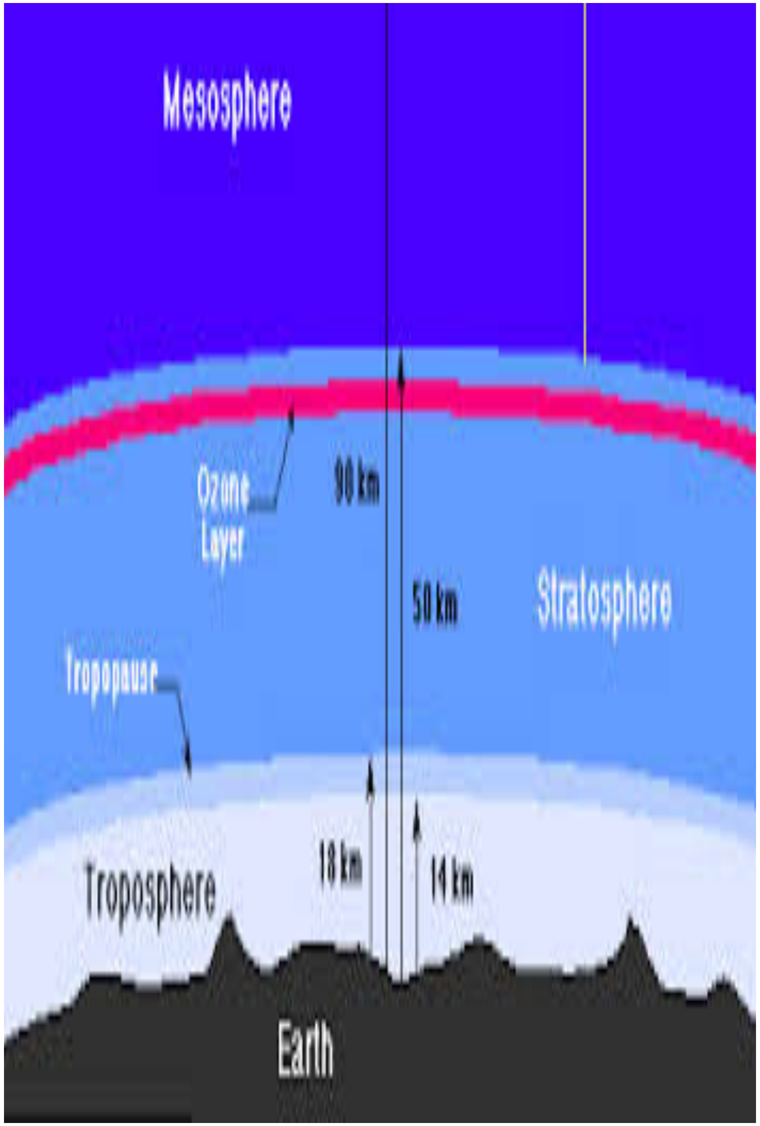
Outline of Presentation

- Introduction
- Description of Tropospheric Models
- Results of Evaluation of Zenith Tropospheric Delay(ZTD) from models
- Concluding Remarks

Introduction

- Troposphere delay modelling is one of the main error sources in the analysis of space geodetic techniques operating at microwave frequencies, such as global navigation satellite systems(GNSS), very long baseline interferometry(VLBI), or Doppler orbitography and radio-positioning integrated by satellite(DORRIS).
- The tropospheric delay is usually separated into a hydrostatic delay that is modelled a priori and a wet delay that is estimated from the space geodetic microwave observations.



$$ZTD = ZHD + ZWD$$

Introduction (contd)

Modeled hydrostatic delays and the estimated wet delays are usually referred to the zenith direction, corresponding mapping functions are required to convert the slant delays in observation direction to the zenith. In addition, troposphere gradients can be estimated to account for asymmetries of the troposphere.

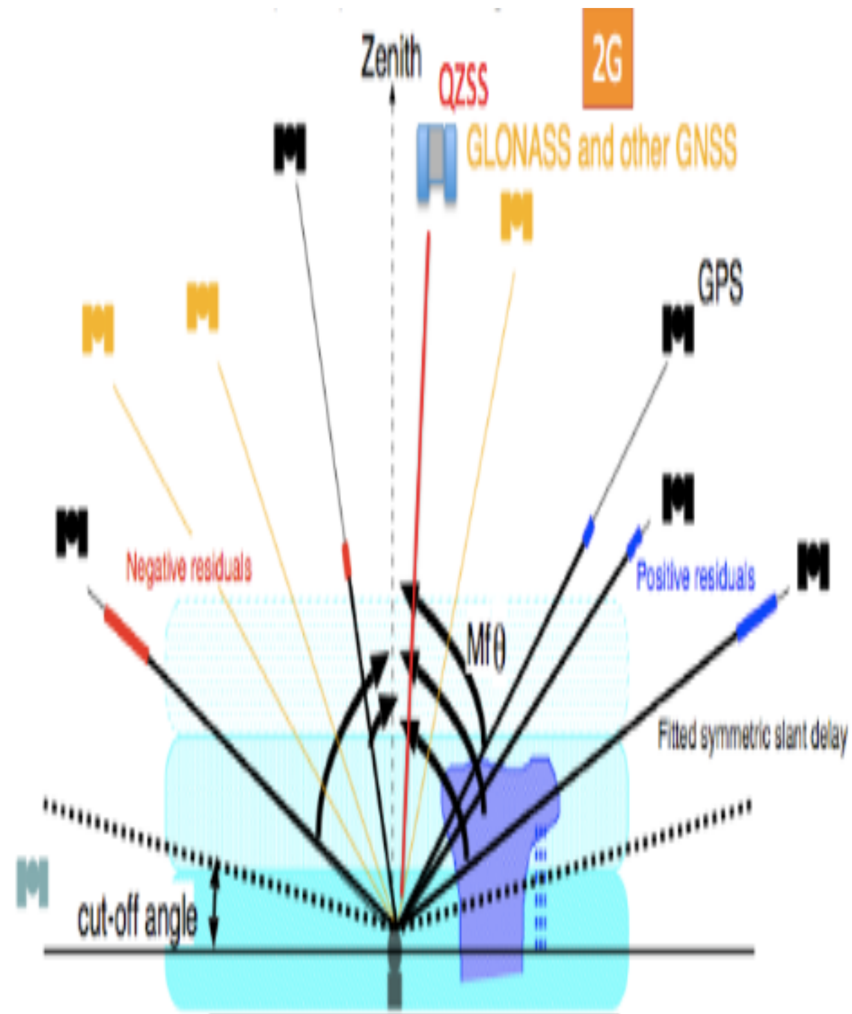


Figure 1: Zenith Direction

Introduction (contd)

- In GNSS positioning, tropospheric delay error typically range between 2.0m to 2.6m. The ZHD constitute 90% of the ZTD, and ZWD is usually less than 10%. The ZHD can be estimated to an accuracy of better than 90% using empirical models(**Hopfield and Saastamoinen models**), that utilizes meteorological data, such as pressure and temperature as well as the position of the user. However, because the inversion of ground meteorological data into the variable vapour content in the atmosphere is very difficult, even the Hopfield and Saastamoinen models have difficulties in meeting the needs for high accuracy GNSS positioning and GNSS meteorological applications.

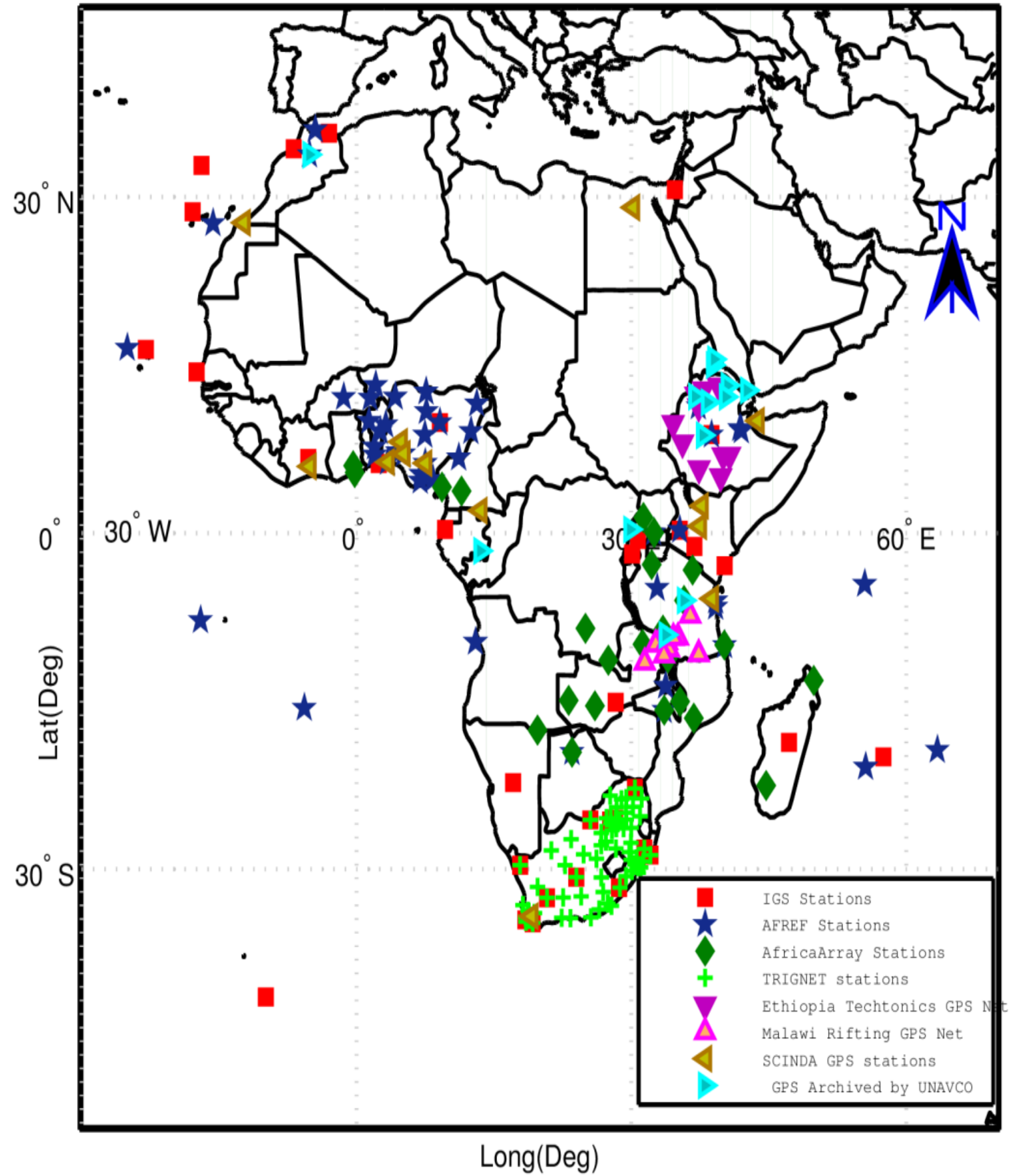
- In practice , user often employs a certain troposphere model based on popularity of the model without giving enough justification. Limited comparisons between some of the models have been carried out in the past for local or regional applications. However, in this contribution , this issue is addressed more comprehensively considering the peculiarities of the African GNSS network.

Introduction (contd)

✓**African GNSS Network :**

❑Isioye, O. A., Combrinck, L., Botai, J. O., and Munghemezulu, C. (2015). The Potential of Observing African Weather with GNSS Remote Sensing. *Advances in Meteorology*, Volume 2015, Article ID 723071, 16pages. (If: 1.483) http://dx.doi.org/10/1155/2015/723071.

✓ **Blind models** : RTCA-MOPS models, ESA model, GPT2 model

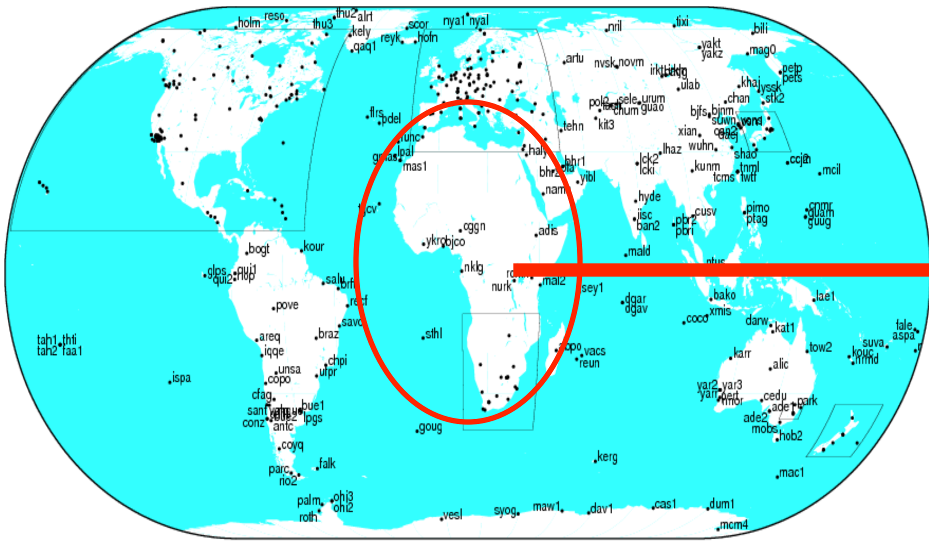


Description of Tropospheric Models

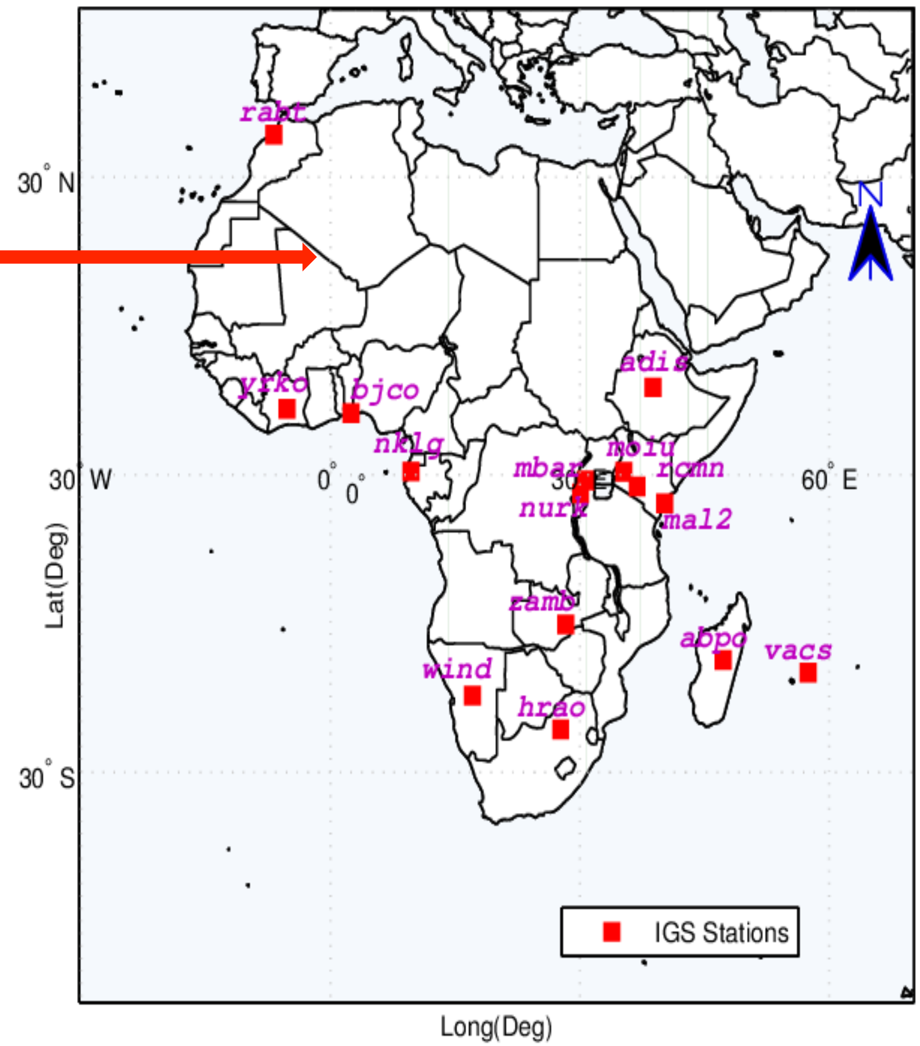
- ✓ Tropospheric product from the International GNSS Service (IGS)
- ✓ *Tropospheric delay correction model from the University of New Brunswick :University of New Brunswick neutral atmosphere delay (UNB3M) model*
- ✓ *Tropospheric delay correction model from the Vienna University of Technology: Global Pressure and Temperature 2 wet (GPT2w) model*

Description of Tropospheric Models (contd)…

❑*IGS Tropospheric Product*



GNSS Stations in Africa



❑**This study analyzes the new IGS ZTD product (available at ftp://cddis.gsfc.nasa.gov/gps/products/trop_new) for the interval January 2013 to December 2013 and for 15 sites distributed across the Africa Continent as indicated by the dots in Figures 2 and 3.**

❑*IGS Tropospheric Product*

Station	Country	Latitude (deg)	Longitude (deg)	Ellipsoidal Height
ABPO	Madagascar	-19.02	47.23	1552.99
ADIS	Ethiopia	9.04	38.77	2439.15
BJCO	Republic of Benin	6.38	2.45	30.6
HRAO	South Africa	-25.89	27.69	1414.3
MAL2	Kenya	-3	40.19	-20.4
MBAR	Uganda	-0.6	30.74	1337.65
MOIU	Kenya	0.29	35.29	2201.53
NKLG	Gabon	0.35	9.67	31.48
NURK	Ruanda	-1.94	30.09	1485.3
RABT	Morocco	34	-6.85	90.1
RCMN	Kenya	-1.22	36.89	1607.54
VACS	Mauritius	-20.30	57.50	420.4
WIND	Namibia	-22.57	17.09	1734.7
YKRO	Cote d'ivore	6.87	-5.24	270
ZAMB	Zambia	-15.43	28.31	1324.91

- **The new IGS ZTD product is based on the precise point positioning technique. It has a higher sampling rate and lower formal errors than the legacy IGS ZTD product [Byun and Bar-Server 2009].** The ZTD can be obtained with typical formal errors of 1.5–5 mm from the IGS
- ***Gaps are common in the data, but at least 6month of ZTD estimates are available for each site.***
- ***The IGS data are down sampled from 5-min to daily intervals***

•Byun, S.H. and Bar-Server, Y. E. (2009). A New type of Troposphere Zenith Path Delay Product of the International GNSS Service, *J. Geod.*, 83(3-4), 1-7.

Description of Tropospheric Models (contd)…

UNB3M Tropospheric Model

➢This model has its algorithm based on the prediction of meteorological parameters values, which are then used to compute hydrostatic and non-hydrostatic zenith delays using the Saastamoinen models.

➢In order to account for the seasonal variation of the neutral atmosphere behaviour, a look-up table of meteorological parameters is used. The parameters are barometric pressure, temperature, water vapour pressure (WVP), temperature lapse rate and water vapour pressure height factor . This look-up table was derived from the U.S. Standard Atmosphere Supplements, 1966 (COESA, 1966)

Average					
φ (deg)	$P_o\,[hPa]$	$T_o\,[K]$	$WVP\,(mbar)$	$\beta_o\,[K/m]$	$\lambda\,[-]$
15	1013.25	299.65	26.31	0.00630	2.77
30	1017.25	294.15	21.79	0.00605	3.15
45	1015.75	283.15	11.66	0.00558	2.57
60	1011.75	272.15	6.78	0.00539	1.81
75	1013.00	263.65	4.11	0.00453	1.55
Amplitude					
φ (deg)	$P_o\,[hPa]$	$T_o\,[K]$	$WVP\,(mbar)$	$\beta_o\,[K/m]$	$\lambda\,[-]$
15	0.00	0.00	0.00	0.00000	0.00
30	-3.75	7.00	8.85	0.00025	0.33
45	-2.25	11.00	7.24	0.00032	0.46
60	-1.75	15.00	5.36	0.00081	0.74
75	-0.50	14.50	3.39	0.00062	0.30

UNB3M Tropospheric Model(contd)

Computes annual average of parameters

$$Avg_\phi = \begin{cases} Avg_{15}, if\ \phi \le 15 \\ Avg_{75}, if\ \phi \ge 75 \\ Avg_i + \dfrac{\left(Avg_{i+1} - Avg_i\right)}{15}\left(\phi - Lat_i\right), if\ \ 15 < \phi < 75 \end{cases}$$

Computes annual amplitude of parameters

$$Amp_\phi = \begin{cases} Amp_{15}, if\ \phi \le 15 \\ Amp_{75}, if\ \phi \ge 75 \\ Amp_i + \dfrac{\left(Amp_{i+1} - Amp_i\right)}{15}\left(\phi - Lat_i\right), if\ \ 15 < \phi < 75 \end{cases}$$

Computed parameter value for specific latitude and DOY

$$X_{\phi,doy} = Avg_\phi - Amp_\phi \cos\left(\left(doy - 28\right)\frac{2\pi}{365.25}\right)$$

UNB3M Tropospheric Model (contd)

Pressure

Gravity at the surface

$$ZHD = \frac{10^{-6} k_1 R}{g_m} \cdot P_o \cdot \left(1 - \frac{\beta H}{T_o}\right)^{\frac{g}{R\beta}}$$

Temperature

Temperature lapse rate

Orthometric height

Gravity at the atmosphere

Refractivity Constants

Gas constant

$$ZWD = \frac{10^{-6}\left(T_m k_2' + k_3\right) R}{g_m \lambda' - \beta R} \frac{e_o}{T_o} \left(1 - \frac{\beta H}{T_o}\right)^{\left(\frac{\lambda' g}{R\beta}\right)-1}$$

WVP height factor

Water Vapour Pressure

Description of Tropospheric Models (contd)…

❑ *GPT2w(Global Pressure and Temperature 2 wet)*

- ✓ GPT2w is an extension of GPT and GPT2 (Boehm *et al.,* 2007; Lagler *et al.,* 2013)
- ✓ GPT2w ("Global Pressure and Temperature 2 wet")is a blind troposphere delay model providing the mean values plus annual and semi - Annual amplitudes of pressure, temperature and its lapse rate, water vapor Pressure and its decrease factor λ, weighted mean temperature, as well as Hydrostatic and wet mapping function coefficients of the VMF1 (Vienna Mapping Function1).

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

•Boehm J, Heinkelmann R, Schuh H (2007) Short note: a global model of pressure and temperature for geodetic applications. *J. Geod* 81(10):679–683. doi:10.1007/s00190-007-0135-3

- ✓ All climatological parameters have been derived consistently from Monthly mean pressure level data of ERA-Interim fields (European Centre For Medium-Range Weather Forecasts Re-Analysis) with a horizontal resolution of one degree, from 2001 to 2010 and the model is suitable to calculate slant hydrostatic and wet delays down to three degrees elevation at sites in the vicinity of the Earth surface using the date and approximate station coordinates as input.

Description of Tropospheric Models (contd)…

- ***GPT2w(Global Pressure and Temperature 2 wet)***
  - ✓ Topographic Representation :1-degree grid at mean ETOPO5 based heights
  - ✓ The wet delay estimation builds upon gridded values of the water vapor pressure, the weighted mean temperature, and the water vapor decrease factor, with the latter being tuned to ray-traced zenith wet delays

✓ New parameters based on Askne and Nordius(1987)………

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

ZWD

Weighted mean temperature of Troposphere

Water vapour decrease factor

- Boehm, J., G. Möller, G., Schindelegger, M., Pain, G., Weber, R., (2014). Development of an improved blind model for slant delays in the troposphere (GPT2w), GPS Solutions, 2014, doi: 10.1007/s10291-014-0403-7.
- Askne and Nordius,(1987) Estimation of tropospheric delay for microwaves from surface weather data, Radio Science, Vol 22(3): 379-386.

Results of Evaluation of ZTD from models

- Normalised Mean Absolute Error (NMAE)

$$NMAE = \frac{\sum_{i=1}^{N}\left(\left|Bias_i\right|\right)}{N\bar{O}}$$

- Model Efficiency (MEF)

$$MEF = 1 - \frac{\sum_{i=1}^{N}\left(Bias_i\right)^2}{\sum_{i=1}^{N}\left(\left|\left(P_i - \bar{O}\right)\right| - \left|\left(O_i - \bar{O}\right)\right|\right)^2}$$

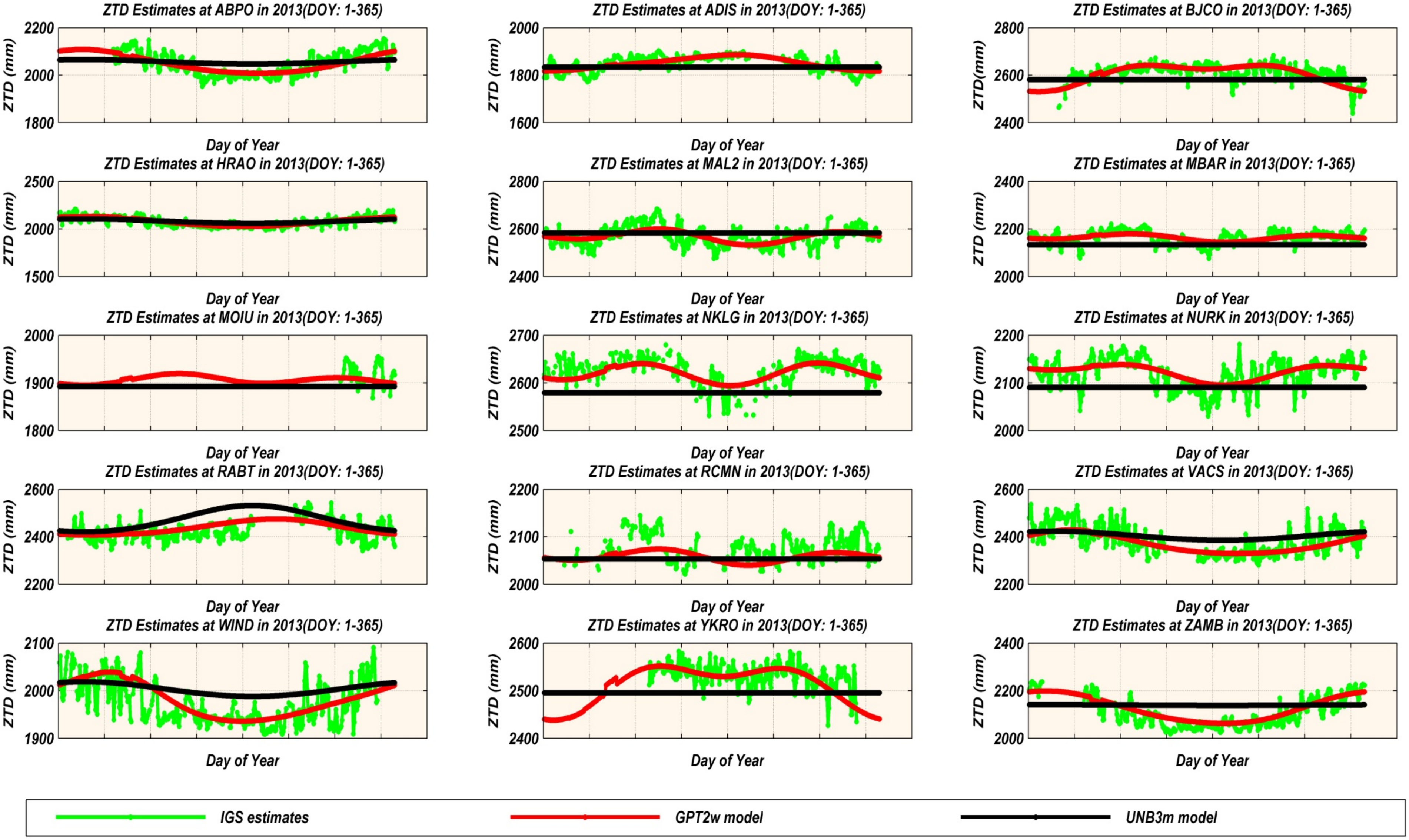
- Root Mean Square Error (RMSE)

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(Bias_i\right)^2}{N}}$$

- Reliability Index (RI)

$$RI = \exp\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\log\frac{O_i}{P_i}\right)^2}$$

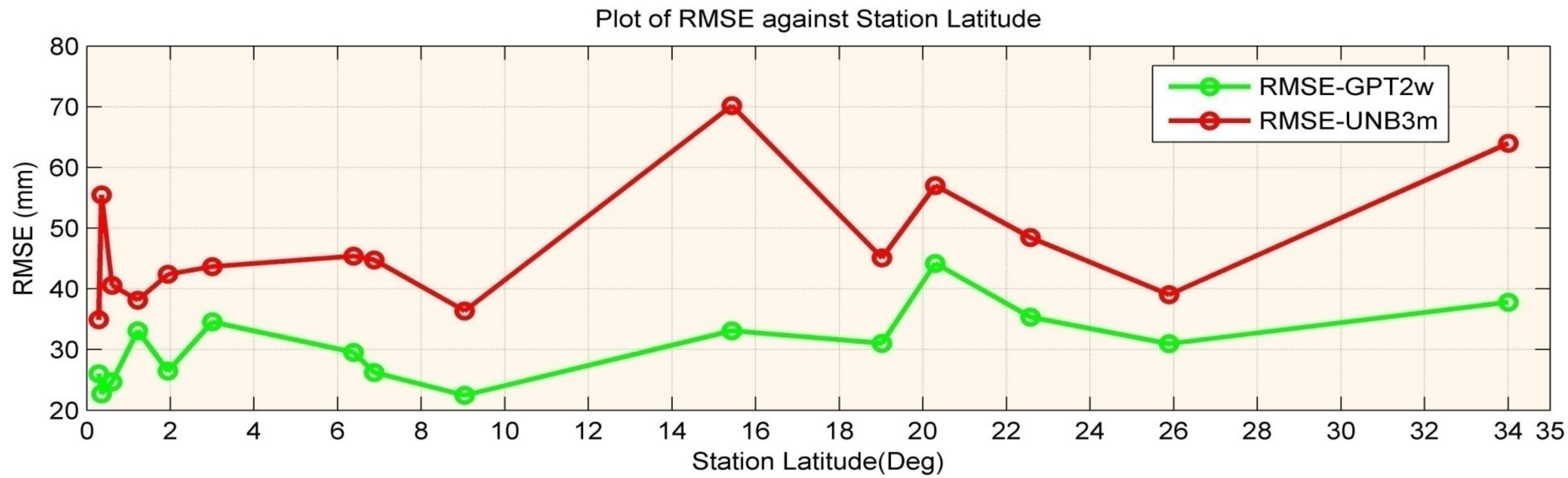
Results (contd)

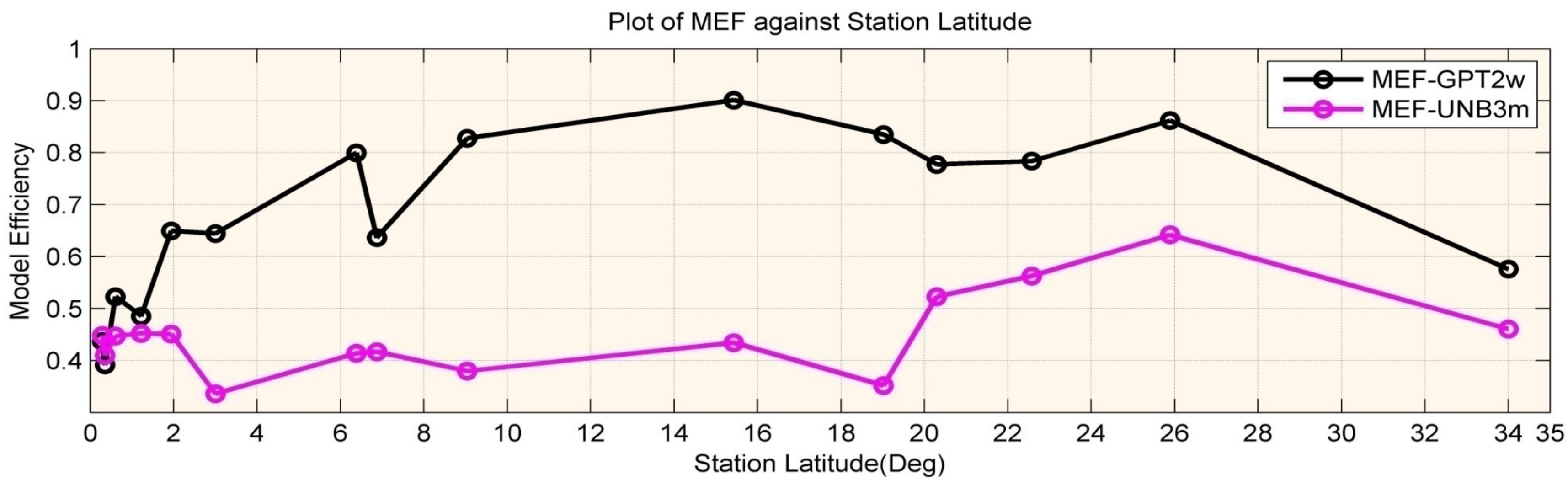


Results (contd)

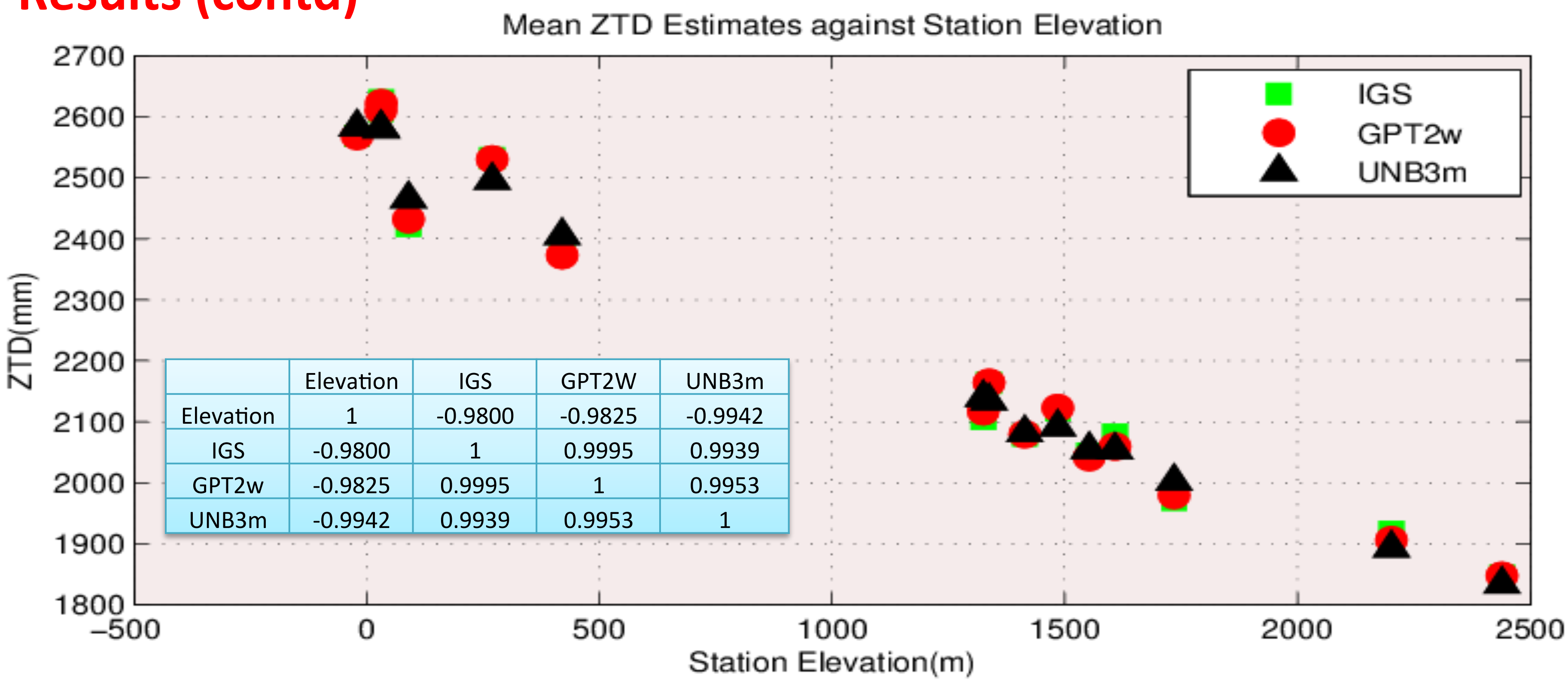
	NMAE	RMSE	MEF	RI	NMAE	RMSE	MEF	RI	NMAE	RMSE	MEF	RI
	ABPO				ADIS				BJCO			
GPT2w	0.0134	31.0320	0.8350	1.0152	0.0095	22.4626	0.8277	1.0123	0.0085	29.5480	0.7997	1.0115
UNB3M	0.0194	45.1071	0.3519	1.0223	0.0173	36.3694	0.3798	1.0199	0.0150	45.4024	0.4138	1.0176
	HRAO				MAL2				MBAR			
GPT2w	0.0114	30.9544	0.8617	1.0149	0.0110	34.5622	0.6444	1.0135	0.0092	24.6734	0.5230	1.0115
UNB3M	0.0159	39.0528	0.6419	1.0189	0.0142	43.6633	0.3361	1.0171	0.0161	40.5798	0.4471	1.0190
	MOIU				NKLG				NURK			
GPT2w	0.0092	26.0287	0.4370	1.0136	0.0069	22.7098	0.3916	1.0087	0.0100	26.4390	0.6495	1.0126
UNB3M	0.0154	34.8988	0.4482	1.0184	0.0193	55.4938	0.4100	1.0215	0.0170	42.3982	0.4510	1.0202
	RABT				RCMN				VACS			
GPT2w	0.0126	37.8190	0.5758	1.0157	0.0133	33.1069	0.4855	1.0160	0.0143	44.2097	0.7774	1.0185
UNB3M	0.0217	63.9707	0.4605	1.0265	0.0147	38.1572	0.4522	1.0185	0.0211	57.0262	0.5229	1.0242
	WIND				YKRO				ZAMB			
GPT2w	0.0140	35.3518	0.7838	1.0180	0.0080	26.2248	0.6363	1.0105	0.0132	33.1040	0.9013	1.0158
UNB3M	0.0218	48.4544	0.5628	1.0248	0.0158	44.7696	0.4170	1.0179	0.0302	70.1788	0.4344	1.0338

Results (contd)

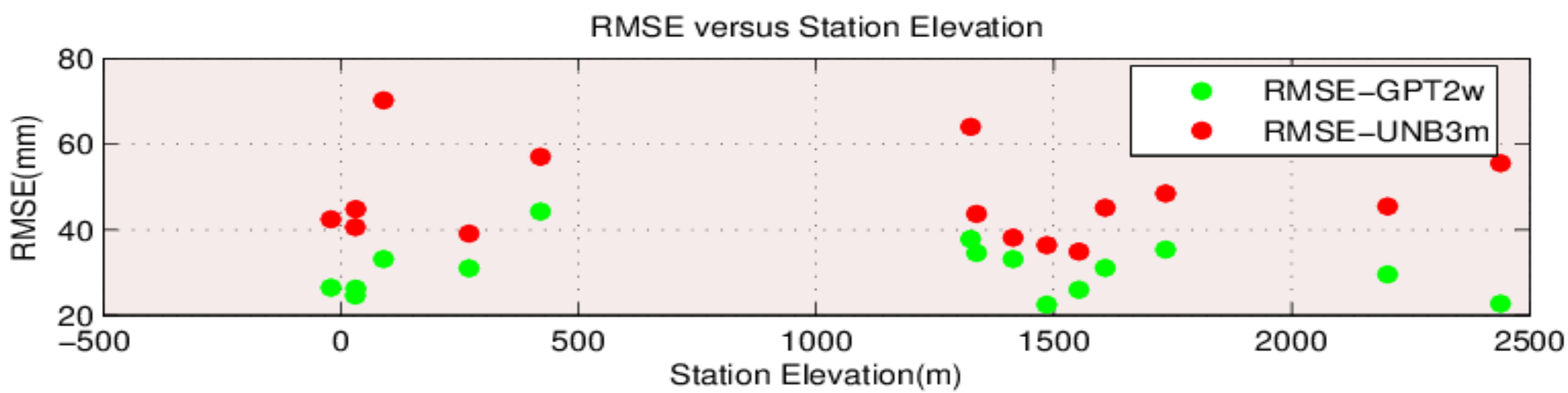




Results (contd)

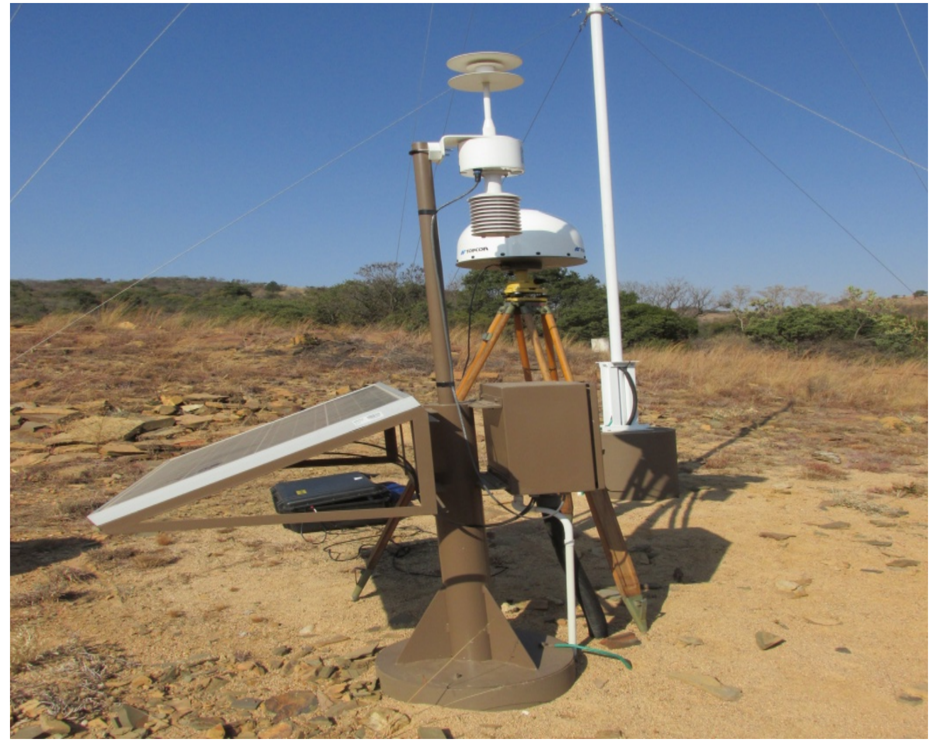


	Elevation	IGS	GPT2W	UNB3m
Elevation	1	-0.9800	-0.9825	-0.9942
IGS	-0.9800	1	0.9995	0.9939
GPT2w	-0.9825	0.9995	1	0.9953
UNB3m	-0.9942	0.9939	0.9953	1



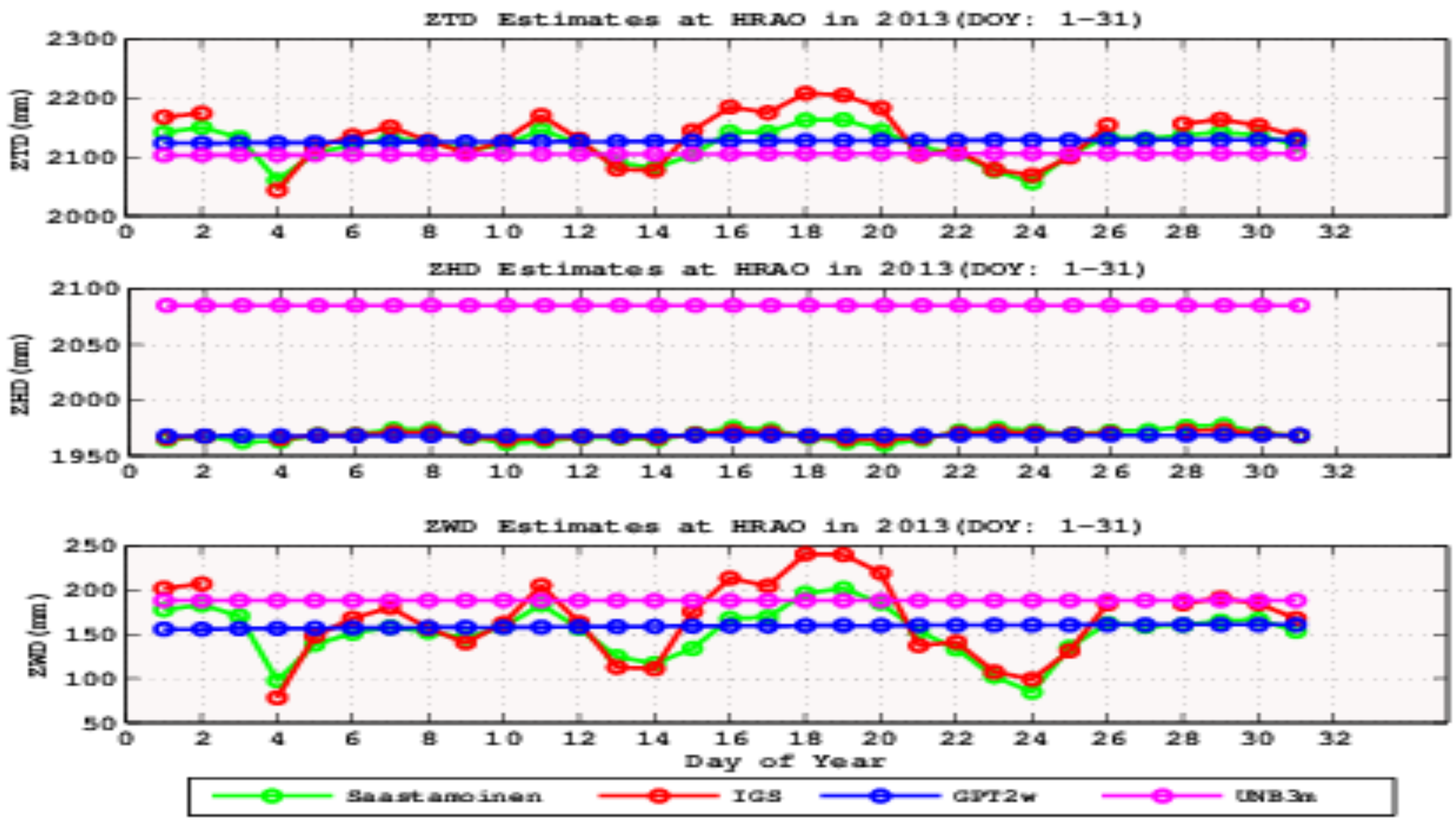
Results (contd)

- ❑ **MET4A meteorological system**
- ✓ **High accuracy fan aspirated meteorological measurement system for GPS meteorology and environmental monitoring**
- ✓ **Pressure accuracy of +/- 0.08hpa from 500 to 1100hpa**
- ✓ **Temperature +/- 0.2deg Celsius**
- ✓ **Humidity +/- 2% to 100% at standard temperature**



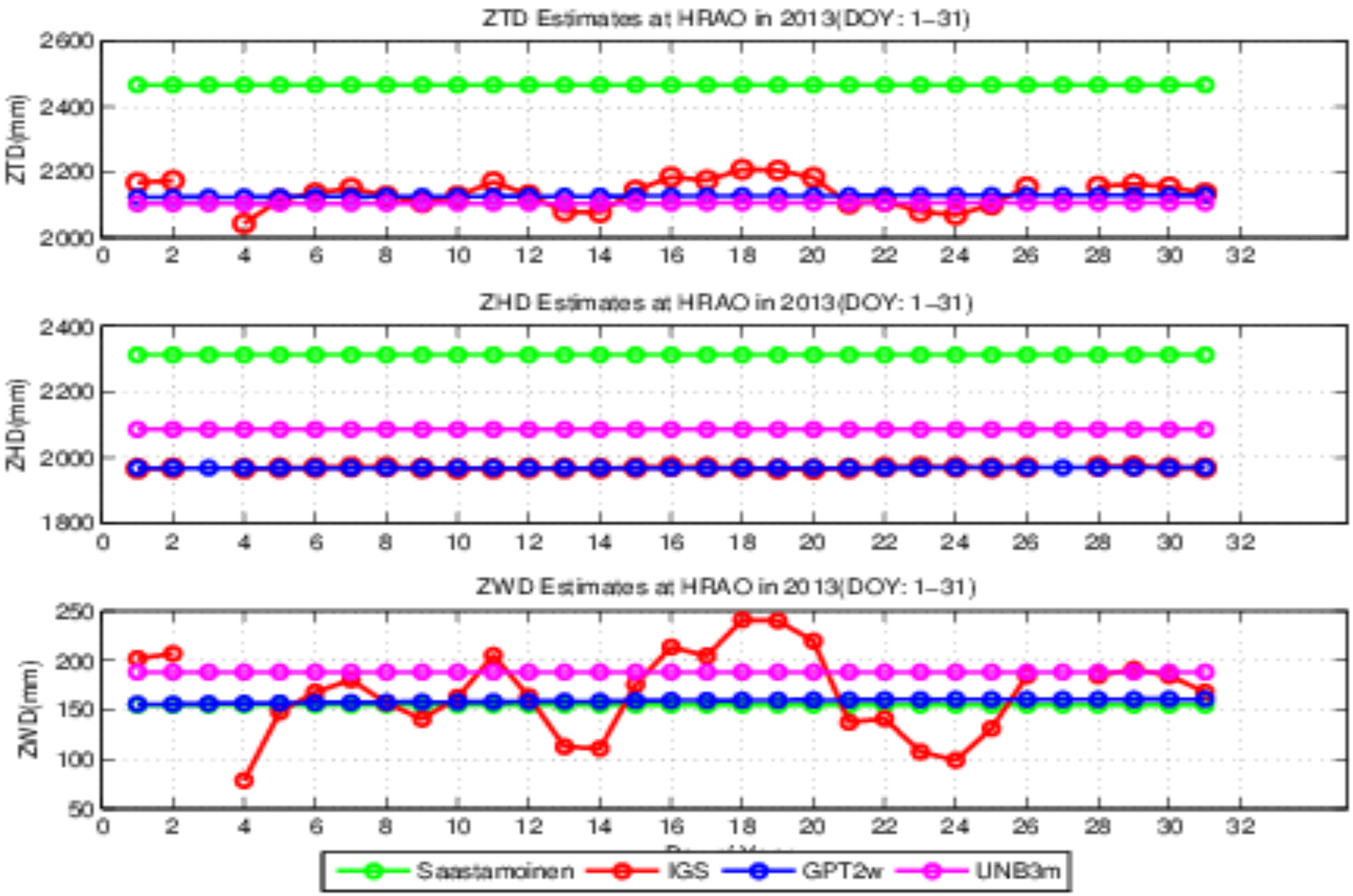
Results (contd)

- Saastamoinen model with measured met parameters



Results (contd)

❑Saastamoinen model with standard parameters



In conclusion

- We have estimated the accuracies of the GPT2w and UNB3m tropospheric correction models over Africa by using global IGS network's GNSS observational tropospheric zenith delay time series and we arrive at the following corrections:

I. The accuracy of ZTD correction from the GPT2w model is well within the range of 50mm , and this accuracy can meet the needs of the tropospheric delay correction of the order of meters, in the GNSS positioning.

II. Both models perform well at the low equatorial region of Africa and also, respond to station elevation in the similar fashion.

III. The GPT2w represents an excellent model for ZHD estimation due to its high accurate pressure estimates.

IV. The Saastamoinen model performs poorly with the use of standard atmospheric parameters and thus fails to address the peculiarities of the African GNSS network. Thus, better estimates of ZTD from GNSS can be obtained with the GPT2w without actual field measurements

V. Finally, there was better agreement between the GPT2w and IGS estimate at all stations. Thus, the GPT2w model can be used as a correction model of the tropospheric error for the GNSS real-time positioning and navigation on the African Continent.

Acknowledgment

- ✓ Office for Outer Space Affairs, United Nations
- ✓ ROSCOSMOS
- ✓ University of Pretoria, South Africa
- ✓ Ahmadu Bello University, Nigeria

- ❑ "GNSS is an enabling technology that can make major contributions to economic growth and societal betterment. It is a key to scientific exploration" …..P. Doherty 2010

Thank you for listening!