MODELLING OF ATMOSPHERIC PARAMETERS OVER NIGERIA BASED ON GNSS DATA

By

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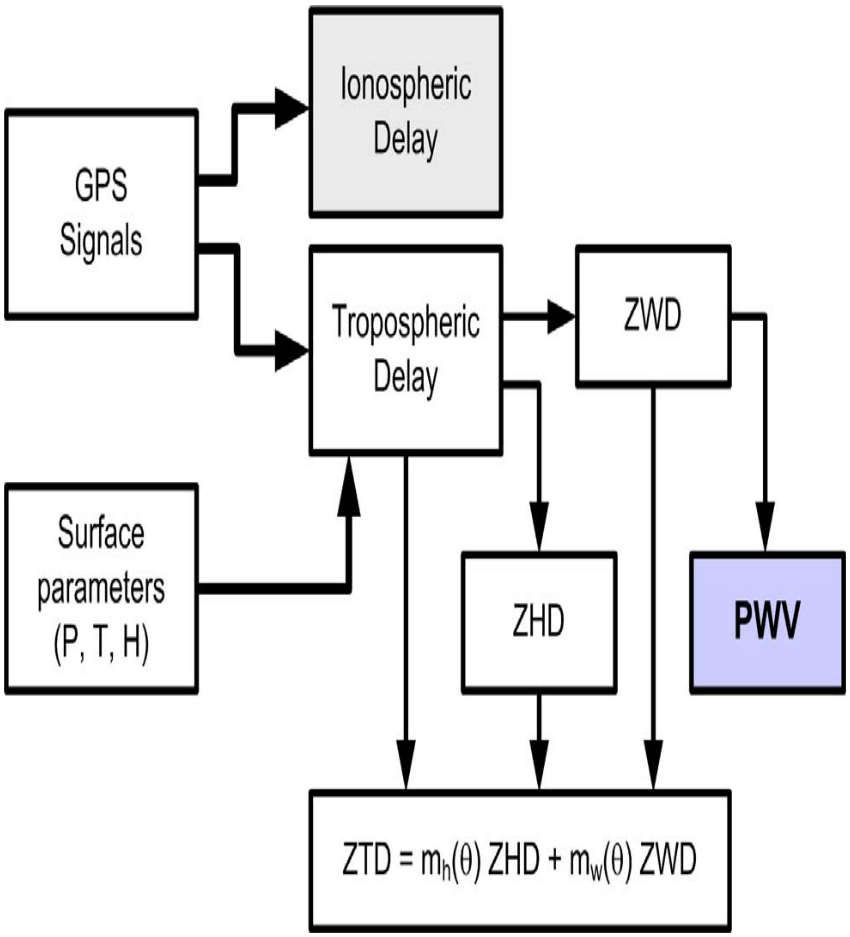
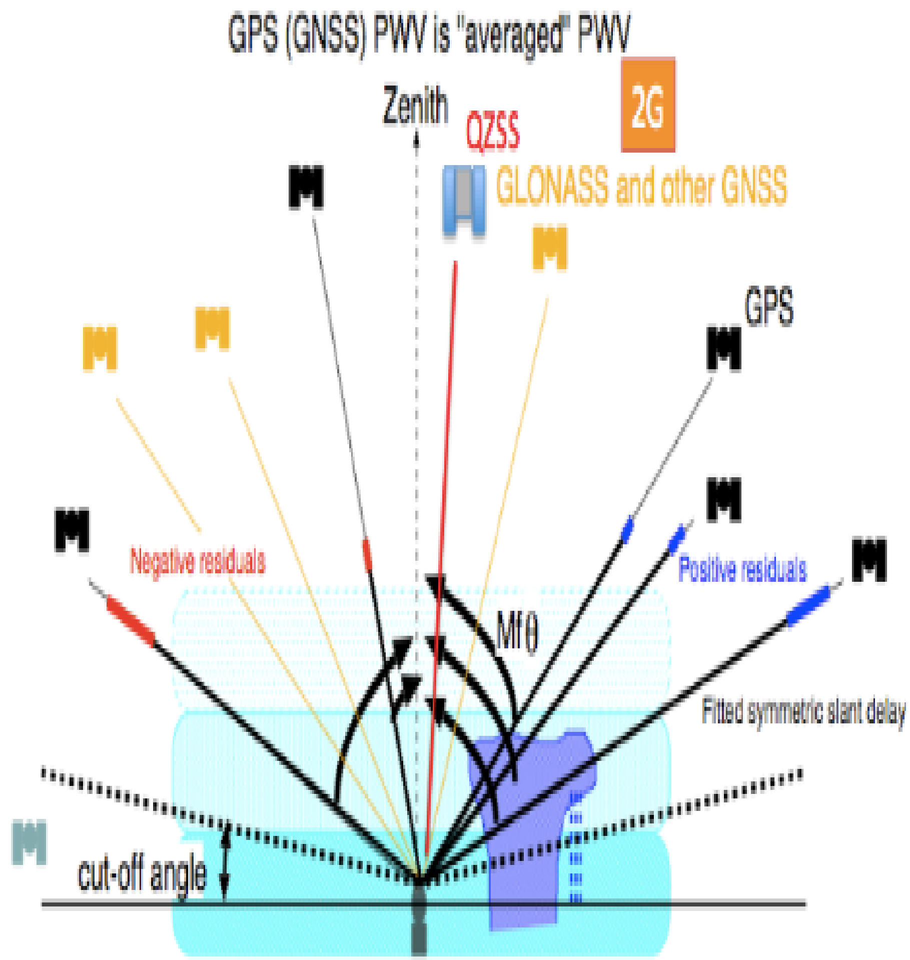
A Presentation at the United Nations /ICTP Workshop on the Use of GNSS for Scientific Application, 1-5 Dec, 2014, Trieste, Italy

OUTLINE OF PRESENTATION

- Background/Concept of GNSS Meteorology
- Data/Data processing
- Analysis of Zenith Tropospheric Delay(ZTD) Estimation from GNSS
- Concluding Remarks/Future Plan and Acknowledgment

Concept of GNSS Meteorology





United Nations /ICTP Workshop on the Use of GNSS for Scientific Application, 1-5 Dec, 2014, Trieste, Italy

Concept of GNSS Meteorology

$$ZTD = ZHD + ZWD$$

$$PWV = \frac{IWV}{\rho_w} = \frac{\left[ZTD_{GNSS} - ZHD\right]}{10^{-6} R_w \rho_w \left[k_2' + \frac{k_3}{T_m}\right]}$$

$$= \Pi\left[ZTD_{GNSS} - ZHD\right] = \Pi \cdot ZWD$$

- Specific gas
- constant

Refractivity Constants

Water Density

Mean Temperature

Operational Requirements and Standards for GNSS Meteorology

- The Global Climate Observing System (GCOS) Reference Upper Air Network (**GRUAN)**
- International GNSS Service **(IGS)**
- World Meteorological Organisation **(WMO)** and its commissions, e.g. Commission for Instruments and Methods of Observations **(CIMO),** Commission on Climatology **(CCI**), Commission for Basic Systems (**CBS**)
- The World Climate Research Programme (**WCRP**)
- New COST action of the European Union: Advanced Global Navigation Satellite Systems' tropospheric products for monitoring severe weather events and climate (**GNSS4SWEC**)
- The climate science community
- Existing observational networks (i.e., Network for the Detection of Atmospheric Composition Change (**NDACC**), and Global Atmospheric watch)
- Global Initiatives(i.e., The Global Space-based Inter-calibration System (**GSICS**) and The "Sustained, Coordinated Processes of Environmental Satellite Data for Climate Monitoring" (**SCOPE-CM**) Initiative).

Operational Requirements and Standards for GNSS Meteorology

- ✓ *GNSS meteorology station requirement*
- ✓ *NSS meteorology network requirement*
- ✓ *GNSS meteorology processing requirement*
- ✓ *GNSS meteorology observables*

Variable	ZTD	ZWD	PWV	PS	Tm
Measurement Range	$1000-3000mm$	$0-500mm$	$0-8mm$	$500-1100hpa$	$20-300k$
Accuracy	$4-6mm$	$6mm$	$1Kgm^{-2}$	$0.01hpa$	$0.2K$
Precision	$4-6mm$	$6mm$	$1Kgm^{-2}$	$0.5hpa$	$0.1K$
Long Term Stability	$0.1-0.4$ mm/dec	$0.1-0.4$ mm/dec	$0.01-0.06$ Kgm^{-2}/dec	0.1 hpa/dec	0.05 K/dec
Temporal Resolution	$1hr$	$1hr$	$1hr$	$1hr$	$1hr$
Data Latency	$1month$	$1month$	$1month$	$1month$	$1month$

Data/Data Processing

- ✓Met data from NCEP/NCAR reanalysis (2010-2012)
- ✓Radiosonde sounding data (2009-2013)
- ✓GNSS data from The Nigerian GNSS Network and selected IGS stations (Jan 2010- Jun 2014)

Data/Data Processing (contd)

NCEP/NCAR Reanalysis 1

✓36 grids points

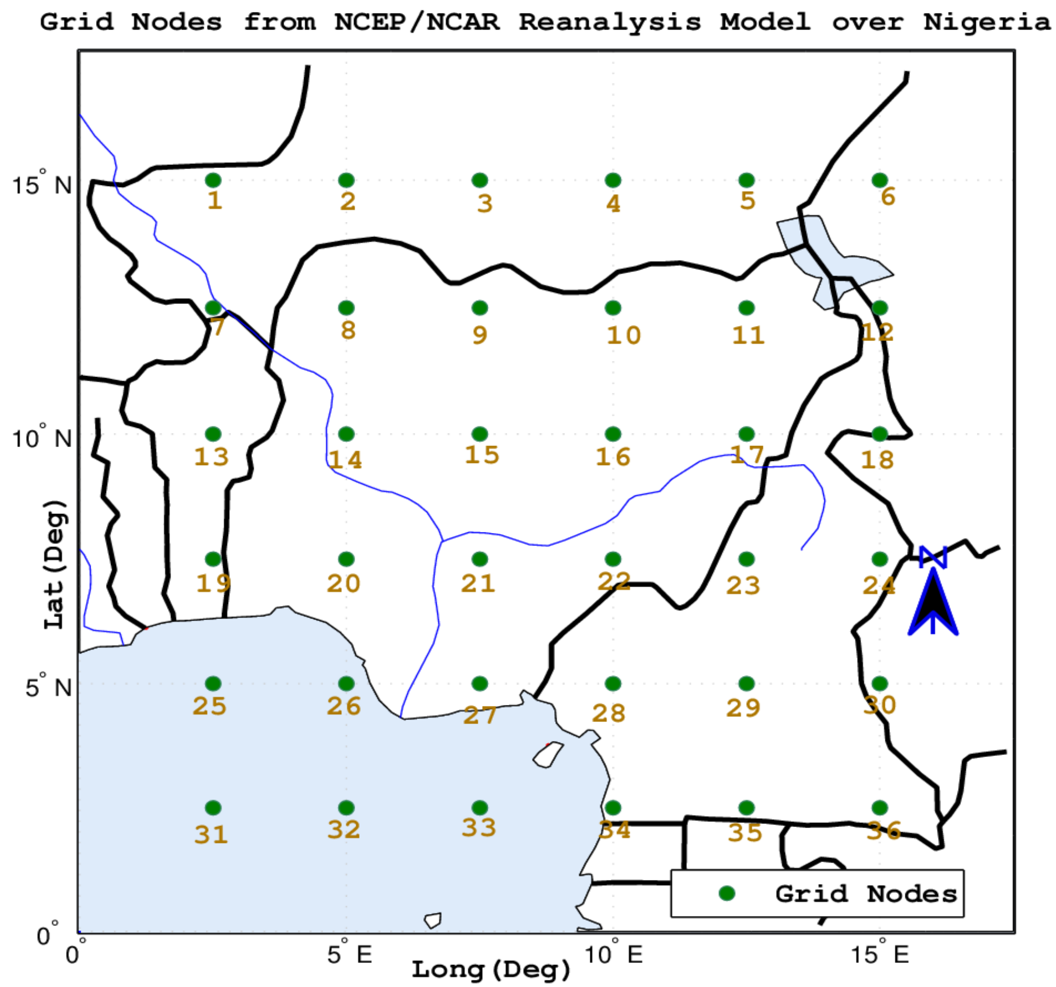
✓17pressure level (1000,925, 850, 700, 600, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, 10)

✓Grid spacing 2.5deg on latitude and longitude

✓Data in netCDF4 format

✓4-times daily(0h, 6h, 12h, and 18h) for Relative humidity, Specific humidity, Geopotential height and Air temperature data

✓Data availability: http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.pressure.html

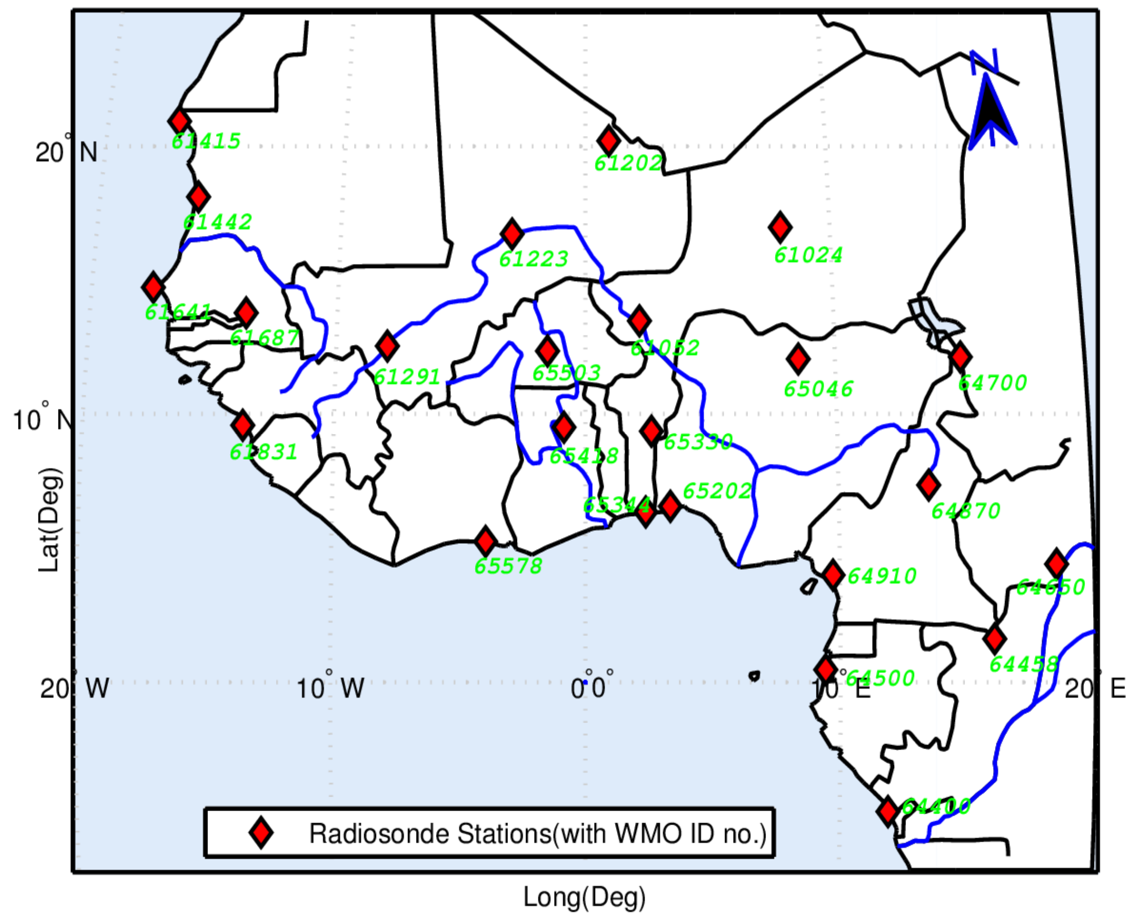


Data/Data Processing (contd)

Radiosonde Data

- ✓**24 Sounding Stations**
- ✓**Fundamental pressure level (1000,925, 850, 700, 600, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, 10)**
- ✓**Unevenly spaced across West African Region**
- ✓**Data in ASCII format**
- ✓**2-4 times daily(Varies from stations depending launches) for Relative humidity, Specific humidity, Geopotential height and Air temperature data**
- ✓**Data availability: ftp://ftp.ncdc.noaa.gov/pub/data/igra**

Map Depicting the Position of Radiosonde Stations in West African Region



Data/Data Processing (contd)

Estimating Mean Temperature of the Troposphere(Tm)

The weighted mean temperature is the vertical column of air above the GNSS receiver, thus:

$$T_m = \frac{\int_h^\infty \frac{e}{T} \cdot Z_w^{-1} dh}{\int_h^\infty \frac{e}{T^2} \cdot Z_w^{-1} dh} = \frac{\sum_1^n \overline{\left(\frac{e_i}{T_i}\right)} \Delta S_i}{\sum_1^n \overline{\left(\frac{e_i}{T_i^2}\right)} \Delta S_i}$$

where, $\overline{\left(\frac{e_i}{T_i}\right)} = \left(\frac{\frac{e_i}{T_i} + \frac{e_{i-1}}{T_{i-1}}}{2}\right), \overline{\left(\frac{e_i}{T_i^2}\right)} = \left(\frac{\frac{e_i}{T_i^2} + \frac{e_{i-1}}{T_{i-1}^2}}{2}\right)$

ΔS_i is thickness of the atmosphere at the *ith* layer and e_i and T_i are the water vapour pressure and temperature at the top of the atmosphere at the *ith* layer, respectively. e_{i-1}, and T_{i-1} are water vapour pressure and temperature at the bottom of the atmosphere at the *ith* layer, respectively, and n is the number of layers.

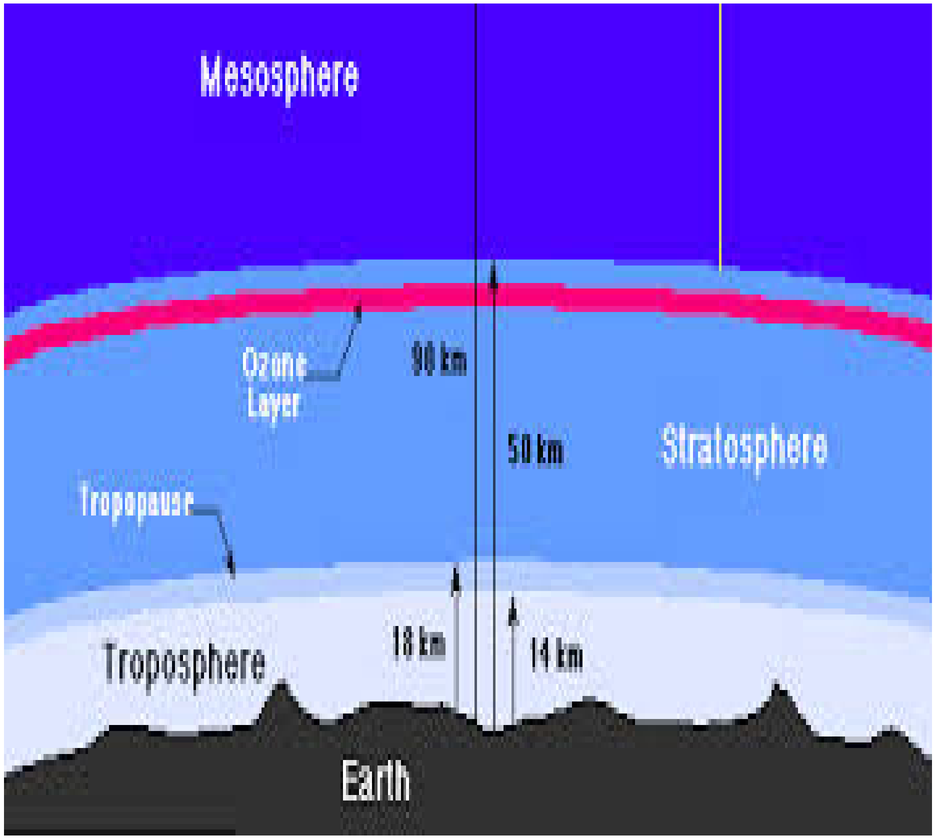
More layers result in higher accuracy. This method is limited by the tempo-spatial resolution of these data products, which is a barrier for GNSS meteorology and is rarely used in real time PWV estimation.

Data/Data Processing (contd)

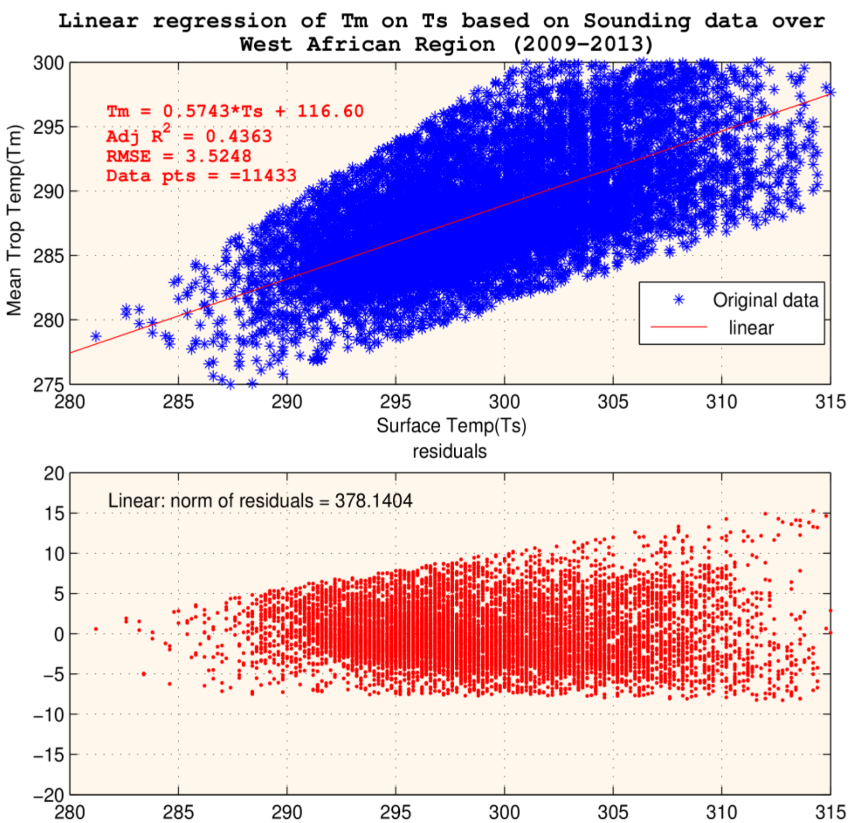
Calculating Tropopause Height

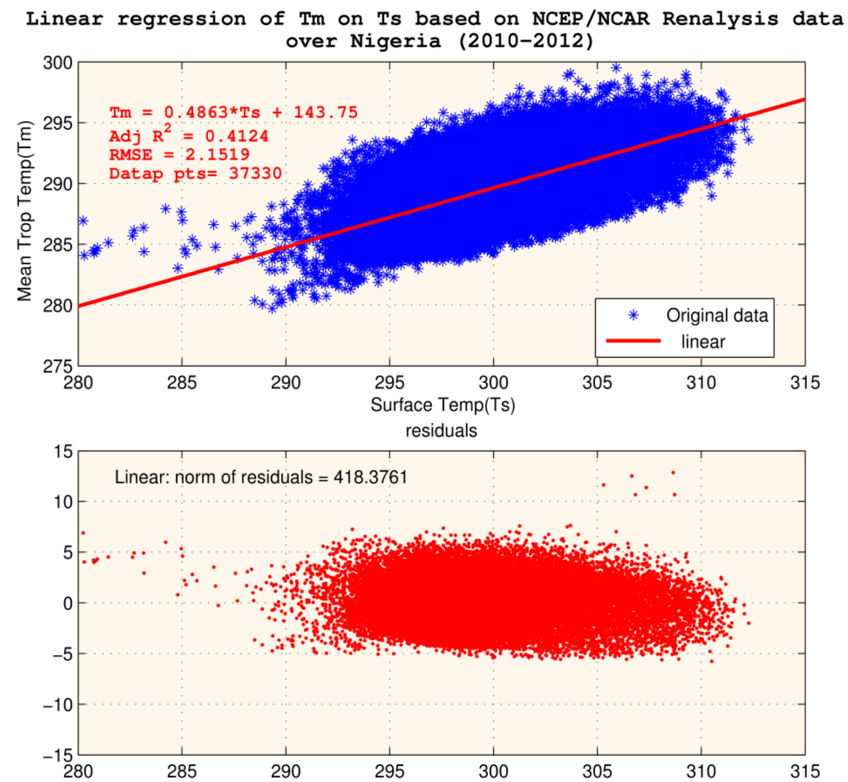
WMO algorithm: *Tropopause is defined as the lowest altitude at which the temperature lapse rate decreases to 2°C km−1, provided that the average lapse rate from this level to any point within the next higher 2 km does not exceed 2°C km−1. We calculate lapse rates using a forward (upward) differencing scheme of the form*

$L(z_i) = -\partial T/\partial z \approx -(T_{i+1} - T_i)/(z_{i+1} - z_i)$, *where L is the lapse rate, T is temperature, and z is altitude.*

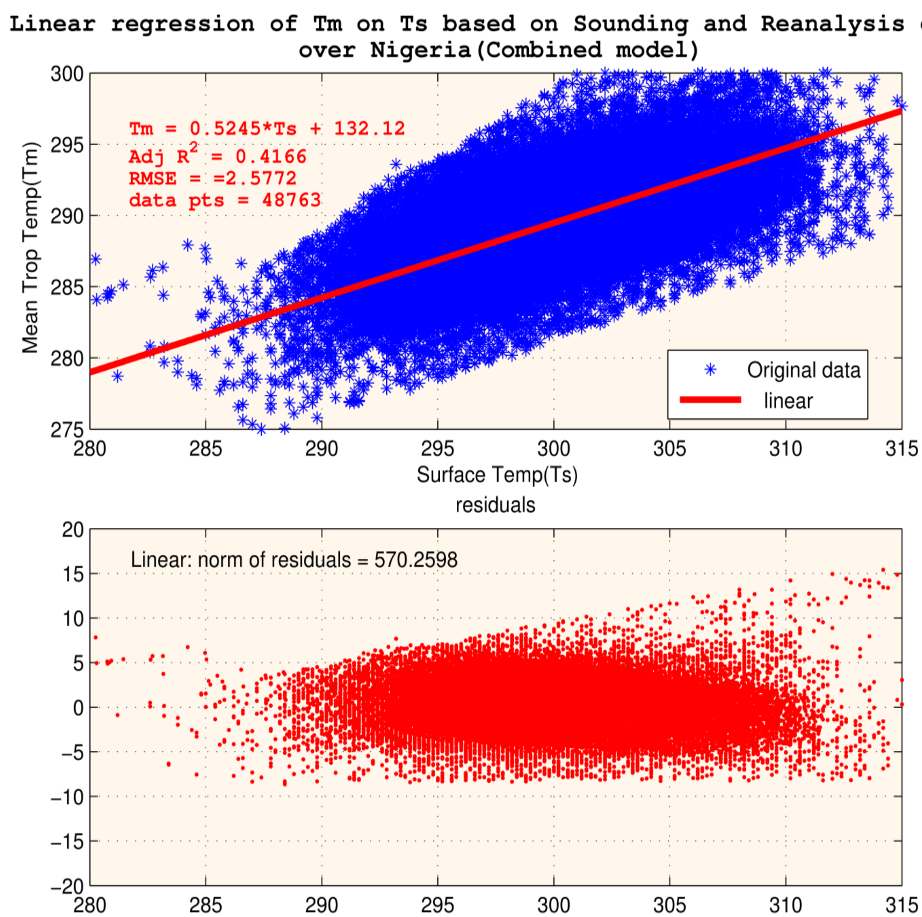


Data/Data Processing (contd)





Data/Data Processing (contd)



- **The Nigerian Weighted Mean Temperature Equation(NWMTE)**
- **Validation of Model (Bevis model, GWMT III, GWMT IV)**
- Isioye, O. A., Combrinck, L. and Botai,O.J.(2014). Analysis of the Weighted Mean Temperature for Nigeria based on NCEP/NCAR Reanalysis and Sounding Data (Under Review).

Data/Data Processing (contd)

The Nigerian Reference GNSS Network(NIGNET)

✓15 CORS operated and managed by the office of the Surveyor General the Federation

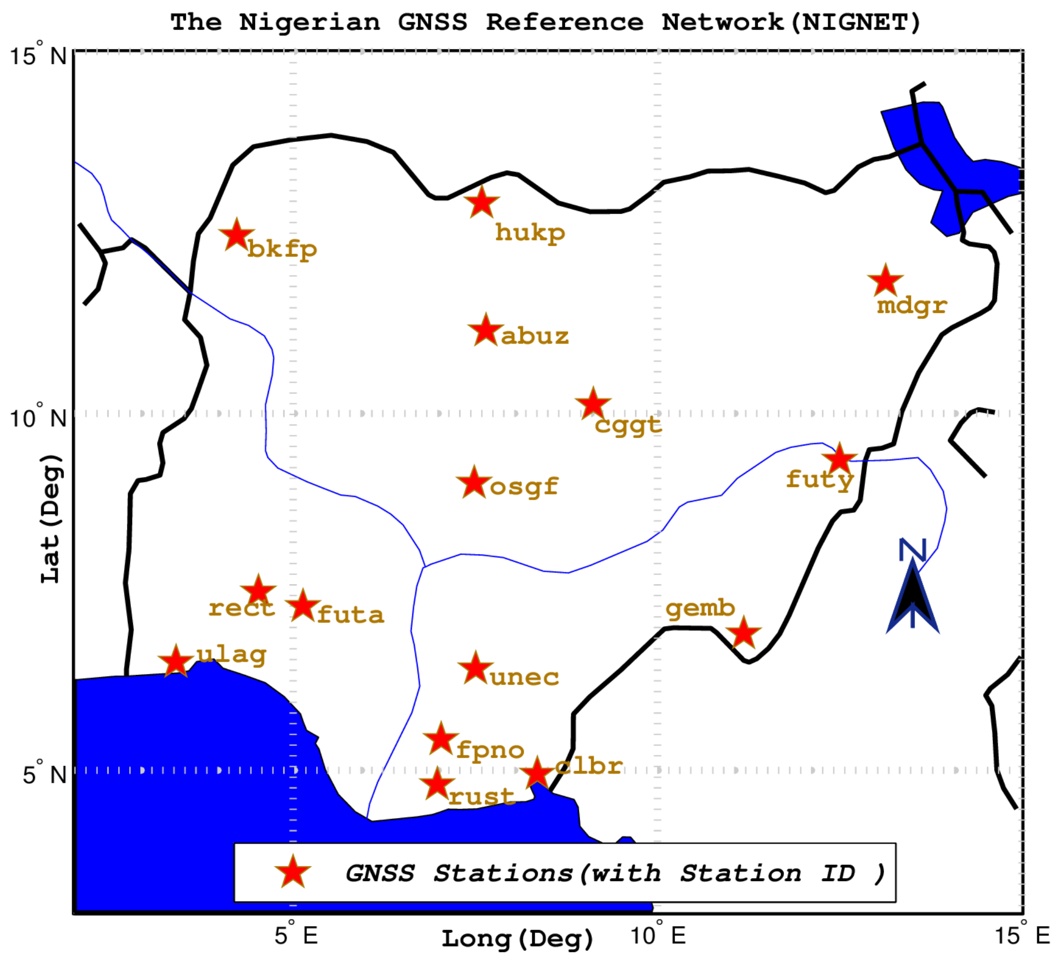
✓4.5 years data used from inception (2010) to June (2014)

✓All stations are AFREF stations

✓Data Format in RINEX

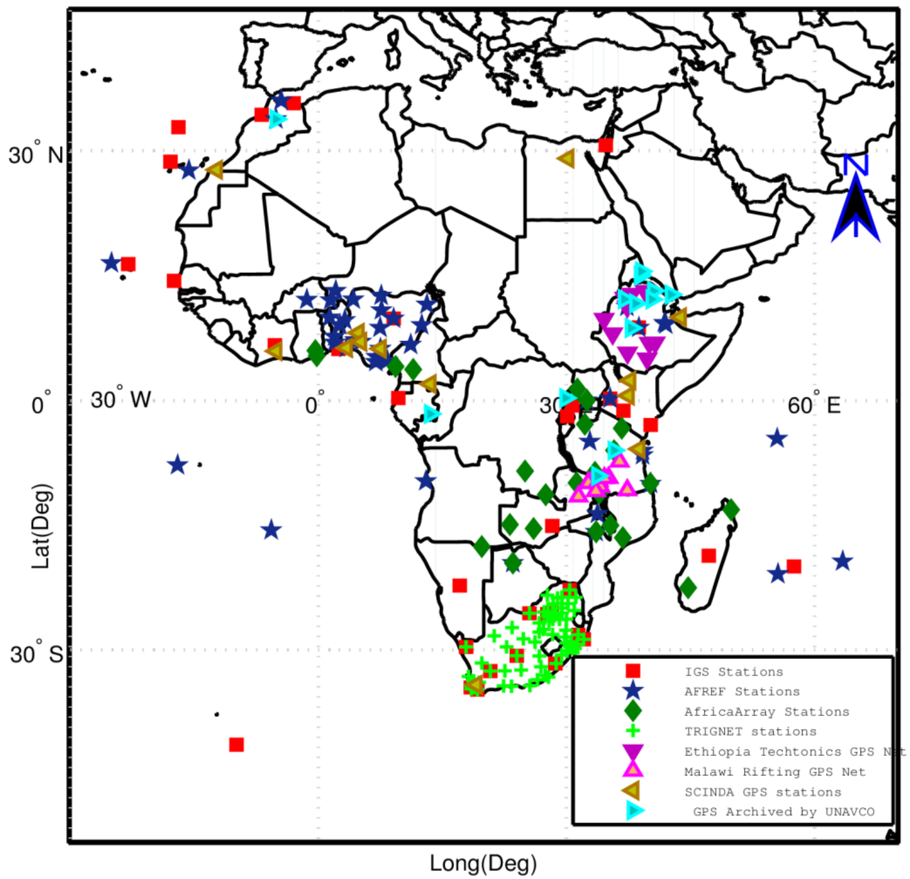
✓GNSS Receivers (Trimble NETR8/NETR9), Antenna (TRM59800.00)

✓Data availability: www.nignet.net or www.afrefdata.org

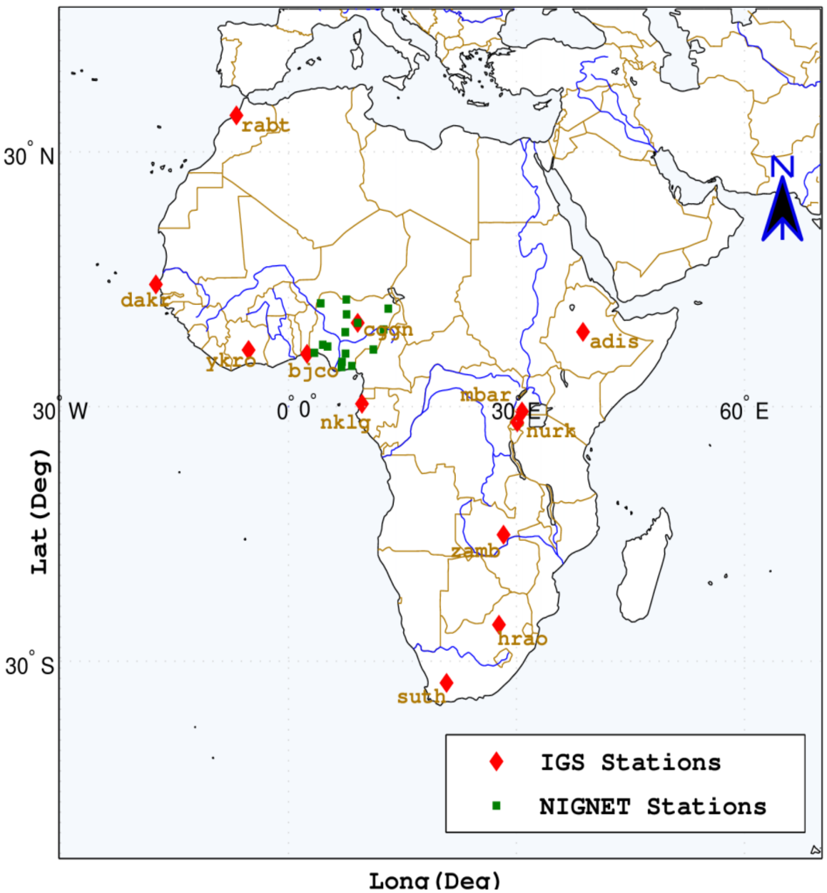


Data/Data Processing (contd)

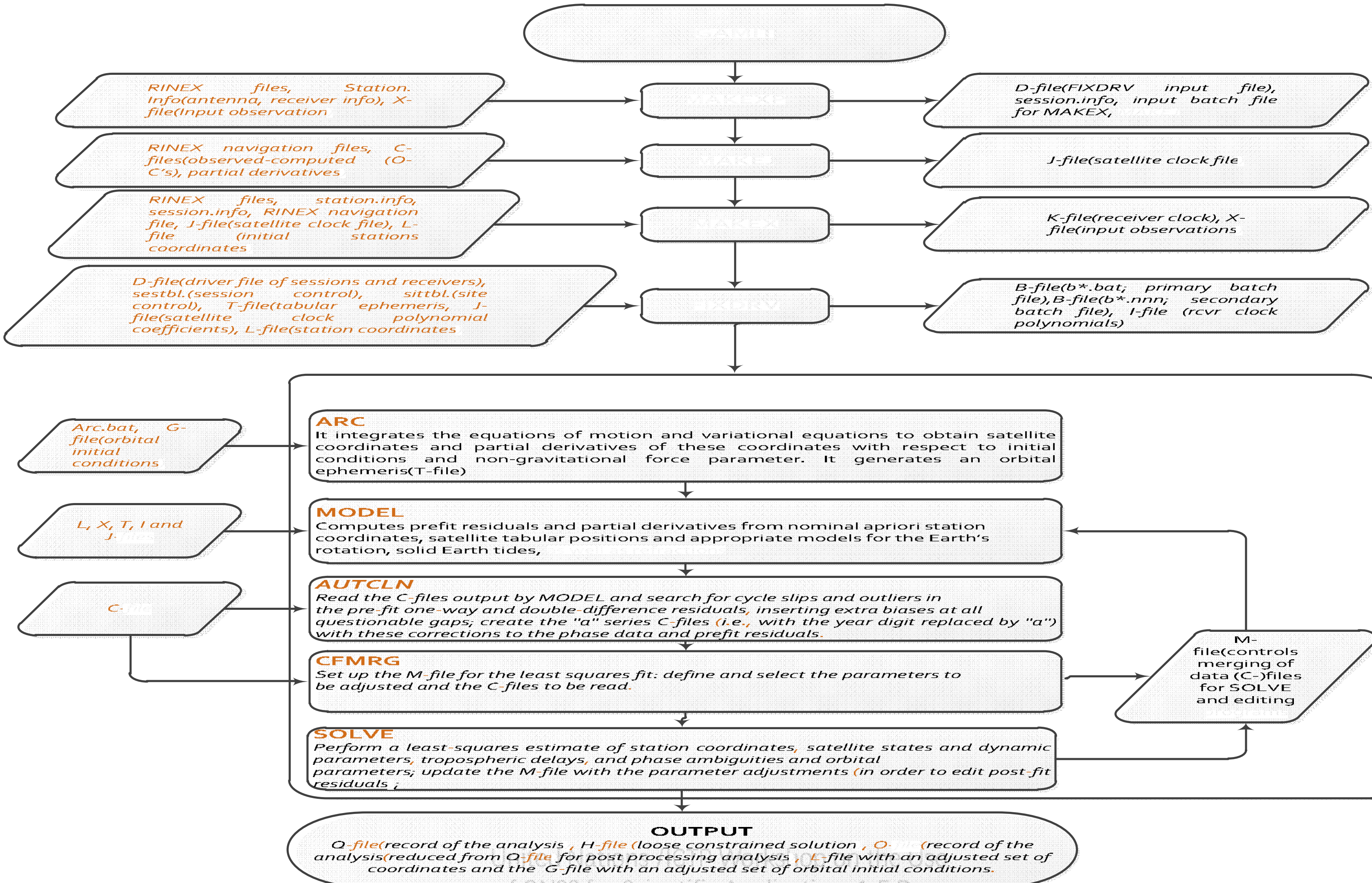
GPS/GNSS Station in Africa(After Isioye et al., 2014)



GPS/GNSS stations utilized in present study



Data/Data Processing (contd)



Data/Data Processing (contd)

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Session Table
Processing Agency = MIT

Satellite Constraint = Y         ; Y/N  (next two lines are free-format but 'all' must be present)
                 all       a      e      i     n       w       M     rad1    rad2  rad3  rad4  rad5  rad6  rad7  rad8  rad9;
                          0.01  0.01   0.01   0.01    0.01    0.01    0.01    0.01  0.01  0.01  0.01  0.01  0.01  0.01  0.01

  << Controls must begin in column 1 >>
Choice of Experiment = BASELINE   ; BASELINE/RELAX./ORBIT
Type of Analysis = 1-ITER         ; 1-ITER(autcln prefit and conditional redo) / 0-ITER (no postfit autcln) / PREFIT
AUTCLN redo = Y                   ; Y/N; 3rd soln only if needed, assume 'Y' if 'Type of analysis = 1-ITER'
Choice of Observable = LC_AUTCLN  ; LC_AUTCLN (default), LC_HELP (codeless L2), L1_ONLY (L1 soln from dual freq),
                                    L2_ONLY (L2 soln from dual freq), L1,L2_INDEPENDENT (L1 + L2 from dual freq)
                                    L1&L2 (same as L1,L2_INDEPENDENT but with ion constraint);
                                    L1_RECEIVER (must add 'L1only' in autcln.cmd)
Station Error = ELEVATION 10 5    ; 1-way L1, a**2 + (b**2)/(sin(elev)**2) in mm. default = 10. 0.
Decimation Factor = 4             ; FOR SOLVE, default = 1
Ionospheric Constraints =  0.0 mm + 8.00 ppm
Ambiguity resolution WL = 0.15 0.15 1000. 99. 15000. ; for LC_HELP, ignored for LC_AUTCLN
Ambiguity resolution NL = 0.15 0.15 1000. 99. 15000. ; allow long baselines with LC_AUTCLN
Zenith Delay Estimation = Y     ; Yes/No  (default No)
Interval zen = 24                ; 2 hrs = 13 knots/day  (default is 1 ZD  per day)
Zenith Constraints = 0.50       ; zenith-delay a priori constraint in meters (default 0.5)
Zenith Variation = 0.02 100.    ; zenith-delay variation, tau in meters/sqrt(hr), hrs (default .02 100.)
Atmospheric gradients = Y       ; Yes/Np  (default No)
Number gradients = 2            ; number of gradient parameters per day (NS or ES); default 1
Met obs source = GPT 50         ; hierarchical list with humidity value at the end; e.g. RNX UFL GPT 50 ; default GTP 50
                                     if [humid value] < 0, use RNX or UFL if available
Output met = Y                  ; write the a priori met values to a z-file (Y/N)
Use met.list = N                ; not yet supported
Use met.grid = N                ; not yet supported
DMap = VMF1                      ; GMF(default)/NMFH/VMF1
WMap = VMF1                      ; GMF(default)/NMFW/VMF1
Use map.list = N                ; VMF1 list file with mapping functions, ZHD, ZWD, P, Pw, T, Ht
Use map.grid = N                ; VMF1 grid file with mapping functions and ZHD
Tides applied = 31               ; Binary coded: 1 earth  2 freq-dep  4 pole  8 ocean  16 remove mean for pole tide
                                 ; 32 atmosphere ;  default = 31
Use otl.list = Y                 ; Ocean tidal loading list file from OSO
Use otl.grid = N                 ; Ocean tidal loading grid file, GAMIT-format converted from OSO
Etide model = IERS03             ; IERS96/IERS03
Earth Rotation = 11              ; Diurnal/Semidirunal terms: Binary coded: 1=pole 2=UT1 4=Ray model; 8=IERS2010 ; default=11
Apply atm loading = N            ; Y/N for atmospheric loading
Use atml.list = N                ; Atmospheric (non-tidal) loading list file from LU
Use atml.grid = N                ; Atmospheric (non-tidal) loading grid file from LU, converted to GAMIT format
Use atl.list = N                 ; Atmospheric tides, list file, not yet available
Use atl.grid = N                 ; Atmospheric tides, grid file
Antenna Model = AZEL             ; NONE/ELEV/AZEL  default = ELEV   Use AZEL for IGS absolute ANTEX files
SV antenna model = ELEV          ; NONE/ELEV       default = NONE   Use ELEV for IGS ANTEX files

Delete AUTCLN input C-files = Y  ; Y/N ; default Y to force rerun of MODEL

 << List of additional controls not commonly - blank first column to indicate a comment >>
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Data/Data Processing (contd)

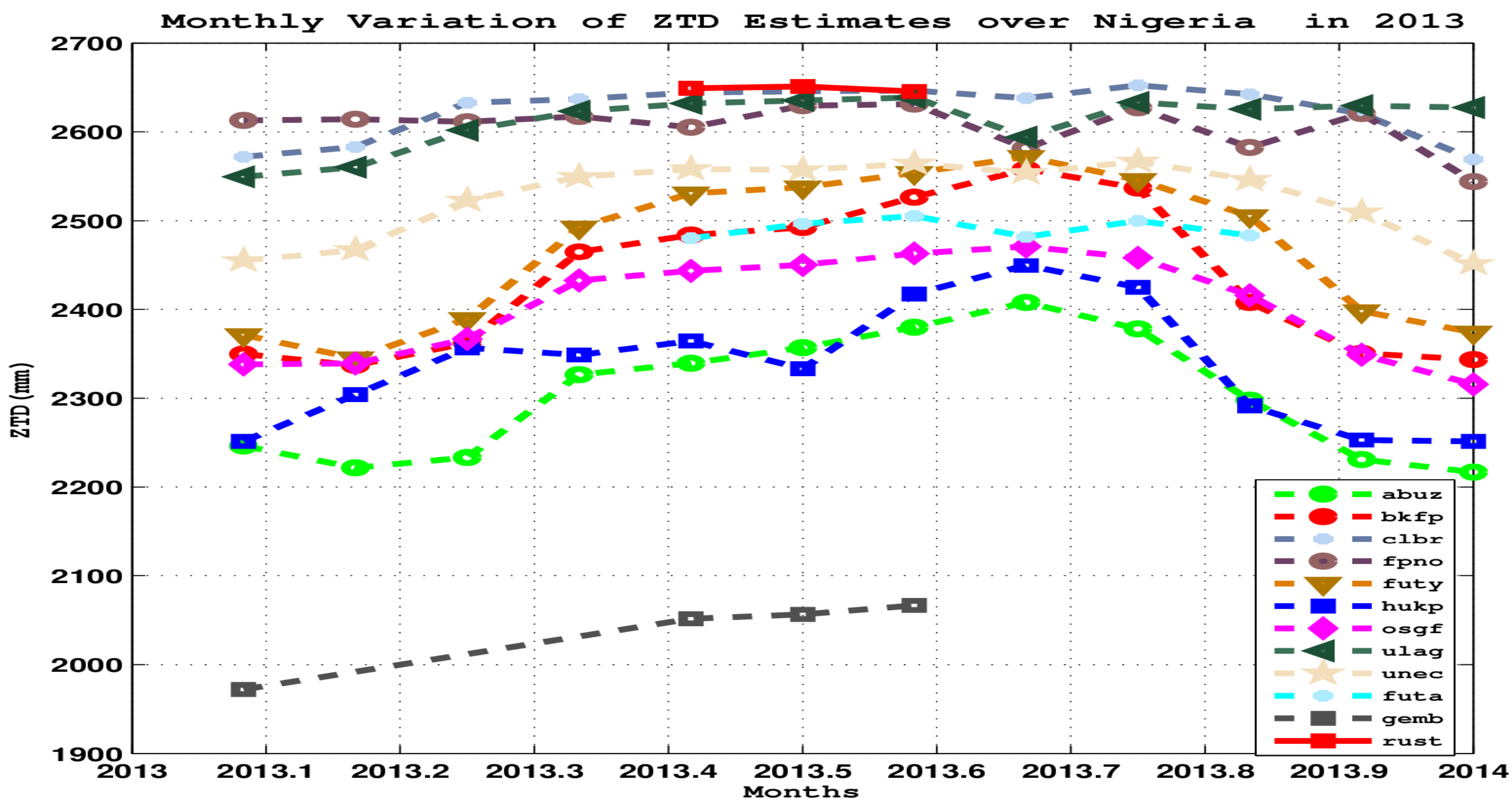
* Estimated atmospheric values for **ABUZ**. Height estimate: 705.3244 +/- 0.0202 m.
* METUTIL Version 3.0 2009-08-27
* Input files: oscala.001 zabuz2.001 ZTD-file sigmas scaled by 1.0

* Yr	Doy	Hr	Mn	Sec	Total Zen	Wet Zen	Sig Zen	PW	Sig PW (mm)	Press (hPa)	Temp (K)	ZHD (mm)	Grad NS	Sig NS	Grad EW	Sig EW (mm)
2012	1	0	0	0.	2204.70	69.00	4.40	11.34	0.72	935.50	297.70	2135.70	7.00	7.90	1.90	10.80
2012	1	2	0	0.	2199.20	63.50	3.10	10.43	0.51	935.50	297.70	2135.70	5.78	7.81	2.22	10.71
2012	1	4	0	0.	2201.20	65.50	2.70	10.76	0.44	935.50	297.70	2135.70	4.57	7.73	2.53	10.61
2012	1	6	0	0.	2208.70	73.00	2.30	11.99	0.38	935.50	297.70	2135.70	3.35	7.64	2.85	10.51
2012	1	8	0	0.	2208.00	72.30	2.40	11.88	0.39	935.50	297.70	2135.70	2.13	7.55	3.17	10.42
2012	1	10	0	0.	2209.30	73.60	2.60	12.09	0.43	935.50	297.70	2135.70	0.92	7.46	3.48	10.32
2012	1	12	0	0.	2204.80	69.10	2.80	11.35	0.46	935.50	297.70	2135.70	-0.30	7.37	3.80	10.22
2012	1	14	0	0.	2200.00	64.30	2.90	10.56	0.48	935.50	297.70	2135.70	-1.52	7.28	4.12	10.12
2012	1	16	0	0.	2194.90	59.20	2.40	9.73	0.39	935.50	297.70	2135.70	-2.73	7.19	4.43	10.02
2012	1	18	0	0.	2199.30	63.60	2.30	10.45	0.38	935.50	297.70	2135.70	-3.95	7.09	4.75	9.91
2012	1	20	0	0.	2201.10	65.40	2.30	10.74	0.38	935.50	297.70	2135.70	-5.17	7.00	5.07	9.81
2012	1	22	0	0.	2198.20	62.50	2.50	10.27	0.41	935.50	297.70	2135.70	-6.38	6.90	5.38	9.71
2012	2	0	0	0.	2194.10	58.40	3.40	9.59	0.56	935.50	297.70	2135.70	-7.60	6.80	5.70	9.60

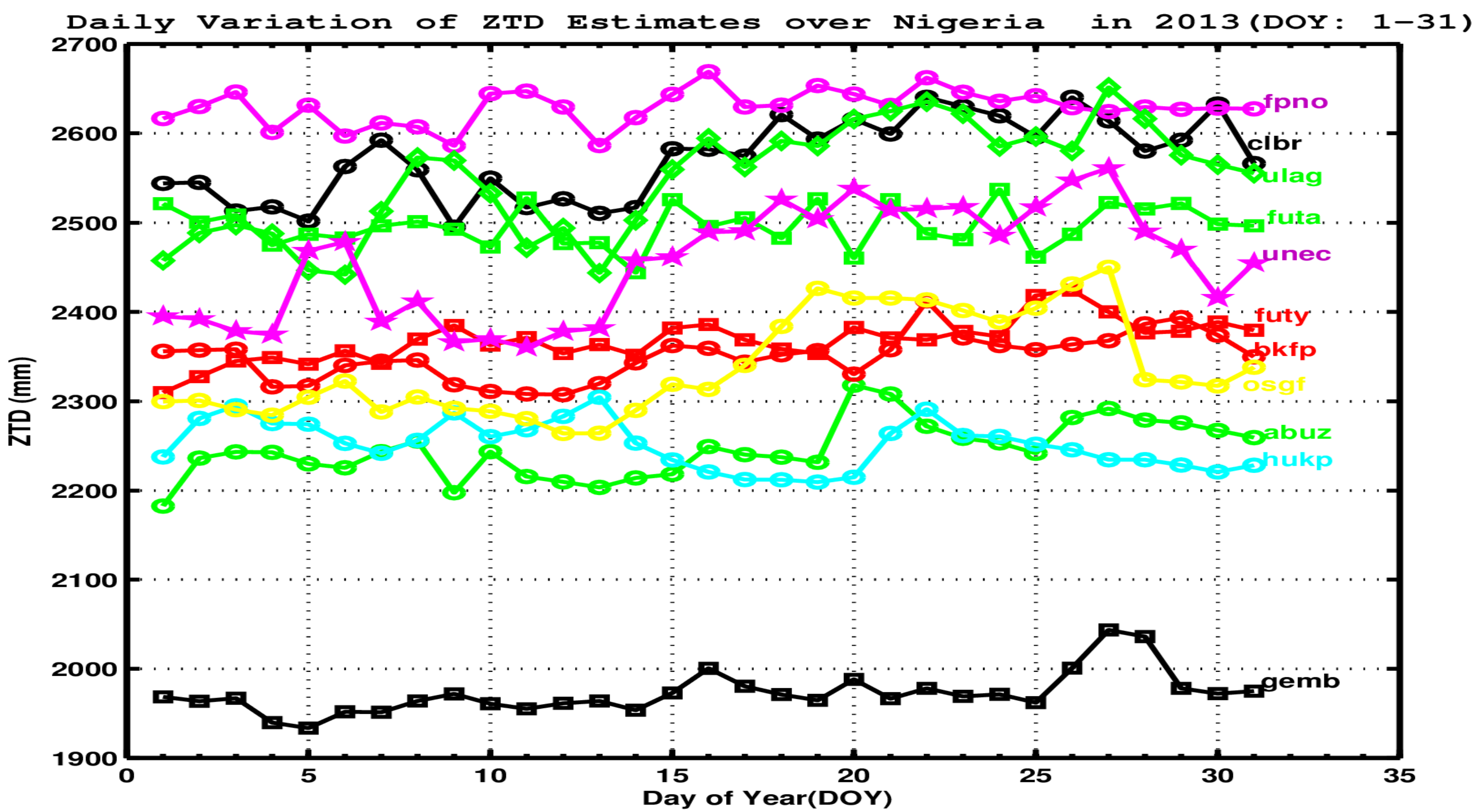
Data/Data Processing (contd)

- Characterization of ZTD estimates(Spatial Variability, Temporal changes/trend, Spectral analysis and test for stationality)
- Validation of ZTD estimates (Analysis centre, Empirical models and refractivity model)

Analysis of Zenith Tropospheric Delay(ZTD) Estimation from GNSS

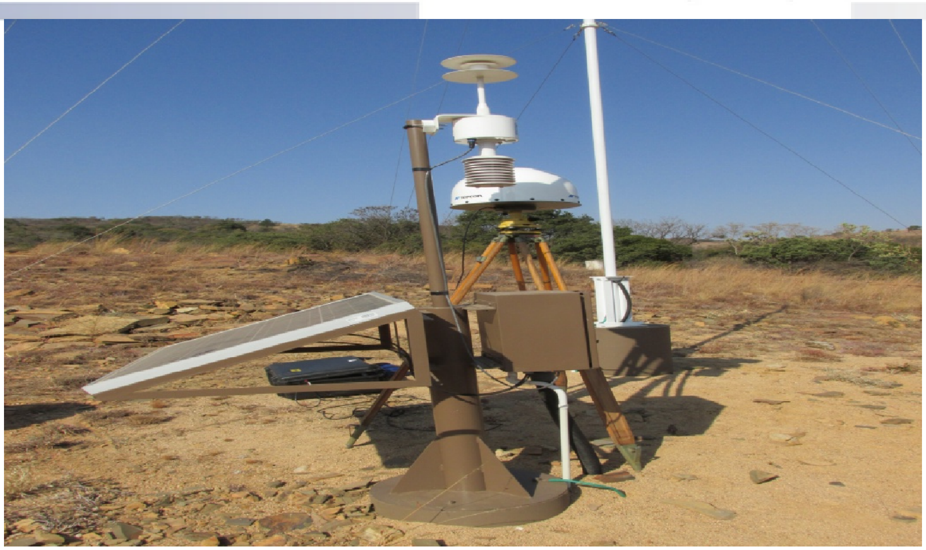


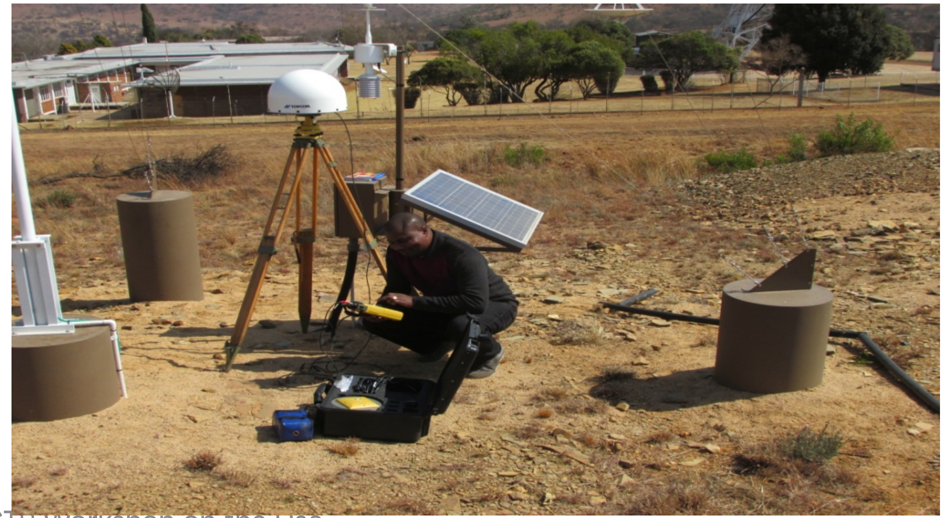
Analysis of Zenith Tropospheric Delay(ZTD) Estimation from GNSS



Future Task

- ✓ Meteorological parameter modelling for GNSS meteorology
- ✓ Validation of PWV estimates form GNSS
- ✓ Characterization of PWV estimates from GNSS
- ✓ Automation of ZTD estimation in GAMIT for Near Real Time Products for weather services(i.e., nowcasting)
- ✓ Exploring the potential of GPS Radio Occultation for GPS Meteorology and possible integration of ground based GNSS Meteorology with RO





Acknowledgment

- ✓ Office for Outer Space Affairs, United Nations
- ✓ 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!