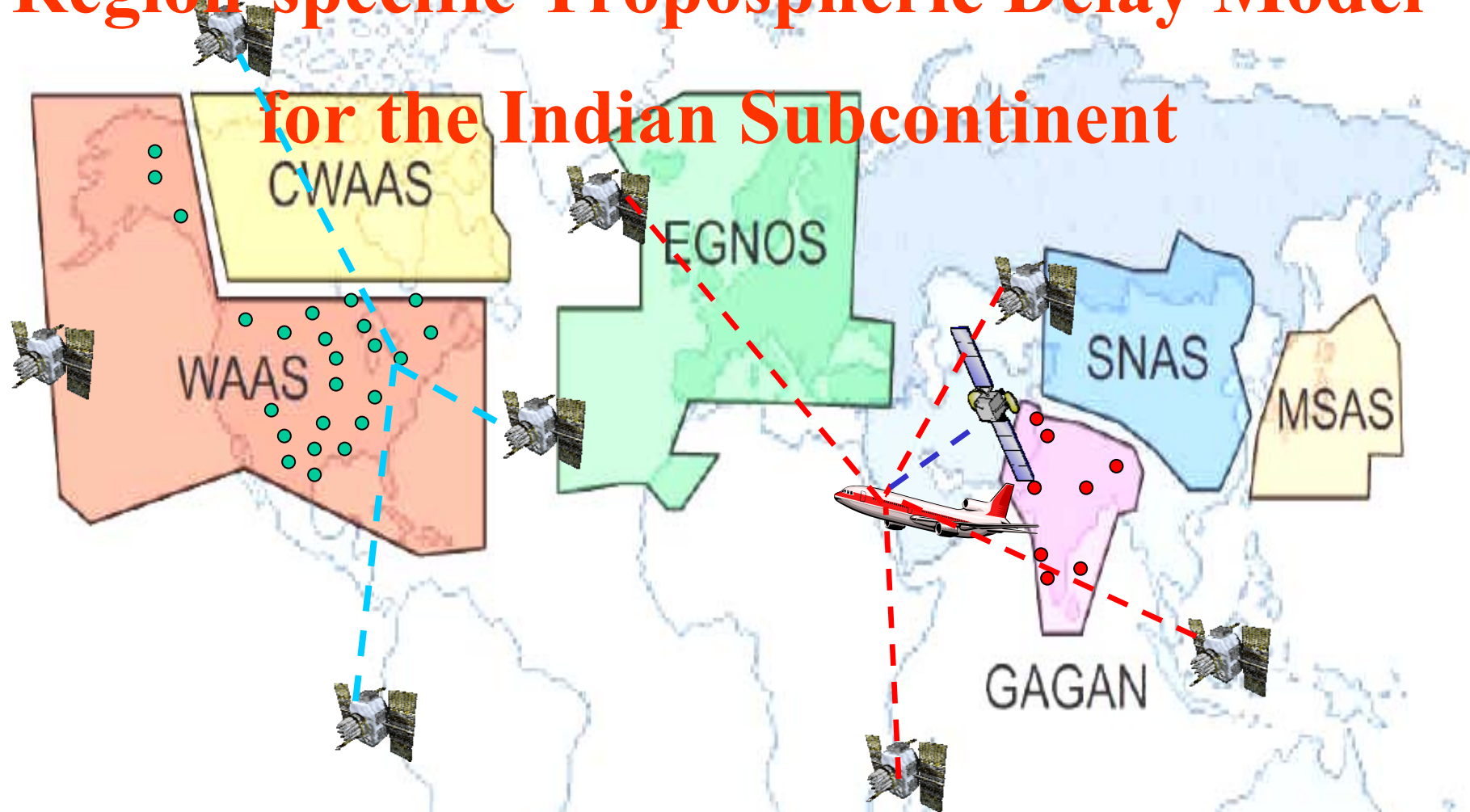# Region-specific Tropospheric Delay Model for the Indian Subcontinent

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Tropospheric Range Error

Being neutral atmosphere is non-dispersive the modeling is the only possible way to estimate ZTD

Development of Tropospheric delay models

Daily radiosonde data (26 km) for 5 years over 18 locations and CIRA data for upper atmosphere

Development of monthly mean atmospheric models for *P, T* and *e (100 m)*

Ray Tracing for dry & wet components of zenith tropospheric Delay (ZTD)

Develop empirical models for ΔR with surface parameters

Day-to-day / seasonal variation of ZTD

Compare Model with estimates

Post analysis of GPS for ΔR

Operational model

Srinagar
Patiala
Delhi
Lucknow
Guwahati
Jodhpur
Ahmedabad
Bhopal
Kolkata
Mumbai
Hyderabad
Vishakhapatnam
Goa
Mangalore
Bangalore
Chennai
Port Blair
Trivandrum

Regional Surface models for the Indian Subcontinent

Surface Model

ZHD (m) = (0.00228 ± 1.4E-6) × P_S

ZWD (m) = 0.06207+0.00271 × e_S + 2.21E-4 × e_S^2

HOPFIELD MODEL PARAMTERS

h_D **(km) = (40.209 ± 0.045)+(0.154 ± 0.002)*T_s (ºC)**

h_W **(km) = (10.474 ± 0.29) + (0.111 ± 0.01)×T_s (ºC)**

Validation of Regional Surface models with ray-tracing

Stn. Code	Dry delay		Wet delay		
	Mean abs. Diff (cm)		Mean abs. diff (cm)		
	Surface model-Ps	Hopfield model	Surface model-e_s	Hopfield model	Surface model-PWV
Trivandrum	1.01 (0.2)	1.24 (0.27)	4.8 (3.7)	4.98 (3.5)	0.17 (0.17)
Portbalir	0.94 (0.4)	1.10 (0.4)	4.4 (3.5)	4.40 (3.3)	0.16 (0.13)
Bangalore	0.45 (0.2)	0.30 (0.2)	4.9 (2.8)	4.20 (2.8)	0.57 (0.21)
Kolkata	0.97 (0.4)	0.80 (0.4)	5.7 (4.0)	5.70 (4.0)	0.30 (0.20)
Ahmedabad	1.10 (0.4)	0.99 (0.5)	4.8 (3.9)	5.00 (3.9)	0.24 (0.21)
Guwahati	0.79 (0.5)	0.93 (0.8)	4.3 (3.7)	5.90 (4.0)	0.24 (0.16)
Delhi	0.28 (0.2)	0.47 (0.25)	4.0 (3.1)	4.90 (3.9)	0.28 (0.21)
Srinagar	3.20 (2.0)	2.90 (2.0)	2.1 (1.8)	1.97 (1.8)	0.50 (0.20)
Ensemble data	0.96 (0.8)	0.90 (0.8)	4.28 (3.4)	4.67 (3.7)	0.33 (0.20)

Accuracy of regional models to estimate ZHD is about 9 mm

Site Specific model is better than Regional model by ~ 5 mm,

Tropospheric Delay Correction in WAAS

Getting these inputs on real-time basis limits the use of the models for navigation.

Alternative method which can be the surrogate for the directly measured input parameters for tropospheric delay models is explored.

▪ WAAS uses the UNB Model (University of New Brunswick Model) to supplement the atmospheric parameters for tropospheric delay correction based on the information of time (DOY) and location (Latitude)

▪ The UNB model uses a lookup table for 5 atmospheric parameters estimated for every 15° lat. interval (Collins and Langley 1997)

Issue on using WAAS over Indian tropical region

➢WAAS is developed primarily based on US Standard Atmospheric data

Region-specific Tropospheric Delay Model over Indian Subcontinent (RTD Model)

Table 1: RTD model parameters

| Latitude	Mean (M)				
	P_o mb	T_o K	e_o mb	β_o K/km	λ_o
5	1005.95	302.00	29.62	5.58	2.73
10	1005.29	303.29	28.93	5.52	2.69
15	1004.97	306.26	25.67	5.71	2.50
20	1006.17	306.37	22.31	6.08	2.33
25	1004.65	304.51	21.5	6.14	2.39
30	1001.41	301.91	22.65	6.28	2.60
Latitude	**Amplitude (A)**				
	P' mb	T' K	e' mb	β' K/km	λ'
5	-1.05	1.42	1.29	0.19	0.44
10	-1.85	2.02	2.89	0.26	0.45
15	-4.50	3.78	6.82	0.67	0.56
20	-6.95	5.11	8.89	1.17	0.53
25	-8.95	6.80	10.73	1.28	0.40
30	-10.3	8.72	11.69	1.17	0.49

Let ξ be the required parameter and t and ϕ are day-of-year and latitude.
$m = (\phi - \phi_i)/(\phi_{i+1} - \phi_i)$

$$\xi(\phi,t)=\xi_o(\phi_i)+\left[\xi_o(\phi_{i+1})-\xi_o(\phi_i)\right]\cdot m-(\xi'(\phi_i)+\left[\xi'(\phi_{i+1})-\xi'(\phi_i)\right]\cdot m)\cdot \cos\left(\frac{2\pi(t-\varphi)}{365.25}\right) \; for \; 5^o < |\phi| < 30^o$$

Phase offset of temporal variations(φ) = 6 (day-of-year) & ξ = required met-parameter

Comparison of RTD model & WAAS model with Surface Model
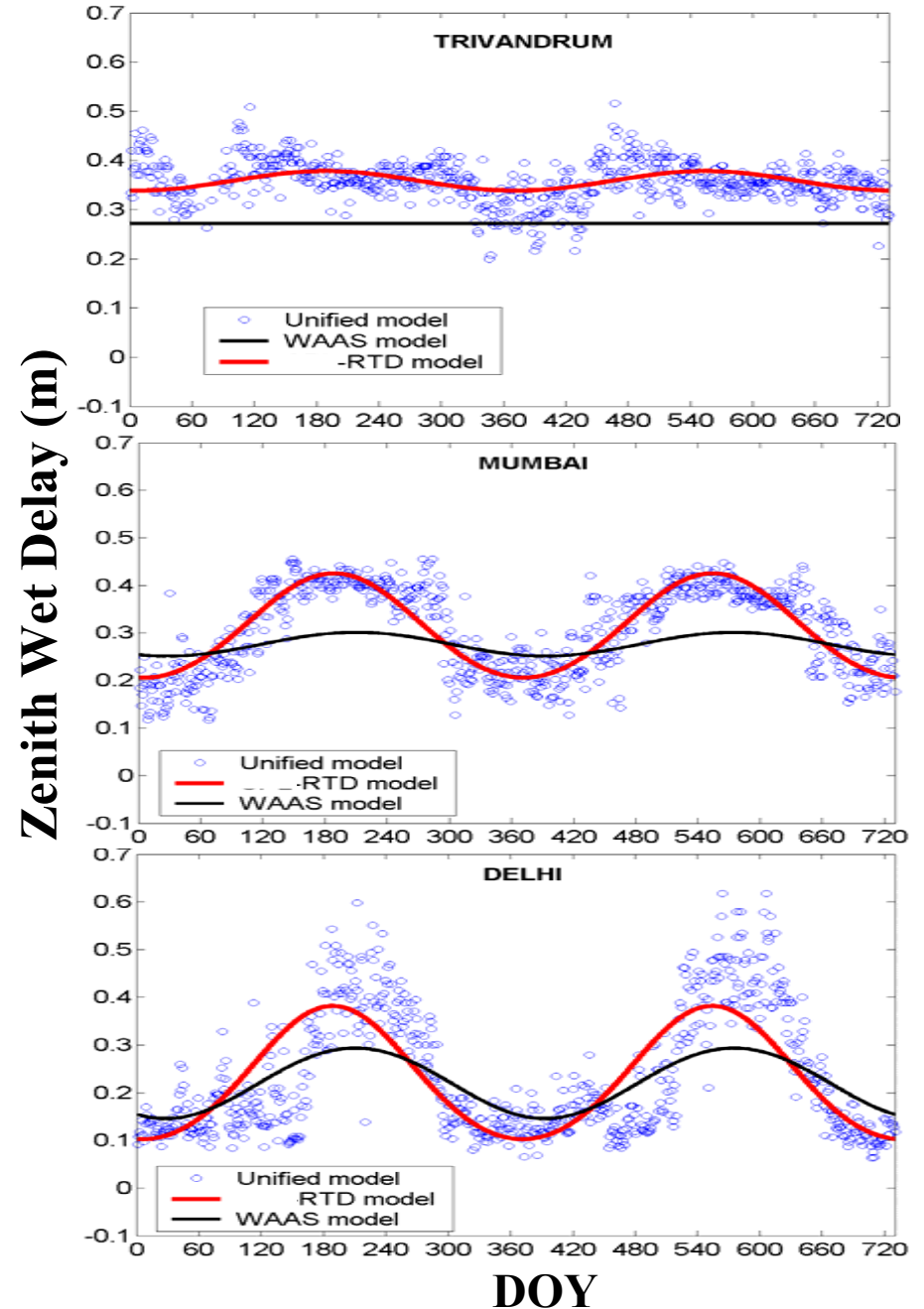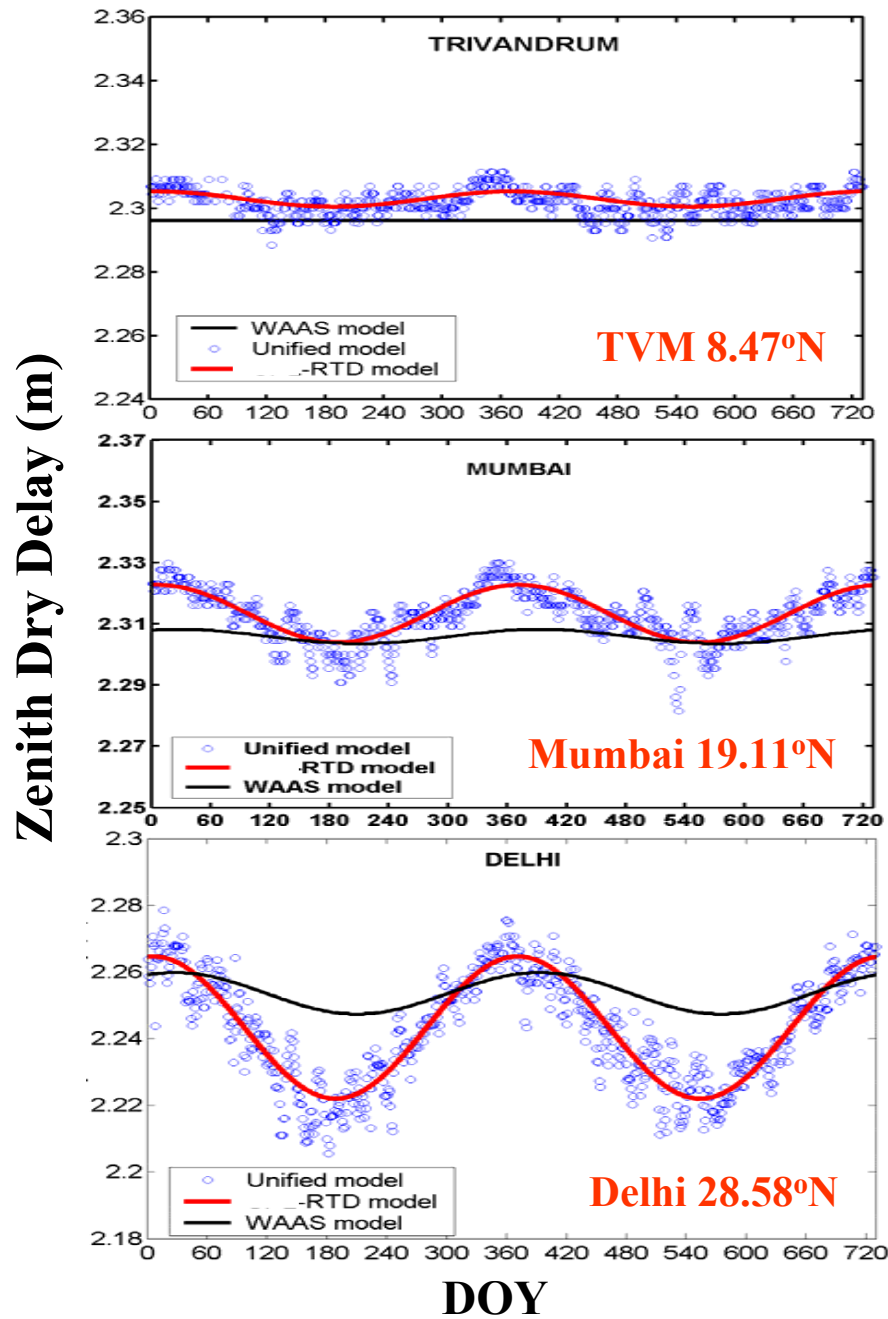
Summary of RTD Model validation with Regional Surface Models based on measured atmospheric parameters

Dry delay

RTD model   *rms* **deviation**

~0.3 ± 0.2 cm (tropical stations)

~0.5 ± 0.4 cm (mid-latitude region)

WAAS model

~1.3 ± 0.5 cm (tropical stations)

~1.3 ± 1.1 cm (mid-latitude region)

Wet delay

RTD model   *rms* **deviation**

~3.5 ± 2.8 cm (tropical stations)

~4.7 ± 3.8 cm (mid-latitude region)

WAAS model

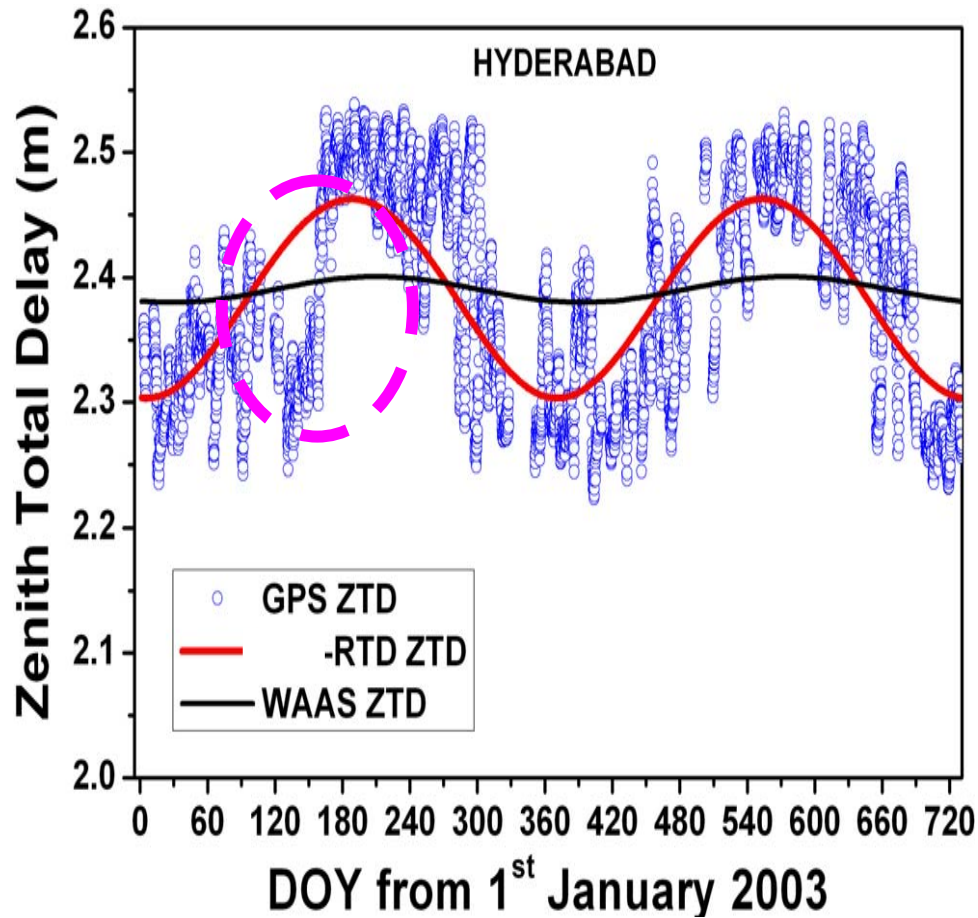~ 7.8 ± 4.1 cm (tropical stations)

~ 7.11 ± 4.9 cm (mid-latitude region)
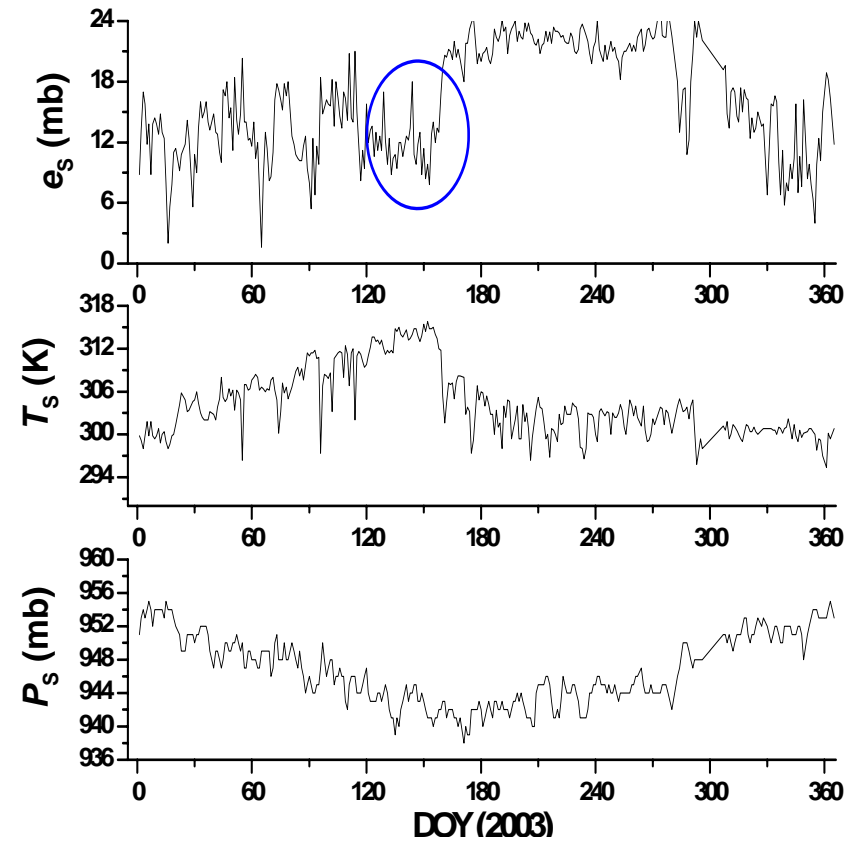
Comparison with GPS Measurements over Bangalore
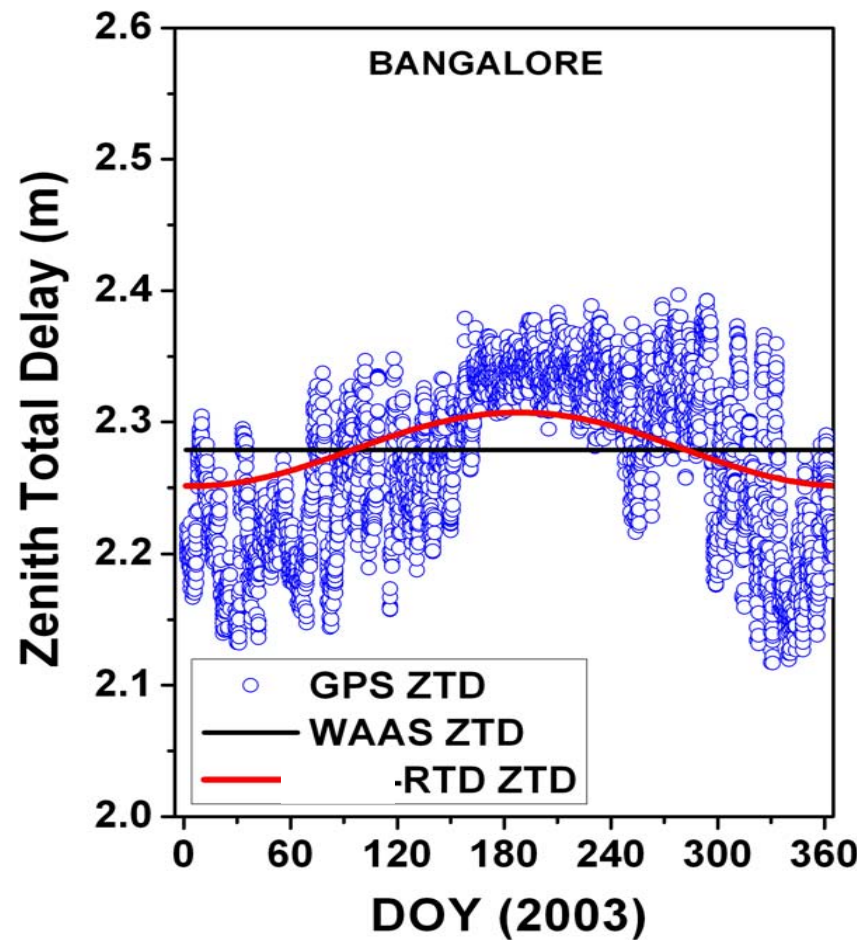
Mean absolute difference: RTD model 4.6 cm
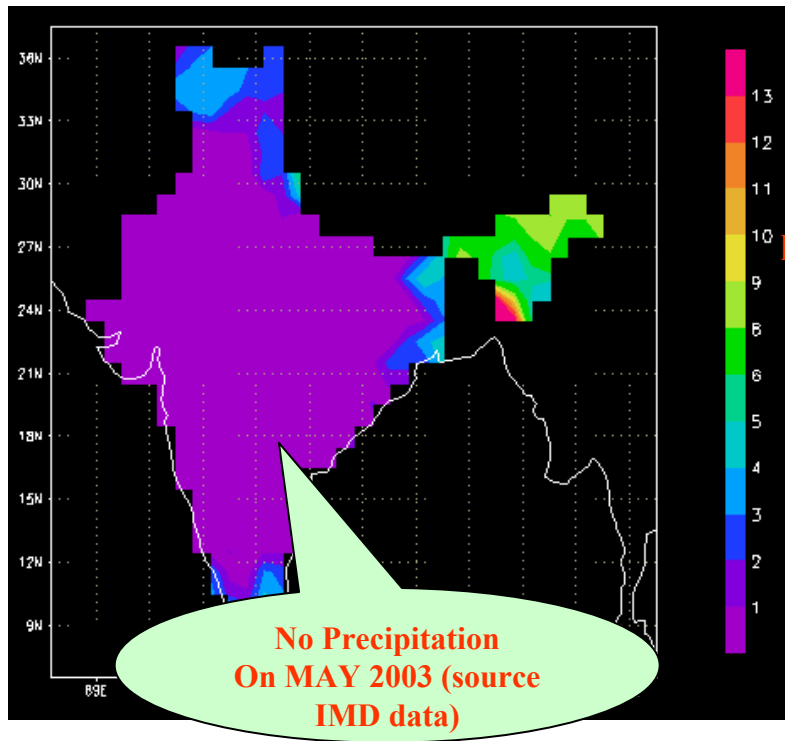The maximum deviation of Bangalore is <13.1 cm

Comparison with GPS Measurements over Hyderabad

Mean absolute diff.: RTD model 4.6 cm

The max. deviation is ~13.5 cm.

RTD and WAAS models fail to respond to the extreme weather event

No Precipitation On MAY 2003 (source IMD data)

- ❖ **In Hyderabad no precipitation fell during the month of May** (Normal monthly rainfall is 40 mm).
- ❖ Temperatures was as high as **40°C** which caused severe drought condition
- ❖ In the Indian state of **Andhra Pradesh**, over 1,200 people died in the heat wave which began in mid-May **(BBC News/OCHA).**

Potential of NCEP-NCAR Surface Meteorological Data
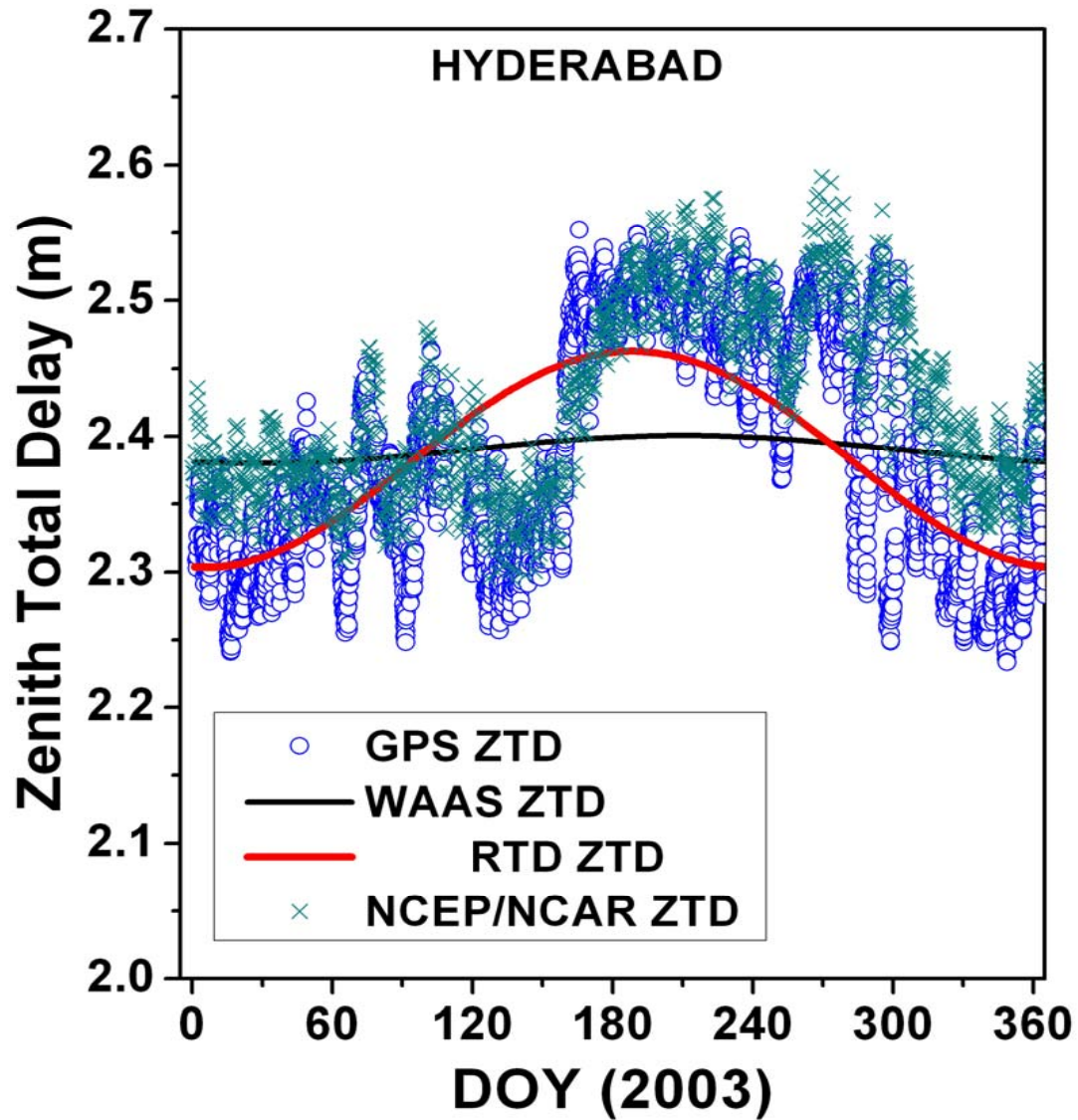
CONCLUSION

RTD model agrees well with Regional delay model with measured surface parameters

Comparison of model prediction with GPS measurements ascertains the validity of the model

Model can not respond to extreme weather events

WAAS model shows good seasonal variation of tropospheric delay only over higher latitude stations (>25°N) of Indian subcontinent