Wide Area Neutral Atmosphere Models for GNSS Applications

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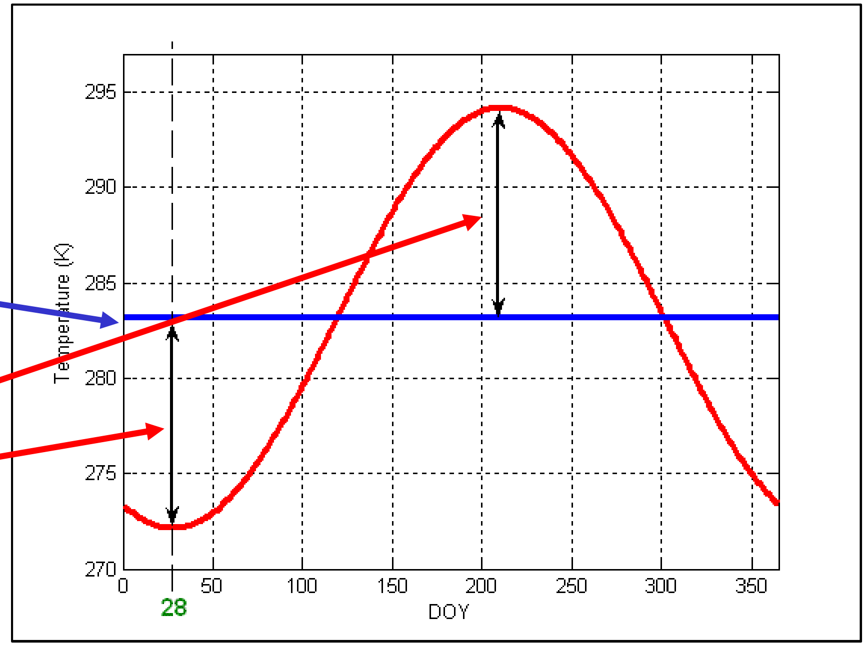
UNB Neutral Atmosphere Models

Average					
Latitude (degrees)	**Pressure (mbar)**	**Temperature (K)**	**WVP* (mbar)**	**β (K.km^{-1})**	**λ (-)**
15	1013.25	299.65	26.31	6.3	2.77
30	1017.25	294.15	21.79	6.05	3.15
45	1015.75	283.15	11.66	5.58	2.57
60	1011.75	272.15	6.78	5.39	1.81
75	1013.00	263.65	4.11	4.53	1.55
Amplitude					
Latitude (degrees)	**Pressure (mbar)**	**Temperature (K)**	**WVP* (mbar)**	**β (K.km^{-1})**	**λ (-)**
15	0.00	0.00	0.00	0.00	0.00
30	-3.75	7.00	8.85	0.25	0.33
45	-2.25	11.00	7.24	0.32	0.46
60	-1.75	15.00	5.36	0.81	0.74
75	-0.50	14.50	3.39	0.62	0.30



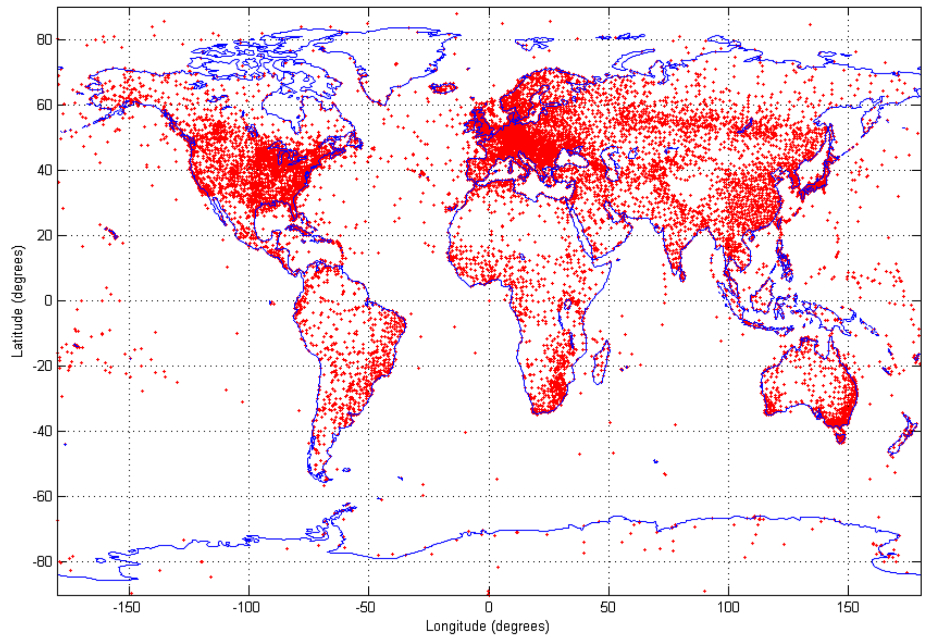
$$X_{\phi,doy} = Avg_{\phi} - Amp_{\phi} \cdot \cos\left((doy - 28)\frac{2\pi}{365.25} \right)$$

$$d_h^z = \frac{10^{-6} k_1 R}{g_m} \cdot P_0 \cdot \left(1 - \frac{\beta H}{T_0} \right)^{\frac{g}{R\beta}}$$

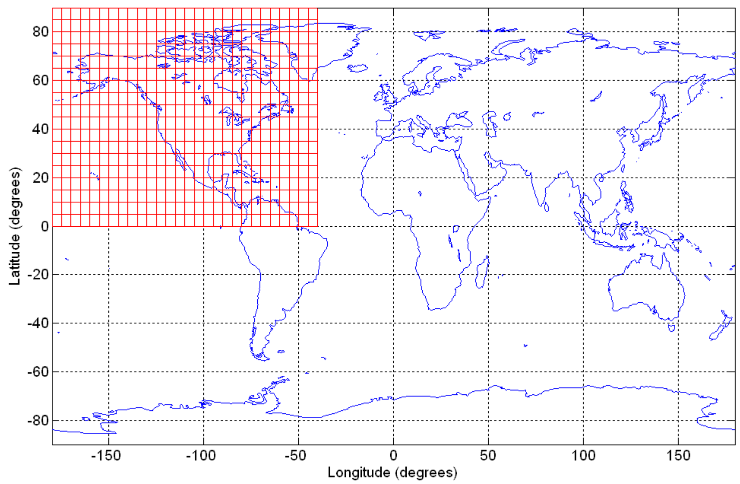
$$d_{nh}^z = \frac{10^{-6}\left(T_m k_2' + k_3\right) R}{g_m \lambda' - \beta R} \cdot \frac{e_0}{T_0} \cdot \left(1 - \frac{\beta H}{T_0} \right)^{\frac{\lambda' g}{R\beta} - 1}$$

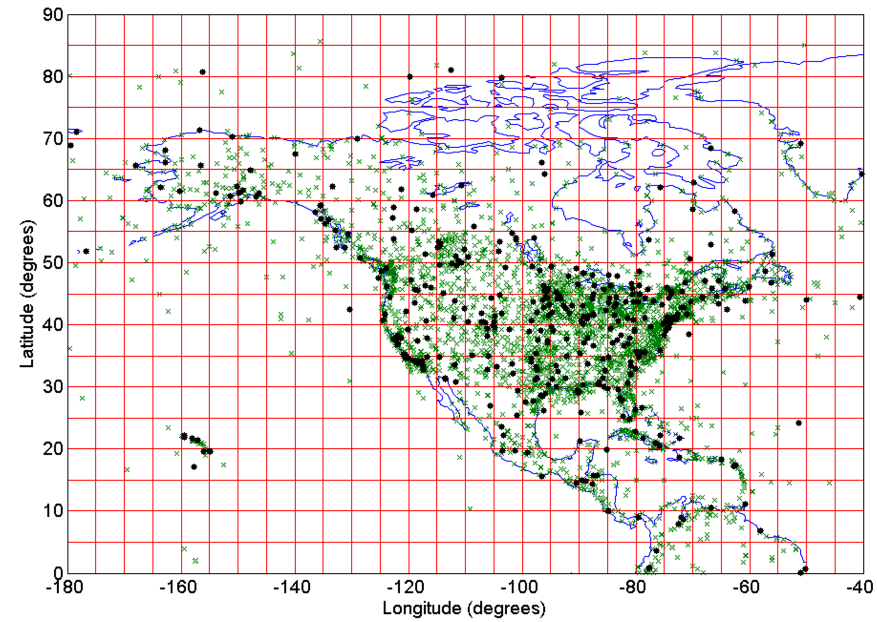
A new model based on wide area grids

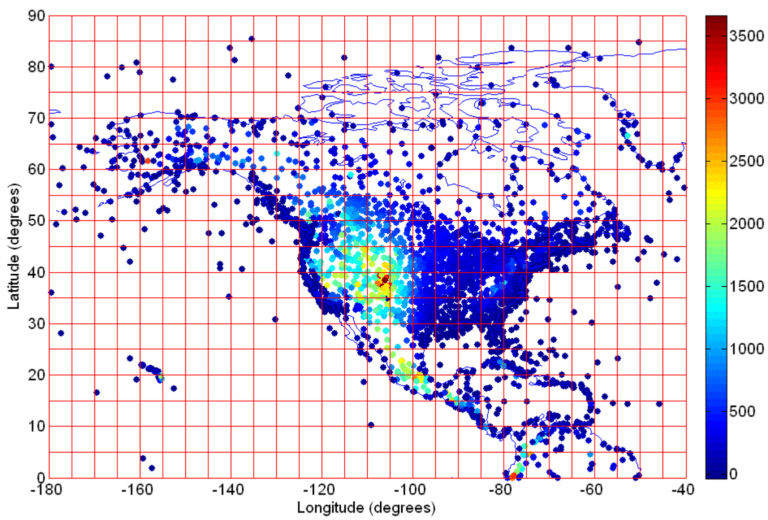
- Use the same physical assumptions of previous versions
- 2D Grid instead of latitude band look-up table
- Calibration dataset: Integrated Surface Hourly (ISH) data base (17415 stations - worldwide) – provided by NOAA
- Jan 2001 – Dec 2005



Wide area model for North America: UNBw.na





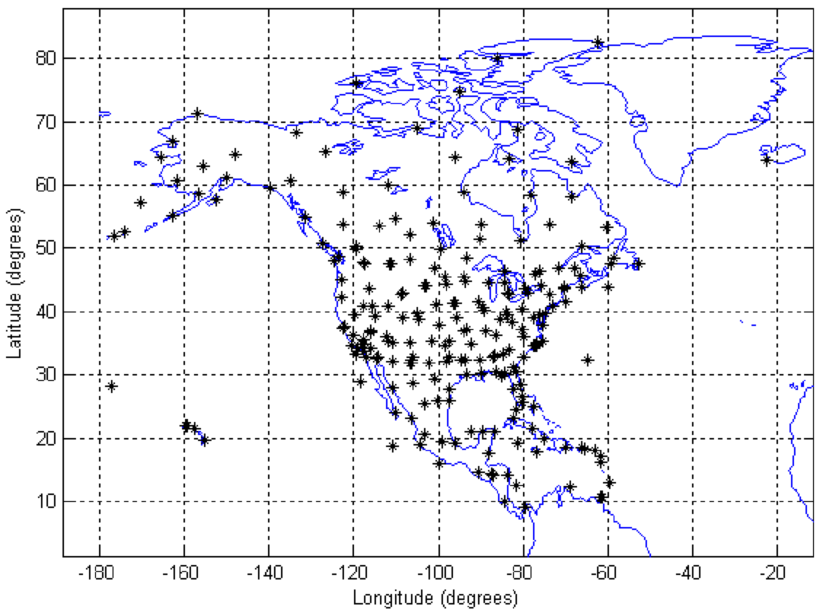


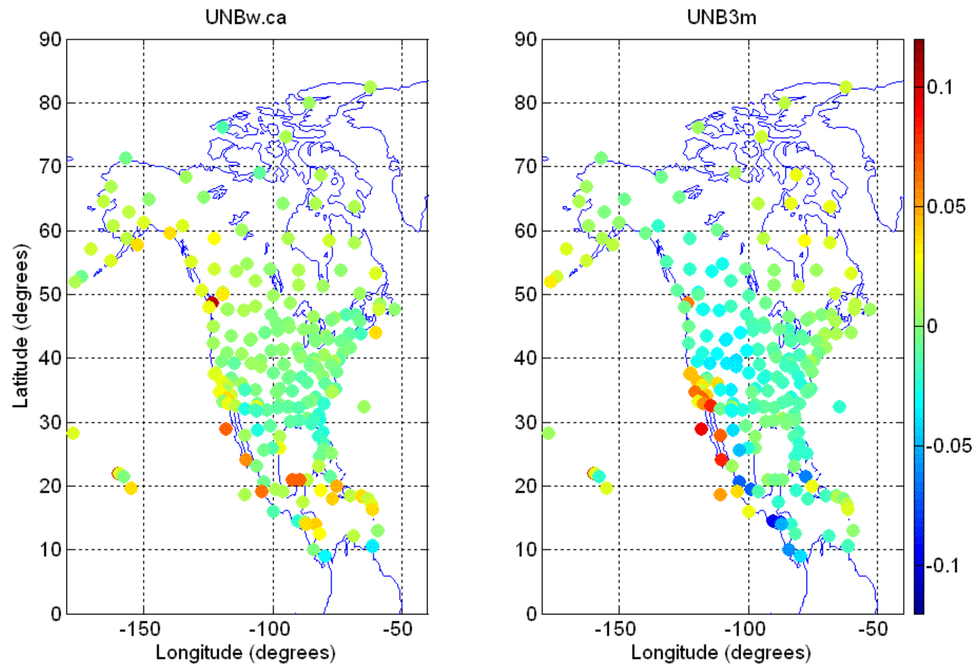
- •Calibration (3600) and test (400) stations
- •Average and amplitude for T, P, RH are determined
- •Main goal: better performance for areas where UNB3m has perfomance below average

UNBw.na model validation

- Surface meteorological parameters
  - 400 control meteorological stations
  - Surface temperature
  - MSL pressure
  - Surface water vapour pressure
- Zenith delays
  - Radiosonde -> ray-traced total zenith delays
- Comparison with UNB3m

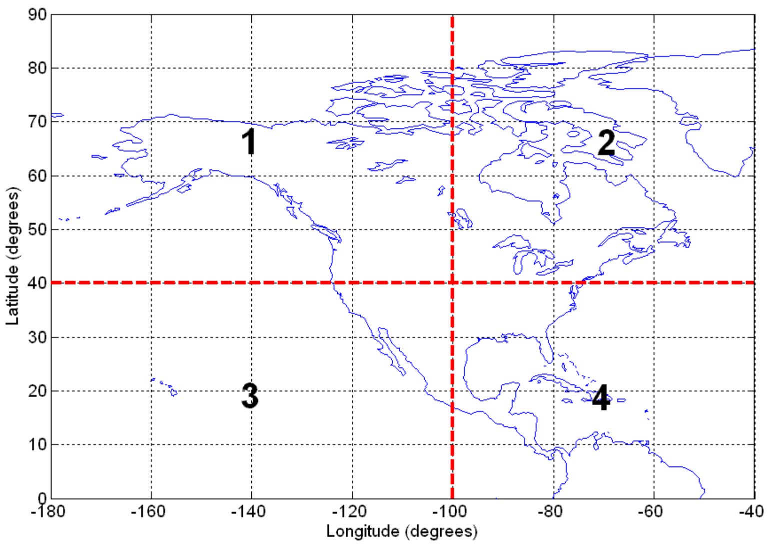
Validation with radiosonde derived total zenith delays (701940 soundings)





	Bias (cm)	Std. Dev. (cm)	RMS (cm)
UNBw.na	3.6	44.8	45.0
UNB3m	-5.2	48.9	49.2

Validation for regions



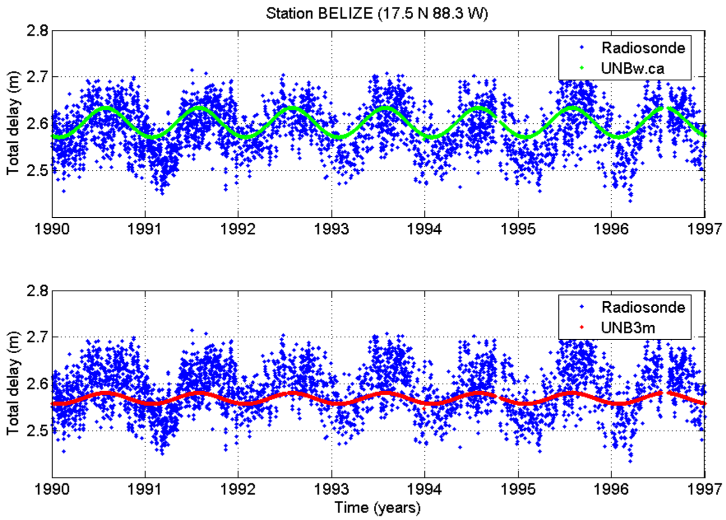
	UNBw.na			UNB3m		
Region	Bias	SD	RMS	Bias	SD	RMS
1	1.0	3.4	3.6	-0.9	3.5	3.7
2	0.4	4.1	4.1	0.5	4.3	4.3
3	0.6	4.4	4.4	0.2	5.7	5.7
4	-0.3	5.4	5.5	-1.3	5.6	5.8

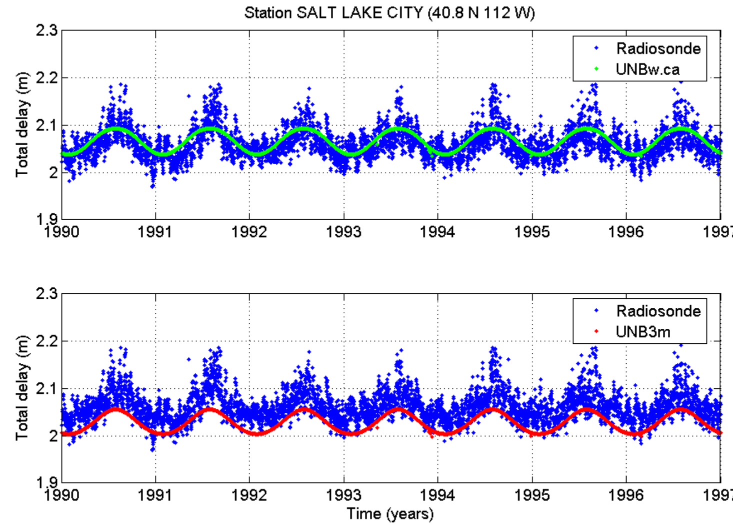
	UNBw.na		UNB3m	
Region	ab	ab-sd	ab	ab-sd
1	2.8	2.2	2.8	2.3
2	3.2	2.6	3.4	2.7
3	3.4	.9	4.5	3.6
4	4.5	3.2	4.7	3.4

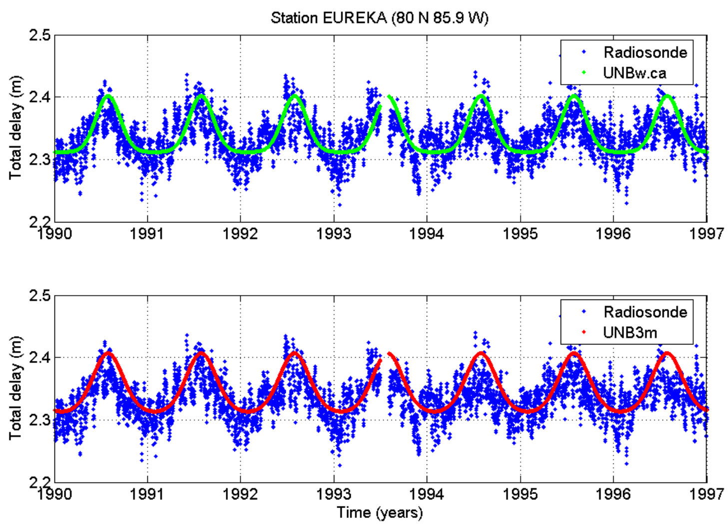
ab: absolute biases (cm)

ab-sd: ab standard deviation (cm)

Examples of improvement for sample stations







	UNBw.na (cm)		UNB3m (cm)	
Station	Bias	rms	Bias	rms
BELIZE	1.4	4.7	2.1	5.3
SALT LAKE CITY	0.5	2.6	-3.3	4.2
EUREKA	0.5	2.9	1.5	3.2

Conclusions and Future Work

- Improvement in zenith delay estimations for regions where the performance of the old model was below average (up to 85 % in bias and 38 % in rms);
- UNBw.na is consistently better than UNB3m in several aspects. The adopted procedure for the grid calibration worked in an adequate way, resulting in a reliable model;
- Assimilation of atmosphere data for lapse rate and WVP height factor adequate calibration;
- Calibration for other regions (e.g. South America).

Wide Area Based Precise Point Positioning

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Precise Point Positioning

- Precise satellite orbits
- Precise satellite clocks
- Carrier-phase measurements
- Residual neutral atmosphere delay estimation
- Consider:
    - » APC variation
    - » Satellite antenna offset
    - » Tides
    - » Phase wind-up
    - » Relativistic effects
    - » Code biases
    - » (…)

GAPS

- GAPS – GPS data Analysis and Positioning Software

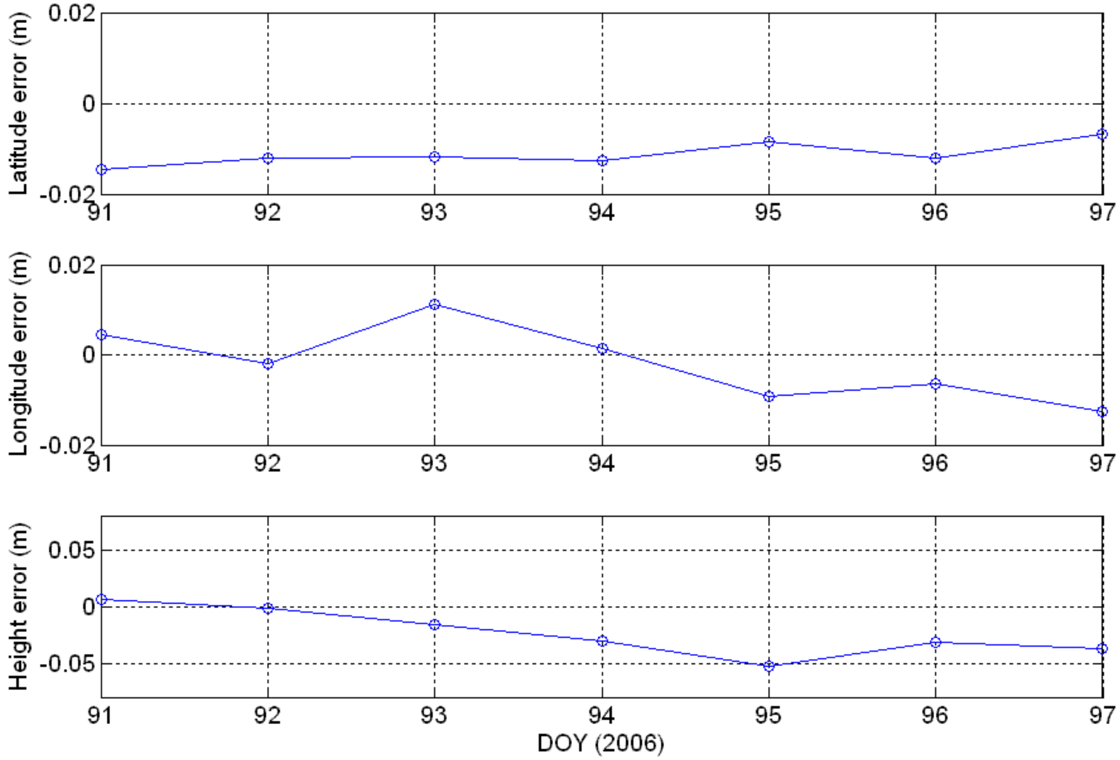
- Precise Point Positioning
- Tools for data analysis and QC
- Static/Kinematic positioning
- Estimation of Neutral Atmosphere delays
- Support Wide Area PPP

GAPS – PPP Performance

UNB1 (former IGS station)

24 h data processing results – doy 91 to 97

Reference – IGS solution for the same week



RMS

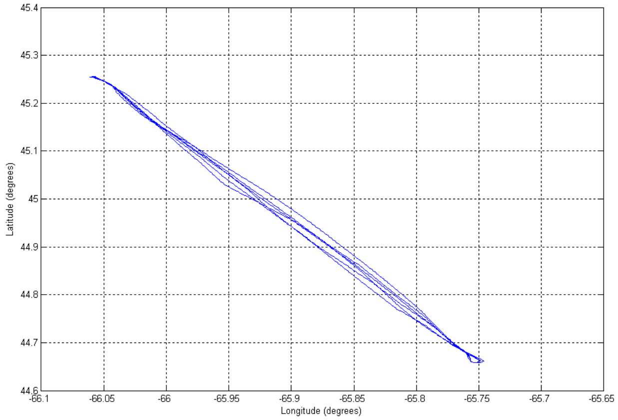
Latitude: 1.15 cm

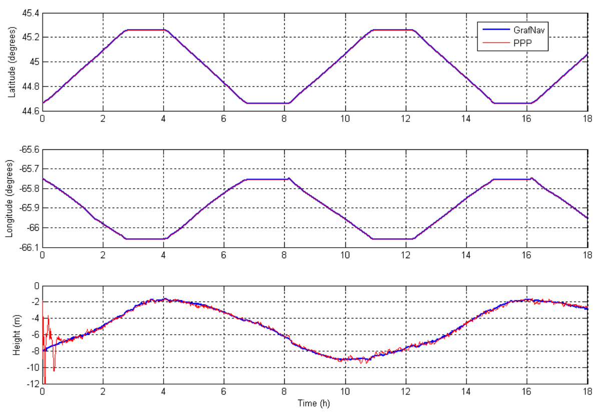
Longitude: 0.79 cm

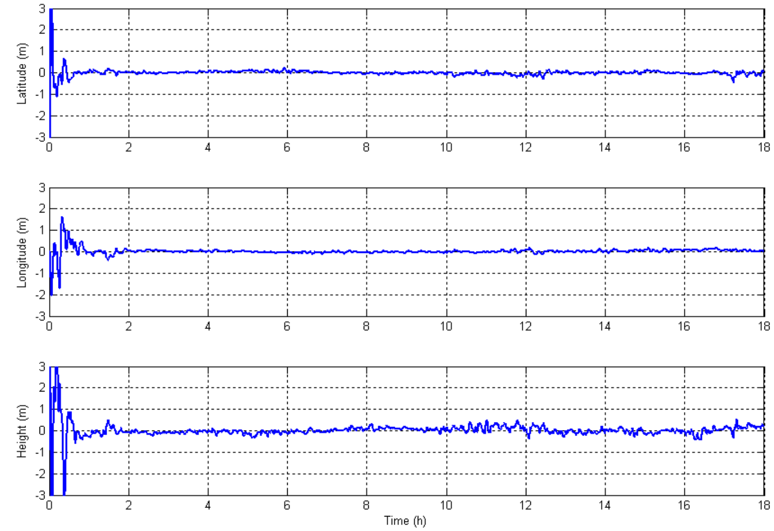
Height: 3.01 cm

GAPS – PPP Performance

Kinematic positioning – Boat on Bay of Fundy
Reference – GrafNav (baseline) Solution







RMS

Latitude: 6.9 cm

Longitude: 5.5 cm

Height: 13.9 cm

UNB

Precise Point Positioning – Ambiguity Parameter

- Undifferenced observations
- Ionospheric free combination
- Ambiguity parameter estimation

$$P_{if} = \rho + c(dT - dt) + T$$

$$\phi_{if} = \rho + c(dT - dt) + T + \lambda_{if} N_{if}$$

$$P_{if} = \alpha \cdot P_1 + \beta \cdot P_2$$

$$\phi_{if} = \alpha \cdot \phi_1 + \beta \cdot \phi_2$$

$$N_{if} = \alpha \cdot N_1 + \beta \cdot N_2$$

Not integer (α, β)

Integer? (N_1, N_2)

Not integer (N_{if})

Wide Area Precise Point Positioning

UNB

$$\phi = \rho + c(dT - dt) + T + \lambda N + \phi_r(t) - \phi^s(t) + b_r - b^s$$

"Ambiguity" parameter

Integer Ambiguity

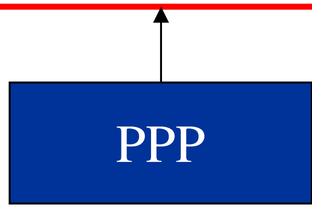
$$\phi = \rho + c(dT - dt) + T - I + \lambda N + (\phi_r + b_r) - (\phi^s + b^s)$$

Receiver biases – handled at the receiver end

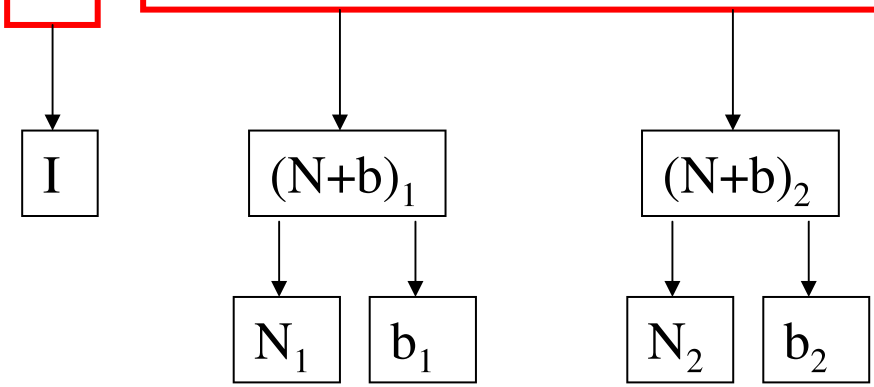
Satellite biases – handled by a wide area receiver network

De-correlation Filter

$$\phi_r^s(t_r) = \rho + c(dT - dt) + T - I + \lambda N_r^s + \phi_r(t_r) - \phi^s(t_r) + b_r - b^s$$

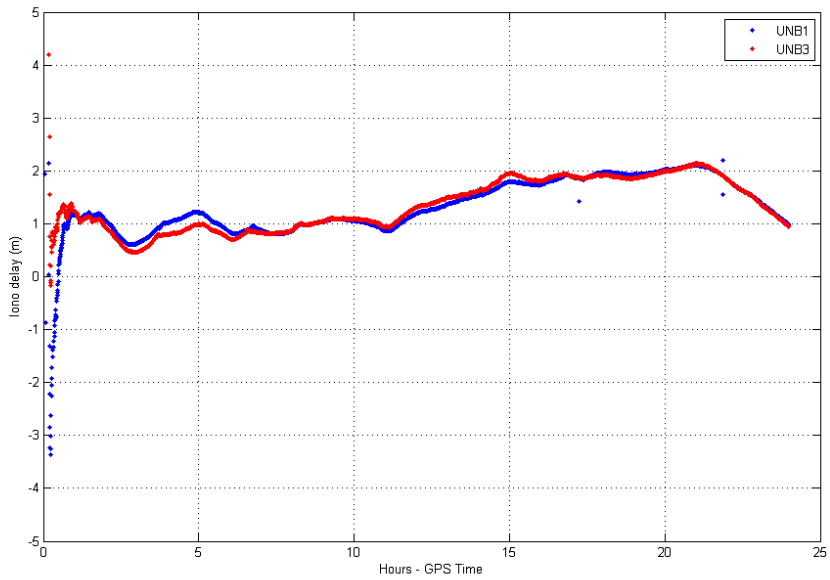


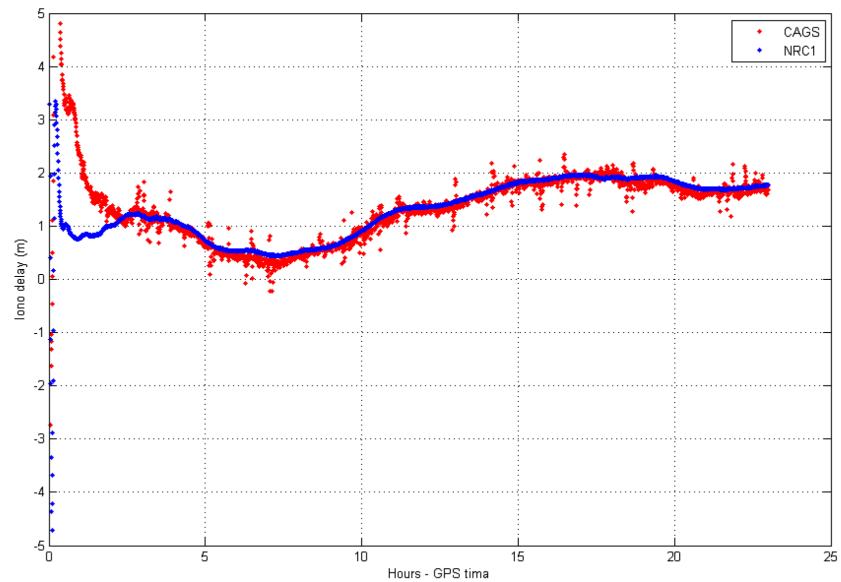
$$\phi_r^s(t_r) = -I + \lambda N_r^s + \phi_r(t_r) - \phi^s(t_r) + b_r - b^s$$



DCF – Ionospheric delay

UNB1 and UNB3 - Two receivers sharing one antenna via splitter

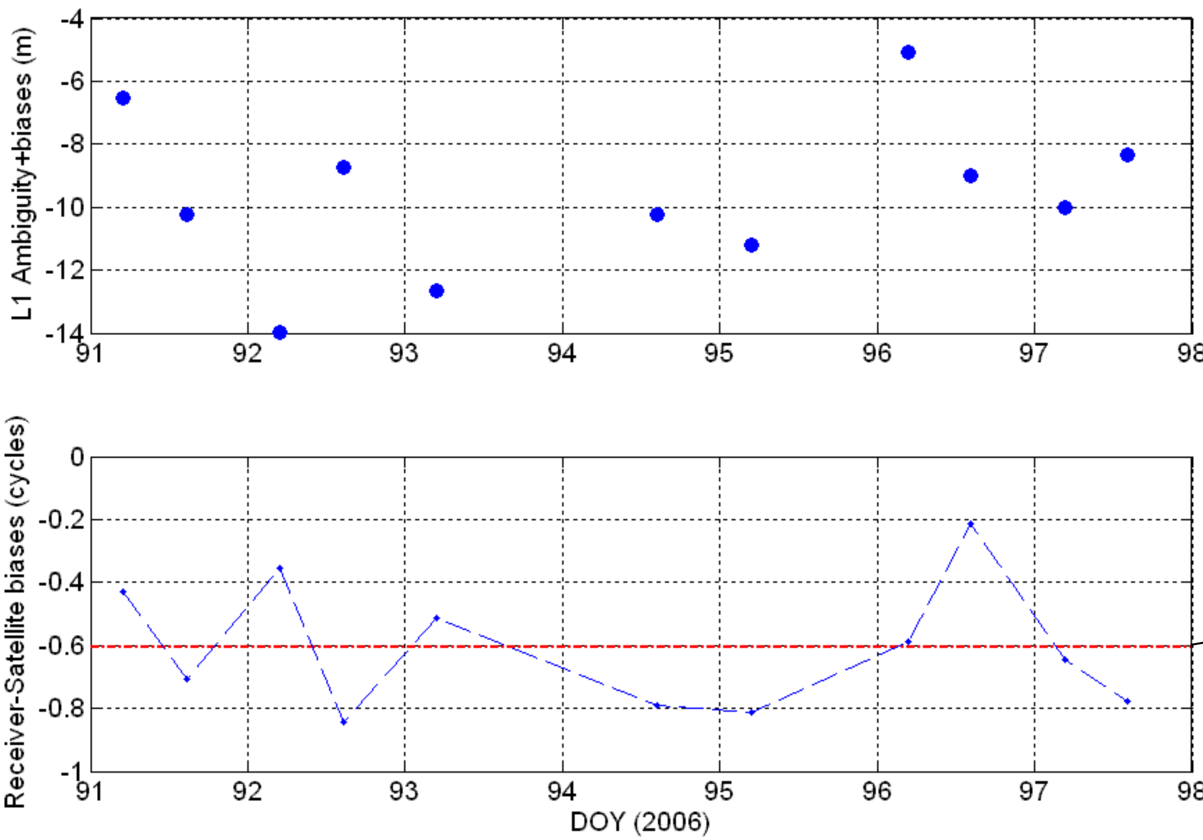




CAGS and NRC1 - Two stations (20 km distance)

L1 Fractional bias

UNB1 and PRN20 – DOY 91 to 97



Day-to-day repeatability of IGS stations' DCBs: 3 to 9 cm (Shaer, 1999)

3.9 cm

-0.61 +/- 0.21 cycles

Conclusions and Future work

- Good agreement between ionospheric delay estimation in nearby stations;
- Capability of estimating carrier-phase based, unbiased ionospheric delays;
- Good repeatability when estimating receiver-satellite differential fractional biases;
- De-correlation filter seems to work properly;
- Analysis with more data;
- Apply biases for isolated receiver after network step.