Modelling the Neutral Atmosphere Propagation Delay at UNB: Past, Present, and Future

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Contents

- UNB3 and its offspring:
  - UNB3 proper, UNB3m and UNBw.na
- NWP for positioning
- UNB-VMF1
  - Idea
  - Structure
  - A few tests

Why UNB3?

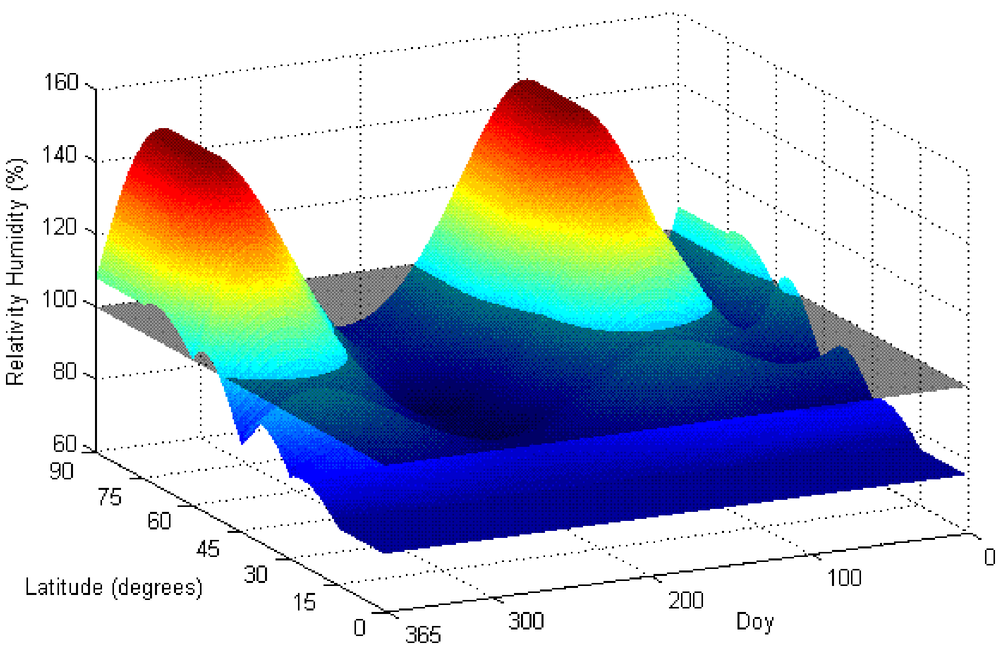
- UNB was tasked by Transport Canada (and, subsequently, Nav Canada) on behalf of the U.S. Federal Aviation Administration to develop a tropospheric propagation delay model for the Wide Area Augmentation System (WAAS).
- A series of models (UNB1 through UNB4) were developed and UNB3 was selected as most appropriate for aircraft navigation and ground-based applications.

UNB3

- Uses Saastamoinen zenith delays, Niell mapping functions, and a look-up table with annual mean and amplitude for temperature, pressure, and water vapour pressure varying with respect to latitude and height derived from model atmospheres.
  - Parameters computed for a particular latitude and day of year using a cosine function for the annual variation and a linear interpolation for latitude.
- Tested against 10 years of radiosonde data.
  - Max residual error of 20 cm.
- The UNB3 model has been extensively used in several regions of the world.
  - Capable of predicting total zenith delays with average uncertainties of 5 cm under normal atmospheric conditions.
- Modified (simplified) version of UNB3
  - Used in GPS receivers utilizing the Wide Area Augmentation System and other space-based augmentation systems (EGNOS, etc.).

UNB3 Model – RH problem

- Humidity values computed from water vapor pressure were not consistent;
- Relative humidity values greater than 100 % for some epochs of the year in certain regions.



Relative humidity values computed from UNB3

- Gray horizontal plane: limit of 100 %
- Worst cases: almost 150 % of relative humidity
- For latitudes greater than 45 degrees RH values are greater than 100 % for half a year.

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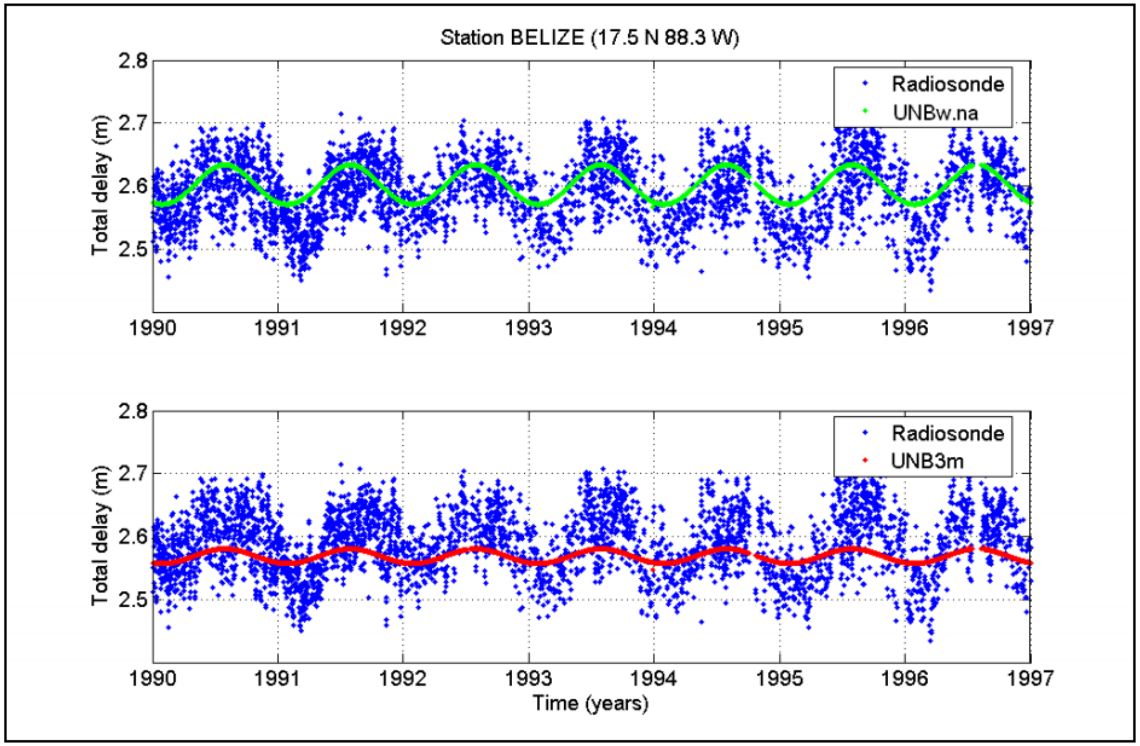
UNB3m

- Uses modified parameter values in UNB3 look-up table and associated UNB3 algorithms.
  - Predictions using relative humidity rather than water vapour pressure.
  - All computations done initially using relative humidity, subsequently converted to water vapour pressure for use in the zenith delay computation.
- Performance investigated using radiosonde data and compared to that of UNB3.
  - Based on ray-tracing analyses of 703,711 profiles from 223 stations in North America and surrounding territory from 1990 to 1996
  - Prediction errors with mean value -0.5 cm and standard deviation of 4.9 cm.
  - Absolute mean error has been reduced by almost 75%.
- UNB3m_pack
  - Distribution package in FORTRAN and MATLAB.
  - [http://gge.unb.ca/Resources/unb3m/unb3m.html .](http://gge.unb.ca/Resources/unb3m/unb3m.html)

UNBw.na

- Wide area neutral atmosphere model for North America
- Grid-based model can perform better than a latitude (only) based model (such as UNB3m).
  - "UNBw.na generally has a better fit to the yearly behaviour of the zenith delays."



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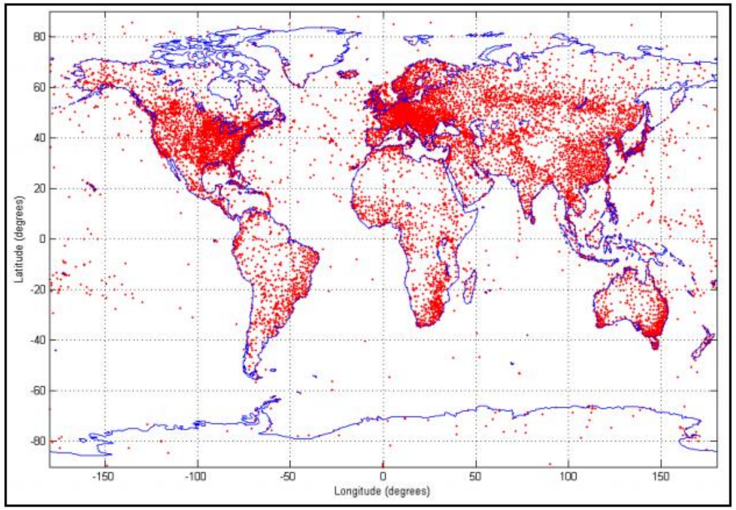
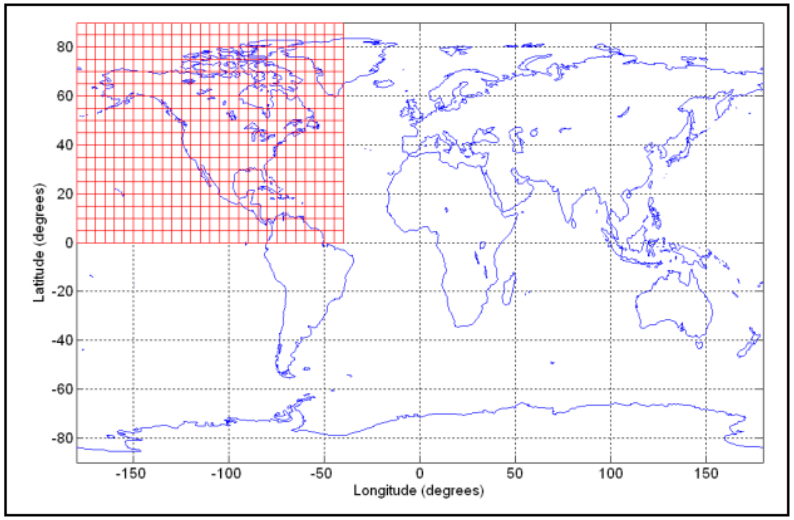
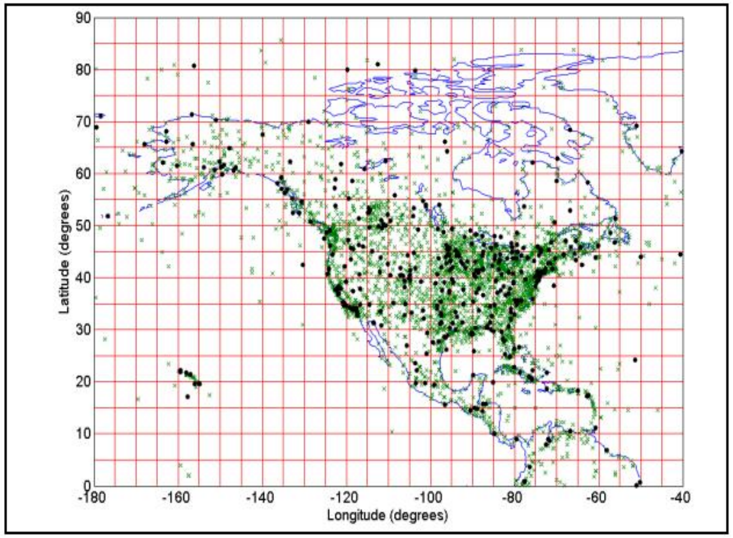
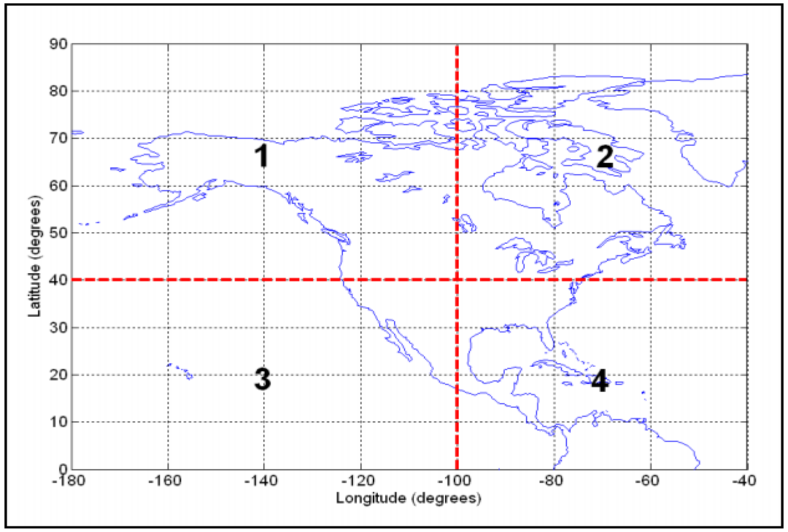
Data and Validation

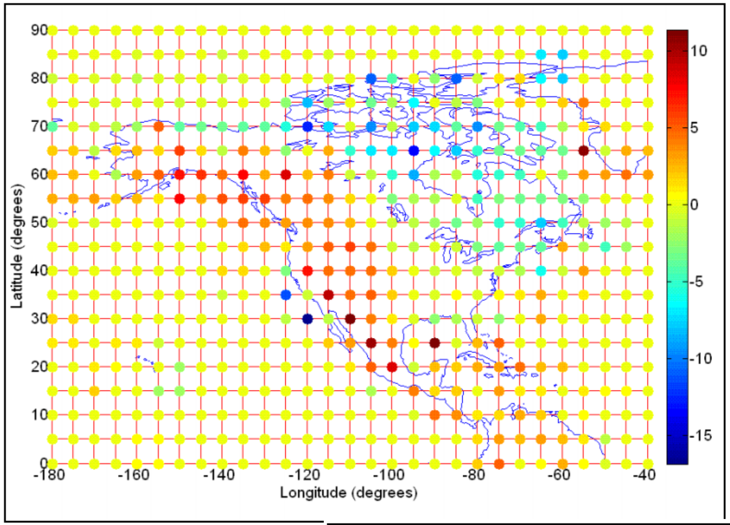


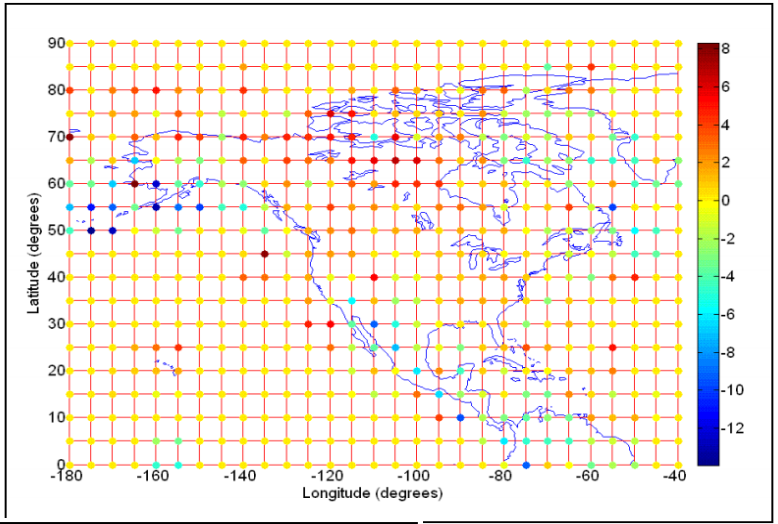


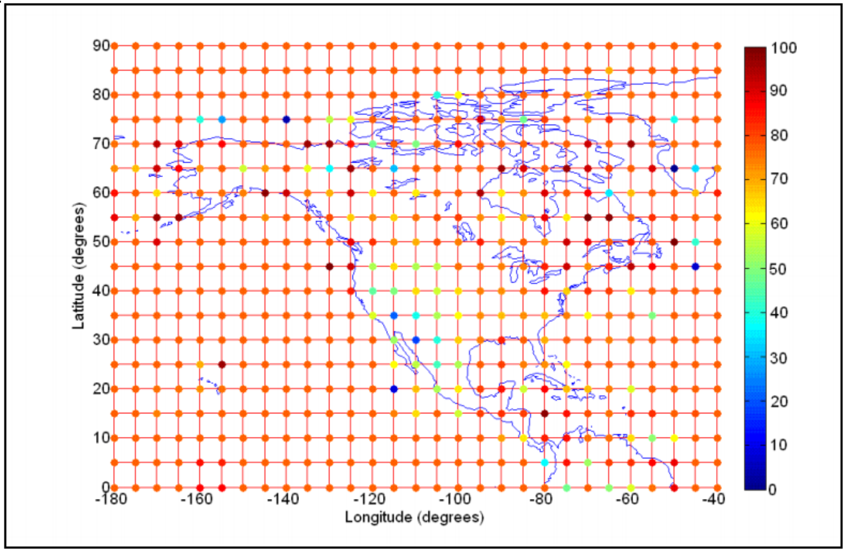




UNBw.na 'versus' UNB3m







UNBabc Low-Elevation-Angle Mapping Function

- Tasked by Nav Canada to develop a low-elevation-angle mapping function for WAAS.
- NMF was considered too complex for some applications while the Chao, B&E, and F&K functions are biased at very low elevation angles.
- The objective was to find a model that would have good performance for elevation angles down to 2 degrees and also be simple enough for real-time implementation in a computation-limited receiver.
- Based on continued-fraction form.
- Bias at 2 degrees from comparison with ray tracing through radiosonde data: 3.82 cm with r.m.s. of 22.17 cm.
- Simplified version adopted for WAAS.

UNB-VMF1

- What is the UNB-VMF1 Service?
  - A free service to the scientific/geodetic community providing geodetic-quality corrections to signal delays caused by the troposphere.
  - UNB-VMF1 provides the "a" coefficient on a global grid
  - Based on the Vienna Mapping Functions developed by the Institute of Geodesy and Geophysics at TU Wien.
- What makes UNB-VMF1 different?
  - Independent state-of-the-art data sources (NWPs):
    - ✓ NCEP Reanalysis I
    - ✓ CMC Global Deterministic Prediction System (GDPS)
  - Independent state-of-the-art ray tracing algorithms:
    - ✓ UNB developed ray tracer by Nievinski (2009)
  - Compatibility with Global Geophysical Fluids Center products.

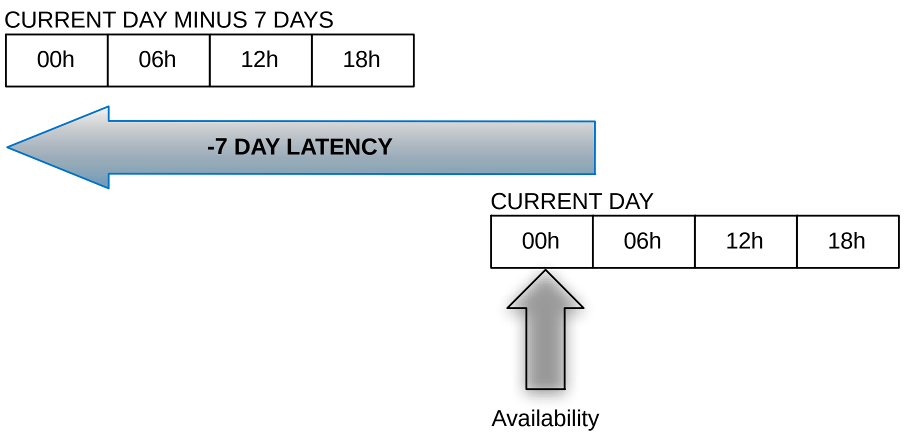
UNB-VMF1 – Product Description

Product Name	Description	Parameters
unbvmfG	2.0x2.5 degree global grid NCEP Re-Analysis I 7 day latency	ah, aw, zhd, zwd
unbvmfGcmc	2.0x2.5 degree global grid CMC GDPS 1 day latency	ah, aw, zhd, zwd
unbvmfP*	2.0x2.5 degree global grid CMC GDPS 0 day latency	ah, aw, zhd, zwd

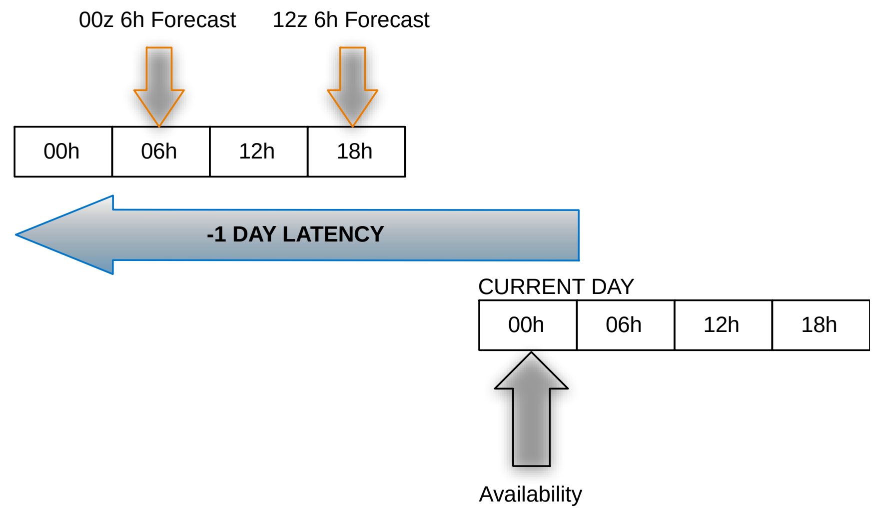
- *unbvmfP produced with 24h, 30h, 36h, 42h forecasts
- Data format follows existing VMF1 service for continuity

UNB-VMF1 – Operational Availability

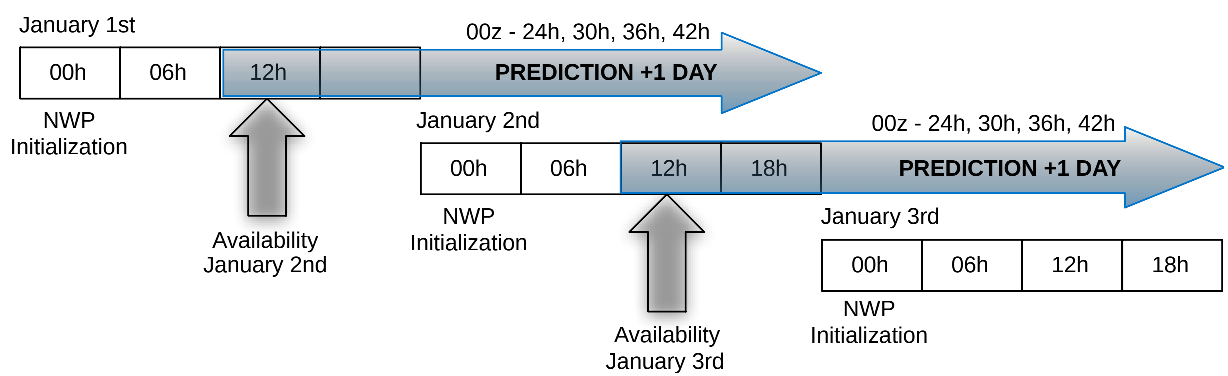
(a) unbvmfG



(b) unbvmfGcmc



(c) unbvmfP



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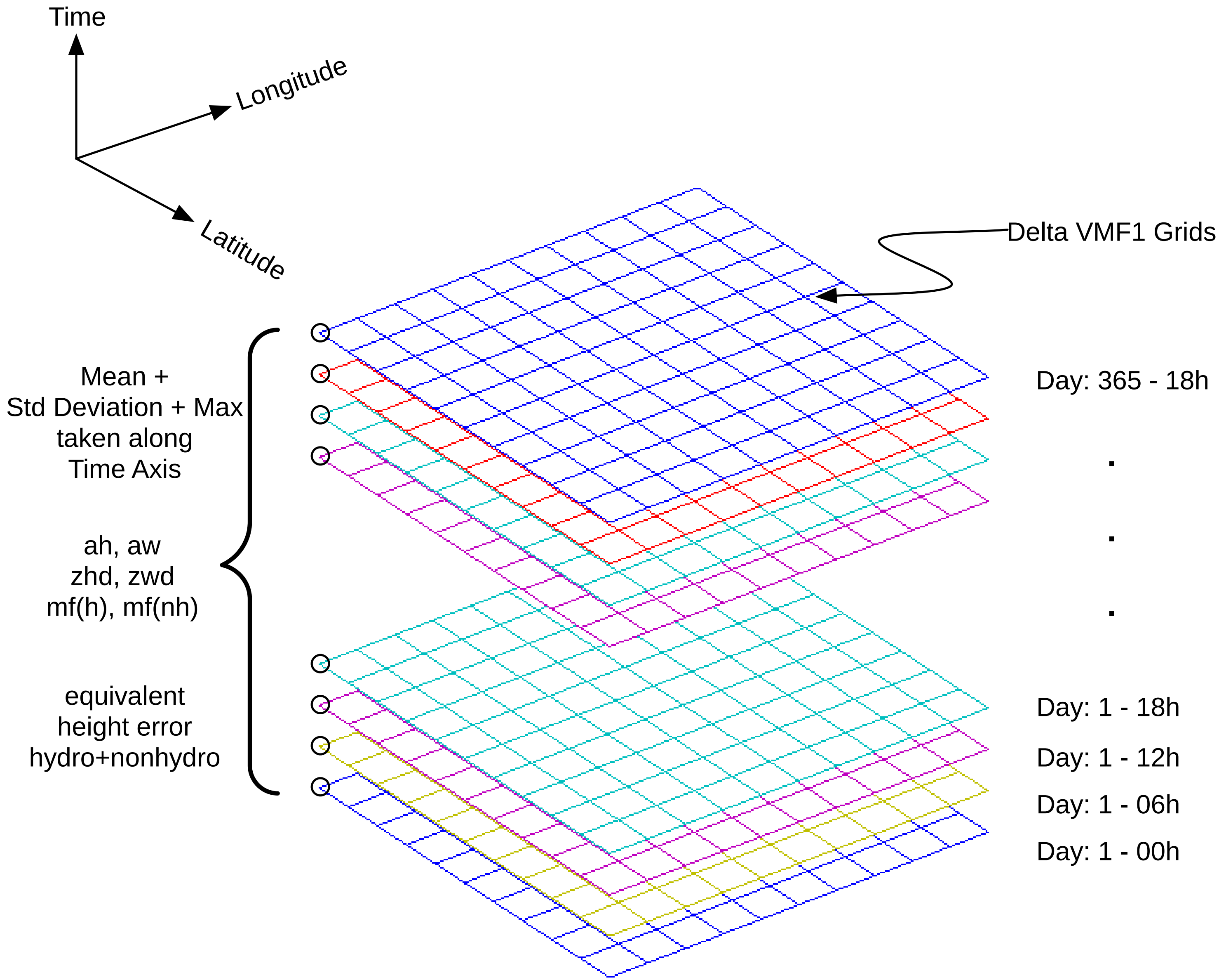
UNB-VMF1

- All UNB-VMF1 products have obtained ***Provisional*** approval status from:
  - International Earth Rotation and Reference Systems Service (IERS) & Global Geophysical Fluids Center (GGFC)
  - Mandatory 2-year evaluation period has begun
  - Expected full approval for EGU 2014
- Data Availability begins (available NOW!):
  - April 20, 2012
- Full historical datasets to be added by end of 2012:
  - 1994-present
  - May not apply to all products (unbvmfGcmc/unbvmfP) due to data source availability.

UNB-VMF1 Summary

- UNB-VMF1 Service operational NOW!
  - Data available from April 20^{th} 2012
  - More data to become available before end of 2012
    - NCEP only (historical availability issues with CMC datasets)
- All UNB-VMF1 products have GGFC/IERS Provisional approval status
  - Full approval for EGU 2014 (pending evaluation period)

http://unb-vmf1.gge.unb.ca

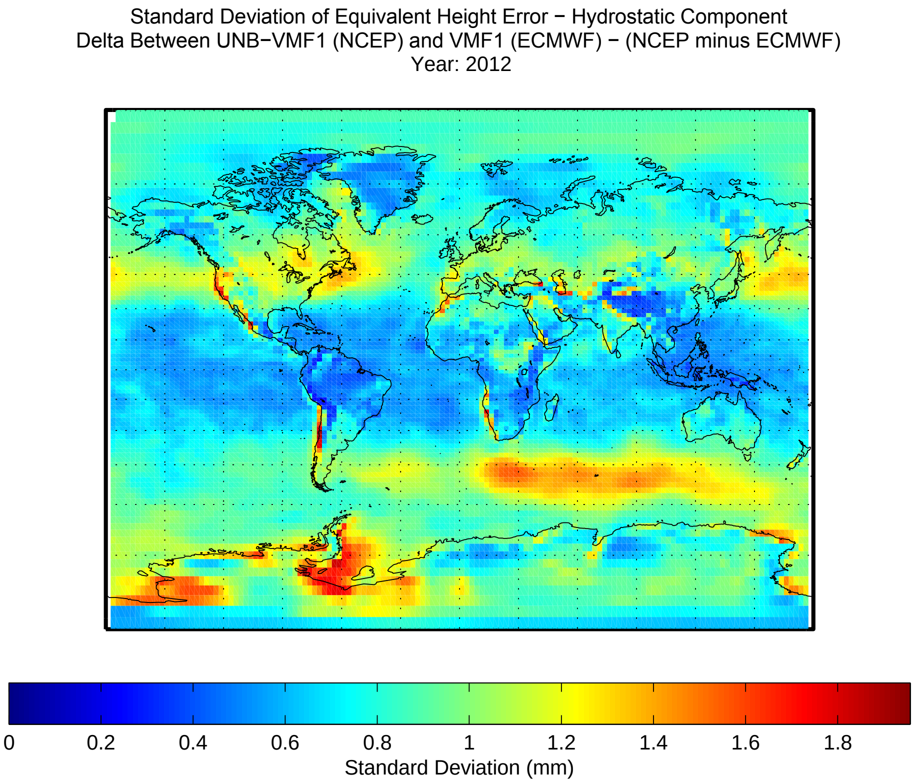


Total: 1460 Epochs = 1 year

Standard Deviation of Equivalent Height Error – Hydrostatic Component

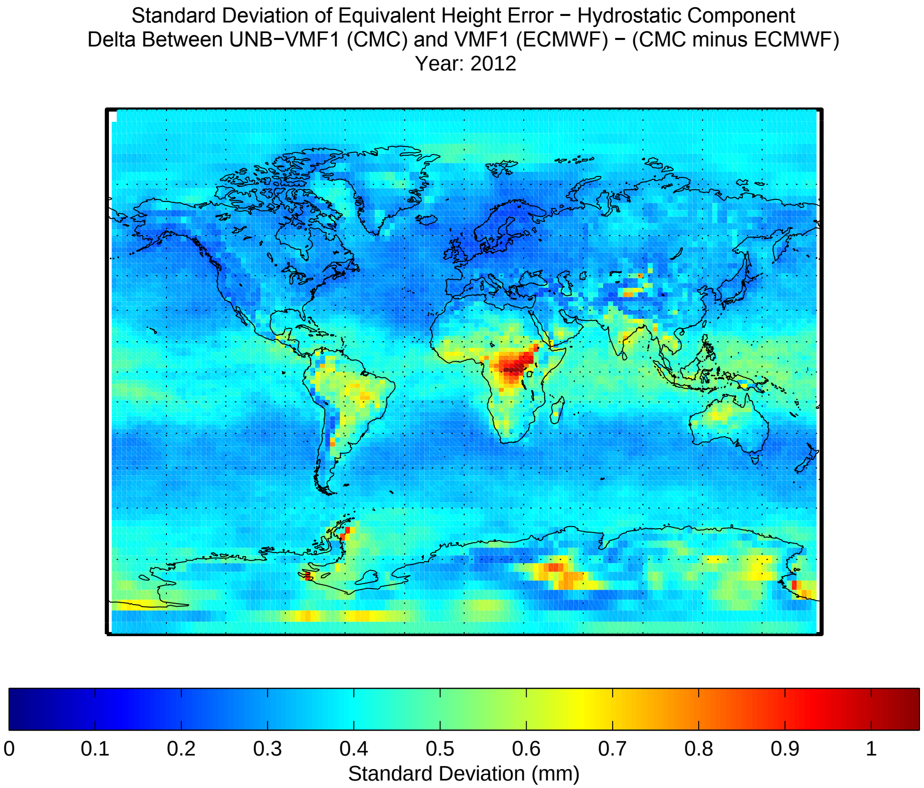
January 1st, 2012 – July 2nd, 2012

NCEP minus ECMWF



Global: +/- 1.3 mm

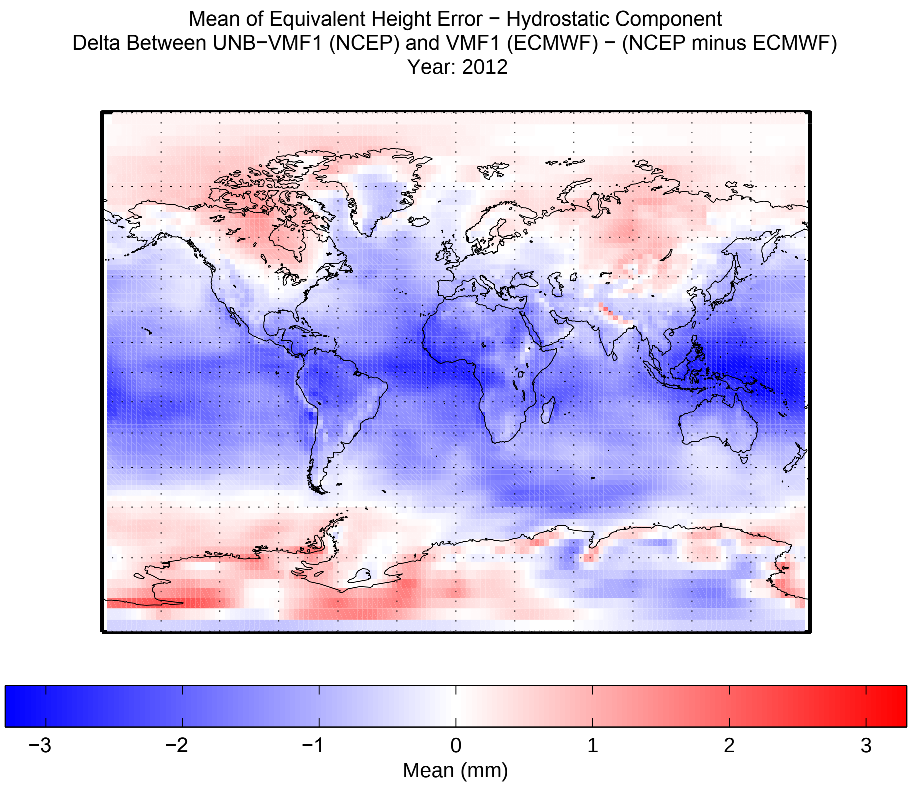
CMC (GDPS) minus ECMWF



Global: +/- 0.95 mm

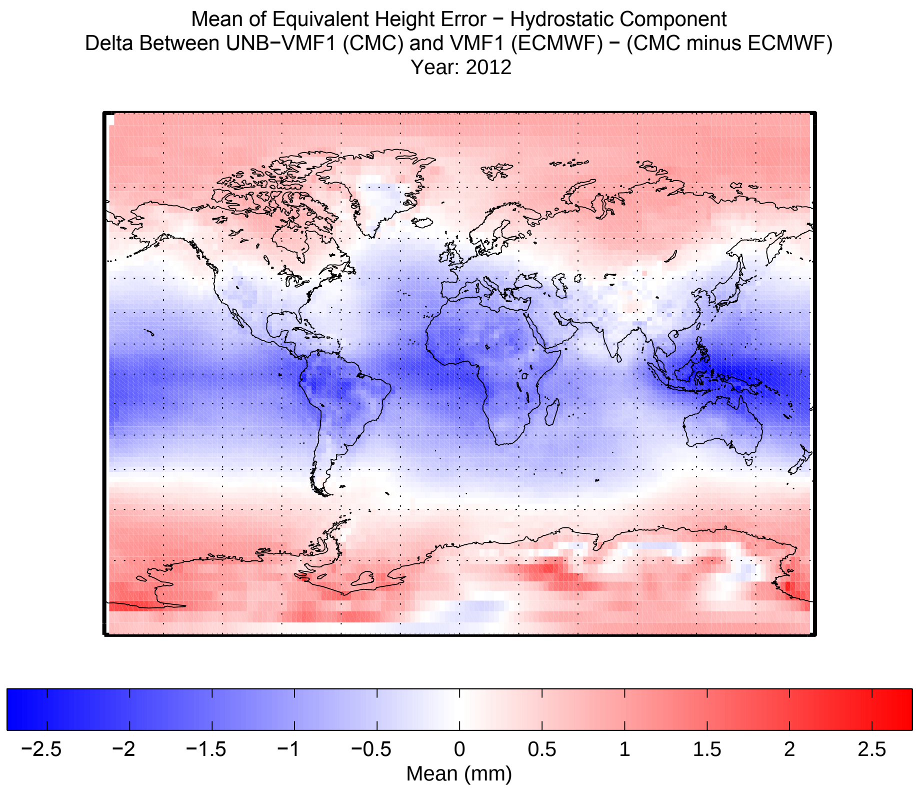
Bias of Equivalent Height Error – Hydrostatic Component

NCEP minus ECMWF



Global: -0.71 mm

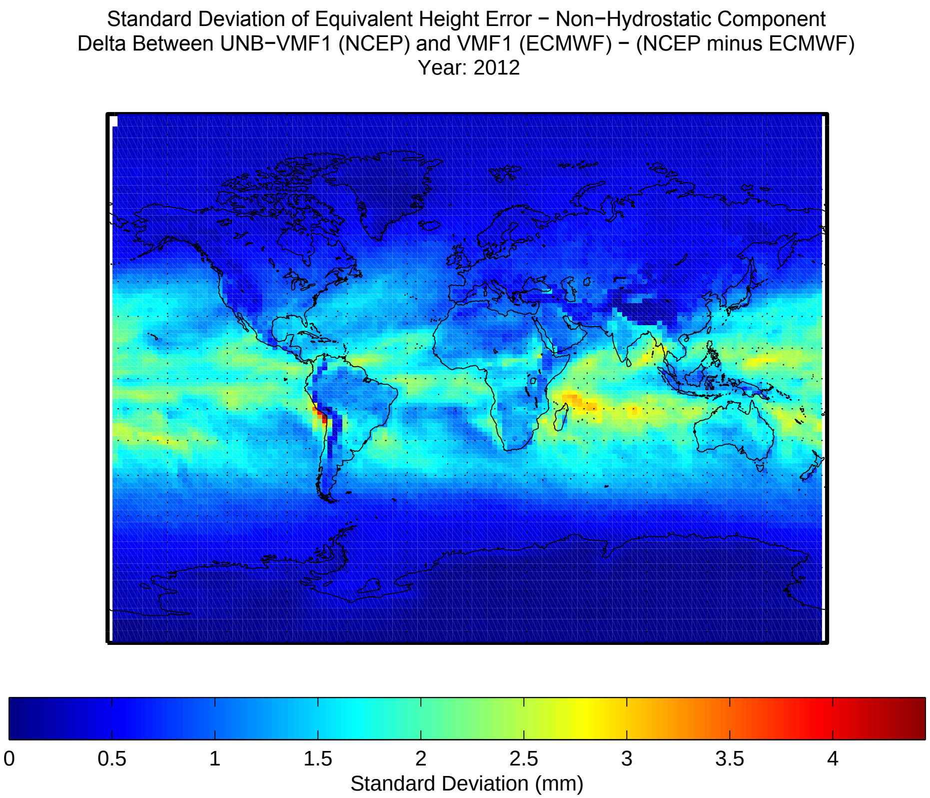
CMC (GDPS) minus ECMWF



Global: -0.24 mm

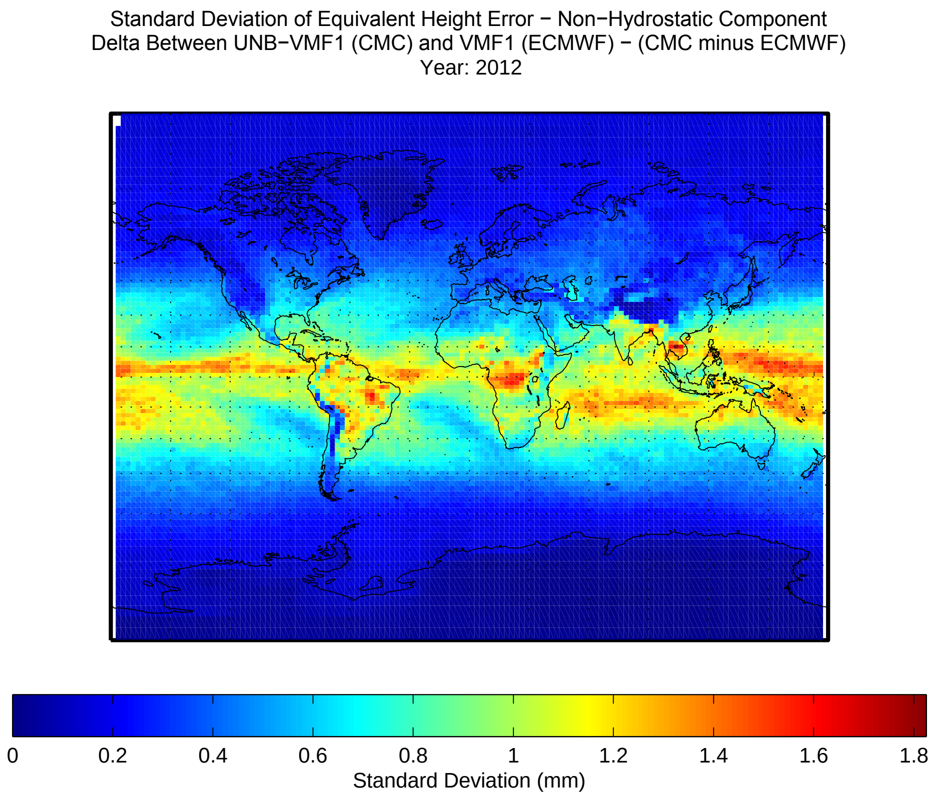
Standard Deviation of Equivalent Height Error – Non-Hydrostatic Component

NCEP minus ECMWF



Global: +/- 1.4 mm

CMC (GDPS) minus ECMWF



Global: +/- 0.72 mm

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Bias of Equivalent Height Error – Non-Hydrostatic Component

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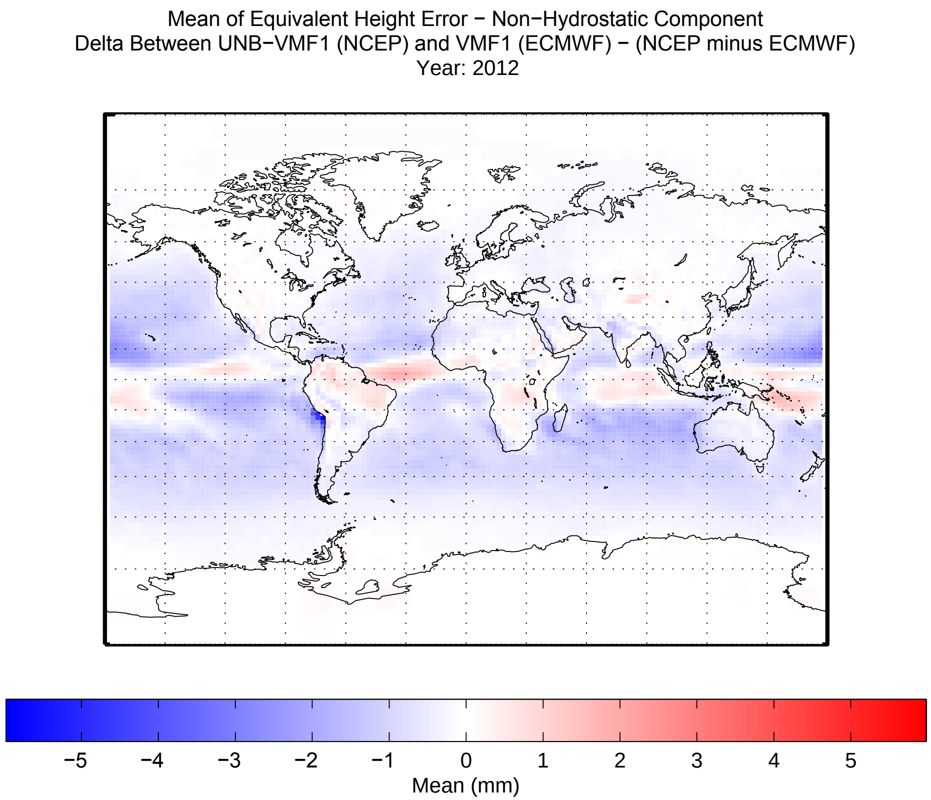
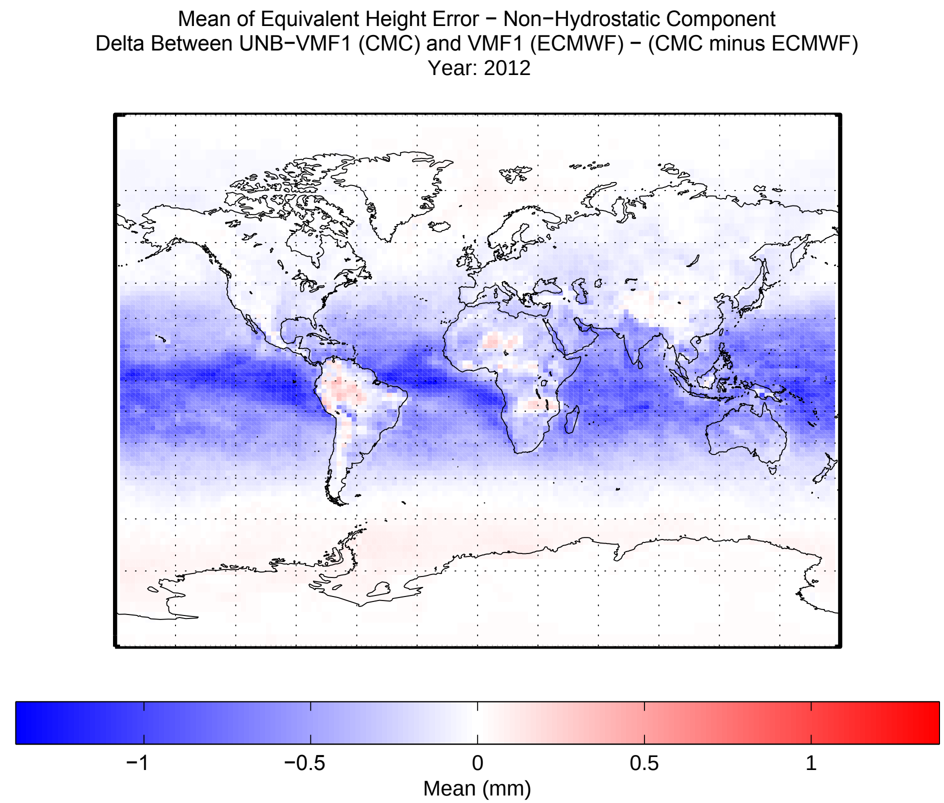
NCEP minus ECMWF



Global: -0.39 mm

CMC (GDPS) minus ECMWF



Global: -0.22 mm

(UNB-VMF1) – (VMF1)

*Global Values

	CMC (GDPS)		NCEP	
Parameter	Mean*	Std* 1σ	Mean*	Std* 1σ
ah	5.29×10^{-7}	2.28×10^{-6}	1.77×10^{-6}	3.08×10^{-6}
aw	3.63×10^{-6}	2.44×10^{-5}	8.78×10^{-6}	5.63×10^{-5}
Zhd (mm)	2.1	3.4	2.7	5.8
Zwd (mm)	5.4	15.7	5.7	30.5

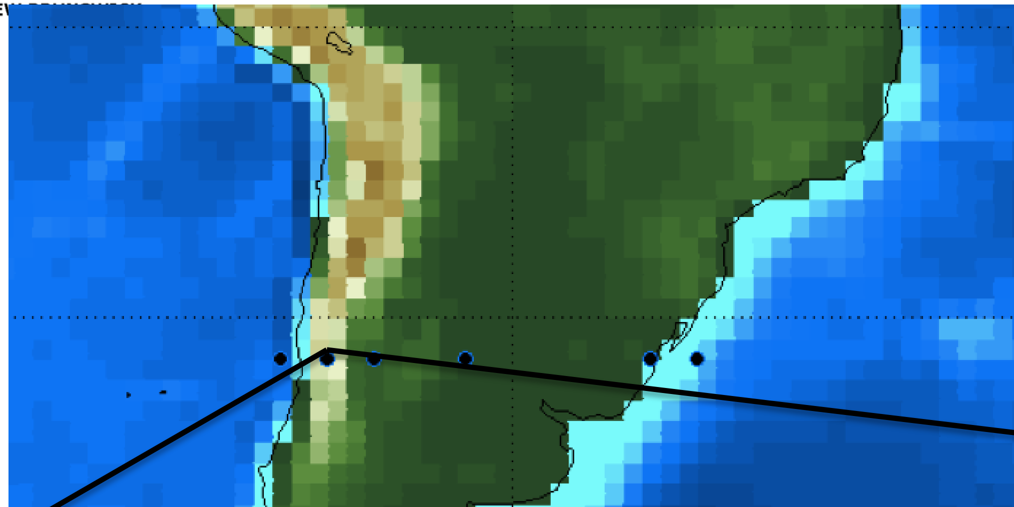
Zhd – hydrostatic zenith delay
Zwd – non-hydrostatic zenith delay
ah – hydrostatic a-coefficient
aw – non-hydrostatic a-coefficient

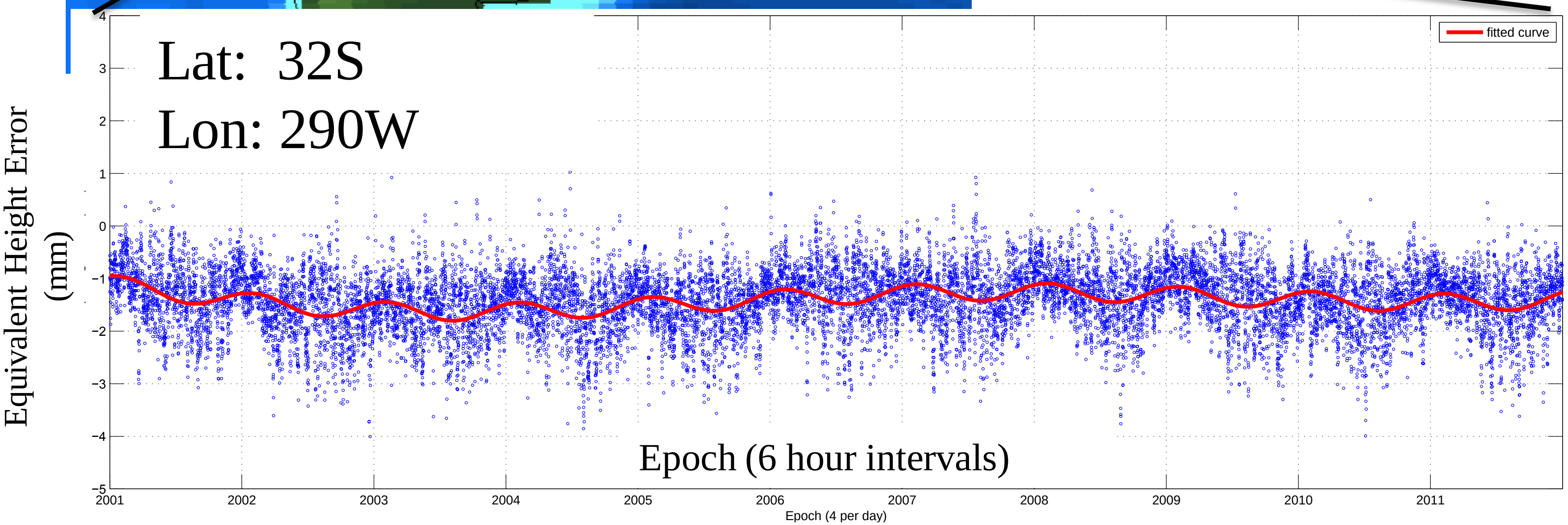
For year 2012

Equivalent Error in Height – Hydrostatic Component

2001 - 2011

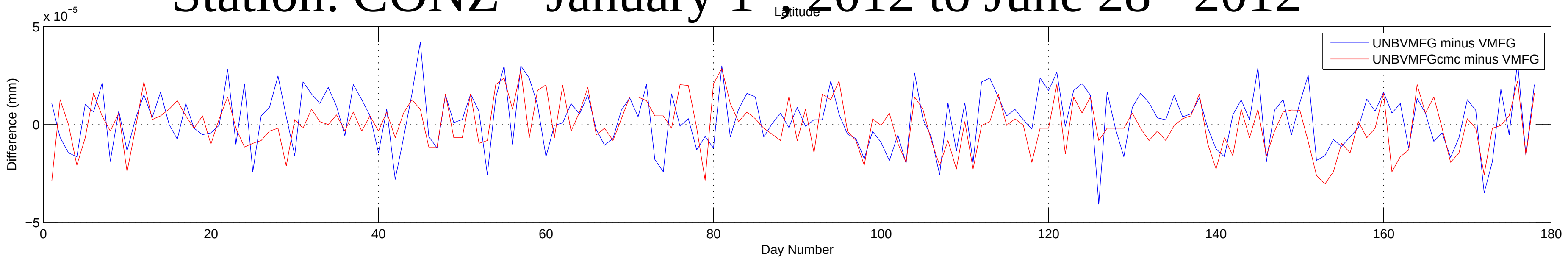
(NCEP minus ECMWF)

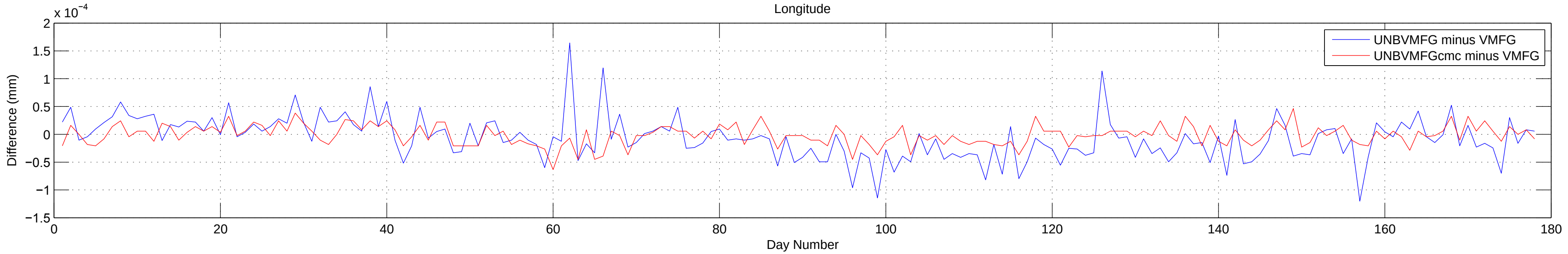


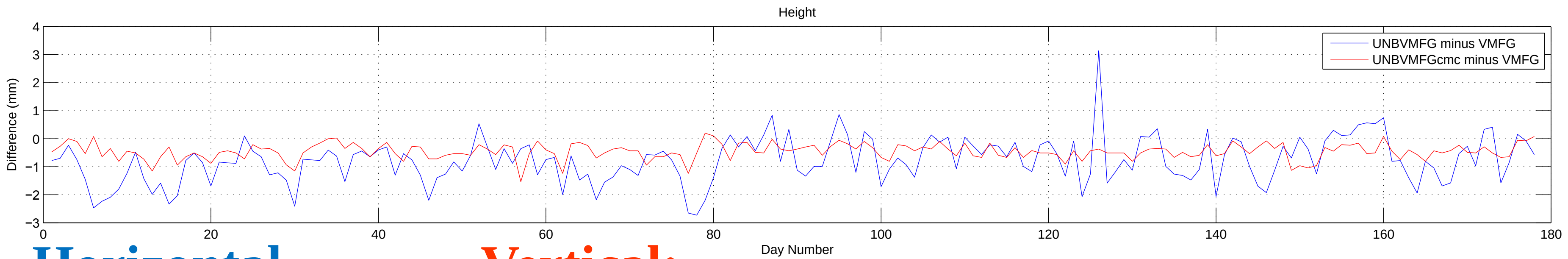


PPP Solution: UNB-VMF1 vs VMF1 (5 degree elevation angle cutoff)

Station: CONZ - January 1st, 2012 to June 28th 2012







Horizontal

Difference is negligible

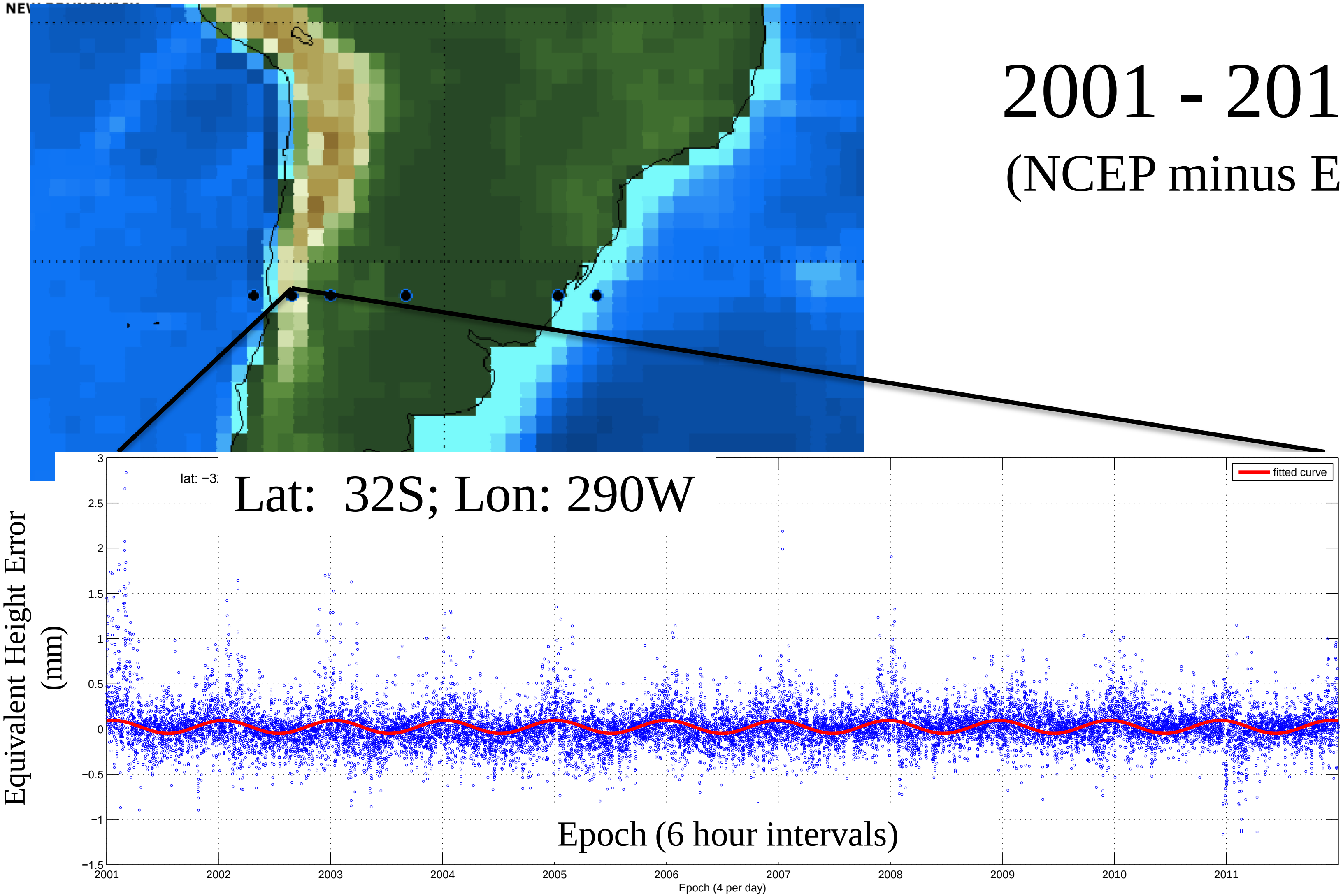
Vertical:

NCEP: -0.778 +/- 0.801 mm CMC : -0.456 +/- 0.281 mm

Equivalent Error in Height – Non-Hydrostatic Component

2001 - 2011

(NCEP minus ECMWF)



Concluding Remarks

- UNB3m
  - Future refinements
- UNBw.**
  - Gridded models for other continents
- NWP for positioning
  - Pros and cons
- UNB-VMF1
  - Availability of the service
  - Reliability ... more tests

Acknowledgments

- NOAA for the provision of NCEP
- CMC for the provision of GDPS
- IGS for the provision of GPS data sets
- Johannes Böhm (TU Vienna)
- Joey Bernard (ACENET, UNB)

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Basic references on VMF1

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MAKING A SIGNIFICANT DIFFERENCE

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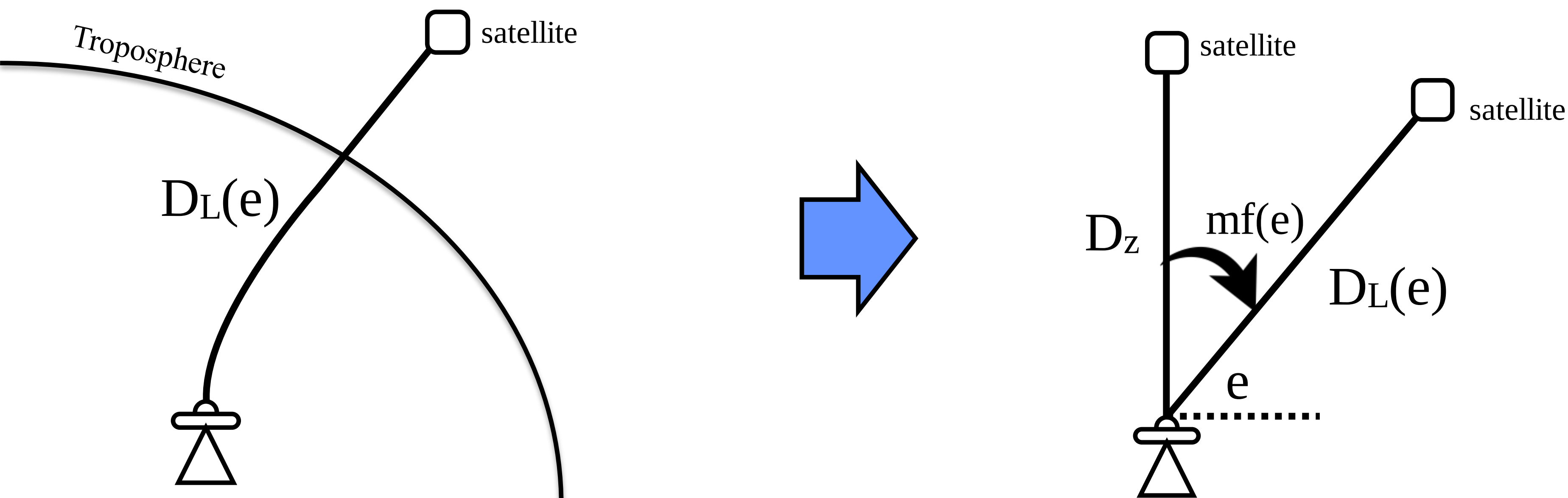
Troposphere Delay Modeling

IERS Conventions (2010)

$$D_L(e) = D_z mf(e) = D_h^z mf_h(e) + D_{nh}^z mf_{nh}(e)$$

$$+\underbrace{m_g(e)\left[G_N cos(a) + G_E sin(a)\right]}_{\text{Horizontal Gradients}}$$



Mapping Functions

➢ Marini Continued Fraction (Herring, 1992):

$$mf(e) = \frac{1 + \frac{a}{1 + \frac{b}{b+c}}}{\sin(e) + \frac{a}{\sin(e) + \frac{b}{\sin(e)+c}}}$$

- Where,
  - ✓ *mf*(*e*) = mapping function
  - ✓ *e* = elevation angle
  - ✓ *a*,*b*,*c* = coefficients (to be solved for)

UNB-VMF1 Coefficients

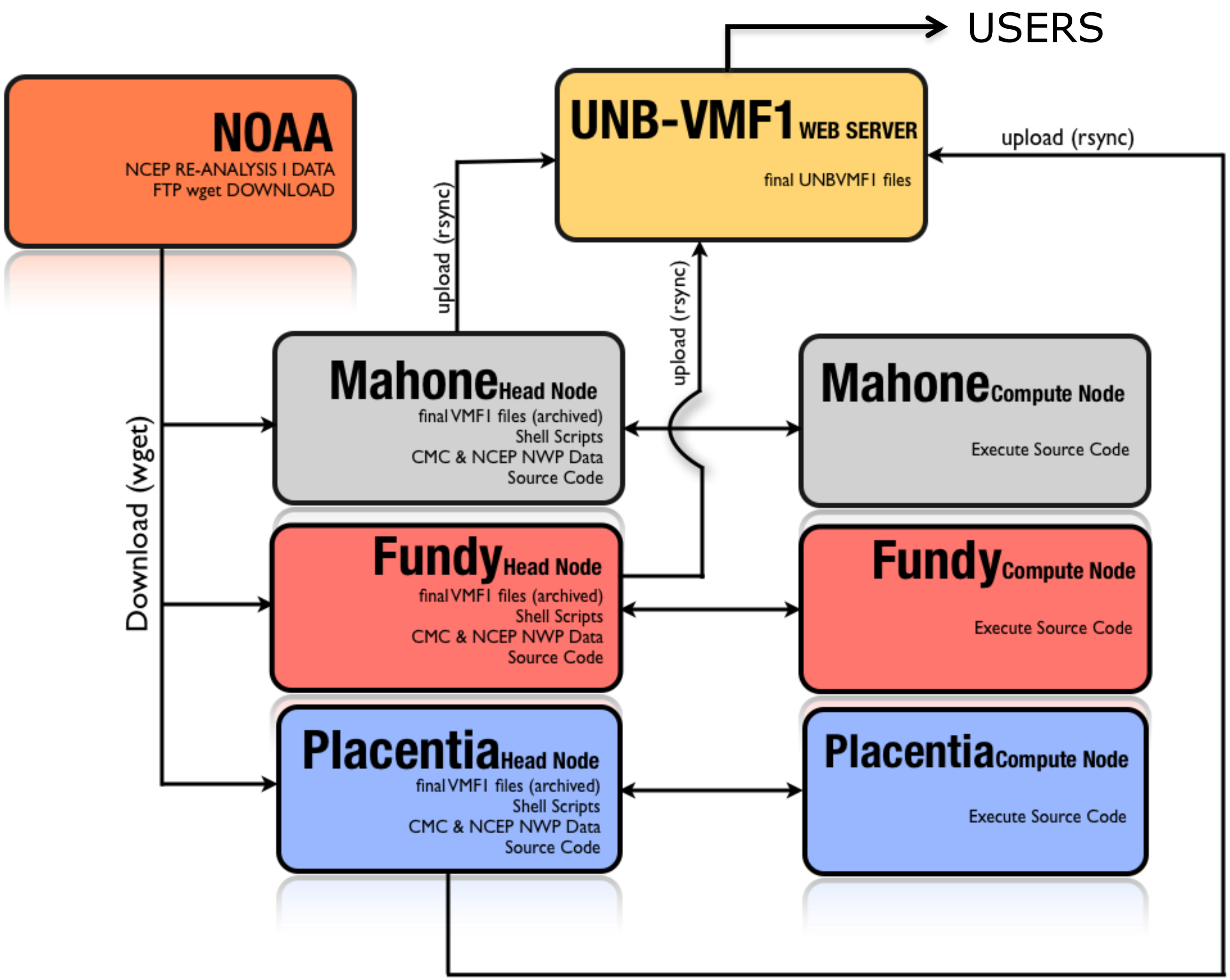
- UNB-VMF1: follows Boehm et al (2006a)
  - Employs the "Fast Method"
  - "b" and "c" coefficients are pre-determined
  - "a" coefficient is then solved by raytracing+inverting Marini continued fraction.

Coefficient	Hydrostatic	Non-Hydrostatic
b	0.0029	Same as Niell (1996)
c	See below	Same as Niell (1996)

$$c = c_o + \left[\left(cos\left(\frac{doy - 28}{365} 2\pi + \psi \right) + 1 \right) \frac{c_{11}}{2} + c_{10} \right] (1 - cos(\phi))$$

Values for c_o , c_{11} , and c_{10} can be found in Boehm et al(2006a)

UNB-VMF1 – System Integration

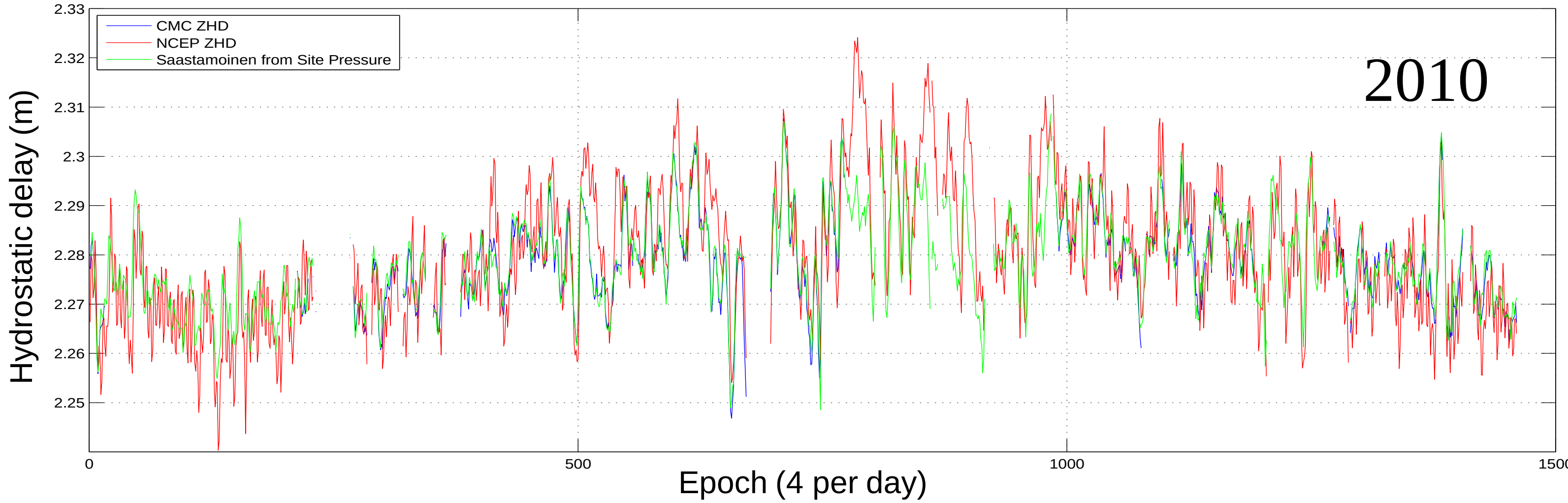


UNB-VMF1 – Data Sources (NWPs)

	NCEP Re-Analysis I	CMC GDPS
Grid Resolution	2.5x2.5 degrees (global)	0.6x0.6 degrees (global)
Pressure Levels	17 (1000-10 mbar) specific humidity ONLY - (1000-300 mbar)	28 (1015-50 mbar)
Type	Analysis	Operational Forecast
Availability	4x Daily (0h, 6h, 12h, 18h)	Initialized 2x daily (0h,12h) with 3h forecasts

UNB-VMF1 – Data Sources (NWPs)

Raytraced ZHD Delay from CMC/NCEP vs Saastamoinen from Measured Pressure



Station CONZ

Difference between Raytraced ZHD from CMC/NCEP and Saastamoinen from Measured Pressure