Minutes of the

Workshop on Numerical Weather Models for Space Geodesy Positioning

Location: Department of Geodesy and Geomatics Engineering, University of New Brunswick

ADI Room, 15 Dineen Dr., Fredericton, NB E3B 5A3

Date: 24 October 2011 – 25 October 2011

List of sessions:

Session 1: Theoretical and observational aspects on neutral-atmosphere

Session 2: Numerical weather prediction models and models derived from ray-tracing

Session 3: Practical aspects dealing with the development and implementation of the UNB-VMF1

Organisation: Department of Geodesy and Geomatics Engineering, University of New Brunswick

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Supporting Organizations

Atlantic Association for Research in the Mathematical Sciences (AARMS)

International Association of Geodesy (IAG)

University of New Brunswick (UNB)

Workshop motivation, description and objectives:

Signals transmitted from Global Navigation System Satellites, such as the US Global navigation Satellite System (GPS) cross the Earth's atmosphere and suffer from refraction, causing the measured distance to be biased (delayed). One of the layers of the atmosphere crossed by the signals is the neutral-atmosphere, which includes the troposphere, where meteorological phenomena happen. The delay suffered by the signal is a function of meteorological parameters, such as pressure, temperature and humidity. A way to deal with this neutral-atmospheric delay has been to use models based on climatology. In the past decade, the use of Numerical Weather Models (NWM), the same ones used for weather forecast, started to be investigated for modelling the neutral-atmospheric delay. The advantage of using NWM is that it provides the best available representation of the neutral-atmosphere at any given time. The disadvantage is that its use is computationally demanding, notably for real-time applications.

At UNB, we have been investigating the use of NWM for space geodesy positioning and applications since 2004, and collaborating with research groups around the world. We have developed a ray-tracer to ray-trace through NWM and we have been developing a service to provide ray-traced neutral-atmospheric delays to be used in GNSS positioning. This service will run under the auspices of the International Association of Geodesy. We have developed capabilities to use the Canadian Meteorological Center GEM Model, as well as NOAA's NCEP model and the European Center for Mid-range Weather Forecasting (ECMWF) model.

This workshop is devoted to the use of numerical weather models, assimilation, modelling, ray-tracing, and slant factor compression, focusing geodetic positioning.

Programme with working titles:

Session 1: Theoretical and observational aspects on neutral-atmosphere

Marcelo Santos:
Opening and Welcome

Richard Langley:
The troposphere: the problem, its modelling and its mapping

Peter Dare:
Measurements, Water Vapour Radiometer, and applications

Session 2: Numerical weather prediction models and models derived from ray-tracing

Marcelo Santos:
GEM Numerical Weather Models

Felipe Nievinski
A snapshot of UNB Ray-tracer

Landon Urquhart
UNB-VMF1: motivation, status and future

Session 2: Numerical weather prediction models and models derived from ray-tracing

Session 3: discussions on ray-tracing and UNB-VMF1

All presentations can be downloaded from the Workshop webpage:
http://gge.unb.ca/MT/Events/Workshop/Workshop.html

Workshop participants

From UNB: Marcelo Santos, Richard Langley, Peter Dare, Matthew MacAdam, Bryan Conrad, Evans Rolstron, Alex Garcia, Andrew Kubiak, Norman Chai, James Mtamakaya, Brett Watson
From University of Colorado: Felipe Nievinski
From Nexteqnav: Landon Urquhart
From Environment Canada: William Richards
From Natural Resouces Canada: François Lahaye

Expenditures covered by AARMS

Reimbursement -		
Airfare- Felipe Nievinski Denver to Fredericton return Oct 23-29/11	$1,345.10	
Accommodations	$360.00	
Parking and Meals	$258.50	
Total Due		$1963.60

Resolutions emanated from the Workshop

1. Description

The University of New Brunswick is proposing the creation of a geodetic corrections service providing tropospheric corrections (atmospheric delays) based on the Vienna Mapping Functions. The creation of the University of New Brunswick's Vienna Mapping Function Service (UNB-VMF1) aims to:

- Improve the availability of the VMF1 corrections, thereby mitigating the impact of any existing service disruptions;
- Provide greater compatibility with other derived numerical weather prediction model (NWP) products (i.e. atmospheric pressure loading);
- Improve robustness of combined products through the generation of the VMF1 from an independent dataset and independent raytracing algorithms.

The UNB-VMF1 is designed to maintain much consistency with the existing VMF1 service operated at the Institute of Geodesy and Geophysics, Vienna, Austria (their VMF1 service can be accessed at the following location: http://ggosatm.hg.tuwien.ac.at/DELAY/). The UNB-VMF1 follows *Boehm et al.* (2006b) utilizing the same orography, output file format, and grid definition as defined by the existing VMF1 service. The UNB-VMF1 service differs only in its raytracing algorithms and source data (NWP). *Nievinski* (2009) define the raytracing algorithms, and the source dataset for the proposed products are NCEP's Re-Analysis I and the Canadian Meteorological Centre's Global Deterministic Prediction System (GDPS). The UNB-VMF1 service will offer three products, but only one is to be considered operational due to the circumstances of source data availability. The following table, Table 1, summarizes the distinguishing characteristics of each of the available products.

Product	Data Source	Grid	Orography	Notes
unbvmfG	NCEP (ReA1)	2.0x2.5	orography.ell	OPERATIONAL (Proposed)
unbvmfGcmc	CMC GDPS	2.0x2.5	orography.ell	Experimental (Proposed)
unbvmfP	CMC GDPS	2.0x2.5	orography.ell	Experimental (Proposed)

Table 1: Summary of Proposed UNB-VMF1 Products

The UNB-VMF1 is produced utilizing the super-computing facilities provided by the Atlantic Canada Computational Excellence Network (ACEnet). The computational aspects have been implemented simultaneously on three independent clusters in the ACEnet network creating a very robust redundant architecture. Figure 1 illustrates the essential components describing the system integration of the UNB-VMF1. Three clusters independently obtain data from its source (the figure shows NOAA, but for the other products the source will be the CMC), and then independently perform the UNB-VMF1 computations. Once computations have been verified, the resulting final product files are then uploaded to the web-sever that resides at the University of New Brunswick. The redundant cluster architecture ensures that the computations will be performed regardless if a single cluster were to go offline for maintenance or any other reason.

The user has access to the datasets through a website located at http://unb-vmf1.gge.unb.ca, which is maintained at the University of New Brunswick in the Department of Geodesy and Geomatics (website is currently operational). The user can also utilize the "wget" program to automate the retrieval process on a regular basis. Data availability is described in §4.0 and a detailed description on how to use "wget" can be found on the website.

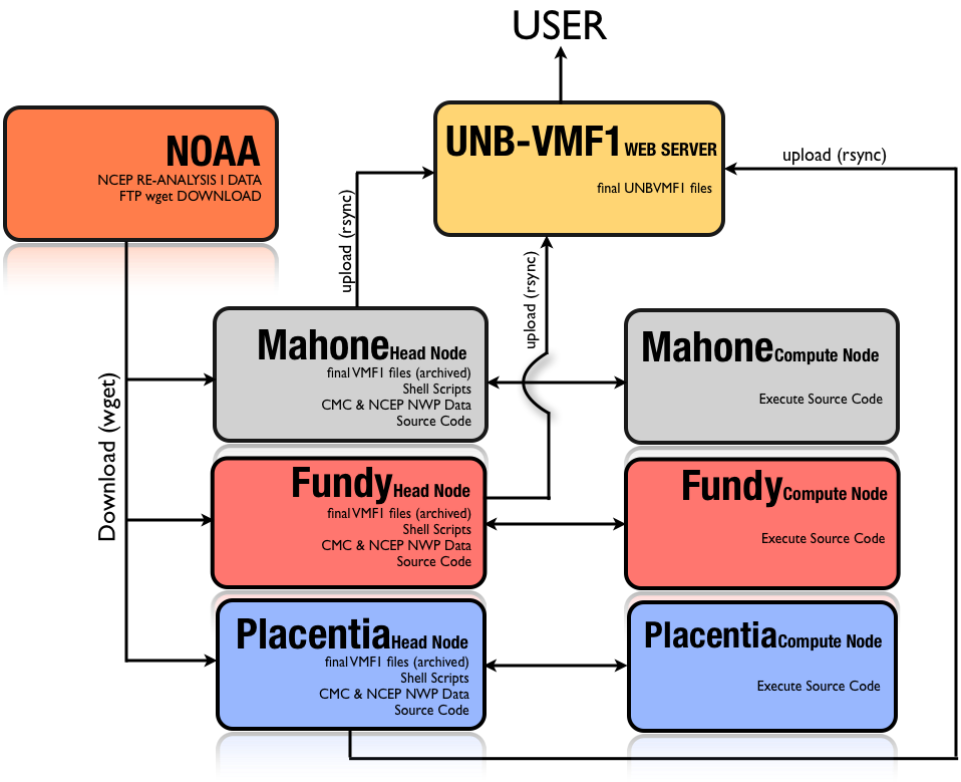

Figure 1: System Integration for UNB-VMF1

2. Source Data Availability

The main operational product (**unbvmfG** – listed in table 1) is produced utilizing NCEP's Re-Analysis I datasets, namely temperature, geo-potential height and specific humidity. The datasets are available for download from National Oceanic and Atmospheric Administration's (NOAA) Earth Systems Research Laboratory website: (www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html). The datasets are continually available and provided with a three-day latency on 2.5 by 2.5 degree grid. The benefit of the NCEP Re-analysis dataset is that it meets the criteria for on-demand downloading. If there were any service disruptions with the NCEP Re-analysis I datasets, past data can be downloaded for all missing epochs when data becomes available.

The designated experimental products (**unbvmfGcmc** and **unbvmfP**) utilize datasets from the Canadian Meteorological Centre (CMC), specifically the Global Deterministic Prediction System (GDPS). This is a

global dataset, where the geo-potential height, specific humidity and temperature are utilized in a 0.6 by 0.6 degree grid. Datasets are available through an http protocol at the following location: http://www.weatheroffice.gc.ca/grib/grib2_glb_HR_e.html. These datasets are considered to be experimental due to the higher risks in data availability, which preclude these datasets from gaining an operational status for the time being. The CMC offers these datasets in a rolling database format. The dataset is available for 24 hours then it is replaced with the next day's set when it is available. If any data is missed (on our end), or if there is a service disruption at the CMC, there is a risk that data could be missed permanently and there is little chance of obtaining historical data from the CMC at the time being. Until arrangements can be made with the CMC the product remains experimental.

3. Reliability

An initial validation campaign has been completed highlighting a small sample of results for the UNB-VMF1 grids. A comparison between zenith delays from the ECMWF and NCEP NWP's has been completed for the year 2010. *Urquhart et al.* (2011) demonstrated that the differences between the raytraced hydrostatic and non-hydrostatic zenith delays are globally -2.4 ± 3.8 mm and 6.4 ± 14.7 mm respectively. When comparing station heights, the differences globally between the ECMWF results and NCEP were 0.8 ± 0.9 mm for the hydrostatic component and -0.4 ± 0.6 mm for the non-hydrostatic component. The initial results show good compatibility with the existing service, but a larger scale validation is still yet to be completed. It is the intention to complete this investigation by years end.

4. Operational Availability

The operational **unbvmfG** product that is produced utilizing NCEP's Re-Analysis I dataset is provided on a 7-day latency that is produced at 6-hour epoch intervals (00, 06, 12 and 18h). This is in part due to the standard latency the input numerical dataset is offered. The additional latency ensures that our production of the product does not interfere with any changes to the original latency. Further, precise/final IGS products are available with specified 12-18 day latency, so UNB-VMF1's operational product can be used effectively with the current IGS product scheduling without concern. Product is currently available for the year 2011 and is available up to 7 days prior to the current epoch. Historical

product will become available once a validation campaign has been completed. The product is available to the user at 0:00 of the current day.

The experimental products, **unbvmfGcmc** and **unbvmfP**, are also currently being produced, but if NWP data is unavailable, missed epochs will not be replaced. Both products are produced at the same intervals as the standard **unbvmfG**, but their latency is different. However, CMC's GDPS is only initialized every 12 hours (0h and 12h), so the epoch at 6h and 18h are produced using 6-hour forecasts relative to their respective initialization times. In contrast, NCEP's Re-Analysis 1 dataset is an analysis-based dataset, but the products produced with the CMC dataset will have the benefit of a finer grid (0.6 degree (CMC) vs 2.5 degree (NCEP)). Since the CMC's dataset has no latency (see §3.0) **unbvmfGcmc** is provided with a 1-day latency, and is available to the user at 0:00 of the current day.

unbvmfP is the predicted product and is available for +1 day (0-day latency) from the current epoch. This predicted product allows users to utilize the UNB-VMF1 with IGS rapid products. The product is produced at the same 6 h intervals as the **unbvmfG**, but with CMC's GDPS dataset at 00h initialization with 24 h, 30 h, 36 h and 42 h forecasts. CMC's 00h dataset is available approximately at 04:00, allowing the **unbvmfP** product to be available to the user at 12:00 of the current day. Table 2 summarizes availability for all products.

Product	Latency	Availability	Available Epochs	On Website
unbvmfG	-7 days	0:00	2011-present (-7)	Now
unbvmfGcmc	-1 day	0:00	2012-01-01 - present (-1)	Pending validation
unbvmfP	+1 day	12:00	2012-03-17 - present (+1)	Pending validation

Table 2: Summary of UNB-VMF1 Product Availability

References

Boehm, J., B. Werl, and H. Schuh (2006b). "Troposphere mapping functions for GPS and very long baseline interferometry from European Centre for Medium-Range Weather Forecasts operational analysis data." Journal of Geophysical Research, Vol. 111, No. B02406, doi:10.1029/2005JB003629.

Nievinski, F. G. (2009). "Ray-tracing Options to Mitigate the Neutral Atmosphere Delay in GPS." M.Sc.E.

thesis, University of New Brunswick, Dept. of Geodesy and Geomatics Engineering, Fredericton, N.B., Canada, May, 232 pp., Technical Report 262, http: //gge.unb.ca/Pubs/TR262.pdf.

Urquhart, L. M. Santos, F. Nievinski, J. Bohm (2011). "Generation and Assessment of VMF1-Type Grids using North-American Numerical Weather Models." presented at XXV IUGG General Assembly, Melbourne, Australia, June 28th – July 7th, 2011.