Range-Extended Post-Processing Kinematic (PPK) in a Marine Environment

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BIOGRAPHY

Marcelo Santos is Associate Professor at the Department of Geodesy and Geomatics Engineering at UNB. He holds a M. Sc. in Geophysics from the National Observatory, in Rio de Janeiro, and a Ph.D. in Geodesy from UNB. He has been involved in research in the fields of space and physical geodesy, GNSS and navigation.

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Karen Cove received her B. Sc. in Geomatics Engineering in 2002 and her M. Sc. E. in 2005 from the Department of Geodesy and Geomatics Engineering at the University of New Brunswick, Canada. She is currently working at CARIS Ltd. Her research interests include GPS positioning and marine boundaries.

Robert Kingdon is a M. Sc. E. student at the Department of Geodesy and Geomatics Engineering, University of New Brunswick. He completed his undergraduate degree in Geomatics Engineering with the Department in May, 2005; He has assisted with GPS processing; although his primary interest is with physical geodesy. He is working under Dr. Marcelo Santos.

Dave Wells is Professor Emeritus in the Department of Geodesy and Geomatics Engineering at UNB, as well as Professor in the Dept. of Marine Science at the University of Southern Mississippi (USM), and Adjunct Professor in the Center for Coastal and Ocean Mapping at the University of New Hampshire. Dave's academic interests include geodesy, applied bathymetry, kinematic positioning, water levels and tides, and hydrographic data management.

ABSTRACT

We have been investigating on the extension in range of baselines used in support to marine applications. Our focus has been with PPK (post-processing kinematic) following the Remondi's lemma: it is better to have a reliable float ambiguity resolution rather than a wrongly fixed ambiguity". We have focused our attention on the residual effect due to differential troposphere. Our investigation makes use of data sets collected under the scope of the Princess of Acadia Project. In this paper, we focus on a storm know as the 2004 Halifax weather bomb. Zenith tropospheric delays have been compared for that time period. It is shown that using Numerical Weather Prediction (NWP) GEM model provides a better agreement with the zenith delay as provided by the IGS tropospheric product for station IGS UNB1. We have developed a program, the UNB NWP Ray-tracing software, intended to compute zenith and slant path delays from NWP data sets. This paper shows the state of the art in our efforts towards using NWP for positioning.

THE PRINCESS OF ACADIA PROJECT

The Princess of Acadia Project main objectives as presented by Santos and Cove (2002) and Santos et al (2004) are:

- To investigate the performance of high-accuracy (cm-level) positioning and navigation using GPS carrier-phase in terms of:
  - area coverage (i.e., distance from reference stations); and,
  - variability in weather conditions, in a marine environment.

- To investigate the seamless representation of a vertical datum, by integrating data from tide gauges.

- To investigate local effects associated with tides (body tides, tidal loading and sea surface topography).

- To investigate site-dependent GPS effects (multipath).

Data from a network of GPS receivers, meteorological stations and tide gauges were collected for a period of over one year (from November 2004 to December 2004) in the area around the Bay of Fundy, located between the Canadian Provinces of New Brunswick and Nova Scotia, in Eastern Canada. A receiver was also set up on board the ferry Princess of Acadia, which connects the cities of St. John, New Brunswick, and Digby, Nova Scotia, as many as 3 times a day. The passing of weather fronts can be seen along the data collection which spans different seasons.

Figure 1 shows the geographic location of the project, with indication of the stations used and their respective distances. The ferry travels the 74 km line between Digby (DRHS) and Saint John (CGSJ). These stations were implemented solely to serve the project. Other stations shown are Fredericton (FDRN) and Halifax (HLFX). The latter stations belong to the Canadian Active Control System, maintained by NRCan.

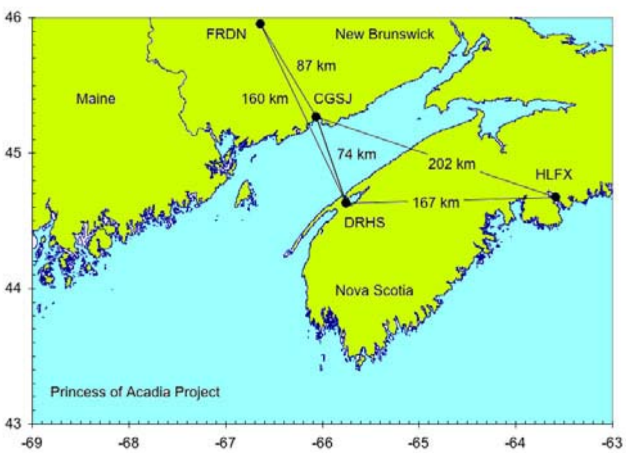

Figure 1: The Princess of Acadia Project location.

Our processing and analysis strategy relies on comparing two kinematic solutions for the receiver on the boat as processed using two different stations: Digby (DRHS) and St. John (CGSJ). The closest solution provides a ground truth for the longer baseline.

THE 2004 HALIFAX WEATHER BOMB

One example on how weather fronts can be an important impacting factor in navigation is provided by the 2004 Halifax weather bomb. On February 18, 2004, the Canadian city of Halifax was hit by a weather bomb, consisting of a strong winter storm associated with heavy snow fall. Figure 2 shows a weather map (from the Weather Network) showing the time when Halifax was started to be hit by the storm. The figure shows the trough in pressure approaching Halifax with a direction indicated by the orange arrow.

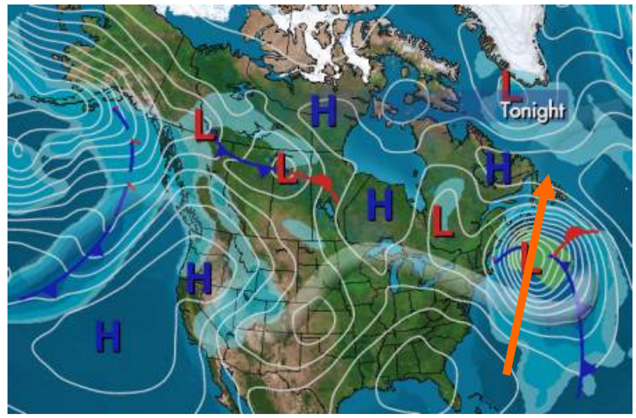

Figure 2: Weather map showing the approaching storm

The effect of such storm and dramatic change in meteorological characteristics can be noted from the analysis of the baseline Digby-Boat and St. John-Boat solutions. Both Digby and St. John stations were affected differently by the storm, therefore, having very different tropospheric values. Also, as the storm moved from South to North, most of the GPS satellite paths were somehow crossing the trough of low pressure. The analysis is based on the processing strategy described previously. The processing was carried out using GrafNav, from Waypoint Consulting, targeting to evidence the effect of the front due to differential troposphere. We shall concentrate on the height component.

Figure 3 shows the height difference between both baselines for February 17, 2005. On this day, as the weather front was still away, the solution difference was quite stable, with a variation at the order of 20 cm, peak to peak, with mean very close to zero. The plot represents a 24 hours long solution, involving the boat as it moved between the two ends of the Bay of Fundy and also time while it remained docked.

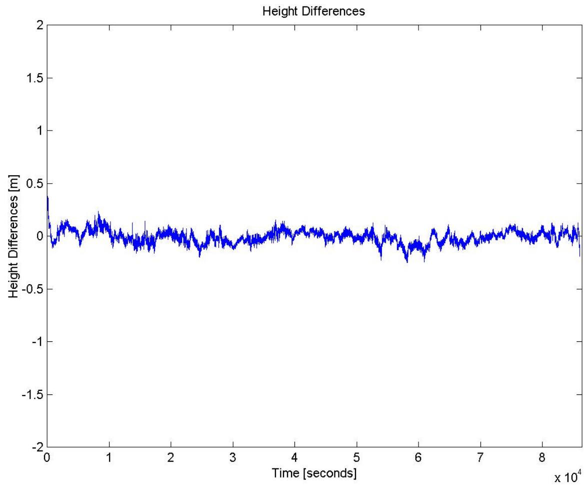

Figure 3: Height difference at the boat, for 17 February

Figure 4 shows the height difference between both baselines for February 18, 2005. On this day, the weather front had its presence felt, more pronounced with the passing of the day. The solution difference shows a remarkable variation. The plot also represents a 24 hours long solution.

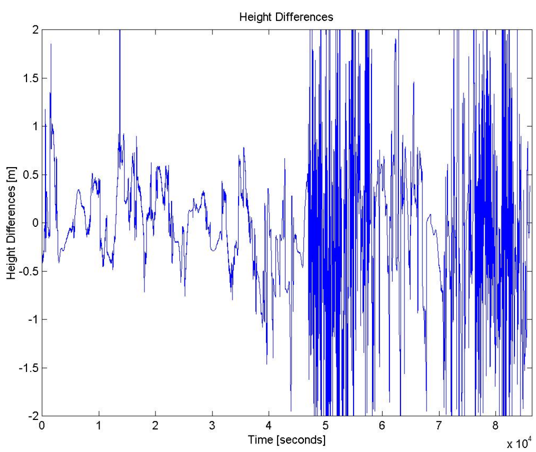

Figure 4: Height difference at the boat, for 18 February

It is evident the effect coming from mis-modelled troposphere.

GEM MODEL

We have turned our attention to the use of Numerical Weather Prediction (NWP) model data for modeling the troposphere (Côté et al., 1998; Cove et al., 2004; Cove, 2005; Nievinski et al., 2005). We have used GEM model, provided by the Canadian Meteorological Center (CMC). A NWP model is a tri-dimension grid field of weather parameters, e.g., temperature, humidity, pressure. From this grid we can calculate a similar grid for refractivity.

We have been using NWP CMC high resolution data provided by the GEM model. This model is composed of 28+1 levels vertical, horizontally space by 15 km, with a temporal latency varying from 3 hours with a coverage from 0 to 12 hours for the predicted model.

Figure 5, from Nievinski et al (2005), shows snapshot of the refractivity field over Canada, May 20, 2005 as derived using CMC NWP data. It can be seen that more information exists at the lower layers of the troposphere where there is higher variability in meteorological parameters.

ZENITH AND SLANT-PATH DELAYS

We have been working on the development and testing of a ray-tracing software called the "UNB NWP Ray-tracing Software" (Nievinski et al., 2005). This software in its current stage considers the (curved) integration path approximated as a straight-line direction between receiver and satellite. That allows us to know the integration path *before* the actual integration. It probably is not valid for very low elevation angles (<10º).

For the calculation of slant delays there is to perform a conversion to geopotential heights, and calibrate the height of the observing site to the model. We have implemented and tested as many as 10 different ways of performing this calibration. In a more (theoretical) rigorous way, the geopotential heights are calculated in the NWP assuming hydrostatic equilibrium and including a term to account for any eventual bias.

New implementation includes taking bending of the actual signals into account. Additional tests being performed include comparison with tropospheric models and mapping functions, testing on static and kinematic baselines and testing on precise point-positioning.

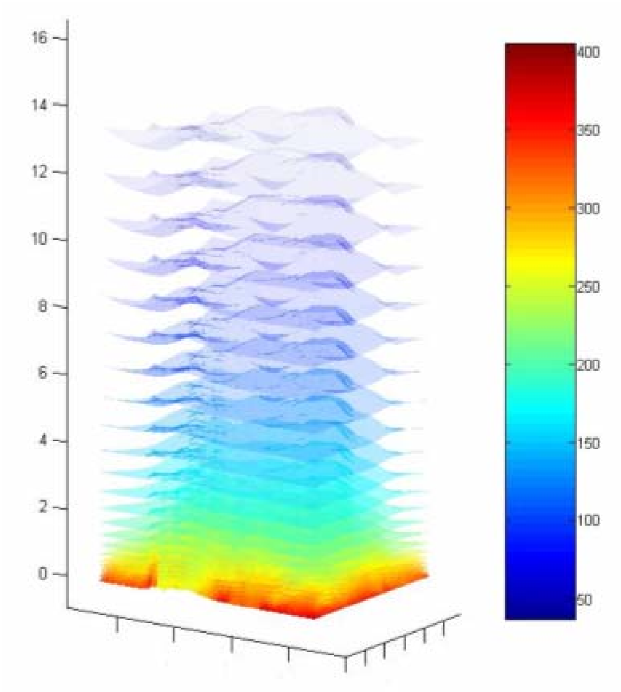

Figure 5: Refractivity field over Canada, May 20, 2005. (Vertical scale exaggerated 100 times)

TEST RESULTS

Tests on the zenith delay have been carried out and reported by Cove (2005) report. Here we will be showing the one which took place at covering the same time as the 2004 Halifax weather bomb. For this comparison, the IGS tropospheric product was taken as ground truth. Testes were performed with data sets collected at the IGS station UNB1, located on the University of New Brunswick Fredericton Campus. Results were generated using GEM NWP model, using Saastamoinen model with the time series of observed surface meteorological parameters and using Saastamoinen model with standard meteorological parameters. Table 1 shows the different processing options used in this comparison.

Table 1: Processing options for the tests

IGS	GPS derived delays from IGS final troposphere zenith path delay product
GEM	Delay estimated from CMC GEM regional model
SAAS	Delays predicted with Saastamoinen model using time series of surface meteorological parameters
SAAS std	Delays predicted with Saastamoinen model using standard surface meteorological parameters

Figure 6 show profiles of the different processing options from Table 1 for four days encompassing the weather bomb, starting from February 17 and ending on February 20, 2004. It can be seen that they all follow the same general trend as the IGS product, except for the one using the standard Saastamoinen.

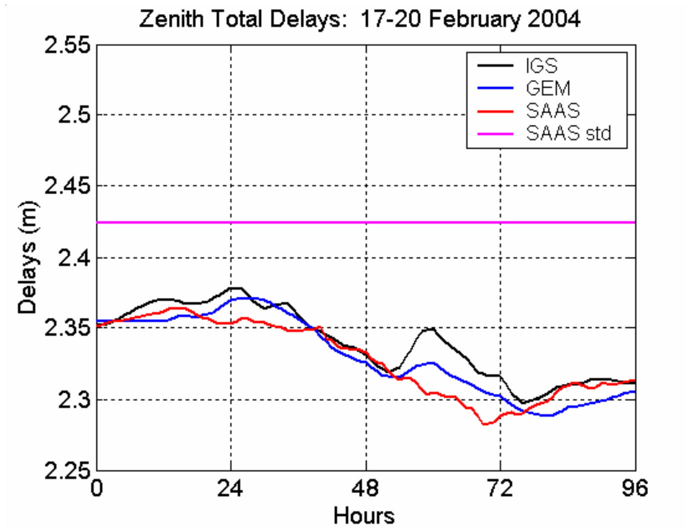

Figure 6: zenith delay profiles

Table 2 summarizes the statistics of the comparisons. The NWP computed zenith delays are closest to the IGS ground truth in mean, standard deviation and RMS.

Table 2: Comparison statistics

Day	RMS Error in Estimation of zenith tropospheric delay (mm)								
	IGS – NWP			IGS – SAAS			IGS – SAAS std		
	St.Dev	Mean	RMS	St.Dev	Mean	RMS	St.Dev	Mean	RMS
48-51	6.5	9.9	11.8	14.2	10.3	17.4	24.7	-84.3	87.8

CONCLUSIONS AND FUTURE WORK

We have summarized the Princess of Acadia Project and its status as far as using numerical weather prediction (NWP) data model in an attempt to derive a more realistic tropospheric modeling. We have focused on the 2004 Halifax weather bomb. We have tested zenith delays at the time around the weather bomb. A description of the UNB NWP Ray-tracing software followed. Comparisons of zenith delay showed a better agreement using NWP with respect to the IGS tropospheric model. Further improvements and testing of the UNB NWP ray-tracing software are required and steps for this testing have been described.

ACKNOWLEDGMENTS

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Another paper in this conference did use the UNB NWP ray-tracing Software. This paper belongs to Session B5, *"Long Baseline GPS RTK Performance in a Marine Environment Using NWP Ray-Tracing Technique …"*

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