AN IMPROVED GPS-BASED PRECISE POINT POSITIONING MODEL

Mohamed Elsobeiey and Ahmed El-Rabbany

Department of Civil Engineering, Ryerson University

RYERSON UNIVERSITY

Outline

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- SECOND-ORDER IONOSPHERIC DELAY
- NOAA TROPOSPHERIC CORRECTIONS
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INTRODUCTION

- Real-time and near real-time GPS precise point positioning (PPP) requires instantaneous/shorter convergence time for the estimated parameters
- Not all errors and biases are rigorously modelled in PPP, which results in correlated residual errors
- Unless accounted for, correlated residual errors slow down the convergence of the estimated parameters
- Some errors can be modeled, while others are difficult to account for

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Second-Order Ionospheric Delay

- GPS Observation Equations

$$P_1 = \rho + c(dt^r - dt^s) + T + \frac{q}{f_1^2} + \frac{s}{f_1^3} + c(d_{P1}^r - d_{P1}^s) + \varepsilon_{P1}$$

$$P_2 = \rho + c(dt^r - dt^s) + T + \frac{q}{f_2^2} + \frac{s}{f_2^3} + c(d_{P2}^r - d_{P2}^s) + \varepsilon_{P2}$$

$$\Phi_1 = \rho + c(dt^r - dt^s) + T - \frac{q}{f_1^2} - \frac{s}{2f_1^3} + c(\delta_{\Phi1}^r - \delta_{\Phi1}^s) + \lambda_1\left[N_1 + \phi_{\Phi1}^r(t_0) - \phi_{\Phi1}^s(t_0)\right] + \varepsilon_{\Phi1}$$

$$\Phi_2 = \rho + c(dt^r - dt^s) + T - \frac{q}{f_2^2} - \frac{s}{2f_2^3} + c(\delta_{\Phi2}^r - \delta_{\Phi2}^s) + \lambda_2\left[N_2 + \phi_{\Phi2}^r(t_0) - \phi_{\Phi2}^s(t_0)\right] + \varepsilon_{\Phi2}$$

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Second-Order Ionospheric Delay

- First-Order Ionosphere-Free Linear Combination

$$P_3 = \rho + c(dt^r - dt^s) + T + \frac{s}{f_1 f_2 (f_1 + f_2)} + b_{P3}^r - b_{P3}^s + \varepsilon_{P3}$$

$$\Phi_3 = \rho + c(dt^r - dt^s) + T - \frac{s}{2 f_1 f_2 (f_1 + f_2)} + b_{\Phi 3}^r - b_{\Phi 3}^s + \lambda_3 N_3 + \varepsilon_{\Phi 3}$$

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Second-Order Ionospheric Delay

- Un-differenced (Traditional) PPP Model

$$P_3 = \rho + c(dt_{P3}^r - dt_{P3}^s) + T + \frac{s}{f_1 f_2 (f_1 + f_2)} + \varepsilon_{P3}$$

$$\Phi_3 = \rho + c(dt_{P3}^r - dt_{P3}^s) + T - \frac{s}{2 f_1 f_2 (f_1 + f_2)} + \lambda_3 N_3' + \varepsilon_{\Phi 3}$$

- where,

$$dt_{P3}^r = dt^r + b_{P3}^r / c = dt^r + \xi_1 d_{P1}^r - \xi_2 d_{P2}^r$$

$$dt_{P3}^s = dt^s + b_{P3}^s / c = dt^s + \xi_1 d_{P1}^s - \xi_2 d_{P2}^s$$

$$N_3' = c(-b_{P3}^r + b_{P3}^s + b_{\Phi 3}^r - b_{\Phi 3}^s) / \lambda_3 + N_3$$

$$\xi_1 = f_1^2 / (f_1^2 - f_2^2), \xi_2 = f_2^2 / (f_1^2 - f_2^2), \lambda_3 = c / (f_1^2 - f_2^2), N_3 = (f_1 N_1 - f_2 N_2)$$

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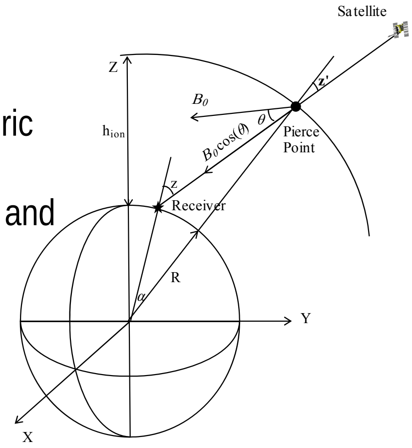
Second-Order Ionospheric Delay

- Factors affecting second-order ionospheric delay

$$s = 7527 c B_0 \cos(\theta) STEC$$

- Magnetic field at the ionospheric pierce point
- Angle between magnetic field and propagation direction
- Total electron content



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Second-Order Ionospheric Delay

- Parameters of Geomagnetic Field

Magnetic field parameters are estimated at the Ionospheric Pierce Point (IPP) using the 11th generation of International Geomagnetic Reference Field model (IGRF)

- Slant Total Electron Content (STEC)

P1-P2 is used and satellites and receiver differential hardware delays are applied

$$STEC = \left[(P_2 - P_1) + c(DCB^{r}_{P1-P2} + DCB^{s}_{P1-P2})\right]\left(\frac{f_2^2}{f_1^2 - f_2^2}\right)\left(\frac{f_1^2}{40.3}\right)$$

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NOAA Tropospheric Model

- NOAA Tropospheric model (NOAATrop) has been developed by the NOAA Forecast Systems Lab
- The NOAA model covers USA and parts of Canada
- NOAATrop is based on numerical weather prediction (NWP) models
- The NOAA model estimates both the zenith hydrostatic tropospheric delay (ZHD) and the zenith tropospheric wet delay (ZWD) every hour
- The NOAATrop was found to be superior to other tropospheric models

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Between-Satellite Single-Difference Model

- BSSD Model

$$P_3^{kl} = \rho^k - \rho^l + c(dt_{P3}^l - dt_{P3}^k) + T^k - T^l$$

$$L_3^{kl} = \rho^k - \rho^l + c(dt_{P3}^l - dt_{P3}^k) + T^k - T^l + \lambda_3\left(N_3^{\prime\prime k} - N_3^{\prime\prime l}\right)$$

where,

$$N_3^{\prime\prime} = c(b_{P3}^s - b_{\Phi 3}^s) / \lambda_3 + N_3$$

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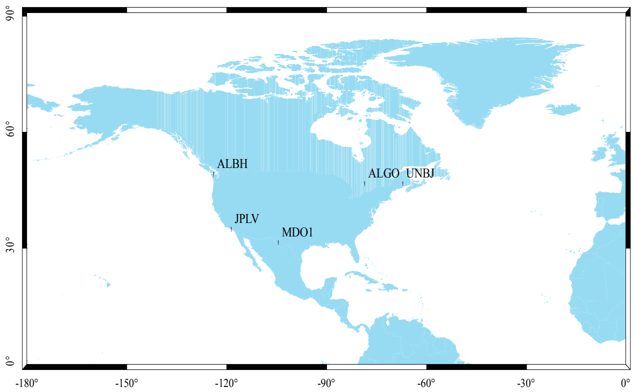
Stations Used to Verify the Developed PPP Model



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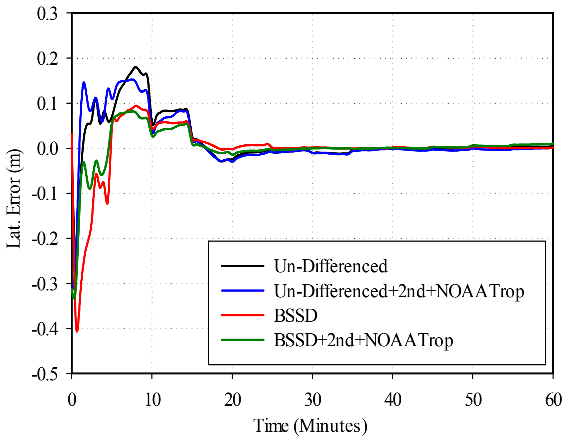
Latitude Error at ALGO IGS station, DOY125, 2010



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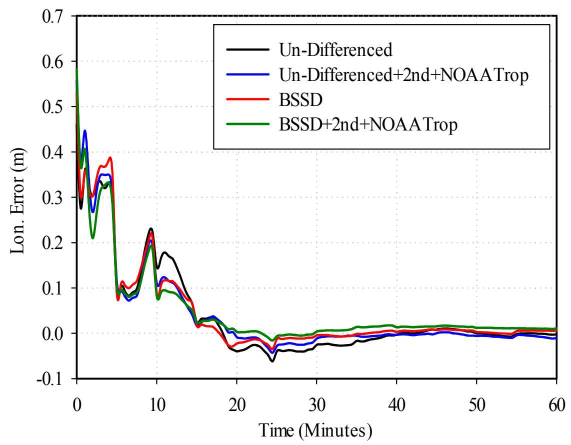
Longitude Error at ALGO IGS station, DOY125, 2010



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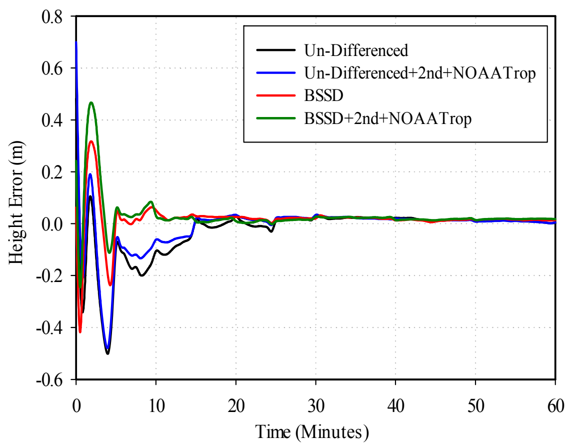
Height Error at ALGO IGS station, DOY125, 2010



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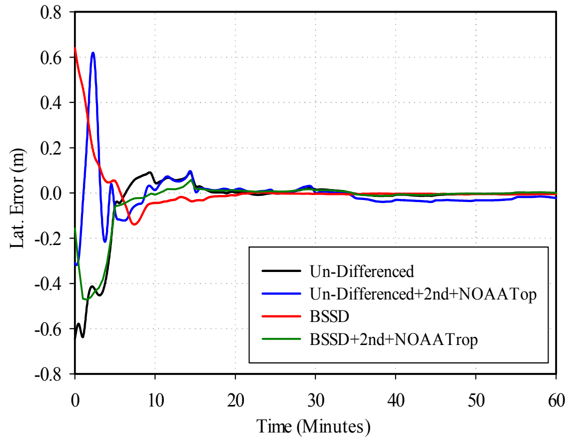
Latitude Error at ALPH IGS station, DOY125, 2010



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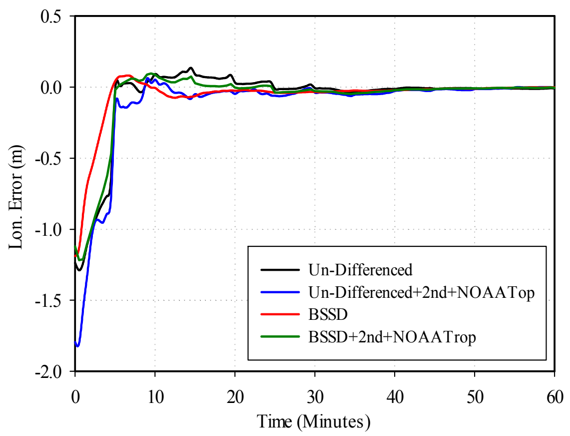
Longitude Error at ALPH IGS station, DOY125, 2010



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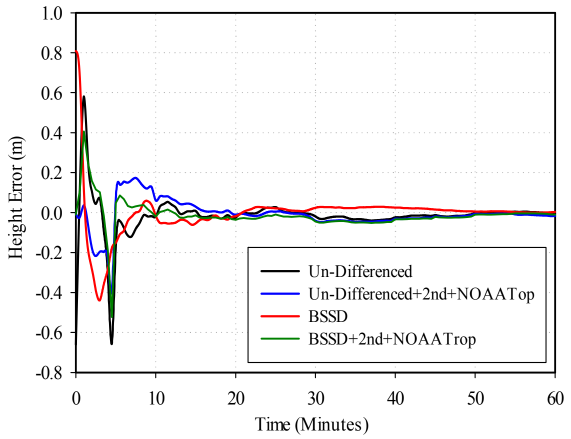
Height Error at ALPH IGS station, DOY125, 2010



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Conclusions

- Between-Satellite Single-Difference (BSSD) model has been developed, which cancels out receiver clock error, receiver hardware delay, and receiver initial phase bias
- It is shown that ionosphere-free, with first and second-order ionospheric corrections applied, between-satellite single difference model improves the PPP convergence time and solution
- BSSD model improves the RMS of the final PPP coordinate solution by up to 40% and improves the convergence time of the estimated parameters by about 30% in comparison with traditional un-differenced PPP model
- Further improvement is expected at high ionospheric peak
- New research, which separates the code and phase clock errors, improves the PPP solution significantly

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