# An Innovation Multi-Constellation GNSS PPP model for Precise Navigation Applications

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# Introduction

- Precise Point Positioning (PPP) is traditionally based on dual-frequency observations of GPS or GPS/GLONASS satellite navigation systems.
- On the other hand, the undifferenced ionosphere-free is commonly used as standard precise point positioning technique.
- However, the existence of receiver and satellite biases which are absorbed by the ambiguities, significantly affected the convergence time.
- Between-satellite-single-difference (BSSD) ionosphere free PPP technique is traditionally used to cancel out the receiver related biases from both code and phase measurements.
- This paper introduces multiple ambiguity datum (MAD) PPP technique which can be applied to separate the code and phase measurements removing the receiver and satellite code biases affecting the GNSS receiver phase clock and ambiguities parameters.

# Problem Statement

- The major drawback of the standard PPP technique is the long convergence time to reach to centimeter positioning accuracy due to:

1. The poor satellite geometry
2. the improper modeling of errors and biases, such as the satellite and receiver code biases.

$$P_{3G} = \rho_G + c[dt_r + B^r{}_G] - c[dt^s{}_G - B^s{}_G] + T_G + e_G$$

$$\Phi_{3G} = \rho_G + c[dt_r + B^r{}_G] - c[dt^s{}_G - B^s{}_G] + T_G + (\bar{\lambda}\bar{N} + \Delta B^r - \Delta B^s)_G + \varepsilon_G$$

# BSSD model

- To completely remove the receiver related biases from both the code and phase GNSS observations, between-satellite-single-difference (BSSD) ionosphere-free PPP technique can be used for combined GNSS observations model.
- For each system, a reference satellite is selected while the other GNSS satellites observations are subtracted from it.

$$P_{3G} - P_{3G}^{l} = \rho_G - \rho_G^{l} - c[(dt^{s}{}_{G} + B^{s}{}_{G}) - (dt^{s}{}_{G} + B^{s}{}_{G})^{l}] + T_G - T_G^{l} + e_G - e_G^{l}$$

$$\Phi_{3G} - \Phi_{3G}^{l} = \rho_G - \rho_G^{l} - c[(dt^{s}{}_{G} + B^{s}{}_{G}) - (dt^{s}{}_{G} + B^{s}{}_{G})^{l}] + T_G - T_G^{l} + [(\overline{\lambda}\overline{N} + \Delta B^{s}) - (\overline{\lambda}\overline{N} + \Delta B^{s})^{l}] + \varepsilon_G - \varepsilon_G^{l}$$

- As can be seen the GNSS receiver clock and biases are totally removed. However, the satellite DCB still exist !

# Developed MAD model

- To remove the effect of the receiver and satellite code biases from GNSS phase measurements, ambiguity-fixed datum technique can be used to separate the code and phase receiver clocks.
- This can be done by fixed one of the satellite ambiguity by arbitrary number
- In this case, the receiver clock combined with the fixed satellite ambiguity will be considered as a receiver clock reference for other phase observations receiver clocks.
- The undifferenced mathematical model can be reformatted by lumping the ambiguity of a reference satellite to the phase receiver clock assuming the ambiguity parameter of the reference satellite is zero.

# Developed MAD model

- Multiple reference satellites are needed to separate the ISBs of code and phase measurements.
- In this model, the phase receiver clock model will be shifted by the ambiguity parameter of the selected GPS reference satellite leading to code biases free as follows:

$$P_{3G} = \rho_G + c[dt^{p}{}_{r}] - c[dt^{s}{}_{Gp}] + T_G + e_G$$

$$P_{3E} = \rho_E + c[dt^{p}{}_{r}] - c[dt_{Ep}{}^{s}] + T_E + c[ISCB_E] + e_E$$

$$\Phi^{1}_{3G} = \rho_G + [cdt^{\phi}{}_{r} + (\overline{\lambda N})^{1}_{G}] - c[dt^{1}{}_{G\phi}] + T^{1}{}_{G} + \varepsilon_{G}$$

$$\Phi^{2}_{3G} = \rho^{2}_{G} + [cdt^{\phi}{}_{r} + (\overline{\lambda N})^{1}_{G}] - c[dt^{2}{}_{G\phi}] + T^{2}{}_{G} + [(\overline{\lambda N})^{2}_{G} - (\overline{\lambda N})^{1}_{G}] + \varepsilon_{G}$$

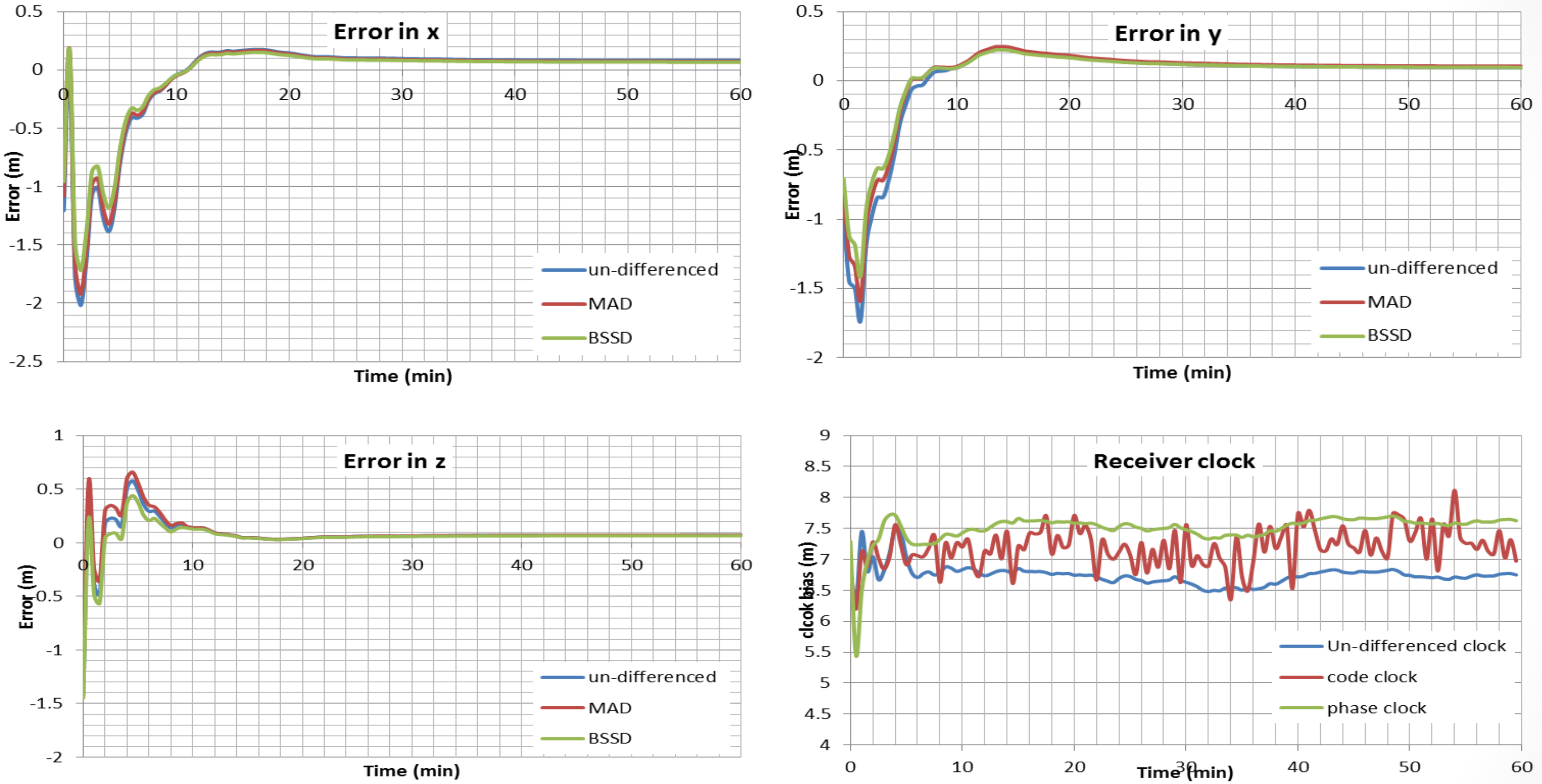
$$\Phi^{1}_{3E} = \rho^{1}_{E} + [cdt^{\phi}{}_{r} + (\overline{\lambda N})^{1}_{G}] - c[dt^{s}{}_{E\phi}] + T_E + [c(ISPB_E) + (\overline{\lambda N})^{1}_{E} - (\overline{\lambda N})^{1}_{G}] + \varepsilon_E$$

$$\Phi^{2}_{3E} = \rho^{2}_{E} + [cdt^{\phi}{}_{r} + (\overline{\lambda N})^{1}_{G}] - c[dt^{2}{}_{E\phi}] + T^{2}{}_{E} + [c(ISPB_E) + (\overline{\lambda N})^{1}_{E} - (\overline{\lambda N})^{1}_{G}] + ((\overline{\lambda N})^{2}_{E} - (\overline{\lambda N})^{1}_{E}) + \varepsilon_E$$

# Analysis and Results

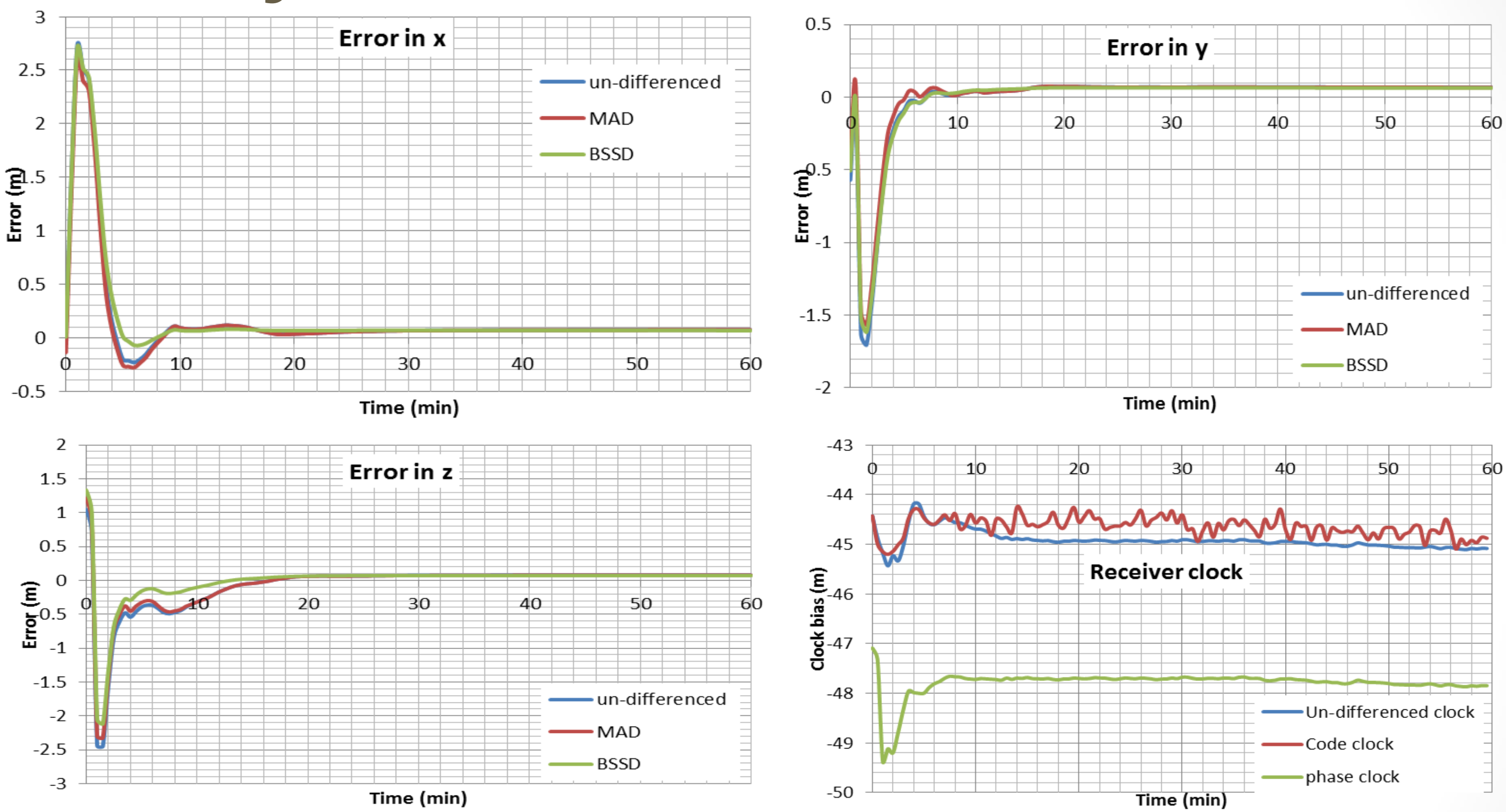
- To test the developed GNSS PPP techniques, namely the standard undifferenced, multiple ambiguity datum (MAD) and BSSD ionosphere-free techniques, GNSS data from four MGEX IGS stations are processed namely BRST, BRUX, FAA1 and GMSD at DOY 1, 2014.
- All GNSS constellation are processed namely GPS, GLONASS, Galileo and BeiDou.
- The IGS MGEX precise orbit and clock products are employed to account for orbital and clock errors.
- Tropospheric errors are accounted for using the UNB3 model
- All remaining errors, including carrier-phase windup, relativity, Sagnac, earth tides, and ocean loading are corrected for with sufficient accuracy using existing models.

# Analysis and Results



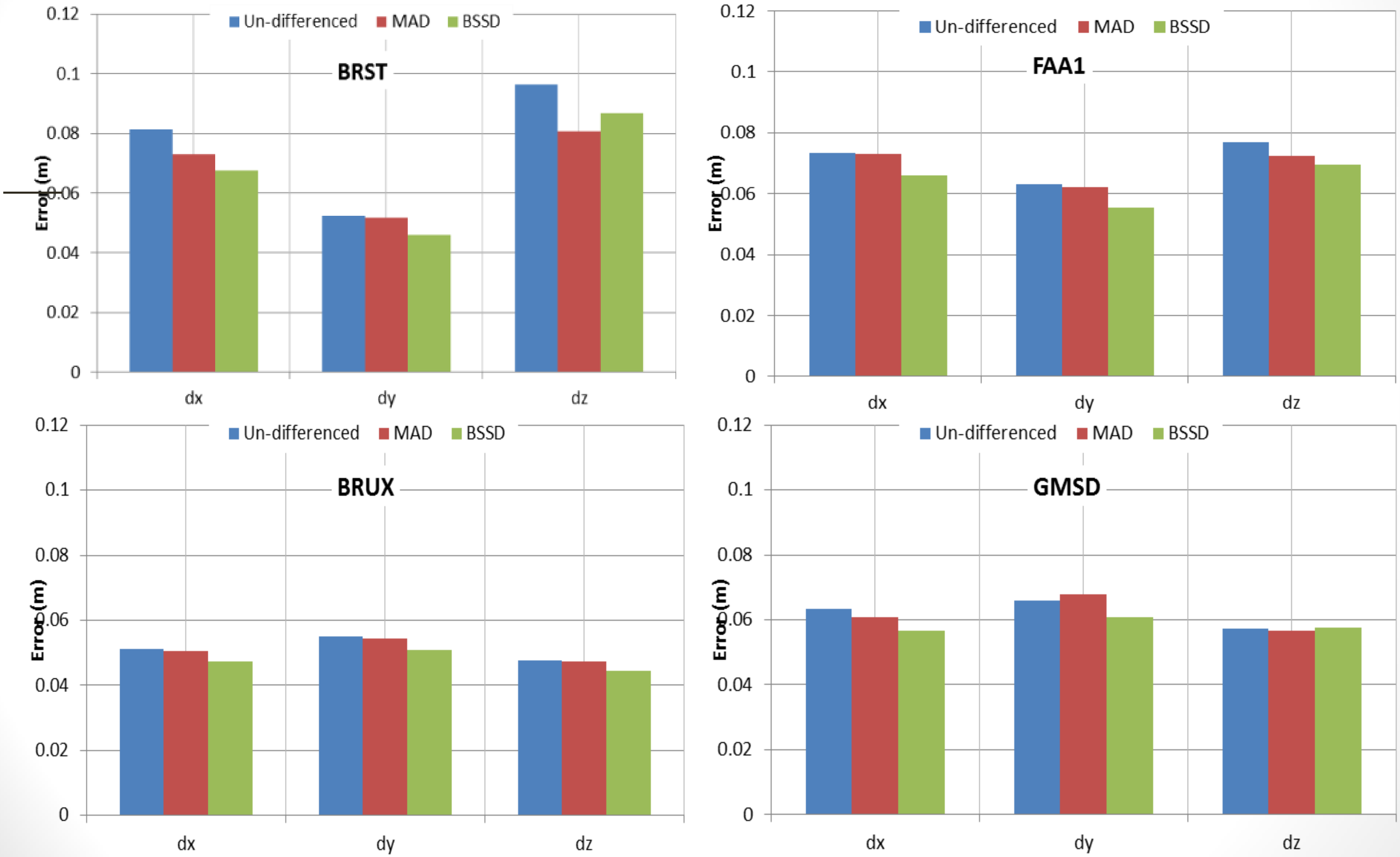

The positioning accuracy for the three GNSS PPP techniques for station BRST

# Analysis and Results




The positioning accuracy for the three GNSS PPP techniques for station BRUX

# Analysis and Results



# Conclusions

- In this paper, three GNSS PPP techniques, namely the undifferenced, between satellite single difference (BSSD) Multiple Ambiguity Datum (MAD) ionosphere-free PPP techniques were developed to process the multi-constellations GNSS observations.
- In multiple ambiguity datum technique, the phase and code clocks are theoretically separate by introducing phase clock parameter biased by the reference satellite ambiguity.
- The BSSD model cancel out the receiver related biases and errors from both GNSS code and phase measurements.
- The IGS MGEX clock and orbital products were used to correct for the satellite clock and orbital errors.
- GNSS data produced from a number of MGEX stations was used to investigate the accuracy and convergence time for the different PPP techniques.

# Conclusions

- The multiple ambiguity datum (MAD) GNSS PPP technique present comparable convergence time compared with the standard un-differenced technique due to

1. The lack of code and phase-based satellite clock products
2. The mathematical correlation between the positioning and clock-ambiguity parameters.

- However, the BSSD model is slightly improved the convergence time compared with other techniques.

- Moreover, The three GNSS PPP techniques show comparable positioning accuracy after one hour of GNSS observations processing.

# Current Research

- Producing a decoupled satellite clock product based on decoupling the phase and code observation to be tested compared with the current IGS products