Assessing the Impact of GLONASS Observables on GNSS Receiver Bias Estimates

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Objectives

- What is the impact of GLONASS observables on the ground-based GNSS receiver bias estimation?
- Are there discernible (e.g., geographical) trends in the GNSS receiver biases when estimating GLONASS biases?
- How do JPL-derived receiver GPS biases compare with other centers?

Introduction

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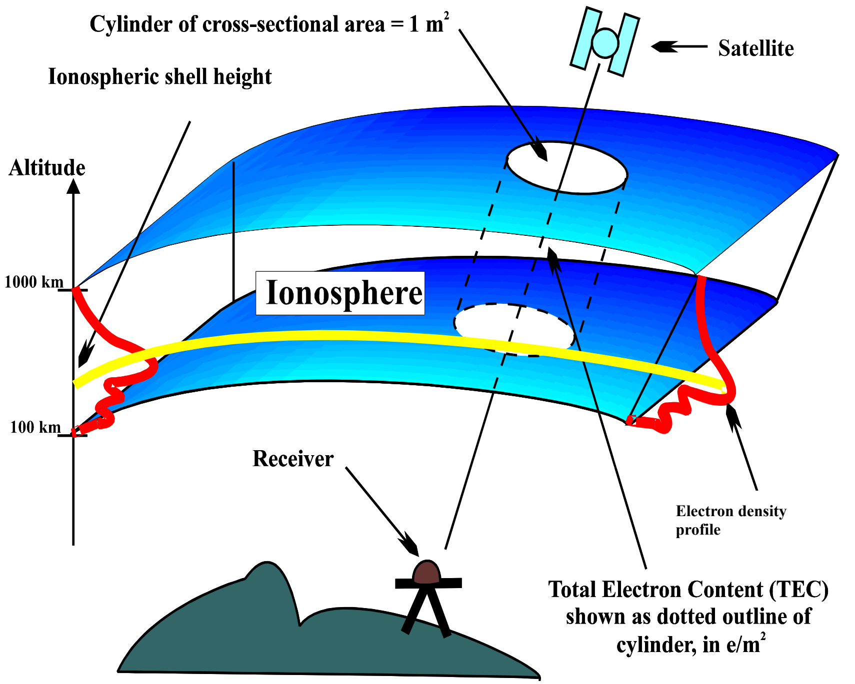
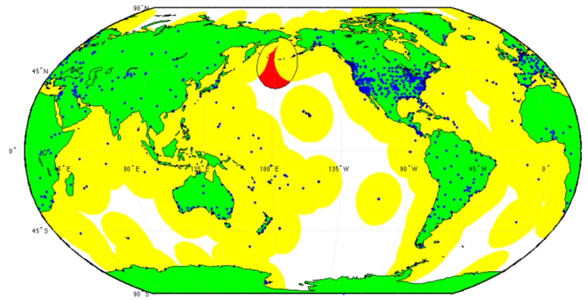
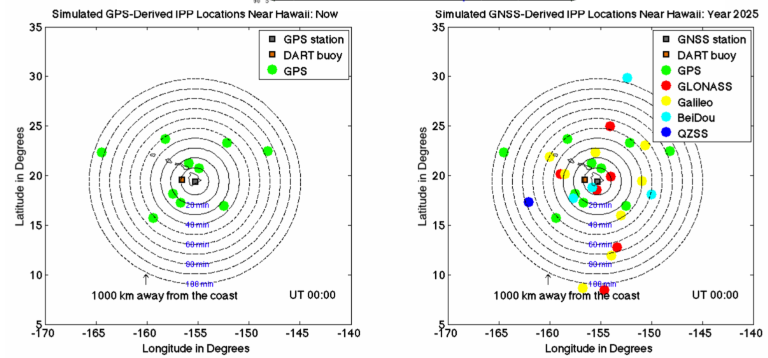


Schematic depicting the vertical variability of the ionospheric electron number density (red lines) and the integrated total electron content (TEC) (black line) between a GPS satellite and a ground – based receiver link.

Current ionospheric ground-based GNSS coverage

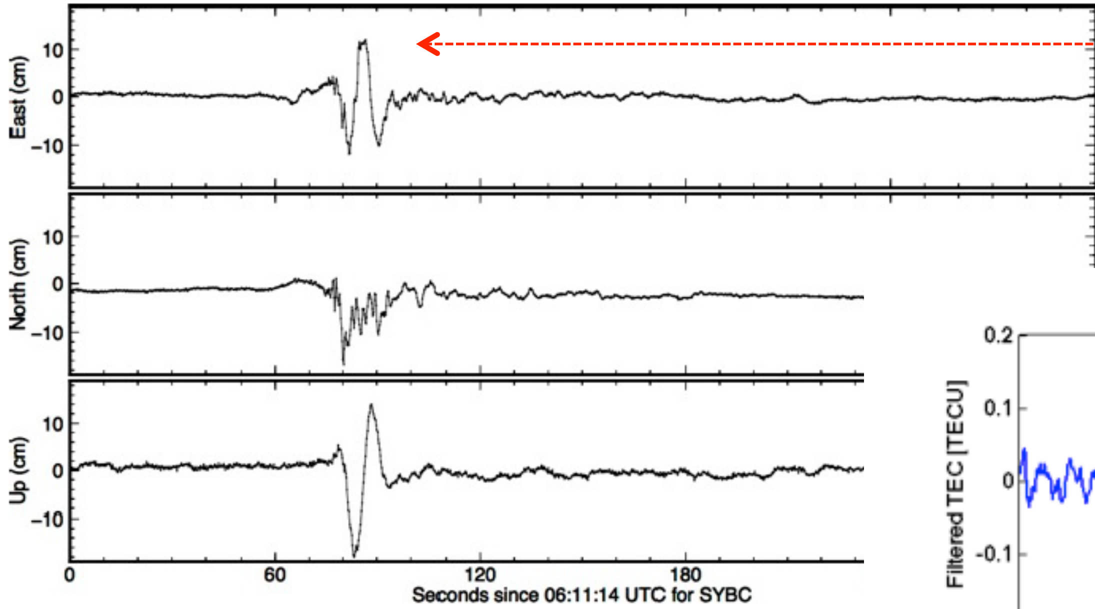




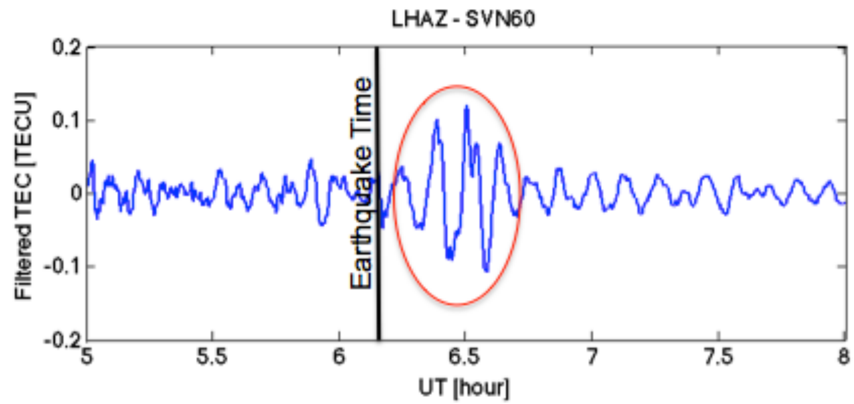
End product: Global Ionosphere Maps

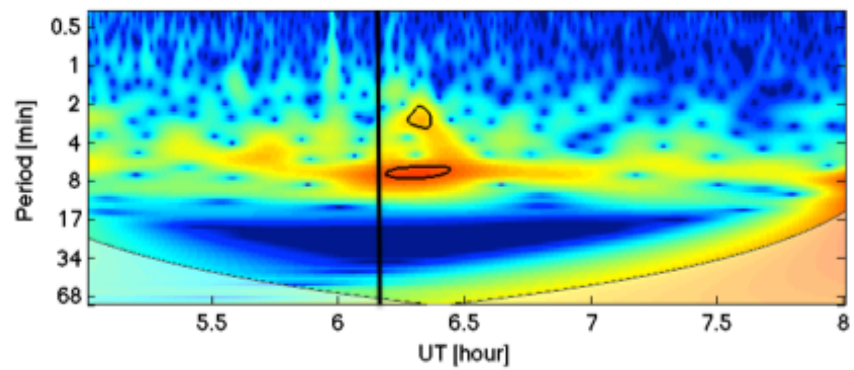
Since the advent of the GLONASS constellation, little attention has been given to the impact of GLONASS data on the quality of TEC maps and associated differential receiver biases

Nepal Mw 7.8 Earthquake Ionosphere Response on April 25, 2015



- 1-sec PPP solution at LHAZ
- Surface displacement at 10 cm level

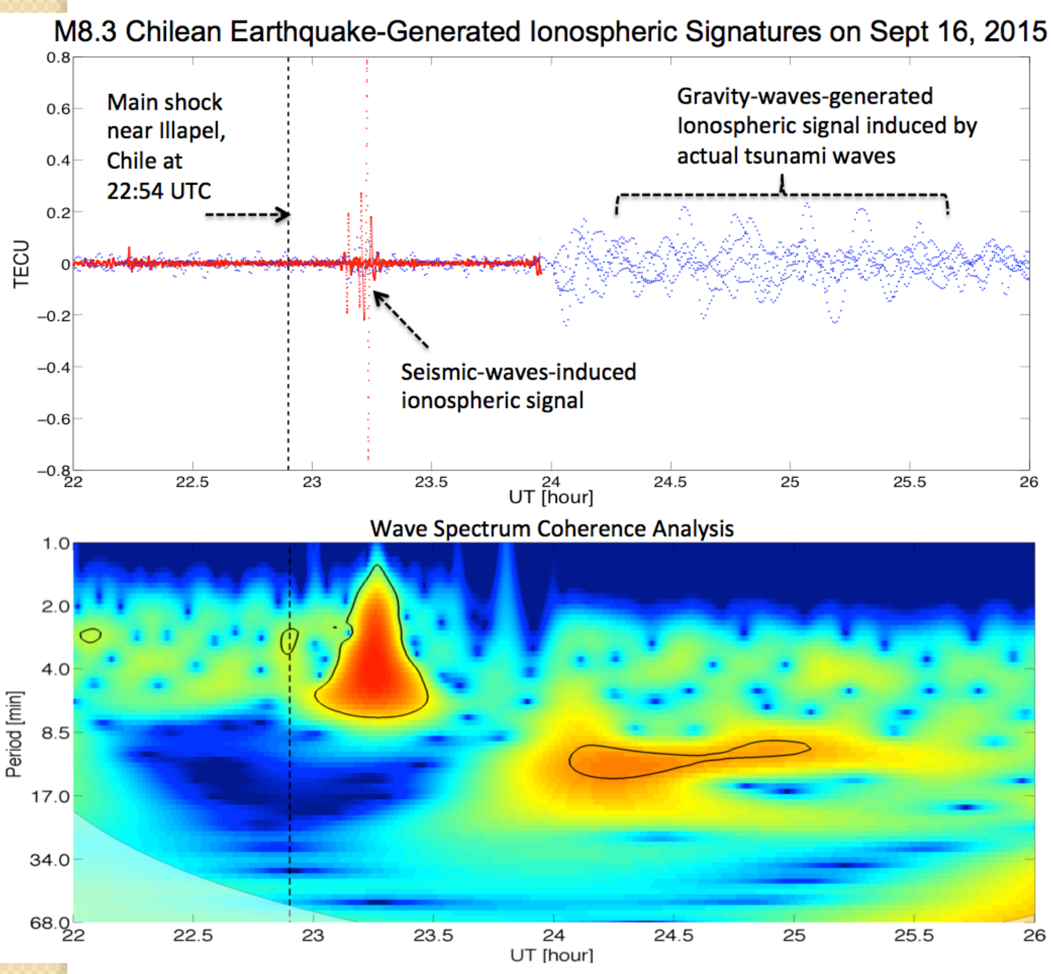


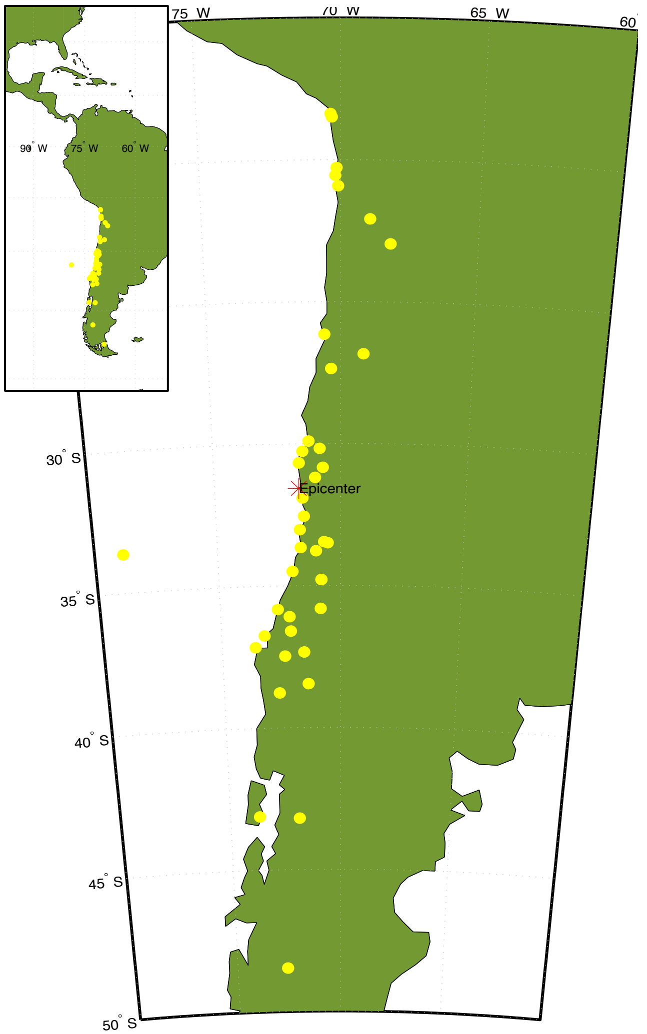


- GPS + GLONASS data processed, all satellites utilized and plotted
- 1-sec data analyzed – filtered for acoustic waves

Sept 16, 2015 Chilean Earthquake and Tsunami Detection Using GPS data

Post-Processed Results
(Non-Real-Time)

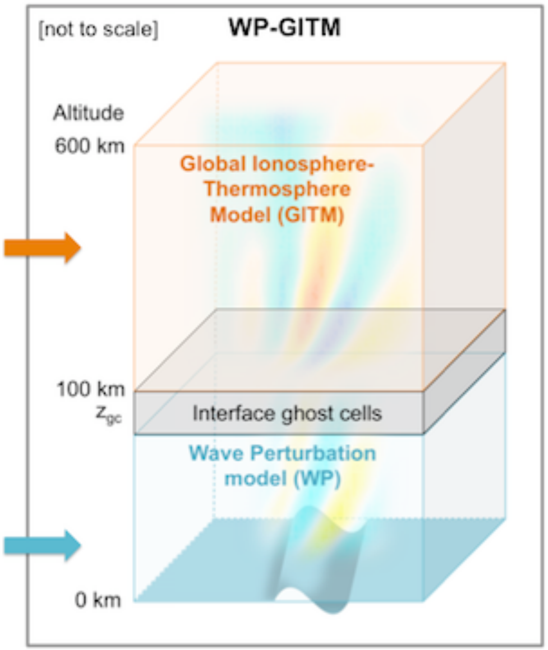




Wave-Propagation Global Ionosphere-Thermosphere Model (WP-GITM) Derived TEC Perturbations and Inversion

Input I
solar wind conditions, solar irradiance, auroral precipitation

Input II
Tsunami wave height, period, wavelength, and propagation direction



Key features of WP-GITM

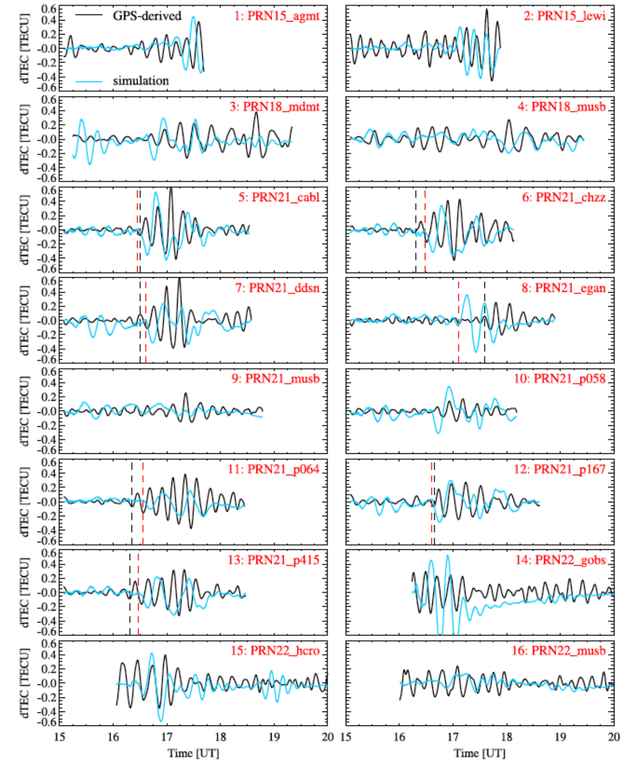
- analytical model WP (0 km – 100 km altitudes) + physics-based model GITM (100 km – 600 km altitudes)
- 10 neutral and 9 ion species
- includes a rich variety of physical processes in the upper atmosphere: chemical reactions, viscosity, heat conduction, radiative cooling, ion-neutral and neutral-neutral collisions, geomagnetic field and earth's rotation
- includes space weather effects: solar extreme ultraviolet heating, auroral particle precipitation, high-latitude electric field
- flexible computational domain and grid resolution

Output
Ionospheric-thermospheric state (densities, velocities, neutral temperature) between 100 km and 600 km altitudes

Validation
ground-based and space-based observations

Inversion Algorithm

Tsunami characteristics



Possible Tsunami Early Warning System

Ionosphere monitoring through ground-based and space-based observations → Inversion Algorithm based on WP-GITM → Tsunami characteristics → Tsunami heights and arrival times at coastal cities → Raise Alarms

Background

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Characteristics of the receiver differential biases:

1. Nearly constant over several days [e.g., *Wilson and Mannucci*, 1993]
2. Day–to–day variability: <1.0 TECU [e.g., *Montenbruck et al.,* 2014]
3. Bias accuracies typically < 1.5 TECU [e.g., *Sardón and Zarraoa,* 1997; *Ma et al.,* 2005; *Komjathy et al.,* 2005; *Dear and Mitchell,* 2006 and *Sarma et al.,* 2008]

All the abovementioned results used only GPS observations.

Now, let us include GLONASS observables!

To–date, only a handful of studies exist to quantify the GLONASS satellite–receiver biases [e.g., *Wanninger,* 2012; *Mylnikova et al.*, 2015]. Yet, questions about **the impact of GLONASS on the receiver bias accuracy, daily scatter, and variability still remain.**

Methodology

GNSS TEC Observation Equation:

$$TEC = M_1(h_1, E_1)\sum_i C_{1i}B_{1i}(\lambda_1, \phi_1) + M_2(h_2, E_2)\sum_i C_{2i}B_{2i}(\lambda_2, \phi_2) +$$

$$M_3(h_3, E_3)\sum_i C_{3i}B_{3i}(\lambda_3, \phi_3) + b_{s,GPS} + b_{r,GPS} + b_{r,GLONASS_f}(GLONASS_f),$$

Limiting factors affecting the TEC estimation

Basis functions
(functions of lat/lon)

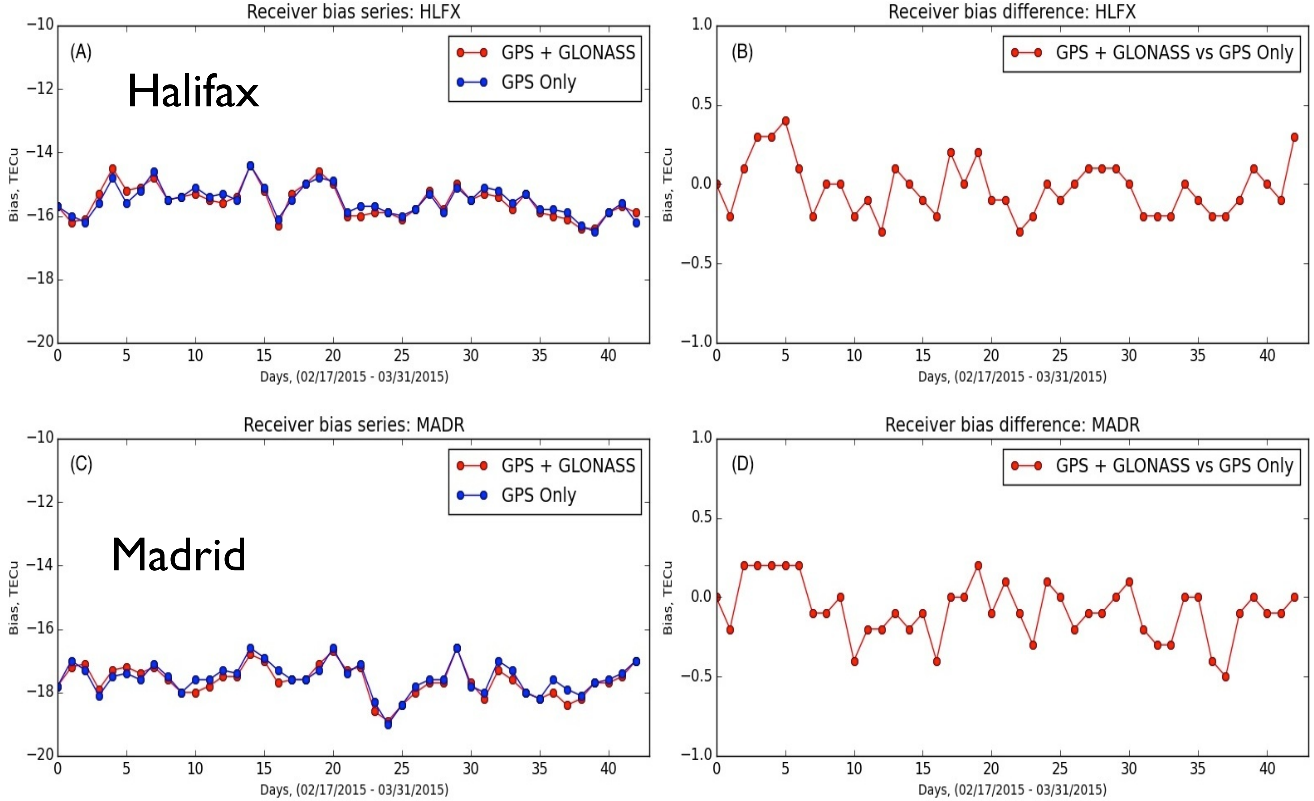
Ground-based receiver differential code biases
GPS and GLONASS satellite biases

Here, we focus on characterizing the behavior of the receiver biases, when including GLONASS observations

Results (1/7)

Characterize the GPS receiver biases using GLONASS observables (Vergados et al., 2015)

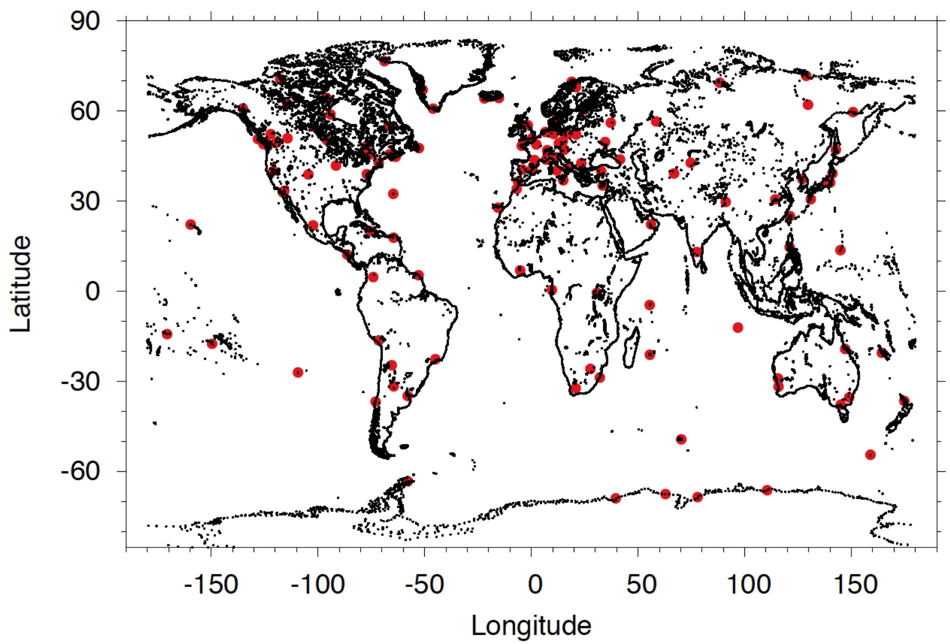
Experiment set-up: We use a month's worth of GPS receiver bias time series from a global network, which tracks both GPS and GLONASS signals. We investigate the impact of GLONASS observations on the GPS receiver biases, and analyze our results as function of latitude to identify trends in the receiver behavior (part of the "GPS Ionosphere Support for NASA's Earth



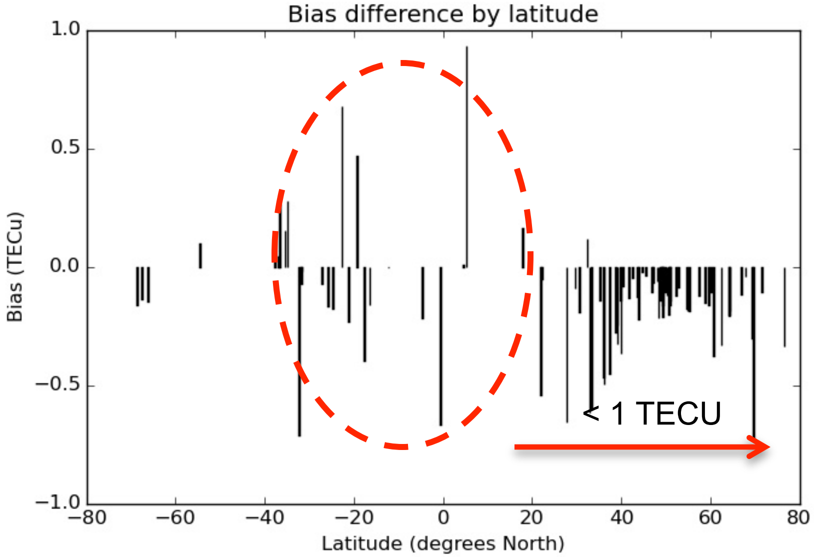
There is a clear day-to-day variability of the receiver biases, the scatter of which is <0.5 TECU (amplitude).

Ground–based receiver bias series for HLFX **(A)** and MADR **(C)** using JPL's GPS only (blue dotted line) and JPL's GPS+GLONASS (red dotted line) solutions. The red dotted line represents the difference in JPL retrievals with and without GLONASS observables for HLFX **(B)** and MADR **(D)**, respectively.

Investigating the GPS receiver bias stabilities with and without GLONASS observables



Ground–based receiver bias differences, between the JPL GPS+GLONASS and GPS–only solutions averaged over 02/17/2015–03/31/2015. A map for 84 GNSS dual-tracking globally–distributed stations is shown above.



Results: GPS receivers in the low latitude (±30°) and high-latitude pole-ward region exhibit higher differences than middle latitude stations, with magnitudes (systematically) shifted by < 1.0 TECU.

An ensemble of 84 GNSS receivers showed that GLONASS observations systematically shift the GPS receiver biases by up to 1.0 TECU.

Results (3/7)

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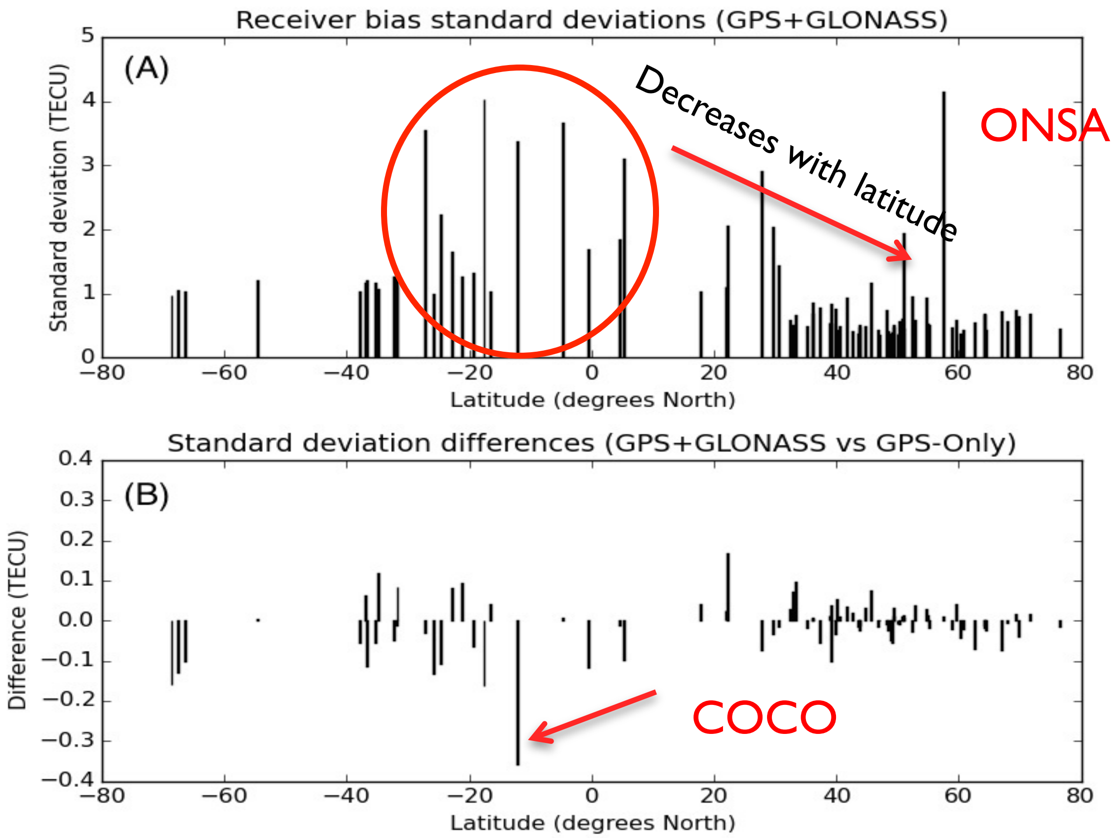
Investigating the GPS receiver bias stability



(A) *Standard deviation of JPL's GPS+GLONASS receiver biases as a function of latitude for all 84 stations.* ***(B)*** *Absolute difference of standard deviation with respect to the GPS–only solution.*

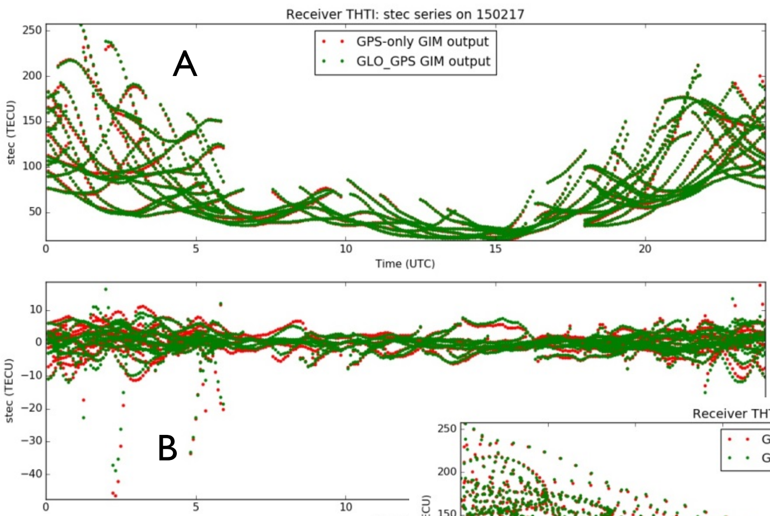
Results:

- The GPS receivers bias scatter is large for stations inside the low latitude region (±30°) and decreases with latitude.
- GLONASS observations affect the GPS bias scatter by a maximum of ± 0.15 TECU (no latitudinal dependency is observed).

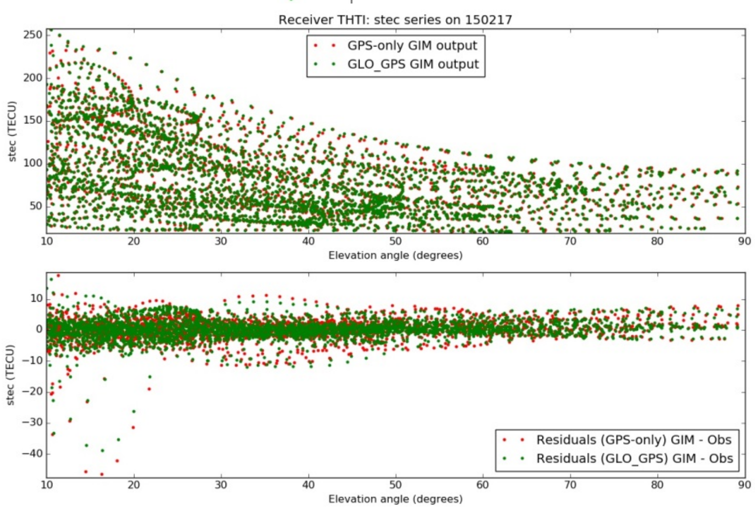
Results (4/7)

Investigating the impact of GLONASS observables on STEC measurements

Low latitude: THTI (17.6S, 149.6W)



(Top) Slant total electron content (STEC) time series at station THTI on February 17, 2015, estimated from GIM using GPS only observations (red) and GPS + GLONASS observations (green). **(B)** STEC residual differences GIM and observations for GPS (red) and GLO+GPS (green) observations.



Results:

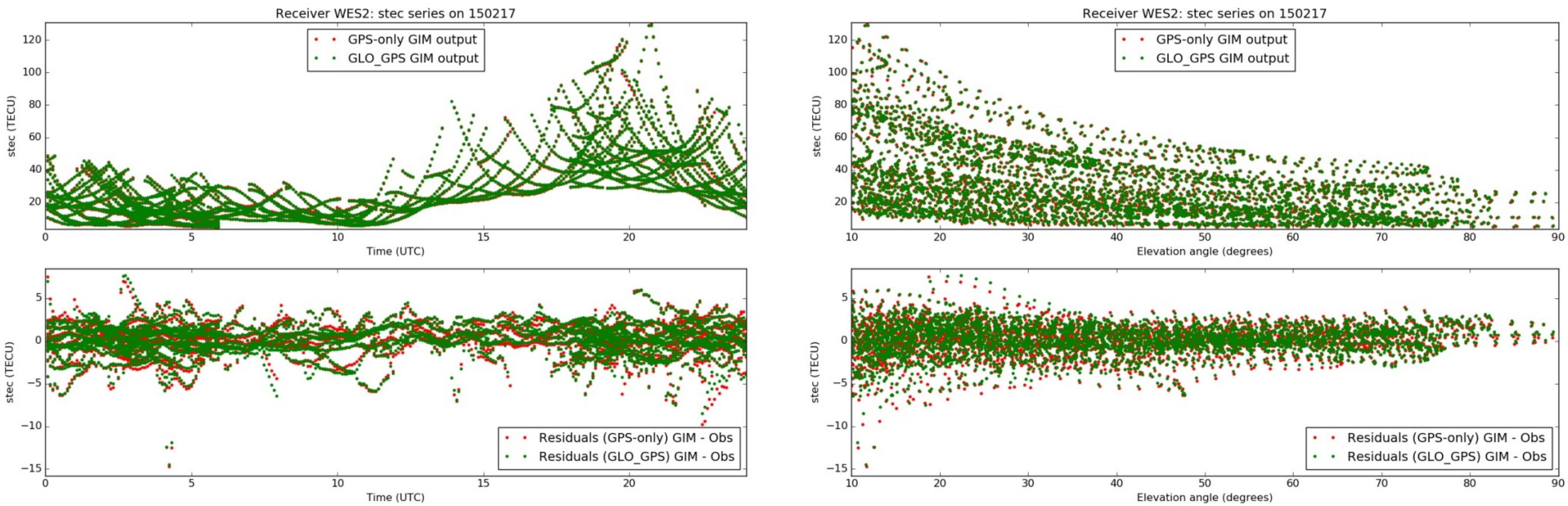
Mean residuals = 0.12 TECU (GPS)

Mean residuals = 0.10 TECU (GLO +GPS)

Results (5/7)

Investigating the impact of GLONASS observables on the STEC series

Middle latitude: WES2 (42.6N, 71.5W)



Results:

Mean residuals = 0.11 TECU (GPS)

Mean residuals = 0.09 TECU (GLO+GPS)

Results (6/7)

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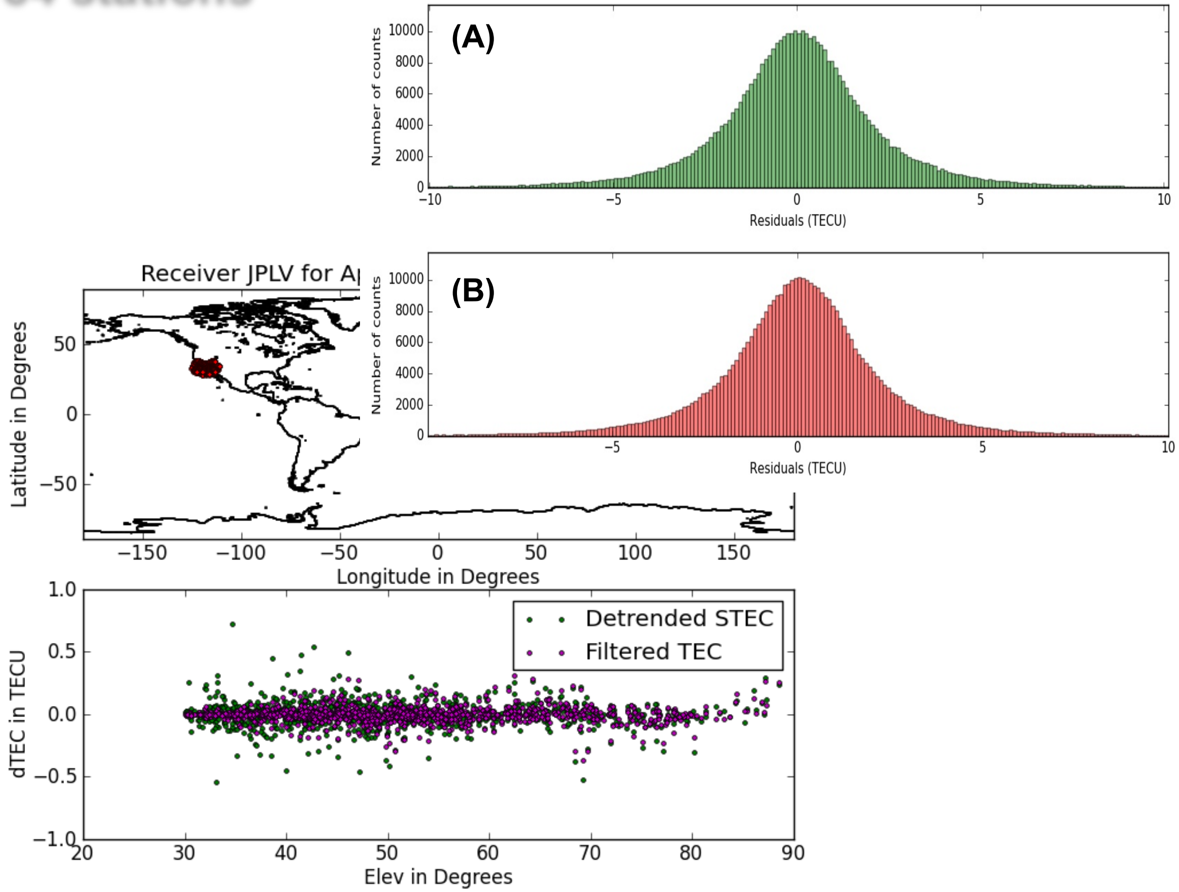
One day (February 17, 2015) statistical analysis of GIM versus residuals using all 84 stations



(A) Histogram of the residual distribution estimated by differencing the STEC GIM-derived and observations using GPS only signals; **(B)** same as (A) but using only GPS and GLONASS signals.

Results:

Mean values:

GPS only mean residual = -0.08 TECU

GPS+GLO mean residuals = -0.06 TECU

25% improvement using GLONASS

Standard deviation around the means:

GPS only std. = 3.93 TECU

GPS+GLO std. = 3.87 TECU

Difference std. = 0.06 TECU

2% improvement using GLONASS

Results (7/7)

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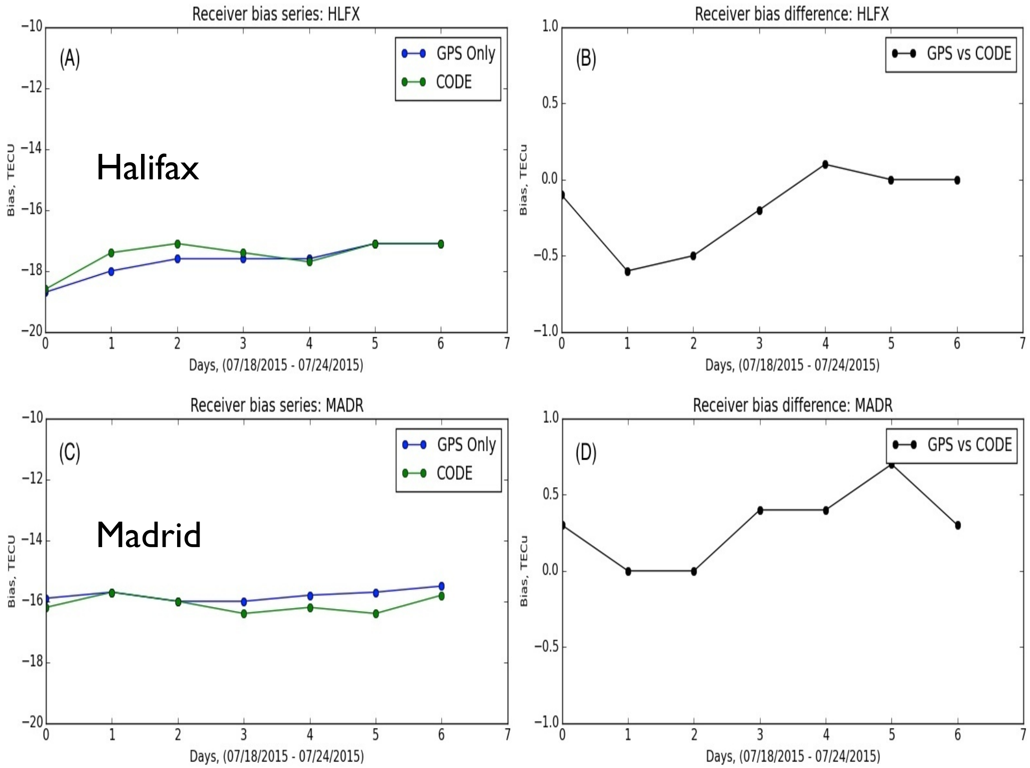
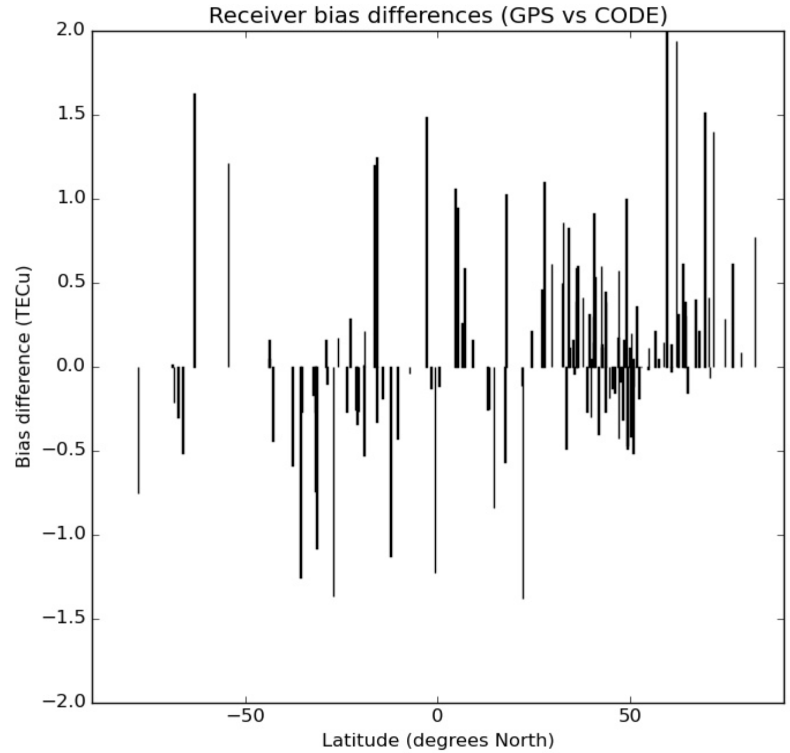
JPL versus CODE receiver bias characteristics' comparisons



Ground–based receiver bias series for HLFX **(A)** and MADR **(C)** using JPL's GPS only (blue dotted line) and CODE's GPS only (green dotted line) data. The differences between the JPL minus the CODE biases are shown in graphs **(B**; HLFX**)** and **(D**; MADR**)**.



<u>Monthly mean receiver bias differences</u> as a function of latitude (JPL minus CODE).

Conclusions: 81% of receivers show differences < 0.5 TECU

Conclusions

1) The GIM products indicate that GLONASS observations systematically shift the GPS receiver biases by up to 1.0 TECU.

2) GLONASS observations affect the scatter of the GPS receiver biases by < 0.3 TECU (except for a few cases) with no discernable latitudinal pattern.

3) The GPS receiver bias scatter is < 1.0 TECU (for the majority of the stations) except for some of the low-latitude stations.

4) Cross – center (CODE versus JPL) comparisons show a < 0.5 TECU differences in GPS receiver biases.

5) GLONASS observations do improve GIM bias repeatabilities, indicating an enhanced representation of the ionosphere compared to using GPS signals alone.

Acknowledgements

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- We would like to thank the Center for Orbit Determination in Europe (CODE) for making publicly available the satellite and receiver biases.

THANK YOU