National Aeronautics and Space Administration

# Evaluating the Impact of GLONASS-Derived TEC Measurements on JPL GIM and JPL/USC GAIM

**Mark D. Butala**, Attila Komjathy, Thomas F. Runge, Brian D. Wilson, Xiaoqing Pi, and Anthony J. Mannucci

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

## 1. Abstract

This work focuses on the opportunity offered by the ever-increasing number of GLONASS-capable dual-frequency receivers in the IGS and other GNSS receiver networks that effectively multiplies the available measurements for ionospheric data assimilation. We present results of our GLONASS-capable data assimilation system from end-to-end: starting with data editing and quality control, followed by our approach to GLONASS inter-frequency bias estimation, and the final assimilation that includes other data sources such as GPS-derived TEC measurements. In this research, we address multiple factors that are influenced by assimilating GLONASS measurements into JPL/USC GAIM. We present comparisons of GIM and GAIM processing results using GPS-only and GPS+GLONASS measurements. We also present comparisons to independent measurements of ionospheric electron content such as from the dual-frequency altimeter Jason-2.

We found that the inclusion of GLONASS data improved repeatability of receiver biases in all cases. GLONASS helped improved TEC accuracies. We recommend the inclusion of GLO data in all our IGS ionospheric products.

## 2. Outline

- Ionospheric estimates using combined GPS + GLONASS networks have been derived
- Bias scatter for GPS and GPS+GLONASS ionospheric estimate is assessed
- GPS and GLONASS ionospheric data quality is compared
- The impact of GLONASS on Global Ionospheric Maps and GAIM is assessed using various techniques
- GLONASS results are validated using Jason VTEC data. Station and deprivation results are presented for further proof of accuracy improvements.

## 3. Background

GPS ionospheric observation equation in GIM:

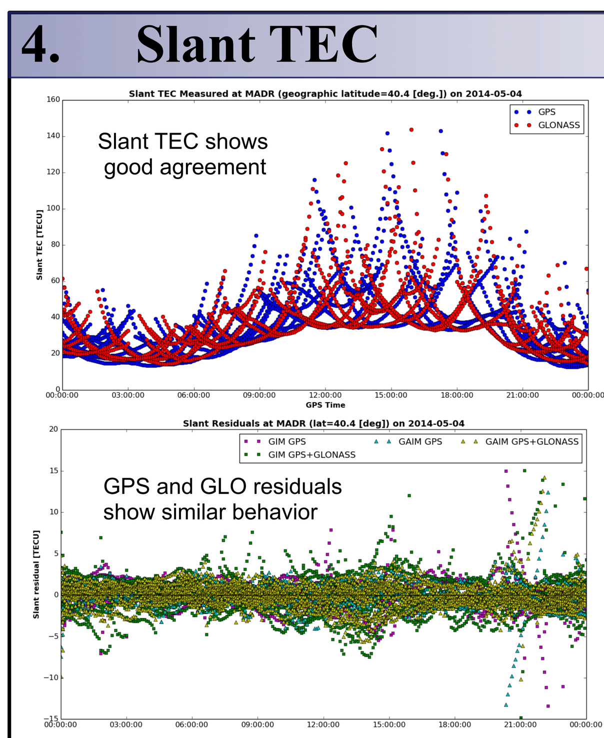
$$TEC_{GPS} = M(h,E)\sum_i C_i B_i(lat,lon) + b_{r,GPS} + b_{s,GPS}$$

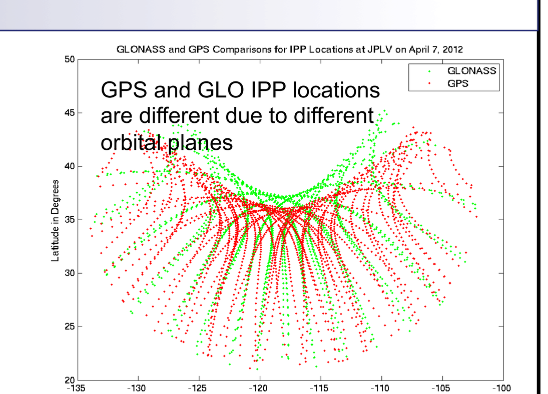
GLONASS ionospheric observation equation in GIM:

$$TEC_{GLO} = M(h,E)\sum_i C_i B_i(lat,lon) + b_{r,GLO}(GLO_s)$$

| | |
|---|---|
| $TEC$ | is the slant TEC for GPS and GLONASS links |
| $M(h_1,E)$ | is the thin shell mapping function for shell 1, etc |
| $B_i(lat,lon)$ | is the horizontal basis function ($C^2$, TRIN, etc) |
| $C_{ij}$ | are the basis function coefficients solved for in the filter, indexed by horizontal (i) and vertical (1,2,3 for three shells) indices |
| $b_r, b_s$ | are the satellite and receiver instrumental biases. GPS satellite biases are estimated once a day. GLO receiver biases are GLO dependent |

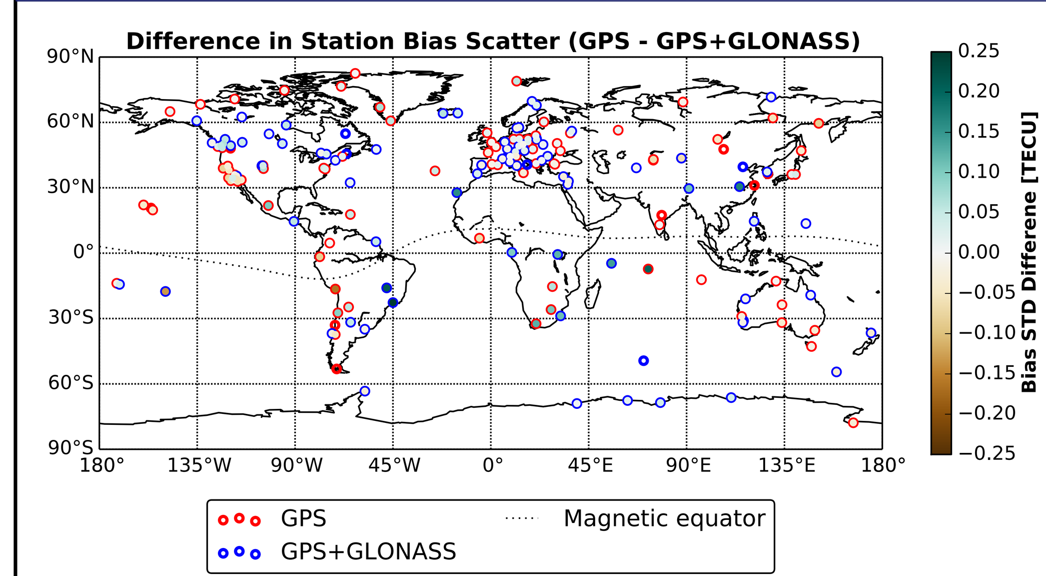
## 4. Slant TEC



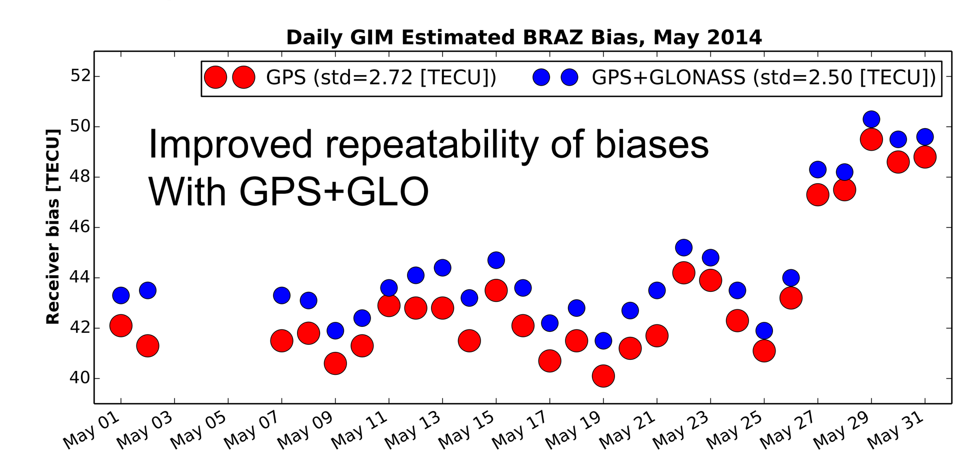




- GPS and GLO TEC show excellent overlap at individual locations
- Ionospheric residuals for GPS and GLO are very similar

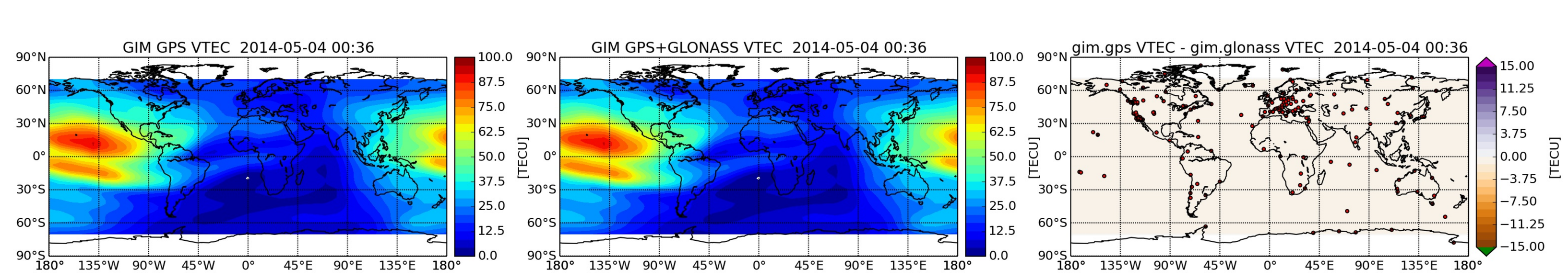
## 5. GLONASS Bias Estimation Results



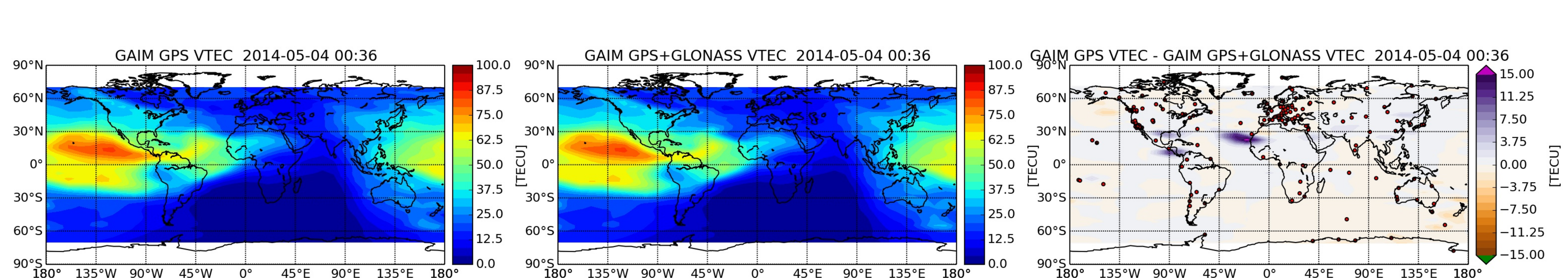

- 30 days of global dataset processed using GPS-only and GPS +GLO tracking stations
- Receiver bias scatter differences above show that GPS+GLO tracking stations exhibit improved repeatability over GPS-only stations
- Bias scatter at BRAZ (Brasilia, Brazil) below displays improvements over using GPS-alone




## 6. Global TEC Maps

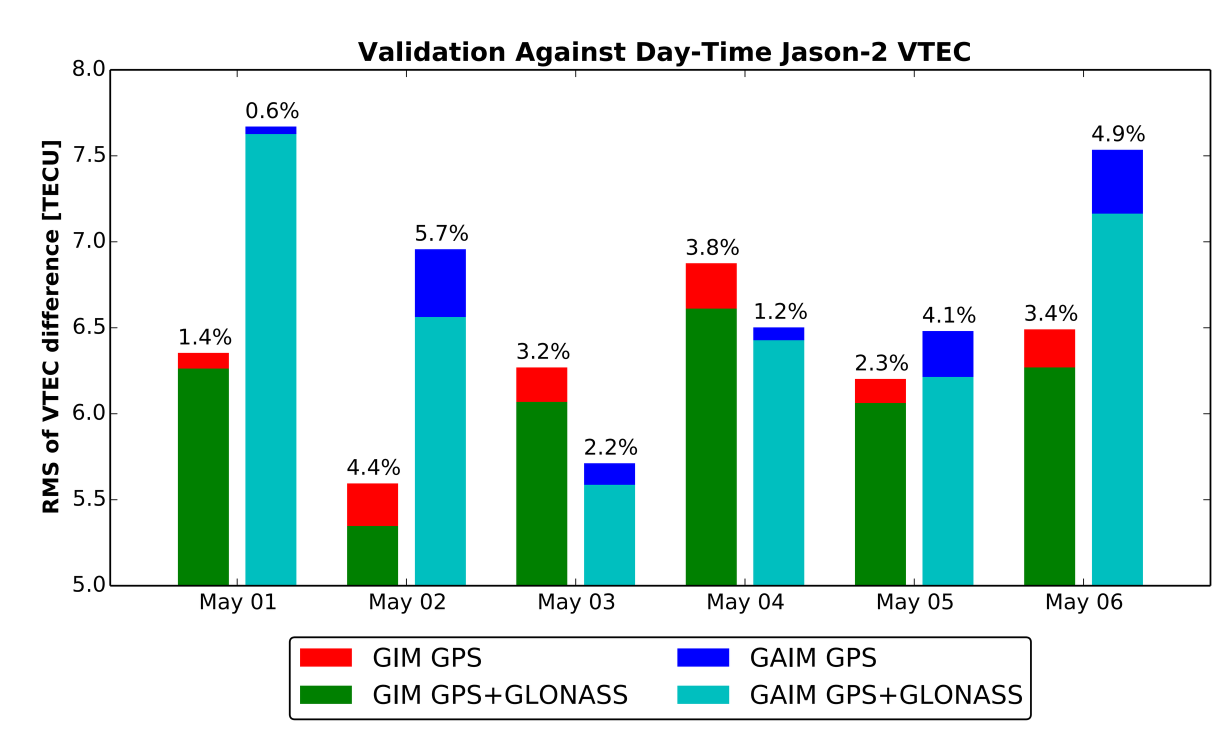



- GIM (GPS) – GIM (GPS+GLO) differences are small on a "global" scale




- GAIM (GPS) – GAIM (GPS+GLO) differences are larger, possibly due to differences in data editing

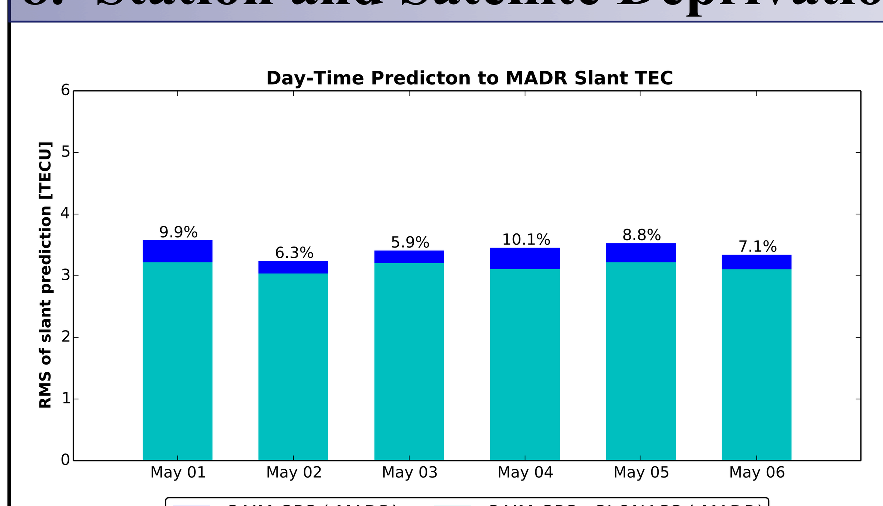
## 7. JASON Validation – Impact of GLONASS on GIM and GAIM

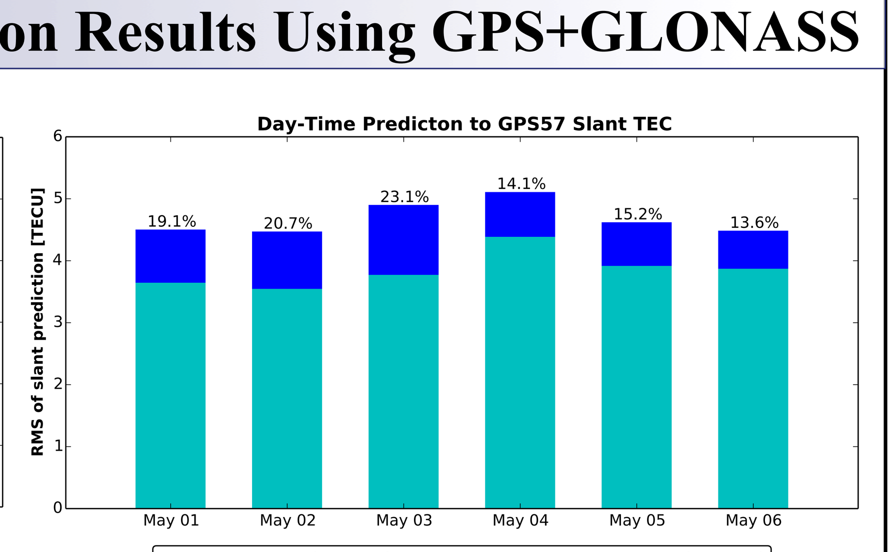



- The question remains: is there an accuracy improvement associated with the inclusion of GLONASS data?
- We used Jason-2 VTEC data for 6 days to validate GIM and GAIM using GPS-only and GPS +GLO datasets

- Including GLO data in the GIM solution improved accuracies for all 6 days investigated. The improvement ranged between 1.4 and 4.4%
- GAIM accuracies improved in all cases ranging between 0.6 and 5.7% by using GLO data

## 8. Station and Satellite Deprivation Results Using GPS+GLONASS




- For additional validation we performed station (MADR) and satellite (GPS57) deprivations and predicted slant TEC for station and satellite not included in the solutions
- GAIM achieved improved accuracies by including GLO data when predicting slant TEC at MADR (left panel)
- GPS57 TEC predictions also improved in all cases using GLO data (right panel)

## 9. Summary and Conclusions

- We now routinely process GLO data in addition to GPS in our daily ionospheric products for Deep Space Tracking calibration using GIM
- We achieved improvements in repeatability of station biases using GLO+GPS for all days we investigated
- Jason-2 VTEC validation results indicate improvement in accuracies using GPS+GLO over GPS-only GIM data processing
- Station and satellite deprivation investigations show consistent improvement of TEC predictions using GPS+GLO datasets over GPS-only processing
- The routine inclusion of GLONASS data is recommended for IGS TEC products

## 8. References

- Komjathy, A., L. Sparks, B. Wilson, and A.J. Mannucci (2005). "Automated Daily Processing of more than 1000 Ground-Based GPS Receivers to Study Intense Ionospheric Storms." *Radio Science*. (40). RS6006 doi: 10.1029/2005RS003279.
- Komjathy, A., B. Wilson, X. Pi, V. Akopian, M. Dumett, B. Iijima, O. Verkhoglyadova, and A. J. Mannucci (2010). "JPL/USC GAIM: On the Impact of Using COSMIC And Ground-Based GPS Measurements To Estimate Ionospheric Parameters." *Journal of Geophysical Research*. doi:10.1029/2009JA014420.

## Acknowledgments

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. Funding from Eric Lindstrom of NASA HQ is gratefully acknowledged.

**National Aeronautics and Space Administration**

**Jet Propulsion Laboratory**
California Institute of Technology
Pasadena, California

www.nasa.gov