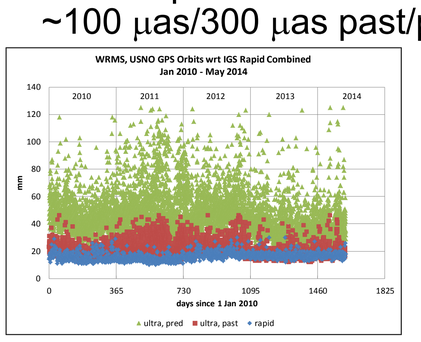
USNO Analysis Center Progress 2012-4

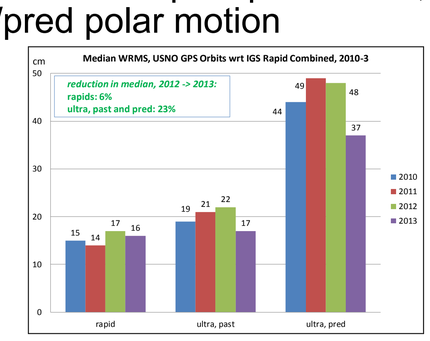
C. Hackman[1], S.M. Byram[1], V.J. Slabinski[1], J.C. Tracey[1] and J.R. Rohde[2]

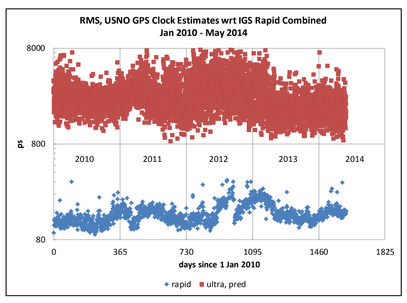
[1]U.S. Naval Observatory, Washington DC; [2]Black Dog GPS, West Palm Beach FL

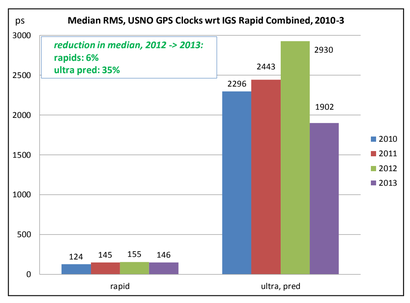
Improvements in USNO RAPID, ULTRA-RAPID (GPS) PRODUCTS

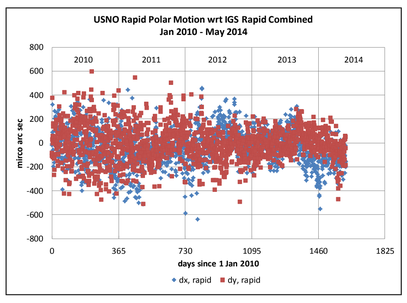
- Products = orbits, clocks, polar motion (PM)
- Improvement = reduction in RMS wrt IGS Rapids
- 13-57% improvement in USNO ultra-rapids
- 6-25% improvement in USNO rapids
- Causes:
  - Improved tie to IGS reference frame
  - Lengthened measurement window used for ultra-rapid predictions to 40 h (was 27)
- Current precision: ~17mm/37 mm past/pred orbits; ~100 μas/300 μas past/pred polar motion

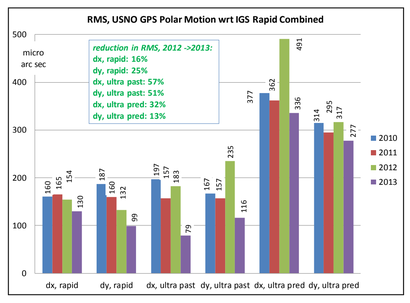


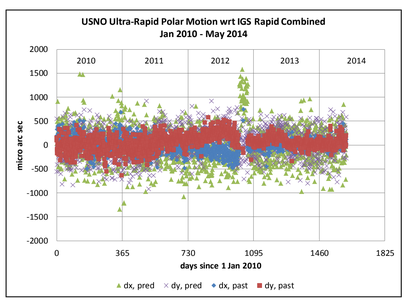












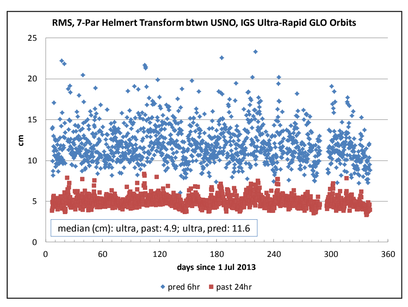
Top row: *weighted RMS of USNO GPS orbit estimates with respect to IGS Rapid Combination."Ultra, past" refers to 24-hour post-processed section of USNO ultra-rapid orbits. "Ultra, pred" refers to first six hours of ultra-rapid orbit prediction.*

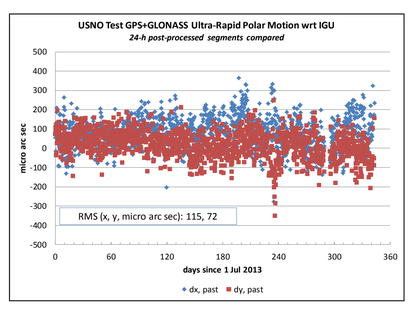
Second row*: RMS of USNO GPS rapid clock estimates and ultra-rapid clock predictions with respect to IGS Rapid Combination*

Rows 3-4*: USNO polar motion estimates minus IGS Rapid Combination values.*

COMBINED GPS/GLONASS

- Have generated GPS+GLO ultras, rapids since 2012
- Ultras under consideration for inclusion in IGV combination
- In-house precision estimates:
  - GLO orbits: 49 mm post-processed; 119 mm predict
  - PM: ~100 μas
- More details: Byram & Hackman, "Multi-GNSS Based Processing at the USNO," PS11





Left*: RMS of USNO ultra-rapid GLONASS orbit estimates wrt IGS Combined* Ultra-rapid *GLONASS orbits. "Ultra, past" refers to 24-hr post-processed section of USNO ultra-rapid orbits. "Ultra, pred" refers to first six hours of ultra-rapid prediction. Helmert transformations computed using Bernese 5.0 Software.* ***Right****: Difference between 24-h post-processed polar motion estimates in USNO test ultra-rapid GPS+GLONASS solution and IGS "IGU" GPS-only ultra-rapid solution.*

PURPOSE

- **USNO has improved its product accuracy – in some parameters, nearly 50% – and initiated new projects since the 2012 IGS Workshop.**
- **It also directs IGS troposphere activities.**

This poster summarizes these developments

AC HISTORY AND ACTIVITIES

- AC since 1997
- Contribute GPS-based rapid, ultra-rapid solutions to IGS Combined Rapid, Ultra-Rapid Products
  - Rapids: orbits, clocks, EOPs for 00-2359 GPST yesterday; released by 1550 UTC today
  - Ultra-rapids: post-processed & predicted orbits, clocks, EOPS. Every six hours; 3 hrs latent
- Produce IGS Final Troposphere Estimates
- Chair IGS Troposphere WG
- Since 2012: produce test GPS+GLONASS rapids, ultra-rapids
- Above estimates generated using *Bernese GPS Software*
- Produce UTGPS, a GPS-based extrapolator of VLBI UT1-UTC estimates, 5 times/day for IERS, which uses it to improve UT1-UTC predictions
- Total: 16 product sets per day; 98-100% on-time rate

2012-4 Analysis Center Publications

Byram, S and C Hackman, High-Precision GNSS Orbit, Clock and EOP Estimation at the United States Naval Observatory, *Proc. 2012 IEEE/ION PLANS*, 659-63, 2012.

Byram, S and C Hackman, IGS Final Troposphere Product Update, Poster Session PS05, 2014 IGS Workshop, Pasadena, CA, 2014.

Byram, S and C Hackman, Multi-GNSS Based Processing at the USNO, Poster Session PS11, 2014 IGS Workshop, Pasadena, CA, 2014.

Dousa, J, S Byram, G Győri, O Böhm, F Zus and C Hackman, Development Towards Inter-Technique Tropospheric Parameter Comparisons and Their Exploitation, Plenary Session PY09, 2014 IGS Workshop, Pasadena, CA, 2014.

Hackman, C, GPS Code/Carrier-Phase Time/Frequency Transfer, *IEEE International Frequency Control Symposium Tutorials*, 149 pp, 2012.

Hackman, C, Mitigating the Impact of Predicted Satellite Clock Errors on GNSS PPP Positioning, *Proc. ION 2014 International Technical Meeting*, 743-50, 2014.

Hackman, C, Impact of Orbit, Clock and EOP Errors in GNSS Precise Point Positioning, *2012 AGU Fall Meeting*, oral presentation G13C-01, 2012.

Hackman, C, Accuracy/Precision of USNO Predicted Clock Estimates for GPS Satellites, *Proc. 44th Ann. PTTI Meeting*, 43-52, 2012.

Hackman, C and S Byram, IGS Troposphere Working Group 2012, *IGS Technical Report 2012*, 195-202, 2013.

Hackman, C and S Byram, IGS Troposphere Working Group 2013, *IGS Technical Report 2013*, in press, 2014.

Hackman, C and D Matsakis, Precision and Accuracy of USNO GPS Carrier-Phase Time Transfer: 2012 Update, *Proc. IEEE IFCS*, 94-99, 2012.

Hackman, C and J Tracey, Monitoring Signal Strength of China's COMPASS/Beidou Satellite Transmissions, Office of Naval Research Science and Technology Partnership Conference, Crystal City, VA, 2012.

Hackman, C, S M Byram, V J Slabinski and J C Tracey, USNO GPS/GLONASS PNT Products: Overview, and GPS+GLONASS vs GLONASS Only PPP Accuracy, *Proc. 2014 IEEE/ION PLANS*, in press, 2014.

Hackman, C, S M Byram, V J Slabinski and J C Tracey, Near-Real-Time and Other High-Precision GNSS-Based Orbit/Clock/Earth-Orientation/Troposphere Parameters Available from USNO, *Proc. 2012 ION Joint Navigation Conference*, 1274-88, 2012.

Hackman, C, S Byram, V Slabinski and J Tracey, United States Naval Observatory Analysis Center Report 2012, *IGS Technical Report 2012*, 86-91, 2013.

Hackman, C, S Byram, V Slabinski and J Tracey, United States Naval Observatory Analysis Center Report 2013, *IGS Technical Report 2013*, in press, 2014.

Hackman, C, S M Byram, V J Slabinski, J C Tracey and J R Rohde, USNO Analysis Center Progress 2012-14, PS01, 2014 IGS Workshop, Pasadena, CA, 2014.

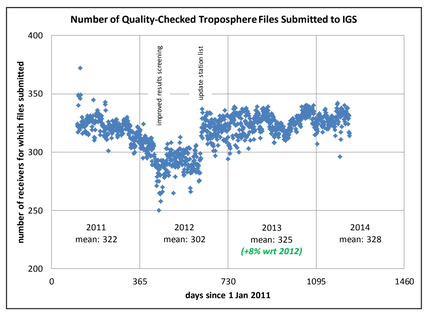
Hugentobler, U and C Hackman, International GNSS Service (IGS) – Products and Models for Precise GNSS Analyses, COST Action ES1206 Meeting, Munich, Germany, 36 pp, 2014.

Slabinski, V, When Did the Mean Solar Day Equal 86,400 SI Seconds?, 45th Meeting, American Astronomical Society Division of Dynamical Astronomy, Philadelphia, PA, 2014.

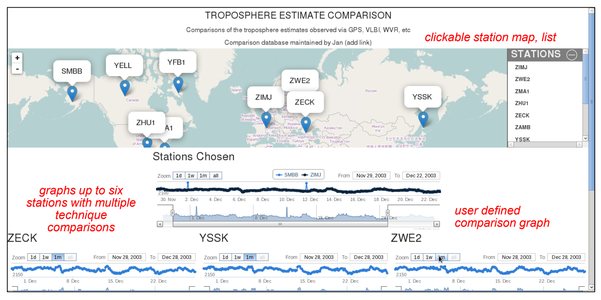
USNO IGS Troposphere Coordination

Produce IGS Final Troposphere Estimates
- ZTD, gradient estimates for every IGS station
- 24-h files (one per station), 5-min estimate spacing
- 10.3M files downloaded in 2013
- 8% increase in # stations processed/day, 2012->2013
- Improved data screening
- More info @ Byram & Hackman, "IGS Final Troposphere Product Update," PS05

Chair IGS Troposphere WG
- ~50 members
- WG splinter meeting Wed PM: all welcome
- Have almost completed 2012-4 main project: building cross-technique (GNSS, VLBI, radiosonde, etc.) tropo-comparison website/database
- More info @ Dousa et al., "Development Towards Inter-Technique Tropospheric Parameter Comparisons…", PY09, Thu AM
- Special thanks: J Dousa, GOP



Number of stations for which IGS Final Troposphere Estimates were produced by USNO

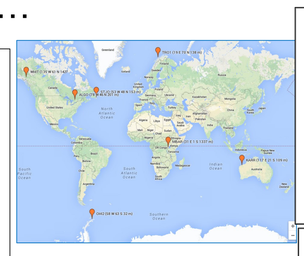


Web interface draft layout

AC GNSS Experiments

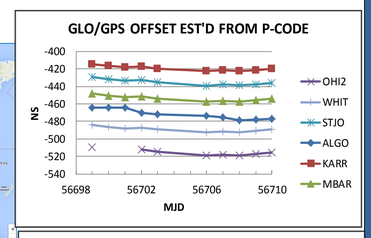
- Always testing new ideas in GNSS-based PNT
- E.g., recently tested GPS+GLO PPP
- Encountered pseudorange-based receiver-dependent bias between GPS-, GLO-based receiver-clock estimates
- Resolving…

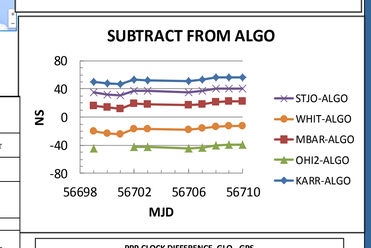
Experiment
- Obtained GPS+GLO measurements from seven receivers 10-21 Feb 2014
- Did PPP using GPS, GPS+GLO and GLO using EMR GLO/GPS orbit products
- 24-hr batches; static positioning
- Receiver-clock estimates every 300 s

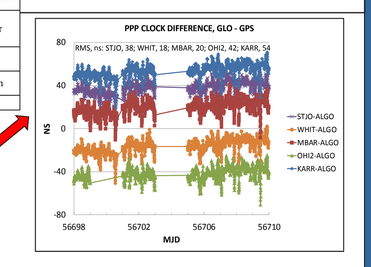


Site locations (above), receiver information (below)

name	east longitude, deg	north latitude, deg	ellipsoidal height, m	receiver type	antenna type	radome type	clock
ALGO	-78	46	201	TPS NET-G3A	AOAD/M_T	none	H-maser
KARR	117	-21	109	TRIMBLE NETR9	TRM59800.00	none	internal
MBAR	31	-1	1337	JAVAD TRE_G3TH DELTA	ASH701945B_M	SCIS	internal
OHI2	-58	-63	32	JPS E_GCD	TPSCR.G3	TPSH	internal
STJO	-53	48	153	JAVAD TRE_G3T DELTA	AOAD/M_T	none	H-maser
TRO1	19	70	138	TRIMBLE NETR8	TRM59800.00	SCIS	internal
WHIT	-135	61	1427	TPS NET-G3A	AOAD/M_T	none	rubidium







GPS-GLONASS System Time differences estimated from pseudorange measurements; relation to PPP time-estimate errors. ***Top****: GPS-GLONASS system time offsets estimated from pseudorange measurements.* ***Middle****: ALGO values subtracted from others.* ***Bottom****: Difference between GLONASS and GPS PPP-derived receiver clock estimates. Note resemblance to middle plot.*

For more information: Christine Hackman, US Naval Observatory, 3450 Massachusetts Ave NW, Washington, DC 20392, USA. Tel: (202) 762-1428. e: christine.hackman@usno.navy.mil. **Products online:** http:/www.usno.navy.mil/USNO/earth-orientation/gps-products