



***USNO Report
to the
CGSIC Timing Subcommittee***

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US Naval Observatory (USNO)
September 14, 2015***



DoD Directive 4650.05 (2008) and 4650.07 (2012)



- ***The Secretary of the Navy shall direct the U.S. Naval Observatory to:***
 - ***Develop and maintain the standards for Precise Time and Time Interval (PTTI) services, earth orientation parameters, and the celestial reference frame for the DoD Components***
 - ***Provide representation to PNT committees and working groups, as necessary***
 - ***Serve as the DoD PTTI Manager for all DoD systems***

***Maintain the Master Clock for the
DoD Community***

- **Master Clock
Washington, DC**
 - 68 High Performance Cesiums
 - 29 Cavity-Tuned Masers
 - 4 Rubidium Fountains



- **Alternate Master Clock
Shriever AFB**
 - 12 High Performance Cesiums
 - 4 Cavity-Tuned Masers
 - 2 Rubidium Fountains in test mode

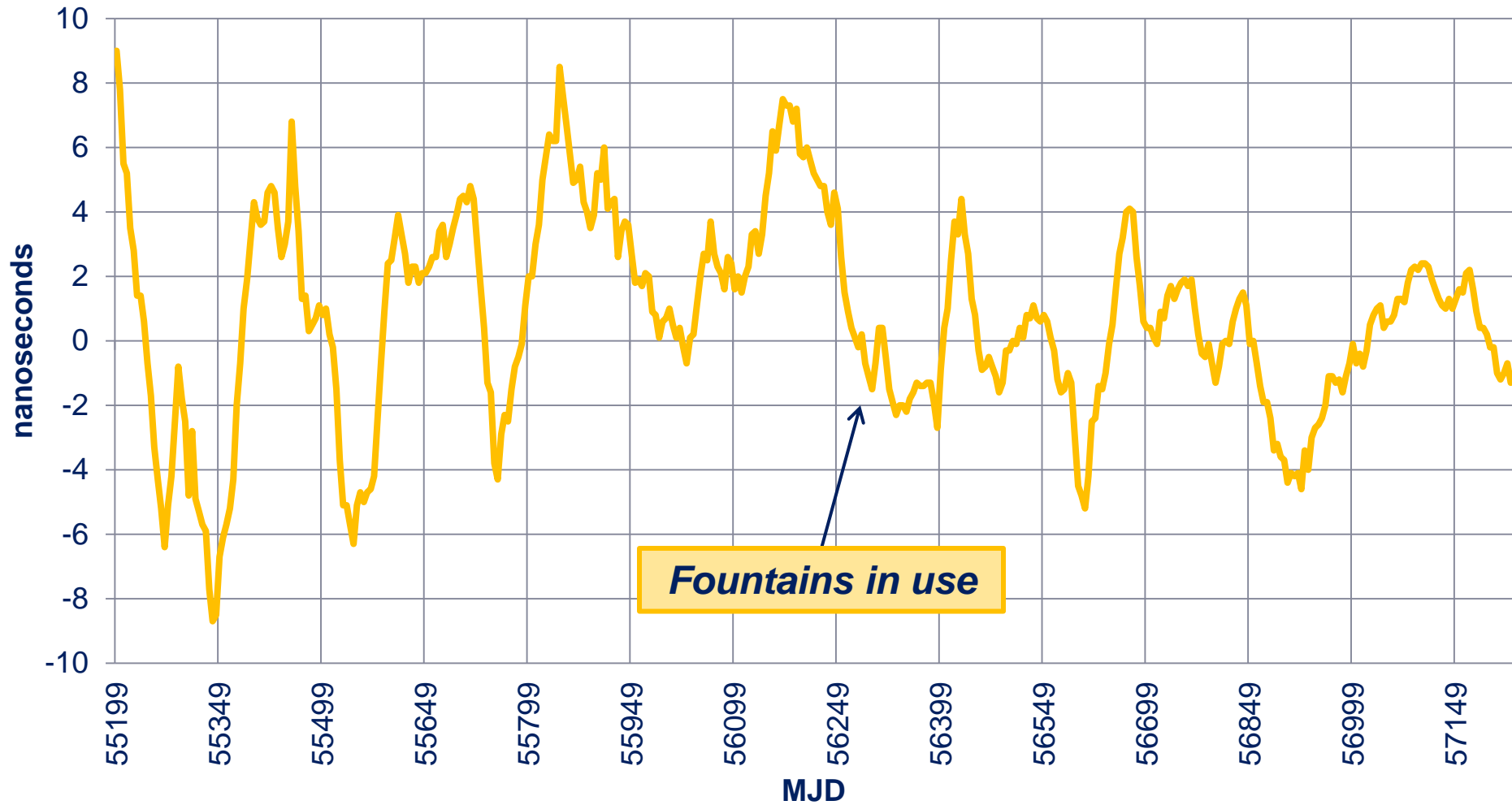


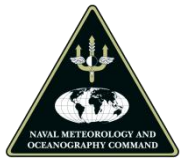


USNO Master Clock and UTC before/after Fountains

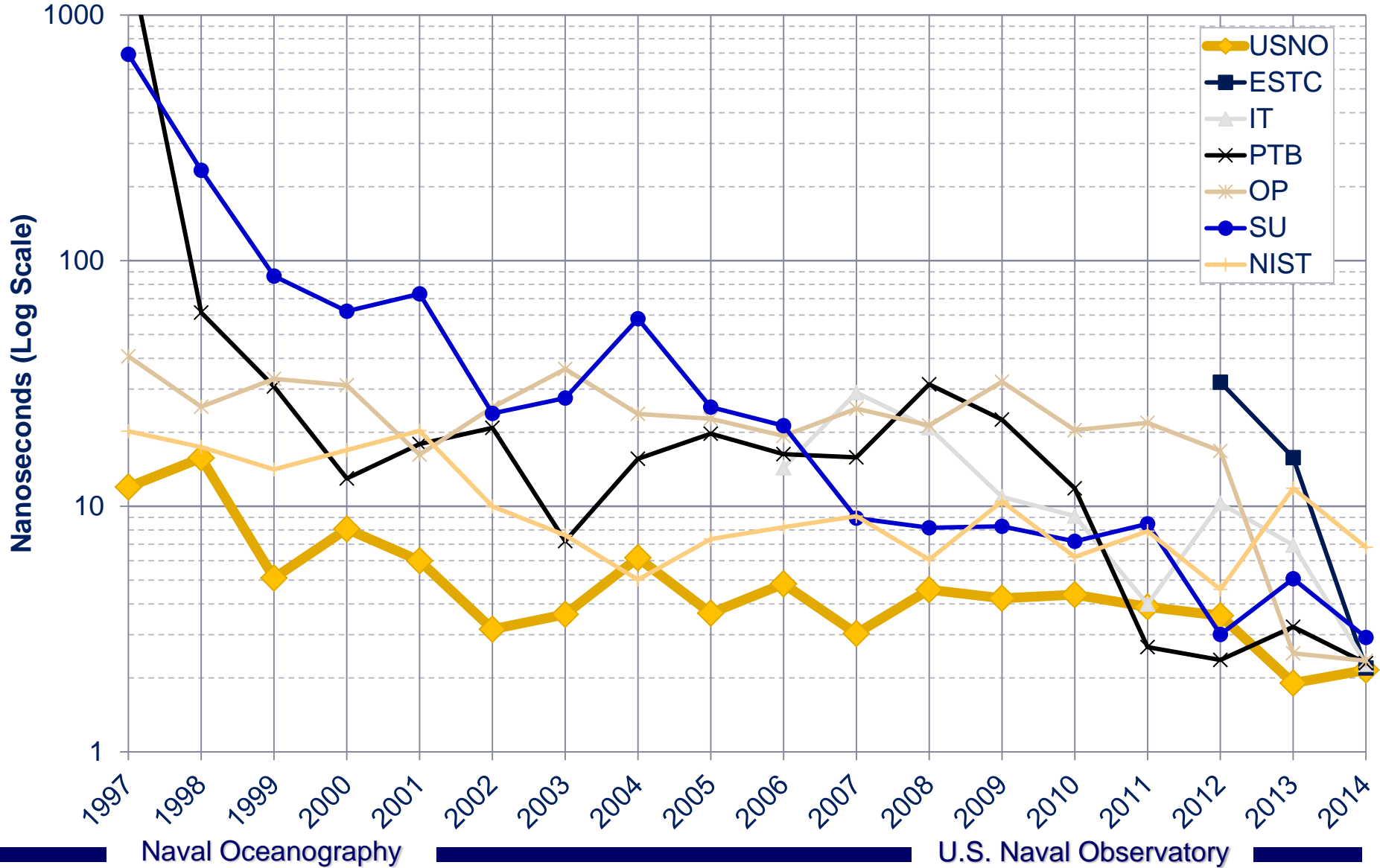


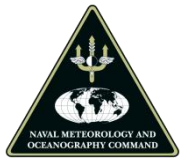
UTC - UTC(USNO)



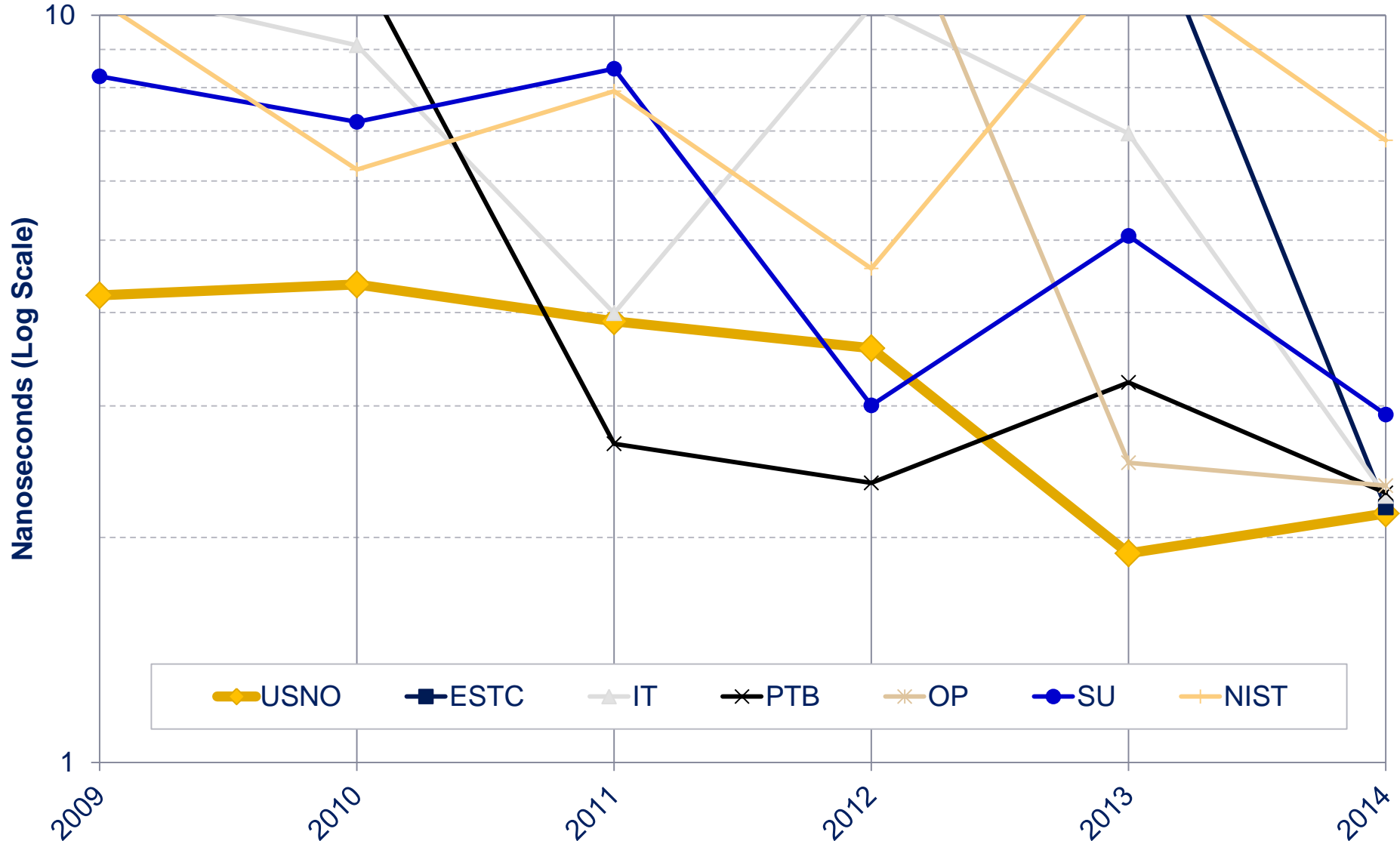


UTC - UTC(LAB) Yearly Root Mean Square (RMS)



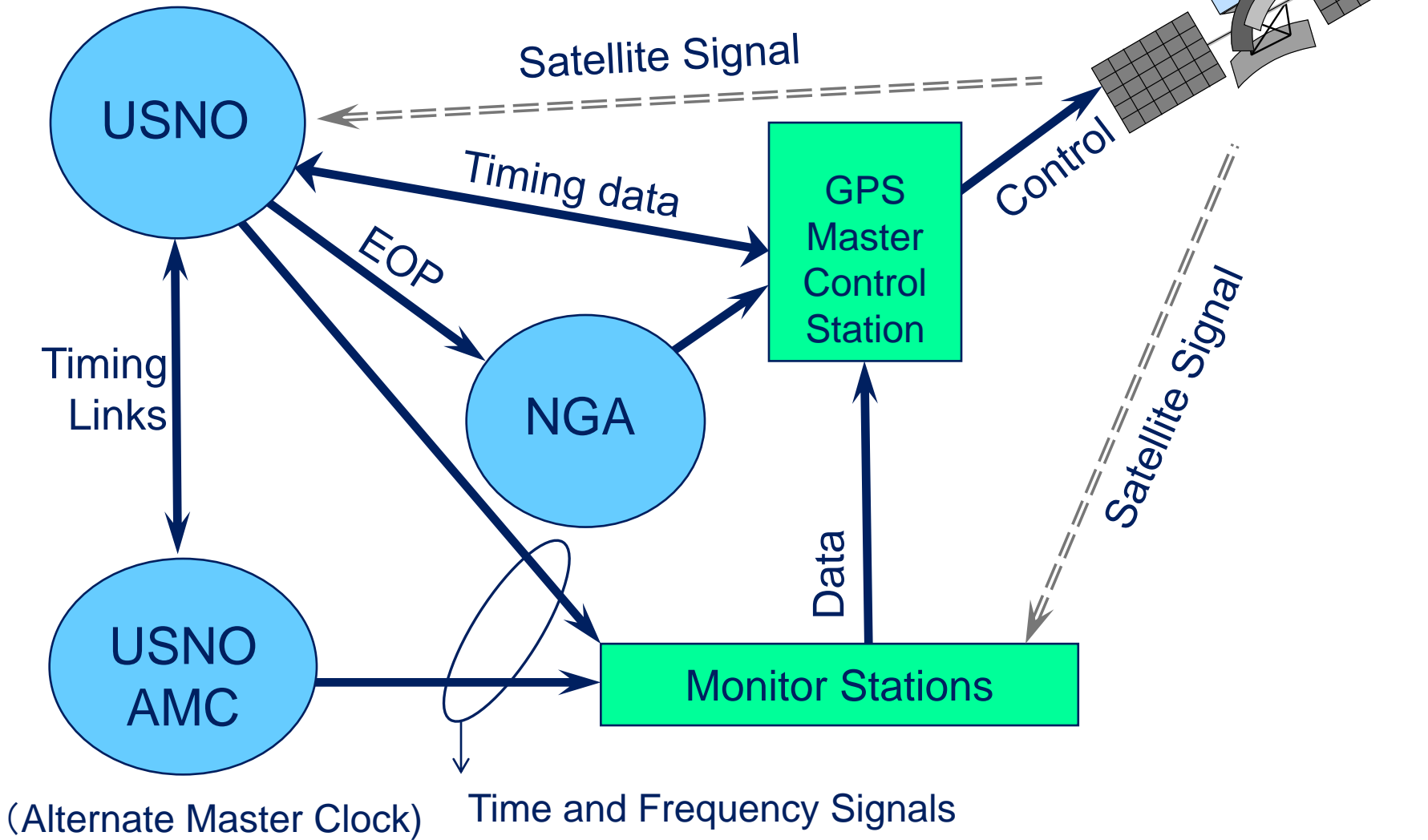


UTC - UTC(LAB) Yearly Root Mean Square (RMS)





USNO Contribution to GPS





GPS Timing and USNO's Contribution



- **GPS Time is a Navigational Timescale**
 - *No leap seconds*
 - *Intelligent average of system clocks*
 - *Satellite and ground clocks*
- **USNO utilizes a specialized set of calibrated GPS timing receivers to track GPS**
 - *We compute the offset of GPS System Time to UTC(USNO) and deliver this to the USAF*
- **USAF 2nd Operations Squadron (2SOPS) uses this data to accelerate GPS Time to match UTC(USNO)**
 - *There are no time or frequency steps in GPS Time, only steps in the acceleration*

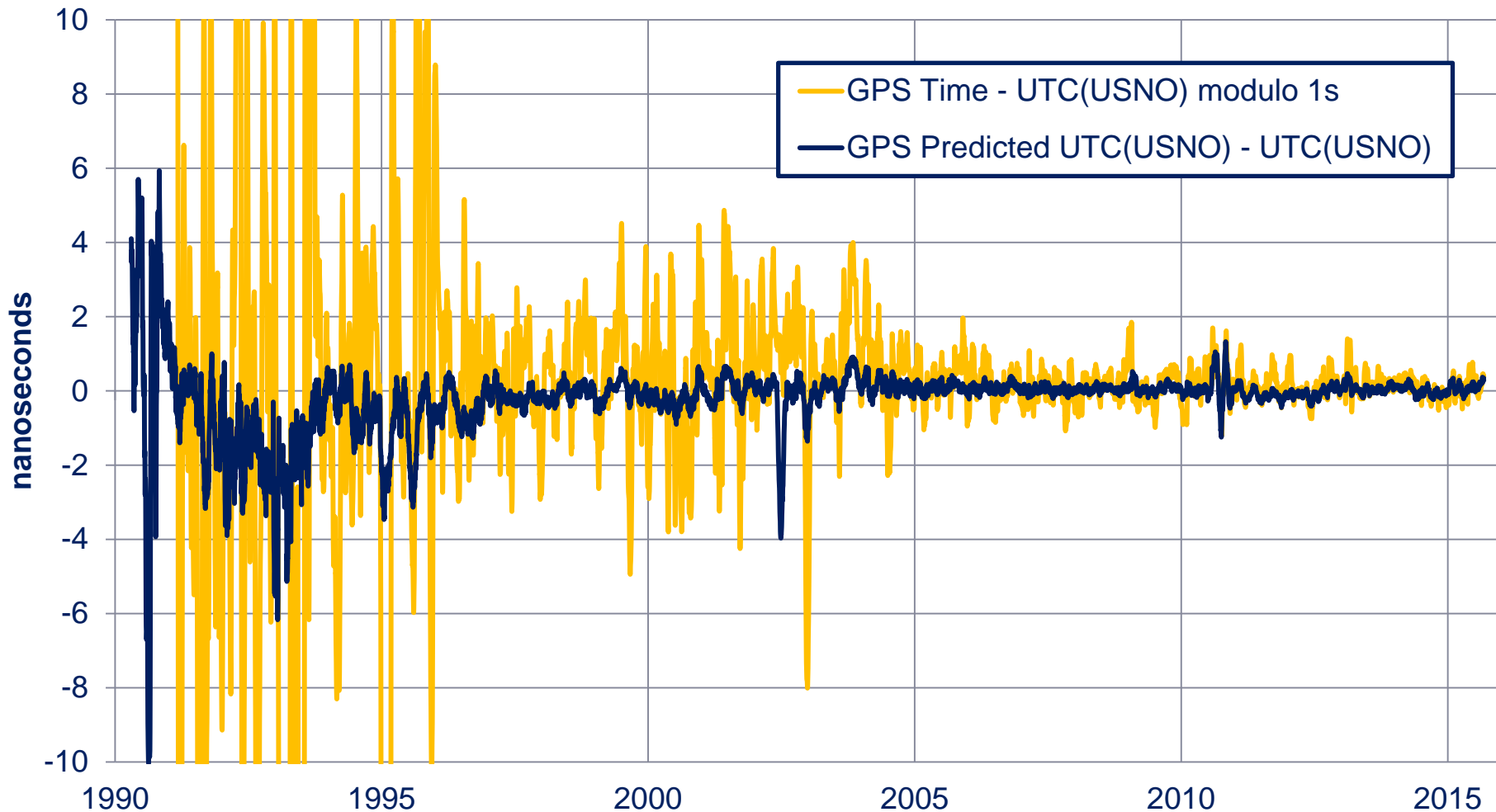


GPS Time Delivery, 30-day Averages



GPS Time and GPS Predicted UTC(USNO)

1 month smoothed



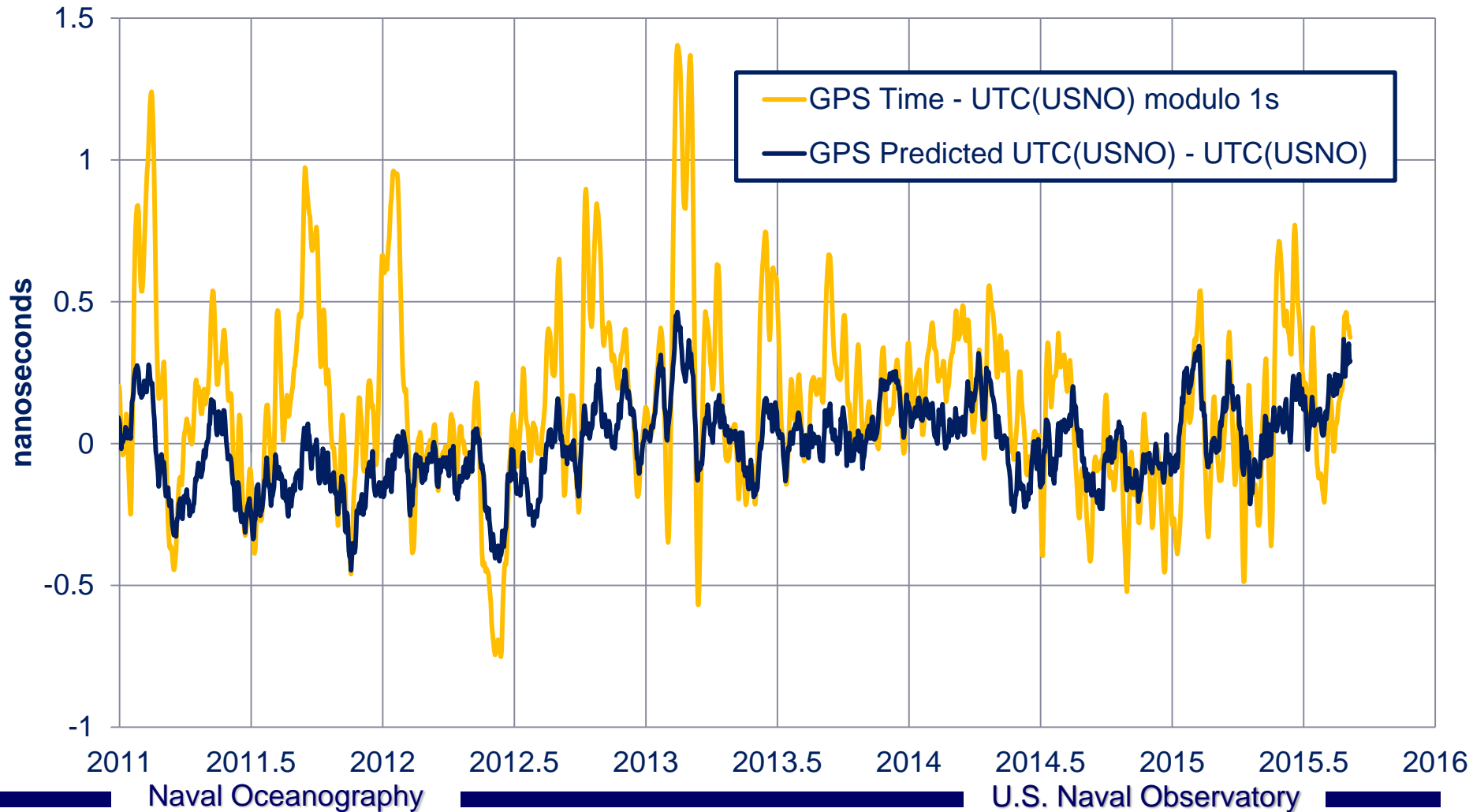


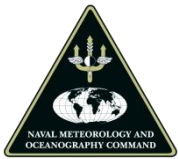
GPS Timing, More Recent History



GPS Time and GPS Predicted UTC(USNO)

1 month smoothed



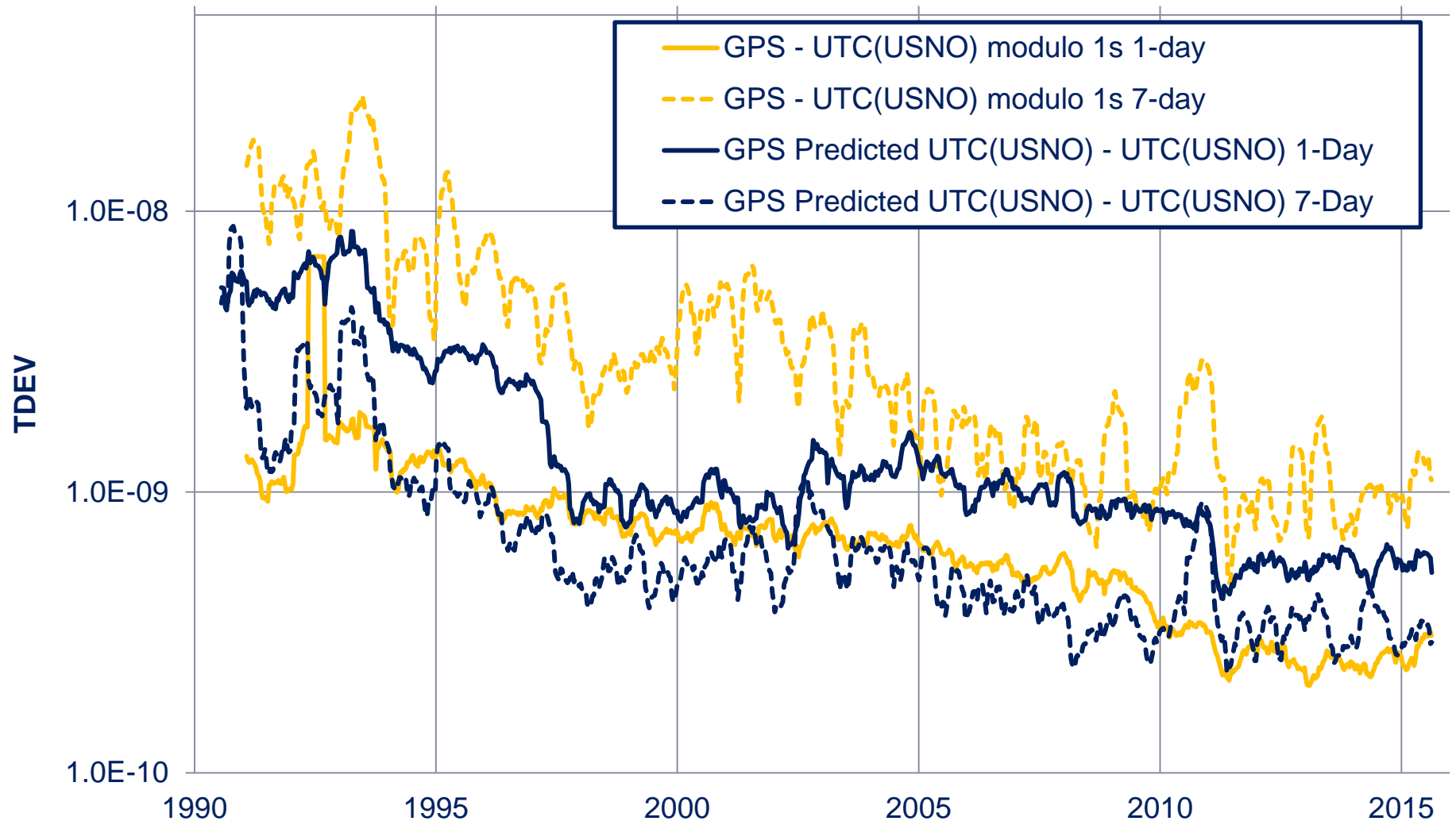


GPS Timing Instability



1.0E-07

Time Deviations Over 6-Month Datasets





Precise Timing Applications



Communications



Power Grid

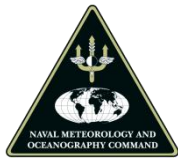


Financial



Scientific

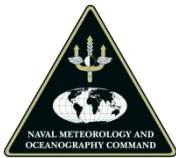
GPS/USNO Provided Timing Service is Critical to the Modern World's Infrastructure



GPS + other GNSS Added Benefit



- ***Increased reliability and availability of Position, Navigation, and Timing***
 - ***Especially for users in challenging environments such as urban canyon users***
- ***Requires coordination between navigational timescales***
- ***USNO and Galileo to broadcast the difference between their navigational timescales***
 - ***Galileo GGTO, GPS-GALILEO Time Offset***
 - ***Parallel operational measurements***
 - ***Shared and Compared***
 - ***System running in test mode***
- ***Bias Measurements being actively measured by USNO***



USNO Additional GPS III support



- ***USNO will act to coordinate GPS Time with other GNSS systems Time and provide a correction message to GPS***
 - ***USNO is presently providing both GLONASS and Galileo time differences in support of special CNAV testing (not presently being broadcast)***
 - ***USNO is moving into an operational phase coordinating the Galileo to GPS Time Offset (GGTO) information with Galileo system***
- ***Also supporting OCX, USNO will work with USAF for the determination of the GPS satellite and reference stations inter-signal and inter-frequency biases***
 - ***This is needed to ensure that average constellation biases are removed in a consistent way to ensure accuracy for timing user community***



CNAV Message Type 35 (GGTO)



- ***CNAV Message Type 35 contains the GPS-to-GNSS Offset (GGTO) for various systems***
- ***Will come online this fall with real data from USNO***
- ***GLONASS and GALILEO planned for broadcast this fall***
- ***Software Development complete, solutions automatically computed daily***
- ***Need to finalize calibration procedure and incorporate receiver calibrations into solutions***
 - ***Utilizing new multi-GNSS simulator***

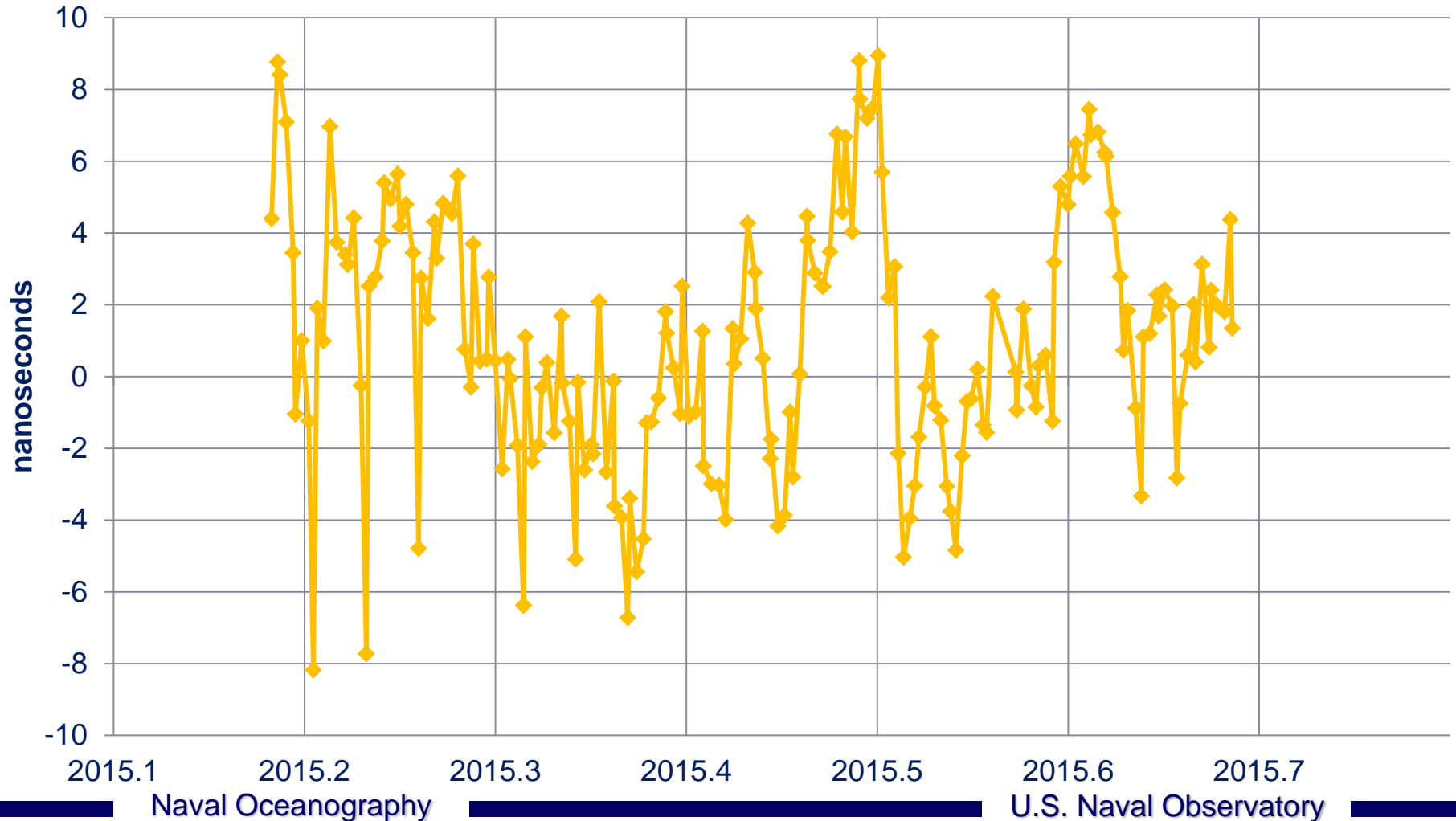


GALILEO GGTO



GPS - GALILEO Time Offset

Measured by USNO Combined Receiver, 1-Day Averages

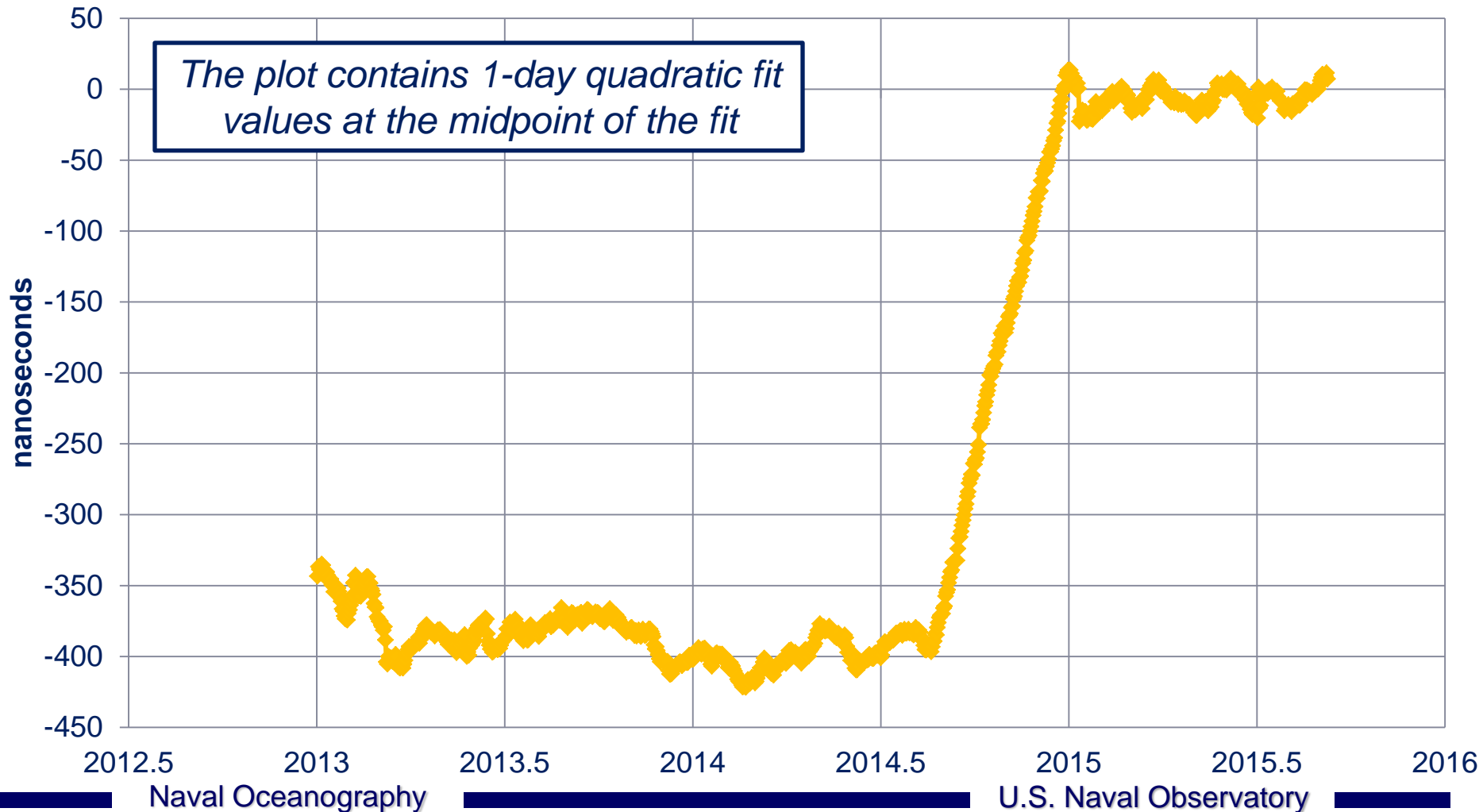


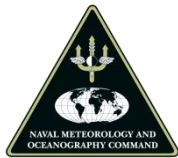


GLONASS GGTO



GPS - GLONASS Time Offset Measured by USNO Combined Receiver

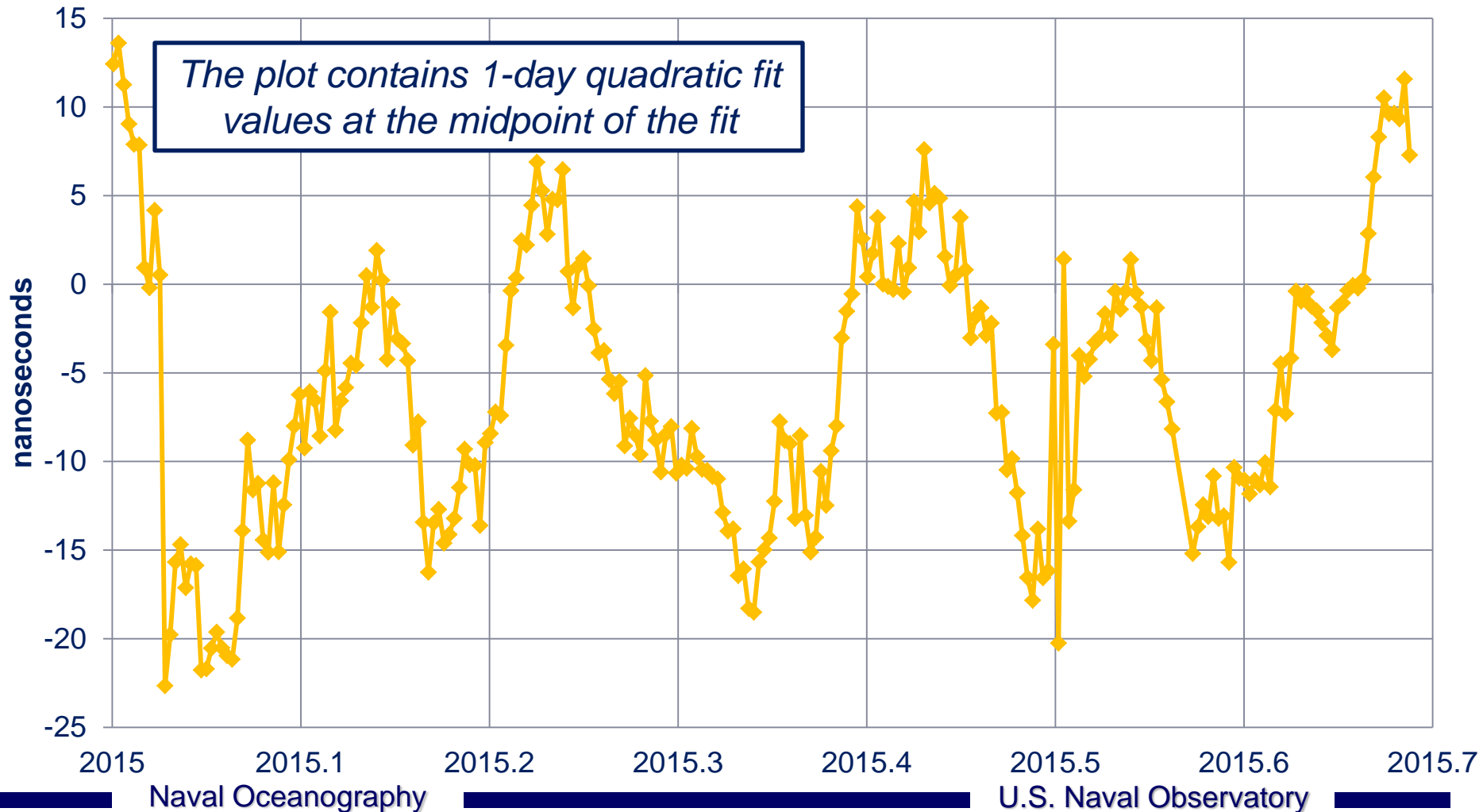


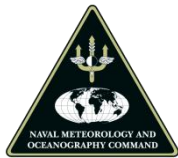


GLONASS GGTO



GPS - GLONASS Time Offset Measured by USNO Combined Receiver

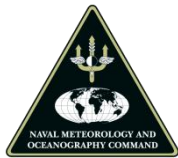




GNSS Operational Changes



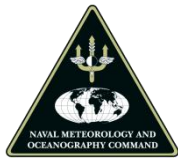
- ***Antenna change prompted new IGS Stations***
 - ***USN3 → USN7***
 - ***USN4 (MGEX) → USN8***
 - ***USN5 (MGEX) → USN9***
- ***Modernization of Processing Tools:***
 - ***Ability to use RINEX3 data files***
 - ***Support for higher data rates***
 - ***Ability to use select signals from differing GNSS***
- ***New HVAC Systems for better environmental control***



Future Emphasis for Reliable Sub-Nanosecond Timing



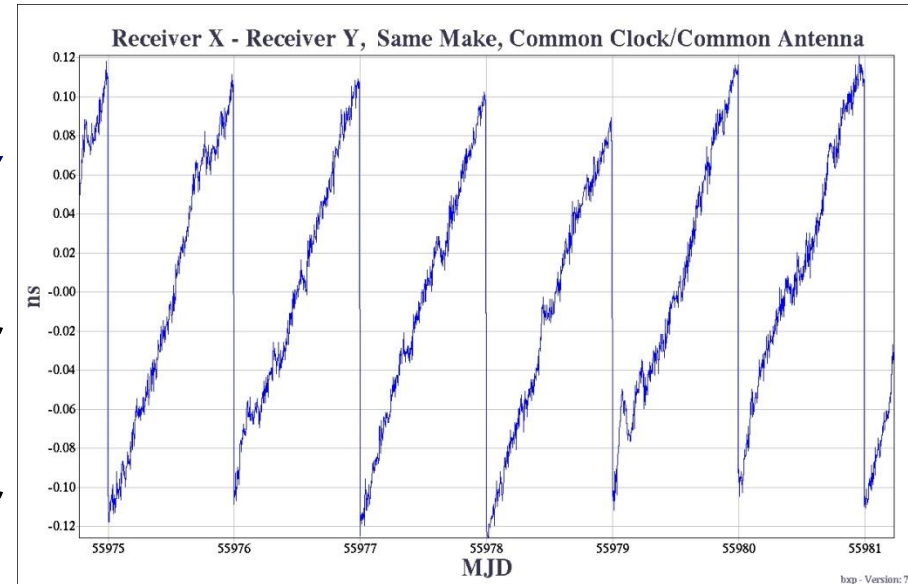
- 1. Stable Timescale Reference***
- 2. Carrier Phase Analysis for GNSS***
- 3. Environmental Control***
- 4. Redundant Independent Receiver Systems***
- 5. Multipath Reduction***
- 6. Calibration, and Recalibration***
- 7. Impedance Matching / Cable Reflections***
- 8. Equipment Design***
- 9. Inter-frequency Bias corrections***



A Fixable Problem in Geodetic Receiver Design



- **Receivers may give carrier phase and code data same timetag**
- **Delays inside the receiver circuitry can cause constant offset in “latching times”**
 - **The carrier frequency is Doppler shifted to higher values when the satellite is rising**
 - **The carrier frequency is Doppler shifted to lower values when the satellite is setting**
- **A too-large latching time offset can therefore result in a systematic frequency difference**
- **It can be up to a few 100s ps/day**
 - **Though often much less**
- **Rule of Thumb: 1 msec latching time offset leads to ~30 ps/day frequency error in PPP**
- **See Matsakis et al. ION-PNT, 2015 and Defraigne et al., IFCS/EFTF 2015**
 - **Article under preparation for Inside GNSS, probably NovDec 2015**





Other Activities



- ***USNO also measures the Earth Orientation Parameters, including the Earth's rotational angle UT1, for GPS and other users***
- ***USNO serves as the rapid service/prediction center of the International Earth Rotation and Reference Systems Service (IERS)***
- ***USNO maintains the Astronomical Almanac with Her Majesty's Nautical Almanac Office in the UK***





Summary



- ***USNO specializes in real-time timekeeping***
 - ***UTC realization***
 - ***Dissemination***
 - ***Monitoring***
 - ***Device and analysis R&D***
- ***Thank you!***
- ***Questions?***