Report From the

U.S. Naval Observatory

Timing Session of the
Civil GPS Service Interface Committee (CGSIC)
September 17, 2012
Nashville, Tennessee

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 DoD and US government PNT systems

USNO Master Clocks

Master Clock
Washington, DC

- 66 High Performance Cesiums
- 37 Cavity-Tuned Masers
- 4 Rubidium Fountains

Alternate Master Clock
Schriever AFB

- 12 High Performance Cesiums
- 4 Cavity-Tuned Hydrogen Masers

GPS Time Transfer

GPS and USNO Provided Precise Time and Time Interval (PTTI) Support

Communications

Power Grid

Banking

Scientific

UTC Time from GPS

- **GPS Time (GPS Internal Navigation Time Scale) is formed by creating a virtual clock "paper clock" through the weighed average of most GPS satellite and ground station clocks.**

- **GPS Time, is not adjusted for leap seconds and is not intended to be used for timing applications. GPS time repeats ever 19.6 years, Epoch #1 started counting whole seconds on Jan 6, 1980. GPS time Epoch #2 started on Aug 22, 1999 and Epoch #3 will start in 2019.**

- **Applying the sub-frame 4, page 18, corrections in the GPS message allows the timing user to recover UTC time traceable to UTC(USNO). CNAV and MNAV have improved versions of his correction defined.**

NOTE: ***The timing calibration bias of the GPS internal navigation time scale is physically established at the United States Naval Observatory (USNO). USNO is responsible for measuring and maintaining the calibration of both the GPS internal navigation time scale and the UTC time products produced by GPS.***

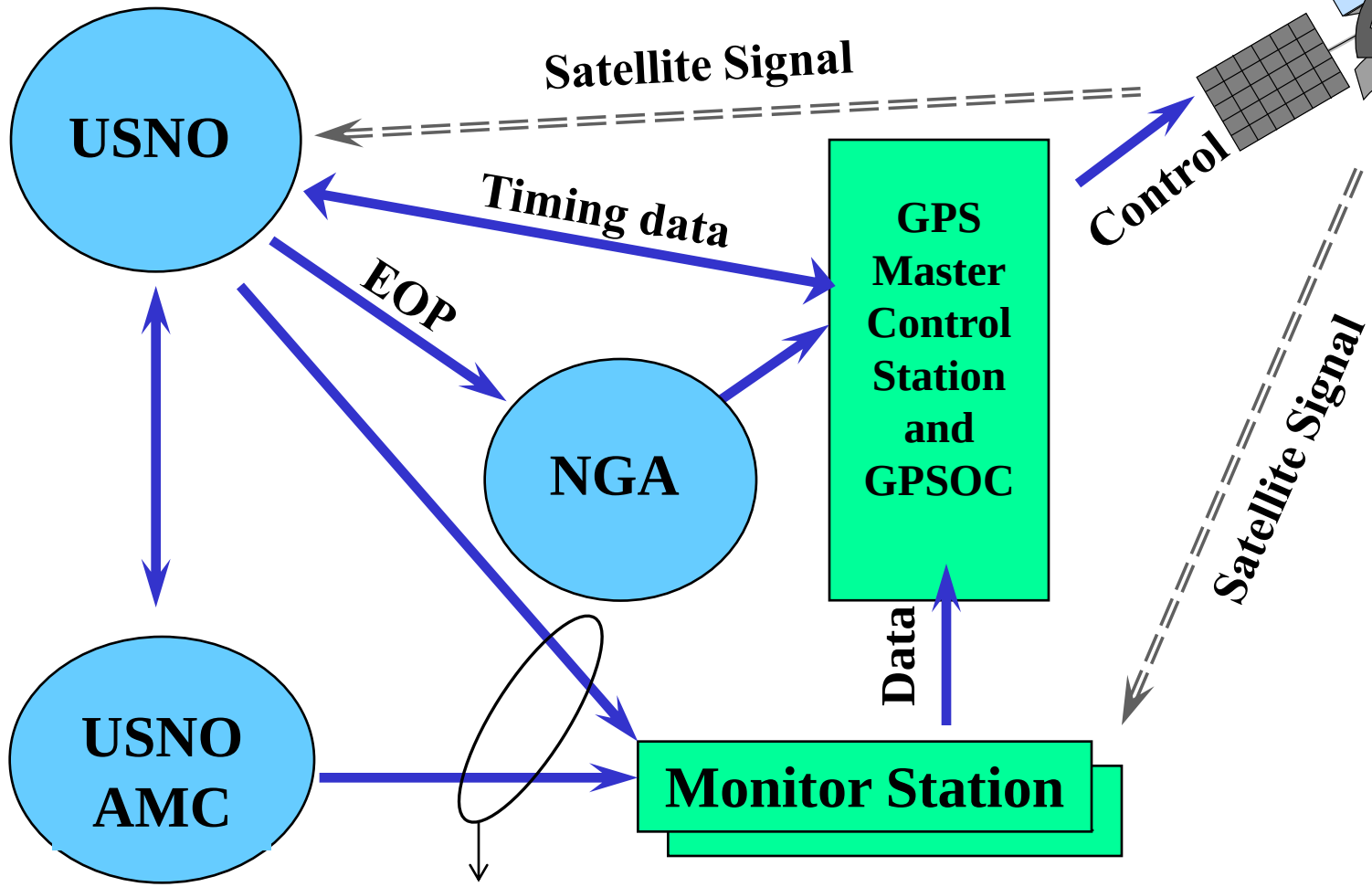
USNO Time Monitor for GPS

USNO employs a bank of specialized SAASM GPS time monitor receivers located at USNO in Washington DC and at the USNO AMC in Col Springs

The USNO time monitor receivers are used to make carefully calibrated measurements of each GPS SV clock relative to UTC(USNO)

These observations are filtered, averaged and provided to 2SOPS (via the USNO to GPS ICD-202 interface) to produce a daily correction which is broadcast to the user in the GPS NAV msg.

USNO Contribution to GPS



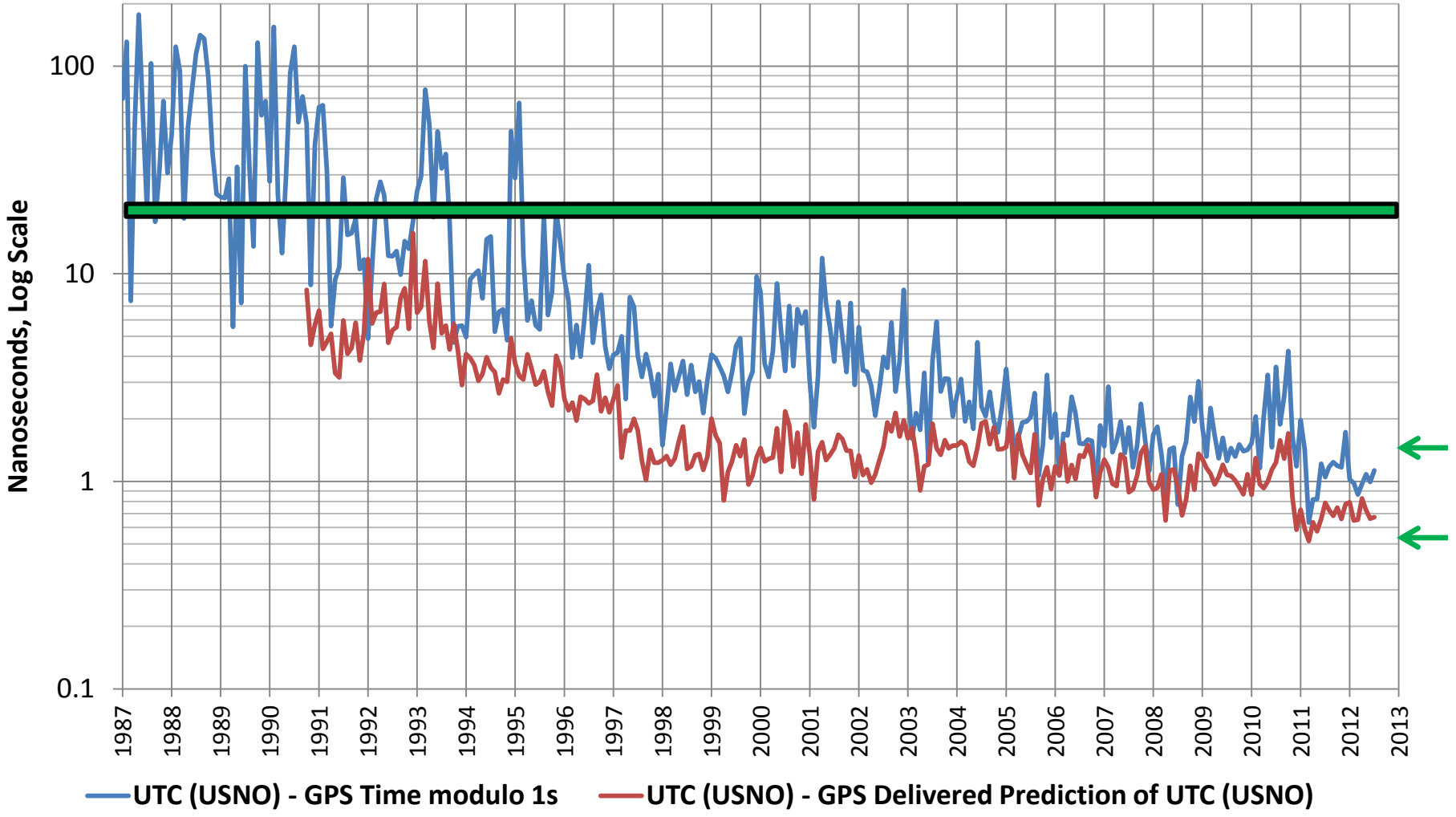
Time and Frequency Signals

Existing USNO GPS Operations

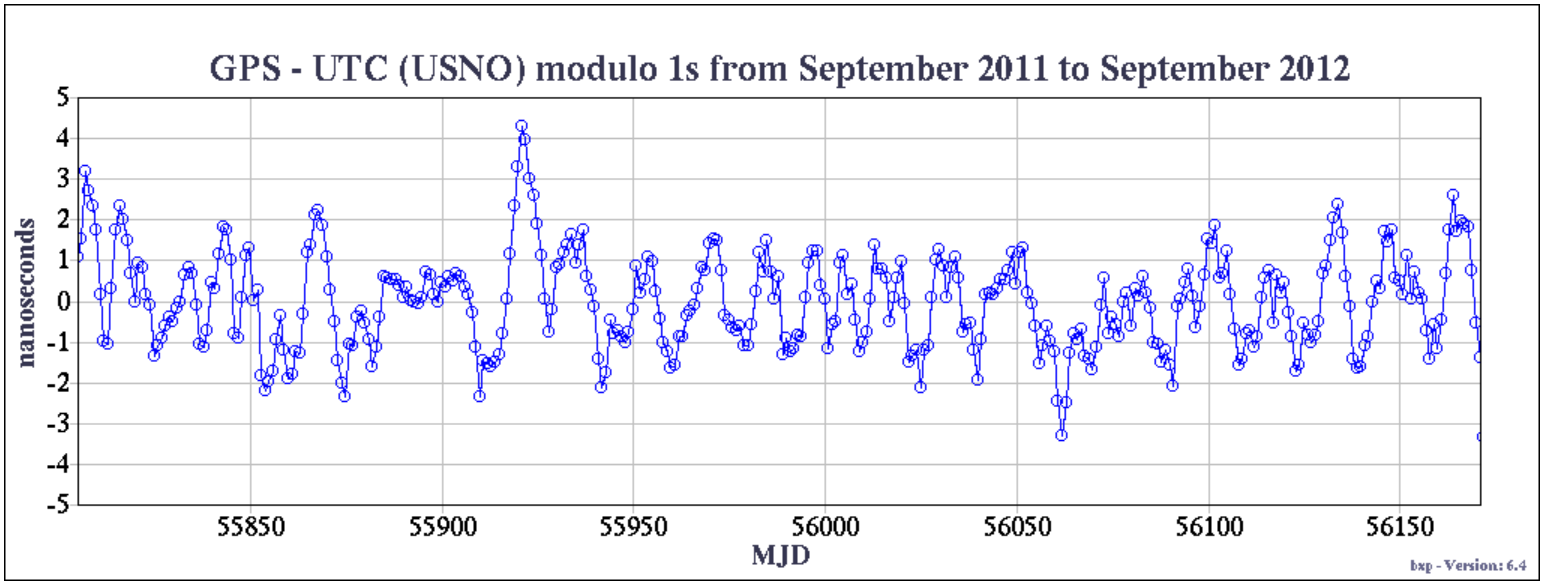
Legacy PPS-SM Units

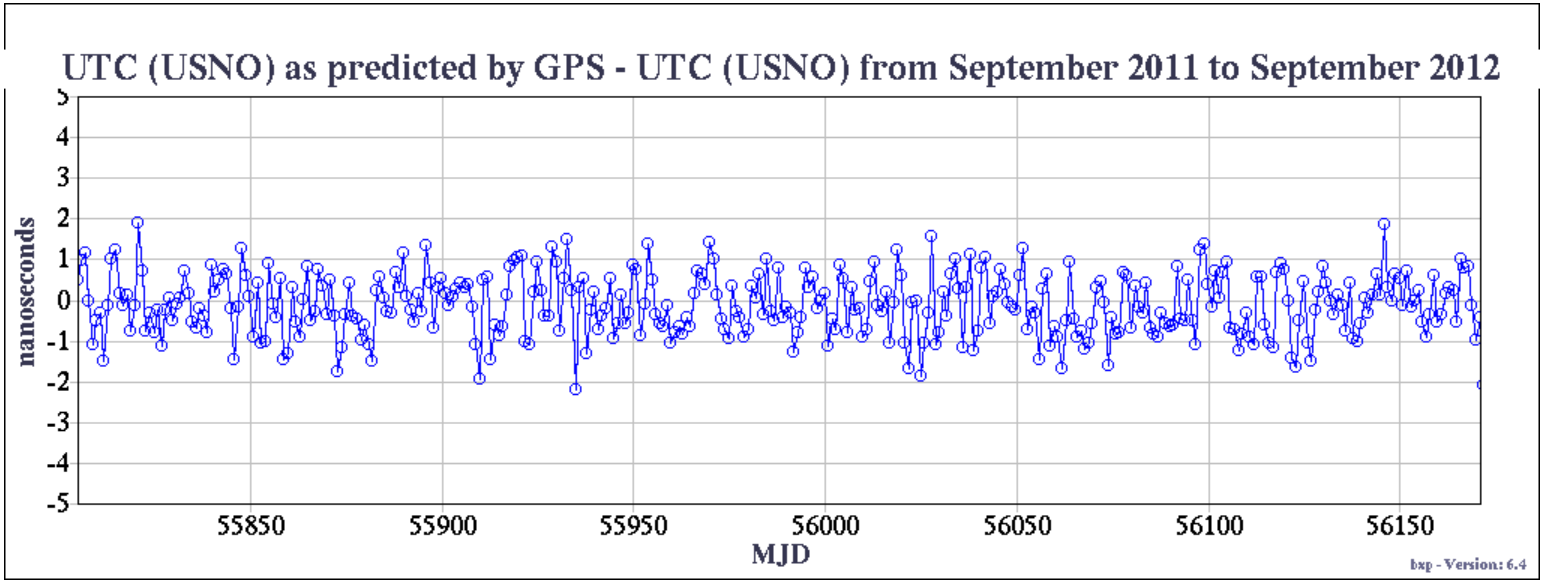
SAASM Units

GPS Timing Service During the Past 25 Years



GPS Time Transfer Performance





USNO Portion of the GPS III Error Budget

All values 1 σ	Threshold	Objective
Signal in Space	0.75 ns	0.25 ns
M-Code Rcvrs	0.625 ns	0.275 ns
UTC(USNO)	0.25 ns/day	.05 ns/day
TOTAL	1.0 ns (1σ)	.375 ns (1σ)

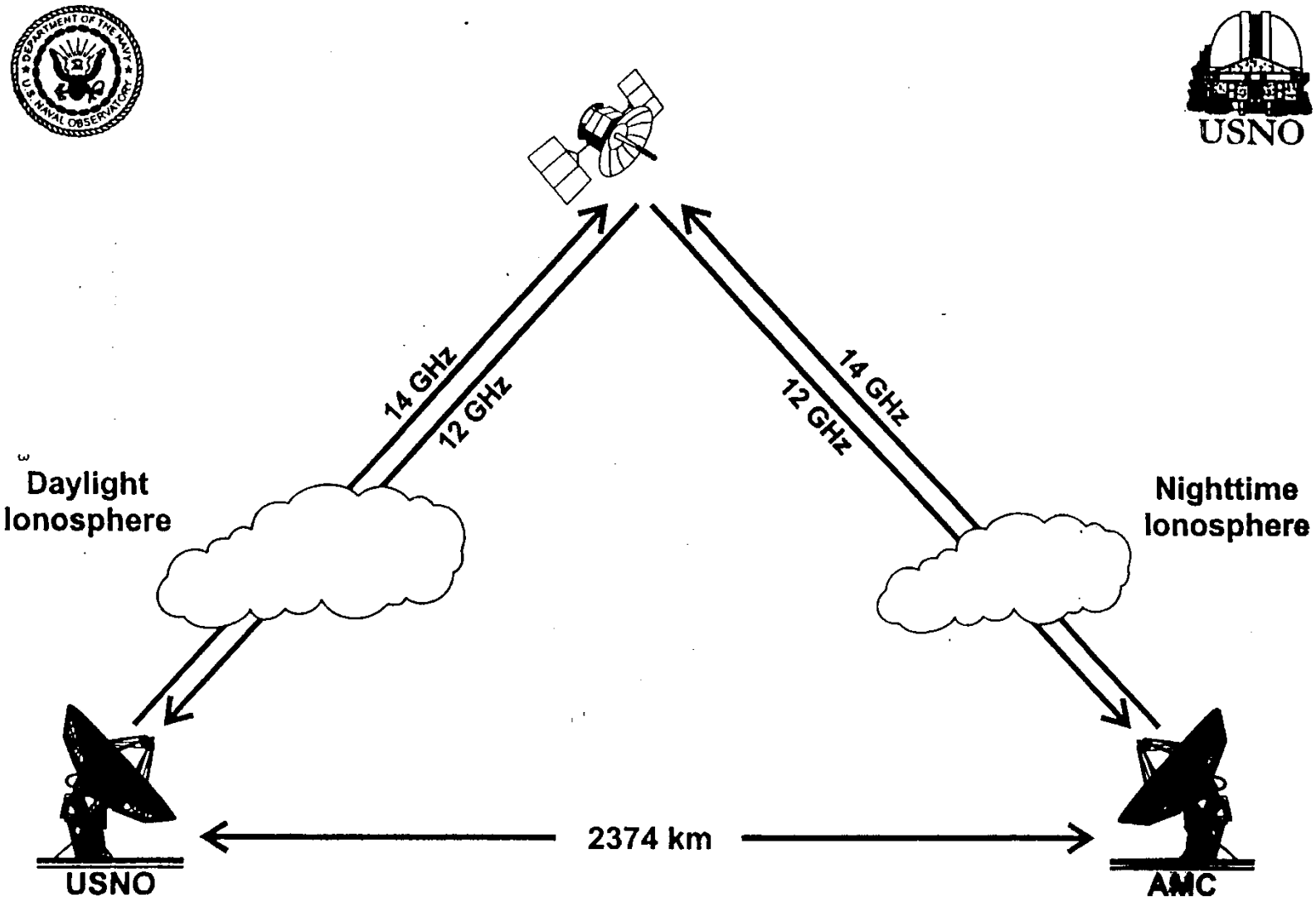
GPS to GNSS Time Offset

Path to operational GGTO generation:

- Determine system-dependent receiver biases
- Gather GNSS data from receivers
  - Done for Galileo and GLONASS
- Assemble data processing tools
  - GLONASS: Testing now
  - Galileo: In progress

TWSTT Time Transfer

Two-Way Satellite Time Transfer

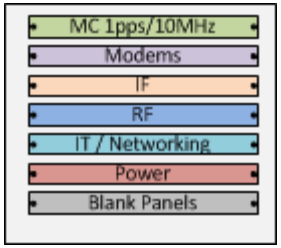


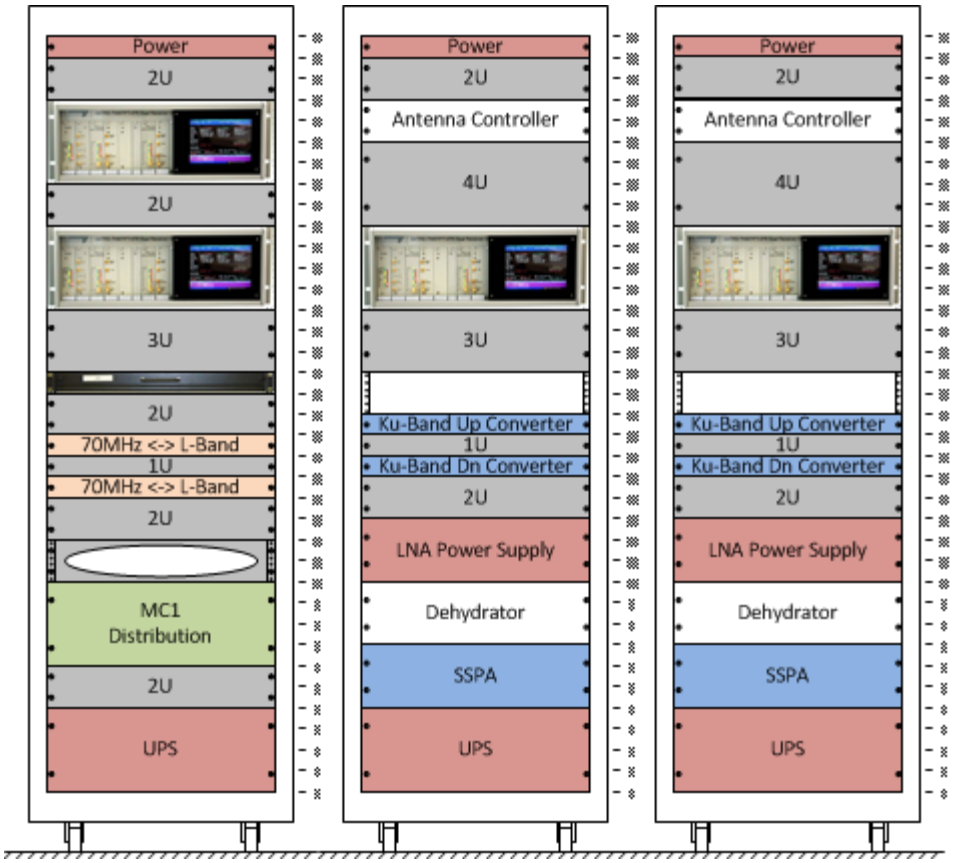
TWSTT at a Glance

- Time at 1.0 nanosecond to specific users
  - Operational with NICT (Japan)
    - Supporting QZSS
    - Uses Hawaii (Kokee Park) for a hop
  - Cape Canaveral operations over extended range
  - Extensions to Pacific
- AMC time link rebuilt
  - Engineering for better and cheaper
    - Thermal Control, Impedance Matching,
  - Calibration requires frequent and expensive travel
- GPS PPP now used for USNO's link to BIPM
  - Sending data from two receivers for redundancy

Projects: Earth Station

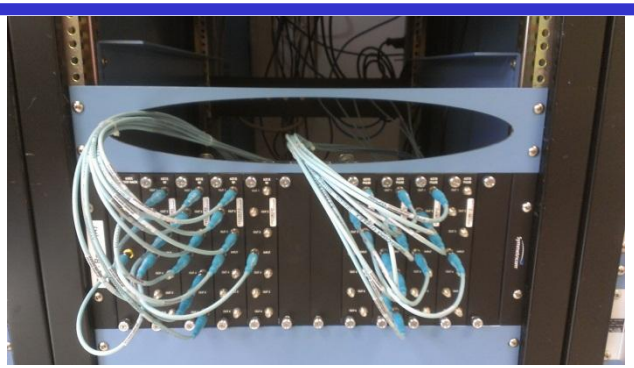
- Replacing old equipment and cables
- Improving air flow
- Updated Labeling
- Measuring Delays



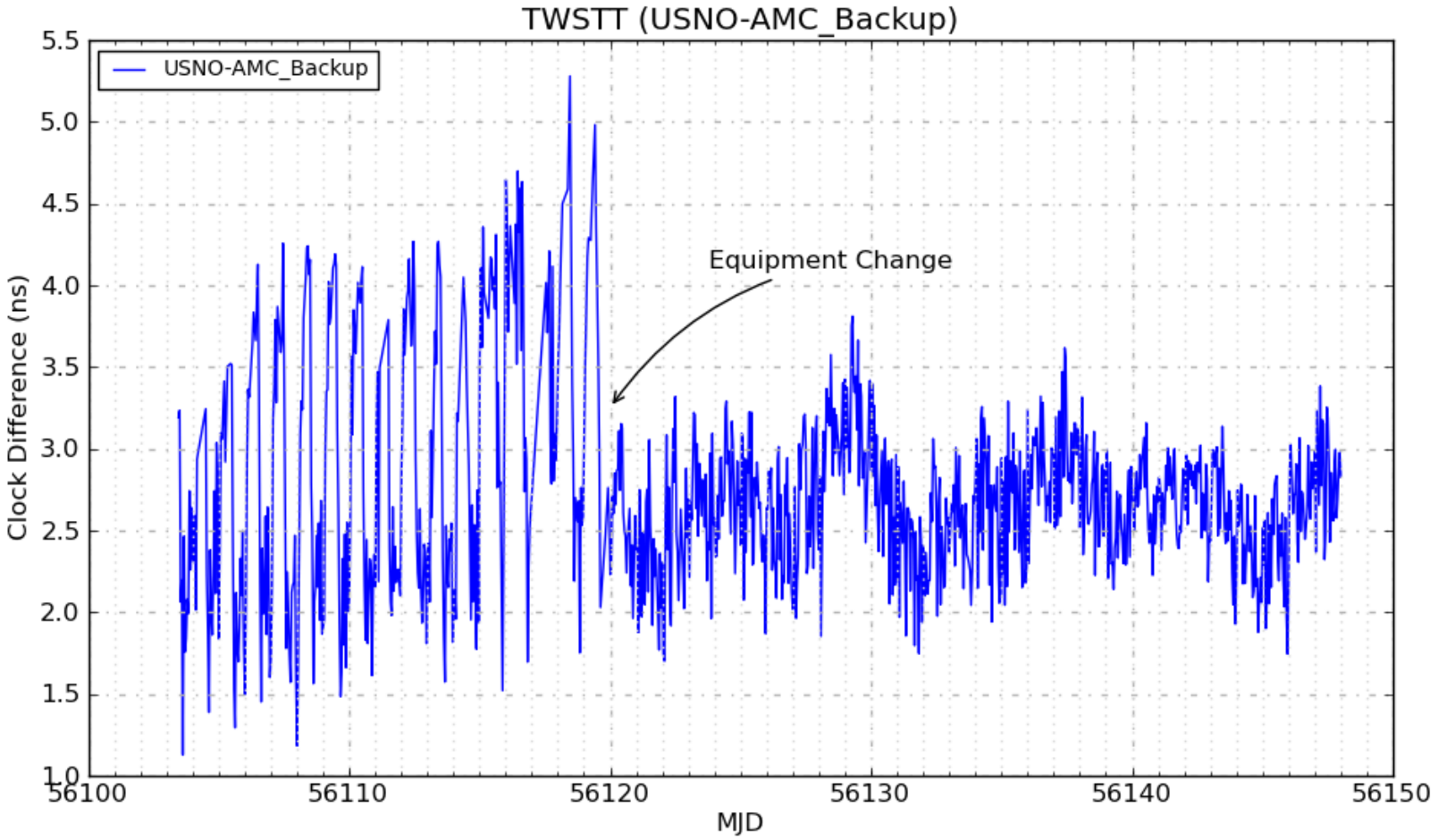


Projects: Earth Station

- Upgrading distribution amplifiers
- Interface panels w/ known delays
- Cable Trays
- Fans
- Battery backup



L-band exterior path antenna



Network Time Protocol

USNO Network Time Servers
Time Service Department

- Internet http://tycho.usno.navy.mil/ntp.html
  - 26 U.S. Stratum-1 Time Servers
  - USNO Master Clock & GPS SPS Time References
  - Millisecond Time Synchronization
  - >200 Billion Network Requests yearly
- SIPRnet
  - 2 U.S. Stratum-1 Time Servers operational
  - USNO Master Clock References
- Pilot Project started for authenticated NTP
  - Limited to DoD only, civilians should contact NIST
- Contact: Jeffrey Prillaman, 202-762-0756
  DSN 762-0756, jeffrey.prillaman@usno.navy.mil

Internet and Other Time Products
Time Service Department

- ftp server, ftp://tycho.usno.navy.mil
  - 9 million connections/month
- Time Service Web server, http://tycho.usno.navy.mil
  - 1.6 million connections/day
  - 2.9 Gigabytes transferred/day
  - Audio Service installed
- Telephone Voice Announcer
  - Traffic up to 4 million calls/year
  - USNO DC, 202-762-1401 (DSN 762)
  - USNO AMC, 719-567-6742 (DSN 560)
- Modem Time
  - Traffic falling, but 50,000 calls/year
  - USNO DC, 202-762-1594 (DSN 762); 1200 baud 8N1
  - USNO AMC, 719-567-6743 (DSN 560); 1200 baud 8N1

UTC Laboratory Issues

Universal Coordinated Time (UTC)

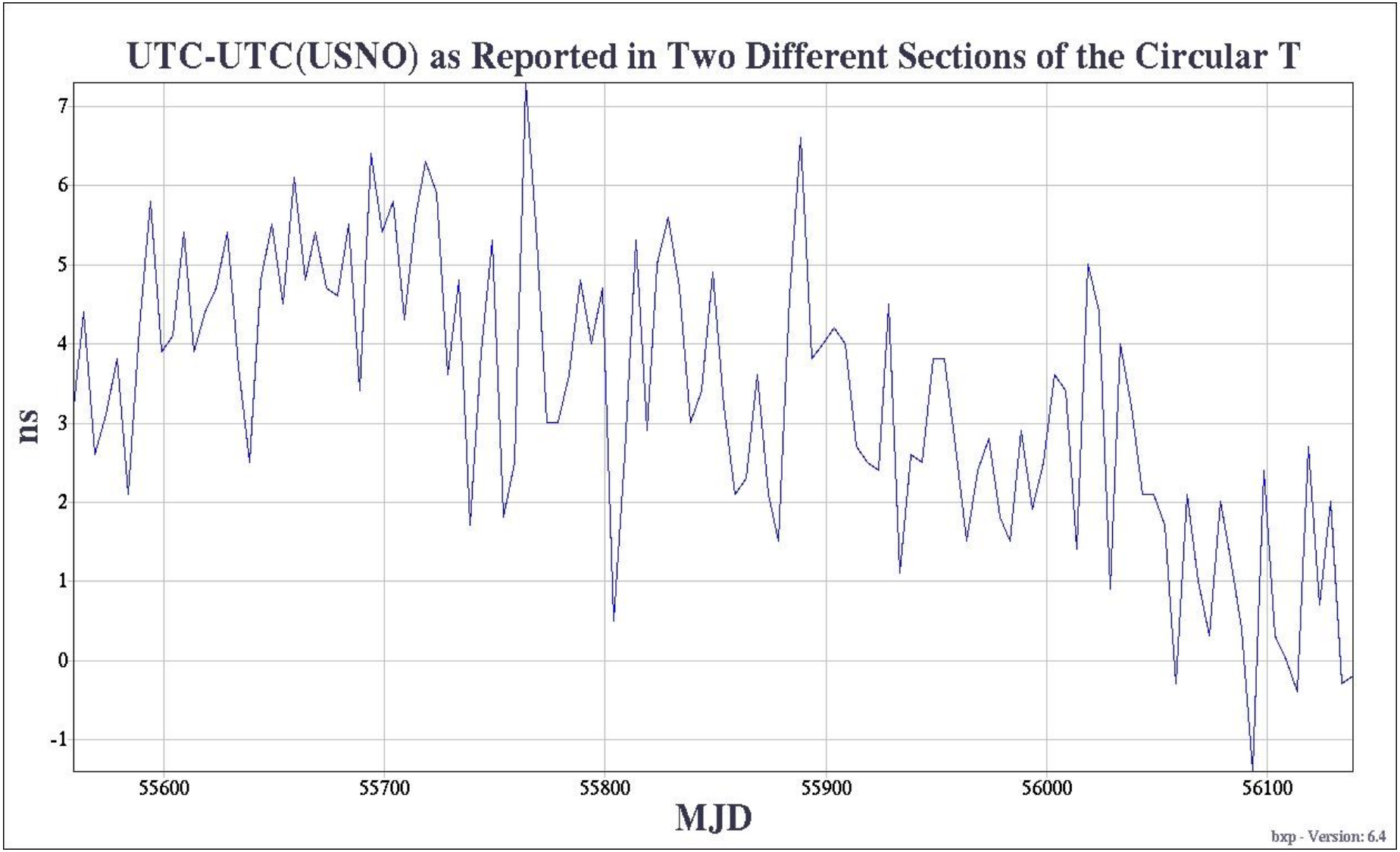
In April 1875, the US Government and sixteen other countries signed the “Convention of the Metre” which is a diplomatic treaty now signed by fifty-six nations.

This treaty gives authority to the Bureau International des Poids et Mesures (BIPM) to act in matters of coordinating world metrology.

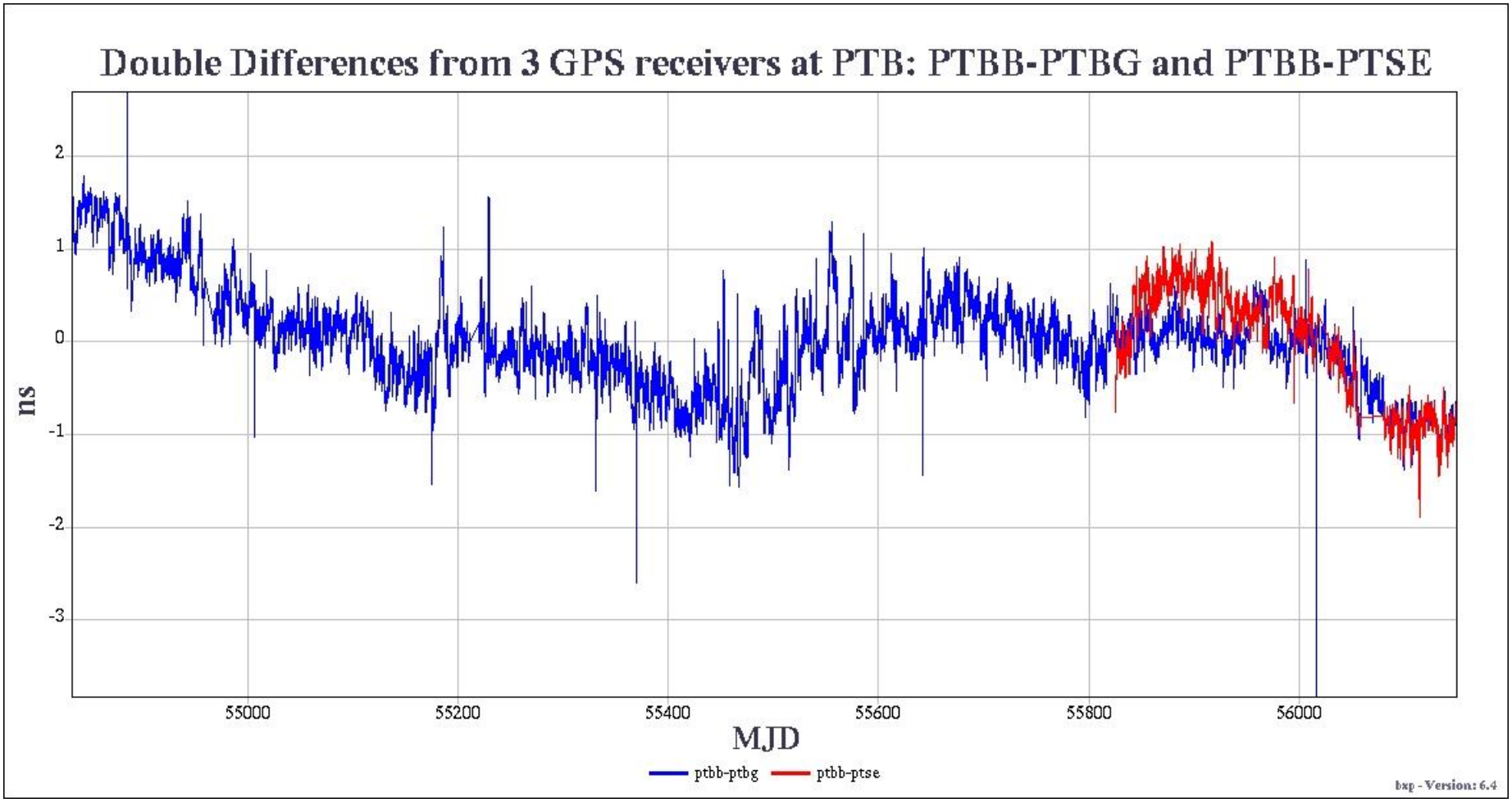
As such the BIPM acts as the coordinator for the standardization of world time (UTC).

UTC- UTC(USNO) Reported Twice in Circular T

Why aren't they identical? Why did the difference change?

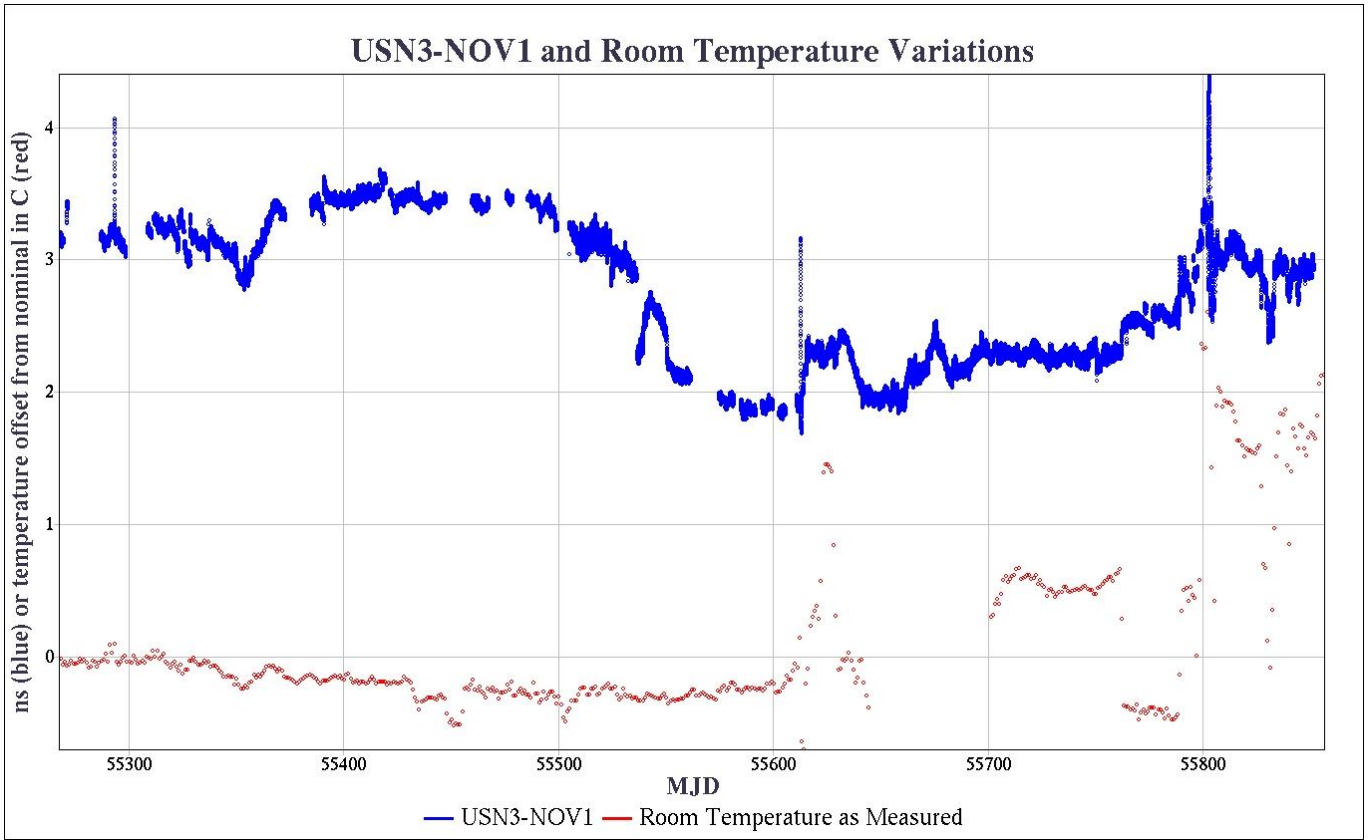


UTC- UTC(USNO) Reported Twice in Circular T
PTB Receiver Changed?

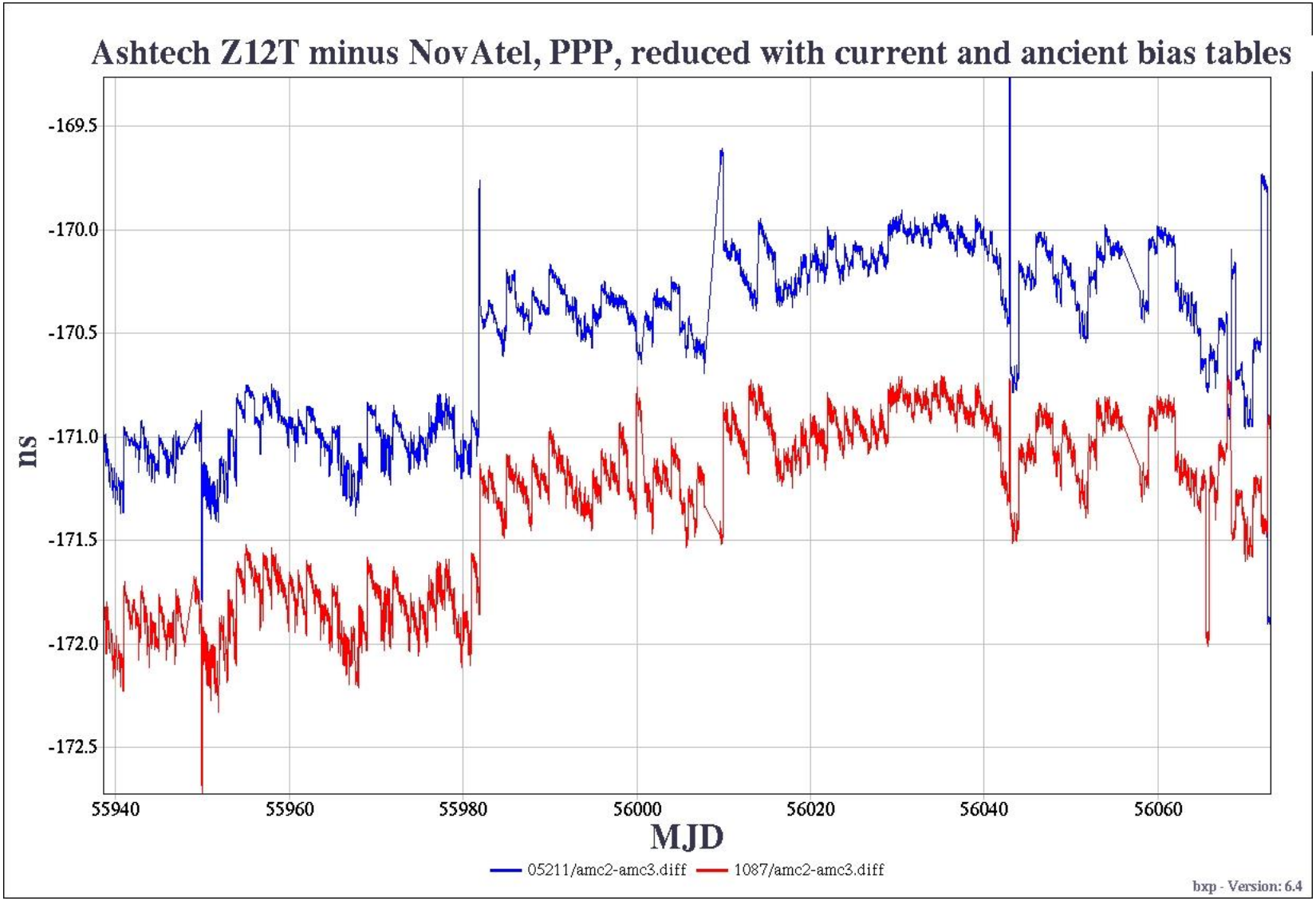


Need for 21st Century Receivers

USNO example shown so as not to embarrass others.
But all time transfer systems do it somewhat
And older GPS receivers do it more
See Jiang et al. PTTI-11

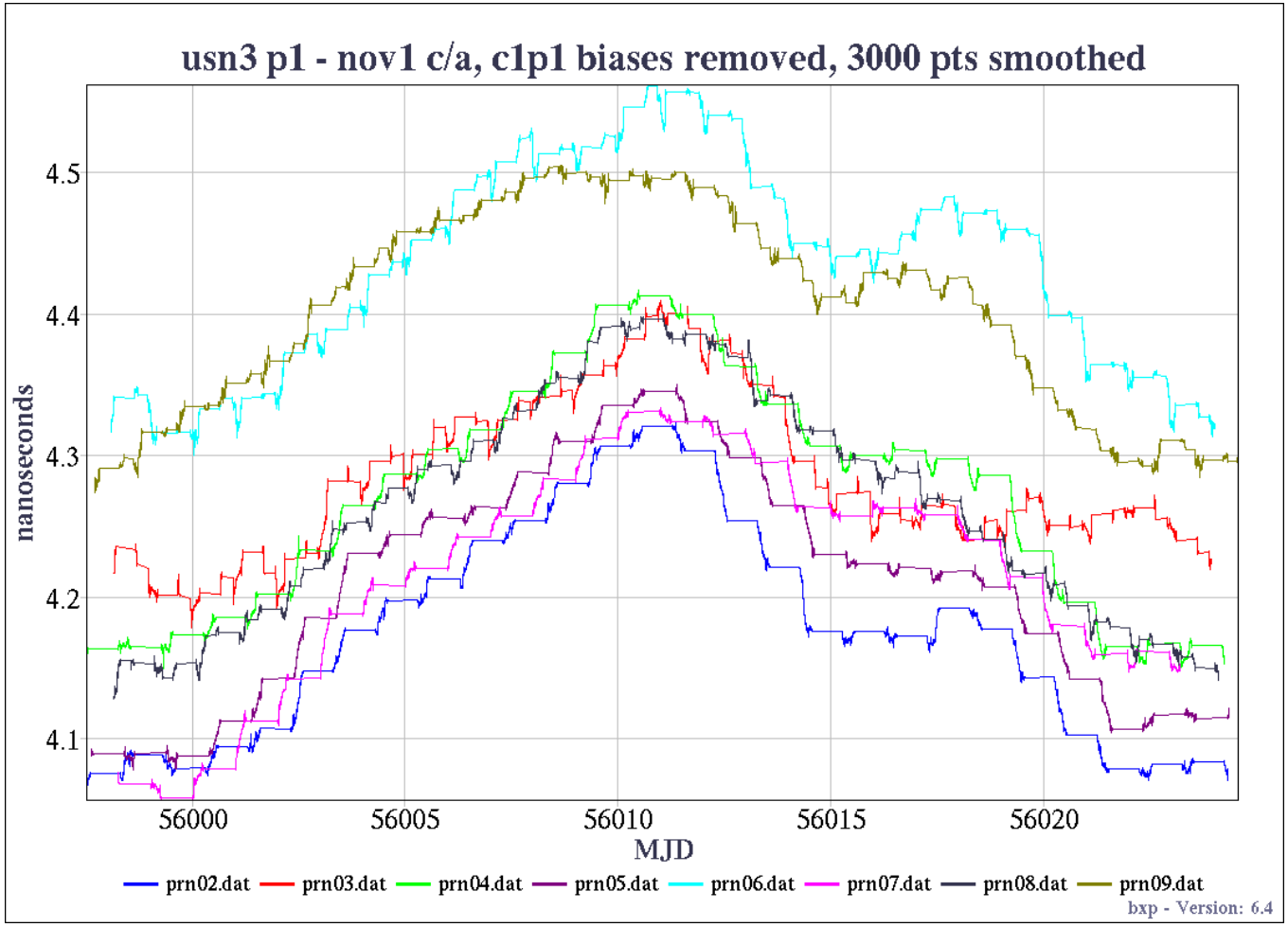


Challenges for Some Models



C-P Bias Corrections Barely Enough

Raw Pseudorange Comparison, Ashtech vs. bias-corrected NovAtel
Each curve is a different satellite



Master Clock Improving

- For Future Requirements
  - GPS III
  - Space
- Order of Magnitude Improvement Coming
  - More robust (reliable)
  - More precise (more self-consistent)
  - More accurate (closer to target)
- We know how to do it
  - Better clocks, better care, better time transfer

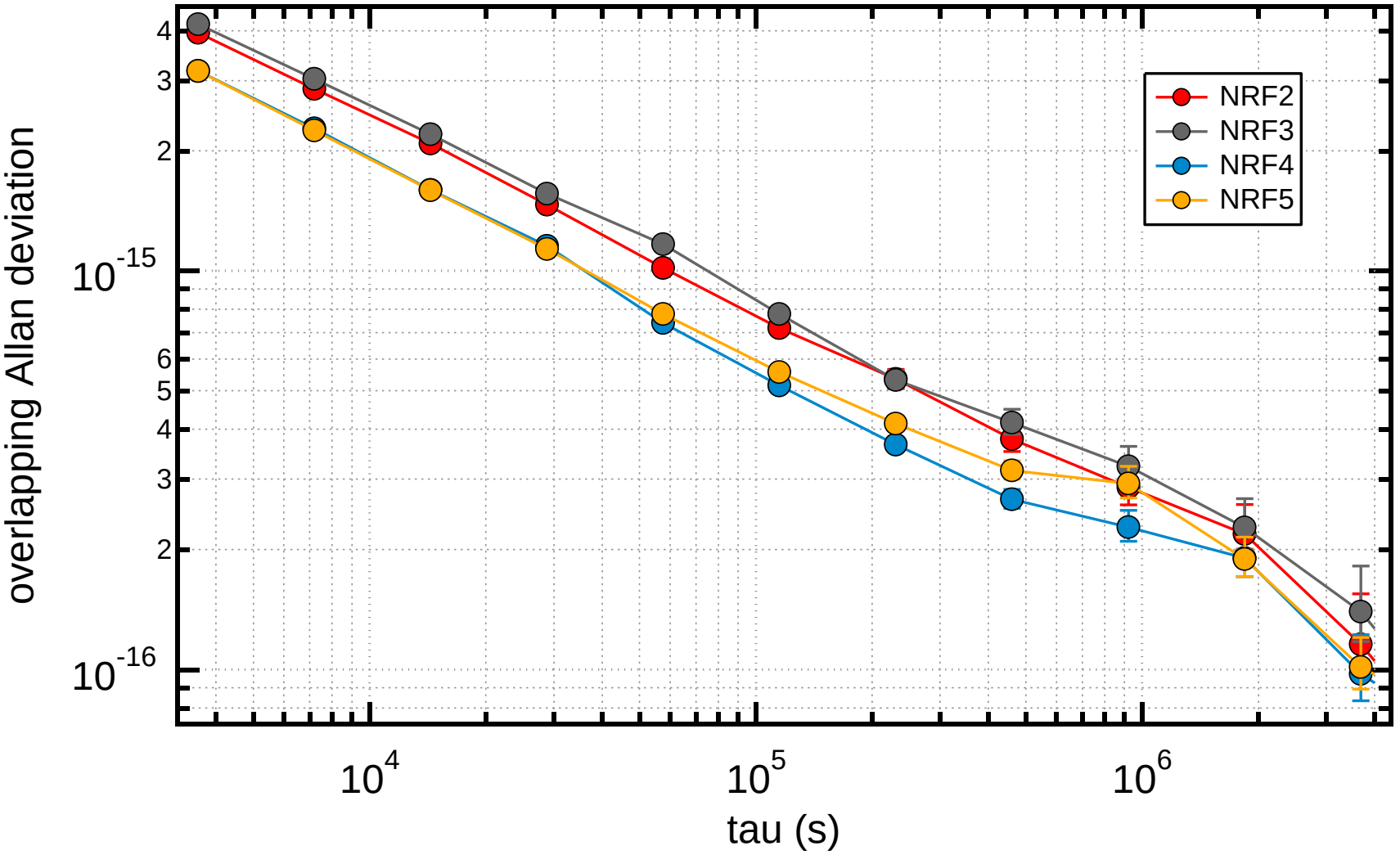
New Clock Building: testing better

Specifications: Temperature +/- 0.1 C Humidity +/- 3% RH *ALWAYS*

Fail-safe HVAC: second room ordered

Four Rb. Fountains In Use

three more under construction



Roadmap to Upgraded GPS

- USNO provides GPS with one datum per day
  - The daily average of UTC(USNO)-GPS
  - Upload source could be USNO-DC or USNO-AMC

- USNO directly supports two GPS Monitor Stations
  - USNO-DC is a GPS monitor station through NGA
  - USNO-AMC provides frequency to Colorado Springs Monitor Station

- In the not-so-distant future (GPS III OCX)
  - M-Code and modernized civilian signal monitoring will be implemented.
  - USNO could upload satellite-specific dual-frequency data as often as every15 minutes.
  - GPS to GNSS Time Offset
  - USNO and GPS to fully coordinate GPS bias signal pairs.
  - USNO-AMC will continue to be able to fully back up USNO-DC
    - Each will have three (3) rubidium fountains

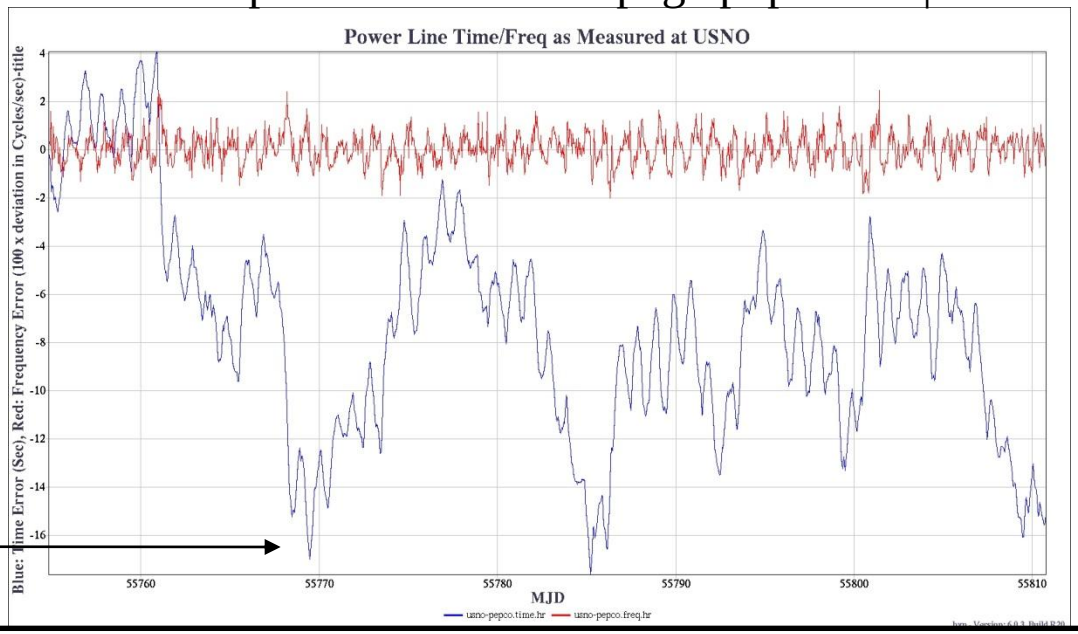
USNO Operational Clock Ensemble

- Clock Chambers Being Upgraded
- Cesium Ensemble
  - Replacement beam tubes fully funded
- Rubidium Fountains added to operational clock ensemble

- USNO also measures the Earth Orientation Parameters, including the Earth's rotational angle, for GPS

Why Does Your Alarm Clock Stay on Time?

- Henry Warren & the Boston Edison Power Co.
  - Demonstration October 16, 1916
- NERC Test under consideration
  - Freq. kept as close to 60 Hz as possible
  - East-coast clocks could drift 20 min/year
  - Other parts of USA to drift less
- See http://www.nerc.com/page.php?cid=6|386



hottest July on record

The Operating Committee in March 2012 voted not to pursue the manual time error correction elimination field trial. Major NIST effort to get this done!

Neutrino Timing for Project MINOS

If not super-luminal, then perhaps super-accurate

A Joint USNO-NIST Collaboration

The Libretto

September 29, 2011 – right after last year's ION Conference!

- OPERA announces that CERN's neutrinos arrived 60 ns too fast at Grand Sasso, Italy

November 18, 2011

- Statistically better firing pattern also yields 60 ns

February 23, 2012

- OPERA retracts its claim (bad cable/connection)

March 26, 2012

- ICARUS reports 7 neutrinos observed at light-speed

March 30, 2012

- OPERA leaders resign (as team leaders)

June 8, 2012 – At the 25th International Conference on Neutrino Physics and Astrophysics in Kyoto

- CERN declares that the speed of neutrinos is consistent with the speed of light, attributing the error to a faulty element in the fiber optic timing system

The MINOS Experiment

Detectors consist of alternating layers of steel plates and scintillator strips in a ~1.3 T toroidal magnetic field

735 km baseline

Conclusions

- **Time between Near and Far changes by less than 1 ns for each 300s point in the PPP solution (1-sigma: 0.248 ns)**
- **A Cs atomic clock has 2-sigma instability around 100 ps at 300 s**
- **Two separate GPS traveling systems had calibrations only 450 ps apart**
- **Multi-day PPP solutions minimize day-boundary discontinuities**
- **Relative timing accuracy better than 1 ns***
  - ***If the calibration works!**

PTTI-12

- PTTI = Precise Time and Time Interval
- PTTI Systems and Applications Meeting
  - Nov 26-29, 2012
  - Reston, VA
- For meeting: http://www.pttimeeting.org
  - For past papers too

Summary

- USNO specializes in real-time timekeeping
  - UTC realization
  - Dissemination
  - Monitoring
  - Device and analysis R&D
- Upgrades are continuously happening
- We work for you