



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

**Stephen Mitchell**

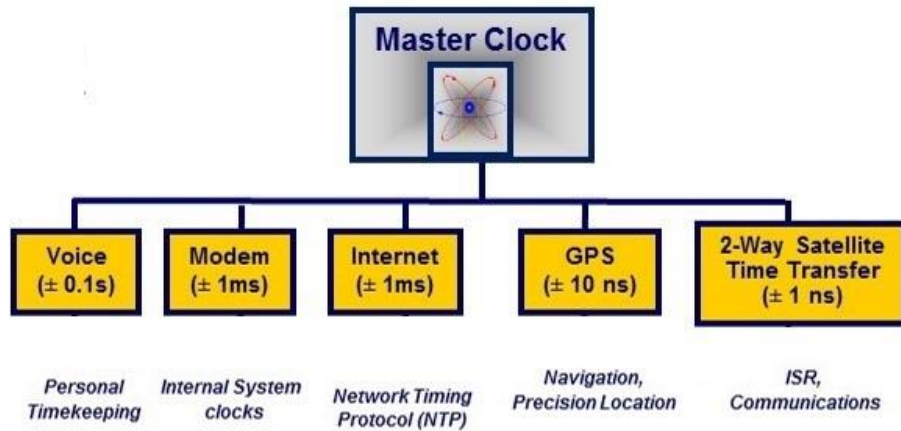
**U.S. Naval Observatory (USNO)**

**September 16, 2019**



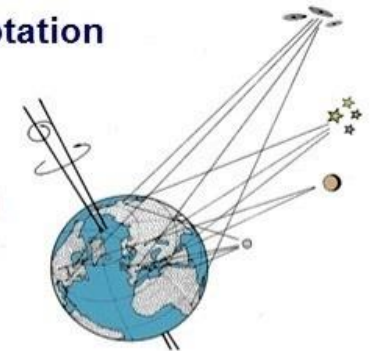
# USNO Mission Areas

## Precise Time

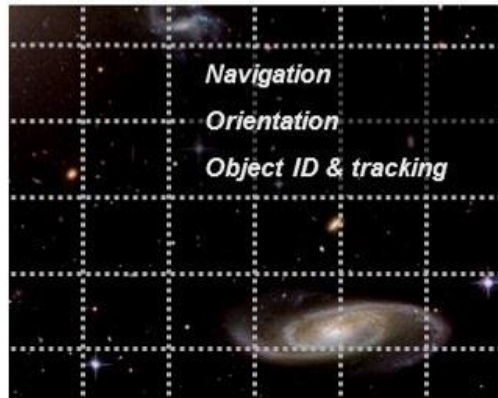
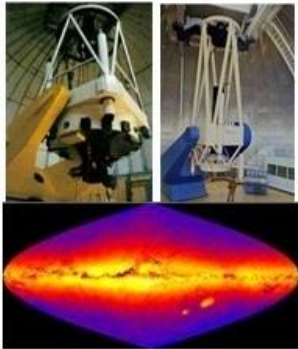


## Earth Orientation Parameters

- ★ Departures from “pure” rotation
- ★ Synchs the earth and its orbiting space platforms
- ★ **GPS Error = 2 meters w/in 1 week & 400 meters at 6 months w/o EOP**



## Astrometry – star positions & motions



## Astronomical Applications



Solar/Lunar Illumination



Almanacs & Celestial Navigation



# Precise Timing Applications



Communications



Power Grid



Financial

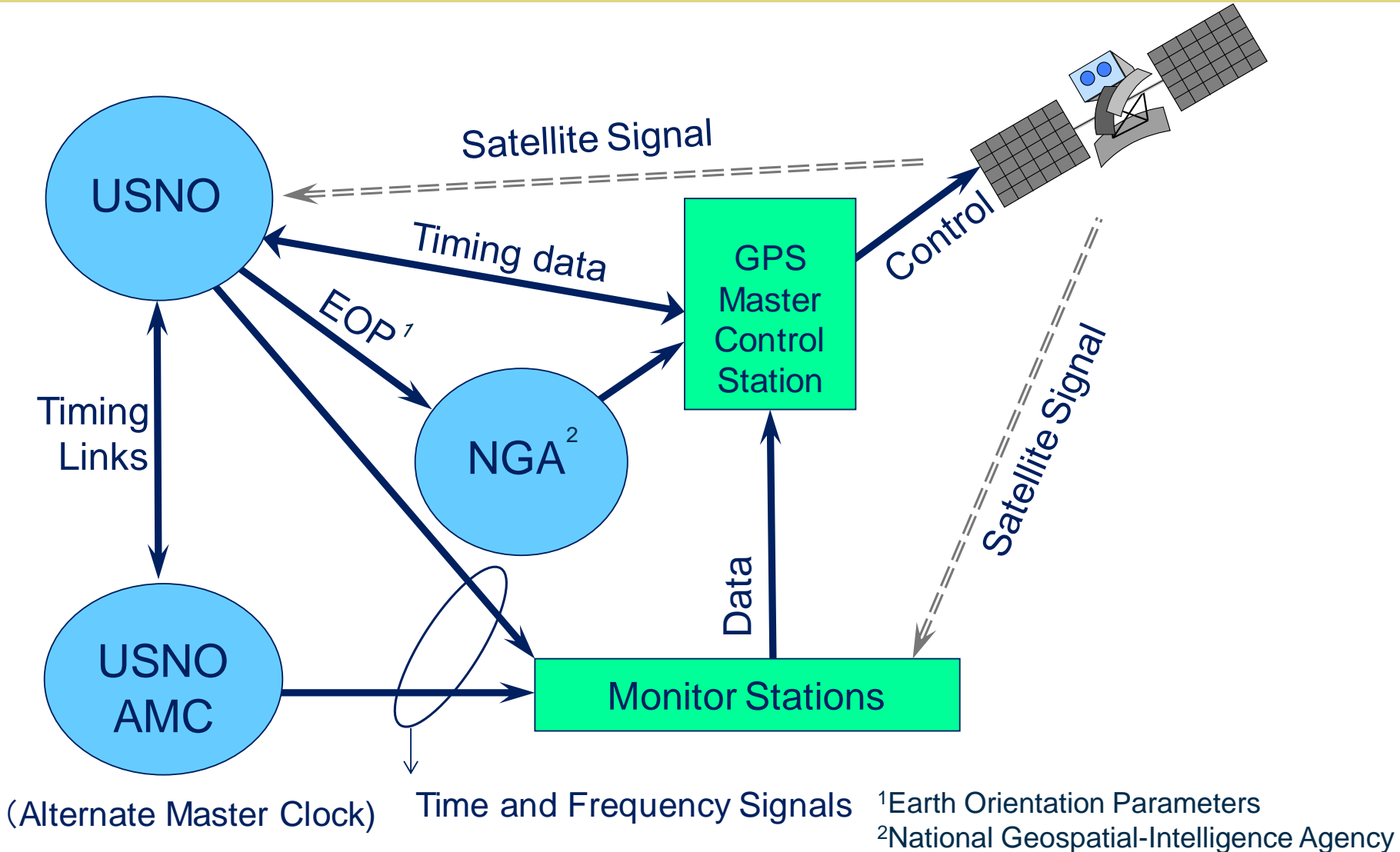


Scientific

Precise Timing is Critical to the  
Modern World's Infrastructure



# GPS Operations and USNO





# GPS Time and USNO

## GPS Time

- Internal system timescale of GPS
- Continuous → No leap seconds; fixed to UTC on January 6<sup>th</sup>, 1980
- 18 seconds off from UTC now
- An intelligent average of satellite and ground monitor station 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 United States Air Force (USAF)

## USAF 2<sup>nd</sup> Space Operations Squadron (2SOPS) use these data to steer GPS Time to match UTC(USNO) modulo 1s

- There are no time or frequency steps in GPS Time, only steps in the frequency drift

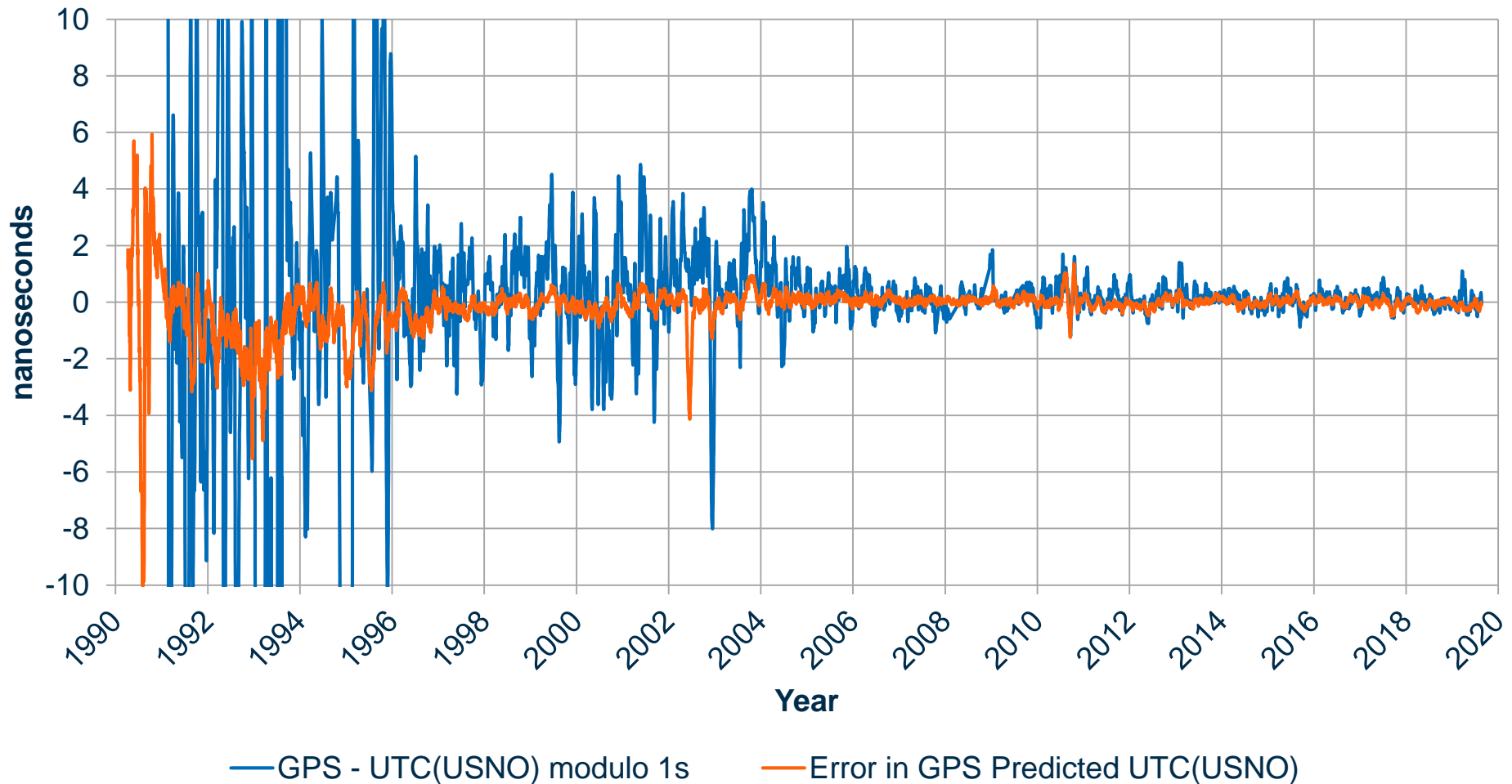
## GPS delivers timing and frequency offsets to convert from GPS Time to a prediction of UTC(USNO)

- This information is contained in the GPS Legacy Navigation (LNAV) data in Subframe 4, Page 18 (SF4P18), and in the modernized Civil Navigation (CNAV) in Message Type 33



# GPS Time Delivery, 30-day Averages

GPS Time and GPS Predicted UTC(USNO)  
1 month smoothed

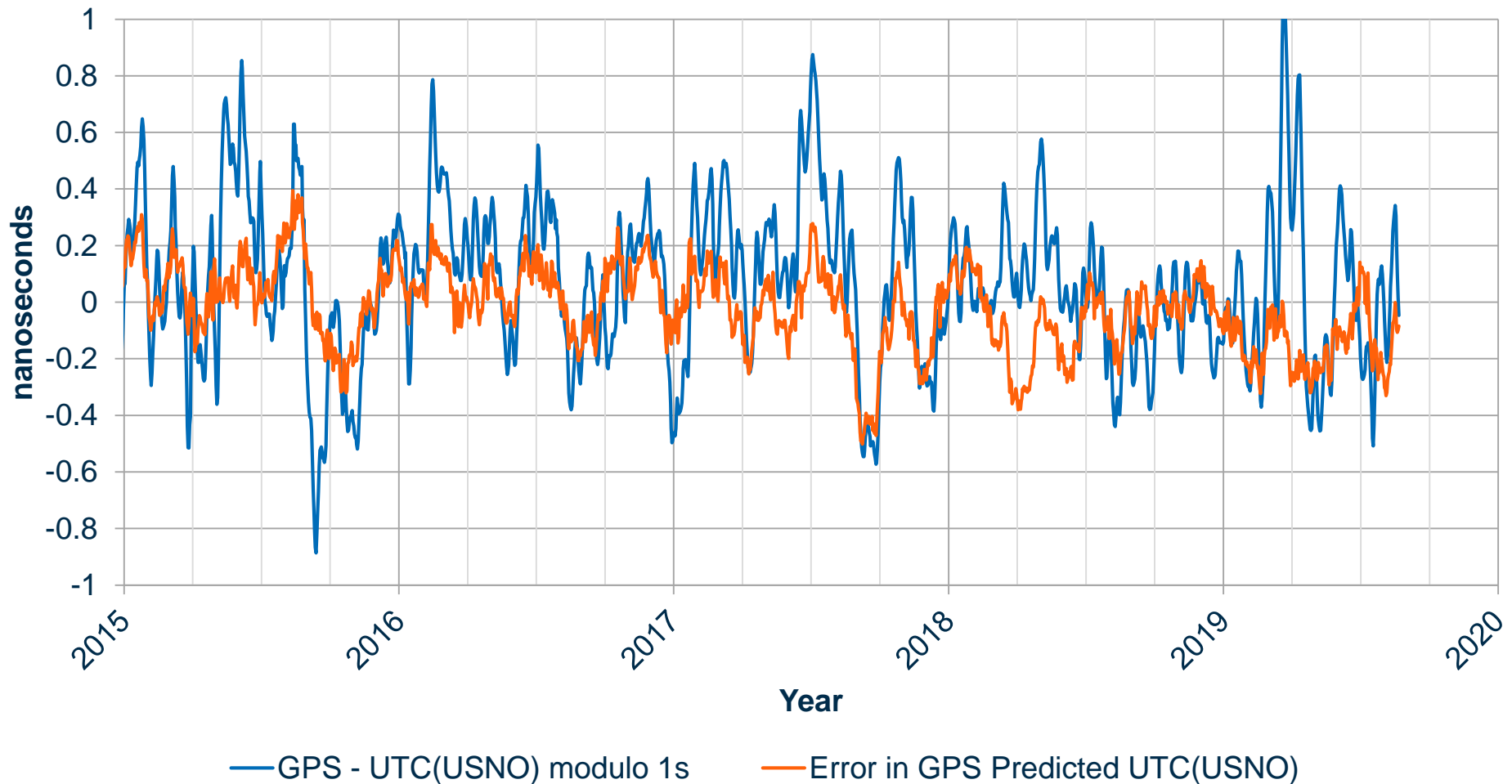






# GPS Timing, More Recent History

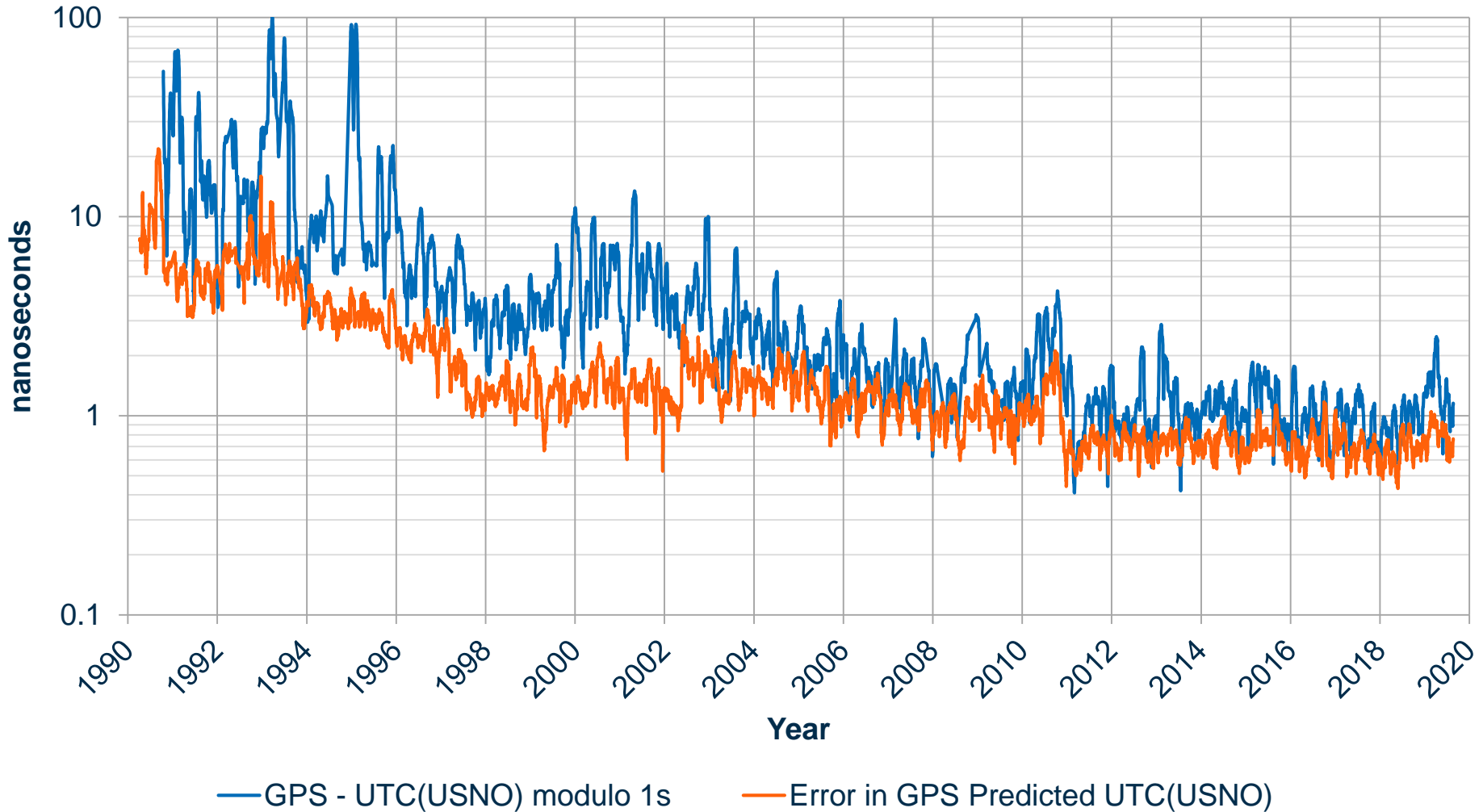
GPS Time and GPS Predicted UTC(USNO)  
1 month smoothed





# GPS Timing Instability

## Monthly RMS of Daily Solutions







# GPS + other GNSS Added Benefit

## GNSS: Global Navigation Satellite System (such as GPS, GALILEO, etc.)

### Increased reliability and availability of Position, Navigation, and Timing

- Especially in challenging environments such as urban canyons where users can only see 1-2 satellites from each system

### Challenge: Ensure interoperability of all different GNSS

- Need to measure and report timing offset between systems
  - GPS-to-GNSS Time Offset (GGTO)
- Requires stable, repeatable GNSS receiver calibration for all GNSS signals

### USNO will provide GGTOs for broadcast by GPS

- USNO is presently providing both GLONASS and Galileo time differences in support of special CNAV testing (not presently being broadcast)
- CNAV Message Type 35 contains the GPS-to-GNSS Offset (GGTO) for various systems
- Current schedule for broadcast is 2022 with the GPS Next Generation Operational Control System (OCX)



# USNO Additional GPS III support

**USNO will act to coordinate GPS Time with other Global Navigation Satellite Systems' Time and provide a correction message to GPS (GGTO)**

**Also supporting OCX, USNO will work with USAF for the determination of the GPS satellite and reference stations inter-signal and inter-frequency biases**

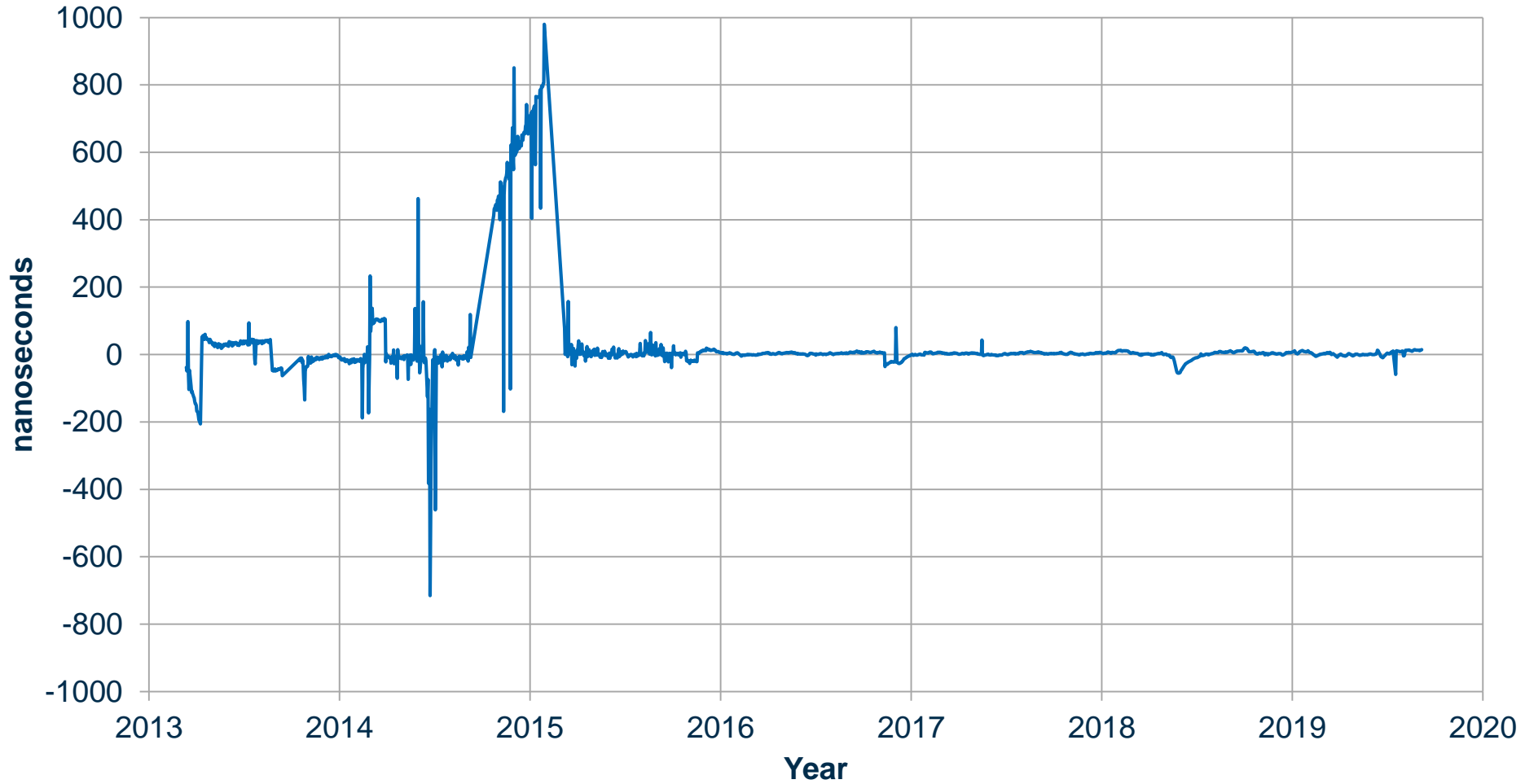
- This is needed to ensure that average constellation biases are removed in a consistent way to ensure accuracy for timing user community
- Absolute calibrations to be used by USNO

**GNSS simulator calibration procedures are being validated and tested to ensure consistency and accuracy**



# GALILEO GGTO

## GPS Time - GALILEO Time (modulo 1s)





# GALILEO GGTO

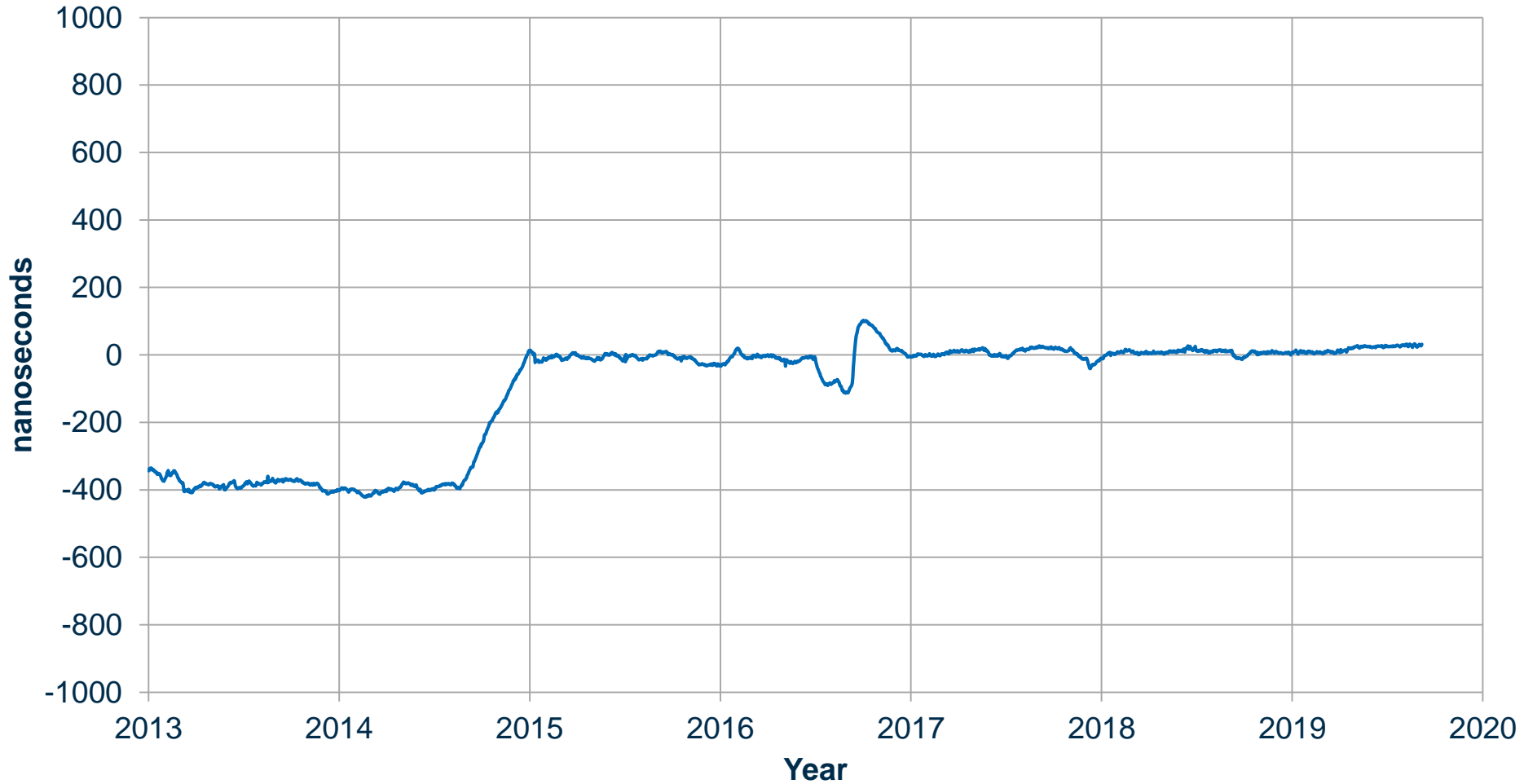
## GPS Time - GALILEO Time (modulo 1s)





# GLONASS GGTO

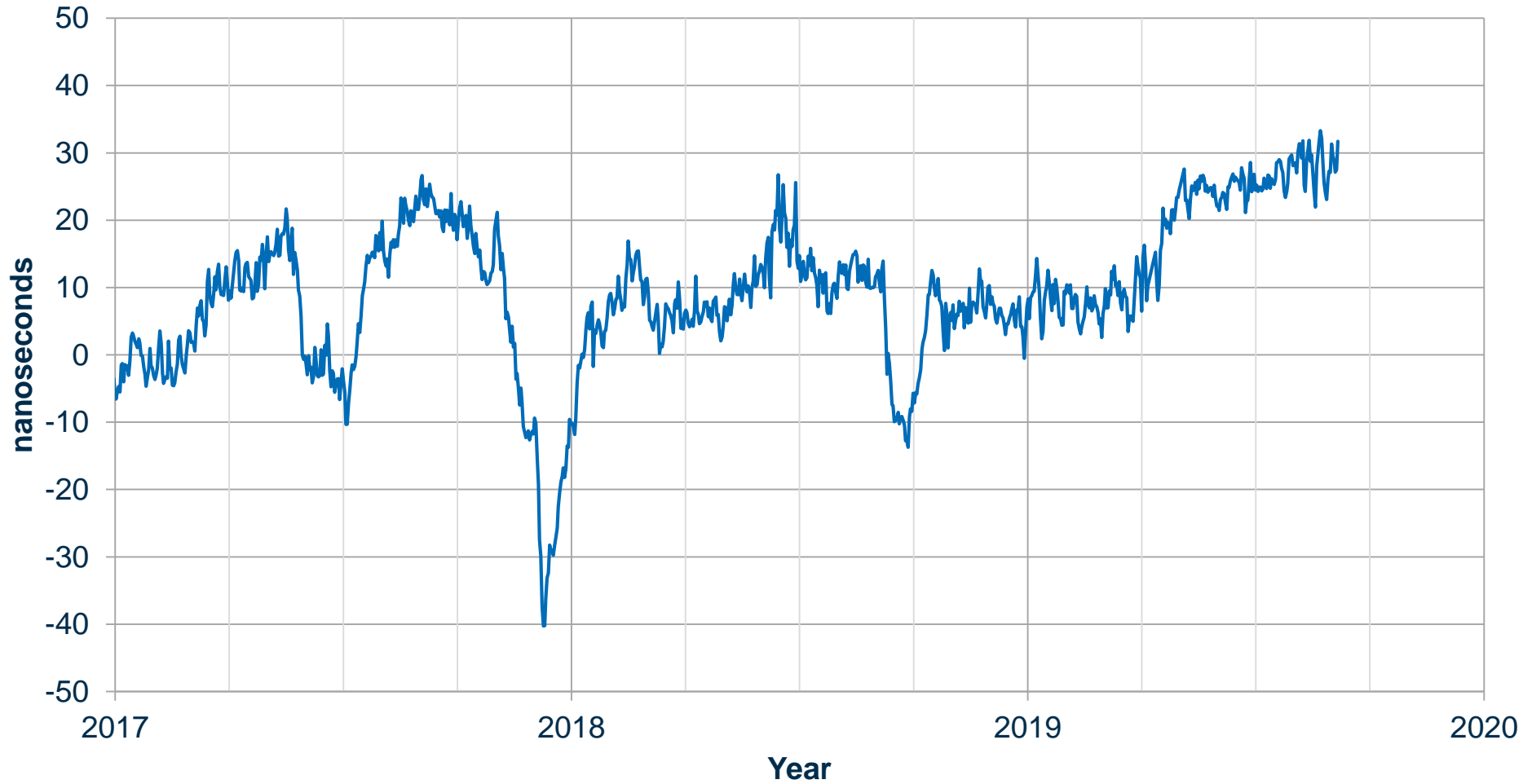
## GPS Time - GLONASS Time (modulo 1s)





# GLONASS GGTO

## GPS Time - GLONASS Time (modulo 1s)







# Summary

## USNO specializes in real-time timekeeping

## GPS supports many Precise Time Users

## USNO provides the timing reference for GPS

- Monitor and report the offset of GPS Time from UTC(USNO)
- Ensure the validity of reported numbers through receiver calibrations

## USNO monitors other GNSS Time

- Will report GGTO data to GPS with OCX





# Backup Slides





# GPS Week Rollover

GPS Time is defined in the legacy GPS navigation message to cover finite period of 1024 weeks due to its 10 bit representation

GPS started on Jan 6, 1980

The first GPS Time Epoch ended on Aug 21/22 1999, the second on April 6/7 2019.

GPS Time is presently in its third Epoch which will end on November 20, 2038.

It is up to the user and user receiver to resolve this week number ambiguity

The Modernized Navigation message has a 13-bit week number, which for all practical purposes will not encounter a rollover