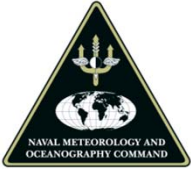


Two-Way Satellite Time Transfer

Co-Program Managers:

Angela McKinley

Jonathan Hirschauer



Overview

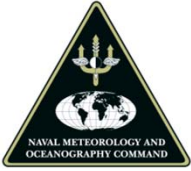


- ★ **People**

- ★ **Projects**

- **Calibration**
- **Earth Station Upgrades**
- **Data Analysis**
- **Testing**

- ★ **Future**



People



★ Time Transfer Division Chief

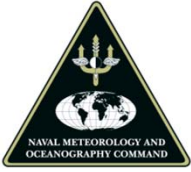
- Edward Powers

★ Electronics Engineers

- Angela McKinley
- Jonathan Hirschauer
- Russell Bumgarner

★ Electronics Technicians

- Jordan Wright
- Michael Christensen

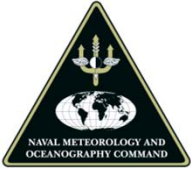


Projects: Calibration



- ★ **NIST**
- ★ **MINOS**
- ★ **PTB**
- ★ **Many Others**



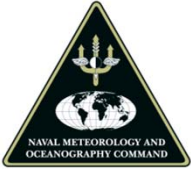


PTB and NIST Calibrations



MJD	Calendar Date	USNO-PTB	Cal-Circular T	Technique/Ref
55301	15APR10	-19.1 ns	-1 ns	GPS [20]
55649	29MAR11	0.1 ns	+2 ns	TWSTT
56072	25MAY12	0.8 ns	+1 ns	TWSTT

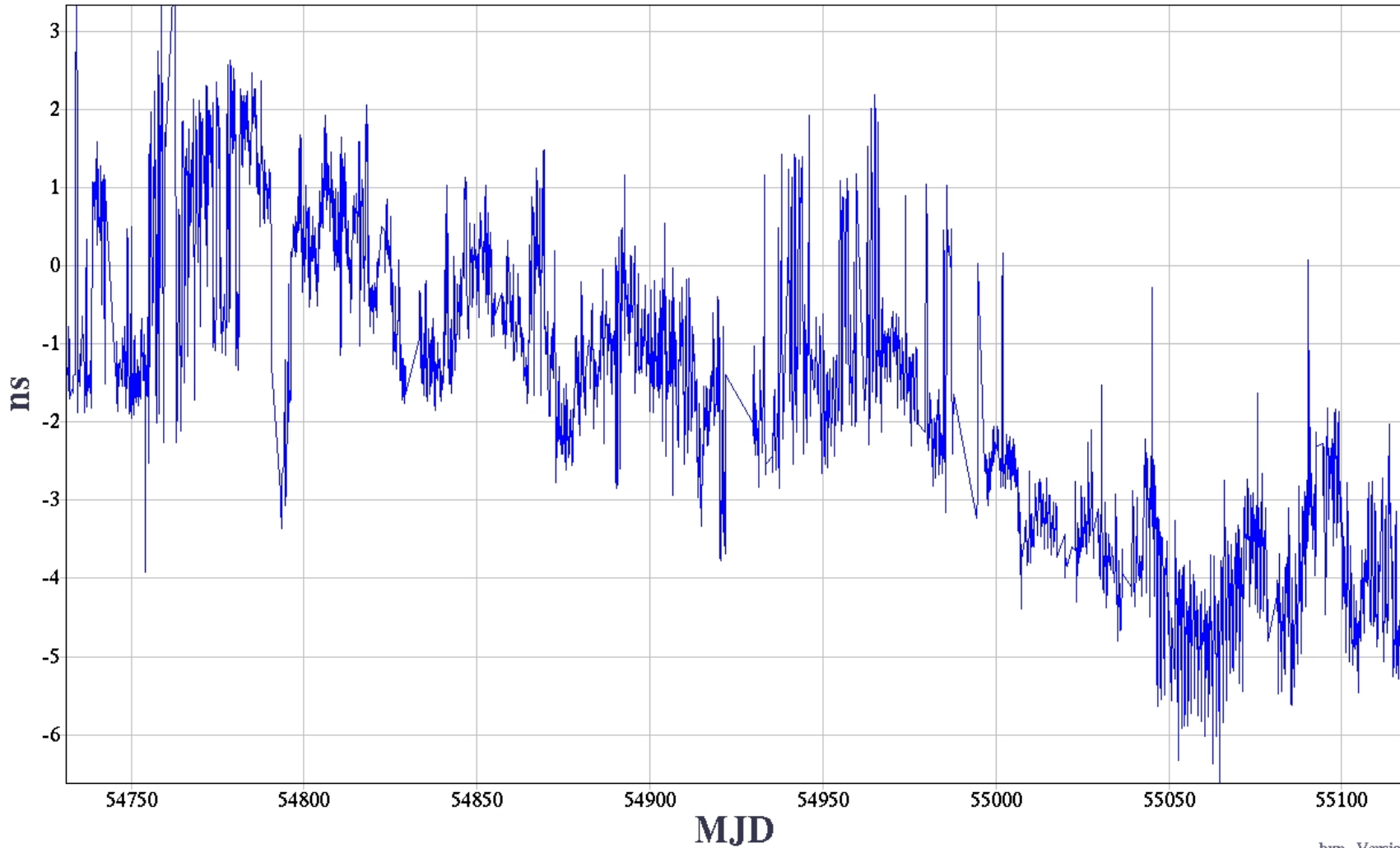
MJD	Calendar Date	USNO-NIST	Cal-CircularT	Cal-CircularT With TWSTT Corrections for USNO-PTB	Technique/Ref
54916	29MAR09	9.9	6.1	-	TWSTT
54992	10JUN09	9.2	7.2	-	TWSTT
55418	10AUG10	-6.0	3.6	4.6	TWSTT
55628	08MAR11	12.3	5.0	3.0	TWSTT
55755	13JUL11	11.5	4.1	4.1	TWSTT
56043	26APR12	10.1	5.7	4.6	TWSTT
56121	12JUL12	5.0	4.2	4.2	TWSTT



I Know What We Did Three Summers Ago



Double-Difference: USNO-PTB Ku-band minus X-band TWSTT

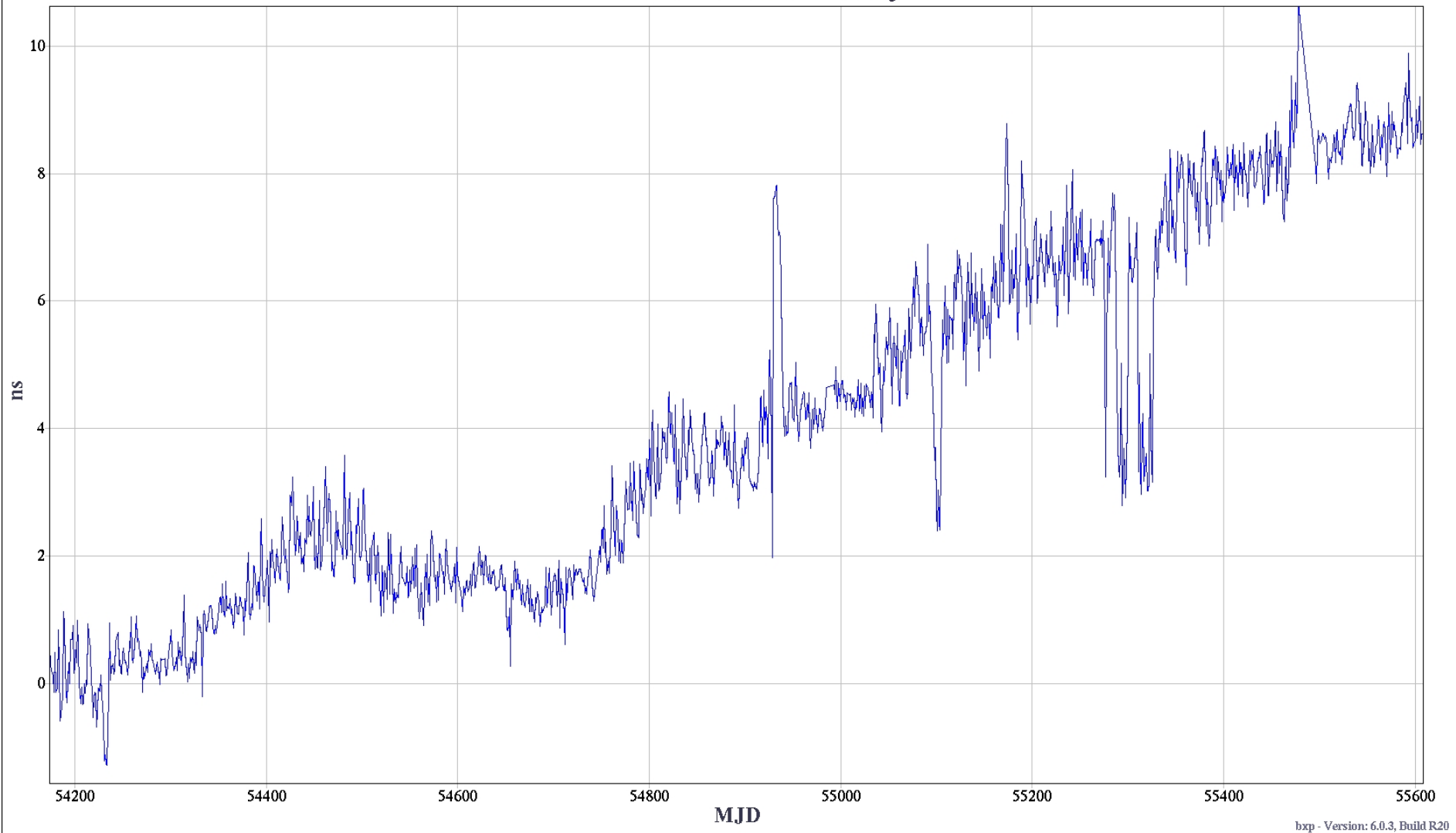




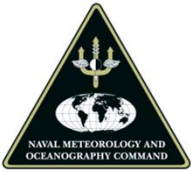
I know why I didn't see this for so long



Two Common-Clock TWSTT Systems

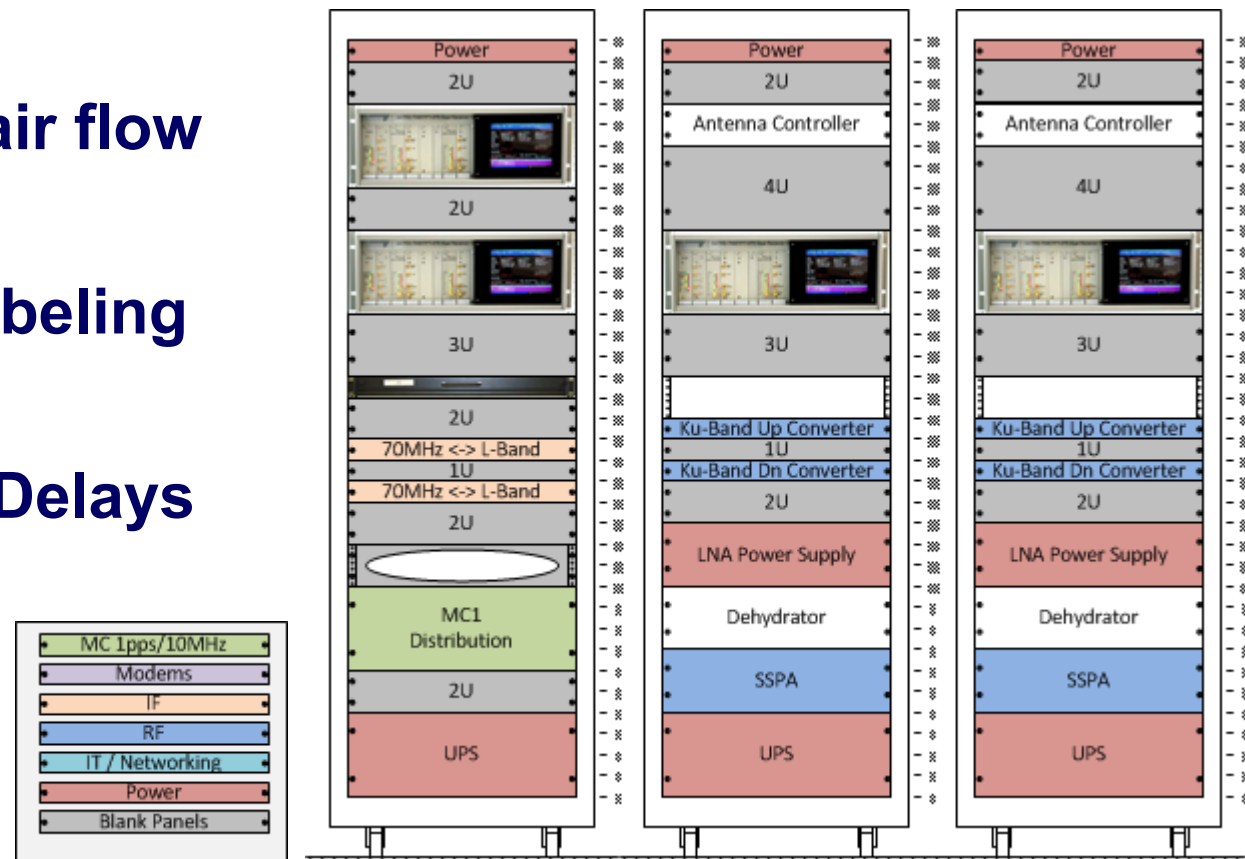


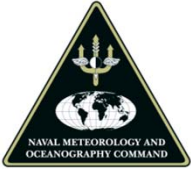
Delay shift could be due to electronics or fiber-optics feeding the TWSTT hardware



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



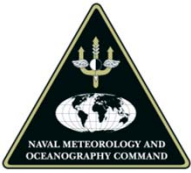


Projects: Data Analysis

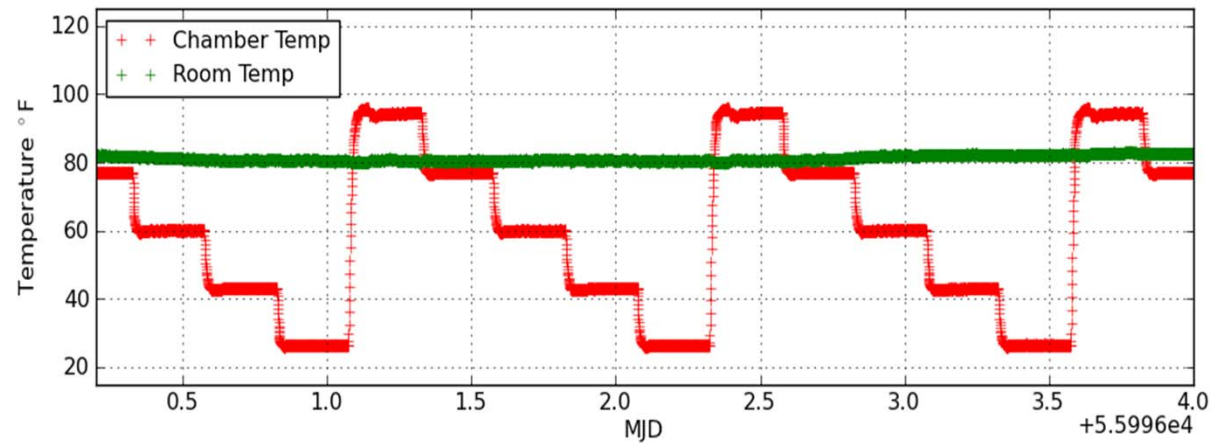
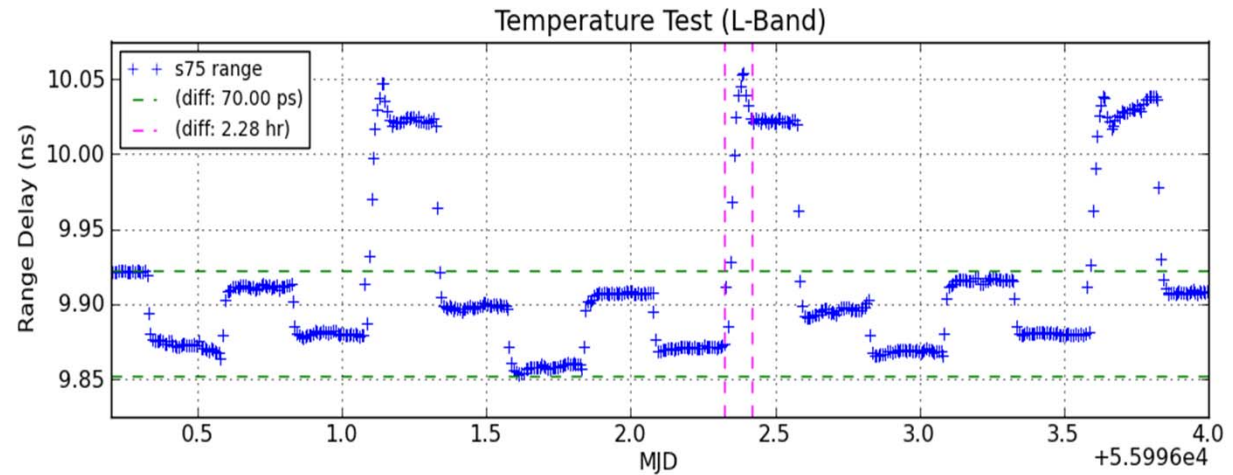
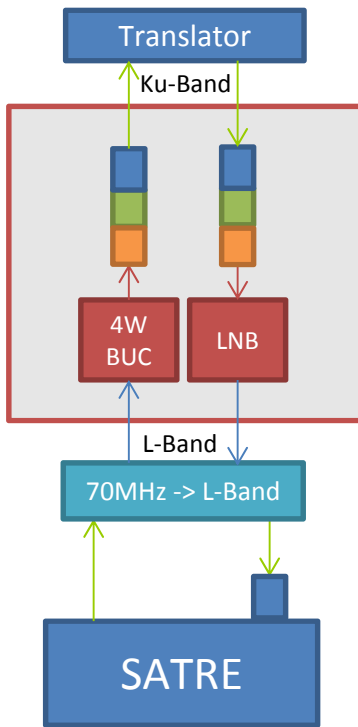


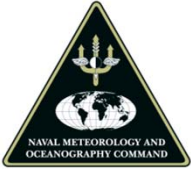
Two-Way Satellite Time Transfer: Data Analysis



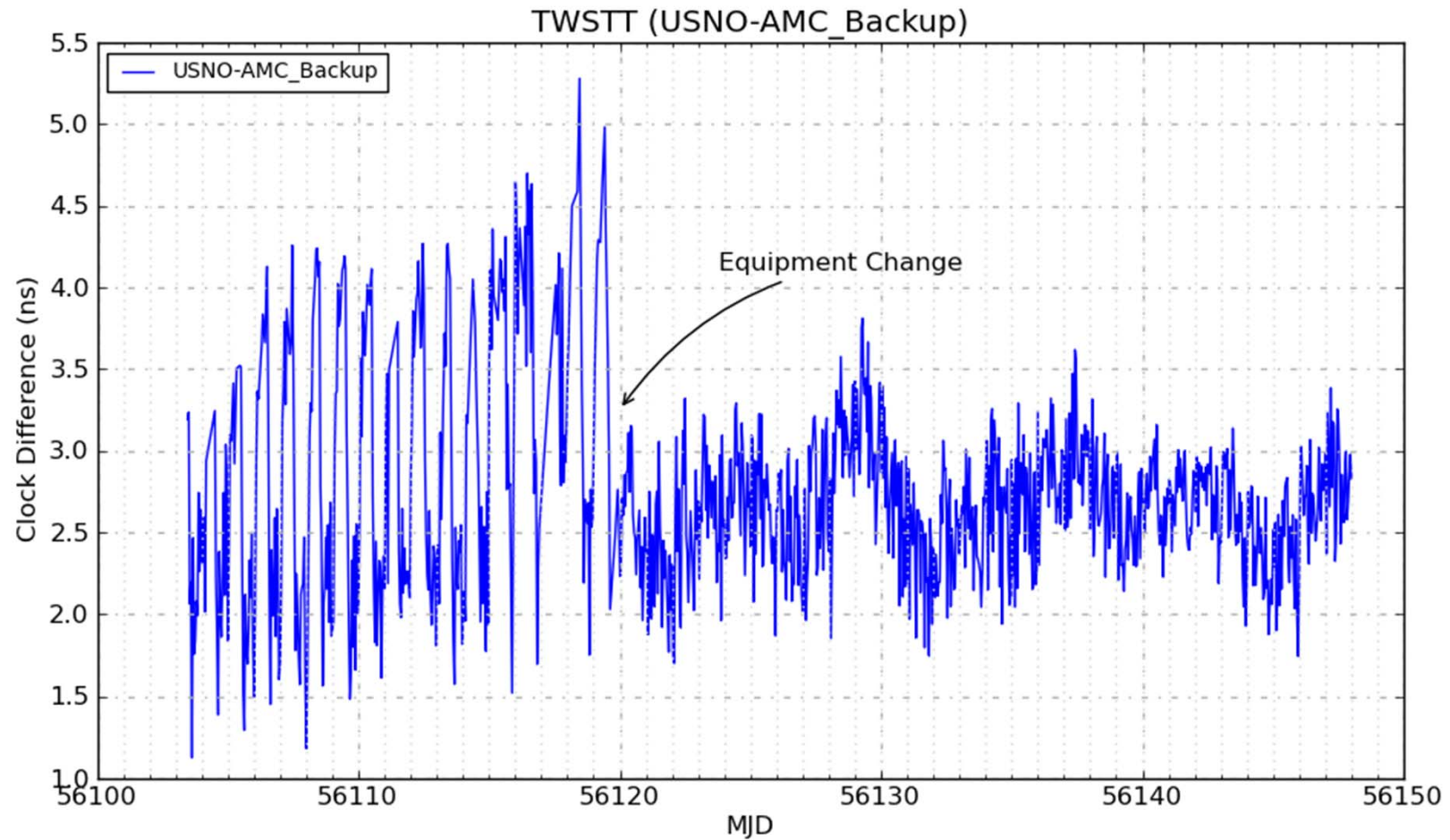


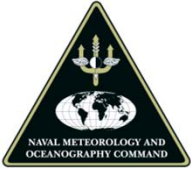
Projects: Testing



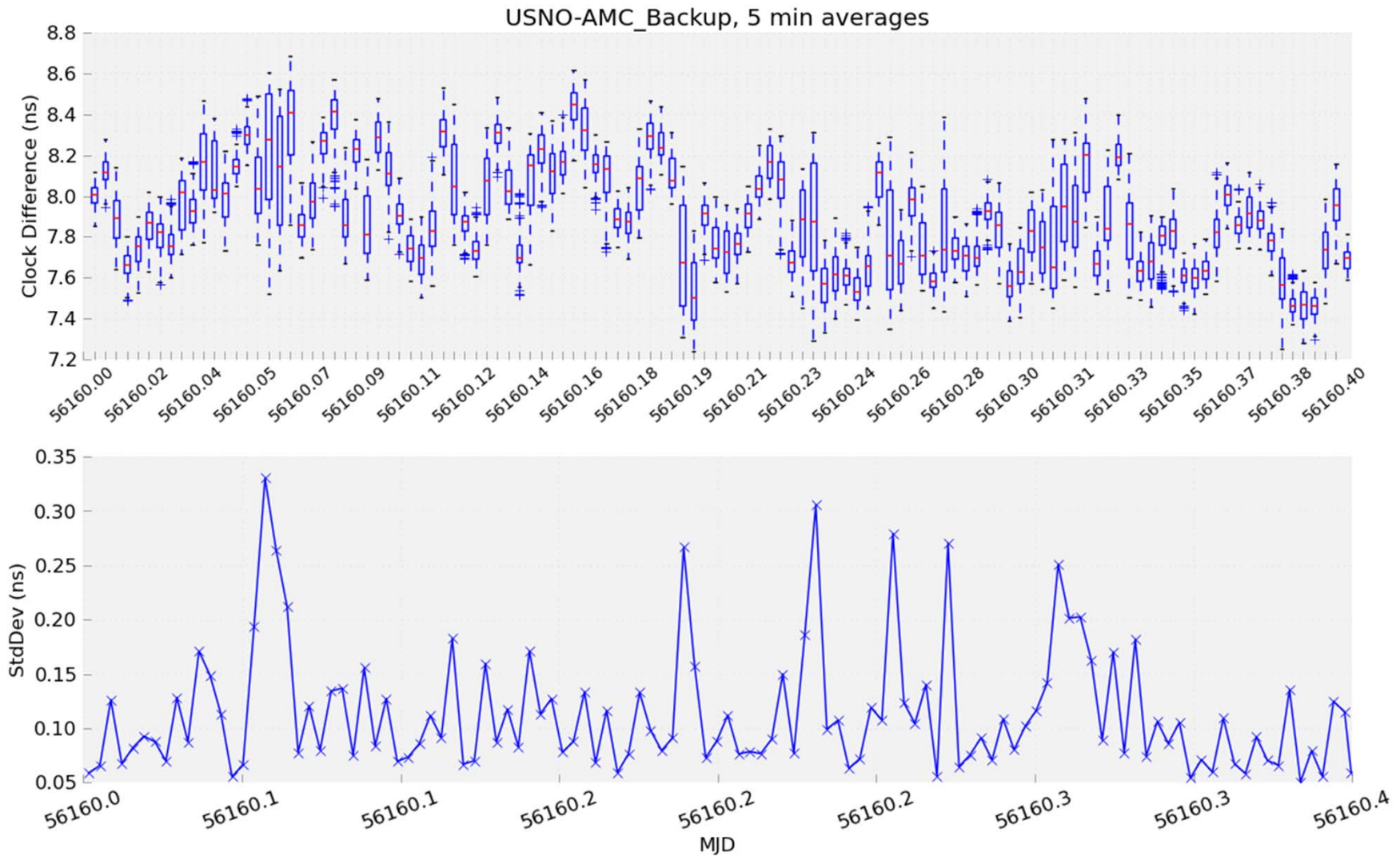


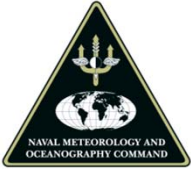
L-band exterior path antenna





Non-Gaussian Noise @ 5 min

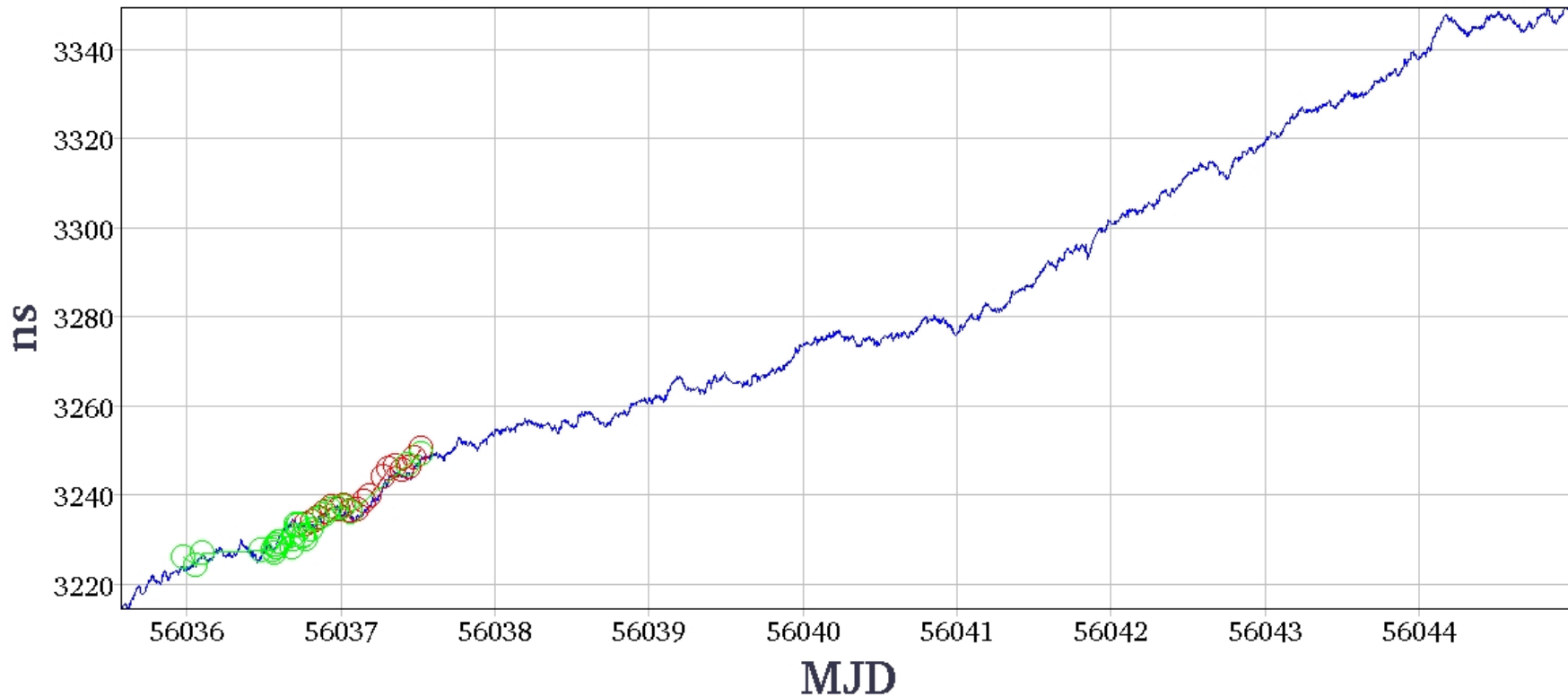




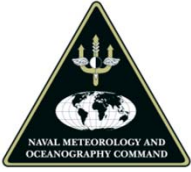
Calibration Works!



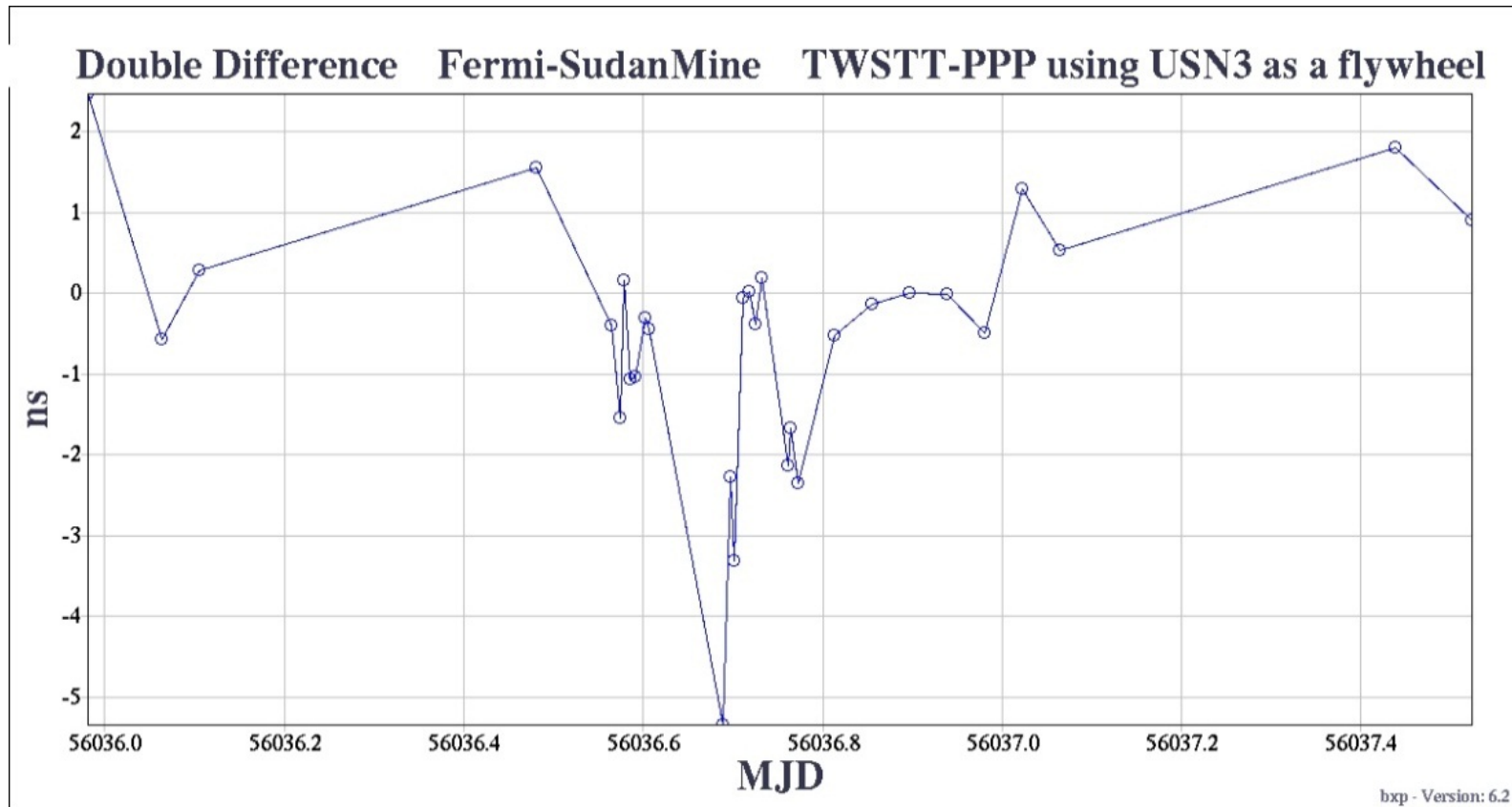
Fermilab-SoudanMine Cesium Clock Differences

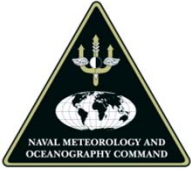


— Measured with GPS PPP —○— Measured with Direct TWSTT —○— Measured with TWSTT to USNO (indirect)

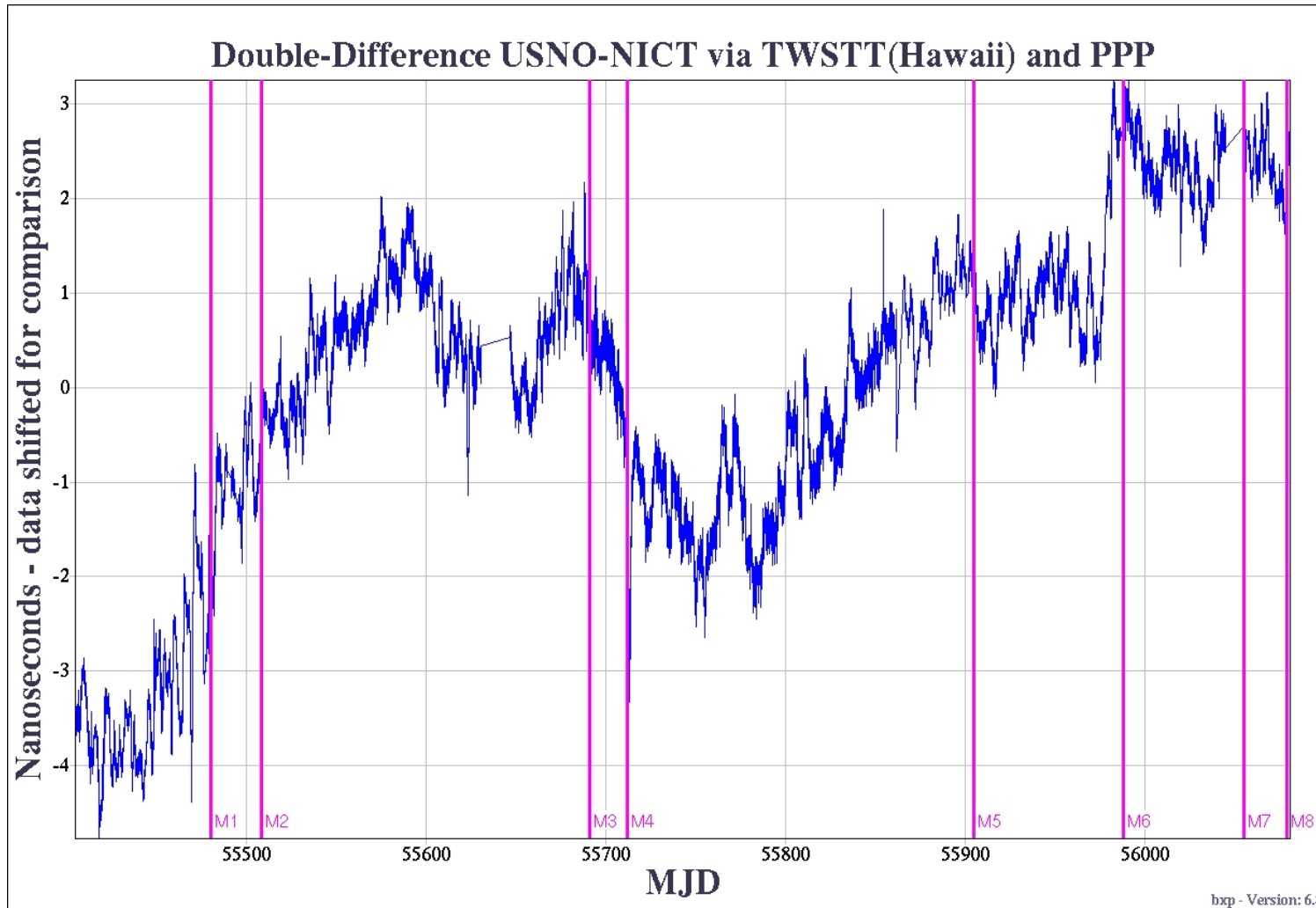


... to 1 ns RMS, with editing

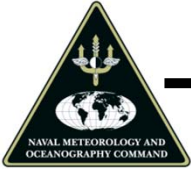




USNO-NICT, PPP-TWSTT

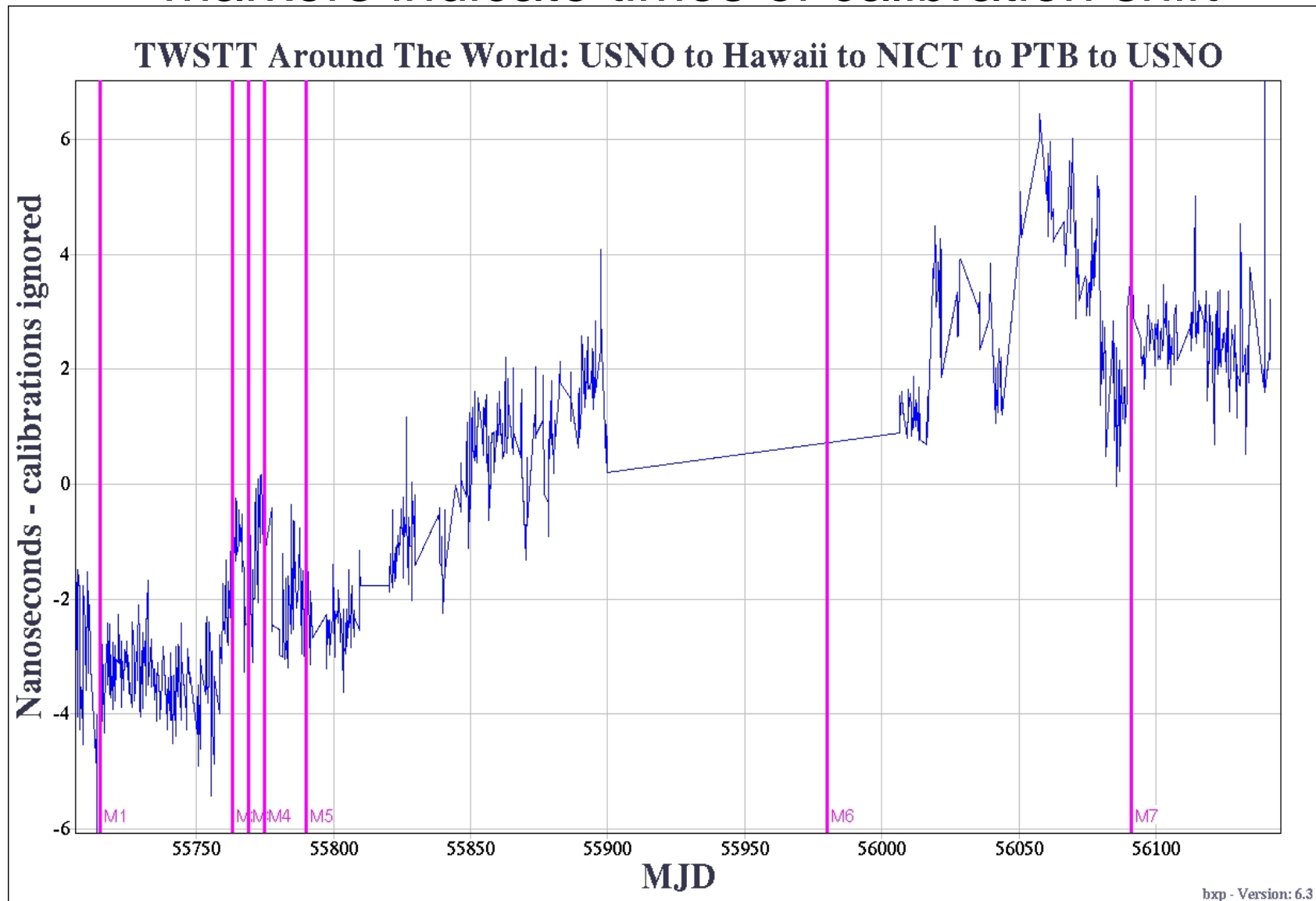


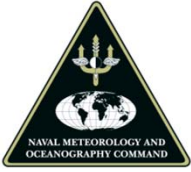
Markers Denote Times of Manual Adjustments



TWSTTing "Round the World"

markers indicate times of calibration shift

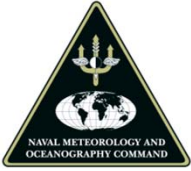




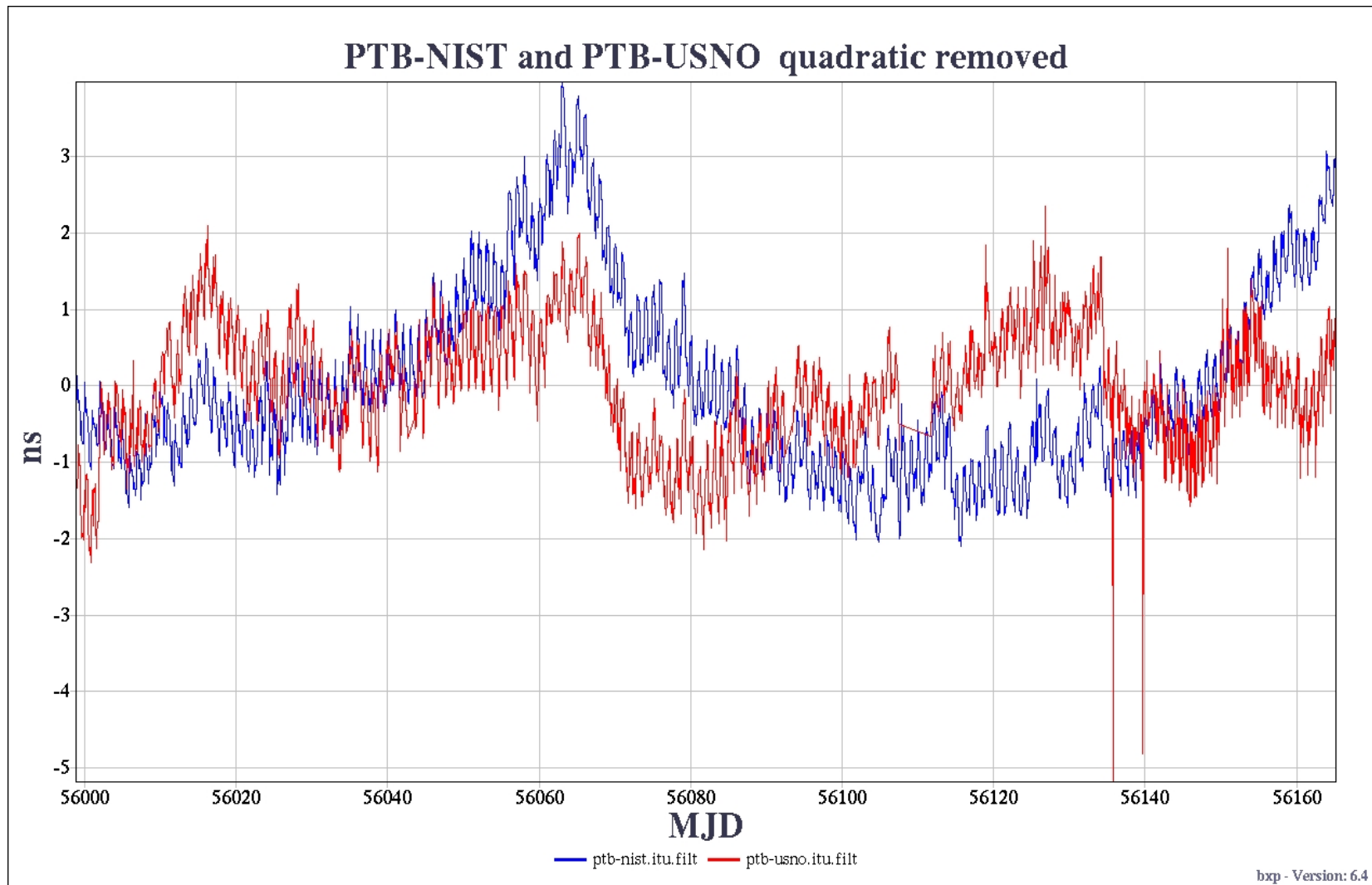
Future Plans (possible)

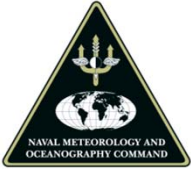


- ★ **Environmental characterization of Equipment Delays**
- ★ **In-Depth Analysis of Non-Gaussian Noise (modems?)**
- ★ **Developing New Calibration Techniques**
 - **Calibration in parts (measure the delay through each device)**
- ★ **Fiber Optic Upgrades/Testing (for AMC link)**
- ★ **In-House TWSTT Modem (FPGA/DSP)**

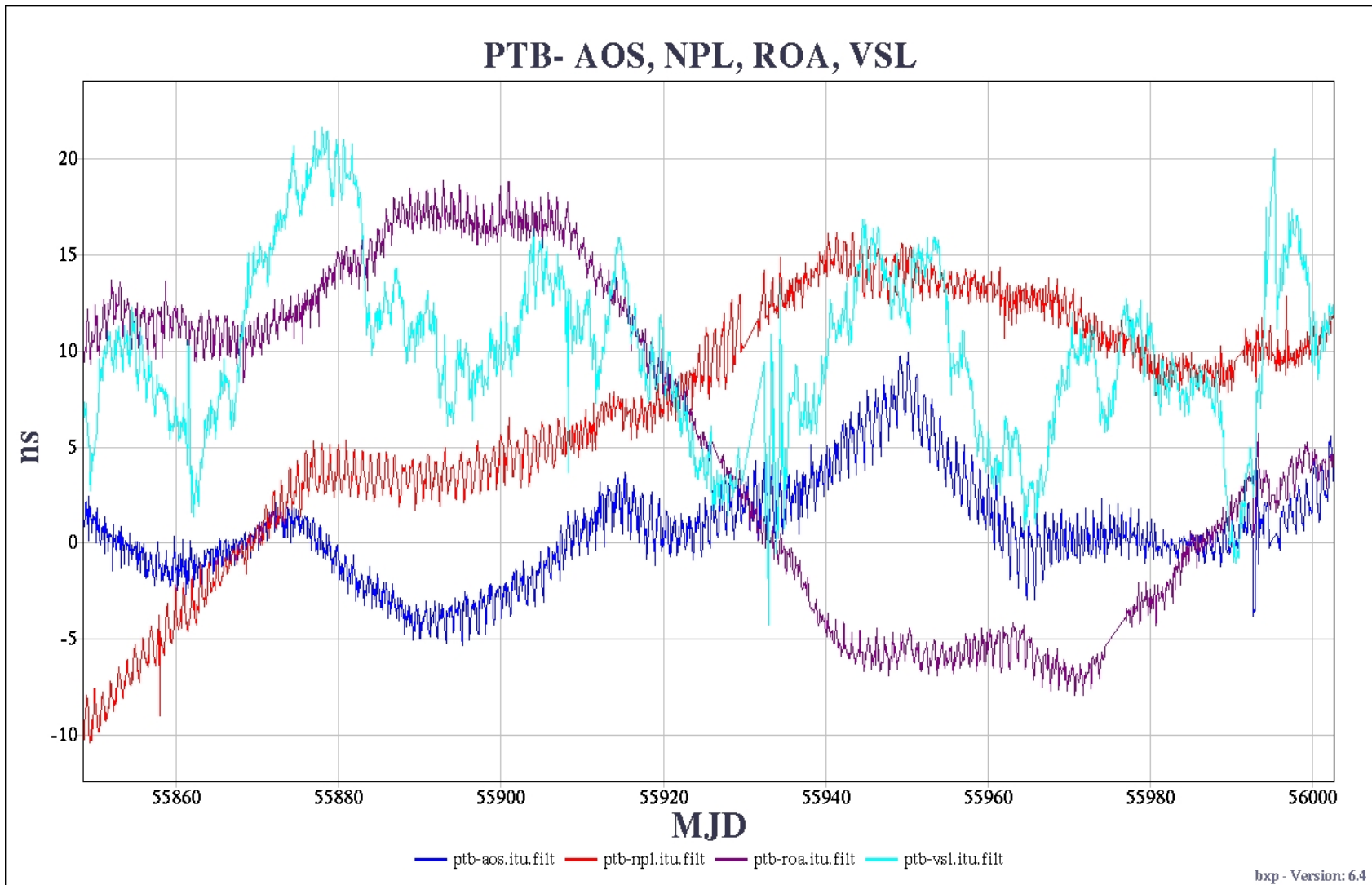


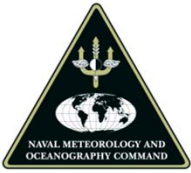
Diurnals PTB-NIST and USNO



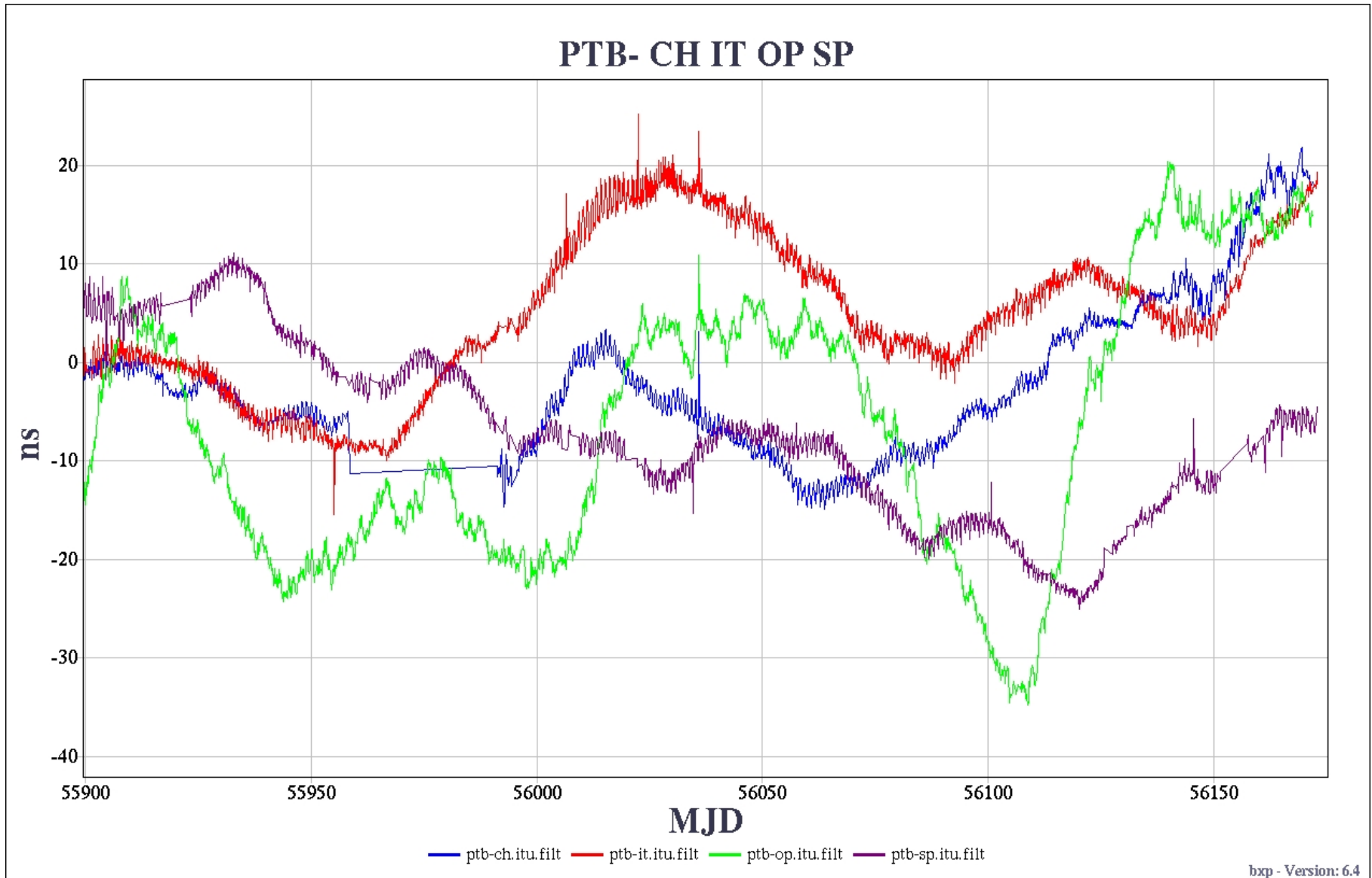


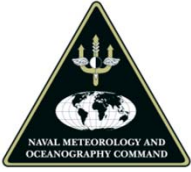
PTB – VSL has no diurnals now





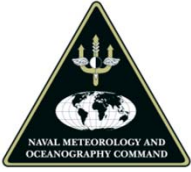
PTB-OP has no diurnals now



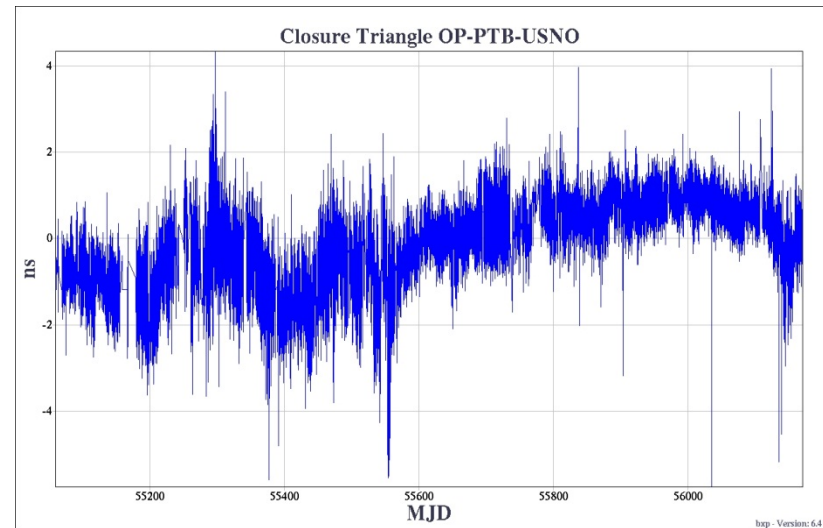
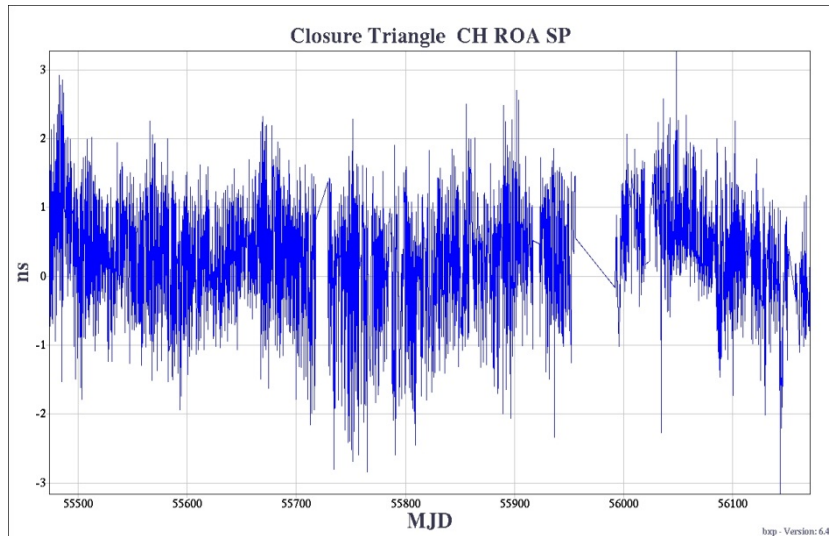
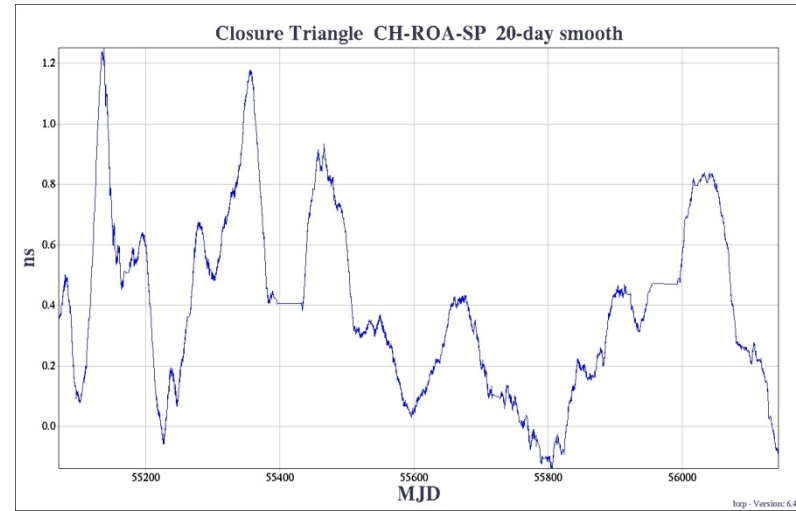
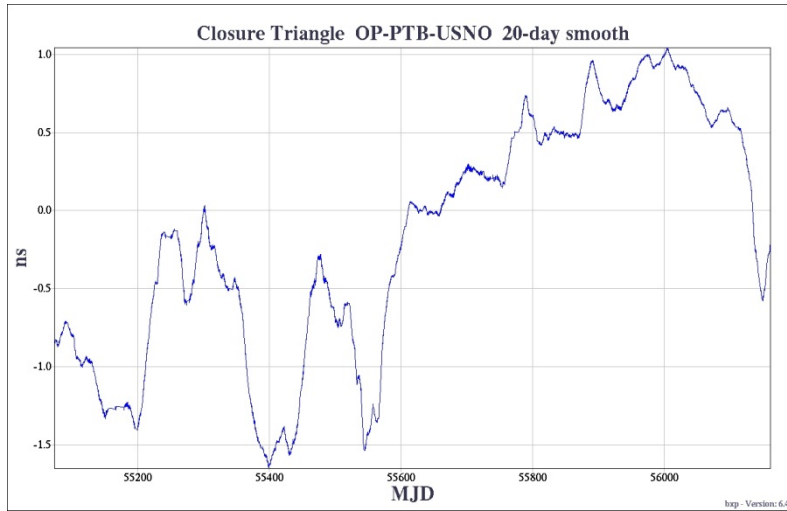


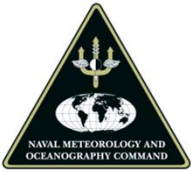
Triangle Closure Sums

- ★ Let X , Y , and Z be UTC of any three labs
- ★ Observe $XY = X - Y$
- ★ Observe $YZ = Y - Z$
- ★ Observe $ZX = Z - X$
- ★ **Triangle Closure Sum = $XY + YZ + ZX$**
 - If properly calibrated it **MUST** be zero
 - Uncalibrated TWSTFT would be zero anyway, except for certain ns-level effects (MBE? See Schaefer's PTTI paper)
 - It is insensitive to clock variations
 - If it changes, then the calibration changed
 - Europe-only sums insensitive to site-based TWSTFT calibration variations
 - Transatlantic sums sensitive to some site-based calibration changes
 - Always it is a lower bound on TWSTFT calibration variations

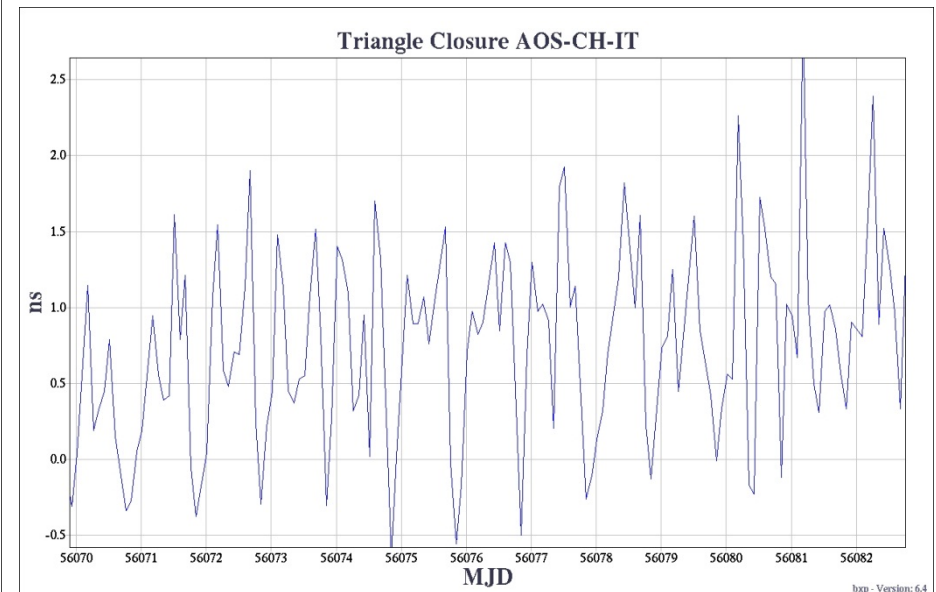
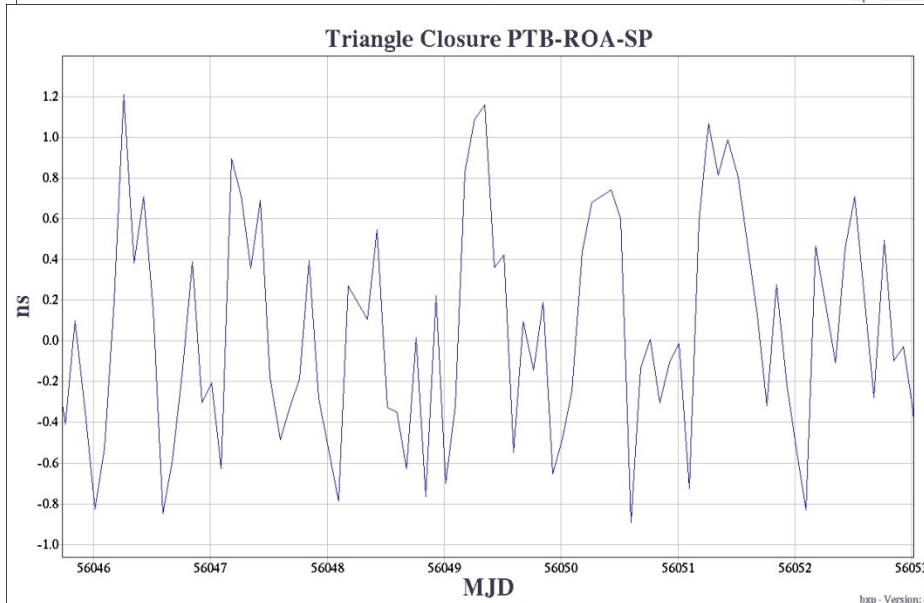
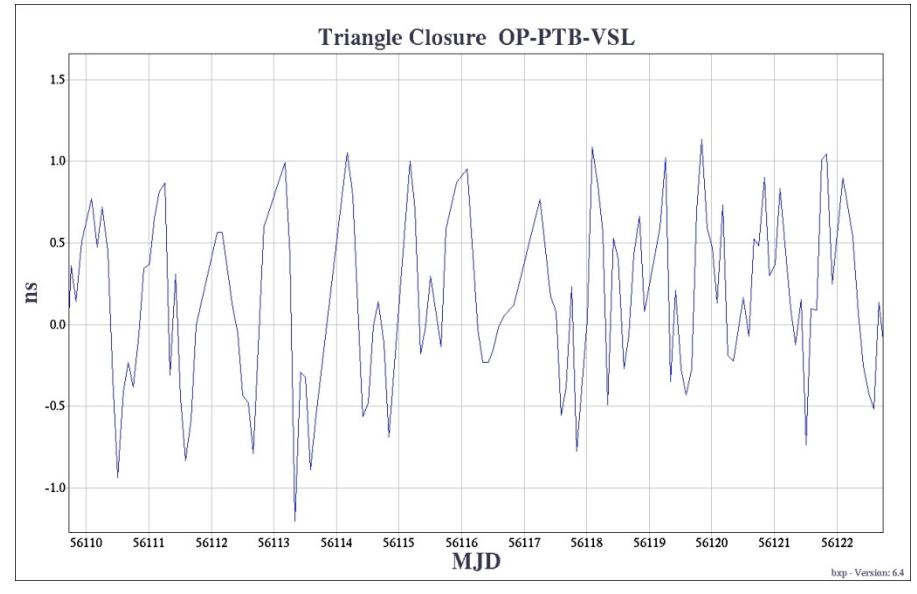
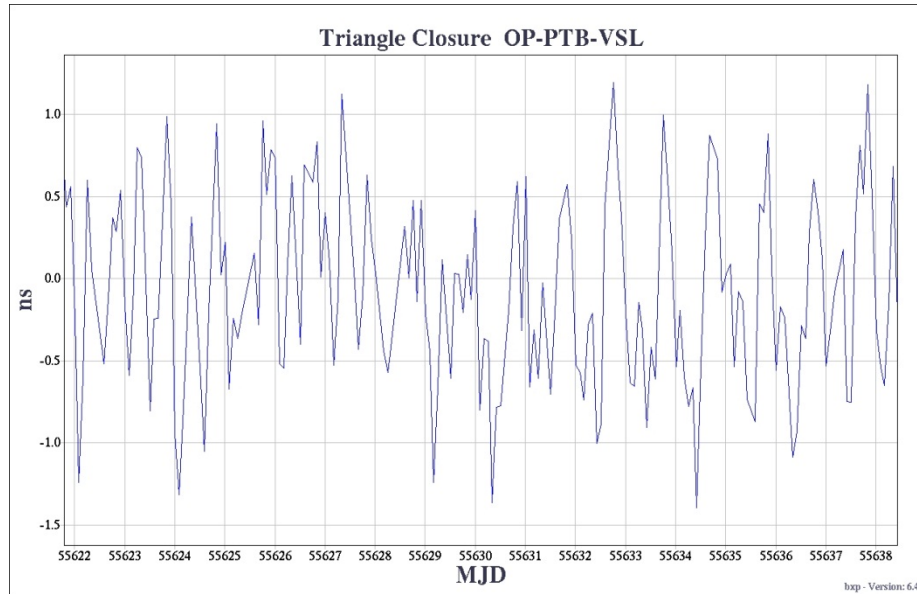


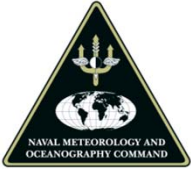
Closure Sums on the Move





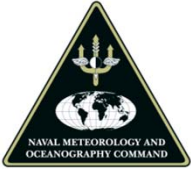
Closure Diurnals – are they real?





-Backup Slides-





TWSTT Challenges

