

Predicting UT1-UTC

a work in progress

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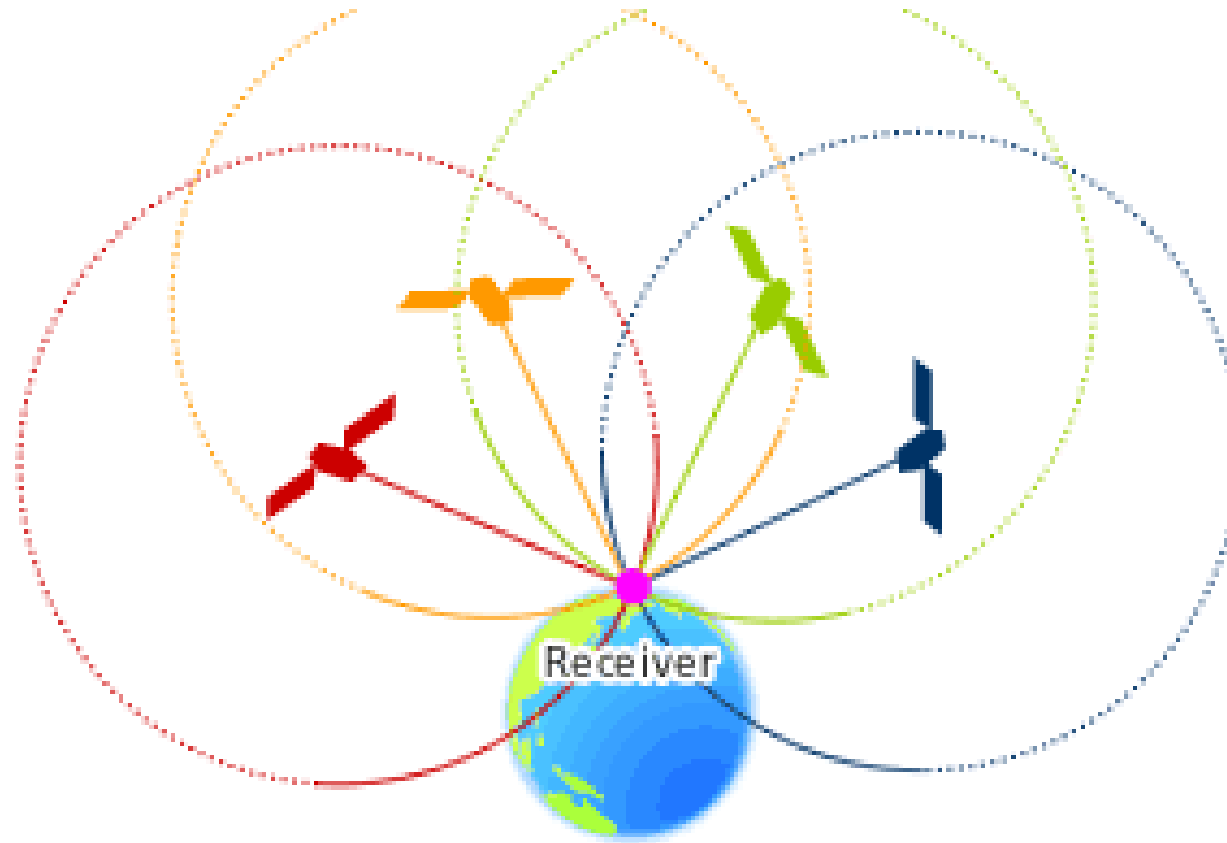
CGSIC Timing Subcommittee

September 24, 2018

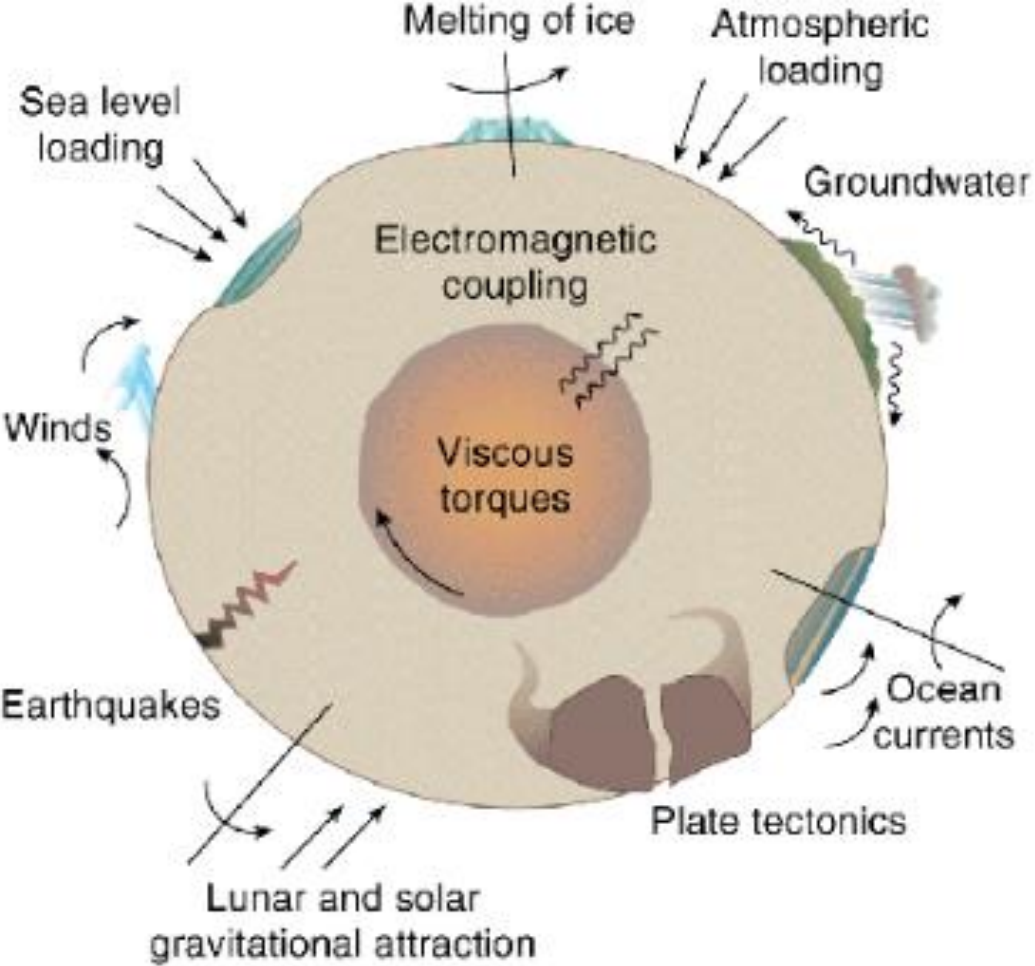
Talk Outline

- Why predict UT1?
- The data
 - IGS products for LOD
 - VLBI solutions for UT1
 - Atmospheric Angular Momentum
- Kalman Filter predictions
- Summary

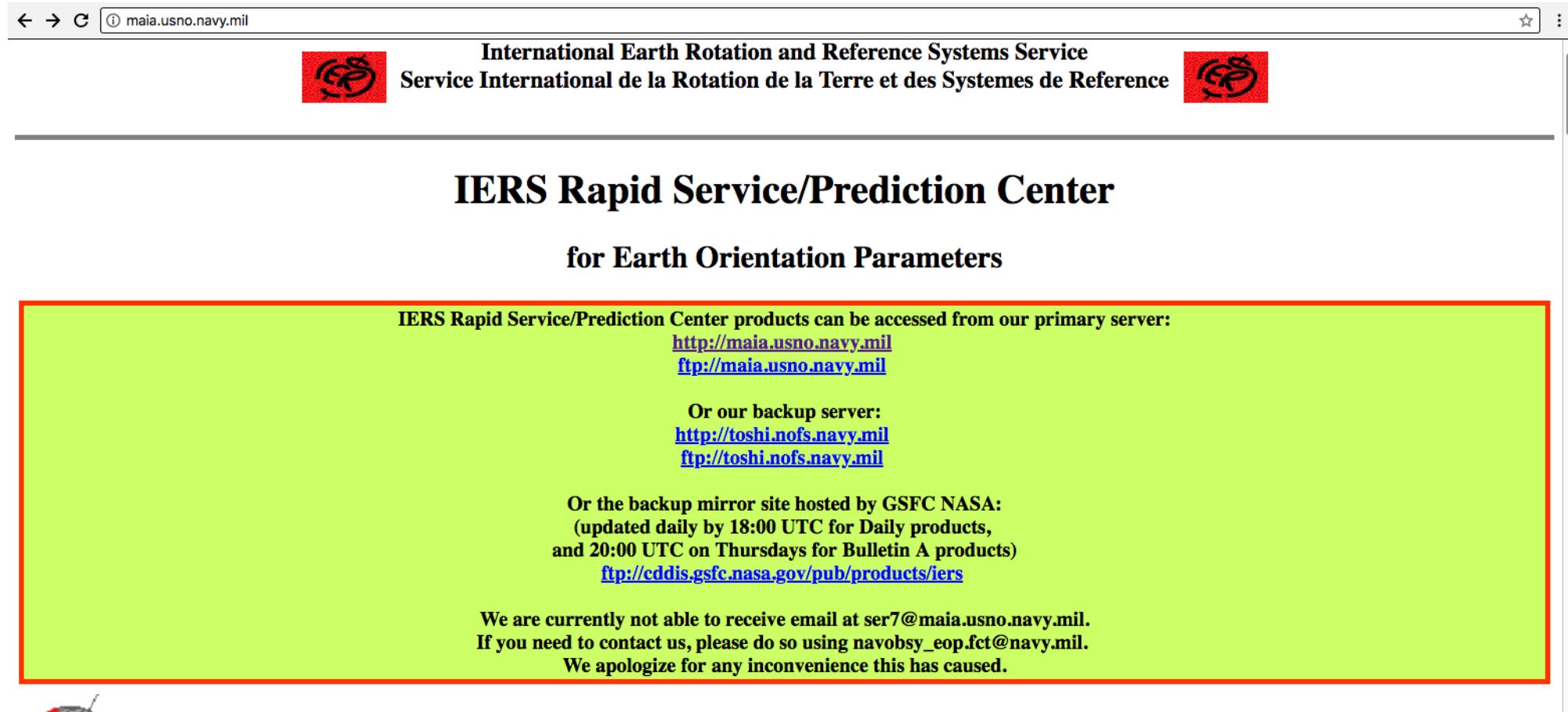
Corrected pseudo-ranges give coordinates with respect to the GNSS constellation





Must also locate the Earth with respect to the constellation



US Naval Observatory to the rescue!



← → C maia.usno.navy.mil ☆

 **International Earth Rotation and Reference Systems Service**
Service International de la Rotation de la Terre et des Systemes de Reference 

IERS Rapid Service/Prediction Center

for Earth Orientation Parameters

IERS Rapid Service/Prediction Center products can be accessed from our primary server:
<http://maia.usno.navy.mil>
<ftp://maia.usno.navy.mil>

Or our backup server:
<http://toshi.nofs.navy.mil>
<ftp://toshi.nofs.navy.mil>

Or the backup mirror site hosted by GSFC NASA:
(updated daily by 18:00 UTC for Daily products,
and 20:00 UTC on Thursdays for Bulletin A products)
<ftp://cddis.gsfc.nasa.gov/pub/products/iers>

We are currently not able to receive email at ser7@maia.usno.navy.mil.
If you need to contact us, please do so using navobsy_eop.fct@navy.mil.
We apologize for any inconvenience this has caused.

Along with a large community of Earth rotation specialists, of course!!

The family of Universal Times

- UT = generic term for the **rotational angle** of the Earth
 - Before the atomic age, UT was considered to be a measure of time itself
 - Nowadays time is best estimated with atomic clocks
 - Coordinated Universal Time (UTC)
 - UT1 = True measure of Earth's rotational angle
 - Other forms of UT, used for research, etc.
 - UT0 = Earth's angle as measured at one site
 - Contaminated by mis-estimation of pole's position
 - UT2 = Rotational angle using model to remove seasonal variations
 - UT1R= Earth's rotation with short-term tidal effects (<40 days) removed
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- See "Science Background" tab of www.iers.org



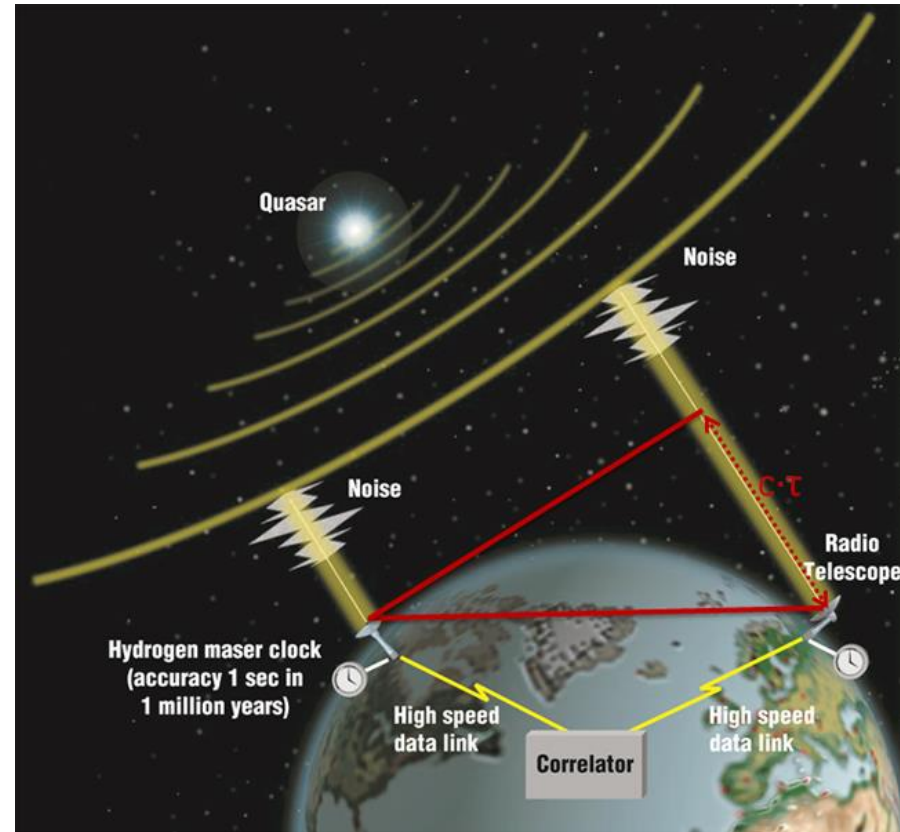
What is the Truth?

- International Earth Rotation and Reference Systems Service (IERS)
 - Bulletin B (Obs. Paris)
 - Up to 60 days late
- IERS Rapid Service/Prediction Center
 - Bulletin A (USNO)
 - Daily predictions and finals
- Jet Propulsion Laboratory (JPL)
 - Both predictions and finals
 - May not be “official”, but highly respected

GPS data can help measure UT1

- Monitor sites sensitive to net rotation between Earth & GPS Constellation
- **Excellent for Length-of-Day**
 - LOD=derivative of UT1
 - IGS product (accurate to 10 microseconds)
- **UTGPS** – a UT1 predictor
 - Method: project GPS constellation forward from last few VLBI points
 - Solar radiation models are limiting factor
 - No one questions Newton's Laws (or Einstein's)

Very Long Baseline Interferometry (VLBI)



gives the most accurate UT1 measurements

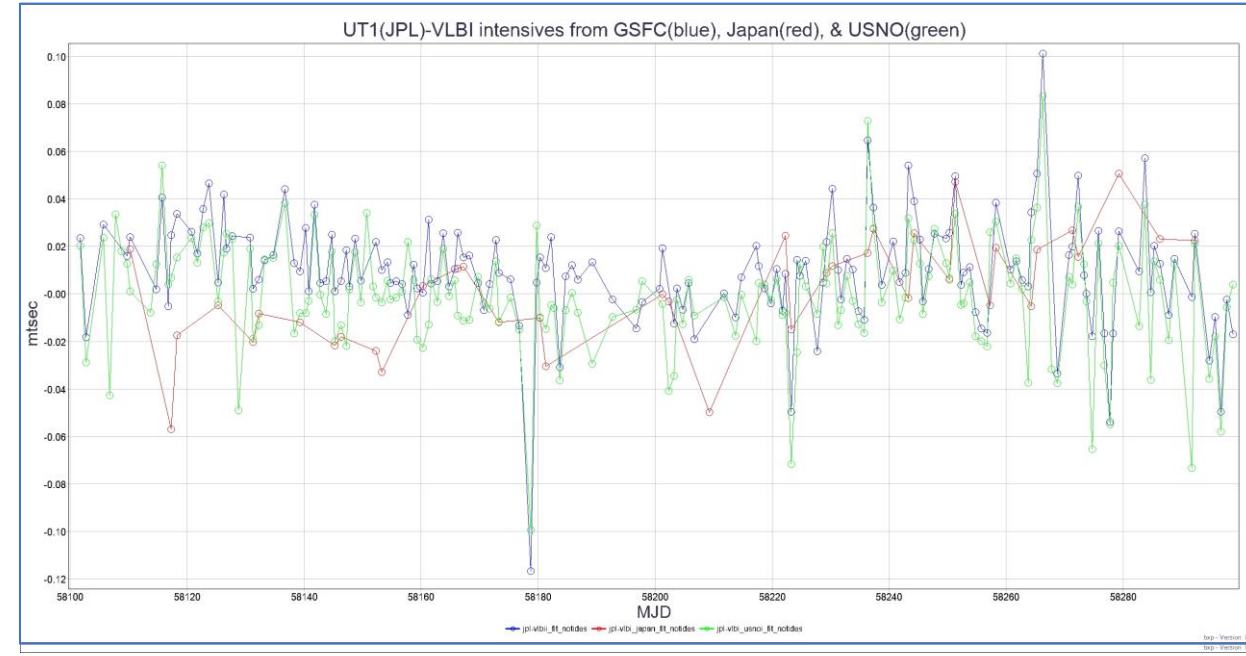
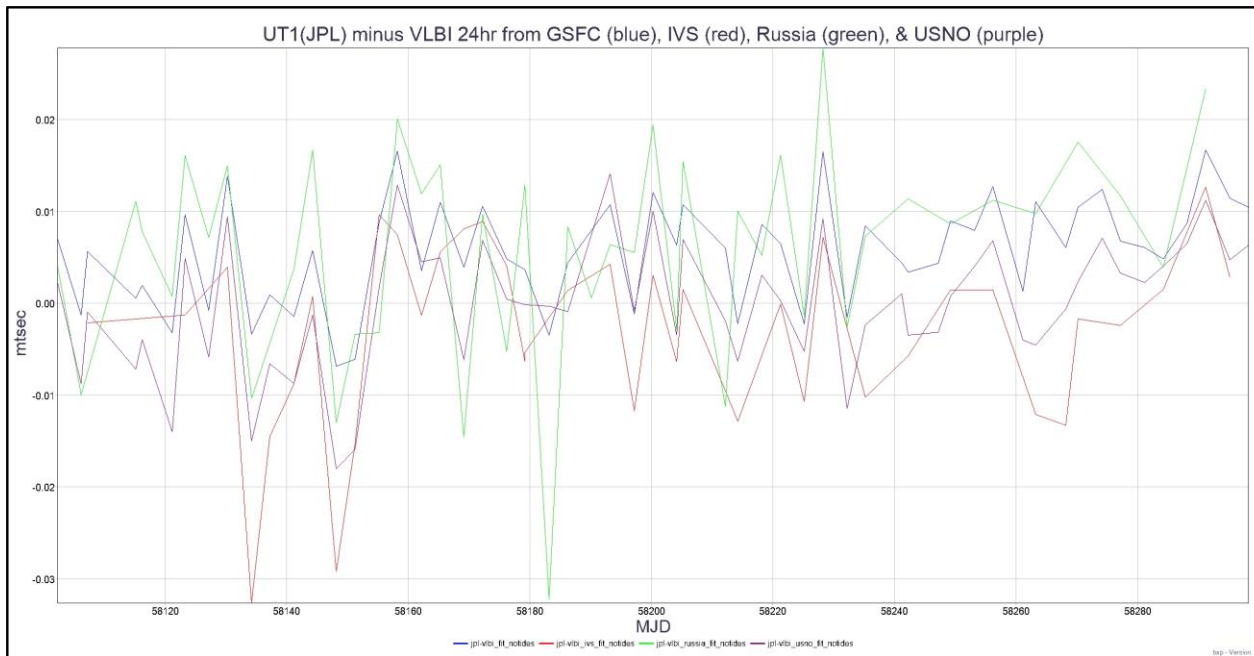
VLBI is a model of Scientific Cooperation

- Data are pooled – everyone has access to all raw data
- Two kinds of observing runs
 1. 24-hour observing runs, every few days
 - UT1 σ ~6-10 μ sec of time
 - ~ 3-week latencies
 - Institute of Applied Astronomy Russian Academy of Sciences (IAA RAS)
 - International VLBI Service (IVS)
 - NASA (GSFC)
 - USNO
 2. 1-hour observing runs, daily (called intensives)
 - UT1 σ ~ 20-30 μ sec of time
 - 1-2 day latencies
 - GSI (Japan) (weekends only)
 - NASA (GSFC)
 - USNO

How do VLBI series stand up against “truth”?

24-hr runs: post-fit RMS ~.006, .01, .01, & .007 mtsec

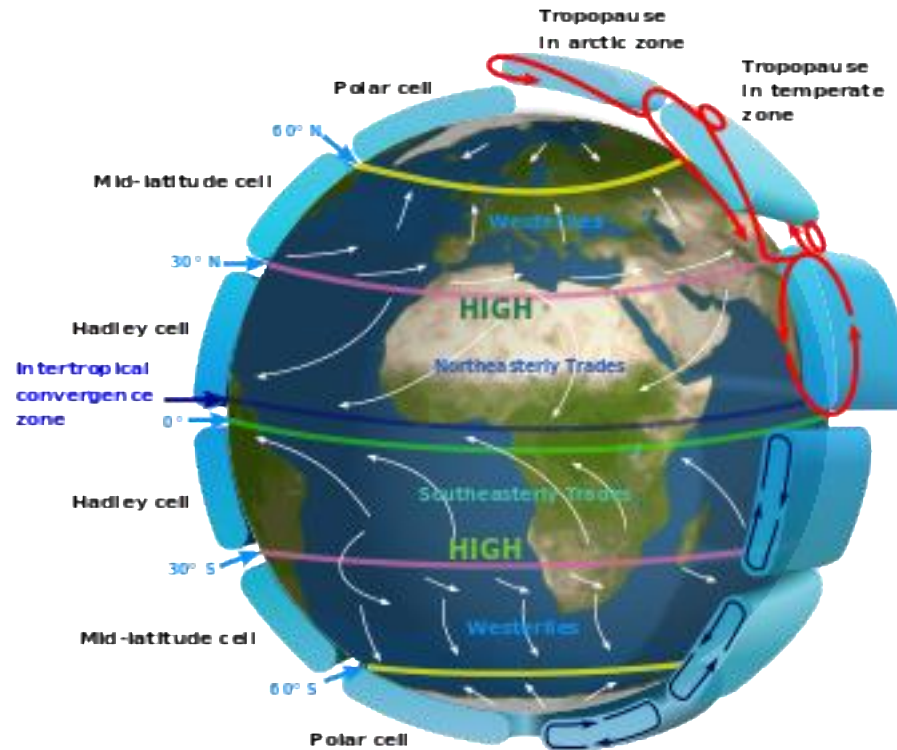
Intensive runs: post-fit RMS ~ .02 mtsec
(less data, rapid turnaround)



Note: correlations abound

0.01 mtsec = .46 cm along Earth's equator = .2 inches

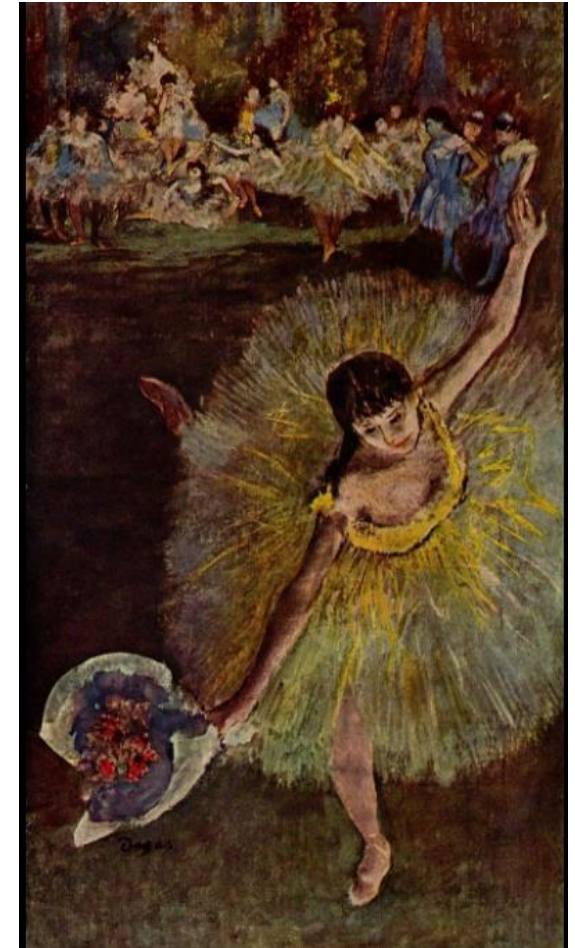
Atmospheric Angular Momentum



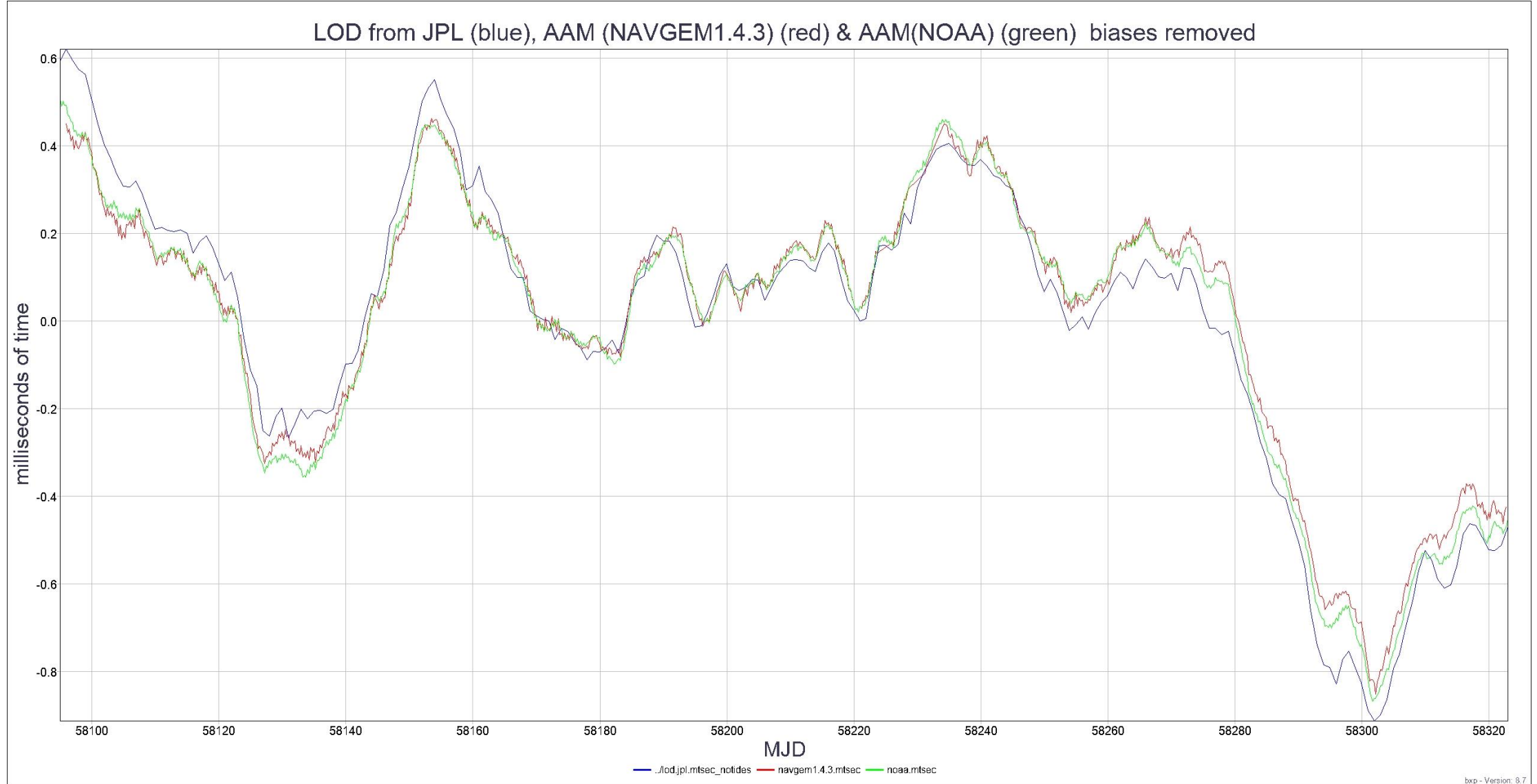
Jet Stream winds can exceed 400 km/hr

Conservation of Angular Momentum

- Total Angular Momentum = sum of four components
 1. “Solid Earth”
 2. Atmosphere
 3. Oceans
 4. Moon
- AAM and LOD should be correlated
 - And they are
 - To the extent the Earth is solid
 - Land tides, sea tides distort the shape
 - The oceans are fluid
 - Yes, the interior is gooey, the crust quakes, and the tides slow things down
 - but not strongly on weekly scales
- All important short-term elements are modelled
 - Inverted barometer on oceans
 - Updrafts, downdrafts, cross drafts, Coriolis forces, etc.

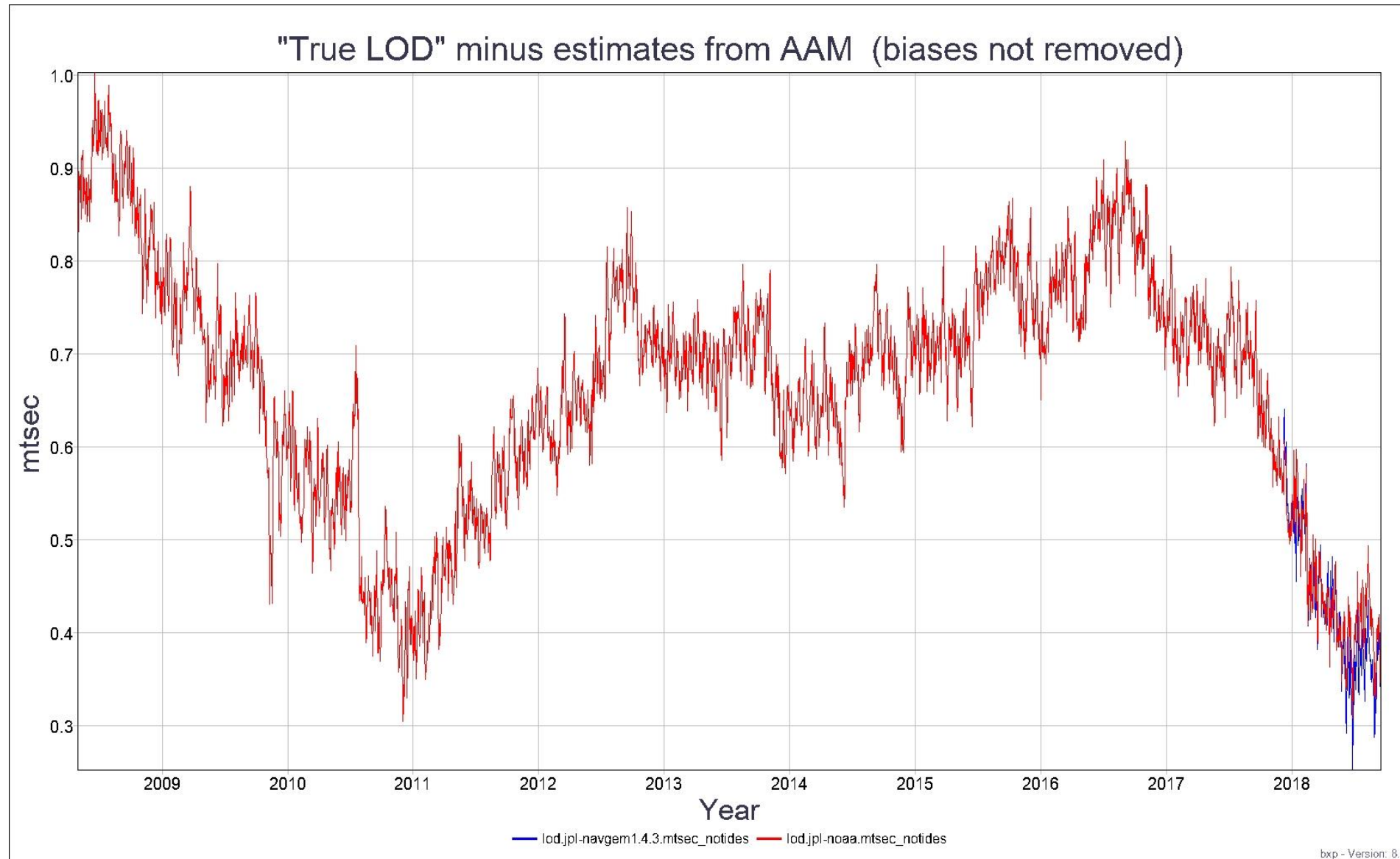


AAM estimators and “true” LOD since Dec 2017

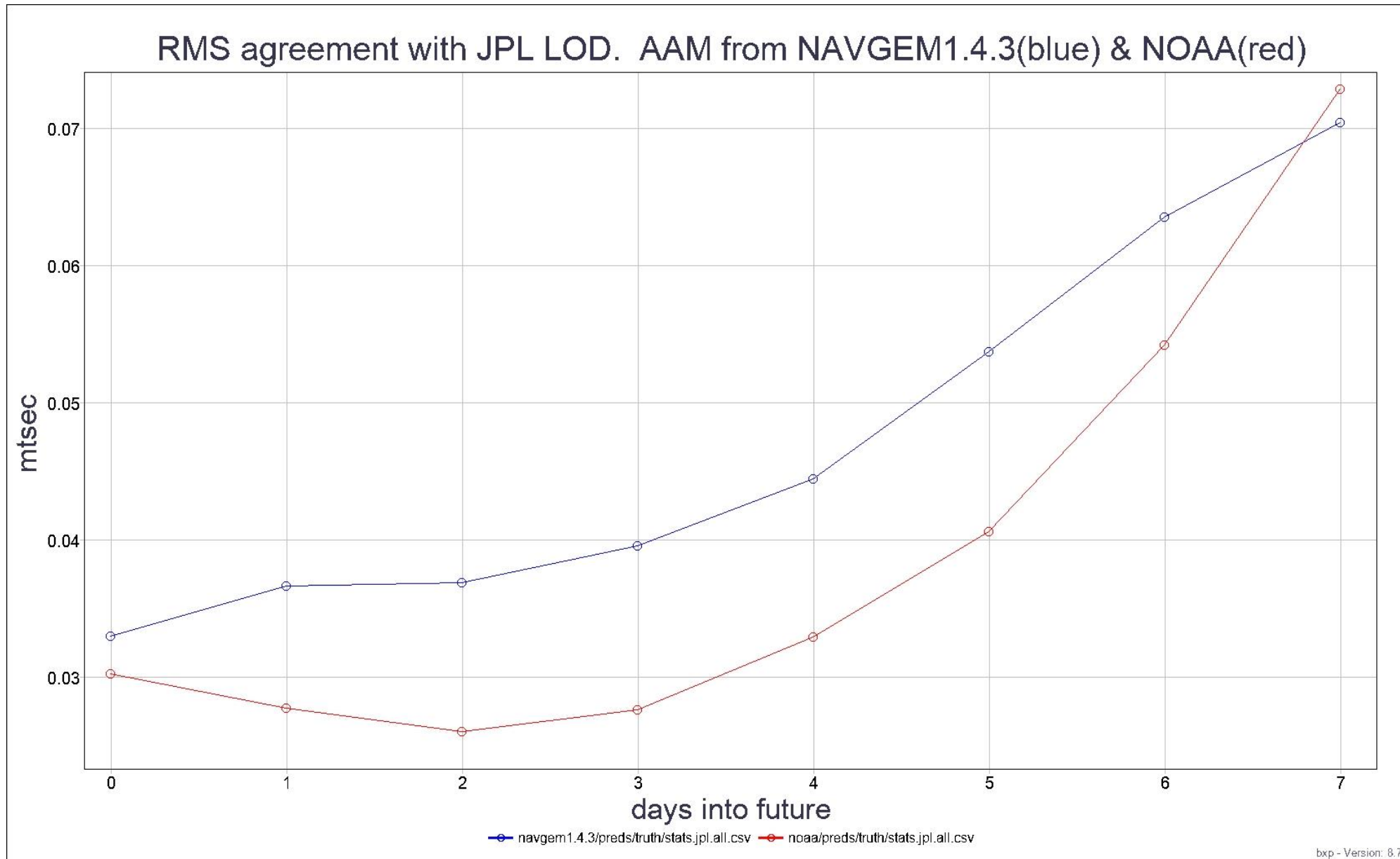


JPL-measured LOD varies almost monotonically from 0.2 mtsec above predictions to 0.1 mtsec below

“True LOD” minus estimates from AAM



How good are AAM predictions of LOD?

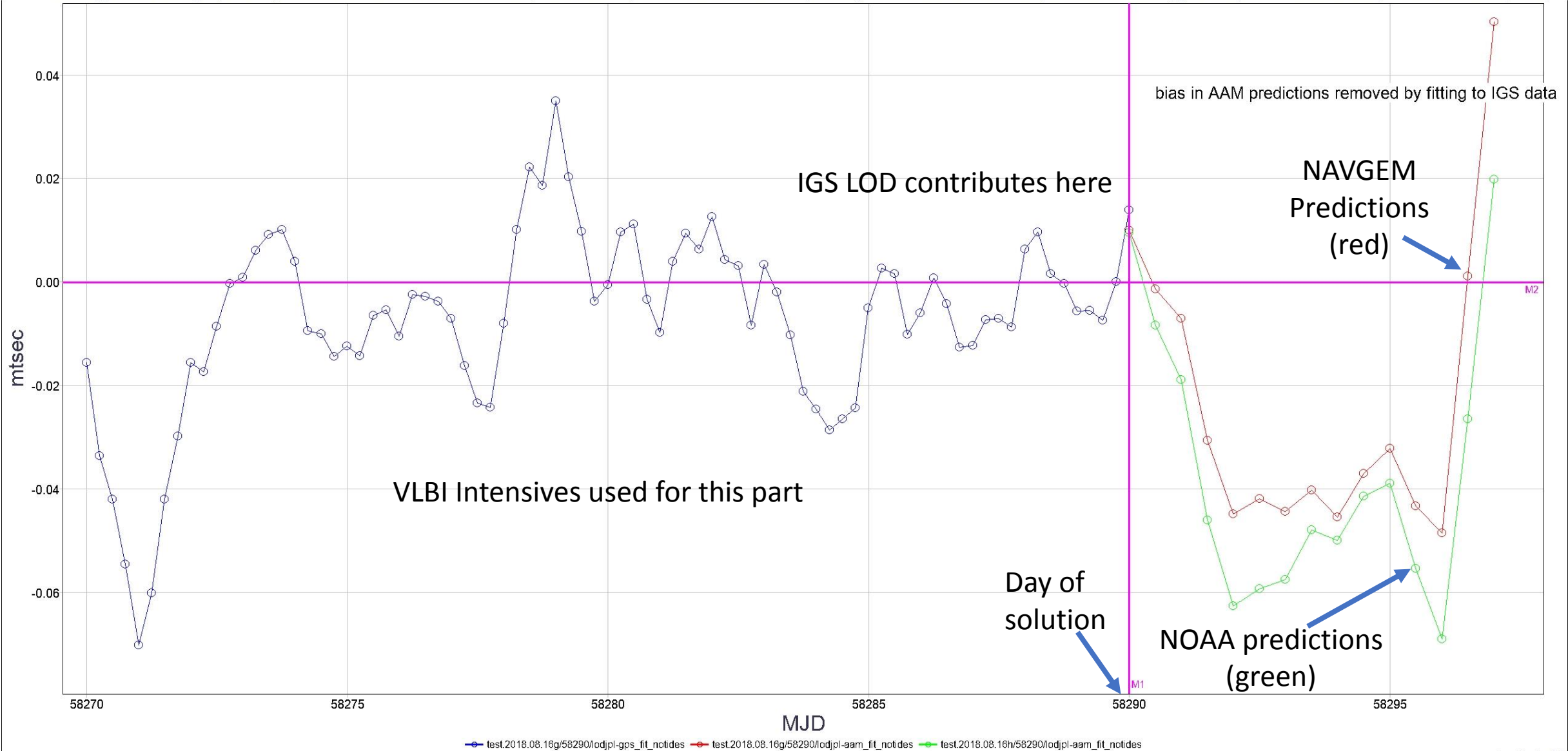


Enter the Kalman Filter

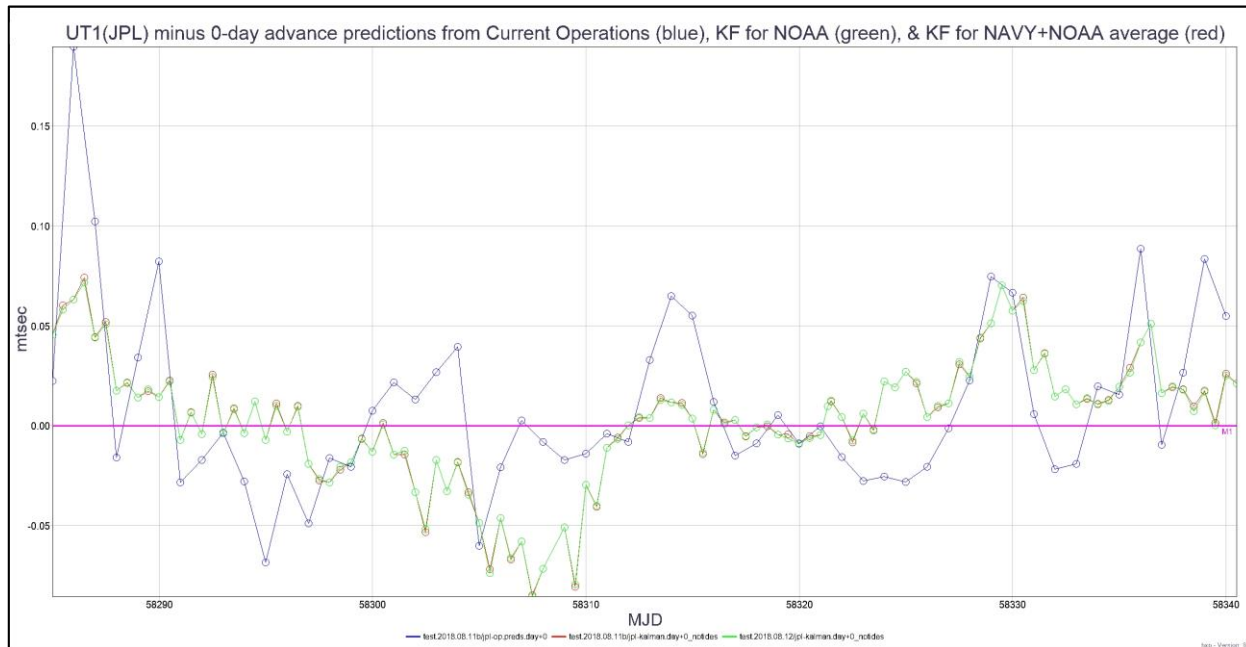
- Outputs: UT1 time series, from past to future
- Inputs
 - VLBI – dominates when available
 - IGS Ultra LOD – from last VLBI to present
 - AAM predictions - used to predict UT1
 - NOAA, NAVY, or their average
 - UTGPS
 - low weight
 - Backup if other data not available

Typical Solutions vs. "Truth"

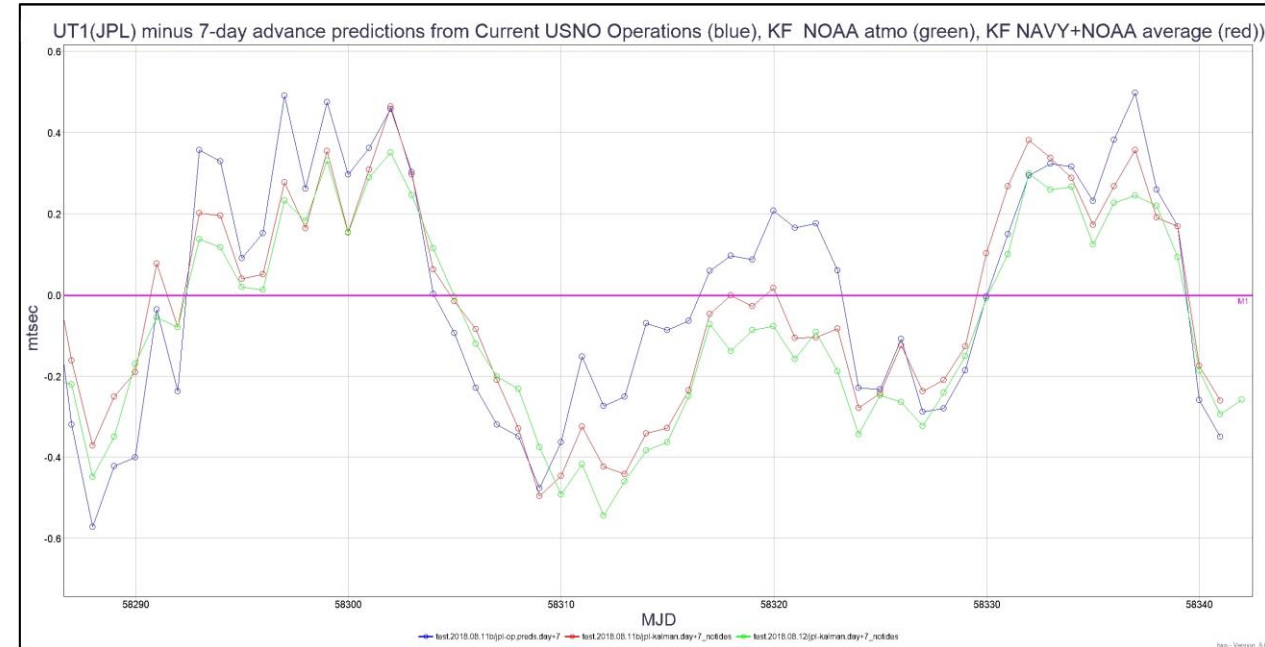
Length of Day (LOD) solution of MJD 58290, June 21, 2018: JPL-IGS(blue) JPL-NAVGEM predictions (green) JPL-NOAA predictions (red)



Results: probably 25% improvement



0 days in advance
AAM predictions not used
RMS, Operations: 0.04 mtsec
RMS Kalman, either AAM model: 0.03 mtsec



7-days in advance
AAM predictions highly important
RMS, Operations: 0.27 mtsec
RMS, Kalman with NOAA: 0.21 mtsec
RMS, Kalman with NOAA+NAVGEN: 0.24 mtsec

Conclusions

- Kalman Filter may lead to improved UT1 predictions
- As AAM predictions improve, better results will follow
 - Ocean AM too