Impact of Modern Earth Orientation Models on GPS Precise Orbit Determination

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Introduction

- Models currently recommended by IERS > 20 years old
- Modern alternatives demonstrate improvements using decade(s) of space geodetic measurements.
- Effects and models considered in this presentation:
  - long-period tidal variations in UT1/LOD (zonal tides):
    - amplitudes up to 0.17 s
    - current recommendation: Yoder et al. (1981)/Wahr and Bergen (1986)/Kantha et al. (1998)
    - model discussed here: Ray and Erofeeva (2014, *JGR*)
    - used for UT1/LOD regularization process
  - diurnal and semi-diurnal variations on ERPs from ocean tides:
    - amplitudes of few hundred μas for polar motion; a few μs for UT1
    - current recommendation: Ray et al. (1994, *Science*) and Chao et al. (1996, *JGR*)
    - model discussed here: Desai and Sibois (2016, *JGR)*
  - libration effects:
    - prograde diurnal component of polar motion variations; amplitudes of up to 16 μas
    - semidiurnal component of UT1; amplitudes of up to 2 μs
    - current recommendation: model from Mathews and Bretagnon (2003, *Astron. Astrophys*.)
    - discussed here: consistency with model for impact of ocean tides on ERPs

Model Description: zonal tide model

- Long-period tidal variations in length of day
  - Model implemented described in [Ray and Erofeeva, 2014, *JGR*]
  - 80 tidal components (with periods 4.7 days-18.6 years) vs. 62 for IERS-recommended model; modern model "consistently includes effects of mantle anelasticity and dynamic ocean tides in all spectral lines": modern model more consistent and with improved accuracy.
  - Model validated against 20 years of space geodetic LOD measurements (SPACE2008 series 1989-2009, [Ratcliff and Gross, 2010]).

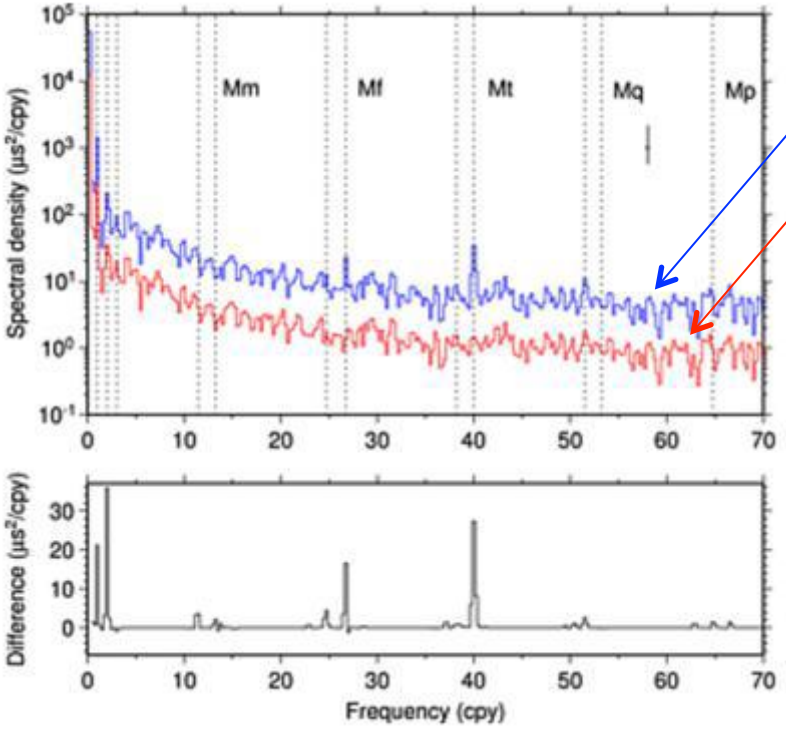


Figure taken from [Ray and Erofeeva, 2014, *JGR*]

"Top: residual spectrum of LOD after removing all geophysical models, including tides." Offset for readability purposes only.

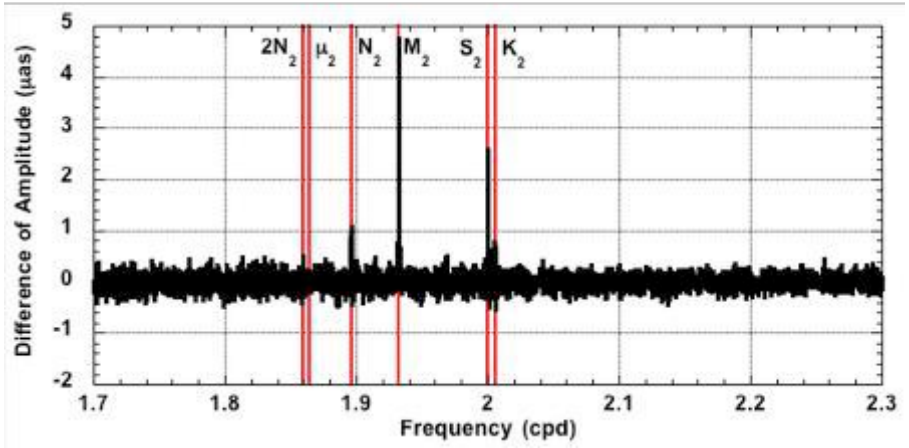
"Bottom: difference between top two curves. Positive difference denotes that energy has been removed from the residual spectrum with Ray and Erofeeva new model. Largest improvements are seen for Sa, Ssa, Mf, and Mt."

Model Description: ocean tide model

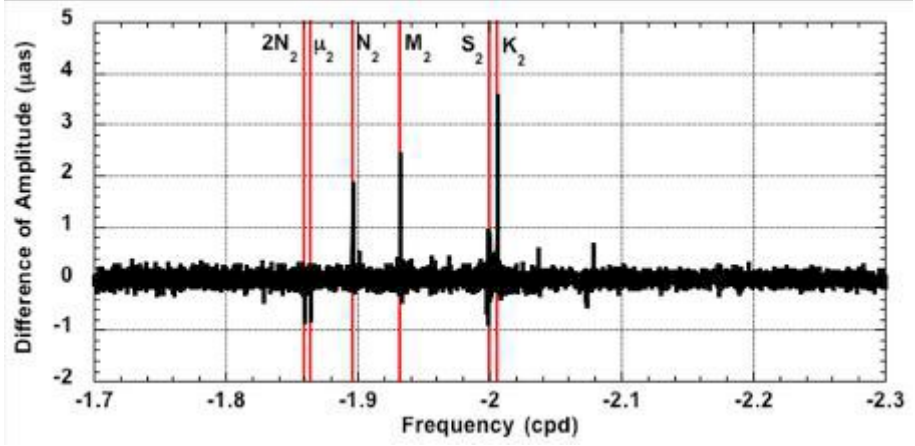
- Predicted effects of ocean tides on diurnal and semi-diurnal ERPs
  - Model implemented described in [Desai and Sibois, 2016, *JGR*], based on TPXO8 hydrodynamic ocean tide model by [Egbert and Erofeeva, 2002*, J. Atmos. Oceanic Technol.*]
  - IERS-recommended model [Ray et al., 1994, *Science*; Chao et al., 1996, *JGR*] based on earlier version TPXO model [Egbert et al., 1994, *JGR*]
  - 159 tidal lines vs. 71 in IERS 2010 model
  - Model validated against 10 years of GPS-based high-frequency polar motion estimates
  - Validation through analysis of relative performance of background models (IERS-recommended vs. TPXO8-based model) using residual tidal signals in 10-year-long series of GPS-based observations of polar motion.
  - Closure of the budget between predictions and GPS-based observations at the level of 10, 2, and 5 μas in prograde diurnal, prograde semidiurnal, and retrograde semidiurnal tidal variations in polar motion, respectively.

Difference of residual amplitude spectra

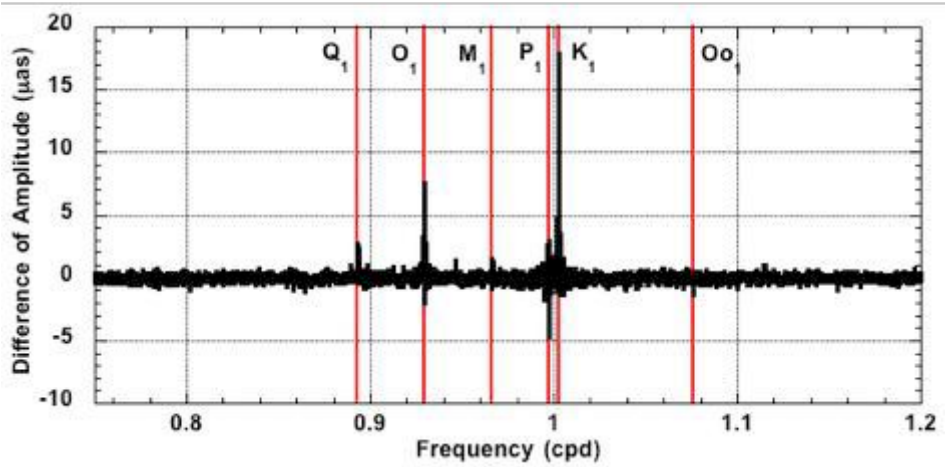
- Prograde Semi-Diurnal: Recommended-Modern



- Retrograde Semi-Diurnal: Recommended-Modern



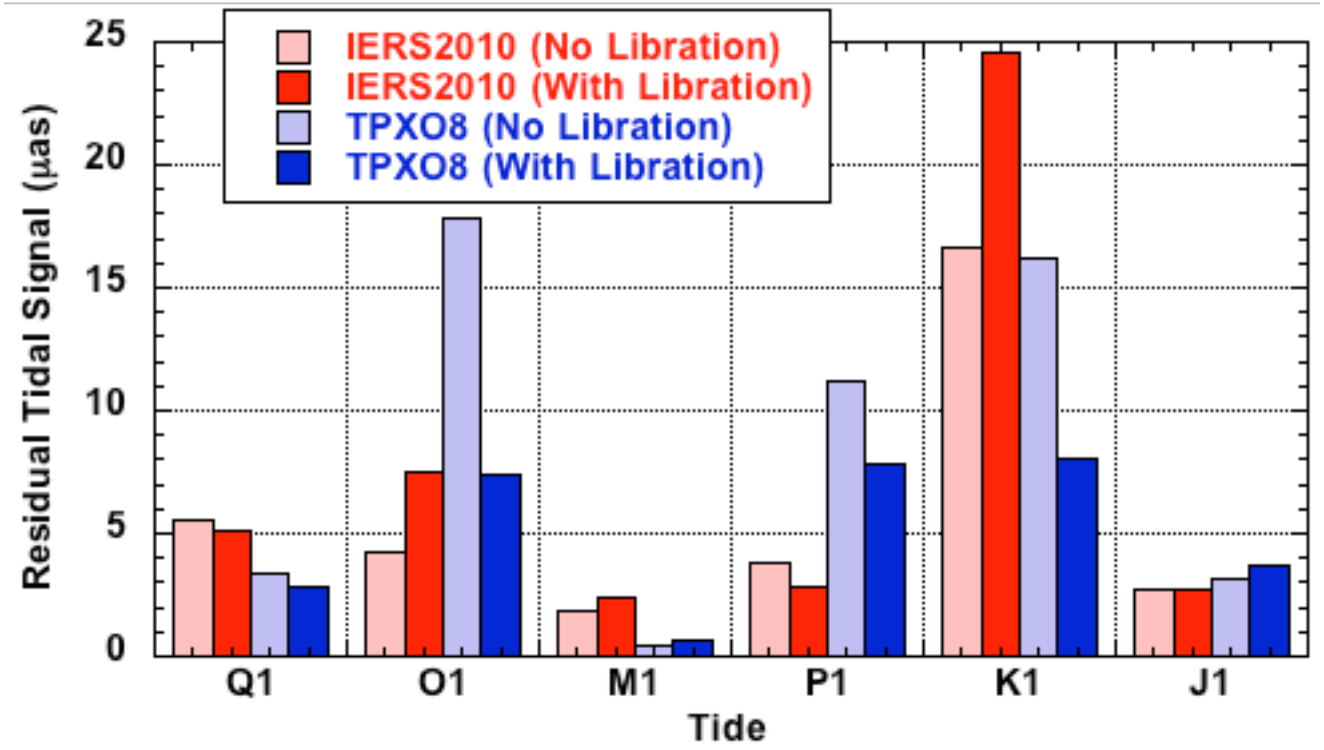
Prograde Diurnal: Recommended–Modern
(both including libration model)



- Values > 0 indicate IERS-recommended model has larger residual signals
- Modern model eliminates systematic signal very near O1
- Modern model has larger residual signal at P1 by 5 μas,
- Residual tidal variations at level of 2-15% of predicted ocean tide effects in the case of modern model
- IERS-recommended model has larger residual signal:
  - for all major tides in prograde semidiurnal,
  - at N2, M2, and K2 in retrograde band,
  - at K1 (18 μas), Q1, and M1

Figures taken from [Desai and Sibois, 2016, *JGR*]

Consistency with libration model



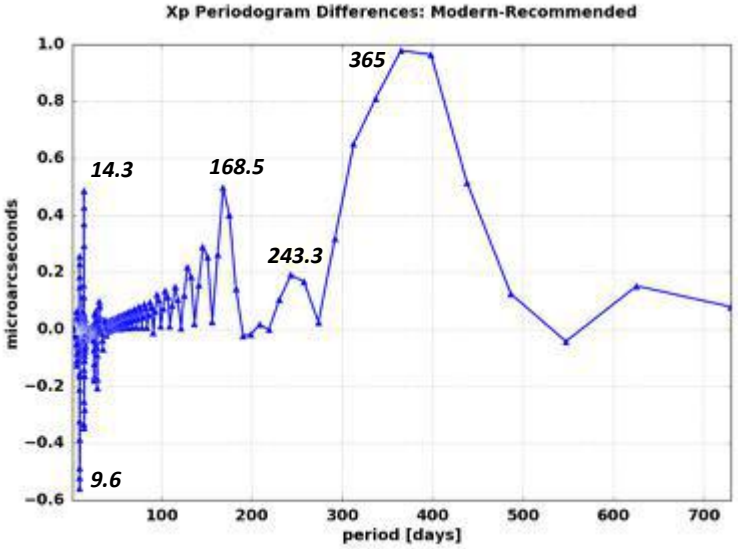
- TPXO8: libration model reduces residual tidal signals in most cases.
- IERS2010: libration model tends to increase residual tidal signals, especially for largest O1 and K1 components.

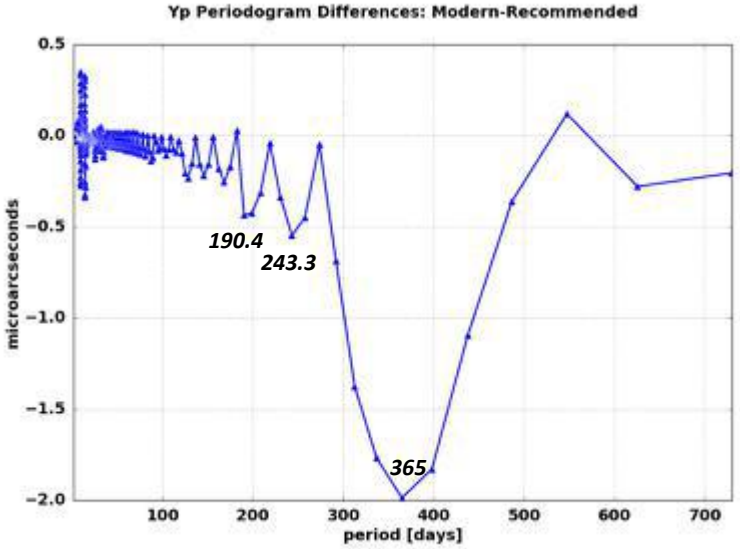
➔ *Better consistency of modern model with conventional libration model.*

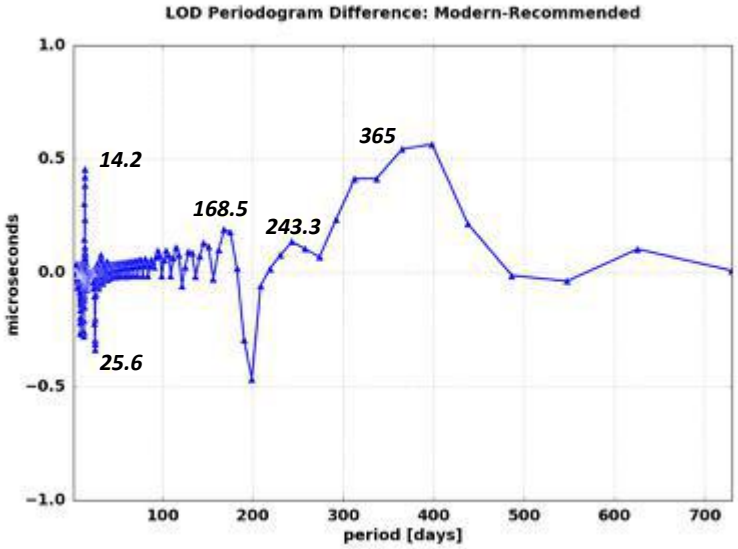
Impact on GPS POD: Methodology

- 3 years, 2014-2016, processed using JPL IGS AC Final strategy
- Baseline runs use:
  - 2010 IERS Conventions model for effects of ocean tides on polar motion, UT1/LOD,
  - 2010 IERS Conventions model for long-period tidal variations in UT1/LOD
- Test runs use:
  - TPXO8-derived model for effects of ocean tides on polar motion, UT1 and LOD,
  - 2010 IERS Conventions libration model,
  - Ray and Erofeeva [2014, *JGR*] model for effects of long-period tides on UT1/LOD
- Same data/network used by the two solutions
- Same daily nominal EO file used by the two solutions (IERS Bulletin A)
- Reference frame is IGS14
- All cases apply:
  - daily values of ERPs using IERS Bulletin A (to model variations with period > 2 days)
    → baseline solution will be intrinsically more internally consistent
  - Conventional nutation model from Mathews et al. [2002]

Simulated impact on daily ERP values





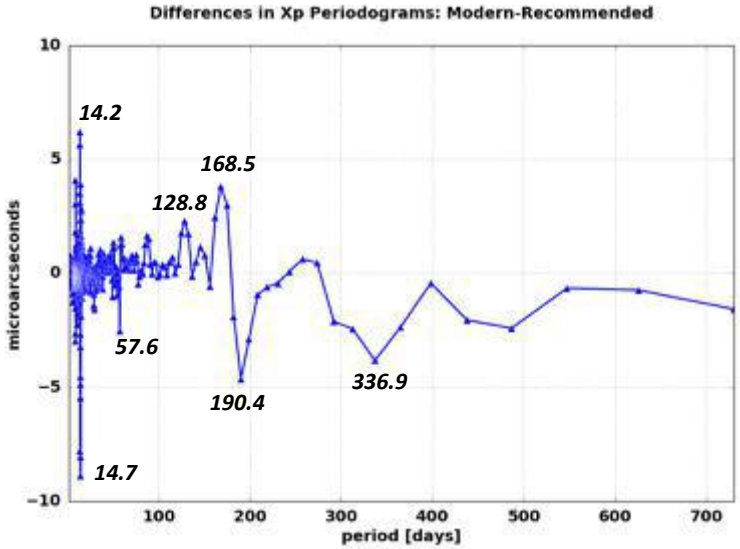


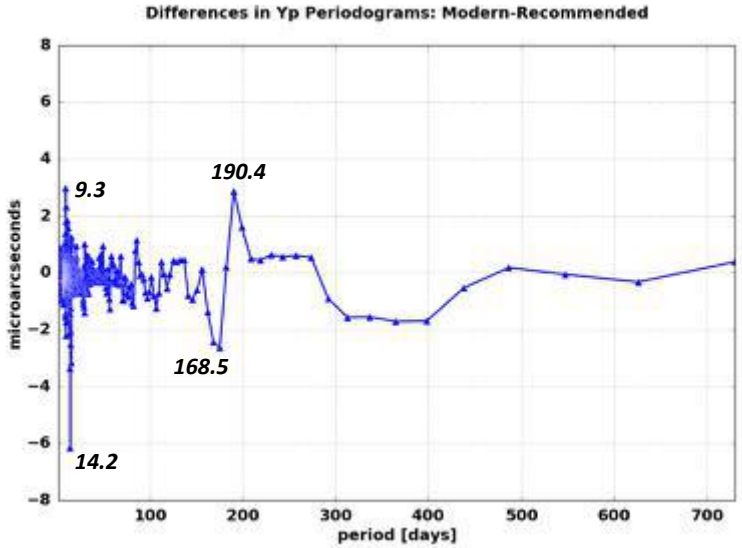
Compute time series of models (TPXO8+Libration vs. IERS2010 model without libration) at 5-min interval over 30-hour arcs spanning 2014-2016;
Compute average ERP value over arcs;

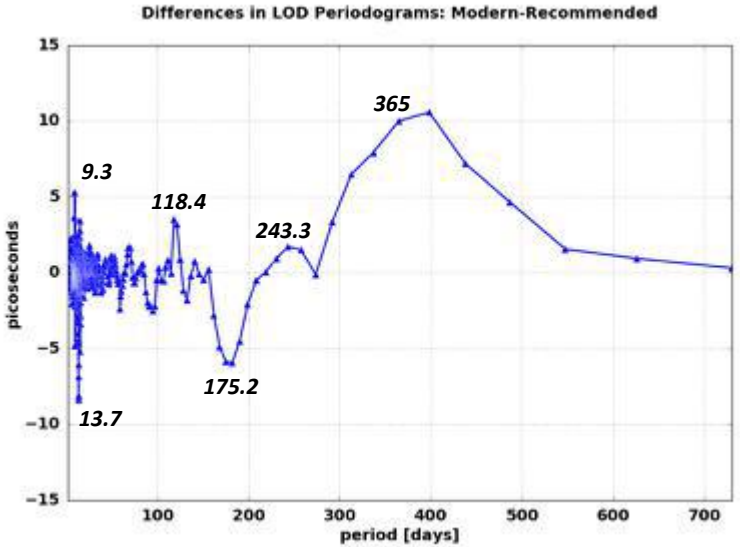
Compute periodograms of mean values;

Plot difference in periodograms

Actual impact on GPS network solutions

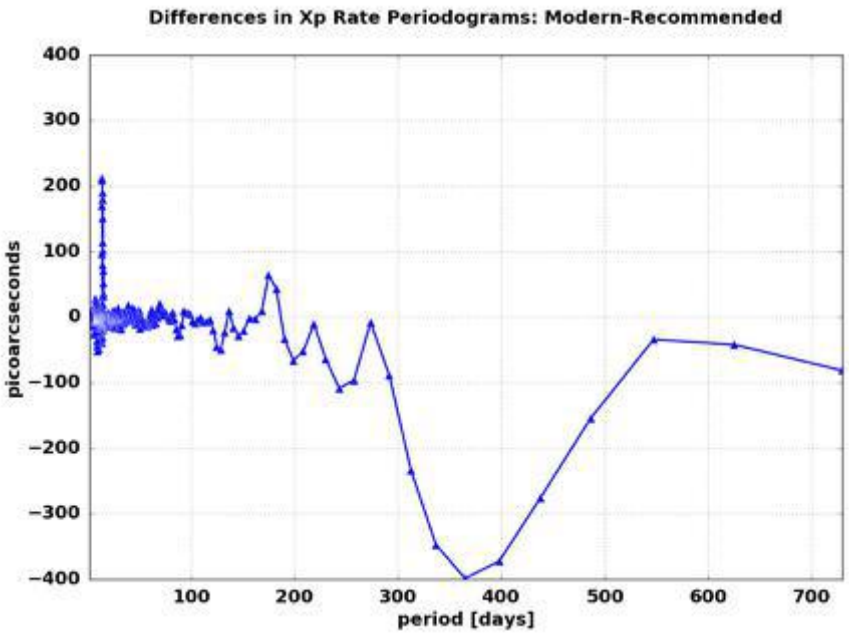


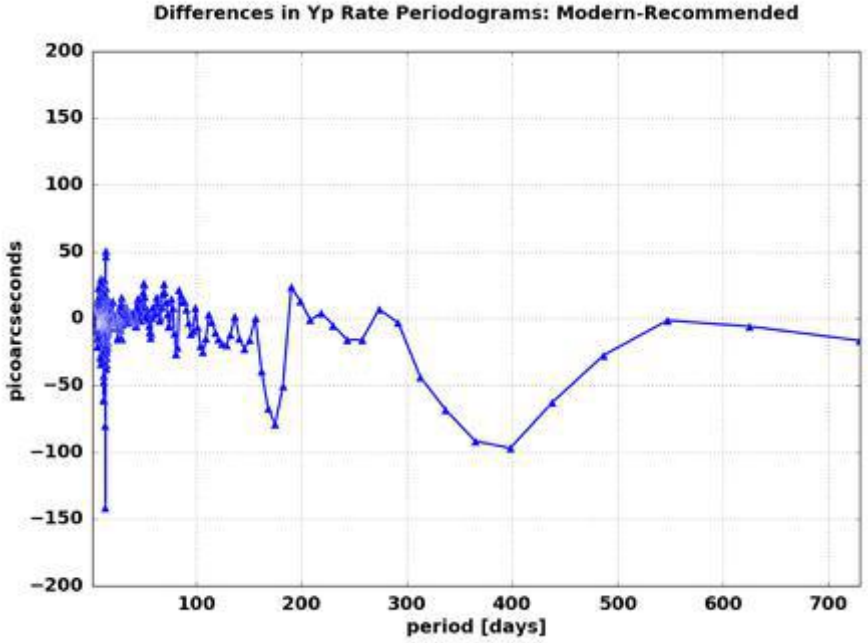




Actual impact on polar motion larger than modeled impact by ~1 order of magnitude due to correlations introduced by multi-parameter estimation in network solution. Periods at which differences manifest not identical to simulated impact.

Actual impact on GPS network solutions





Actual impact on GPS network solutions

- Post-fit Residuals

	PC [cm]	LC [mm]
IERS-recommended Models	rms = 58.517 median = 55.973	rms = 9.462 median = 9.478
Modern Models	rms = 58.493 median = 55.973	rms = 9.458 median = 9.478

- Orbit/Clock Precision (internal overlaps)

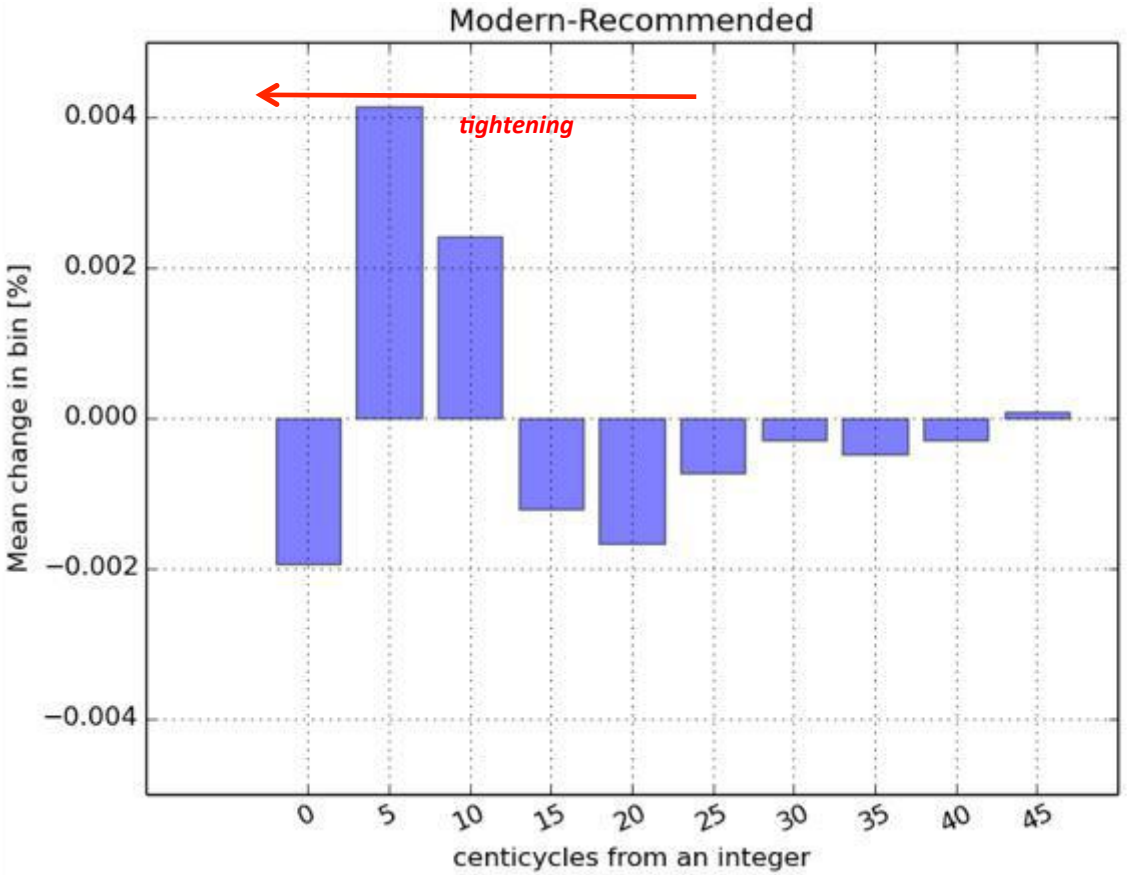
	1D-RMS Orbits [cm]	RMS Clocks [cm]
IERS-recommended Models	rms = 1.504 median = 1.419	rms = 2.367 median = 2.24
Modern Models	rms = 1.501 median = 1.421	rms = 2.360 median = 2.23

- Orbit/Clock Differences

	1D-RMS Orbits [cm]	RMS Clocks [cm]
Modern vs. IERS-recommended Models	rms = 0.181 median = 0.171	rms = 0.196 median = 0.190

Actual impact on GPS network solutions

- Ambiguity resolution analysis
  - improvement in bias fixing means better measurement modeling
  - overall tightening of the histogram closer to integer for solutions corresponding to the modern models → **very slight improvement**



Conclusion and References

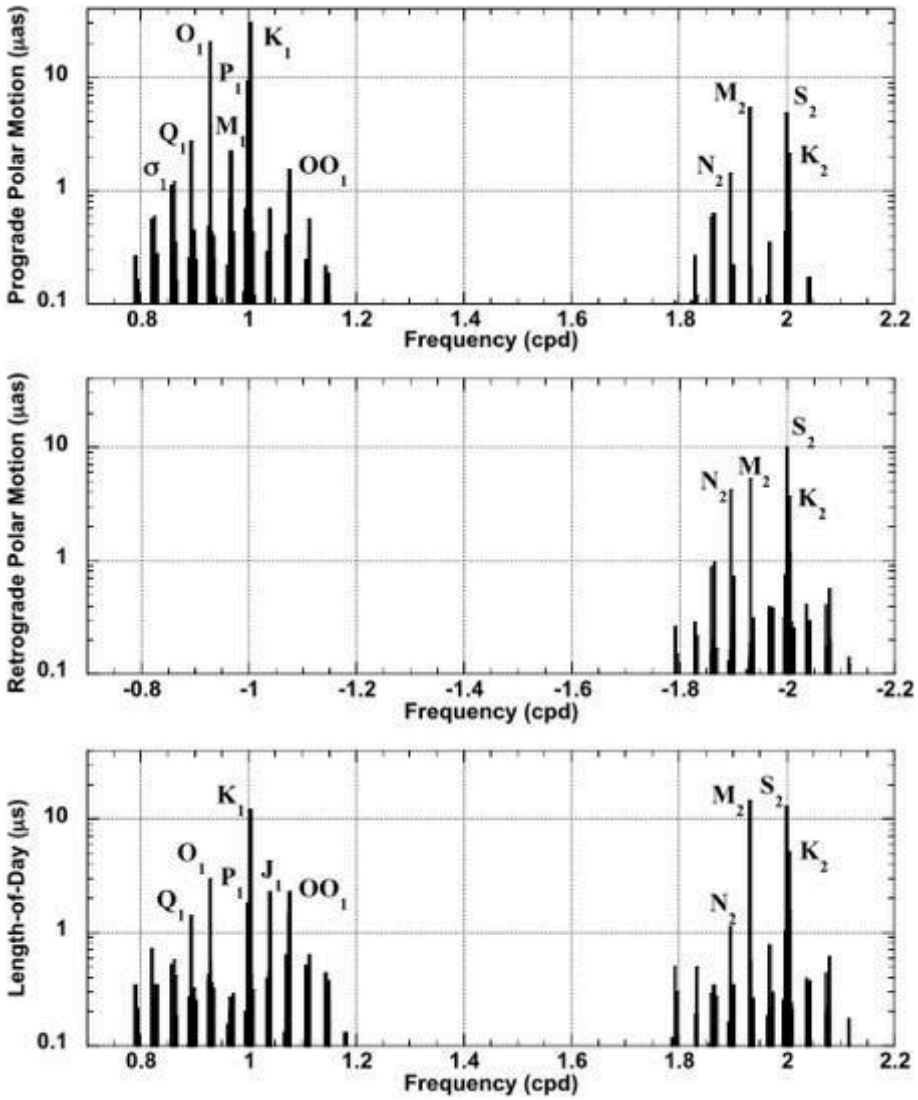
- Modern models are available for impact of ocean tides and tidal deformation on Earth Rotation Parameters.
- In particular, better consistency of modern ocean tide model with the conventional libration model.
- As expected due to use for UT1/LOD internal regularization process only, impact of modern zonal tides model on GPS POD results is negligible.
- Impact on GPS POD of using modern ocean tide model is a small but detectible improvement relative to use of IERS-recommended models.

References:

- 2010 IERS Conventions:
  - Petit, G. and Luzum, B. (2010). "*IERS conventions (2010)*" IERS-TN-36
- Impact of ocean tides on Earth's rotation
  - Desai, S.D. and Sibois, A.E. (2016). "*Evaluating predicted diurnal and semidiurnal tidal variations in polar motion with GPS-based observations*". Journal of Geophysical Research: Solid Earth, 121(7):5237-5256
  - Sibois, A.E. et al. (2017). "*Analysis of decade-long time series of GPS-based polar motion estimates at 15-min temporal resolution*". Journal of Geodesy
- Libration effects
  - Mathews, P. M. and Bretagnon, P. (2003). "*Polar motions equivalent to high frequency nutations for a non-rigid Earth with anelastic mantle*". Astronomy & Astrophysics, 400(3):1113-1128
- Long-period tidal variations in UT1/LOD
  - Ray, R.D. and Erofeeva, S.Y. (2014). "*Long-period tidal variations in the length of day*". Journal of Geophysical Research: Solid Earth, 119(2):1498-1509

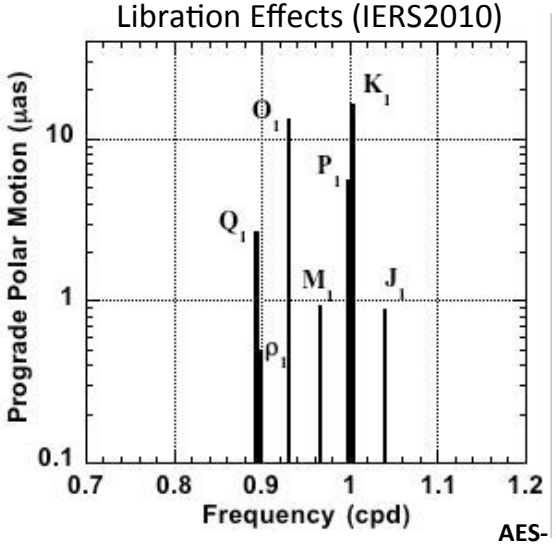
Backup: model differences

TPXO8-IERS2010 Differences

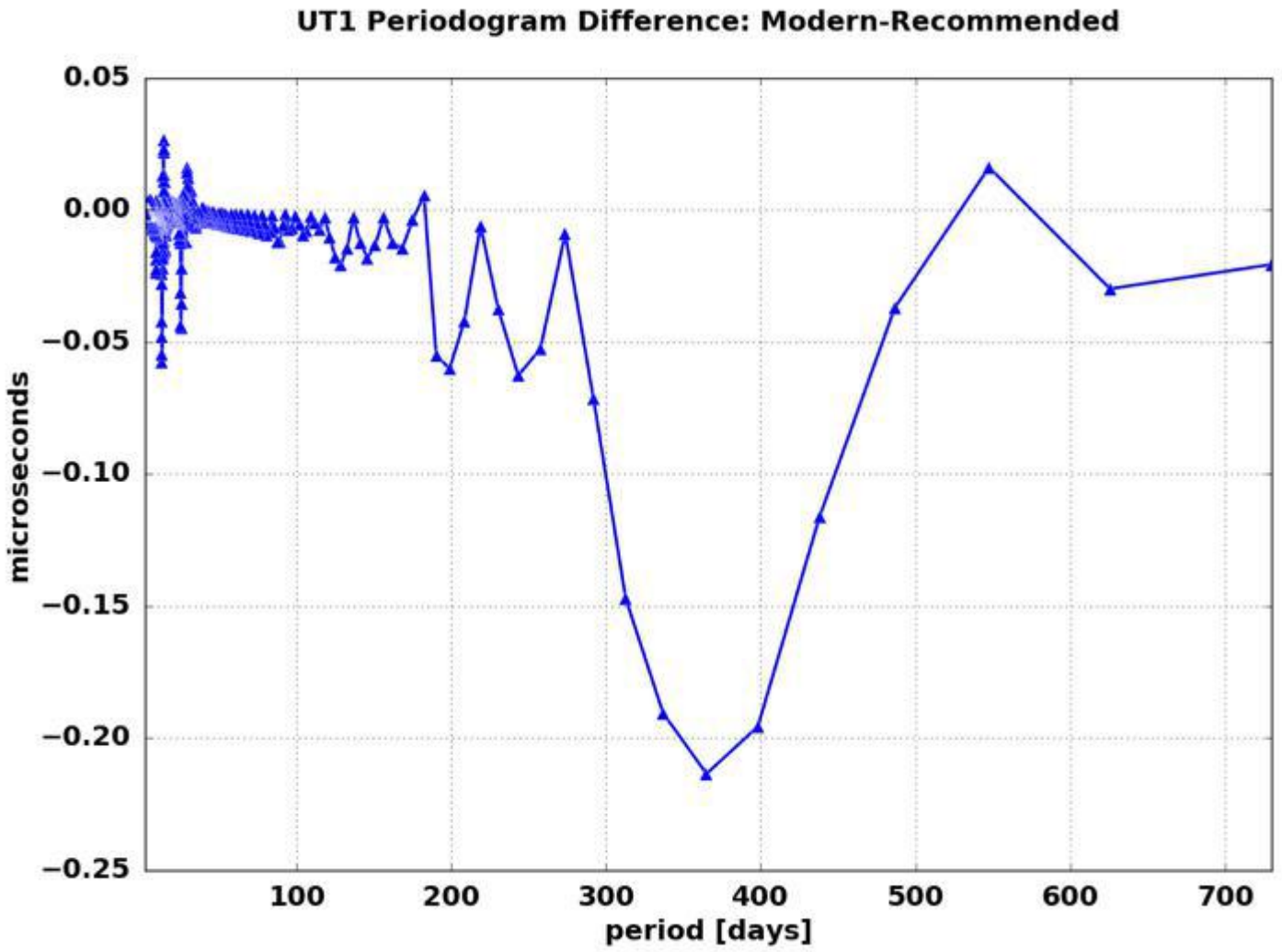


- Differences between ocean tide models are larger by factor of 1.5-2 compared to libration effects.
  - Ocean tide model differences for K1, O1, and P1: 30, 20, and 9 μas.
  - Libration effects for K1, O1, and P1: 16, 13, and 6 μas.
- Largest differences in semidiurnal band are for the 4 primary tidal components: M2, S2, K2, and N2: 1-10 μas.

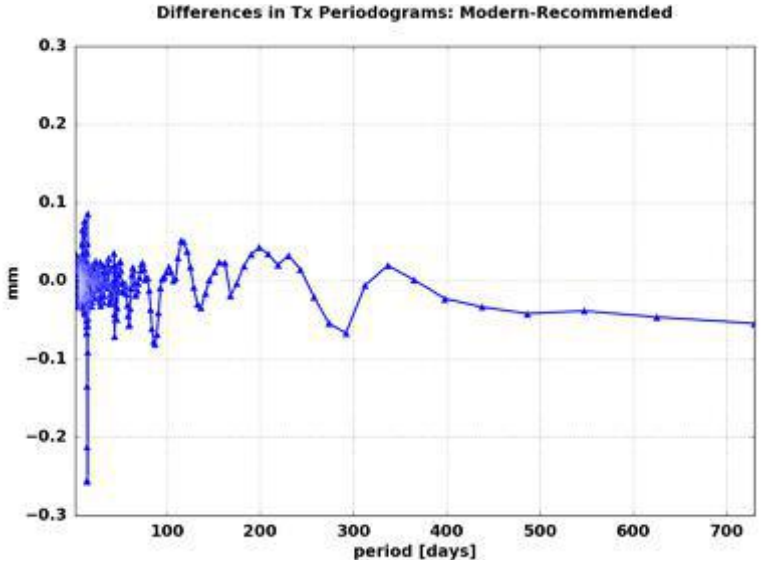
Libration Effects (IERS2010)

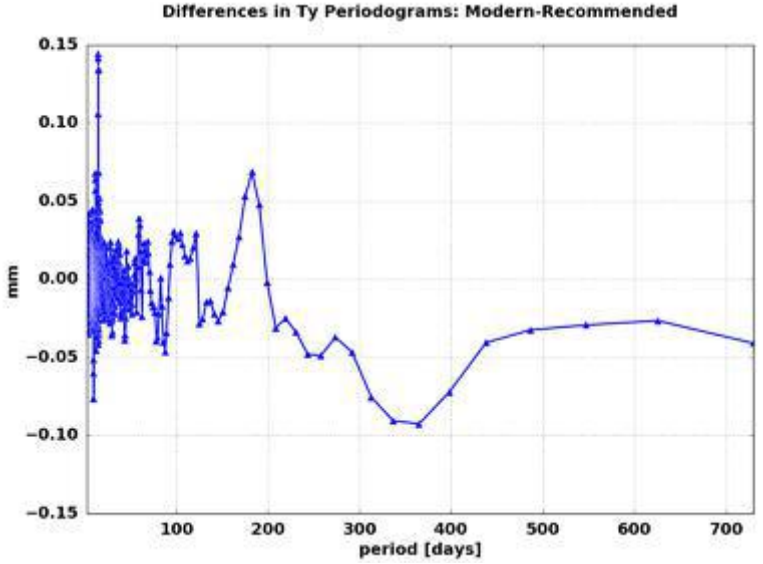


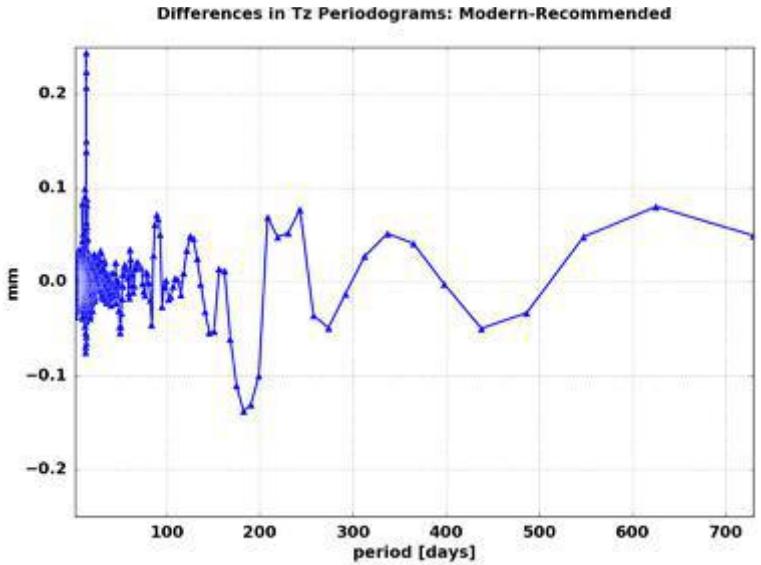
Simulated impact on daily UT1

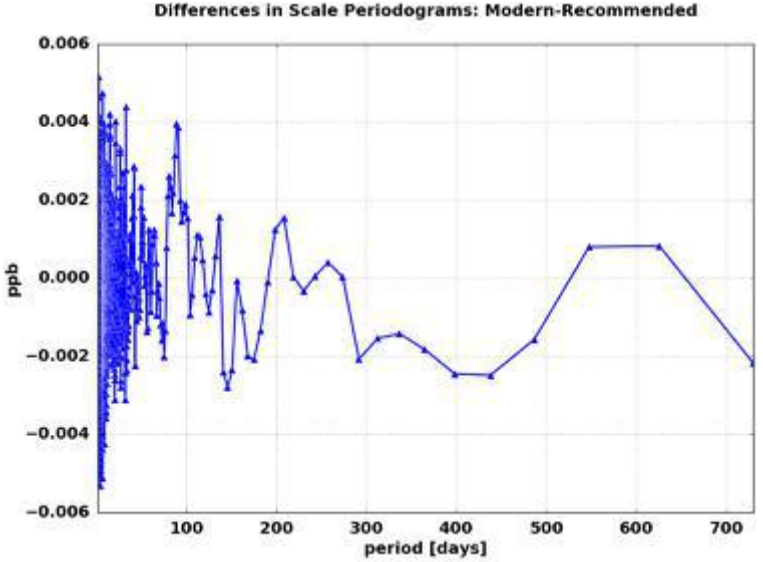


Backup: Impact on network frame parameters









Backup: Impact on network frame parameters