GSC Analysis Center Improvements in DORIS Satellite Processing Following ITRF2014

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La Rochelle, FRANCE
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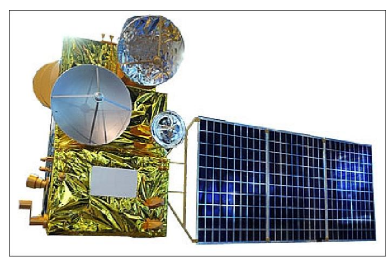
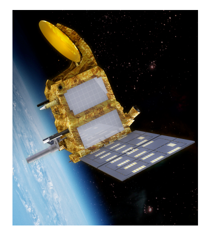




Outline

I. SINEX series update.

II. Tests of a new SINEX series (wd28).

III. Tests with ITRF2014, DPOD2014. Some DORIS-related results.

IV. Issues with IERS2010 pole model.

V. Summary

SINEX Delivery Update

- 13 New DORIS stations beginning Sept. 1, 2013
  ADHC GONC GR4B KEUC LAOB MAUB OWEC PDNC ROWC SOEB STKB SYQB TRJB

➔ (switch from DPOD2008v13 to DPOD2008v15)

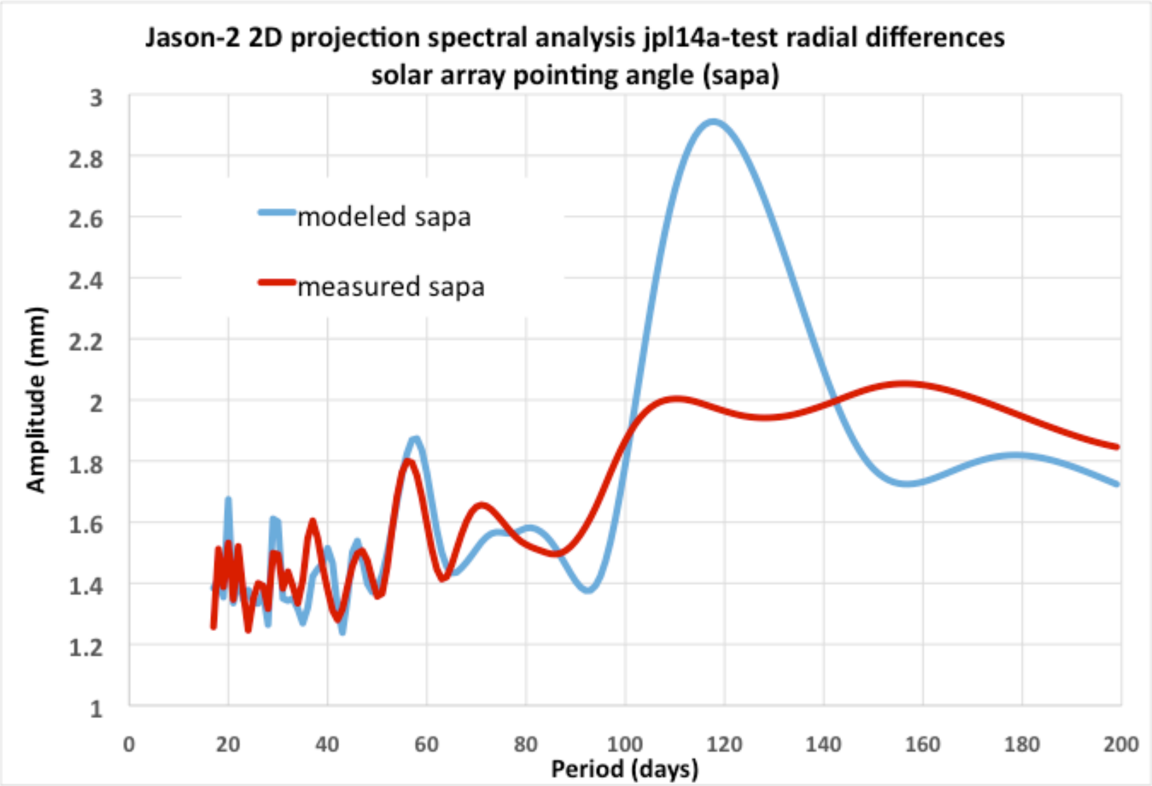
- wd26: 156 weekly files: 2013 to 2015 redelivered.
  (wd26 = Jason2, Cryosat2, SPOT5, HY2A)

- Current operational series:
  wd27 = wd26 + SARAL (**130317 to 160626**).
- Test series: wd28 = wd27, + apply solar array quaternions on Jason-2. (**080713 to 160626**).

N.B. For GSC work with ITRF2014, Spacecraft body quaternions have always been applied for Jason-2! The new tests involve only orientation of the solar arrays!!

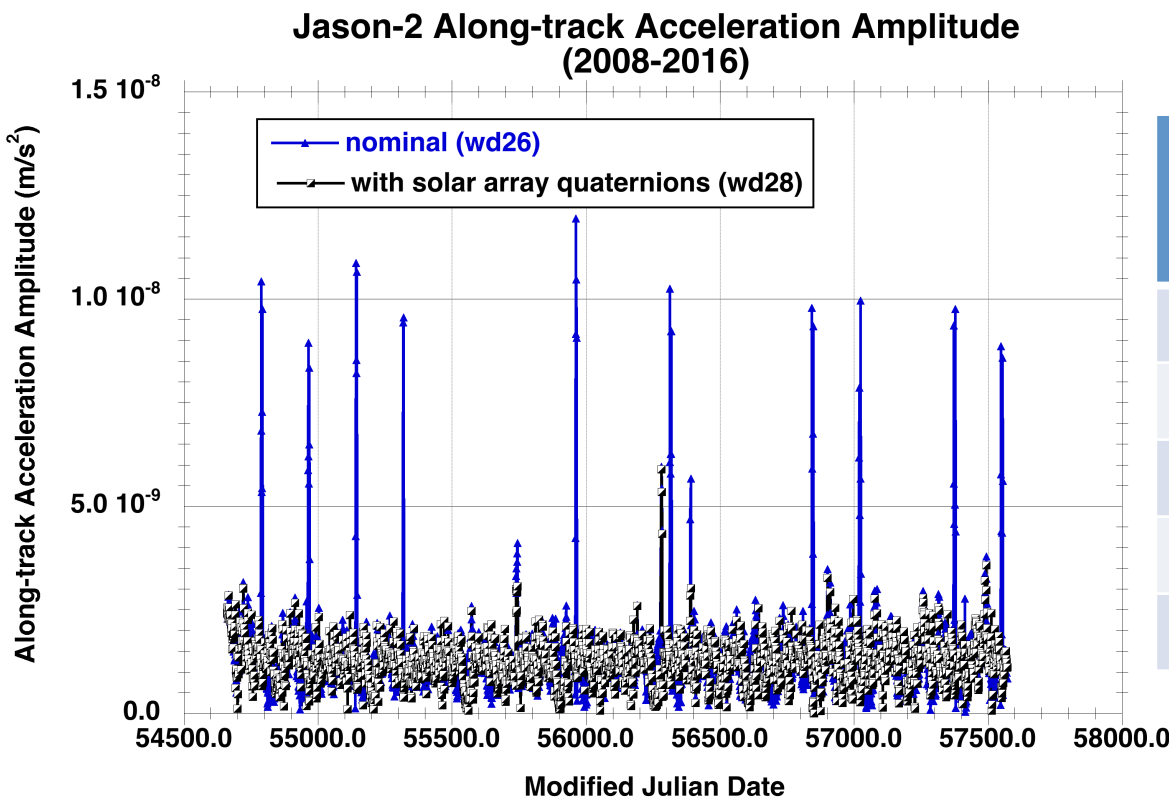
Tests with Solar Array Quaternions (J2)

JA2- Solar Array quaternions Improve Force Model; Diminish differences between SLR/DORIS dynamic and JPL/GPS Red-dynamic orbits.



Presented at the OSTST, Reston, October 2015.

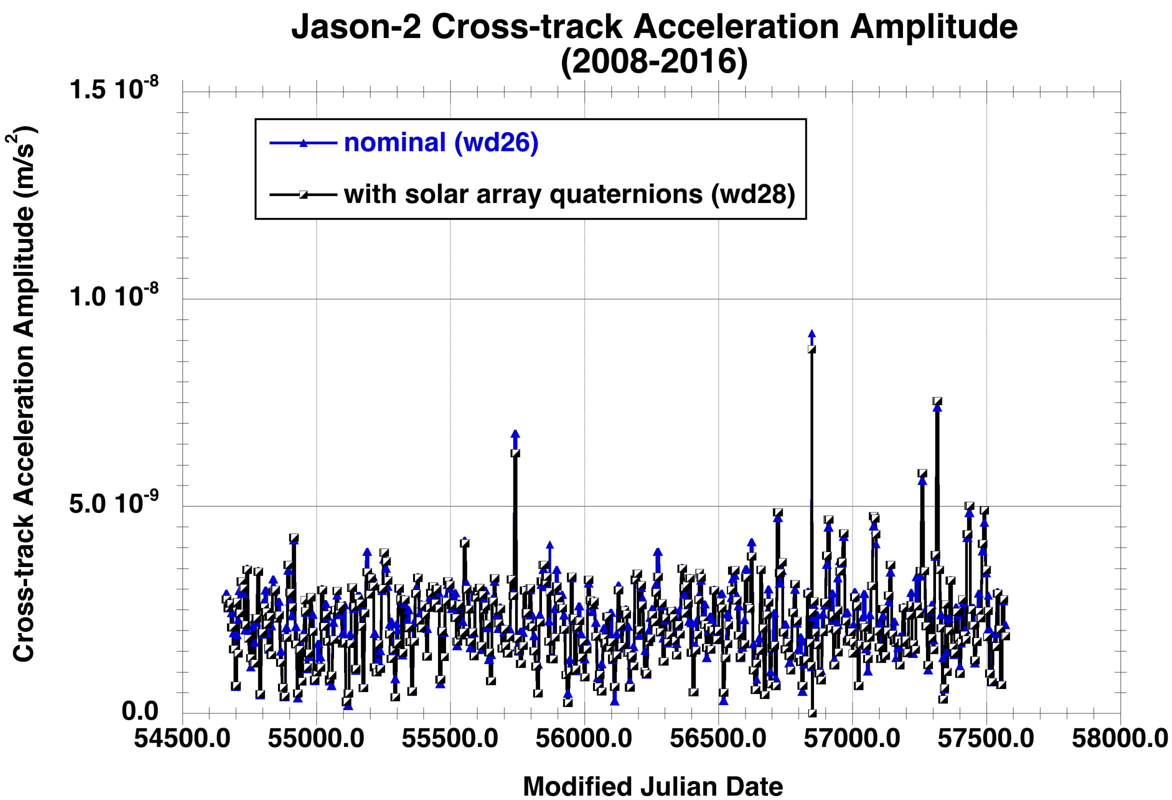
Tests with Solar Array Quaternions (J2)



	wd26 – no SAPA (nm/s²)	wd28- w. SAPA (nm/s²)
mean	1.39	1.25
median	1.26	1.25
RMS	1.73	1.35
stddev.	1.03	0.51
n	2836	2836

Inclusion of solar array quaternions to model solar array orientation improves non-conservative force modeling – not just SRP!!
The extrema in adjusted along-track OPR amplitudes are reduced.

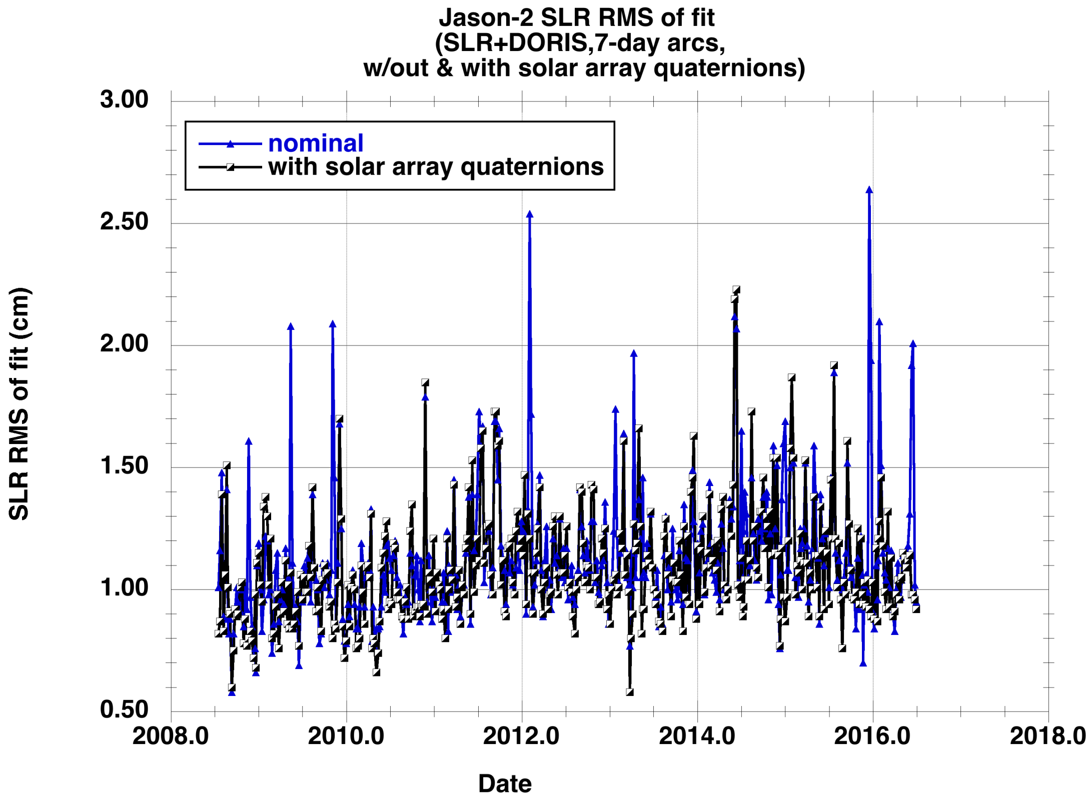
Tests with Solar Array Quaternions (J2)



	wd26 – no SAPA (nm/s^2)	wd28- w. SAPA (nm/s^2)
mean	2.29	2.16
median	2.33	2.06
RMS	2.47	2.37
stddev.	0.94	0.99
n	2836	2836

Use of solar array quaternions only slightly reduces the empirical Cross-track OPR amplitudes.

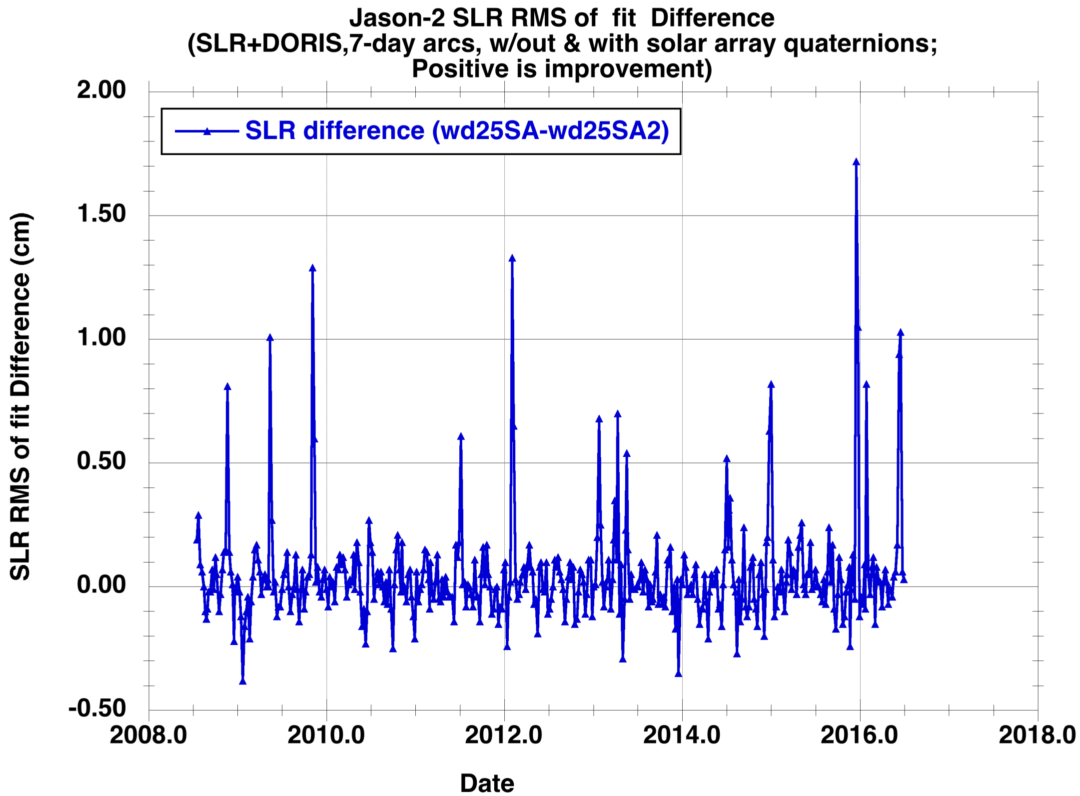
Tests with Solar Array Quaternions (J2)



	wd25 – no SAPA (cm)	wd25SA2- w. SAPA (cm)
mean	1.13	1.08
median	1.08	1.04
max	2.64	2.23
min	0.58	0.58
stddev.	0.0108	0.0127
n	432	432

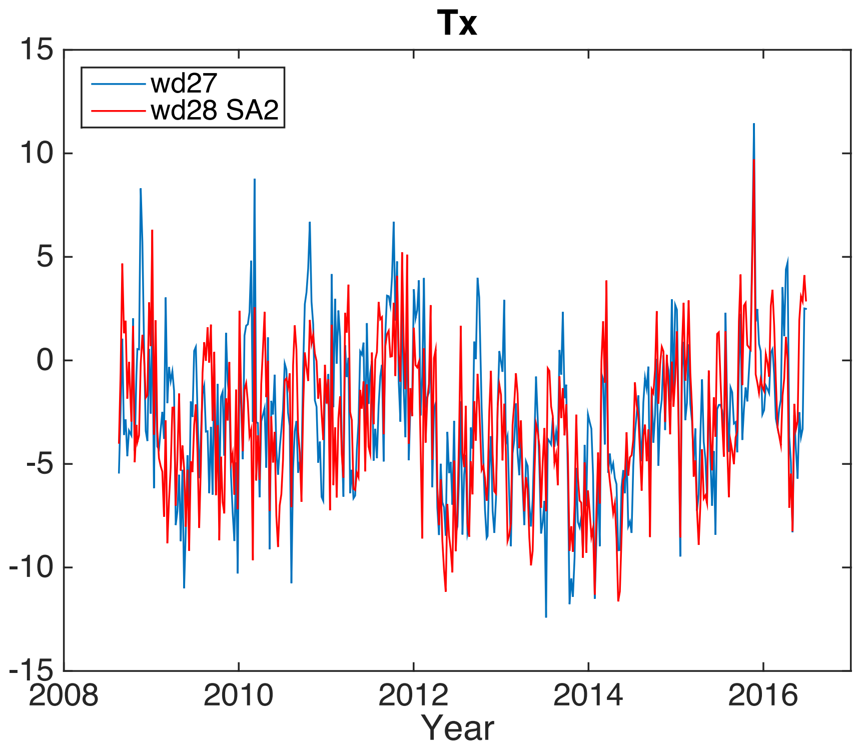
The use of the solar array quaternions slightly reduces the overall RMS of fit (even in the presence of OPR's), but seems to improve fits for outlier arcs.

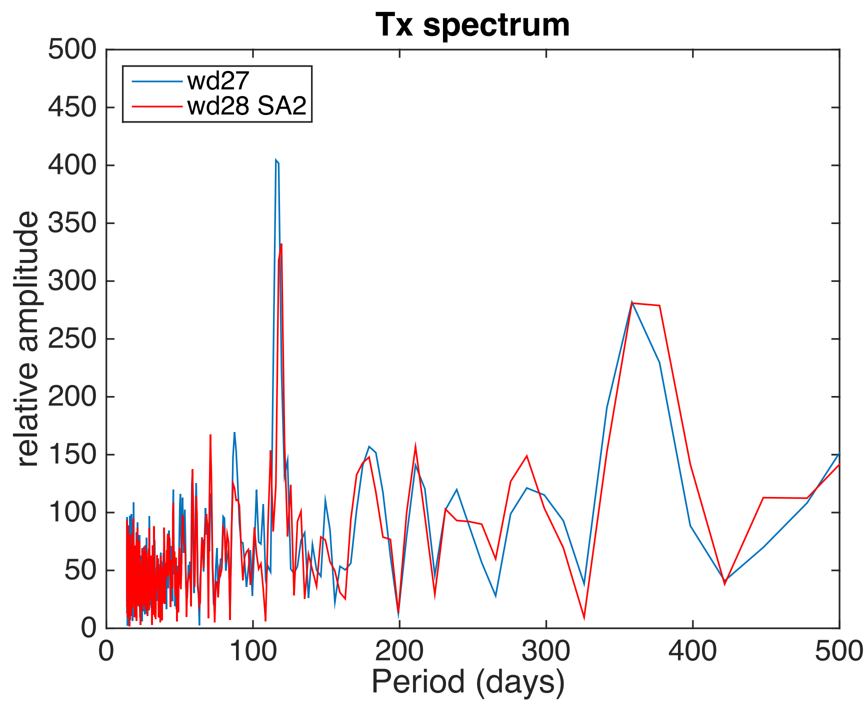
Tests with Solar Array Quaternions (J2)



Some arcs (~4%) are highly sensitive to use of quaternions to model orientation and motion of solar arrays (the nominal attitude law is not adequate).
cf. (Improvement in SLR RMS of fit of 0.5 to 1.7 cm).

Tests with Solar Array Quaternions (J2) Impact on TRF parameters: Tx

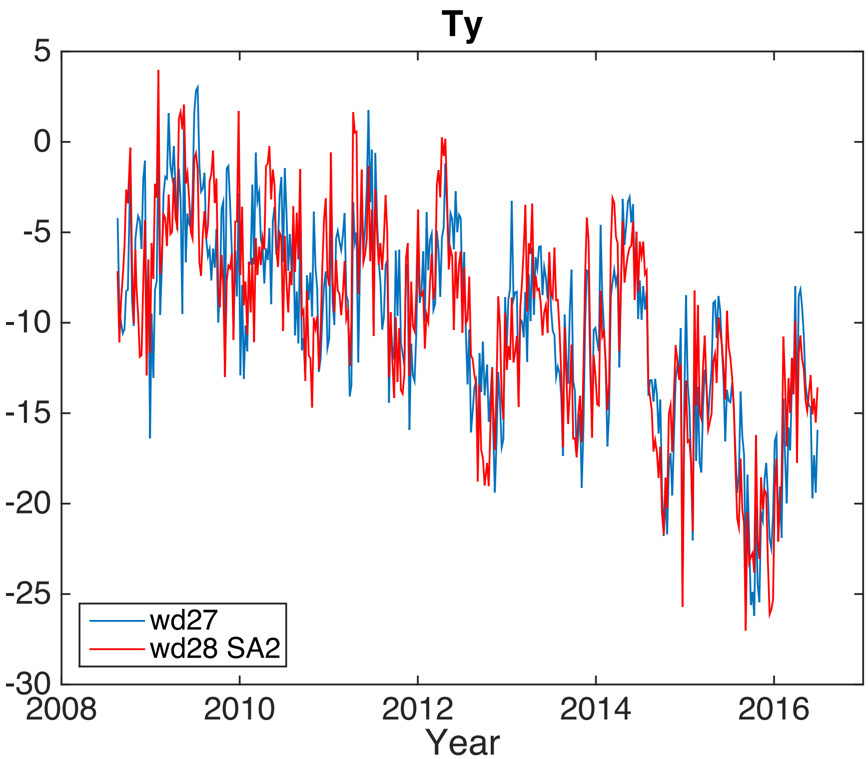


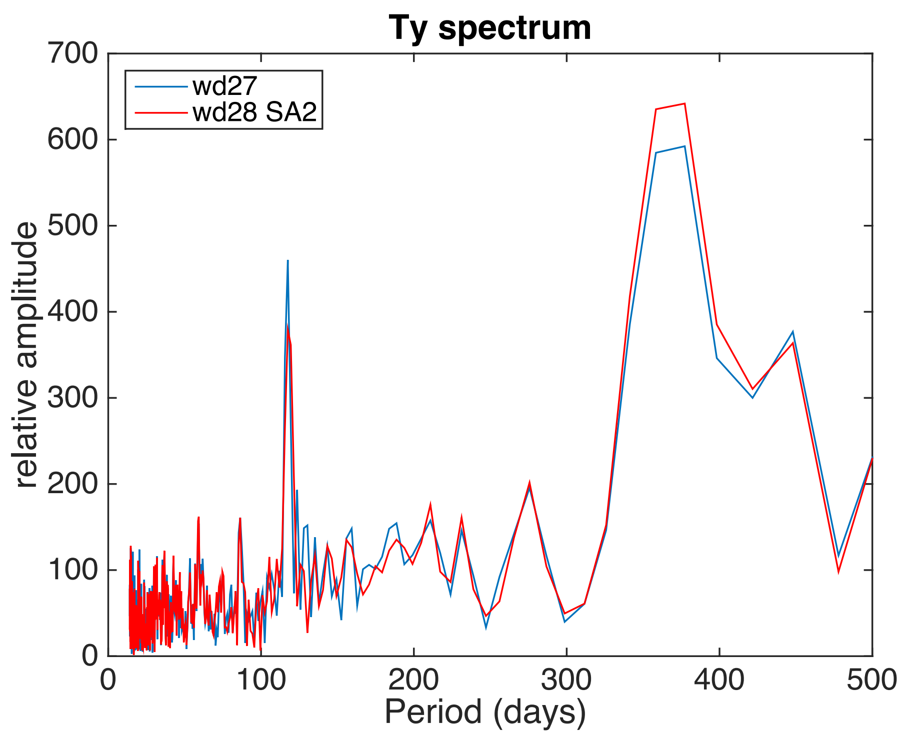


Slight reduction in ~117-day signal in Tx. Also a reduction in scatter of Tx. Tricky to quantify because of the longer period (non-stationary) signals (1.75-2.0 yrs), which are evident in Ty & Tz as well. Annual Amplitude: 1.3 – 1.5 mm

From Guilhem: For wd28 & wd26: Tx (117days) reduced from ~2mm to ~ 1mm

Tests with Solar Array Quaternions (J2) Impact on TRF parameters: Ty

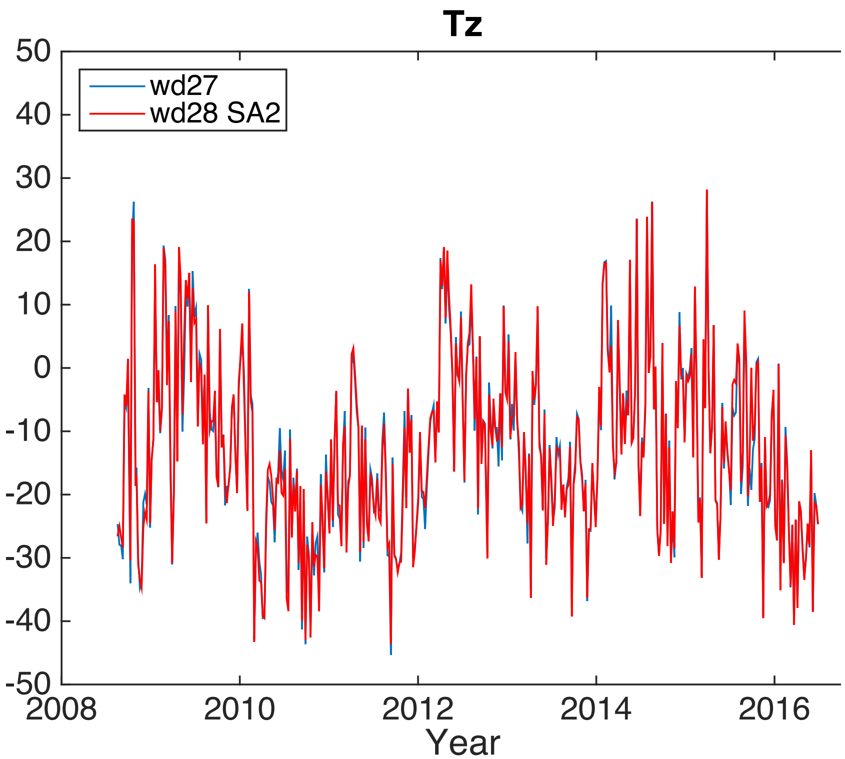


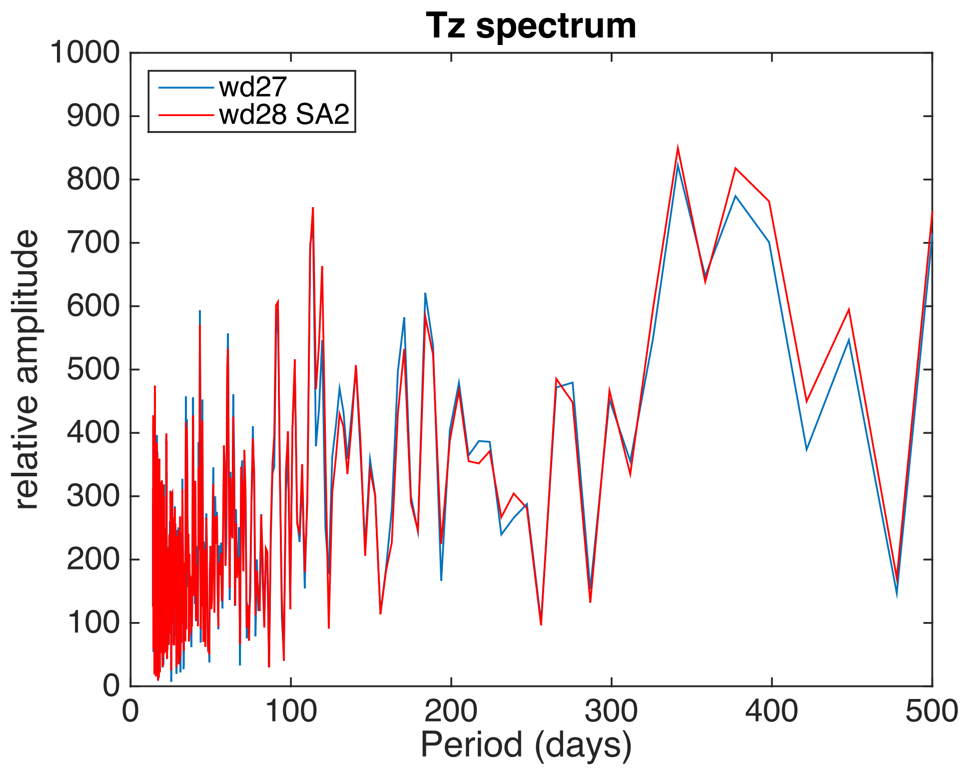


Slight reduction in ~117-day signal in Ty; Slight increase in annual signal.
Trend in Ty is unchanged: ~ -1.7 mm/yr. Annual signal: 3.4 mm (wd26), 3.7 mm (wd28).

From Guilhem: For wd28 & wd26: Ty (117days) reduced from ~2.0 mm to ~ 1.8 mm

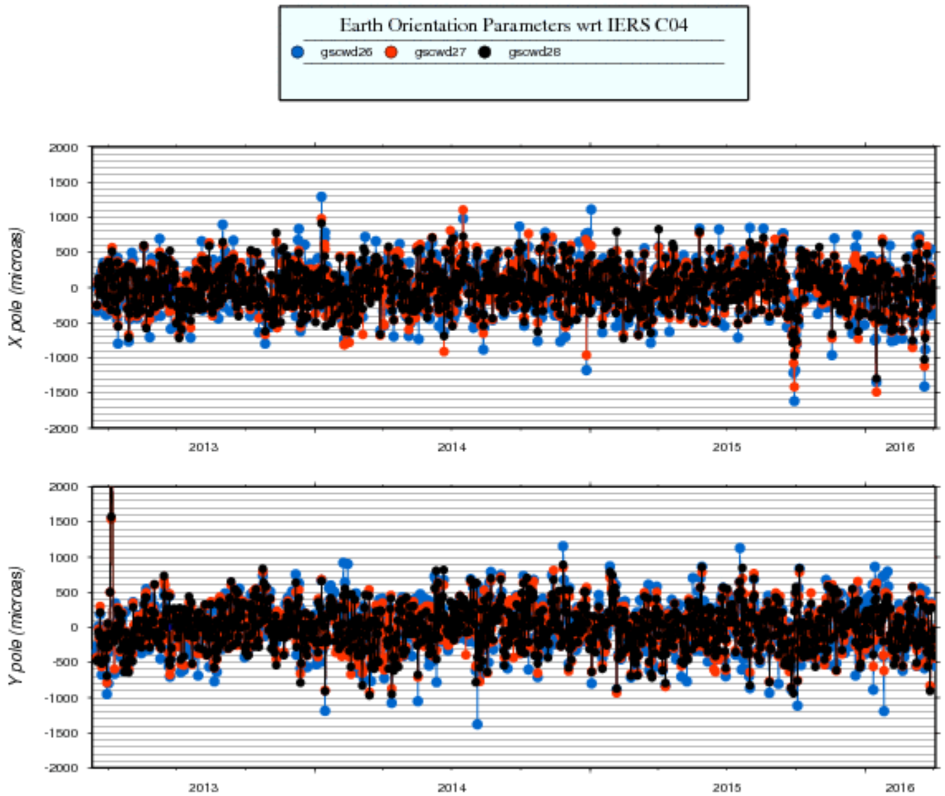
Tests with Solar Array Quaternions (J2)
Impact on TRF parameters: Tz





Slight increase in ~117-day signal in Tz?
No change in annual signal.
Pattern of Tz unchanged.

Tests with Solar Array Quaternions (J2) Evaluation of EOP (1):



AC	serie	# days	X pole (mas) trend	X pole (mas) mean	X pole (mas) std	Y pole (mas) trend	Y pole (mas) mean	Y pole (mas) std
gsc	26	1113	11.867	-2.293	337.616	-34.061	-1.665	341.438
gsc	27	1117	16.627	-2.235	302.538	-28.824	2.164	317.135
gsc	28	1110	14.578	-0.804	289.368	-37.174	2.492	322.472

(1) Addition of SARAL reduces stddev of EOP differences with IERSC04 from 337-341 µas to 302-317 µas. Visibly seems to reduce some scatter.

(2) J2 solar array quaternions are a tossup:
Xpole stddev. 302-> 289;
Ypole stddev. 317-> 322.

EOP Evaluation From Guilhem Moreaux:

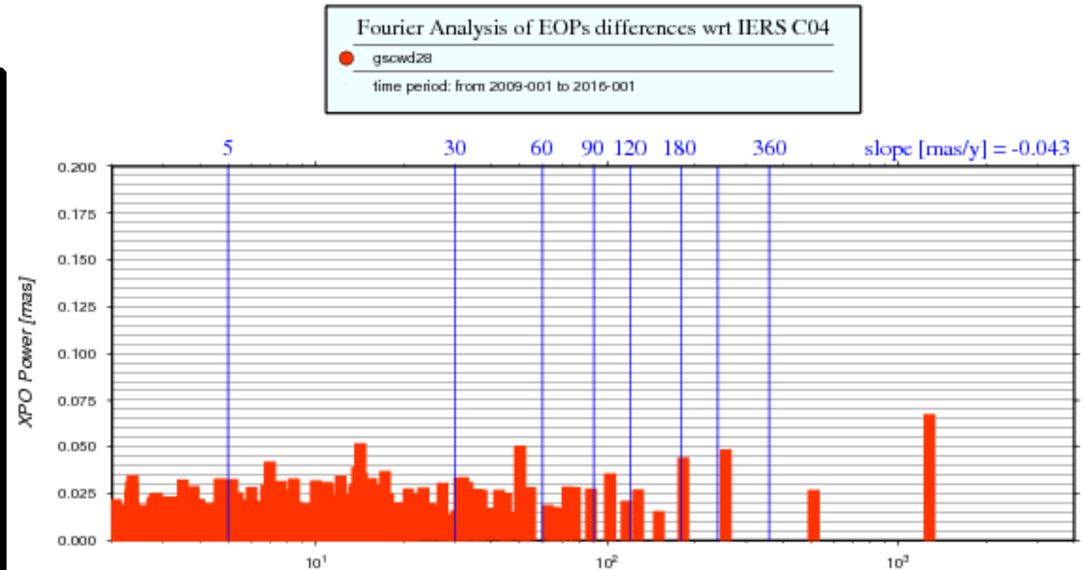
Evaluation of EOP: Discussion

From **Moreaux et al. (2016, AdvSpRs)** std. dev. of differences for IDS09 EOP with IERSC04 are 245 µas and 235 µas, respectively. Strong signals were found at periods of 14, 40, 59 days 117-days (Amplitudes of 44-78 µas).

Also identified in DORIS products:
Bloßfeld et al. (2016, AdvSpRs),
Tornotore et al. (2016, AdvSpRs).

It behooves all the ACs to consider what type of mismodeling could engender these types of signals.

The IGS and ILRS have looked quite carefully at error signals in their EOP products.



gscwd28 Xp EOP Evaluation (FFT) From Guilhem Moreaux:

Which peaks are significant? Where to begin?

- **14 days: tidal or Nyquist (2X 7-day SINEX solution cycle)?**
- **39-40 days: 3rd subharmonic of Jason-2 draconitic?**
- **59 days: tidal or 2nd subharmonic of Jason-2 draconitic.**

117 days: Jason-2 draconitic.
180 days; 365 days: Time-variable gravity? Geocenter? Inadequacy of pole model?

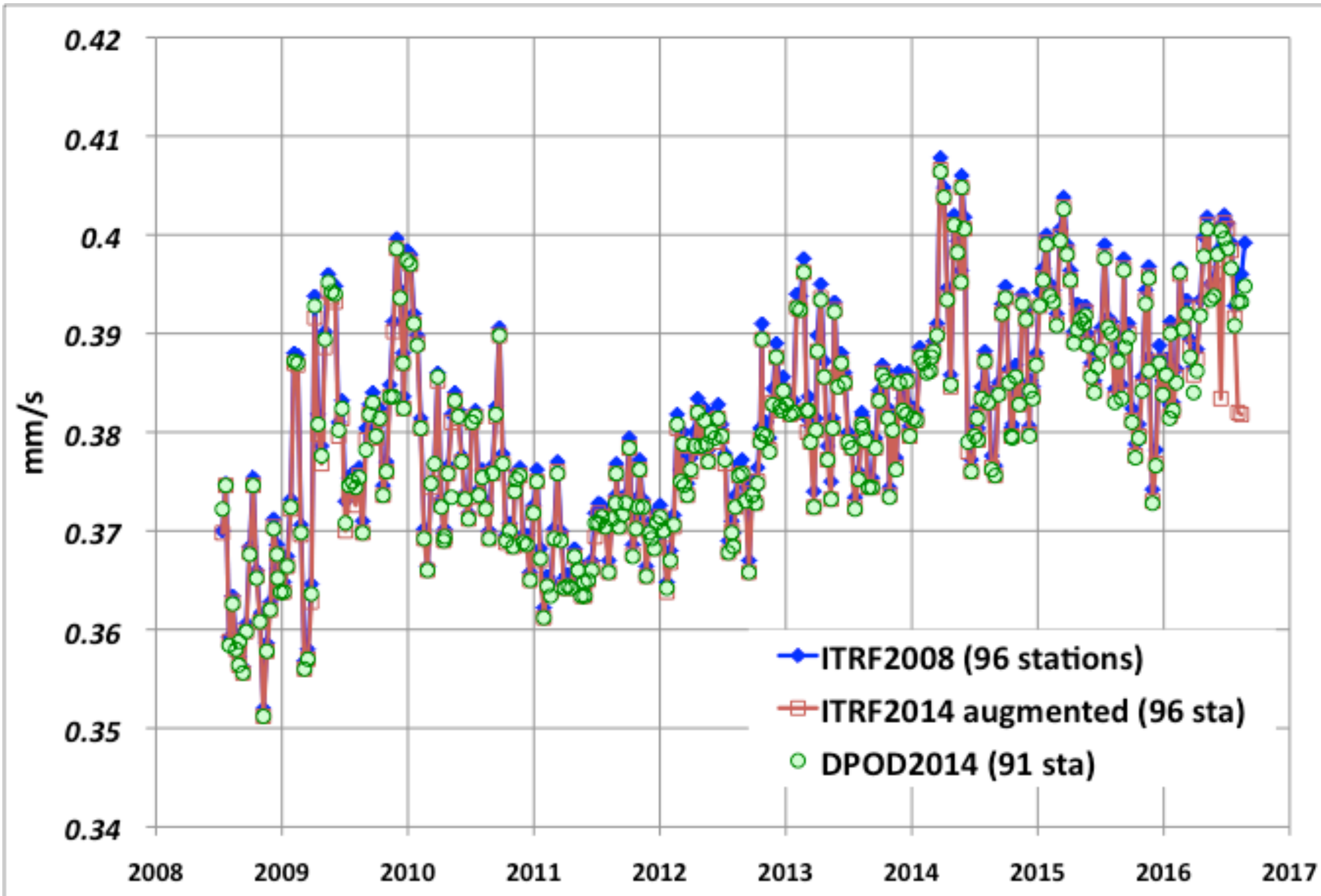
- **435 days? Chandler wobble; Inadequacy of pole model?**

Use of solar array quaternions on J2, reduces Xp 117-day signal fom ~40 µas to ~23 µas; (Yp 117 day signal. 27 to 30 µas) .

GSFC POD evaluation of DORIS Station Sets.

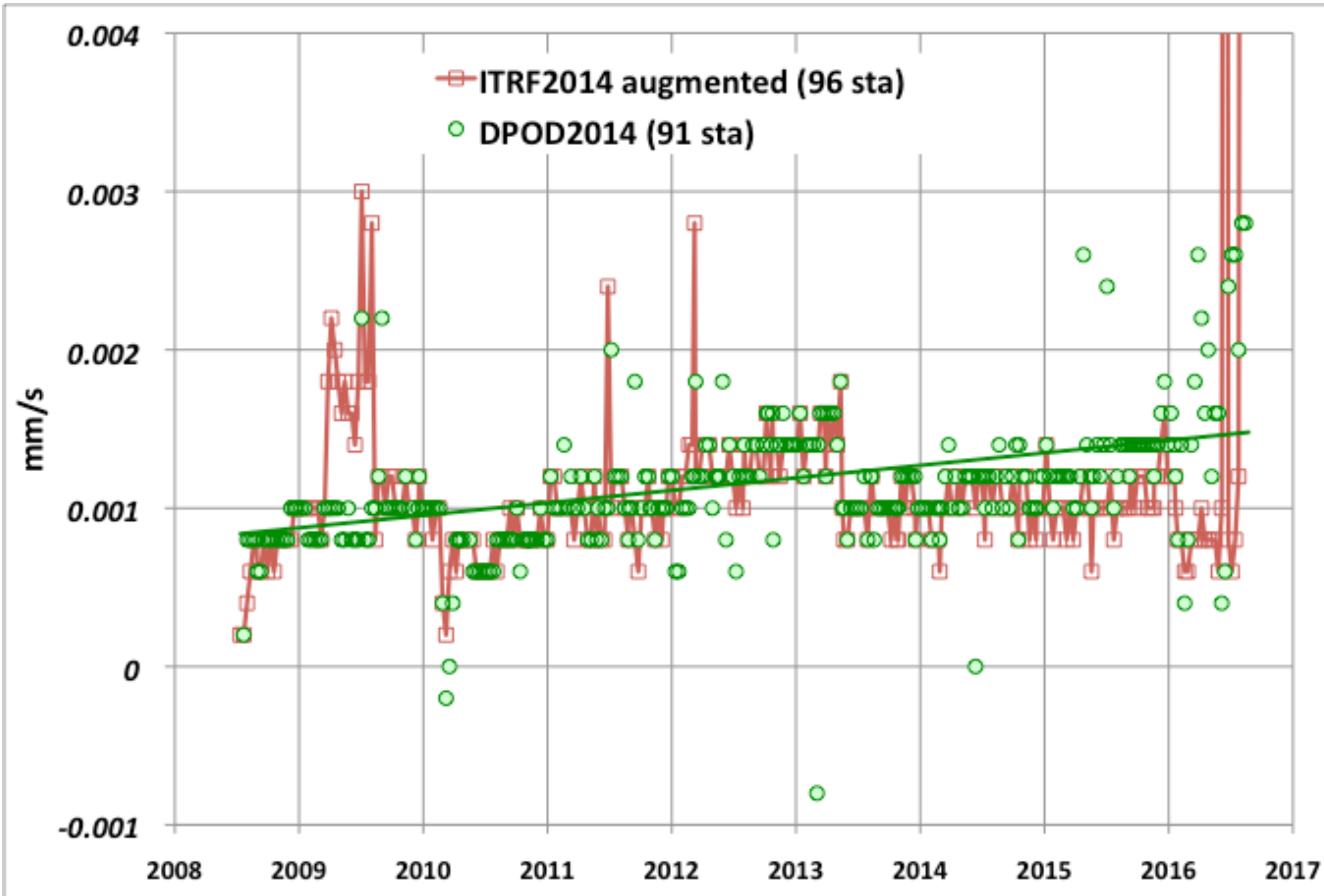
DORIS complement	Number stations (4-character)	Description
Total	195	Nikita's tally (October 15, 2016)
DPOD2008.v15	192	CLS DPOD2008.v15 plus 5 stations: JIWC PDOC SAPC KEVC MNAC missing from Total: WEUC OWFC KIVC
ITRF2014 (IGN) augmented	192	32 stations added from DPOD2008.v15 using 14-parameter transform
DPOD2014.v02	180	missing from Total: WEUC OWFC KIVC JIWC PDOC SAPC KEVC MNAC ARLA KRUA RICA SOCA TLIA TROA HVOA

Jason-2 DORIS residuals (080712 – 160831)

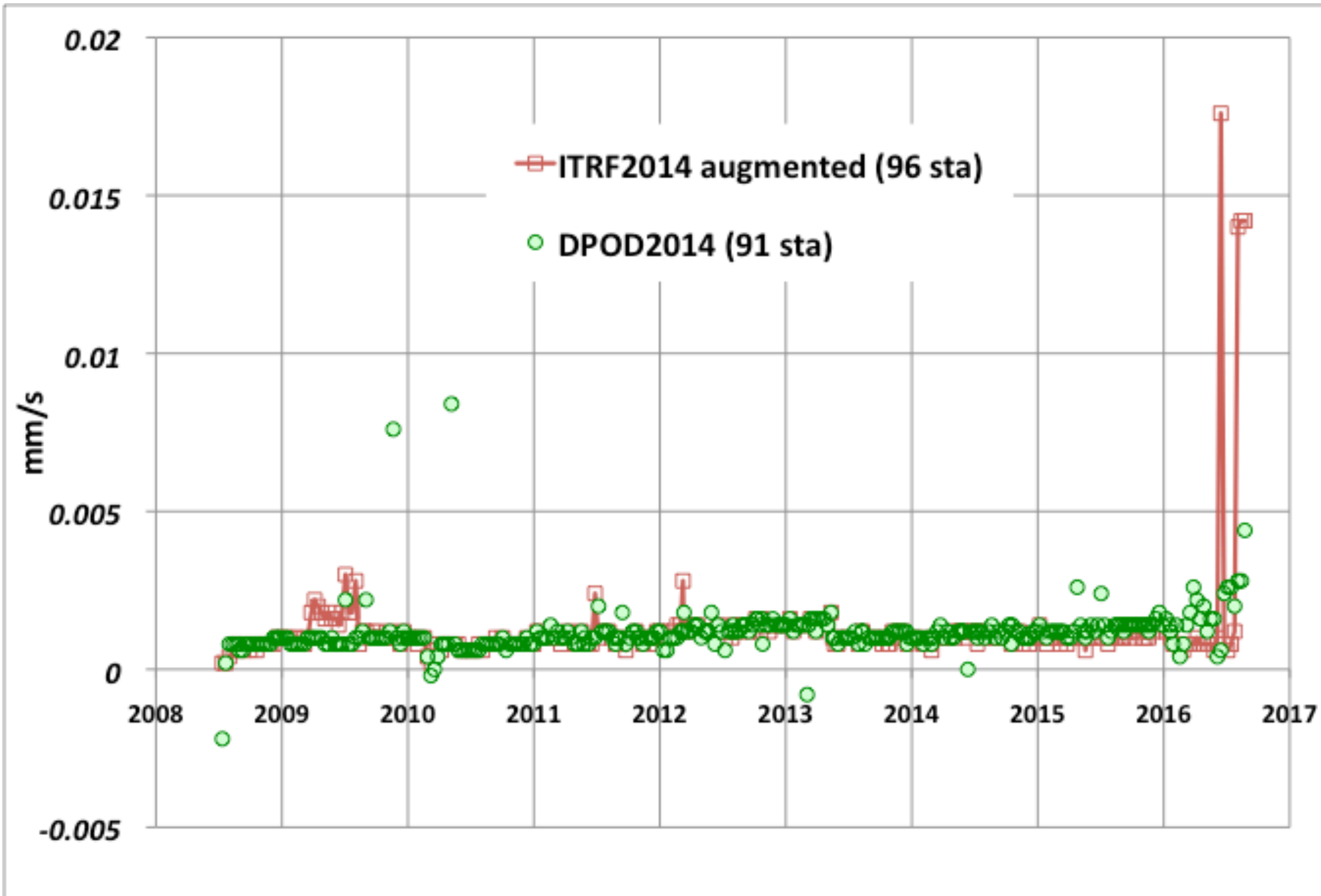


DPOD2014 missing: JIWC PDOC SAPC KEVC MNAC

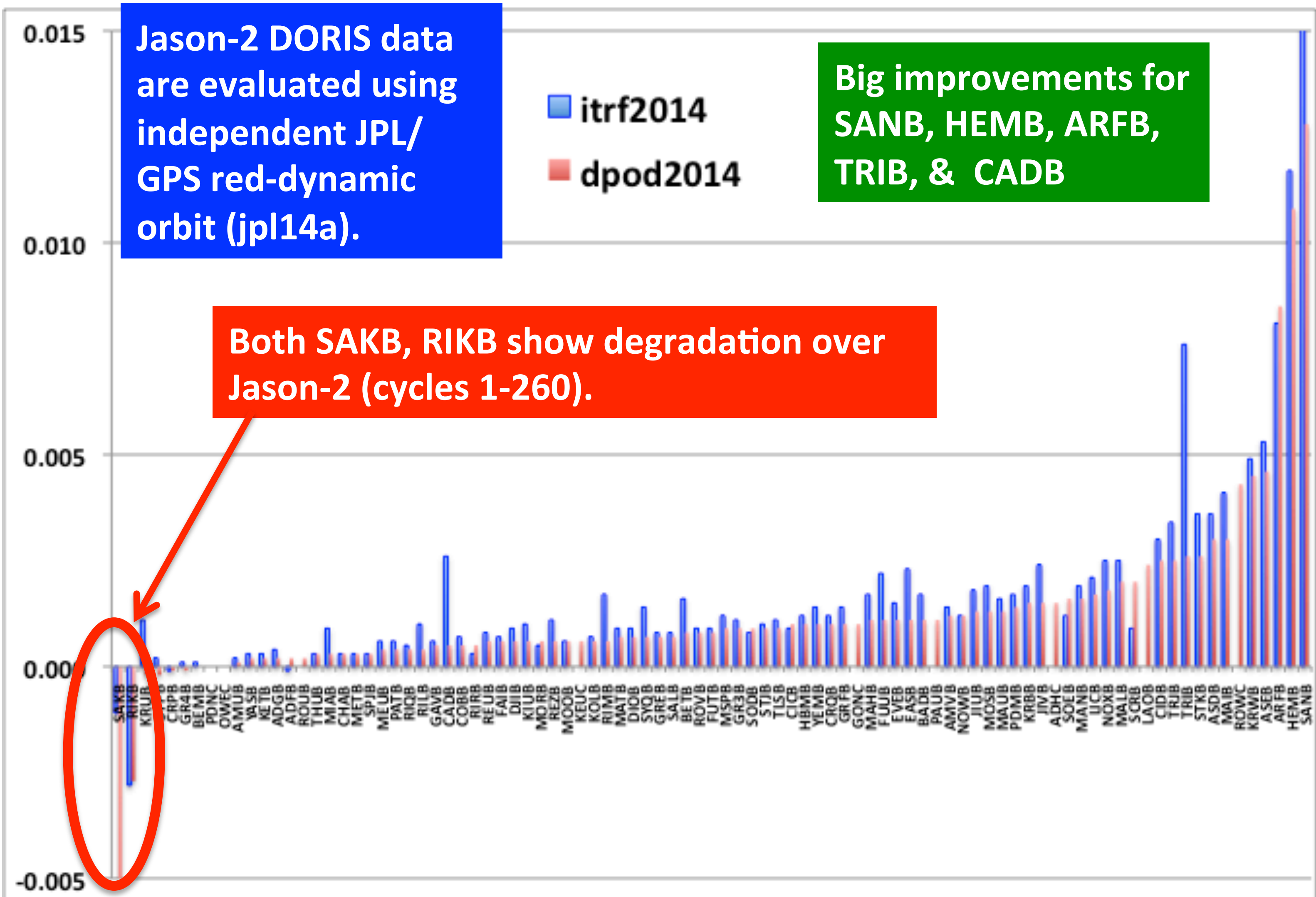
Difference Jason-2 DORIS residuals ITRF2008 – Test
Positive => improvement for Test



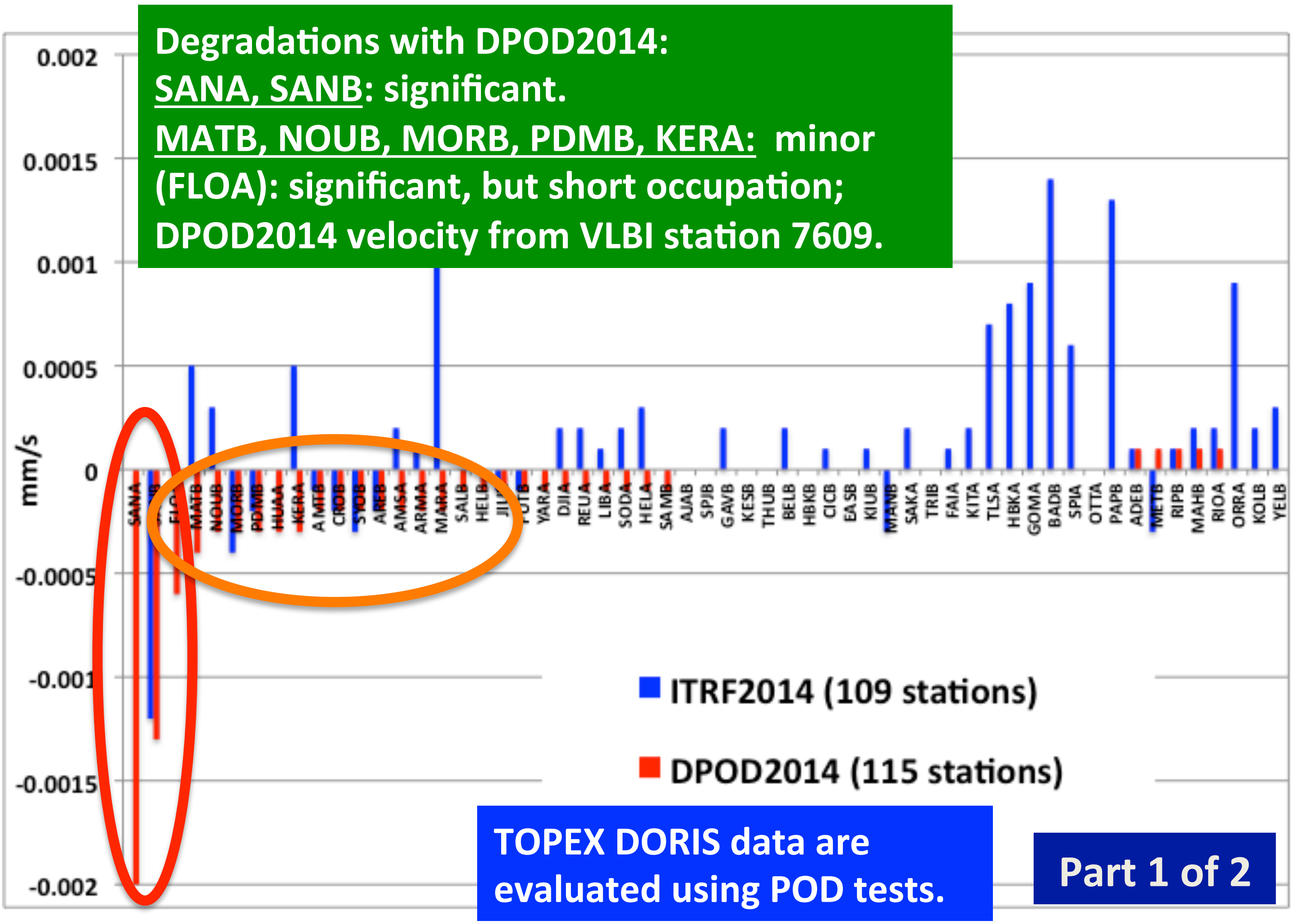
Difference Jason-2 DORIS residuals ITRF2008 – Test Positive => improvement for Test



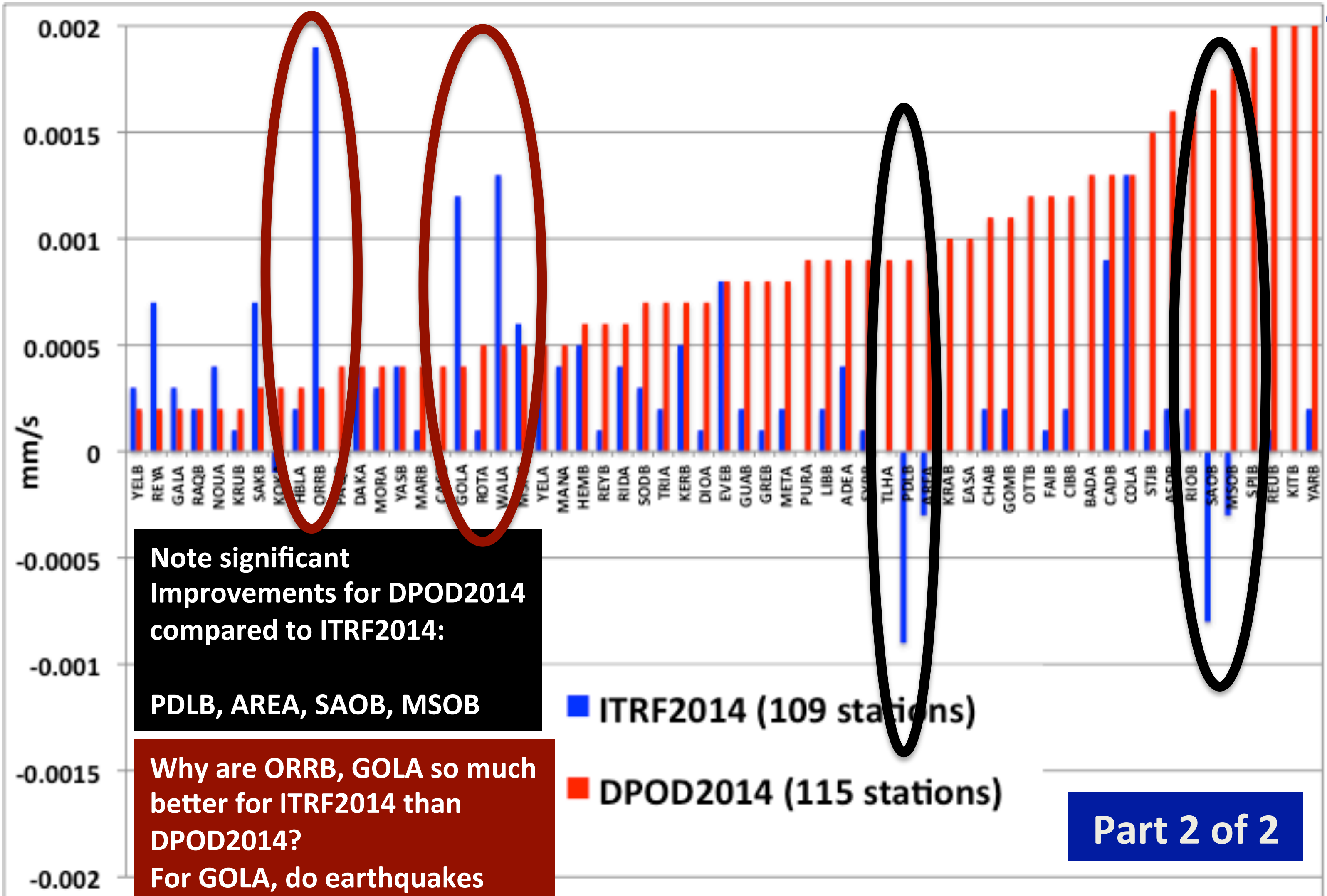
Jason-2 DORIS dpod2008 - *Test* RMS residual differences using jpl14a orbit, cycles 1-260 (mm/s) positive => improvement for Test



TOPEX/Poseidon POD DORIS dpod2008 - *Test*
RMS residual differences (mm/s)
positive => improvement for Test



TOPEX/Poseidon POD DORIS dpod2008 - *Test*
RMS residual differences (mm/s)
positive => improvement for Test



Note significant Improvements for DPOD2014 compared to ITRF2014:

PDLB, AREA, SAOB, MSOB

Why are ORRB, GOLA so much better for ITRF2014 than DPOD2014?
For GOLA, do earthquakes complicate time series in 1993 & 1994?

Pole Modeling Issues (1)

$$\bar{x}_p(t) = \sum_{i=0}^{3} (t - t_0)^i \times \bar{x}_p^i, \qquad \bar{y}_p(t) = \sum_{i=0}^{3} (t - t_0)^i \times \bar{y}_p^i, \qquad (7.25)$$

where t_0 is 2000.0 <9> and the coefficients $\bar{x}_p^i$ and $\bar{y}_p^i$ are given in Table 7.7.

Table 7.7: Coefficients of the IERS (2010) mean pole model

	Until 2010.0		After 2010.0	
Degree i	$\bar{x}_p^i$ / mas yr^{-i}	$\bar{y}_p^i$ / mas yr^{-i}	$\bar{x}_p^i$ / mas yr^{-i}	$\bar{y}_p^i$ / mas yr^{-i}
0	55.974	346.346	23.513	358.891
1	1.8243	1.7896	7.6141	-0.6287
2	0.18413	-0.10729	0.0	0.0
3	0.007024	-0.000908	0.0	0.0

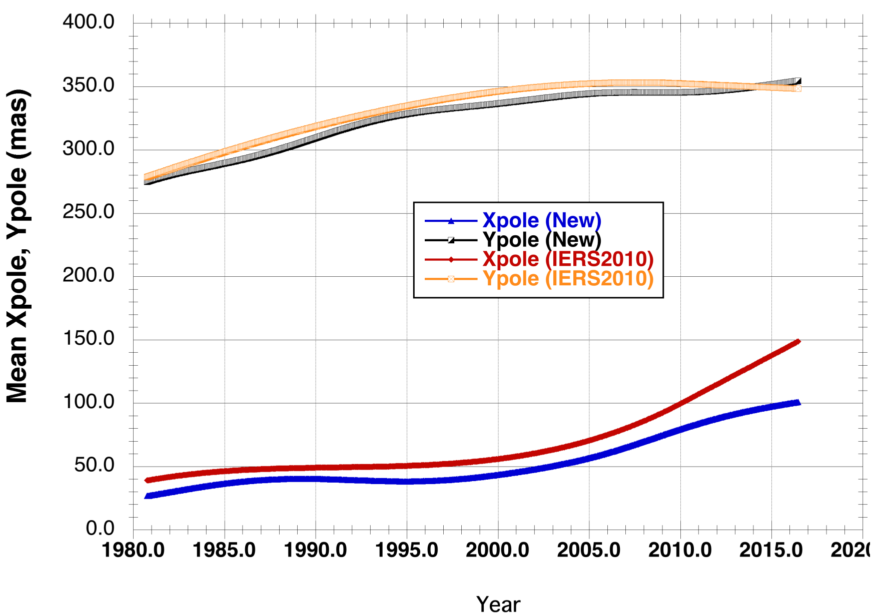
Current model from IERS2010 Conventions is a Cubic model until 2010, and then a linear model after 2010.0.

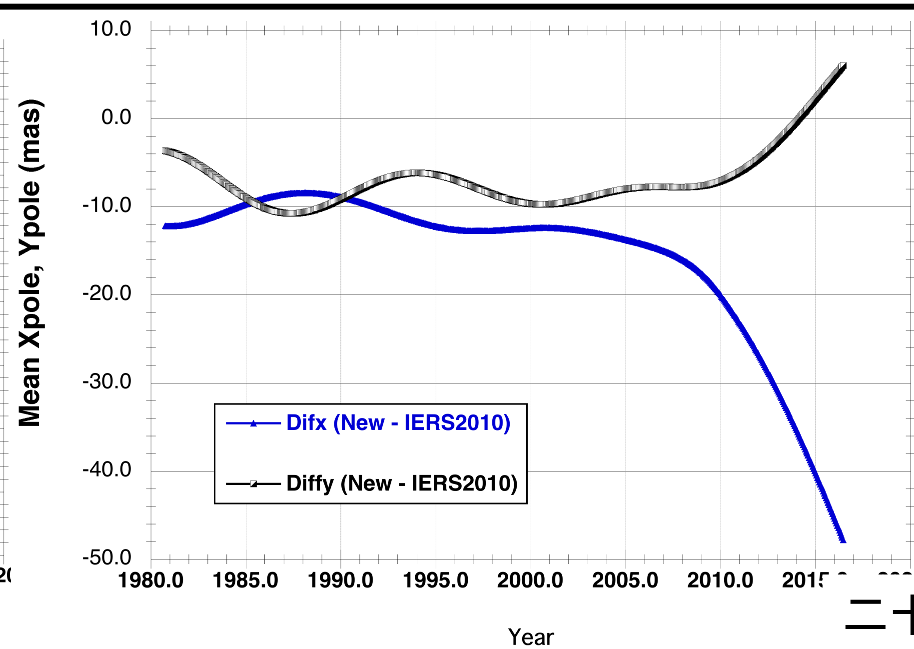
Pole Modeling Issues (2)

Using Tabulations of the mean pole from IERS website, it is easy to see that the IERS2010 pole model is no longer adequate and is deviating from reality;
Several papers have discussed this subject, e.g.

Chen JL, CR Wilson, JC Ries and BD Tapley (2013), "**Rapid ice melting drives Earth's pole model to the east**", *Geophys. Res. Lett., 40*, 2625-2630.

Adhikari S, and ER Ivins (2016**), "Climate-driven polar motion: 2003-2015**", Science Advances, 2(4), e1501693.





Pole Modeling Issues (3)
Implications (1)

King and Watson (2014), "Geodetic vertical velocities affected by recent rapid changes in polar motion", Geophys. J. International, 199, 1161-1165.

- "Secular motion of the pole results in a large-scale secular deformation of the Earth."
- "Geodetic velocities determined since ~2005 are biased by ±0.38 mm/yr relative to the longer-term deformation pattern."

"Another such source of gravity field variability is the solid Earth pole tide: the deformation within the solid Earth caused by motion of the rotation axis relative to the Earth's surface (this motion of the rotation axis is referred to as "polar motion"). Polar motion causes the centrifugal force to change at every point within the earth and that induces deformation. That deformation is called the solid Earth pole tide, and it causes a time-dependent gravity signal ..." Wahr et al. (2015)

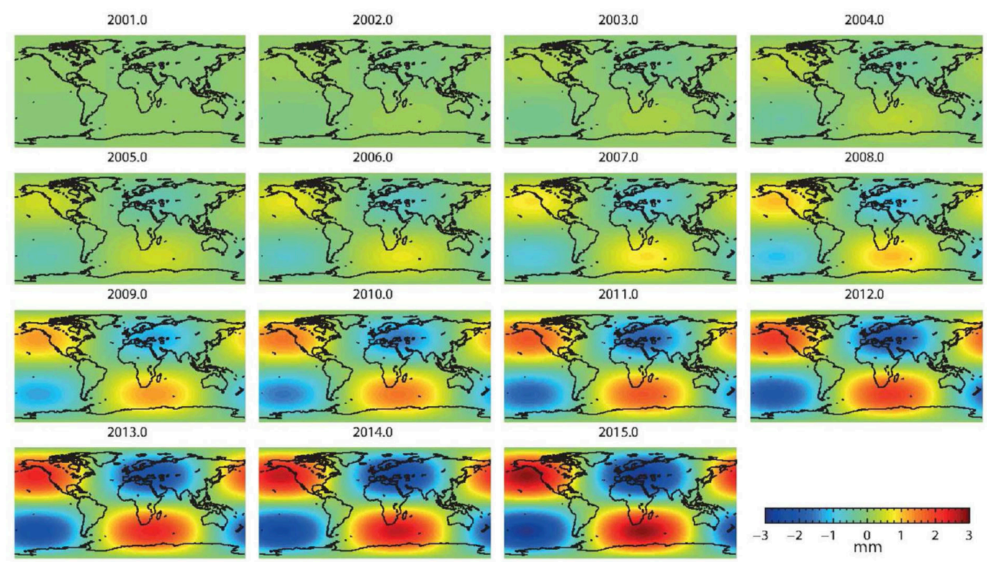


Figure 2. Modelled deformation patterns for 2001 January 1 to 2015 January 1 expressed as anomalies to the average pattern (related to polar motion) over the 20th century.

Pole Modeling Issues (4)
Proposed Solution:

http://62.161.69.134/iers/convupdt/convupdt_c7.html

Updates to the IERS Conventions (2010): Chapter 7
Displacement of reference points
Working version last updated: 19 June 2015 see List of updates

ext of chapter 7: PDF file.

gures (eps format) for Chapter 7.

ubroutines and other files for Chapter 7.

- DEHANTTIDEINEL.F - Subroutine to compute tidal corrections of station displacements caused by lunar and solar gravitational attraction. Provided by V. Dehant. Updated 23 October 2007, 19 February 2009, 10 April 2009, 26 March 2012, 10 June 2013, 19 June 2015. All subroutines needed for compilation are provided here.
- HARDISP.F - Program to compute ocean tidal loading from a table of amplitudes and phases of the 11 main tides. Provided by D. Agnew. Updated 19 February 2009, 10 April 2009, 26 March 2012, 19 June 2015. All subroutines needed for compilation are provided here.
- ARG2.F - Subroutine to compute the angular argument which depends on time for 11 tidal argument calculations. From a Table by E.W. Schwiderski. This routine replaces the previous routine ARG.F. Main changes are the use of double precision for all variables and of the 4-digit year as an input argument.
- IERS_CMP_2015 - Subroutine to generate the IERS Conventional Mean Pole (2015) as described in section 7.1.4. The subroutine also allows to generate past versions 2003 and 2010 of the IERS CMP, see the comments of the subroutine.
- opoleloadcoefcmcor.txt.gz - Table of coefficients for the ocean pole tide loading model (gzipped). Provided by S. Desai.
- opoleloadcmcor.test - Test run for the ocean pole tide model. Provided by S. Desai. Additional information provided 19 June 2015

ee also Additional material.

ftp://tai.bipm.org/iers/convupdt/chapter7/IERS_CMP_2015.F

```
      SUBROUTINE IERS_CMP_2015   (version, epoch,x,y,error)
*+
*
*  This routine is part of the International Earth Rotation and
*  Reference Systems Service (IERS) Conventions software collection.
*
* This subroutine provides the angular coordinates of the IERS Conventional Mean Pole (CMP)
* to be used in the analysis of space geodesy data after 1970.
* Starting with the version CMP(2015), the coordinates are
* based on the table of values from ftp://hpiers.obspm.fr/iers/eop/eopc01/mean-pole.tab
* See IERS Conventions Section 7.1.4 at http://tai.bipm.org/iers/convupdt/convupdt.html for details.
* The subroutine also provides previous versions of the CMP in the IERS Conventions (2003) and (2010)
*
*
```

To be updated every February. Acc. to ECP from Potsdam ILRS AWG meeting (Oct 2016): “DO NOT USE IERS-supplied pole table”. Use subroutine.

Pole Modeling Issues (5)
Pole tide & time-variable gravity:

Wahr J, RS Nerem SV Bettadpur (2015), "The pole tide and its effect on GRACE time-variable gravity measurements: Implications for estimates of surface mass variations",
J. Geophys. Res-Solid Earth, 2015, 120, 4597-4615.

1. Dynamical effect of the Pole tide must be removed in order to interpret GRACE-measured time-variable gravity as surface-mass variations.

2. The current IERS specifications for the pole and evaluation of the pole tide leave long-period signals in the GRACE time series; Different GRACE centers actually do things differently and different corrections are necessary.

3. The paper recommends treating as a "mean pole" only that induced by GIA, and the rest as induced by mass variations. That "difference" is what would enter into the pole tide calculations, instead of the deviations from the current mean pole and actual pole.

Pole Modeling Issues (6)
What we need:

1. Clear definition of what we should be using as a mean pole, taking into account recent papers of Wahr et al. (2015), King and Watson (2014).

2. Clear specification of how we should apply the pole tide correction (geometric and dynamic corrections).

3. Clear specification of background C_{21} S_{21} to use so that figure axis is consistent with pole model and background models for pole tide.

Summary

1. We have developed an updated time series (wd28) that uses the Jason-2 quaternions to orient the solar arrays. The benefits cannot be overemphasized. We should have complete quaternion sets, including solar array quaternions for other DORIS satellites as a matter of course: HY-2A?? SARAL?? Can the IDS write to the projects to request this information?

2. In future work we collaborate with Univ. College London to implement a Jason-2 UCL model that includes solar array "true" orientation.

3. Continue evaluation tests with DPOD2014 and adopt this as soon as the DPOD2014 is finalized.

4. Evaluate downweighting of low-elevation DORIS data, where DORIS data are affected by multipath,troposphere or ionosphere refraction mismodelling.

5. Implement whatever final recommendations are made for modeling of pole, evaluation of pole tide, and C_{21} & $S_{21.}$

Backup Slides

TOPEX/Poseidon DORIS residual summary 920925 – 041102 (cycles 1-446)

Test SLR+DORIS orbits	DORIS points	SLR points	DORIS RMS (mm/s)	SLR RMS (cm)	Xover * RMS (cm)
std1504 (ITRF2008)	55690	5213	0.4953	1.553	5.611
itrf2014_augmented	55777	5211	0.4955	1.581	5.612
dpod2014	55950	5211	0.4950	1.580	5.611

* independent TOPEX altimeter GDR data cycles 1-446