Improvements to the GSC Processing and Impact on Geodetic Products

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GSC SINEX Delivery Summary

(*delivered to IDS Data Centers*)

SINEX series	Description	Dates
gscwd26	ITRF2014 series (Lemoine et al., Adv Space Res., 2016)	1999-DOY285 to 2016-DOY269.
gscwd27	gscwd26 + SARAL	2013-DOY006 to 2016-DOY178.
gscwd28	gscwd27 + use Solar Array quaternions to model attitude of Jason-2	2008-DOY195 to 2016-DOY360
gscwd29	gscwd28, but use dpod2014_v04 as a priori, instead of dpod2008	2008-DOY020 to 2017-DOY176
gscwd30	Test series only. gscwd29+ Jason-3: -no special handling for SAA stations (J3)	2016-DOY010 to 2017-DOY176
gscwd31	gscwd29 + Jason-3, SAA stations adjusted separately on J3 matrix before addition of J3 to combination.	2016-DOY003 to 2018-DOY175
gscwd32	**gscwd31 + (1) New version of GEODYN (1802) with updates for Earth Tides, Tidal EOP, and handling of Biases, and (2) New offset for HY-2A.**	**2016-DOY003 to 2018-DOY175**

The gscwd32 series is currently under evaluation.

Motivation: Update modelling in advance of next ITRF reprocessing

1	Update modeling of static and time-variable gravity.
2	Adopt new offset for HY-2A.
3	Further improve non-conservative force modelling for DORIS satellites, in order to remove draconitic signals in DORIS products.
4	Use new version of GEODYN (1802) that includes different updates: (A) Slight updates to modelling of Earth tides. (B) Slight changes to modelling of Tidal EOP. (C) More rigorous handling of biases (range-rate and troposphere)
5	Test new models of Tidal EOP (as part of IERS Working Group led by John Gipson, IVS Analysis Coordinator).
6	Switch to RINEX processing for all DORIS satellites.
7	Add new satellites (Sentinel-3A, 3B).
8	Test new USO models for Jason-2, and Jason-3 based on results from T2L2.
9	Adopt updated troposphere refraction model & corrections (e.g. VMF1 + use of lower elevation data) and more recent ocean tide model (e.g. GOT4p10c).
10	<u>Operational considerations</u>: If possible simplify scripts, and pre-processing to minimize complexities in routine processing.

Motivation: Update modelling in advance of next ITRF reprocessing

1	Update modeling of static and time-variable gravity.
2	Demonstrate a method to further improve non-conservative force modelling for DORIS satellites, in order to remove draconitic signals in DORIS products.
3	Test and Adopt new offsets for HY-2A.

Topics discussed in this presentation today.

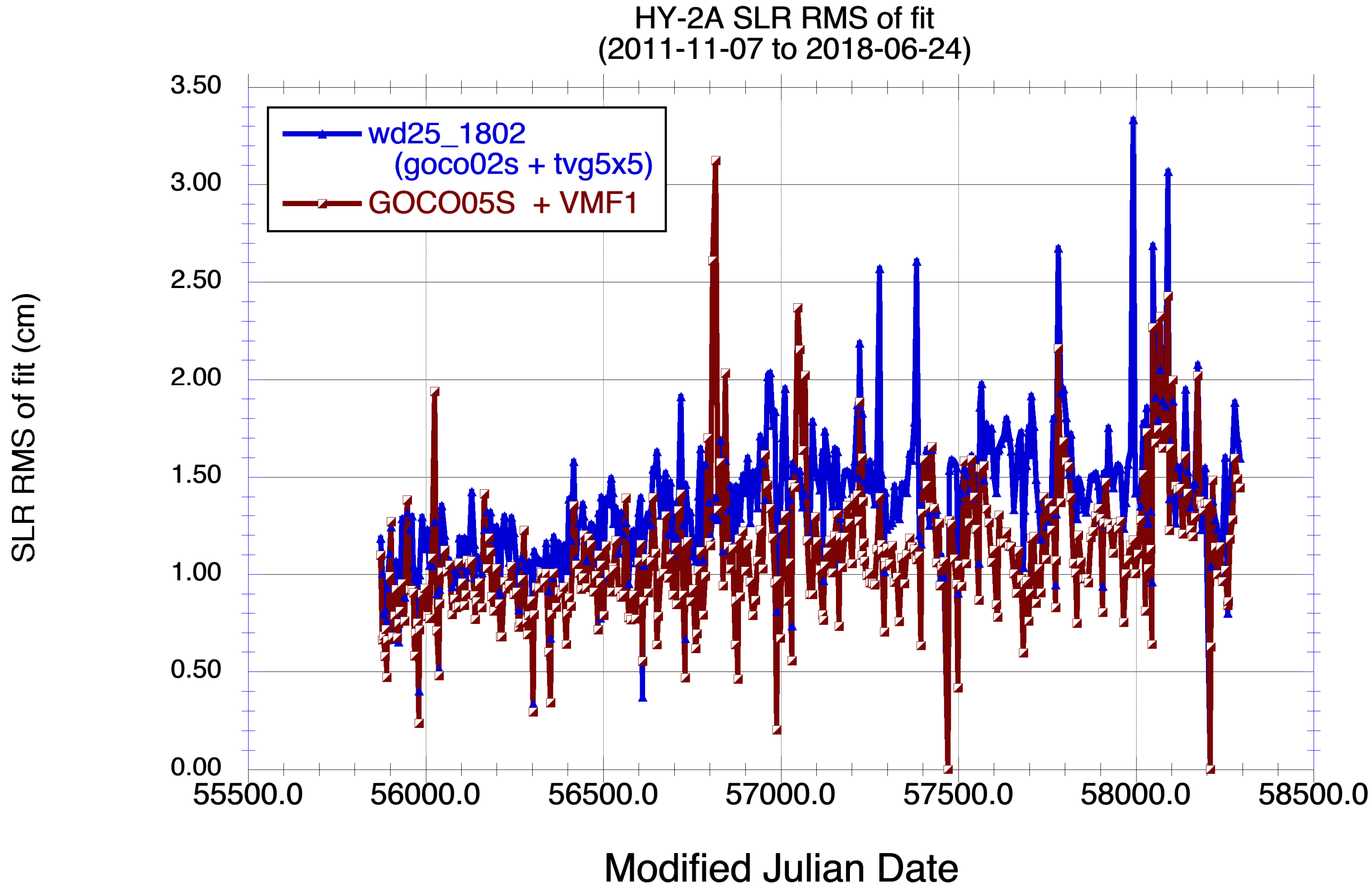
Present Gravity Modelling

Model	Name/Description	Comment
Static Gravity	<u>**GOCO02S**</u>: Based on GRACE (7 yrs), GOCE (~22 months), CHAMP (~8 yrs), SLR Satellites (~5 yrs)	Goiginger et al. (2011)
Time-Variable Gravity (TVG): (Low Degree Field)	Time series of 5x5 coefficients based on processing data to SLR-DORIS satellites.	Time series developed for ITRF2014 back to 1992, and continued on best efforts basis.
TVG(Higher harmonics)	Use annual harmonics from GSFC GRACE solutions.	Updated from Luthcke et al. (2006)
<u>Advantages</u>:	Time series approach provides good detail for modelling TVG, and is better than a model like EIGEN-6S. This approach worked well for period pre-GRACE.	
<u>Disadvantages</u>:	(1) Static model is now dated; (2) TVG has evolved considerably since ~2010; (3) **Very labor Intensive**.	

Proposed Update to Gravity Model for GSC

Model	Name/Description	Comment
Static Gravity	**<u>GOCO05S</u>**: Based on 15 Satellites: GRACE (2003-2014); GOCE; 7 GPS-Tracked LEOs; 6 SLR satellites.	Torsten Mayer Gürr et al. (2015)
Time-Variable Gravity (TVG):	GOCO05S solution includes secular rates and annual terms determined from 2003 to 2014.	TVG components are available to 90x90. For DORIS satellite POD processing, use to 50x50 seems sufficient.
<u>Advantages</u>:	The modeling of static and time-variable gravity is more homogeneous than in the current modeling. There is no need to “cut and paste”, at least between 2003-2014.	
<u>Disadvantages</u>:	(1) Solution must be ”adapted” for period before GRACE; (2) Some accommodation of changes in TVG will be necessary for 2014 and later. The problem is availability of information (*The GRACE s/c were inconsistent in their supply of solutions for 2014 and later due to spacecraft issues*).	

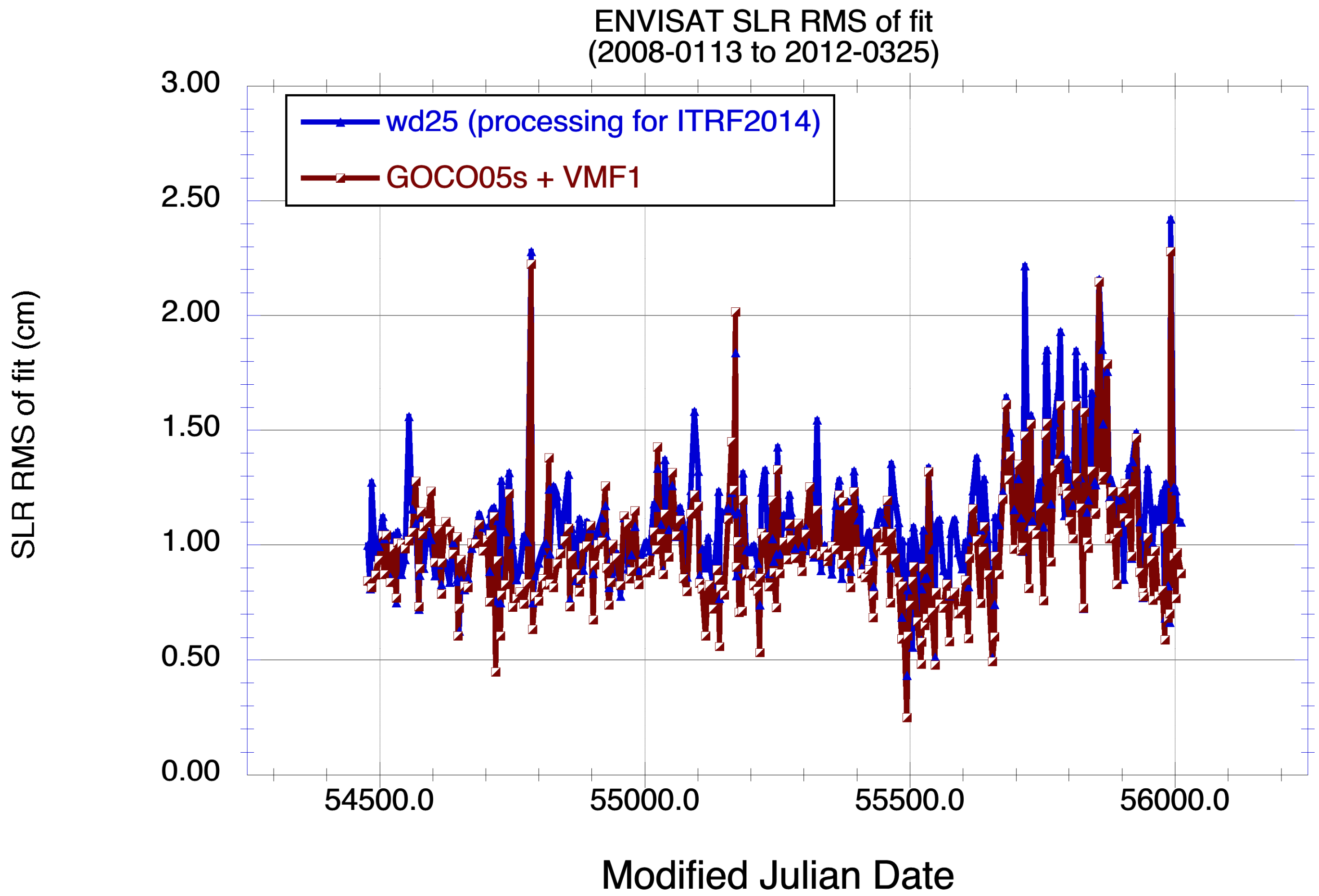
Tests of GOCO05s: HY-2A



SLR RMS of fit:

- **wd25, (updated with ITRF2014/DPOD2014) = 1.397 cm**
- **GOCO05s + VMF1 = 1.089 cm**

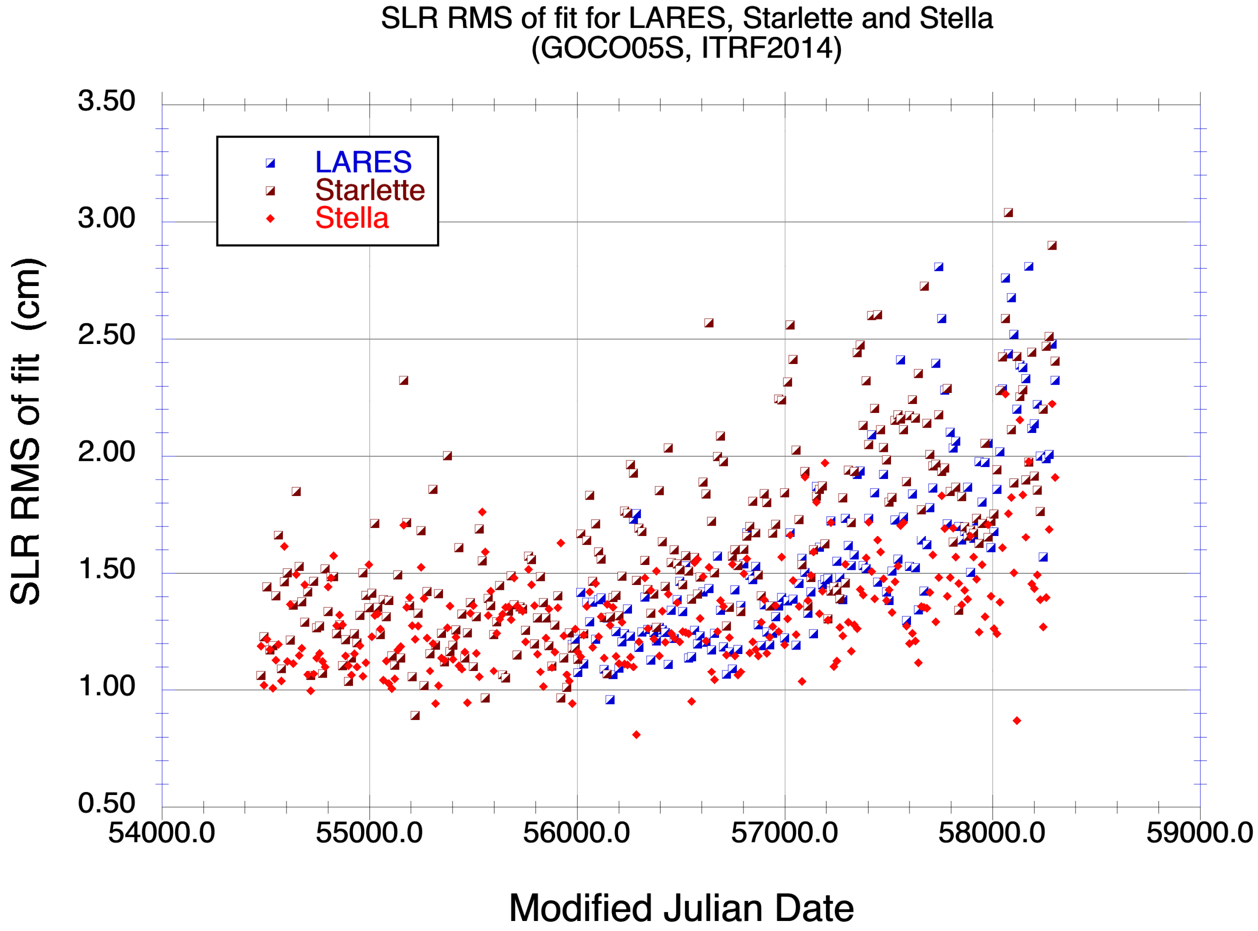
Tests of GOCO05s: ENVISAT



SLR RMS of fit:

- **wd25, (updated with ITRF2014/DPOD2014) = 1.093 cm**
- **GOCO05s + VMF1 = 0.983 cm**

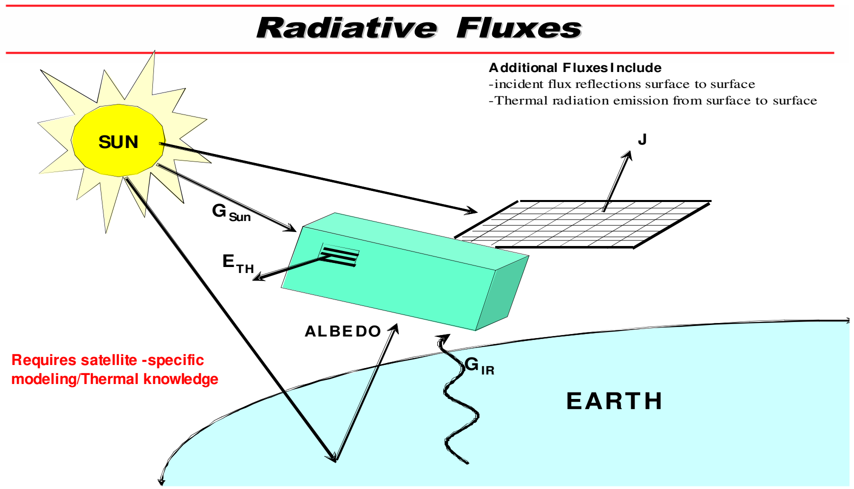
Tests of GOCO05s: SLR Satellites

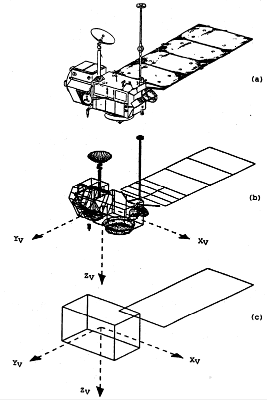


SLR RMS of fit for LARES, Starlette, Stella:

- **Generally 1.00 – 1.50 cm through ~MJD 57000**
- **Secular increase after ~MJD 57000 (early 2014) consistent with expectations that fit would degrade as time away model data period (2003.0-2014.0) increases.**

Issues with Modelling Radiation Pressure (SRP & PRP)





Marshall & Luthcke, 1994

Sat.	A/m 10^{-4} m^2/kg
Cryosat2	
Envisat	~89 (SA)
HY2A	
Jasons	~190 (SA)
TOPEX	~106 (SA)

Requirements:

1. Need surface properties & shape to derive a macromodel or to do ray-tracing (*as in a UCL-type model*)
2. Need attitude model or quaternions to properly model orientation, especially for moving appendages.
3. Reflections, self-shadowing and thermal emission accelerations ignored in a "macromodel" → Need more complex model (e.g. UCL).

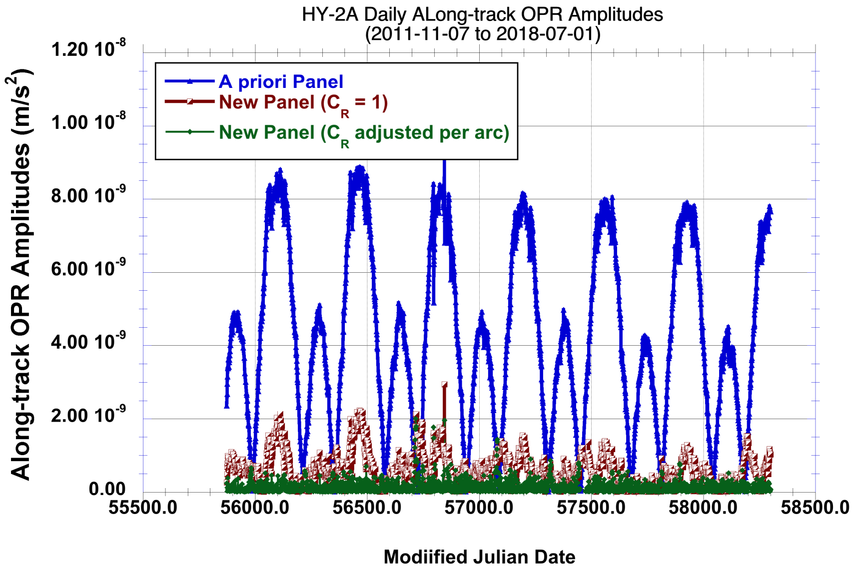
If any of these requirements are not met, then there will be residual accelerations that may have a draconitic or a seasonal signature. Keep in mind for next slides.

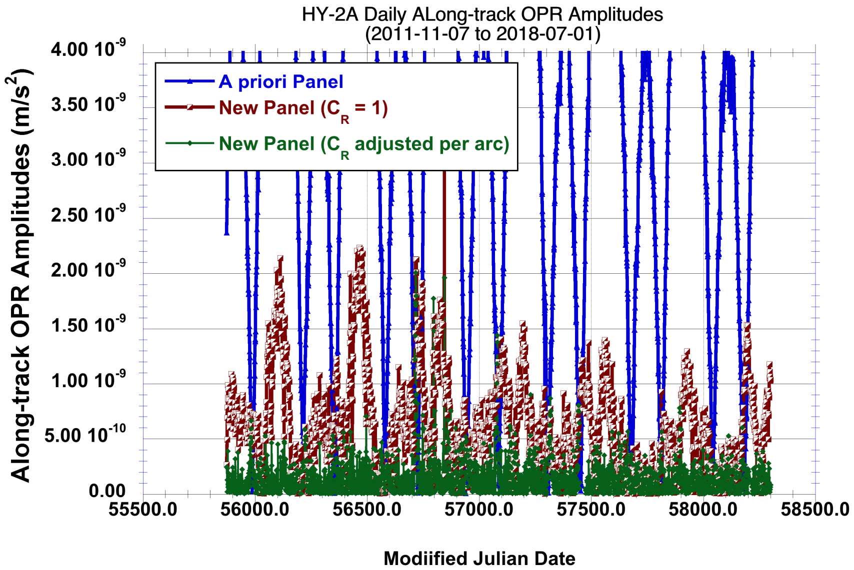
How do we Improve Modelling of Radiation Pressure over previous IDS-related work, i.e. for ITRF2014?

How do we improve modelling?:

1. Use best available macromodel, or a more detailed model ("UCL-type" model), bearing in mind the intrinsic assumptions of the particular approach.
2. Use quaternions rather than an attitude model, if they are available for s/c and/or appendage orientation.
3. Retune parameters if necessary using mission data.
4. Adjust C_R **"per arc",** as in Flohrer et al. (2011) [*"Generating precise and homogeneous orbits for Jason-1 and Jason-2"*, Adv. Space Res.].
   - Adjustment of C_R per arc can help to accommodate failure of model to account for any unmodelled effects, and reduce amplitude of resultant empirical accelerations.
   - CAVEAT EMPTOR! This approach will reduce size of along-track accelerations but not the cross-track OPR amplitudes!

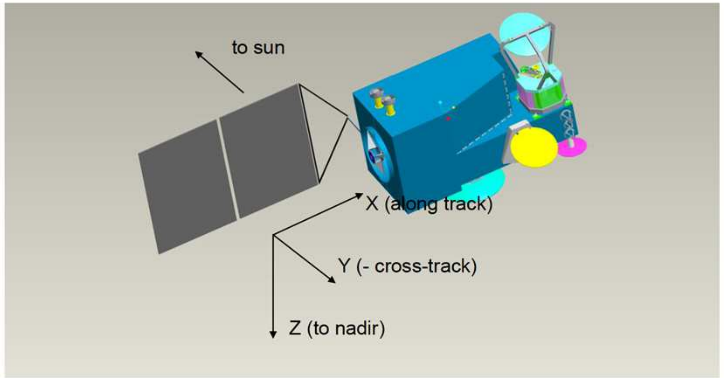
Preliminary Results for HY-2A (1)



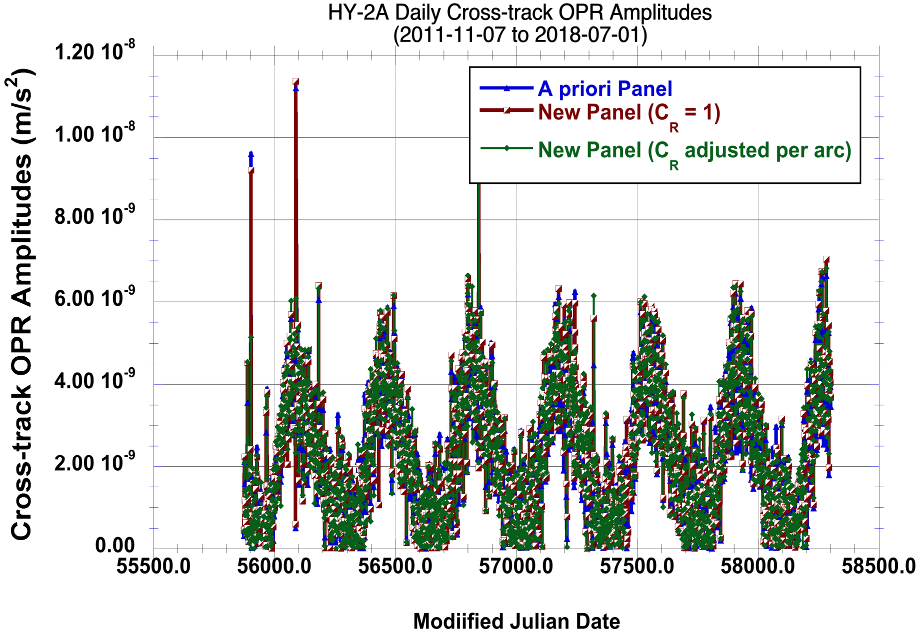


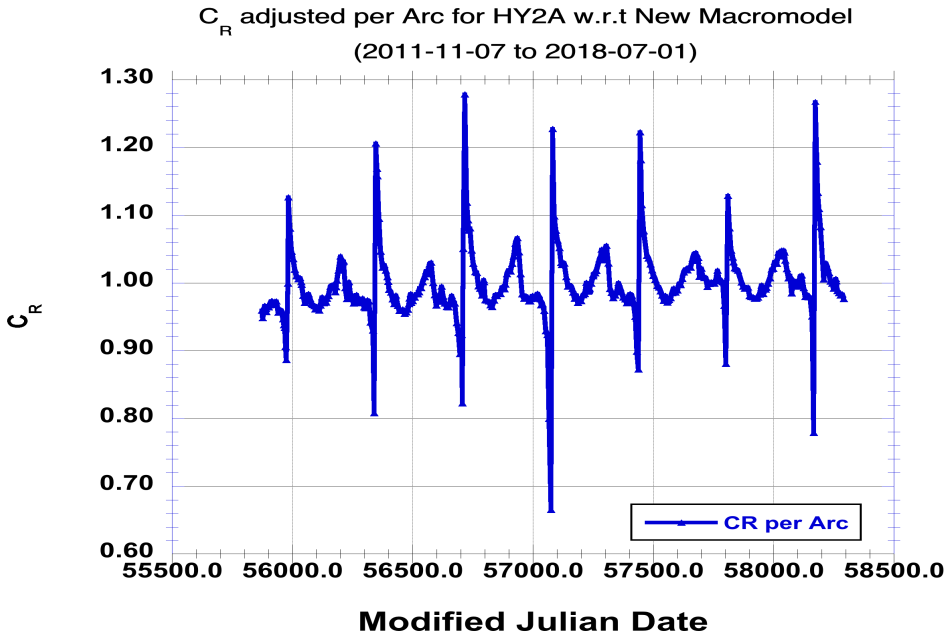
Tests all performed using GOCO05S + VMF1 as background models.

1. A priori Panel: Similar to values supplied in IDS documentation.
2. New Panel: Adjust specular reflectivity of panel that represents solar array. The *a prio*ri value of zero is unrealistic.



Preliminary Results for HY-2A (2)





Tests all performed using GOCO05S + VMF1 as background models.

Panel Model	C_R	Along-track OPR's (nm/s^2)		Cross-track OPR's (nm/s^2)		Along-track Const. (nm/s^2)	
		Avg.	Std. Dev.	Avg.	Std. Dev	Avg.	Std. Dev
A priori	1	4.37	2.48	2.28	1.52	-1.53	0.41
New	1	0.61	0.44	2.32	1.56	-1.53	0.41
New	Adjust	0.15	0.17	2.32	1.54	-1.52	0.41

Preliminary Results for HY-2A (3) Summary

Series	Narcs	Avg. SLR RMS (cm)	Avg. DORIS RMS (mm/s)	Comment
wd25, with SLRF2014 and DPOD2014	329	1.431	0.4052	GOCO02s + TVG5x5+GMF/GPT
A priori Panel	408	1.089	0.3939	GOCO05s+VMF1
New Panel, C_R=1	407	1.089	0.3942	GOCO05s+VMF1
New Panel, Adjust C_R	402	1.067	0.3960	GOCO05s+VMF1

1. Although Along-track OPR's are dramatically reduced, cross-track OPR's are unchanged. (*This is consistent with previous experience with macromodel tuning, e.g. Le Bail et al. 2010, Lemoine et al., 2016*).
2. Adjusted C_R's reflect partially inadequacy of fixed attitude law provided in IDS documentation. They seem to indicate the attitude of the s/c w.r.t the Sun must undergo a major change (a flip?) each year in mid. to late February. If the orientation is wrong for radiation pressure modeling – it is also wrong for drag modelling!
3. The quaternions would provide a more stable background model for nonconservative force modeling but still might not obviate the need for arc-by-arc adjustment of C_R.

Preliminary Results for Jason-2 (1)

Test	N	Along-track (nm/s^2)		Cross-track (nm/s^2)	
		mean	median	mean	median
A priori Panel, Cr=0.945, Old TSI	521	0.895	0.689	2.328	2.304
A priori Panel, Cr=0.945, new TSI	521	1.089	1.018	2.262	2.225
New Panel, Cr=1, new TSI	521	0.986	0.876	2.127	2.051
New Panel, new TSI, Adj Cr	521	0.441	0.314	2.207	2.139

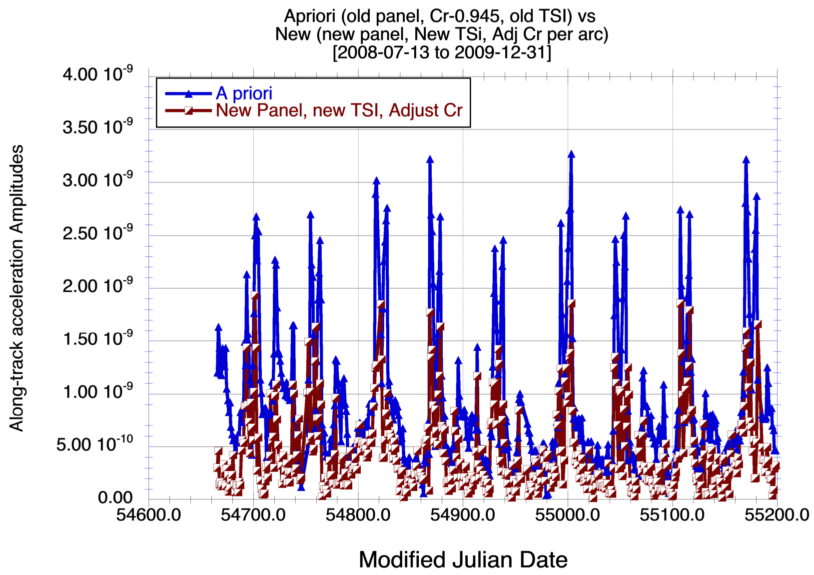
Old Total Solar Irradiance (TSI) = 1367 W/m^2
New Total Solar Irradiance (TSI) = 1360.45 W/m^2

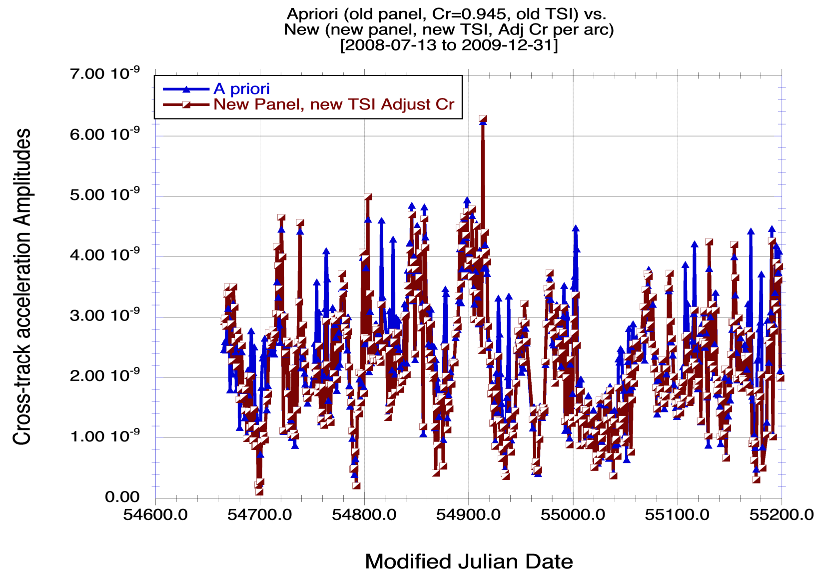
New Panel, adjusts specular reflectivity of solar arrays, and -X panel.

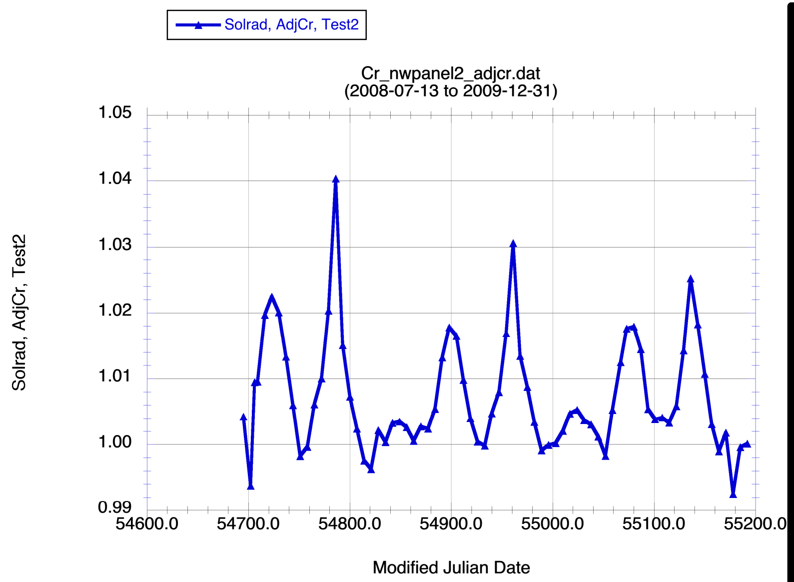
Tests used 78 SLR+DORIS arcs, 2008-07-13 to 2009-12-31).

Tests all performed using GOCO05S + VMF1 as background models.

Preliminary Results for Jason-2 (2)

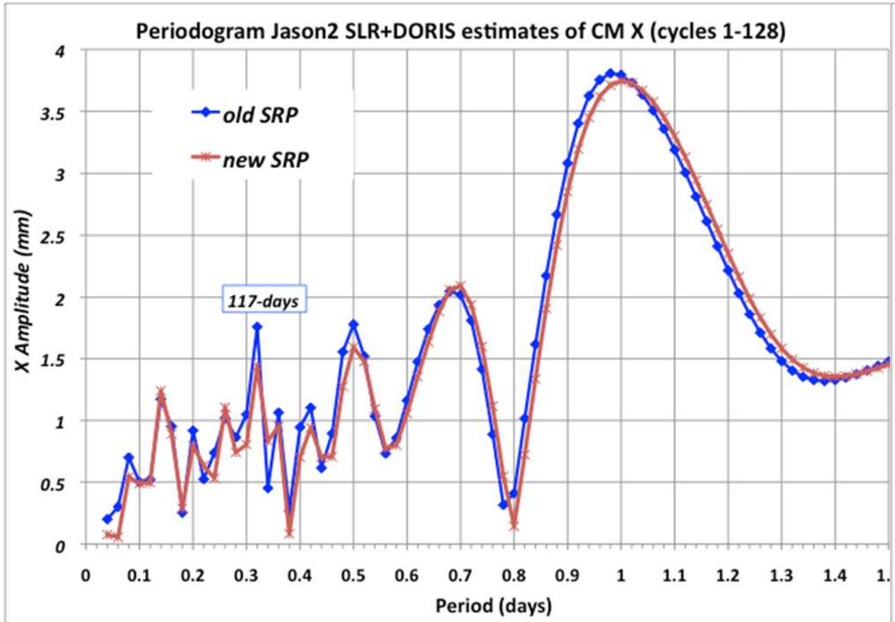


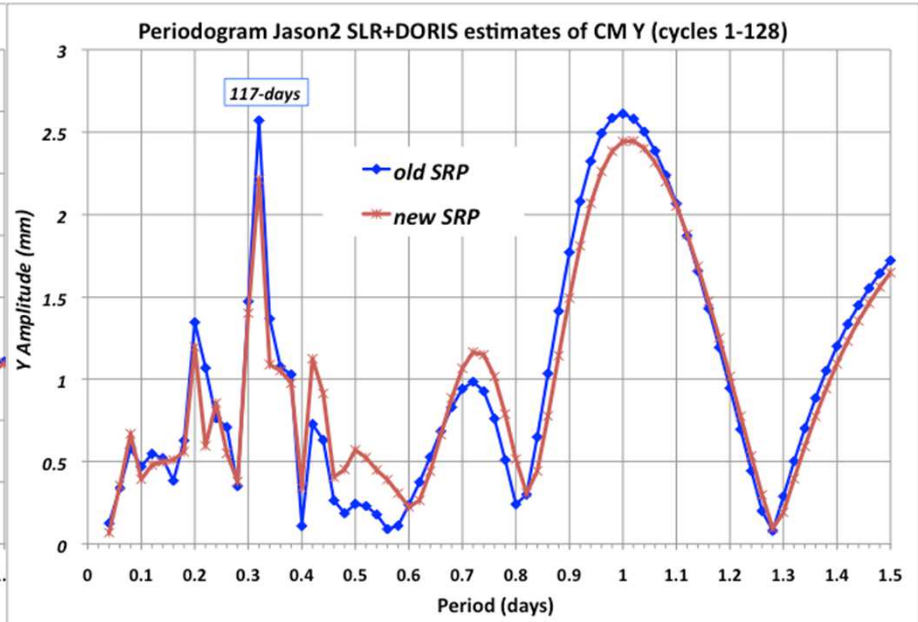




1. Same strategy as on HY-2A works on Jason-2; (*Adopt new TSI, Retune macromodel, Adjust C_R per Arc*).
2. C_R Curve for Jason-2 is qualitatively similar to results from Flohrer et al. (2011).
3. This empirical approach is in addition to best possible modeling (*macromodel + use of s/c and solar array quaternions*). Therefore the C_R adjustments accommodate residual unaccounted for model errors. **CONSTANT C_R per macromodel is not adequate!!!**

Preliminary Results for Jason-2 (3): Impact on Geocenter estimates (X,Y)



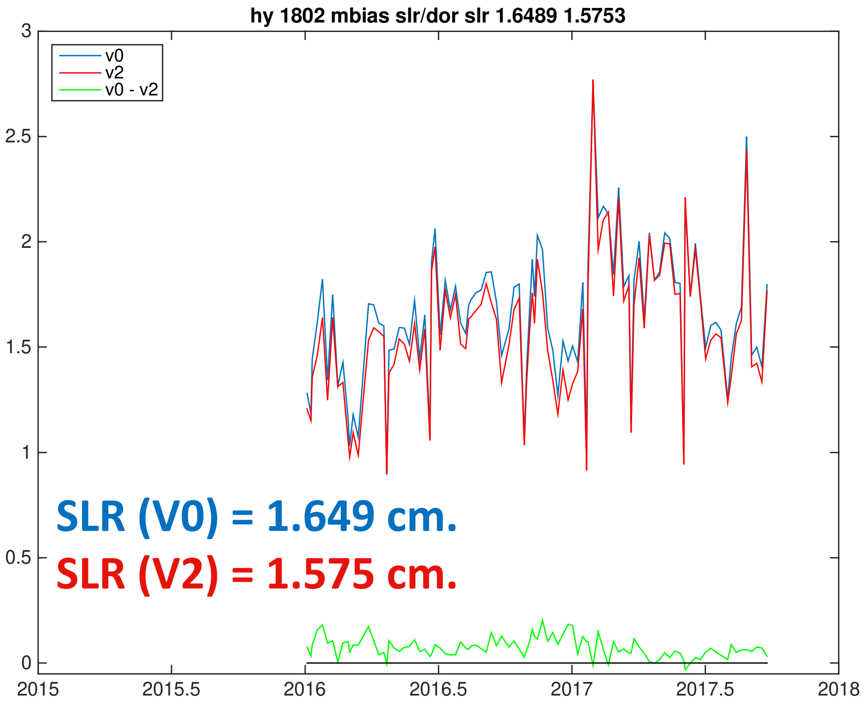


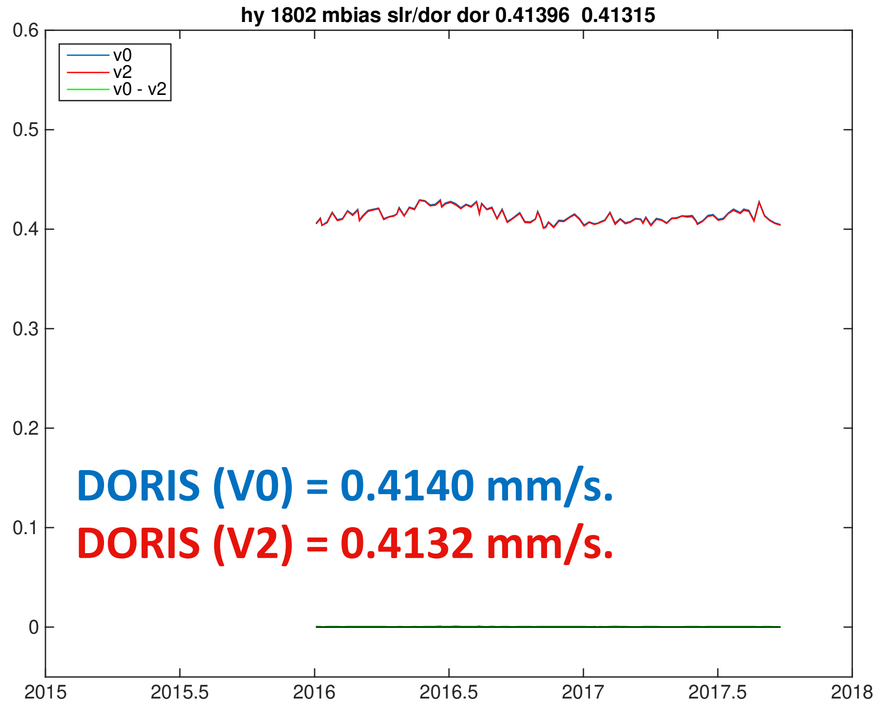
New SRP model, including Arc-by-arc estimation slightly reduces amplitude of 117-day (draconitic) signals in X,Y geocenter estimates, with Jason-2 SLR/DORIS data.

Testing of HY2A Offset (1)

Offset	Type	X(m)	Y (m)	Z (m)
Original (V0)	DORIS	0.850	-0.750	1.3060
	SLR	0.31126	-0.21381	0.994
Update SLR & DORIS (V2)	DORIS	0.850	-0.750	1.3260
	SLR	0.31126	-0.21381	0.9844

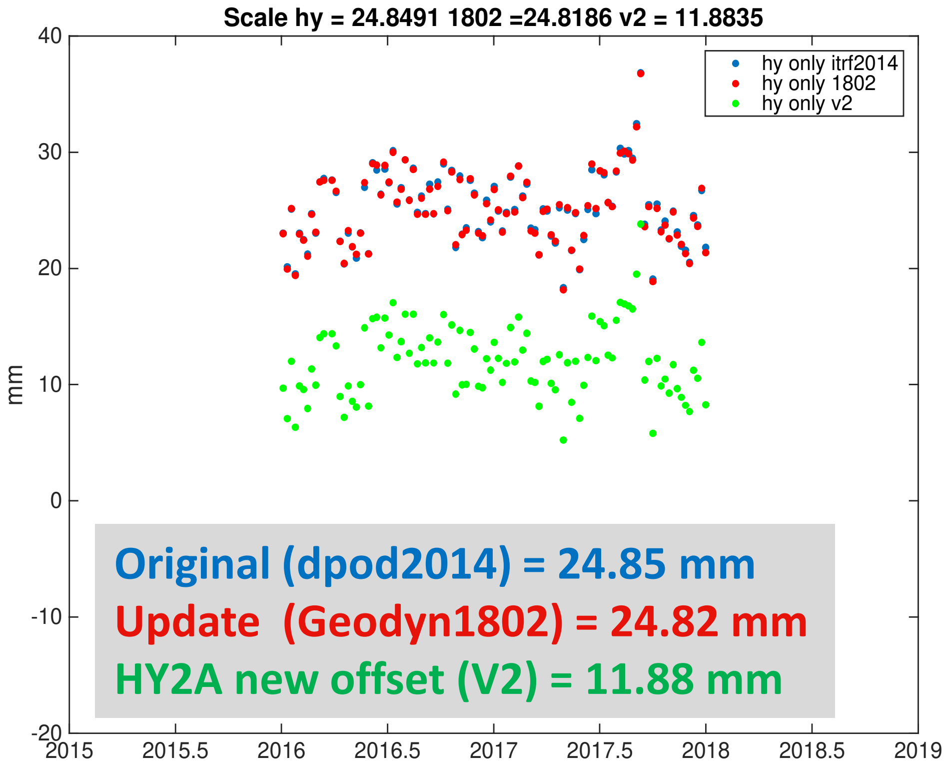
Impact on HY2A SLR/DORIS POD



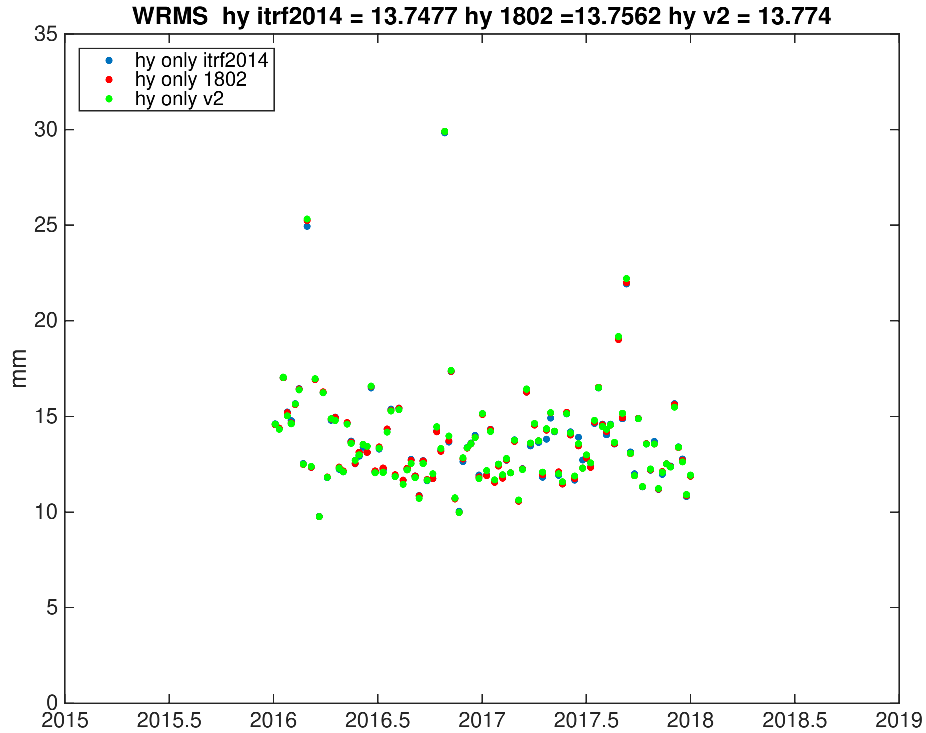


Testing of HY2A Offset (2)

Impact on HY2A-only scale (single-satellite SINEX solution)



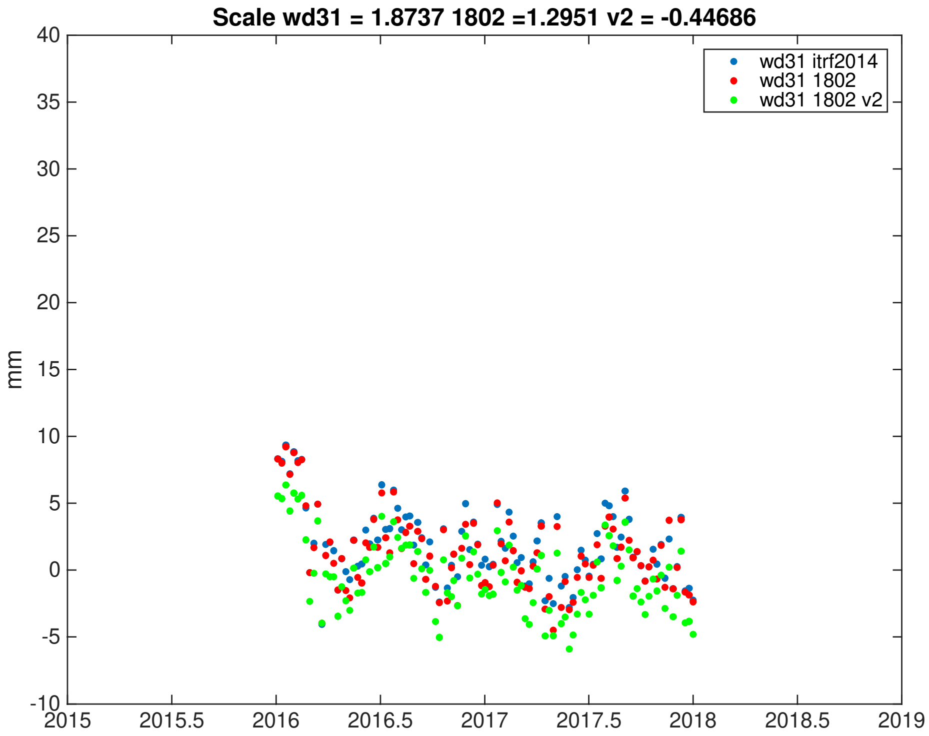
WRMS for HY2A single-satellite SINEX



Original (dpod2014) = 13.75 mm
Update (Geodyn1802) = 13.76 mm
HY2A new offset (V2) = 13.77 mm

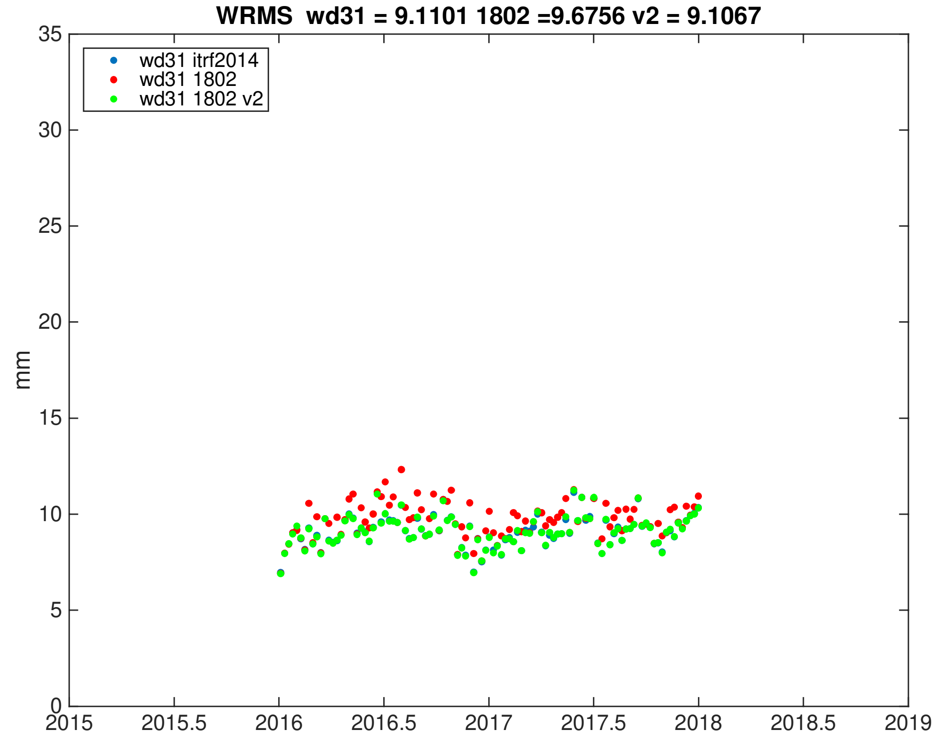
Testing of HY2A Offset (3)

Impact on wd31 scale (multi-satellite SINEX solution)



Original (dpod2014) = 1.874 mm
Update (Geodyn1802) = 1.295 mm
HY2A new offset (V2) = -0.447 mm

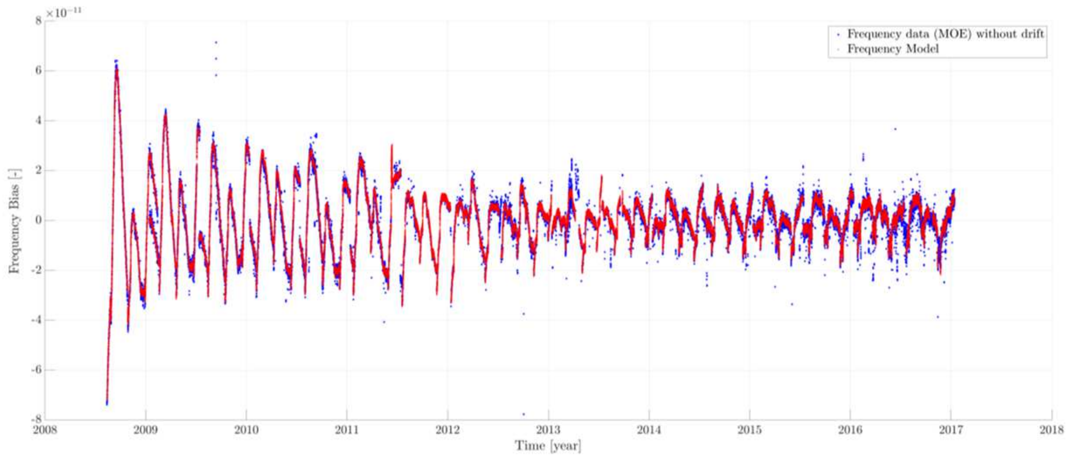
WRMS for multi-satellite SINEX



Original (dpod2014) = 9.11 mm
Update (Geodyn1802) = 9.68 mm
HY2A new offset (V2) = 9.11 mm

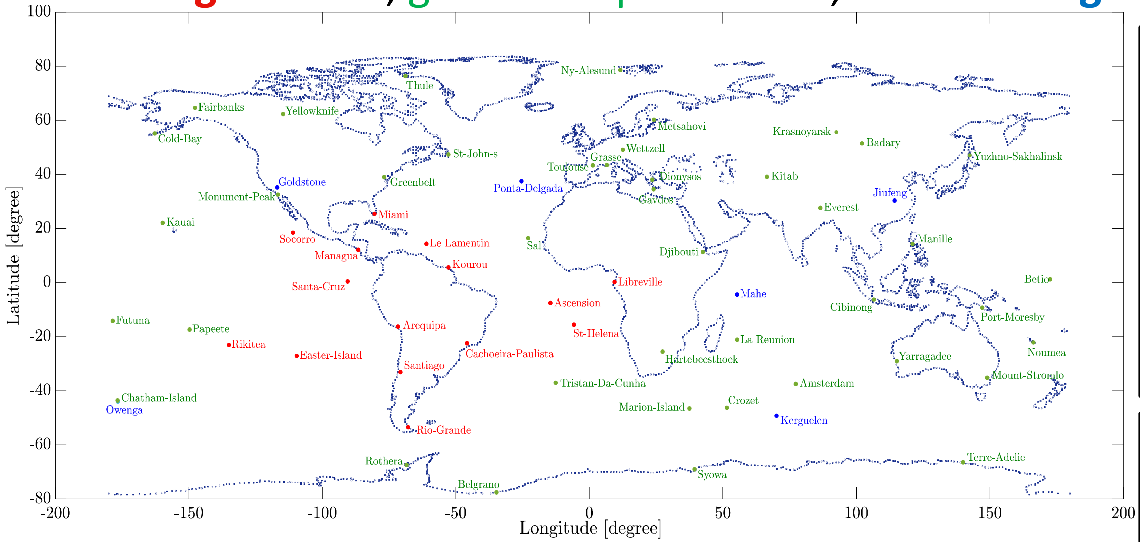
Progress Toward a Better USO Model for Jason-2 (1)

DORIS/USO Model for Jason-2 2008-2017, from T2L2



”Long-Term Behavior of the DORIS Oscillator under Radiation: The Jason-2 case”
A Belli, P Exertier, ***IEEE transactions on ultrasonics, ferroelectrics, and frequency control*, 2018,**
DOI: *10.1109/TUFFC.2018.2855085*

Impact of this model in Jason-2 DORIS residuals (mean over 8 years),
Red = degradation, green = improvement, **blue = no significant change**

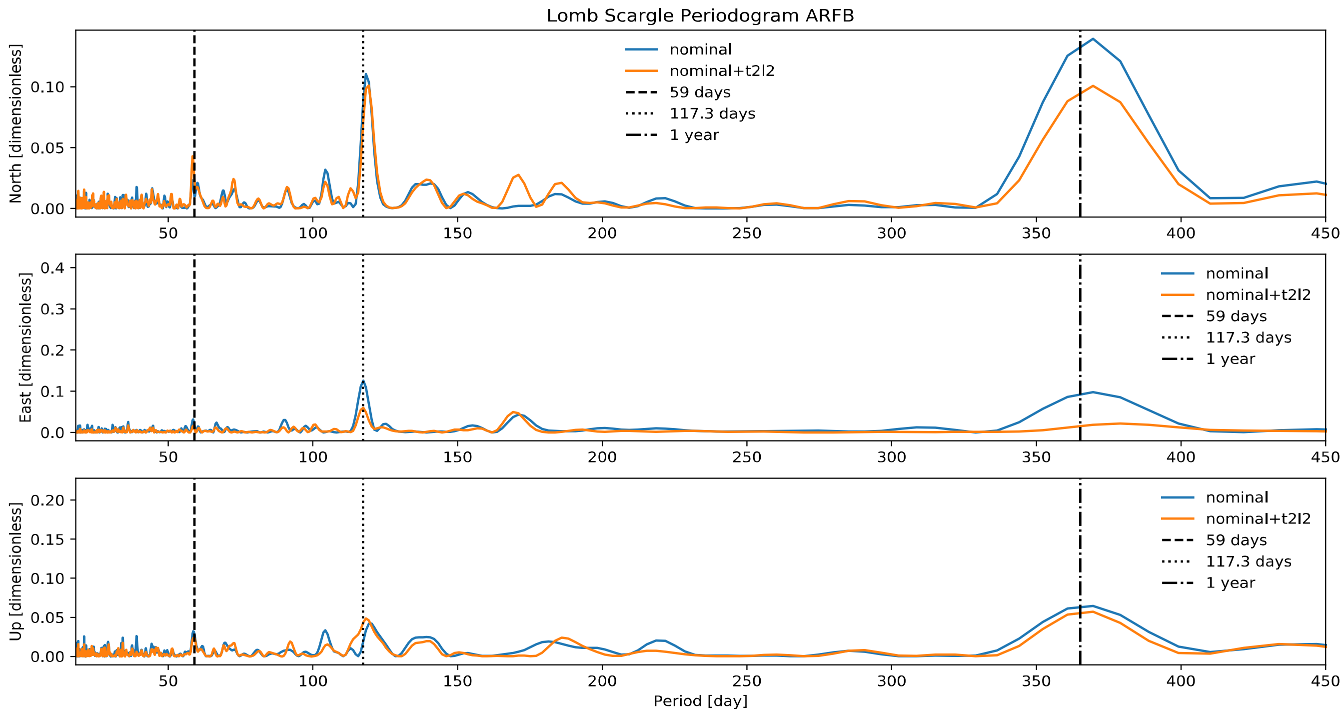


Does this pattern in the residuals appear because the positions and of these SAA stations in DPOD2014 have been degraded by the un-accounted-for frequency perturbations?

Belli et al., COSPAR 2018, Pasadena, California

Progress Toward a Better USO Model for Jason-2 (2)

Example: Impact on Arequipa (ARFB)



Time series of DORIS coordinates were obtained from adjusting the DORIS coordinates of stations tracking Jason-2 in the SLR2014 frame. The time series that uses the improved USO corrections, reduces the magnitude of the 117-day signals in the coordinates.

Belli et al., COSPAR 2018, Pasadena, California

Summary

1**. We are making progress on testing model improvements in advance of the reprocessing for the next ITRf2014.**

2. It would seem sensible to adopt GOCO05s as an interim new model, even though we must still modify adapt the field behavior, at least w.r.t .the low degree coeffcients, before 2003 and after 2014.

3. The new SRP strategy seems promising, but we still need to verify its impact on geodetic performance. We suggest to the IDS AC's, this strategy of +arc-by-arc CR estimation strategy is easy to implement, and that it would be worth testing.

4. The task of evaluating the new USO model on Jason-2 is underway, and as a first step, a manuscript describing its impact on geodetic estimation is under preparation.