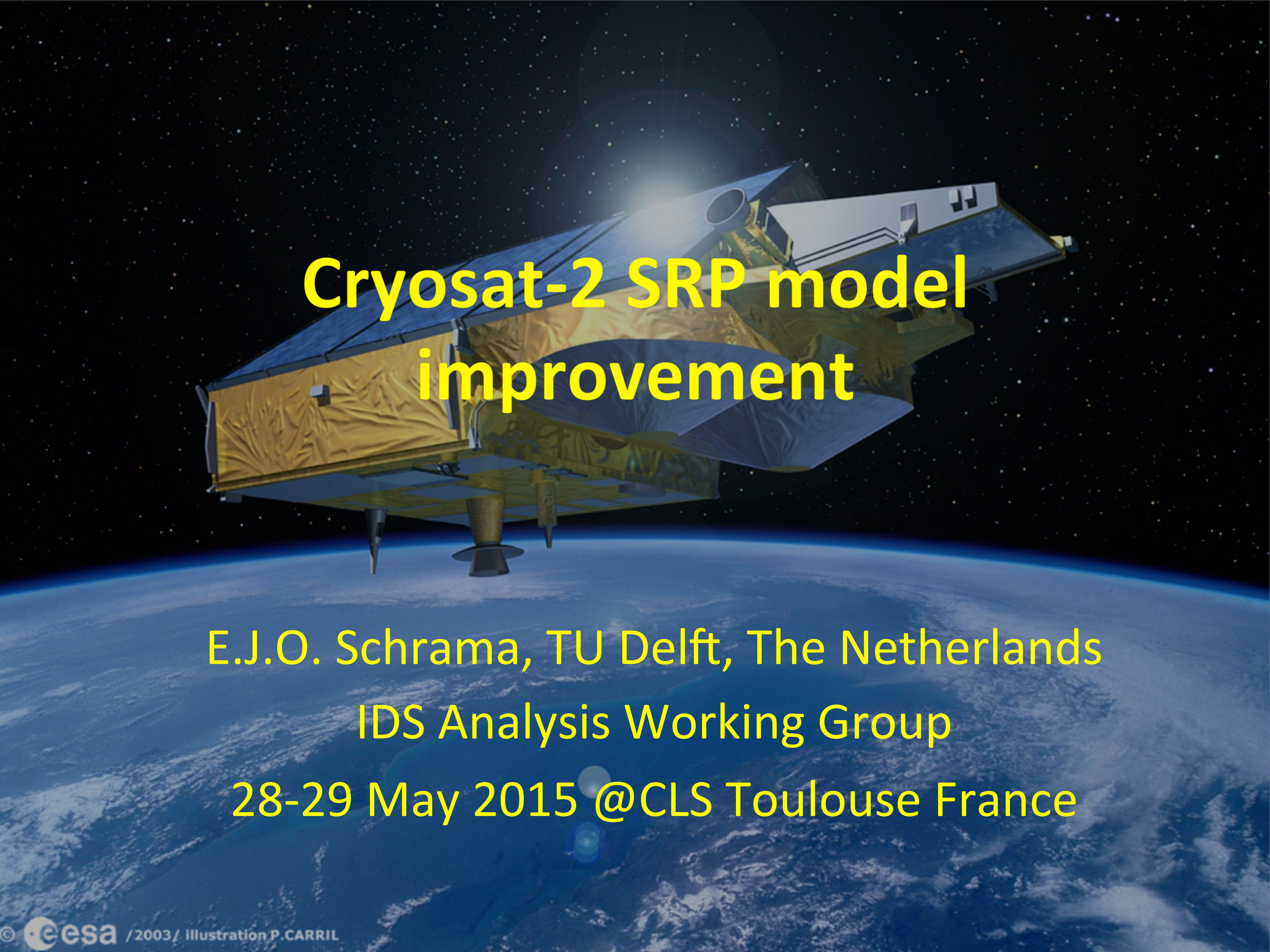

Cryosat-2 SRP model improvement

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IDS Analysis Working Group

28-29 May 2015 @CLS Toulouse France

Overview of talk

- TU Delft involvement: validation/calibration within the CryoSat-2 community
  - DORIS tracking data, ~50 beacons from the IDS, 10s Doppler data
  - SLR Tracking data: ~10 stations from the ILRS, Independent sparse laser data
  - Do quality checks, internal, external, forcing
- Latest developments
  - Changes in the Solar Radiation Pressure modeling
  - Precision Orbit Determination up to 6-February 2015

Updates

- During the OSTST in Konstanz 2014 we used a reference panel model; this model originated from ESA document(s) that we received between 2004 and 2010.
- Update of SRP and offsets, at the moment we have four set-ups under consideration
- Purpose is to review the level of empirical accelerations that remain when you apply the SRP models to CS2.

Solar radiation pressure model

- At the micro-level a satellite panel is too detailed
- We condense it into something more simple, called a macro-model, usually it is a box-wing type of model
- Precision orbit determination software could handle both micro and macro models, but, we chose for efficiency, so we take the macro-model
- SRP parameters are provided for panels in a satellite frame, this problem is connected to the offset problem, the latter follows from a pre-launch satellite survey.

ESA CryoSat-2 wire frame model

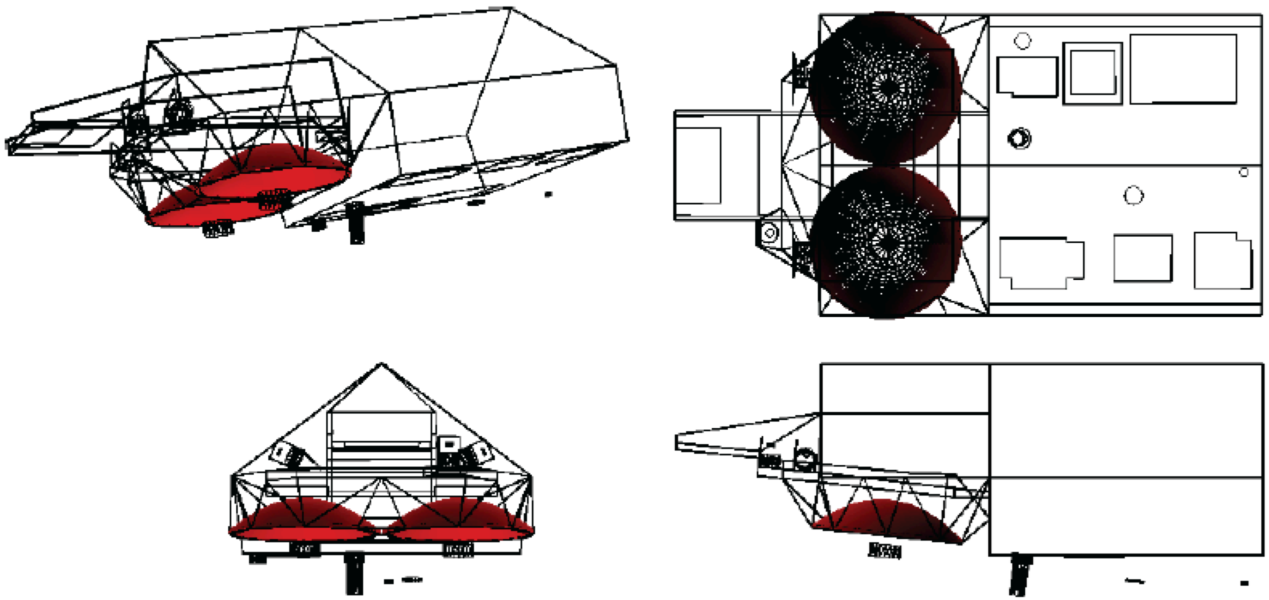


Figure 5.4: *Wire-frame of the first micro model of Cryosat-2. All the elements that are not polygons, cylinders or parabola are missing. Top left: 3D view, top right: top view, bottom left: front view and bottom right: side view.*

Thesis Bart Root

EADS CryoSat-2 model

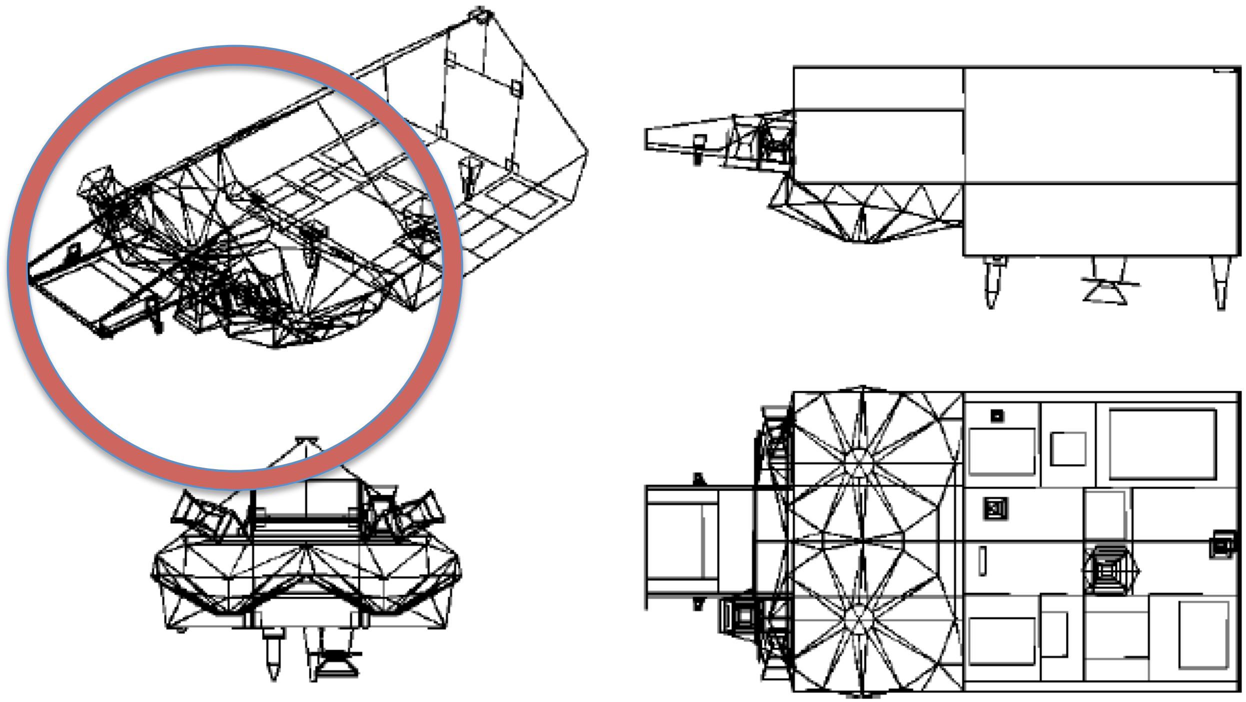
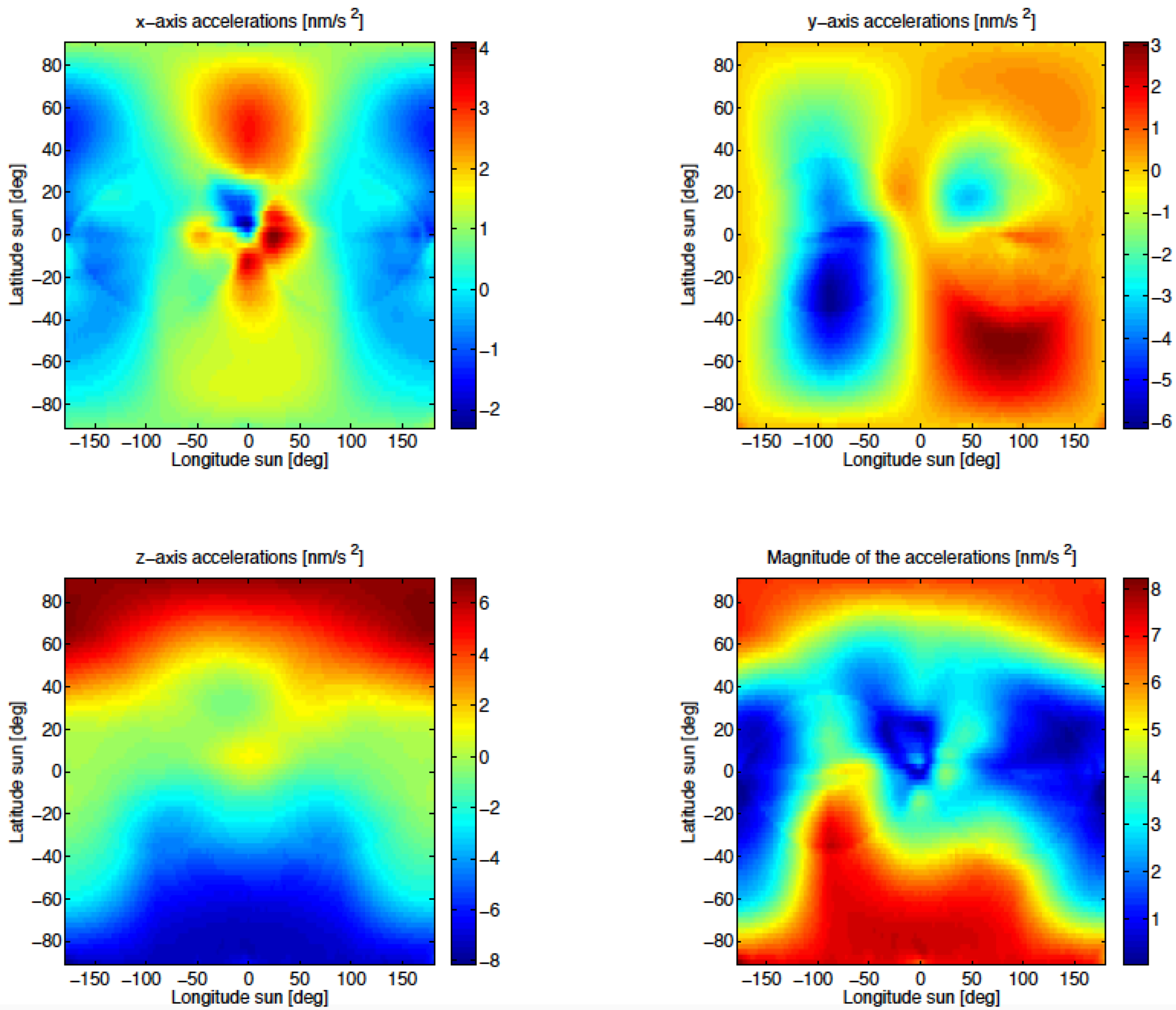


Figure 5.5: *Wire-frame of the EADS micro model of Cryosat-2. This is the second model that will be used. Top left: 3D view, top right: top view, bottom left: front view and bottom right: side view.*

Thesis Bart Root



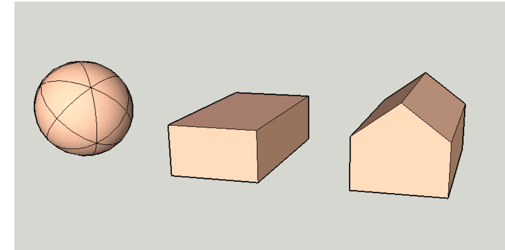
There is agreement between independent models at the 5 nm/s^2 level,

Empirical parameters take care of the remaining accelerations at 1/rev

5 nm/s^2

Figure 5.22: *The latitude and longitude plot of the difference between the two different micro models. The results are generated by computing the difference by ESA model (setup D) minus the EADS model (setup E).*

Solar radiation pressure macro model



- The assumption is that a macro model can be used during POD.
- Tuning of the C_r scaling parameter and empirical acceleration parameters takes away the residuals
- There are four set-ups for this study:
  - Canonball model: this is the simplest approach
  - ESA V_0 model: six panels and offsets according to an early reference that we got from ESA
  - ESA V_1 model: like V_0 but with updated SRP parameters
  - CNES model: house model, 7 panels and updated offsets

SRP calibration procedure

- For all SRPs we want to see what happens with C_r since the start of the mission. There are almost four **β** cycles for this exercise
- Turn off all options in GEODYN that estimate parameters related to general acceleration modeling, normally we estimate once per orbit cos/sin empirical accelerations parameters once per 24 hours
- Estimate an average scale for C_r from all arcs (6 days in length, depending on the maneuvers)
- Implement the average of the C_r and rerun all jobs where we estimate the empirical acceleration parameters

Average C_r values

Model	Faces	Description	C_r found
Canonball	1	Sphere	2.5093
ESA V0	6	Box	0.8805
ESA V1	6	Box	0.8665
CNES	7	House	1.0295

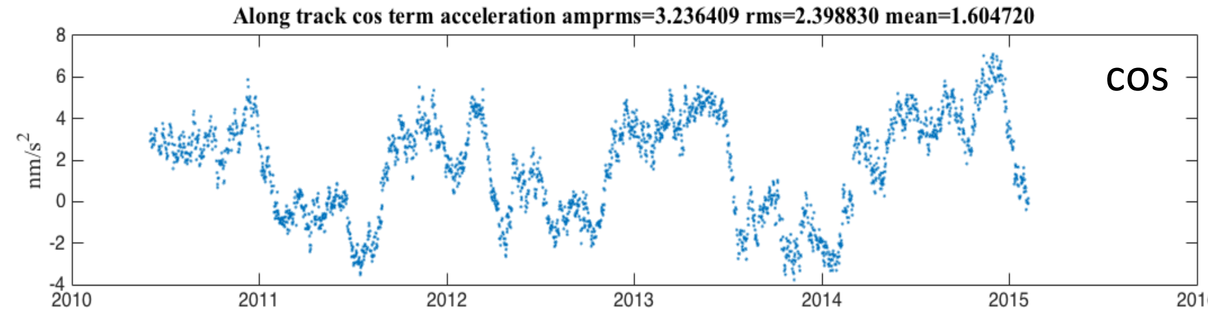
From this point fix the C_r parameters and estimate:

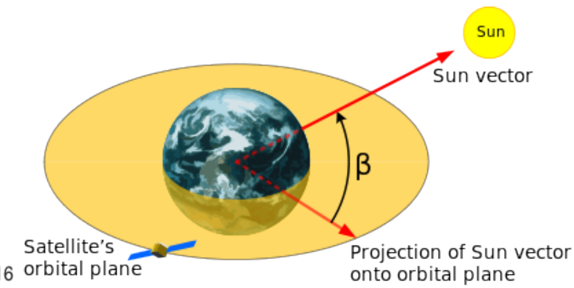
- Empirical parameters along-track and cross-track axes
- Drag parameters every 3 hours

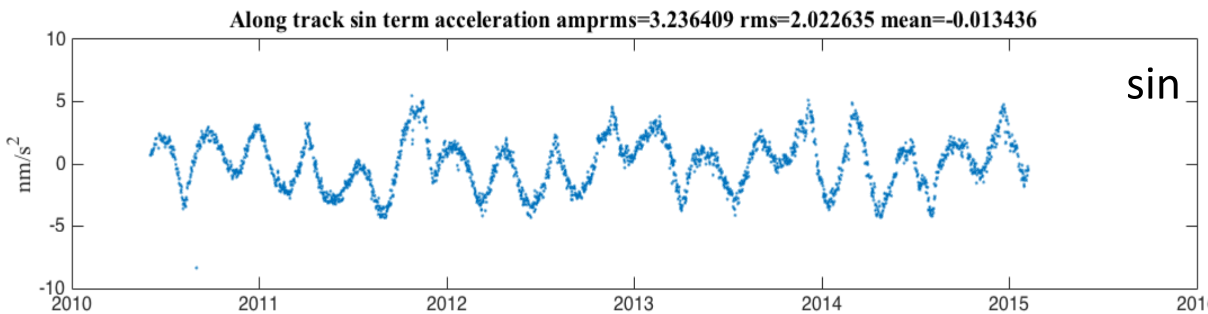
24h intervals

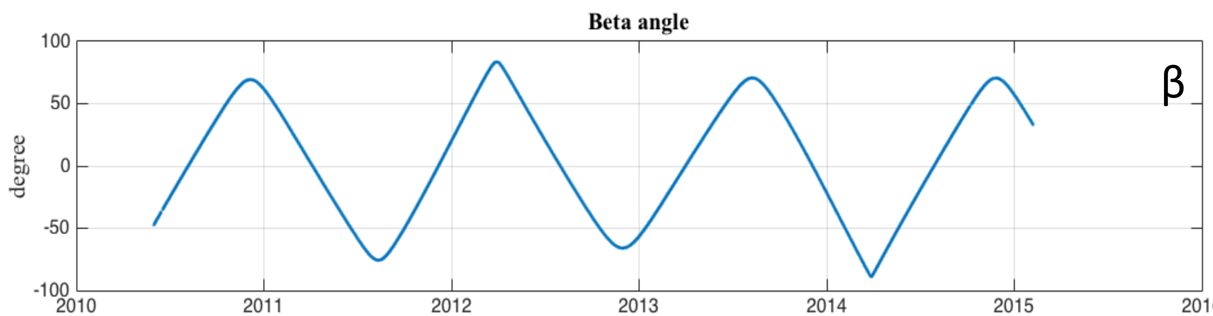
Forcing Parameters vs beta angle

ESA0

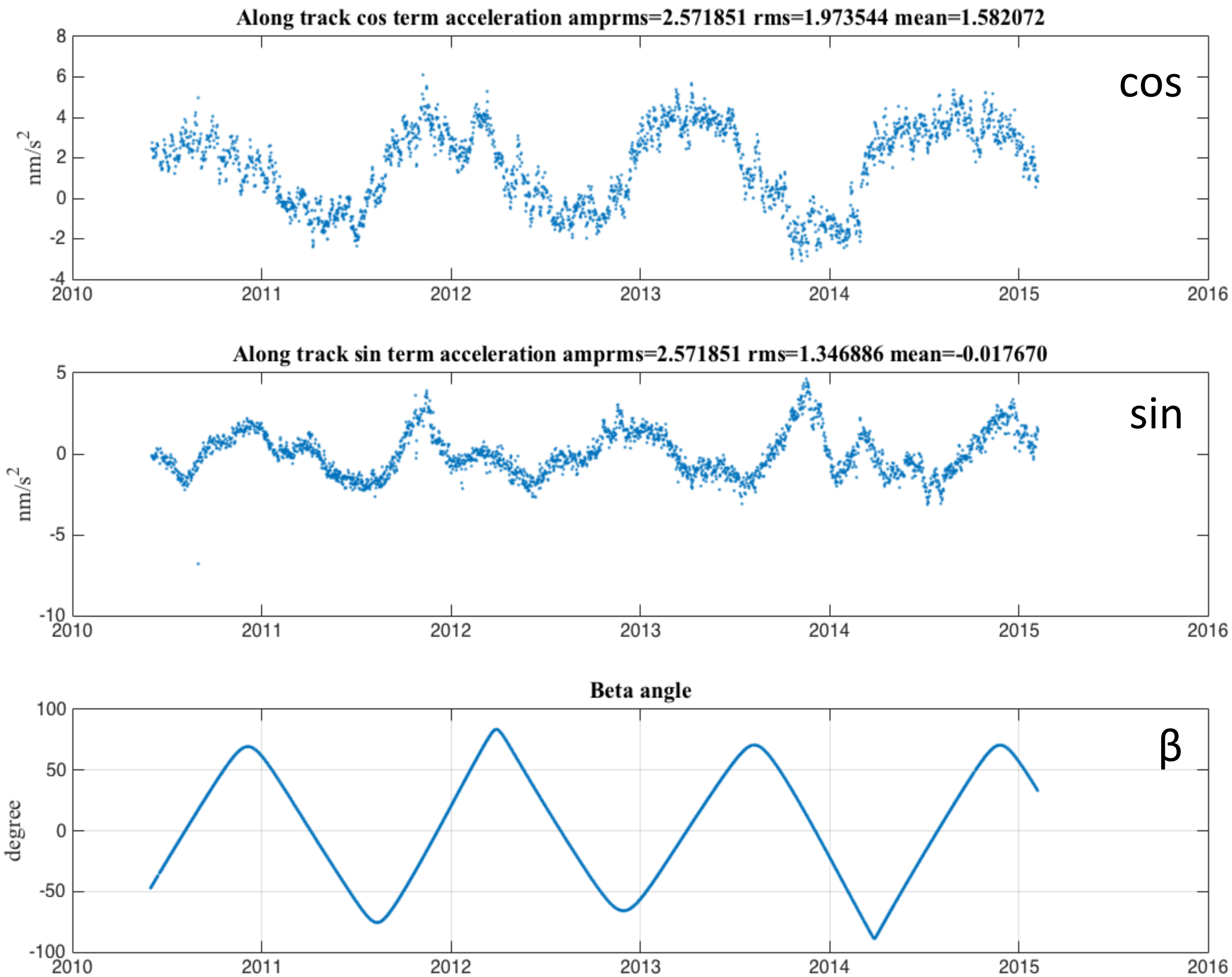


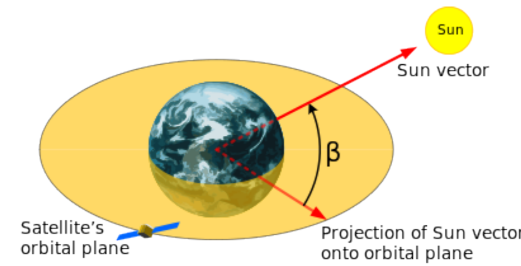






Forcing Parameters vs beta angle





Acceleration parameters

	Along		Cross		Total
Run	cos	sin	cos	sin	
Canonball	2.17921	1.38985	5.13789	2.89590	6.65652
ESA V0	2.39883	2.02263	1.81819	1.69878	4.33341
ESA V1	2.36953	2.41120	2.43125	2.00641	4.88933
CNES	1.97354	1.34689	1.82966	1.88589	3.91193

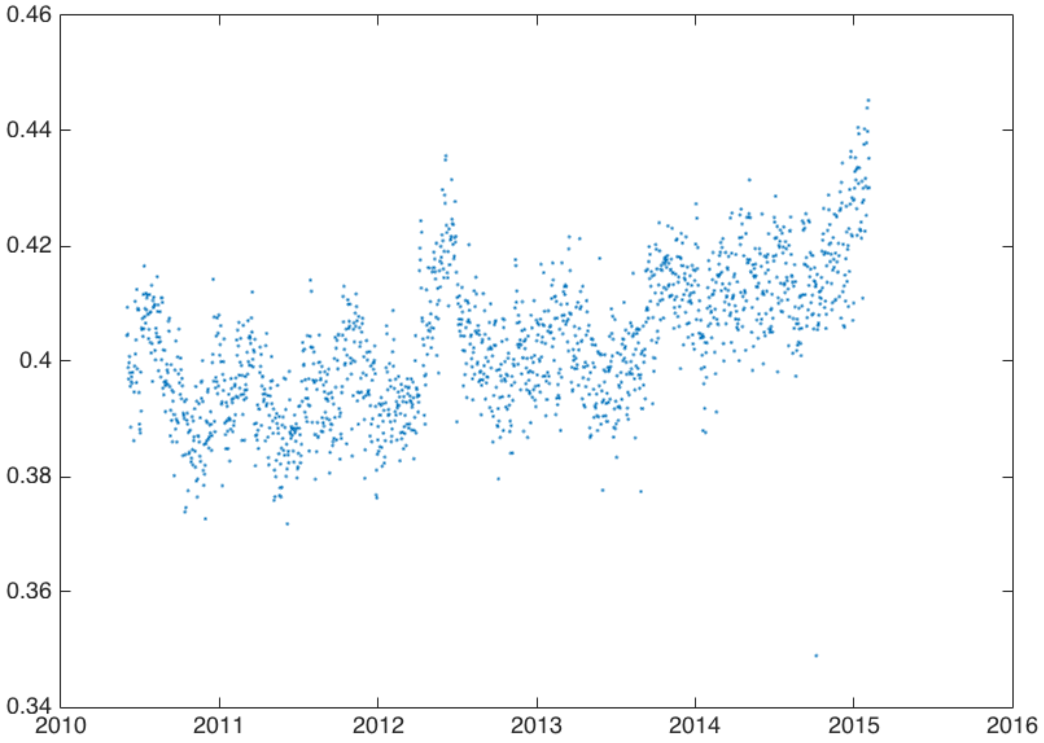
Units: nm/s^2

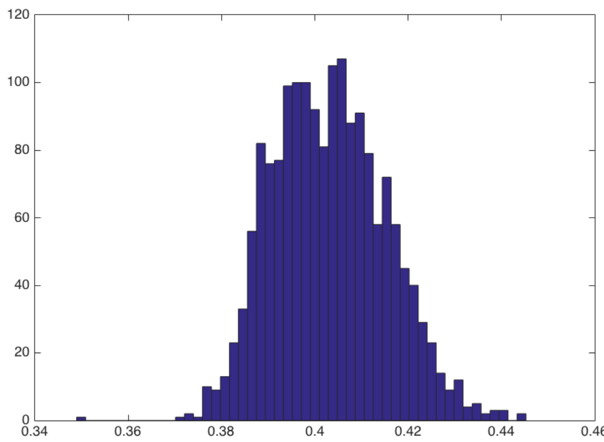
Conclusion :

- CNES SRP model is the winner
- Cross track component mostly affected

DORIS 10s residuals

The residuals increase
Jump in 2015



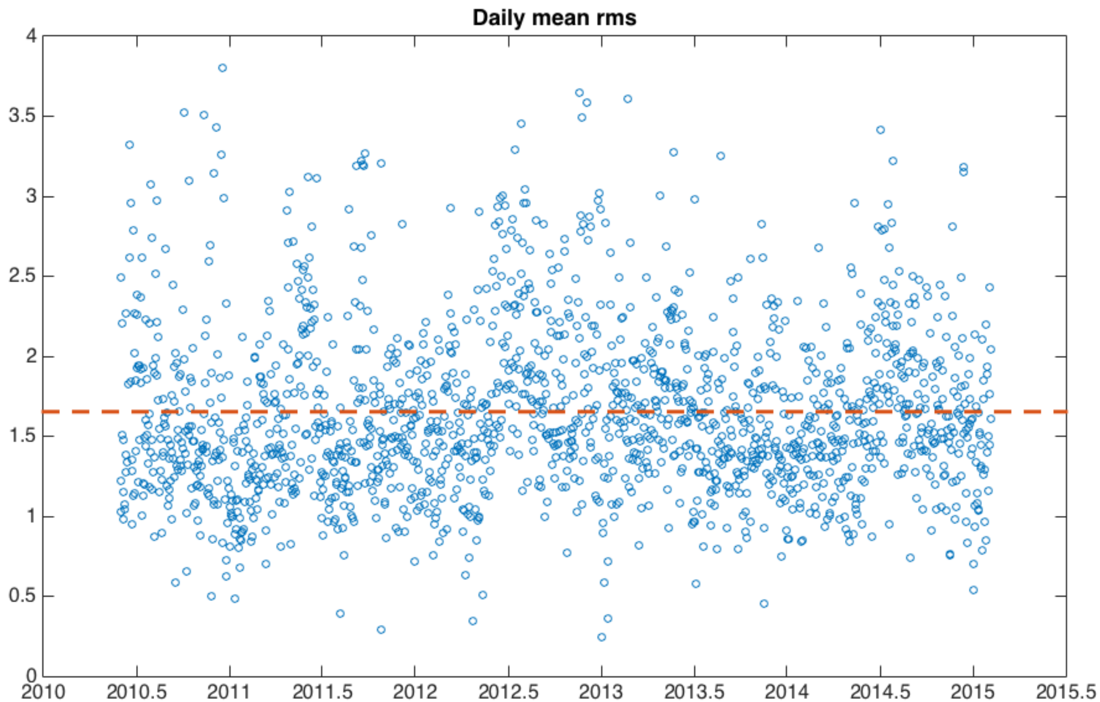


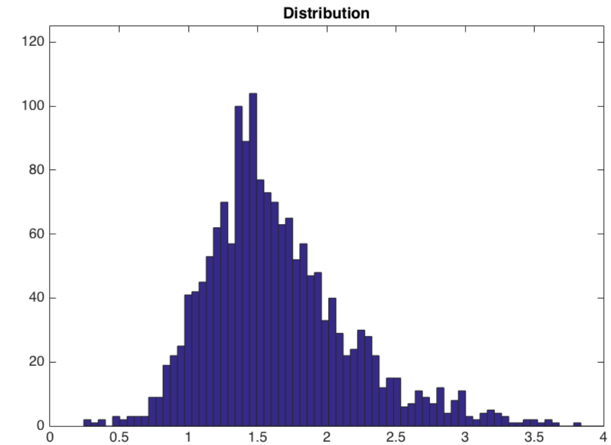
Median or mean
0.40 mm/s

Histogram not significantly affected SRP/offset model

Satellite laser ranging residuals

Mid-2012 there is a slight increase (but also 2014.5)





Around 1.6 cm rms

Histogram slightly affected by SRP/offset model

Fit statistics DORIS/SLR

Doris:

Run	Mean	Median	Skewness	Kurtosis
Canonball	0.40300	0.40266	0.16674	2.78011
ESA V0	0.40309	0.40280	0.16331	2.76544
ESA V1	0.40297	0.40268	0.16321	2.76965
CNES	0.40295	0.40274	0.15782	2.76979

SLR:

Run	Mean	Median	Skewness	Kurtosis
Canonball	1.76301	1.66463	0.74055	3.44202
ESA V0	1.91574	1.86089	0.47153	3.46646
ESA V1	1.64998	1.56680	0.69744	3.56531
CNES	1.62930	1.54512	0.71297	3.60059

Radial fit by external product

Run	NAV	MOE	POE
Canonball	0.068570	0.017158	0.016177
ESA v0	0.068551	0.017129	0.016142
ESA v1	0.068561	0.017130	0.016139
CNES	0.068560	0.017115	0.016119

Conclusion: SRP model tuning is nearly invisible in this test

Summary (1)

- EADS vs ESA micro model -> acceleration differences 5 nm/s^2 (or 5% or the total SRP effect)
- Four SRP setups compared
  - Empirical accelerations improve for the 7 panel roof model
  - Significant Improvement visible in the cross-track accelerations
  - Overall acceleration level goes from 6.65 down to 3.91 nm/s^2 (canonball vs 7 panel)

Summary (2)

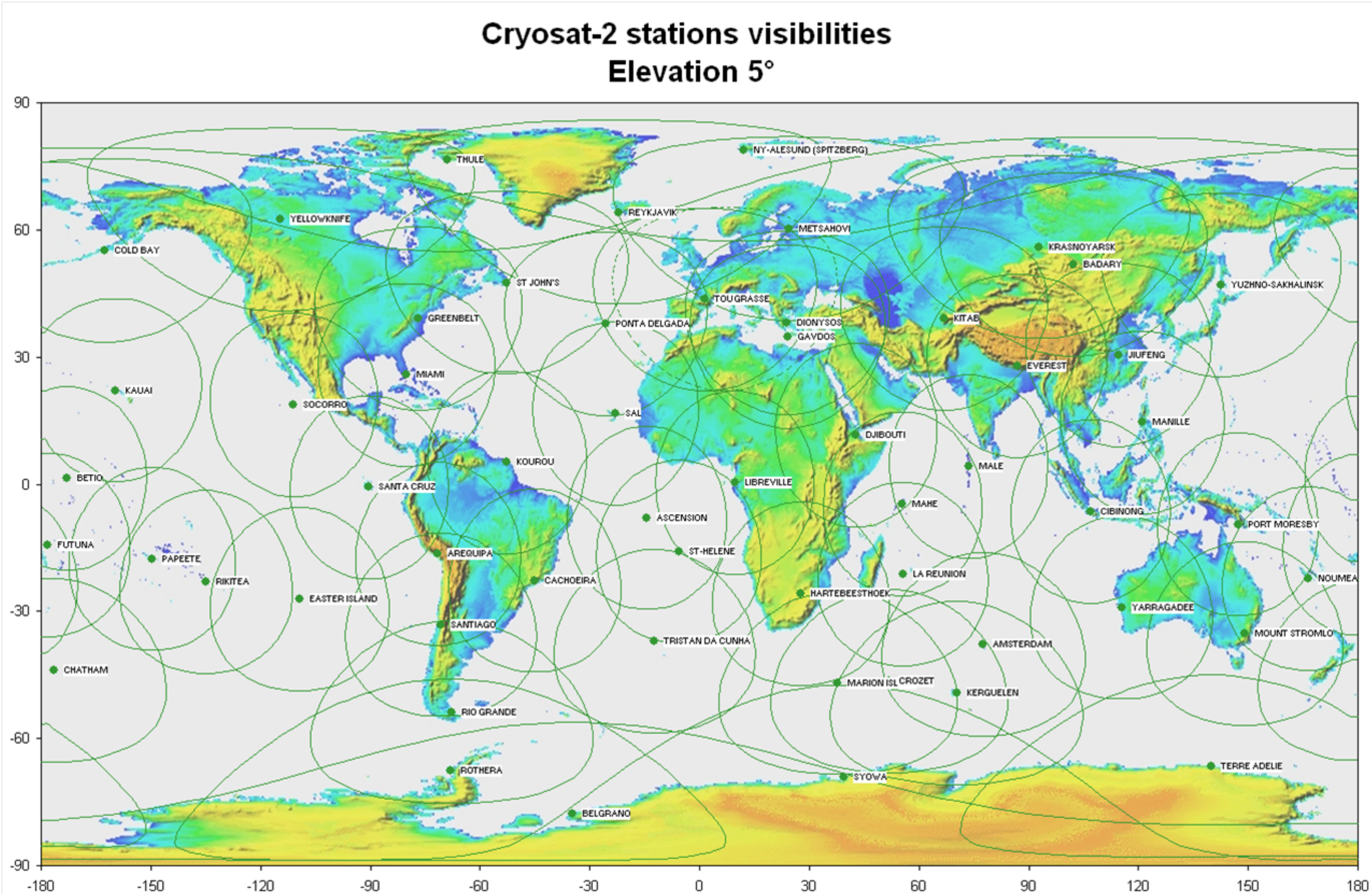
- Data fits
  - 10s Doppler fits are not really affected
  - SLR fits are clearly improved
- External comparison
  - No significant effect by SRP model choice.
  - Radial consistency between 1.5 to 2.0 cm wrt POE, average **1.612 cm** between two independent procedures, **1.140 cm** if we consider the orbit products uncorrelated.
  - The real-time DIODE Navigator data has been improved, since Aug 2012 we see a radial consistency < 5 cm

Backup slides

Models, tools etc

- Station coordinates and Earth rotation parameters:
  - DORIS and SLR station coordinates in DPOD2008/SLRF2008
  - IERS data, polar motion, length of day from Bulletin B
- Satellite Dynamics
  - EIGEN5c gravity model
  - Temporal gravity from GRACE to degree and order 20
  - FES2004 ocean load tides
- Spacecraft specific models
  - SRP model, DORIS antenna offsets, LRA offsets (4 setups)
  - Satellite attitude reconstructed from star camera quaternions
  - Raw navigator product, XML to flat ascii
  - ftp://dutlru2.lr.tudelft.nl/pub/ejo/cryosat2/ ← issues

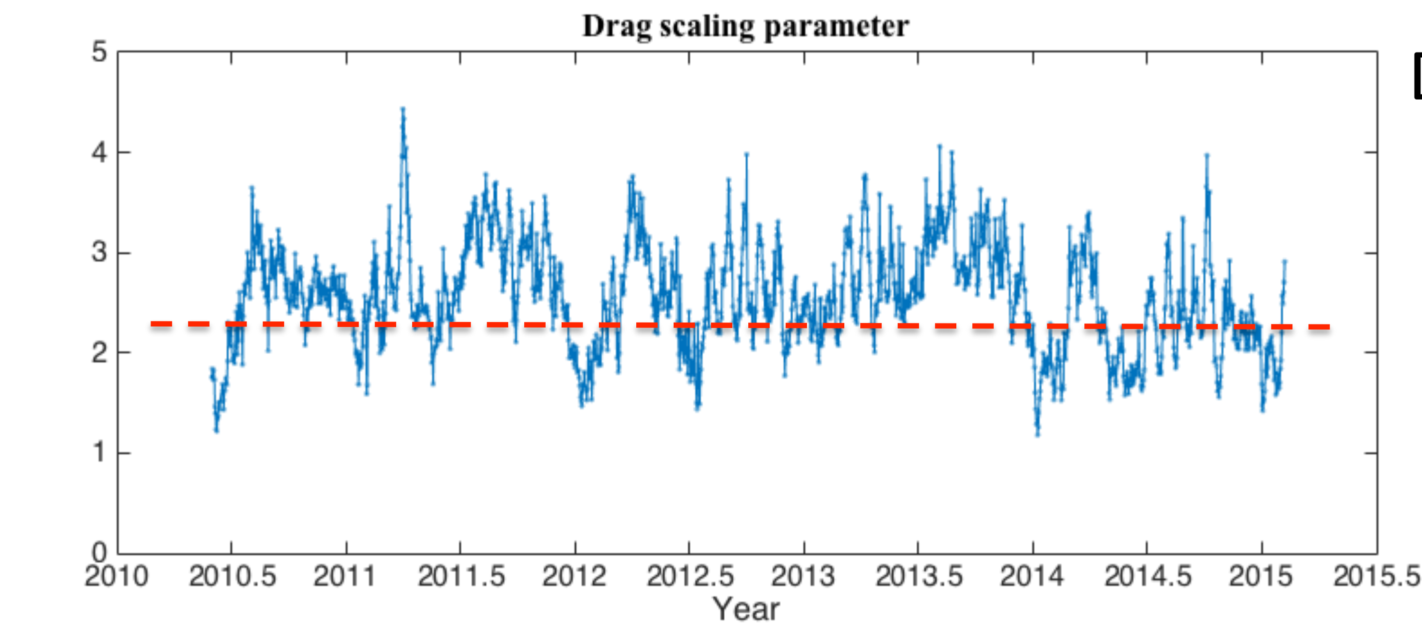
DORIS network



IDS website

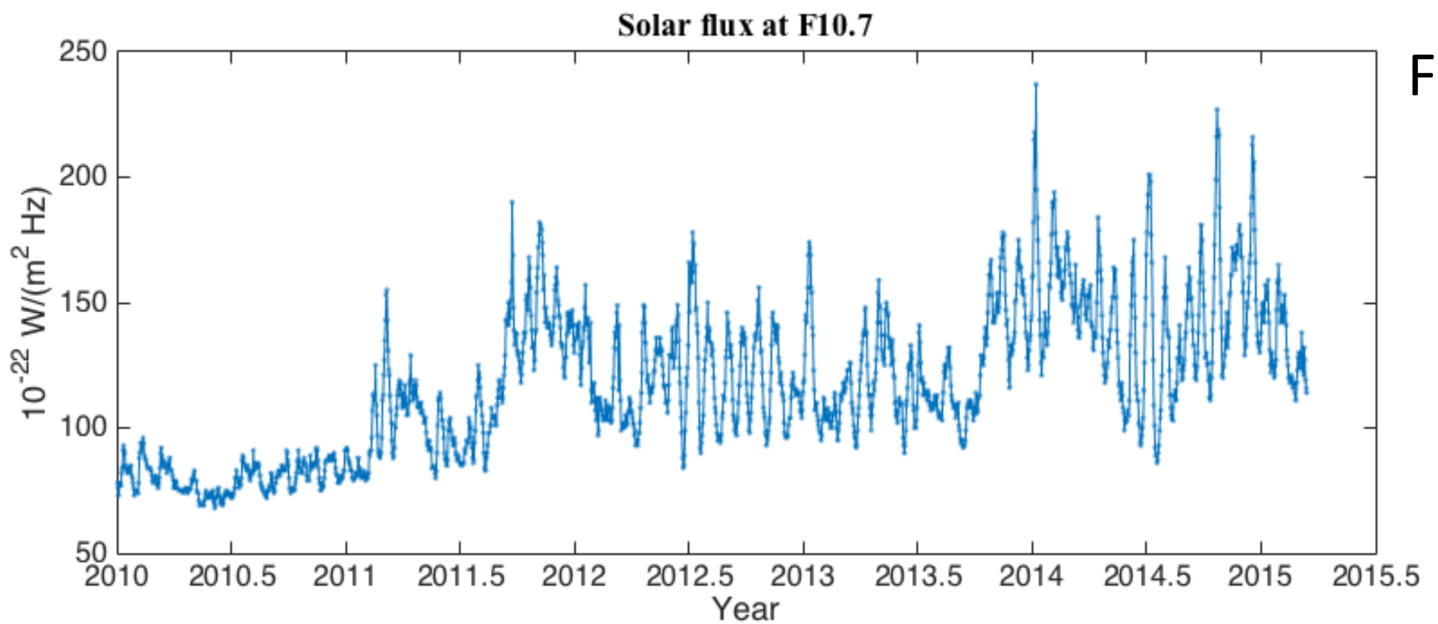
CNES

Drag

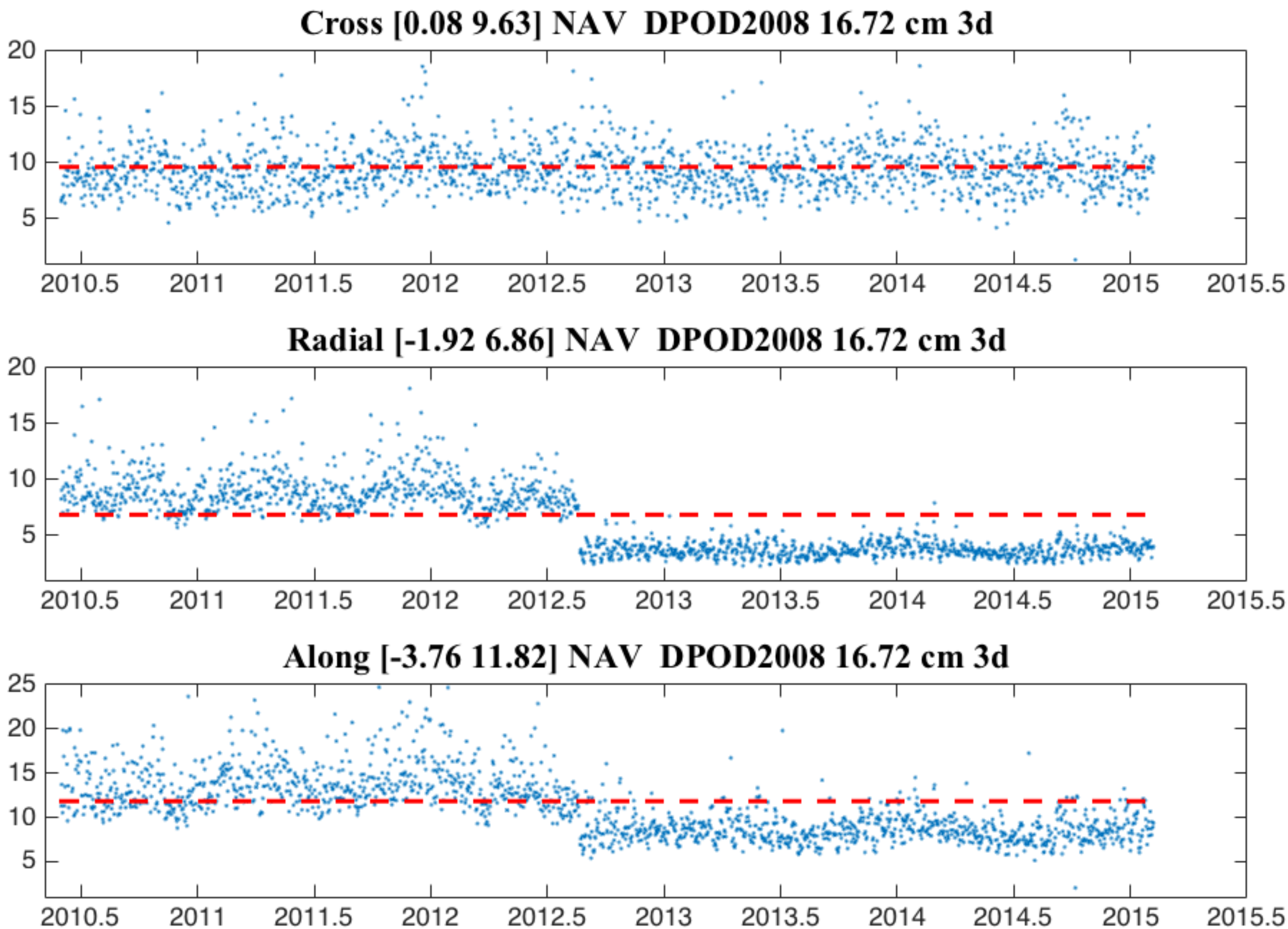


Hardly any change as a result of SRP model updates

F10.7



Adjusted every 3 hours
Consecutive constraints



Cross [0.08 9.63] NAV DPOD2008 16.72 cm 3d
Radial [-1.92 6.86] NAV DPOD2008 16.72 cm 3d
Along [-3.76 11.82] NAV DPOD2008 16.72 cm 3d
2010.5
2011
2011.5
2012
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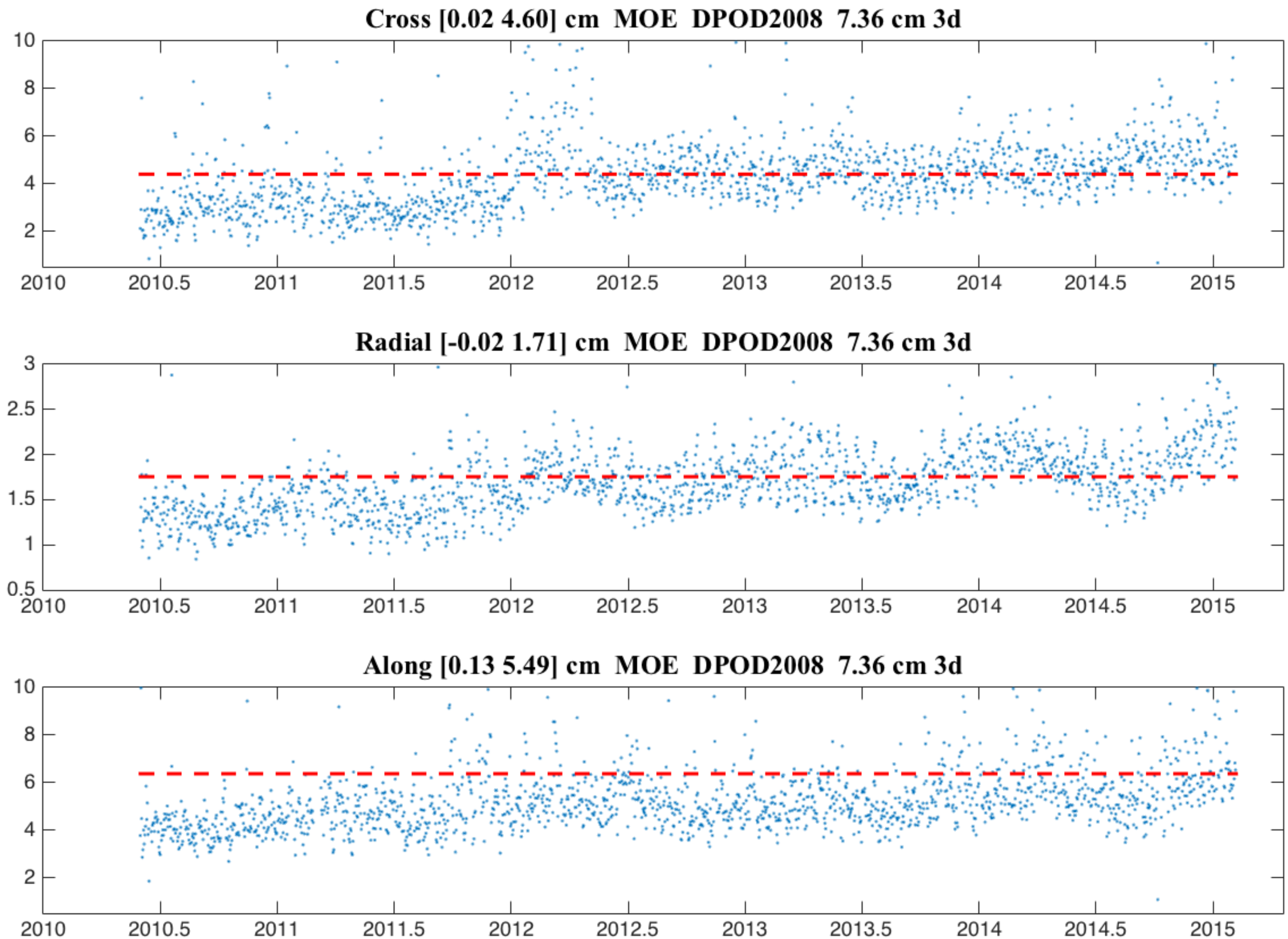
2013
2013.5
2014
2014.5
2015
2015.5


Cross [0.02 4.60] cm MOE DPOD2008 7.36 cm 3d
10
8
6
4
2
2010
2010.5
2011
2011.5
2012
2012.5
2013
2013.5
2014
2014.5
2015
Radial [-0.02 1.71] cm MOE DPOD2008 7.36 cm 3d
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2
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2015
Along [0.13 5.49] cm MOE DPOD2008 7.36 cm 3d
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2010.5
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2011.5
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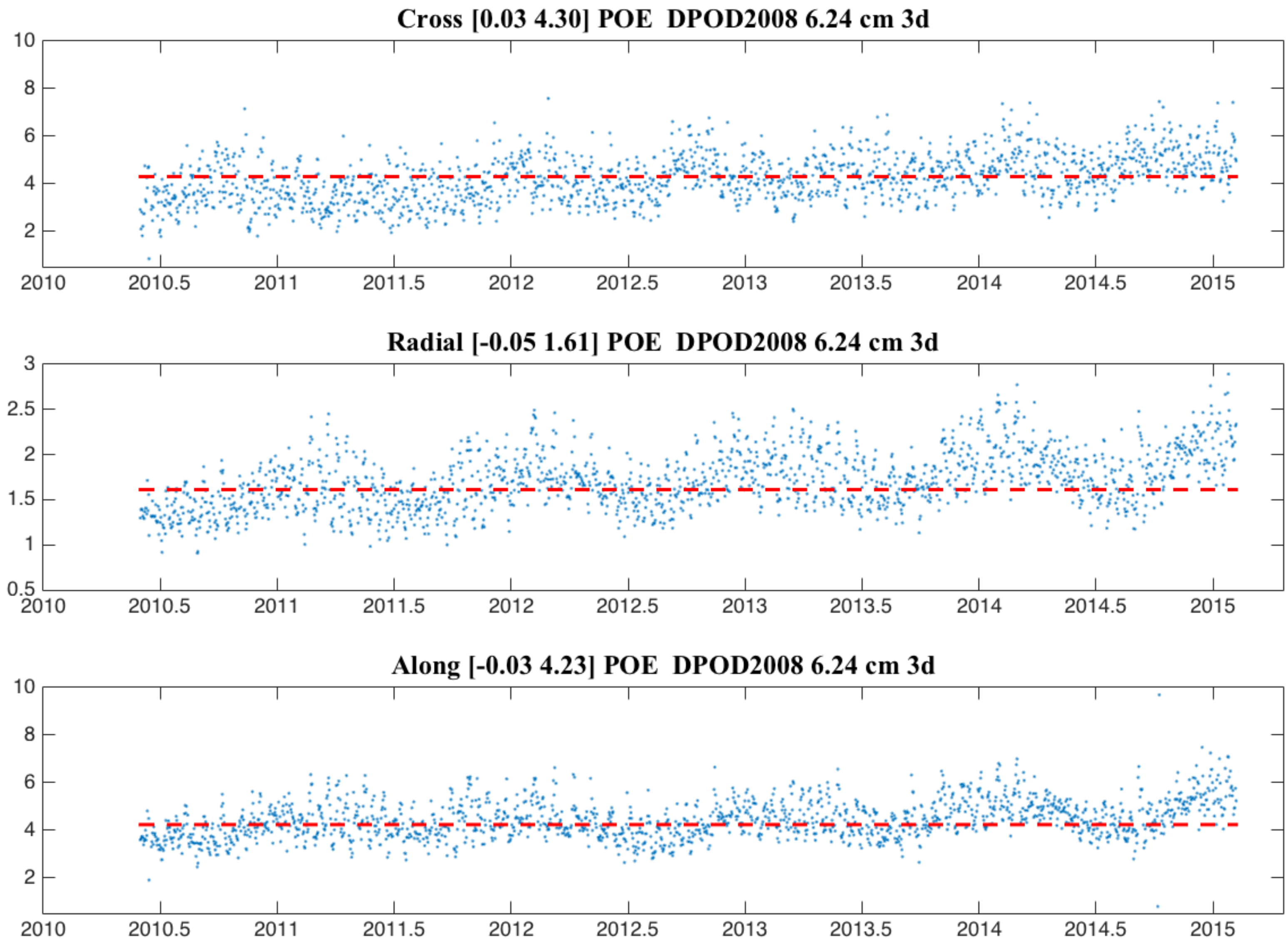
2012.5
2013
2013.5
2014
2014.5
2015

External orbit comparison

- We compare to CNES products
  - Real time navigator orbits, computed within the receiver real time
  - Rapid science orbits, produced within approximately one or two days (satellite maneuvers may cause confusion, anomalies)
  - Delayed final solutions, converged product after a month, ie. when IERS bulletin B products have converged.


Cross [0.03 4.30] POE DPOD2008 6.24 cm 3d
Radial [-0.05 1.61] POE DPOD2008 6.24 cm 3d
Along [-0.03 4.23] POE DPOD2008 6.24 cm 3d
10
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6
4
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2.5
2
1.5
1
0.5
2010
2010.5
2011
2011.5
2012
2012.5
2013
2013.5
2014
2014.5
2015

What to distribute from this activity

- TU Delft quaternion solutions, flat ascii
- Converted navigator orbits, flat ascii
- POD solutions based on the latest SRP model, either internal flat ascii format, or within SP3

Requirements POD

① TUD-ASM generates independent Precise Orbits products for cross-validation with the Cryosat operational orbits generated by the CNES.
② TUD-ASM regularly assesses the quality of the Cryosat operational orbit products by cross-validation with its orbit solutions.
③ TUD-ASM will make their precise orbits solutions available by means of anonymous ftp to the user community.
④ TUD-ASM assesses the quality and validity of the Cryosat star trackers quaternions, and will make spacecraft quaternions available via anonymous ftp to the user community.
⑤ TUD-ASM reports on the Cryosat SLR tracking acquisitions (e.g. trend and world coverage).
⑥ TUD-ASM assesses their orbit product performances, and investigated the need for new orbit determination techniques and models.
⑦ TUD-ASM reports their precision orbit determination performance assessments at the Cryosat quality working group (QWG) meetings.

Deliverables within POD

① **D1a:** Validation of precise orbits presented at Cryosat QWG meetings which are organized twice per year (✔)

② **D1b:** Yearly Report (too early)

③ **D1c:** TUD-ASM orbit solution product specifications document (after this QWG)