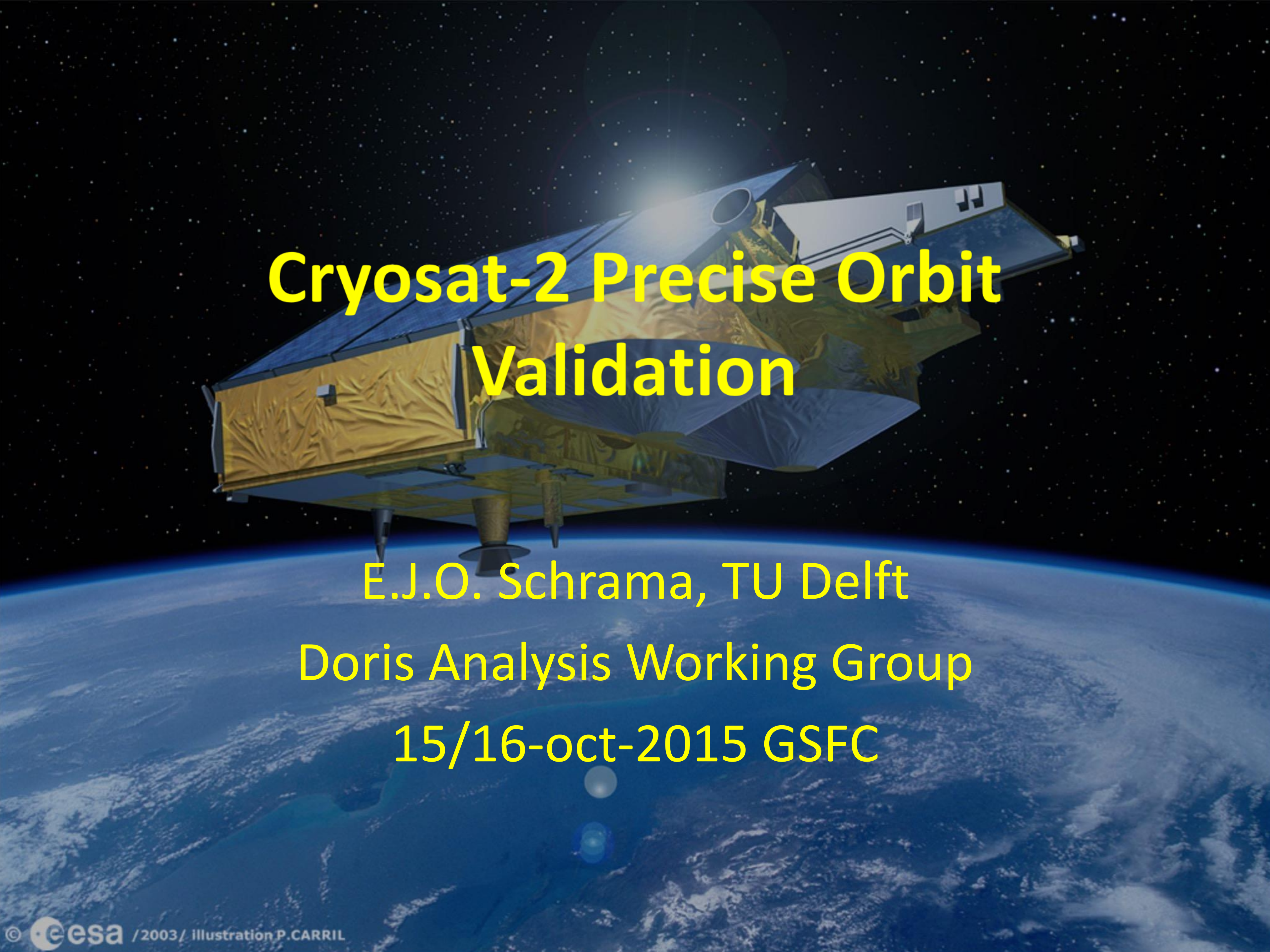


Cryosat-2 Precise Orbit Validation

E.J.O. Schrama, TU Delft

Doris Analysis Working Group

15/16-oct-2015 GSFC

TU Delft involvement

- Validation activities 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
- Quality checks,
  - Internal consistency with tracking data
  - Level empirical acceleration parameters
  - External comparison the CNES products
- POD complete up to 11-September-2015

Models, tools etc

- Station coordinates and Earth rotation
  - DORIS and SLR station coordinates in DPOD2008/SLRF2008
  - IERS: polar motion, length of day from Bulletin B (one month latency)
- Geophysicals
  - EIGEN5c gravity model
  - Temporal gravity from GRACE to degree and order 20
  - FES2004 ocean load tides
- Spacecraft
  - SRP model, DORIS antenna offsets, LRA offsets (4 setups)
  - Satellite attitude reconstructed from star camera quaternions
  - Consider different arc lengths, and empirical parameter set-ups

Solar radiation pressure model (1)

- Micromodels from EADS and ESA and their differences
- Macro models models tested
  - Canonball
  - EADS v0
  - EADS v1
  - CNES
- Calibration of the macro model, estimate C_r
- Review the level of empirical accelerations and the consequences for precision orbit determination of CryoSat-2

Solar radiation pressure model (2)

- 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

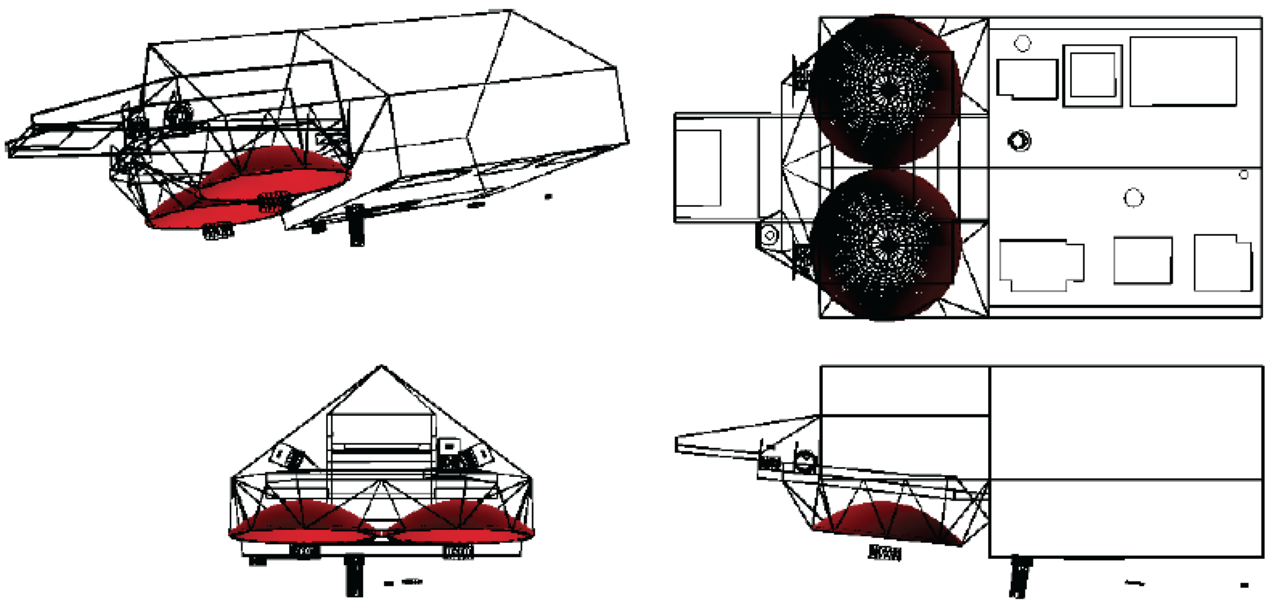


Figure 5.4: *Wire-frame of the first micro model of Cryosat-2. All the elements that are not polygons, cylinders or parabola are missing. Top left: 3D view, top right: top view, bottom left: front view and bottom right: side view.*

Thesis Bart Root

EADS CryoSat-2 model

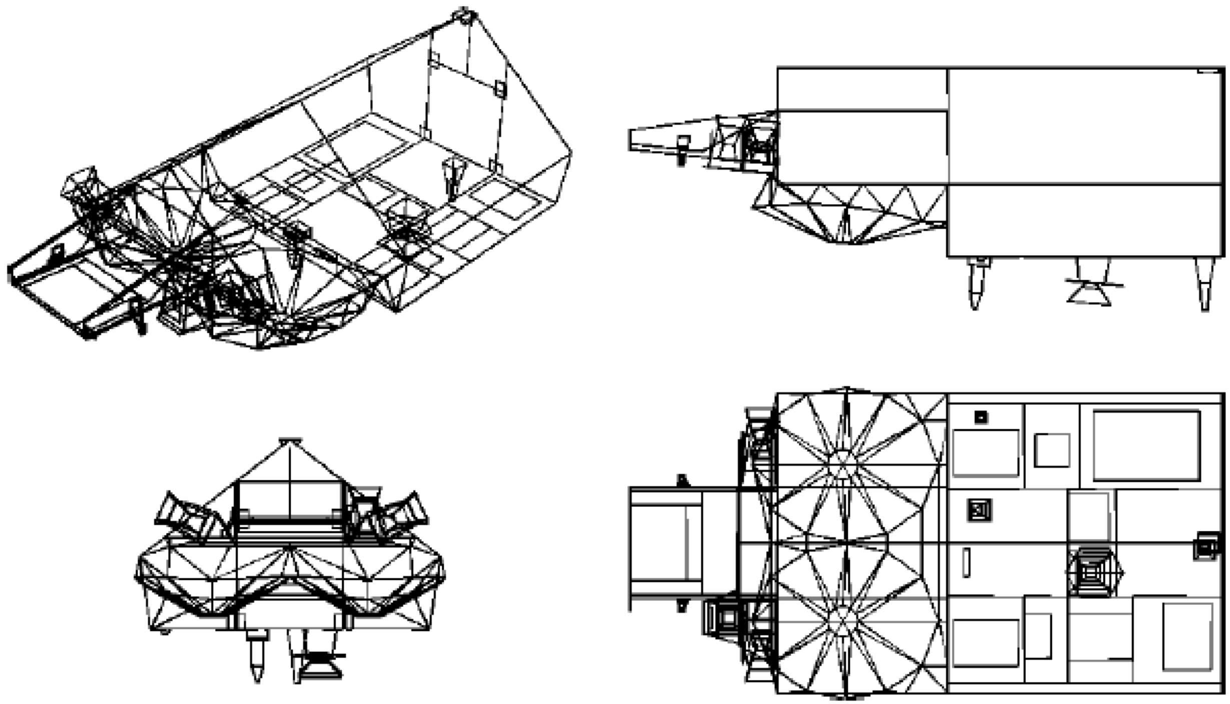
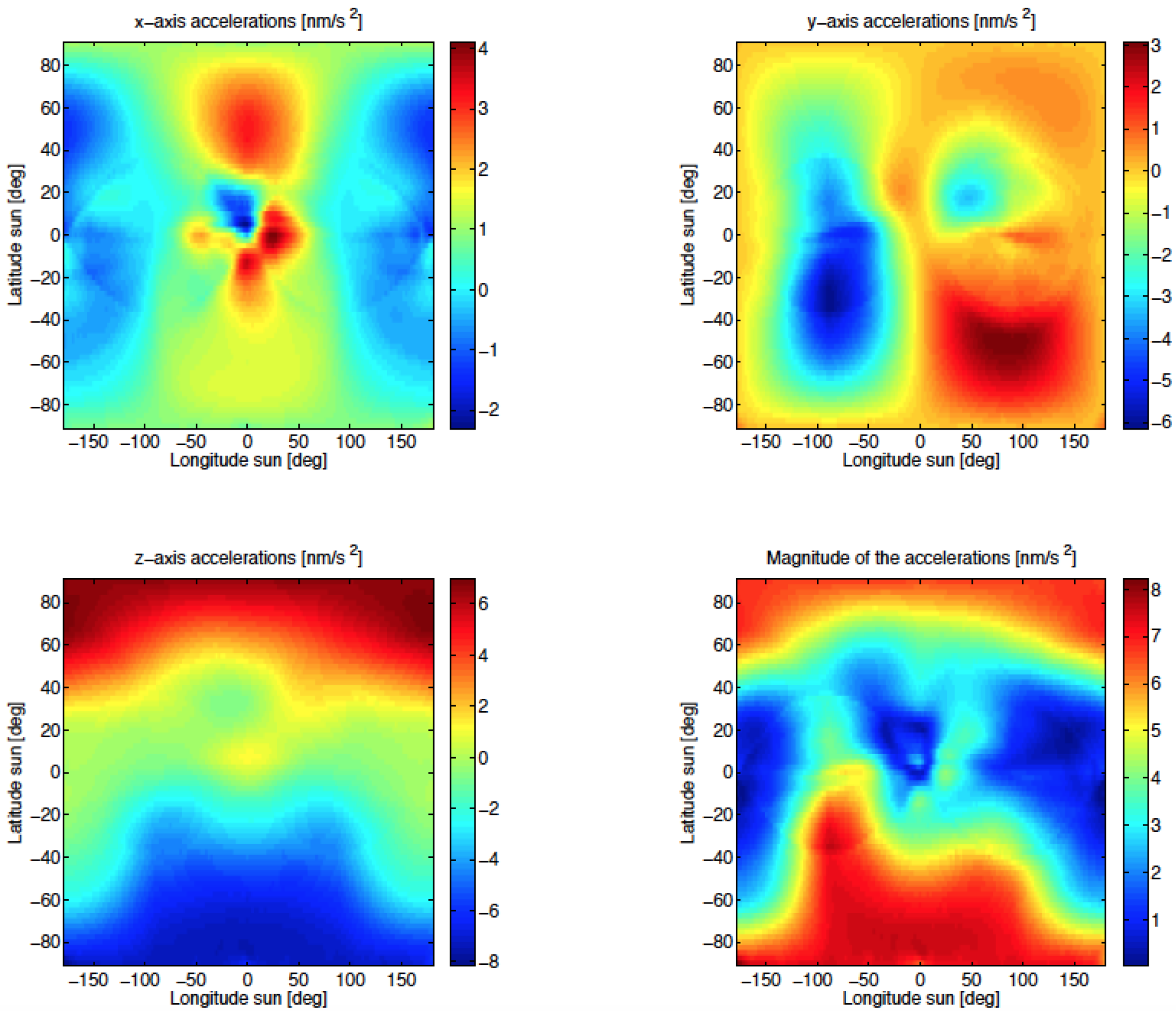


Figure 5.5: *Wire-frame of the EADS micro model of Cryosat-2. This is the second model that will be used. Top left: 3D view, top right: top view, bottom left: front view and bottom right: side view.*

Thesis Bart Root



Conclusion:

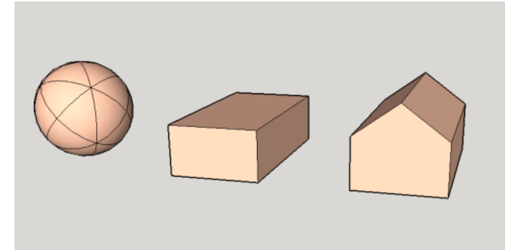
It is hard to find agreement below the 5 nm/s^2 level,

A better approach is to estimate empirical parameters for the remaining accelerations, and we do this 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 and that 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

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	Cr found
Canonball	1	Sphere	2.5093
ESA V0	6	Box	0.8805
ESA V1	6	Box	0.8665
CNES	7	House	1.0295

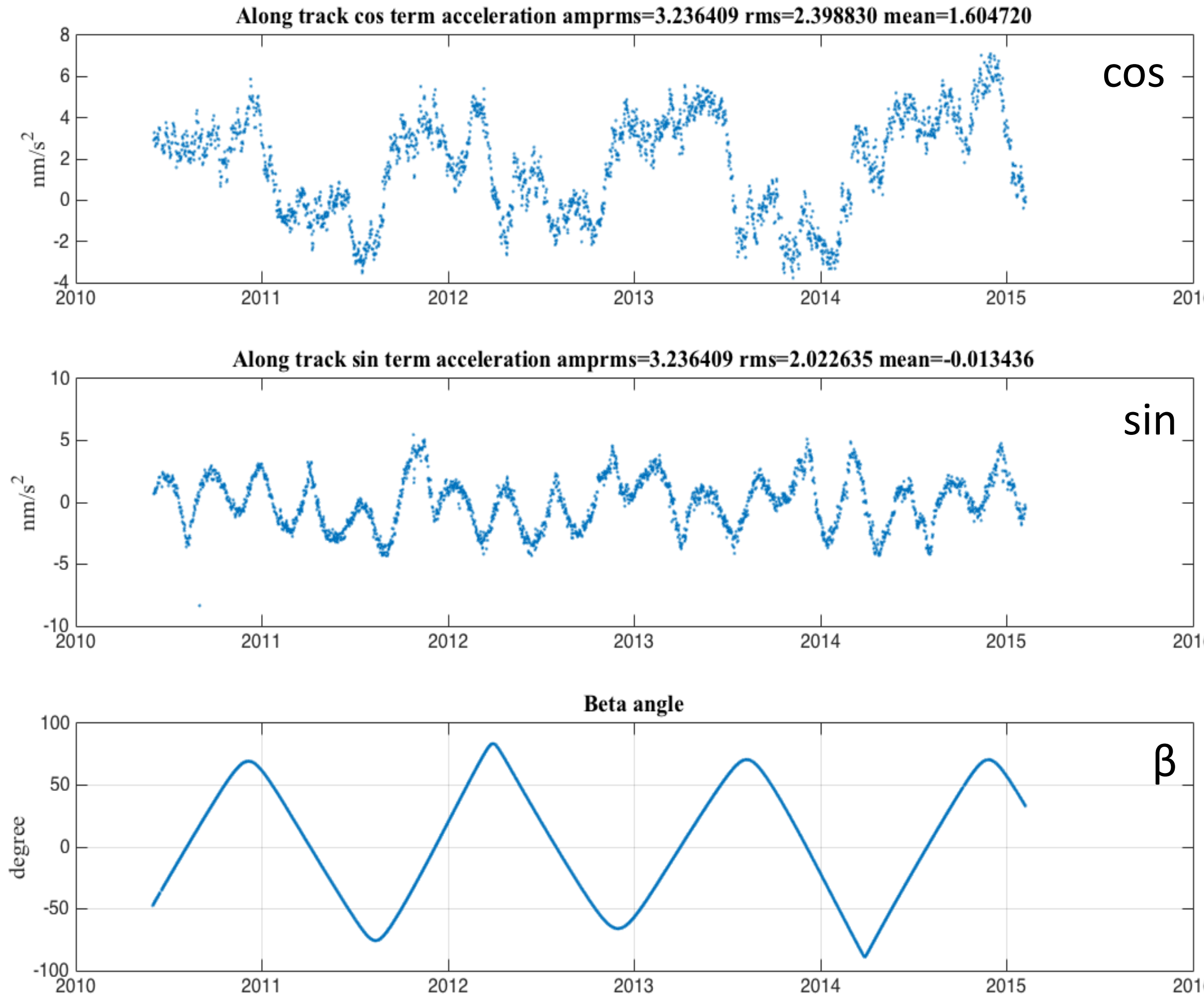
From this point fix the C_r parameter and estimate:

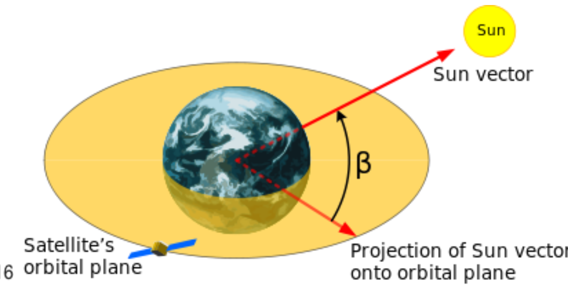
- Empirical accelerations: 24 hour patches along- and cross-
- Drag parameters every 3 hours

24h intervals

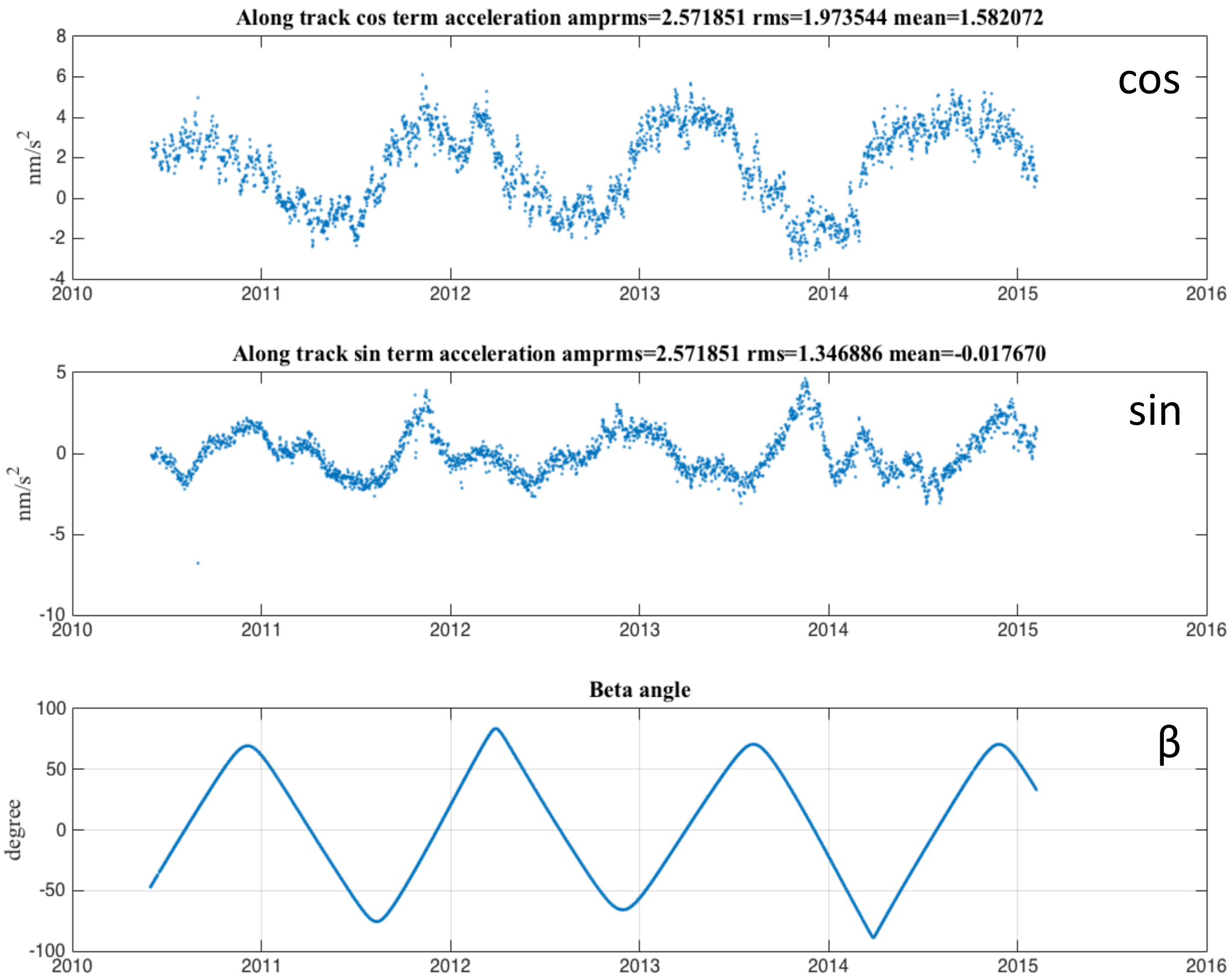
Forcing Parameters vs beta angle

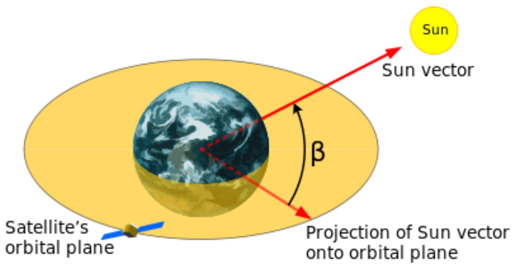
ESA0





24h intervals — Forcing Parameters vs beta angle — CNES





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

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:

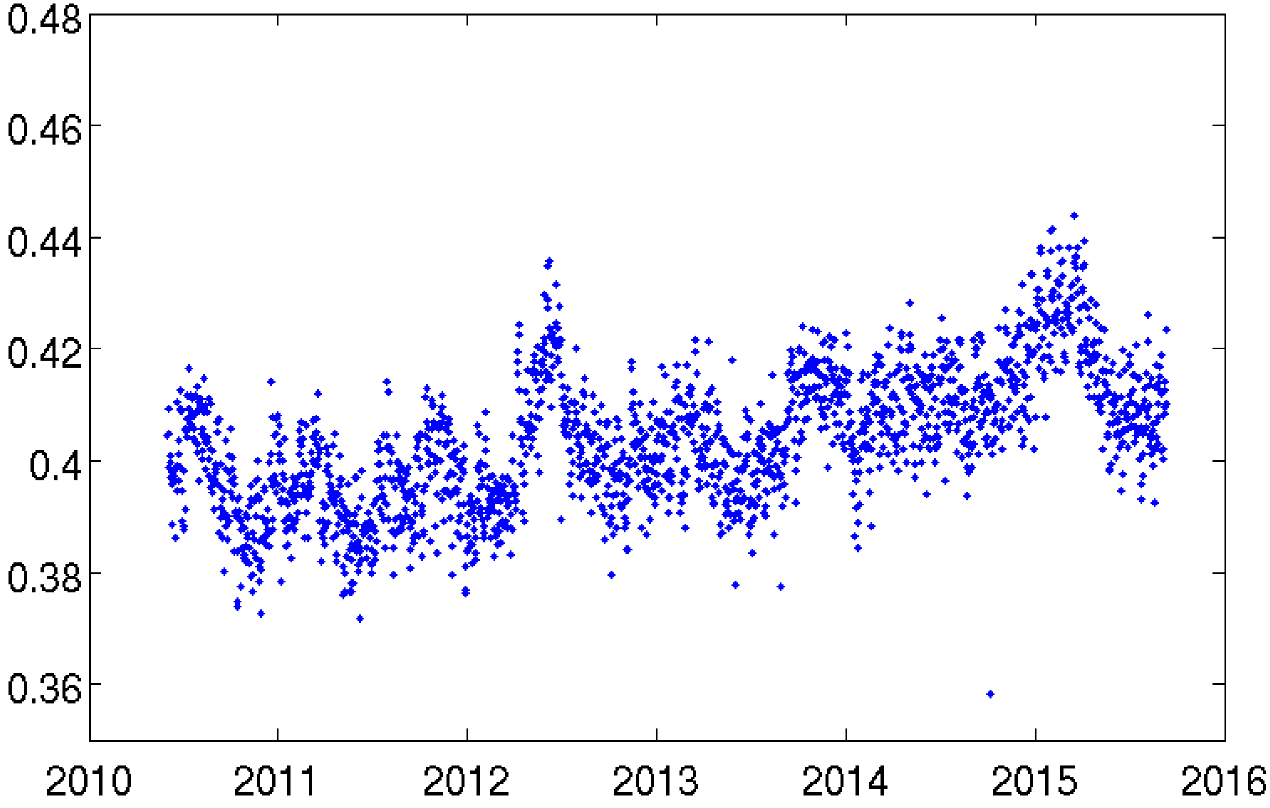
Run	Mean	Median	Skewness	Kurtosis
Canonball	1.76301	1.66463	0.74055	3.44202
ESA V0	1.91574	1.86089	0.47153	3.46646
ESA V1	1.64998	1.56680	0.69744	3.56531
CNES	1.62930	1.54512	0.71297	3.60059

Outcome SRP model evaluation

- SRP calibration period jun-2010 and mar-2015
- Continue with the 7 panel CNES model
- Processed all data up to 11-Sep-2015
- 24h empirical parameters along/cross 1 cpr
- 3 hour drag parameters
- Weak drag constraints

DORIS 10s residuals

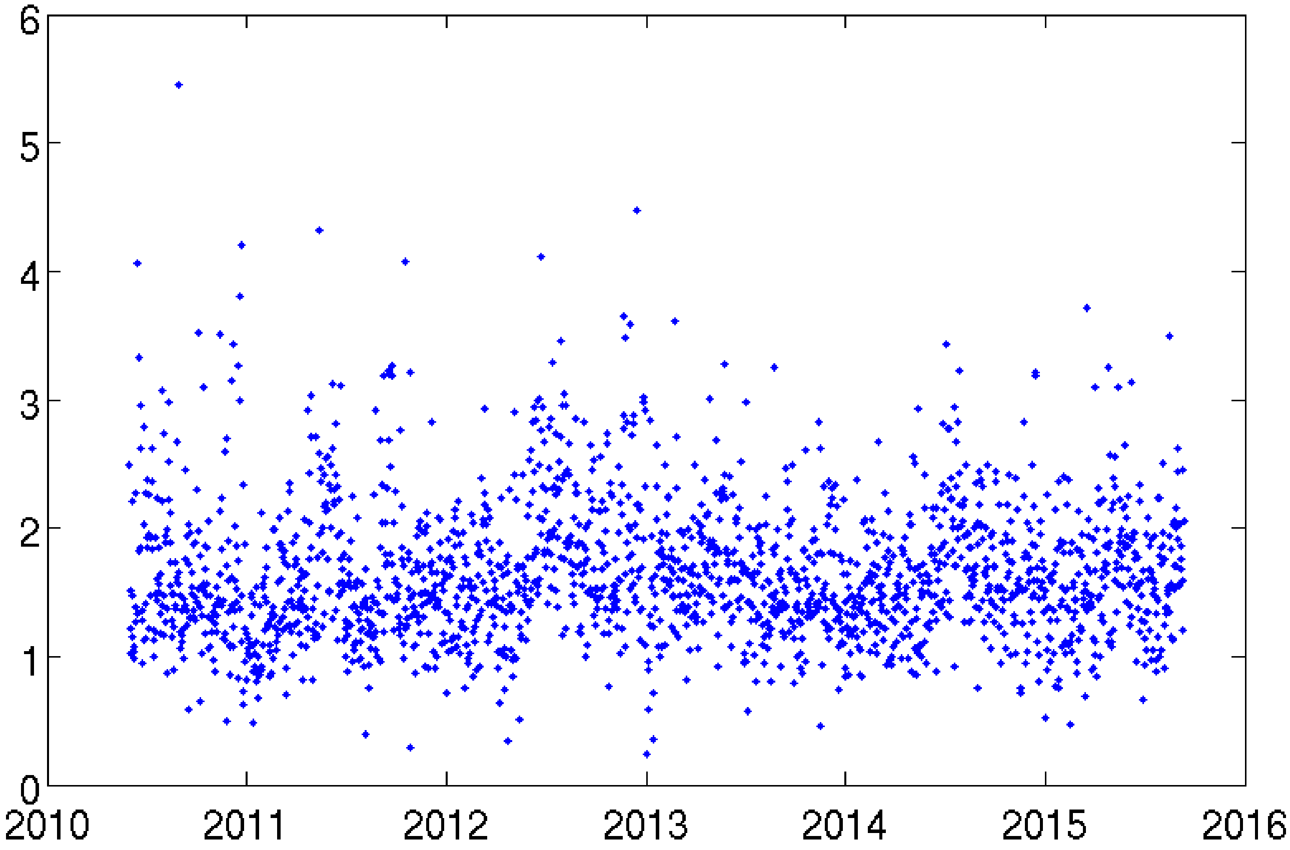
Median or mean
0.40 mm/s



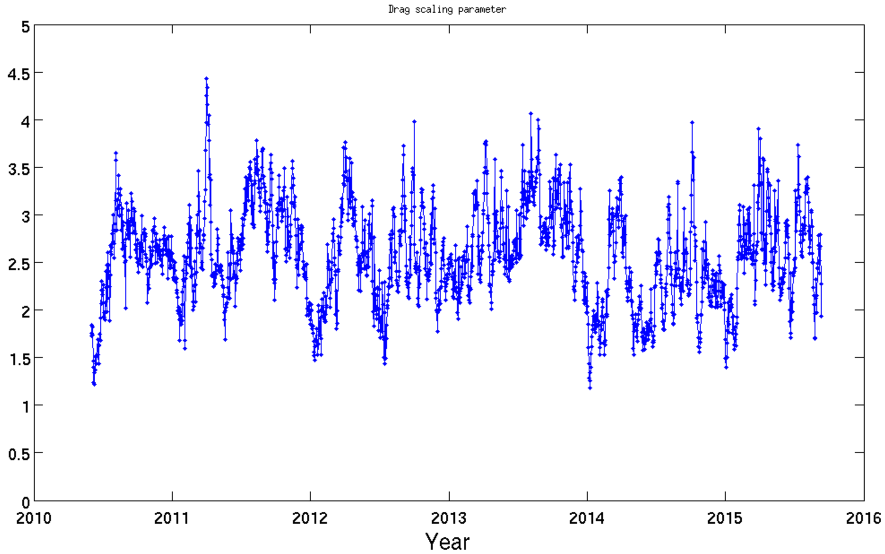
Histogram not significantly affected SRP/offset model, there are weeks where
The 10s residuals that stand out compared to the rest, reason is unclear

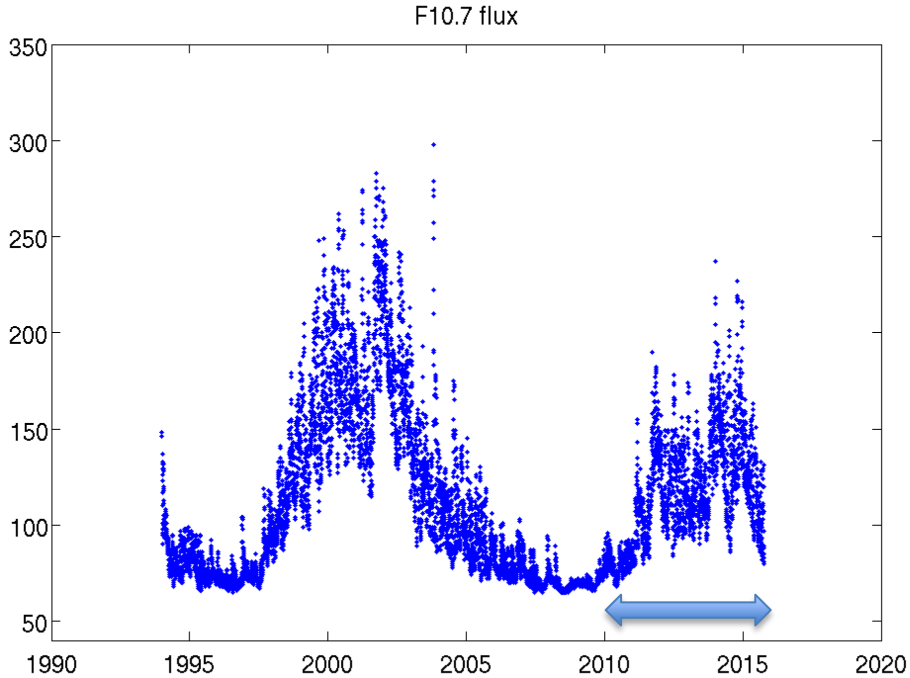
Satellite laser ranging residuals

Around 1.6 cm rms



Histogram slightly affected by SRP/offset model, essentially the fit remains as is





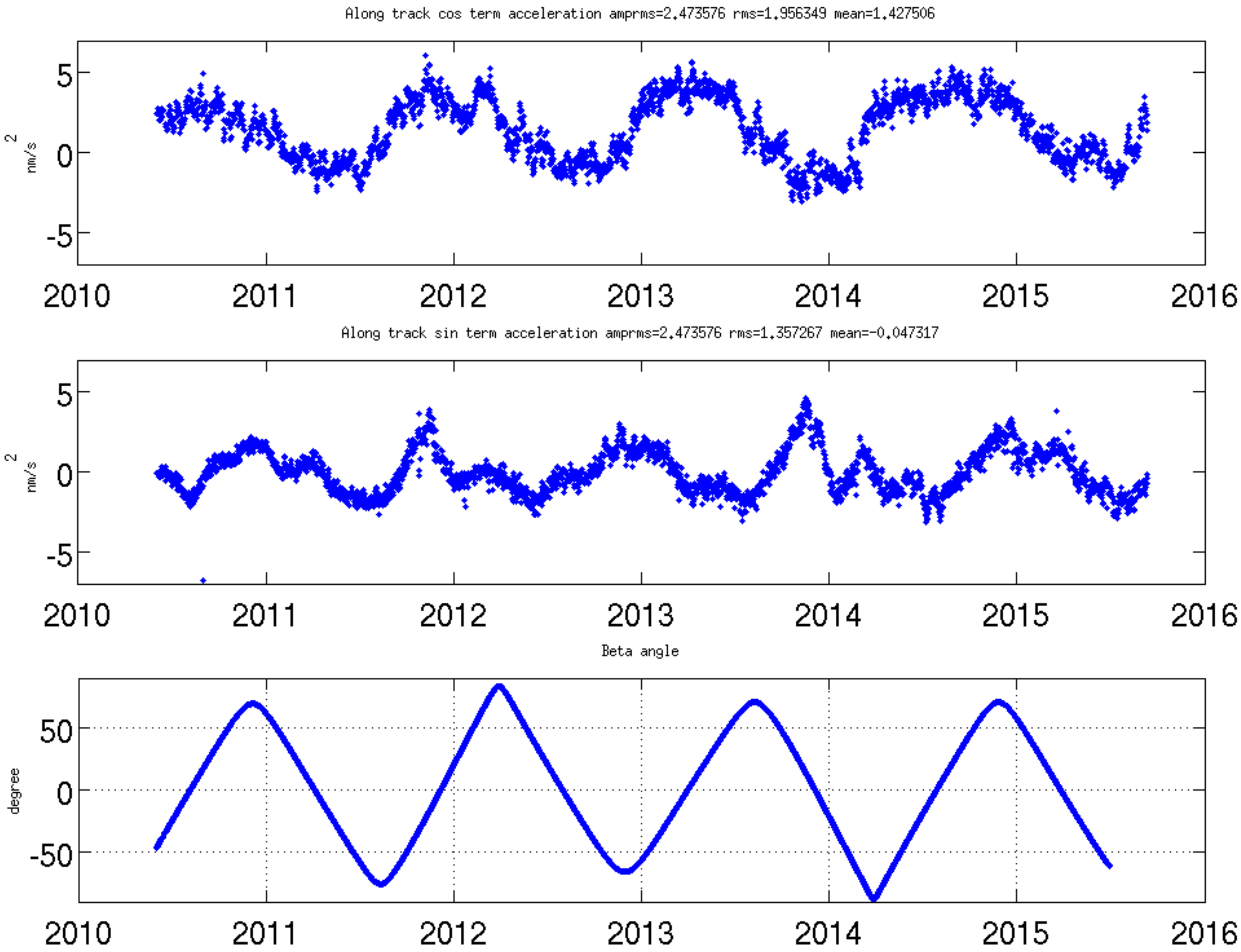
Drag

Adjusted every 3 hours
By consecutive constraints, mostly unaffected by SRP model updates

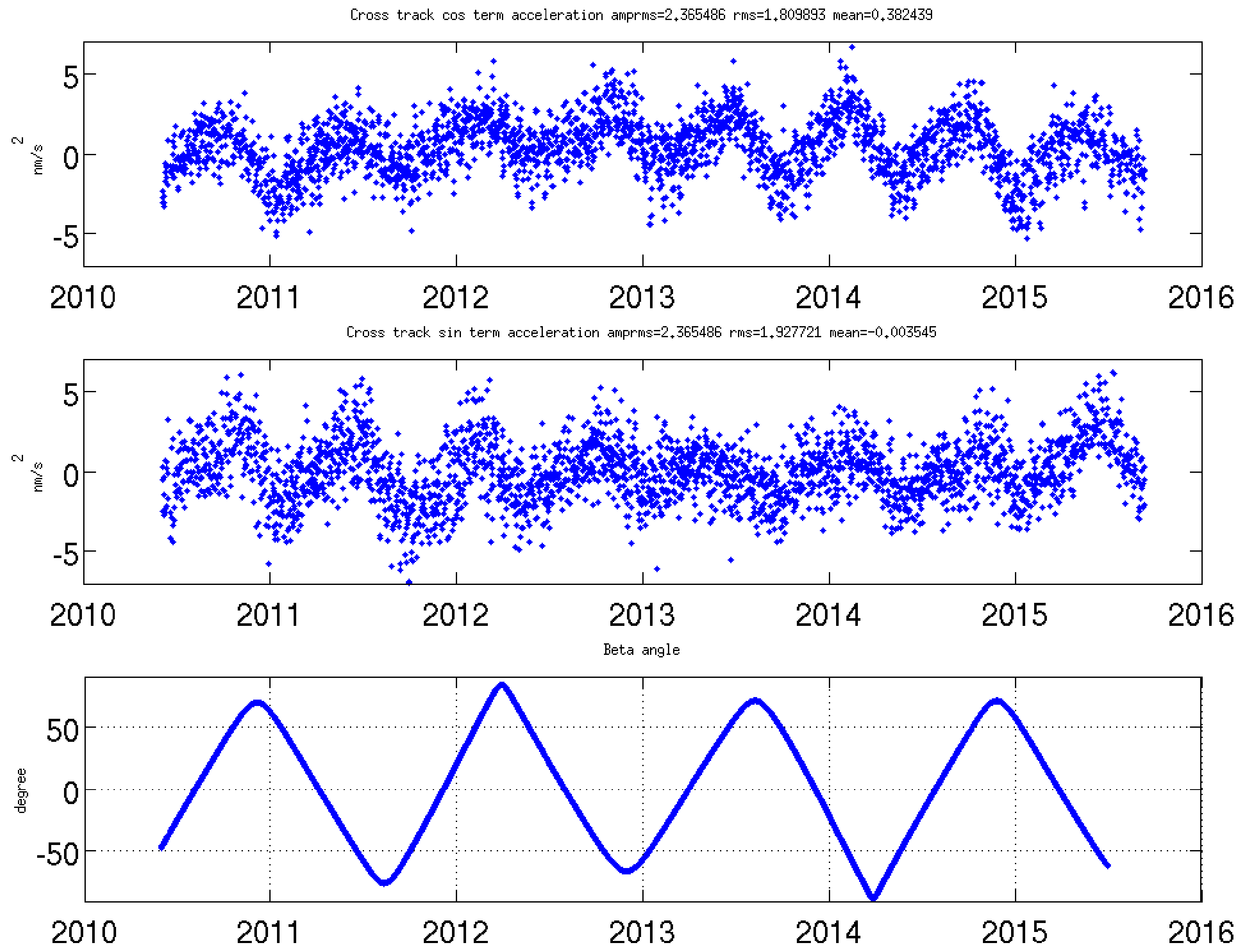
F10.7 space weather

At the end of a solar max

Along track empirical parameters



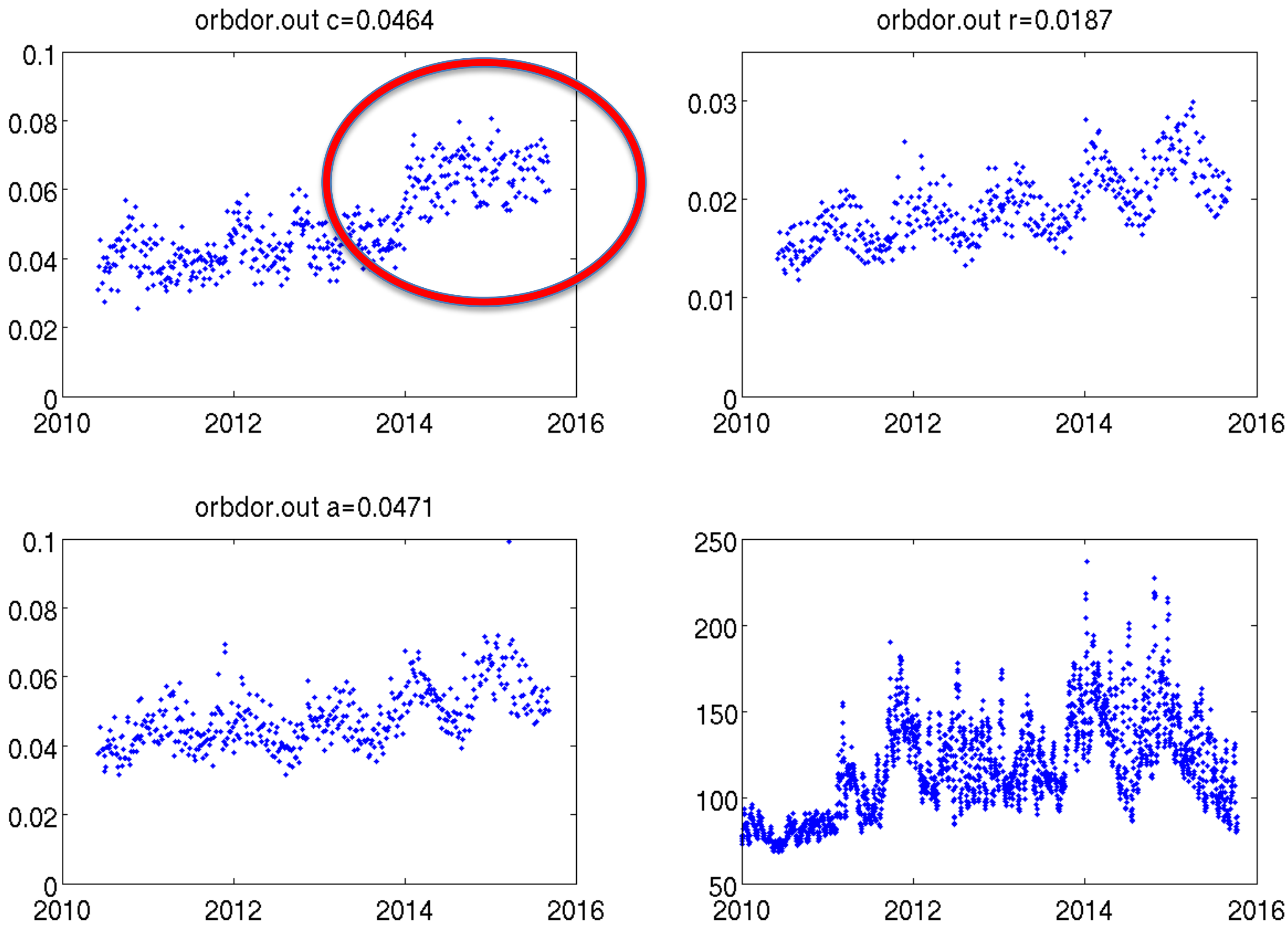
Cross track empirical parameters



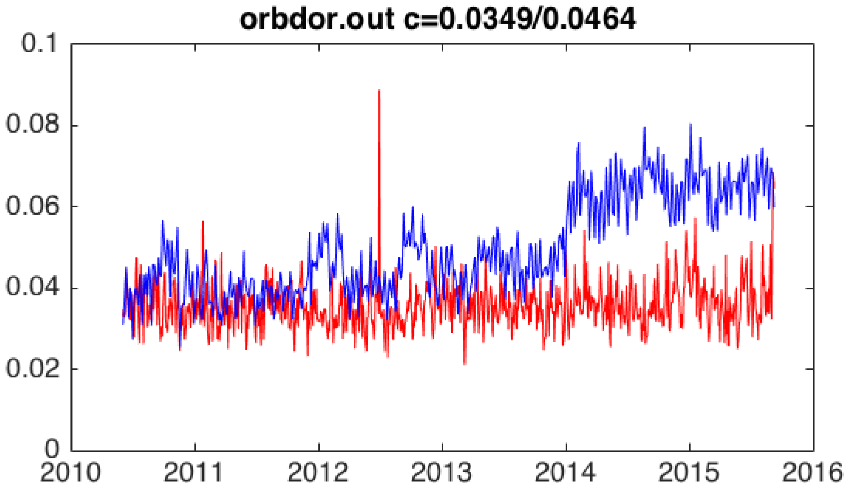
External orbit comparison

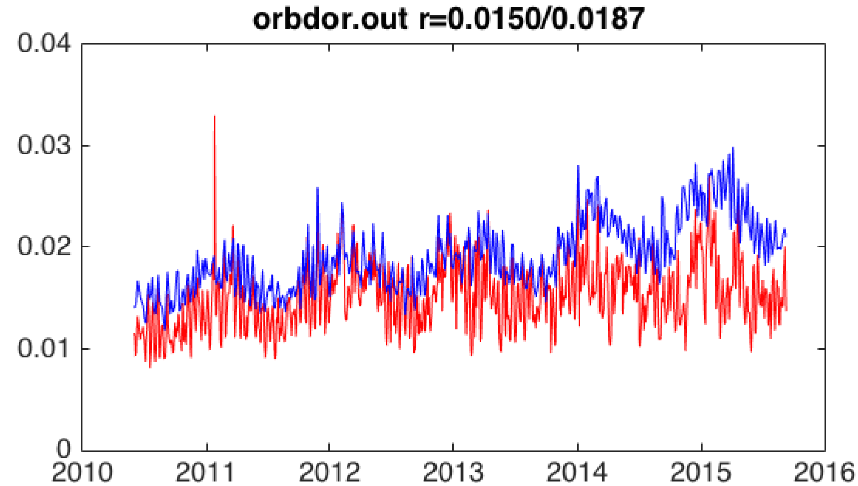
- We compare against the CNES products
  - Real time navigator orbits, computed within the receiver real time
  - Rapid science orbits, produced within approximately one or two days (satellite maneuvers may cause confusion, anomalies)
  - Delayed final solutions, converged product after a month, ie.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

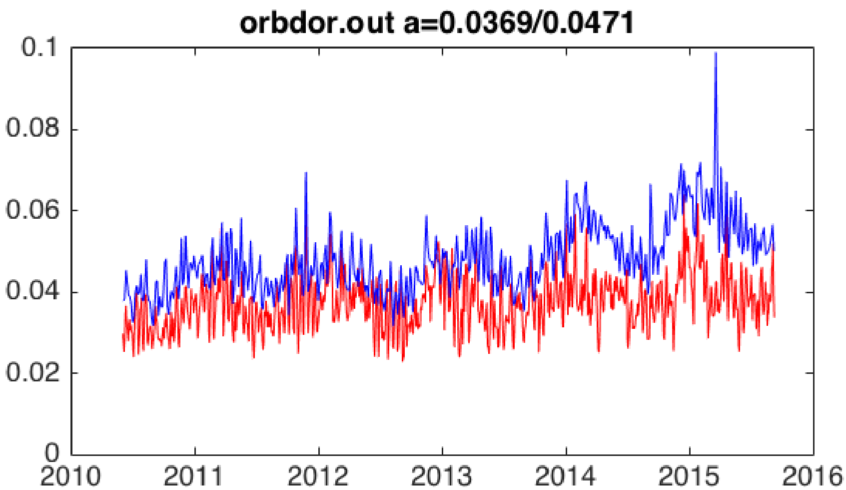
144 hour arcs, 24 hour empirical accelerations, 3 hour drag parameters

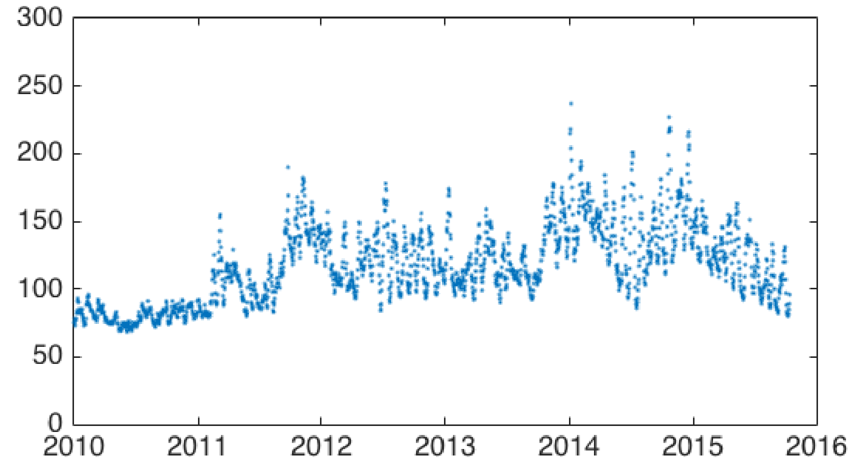


72 hour arcs, 6 hourly empirical accelerations, 3 hour drag parameters



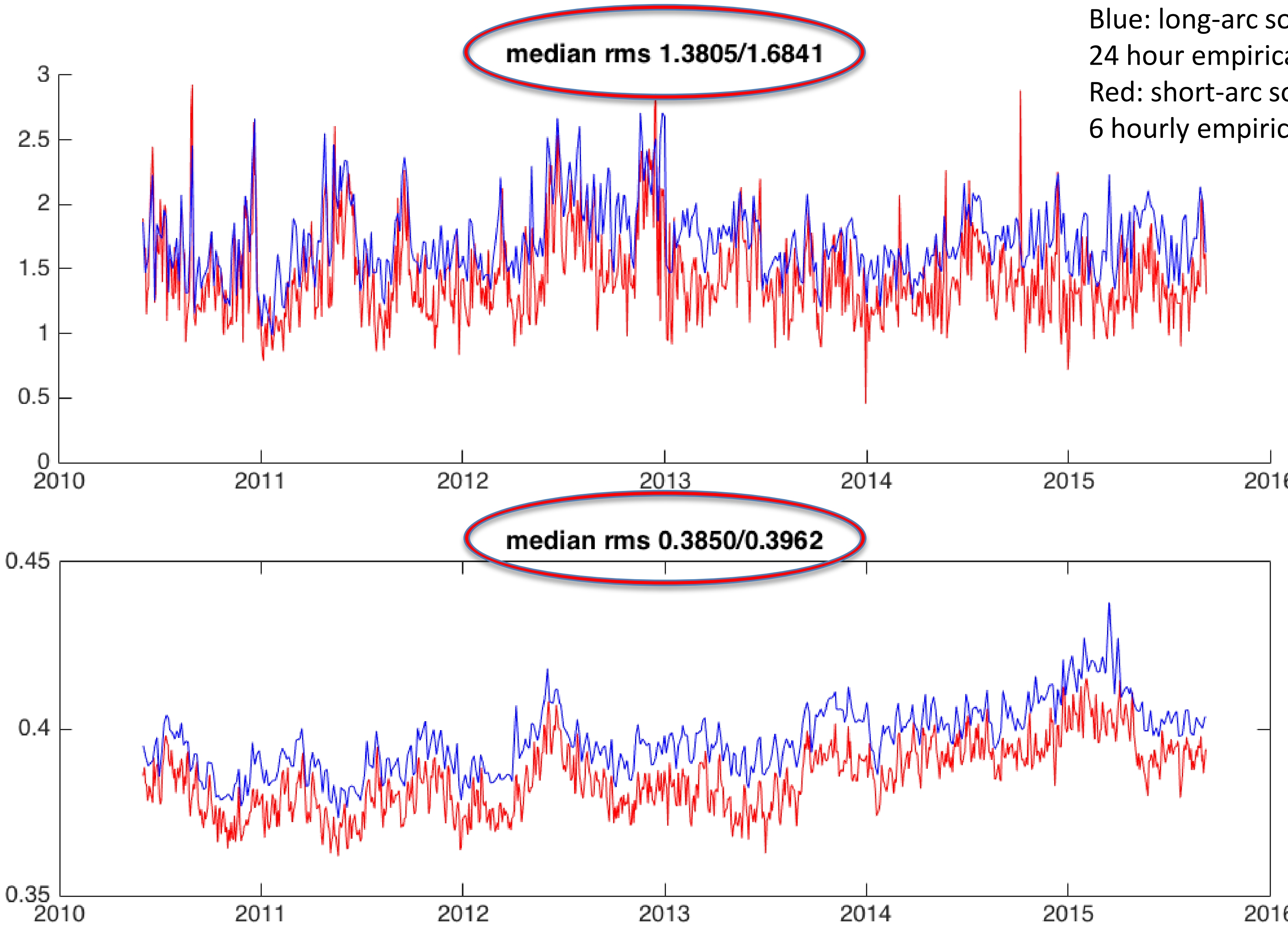






Doris and SLR residuals for long-arc (6 day) and short-arc (3-day) solutions

Blue: long-arc solution
24 hour empiricals
Red: short-arc solution
6 hourly empiricals



Conclusions (1)

- SLR: independently it yields 4 cm orbits radially, residual of fit consistent at **1.55** cm (median). Low weight with respect to DORIS
- DORIS: consistent fits at 0.402 mm/s based on 10 second data, CNES: Rinex data, ours: 10s Doppler counts

Conclusions (2)

- 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
  - 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)
- SLR fits clearly improve for each SRP model

Conclusions (3)

- We compare against Navigator orbits, rapid science MOE and the final solution POE orbits
- The real-time DIODE Navigator data has been improved, since Aug 2012 we see a radial consistency < 5 cm
- Radial fit can be reduced to around 1.5cm relative to the POE product, results are affected by the empirical parameters set-up
- Short arc vs Long arc strategy