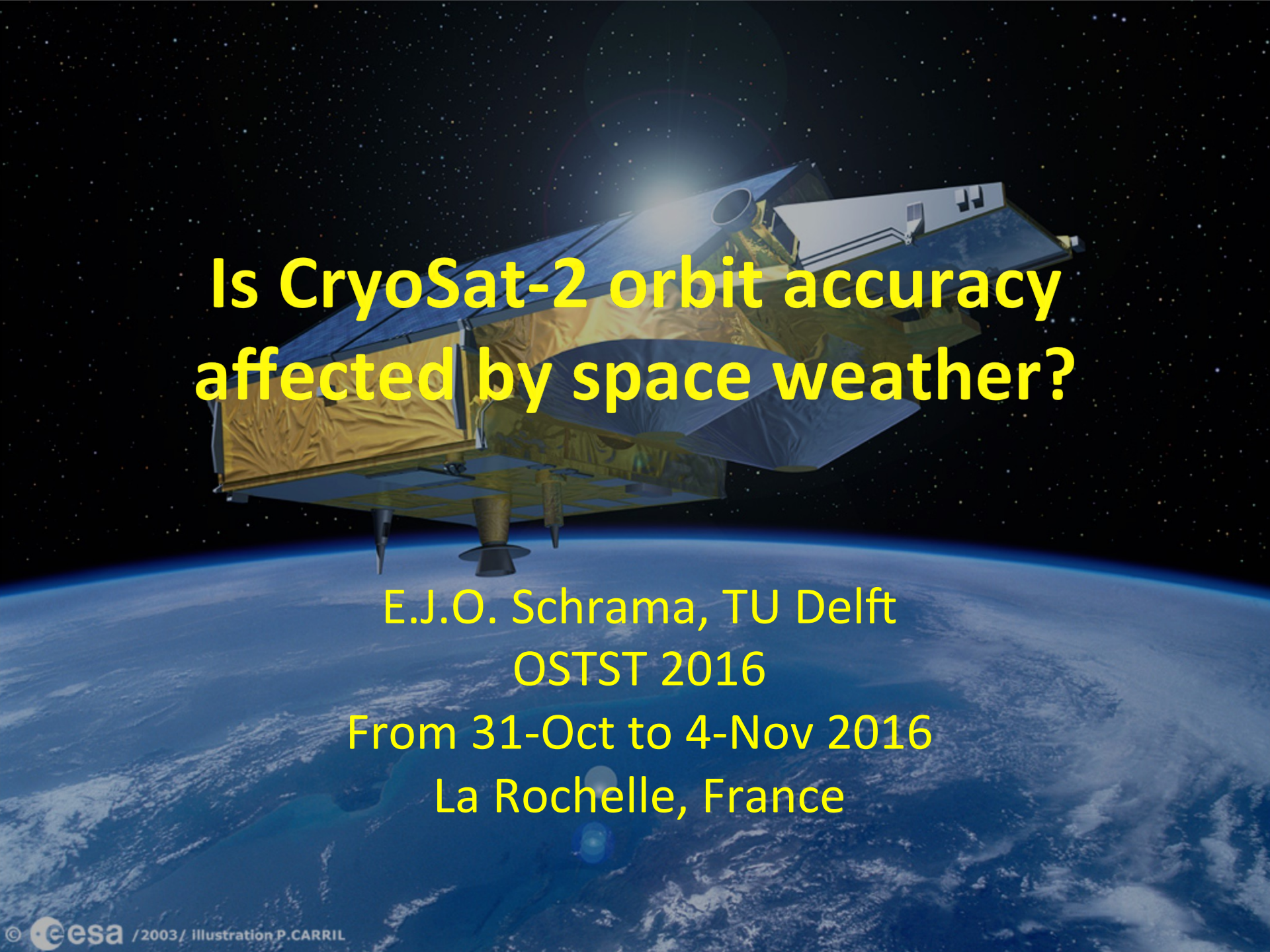


Is CryoSat-2 orbit accuracy affected by space weather?

E.J.O. Schrama, TU Delft

OSTST 2016

From 31-Oct to 4-Nov 2016

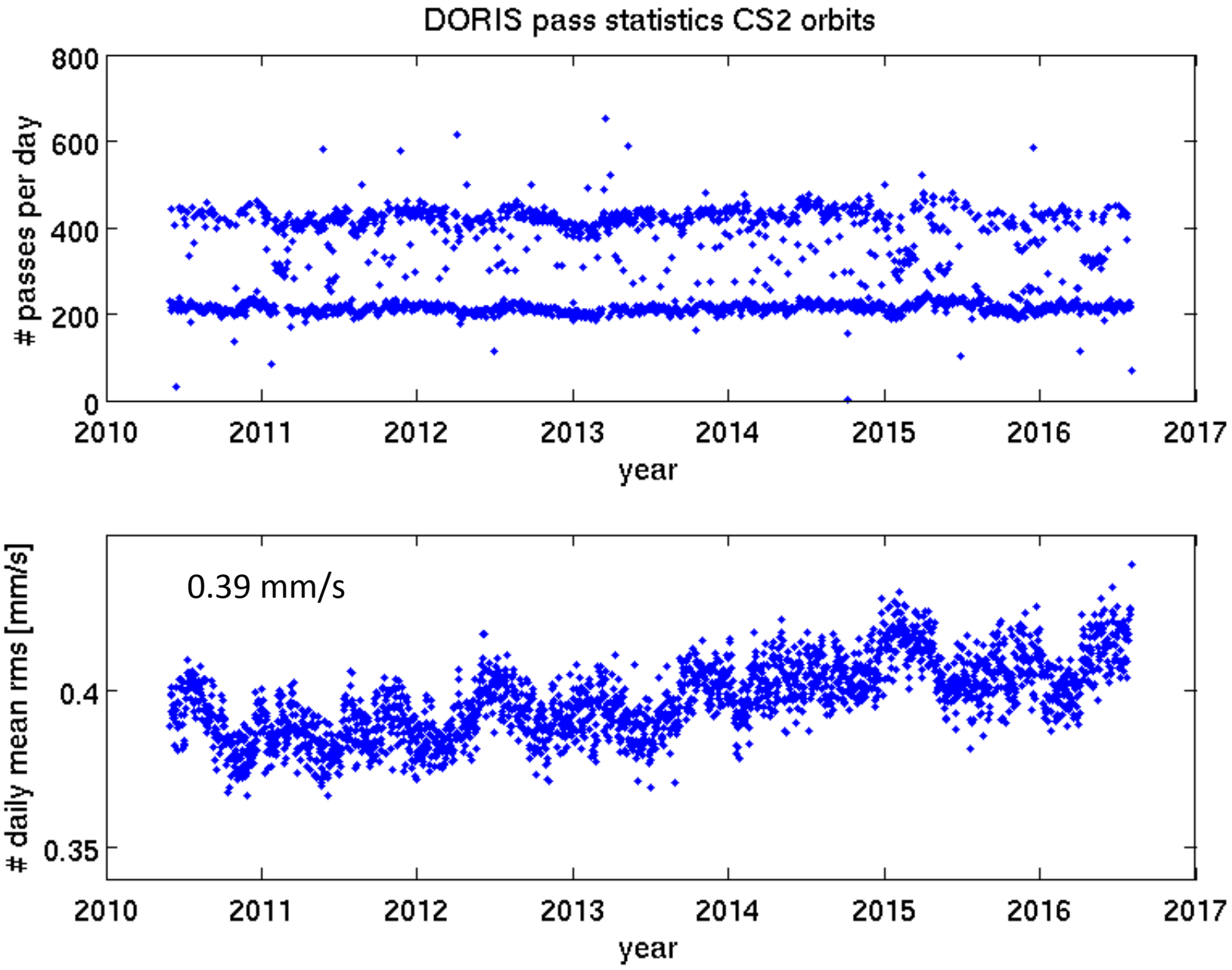
La Rochelle, France

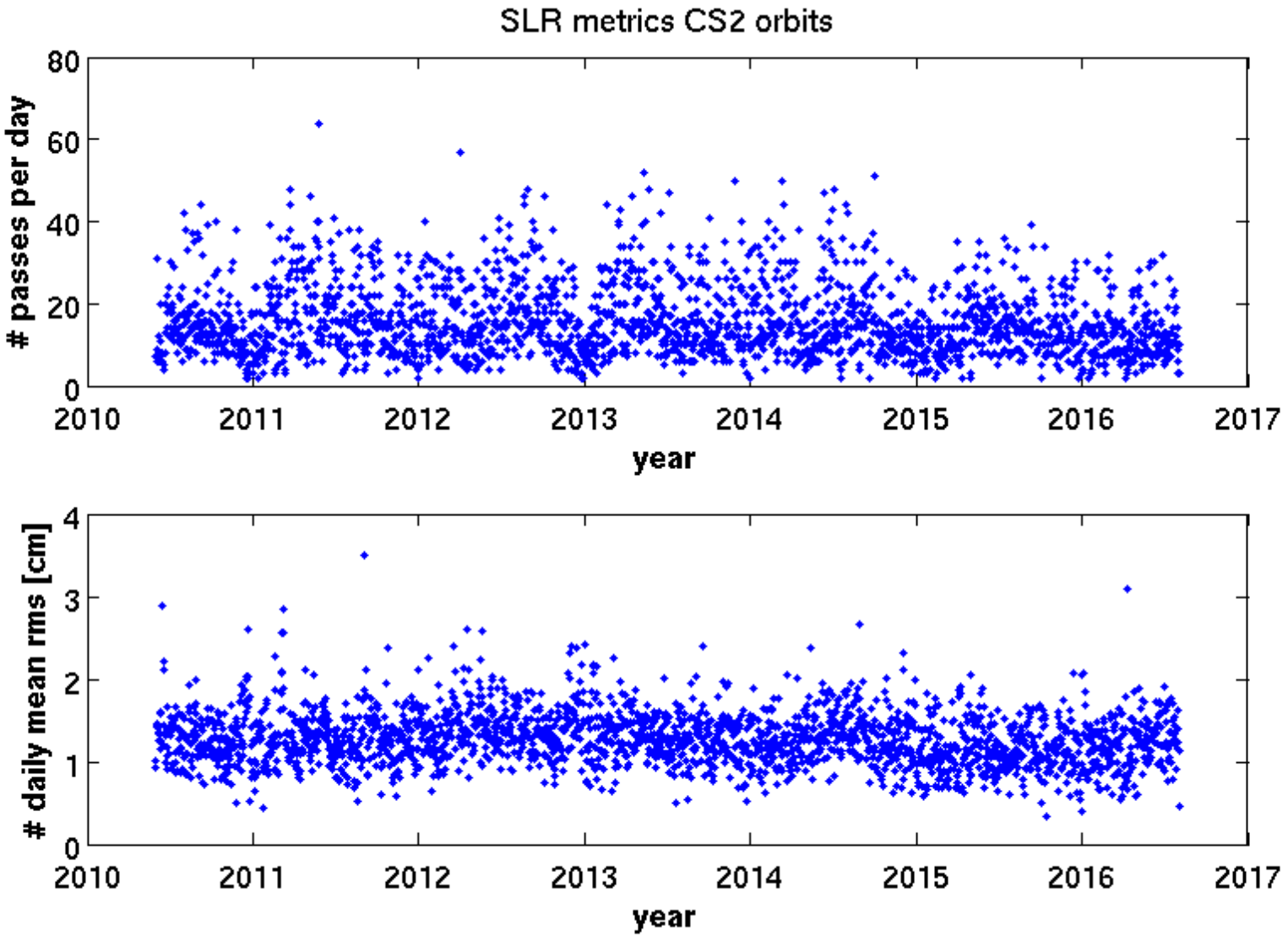
Overview of talk

- TU Delft involvement: validation/calibration within the CryoSat-2 community
  - DORIS tracking data, 59 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, residuals
- Latest developments
  - Extend orbits up to 1-Aug-2016
  - Investigate DORIS residuals and investigate whether we can see anything related to Space Weather / South Atlantic Anomaly

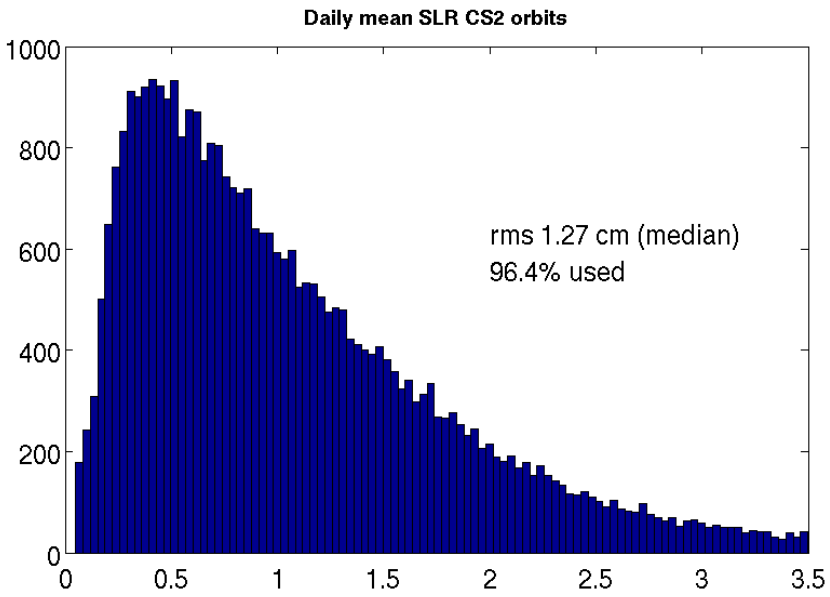
Models, tools etc

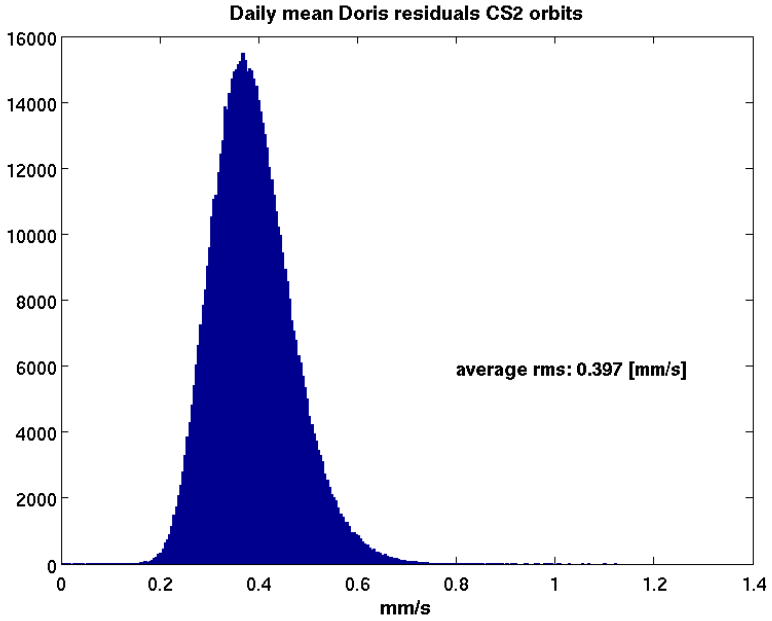
- GEODYN software from NASA/GSFC plus own tools.
- Station coordinates and Earth rotation parameters:
  - DORIS and SLR station coordinates in DPOD2008/SLRF2008
  - IERS data, polar motion, length of day from Bulletin B
- Satellite Dynamics
  - EIGEN5c gravity model, third body gravity etc
  - Temporal gravity from GRACE to degree and order 20
  - FES2004 ocean load tides
  - Frequency offsets and tropospheric biases estimated by pass
- Spacecraft specific models
  - Panel model, antenna offsets, LRA offsets, from IDS
  - Satellite attitude reconstructed from star camera quaternions
  - ftp://dutlru2.lr.tudelft.nl/pub/ejo/cryosat2/quaternion/
  - Emprical accelerations (6h), Drag (3h), SRP model calibration

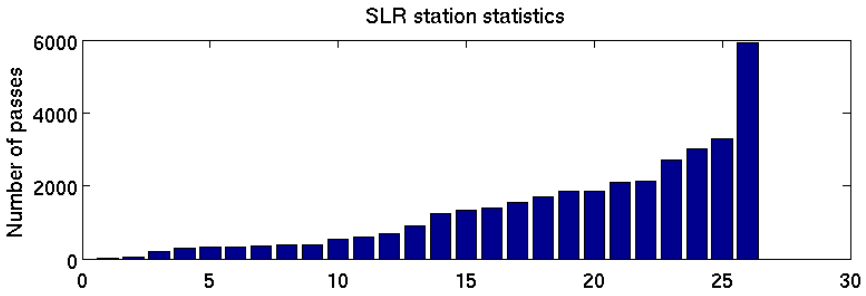

DORIS pass statistics CS2 orbits
passes per day
800
600
400
200
0
2010
2011
2012
2013
2014
2015
2016
2017
year
daily mean rms [mm/s]
0.39 mm/s
0.4
0.35
2010
2011
2012
2013
2014
2015
2016
2017
year

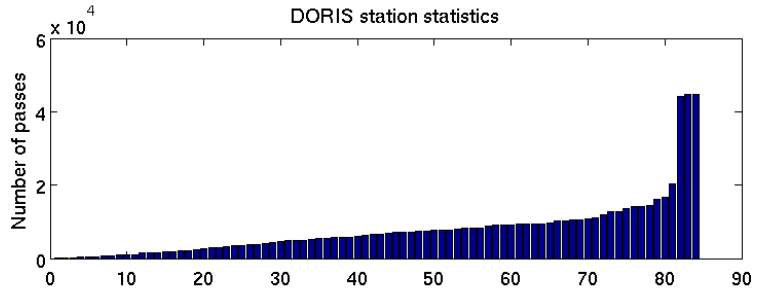


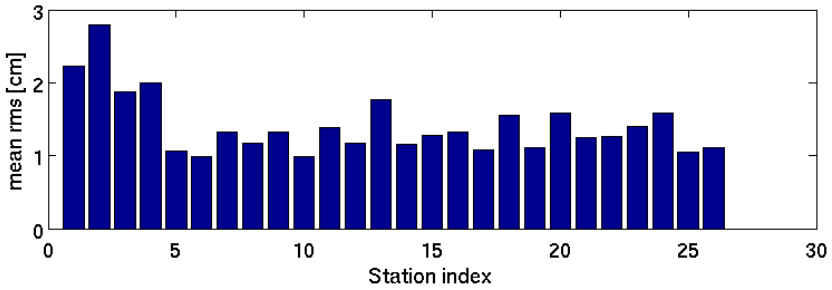
SLR: residual of fit consistent at 1.27 cm rms (median). Low weight wrt DORIS, independently it yields ≈4 cm orbits radially,

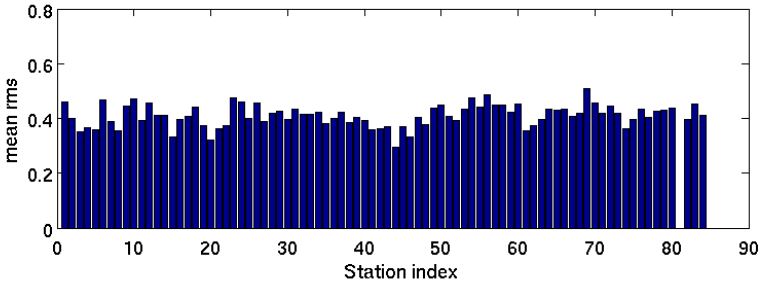

Daily mean SLR CS2 orbits
rms 1.27 cm (median)
96.4% used

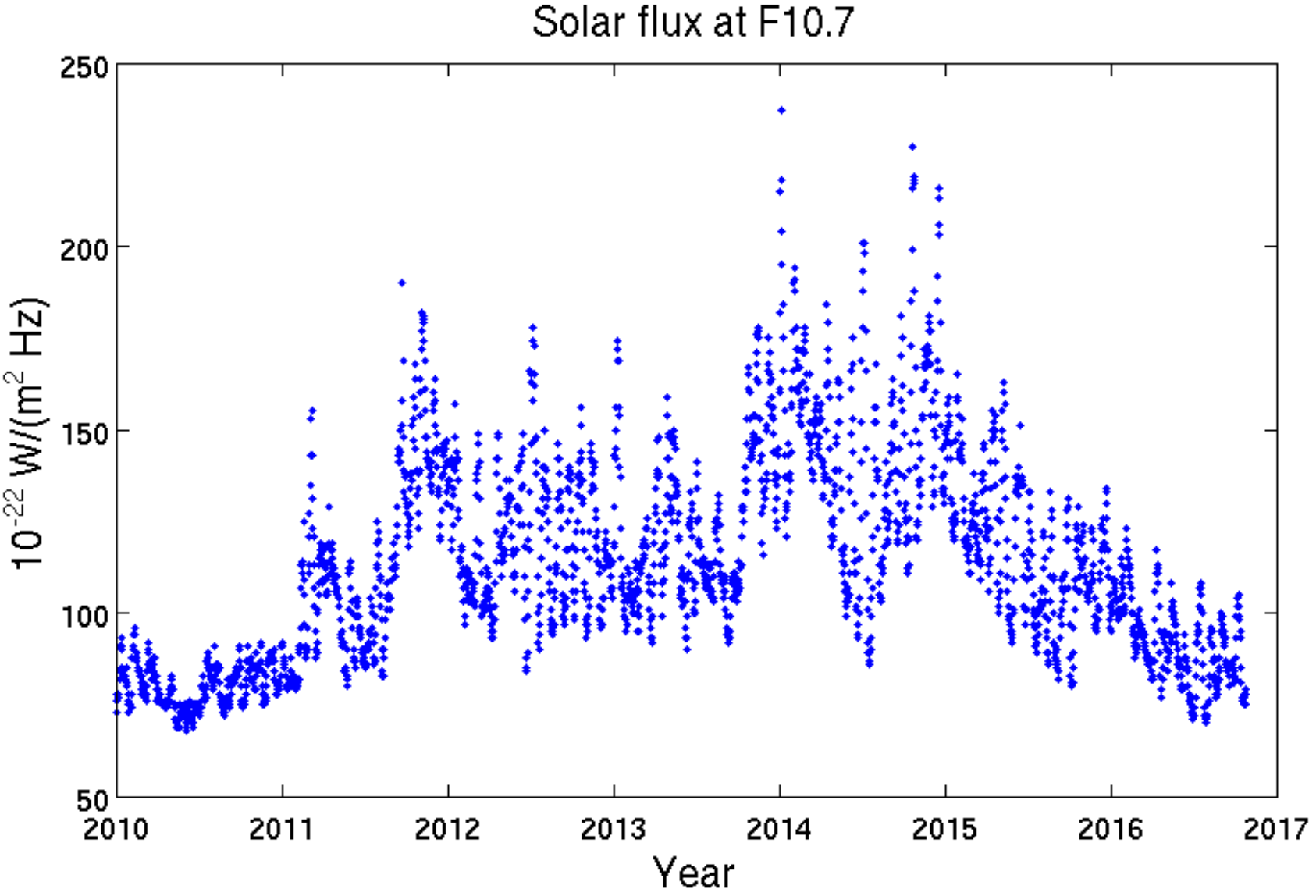

Daily mean Doris residuals CS2 orbits
average rms: 0.397 [mm/s]
mm/s

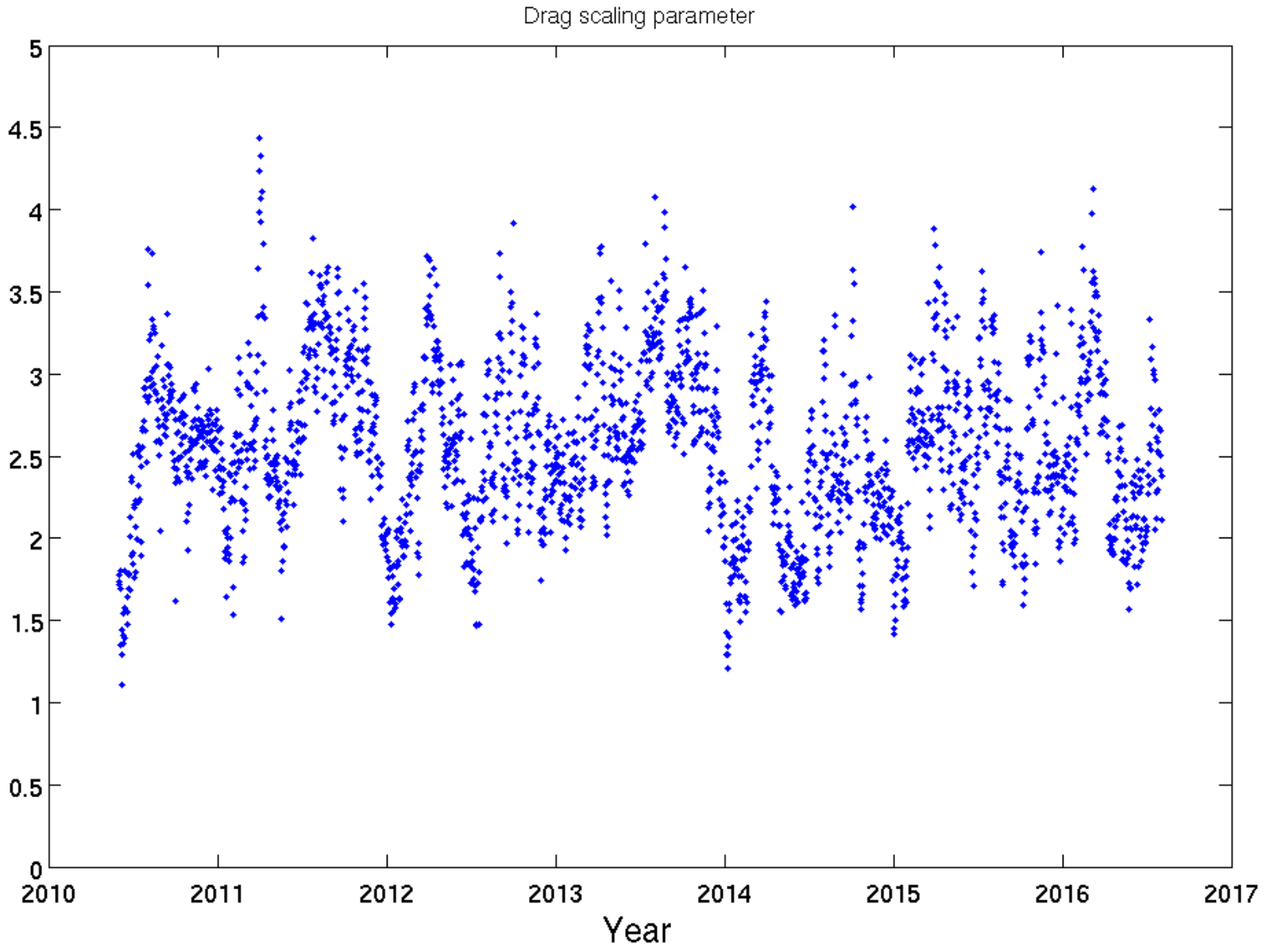

SLR station statistics
Number of passes


DORIS station statistics
x 10^4
Number of passes

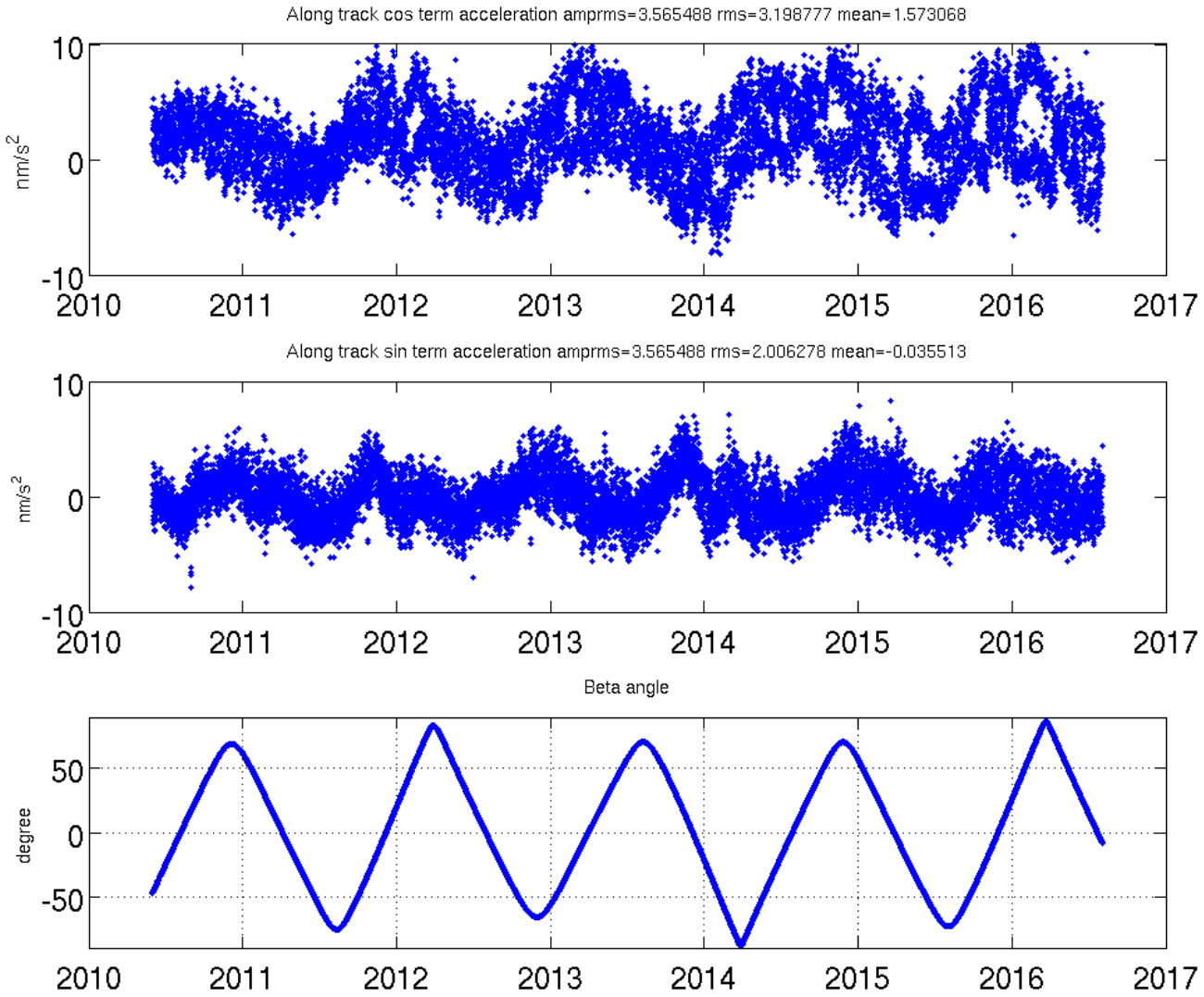

mean rms [cm]
Station index


mean rms
Station index


Solar flux at F10.7
250
200
150
100
50
10^{-22} W//(m^2 Hz)
2010
2011
2012
2013
2014
2015
2016
2017
Year

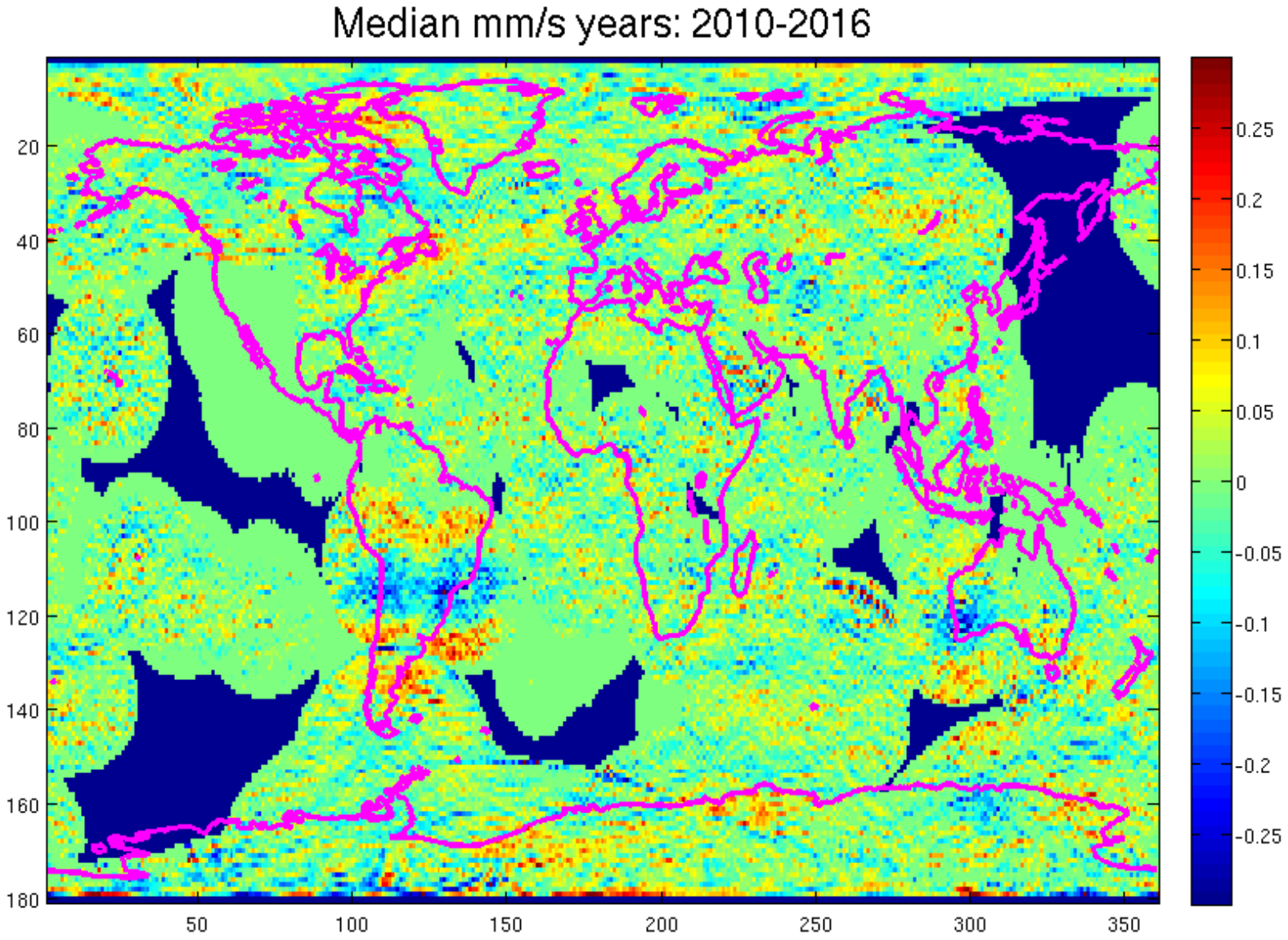

Drag scaling parameter
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
2010
2011
2012
2013
2014
2015
2016
2017
Year

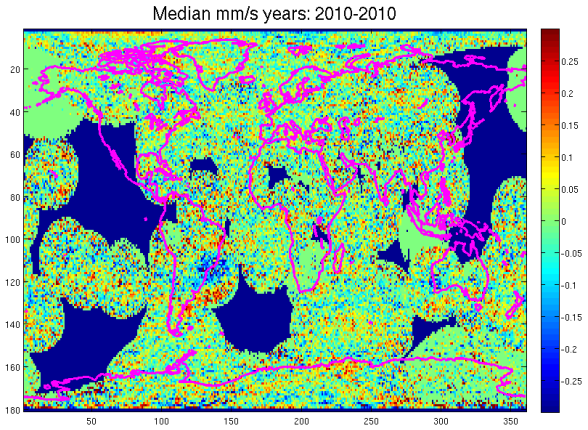
Empiricals 6 hour intervals, Drag: 3 hours

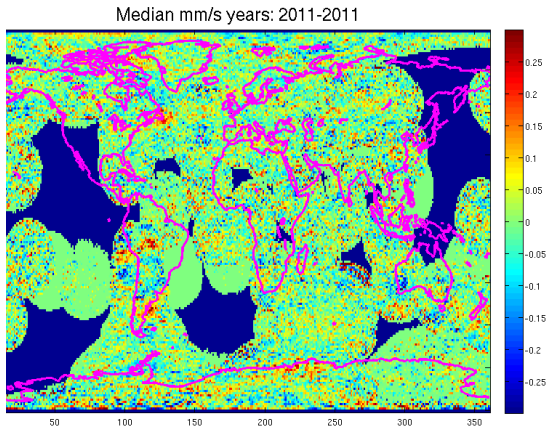


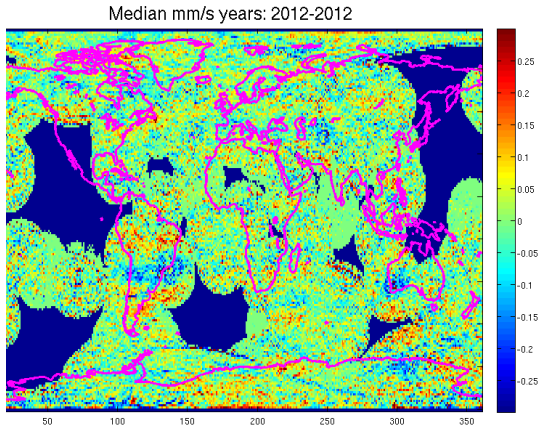
3.19 nm/s^2

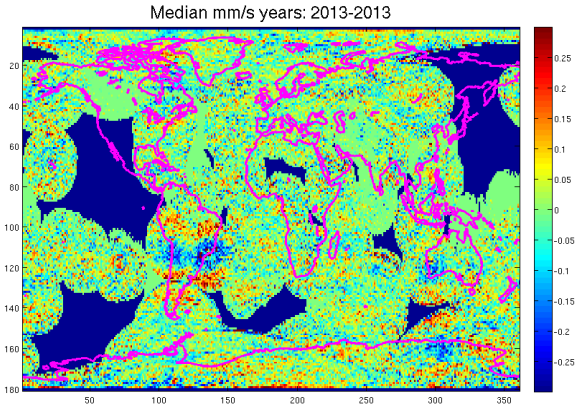
2.01 nm/s^2

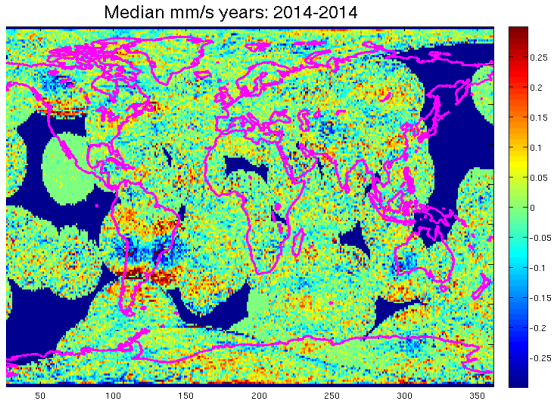

Median mm/s years: 2010-2016
20
40
60
80
100
120
140
160
180
50
100
150
200
250
300
350
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25

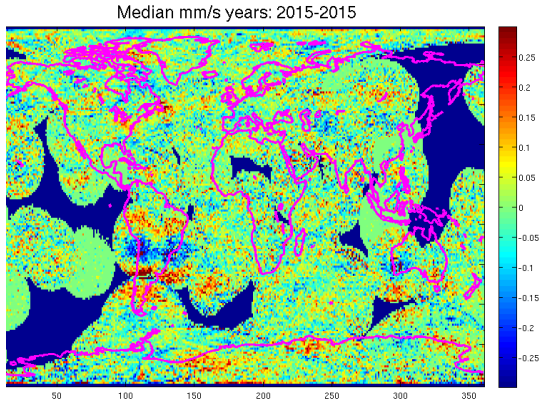


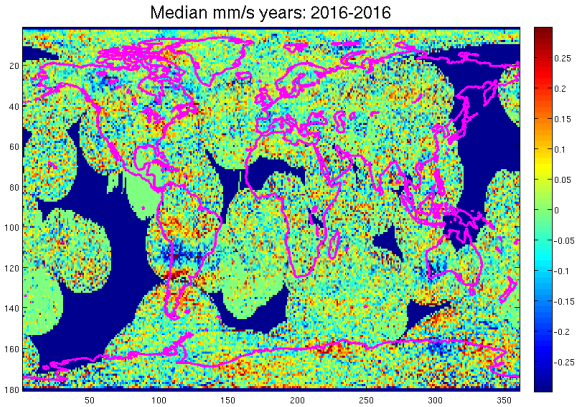










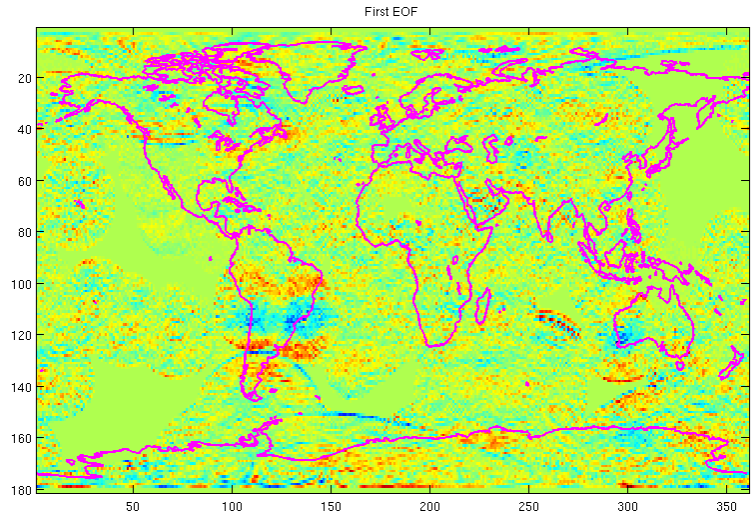


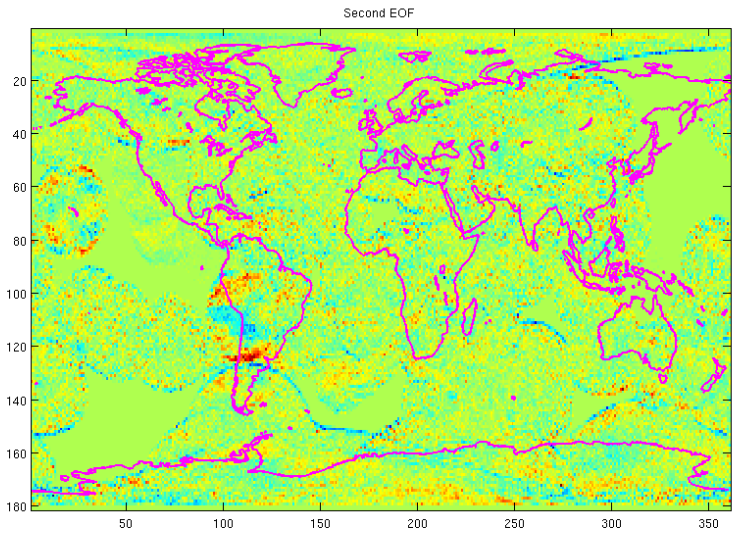
As far as possible: annual maps of the evolution of the DORIS tracking residual anomalies, April 2010 To Aug-2016

EOF mode 1

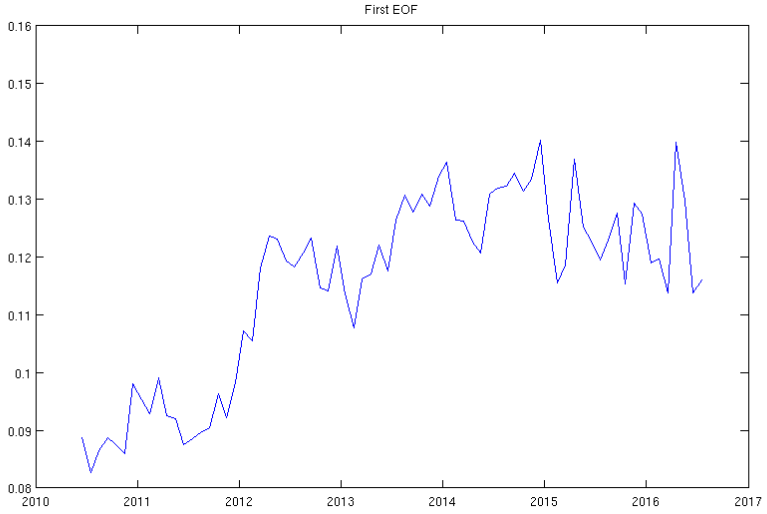
EOF mode 2

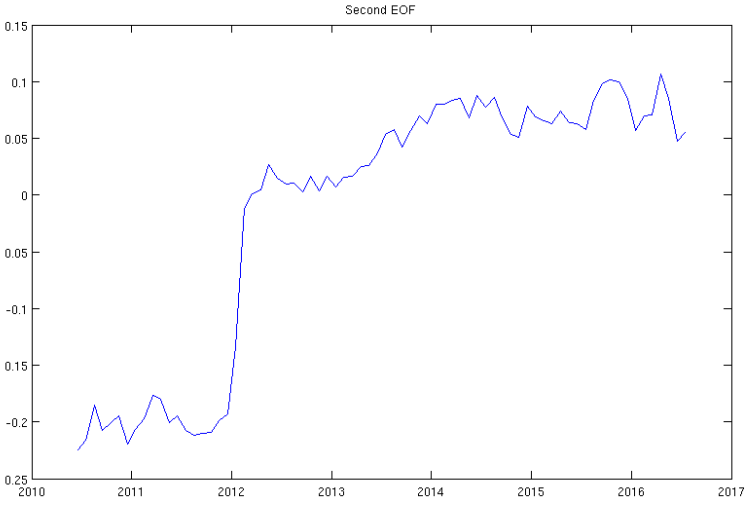
U





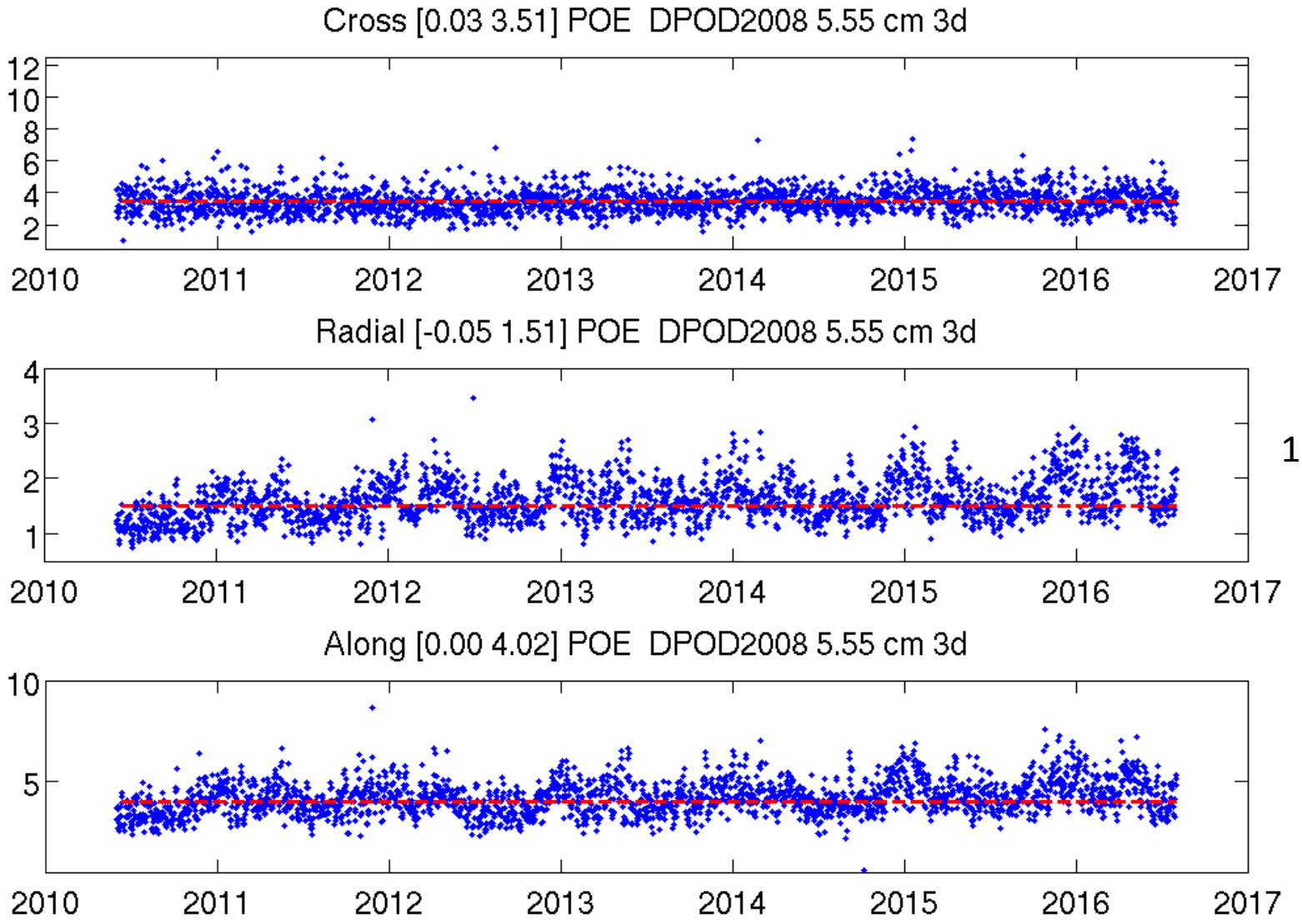
V





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 (discussion on predicted satellite maneuvers)
  - Delayed final solutions, converged product after a month, ie. when IERS bulletin B products have converged.


Cross [0.03 3.51] POE DPOD2008 5.55 cm 3d
12
10
8
6
4
2
2010
2011
2012
2013
2014
2015
2016
2017
Radial [-0.05 1.51] POE DPOD2008 5.55 cm 3d
4
3
2
1
2010
2011
2012
2013
2014
2015
2016
2017
Along [0.00 4.02] POE DPOD2008 5.55 cm 3d
10
5
2010
2011
2012
2013
2014
2015
2016
2017

1.51cm

Conclusions 1

- SLR: median of SLR residuals at 1.26 cm
- DORIS: consistent fits at 0.39 mm/s based on 10 s data
- The south atlantic anomaly area is visible in the CryoSat-2 residuals, shows up in the EOFs.
- There are systematic differences that can not be explained in the current parameterization with:
  - Frequency biases that we solve for by beacon
  - Tropospheric biases that we solve for by pass
  - Empirical acceleration modelling (6 hours) or drag (3 hours)
- The median of the residuals varies by ±0.1 mm/s in the South Atlantic Anomaly, effect is visible in median of annual or longer time scale binned residuals

Conclusions

- Empirical accelerations vary around 2 to 3 nm/s^2 in the along track direction for CryoSat-2.
- We compare against Navigator orbits, rapid sciences CNES MOE and the final solution POE orbits
- Radial consistency between 1.51 cm wrt POE, 1.63 cm wrt to the MOE
- The real-time DIODE Navigator data has been improved, since 2012.6 we see a radial consistency 3.45 cm, before that time it was 8.95 cm