Status of Precise Orbit Determination at Cryosat's first birthday

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Analysis Working Group 23-24 May 2011 Paris France

Precision orbit determination

- GEODYN software from NASA GSFC plus own tools.
- DORIS and SLR station coordinates are in two coordinate systems: DPOD2005 or ITRF2008
- IERS standards implemented
- EIGEN5c gravity model
- FES2004 ocean load tides
- Panel model, antenna offsets, LRA offsets, provided by ESA
- Attitude model derived from star camera quaternions

Precision orbit determination

- POD needs an initial state-vector, there are three options:
  - which we acquire from DORIS navigator orbits.
  - as a backup we can use NORAD TLEs.
  - generate our own initial state vectors from overlaps
- DORIS/IDS: 10s range rate exchange format 2.2 data, ILRS SLR data acquired from CDDIS.
- General accelerations at 1 cycle per orbit in cross/along track direction at daily time steps,
- Cd estimated as 3 hourly constants,
- Cr=0.92 estimated from a reference run.
- DORIS ground beacon frequency offsets and tropospheric delay are estimated, for a few ILRS stations we estimate timing and range biases, also: SLR data has low weight compared to DORIS.
- A 10 degree elevation cut-off mask is used,
- Analyzed window is 1-jun-2010 till 21-apr-2011

Cryosat Attitude modelling

- For POD we need an attitude law of the spacecraft, the CS2 attitude law is externally provided by means of a series of smoothed quaternions
- Star tracker quaternion data as CS_OPER_STR[1-3]ATT*.tgz files are downloaded from the CALVAL server
- Star-tracker quaternions are transformed to spacecraft fixed quaternions, analysis with navigator or MOE orbit yields the required "pitch roll and yaw" reconstruction of CS2
- Compression procedure generates smoothed attitude model (old approach). The new approach is simply a lookup table, we only concentrate on 4 degree yaw oscillation
- Smoothed quaternions for POD are reconstructed from this model
- We avoid all situations where CS2 deviates from a nominal yaw steering.

Maneuvers

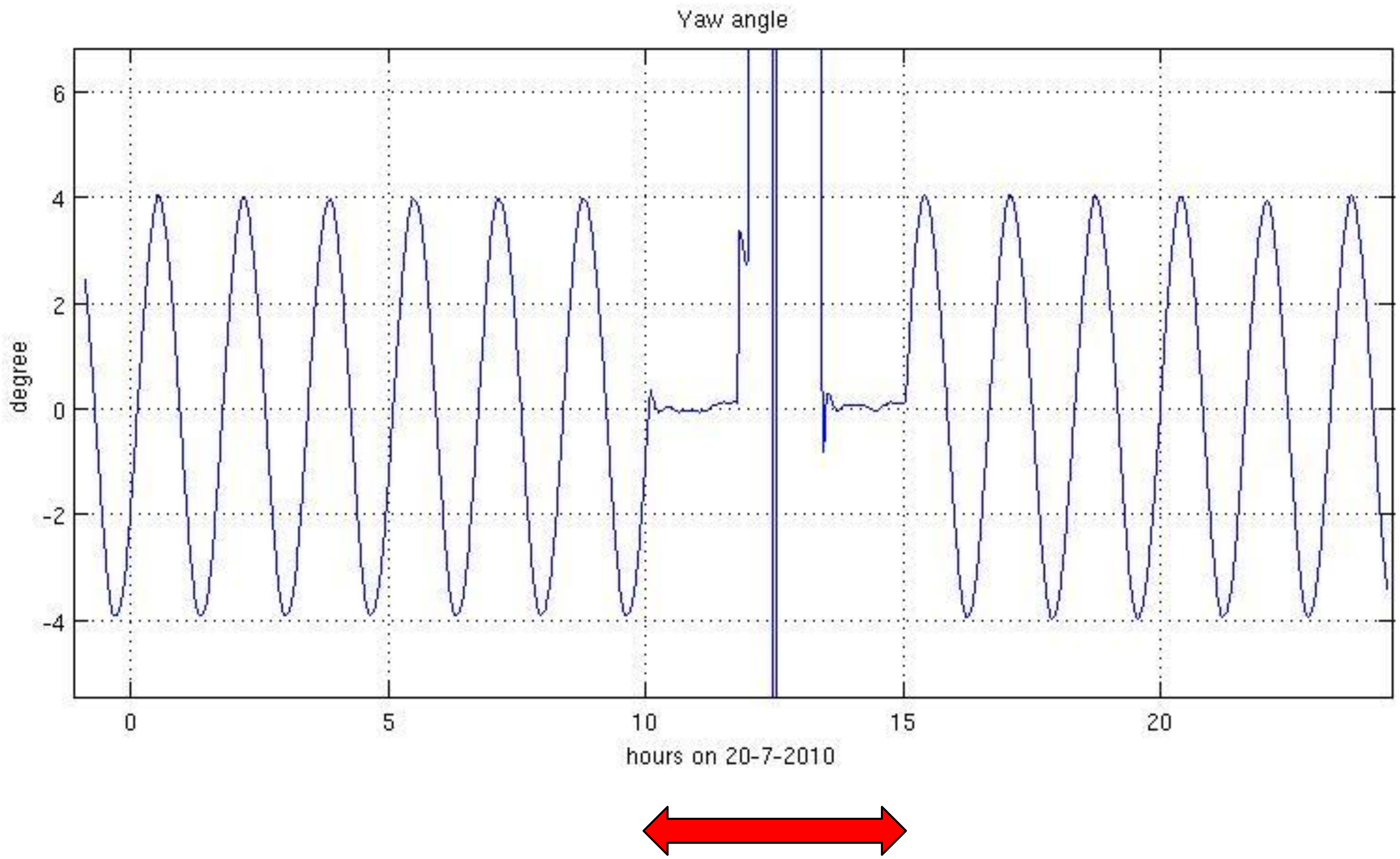
- Before 1-jun-2010 there were many maneuvers, and we made no attempt to compute orbits for this period

- In 2010 maneuvers on 15-6, 18-6, 20-7, 2-10, 28-10 and 16-12
- In 2011 maneuvers on 21-1 and 11-3, S/C anomaly 27-1, 11-3 and 14-4

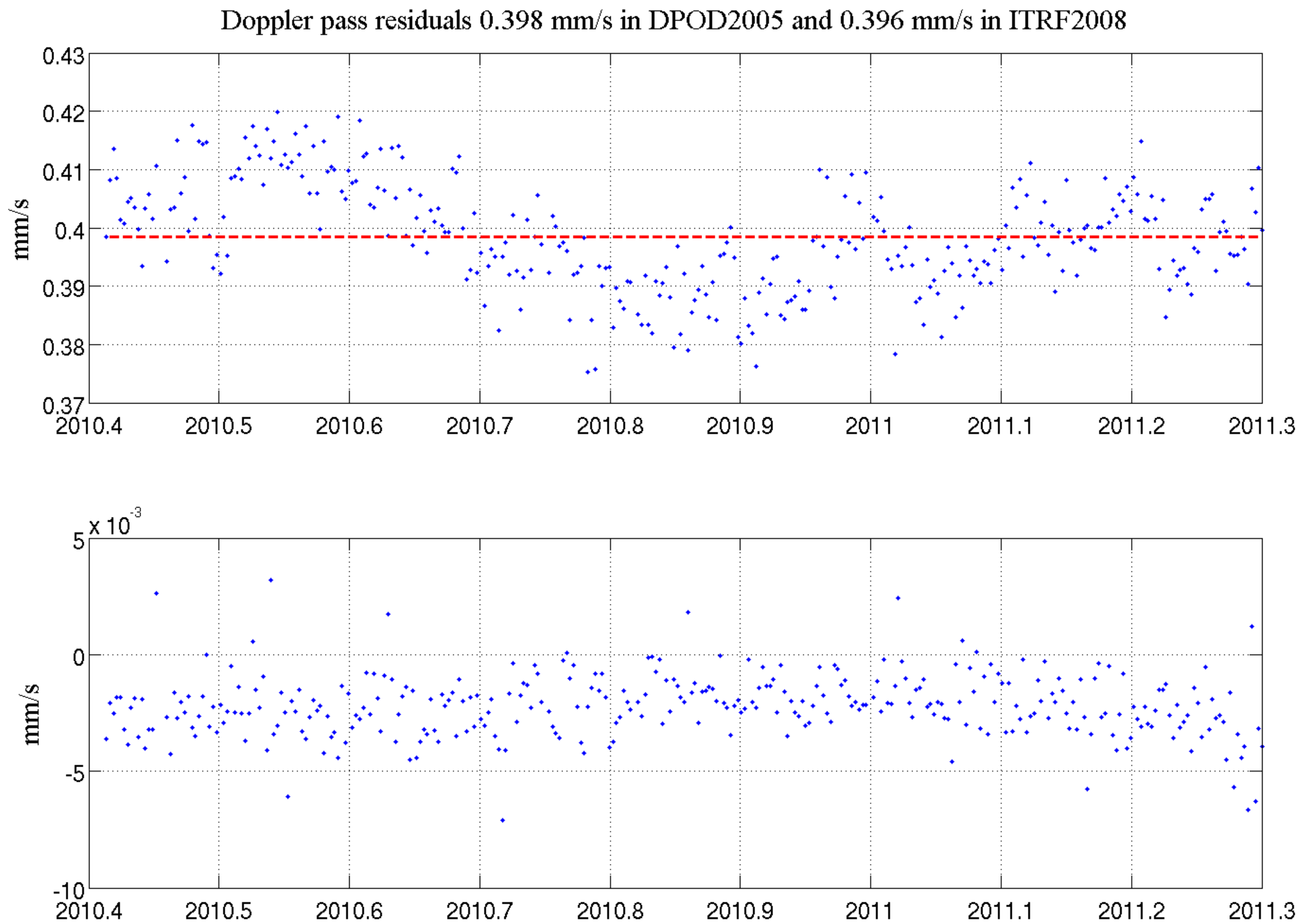
- Two options:
  - Integrate through maneuvers, experience with ERS-1/2 etc showed that this works when the maneuvers are short
  - Avoid maneuvers, wait till the nominal attitude law is re-established

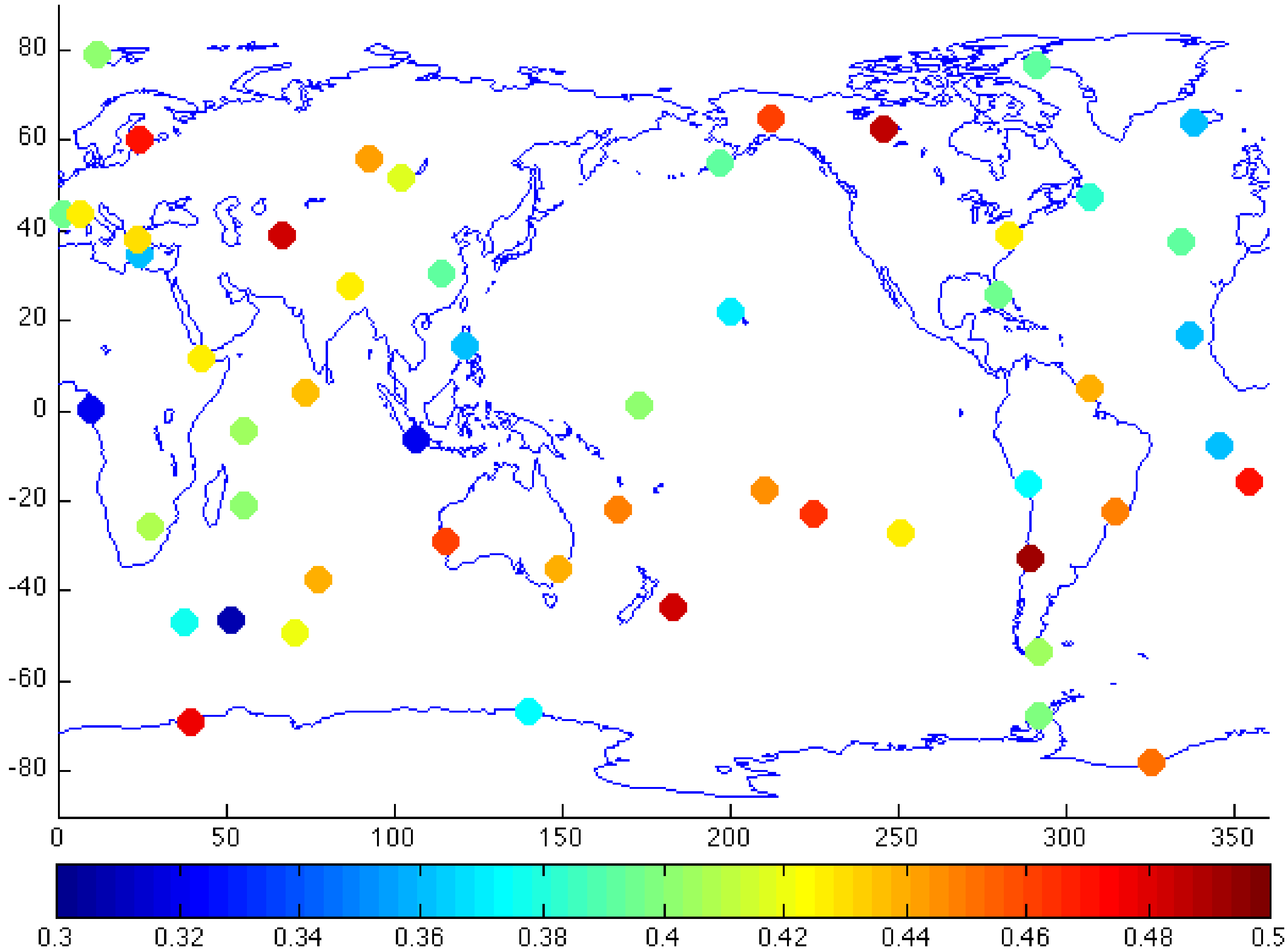
- For CS2 we think that the second option is a better choice, so we implemented this scheme for orbits generated since 1-jan-2011, and reprocessed all orbits since 1-jun-2010.

Maneuver with yaw flip 20-jul-2010

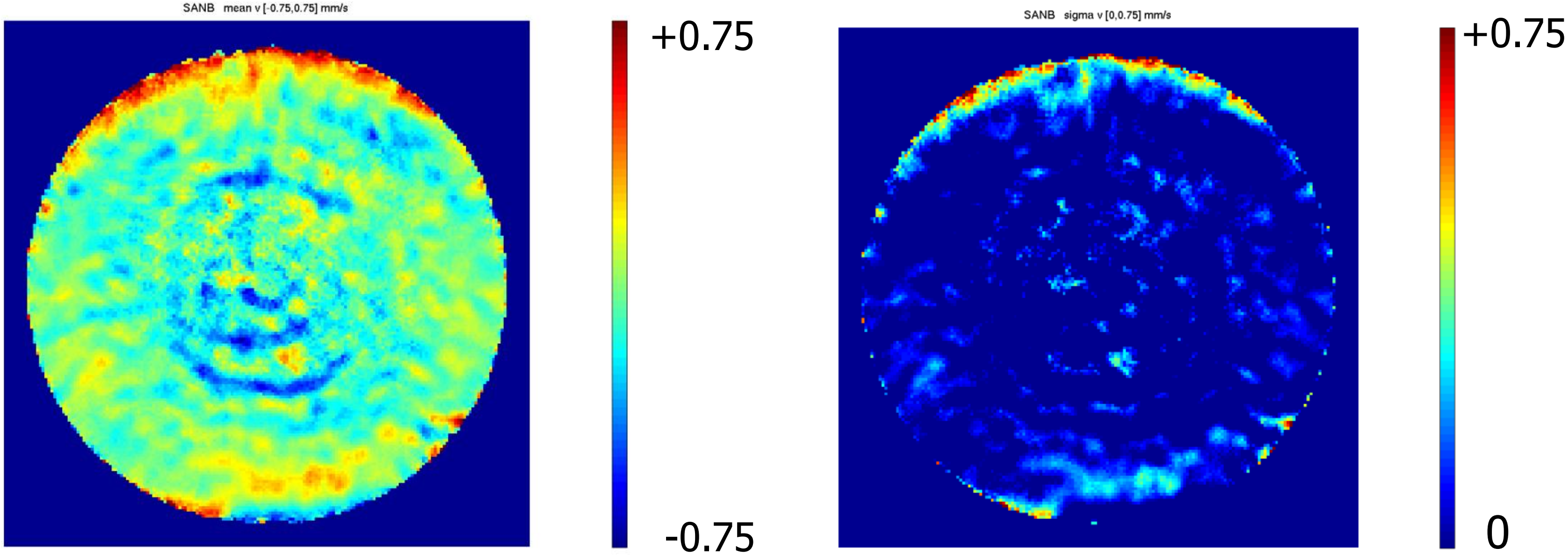


Maneuver without yaw flip on 28-oct-2010


Doppler pass residuals 0.398 mm/s in DPOD2005 and 0.396 mm/s in ITRF2008
0.43
0.42
0.41
0.4
0.39
0.38
0.37
mm/s
2010.4
2010.5
2010.6
2010.7
2010.8
2010.9
2011
2011.1
2011.2
2011.3
x 10^-3
5
0
-5
-10
mm/s

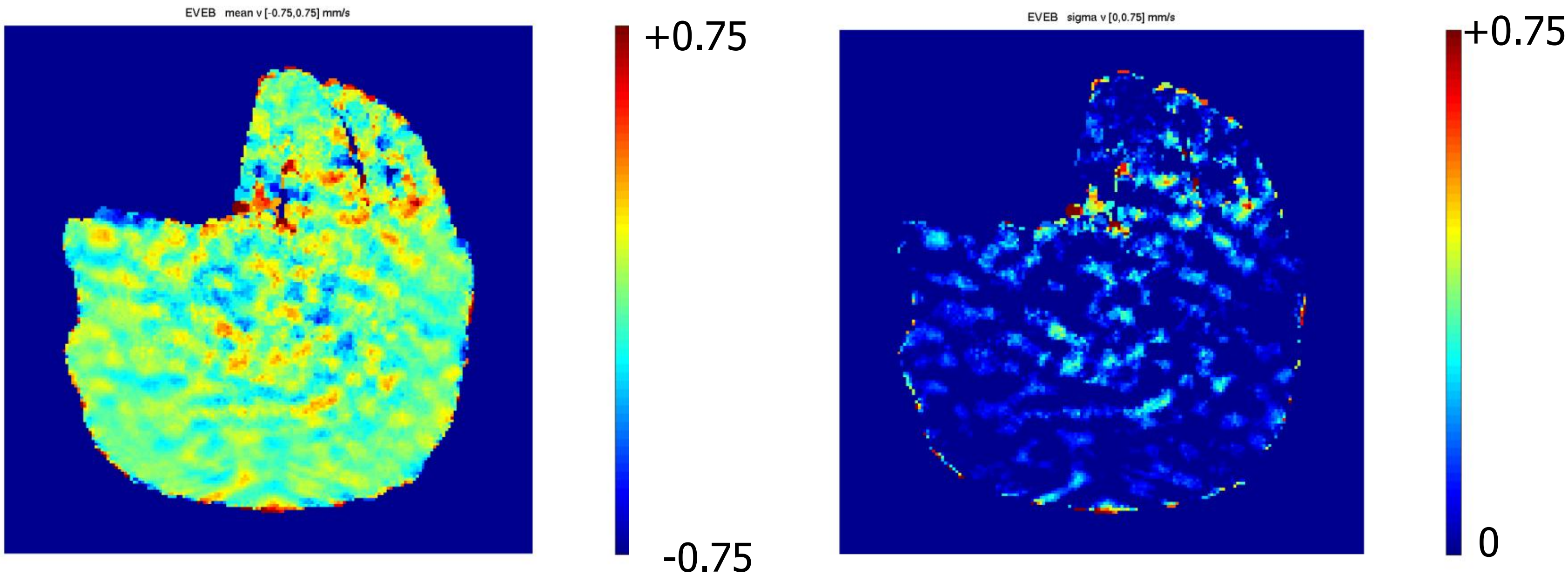

80
60
40
20
0
-20
-40
-60
-80
0
50
100
150
200
250
300
350
0.3
0.32
0.34
0.36
0.38
0.4
0.42
0.44
0.46
0.48
0.5

sanb



SANB mean v [-0.75,0.75] mm/s
+0.75
-0.75
SANB sigma v [0,0.75] mm/s
+0.75
0

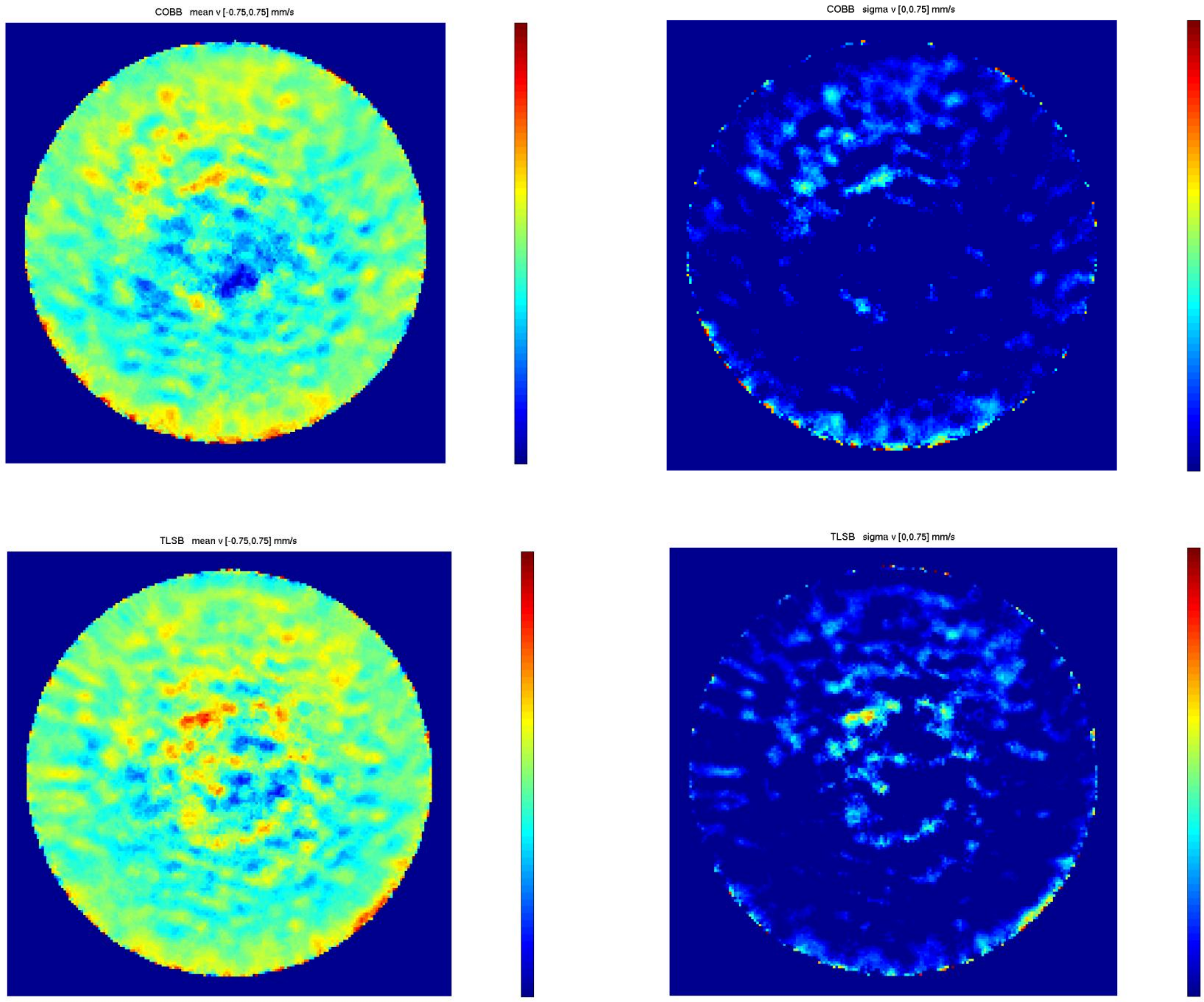
eveb



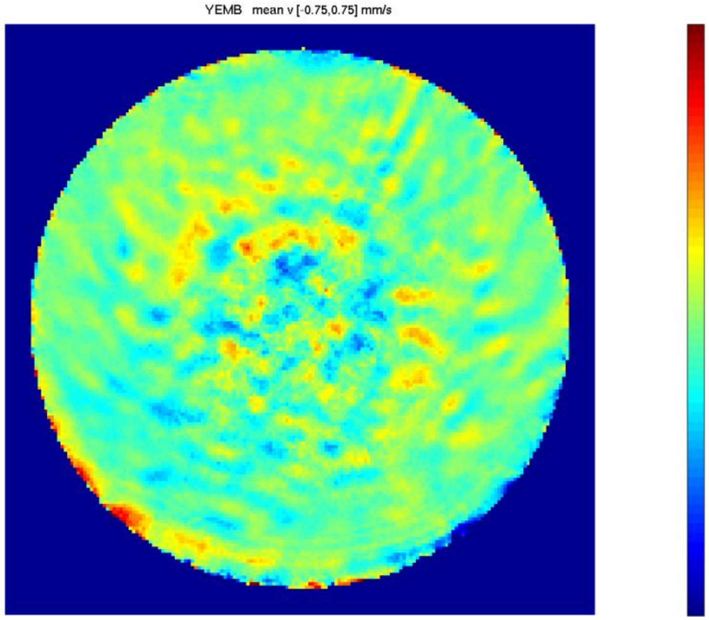
EVEB mean v [-0.75,0.75] mm/s
+0.75
-0.75
EVEB sigma v [0,0.75] mm/s
+0.75
0

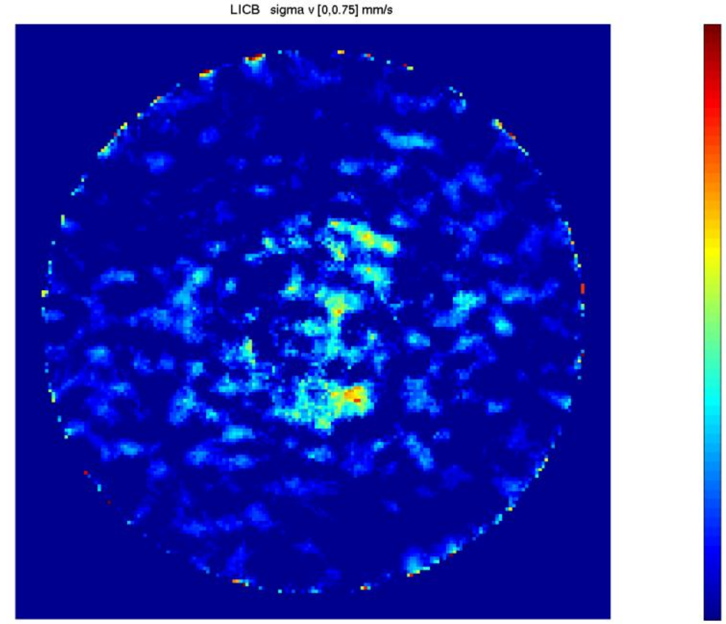
cobb

tlsb

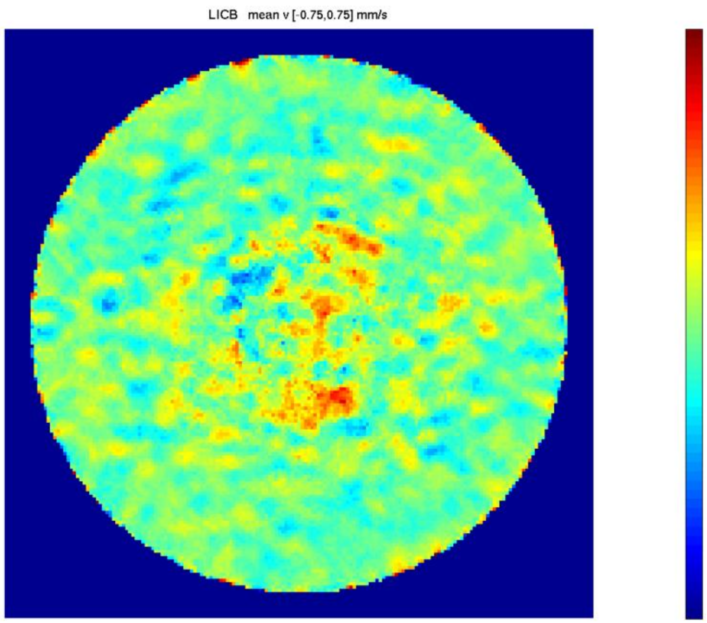

COBB mean v [-0.75,0.75] mm/s
COBB sigma v [0,0.75] mm/s
TLSB mean v [-0.75,0.75] mm/s
TLSB sigma v [0,0.75] mm/s

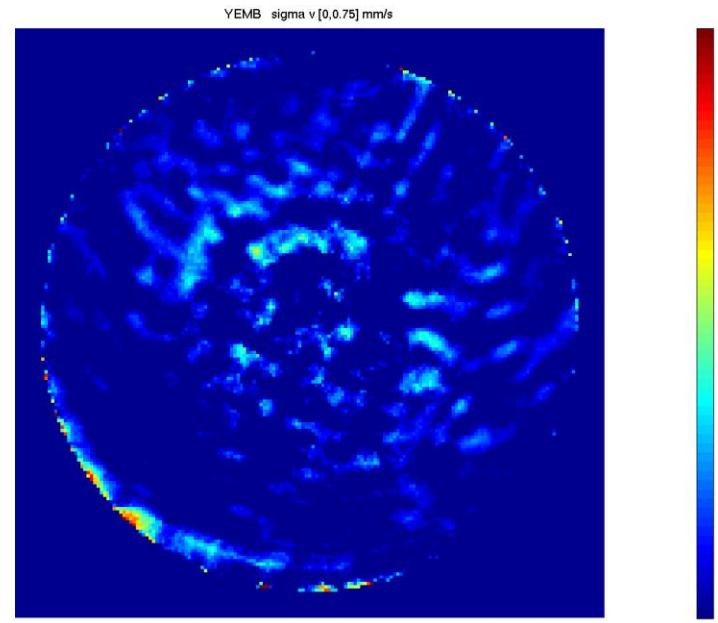
yemb


YEMB mean v [-0.75,0.75] mm/s

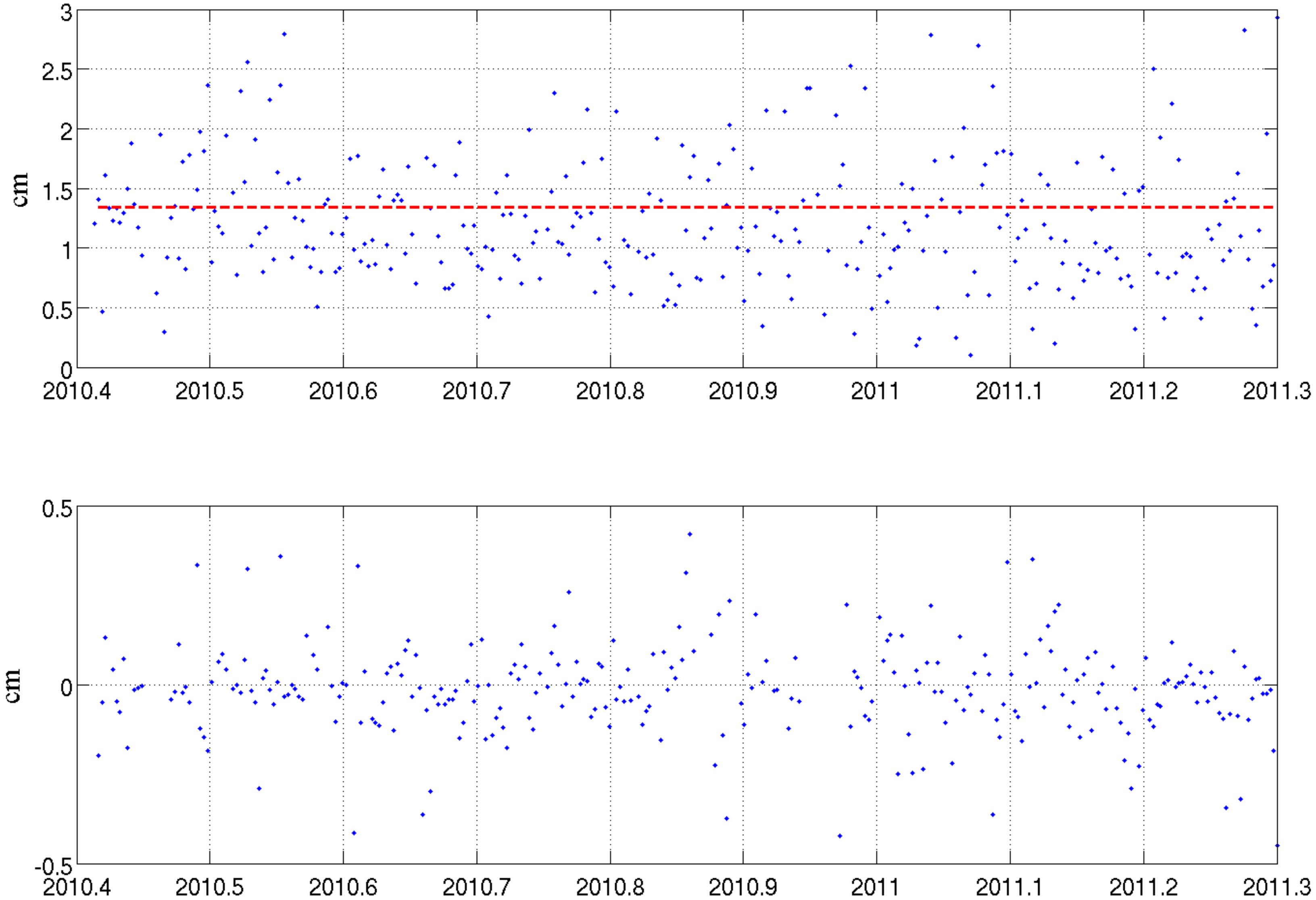

LICB sigma v [0,0.75] mm/s

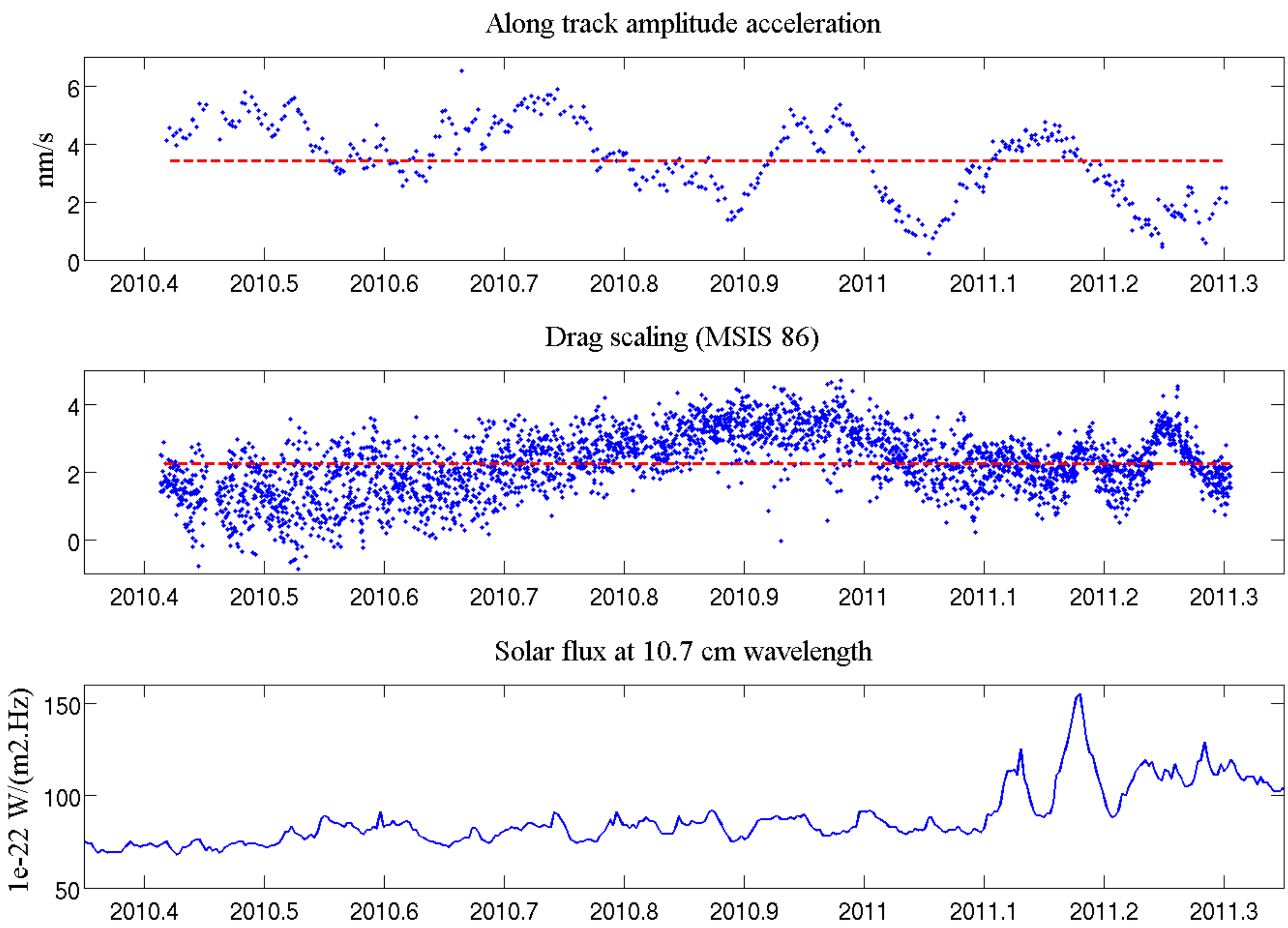
licb


LICB mean v [-0.75,0.75] mm/s


YEMB sigma v [0,0.75] mm/s

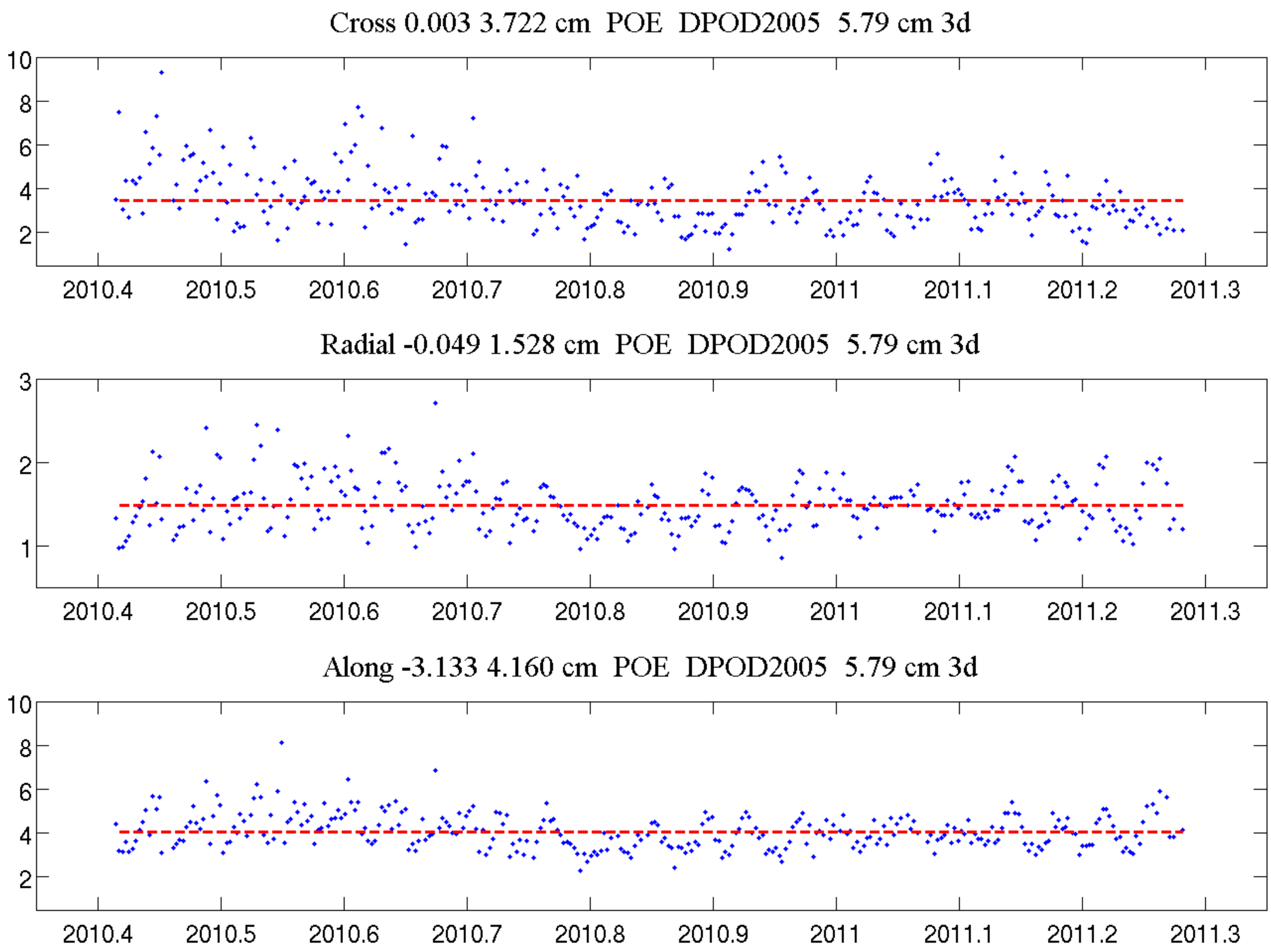
SLR pass residuals 1.343 cm in DPOD2005 and 1.435 cm in ITRF2008



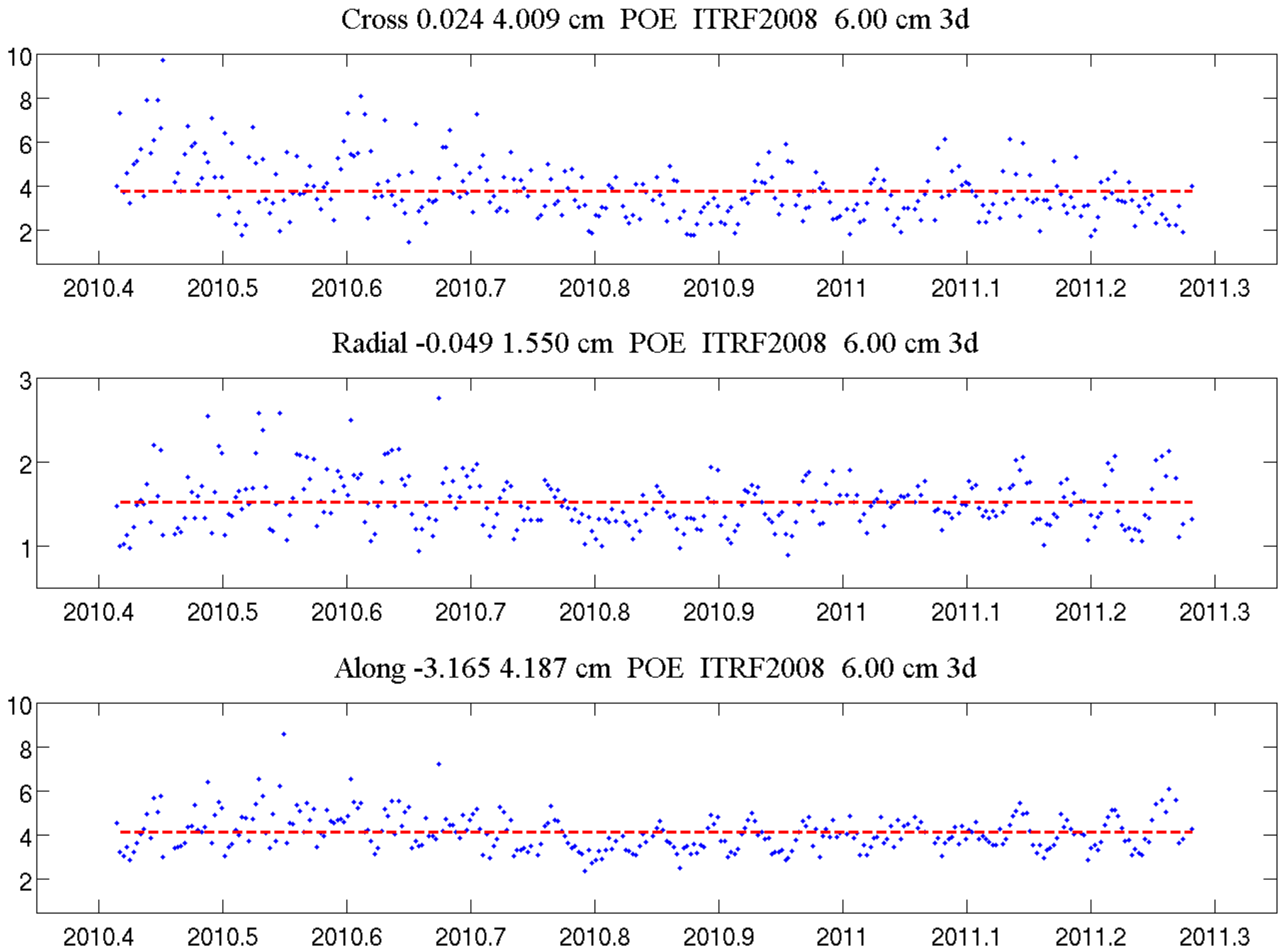

Along track amplitude acceleration
nm/s
Drag scaling (MSIS 86)
Solar flux at 10.7 cm wavelength
1e-22 W/(m2.Hz)
2010.4
2010.5
2010.6
2010.7
2010.8
2010.9
2011
2011.1
2011.2
2011.3

Comparison to external orbits

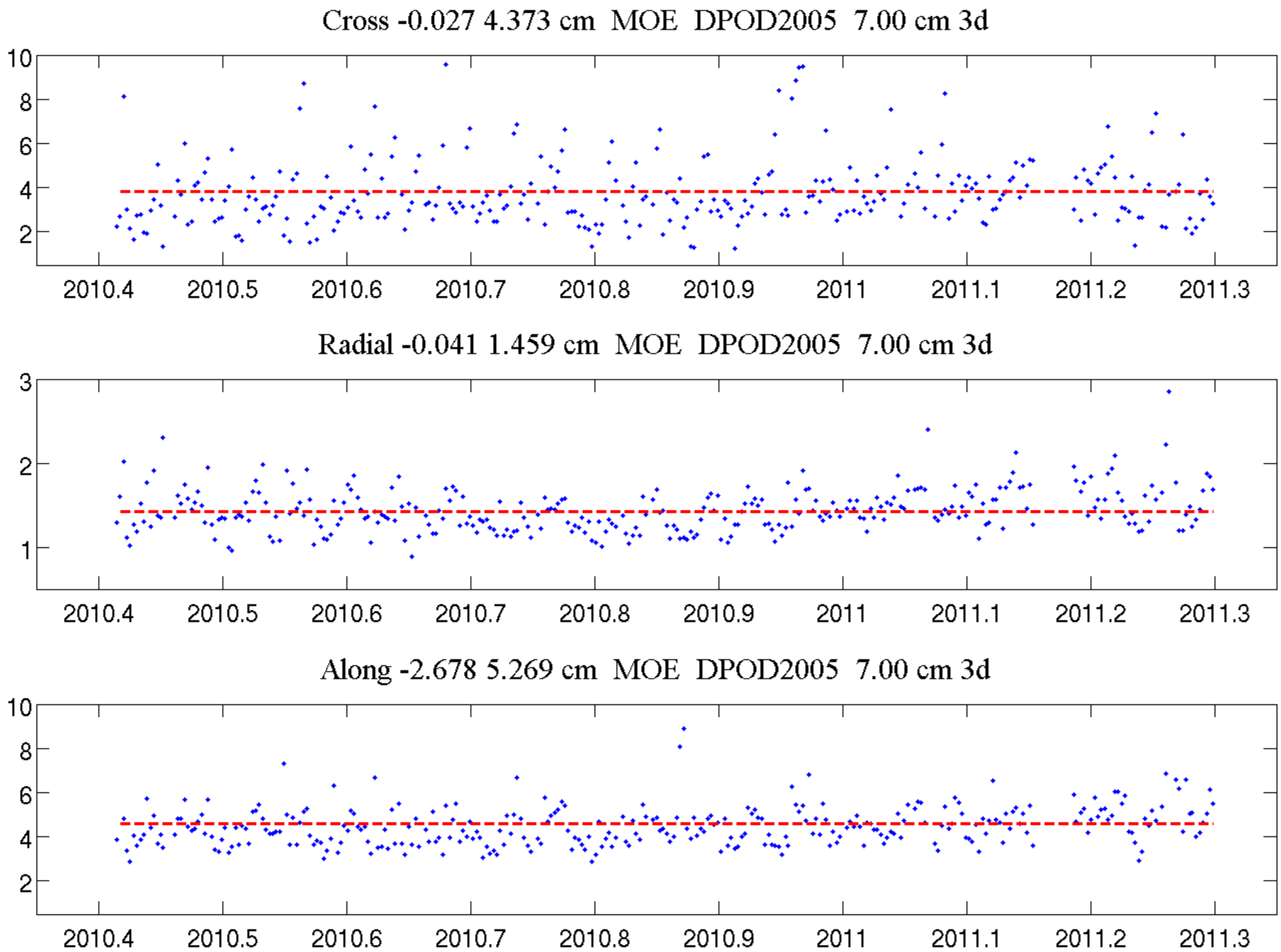
- Used in this study were:
  - The DORIS navigator orbit, comes directly from the spacecraft
  - CNES MOE and POE orbits, MOE latency is like 1 day, POE latency is approximately 30 days.
- Differences between the “our” orbits and externally provided products are represented as radial differences, cross-track differences and along track differences. Radial differences are most relevant for CS2.
- At best we show the correspondence between various techniques obtained with the same data. But, if you did the same, the difference shouldn’t be there.

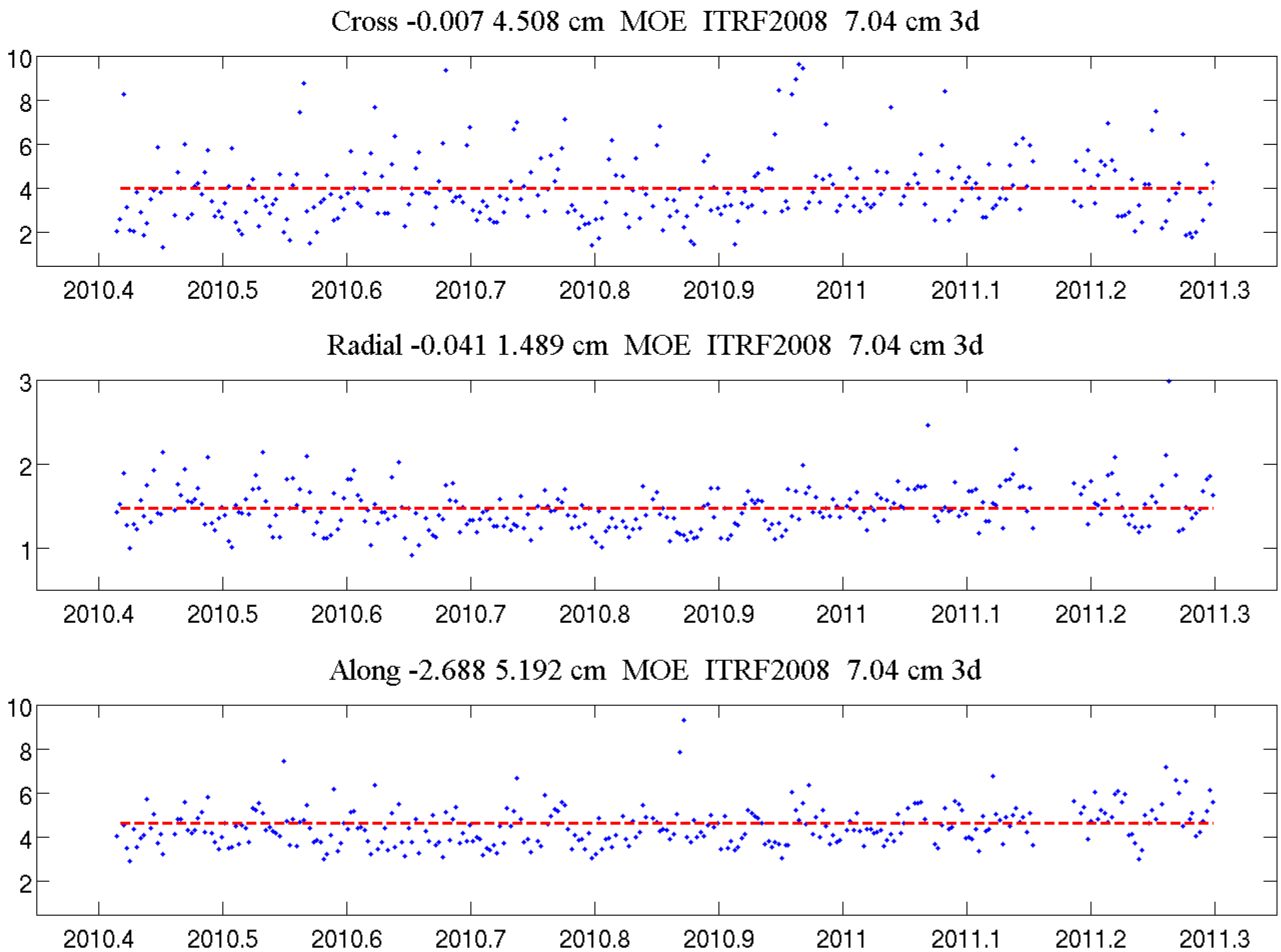


Cross 0.003 3.722 cm POE DPOD2005 5.79 cm 3d
Radial -0.049 1.528 cm POE DPOD2005 5.79 cm 3d
Along -3.133 4.160 cm POE DPOD2005 5.79 cm 3d
2010.4 2010.5 2010.6 2010.7 2010.8 2010.9 2011 2011.1 2011.2 2011.3



Cross 0.024 4.009 cm POE ITRF2008 6.00 cm 3d
10
8
6
4
2
2010.4
2010.5
2010.6
2010.7
2010.8
2010.9
2011
2011.1
2011.2
2011.3
Radial -0.049 1.550 cm POE ITRF2008 6.00 cm 3d
3
2
1
Along -3.165 4.187 cm POE ITRF2008 6.00 cm 3d


Cross -0.027 4.373 cm MOE DPOD2005 7.00 cm 3d
10
8
6
4
2
2010.4
2010.5
2010.6
2010.7
2010.8
2010.9
2011
2011.1
2011.2
2011.3
Radial -0.041 1.459 cm MOE DPOD2005 7.00 cm 3d
3
2
1
2010.4
2010.5
2010.6
2010.7
2010.8
2010.9
2011
2011.1
2011.2
2011.3
Along -2.678 5.269 cm MOE DPOD2005 7.00 cm 3d
10
8
6
4
2
2010.4
2010.5
2010.6
2010.7
2010.8
2010.9
2011
2011.1
2011.2
2011.3


Cross -0.007 4.508 cm MOE ITRF2008 7.04 cm 3d
10
8
6
4
2
2010.4 2010.5 2010.6 2010.7 2010.8 2010.9 2011 2011.1 2011.2 2011.3
Radial -0.041 1.489 cm MOE ITRF2008 7.04 cm 3d
3
2
1
2010.4 2010.5 2010.6 2010.7 2010.8 2010.9 2011 2011.1 2011.2 2011.3
Along -2.688 5.192 cm MOE ITRF2008 7.04 cm 3d
10
8
6
4
2
2010.4 2010.5 2010.6 2010.7 2010.8 2010.9 2011 2011.1 2011.2 2011.3

Discussion

- At the CS2 workshop on Feb 1-3 at ESRIN Frascati we showed orbits complete to the end of December, presently all our orbits are reprocessed up to 21-april-2011.

- Since Jan 2011 we noted that the reliability of the products on the ESA calval server has deteriorated. Some data is missing or incomplete. This is the case for the star trackers, the navigator orbit and the MOE orbit. It is an issue that we discuss with ESA.

- Processing on our side has improved, automation of various scripts to generate quaternion files, etc.

- Flux table update frequency improved (GFZ F10.7, NOAA Kp Ap)

Discussion and conclusions

- SLR fits on average 1.343 – 1.435 cm rms
- Doppler fits on average 0.396 – 0.398 mm/s
- Presently a radial difference of 1.46 – 1.55 cm rms shows up when we compare our solutions to the CNES orbits.
- The POE orbits are better than the MOE orbits, especially in 3D
- The MOE orbits are more rapidly available (delay is about 1 day), the POEs are available within approximately 6 weeks. There are some occasional mishaps in the MOE product near maneuvers.
- Navigator orbits are directly available, they show a cross-track difference of approximately 10 cm rms, radial: 9 cm rms, and along track: 13 cm rms. There are also larger systematic offsets.

Discussion and conclusions

- Latency of our orbit product depends on the update frequency of:
  - IERS EOP parameters and flux tables (GFZ: F10.7, NOAA: Kp and Ap)
  - DORIS 10s range change data from IDS

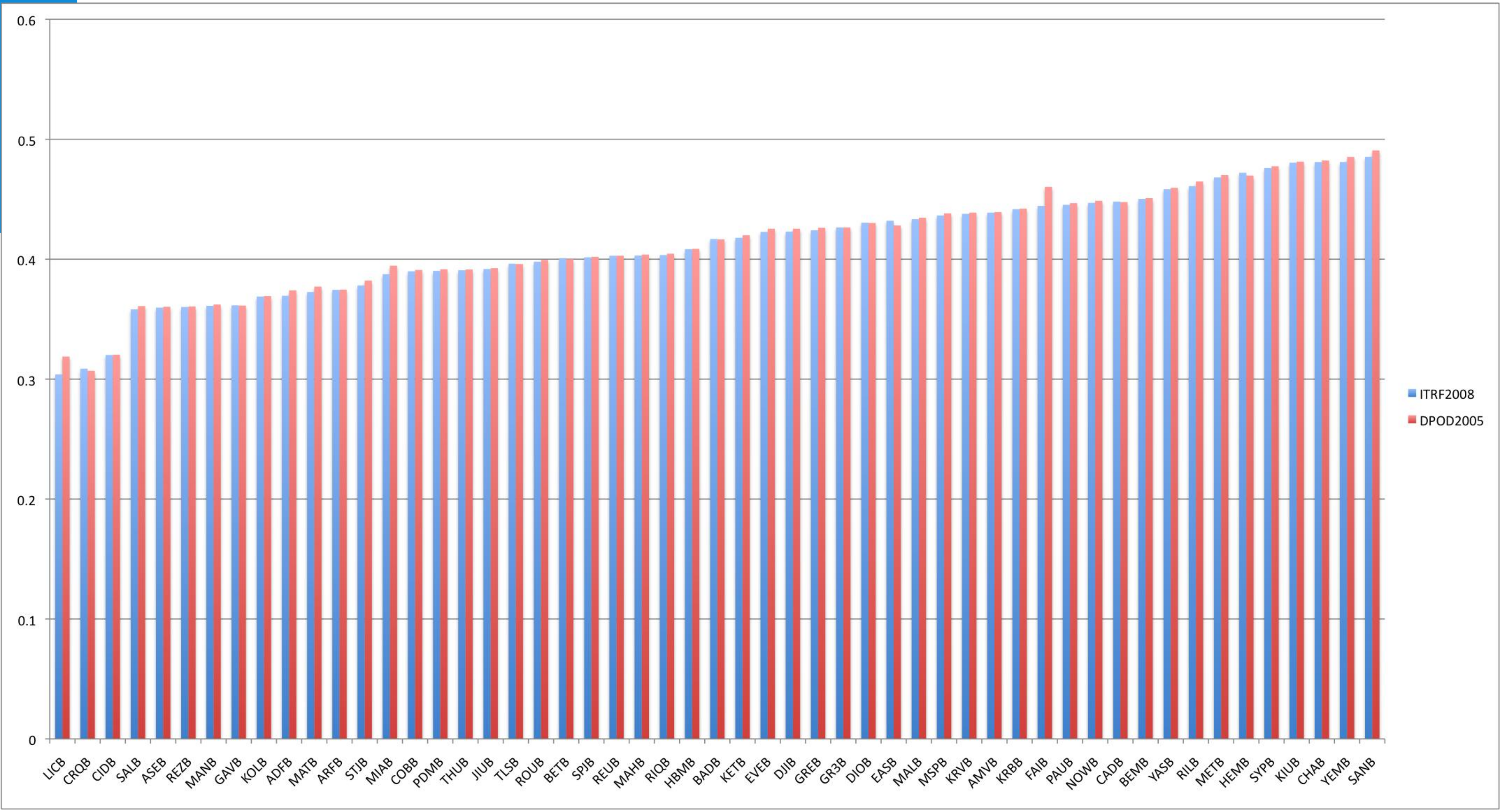
- Typically we are 1 month late, but it could be improved if needed, our group provides for instance rapid science orbits for GOCE.

- Orbit accuracy may depend on solar activity which could become worse when we go towards a solar maximum.

- Outlook:
  - Improvements in dynamic models, such as the drag model, and the radiation pressure model.
  - Implement beacon phase error maps
  - RINEX Doppler data and new SLR data format.

Back-up slides

DORIS residuals by station



SLR residuals by station