Impact of GNSS Orbit Modeling on Reference Frame Parameters

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Outline

Orbit modeling

- Every satellite method of space geodesy has to determine orbit parameters of the observed satellites when solving for global parameters of geophysical interest (geocenter, Earth rotation parameters, ...)

  $\longrightarrow$ Orbit modeling deficiencies map into parameters!
- Most important non-gravitational force: Solar radiation pressure (SRP). Causes orbital perturbations of $\sim$100 m after one revolution.
- A priori SRP modeling: E.g. ROCK models for GPS, or box-wing models
- Empirical SRP modeling: Estimate appropriate empirical accelerations. E.g. **ECOM**.

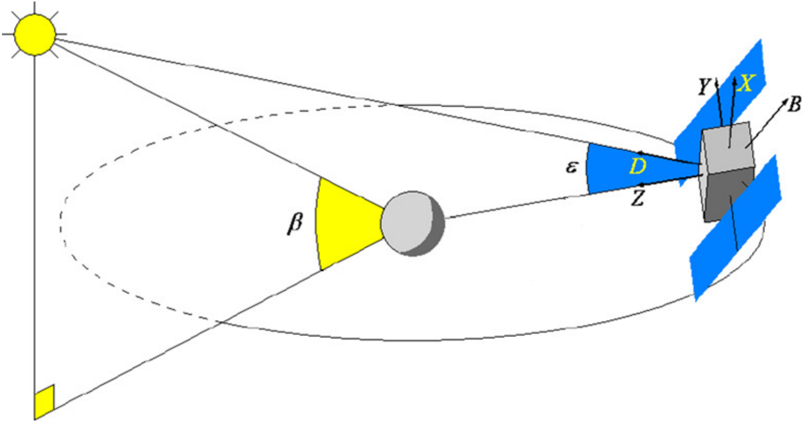
The ECOM

CODE: Center for Orbit Detrmination in Europe

Empirical CODE Orbit Model (ECOM, Beutler et al., 1994):

- Motivated by the lack of reliable satellite information and the concern that estimating a scaling factor for the ROCK models is not sufficient
- Decompose perturbing accelerations into three orthogonal directions suitable for SRP modeling

The ECOM (2)



The ECOM (3)

A priori model → $\vec{a}_0$

Argument of latitude → u

$$\vec{a} = \vec{a}_0 + D(u)\vec{e}_D + Y(u)\vec{e}_Y + B(u)\vec{e}_B \,,$$

The ECOM (3)

$$\vec{a} = \vec{a}_0 + D(u)\vec{e}_D + Y(u)\vec{e}_Y + B(u)\vec{e}_B \,,$$

$$\begin{aligned} D(u) &= D_0 + D_c \cos u + D_s \sin u \\ Y(u) &= Y_0 + Y_c \cos u + Y_s \sin u \\ B(u) &= B_0 + B_c \cos u + B_s \sin u \,, \end{aligned}$$

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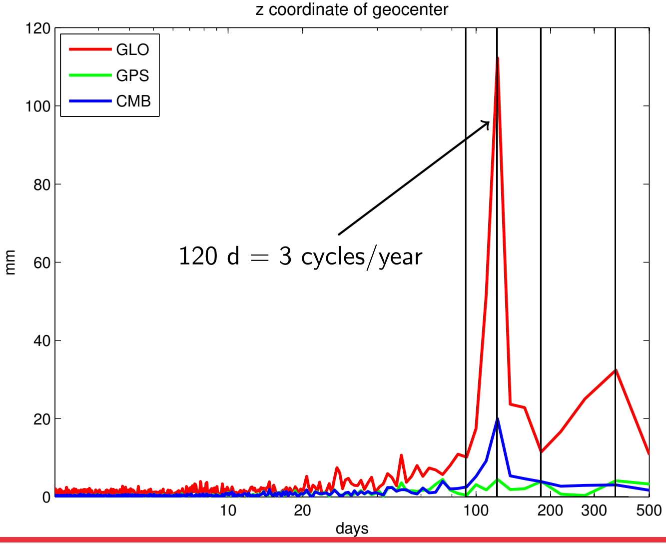
$$\begin{aligned} D(u) &= D_0 \\ Y(u) &= Y_0 \\ B(u) &= B_0 + B_c \cos u + B_s \sin u \,, \end{aligned}$$

5-parameter ECOM, widely and successfully used for the last 20 years.
At CODE since mid 2013 without a priori model $\vec{a}_0$.

Problems with the ECOM

Traditional ECOM shows deficiencies when applied to GLONASS:



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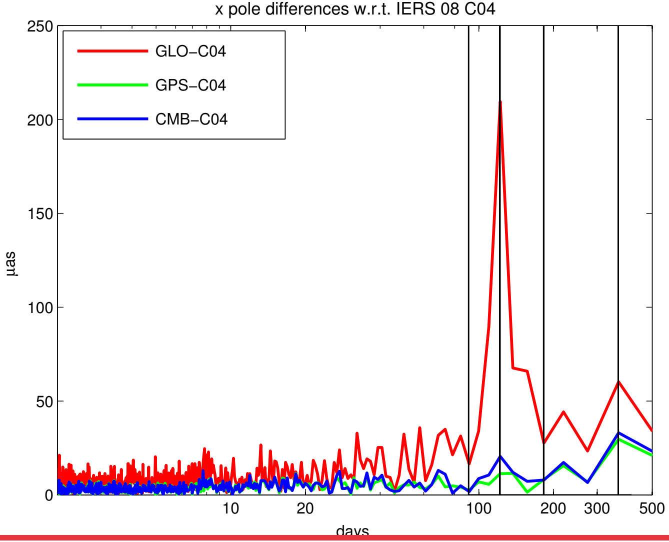
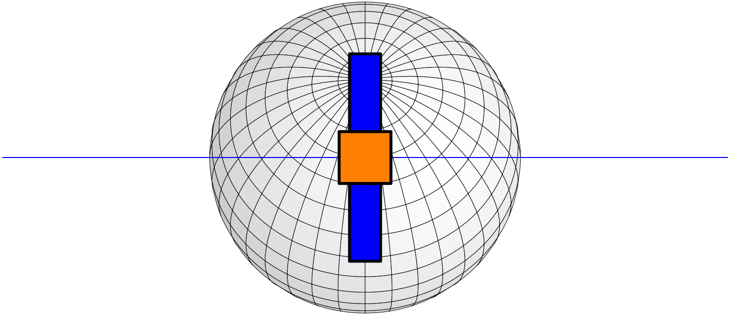


Problems with the ECOM

- GLONASS induces huge artifacts in time series of geodynamical and reference frame parameters
- Meindl et al., 2013 explained mechanism how this could be introduced into geocenter results
- Rodríguez-Solano et al., 2014 traced back the problems to the ECOM: Using an adjustable box-wing model significantly reduces the spurious signals

$\longrightarrow$ Revise ECOM!

Observing GLONASS satellite from Sun ($\beta = 0^\circ$)



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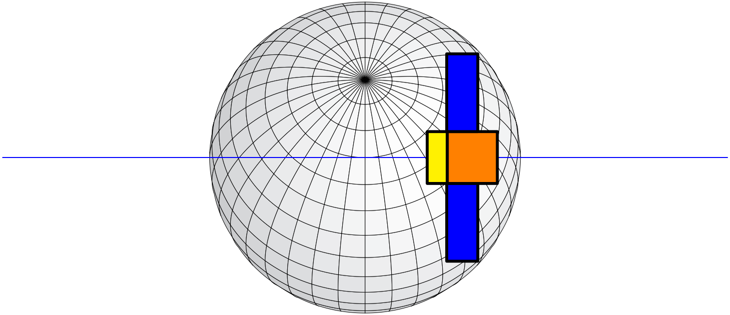

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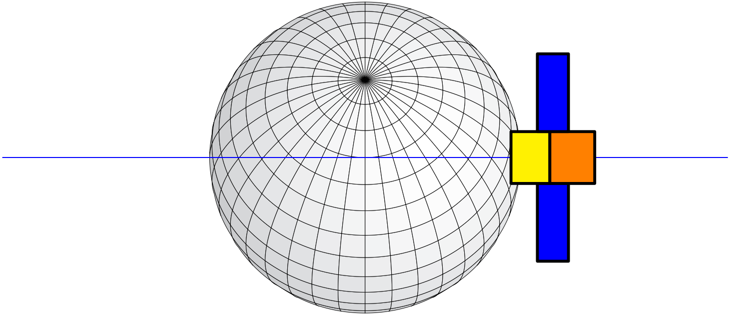

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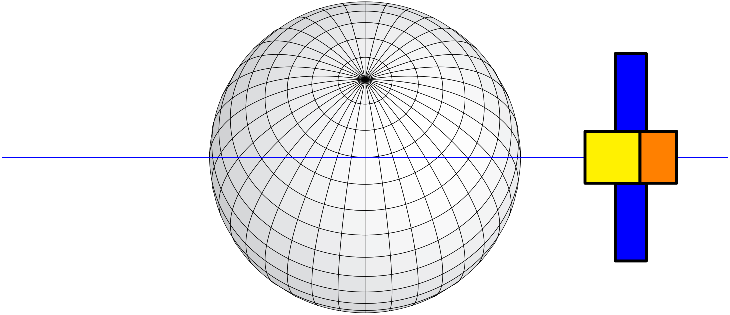

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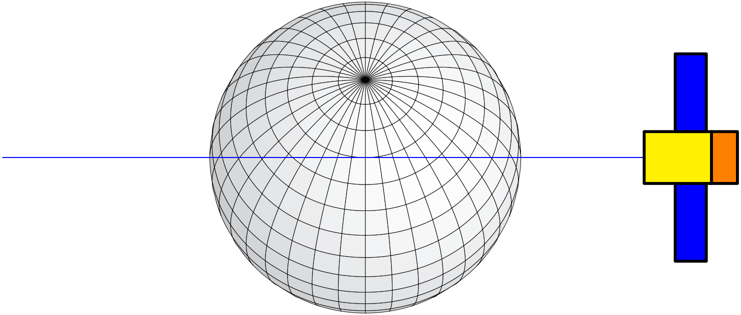

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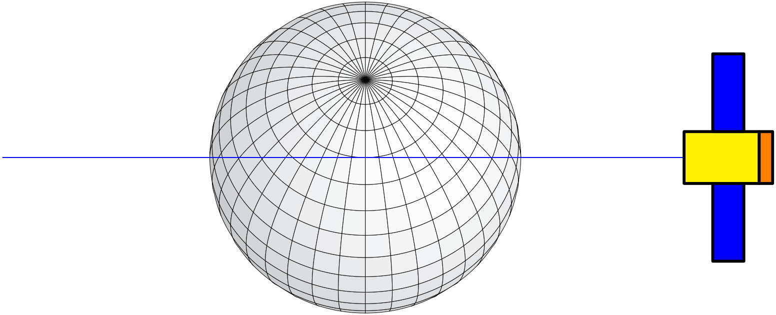

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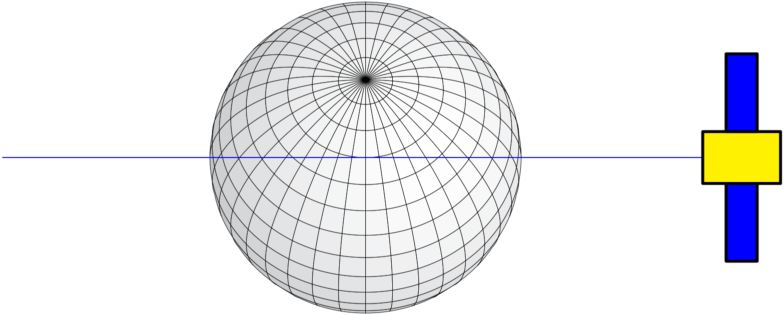

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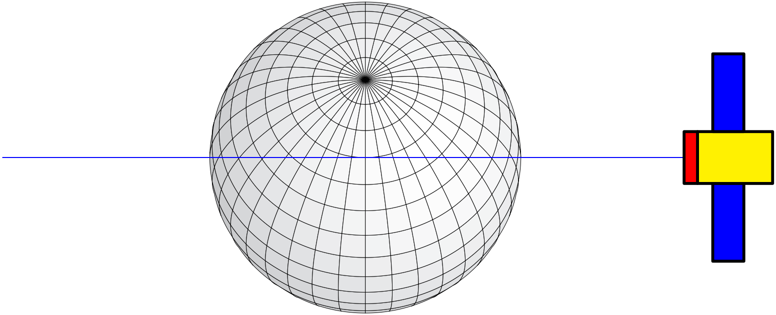

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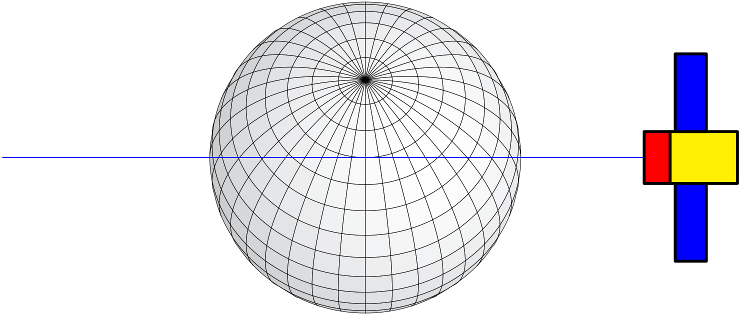

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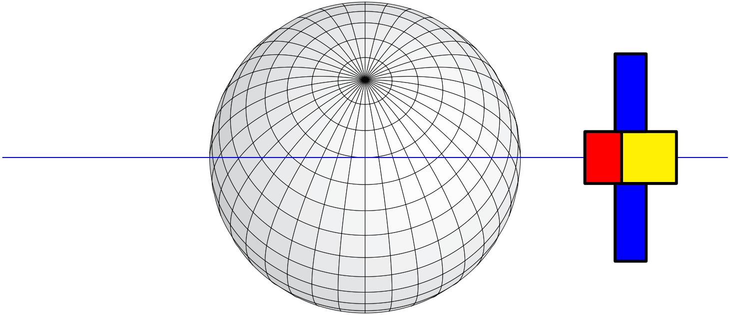

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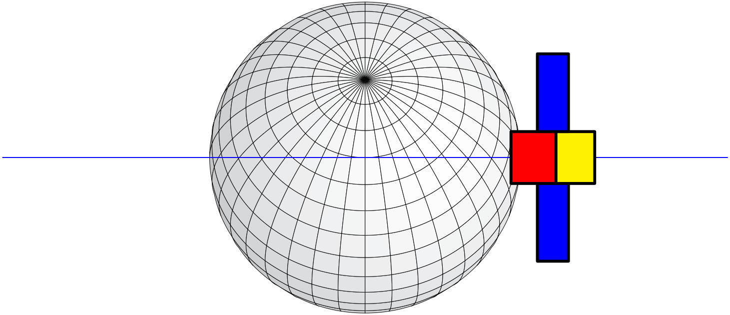

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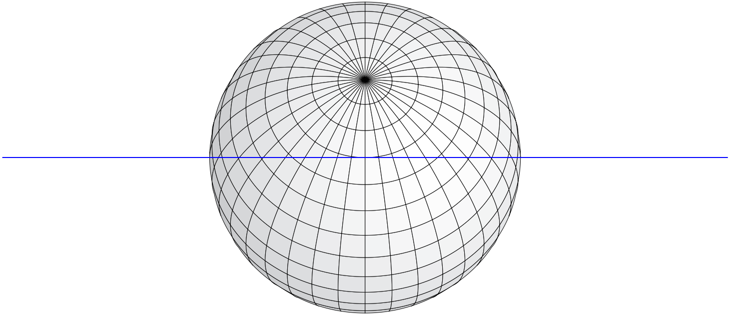

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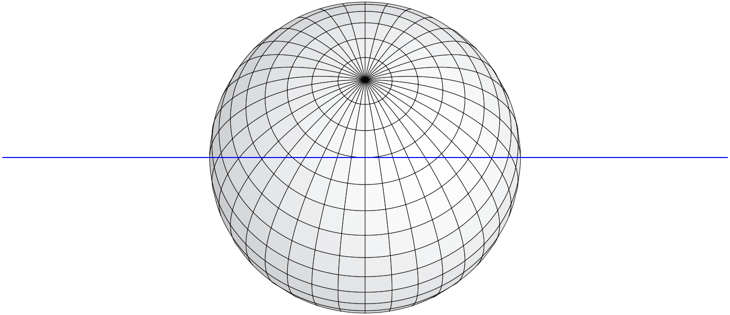

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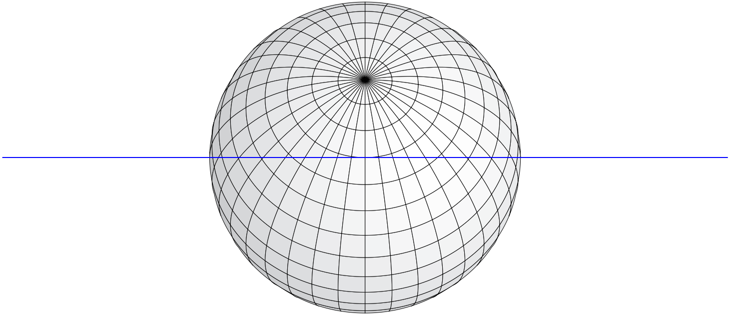

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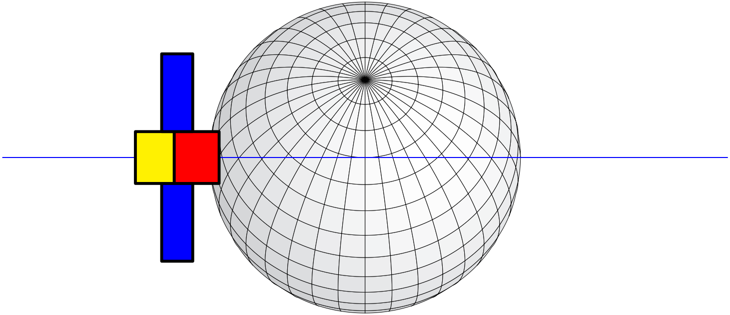

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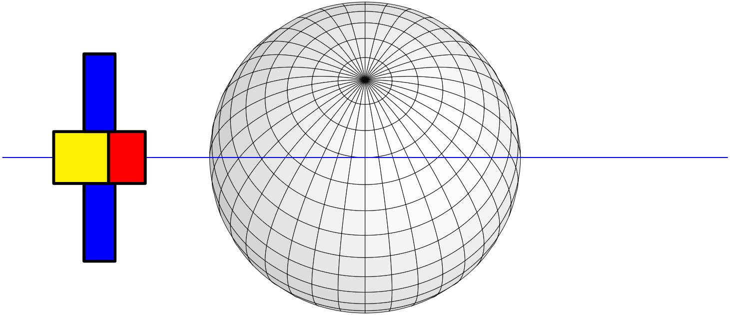

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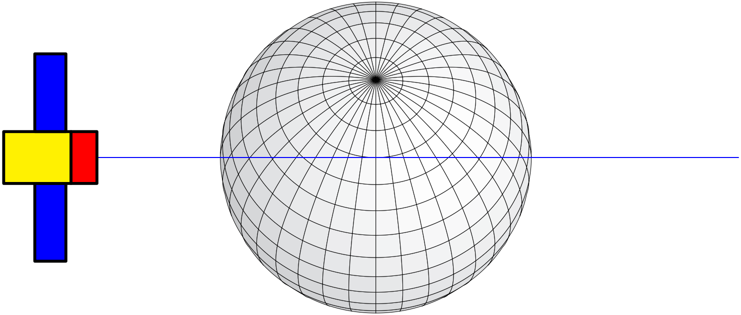

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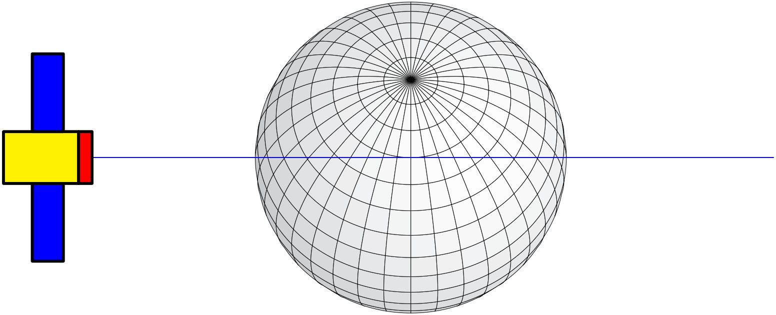

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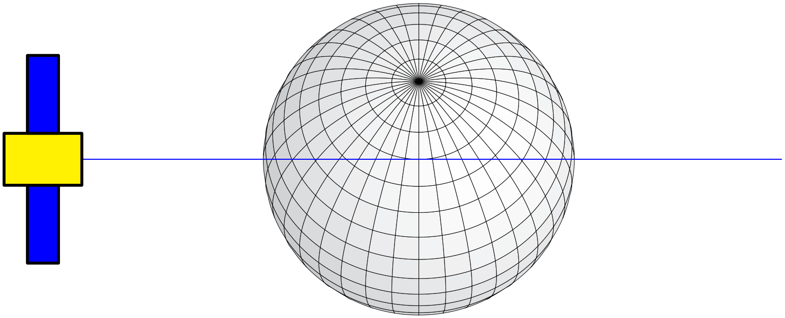

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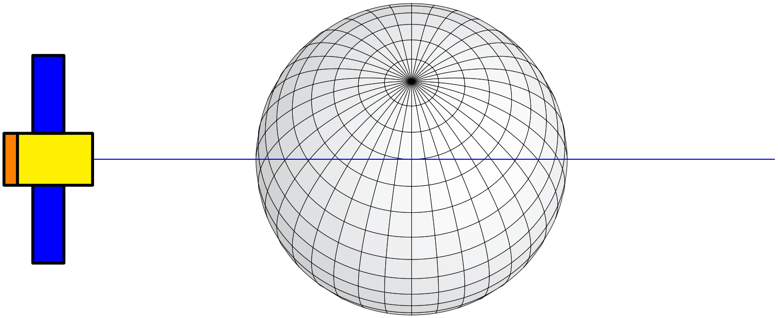

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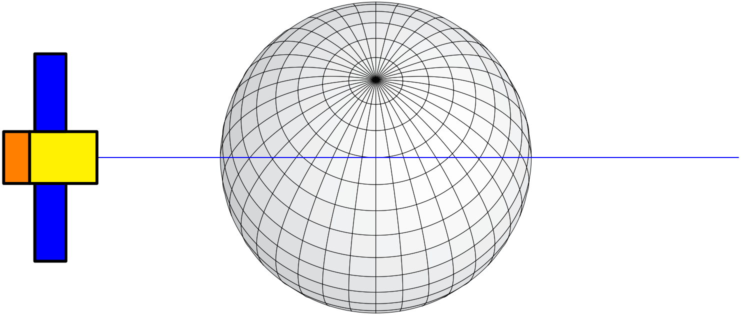

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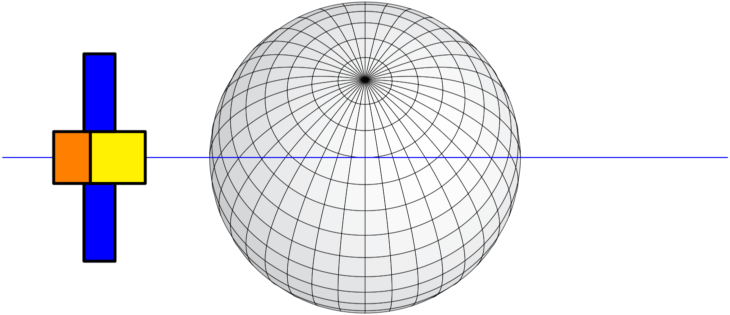

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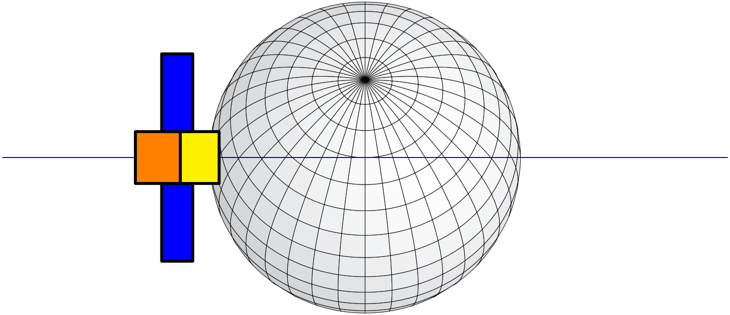
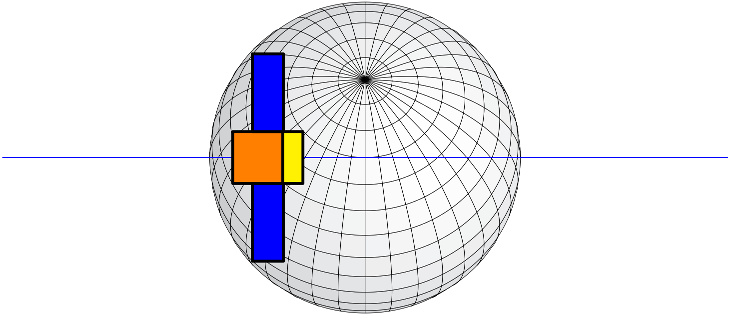


Observing GLONASS satellite from Sun
($\beta = 0^\circ$)



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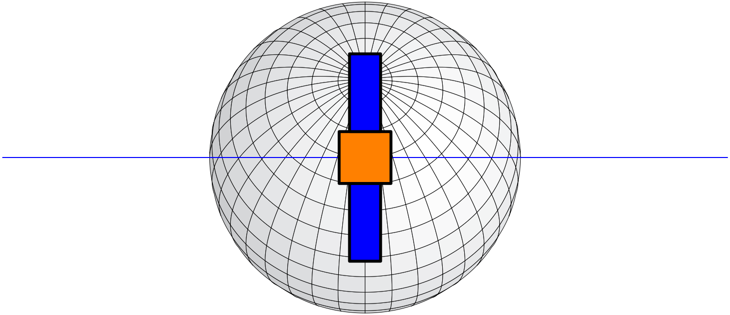


Extending the ECOM

- Solar panels are (ideally) always perpendicular to $\vec{e}_D$ and only cause a (large) contribution to D_0.
- For elongated satellite bodies (like GLONASS), the periodic D-terms must not be negected!
- The periodic terms become more important for low β-angles
- **For perfect yaw-steering attitude of a satellite with symmetric surface propierties**:
  - D-terms: D_0, D_2, D_4,...
  - B-terms: B_1, B_3, B_5,...
- A Sun-fixed angular argument is more appropriate for interpretation of estimated ECOM parameters. Use

$$\Delta u \doteq u - u_s$$

where u_s is the argument of latitude of the Sun.

Extending the ECOM

$$D(u) = D_0$$

$$Y(u) = Y_0$$

$$B(u) = B_0 + B_{1,c}\cos(u) + B_{1,s}\sin(u)$$

Extending the ECOM

$$D(u) = D_0 + D_{2,c}\cos(2\Delta u) + D_{2,s}\sin(2\Delta u)$$
$$+ D_{4,c}\cos(4\Delta u) + D_{4,s}\sin(4\Delta u) + \ldots$$

$$Y(u) = Y_0$$

$$B(u) = B_0 + B_{1,c}\cos(\Delta u) + B_{1,s}\sin(\Delta u)$$
$$+ B_{3,c}\cos(3\Delta u) + B_{3,s}\sin(3\Delta u) + \ldots$$

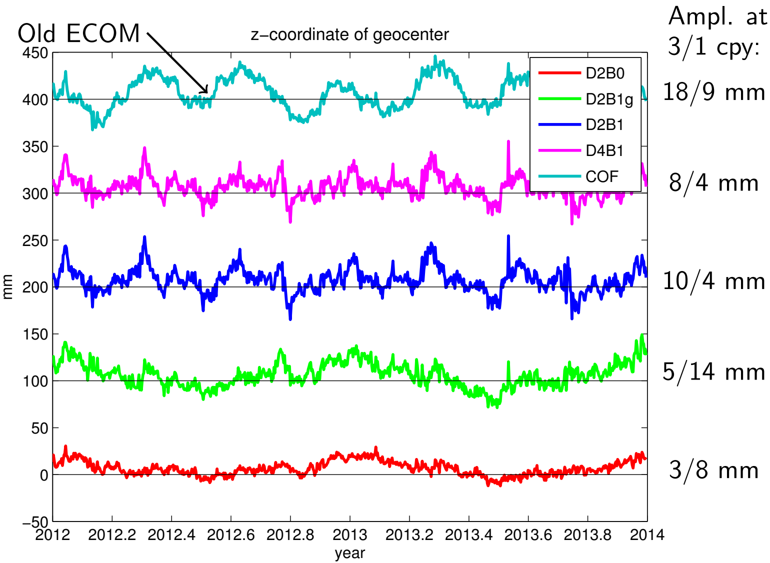
The new ECOM

Different parametrizations were extensively tested using as quality measures

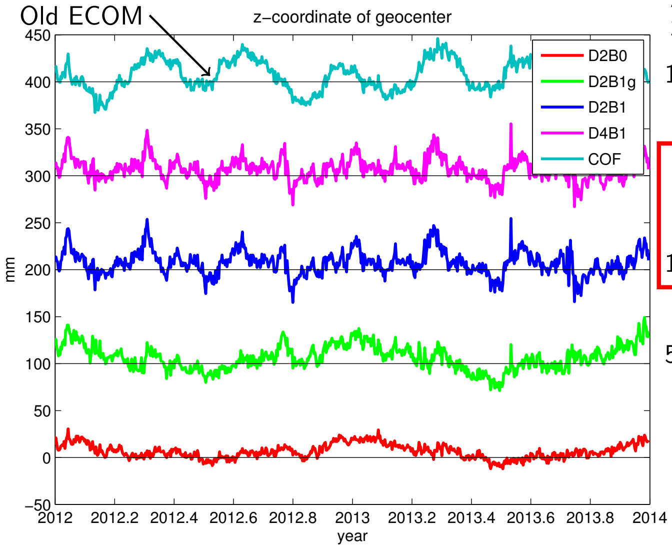
- Geocenter coordinates,
- ERPs,
- Station coordinates,
- Satellite orbits,
- SLR validation of satellite orbits.

Sol	D_2	D_4	B_1	# par
D2B0	yes	no	no	5
D2B1g	yes	no	GPS	5(GLO), 7(GPS)
D2B1	yes	no	yes	7
D4B1	yes	yes	yes	9
COF (D0B1)	no	no	yes	5

The new ECOM


Old ECOM
z−coordinate of geocenter
450
400
350
300
250
200
150
100
50
0
−50
mm
2012
2012.2
2012.4
2012.6
2012.8
2013
2013.2
2013.4
2013.6
2013.8
2014
year
D2B0
D2B1g
D2B1
D4B1
COF
Ampl. at
3/1 cpy:
18/9 mm
8/4 mm
10/4 mm
5/14 mm
3/8 mm

The new ECOM



Ampl. at 3/1 cpy:

18/9 mm

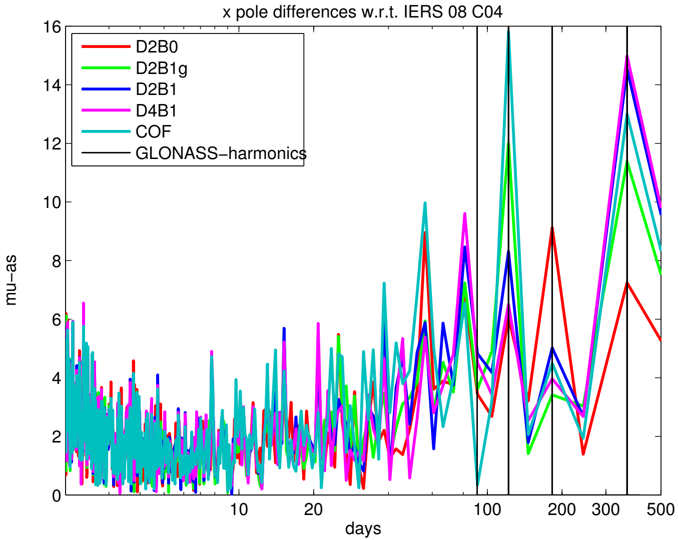
8/4 mm

10/4 mm

5/14 mm

3/8 mm

The new ECOM

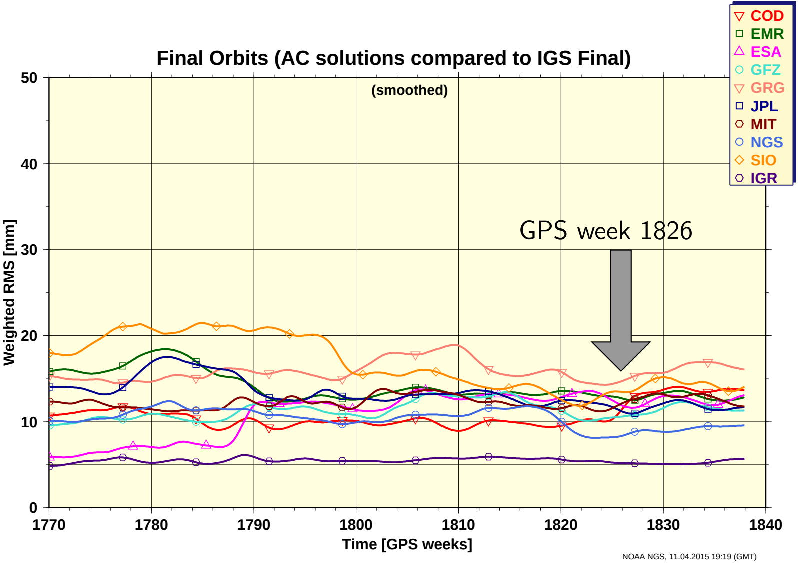

x pole differences w.r.t. IERS 08 C04
D2B0
D2B1g
D2B1
D4B1
COF
GLONASS−harmonics
mu−as
days
0
2
4
6
8
10
12
14
16
10
20
100
200
300
500

Conclusions

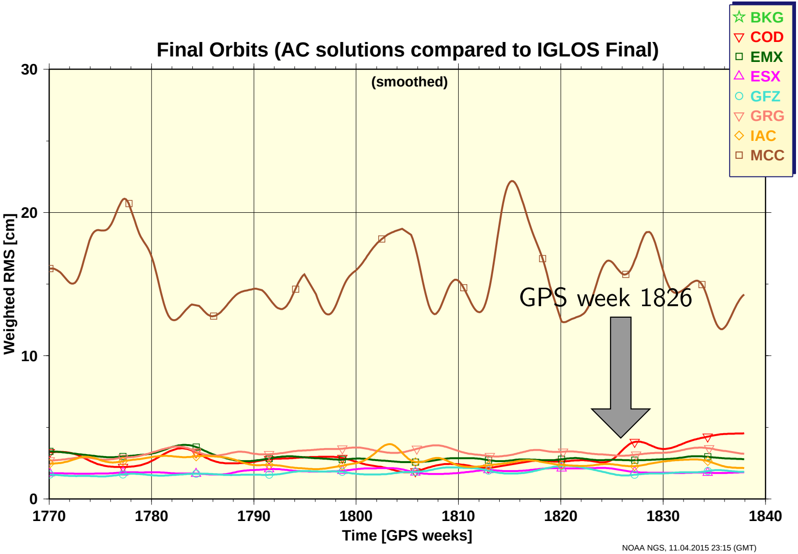
- The classic ECOM performs well for GPS, but must be extended by even-order periodic D-terms when applied to elongated satellite bodies (e.g. GLONASS, Galileo). Significant reduction of GLONASS-induced spurious signals.
- CODE IGS contributions based on D4B1 model since January 4, 2015 (GPS week 1826)
- For impact of extended ECOM on multi-GNSS orbit and clock solutions: see presentation of **Lars Prange on Thursday, 14:00, in Session G1.3, room G12**.
- See "CODE's new solar radiation pressure model for GNSS orbit determination", accepted for publication at J. Geod., DOI: 10.1007/s00190-015-0814-4

Thank you

Consistency with other solutions (GPS)



Consistency with other solutions (GLONASS)



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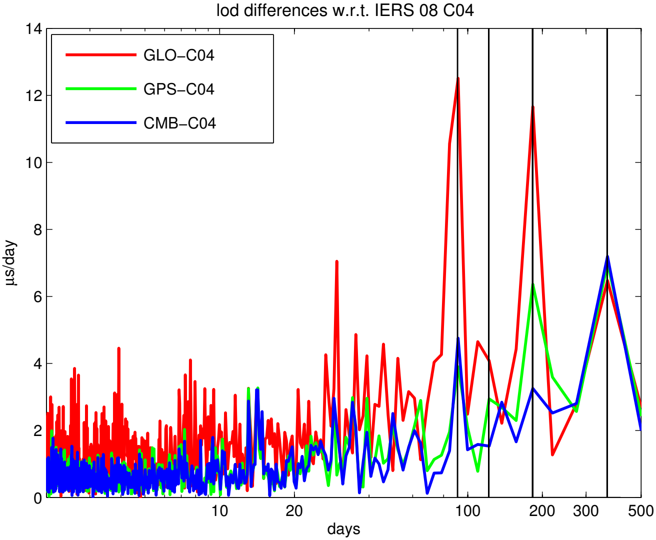
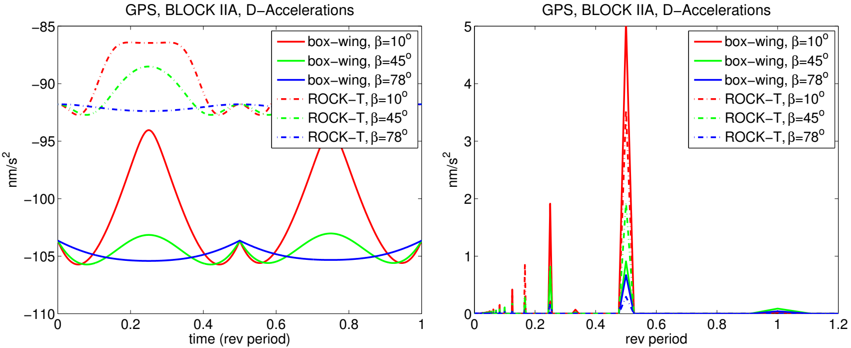
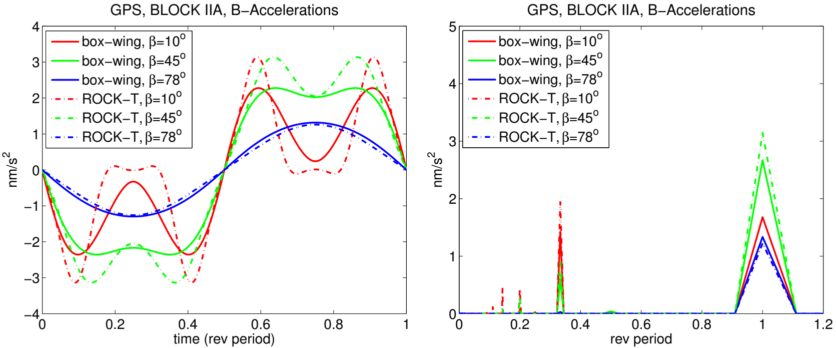


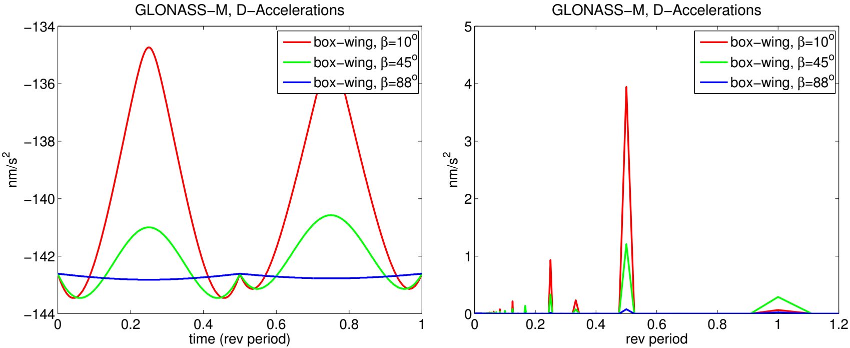
ROCK and BW accelerations for GPS (D)



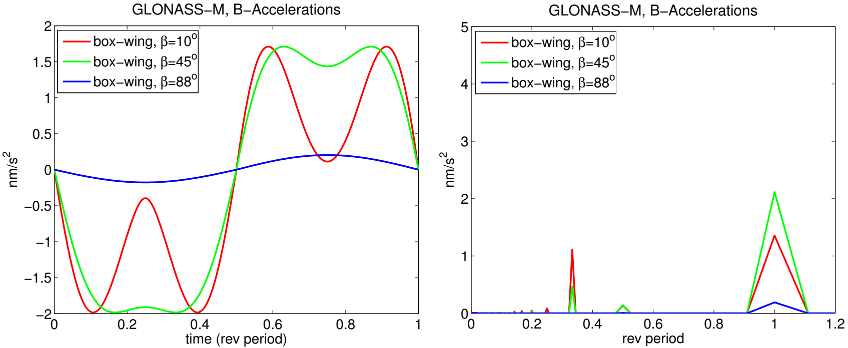
ROCK and BW accelerations for GPS (B)



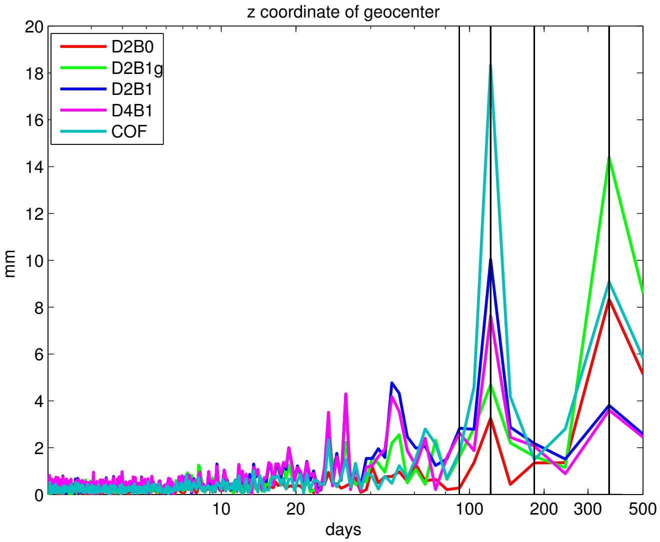
BW accelerations for GLONASS (D)



BW accelerations for GLONASS (B)



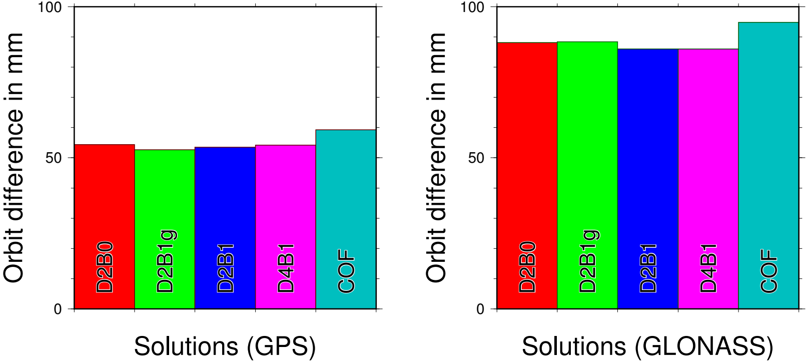
Geocenter



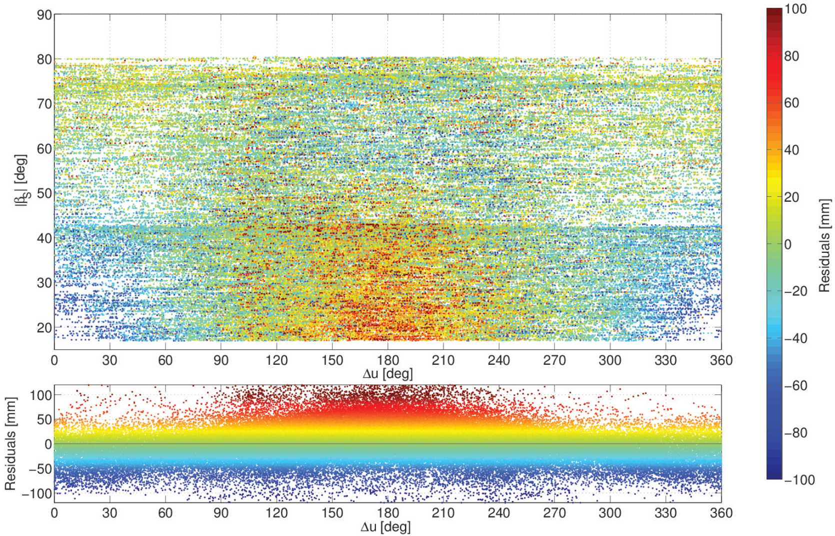
z coordinate of geocenter
D2B0
D2B1g
D2B1
D4B1
COF
mm
days
20
18
16
14
12
10
8
6
4
2
0
10
20
100
200
300
500

Orbits

Mean 3-dimensional orbit misclosures at day boundaries



SLR residuals of GLONASS (COF)



SLR residuals of GLONASS (D2B1)