Comparison of different Radiation Pressure models for GNSS orbit determination

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Context

I. The incomplete modeling of non gravitational forces (solar pressure, earth radiation, thermal effects and antenna thrust effects) acting on GNSS satellites remain the major sources of errors in GNSS precise orbit modeling.

II. Our group process routinely GNSS orbits with GINS software since 2007 (we participate to IGS final products since may 2010 : grg products)

III. Gins software, initially dedicated to LEO missions for gravity recovery contain accurate models for non-gravitational forces.
These models have been compared with accelerometer measurements on CHAMP&GRACE mission and such comparison prove that non gravitational forces can be computed accurately if all optical and surface properties of the elements of the satellite are known.

In an ideal world we would expect to have either :

-Pre launch ground measurements of these effects including optical properties of all surfaces.

-On board measurement of these forces using precise accelerometers.

Other IGS-ACs dynamical models

- Rock models (Fiegel &Gallini , 1996) , derived from Box & wings (block I/IIA)
- JPL-models (GSPM04, GSPM10 ,Bar-Sever et al., 2004, 2005,2010) *
- Extended CODE RPR Orbit Model models (Beutler et al 1994, Springer et al. 1999)*

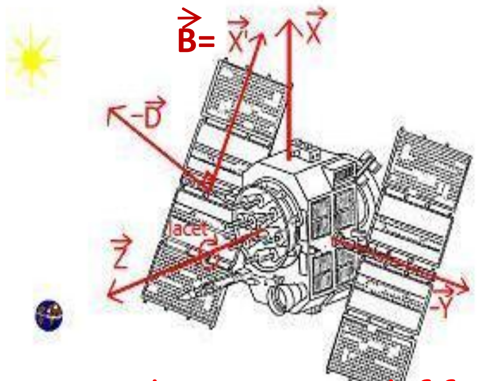
Sinusoidal models, expressed either in satellite body fixe frame (XYZ, with β, ε angles), or in Sun-oriented frame (DYB, with β, μ angles).

*** coefficients of these models were adjusted on previously determined precise orbits**
=> These models do not discriminate between all the non-gravitational effects
=> They may contain systematic errors that were in previously determined orbits (but use of long arcs allow to observe secular contribution)

Even with a good a priori RPR model there is need for additional empirical coefficients (Scale, Y-bias, 1/rev terms or stochastic pulses) adjusted on measurements.
The various sets of these coefficients are chosen to minimize the residuals to measurements and their correlations with EOP, geocenter motion, Lod,...

Grg dynamical modeling formulation

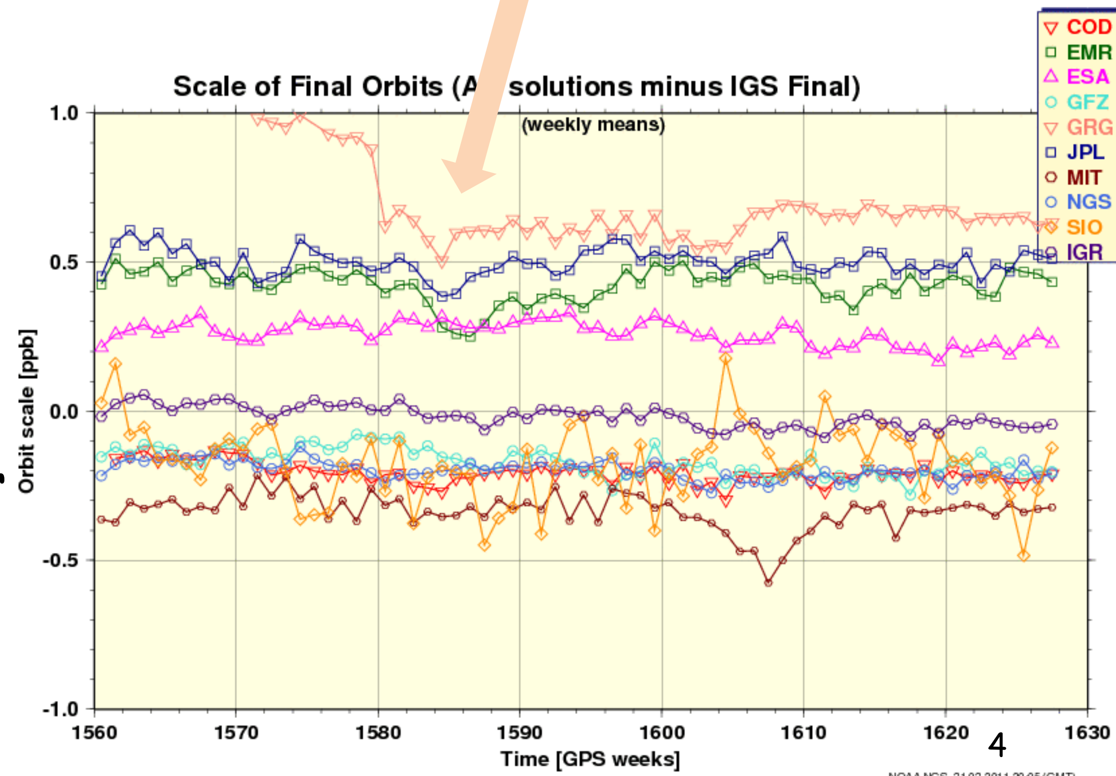
- B&W a priori model for solar pressure and albedo
- Adjusted empirical coefficients : scale on solar pressure force, Y bias, and once per rev terms in the (B,D) plane (6 parameters)



Two models of B&W have been used so far:
- complete (8 to 10 element) (before w1582)
- solar panels only (after gps week 1582) .

=> Today major differences relative to other IGS- Acs :
- GRG solution scale (mainly due to albedo modeling as for JPL&ESA, EMR?)

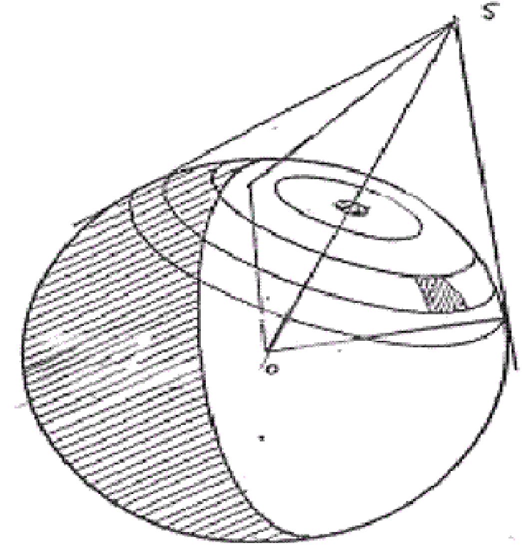
- If let free, GRG LOD estimate have a significative bias vs other solutions => The LOD is today constrained to IERS a priori in our solution (and excluded from the IGS combination).



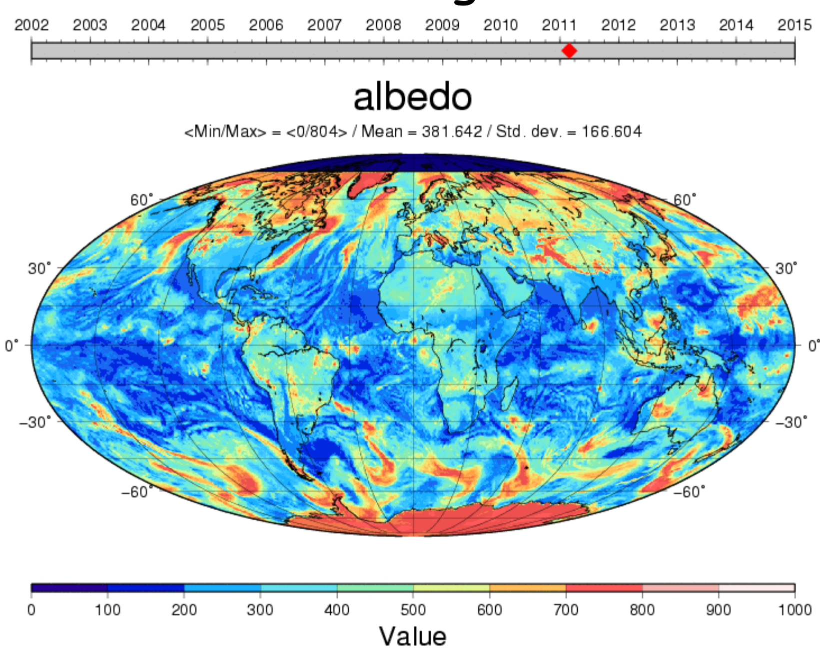
Albedo and infrared Flux

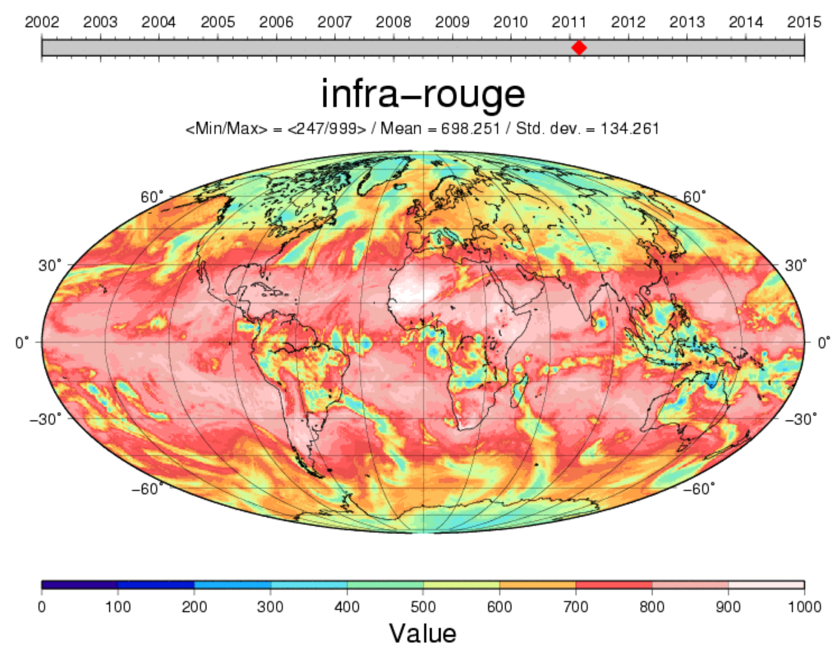
Albedo and infra red fluxes are computed from 6-hours ECMWF grids of reflectivity and emissivity.

-> In practice for GNSS satellites we compute the sum of the contribution of each visible sub satellite cells (4.5 °x4.5 °).

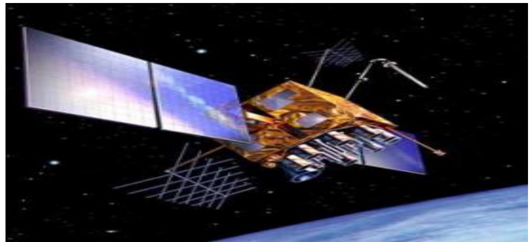


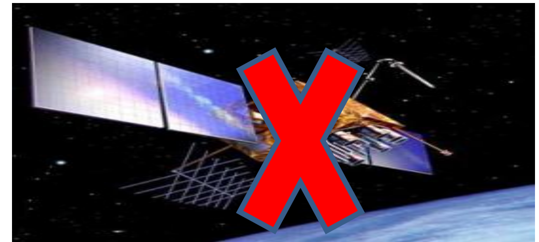
Examples of such grids (0.5° x 0.5°) for March 2011 are given below.

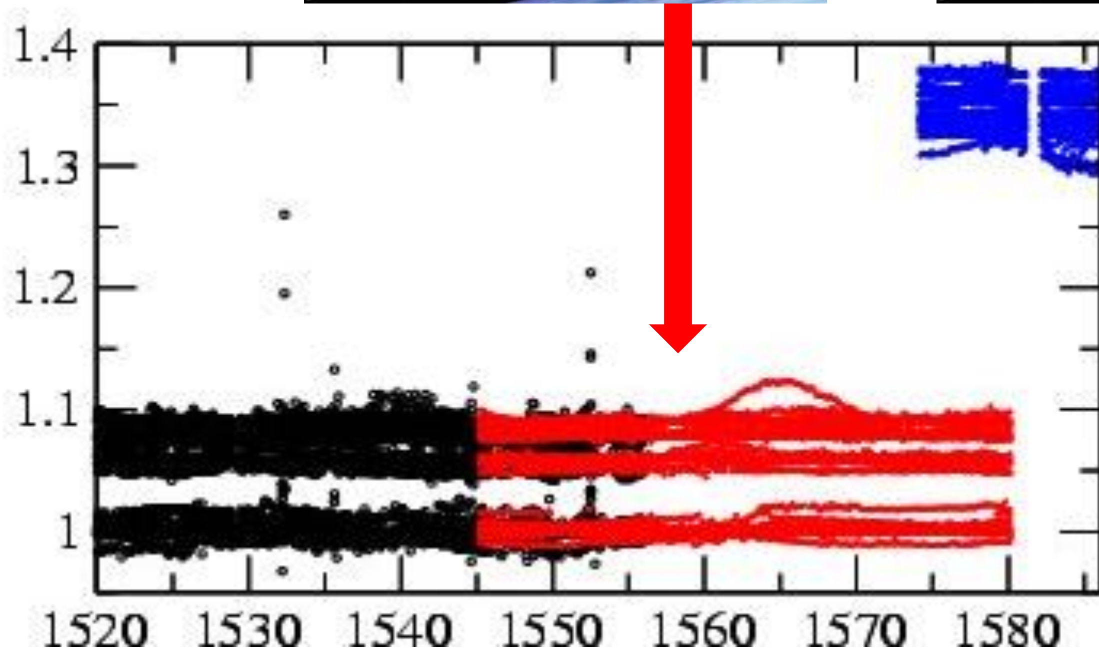




Change in adjusted SRP scale from B&W to "W only"







Adjusted scale factor for the different solutions and satellites. Free and fixed ambiguities (black and red), simplified model (blue).

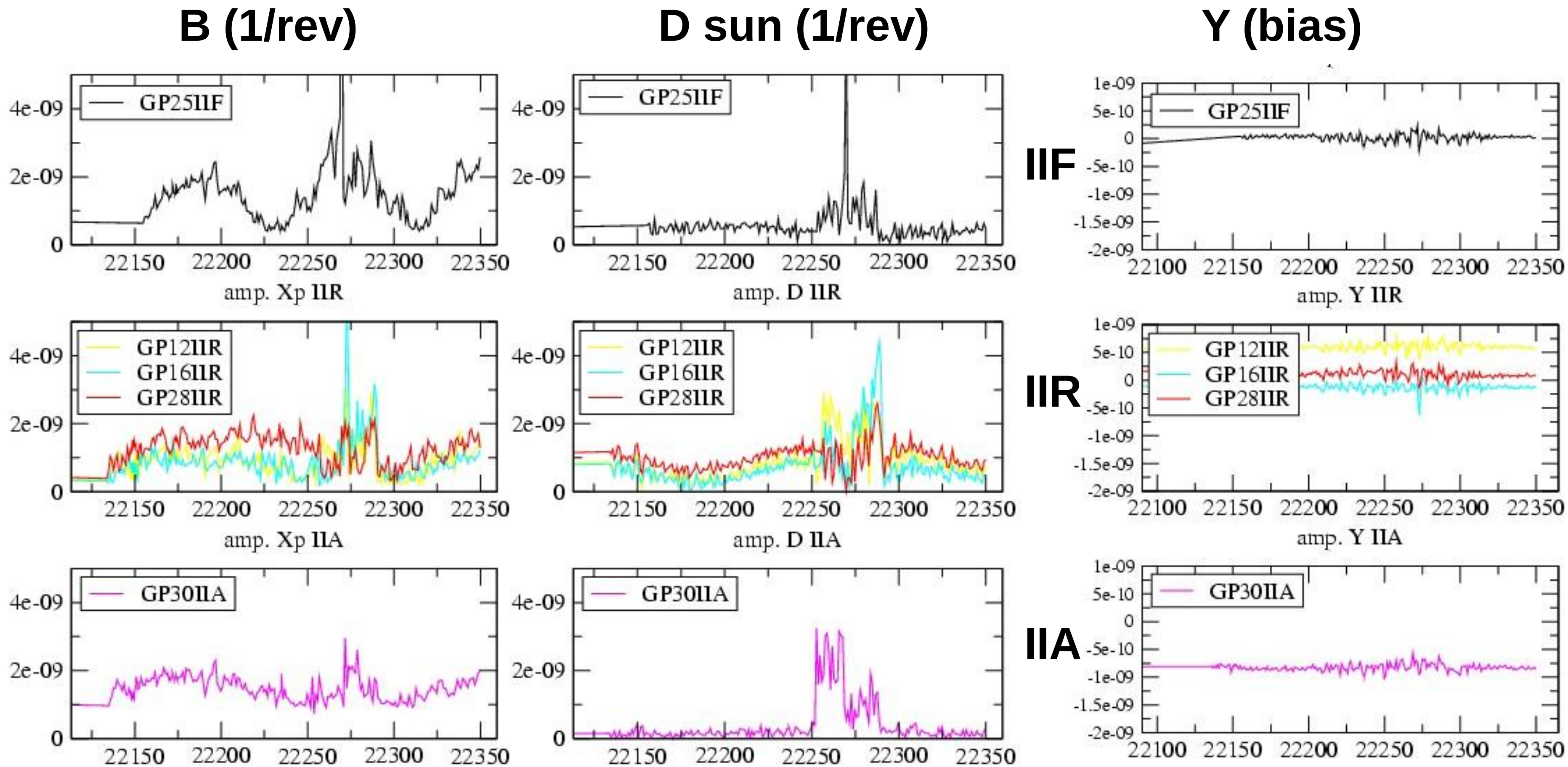
IIR

IIA

Undifferenced ambiguity fixing

=> ~ 30-35 % of the force due to the central body !

Amplitude of empirical terms over ~7 months (m s^{-2}) - LOD constrained



=> Large differences in amplitude variation for the different blocks

=> IIR sats exhibit large amplitude D (to sun) terms vs IIA (recent IIF more stable than IIR) : more “optical” dissymmetry of the +Z/-Z faces of the box?

(Orbit quality given by grg recent products)

Differential acceleration between some analysis center solutions

Source of data : official final sp3 files

Method : Estimation of RTN accelerations necessary to transform a solution to another solution

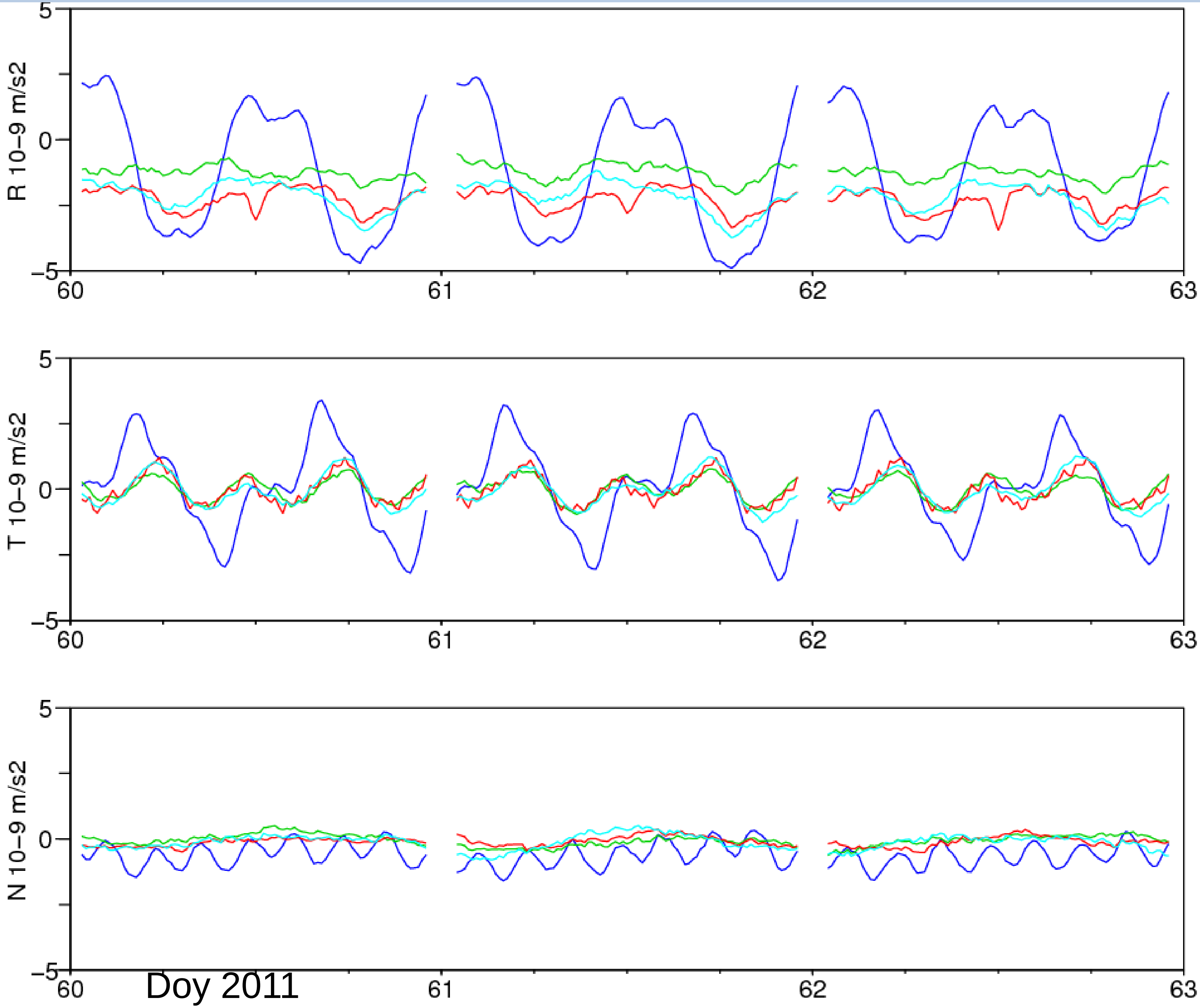
=> Supposed to represent surfaces forces modelling differences as gravitation models are well defined

⇒ Contains a priori SRP models used **and** adjusted empiricals terms differences

Results for doys 60 61 62 2011 **jpl**/**esa**/**cod**/**ngs** compared to grg

GPS 14 / IIR

jpl/esa/cod/ngs

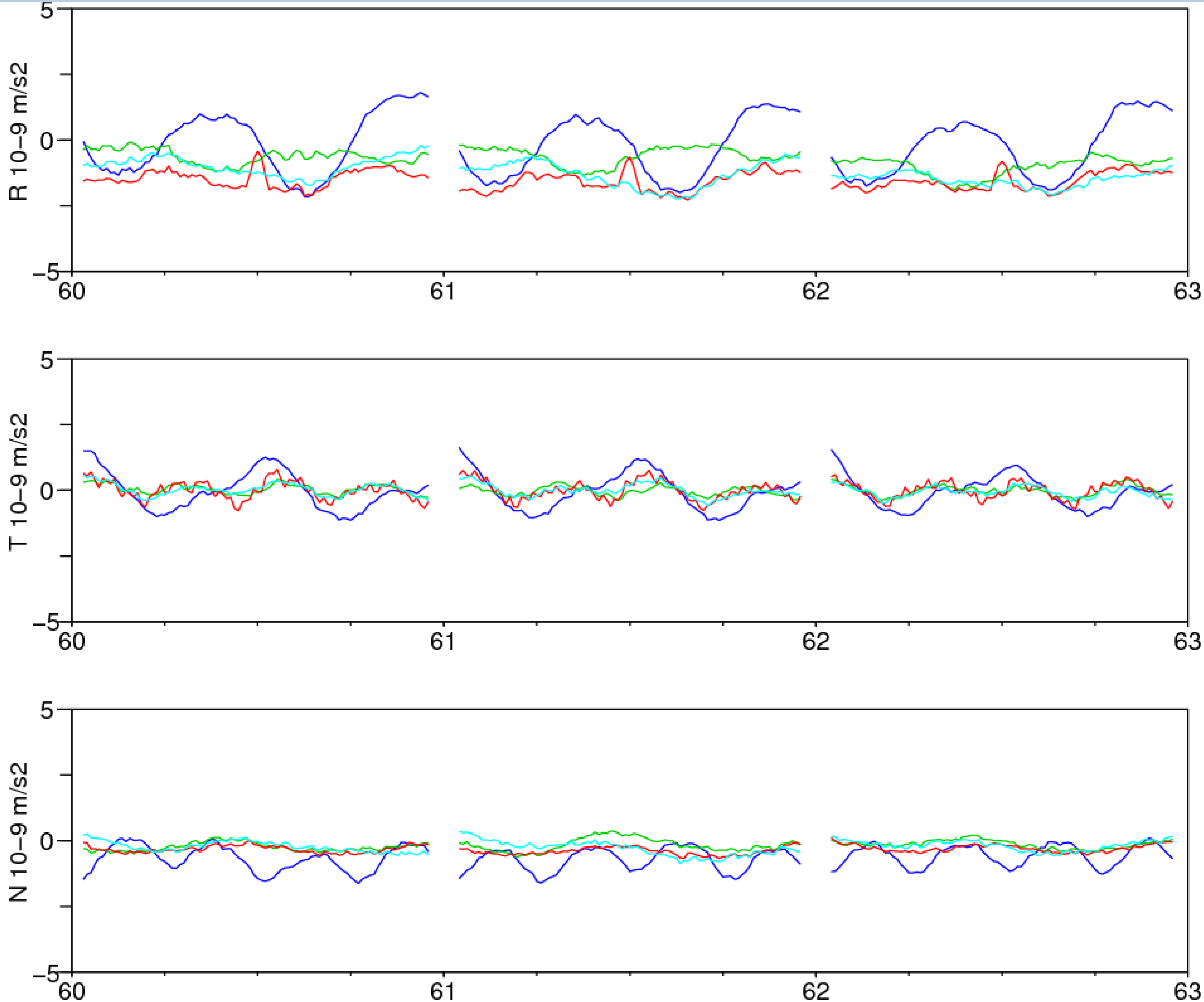


Radial bias
Albdedo ?

1/rev &
2/rev terms
tangential

4/rev in jpl
Solution rel.
to the others

GPS 05/ IIR jpl/esa/cod/ngs



cod / **ngs** have very close modelling, **esa** also.

Jpl has a very different behaviour compared to all the other solutions. (linked to JPL a priori model)

Summary / conclusions / perpectives

- Box in « box & wings » represent ~30% of direct solar effect contribution

- IIR exhibit larger 1/rev. amplitude in D (to sun) than IIA.

- The acceleration comparisons provide a new tool to analyse orbits and models differences.

- We observe quite « large » differences between the Acs modelisations

- The chosen representation of SRP models should be balanced between physical considerations (geometry, materials) and current parameters observability problems (with limited number of revolutions).

- Satellite fixed frame models (like JPL-ones) are more appropriate to represent the physical caracteristics of the satellites.

Box & Wings : general formulation

Example for **planar** surfaces (equivalent formulaes exist for **spherical,parabolic**, **cylindric** surfaces, etc….)

Ri, the reflectivity of the of the elementary surface depend of surface nature and optical properties given by absorption and reflectivity coefficients : Ka, Kd and Ks (Ks + Ka + Kd = 1)

$$\vec{A}cceleration = \frac{\Phi}{m}\sum_i S_i \vec{R_i}$$

$$\vec{R_i} = -\cos\theta\left[(K_A + K_D)\vec{s} + \left(\frac{2}{3}K_D + 2K_S\cos\theta\right)\vec{n}\right]$$