Impact of Earth Radiation Pressure on LAGEOS Orbits and on the Global Scale

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Earth Radiation Pressure

The indirect solar radiation pressure reflected or re-emitted by the Earth's surface is one of the most important non-gravitational forces perturbing the orbits of geodetic satellites. These accelerations may exceed 15% of the direct solar radiation pressure for LAGEOS satellites. In this study the impact of Earth radiation pressure is assessed not only on LAGEOS-1/2 orbits, but also on other parameters derived from SLR observations, e.g., the global scale, geocenter and station coordinates. We consider independently two types of accelerations (Fig.1, 2):

❖Reflected visible radiation (reflectivity),
❖Emitted radiation (emissivity).

We make use of the monthly global maps of Earth reflectivity and emissivity from the CERES project (Clouds and the Earth's Radiant Energy System, Wielicki et al (1996)). The largest albedo reflectivity is found in the Polar Regions, whereas the largest emissivity can be found in the tropic areas (Fig. 3, 4). More than 60% of the total Earth radiation pressure forces is due to infrared emissivity.

The impact of radiation pressure on LAGEOS satellites is characterized by two parameters: the area-to-mass ratio: A/m; and radiation pressure coefficient: $C_R = 1 + 4/9\,\delta = 1.13$, where δ is a diffusion coefficient (fraction of diffusely reflected photons). The acceleration due to Earth radiation pressure on spherical satellites $\boldsymbol{A}_a$ reads as:

$$\boldsymbol{A}_a = \left(\frac{a_u}{r_o}\right)^2 \frac{A}{m}\frac{S}{c}\sum_{\phi}\sum_{\lambda}\left(a_{v,\phi,\lambda}\left(1+\frac{4}{9}\delta_v\right)C_o\cos z_o + \alpha_{IR,\phi,\lambda}\left(\frac{1}{4}+\frac{1}{9}\delta_{IR}\right)\right)\frac{a_e^{\,2}\sigma}{\pi}\cos z_s\,\frac{\boldsymbol{r}-\boldsymbol{r}_s}{|r-r_s|^3}$$

with: a_u - astronomical unit, r_o – distance between the Earth and Sun, S – solar constant, c – speed of light, a_e – Earth radius, r – geocentric position a surface element σ, r_s – geocentric position of the satellite, φ, λ – latitude and longitude of a surface element σ, $\alpha_{v,\phi,\lambda}$ - coefficient of reflectivity of a surface element σ, $\alpha_{IR,\phi,\lambda}$ - coefficient of emmisivity of a surface element σ, C_o - coefficient characterizing illuminated surface area: C_o=1 for illuminated surface and C_o=0 for the surface area in shadow, δ_v – satellite diffusion coefficient for visible radiance, δ_{IR} – satellite diffusion coefficient for infrared radiance, z_o - zenith distance of the Sun w.r.t. surface element, z_s - zenith distance of the satellite w.r.t. a surface element.

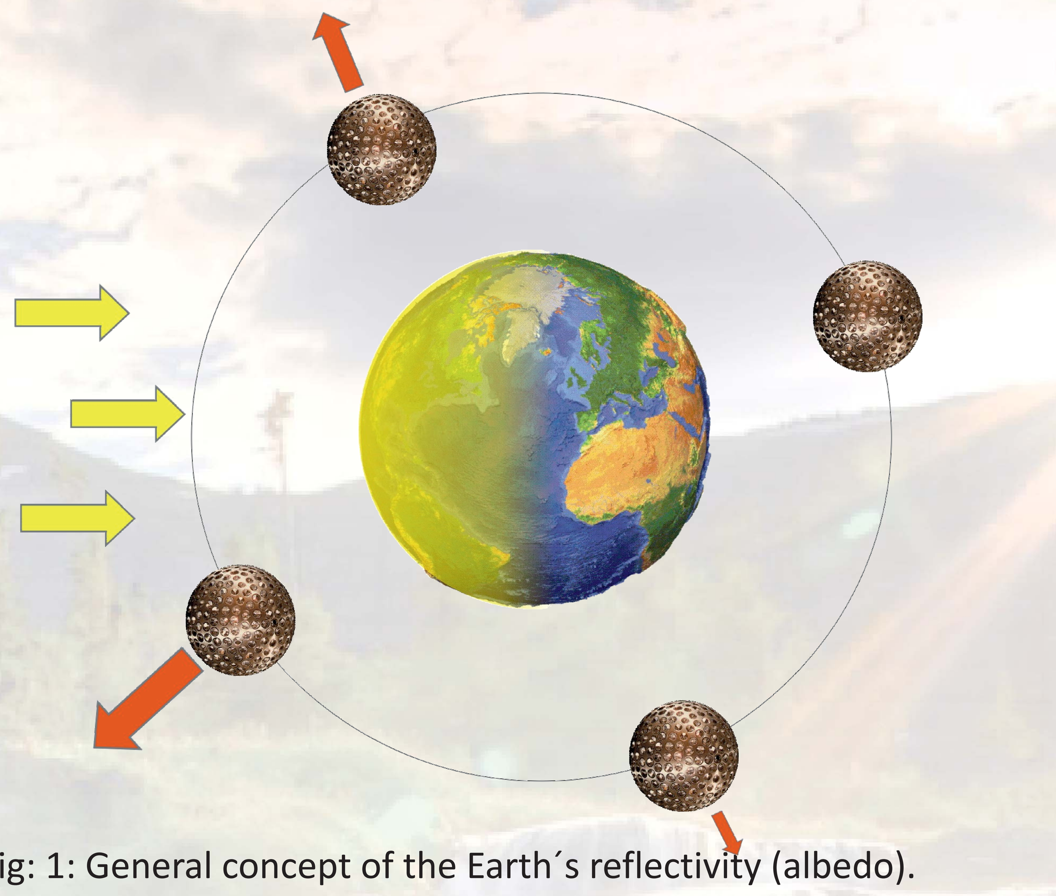


Fig: 1: General concept of the Earth´s reflectivity (albedo).

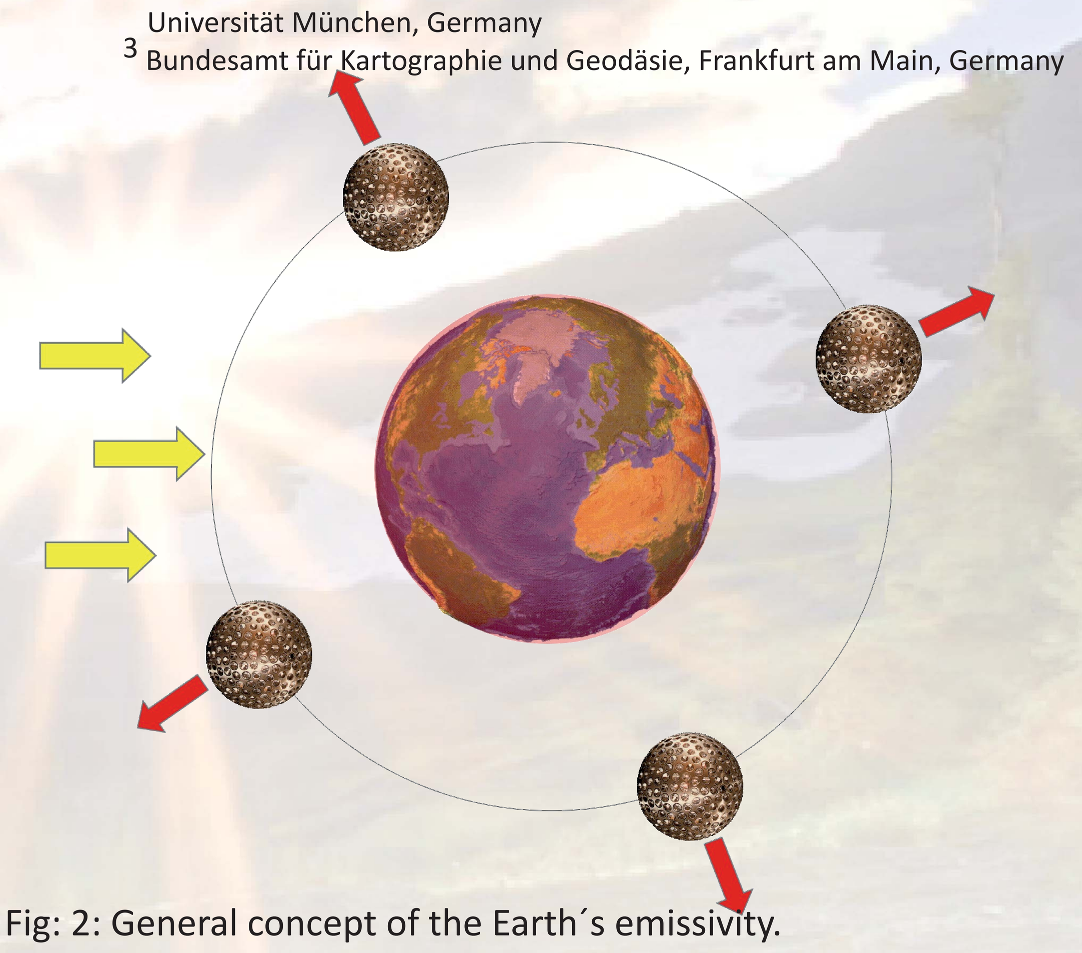


Fig: 2: General concept of the Earth´s emissivity.

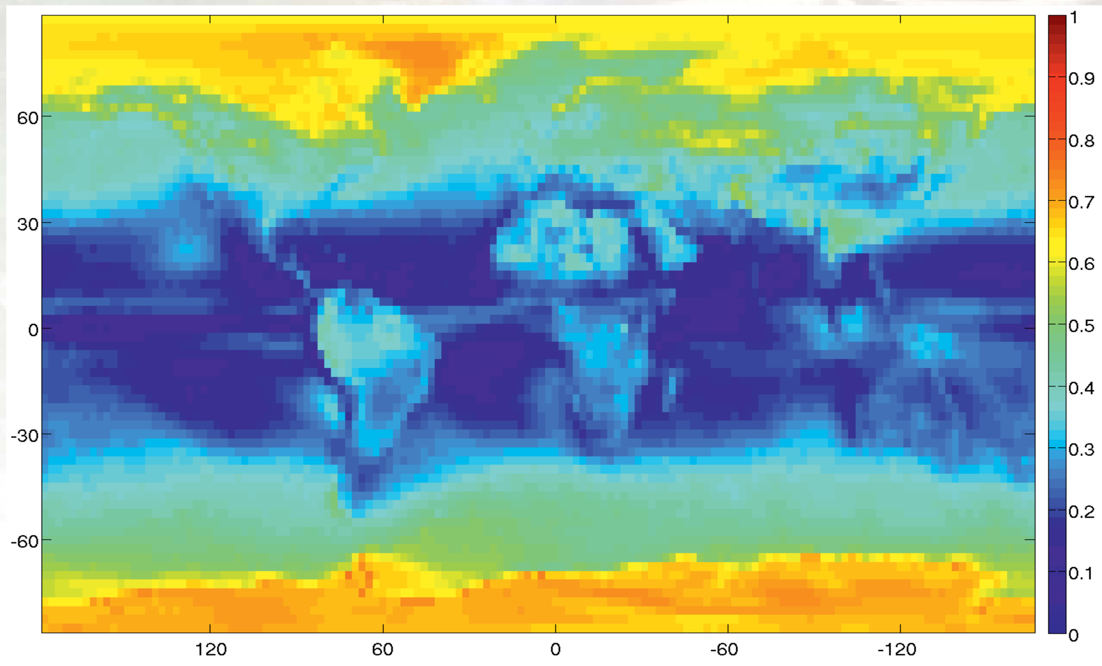


Fig: 3: Map of mean Earth´s reflectivity in April from CERES.

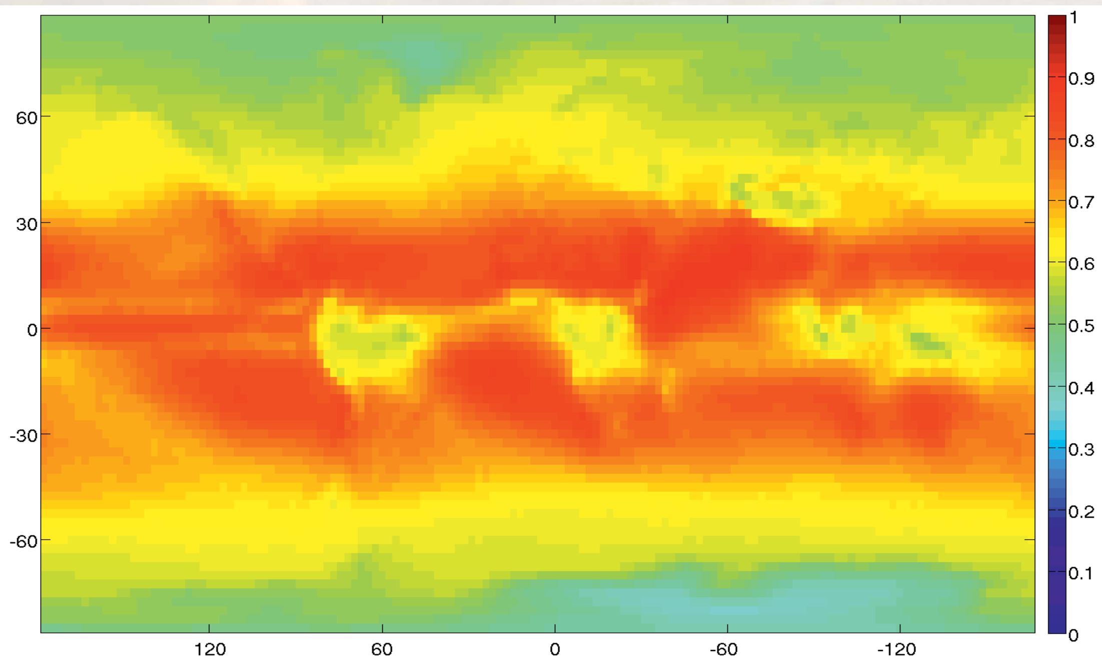


Fig: 4: Map of mean Earth´s emissivity in April from CERES.

LAGEOS Orbits

Figure 6 shows the accelerations applied on LAGEOS-2 due to the reflectivity (left) and reflectivity and emissivity (right) in the radial direction (R), whereas Fig 7 shows the reflectivity and emissivity accelerations in the along-track (S, left) and out-of-plane (W, right) directions. Maximum acceleration, amounting $4.4{\cdot}10^{-10}$ m/s^2, is in the radial direction (Fig. 6). Albedo reflectivity depends on the relative position of the Sun, whereas the emissivity imposes a rather constant acceleration regardless of the relative Sun-Earth-satellite configuration. The Earth radiation pressure in S and in W are a factor of fourteen smaller than in R.

The constant radial force is acting in the opposite direction to the gravitational attraction of the Earth. Hence, this radial acceleration has an impact on the dynamical global scale, defined as *GM* (the product of the gravitational constant *G* and the mass *M* of the Earth). Well established *GM* is of crutial interest in SLR data analyses, because the currently accepted conventional value of *GM* was derived using SLR tracking of LAGEOS.

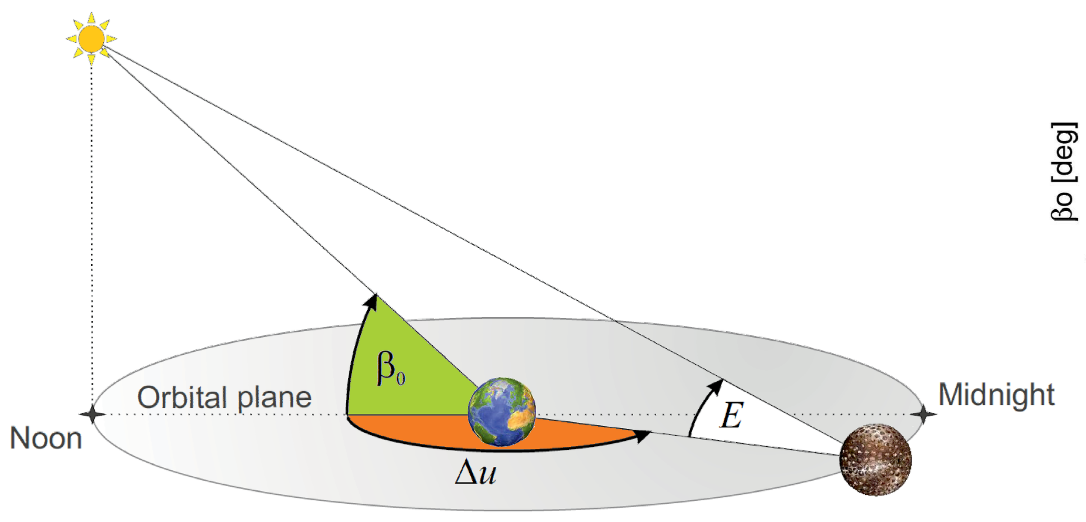


Fig: 5↑: Satellite-Sun-oriented reference frame.

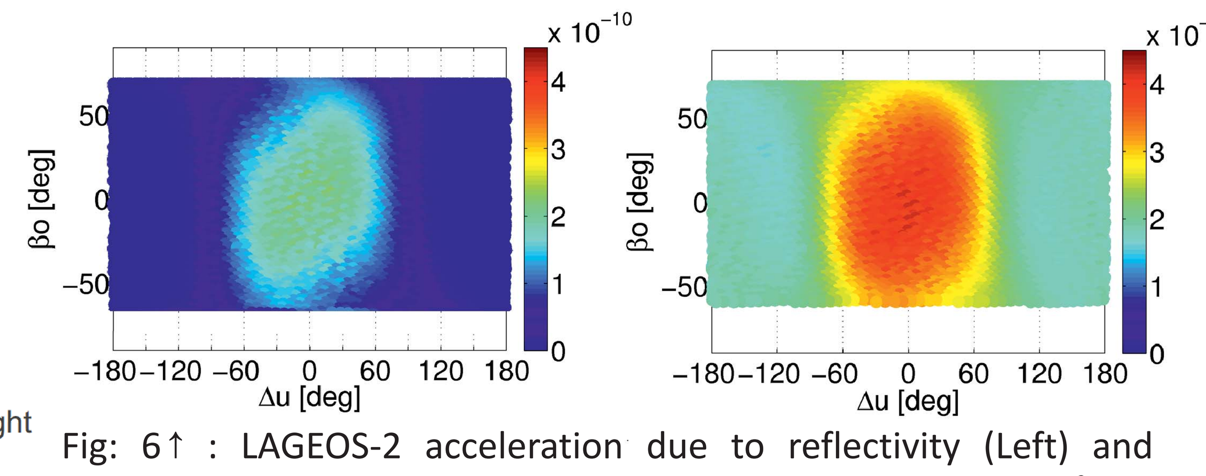


Fig: 6↑ : LAGEOS-2 acceleration due to reflectivity (Left) and reflectivity + emissivity (Right) for the radial direction. Units: m/s^2.

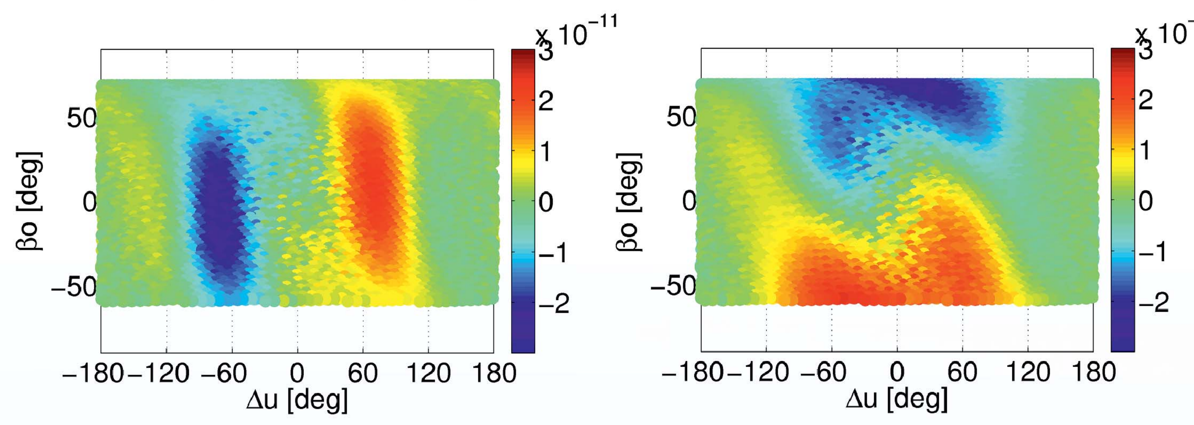


Fig: 7→ : LAGEOS-2 acceleration due to reflectivity and emissivity in the along-track (Left) and out-of-plane (Right) directions in the satellite-Sun-oriented frame. Units: m/s^2.

Scale

Four years of LAGEOS data are processed with different Earth radiation pressure modeling. Figure 8 shows the difference between the scale of the SLR network between the solution without (solution 1) and with radiation pressure applied (solutions 2-4). The emissivity causes a scale difference of 0.05 ppb, whereas the reflectivity causes an additional scale difference of 0.02 ppb. The total difference of 0.07 ppb corresponds to 0.5 mm w.r.t. the Earth's radius.

Considering the Kepler`s third law $a^3n^2=GM$ and assuming fixed *GM*, the semi-major axis *a* is reduced by a radial acceleration R_a by:

$$\Delta a = -\frac{4}{3}\frac{R_a a^3}{GM}$$

The LAGEOS-1/2 orbits are reduced due to albedo by about 1.5 mm (0.5 mm due to reflectivity + 1.0 mm due to emissivity, see Fig. 9).

Fig: 8↑: Differences of the scale between solution 1 and solutions 2-4 from the Helmert transformation of SLR station coordiantes.

	Infrared emissivity	Albedo reflectivity
Solution 1	NO	NO
Solution 2	YES	NO
Solution 3	NO	YES
Solution 4	YES	YES

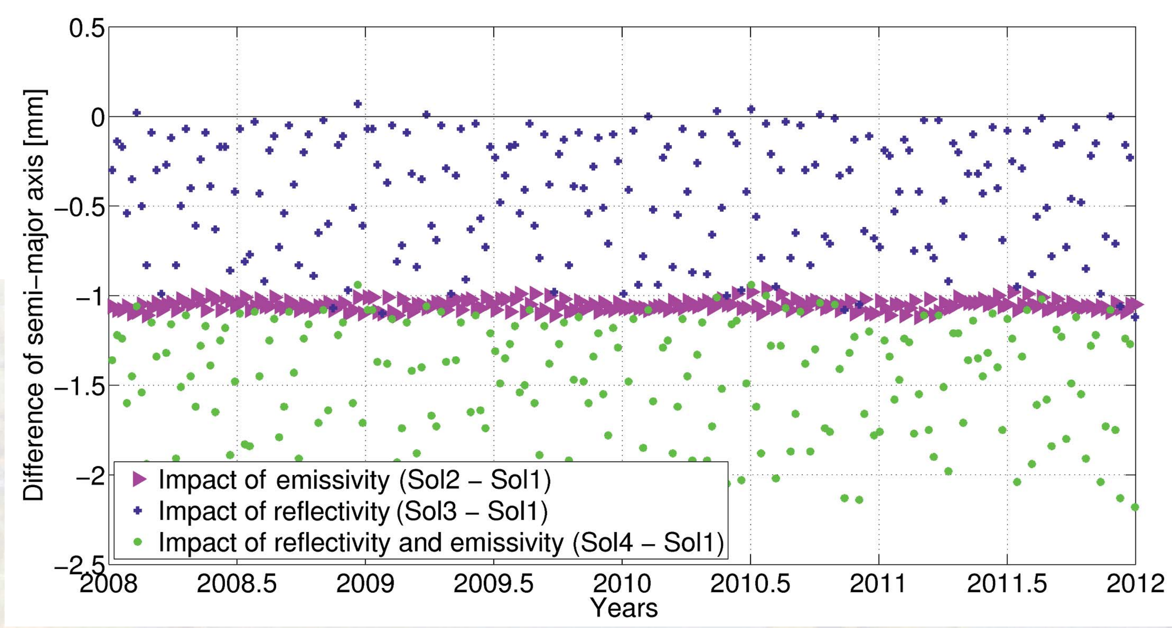


Fig: 9:Differences of LAGEOS-2 semi-major axis between solution 1 (without Earth radiation pressure) and solutions 2-4.

Station Coordinates

Modeling of radiation pressure has an impact on estimated station heights: the up component is systematically shifted by −0.4 mm due to reflectivity, and −0.2 mm due to emissivity (Fig. 10), when the range biases are not estimated. The estimated range biases entirely absorb the differences in radiation pressure modeling (Fig. 11).

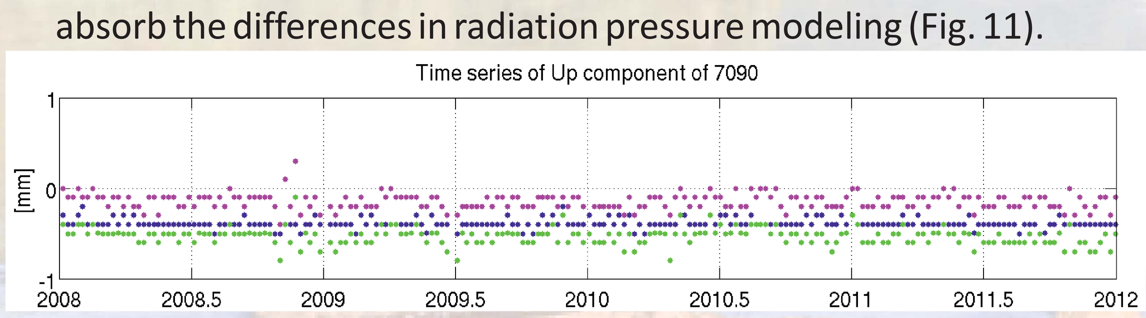
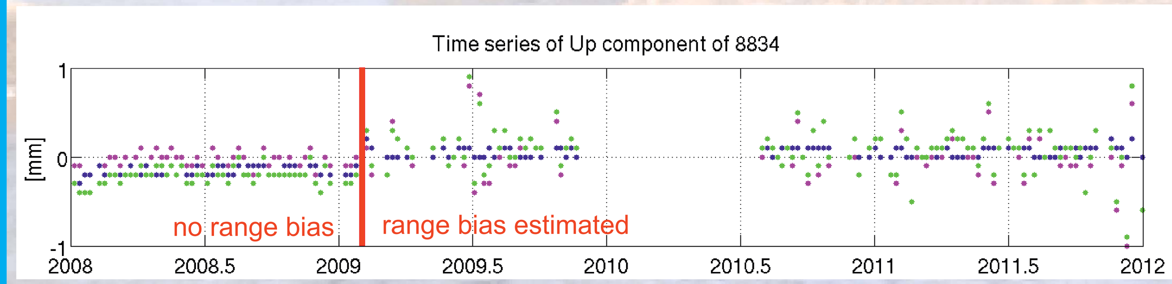


Fig: 10↑ : Differences of station heights between solution 1 and solutions 2-4 for Yarragadee (Australia), with no range biases.



ILRS Analysis Center	Reflectivity	Emissivity
Federal Agency for Cartography and Geodesy (BKG)	Yes	Yes
Goddard Earth Science and Technology Center (GEST)	Yes	Yes
NERC Space Geodesy Facility (NSGF)	Yes	No
Groupe de Recherche en Géodésie Spatiale (GRGS)	Yes	No
Centro di Geodesia Spaziale, Agenzia Spaziale Italiane (ASI)	Yes	No
Deutsches Geodaetisches Forschungsinstitut (DGFI)	Yes	No
GeoForschungsZentrum Potsdam (GFZ)	No	No
European Space Operations Centre (ESA/ESOC)	?	?

Tab: 1 ↑ : Application of albedo modeling in products of the ILRS Analysis Centers from SINEX headers or from the Analysis Strategy Summary, as of September 2013..

Fig: 11 ← : Differences of station heights between solution 1 and solutions 2-4 for Wettzell (Germany) with the estimation of range bias starting with February 2009.

Summary

❖Earth radiation pressure has an impact on LAGEOS´ semi-major axis. When the Earth radiation pressure modeling is applied, the semi major axis is reduced by 1.5 mm.
❖Earth radiation pressure affects the global scale by 0.07 ppb, corresponding to 0.5 mm w.r.t. the Earth's radius.
❖Station heights are affected by -0.6 mm on average, but estimated range biases absorb the differences in modeling.
❖Different radiation pressure modeling may cause some inconsistencies between the products of the ILRS Analysis Centers (Tab.1),
❖Geocenter coordinates are slightly affected by modeling of Earth radiation pressure with differences about 0.2 mm for the Z component (not shown here, see Sosnica 2013).

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