Comparison of Earth radiation pressure models for DORIS satellites

C. Rodriguez-Solano[(1)], P. Štěpánek[(2)] and U. Hugentobler[(1)]

(1) Institut für Astronomische und Physikalische Geodäsie, Technische Universität München (rodriguez@bv.tum.de)
(2) Geodetic Observatory Pecný, Research Institute of Geodesy, Topography and Cartography in Zdiby

1. Earth radiation pressure models

At low satellite altitudes the magnitude of the Earth radiation pressure, consisting of reflected (visible) sunlight and emitted radiation, can reach similar magnitudes as the solar radiation pressure. These last two forces together with atmospheric drag are the most important non-conservative forces acting on low orbiting satellites, like DORIS satellites. Consequently, the modeling of Earth radiation pressure is required for precise orbit determination.

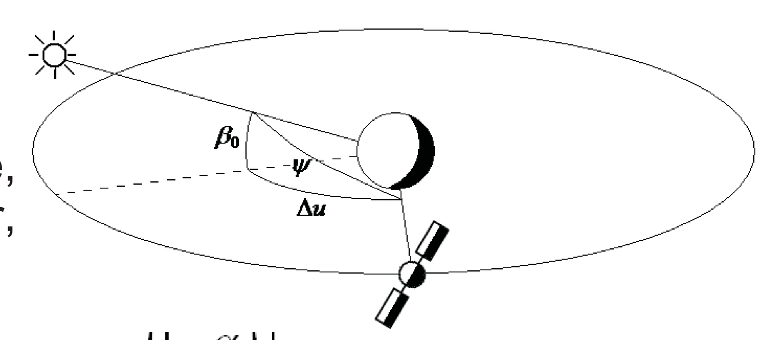
The Earth radiation pressure computation includes the follwing steps:

1) Determination of solar irradiance received by each surface element of the Earth.
2) Computation of the irradiance received by the satellite based on the reflectivity and emissivity coefficients of the Earth's surface element, assuming the Earth as a Lambertian sphere.
3) Interaction of irradiance from each surface element with the satellite macro model.

In this study different Earth radiation pressure models were investigated. In the next sections the corresponding reflectivity and emissivity coefficients for February, 2011 are shown as function of latitude and longitude. Moreover, the acceleration acting on a satellite at 700 km altitude with an area-to-mass ratio of 0.011 m^2/kg, i.e., a Cryosat-2 type satellite, is shown for all possible positions of the satellite for 12:00 UTC.

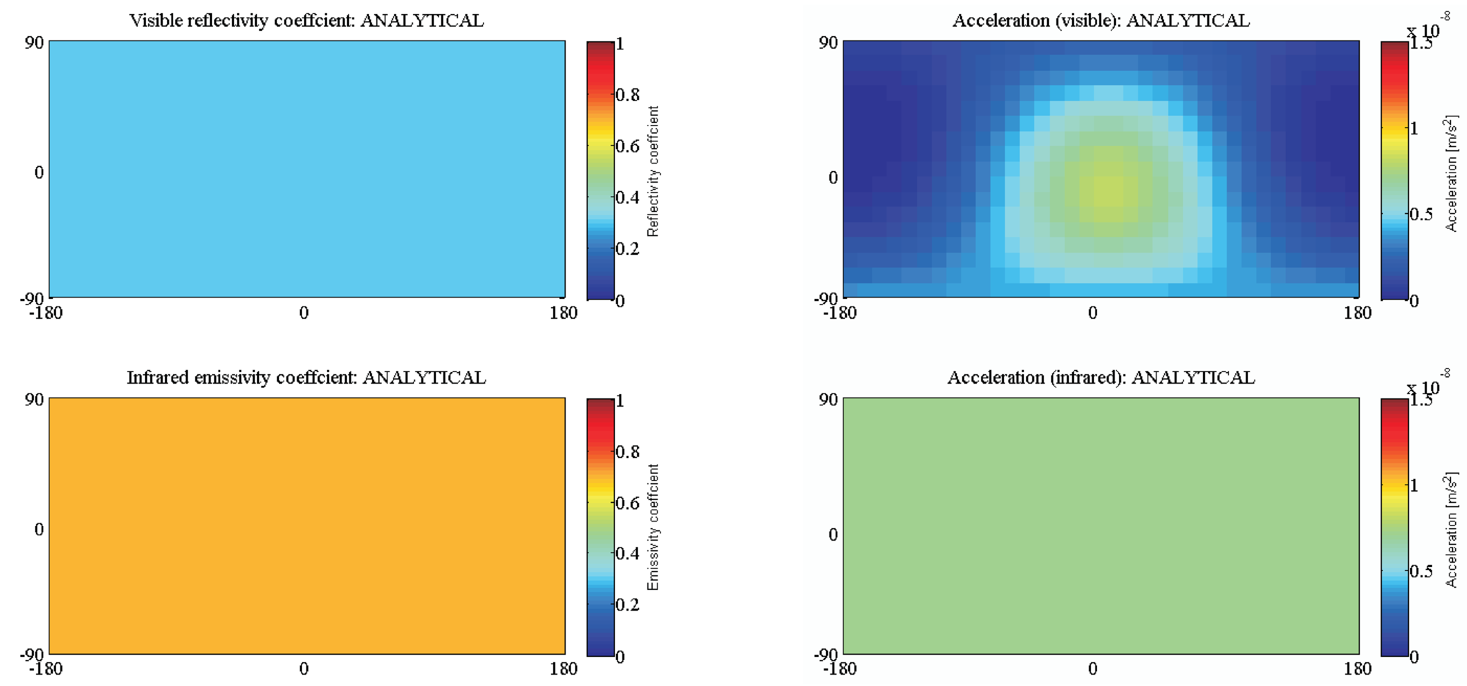
1.1 Analytical model

The albedo is assumed to be constant, i.e, reflectivity = 0.3 and emissivity = 0.7. Moreover, the Earth is considered as a radiation point.



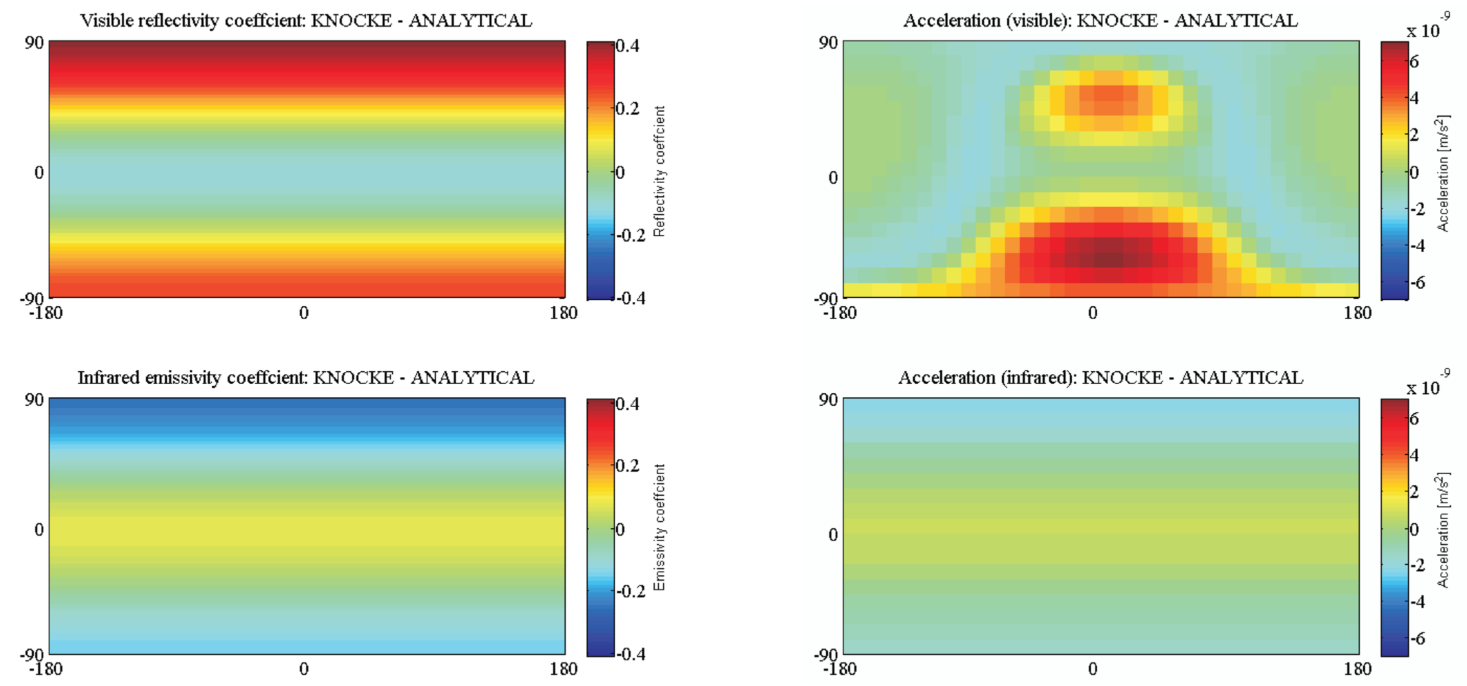
$$\vec{E}_{ERM-A}(\psi,h)=\frac{A_E E_{sun}}{(R_E+h)^2}\left[\frac{2\alpha}{3\pi^2}\left((\pi-\psi)\cos\psi+\sin\psi\right)+\frac{(1-\alpha)}{4\pi}\right]\hat{r}$$

$A_E = \pi R_E^2$, R_E = 6378 km, E_{SUN} = 1367 W/m², h = satellite altitude, α = albedo (≈ 0.3)



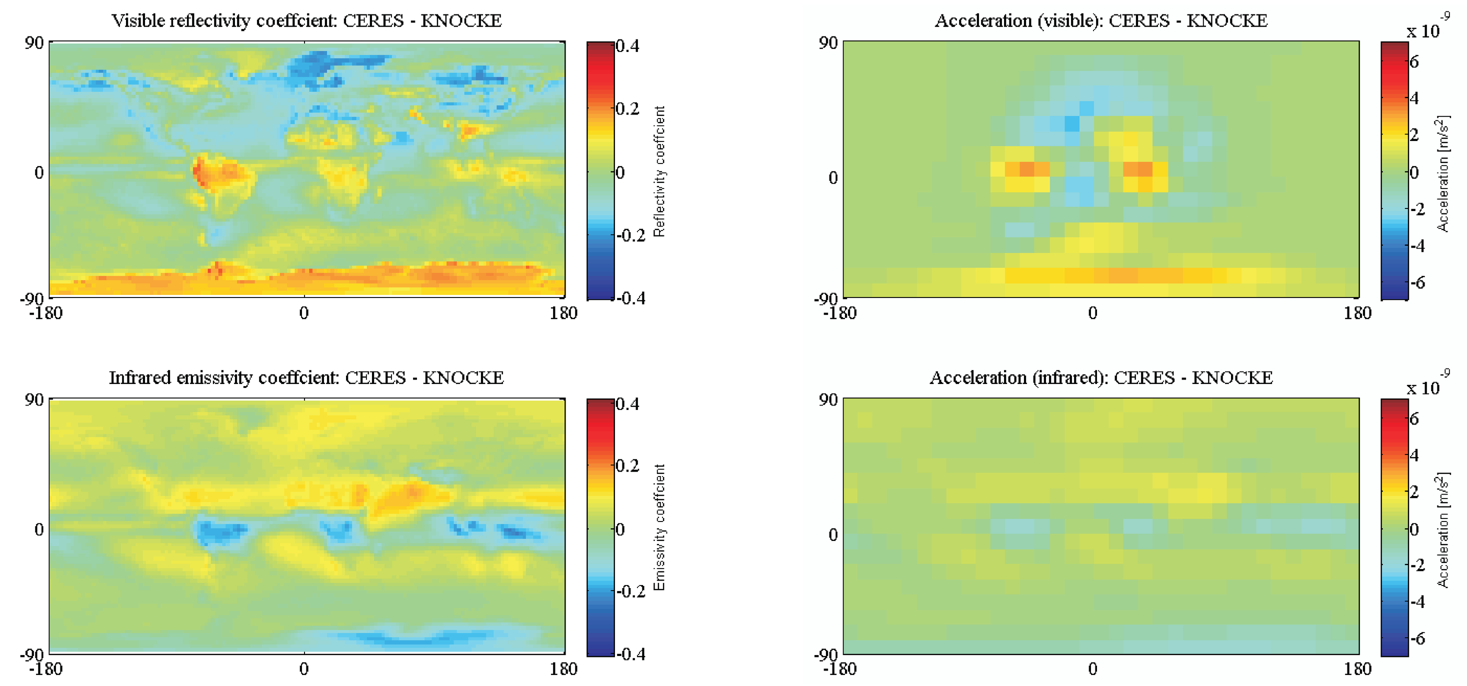
1.2 Knocke model

The reflectivity and emissivity coefficients have a latitude and time dependency (Knocke et al., 1988). Moreover, the irradiance is computed numerically using a finite Earth radius.



1.3 CERES model

The reflectivity and emissivity coefficients have a latitude, longitude and time dependency based on CERES data (Clouds and Earth´s Radiant Energy, NASA) . CERES data is monthly available with a 2.5° X 2.5° spatial resolution. Moreover, the irradiance is computed numerically using a finite Earth radius. The model is described in Rodriguez-Solano, et al. (2012) together with the impact on the orbits of GPS satellites.



2. Impact on the orbits

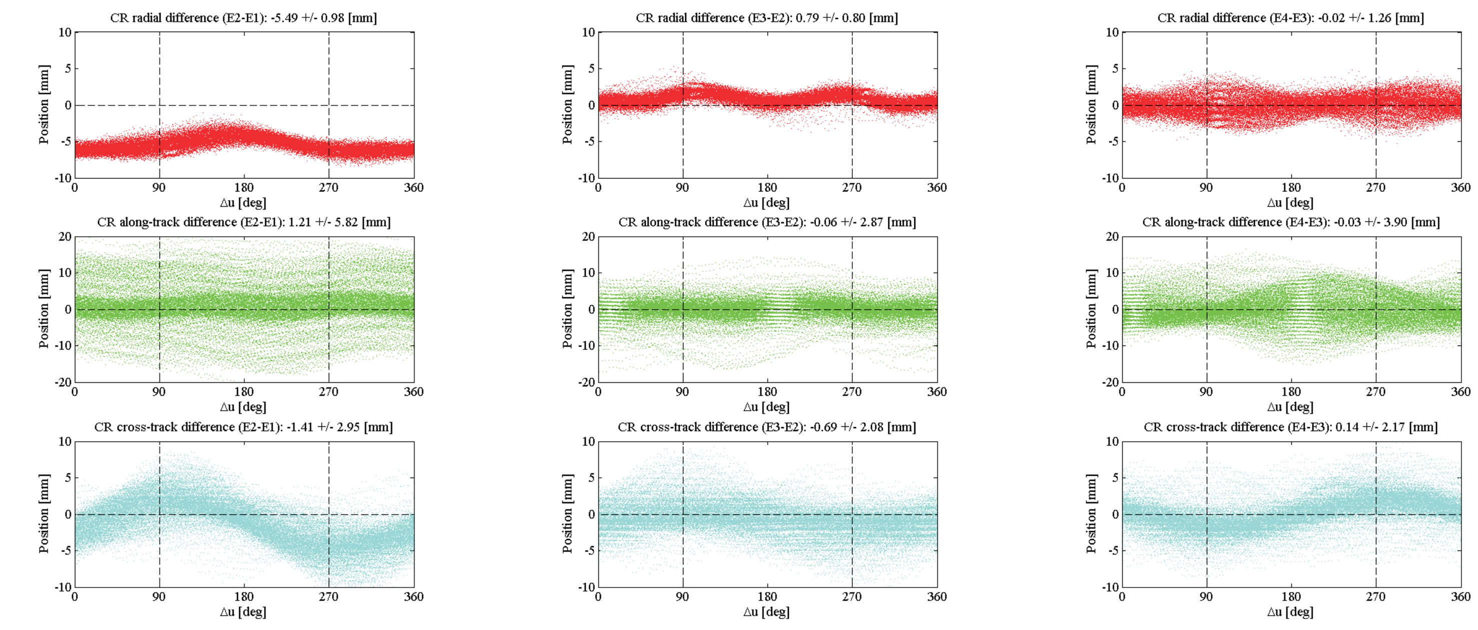
The acceleration acting on the satellites was introduced in the computation of DORIS satellite orbits to assess the impact of different Earth radiation pressure models on the orbits. The period of doy 32-63, 2011 was selected for these experiments. Here only results for Cryosat-2 and Jason-2 are shown. These two satellites have different altitudes and shapes. Cryosat-2 is at a low altitude (~700 km) and without moving parts, while Jason-2 is at higher altitude (~1300 km) and has large moving solar panels.

Earth radiation pressure was used as a priori acceleration, while for solar radiation pressure and atmospheric drag the following parameters were estimated:

- Solar radiation scaling factor of macro models, once per day.
- Atmospheric drag scaling factors for MSIS-86, every 6 hours.
- Once-per-revolution harmonics in along- and cross-track directions, once per day.

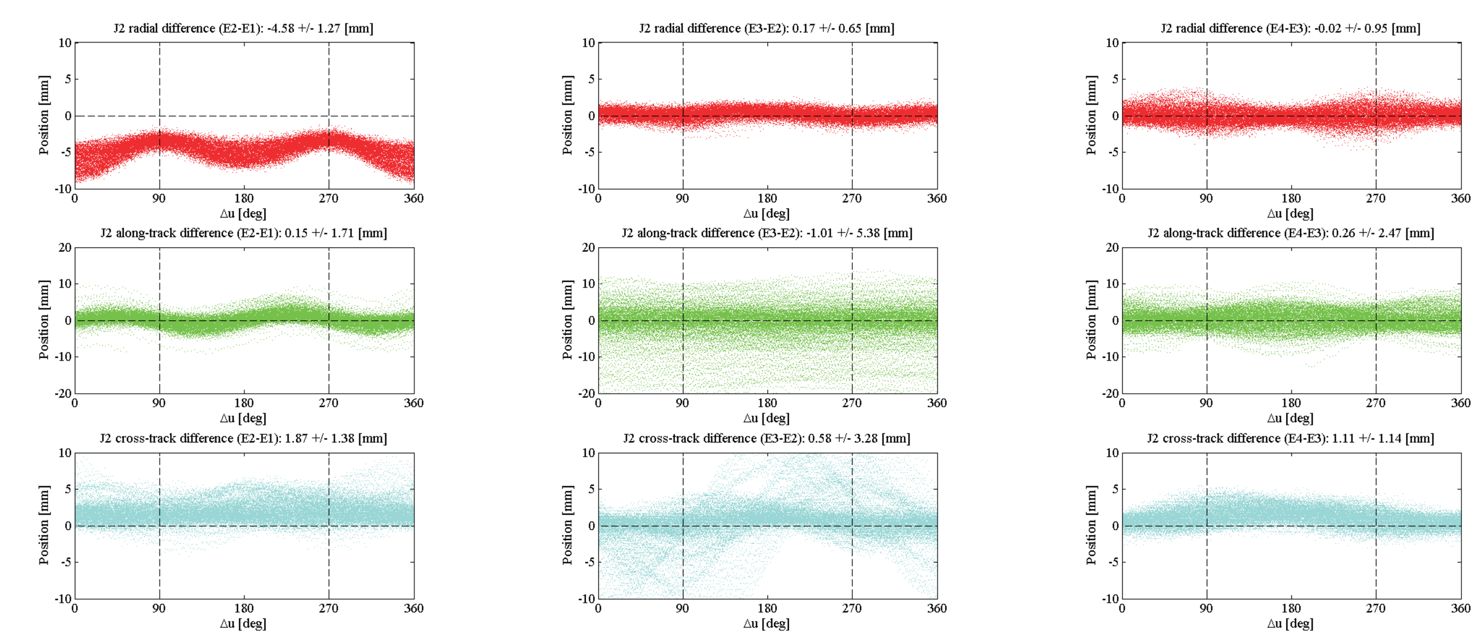
The following figures show the orbit differences in radial, along- and cross-track directions, by introducing models of increasing complexity. The orbit differences are plotted as a function of the argument of latitude w.r.t. the argument of latitude of the Sun.

2.1 Cryosat-2



Analytical vs None | Knocke vs Analytical | CERES vs Knocke

2.2 Jason-2



Analytical vs None | Knocke vs Analytical | CERES vs Knocke

2.3 Internal and external quality measures [mm]

		RMS of orbit overlaps			Mean w.r.t. SSALTO orbits			STD w.r.t. SSALTO orbits		
		Radial	Along	Cross	Radial	Along	Cross	Radial	Along	Cross
Cryosat-2	None	21.7	119.5	78.5	5.9	3.9	1.0	1.4	15.6	1.1
	Analytical	21.9	122.0	79.3	0.2	5.3	-0.4	1.3	15.5	1.0
	Knocke	21.8	133.2	78.1	1.1	5.2	-1.1	1.3	15.5	0.9
	CERES	22.4	121.0	77.9	1.0	5.2	-0.9	1.3	15.3	1.0
ENVISAT	None	40.5	113.6	73.2	4.1	6.4	0.2	1.2	17.8	1.2
	Analytical	40.7	114.4	73.9	0.7	6.7	-0.7	1.2	18.0	1.3
	Knocke	40.6	109.5	73.4	1.0	5.2	-1.0	1.1	17.6	1.3
	CERES	40.4	115.3	73.8	1.0	6.7	-0.9	1.1	18.1	1.3
Spot-4	None	43.7	172.1	127.2	1.1	13.4	-1.1	1.6	26.1	1.4
	Analytical	44.0	175.5	127.9	-2.1	13.6	-2.0	1.6	26.2	1.4
	Knocke	43.9	173.4	126.1	-1.9	12.2	-2.3	1.5	26.0	1.4
	CERES	43.7	172.1	127.6	-1.9	13.7	-2.2	1.6	25.8	1.4
Spot-5	None	32.8	131.8	83.5	0.0	-5.1	1.1	1.4	18.9	1.2
	Analytical	33.4	130.4	82.7	-3.5	-4.8	0.6	1.5	19.0	1.3
	Knocke	33.6	127.5	83.5	-3.4	-3.7	0.5	1.5	18.8	1.2
	CERES	33.0	132.4	82.8	-3.3	-4.1	0.4	1.6	19.2	1.3
Jason-2	None	17.4	104.2	94.3	5.3	-7.8	-3.9	0.9	21.2	11.0
	Analytical	16.9	105.7	94.0	0.6	-7.6	-2.0	1.2	20.9	10.3
	Knocke	17.1	105.2	93.1	0.9	-8.6	-1.4	1.1	18.7	10.6
	CERES	17.1	104.3	93.0	0.8	-8.4	-2.6	1.1	18.1	10.9

3. Conclusions

The main effect of Earth radiation pressure on DORIS satellite orbits is a radial reduction of around 5 mm. This change of the orbits improves the radial consistency to external SSALTO orbits for Cryosat-2, ENVISAT and Jason-2, while for Spot-4 and Spot-5 it degrades the radial consistency. The Earth radiation pressure models show differences at the $1X10^{-9}$ m/s² level or higher for the resulting accelerations and few millimeter in the orbit differences in radial, along- and cross-track directions. These differences between models are, however, not reflected in the orbit overlaps errors. This internal quality measure even shows in some cases a small degradation when introducing Earth radiation pressure (e.g. None vs Analytical). As next step an indepent orbit validation with SLR measurements is planned.

REFERENCES

Knocke PC, Ries JC, Tapley BD (1988) Earth radiation pressure effects on satellites. Proceedings of AIAA/AAS Astrodynamics Conference, 577-587.

Rodriguez-Solano CJ, Hugentobler U, Steigenberger P (2012) *Impact of Albedo Radiation on GPS satellites.* Proceedings of the 2009 IAG Symposia, vol. 136, 113-119.

IDS Workshop 2012, Venice, Italy