Earth radiation pressure model for GNSS satellites

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1. Introduction

Earth radiation (visible and infrared) has a small impact on GNSS due to the large distance between the satellites and the Earth. The effect on the orbits is mainly a reduction of 1-2 cm in the radial component, and smaller perturbations in the along-track and cross-track components. Despite the small magnitude of the effect it has been shown that it can partially correct the bias observed in the SLR residuals (Ziebart et al., 2007, Rodriguez-Solano et al., 2010). Earth radiation pressure also has the effect of reducing the spectra at orbit related frequencies observed in ground tracking stations displacements. Not all IGS Analysis Centers are yet modelling Earth radiation pressure.

We propose here an easy-to-use Earth radiation pressure model for GNSS satellites (GPS and GLONASS) that can eventually be used within the IGS in the operational processing as well as for reprocessing. The Earth radiation pressure model has been developed within the **IGS Orbit Modeling Working Group**.

2. Earth Radiation Model

The Earth radiation model includes: 1) the determination of the solar irradiance received by each surface element of the Earth, 2) the computation of the irradiance received by the satellite based on the reflectivity and emissivity coefficients from CERES (Clouds and the Earth's Radiant Energy System) data of the Earth's surface element, assuming the Earth as a Lambertian sphere. The irradiance from each surface element can then interact with the satellite model.

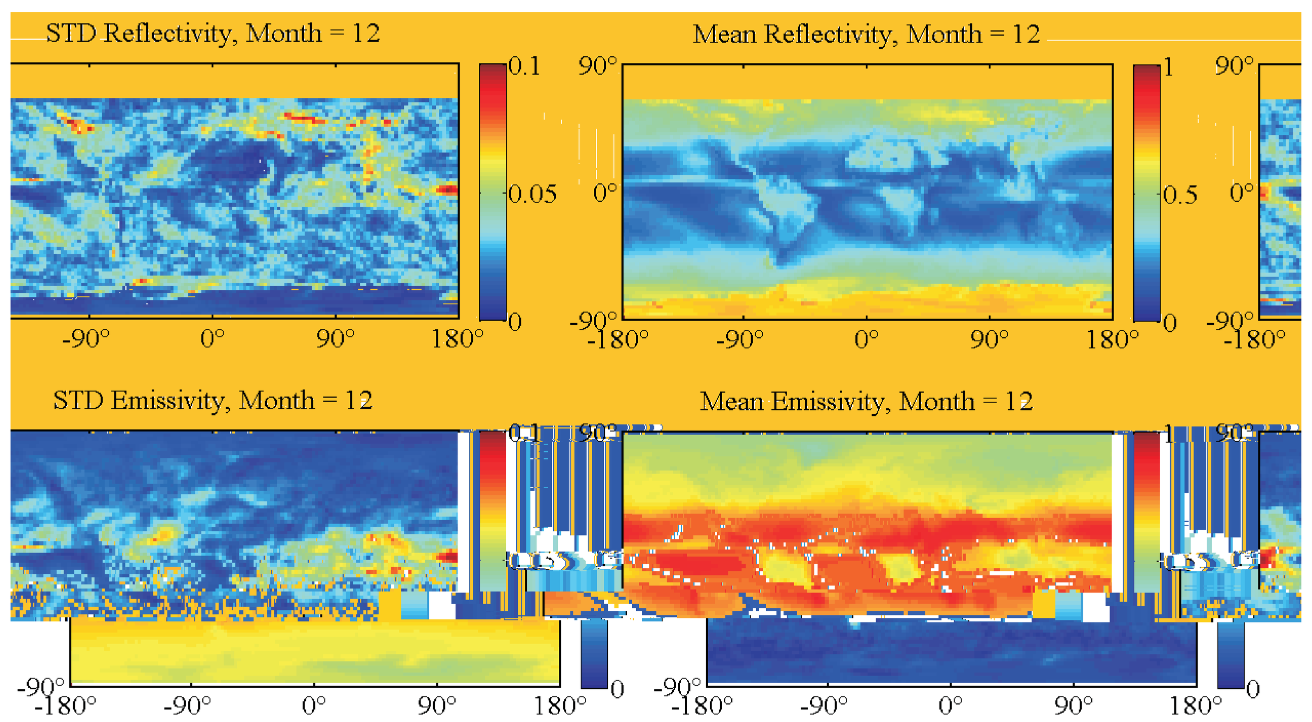

Fig. 1. Mean and standard deviation (STD) of CERES data (reflectivity and emissivity, for the month of December) derived from 10 years of data (2000-2009).

The CERES data is available from March 2000 until today (with a delay of few months). This is not enough for reprocessing or for operational use within the IGS. A model has thus been constructed by taking the monthly means of the CERES data separately for each month (Fig. 1). This simplification is justified as the impact on the acceleration is very small (Fig. 3).

3. Box-Wing Satellite Model

The use of a box-wing satellite model is a key element for the correct modelling of Earth radiation pressure (Rodriguez-Solano et al., 2010), mainly due to the change of the solar panels w.r.t. the Earth over one revolution.

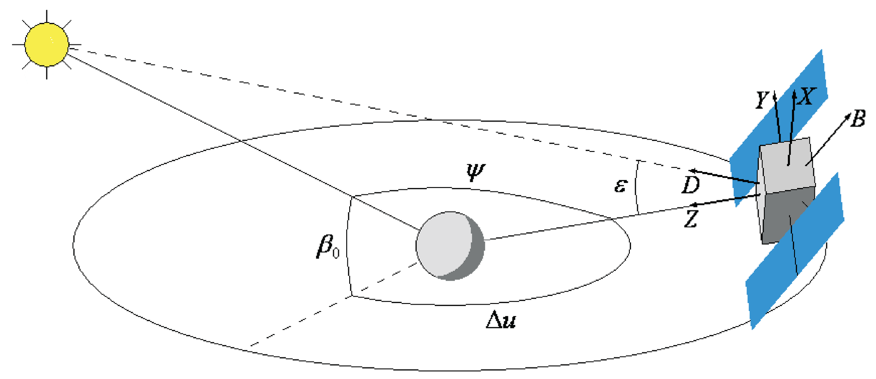

Fig. 2. Relative geometry of satellite, Earth and Sun, defined by the Sun elevation angle β_0 above the orbital plane, the argument of latitude Δu of the satellite w.r.t. the argument of latitude of the Sun and the angle ψ satellite-Earth-Sun ($\cos\psi = \cos\beta_0 \cos\Delta u$).

The GPS box-wing models are based on Fliegel et al. (1992) and Fliegel and Galini (1996) for Block IIA and IIR respectively. More recently GLONASS and GLONASS-K box-wing models have been constructed based on similar assumptions as Ziebart (2001) for the optical properties of the satellite surfaces. In a similar way, a box-wing model has been constructed for GPS-IIF, while for the new GLONASS-K dimensional data is missing.

To complete the model, the nominal attitude of the satellite is used, i.e., with navigation antennas always pointing to the Earth and solar panels always pointing to the Sun. Additionally the thrust due to the navigation antennas (around 80 Watts) is introduced as proposed by Ziebart et al. (2007).

4. Resulting Acceleration

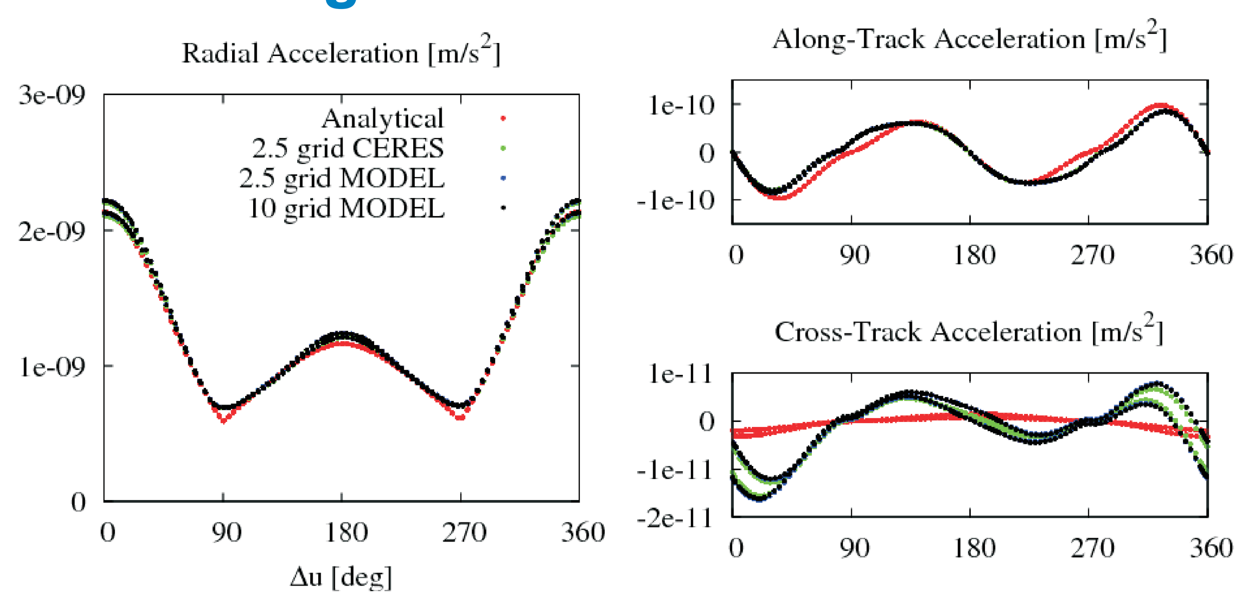

Fig. 3. Acceleration acting on PRN 01 (GPS-IIA) for day 80 of 2008, comparison of different Earth radiation models.

By combining the irradiance from each surface element of the Earth with the satellite model we obtain a force acting on the satellite. By integrating the forces over the visible part of the Earth and dividing by the mass of the satellite, we obtain the acceleration for an specific satellite position.

The impact of different Earth radiation models on the acceleration is shown in Fig. 3. The major differences are due to the analytical Earth radiation model (constant albedo = 0.3) and the model based on CERES data. Note that using the monthly MODEL of the CERES data has almost no effect on the acceleration, mainly due to the large distance between GNSS satellites and the Earth. The same is valid if the integration grid is changed from 2.5°×2.5° to 10°×10°, increasing greatly the computation speed of the model subroutine.

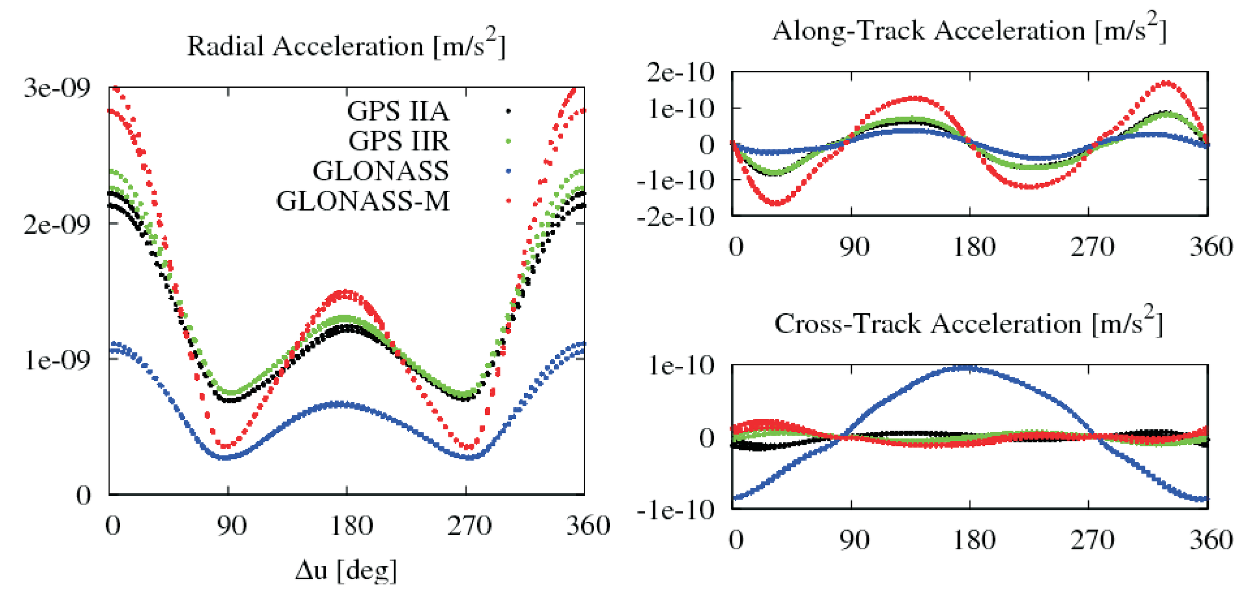

Fig. 4. Acceleration acting on different GNSS satellites*, for day 80 of 2008, using the CERES model (10° grid).

The acceleration for different types of satellites is shown in Fig. 4, where the higher area to mass ratio of the GLONASS-M satellites compared to the GPS satellites is evident. GPS-IIF also have a high area to mass ratio and the same is expected for the new GLONASS-K spacecraft.

*PRN 01 (IIA, β_0=-0.5°), PRN 19 (IIR, β=0°), PRN 101 (GLO, β_0=-53°), PRN 124 (GLO-M, β_0=1.4°)

5. Impact on GPS Station Positions

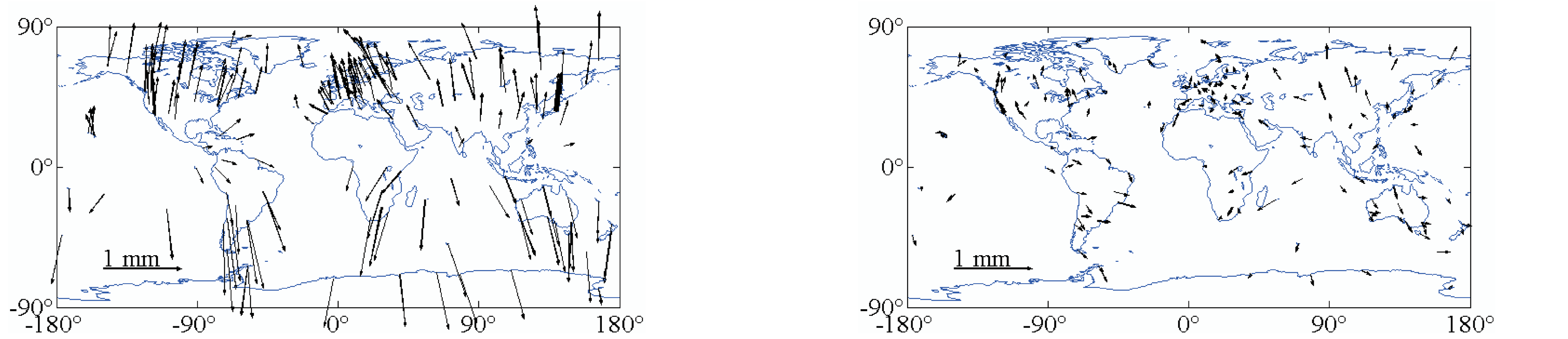

Fig. 5. Change in the horizontal position estimates of GPS ground tracking stations, due to Earth radiation pressure for: day 61 (left) and day 91 (right) of year 2007

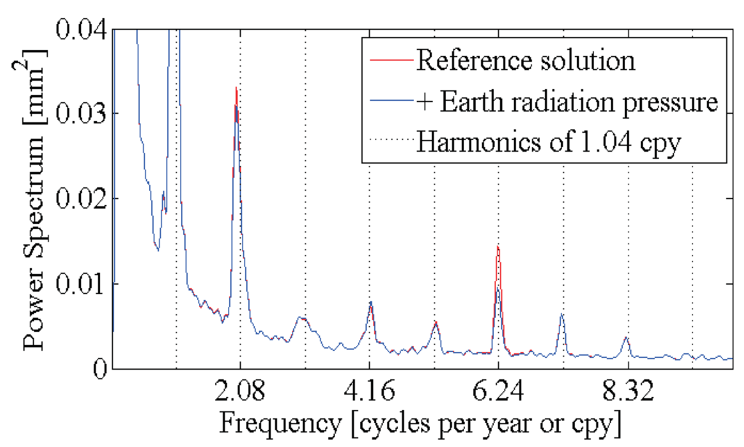

Fig. 6. North component power spectrum, with and without Earth radiation pressure, from 9 years of GPS daily position estimates (2000.0 to 2009.0).

The impact of Earth radiation pressure on the position estimates of GPS ground tracking stations is more significant, compared to the geocenter, as shown in Fig. 5. Mainly a change in the North component position estimates is found at the submilimeter level. Moreover this effect is not constant in time but has a main frequency of around six cycles per year. Therefore we find a reduction of around 38 %, at the sixth peak of the spectra of the North component (Fig. 6). This a very important result since, as mentioned by Ray et al. (2008), the sixth peak in the North component is one of the sharpest and highest.

6. Implementation Issues

The subroutine to compute the Earth radiation pressure acting on GNSS satellites is written in Fortran 77 and has the following options to be chosen:

- Earth radiation model to use (Analytical or CERES model)
- use of antenna thrust
- grid for numerical integration (2.5°, 5.0° or 10°)
- reference frame for resulting force (inertial, satellite body-fixed, Sun-fixed or radial, along- and cross-track)

The subroutine requires the following inputs:

- satellite position and velocity
- position of the Sun
- rotation matrix from inertial to Earth-fixed reference frame
- month of the year
- block type of the satellite

The only output is the acceleration vector acting on the satellite. The subroutine is available via email (rodriguez@bv.tum.de).

7. Conclusions

An Earth radiation pressure model has been developed for GPS and GLONASS satellites, the model is suitable for reprocessing or for operational use within the IGS. The model has been tested, with 9 years of tracking data, for GPS satellites (IIA and IIR) and tracking stations. The other types of satellites are implemented but not yet tested with long time series of data. The main drawback in the model is the uncertainty in the satellite dimensions, optical properties and mass, due to not enough or unprecise information. These errors, however, are expected to change the scale of the acceleration but not its general shape.

As demonstrated in previous studies, the use of Earth radiation pressure reduces the GPS-SLR anomaly and also the spectra of GPS station position at orbit related frequencies. Therefore the use of an Earth radiation pressure model is highly recommended.

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