710947 - Impact of Albedo Modelling on GNSS Satellite Orbits and Geodetic Time Series

U. Hugentobler[(1)], C. Rodriguez-Solano[(1)], P. Steigenberger[(1)], R. Dach[(2)] and S. Lutz[(2)]

[(1)]Technische Universität München, Arcisstraße 21, 80333 Munich, Germany, Email: urs.hugentobler@bv.tum.de
[(2)]University of Bern, Sidlerstraße 5, 3012 Bern, Switzerland

1. INTRODUCTION

GNSS is a vital space technique for reference system realization. However navigation satellite orbits do not contribute to the definition of the datum of the International Terrestrial Reference Frame. The reasons reside in the sensitivity of the large satellite structures to direct and indirect solar radiation pressure.

GNSS orbit modeling deficiencies cause peculiar patterns observed in Satellite Laser Ranging (SLR) residuals, which were first noted by Urschl et al. (2008) and are presented in Fig. 2. In addition, orbit related frequencies were identified in geodetic time series such as apparent geocenter motion by Hugentobler et al. (2006) and station displacements derived from GNSS tracking data by Ray et al. (2008), shown in Fig. 3 and Fig. 4. Particularly an anomalous frequency of 1.04 cpy was found, corresponding to a period of about 350 days which is very similar to the "GPS draconitic year", the repeat period of the Sun with respect to the satellite constellation, see also Fig. 1.

A probable candidate for radiation pressure mismodeling is related to Earth albedo radiation consisting of visible reflected light and infrared emitted radiation, an effect that is currently not yet included in the computation of most analysis center contributions to the IGS final orbits. Furthermore, as albedo radiation depends on the position of the Sun with respect to the satellite, it is also a good candidate for causing the observed anomalous frequency in the geodetic time series.

2. ALBEDO MODELLING

The irradiance received by an artificial satellite, due to the Earth's reflected (visible) and emitted (infrared) radiation, is calculated by:

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 (from NASA's CERES project) of the surface element.
3. Integration of irradiance over all surface elements visible to the satellite.

The irradiance at the satellite position is then used to compute the acceleration acting on the satellite by using:

1. Box-wing model based on Fliegel et al. (1992).
2. Nominal attitude, i.e., navigation antennas always pointing to the Earth and solar panels always pointing to the Sun.
3. Block specific dimensions and optical properties.
4. Thrust due to navigation antennas.

The acceleration acting on a GPS satellite is shown in Fig. 6 as a function of the satellite position along the orbit, however Earth radiation and satellite models primarily depend on the angle ψ shown in Fig. 5. More details of the models can be found in Rodriguez-Solano et al. (2009).

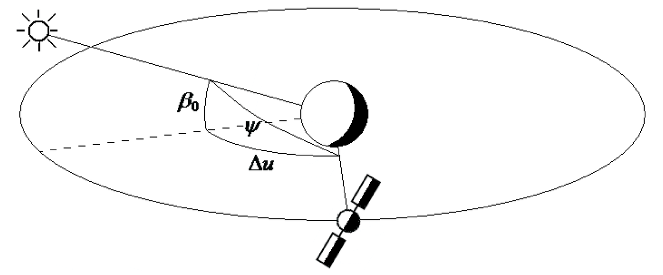

Fig. 5. The angle ψ satellite - Earth - Sun is related to the orientation of the Sun with respect to the satellite and its orbit by $\cos\psi=\cos\beta_0\cos\Delta u$.

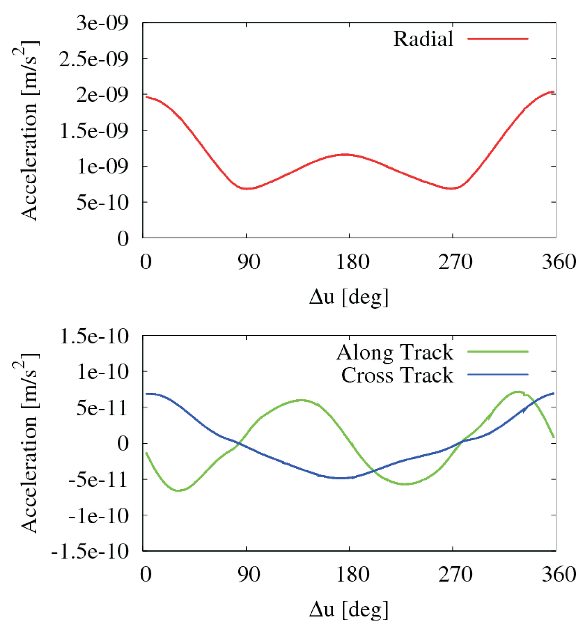

Fig. 6. On-orbit acceleration acting on the GPS satellite SVN36 for β_0=20.2° due to albedo radiation. Note that for 90°<Δu<270° the satellite mainly sees the non-illuminated part of the Earth.

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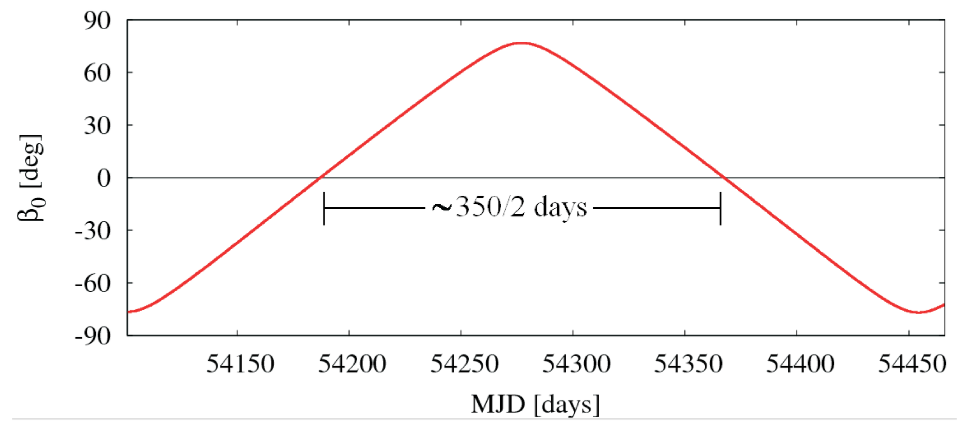

Fig. 1. Sun elevation angle (β_0) above the orbital plane for SVN36 and year 2007, see also Fig. 5.

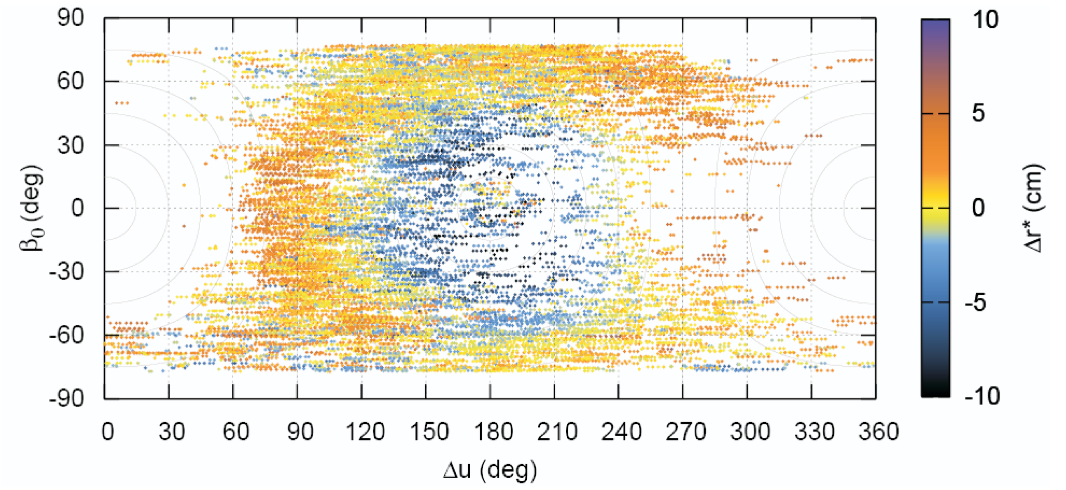

Fig. 2. SLR range residuals minus mean value for the GPS satellites SVN35 and SVN36 derived from CODE final orbits. Residuals plotted in a Sun-fixed reference system, see also Fig. 5. Urschl et al. (2008).

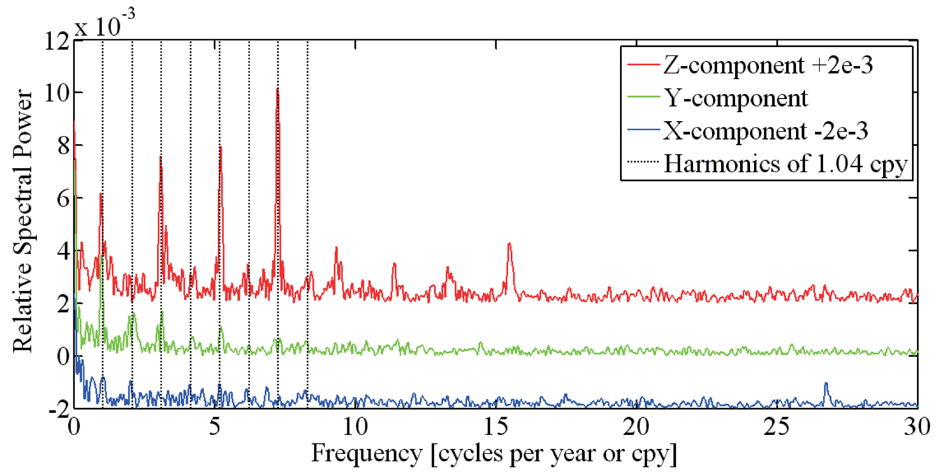

Fig. 3. Spectra for the daily geocenter coordinates estimated from 2000.0 to 2009.0. No albedo model included. The harmonics of 1.04 cpy correspond to the period of 350 days.

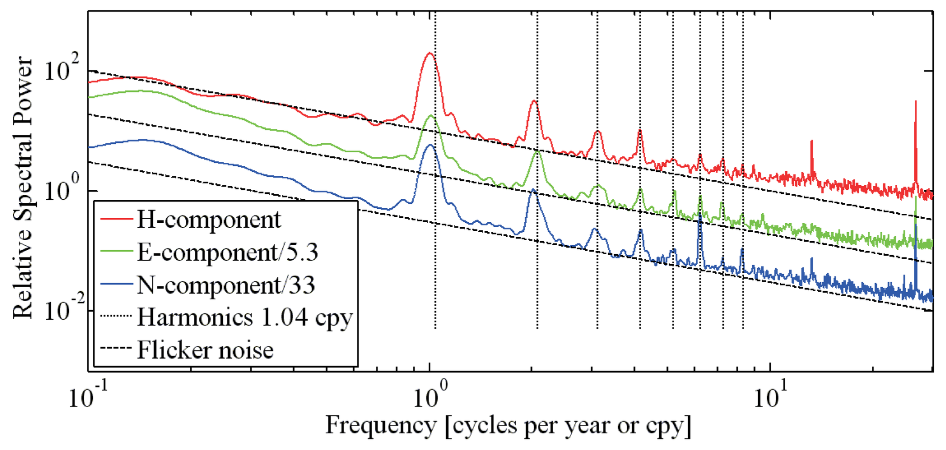

Fig. 4. Spectra for GPS daily station position estimates from 2000.0 to 2009.0, without albedo. 201 IGS sites with more than 38% of data used in the computation of a Lomb-Scargle periodogram, employing the same procedure as Ray et al. (2008).

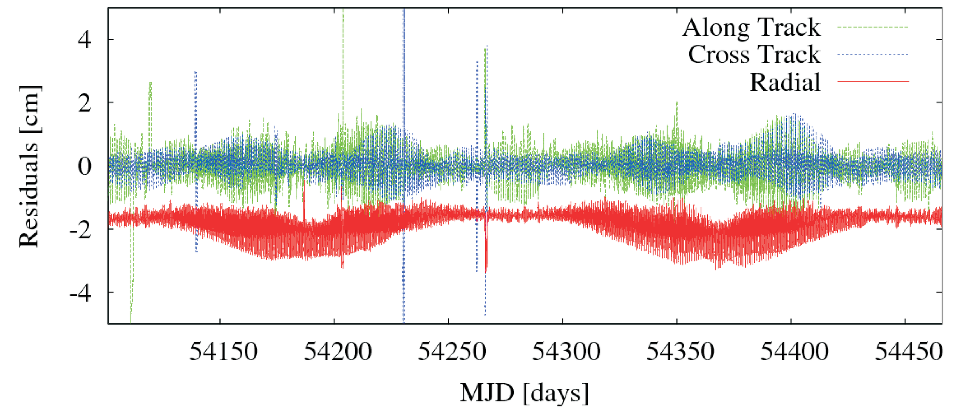

Fig. 7. Residuals of GPS orbits with albedo minus orbits without albedo for SVN36 and year 2007.

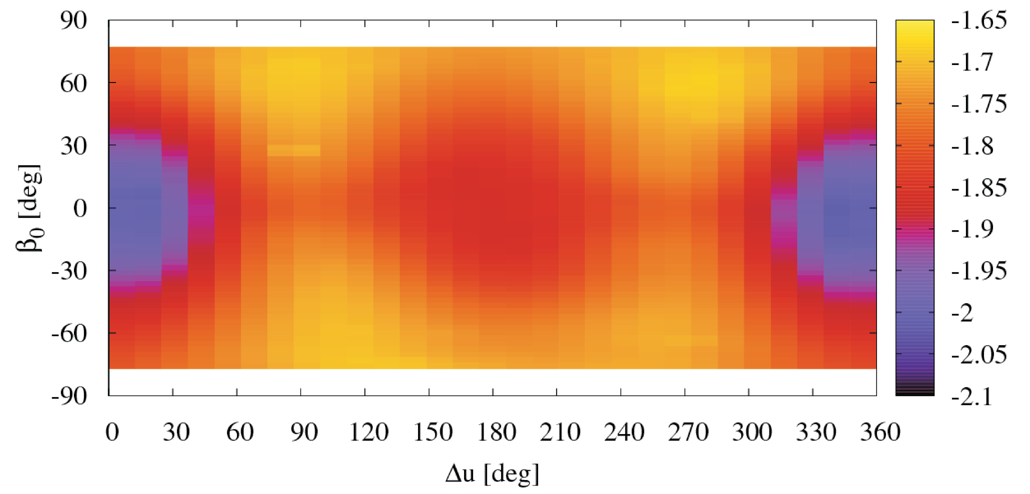

Fig. 8. Radial residuals in cm of GPS orbits with albedo minus orbits without albedo for SVN36 and year 2007 in a Sun-fixed reference system.

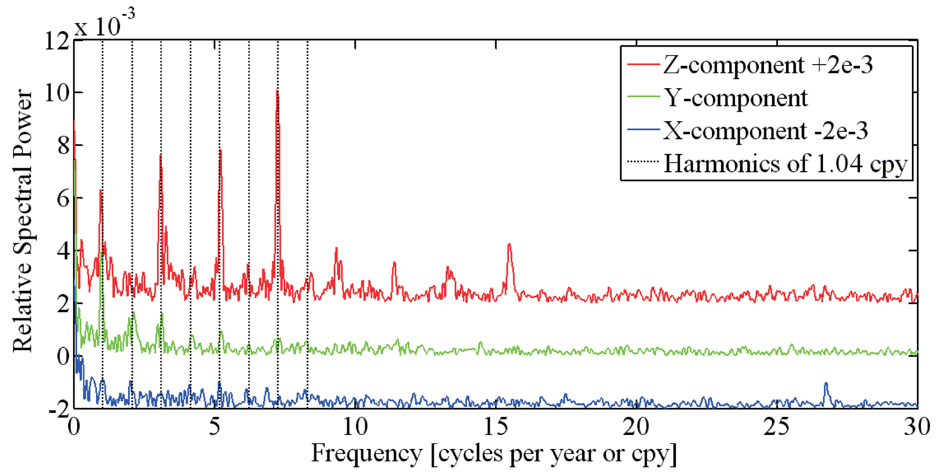

Fig. 10. Spectra for the daily geocenter coordinates estimated from 2000.0 to 2009.0. Albedo acceleration included in the orbits.

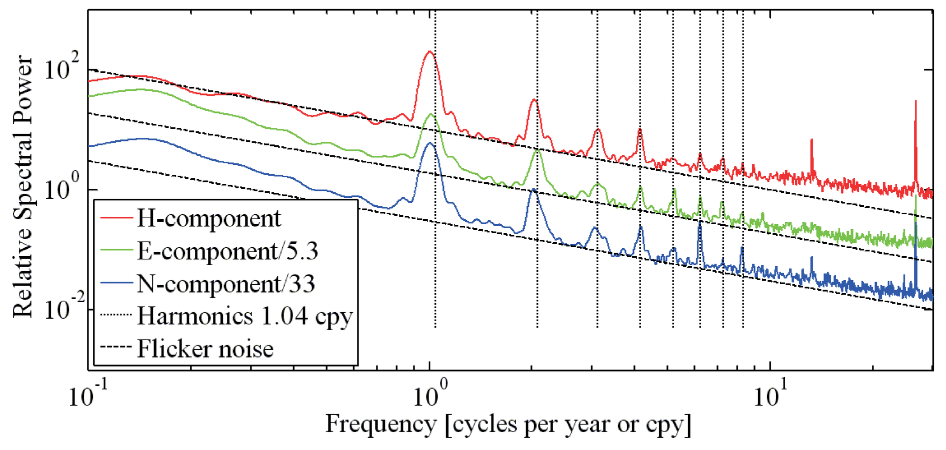

Fig. 11. Spectra for GPS daily station position estimates from 2000.0 to 2009.0. Albedo acceleration included in the orbits.

3. IMPACT ON GPS SATELLITE ORBITS

The acceleration induced by albedo radiation was introduced in the estimation of GPS satellite orbits, by employing the processing scheme of the CODE (Center for Orbit Determination in Europe) with the Bernese GPS Software, see for example Steigenberger et al. (2009). In total one year (2007) of GPS tracking data from about 190 IGS stations was analyzed.

Fig. 7 shows the differences between the orbits that include albedo radiation and orbits determined with no albedo for SVN36. As one prominent feature one can observe the radial offset between the orbits. As already noted by Ziebart et al. (2007) this effect reduces the aberrant SLR - GPS anomaly by 1-2 cm. The reason for this radial reduction of the orbits is that GPS measurements, being essentially angular measurements due to required clock synchronization, mainly determine the mean motion of the satellite. As a matter of fact, a constant positive radial acceleration (equivalent to a reduction of GM) decreases the orbital radius according to Kepler's third law.

Note also the dependency of the radial orbit differences (Fig. 7) with respect to the Sun elevation angle above the orbital plane (β_0) plotted in Fig. 1. Consequently this kind of perturbation should have a main repeat period close to half of the "GPS draconitic year", that is about 350/2 days.

The radial orbit differences are also plotted in a Sun-fixed reference system in Fig. 8. We observe a significant radial deformation of the orbits as a function of satellite position with respect to the one of the Sun that resembles the pattern observed by Urschl et al. (2008) in Fig. 2 for SLR residuals on the night-time side of the Earth. The amplitude of the effect is, however, only about 2 mm compared to the 5 cm effect in Fig. 2. Note, however, that such a pattern is not present for a simple satellite model without solar panels, where we would see a minimum in the radial acceleration for 90°<Δu<270° instead of a local maximum as shown in Fig. 6.

Finally in Fig. 9 the change of two out of five estimated radiation pressure parameters due to albedo is shown. Albedo acceleration mainly acts on the plane containing satellite, Earth and Sun, defined also by the D and X directions in a Sun-fixed coordinate system. The change is one order of magnitude lower than the albedo acceleration (Fig. 6) but indicates that these parameters can partially absorb this effect.

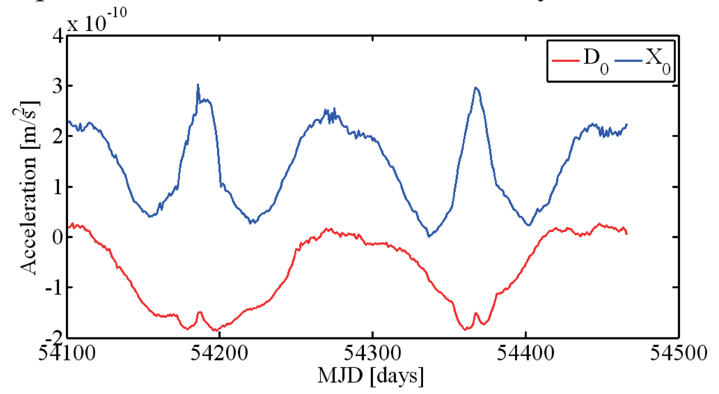

Fig. 9. Change of radiation pressure parameters estimated by CODE: albedo minus no albedo. D_0 is acting in the Sun direction and X_0 is perpendicular to the Sun direction and to the solar panels axis.

4. IMPACT ON GEODETIC TIME SERIES

The impact of the albedo radiation on the geodetic time series was studied by computing the geocenter and global station coordinates for 9 years of GPS tracking data (2000.0 to 2009.0), as it is done by CODE.

Although the impact of albedo acceleration on the orbits has a repeat period close to half of the "GPS draconitic year", there is no significant difference by including this type of acceleration in the spectra of the geocenter and station coordinates, as can be seen in Fig. 10 and Fig. 11.

The reason for the very small impact on the spectra could be that there is still a non-modeled effect on the GPS orbits, which is larger than the albedo radiation and which also has a periodicity of 350 days. A probable candidate for orbit mismodeling is then the direct solar radiation pressure. On the other hand, Ray et al. (2008) suggested that the anomalous frequency observed in the GPS time series could be caused by multipath at the receivers.

5. CONCLUSIONS

The acceleration caused by albedo radiation has a non-negligible effect on the orbits of GPS satellites, this effect is mainly a mean reduction of the orbit radius by about 1 - 2 cm. The radial orbit differences obtained by considering an albedo model based on a box-wing satellite model show a prominent dependency of the satellite's position with respect to the direction of the Sun. The corresponding pattern (Fig. 8) has similarities to the pattern found by Urschl et al. (2008), see Fig. 2. The size of the effect is, however more than a magnitude smaller. Nevertheless, albedo may have the potential to explain a part of this behavior.

The results of our study clearly indicate consistently with the findings of Ziebart et al. (2007) that albedo radiation as well as antenna thrust should be considered for high precision GPS orbit determination. However, the impact of albedo radiation on the geodetic time series is found to be very small and the anomalous frequencies observed in the geocenter and station coordinates computed from GPS tracking data remain yet without an explanation.