

Analytical SRP Model for GLONASS: Initial Results

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1.0 Introduction

The surface area of the GLONASS IIV solar panels (23.616m^2 , cp. GPS block II panels: 10.866m^2) (Fliegel et al, 1992, and GEOZUP, 1998) makes it intuitively obvious that solar radiation pressure (SRP) is a significant perturbing acceleration on the GLONASS orbit. Although the effects of SRP on an orbit can be estimated empirically with great precision for highly redundant solutions (Beutler et al, 1994), analytical models are useful for reducing the number of parameters in a solution, for data processing where fewer observations are available and for interpolating to intermediate epochs when using precise orbits. Furthermore, analytical models enable greater insight into the physical processes. However, accurate analytical models can be difficult to compute for spacecraft of complex shape, such as the GLONASS IIV satellite (see fig.1). This is principally due to the effects of spacecraft components shadowing each other, and because of secular and other periodic variations, possibly due to attitude control limitations (Kuang et al, 1996) and weathering of the spacecraft materials. Furthermore, accurate data for the spacecraft materials and dimensions are not always available.

The objective for this study was to develop a method for computing analytical SRP models for spacecraft of complex shape. Thereafter, apply the algorithm to the GLONASS IIV satellite and test the model.

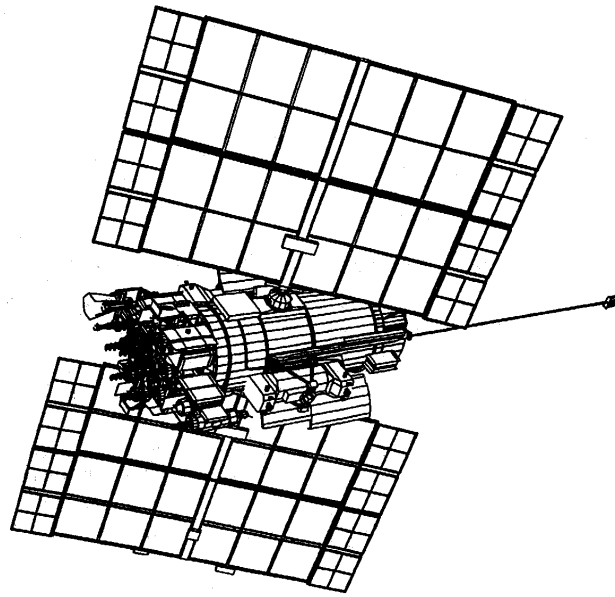


Figure 1: GLONASS IIv spacecraft

2.0 Method

2.1 Algorithm for computing the SRP model

The spacecraft structure is broken down into a composite of regular and irregular polygons bound within planar surfaces. The software reads a user defined file of component vertices, in a body-fixed coordinate system, and computes the equation of the plane of, and the normal to, each component. Cylindrical components are tessallated by the software into thin, planar strips. The file also includes the specularity and reflectivity coefficients for the surface materials.

The photon flux is simulated with a pixel array. This is a grid of small rectangles in a plane orthogonal to the Sun-spacecraft vector. The user specifies the resolution of the array. See figure 2. Each pixel is converted to a ray by adding the normalised Sun-spacecraft vector to the pixel coordinates. This ray is then projected towards the spacecraft and tested for intersection with the spacecraft components.

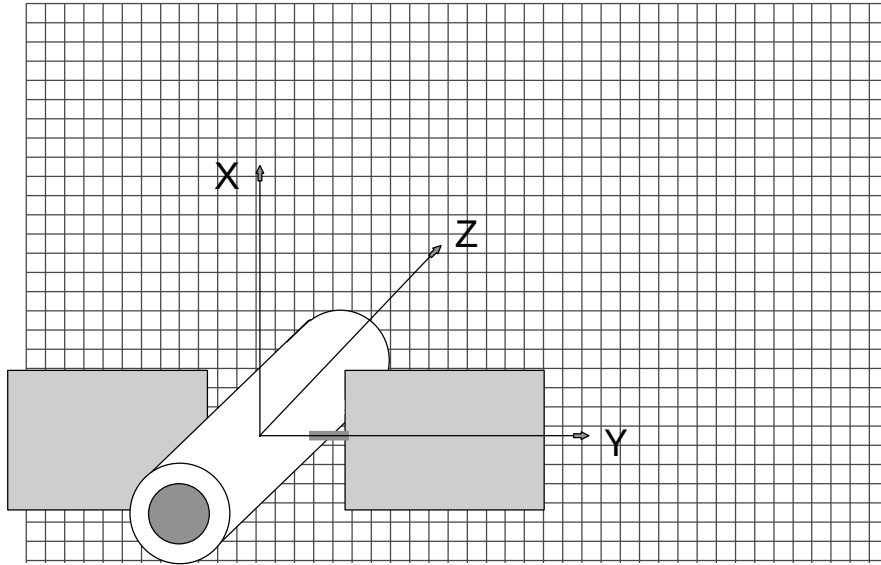


Figure 2: Body-fixed coordinate system and pixel array

The intersection test works as follows. For each spacecraft component the equation of the plane is calculated. If the ray is not parallel to the plane the intersection point of the plane and the ray is found. A point-in-polygon test determines whether the intersection point is within the limits of the spacecraft component. See figure 3. If the spacecraft component can be intersected by the ray, the length of the vector from the centre of the pixel to the intersection point is calculated. This is carried out for all spacecraft components which the ray intersects. The intersected component with the shortest associated ray is the surface struck by the light represented by the pixel.

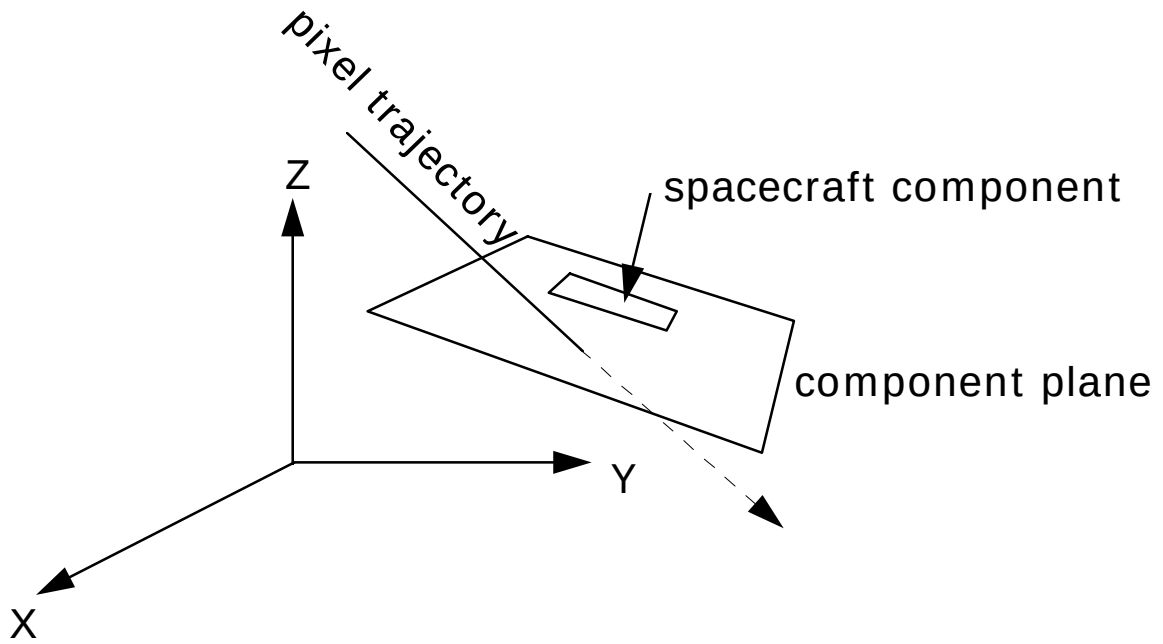


Figure 3: Pixel trajectory intersects component plane

The reflectivity and specularity coefficients of the struck component, and the angle between the normal to the surface and the ray, are used to calculate the force due to the light both normal and tangential to the surface. Hence, these forces are resolved into body-fixed axis components.

This process is carried out for all the pixels in the array, and the accelerations are added together. This computes the SRP acceleration on the spacecraft for one Sun-spacecraft vector. The user specifies a rotation angle, and this is used to rotate the pixel array about the spacecraft Y-axis, simulating a new Sun-spacecraft vector. Any spacecraft component that changes in orientation with respect to the body-fixed axes as the Sun-spacecraft vector changes is adjusted accordingly. The integration over the pixel array is carried out again. The pixel array is rotated in steps of the rotation angle until 360° has been swept out. This produces a set of data points corresponding to the SRP acceleration on the spacecraft at a set of unique angles of incidence.

A Fourier series is fitted to the data for the spacecraft X- and Z-axes, using the so-called EPS (Earth-probe-Sun) angle as the independent variable (conventional models assume that the spacecraft Y-axis is parallel to the solar panels and hence normal to the photon flux direction, therefore, in theory, there will be no Y-component due to SRP) (Beutler, 1996). Hence, knowing the positions of the spacecraft and the Sun at a particular epoch, the series can be used to calculate the acceleration of the spacecraft due to SRP.

2.2 Orbit Integration

The model is tested by calculating the spacecraft trajectory using a dynamic model alone (that is the trajectory is not constrained by range measurements from reference station receivers or SLR). The initial conditions are taken from the IGEX-98 precise orbits, and the resulting trajectory is compared to the statistically determined trajectory at 15 minute intervals.

In order to incorporate the developed SRP models the integrator was written by the author. At this stage the dynamic model consists of:

- 1) spherical harmonic coefficient model of Earth gravity to degree and order 4 (EGM96)
- 2) solar gravity
- 3) lunar gravity
- 4) custom SRP model

Because of the limited gravity field expansion the results for this study are given over three hour integration periods, that is, arc lengths of approximately 35,000km.

The integrator uses a Runge-Kutta four-step procedure and Cowell's method. Given the low eccentricity of the GLONASS orbit and the slow variation of the dynamic parameters this should give adequate results.

3.0 Results

The results are calculated by differencing the integrated trajectory (using various force models) with the CODE precise trajectory.

The results presented are for GLONASS PR4, over a three hour trajectory starting from 1998 10 26 0h 0m 0s UTC. These results are typical for the arcs integrated so far in the study, which are all from the same day. The model assumes that the spacecraft thermofolds are in the closed position.

The first set, charts 1-3, contrasts the integrated trajectory derived from the available gravitational force models alone (Earth degree and order 4, solar and lunar point mass gravity) with the dynamic model using the gravitational forces and the analytical SRP model. The residuals are in the ECEF coordinate system.

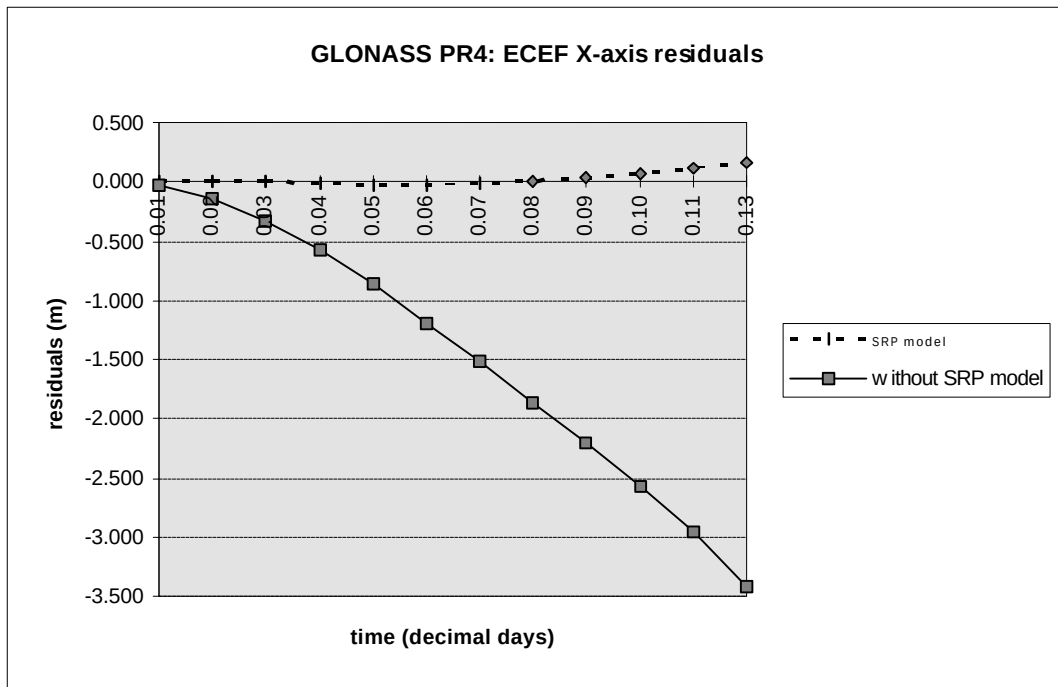


Chart 1

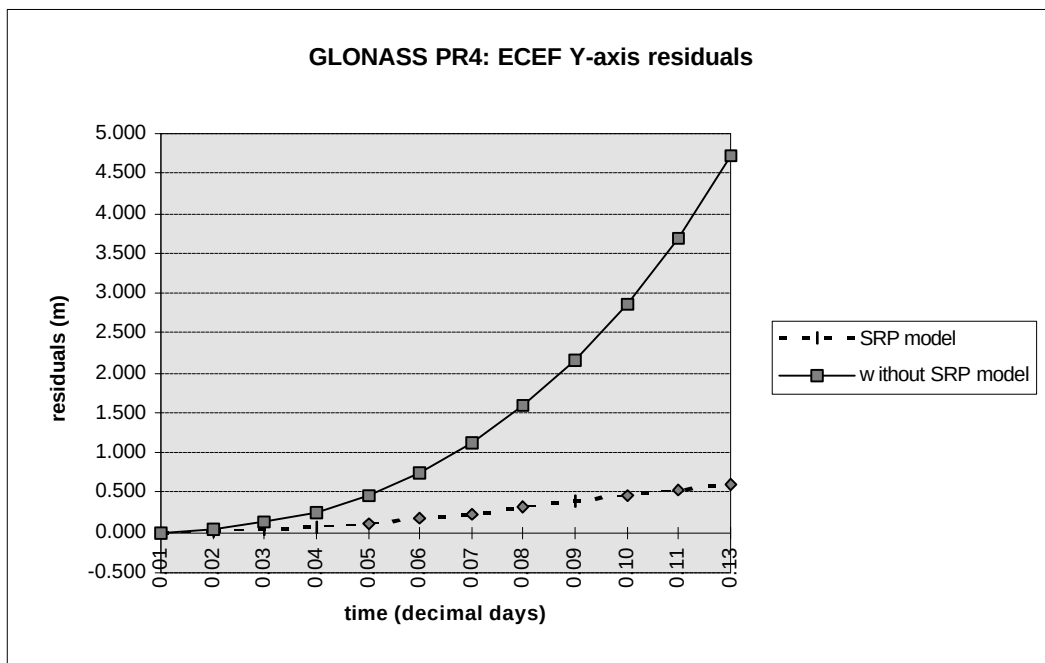


Chart 2

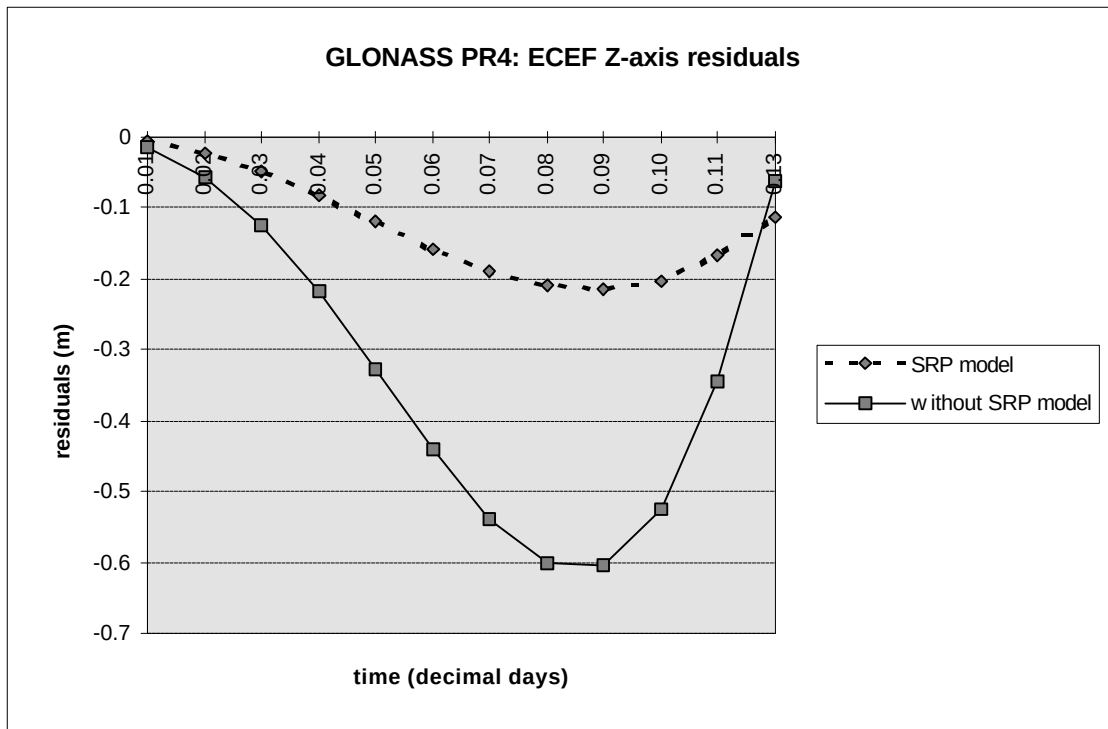


Chart 3

Chart 4 compares the residuals for the SRP model trajectory in the ECEF X, Y and Z axes.

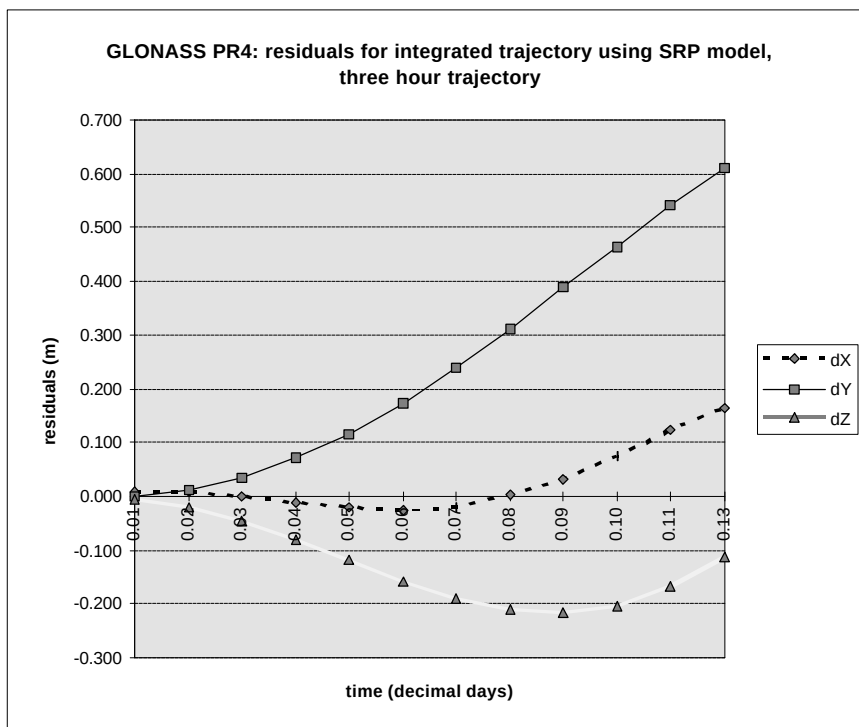


Chart 4

4.0 Discussion

To accurately assess the analytical SRP model by means of orbit integration would require complete modelling of all other non-negligible forces acting on the spacecraft, as well as a known reference trajectory with no errors. As the GLONASS constellation is in a lower orbit compared to GPS it is more sensitive to higher order gravity terms in the Earth gravity field spherical harmonic expansion, although the ground track repeat pattern for GPS can cause resonance effects which would be much smaller for GLONASS (the GPS ground track repeats daily, to a first approximation, whereas GLONASS repeats every eight days). The author intends to extend the gravity field modelling for the orbit integration to degree and order 10, and to include contributions due to the gravity of Jupiter, Saturn, Mars and Venus, as well as tidally induced variations to the potential. Whilst this is readily achievable there are more problematic areas:

- 1) due to the size of the solar panels, and the average altitude of the orbit, albedo and atmospheric drag may be non-negligible. Both of these are difficult to model accurately due to the chaotic nature of the environment variables.
- 2) thermal re-radiation
- 3) the position of the spacecraft thermofolds as a function of time or temperature
- 4) assumptions about the surface material properties (this model has assumed weathered aluminium for most of the bus components, and solar panel materials identical to GPS counterparts)
- 5) the precise attitude of the spacecraft (noon-day turns, accuracy of the boresight pointing and sensing of the Sun's position)
- 6) lastly, unpredictable yawing of the spacecraft during eclipse periods

Having outlined all these problem areas it is clear from the results that the initial SRP model developed for this study is a significant improvement to the dynamic model for the spacecraft. The modelling algorithm successfully copes with the complexity of the spacecraft form and allows the investigator to vary the modelling parameters to assess improvements in accuracy. These might include varying the resolution of the pixel array, increasing the number of points at which the acceleration on the spacecraft is computed (the model used in the study used a pixel resolution of 10mm and calculated the acceleration at intervals of 36° in the EPS angle), and setting higher precision for the Fourier coefficients as well as increasing the number of terms in the series. For precise orbit applications the estimation of empirical scaling factors would compensate for most of problems 1-5. Problem 6 can be avoided by simply screening for periods of eclipse. The analytical model itself can be improved by the following:

- adapt the SRP modelling algorithm to take into account the light reflected from one spacecraft component onto another (work in progress)
- if the thermofold position is related to the central bus temperature some attempt at modelling may be feasible
- assess secular and periodic variations in the solar irradiance value by using the empirical SRP scaling factor data provided by IGS global network analysis of GPS

5.0 Conclusions

A new algorithm for computing analytical solar radiation pressure models has been developed. The principal advantage of this pixel array algorithm is that it handles complex shapes in an efficient and accurate manner, particularly with respect to accounting for the shadowing of components. The algorithm has been successfully applied to the GLONASS IIv spacecraft. Integration of the spacecraft second order differential equation of motion, incorporating the developed SRP model, over a three hour trajectory, results in residuals of the order of 0.5m when compared to the precise orbit produced by CODE. Further developments have been outlined to improve and test this model over longer arcs.

6.0 REFERENCES

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