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Measuring the Earth's global radiation balance through orbital dynamics

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Abstract

We study the possibility of estimating the global scattered radiation flux of the Earth by its radiation-pressure effect on satellite orbits. We perform numerical simulations of typical GNSS orbits, computing various estimates of the magnitude of this effect. We find that changes to orbits caused by reasonable changes in Earth albedo are within detectable limits of modern observational technology, as long as other perturbing forces are modeled well enough.

1 Introduction

We are studying the retrieval of the spherical albedo and net scattered (short-wave) radiation of the Earth from the perturbations caused by the planet's radiation on the dynamics of its satellites. The spherical or Bond albedo gives the ratio of the fluxes incident on and scattered by the planet. The net radiation represents the net heat input into the planet's climate system and drives changes in its atmospheric, surface, and ocean temperatures.

The spherical albedo is the average of the surface albedo of the Earth, which varies greatly depending on the terrain. The polar ice caps have albedos as high as 0.7 while forests and the sea are darker. The global albedo of the Earth is approximately 0.31.

The radiation flux from the Earth illuminates orbiting satellites, which causes a radiation-pressure force. The direction and magnitude of this force depends on the satellite's position in orbit, but generally it causes a radial pressure away from the Earth of some nano-Pascals. For a typical GNSS satellite cross section, this is an acceleration in the order of 10^{-10} m/s^2 [1, 2]. A related radiation-pressure force is caused by the thermal (long-wave) radiation, from emission of absorbed Solar energy, which must be modeled similarly, but has a different distribution on the Earth's surface.

Satellite laser ranging (SLR) is a method of measuring distances to satellites using precise timing of laser pulses. Many satellites, such as the Russian GLONASS and European Galileo GNSS satellites, are equipped with laser retroreflectors, which allow laser ranging to high altitude orbits. Ranges to satellites from a ground station can be measured with an accuracy of centimetres, depending on the satellite altitude and SLR system specifications.

The ultimate aim of the study is inverting the problem and estimating the Earth albedo based on observations of satellites. Observing the orbital positions of a constellation of satellites surrounding the Earth, like GLONASS and Galileo, could provide simultaneous global information on the radiation flux of the Earth.

Modeling these forces truly accurately requires a detailed treatment of the spacecraft shape and reflection properties. Advancement of these techniques is one of the sub-goals of this project.

2 Methods

Here we investigate the effect of the spherical albedo on satellite orbits with the help of a simplified model. We simulate the propagation of satellite orbits using a new orbital simulation software. The simulation can be configured to take into account any combination of the main perturbing forces on medium and high Earth orbits [3].

The orbits studied were Galileo-like, with 56° inclination and a 14-hour period. The orientation of the satellite is derived from the yaw-steering attitude model used by GNSS satellites. In this early study, we use a box-wing satellite model for computational efficiency, though an arbitrary triangulated shape model can be used. A BRDF consisting of diffuse and specular components is used for the satellite surface.

We assume a diffusely reflecting Earth with a two-component surface albedo. The albedo in the polar regions is varied. A range of albedo values is studied, covering annual variation and conceivable future changes. The changes in orbits are charted as a function of the albedo and orbital plane (relative to the solar direction).

3 Conclusions

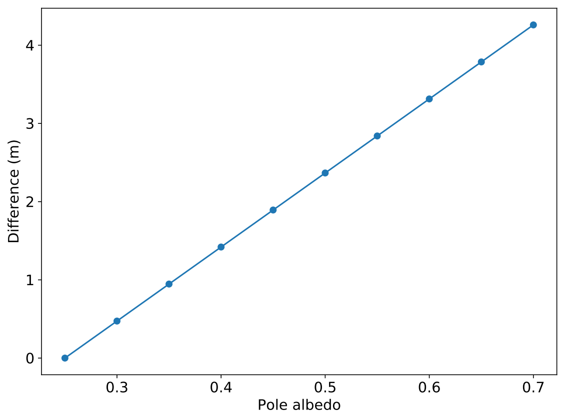

Figure 1: Relative displacement of the satellite after one orbit as a function of polar albedo, while the mid-latitude albedo is held constant at 0.25.

We find that under the influence of only the Earth-reflected radiation pressure, there is a clear linear relationship between the Earth's albedo and a displacement in the satellite's position after one orbit (Figure 1). This change is in the tens of centimetres range for albedo variations of 1%. These kinds of changes are theoretically detectable with modern SLR systems. The main caveat is that the other perturbative forces, particularly the Solar radiation pressure, must be modelled well enough to separate the Earth radiation pressure clearly. These are still areas of improvement in this modelling.

These results suggest that inversion of the global reflected radiation flux from changes to the orbits in a constellation of GNSS satellites is feasible.

Acknowledgements

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