Space sunshade for global warming mitigation : dynamics and station keeping

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Abstract. A steady rise in worldwide temperature has prompted investigations into different approaches to combat global warming. Geoengineering, or manipulation of Earth's climate from external to it, has been considered as a climate mitigation strategy since the 1980s [1,2]. Here, space-based solar shades are used to reduce the amount of sunlight received on Earth. Different solar shades are considered, and the associated dynamics and efficacy are examined.

Introduction

The most popular solar shading concept is a shade mounted at L1, the Lagrange point between the Earth and the Sun, at 1.5 million km from the Earth. L1 is a saddle point with motions along the Earth-Sun direction being unstable and along the normal direction being stable. The instability results in the need for station keeping manoeuvres, with actuations Δv averaging about 1-2 m/s per annum [3]. A second alternative is a shade in a geosynchronous orbit. Luni-solar perturbations adversely affect the position of derelict satellites in this orbit [4], amounting to a station keeping requirement of about Δv = 45 m/s per annum. Nevertheless, the orbit proximity may offset the increased station keeping requirements and simplify the travel logistics.

Results and Discussion

For a solar shade of large surface area and a low mass, the solar radiation pressure is significant. This force has the same $1/r^2$ dependence as Sun's gravitational pull, but this is directed away from the Sun and normal to the shade. In a recent work [5], it has been proposed to use radiation pressure for long-distance navigation of a sunshade. Here, the potentially stabilizing effects of a variable-area shade will be examined. The equation of motion of the shade in the rotating Earth-Sun reference frame is

$$m\ddot{\mathbf{r}} = -\frac{GM_e m}{|\mathbf{r}-\mathbf{r}_e|^3}(\mathbf{r}-\mathbf{r}_e) - \frac{GM_s m}{|\mathbf{r}-\mathbf{r}_s|^3}(\mathbf{r}-\mathbf{r}_s) + \frac{kA}{|\mathbf{r}-\mathbf{r}_s|^2}\hat{\mathbf{x}} + m\omega^2\mathbf{r} - 2m\boldsymbol{\omega}\times\dot{\mathbf{r}} \qquad (1)$$

where $\mathbf{r}$ denotes the position of the shade from the origin at the Sun-Earth center of mass, x is the direction from Sun to Earth, M_e, $\mathbf{r}_e$, M_s and $\mathbf{r}_s$ are the masses and position vectors of the Earth and Sun from this origin, $\boldsymbol{\omega}$ is the rotation rate of the non-inertial frame, and G the gravitational constant. The extra term is the third one, which arises from the radiation pressure; it is proportional to the area A of the sunshade and a constant k. For shade with extensible panels, long-term bounded trajectories may be devised which maintain position by deploying and retracting the panels. An L1 sunshade provides nearly uniform cooling over the entire Earth, as shown in Fig. 1L, while a geosynchronous shade has the potential for significant local cooling and negligible cooling across the entire Earth (see Fig. 1R, for a shade at a radius of 20 km).

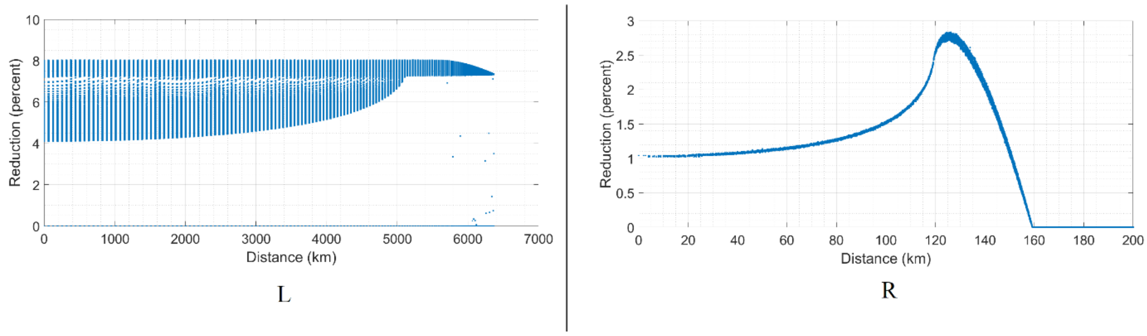

Figure 1 : Solar radiation percentage reduction at points on the Earth's surface as a function of radial distance from the Earth's location directly in front of the shade. In the panel L, the situation for a shade of radius 2000 km mounted at L1 is shown. The overall reduction is 6.6 percent across the entire Earth. There are multiple reductions for each distance due to different angles of depression and azimuth.

It is hoped that for an extended object such as a sunshade, opposing destabilizing tendencies may be harnessed to achieve a net reduction in station-keeping requirements. Further details will be presented at the conference.

References

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