Response to reviewers

Thomas Hocking, Linda Megner, Maria Hakuba, Thorsten Mauritsen

Introduction

We are grateful to Seiji Kato for further comments on the manuscript "Impact of reflected shortwave anisotropy on satellite radiometer measurements of the Earth's energy imbalance" (egusphere-2025-829). The original comments are reproduced in black on the next page, with our responses in blue.

A full record of the exact modifications in the revised document are available as a manuscript with tracked changes, uploaded separately.

Constellations

In Table 3 and throughout the main body of the manuscript, we have replaced 73°+82° with the 2x82° constellation, since this constellation is the primary configuration under consideration for the proposed ECO mission at the time of writing. Results for the 73°+82° constellation are now found in the new appendix, alongside results for various other combinations.

Previous work

We have added sections 2.1 and 3.1 to more clearly highlight the changes in the current study compared with the Hocking et al. (2024) article.

Comments by Seiji Kato

The authors test whether a combination of satellites on different orbits can sample all scenes uniformly in spatial and temporal space so that the top-of-atmosphere net irradiance (or Earth energy imbalance) can be accurately measured. I start realizing this is the main objective of this paper after the third review. The main objective is not clearly described in the current manuscript.

The broader context of our work is indeed that we want to determine the potential of wide-field-of-view instruments for measurements of the annual global EEI, and we have tried to explain our goal better in the latest version of the manuscript. For this particular study, our focus is specifically on the impact of reflected shortwave anisotropy. In connection with previous work using a simpler Lambertian assumption, a recurring topic of discussion has been the fact that individual measurements of reflected shortwave radiation are affected by anisotropy, and the seemingly simple question of 'How do the global annual mean results change when reflected shortwave anisotropy is accounted for?'. Our aim with the current study is to address this question.

The end of the Introduction has been revised to describe the main objective more clearly.

If the authors need to achieve their goal, they need to model radiation field accurately to test combinations of different orbits. In order to do this, as I wrote in the first review, they need to use level 2 (footprint base) data product. If they want to leave the analysis that I suggested for the next project and want to stay with the CERES SYN product, then they should do the following. They might be doing this but mixing with a "Lambertian" assumption made the reader hard to understand.

The usage of level 2 data is beyond the scope of our current investigation, but we will consider this for a later study. The Lambertian assumption and the contrast between the Lambertian case and the anisotropic case are a key part of this study, to investigate the impact of anisotropy. We have revised part of the Introduction to describe the main objective more clearly, and we hope that the revised manuscript is easier to understand as a result.

Use ERBE ADM, apply 1 degree by 1 degree scenes, and estimate radiance toward the nonscanner. Integrate the radiances over the field-of-view of the instrument. Compute annual mean irradiances at the satellite orbit. Compute the irradiance absorbed by the Earth using annual mean solar constant. Scale the absorbed flux to the flux at the reference level. This approach does not provide regional fluxes and only provides one number per year but avoids using shape factors.

We have tried to explain our method better in the latest version, and this is indeed what we are doing: Estimate radiances, integrate them over the instrument field of view and scale the flux to the reference level to provide a single number per year. The new Sect. 2.1 should make it easier to avoid confusion. We do not specifically use the absorbed irradiance and the annual mean solar constant to compute satellite-estimated incoming fluxes, since our focus is on the outgoing radiation and particularly the reflected shortwave radiation. Our computed values for the outgoing radiation are compared with the outgoing radiation from SYN.

They should do this for at least multiple years and compare their estimates with global mean net TOA irradiances from SYN. Plot the time series of annual mean net TOA irradiance for the comparison.

We carry out our analysis for a period of five years (2001-2005). A plot has been added of the annual time series for our synthetic satellite estimates relative to the SYN reference data. We specifically show the total outgoing radiation in order to focus on the impact of reflected shortwave anisotropy. We currently disregard direct incoming sunlight, but a comprehensive investigation that properly accounts for this is planned for a future study.

Because the area for which ERBE ADM is applied is large (100 km by 100 km) in this study with SYN1deg, partly cloudy scenes happen more often than overcast or clear scenes. Therefore, the modeled radiance field may not be accurate. While Improving radiance field with level 2 data (or higher spatial resolution) is left for a next step, this study can demonstrate the steps needed to prove the concept.

We have added information in Table 1 about how often different scenes occur in the input data, and added a comment in Section 2.3.3 about cloudiness in 100 km by 100 km grid cells. The overall distribution of scene types is similar to the distribution from FM5 measurements on the S-NPP satellite (Mathew van den Heever, personal communication, Fig. 1).

Estimating the absolute value of annual mean net TOA irradiance with a limited number of satellites is difficult. Even with two sun-synchronous satellites and one satellite on an inclined orbit, their observations do not fill all temporal and spatial space everywhere. Without filling missing irradiances with auxiliary observations, such as geostationary satellites, I would think that it is difficult to estimate the absolute value of net TOA irradiance. But I guess that it is to be demonstrated.

It is true that this is difficult, and this is a reason why it is valuable to investigate this issue. The challenges are particularly visible when considering the large differences between individual measurements. Despite incomplete temporal and spatial coverage, the error over extended measurement time series as for the global mean estimate is in many cases small. This is especially true for satellites or combinations of satellites that avoid systematic biases in their sampling of diurnal variations over the course of a year (Fig. 2). Based on our simulations of 240 satellite years, we find that it is possible to choose two-satellite constellations for which the root-mean-square sampling error in the global mean is at most 0.11 Wm^{-2}.
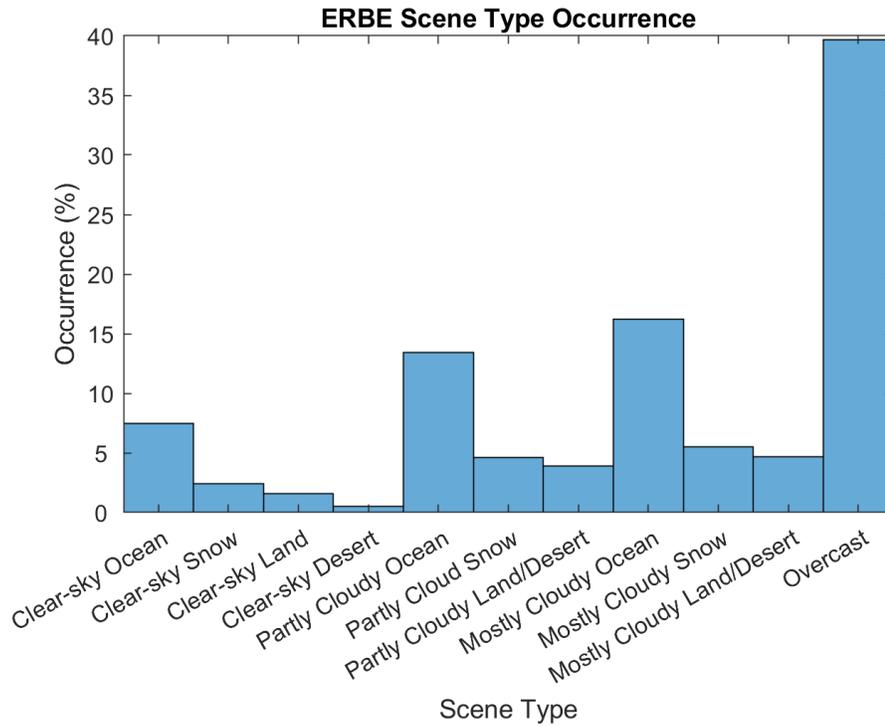
Figure 1: Rate of occurrence for ERBE scene types, based on 1/10th of the 2020 dayside RAPS measurements from the FM-5 instrument on the S-NPP satellite. Courtesy of Mathew van den Heever.
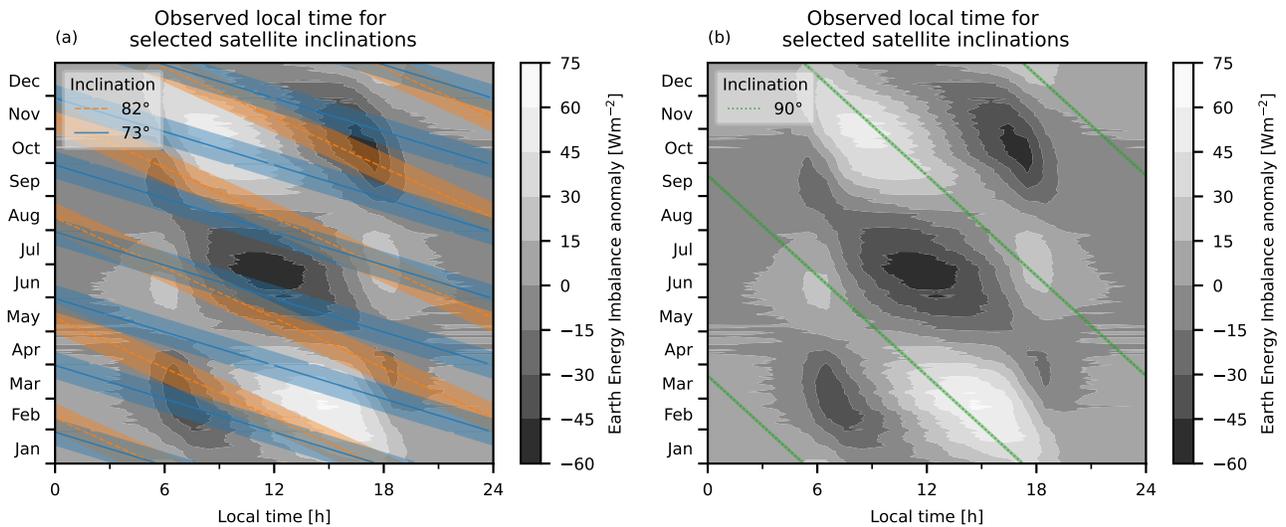

Figure 2: The annual and diurnal cycles of the EEI result in periodic anomalies. Satellites in different orbits sample these anomalies differently, which may result in smaller or larger systematic errors. Reproduced from Hocking et al. (2024).