Earthshine Variability – extent and observability

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Abstract

CERES global-mean monthly-average albedo data are inspected and compared to GERB half-Earth instantaneous values. CERES data are found to have very little (consistent with *zero*) long-term trend, and variability of the monthly means at the 0.25 - 0.6% range, while GERB data indicates 3–7 times more variability in monthly-mean values. Some aspects of the natures of the data-sets go toward explaining the different levels of the deduced variability.

Considering the implications of two observing strategies, we find that with 10 years of observations, complete monthly-mean global-average data could set limits to the albedo trends at the ±0.23% level, while 100 or 200 observing nights per year for ten years of instantaneous single-station values could be used to limit trends at the ±0.74 and ±0.54% levels.

Expectations for a positive feedback loop near -1 to -2 %/K in the albedo-temperature coupling are based on global climate modelling, and coincides closely with expectations based on considerations of energy-balance. Provided such a coupling exists in nature we can understand why no albedo change was observed during the 2000–2012 period, and expect that observations during the last half-century would have been able to show global albedo changes - provided global coverage had been available. Considering a single instrument and the above limitations we could probably not even detect a half-century of warming by its effect on global-mean albedo.

Considerations for the future could therefore suitably focus on how a single instrument could be used for studies of changes in albedo that are not trend-like, while at the same time it was a part of a global network of extended-operation telescopes.

Part I
Earthshine variability

1 CERES data

Global mean albedo is monitored via the CERES instrument, and is available in data products. Monthly mean values, at 1 degree spatial resolution, for outgoing shortwave and incoming shortwave fluxes are published. A continuous dataset covers the period 2000-2012[1]. The albedo is calculated as the ratio of outgoing shortwave and incoming (basically the solar irradiance but scaled according to the inclination of the surface element in question) at the TOA. In Figure 1 the global-mean monthly-average albedo from CERES is shown.

Interestingly, the CERES albedo has no significant trend. The trend of the anomaly data is ten times smaller than its uncertainty. Using the uncertainty to set upper limits to the trend we get $\pm 0.15\%$ over the data period. During the period 2000-2012 the Earth's mean near-surface temperature 'hesitated' and only rose by 0.1 degree C. It is not well known whether the Earth's albedo should rise or fall when T rises - this fundamental property has to do with 'positive vs negative feedbacks'. It is, however, *annoying* that T was not rising rapidly during the period when albedo was observed! Albedo could be constant because albedo is not affected by climate change or because there was, in this period, no significant climate change!

The monthly mean values and their standard deviations are shown in Table 1. The annual mean (norm. cos(lat)-weighted) value is 0.34 ± 0.013. The monthly means show the traditional seasonal cycle with a strong NH winter peak and a secondary SH winter peak. Standard deviations of the monthly anomalies range from 0.25 to 0.6 % of these means.

2 GERB data

GERB data provides calibrated visual-band images of the Earth[2]. Using the idea that variability in flux is proportional to variability in the representative albedo we use GERB flux data to explore albedo variability at shorter time scales than in the CERES data.

The GERB instrument sits on the MSG2 satellite over lon,lat=0,0. We

[1] ceres.larc.nasa.gov
[2] GERB data

have taken data at 15-minute intervals for 10 weeks during one year - one week for each of ten months (two months had missing data). The data shows the Earth in full daily cycles over a week in each month and thus has full-face, quarter, half etc., phases. Since the instrument delivers absolute calibrated data we can sum over each image and get the total flux reaching the satellite at each instant. Plotting this against time of day we get the first panel in Figure 2. The thickness of the sequence of symbols reveals the day-to-day variability of the terrestrial flux. The phase-curve shape itself is due to the coming and going of phases, but the width of the 'rope' of plot symbols is due to cloud banks coming and going, and seasonal variations in land surface albedo.

2.1 Discussion

The global mean CERES data have less variability than the GERB data. Why?

Chiefly because the CERES data are monthly mean data. The GERB data are instantaneous values. If they are averaged into monthly means what would their S.D. be? That is a little tricky to estimate: While we only have 7 values taken in sequence in each of ten months we can combine the values from different months and see what the standard deviation is at a given phase. This is essentially what the 'rope thickness' in the first panel of Figure 2 shows. Given a standard deviation of 10% near the 0.2 fraction of the day we estimate that the monthly mean value, at that particular phase, would have a standard deviation of the mean of 1.8% if 30 daily values were averaged. This is still about 3 - 7 times more than the values seen in Table 1. Why?

GERB looks at half the Earth - CERES looks at all of the Earth. That alone gives a factor of $\sqrt{2}$ provided the data are independent on the two Earth-halves. It could also be because the GERB data shows just part of the Earth and as cloud banks disappears out of view around the limb of Earth the variance is affected, while in CERES data the same cloud bank is present somewhere for the lifetime of the cloud system, which lessens the variability when a global average is taken.

3 Summary of variability aspects

1. Global-mean monthly-averaged CERES data has no significant trend over 12 years. Monthly mean values vary by 0.25 – 0.6%.

2. Global-mean instantaneous values of GERB fluxes vary by 10 % at a representative phase. Averaged monthly the data would vary by some 3-7 times more than CERES data - but are for half the Earth-disk only.

Part II
Earthshine change observability

Now that we know how variable earthshine is expected to be, we need to consider what limits we can set on its changes given different observing strategies. We will consider two: One is the long-term acquisition of CERES-type data - that is, global-mean monthly-average data, only possible with several globe-spanning telescopes in cooperation; and the other is the acquisition of instantaneous values from a single instrument.

4 Long-term trends in albedo

One of the interests we have for albedo observations is the detection, or exclusion of, long-term trends. Variability at several time-scales is of interest, but let us first consider what can be done in terms of the simplest possible detection: If we assume global-mean albedo is a constant, which limits can we expect to set on trend detection during a long observing period?

4.1 CERES-type data

For monthly-mean global-average CERES-type albedo data we can test the null hypothesis

H_0: **global-mean albedo has no long-term trend**

by Monte Carlo means: We construct 10 year time series of 120 points each, with each value drawn from a population with that months' mean and standard deviation (as given in Table 1); a climatology is constructed and subtracted from the sample series; a straight line is fitted to the anomalies and the change from one end to the other expressed as a percentage of the mean. This is done 10.000 times and the 5th and 95th percentiles extracted from the distribution of trends.

We find that the upper/lower 5% percentiles are at $\pm$ 0.23% of the series mean.

Thus, any observed trends outside this range have at most a 10% probability of occurring by chance, under the Null hypothesis.

4.2 Instantaneous data

If we only have access to one instrument we will (see Section 3, above) get data that are highly variable. At the same time we will have more data points - what sort of limits can we put on trends, given the same Null hypothesis as before?

We showed that the instantaneous albedo determinations have a variability that depend a lot on the phase at which the observation is performed, with least variability for 'Full Earth' conditions, and most at 'New Earth' conditions. The best earthshine observations are obtained between 40 and 140 degrees (Full Moon at 0 degrees). Let us pick '3/4-Earth' conditions. According to Figure 2 we can expect something like 10% variability. As before, we simulate 10 years of observations, this time for 100 and 200 nights of observations per year. Figure 3 shows the results.

They are - under the Null hypothesis - that upper and lower 5%-ile limits can be set at $\pm 0.74\%$ of the mean if 100 observing nights per year for ten years occur; 5%-ile limits for 200 nights per year for 10 years can be set at $\pm 0.54\%$ of the mean.

5 Summary for detectability

We have shown that:

1. CERES-type global-mean monthly-average data have a low variability and can be used to set limits to trends at the $\pm 0.23\%$ level, if good values are obtained for all months during 10 years.

2. For instantaneous values we can expect to set limits to long-term trends at the 0.5 to 0.75% levels, given 200 or 100 observing nights per year, respectively, for ten years.

Part III
Perspectives

It seems that with global coverage, observations have a chance to set interesting limits to albedo trends; with instantaneous data from a single station the limits are wider and it seems necessary to consider if they are too wide to be of interest for climate-change studies, or are more suitable for other categories of albedo studies.

Considerations of earthshine varaibility similar to the above are discussed in Loeb et al. (2007). Their discussion is cast in terms of explaining why the BBSO earthshine observations were so variable, and seem to be able to remove phase-dependence from the BBSO data - without giving many details. They also show that the short term variations in CERES albedo are highly correlated with the MODIS cloud product (Platnick et al. 2003) - i.e. short-term variations are due to clouds. We might follow a similar strategy in seeking a use for our single-station data.

Theoretical considerations of climate change scenarios largely depend on modelling - it is evident from available ensembles of climate change calculations, such as the CMIP3 [3] and CMIP5 project data, that models expect global mean albedo to fall during climate warming. The range of CMIP5-model changes in global-mean albedo and surface temperature under a quadrupling of carbon dioxide is shown in Table 2. The majority show a drop of several percent in albedo following the rise in carbon dioxide, along with several degrees of warming. Three of the 22 models have near zero change in albedo. Results also plotted in Figure 4. The drop in albedo as warming occurs corresponds to 'positive feedback' in the model systems - Earth absorbs more sunshine as GHG-increases induce global warming. This in turn warms the Earth further. Runaway is avoided because radiation to space in the longwave also rises. The ensemble median seems to indicate a 5 degree warming accompanied by a 4% drop in albedo. If this is what nature is like we see that the 0.1 K warming during the 2000–2012 period should be accompanied by a 0.09% drop in albedo. This is clearly undetectable even with a decade of 'CERES-type data' and was indeed not seen by CERES itself. A 0.5 degree rise in temperature, such as occurred during the last half-century, would be detectable - in CERES-type data - if nature behaves as the median of the GCM models in CMIP5. The use of CMIP5 models in understanding the radiative budget of Earth is also discussed in Wild et al. (2012).

[3] The CMIP3 home page

References

Loeb, N. G., Wielicki, B. A., Rose, F. G., and Doelling, D. R. (2007). Variability in global top-of-atmosphere shortwave radiation between 2000 and 2005. *Geophysical Research Letters*, 34:3704.

Platnick, S., King, M. D., Ackerman, S. A., Menzel, W. P., Baum, B. A., Riedi, J. C., and Frey, R. A. (2003). The MODIS cloud products: algorithms and examples from terra. *IEEE Transactions on Geoscience and Remote Sensing*, 41:459–473.

Wild, M., Folini, D., Schär, C., Loeb, N., Dutton, E. G., and König-Langlo, G. (2012). The global energy balance from a surface perspective. *Climate Dynamics*.

Table 1: Monthly means, and standard deviation, of CERES global-mean data for 2000-2012. From the CERES CMIP5 archive. S.D. expressed as a percentage of each month's mean value.

Month	Mean	S.D. in % of Mean
1	0.358658	0.36
2	0.348217	0.39
3	0.324562	0.41
4	0.338381	0.41
5	0.343739	0.59
6	0.344791	0.56
7	0.338398	0.42
8	0.332497	0.42
9	0.319038	0.44
10	0.338668	0.57
11	0.356684	0.26
12	0.362311	0.48

Table 2: Changes in global-mean monthly-averaged albedo and surface temperatures in CMIP5 models following a quadrupling of the model carbon dioxide levels from preindustrial levels.

Model	ΔA abs.	ΔA %	ΔT K
CM5A-LR	-0.03305	-9.5	5.95
IPSL-CM5A-MR	-0.03169	-9.2	5.88
MIROC-ESM	-0.02649	-7.6	6.00
ACCESS1-3	-0.02076	-6.4	5.03
HadGEM2-ES	-0.02064	-6.3	6.30
CNRM-CM5	-0.01723	-5.4	5.36
CSIRO-Mk3-6-0	-0.01786	-5.2	5.71
ACCESS1-0	-0.01633	-5.0	5.66
CM5B-LR	-0.01718	-5.0	4.22
CanESM2	-0.01560	-4.7	5.90
MRI-CGCM3	-0.01501	-4.5	4.31
NorESM1-M	-0.01557	-4.5	4.37
MPI-ESM-LR	-0.01525	-4.4	6.00
bcc-csm1-1-m	-0.01415	-4.1	4.76
FGOALS-s2	-0.01278	-4.1	6.16
MPI-ESM-MR	-0.01347	-4.0	5.57
MPI-ESM-P	-0.01285	-3.7	5.83
MIROC5	-0.01235	-3.6	4.03
bcc-csm1-1	-0.01238	-3.5	4.78
inmcm4	-0.00238	-0.7	3.17
GISS-E2-H	0.00157	0.5	4.06
GISS-E2-R	0.00311	0.9	3.49

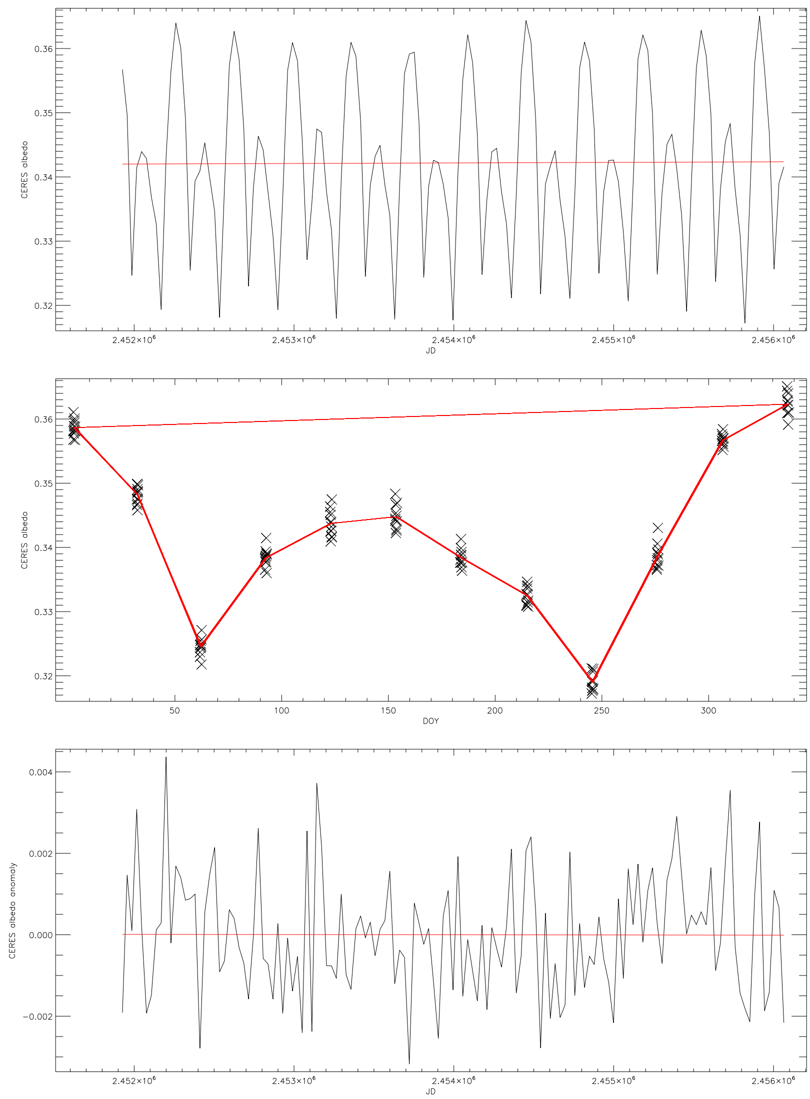

Figure 1: CERES data, from 2000–2012, from the CMIP5 archive. **Top panel** shows global-mean monthly-average albedo. Average is taken over the $cos(latitude)$-weighted grid-box values. Regions with very low incoming solar irradiation are omitted (limit is at 12 W/m^2). **Middle panel** shows the monthly-mean values and climatological mean (red). **Bottom panel** shows albedo anomaly.

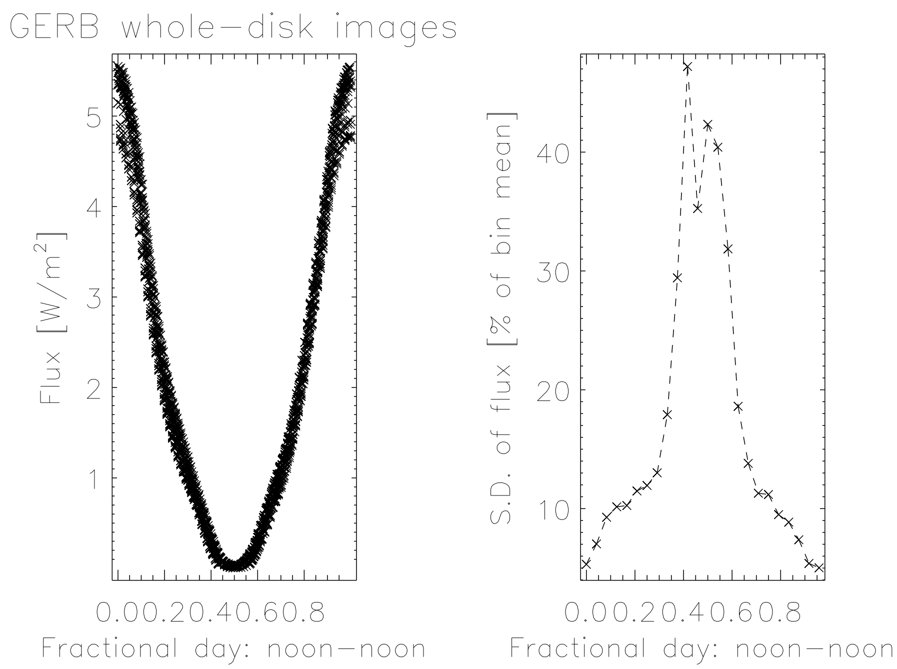

Figure 2: GERB data for 10 full weeks over a year, at 15-minute resolution (some data gaps). Left panel shows the total flux in each frame plotted against fraction of day with local midnight in the center and noon at the sides. Second panel shows the standard deviation in 1-hour bins along the phase curve, expressed as a percentage of the mean of the bin.

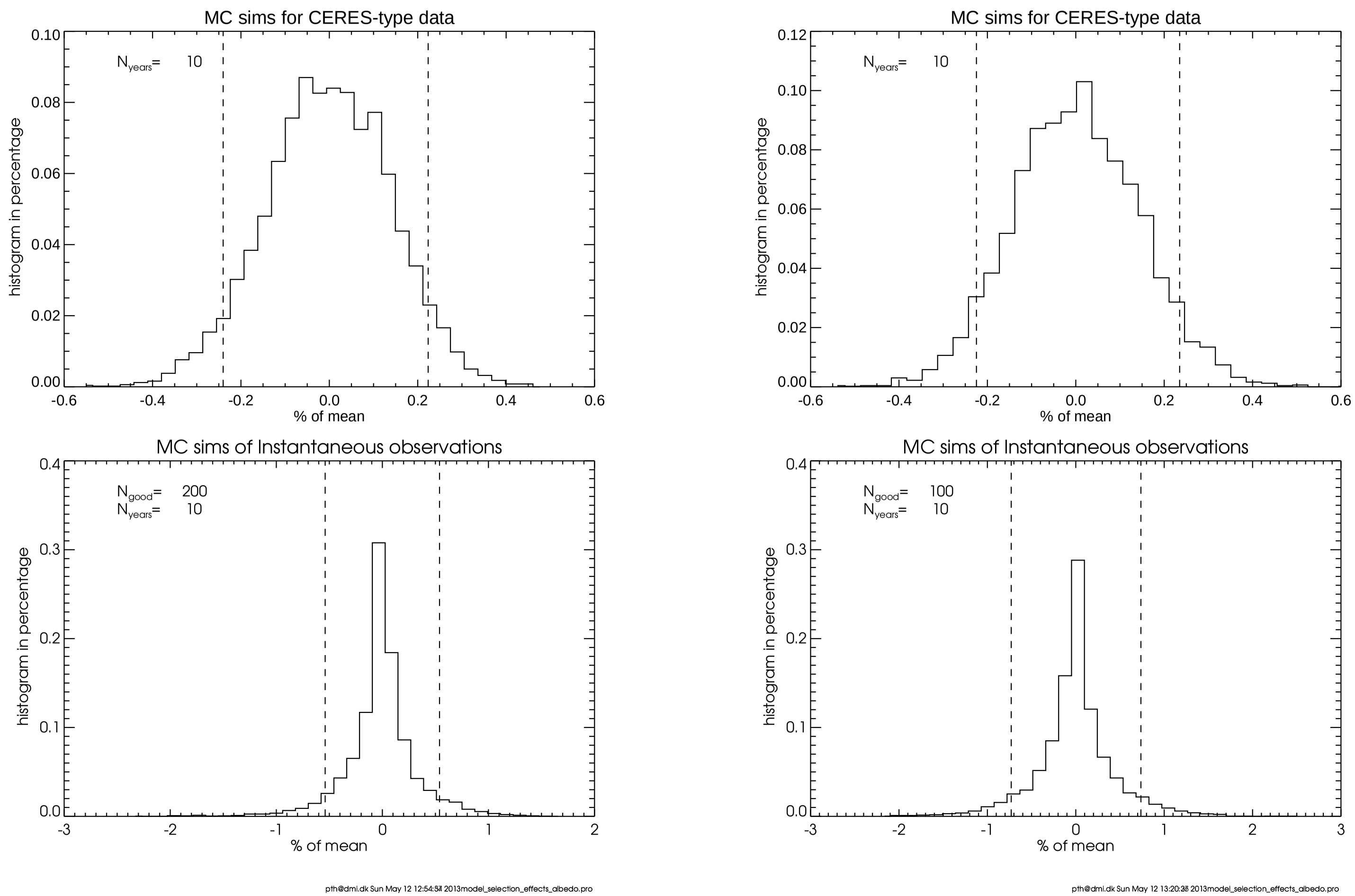

Figure 3: Monte Carlo simulations of trends in data under sampling. Left panels: CERES-type data simulated (top) and instantaneous values (bottom) for 100 observations per year for 10 years. Right panels: Top - same as before; Bottom panel - as on the left but for 200 good nights per year. Vertical dashed lines indicate the left and right 5%-tile points.

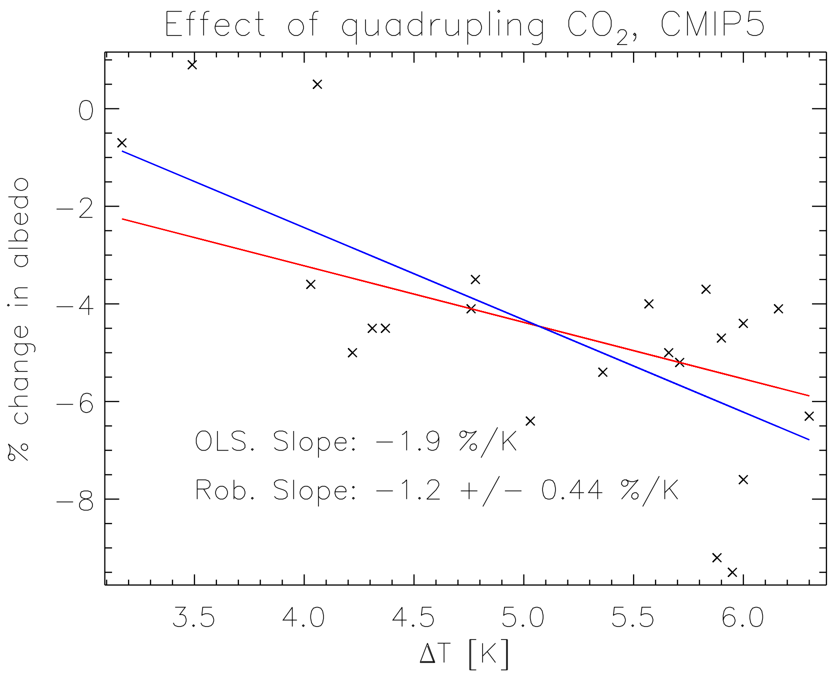

Figure 4: 22 CMIP5 models' changes in global-mean albedo and global-mean surface temperatures, following a quadrupling of the carbon dioxide. Red line is a robust fit, blue is OLS.