Changes in Earth's Albedo Measured by Satellite

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The albedo of Earth, i.e., the fraction of the global incident solar radiation that is reflected back to space, is a fundamental parameter of global energy balance (*1*). Measurements from space since the 1970s give a global annual Earth albedo of ~0.29. The average incident solar radiative flux is 341 W m^{-2}, so that a change in albedo of 0.01 represents a global energy balance change of 3.4 W m^{-2}, similar in magnitude to the impact of doubling carbon dioxide in the atmosphere. Global albedo can change with changes in Earth's cloud fractional coverage, cloud thickness, aerosol amount, forest cover, or snow and ice cover. For example, a 2-year change in albedo was caused by the large Mount Pinatubo volcanic eruption in June 1991. Stratospheric aerosols from the eruption increased global albedo by up to 0.007 because of the reflection of an additional 2.5 W m^{-2} of solar radiation over the following 2 years (*2*, *3*). A recent report (*4*) claims to have detected an even larger increase in albedo, although not connected to any specific event like a volcanic eruption, between 2001 and 2003. We examined recent global satellite observations designed to measure the variations in planetary albedo, the broadband CERES (Clouds and the Earth's Radiant Energy System) observations from the NASA Terra spacecraft, in order to determine if substantial changes occurred over that period.

Figure 1 shows the anomalies in albedo from the monthly time series of the CERES global satellite measurements, which began in March 2000. To eliminate the large seasonal cycle in the data, we deseasonalized the CERES monthly anomalies by differencing each January from the average of all four January months from March 2000 through February 2004. The data plotted is from the CERES Terra FM1 instruments Edition 2 ES-4 data product (*5*, *6*). Anomalies are shown versus the 4-year average and are given in terms of global reflected broadband shortwave flux as well as in global albedo units. The CERES data cover the entire Earth, for the entire solar spectrum from 0.3- to 4-μm wavelength. The earthshine results are primarily for visible wavelengths and represent about half of Earth's surface (*4*).

The global CERES observations show a small decrease of ~2 W m^{-2} in shortwave reflected flux, equal to an albedo decrease of 0.006. These results stand in stark contrast to those of Pallé *et al.* (*4*), which show a large increase of 6 W m^{-2} or an albedo increase of 0.017, as shown for comparison in Fig. 1.

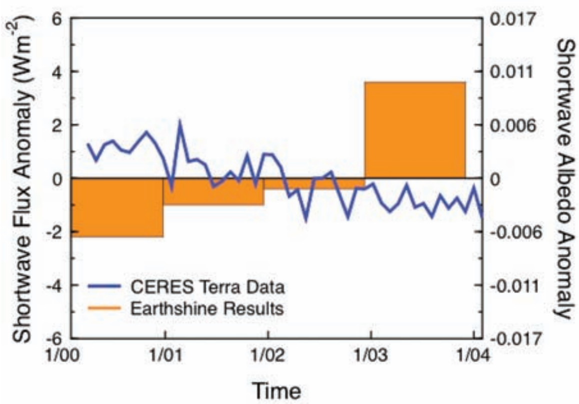

Fig. 1. Comparison of global satellite anomalies in reflected solar flux for 2000 through 2003. Earthshine results from (*4*) are shown in orange, and blue indicates the global satellite results from the CERES radiation budget instrument designed to measure global albedo from the NASA Terra spacecraft.

Comparison of independent observations from the two Terra CERES instruments indicate that ~1.1 W m^{-2} of the decrease in reflected flux observed by CERES FM1 may be explained by ultraviolet radiation exposure during a hemispheric scan mode used early in the observations. This would further reduce the CERES anomaly to 0.9 W m^{-2}. The FM1 instrument used this hemispheric scan mode for half of the first 2 years in orbit and has remained in normal cross-track Earth imaging since November 2001.

What is the effect of albedo change on climate? If the change is caused by changing land surface, aerosols, or snow and ice cover, then the earth should cool with increasing albedo and warm with decreasing albedo. This is because these changes in the Earth system have large effects on reflected solar radiation but much smaller effects on emitted thermal infrared cooling to space. If such changes had occurred at the magnitude of the earthshine data in (*4*), a global cooling twice the level of the ~0.25°C of the Pinatubo eruption would be expected, even over short time periods (*3*). Such a cooling has not been observed.

A second possibility would be a large decrease in global ocean heat storage. Observations of annual mean global ocean heat storage for 1992 through 2002 (*7*) show an 0.7 W m^{-2} increase in global ocean heat storage from 2000 to 2002. Sampling noise in the ocean heat flux is estimated at 0.4 W m^{-2} at 1σ (*7*). To be directly comparable to global reflected solar flux changes, the ocean heat storage flux was scaled from the ocean-only area used by Willis *et al.* (*7*) to global surface area. If only albedo changes were occurring, the ocean heat storage data would require an 0.7 ± 0.8 W m^{-2} decrease in reflected flux from 2000 to 2002, with 95% confidence. This change is consistent with the CERES data but not with the earthshine results.

The above discussion, however, considers only the effect of albedo change. Cloud changes would affect both albedo and Earth's thermal infrared cooling to space. Could this be the cause of changes in albedo that are not affecting surface temperature or ocean heat storage? We examined the CERES global thermal infrared radiative fluxes and the Moderate Resolution Imaging Spectrometer (MODIS) global derived cloud properties (CERES Edition 2 SSF data), but neither showed the large cloudiness changes that would be required to match an increased global albedo from 2000 to 2003 (*4*). The much smaller CERES flux and MODIS cloud changes are still within interannual variability, and a longer Terra data record is required to evaluate key issues like cloud feedback in the climate system.

References and Notes

1. B. A. Wielicki *et al.*, *Bull. Am. Meteorol. Soc.* **76**, 2125 (1995).
2. P. Minnis *et al.*, *Science* **259**, 1411 (1993).
3. J. Hansen *et al.*, *J. Geophys. Res.* **107**, 4347 (2002).
4. E. Pallé *et al.*, *Science* **304**, 1299 (2004).
5. B. A. Wielicki *et al.*, *Bull. Am. Meteorol. Soc.* **77**, 853 (1996).
6. K. J. Priestley *et al.*, *SPIE Proc.* **5151**, 282 (2003).
7. J. K. Willis *et al.*, *J. Geophys. Res.* **109**, C12036 (2004).
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