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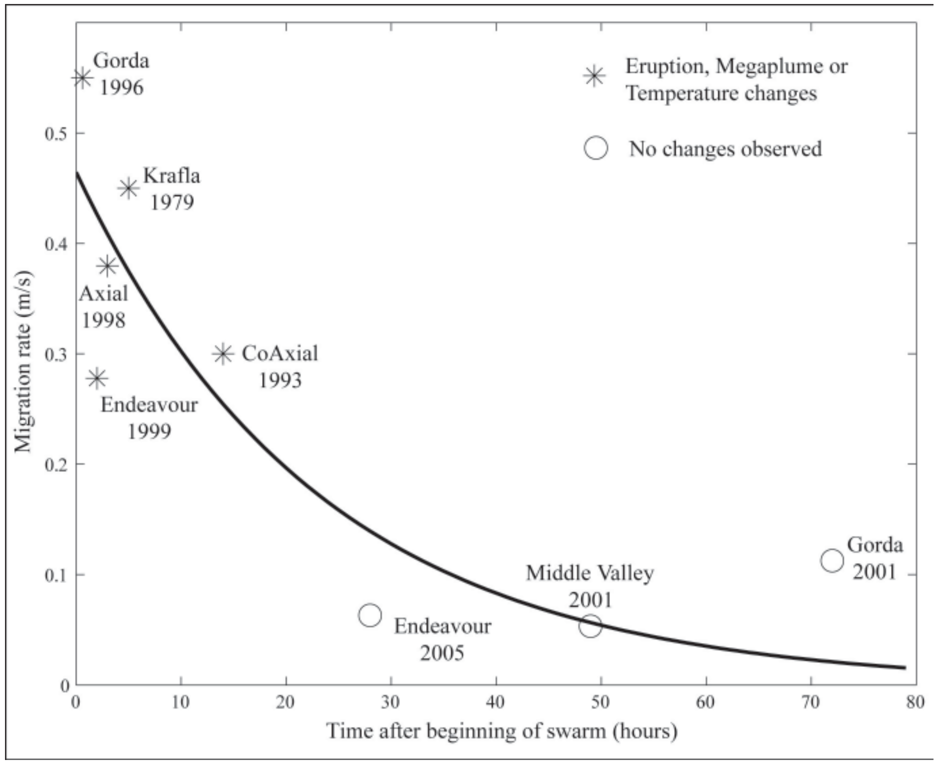

Fig. 2. Diagram of earthquake migration rate (meters per second) versus onset of migration (hours after beginning of swarm) for swarms shown in Figure 1. Swarms associated with seafloor eruptions, fluid temperature changes, or megaplume events are shown as stars; swarms with no clear magmatic activity or megaplumes are shown as circles. The logarithmic decay curve illustrates apparent nonlinear relationship. The subaerial 1979 Krafla (Iceland) dike injection event is added for comparison.

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Can Earth's Albedo and Surface Temperatures Increase Together?

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Changes in climate depend essentially on three basic parameters, the amount of incident sunlight, the fraction of this sunlight that is reflected by the Earth, and the trapping of the Earth's infrared radiation by greenhouse gases. The Earth's reflectance of the Sun's radiation back to space—or albedo—is the least well studied of the three.

The albedo depends primarily on cloud properties, and ground-based and satellite studies published within the past 3–4 years have shown a surprisingly significant interannual and decadal variability in this parameter. The variability in reflectance is tied to changes in cloud location, amount, and thickness. However, clouds are very poorly parameterized in climate models. Thus, the scale of these variations presents a fundamental, and as yet unmet, challenge to understanding and predicting the Earth's climate.

The sign and magnitude of albedo changes over the past five years have been under debate. The evidence from a variety of sources suggests that the Earth's albedo has increased from 2000 to 2004. However, the rising planetary albedo, and the increase of sunlight being reflected back into space, has not led to a reversal of global warming.

The most up-to-date cloud data, released in August 2005 from the International Satellite Cloud Climatology Project (ISCCP), a careful compilation of cloud observations covering the entire Earth from a range of meteorological satellites, reveal that the explanation of this seeming anomaly lies primarily in a redistribution of the clouds. Whereas low clouds have decreased during the most recent years, high clouds have increased to a larger extent, leading to both an increase in cloud amount (higher albedo) and an increased trapping of infrared radiation by clouds (increased heating).

Measuring the Earth's Albedo

To derive ideal estimates of the Earth's reflectance, it would be necessary to observe reflected radiances at all angles from all points on the Earth, which is technically impossible. Therefore, all measurements from which albedo can be inferred require assumptions and/or modeling. During recent decades, there have been some efforts to measure the Earth's albedo from space; but a long-term data series of the Earth's albedo is difficult to obtain due to the complicated intercalibration of the different satellite data and the long gaps in the series. However, the availability of different albedo (and cloud) databases, and their intercomparisons, can help to constrain the assumptions necessary to derive estimates. Thus, long-term ground-based estimates of the Earth's reflectance,

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complementary to those from satellites, are an advantage.

Data compiled from ground-based radiometer networks and sunshine recorders show, with some confidence, that sunlight reaching the ground decreased strongly (so-called global dimming) from the 1960s through the mid-1980s [*Stanhill and Cohen,* 2001; *Wild et al.,* 2005]. With greater confidence, data from the Earth Radiation Budget Experiment (ERBE, a set of satellite instruments designed to measure the Earth's energetic balance) and Earthshine (ES, ground-based measurements of reflectance based on the dayside earthlight reflected from the Moon back to the nighttime observer, see *Pallé et al.* [2003] for details), show that more sunlight has been reaching the Earth's surface from the mid-1980s to 2000 [*Wielicki et al.,* 2002; *Pallé et al.,* 2004; *Wild et al.,* 2005], although the magnitude of these changes is still in dispute [*Pallé et al.,* 2005].

Since 2000, ES observations indicate an increasing albedo [*Pallé et al.,* 2004], whereas Clouds and the Earth's Radiant Energy System (CERES) satellite data report the opposite result [*Wielicki et al.,* 2005]. A recent intercomparison of several albedo-related data sets strengthens the case for an increasing global albedo post-2000, consistent with the original ES result [*Pallé et al.,* 2005].

However, it has been argued that an increasing albedo over the past five years is inconsistent with observed behavior in the global land and sea surface temperatures and ocean heat content [*Wielicki et al.,* 2005]. Simply put, other climate parameters being constant, an increase in the albedo implies a decrease in the sunlight absorbed by the planet, thereby leading to cooler temperatures.

Clouds, though, have two opposing effects on the Earth's radiation budget: They reflect shortwave radiation (a negative forcing cooling the planet) and they trap infrared/heat radiation (a positive forcing). The net cloud radiative forcing is about -13 watts per square meter [*Ramanathan et al.,* 1989], but various cloud types contribute differently to this forcing: Optically thick low-lying clouds have a strong cooling effect, while high thin cirrus warm.

The Role of Clouds

In August 2005, ISCCP global cloud data were released covering 2001–2004, and this most up-to-date set serves to clarify the evolution of the albedo. The data show that the cloud amount increased by 2–3% from 2000 to 2004. In particular, the ISCCP cloud amount data show a sinusoidal behavior over the last 20 years (see top panel in Figure 1), with a decline in all cloud types from the late 1980s through the late 1990s; the total then began increasing in about 2000.

However, low clouds continued to decrease post-2000, while middle and high clouds increased. In the bottom panel of Figure 1, the globally averaged cloud amount has been divided into low ($p > 680$ mbar) and middle combined with high ($p < 680$ mbar) cloud types and averaged in five-year bands.

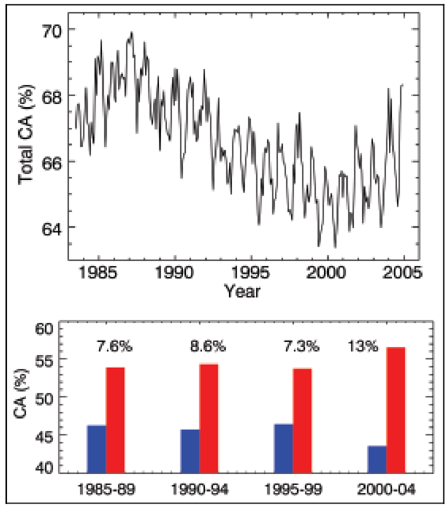

Fig. 1. (top) Globally averaged monthly mean total cloud amount from the ISCCP data. The overall decrease in cloud amount from 1985 to 2000 is about 4–5% with a recovery of about 2–3% from 2000 to 2004. (bottom) Globally averaged 5-year mean low (blue) and middle + high (red) cloud amounts. The difference in percent between low and middle + high cloud amounts is also given on top of each of the four 5-year intervals. Note the near doubling of this difference over the 2000–2004 period with respect to the previous means.

The difference in cloud amount between middle- and high-lying clouds, and low-lying clouds remained around 7–8% from 1985 to 1999, but almost doubled (13%) over the past five years (see bottom panel of Figure 1). This shift toward high cloud types decreased the negative cloud forcing, and so increased the net.

In this way, the recent increase in albedo, following the increase in cloud amount, is not necessarily inconsistent with the observed global temperatures. It seems that under the right circumstances either an increase or a decrease in albedo can lead to higher temperatures. This explanation presents the most consistent picture for all of the data sets. Furthermore, it is a cautionary note against inferring changes in net radiative forcing from shortwave data alone (e.g., the global dimming and subsequent global brightening seen in ground-based data).

Pallé et al. [2004] used a multiple regression of 1999–2001 ISCCP data with overlapping ES observations to construct from the former a proxy for the Earth's reflectance. Here that proxy has been projected forward beyond 2001 through 2004 using the new ISCCP data. The result, plotted in Figure 2, shows an increasing trend after 2000, in agreement with the ES data.

The disagreement in 2003 may be associated with the sparse ES data available for that year: slightly more than one half of the annual average number of observations from 1999 to 2004, but with a normal seasonal distribution (E. Pallé et al., Seasonal and interannual trends in Earth's reflectance, 1999–2004, submitted to *Journal of Geophysical Research*, 2005).

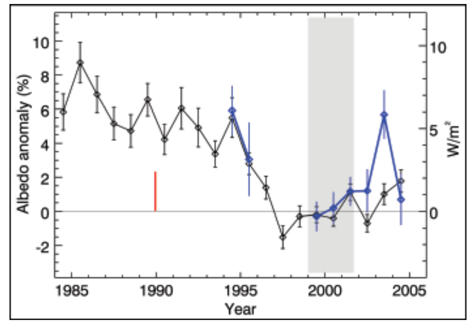

Fig. 2. Globally averaged reconstruction (black) of albedo anomalies from ISCCP cloud amount, optical thickness, and surface reflectance (following Pallé et al., *2004). The observed Earthshine albedo anomalies are in blue. All observations agree with the reconstruction to within the 1 σ uncertainties, except for the year with sparse ES data, 2003. The shaded region 1999 through mid-2001 was used (as in* Pallé et al., *2004) to calibrate the reconstruction and is the reference against which anomalies are defined. The vertical red bar indicates the estimated size of the forcing by greenhouse gasses since 1850.*

Note that these changes in reflectance imply climatologically significant changes (a few watts per square meter) in the shortwave radiative forcing. ISCCP cloud data can also be used as inputs for global albedo models using ERBE bidirectional reflectance tables, which provide empirical determinations of local albedos for various terrestrial scenes as a function of angle of incidence and reflection (see *Pallé et al.* [2003] and references therein for details on these models). The whole-Earth albedos that were derived from these post-2000 ISCCP data show the same increasing trend as the ES observations, and no trend at all if the cloud amount is artificially fixed to that of year 2000 (not shown).

The 2005 update of the ISCCP data confirms an increasing global albedo since 2000, but this is only the most recent change in climatologically significant reflectance variations extending over the past two decades. Accounting for such variations in global climate models is essential to understanding and predicting climate change.

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NEWS

NASA Terminates Two Earth Observation Missions

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Citing a lack of available funds, NASA has ended support for two Earth observation missions: Hydros, which never left the formulation phase, and the Deep Space Climate Observatory (DSCOVR), which was already built and waiting for launch.

Richard Anthes, president of the University Corporation for Atmospheric Research, Boulder, Colo., said that these two new cancellations are "further evidence that…the nation's Earth-observation satellite programs are at risk."

Anthes co-chairs a committee of the National Research Council (NRC) of the U.S. National Academies that is conducting a decadal survey of Earth science and applications from space, which should be completed by the end of 2006. In a September 2005 interim report, the committee concluded that the U.S. system of Earth observation satellites was "at risk of collapse," in part because of the cancellations or delays of six other missions (see *Eos, (86)*43, 2005).

Hydros was selected as an alternate mission in 2002 in the third round of competition for the Earth System Science Pathfinder (ESSP) program—which funds small- and medium-sized Earth science missions—and had a tentative launch date of September 2010. The mission would have used low frequency mapping radar and radiometer instruments to measure soil moisture for use in weather and climate prediction models, in drought mitigation efforts, and for better understanding of the global hydrologic, energy, and carbon cycles.

Hydros, unlike other current and planned satellites that use high frequency ranges, would be able to make these measurements under vegetation canopies and would be able to determine if the moisture is frozen, which is important for weather and climate prediction, according to mission principal investigator Dara Entekhabi, of the Massachusetts Institute of Technology, Cambridge.

NASA allowed Hydros to enter the formulation phase in 2003, and mission science and engineering teams were working on algorithms and instrument and spacecraft specifications until they received notice from NASA in December 2005 that the agency would no longer fund the project because it only had funds for the two primary missions, the Orbiting Carbon Observatory and Aquarius. NASA had spent about $5 million total on Hydros, according to Entekhabi.

Anthes said the termination of Hydros "means that [ESSP] is indefinitely delayed at best and, at worst, it is dead." The 2005 NRC report had highlighted ESSP as a critical need for the nation's Earth observation programs.

Jack Kaye, director of the research and analysis program in NASA's Earth-Sun System Division, said that NASA plans to have another round of ESSP competition, although no date has been announced. Hydros investigators can re-propose the mission in the next round of ESSP competition, Kaye said.

A Satellite Grounded

DSCOVR has a longer history: In March 1998, then U.S. Vice President Al Gore proposed a mission named Triana to provide real-time images of the Earth from the Lagrange-1 (L-1) point, where the gravitational forces of the Earth and Sun are equal. Panned by some Republicans as 'Goresat', the mission was reborn as DSCOVR following a 2000 NRC report that noted its scientific importance. The satellite was originally scheduled for launch via the space shuttle in 2001 but was delayed and then put on indefinite hold following the loss of Columbia in 2003.

The satellite would provide a continuous synoptic view of the Earth and facilitate climate science by measuring energy reflected (albedo) over an entire hemisphere. No other satellites can currently obtain these measurements, which are needed to determine the effect of albedo on climate, according to DSCOVR principal investigator Francisco Valero, of the University of California San Diego, Scripps Institution of Oceanography. In addition, DSCOVR would be able to monitor solar activity and act as an early warning system for solar storms that could damage communications systems on Earth, he said.

NASA has already spent $100-120 million on DSCOVR, and Valero estimated that the launch and operations, including adapting it to a new launch vehicle, would cost another $60–120 million. However, he noted that the costs could be shared between NASA and the U.S. National Oceanic and Atmospheric Administration, which has expressed interest in the satellite's solar monitoring capabilities for use in disaster prevention and has commissioned a study of the agency's possible participation.

Kaye said that in the current budget environment that has left NASA with limited funds for Earth science, it did not make sense for NASA to continue supporting DSCOVR in the indeterminate state it was left in following the loss of its launch vehicle.

"Nobody likes to start something and not be able to finish it," he said. "But at some point, you have to manage with the budget you have and make priority-based decisions."

However, Valero said that NASA has to decide to choose projects that are not cancelled before they fly because it is a waste of money and the time and effort of the scientists involved.

—SARAH ZIELINSKI, Staff Writer