MEETINGS

Global Dimming Comes of Age

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Thirty years ago, scientists from the Smithsonian Institution, Washington, D.C., and the National Physical Laboratory, Jerusalem reported "severe changes over the years in solar radiation" and issued a call for "a careful study of incoming radiation at different places throughout the world...to determine the exact kind, order of magnitude and their causes..." [*Suraqui et al.*, 1974].

The "severe changes" referred to emerged from the measurements at the site of the Smithsonian Institution's former solar radiation monitoring station on Mount St. Katherine in the southern Sinai peninsula (28°31' N, 33°56'E, 2643 m altitude). Measurements using modern radiometers as well as some of the original instruments used between 1933 and 1937 showed a 12% loss in global radiation during the intervening four-decade interval.

As part of the 1957/1958 International Geophysical Year (IGY), a worldwide network of solar radiation measurement stations had been established. Four decades later, analyses of the IGY records confirmed that a widespread decrease in solar radiation (now widely termed global dimming) had occurred which globally averaged between 1.4% and 2.7% per decade depending on the study [*Gilgen, et al.*, 1998; *Stanhill and Cohen*, 2001; *Liepert*, 2002]. Signs of recovery in the 1990s were reported at the scientific meeting described here.

The same questions as those posed at Sinai 30 years ago were the subject of three sessions of the 2004 Joint Assembly of the American and Canadian Geophysical Unions held 17–21 May 2004 in Montreal, Canada. This first scientific meeting to address global dimming, entitled "Magnitude and causes of decreasing surface solar radiation," attracted much attention from both the scientific community and the media.

The Global Picture

The sessions began with a history of the evidence for global dimming, followed by a discussion of the possible causes of the multidecadal variations in surface solar radiation. After contrasting the roles of anthropogenic aerosols and greenhouse gases versus natural changes in cloudiness and surface albedo, the results of climatic simulations with general circulation models were presented. It was shown that the increasing anthropogenic greenhouse gas and aerosol concentrations may be responsible for the observed reduction of surface solar radiation and consequent spin-down of the hydrological cycle with reduced evaporation and precipitation. In his keynote address, V. Ramanathan enforced this hypothesis with results from the recent Indian Ocean Experiment (INDOEX), which quantified the impact of aerosols on the surface solar flux during the winter monsoons and so enabled their impacts on climate and the hydrological cycle to be addressed. His general discussion of the impact of changes in aerosol load on the Earth's radiation budget highlighted the latter's long-term variability, an important feature previously neglected or underestimated.

The extent to which broadband top-of-the-atmosphere radiative fluxes measured from numerous satellites over the past 20 years can be used to accurately estimate changes at the surface on a global scale was examined using data gathered in NASA's GEWEX program. The global surface radiation budgets (SRB) calculated with a 2.5° resolution using the 20 years of NOAA/NASA Pathfinder satellite observations combined with reanalysis data illustrate the potentials and difficulties of this approach.

A recent study of the Earth's albedo—by measuring the Sun's reflectance from the Earth's surface—on the surface of the Moon was described. The Earth-to-Sun shine ratio measurements show a decrease in albedo from the late 1980s to the late 1990s in accordance with results of the International Satellite Cloud Climatology Project (ISCCP), with a marked reversal in the last 3 years [*Palle et al.*, 2004].

The final contribution to this session sounded a cautionary note by drawing attention to the potential errors involved in the solar radiation measurements on which the evidence for changes is based, and it was concluded that their magnitude, especially prior to the mid 1970s, could be of the order of the changes reported. Examples of long-term records from well-maintained solar radiation sites in the United States were presented that show a decline in the 1960s to 1980s and a recovery afterward.

A Widening Body of Evidence

The second session was entitled "More evidence." One presentation focused on extending the record of surface solar radiation back beyond the past 50 years for which standard pyranometer measurements are available, by using other climate records that can serve as proxies for solar radiation. Of the options discussed, sunshine duration measurements, dating back 125 years, appear the most promising, but visibility observations, available from sea as well as on land, may also hold keys to the past.

The latest results of means and trends of shortwave radiance at the surface using high-quality data from eight stations of the Baseline Solar Radiation Network (BSRN) were presented, and they show that at some of these locations solar radiation has been recovering since the 1990s.

Documented and widespread decreases in pan evaporation have been taken as evidence for global dimming, but have not been reported previously from the southern hemisphere. Australian data showed that evaporation from 1970 on has been decreasing "down under" at about the same rate as in the northern hemisphere, but with a continuing downward trend in the 1990s to 2002. Does this imply that global dimming in Australia and New Zealand is also of similar magnitude and continues to decline? If so, the cause is not changing cloudiness, as no evidence for such changes was found in an analysis of 23 years of cloud statistics for Australia based on the High-Resolution Infrared Radiation Sounder (HIRS) data.

The question of solar radiation changes in another part of the southern hemisphere was addressed in an analysis of data series of 21 to 41 years' duration from South Africa and Namibia. Although changes in the direct and diffuse components of solar radiation were not uniform, significant decreases in global radiation were observed at most stations, accompanied by increasing diffuse and decreasing direct radiation, changes which were particularly large after major volcanic eruptions when enhanced light scattering increases diffuse solar radiation.

The interannual variability of longwave outgoing and incoming shortwave radiation was the subject of a study of the interaction between "greenhouse gas" forcing and global dimming. Measurements from the Western Alps, beginning in the mid-1990s, show that in this region decreases in surface solar radiation were balanced by increases in downward longwave radiation. These increases were higher than expected from the observed increases in surface temperatures and concentrations of CO_2 in the atmosphere, and they were attributed to the measured increases in air water vapor concentration. It was argued that enhanced atmospheric transport of moisture caused this phenomenon.

A major topic in the poster presentations was the role of anthropogenic aerosols on solar radiation in particular and climate in general. One such study reported on the influence of absorbing aerosols, i.e., dust and black carbon, on solar dimming over the Arabian Sea and its impact on the monsoon system. Another described a new automated algorithm for retrieving aerosol properties from measurements of diffuse and global narrowband solar radiation. The variability of aerosol optical depths resulting from natural and man-made hazards such as fires was the subject of a poster which also dealt with their effects on human health. A series of posters analyzed in some detail the time course of changes during 40 years in global, diffuse, and direct radiation measured at Bet Dagan, Israel (32°00'N, 34°49'E, 30 m altitude), an urban site in the eastern Mediterranean coastal plain. The largest declines occurred at midday late in the winter season and throughout the year in the morning and evening hours. The dimming at low solar elevations was attributed to increasing smog, while the noontime changes in winter were correlated with changes in prevailing wind direction.

The evidence gathered at this meeting suggests that surface solar radiation is more variable than previously thought and declined by about 2% per decade in the second half of the twentieth century, possibly with some recovery in the 1990s. The "dimming" seems widespread and "global" at least over land. Possible causes discussed include, in order of probability, anthropogenic aerosols, major volcanic eruptions, and increasing cloudiness. How much of the "missing" solar radiation is absorbed by the atmosphere or reflected back to space is a key question for climate research.

Following the formal sessions, convened by the authors of this report, a meeting of the participants encouraged them to prepare an edited proceedings of the sessions, and they accepted an offer by M. Roderick to prepare a bibliography on global dimming, which is now available at www.greenhouse.crc.org.au/crc/research/c2_bibliog.htm.

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FORUM

The EPICA Challenge to the Earth System Modeling Community

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One of our major aims as Earth systems scientists is to predict how the Earth will behave in the future, particularly in the face of changes imposed upon it as a result of human activities. These predictions are made using models and concepts that are in part derived from observation of how the system has behaved in the past. However, these observations, which come from paleo-records, are also one important tool for validating the models. The imminent appearance of a new ice core data set presents a unique opportunity for a test of our understanding, particularly of the climate/carbon system. Members of the European Project for Ice Coring in Antarctica (EPICA) and others here present a challenge to the modeling communities and other interested parties.

The Vostok ice core record [*Petit et al.*, 1999] has become an iconic data set. It presents the climate of the last 420 kyr, showing the rise and fall of Antarctic temperature through four complete glacial/interglacial cycles. The most striking finding is that CO_2 and CH_4, the two most significant greenhouse gases (after water vapor), also rise and fall, in a remarkably similar fashion. When Antarctic temperature is calculated including a correction for the climate of the water vapor source region [*Cuffey and Vimeux*, 2001], the correlation between CO_2 and Antarctic temperature over the last 150 kyr has an r^2 of 0.89!

As stated elsewhere [*EPICA Community Members*, 2004], the Vostok data set has become a compelling target against which other climate records and modeling efforts are measured. What is the significance of the apparent lower (glacial) bound of about 180 ppmv in CO_2, and of the upper (interglacial) bound of around 280 ppmv (and the equivalent bounds in methane)? Is the behavior seen fully consistent (as it looks) with the idea that the greenhouse gases are operating as amplifiers to otherwise smaller initiators? And which processes are responsible for the changes in CO_2 and CH_4?

These questions are not yet fully answered, but a number of ideas appear in the literature. In June 2004, the members of EPICA presented a long-awaited record (from Dome C) that extends the Antarctic climate record back to 740 kyr, with the prospect of up to a further 200 kyr to come [*EPICA Community Members*, 2004]. The data reflect very clearly a change of behavior just before the "Vostok era" that has been termed the mid-Brunhes event. In the earlier period, the glacial/interglacial cycles in Antarctic temperature are of much lower amplitude, with the interglacials particularly weakened (although of longer duration than the later ones). There is no obvious external explanation for this change of behavior.

In presenting their new data, the EPICA team extended the greenhouse gas records only by 20 kyr, to around 430 kyr. Trace gas analyses are under way but take much longer than do the measurements already published from the core; it is expected that a full record extending to at least 740 kyr will not be available until at least the end of 2004. The prospect of a substantially longer record poses some fascinating new questions: What will be the CO_2 and CH_4 concentrations in the weak interglacials of the earlier period? Will CO_2 still be at the standard "interglacial level" of 280 ppmv, or will it scale with Antarctic temperature and stand at about 240 ppmv (and similarly for methane)? Some authors have wondered whether CO_2 could have been on a long-term trend downward during the Quaternary; such a trend might have been responsible for changes in frequency and amplitude of climatic cycles during this time. Is any trend apparent over the last 800 kyr?

These questions are likely to be answered when the new records are completed. However, a group within both the ice core and modeling communities would like to use the imminent arrival of these records as a challenge. What do the modeling community, and others who are putting forward ideas, believe we will see, and why? The purpose of the "EPICA challenge" is not to find a right answer, and declare a winner; indeed with our present knowledge it is more than likely that someone can get the right answer for the wrong reason. Rather the idea is to provide an impetus for modelers to expose the assumptions and arguments behind their predictions, leading to a more open discussion once the data are revealed.

We therefore invite anyone interested in doing so to predict what carbon dioxide and methane will look like back to at least 800 kyr B.P., and to explain their reasoning, whether the result comes from a simple concept or from a full model run. Time is short, because it is possible that the first outline data sets will be available for presentation at the AGU Fall Meeting (13–17 December 2004). The data groups involved will endeavor to keep the data under wraps until then. Some modeling groups may like to submit their ideas in full to journals or at meetings. However, the PAGES International Project Office has also offered to collate and summarize responses that are received there before 15 November. To be included, please send your ideas with one figure and a short caption (200 words maximum, explaining why the main features occur) to Christoph Kull (christoph.kull@pages.unibe.ch).

The AGU Fall Meeting includes a Union session entitled "Climate of the past million years" (U01), and a summary of the submissions will be included on one or two posters at this session. A short article in the PAGES newsletter may also be produced. The EPICA Dome C temperature and dust data sets, extending 740 kyr back in time, are available from the World Data Center for Paleoclimatology (http://www.ngdc.noaa.gov/paleo/icecore/antarctica/domec/domec_epica_data.html). Data from the Vostok ice core for model testing can be downloaded from the same site (http://www.ngdc.noaa.gov/paleo/icecore/antarctica/vostok).

The EPICA challenge has no prize other than the prospect of a greatly increased understanding of the way Earth works. Fire up your computers, sharpen your pencils, and polish your crystal balls: the EPICA challenge is on!