

FORUM

Reconciling Global Warming and Dimming

A Perspective on Global Warming, Dimming, and Brightening

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Heated discussion of climate change is not a new feature of public debate, as *Fleming* [1998] has demonstrated in his studies of the historical perspectives of this topic. Nevertheless, a strong case can be made that the current level of public concern and even apprehension may be unprecedented. The purpose of this article is to draw attention to the challenge that recently reported changes in solar radiation at the Earth's surface, $E_{g\downarrow}$, pose to the consensus explanation of climate change.

Global Dimming and Brightening

There is evidence that changes in $E_{g\downarrow}$ have occurred during the past 50 years. A bibliography of the published literature appears at http://www.greenhouse.crc.org.au/crc/research/c2_bibliog.htm

An example of these changes, based on measurements made in Israel, is presented in Figure 1a. The figure shows that a widespread reduction in solar radiation at the Earth's surface, often referred to as global dimming, lasted from the mid-1950s until the mid-1980s when a recovery, referred to as global brightening, started. An analysis of many reports of global dimming over the land surfaces of the Earth yielded a total reduction of 20 W m^{-2} (watts per square meter) over the 1958–1992 period [Stanhill and Cohen, 2001]. This negative shortwave forcing is far greater than the 2.4 W m^{-2} increase in the positive longwave radiative forcing estimated to have occurred since the industrial era as a result of fossil and biofuel combustion [IPCC, 2001]. This long-wave heating caused by increased concentrations of the so called greenhouse gases is what provides the consensus explanation of global warming.

Records from six widely separated measurement sites (Figure 1b) show that the reversal from global dimming to global brightening occurred almost simultaneously some 20 years ago; this conclusion agrees with the measurements from the World Meteorological Organization's Baseline Surface Radiation Network reported by *Wild et al.* [2005].

The cause of these large changes in $E_{g\downarrow}$ is not known. The one most often suggested—changes in anthropogenic emissions of aerosols [Stanhill and Cohen, 2001]—presents a number of difficulties. First, the estimated negative shortwave forcing attributable to aerosol emissions is only one tenth of the measured reduction. Second, the recent widespread reversal of global dimming was measured at sites that have very low concen-

trations of anthropogenic aerosols as well as in areas such as China where such emissions are high and still increasing [Che et al., 2005]. Third, large changes in $E_{g\downarrow}$ were found in the United States during the first half of the twentieth century, similar in size to those occurring in the second half, despite very different rates of aerosol emission [Stanhill and Cohen, 2005].

Whatever the cause of changes in $E_{g\downarrow}$, the contradiction between global warming and global dimming remains. Theoretically, this paradox was resolved in a model experiment that showed that the direct and indirect effects of anthropogenic aerosols could alter the energy balance at the Earth's surface, reducing evaporation more than net all-wave radiation, and thus lead to an increase in the sensible heat flux and surface air temperature [Liepert et al., 2004]. However, no evidence for a slowing down of the Earth's hydrological cycle has been reported, whereas the many reports of reductions measured in pan evaporation (potential evaporation) can more simply be explained by those measured in $E_{g\downarrow}$. Thus, the paradox remains unsolved.

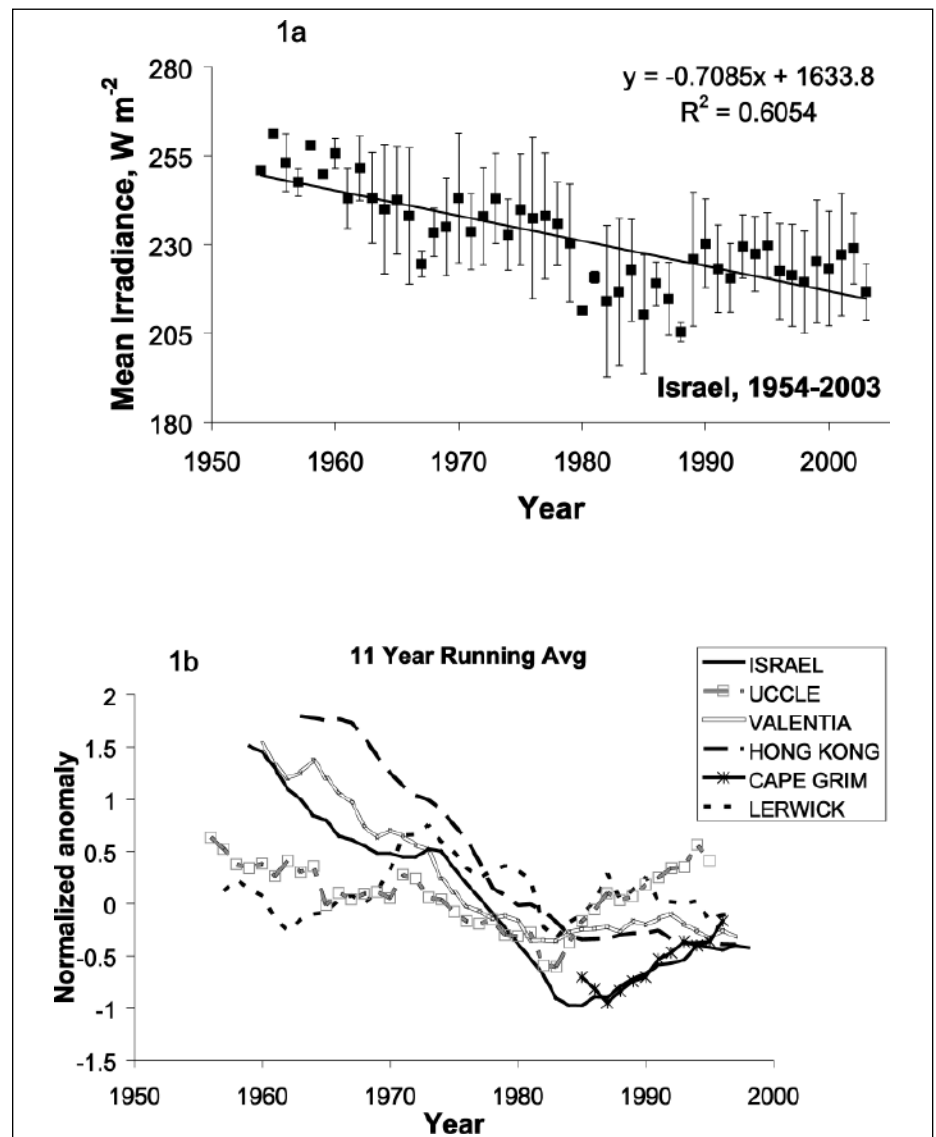


Fig. 1. (a) Fifty years of global radiation measurements in Israel, 1954–2003. Based on 233 mean annual values of $E_{g\downarrow}$ measured with calibrated thermopile pyranometers at 20 sites, the spatial variation around the mean annual values is indicated by vertical bars representing ± 1 standard deviation, W m^{-2} . (b) Eleven-year running mean of normalized anomalies of annual means of $E_{g\downarrow}$ measured with calibrated thermopile pyranometers at Israel, 1954–2003; Uccle, Belgium, 1951–2000; Valentia, Ireland, 1955–2002; Hong Kong, China, 1958–2000; Cape Grim, Australia, 1980–2001; and Lerwick, United Kingdom, 1952–2002. Data courtesy of national meteorological services.

In due course, climate change science no doubt will provide an explanation for global dimming and brightening and enable these oscillations to be reconciled with those in global warming. What is difficult to account for is the way in which the Intergovernmental Panel on Climate Change (IPCC), charged with providing the world's governments with an overview of climate change science, has responded to this major challenge to the consensus explanation.

It is now 30 years since the publication of a paper calling attention to a large reduction in shortwave radiation measured over a 40-year interval at an isolated mountaintop desert site [Suraqui *et al.*, 1974]. This finding was followed by the more than 70 others listed in the bibliography previously cited.

No reference to these findings has appeared in the three massive IPCC assessment reports published during the past 15 years. This omission is surprising in view of the important practical consequences of changes in $E_{g\downarrow}$ in addition to their theoretical significance for climate change. These consequences stem from the ubiquitous role of solar energy in powering the Earth's life-sustaining water, carbon, and atmospheric cycles. One such effect of global dimming already noted can be seen in the widespread reports of reductions in potential evaporation listed in the global dimming bibliography site. Another practical consequence, that of global brightening, may have already appeared in

the increased net primary production of vegetation monitored from satellites over most of the Northern Hemisphere since the early 1980s [Broun *et al.*, 2004].

The omission of reference to changes in $E_{g\downarrow}$ in the IPCC assessments brings into question the confidence that can be placed in a top-down, 'consensus' science system that ignores such a major and significant element of climate change.

A separate and more fundamental question is whether scientific understanding of climate change is now sufficient to produce a useful consensus view. Is climate change a science or is it a trans-science, asking questions that can be stated in the language of science but that are currently beyond its ability to answer?

The cautionary note global dimming and brightening sounds for climate change scientists is not a new one; rather it strikingly vindicates the two rules of climate change set out by Peter Wright 30 years ago [Wright, 1971]. The first rule states that some feature of the atmosphere can always be found that will oscillate in accordance with your hypothesis; the second states that shortly after its discovery, the oscillation will disappear.

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New Madrid GPS: Much Ado About Nothing?

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Two articles in this issue address the surprising and intriguing negative result that high-precision geodetic measurements find no compelling evidence for crustal motions in the New Madrid Seismic Zone of the central United States.

The geodetic measurements have drawn great interest because they add another puzzle to the many surrounding New Madrid. This area is the best known case of large earthquakes within the interior of the plates, in continental lithosphere. Such earthquakes are much rarer and release much less seismic energy than those at plate boundaries. Because idealized plates are perfectly rigid, these earthquakes demonstrate that deformation occurs within plates and provide a lower bound on their rigidity. Moreover, precisely because such earthquakes are rare, they pose a hazard to areas that are less well prepared for earthquakes than areas with more active ones. Assessing the hazard is further complicated by a growing sense that earthquakes within plates migrate among seismic zones that 'turn on,' remain active for some time, and then 'turn off.'

The potential hazard is illustrated by the large (magnitude 7) earthquakes that occurred in 1811 and 1812, causing shaking across much of the area. Houses collapsed in

the tiny Mississippi River town of New Madrid, Mo., and minor damage occurred in St. Louis, Mo., Louisville, Ky., and Nashville, Tenn. The smaller earthquakes that continue today, which may be aftershocks of the 1811–1812 events, are more of a nuisance than a catastrophe. For example, the largest earthquake in the past century, the 1968 (magnitude 5.5) southern Illinois earthquake, was widely felt and caused damage but no fatalities. However, large earthquakes like those of 1811–1812 would be much more destructive. Paleoseismic data suggest that these have occurred about 500 years apart in the past 1000 years and hence may recur.

Surprisingly little is known about these earthquakes. It is not clear why they occur, when they started, when, if ever, they will recur, and how large a hazard they pose. As a result, researchers looked to the new tool of GPS geodesy for new insights and were surprised by the results [Newman *et al.*, 1999].

A GPS measurement yields a site's position to a precision of millimeters, so a series of measurements over time gives its velocity. This is typically plotted as a velocity vector from the site's position, with an error ellipse about the vector's head showing the uncertainty in velocity. Ideally, the ellipse is a small region about the vector's head, showing that the velocity is well constrained. This is far from the case for sites in the New Madrid zone (Figure

1, top). The site velocities shown, which are motions with respect to the rigid North American plate, are small—less than 2 millimeters per year—and generally within their error ellipses. Hence most sites show no motion significantly different from zero. In other words, the GPS data do not require that they be moving at all, and restrict any motion to being very slow. Moreover, the vectors do not show the spatially coherent pattern typically seen in deforming seismic zones.

The results are gratifying from the view of plate tectonics, in that they and sites elsewhere in eastern North America show that the plate is quite rigid, with the major deviation being vertical motion due to postglacial adjustment. Beyond this motion, there is no clear case for tectonic effects, in that the small motions could be a combination of observational and analysis errors, and small motions of the geodetic monuments. However, much faster motion had been expected because of the earthquakes. It had been suggested that the earthquakes of 1811–1812 were magnitude 8 events and occurred about every 500 years. If so, more than 5 millimeters per year of average motion during the interval between earthquakes would be needed to store up the slip for a future large earthquake (Figure 1, middle). Hence, the first inference from the slow motions was that typical large earthquakes in the area are smaller, magnitude 7, in accord with recent analysis of historic records of the intensity of shaking

LETTERS

Comment on "A Perspective on Global Warming, Dimming, and Brightening"

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In his 30 January 2007 *Eos* Forum article, Stanhill [2007] writes about "...the challenge that recently reported changes in solar radiation at the Earth's surface...pose to the consensus explanation of climate change," referring to the "consensus" assessment reports of the Intergovernmental Panel on Climate Change. Here we offer an alternative perspective on this issue.

What Is Global Dimming/Brightening?

Stanhill and Cohen [2001] coined the expression "global dimming" for the reductions in total surface solar radiation of 2.7% per decade or 20 watts per square meter (W/m^2) observed from the mid-1950s to the mid-1980s at 30 sites. However, on the basis of about 300 Global Energy Balance Archive (GEBA) [Gilgen et al., 1998] stations, Liepert [2002] estimates a much smaller 1.3% decline per decade (7 W/m^2 on average) from 1961 to 1990. From the mid-1980s up through 2000, total solar radiation at many of these sites either stopped declining or increased, which Wild et al. [2005] coined as "brightening." Satellite-derived estimates confirm this brightening [Pinker et al., 2005; Romanou et al., 2007].

From the beginning of widespread measurements, scientists identified variability of cloudiness and atmospheric turbidity as the main causes of the variations in solar irradiance. In the ongoing discussion, though, "global dimming" and "global brightening" quickly became associated with either rising or falling anthropogenic aerosol particle concentrations. An example is given by Alpert et al. [2005], who reported declining trends of 12 W/m^2 at highly populated sites from 1961 to 1990. On the one hand, this "urbanization effect" associated with spatially and temporally inhomogeneous air pollution is still smaller than the decline shown above by Stanhill and Cohen [2001]. On the other hand, studies of solar radiation measurement records in remote locations

show similar dimming (1.6 W/m^2 per decade given by Alpert et al. [2005]) and brightening patterns worldwide [see also Wild et al., 2005; Schwartz, 2005; Dutton et al., 2006]. Hence, the dismissal of observed solar radiation variations as purely locally biased can be regarded as premature as well. Estimating global averages based on the more than 300 existing and unevenly distributed long-term records of solar radiation, though, is prone to large uncertainties and remains a challenging task.

Why Is Dimming/Brightening a Considerable Climate Factor on a Global Scale?

Besides the magnitude and scale of the observed changes, there are further globally observed indications—including the different trends between nighttime and daytime temperatures [Wild et al., 2007], observations of pan-evaporation, and distinct patterns in ocean heat uptake—that are consistent with multidecadal variations in surface solar radiation. These changes observed at the surface can differ from radiative flux changes at the tropopause where forcings are typically calculated. For example, soot particles reduce solar radiation at the ground and absorb solar energy in the layer where aerosols exist, but soot particles do not necessarily cause a forcing at the tropopause level. Furthermore, the well-known fact that the surface radiative budget alone is not balanced enables the reconciling of global dimming and global warming, although Stanhill [2007] challenged this fact. Energetic adjustments can and do take place through the nonradiative fluxes. Evaporation and sensible heat fluxes are indeed reduced [Liepert et al., 2004] in simulations that include anthropogenic aerosol effects in addition to greenhouse gas forcing. These changes of all energy fluxes at the surface have broad consequences for the climate system beyond cooling and warming, and the water cycle seems most sensitive to dimming and brightening.

In summary, this discussion is a reminder that radiation as part of the energy budget at the surface is an important integrative climate parameter that can be measured with known accuracy [Ohmura et al., 1998] and should hence be monitored and analyzed.

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Further Comment on “A Perspective on Global Warming, Dimming, and Brightening”

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In a recent *Eos* Forum article, Stanhill [2007] suggested that there is an unexplained inconsistency between “global dimming” and global warming. This contention is mistaken.

Stanhill’s argument is based on select local observations that show reductions in the surface shortwave downwelling radiation (SWD) from the 1950s to the 1980s of about 20 watts per square meter (W/m^2) [Stanhill and Cohen, 2005]. Stanhill errs in equating these surface flux changes (the “dimming”) with the radiative forcing from anthropogenic greenhouse gases (currently about $2.6 W/m^2$). Radiative forcing is defined at the tropopause (not the surface) specifically to provide a good prediction for eventual model responses. Changes in aerosols and clouds result in large changes in SWD, but they do not translate into similarly large changes in tropopause forcing since the aerosols and clouds absorb energy in addition to reflect it.

This is most clearly demonstrated in the Coupled Model Intercomparison Project phase 3 (CMIP3) suite of twentieth-century simulations (http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php) that indicate a global dimming of $1\text{--}4 W/m^2$ over the entire twentieth century (Figure 1), associated predominantly with aerosol effects [Romanou *et al.*, 2007]. Simultaneously, all CMIP3 simulations show global warming of $0.4^\circ\text{--}0.7^\circ\text{C}$. The combined effect of aerosols and greenhouse gases at the tropopause is dominated by longwave changes, even while the aerosols cause surface dimming.

We also question the representativeness of Stanhill’s selected stations for determining a global trend. For instance, a satellite-derived estimate of surface fluxes (International Satellite Cloud Climatology Project [Zhang *et al.*, 2004]) shows a small globally averaged increase in the SWD of $0.04 W/m^2$ per year from 1984 to 2000, but there is significant spa-

tial inhomogeneity. Using select station locations gives a much larger trend of $0.5 W/m^2$ per year (in agreement with other analyses), but it is not representative of large areas of SWD reductions (namely, the Arctic, South and East Asia, and sub-Saharan Africa).

Understanding anthropogenic climate change depends on multiple lines of evidence and a variety of observations. “Global dimming” is an integral part of that evidence, not a contradiction to it.

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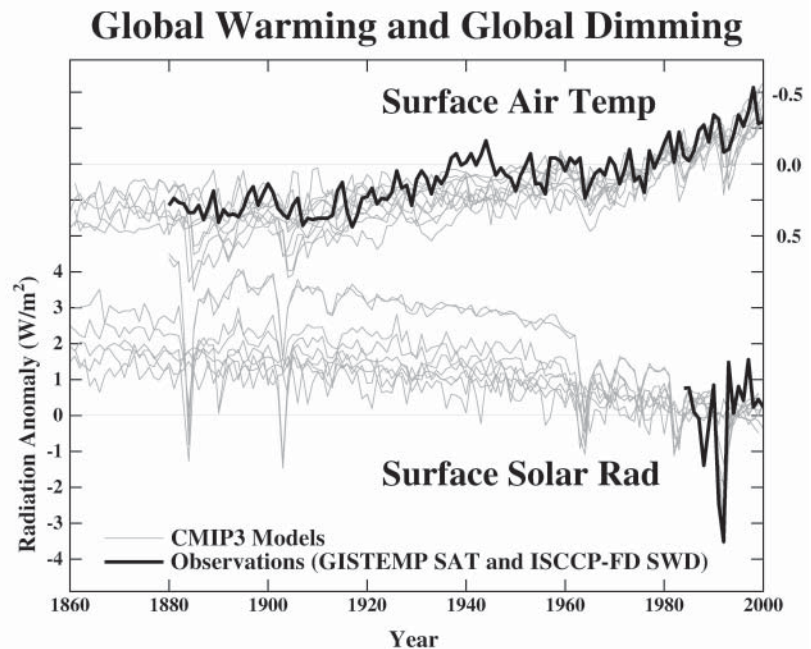


Fig. 1. The global surface air temperature (SAT) and surface shortwave radiation (SWD) anomalies for nine models (ensemble means) and observations. Anomalies are with respect to 1950–1999 for SAT and 1984–1999 for SWD.

Reply to Comments on “A Perspective on Global Warming, Dimming, and Brightening”

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The welcome comments by *Liepert et al.* [this issue] on my Forum article stress the importance of shortwave radiation forcing at the Earth's surface for understanding current climate change and the forcing's consequences for the life-sustaining solar-powered water and carbon cycles. I agree with their call for continued and expanded support for long-term programs to monitor and analyze these changes. Such programs are especially relevant in the Earth's polar regions and ocean surfaces where the solar radiation measurement network is smaller now than when it was established by the International Geophysical Year 50 years ago.

Monitoring of the downwelling and upwelling longwave and shortwave components of the surface radiation balance in these regions can, and should, be supplemented with measurements of the latent and sensible heat fluxes to establish the consequences of global dimming and brightening. The need for such measurements to explain the

rapid warming occurring on the coasts of Antarctica at twice the global rate was emphasized 10 years ago [*Stanhill and Cohen, 1997*].

The fact that global warming and dimming coexist at the Earth's surface was a major point in my Forum article, and it is reassuring that the results of the suite of climate model experiments presented by *Schmidt et al.* [this issue] in their response agree with the measured results. However, I cannot agree that these results have established the validity of their explanation for this paradox, i.e., that changes in the concentrations of radiatively active gases and aerosols have altered the fraction of global radiation retained in the radiation balance at the Earth's surface and/or in the partitioning of the radiation balance between latent and sensible heat. While this is possible, if unverifiable, at the tropopause, it is difficult to conceive how it could occur over the major part of the Earth's surface covered with water or on those land surfaces in which evaporation is unlimited by water supply.

Whatever explanation of the seeming paradox proves correct, it is difficult to accept the Schmidt et al. view that the detailed discussion of aerosol and cloud effects contained in the Intergovernmental Panel on Climate Change reports justifies the absence of any direct mention of the measured changes in global radiation. Their own response highlights the need for discussion of this finding because of its relevance to the causes of climate changes.

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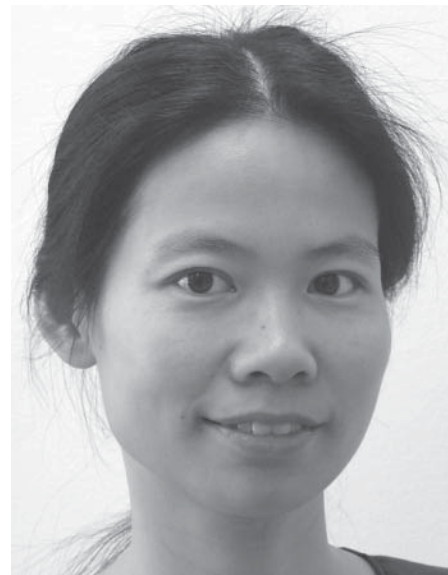
Yingjuan Ma Receives 2007 F. L. Scarf Award

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Yingjuan Ma has been awarded the AGU F. L. Scarf Award, given annually to a recent Ph.D. recipient for outstanding dissertation research that contributes directly to solar-planetary sciences. Ma's thesis is entitled “3D multi-species global MHD studies of the solar wind interaction with Mars and Saturn's magnetospheric plasma flow with Titan.” She will be formally presented with the award at the SPA Section Dinner during the 2007 AGU Fall

Meeting, which will be held 10–14 December in San Francisco, California.

Yingjuan Ma received her B.S. in 1997 and a M.S. in 2000 in space science from University of Science and Technology of China. She received her Ph.D. in atmospheric and space sciences under the supervision of Andrew F. Nagy in 2006 at University of Michigan in Ann Arbor. Her research interests include MHD modeling of plasma interactions around unmagnetized and weakly magnetized solar system bodies.



Yingjuan Ma