EXCESS SOLAR ABSORPTION IN CLOUDY ATMOSPHERES

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One of the most insidious and nefarious properties of scientific models is their tendency to take over, and sometimes supplant reality. Erwin Chargaff

Do cloudy skies absorb more solar radiation, when compared with that in the surrounding clear skies? Even a qualitative answer to this question has eluded experimentalists and modelers for nearly four decades. The fundamental reason is a systematic discrepancy between the models and the observations (Stephens and Tsay, 1990; and Liou, 1992). Model clouds are brighter and less absorptive than observed clouds. As summarized in Liou's (1992) book, "Reflectance and absorptance computed from theoretical programs.... are generally higher and lower respectively than observed data. The largest cloud absorptance derived from theoretical calculations has an upper limit of $\simeq$ 20%.... However, the observed cloud absorptance could be larger than 30%." The discrepancy was largely attributed to uncertainties in the observations.

What is the implication of this discrepancy to climate? To answer this question, we must consider the effect of clouds on the solar absorption by the atmospheric column between the surface and the top of the atmosphere (TOA) (at least the tropopause), as opposed to the details of the absorption of a particular cloud layer. Why is the column absorption important? A fundamental quantity in climate studies is the average solar energy absorbed by the Earth's surface. Since earth radiation budget satellites yield the surface-atmosphere column solar absorption, knowledge of the atmospheric column solar absorption can be used to obtain the surface absorption as a difference between the two. Let us begin with models first, since we lack global scale surface or atmospheric observations.

Modern day general circulation models *(GCMs) conclude that cloudy skies absorb the same amount of solar radiation as clear skies.* This is remarkable since clouds, by scattering and absorbing solar radiation, significantly alter the solar radiation; yet, in the models the various effects cancel each other such that clouds reflect solar radiation to space and transmit the rest to the surface without altering the atmospheric solar absorption.

How do we test this GCM prediction? Conceptually it is simple. We need earth radiation budget measurements from space or from the tropopause to estimate the energy reflected to space and collocated radiometers at the surface or well below the cloud layers to estimate the transmitted radiation. The difference between the two measurements can yield the absorbed radiation in the atmospheric column. Comparison of the atmospheric solar absorption under clear and cloudy skies can be used to examine whether clouds enhance the solar absorption.

Three independent observational studies (Cess, et al., 1995; Pilewskie and Valero, 1995; and Ramanathan, et al., 1995; over a dozen international groups participated in the three papers), employing variants of the above technique with independent instruments and independent measuring platforms (ranging from high altitude aircraft, satellites, ships, buoys and atmospheric soundings), have failed to confirm the GCM result. For the cloud systems in the tropical Pacific, which is one common feature of the three studies, they conclude that cloudy skies absorb about 8% more (or about 35 $W.m^{-2}$ more) of the TOA solar insolation when compared with clear sky values.

An article by Stephens (also see Stephens, 1996) in an earlier issue of this newsletter, which is a summary of a panel report, has raised scientific questions about the three observational studies. These questions and critiques have been rebutted in detail in a peer reviewed journal (Cess and Zhang, 1996; and Pilewskie and Valero, 1996).

In summary, ***climate models are missing a large heat source in the tropical atmosphere and are compensating for it by overestimating the solar energy absorbed by the sea surface and the land surface. Globally (Cess et al., 1995), GCMs that constrain their planetary albedos with satellite data, may overestimate the solar energy reaching the surface by as much as 8%, or equivalently 25 $W.m^{-2}$.***

Re-evaluation of the Surface Solar Energy Budget: Within the last 5 years, two independent observational studies (Ohmura and Gilgen, 1993; Gleckler and Weare, 1995) have re-evaluated the surface solar energy budget. Both of these studies are in support of the above three studies with respect to the sign, as well as the magnitude of the discrepancy between observations and models. The Ohmura and Gilgen (1993) study uses the global energy balance archive (GEBA) data set and concludes: "The global annual mean shortwave solar radiation is estimated at 142W.m^{-2} or 42% of the extra-atmospheric solar radiation, 17 W.m^{-2} smaller than the previous estimates." The 142 W.m^{-2} is the net (down - up) short-wave radiation at the surface. The discrepancy is even larger (closer to 25 W.m^{-2}) if we compare with just the model estimates. As summarized in Kiehl and Trenberth (1996), model estimates are closer to 170 W.m^{-2} or 50% of the TOA solar insolation; these numbers are to be compared with the GEBA data set values of 142 W.m^{-2} or 42%.

The Gleckler and Weare study, which employs the Comprehensive Ocean-Atmosphere Data Set (COADS) focuses on just the world oceans and concludes: "Preliminary comparison of zonal average fluxes suggest that most atmospheric general circulation models produce excessively large ocean surface fluxes of net solar heating...." The global extent of the problem (as opposed to just the tropics) is also hinted in this study, which compares 30 GCM simulations with observations: for example, it finds: "... in the mid-latitudes very few models have shortwave fluxes in the range of the observations."

Clearly, there is a serious gap in our knowledge. The accumulated evidence is overwhelming to re-examine the treatment of radiation in GCMs.

Is this anomalous or excess absorption? Anomalous means "deviating from a general rule or accepted notions of order" (Webster's dictionary). As far as we know, there is no rigorous proof that clouds should have no net effect on the atmospheric column absorption, when compared with clear sky absorption. Our notion of zero net effect is largely based on radiation models. Some of the fundamental flaws of our radiation models, at least those used to assert the zero net cloud effect, is that they assume: 1) clouds are flat plates with horizontally homogeneous properties, 2) cloud drops and crystals are made of pure water; and, 3) the absorption is by Lorentzian lines with arbitrarily specified wavelength cutoffs, and 4) poor treatment of aerosol effects. These assumptions have served us well in the past, but we should not be surprised if they have outlived their usefulness. We need more sophisticated laboratory, *in-situ* and remote observations; we also need models of realistic cloud shapes and sizes. In the mean time, it is safe to consider this phenomenon as simply "excess absorption" to point out that there is excess solar absorption in cloudy atmospheric columns, when compared with clear sky column absorption.

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