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An Absorbing Mystery

In January, after a year of duelling with angry critics in conference presentations and seminars, Cess *et al.*[1] and Ramanathan *et al.*[2] published their controversial challenge to the field of atmospheric solar radiation. Ramanathan's group suggested that the tropical Pacific energy budget could only be balanced by assuming dramatically enhanced absorption of solar radiation in clouds. Cess's group, using collocated satellite and surface radiation data from five locales ranging in latitude from Point Barrow, Alaska to Cape Grim, Australia, found the enhanced absorption to be *global*. In March, Pilewski & Valero[3] published stacked-aircraft measurements from the tropical Pacific which corroborated these findings. All three groups found an absorption far in excess of what any current model can possibly predict[4]. If the enhanced cloud absorption is real, the additional amount of solar energy absorbed in the atmosphere, and thereby denied to the Earth’s surface, is large enough to dramatically alter our notions of how the current climate works. It would cause the biggest change in our understanding of the Earth’s energy balance since the late 1960s, when satellites showed that the Earth reflects only 30% of the incident sunlight, not 35–40% as previously thought.

On page 486 of this issue, Zhanqing Li *et al.*[5], using a different and geographically more extensive surface radiation dataset than Cess used, find that the enhanced absorption occurs only in *warm seasons* — mainly in the tropics and midlatitude summers. At other times, Li finds a tendency toward larger absorption than predicted by current models, but far less than Cess finds. Li furthermore finds that the absorption effect is highly *variable* at all latitudes, whereas Cess finds it to be remarkably constant. Some modelers find this lack of variability in the Cess result even harder to accept than its magnitude, because even when they make their model clouds more absorbing, model-predicted absorption still varies considerably with latitude and other factors.

None of these authors[1-5] offer any theoretical explanation for enhanced absorption, although

Li speculates that there may be no mystery absorber and that, instead, algorithms used to process ERBE satellite data may be wrong for highly heterogeneous cloud scenes, such as in the Shuttle

Typical heterogeneous cloud field in the tropics, from NASA Shuttle flight STS-035. Such irregular cloud formations may lead to difficulties in processing satellite radiation measurements. (NASA Johnson Space Center)

photograph shown here. (Li's, Cess', and Ramanathan's analyses depend heavily on ERBE, NASA's 1985-1990 Earth Radiation Budget Experiment.) Such scenes, with towering convective clouds, are more prevalent in warm seasons — the very seasons where Li finds the anomaly. And it must be admitted that our understanding of solar radiation reflected from such cloud scenes is poor. However, ERBE was the result of a gargantuan effort on the part of a great many talented people in NASA and at universities, and if ERBE algorithms were wrong in the tropics, it would be just as stunning as if cloudy columns contain some elusive mystery absorber.

Li *et al.* also speculate that highly absorbing aerosols from biomass burning may cause enhanced tropical absorption. However, tropical biomass burning occurs during a two-month period, and the resulting aerosols are washed out of the atmosphere within a month after burning ceases. Since enhanced absorption is seen in *every* month, this explanation seems unlikely.

Did this challenge catch the atmospheric solar radiation field napping? Yes and no. The field was wide awake in developing applications (mainly to remote sensing and climate modeling), but napping in basic research. Most practitioners assumed the current list of atmospheric absorbers was complete and well-understood, and that it was safe to use one-dimensional models (which include vertical but no horizontal variation) rather than full three-dimensional models. Model testing in the atmosphere was perfunctory, with little effort to measure model input variables definitively. Now and then, there were wakeup calls, but these were quickly forgotten. Even nagging anomalies in clear-sky absorption observations, as well as huge disagreements among models[6], have remained largely unresolved. The near-infrared absorption spectrum of the dominant solar absorber, water vapor, has been revised several times in the last 20 years, and it may not be right yet — especially the all-important continuum component, about which virtually nothing is known.

Anomalous cloudy-column absorption was already being reported in the 1950s[7]. Early measurements were easy to ignore for a variety of reasons — but as the experiments got better, reports of enhanced absorption not only persisted, but were reinforced by observed deficits in near-infrared (wavelengths 0.7 to 3 microns) cloud reflectivity[7]. Meanwhile, however, other careful observations showed no disagreement with models. Recent measurements by Hayasaka et al.[8] recapitulate, in microcosm, this history: in some cases models correctly simulated near-infrared cloud reflectivity observations, in some cases they didn't. The models were correct when the clouds "looked" more homogeneous, Hayasaka said. But even very homogeneous-looking clouds have large turbulent variations in liquid water column amount[9] that are poorly discernible by eye; there is really just a *continuum* of degrees of inhomogeneity, and it is hard to see how there could be an inhomogeneity threshold past which models suddenly fail.

Fortunately, the United States ARM (Atmospheric Radiation Measurements) program has planned month-long aircraft campaigns to carefully test the enhanced absorption hypothesis. These are scheduled at the ARM Oklahoma site this fall, and again in the spring, using the exciting new unmanned aeroplanes pioneered by ARM as research platforms. They will eliminate many of the unavoidable uncertainties in comparing satellite and surface radiation measurements; for example, identical high-quality radiometers will be used on all aircraft and at multiple sites on the surface. And better spectral resolution will pin down which spectral regions are doing the absorbing, something which the satellite and surface radiometers used by Cess and Li couldn't tell us.

"Enhanced cloud absorption" is a difficult pill for the atmospheric solar radiation field to swallow. Its theoretical models, on which large application programs in remote sensing and climate modeling are based, have been impugned. Now it must backtrack and fill gaping potholes in fundamental knowledge, including: unscrambling three-dimensional inhomogeneity effects from true absorption effects; doing spectroscopy in real and artificially-generated clouds; and finding out why shortwave models can't even agree with one another. Accelerated development of promising new tools to map out the internal water structure of clouds is needed, to provide input to three-dimensional radiation modeling efforts. Only with much greater attention to such basics can we begin to close this gaping uncertainty in current models.

Warren J. Wiscombe is in the Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland 20771, USA.

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