by Dan Whipple

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The Earth's climate is fundamentally tied to the amount of solar radiation absorbed by the surface. Not all incoming energy is absorbed. Some is reflected back into space by clouds, atmospheric gases, and by the surface itself.

Satellite measurements in recent years have quantified the Earth's reflectance, but much is still unknown about how the atmosphere absorbs incoming sunlight in the shortwave portion of the electromagnetic spectrum. In particular, scientists are interested in measuring the effect clouds have on incoming sunlight. Radiation models indicate that cloudy skies absorb about as much shortwave energy as do clear skies. But recent studies indicate that clouds absorb significantly more shortwave radiation than models predict.

"This speaks to the fundamental atmospheric physics of the planet," said Charles Zender, a postdoc with the Climate and Global Dynamics Division of the National Center for Atmospheric Research. "The planet is covered about 50 percent of the time by clouds. So at any given point, on average, a cloud is there half the time. So we measured the radiation field during a cloud event to see if we were correctly predicting the energy absorption going on in the atmosphere in our climate and weather forecast models."

The results show a relatively large discrepancy between climate model predictions and actual radiation behavior measurements. The climate models overestimate the amount of solar radiation heating the ground and/or being reflected back out to space (and not heating anything). The researchers' work indicates that this radiation may in fact be absorbed by clouds, thus heating the atmosphere more than the models predict measurements.

"This has a large implication for the validity and the prediction that climate and weather forecast models make," Zender said.

Ozone and water vapor in the atmosphere absorb most but not all of the shortwave solar radiation that gets absorbed. These contributions to absorption have been measured fairly well. But other trace gases in the atmosphere also absorb a small but significant part of the solar shortwave radiation; and these gases would have biased the results of the experiment if their concentrations and absorptive effects were not accounted for in the study.

"We had measurements of the most important trace gases, ozone and water vapor," Zender said. "But we didn't have nitrogen dioxide measurements. We were working at such high levels of precision that the contribution of nitrogen dioxide to the absorption of sunlight was significant."

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The image above was acquired by the MODIS Airborne Simulator, flying aboard NASA's ER-2 aircraft, on Oct.17, 1995. The flight path followed the Salt Fork Arkansas River east, through Oklahoma, to its confluence with the Oklahoma River, south of Ponca City, OK. (Image courtesy of MODIS Airborne Simulator ARESE Campaign)

[Note to researchers: SAGE II, launched in October 1984, uses a technique called solar occultation to measure attenuated solar radiation and to determine the vertical distribution of stratospheric aerosols, ozone, nitrogen dioxide, and water vapor all around the Earth. For more information, visit the Langley Atmospheric Sciences Data Center DAAC.]

"We needed to estimate how much nitrogen dioxide there was over Oklahoma during the field experiment. It was something that just wasn't measured," he said.

Then, Zender found out about the ARM Enhanced Shortwave Experiment (ARESE) that was conducted in the skies over Oklahoma between Sept. 22, 1995, and Nov. 1, 1995. Researchers designed that experiment to measure precisely the absorption of solar radiation in clear versus cloudy skies. They flew two aircraft in formation—one directly above the other—with instruments that measured, among other things, nitrogen dioxide at different altitudes. The ARESE data reside at the Langley Research center.

"So we went to the DAAC, and I pulled down the SAGE nitrogen dioxide climatology and found the overflights of the ground station we were working with. For those times I looked at the nitrogen dioxide concentration, actually the DAAC had the vertical distribution of it, every kilometer or so, from about 12 kilometers (altitude) to 25 kilometers—almost the entire stratosphere."

By combining the SAGE stratospheric data with an estimate for the tropospheric concentration, Zender estimated the total concentration of nitrogen dioxide in a column through which sunlight passed. He was thus able to account for the radiation absorption by nitrogen dioxide.

"What we were looking for was absorption we couldn't explain," Zender said. We knew how much sunlight was entering the top of the atmosphere and we knew how much was hitting the surface. We also knew how much was at about one kilometer and 13 kilometers because we had aircraft at those altitudes measuring sunlight." This combination gave them a vertical distribution of sunlight in the atmosphere.

"We could rule out some of the absorption's being mysterious because we knew it was absorption by nitrogen dioxide," he added. "It wasn't very much, but we were doing a high precision model-observation comparison."

Yet, even after accounting for absorption by all known trace gases, clouds and aerosols, the total absorption of solar radiation in cloudy conditions was still not explained. "In other words," Zender said, "there's something missing in the theory."

In clear skies, the model and the observations agreed very well, with no statistically significant discrepancy between the model estimates and the observations.

Under cloudy skies, however, the difference was substantial. Models underestimate the absorption in clouds by a factor of about 40 percent. "We couldn't explain 100 watts of the 250 watts of absorption we measured in overcast skies at noontime," Zender said.

Zender said the study found no evidence for enhanced absorption in the clear skies during ARESE, but found strong evidence for enhanced radiation absorption in cloudy skies. But, he said, the ultimate causes for this absorption, both in the visible and near-infrared parts of the spectrum, are unknown.

Since the sun strikes the Earth for only half the day in any given spot, and clouds are present only half the time, and not all clouds are as thick as those in the Oklahoma experiment, the average absorption discrepancy worldwide is about 7 percent of the solar energy received by the Earth. "This has strong implications for the accuracy of weather and climate forecasts," Zender said.

The impact won't be manifested in short-term forecasts, but over a week or longer, the additional heating of the atmosphere from cloud absorption of solar radiation can affect the climate in ways the forecast models currently cannot predict.

"These general circulation models are the models we use to understand global change," Zender said. "So when we speak of how much a doubling of carbon dioxide sswill change the climate, that's all a prediction from a general circulation model. Until they're able to predict the present climate correctly, you have to limit your confidence in what they tell you about the future climate.

"Global change is something that occurs on top of existing cloud absorption, and we're not getting that right."

Zender, C. S., B. Bush, S. K. Pope, A. Bucholtz, W. D. Collins, J. T. Kiehl, F. P. J. Valero, and J. Vitko, Jr. 1997. Atmospheric absorption during the Atmospheric Radiation Measurement (ARM) Enhanced Shortwave Experiment (ARESE). *Journal of Geophysical Research* 102(25): 29,901-29,915.