

tion of seismic oscillation. From among the many spikes due to noise and artifacts of the Fourier analysis, Kjeldsen and coworkers had to extricate the sequences of equally spaced eigenfrequencies that are characteristic of solar-like oscillation.

The obvious method is to do a Fourier analysis of the power spectrum in search of a repeated frequency spacing of about the predicted size. But that kind of second Fourier analysis of a Fourier power spectrum is notoriously sensitive to spurious sidelobes caused by periodic interruptions of the observing period: Shutting down at dawn every day produces beat-frequency sidelobes at a spacing of $11.6 \mu\text{Hz}$ (the reciprocal of 24 hours) on either side of any true eigenmode peak.

Therefore Kjeldsen and company created what they call a comb-response function as an alternative to repeated Fourier analysis and its pitfalls. Unlike Fourier analysis, the comb-response function presupposes the presence of sequences of equally spaced frequency peaks. Testing this new analytic tool against simulated stellar oscillation data with obtrusive interruptions and lots of noise, the group was able to retrieve the correct eigenfrequencies reasonably well.

The end result of applying the comb-response analysis and additional cleaning algorithms to the power spectrum of last year's six-night observation of the η Boötes Balmer absorption lines is the figure on page 20. Fitting the peaks to theoretical formulae that give the eigenfrequencies in terms of the mode order numbers and empirical stellar parameters yields the n and l labels attached to the various peaks. The fitted spacing between consecutive peaks of the same l turned out to be $40.3 \mu\text{Hz}$, which is in reasonable agreement with what's predicted by scaling arguments applied to the helioseismological results.

This observed spacing and other parameters fitted from the η Boötes Balmer-line oscillation data bear directly on internal properties of the star that are not otherwise accessible. "But before we present a detailed comparison with astrophysical theory," says team member Søren Frandsen, "we want to make sure we haven't just been modeling noise and analytical artifacts. With all those diurnal sidelobes it gets very complicated."

Seeking confirmation

As we go to press, Kjeldsen and company are spending Easter week in pursuit of the obvious remedy. No one telescope (except near the poles

in winter) can escape the artifacts generated by having to stop observing every day at dawn. But two telescopes in widely separated time zones can do the trick. With one telescope in Chile and another in Australia, the group will spend the week monitoring the Balmer absorption lines of α Centauri. Aside from being very similar to the Sun, α Centauri has the distinction of being our nearest neighbor: It's only 4.3 light-years away. In addition to providing almost continuous coverage, both these telescopes are considerably larger

than the 2.5-meter instrument that provided the η Boötes data. "So our signal-to-noise ratio should also be much better," Frandsen told us. "If α Centauri confirms what we believe we found with η Boötes, asteroseismology will really be in business."

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Clouds Cast a Shadow of Doubt on Models of Earth's Climate

Clouds have always bedeviled those trying to model Earth's climate, because they are such complex systems, involving parameters whose size and time scales range over many orders of magnitudes. (See the article by Jeffrey Kiehl in *PHYSICS TODAY*, November 1994, page 36.) While struggling to represent clouds realistically in their models, atmospheric researchers have at least felt that they understood the basic physics of clouds. But now they are not so sure.

The conventional wisdom has been that clouds reflect some of the solar radiation entering the atmosphere but do not absorb any more radiation than a clear sky would. There have been hints, however, from experiments going back more than 40 years that clouds are not transparent but absorb an appreciable amount of solar radiation.¹ Until recently those experiments could be dismissed as inconclusive. But it's proving hard to ignore the evidence accumulated by three recent studies.²⁻⁴ Each of those studies measured by a different method the short-wavelength (0.25–4.0 microns) absorption by clouds, and all arrived at the same conclusion—that clouds are absorbing more short-wavelength radiation than is calculated by the radiative-transfer models used in simulations of Earth's climate.

The latest evidence leaves atmospheric scientists scratching their heads. If the measurements are correct, what is the theory missing? According to Tom Ackerman of Penn State, there are only a handful of possibilities, and none seems to be of the right size or nature to explain the observed discrepancies. More experiments are now planned to verify the existence of the larger-than-expected shortwave absorption and to determine its dependence on wavelength,

According to three recent experiments, clouds appear to be absorbing more of the incoming solar radiation than they should—at least if our current understanding of cloud physics is correct. Researchers plan additional experiments, capable of measuring the wavelengths at which the absorption occurs, to obtain more clues about the source of the discrepancy.

as a clue to the possible cause.

Deducing the cloud absorption

To find how much a cloud is attenuating the shortwave radiation, ideally one would like to station radiometers both above and below the cloud, recording the net shortwave flux at the two heights simultaneously. Moreover, one would want to take such measurements at stations around the globe and for long periods of time, because the nature of clouds varies temporally and spatially. In the real world, however, the possibilities are far more constrained. Information about the shortwave radiation at the cloud tops comes from the Earth Radiation Budget Experiment, which collected data only from 1984 to 1990; the data came from scanning instruments aboard several satellites. (See the article by V. Ramanathan, Bruce R. Barkstrom and Edwin F. Harrison in *PHYSICS TODAY*, May 1989, page 22.) Continuous, calibrated ground-based measurements are available from instruments at only a handful of stations worldwide. Additional data come from instruments aboard aircraft, but few of those airborne measurements have involved coordinated flights of stacked planes flying above and below the clouds.

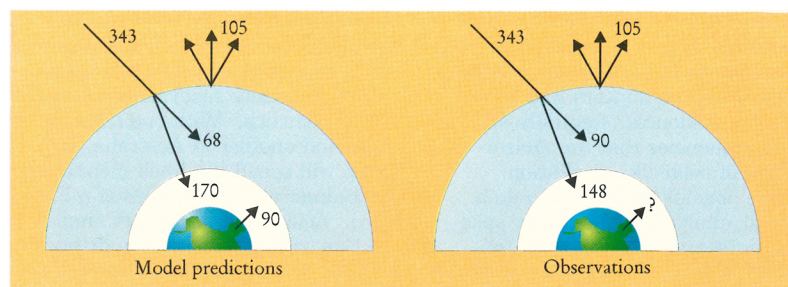
In one of the recent studies, Robert Cess of the State University of

New York, Stony Brook, spearheaded a multi-institutional comparison of existing ground-based measurements with satellite data gathered by ERBE instruments over the same spots during the same time intervals.² The ground stations were located at five geographically diverse sites in Alaska, Colorado, Wisconsin, American Samoa and Tasmania.

The group led by Cess used the data to calculate the shortwave cloud forcing, C_s , which is the difference between the net downward flux in all sky conditions and that in a clear sky. For example, the cloud forcing at the top of the atmosphere, $C_s(\text{TOA})$, is negative, because clouds reflect more short-wavelength radiation than a clear sky would. If the clouds do not absorb any short-wavelength radiation, the cloud forcing at the surface of the Earth, $C_s(\text{S})$, should be the same as that at the top of the atmosphere. But if clouds soak up a sizable portion of the Sun's rays, the cloud forcing will be greater below them than above them, and the ratio $C_s(\text{S})/C_s(\text{TOA})$ will exceed 1. Most climate models today predict very little shortwave absorption by clouds and hence calculate a ratio close to 1. By contrast, Cess and his colleagues found that the ratio at the Boulder station is 1.46.

The collaboration could not directly measure the ratio $C_s(\text{S})/C_s(\text{TOA})$ at the other sites, because of limitations in the data. They could, however, determine a related parameter, involving measurement of only the sunlight incident on and reflected from the top of the atmosphere, and that transmitted to Earth's surface. From that parameter, in turn, the team could derive an estimate of the cloud-forcing ratio. At all locations $C_s(\text{S})/C_s(\text{TOA})$ was close to the value of 1.46 determined from the Boulder data. In units of flux, the surface cloud forcing is roughly 30 W/m^2 more than is calculated by a typical atmospheric general circulation model.

The collaboration headed by Cess stumbled onto this discrepancy while analyzing the data with another goal in mind. So did V. Ramanathan of the Scripps Institution of Oceanography in San Diego and a group of collaborators,³ who were studying the radiation balance in the "warm-pool" region of the Pacific Ocean, extending from 140°E to 170°E and from 10°N to 10°S . Ramanathan's group attempted to balance the heat budget for the warm pool, using all available data on energy flows into and out of the region. To balance the budget the group had to assign a value of -100 W/m^2 to the short-wave cloud forcing at the surface, $C_s(\text{S})$, compared with a value of -66 W/m^2 at



PATH OF SHORT-WAVELENGTH RADIATION. **a:** Radiative-transfer models predict that of the solar radiation (343 W/m^2) arriving at the top of the atmosphere (blue shading), 105 W/m^2 is reflected, 68 W/m^2 is absorbed by the atmosphere (whether clouds are present or not), and 170 W/m^2 is transmitted to the surface of the Earth (green). **b:** Measurements now indicate that clouds may absorb 90 W/m^2 , 22 W/m^2 more than calculated. The effect on the radiative flux from the surface is uncertain. All numbers are approximate. (Data courtesy of V. Ramanathan, Scripps Institution of Oceanography.)

the top of the atmosphere. Thus, Ramanathan and his group found the ratio $C_s(\text{S})/C_s(\text{TOA})$ to be 1.5, consistent with the value determined from the ERBE data.

The third study⁴ was the most direct, involving measurements of the flux by identical instruments mounted on airplanes flying simultaneously above and below a given cloud. The flights were made during two studies of ocean-atmosphere interactions known as the Tropical Ocean Global Atmosphere-Coupled Ocean Atmosphere Response Experiment and the Central Equatorial Pacific Experiment. An ER-2 aircraft flew above the clouds at an altitude of about 20 kilometers while a second aircraft (either a DC-8 or a Learjet) flew the same path below the cloud at a height between 8 and 12 km. The measurements made by instruments on the two planes were usually taken within seconds of each other.

Peter Pilewskie of NASA Ames Research Center and Francisco Valero, now at Scripps, analyzed the data from the TOGA-COARE and CEPEX flights to deduce the absorption of solar radiation by clouds. They found a ratio of cloud forcing equal to 1.58. The numerator in this ratio is the cloud forcing at 8–12 km, rather than at the surface, and hence cannot be directly compared with the cloud-forcing ratios reported by the other two studies. Nevertheless it is consistent with the others in pointing to a large discrepancy with model calculations.

Each of the recent experiments has its strengths and weaknesses. There is a possibility of a statistical error in the studies led by Cess and Ramanathan because the groups had to apply a correction to extract the total flux from the satellite measurements. Cess dismisses this concern,

because his study determined the difference between two readings. The aircraft instruments were hemispheric radiometers, which directly measure the flux, but they sampled only one geographical region for a total of 33 hours of flight time. Valero nevertheless stresses that the planes covered an area of 6 million square kilometers and flew through all kinds of clouds.

Possible explanations

If the results are real, where does the problem lie? One might look for answers in the optical properties of clouds. Could cloud droplets or ice crystals have more particulate matter than expected, increasing the cloud absorption? Could the index of refraction of liquid water or ice somehow be altered by absorption of aerosols or by the presence of bubbles? Is the continuum absorption by water vapor enhanced within clouds? Might the cloud droplets be larger than anticipated? Most of these hypotheses have been examined to some extent and found wanting, but verification of the discrepancy between experiment and observation may force a deeper look. Alternatively, one might question the accuracy of representing clouds in models as plane parallel sheets rather than as the spatially heterogeneous structures actually observed.

It is hoped that some clues will emerge from an experiment scheduled for fall. The study, sponsored by the Department of Energy with some support from NASA, is specifically designed to investigate the anomalous absorption and the wavelengths at which it occurs. For example, if the absorption is primarily in the visible, the culprit could be particulates in the clouds. If it is in the near-infra-

red, as suggested by some earlier experiments,⁵ the problem may be the physical properties assumed for water.

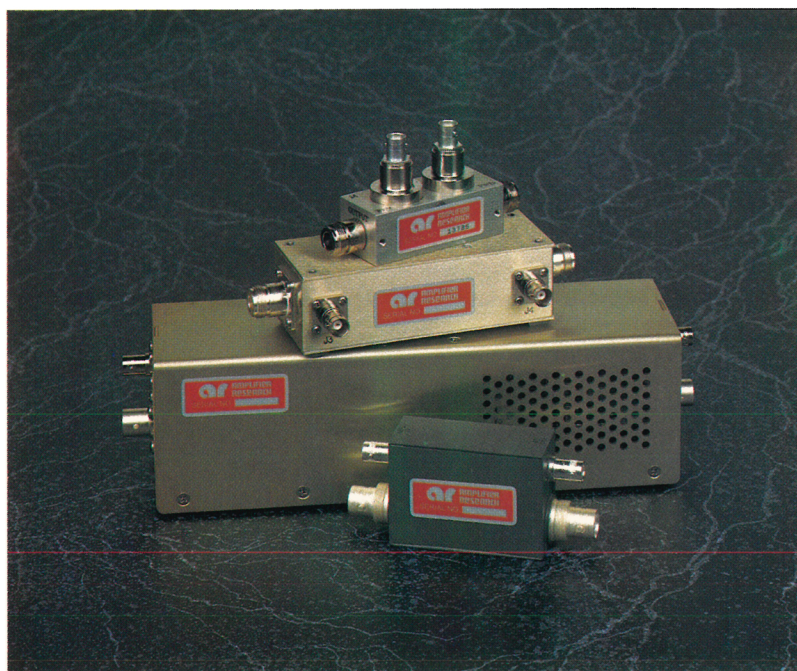
The planned experiment will use ground-based radiation monitors already in place in Oklahoma, at the southern great plains site of DOE's Atmospheric Radiation Measurement program. The monitors will be augmented by identical sets of Valero radiometers on the ground and aboard three planes: an ER-2 flying at 20 km, an unmanned aerospace vehicle at 10-12 km and an Otter plane at about 1 kilometer. Some of the radiometers measure total flux and some measure the flux at particular wavelengths. The measurement program will also include chemical sampling of the clouds.

The climate modelers cannot put the excess solar absorption into their models until its cause is known. V. Ramaswamy of the Geophysical Fluid Dynamics Laboratory in Princeton, New Jersey, noted that an excess absorption of some 25 W/m² would require a significant reworking of the heat distribution, with more energy going into the atmosphere and less into the surface. To illustrate the magnitude of the potential impact of short-wave cloud absorption on climate, Jeffrey Kiehl and his colleagues at the National Center for Atmospheric Research in Boulder, Colorado, forced their global climate model to manifest the observed behavior by decreasing the single scattering albedo.⁶ In response, with less heat reaching the surface, the surface latent heat flux, and hence the precipitation, decreased. There was also a weakening of the north-south Hadley circulation, which is driven by the difference in surface energy deposited in the tropics and at the poles.

—BARBARA GOSS LEVI

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