
Reflecting on

Scripps Researchers Heat Up Debate on Role of Clouds in Global Climate

Clouds:

Francisco Valero, director of Scripps's Atmospheric Research Laboratory.

BY MARIO C. AGUILERA

Enter Francisco Valero's office at Scripps and you encounter an atmosphere of calm and order. Four Picasso prints hang on the walls. Two large cherry-wood bookshelves support volumes of journals and textbooks, a stereo that sends melodies of Mozart and Bach softly through the air, and a photograph of Valero's two grandchildren. A sense of quiet commitment to the work at hand is reinforced by the researcher's easy smile.

Valero directs Scripps's Atmospheric Research Laboratory, where a team of researchers conducts groundbreaking studies of clouds and their role in regulating the balance of solar radiation on Earth.

He grapples daily with issues critical to understanding whether Earth's climate is changing, by how much, and how human activities influence phenomena such as global warming and the greenhouse effect. Valero attacks these issues with an intensity and determination that belie his greying hair, pressed slacks, and button-up sweater.

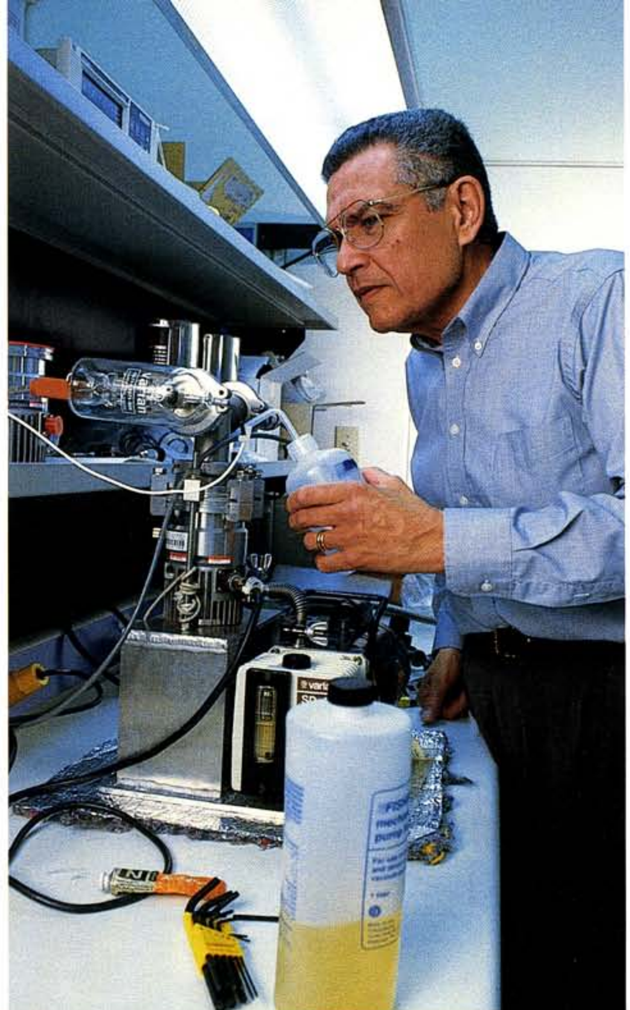
Clouds absorb, reflect, and transmit sunlight and affect how solar radiation is distributed within the atmosphere. They also impact the exchange of heat among the atmosphere, the oceans, and the solid land or ice. These fundamental roles, Valero believes, are not clearly understood, but must be if scientists are to accurately predict regional and global climate change.

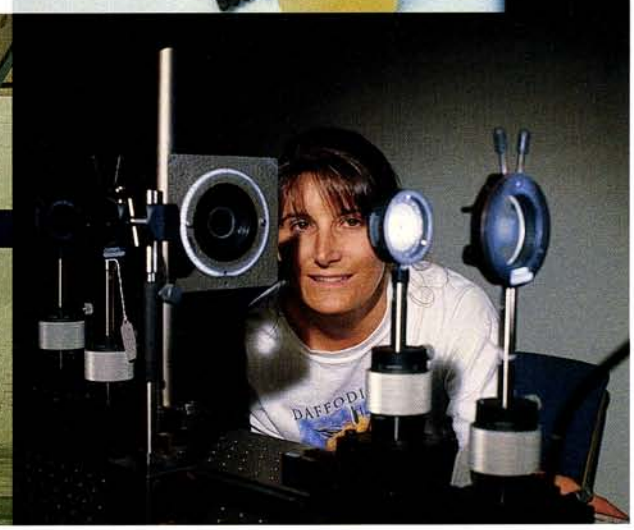
"We need to understand what clouds are doing, and we need to understand it as soon as possible," Valero said.

When sunlight reaches Earth, it is partially reflected back into space and partially absorbed by the atmosphere and the planet's surface. This energy is a major driver of atmospheric, oceanic, and solid-earth processes, including climate and life itself. The earth system in turn radiates energy back into space partly in the form of thermal infrared radiation, or heat. The balance between the incoming solar radiation and the outgoing thermal infrared radiation is a basic element of Earth's energy budget. Climate and climate change, including global warming, are driven by this radiative balance.

Valero is convinced that the theoretical numerical models scientists use to describe climate processes need to be revised to account for excess cloud absorption. Previous experiments that measured the absorption of solar radiation by clouds indicated discrepancies between models and observations. However, these discrepancies were generally dismissed as inaccuracies in the observations.

Because of new research, including studies by Valero's Atmospheric Research Laboratory team, scientists are now engaged in a renewed debate over just how large a role clouds play.





Top right, Valero tests an instrument prior to aerial deployment. **Above left,** A C-130 flown by the National Science Foundation is used as a flying laboratory. **Above right,** Research associate Sabrina Simpson with an array for calibrating optical instruments.

The present controversy started in 1995 when three independent teams published papers in the journal *Science*. One team, headed by Robert Cess of the State University of New York at Stony Brook, reported, on the basis of satellite data analysis, that clouds absorb more solar radiation than predicted by theory. Another team, led by Veerabhadran Ramanathan, director of Scripps's Center for Clouds, Chemistry, and Climate, concluded, on the basis of radiative balance arguments, that clouds in the tropical Pacific absorb about 15 times as much solar radiation as estimated in many global climate models.

Two months later the plot thickened. Valero and Peter Pilewskie of the NASA Ames Research Center published a report in *Science* that documented accurate observations made through direct flight measurements of excess solar absorption by clouds. These were the first direct observations of this type made using multiple aircraft flying over cloud systems spanning thousands of miles in diameter.

"These papers, published within two months, brought about quite a bit of debate in the radiative transfer community," said Valero, who also serves as director of the Scripps-NASA Joint Center for Observational System Science. "These debates can get very heated and challenge scientists to find the truth. Whatever the outcome, benefit will certainly come from the numerous and substantial research efforts that resulted."

Valero is convinced that the debate is crucial not only to scientists, but to those who develop environmental policies. Legislators rely on the scientific community when drafting environmental law, such as occurred at the 1997 Kyoto Earth Summit.

"We're talking about a difference in the amount of solar absorption by clouds that affects climate on a planetary scale," Valero said. "So this is a major com-

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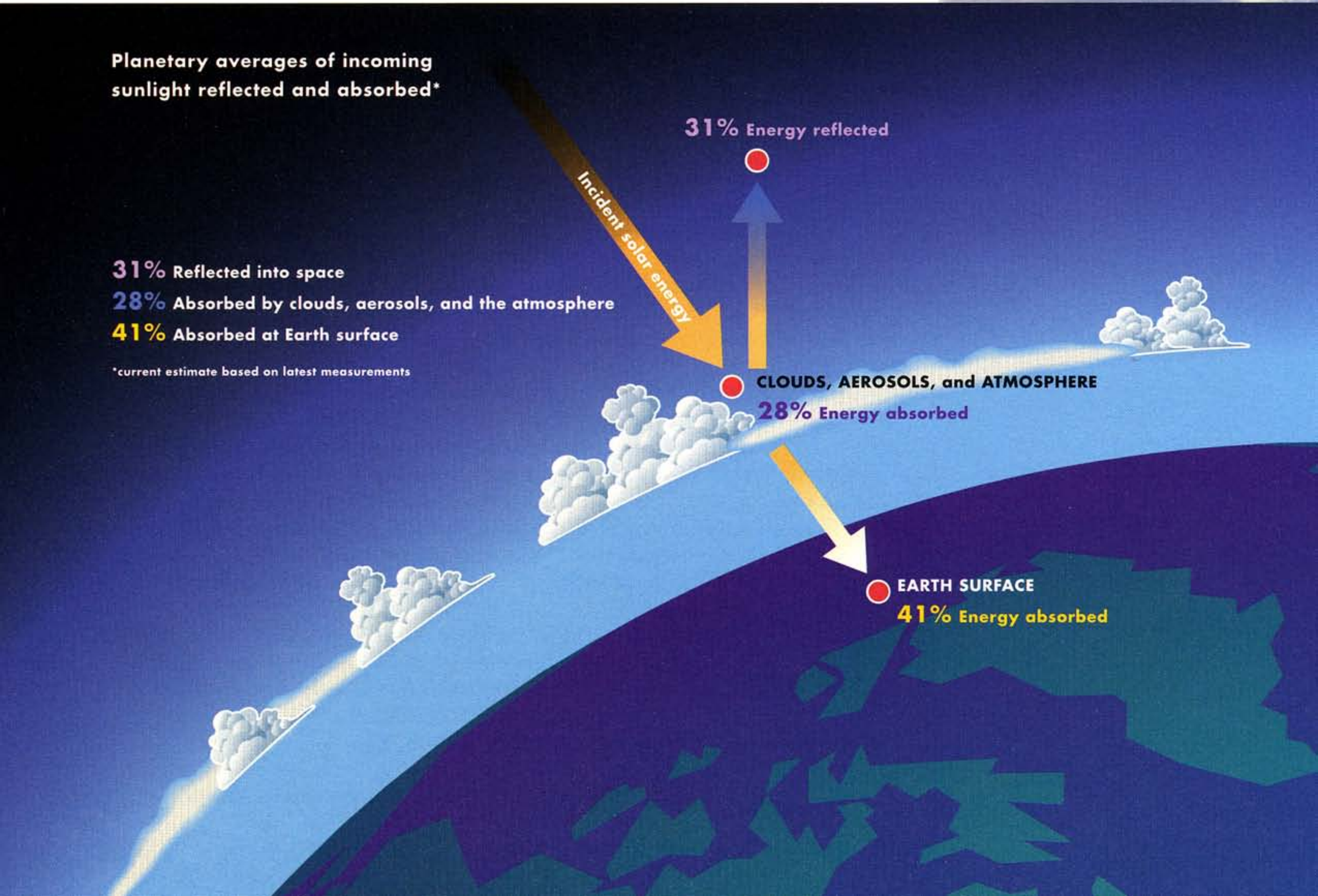
The gaping cargo bay of the C-130.



CLOUD MEASUREMENTS COMING

Clouds have been studied for many years, but because of their varying shapes and sizes, fleeting nature, and complex effect on solar radiation, they remain a perplexing atmospheric force to measure.

For example, although scientists have measured the absorption of sunlight by clouds for more than two decades, the findings were typically disregarded because they contradicted well-established theories and were not considered reliable. Only in the past few years have measurements, techniques, and instruments become refined enough for scientists to rethink the limited role given to clouds and cloud absorption.

Francisco Valero, director of Scripps's Atmospheric Research Laboratory, and a team of Scripps researchers were the first to make direct hands-on observations of clouds and their absorption of solar radiation using multiple, coordinated aircraft measurements. In the past, measurements of clouds were performed from the ground, ships, satellites, or a single airplane. A more complete approach is to make measurements from all these platforms simultaneously.

According to Valero, the group's goal in measuring clouds and cloud absorption is to create a profile of measurements from space to Earth. This allows them to obtain data from above and below the clouds at the same time. By measuring the amount of sunlight and infrared radiation that is going both up and down at each level, the effect of the clouds on this radiation can be estimated.

Observations from satellites are at the top of the "stack" profile and give the group measurements of such things as cloud cover and solar reflectivity. The team uses a high-altitude NASA ER-2 aircraft flying at an altitude of about 12 miles (19 km), above most of the atmosphere, to validate the satellite data.

The second level of measurements comes from another high-altitude airplane that flies in the region of the atmosphere where commercial airliners typically fly. The group has used a German-built reconnaissance plane, the Grob Egrett, flying at around nine miles (14.5 km) high to get these measurements.

Measurements from below the clouds come from a low-flying airplane, such as a Twin Otter, which flies at around a mile or less off the ground, to form yet another level of the profile. All of these airplanes attempt to fly in a coordinated vertical line so that they view the same cloud systems simultaneously.

The final component of the space-to-earth profile is instrumentation set on the ground or on ships that measure the amount of radiation hitting the earth's surface. The team also uses instrumented balloons, called sondes, that measure water vapor, temperature, and ozone levels at various heights to validate the aircraft measurements.

Recently the group employed a remote-controlled airplane in an experiment over the skies of Oklahoma. Built by General Atomics of La Jolla, California, the unmanned aerospace vehicle (UAV) was used in place of the high-flying Grob Egrett. It was controlled from the ground by a pilot sitting in a "virtual cockpit" using a joystick and rudder pedals to control the UAV's direction by radio signals transmitted to the plane. A global positioning system showed the location of the UAV, while a video camera in the nose of the airplane allowed the pilot to see where it was going.

At only 28 feet long and with a 55-foot wingspan, the UAV carried a heavy payload of 370 pounds of scientific instrumentation and more than 500 pounds of fuel. After 26 hours in the air, the UAV completed the longest continuous scientific observation of the atmosphere ever performed by an airplane.

Although they were originally developed for defense purposes, UAVs are ideal for scientific measurement because of their potential to reach heights and endure lengths of deployment that outperform human-piloted aircraft. Scientists are optimistic that UAVs—along with conventional aircraft, ships, satellites, balloons, and other instrument platforms—will become an important tool to help unravel the mysteries of cloud research.

Written in collaboration with Anthony Bucholtz

OF AGE

NASA's ER-2, formerly the U-2 spy plane, is a jet aircraft capable of flying to the upper reaches of the atmosphere, where its observations can be used to validate satellite data.

The Grob Egrett is a propeller aircraft built in Germany to fly high-altitude reconnaissance missions. Flying at over 45,000 feet, it is used to take measurements above the highest clouds.

The unmanned aerospace vehicle (UAV) was used to conduct a recent high-flying experiment in place of the Grob Egrett. The unpiloted aircraft is remotely controlled using radio signals from a land-based virtual cockpit.

The C-130 "Hercules" is the military's standard cargo plane. This version, flown by the National Science Foundation, performs a wide range of duties during mid- to low-altitude observation flights.

Another low-flying aircraft is the DeHavilland Twin Otter, suitable for making measurements and observations below the clouds.

Left, Postdoctoral researcher Brett Bush examines an instrument mounted on the fuselage of the C-130. **Bottom left,** Postdoctoral researchers Anthony Bucholtz (rear) and Brett Bush in an airborne laboratory aboard the C-130.

ponent that we must understand in order to talk about climate change, global warming, El Niño, or other climate factors."

Valero, who spent 25 years at the NASA Ames Research Center before coming to Scripps in 1994, said that when the new results in cloud research were first presented, it became clear that convincing the scientific community would require rigorous scientific evidence and plenty of discussion. "Every time a scientific paradigm is challenged, there is a reaction," Valero explained. "Debate and controversy are at the heart of scientific progress."

Inherent in this debate is the question of why the excess absorption of solar radiation by clouds was not included in the global climate models in the first place. The answer, according to Valero, is that not enough was known about clouds and how they relate to climatological forces.

Human activity adds an additional dimension to these complex interrelationships. Natural and manufactured aerosols and other pollutants interact and change the physics of clouds and their chemical composition. However, scientists assumed, based on their conventional models, that clouds are perfectly clean and free of pollution. Valero and others are now asking how aerosols and pollution might enhance a cloud's ability to reflect radiation, or conversely, increase the capacity of clouds to absorb radiation. They are convinced that such effects change the distribution of radiative energy within the atmosphere and between the atmosphere and Earth's surface, consequently affecting the radiative balance and, ultimately, climate.

For example, smoke from a ship, when viewed by satellite, can be seen to have a direct physical impact on clouds. Scientists have seen ship smoke rise into the clouds and subsequently make them brighter by modifying their microphysical properties (a phenomenon known as the Twomey effect). The albedo, or reflective power of the clouds, is increased in this case. Another example is seen in high-altitude airplanes and rockets that create contrails, streaks of condensed water vapor. These can become precursors of cirrus clouds, which typically form at altitudes of 20,000 feet (6,100 m) above the ground, or higher, and absorb and reflect radiation that would otherwise have gone unhindered.

"So we have the clouds that we know very little about, we have natural and man-made aerosols that we know very little about, we have atmospheric gaseous pollution that we know very little about, but we know that when mixed, they change and behave differently," said Valero. "So it's a very complex problem.

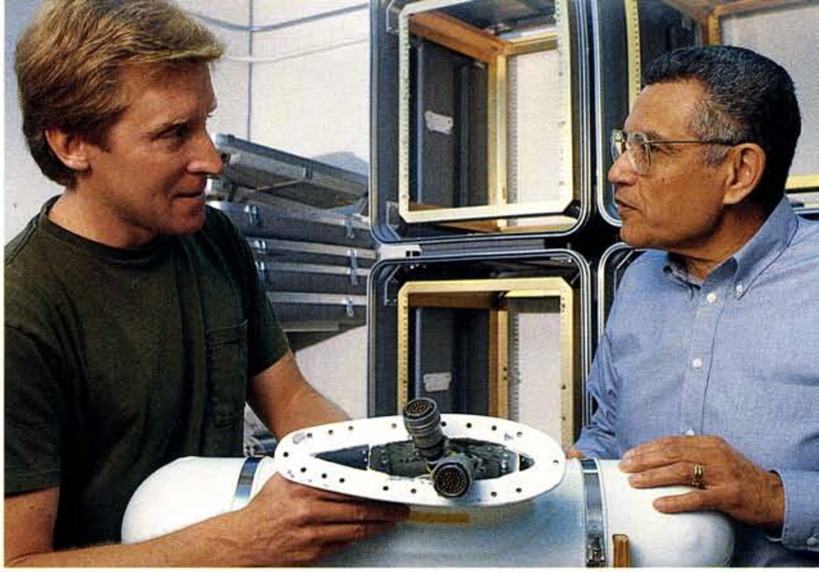
"What we do know is that if we increase or decrease the amount of clouds, or if we change the properties of clouds through interaction with aerosols and pollution, this affects the energy budget, and energy is the bottom line when it comes to climate and climate change."

The Scripps Atmospheric Research Laboratory team documented additional evidence for the vital role that clouds play in solar radiation absorption in two papers describing a series of experiments conducted in 1995 at the Atmospheric Radiation Measurement (ARM) Cloud and Radiation Testbed in Oklahoma.

In these experiments, aircraft flew in a stacked formation above and below clouds to measure how much radiation was absorbed, reflected, and transmitted by the clouds. Analysis of the observations shows that cloudy skies absorb much more solar radiation than clear skies. Traditional understanding was

that a cloud-free atmospheric column—from the earth's surface to the top of the atmosphere—absorbed about the same amount of solar radiation as an equivalent atmospheric column containing clouds. Conventional radiative transfer models also failed to properly evaluate not only the amount of solar energy absorbed by clouds, but also the amount of radiation reflected by clouds.

Since the 1995 experiment, the Atmospheric Research Laboratory group has turned its attention from the "how much" question of cloud absorption to the question of "how" clouds are doing all this absorbing. Group members Anthony Bucholtz, Brett Bush, Shelly Pope, and Sabrina Simpson are developing ways to include excess cloud absorption in



Bucholtz and Valero discuss an aircraft instrument pod.

radiative transfer models consistent with the group's aircraft and surface observations. As the debate has spread and deepened in the scientific community, some researchers have begun to figure excess cloud absorption into their atmospheric general circulation models.

Working in an area with so many unanswered questions gives Valero a daily sense of urgency. He admits that he often "can't wait to get to work" to dive into the scientific riddles. To help deal with the conflicts, the debates, and the challenges involved in such intense research, his team consistently keeps humor a vital part of its disposition.

"The humor is one nice thing about working with Valero; it keeps the group relaxed," said Bucholtz, a Scripps associate specialist who has worked with Valero since 1991. "But ultimately, Francisco makes sure we're doing things right."

Humor, according to Valero, enhances the joy associated with the search for the unknown. Open discussion and trust energize and motivate the team. After all, it's energy, whether the kind emitted by sunlight or the kind pushing Valero and his group, that is the key to change.

"Whether we are right or wrong, the bottom line is that we must know what is happening with clouds," Valero said. "Scientific debate is fundamental to the scientific process because it forces you to answer the hard questions, the ones people bring in that you might not even have thought about. Just trying to answer the hard questions pushes everyone to put forth their best effort.

"Ultimately our ideal is to understand how the planet works; how energy, the major driving force in Earth's system, comes in and goes out; and even how the changing environment interacts with life itself. Those are tremendous questions we really want to know the answers to. To find such answers will require the efforts of many scientists working in a variety of disciplines. There's so much to learn about nature's secrets. It makes our life beautiful."