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Clouds in a Clear Sky [1]

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Published in 1996

Scientists have detected a nearly invisible cloud layer that may explain dryness in the stratosphere.

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Why one of the driest regions in the stratosphere should be found within the first few kilometers above a comparatively saturated tropical troposphere is a contrast that has prompted theory and investigation for years. Clearly, dehydration of rising air occurs, but in the absence of visible cloudiness the exact drying mechanisms accounting for the dramatic shifts in water vapor content at these altitudes have eluded definition. Now, visualization of a persistent but practically invisible layer of thin cirrus clouds in recent lidar and SAGE II (Stratospheric Aerosol and Gas Experiment II) data has not only supplied modelers with new possibilities for understanding water vapor dynamics, the clouds' special characteristics raise new questions about their radiative and other climatic effects.

The clouds have been spotted from time to time since the mid-1970s, according to Eric Jensen, a research scientist at NASA Ames Research Center. "During the CEPEX experiment in the western Pacific, researchers were seeing them most of the time with downward-looking lidar on the NASA ER2 aircraft." Lidar stands for light detection and ranging; the instrument uses a laser to generate intense pulses that are reflected from atmospheric particles of dust and smoke.

"On nearly every flight researchers saw a thin layer of cirrus clouds very near the tropopause, that are essentially ignored by satellite retrievals of cloud radiative forcing because they're 'sub-visible' and treated as clear sky," Jensen said. "From the ground, it looks like a perfectly clear sky day," he said, "but on the plane, high, near the tropopause, when you look at them on edge, you can see these clouds."

"Sub-visible cirrus are in a very different environment than typical cirrus clouds," Jensen said. "I was curious about why they were there, and why the layer persisted." Questions about the relationship between water vapor budget and the clouds' formation process, and the effect heating has on their life spectrum, prompted Jensen, with colleagues who shared his interest, to develop a detailed model that could simulate the clouds' physics.

Measurements from satellites, lidar, and aircraft indicate that the layer forms most frequently, and exists up to 80 percent of the time, over the tropical western Pacific. "We didn't have any case where there was enough data to initialize a model," Jensen said. Without required model inputs, temperature, water vapor, and vertical wind speed, the team idealized simulations, using available data as a guide to check for reasonable results, he said.

"It's very hard to do an actual case study," Jensen said. "You have to know what happened; what the atmosphere was like before the clouds formed, as the clouds were forming, and after they formed. Usually you don't have all that information. You make a lot of assumptions. For instance, vertical wind speed is very difficult to measure by any means, so not much is known about what the updraft velocities are. Along the way I did a lot of different simulations using a wide variety of initial conditions.

"The point of the model is to understand the important processes," Jensen said. Besides arriving at two plausible theories for explaining sub-visible cirrus cloud formation, his research indicated that cloud formation and stratospheric dehydration processes are symbiotically linked.

"It's a freeze-drying process," he said. In the tropical western Pacific, tropopause temperatures are at their lowest levels. Like typical cirrus, sub-visible cirrus can form when layers of slowly rising humid air cool and reach saturation. Ice crystals can then nucleate, grow, and precipitate. But compared to typical cirrus clouds composed of ice crystals of a few hundred microns' length, cirrus formations in the upper tropopause are almost certainly composed of very small ice crystals of 20 or 30 microns or less, Jensen said, because the growth rate of ice crystals at minus 70 to 80 degrees Celsius is much slower than at warmer temperatures. The smaller, lighter, ice crystals also precipitate at slower rates, so cirrus in the tropopause last longer than do typical midlatitude cirrus formations. The larger ice crystals of typical cirrus fall away quite rapidly, so that the clouds dissipate in a matter of hours, compared to days for sub-visible tropospheric cirrus.

The modelers also simulated the formation of sub-visible cirrus due to outflow from deep convective systems circulating from the surface all the way up to the tropopause in strong upward drafts. The scenario resulted in the formation of huge anvil clouds covering thousands of kilometers. Because these clouds were composed of ice crystals of widely varying sizes, a natural sorting process would occur.

"The bigger crystals fall out faster, the smaller ones take a day or so," Jensen said. Then, he said, the persisting layer of small ice crystals is sheared and stretched by strong tropospheric winds. The modeled results were validated by lidar data that show sub-visible cirrus to be only a few hundred meters thick, compared to midlatitude cirrus that are often a few kilometers thick.

The frequent presence of sub-visible cirrus indicates that air near the tropopause is moving slowly upward a large fraction of the time, Jensen said. And while the research satisfied some of his curiosity, questions remain about what effects the sub-visible cloud layer could have on climate. "Even though sub-visible cirrus have low optical depth, they cover a large region of the tropics, so they might have a significant effect," Jensen said.

"One of the big uncertainties is that we really don't know much about the radiative, optical properties of the clouds. We don't know how much infrared radiation they absorb, or the heating rates, or how any of that would impact the radiative budget." A follow-up field experiment has been planned, he said. "We need to go out and make more measurements."

Resource(s)

The SAGE II instrument was launched aboard the Earth Radiation Budget Satellite (ERBS) in October 1984. The instrument 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.

These data are used to estimate long-term trends and identify responses to episodic events such as volcanic eruptions. For instance, SAGE II data have been used to show the stratospheric impact of the 1991 Mount Pinatubo eruption, identify a negative global trend in lower stratospheric ozone during the 1980s, and quantitatively verify positive water vapor feedback in current climate models.

The constituent record provided by SAGE II will be continued and improved by its successor SAGE III, currently planned for multiple launches beginning in the year 2000 as part of the Earth Observing System.

SAGE II data are available via ftp and on electronic media through the Langley Research Center DAAC.

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