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CALIPSO:

Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations

From hazy days, to hurricanes, to summer heat waves, we have all experienced the infinite variability of our complex atmosphere. Polluted air days, catastrophic weather events and long-term changes in climate are just a few examples of environmental factors that can affect our quality of life, our economy and even our health. Small particles in the air, called aerosols, together with thin, semi-transparent clouds, play a major role in regulating Earth's air quality and climate. Scientists are studying both of these atmospheric components to answer difficult questions about the vitality of our planet and to better predict atmospheric conditions and changes.

An average adult breathes more than 3000 gallons of air every day, and breathing polluted or poor quality air can be harmful to our health. Aerosols, both natural and human-made, can affect our air quality. In addition, because clouds form on aerosol particles, changes in aerosols can transform clouds, precipitation and atmospheric circulation patterns; and, over time, clouds can alter the Earth's climate. Scientists use computer-forecasting tools, called models, to make predictions about our weather, air quality and climate change. These forecasting tools are highly advanced, but still inadequate when it comes to accounting for the atmospheric effects of thin clouds and aerosols. In order to make better predictions of changes in our Earth system, we must include accurate characterizations of clouds and aerosols in computer models and forecasts.

NASA's Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite uses an innovative method to explore our atmosphere and study aerosols and clouds. CALIPSO provides, from space, the first global survey of cloud and aerosol profiles and physical properties, with seasonal and geographical variations. Especially exciting about CALIPSO is its unique capability to collect information about the vertical structure of clouds and aerosols and their overlap unavailable from other Earth observing satellites. These observations, when combined with coincident data from other missions, will greatly enhance our understanding of how aerosols and clouds interact, the quantity of aerosols produced worldwide, how aerosols are transported and how long they remain in the atmosphere. CALIPSO measurements will ultimately contribute to improved predictions of weather, climate and air quality.

Figure 1: An artist's rendition of what the CALIPSO satellite would look like from space. Using pulses of laser light from an instrument called a lidar, CALIPSO takes global measurements of the atmosphere, studying small particles in the air, called aerosols, and multi-layered clouds to better understand Earth's weather, climate and air quality. (Image courtesy of CNES.)

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How Aerosols and Clouds Affect Climate and Air Quality

Our climate is the product of a delicate and complicated balance of energy – a balance between energy received from the sun and energy reflected and emitted back to space from Earth. Clouds affect the radiation balance directly by reflecting sunlight into space, which prevents energy from reaching the surface, thus cooling both the ground and the atmosphere. Clouds can also absorb heat emitted by the Earth, called thermal radiation. When clouds absorb this thermal radiation, less energy escapes to space and the planet warms. The degree to which the energy balance tips in one direction – either warming or cooling – is heavily dependent on the altitude, thickness and overlapping structure of clouds.

Low lying clouds, which are often made of water droplets, have almost the same temperature as the surface, so when they absorb thermal energy emitted by the surface they re-emit it at the same temperature. Low lying clouds cause little change on the flow of thermal energy – their primary role is to reflect solar energy. High thin clouds, on the other hand, are colder and capture more heat from the surface and emit less energy to space. They often reflect less solar energy than the heat they absorb, thus warming the atmosphere. High clouds are colder and are mostly made of ice. Knowing where clouds are in altitude, as well as their composition (ice or water) will help scientists to better understand the affects of clouds on changes in atmospheric circulations and on climate. To further complicate matters, clouds often overlap, making them very difficult to study.

Aerosols can also directly affect the radiation balance and impact climate. Like clouds, aerosols can reflect sunlight back to space and cool the atmosphere. For example, the haze layer formed from sulfuric acid industrial pollution reflects sunlight. Unlike clouds, however, aerosols can absorb sunlight and warm the atmosphere. "Black carbon," such as soot emitted by diesel engines, is a type of aerosol that can absorb significant amounts of sunlight, particularly when these layers lie over a bright surface like a low lying cloud. It is important that we distinguish among the different types of aerosols and have accurate knowledge of the altitude of aerosol layers in order to know their effect on Earth's energy balance. Learn more about aerosols in "Aerosols: More than Meets the Eye," a "NASA Facts" publication (NASA GSFC).

Figure 2: Multi-layered clouds, like those seen below, are a major source of uncertainty for scientists studying Earth's radiation balance. CALIPSO's imaging and lidar system provides new insight into clouds, specifically high thin clouds that are often invisible to radar. (NASA image courtesy Doug Stoddard and NASA's Students' Cloud Observations On-Line [S'COOL] Program.)

Figures 3a and 3b: The amount of aerosol present when a cloud forms impacts the characteristics of the cloud that forms. Figure 3a shows a "non-polluted" case, and Figure 3b showsa a "polluted" case. In both cases, the same amount of water vapor is present, but in the "polluted" case, the water molecules are spread out over many more particles and it takes longer for water droplets to grow large enough to fall as precipitation (see insets). (Image credit Alex McClung, SSAI/NASA GSFC, and University Corporation for Atmospheric Research.)

Aerosols can also change the properties of clouds and indirectly affect our climate. Cloud droplets form around aerosols such as salt from sea-spray, dust blown from the desert or fine particles from industrial emissions. Changing the characteristics of these aerosols, such as their number and size, can change the characteristics of the cloud droplets and, thus, the clouds that they form. As an example, scientists have observed that clouds below exhaust plumes from ships are brighter. This change in the clouds results from smaller particles in the exhaust that cause more numerous, but smaller cloud droplets to form. With the smaller cloud droplets, the clouds can also remain intact longer because precipitation in these clouds is slower to form. Conversely, scientists believe that under some circumstances aerosols cause clouds to dissipate faster and some aerosols even prevent clouds from forming in the first place. Unfortunately, how aerosols affect clouds remains a mystery, and we don't know exactly which of these processes is significant enough to effect our weather, climate and air quality.

Aerosols often have some serious impacts on society – posing a threat to public health and even endangering air traffic. On hot, humid, stagnant summer days, the air quality over urban areas often reaches unhealthy levels and aerosols are a primary culprit. Tiny aerosol particles with diameters less than 2.5 millionths of a meter (1 ten-thousandth -of an inch) can work their way deep into the lungs and aggravate or cause breathing problems. The risk is particularly high for the elderly and the very young. Aerosols can also threaten the safety of aviation. They reduce visibility over heavily polluted areas, and during volcanic eruptions, planes have to reroute around the eruption to prevent particles from being taken into their jet engines.

Why we Need CALIPSO?

To improve predictions of climate change, to help devise strategies for limiting pollution and to improve forecasts of harmful air quality conditions, we need better information on aerosol sources and how aerosols enter the atmosphere and interact with circulation patterns. A key piece of information that is not provided by currently operating observational satellites is the altitude of aerosol layers in the atmosphere, a deficiency that is hindering our ability to improve forecasts.

Obtaining better information on the height and thickness of clouds is also needed. At present, scientists have considerable difficulty predicting the area coverage, water and ice content and altitude of clouds. Inaccuracies in these parameters can lead to large errors in estimates of precipitation and the effects of clouds on atmospheric circulation and climate.

Having better information on aerosols and clouds will be used by scientists in computer programs called climate models to understand the behavior of and make predictions about climate. Climate models are mathematical representations of natural processes that occur in the atmosphere, in the oceans and on the land. While they are invaluable tools, we need scientific studies to learn how to improve the models so that they make better predictions. In these models clouds and aerosols are often poorly represented. At best, scientists are making only rough estimates of their effects on the atmosphere, rather than using actual data to guide the simulations. Researchers need to learn more about how clouds and aerosols help cool and warm the Earth, how they interact with each other and how

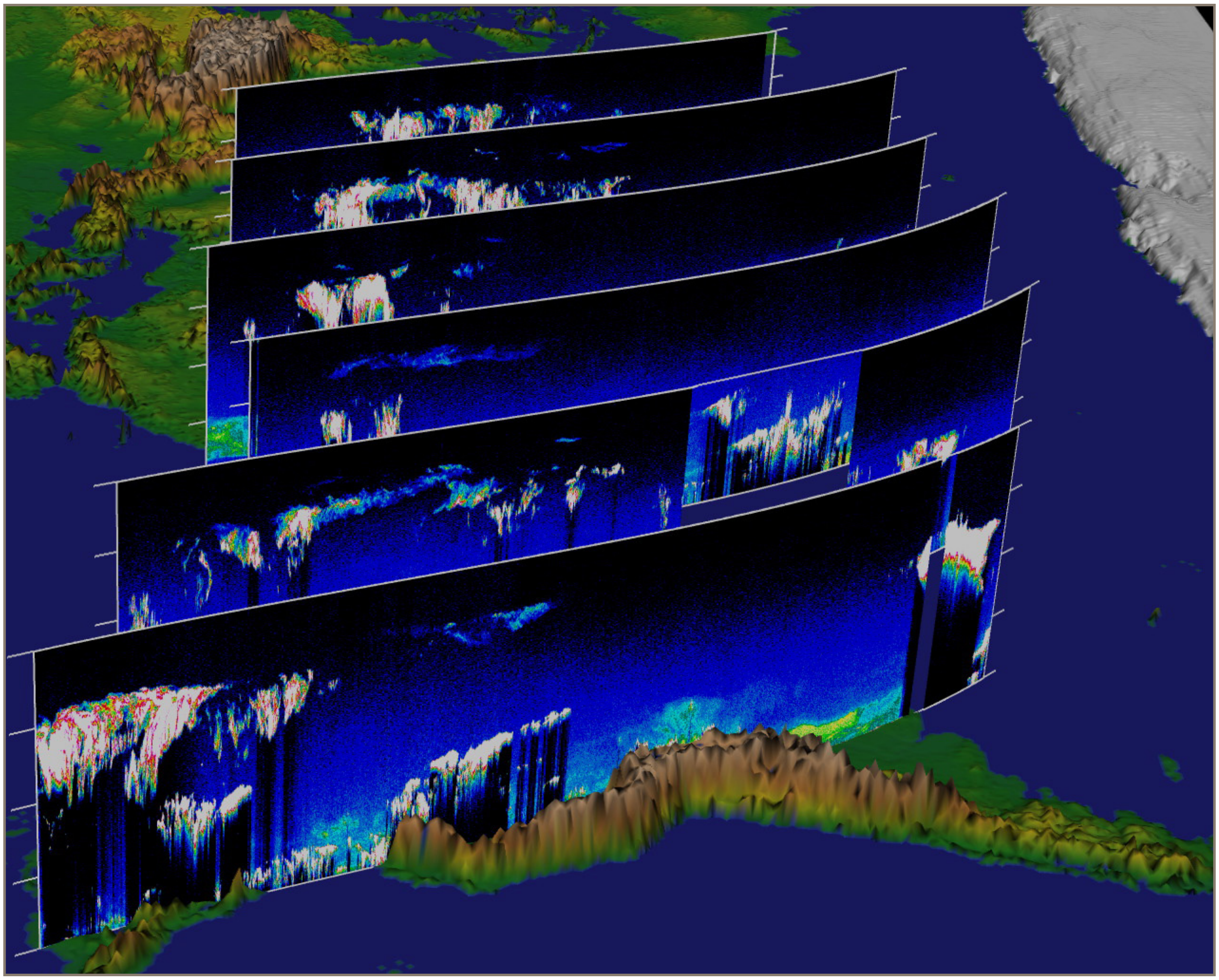

Figure 4: Demostrating that lidar measurements could be taken from space, the LITE mission (Lidar In-space Technology Experiment), conducted in 1994 on the Space Shuttle, was really the proving ground for CALIPSO's lidar technology. Shown above is a visualization of LITE data where lidar proflies are combined into slices of the atmosphere. A number of slices from different orbits shown side-by-side reveals the 3-D distribution of aerosols and clouds around the globe. In this image, South America is seen in the foreground and North America is in the background. In the lidar profiles, high, thin clouds; low layers of aerosols, like dust and biomass burning; and thick, tropical convective cloud systems can all be seen. (NASA image by Chip Trepte and Kurt Severance.)

human activities will change them and their effects on the climate in the future.

How CALIPSO sees the atmosphere

Scientists have been observing clouds and aerosols globally from space for many years using passive imagers – sensors that measure the amount of radiation reflected and emitted by the Earth. These sensors observe how clouds and aerosols vary with latitude and longitude, but provide, at best, limited information on how they vary with altitude. CALIPSO combines an innovative combination of an active lidar (light detection and ranging) instrument with passive infrared and visible imagers to probe the vertical structure and properties of thin clouds and aerosols over the globe.

The lidar is an active remote sensing technique, where pulses of light are sent from the satellite toward the surface and the amount of light that is reflected, or scattered back to the spacecraft from thin vertical segments of the atmosphere is measured. It is similar to radar in operation; however, lidar uses short pulses of laser light instead of radio waves to probe the atmosphere. The lidar data from CALIPSO allows scientists to identify the composition of clouds, to estimate the abundance and sizes of aerosols and to determine precisely the altitudes of clouds and aerosol layers and the extent of layer overlap.

Each lidar measurement is a 100-meter wide snapshot or profile of the atmosphere. The profiles can be streamed together to paint a picture of what a vertical slice of our atmosphere looks like. If you could envision the observations from other satellites appear like X-ray images of the human body, then lidar would provide a view like a CAT scan – an advanced 3-D imaging technique that shows the spatial relations between different objects as well as their relative depth. With an X-ray, you can see inside the human body, but you can't tell how things are layered. The CAT scan, and thus the lidar, is a breakthrough because it allows us to see the layers beneath other layers. The CAT scan sees layers of human organs and tissues, while the lidar sees layers of aerosols and clouds. Lidar measurements are also unique because the slices of the atmosphere taken from multiple orbits can be combined to create a 3-D view of aerosols and clouds over the entire globe.

Complementing CALIPSO's lidar, is a sensor called the Imaging Infrared Radiometer, or IIR. The IIR is provided by the French Centre National d'Etudes Spatiales (CNES), NASA's partner in the CALIPSO mission. This instrument has a swath of 64 kilometers (about 40 miles) across the satellite ground track and measures, at three different wavelengths, the outgoing thermal radiation emitted toward space from the atmosphere. Its design allows scientists to estimate the size of ice cloud crystals and helps to estimate the amount of heat clouds absorb and emit. The lidar measurement aids our interpretation of the IIR observations with concurrent measurements of the altitudes of these clouds.

A third instrument that CALIPSO carries is a high-resolution digital camera. This camera, called the wide-field camera, or WFC, provides a large-scale view of the atmosphere surrounding the thin column of air probed by the CALIPSO lidar, providing a context for interpreting the observations. From these images, scientists will be able to tell whether a cloud feature seen by the lidar is a small, isolated cloud or one that is part of a larger field of clouds. Together, the innovative combination of the lidar, the IIR and the WFC will strengthen our understanding of cloud properties like never before.

The Future of CALIPSO

With an expected three year lifetime, CALIPSO is designed to fly in formation with four other satellites, called the "Afternoon-Train" or the "A-Train" satellite constellation, that collect a wide variety of coincident measurements. The five members of the A-Train include, Aqua, Aura, CALIPSO, CloudSat, and PARASOL (Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar). A sixth mission, Orbiting Carbon Observatory (OCO) will eventually join the constellation.

Each satellite in the A-Train formation measures the atmosphere somewhat differently and, thus offers unique and complimentary information on clouds and aerosols. CALIPSO provides profile observations of aerosols and thin clouds. Aqua, the lead spacecraft, provides additional observations of clouds and aerosols using passive sensors with greater horizontal coverage, but very limited altitude information. It also provides valuable information on environmental conditions needed to understand how aerosols and clouds form and change. CloudSat, CALIPSO's launch partner, uses a revolutionary radar to probe the internal structure of clouds. PARASOL uses polarized light measurements to help distinguish between different types of natural and human-produced aerosols. And finally, Aura studies key atmospheric pollutants that can help show the sources of aerosols and how they are transported. Combining the A-Train observations provides an unprecedented opportunity to better understand our delicate Earth system than could be gained from a single satellite alone.

The near-simultaneous A-Train observations are achieved through high-precision satellite formation flying. The leading (Aqua) and trailing (Aura) spacecraft in the formation are maintained in orbit within 15 minutes of each other, while traveling at over 15,000 miles per hour. CloudSat and CALIPSO are controlled to an even finer requirement, within 15 seconds of each other, so that both instrument suites can view the same cloud area at nearly the same moment. Because CloudSat and CALIPSO are so closely aligned, and because they take complementary measurements, their measurements can be combined virtually seamlessly. CALIPSO is sensitive to semi-transparent clouds and aerosols not seen by CloudSat's radar, while the radar is able to penetrate dense clouds which block the lidar pulse.

Upon successful completion of the CALIPSO mission, the collected data will allow scientists to better understand aerosols and clouds and, ultimately, improve forecasts of air quality and climate. CALIPSO observations will improve global estimates of how aerosols affect the Earth's radiation balance. Using CALIPSO's data, scientists will have new ways to determine how the climate, aerosols and clouds interact.

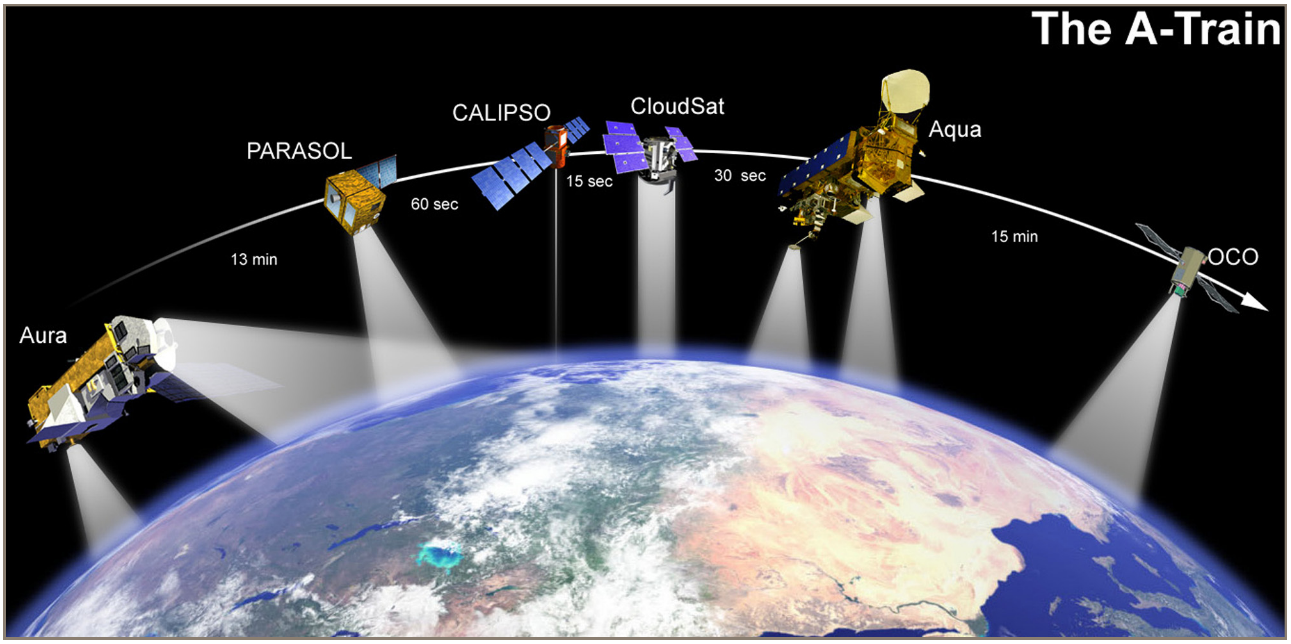

Figure 6: CALIPSO is part of a constellation of satellites called the A-Train: Aura, PARASOL, CALIPSO, CloudSat, Aqua and eventually, OCO. The concept behind the A-Train comes from the idea that no single tool can do everything. To build a house, for instance, carpenters, plumbers, roofers, electricians and others apply unique skills and tools to discreet tasks, while collectively focusing on a larger job at hand. Similar to building a house, the string of A-Train satellites flying in a precise formation allows discreet instruments to bring their unique obseravation abilities to bear on essentially the same place on Earth at the same time. (Image courtesy of Alex McClung, SSAI/GSFC; some caption text courtesy of Michael Starobin, GSFC.)

CALIPSO Team Members

CALIPSO is a joint partnership between the United States (NASA) and France (CNES). Other team members include Ball Aerospace & Technologies Corp., Hampton University and Institut Pierre Simon Laplace.

Summary

CALIPSO will provide us global 3-D perspectives on Earth's aerosols and clouds that will answer questions about how they form, evolve and affect our weather, climate and air quality. CALIPSO employs innovative measurement technologies that will probe Earth's atmosphere as never before. In partnership with the satellites in the A-Train, CALIPSO fuels discoveries that will improve our air quality and climate forecasts, while helping public policy makers and business leaders make more informed, long-term environmental decisions about public health and the economy.

The Earth-Sun System Division of NASA's Science Mission Directorate is dedicated to connecting these Earth observations to practical applications in society so that its science results serve society and the maximum number of people possible benefit from NASA research. This dedication is a manifestation of NASA's vision to improve life here and its mission to understand and protect our home planet.

For more information on CALIPSO, visit:

http://www.nasa.gov/calipso