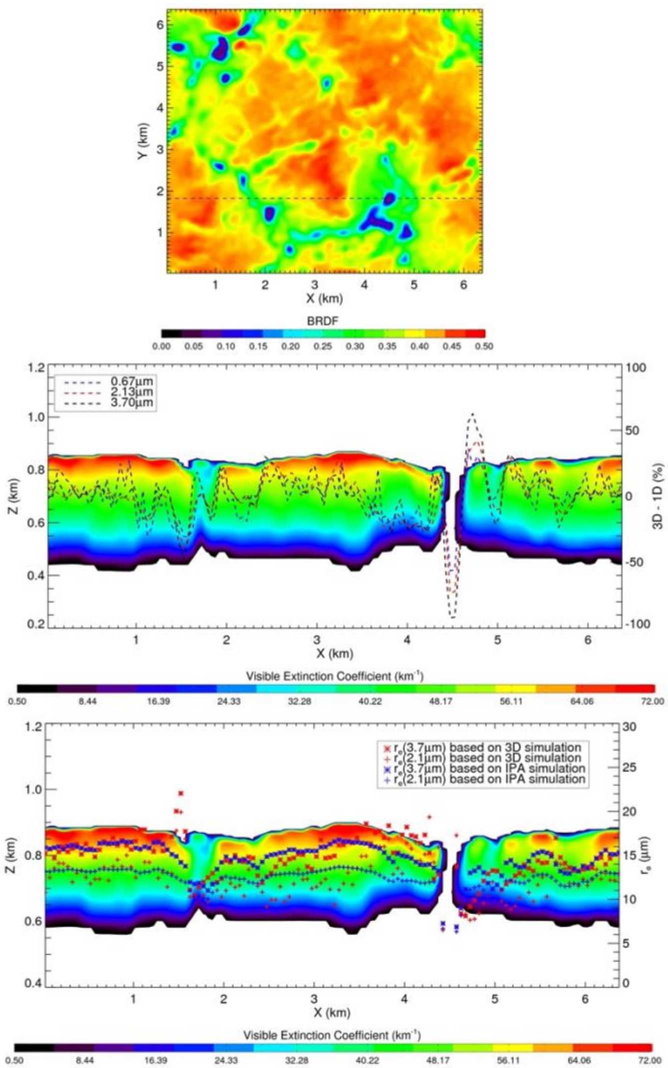
Assessing MODIS MBL cloud retrieval using Large-Eddy Simulation and 3D RT model

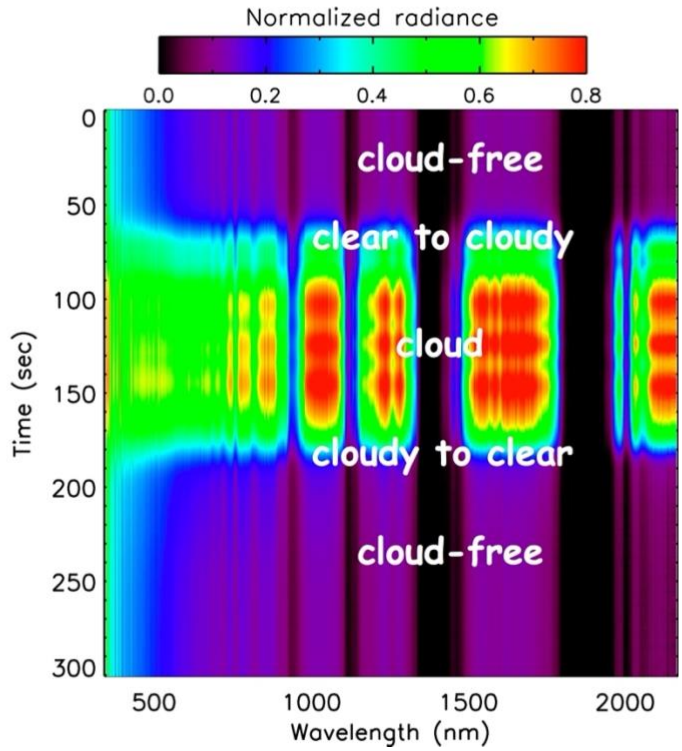


Marine Boundary Layer (MBL) clouds are thought to be at the heart of cloud feedback uncertainties in climate models. How and to what extent man-made aerosols may affect the properties of MBL clouds is poorly understood. Measures to address these issues rely heavily on satellite-based remote sensing of the microphysical and optical properties of these clouds. The image shows recent research activities by branch scientists of assessing how the 3D cloud structure (i.e., cloud top entrainment, cloud particle size vertical variation and drizzle) and 3D radiative effects influence MODIS MBL cloud retrieval. MODIS (or Moderate Resolution Imaging Spectroradiometer) is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites. The upper panel shows the cloud optical thickness simulated from a Large-Eddy Simulation (LES) model (Stevens et al. 1998 JAS). The middle panel shows the differences in the upwelling radiances at three wavelengths used for MODIS cloud retrieval at nadir between 3D (simulated using I3RC) and 1D (simulate using DISORT) radiative transfer simulations. The solar zenith and azimuth are 600 and 00 (x+ direction), respectively. In 3.7 mm simulation, only the solar reflectance component is considered (i.e., assuming the thermal component is "perfectly corrected" by the atmospheric correction step in MODIS retrieval). MODIS cloud effective radius retrievals based on simulated radiances are shown in the lower panel. Note that in the "shadowing region" (for example around 4km), the cloud appears darker in the 3D simulation than the 1D simulation due to the "shadowing effect". As a result, the effective radius retrievals based on 3D radiance are larger in these regions. This research will help scientists to better understand how cloud structure and 3D radiative effects influence satellite retrieval data.

Zhibo Zhang and Steven Platnick

What's going on around cloud edges: interpretations of spectral measurements of the overhead radiance

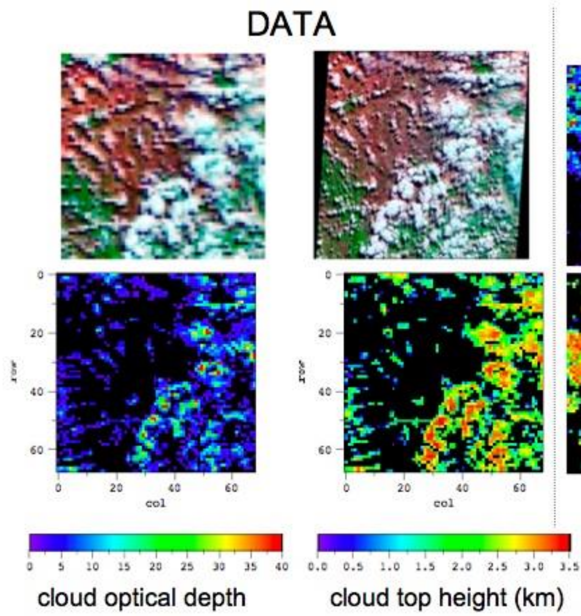
ARM shortwave spectrometer



Although clouds seem to have a distinct boundary, it has been difficult to define the boundary from remotely-sensed measurements. This problem has major climatic consequences, in particular on studies of aerosol-cloud interactions, which require a precise separation of cloudy and cloud-free air. The image at the left shows the new Atmospheric Radiation Measurement (ARM) program Shortwave Spectrometer (SWS) that provides rich information for studying aerosol and cloud properties in the transition zone between cloudy and cloud-free areas. The SWS, deployed in March 2006, looks straight up and measures overhead radiance at 418 wavelengths in the visible and infrared spectral region, with an unprecedented 1-sec sampling resolution. The image at the right panel (time versus wavelength) shows how overhead radiances change when a cumulus cloud passed by at the ARM Oklahoma site. At each wavelength the radiance has been normalized by the radiance at the top of the atmosphere. During the first minute and the last two minutes, low radiance (blue, purple color) indicates that the sky is cloud-free. During the remaining two minutes (60 to 180 sec.), high radiance (red color) indicates that the cumulus cloud has passed by. It is evident that there are two transition periods (green color) between cloudy and cloud-free periods. Click here to see the time series of total sky images for this case. Analyzing spectral behavior of the overhead radiance measured by the SWS helps us to learn more about radiative properties of aerosols and clouds, including optical depth and particle (droplet) size, in the transition zone between cloudy and cloud-free areas. Knowledge of aerosol and cloud properties corresponding to SWS-observed radiative signatures will advance our understanding of physical processes such as evaporation and activation of cloud droplets, rising humidity, and humidification of aerosols as well as modeling aerosol-cloud interactions and predicting cloud evolutions.

Christine Chiu, Alexander Marshak

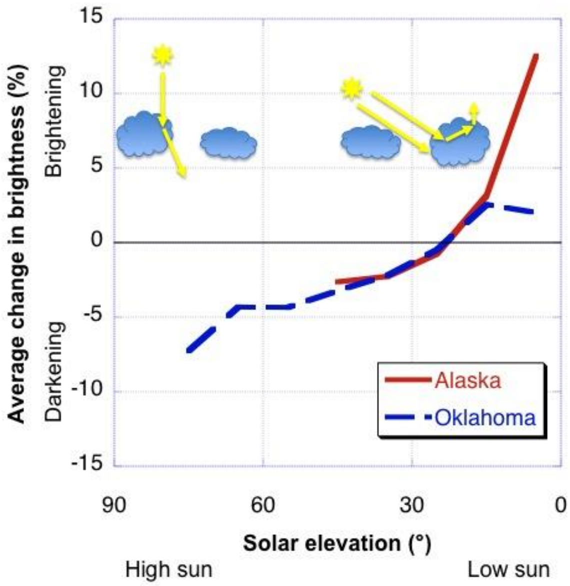
A Simple Stochastic Model for Generating Broken Cloud Optical Depth and Cloud Top Height Fields



In order to better understand and predict shortwave radiation in realistic cloudy atmospheres, we need to specify the 3D distribution of cloud liquid water. Realistic cloud fields and spatial distributions of cloud liquid water can be obtained from either dynamical or stochastic cloud models. Based on cloud dynamics, physical cloud models such as a large eddy simulation or a cloud resolving model are physically consistent but require specification of a lot of atmospheric parameters and often are computationally expensive. On the other hand, stochastic cloud models based on aircraft, satellite or ground measurements of cloud structure are computationally inexpensive and can output a much larger range of scales than dynamical models. For the last two decades many different cloud stochastic models have been developed. There are two classes of cloud stochastic models. One class uses only a few parameters to simulate the main aspects of the realistic cloud fields like mean, standard deviation and correlation often assumed to be a power-law. These models are very simple and are generally used to test hypothesis and better understand cloud-radiation interaction. Another class of cloud stochastic models provides a statistical reconstruction of an observed field and generates the detailed cloud structure. They are also called statistical cloud generators. The images on the right show an example of stochastic fields simulated by one of these generators. Four images on the left show a 68 km by 68 km region in Brazil centered at 17oS and 42oW collected on August 9, 2001 at 10:15 local time by MODIS with 1 km resolution (upper left) and ASTER with 15 m resolution (upper right). Two lower images illustrate cloud optical depth (lower left) and cloud top height (lower right) obtained by the MODIS operational cloud retrieval algorithm. The four images on the right show two realizations of cloud optical depth (upper plots) and two realizations of cloud top height (lower plots) that correspond to the 2nd realization of cloud optical depth. The generated fields have the same statistical characteristics (covariance of the cloud mask, histograms, and joint conditional distribution) as the original fields on the left. The images on the right are generated by a simple stochastic cloud model described in the paper published in the Journal of the Atmospheric Sciences in January 2009. The paper provides a theoretical background to the publicly available software “Simulation of a two-component cloud field” that has been recently released and can be freely downloaded here.

Alexander Marshak

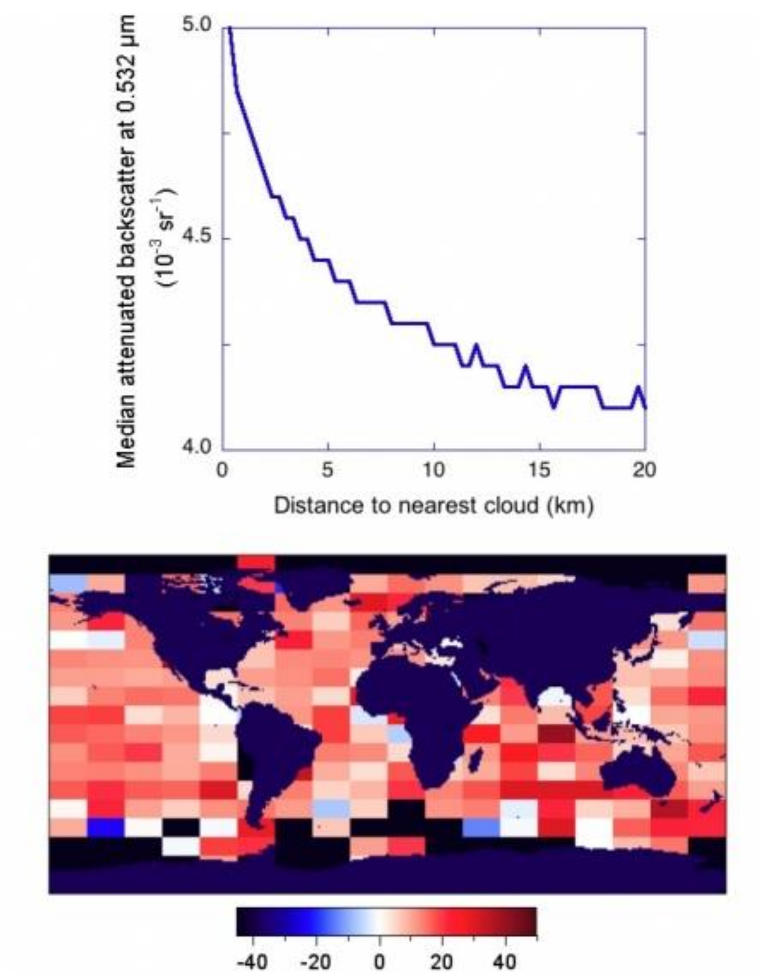
Cloud brightness changes caused by horizontal radiative interactions



This image shows the way horizontal radiative interactions influence cloud brightness in satellite images. The influence is calculated by comparing two sets of simulated satellite images, one that includes horizontal radiative effects and one that does not. Both kinds of simulations were carried out for the same yearlong set of cloud observations at two locations where instruments of the U.S. Department of Energy Atmospheric Radiation Measurement program provide highly detailed information about the clouds aloft. The figure shows that for high sun the dominant effect is sunlight escaping to the ground through cloud sides. This makes it easier for sunlight to pass through the cloud layer and reduces the light reflected to space, thus darkening satellite images. For low sun, however, horizontal effects that brighten satellite images become stronger. For example, cloud sides intercept sunlight and prevent it from reaching the ground easily in gaps between clouds. While earlier studies by researchers at the Climate and Radiation Branch and elsewhere discussed various aspects of these processes, the new dataset reveals their typical magnitude (also indicating, for example, that they are stronger than average for cumuloform cloud types and weaker for stratiform cloud types). Such information can help improve the accuracy of satellite data interpretation methods, which currently don’t consider these processes in measuring cloud properties such as water content and particle size.

Tamas Varnai

CALIPSO Observations of Aerosol Changes Near Clouds

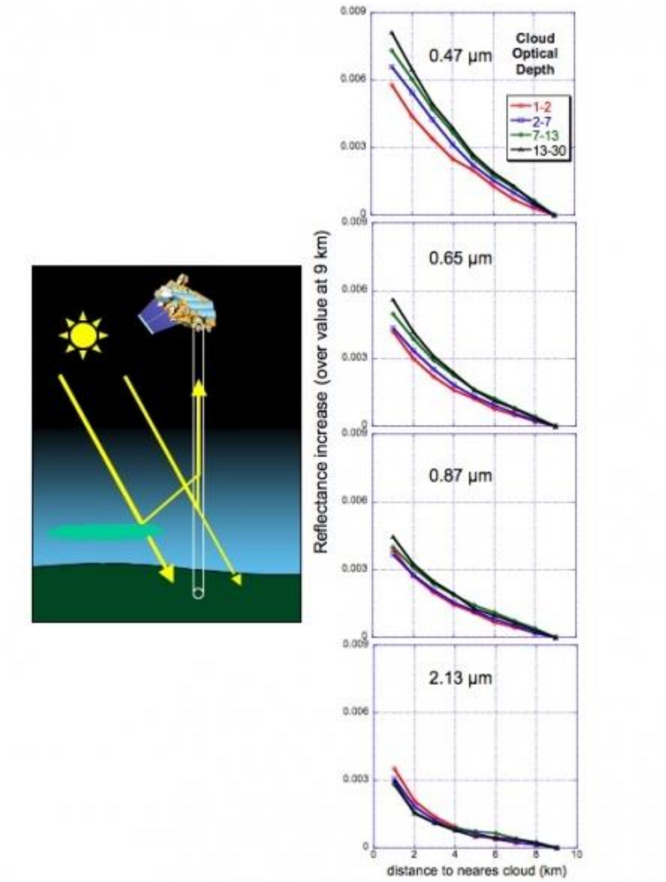


Relative difference of median 532 nm attenuated backscatter values at 0-5 km and 15-20 km distance from clouds (%)

The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite provides measurements of the vertical structure and properties of thin clouds and aerosols over the globe. This image is based on a month long dataset of global lidar observations by CALIPSO. It illustrates that clouds are surrounded by a transition zone of systematically changing aerosol properties. The figure confirms earlier studies (e.g., Koren et al. (2007), which detected transition zones in the immediate vicinity of clouds (extending up to 3-4 km) in several geographical regions. However, the top panel of this image also reveals that the transition zone is much wider than previously thought, and over oceans it typically extends to about 15 km away from clouds. This confirms that the enhanced clear sky brightness in the vicinity of clouds observed by MODIS is due not only to three-dimensional radiative interactions between cloudy and clear areas (e.g., Image of the Week from March 2008) but also to optically thicker aerosol near clouds. The bottom panel shows that the transition zone is a global phenomenon that appears in most oceanic regions. Detailed analysis of the CALIPSO dataset also reveals that the transition zone is confined to altitudes below the top of nearby clouds, and that aerosol particle size is increased near clouds. These trends agree with earlier studies (e.g., Tackett and Di Girolamo 2009) that found the transition zone to arise from two processes: aerosol swelling in the humid air near clouds, and the collision and subsequent evaporation of cloud droplets, which merges many small aerosol particles into fewer bigger ones. Characterizing the transition zone is important for better understanding two critical yet poorly understood aspects of anthropogenic climate change—aerosol-cloud interactions and aerosol radiative effects—and for devising effective sampling strategies for measuring aerosol properties from space.

Tamas Varnai (UMBC/JCET) and Alexander Marshak (NASA/GSFC)

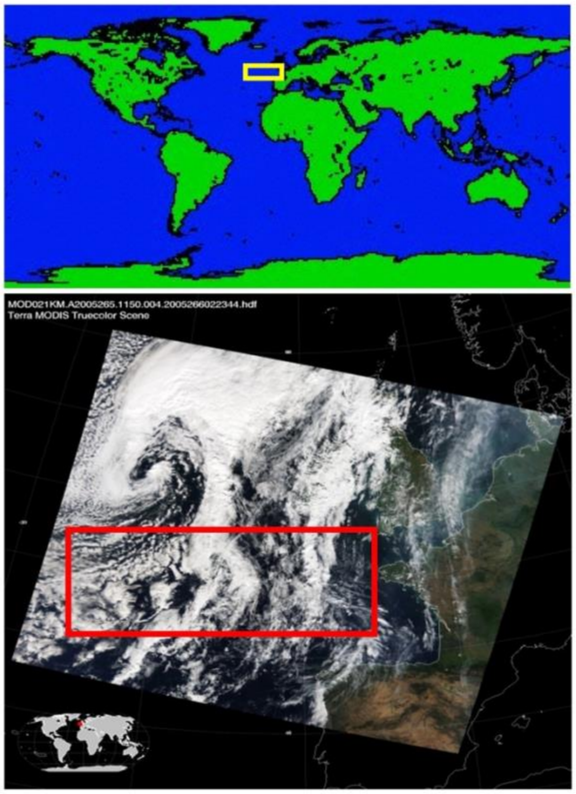
Cloud-Free Air is Brighter at Shorter Wavelengths Around Thicker Clouds

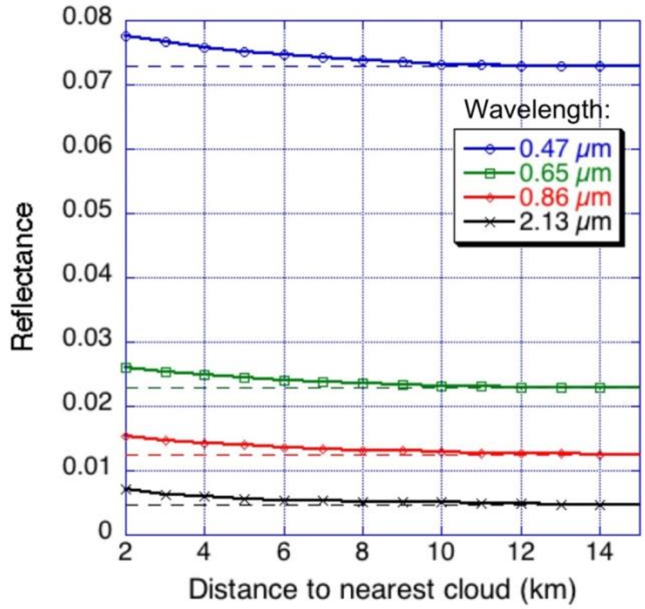


These images illustrate a recent study on aerosol-cloud interactions, a problem that scientists at the NASA/Goddard Space Flight Center's Climate and Radiation Branch have studied extensively. To understand these interactions and their effects on climate, researchers often use satellite measurements of aerosol near clouds. However, the vicinity of clouds introduces a number of complications into space-based aerosol measurements; three-dimensional (3D) radiative interactions between clouds and their surroundings is one of them. The left panel illustrates the main mechanism of such 3D interactions: clouds reflect sunlight toward nearby cloud-free areas, thus enhancing the illumination of air molecules that scatter light toward our satellites. Theoretical studies suggest that ignoring this 3D enhancement risks overestimating the amount of light-reflecting aerosol near clouds. The right panels show satellite observations which confirm that 3D effects are indeed important at the shorter wavelengths visible to the human eye. For each wavelength, a separate panel summarizes hundreds of images taken by the Terra satellite's MODIS instrument over the North-East Atlantic Ocean (click here for the location). As the 3D mechanism on the left suggests, average clear-sky brightnesses increase near clouds. The top panels even show that at the shorter wavelengths where air molecules are effective scatterers, the increase is stronger if the nearby clouds are thicker and reflect more sunlight toward cloud-free areas. At longer wavelengths, however, weak scattering by air molecules makes 3D effects negligible, and this makes clear-sky brightnesses independent from cloud thickness. We note that at longer wavelengths, the modest increase near clouds is caused by a slight blurring due to instrument imperfections, the presence of small undetected cloud puffs, and changes in aerosol properties (for example swelling in the humid air near clouds). Analyzing 3-D effects will help improve the accuracy of space-based aerosol measurements and will help better understand the way aerosols (including human emissions) influence clouds and climate.

Tamas Varnai, Alexander Marshak

Enhanced Clear Sky Brightness in the Vicinity of Clouds

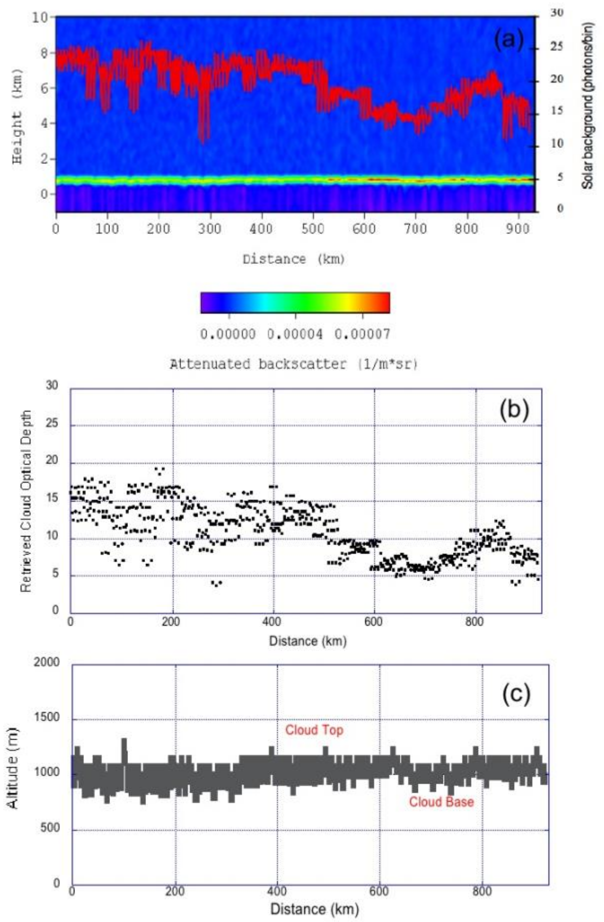




These images illustrate a study on the effect that atmospheric aerosols have on clouds and climate. NASA's Goddard Space Flight Center Climate and Radiation Branch scientists have studied various aspects of this effect, including the problem of accurately measuring aerosol properties near clouds. An important concern is whether current methods are accurate in attributing brightness variations near clouds to changes in the abundance and size of aerosol particles that reflect sunlight. Undoubtedly, an increase in brightness can indeed indicate optically thicker aerosol near clouds; for example, aerosols grow in the vicinity of clouds because of moist cloud environment. Detailed analysis similar to that presented in the publication Observations of Three-Dimensional Radiative Effects that Influence MODIS Cloud Optical Thickness Retrievals, however, reveals that other factors can also play an important role in enhanced brightness values near clouds. These factors include a blurring due to instrument imperfections, the presence of small undetected cloud puffs near cloud edges, and three-dimensional radiative interactions between cloudy and clear areas. Such three-dimensional effects occur when solar photons scattered from clouds can interact with air molecules, aerosol particles, and underlying surface that can reflect the photons back to satellite detectors. The top left panel of the image identifies an approximately 1000 km by 500 km size area of the Atlantic Ocean that has been used for an extensive statistical analysis of this problem. The bottom left panel illustrates a sample image of this area viewed by the MODIS instrument on board the Terra satellite. The right side panel shows results from the statistical analysis of hundreds of such images collected in September over a seven year long period from 2000 to 2006. The figure reveals that satellite images are indeed systematically brighter near clouds. (For reference, dashed lines indicate the average brightness far away from clouds.) Incorporating the additional factors mentioned above will improve the accuracy of space-based aerosol measurements and will help better understand the way aerosols (including human emissions) influence clouds and climate.

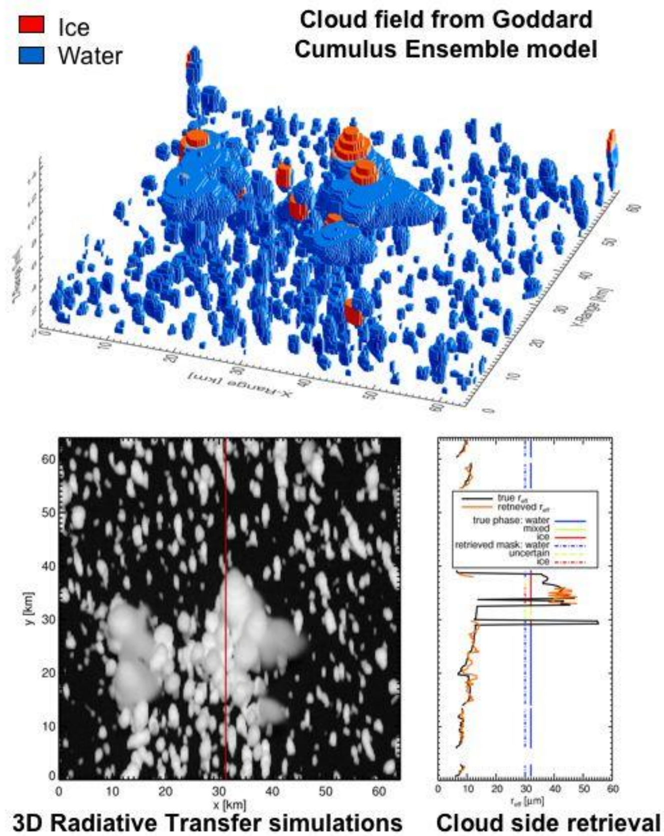
Tamas Varnai, Alexander Marshak

Retrieving thick cloud optical depth from space-borne lidar observations



By emitting laser pulses and measuring the reflected signal, space-borne lidar systems, such as the Geoscience Laser Altimeter System (GLAS) aboard the Ice Cloud and Elevation Satellite (ICESat) spacecraft, provide vertical distribution of cloud and aerosol layers. This retrieval technique is called active remote sensing. For polar regions, space-borne lidars accurately retrieve cloud top height and distinguish clouds from clear areas, which is very difficult to accomplish for passive remote sensing techniques. However, laser beams emitted from space-borne lidars can only penetrate clouds to a limit of a few optical depths. As a result, only the optical depth of thin clouds can be retrieved from the reflected lidar signal. Is it possible to obtain thick cloud optical depths from GLAS and other space-borne lidar instruments? The answer is YES. This can be achieved by calibrating the reflected solar background light received by the GLAS photon detectors. For lidars, the reflected sunlight has been regarded as a noise that needs to be subtracted from the reflected laser signal. However, once calibrated, it becomes a signal that can be used to studying the properties of optically thick clouds. In other words, we use the GLAS detector as a visible radiometer at the lidar wavelength. The above images show how optical depth of thick clouds can be obtained from the calibrated GLAS solar background. Panel (a) displays a marine stratocumulus scene over the southern Pacific Ocean observed by GLAS on November 1, 2003. We plotted here the GLAS 532 nm backscatter image along with the corresponding solar background (red curve). The cloud deck is optically thick and the standard GLAS active remote sensing is unable to retrieve its optical depth. Instead, panel (b) illustrates the cloud optical depth information retrieved from GLAS solar background signal. Finally, panel (c) shows the cloud top and base height of the cloud deck. The cloud top height is detected from GLAS active remote sensing while the cloud geometrical thickness is calculated using an empirical relationship between cloud optical and geometrical thicknesses. More details about these results can be found in a paper Retrievals of thick cloud optical depth from the Geoscience Laser Altimeter System (GLAS) by calibration of solar background signal recently submitted to the Journal of Atmospheric Sciences. To learn how solar background light can be used for ground-based micropulse lidars, see this previous image.
Alexander Marshak, Yuekui Yang

Remote sensing of cloud sides of deep convective clouds



CLAIM 3D -- the three-dimensional cloud and aerosol interaction mission proposal -- is a satellite sensor combination proposed by scientists from NASA's Climate and Radiation Branch and the University of Maryland Baltimore County. It combines measurements of aerosol characteristics in the vicinity of clouds and profiles of cloud microphysical characteristics. Such a set of collocated measurements will allow new insights into the complex field of cloud-aerosol interactions affecting directly the development of clouds and precipitation, especially in convection. A core instrument is the Cloud Scanner (see October 21, 2007 Image of the Week) which measures radiance reflected or emitted by cloud sides at several wavelengths. A profile of cloud phase and particle size on a high spatial resolution of a few hundred meters will be retrieved from these measurements. For this sensor an experimental retrieval was developed and successfully tested. The retrieval accounts statistically for the complexity of cloud structures and 3D radiative transfer at high resolution. These figures present the test of the proposed retrievals using a completely synthetic test bed. Cloud fields from the Goddard Cumulus Ensemble model (top image) were used as input to a 3D radiative transfer model which simulates the cloud scanner observations (bottom left image). The Bayesian retrieval of particle size distribution was then applied to the simulated data. The retrieved vertical profiles of cloud particle size and cloud phase were compared with the "true" data from the cloud model. The bottom left image shows the simulated observation for the cloud structure above looking on the cloud scene at 60 degrees from the "south" of the scene. The plot on the right shows the true and retrieved cloud properties along the red line in the left image. Mostly cloud sides are observed showing small (up to 12 μm) water droplets and much larger (> 30 μm) ice particles. The results of comparison are very encouraging showing that the method is clearly capable of retrieving the cloud properties along the profile with a high accuracy.

Tobias Zinner, Alexander Marshak and Vanderlei Martins

Lidar solar background light helps studies of aerosol-cloud interactions

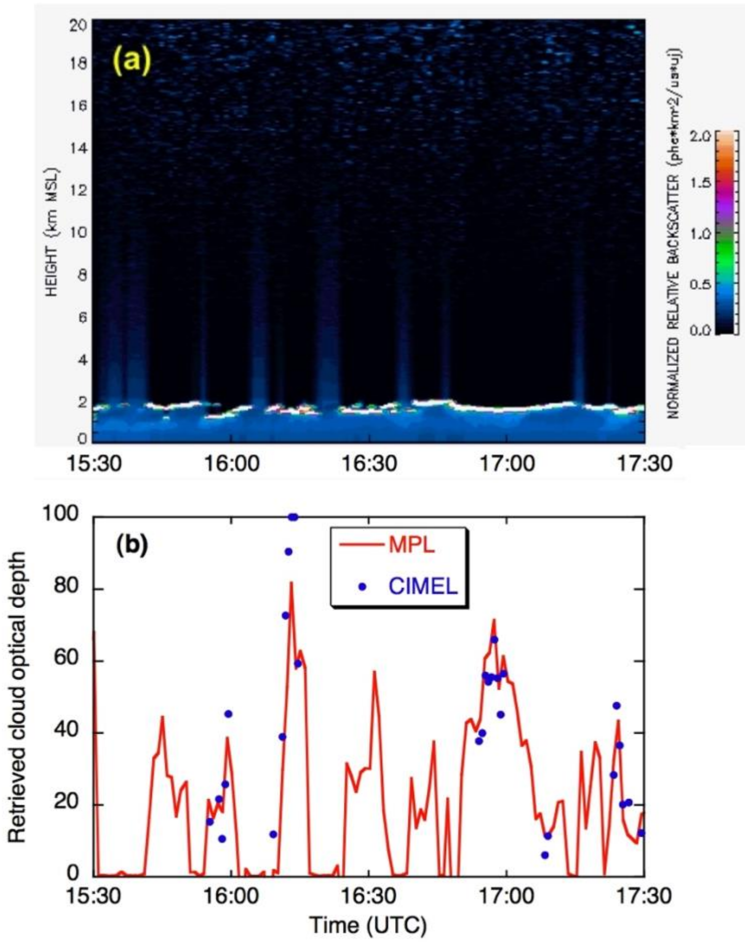
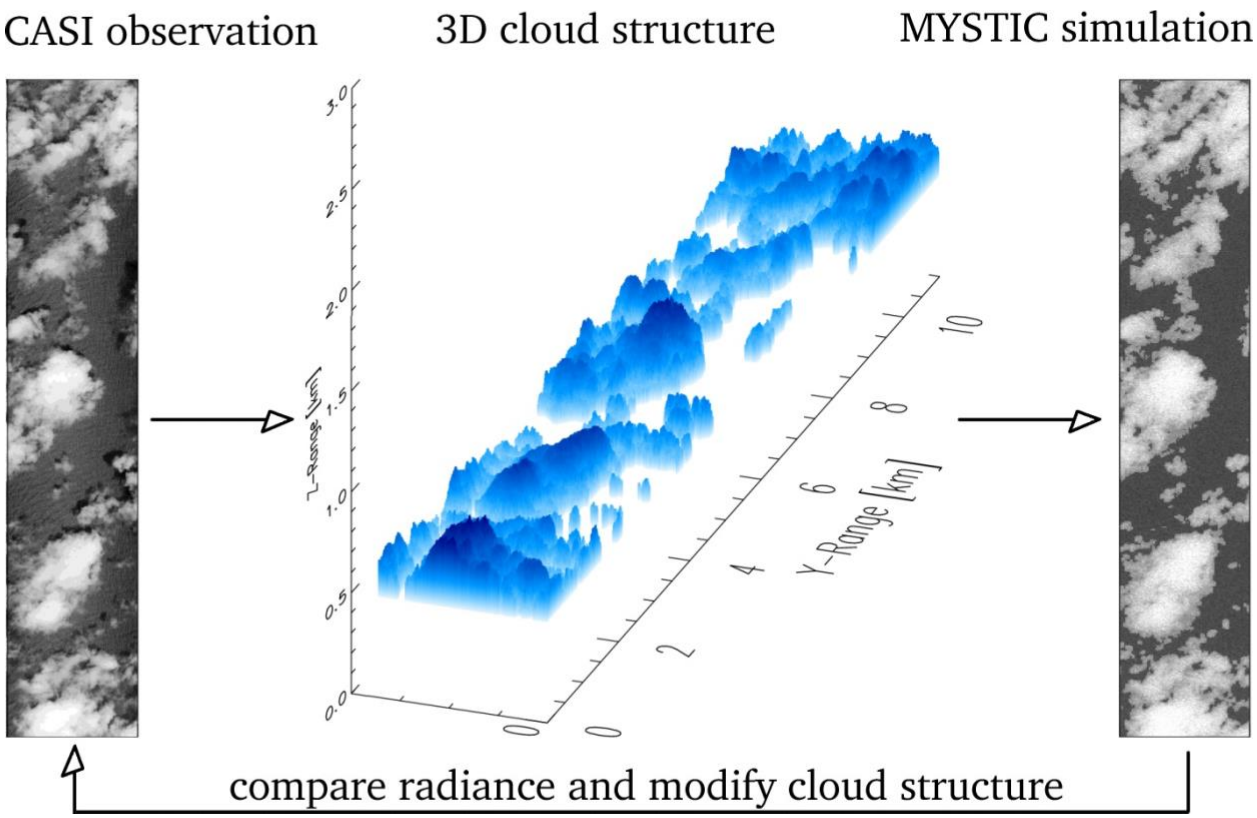


image shows that solar background light measurements from pulsed lidars can help us better understand interactions between aerosol and cloud. Lidars are commonly used to retrieve vertical distributions of aerosol and cloud layers. The underlying retrieval principle is that the returned signal is proportional to the amount of light backscattered by atmospheric molecules, aerosols and clouds. Measured photon counts are converted into attenuated backscatter profiles, and during the process a number of noise sources need to be accounted for. Solar background light is one of them. Because of limited power, the lidar pulse does not easily penetrate thick clouds, and thus it is widely believed that lidar cloud retrievals (other than cloud base altitude) are limited to optically thin clouds. We have demonstrated that lidars can retrieve optical depths of thick clouds using solar background light as a signal, rather than only noise to be subtracted, as is usually done. The upper panel is a time series of micropulse lidar (MPL) backscatter vertical profiles at NASA/Goddard Space Flight Center on October 29, 2005. Broken clouds were observed, e.g. no cloud or thin clouds at 16:40 and thick clouds at 17:00. The bottom panel shows cloud optical depth retrievals during the same time period, using MPL solar background light (red lines) and AERONET Cimel sunphotometer measurements (blue dots). Validations show that retrieved cloud optical depths agree within 10–15%. More details about this case can be found in MPL-net and this previous image. In short, one can retrieve not only aerosol properties during clear-sky periods via lidar returned signals (active remote sensing), but also the optical depth of thick clouds during cloudy period via solar background lights (passive remote sensing). This indicates that, in general, it may be possible to retrieve both aerosol and cloud properties using a single lidar. Thus, lidar observations have great potential to serve as a unique dataset allowing us to better understand how changes of aerosol in the environment impact cloud properties. The results of this research were recently published in Geosci. Remote Sens. Lett.
Christine Chiu, Alexander Marshak and Warren Wiscombe

Derivation of Realistic High-resolution Cloud Structure

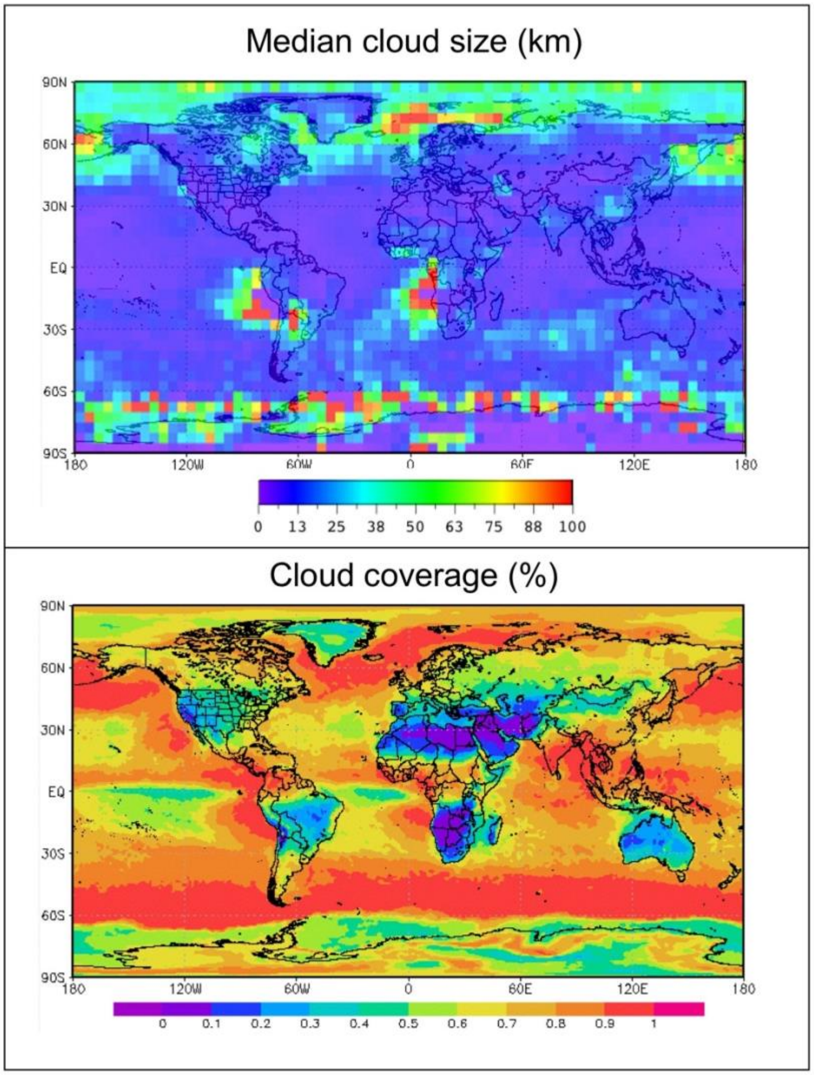


Clouds

Clouds with their three-dimensional structure are highly volatile objects to study. Currently there are no techniques to measure 3D fields of cloud properties. Various means of measuring them like airborne in-situ, ground-based cloud radar, passive and active satellite remote sensing can only provide a 2D cross section of their full 3D structure. At the same time, the clouds high variability in all three dimensions is a source of uncertainty for many algorithms that depend on assumptions (or simplifications) to overcome the informational gaps. Therefore, there is an urgent need for a numerical technique to derive realistic 3D cloud structure. This image illustrates a possible approach to fill the gap. It shows a numerical technique developed at the German Aerospace Center (DLR Oberpfaffenhofen) and recently reported at the ARM Cloud Properties Working Group Meeting (Annapolis, MD) by Tobias Zinner, a NASA/GSFC Climate and Radiation Branch visiting scientist and DFG (German Research Foundation) Fellow. An initial guess of the horizontal distribution of cloud liquid water and cloud top height is retrieved using standard remote sensing methods from a high resolution (15 m) image observed by a Compact Airborne Spectrographic Imager (CASI, data provided by Free University Berlin. An iterative process of corrections starts from this first guess. During the iterations, 3D simulated (right image) and originally observed (left image) radiation fields are compared. This leads to a cloud structure for which the simulated field best matches the observed one. The 3D radiative transfer process is simulated using the MYSTIC model developed by Bernhard Mayer (1999).

Tobias Zinner and Alexander Marshak

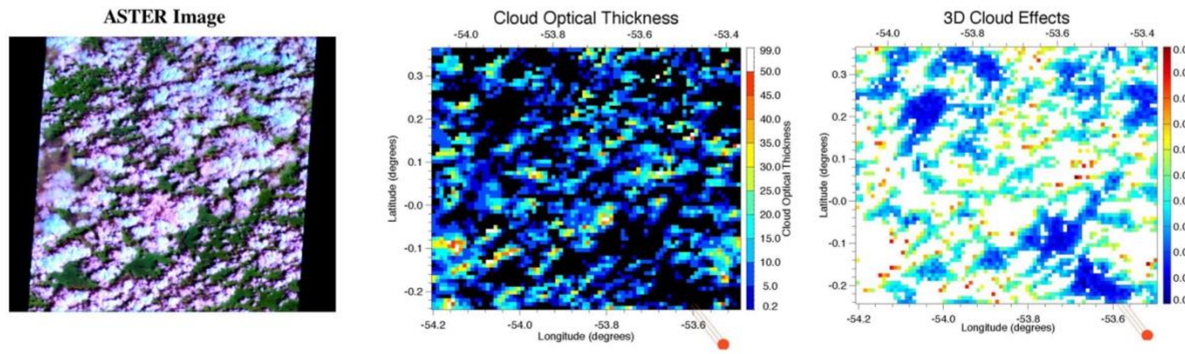
Correlation between horizonal cloud size and fractional cloud coverage



This image combines possibly the first global map of horizontal cloud size with the concurrent map of fractional cloud coverage. Both maps are based on MODerate resolution Imaging Spectral radiometer (MODIS) observations from June to August 2005. In many areas, cloud fraction and cloud size are well-correlated: higher cloud fraction corresponds to more horizontally extended clouds. For example, the North Pacific and North Atlantic Oceans are often covered by extended stratiform clouds that reach their maximum size and frequency in summer. The frequent stratocumulus clouds off the coasts of Peru and Angola also tend to occur in large overcast decks. In other areas, however, correlation is poor: high cloud coverage does not correspond to large clouds. For example, clouds associated with the Intertropical Convergence Zone (ITCZ) near the equator, or with the summer monsoon in India and Indochina, are often caused by convection and hence are relatively smaller, while the stratocumulus decks off the coast of California appear to consist of largely broken, smaller elements.\r\n\r\nThe cloud size map was constructed using observations from virtually all daytime data granule extracted at the Goddard Earth Sciences Data and Information Services Center (GES DISC) MODIS data pool, by considering all liquid phase clouds that were flagged as “high confidence” by the operational MODIS optical thickness retrieval algorithm. The cloud coverage map was generated by the Giovanni MODIS Online Visualization and Analysis (MOVAS) tool, using the MODIS/Terra Atmosphere Monthly Global Product.

Tamas Varnai and Alexander Marshak

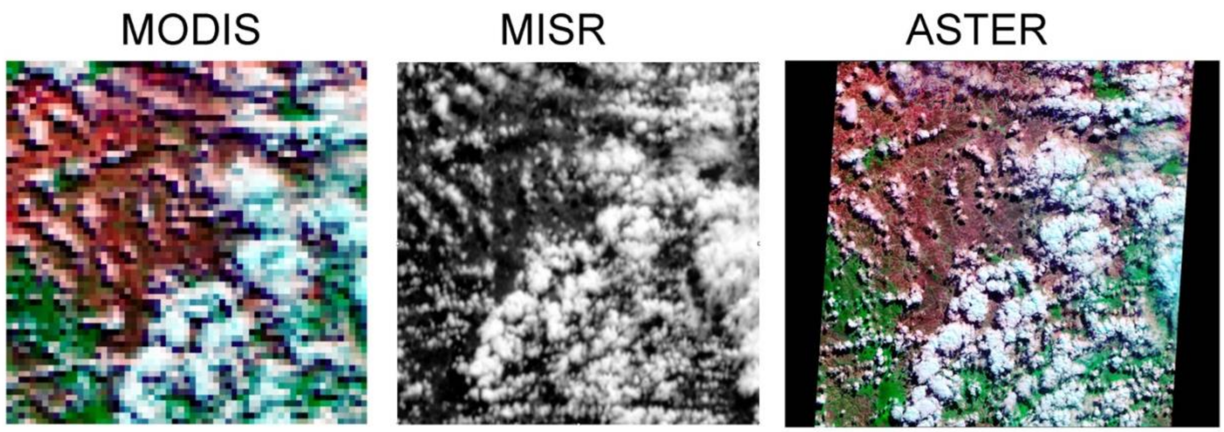
Three-dimensional (3D) radiative effects of clouds in biomass burning Amazon Basin



Often the Earth's atmosphere is assumed to be horizontally uniform for simplicity. However this assumption is often not valid, particularly in a cumulus cloud field such as the one in the left panel. In that case, the full 3D radiative transfer process has to be considered. The left panel is a high-resolution ASTER image of a cumulus cloud field over the biomass burning region in Brazil. The 60km by 60km image is centered on the equator at 53.78 degrees West and was taken on January 25, 2003 with solar zenith angle of 32 degrees and solar azimuth angle of 129 degrees. The incident solar beam is schematically indicated in the middle and right panels. The middle panel is a collocated MODIS image of cloud optical thickness showing considerable non-uniformity. (Clear pixels are masked as black). The size of the image is 80km by 60km with a resolution of 1km. The cloud cover is 53 percent. The right panel shows the difference between a 3D radiation field and its 1D counterpart in the clear region with aerosol optical thickness of 0.1 and non-reflecting surface. (Cloud pixels are masked as white). It is evident that over non-reflecting surfaces, clouds enhance clear region reflectance almost everywhere. This may result in overestimation of aerosol optical depth in the vicinity of clouds. This biomass burning Amazon Basin cumulus cloud scene was selected as a new case for the Phase III of I3RC to evaluate the performance of various 3D radiative transfer codes. In addition to ASTER and MODIS, Multi-angle Imaging Spectro-Radiometer (MISR) measurements of the scene are also available and will be used for the retrieval of cloud and surface properties. Click here for more information about the I3RC project, and to read a recently accepted BAMS paper by Cahalan et al. (2005). These images show the complexity of a typical cumulus cloud field. As we continue to improve our understanding of the climate system, we expect to encounter more complex phenomena where 3D radiative transfer becomes crucially important.

Guoyong Wen and Alexander Marshak

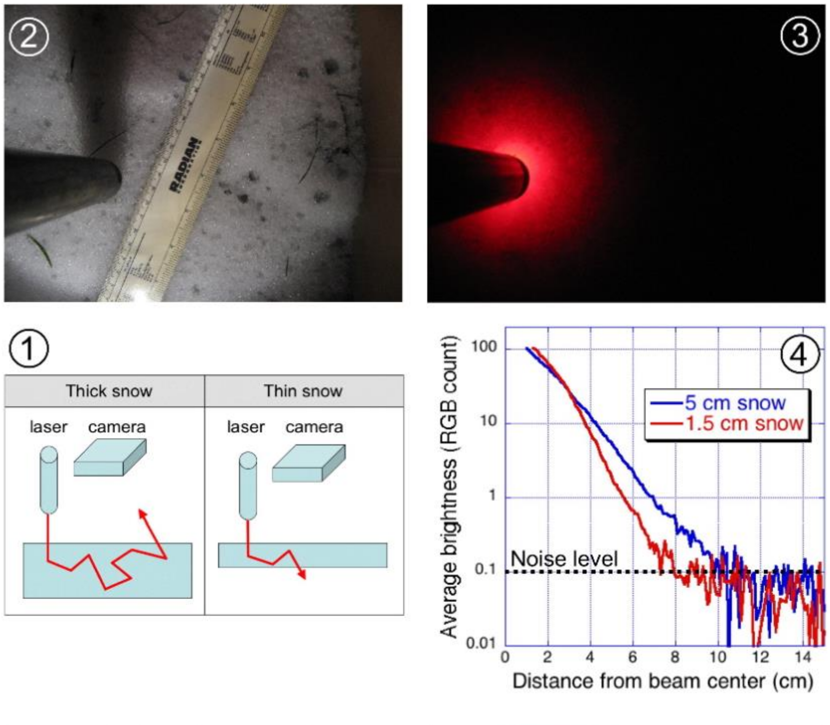
MODIS, MISR, and ASTER images in the Intercomparison of 3D Radiative Codes (I3RC) project



These images show the way three different instruments on board the Terra satellite viewed an approximately 60 km by 60 km area in South-Eastern Brazil on August 9, 2001. Each instrument has a different strength: one takes measurements at numerous wavelengths, another at several view directions, and the third one at a very high spatial resolution. The combined information from the three instruments makes it possible to determine atmospheric and surface properties more accurately than any single instrument would allow. The scene reconstructed from the combined information will be used in the I3RC project for evaluating the performance of various radiative transfer models that simulate 3D radiative processes in the atmosphere. This will be part of a third phase of intercomparisons, which will follow the first two phases described by Cahalan et al. (2005). Case studies of different degrees of 3D complexity, from plane-parallel marine stratocumulus to broken cumulus clouds, will allow us to create a database from which students can learn about 3D radiative transfer and understand where and how plane-parallel approaches to radiative transfer break down. The left panel shows a 1 km-resolution color-composite image using three of the 36 wavelengths measured by the MODIS instrument. Operational MODIS cloud, aerosol, and surface products provide our initial estimate for scene properties, which are then refined using data from the other instruments. The middle panel shows a 275 m-resolution MISR image taken at the wavelength of red light at 60 degree view angle. MISR images taken from nine separate directions reveal the solar reflection properties of the surface as well as the magnitude of some 3D radiative interactions that occur in clouds. Finally, the right panel shows a 15 m-resolution image taken by ASTER. This high-resolution image captures the small-scale cloud variability that gives rise to a variety of 3D radiative effects, thus allowing more thorough intercomparisons. We note that while the MODIS image contains only 3600 pixels, the ASTER image contains as many as 16 million pixels.

Alexander Marshak and Tamás Várnai, with help from Guoyong Wen and Lazaros Oreopoulos

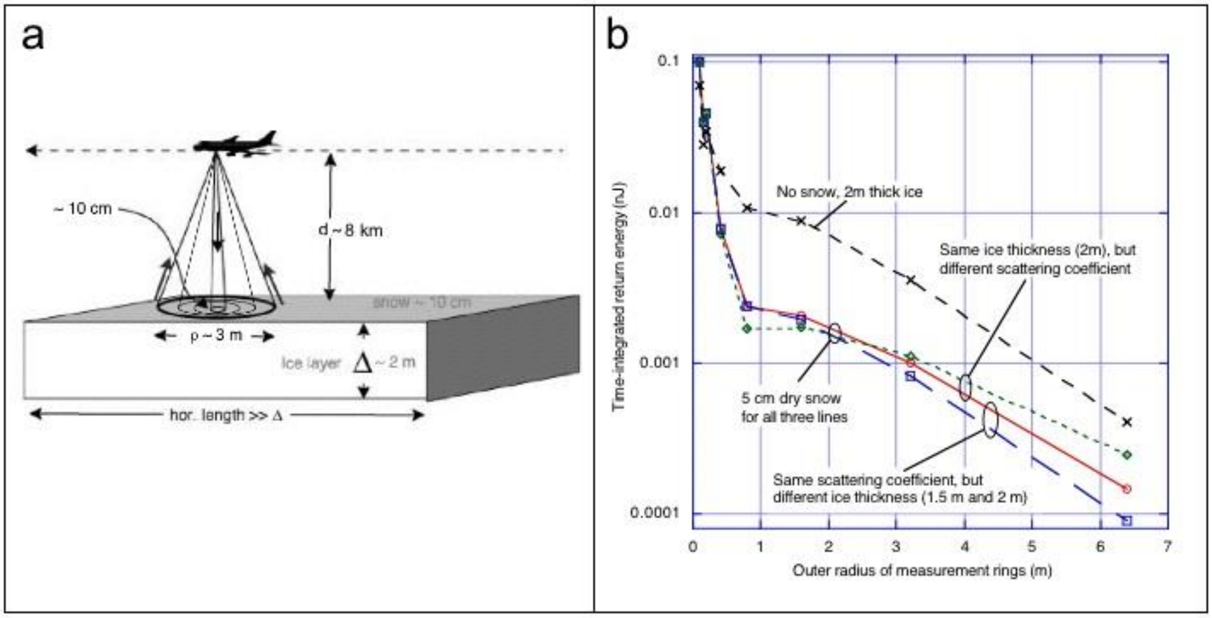
Halo observations in snow



These images show the first demonstration of a new concept for airborne snow thickness measurements. Panel 1 illustrates that while in thick snow photons can travel far, in thin snow they often escape through the bottom and get absorbed by the ground. This difference allows one to infer snow thickness by measuring the size of the bright halo that forms around an illuminated spot. Panel 2 shows the view of a camera set up for ground-based demonstrations of this measurement concept. The black tube at left contains the light of a red laser pointer inside a small spot. The ruler provides scale but, of course, is not present at the time of actual halo observations. Panel 3 displays one of the first snow halo observations, from the night of December 5, 2007. It was taken over 5 cm deep fresh snow in Silver Spring, Maryland. The analysis of such images in Panel 4 confirms that indeed, the bright halo extends farther in thick snow. This result helps pave the way toward building a new lidar instrument for airborne snow thickness measurements. The new instrument could survey snow thickness over large areas and could even contribute to the validation of satellite-based snow measurements. For more information, see Várnai, T., and R. F. Cahalan, 2007: Potential for airborne offbeam lidar measurements of snow and sea ice thickness, J. Geophys. Res., 112, C12S90, doi:10.1029/2007JC004091.

Tamas Varnai

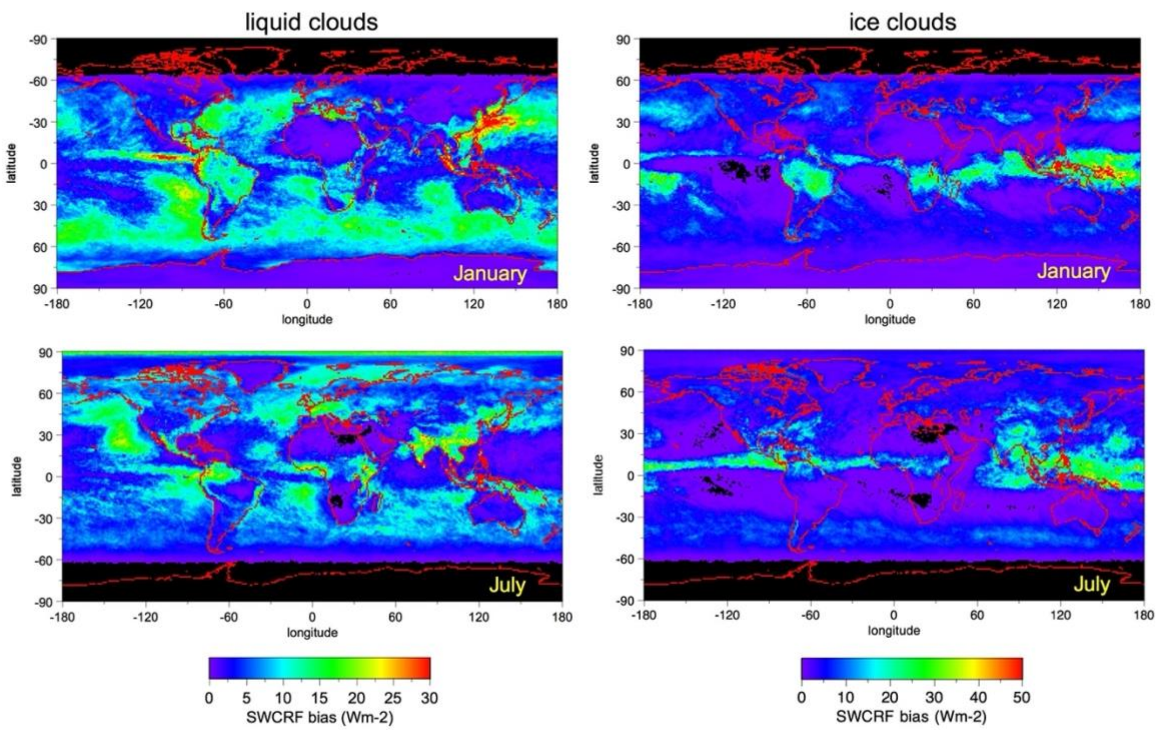
Concept of new lidar measurements of snow and sea ice thickness



The left panel (a) shows the typical setup of proposed snow and sea ice thickness measurements: An airborne lidar illuminates the surface with a tightly focused laser beam and measures the light returning from increasingly wide concentric rings, thus observing the way light spreads inside snow and ice. A comparison of the red and blue curves in the right panel (b) reveals that snow and ice thickness affect the return energy measured at each ring: The bright halo around the illuminated spot extends farther out in thicker layers, because photons can travel longer without escaping through the bottom. The figure also shows that snow and sea ice measurements pose different challenges. While sea ice is usually much thicker, snow contains a much higher concentration of scatterers (there are more crystals in snow than bubbles in ice). As a consequence, sea ice halos are larger but snow halos are brighter. Simulation results suggest that airborne sea ice measurements are possible at night and that snow measurements are possible during both night and day. For moderate snow and sea ice thicknesses (around 30-50 cm for snow and 3 m for ice), limitations in instrument performance are expected to cause measurement uncertainties on the order of 10%. These results indicate that instruments using the new approach have the potential to become an important component of future snow and sea ice observing systems. Such measurements can help better understand snow and sea ice processes, and can also contribute to the validation of satellite measurements. For more information, see Várnai, T., and R. F. Cahalan, 2007: Potential for airborne offbeam lidar measurements of snow and sea ice thickness. J. Geophys. Res.

Robert F. Cahalan (NASA) and Tamás Várnai (UMBC JCET)

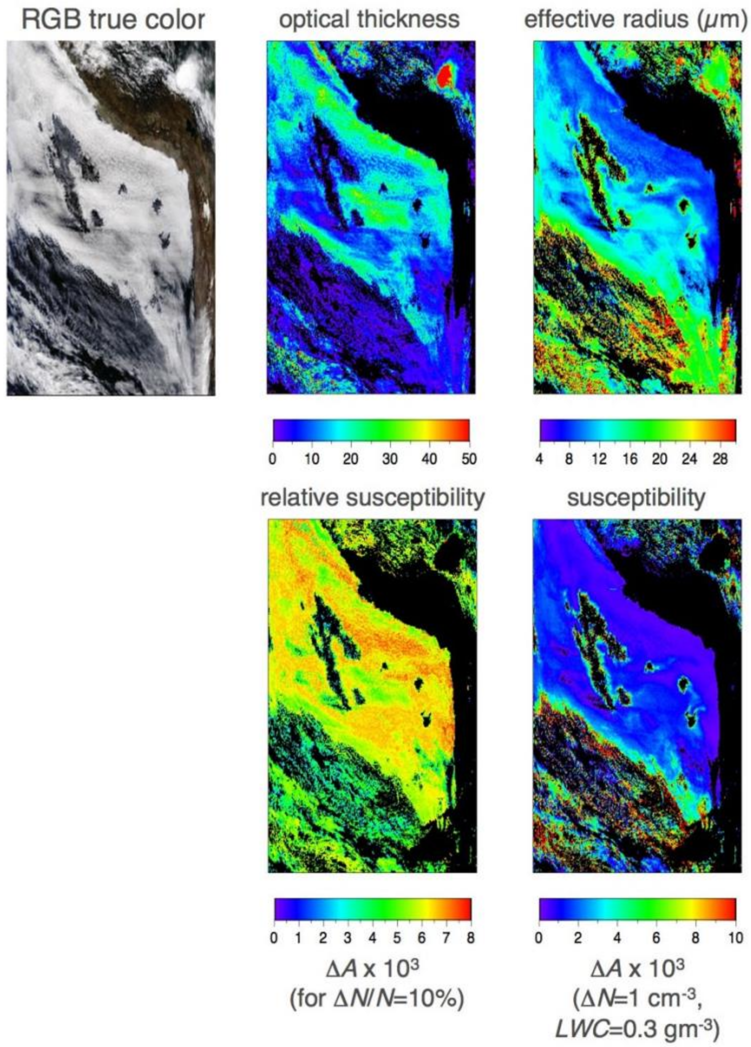
Shortwave cloud radiative forcing bias due to cloud inhomogeneity



The schemes that calculate the energy budget of solar and thermal radiation in Global Climate Models (GCMs), our most advanced computers tools for predicting climate change, commonly assume clouds are horizontally homogeneous at distances as large as 100 miles. However, this assumption, used for convenience, computational speed, and lack of knowledge on how to treat small scale cloud variability, is known to be inaccurate. In a recently published paper (see reference below) we provide a description of the errors in solar radiation reflected by the planet when cloud variability is neglected across distances approximating 60 miles. To make these error estimations possible, we use cloud retrievals from the instrument MODIS on the Terra and Aqua satellites, along with atmospheric and surface information, as input into an algorithm, of the type used in GCMs, that calculates the fraction of solar radiation reflected, transmitted and absorbed by the atmosphere-surface system. Since MODIS provides information on cloud variability below 60 miles we can run the radiation algorithm both for the variable and the (assumed) homogeneous clouds. The difference between these calculations for reflected or transmitted solar radiation constitutes the bias that GCMs would commit if they were able to perfectly predict the mean cloud properties, but assumed that clouds were homogeneous for radiation calculations. We find that the global average of this bias is at least as big as the additional amount of thermal energy that would be trapped if we were to double carbon dioxide from current concentrations. We should therefore intensify our efforts to predict horizontal cloud variability in GCMs and account for its effects on radiation calculations. The figure shows the geographical distribution of the bias at the time of satellite overpass for clouds classified to be of liquid and ice phase by the MODIS algorithm. Terra and Aqua values for January and July 2005 have been averaged. The patterns are distinctly different for the two cloud phases reflecting known cloud patterns and regimes (mid-latitude storm tracks, ITCZ, etc.) For a detailed analysis of the shortwave radiative forcing bias due to cloud inhomogeneity please see:\r\n\r\nOreopoulos, L., S. Platnick, G. Hong, P. Yang, and R. F. Cahalan, 2009: The shortwave radiative forcing bias of liquid and ice clouds from MODIS observations. Atmos. Chem. Phys. 9, 5865-5875.

Lazaros Oreopoulos

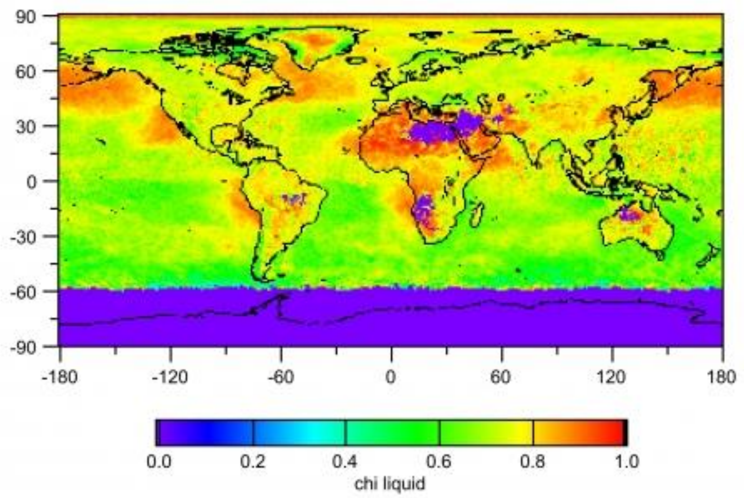
Observations of Cloud Susceptibility

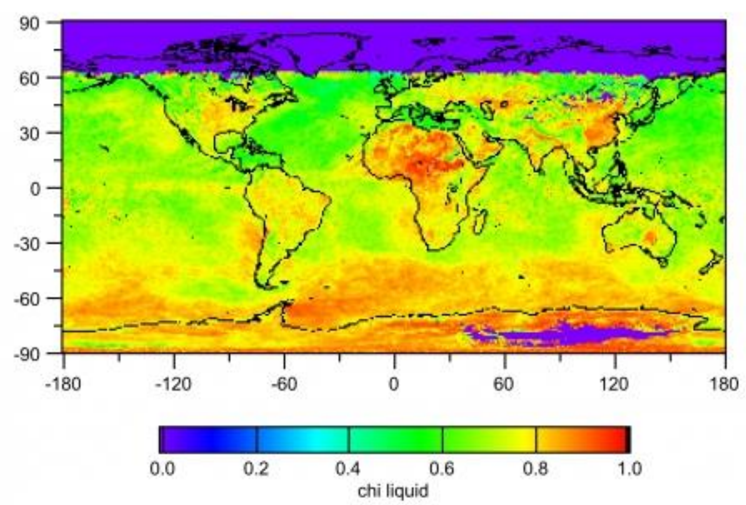


The sensitivity of the top-of-atmosphere (TOA) albedo to changes in liquid water cloud droplet number concentration derived from MODIS Terra operational cloud retrievals (MOD06) of extensive marine stratocumulus clouds off the coasts of Chile and Peru on 18 July 2001. This droplet concentration sensitivity, also known as "cloud susceptibility", is a measure of the potential effect of aerosols on cloud radiative properties, i.e., the 1st indirect effect of aerosols or the "Twomey effect". The MODIS data granule (5 minutes of data) true color composite is shown in the upper left image. In the northern part of the image, a convective system of predominantly ice phase clouds is seen over the Amazon basin along with some liquid phase clouds. Two susceptibilities are calculated from the MODIS retrievals. The standard susceptibility dA/dN, where A is albedo and N is droplet concentration, is approximated with a broadband radiation model by calculating the radiative effect from increasing the absolute concentration by 1 cm-3 with liquid water content being held to a constant value of 0.3 gm-3. This is shown in the lower right image in terms of the resulting broadband TOA perturbation ΔA, which includes surface albedo and atmospheric effects. A relative susceptibility (perturbation due to a relative change in the droplet concentration) is shown in the lower left image for ΔN/N=10%. Note that the two susceptibilities have different dependencies on the cloud effective radius (top right) and optical thickness (top middle). The ability to calculate cloud susceptibilities directly from observational data allows for realistic assessments of 1st indirect effect radiative forcing scenarios, as well as a means for validating global susceptibilities from climate models.

Steven Platnick and Lazaros Oreopoulos

Cloud inhomogeneity from MODIS

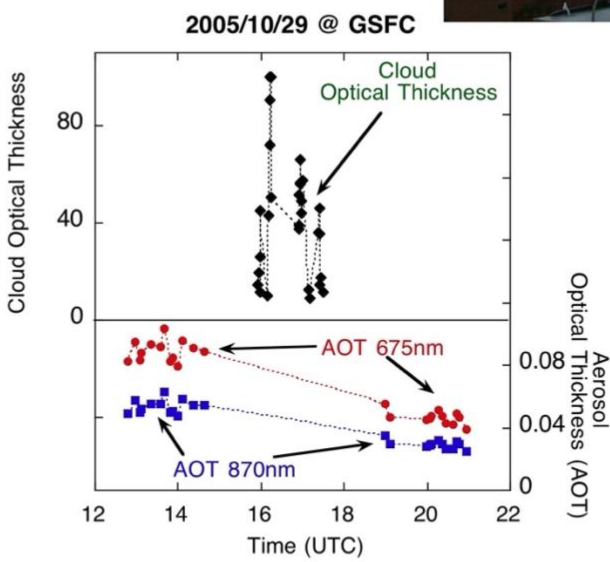


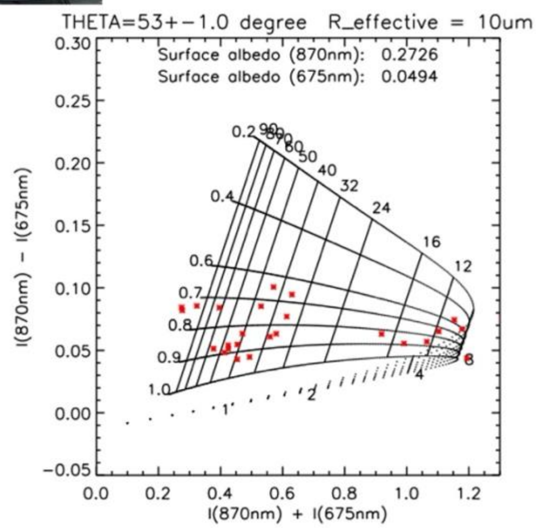


Horizontally inhomogeneous clouds reflect, transmit, absorb, and emit different amounts of solar or thermal (infrared) radiation than their homogeneous counterparts. By quantifying cloud inhomogeneity on a global basis we hope to make advances in the representation of clouds of Global Climate Models. If the model clouds are not realistic, errors in the estimates of Earth's radiation budget will be inevitable without some kind of model "tuning". Assuming that one day we will be able to predict cloud variability in climate models, we would like to examine whether the modelled variability exhibits similar magnitudes and features as the variability in the observations. For example, work by Oreopoulos and Cahalan (see reference below) finds that clouds are more variable over oceans than over land, more variable during the winter than the summer, more variable in the afternoon than in the morning. Will the models be able to reproduce these results? The figure provides a global picture of cloud inhomogeneity at ~100 km (1x1 degree) scales from 1 km observations by the instrument MODIS aboard the Terra satellite. The top panel is for the month of July 2003 and the bottom panel for the month of January 2004. Only clouds consisting of liquid cloud droplets are represented in this figure. As a measure of cloud inhomogeneity we use the parameter chi, defined as the ratio of the logarithmic to the linear mean of cloud optical thickness corresponding to each 100 km region. This ratio is approximately the factor by which the mean regional optical thickness should be scaled in order to recover the correct domain-averaged solar flux reflected by clouds. The smaller chi is, the more inhomogeneous the clouds are. The figure shows that strong fluctuations of cloud inhomogeneity both geographically and seasonally take place.

Lazaros Oreopoulos and Robert Cahalan

Measuring aerosol and cloud properties from the roof of Building 33

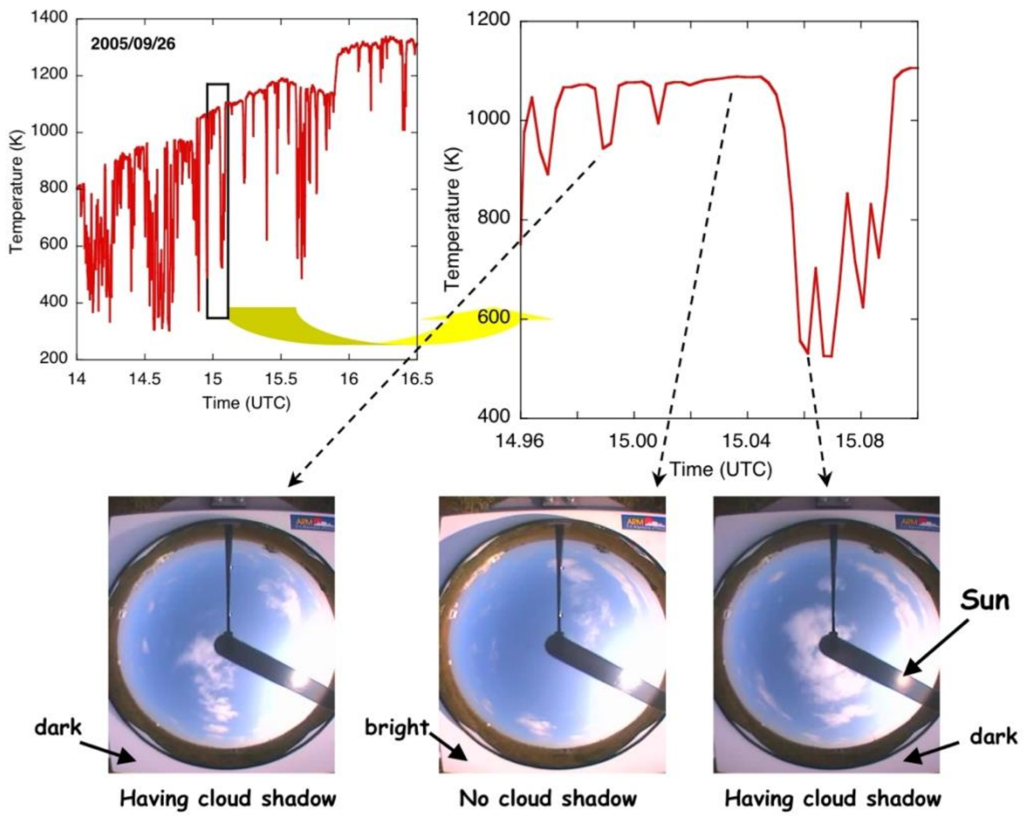




This image of the week is a continuation of the image that appeared on August 15, 2004. The top panel shows the multi-channel Cimel radiometer, located on the roof of Building 33 at Goddard Space Flight Center, looking straight up and measuring zenith radiance. This is a new feature of AERONET and it is called a "cloud mode." The cloud mode uses AERONET "idle time" inappropriate for aerosol study to monitor cloud optical properties. When the Sun is blocked by clouds (as seen at the top image) the radiometer looks straight up and takes 10 measurements of zenith radiance with a 9-second temporal resolution. \r\n\r\nThe left bottom panel illustrates a time series of both aerosol and cloud optical thicknesses observed from the roof of Building 33 on October 29, 2005. The sky was clear in the morning and late afternoon when the aerosol optical thickness retrieval was performed. At noon, the sky became overcast, clouds blocked the Sun, and the radiometer worked in the cloud mode retrieving cloud optical thickness. The cloud retrieval algorithm uses Cimel measurements at 675 and 870 nm; it is based on the assumption that cloud optical properties are similar at these wavelengths while vegetated surface reflectances vary significantly. In addition to cloud optical thickness, the algorithm also estimates the effective cloud fraction. Both cloud optical thickness and cloud fraction are vital for any cloud-radiation parameterization. The right bottom panel shows a look-up-table used for the retrievals of both cloud optical thickness and cloud fraction on October 29.

Alexander Marshak and Christine Chiu

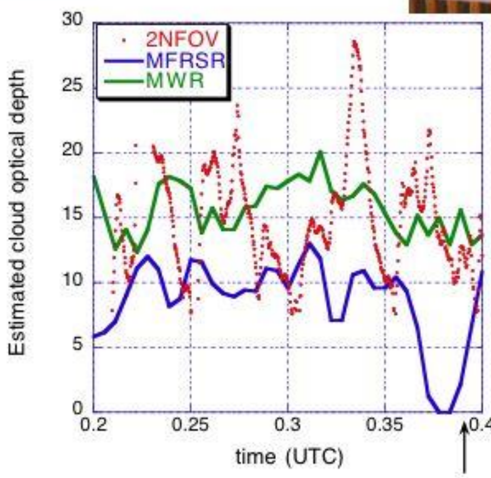
Measuring low liquid water paths from an Infrared Thermometer



This image shows measurements of the sky temperature from the new Atmospheric Radiation Measurement ARM Program Infrared Thermometer (IRT) at the Southern Great Plains (SGP) site in Oklahoma on September 26, 2005. This customized IRT looks toward the Sun and measures solar radiation with a narrow field of view of 1.1 degree at the wavelength spectrum of 10.5 – 11.5 microns. This wavelength region is in the most transparent part of the atmospheric window (8 – 12 microns), since it radiates the least IR radiation and avoids strong ozone absorption at 9.6 microns. When clouds block the scene in the field of view of the IRT, the solar beam is attenuated, and thus a lower temperature (less radiation) is measured (as shown by many dips in the temperature time series). We enlarge the plot around 15 UTC and show it on the right panel along with images from the ARM Total Sky Imager TSI. Clearly, when a decrease in the IRT temperature occurs, we see a dark background (due to cloud shadows) in the corresponding TSI image as well, indicating that the sun is blocked. This IR Thermometer is designed to measure low liquid water paths (LWP). Laboratory experiments and theoretical calculations have confirmed that the transmission of the solar beam in this window around 11 microns gives direct information on LWP. However, this idea works only when clouds contain low LWP. Clouds having high LWP emit significant IR radiation. If the solar radiation (i.e., signal) is drowned by the cloud-emitted thermal radiation (i.e., noise), the signal-to-noise ratio is not sufficiently large to retrieve liquid water path accurately. It has been found that half the clouds observed at the ARM SGP site have low liquid water paths below 100 g/m2. These types of clouds are important from a climate sensitivity point of view, but unfortunately it is often not accurately detected by microwave radiometers. The new customized IRT has the ability to provide accurate liquid water path for such clouds. Long-term measurements of the IRT will be very valuable for the climate community in order to better understand the feedback of clouds on global radiation budget.

Warren Wiscombe, Christine Chiu and Alexander Marshak

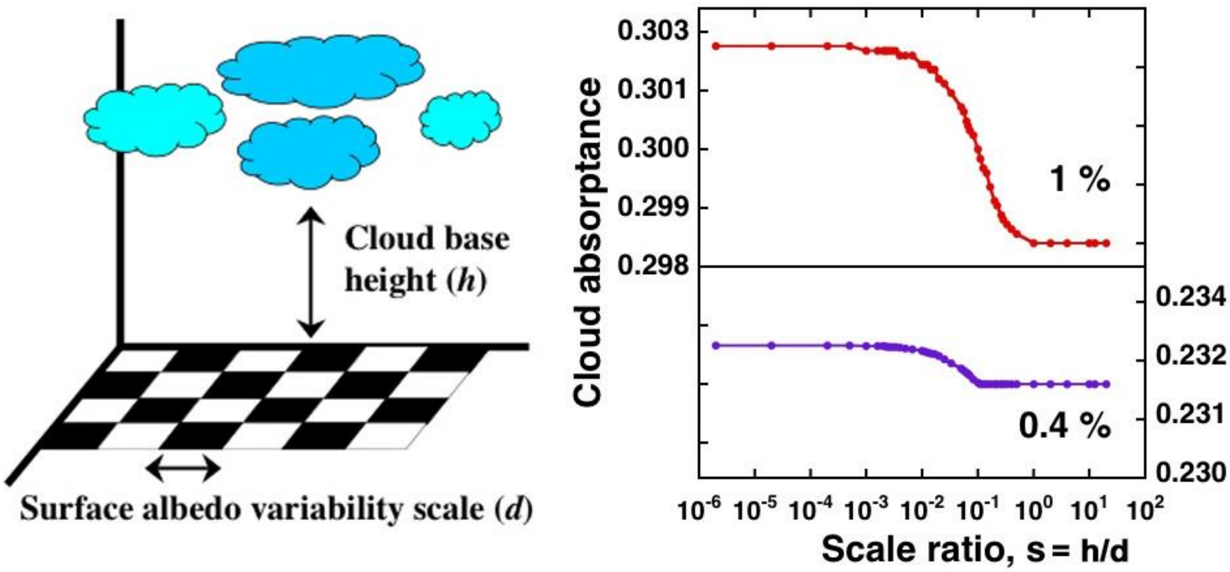
Cloud measurements at the ARM Mobile Facility at Point Reyes National Seashore



Members of the NASA/GSFC Climate and Radiation Branch joined the Point Reyes field campaign and deployed the ARM passive two-channel Narrow Field-Of-View (2NFOV) radiometer in June 2005. Point Reyes is ideal for our work because of the high abundance of clouds. The upper-right image is a sky-image snapshot taken at 00:22:30 UTC on June 21, and the graph below is the estimate of cloud optical depth over a 12-minute period. (The arrow at the lower-right corner indicates the time of the sky image snapshot.) The retrievals from 2NFOV (red dots) captures local rapid changes in 3-dimensional cloud structures at the natural time scale of clouds, made possible because of the one-second sampling resolution of 2NFOV measurements. The other two retrievals are from a Microwave Radiometer (MWR) (instrument on the right in the upper left image and a Multi-Filter Rotating Shadowband Radiometer (MFRSR). Marine stratus clouds are one of the most prevalent clouds on Earth, and are an essential element in our climate system. To further our understanding of the interactions of this type of cloud and radiation, the Atmospheric Radiation Measurement (ARM) Mobile Facility (AMF) has been deployed since May 2005 at the Point Reyes National Seashore in California. This field campaign will be collecting valuable measurements until September 2005. Click here to view photographs. The AMF is located in the small patch of trees in the center. What quantity of clouds do we expect to obtain in order to better model cloud-radiative interactions? Cloud optical depth is one of the most important optical properties and vital for any cloud-radiation parameterization. If we cannot confidently and unambiguously measure it, we will never be able to check the validity of any cloud model. To estimate cloud optical depth from ground-based observations, members of the NASA/GSFC Climate and Radiation Branch pioneered an algorithm to retrieve cloud optical depth from the ARM passive two-channel Narrow Field-Of-View radiometer, called the 2NFOV (instrument on the left in the upper left image). The 2NFOV radiometer views straight up, and measures downward radiance at the red and near-infrared wavelengths. Since vegetated surfaces reflect substantially different amounts of radiation in these two wavelengths, we can extract information on cloud optical depths from the resulting difference in radiances between these two channels. This algorithm works not only for overcast clouds like stratus, but also for broken clouds like cumulus.

Alexander Marshak, Christine Chiu and Warren Wiscombe

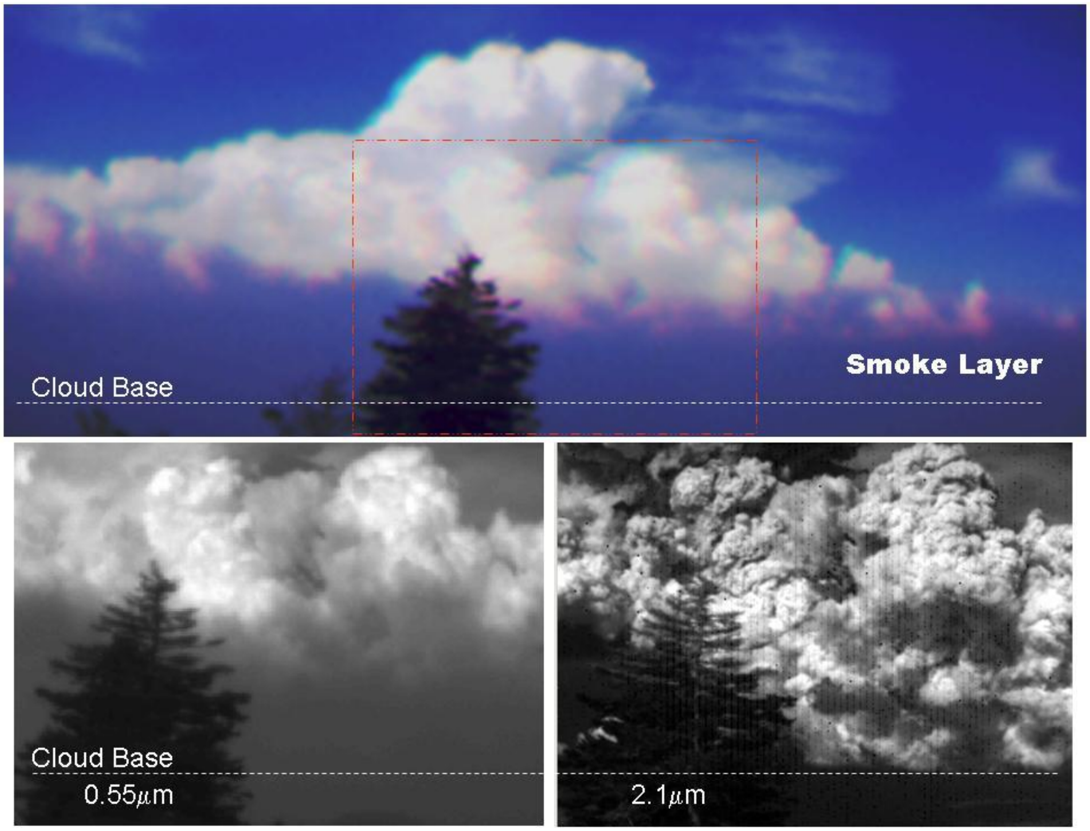
Can patchiness in the surface reflection underneath clouds explain the discrepancy between observed and calculated cloud absorption of sunlight?



One of the major concerns in the atmospheric community has been a discrepancy between measured and model-calculated sunlight absorbed by clouds. It is often referred to as the Òenhanced cloud absorptionÓ anomaly. This anomaly could have a significant impact on climate modeling and remote sensing applications. Various explanations have been offered, but, upon close examination, have failed to account for it. It has been suggested that some of the anomaly may be due to a failure to model the patchiness of surface reflection beneath clouds, which can indirectly affect cloud absorption through multiple cloud-to-ground reflections. But a careful analysis of this effect was lacking. Therefore, a three-dimensional radiative transfer model was used to calculate cloud absorption in the presence of the simplest possible surface inhomogeneity Ð a checkerboard, as depicted in the left panel. The checkerboard surface is a black and gray pattern approximating the actual variability observed at an Oklahoma field site of the Atmospheric Radiation Measurement (ARM) program. The right panel shows cloud absorptance as a function of the scale ratio s = h/d , defined as the ratio of the height of the cloud base above the surface to the horizontal scale of surface variation. A fairly simple case was first examined (upper right panel) for a single wavelength of sunlight and for the Sun directly overhead. When the cloud base is far from the ground (large s), the model predicts that the cloud absorptance is the same as it would be if the surface were replaced with a uniformly-reflecting surface with albedo equal to the average albedo of the checkerboard. As the cloud base approaches the ground (small s) the absorptance increases, and each portion of the cloud interacts radiatively only with the part of the checkerboard immediately below it. The change in absorptance between these two extremes is only about 1 percent, however, for this simple case. The change is even less when averaged over cloud inhomogeneities, over all wavelengths of sunlight and over all illumination angles (lower right panel). The average effect of surface heterogeneity on cloud absorption thus appears to be less than 0.5%, equivalent to a change in surface heating of about ~ 1 W/m2. This 1 W/m2 difference is not only less than uncertainties due to water vapor and aerosol effects, but also much less than the discrepancy (order of 10 W/m2) between measured and model-calculated cloud absorption. These results therefore strongly suggest that accounting for surface heterogeneity in radiative transfer models cannot explain anomalous cloud absorption. The results of this research were recently published in Geophysical Research Letters.

Warren Wiscombe and Christine Chiu

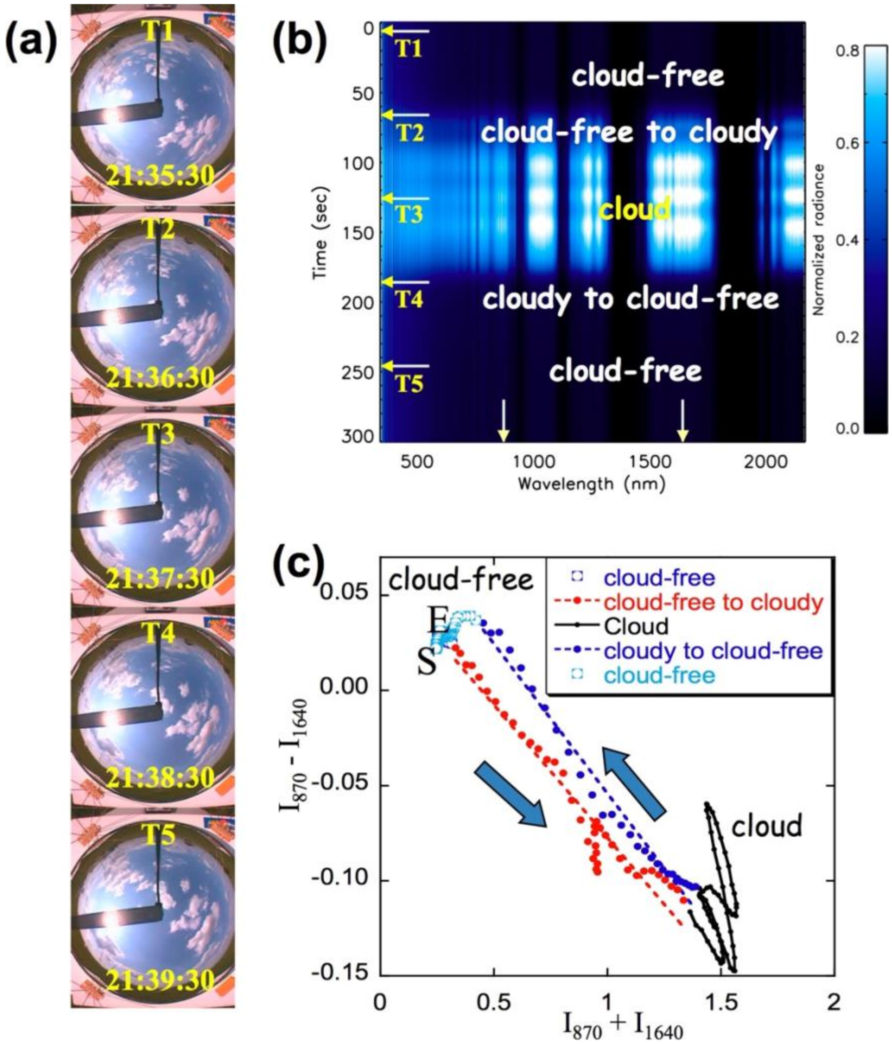
Your eyes can trick you: Where is the cloud base?



The top image is a color composite of blue (410nm), green (550nm) and red (670nm) images on the background of a thick smoke layer. The cloud base is not visible in the smoke background and the smoke itself is confused with the blue sky and the horizon. The two pictures on the bottom contain (a) the visible (550nm) and (b) the near infrared (2100nm) pictures of a piece of the same cloud (red box in the top image) showing the different details covered by both wavelengths. The visible picture (a) shows a cloud structure like we see with our eyes (as the color composite). The 2100nm picture (b) shows two very distinct characteristics as compared to the visible one. 1- The 2100nm picture (b) can see through the smoke and clearly shows a much lower cloud base, which is completely ignored by a naked eye observer or by the analysis of the visible picture. This happens because smoke particles are on average much smaller than 2100nm, producing a weak interaction between light at this wavelength and the smoke. 2 - Picture (b) also shows enhanced details in the cloud structure that cannot be observed in the visible one. The structure in 2100nm makes the cloud appear like a volcano or a smoke plume. This characteristic comes from the fact that light at 2100nm is "strongly" absorbed by cloud droplets and on average undergoes much fewer scattering events inside the cloud than light in visible wavelengths. In contrast, visible wavelengths are subjected to "negligible" absorption by the cloud droplets and produce a much smoother picture. In reality, the 2100nm picture shows more realistic details of the cloud dynamic and microphysical structure, which gets lost in the smoothing effect produced by visible light. These pictures were taken in July 2007, during a field campaign in Mount Gibbes/Mount Mitchell, North Carolina, in collaboration with the North Carolina State University. These were the first tests of the NASA Goddard/UMBC cloud side imagers. This system was designed for the study of the interaction between aerosol particles and clouds. There is strong evidence in the literature showing how man made pollution and other aerosols can affect clouds and precipitation. The system also allows for quantitative measurements of the size of the cloud droplets, and for the discrimination of the cloud thermodynamic phase (ice, water, or mixed phase).

Vanderlei Martins

Using the ACRF Shortwave Spectrometer to Study the Transition Between Clear and Cloudy Regions



To the naked eye, clouds appear to have sharp boundaries; however, this is merely an illusion. Cloud boundaries are actually somewhat fuzzy, with the transition from cloud to clear stretching over as little as 50 m to as much as several hundred meters. Fuzzy cloud boundaries create major headaches for studies of aerosol indirect effect and aerosol radiative forcing – especially when, as with most satellite instruments, spatial resolution is too poor to resolve the transition zone. This argues strongly for the use of ground-based instruments with spatial resolution on the order of meters, and temporal resolution better than a few seconds, to study the transition zone. One-second-resolution zenith radiance measurements from the new Atmospheric Radiation Measurement (ARM) Climate Research Facility (ACRF) shortwave spectrometer (SWS) provide a unique opportunity to analyze the transition zone. We have used two wavelengths, 870 and 1640 nm, from the SWS spectra to study the transition zone on the sides of clouds. These two wavelengths provide information about optical depth and particle size and are nearly free of the confounding effect of Rayleigh scattering. In the transition zone, we find a remarkable linear relationship between the sum and difference of radiances at 870 and 1640 nm wavelengths. The linear behavior allows us to neatly separate effects of aerosols and clouds. The intercept of the line is determined mostly by aerosol optical depth and size, while the slope of the line is determined mostly by cloud droplet size. This linearity also can be predicted from simple theoretical considerations and furthermore supports the hypothesis of inhomogeneous mixing, whereby optical depth increases as a cloud is approached but the effective drop size remains unchanged.

Alexander Marshak, Christine Chiu, Yuri Knyazikhin