CloudSat/CALIPSO Science Workshop

28-31 July 2009
Monona Terrace, Madison WI

Abstracts of Oral Presentations

Steve Ackerman
(UW/CIMSS/AOS)

Welcome to Madison WI
Open remarks and welcoming

Chip Trepte
(NASA LaRC)

Brief Overview of CALIPSO Mission

Deborah Vane
(JPL)

Brief Overview of CloudSat Mission

Tobias Wehr
(ESA)

Status Report EarthCARE
The Earth Cloud Aerosol and Radiation Explorer, EarthCARE, is a joint ESA-JAXA mission for the study of clouds and aerosols and their relation to radiation. EarthCARE will embark four instruments, a high spectral resolution lidar operating at 355nm, a 94-GHz cloud radar with Doppler capability, a multi channel imager and a broad-band radiometer. The mission is presently in industrial phase B with a launch target date in 2013. Science and engineering requirements have been consolidated and instrument/system design phase is close to completion. The scientific preparation of the mission is presently focussing on the definition of level 2 data products and the development of their retrieval algorithms. This presentation will give an overview of the EarthCARE science status.

Hal Maring
(NASA HQ)
Co-Authors: Hal Maring and David Considine

Programmatic Status Report
Three items will be addressed:
- A status report on the Science Team Recompetition
- A status report on the ACE Decadal Survey Mission Study
- Introduction of the new C&C Program Scientist

David Winker
(NASA Langley Research Center)

Overview of Version 3 Data Products

Graeme Stephens
(Colorado State University)

Overview of CloudSat Products and Science

Steven Miller
(Colorado State University--CIRA)
Co-Authors: Steve Miller, Rich Bankert, John Forsythe, Phil Partain, Manajit Sengupta, Cristian Mitrescu, Richard Austin

Statistical Extension of CloudSat Curtain Observations to a Regional Swath
CloudSat provides the first global observations of vertically-resolved cloud structure, cloud base heights (ceilings), multi-layered cloud systems, synoptic-scale storm cross-sections, and detection of light precipitation regimes. Since the CloudSat radar is a non-scanning system (providing only a nadir cross-section, or 'curtain' slice of the atmosphere

along its orbital ground track) it does not capture the full three-dimensional view of the cloudy scene. The lack of swath data limits the utility of CloudSat to some operational users and modelers seeking to observe, validate, or assimilate cloud information on regional scales. However, in many cases (and as readily noted by surface observerations) clouds of a similar classification (e.g., cumulus, cirrus, stratiform, etc.) observed locally are representative of others in the vicinity, such that simple distance-weighted correlations may provide a reasonable estimate of structure and boundary properties for other clouds in the region. Here, we use a two-year compilation of CloudSat data to examine to what extent cloud classification can be used as a constraint to defining cloud vertical structure and geometric boundaries. Statistics are compiled on along-track CloudSat data, and then applied in off-track directions. Strengths and limitations of the technique are discussed.

Patrick Minnis

(NASA Langley Research Center)
Co-Authors: Patrick Minnis, Yuhong Yi, William L. Smith, Jr., Sunny Sun-Mack, Yan Chen, Doug Spangenberg, Rabindra Palikonda, J. Kirk Ayers

New Formulas for Estimating Cloud Thickness from Satellite Imagery Based on CloudSat-CALIPSO Data

Developing three-dimensional characterizations of clouds from passive satellite imagery requires a means for estimating the physical thickness of clouds. Empirical methods, based on limited amounts of surface and airborne cloud lidar and radar data, have been used to estimate cloud thickness based on the cloud temperature and optical depth from a variety of passive satellite imagers. The CloudSat and CALIPSO data greatly expand the potential database for deriving such information. Matched Aqua MODIS, CloudSat, and CALIPSO data taken from different months are used to develop and test new formulae to provide improved estimates of cloud thickness based on cloud phase, temperature, optical depth and effective particle size. The MODIS cloud parameters, derived using the CERES-MODIS methods, are correlated with the thicknesses derived from the CloudSat and CALIPSO data. The resulting formulas are applied to MODIS data taken in different months and also to data from the Geostationary Operational Environmental Satellite (GOES). The new estimates are significantly more accurate than those based on the older methods with biases reduced to near zero for both liquid and ice water clouds. The results should enable more accurate 3-dimensional characterizations of clouds from passive imagers.

William Rossow

(CREST at City College of New York)
Co-Authors: William B. Rossow, Yuanchong Zhang, Cindy Pearl, Ademe Mekonnen, Eric Tromeur

Overview of new Level 3 Products

This is a report on several lines of research to combine CloudSat–Calipso observations with other satellite cloud and atmospheric observations, particularly ISCCP, to elucidate the global three dimensional structure of clouds and how it evolves with changes in the atmospheric general circulation. Since a crude cloud vertical structure (CVS) was previously estimated by combining ISCCP and a cloud layer climatology based on radiosonde humidity profiles and used to calculate radiative flux profiles in the ISCCP–FD product, the first task is to evaluate this statistical model of CVS which assigns specific layering to each cloud type defined by ranges of cloud top pressure and optical thickness. Next new CVS statistical models are being produced using the cloud type approach and using composites by weather states identified as distinct mesoscale patterns of cloud properties. Other studies focus on specific types of meteorological phenomena, namely tropical convection and midlatitude cyclones, by forming Lagrangian composites of the CloudSat–Calipso CVS as functions of storm age and type. Lastly, two studies are underway to elucidate the interaction of components of the larger scale circulation tropical with deep convection; the initial focus in on the Madden–Julian Oscillation and African Easterly Waves. Early results from all of these studies will be summarized.

Simone Tanelli

(Jet Propulsion Laboratory)
Co-Authors: S. Tanelli, S. L. Durden, G. Dobrowalski

Cloud Profiling Radar: status, performance and new products

We will report on the status and performance to date of the Cloud Profiling Radar, with focus on calibration and stability, impact on the L1B product and changes planned for R05. We will also describe the new CloudSat brightness temperature products to appear in R05, their strengths and limitations, estimated performance and samples.

Elizabeth Dupont

(University of Utah)
Co-Authors: 1.Elizabeth Dupont, Gerald Mace, Patrick Minnis and Rabindra Palikonda. 2. Elizabeth Dupont and Gerald Mace

Comparison of Water Path Values from CloudSat and Meteosat-8 2. Cluster Analysis of Atlantic Cirrus Clouds and Synoptic Scale Dynamics of Growing and Dissipating Cirrus Events

1. Values of water path derived from two different algorithms are compared for Atlantic cirrus events. An experimental Z-τ; algorithm is used to derive water content from A-train data. The VISST/SIST algorithm is used to derive total water path from the SEVIRI instrument on Meteosat-8. CloudSat profiles are collocated in time and space with points in the SEVIRI dataset and averaged to match the resolution of the SEVIRI data.

The agreement between the water path values will be discussed. Using CloudSat data, individual cirrus events will be examined to determine under what conditions the algorithms compare well and under what conditions the algorithms compare poorly to identify possible weaknesses in the algorithms.

2. Knowledge of how large-scale dynamics are coupled with microphysics is useful for understanding cirrus cloud behavior and for parameterizing cirrus clouds in models. Atlantic cirrus events observed by CloudSat are classified based on pressure- radar reflectivity patterns using a k-means clustering algorithm. The three cirrus clusters identified are thin cirrus, thick cirrus, and cirrus with precipitating mid- and low-level clouds.

To characterize the tendencies of cirrus events, observations from geostationary satellite data are used to track the cirrus events in time by following patterns of 6.2μm brightness temperature. Cirrus events are classified as growing if the average brightness temperature is decreasing in time and are classified as dissipating if the average brightness temperature is increasing in time. Using NCEP/NCAR reanalysis data, the composite dynamics of each cirrus cluster are investigated to determine how the large-scale meteorology plays a role in the evolution of the cirrus events. Composite results indicate that growing cirrus events are found in regions of stronger upper-level rising motion than dissipating cirrus.

Daniel Henz

(University of Wisconsin Madison)
Co-Authors: Daniel Henz, Tempei Hashino, Greg Tripoli, Eric Smith

A 2-d modeling approach for studying the formation, maintenance, and decay of Tropical Tropopause Layer (TTL) cirrus associated with Deep Convection

This study is being conducted to examine the distribution, variability, and formation-decay processes of TTL cirrus associated with tropical deep convection using the University of Wisconsin Non-Hydrostatic modeling system (NMS). The experimental design is based on Tripoli, Hack and Kiehl (1992) which explicitly simulates the radiative-convective equilibrium of the tropical atmosphere over extended periods of weeks or months using a 2D periodic cloud resolving model. The experiment design includes a radiation parameterization to explicitly simulate radiative transfer through simulated crystals. Advanced Microphysics Prediction System (AMP) will be used to simulate microphysics by employing SHIPS (Spectral Habit Ice Prediction System) for ice, SLiPS (Spectral Liquid Prediction System) for droplets, and SAPS (Spectral Aerosol Prediction System) for aerosols. The ice scheme called SHIPS is unique in that ice particle properties (such as size, particle density, and crystal habitats) are explicitly predicted in a CRM (Hashino and Tripoli, 2007, 2008). The Advanced Microphysics Prediction System (AMPS) technology provides a particularly strong tool that effectively enables the explicit modeling of the TTL cloud microphysics and dynamical processes which has yet to be accomplished by more traditional bulk microphysics approaches. On going studies will be to compare the ice and aerosol properties simulated in the TTL by NMS/AMPS model to CloudSat and CALIPSO observations as well as the extensive in situ and remote sensed aircraft observations gathered during NASA's Tropical Composition, Clouds, and Climate Coupling experiment (TC4).

Michael Schwartz

(University of Utah)
Co-Authors: Chris Schwartz, Jay Mace

Co-occurrence Statistics of Tropical Tropopause Layer Cirrus with Lower Cloud Layers as Derived from CloudSat and Calipso Data

Radar and lidar data collected by instruments aboard the CloudSat and Calipso satellites are used to demonstrate statistics of the spatial variability of tropopause transition layer (TTL) cirrus along with their tendency to occur with or without lower clouds. TTL cirrus occurrence patterns contain maxima over the tropical convective areas of South America, of Africa, and of the west Pacific. It is demonstrated from co-occurrence statistics that TTL cirrus events and general lower cloud events are nominally independent in a zonal average; however, tendencies towards co-occurrence between TTL cirrus and lower clouds that appear in specific base height and geometrical thickness bins exist.

Matt Rogers

(Colorado State University)
Co-Authors: Matt Rogers, Graeme Stephens, Deb Vane

Comparison of CEN and CloudSat 2B-CLDCLASS observations

Individual surface observations of cloud type taken by trained student observers participating in the CloudSat Education Network (CEN) are compared with observations from the CloudSat 2B-CLDCLASS cloud classification product. The CloudSat Education Network consists of over eighty schools trained in cloud observations, and are located across five continents. Surface observations of clouds from the CEN are taken coincident with CloudSat overpasses of the CEN school location, facilitating direct comparison between the satellite-derived cloud type product and the surface observations. Agreement between the two sets of observations are comparable to studies using WMO observations made by trained meteorologists, making the near-global CEN network a potentially useful source for ground verification of satellite-observed cloud properties.

Peter Falcon

(JPL)

NASA EDCAT's science and outreach metric reporting

NASA's EDCAT's database is a component of NASA's criteria for determining a centers overall grade and funding. Input from the science community is sorely needed to capture all science activities and increase the projects profile.

Ziad Haddad

(JPL)
Co-Authors: Kyungwon Park and Ziad Haddad

Combining radar profiles from CloudSat with AMSR-E and AMSU-B passive microwave radiometric observations to estimate precipitation in polar regions

Climate models suggest that global change will manifest itself most significantly in the polar regions, and its effect on high-latitude precipitation will be critical for arctic ecosystems. While recent studies have shown that microwave radiances measured by operational microwave humidity sounders, such as the Advanced Microwave Sounding Unit (AMSU) and the Microwave Humidity Sounder (MHS), are sensitive to falling snow, the radiometrically cold polar surface signatures make it very difficult to retrieve snowfall rates from these measurements. In this project, we develop an approach to estimate snowfall by correlating three years (2006-2008) of MHS/AMSU-B radiances to near-simultaneous radar reflectivity profiles from the 94-GHz CloudSat radar, which is sensitive to high latitude precipitation. Since the microwave sounding channels are affected by the variable surface emissivity, the crucial first step is to separate these data by fractional ice coverage. We then use a principal components analysis to quantify the variations due to the radiometric signatures of the precipitation from those of the surface. Finally, we quantify the correlation between the higher principal components (orthogonal to the surface variability) of the microwave radiances and the precipitation-sensitive CloudSat radar reflectivities.

Robert Houze

(University of Washington)
Co-Authors: R. A. Houze, Jr., and Jian Yuan

Structure of Mesoscale Convective System Anvil Clouds as Seen by CloudSat

Mesoscale Convective Systems (MCSs) occurrence over the entire tropics has been determined by analyzing CloudSat data obtained in all the upper-level cloud shields and raining areas observed by MODIS AMSR-E over a one year period. An algorithm has been developed and applied to the MODIS brightness temperatures and AMSR-E rain rate products to identify and label each MCS and its anvil. The CloudSat Cloud Profiling Radar (CPR) data are used to characterize the vertical structure of the anvils. The algorithm performs well, identifying the largest cold-topped MCSs over the western Pacific, in the region of the Madden-Julian Oscillation (MJO), and the smallest cold-topped systems over tropical Africa. Over the eastern tropical Pacific and Atlantic Oceans, MCSs are found to have warmer cloud tops. From the tracks of CloudSat across the objectively identified MCS anvils in each of these regions, statistics have been obtained on the structure of MCS anvils as seen by the CPR. Reflectivity data in the anvils are categorized by the thickness (vertical extent) of the cloud in which the observations are obtained and by distance from the raining core of the MCS. In thinner anvils and portions of anvils located far from the raining core of the MCS, contoured frequency by altitude diagrams (CFADs) show narrow PDFs of reflectivity at all levels of the anvil cloud, suggesting that the particles are simply growing by stratiform microphysics (vapor diffusion and aggregation). Within portions of thick anvil clouds (>6 km in vertical extent) close to areas of active rainfall CFADs show broader distributions of reflectivity at all levels with the modal values of higher reflectivity in the lower portions of the anvil clouds. This is especially true in continental regions such as sub-Saharan Africa, where the anvils are adjacent to extremely vigorous convection which likely ejects graupel particles into the anvils. Over oceanic regions, where the convection is less vigorous and stratiform rain regions are large, the thick anvils have narrow distributions of reflectivity with modal values increasing downward, consistent with stratiform microphysics. The statistics on horizontal and vertical structures of anvils being provided by this study present an observational data base against which models which aim to simulate upper-level cloud structure around the globe may be tested.

Anthony Illingworth

(Dept of Meteorology, Univ of Reading)
Co-Authors: A.J. Illingworth and L.D. Harkess-Smith.

Drizzle rates inferred from CloudSat/Calipso compared to their representation in the operational forecast models

Drizzle rates from low altitude liquid water clouds derived from the Cloudsat radar and Caipso lidar are compared with the drizzle held in the ECMWF and Met Office operational models. The liquid water within the cloud is derived from the MODIS reflectivities and the attenuation of the ocean radar surface return. Cloud depth is inferred from the lidar returns, and the drizzle rate from the radar backscatter. Forward modelling of the radar reflectivity from the two models predicts a value which is an order of magnitude greater than what is observed. It is clear that the models are converting too much cloud liquid water into drizzle. Changes to the parmeterisation schemes to correct for this will be discussed.

Johnny Luo

(City College of New York, CUNY)
Co-Authors: Johnny Luo, G. L. Liu, and Graeme Stephens

Deep Convective Processes from the A-Train Perspective

Traditionally, convective processes are studied most often using data collected during field campaigns. Satellite observations of convection are paid less attention to in the research community (but are extensively used in the operational meteorological services) probably because they do not offer as “detailed” a view of convective systems. With the launch of new generation sensors, most notably

TRMM and CloudSat, we are now able to view convection from fundamentally new standpoint, and by relating these new dimensions of earth observations to existing operational capability (e.g., GEO data which offers larger spatial and temporal context), we are entering into a stage where innovative analysis of satellite data reveal tremendous new insights into convective processes. This talk will give a few examples (all from recent publications of the authors) how A-Train data are used to study deep convective processes, such as inference of penetrative deep convection lifecycle and estimation of convective buoyancy. Also, we will discuss a new framework with which GCM cumulus parameterization can be evaluated using A-Train data.

Gerald Mace

(University of Utah)

The vertical distribution of cloud occurrence within the ISCCP cloud top pressure-optical depth regimes

The vertical distributions and properties of clouds on Earth, both simulated and observed, are traditionally considered in terms of 9 regimes classified in terms of the column optical depth (tau) and the cloud top pressure (CTP) as defined by ISCCP. These CTP-tau regimes have come to intuitively signify certain cloud types. For instance, the regimes that include columns with CTP<440 mb are intuitively classified as thin cirrus, cirrostratus, and deep convection for increasing tau. We analyze the vertical distribution of cloudiness within these regimes and show that these intuitive assumptions regarding what types of clouds populate the regimes are mistaken - especially for columns with CTP<440 mb. In addition, we show the implications of this error on interpreting cloud radiative heating in the atmosphere.

Jacques Pelon

(UPMC, CNRS, IPSL/LATMOS)
Co-Authors: J. Pelon, M. Faivre, G. Seze, P. Dubuisson, A. Garnier, N. Pascal, L. Doppler, and the CALIPSO/IIR working group

High Cloud properties from IIR and CALIOP observations

Upper level clouds are of particular importance in climate change issues due to their contribution to radiation budget and their induced forcing. A better caracterization in their properties (and underlying layers) is however required. In the frame of the CALIPSO mission, developed in collaboration between NASA and CNES, observations from CALIOP and the Infrared Imaging Radiometer (IIR) are exploited to retrieve ice cloud properties in the upper troposphere.

Lidar observations from CALIOP is used to provide identification of optically thin upper level clouds, possibly not detected by radar, which are categorized in scenes further analyzed to retrieve emissivities with the IIR with respect to clear or cloudy references. Differences in emissivities in the three spectral IIR bands are then used to analyze cloud microphysics.

In this presentation, after a short introduction on observations and analysis method, synergies between lidar and IR radiometer instruments are discussed in the frame of case studies performed to retrieve ice cloud properties. Preliminary statistics of cloud radiative properties are then presented as a function of region and altitude.

Zhien Wang

(University of Wyoming)
Co-Authors: Zhien Wang, Qun Miao, Damao Zhang and Min Deng

The abundance and challenge of mixed-phase clouds: a new perspective from CloudSat and CALIPSO measurements

Mixed-phase clouds play an important role in the climate system, but are still poorly understood and simulated. CloudSat and CALIPSO measurements provide the first opportunity to accurately determine the mixed-phase cloud global distribution and new potentials to better characterize their properties. By combining lidar's high sensitivity to high concentration small water droplets and radar's high sensitivity to low concentration large ice particles, an algorithm is developed to reliably identify mixed-phase clouds based on CloudSat and CALIPSO measurements. Results from the first two-year observations indicate high mixed-phase cloud occurrence in mid-latitude and Polar Regions. Mixed-phase cloud geographical and vertical distributions and ice properties in them will be discussed in details. By combining CloudSat and CALIPSO observations and the IPCC climate model simulations, we found that high mixed-phase cloud occurrence regions highly correlate to regions with large inter-model differences in simulated cloud feedbacks under the double CO2 condition, which highlights the urgency to improve mixed-phase cloud representation in climate models. Further analyses of CloudSat, CALIPSO and other A-train observations needed to advance our understanding of mixed-phase clouds will be briefly discussed.

Robert Wood

(University of Washington)
Co-Authors: Robert Wood, Louise Leahy, Robert Charlson, Jayson Stemmler

Precipitation and albedo variability in marine low clouds

CloudSat observations are revealing that even shallow marine boundary layer clouds frequently precipitate and that the precipitation they produce can play an important role in boundary layer and dynamics and cloud mesoscale organization. Here, we use data from CALIPSO, CloudSat, and MODIS to examine links between precipitation formation and the spatial variability and radiative properties of marine low clouds. A large fraction of marine low cloud especially over the more remote parts of the oceans are optically thin and appear to occupy a distinct mode in the distribution of integrated lidar backscatter. We will present data to examine the hypothesis that such thin clouds are preferentially found in the vicinity of optically thick precipitating clouds.

James Campbell

(UCAR VSP/Naval Research Laboratory)
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Assimilating CALIPSO Aerosol Profiles to Investigate Saharan Dust Storm Phenomenology

The Navy Aerosol Analysis and Prediction System (NAAPS) is a global transport model equipped with a newly-designed scheme for 3D-VAR assimilation of CALIPSO aerosol extinction profiles. Whereas MODIS and MISR measurements of aerosol optical depth are assimilated to regulate the two-dimensional distribution of NAAPS aerosol mass concentration, information from CALIPSO critically constrains the vertical profile. Furthermore, information gained from linear depolarization measurements and the two-channel color ratio can be used to interpret likely species type. Source functions alone are incapable of initializing presence and vertical distribution for all potential scenarios of aerosol production. Used in tandem with assimilation, a significantly more robust estimate of the global aerosol field is possible.

Elevated/advecting dust layers, with high scattering cross-sections and relatively strong depolarizing potential, represent an ideal scenario to test CALIPSO assimilation and investigate plume phenomenology. We demonstrate recent achievements gained by applying 3D-VAR CALIPSO assimilation using examples of NAAPS output. We describe steps made towards understanding spatial co-variance parameters that will help broaden the two-dimensional/spatial influence of CALIPSO-derived information relative to the model domain. The physical evolution of a Saharan dust plume is shown as it advances across the tropical Atlantic basin using assimilated analyses and ground validation. Forecast skill for sample post-assimilation NAAPS runs is described.

Helene Chepfer

(IPSL/LMD)
Co-Authors: H. Chepfer, S. Bony, A. Bodas, J. Cole, JL Dufresne, R. Forbes, Y. Zhang, D. Konsta, C. Nam, D. Tanré, Y. Tsushima, D. Winker.

Evaluation of the cloudiness simulated by several climate models using CALIPSO and PARASOL observations.

Clouds remain the main source of uncertainty for climate sensitivity estimates from climate models and a major limitation to the reliability of climate change projections. To improve the reliability of climate change projections, it is therefore imperative to improve the representation of cloud processes in models. This first requires to carry out thorough evaluations of the cloud description in climate models.
The new A-train observations give for the first time direct information on the cloud vertical structure together with cloud radiative properties. However, the definition of clouds is not unique, nor among observations, even less between models and observations. Therefore this new generation of satellites will help to constrain the cloud description in climate models only if we are able to bridge the gap between the climate models and satellite observations. For this purpose, the Cloud Feedback Model Intercomparison Program (CFMIP,www. cfmip.net) has developed an observations simulator package (COSP) which includes a CALIPSO and a PARASOL simulator; COSP simulates the cloud properties that would be seen by the satellites if they were flying above an atmosphere similar to that predicted by the model.
This presentation will synthetize results of comparisons between cloud properties observed with CALIPSO and PARASOL and simulated by different GCMs (IPSL, UKMO, NICAM, ECHAM, GFDL, NCAR, ECMWF, CCMA) through COSP for the year 2007. We will focus on the evaluation of the cloud cover, the cloud vertical distribution, the cloud optical depth and radiative fluxes at the top of the atmosphere.

Catherine Naud

(Columbia University / NASA-GISS)
Co-Authors: Catherine M. Naud, Anthony D. Del Genio, Mike Bauer and William Kovari

Cloud vertical distribution across warm fronts from CloudSat-CALIPSO and the GISS GCM

Cloud vertical distributions across extratropical warm fronts are obtained using two consecutive winters of CloudSat-CALIPSO observations and NCEP reanalysis atmospheric state parameters over the northern and southern hemisphere oceans. These distributions generally resemble those from the original model introduced by the Bergen School in the 1920s, with the following exceptions: (1) Substantial low cloudiness which is present behind and ahead of the warm front; (2) Ubiquitous high cloudiness, some of it very thin, throughout the frontal region; (3) Upright convective cloudiness near and behind some warm fronts. One winter of GISS general circulation model simulations of northern and southern hemisphere warm fronts at 2ºx2.5ºx32L resolution gives similar cloud distributions but with much lower cloud fraction, a shallower depth of cloudiness, and a shorter extent of frontal tilted cloud cover in the cold sector. A close examination of the relationship between the cloudiness and relative humidity fields indicates that the water vapor is not lifted enough in modeled midlatitude cyclones and this is related to weak vertical velocities in the model. The model also produces too little cloudiness for a given value of vertical velocity or relative humidity. The current underestimate of modeled cloud cover in the storm tracks, and in particular the 50-60ºS band of the southern oceans, has implications for global climate sensitivity and indicates the need for a parameterization of slantwise convection in climate GCMs. Our front detection procedure might serve as a basis for designing such a scheme.

Jean-Jacques Morcrette

(ECMWF)
Co-Authors: J.-J. Morcrette, A. Benedetti, L. Jones, P. Bechtold, O. Boucher

Using CloudSat/CALIPSO to validate GEMS-AER analyses and forecasts

As part of the GEMS project (Global Environmental Monitoring using Satellite and in-situ data),

ECMWF has produced meteorological forecasts including aerosol quantities over the period 2003-2007, based on initial aerosol conditions obtained after assimilation of MODIS Terra and Aqua optical depths at 550 nm. Since July 2007, the same system has been used to produce near-real time forecasts and analyses of aerosol parameters, which are routinely verified against AERONET data. Recently, we have started using CloudSat/CALIPSO data to validate the vertical distribution of the model clouds and aerosols. Results of these comparisons to observations will be shown, the discrepancies discussed and possible improvements outlined.

David Stokowski

(Laboratory for Atmospheric and Space Physics (LASP)/University of Colorado - Bouler)
Co-Authors: David M. Stokowski, O. Brian Toon, Andrew Gettelman, Charles Bardeen

A CALPISO Subvisible Cirrus Climatology with Initial Comparisons with CAM4 Microphysics

We have constructed a subvisible cirrus (SVC) climatology using the level 2 cloud layer data generated from CALIPSO. This climatology has shown similar global SVC coverage to the work of Wang, et. al (1996), which used the SAGE II instrument. The SVC thicknesses show a mode between 300m & 360m for clouds poleward of 60˚N/S, and a mode between 480m & 540m for both mid-latitude and tropical clouds. For tropical SVCs two modes are present in the mid-layer temperature field, which is not visible in either the mid-latitudes, or polar regions. There are also two modes present in the extinction histogram, calculated globally, whereas only one is present in the corresponding optical depth histograms. This information appears to support the presence of two formation mechanisms of SVCs as outlined by Jensen, et. al (1996). Finally, we use CALIPSO cloud properties in a preliminary evaluation of new parameterizations of ice clouds in a Global Circulation Model, the National Center for Atmospheric Reserach (NCAR) Community Atmospheric Model (CAM).

Hui Su

(Jet Propulsion Laboratory)
Co-Authors: Hui Su, Jonathan Jiang, Joao Teixeira, Andrew Gettelman, Xianglei Huang, Graeme Stephens, Deborah Vane

Evaluate Cloud Simulations in Climate Models using CloudSat Observations

We have examined CloudSat observed ice water content and liquid water content profiles sorted by a number of large-scale variables, including vertical velocity at 500 hPa, sea surface temperature (SST), surface convergence, SST gradient, precipitation, water vapor path, convective available potential energy and lower tropospheric stability. We use these regime-sorted cloud profiles as new metrics to evaluate cloud simulations in three state-of-the-art climate models, i.e., the GEOS-5, NCAR CAM and GFDL AM2. We find that the model simulated cloud vertical profiles have large discrepancies from the CloudSat observations. Using multiple large-scale “regime identifiers” reveals different facets of the physics of cloud parameterizations in the models. Similar composite analyses were conducted for atmospheric water vapor. It is found that the models simulate water vapor better than clouds.

Joao Teixeira

(JPL)
Co-Authors: Joao Teixeira, Brian Kahn, Seungwon Lee and Hideaki Kawai

Cloud Parameterizations and Satellite Observations

Climate and weather prediction models are still quite inaccurate in representing processes such as clouds, turbulence and convection. The essential problem is that these processes can occur in a variety of scales, from the planetary scale to very small scales that cannot be represented explicitly in any atmospheric model. This talk will focus on: (i) new approaches for cloud parameterization that make use of probability density functions (PDFs) of thermodynamic variables and (ii) the utilization of satellite observations such as CloudSat and CALIPSO to characterize these PDFs. In particular we will discuss the properties of cloud water PDFs and the implications in terms of PDFs of moist conserved variables such as total water content used in models.

Jean-Pierre Blanchet

(University of Quebec at Montreal (UQAM))
Co-Authors: Jean-Pierre Blanchet, P. Grenier, R Munoz-Alpozar, T. Ayash and E. Girard

Aerosol, Cloud, Radiation, Precipitation and Circulation Interactions in the Arctic as Revealed by CloudSat-CALIPSO during Winter

CloudSat and CALIPSO have shown very extensive thin ice cloud (TIC) formation in the Arctic during winter, revealing important atmospheric feedbacks on a seasonal time scale. We have identified two coupled feedbacks playing key roles in the generation of extremely cold winter anomalies. One is acting in the vertical and the other in the horizontal directions. During most intense storm episodes, the normal anticyclonic polar cell reverses on the scale of the Arctic Ocean, replacing normal Polar anticyclone by a marked cold low. CloudSat-CALIPSO observations and model simulations show that during these episodes, cold-dry air converges slowly to the Pole region, lifting dry adiabatically cold air masses and effectively converting angular momentum into APE which eventually feeds into the generation of new winter storms at lower latitudes. At the same time in the vertical direction, long range transported anthropogenic aerosols into these large cold lows are deeply mixed up to 6 or 7 km in the vortex, producing intricate thin ice clouds (TIC), unique to the High Arctic winter. TIC formation is promoted by ubiquitous acid coated aerosols which inhibit ice nucleation but favors rapid growing crystals. In turn, these sparse large crystals effectively precipitate, dehydrating the cold air mass, further directly and indirectly enhancing cooling of the coldest air masses. Using model simulations, ground based observations and satellite data from the A-Train, we investigated these processes over the last three years. There understanding and their proper representation into atmospheric models should help improving winter forecast at high and mid latitudes. Also, several climate models tend to overestimate Arctic warming during the coldest months. We believe that these missing processes in the models might explain a significant portion of their present bias.

Jim Coakley

(Oregon State University)
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CALIPSO-MODIS Observations of Increases in Aerosol Optical Depths in the Vicinity of Marine Stratocumulus

Aerosols not only affect droplet sizes and number concentrations in marine stratocumulus but in turn the moist cloud environment causes the aerosol particles to grow. In addition, the enhanced illumination of the cloud-free air in the vicinity of clouds leads to overestimates of aerosol optical depths and fine mode fractions retrieved from satellite imagery data. Large (~75 km) cloud-free ocean regions bounded on at least one end by a layer of marine stratocumulus were examined to deduce the effects of the clouds on the scattering properties of nearby aerosols. CALIPSO aerosol optical depth retrievals composited for more than a year and covering the global oceans, 60°S-60°N, reveal that the fractional increases in aerosol optical depths in going from a cloud-free 5-km region 35 km from a cloud boundary to one adjacent the clouds is 22% at 532 nm and 33% at 1064 nm for nighttime observations and 36% at 532 nm and 33% at 1064 nm for daytime observations. The reductions in the associated 532/1064 Ånsgtröm Exponents are 0.065 for the nighttime observations and 0.034 for the daytime observations. All of the changes are statistically significant at the 90% confidence level or greater and the daytime estimates are consistent with the nighttime estimates given the factor of 2-3 greater noise levels associated with the daytime retrievals. For comparison, the MODIS aerosol retrievals collocated with the daytime CALIPSO retrievals suggest that the fractional increases in aerosol optical depths in going from a cloud-free 10-km region 35 km from a cloud boundary to one adjacent the clouds are 9% at 550 nm and 15% at 1240 nm. The reduction in the associated 550/1240 Ånsgtröm Exponent is 0.099. These increases in aerosol scattering are somewhat smaller than the 40%-80% increases in aerosol scattering cross sections inferred from aircraft measurements of the rise in relative humidity in the vicinity of marine stratocumulus. These differences may be attributable to the ensemble of cloud thicknesses and opacities encountered in this study. The decrease in Ånsgtröm Exponent found in the MODIS observations, for example, is contrary to the increases in fine particle fractions reported for cloudy regions in a number of other studies.

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In Search of Aerosol-Cloud Interactions in Arctic Mixed-Phase Stratiform Clouds

Low-level mixed-phase clouds have significant impacts on the radiative budget of the Arctic atmosphere (Curry et al., 1996). Numerical studies of these clouds illustrate a strong sensitivity of mixed-phase cloud lifetime to simulated ice nucleation rate (de Boer, 2009; Harrington et al., 1999; Jiang et al., 2000). Recent studies have attempted to explain ice nucleation within these layers through several mechanisms (de Boer et al., 2009; Fridlind et al., 2007). In order to evaluate the validity of the proposed pathways, work is being completed to study cloud aerosol interactions leading to ice formation. In combination with surface instruments, CALIPSO and CloudSAT data are used to observe mixed-phase cloud edges over Ellesmere Island, Canada, and to evaluate whether aerosol layers at or above cloud altitude are required for cloud formation and maintenance. Background information on potential nucleation pathways in these clouds and results demonstrating effects of aerosol layer location and aerosol type will be shown. In addition, successful applications of satellite measurements in this effort, as well as challenges in their utilization will be discussed.

Yongxiang Hu

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A study of the link between sulfate particles and the presence of supercooled water

Cloud phase can be determined by CALIPSO measurements unambiguously (Hu 2007, Hu et al., 2009JTech). Using the CALIPSO cloud phase identification, a high probability of supercooled water cloud occurrence is detected at regions where sulfate particles are present (Hu et al., 2009JGR). The finding suggests that the sulphate particles deactivate ice nuclei and affect the cloud life cycle and cloud radiative properties. The frequent presence of supercooled water in Southern Oceans is primarily due to the high DMS concentration. The frequent presence of supercooled water in Northern Hemisphere is primarily due to the coal burning during winter in Europe, Northeastern America, and China.

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CALIPSO observations on dust emission and transport associated with Saharan cyclones: The February 2007 case

The dust activity over North Africa associated with the Saharan depression event in February 2007 is investigated by mean of spaceborne observations and ground based measurements. The main characteristics of the cyclone as well as the meteorological conditions during this event are described using the European Centre for Medium-range Weather Forecasts (ECMWF). The dust storm and cloud cover over North Africa is thoroughly described combining for the first time Spinning Enhanced Visible and Infra-Red Imager (SEVIRI) images for the spatio-temporal evolution and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) and CloudSat observations for the vertical distribution.

The Saharan depression formed over Algeria in the lee of the Atlas Mountain on the afternoon of February 20 in response to midlatitude trough intrusion. It migrated eastward with a speed of 11 ms^{-1} and reached Libya on February 22 before exiting the African continent toward the Mediterranean Sea on February 23. The horizontal scale of the cyclone at the surface varied between 800 km and 1000 km during its lifetime. On the vertical the cyclone extended over 8 km and a potential vorticity of 2 PVU was reported on its centre at 3km in altitude. The cyclone was characterised by a surface depth of 9 hPa, a warm front typified at the surface by an increase in surface temperature of 5°C, and a sharp cold front expressed by a drop in surface temperature of 8°C and an increase in 10m wind speed of 15 ms^{-1}.

The cyclone provided a dynamical forcing that led to strong near-surface winds and produced a major dust storm over North Africa. Heavy dust load was seen along the cold front and the southeastern edge of the cyclone accompanied by a deep cloud band along its northwestern edge. The dust was transported all around the cyclone leaving a clear eye on its centre. On the vertical, slanted dust layers were consistently observed during the event over North Africa. Furthermore, the dust was lofted to altitudes as high as 7 km, becoming subject to long range transport.

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Evidence of Giant CCN Impacts on Maritime Cloud Properties

Recently developed CloudSat precipitation products are shedding new light on the processes underlying the onset of precipitation in maritime clouds. This presentation leverages high quality estimates of rainfall incidence from CloudSat in conjunction with other A-Train observations to assess the potential impacts of sea salt aerosols on the properties of maritime clouds. The results suggest that the nucleation of large sea salt particles may provide a source of embryonic raindrops in maritime clouds enhancing their ability to produce rainfall, inhibiting their vertical development, and ultimately reducing their lifetime. This stands in direct contrast to the effects of sulfate aerosols that are generally found to suppress the formation of precipitation and enhance cloud vertical development. The net effect of aerosols on the onset of precipitation in any given region is, therefore, defined by the relative magnitudes of the competing effects of sulfate aerosols and sea salt particles, the strengths of which depend strongly on both cloud liquid water path and the thermodynamic properties of the local environment.

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Warm rain detection and impact by aerosols

Detection and quantification of warm rain has been a challenging tasks by means of conventional remote sensing techniques. Their merits and limitations are examined by using synergic measurements from CloudSat, MODIS and AMSR-E. The impact of aerosols on the frequency of warm rain and cloud thickness are also investigated. The findings are somewhat stunning to see.

Jens Redemann

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The combined use of MODIS, CALIPSO and OMI level 2 aerosol products for calculating direct aerosol radiative effects

We describe our strategy for combining MODIS spectral AOD (aerosol optical depth), CALIPSO aerosol extinction and backscatter, and OMI AAOD (absorption aerosol optical depth) measurements for the purpose of calculating direct aerosol radiative effects. In the first step, our strategy for combining the MODIS, OMI and CALIOP aerosol data seeks to find all the combinations of MODIS microphysical aerosol particle models that are reconcilable with the OMI and CALIOP observations within the uncertainties of their respective retrievals. In a second step, we use these models to forward calculate the aerosol radiative properties required for a full assessment of the direct aerosol radiative forcing, i.e., spectral extinction/AOD, single scattering albedo and asymmetry parameter. In the final step, we use a radiative transfer model to determine how the range of microphysical retrievals translates into a range of radiative forcing estimates. We show sensitivity studies and first results from actual collocated data collected in August 2007. As a prerequisite for our study we needed to assess the availability of collocated data and their level of consistency for comparable measurement quantities from the different A-Train sensors. For four months in 2007, comparisons of the standard MODIS-Aqua level-2 spectral AOD data to the AOD calculated from the initial and the latest release of the CALIOP level-2 aerosol extinction profile data set show how the use of appropriate quality flags in the CALIOP product and a restriction to scenes with cloud fractions below 1% (as defined in the MODIS aerosol retrievals) results in generally good correlation between the two data sets and rms differences in AOD of 0.1 or less. Analysis of a few days of the most recent version of CALIOP aerosol level-2 extinction profiles shows a higher density of data at latitudes between 40S and 40N.

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Characterization of Direct and Indirect Forcing of Mineral Dust Using CALIPSO Space Lidar Data in Conjunction with A-Train Observations and a Regional Transport Model WRF-DuMo

A better understanding of the properties and spatiotemporal distribution of atmospheric dust aerosol is needed to improve assessments of aerosol direct and indirect (via clouds) radiative forcing on climate and the impact of aerosol on the hydrological cycle. We use CALIPSO data in conjunction with A-Train satellite multi-sensor observations (CloudSat, Ozone Monitoring Instrument, OMI, and Moderate-Resolution Imaging Spectroradiometer, MODIS), ground-based lidar and sunphotomer data, and a WRF-DuMo regional dust transport model to investigate the dynamics of dust plumes originating in East Asia and Northern Africa on a case-by-case basis. Aerosol optical depth and particle depolarization ratio were retrieved from CALIPSO observations and analyzed against independent observations and modeling results with the focus on regional specifics of dust properties.

Based on CALIPSO and other observations, we investigated the importance of the layered vertical distribution of dust and clouds on the radiative energy balance. The effect of the aging of dust and its mixing with other aerosols was also examined. Observations along with modeling results were used to constrain the range of regional radiative forcing and heating/cooling rates in representative dust and dust-pollution laden conditions. We also examined changes in cloud properties, including effective radius and LWP, in the presence of dust. Implications to dust-related changes in the amount and distribution of precipitation will be addressed. The need for satellite remote sensing to aid in the improved assessment of diverse dust impacts will be highlighted.

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Using Airborne High Spectral Resolution Lidar Data to Evaluate Combined CALIPSO-MODIS Retrievals of Aerosol Extinction Profiles

Aerosol extinction profiles derived using CALIOP aerosol backscatter profiles constrained by Aqua MODIS Aerosol Optical Thickness (AOT) measurements are evaluated using aerosol extinction profiles measured simultaneously by the NASA Langley Research Center airborne High Spectral Resolution Lidar (HSRL). These combined CALIOP+MODIS retrievals were limited to cases where the MODIS AOT was greater than 0.2 (over land) and 0.15 (over water) in order to limit the uncertainties in the retrieved products associated with the uncertainties in the MODIS AOT. The combined CALIPSO+MODIS aerosol extinction retrievals were performed for 58 profiles (45 over land and 13 over water) on 25 days between June 2006 and July 2008 for which there were coincident airborne HSRL data. Aerosol extinction values derived from the combined CALIPSO+MODIS retrievals agreed with the airborne HSRL extinction measurements to within ±0.024 km 1 ± 20% for at least two-thirds of land points and within ±0.03 km 1 ± 20% for at least two-thirds of ocean points. These results and comparisons with the CALIPSO provisional level two products indicates that constraining the CALIOP aerosol extinction retrievals with the MODIS AOT can significantly improve the accuracy of the CALIOP extinction profiles.

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Uncertainties of cirrus OD retrievals from active and passive A-Train measurements

We compare retrievals of cirrus cloud optical depth from active (CALIOP) and passive (MODIS) measurements. Systematic uncertainties for both CALIOP and MODIS optical depths are found and investigated using TOA radiative closure

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Comparison of SEVIRI Cloud Vertical distribution with new space Lidar observation

Cloud fraction value, a sensitive parameter for climate studies which is directly derived from satellite observation, is fairly variable from one instrument to the other. Its determination is linked to the detection performance of each instrument at a given spatial scale as well as specific analysis methods employed as a function of cloud and surface type as well as day/night operation. To better understand bias and errors in retrieving cloud fraction, we have made a first comparative analysis of cloud detection between retrievals from passive radiometry (SEVIRI on MSG using the Satellite Application Facility For Now Casting classification) and from active sensors (GLAS on Icesat and CALIOP on CALIPSO) in terms of total cloud cover over two weeks in October 2003 and one month in October 2006 in the same area (Atlantic ocean, Europe and Africa). For SEVIRI, the SAFNWC classification has been used and for GLAS and CALIOP, the level2a 7km and 5km cloud layer products have bee used respectively. We also refer to ISCCP analysis over the same periods and area, and we used an ISCCP-like cloud classification separating for ocean/land and day/night observations. Two types of major differences were observed. We first show that adjusting the sensitivity for high clouds for the active sensor observations allows to optimize the agreement between analyses, in terms of total cloud fraction, excepted over ocean during day. Eliminating clouds with optical thickness smaller than 0.2 in lidar measurements thus gives cloud fractions (CFs) in agreement between the lidar and SEVIRI classifications to better than 0.02 over ocean at night and land during day and better than 0.04 over land at night. It however stays larger than 0.05 over ocean during daytime. ISCCP gives lower values than SEVIRI and GLAS or CALIOP over ocean. Surprisingly, it is the opposite during day over land. Looking in more details to the three agreeing cases, it was evidenced that cloud types only agree to within 90% both ways, but compensations occur. More important is the discrepancy observed in the fourth case, which was found to be due to low clouds over ocean missed by the lidar sensor during daytime near the Inter Tropical Convergence Zone (ITCZ) where semi-transparent high clouds are also detected. In this region, a larger frequency of low cloud layer can be found at 80km compared to 5km in the CALIOP cloud layer product. Going further in the analysis, a pixel to pixel comparison between the three active and passive instruments has been performed which allowed to better identify differences and compensations. Bias are estimated and recommendations are made for further analysis.

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Long-term aerosol and cloud database from correlative CALIPSO and EARLINET observations

The European Aerosol Research Lidar Network EARLINET performs correlative observations during CALIPSO overpasses based on a sophisticated measurement strategy since June 2006 (see Pappalardo et al., this workshop). Currently, with support from the European Space Agency, we establish a long-term aerosol and cloud database from EARLINET-CALIPSO observations. This database shall provide a tool for homogenizing long-term space-borne observations conducted with different lidar instruments, operating at different wavelengths, on various platforms. The database is also used to study the representativeness of the limited number of satellite lidar cross sections along an orbit against long-term lidar network observations on a continental scale.

The ideas and contents of the database are illustrated based on the example of a major Saharan dust outbreak over Europe in May 2008 during which about 80 EARLINET measurements were performed in correlation with several CALIPSO overpasses. Based on this extensive dataset, aspects of cloud/aerosol discrimination and aerosol typing are discussed and a statistical analysis of dust properties in terms of intensive optical properties (lidar ratios, Ångström exponents, color ratios) derived from EARLINET measurements is presented. The event is also used to demonstrate the methodology for the investigation of spatial and temporal representativeness of measurements with polar-orbiting satellites.

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Studies of polar stratospheric clouds, tropical stratospheric clouds and tropospheric aerosols using CALIPSO data; modeling and laboratory support

We are currently working on three projects using Calipso data, and one project to help with interpretation of the Calipso data. Here I will summarize our laboratory work on phase functions and optical constants for aerosols and clouds. I will also summarize our work on Asian dust. We have just started our modeling of polar stratospheric clouds, while our work on cirrus will be discussed elsewhere at this meeting.

We have now completed the construction of an instrument to determine the phase functions of aerosols and of cloud particles. The instrument consists of several parts. First, there is a particle generation section. For ice crystals this is a long cooled tube into which either humidified air, or atomized droplets are injected. For aerosols a variety of generation techniques are used depending on the aerosol type under consideration. There is then a particle sizing instrument. For aerosols this is a DMA, which allows for size selecting the particles. For cloud particle we are using a cloudscope, which is an optical imaging device that allows the ice crystals to be seen. Once characterized, the particles move into a polar nephelometer where the phase functions are measured at two wavelengths that are close to those used by CALIPSO. To date we have obtained data from both ice crystals and aerosols. We have two goals at the moment. The first is to determine if there is wavelength dependence to the backscatter from ice crystals. This is important because of the way CALIPSO calibrates the infrared channel. Secondly, we will determine if the refractive index determined from cavity ring down extinction measurements of absorbing aerosols can be either improved or better determined by also fitting to the phase function.

We are continuing to work on a paper that uses CALIPSO data to constrain the altitude of dust as it travels over the Pacific Ocean from Asia as modeled with the NCAR CAM model and CARMA. CAM is the NCAR climate model, which we run in an off-line mode so that we can simulate actual events using NCEP data to drive the winds. We have added a sectional microphysics model, CARMA, to CAM which allows us to perform detailed simulations of the particle size distributions of aerosols as they move from their source to their sink. We have been able to constrain the wavelength dependence of the optical depth, and of the single scattering albedo from AERONET data, and to some extent from satellite data. However, CALIPSO provides the first insight into the vertical distribution of the dust. Figure 1 top, for a few days in May 2007, shows that the model does well over China, capturing dust up to about 7 km. The model is low near the ground because it does not include pollution aerosols in addition to dust. In Fig. 1 bottom, CALIPSO suggests that the dust is elevated above the marine boundary layer in a distinct layer from 2-4 km. The model, however, shows the dust extending down to 1 km. The model lacks sea salt so the marine boundary layer aerosols are not shown. Note in both cases that the model is numerically in good agreement with the CALIPSO extinction values. This work is being done by graduate student Lin Su. Her paper in preparation is L. Su and O. B. Toon, Numerical Simulations of Asian Dust Storms Using a Coupled Climate/Microphysical Model, J. Geophys. Res. In prep. (2009).

Several issues remain to be better understood in this work. These include how to compare the model of a dust event, with data from the small number of overpasses made through it by CALIPSO. A second issue is to better understand the CALIPSO extinction to backscatter ratio. We are trying to determine if this can be measured directly by comparing CALIPSO backscatter and AERONET extinction, and whether the ratios can be related to particle properties.

Eric Jensen

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Using heating rates derived from CALIPSO measurements to diagnose transport pathways through the tropical tropopause layer

It has been recognized that trace gas concentrations at the tropical tropopause serve as a chemical boundary condition for the stratosphere. As a result, there has been considerable recent interest in the transport pathways through the Tropical Tropopause Layer (TTL), typically defined as the layer between the main convective outflow layer (about 13 km) and the lowermost stratosphere. CALIPSO provides unprecedented information about the properties, regional distribution, and height distribution of clouds in the TTL. This information has recently been used in radiative transfer calculations to calculate the spatial distributions of radiative heating in the TTL. We use these radiative heating rates, along with diabatic trajectory calculations to determine the pathways of air parcels that ascend through the TTL and ultimately enter the stratosphere. We specifically address the following two science questions: (1) What fraction of air parcels detrained from the main convective outflow level actually make it to the tropical tropopause? (2) What convective outflow levels (ranging from the main outflow level near 13 km to the rare extreme convective systems that extend to near the tropopause (16-17 km)) dominate the flux of air into the stratosphere?

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Observations of small-scale variability of cloud water content, temperature, and water vapor

The spatially and temporally collocated CloudSat and Atmospheric Infrared Sounder (AIRS) instruments observe vertically resolved profiles of key thermodynamic properties that include cloud water content (CWC), temperature and water vapor. Together, both instruments are used to quantify small-scale distributions (smaller than a GCM grid box) of these key thermodynamic variables. In this paper, the statistical moments of CWC (mean, variance, skewness, and kurtosis) are shown to have substantial spatial, temporal and cloud type variations. Similarly, the statistical moments of temperature and water vapor are related to the moments of CWC, which yield some additional insights on cloud processes. The importance of making high spatial and temporal resolution soundings of temperature, water vapor, and cloud properties in clear and cloudy conditions to evaluate and improve subgrid-scale cloud parameterizations is highlighted.

Terry Kubar

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Towards an Improved Understanding of the Boundary Layer and Vertical Cloud Structure in the Transition from the Tropical to Subtropical Pacific Cross Section

Using a combination of active (Calipso, CloudSat) and passive (MODIS) satellite sensors along with ECMWF analysis temperature and humidity profiles, cloud profiles are aggregated to elucidate the low cloud and boundary layer structure across a Pacific cross section which encompasses deep convection, trade cumuli, and stratocumuli clouds. While low clouds are frequently present across much of the cross-section, their abundance in isolation from higher clouds is strongly connected to a stability parameter referred to as ΔMSE, the moist static energy difference at either 700mb or the inversion (where it is indicated by ECMWF) and the surface. While r2 is very high between ΔMSE and low cloud frequency during JJA (0.93 for MODIS and 0.88 for Calipso) , the slope of low cloud frequency and ΔMSE is reduced a bit during SON, and is greatly reduced during DJF, when the subtropical high is weaker and mid and upper level cloudiness are more prevalent over the subtropics.

When the subtropical regime is well defined during JJA and SON (e.g., a very dry mid-troposphere), for TSFC < 295 K, all boundary layer parameters grow sharply with temperature, including low cloud tops, inversion heights, the height of the sharpest relative humidity gradient, and the level where the vertical gradient of MSE is zero. An apparent transition region occurs between 295 K <

TSFC < 298 K, and middle and deep convection are observed for TSFC at and above 298 K.

Over the subtropics, low cloud top height as sensed by Calipso closely follows the inversion height as indicated by ECMWF. As the inversion strength increases, both low clouds and inversions become shallower. Calipso and MODIS uniform single-layer low cloud frequency generally agree quite well, but CloudSat only senses 35% of such clouds during JJA and 42% during SON, as it misses many of the low stratiform clouds below one km that are widespread in the subtropics and thus radiatively important.

Michael Pitts

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Studies of Polar Stratospheric Cloud Coverage and Composition

Although not a primary goal of CALIPSO, the CALIOP lidar system is providing unprecedented new information on the characteristics of polar stratospheric clouds (PSCs). In this paper, we describe our second-generation PSC detection algorithm that uses both the CALIOP 532-nm scattering ratio (ratio of total to molecular backscatter coefficients) and 532-nm perpendicular backscatter coefficient in a successive horizontal averaging scheme. Including the perpendicular backscatter data enhances the detection of tenuous PSC mixtures containing low number densities of non-spherical particles (presumably nitric acid trihydrate, or NAT) and produces about a 15% increase in PSC areal coverage compared to our original algorithm. Based on theoretical optical calculations of backscatter and depolarization, we have defined four CALIOP-based PSC composition classes: supercooled ternary solution (STS), ice, Mix1, and Mix2, with the latter two denoting mixtures of STS with NAT particles present in lower or higher number densities/volumes, respectively. We present example results for PSC coverage and composition for the three Antarctic and Arctic seasons probed by CALIOP to date, illustrating interannual variability in PSC areal coverage and the well-known contrast between the Antarctic and Arctic. We also show distinctive seasonal and altitudinal variations in Antarctic PSC composition, which can be related to changes in HNO3 and H2O observed by the Microwave Limb Sounder on the Aura satellite. Finally, we compare estimates of PSC area and volume based on CALIOP data with thermodynamic surrogates commonly used to parameterize PSCs in chemical transport models.