Climate Modeling Best Estimate (CMBE) – A New ARM Data Product for Climate Modeling Studies

Shaocheng Xie, Renata McCoy, and Stephen Klein/ LLNL

Science Question

How to transform detailed ARM observations into a form that can be easily used by the climate community for model evaluation and development?

Approach

Develop a best-estimate integrated data product which consists of cloud, radiation, and other important geophysical parameters that are well observed by ARM over many years on a common grid with a temporal resolution comparable to that used in climate model output.

Integrated ARM Data

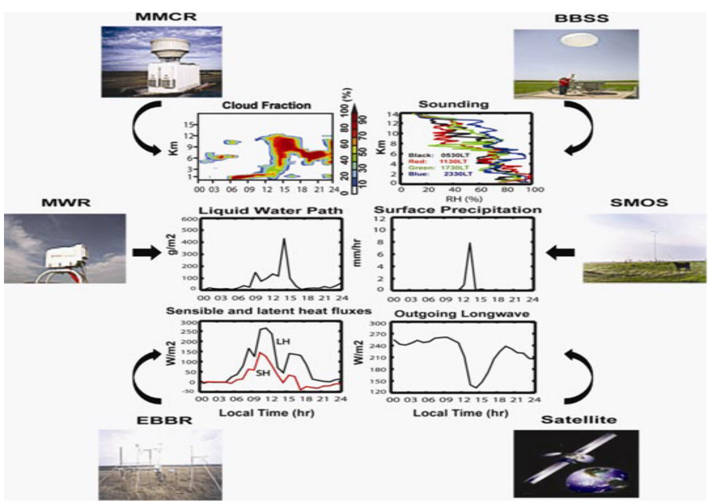


Fig. 1. An example shows the use of data from numerous instruments at the ARM SGP site to illustrate the evolution of cloud and radiative properties associated with a frontal cloud system observed at SGP.

Summer Diurnal Cycle of Cloud Fraction at SGP

Climate Model vs. ARM data

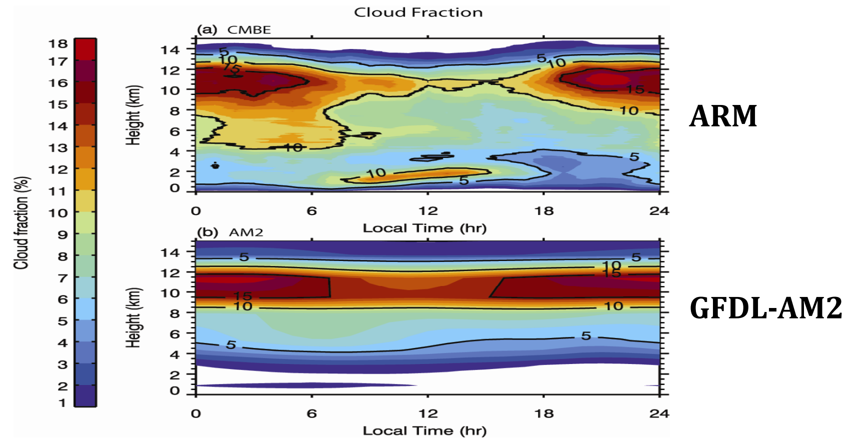


Fig. 2. An example shows the use of long-term CMBE data to evaluate the NOAA GFDL climate-model simulated diurnal cycle of cloud fraction in the summer months.

Key Accomplishment

A long-term integrated best-estimate data product has been developed over the five ARM primary research sites, which greatly facilitates the use of ARM data in the climate community (e.g., NCAR, GFDL, ECMWF) for model evaluation and development.

Publication

Xie, McCoy, Klein, et al. 2010: ARM Climate Modeling Best Estimate Data – A New Data Product for Climate Studies. *Bull. Amer. Meteor. Soc.*, **91**, 13–20.

Convective Cloud Life Cycle Observations during MC3E

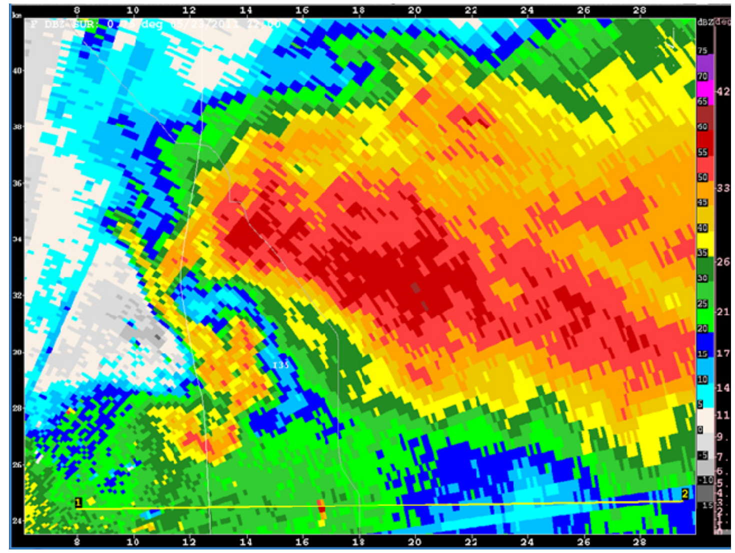
Michael P. Jensen/ Brookhaven National Laboratory

Science Question

How can we best represent the life cycle of convective cloud systems in large-scale atmospheric models?

Approach

- MC3E, a joint DOE and NASA field campaign, took place from 22 April – 6 June 2011 at the ARM Southern Great Plains site
- Coordinated surface (particularly radar and radiosonde), aircraft (ER-2 and UND Citation) and satellite observations
- First detailed observations from many of the new ARRA instruments



Hook echo (tornado signature) observed by the new ARM C-band radar on 23 May 2011.

Key Accomplishment

The collection of an important multi-platform, multi-agency data set over a variety of conditions that will be useful for improving the representation of convective clouds in large-scale models.

Publication

Jensen et al., 2010: Midlatitude Continental Convective Cloud Experiment (MC3E) Science and Implementation Plan. DOE/SC-ARM/10-004.

A 10-Year Climatology of Cloud Cover and Vertical Distribution Derived From Both Surface and GOES Observations Over the DOE ARM SGP

Xiquan Dong, University of North Dakota (dong@aero.und.edu)

Science Question

Are surface and satellite observations comparable?

Approach

Analysis of one decade of radar-lidar and GOES observations at the ARM SGP site reveals that there is excellent agreement in the long-term mean cloud fractions (CF) derived from the surface and GOES data, and the CF is independent of temporal resolution and spatial scales for grid boxes of size 0.5° to 2.5° as shown in Fig. 1. When computed over a 0.5-hr (4-hr) period, cloud frequency of occurrence (FREQ) and amount when present (AWP) derived from the point surface data agree very well with the same quantities determined from GOES for a 0.5° (2.5°) region centered on the ARM SGP site. The values of FREQ (AWP) derived from the radar-lidar observations at a given altitude increase (decrease) as the averaging period increases from 5 min to 6 hours. Similarly, CF at a given altitude increases as the vertical resolution increases from 90 to 1000 m (Fig. 2). The profiles of CF have distinct bimodal vertical distributions with a lower peak between 1 and 2 km and a higher one between 8 and 11 km. The 10-year mean total CF, 46.9%, varies seasonally from a summer minimum of 39.8% to a maximum of 54.6% during the winter.

Xi, B., **X. Dong**, P.Minnis, M. M. Khaiyer, 2010: A 10-year climatology of cloud cover and vertical distribution derived from both surface and GOES observations over the DOE ARM SGP Site. *J. Geophys. Res.* 115, D12124, doi:10.1029/2009JD012800.

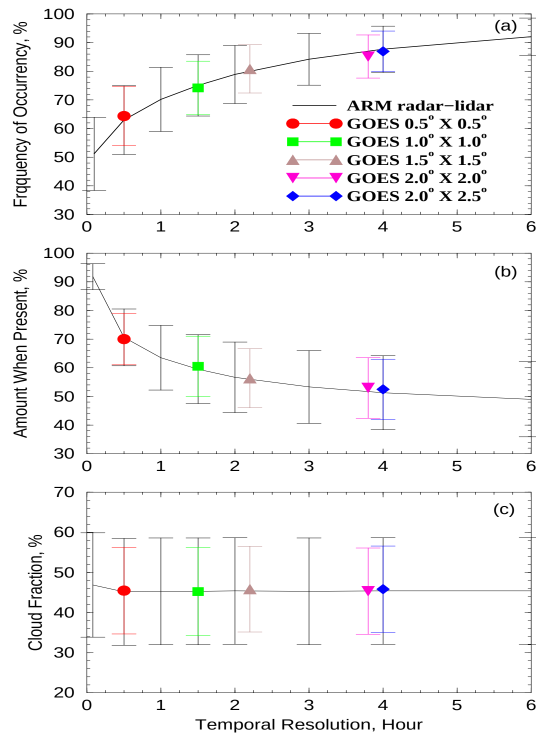


Fig. 1. Dependence of (a) cloud frequency of occurrence (FREQ), (b) amount when present (AWP), and (c) cloud fraction (CF) on temporal resolutions of ARM surface radar/lidar observations during the period 1997–2006, and on grid boxes of satellite observations during the period from May 1998 to December 2006 at the ARM SGP site.

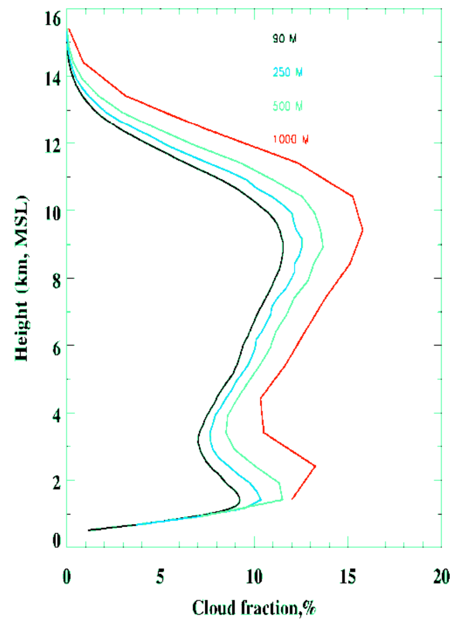


Fig. 2. Mean vertical distributions of CF derived from the ARM radar-lidar observations with a 5-min temporal resolution and vertical resolutions of 90 m, 250 m, 500 m, and 1000 m at the ARM SGP site, 1997–2006.

Key Accomplishment

Cloud fractions-derived surface and satellite observations are comparable, while their FREQ and AWP depend on temporal and spatial resolutions.

The Variability of Tropical Ice Cloud Properties Across "Regimes"

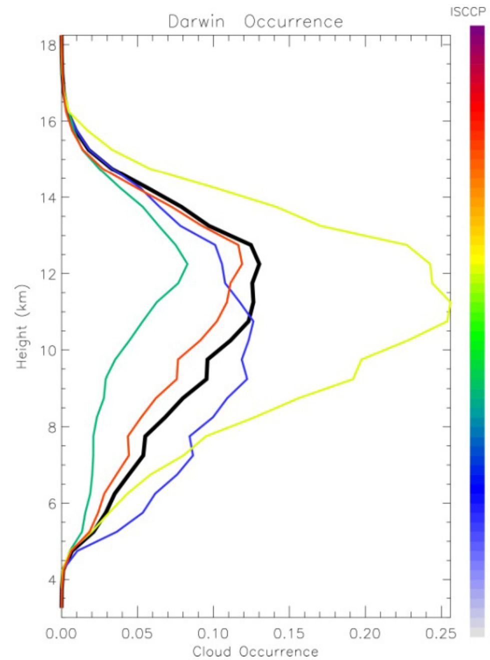
Alain Protat / CAWCR, Melbourne

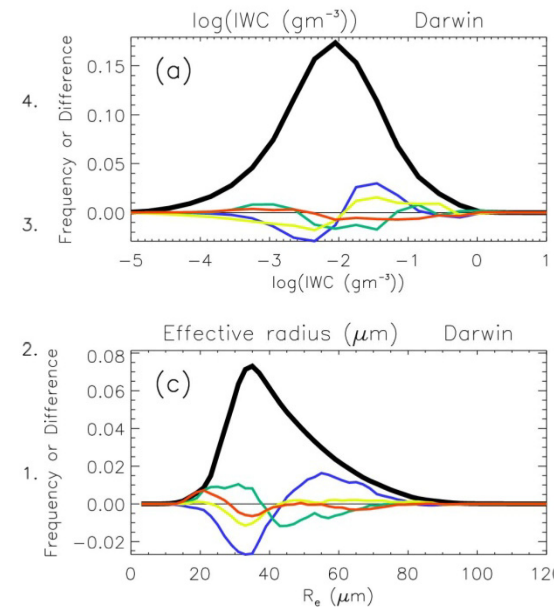
Science Question

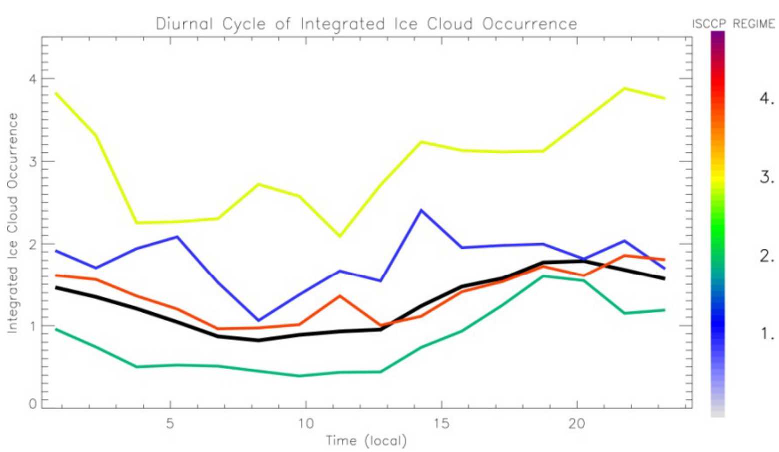
How do tropical ice cloud properties vary as a function of large-scale regimes ? Can current cloud parameterizations in models reproduce this observed variability ?

Approach

Characterize the tropical ice cloud properties (occurrence, fraction, microphysics, diurnal cycle) using ARM Darwin radar-lidar observations. Characterize large-scale regimes in different ways (local regimes using radiosondes, ISCCP cloud regimes, and MJO phases). Bin the tropical ice cloud properties by regimes and characterize the obtained variability.







Key Accomplishment

The variability of tropical ice cloud properties as a function of "regimes" is generally large and needs to be well reproduced by current model parameterizations.

Publication

Protat, A., et al., 2011: The variability of tropical ice cloud properties as a function of the large-scale context from ground-based radar-lidar observations over Darwin, Australia. Atmospheric Chemistry and Physics, Accepted, August 2011.

The Evaluation of A-Train Cloud Ice Microphysical Products

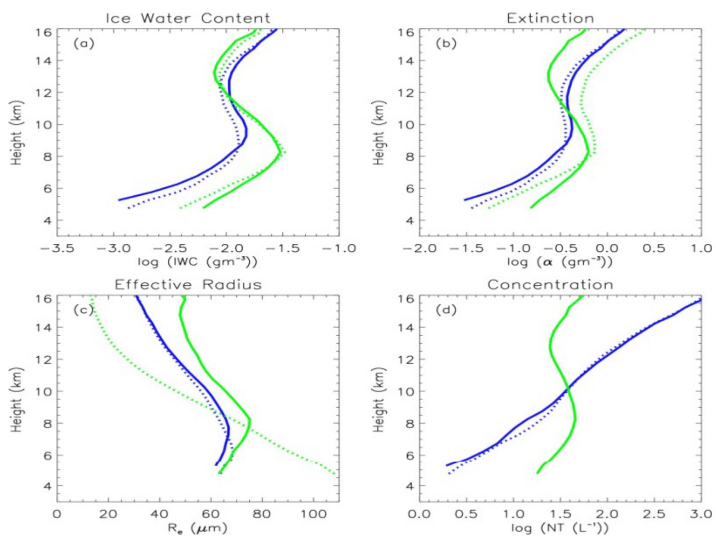
Alain Protat / CAWCR, Melbourne

Science Question

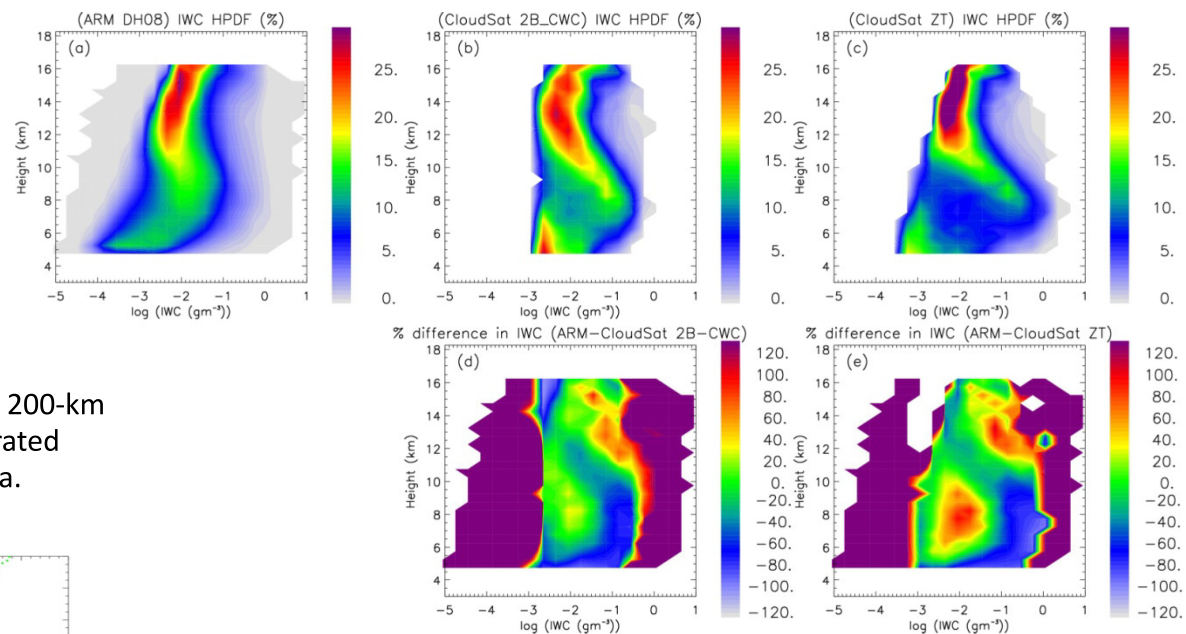
Can we use current ice cloud microphysical products from the CloudSat-CALIPSO for climatology/climate - NWP model evaluation?

Approach

Compare extractions of satellite products within a 200-km range from the Darwin ARCS site to more elaborated radar-lidar retrievals from the ground-based data.



Comparison of joint histograms of IWC, extinction, effective radius and total concentration derived from ARM data and CloudSat-only products.



Comparison of joint histograms of ice water content derived from ARM data and CloudSat-only products.

Key Accomplishment

Current CloudSat and CALIPSO products include biases that need to be considered for climatologies and the evaluation of the representation of clouds in models.

Publication

Protat, A., et al., 2010: The evaluation of CloudSat-derived ice microphysical products using ground-based cloud radar and lidar observations. J. Atmos. Oceanic Tech., 27, 793–810.

Analytical Relationship between Cloud Radiative Forcing, Cloud Fraction, and Cloud Albedo

PI: Yangang Liu (Brookhaven National Laboratory)

Science Question

- The relationship between cloud radiative forcing, clouc fraction, and cloud albedo is essential to addressing cloud-radiation-climate interactions in both models and observations, but is poorly quantified.
- There is a lack of a much-needed surface-based approach for estimating cloud albedo.
- Multiscale variations are not well understood.

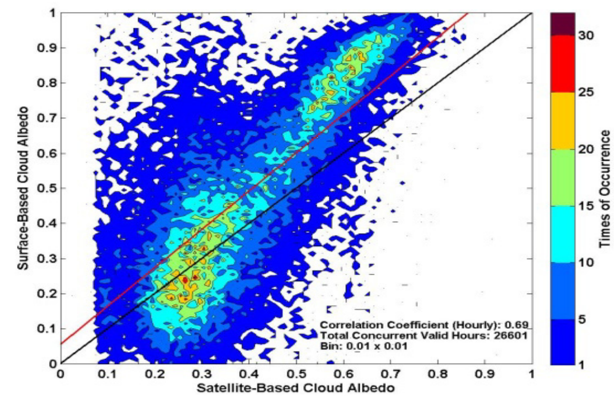


Fig 1. Comparison of the surface-based cloud albedo with those derived from the GOES satellite. The red and black lines represent the linear fit to all the data points and perfect match, respectively.

Approaches

- Seek an analytical expression for quantifying the relation between cloud radiative forcing, cloud fraction, and cloud albedo.
- Develop an approach for estimating cloud albedo from surface-based radiation measurements.
- Apply the newly derived expressions/methods to examine various decade-long data sets collected at the SGP site.
- Data examined include surface radiation measurements, ARSCL, and GOES products

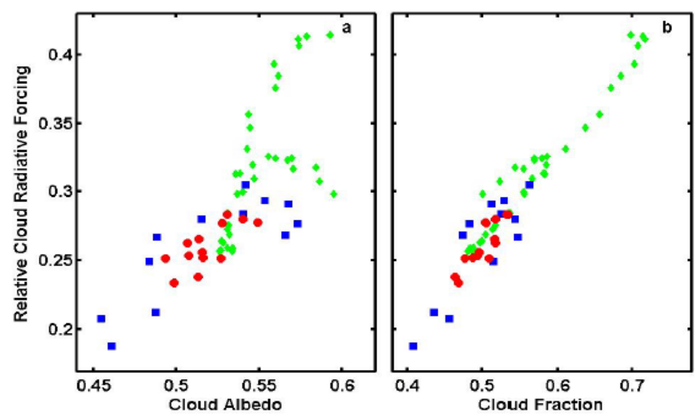


Fig 2. Correlation between the relative surface shortwave cloud radiative forcing and cloud albedo (a), and cloud fraction (b). The colors of red, green, and blue denote hourly, monthly, and annual averages, respectively.

Key Accomplishment

A new analytical relationship between relative cloud radiative forcing, cloud fraction, and cloud albedo is derived; a new approach for estimating cloud albedo from surface radiation measurements is established; and decade-long data sets are examined. The results offer important implications for model evaluation, and future observational investigation of several key issues such as cloud absorption, diffuse radiation, and cloud albedo-fraction relationship.

Publication

Liu, Y., W. Wu, M. P. Jensen, and T. Toto, 2011: Relationship between cloud radiative forcing, cloud fraction and cloud albedo, and new surface-based approach for determining cloud albedo. Atmos. Chem. Phys., 11, 7155–7170. doi:10.5194/acp-11-7155-2011

Impact of 2D Radiative Interactions on Solar Heating

Tamás Várnai / University of Maryland, Baltimore County

Science Question

How do radiative interactions of nearby atmospheric columns impact solar heating?

Approach

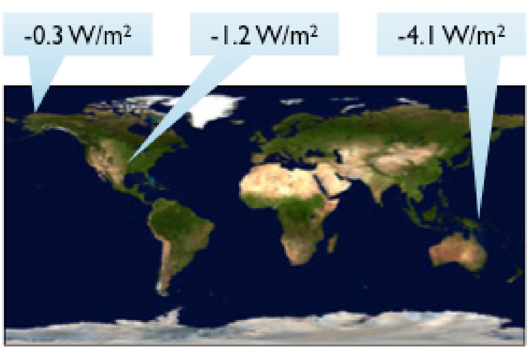
Created multi-year data sets of 2D cloud structures using ARM cloud products at the SGP, NSA, and TWP sites.

Compared the results of two sets of solar heating calculations for the observed cloud fields:

(i) Considering 2D interactions among nearby atmospheric columns

(ii) Treating each atmospheric column separately, as the 1D radiation modules in current cloud resolving simulations do.

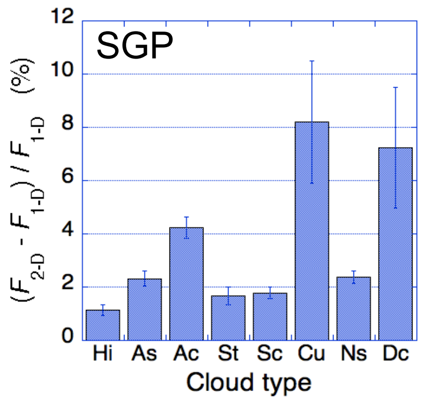
Multi-year full-day (24-hr) average difference between 2D and 1D calculations of reflected sunlight

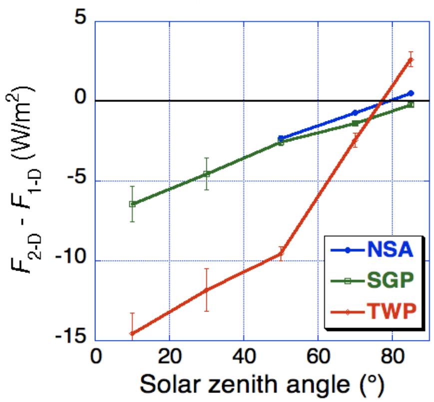


2D effects tend to be strongest for convective clouds high sun

Cloud absorption

Scene reflection





Key Accomplishment

2D radiative processes were shown to increase average solar heating by several W/m² over the 1D radiation calculations used in dynamical models.

Publication

Várnai, T. (2010): Multiyear statistics of 2-D shortwave radiative effects at three ARM sites. J. Atmos. Sci., **67**, 3757-3762.

Coupling Boundary-Layer Turbulence to Shallow Cumuli

Larry Berg, William Gustafson Jr., Evgueni Kassianov, and Charles Long

Science Question

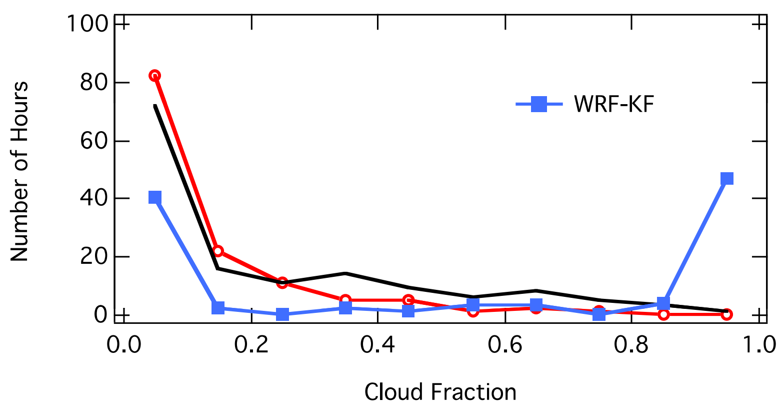
Shallow cumuli are ubiquitous over many parts of the globe, and have a large influence on the Earth's radiative energy balance. Current parameterizations for shallow cumuli do not accurately predict either the frequency or the radiative forcing associated with shallow clouds. *Can they be improved?*

Approach

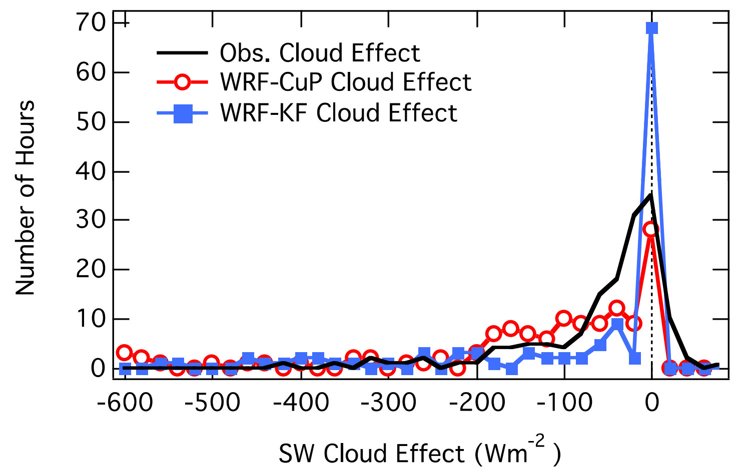
The Weather Research and Forecasting (WRF) model has been modified to improve the treatment of shallow cumuli:

•The convective trigger in the standard Kain-Fritsch convection scheme has been replaced. The new trigger (the Cumulus Potential scheme; CuP) uses the distribution of temperature and humidity in the model grid box to initiate convection.

•Two new data sets were developed for verification: (1) a climatology of cloud statistics and (2) a climatology of the cloud effect on downwelling shortwave radiation at the surface.



Histogram of cloud fraction observed at the ARM SGP Central Facility (black), predicted by the modified version of WRF (red), and by the standard version of WRF (blue) for days with shallow cumuli.



Histogram of shortwave cloud effect observed at the ARM SGP Central Facility (black), and modeled using the modified version of WRF (red), and the standard version of WRF (black) for days with shallow cumuli.

Key Accomplishment

Prediction of the surface shortwave radiative forcing has been significantly improved.

Publications

Berg, L. K., E. I. Kassiaonv, C. N. Long, and D. L. Mills, 2010: Surface radiative forcing by shallow cumuli at the ACRF SGP. *J. Geophys. Res.*, **116**, doi:10.1029/ 2010JD014593.

Berg, L. K., and E. I. Kassianov, 2008: Temporal variability of fair-weather cumulus statistics at the ARM SGP site. *J. Climate*, **21**, 3344–3358.

Berg, L. K., and R. B. Stull, 2005: A simple parameterization coupling the convective daytime boundary layer and fair-weather cumuli. *J. Atmos. Sci.*, **62**, 1976–1988.

ASR Atmospheric System Research

Seeking an Integrative Approach for Quantifying Different Entrainment-Mixing Mechanisms

PI: Yangang Liu (Brookhaven National Laboratory)

FASTER FAst-physics System TEstbed and Research

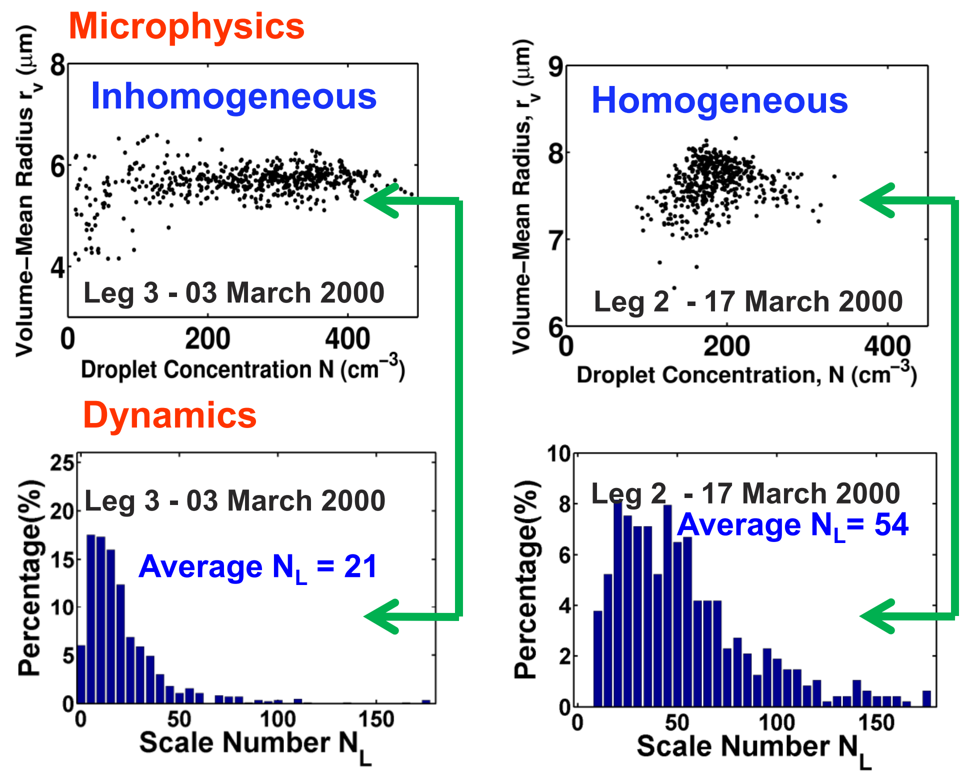
Science Question

Turbulent entrainment-mixing processes greatly affect cloud microphysics and cloud-climate interactions; however, they are poorly understood and represented in climate models, esp. the thermodynamic-dynamic-microphysical connection.

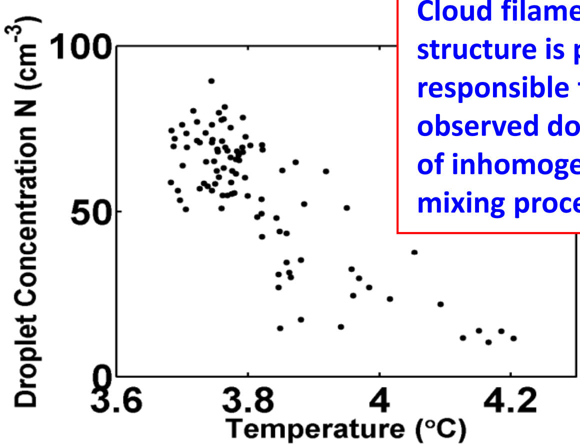
Approach

Examine different entrainment-mixing mechanisms based on microphysical, dynamical and thermodynamic relationships.

A new transition scale number (N_L) is proposed to study the transition from homogeneous (large N_L) to inhomogeneous mixing process (small N_L) and distinguish the two processes.



Thermodynamics



Cloud filament structure is partially responsible for the observed dominance of inhomogeneous mixing process.

Key Accomplishment

A new scale number is defined; combined analysis of microphysics, dynamics and thermodynamics shows dominance of inhomogeneous entrainment-mixing process in the stratocumuli during March 2000 Cloud IOP at SGP. Results shed new light on parameterization/evaluation of entrainment-mixing effect on essential microphysical relationships.

Publication

Lu, C., Y. Liu, S. Niu, 2011: Examination of Turbulent Entrainment-Mixing Mechanisms Using a Combined Approach. JGR, (tentatively accepted).

Multiple Scale Simulations of Boundary Layer Clouds

P. Zhu/FIU • B. Albrecht/RSMAS • V. Ghate/Rutgers U.

Science Question

How can advanced ARM low-altitude cloud observations, such as Doppler radar measurements, be effectively combined with high resolution simulations to understand cloud processes and improve cloud parameterizations?

Approach

This study introduces a flexible multiple nested modeling framework developed from WRF for boundary layer cloud research. It features a nested large-eddy simulation (LES) in a hindcasting mode that allows a direct comparison with ARM high resolution remote sensing measurements.

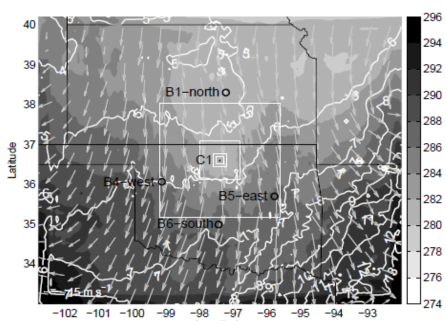


Fig. 1. Multiple nested WRF domains.

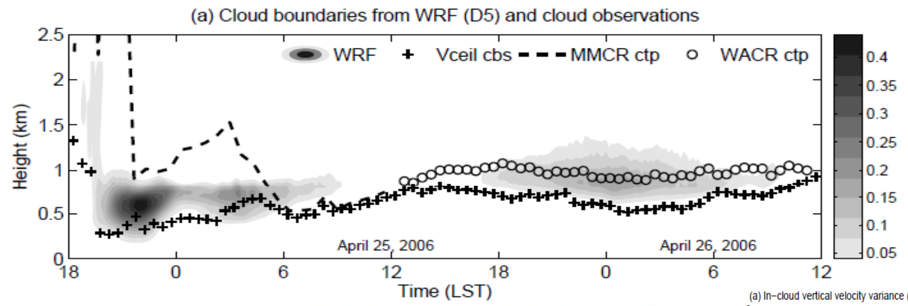


Fig. 2. Observed stratocumulus clouds at SGP compared with those from WRF-LES.

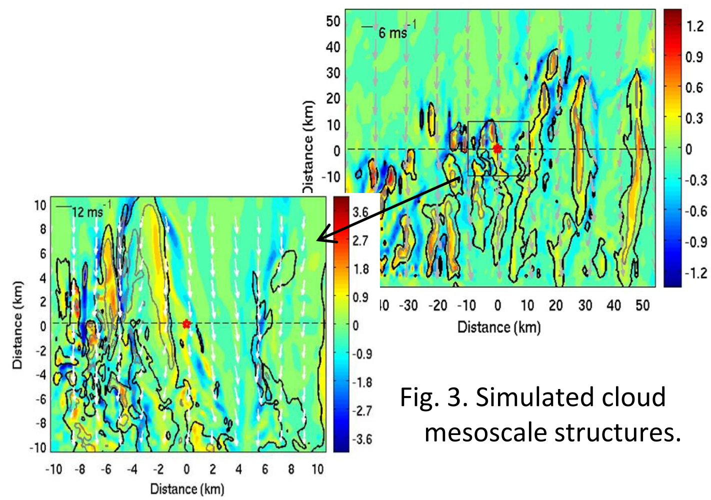


Fig. 3. Simulated cloud mesoscale structures.

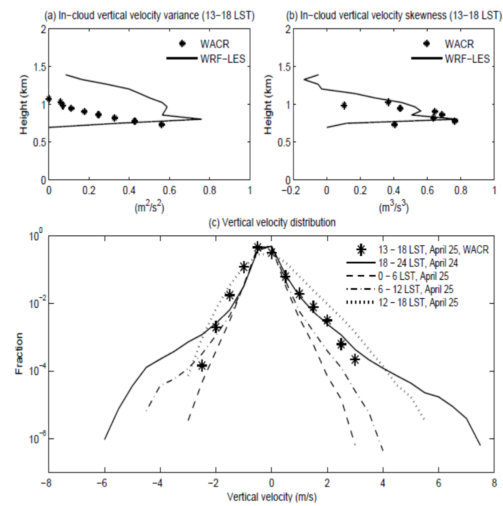


Fig. 4. Observed and simulated vertical velocity statistics.

Key Accomplishment

The newly developed flexible framework allows an extensive use of observations collected at the various DOE climate observational sites to address issues regarding the treatment of boundary-layer clouds in GCMs, particularly for clouds in heterogeneous conditions and strongly modulated by mesoscale organizations.

Publication

Zhu et al., 2010: Multiple scale simulations of stratocumulus clouds. *J. Geophys. Res.*, **115**, D23201, doi:10.1029/2010JD14400

DOE Climate Facility Data Used to Study Arctic Clouds and Radiation Budget

Xiquan Dong, University of North Dakota (dong@aero.und.edu)

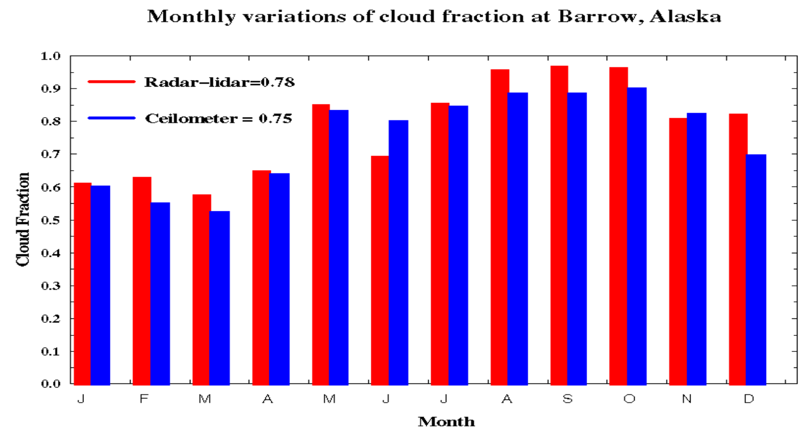
Science Question

Are SW and LW CRFs balanced at ARM NSA?

Approach

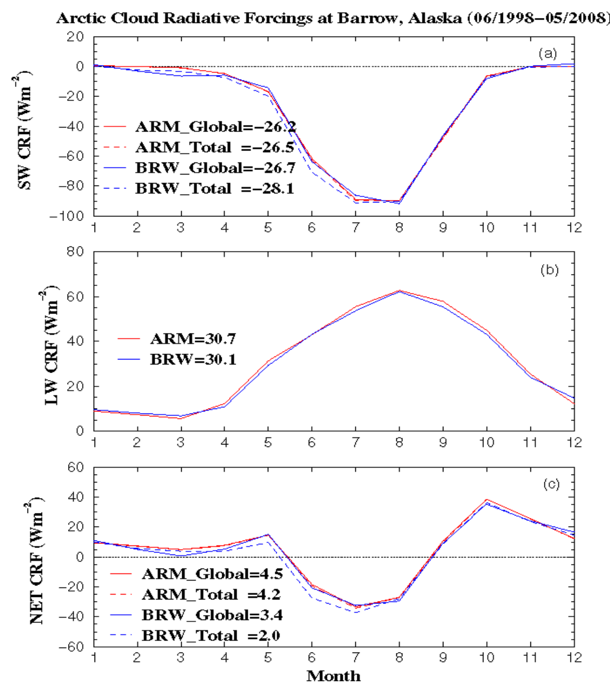
A 10-year record of Arctic cloud fraction and radiative forcing has been generated using data collected at the ARM North Slope of Alaska (NSA) site and the nearby NOAA Barrow Observatory (BRW) from June 1998 to May 2008. Long-term analysis results indicate that the annual cloud coverage is about 0.778 with a minimum of 0.574 in March and a maximum of 0.965 in September. Compared with other studies, it was also found that infrared heating by clouds does not change over the Arctic regions significantly, but the total cloud induced radiative heating changes from negative to positive from Alaska to the Beaufort Sea. This result indicates that Barrow is near the critical latitude for which cloud-induced infrared radiative heating is in approximate balance by those changes in cloud-induced solar radiation. These results should be valuable for enabling climate modelers to quantitatively evaluate climate model simulations over the Arctic region, leading to identification of source for modeling errors and possible cloud-radiation formulation improvements.

Dong, X., B. Xi, K. Crosby, C.N. Long, R. Stone and M. Shupe, 2010: A 10-yr Climatology of Arctic Cloud Fraction and Radiative Forcing at Barrow, Alaska. *J. Geophys. Res.*, 115, D12124, doi:10.1029/2009JD013489.



Key Accomplishment

Arctic clouds increase from winter to summer with an annual average of 0.78, and Barrow is near the critical latitude for which cloud-induced infrared radiative heating is in approximate balance by those changes in cloud induced solar radiation.



Observing Properties of Single-Layer Arctic Stratocumulus Leads to Largest International Cloud Model Intercomparison

Greg McFarquhar, Hans Verlinde, Ann Fridlind and Steve Klein

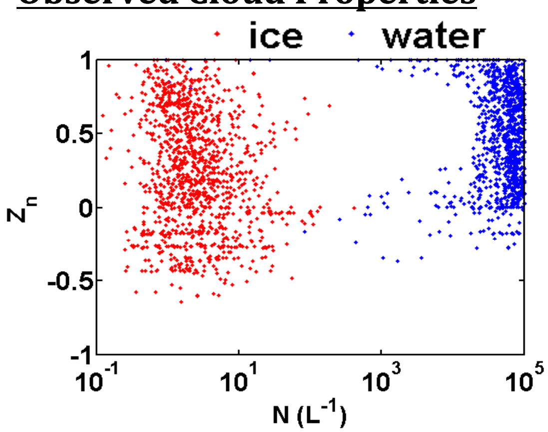
Science Question

What controls cloud microphysical properties in persistent mixed-phase Arctic stratocumulus, and how can these processes be represented in models?

Approach

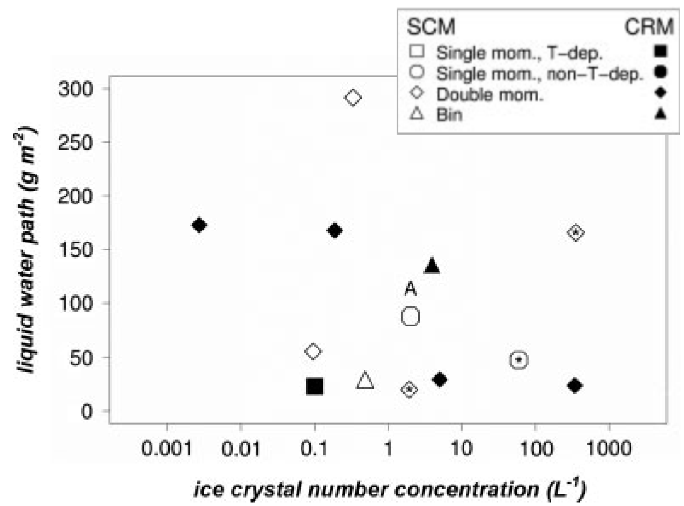
- Derive vertical profiles of cloud properties observed by instrumented aircraft that flew > 100 ramped ascents/descents through clouds over North Slope of Alaska
- Compare observed properties against those modeled using varying ice formation mechanisms to identify processes responsible for formation of ice
- Simulate cloud properties with 26 different models to determine which models and processes give optimum representation of observed microphysics

Observed Cloud Properties



Observed water droplet and ice concentration Ni as function of normalized cloud altitude used to assess models.

Modeled Cloud Properties



Single-column model (SCM) and cloud-resolving model (CRM) Ni predictions vary by over five orders of magnitude under these common Arctic conditions. Observed values indicated by A.

Comparison suggests models with more sophisticated microphysics (bin-resolved) better match aircraft observed properties. Because of scatter, limitations of using one case study, and uncertainties in data, similar comparisons now being conducted using more comprehensive aircraft observations obtained in ARM 2008 Arctic cloud experiment.

Key Accomplishment

Synergy of ARM field observations and ASR models shows advances in cloud microphysics schemes are necessary for modeling observed cloud properties; understanding of mechanisms responsible for ice in Arctic clouds will benefit representation of such processes in climate models.

Publications

Verlinde et al. (BAMS, 2007), McFarquhar et al. (JGR, 2007), Fridlind et al. (JGR, 2007), Klein et al. (QJRMS, 2009)

Impacts of Small Ice Crystals in Climate Simulations

Greg McFarquhar & David Mitchell

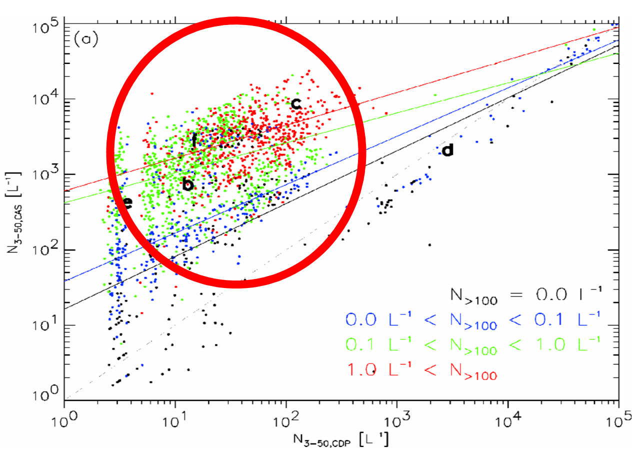
Science Question

How important are representations of ice crystals with maximum dimensions < 50 mm to predictions of climate change in global models?

Approach

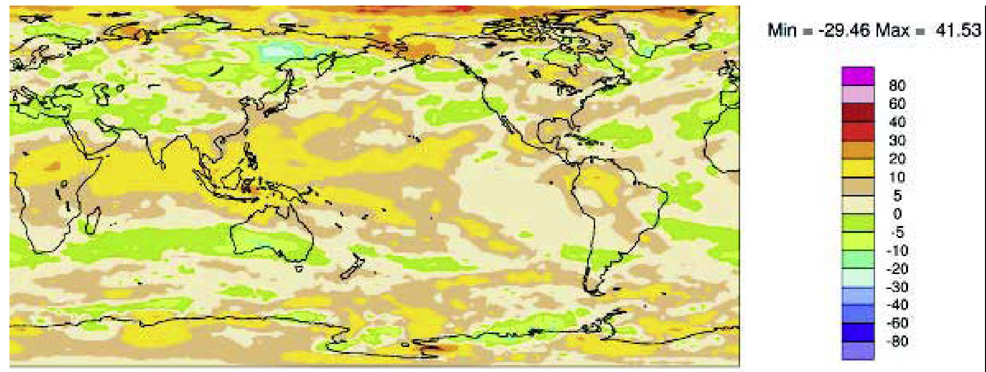
- Use in situ aircraft observations to identify range of uncertainty in concentrations (N) of small ice crystals.
- Conduct a sensitivity study with NCAR CAM5 climate model to determine effect of alternate representations of small ice crystals on ice fall speeds, cloud life cycles, cloud radiative forcing, and heating rates.

Impact of crystal shattering on measurements of small ice crystals



Red circle shows CAS probe over-estimates small crystal N compared to CDP probe due to shattering of large particles on probe tips and inlets.

Simulations using alternate representations of small crystal size distributions



Uncertainty due to shattering on probe tips guided study looking at differences in simulations with alternate representations of small ice. Differences of ~ 60% in predicted ice water path found→ big impact on predicted cloud forcing and heating rates!

Key Accomplishment

More realistic portrayal of small ice concentration in CAM5 parameterizations obtained from this data analysis/modeling study.

Publications

McFarquhar et al. GRL (2007), Mitchell et al. GRL (2008)

Mechanisms Affecting Transition from Shallow to Deep Convection over Land

Yunyan Zhang and Stephen A. Klein / Lawrence Livermore National Lab

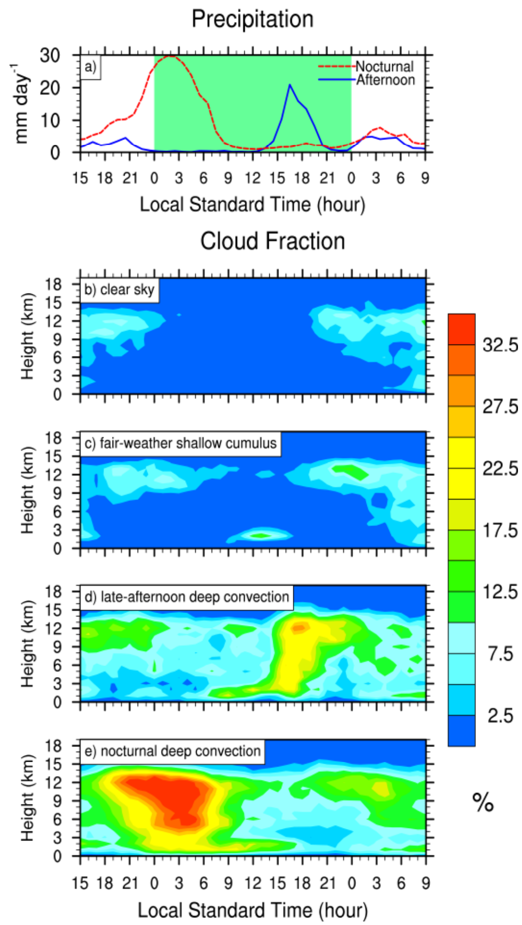
Science Question

1. What environmental parameters differ between the two convection regimes, fair-weather shallow cumulus versus late-afternoon deep convection, especially in the late morning a few hours before deep convection begins?
2. Is there any correlation between environmental parameters and rain statistics on days with late afternoon deep convection?

Approach

Based on observations of surface precipitation and cloud fraction at Southern Great Plains (SGP), we categorize and construct diurnal cycle composites to represent typical convective weather regimes at SGP.

Various datastreams collected at SGP (such as soundings, radar retrievals, surface meteorological measurements, and reanalysis data) are used to study the transition mechanisms from shallow to deep convection, such as the impacts from free-troposphere humidity preconditioning, atmospheric stability, and boundary-layer inhomogeneity.



Diurnal cycle composites of precipitation and clouds for different convection regimes

Results

Compared with fair-weather shallow cumulus days, on late-afternoon deep convection days:

1. Higher value of 2–4 km relative humidity (RH) is found at 1130 local time, a few hours before deep convection develops; this higher RH is also associated with longer rain duration and quicker rain onset .
2. Larger inhomogeneity in the surface moist static energy (represented by standard deviation, MSE STD) is found before and during precipitation events; correlation between MSE STD and precipitation rate shows that MSE STD leads precipitation, especially at the earlier stage of deep convection.

Key Accomplishment

Convective-regime-oriented composites from an 11-year span of comprehensive measurements collected by the DOE ARM Climate Research Facility at the Southern Great Plains site provide the ability to generate a systematic assessment of mechanisms controlling the transition from shallow to deep convection.

Publication

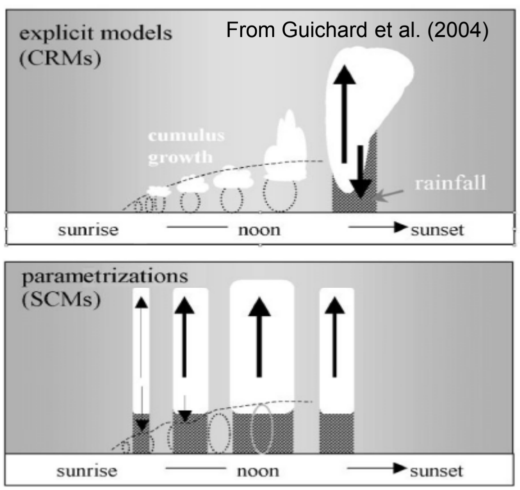
Zhang and Klein, 2010: "Mechanisms affecting the transition from shallow to deep convection over land: Inferences from observations of observations of the diurnal cycle collected at the ARM Southern Great Plains site". *Journal of the Atmospheric Sciences*, 67(9), 2943-2959.

Improving the Diurnal Cycle of Convection in Climate Models

Tony Del Genio/NASA GISS

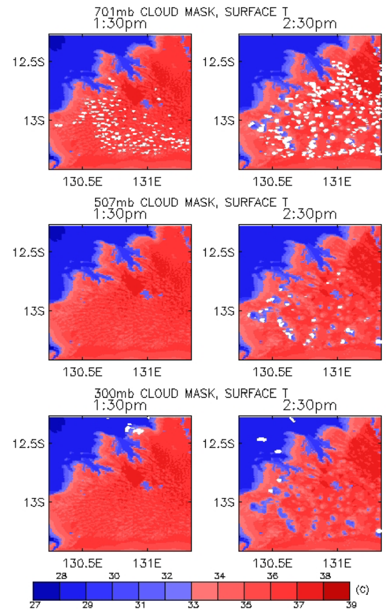
Science Question

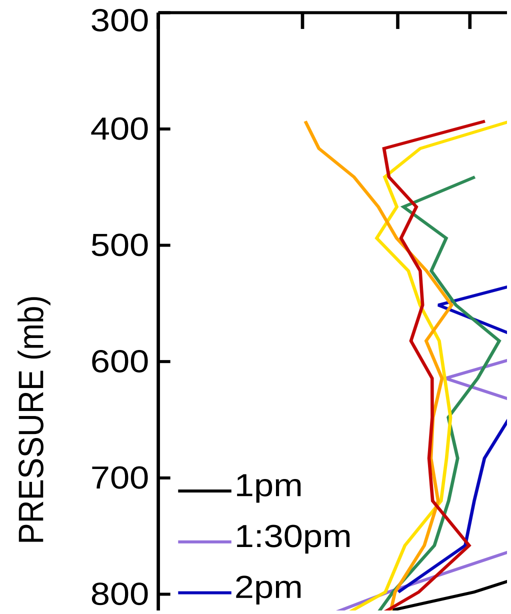
Observed continental summer rainfall begins in mid-- afternoon and peaks in late afternoon or evening. GCMs start raining in the morning, and their rain peaks near noon. Why do they produce rain too soon, and how can we parameterize the important processes that delay the onset of rain?



Approach

- Force the WRF CRM with ARM data during the TWP-ICE IOP monsoon break period.
- Identify convective clouds at different times during the transition from shallow to deep convection.
- Calculate mixing rate of dry air into clouds and test different parameterizations of this process.





WRF clouds develop in early afternoon but do not become deep until hours later. Analysis shows that less dry air is mixed (entrained) into the deeper clouds than the shallower clouds.

Key Accomplishment

A parameterization proposed by Gregory (2001) is the only one that reproduces the WRF behavior. This scheme has now been implemented in several GCMs (GISS, MIROC) for IPCC AR5.

Publication

Del Genio, A.D., and J. Wu, 2010: The role of entrainment in the diurnal cycle of continental convection. *J. Clim.*, **23**, 2722-2738.

ASR Atmospheric System Research

Understanding and Improving CRM and GCM Simulations of Cloud Systems with ARM Observations

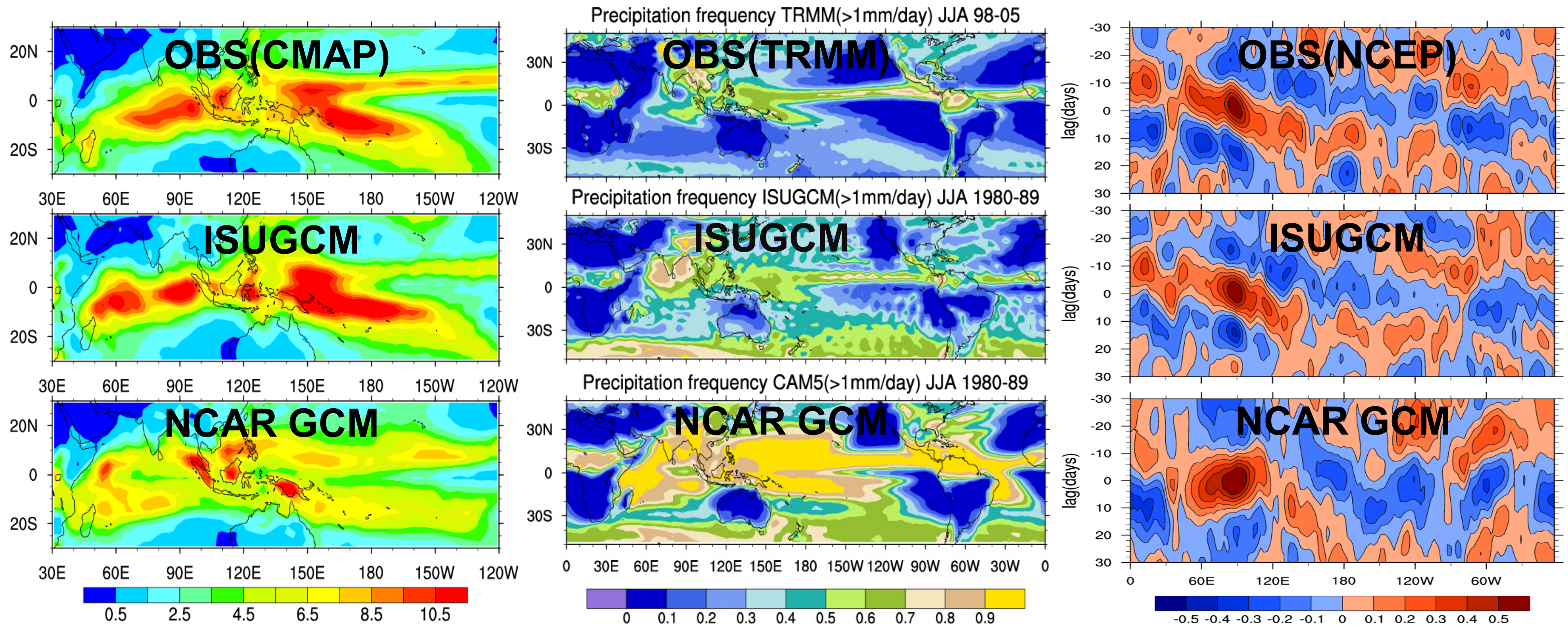
Xiaoqing Wu (Iowa State University)

Scientific question: What are the mechanisms and physical processes through which convection and clouds affect global climate mean state and variability?

Approach: Improved parameterization of convection and cloud using long-term cloud-resolving model (CRM) simulations forced by the ARM observations**.**

Accomplishment: Moist convection simulated by the GCM with the improved convection closure and CRM-derived trigger condition occurs less frequently, which allows more vigorous precipitating cloud systems and consequently results in better GCM simulations of global mean precipitation, frequency, and MJO activity.

Publications: Deng and Wu (2011, 2010, JC); Wu et al. (2008, JAS); Wu et al. (2007, GRL)



ASR Atmospheric System Research

Parameterization of Microphysics in Convection

Guang Zhang, Scripps Institution of Oceanography

Science Question

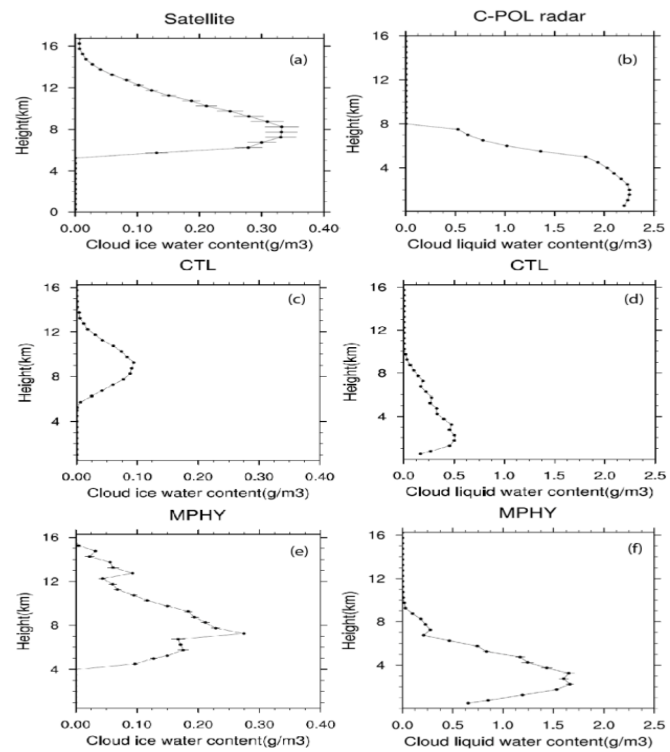
How do microphysical processes in convection affect convection-cloud interaction, and how do we represent them in GCMs?

Approach

An efficient two-moment microphysics parameterization scheme for convection is developed to improve the representation of convective clouds and their interaction with large-scale clouds and aerosol in global climate models (GCM). Observational data from satellite and radar during the ARM Tropical Warm Pool-International Cloud Experiment (TWP-ICE), together with the single-column version of the NCAR Community Atmosphere Model (CAM3.5), are used to evaluate the parameterization.

Results

Cloud ice and liquid water contents in convective updrafts are calculated using the microphysics parameterization. For the convectively active period during the TWP-ICE field campaign, they are nearly three times higher than using a simple parameter to represent conversion from cloud water to rain. The results are in much better agreement with ARM radar observations and satellite observations. The parameterization enhances the effect of convection on large-scale clouds and their associated hydrological cycle.



Vertical profiles of cloud ice (left column) and liquid water (right column) in convective updrafts during active monsoon period of TWP-ICE from (a, b) observations, (c, d) control simulation (CTL), and (e, f) microphysics parameterization (MPHY).

Key Accomplishment

The microphysics parameterization produces much higher cloud ice and liquid water in convective updrafts than without detailed microphysics, and it leads to more detrainment of cloud ice and liquid water from convection into large-scale clouds.

Publication

Song, X., and G. J. Zhang, 2011: Microphysics parameterization for convective clouds in a global climate model: Description and single-column model tests. *J. Geophys. Res.*, **116**, **D02201**, doi:10.1029/2010JD014833.

Convective Cold Pool Properties from Oklahoma Mesonet Data

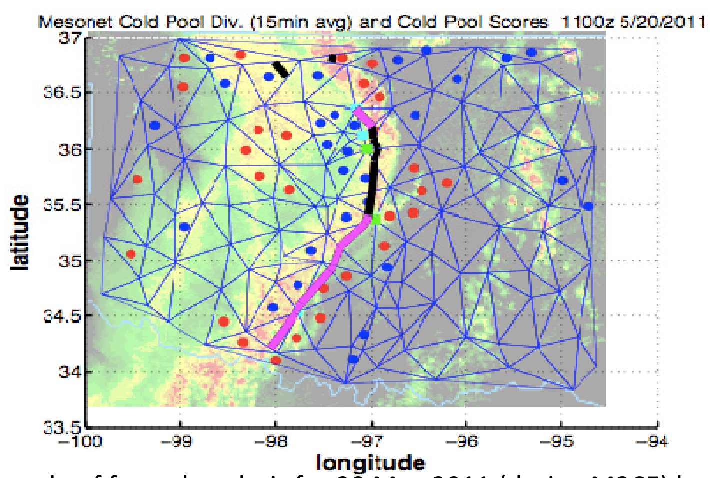
Steven K Krueger, University of Utah, Salt Lake City, Utah

Science Question

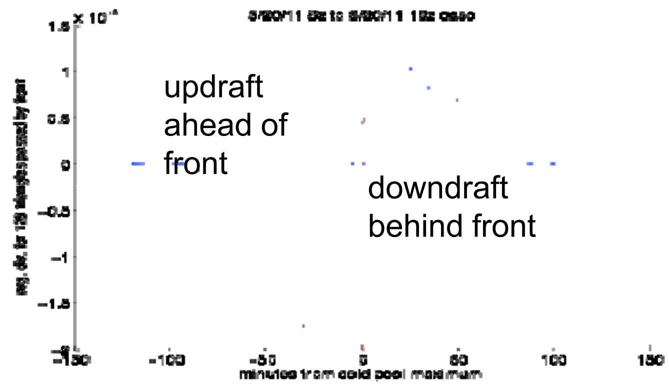
Can cold pool properties and mesoscale updraft and downdraft velocities be retrieved or estimated from surface Mesonet observations?

Approach

During the past year, we implemented an objective method to locate convective cold pool boundaries (gust fronts) using Mesonet station time series and applied the method to four summer months of 5-minute data from the Oklahoma Mesonet.



Example of frontal analysis for 20 May 2011 (during M3CE) based on Mesonet station time series. Red dots indicate triangles with strong convergence. Dark blue dots indicate triangles with strong divergence.



Average divergence of Mesonet triangles passed by gust fronts on 20 May 2011 (during M3CE). The corresponding cloud-base mesoscale vertical velocity extremes are about 0.2 and -0.1 m/s. M3CE and vertical velocity measurements from ARM scanning Doppler radars will allow us to evaluate and improve our mesoscale vertical velocity estimates from Oklahoma Mesonet data, which are available for more than 15 years.

Key Accomplishment

Data sets of observed convective cold pool properties are being produced that can be used to evaluate convective microphysics parameterizations and cold pool parameterizations used in large-scale cumulus parameterizations.

Publication

Sun, R., and S. K. Krueger, 2007: Mesoanalysis of the Interactions of Precipitating Convection and the Boundary Layer. 12th Conference on Mesoscale Processes, Waterville Valley, NH, Amer. Meteor. Soc.

http://ams.confex.com/ams/pdfpapers/126052.pdf

Observations of Anvil Clouds of Tropical Mesoscale Convective Systems

Robert Houze/ University of Washington

Science Question

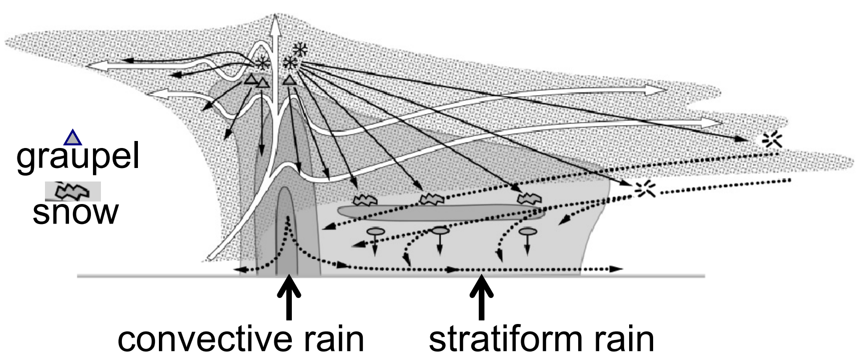
How do tropical mesoscale convective systems, produce the extensive upper-level anvil clouds that dominate cloudiness in the tropics?

Approach

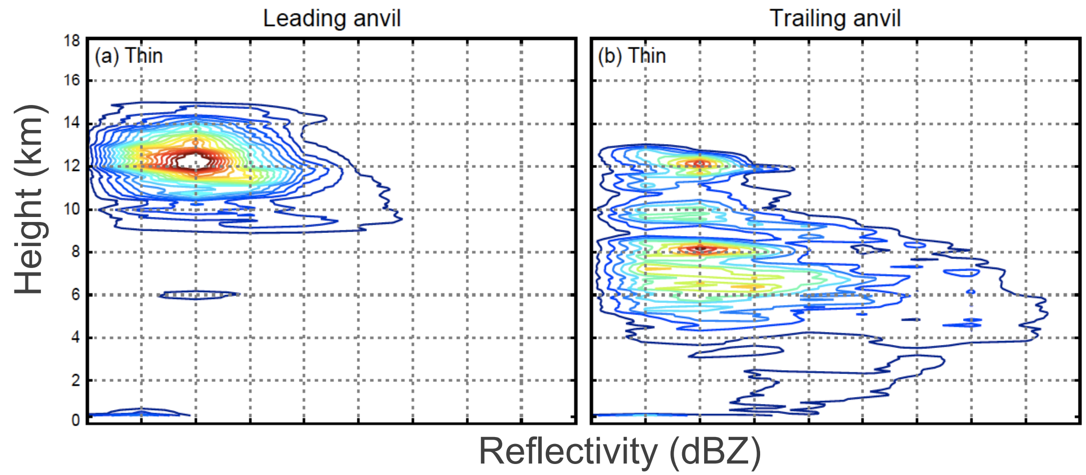
•Used vertically pointing ARM cloud radar at Niamey in conjunction with scanning C-band precipitation radar.

•Used ARM cloud radar to characterize the structure of the anvils of squall-line systems moving over Niamey.

Conceptual Model



Probability distributions of reflectivity in thin anvils (<2 km deep)



- Thin anvils are concentrated at high levels in leading convective anvils and are at lower and more varied altitudes in stratiform anvils.
- Results for thick anvils (not shown) indicate graupel dominates in leading convective anvils and snow dominates in stratiform anvils.

Key Accomplishment

Showed microphysical differences between anvils produced directly by convective regions and anvils produced by stratiform regions.

Publication

Cetrone, J., and R. A. Houze, Jr., 2011: Leading and trailing anvil clouds of West African squall lines. *J. Atmos. Sci.*, **68**, 1114-1123.

Tropical Observations Lead to Four-Part Model Intercomparison

A. Fridlind/NASA • C. Jakob/Monash U • Y. Lin/GFDL • S. Xie/LLNL • P. Zhu/FIU

Science Question

Can models reproduce key observed features of tropical deep convection, driver of atmospheric circulation?

Approach

Four interlocking model intercomparison studies use ARM data from the Tropical Warm Pool-International Cloud Experiment (TWP-ICE)

- cloud-resolving models (CRMs)
- limited-area models (LAMs)
- general circulation models (GCMs)
- single-column model (SCMs)

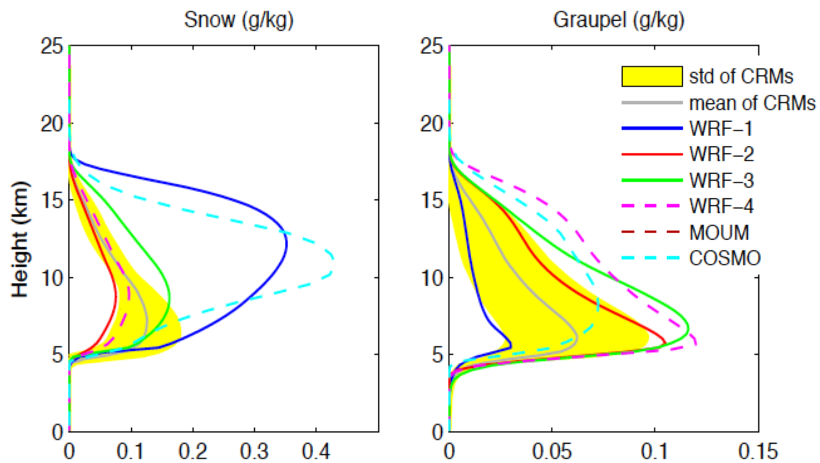
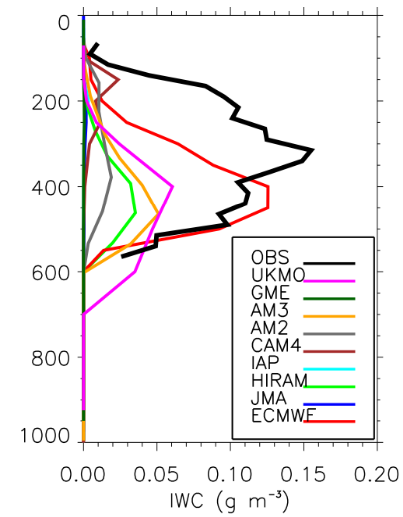


Fig. 2. Comparison of snow and graupel contributions to ice water content in CRMs (yellow range) and LAMs (colored lines) [supplied by P. Zhu].

Fig. 3. Range of ice water content (IWC) in global models displays a similar variability [supplied by Y. Lin].



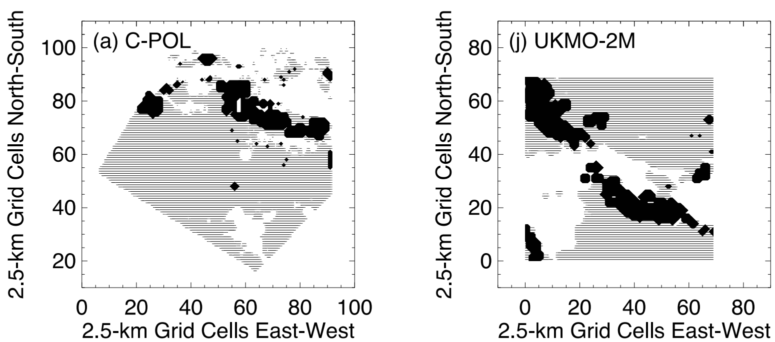


Fig. 1. Snow-rich stratiform areas (shaded) and graupel-rich convective areas (black) as observed (left) and in a CRM (right) [supplied by A. Fridlind].

Key Accomplishment

Established that ice is highly variable in *all* models, and future efforts must focus on better constraining radiatively important ice structures and properties.

Publications

- Xie et al., *J. Clim.*, 2010 (model forcing data)
- Fridlind et al., *J. Geophys. Res.*, 2011, submitted (CRMs)
- Zhu et al., *J. Geophys. Res.*, 2011, submitted (LAMs)
- Lin et al., manuscript in preparation (GCMs)
- Davies et al., manuscript in preparation (SCMs)
- Petch et al., manuscript in preparation (integrated analysis)

LAM Intercomparison Study of TWP-ICE Deep Convective System

P. Zhu/FIU • J. Dudhia/NCAR • P. Field/Met O. • K. Wapler/Deu. Wet. • A. Fridlind/NASA • A. Varble/U. Utah • E. Zipser/U. Utah • J. Petch/Met O.

Science Question

How well can the tropical monsoonal deep convection, the associated cirrus/cirrostratus outflow, and the life cycle of mesoscale convective systems (MCSs) be reproduced by limited area models (LAMs) forced by reanalyses or global forecast data?

Approach

Forced by the ECMWF analyses or global model forecast, six LAM simulations from three different models, WRF, MOUM, and COSMO, were intercompared based on the simulations of the strongest deep convective event during the active monsoon period of TWP-ICE.

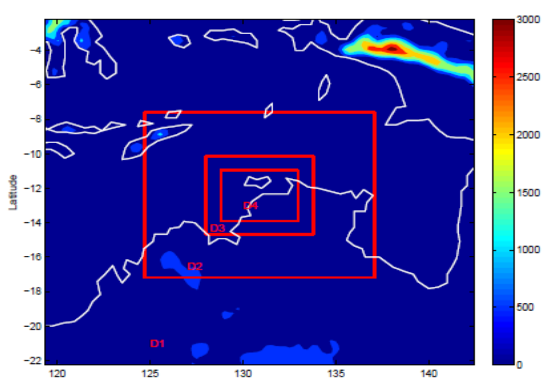


Fig. 1. LAM domain configuration.

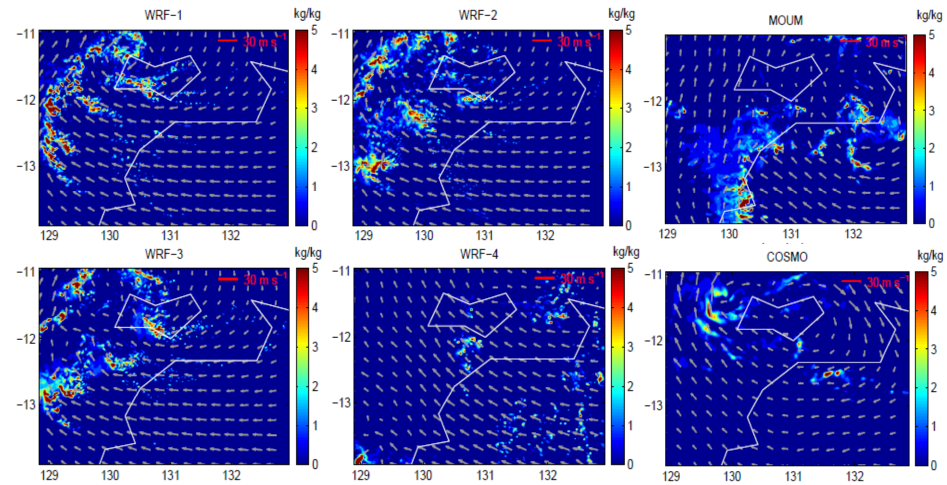


Fig. 2. Cyclonic flow and hydrometeor mixing ratio at 2 km during the convective event.

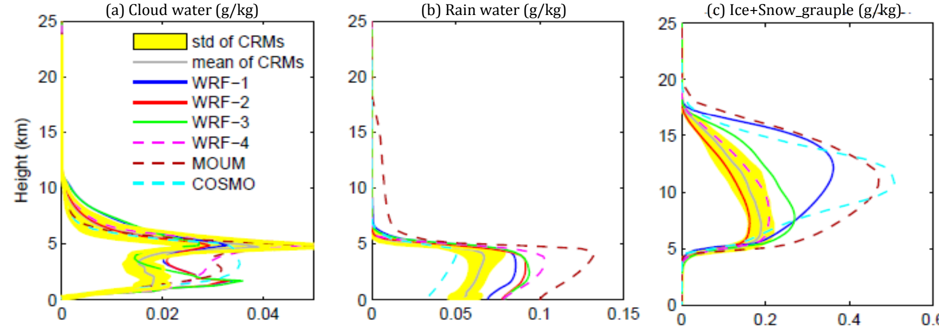


Fig. 3. Vertical profiles of hydrometeor mixing ratio from LAMs compared with CRMs.

Key Accomplishment

All LAMs are able to simulate the observed closed cyclonic flow associated with the monsoonal trough, a feature that cannot be simulated by CRMs with periodic lateral boundary conditions. It remains a question to what extent the oversimplified dynamic fields in CRMs can affect the fidelity of simulated convective clouds.

Publication

Zhu et al., 2010: A limited area model (LAM) Intercomparison study of a TWP-ICE active monsoon mesoscale convective event. *J. Geophys. Res., submitted*

High Frequency Gravity Waves Generated by Tropical Convection During TWP-ICE

Chi Mai Nguyen and Michael J. Reeder (Monash University)

Todd P. Lane (University of Melbourne)

Science Question

What is the relationship between tropical diabatic heating and the generation of high-frequency gravity waves?

The answer to this questions has practical implications for (1) the production of tropical cirrus and (2) the parameterization of gravity wave drag in climate models.

Approach

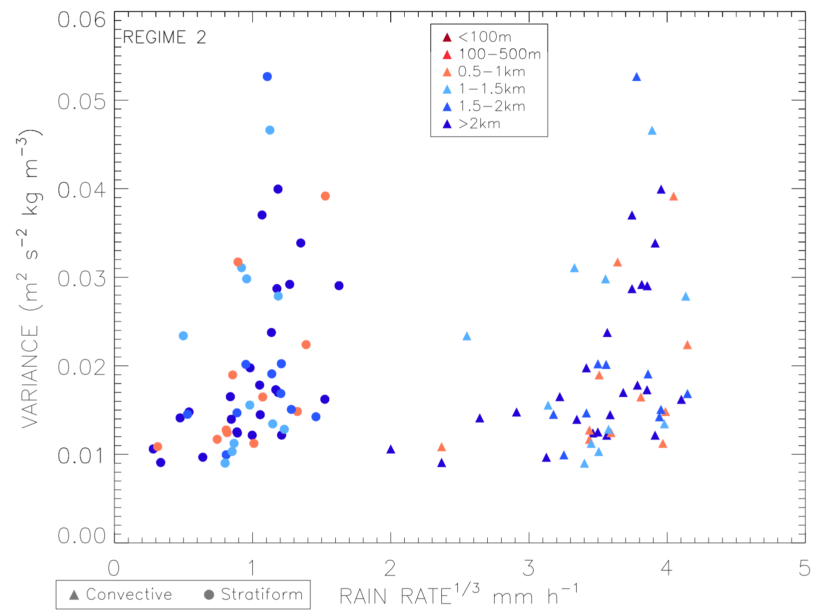
The high frequency part of the spectrum is derived from perturbations in the ascent rate of the radiosonde balloons released during TWP-ICE.

As the waves are generated by the clouds, the variance of the vertical motion perturbations ($\rho w'^2$) in the lower stratosphere is closely related to convective activity in the troposphere.

The figure is a scatter plot of $\rho w'^2$ in the stratosphere as a function of the cube root of the convective and stratiform rainfall rates, which are related to the diabatic heating rates.

Reference

Nguyen, C. M., M. J. Reeder and T. P. Lane. 2011. Convectively-generated gravity waves observed during TWP-ICE. *International Union of Geodesy and Geophysics General Assembly*, Melbourne, Australia.



Key Accomplishment

At low rain rates, the wave activity increases with increasing rain rate, whereas at higher rain rates the wave activity is independent of the rain rate. The implication is that in deep convective clouds, the waves are generated by something other than diabatic heating, presumably overshooting convective tops.

Do We Observe Aerosol Impacts on DSDs in Strongly Forced Tropical Thunderstorms?

Peter May and colleagues, CAWCR, Bureau of Meteorology

Science Question

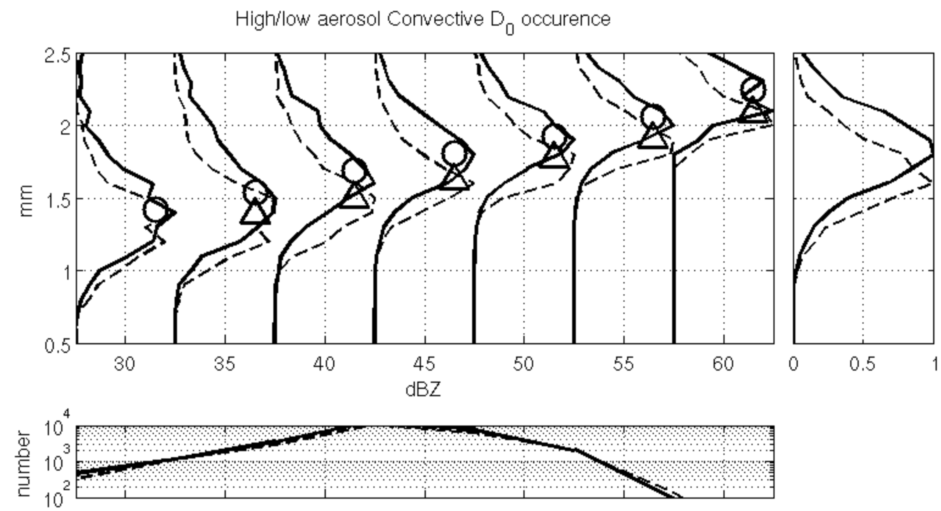
Do we observe aerosol impacts on DSDs in strongly forced tropical thunderstorms?

Approach

Rain drop size distributions retrieved from polarimetric radar similar to the new radars deployed at SGP and Manus.

Use regularly occurring storms near Darwin where thermodynamic issues are minimised as a test.

Calculate conditional PDFs during high and low aerosol conditions with similar thermodynamic environment.



High aerosol concentration: solid lines
Low aerosol concentration: dashed lines

Key Accomplishment

Demonstrated significant variations where high aerosol is associated with larger drops and lower concentrations.
Caveat: there may be some residual thermodynamic effects, but the result is robust against storm intensity.

Publication

May, P.T., V.N. Bringi and M. Thurai, 2011: Do we observe aerosol impacts on DSD's in strongly forced tropical thunderstorms? J. Atmos. Sci., (accepted)

Thermodynamics of the Madden–Julian Oscillation (MJO) in a Regional Model with Constrained Moisture

Samson Hagos and L. Ruby Leung (Pacific Northwest National Laboratory), Jimy Dudhia (NCAR)

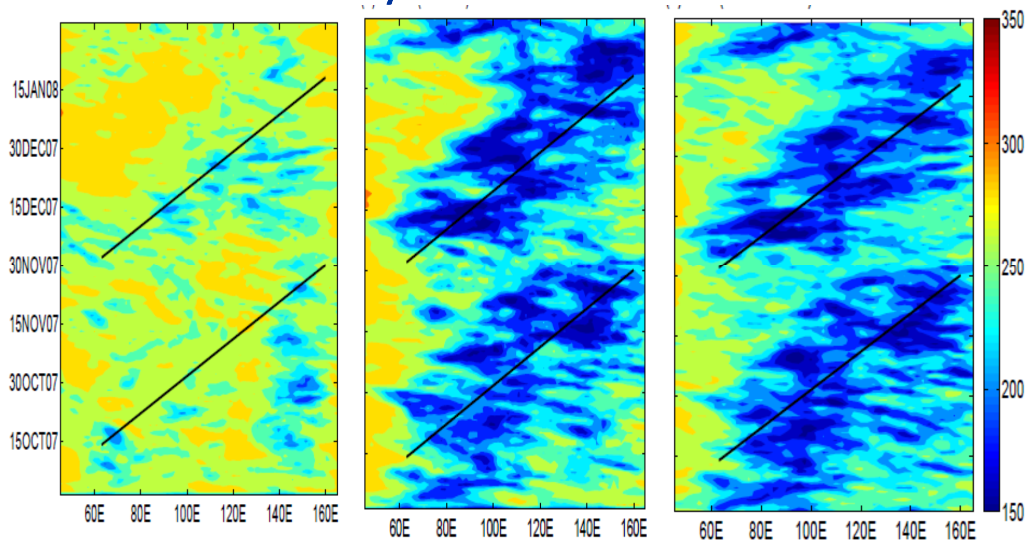
Science Question

What are the thermodynamic processes that sustain the MJO?

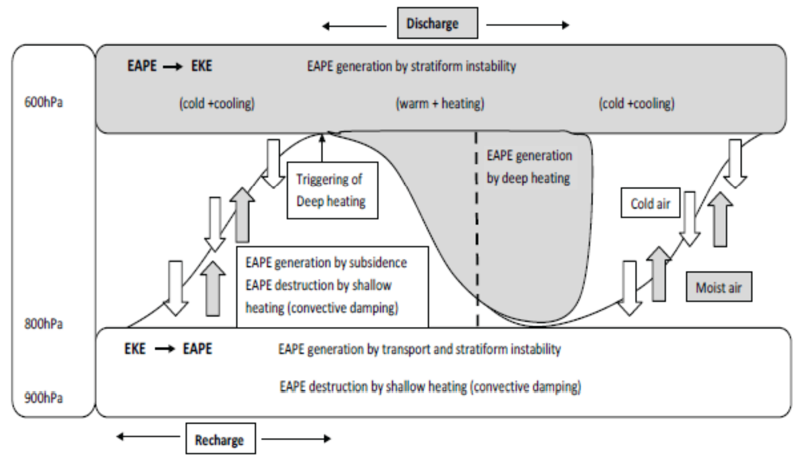
Approach

A regional model is constrained by moisture fields from an observational reanalysis to reproduce two observed MJO episodes. The moisture and heat budgets of the constrained and unconstrained model are analyzed to obtain insight into the key processes that sustain the MJO and to understand the nature of the limitations in the model's cumulus parameterization.

Unconstrained Model | **Model constrained by observations** | **Satellite observations**



OLR (Wm^{-2}) of two MJO episodes observed during the winter of 2007–2008. The lines mark propagation speeds of 4m/s.



A simplified paradigm of eddy available potential energy cycle in the observationally constrained model MJO.

Key Results

The evolution of the vertical structure of heating and moistening from clouds plays a critical role in the thermodynamics of the MJO. Deficiencies in these aspects of model parameterizations lead to the poor representation of MJO in the unconstrained model simulation.

Publication

Hagos, S., L. R. Leung, J. Dudhia 2010: Thermodynamics of Madden-Julian Oscillation in a regional model with constrained moisture. J. Atmos. Sci., (In Press).