Research Reports from the Cloud Modeling Working Group

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ACRF Data ↔ Modeling Skill

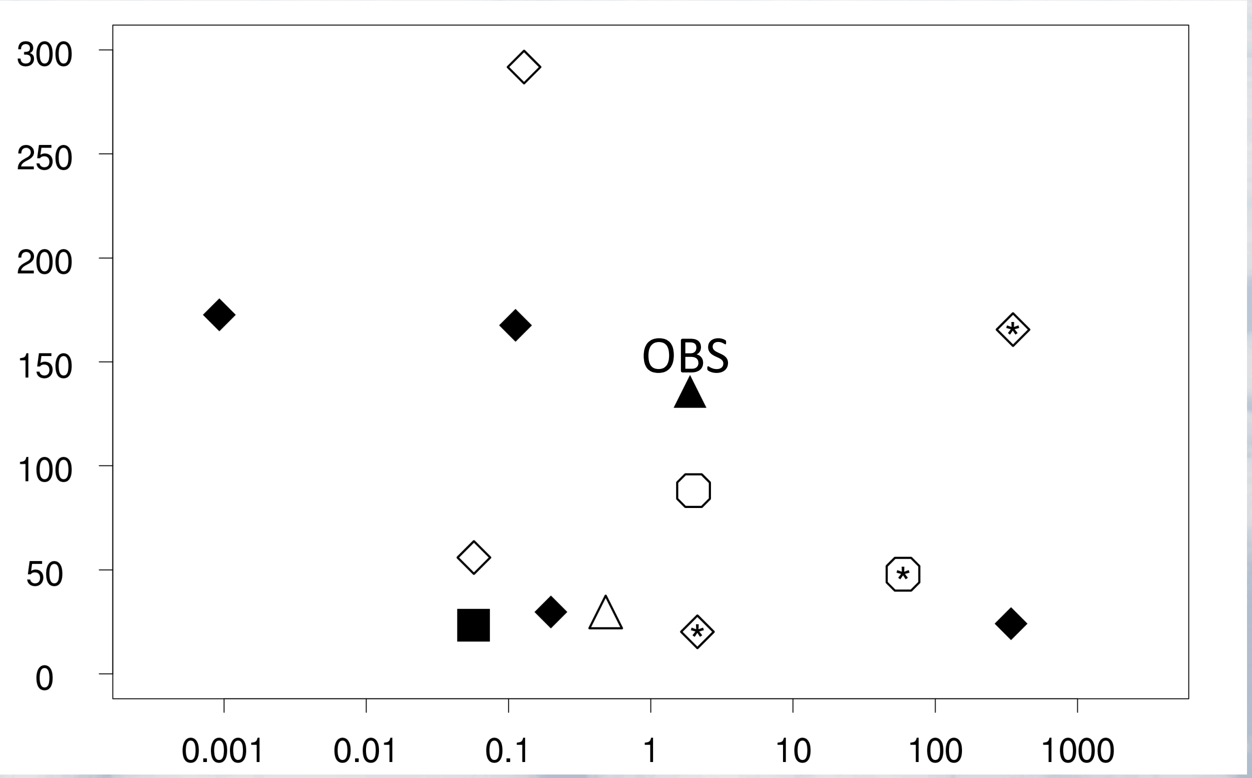
- Model intercomparisons
  - M-PACE (NSA)
  - TWP-ICE (TWP)
  - ISDAC (NSA)
- Other scientific accomplishments
- Science plan contributions
  - Priority science questions
  - Data needs

M-PACE Intercomparison Wrap-Up

- 26 models took part
- Two papers in press at QJRMS
  - H. Morrison and 29 co-authors (Case A)
  - S. Klein and 40 co-authors (Case B)
- Models tend to underestimate the amount of supercooled liquid in single-layer clouds but overestimate it in multi-layer clouds
- More sophisticated cloud microphysical parameterizations do perform better, but …

M-PACE Intercomparison Wrap-Up

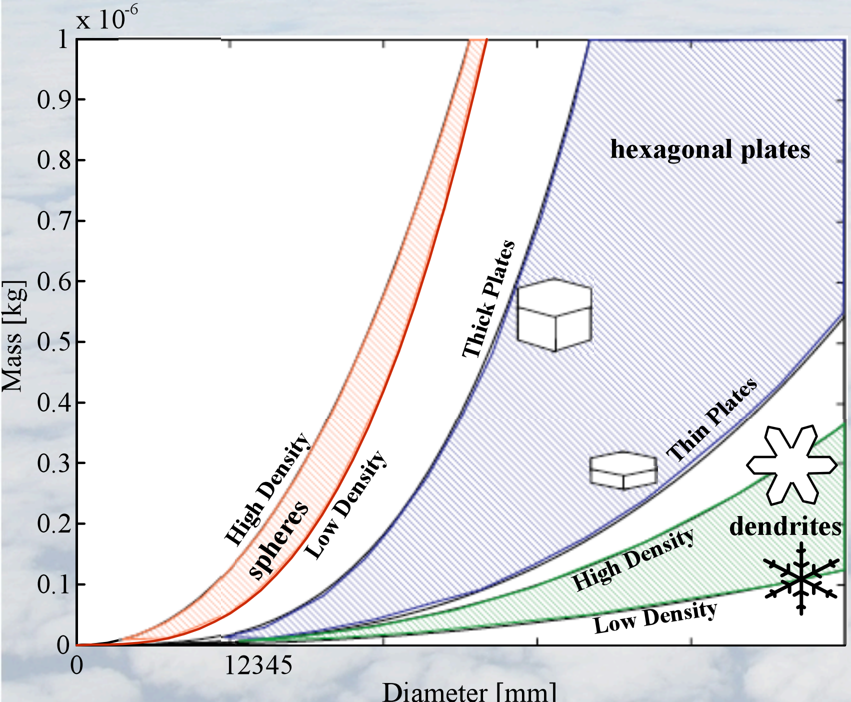
liquid water path
(g m⁻²)



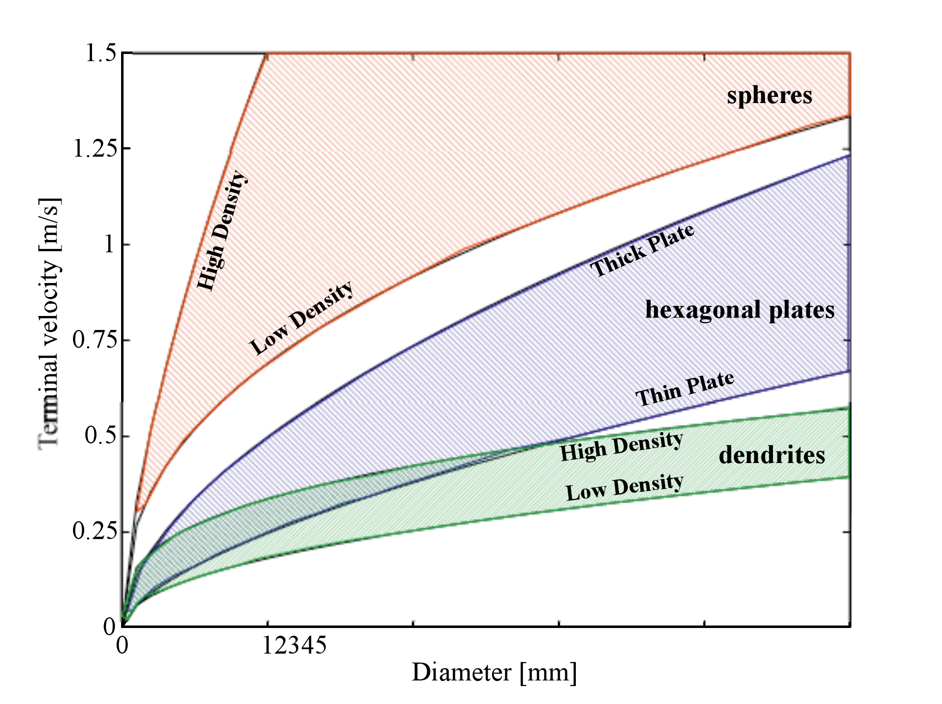
ice crystal number concentration (L^{-1})

Effect of Assumed Ice Habit (Case B)

Mass-size relation



Fallspeed-size relation



- Models assume simple mass-size and fallspeed-size relationships
- Based on data, but with large ranges
- Typically must assume some habit type a-priori

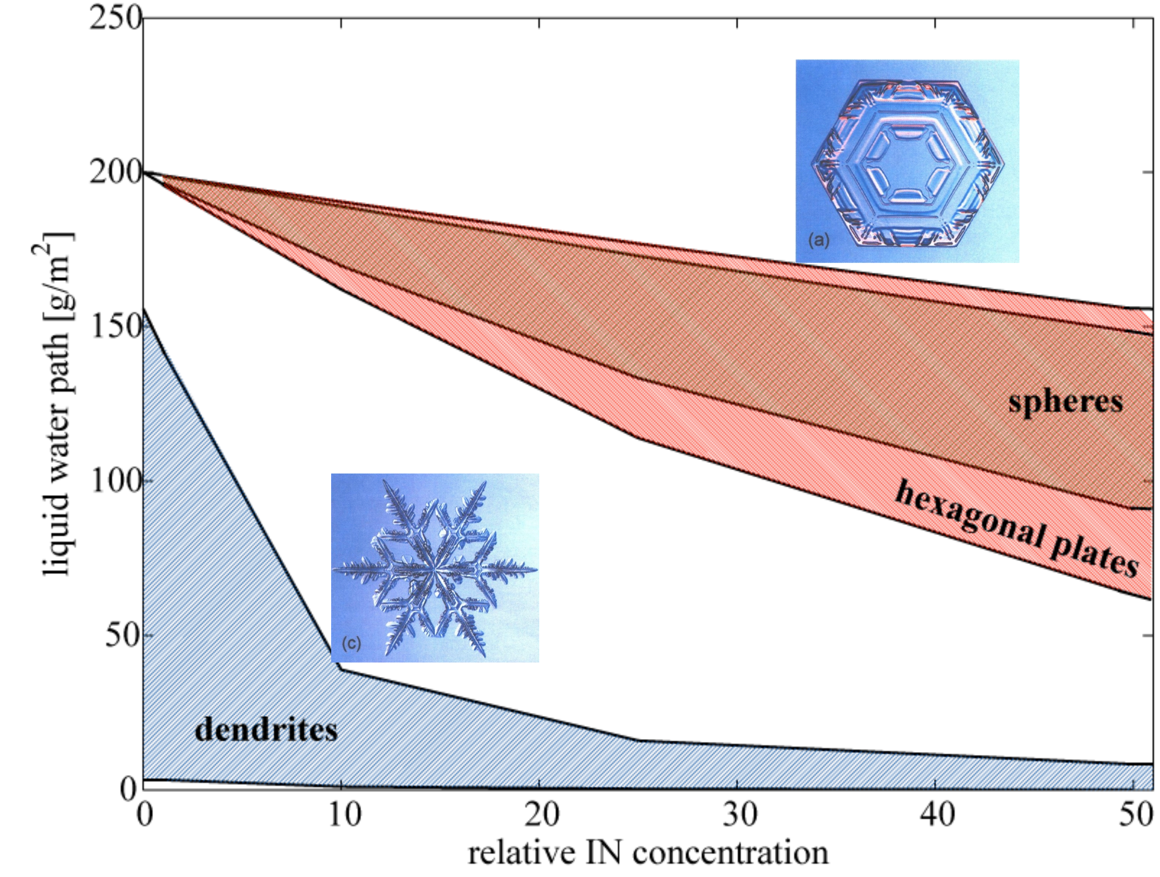
Effect of Assumed Ice Habit (Case B)

POSTER 3L

- **Compact habits (spheres, plates)**
  Slow growing, fast falling
  Less sensitive to ice concentrations

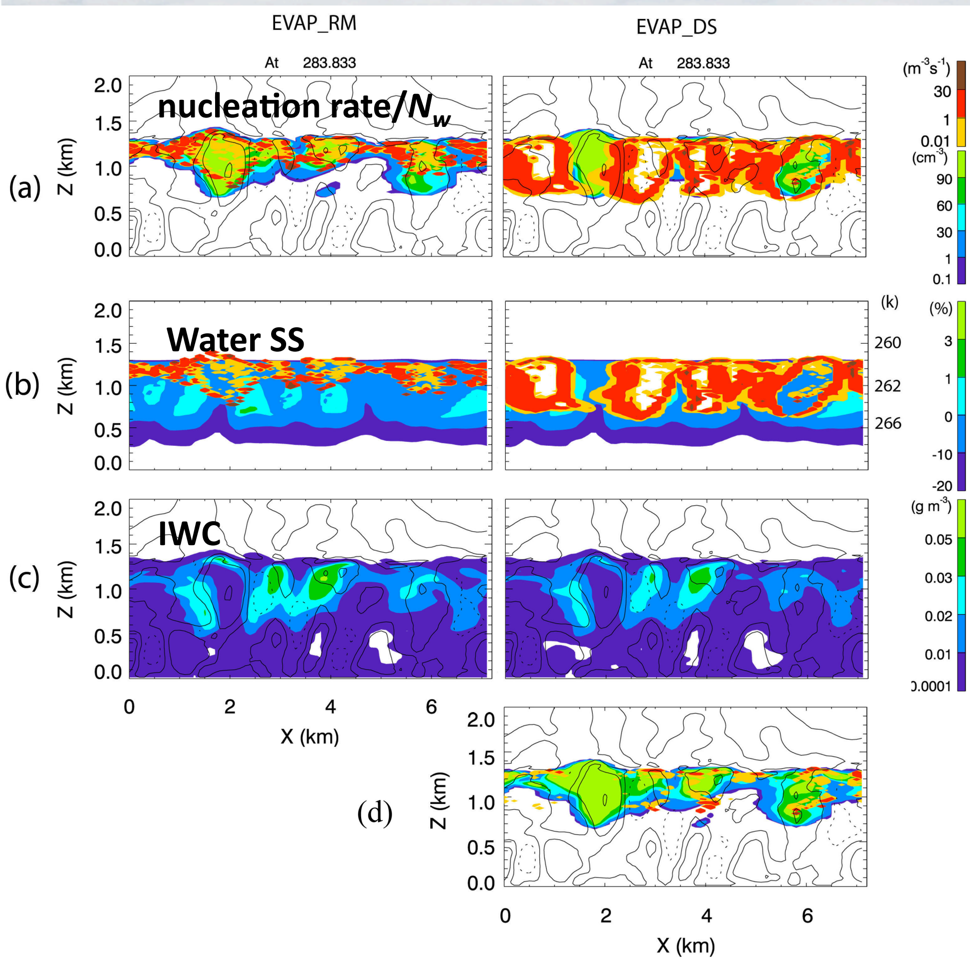
- **Less compact (dendrites)**
  fast growing, slow falling
  Sensitive to ice concentrations

- **A. Avramov, J. Harrington, et al.**
  JGR, submitted



Effect of Ice Formation Location (Case B)

Fan, J., M. Ovtchinnikov, J. M. Comstock, S. A. McFarlane, and A. Khain (2009)
***J. Geophys. Res.*, 114, D04205, doi:10.1029/2008JD010782.**



Key results:

✦ Ice nucleation from activation of evaporation nuclei occurs mostly near cloud top areas, while ice nucleation from the drop evaporation freezing has no significant location preference. Although ice nucleation occurs at very different rates and locations, two mechanisms give similar cloud properties.

✦ IN recycling from ice evaporation is very important to maintain the steady ice formation in mixed-phase clouds.

Data streams used:

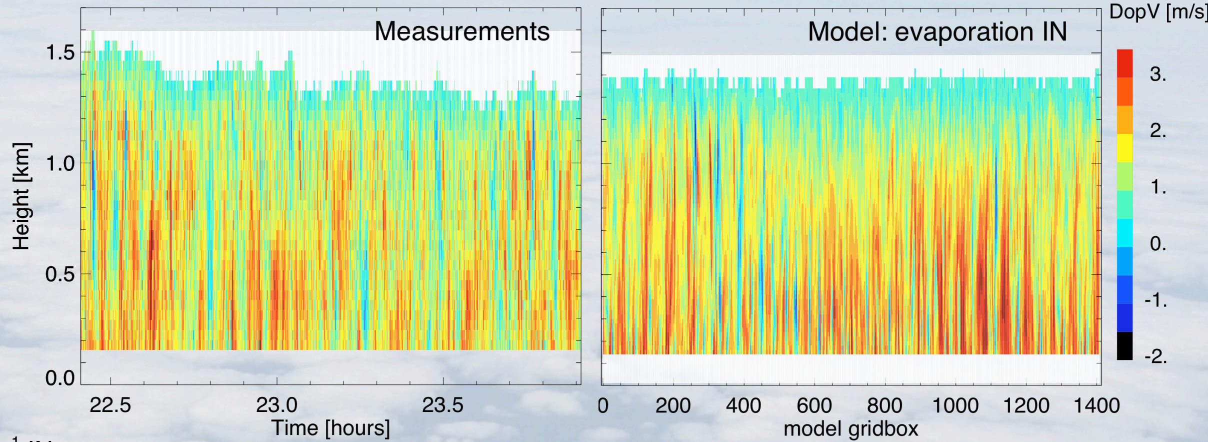
(a) In-situ aircraft data: IN and microphysical properties.

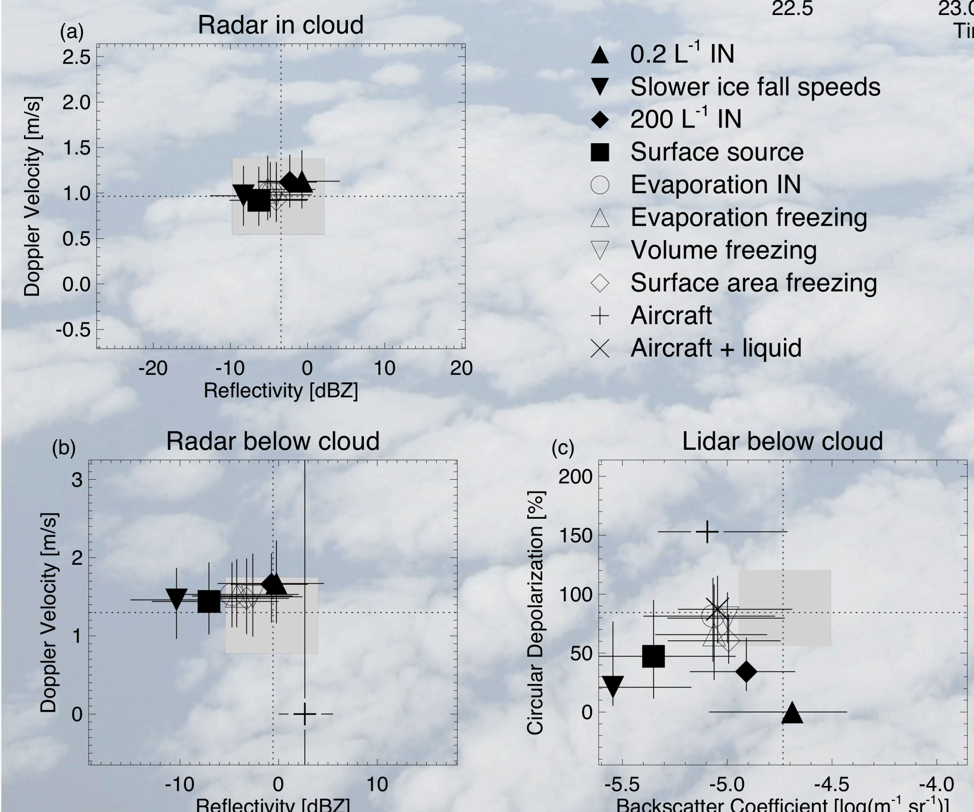
(b) Ground-based remote sensing data:

- MMCR radar reflectivity, Doppler velocity, etc.
- Radar and lidar retrievals: LWP, IWP, cloud base, etc.

Constraints from MMCR and HSRL (Case B)

- **Context**: Arctic aerosol indirect effects on mixed-phase clouds may be accelerating sea ice melt
- **Past Results**: Detailed model simulations and aircraft data indicate that ice formation is not understood (Fridlind et al., 2007)





- **Approach**: Simulate MMCR cloud radar reflectivity and Doppler velocity, AHSRL **lidar backscatter cross-section and circular depolarization**
- **Results**: Additional evidence of crucial gaps in knowledge of cloud ice formation
- **Publication**: "An evaluation of ice formation …" by Bastiaan van Diedenhoven et al. (*JGR*, in press)
- **Related Work**: Simulations now being used at JPL to study radar configurations for the ACE Decadal Survey mission

POSTER 3A

GCM Aerosol-Cloud Interactions (Case B)

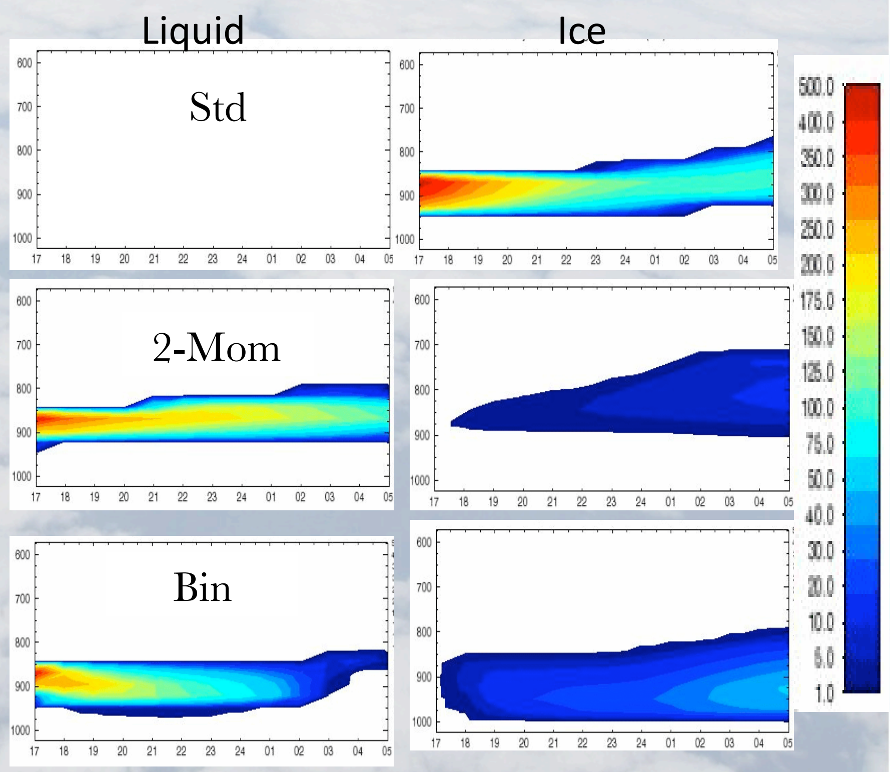
To understand details of aerosol-cloud processes most critical in representing climate we
(1) use detailed models (SCM and WRF) with ARM IOP data to improve cloud parameterizations and then implement them in a GCM;
(1) compare cloud and radiation parameters with CMBE data to develop useful metrics.

Results

1. The standard bulk scheme in the GISS SCM now includes a two-moment (2-Mom) and a bin resolved cloud scheme.
   This allows for a **better representation of liquid to ice mixing ratios for mixed-phase clouds** and compares well with observations (**MPACE 2004 campaign**) (Sednev et al. 2008, ACPD)

2. The two-moment scheme (Morrison et al. 2008) is now implemented in the GISS GCM and is being evaluated with **ARM CMBE data** from the SGP, TWP and NSA sites (Menon et al. 2009 in preparation, also see ARM Poster).

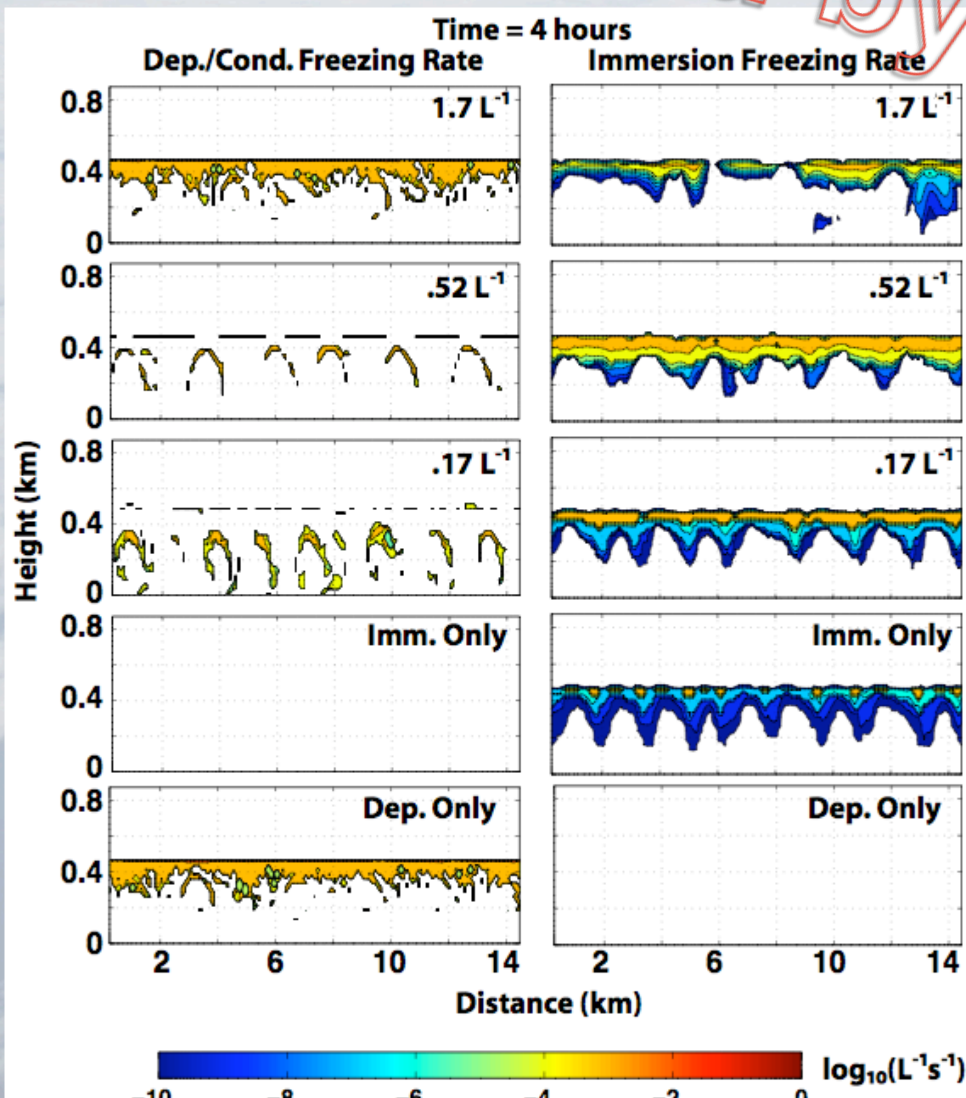
MPACE 2004 IOP Simulation



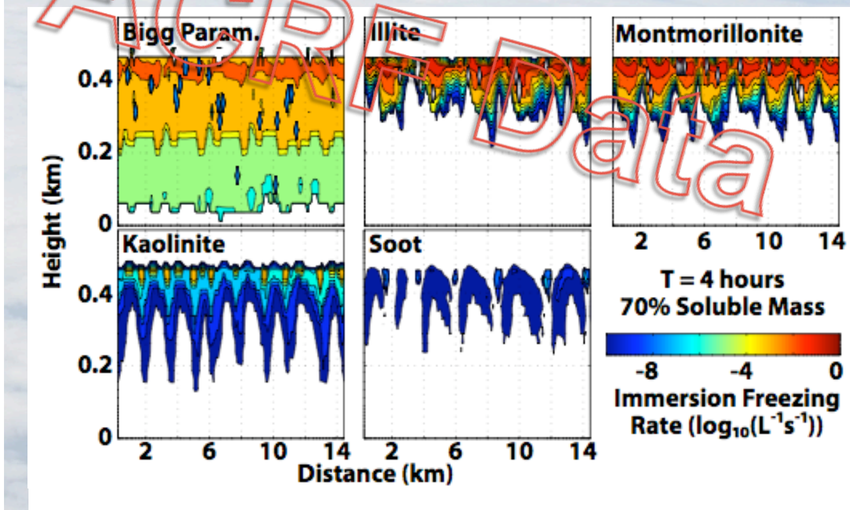
Pressure versus time (10/12: 1700 to 10/13 0500) of liquid and ice contents (mg m^{-3}) in the SCM.

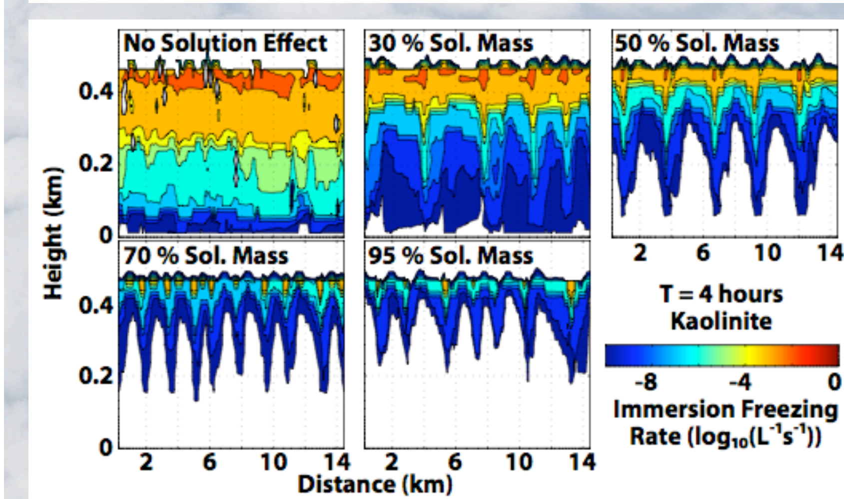
Behavior of Immersion Ice Nuclei (SHEBA)

Nucleation Mode Analysis



Aerosol Influence





TWP-ICE Break-out @ 3:30-5 PM

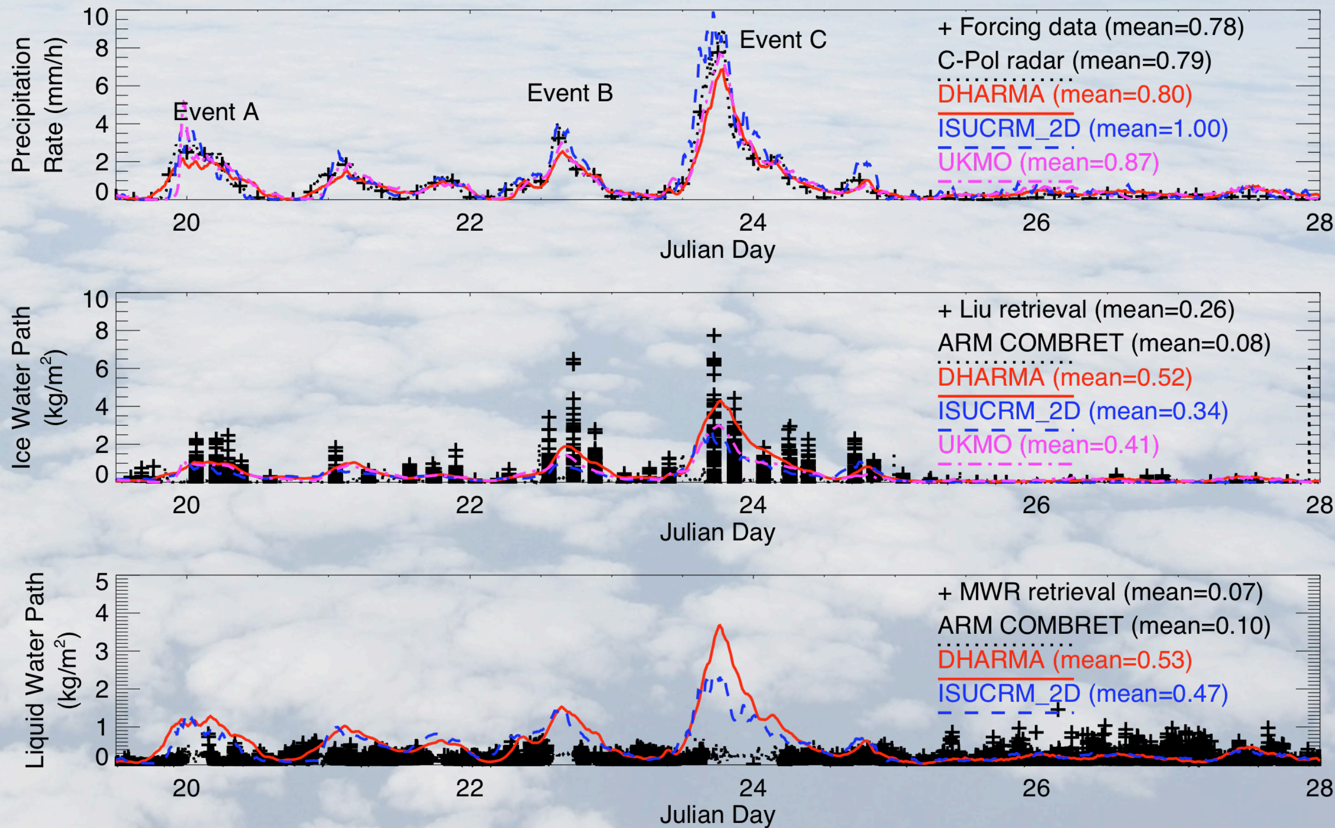
TWP-ICE Intercomparison Game-On

- Four prongs
  - Cloud-resolving models (CRMs)
  - Single-column models (SCMs)
  - Limited-area models (LAMs)
  - Numerical weather prediction (NWP) models
- Coordination
  - Jon Petch, UK Met Office
  - GEWEX Cloud System Study program's Precipitating Cloud Systems (PCS)
  - Stratopheric Processes and their Role in Climate (SPARC)

Poster 6H
Poster 6L

TWP-ICE CRM / Fridlind

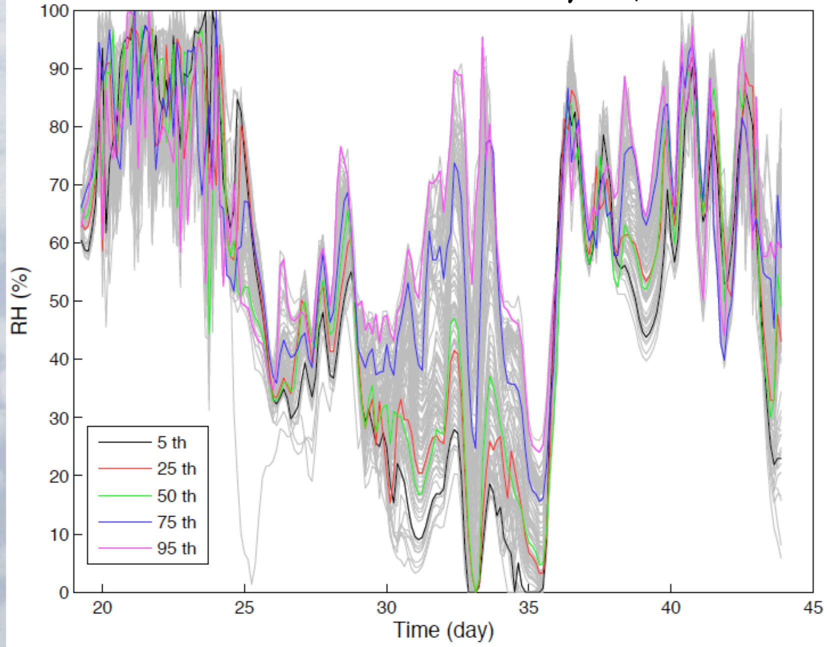
- 16 days
- Due 1 July
- What is simulation fidelity?
- How does convection influence UT water vapor?
- What processes control anvil cirrus evolution?
- Posters 6H (results) and 6L (radar analysis)

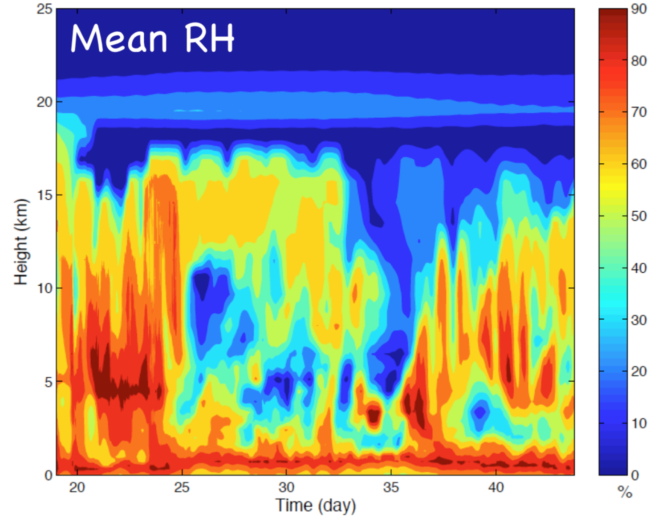


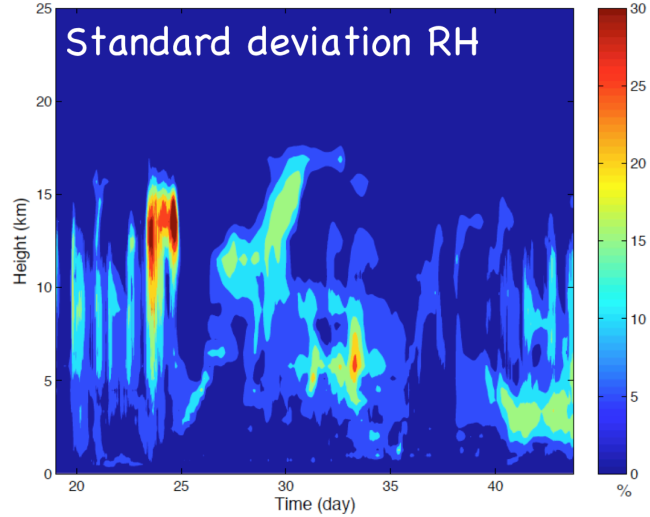
TWP-ICE SCM / Laura Davies

TWP-ICE SCM intercomparison

500 mb Relative humidity (liquid water)







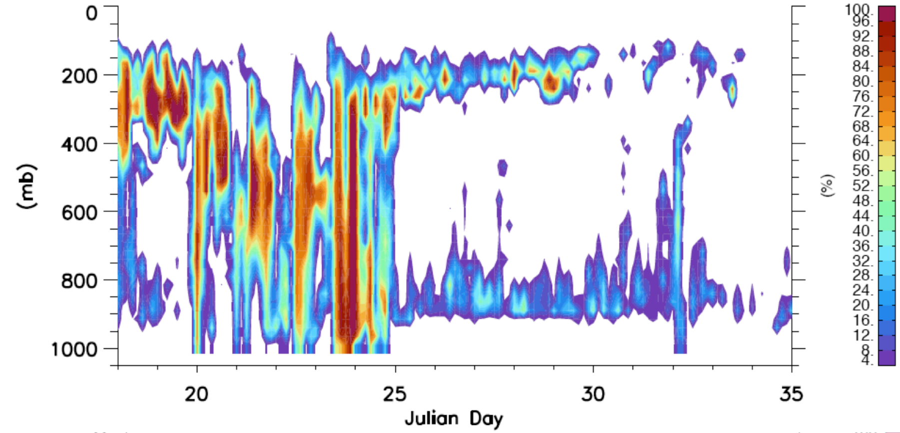
http://users.monash.edu.au/~ladavies/gcss.html

laura.davies@sci.monash.edu.au

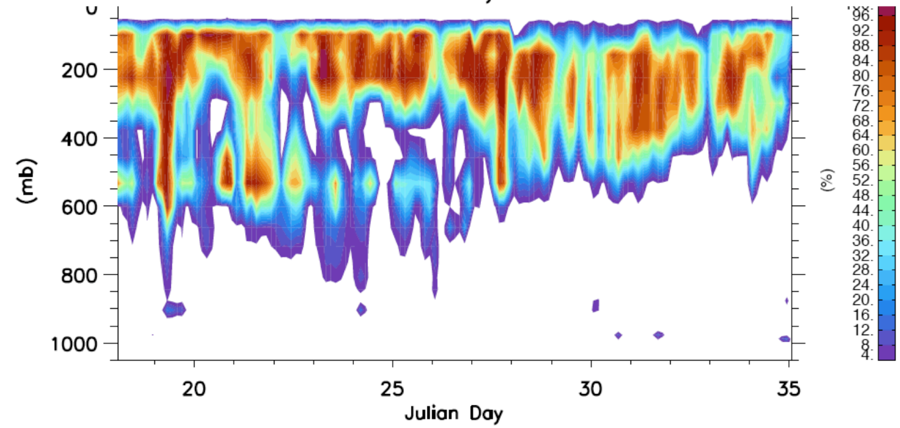
TWP-ICE NWP / Yanluan Lin

TWP-ICE NWP Simulations

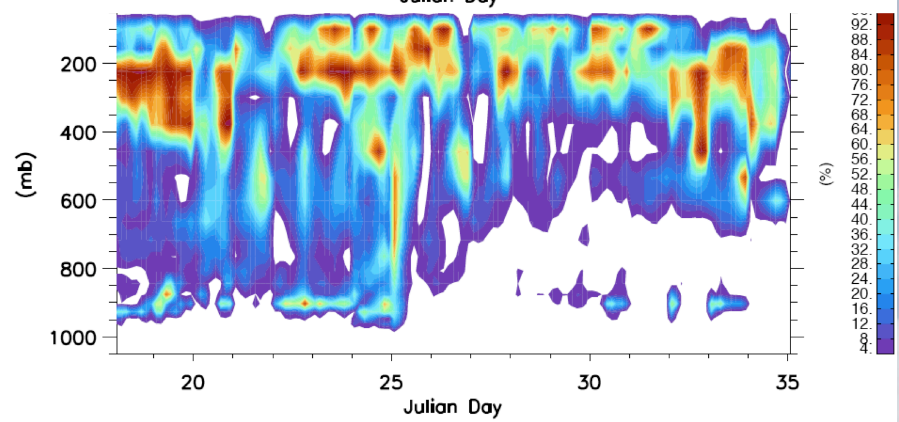
OBS cloud fraction



GFDL AM3

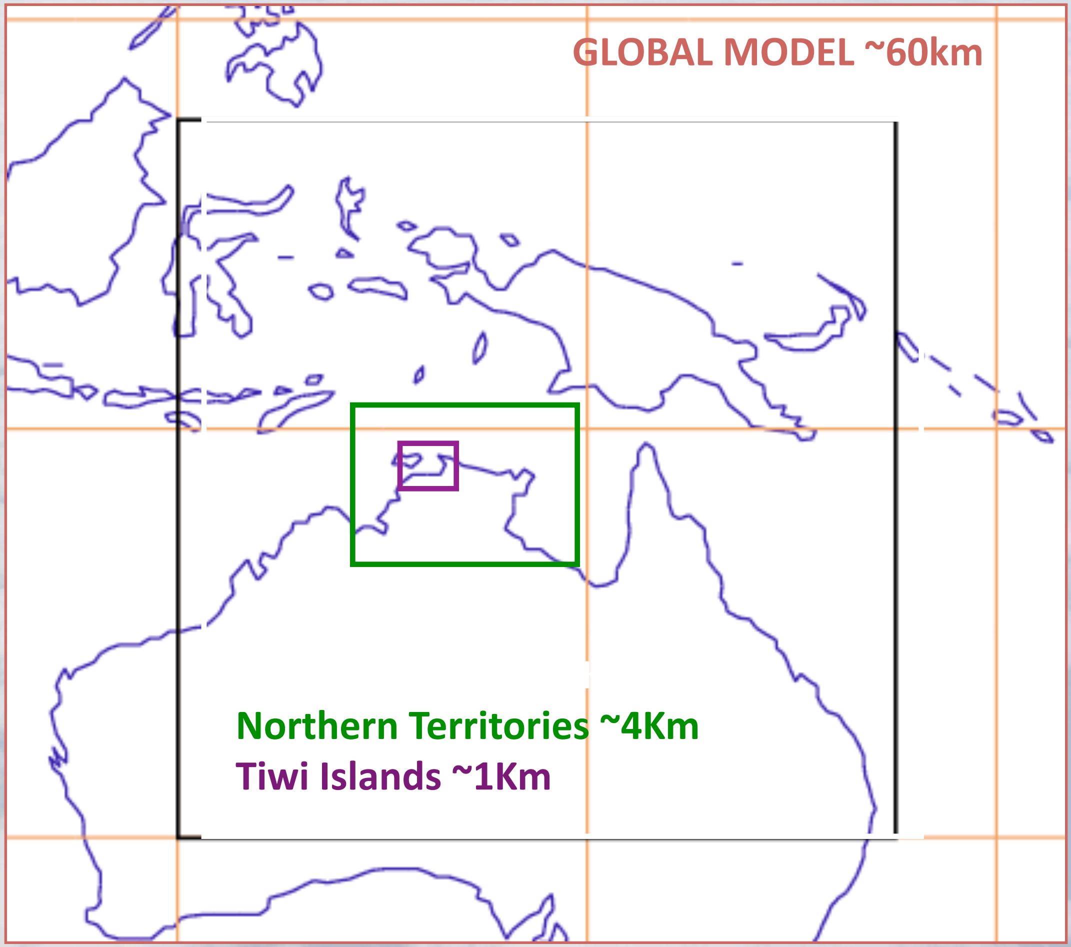


GFDL AM2



TWP-ICE LAM / Maria Russo

Nested model approach:



Centre *for* **Atmospheric Science**

UNIVERSITY OF CAMBRIDGE

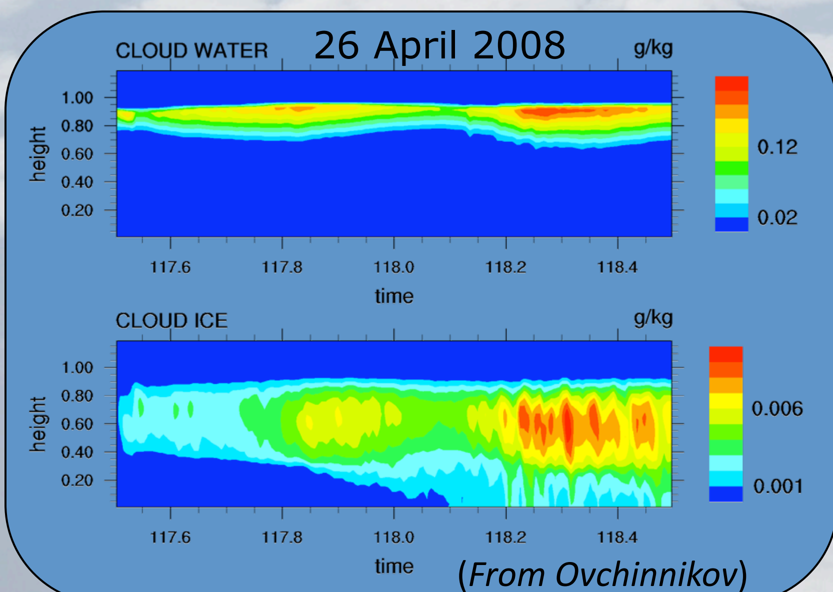
ISDAC

ISDAC BREAK-OUT @ 1-3 PM

*(**I**ndirect **S**emi-**D**irect **A**erosol **C**ampaign, McFarquhar & Ghan* PI's*)*

- Two "golden" days, 8 & 26 April 2008:
  - Single-layer mixed-phase clouds;
  - Multiple flights + ground observations;
  - Exceptional aerosol measurements (size, composition, hygroscopicity, CCN, IN, etc)
- Opportunities for closure studies, process and regional modeling

(From Korolev)



(From Ovchinnikov)

- Large-scale forcing available
- Contrast with M-PACE:
  - polluted vs. "clean" environment;
  - radiatively vs. surface-flux driven clouds.

ACRF Data ↔ Modeling Skill

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  - M-PACE (NSA)
  - TWP-ICE (TWP)
  - ISDAC (NSA)
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POSTER 8B

Representation of Shallow Cu In WRF

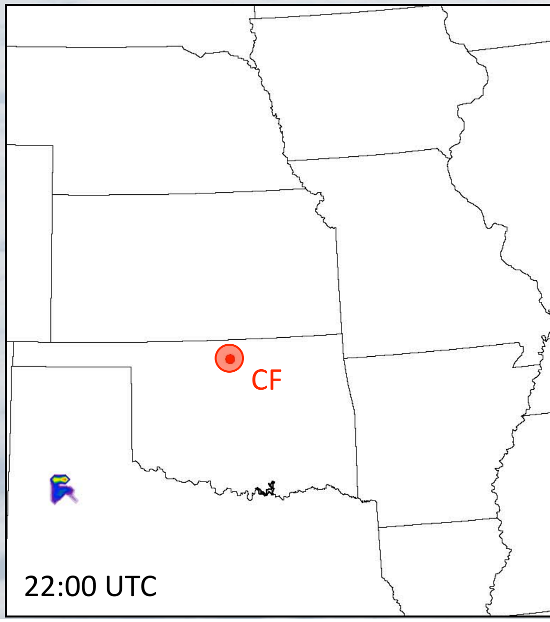
(Berg et al.)

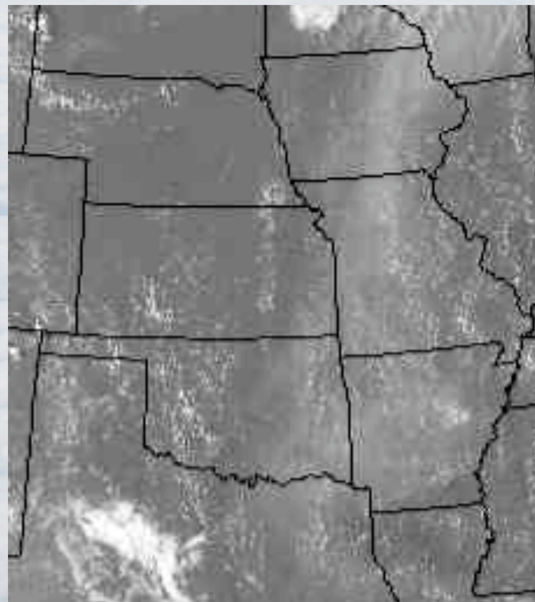
- The Cumulus Potential (CuP) scheme couples boundary-layer turbulence with shallow clouds (Berg and Stull 2005)
  - Replace trigger function in Kain-Fritsch scheme
- Used operationally in support of CLASIC
- Two data sets of have been constructed for model evaluation
  - Cloud macroscale properties (Berg and Kassinov 2008)
    - Data from TSI, ARSCL
  - Surface cloud radiative forcing (Berg et al., Poster 8B)
    - Data from ACRF VAPS: ARSCL, SWFLUANAL
    - Data from ACRF PI Product: RADFLUXANAL (created by C. Long)

POSTER 8B

CuP Case study results, 18 July 2004

Default WRF Cloud Frac., z=3 km

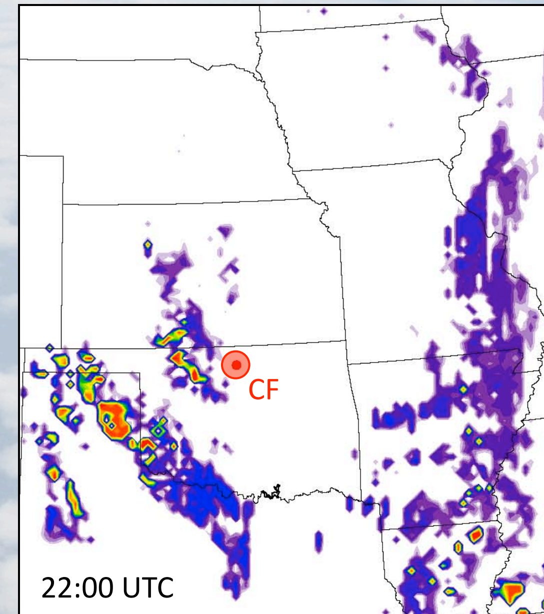


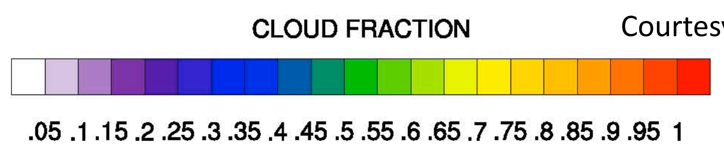


GOES Image 22:02 UTC

Courtesy of NASA LARC

CuP WRF Cloud Frac., z = 3 km



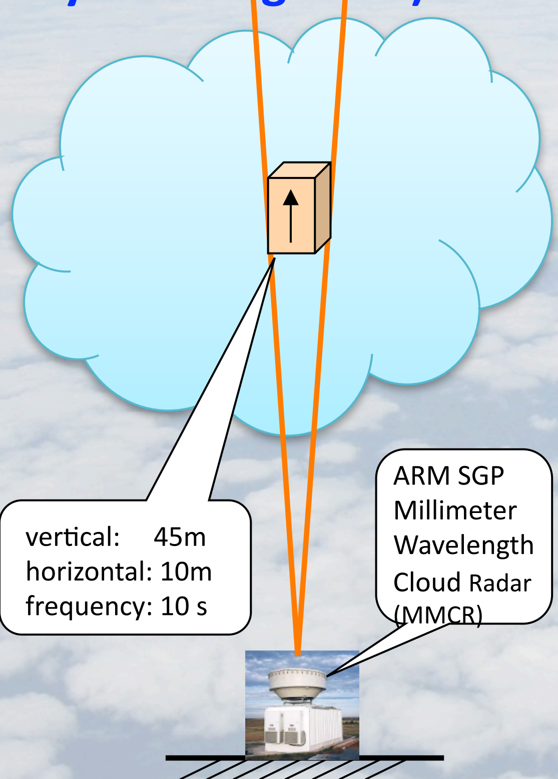


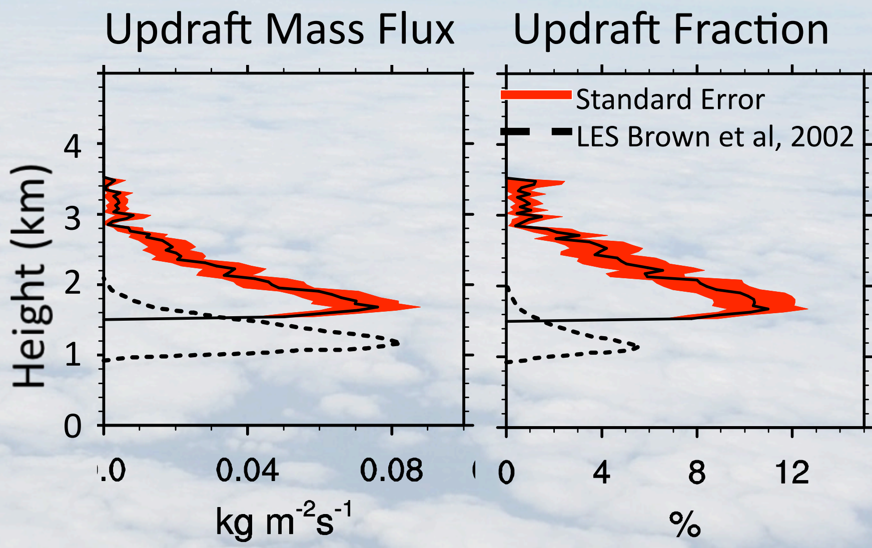
CF TSI Image at 22:00 UTC

- Default KF: No clouds near CF
- CuP-KF: Clouds near CF, increased convection within the domain

Use ARM data to assess convection theories – 1

(Yunyan Zhang et al.)





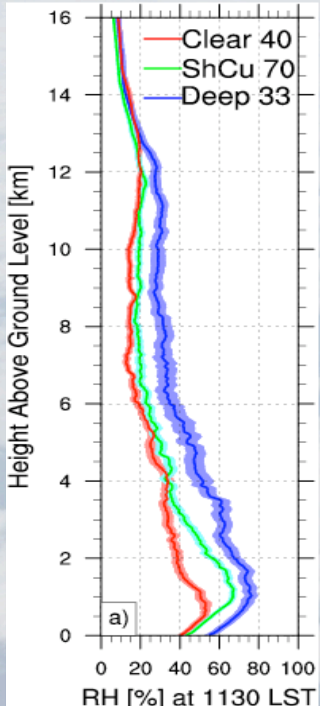
Vertical Velocity of cloud liquid droplets in non-precipitating shallow cumulus is retrieved uniquely based ARM MMCR measurement (Pavlos Kollias).

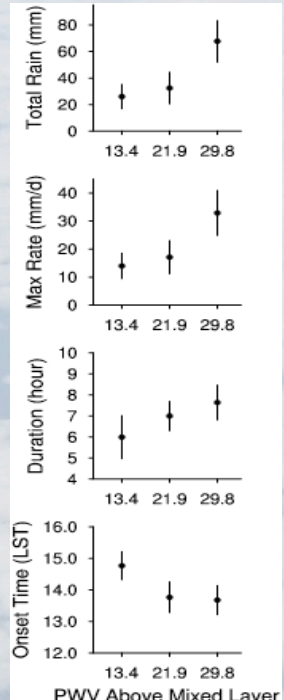
- The updraft mass flux and updraft fraction are comparable to previous LES study
- the net mass flux behavior fluctuates around zero at all levels because of the similarity between updraft and downdraft
- We plan to perform LES for the composite case and sample it the same way as OBS do to investigate if these OBS are specific feature for shallow cumulus over land

Reference Poster: Zhang, Klein & Kollias

Use ARM data to assess convection theories - 2

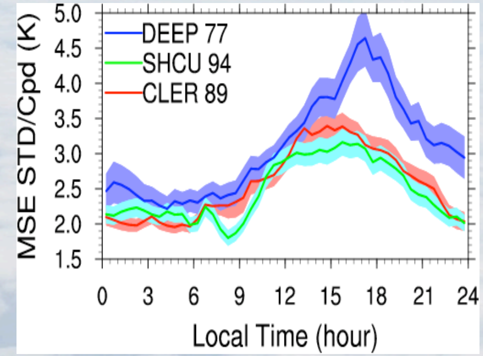
On the preconditioning of free troposphere humidity for deep convection



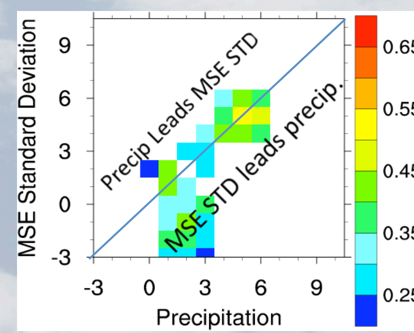


- The composite relative humidity (RH) is larger in late-afternoon deep convection days than in clear-sky or shallow cumulus days at 1130 local time, a few hours before deep convection develops
- The afternoon rain statistics is related to the precipitable water vapor (PWV) above mixed layer at 1130 local time (data from LSSONDE & ABRFC precip)

The impact of boundary layer inhomogeneity on deep convection



- The surface moist static energy (MSE) standard deviation (STD) is larger in late-afternoon deep convection days than in shallow cumulus days since noon



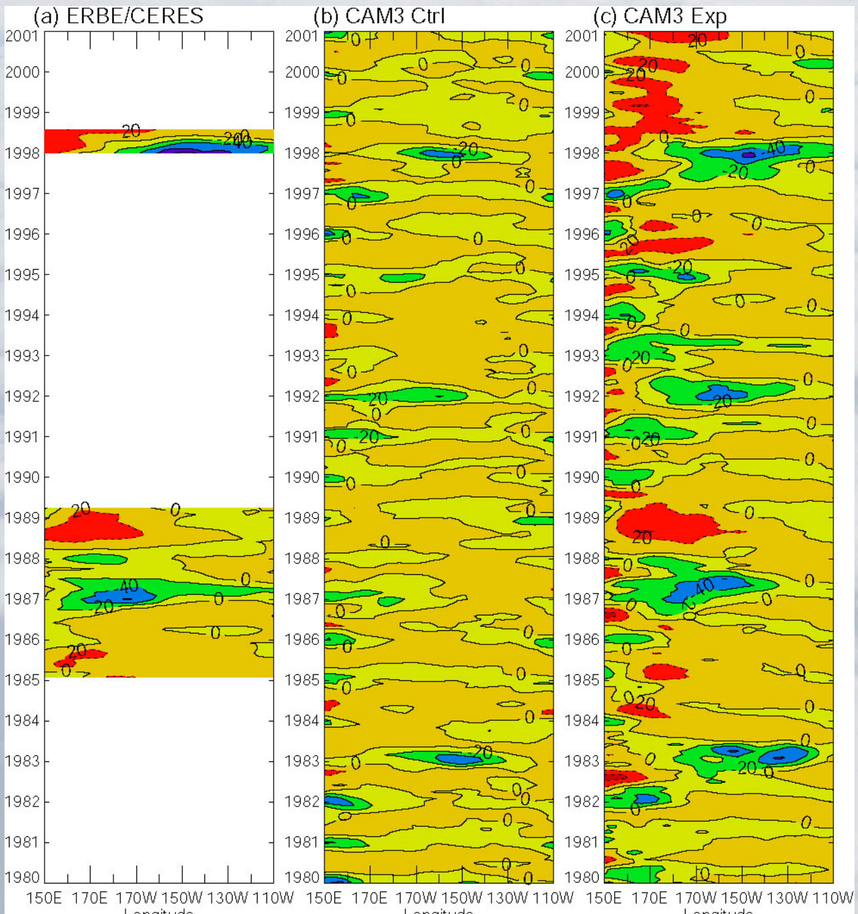
- Correlation between MSE STD and precip. rate shows that MSE STD leads precip. especially at the earlier stage of deep convection (data from SMOS and OK Mesonet)

Reference Poster: Zhang, Klein & Kollias

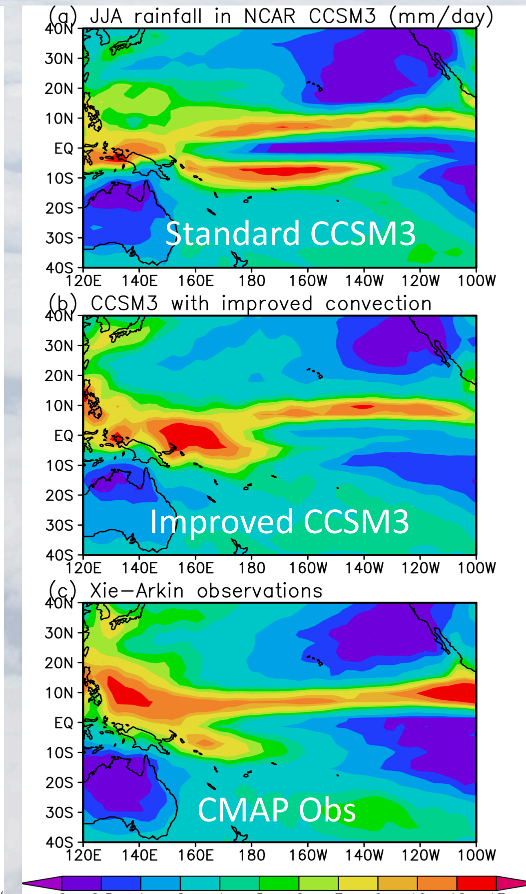
Using ARM data to improve convection parameterization and GCM simulations (Guang Zhang)

1. Improve cloud shortwave response to El Nino in NCAR CAM3 (Li and Zhang, JGR 2008)
2. Reduce double ITCZ biases in the NCAR CCSM3 (Zhang and Wang, GRL 2006)
3. Further improve convection parameterization by incorporating the effect of lateral entrainment in convection closure assumptions (Zhang JGR 2009)

ERBE/CERES **CTRL** **IMPROVED**



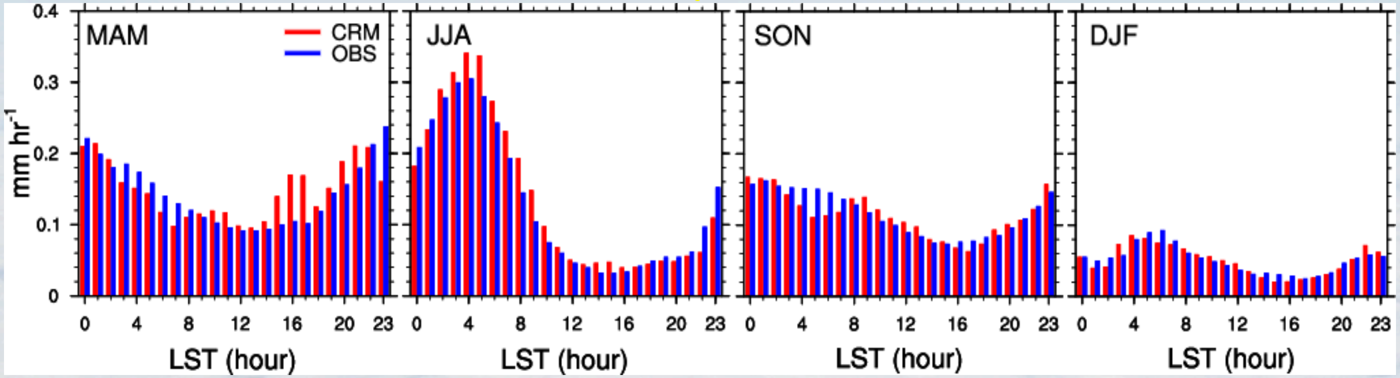
SWCF response to El Nino



Double ITCZ

ARM data used for convection parameterization development and improvement: SGP and TWP-ICE SCM Forcing data, C-Pol Radar data

Diurnal variation of precipitation from ISUCRM and ARM observations over the SGP in four seasons of year 2000 (Wu et al. 2008, JAS)

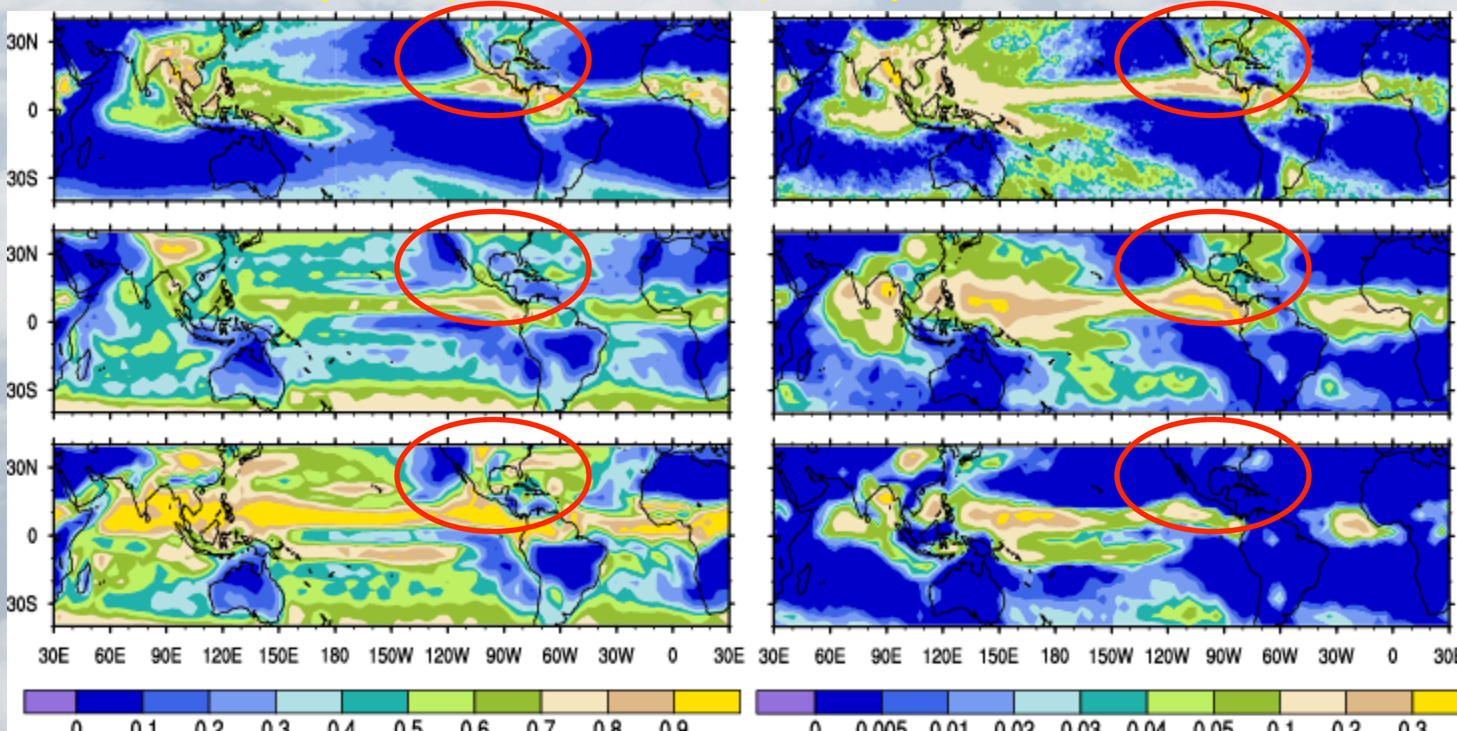


Summer (JJA) precipitation frequency (Wu et al. 2007, GRL)

TRMM

ISUGCM

CCSM



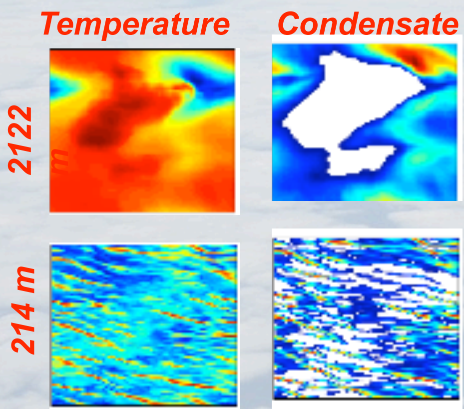
Daily rain rate > 1 mm day^{-1} Daily rain rate > 20 mm day^{-1}

Cloud Overlap Modeling with Gaussian Copulas

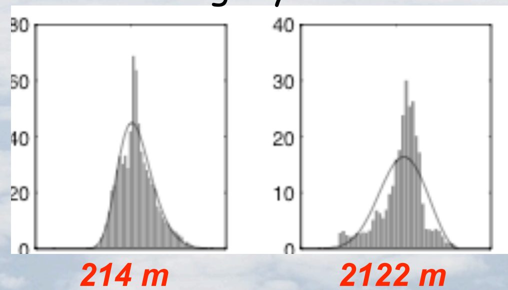
(Norris, Oreopoulos, Hou, Tao, Zeng)

POSTER 12J

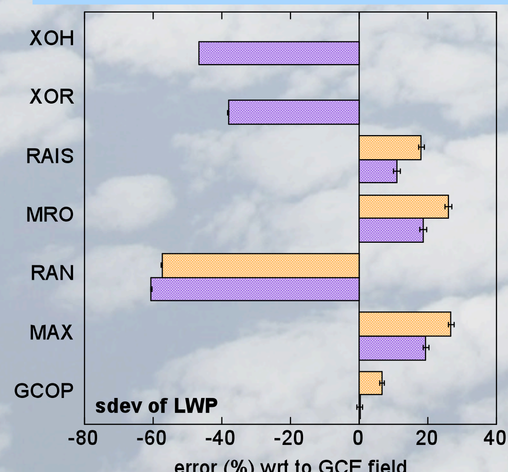
CRM application (Norris et al., QJRMS, 2008)

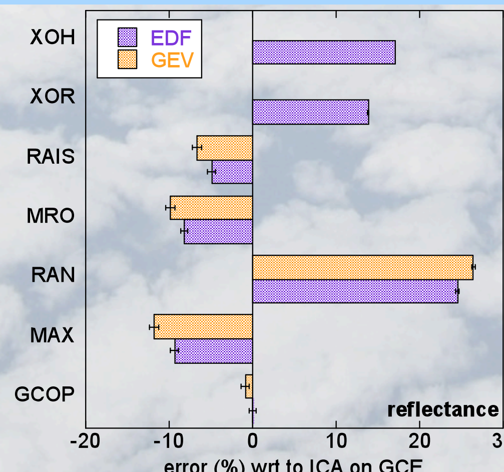


Modeling layer PDFs



GCOP=Gaussian Copula
MAX=Maximum Overlap
RAN=Random Overlap
RAIS=Räisänen-like generalized overlap
XOR=Exact overlap, randomized WC
XOH=Exact overlap, homogenized WC
MRO=Maximum Random Overlap (Geleyn & Hollingsworth)

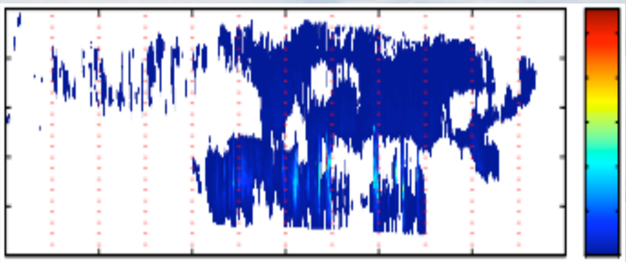




average of 100 ICA realizations of 128x128 subcolumns

ARM application (see Norris et al., poster)

Microbase 10 sec data



- Copula fits are possible if enough of the condensed tail of the total water distribut-ion is observable.
- The variance of copula-generated IWP fields agree fairly well with that of original fields.
- Parameterization of the copula covariance matrix will advance GCM cloud overlap.

ARM Project Title: Development of ensemble neural network convection parameterizations for climate models using ARM data

PI: M. Fox-Rabinovitz (University of Maryland (UMD)), Co-PI: V. Krasnopolsky (UMD and NCEP), POSTER 4H
Co-I: P. Rasch (DOE PNNL and NCAR), Collaborators: Y. Kogan (OU), and A. Belochitski (UMD)

Project Period: 08/01/08 - -7/31/11, *Acknowledgements:* Prof. M. Hairoutdinov, SUNY, Dr. P. Blossey, UWA

The research is aimed at development of novel and more sophisticated and fast convection parameterizations for multi-scale complex systems climate models based on applying statistical learning techniques, namely Neural Networks (NN), i.e. on direct learning cloud physics from simulated SAM/CRM data. NN serves as an interface transferring information about sub-grid scale processes from fine scale data or models (CRMs) into larger scale GCMs (i.e., for upscaling). The impact of the choice of inputs/ outputs for developing NN convection parameterizations on their accuracy is shown in Figs. 1, 2.

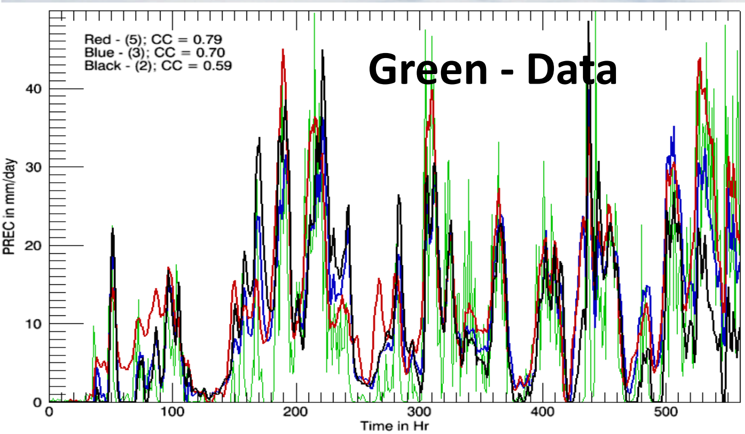


Fig. 1 NN Performance - PREC

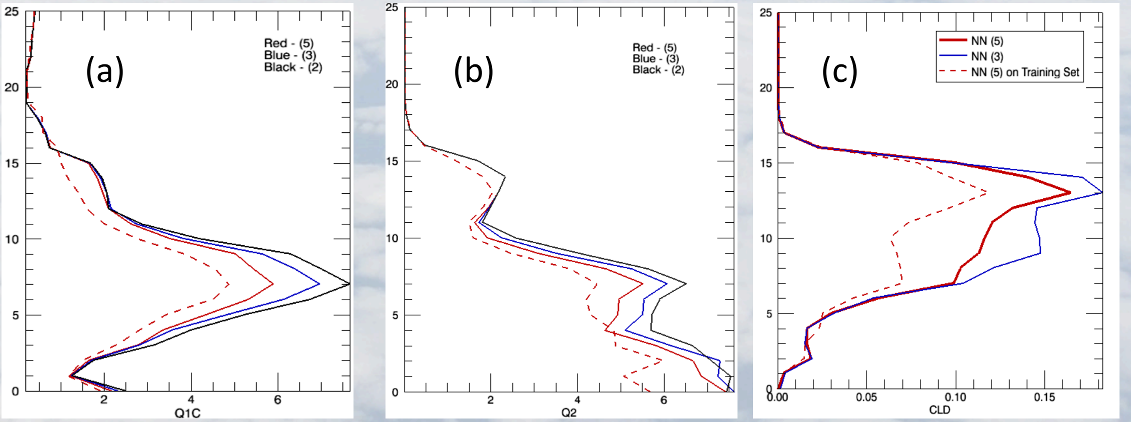


Fig. 2 NN Performance: for (a) Q1C, (b) Q2 (b), (c) Cloud Fraction (CLD)

NN Architectures (defined below in Conclusions, item 4): Black – (2), Blue – (3), Red - (5), Red dashed – (5) on training set

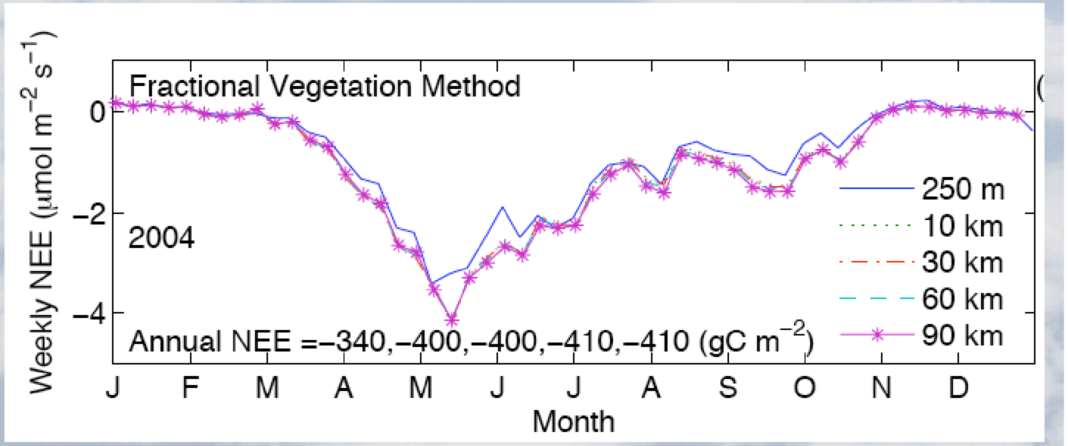
Conclusions:

1. Methodology for development of NN convection parameterizations for climate models based on learning from SAM simulated data has been formulated. ARM, TOGA-COARE and other relevant data are used for driving SAM simulations.
2. Training data sets have been produced using SAM simulated ensemble data produced with different initial conditions.
3. NN convection parameterizations with different NN architectures have been developed and their accuracy estimated. Errors for precipitation, Q1C & Q2, and CLD decrease for the NN architecture (5) vs. the NN architectures (2) and (3).
4. Significant improvement is obtained for NN precipitation accuracy (Fig. 1): CC (Correlation Coefficient) increases: (a) from CC = 0.59 for the NN Architecture (2) with Inputs: temperature (TABS) and water vapor (QV) profiles and Outputs: Q1, Q2, and PREC profiles; (b) to CC = 0.70 for the NN Architecture (3) with the additional Input: the vertical velocity (W) profile; (c) to CC = 0.79 for the NN Architecture (5) with the additional Output: the cloud fraction (CLD) profile. Q1C, Q2, CLD also improved for (5) (Fig. 2).

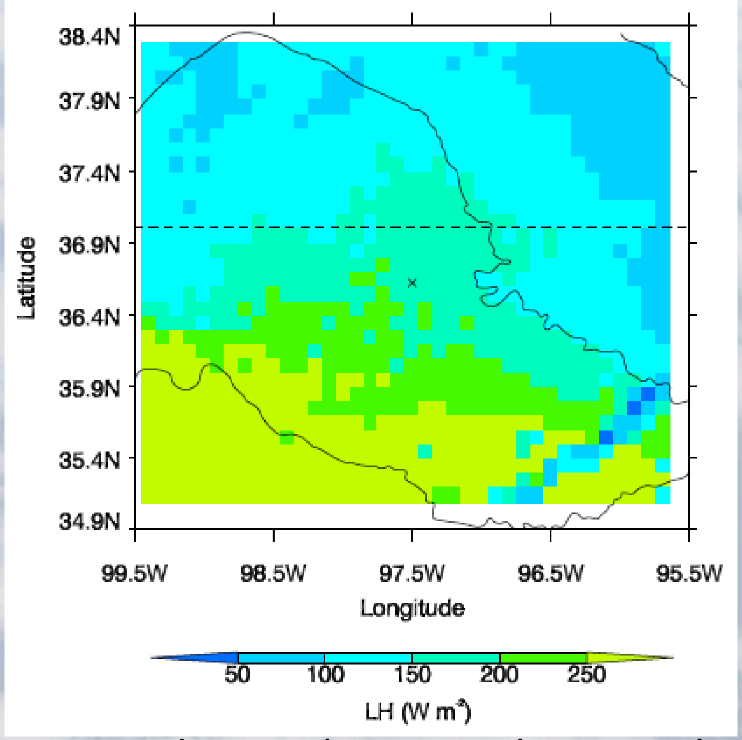
ACRF CO_2, LH, and SH Exchanges

Riley et al. (submitted JGR-B; 2009)

- Integrated climate forcing, satellite observations, eddy covariance measurements, and a land-surface model
- Land-cover heterogeneity strongly affected flux estimates



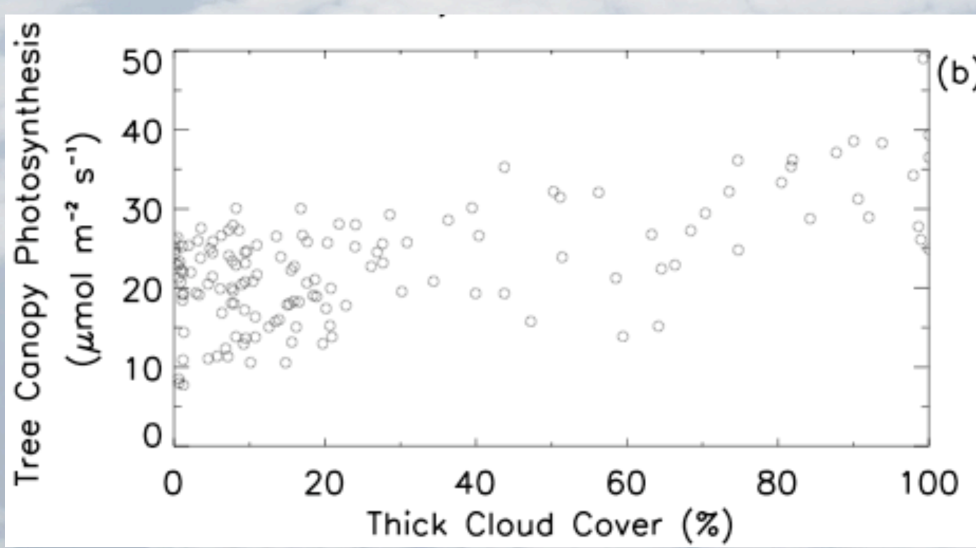
Predicted regional ACRF CO_2 fluxes differed by up to 20% as the resolution changed.

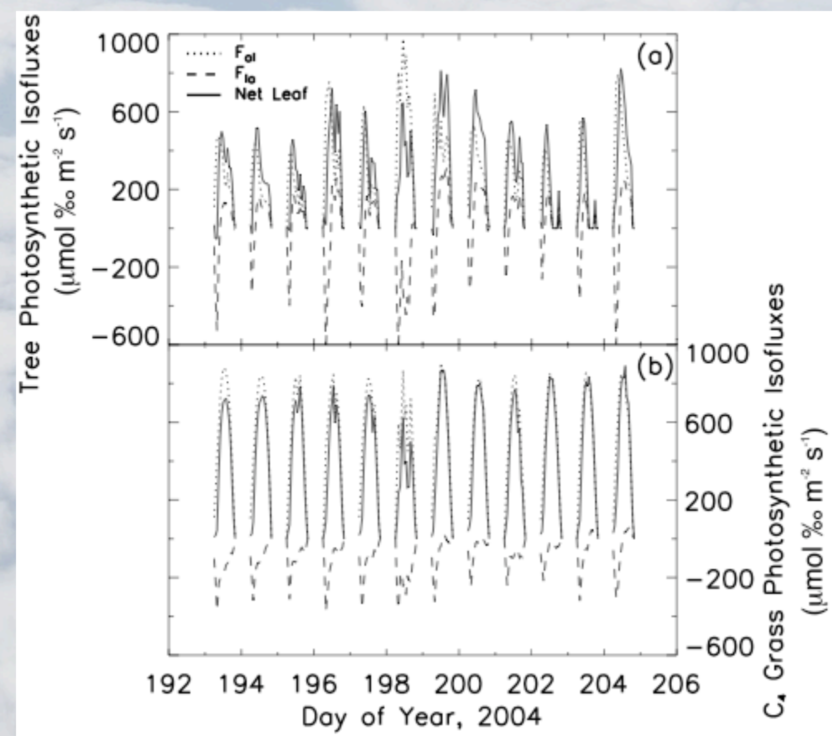


Noon LH fluxes varied strongly across the ACRF, but are less heterogeneous than CO_2 fluxes.

Clouds and Diffuse Radiation Impacts on Surface Fluxes

- Isotopes (I.e., ^{18}O) in H_2O and CO_2 reflect surface exchange variations
  - Used ACRF CF 60 m tower data for model forcing
- Clouds have a large impact on ecosystem CO_2 and H_2O fluxes, and on leafwater $\delta^{18}O$ values and $C^{18}OO$ exchanges
  - Despite lower irradiance under clouds, predicted forest photosynthesis was higher than on clear days; opposite effect was predicted for grasses
  - Highest tree canopy $C^{18}OO$ fluxes under partly cloudy conditions; highest grass canopy $C^{18}OO$ fluxes under clear skies





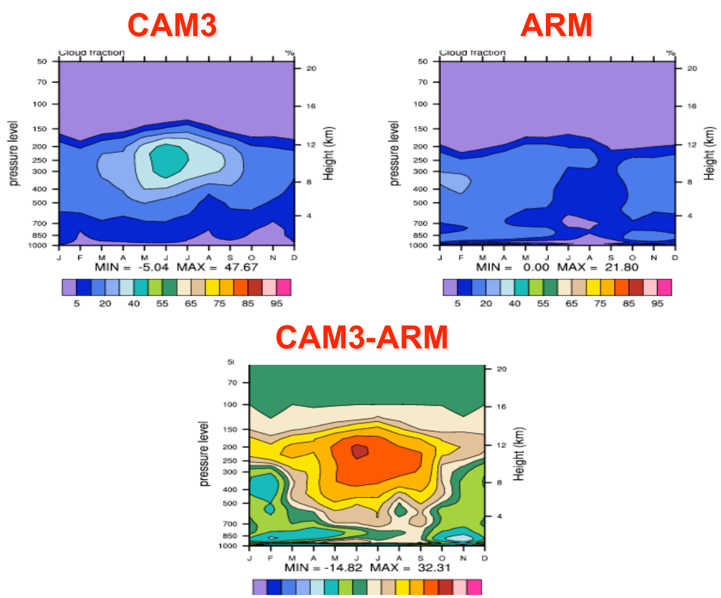
Still, Riley et al. *JGR-B* 2009

Climate Modeling Best Estimate (CMBE) Data Used in NCAR and GFDL (Xie, Klein, et al.)

POSTER 12L

NCAR CAM3

Seasonal Variation of Clouds at SGP



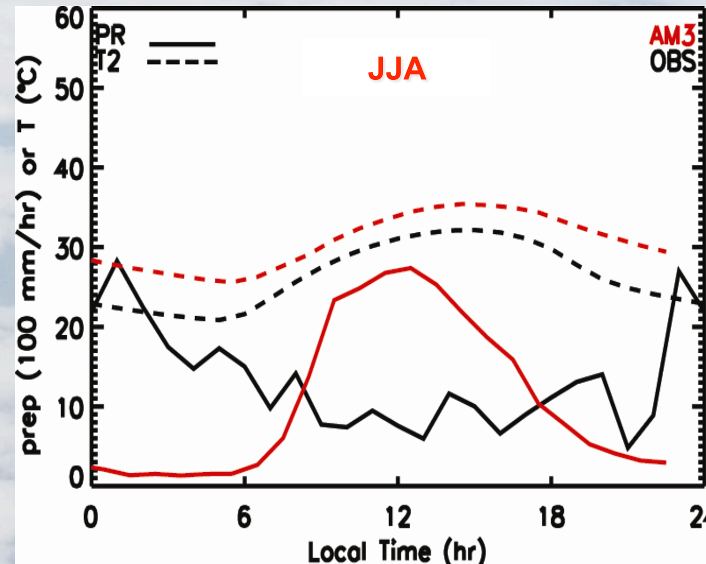
(Courtesy of R. Neale of NCAR)

CAM3 produces too much high cloud in warm season (May-Sept) and less mid- or low-level cloud in cold season (Oct. – April) at SGP .

GFDL AM3

POSTER 4K

Diurnal Cycle of T2m and Precip at SGP



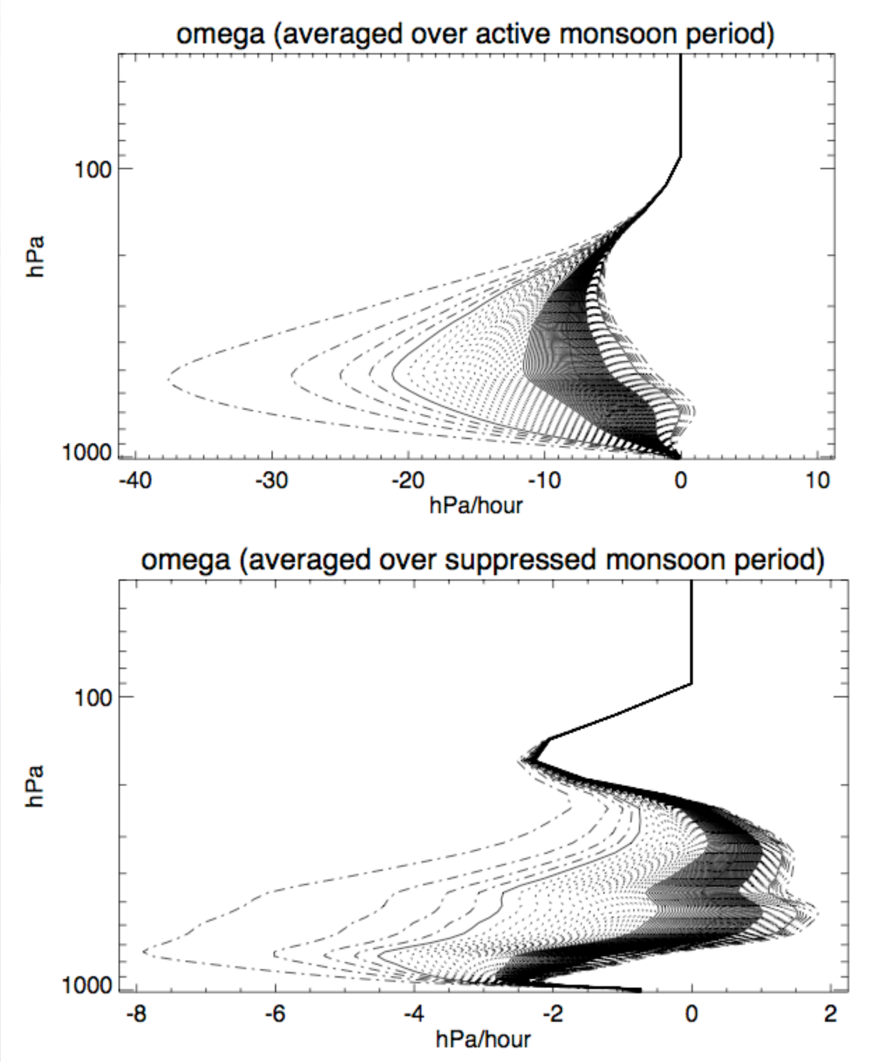
(Courtesy of Y. Lin of GFDL)

AM3 shows a warm bias in 2 meter temperature and fails to capture nocturnal precipitation during the summer months at SGP.

TWP-ICE Break-out @ 3:30-5 PM

Ensemble Forcing data sets

(Jakob et al.)



- Method:
- Estimate errors in rainfall retrievals from radar
- Feed rainfall pdf into variational analysis to provide 100 forcing data sets
- Available data:
- The method has been successfully applied to the TWP-ICE period
- Data is available through the TWP-ICE SCM intercomparison
- Future plans:
- Work on creating a continuous ensemble forcing set for two full wet seasons at Darwin is almost complete.

ACRF Data ↔ Modeling Skill

- Model intercomparisons
  - M-PACE (NSA)
  - TWP-ICE (TWP)
  - ISDAC (NSA)
- Other scientific accomplishments
- Science plan contributions
  - Priority science questions
  - Data needs

Science Plan Input

- What are the outstanding aerosol, cloud, radiation and precipitation questions for ARM science in the next five years?
  - Better understanding of the entrainment at the PBL top for shallow cumulus clouds
  - Better understanding of the interactions among cirrus, stratiform anvils, convective updrafts and downdrafts, entrainment, and PBL inhomogeneities that trigger convection
  - Almost every aspect of convection (closure, trigger, entrainment effects), ice nucleation, ice microphysics, and ice fall speeds, and precipitation overlap, as well as cloud fraction and PDF condensate overlap
  - Better understanding of the behavior of oceanic versus land convection
  - Better understanding of the interactions and feedbacks between cloud dynamics and cloud microphysics, including but not limited to the role of aerosols
  - Better understanding of the role of ice nuclei in the climate system
  - Some continued focus on the radiative impact of various cloud types (may be wise to use findings from cloud-climate feedback studies to provide this focus)
  - Better understanding of global dimming and brightening phenomena
  - Evaluations of the above processes in CRM/LES and parameterization in GCMs

Science Plan Input

- What ARM observations and data products are needed to address these questions? Are current ARM locations sufficient?
  - Properties of precipitating clouds
  - Vertical velocities in both non-precipitating and precipitating clouds and also in clear air (perhaps from doppler lidar just beneath cloud base)
  - Collocated measurements of cloud properties, aerosols and cloud-scale vertical velocity, as well as the large-scale conditions in which the cloud fields are embedded
  - Cloud particle size, number concentration, size distribution parameters
  - Better mixed phase detection
  - Ice nucleus measurements
  - Integrated retrievals that are time continuous and have adaptive error bars
  - Ensemble forcing data sets
  - Of course the current locations are not sufficient
  - A TWP site with a weather radar would be good (e.g., Kwajalein)

Science Plan Input

- How can ARM be more effective in improving aerosol, cloud, radiation and precipitation parameterizations in global climate models?
  - Provide first order variables for convenient use by the modeling community, such as cloudiness and aerosol optical depth
  - Support and expand VAPs (in particular the CMBE) because the data base is still hard for modelers to use
  - Organize IOP campaigns in which people with interests in observations, process understanding, and modeling truly work together
  - Work and leverage with other programs such as DOE ASP, NASA to obtain coordinated measurements
  - Support further evaluation of LES and CRM models
  - Support further development of methodologies that evaluate simulated precipitation, such as the GCM NWP-mode framework (CAPT)

Science Plan Input

- How can ARM science be more effective in addressing the outstanding science questions identified by organizations such as the Intergovernmental Panel on Climate Change and the National Academy of Sciences?
  - Reduce uncertainties associated with (understand) cloud-climate feedbacks
  - Understand aerosol indirect effects in climate models
  - To address IPCC concerns about low-level clouds, deploy in trade Cu
  - Encourage ARM scientists to participate in the national and international assessment processes (built-in mechanism needed?)

ACRF Data ↔ Modeling Skill

- Today
  - Tony Del Genio, NASA GISS: The Role of Entrainment in the Transition from Shallow to Deep Convection
  - Yanluan Lin, NOAA GFDL: A New Ice Fall Speed Parameterization Considering Riming and Its Tests in the Geophysical Fluid Dynamics Laboratory (GFDL) Global Climate Model (GCM)
  - Maike Alhgrimm, ECMWF: Evaluation of Shallow Convective Cloudiness Across European Centre for Medium-range Weather Forecasts (ECMWF) Model Cycles
  - Jerome Fast: The Aerosol Modeling Testbed: A Community Tool to Objectively Evaluate Aerosol Process Modules
- Tomorrow
  - Seoung-Soo Lee: Aerosol Effects on Liquid Water Path of Thin Stratocumulus Clouds
  - Hugh Morrison, NCAR: A Novel Approach for Treating Ice Microphysics in Bulk and Bin Schemes: Application to TWP-ICE Deep Convection
  - Martial Haeffelin: Cirrus Cloud Radiative Forcing on Surface-level Shortwave and Longwave Irradiances at Regional and Global Scale