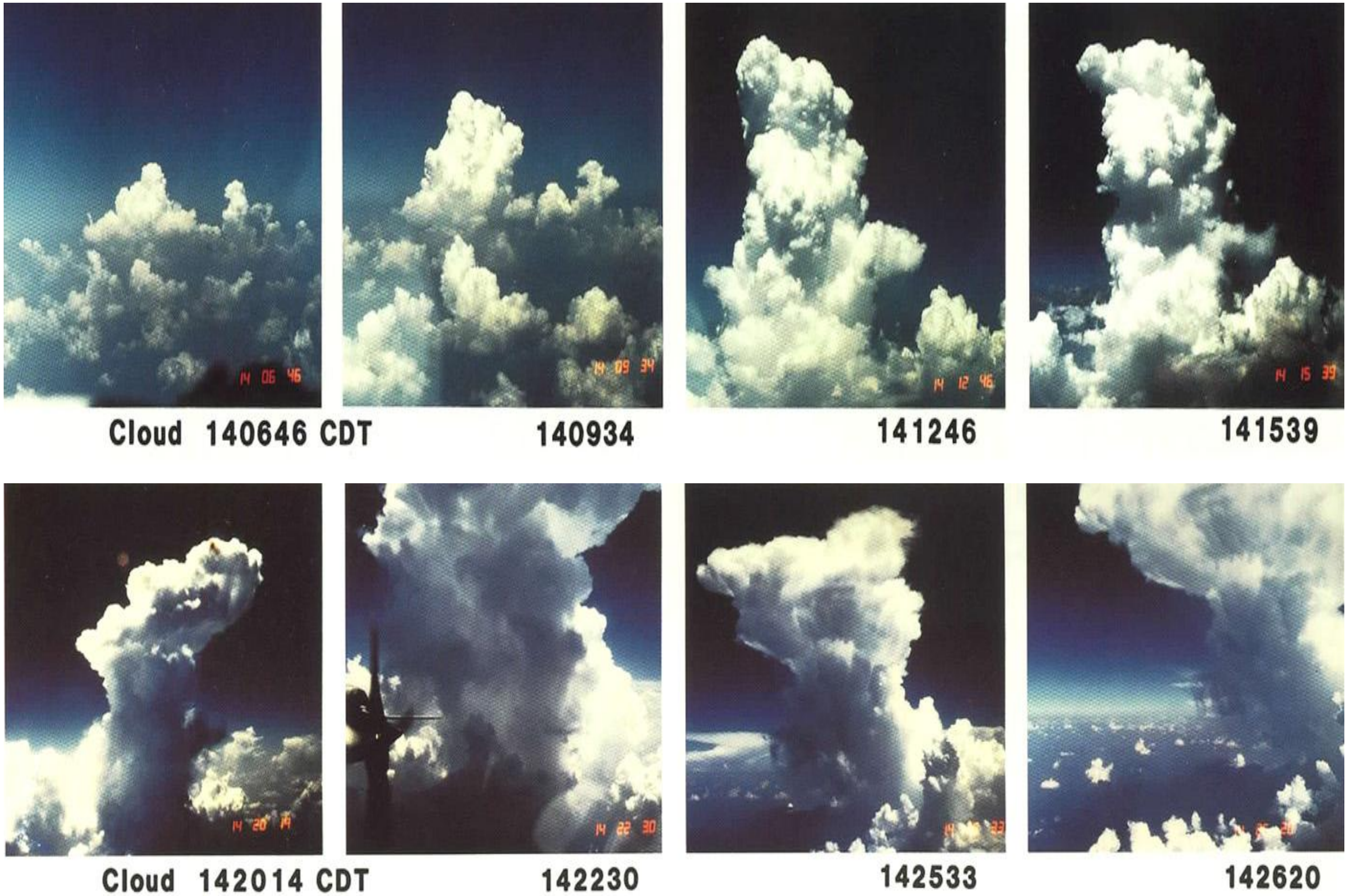


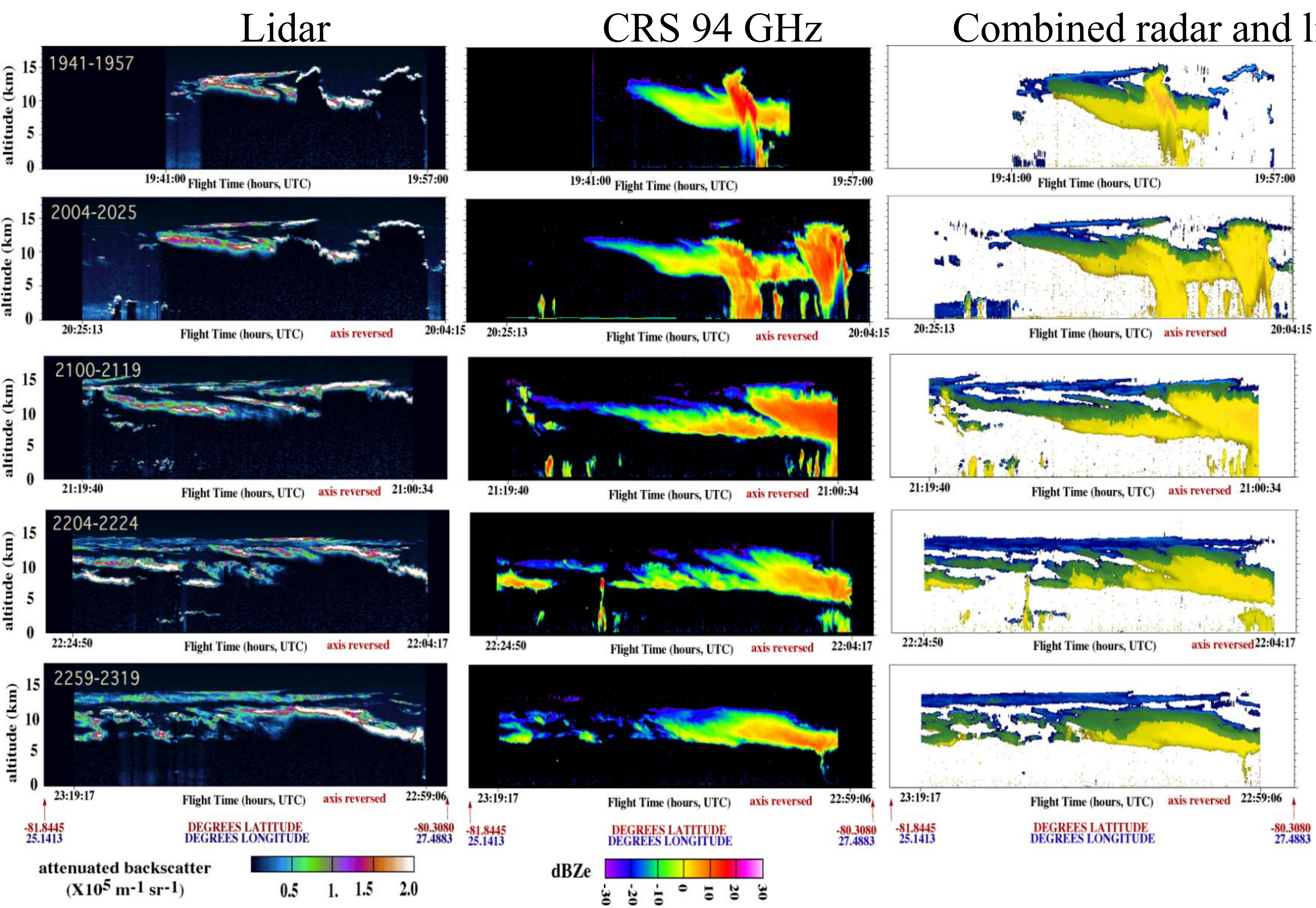
T. Fujita

In 20 minutes period: Cloud Mergers, Turbulence, Microphysics, Dynamic, and Radiation

Cloud Resolving Model Simulation: can capture observed cloud evolution with improved microphysics and with 250 m grid spacing, 3 second time step

1/30

Evolution of Convection and Cirrus Layers



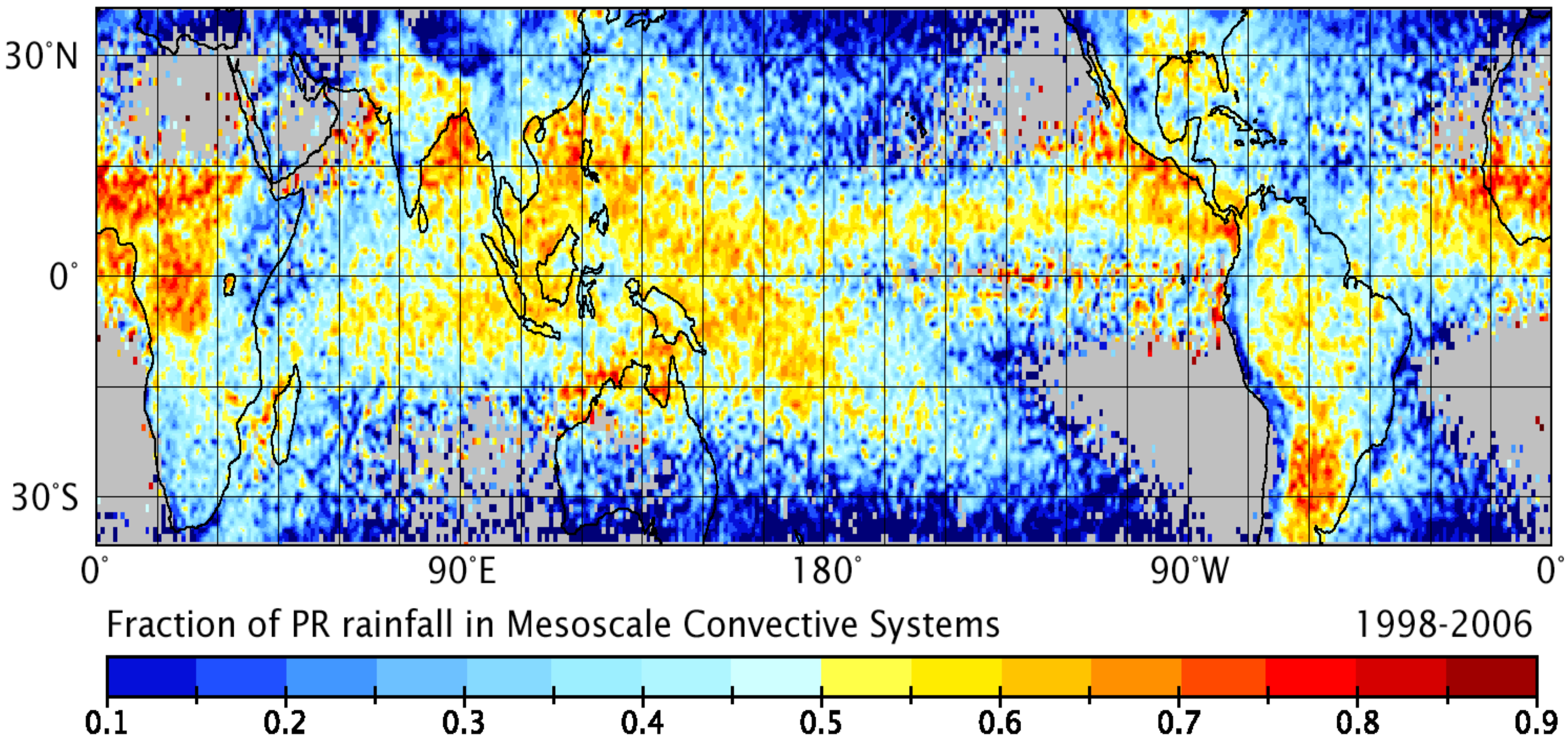
7 min

~1 hr

Horizontal scale: 150 km

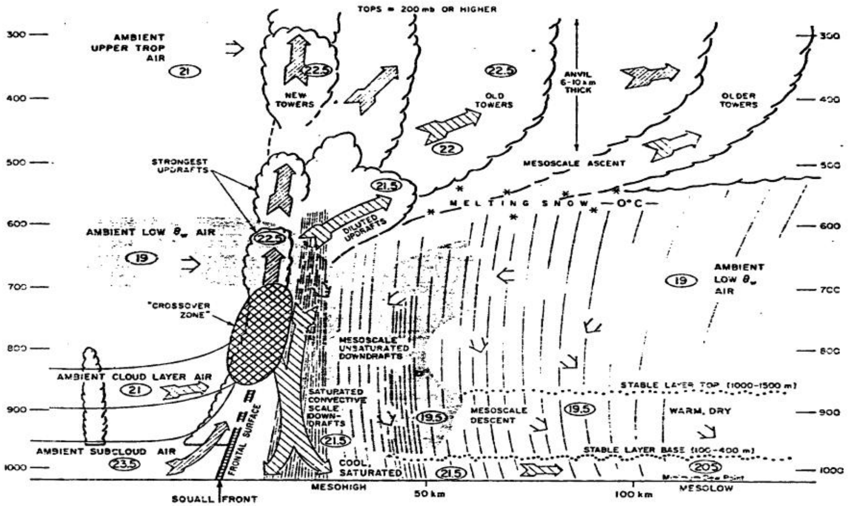
G. Heymsfield

Importance of MCSs in contribution of global precipitating processes



Fraction of estimated rainfall from precipitation features >= 100 km in maximum dimension as measured by the **TRMM precipitation radar (PR) from January 1998 through December 2006** using the methodology of Nesbitt *et al.* (2006).

Mesoscale Convective Systems contribute ~ 50% rainfall globally

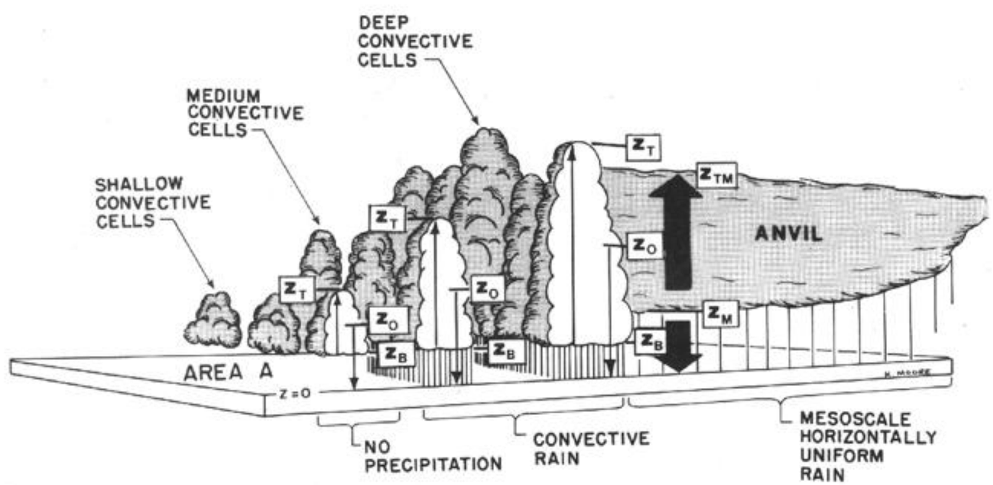


Idealization of a tropical oceanic mesoscale convective system with leading-line/trailing stratiform structure. Parcels of subcloud boundary layer air rise and form the basic convective updrafts. Ambient cloud layer air is entrained into the updrafts. The updraft parcels rise till they lose their boundary by entrainment or by encountering a stable layer in the environment. Entrainment of ambient low equivalent-potential-temperature Air weakens updrafts and forms convective-scale downdrafts, which sink to the surface in the convective precipitation zone. Note that the system has three-dimensionality such that the updraft and downdraft trajectories are not collocated, and the convective region contains a "crossover zone" where convective-scale updrafts and downdrafts coexist. Adapted from Zipser (1977).

Zipser, E. J., 1977: Mesoscale and convective-scale downdrafts as distinct components of squall-line structure. Mon. Wea. Rev., 105, 1568-1589.

GATE (1974): Mesoscale Features & Stratiform Precipitation

Schematic of a typical population of clouds over a tropical ocean. Thin arrows represent convective-scale updrafts and downdrafts. Wide arrows represent mesoscale updrafts and downdrafts. Other details and symbols are described in the text. Adapted from Houze et al. (1980).



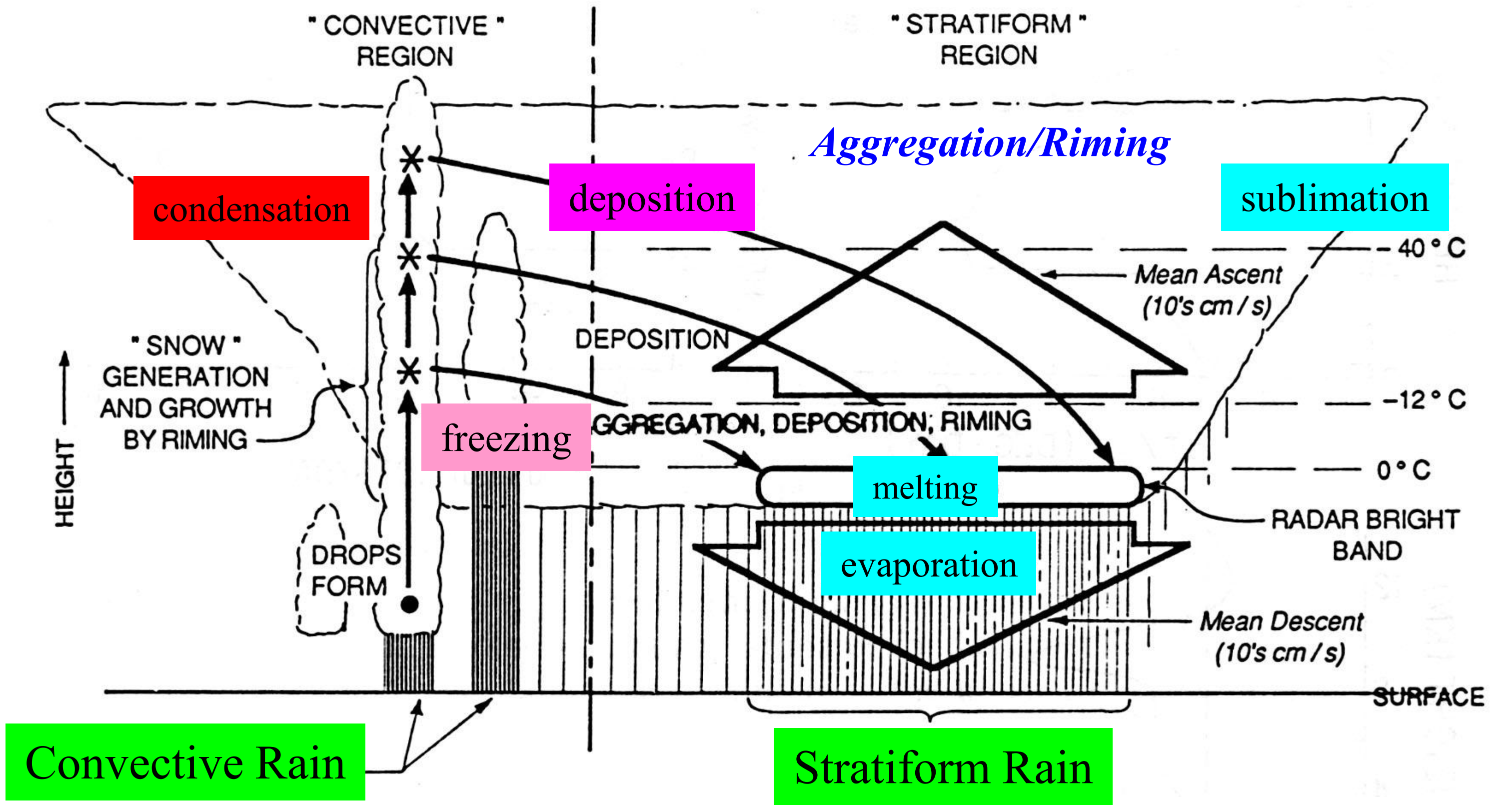
Houze, R. A., Jr., C.-C. Cheng, C. A. Leary, and J. F. Gamache, Diagnosis of cloud mass and heat fluxes from radar and synoptic data. J. Atmos. Sci., 37. 754-773.

Vertical profiles of microphysics (heating) for idealized convective systems

~50% rainfall contributed by the convective systems (with large stratiform cloud)

Where is the origins of growth mechanisms of particles in stratiform region?

Mesoscale ascending and/or horizontal fluxes of hydrometeors from convective region



Schematic of a microphysical processes associated with a tropical mesoscale convective system in its mature stages. Straight, solid arrows indicate convective updraft, wide, open arrows indicate mesoscale ascent and subsidence in the stratiform region Where vapor deposition and evaporation occur. Adapted from Houze (1989).

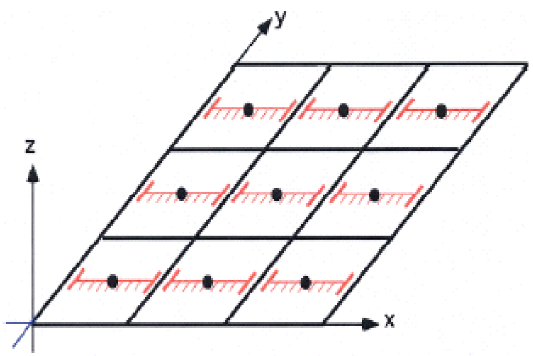
Houze, 1989: Observed structure of mesoscale convective systems and implications for large-scale heating. *Quart. J. Roy. Meteor. Soc.*, **115**, 425-461.

Type of Model (Spatial Scale)	Strengths	Weaknesses
GCMs (10^2 km)	Global Coverage Climate Change Assessment	Coarse Resolution Cumulus Parameterization
Regional Scale Models (10^1 - 10^0 km)	Regional Coverage – Regional Climate Better parameterization (nesting technology)	No Feedback to Global Circulation Case Study
Cloud Resolving Models (10^0 – 10^{-1} km)	Better physics Better Treatment of Cloud-Radiation Interaction	No Feedback to Global Circulation Small Domain Case Study (Field Campaign)
Coupled GCM-CRM (MMF) (2-4 km)	Global Coverage CRM-Based Physics	Computational Cost 2D CRM Embedded
Global Cloud Resolving Model (3.5 km)	Global Coverage CRM-Based Physics	Computational Cost Data Management/Analyses

MMF: Multi-scale Modeling framework

Computational Cost of MMF:

10^3 compared to 2.5° x 2.5° GCM
10^1 compared to 0.25° x 0.25° GCM
Same as 0.125° x 0.125° of GCM



Each GCM box - 2D CRM

Nesting: Cumulus parameterization is still needed

Microphysics in Multi-Scale Modeling System with Unified Physics

W.-K. Tao

Goddard Mesoscale Dynamic & Modeling Group

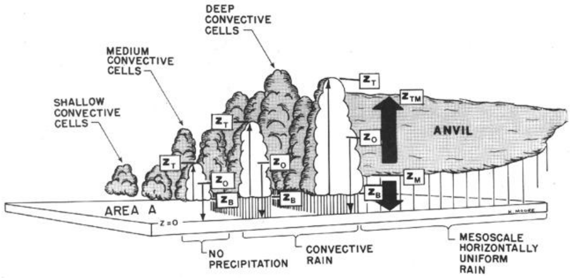
NASA Precipitation Measuring Mission (PMM), NASA Modeling Analyses Prediction (MAP), NASA Energy Water cycleS (NEWS), AIST

http://portal.nccs.nasa.gov/cloudlibrary/index2.html

Multi-Scale Modeling System with Unified Physics

Improvements and the Performances of the Multi-Scale Modeling System (CRM/microphysics – WRF/Typhoon case)?

Current & future Applications and Improvements (Global Modeling)



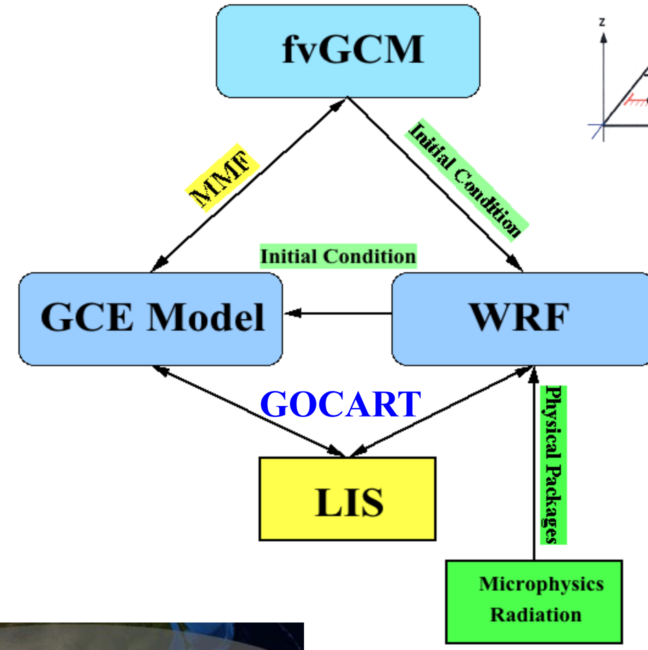
Local <----> Global

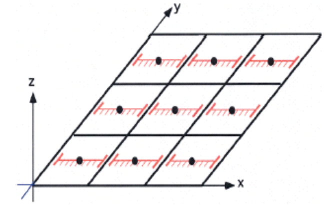
Meso-scale

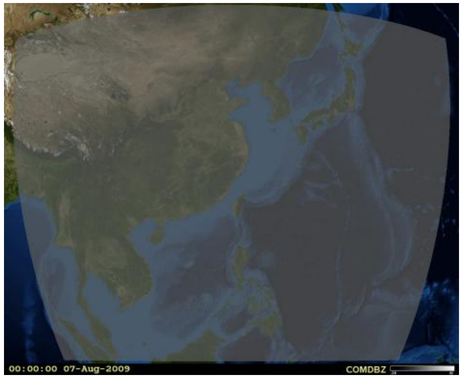
Goddard Multi-scale Modeling System with Unified Physics

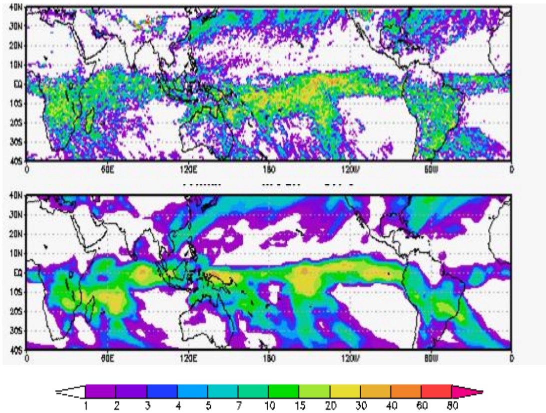
Recently, a multi-scale modeling system with unified physics was developed at NASA Goddard. It consists of **(1) the Goddard Cumulus Ensemble model (GCE), a cloud-resolving model (CRM), (2) the NASA unified Weather Research and Forecasting Model (WRF), a region-scale model, and (3) the coupled fvGCM-GCE, the GCE coupled to a general circulation model (or GCM known as the Goddard Multi-scale Modeling Framework or MMF).** The same cloud microphysical processes, long- and short-wave radiative transfer and land-surface processes are applied in all of the models to study explicit cloud-radiation and cloud-surface interactive processes in this multi-scale modeling system. This modeling system has been coupled with a multi-satellite simulator for comparison and validation with NASA high-resolution satellite data. The left figure shows the multi-scale modeling system with unified physics. The GCE and WRF share the same microphysical and radiative transfer processes (including the cloud-interaction) and land information system (LIS). The same GCE physics will also be utilized in the Goddard MMF.

The idea to have a multi-scale modeling system with unified physics is to be able to propagate improvements made to a physical process in one component into other components smoothly and efficiently.





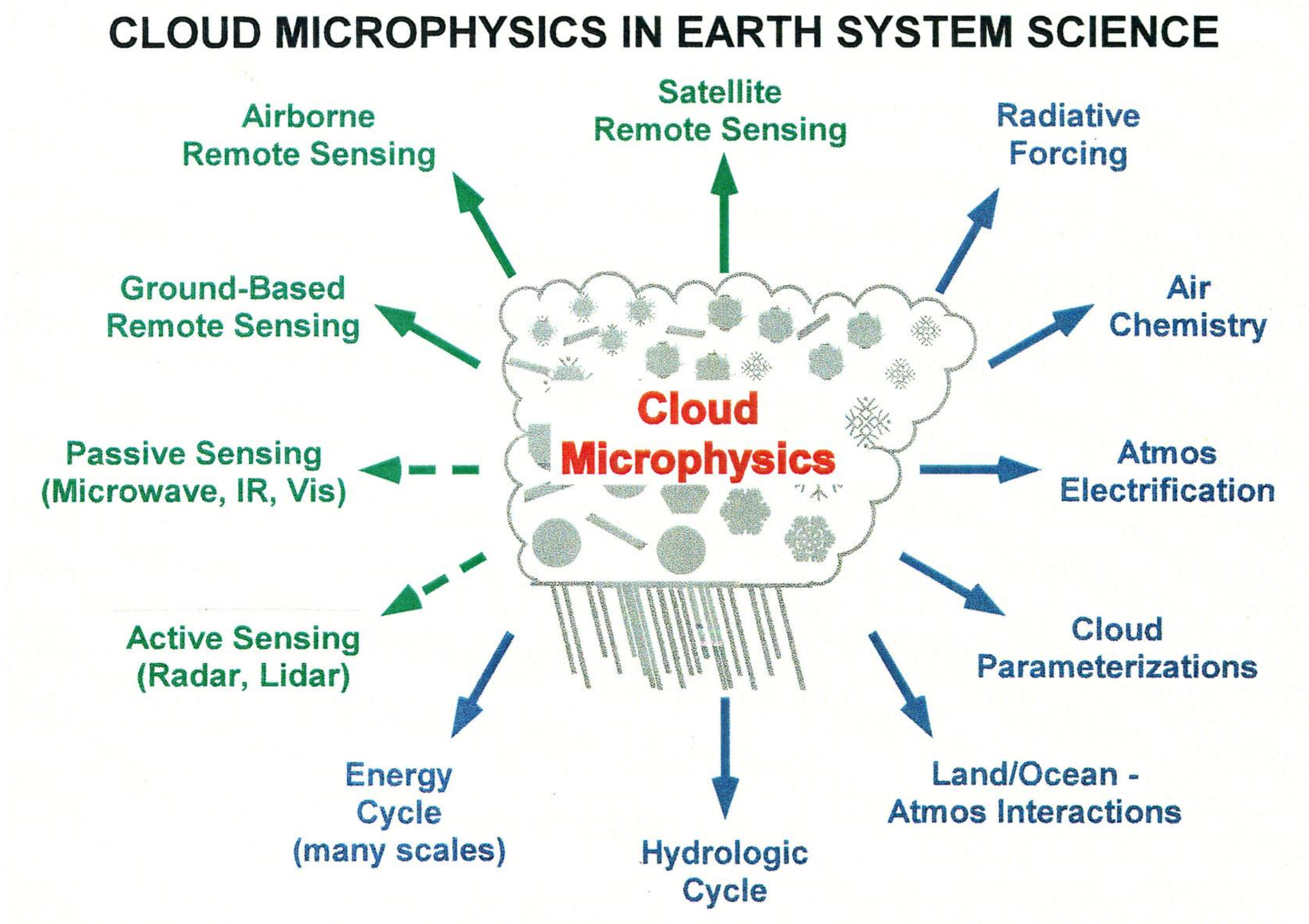




Left panel shows the WRF (1.67 km) Typhoon Katrina (2009) simulation.
Right panel shows the MMF simulated and TRMM observed rainfall.

MMF: Multi-Scale Modeling Framework
LIS: Land Information System
GCE: Goddard Cumulus Ensemble Model
WRF: Weather Research Forecast

Tao, W.-K., D. Anderson, J. Chern, J. Estin, A. Hou, P. Houser, R. Kakar, S. Lang, W. Lau, C. Peters-Lidard, X. Li, T. Matsui, M. Rienecker, M. R. Schoeberl B.-W. Shen, J.-J. Shi, and X. Zeng, 2009: Goddard Multi-Scale Modeling Systems with Unified Physics, *Annales Geophysics*, **27**, 3055-3064.



Schematic diagram showing the interactions between microphysics with other Erath System Science

Tao, W.-K., and M.Moncrieff, 2009;Multi-scale cloud system resolving modeling, Reviews of Geophysics.

Microphysics in GCE, WRF, MMF and Stretched Global CRM

One-Moment (Warm Rain only, 2ICE, 3ICE-graupel, 3ICE-hail) (Tao and Simpson 1993, Tao et al. 2003, Lang et al. 2007)

One-moment 3ICE-graupel but improved - reducing 40 dBz aloft (Lang et al. 2011 – in press, Tao et al. 2011)

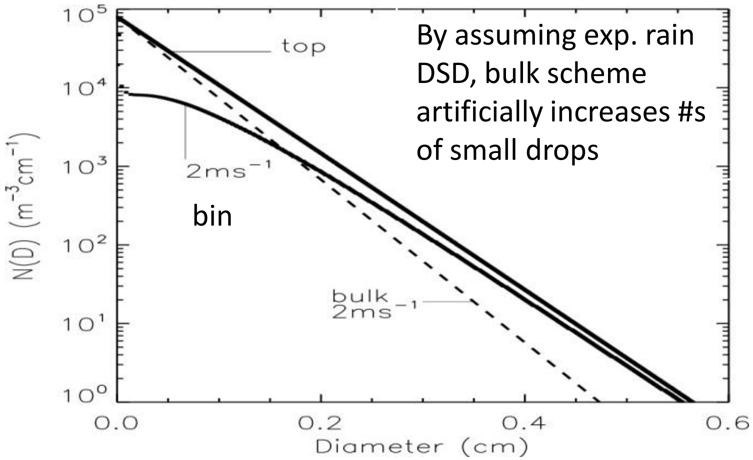
One-moment 3ICE-graupel - Temperature Dependent Drop Size Distribution (TeDD) (Matsui et al. 2009; Zeng et al. 2011)

One-moment - 4ICE (cloud ice, snow, graupel and hail)

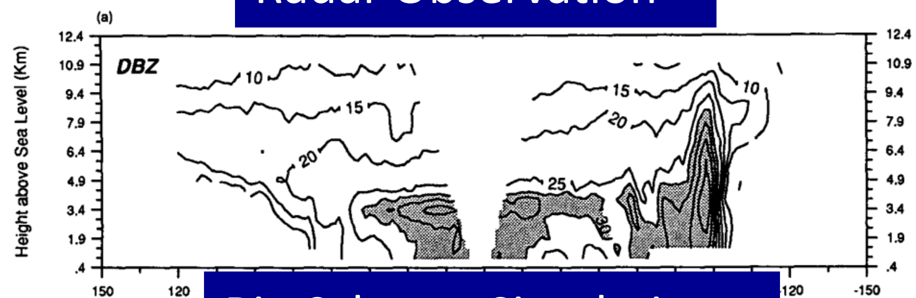
Two-moment - 2-liquid, 3ICE-graupel (based on spectral bin microphysics – could add more moments for chemistry, testing now)
30% more expensive than one-moment bulk scheme

Spectral bin microphysics (Tao et al. 2007; Li et al., 2009; Iguchi et al. 2011)
16 times or 1600% more expensive; 256 CPUs

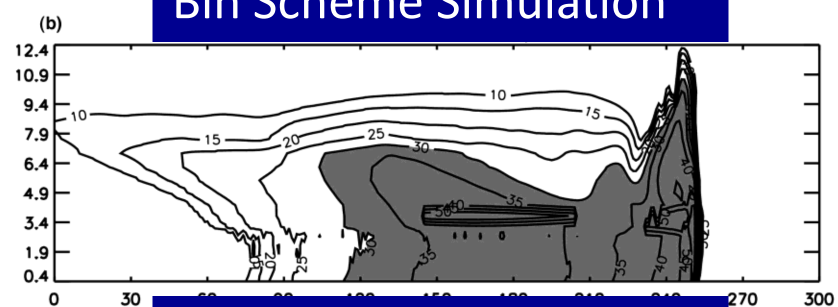
Improving Bulk Microphysics in GCE Using Bin Spectral Scheme (Li, Tao et al., JAS, 2009)



Radar Observation

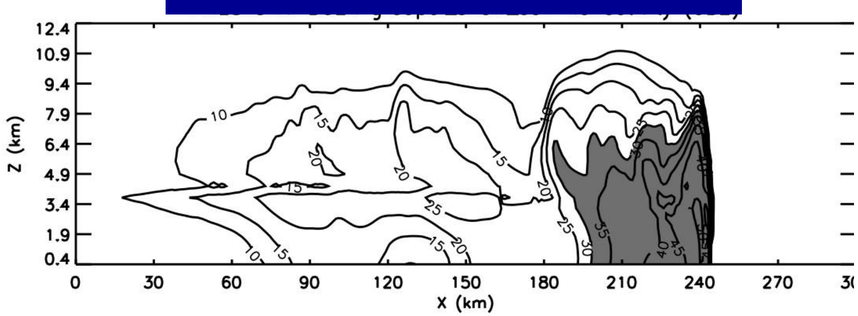


Bin Scheme Simulation

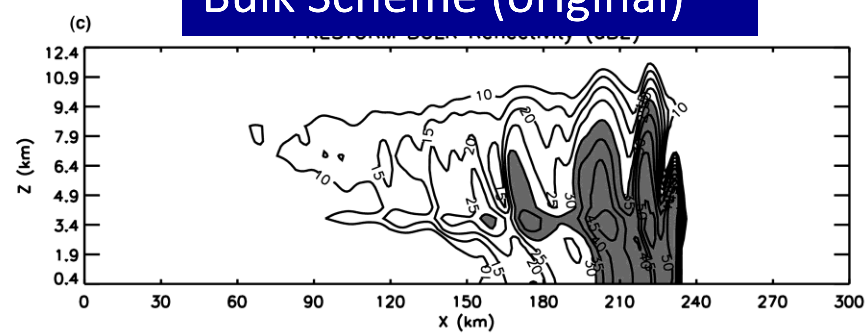


Bin Scheme is used to correct the overestimation of rain evaporation in bulk scheme and the density and fall speed of graupel in bulk scheme

Bulk Scheme (Tuned)

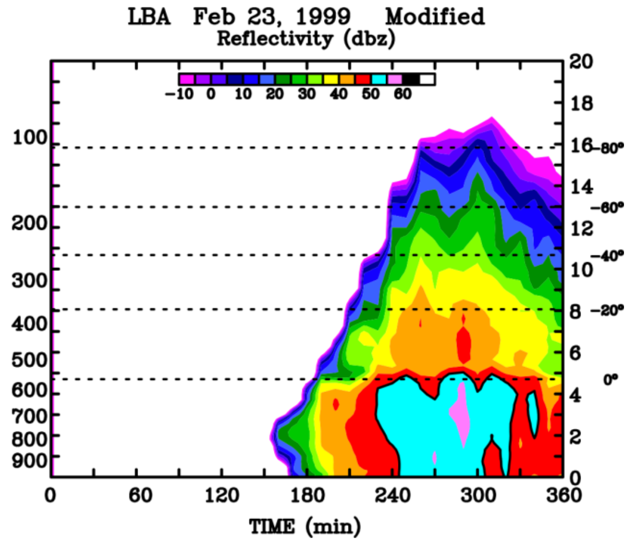


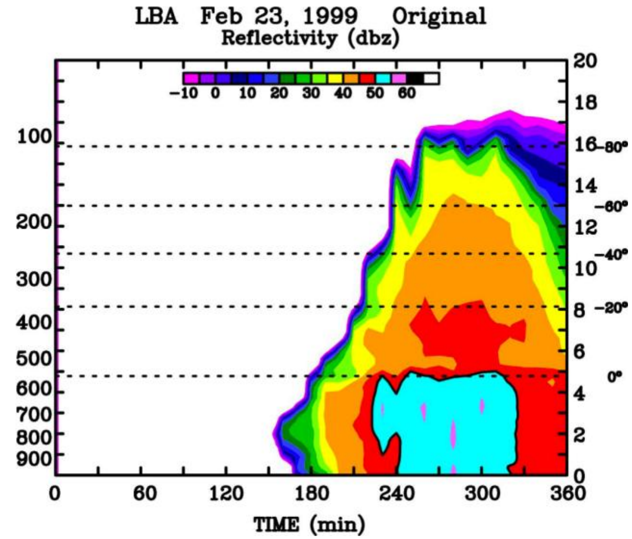
Bulk Scheme (original)



LBA (GCSS)

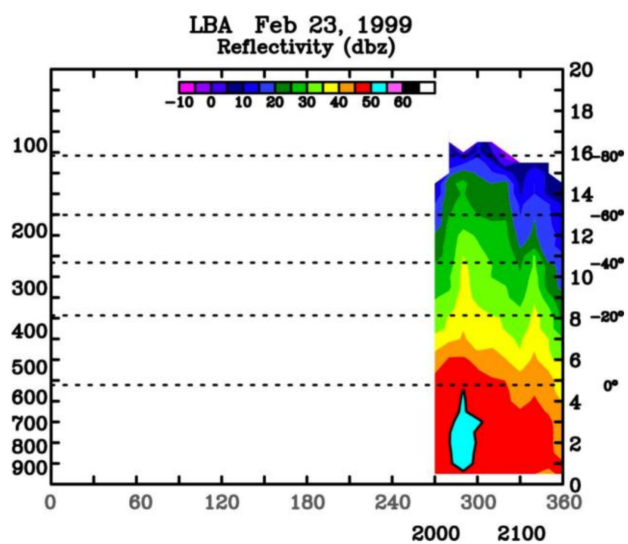
Improved

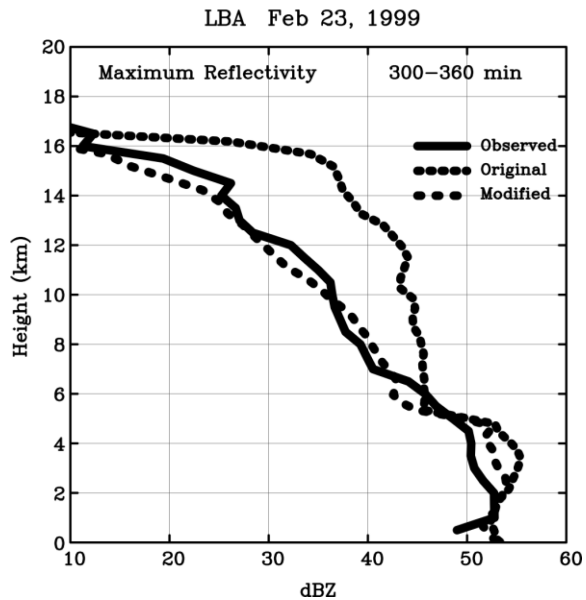




250 m resolution

Observed

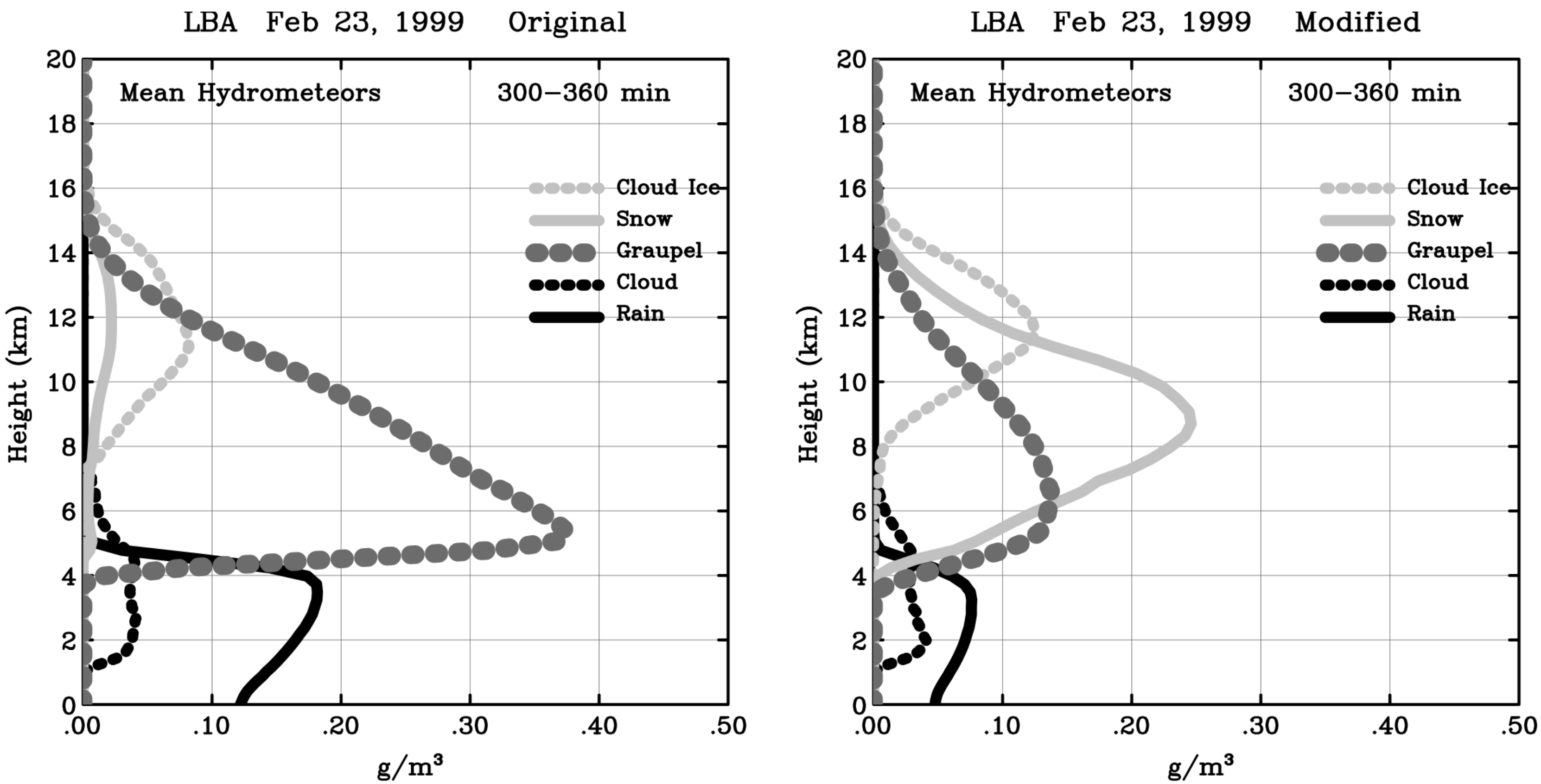




Lang et al. 2011

Reducing over-estimated 40 dBZ aloft

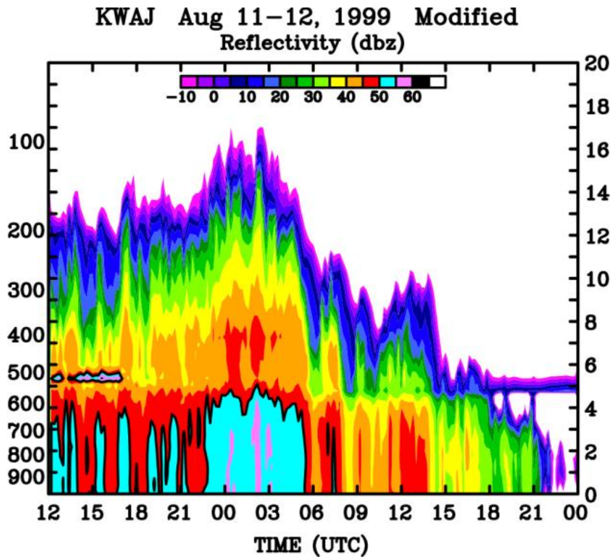
Improved

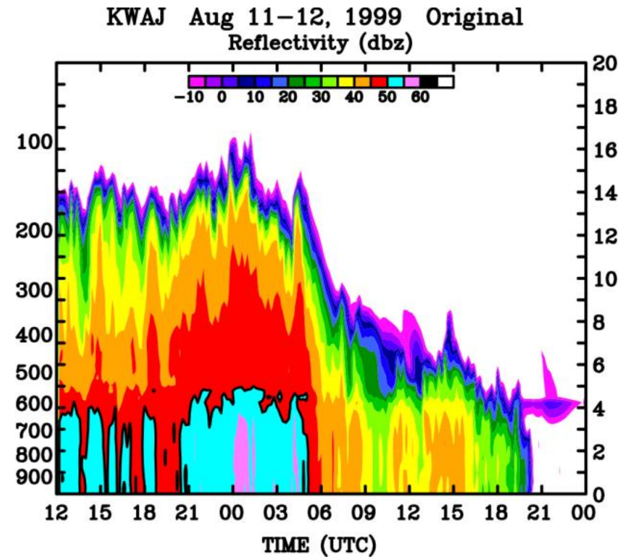


Reduce the graupel, but increase both cloud ice and snow
Reduce the rainfall due to less melting by smaller graupel
(not true for CRM simulation with fixed large-scale advective forcing

Lang et al. (2011)

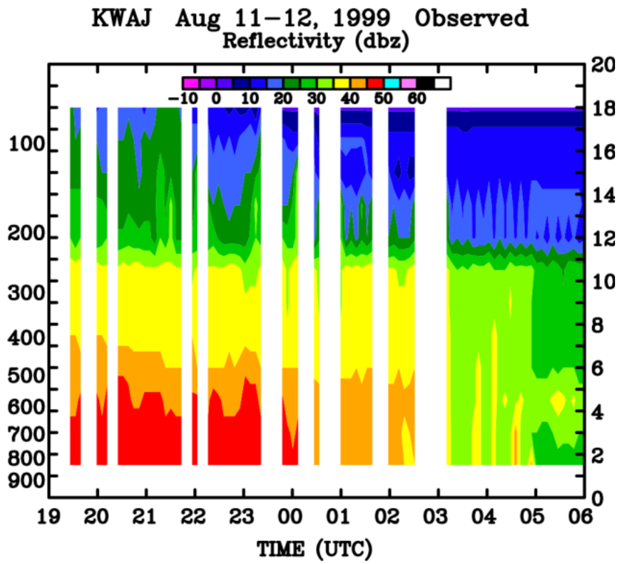
Improved

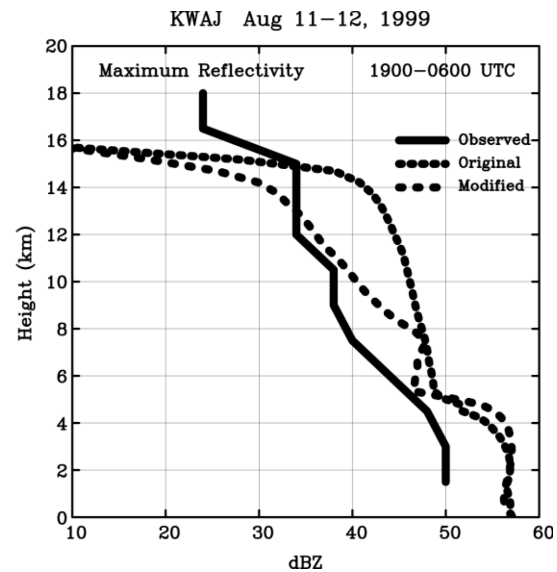




1 km resolution

Zipser's Group



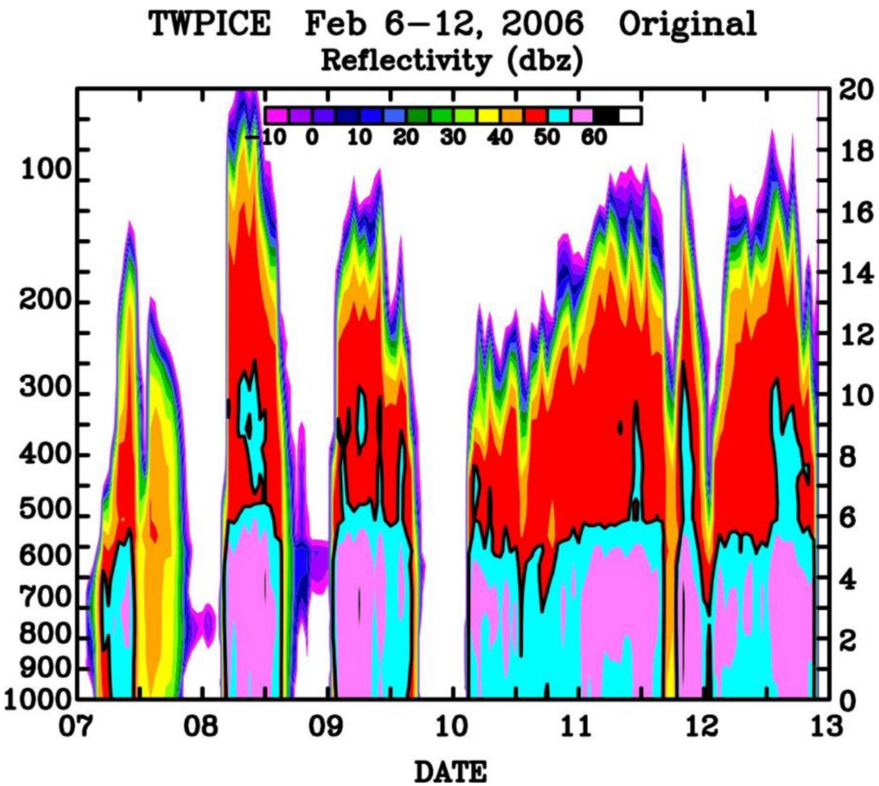


KWAJEX

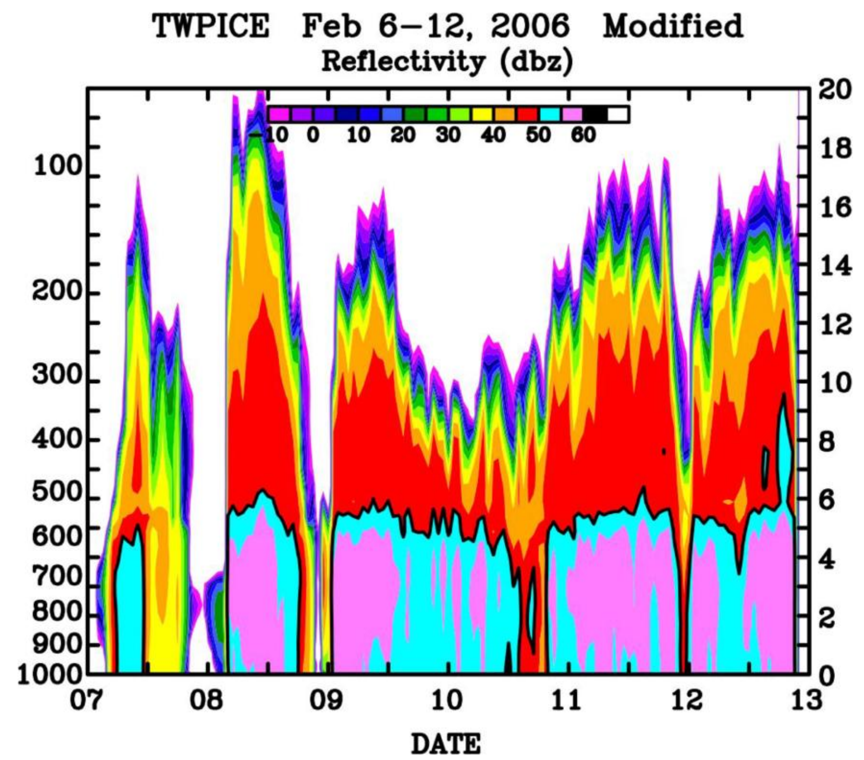
Lang et al. (2011)

TWPICE (*6 days*)

Original



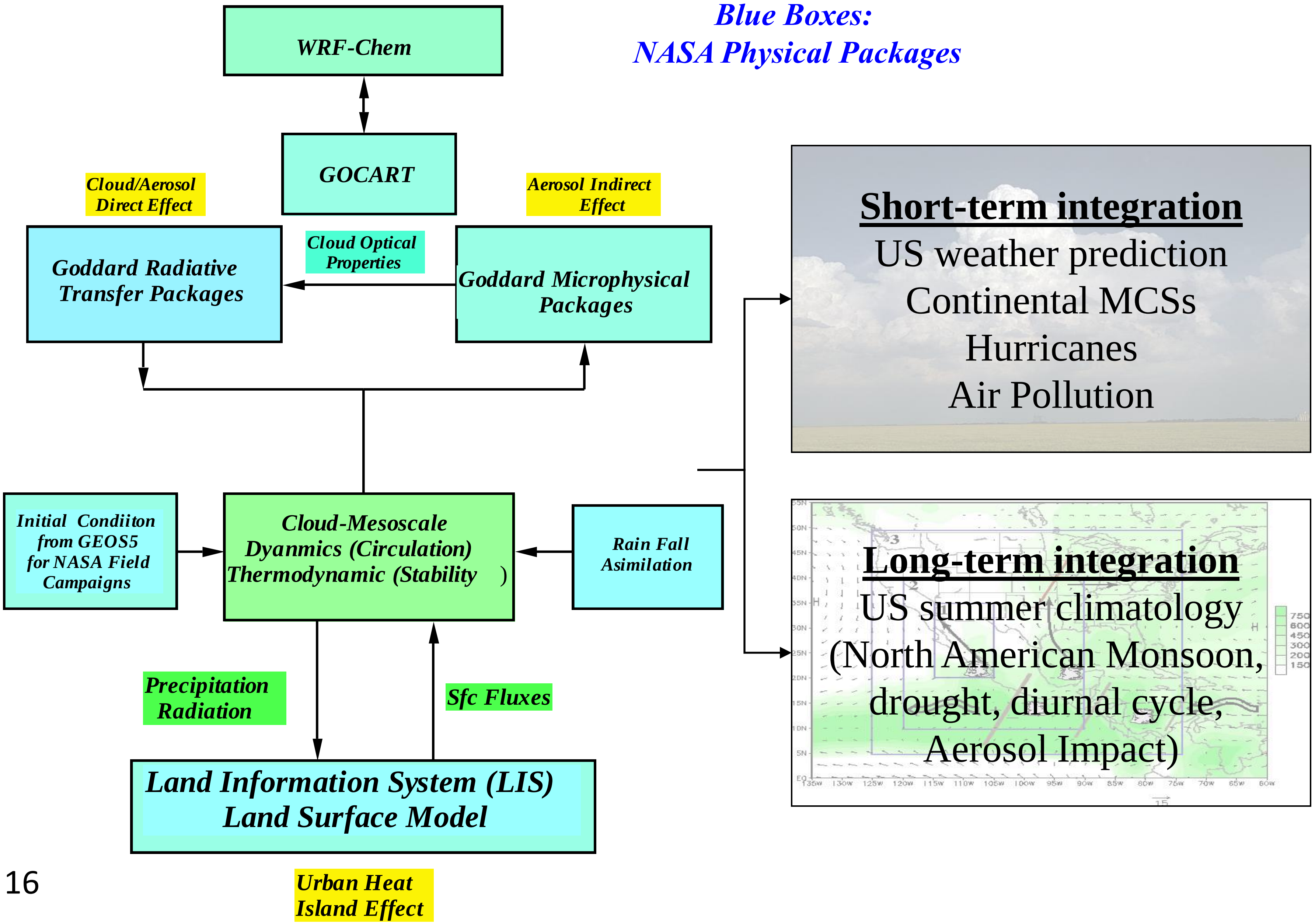
Improved



The improved microphysics scheme can not only show better performance for simulating a short life of S. American line convection, but it also has performance for simulating clouds/cloud systems occurred in KWAJEX and TWP-ICE.

Question: Can the improved microphysics scheme also have better rainfall forecast for a Typhoon case using a different model?

NASA Unified (nu) WRF

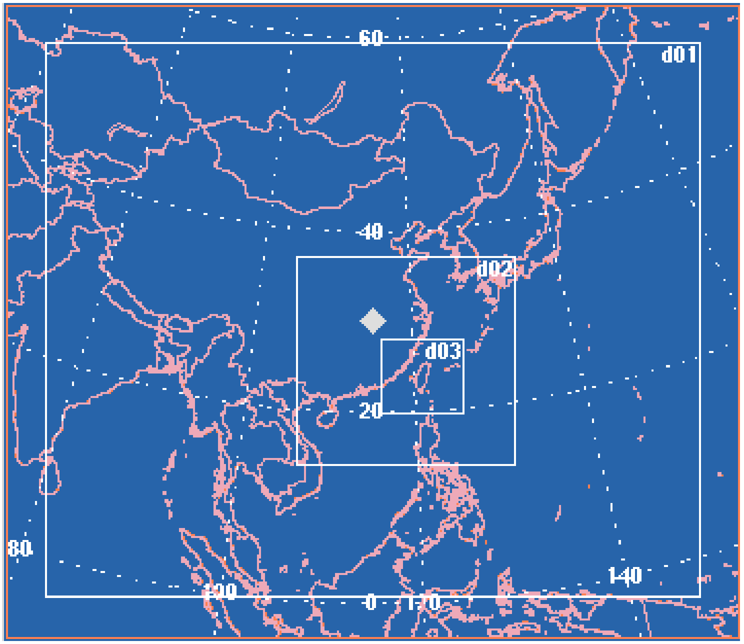


Typhoon Morakot (2009)

after

before

Shiao-Lin Village in the mountain area of Southern Taiwan. Almost 600 people (most of the population of the village) were buried by the mudslide



391x322, 475x427, and 538x439
18, 6 and 2 km

61 vertical layers

Initial condition: NCEP GFS 1^0 global analysis

72 h integration starting at 00Z August 7 - 00Z August 10 2009

Physics:

- **Cu parameterization: Grell-Devenyi scheme (for the outer grid only)**
- **Cloud microphysics:**

  Goddard microphysics 3ice-Graupel

  Improved 3-ice Graupel
- **Radiation:**

  Shortwave: New Goddard

  Longwave: New Goddard
- **PBL parameterization:**

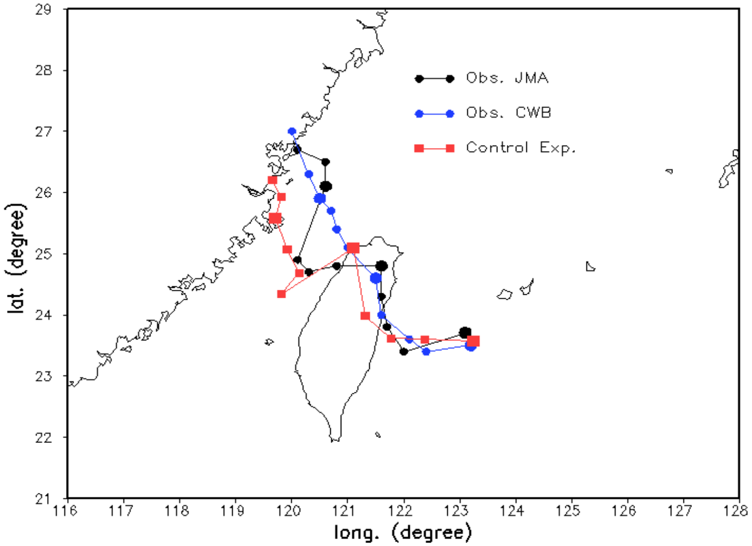
  YSU scheme
- **Surface Layer: Monin-Obukhov (Janic)**
- **Land Surface Model: Noah land-surface**

Red: Not in NCAR WRF 3.1.1 Yet, but in NASA Unified WRF

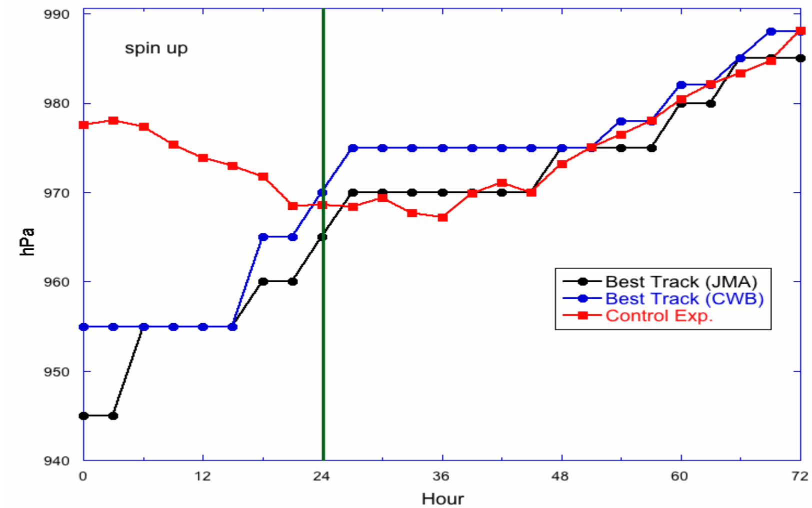
Tao et al. 2011

00Z August 7 - 00Z August 10 2009

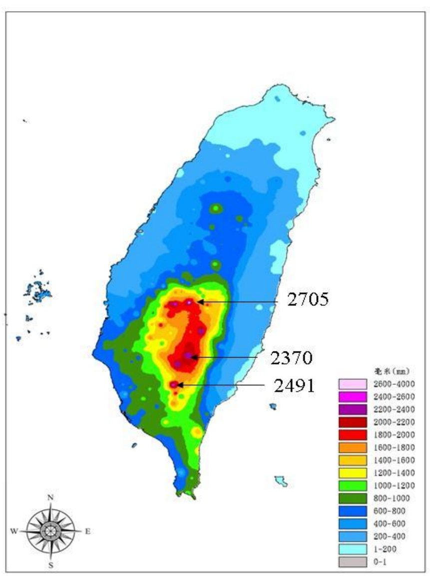
Track

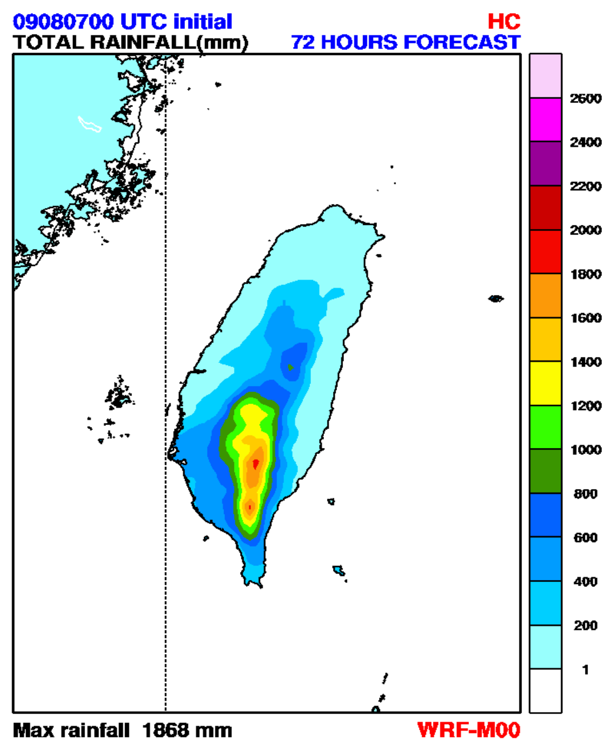


MSLP



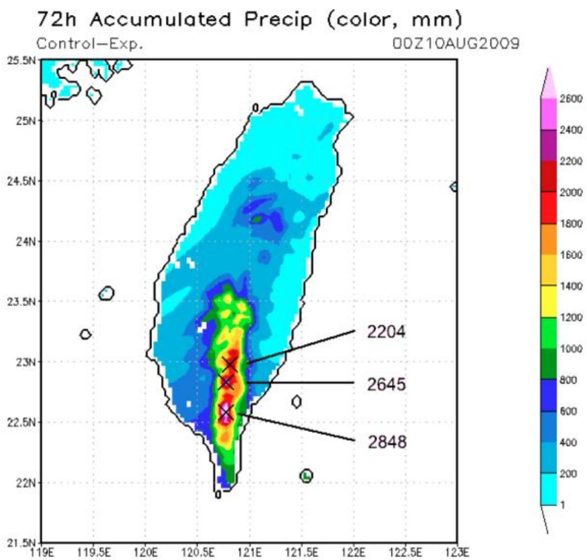
Observed
Max 2705 mm
~400 rain gauge
stations



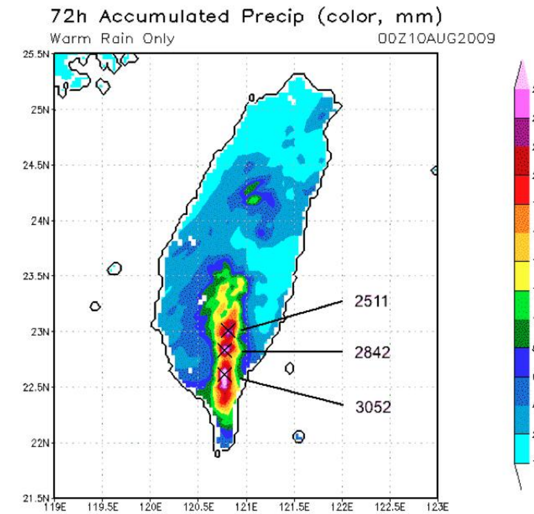


CWB
Operational
Max 1868 mm

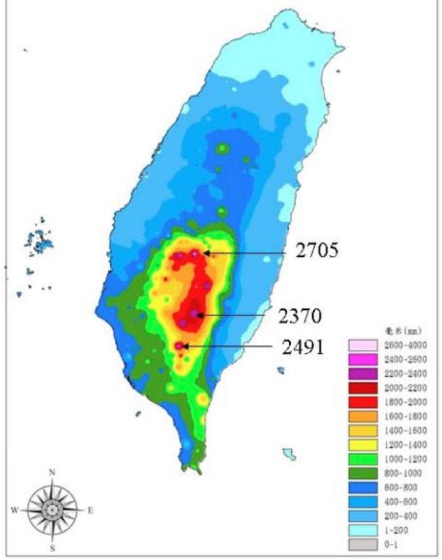
Microphysics and PBL experiments - 72h accumulated rainfall

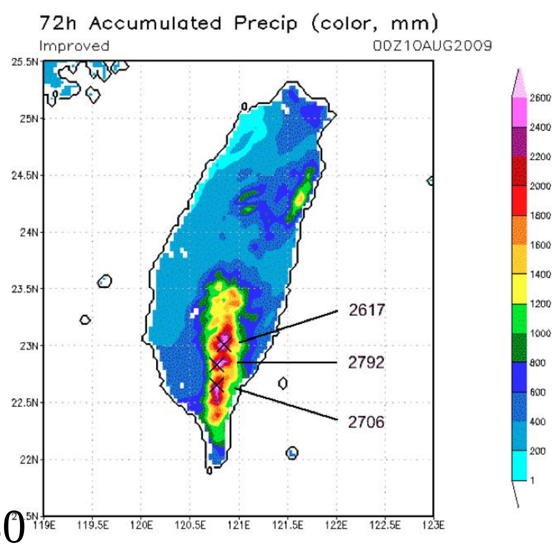


Warm rain →



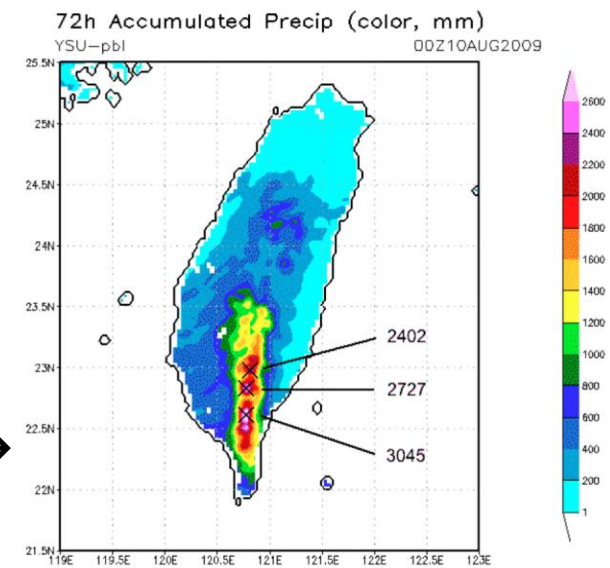
Observed





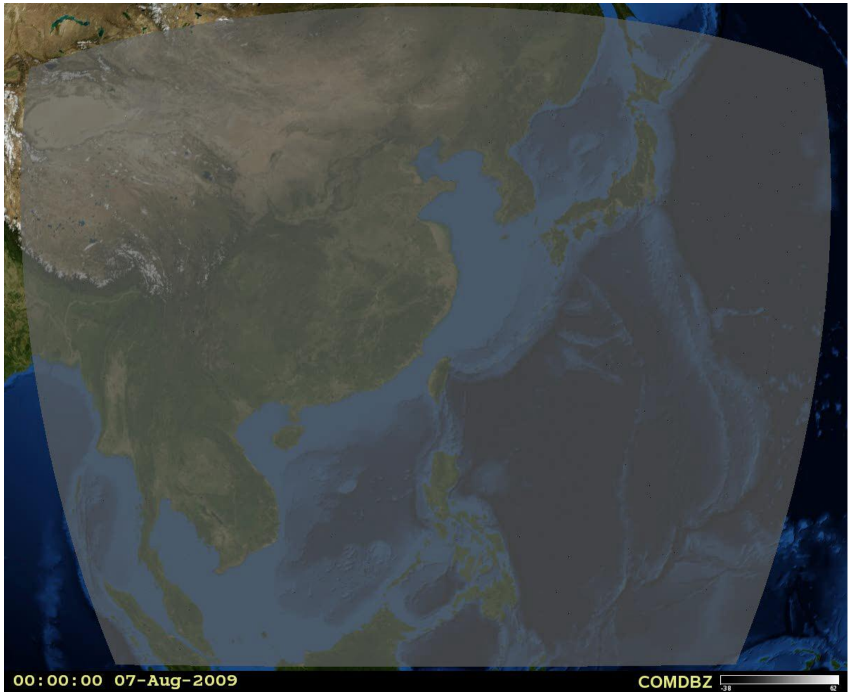
←-- Improved

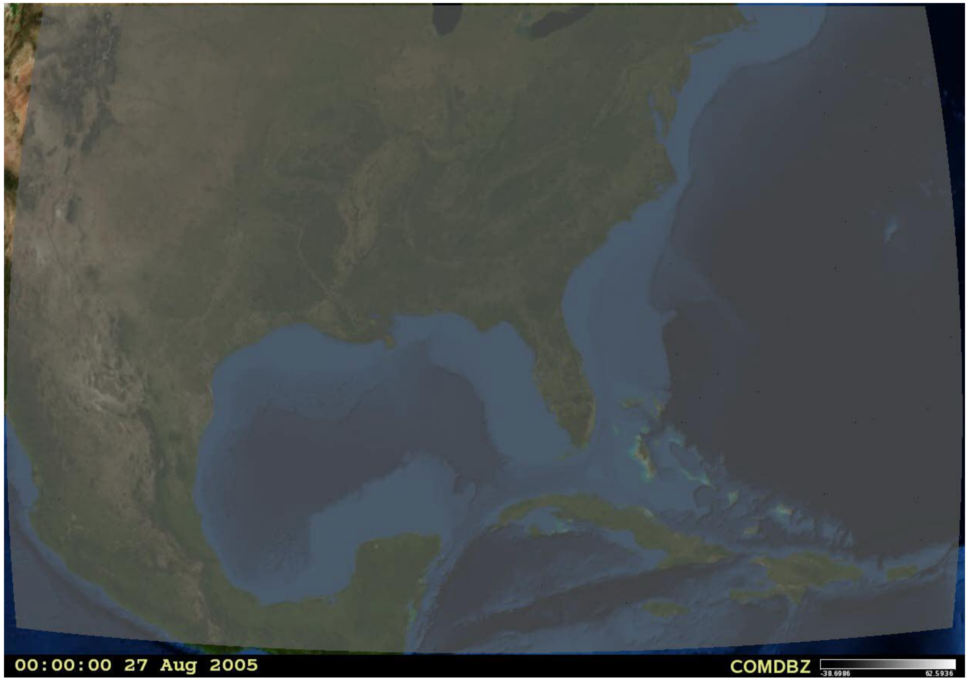
MYJ PBL →



COMDBZ

Typhoon Morakot (2009) ->
72 s loop

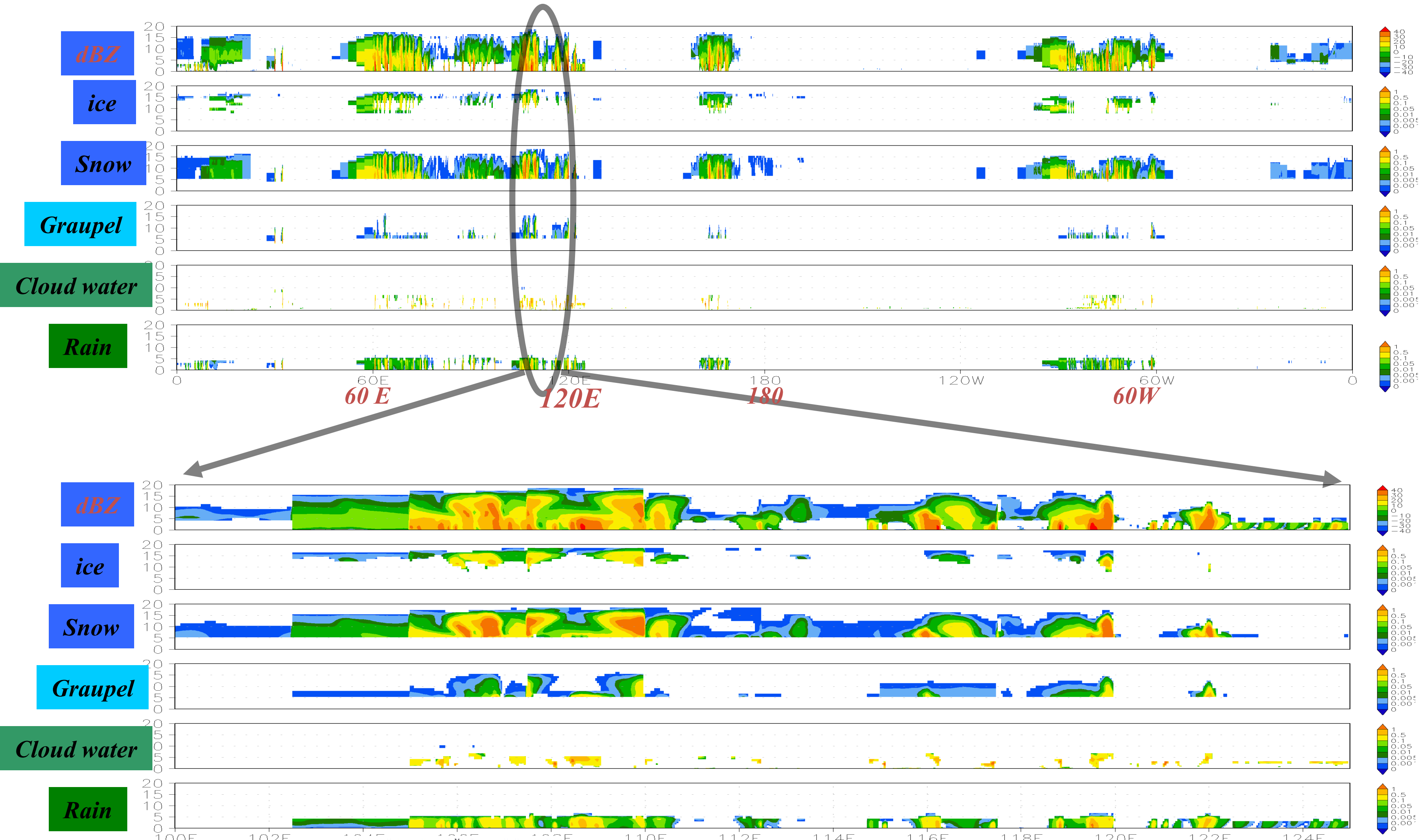




← Hurricane Katrina (200)
18 s loop

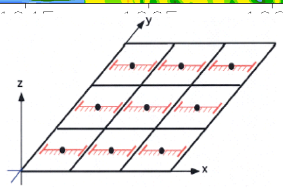
Tracer/Trajectory Analysis

Goddard MMF Simulated Cloud Species (at Equator, 0000UTC December 2004)

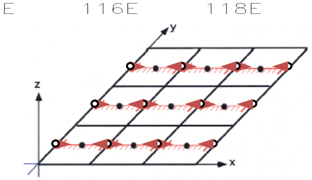


100 E

120 E

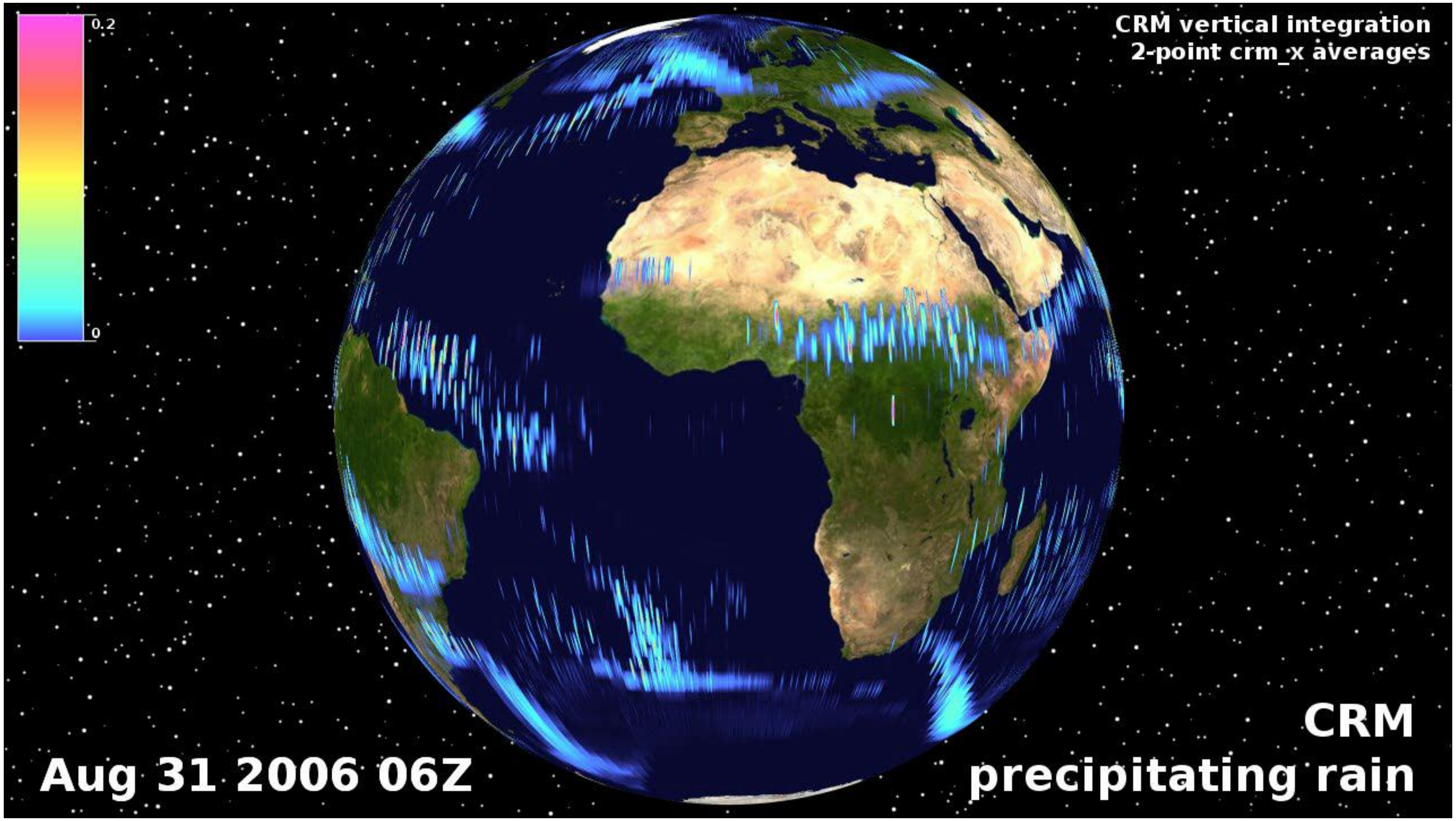


-----> 2D Global



Shallow Convection

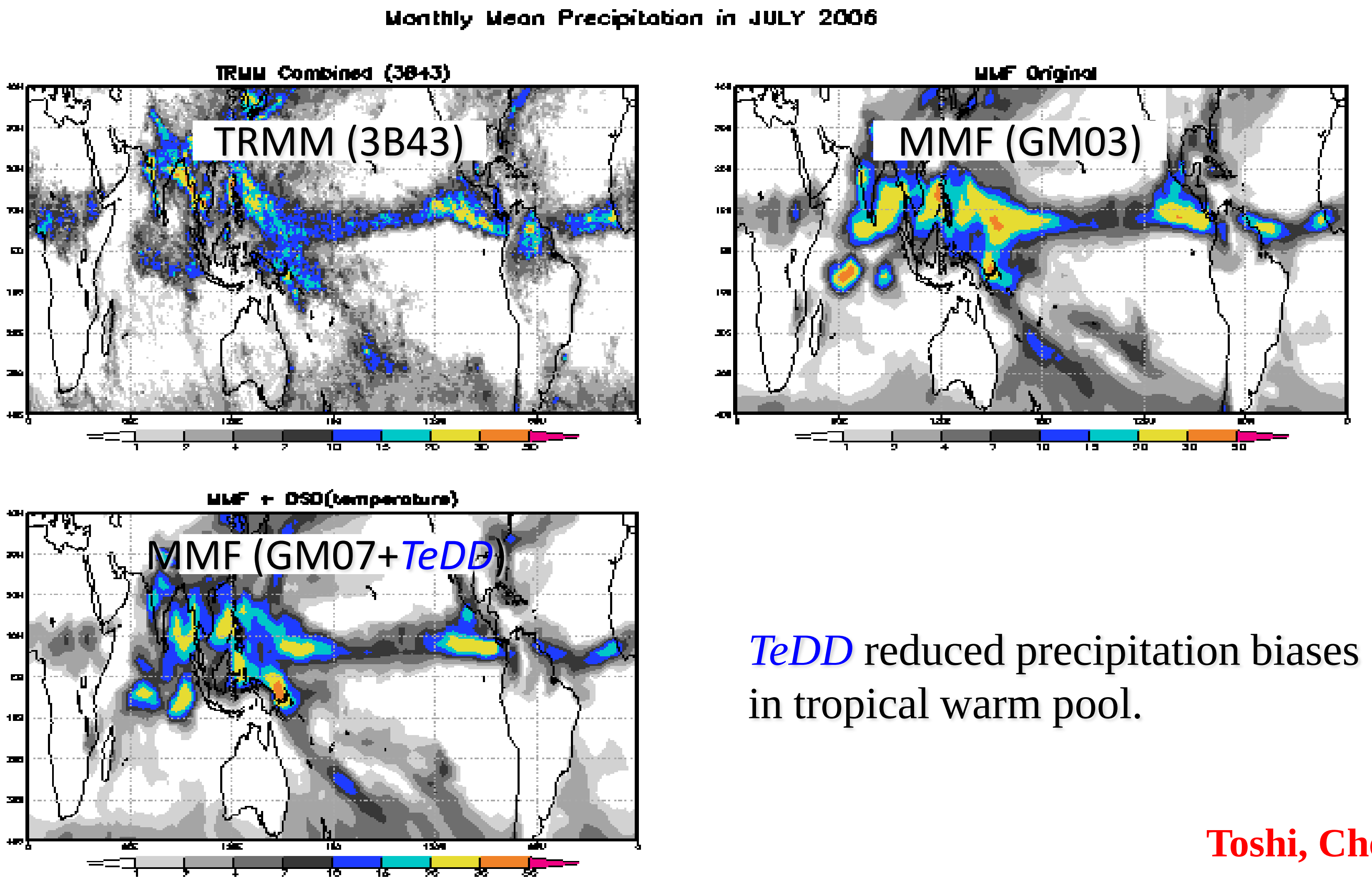
Goddard Multi-scale Modeling Framework (MMF)



1) Tropical waves move off the coast of Africa and propagate westward. [It is known that tropical cyclogenesis can be initialized (or triggered) by these tropical waves. Therefore, accurate simulations of their interactions with small-scale convection are important for improving the simulations of TC genesis.]
2) The eastward-traveling system in the southern hemisphere (SH) are the so-called the polar vortex, which is most powerful in the hemisphere's winter (JJAS, in the SH).
3) The equatorial Amazon has abundant rain between November and May. During the Brazilian spring season (October/November/December), most of the countries get wetter, except for the Brazilian northeast.
4) In comparison, during this period (winter in the northern hemisphere), mid-latitude periodic frontal systems move eastward across the USA.
5) Near the end of simulations, heavy precipitations appear near the ITCZ

Shen/Chern

Surface Precipitation

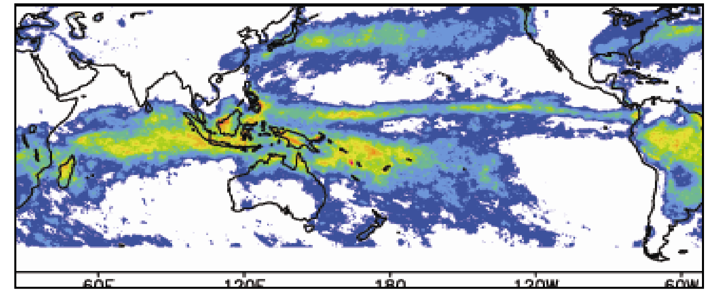


TeDD reduced precipitation biases in tropical warm pool.

Toshi, Chern

Precipitation (Jan)

TRMM



SJ Lin's dynamics core

GCE microphysics

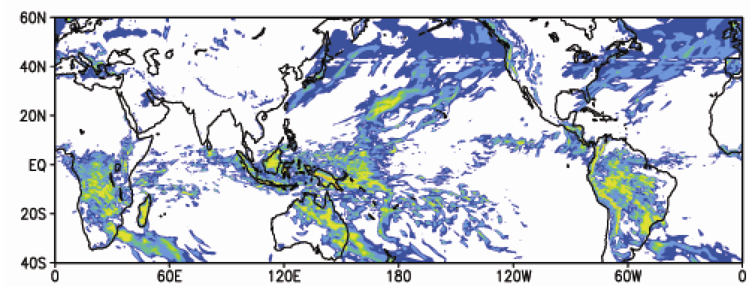
SAS

Turbulence closure

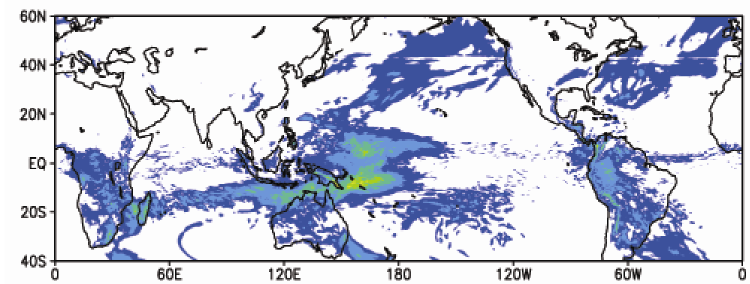
Stretched grid (6~55km)

vertical Level (40)

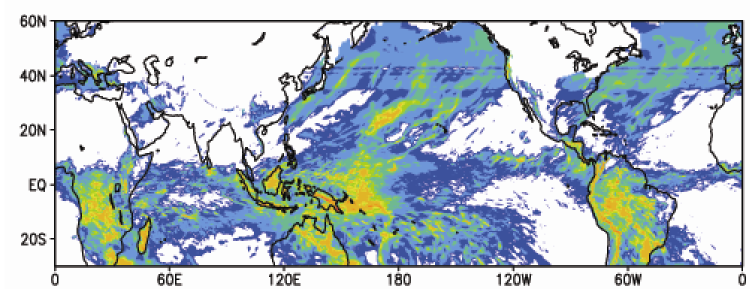
Convective precipitation (SAS)



Microphysics precipitation

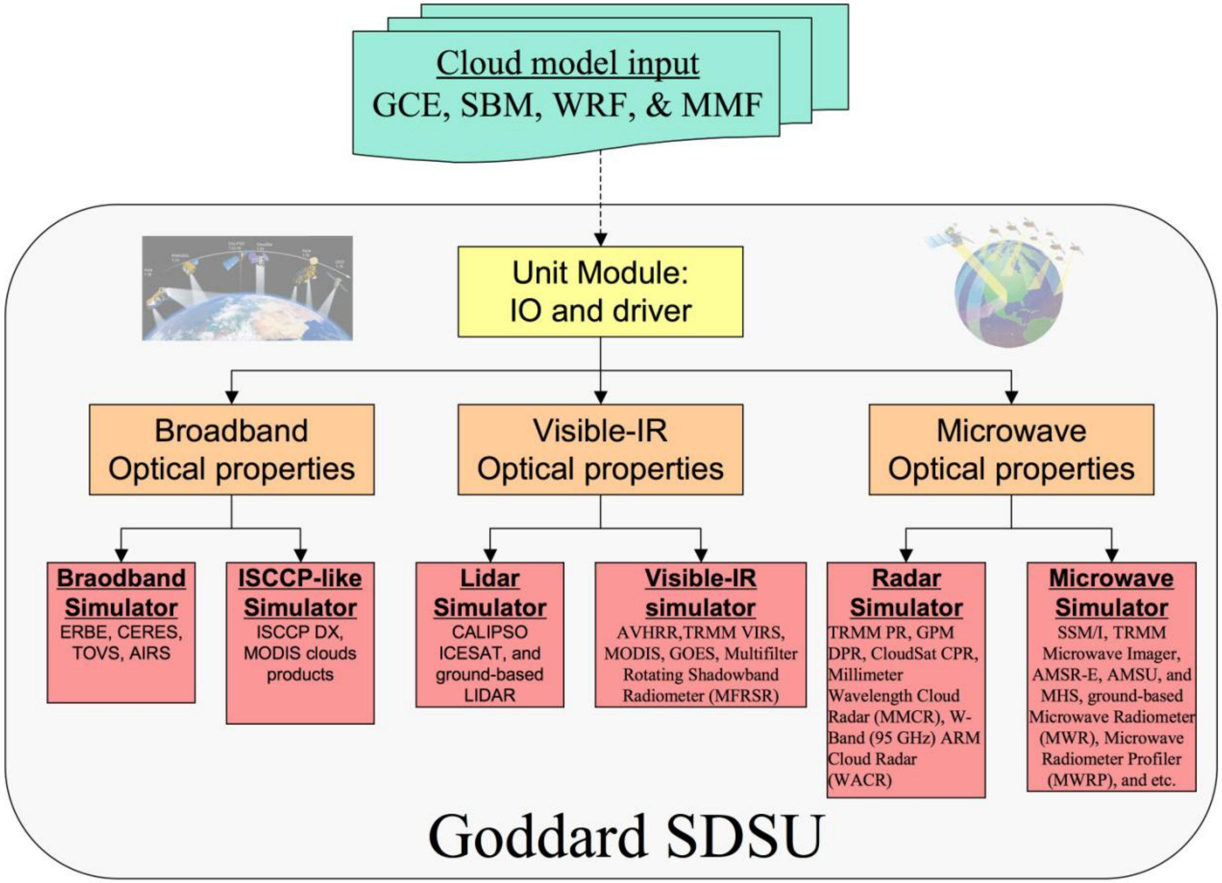


Total precipitation (SAS +MP)



Yang/SNU, Korea

Goddard Satellite Data Simulation Unit (SDSU)
for evaluating models' performance and supporting NASA's satellite missions

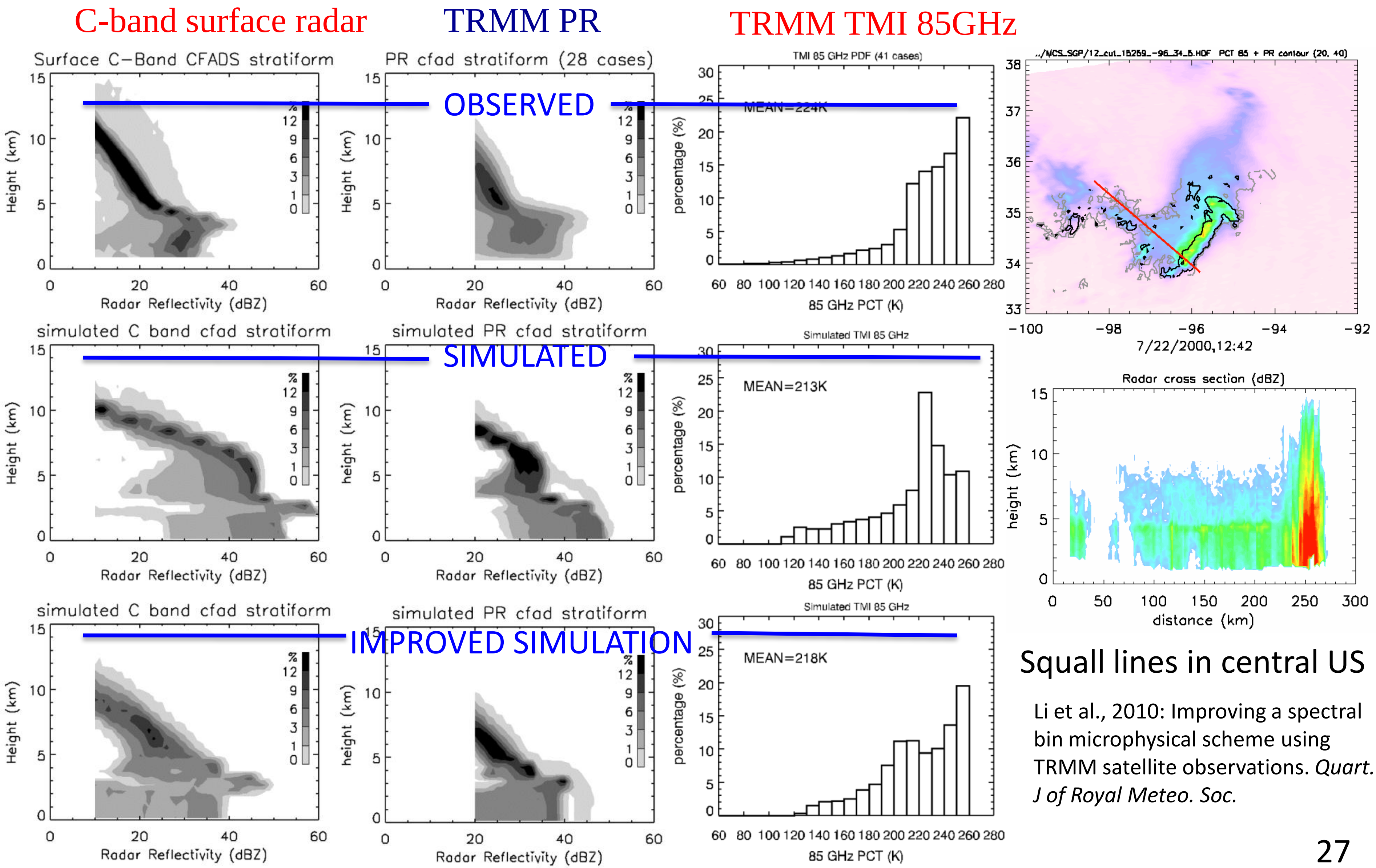


Examine an evaluation method for Goddard multi-scale modeling system by using direct measurements from space-born, airborne, and ground-based remote sensing.

Support the NASA's satellite mission (e.g., A-Train, GPM and ACE) through providing the virtual satellite measurements as well as simulated geophysical parameters to satellite algorithm developers.

Masunaga, H., Matsui, T., W.-K. Tao, A. Y. Hou, C. Kummerow, T. Nakajima, P. Bauer, W. Olson, M. Sekiguchi, and T. Y. Nakajima, 2011: Satellite Data Simulation Unit: Multi-Sensor and Multi–Frequency Satellite Simulator package, *Bulletin of American Meteorological Society*.

IMPROVE BIN MICROPHYSICAL SCHEME USING TRMM DATA



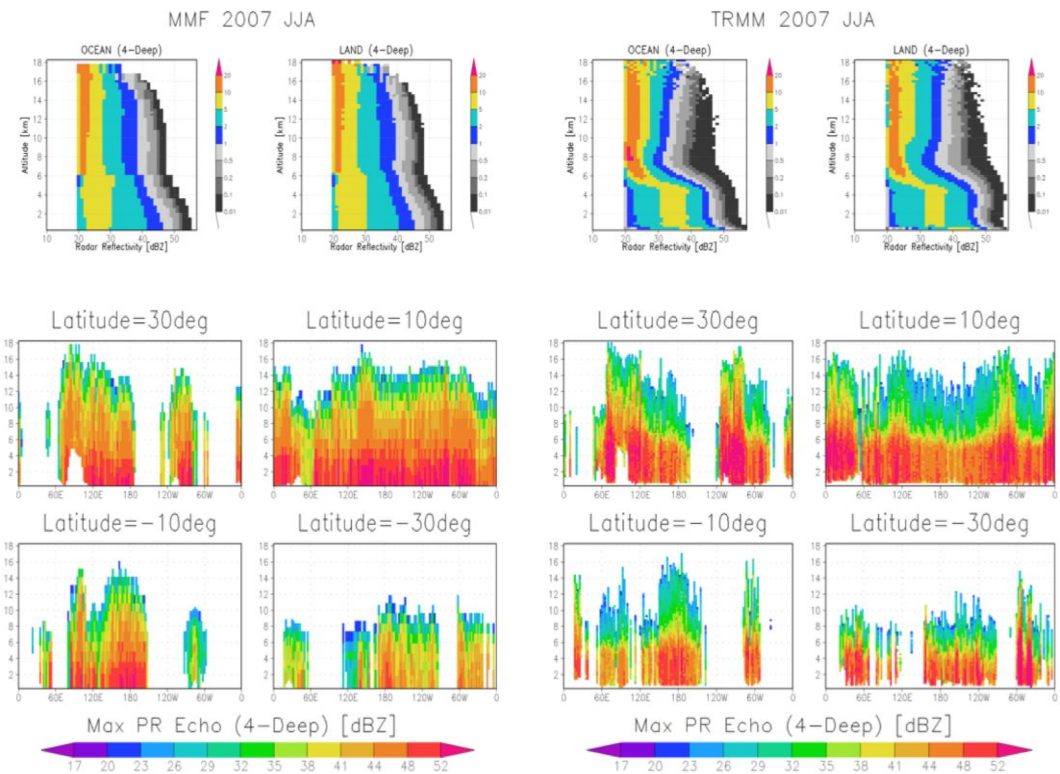
Squall lines in central US

Li et al., 2010: Improving a spectral bin microphysical scheme using TRMM satellite observations. *Quart. J of Royal Meteo. Soc.*

Coupled the MMF and Satellite Simulator as a New Approach for Using NASA Satellite Data

The MMF can explicitly simulate cloud processes and cloud properties at the natural space and time scales of cloud systems. When the MMF coupled with the **Goddard Satellite Data Simulation Unit(SDSU), the radiances and radar reflectivities/attenuation, can be directly extracted from the cloud-resolving model (CRM) -based physics embedded within the MMF and compared against NASA high-resolution satellite measurements.** This approach could be a new pathway for using NASA satellite data to improve our knowledge of the cloud physical processes and leads to new improvements in cloud microphysical schemes.

The MMF requires a substantial amount of computing time (about 200-500 times of the traditional GCMs). Future works of MMF development will include long-term climate simulations with much higher resolutions in both the GCM and the CRM as well as more detailed microphysical schemes and coupling with land/ocean processes. The unprece-dented spatial resolution, complexities in model physics and coupling with land/ocean models will continually push the envelope of the requirement of computing resources. **It is expected to require at least 10 million CPU hours on thousands of processors and 100 TB of disk space for our future research.**



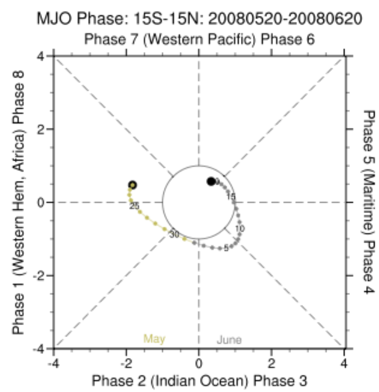
Contoured Frequency Altitude Diagrams (CFADs) of PR reflectivity (top panels) from MMF simulations (left) and TRMM (right) in the summer 2007 provide a useful statistical description that illustrates the effects of precipitation microphysics at different altitudes. **The predicted and observed PR reflectivity at different latitude bands (lower panels) reveals that fvMMF over-predicted the PR reflectivity and did not produced the observed land-ocean contrast. These results provide better direction to improve the model cloud physics**

Goddard MMF Hindcast Experiments of MJO cases during YOTC

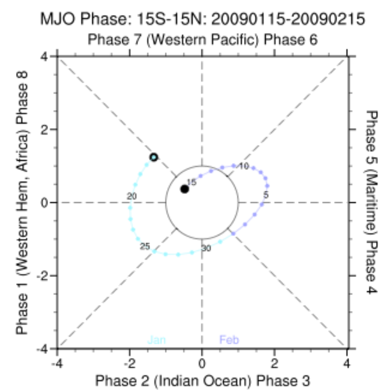
Cases	Period
Case 1	5/20/2008- 6/20/2008
Case 2	01/15/2009- 02/15/2009
Case 3	04/01/2009- 05/01/2009
Case 4	11/01/2009- 12/01/2009
Case 5	11/10/2009- 12/10/2009
Case 6	12/15/2009- 01/15/2010

Observed MJO Phase plots

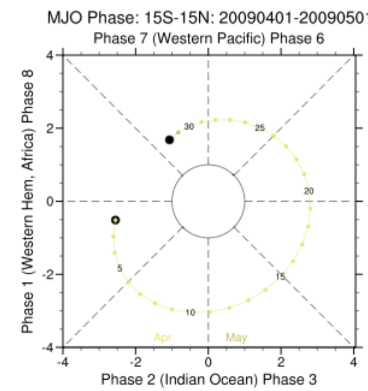
Case 1



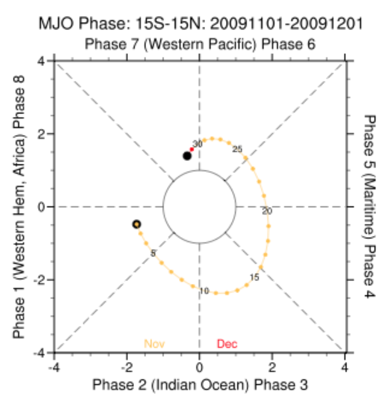
Case 2



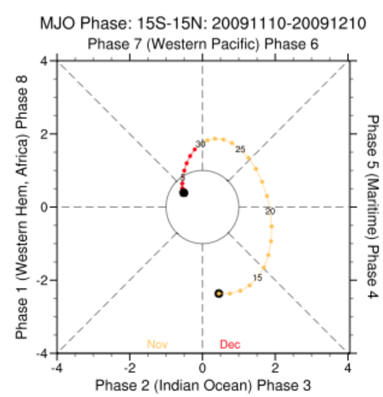
Case 3



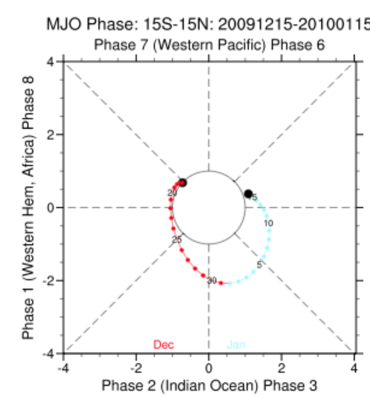
Case 4



Case 5

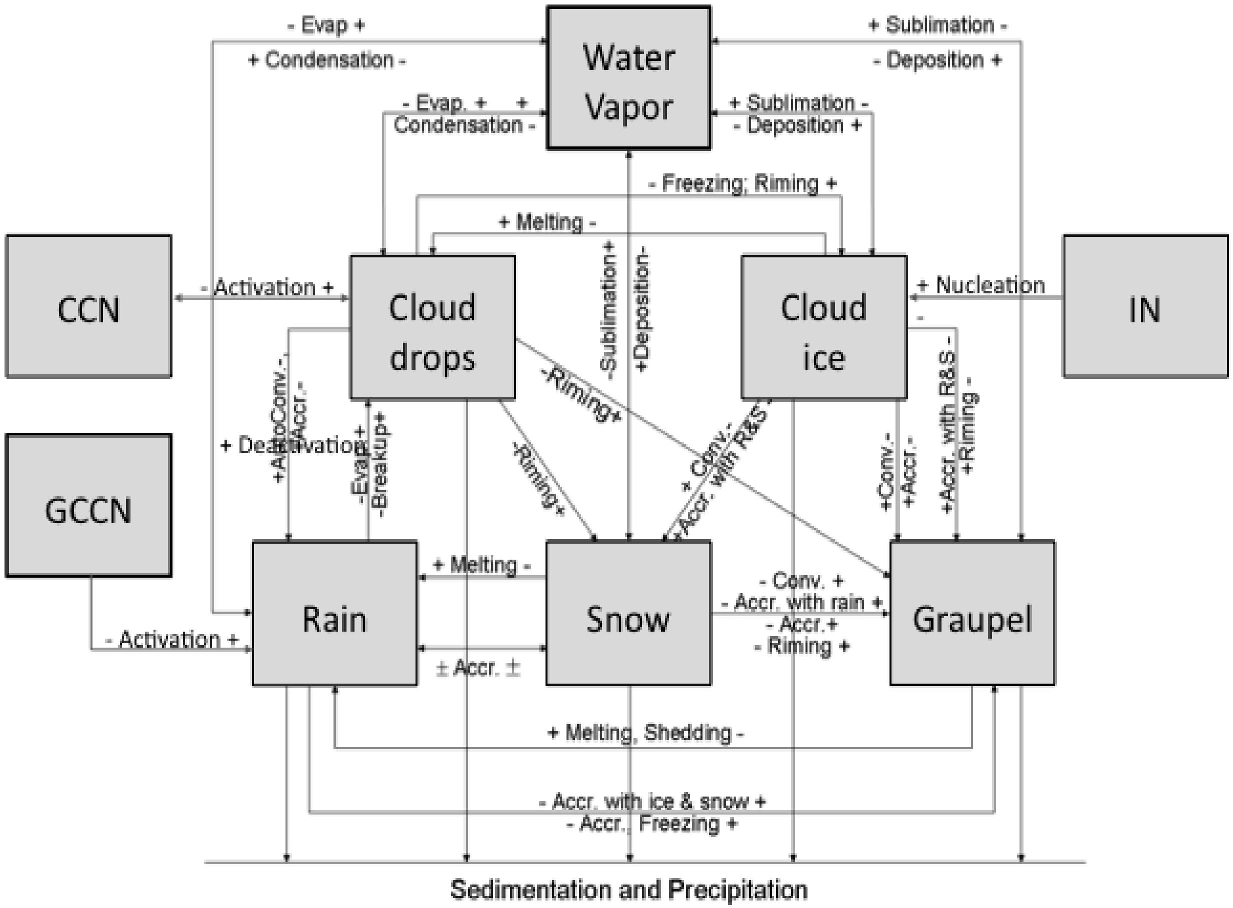


Case 6



Chern/Shen

2-Moment Microphysics Scheme for Cloud-Precipitation-Aerosol Interaction



Schematics of the bulk microphysical processes in the typical two water and three-class ice scheme. Boxes represent the bulk classes of water and aerosol particles, and the arrows represent conversion pathways with plus and minus signs indicating direction of the named conversion process. In addition to prediction the mass of cloud water species (cloud drops, rain, cloud ice, snow and graupel), the number of concentration of cloud water species is also predicted.

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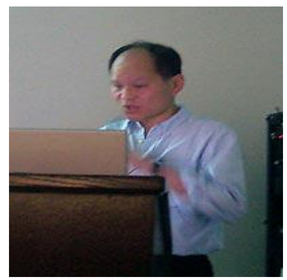

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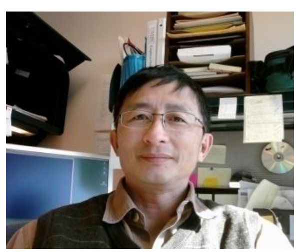
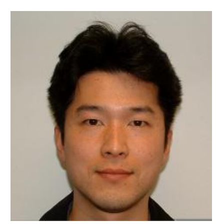


Roger Shi
WRF



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GCE

http://portal.nccs.nasa.gov/cloudlibrary/index2.html

Terminal Velocity of Precipitating particles aloft

$$V(d)=V_o(d)[\text{AirDensity}_o/\text{AirDensity}]^{0.4}$$

Referent state of AirDensity_o : Two different assumptions

A constant air density at 1013 mb and at 20 C^o (based on Foote and Du Toit, 1969) - In Lin, WSM6 and others (WRF)? 2856 / 3345 mm

Air density at model surface (varies with time and location) - In GCE and other CRMs - 2529 / 2893 mm