Evaluating the Impact of Cloud-Aerosol-Precipitation Interaction (CAPI) Schemes on Rainfall Forecast in the NGGPS

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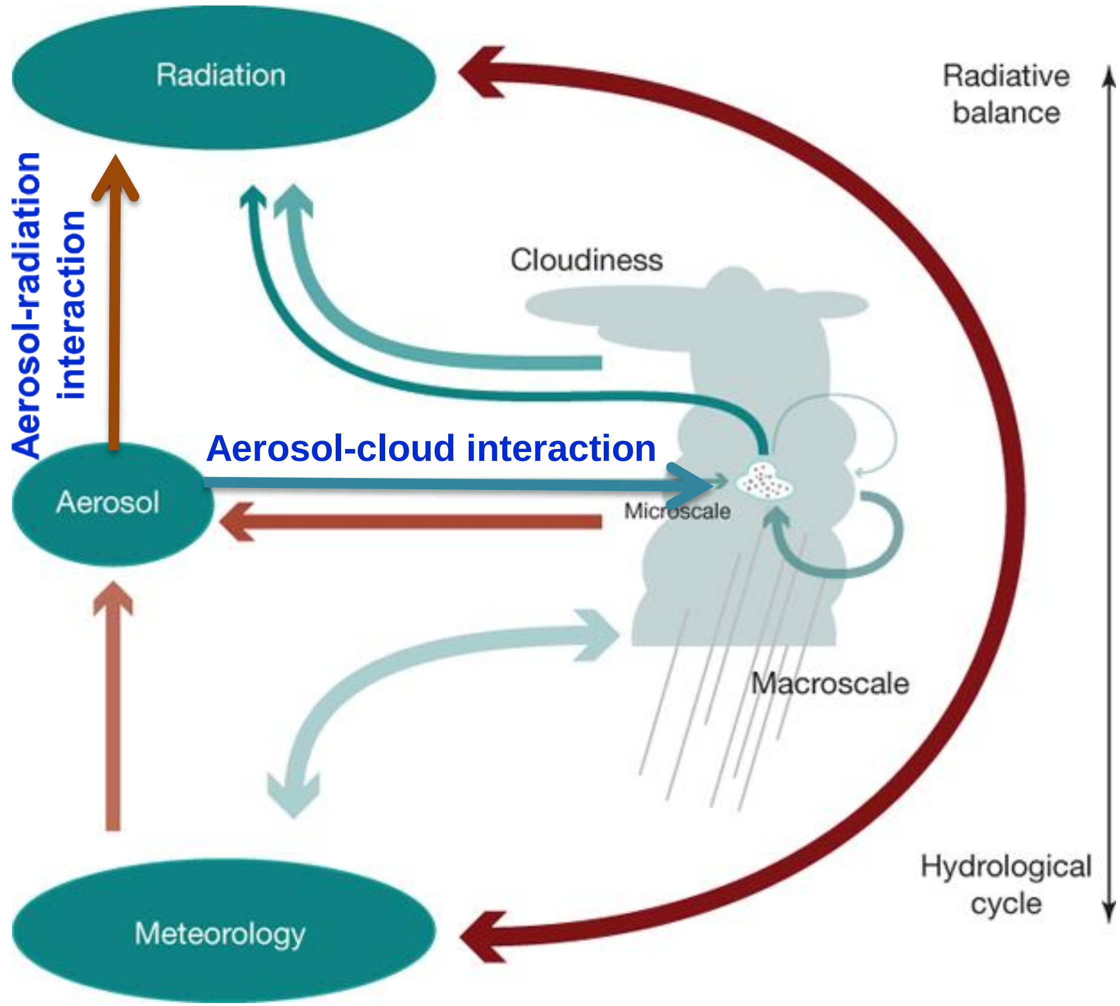
Motivation

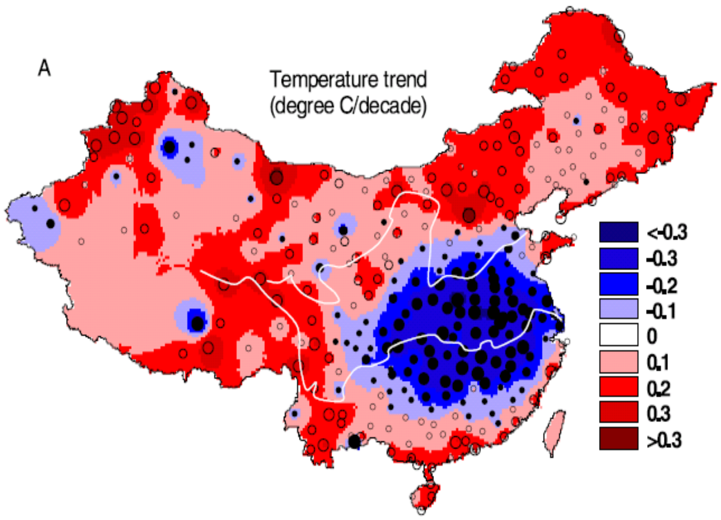
- **Aerosol is a significant factor impacting clouds and convection**
- **Cloud feedback including convective mixing is major contributor of model uncertainty (Sherwood et al., 2014, Nature)**
- **One of the urgent need is to understand how clouds and convection interact with circulation (Bony et al., 2015 (Nature Geosci).**



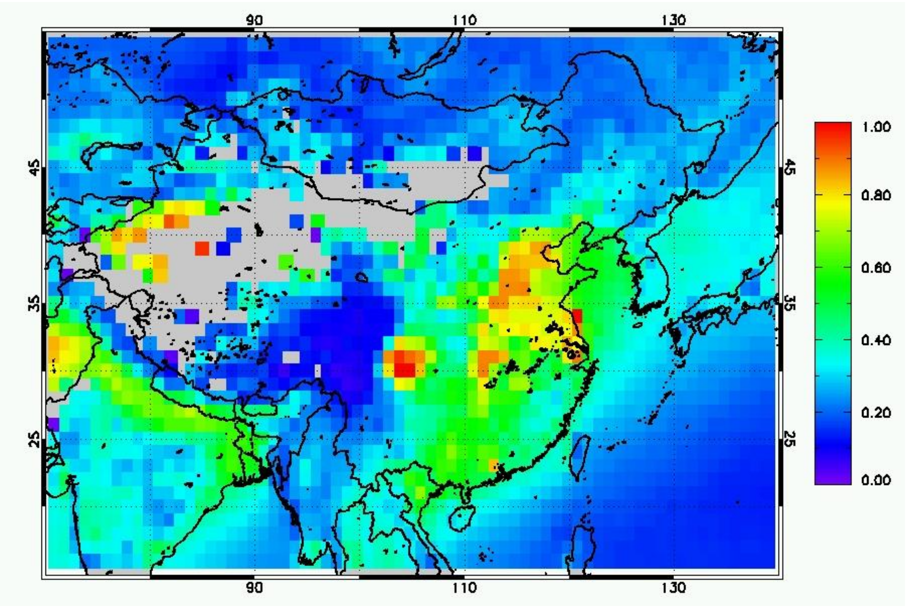
Based on Stevens and Feingold, (Nature, *2009)*

Do & how aerosols affect weather ?

Aerosols Affect Temperature

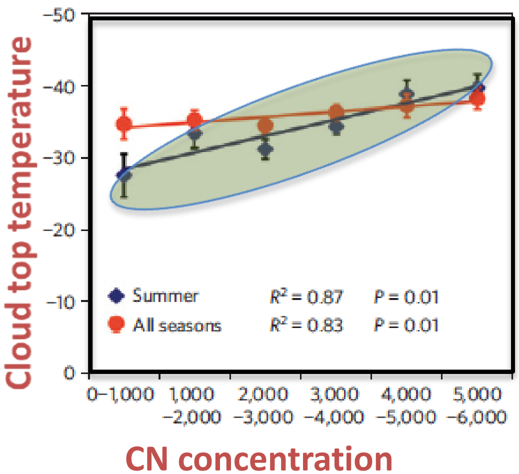


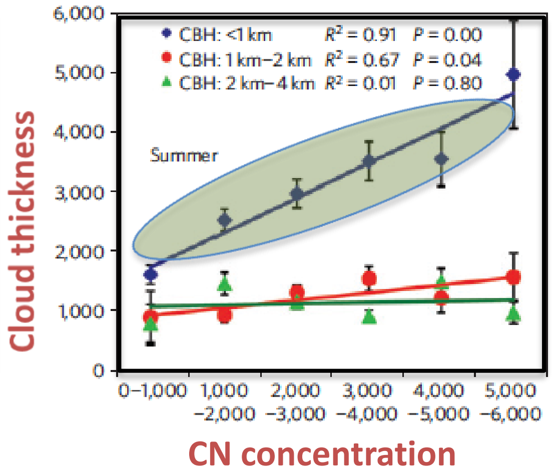
Mean MODIS AOT

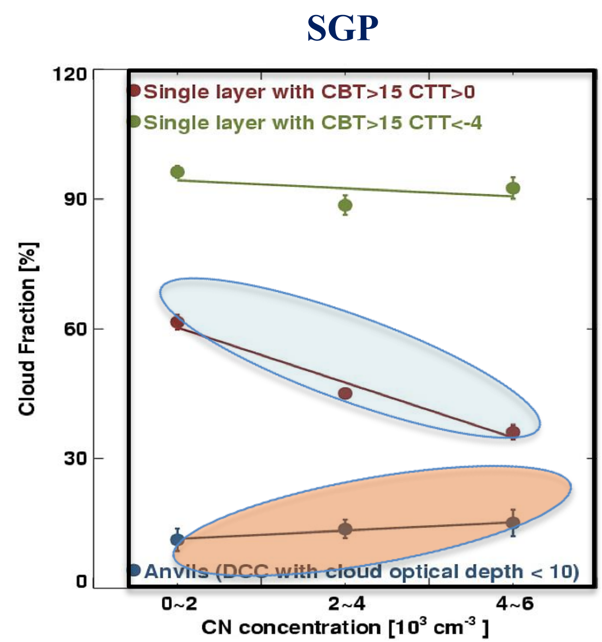


Aerosols Affect Cloud

ARM Southern Great Plain (SGP) (Li et al. 2011)

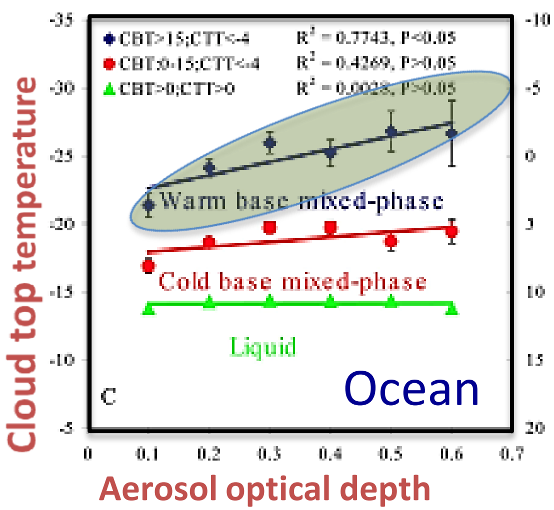


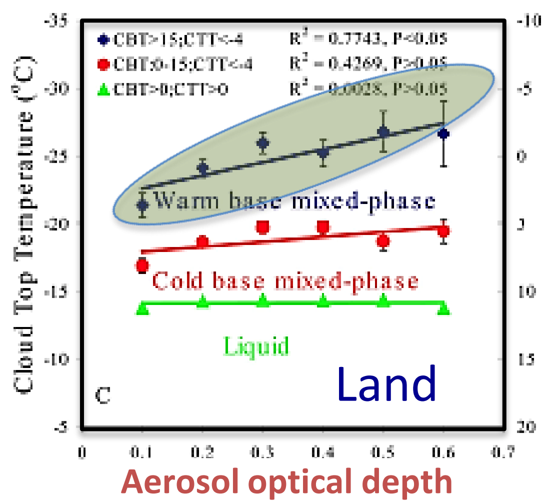


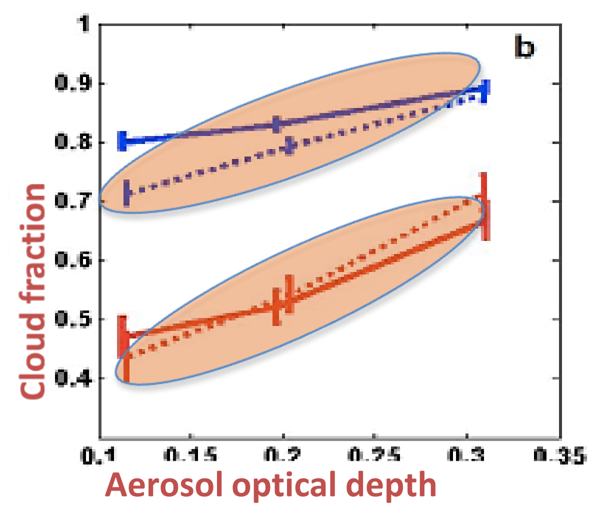


Yan et al. (2014, ACP)

Tropical Western Pacific (TWP) (Niu & Li, 2012)

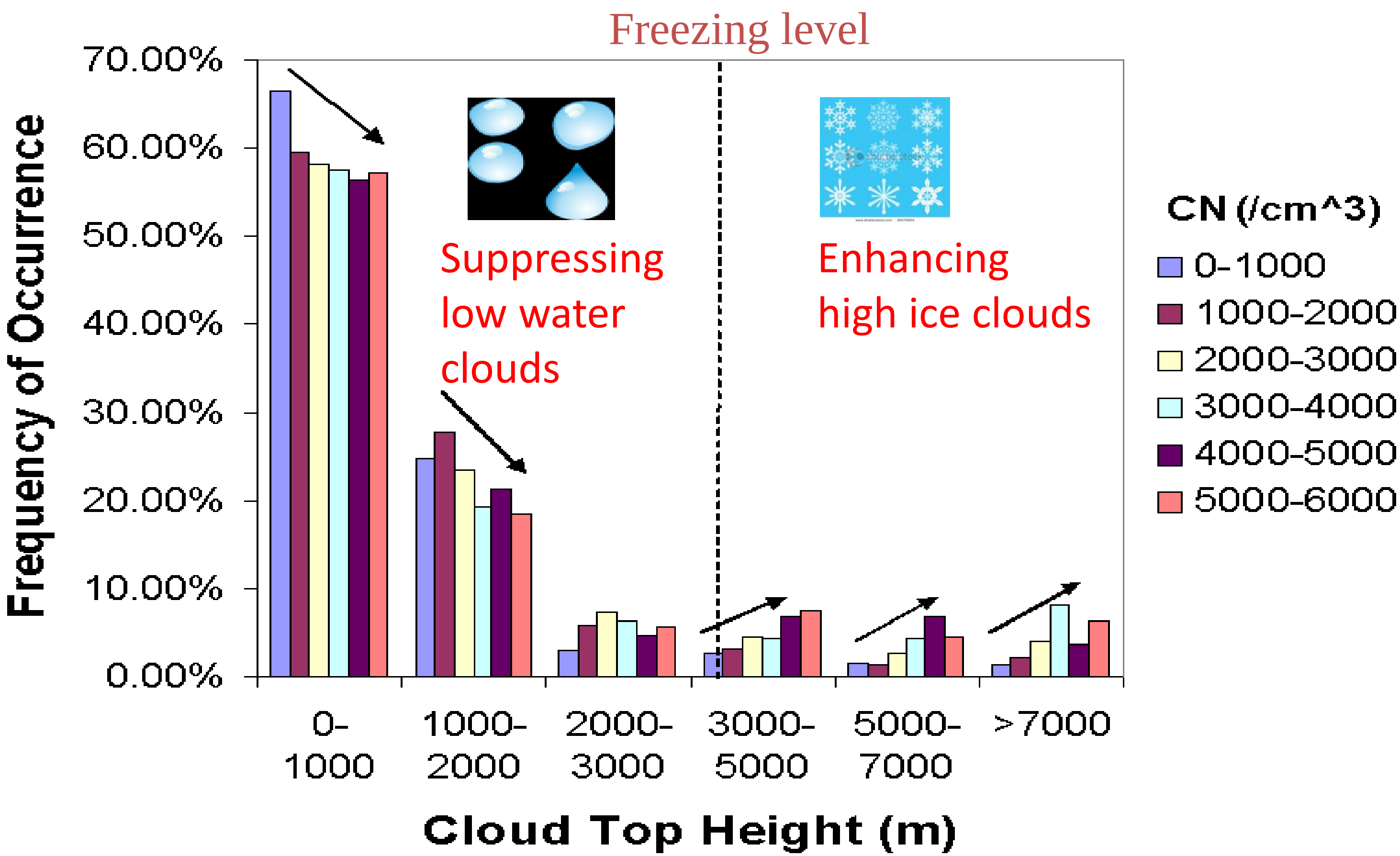






Koren et al., ACP, 2010

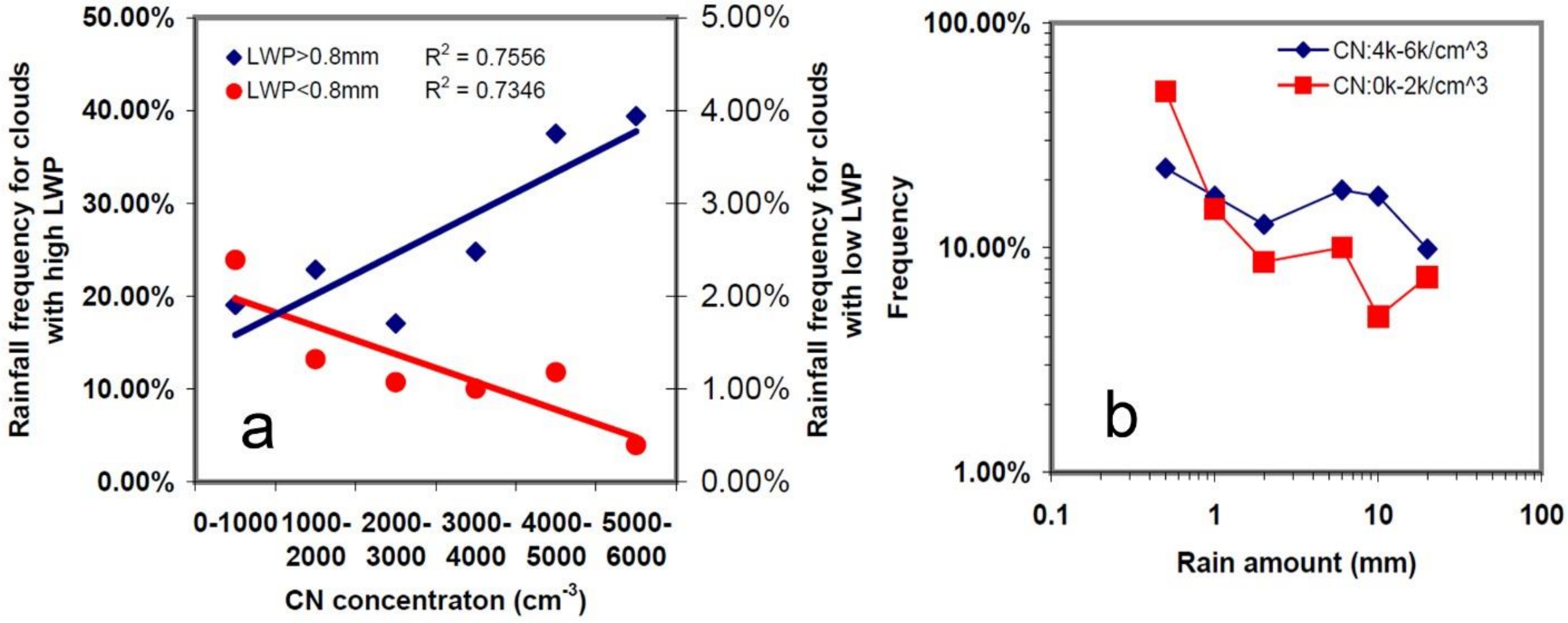
Effects of Cloud Phase
Frequency of Occurrence of Cloud Top Height:



As CN increases, high clouds occurred more frequently but low clouds occurred less frequently

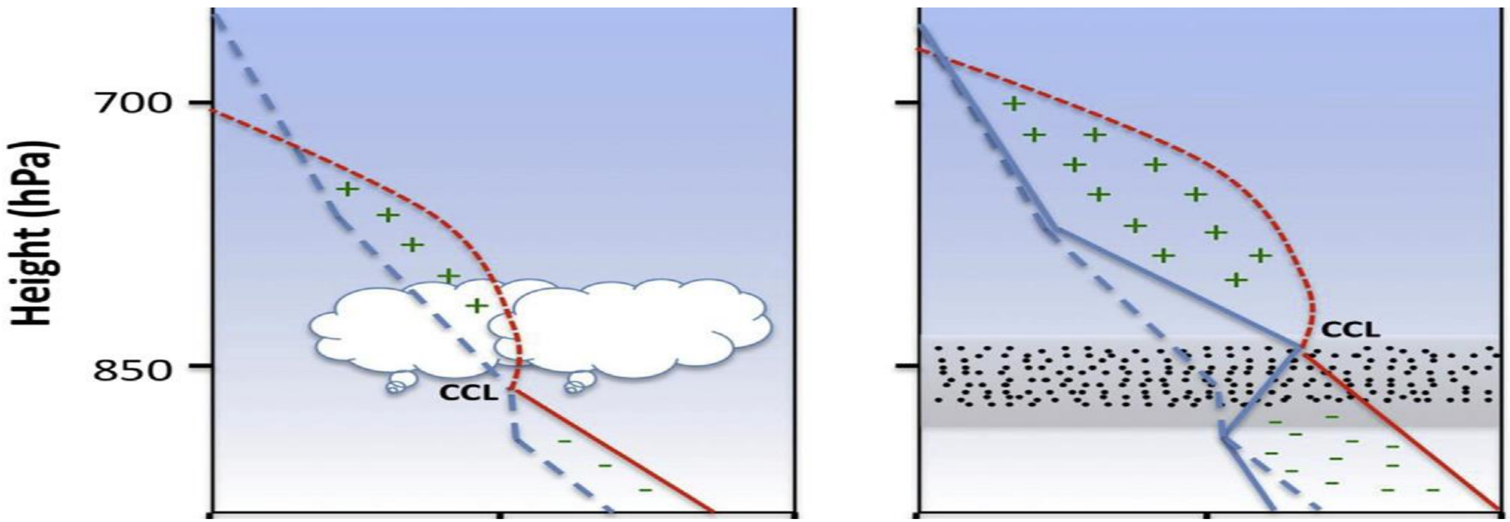
Li et al. (2011, Nature-Geosci)

Aerosols Affect Precipitation

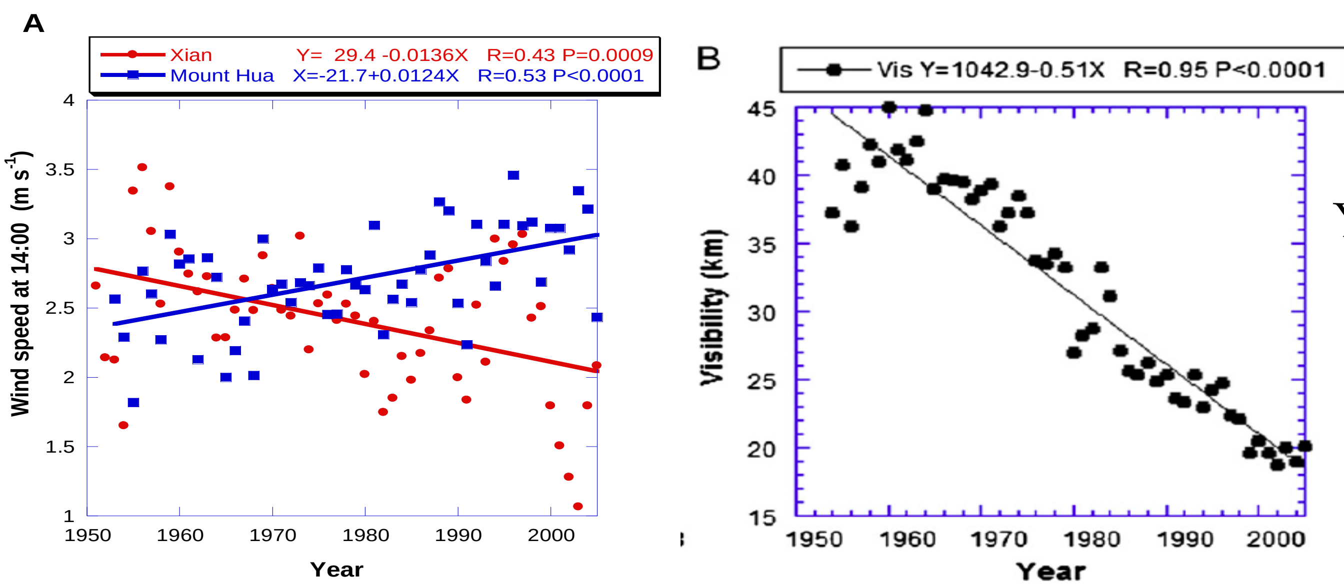


Li et al. (2011, Nature Geosci)

Aerosols Affect Circulation

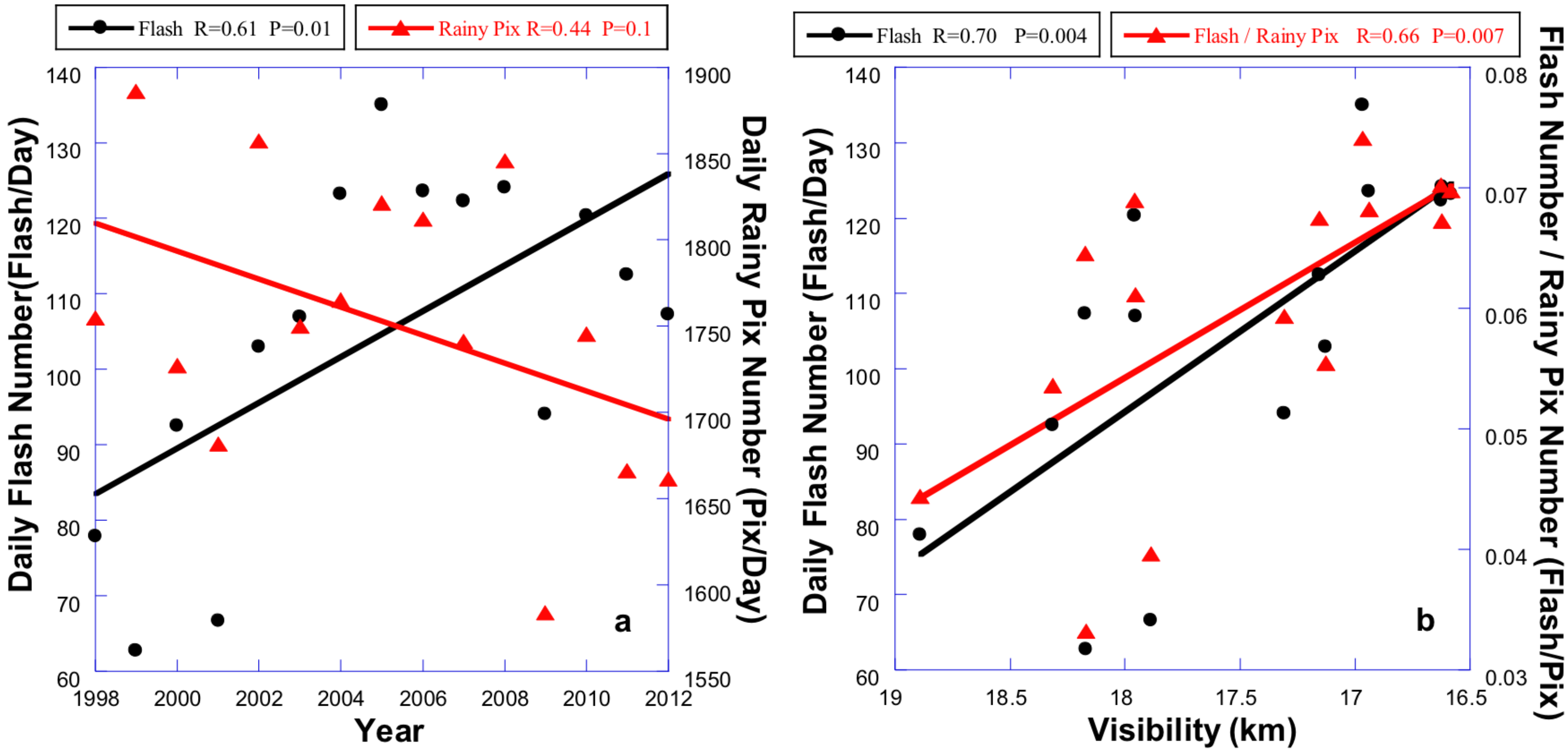


Wang et al. (2013, AE)



Yang et al. (2013, JASTR)

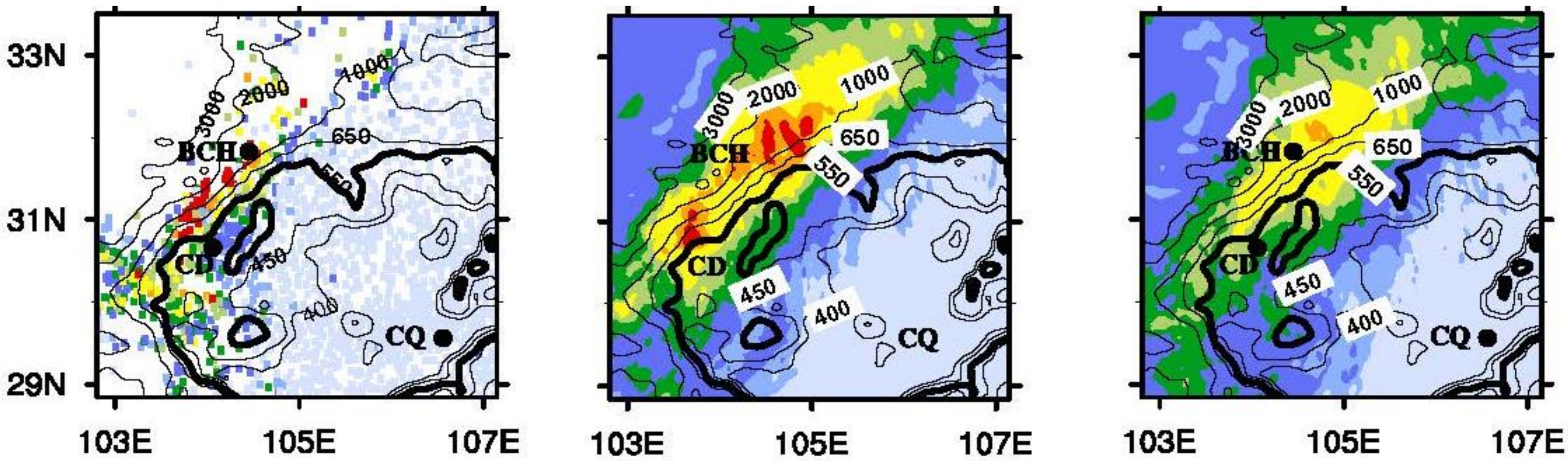
Aerosols Affect Thunderstorms



Yang and Li (2014, JGR)

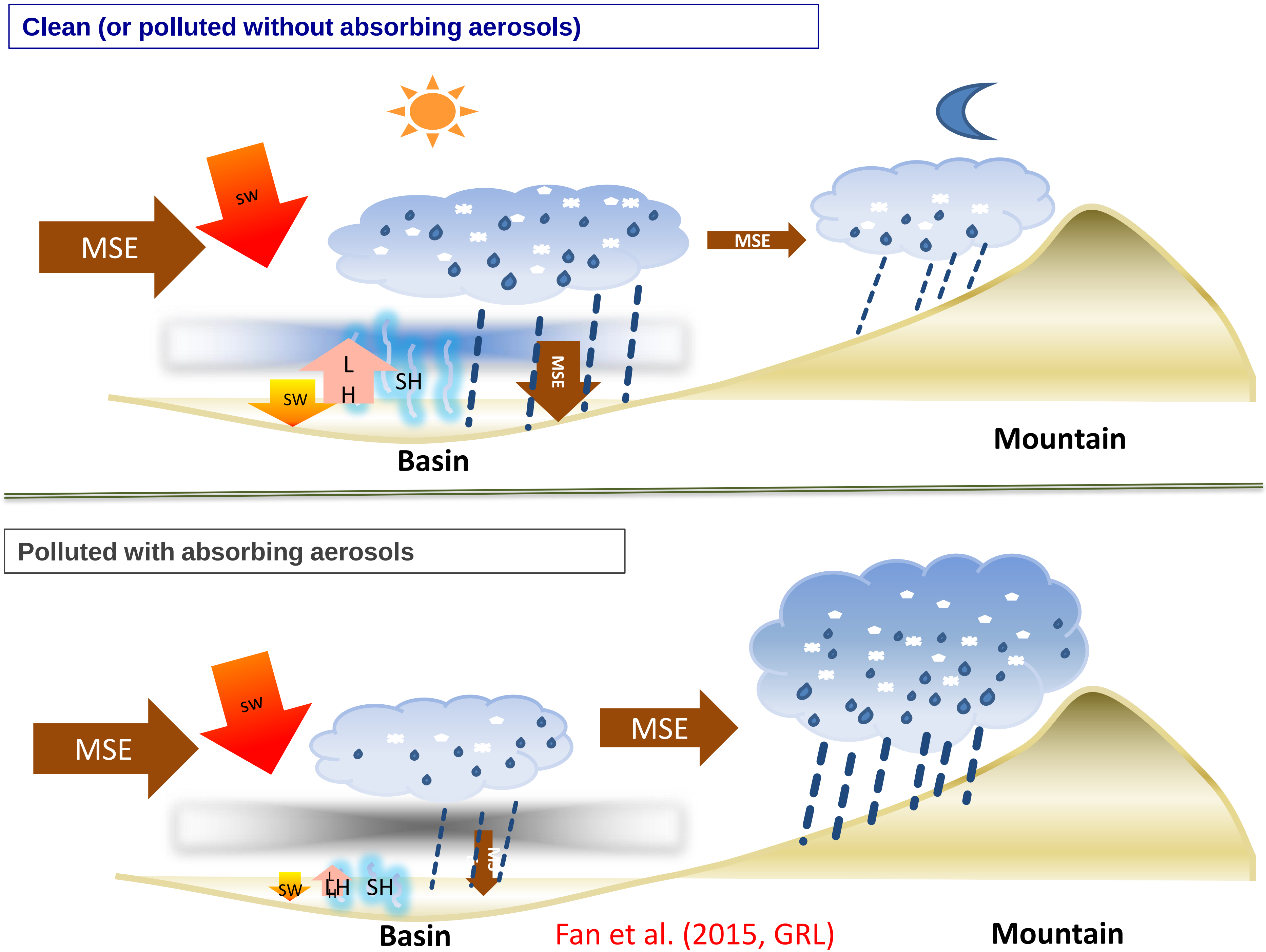
Aerosols Affect Flood

Rain gauge | **P_ALL (current emissions)** | **C_ALL (Clean case)**



The paper is "most shared in AGU journals", as it has been reported in *Nature, Science, BBC, Homeland Security News, Smithsonian Mag, …..*

Fan (2015, GRL)


Clean (or polluted without absorbing aerosols)
MSE
SW
MSE
L
H
SH
SW
MSE
Basin
Mountain
Polluted with absorbing aerosols
MSE
SW
MSE
SW
LH
SH
Basin
Fan et al. (2015, GRL)
Mountain

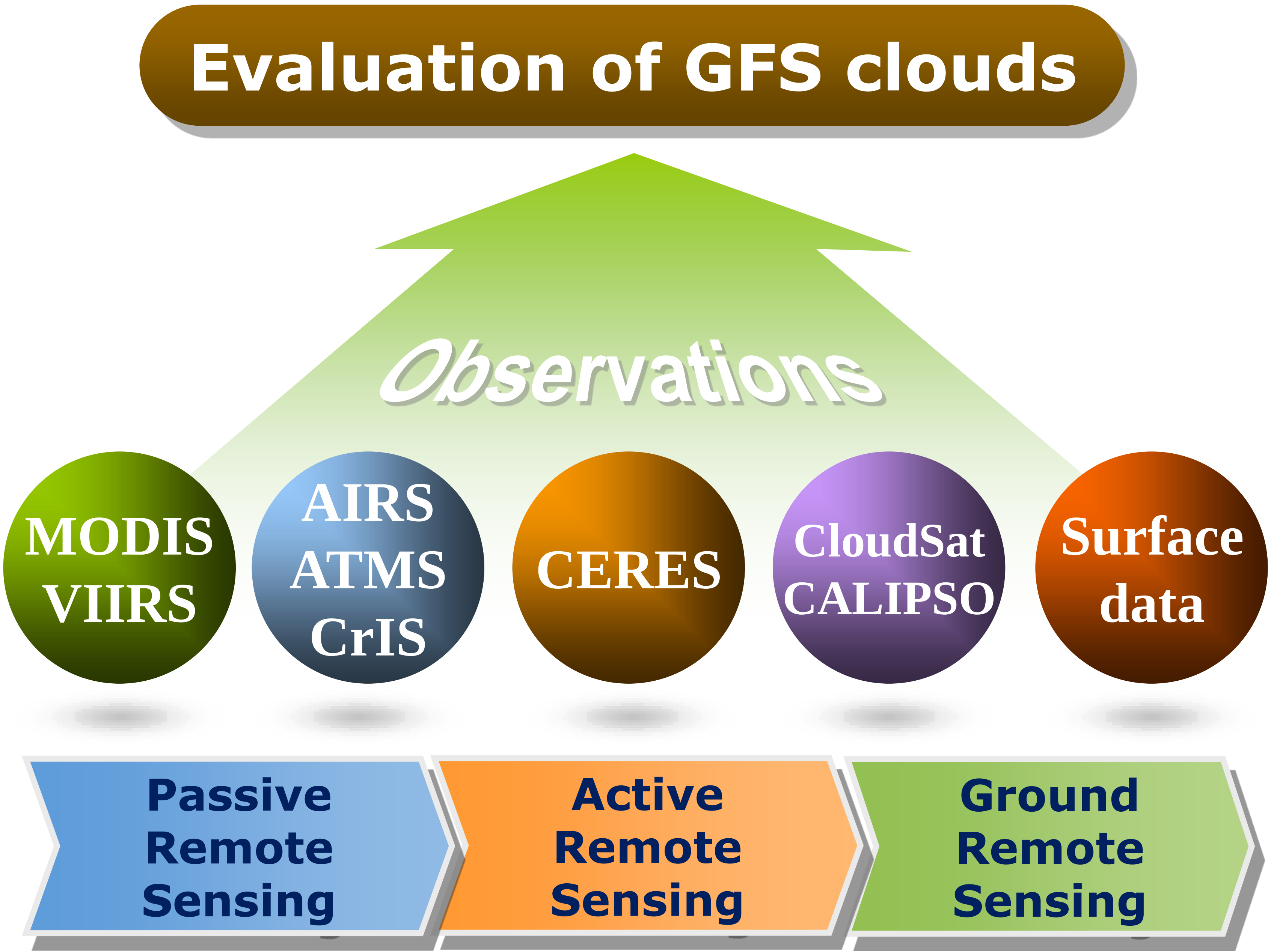
Our Objectives:

- Identify systematic errors in the NCEP NWP results that are related to aerosols using global satellite and ground-based products;

- Evaluate the effects of physical schemes associated with accounting for the aerosol

- Understand and improve the performance of GFS with the aid of a high-resolution cloud-resolving model (CRM).

Data


Evaluation of GFS clouds
Observations
MODIS VIIRS
AIRS ATMS CrIS
CERES
CloudSat CALIPSO
Surface data
Passive Remote Sensing
Active Remote Sensing
Ground Remote Sensing

Previous Diagnosis Studies

Yoo, H., and Z. Li, 2012, Evaluation of cloud properties in the NOAA/NCEP Global Forecaster System using multiple satellite product, *Climate Dynamics*, 10.1007/s00382-012-1430-0

Yoo, H., Z. Li, Y.-T. You, S.Lord, F. Weng, and H. W. Barker, 2013: Diagnosis and testing of low-level cloud parameterizations for the NCEP/GFS model satellite and ground-based measurements, *Clim. Dyn.*, doi:10.1007/s00382-013-1884-8.

Zhang, J., Z. Li, H. Chen, H. Yoo and M. Cribb, 2014, Cloud vertical distribution from radiosonde, remote sensing, and model simulations, *Climate Dynamics*, 43:1129–1140, DOI 10.1007/s00382-014-2142-4.

Apprach

1 Diagnosis

- Diagnosis of the state of GFS model parameterization of cloud variables such as cloud fraction, cloud optical depth, liquid & ice water path

2 Analysis

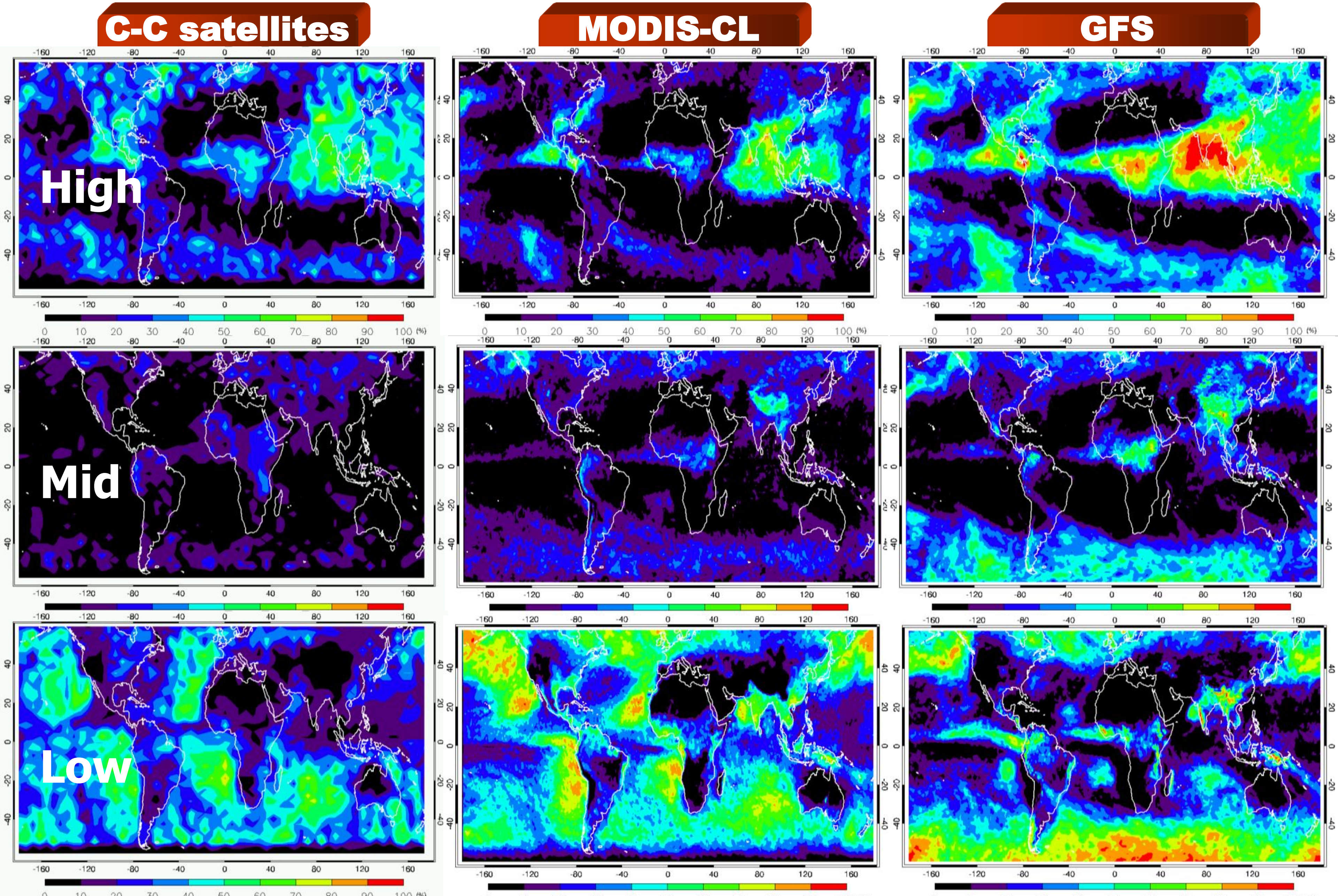
- Assessment of atmospheric meteorological Variables (e.g. RH, T) leading to cloud formation in the GFS model against observational data

3 Application

- Testing of Cloud fraction Scheme
- Testing of Cloud Overlap Scheme

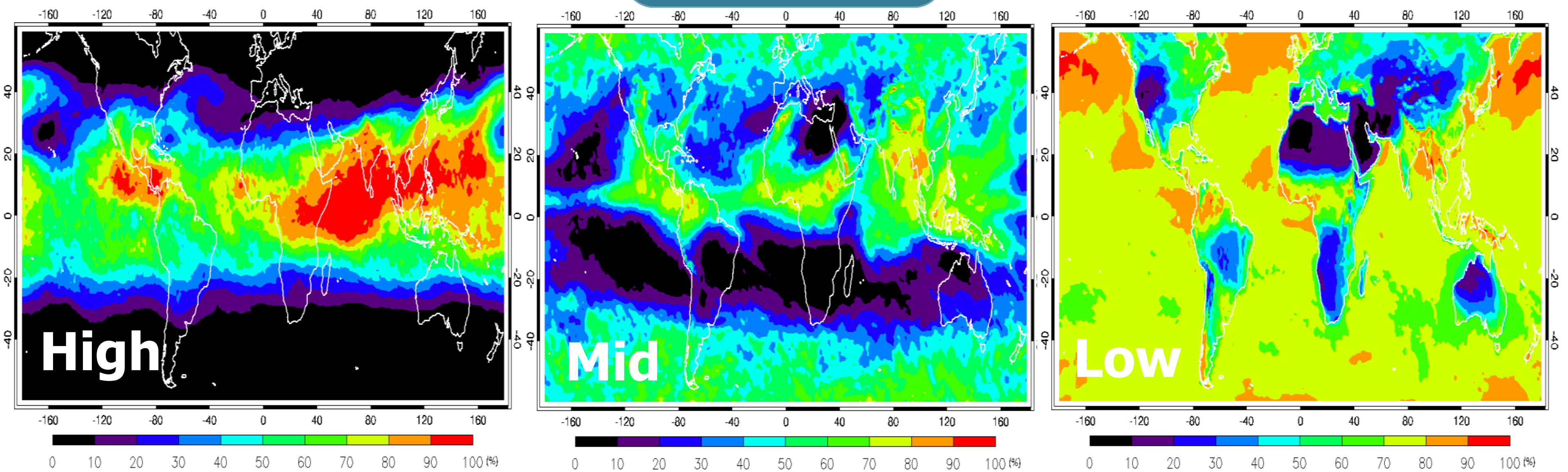
- Findings of aerosol climate effects and Implications for weather & climate modelingt

Comparison Cloud Fraction - July

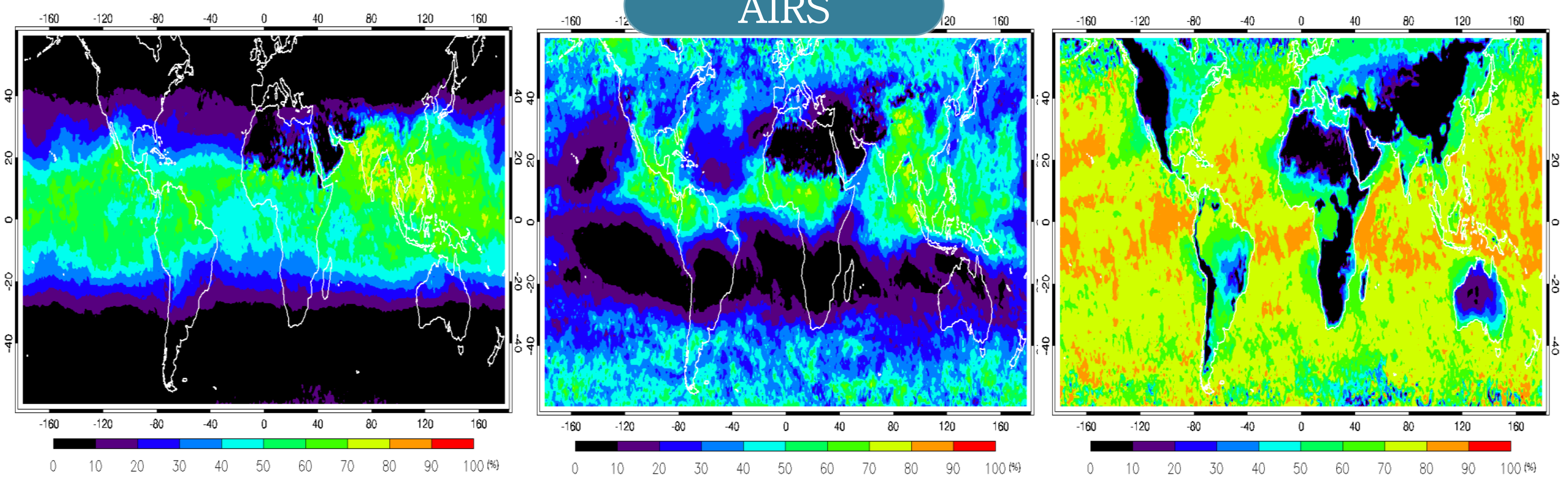


Comparison of RH Fields

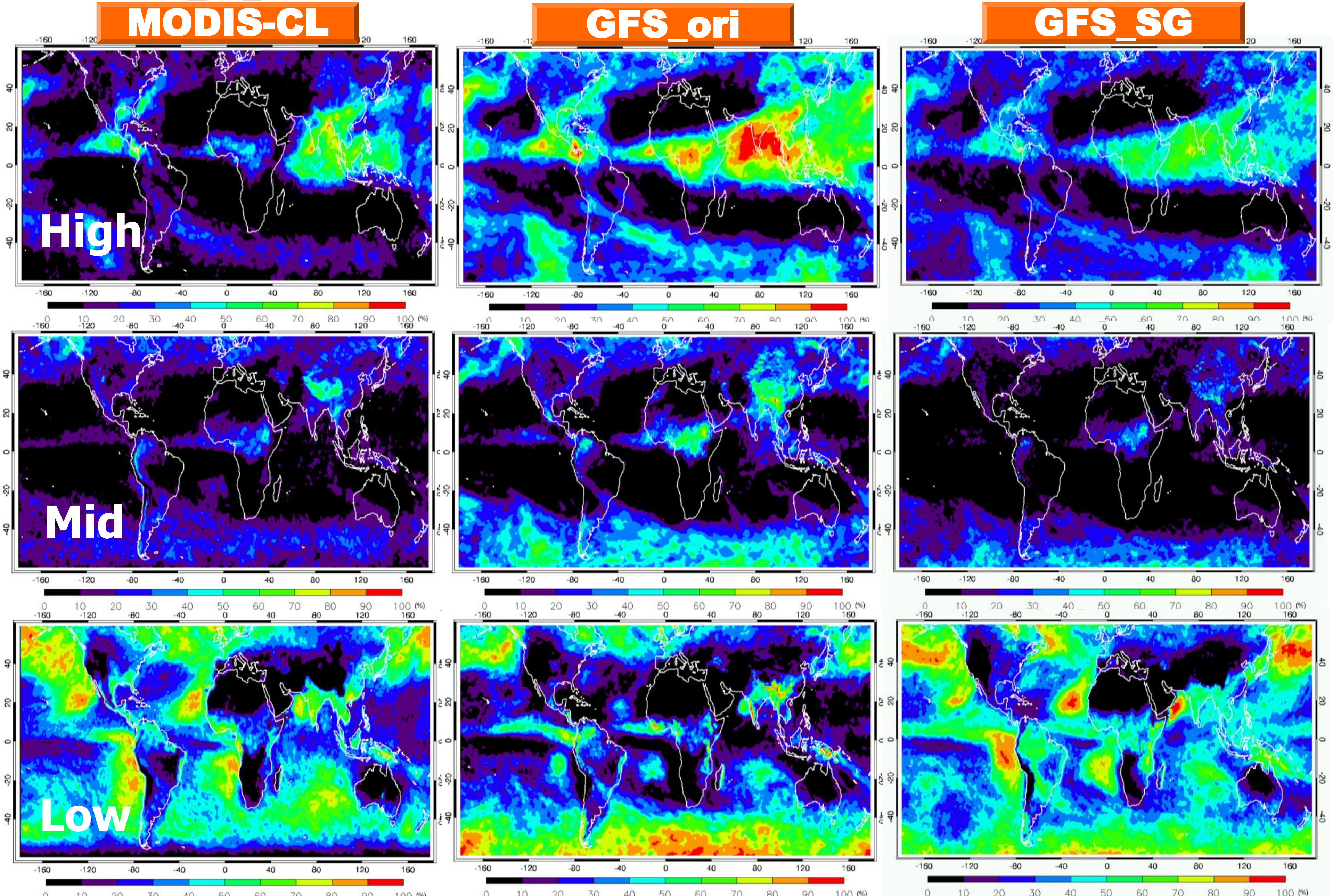
GFS



AIRS



Application : cloud fraction - July



2) Understanding the performance and improvement of the impact of the parameterization schemes on CAPI by using CRM and single column model (SCM) simulations for convective and stratiform cloud systems:

- Generate benchmark results by a CRM with full-fledged physics at varying resolutions to evaluate the impact of model grids on accounting for physical processes involving cloud-aerosol-precipitation interactions (CAPI);

- Evaluate the errors in the new parameterization schemes in terms of the simulation of clouds and their interactions with aerosol by running the CRM with the same parameterization schemes related to CAPI processes and forcing data from both Global Forecast System (GFS) simulations and observation analyses.

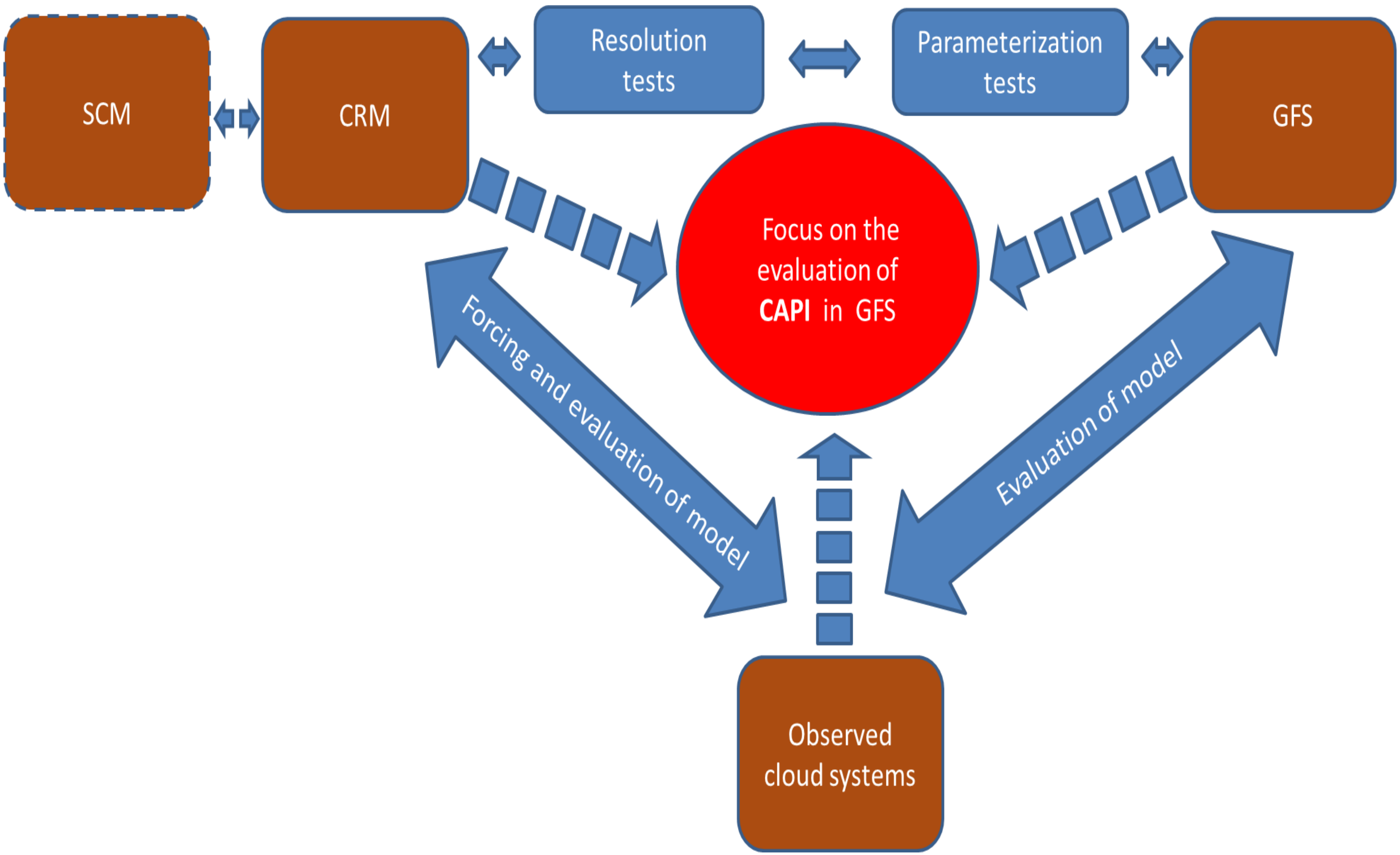
New Schemes to be Evaluated

(1) MG scheme
Use of a threshold mixing ratio and a constant collection efficiency and thus no consideration of spectral information from cloud particle size distributions for autoconversion and collection processes; use of mass-weight mean terminal velocity and thus no consideration of spectral information for sedimentation processes; use of a saturation adjustment.

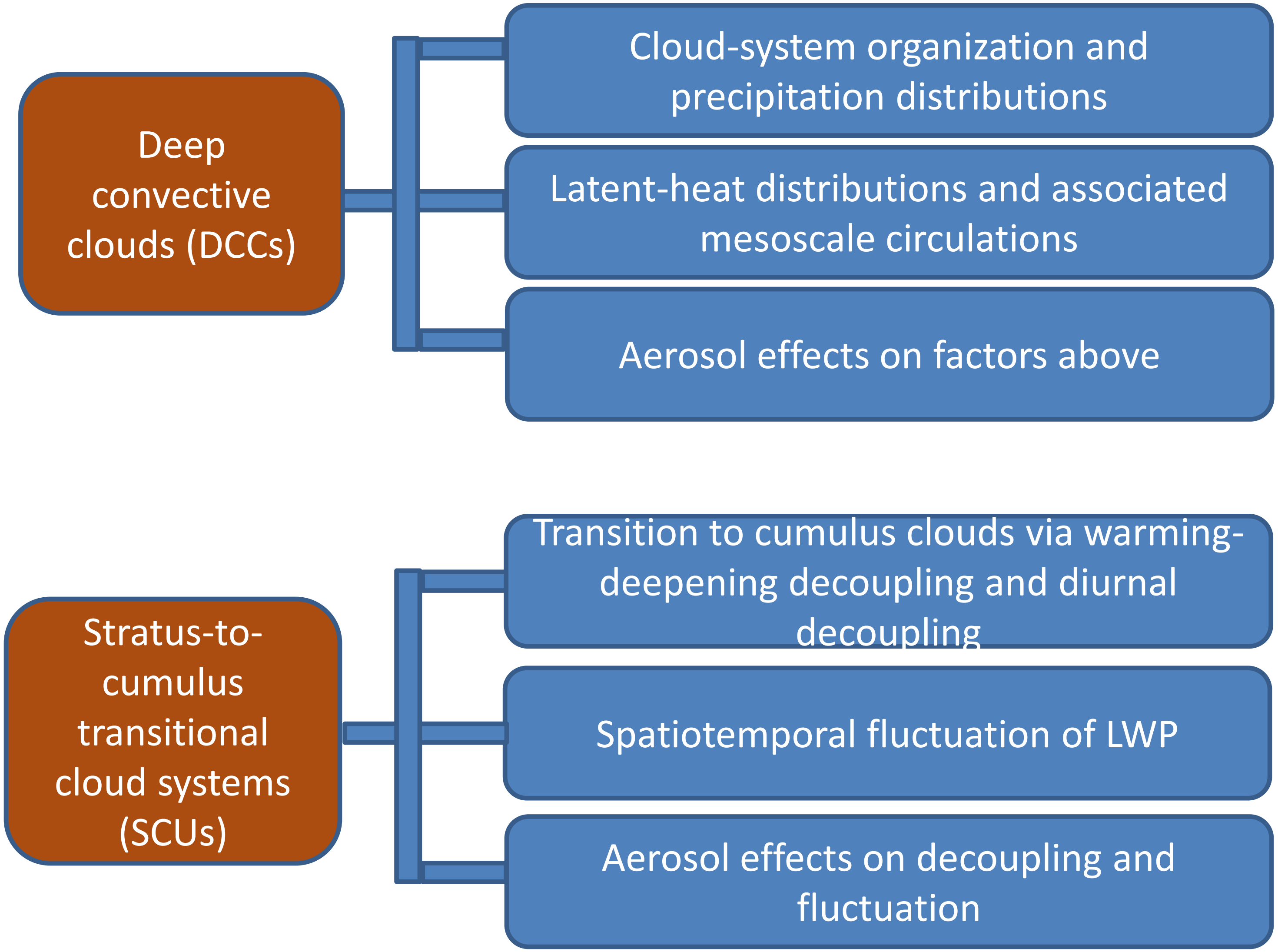
(2) Scale-aware cumulus parameterization
Use of a scale-aware approach which enables the application of cumulus parameterization to both fine and coarse scales. No consideration of mesoscale circulation, cloud system organization, and aerosols.

(3) SHOC scheme
Use of joints PDFs of cloud variables to represent subgrid-scale variability of those variables, which are then used to represent interactions between subgrid-scale turbulence and this variability. PDFs are assumed to follow a specific form of distribution such as the log-normal distribution.

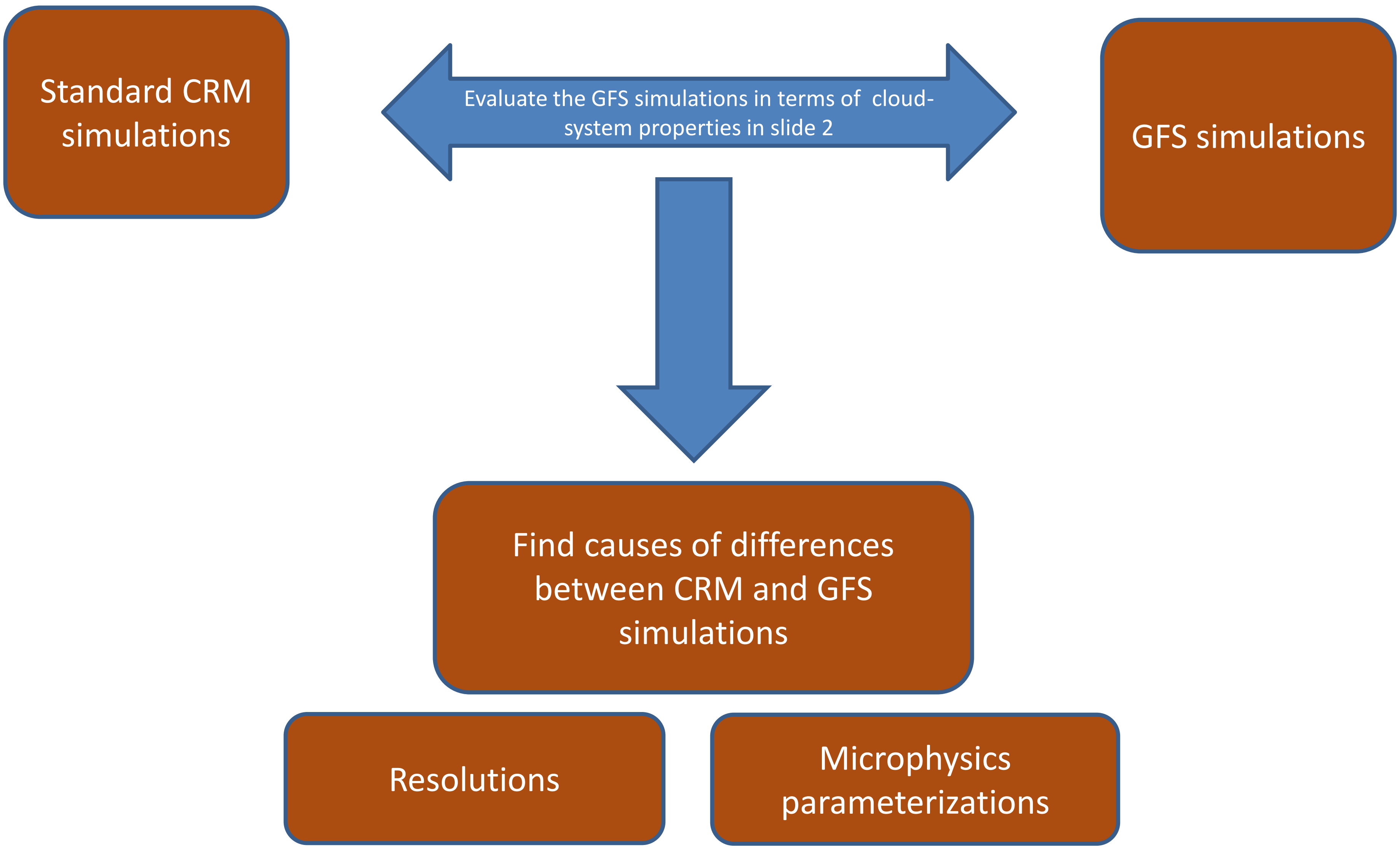
Basic outline for the modeling work



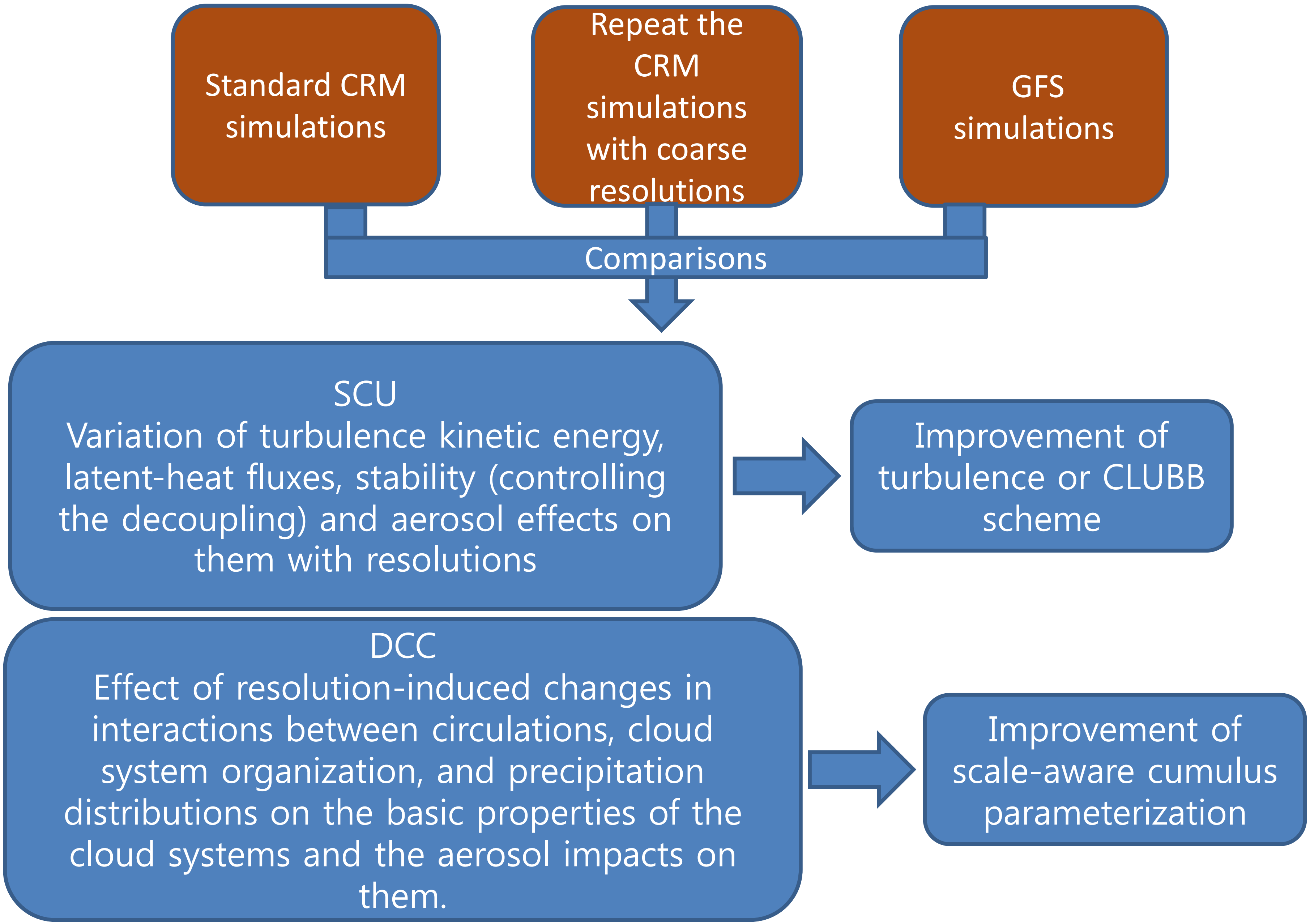
Selection of cloud systems



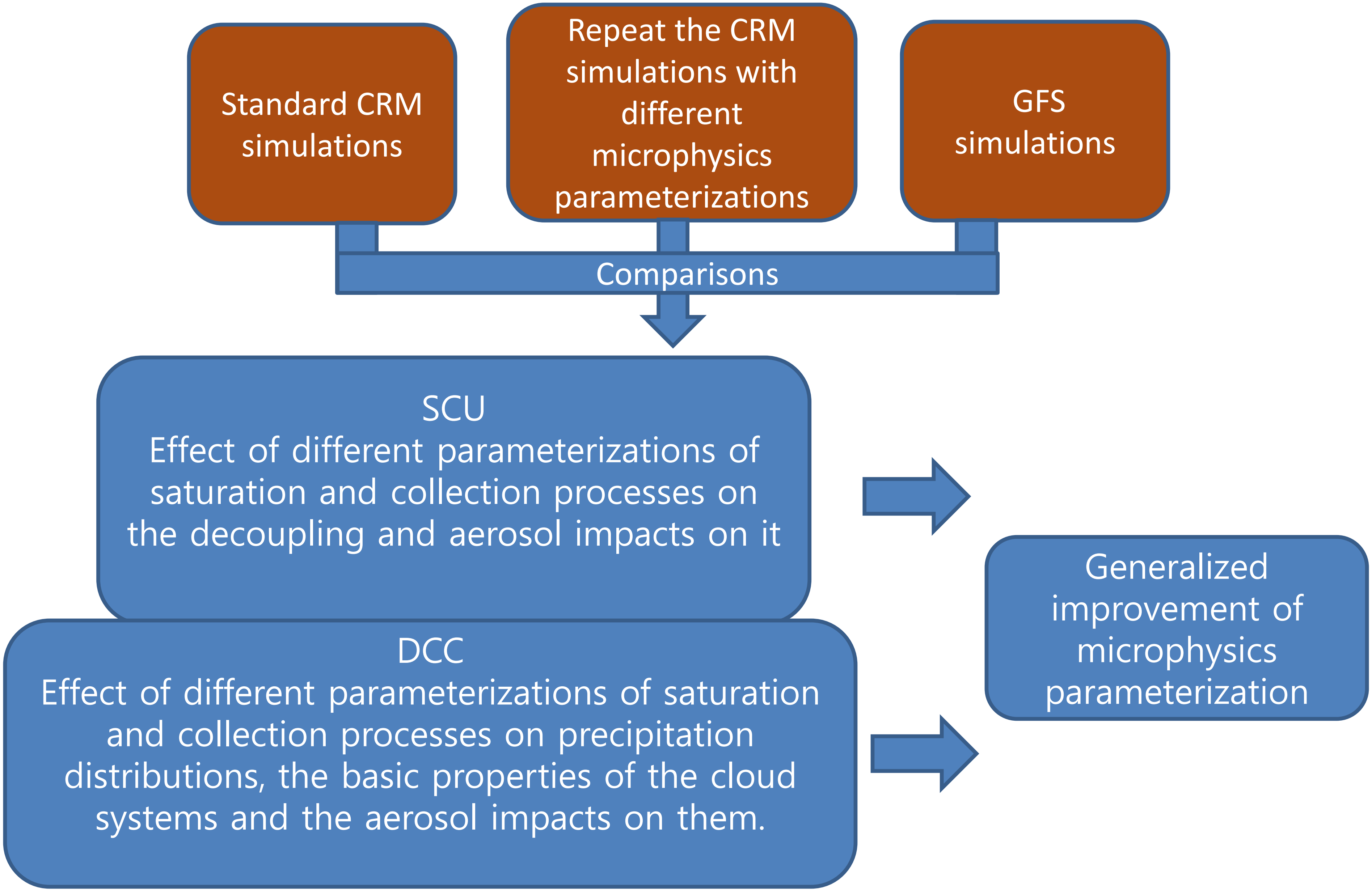
Evaluate the GFS simulations against the CRM simulations



Sensitivity tests for resolutions



Sensitivity tests for microphysics parameterizations



Major Tasks

- Evaluation of the GFS baseline model: before any new physical scheme is implemented into the GFS, we will evaluate its performance in simulating clouds, aerosols, and their interactions so that changes incurred by the introduction of any new scheme can be evaluated against benchmarks

- Select the DCC and SCU systems from the IOP sites. Collect observed and GFS-produced data from the selected cloud systems and run the CRM and SCM (if available).

- Evaluate CRM, SCM and GFS simulations against observations to identify differences between the CRM, SCM, and GFS simulations.

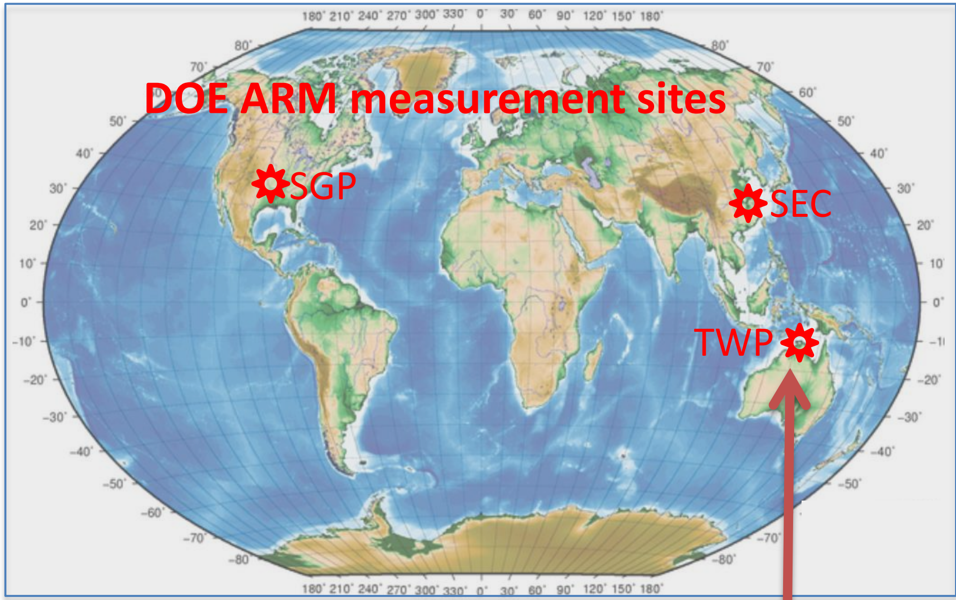
- Repeat the CRM simulations with varying resolutions and analyze changes in latent heat and radiative fluxes, stability, turbulence, circulations, cloud system organization, and precipitation distributions, and aerosol effects on them.

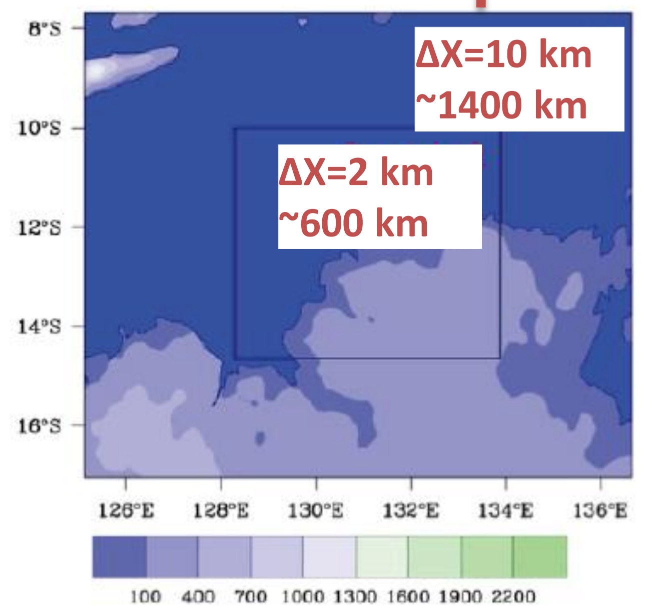
- Repeat the above but with each change in model physical schemes.

Cases selection: taking advantage of the ARM sites

- **One-month regional CRM simulations with spectral-bin microphysics (SBM)**

- **TWP** (**Jan.15-Feb.15, 2006**): tropic oceanic convection
- **SEC**- SE China (**July 2008**): summer convection of mid-latitude coastal area
- **SGP** (**June 2008**): mid-latitude inland summer convection.

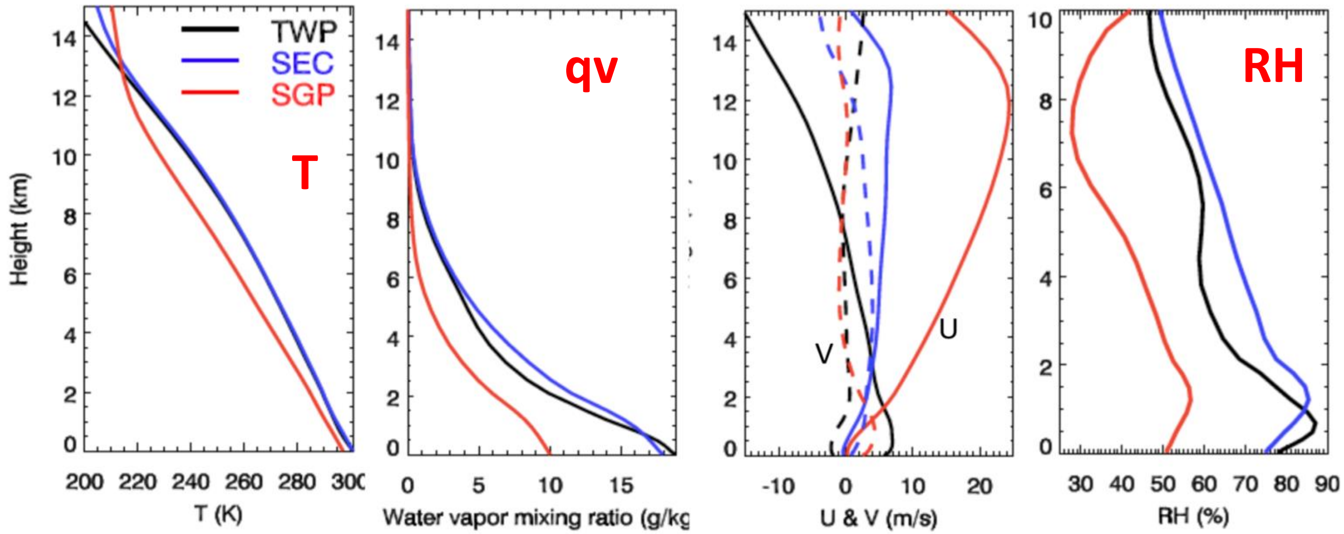


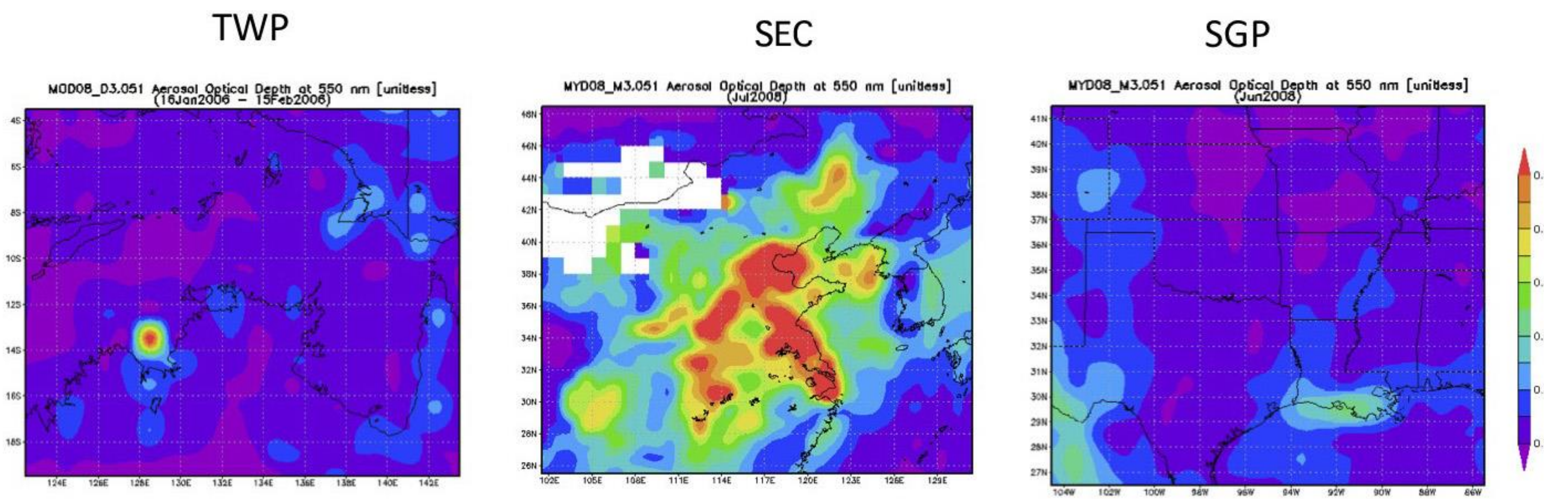


Covering all kinds of environment conditions: from dry to humid, weak to strong wind shear, isolated convection to convection system

Fan J. et al., PNAS, 2013

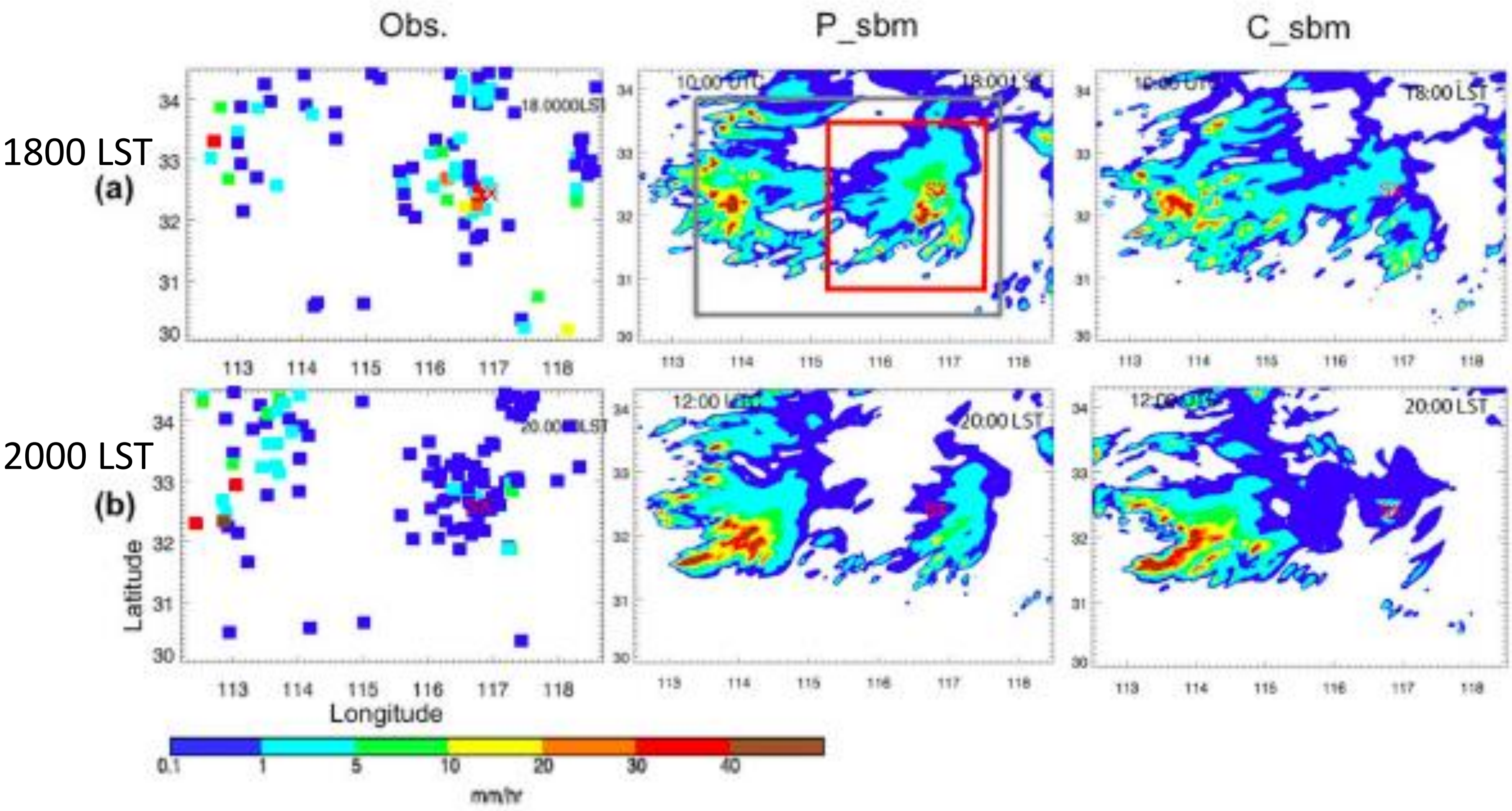
Meteorological and aerosol conditions





- **TWP and SEC : humid with weak wind shear; SGP: dry and strong wind shear**
- **TWP and SGP are clean and SEC is polluted (6*280 cm^{-3}) conditions**
- **Clean (280 cm^{-3}) and polluted (6*280 cm^{-3}) are run for each case**

MCS in Southeast of China during AMF-China



Fan et al. 2012

Major Foci of Evaluation and Diagnosis Studies

1. Spatial distribution of clouds

2. Deep convective clouds and aerosol from model vs observations

3. Systematic rainfall forecast errors vs aerosol, with particular attention to China as a representative of polluted environment

Thank you !