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

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Introduction

1. Forecasting rainfall is most challenging which requires good performance in modeling many pertinent variables such as humidity, updraft, cloud, etc.

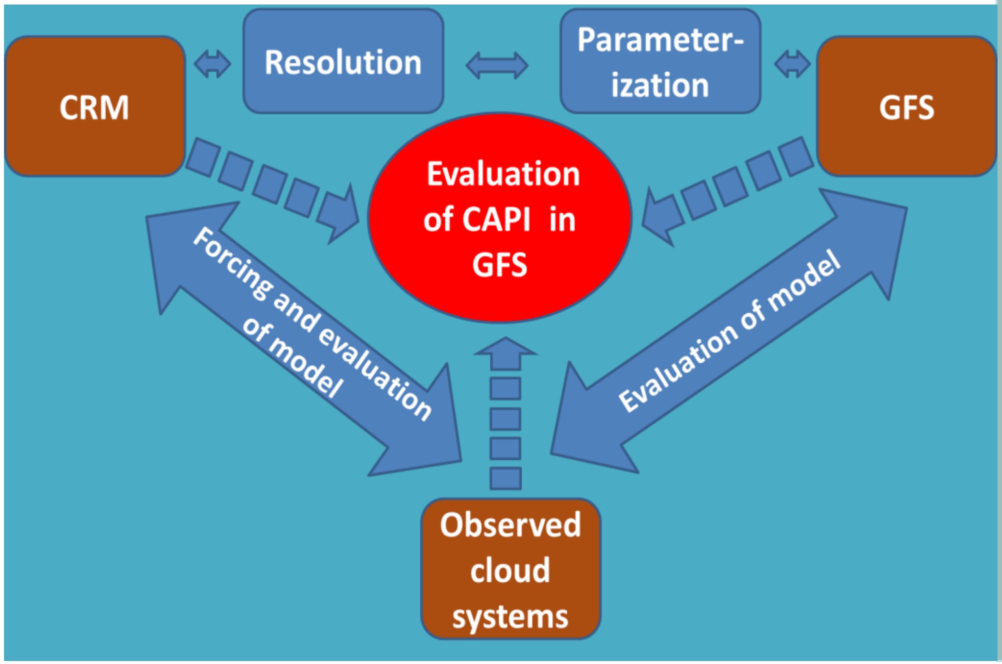
2. Cloud-Aerosol-Precipitation-Interaction (CAPI) is being increasingly recognized as an important process driving the water and energy cycles. CAPI is not considered in current GFS.

3. A suite of new physical schemes such as the Morrison and Gettelman two-momentum cloud microphysical scheme are or will be implemented into the NCEP's Next Generation Global Prediction System (NGGPS).

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

Goal:

Improve cloud and rain forecasting by accounting for aerosol effects following data analysis, cloud resolving modeling (CRM) to evaluate and improve the NGGPS



Deliverables

- Identified NWP forecast errors due to un-accounted aerosol effects using satellite and ground-based data;
- Evaluation the performance of physical schemes accounting for the CAPI;
- Improve understanding of the performance of new physical schemes with the aid of a cloud resolving model.

Major Tasks

1. Use a variety of observation data to continue identify and quantify the impact of aerosol on cloud and precipitation.

2. Evaluate the performance of the GFS baseline model in simulating clouds and precipitation before any new scheme is introduced as benchmarks.

3. Investigate any dependence of model biases in simulating clouds and precipitation on aerosol properties under different meteorological conditions.

4. Select certain cloud systems, run the CRM with NGGPS-selected parameterization schemes, and compare the CRM against GFS/NGGPS results .

Task 1

Identify and quantify the impact of aerosol on cloud and precipitation.

Publications

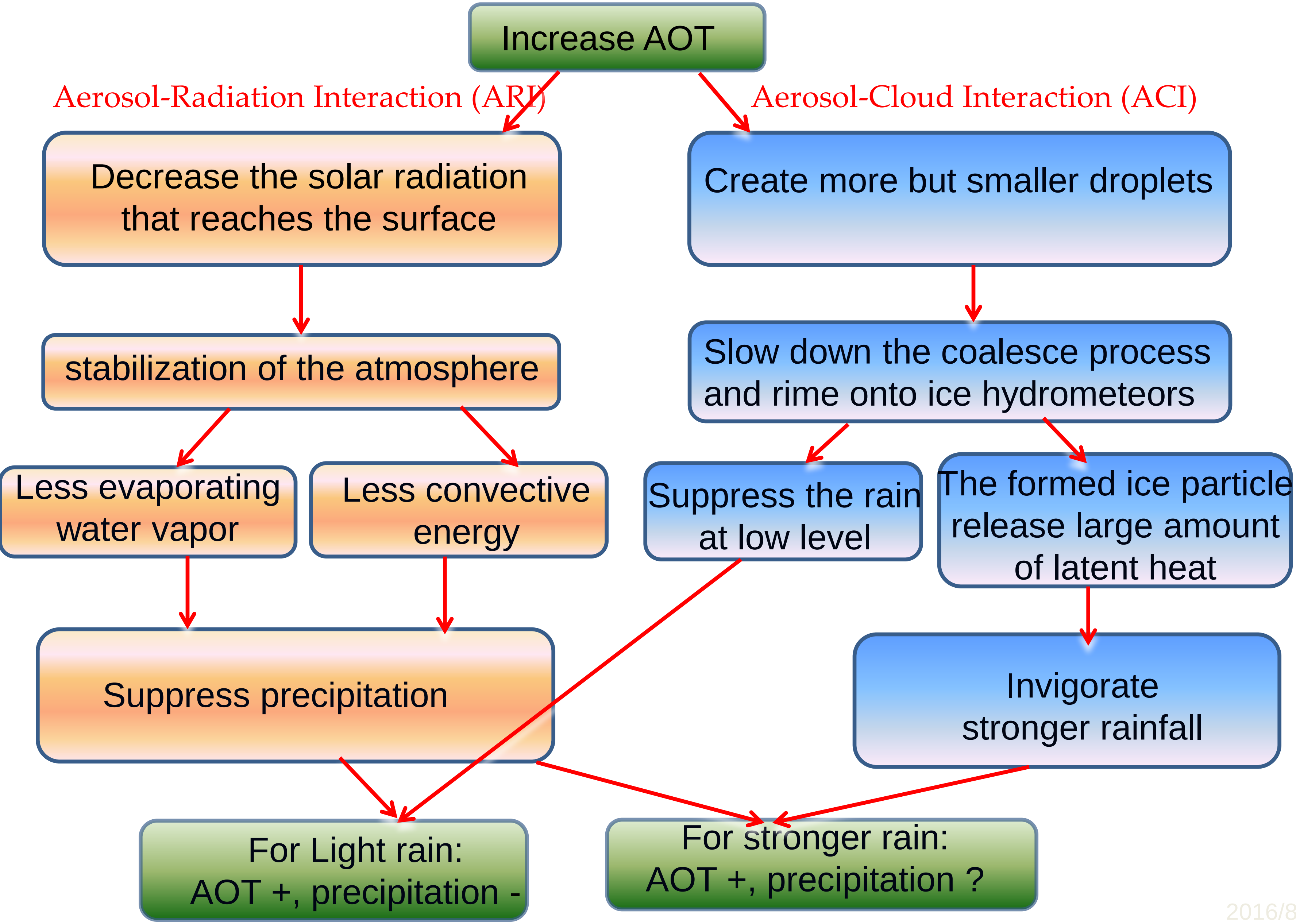
Yang, X., Z. Li, L. Liu, and L. Zhou, 2016: Distinct impact of aerosol type on the weekly cycles of thunderstorms in China, *Geophys. Res. Lett.*, in press.

Lee, S.-S., J. Guo, and Z. Li, 2016: Delaying precipitation by air pollution over the Pearl River Delta. Part II: Model simulations, *J. Geophys. Res. – Atmos.*, revised.

Guo, J., M. Deng, S.-S. Lee, F. Wang, Z. Li, P. Zhai, H. Liu, W. Lv, W. Yao, and X., Li, 2015: Delayed diurnal changes in precipitation and lightning by air pollution over Pearl River Delta: observational evidences and model simulations, *J. Geophys. Res. – Atmos.*, in press.

Zhu, Y., X. Yu, Z. Li, and D. Rosenfeld, 2015: Separating aerosol microphysical effects and satellite measurement artifacts of the relationships between warm rain onset height and aerosol optical depth, *J. Geophys. Res. Atmos.*, 120, doi:10.1002/2015JD023547.

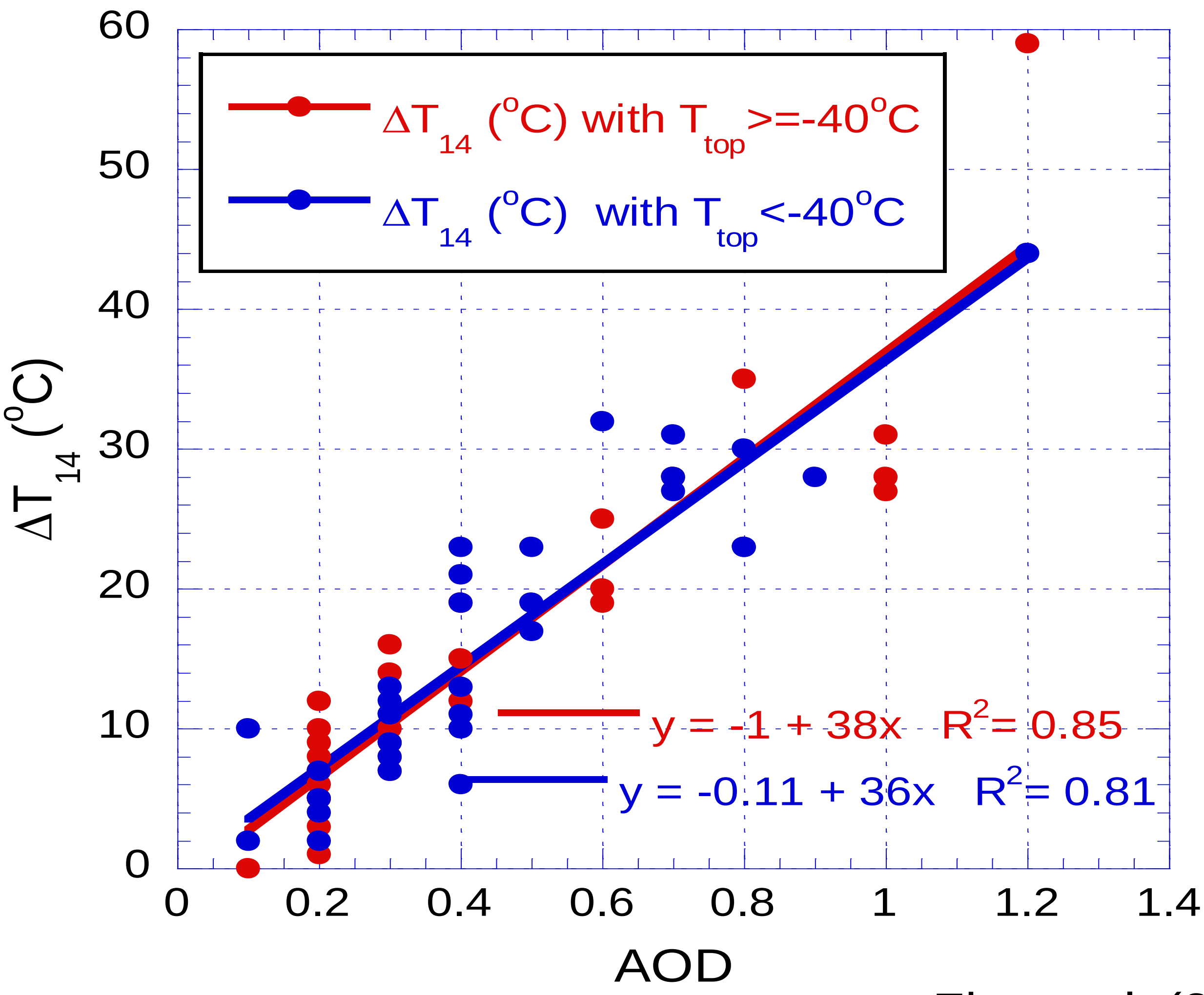
Mechanisms of CAPI



2016/8/9

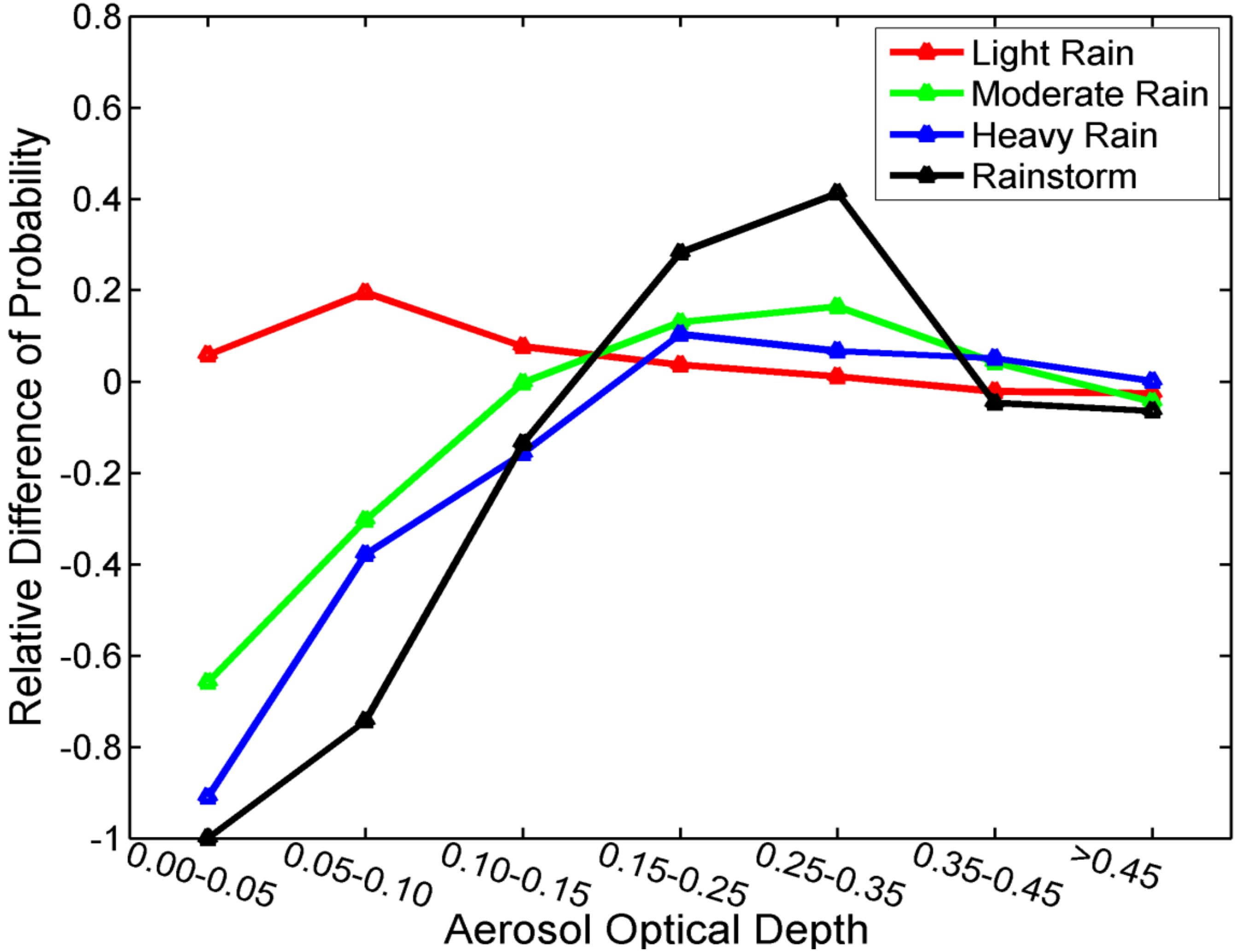
Relationship between cloud thickness of raining and aerosol

a



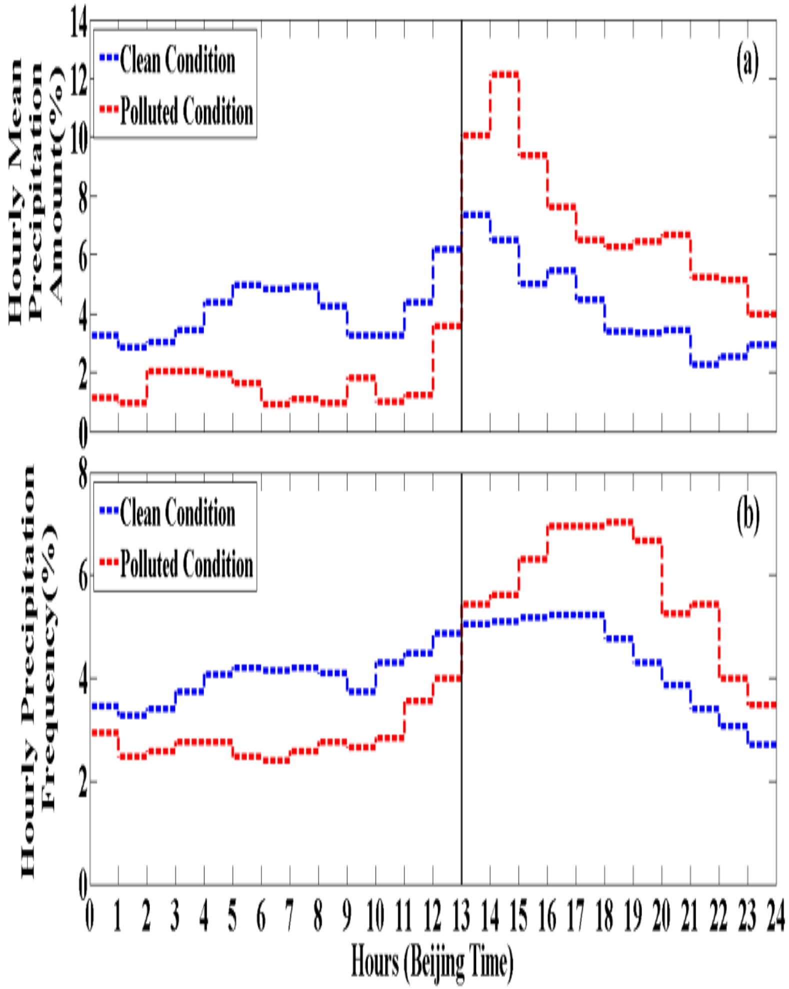
Zhu et al. (2015, JGR)

Non-linear Relationship Aerosol & Precipitation

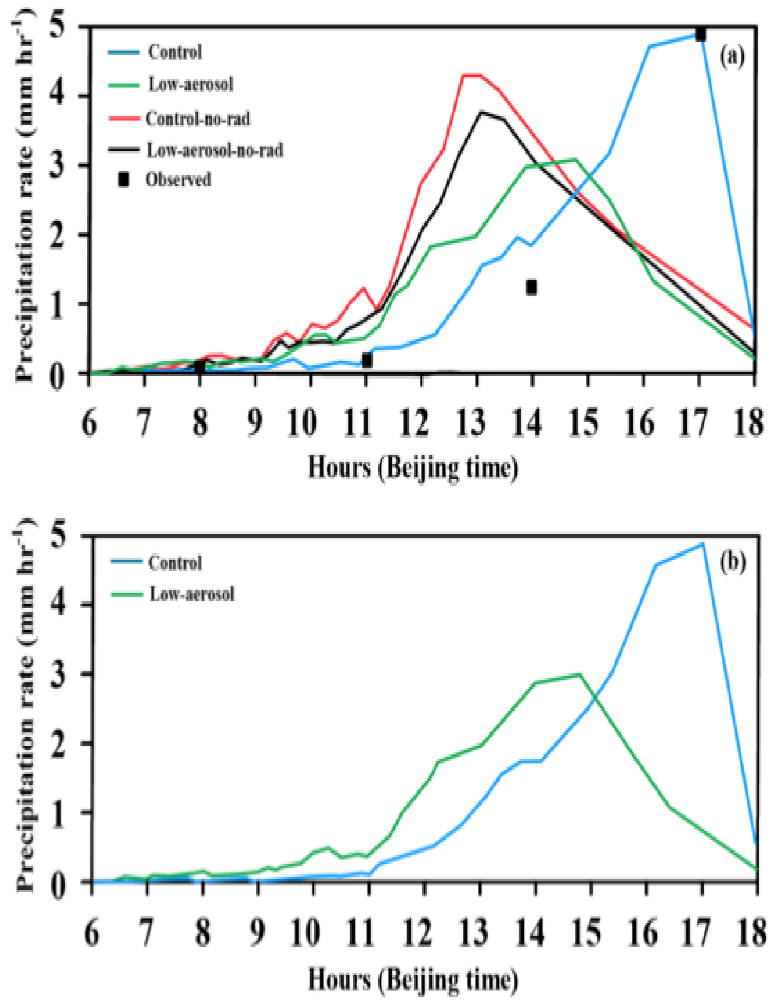


Jiang et al. (2016, JGR)

Diurnal Cycle of Rainfall from Deep Clouds Contrast between Clean & Dirty Air



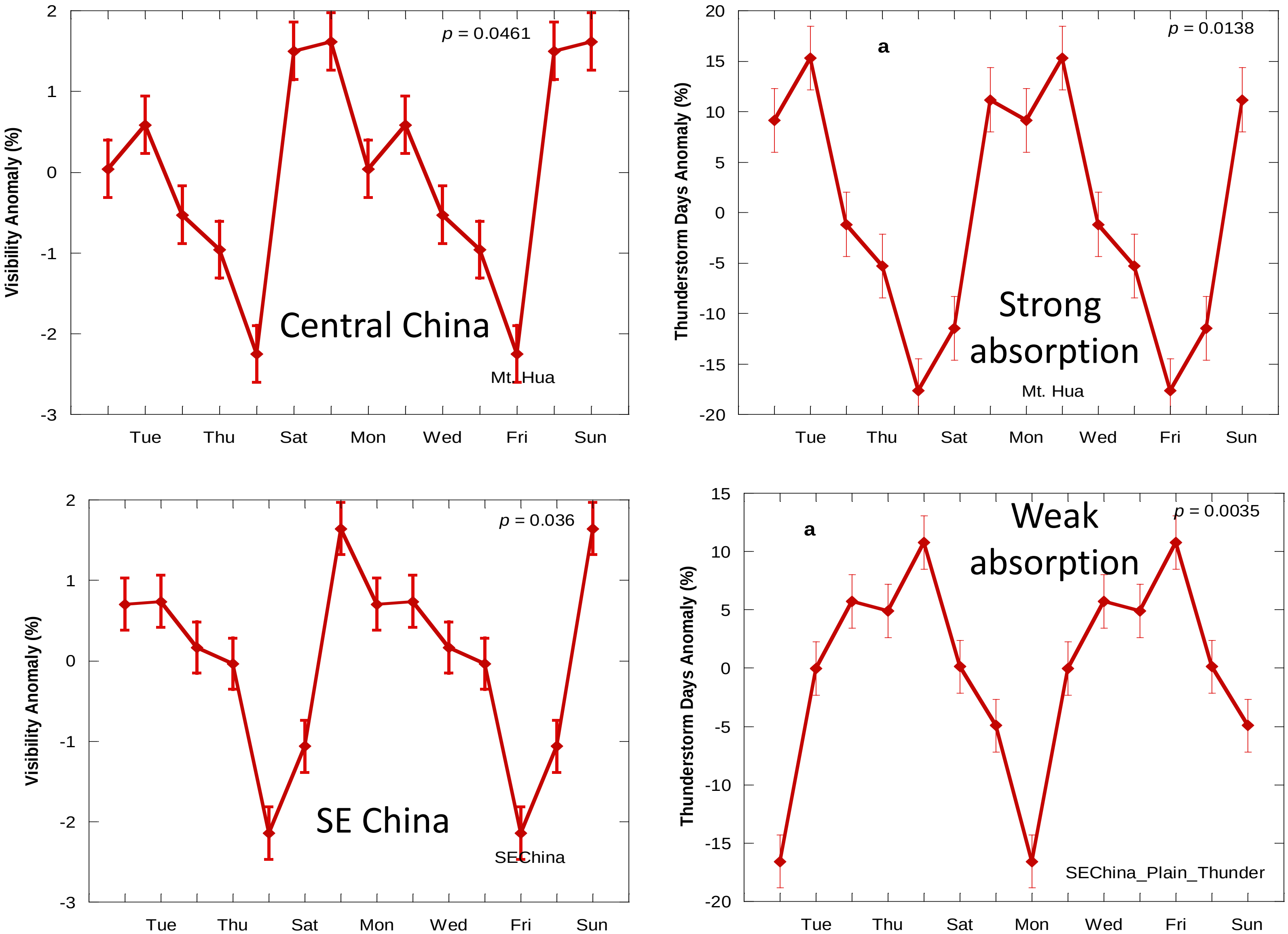
Guo et al. (2016, JGR)



Lee et al. (2016, JGR)

Visibility

Thunderstorms



Yang et al. (2016, GRL)

Task 2

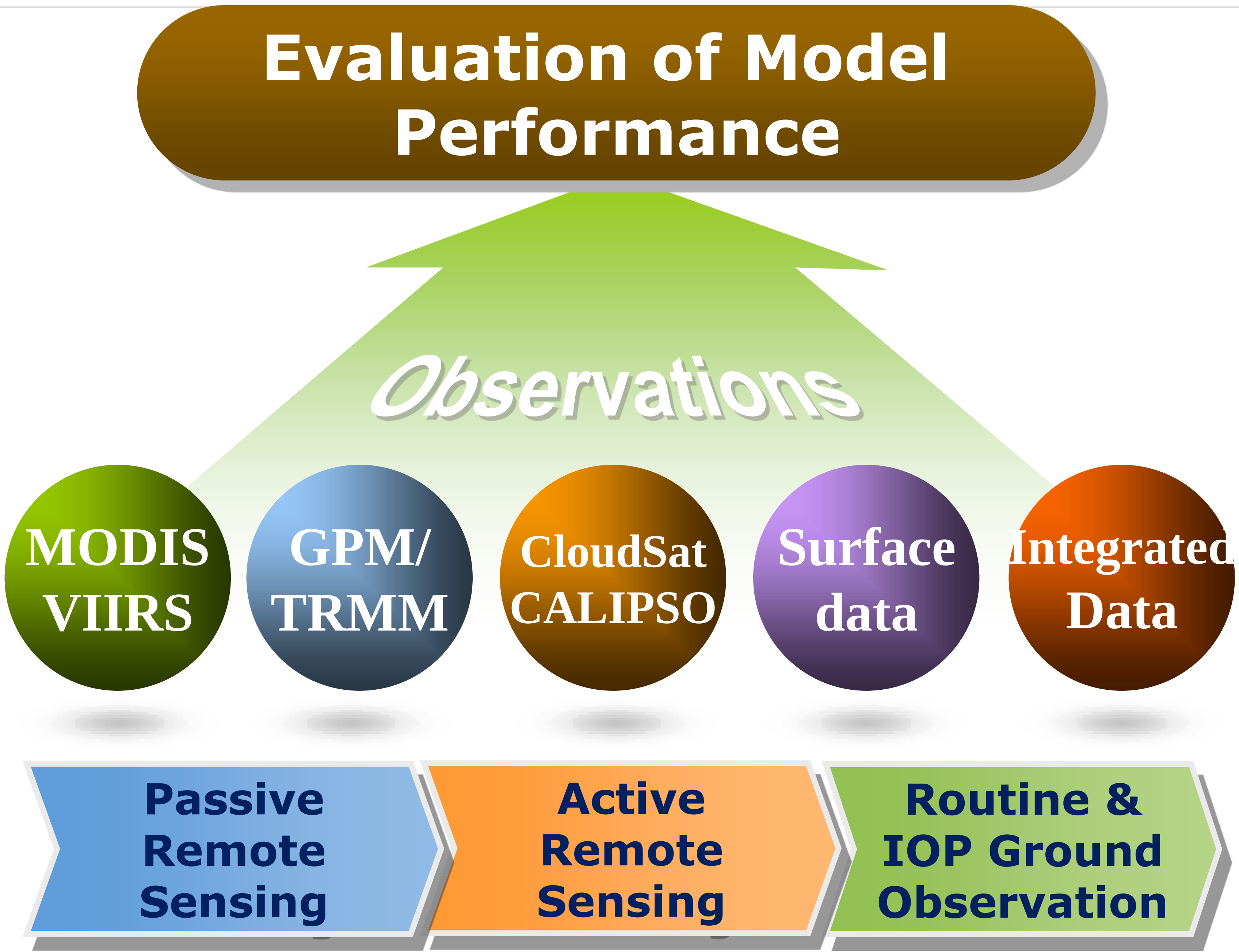
Evaluating the performance of the GFS baseline model before new schemes are introduced

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

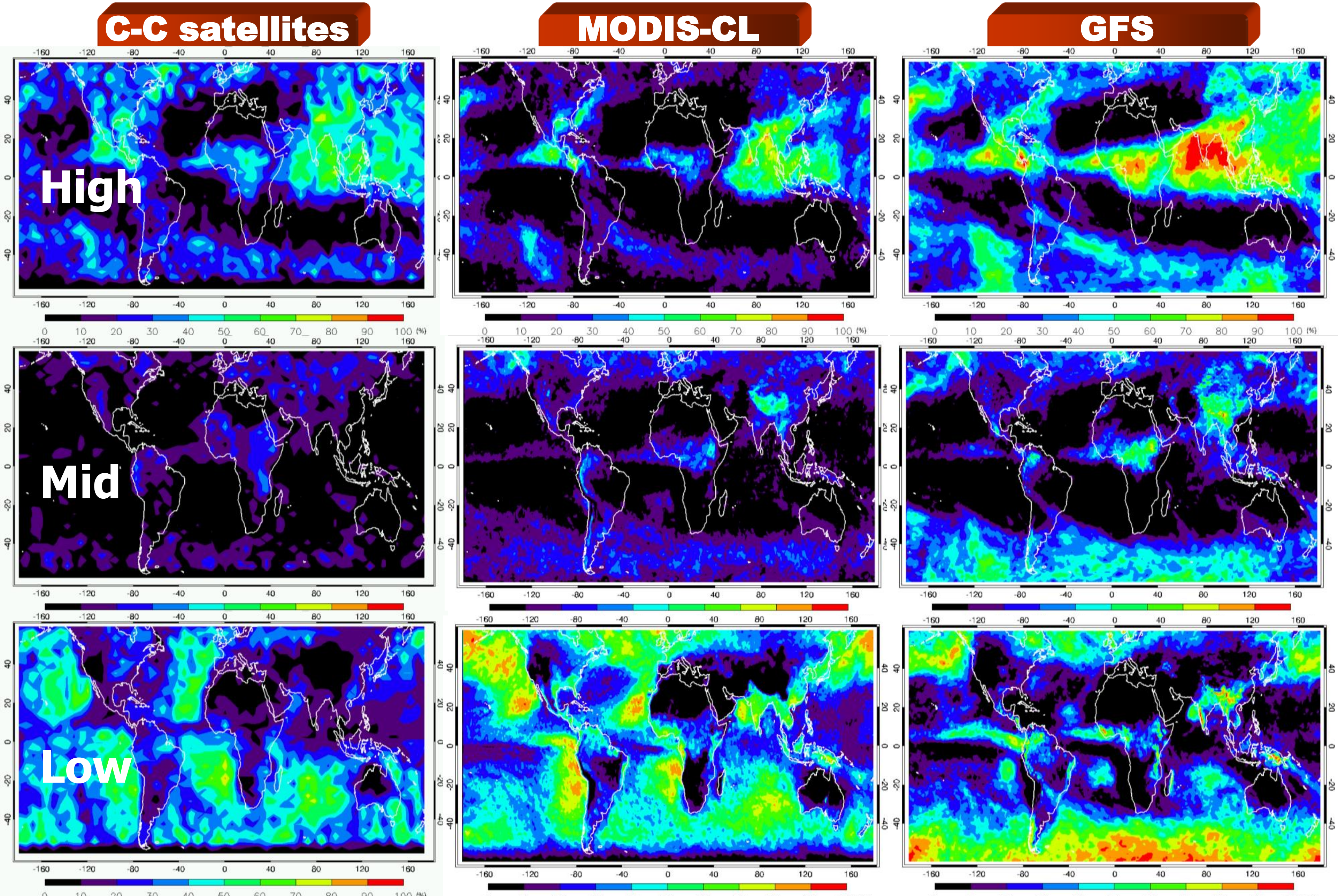
Yoo, H., Z. Li, Y.-T. You, S.Lord, F. Weng, and H. W. Barker, 2013: Diagnosis and testing of low-level cloud parameterizations for the NCEP/GFS model satellite and ground-based measurements, *Clim. Dyn.*, doi:10.1007/s00382-013-1884-8.

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.



Evaluation of Model Performance
Observations
MODIS VIIRS
GPM/ TRMM
CloudSat CALIPSO
Surface data
Integrated Data
Passive Remote Sensing
Active Remote Sensing
Routine & IOP Ground Observation

Comparison Cloud Fraction - July



1. GFS Baseline Model Evaluation

Diagnosis of cloud, meteorological variables from the current Global Forecast System (GFS) model with observations before any CAPI effect is introduced to examine if any errors are seen due to cloud-aerosol interaction.

- **The GFS model upgraded shallow convective scheme by replacing the old turbulent diffusion-based approach with a mass flux parameterization in 2010.**

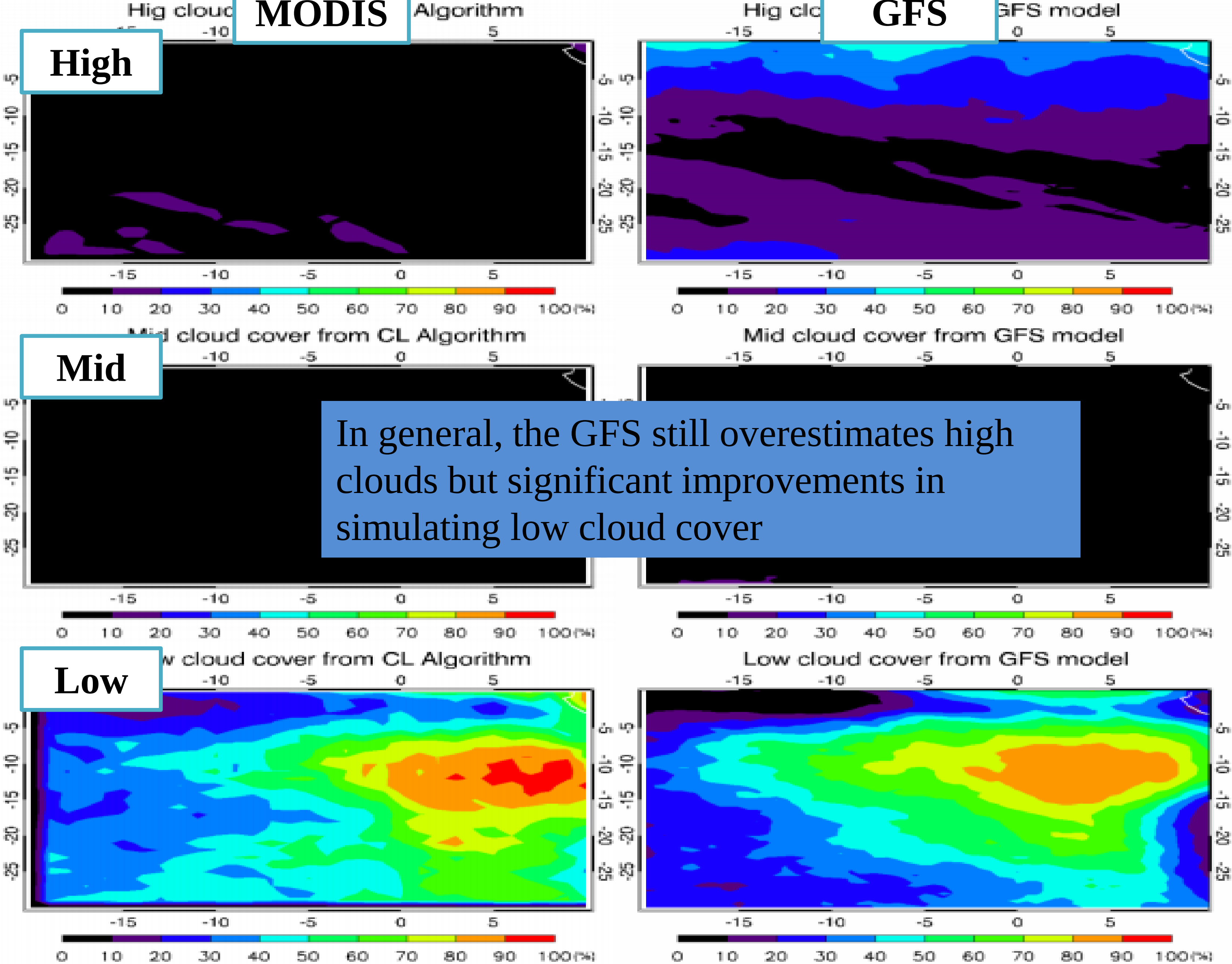
- **The new double-moment cloud microphysics scheme and a multimodal and double-moment Modal Aerosol Module(MAM-7) will be implemented into the GFS model to account for cloud-aerosol interaction effect through NCEP-GMAO collaborations.**

2. Data

- **GFS model (Forcast):** 0.5 deg * 0.5 deg, 3-hourly (Forecast at 00 UTC)
- **AIRS data** Atmospheric InfraRed Sounder to compare temperature profile
- **MODIS data** To see cloud fraction retrieved by the CL algorithm

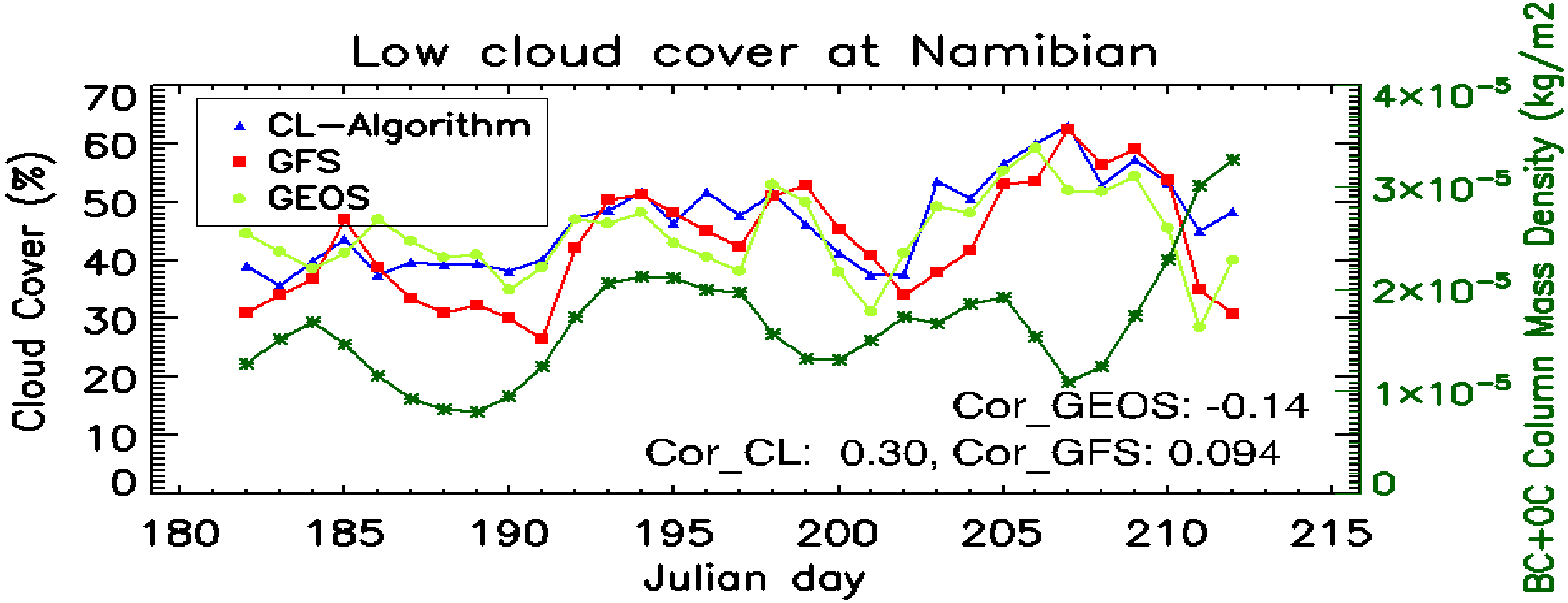
3. Target

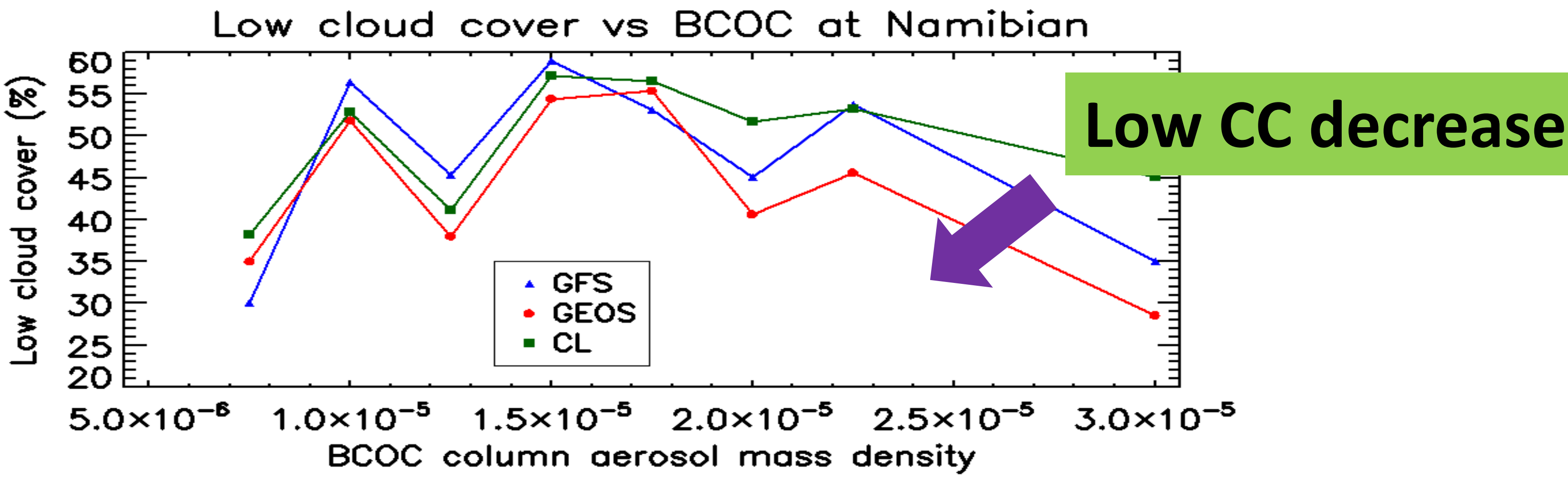
Namibian region: Lat: 0 to -30, Lon: -20 to 10 E (July 2014) to see black and organic carbon effect on temperature, cloud mixing ratio, and cloud fraction



In general, the GFS still overestimates high clouds but significant improvements in simulating low cloud cover

Focus on Low cloud as marine stratocumulus clouds are common





Low-level clouds have slight variations in this region and absorbing aerosol emitted by biomass burning can modify low-level cloud properties through cloud-aerosol interactions.

Task 3

Investigating any dependence of model biases in simulating clouds and precipitation on aerosol properties

2.Data and Methodology

Data:

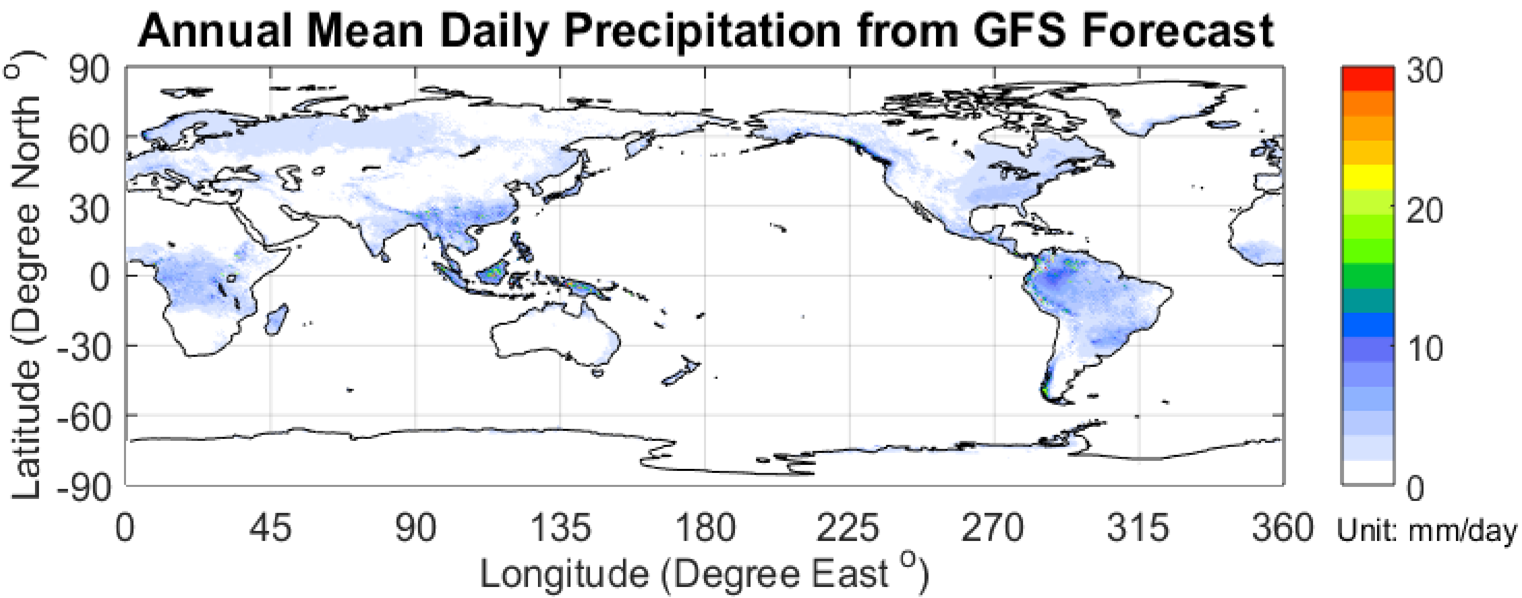
Precipitation:

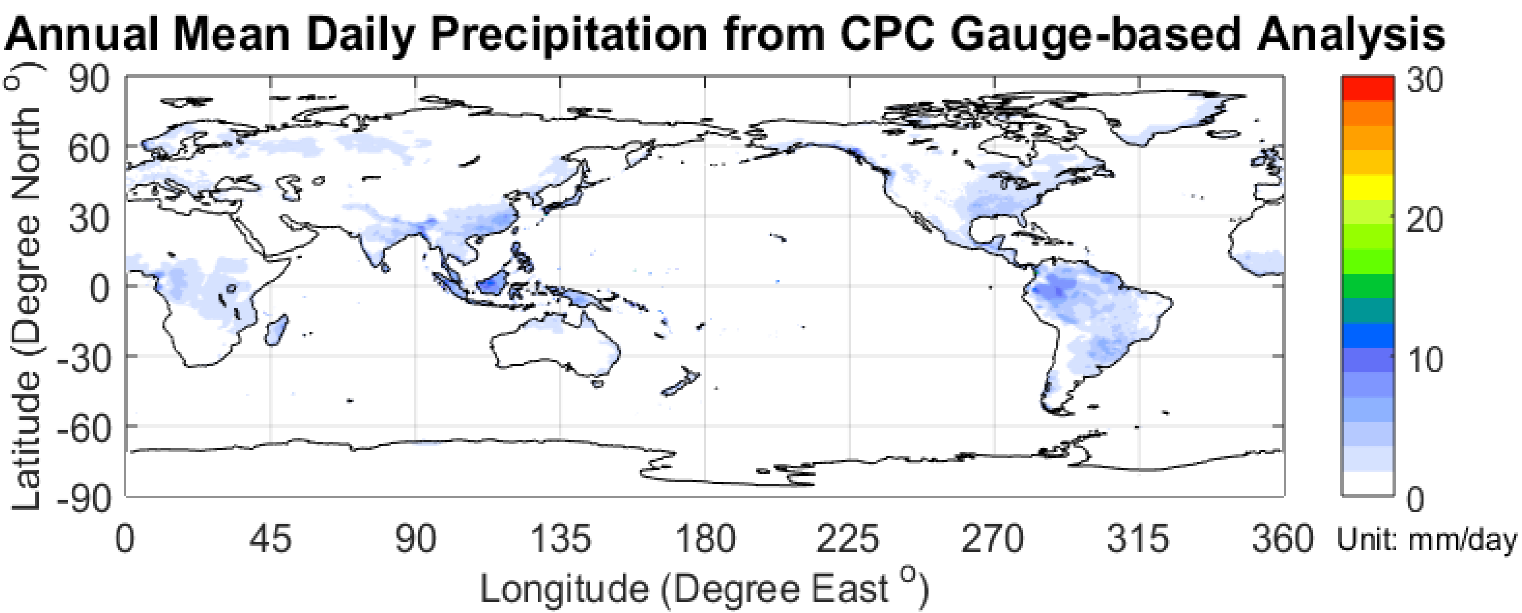
Forecast: GFS(gfs_4), 0.5deg*0.5deg, Globally, 3-hourly (forecast at 00 UTC), year 2015

Gauge based: CPC unified gauge based Analysis, 0.5deg*0.5deg, Globally, daily, year 2015

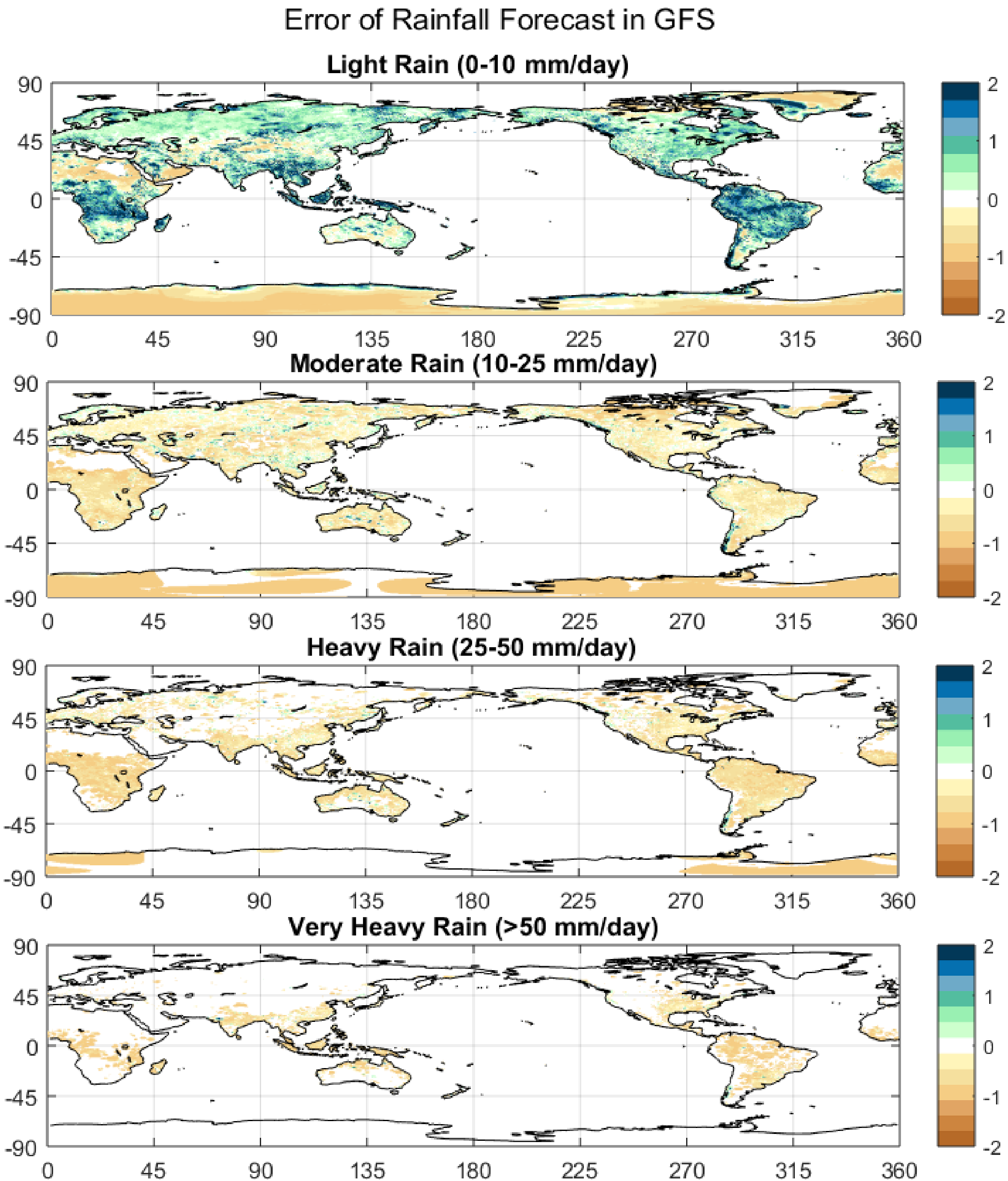
Aerosol: NASA MERRA2 Aerosol Reanalysis AOD, 0.625deg*0.5deg, Globally, hourly, year 2015

Preliminary Results



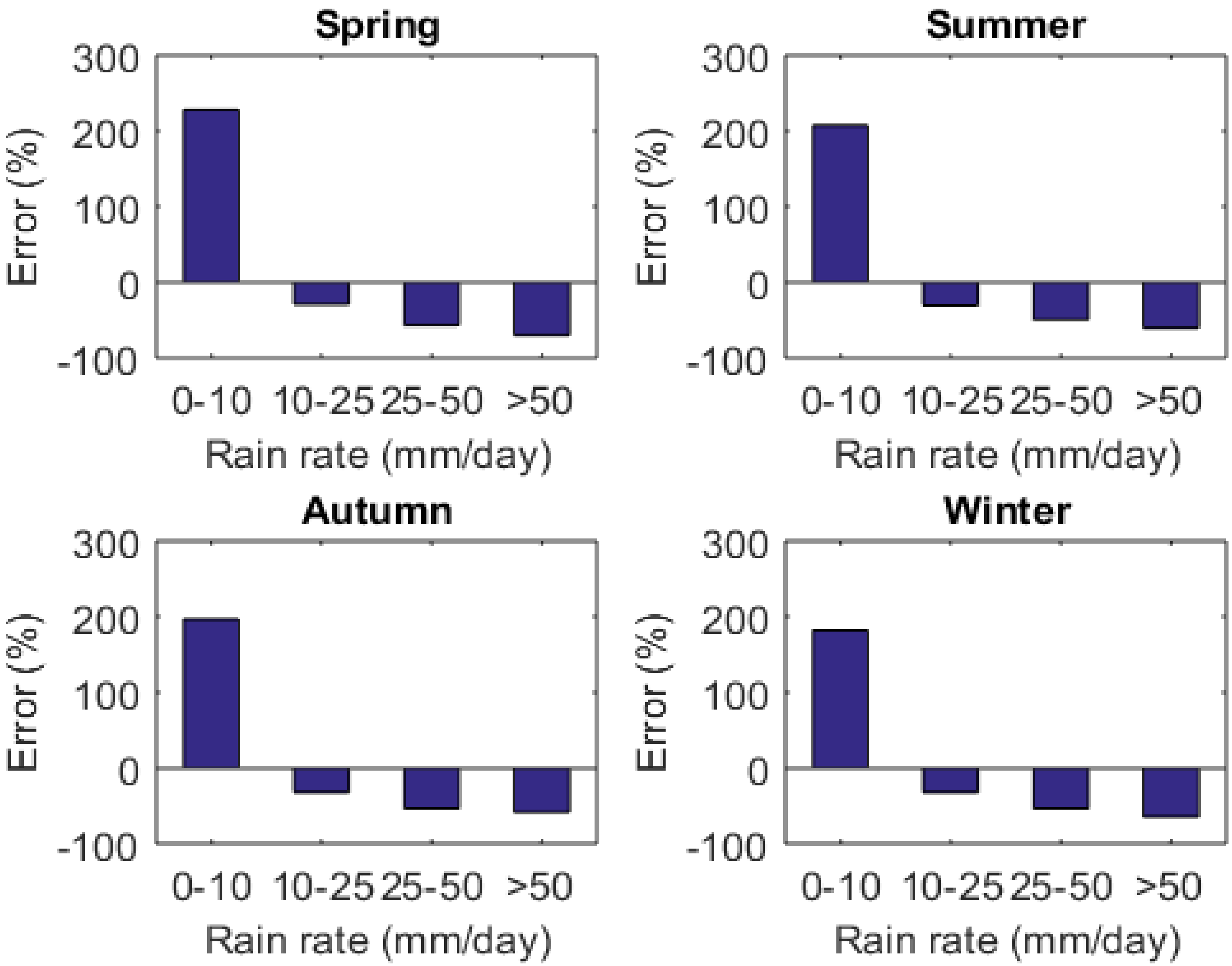


Comparison of the pattern of rainfall from GFS forecast and CPC observation.
In general, the GFS rainfall forecast catches the main patterns.

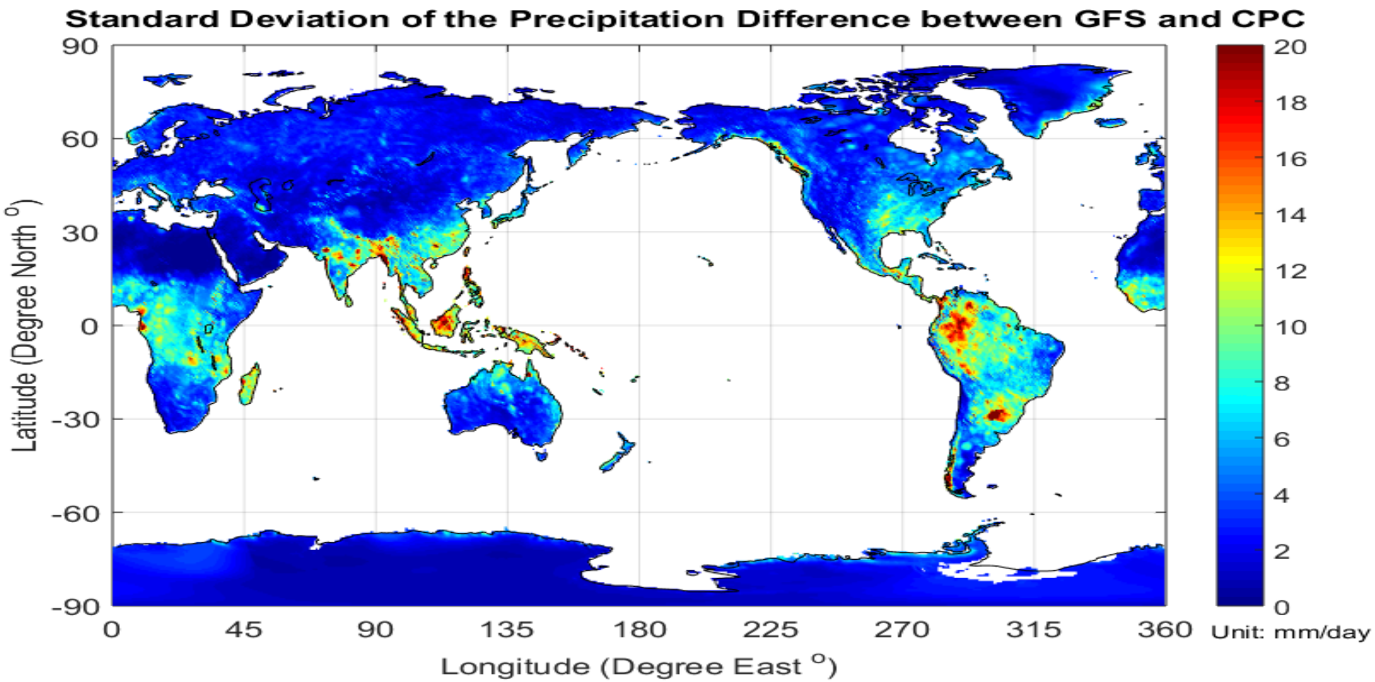


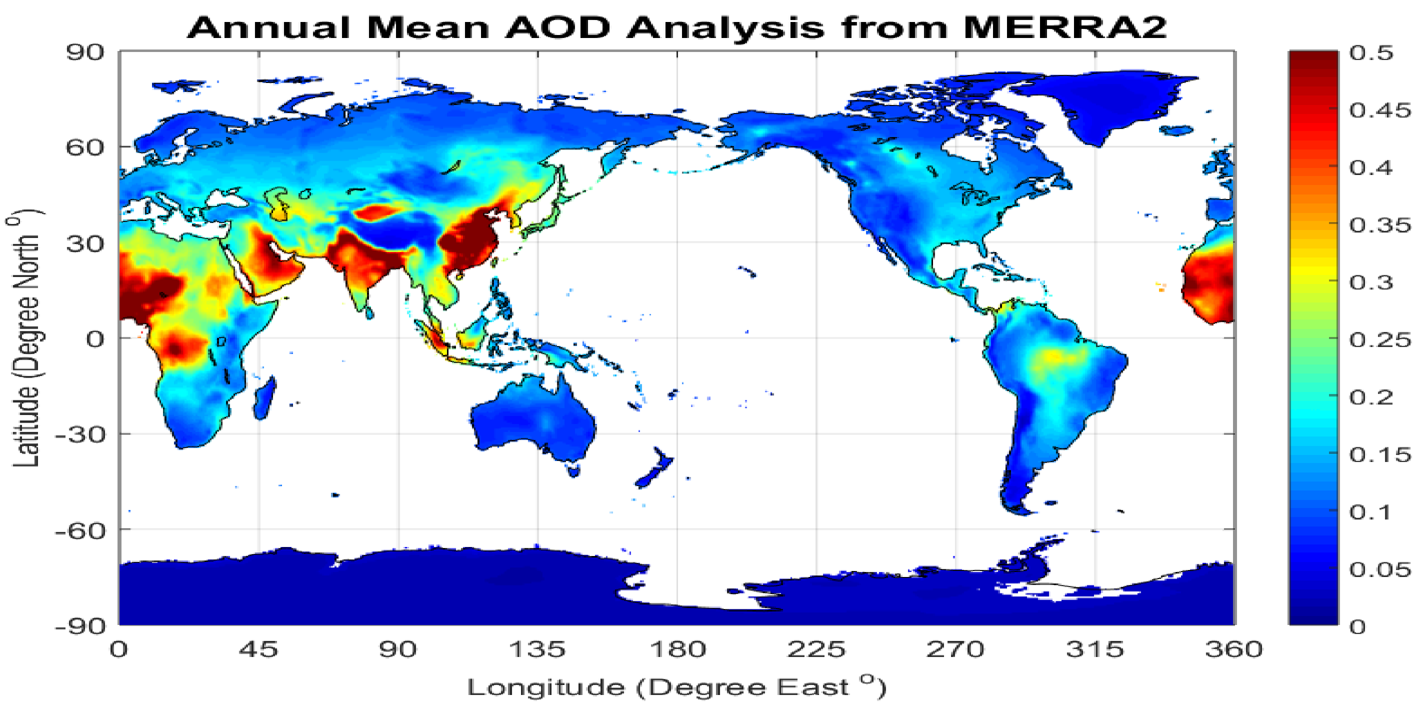
Error= (rain_gfs-rain_obv) / rain_obs

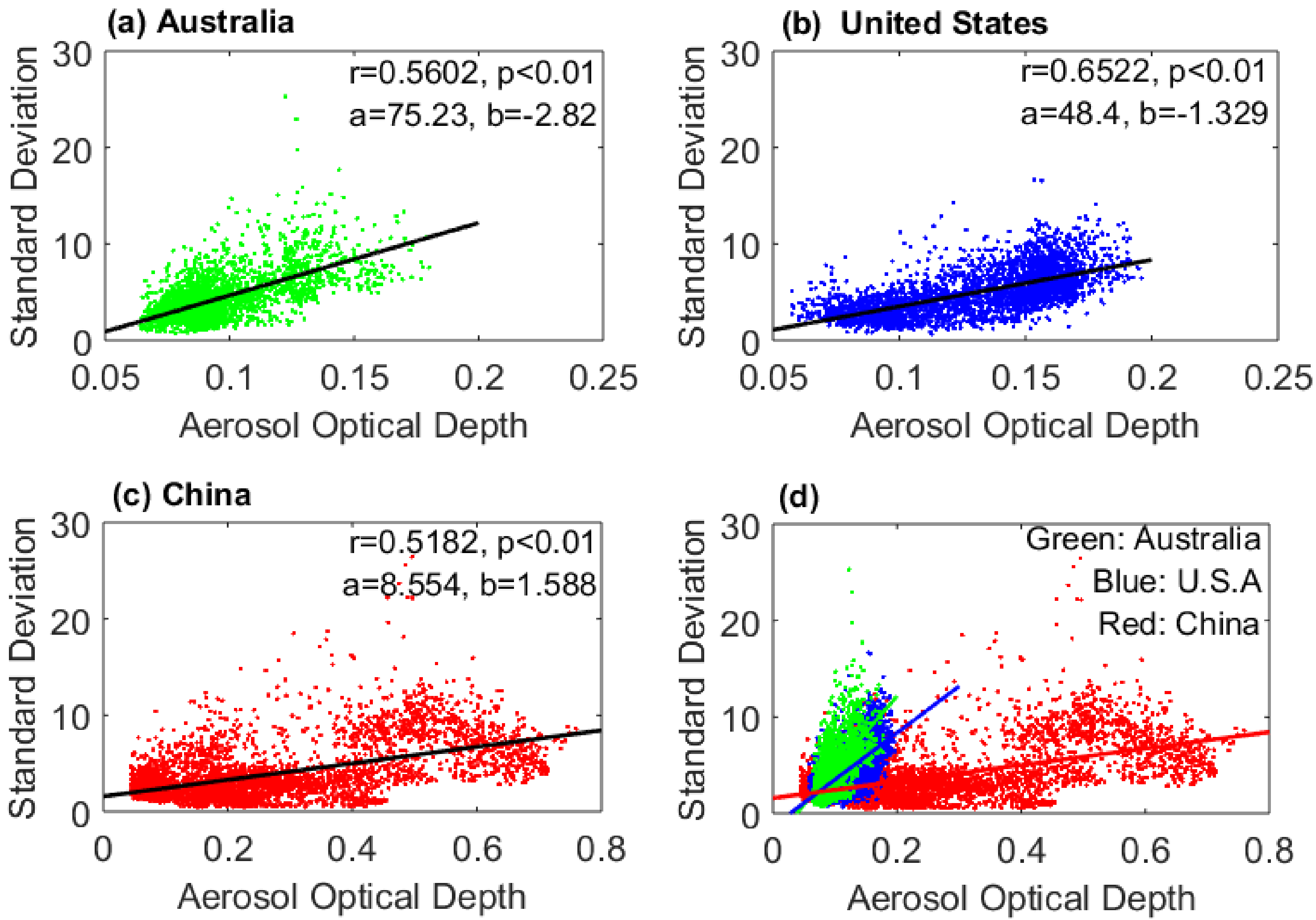
The GFS overestimates light rain, but underestimates heavier rain.



GFS overestimates light rain and underestimates the stronger rain.


Standard Deviation of the Precipitation Difference between GFS and CPC
Latitude (Degree North °)
90
60
30
0
-30
-60
-90
0
45
90
135
180
225
270
315
360
Longitude (Degree East °)
20
18
16
14
12
10
8
6
4
2
0
Unit: mm/day

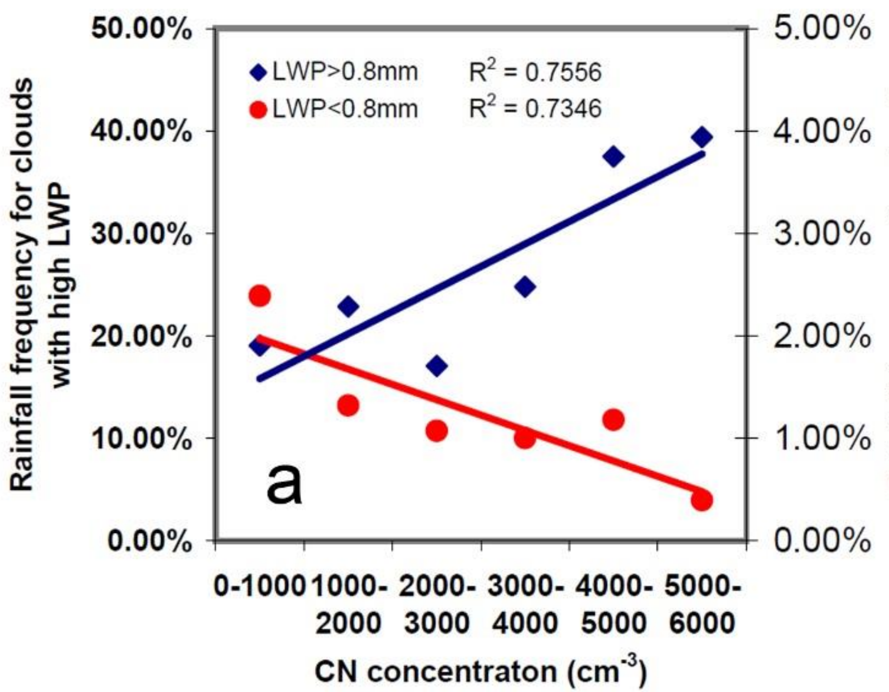

Annual Mean AOD Analysis from MERRA2
Latitude (Degree North °)
90
60
30
0
-30
-60
-90
0
45
90
135
180
225
270
315
360
Longitude (Degree East °)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0

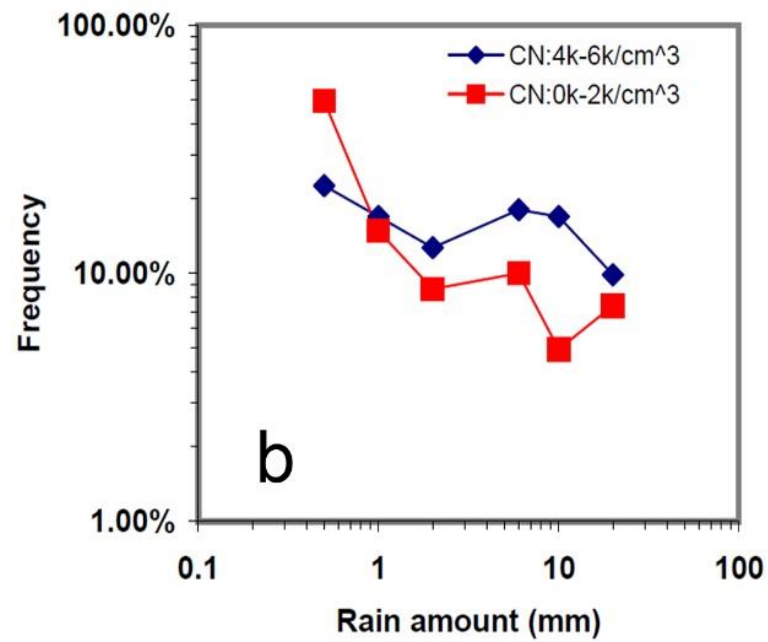


1. We have investigate the relationship of the standard deviation and aerosol optical depth in three countries Australia, United States, China.The result shows that in the three countries, standard deviation and AOD has significant positive correlation (r=0.5602, 0.6522, 0.5182 for Australia, US, and China, respectively).

2. The places with high AOD tend to have larger forecast difference.

Why do aerosols link to the standard deviation of rainfall forecast error



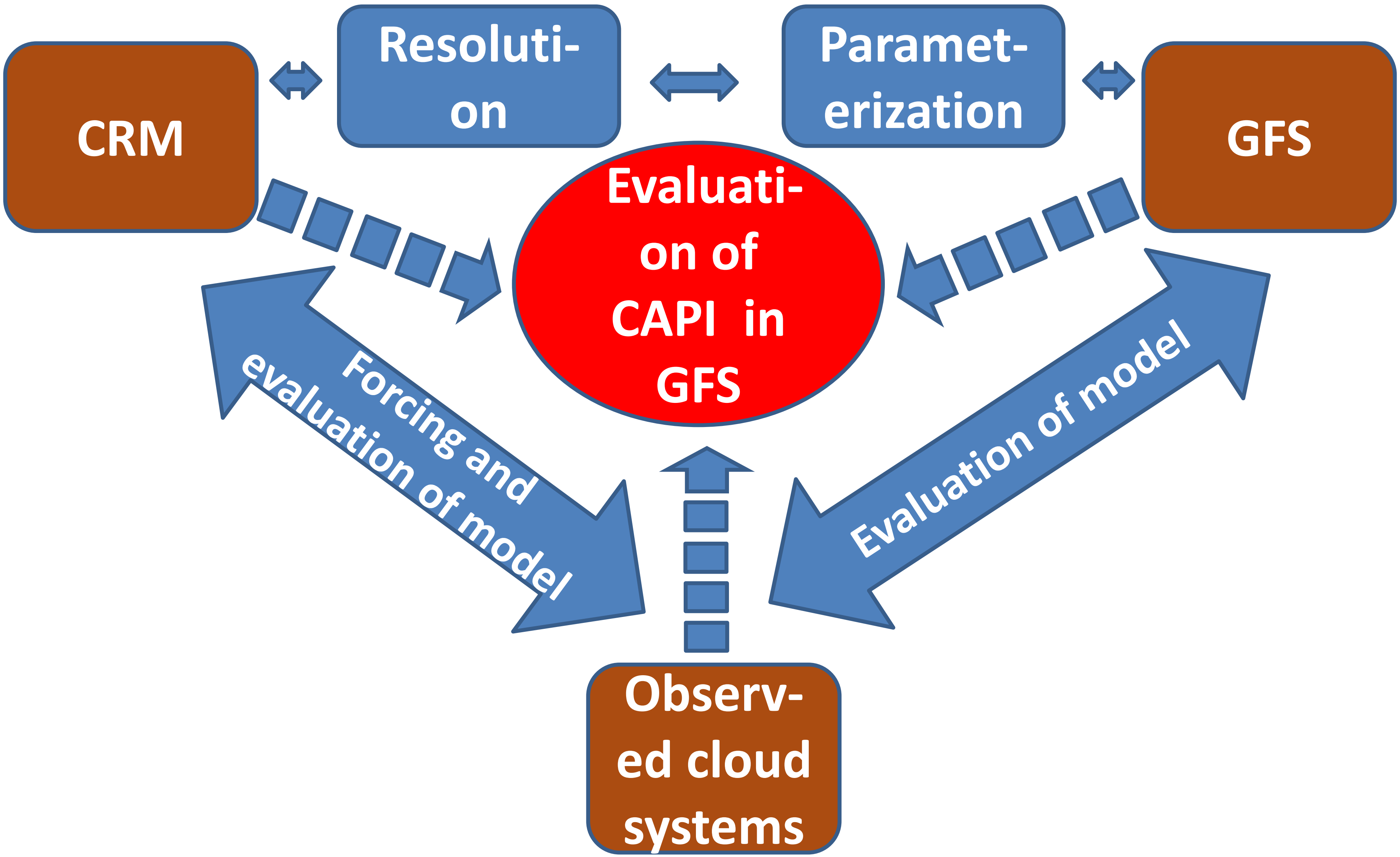


Li et al. (2011, Nature Geosci)

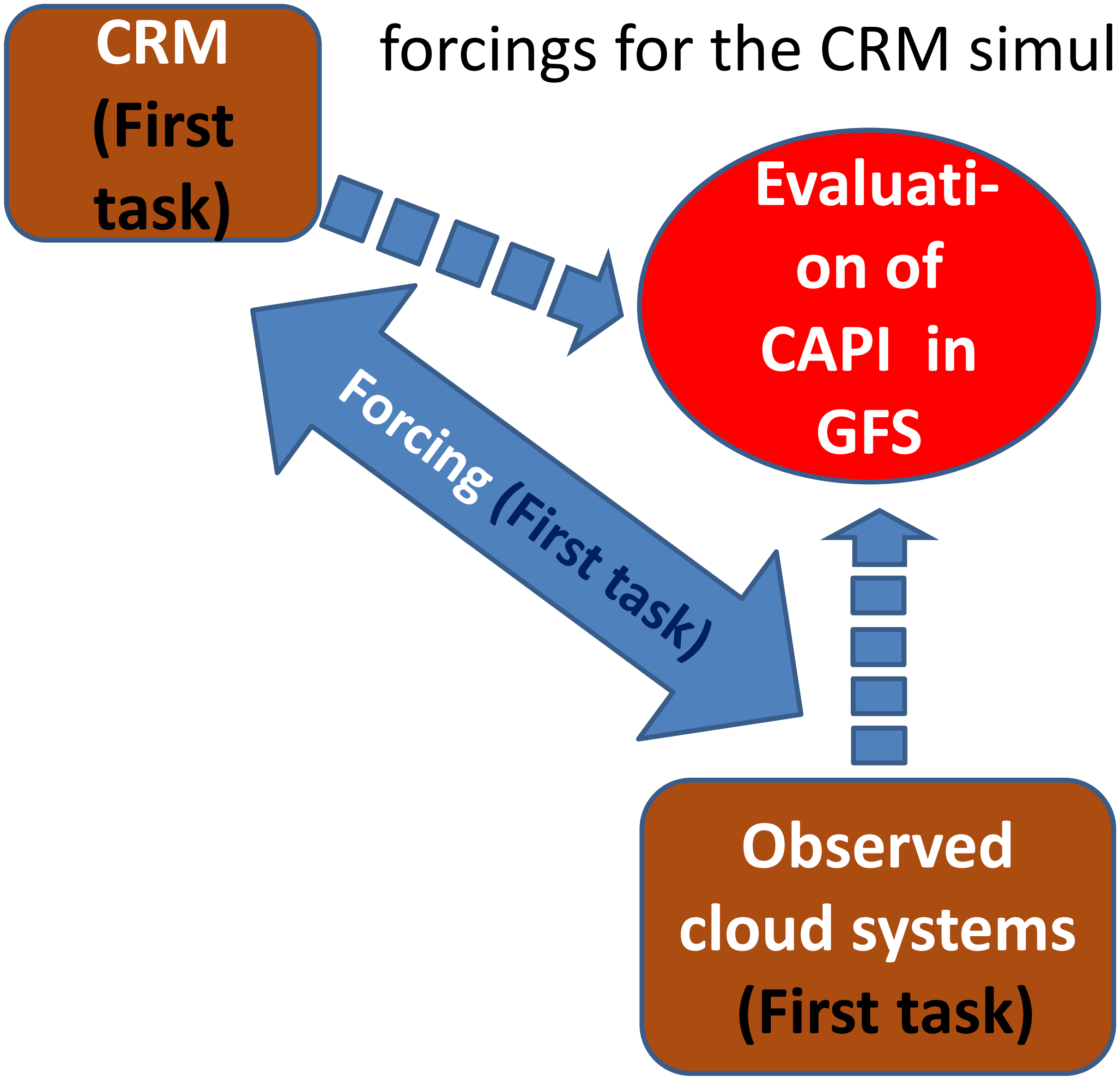
Task 4

Test NGGPS-adopted parameterization schemes using WRF

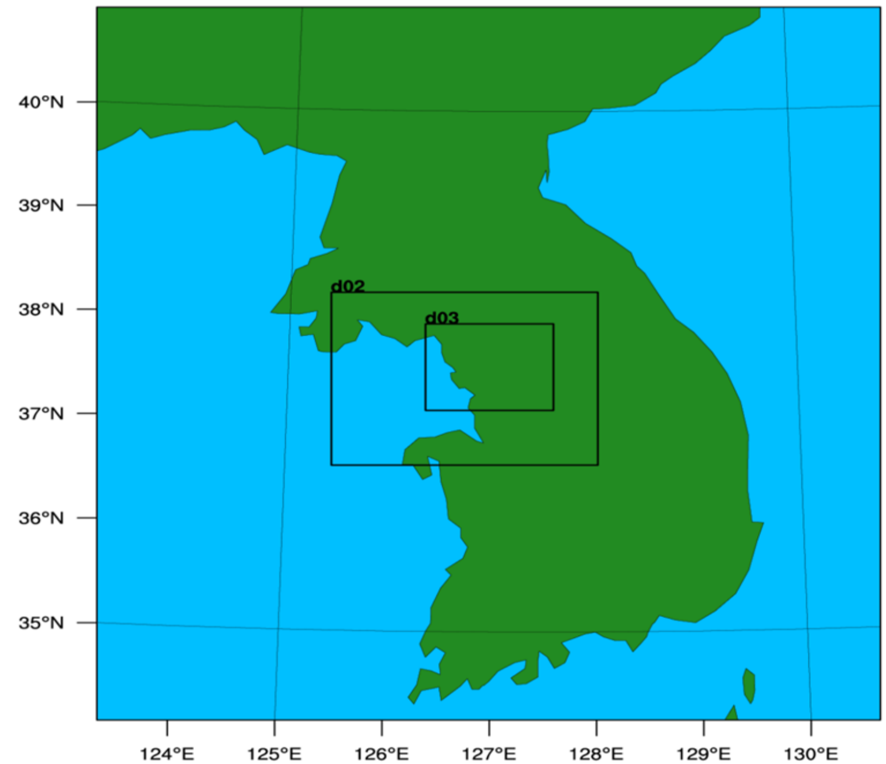
Basic outline for the modeling work



Completed first task: select observed cloud systems and extract forcings for the CRM simulations



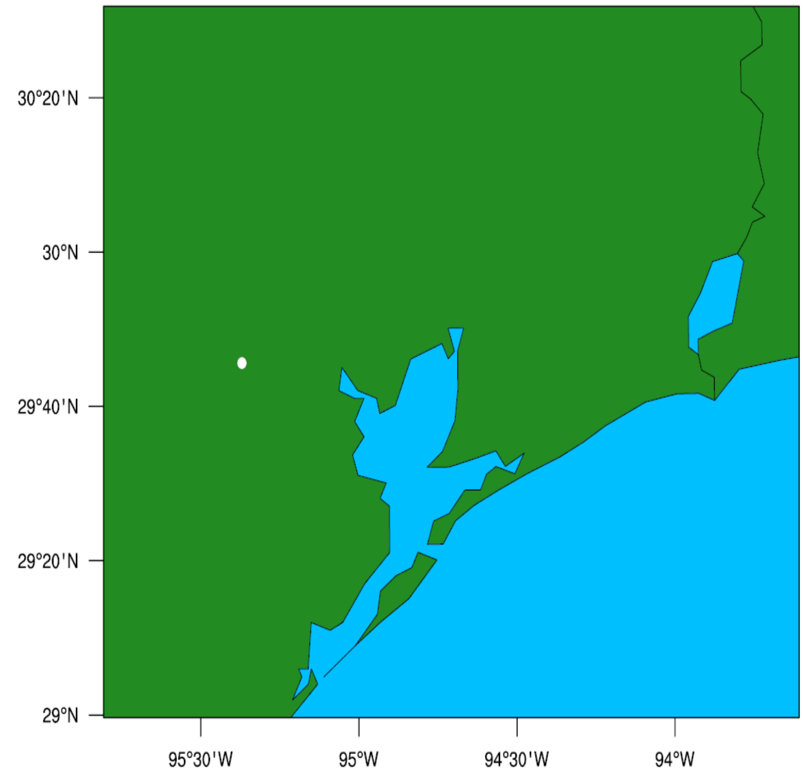
Seoul case (D03)



- A mesoscale system of convective clouds, 37.57° N, 126.57° E
- 09:00 LST (local solar time) July 26th – 09:00 LST July 27th 2011

the Houston case

Domain_500m



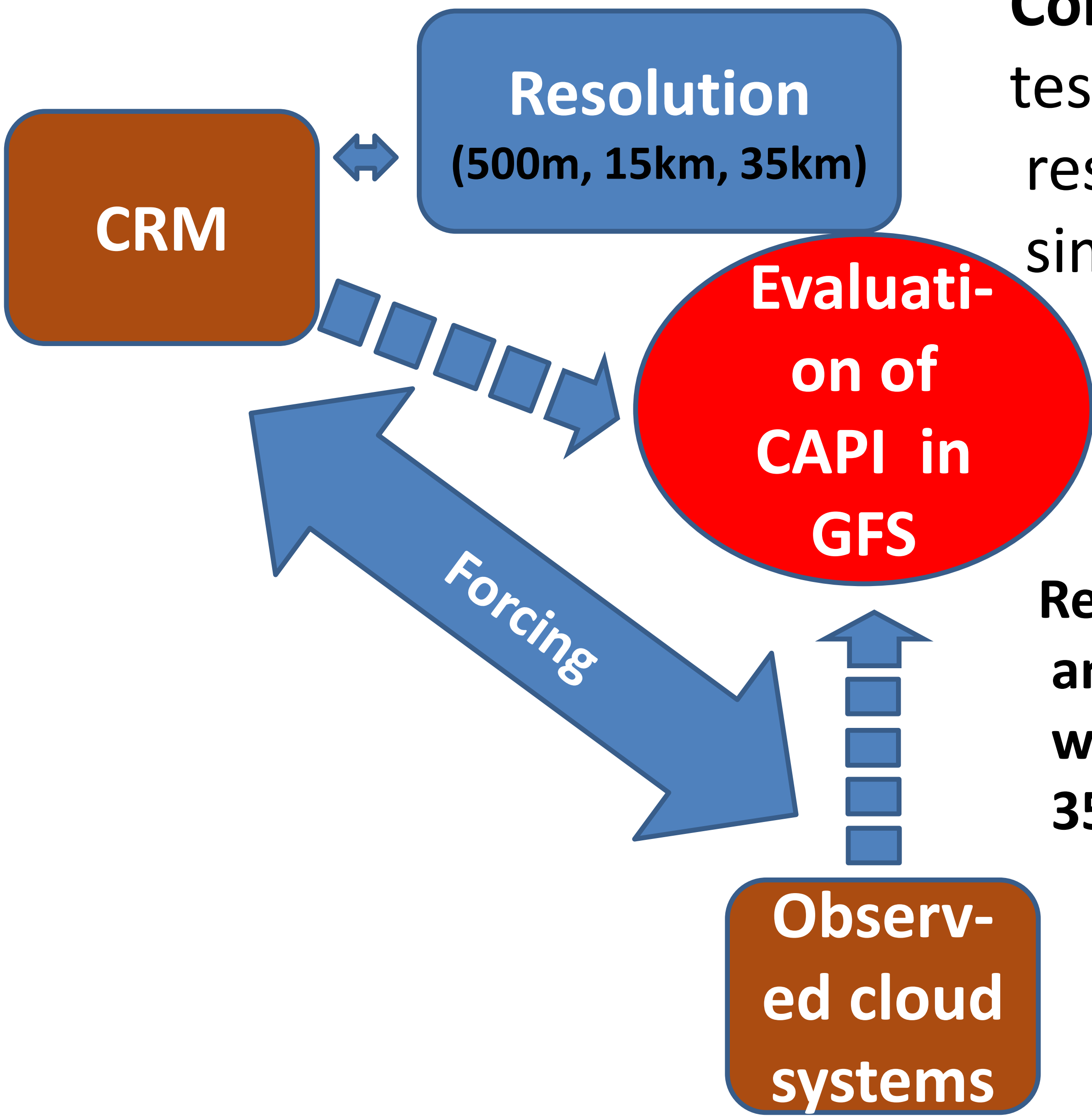
- A mesoscale system of convective clouds 29.42° N, 94.45° W
- 07:00 LST June 18th – 03:00 LST June 19th in 2013

Model Description

- **The WRF model coupled with bin and bin-emulating microphysics schemes**

Simulations

- **Control run (500-m, resolution and bin scheme)**
- **Low-aerosol run: repeated control run with aerosol concentration reduced by a factor of 10**

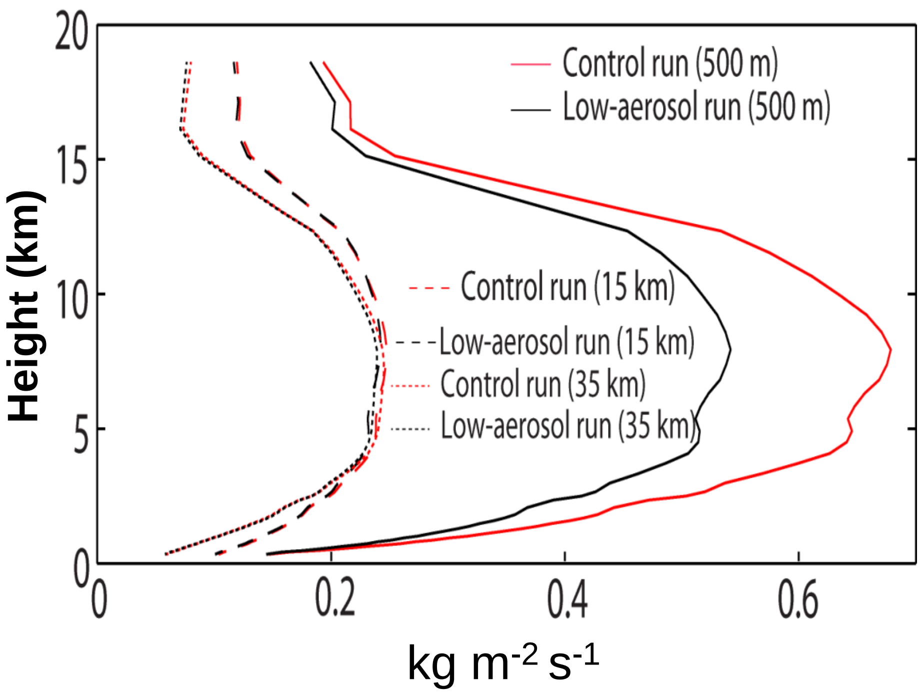


Completed second task: test on the effects of resolutions on the simulations of CAPI

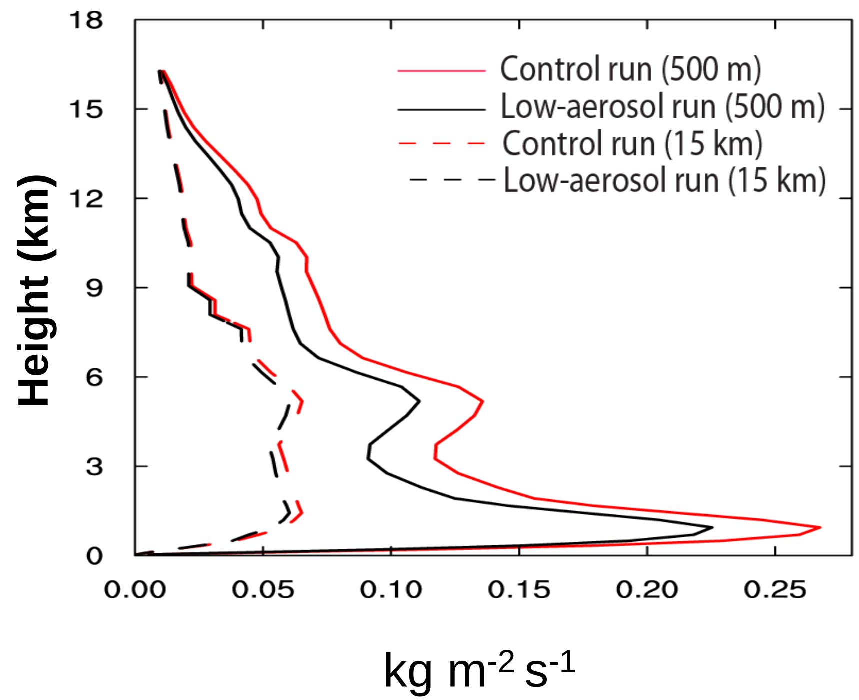
Repeat the control run and the low-aerosol run with 15-km and 35-km resolutions

Updraft mass fluxes

Seoul case

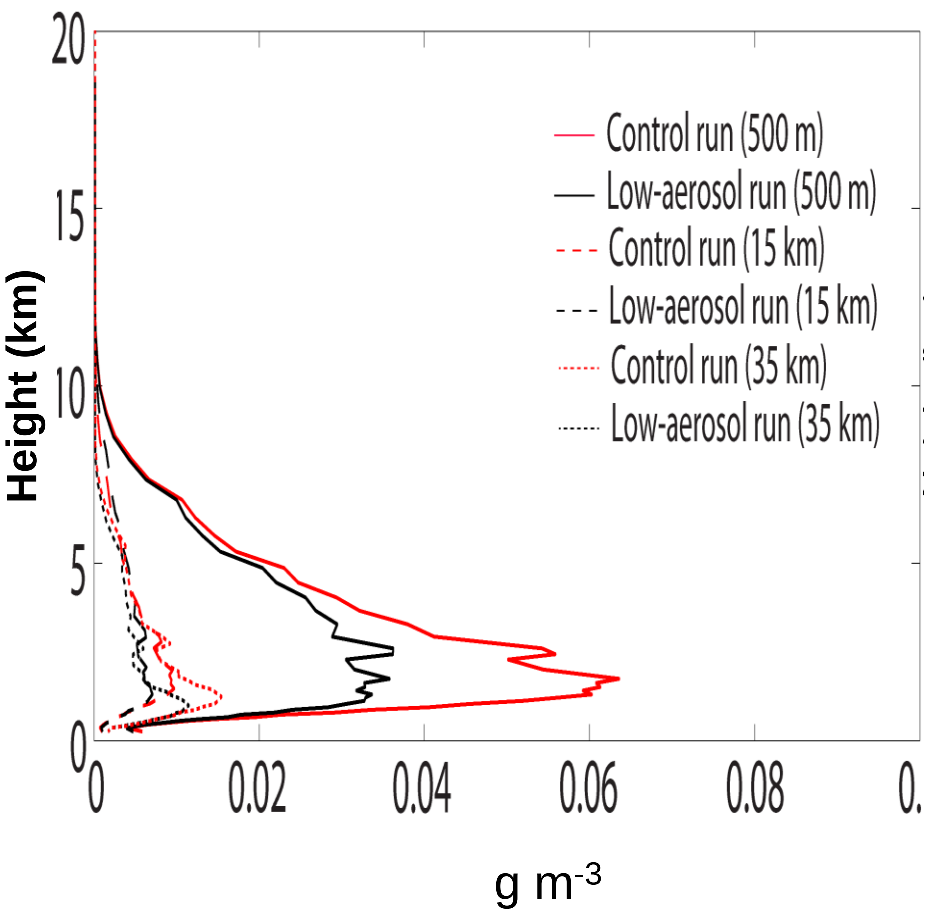


Houston case

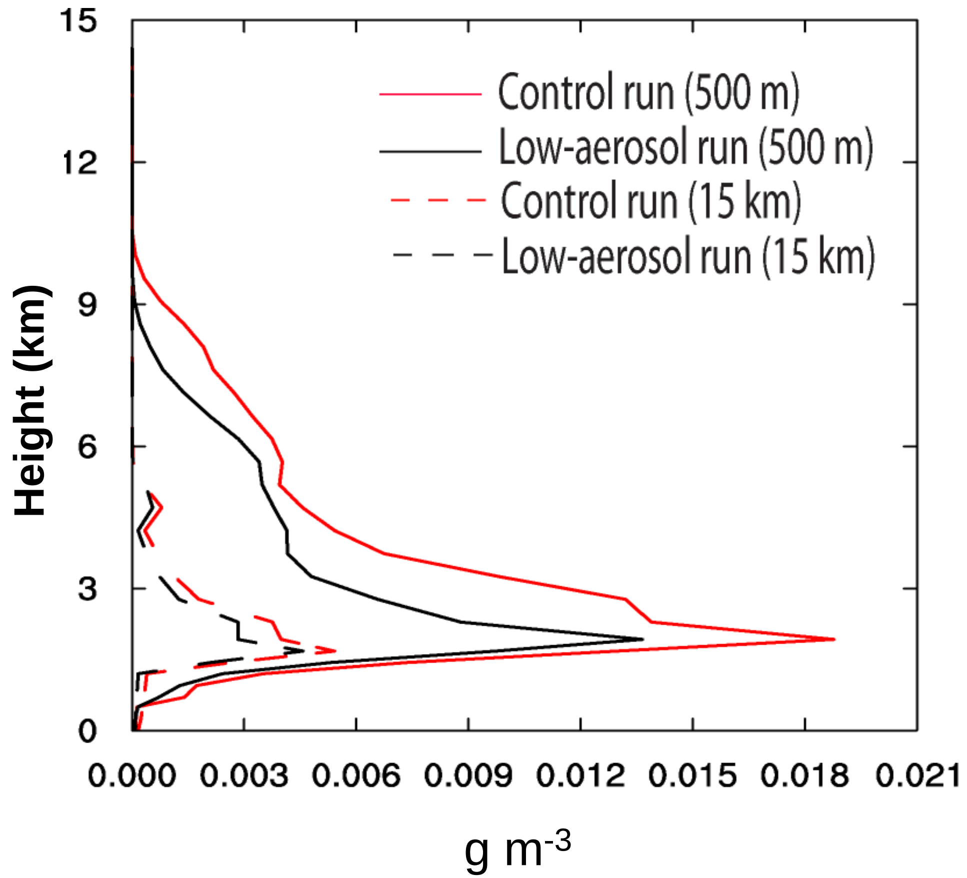


Cloud-liquid content

Seoul case

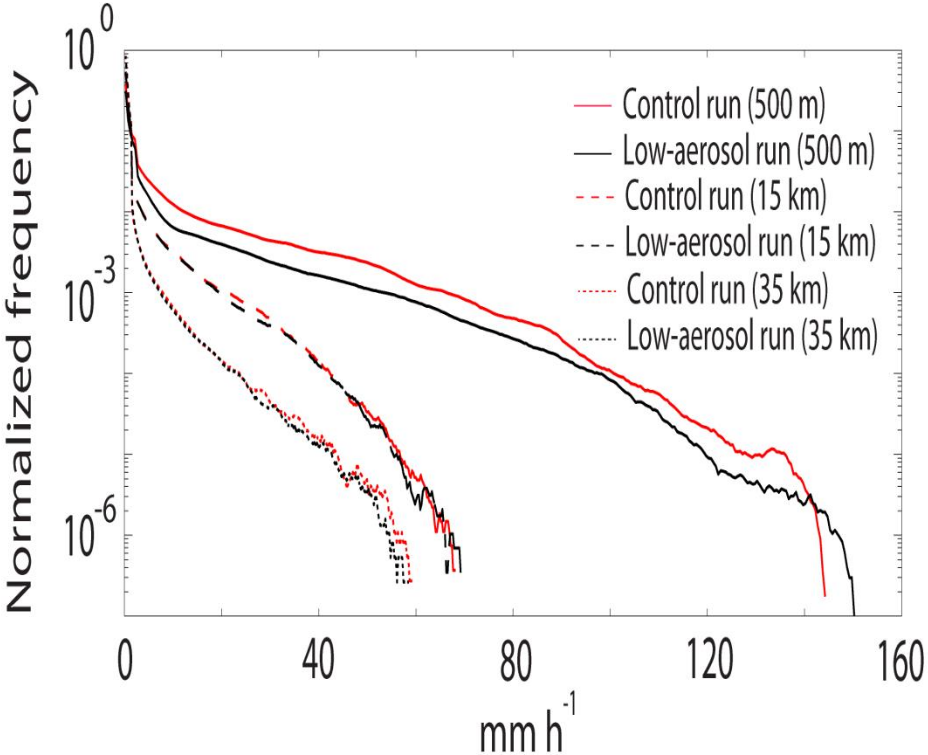


Houston case

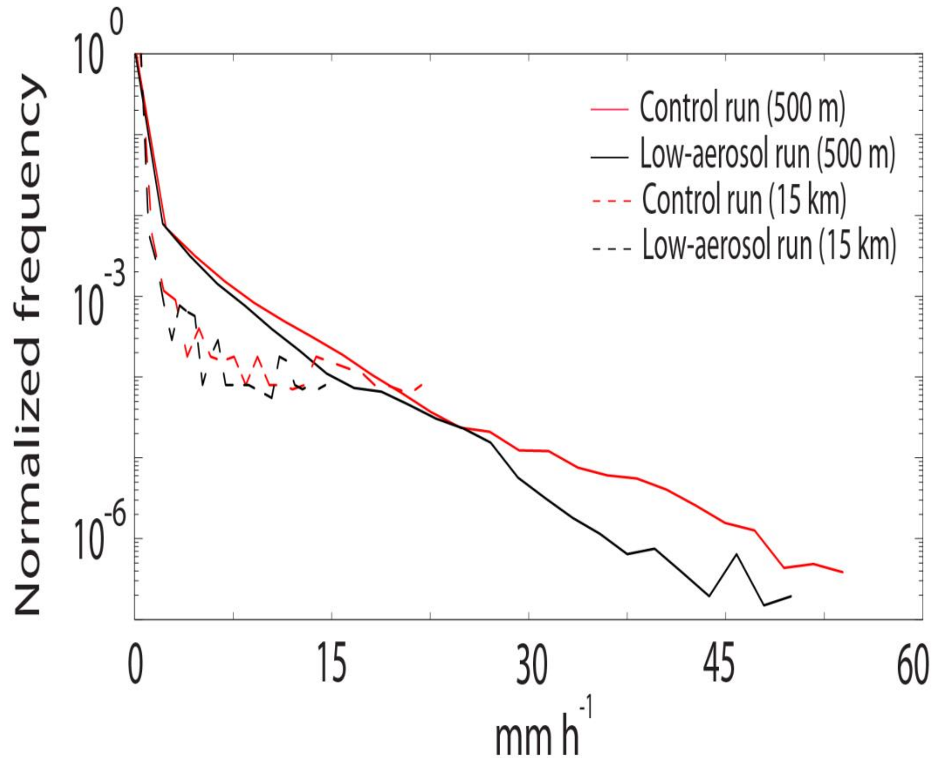


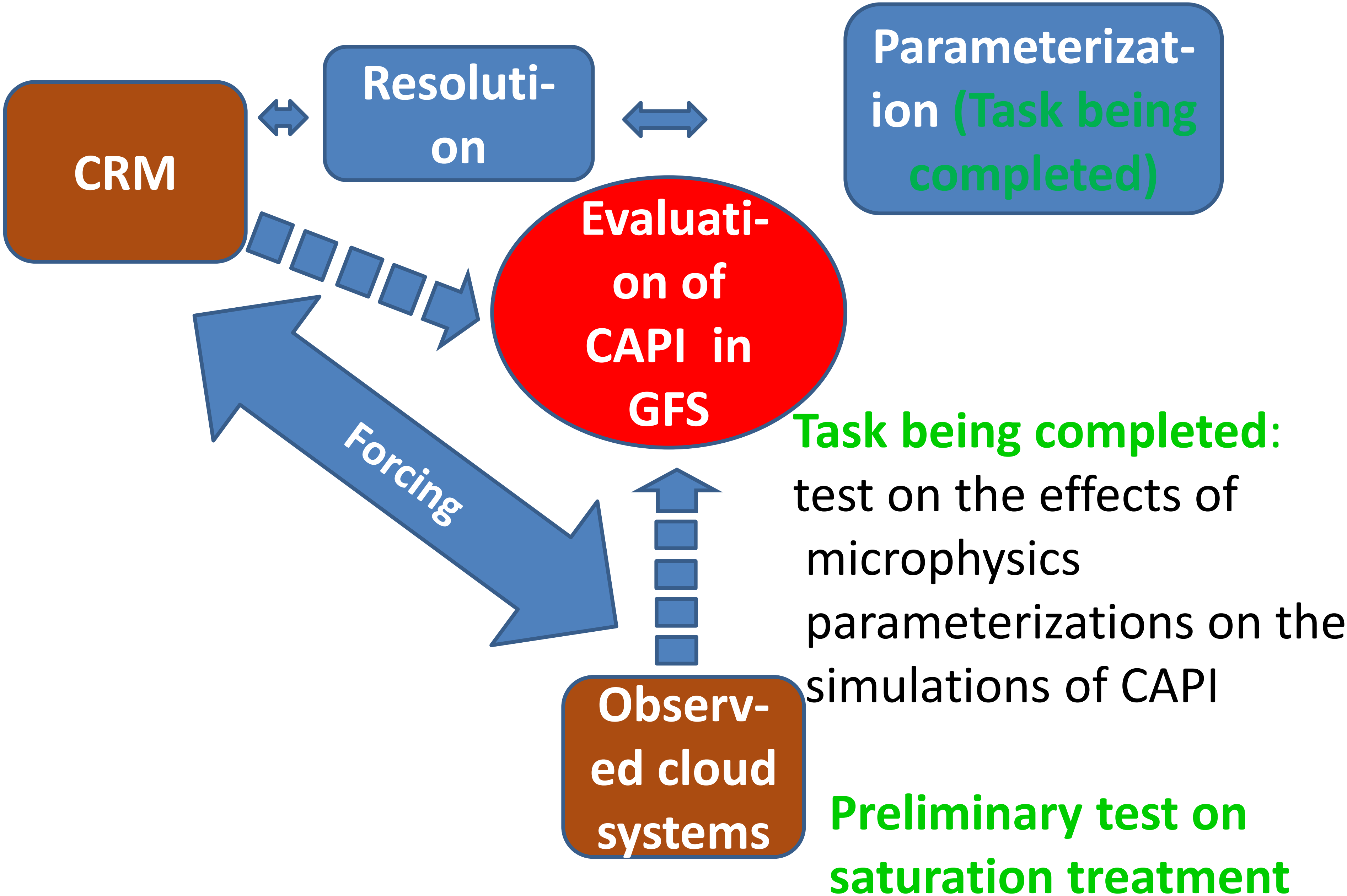
Precipitation frequency

Seoul case



Houston case

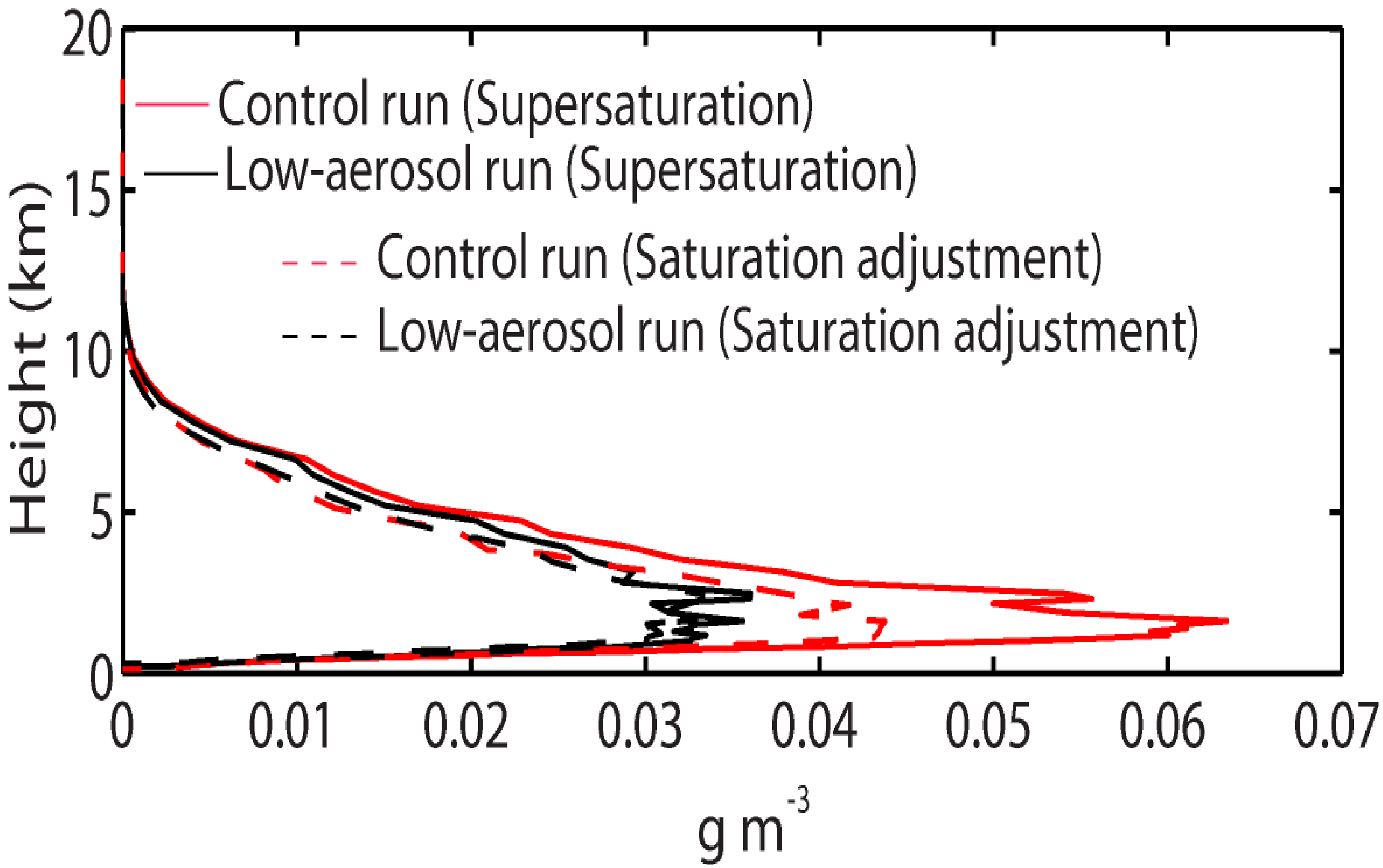




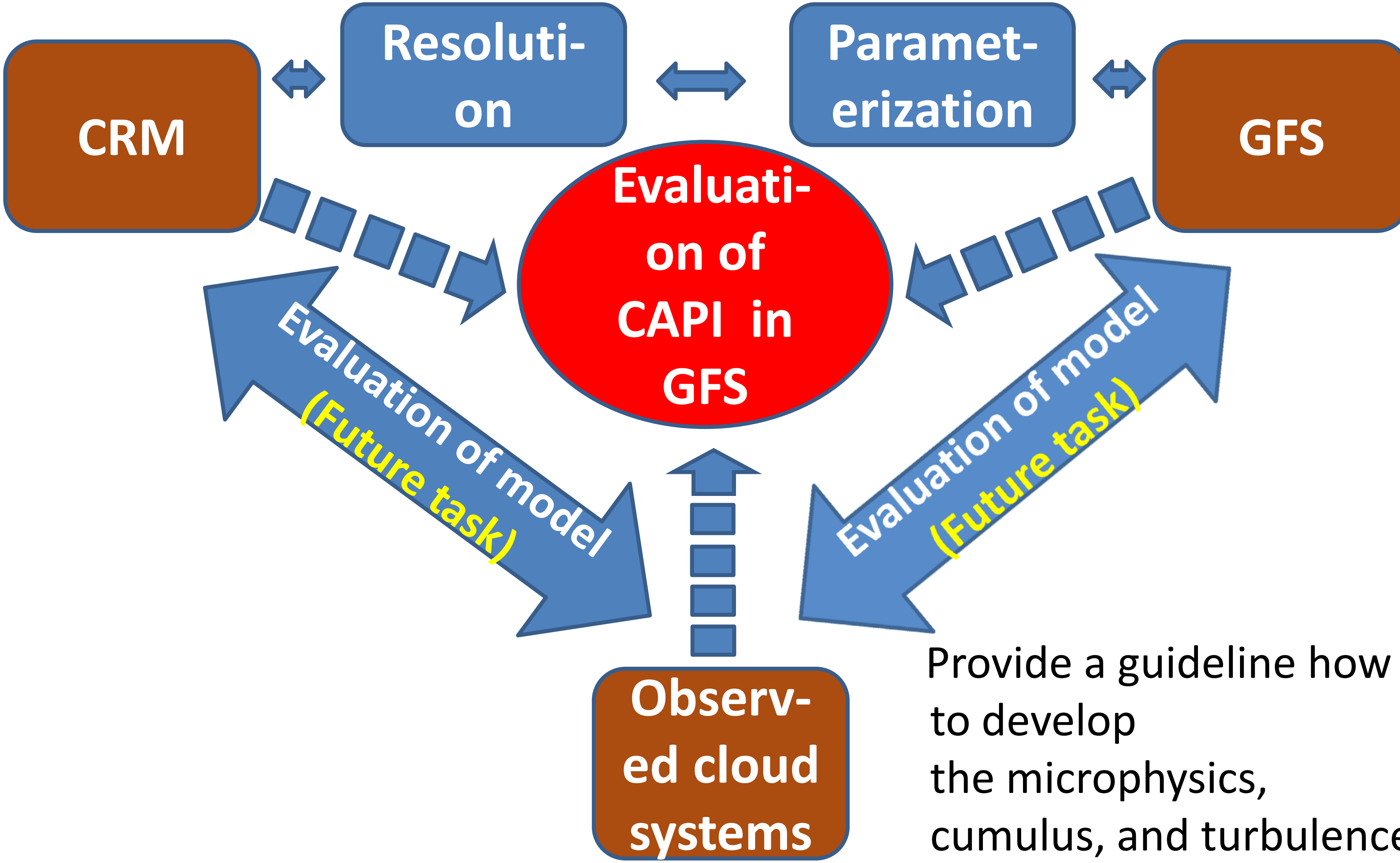
CRM
Resoluti-on
Parameterizat-ion (Task being completed)
Evaluati-on of CAPI in GFS
Forcing
Observ-ed cloud systems
Task being completed:
test on the effects of microphysics parameterizations on the simulations of CAPI
Preliminary test on saturation treatment

Cloud-liquid content

Seoul case



Future tasks



Provide a guideline how to develop the microphysics, cumulus, and turbulence schemes

Summary and Conclusions

- Analyses of multiple observation data revealed a wide-range impact of aerosol on rainfall: suppressing light rain from warm clouds, delaying connective rain to later afternoon, etc.
- Significant improvement has been made in simulating marine boundary-layer clouds in eastern oceans, but overestimation of high clouds remain.
- Differences between forecasted and observed rainfall on global scale reveal certain resemblance to aerosol loading which appears to have stronger impact on the variability of rainfall than on mean rainfall amount.
- It is important to treat sub-grid small-scale updraft cores in CAPI . The use of saturation adjustment underestimates aerosol effects on clouds.

Future tasks

- Continue to examine GFS performance in simulating clouds, and other meteorological variables under the different aerosol conditions using satellite and ground measurements

- Close-up investigation on aerosol effects on rainfall (physical analysis), with particular attention towards interactions between dynamic and thermal variables susceptible to aerosol.

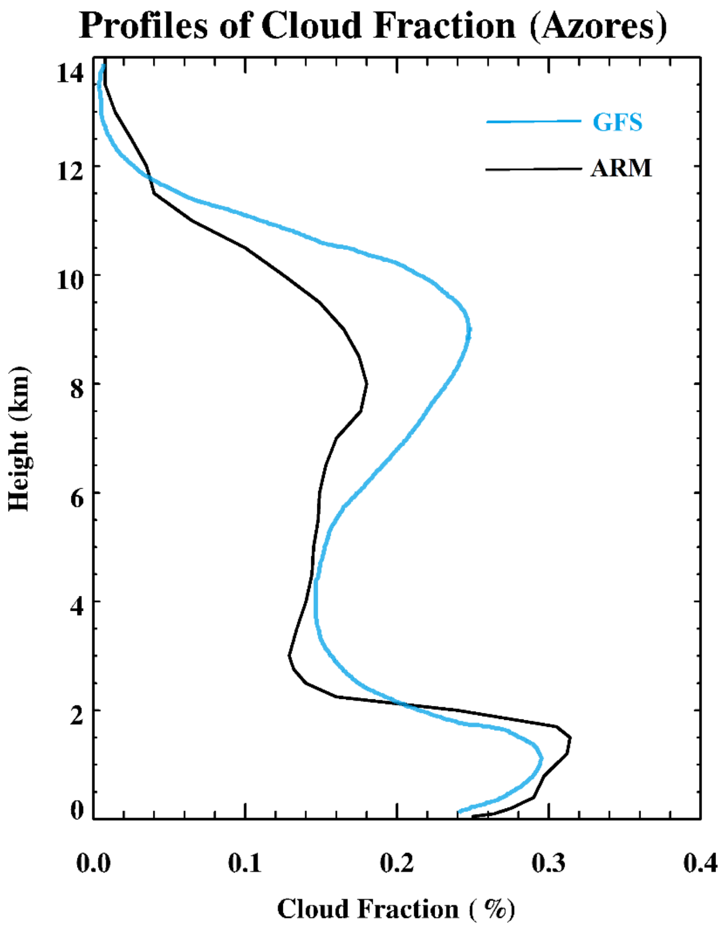
- Better understanding how small-scale updrafts control the sensitivity, frequency distributions of updrafts.

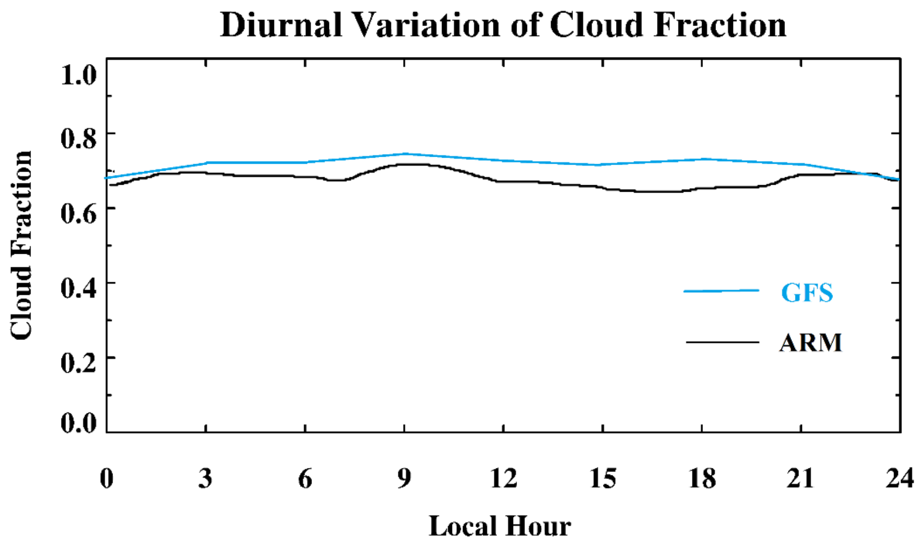
- Understanding the development of turbulence and cumulus schemes on cloud simulations in the GFS/NGGPS

Thank you !

GFS evaluation at ARM sites

Azores

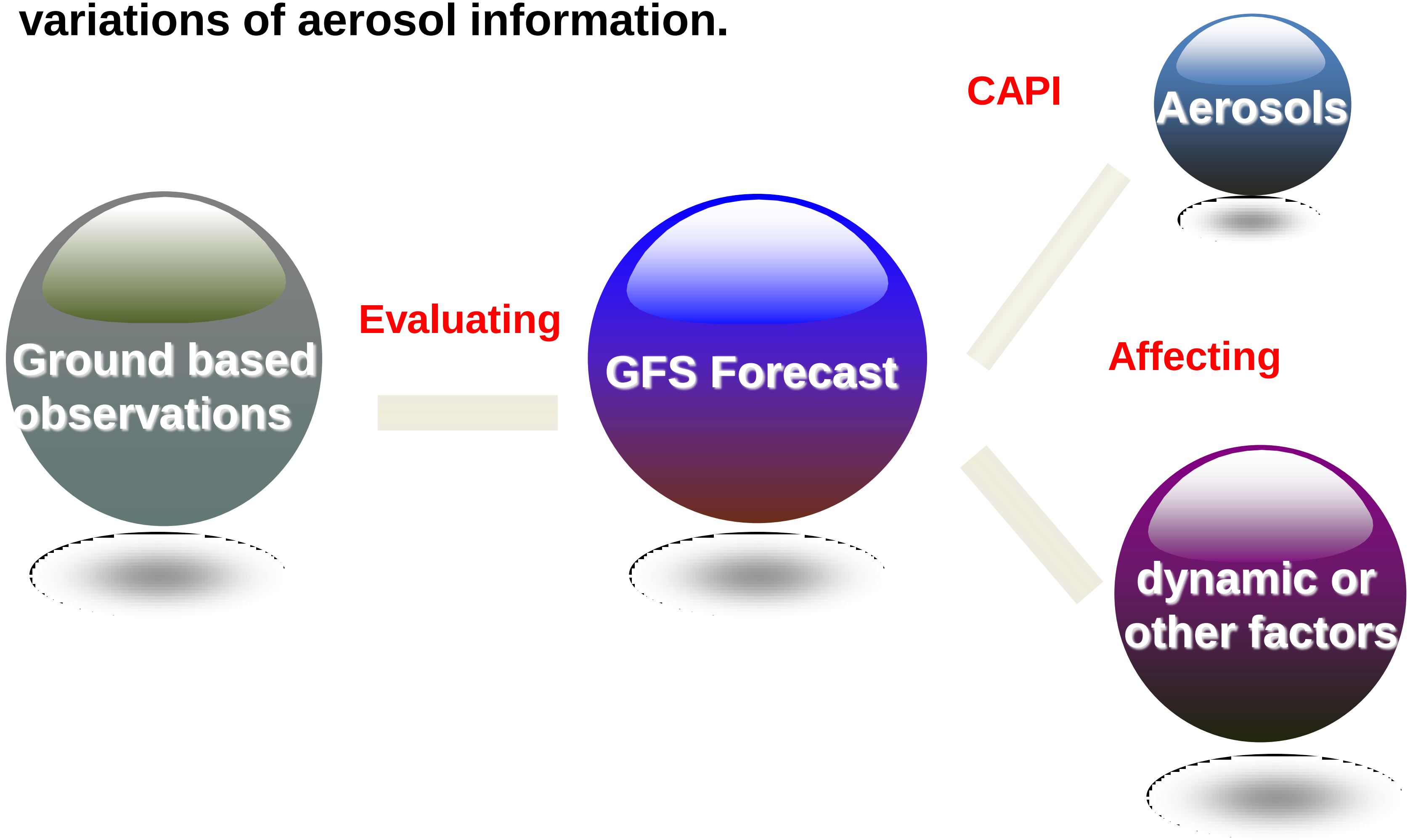




CF	Annual	Summer	Winter
GFS	0.73	0.62	0.83
ARM	0.71	0.61	0.79

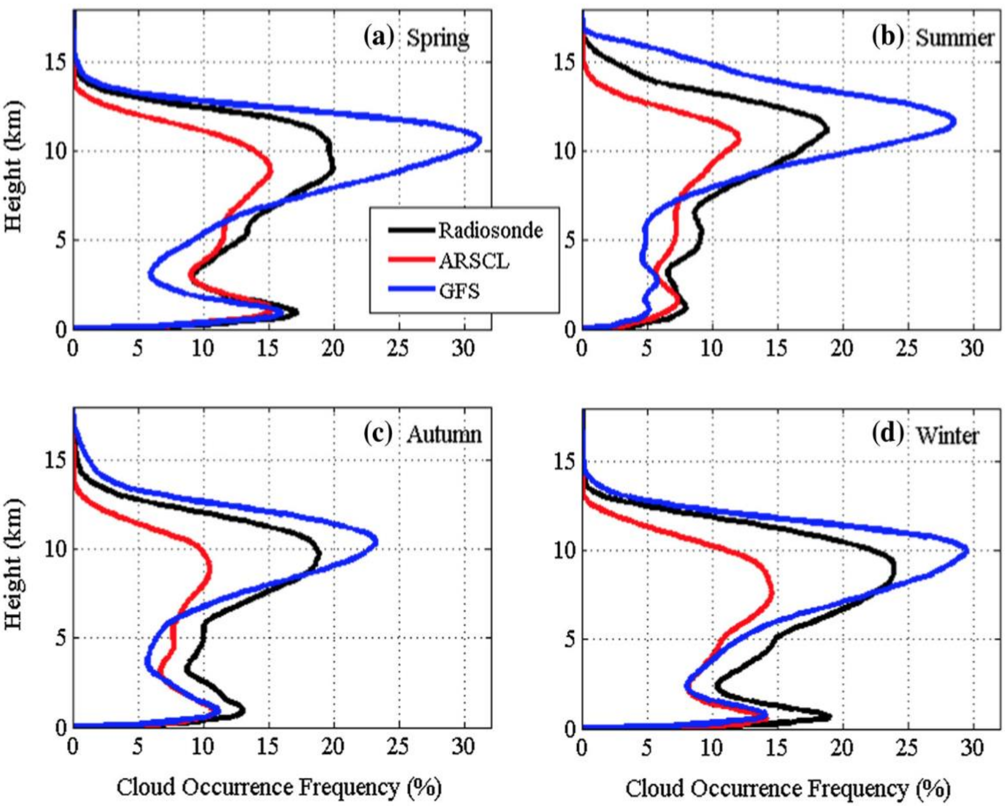
Looking for signs of CAPI impact on rain

Evaluate the current forecasting data from the Global Forecast System (GFS) against rainfall observations before any CAPI effect is introduced to investigate if any model biases bear resemblance to the variations of aerosol information.

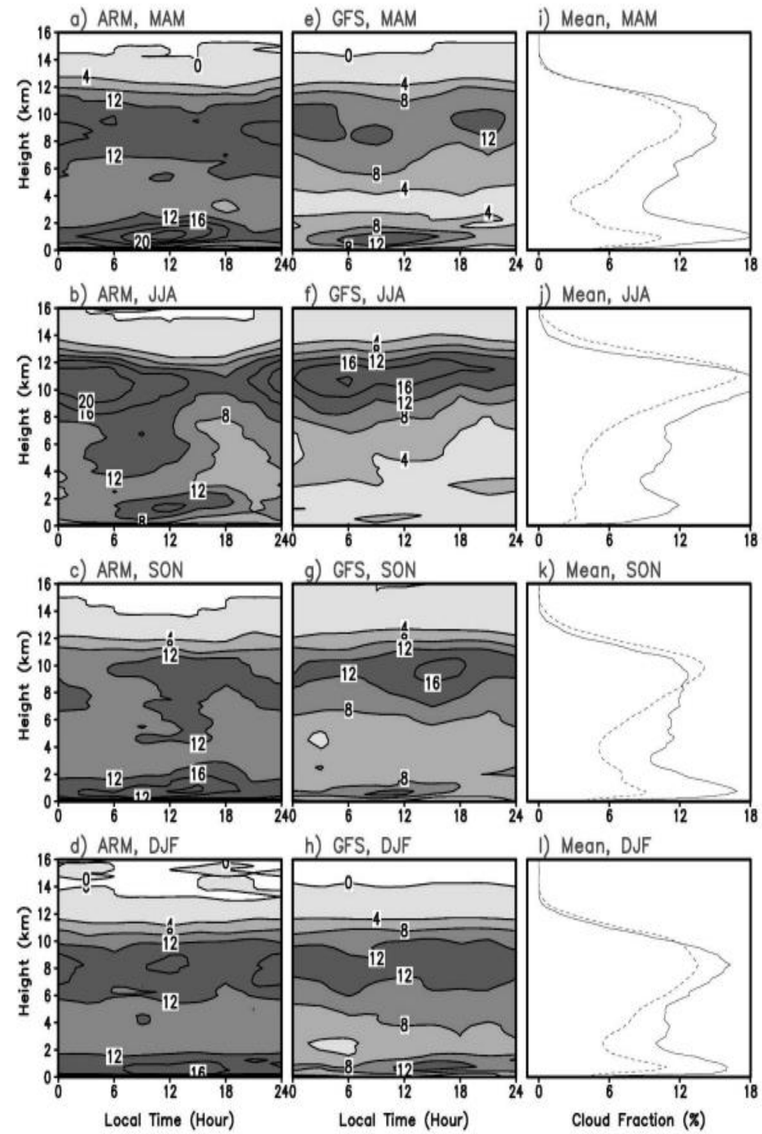


GFS evaluation at ARM sites

SGP



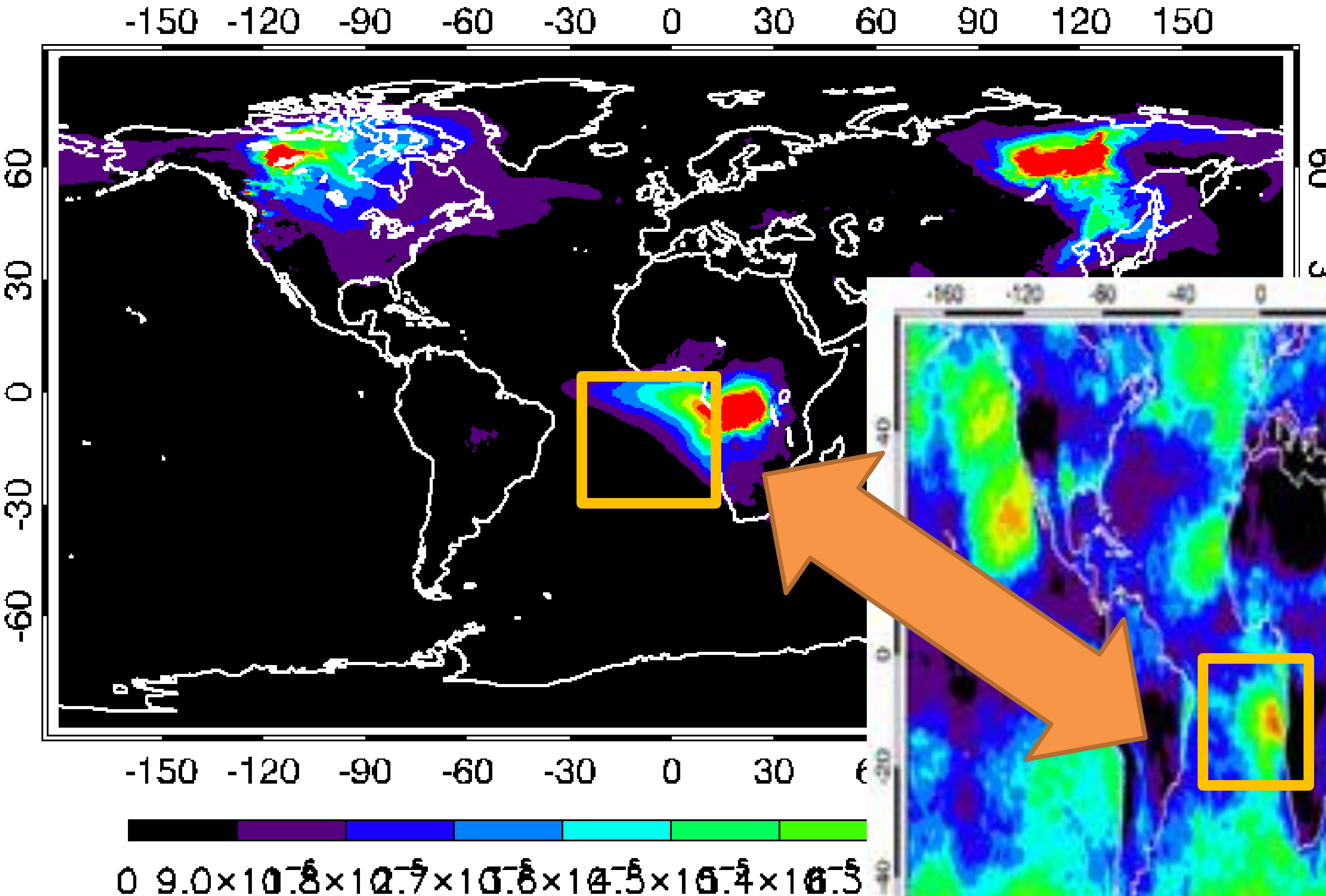
J.Zhang et al 2014

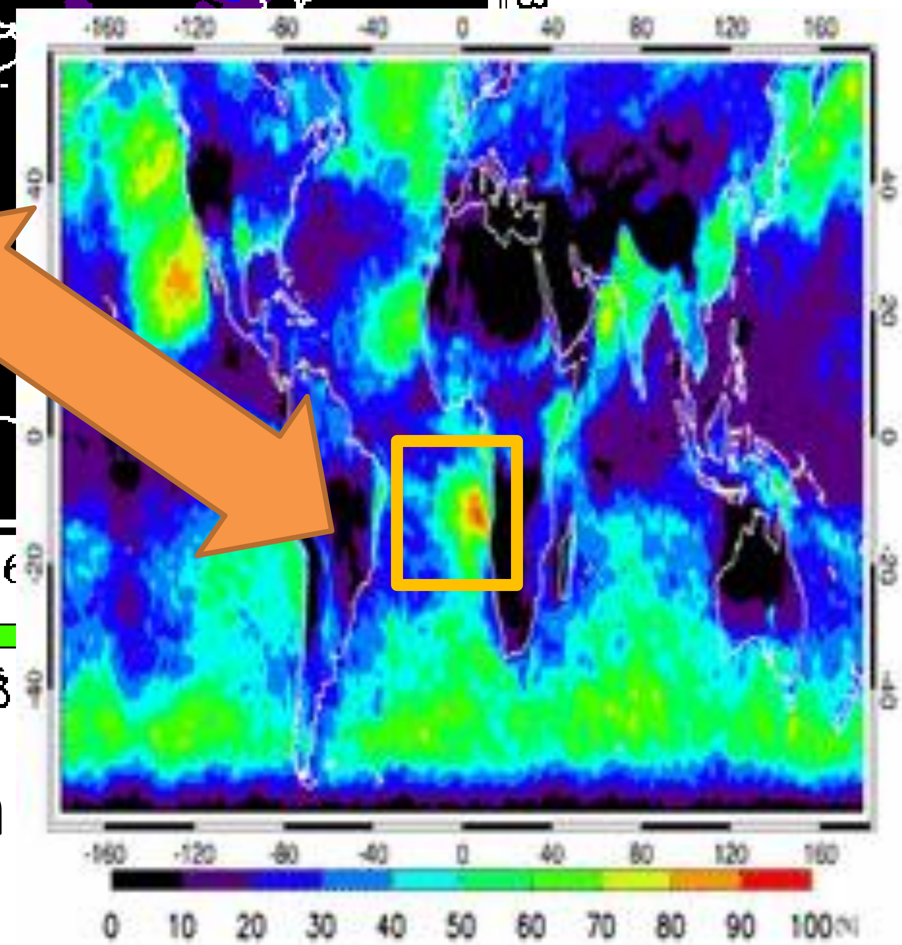


Yang et al 2006

Overall, the GFS model simulates less low-level and more high-level clouds than observations

GEOS BC + OC column mass density in July 2014





Low cloud fraction from CL algorithm