Using multiple observations and retrievals to evaluate WRF-simulated MCS precipitation under different synoptic patterns over the CONUS

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Objectives:

1) A 4D (3D+time) database of the MCS IWC/IWP was generated and used to investigate MCS IWP-precipitation relationship (Tian et al. 2016 and 2020)

2) Evaluate the NOAA WRF simulated MCS's precipitation over Great Plains under different synoptic patterns (extratropical cycle and subtropical ridge) (Wang et al. 2019)

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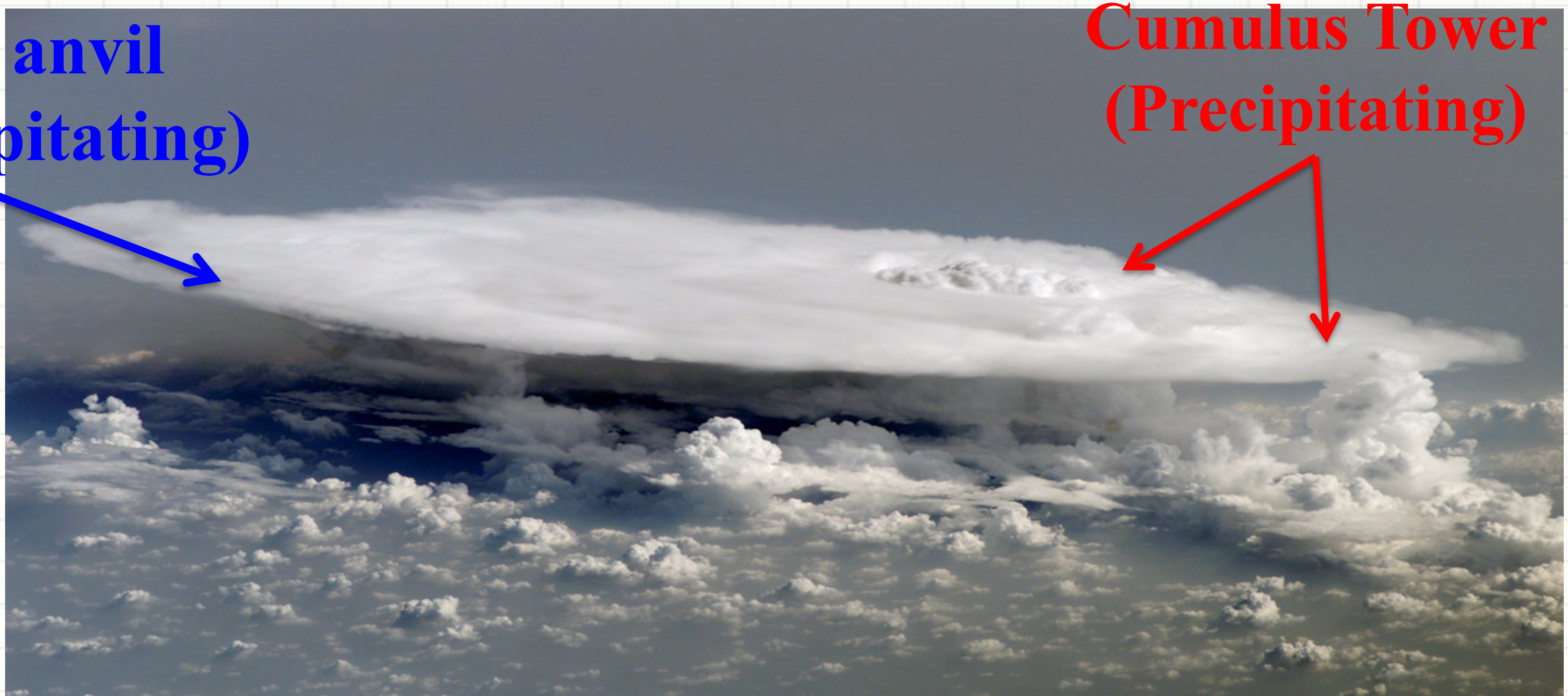
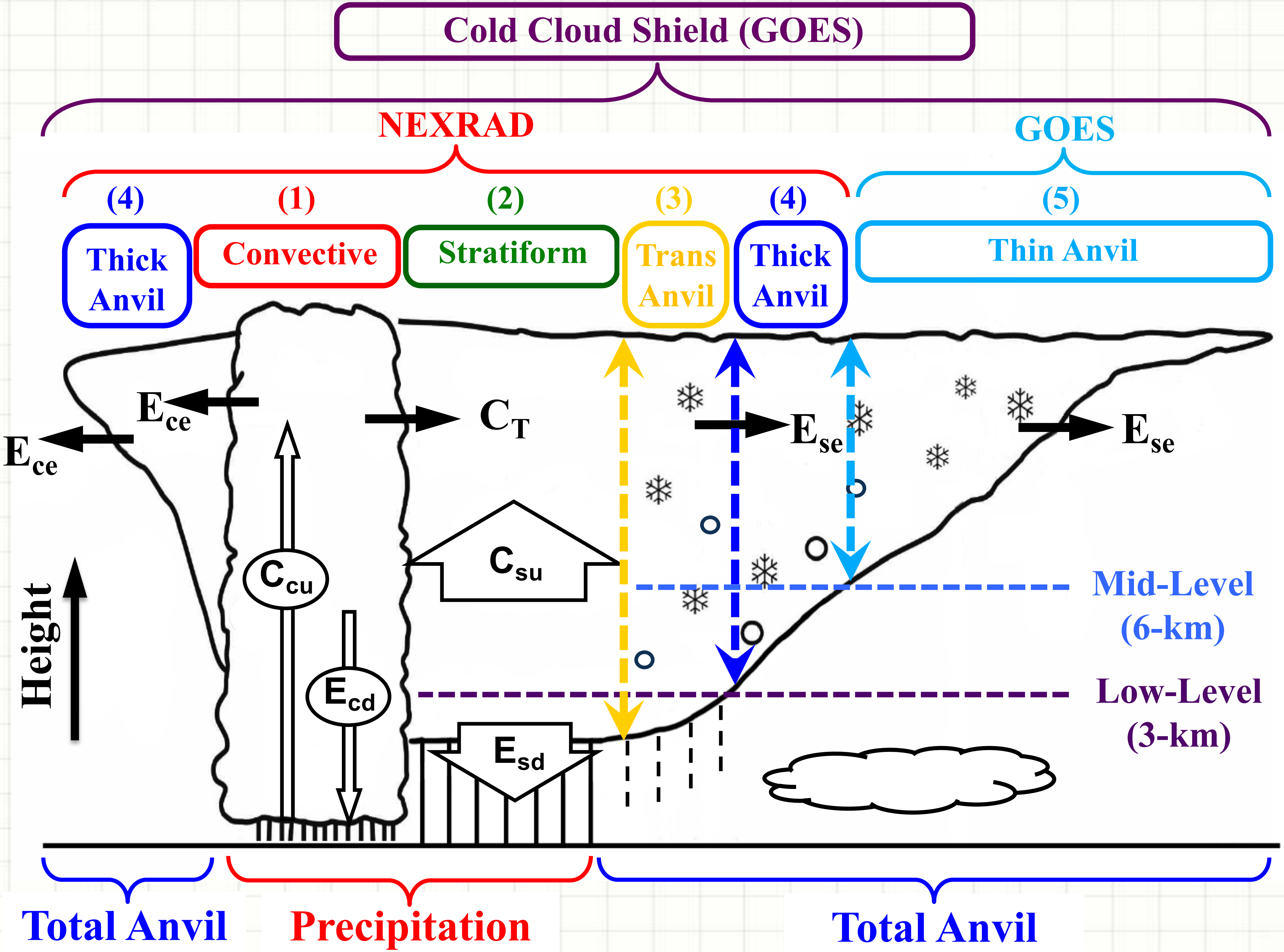
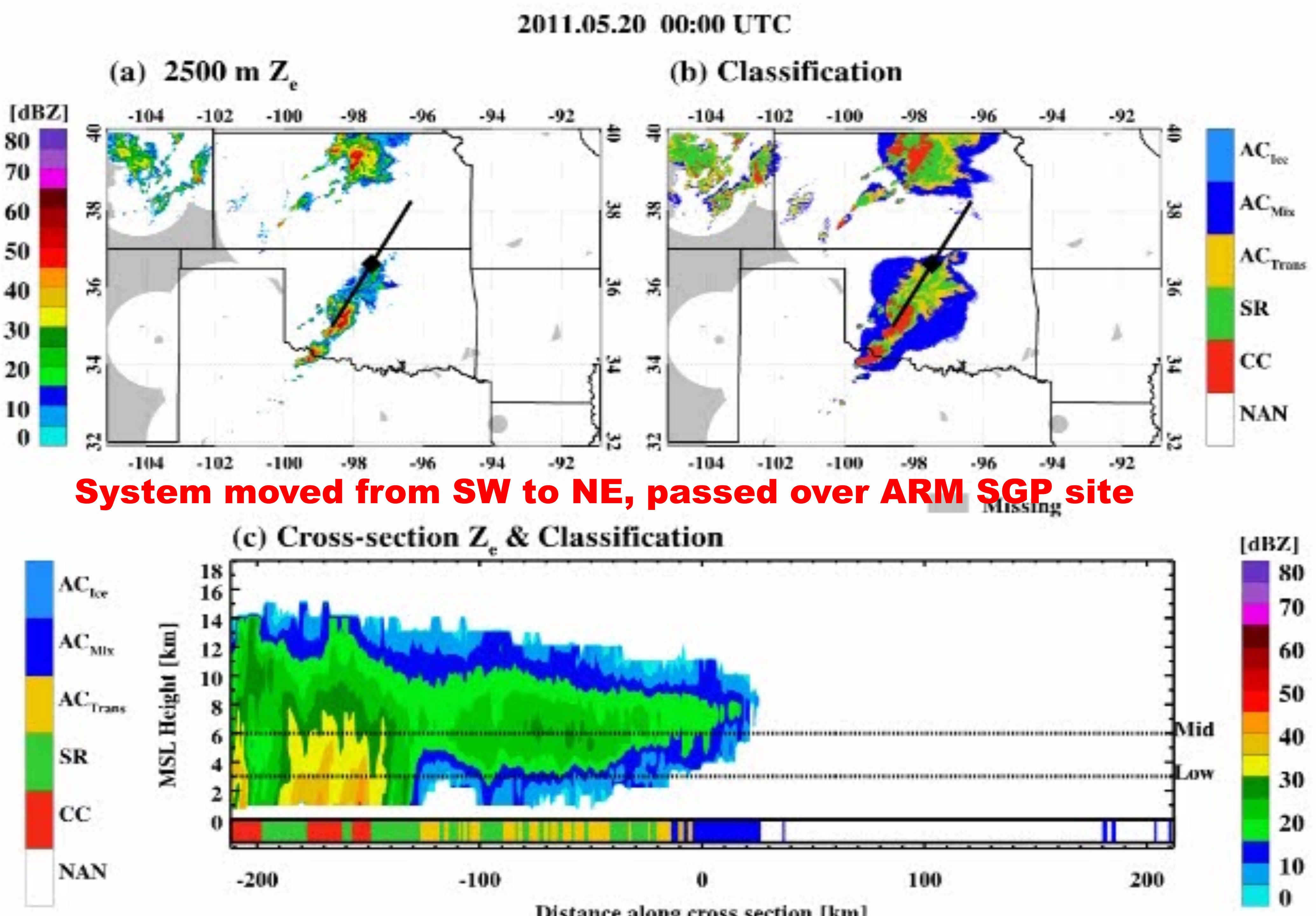
Motivations: Mesoscale Convective System (MCS)

- MCS has two main components
  - **Cumulus tower:** important to hydrologic cycle and atmospheric circulation due to heavy rainfall
  - **Cirrus anvil cloud:** dominate radiation budget due to large area coverage
- High impacts on both weather and climate




Cold Cloud Shield (GOES)
NEXRAD
GOES
(4) Thick Anvil
(1) Convective
(2) Stratiform
(3) Trans Anvil
(4) Thick Anvil
(5) Thin Anvil
E_{ce}
E_{ce}
C_T
E_{se}
E_{se}
C_{cu}
C_{su}
E_{cd}
E_{sd}
Height
Mid-Level (6-km)
Low-Level (3-km)
Total Anvil
Precipitation
Total Anvil



System moved from SW to NE, passed over ARM SGP site

Objective 1: A 4D database and application

(Supported by DOE ASR and CMDV programs)

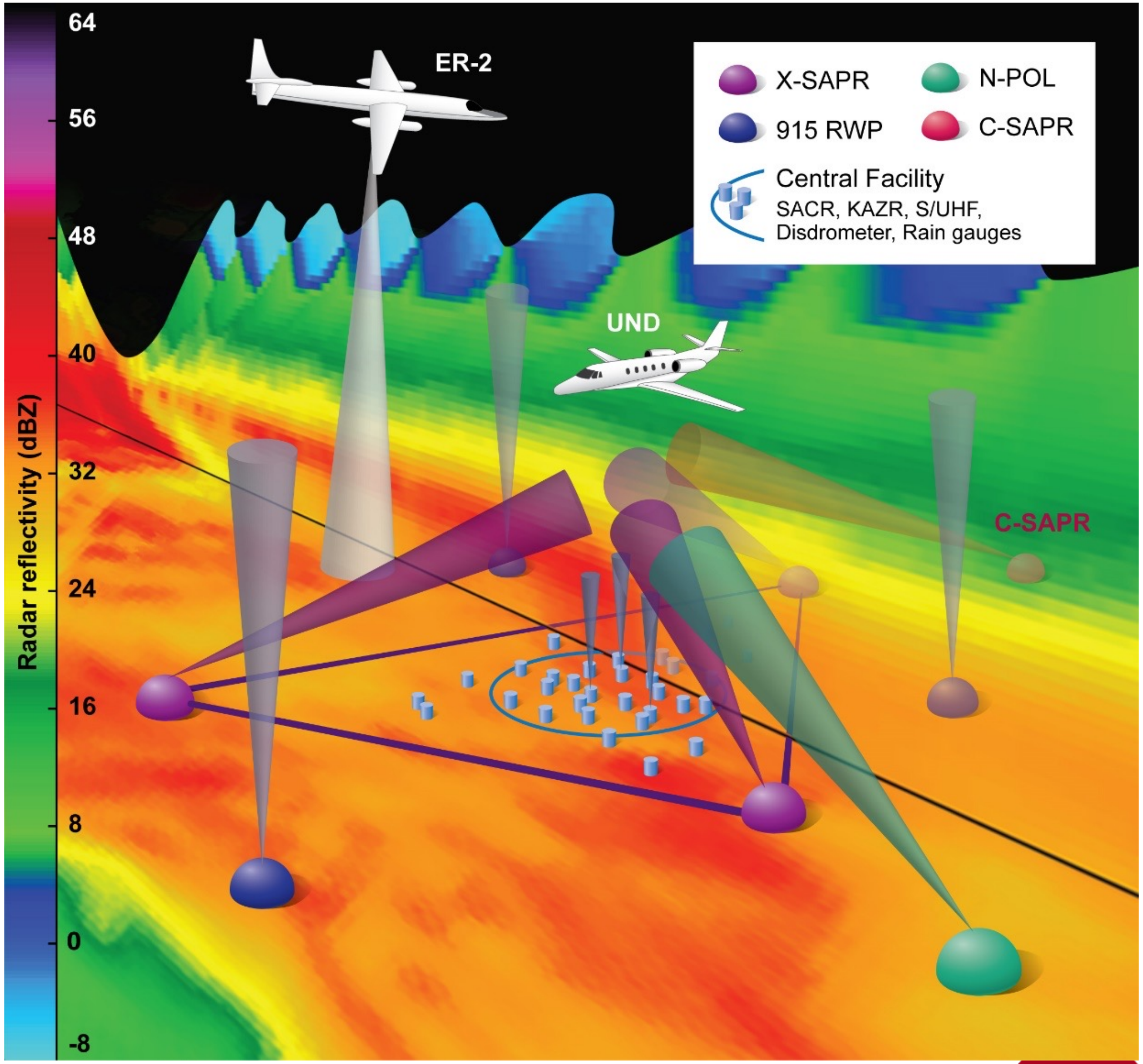
Motivation

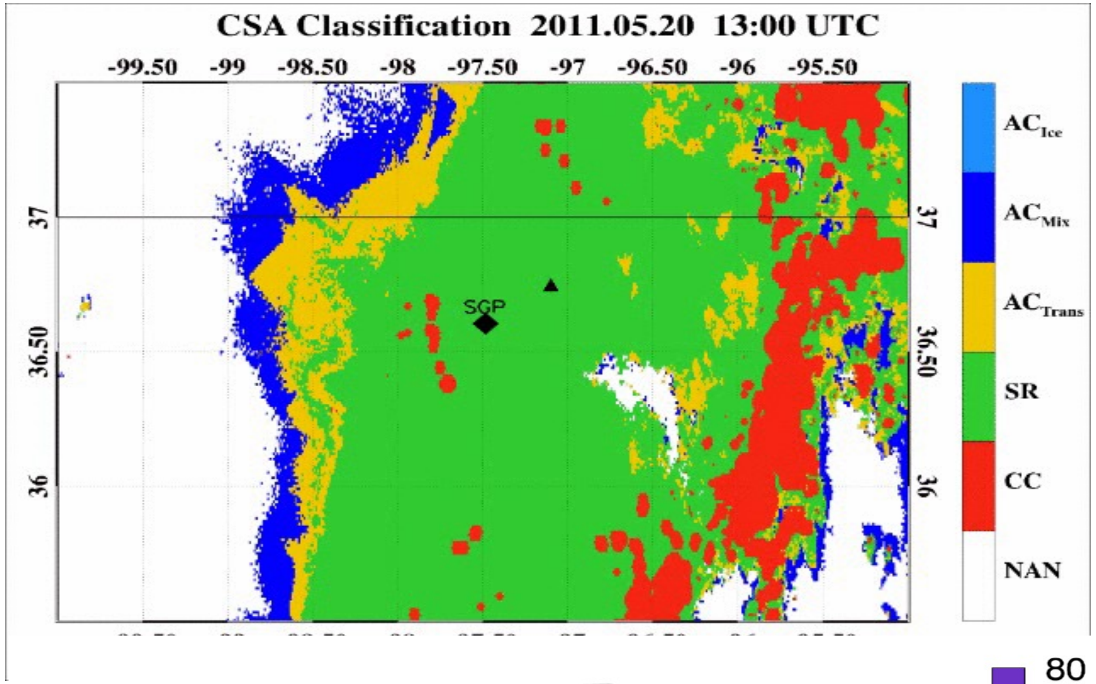
- **Underestimation of MCS stratiform precipitation has been a long-standing model issue (e.g., Varble et al. 2014; Morrison et al. 2015; Fridlind et al. 2017, Han et al. 2019).**
- **Developing new methods to provide MCS microphysical properties is critically needed to improve the understanding on MCS processes.**

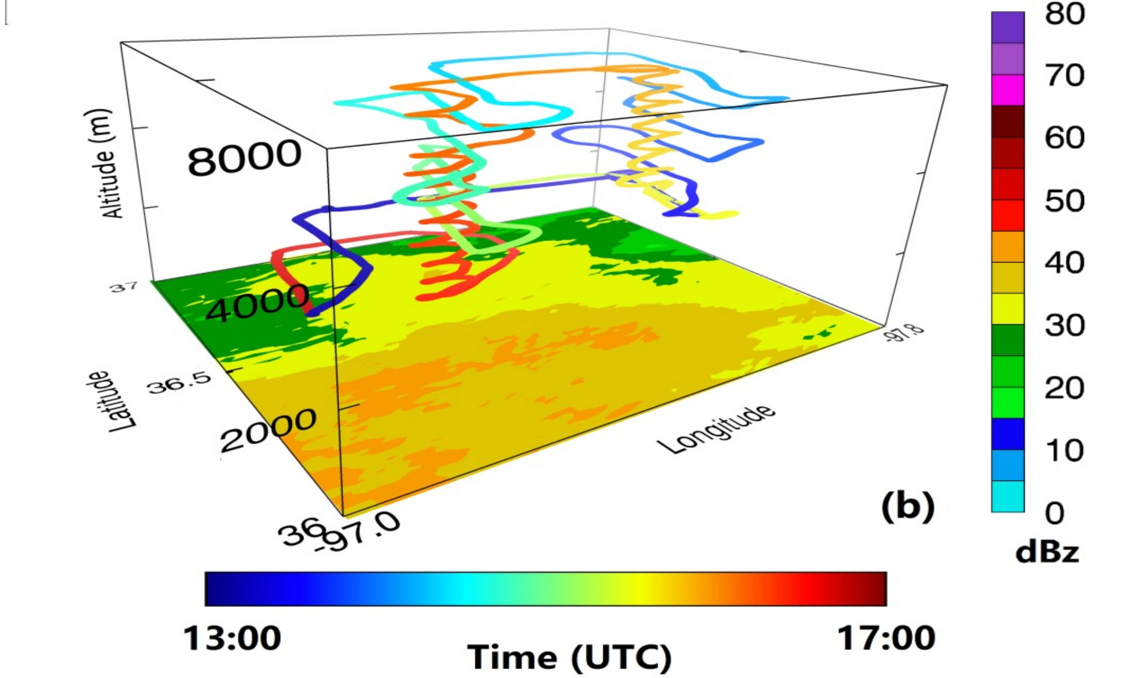
Outline

- **Algorithm Development: MCS Ice Cloud Microphysical Properties (Tian et al. 2016, JGR)**
- **Applications of Microphysics Retrievals: Statistical Analysis of Warm Season MCS Precipitation and Ice Cloud Microphysical Properties over the Great Plains and Evaluation of Model Simulations (Tian et al. 2020)**

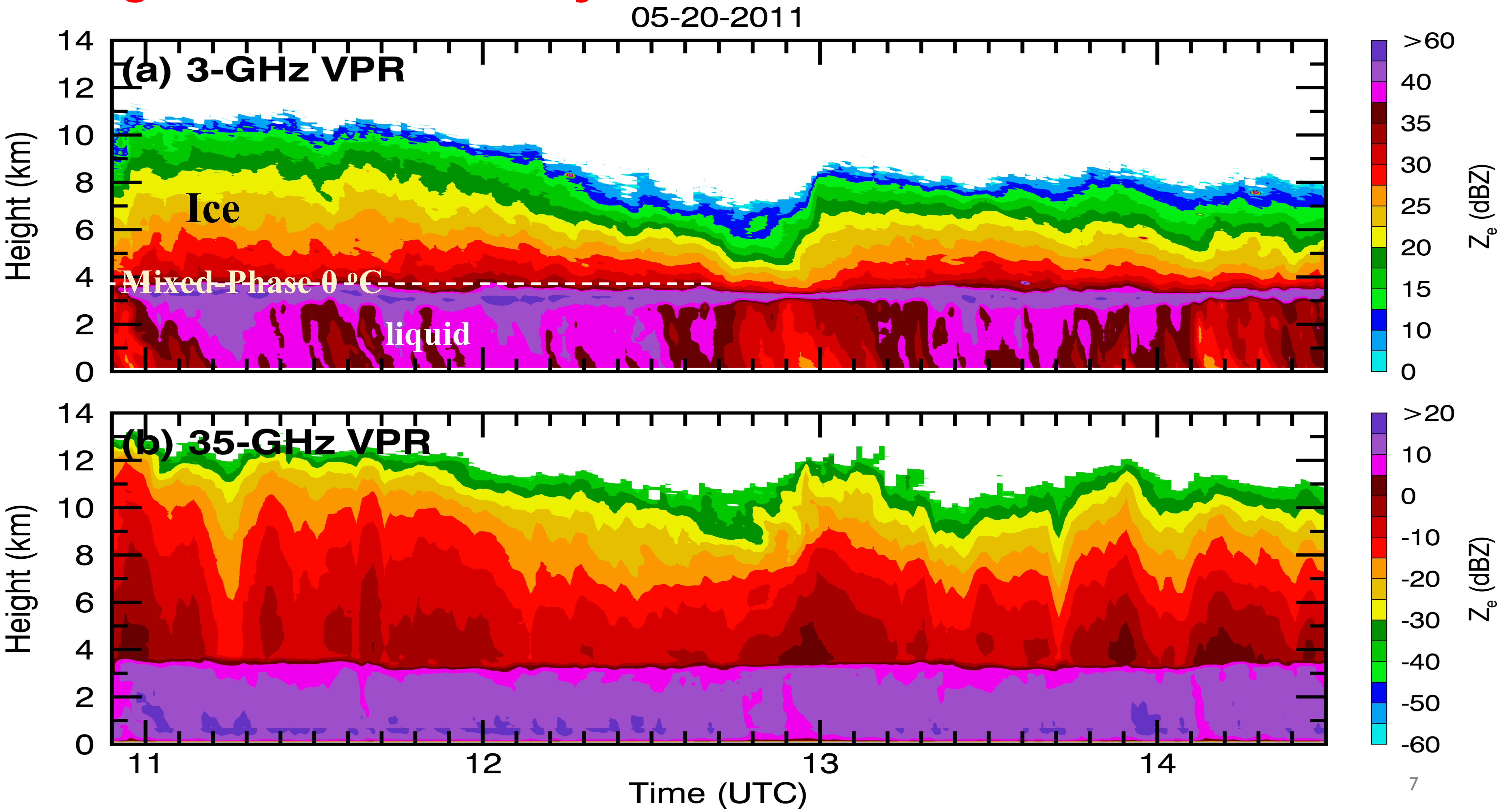
DOE ARM MC3E field campaign and remote sensors (15 flights, with a total of 43 flight hours)



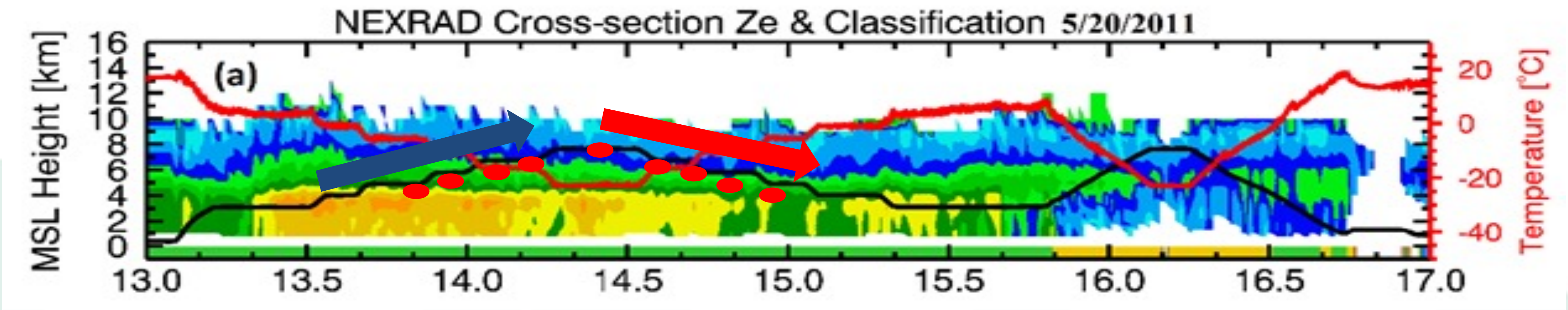


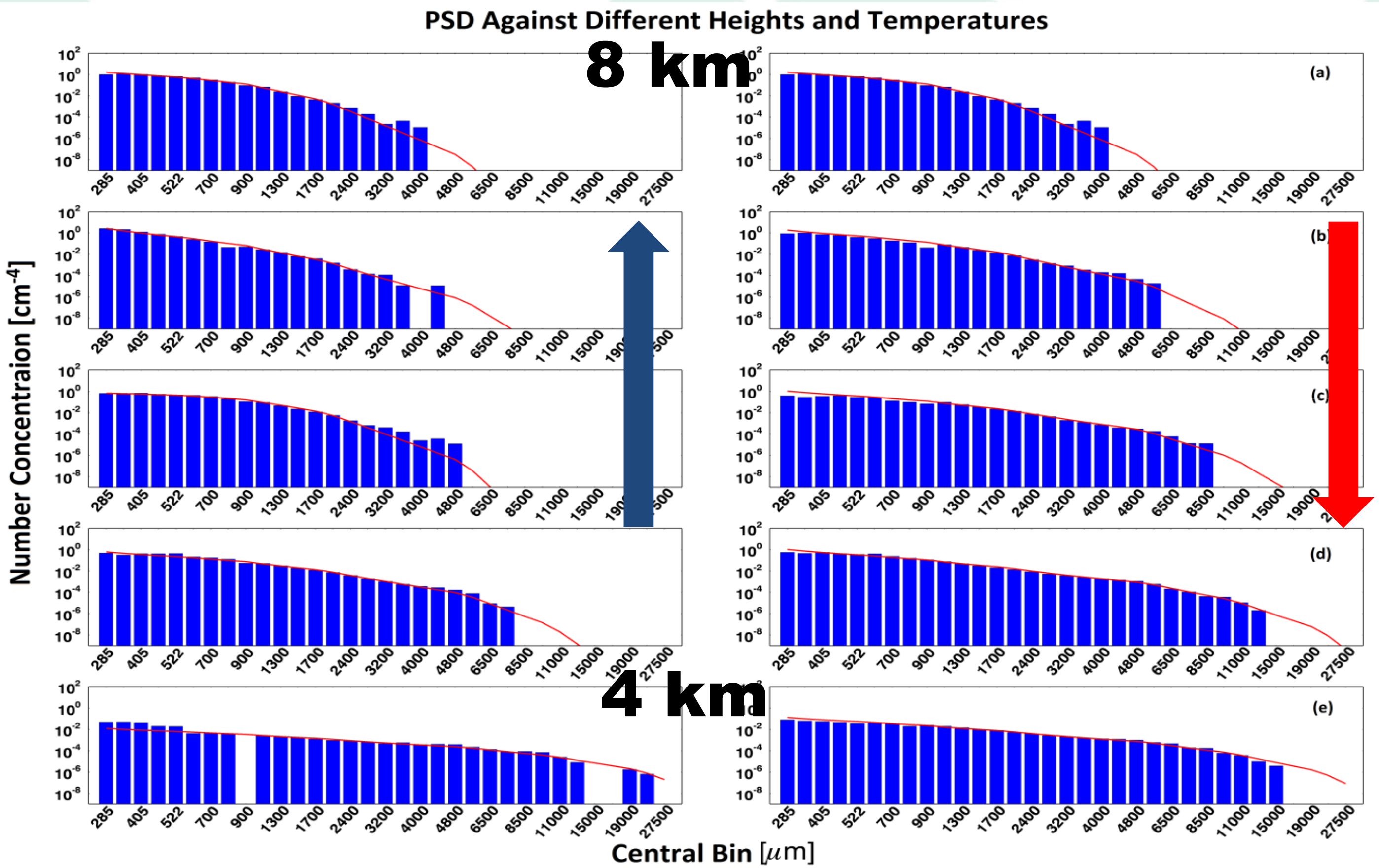


Using 3-GHz radar to study MCS structure better than 35-GHz radar



Vertical Distribution of PSDs derived from 2DC+HVPS





1. From 4km to 8 km, max Ds decrease from 27,500 μm to 4,000 μm, whereas Nt increase 100 times

2. Gamma-type-size-distributions have been derived from original PSDs as

$$N(D) = N_0 D^{\mu} e^{-\lambda D}$$

Retrieval Methods

Particle Size Distribution (PSD): Gamma function is used to capture PSD information

$$N(D) = N_0 D^{\mu} e^{-\lambda D}$$

N_0 (intercept), λ (slope), and μ (shape)

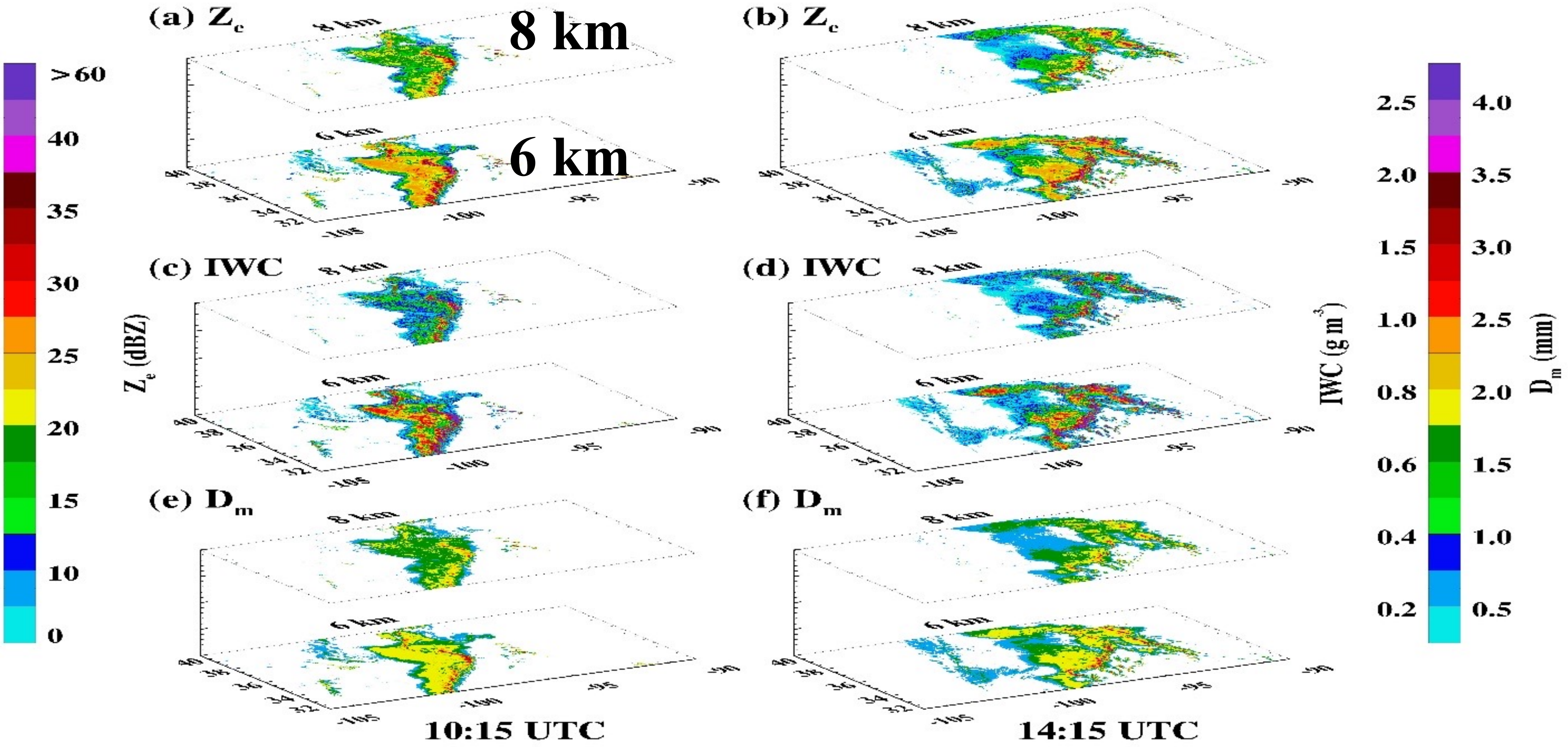
Ice Water Content (IWC, Bulk Property) (unit : g /m^3)

$$\mathrm{IWC} = \int_{D_{min}}^{D_{max}} m(D)\, N(D) dD,$$

Radar Reflectivity Factor (for ice under Rayleigh assumptions) (unit: mm^6/m^3 or dBZ)

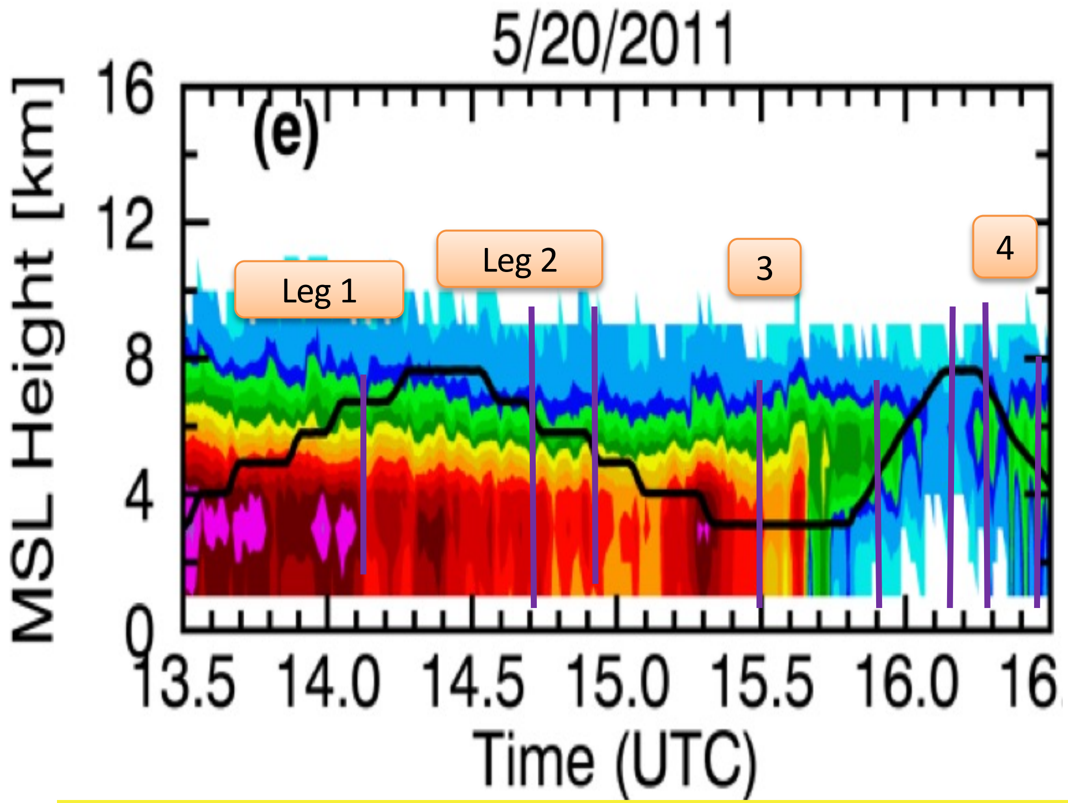
$$Z_e = \frac{|K_i|^2}{|K_w|^2}\left(\frac{6}{\rho_i \pi}\right)^2 \int_{D_{min}}^{D_{max}} m(D)^2 N(D) dD,$$

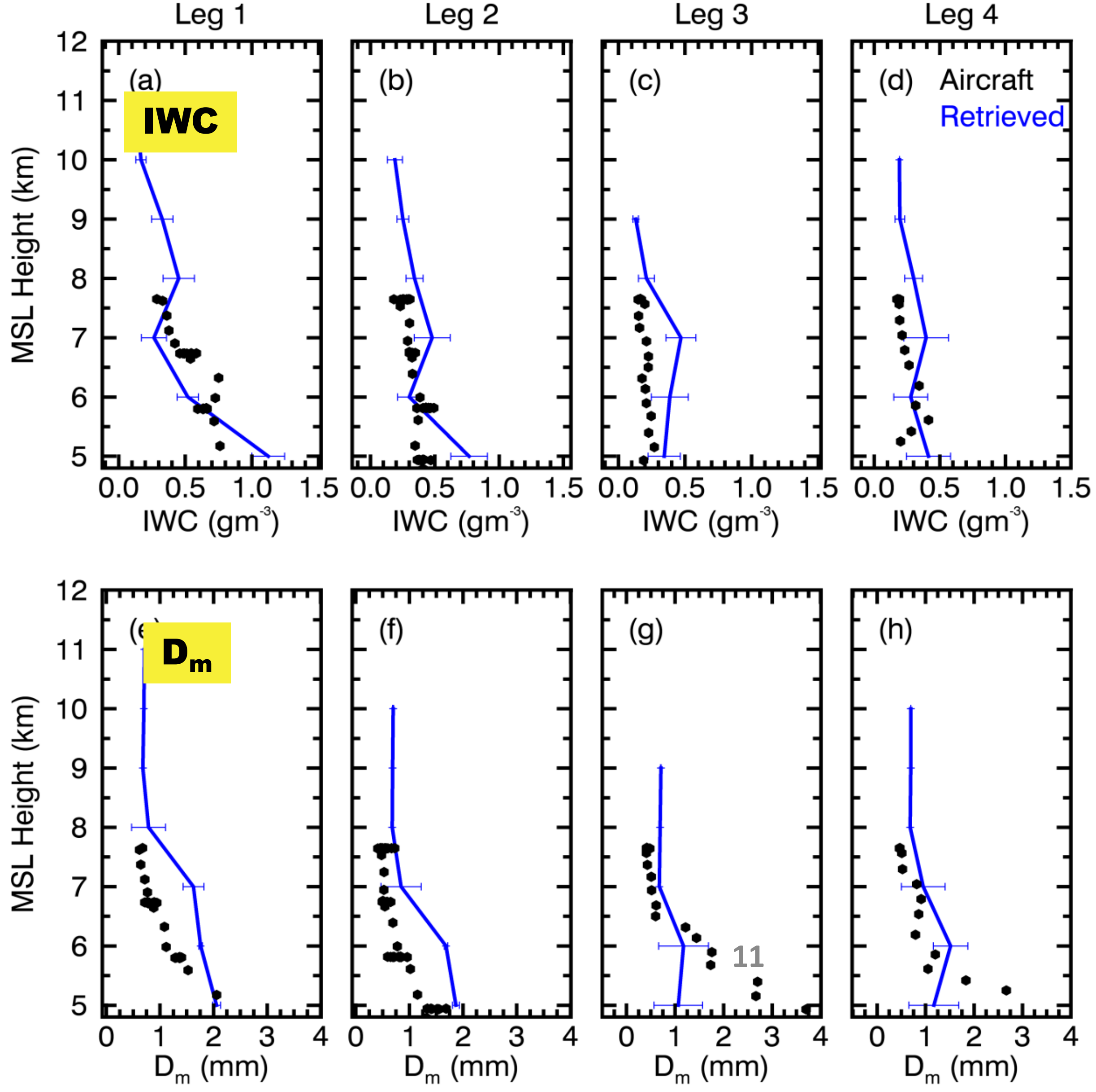
New retrievals for 4D MCS/DCS microphyscial properties



Retrievals show different cloud microphysical structures both **horizontally and vertically** as well as their **evolution with time** in **stratiform rain and thick anvil regions of MCSs**.

Validating NEXRAD retrieved IWCs using aircraft in situ measurements



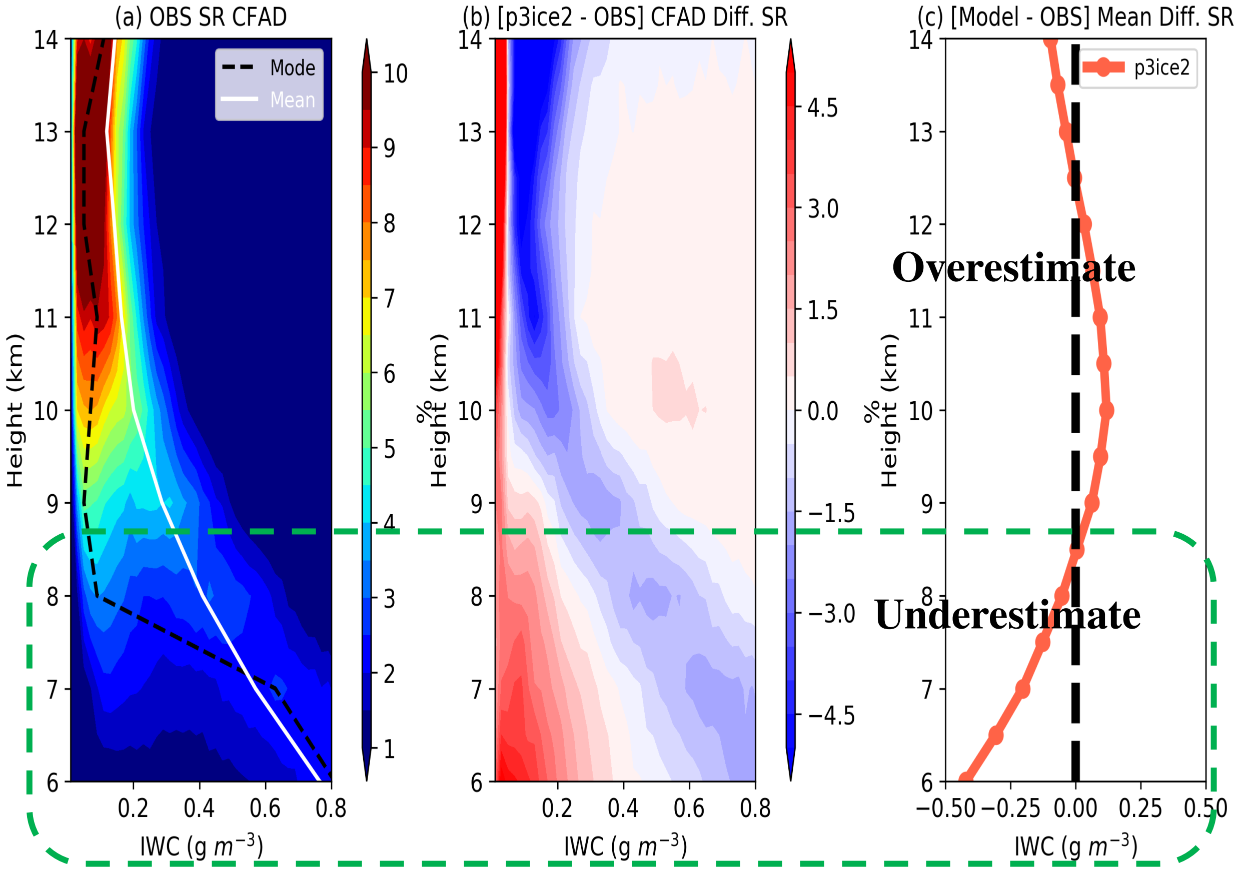


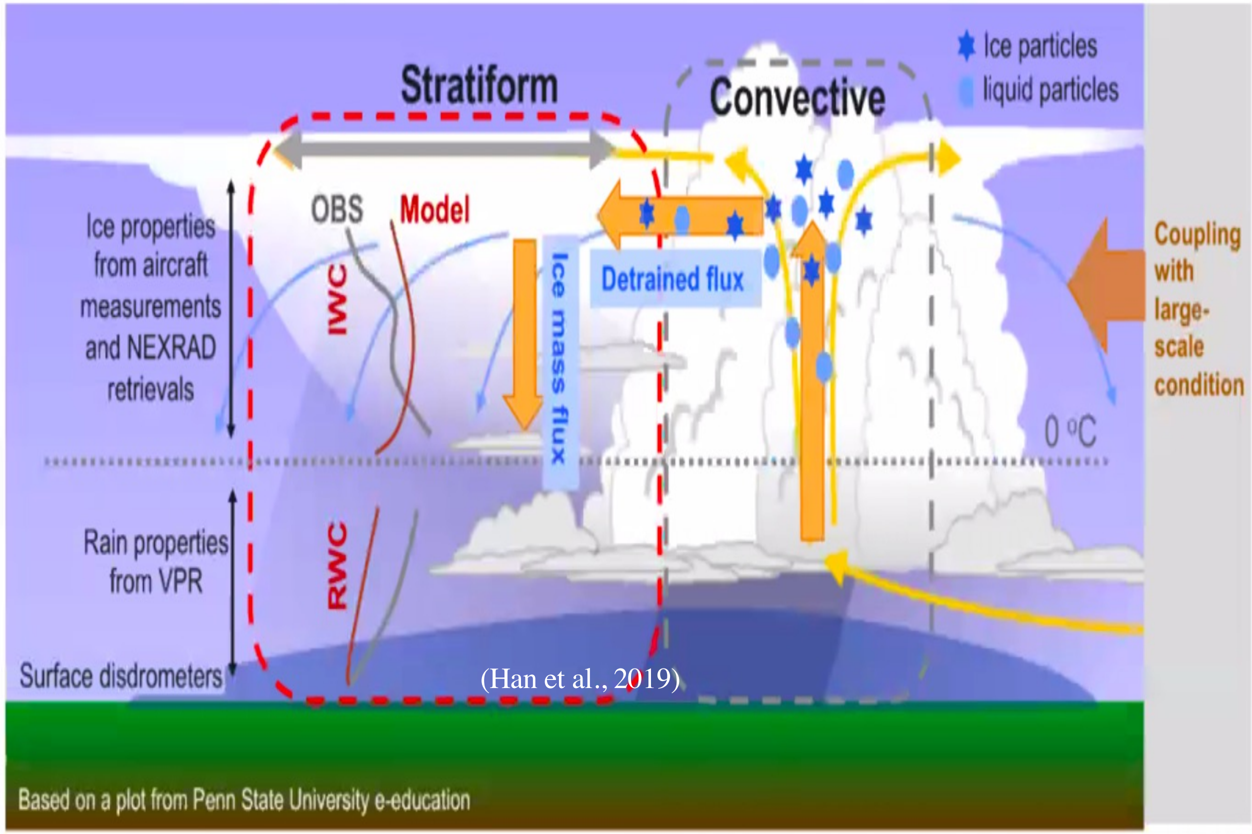
- **Both IWC and D_m decrease with height**

- **Statistical comparison during MC3E**

	Aircraft	Retrievals
IWC	**0.47 gm^{-3}**	**0.63 (+34%)**
D_m	**2.02 mm**	**1.63 mm (-19%)**

MODEL Evaluation





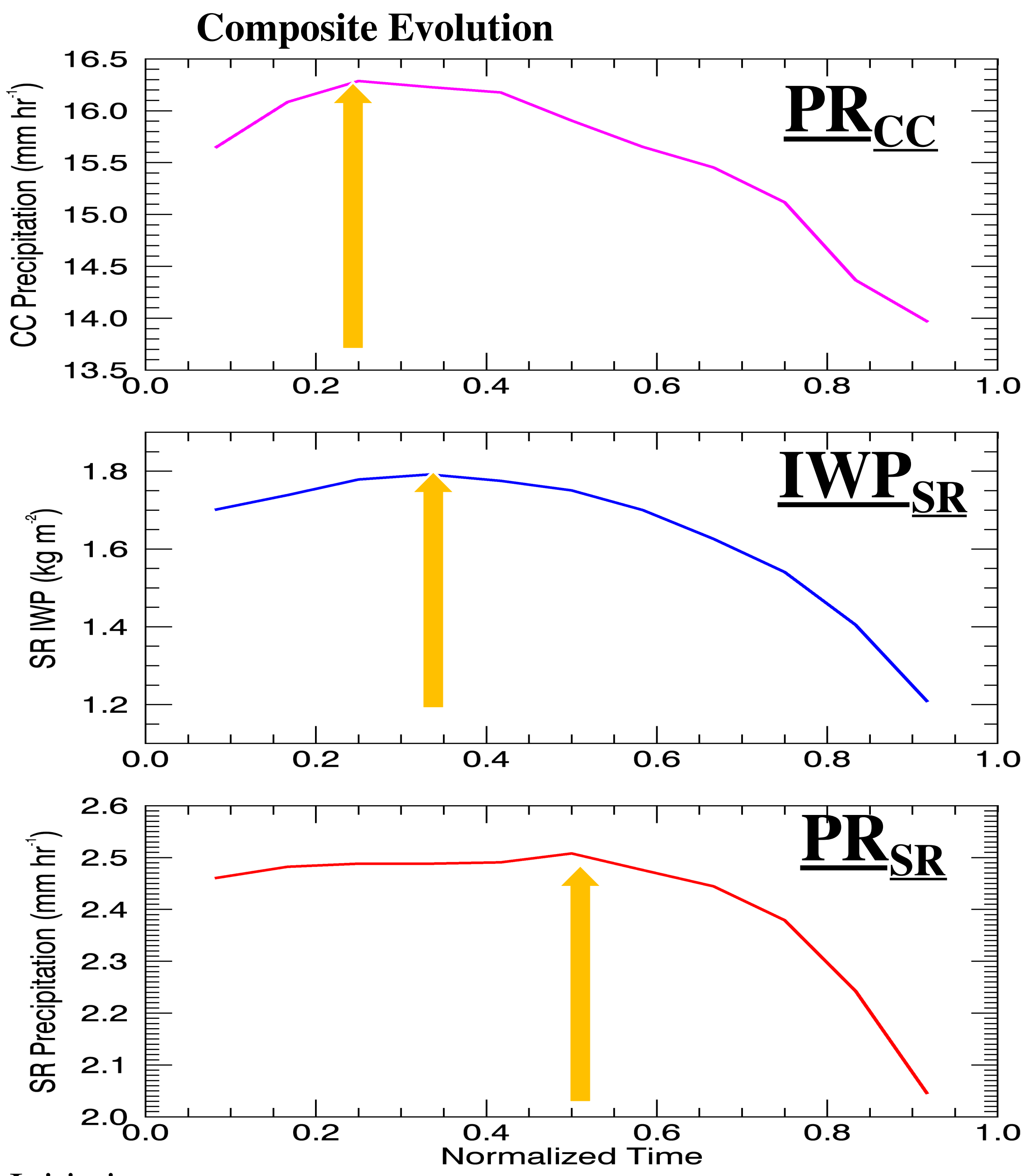
(Han et al., 2019)

Model overestimated IWC at upper levels and underestimated at lower levels in MCS/DCS stratiform regions

(Han et al., 2019)

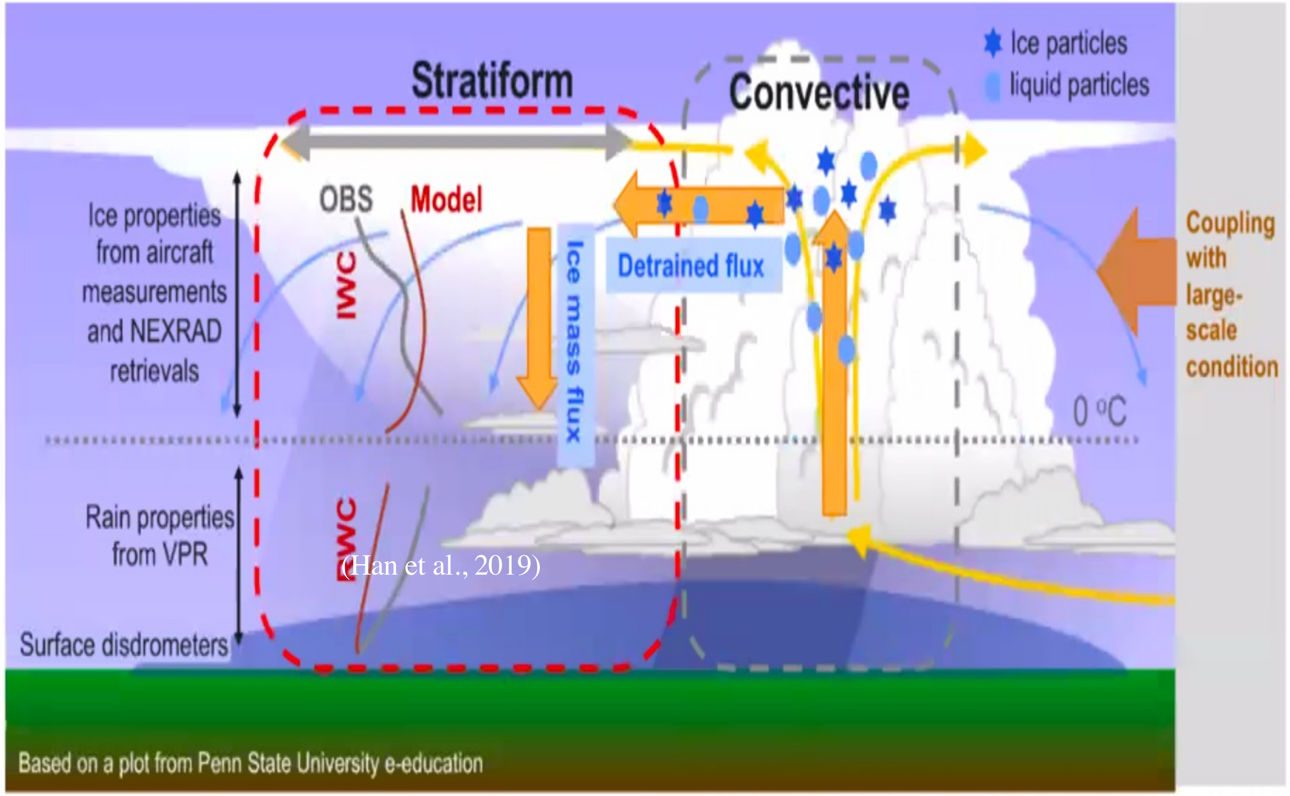
Model also underestimated RWC below melting layer→underestimate SR Preci.

Physical Processes in MCSs?



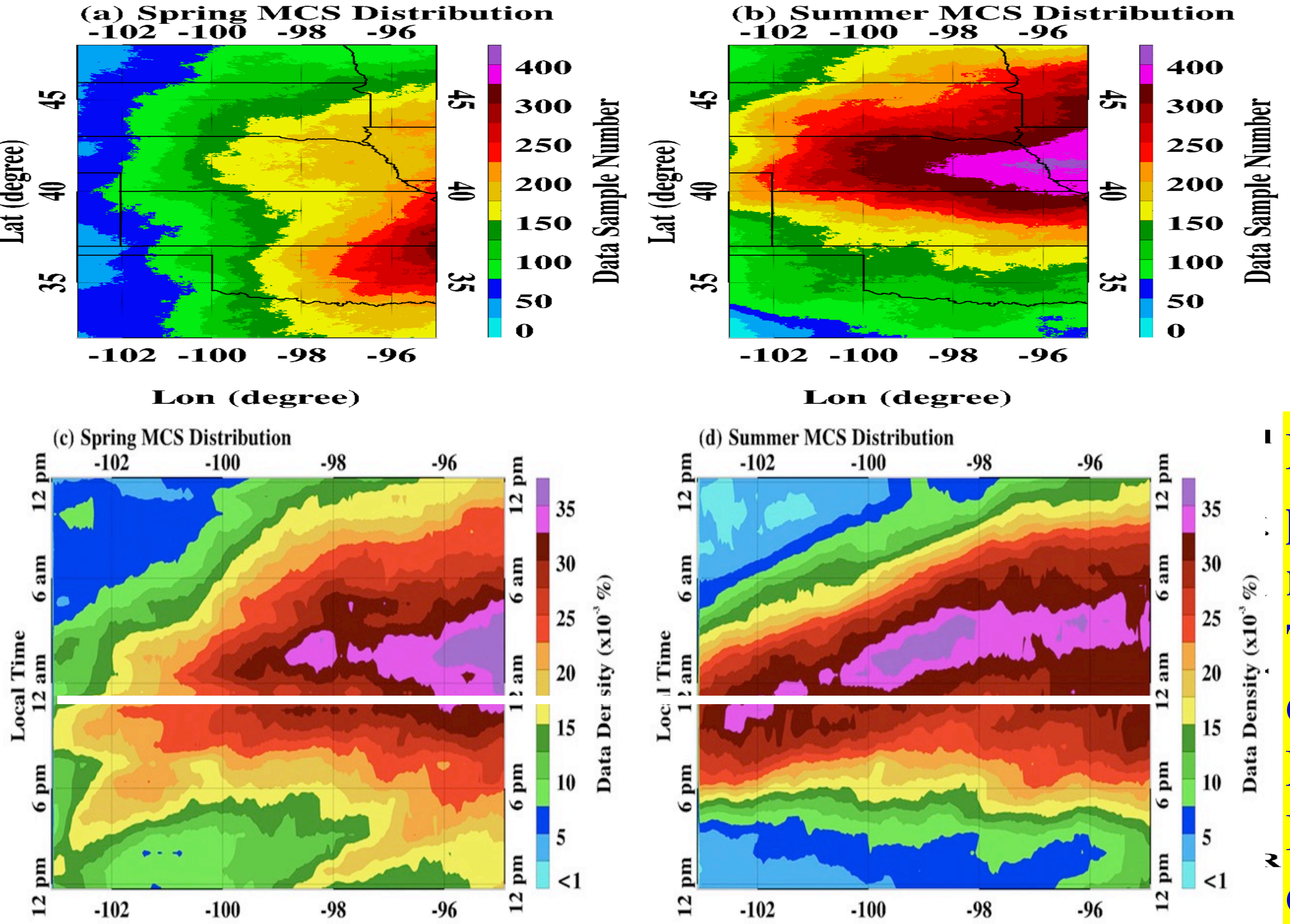
Initiation Dissipation

Does the shift of peak timing indicate some processes?



T1: MCS CC areas contribute heavy precipitation first ;
T2: Ice particles in CC areas are detrained to SR areas with depositional grow ;
T3: Large ice particles travel/survive long distance, fall into dry layers, melt to rain drops and form the stratiform precipitation.

Spatial and diurnal variations of MCS precipitation over the Great Plains



More precipitation during summer than Spring

More precipitation over east than west.

MCS occurrence and precipitation peaked right after midnight. This is a special characteristics of MCS over Great Plains, differing to other regions.

Summary Part I

1) A 4D database of MCS ice cloud properties has been generated using NEXRAD radar reflectivity and aircraft derived PSD, and validated by aircraft in situ measurements.

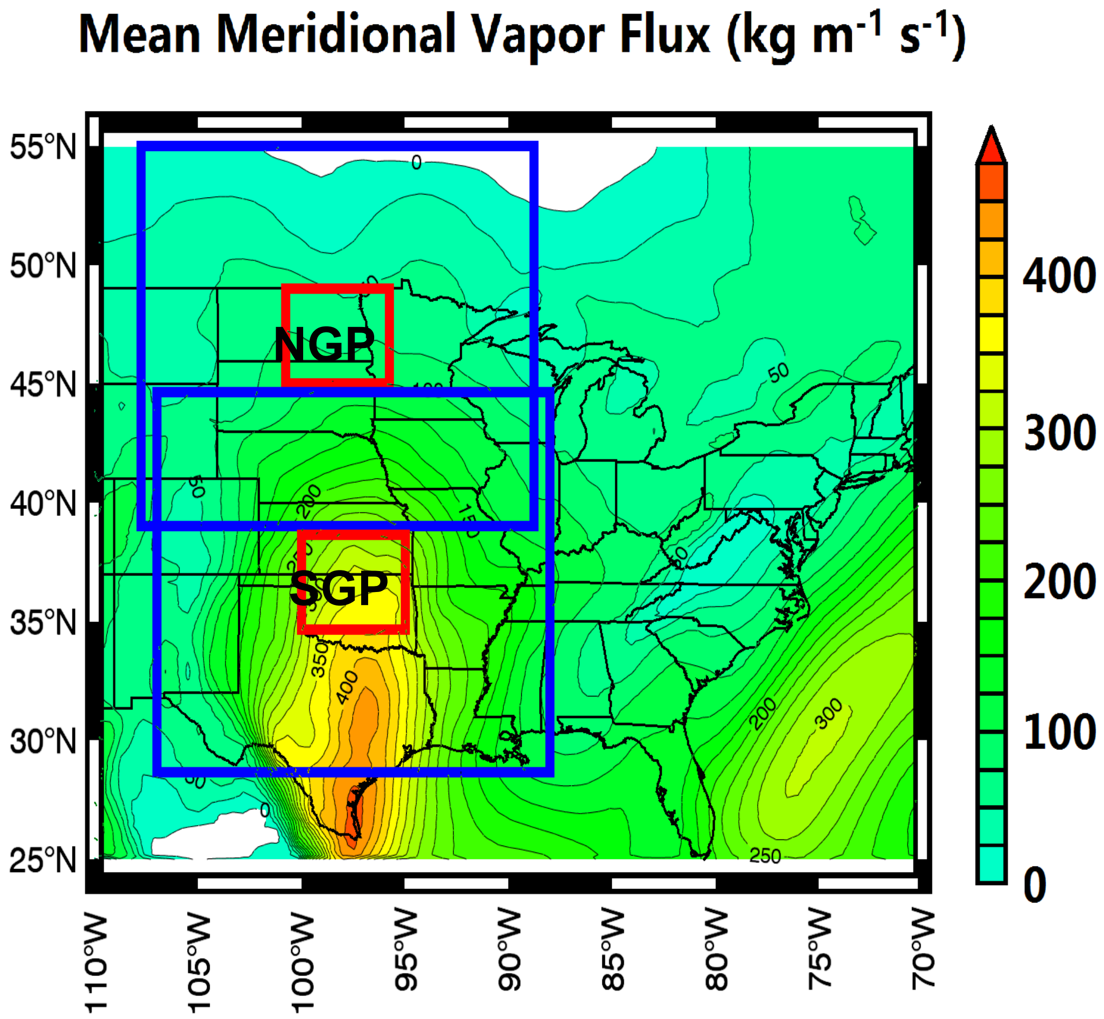
2) These results were used to evaluate model simulations where Model overestimated IWC at upper levels and underestimated at lower levels in MCS/DCS stratiform regions.

3) The spatial variability and nocturnal peaks of MCS precipitation are primarily driven by the MCS occurrence rather than the precipitation intensity.

Part II: Evaluate NOAA NSSL WRF simulated precipitation

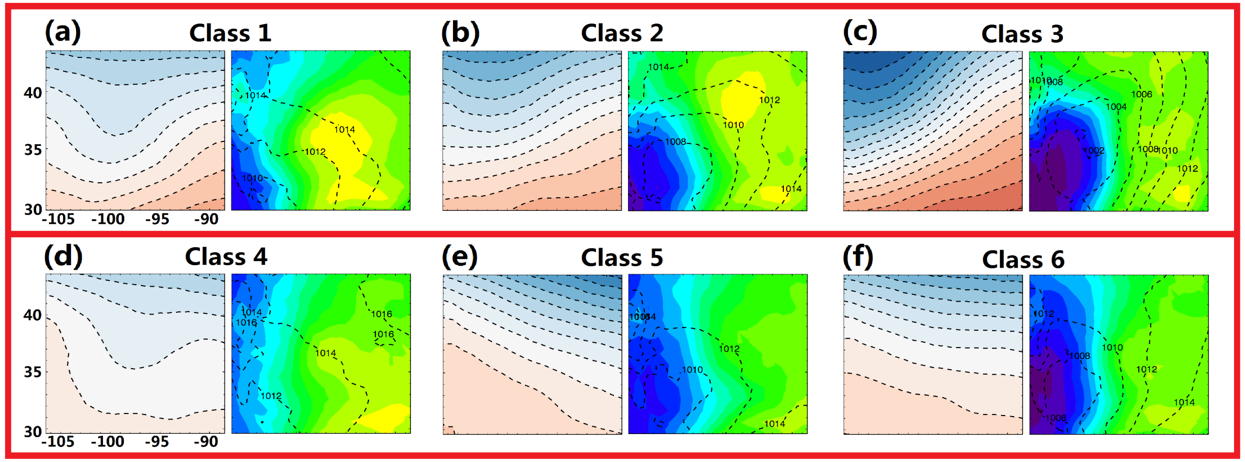
(Supported by NOAA R2O program)

- **Location:** SGP and NGP
- **Duration:** 2007-2014 warm season (Apr. – Sep.)
- **Target:** Heavy precipitation events (upper 90% of regional precipitation)
- **Classification method:** Self-Organizing Map (SOM)
- **Classification input:** NARR data (MSLP, wind/geopotential/RH/ at 500/900 hPa)
- **Observation:** NCEP Stage IV
- **Simulation:** Long-term WRF by NSSL

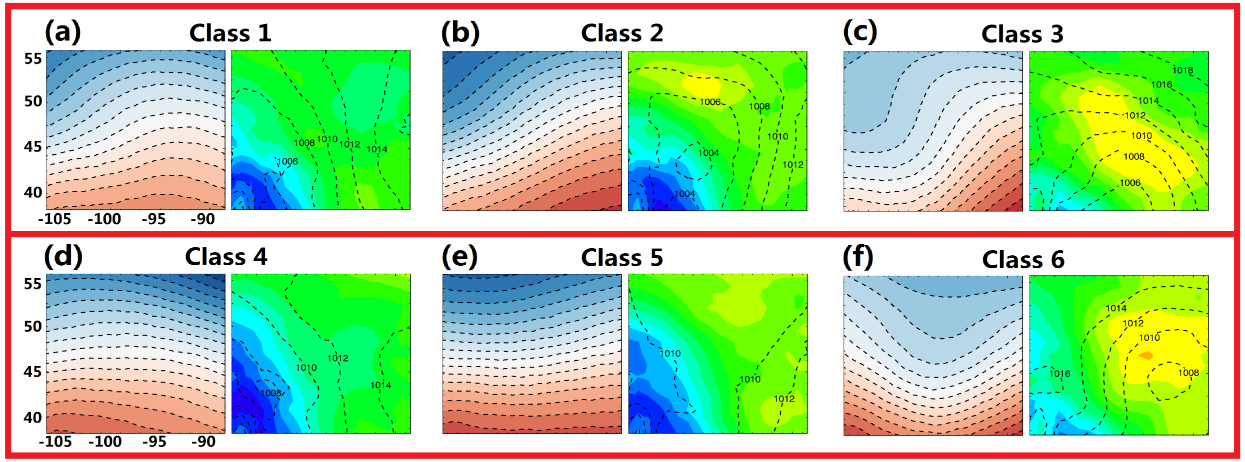


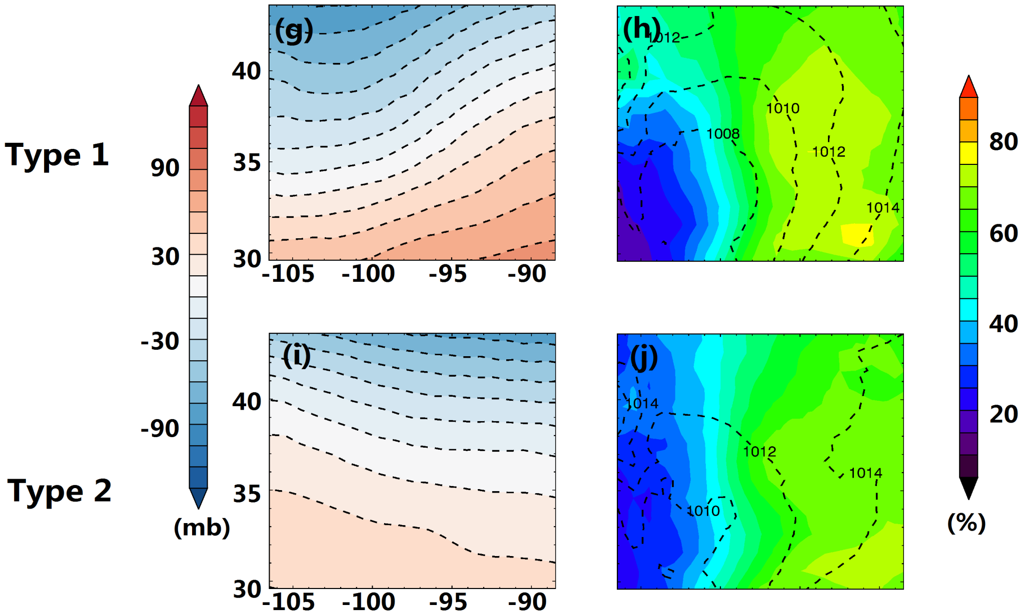
Using Self-Organizing Map to identify Synoptic Patterns

SGP



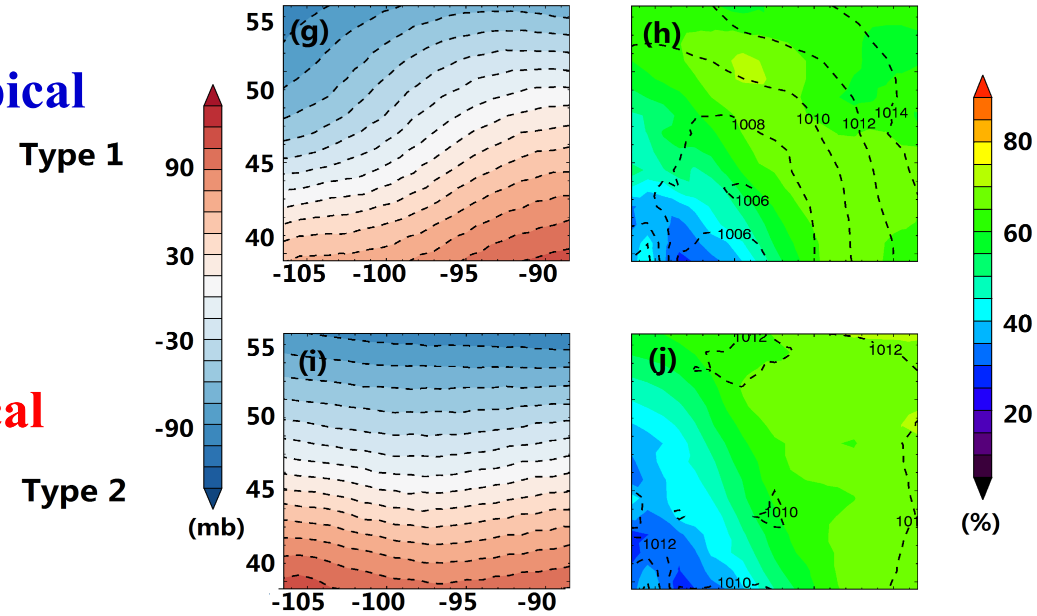
NGP



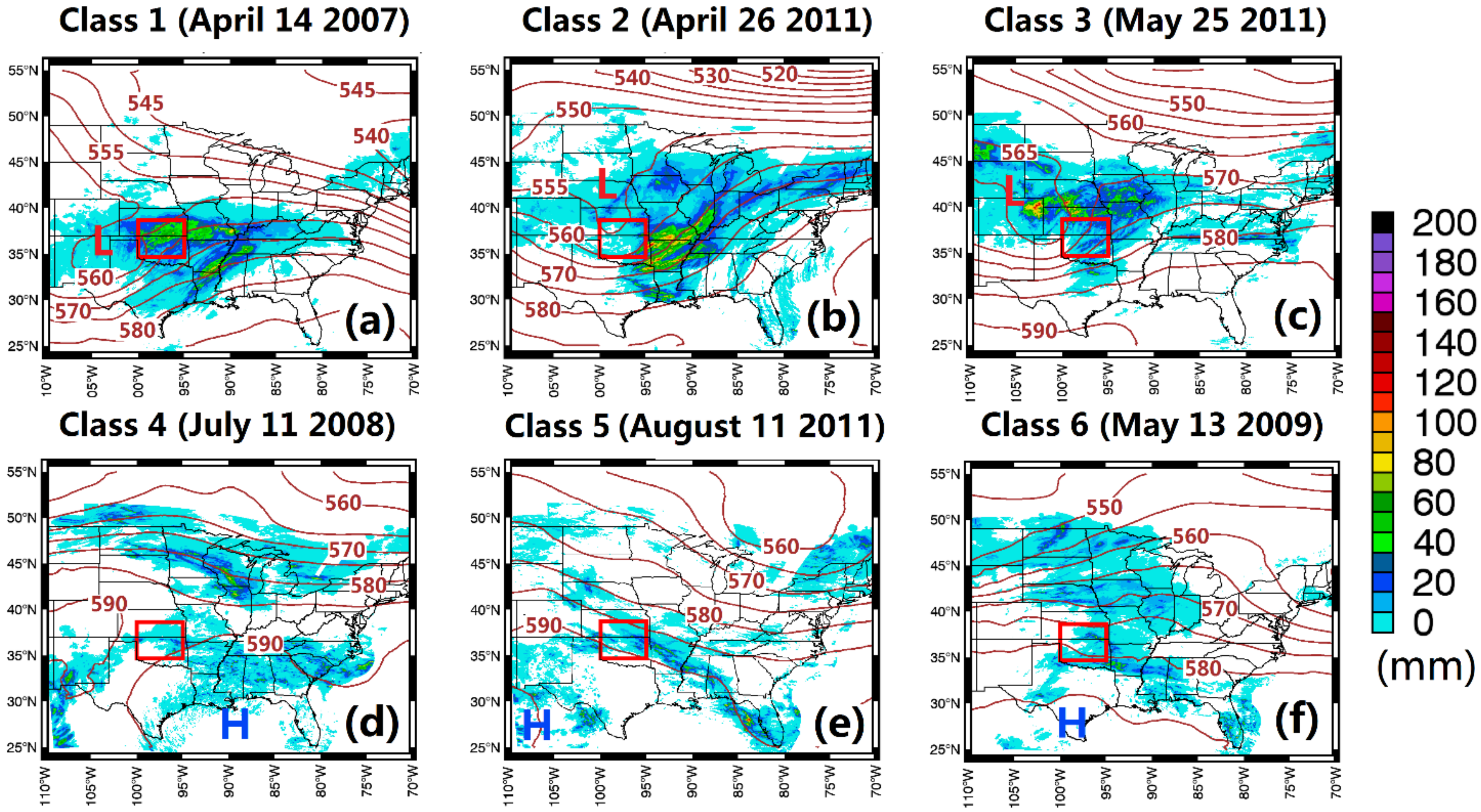


Extratropical cyclone

Subtropical ridge

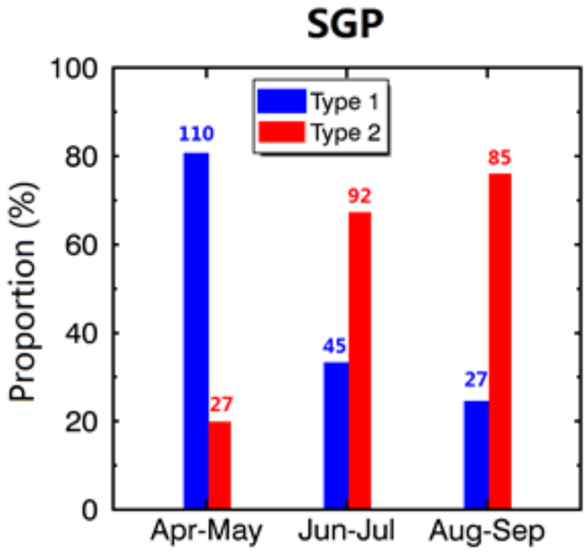


Examples of the SGP SOMs



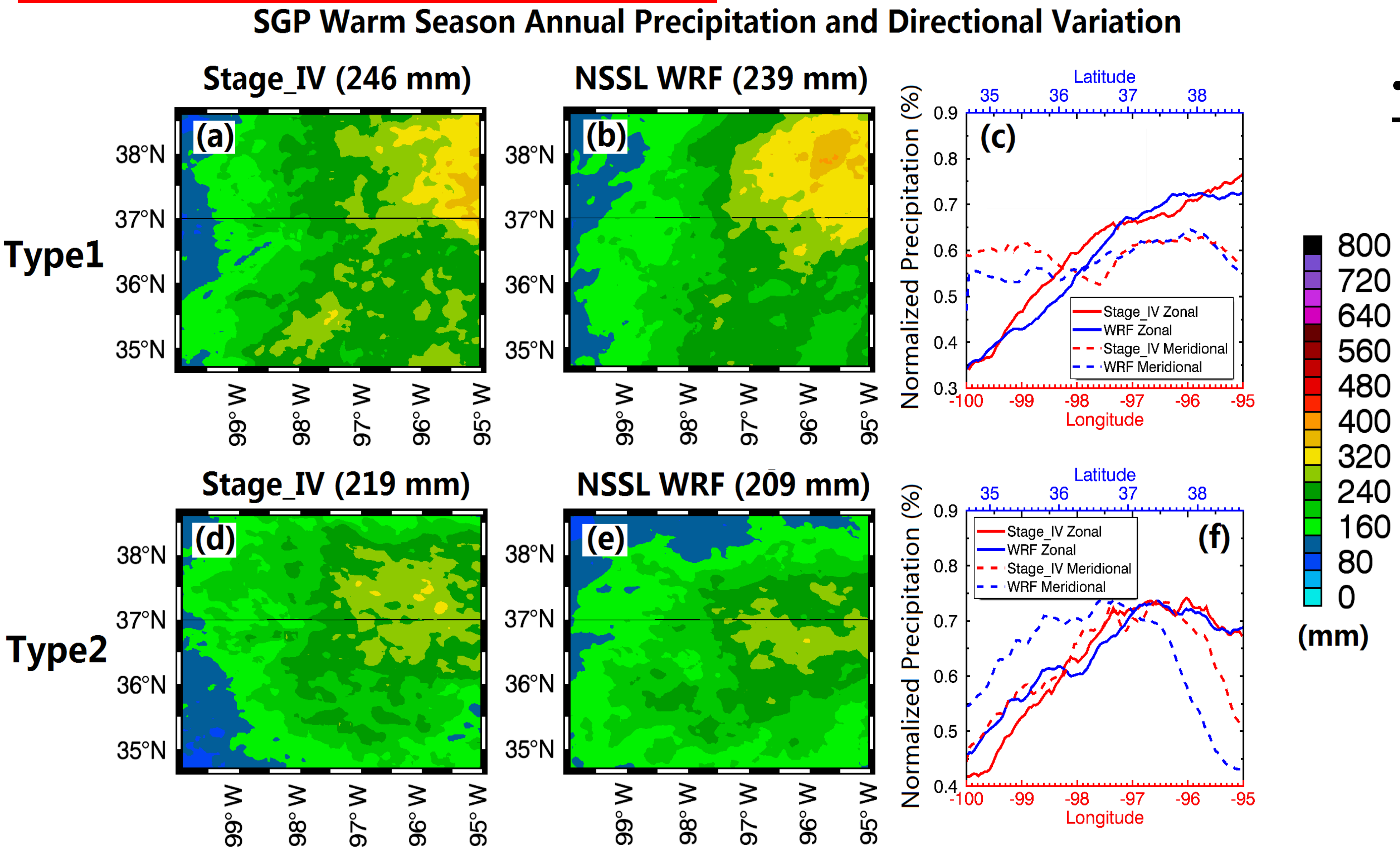
Type I: Extratropical cyclone:
Polar jet stream causes upper level divergence and surface low is generated

Type II: Subtropical ridge:
Subsidence inversion is strong at the high center but weakens towards the periphery of the high.



Extratropical cyclone dominates during April-May but Subtropical ridge is dominant from June to September

WRF Evaluation (SGP)



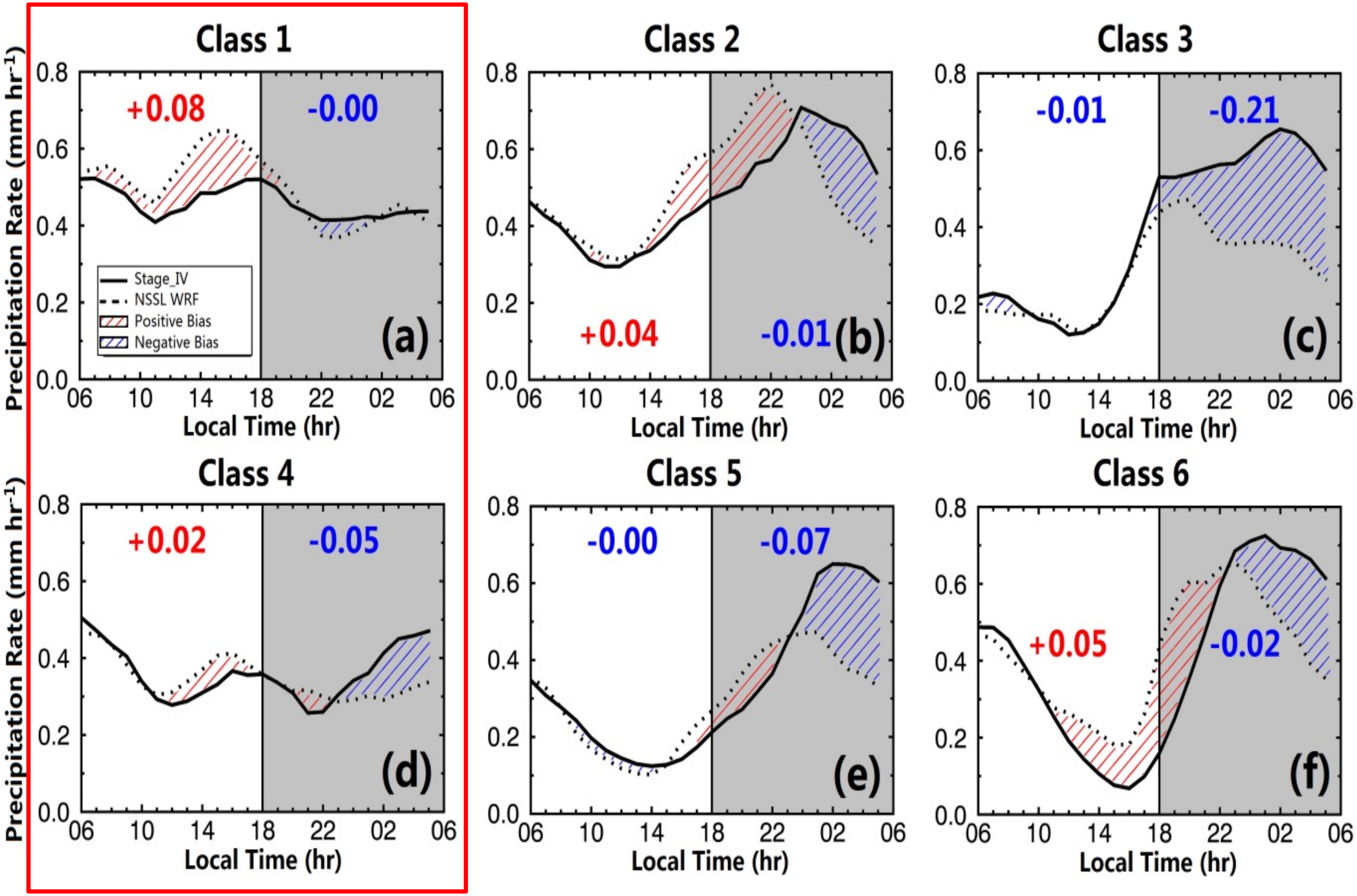
- **Total precipitation**
Type 1 > Type2

- **Spatial pattern:**
Type 1 zonal gradient (W-E)
Type 2 meridional gradient (N-S)

- **WRF:**
Negative bias
Type 1 better than Type 2

WRF Evaluation by Class (SGP)

Diurnal cycle analysis

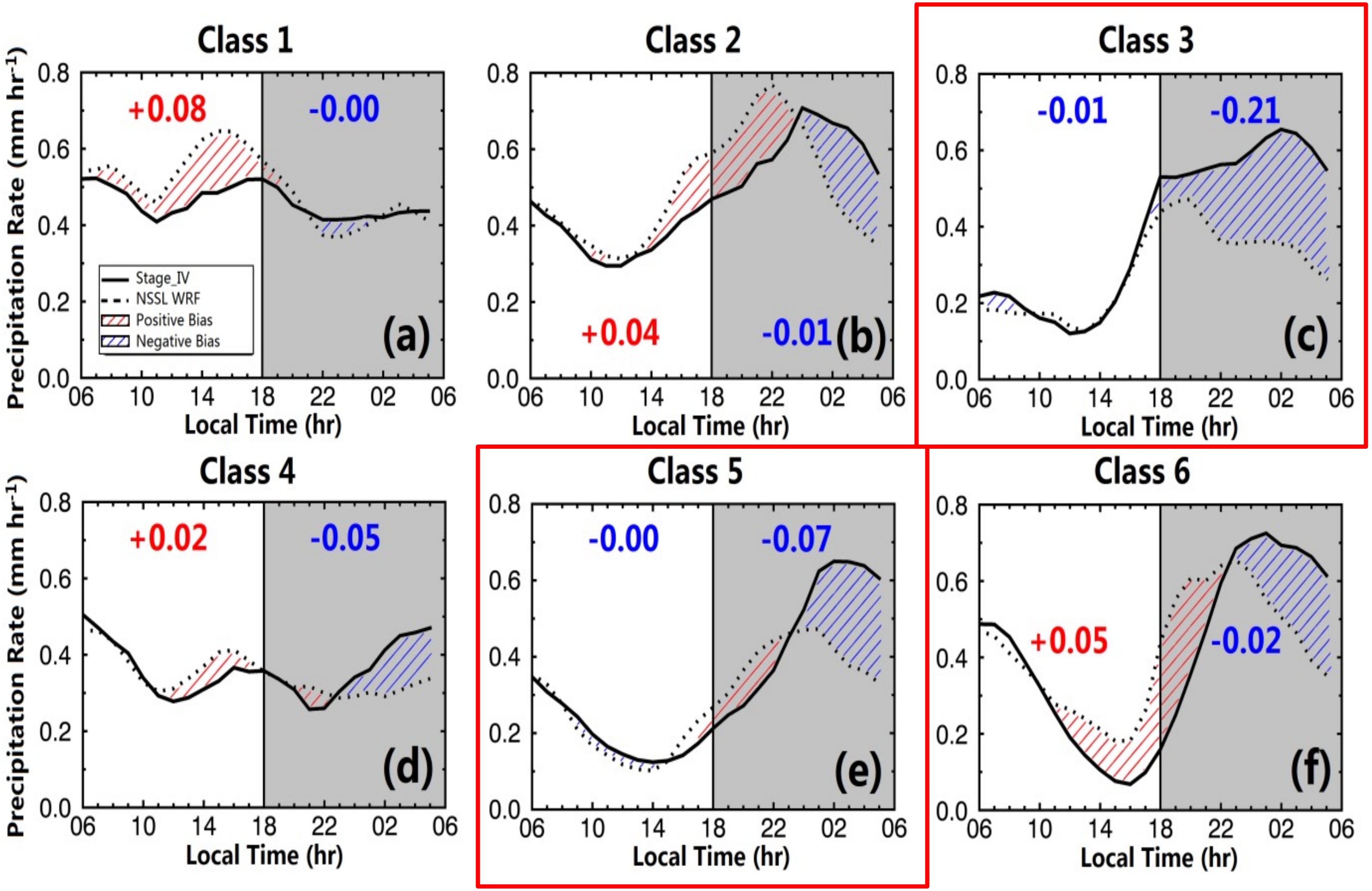


Classes 1 and 4:

- Flat diurnal variation (Stratifrom Rain, SR)
- Bi-modal pattern
- WRF well simulates

WRF Evaluation by Class (SGP)

Diurnal cycle analysis

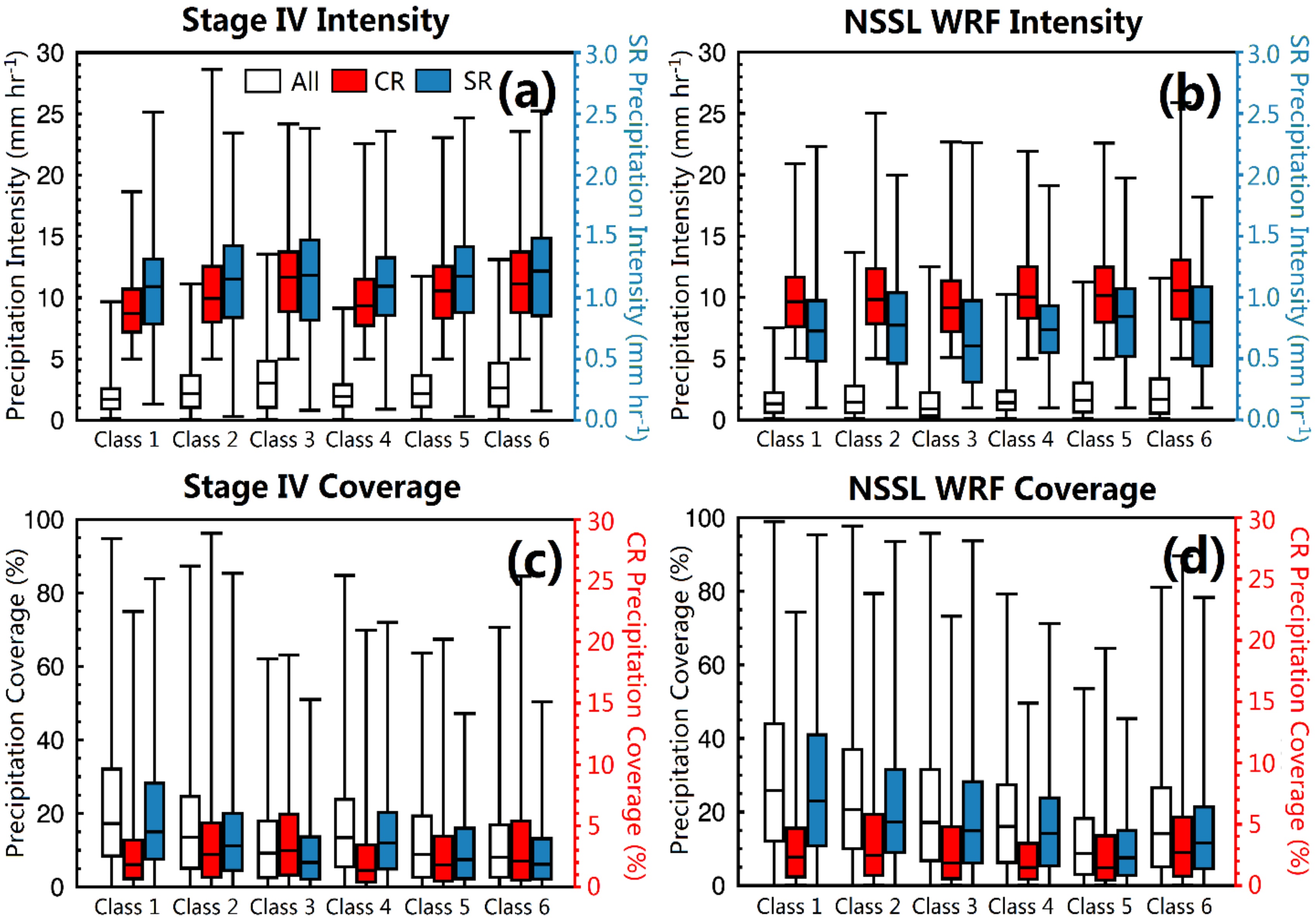


Classes 3 and 5:

- The largest diurnal variation
- Follows the typical pattern
- Daytime WRF well matches
- Nighttime WRF severely undersimulates
- Simulated convection ends too soon

WRF Evaluation by Class (SGP)

SR vs. CR Components



Intensity: CR = 10 * SR
Coverage: CR = ¼ SR

Class 1/4:

- The least all/CR/SR intensities, and the least CR coverage, but
- The largest all/SR coverage
- SR dominance

Class 2/3/5/6:

- Higher all/CR/SR intensities
- Higher CR coverage
- Lower all/SR coverage
- CR dominance

CR intensity/coverage is better simulated than SR

Summary of Part II

- **SOM works well for the separation of synoptic patterns (extratropical vs. subtropical) and the dominant precipitation types (SR vs. CR)**

- **WRF better matches in overall CR intensity/coverage than SR**

- **Better simulation in extratropical cyclone than in subtropical ridge**

Xiquan Dong's research group