Investigation of MCS Cloud-precipitation Processes and Properties through an integrative analysis of aircraft in-situ measurements, ground-based remote sensing and WRF simulations

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Outline

I) MCS cloud and precipitation

- **A: Lifecycle of classified MCS's components**
- **B: Evaluation of WRF simulated precipitation using Stage IV dataset**
- **C: Aircraft in-situ measurement and surface retrievals during MC3E**

II) MBL aerosol and cloud properties

III) CMIP5 evaluation using satellite observations

Part IA: Lifecycle of classified MCS's components

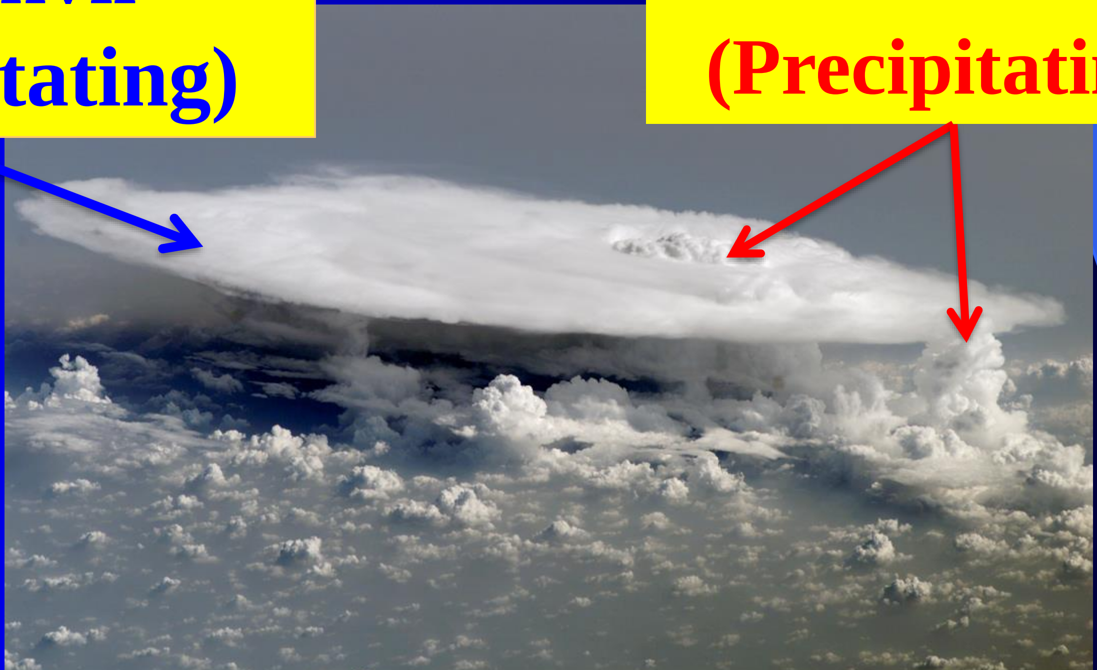
- **Feng et al. 2011 and 2012 (JGR)**

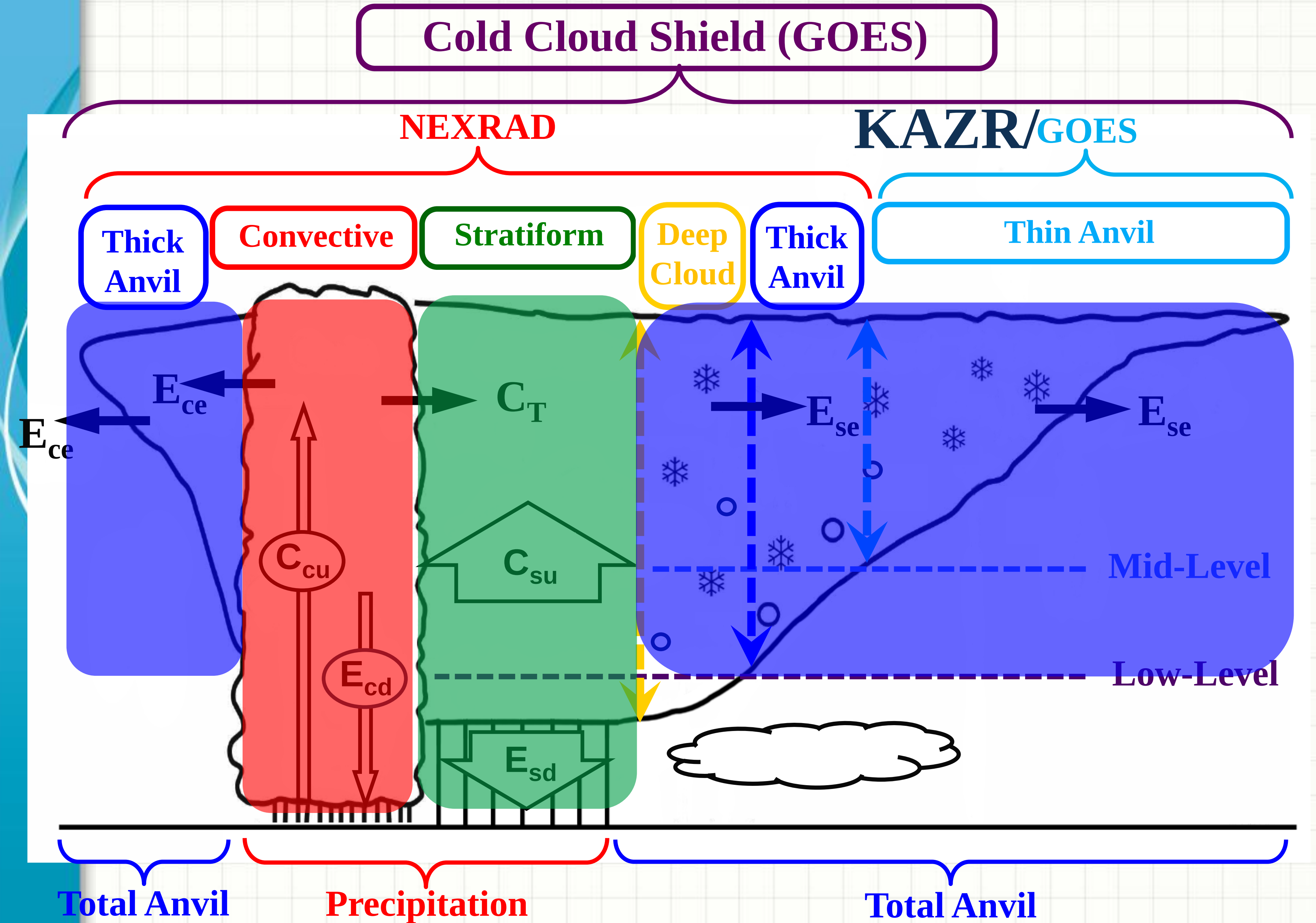
Why do we need to study Mesoscale Convective System (MCS)

- MCS has two main compoments
  - 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

Cirrus anvil (Non-precipitating)

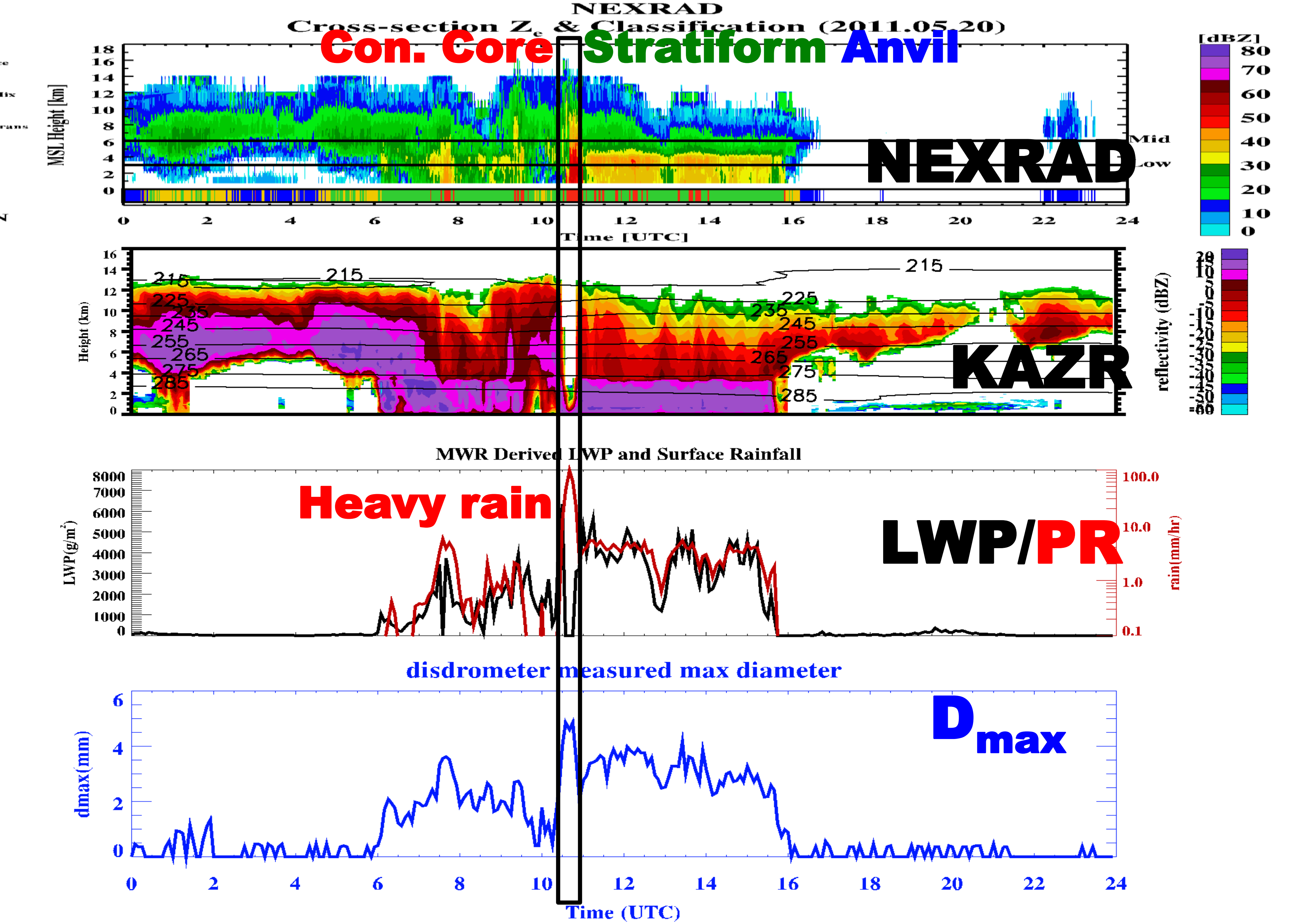
Cumulus Tower (Precipitating)



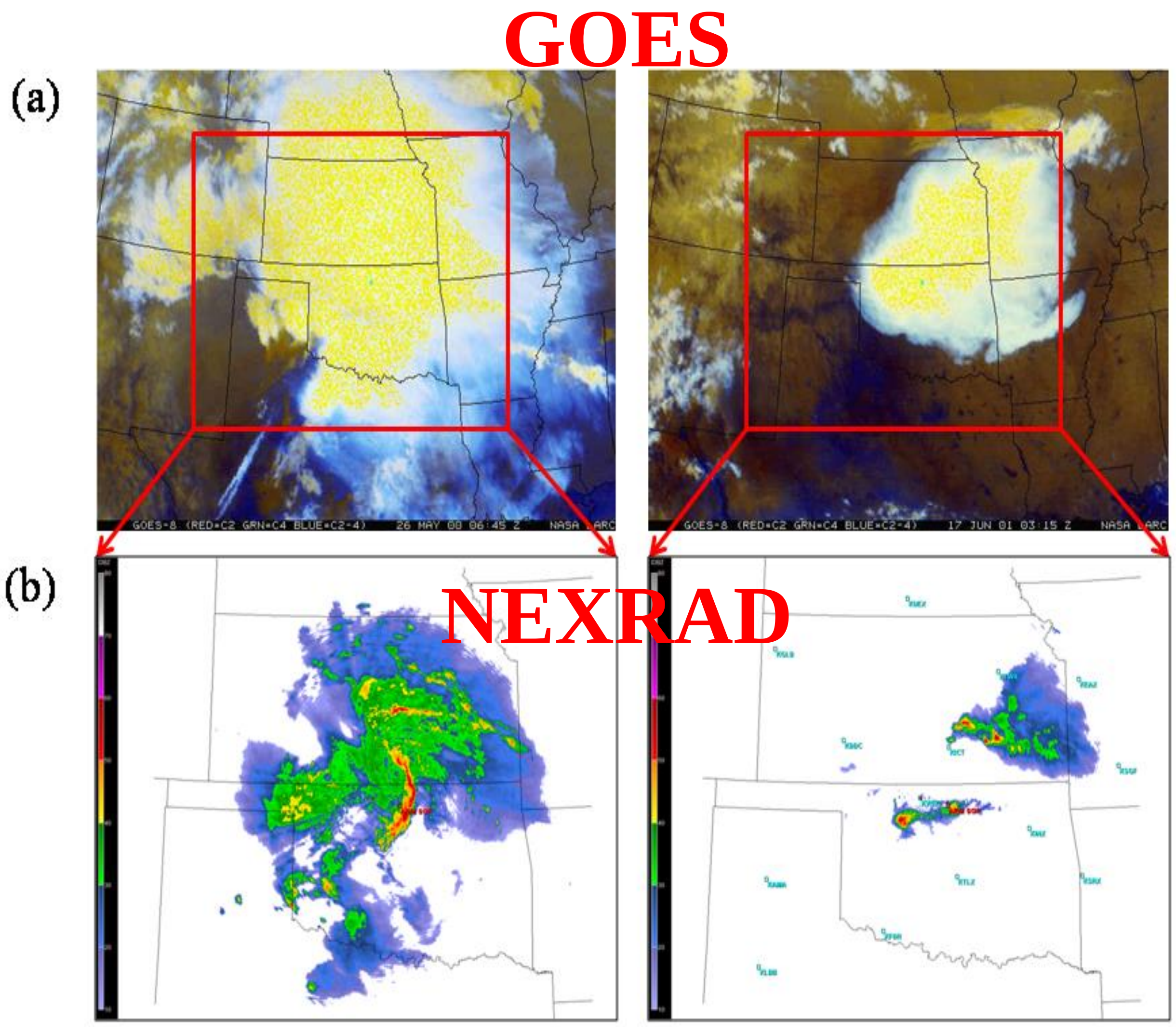


Feng et al. (2011) JGR

Studying DCS cloud and precipitation during MC3E

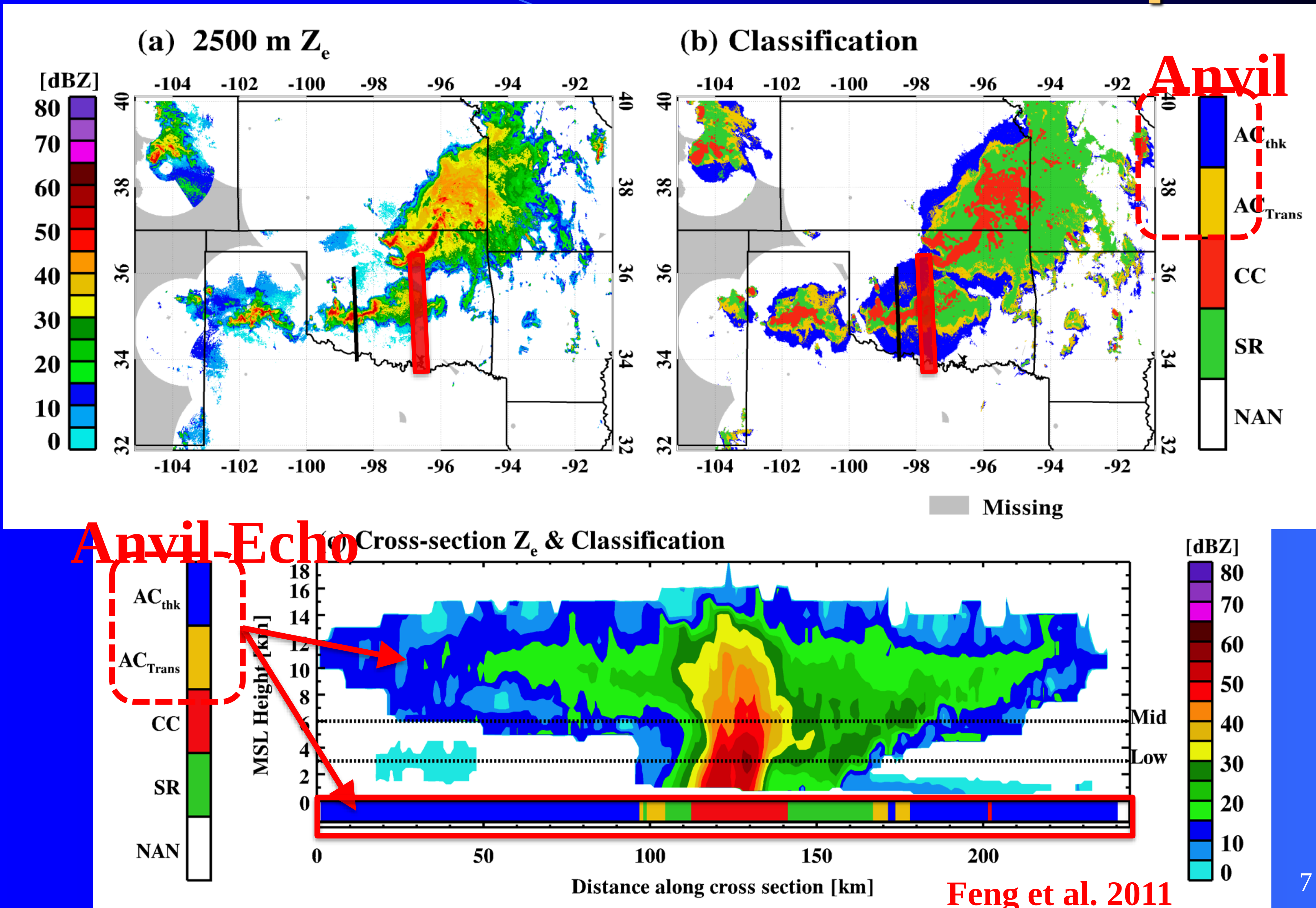


Why we need satellite observations?

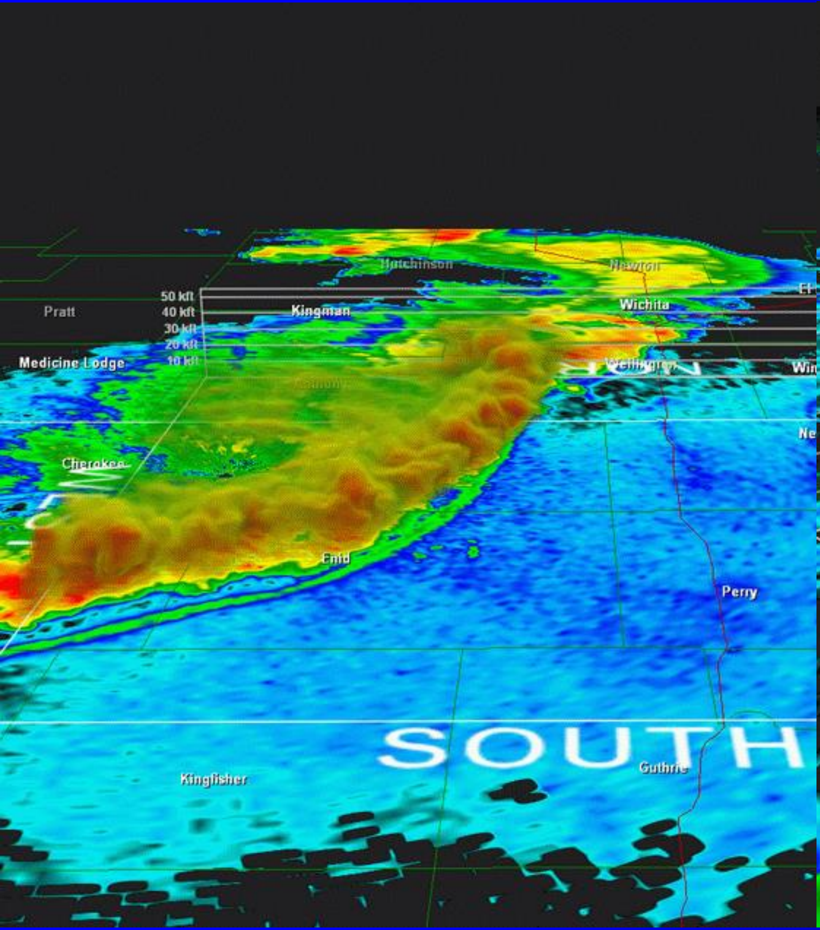


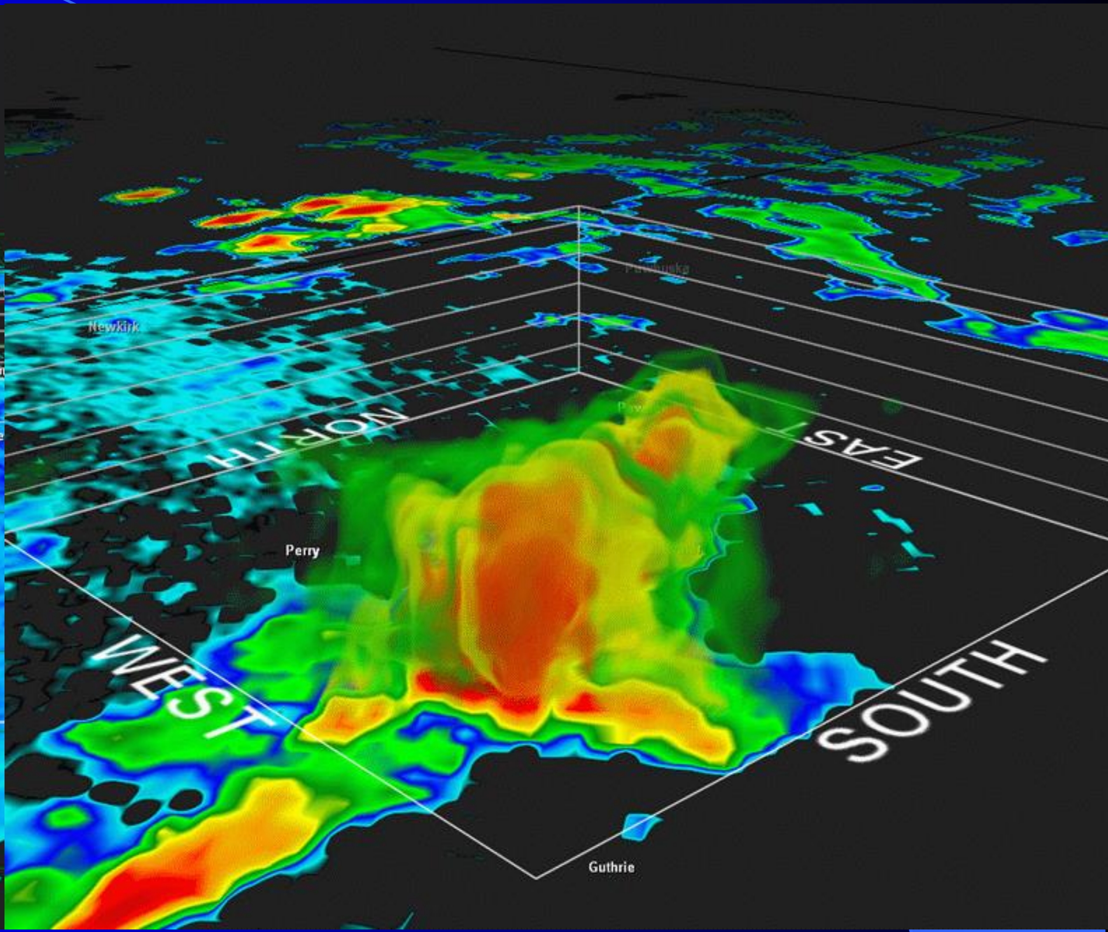
- NEXRAD data associated with the GOES-retrieved cold cloud-top temperatures (yellow color)
- However the stratiform regions (especially for cirrus anvils) (white color) were not observed by NEXRAD.

Radar Classification Example

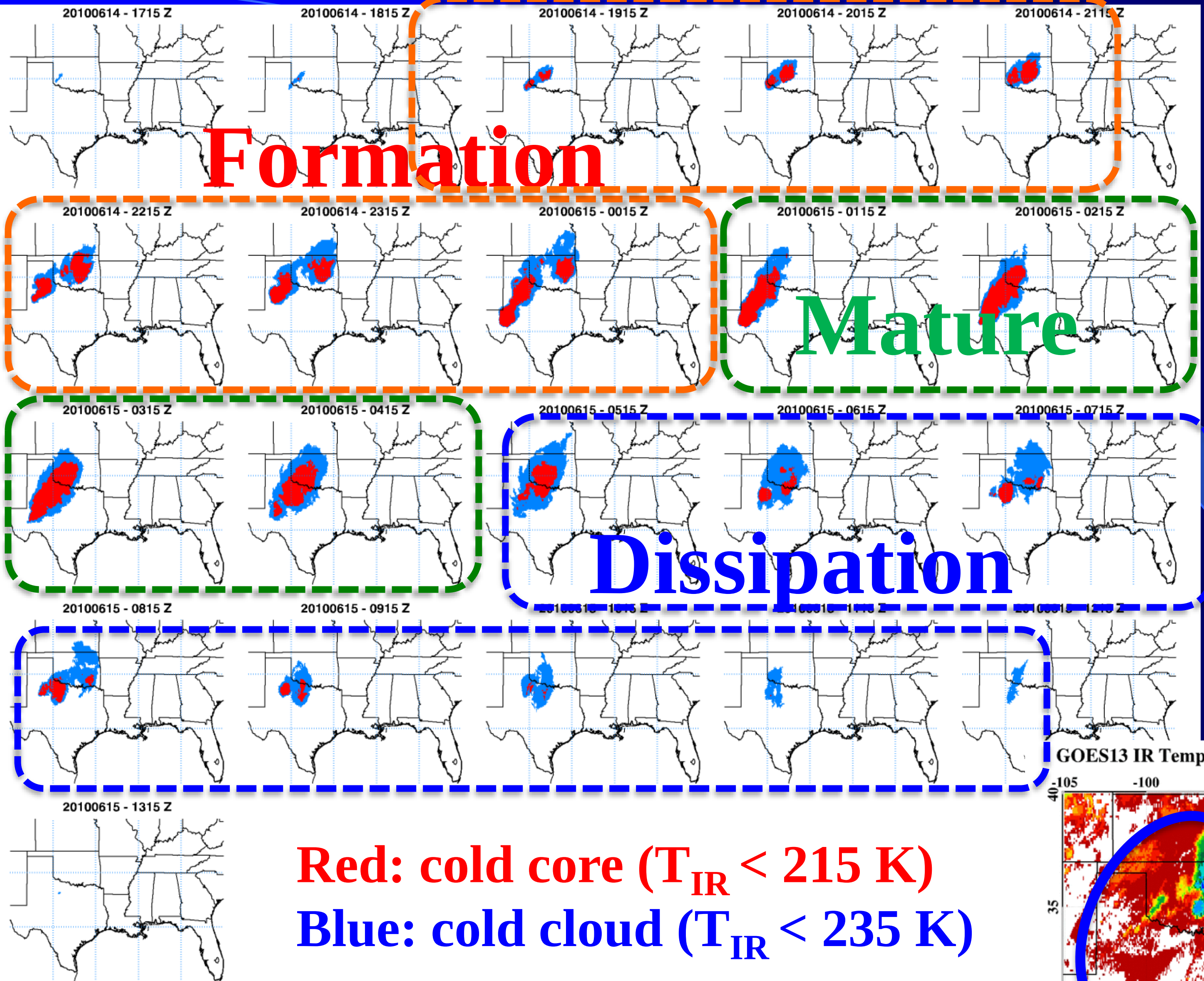


What are their 3D structures ?





This 3-D database will be used to investigate the vertical and spatial structures of a MCS.

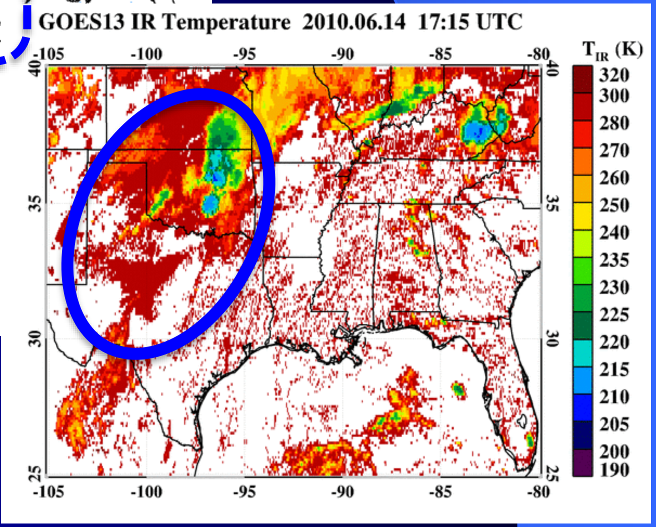


Red: cold core (T_{IR} < 215 K)

Blue: cold cloud (T_{IR} < 235 K)

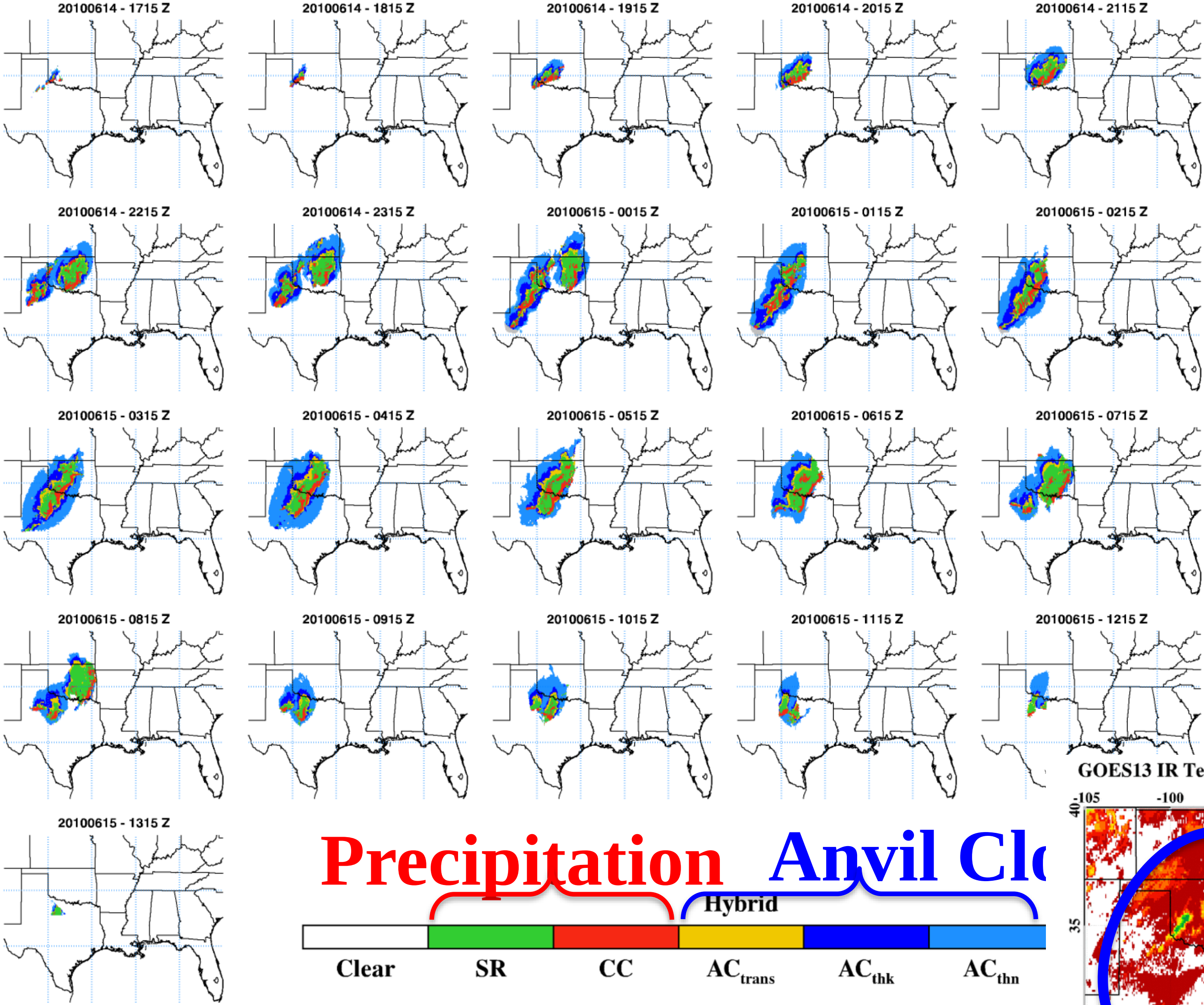
Example of one tracked system using GOES IR temp

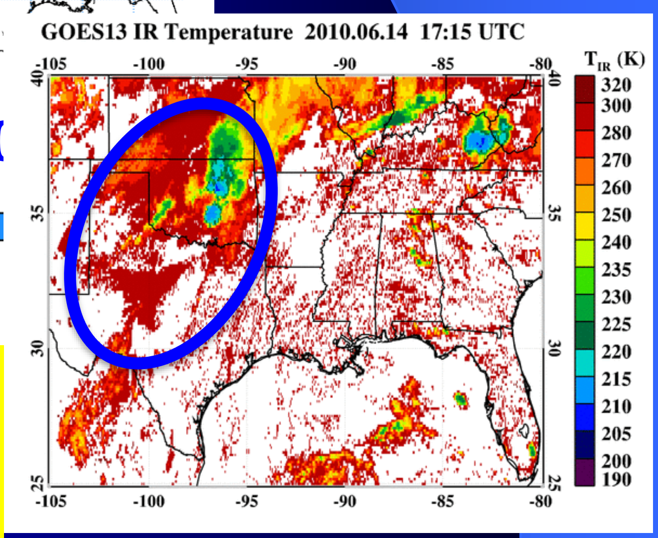
Feng et al. 2012



The formation-mature-dissipation processes of a MCS

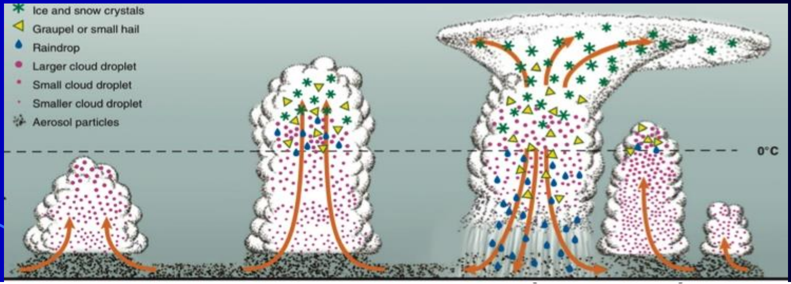
Linked tracking results with Hybrid Classification



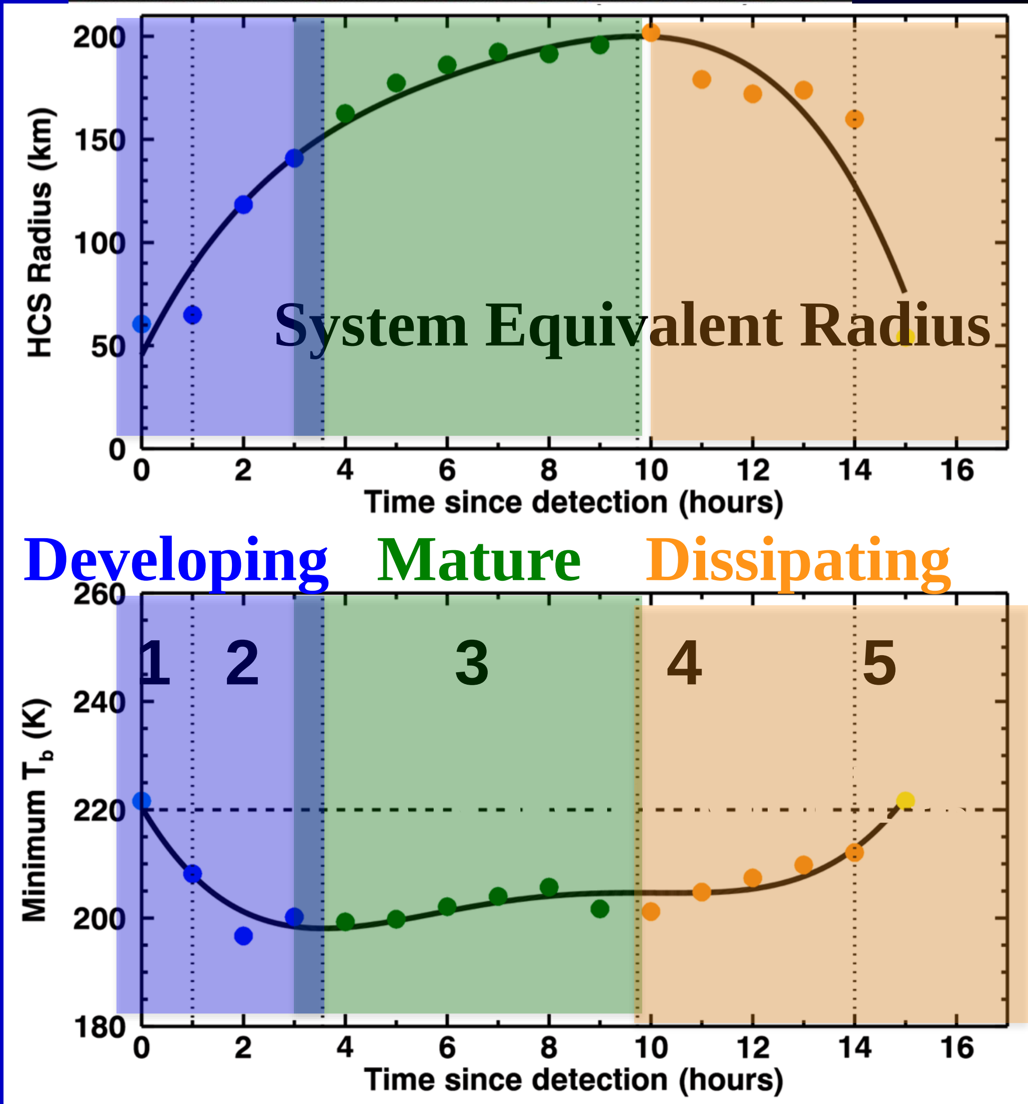


- **Derive statistics for each system using information from hybrid classification**

Define Life Cycle Stages

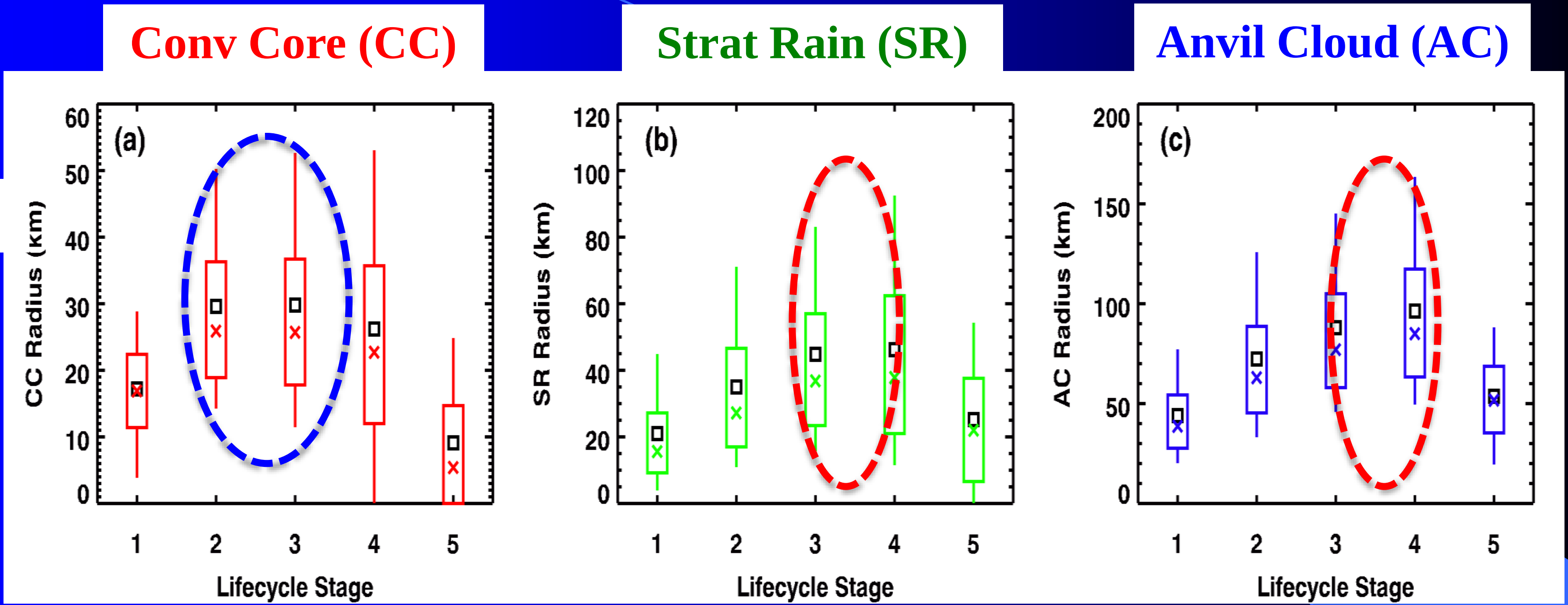


- Reason: composite systems with different lifetimes
- Based on tendency of system size and T_{IR}
- Developing (1, 2)
  - Before reaching min T_{IR}
  - Warm developing (T_{IR} > 220K)
  - Cold developing (T_{IR} < 220K)
- Mature (3)
  - Min T_{IR} < time < Max Radius
- Dissipating (4, 5)
  - Cold dissipating
  - Warm dissipating
- Group all systems based on defined stages



Definition from Futyan and Del Genio (2007)

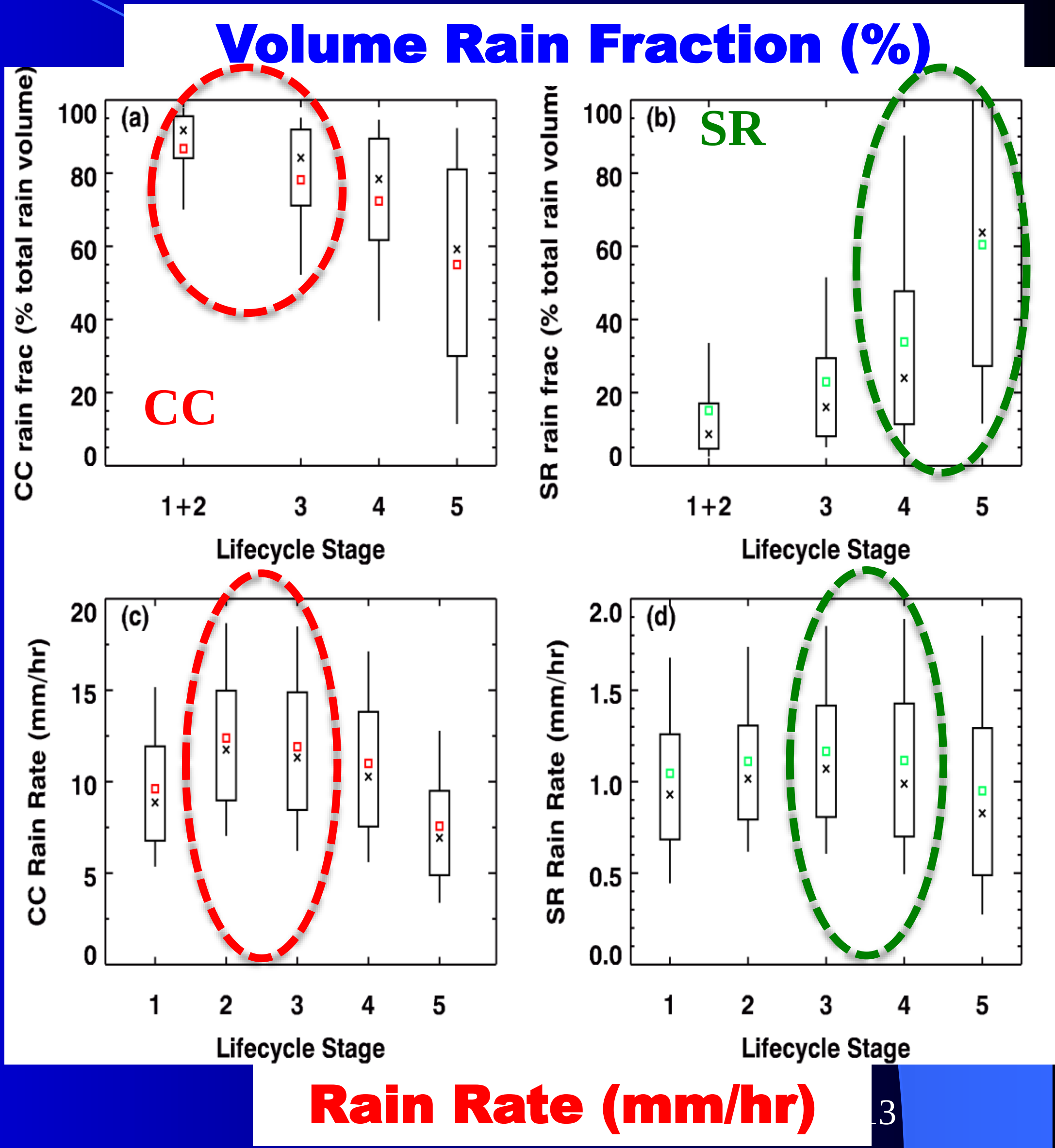
Composite by Life Cycle



- **<u>Time period</u>: May-Aug, 2010-2011 (hourly data)**
- **<u>Total number of tracked systems</u>: 3995**
- **CC expands quickly in developing stage, reach maximum between cold developing/mature stage**
- **SR/AC size have *similar tendency*: gradually grow and reach maxima at cold dissipating stage**
- **CC area: 9%, SR area: 18%, AC area:73%**

Precipitation Evolution

- **Precipitation comes almost exclusively from convective rain in developing and mature stage**
- **Stratiform rain gradually becomes more important as system dissipates**
- **CC/SR rain rate evolution similar to sizes**
- PR_{CC} **is 10 ×** PR_{SR}



Part IA: Summary

1) Developed a method to classify the MCS's components (CC, SR, and AC) and then investigate their cloud and precipitation properties.

2) Developed a tracking method to track the MCS's lifetime and to investigate the MCS's formation-dissipation processes, as well as their precipitation properties, such as

→MCS component sizes increase with lifetime

→CC area: 9%, SR area: 18%, AC area: 73%

→PR_{CC} is 10× PR_{SR}

Part IB.

Evaluation of NSSL WRF simulated precipitation using Stage IV dataset

Wang et al. 2018 MWR

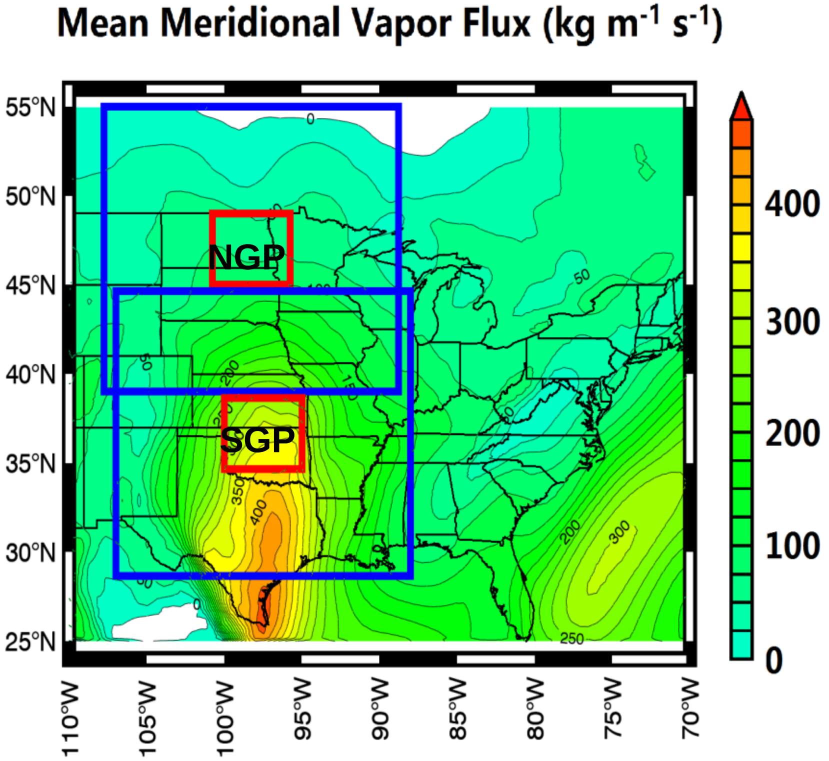
Objectives

To evaluate the NSSL-WRF simulated heavy precipitation by

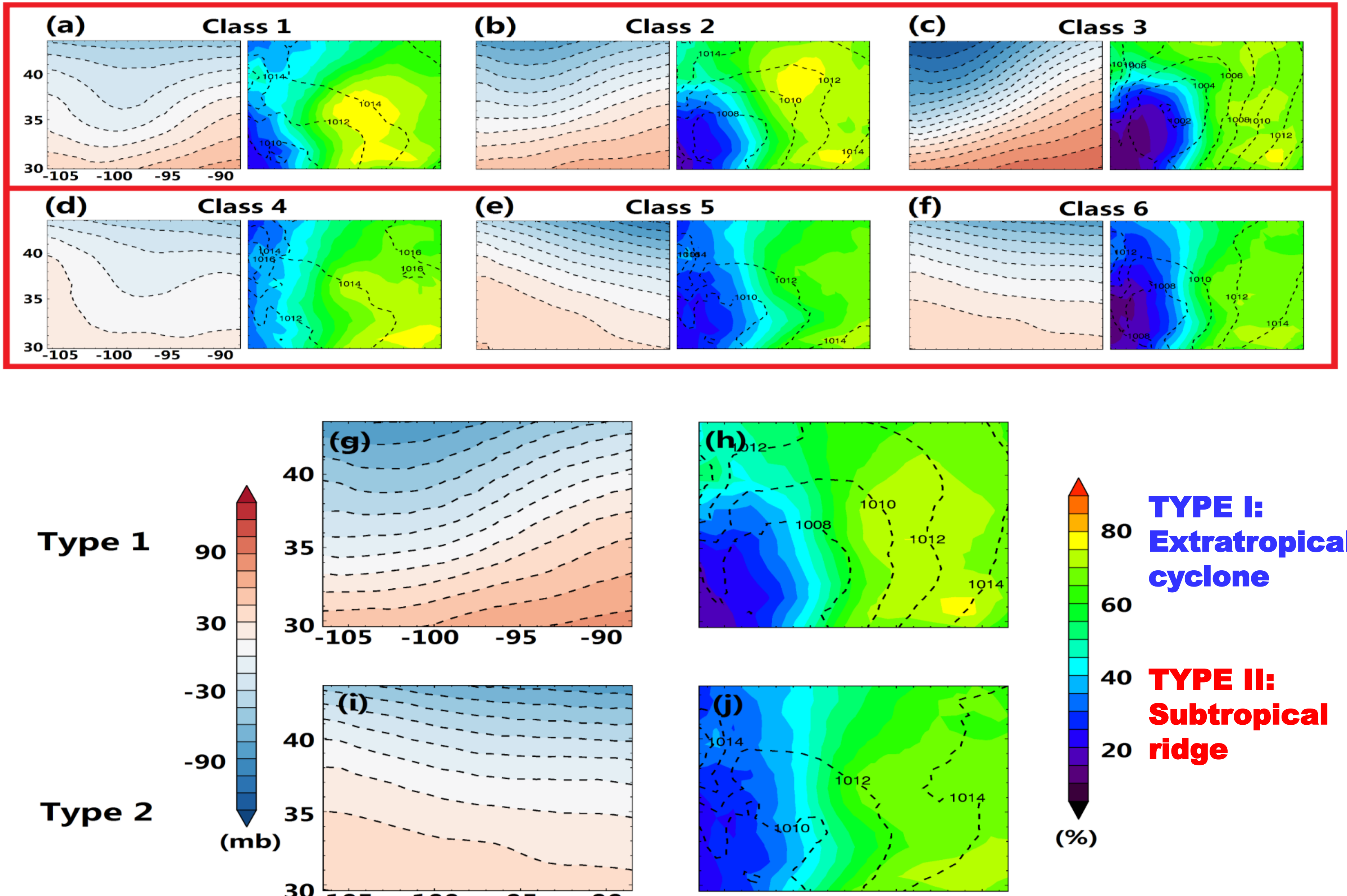
- **Regions: (SGP vs. NGP)**
- **Primary precipitation type: (convective rain CR vs. stratiform rain SR)**
- **Dominant atmospheric synoptic pattern: (extratropical cyclone vs. subtropical ridge).**

Specifications of Evaluation

- **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

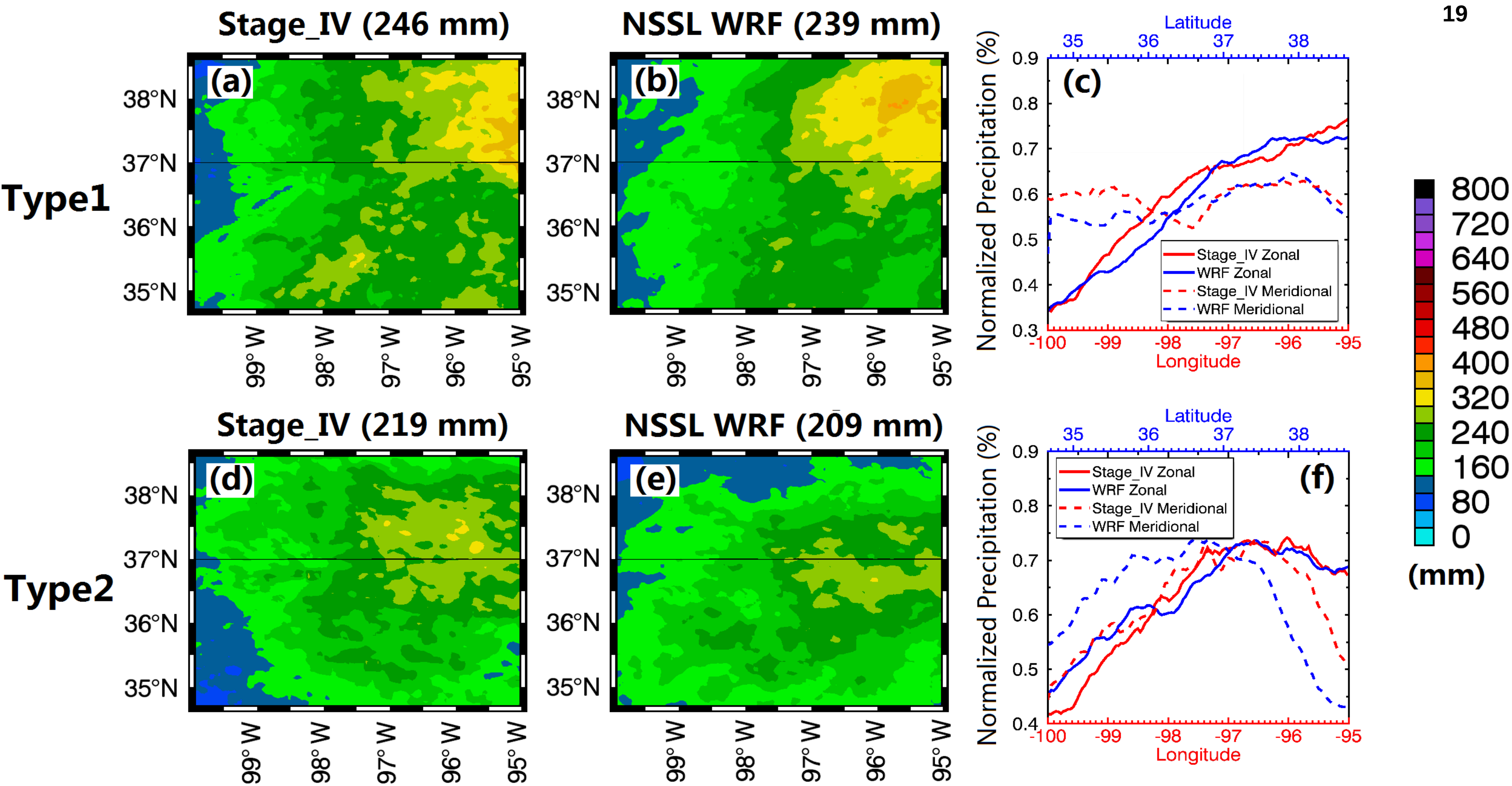


Self-Organizing Map Method (SOM) Results at SGP



WRF Evaluation (SGP)

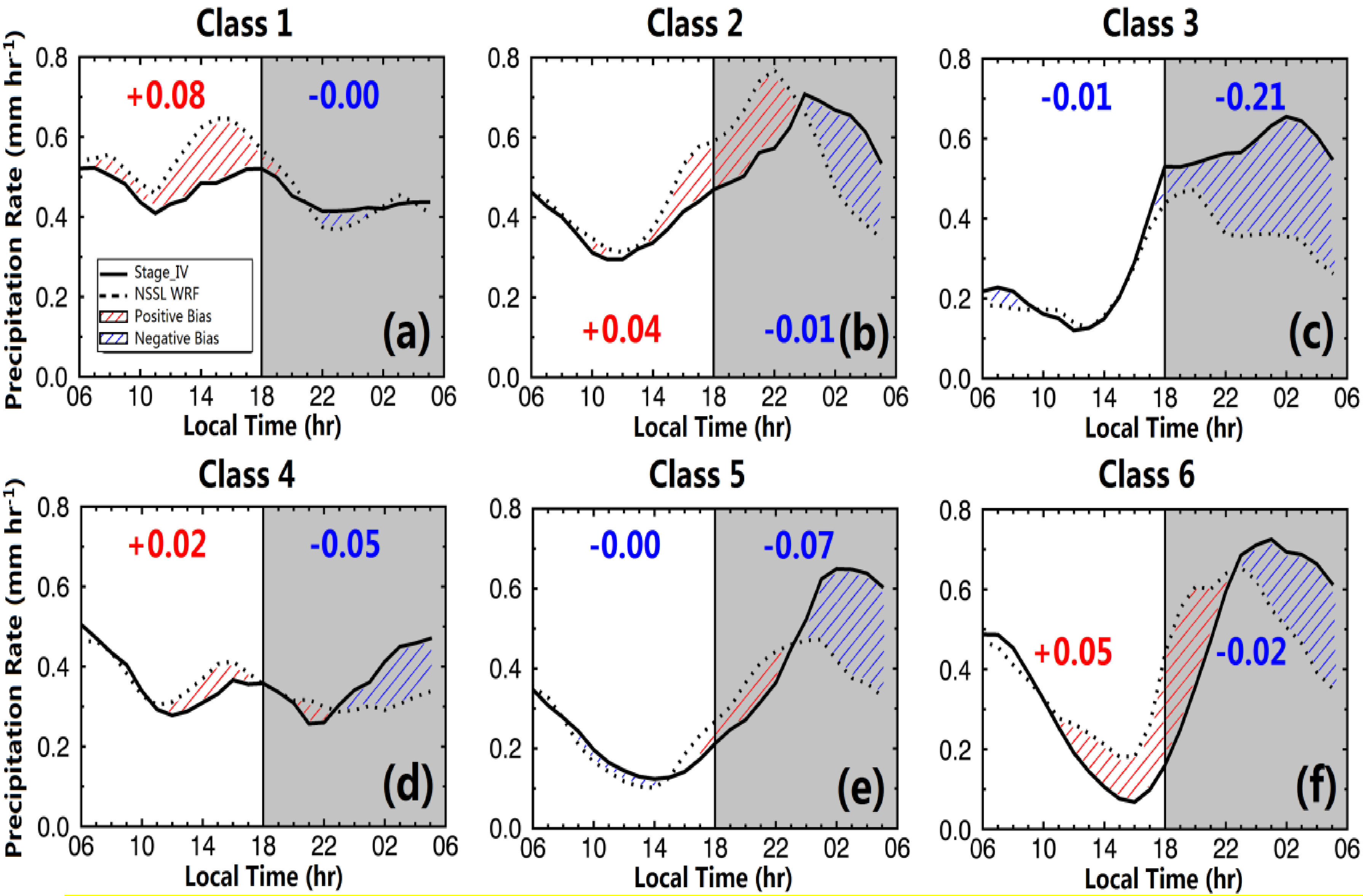
SGP Warm Season Annual Precipitation and Directional Variation



- **Total precipitation: Type 1 > Type2**
- **Spatial pattern: Type 1 zonal gradient (west-East);**
- **Type 2 meridional gradient (North-South)**
- **WRF: Negative bias; Type 1 better than Type 2**

WRF Evaluation by Class (SGP)

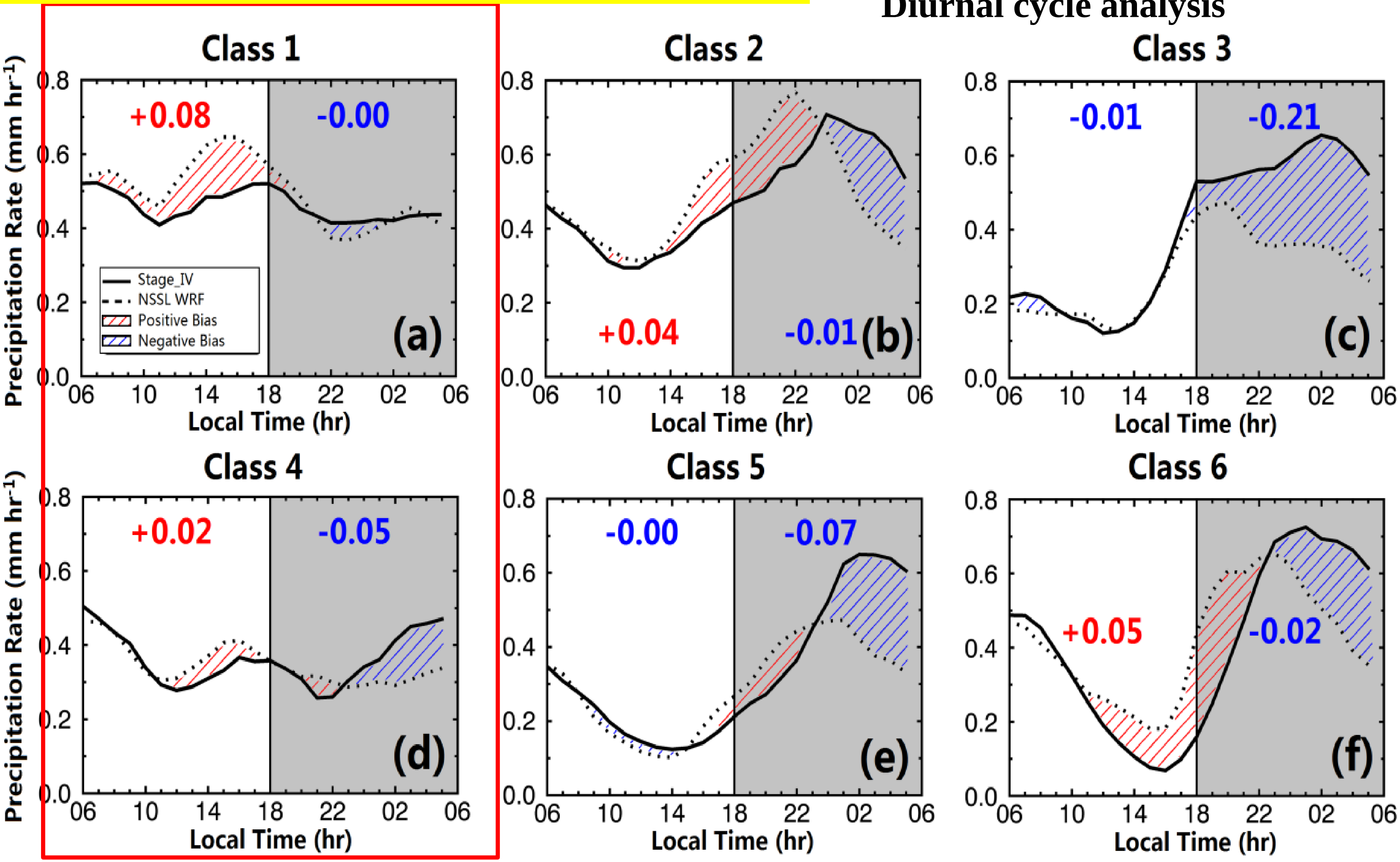
Diurnal cycle analysis



From left to right, diurnal variation becomes stronger

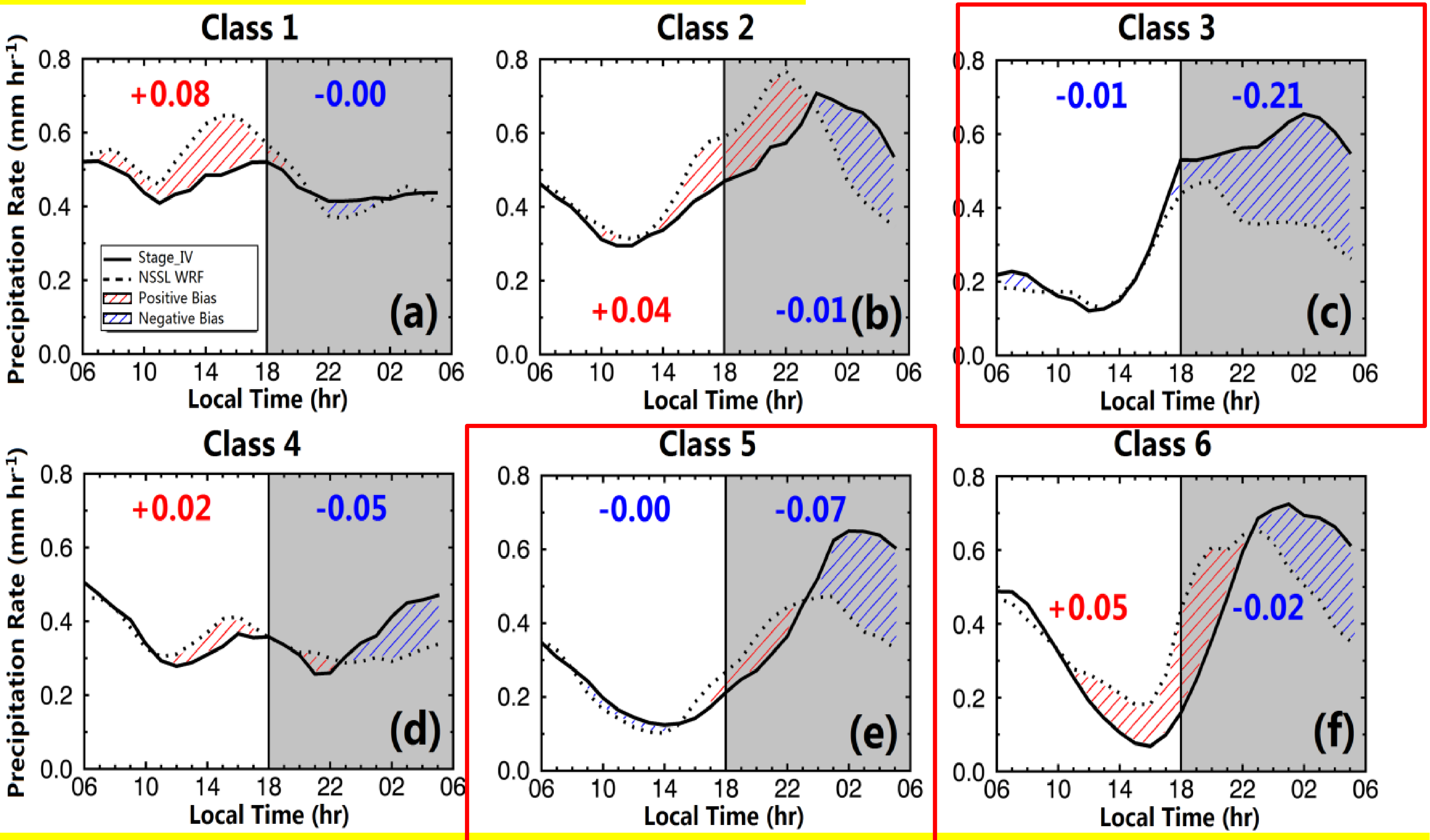
WRF Evaluation by Class (SGP)

Diurnal cycle analysis



Classes 1 and 4:
(1) Flat diurnal variation (SR); (2) Bi-modal pattern; (3) WRF well simulates

WRF Evaluation by Class (SGP)

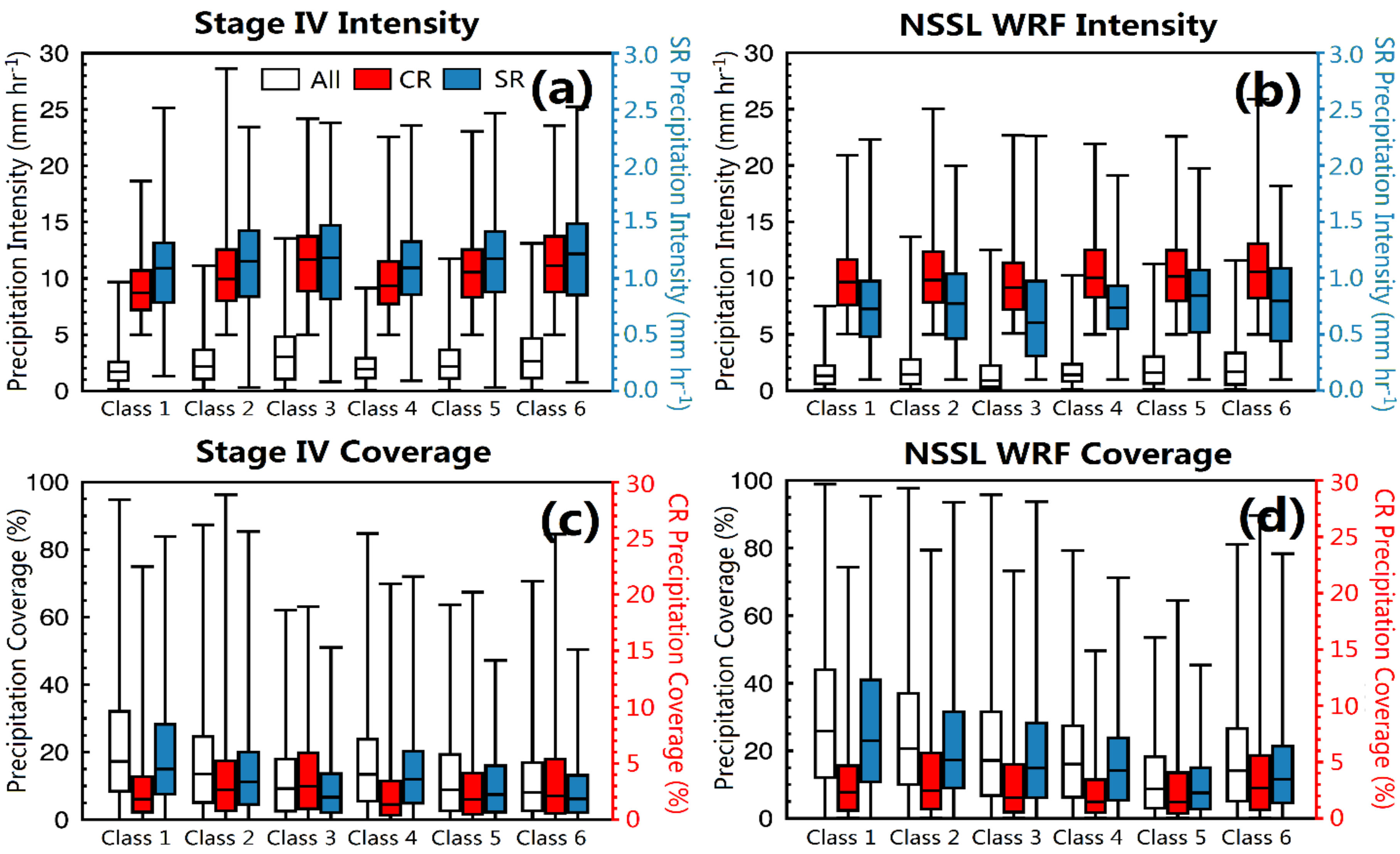


Classes 3 and 5:

(1)The largest diurnal variation, (2) Follows the typical pattern, (3) Daytime WRF well matches, (4) Nighttime WRF severely undersimulates, and (5)Simulated convection ends too soon

WRF Evaluation by Class (SGP)

SR vs. CR Components



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

CR intensity/coverage is better simulated than SR

Summary of Part IB

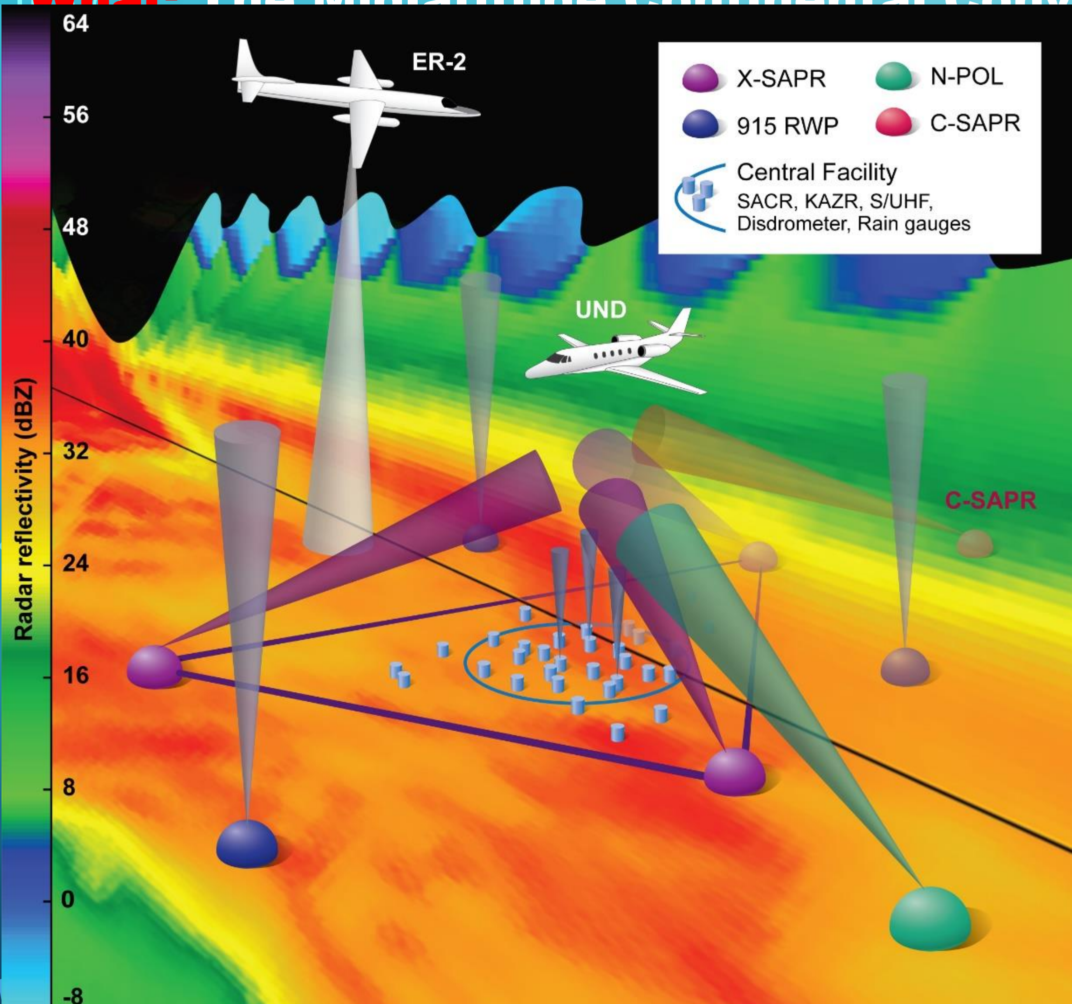
- **SOM works well for the separation of synoptic patterns (extratropical vs. subtropical) and the dominant precipitation types (SR vs. CR)**
- **WRF better matches in overall CR intensity/coverage than SR**
- **Better simulation in extratropical cyclone than subtropical ridge**

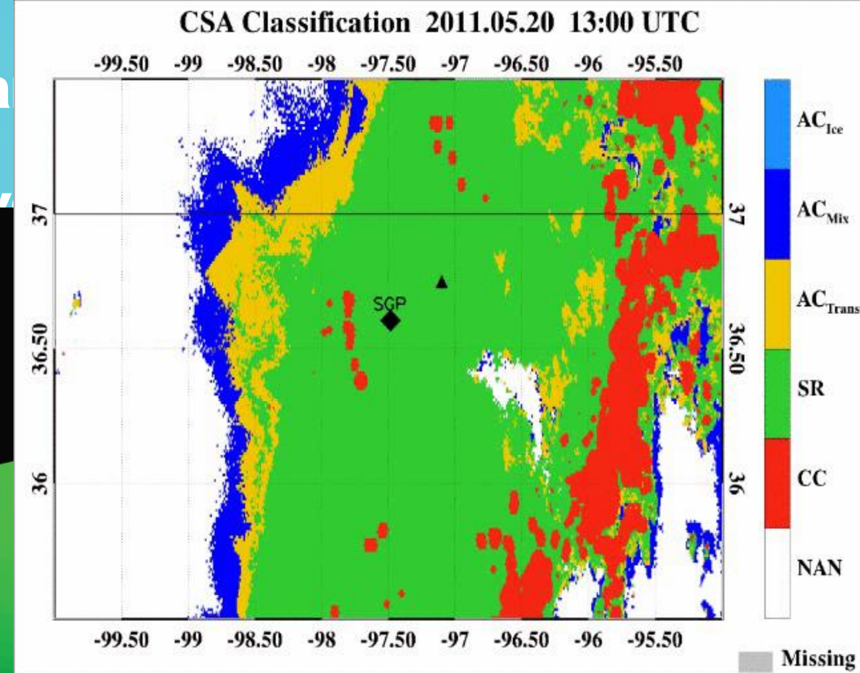
Part IC: Aircraft in-situ measurement and surface retrievals during MC3E

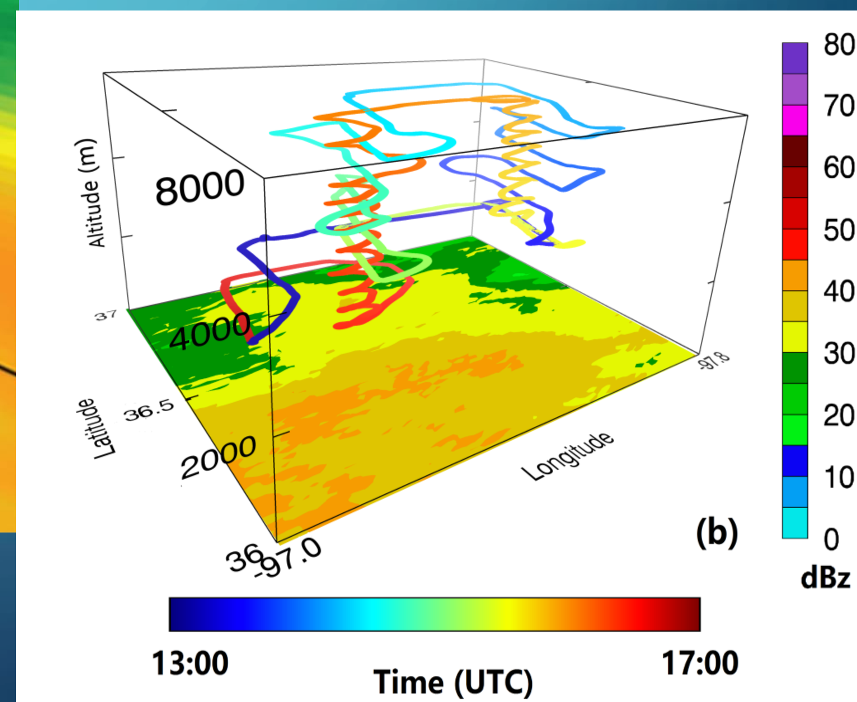
- **Wang et al. (2015) and Tian et al. (2016)**

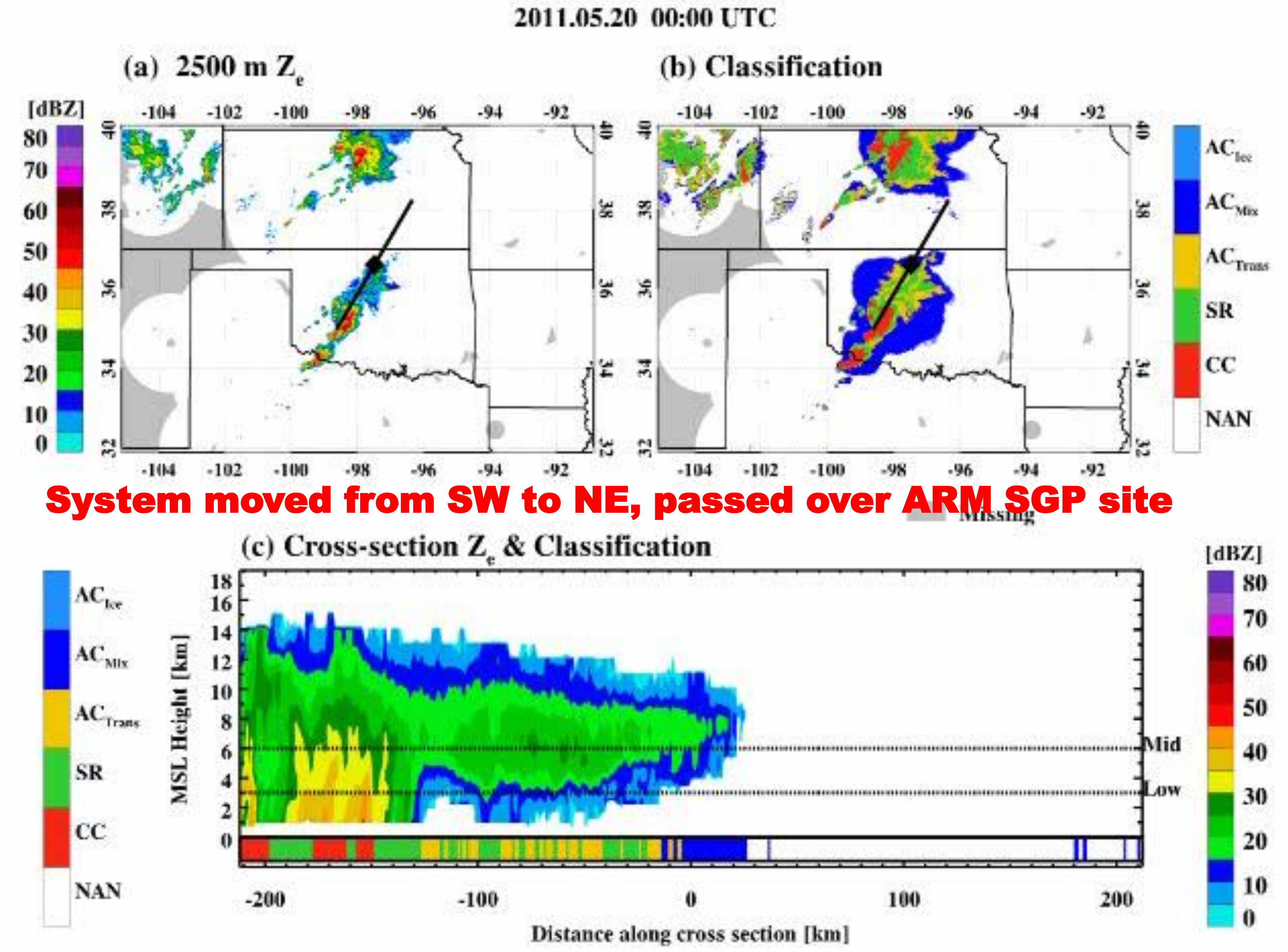
0. Introduction of field campaign a

What: The Midlatitude Continental Conv







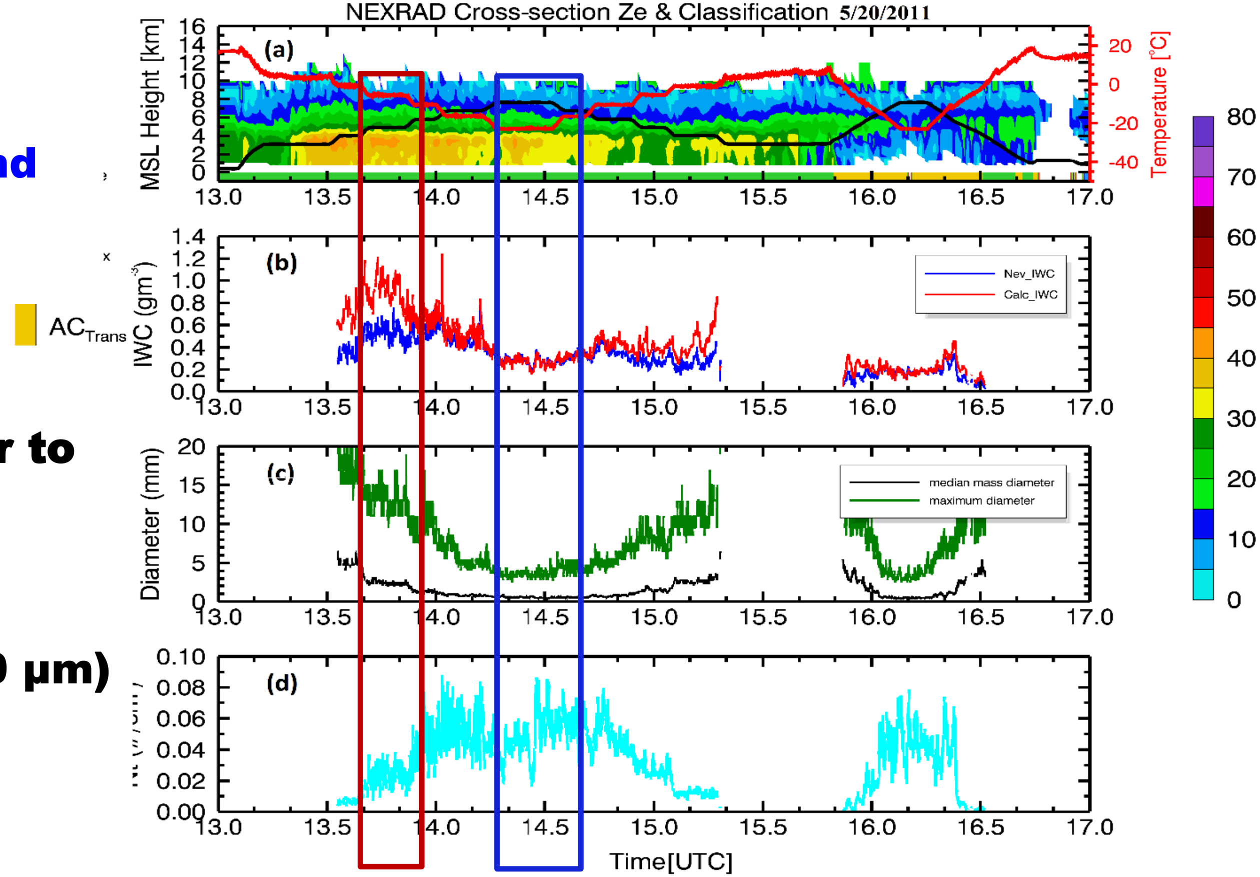


System moved from SW to NE, passed over ARM SGP site

How can we provide reliable ice cloud properties of DCS from aircraft in situ data?

Outstanding Issue:

Nevzorov probe measured IWCs are lower than ground truth because it can only measure D_{max}< 4 mm.



Approach

Step 1: **Using multi-sensor to eliminate SLWC**

Step2: **Constructed a full spectrum of PSDs from 2DC+HVPS (D=120–30,000 µm)**

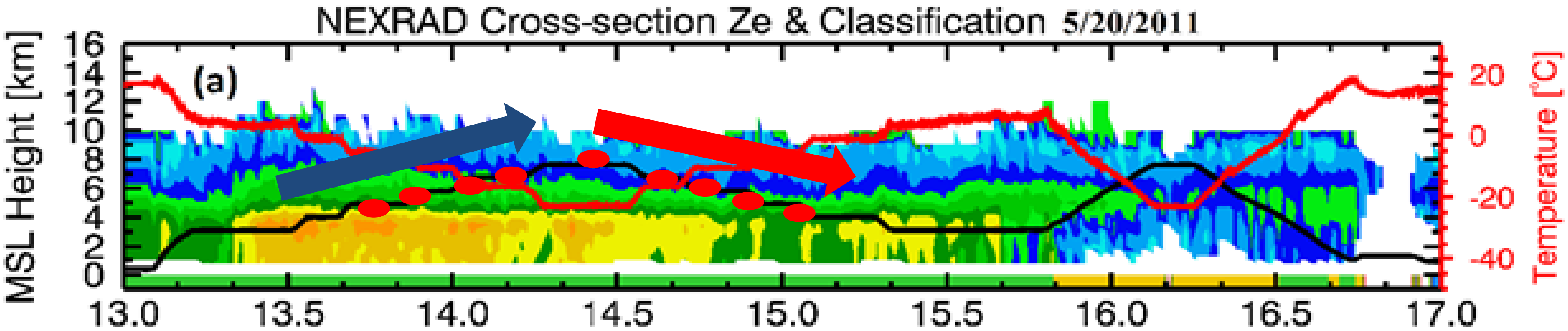
Step3: **Build a new mass-dimension relation $IWC_{NEV}(D_{max}<4\ mm) \sim 0.00365D^{2.1}$**

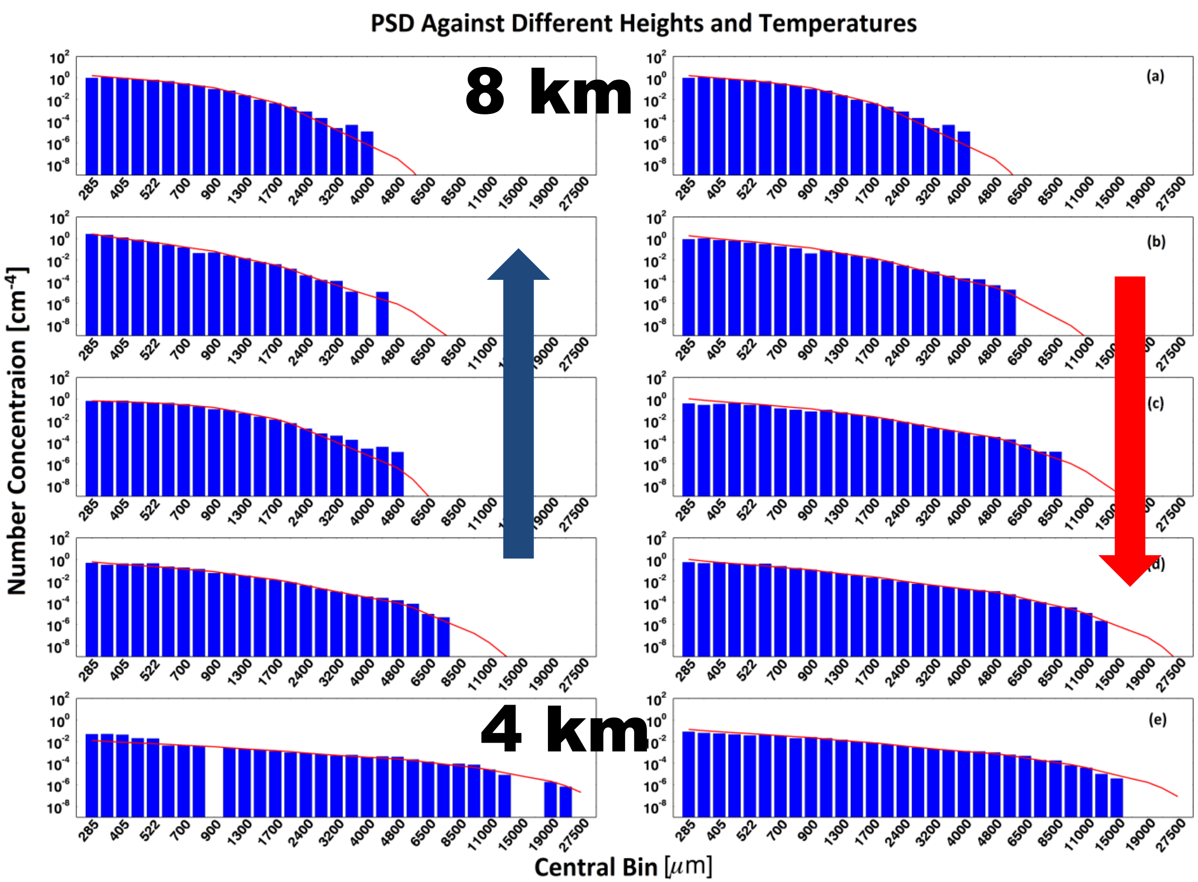
Step 4: **Applying this relationship to a full spectrum of PSDs to calculate IWCs (best-estimated)**

Cloud Top (14:30 UTC) : D_{max}<4 mm, the Nevzorov-measured IWCs are almost the same as the best-estimated IWCs.

Near Melting band (13:45 UTC): D_{max}>4 mm, Nevzorov IWCs << best-estimated IWCs

Constructed a full spectrum of PSDs from 2DC+HVPS and derived Gama-Distribution





1. **Maximum Ds decrease from 27,500 μm to 4,000 μm, whereas Nt increase 100 times when aircraft ascended from 4 to 8 km**

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

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

Retrieve Ice Microphysical Properties

Using empirical relationships from aircraft (Wang et al., 2015), we can estimate the ice water content using radar reflectivity.

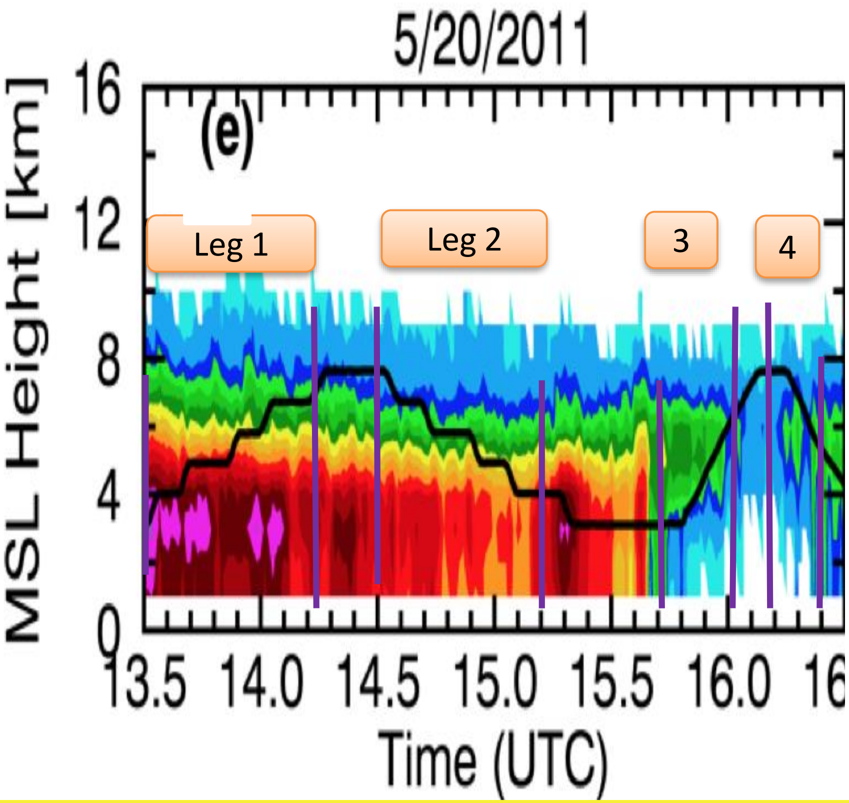
$$\frac{Z_e}{\mathrm{IWC}} = \frac{\frac{|K_i|^2}{|K_w|^2}\left(\frac{6}{\rho_i \pi}\right)^2 \int_{D_{\min}}^{D_{\max}} m(D)^2 D^{\mu} e^{-\lambda D}\, dD}{\int_{D_{\min}}^{D_{\max}} m(D) D^{\mu} e^{-\lambda D} dD}$$

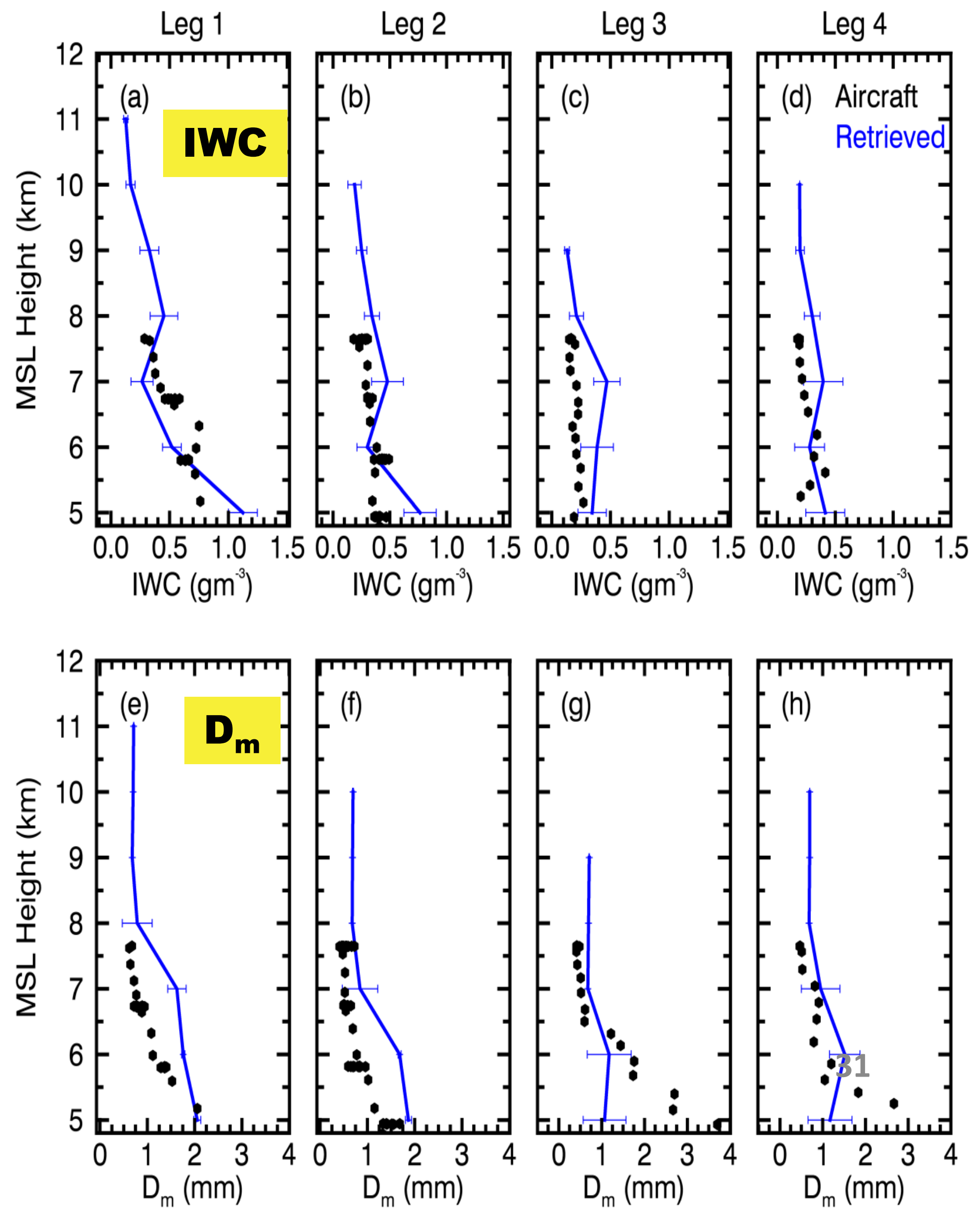
$$N(D) = N_0 D^{\mu} e^{-\lambda D}$$

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

$$m(D) = 3.65 \times 10^{-3}\ \mathrm{g\,cm}^{-2.1}\, D^{2.1}$$

Validating NEXRAD retrieved IWCs using aircraft in situ measurements





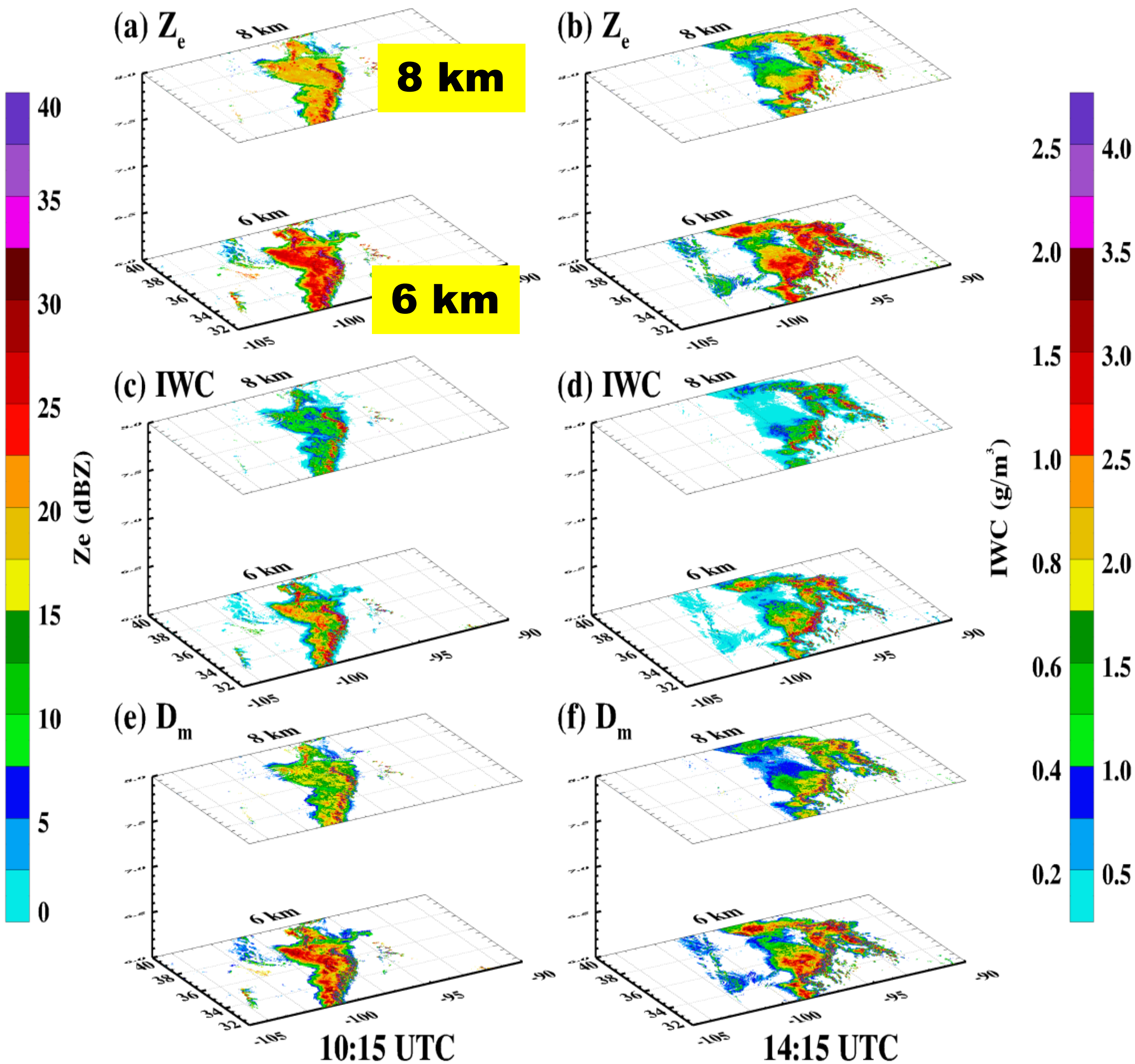
- **Both IWC and D_m decrease with height**

- Statistical comparison during MC3E

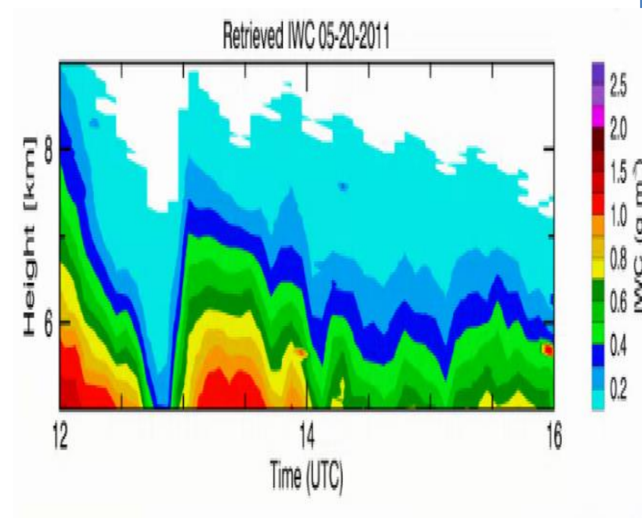
	Aircraft	Retrievals
IWC	**0.47 gm^{-3}**	**0.63 (+34%)**
D_m	**2.02 mm**	**1.63 mm (-19%)**

4D (Space+Time) NEXRAD Reflectivity and IWC and Dm Retrievals

10:15 UTC **14:15 UTC**

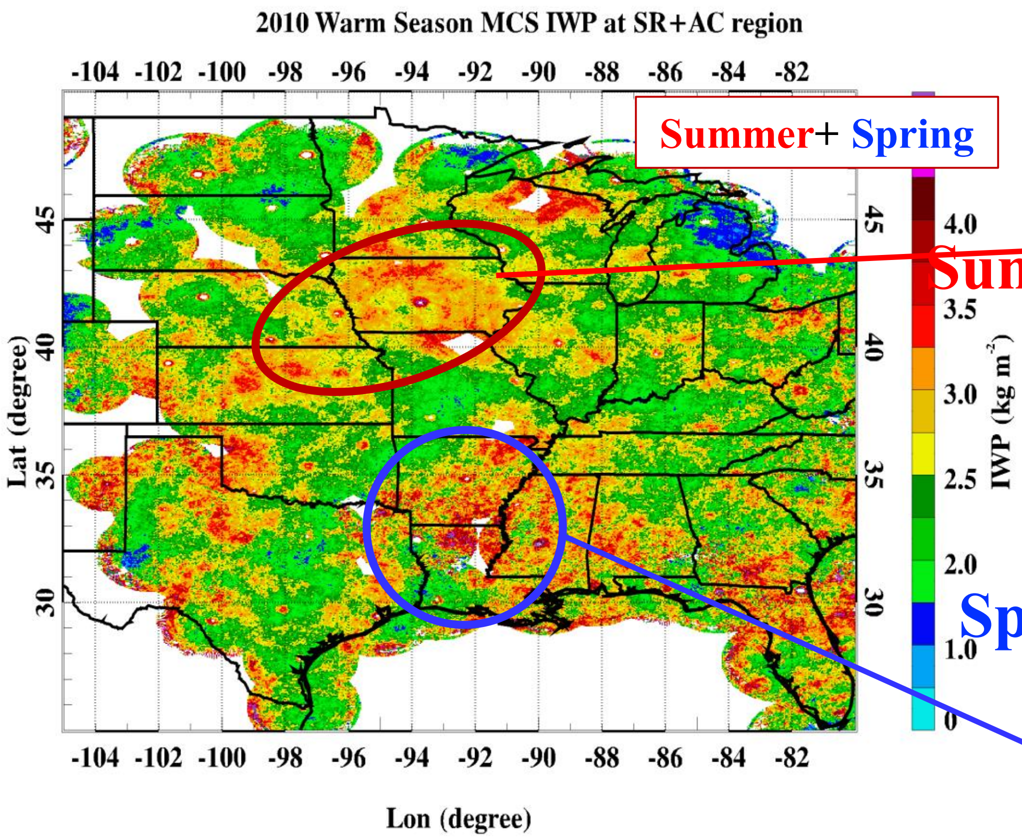


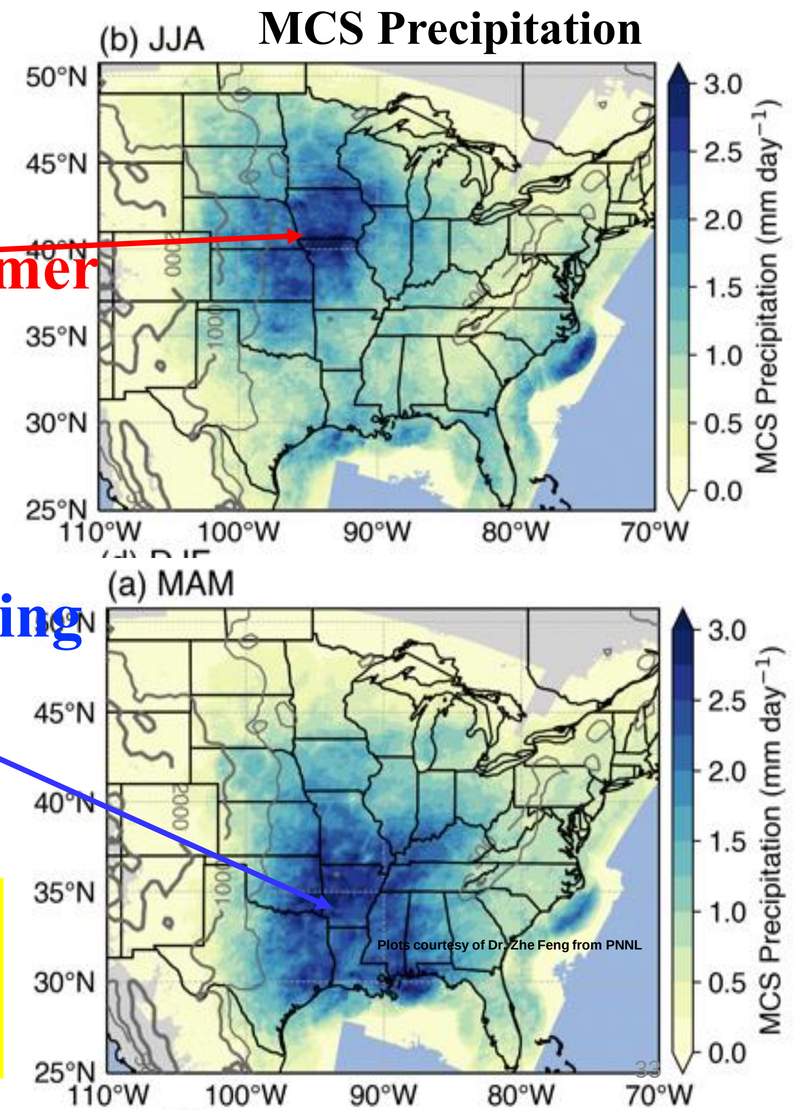
Vertical Distributions of Retrieved IWC at ARM SGP site



Statistical analysis of warm season MCs ice cloud microphysical properties

Do IWPs have similar spatial distributions as precipitation?



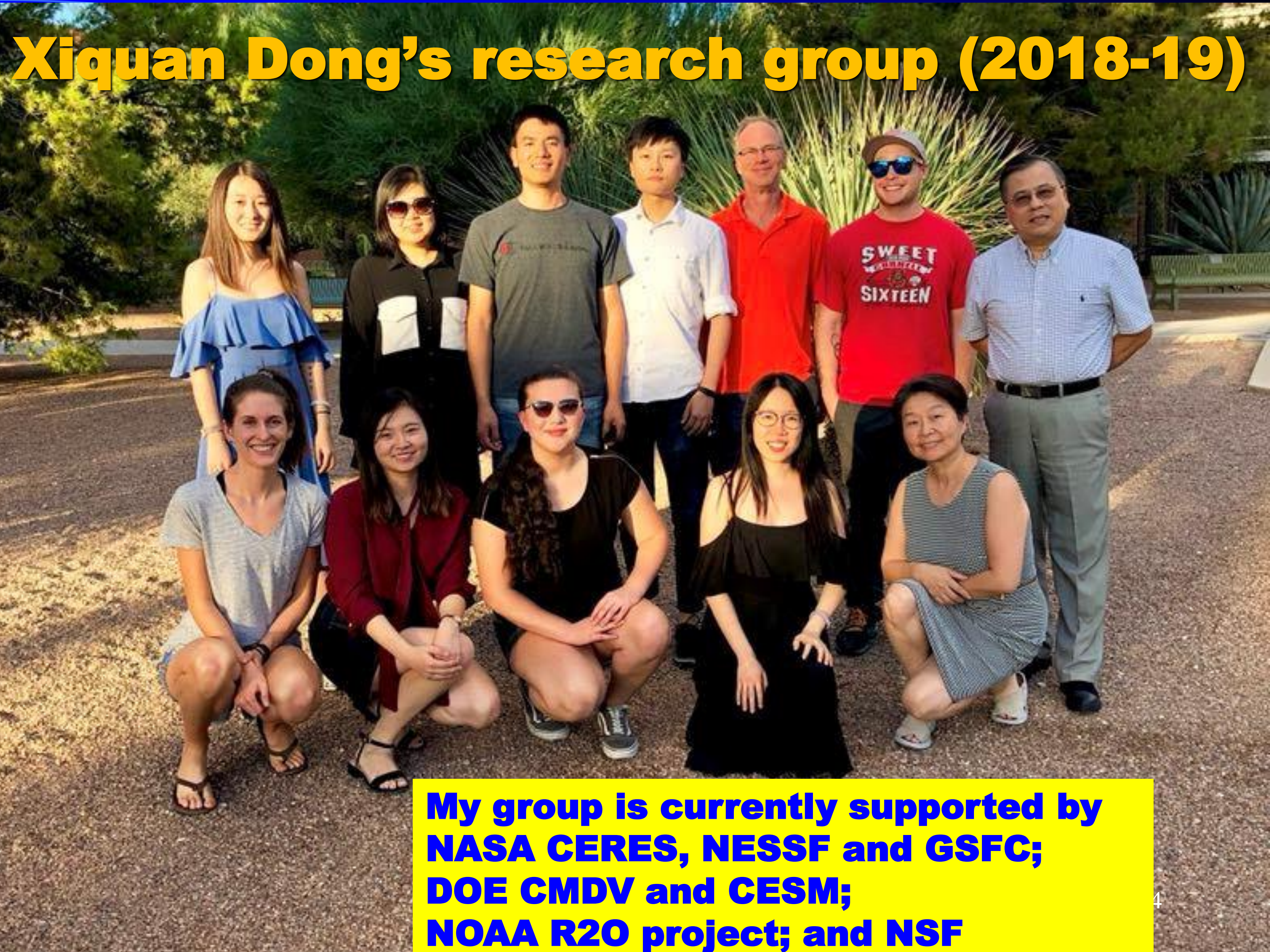


IWPs indeed have similar spatial distributions as precipitation:

Summer : More IWPs and Precipitation over NGP

Spring : More IWPs and precipitation over SGP

Xiquan Dong's research group (2018-19)



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