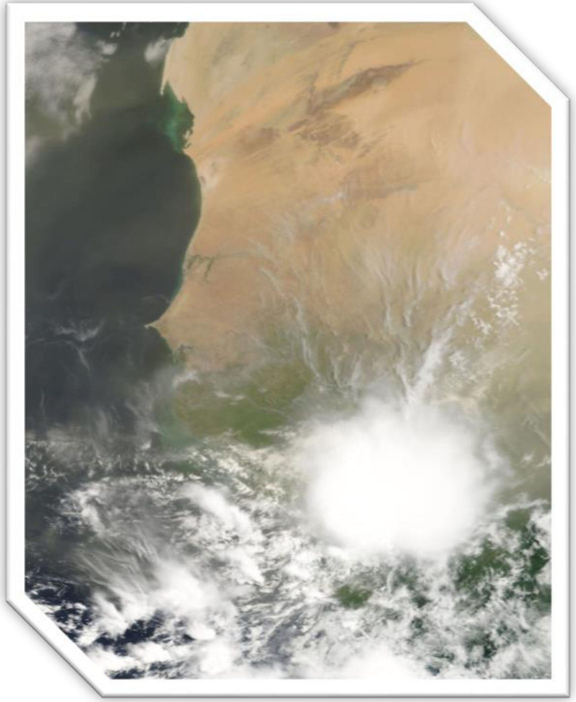

Meteorology And Climate – Modeling for Air Quality (MAC-MAQ) Conference

The Comparison of Dust-Radiation versus Dust-Cloud Interactions on the Development of a Simulated Mesoscale Convective System over North Africa

2019.9.12

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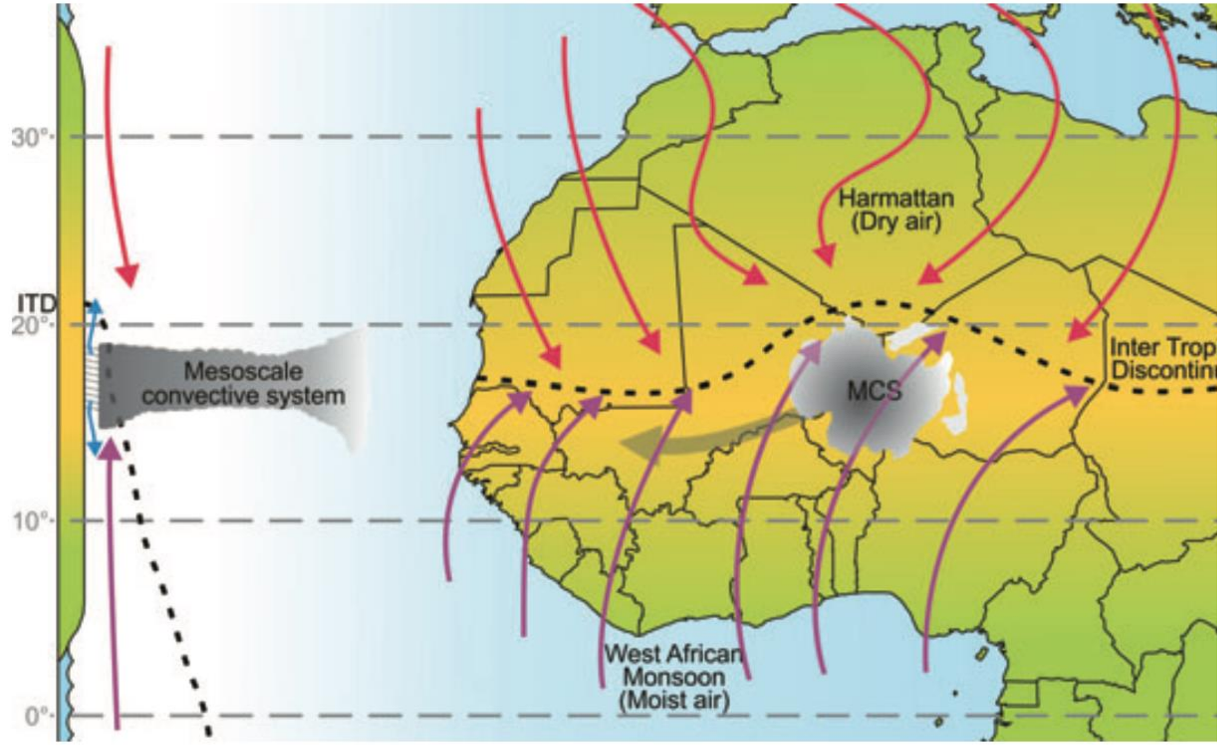
Supported by NASA CloudSat and CALIPSO Science Team Program (NNX16AP17G)

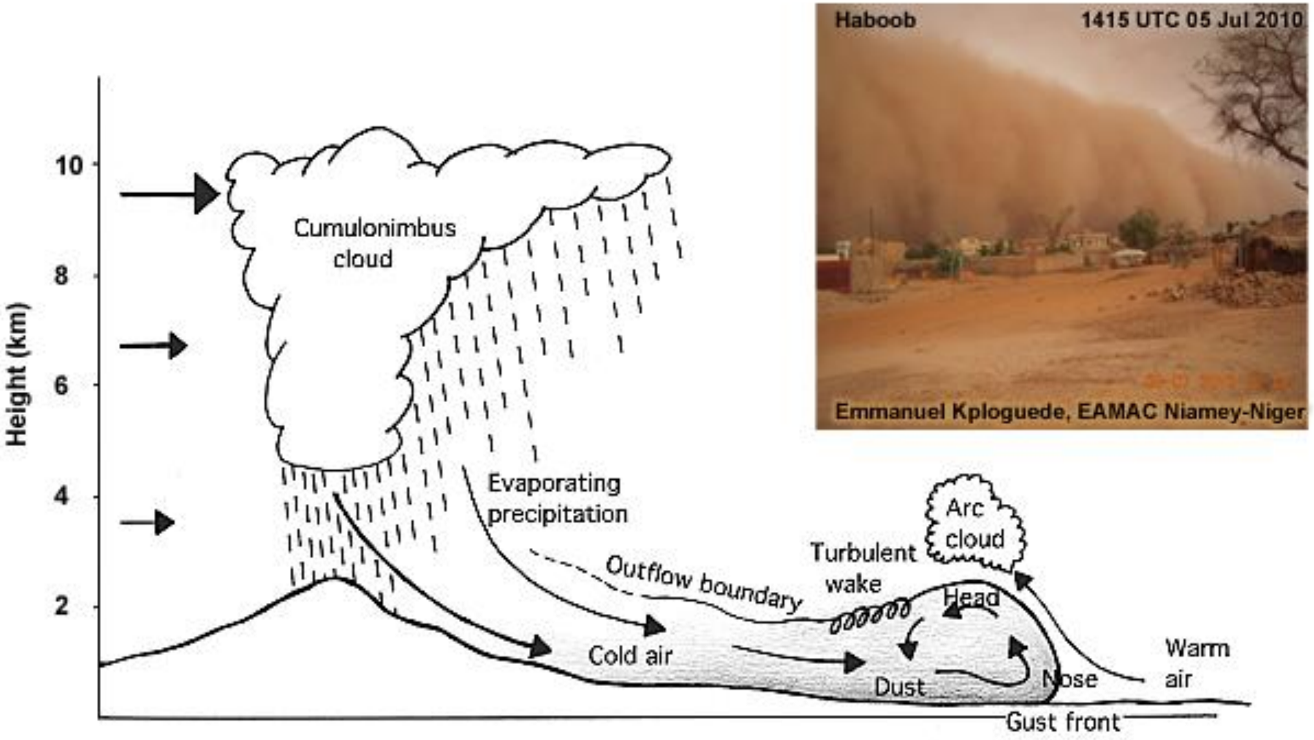
Introduction

High likelihood for interaction between an MCS and a massive dust plume



(Roberts and Knippertz, 2012)

Haboob



(Knippertz et al. 2007)

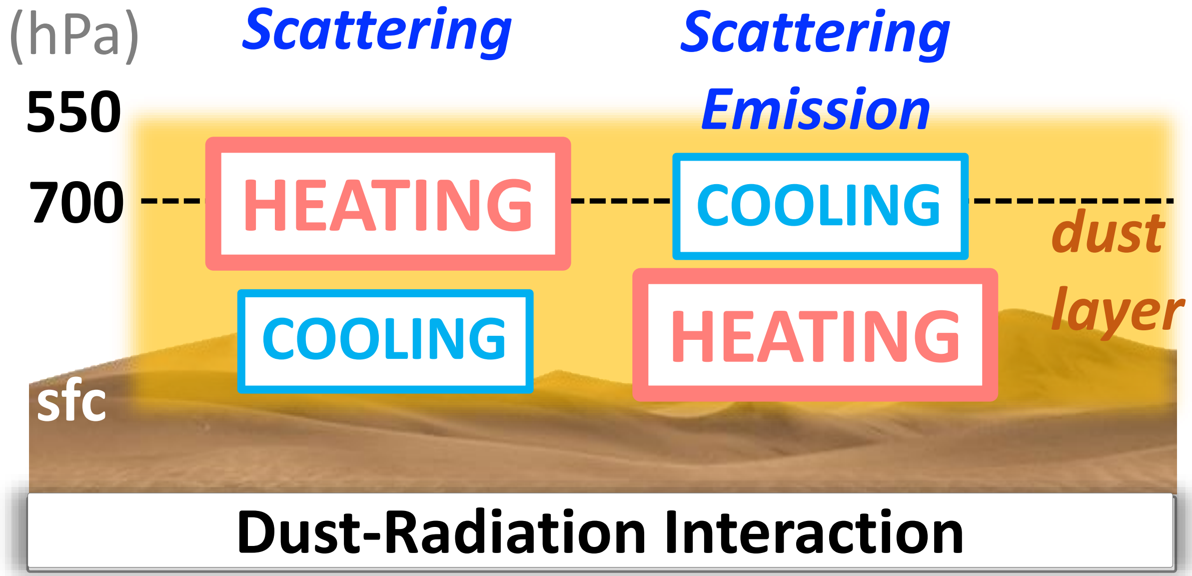
Cold air generated by westward-propagating MCSs reaches the arid desert and produces haboob.

Introduction

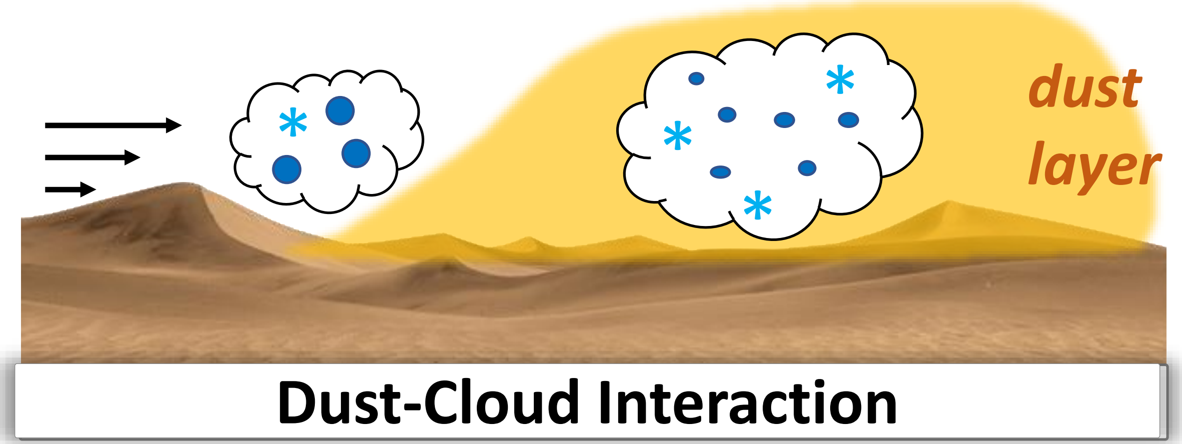
What is the relative importance and impacts of dust-radiation and dust-cloud effects on MCS development over North Africa?

SW
Absorption
Scattering

LW
Absorption
Scattering
Emission



Increase IN/CCN
cloud micro- and macro- structure
lifetime and precipitation



Instability

$$\sigma = \frac{g}{\theta}\frac{d\theta}{dz}$$

Thermal wind relation

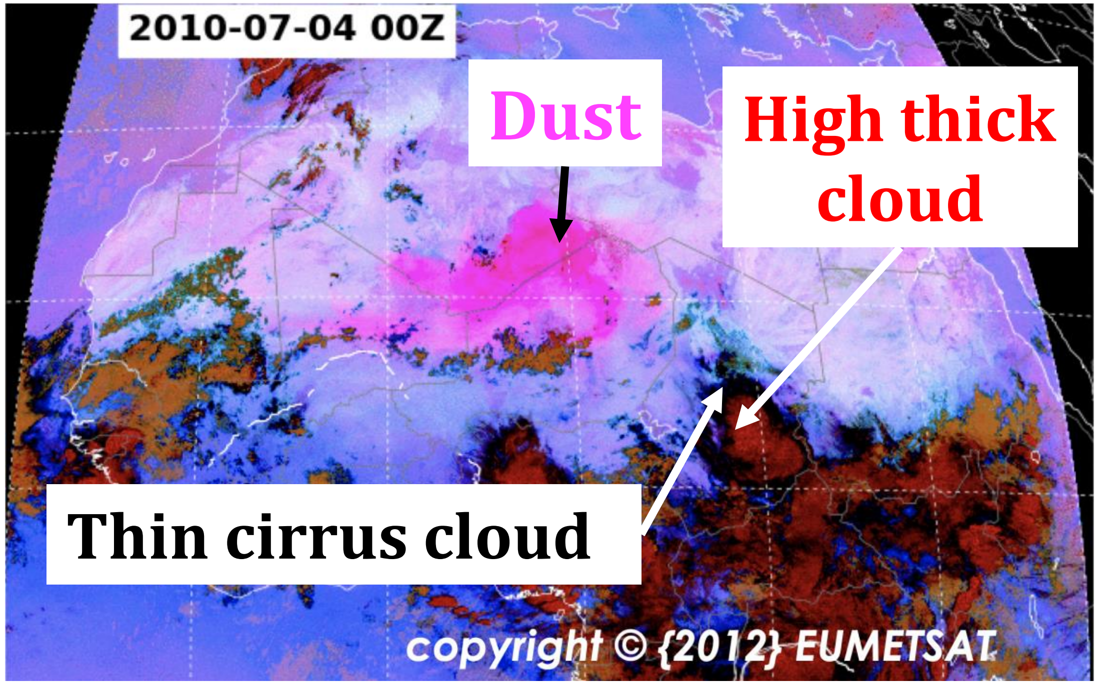
$$\vec{V}_T = \frac{R}{f}\hat{k}\times\nabla\bar{T}\, ln\frac{p_L}{p_U}$$

Convective invigoration

Cloud-radiation interaction

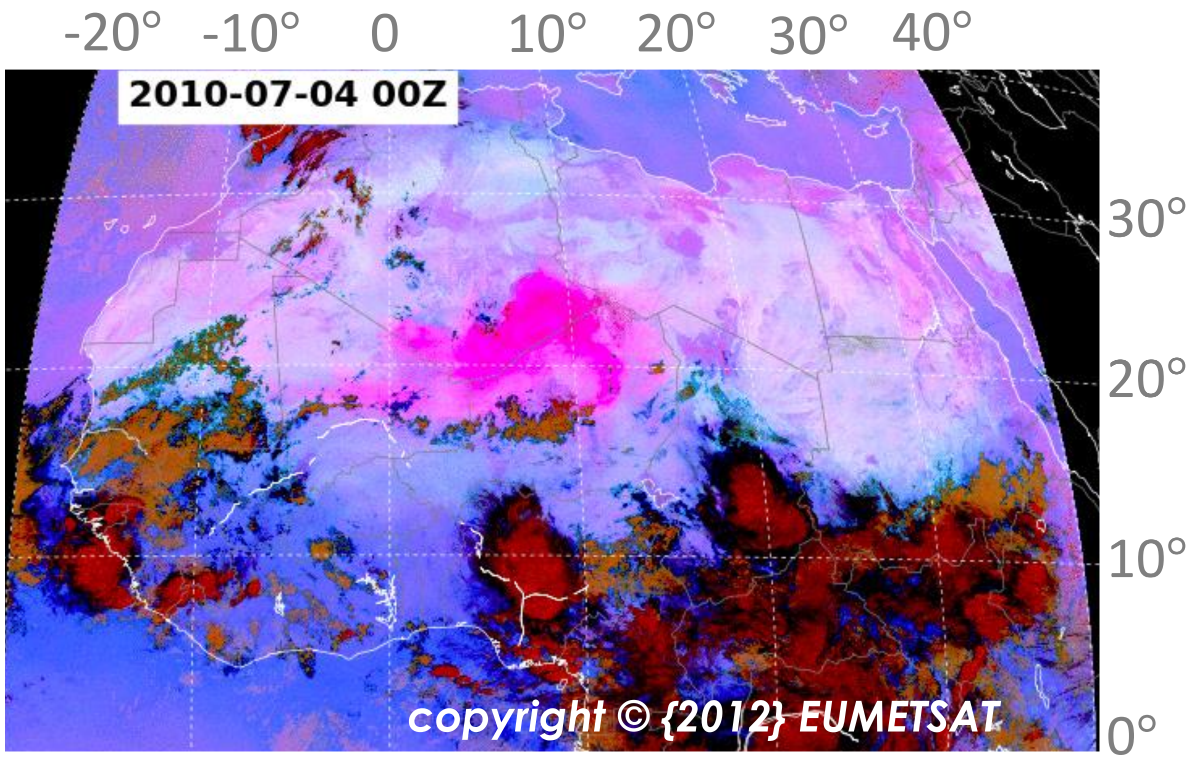
A MCS case

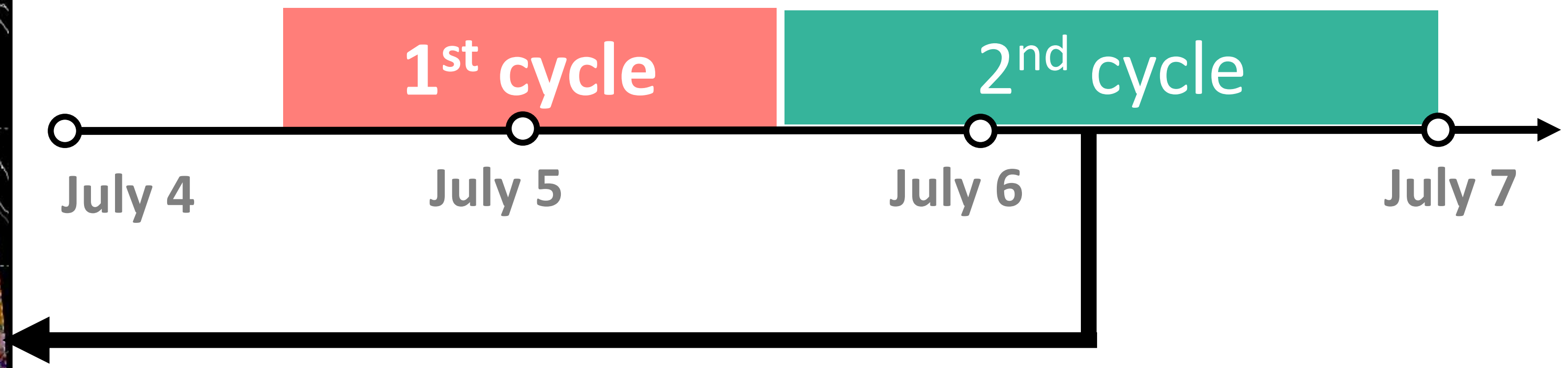
- An MCS over North Africa: 04-07 July 2010
- Two convective cycles

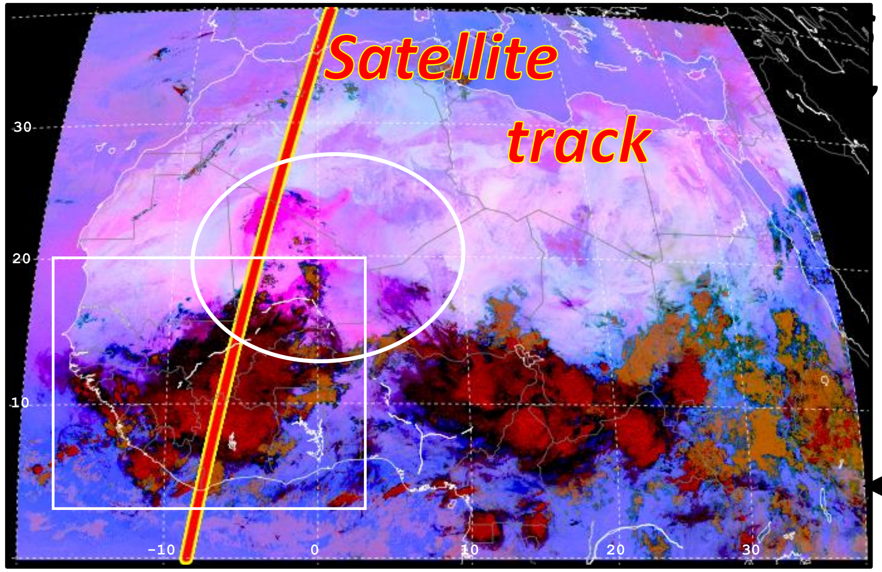


A MCS case

- An MCS over North Africa: 04-07 July 2010
- Two convective cycles
- Developed near a moderate dust plume
- CloudSat and CALIPSO satellites passed over the MCS



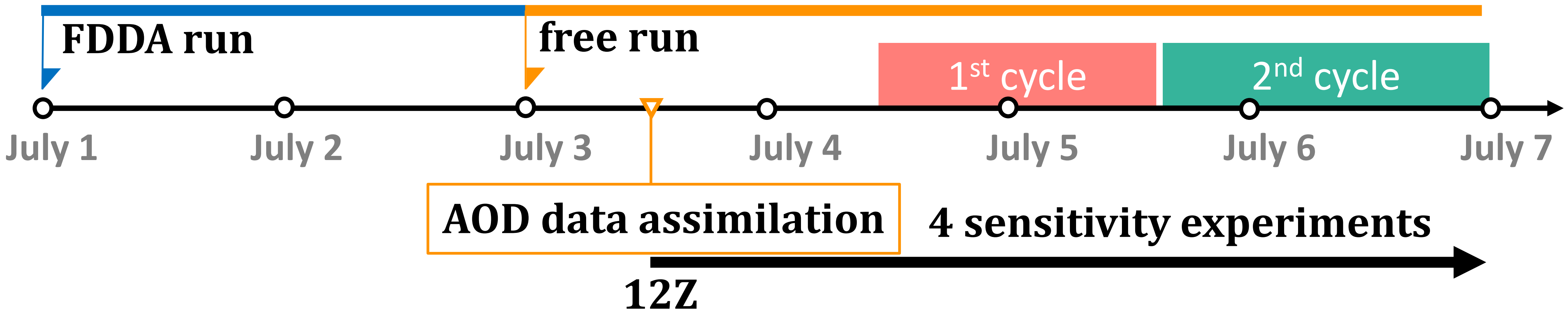




July 6 02Z (2nd cycle)

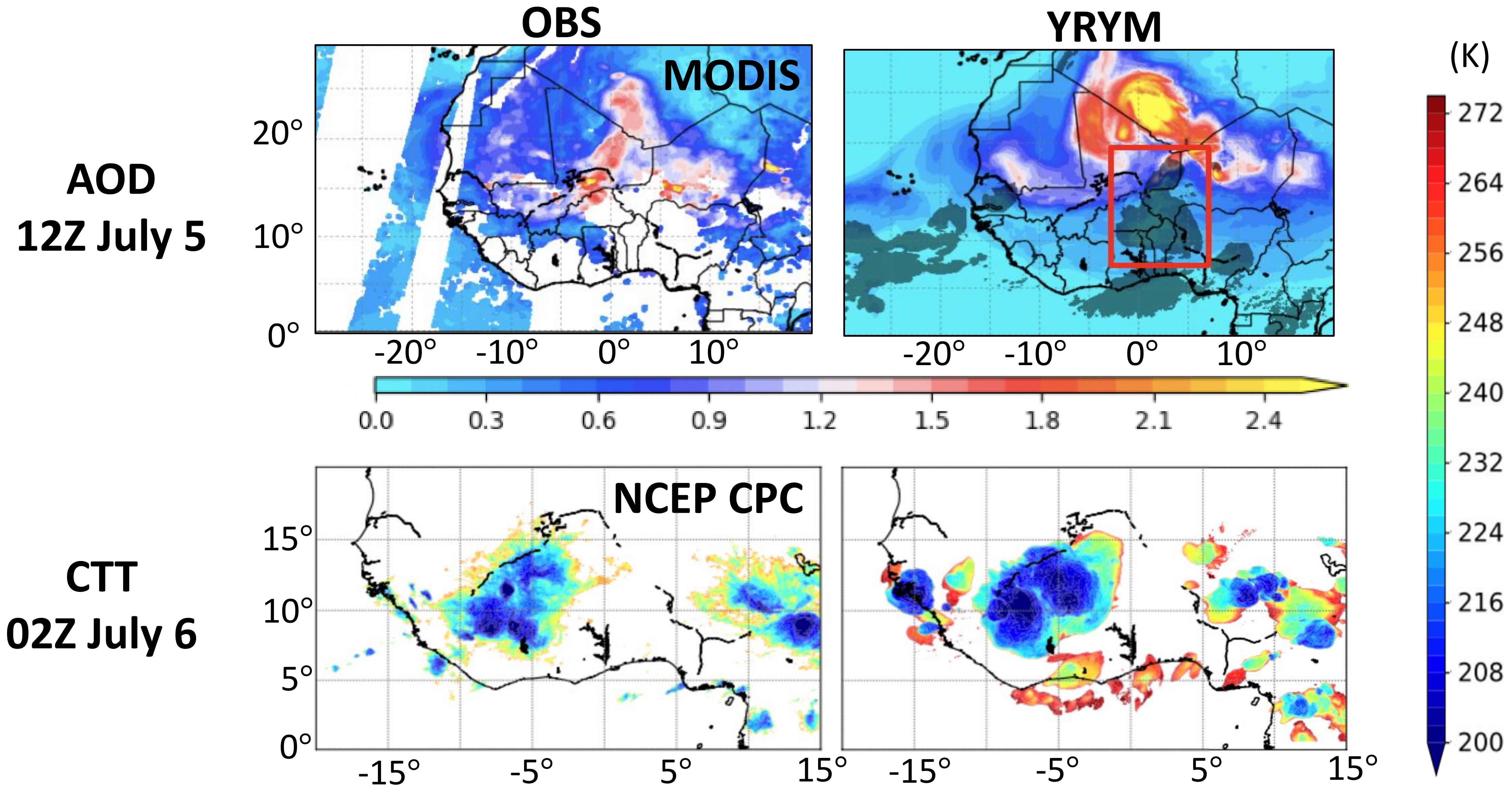
Model & Experiments

- **WRF-dust model** *(Chen et al. 2010, 2015)*
- **Three domains** – 27, 9 and 3 km
- **Dust-Radiation**: GSFC SW/LW scheme *(Chou et al. 2001)*
- **Dust-Microphysics**: 2-moment scheme *(Cheng et al. 2010)*
- **Other physics schemes**: MRF PBL, Kain-Fritsch cumulus



Experiments		Dust-Cloud Interaction (Dust-MP)	
		ON	OFF
Dust-Radiation Interaction (Dust-RA)	ON	YRYM	YRNM
	OFF	NRYM	NRNM

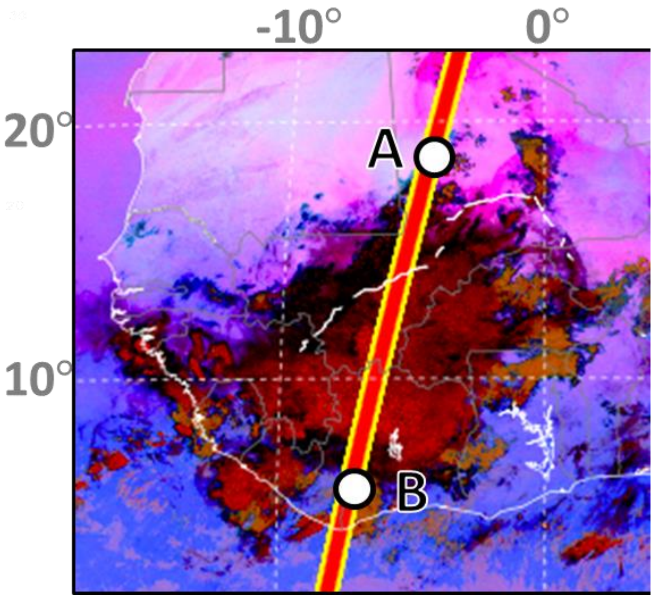
Verification – Aerosol Optical Depth (AOD) & Cloud Top Temperature (CTT)

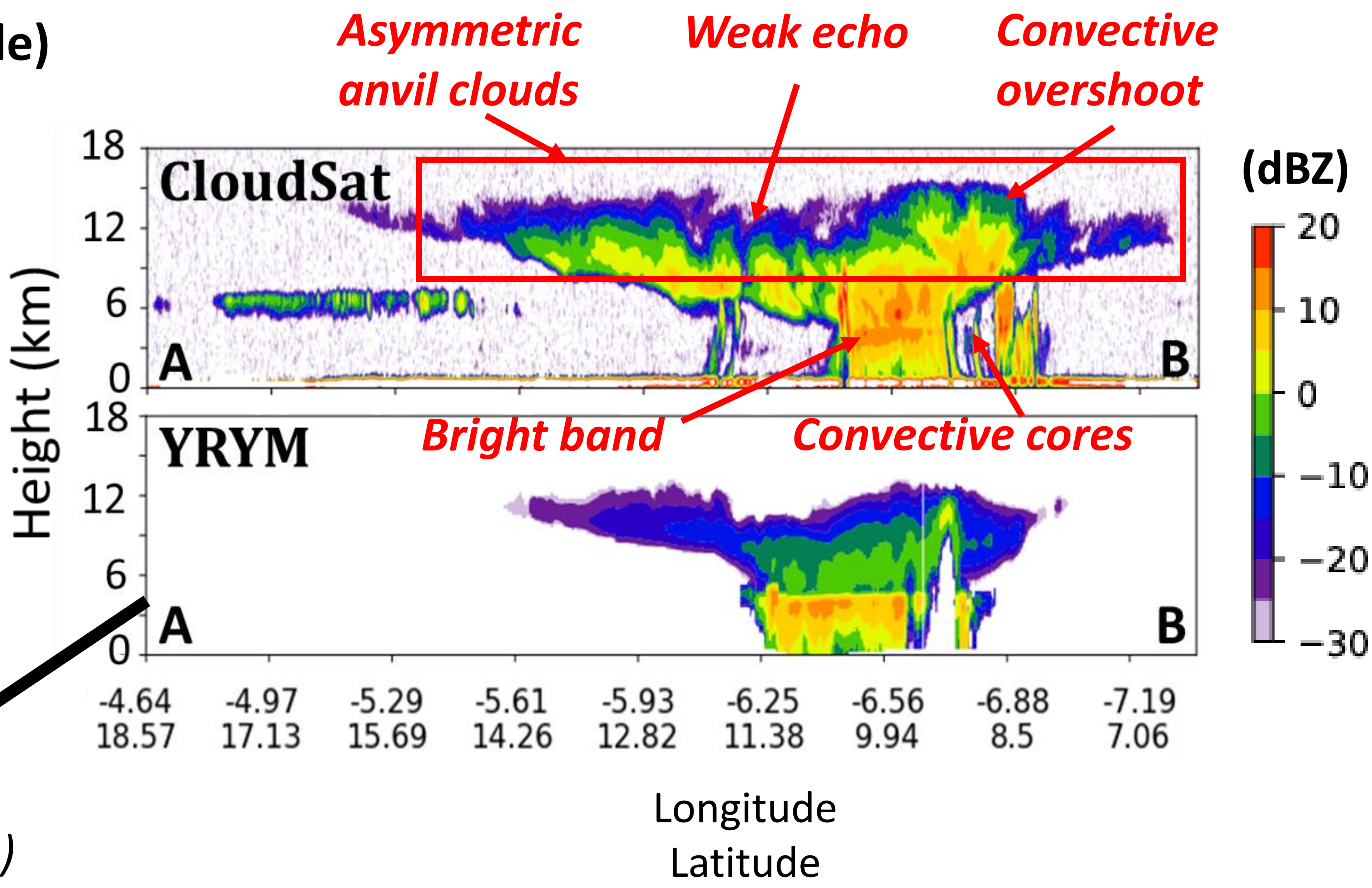


Verification – MCS Structure

Radar reflectivity

2010-07-06 02Z (2nd cycle)



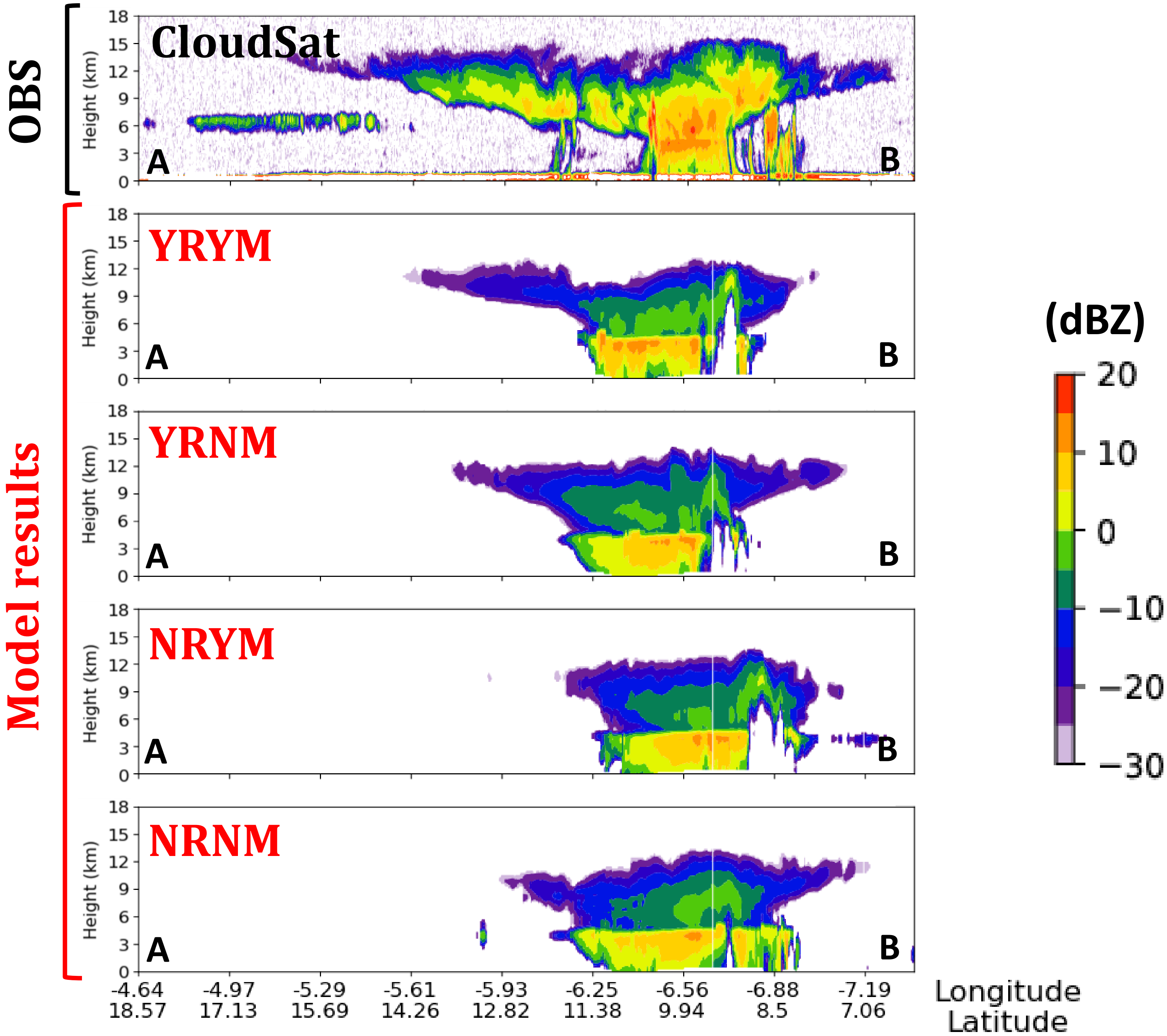


Goddard Satellite Data Simulator Unit

(Matsui et al 2013, 2014)

MCS Comparison

Radar reflectivity



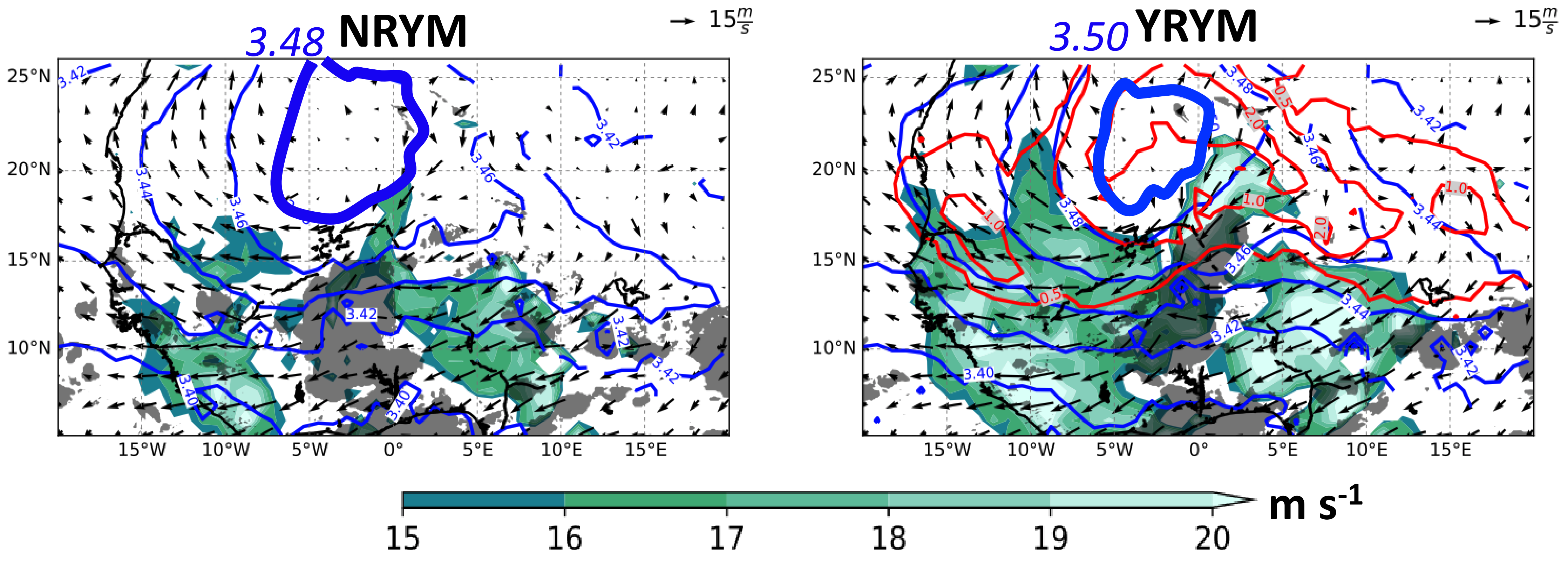
Vertical wind shear

Color shading & arrow: ***600-900 mb Vertical wind shear (m s^{-1})***
Grey shading: ***model cloud***
Blue contours: ***600-900 mb thickness (m)***
Red contours: ***AOD***

Thermal wind relation

$$\vec{V}_T = \frac{R}{f}\hat{k}\times\nabla\bar{T}\,ln\frac{p_L}{p_U}$$

2010-07-05 18Z (2nd cycle)



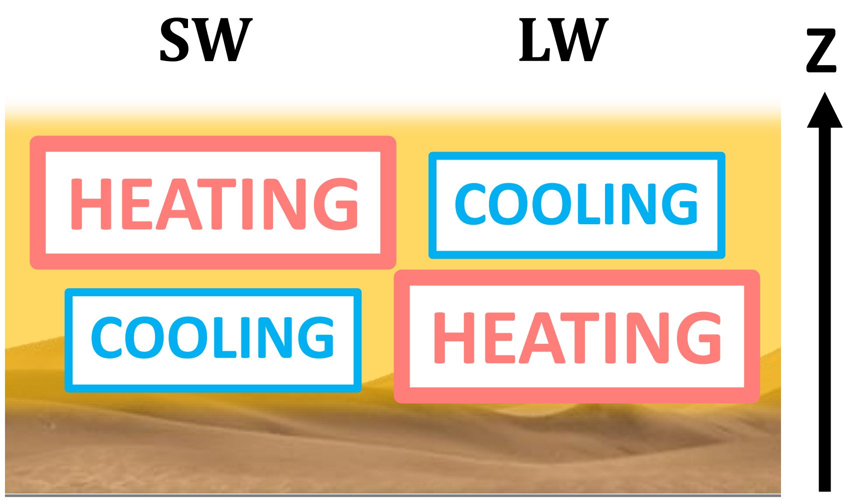
Convective energy & Surface Radiation Fluxes

[Day]

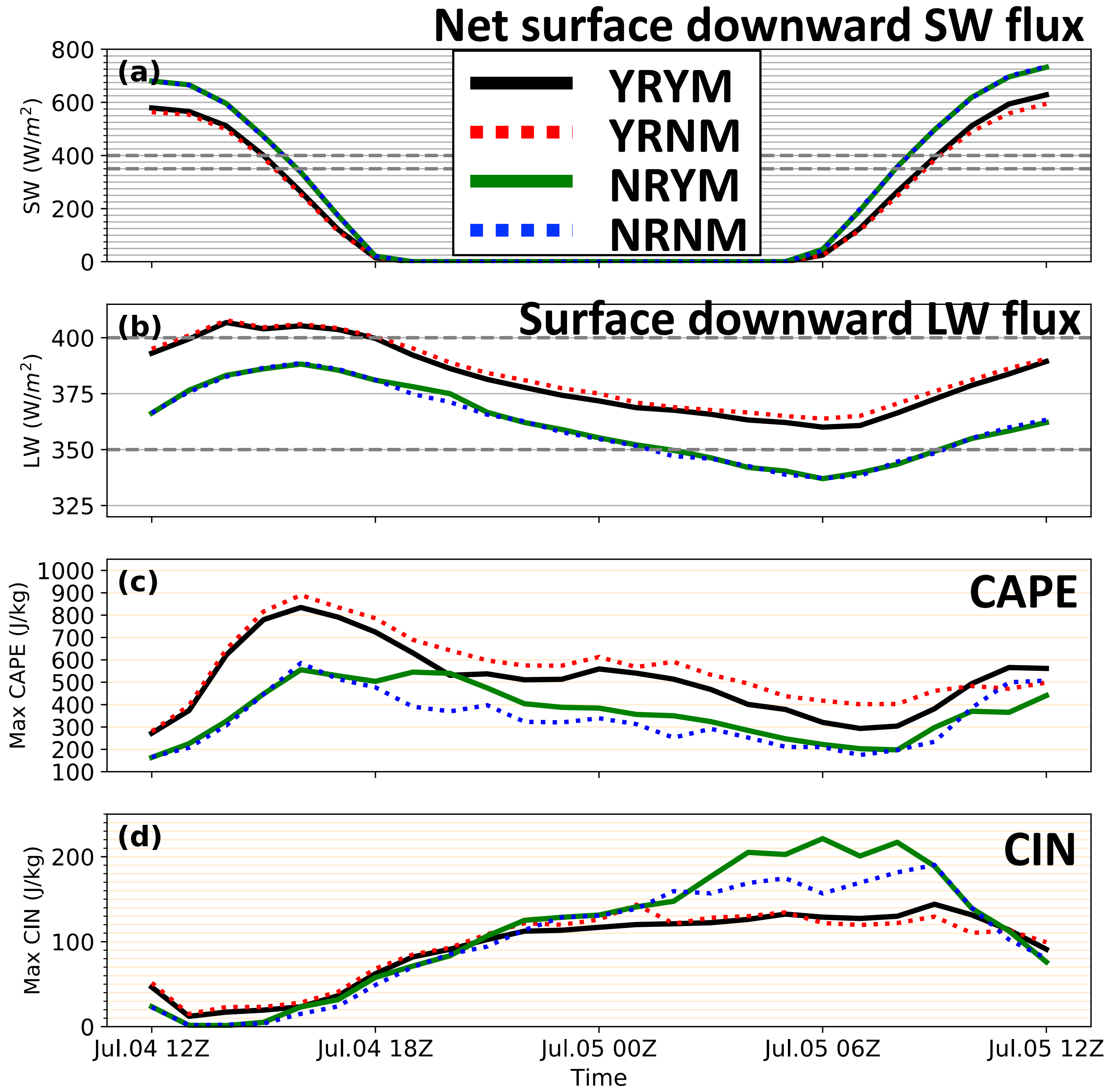
- *Stabilization*
- *Larger CIN and CAPE*

[Night]

- *Reduce stability*
- *Promote storm intensification*



Dust-Radiation Interaction



MCS Strength & Cloud Properties

[Area-Summed over MCS]

Color shading:

Total hydrometeors (kg m^{-3})

[Area-Averaged over MCS]

Black contours:

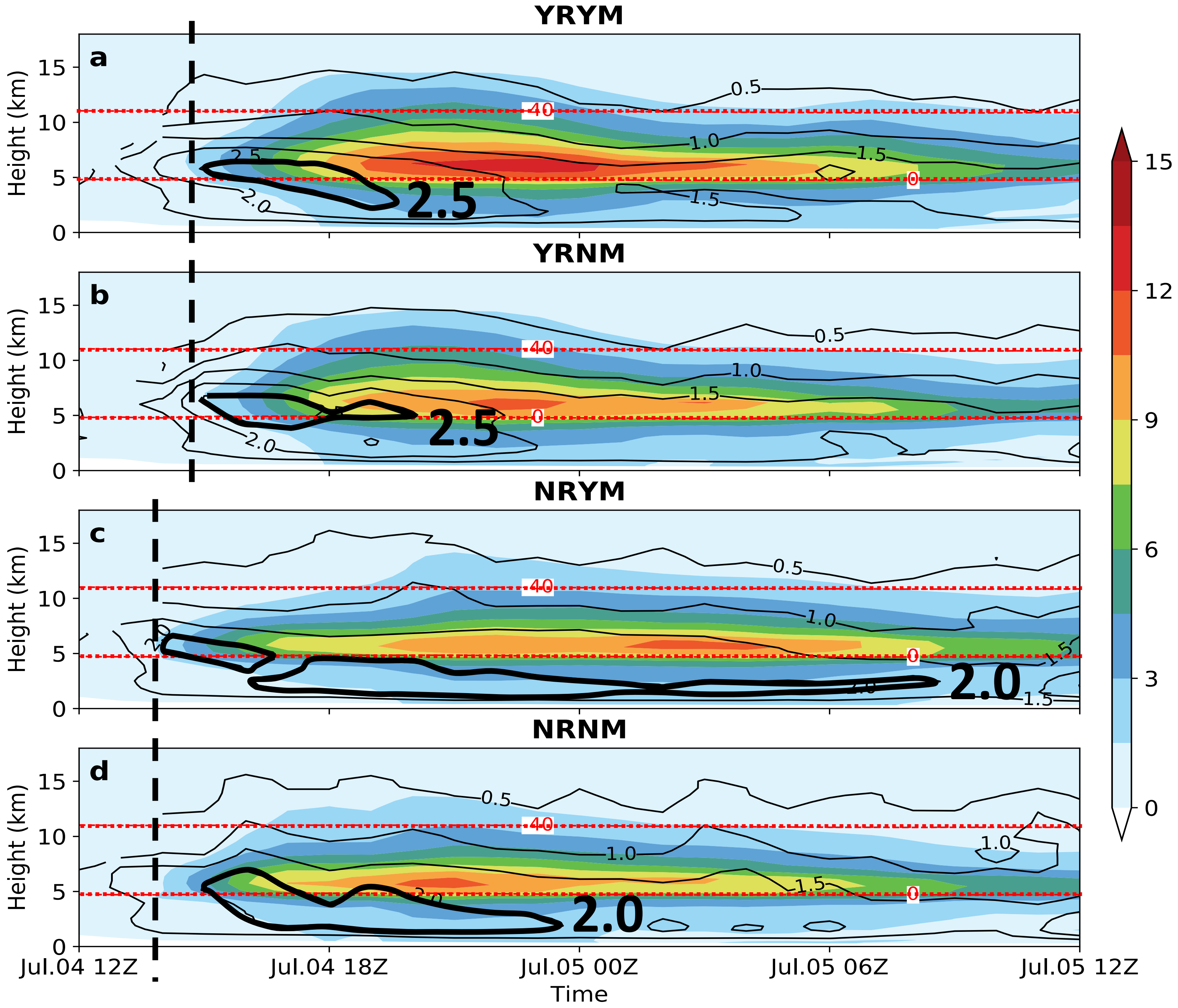
Convective updraft mass flux

= (ρw) (kg m^{-2} s^{-1})

[Only for grids with w > 1 ms^{-1}]

Red dotted lines:

0 & -40 °C isotherms



Differences: MCS Strength & Cloud Properties

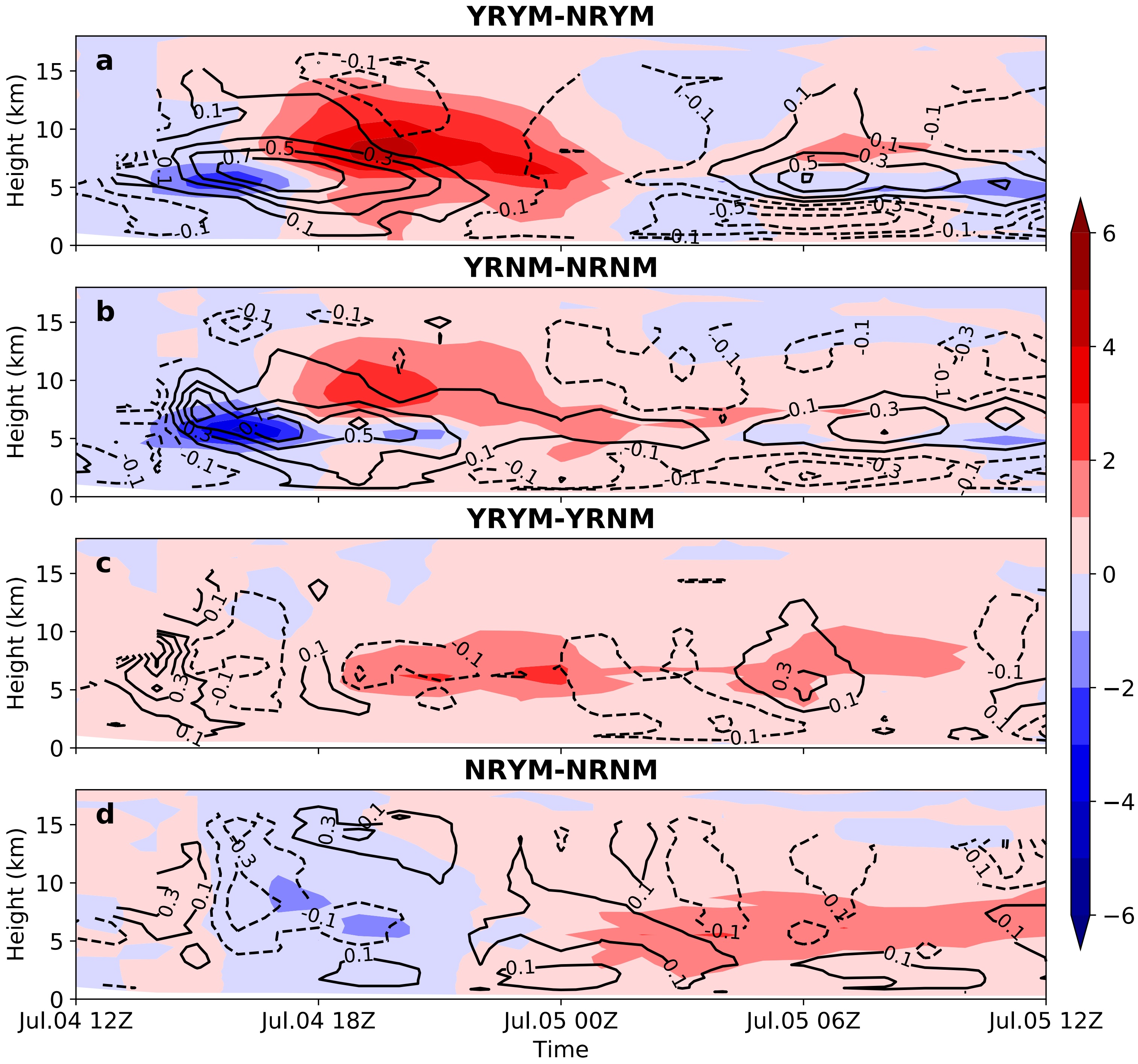
Percentage increase of accumulated rainfall (ref: NRNM) 7/4 12Z – 7/5 12Z	
Dust-RA	14%
Dust-MP	18%
Both	39%

Dust-RA effect (w/ MP)

Dust-RA effect

Dust-MP effect (w/ RA)

Dust-MP effect



Ice Particle Freezing Rate

[Averaged over MCS & 7/4 12Z - 7/6 02Z]

Solid lines:

Homogeneous nucleation

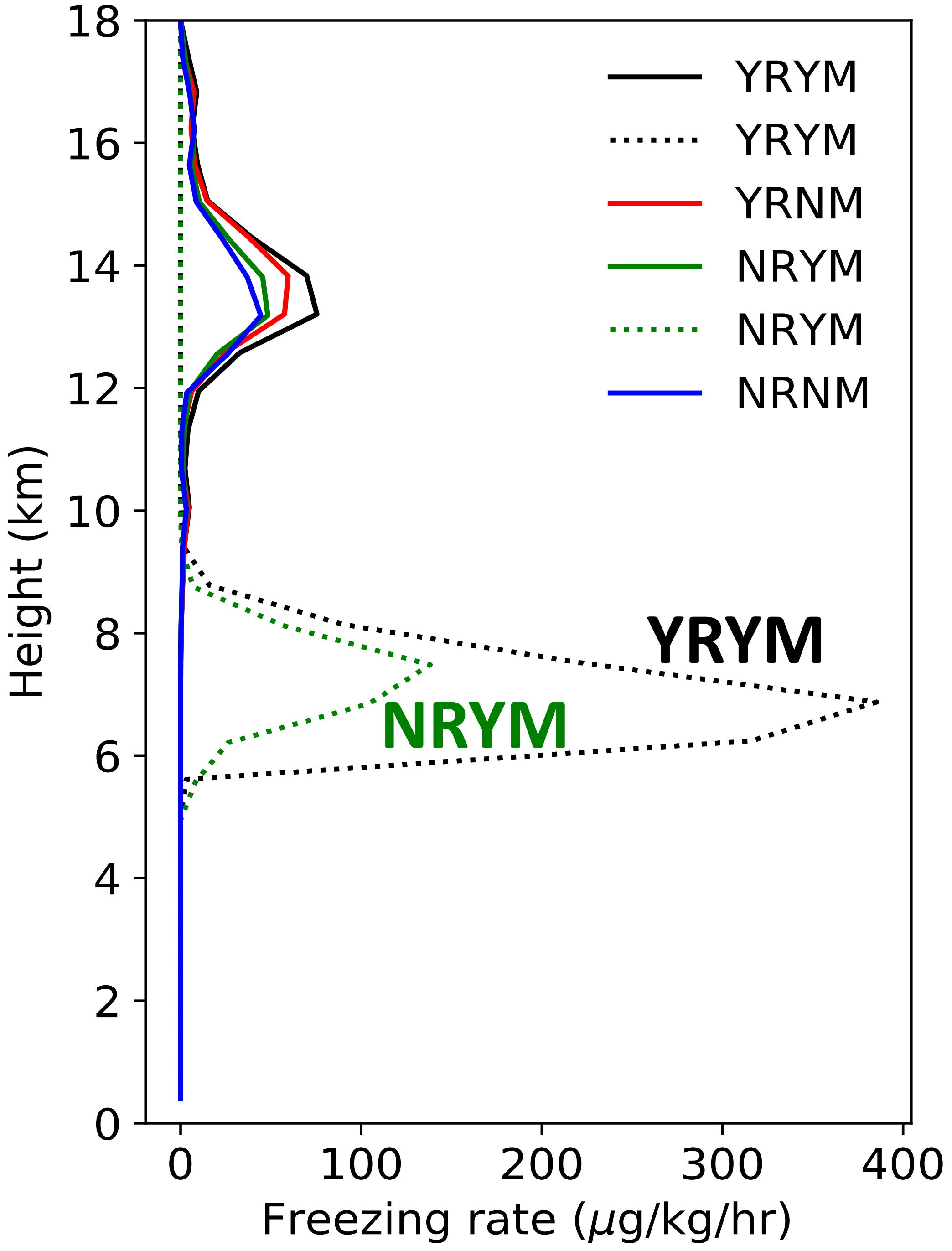
+ deposition nucleation on dust particles

+ heterogeneous freezing on bk aerosols

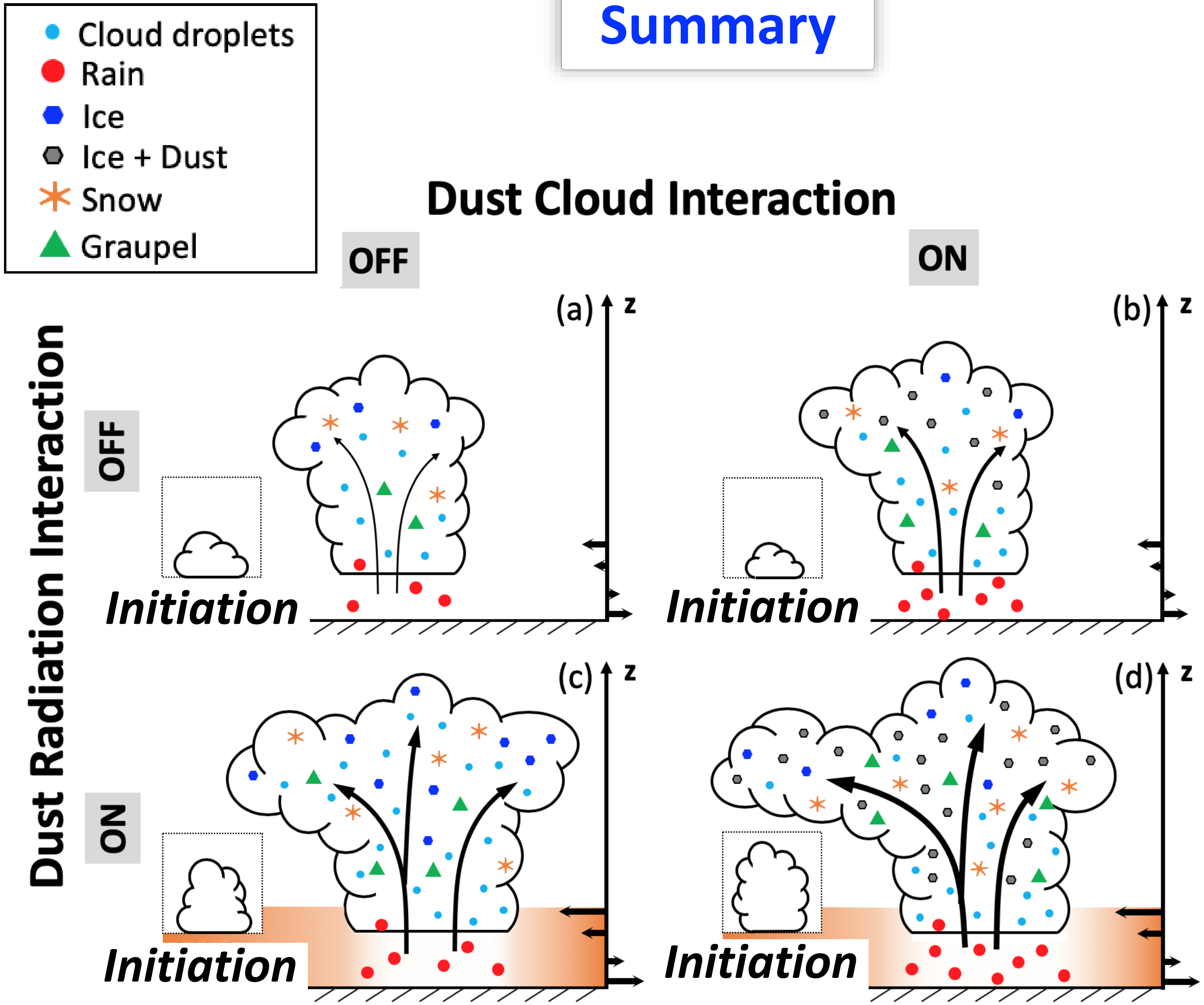
dotted lines:

Immersion freezing on dust particles

The dust-MP effect enhances the dust-RA effect on MCS development by enhancing immersion freezing



Summary



- HIGH dust concentration: **dust direct effect > dust indirect effect.**
- The dust-radiation interaction: stronger storms with more extensive anvil/stratiform cloud.
- The dust-cloud interaction:
  - slows initial storm development
  - enhances immersion freezing
  - extends cloud lifetime.
- The impacts of the **dust indirect effect on the MCS's development are strongly modulated by the simulation of dust-radiation interactions.**

Thank you

Huang C.-C, S.-H. Chen, Y.-C. Lin, K. Earl, T. Matsui, H.-H. Lee, I-C Tsai, J.-P. Chen, and C.-T. Cheng, 2019: The Comparison of Dust-Radiation versus Dust-Cloud Interactions on the Development of an MCS over North Africa. *Mon. Wea. Rev.*, **147**, 3301–3326

WRF dust model

WRF + Dust continuity equation (5-12 bins)

$$\frac{\partial \mu\gamma}{\partial t} = \nabla \cdot \vec{V}\mu\gamma + C_{pbl} + C_{con} + C_{mic} + S_\gamma + E_\gamma$$

γ : *Dust mixing ratio;* $\mu = p_{hs}$-p_{ht} *(mass)*

$C = \mu\gamma$ *(Coupled dust mixing ratio)*

S_γ : *Sedimentation (time splitting)*

E_γ : *Source / Sink (emission, wet scavenging, dry deposition)*

Dust emission:

- *Barren type vegetation*
- *Soil moist volumetric fraction < 0.2*
- *10-m wind > 6.0 ms*$^{-1}$

Tegen and Fung (1994); Kok et al. 2011

Hygroscopicity parameter

κ=0.05 (Koehler et al. 2009)

Dust-cloud-radiation Interaction

- *Dust-Radiation: Goddard Space Flight Center SW/LW radiation scheme (Chou and Suarez, 1999; Chou et al. 2001)*
- *Microphysics: 2-moment microphysics scheme (Cheng et al. 2010)*

A MCS case

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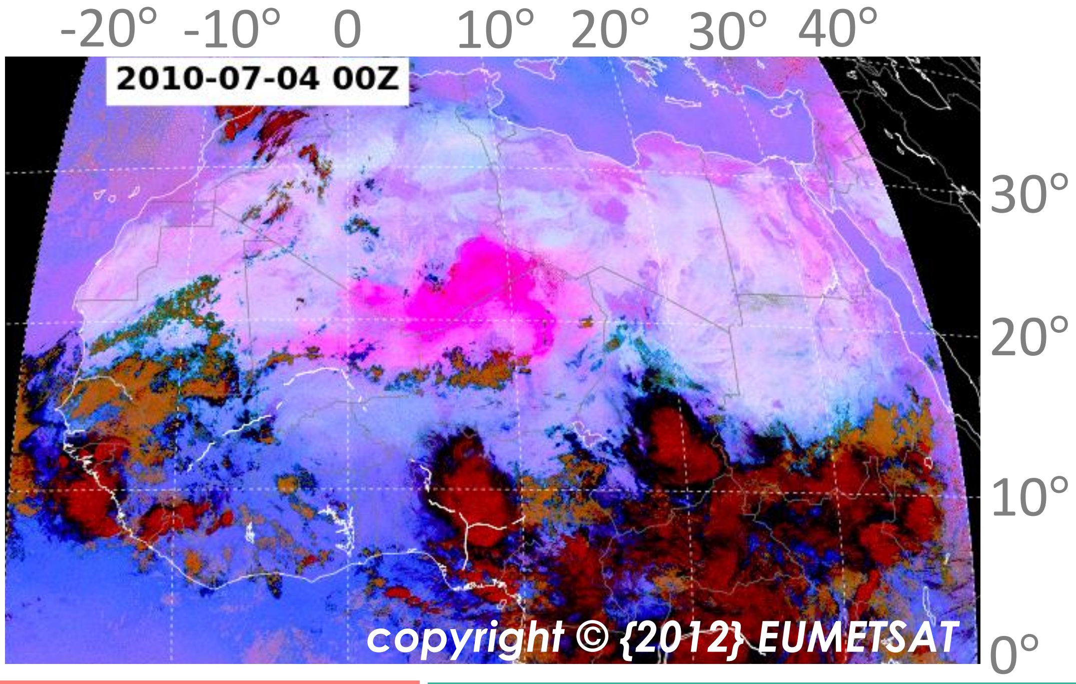
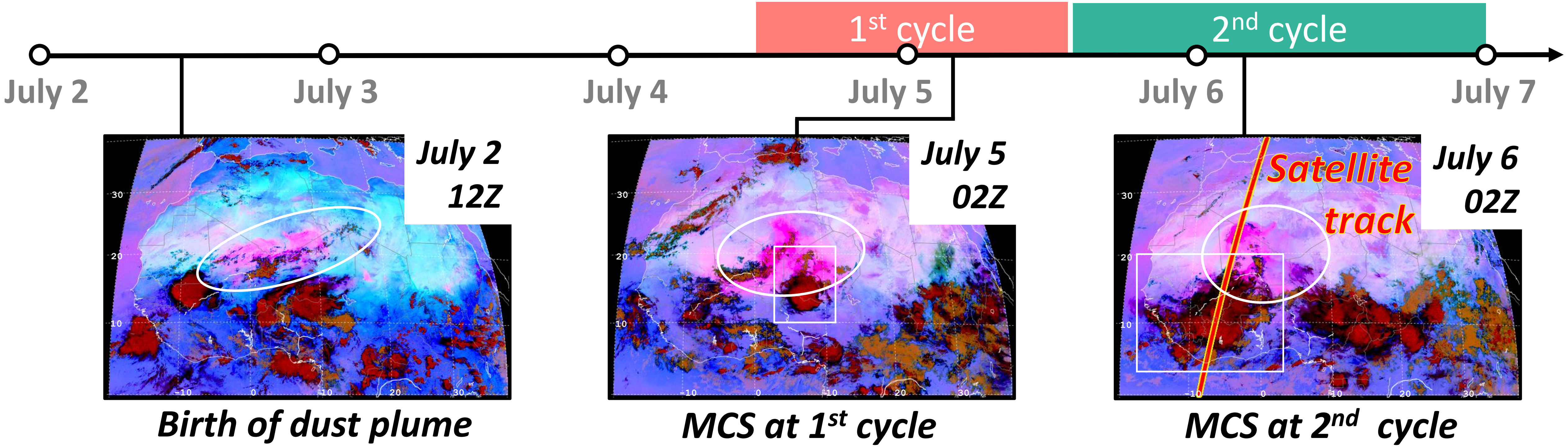
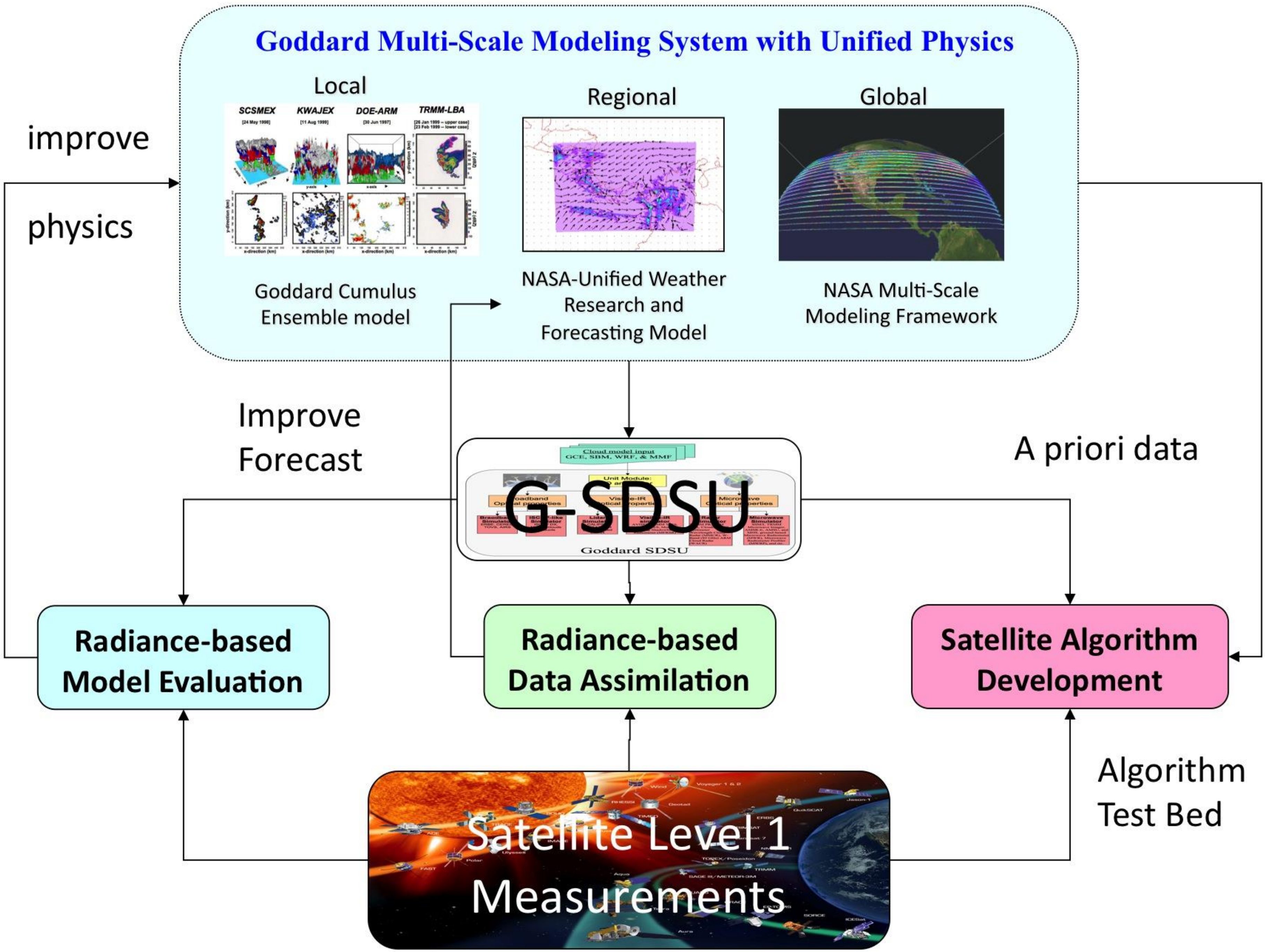
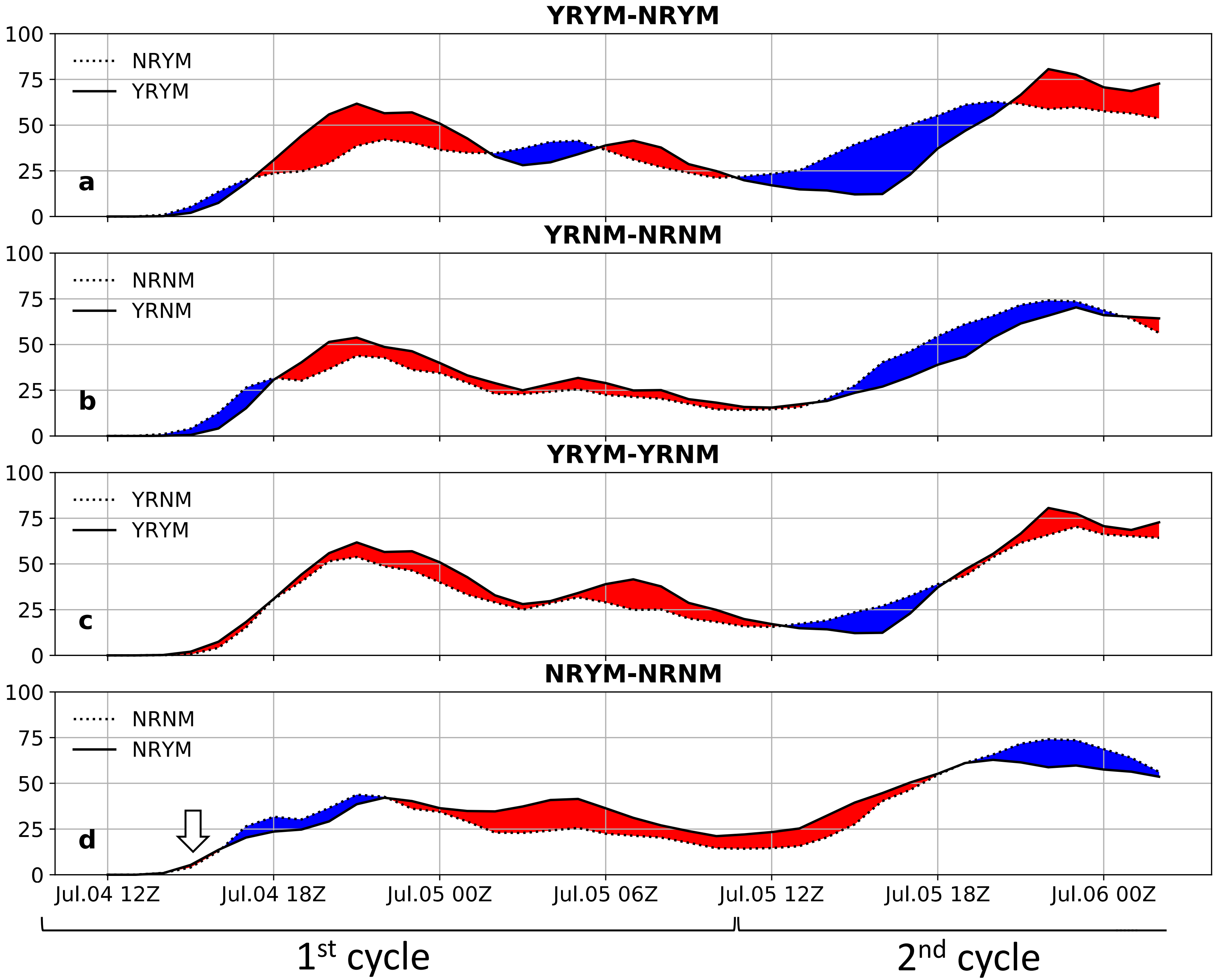


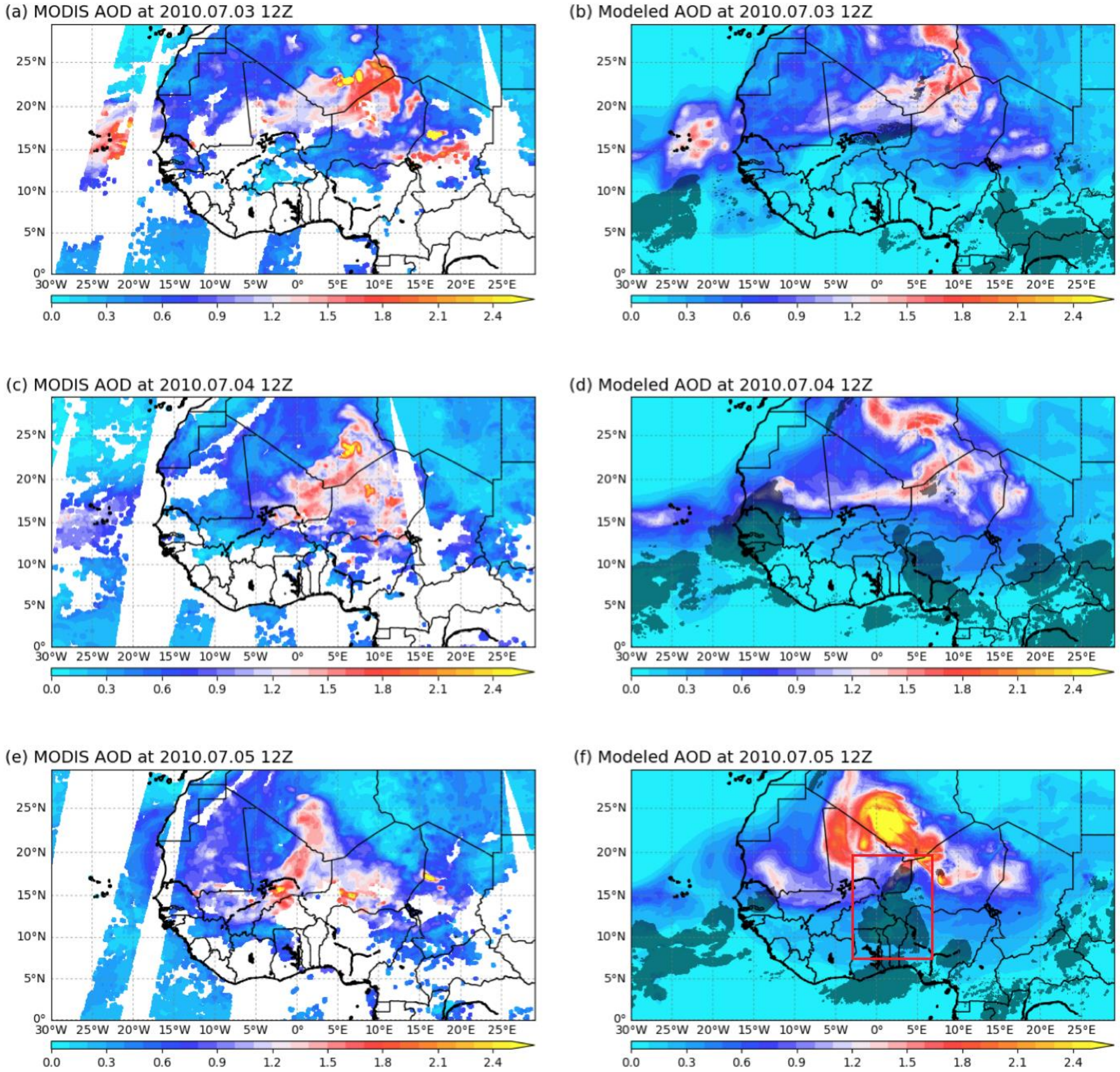



Goddard Multi-Scale Modeling System with Unified Physics
Local
Regional
Global
Goddard Cumulus Ensemble model
NASA-Unified Weather Research and Forecasting Model
NASA Multi-Scale Modeling Framework
improve
physics
Improve Forecast
A priori data
G-SDSU
Goddard SDSU
Radiance-based Model Evaluation
Radiance-based Data Assimilation
Satellite Algorithm Development
Algorithm Test Bed
Satellite Level 1 Measurements

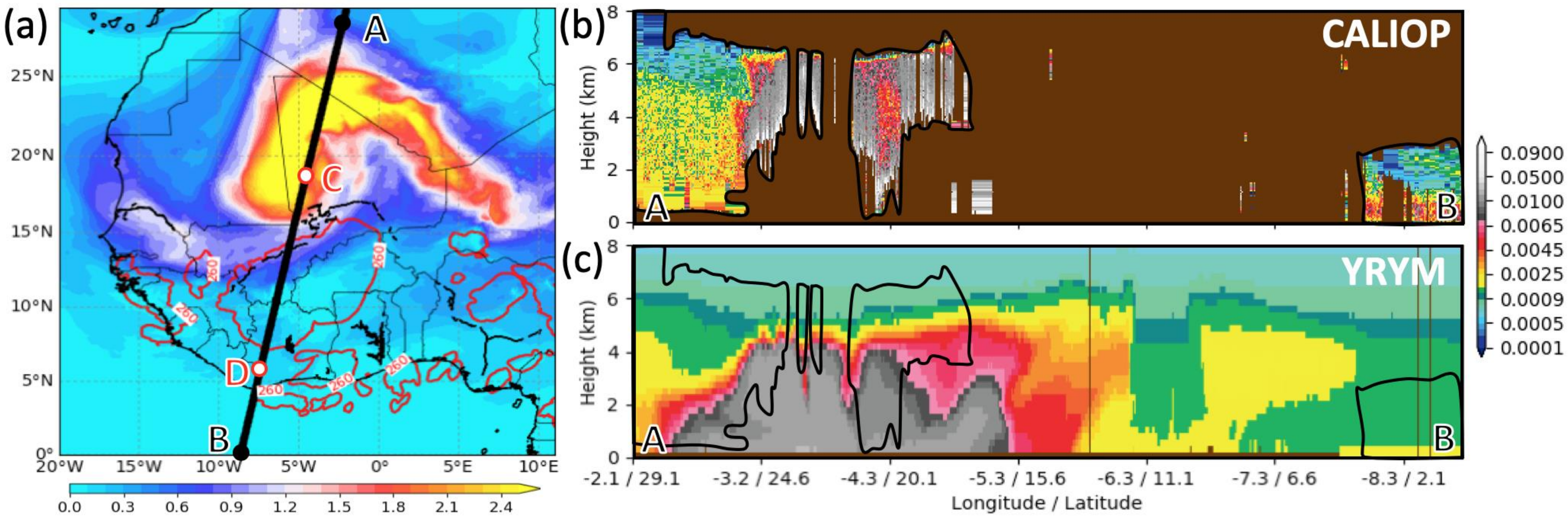
Precipitation Rate



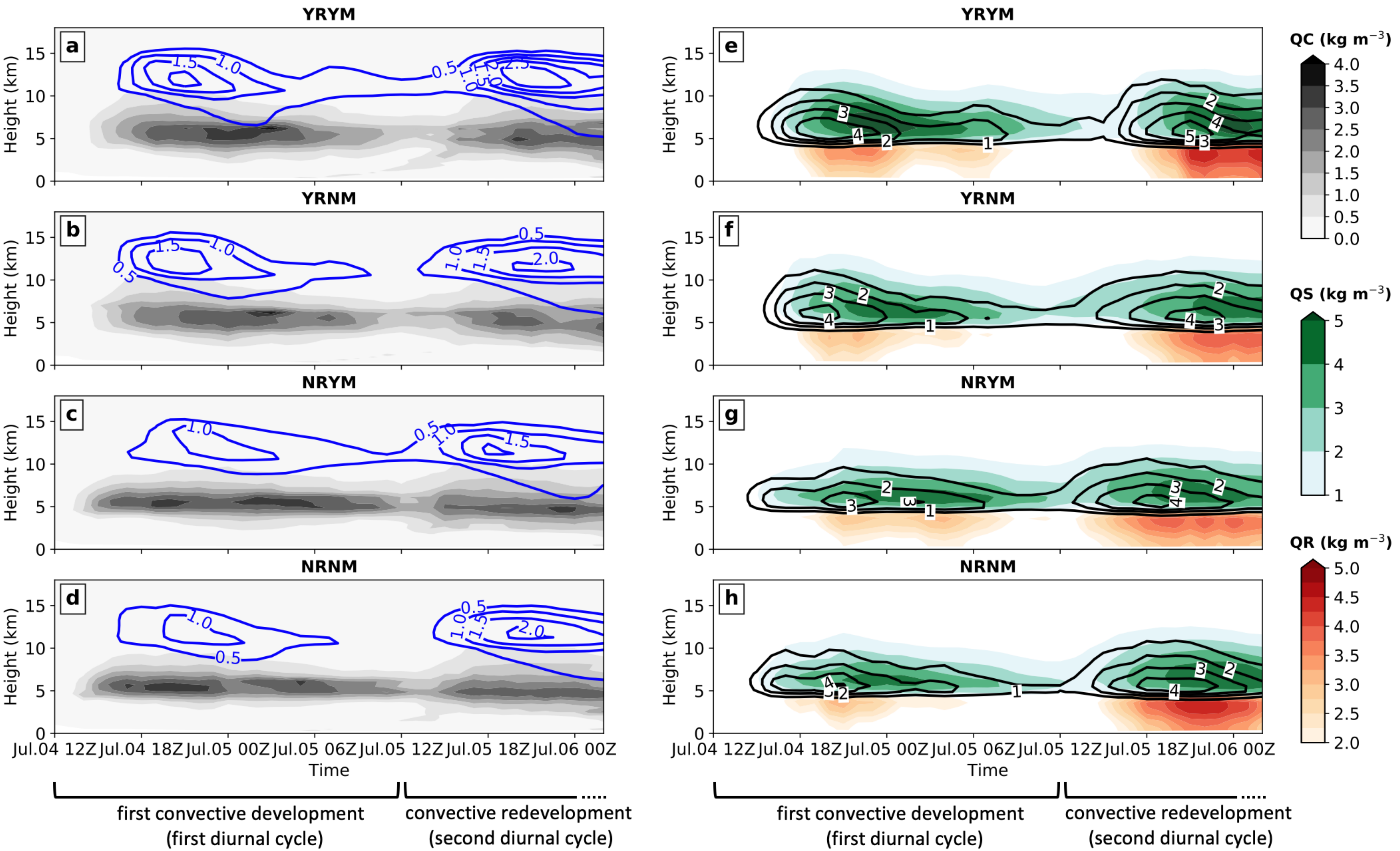
AOD verification



CALIPSO



(a)
A
C
D
B
260
25°N
20°N
15°N
10°N
5°N
0°
20°W
15°W
10°W
5°W
0°
5°E
10°E
0.0
0.3
0.6
0.9
1.2
1.5
1.8
2.1
2.4
(b)
CALIOP
(c)
YRYM
Height (km)
0
2
4
6
8
0.0900
0.0500
0.0100
0.0065
0.0045
0.0025
0.0009
0.0005
0.0001
-2.1 / 29.1
-3.2 / 24.6
-4.3 / 20.1
-5.3 / 15.6
-6.3 / 11.1
-7.3 / 6.6
-8.3 / 2.1
Longitude / Latitude


YRYM
YRNM
NRYM
NRNM
a
b
c
d
e
f
g
h
Height (km)
Time
Jul.04 12Z
Jul.04 18Z
Jul.05 00Z
Jul.05 06Z
Jul.05 12Z
Jul.05 18Z
Jul.06 00Z
QC (kg m^{-3})
QS (kg m^{-3})
QR (kg m^{-3})
first convective development
(first diurnal cycle)
convective redevelopment
(second diurnal cycle)