Model Performance of Storm-Resolving Model in simulating Mesoscale Convective Systems in eastern China

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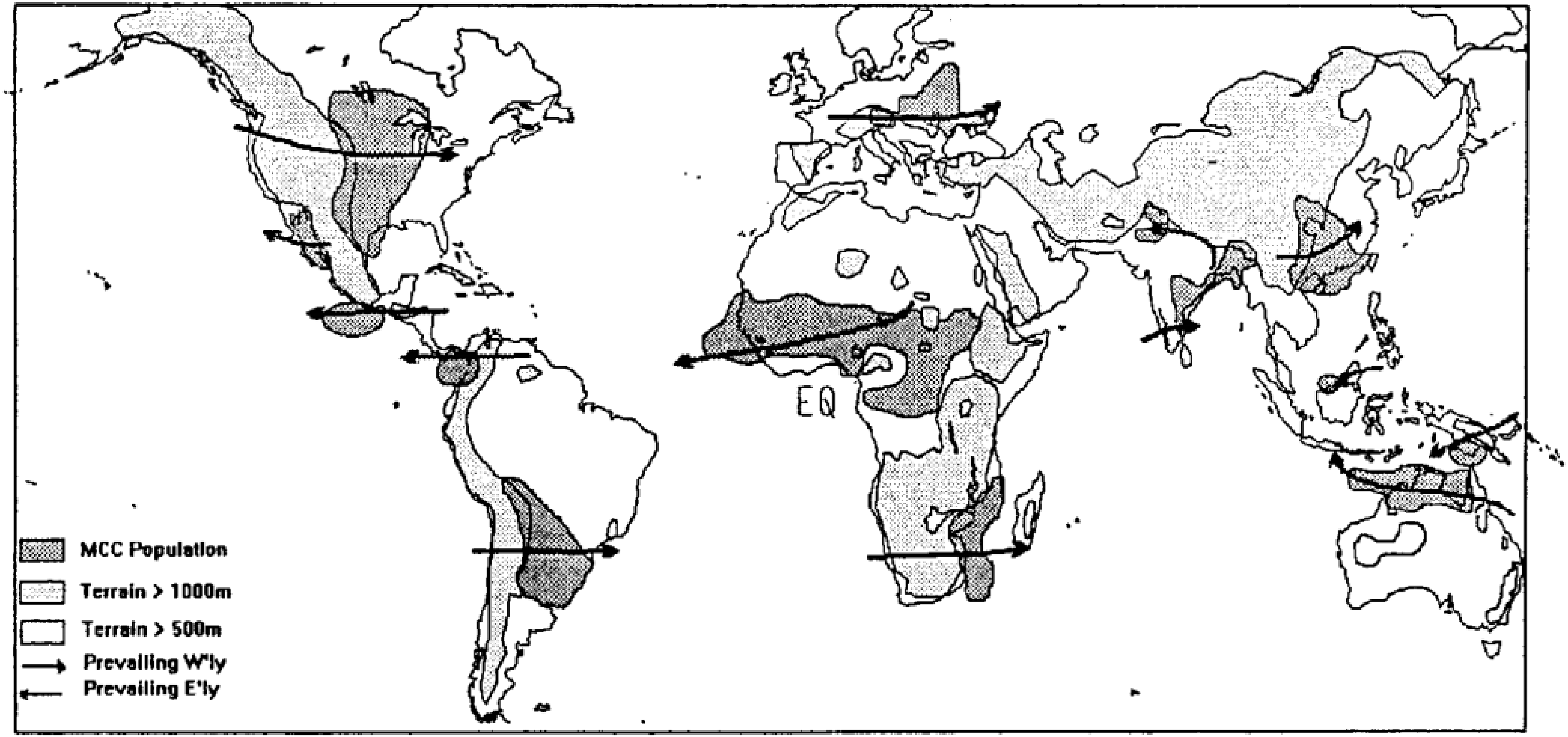
OUTLINE

1. An overview of MCSs
2. Scientific problems to be solved
3. Data and method
4. Results
   - a. Mesoscale convective systems precipitation characteristics over East Asia
   - b. Simulating MCSs over East Asia with ICON (HD(CP)^2-MCEA experiment)
5. Conclusion and Prospects

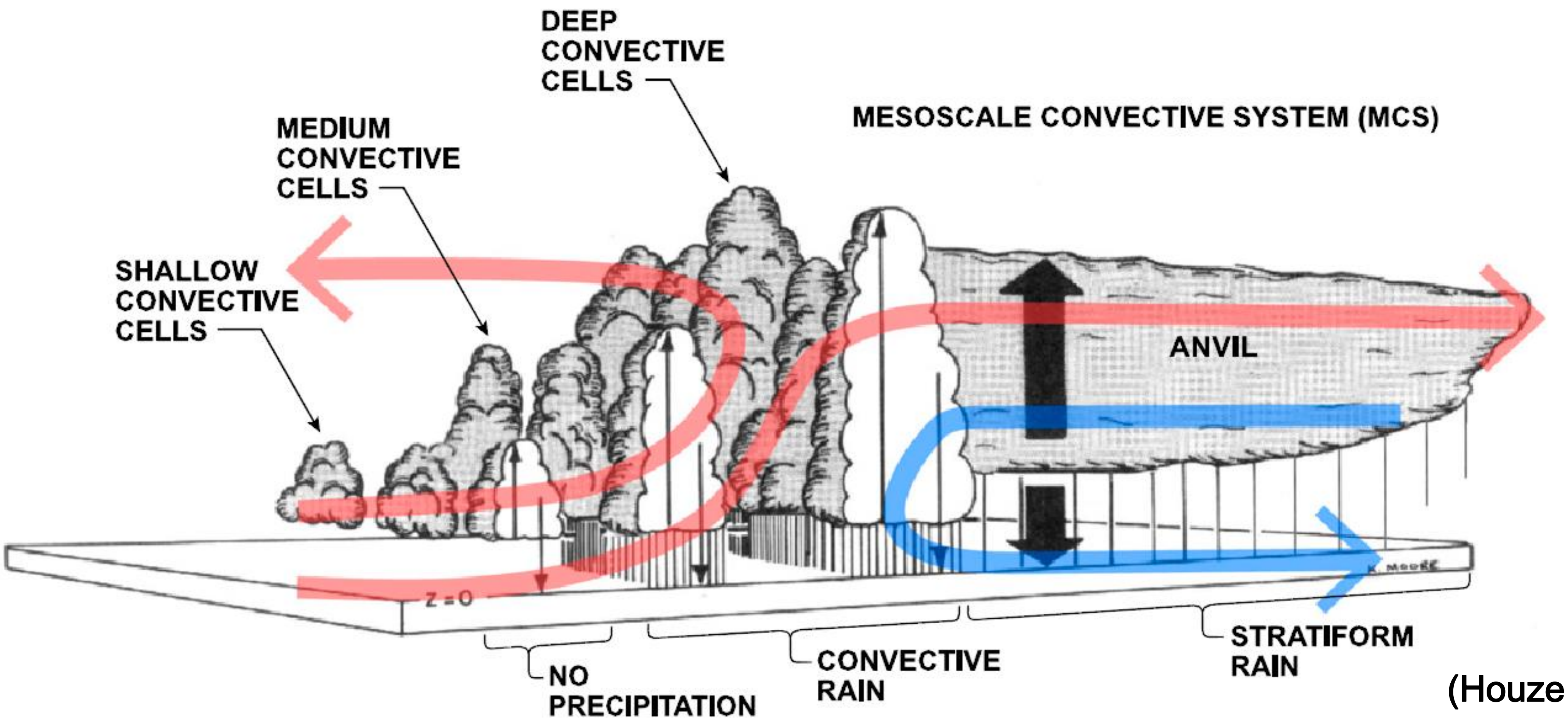
MCSs --- prefer to generate in the downstream of huge mountain

Orogenic MCSs downstream of mountain ranges



Liang and Fritsch (1997)

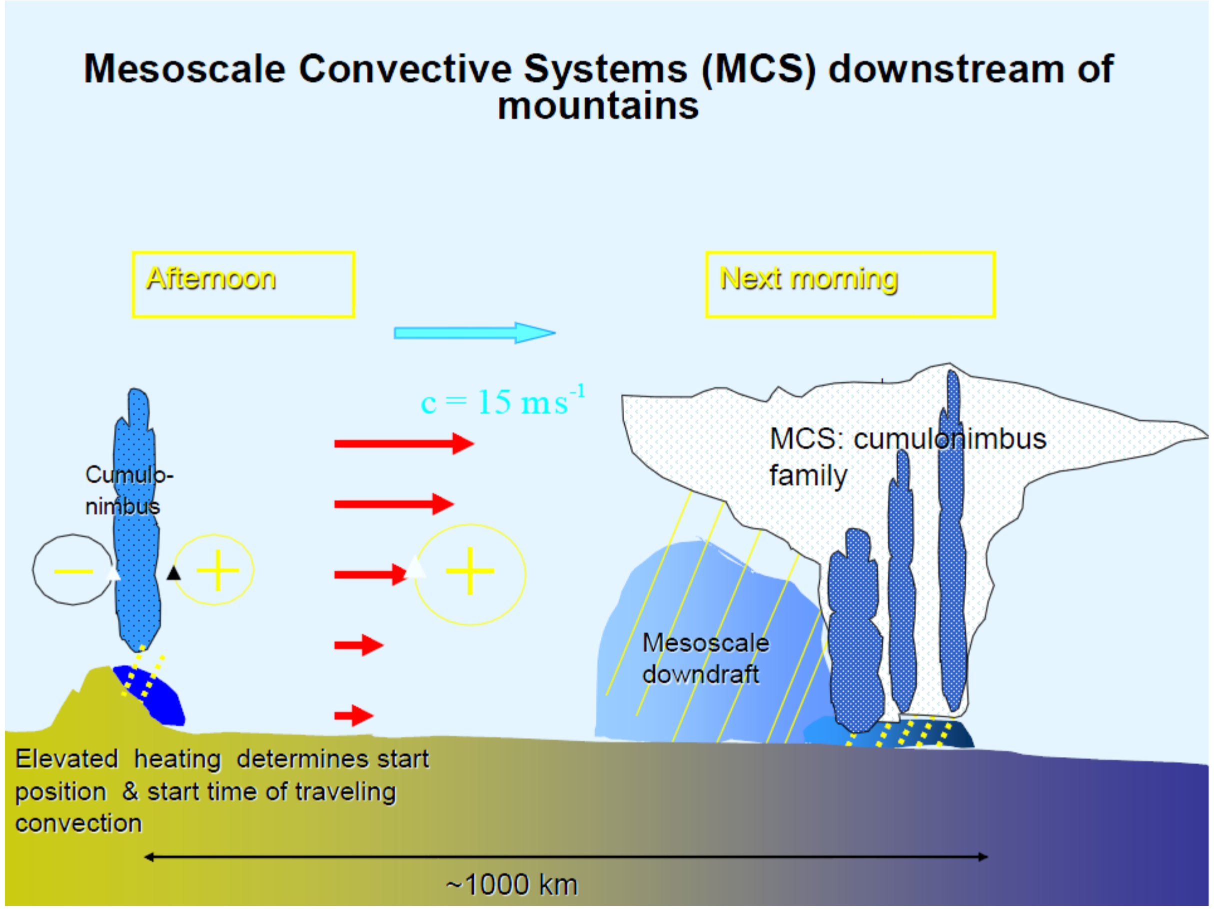
MCSs: a combination of shallow, medium and deep convection—requires model to resolve convection explicitly with finer resolution



(Houze 2018)

FIG. 17-52. Overlay of a convective cloud population and superimposed layered overturning. Adapted from Houze et al. (1980) and Moncrieff et al. (2017).

MCSs downstream of mountains: OBS and model simulations



(From ROY Rasmussen's talk 2017, @IAP)

1) Observation: More frequent intense and long-lived storms do-minate the springtime trend in central US rainfall（Feng et al. 2017）

2) Model simulations：

a) However, current climate models could not adequately simulate MCSs due to coarse resolution and its dependence on the deep convection scheme (Bukovsky et al. 2010; Kooperman et al. 2014; Feng et al. 2017; Zhang et al. 2017)

b) WRF CONUS simulation (4km) could capture the main characteristics of MCSs over US continent (Prein et al. 2017); and intense summertime MCS frequency will more than triple in North America, also increase in maximum precipitation rates (15-40%) and the increase (30-80%) of total MCSs precipitation volume (Prein et al. 2017)

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Scientific questions

1) Mesoscale convective systems precipitation characteristics over East Asia: regional differences and seasonal variations **(Result section: P1)**

2) Can Storm Resolving Models (SRMs) successfully simulate the precipitation characteristics of summer MCSs over East Asia? Through a typical Mei-yu front heavy precipitation event **(Result section: P2)**

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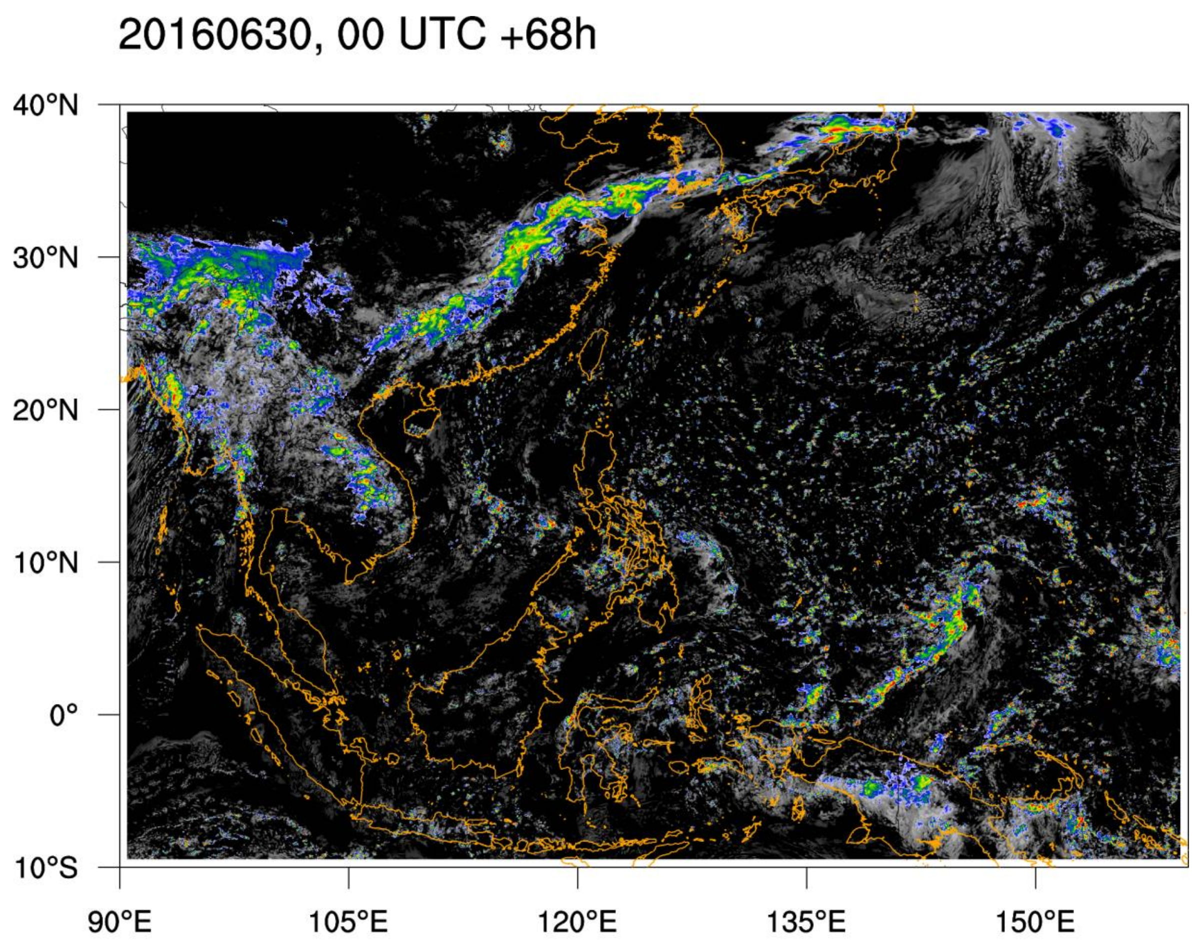
Observation used and Experiment design

1) **Observation: CMPA V1.0** (spatiotemporal resolution: ~10km, hourly; Shen et al. 2014, Pan et al. 2015);

2) Studying period: P1—MAM, JJA and SON from 2008-2016; P2—focus on an extreme precipitation event in 2016

3) **HD(CP)^2-MCEA experiment** (Dr. Daniel Klocke performed, more details can be found at Stevens et al. 2020)



ICON-2p5 (NWP at 2.5 km)

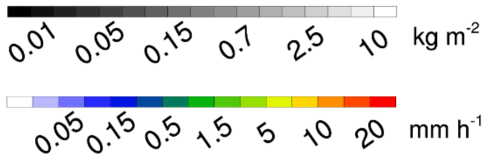
Domain:

latitude: 9.5S-39.5N; longitude: 90.5-159.5E

Initialized at every 00Z from 26th June to 10th July, each continuously run for 48 hours

Initialization/Boundaries: IFS analysis (9.5km)

Here we use each 24-48h simulation to analyze. To improve the comparability, the precipitation variable were remapped onto the same grid as observational precipitation.



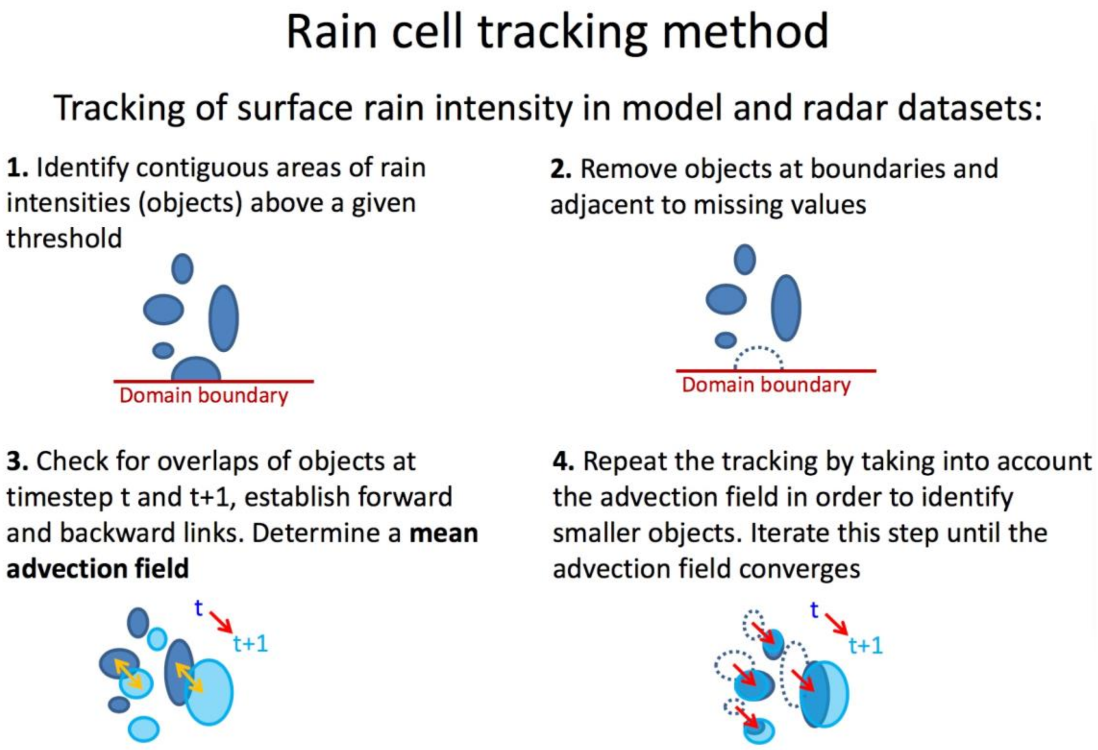
MCSs detection and tracking by using iterative rain cell tracking method

MCS definition—using hourly precipitation variables (similar definition could be found in Houze 2004, 2018; Clark et al. 2014; Prein et al., 2017a, b) :

1) Rainfall Area (S): Over 3600 km^2 (minimum length of 100~400 km and a minimum depth of 9~36 km)；

2) Rainfall Intensity (I): exceed 3.0 mm h^{-1};

3) Rainfall Duration (D): long duration MCSs: at least 6 hours.



(Moseley et al. 2014, 2019)

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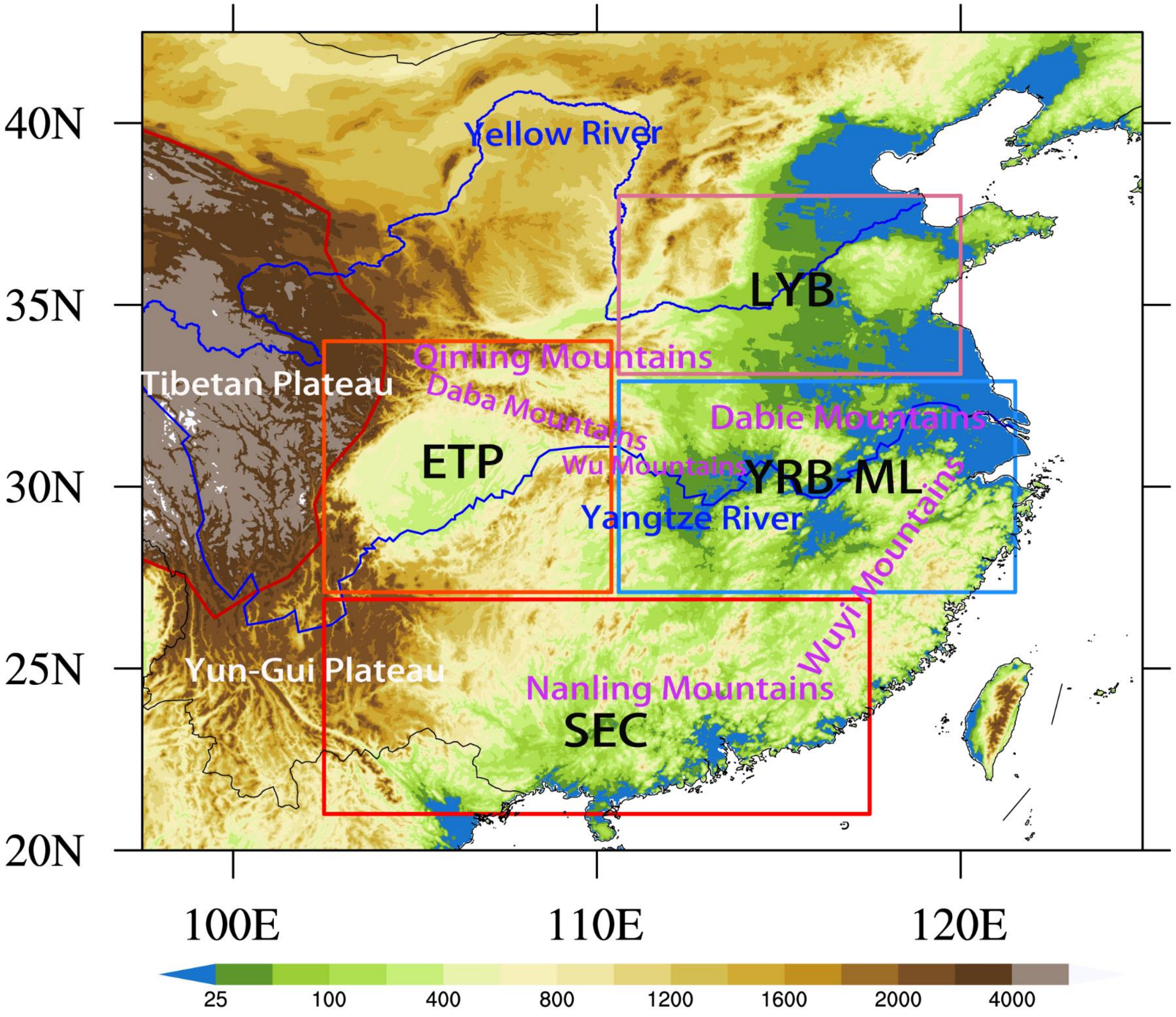
Topography over Eastern China and four sub-regions focused in this study



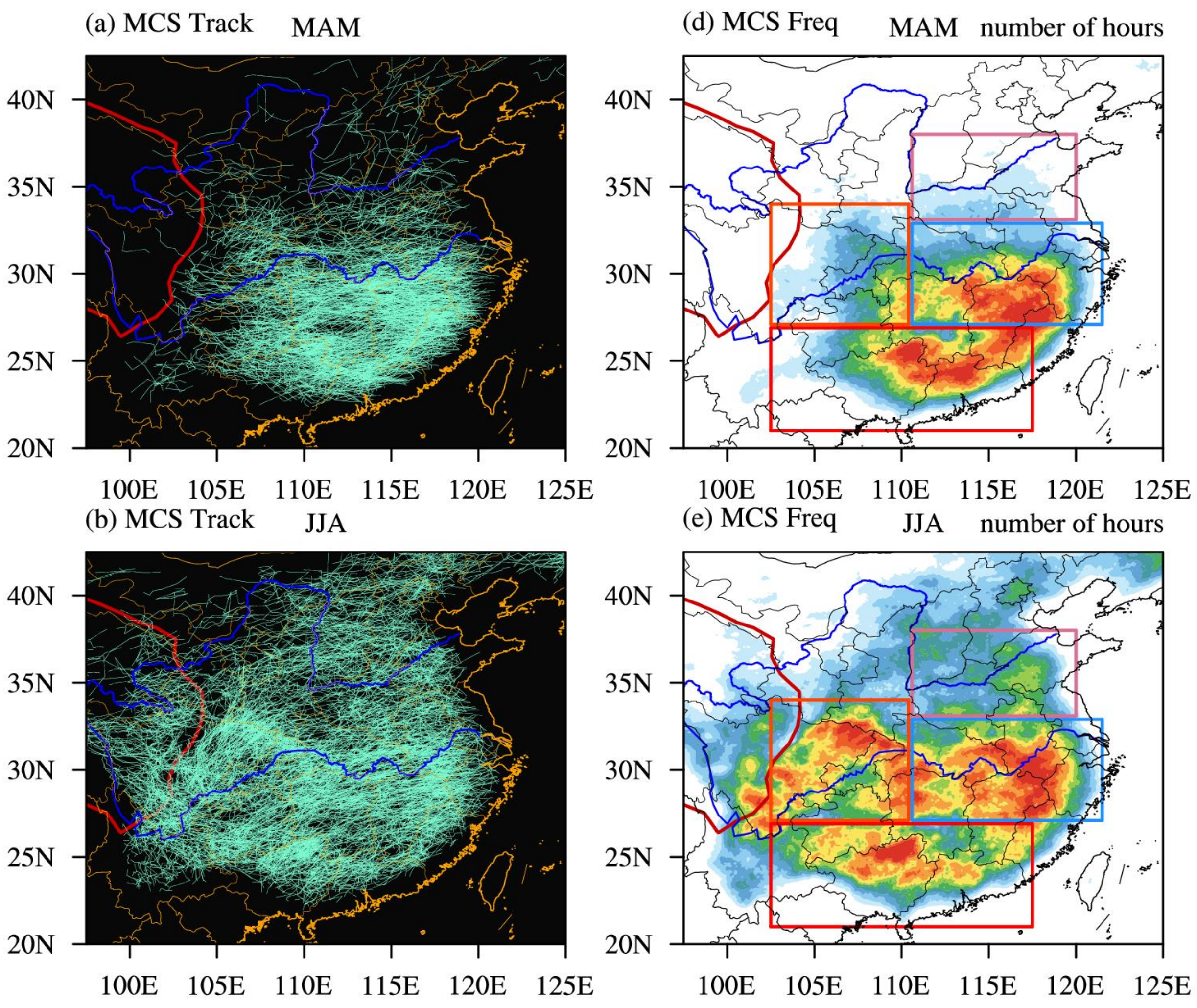
ETP: the eastern periphery of the Tibetan Plateau

YRB-ML: the middle-to-lower reaches of the Yangtze River Basin

SEC: southeastern China

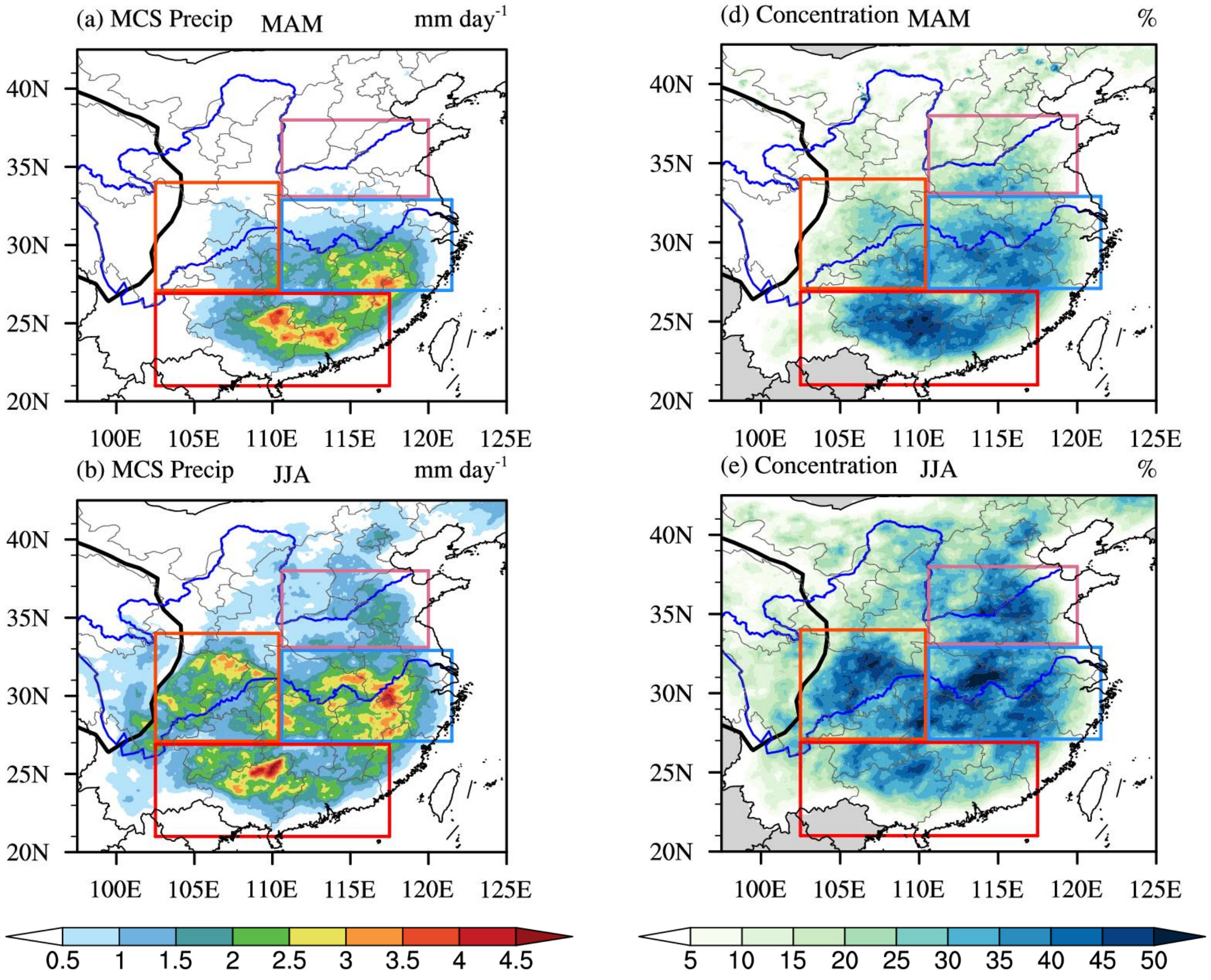
LYB: the lower reaches of the Yellow River Basin

MCS tracks (left) and MCS precipitation frequency (right)



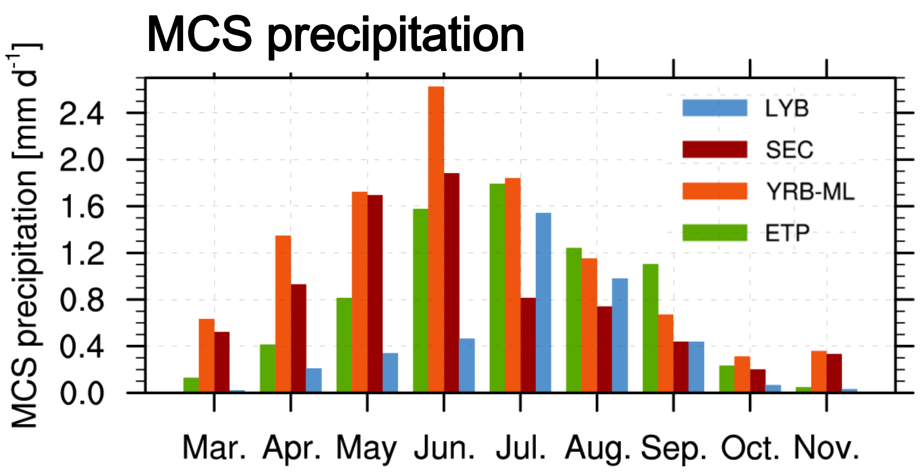
1) MCS precipitation could be found in spring and occurs most frequently in summer, then it becomes relatively less in autumn;
2) In summer, a northward migration of MCS activities can been seen due to the monsoonal march, not only can MCSs still occur over the western part of SEC and YRB-ML, but also another MCS population center arises over the ETP.

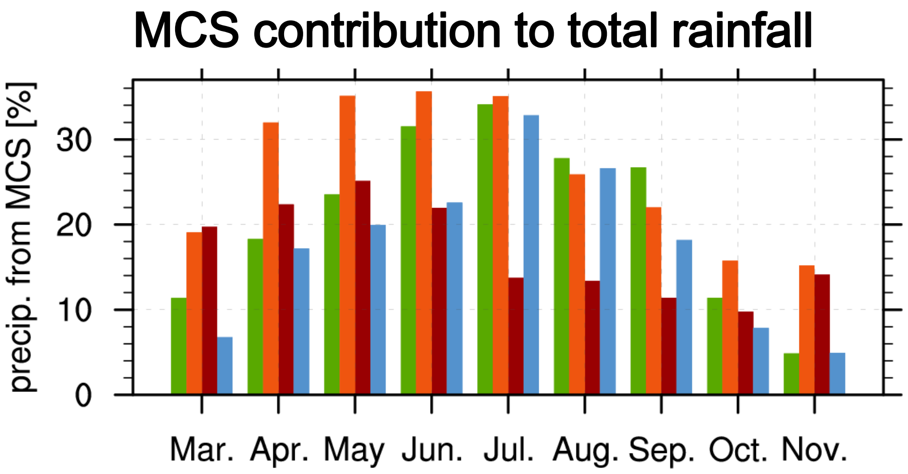
MCS precipitation (left) and MCS contribution to total precipitation (right)



1) The overall pattern of MCSs precipitation amount is quite consistent with the frequency of MCS occurrence;
2) MCS contributes 45.0~50.0% to total rainfall in some regions of the YRB-ML and ETP, indicating that the long-lived and intense MCSs play an important role in the water cycle over eastern China during warm seasons.

Monthly total precip., MCS precip. and its contribution to total rainfall

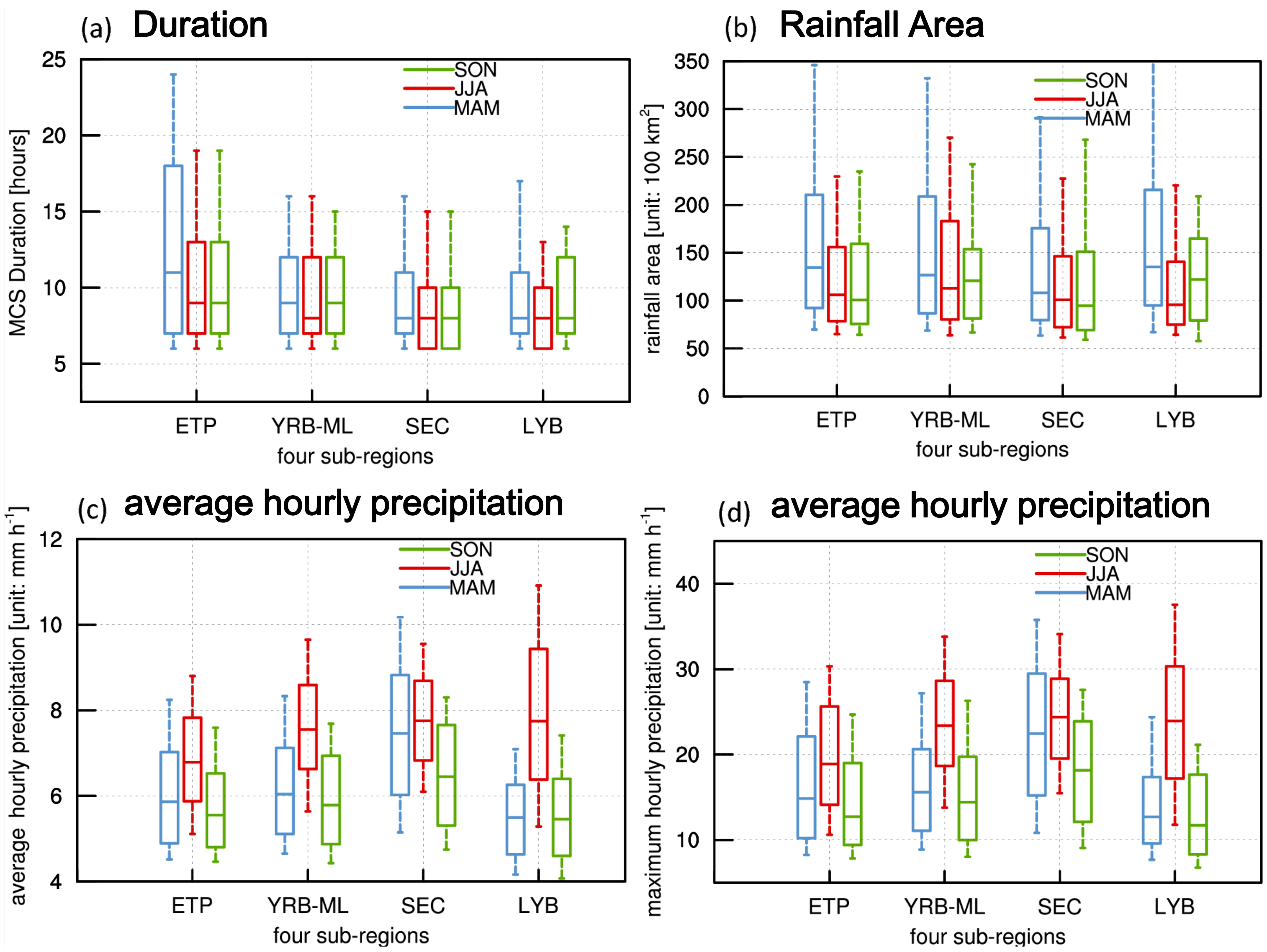




	MCSs propagation speed (unit: km h^{-1})			The number of hours when occurring extremes (i.e., when the MCSs maximum hourly precipitation ≥ 50.0 mm h^{-1})		
	Spring	Summer	Autumn	Spring	Summer	Autumn
ETP	55.4	43.0	42.8	49	185	19
MY	60.0	49.2	52.9	34	193	9
SEC	53.6	44.8	47.5	186	150	14
LYB	59.8	45.5	46.3	0	126	10

1) All four sub-regions exhibit a significant seasonal cycle associated with different large-scale circulations due to monsoonal march and retreat;
2) YRB-ML receives the largest amount and exhibits the most pronounced seasonal cycle of MCSs precipitation in eastern China. MCSs precipitation over YRB-ML can exceed 2.6 mm d^{-1} in June, contributing over 30.0% of April to July total rainfall.
3) MCSs over YRB-ML have larger propagation speeds.

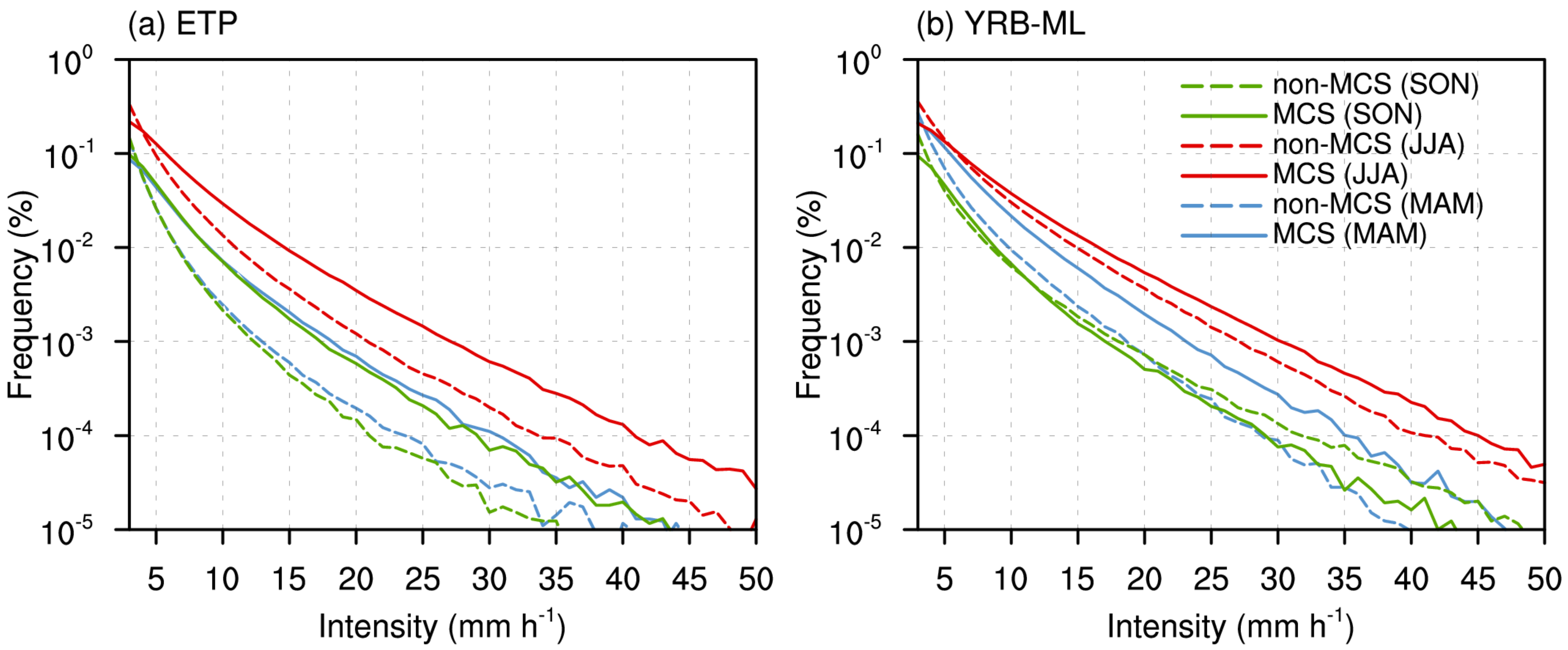
Overall MCS statistical characteristics in spring, summer and autumn



1) Long-lived MCSs occur over the eastern periphery of the Tibetan Plateau (ETP), 25% of MCSs over the ETP persist for more than 18 hours in spring.
2) Spring MCSs feature larger rainfall areas and longer durations; Summer MCSs have a higher precipitation intensity.

Box plot: the horizontal bars denote the medium values, the boxes indicate the interquartile range (25% and 75%), and the whiskers represent 10% and 90% percentile values

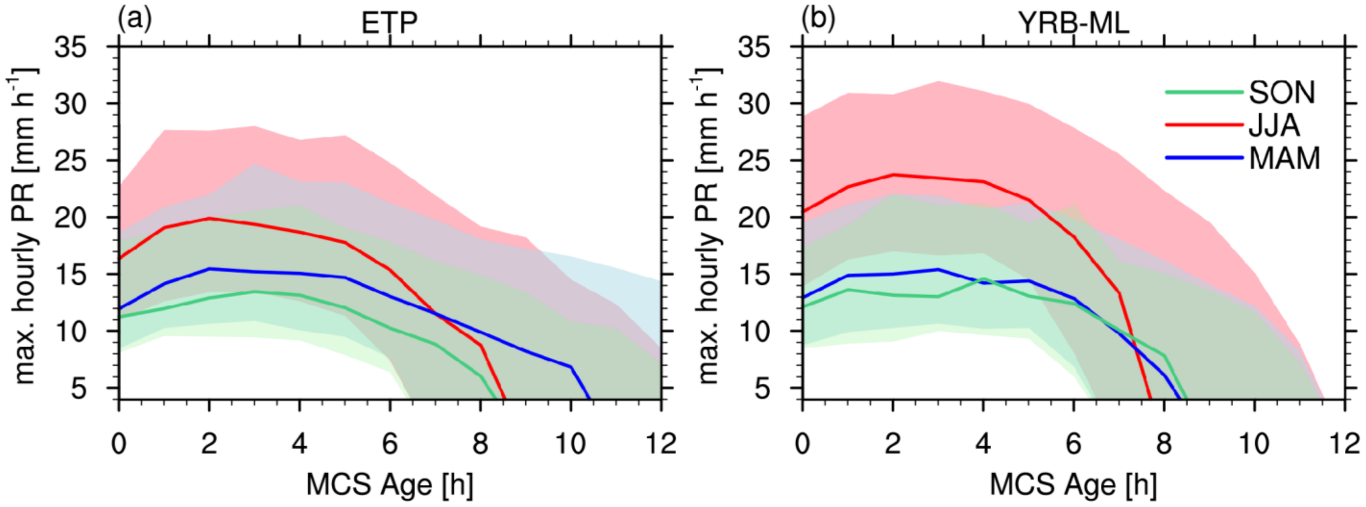
Frequency-intensity structure of MCSs and non-MCSs hourly precipitation



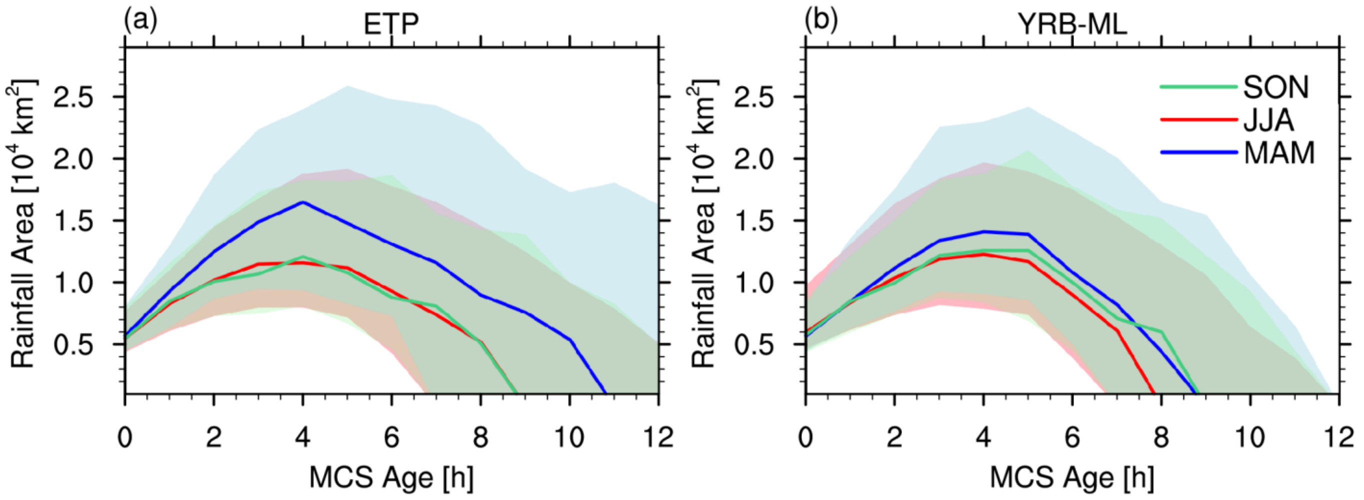
- The frequency of intense precipitation from MCSs is substantially higher than that from non-MCSs precipitation over the ETP, YRB-ML and LYB in summer, especially over the ETP in all three seasons, indicating that MCSs plays a dominant role in contributing to summertime extreme intense precipitation events

The dynamic evolution of MCS precipitation characteristics over ETP and YRB-ML

The dynamic evolution of MCS maximum hourly precipitation (unit: mm h^{-1})



The dynamic evolution of MCS rainfall area (unit: 10^4 km^2)



1) There is a rapid intensification in the first two hours after the MCS genesis, in which the maximum hourly precipitation reaches its peaking phase. It peaks two hours before MCSs reach their largest size;

2) The maximum hourly precipitation persists in the next 2~3 hours, then it decreases rapidly when the MCS rainfall area becomes smaller.

3) Springtime MCSs over the ETP have a larger rainfall area, with a higher growth rate of rainfall area during the first four hours, and they last longer than that of the other three sub-regions.

1. Short summary for the MCS precipitation characteristics over East Asia: regional differences and seasonal variations

We have used the IRT method to investigate MCS precipitation characteristics over East Asia (2008~2016), focusing on the regional differences and seasonal variations:

1) The YRB-ML receives the largest amount and exhibits the most pronounced seasonal cycle of MCS precipitation in eastern China. MCS precipitation over YRB-ML can exceed 2.6 mm d^{-1} in June, contributing over 30.0% of April to July total rainfall. Particularly long-lived MCSs occur over the ETP, 25% of MCSs over the ETP persist for more than 18 hours in spring.

2) Spring MCSs feature larger rainfall areas, longer durations and faster propagation speeds. Summer MCSs have a higher precipitation intensity, with a more pronounced diurnal cycle.

3) MCSs reach peak hourly rainfall intensities during the time of maximum growth (a few hours after genesis), reach their maximum size around 5 hours after genesis, and start decaying thereafter.

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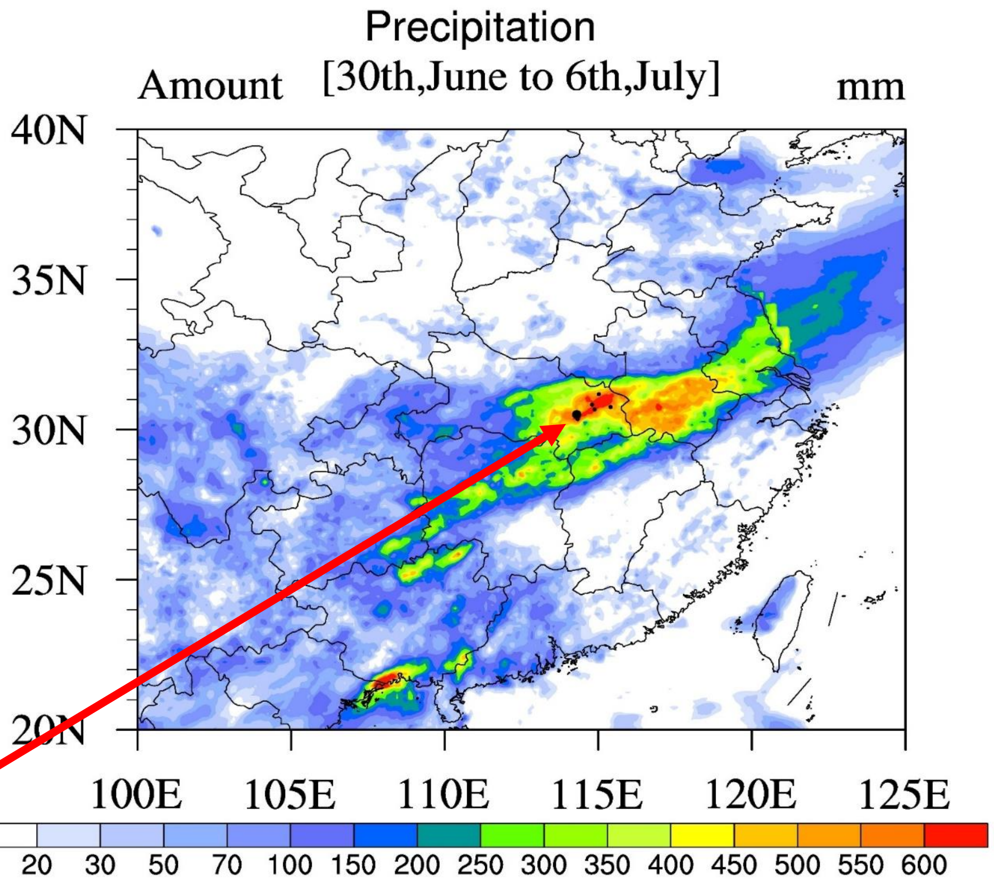
2016 Eastern China flooding (a typical “Mei-yu” front heavy rainfall)

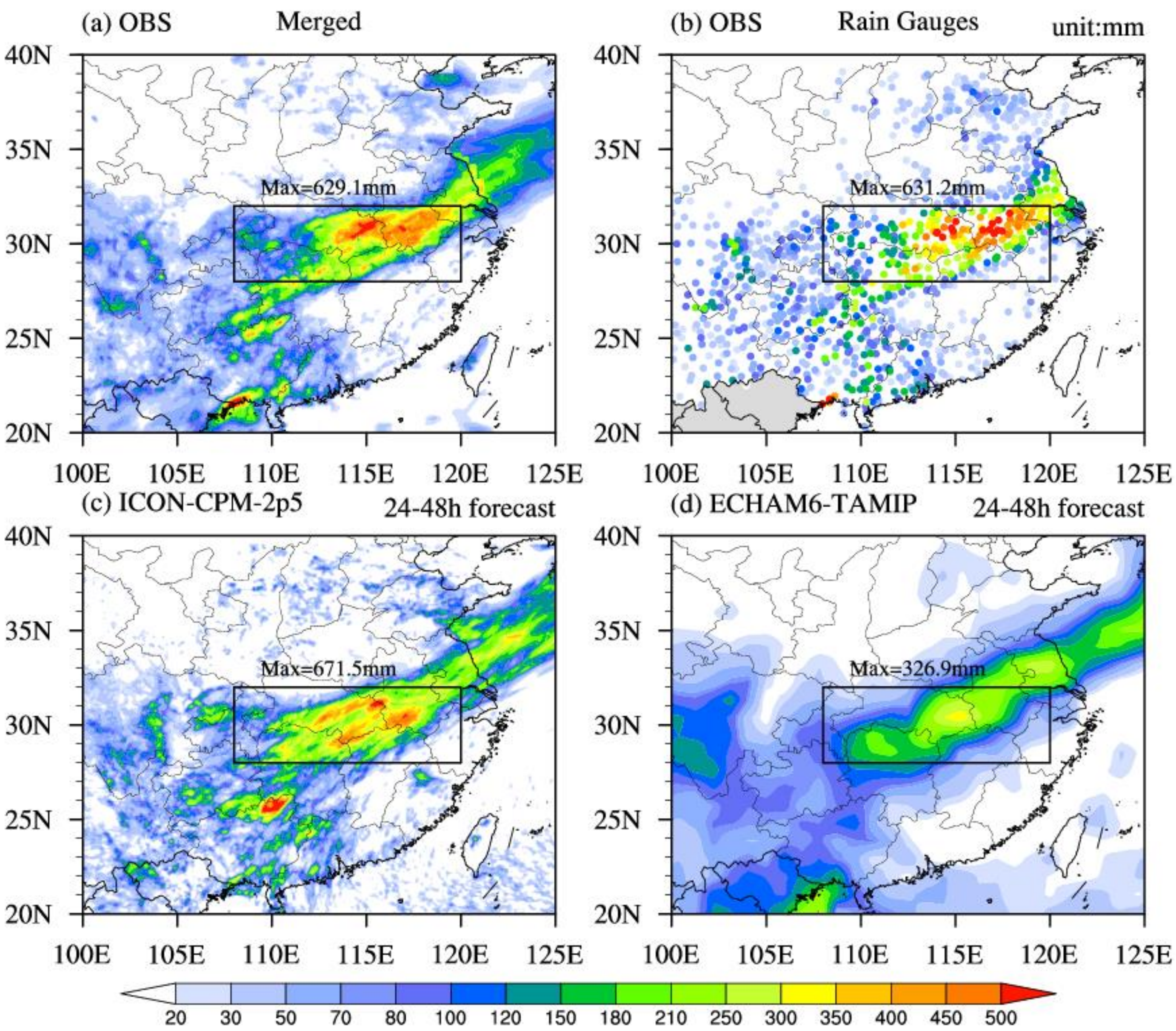
The second-costliest monsoon flood on record in China



From *Wuhan Meteorological Observatory*

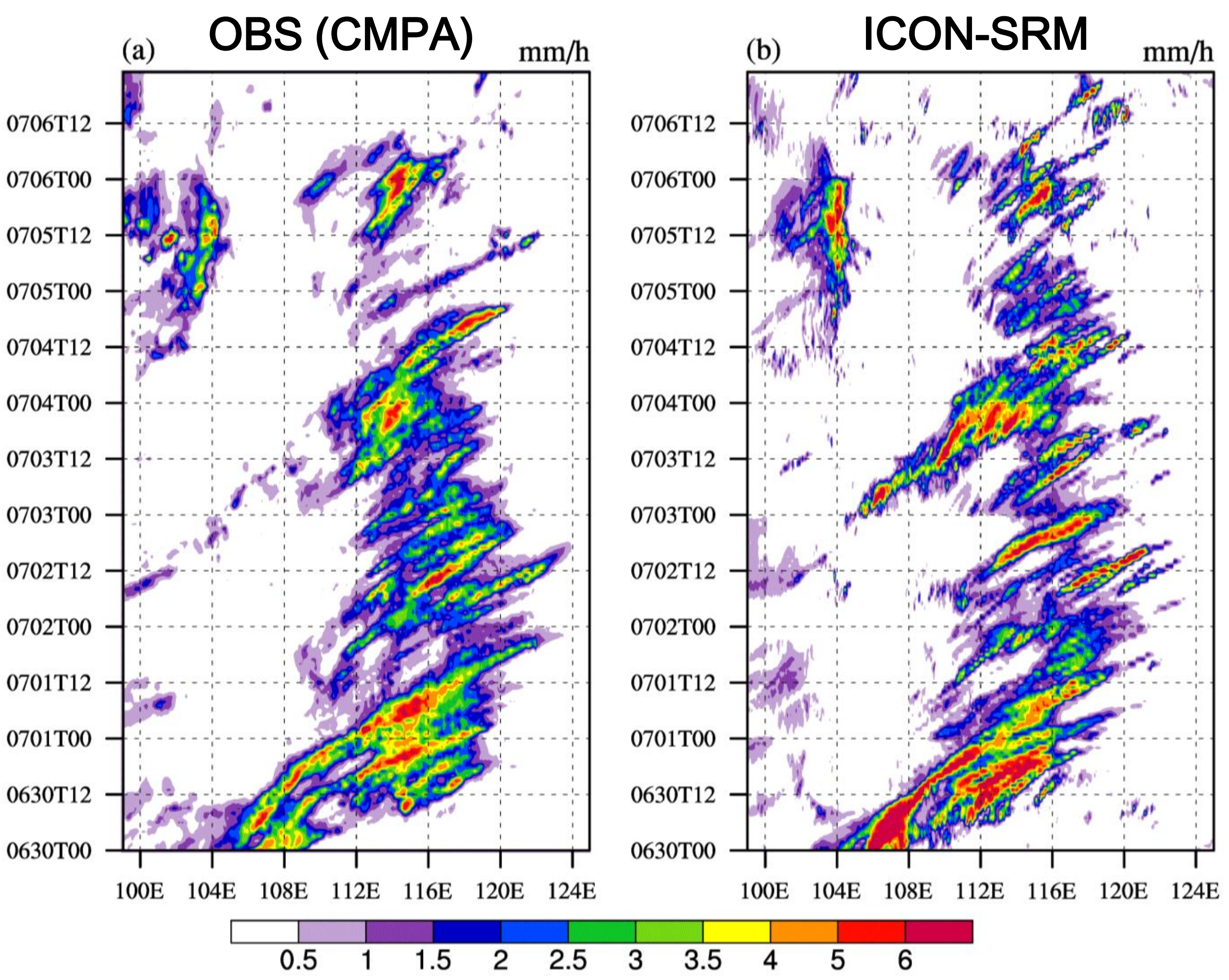
Puxi Li, Tianjun Zhou, Kalli Furtado*, Haoming Chen, Jian Li, Zhun Guo, Sean Milton and Paul R. Field. Li P , Guo Z , Furtado K , et al. Prediction of heavy precipitation in the eastern China flooding events of 2016: Added value of convection-permitting simulations[J]. Quarterly Journal of the Royal Meteorological Society, 2019, 145(724). doi: 10.1002/qj.3621

Spatial pattern of accumulated rainfall amount (OBS and model simulations)



Eastward propagation of heavy precipitation (OBS and simulation)

Hovemuller diagram of hourly precipitation



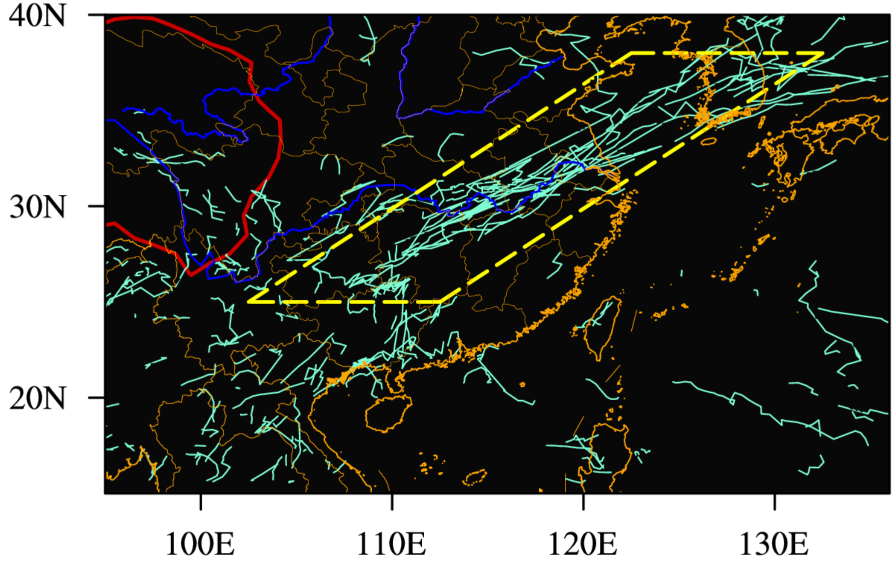
Along the Yangtze River valley

28-32N mean

MCS tracks and MCS precipitation

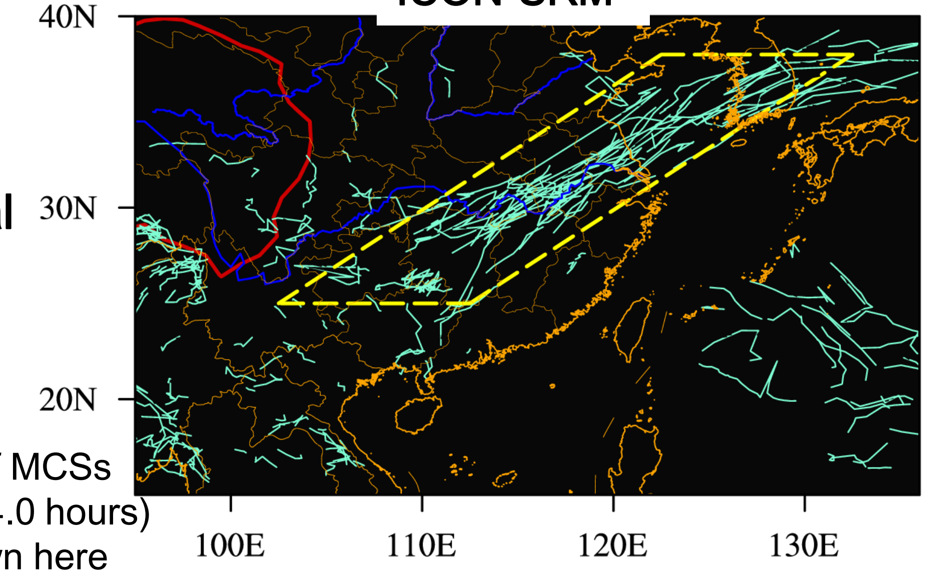
MCS tracks OBS

83 in total



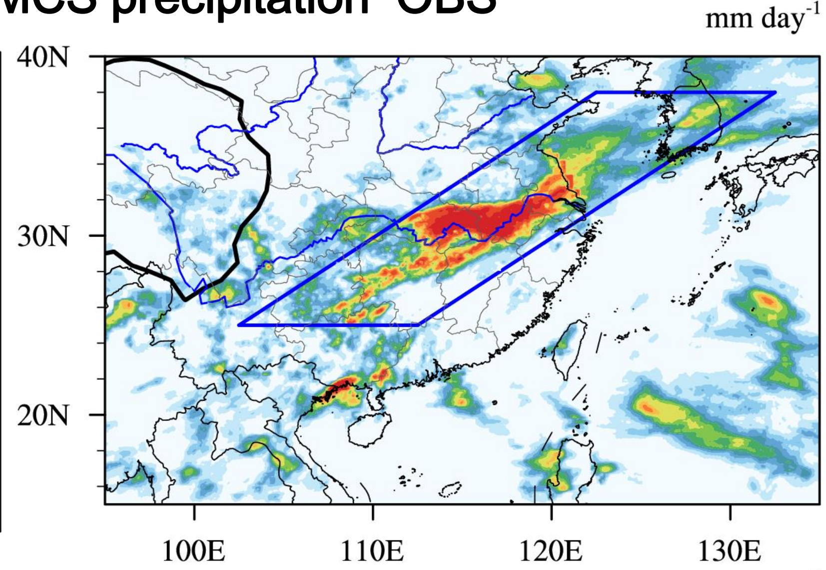
(b) MCS Track **ICON-SRM**

85 in total

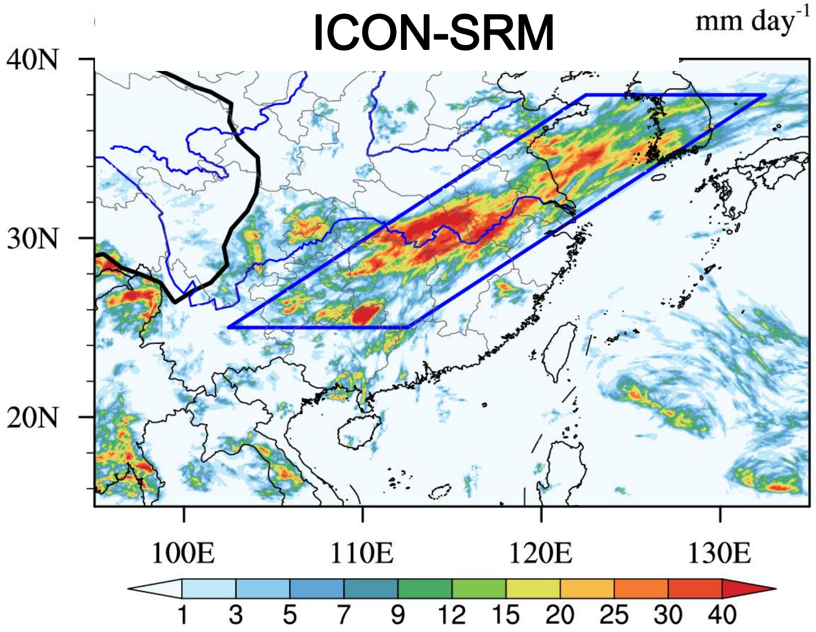


Tracks of MCSs (duration≥4.0 hours) are shown here

MCS precipitation OBS



ICON-SRM



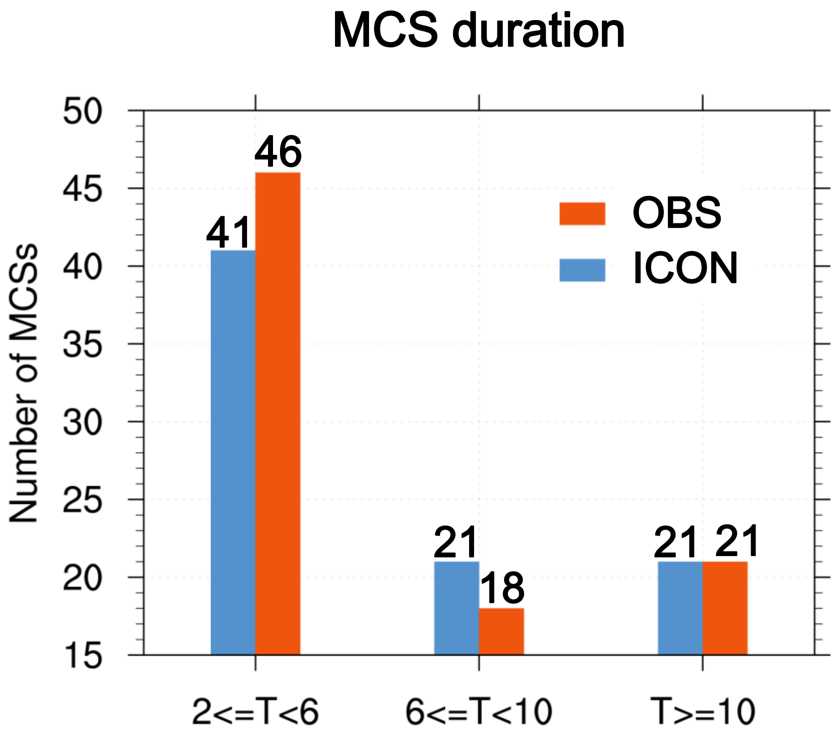
The term "MCSs" used in this work is defined relatively loosely, to encompass a broader population of mesoscale convective entities:

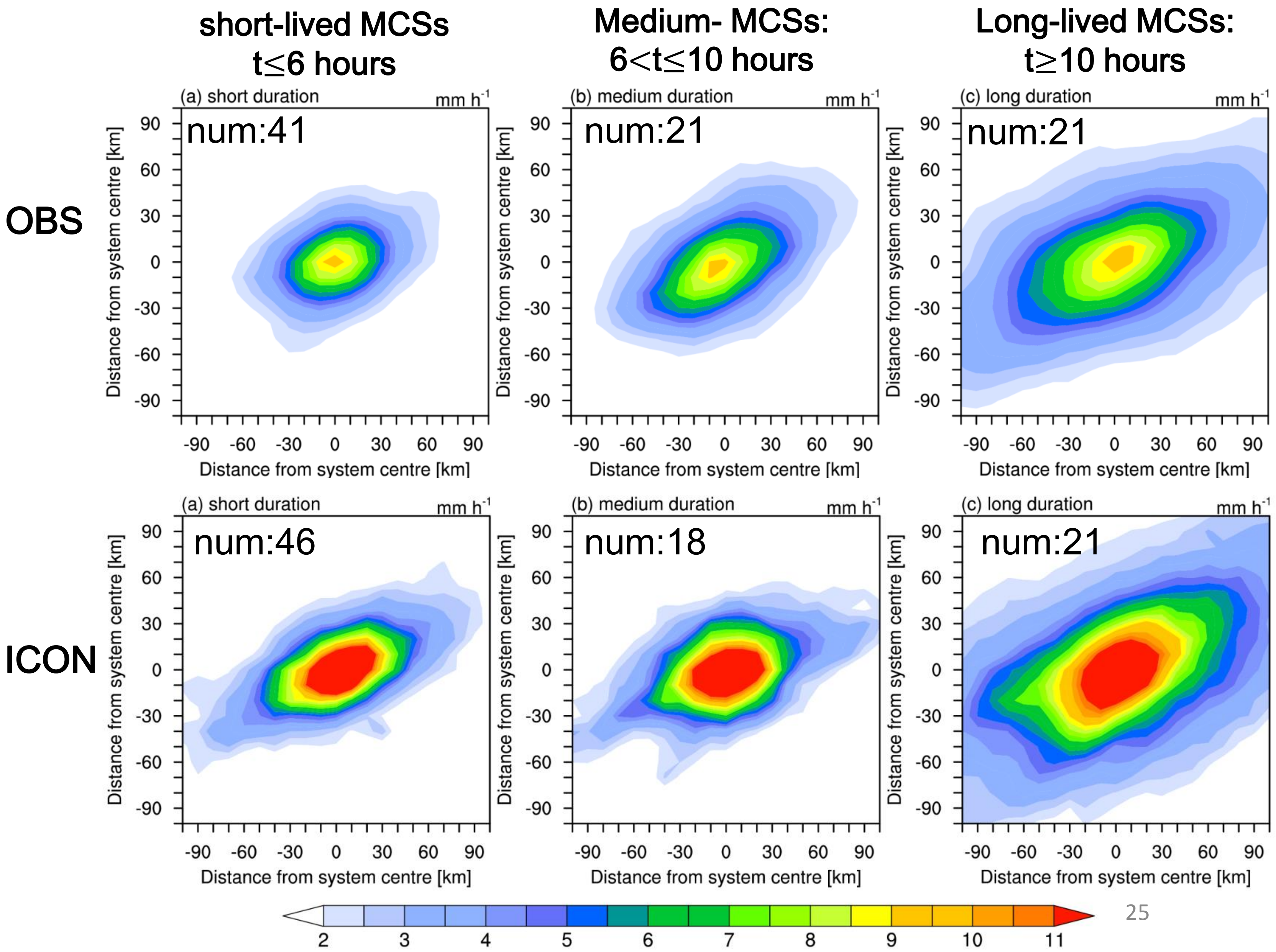
1) minimum length of 200 km;

2) Rainfall intensity≥3.0 mm h^{-1};

3) Rainfall duration≥ 2hours.

MCS precipitation characteristics (duration, rainfall area, average precipitation)

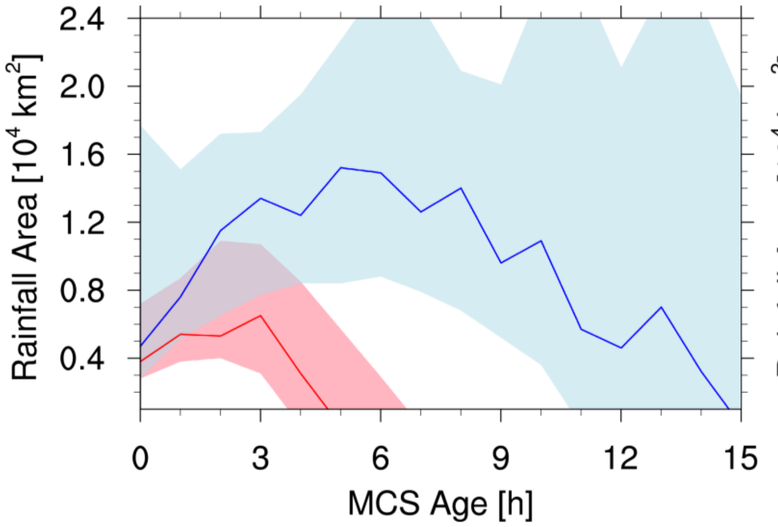




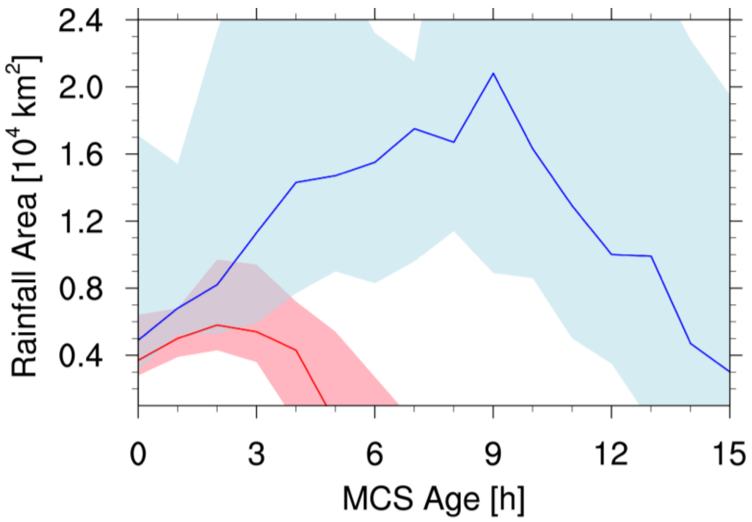
The dynamic evolution of MCS precipitation characteristics

rainfall area

OBS

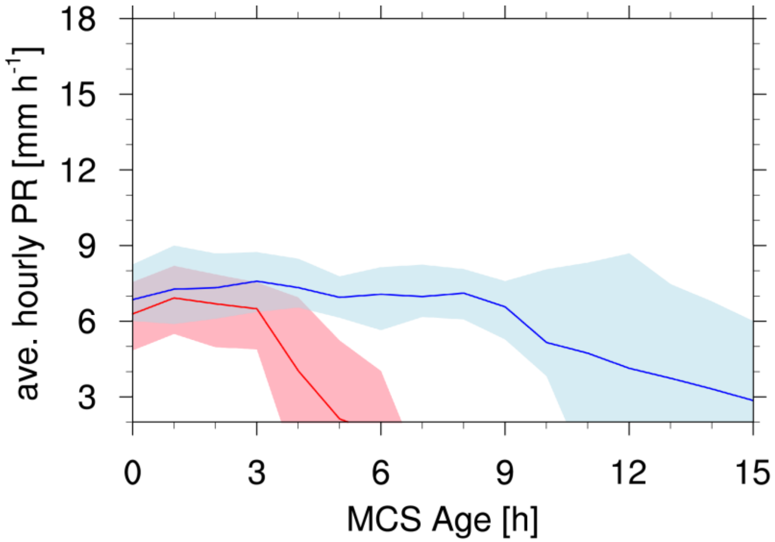


ICON-SRM

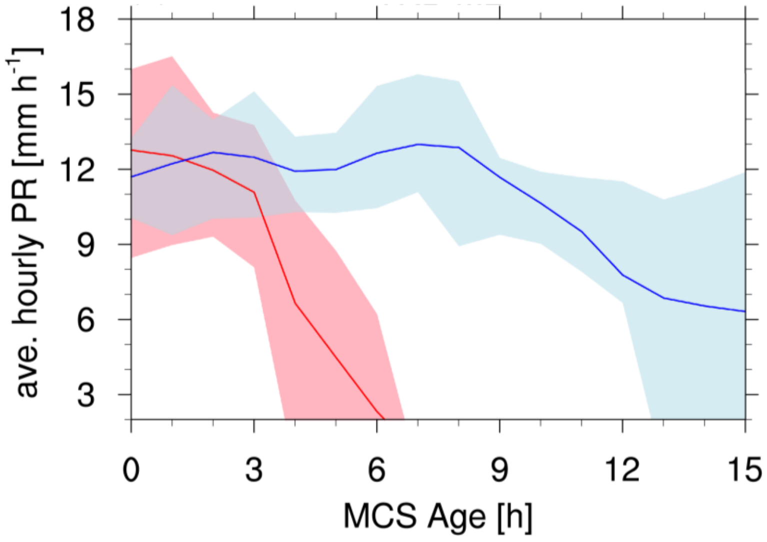


average hourly precipitation

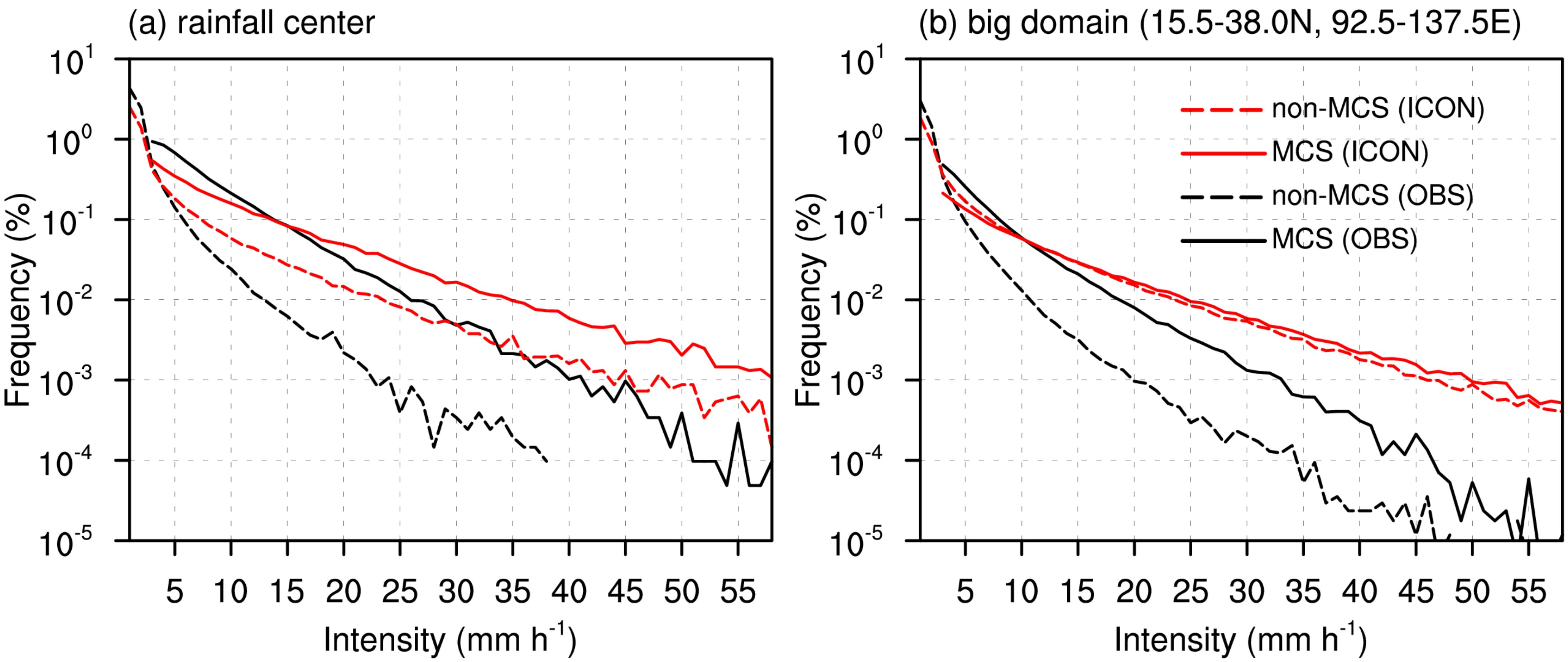
OBS



ICON-SRM



“Frequency-Intensity” structure of MCS precipitation



2. Short summary for simulating MCSs over eastern China with ICON HD(CP)^2 during a typical Mei-yu heavy rainfall event

We have used the IRT method to identify and track MCSs over eastern China in both observation and ICON-SRM during a typical Mei-yu heavy rainfall event:

1) An extremely heavy rainfall event hit YRB-ML from 30th June to 6th July in 2016. This event was characterized by high precipitation intensity, long duration rainfall and was associated with large-scale circulations that were favorable for producing extremes of organized MCSs in the Mei-yu front region.

2) ICON-SRM can reasonably simulate the eastward propagation of rain-band, and well reproduce MCS precipitation characteristics (MCS duration, rainfall area and the dynamical evolution) along the Mei-yu front. But it overestimates MCS precipitation intensity, associated with stronger upward motions.

Conclusion and Prospects

CONCLUSIONS:

1) Precipitation characteristics of MCSs over East Asia exhibit distinct regional differences and remarkable seasonal variations. YRB-ML receives the largest amount and exhibits the most pronounced seasonal cycle of MCSs precipitation in eastern China.

2) Spring MCSs feature larger rainfall areas, longer durations and faster propagation speeds. Summer MCSs have a higher precipitation intensity, and a more pronounced diurnal cycle.

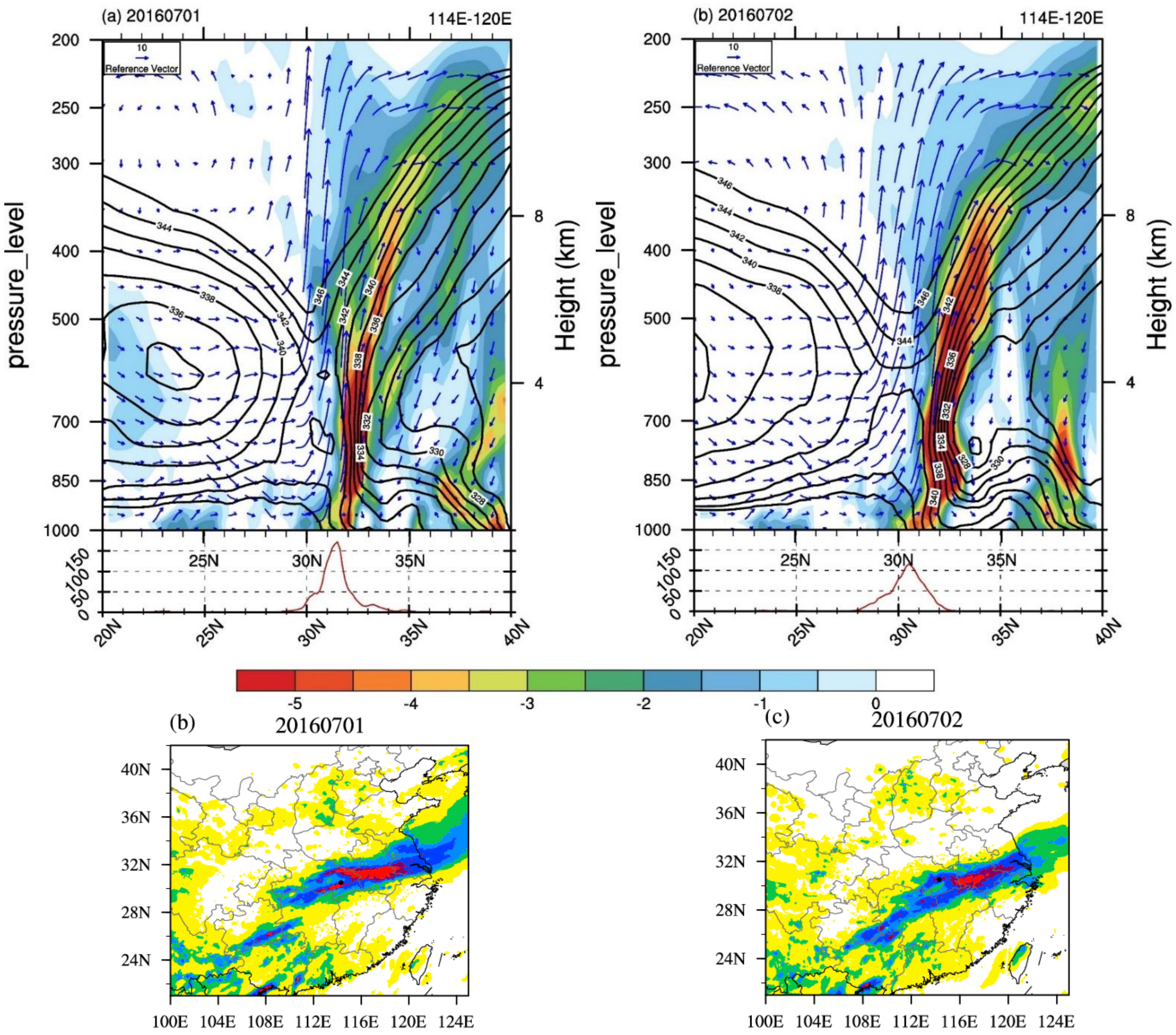
3) ICON-SRM can reasonably capture the observed MCS precipitation characteristics but overestimate MCS precipitation intensity, associated with stronger upward motions.

PROSPECTS:

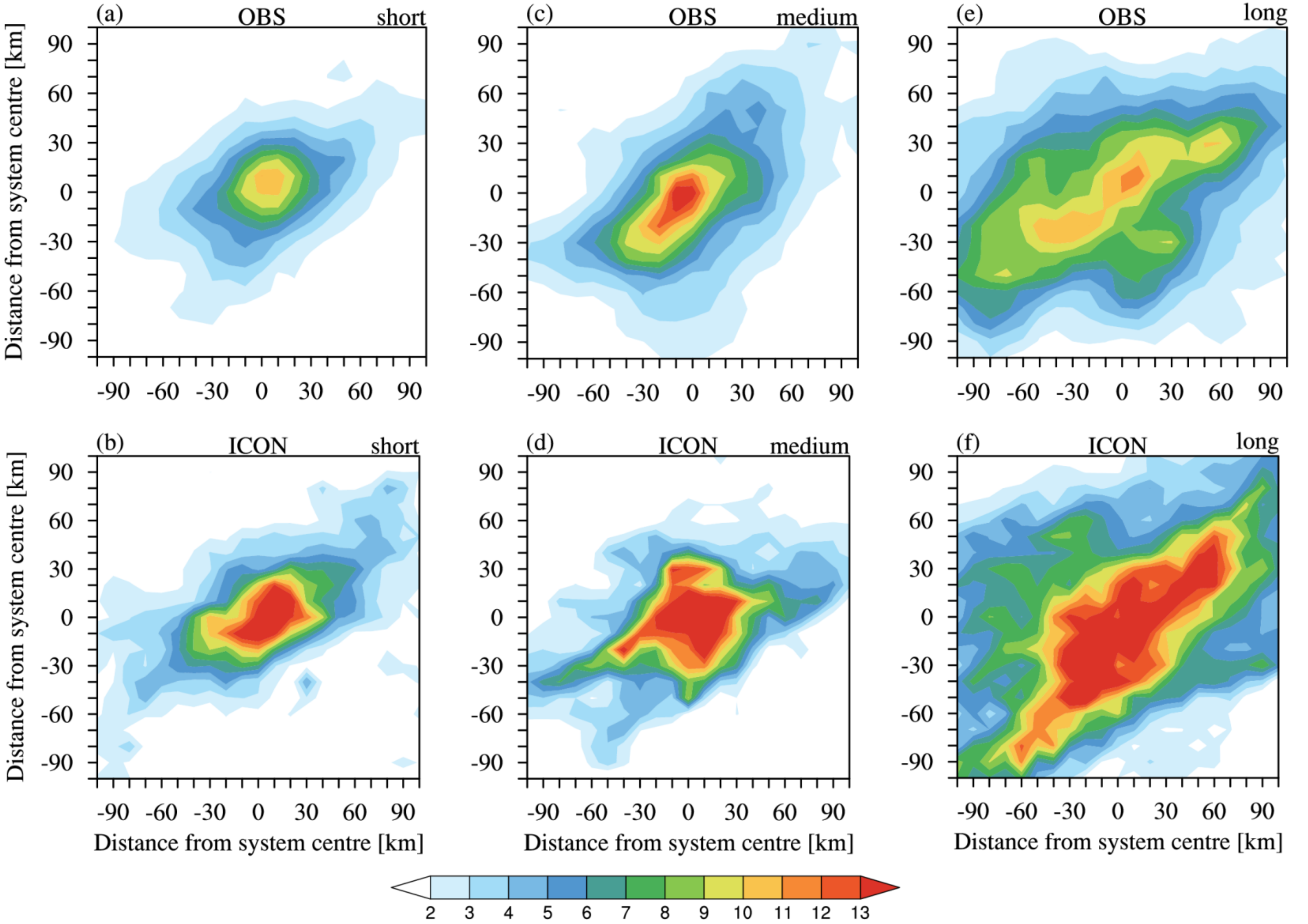
1) Internal structures of MCSs, as well as the large-scale circulations will be further investigated (ongoing work).

2) More CPM simulations with longer time-period are needed to thoroughly evaluate CPM performance in simulating MCSs, and to investigate future changes of MCSs.

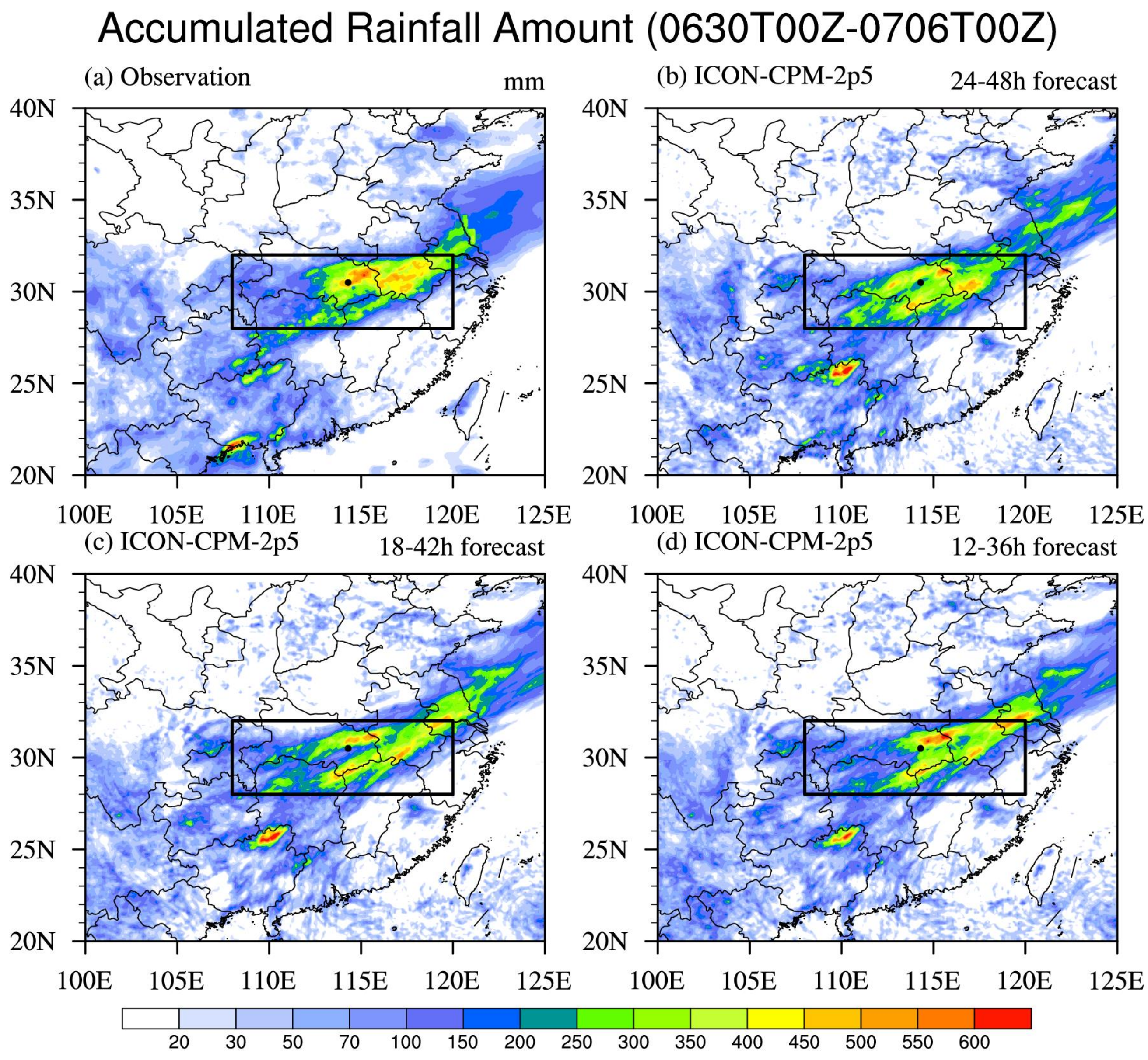
Vertical Structure of Mei-yu front



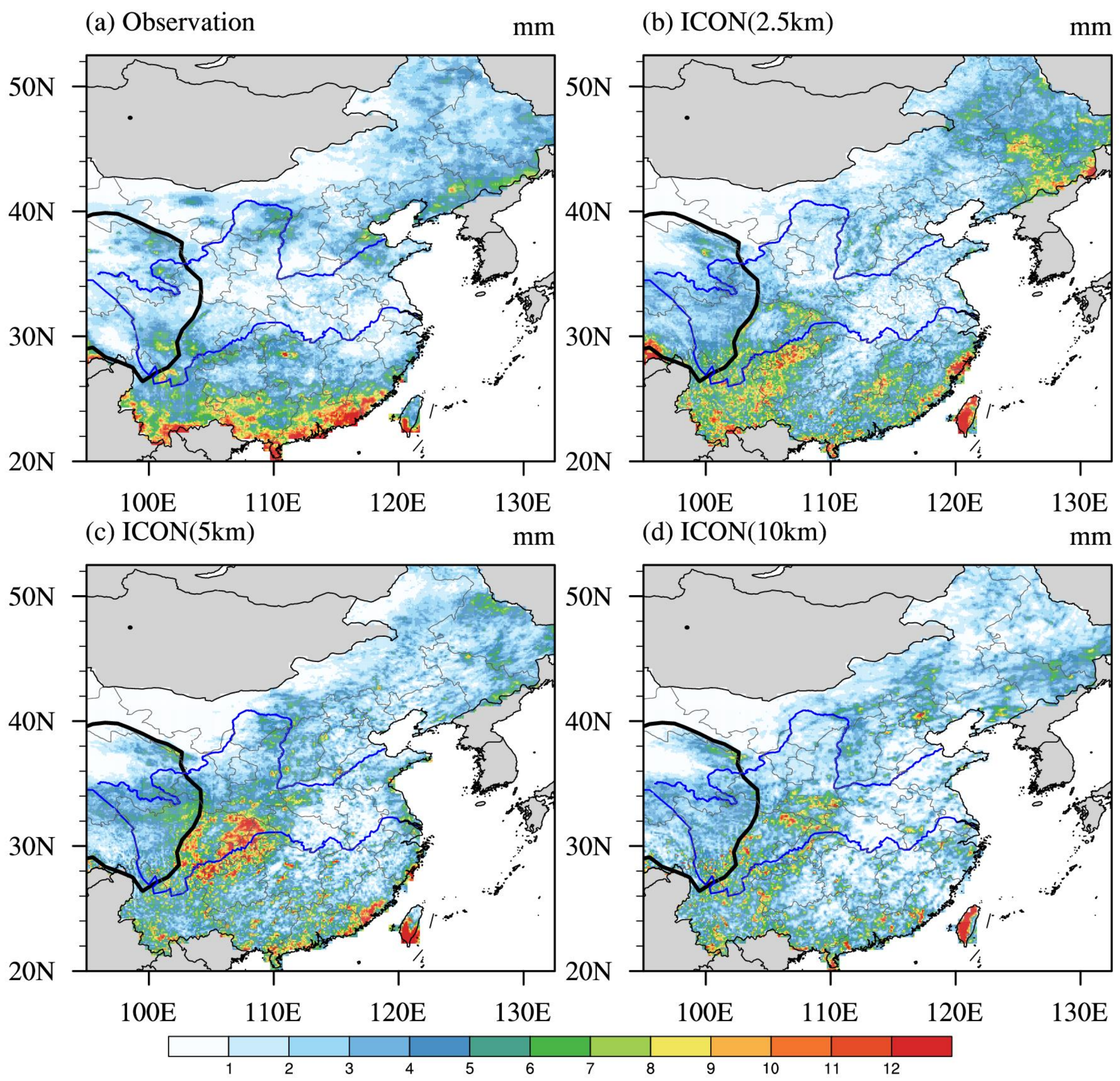
MCS composite at peak phase



12-36h forecast, 18-42h forecast and 24-48h forecast of ICON-SRM

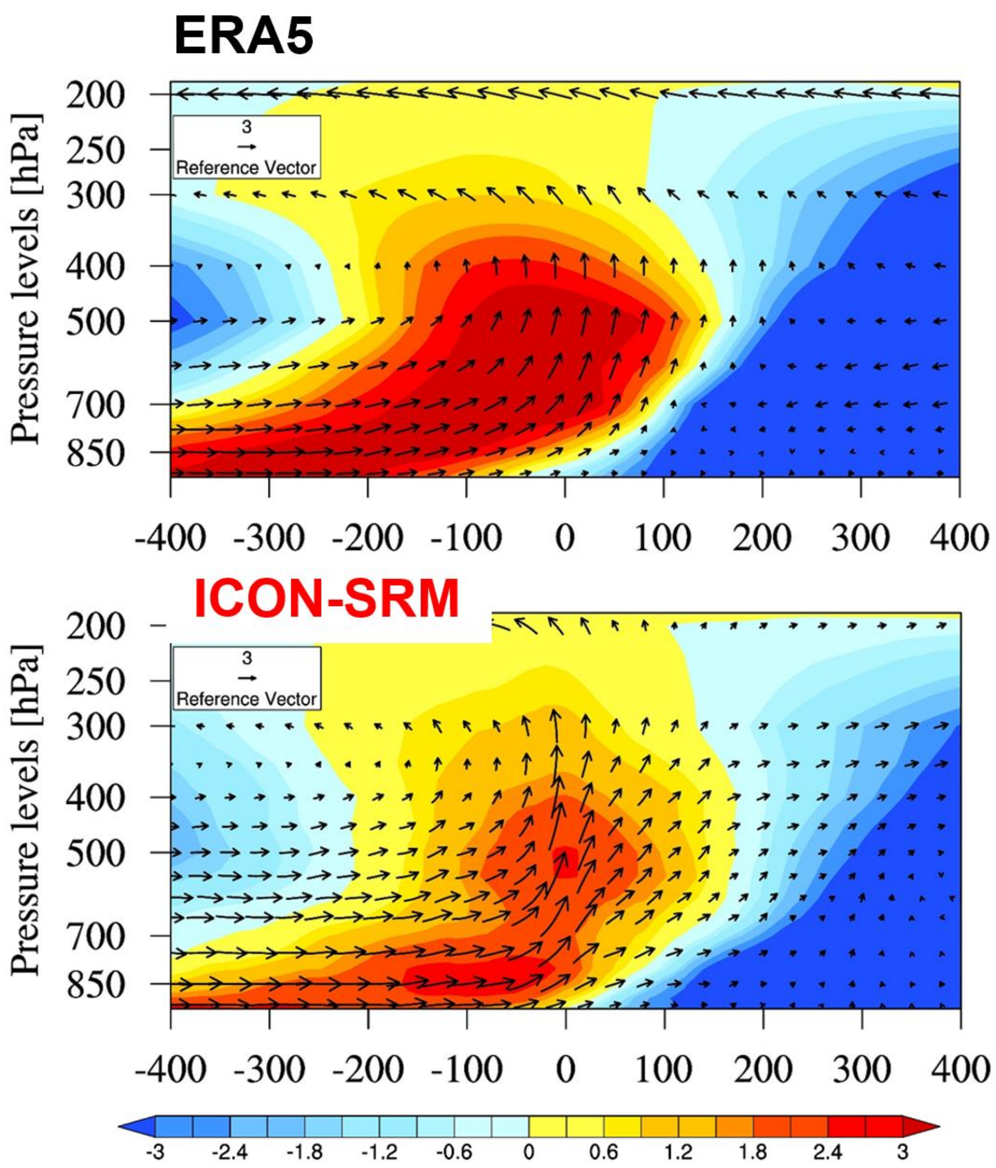


Global ICON-SRM (one-month long simulation: August, 2016)



no_conv experiment

Vertical structure of MCS in ERA5 and ICON-SRM



The shading area indicates the anomaly equivalent potential temperature (unit: K);

the vector indicates the horizontal wind (unit: m s^{-1}) and vertical upward motion (unit: -1.0×10^{-2} Pa s^{-1});

The x axe shows relative distance away from the MCSs center (south-to-north direction; unit: km).

unit: km

averaged along east-to-west axis within 400.0 km of the MCS rainfall center.