中国气象局地球系统数值预报中心
CMA EARTH SYSTEM MODELING AND PREDICTION CENTRE

Evaluation and Error Analysis of the July 2021 Extremely Severe Rainstorm Simulated by CMA-MESO Model

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10 Sep 2024

CONTENT

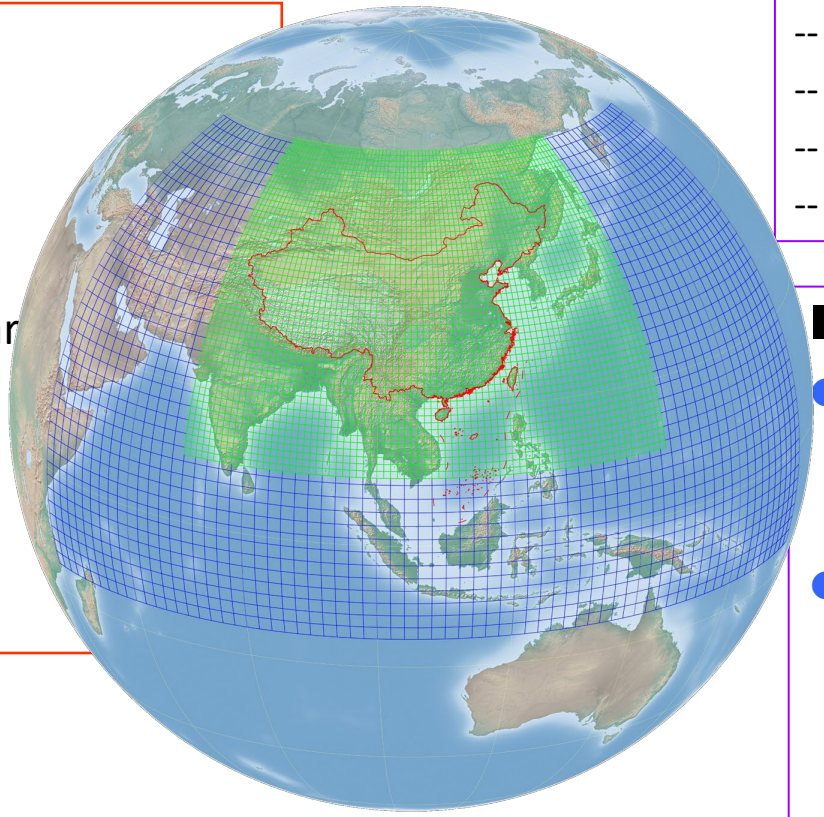
OUTLINE

1. Introduction of CMA-MESO V5.1

➢ Mesoscale numerical weather forecasting model of China Meteorological Administration

■ Basic

- Horizontal grid-spacing
  -3 km* 3km
- Vertical level
  - 50 levels
- Background field and lateral boundar
  - NCEP-GFS
- Daily routine
  - cycle: 8 /day
  - forecast time: 36/72 hours
  - forecast area: 10~60.1° N，70~145° E



■ Physical process

-- Radiation: RRTM LW & Dudhia SW

-- Cumulus: shallow convection

-- microphysics: WSM6

-- Cloud : EC

-- Land surface: NOAH

-- PBL : NMRF PBL

■ Assimilation system

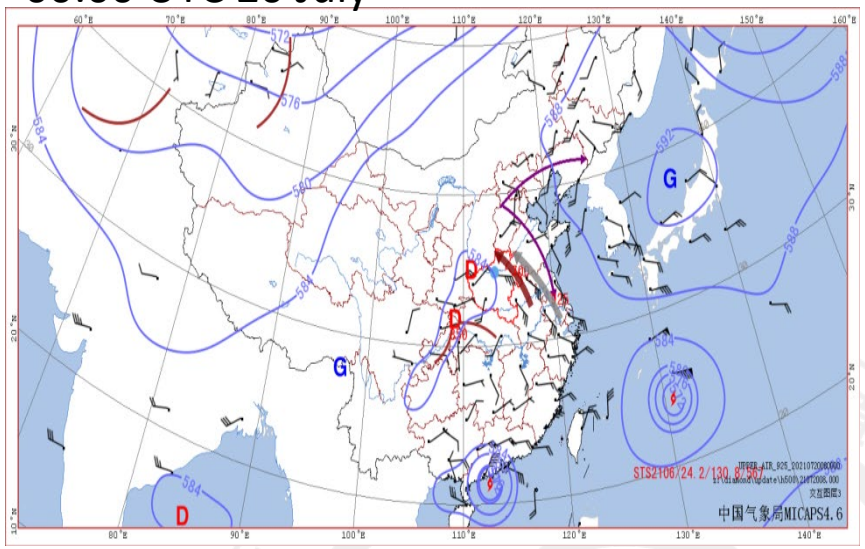
- Assimilation methods
  - high resolution 3D variational assimilation
  - 3D cloud analysis
- Observations
  - conventional observation
    - sounding、boats、bouy、airport
    - Meteorological station
  - unconventional observation
    - radar
    - satellite

2. Weather Background and Methods

■ Weather Background

17-21 July 2021 extremely severe rainstorm in Henan province

00:00 UTC 20 July



- ✓ 24h accumulative precipitation of 20 national meteorological stations in Henan province exceeded historical extreme value
- ✓ 1h precipitation (08:00-09:00 20 July) at Zhengzhou Station was 201.9 mm, exceeded historical extreme value.
- ✓ Long duration、very extreme、severe floods and urban waterlogging

200hPa: upper-level ridge –stable maintenance

500hPa: multiple synoptic-scale system – Inner Mongolia continent high, subtropical high, Typhoon In-Fa , Typhoon Cempaka.

850hPa: vortex

■ Research Methods

- Radar and satellite were applied to evaluate simulated echoes and cloud
- Diagnose source of model error from the perspective of rainstorm mechanism

Echo evaluation method

observation： MaxEcho of national radar
model： MaxEcho of CMA-MESO

threshold value

stratiform clouds （20-35 dBZ）
convective storms （35-50 dBZ）
severe convective storms （≥50 dBZ）

total hours：
occurred total hours

average intensity：
total intensity divide total hours

Cloud evaluation method

observation： Himawari-8 satellite brightness temperature in infrared channel
model： CMA-MESO simulated brightness temperature in infrared channel

MODE: object-based diagnostic evaluation

identify and match observation and simulated targets
Calculate target similarity and evaluate multiple attributes

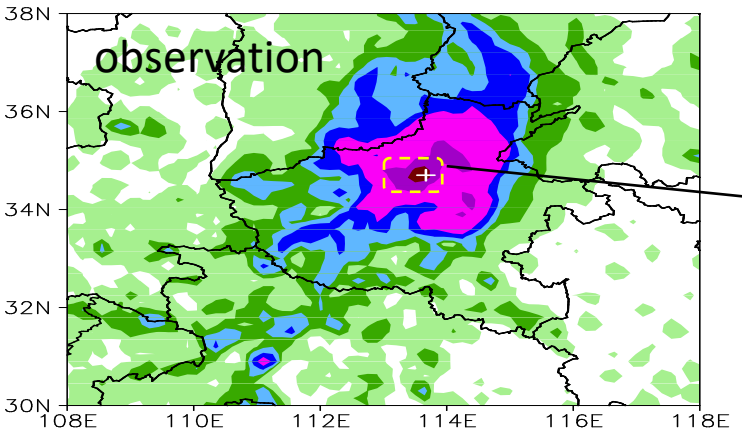
Target area temporal evolution

Target intensity temporal evolution

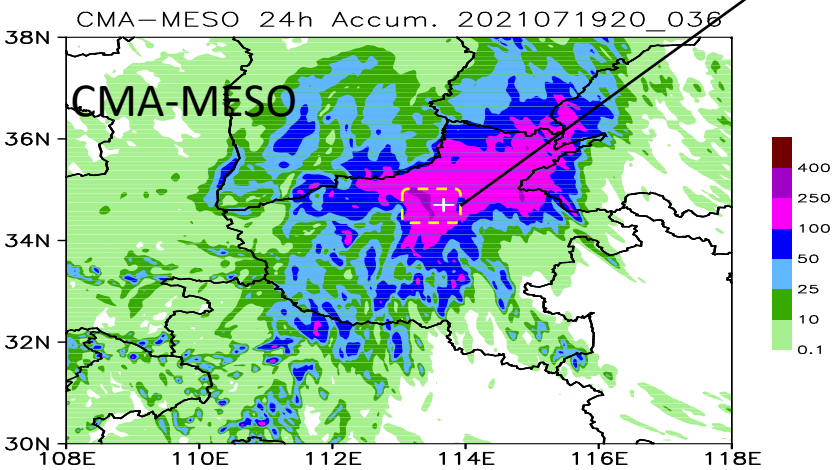
Target position bias

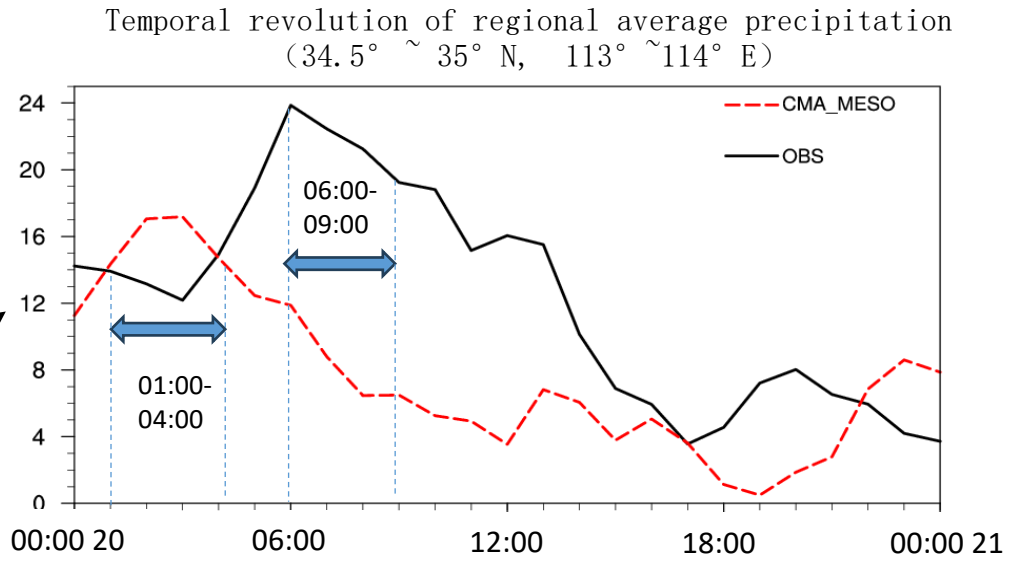
3. Model Evaluation and Error Analysis

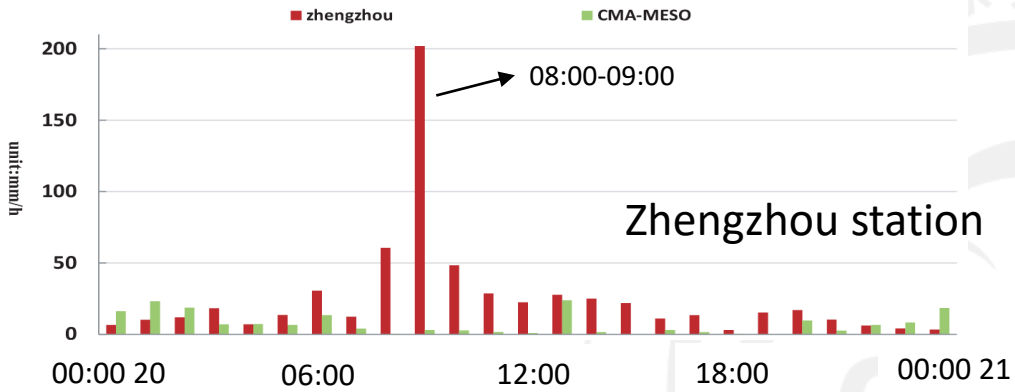
■ Precipitation Evaluation



Note: the cross marks the location of Zhengzhou Station





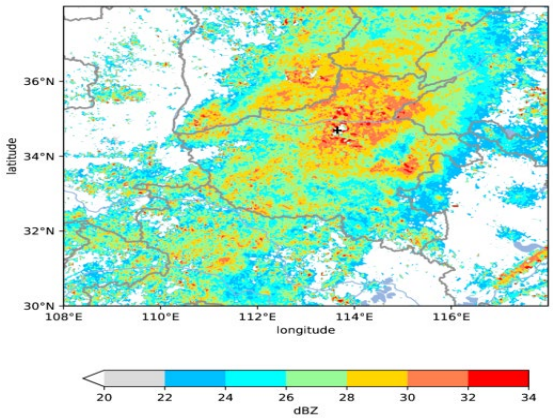


- Well capture main rain band, but underestimate precipitation exceeded 250 mm
- heavy rain center was obvious small and slightly westward to observation
- forecast error on temporal evolution of precipitation, fail to predict extreme precipitation

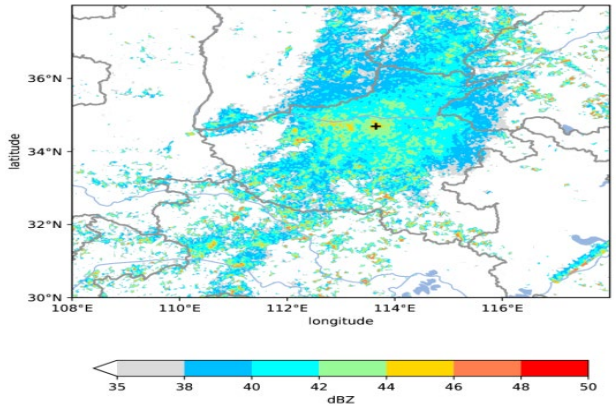
3. Model evaluation and error analysis

■ **Echo Evaluation– average intensity**

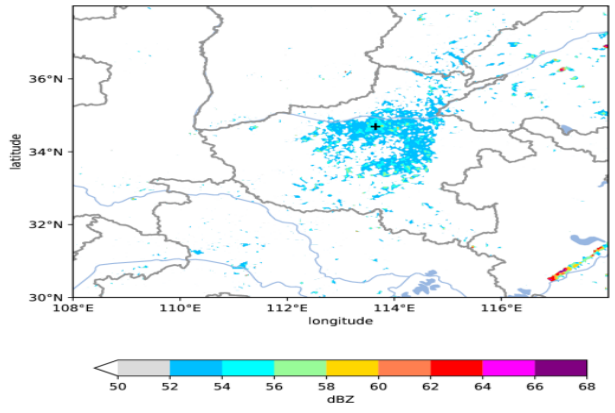
radar



stratiform clouds

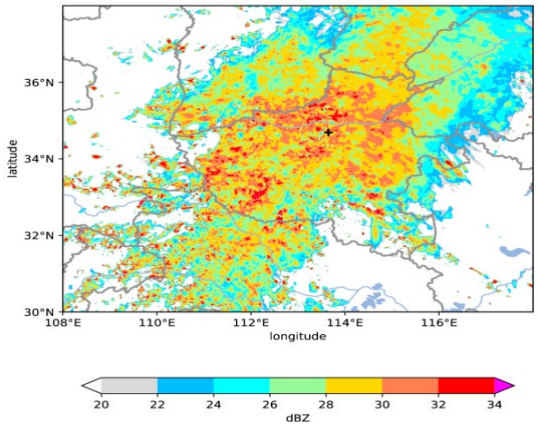


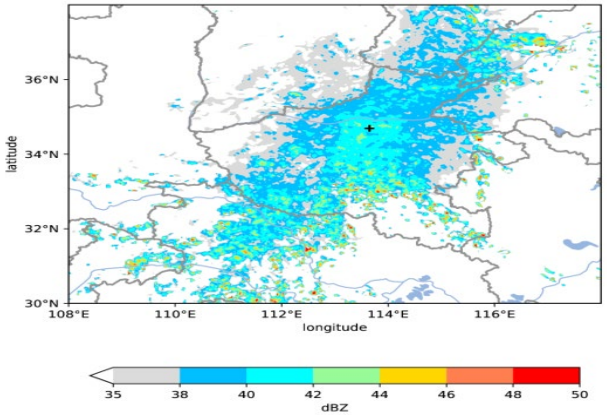
convective storm

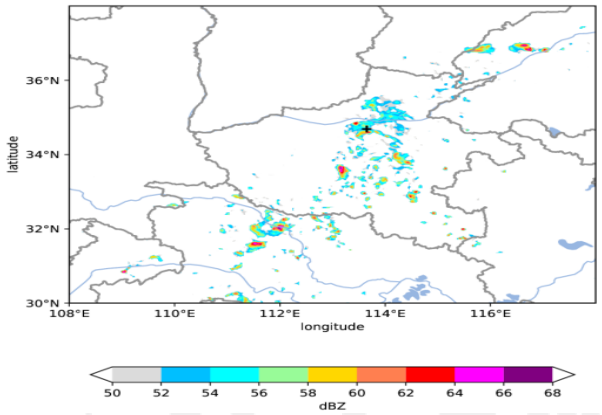


severe convective storm

CMA-MESO



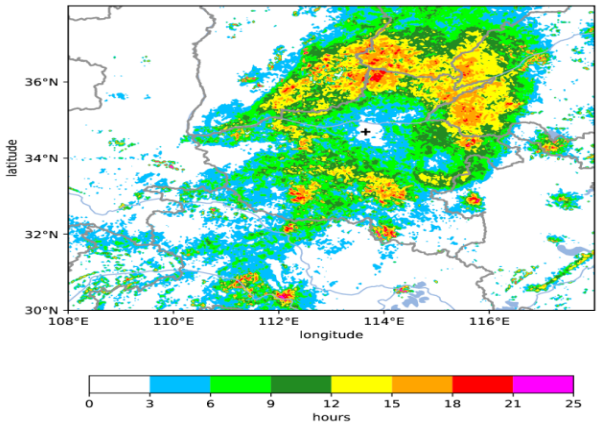




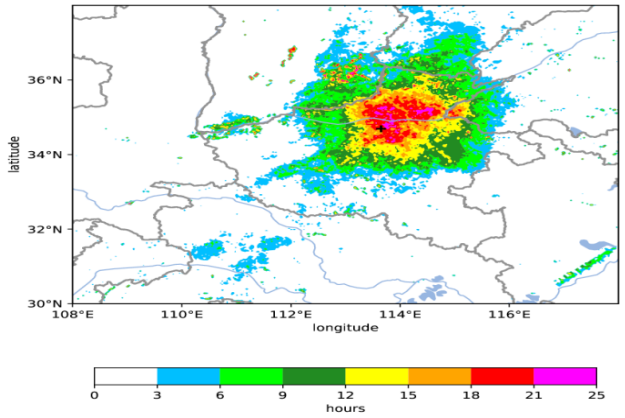
- Average intensity of simulated stratiform clouds were stronger
- convective storm and severe convective storm were similar to observation

■ Echoes Evaluation – total hours

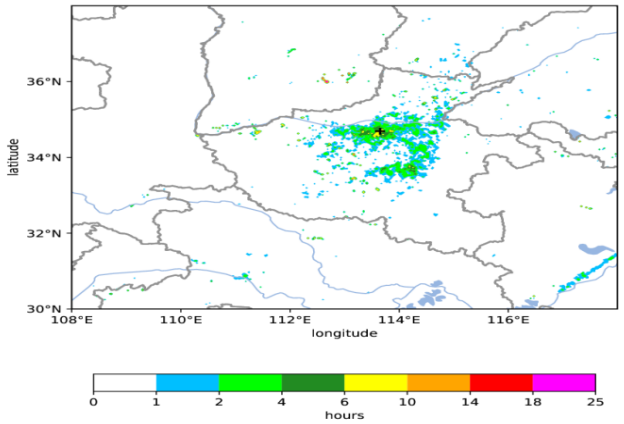
radar



stratiform clouds

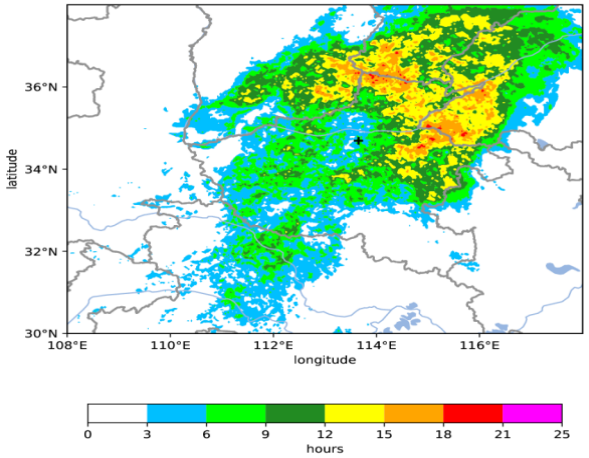


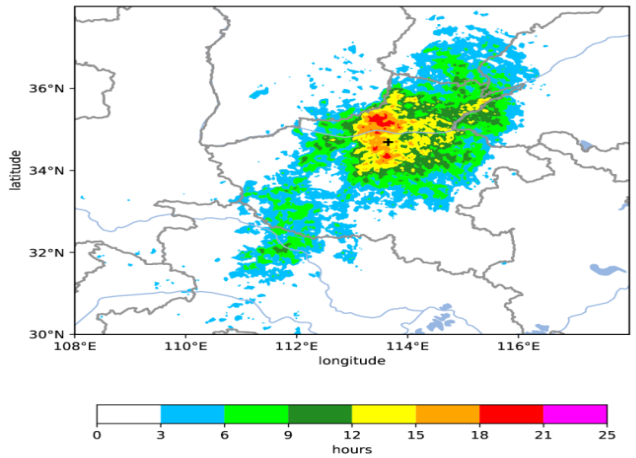
convective storm

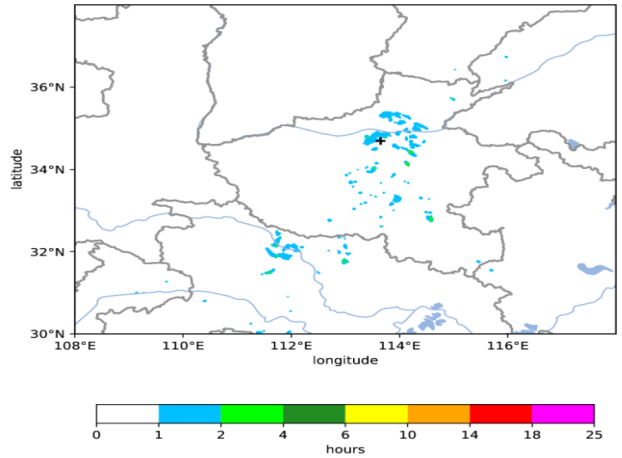


severe convective storm

CMA-MESO



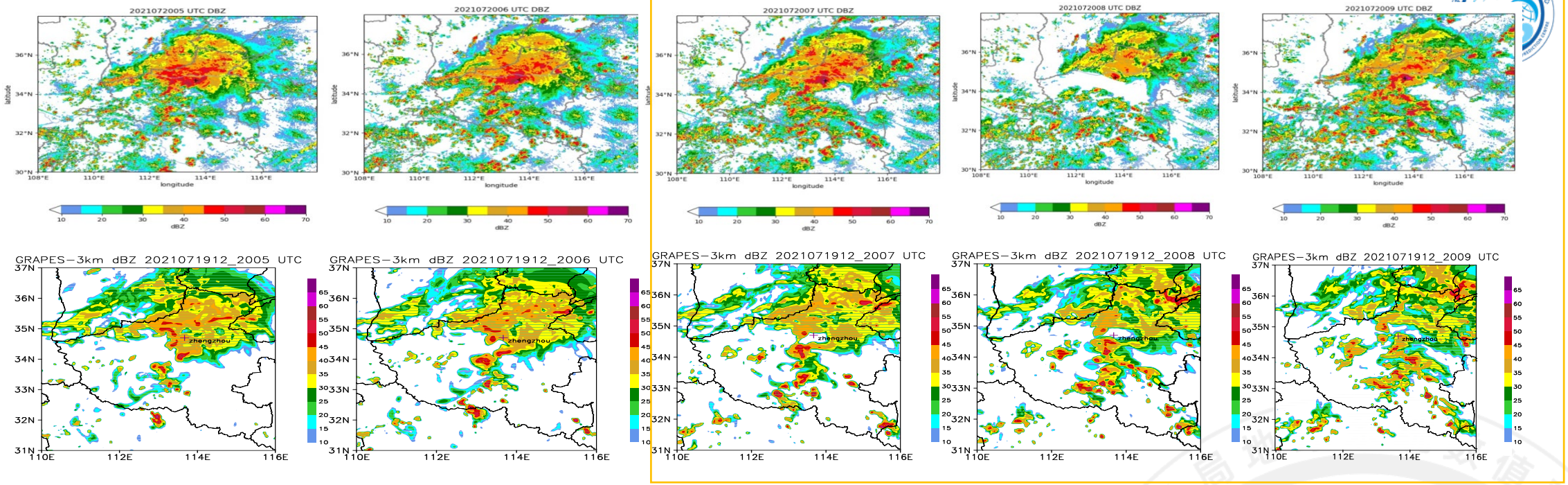




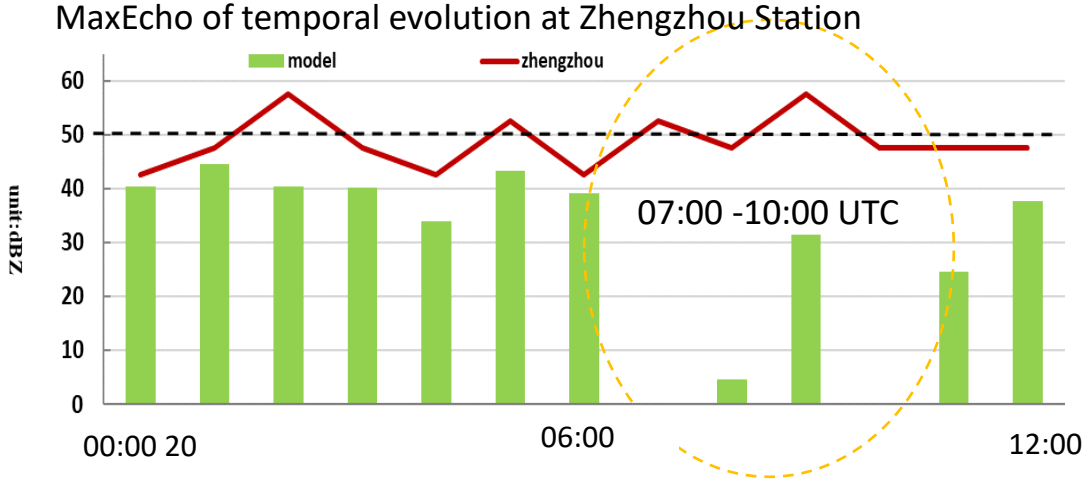
- Observed stratiform clouds were maintained for a long time, well captured.
- Observed convective storms were maintained for 12-21h， severe convective storms were maintained for 2 -10h, but the model seriously underestimated the total hours of convective storm and severe convective storm

■ Echoes Evaluation – hourly MaxEcho

radar



CMA-MESO



Failed to predict strong echoes at Zhengzhou station from 07:00 to 10:00 (2h before and after extreme precipitation)

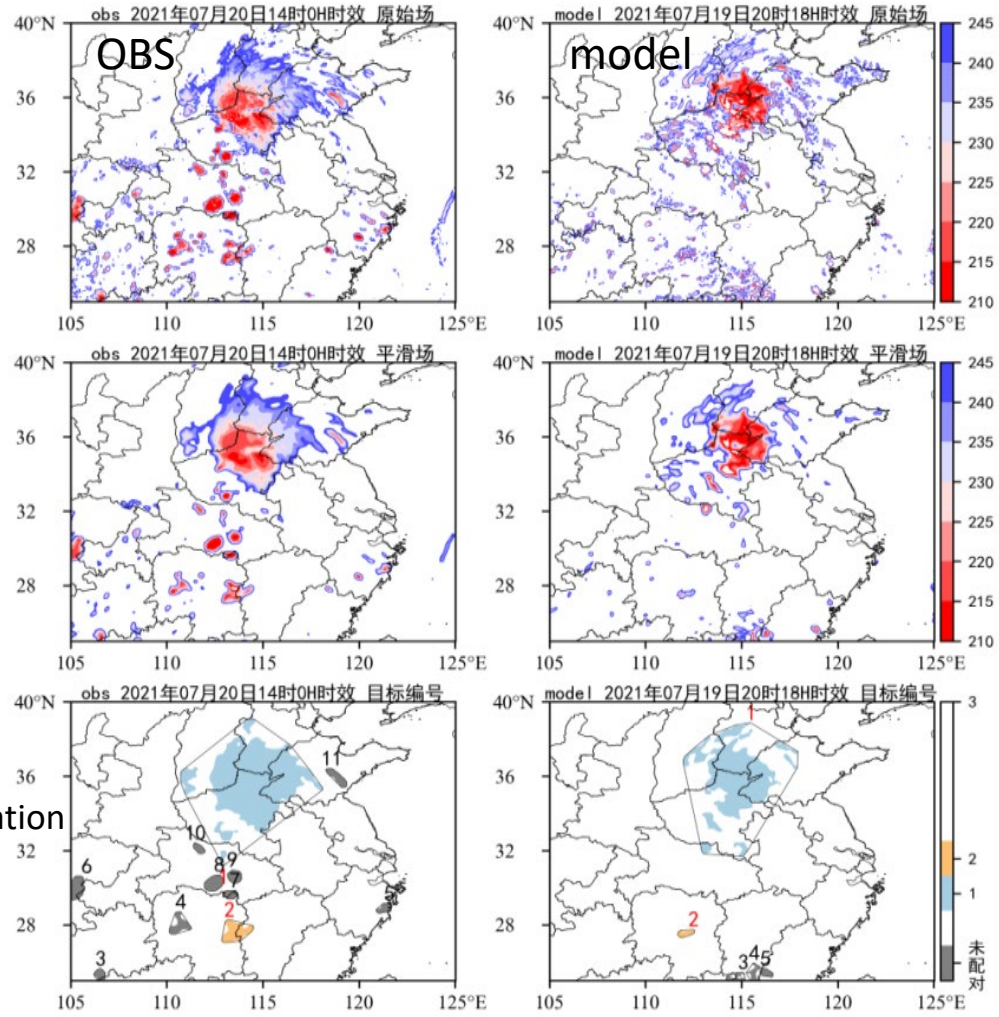
■ Cloud Evaluation

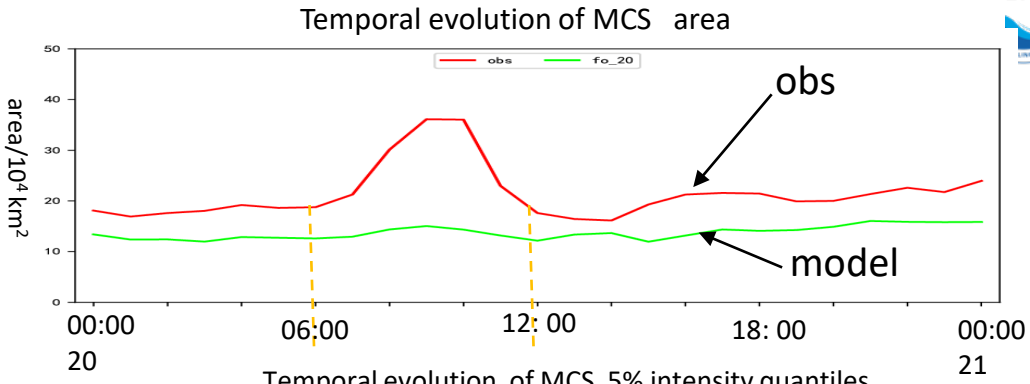
06:00 UTC 20 July 2021

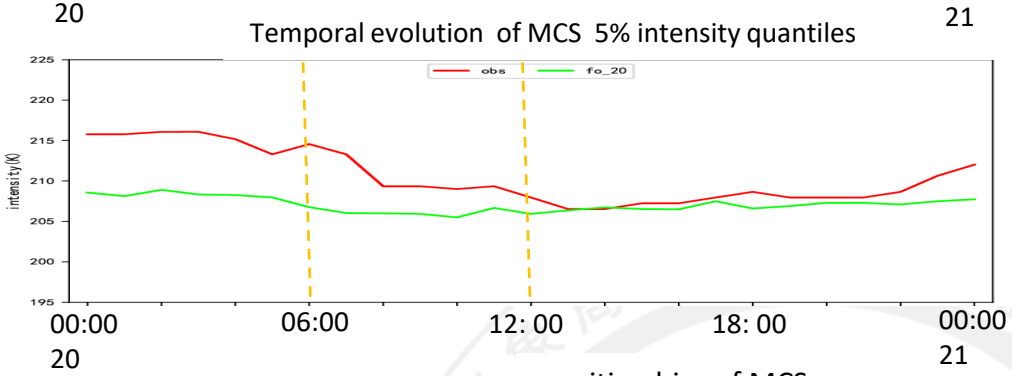
Original field

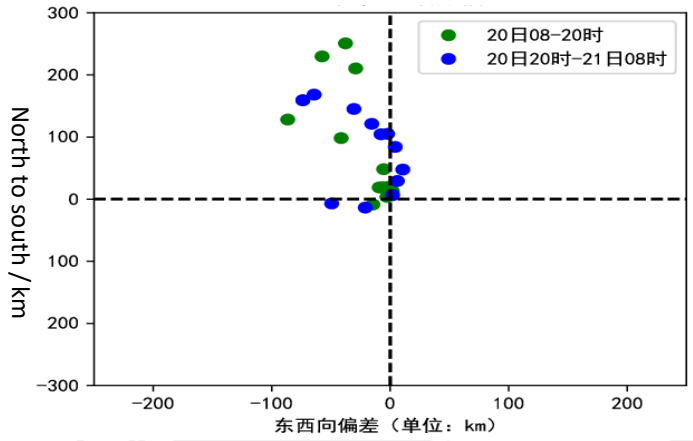
Smooth field

Target identification number









- 06:00 – 12:00： observed MCS area increased by 90%、brightness temperature increased by 10k. Missed the sharply strengthening.
- Positions of simulated MCS were mainly westward and northward to observation

Conclusion of Model Evaluation：

CMA-MESO model well captured the shape of rain band , duration of weak echoes , and the evolution trend of intensity and area of MCS in the early and late stages of the primary precipitation process. But model deviations mainly occurred in the stage of the primary precipitation process:

（1）obviously underestimated strong precipitation , failed to predict extreme precipitation at Zhengzhou Station

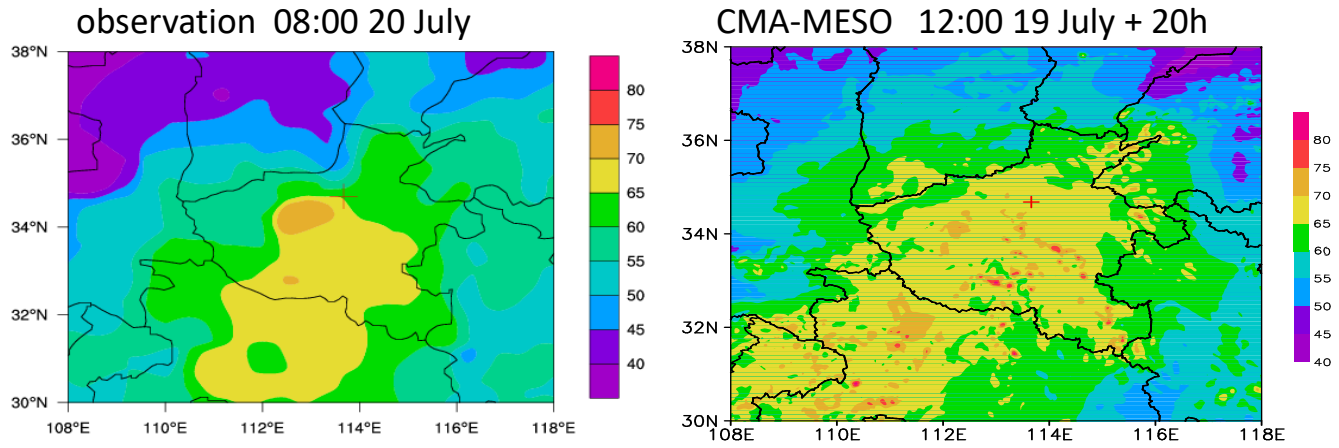
（2） forecast error on temporal evolution of precipitation

（3） seriously underestimated total hours of convective storm and severe convective storm, missed sharply strengthening of MCS, position bias of MCS and center of rainstorm.

3. Model evaluation and error analysis

■ **Error Analysis——water vapor**

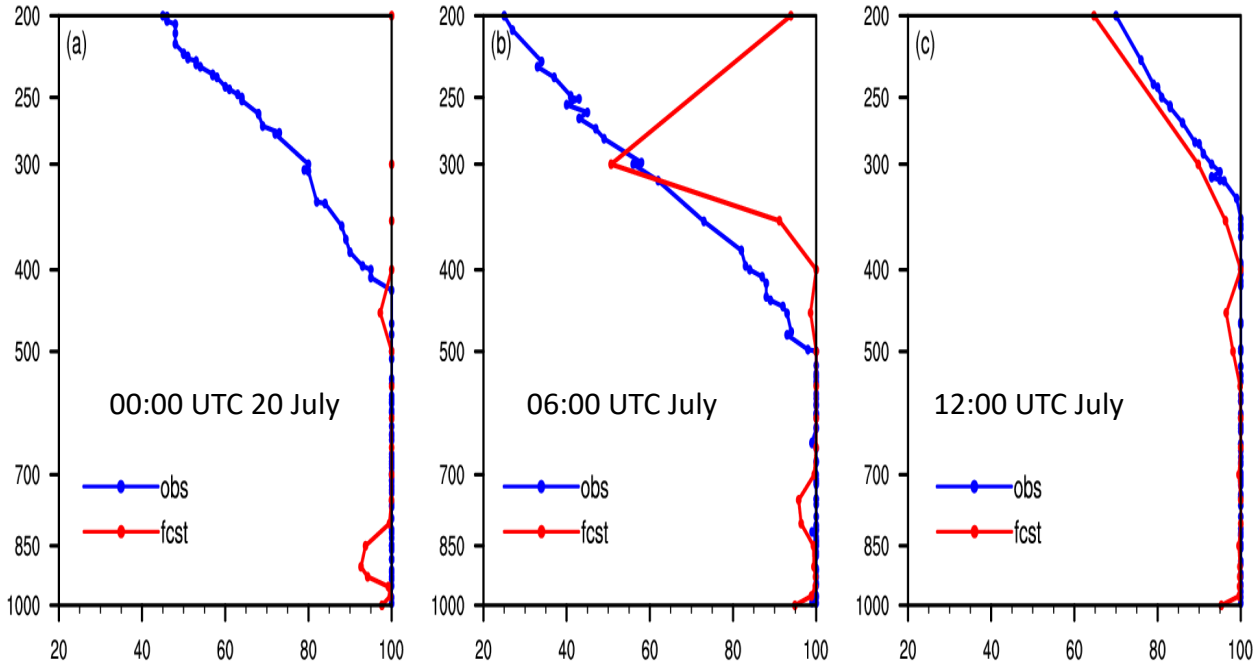
PW



- Simulated 65mm of PW， underestimated strong center exceed 70mm
- Incorrect vertical distribution of simulated water vapor lead to insufficient atmospheric instability

RH profiles

Zhengzhou Station



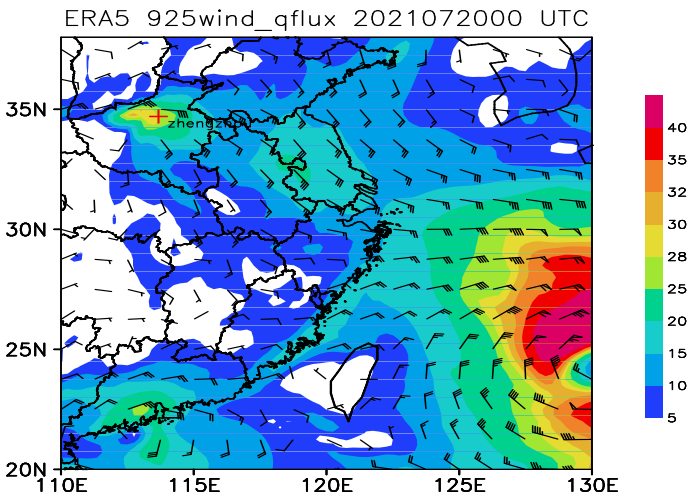
Sounding and simulation at Zhengzhou Station

Convective index \ Time		00:00 UTC 20	06:00 UTC 20	12:00 UTC 20
CAPE	Sounding	685.3	91.5	9.3
/ (J/kg)	CMA-Meso	152.6	502.3	39.1
BLI	Sounding	-2.2	-0.8	-0.1
/℃	CMA-Meso	-0.8	-0.7	-0.1

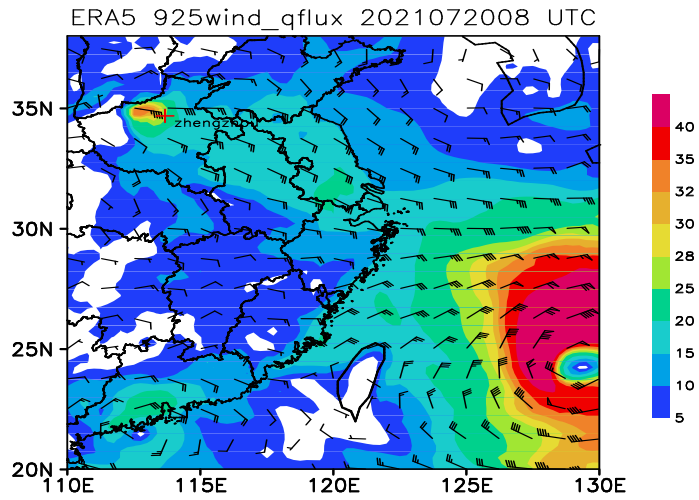
■ Error Analysis——water vapor flux

Typhoon In-Fa

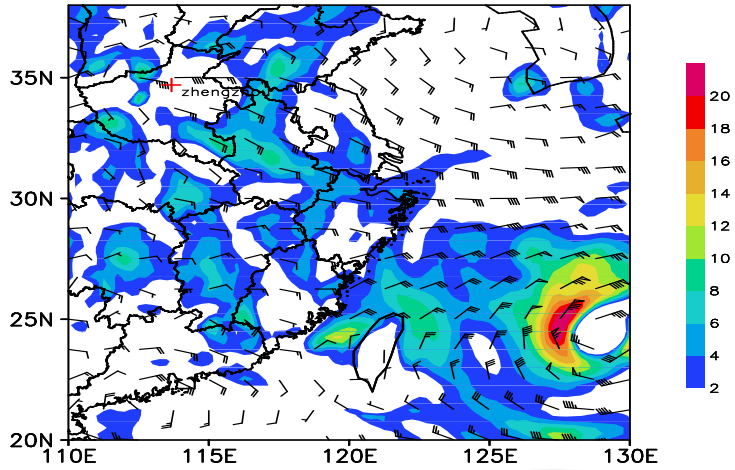
00:00 UTC

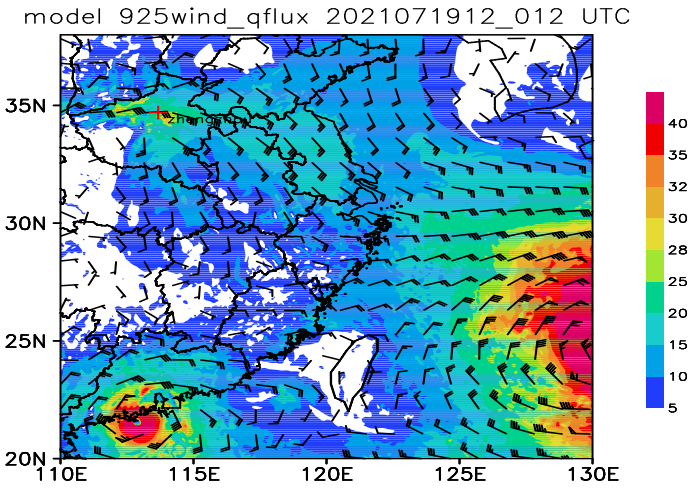


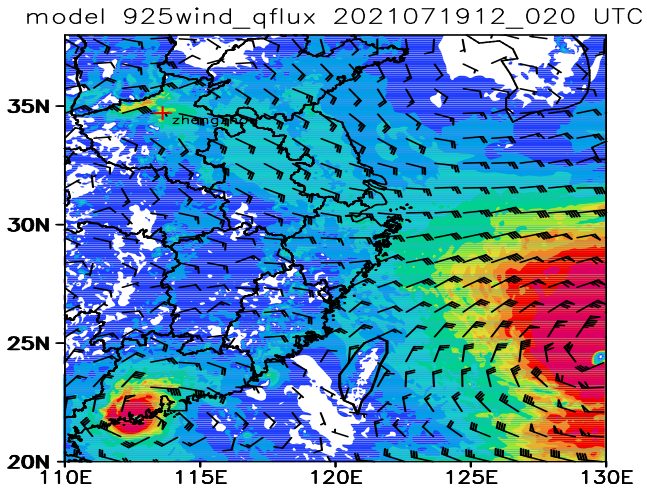
08:00 UTC

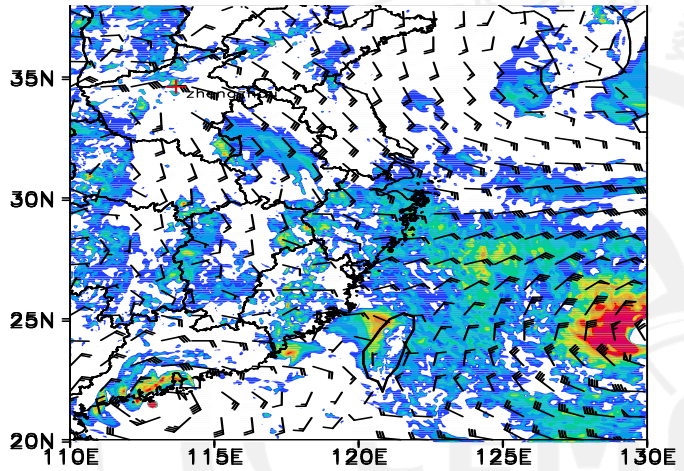


Different value 08:00 – 00:00 UTC







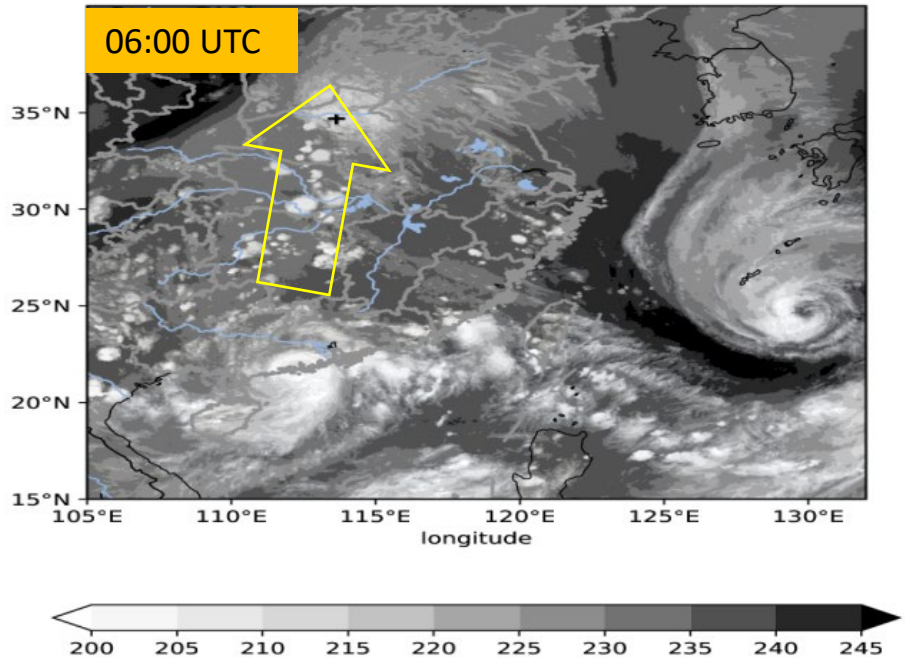


- water vapor was mainly transported from Typhoon In-Fa.
- water vapor transport increased obviously and its strong center at Zhengzhou station also increased
- Failed to simulate the increasing evolution of water vapor transport and simulated water vapor flux at Zhengzhou station was obvious weaker

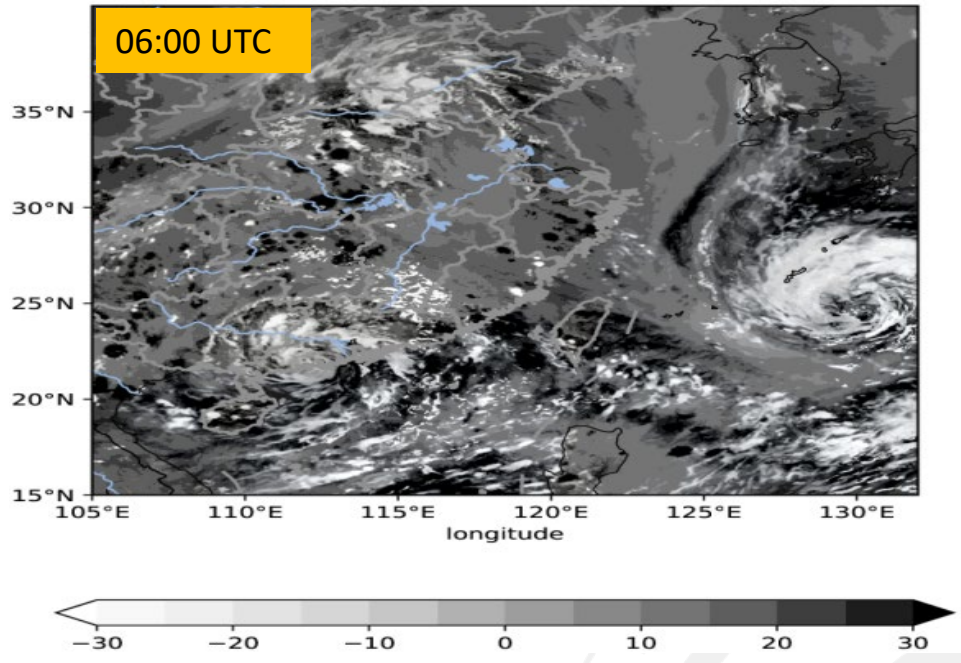
■ Error Analysis——water vapor flux

Typhoon Cempaka

Water vapor cloud image of Himawari-8 satellite



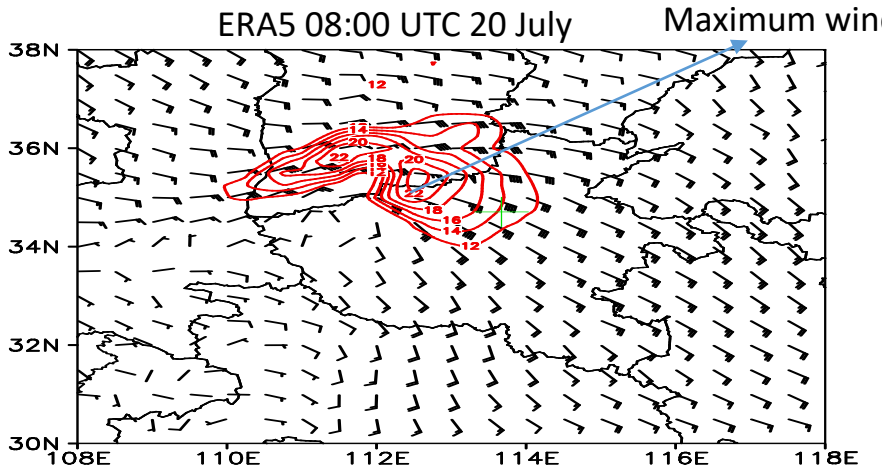
Deviation between CMA-MESO model and observation

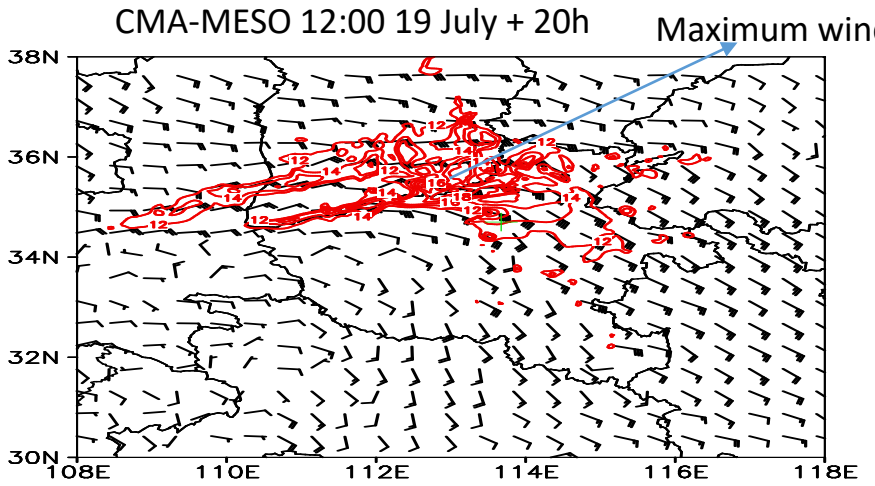


- 06:00, a water vapor conveyor belt from south to north originated from Typhoon Cempaka was also observed
- model underestimated water vapor transport from Typhoon Cempaka

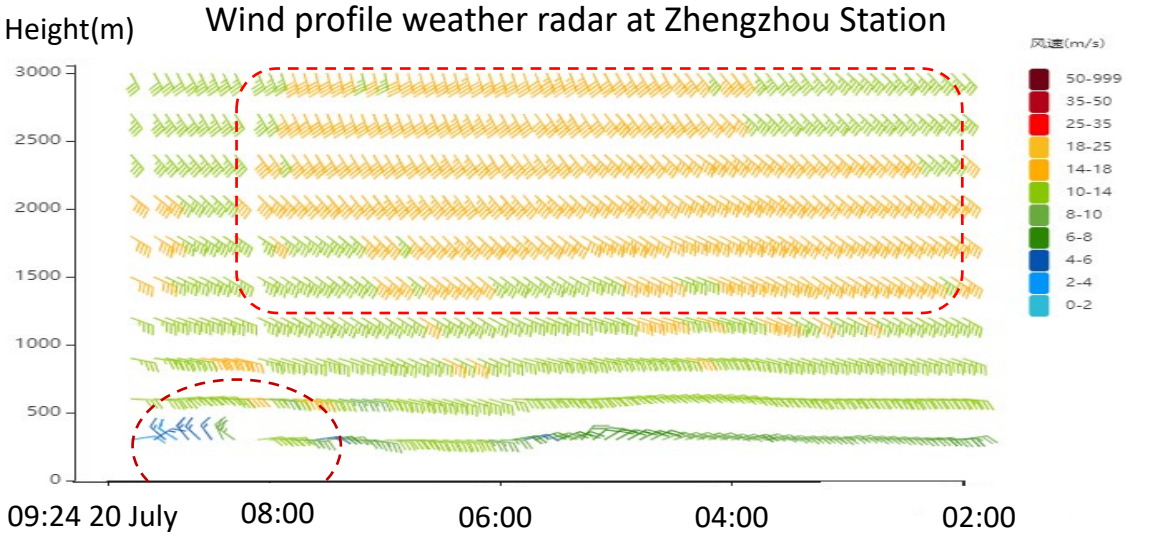
■ Error Analysis——low-level wind

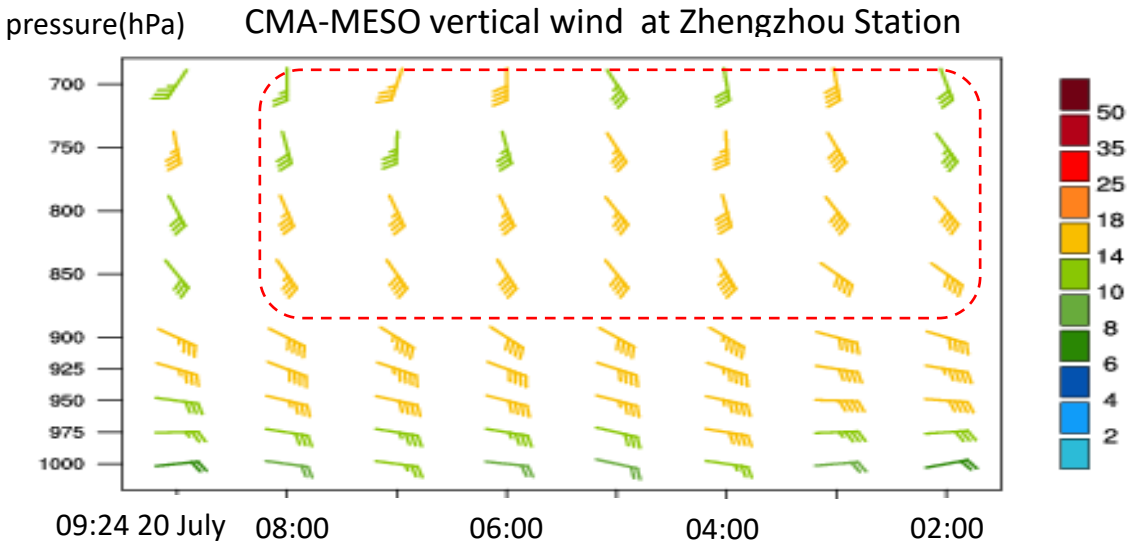
850hPa





- simulated low-level eastly jet stream was 4m/s weaker than ERA5
- Since 02:00， observed low-level southeast jet stream began to intensify, but simulated low-level jet stream was weaker
- 08:00, significant wind shear near the surface resulted in strong convergence, but failed to simulate

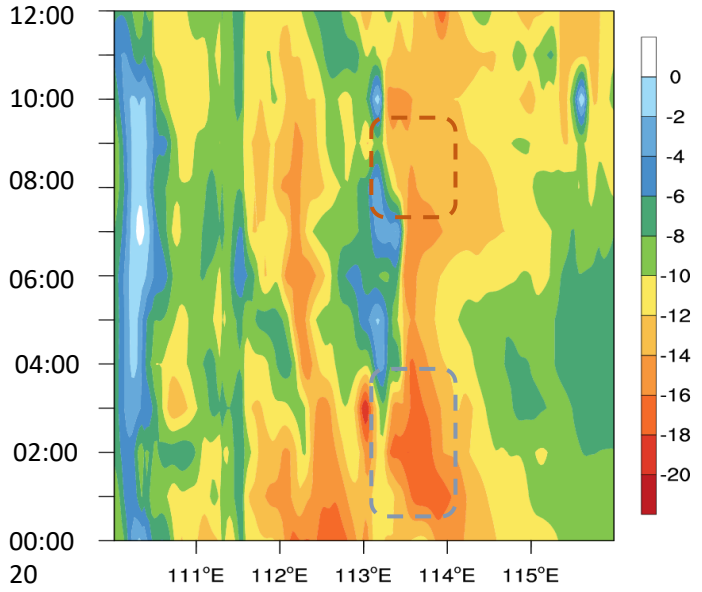




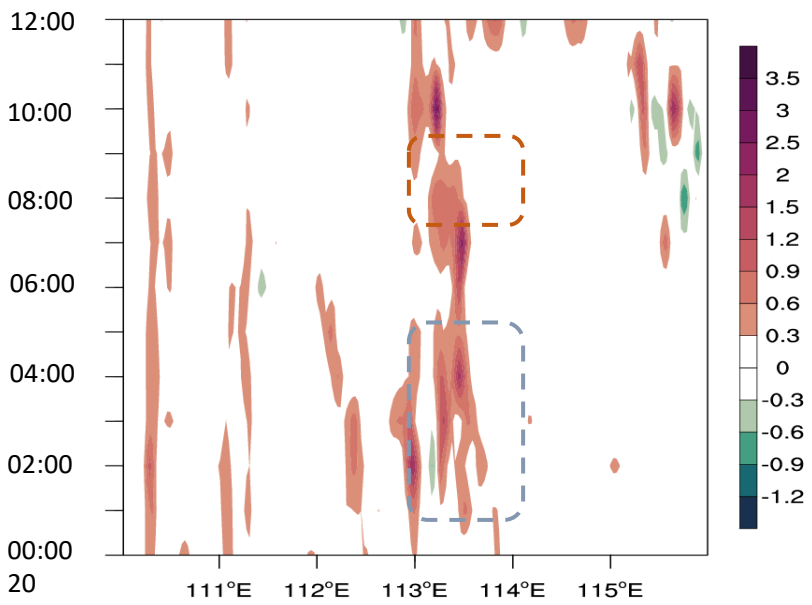
■ Error Analysis——temporal evolution of precipitation

zonal cross-section along 34.7° N (latitude of Zhengzhou Station)

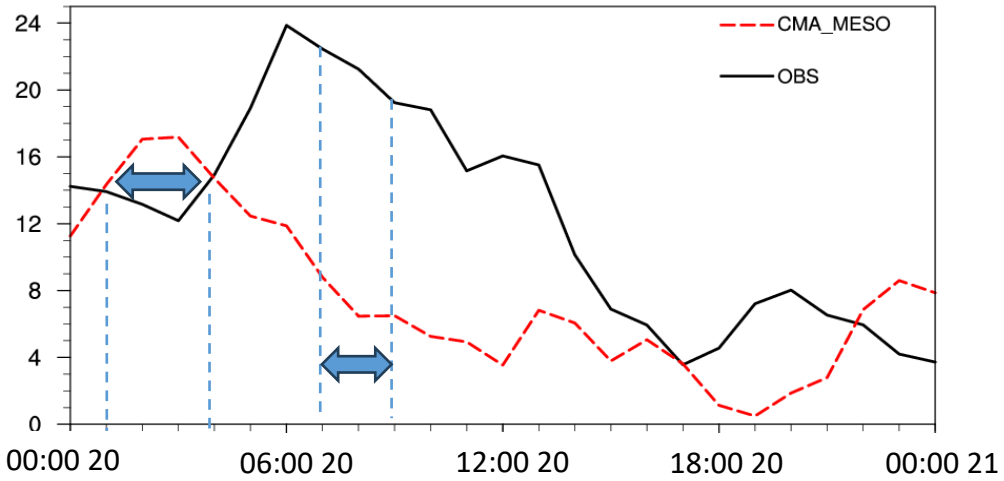
CMA-MESO 925hPa U wind



CMA-MESO 850hPa vertical speed



Regional average precipitation (34.5° ~ 35° N, 113° ~114° E)



According to previous studies, the strengthening of low-level jet stream is benefit to cyclone shear, resulting in development of upward movement at low level, besides, strong low-level jet transports momentum, water vapor and energy in the rainstorm area by enrolling, thus strengthening convection and precipitation.

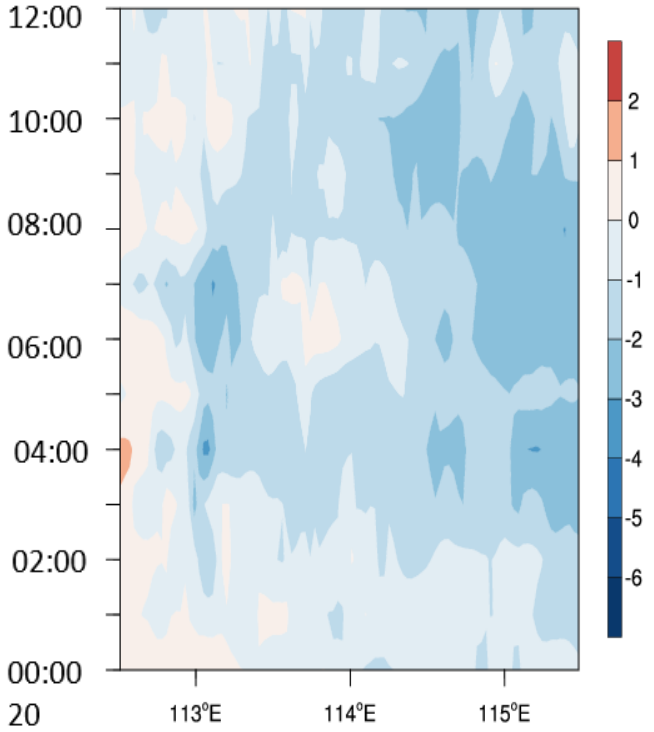
- low-level easterly jet and ultra-low-level easterly jet intensified and maintained since on 19 July
- 01:00-04:00， simulated easterly jet pulsation increased significantly, vertical velocity also intensified. simulated precipitation reached to its peak
- 07:00-09:00, simulated easterly jet pulsation decreased , vertical velocity decreased, seriously underestimated precipitation

Error of temporal evolution of precipitation was closely related to insufficient ultra low-level easterly jet pulsation

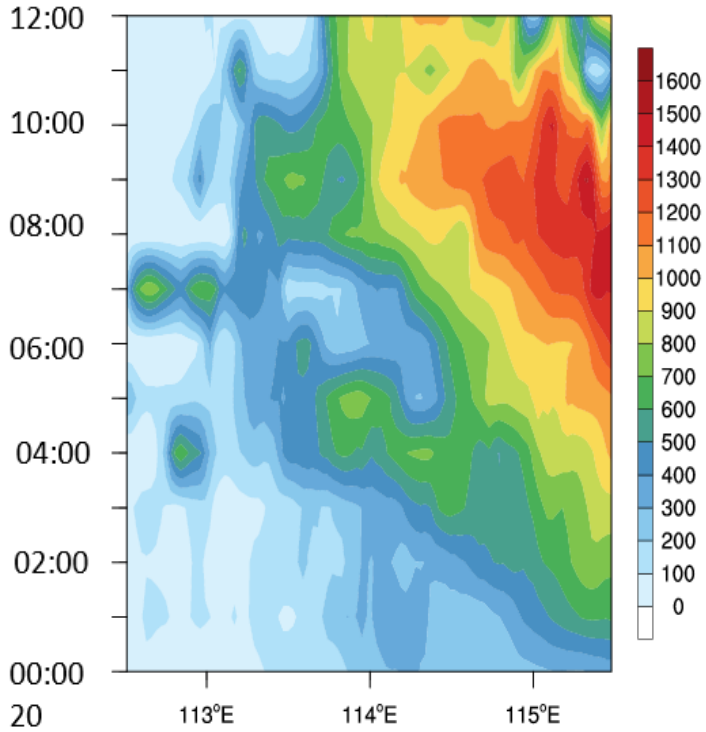
■ Error Analysis——convection

zonal cross-section along 34.7° N

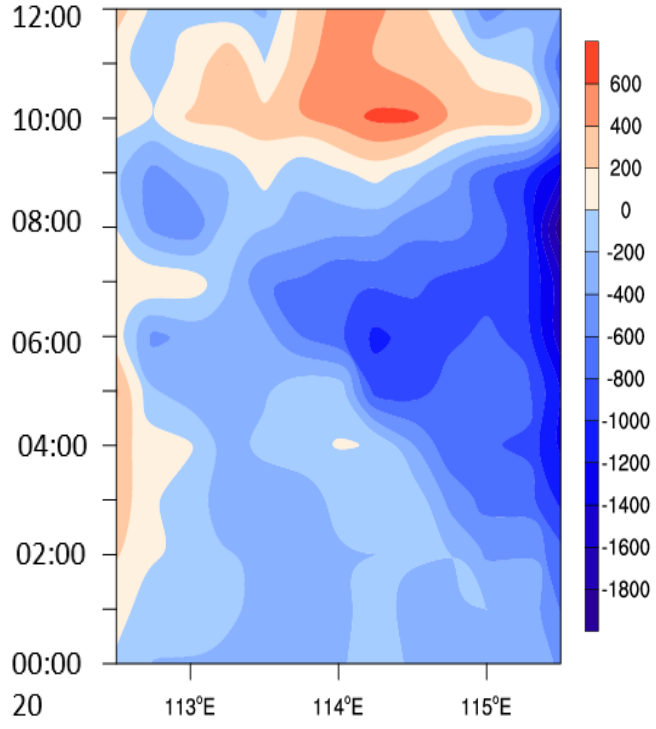
CMA-MESO BLI



CMA-MESO CAPE



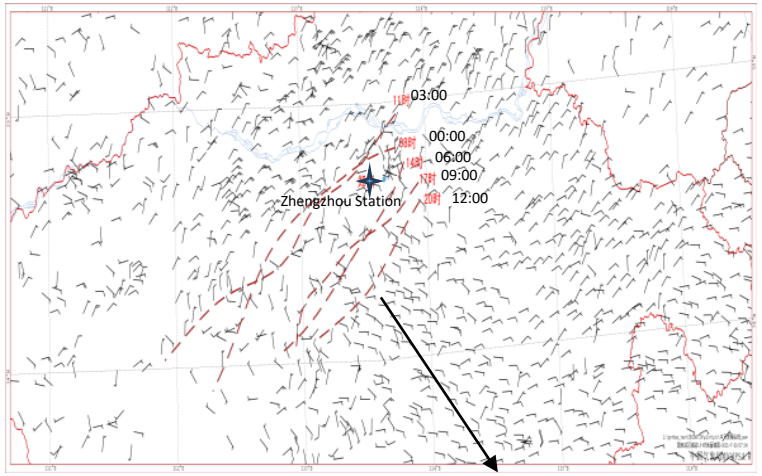
CMA-MESO – ERA5 CAPE



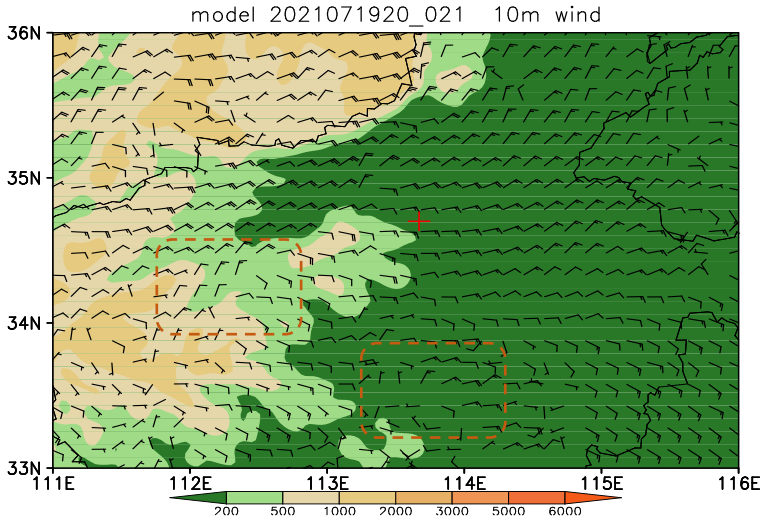
- Simulated BLI was 0~ -1K, insufficient atmospheric instability
- Simulated CAPE was 600~1000 J/kg lower than ERA5

■ Error Analysis——convection

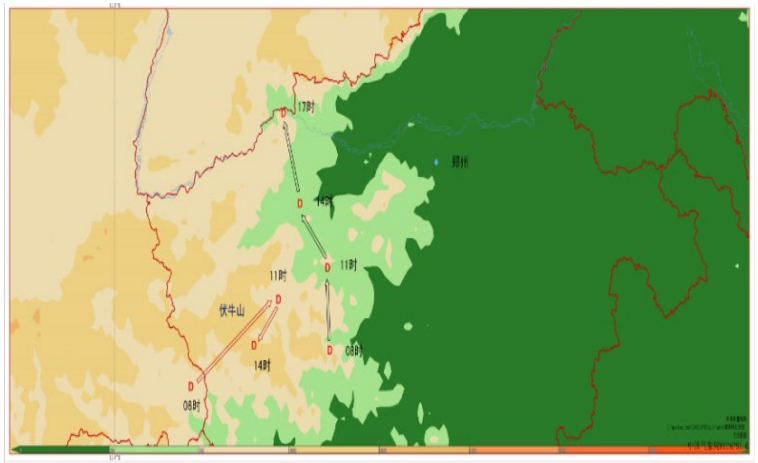
Observed surface wind on 09:00 20 July



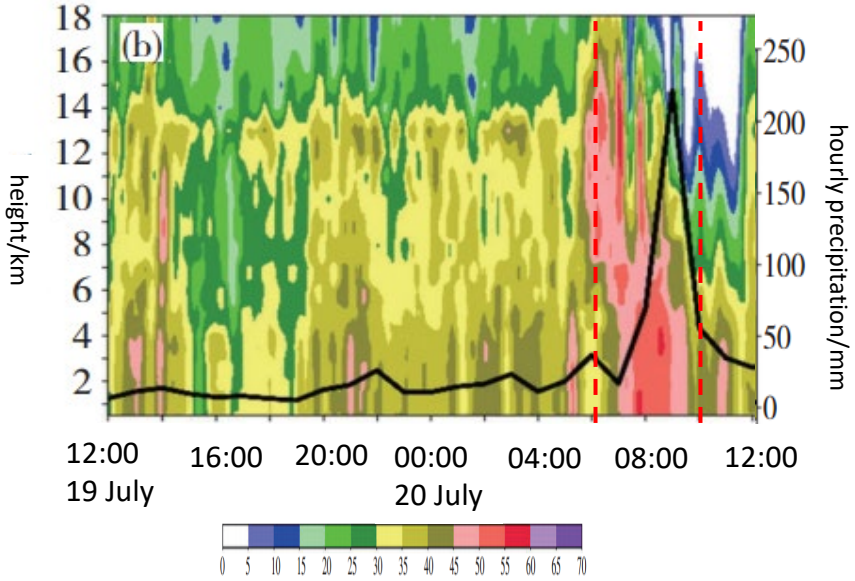
Mesoscale convergence lines



ERA5 (black line) and model (red line) vortex center path evolution

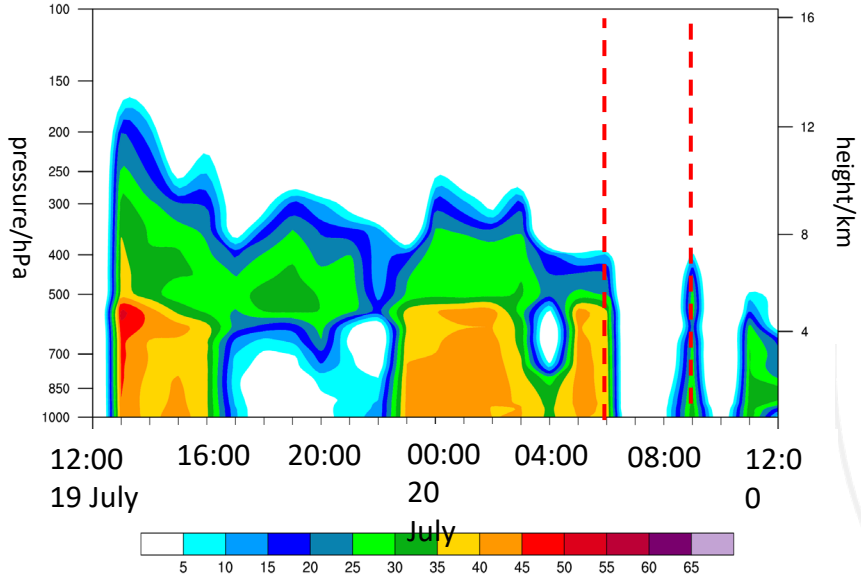


vertical cross-section of echoes Zhengzhou Radar



(Aifang Su et al, 2021)

Simulated vertical cross-section of echoes at Zhengzhou Station



- 00:00 - 12:00, mesoscale convergence lines on surface near Zhengzhou Station. Model missed
- Before 06:00, observed echo top exceeded 12km. 06:00 – 09:00, strong echo top exceeded 10km. Deep wet convective type of rainstorm
- Before 06:00, simulated echo top not exceeded 6 km. simulated convection not strong enough. 06:00 - 09:00, model failed
- Positions of simulated vortex were westward to ERA5. Reason for position bias of MCS and center of rainstorm

4. Conclusion of Model error diagnose：

（1）Model deviation was mainly owing to the incorrect simulation of water vapor, incorrect vertical distribution lead to insufficient atmospheric instability, and simulated water vapor transports from Typhoon In-Fa and Typhoon Cempaka were both weak.

（2）simulated weak low-level jet and insufficient ultra low-level easterly jet pulsation directly lead to insufficient water vapor transport from Typhoon In-Fa. Error of temporal evolution of precipitation was closely related to insufficient ultra low level easterly jet pulsation.

（3）Model ‘s failure in forecasting stably maintaining mesoscale convergence lines on the surface, in conjunction with deficiency of atmospheric instability and CAPE, made simulated convection not strong enough, thus caused inadequate maintaining of convective storm and severe convective storm

（4） Position of simulated vortex were westward to ERA5, causing position deviation of MCS and center of rainstorm

Wan Z W，Sun S Y，Bin zhao，et al，2024. Evaluation and error analysis of the July 2021 extremely severe rainstorm in Henan Province simulated by CMA-MESO model[J]. Meteor Mon, 50(1):33-47 (in Chinese)

DOI:10.7519/j.issn.1000-0526.2023.062101

Thank you !