Applied research of doppler radar for rainfall prediction at medium and small basin

Jiyang Tian
Senior Engineer

3 March 2021 Beijing

IWHR
中国水利水电科学研究院
China Institute of Water Resources and Hydropower Research

Content

- Why doppler radar
- Radar data assimilation for NWP
- Nowcasting forecast with doppler radar
- Conclusions

Content

- **Why doppler radar**
- **Radar data assimilation for NWP**
- **Nowcasting forecast with doppler radar**
- **Conclusions**

Why Doppler Radar

The flood management system at large basin Turn to completed → **Pay attention to flash flood management at Small and medium scale catchment**

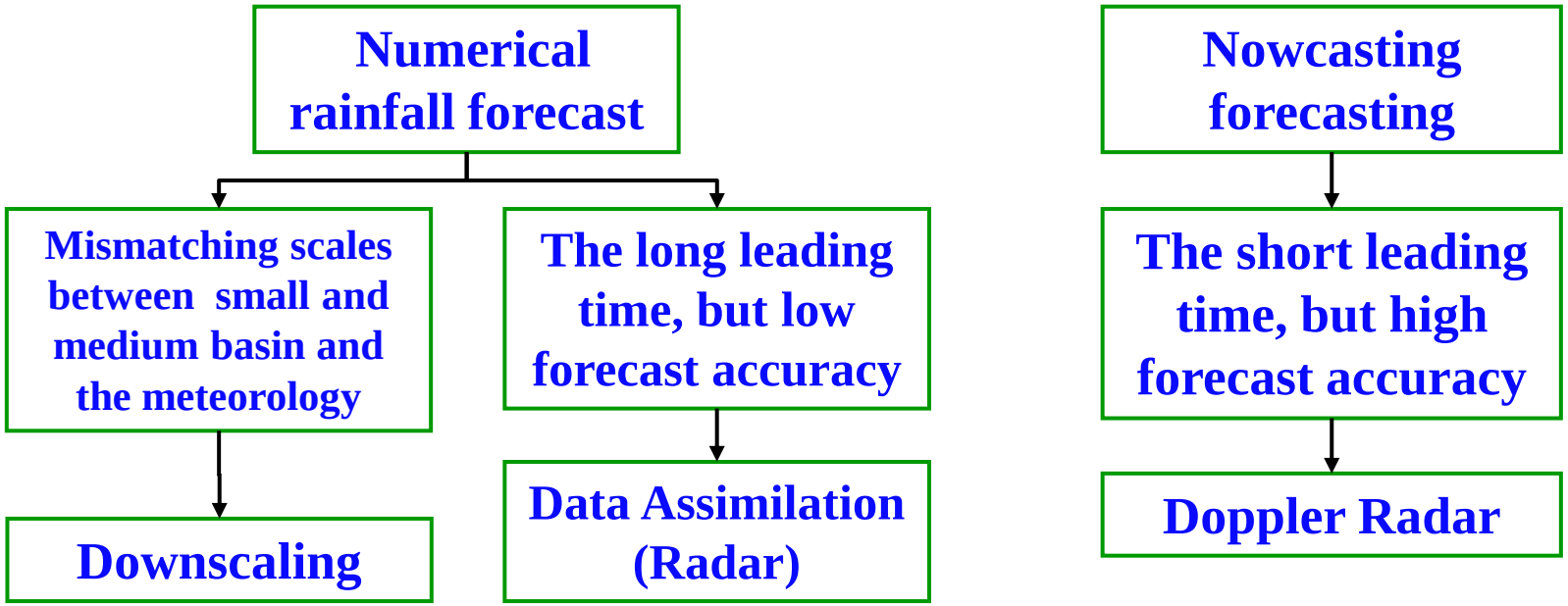
The short time of concentration In medium and small basin → **High requirement of flash flood leading time**

The high flood peak, but short process → **High requirement of forecast accuracy**

The lengthen of leading time, and the improvement of forecast accuracy

Why Doppler Radar

It is necessary to carry out the research of high-precision rainfall forecast and develop rainfall forecasting before flood events instead of forecasting after events.



Radar data have high spatial-temporal resolution, so for the weather observation of medium and small basin, this benefit makes it become the best choice for numerical rainfall forecasting

How should radar data be assimilated in order to make the effective improvement on the accuracy of numerical rainfall forecasting?

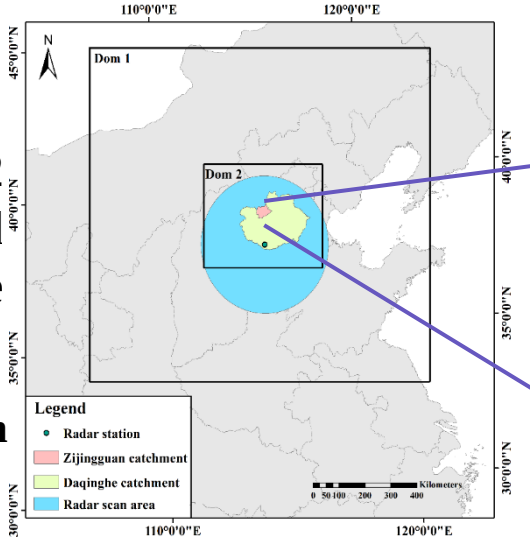
Whether the general nowcasting methods could meet the need of rainfall forecasts on the field of flood forecasts at the small and medium scale of catchment?

Why Doppler Radar

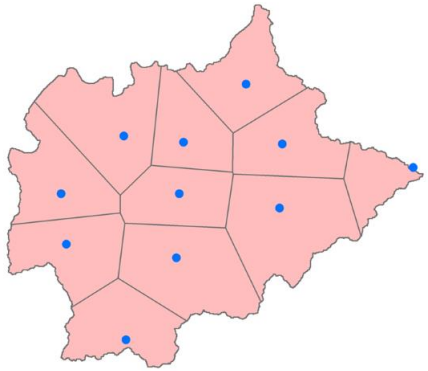
◆ （1）Study area and storm event

- Zijingguan catchment with 1760 km^2
- Storm event: high intensity rainfall (172 mm/24h) occurs on 21 July 2012 and peak flow reaches 2580 m^3/s at the catchment outlet.

Caused by the intersection of cold and warm airflow and the uplift of terrain



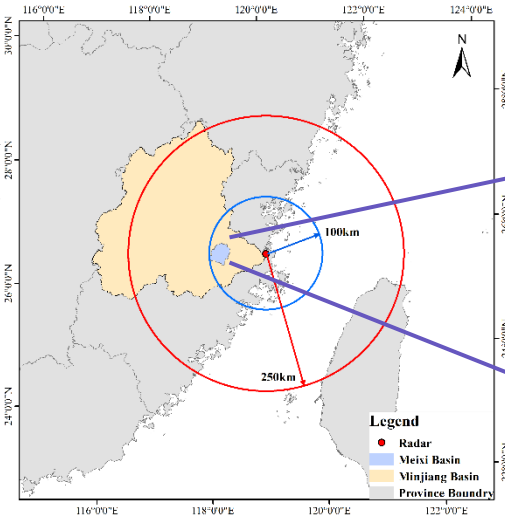
The Semi-humid and semi-arid region in the northern of China

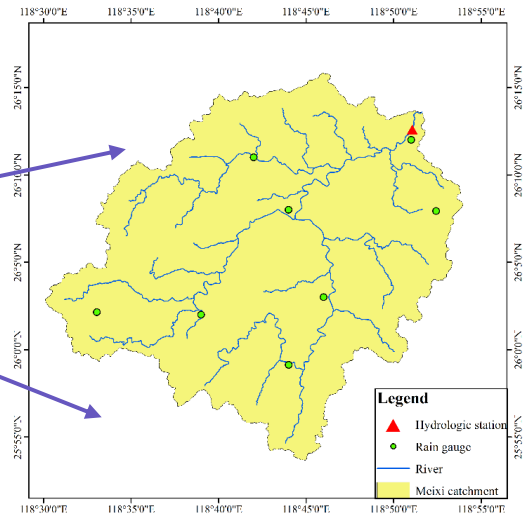


◆ （2）Study area and storm event

- Meixi catchment with 956 km^2
- Storm event: 1) high intensity rainfall (242 mm/24h) occurs on 8 July 2016 and peak flow reaches 4710 m^3/s at the catchment outlet; 2) With relative uniform rainfall distribution (84 mm/24h) occurs on 3 August 2012; 3) With uneven rainfall distribution (66 mm/24h) occurs on 17 June 2014

Caused by typhoon





The humid region on the southern of China

Content

- Why doppler radar
- **Radar data assimilation for NWP**
- Nowcasting forecast with doppler radar
- Conclusions

Radar data assimilation for NWP

◆ Model and configuration

- **WRF model**

  input data: GFS with the grid resolution of 1×1°

  domain setting: downscaling ratio 1:3

  vertical level: top level (50hPa), 40 vertical pressure levels

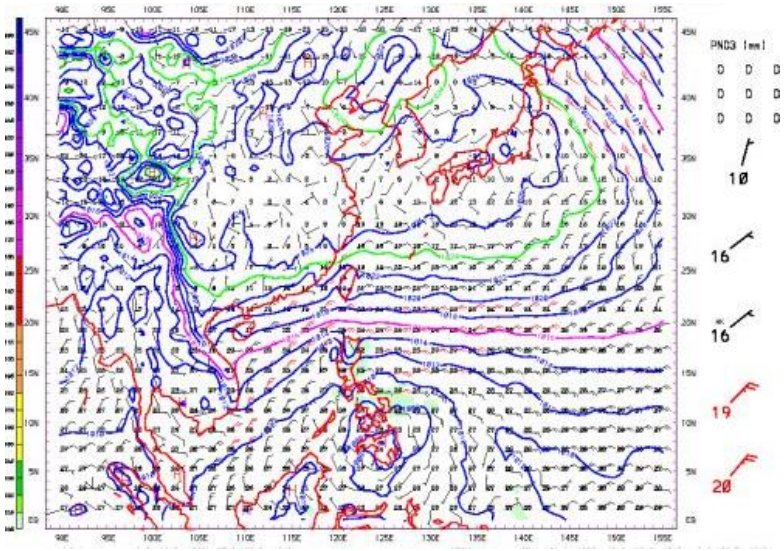
  physical parameterizations: WSM6, RRTM/Dudhia, Noah, MYJ, KF

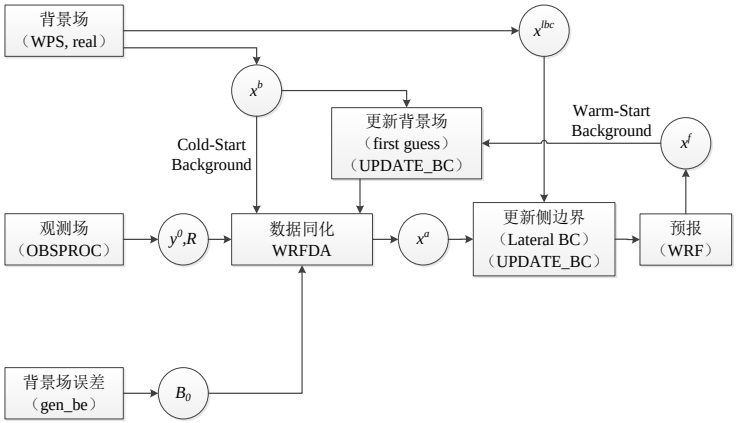
- **3-DVar data assimilation**

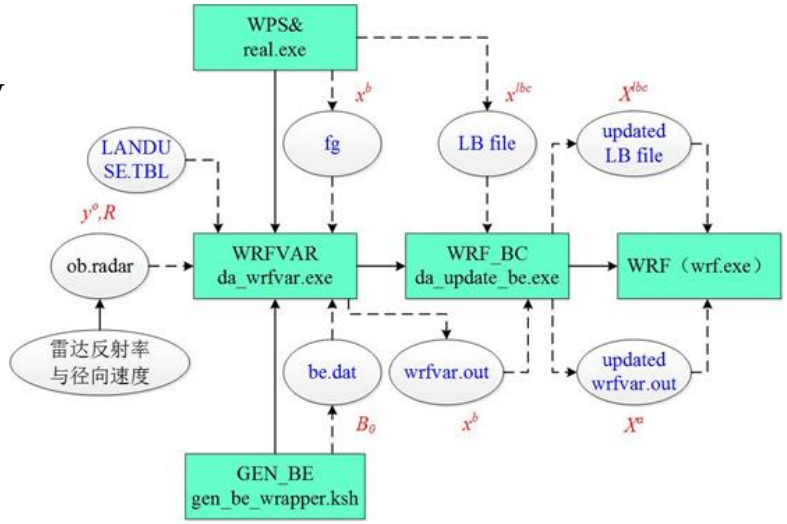
  BE: CV3

  Assimilation time interval: six hours, three hours, one hours

  Assimilated data: radar reflectivity and radial velocity







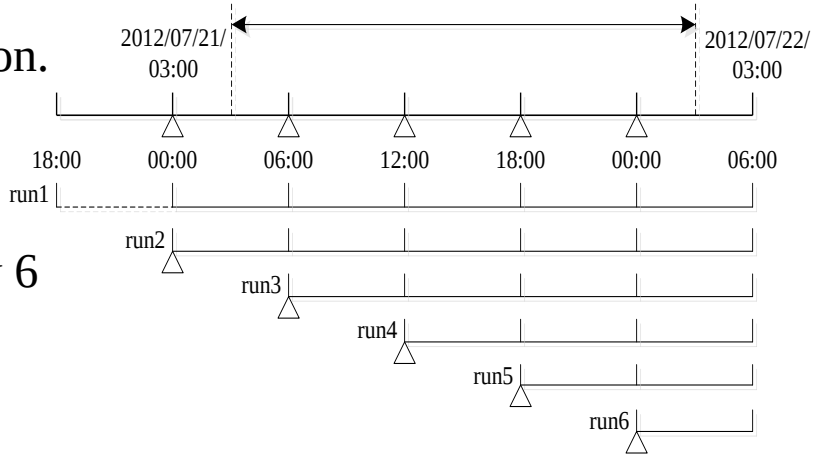
Radar data assimilation for NWP

◆ Assimilation scenario design

- **Cycling run (time interval 6h for example)**

run1 is the initial WRF run without data assimilation. The first 6 h, which is represented by a dashed line segment, is for the model spin-up.

run2, run3, run4, run5 and run6 are executed every 6 h to show the rainfall improvement for the entire storm duration by each time of radar data assimilation.

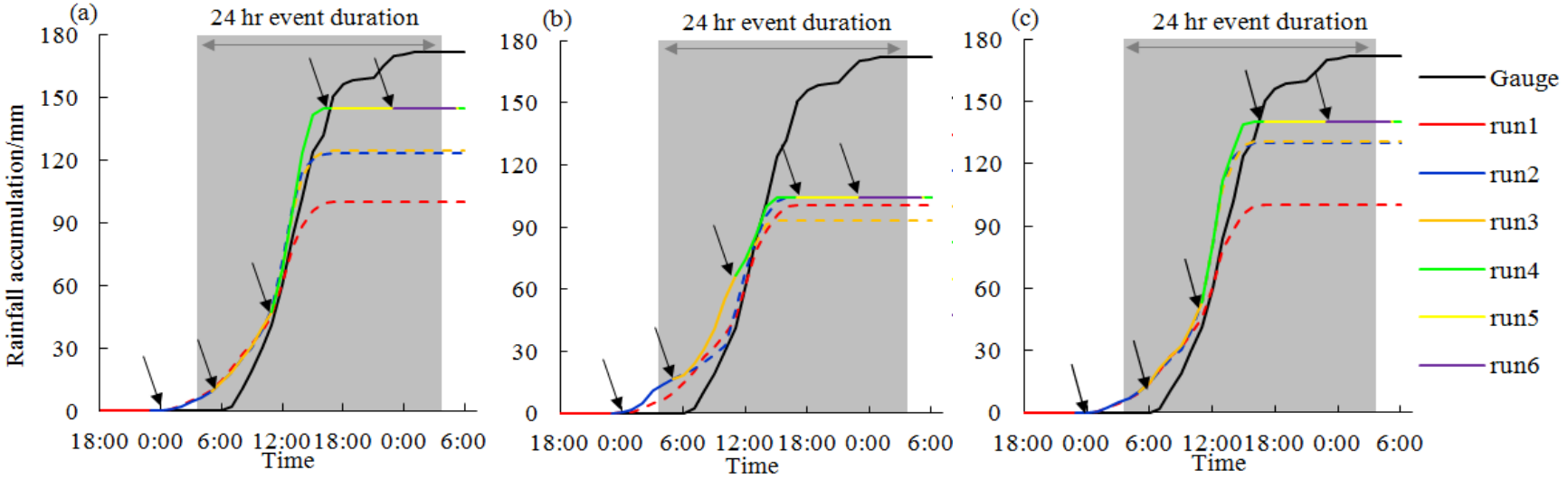


◆ Data assimilation scenario

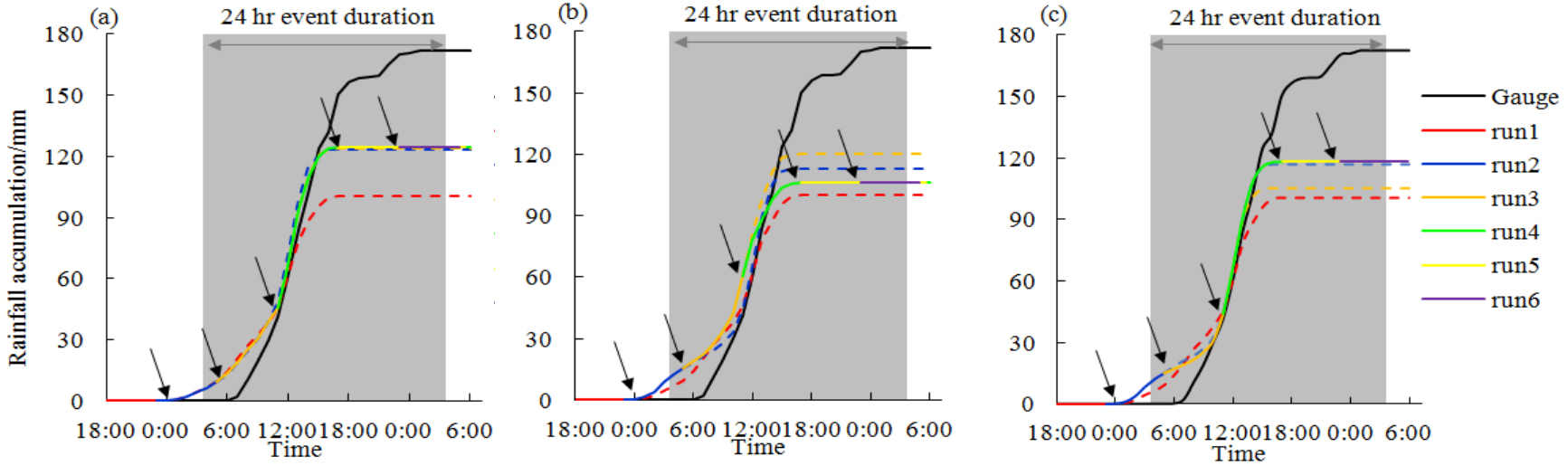
- **7 data sets:** according to the observation heights: (1) <500 m, (2) <1000 m, (3) <2000 m, (4) 500~1000 m, (5) 1000~2000 m, (6) >2000 m, and (7) all layers
- **Assimilation time interval:** six hours, three hours, one hours
- **Assimilated data:** (1) radar reflectivity, (2) radial velocity, (3) radar reflectivity and radial velocity

Radar data assimilation for NWP

- **Zijingguan catchment, rainfall occurrs on 21 July 2012, assimilation time interval 6 h**



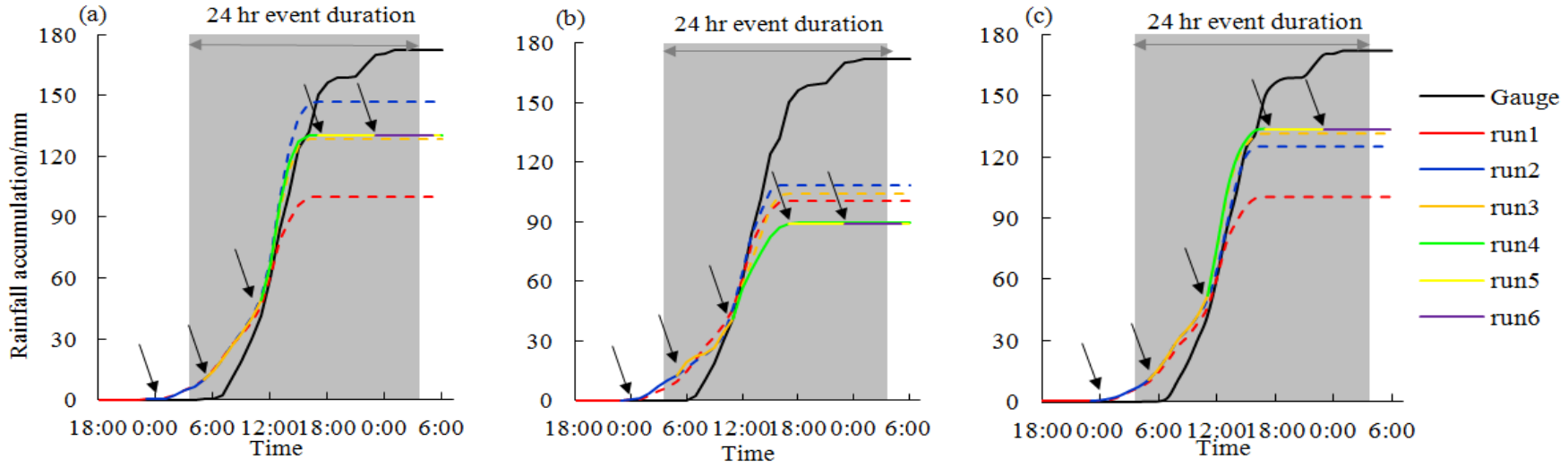
Assimilation results (<500m): (a) reflectivity; (b) velocity; (c) reflectivity and velocity



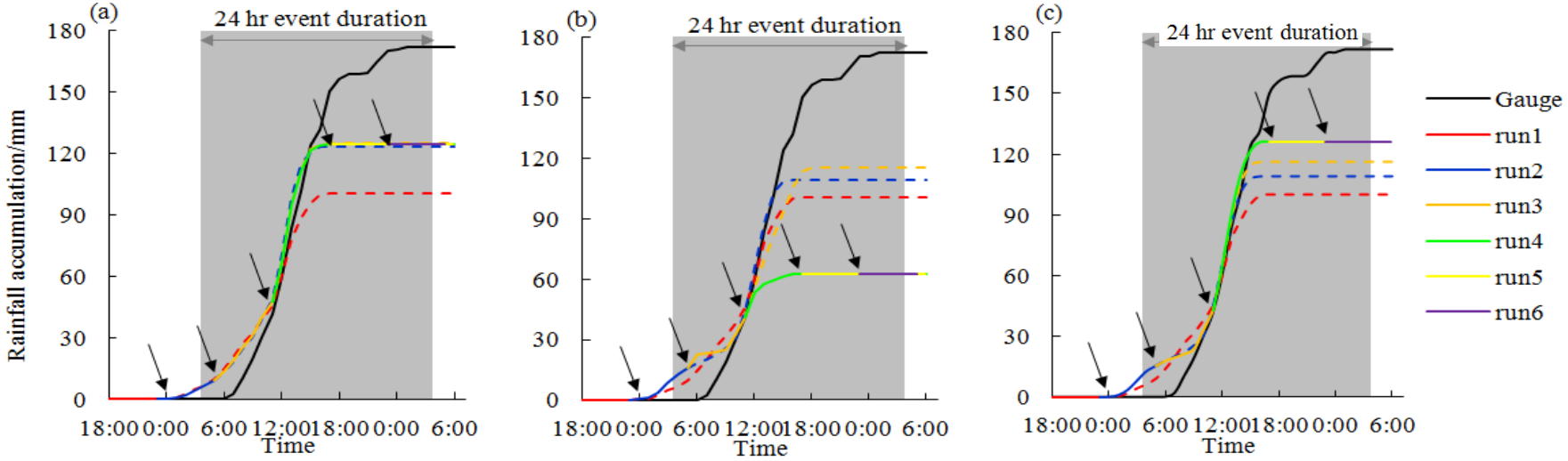
Assimilation results (<1000m): (a) reflectivity; (b) velocity; (c) reflectivity and velocity

Radar data assimilation for NWP

- **Zijingguan catchment, rainfall occurs on 21 July 2012, assimilation time interval 6 h**



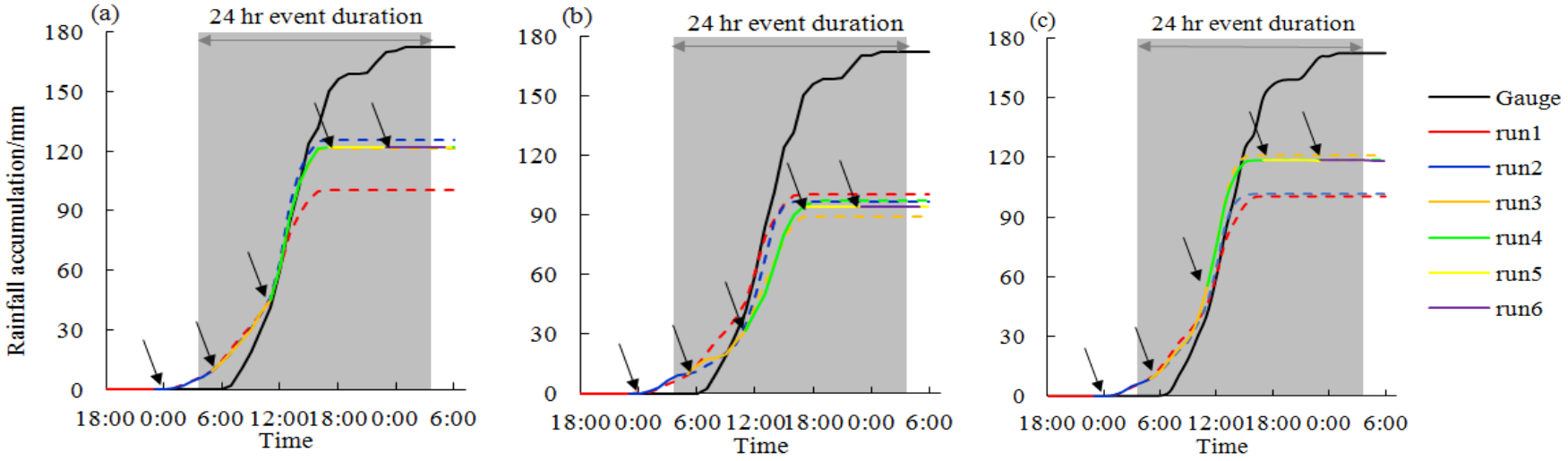
Assimilation results (<2000m): (a) reflectivity; (b) velocity; (c) reflectivity and velocity



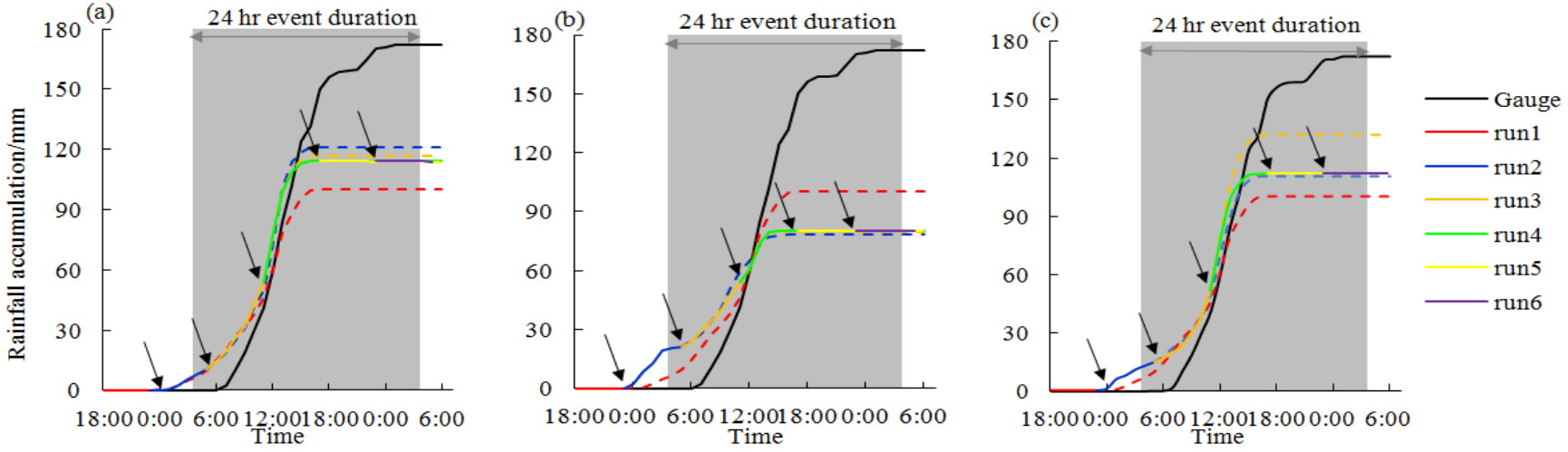
Assimilation results (500~1000m): (a) reflectivity; (b) velocity; (c) reflectivity and velocity

Radar data assimilation for NWP

- **Zijingguan catchment, rainfall occurrs on 21 July 2012, assimilation time interval 6 h**



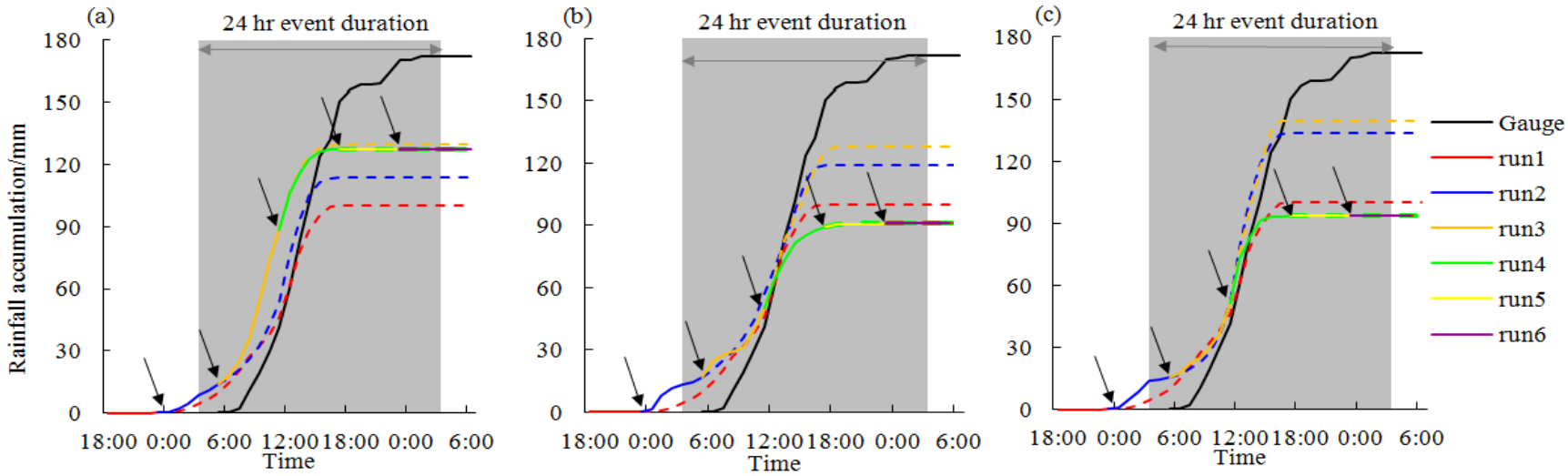
Assimilation results (1000~2000m): (a) reflectivity; (b) velocity; (c) reflectivity and velocity



Assimilation results (＞2000m): (a) reflectivity; (b) velocity; (c) reflectivity and velocity

Radar data assimilation for NWP

- **Zijingguan catchment, rainfall occurrs on 21 July 2012, assimilation time interval 6 h**



Assimilation results (all layers): (a) reflectivity; (b) velocity; (c) reflectivity and velocity

- Assimilating radar reflectivity lower than 500 m is the best choice.
- Higher layers come from the assimilated radar reflectivity or both types of radar data, the less improvements are found with the rainfall forecasts.
- Involvement of radar reflectivity or both types of radar data in higher layers may sometimes reduce the effect of rainfall improvements.

Radar data assimilation for NWP

◆ **Zijingguan catchment, rainfall occurrs on 21 July 2012, , assimilation time interval 6 h**

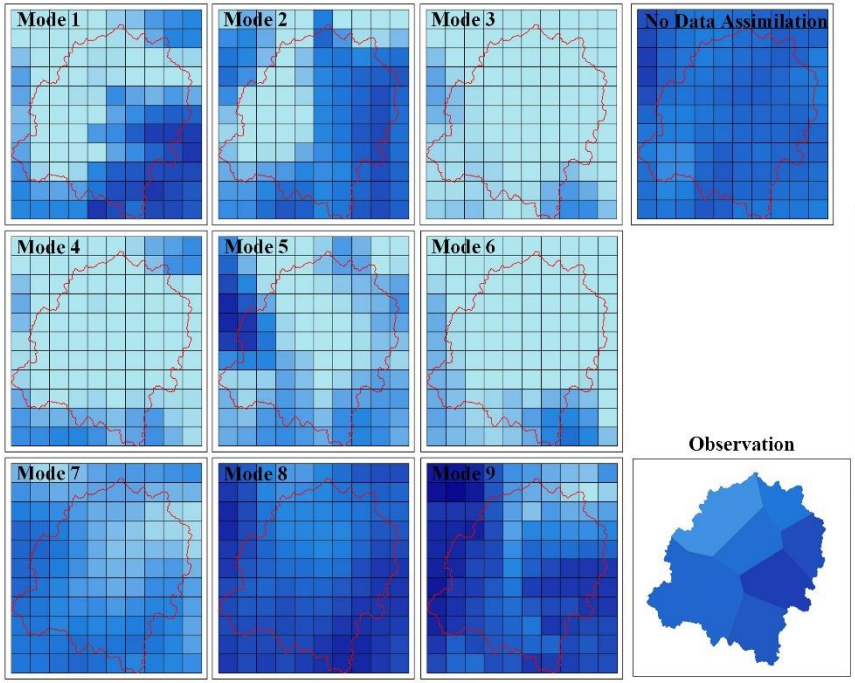
24h rainfall accumulations (mm) and relative errors (%) of the assimilation scenarios

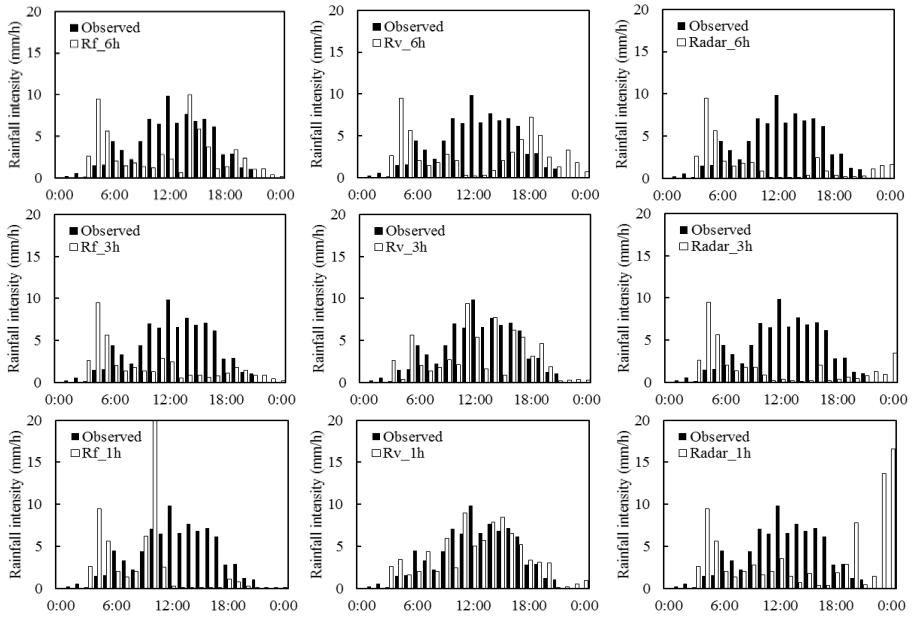
Data set	Elevation	Original run	Data assimilation run		
			Reflectivity	Velocity	Reflectivity + velocity
1	<500 m	95.54 (-44.51)	140.60 (-18.34)	93.05 (-45.95)	135.60 (-21.24)
2	<1000 m	95.54 (-44.51)	120.09 (-30.25)	97.54 (-43.35)	109.54 (-36.38)
3	<2000 m	95.54 (-44.51)	125.90 (-26.88)	81.80 (-52.49)	128.50 (-25.37)
4	500~1000 m	95.54 (-44.51)	119.95 (-30.33)	54.26 (-68.49)	117.52 (-31.74)
5	1000~2000 m	95.54 (-44.51)	117.64 (-31.67)	87.74 (-49.04)	113.58 (-34.03)
6	>2000 m	95.54 (-44.51)	108.84 (-36.78)	60.85 (-64.66)	100.90 (-41.39)
7	all layers	95.54 (-44.51)	118.92 (-30.93)	77.65 (-54.90)	79.76 (-53.67)

Reason: With the increase of the air height, rainwater gradually turns to ice crystal, which is assimilated by WRF-3DVar as rainwater in upper air.

Radar data assimilation for NWP

◆ Meixi catchment, rainfall occurrs on 3 August 2012



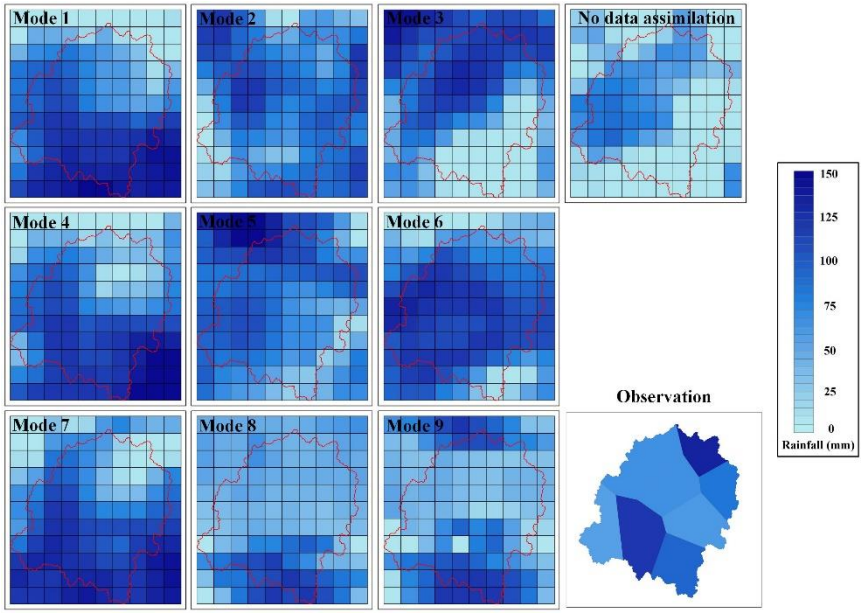


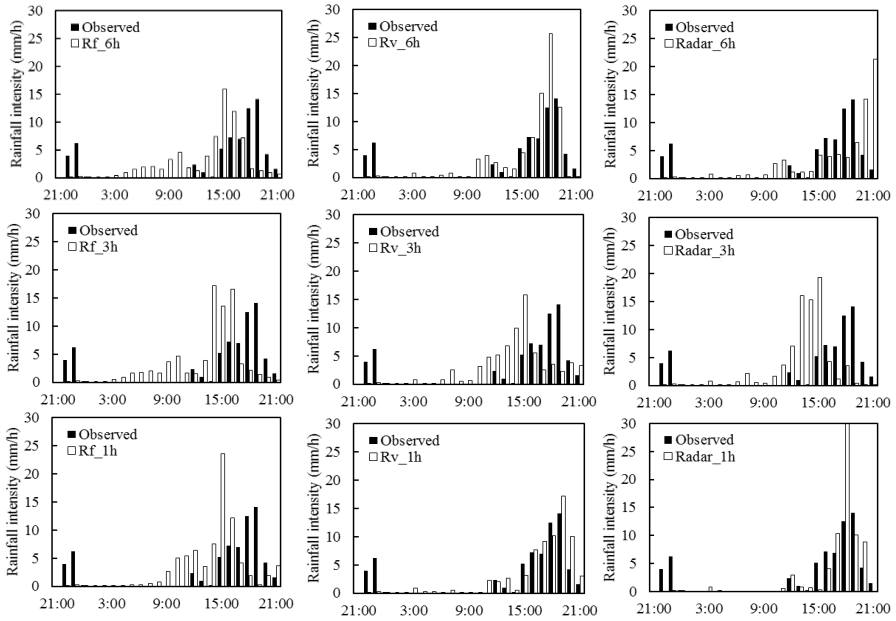
The spatial and temporal distribution of rainfall predicted by mode 8 is obviously improved, but the other assimilation modes perform not well. For rainfall with uniform spatial and temporal distribution, it is more important to choose data assimilation mode.

Mode	Time interval	Assimilated data
1	6h	Reflectivity (＜500m)
2	6h	Velocity
3	6h	Reflectivity (＜500m)+Velocity
4	3h	Reflectivity (＜500m)
5	3h	Velocity
6	3h	Reflectivity (＜500m)+Velocity
7	1h	Reflectivity (＜500m)
8	1h	Velocity
9	1h	Reflectivity (＜500m)+Velocity

Radar data assimilation for NWP

◆ Meixi catchment, rainfall occurrs on 17 June 2014



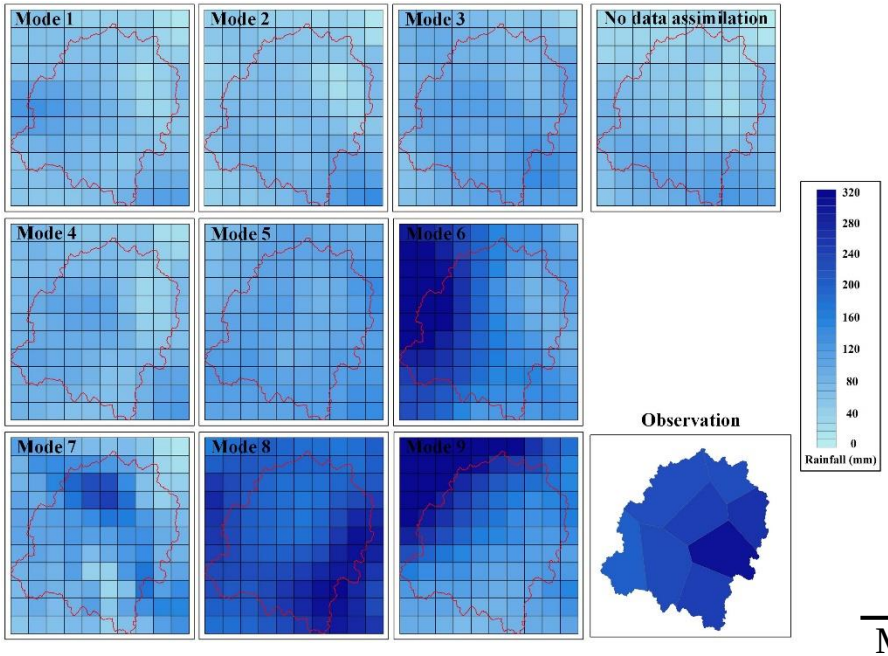


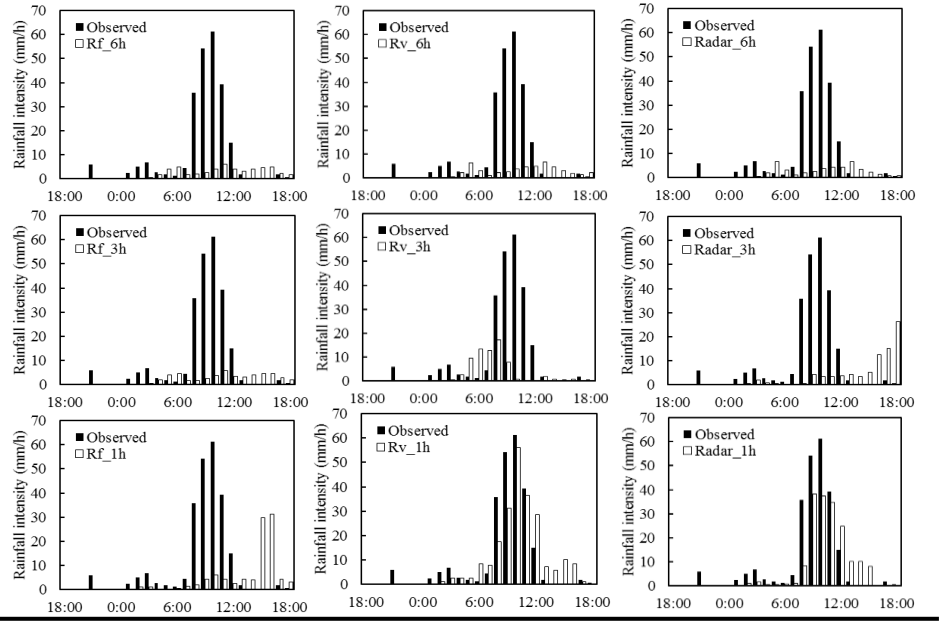
The rainfall forecasts have been improved with all data assimilation modes

Mode	Time interval	Assimilated data
1	6h	Reflectivity (＜500m)
2	6h	Velocity
3	6h	Reflectivity (＜500m)+Velocity
4	3h	Reflectivity (＜500m)
5	3h	Velocity
6	3h	Reflectivity (＜500m)+Velocity
7	1h	Reflectivity (＜500m)
8	1h	Velocity
9	1h	Reflectivity (＜500m)+Velocity

Radar data assimilation for NWP

◆ Meixi catchment, rainfall occurrs on 8 July 2016





Mode	Time interval	Assimilated data
1	6h	Reflectivity (＜500m)
2	6h	Velocity
3	6h	Reflectivity (＜500m)+Velocity
4	3h	Reflectivity (＜500m)
5	3h	Velocity
6	3h	Reflectivity (＜500m)+Velocity
7	1h	Reflectivity (＜500m)
8	1h	Velocity
9	1h	Reflectivity (＜500m)+Velocity

The rainfall forecasts have been improved with all data assimilation modes

Radar data assimilation for NWP

- **Different assimilation time intervals**
  - when the assimilation time interval is 6h, radar reflectivity assimilation is the best choice;
  - when the assimilation time interval is 3 h or 1 h, radial velocity assimilation is the best choice;
  - when the assimilation time interval is 1 h, radial velocity is the best choice. The rainfall forecast is much closer to the observed rainfall.
- **Different assimilation data**
  - when radar reflectivity is assimilated, increasing the assimilation frequency of radar reflectivity cannot guarantee the increase of rainfall forecast accuracy;
  - when radar reflectivity and radial velocity are assimilated at the same time, the assimilation is gradually improved with the decrease of assimilation time interval, but some evaluation indices still fluctuate;
  - when radial velocity is assimilated, the assimilation effect decreases with the assimilation time interval, and the rainfall forecasts have gradually been improved.

Overall, reasonable radar data assimilation can improve the accuracy of rainfall forecast by 20 % ~ 40 %.

Content

- Why doppler radar
- Radar data assimilation for NWP
- **Nowcasting forecast with doppler radar**
- Conclusions

Nowcasting forecast with doppler radar

◆ Model and configuration

- **Optical flow and ensemble forecast**

  Gauss perturbation: 30 members

- **Intense precipitation identification**

  Precipitation type: convective precipitation, stratiform precipitation without the influence of bright band, stratiform precipitation with the influence of bright band

  Z-R relationship: different Z-R for different precipitation type

- **Evaluation indices**

Relative error for 24-h accumulated areal rainfall

$$RE = \frac{P' - P}{P} \times 100\%$$

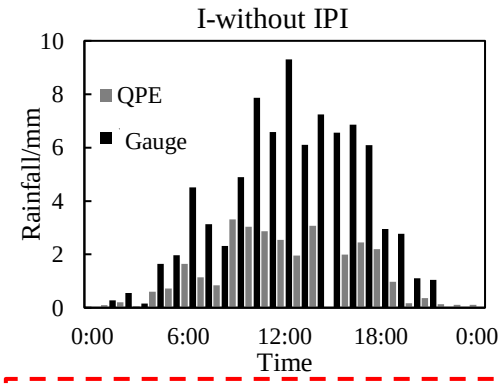
Ratio of root mean square error for spatiotemporal patterns

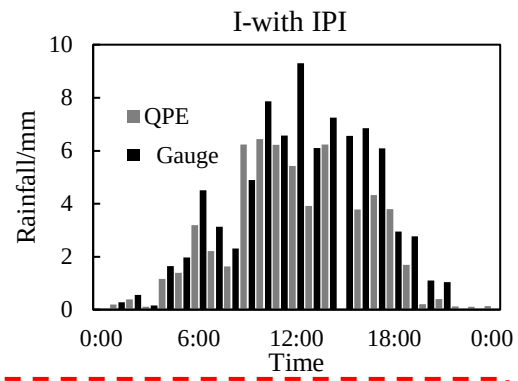
$$RMSE = \frac{\sqrt{\frac{1}{M}\sum_{j=1}^{M}\left(P_j' - P_j\right)^2}}{\frac{1}{M}\sum_{j=1}^{M}P_j}$$

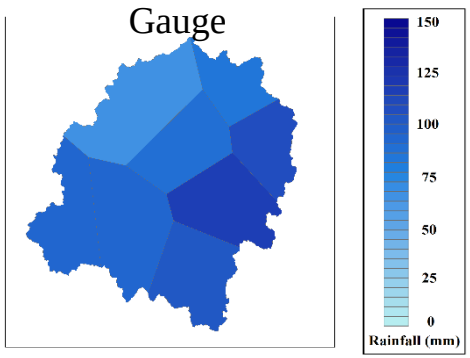
Nowcasting forecast with doppler radar

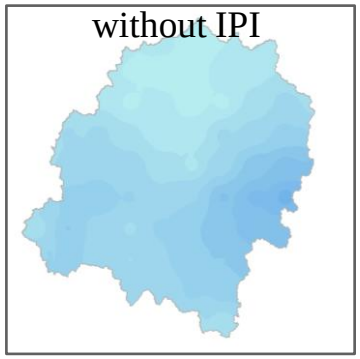
Evaluation indices for QPE

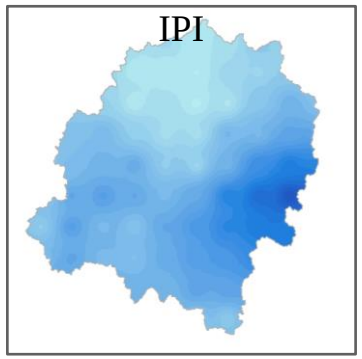
Events in Meixi catchment	*RE*（%）		*RMSE in spatial dimension*		*RMSE in temporal dimension*	
	without IPI	**IPI**	**without IPI**	**IPI**	**without IPI**	**IPI**
3 August 2012 (I)	-63.52	-29.29	0.71	0.37	0.82	0.53
17 June 2014 (II)	-51.40	31.06	0.55	0.48	0.85	0.90
8 July 2016 (III)	-71.35	-31.07	0.70	0.54	1.34	0.70





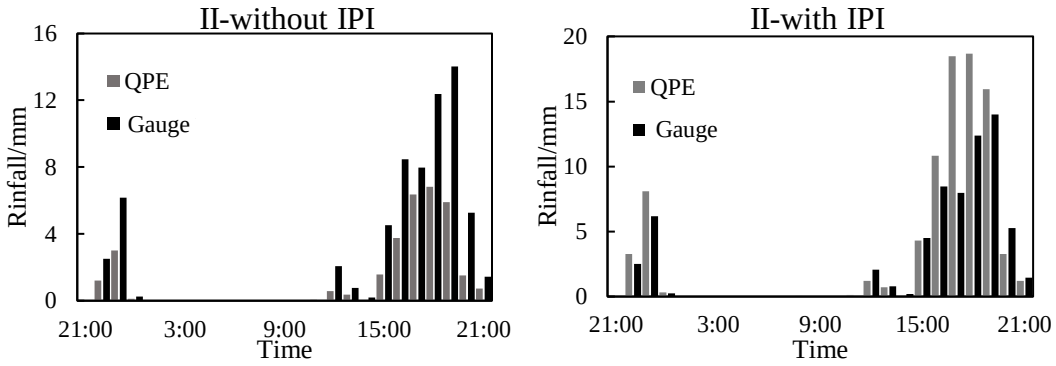




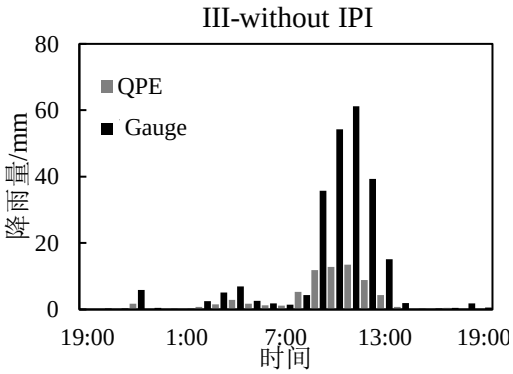


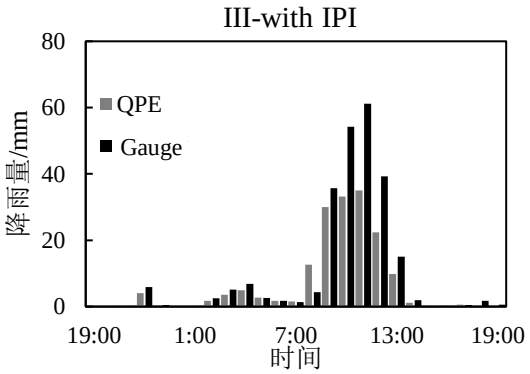
with heavy rainfall identification, the RE of 24-hour accumulated QPE for rainfall event I is reduced by 34.23%, the RMSE in spatial dimension is reduced by 0.34, and the RMSE in temporal dimension is reduced by 0.29. In general, the accuracy of radar inversion is significantly improved.

Nowcasting forecast with doppler radar

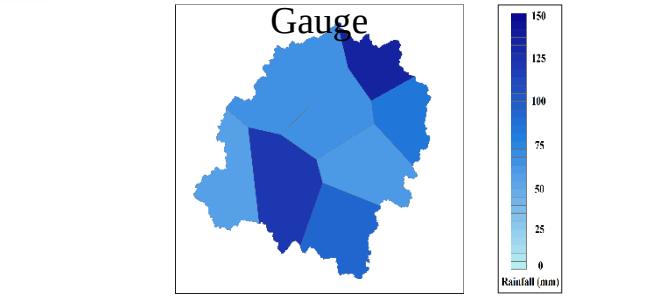


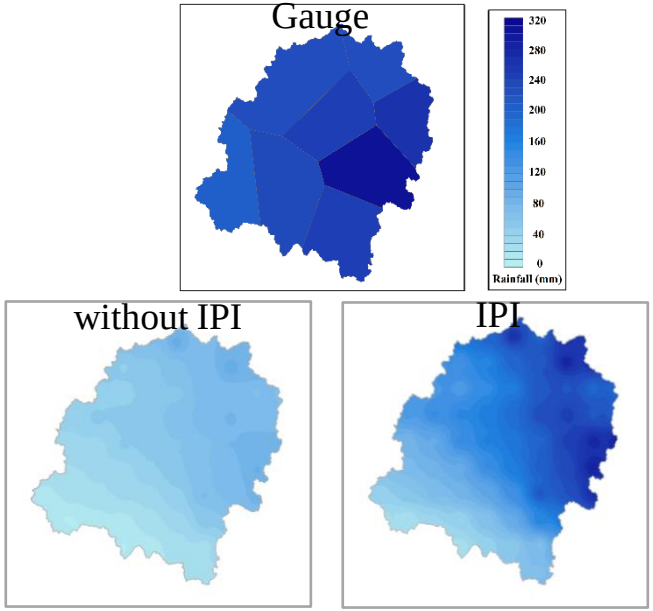
For the rainfall event on June 17th of 2014, with heavy rainfall identification, the RE of 24-hour accumulated QPE for rainfall event II is reduced by 20.34%, the RMSE in spatial dimension is reduced by 0.07, and the RMSE of temporal dimension is increased by 0.05. In general, the accuracy of radar inversion is certainly improved.



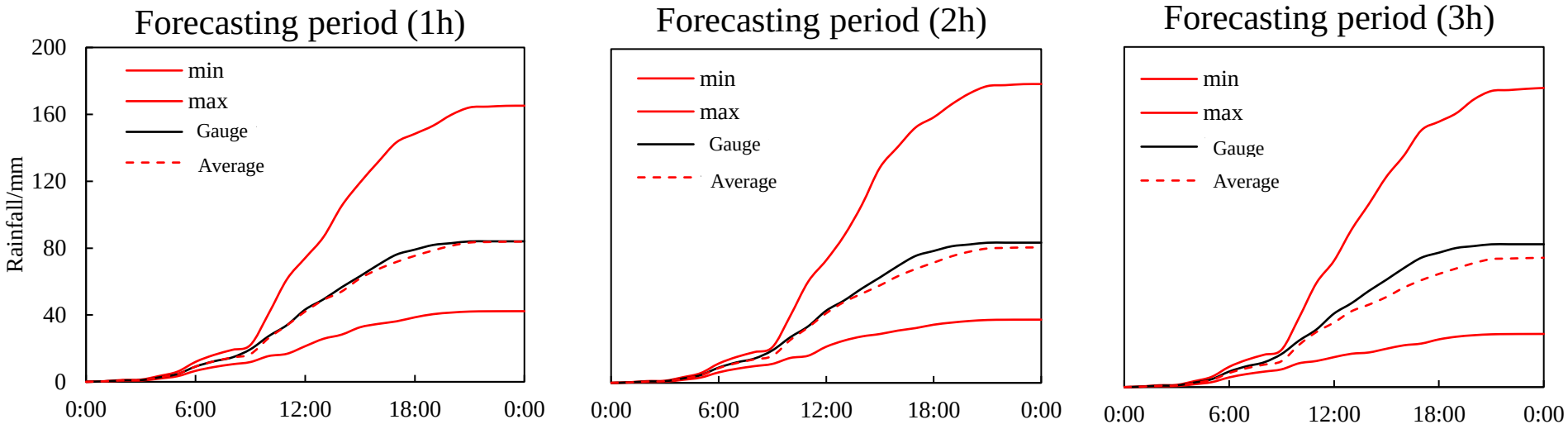


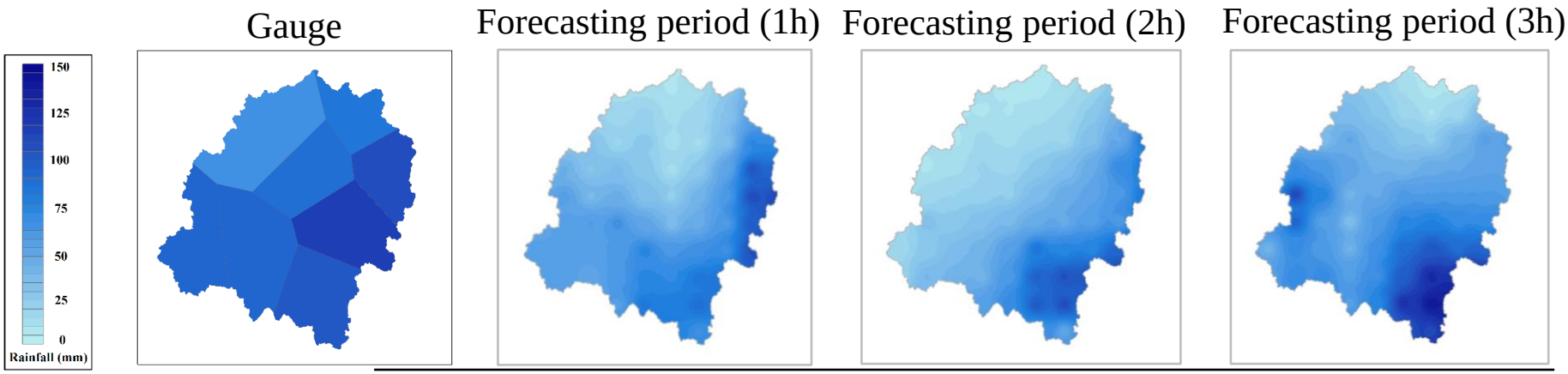
For the July 8th of 2016, with heavy rainfall identification, the RE of 24-hour accumulated QPE for rainfall event II is reduced by 40.28%, the RMSE in spatial dimension is reduced by 0.16, and the RMSE in temporal dimension is decreased by 0.64. In general, the improvement of radar inversion accuracy is most significant among these three rainfall events.





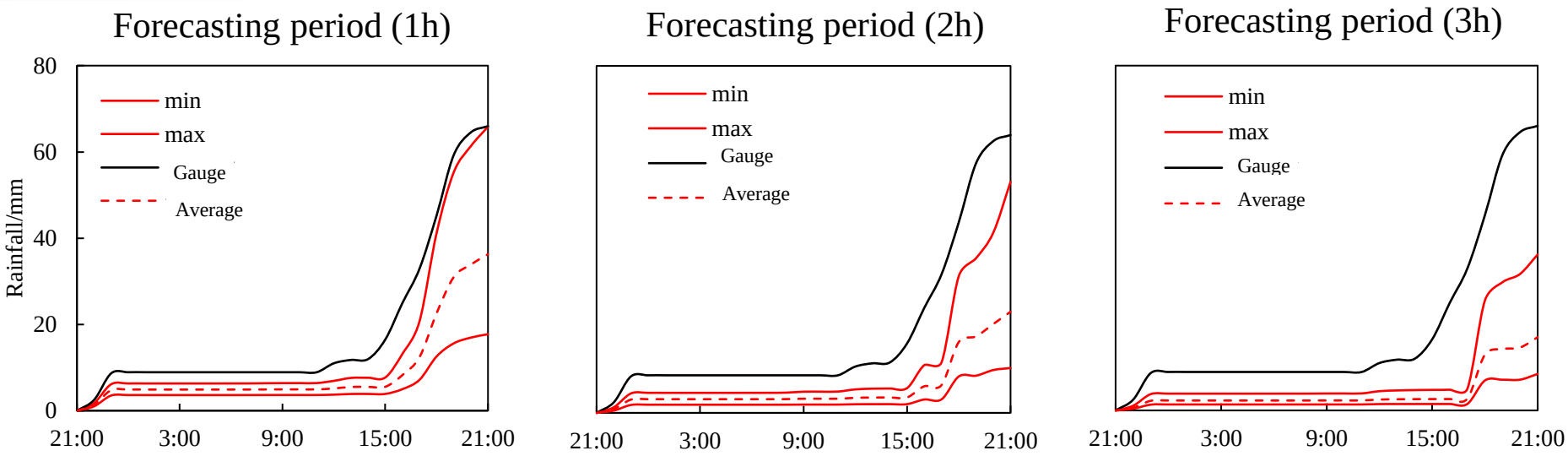
Nowcasting forecast with doppler radar

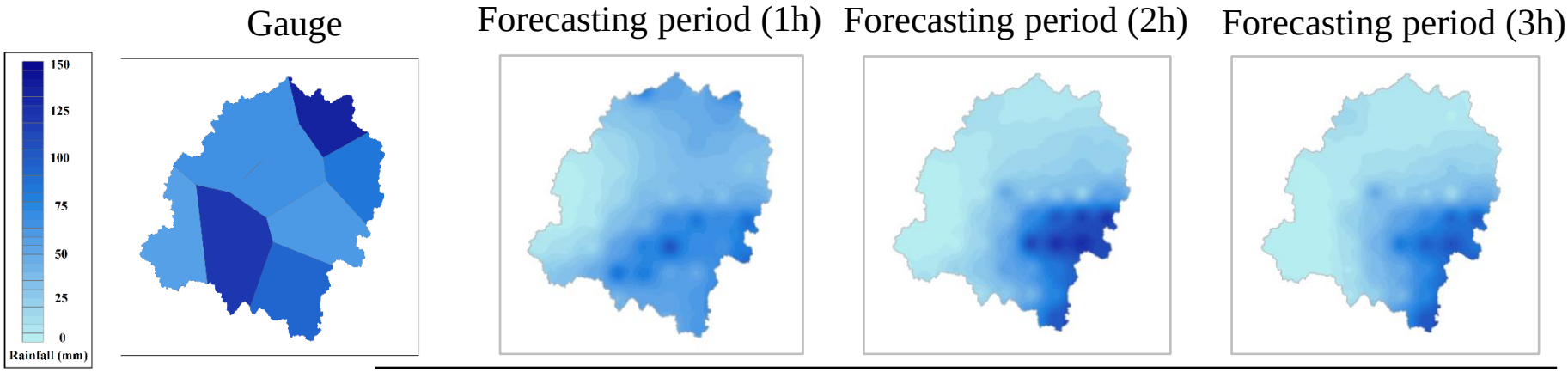




Ensemble average	RE（%）	RMSE	
		Spatial dimension	Temporal dimension
Forecasting period (1h)	-3.64	0.31	0.35
Forecasting period (2h)	-7.5	0.33	0.45
Forecasting period (3h)	-13.88	0.44	0.5

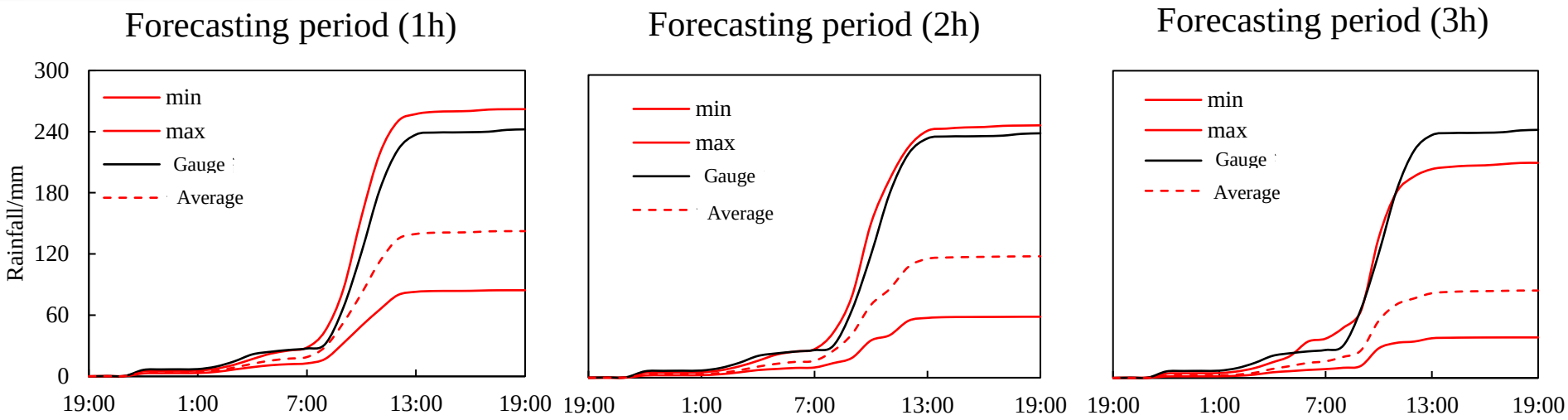
Nowcasting forecast with doppler radar

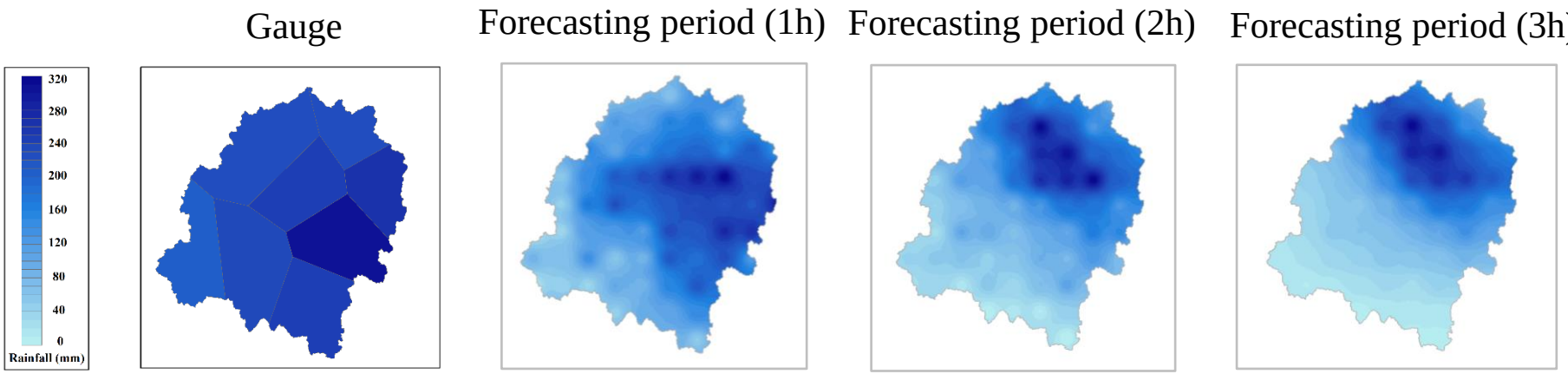




Ensemble average	RE（%）	RMSE	
		Spatial dimension	Temporal dimension
Forecasting period (1h)	-46.76	0.77	0.66
Forecasting period (2h)	-65.22	1.20	0.80
Forecasting period (3h)	-75.23	1.32	0.89

Nowcasting forecast with doppler radar





Ensemble average

	RE（%）	RMSE	
		Spatial dimension	Temporal dimension
Forecasting period (1h)	-42.75	0.85	0.57
Forecasting period (2h)	-52.23	1.08	0.67
Forecasting period (3h)	-66.34	1.26	0.81

Content

- Why doppler radar
- Radar data assimilation for NWP
- Nowcasting forecast with doppler radar
- **Conclusions**

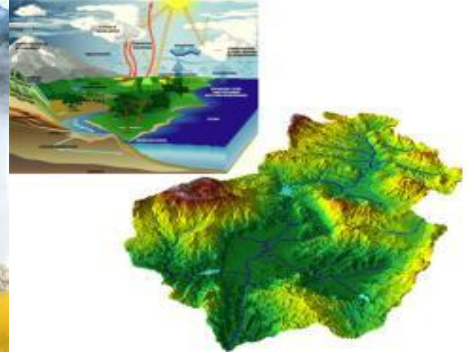
Conclusions

➢ The main conclusion

- Reasonable radar data assimilation can effectively improve the accuracy of numerical rainfall prediction.
- Heavy rainfall identification can effectively improve the accuracy of doppler radar rainfall measurement.
- The method of traditional nowcasting forecasting has better prediction for rainfall with uniform spatial-temporal distribution, but has poor prediction for short-term rainfall and heavy rainfall.

➢ The future expectation

- Considering the combining use of forecast method based on the physical mechanism and forecast experience.
- X-band rain radar should be used to improve the rainfall monitoring and forecasting in key areas.

Thanks for your attention!

中国水利水电科学研究院
China Institute of Water Resources and Hydropower Research