Ensemble flood forecasting based on ensemble precipitation forecasts and distributed hydrological model

Hongjun Bao

PH.D, Professor, Senior Engineer

Director of hydrometeorological forecasting team of NMC

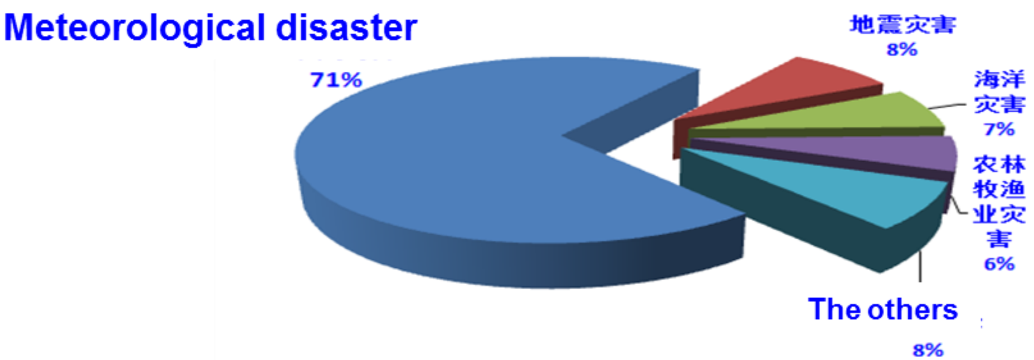
National Meteorological Center of CMA

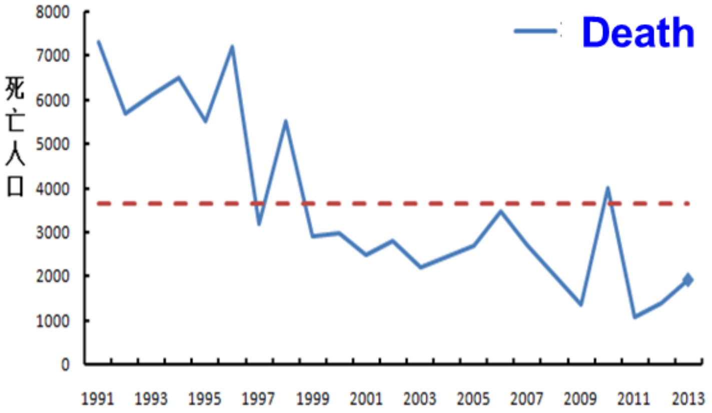
Austin, TEXAS, USA - Jan. 11th,2018

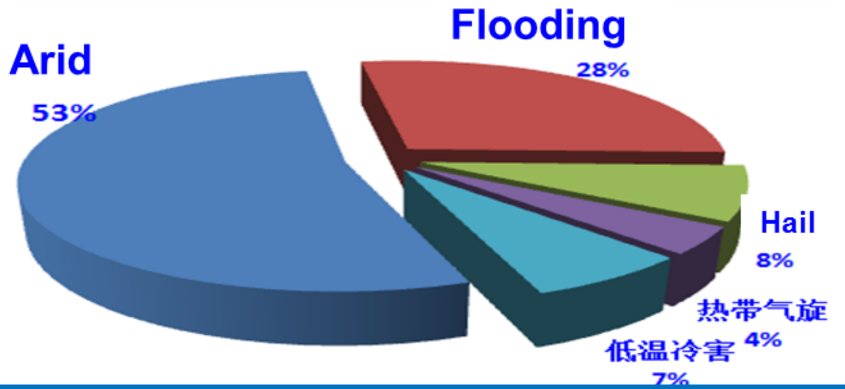
National Meteorological Center of CMA

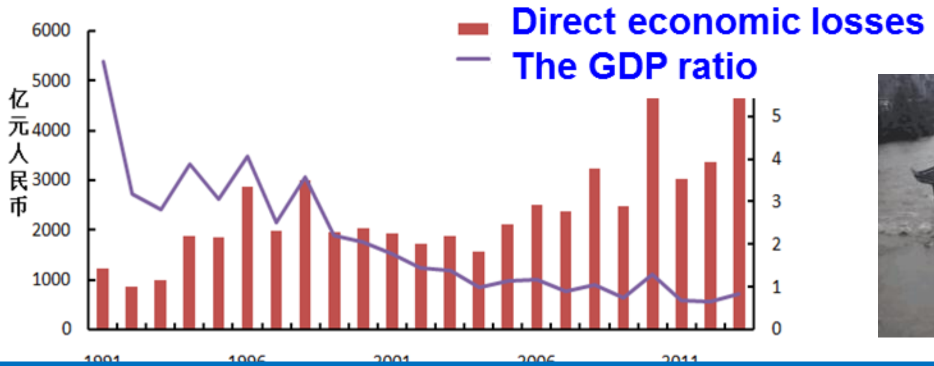
OUTLINE

1. BACKGROUND









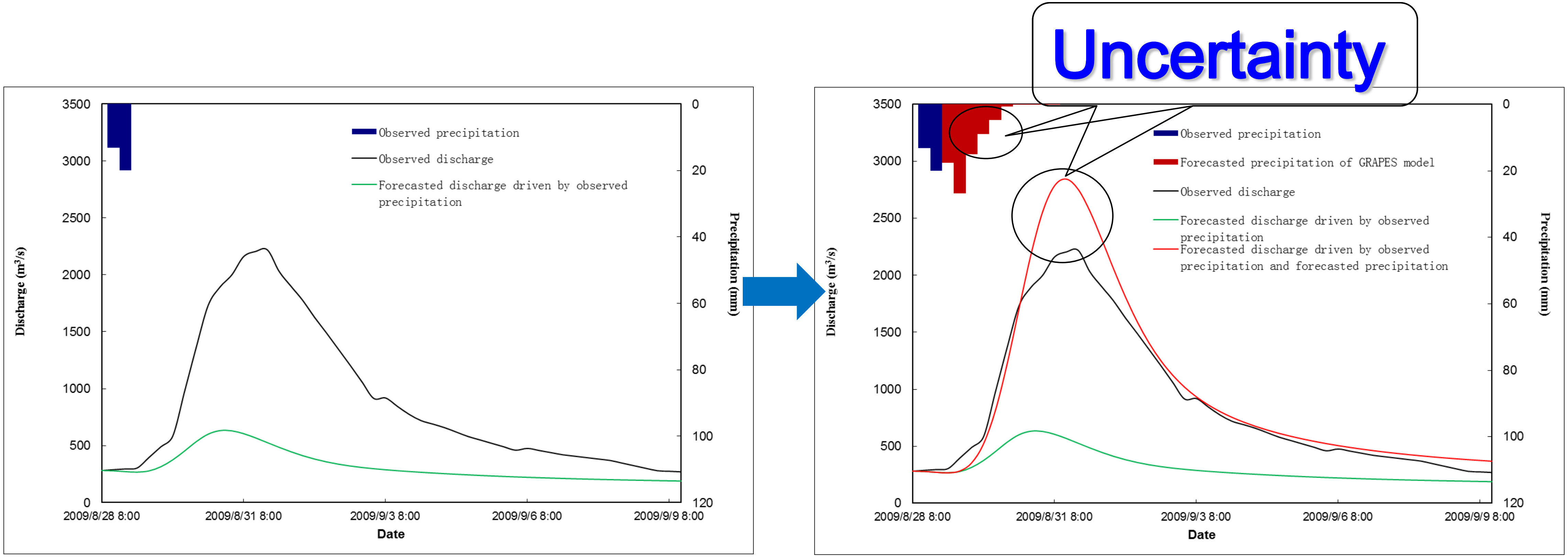
- The losses of meteorological disaster alone contribute 71% of the total natural losses, the mean number of death for meteorological disaster is 3633, and the direct economic losses is RMB 238 billion losses from 1991 to 2013 in China. (National Climate Center, 2014)
- Flooding disaster accounts for 28% of meteorological disaster. (National Climate Center, 2014)
- Flood forecasting has become one of the most important non-engineering measures for reducing flooding losses.

Nat

1. BACKGROUND

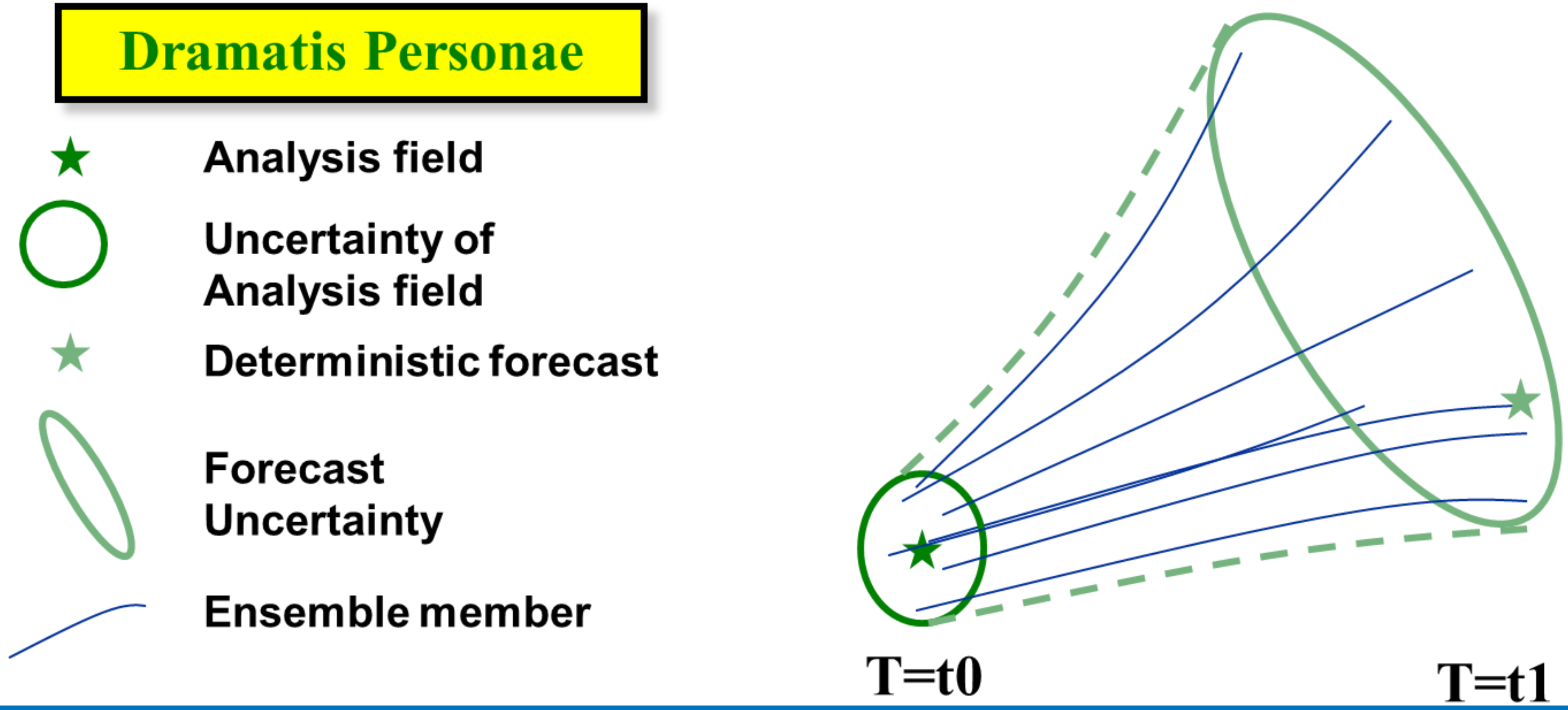
- Flood protection and awareness have continued to rise on the political agenda accompanied by a drive to “improve” flood forecasts.
- Operational flood forecasting systems form a key part of “preparation” for flood events by providing early warnings several days ahead.
- Giving flood forecasting services, civil protection authorities and the public adequate preparation time and thus reducing the impacts of the flooding.
- Many flood forecasting models rely on precipitation inputs, which come initially from observation networks (rain gauges) and radar.
- For medium term forecasts, Numerical Weather Prediction (NWP) models must be used.

1. BACKGROUND



- The incorporation of numerical weather prediction (NWP) into a flood forecasting model can increase forecast lead times from a few hours to a few days.
- To some extent, the uncertainties of precipitation forecasts correspond to that of flood forecasts.

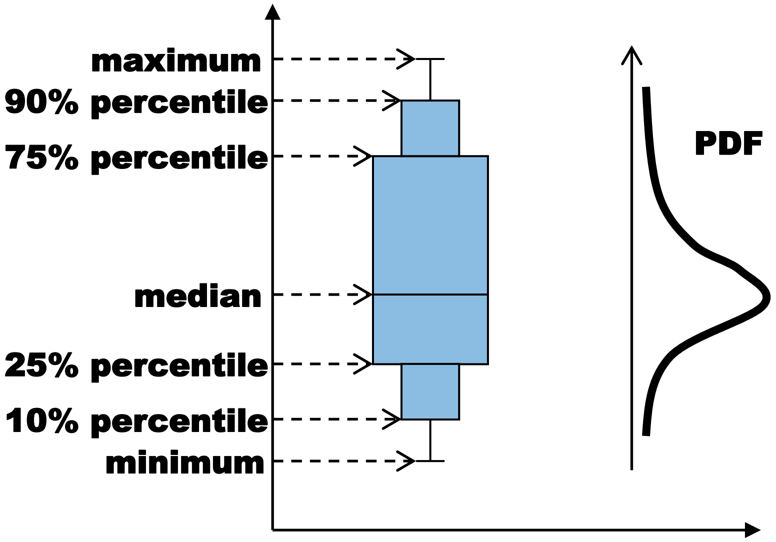
1. BACKGROUND

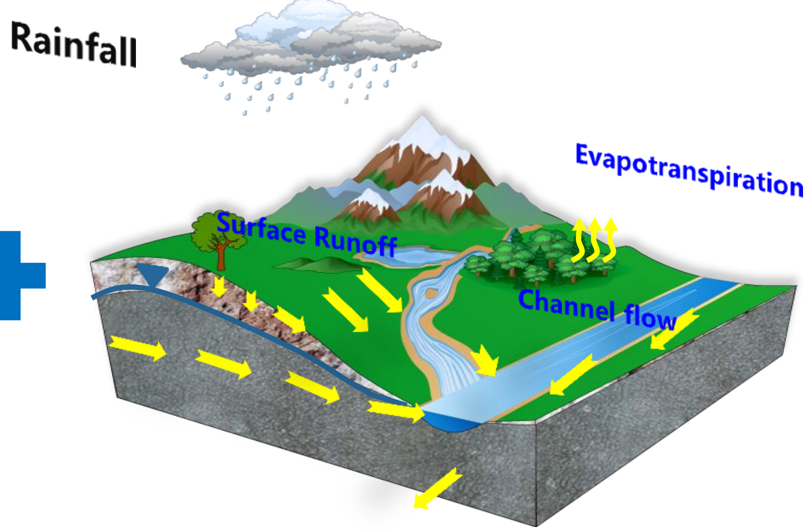


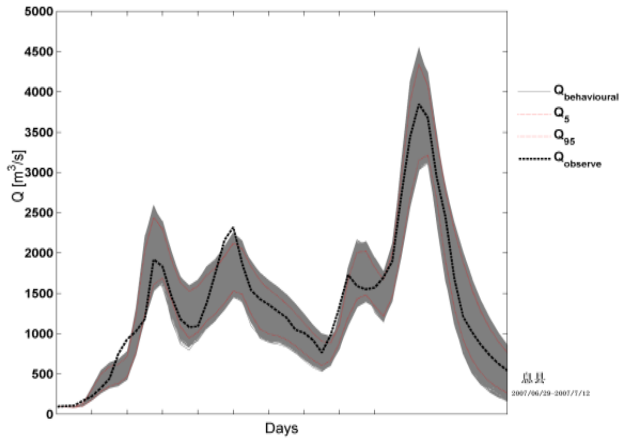
- Single deterministic weather forecast from NWP can't take uncertainties and systematic biases into consideration and hence often fail to replicate weather variables correctly.
- Ensemble Prediction Systems (EPS) have evolved over the last two decades to simulate the effect on weather forecasts of observation uncertainties, model, imperfect boundary conditions and data assimilation assumptions (Park et al., 2007).
- EPS can potentially benefit hydrologists and water managers , which has been demonstrated by HEPEX.

1. BACKGROUND

Develop an ensemble flood forecasting model







TIGGE

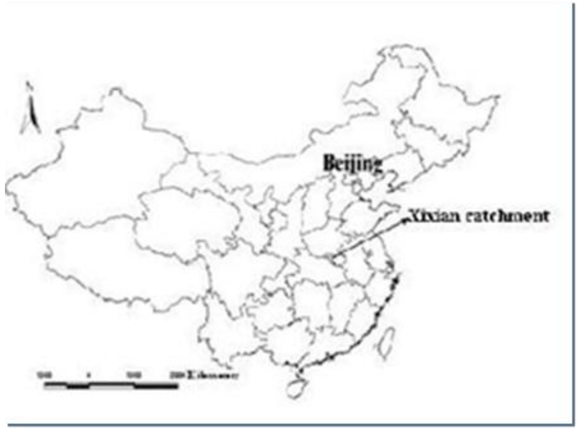
CMC/CMA/ECMWF/UKMO/NCEP

GMKHM hydrological model

Ensemble flood forecasting

- Develop atmospheric-hydrologic flood forecasting model cascade driven by TIGGE ensemble forecasts.
- Apply the model cascade to the Xixian catchment and compare the simulation results driven by TIGGE forecasts and raingauge observation.

Study area



Xixian basin

- Huaihe River is located between latitudes 31° N and 35° N and longitudes 112ºE and 121ºE. It originates in the Tongbai Mountains, and flows over four provinces in east-central China.
- The Xixian catchment, located in the upstream of the Huaihe River, has a drainage area of 8826 km2 and the catchment average annual precipitation is 1145 mm, 50% of which is within the period of the flood season (June-September).

2. STUDY AREA AND DATA

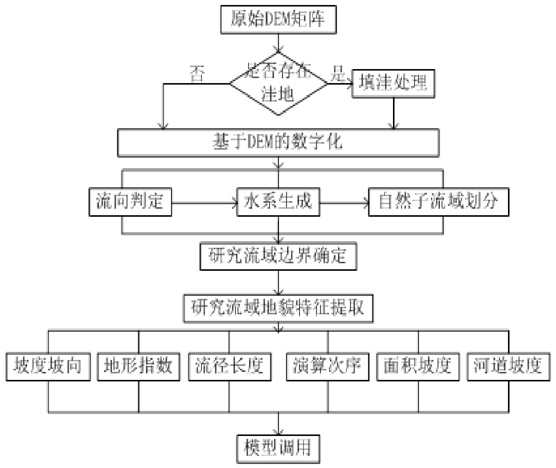
Data

Country/Region	Meteorological centre	Centre Abbreviation	Centre Code	Ensemble members
Canada	Canadian Meteorological Centre	CMC	BABJ	14+1
China	China Meteorological administrator	CMA	CWAO	14+1
Europe	European Centre for Medium-Range Weather Forecasts	ECWMF	ECMF	50+1
UK	Meteorological Office	UKMO	EGRR	23+1
USA	National Centres for Environmental Prediction	NCEP	KWBC	14+1

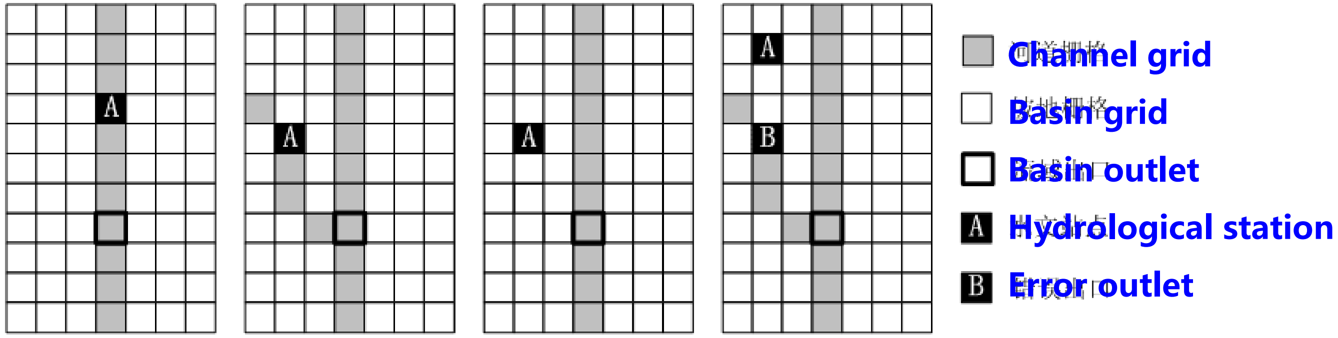
Station	Number	Date	Time scale
Rainfall	10	1980-	6h
hydrological	1	1980-	6h
evaporation	1	1980-	24h

- **Observed hydrometeorological data were obtained from China Meteorological Administration (CMA) and Ministry of Water Resources(MWR), TIGGE data were obtained from TIGGE-China.**
- **When the study was conducted, EPS data was available from five centers in the TIGGE database with the majority delivering EPS from January 2007 onwards.**
- **The flood event taking place in July 2007 was selected as the flood event in the study area. The only five centres data is available in the TIGGE database during the studied flood occuring.**

Digital Basin



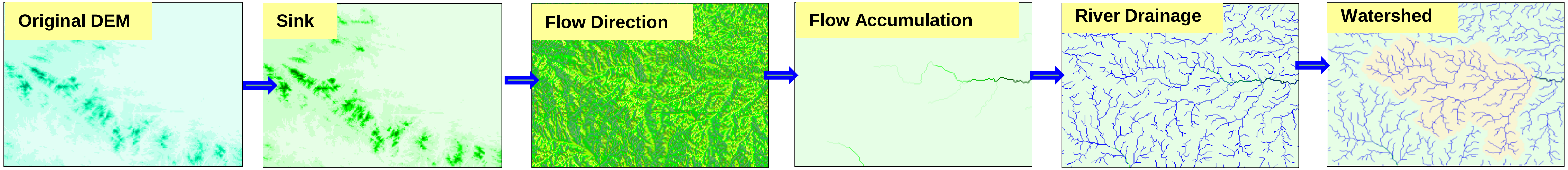
Flow chart of basin extraction from DEM



（a）正确的河道 （b）错误的河道 （c）不位于河道 （d）先流经错误的河道

Objective function ： $\left|\frac{A_i - A_g}{A_g}\right| \times 100\% \le \delta$

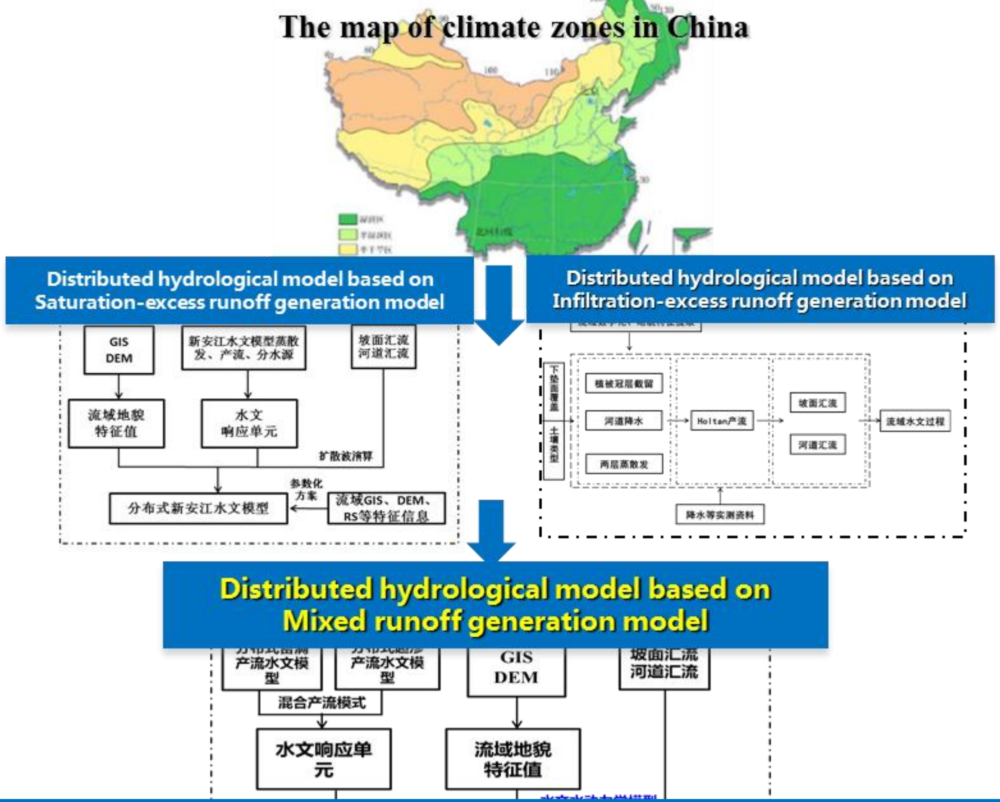
Search along flow direction

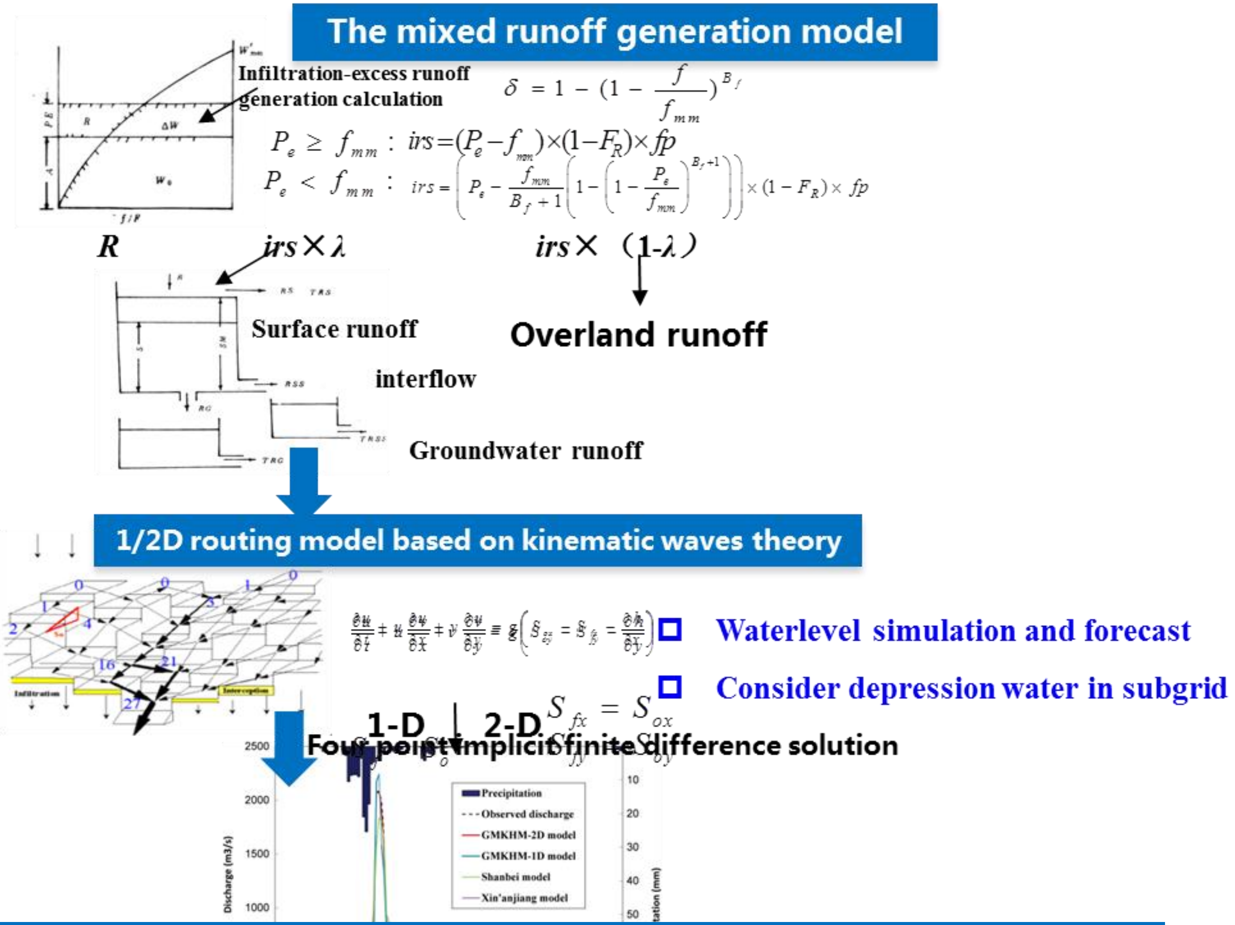


- The basin correction method, based on objective function of basin area, improve the accuracy of digital basin.
- The test basin can be extracted based on DEM data and basin correction method.

3. APPLICATION

GMKHM distributed hydrological model





The Grid-and-Mixed-runoff-generation-and-two-dimensional-Kinematic-wave-based distributed hydrological model (GMKHM model), coupling a mixed runoff generation model and overland flow routing model based on kinematic wave theory, was applied for flood simulation and forecasting.(Bao et al,2017)

3. APPLICATION

Calibration and validation of GMKHM model

Nash Sutcliffe coefficient:

$$N_s = 1 - \frac{\sum_{i=1}^{n}\left[Q_{obs}(i) - Q_{cal}(i)\right]^2}{\sum_{i=1}^{n}\left[Q_{obs}(i) - \overline{Q}_{obs}\right]^2}$$

Q_{obs} is the total observed flood volume.

Q_{cal} is the total calculated flood volume.

$Q_{obs}(i)$ is observed discharge during the ith time step.

$Q_{cal}(i)$ is calculated discharge during the ith time step.

$\overline{Q}_{obs}$ is daily mean observed discharge.

- **20 flood events from 1990 to 2008 that took place in the Xixian catchment were used for model calibration and verification at a 6-hour time step.**
- **The Xixian catchment was divided into 10 sub-catchments by using Thiessen polygon method.**
- **According to the Accuracy Standard for Hydrological Forecasting in China, the Nash Sutcliffe coefficient and the percent absolute error of peak flow, runoff volume and peak time are four important criteria to evaluate flood simulation and flood forecasting.**
- **thirteen flood events were chosen to calibrate the GMKHM model parameters and seven flood events to verify the model in Xixian catchment.**

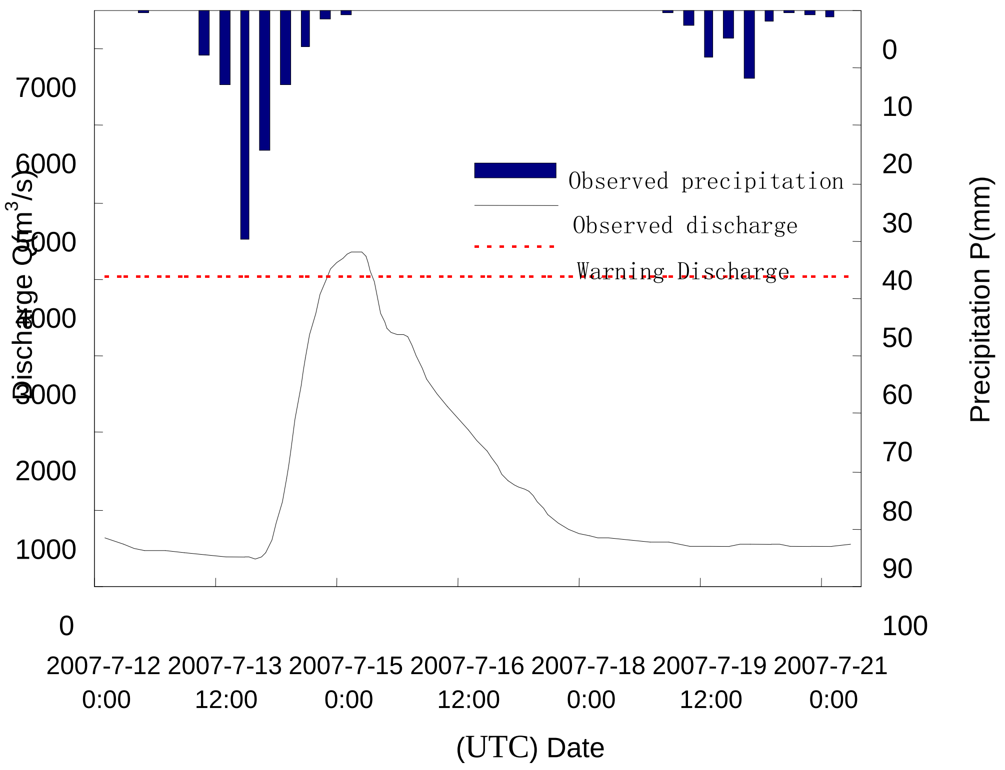
Calibration and validation of GMKHM model

	Flood code	Peak flow （m^3/s）	Runoff (mm)	Relative error of Peak flow (%)	Relative error of runoff (%)	Peak time error (hour)	Nash Sutcliffe coefficient
Calibration	19910517	1670	100.4	5.0	15.1	-1	0.83
	19910629	4410	187.4	12.0	-0.5	0	0.95
	19910801	4420	108.3	0.3	-17.8	0	0.97
	19910901	524	41.3	0.8	1.1	-2	0.87
	19950705	2300	48.7	6.1	1.2	0	0.96
	19960619	4450	280.1	9.0	-1.0	0	0.95
	19980701	2510	60.9	0.4	-26.6	-1	0.89
	19980803	4800	323	-6.0	-14.7	0	0.91
	20000624	3150	145.8	5.1	-10.3	0	0.89
	20020621	5080	164.6	6.1	-7.8	0	0.92
	20030621	3900	143.9	11.5	5.2	0	0.96
	20030716	3800	114.7	-7.6	-3.3	0	0.94
	20040715	950	32.7	-7.3	7.8	0	0.90
Validation	20040728	2520	66.8	-8.7	1.4	1	0.84
	20050623	1560	34.9	-6.1	18.8	0	0.92
	20050704	6000	159.8	-14.5	-7.1	0	0.98
	20050820	3830	175.9	0.2	-8.5	-1	0.92
	20050828	3830	123.1	-5.4	10.0	1	0.92
	20070711	4330	107.2	11.3	-1.1	0	0.94
	20080722	3700	85.2	6.1	1.2	1	0.91
Absolute mean				6.5	8.0	0.35	0.92

- **The ratios of qualifying peak flow, flood runoff and peak time for the GMKHM model applied to the Xixian catchment are 100%, 90.0% and 95.0% respectively. The Nash coefficients of all of the events in the table are greater or equal to 0.80 for the GMKHM model; the Nash coefficients of 12 floods are greater than 0.90 for the GMKHM model.**
- **the performances of the GMKHM model satisfy the first grade of flood forecasting calibration or validation (all of three ratios are more than 85%) in terms of the standard established by MWR, China.**

3. APPLICATION

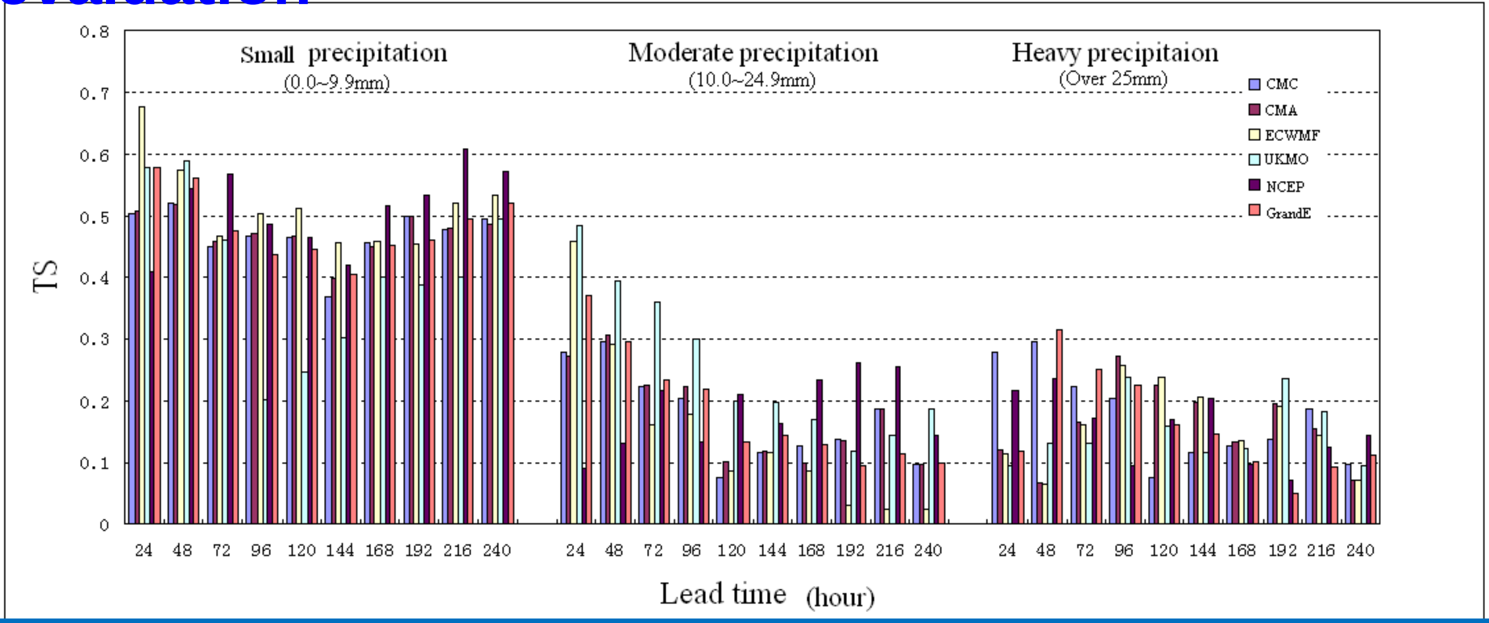
Studied case



- This study focused on one flood event that took place in July 2007 . The flood warning level at the Xixian station is 41.50 m and corresponds to a discharge of 4034 m3/s. The warning level was reached at 0000 (UTC) on 15 July 2007 for the studied flood event and exceeded in the subsequent one day.

3. APPLICATION

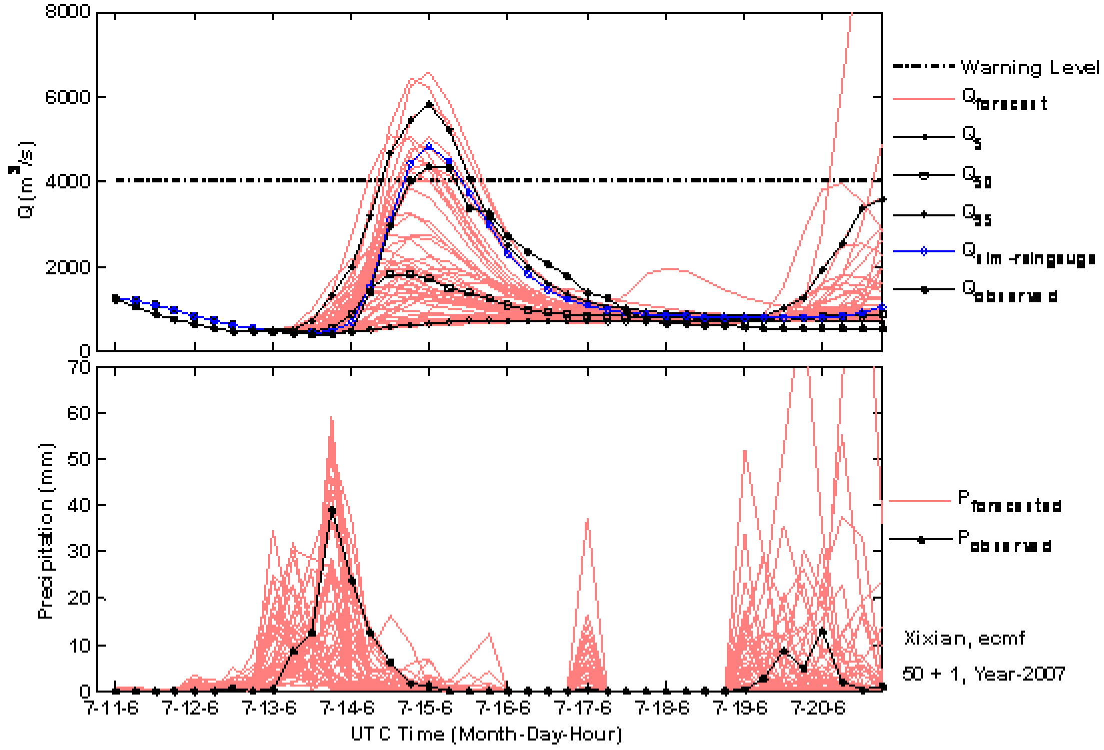
Precipitation evaluation



- we examined the feature by visually comparing Pf of small, moderate and heavy precipitation with thresholds per day of 0.0~9.9mm, 10~24.9mm, over 25mm respectively(defined by CMA), and threat scores (TS) method was employed.
- the five EPSs and grand ensemble have diferent performance. small precipitation :CMA, ECMWF and NCEP are better. moderate precipitation: UKMO performs better. Five EPSs all have the TS value below 0.30. Grand ensemble has a slightly better TS value than CMA and CMC.

3. APPLICATION

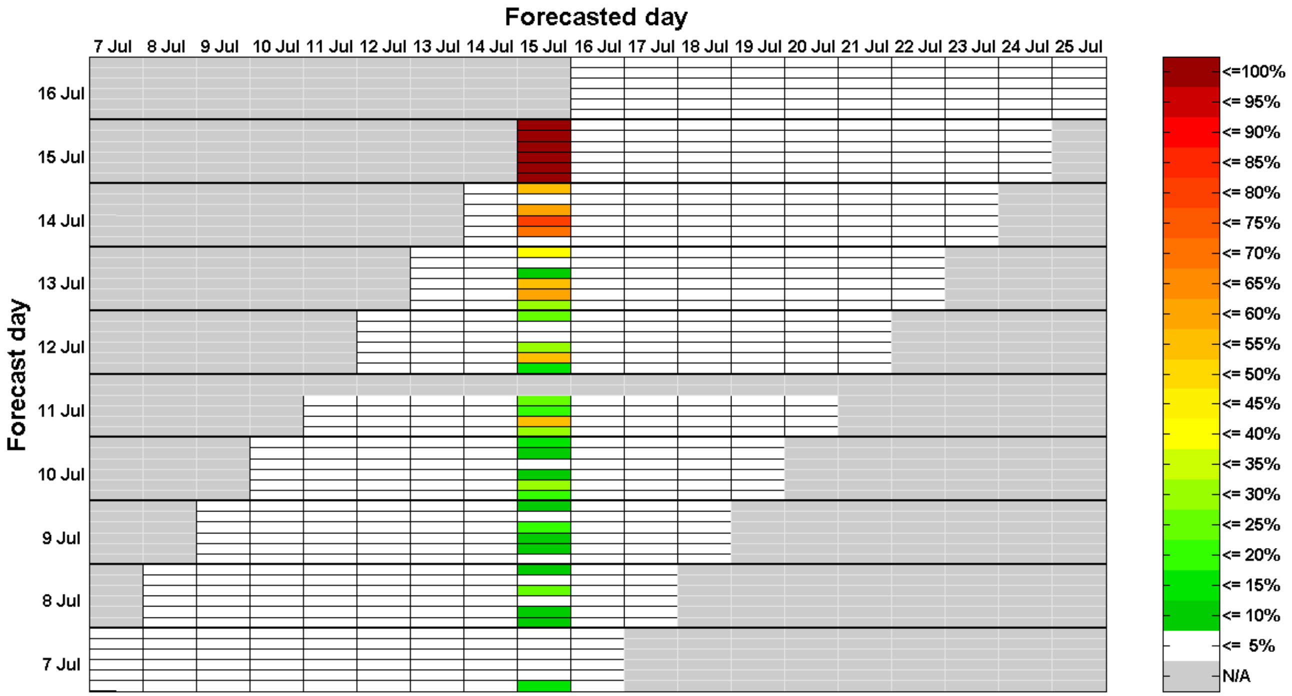
Ensemble flood forecasting



- All ECMWF forecast members issued on 12 July 2007 displayed the best agreement for the rainfall event occurred on 13 July 2007. Similarly, the amount and timing of the rainfall between 13 July 2007 and 15 July 2007 were best forecasted with 2-day lead time, i.e. from 14 July 2007 to 16 July 2007.
- In comparison to the observed discharge, the ensemble of Q_f was underestimated by approximately 10-30% for all forecast members varying from day to day. In this study, Q_{50} is very comparable with the $Q_{sim\text{-}raingauge}$ for ECWMF, and Q_{95}, Q_{50}, Q_{50}, Q_{95} for CMC, CMA, UKMO, NCEP respectively.

3. APPLICATION

Flood warning



The warning table for the studied flood event. The six horizontal bars from bottom to top represent the five centres (CMC, CMA, ECWMF, UKMO, NCEP), and the ensemble of the five forecast centres.

- The warning table shows the forecasts ability to predict the individual events. The studied flood event is well predicted by all centers with a few days in advance. The percentages correspond to the percentage of members higher than the alert threshold.

4. CONCLUSIONS

the GMKHM model can perform well for flood simulation and forecasting in the Xixian catchment, and The TIGGE archive is a promising tool for issuing a fairly reliable warning as early as 10 days in advance with producing forecasts of discharge comparable with the observed discharge.

Techniques to deal with multi-model forecasts need to be developed. In this study, the principle of equal probability of selection was applied. Different weather forecasts may be assigned a different weight coefficient, which might improve the performance of the grand ensemble.

A spatial and temporal correction to the ensemble weather predictions to resolve discrepancies in the spatial distribution and timing should be developed for flood forecast. The precision of rainfall forecast affects an offset of the peak in term of timing and magnitude that led to the partial failure in early flood warning in hydrological forecasting.

ACKNOWLEDGEMENTS

- Funded by the National Natural Science Foundation of China(41775111 and 51509043) and the National Key Technologies R&D Program of China(2016YFC0402702).
- Thank Prof. Li Z， Drs. He Y and F. Pappenberger et al.

- Some related publications

Bao H J, Wang L L,Zhang K, Li Z J . 2017. Application of a developed distributed hydrological model based on the mixed runoff generation model and 2D kinematic wave flow routing model for better flood forecasting, Atmospheric Science Letters, 18(7):284-293.

Bao Hongjun, Li Zhijia, Wang Lili,et al. 2017. Flash flood forecasting method based on Distributed Hydrological Models in a small basin and its application. Torrential Rain and Disasters, 36(2): 156-163.

Bao Hongjun,Wang Lili, Shen Xueshun,et al. 2016.A Review: Advances of Flood Forecasting of Hydro-Meteorological Forecast Technology. Meteorological Monthly, 43(9): 1045-1057.

Bao H J, Zhao L N, He Y, et al. 2011.Coupling ensemble weather predictions based on TIGGE database with Grid-Xinanjiang model for flood forecast. Advances in Geosciences, 29:61-67.

Thank you for your attention!

谢谢 ！

Contact: baohongjun@cma.gov.cn