A GIS based distributed hydrological forecast system

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Abstract: The currently used hydrological forecast system in China is mainly focused on flood and the flood forecasting frameworks are typically based on point discharge measurements and predictions at discrete locations, hence they can’t provide spatio-temporal information of hydrological elements, such as evapotranspiration, soil moisture, ground water table, and flood inundation extents over large scales and at high spatial resolution. The use of distributed hydrological model has recently appeared to be the most suitable option to bridge this gap. A GIS based distributed hydrological forecast system is established, and the hydrological processes are conceptually divided into five simulation modules, which are runoff generation, runoff concentration, flow routing, reservoir regulation and inundation, respectively. The input forcing data and the output results are all gridded and standardized. An open source GIS platform is employed to process the massive geomorphological data, soil data, Land Use and Land Cover data, etc.

Keywords: Hydrological forecast system; distributed hydrological model; open source GIS

Introduction

China has been developing a National Flood Forecast System (NFFS) since 1998, and there are three components shown in Figure 1 included, which are calibration part, operational forecast part and extended streamflow prediction part, respectively. The calibration part is used to calibrate and validate the model parameters based on the historical data, the operational forecast part is used to make flood forecast in a real time manner through the interactive process between forecaster and the system, and the extended streamflow prediction part is used for long term forecast at the help of statistical analysis and probabilistic predictions.

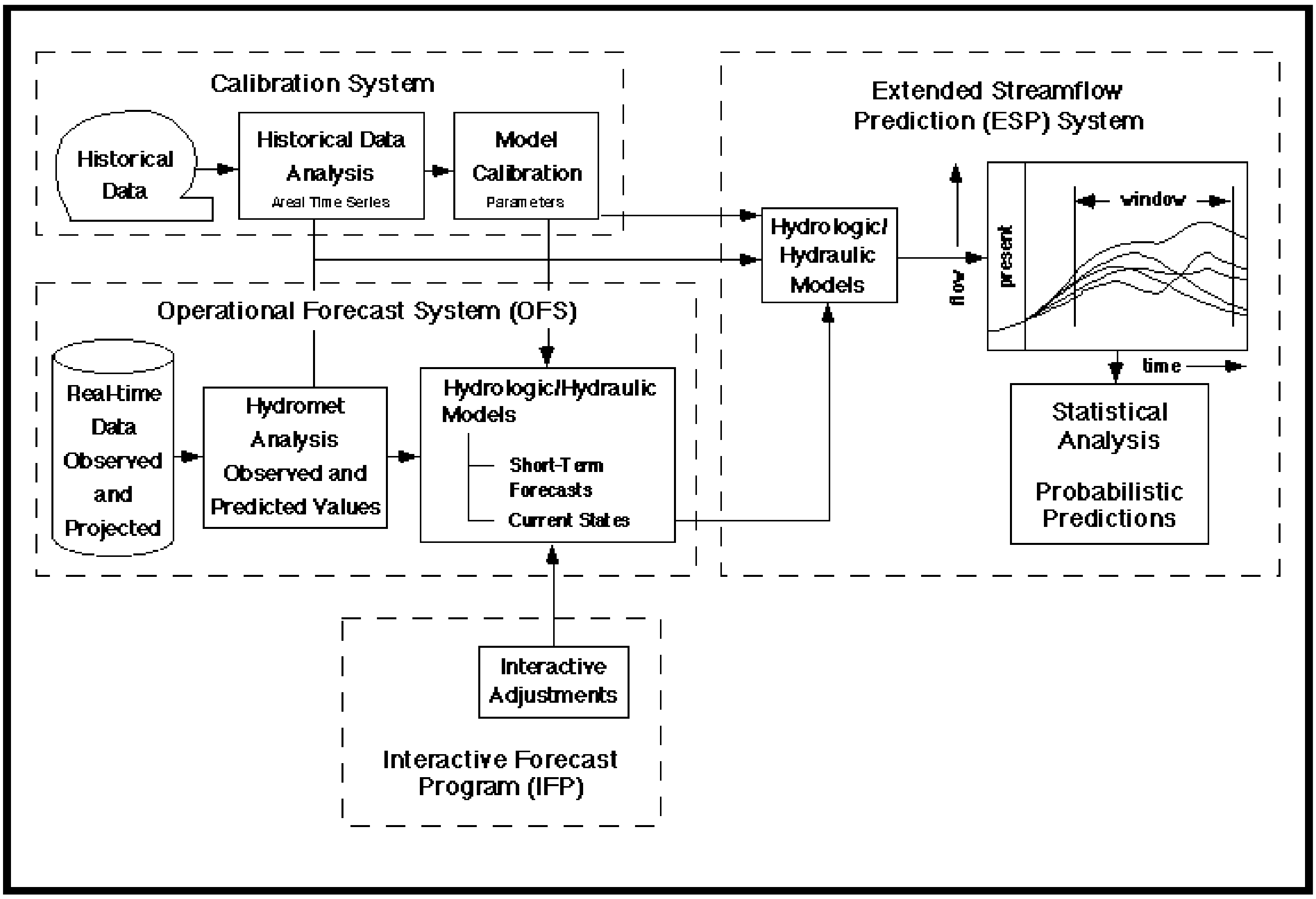
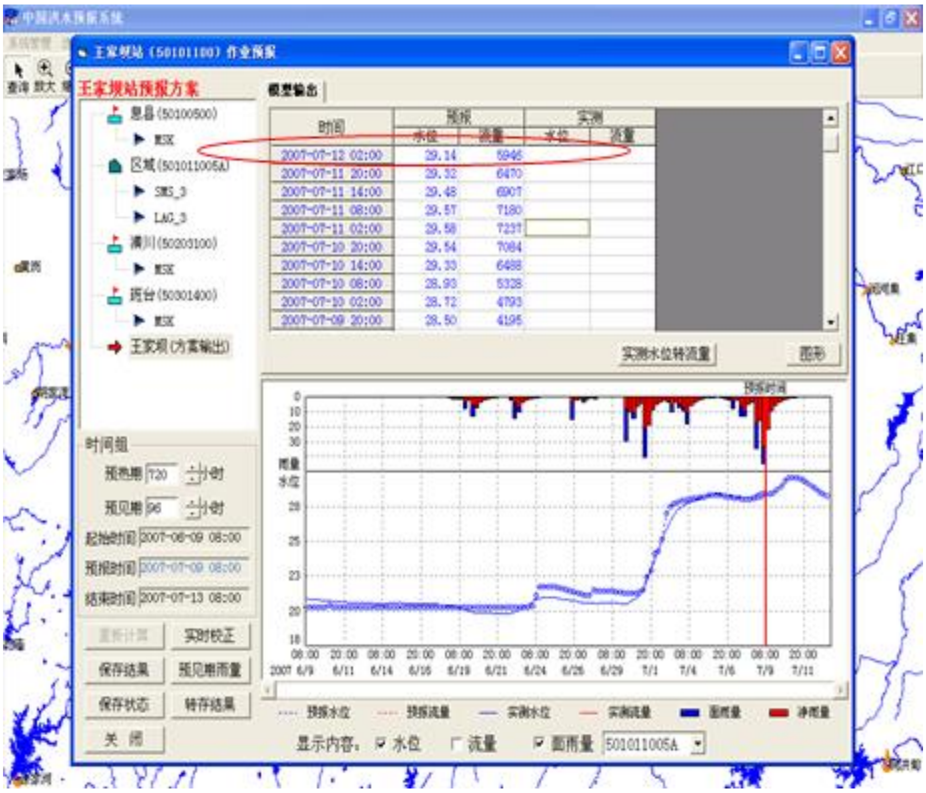


Fig. 1 The three components of NFFS of China



时间	预报		实测	
	水位	流量	水位	流量
2007-07-12 02:00	29.14	5946		
2007-07-11 20:00	29.32	6470		
2007-07-11 14:00	29.48	6907		
2007-07-11 08:00	29.57	7180		
2007-07-11 02:00	29.58	7237		
2007-07-10 20:00	29.54	7084		
2007-07-10 14:00	29.33	6488		
2007-07-10 08:00	28.93	5328		
2007-07-10 02:00	28.72	4793		
2007-07-09 20:00	28.50	4195		

时间组
预热期 720 小时
预见期 96 小时
起始时间 2007-06-09 08:00
预报时间 2007-07-09 08:00
结束时间 2007-07-13 08:00

显示内容： ☑ 水位 ☐ 流量 ☑ 面雨量 501011005A

Fig. 2 The interface of NFFS

The interface of NFFS is shown in Figure 2, some main factors such as the warm up period and leading time of forecast are left for the forecasters to change, and the parameters of different models can also be altered to get the best fitting line. The forcing data comes from the rainfall observations and the NWP results, and the results are usually the discharge at specific cross sections. The models used mostly in NFFS includes Xin’an jiang, Unit hydrograph and Muskingum among others. Once the discharge is calculated, the water level is interpolated through the stage-discharge curve. At present, there are about 2000 cross sections located in the main rivers of China, and overall forecast accuracy is about 75%.

The shortcoming of NFFS is that the flood forecasting framework was typically based on point discharge measurements and predictions at discrete locations, hence they can’t provide spatio-temporal information of hydrological elements, such as evapotranspiration, soil moisture, ground water table, and flood inundation extents over large scales and at high spatial resolution. Distributed hydrological model has recently appeared to be the most suitable option to bridge this gap, such as the newly developed WRF-Hydro model used in NOAA, which is shown in Figure. 3

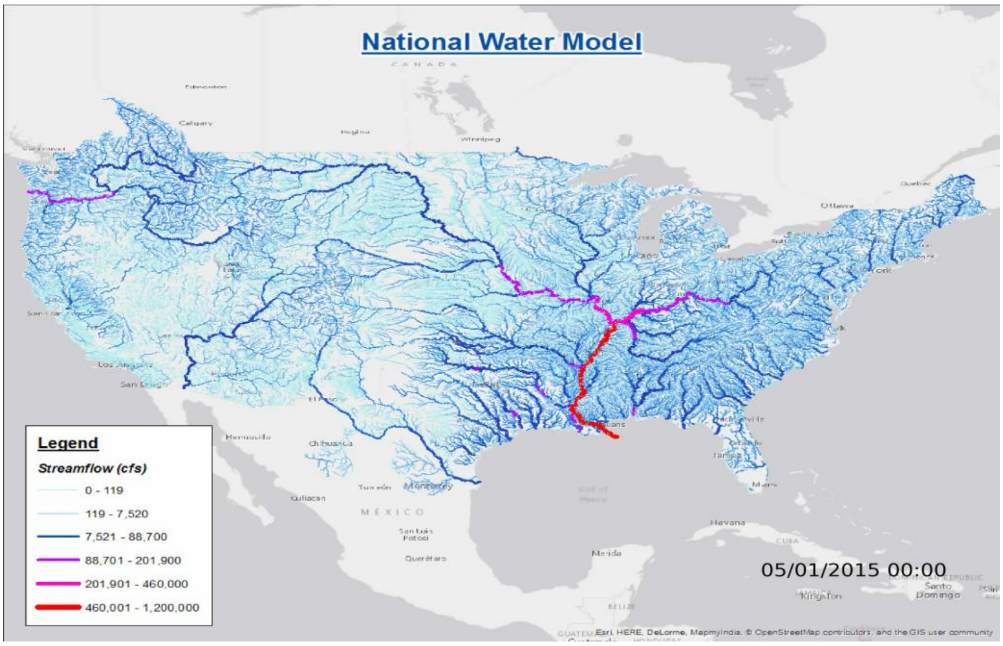


Fig. 3 The newly developed National Water Model of CONUS

Take the NFFS of China and NWM of US into consideration, we developed a GIS based distributed hydrological forecast system. In the following part of this paper, the structure of this system is described firstly, then the data needs and model results are introduced, and the final part is about discussion and summary.

Structure of the system

The structure of the distributed hydrological forecast system newly established is shown in Figure 4. The hydrological processes are conceptually divided into five simulation modules, which are runoff generation, runoff concentration, flow routing, reservoir regulation and inundation mapping, respectively. The input forcing data include observed and predicted precipitation, and if real time meteorological data not available, the average evapotranspiration of historical data could be used as the alternative of potential ET. The model output include the real ET, surface runoff, soil runoff, groundwater, soil moisture, stage and discharge at specific cross sections, the inflow and outflow of reservoir, and the inundation depth and area, etc. The input and output data are all gridded and standardized.

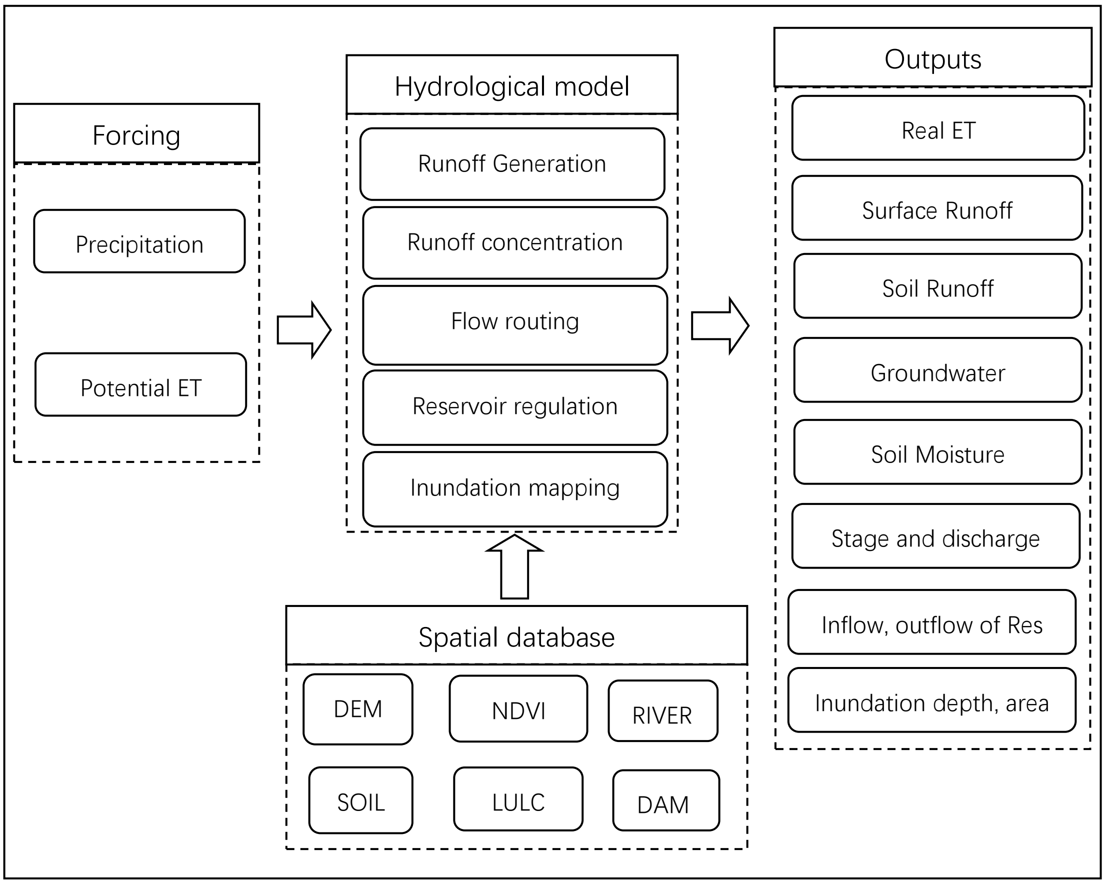


Fig. 4 The structure of distributed hydrological forecast system established

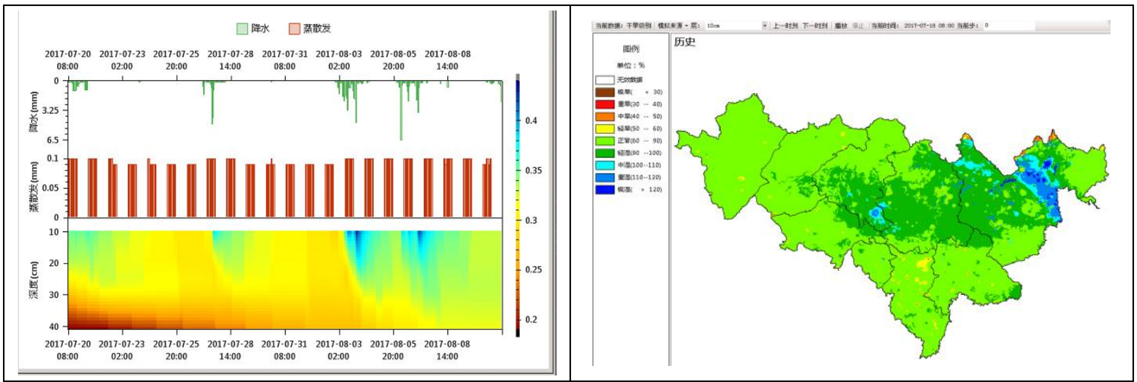
The basic geostatic data includes DEM, SOIL, NDVI and LULC, the river and dam data is also necessary for the simulation. An open source GIS platform is employed to process these massive geostatic data.

The rainfall infiltrated into soil on each grid is calculated through solving the Richards equation layer by layer, the net rainfall on the hillslope is concentrated into the river using manning equation, and the flow in the river is routed from upstream to downstream in Muskingum method. As for the reservoir, the water balance and weir/sluice flow equations are employed to calculate the outflow and the variation of water level. The HAND (Height Above the Nearest Drainage) method used in WRF Hydro model is borrowed here for flood inundation mapping over large scales and at high spatial resolution.

Data and results

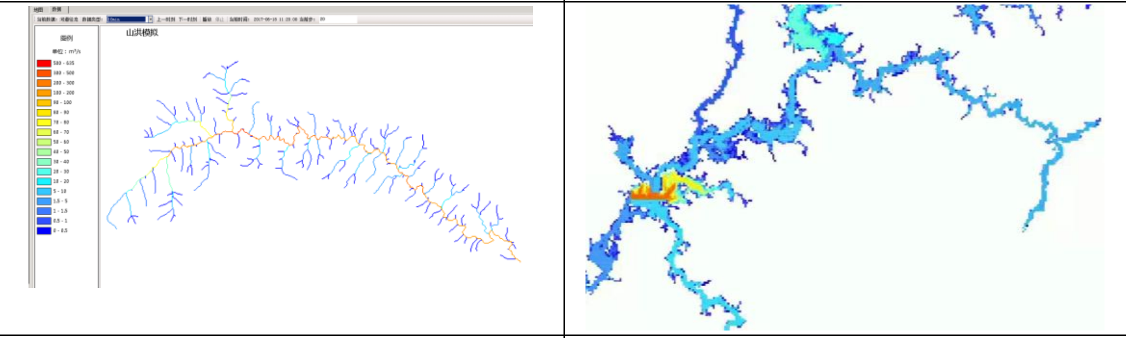
As described above, the basic data needs are the precipitation, whatever it is historical or predicted. The other data is potential ET, which is used for the real time ET calculation. All these data should be prepared in advance and gridded in standard format, such as netcdf format. The other basic data, such as DEM, SOIL, NDVI and LULC, are assumed at hand already. If not, you can download these data from some public websites, such as SRTM, FAO, etc.

Figure 5 shows some typical outputs from this new system. Figure 5(a) is the rainfall, real ET and the soil moisture profile of one grid. The variation of soil moisture at different depth can be clearly recognized with the varying precipitation, and the water flows from the surface to downward as the rainfall occurs, if the rain stops, the soil will lose moisture from bottom to upward. Figure 5(b) shows the relative humidity of soil at 10cm depth. The relative humidity of soil at other depths are also simulated. This product could be used as an indicator of drought assessment. Figure 5(c) is the flow routing image of one small river, as the discharge of every river reach has been computed, the dynamic routing process from tributaries to main stem and from upstream to downstream could be visualized at the help of GIS tools. Figure 5(d) shows the real time inundation map of flood, in which the different colors represent different inundation depths. It should be noticed that the resolution of the DEM in 5(c) and 5(d) is about 30m, you can replace it with your own data to get better results.



（a）rainfall, ET and soil moisture profile of one grid

（b）the relative humidity of soil at 10cm



（c）the flow routing map of one small river

（d）the real time inundation map

Fig. 5 Some typical outputs of the new system

Discussion and summary

There are a lot of indispensable problems unresolved. Firstly, the initial condition of the simulation area is very complex and very hard to access. Soil moisture of each grid is the most important part, as it influence the runoff generation to a very large extent and we only have very limited observations. Other uncertainties of initial condition include but not limited to the groundwater table, the water volume stored in hundreds of thousands of reservoirs, the detention/retention depth on the surface, etc. Data assimilation techniques might be possible resolutions we should resort to. Secondly, some parameters of the distributed hydrological model still need to be calibrated and validated. For example, the roughness of the river, the specific yield of the ground water, the unsaturated hydraulic conductivity of soil, and so on. Due to the complexity of the model, the calibration and validation work is somehow time and human consuming. Thirdly, the conversion of discharge to water level is a dangerous jump as there are only very limited cross section measurements. The geomorphology under the water is very difficult to obtain for so many river reaches, unless you can arrange some remote sensing work when there is no water or at low flow season. What is more, some infrastructure constructions like the dykes or detentions will also influence the water flows and in turn the inundation scope, which are also factors you cannot ignored when doing the simulation.

Anyway, even there are so many problems to face, we still make an extraordinary progress in a very short time. In future, we also plan to use different NWPs and different hydrological models to do ensemble forecasts and probability forecast, and the reservoir regulation schemes under the circumstance of uncertain and risk. Besides, we still want to issue hydrological warnings to the public based on the inundation mapping results. There is still a long way to go.

Criteria	Self-evaluation
1.length	1546
2.Addressed options; original content	Yes, Option A and it is original
3. organized, easy to follow; includes summary	Yes
4. use graphics and tables at appropriate	Yes
5. refer to topics in the course	Yes, modeling and remote sensing are referred.