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Distributed Hydrological Model for Water Resources Management

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Outline

1. Requirements from the Water Management
2. Current Hydrological Model and Gaps
3. An Example in the Yangtze River of China
4. Summary

1. Requirements from the Water Management

Asia is Facing Many Common Water Issues

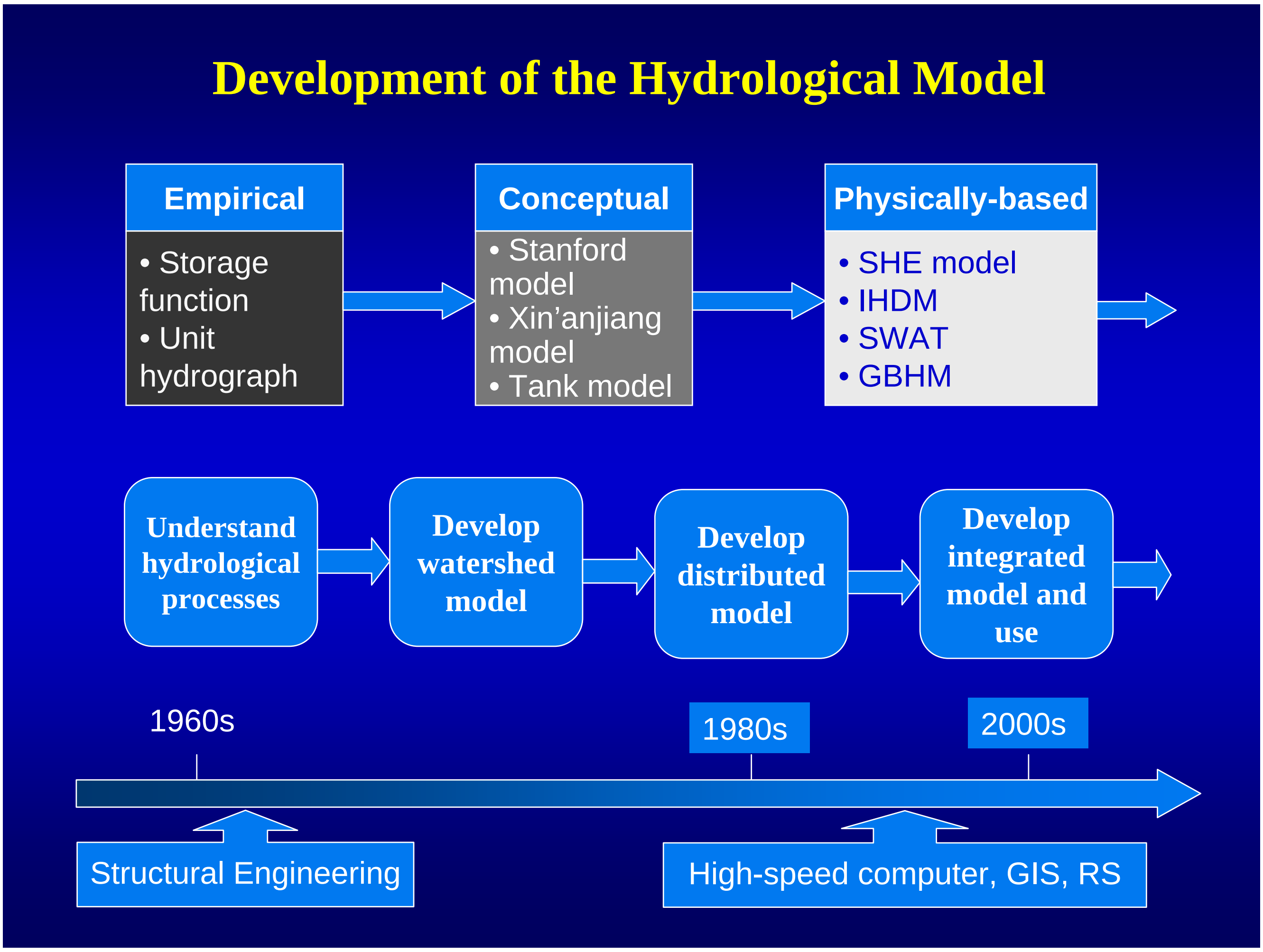
- Due to its monsoon climate characteristics and the largest population in the world, Asia faces many common water issues -- water scarcity, flood, drought, water pollution and ecosystem degradation.
- Many Asian developing countries lack of the core technical tools for integrated water resources management.

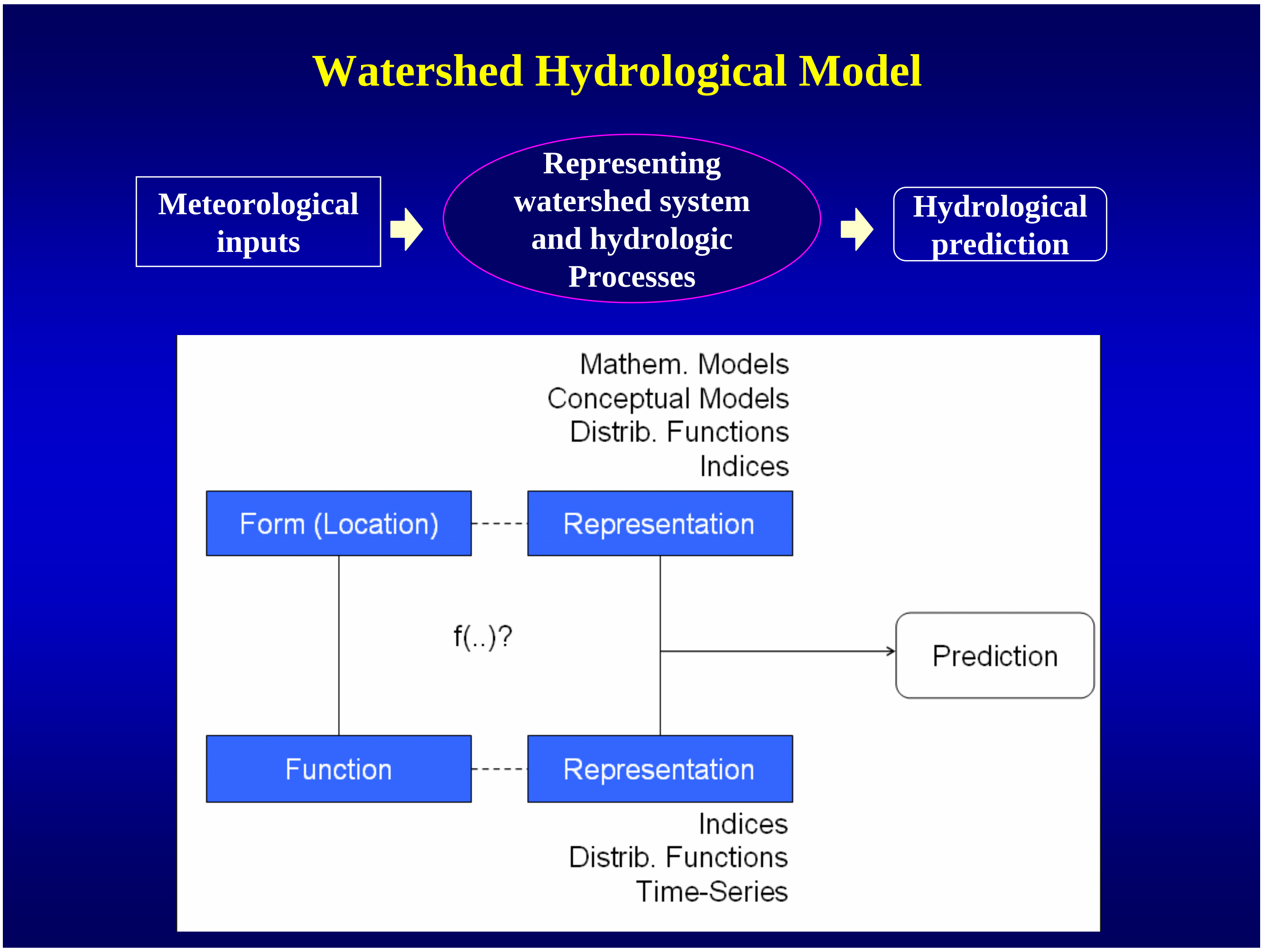
Recent Floods and droughts occurred in the Yangtze River basin, China

Requirement to Hydrological Model for the Water Management

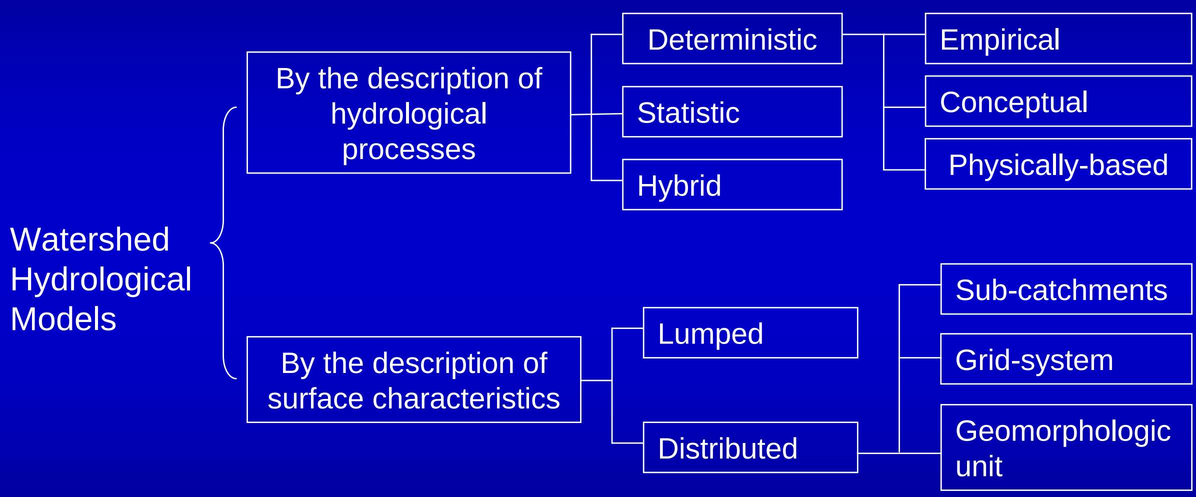
- It is needed to predict the changes in water availability under the changes in climate and land use.
- Flood forecast should have enough accuracy and leading time.
- It needs appropriate drought indicators for different water sectors and sophisticated tools. The hydrological model can be potentially useful.

2. Current Hydrological Model and Gaps

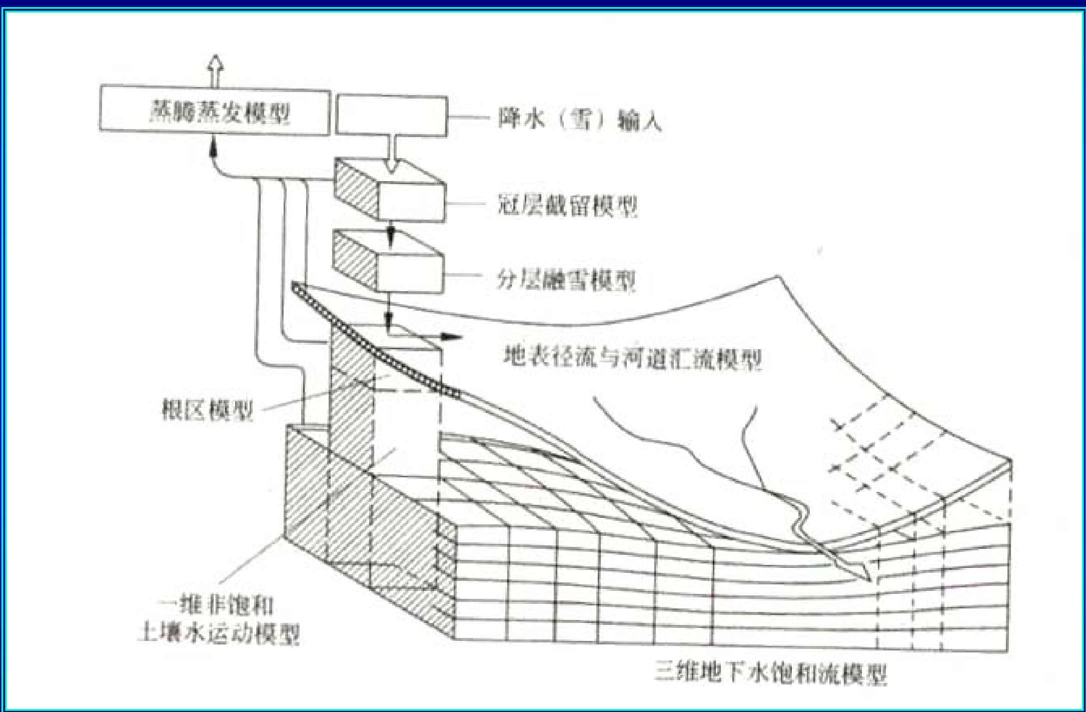

Development of the Hydrological Model
Empirical
• Storage function
• Unit hydrograph
Conceptual
• Stanford model
• Xin'anjiang model
• Tank model
Physically-based
• SHE model
• IHDM
• SWAT
• GBHM
Understand hydrological processes
Develop watershed model
Develop distributed model
Develop integrated model and use
1960s
1980s
2000s
Structural Engineering
High-speed computer, GIS, RS


Watershed Hydrological Model
Meteorological inputs
Representing watershed system and hydrologic Processes
Hydrological prediction
Mathem. Models
Conceptual Models
Distrib. Functions
Indices
Form (Location)
Representation
f(..)?
Prediction
Function
Representation
Indices
Distrib. Functions
Time-Series

❖Classification of the Hydrological Models

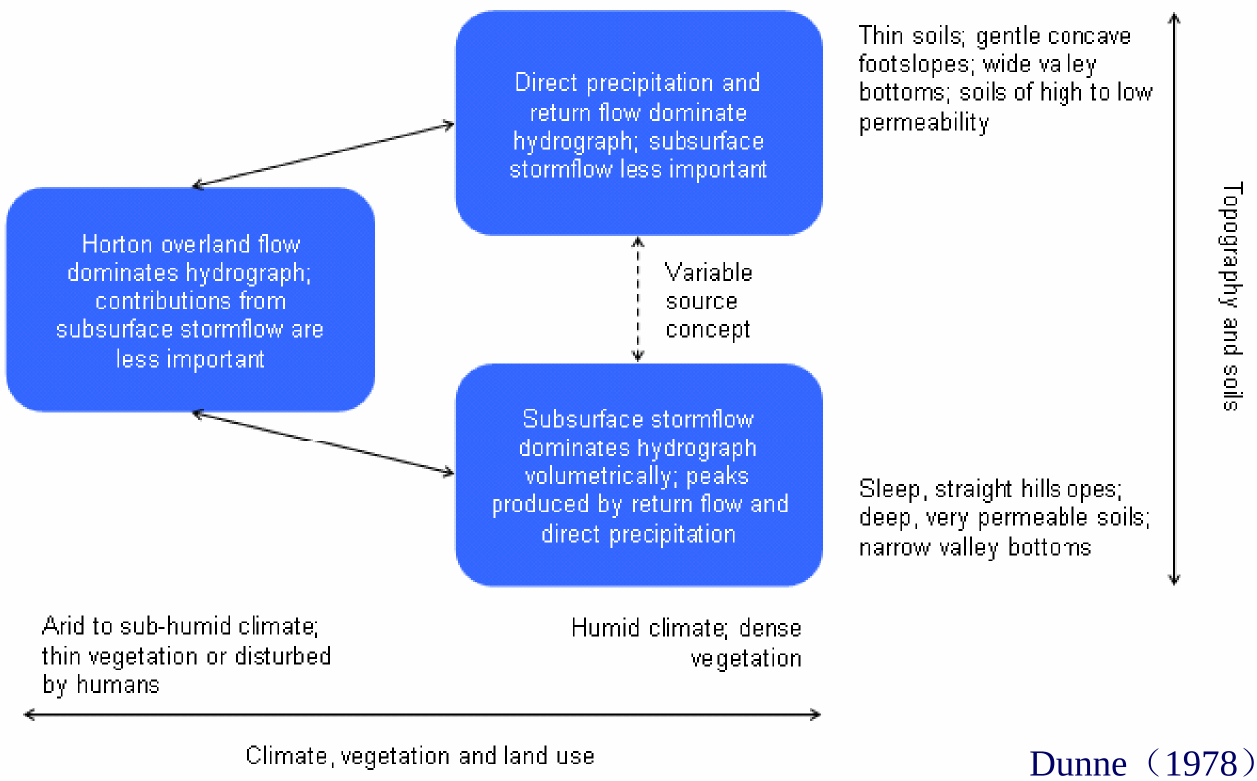


❖ An Example of the **Distributed Hydrological Model – SHE Model**



Typical structure of Distributed Hydrological Model

❖ Rainfall-runoff Generation Mechanism: Infiltration and Saturation Excess



Dunne（1978）

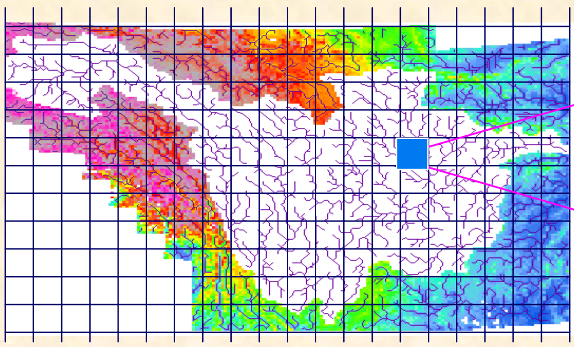
Gaps of the Current Hydrological Model

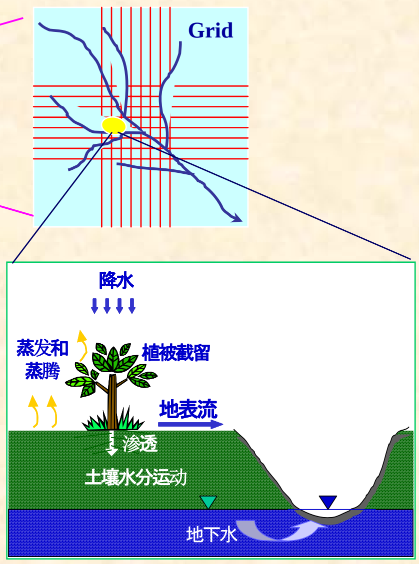
- Lack of sufficient accuracy for distinguishing the effects on the water resources from climate change and human activity.
- Lack of sufficient leading time in the real time flood forecast.
- Lack of appropriate drought indicators regarding different water users.

3. An Example in the Yangtze River of China

(1) Model Structure

GBHM **(Geomorphology- Based Hydrological Model, 1998)**





Representing the basin using:

- **Basin → sub-basin → flow interval → grid →** **hillslope**
- **Sub-grid parameterization:** topographical and land use heterogeneity

(2) Physically-based representation of the hydrological processes

Potential evaporation (water surface): $$E_p = \frac{\Delta}{\Delta+\gamma}(R_n + A_h) + \frac{\gamma}{\Delta+\gamma}\frac{6.43(1+0.536U_2)D}{\lambda}$$

Crop reference evaporation: $$E_{rc} = \frac{\Delta}{\Delta+\gamma^*}(R_n - G) + \frac{\gamma}{\Delta+\gamma^*}\frac{900U_2 D}{T+275}$$

Actual evapotranspiration:

$$E_{\text{canopy}} = K_c E_p \quad \text{(Canopy evaporation)}$$

$$E_{\text{tr}}(z_j) = K_c E_p f_1(z_j) f_2(\theta_j)\frac{LAI}{LAI_0} \quad \text{(Transpiration)}$$

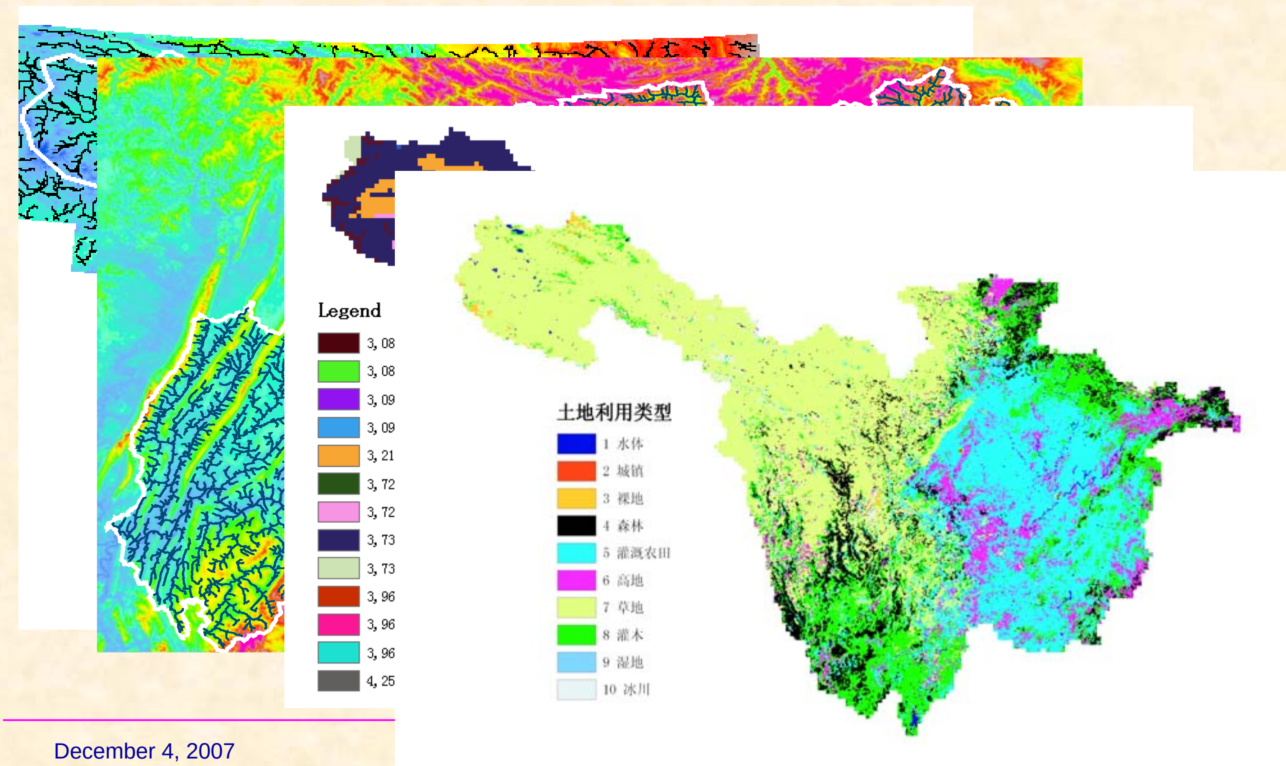
$$E_s = K_c E_p f_2(\theta) \quad \text{(soil evaporation)}$$

Canopy interception: $$S_{C0} = 0.1 \quad LAI \quad \text{(Interception capacity)}$$

Soil water movement: $$\frac{\partial\theta(z,t)}{\partial t} = -\frac{\partial q_v}{\partial z} + s(z,t) \quad q_v = -K(\theta)\left[\frac{\partial\psi(\theta)}{\partial z} - 1\right]$$

Sub-surface flow: $$q_{sub} = K(\theta)\sin\beta$$

(3) GIS Data: DEM, Soil and Land-use Maps



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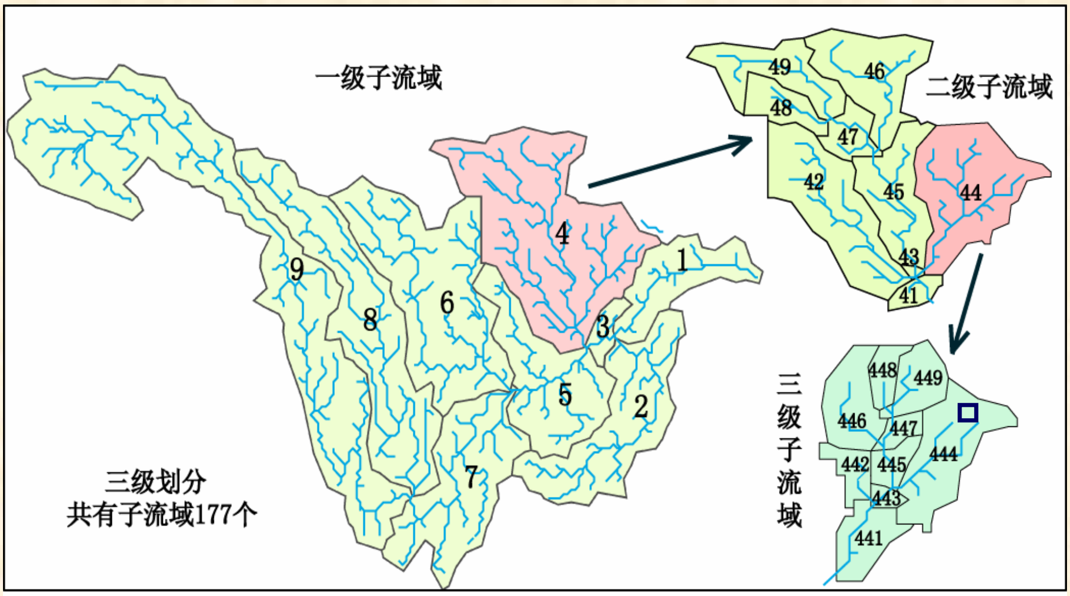
Subdivision of the Upper Yangtze River Basin



Large grid size (10km×10km) and a sub-grid parameterization scheme are used.

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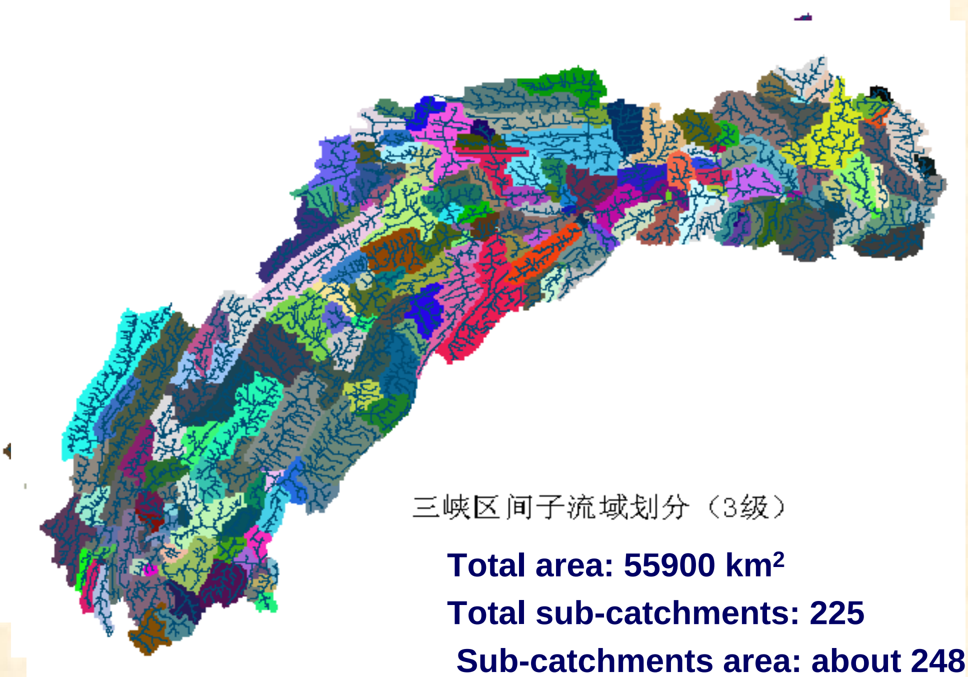
Sub-division of the Three Gorges region



Total area: 55900 km^2

Total sub-catchments: 225

Sub-catchments area: about 248 km^2

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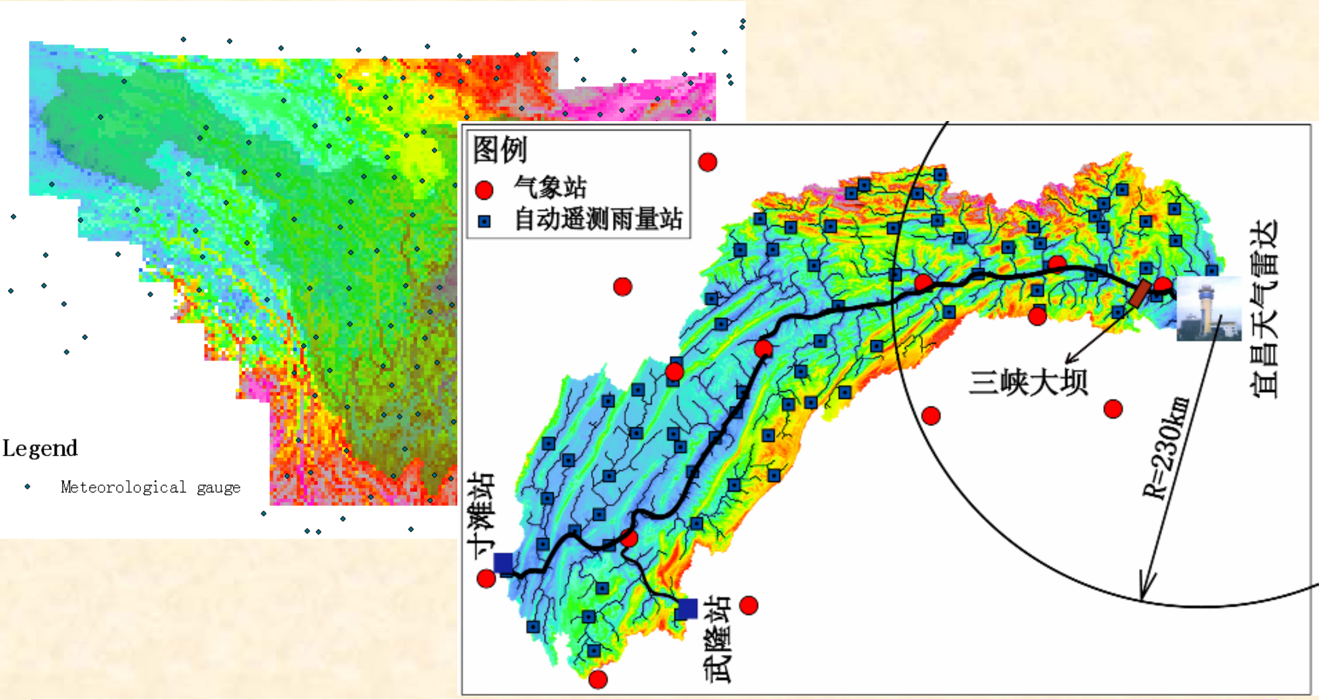
(4) Meteorological Inputs



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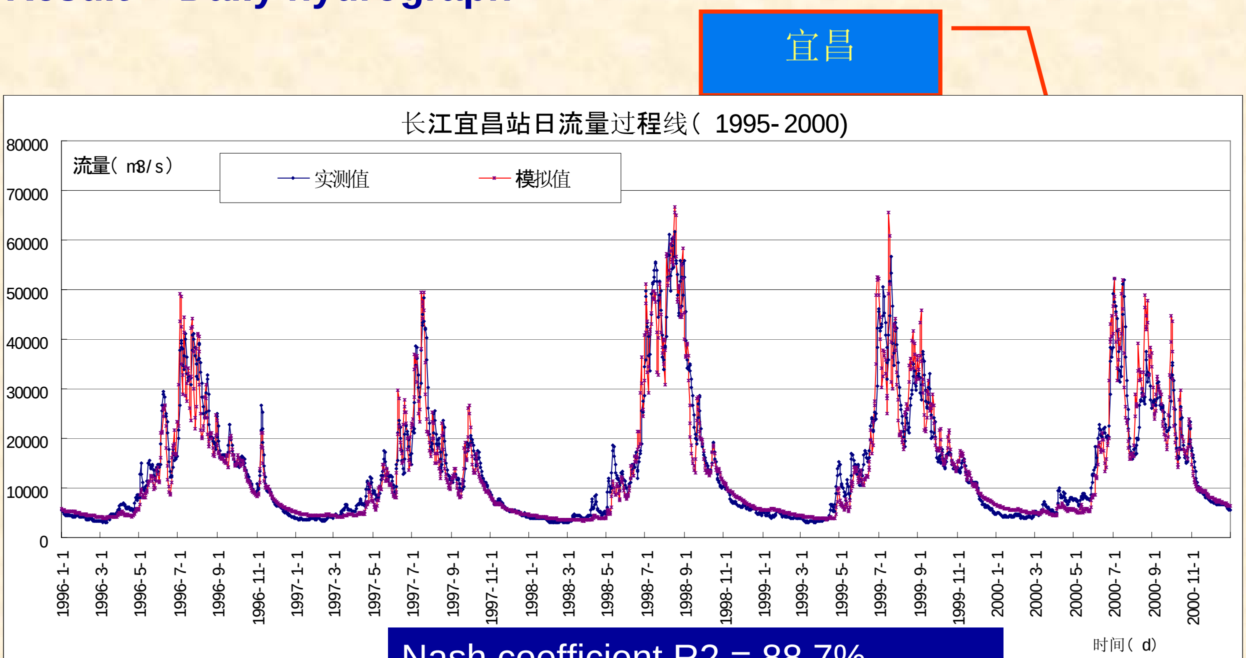
(5) Water Resources Assessment

Result -- Daily hydrograph



Nash coefficient R2 = 88.7%

Relative error RE= 0.5%

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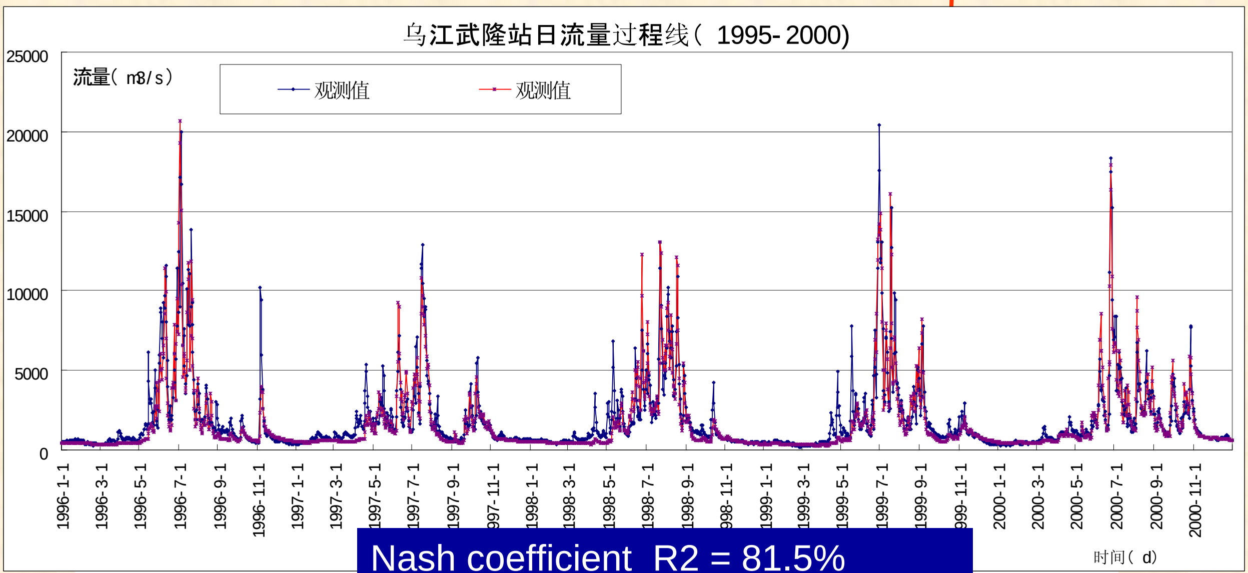
乌江武隆



Nash coefficient $R2$ = 81.5%

Relative error RE= -1.7%

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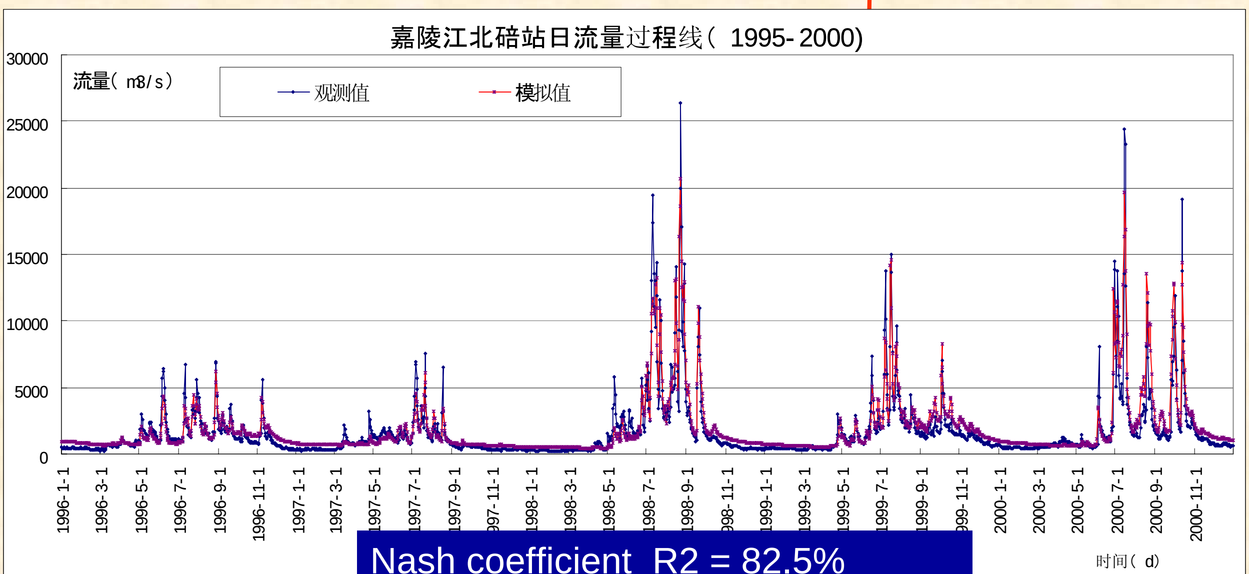
嘉陵江北碚



Nash coefficient $R2$ = 82.5%

Relative error RE= 5.3%

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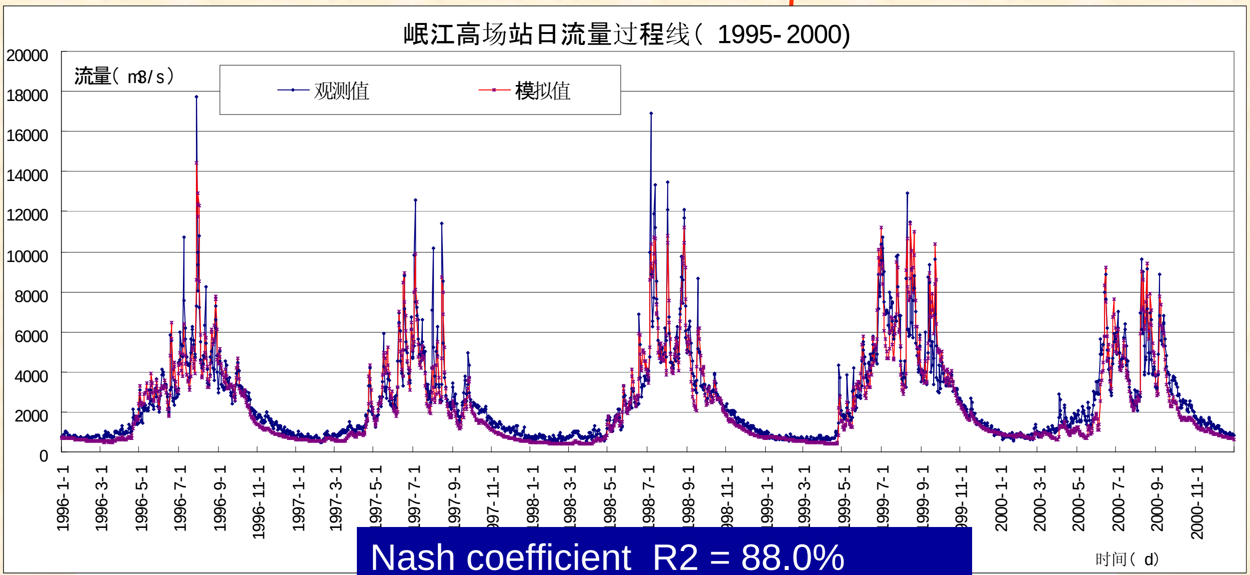
岷江高场



Nash coefficient R2 = 88.0%

Relative error RE= -6.0%

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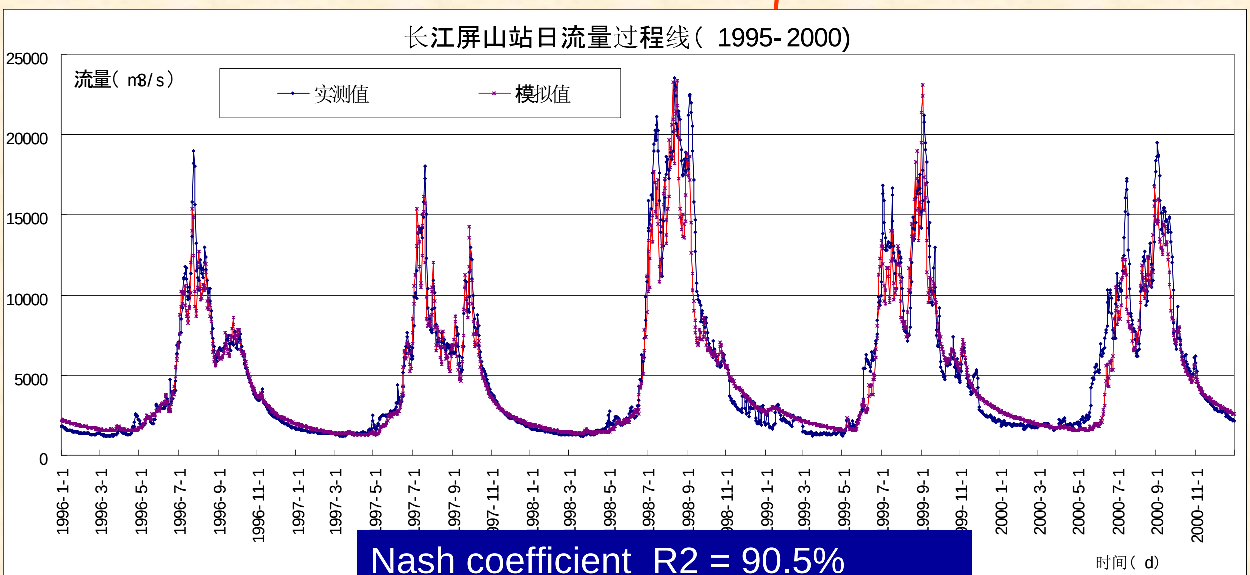
金沙江屏山



Nash coefficient R2 = 90.5%

Relative error RE= -0.4%

(6) Drought Assessment

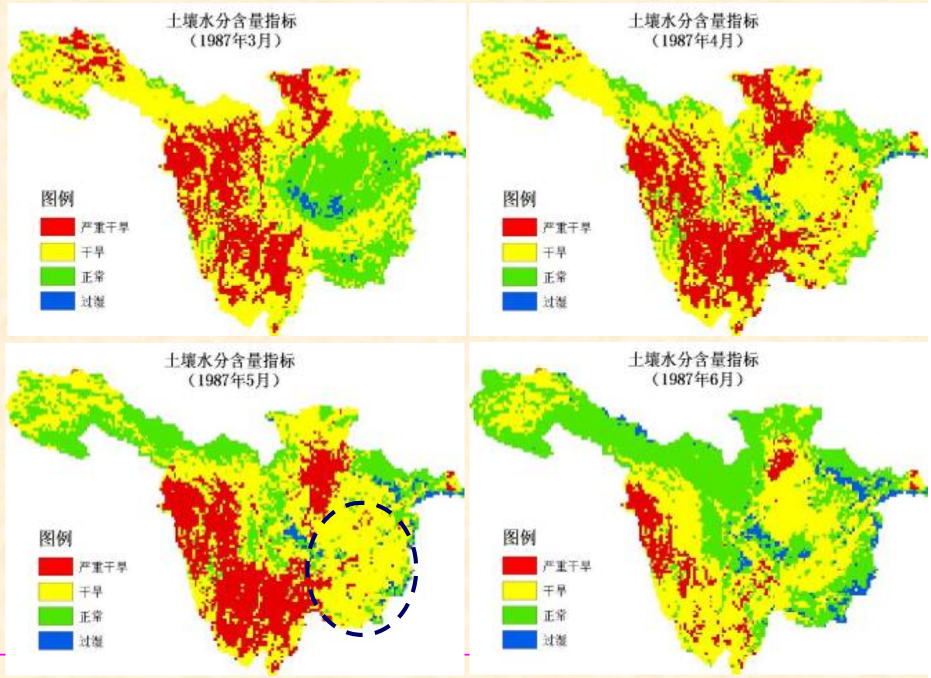
Land Use

土壤相对含水量	旱情等级
<40%	严重干旱
40% ~ 60%	干旱
60% ~ 80%	正常
>80%	过湿

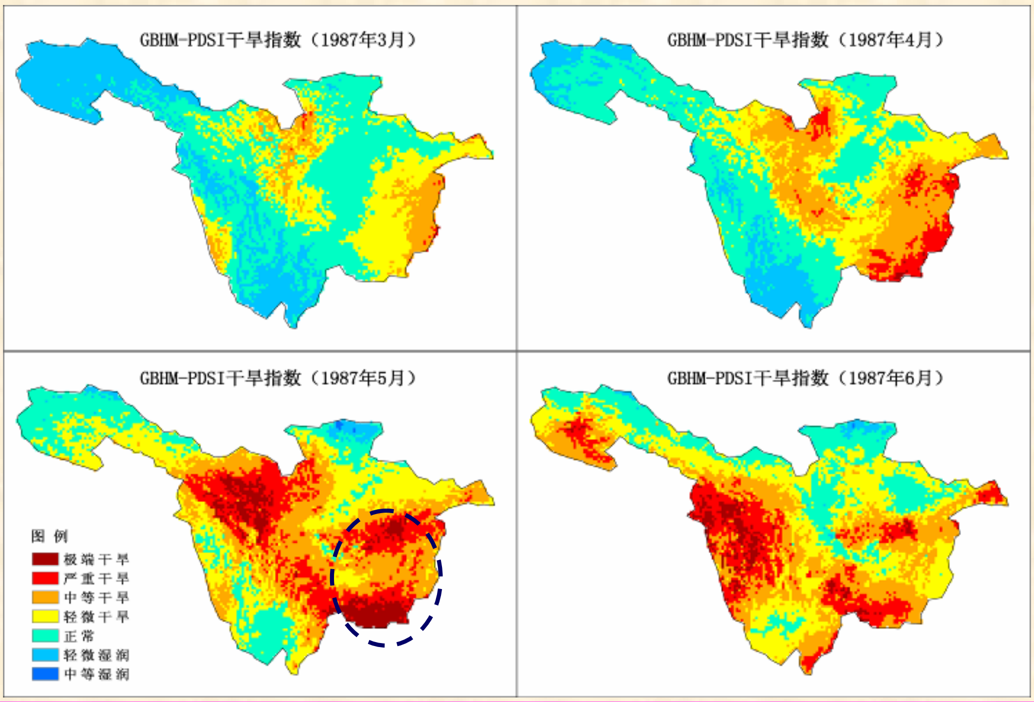
Crop

土壤相对含水量	旱情等级
<60%	严重干旱
60% ~ 90%	干旱
>90%	正常

Drought Index using soil moisture



Drought Index using DHM Results



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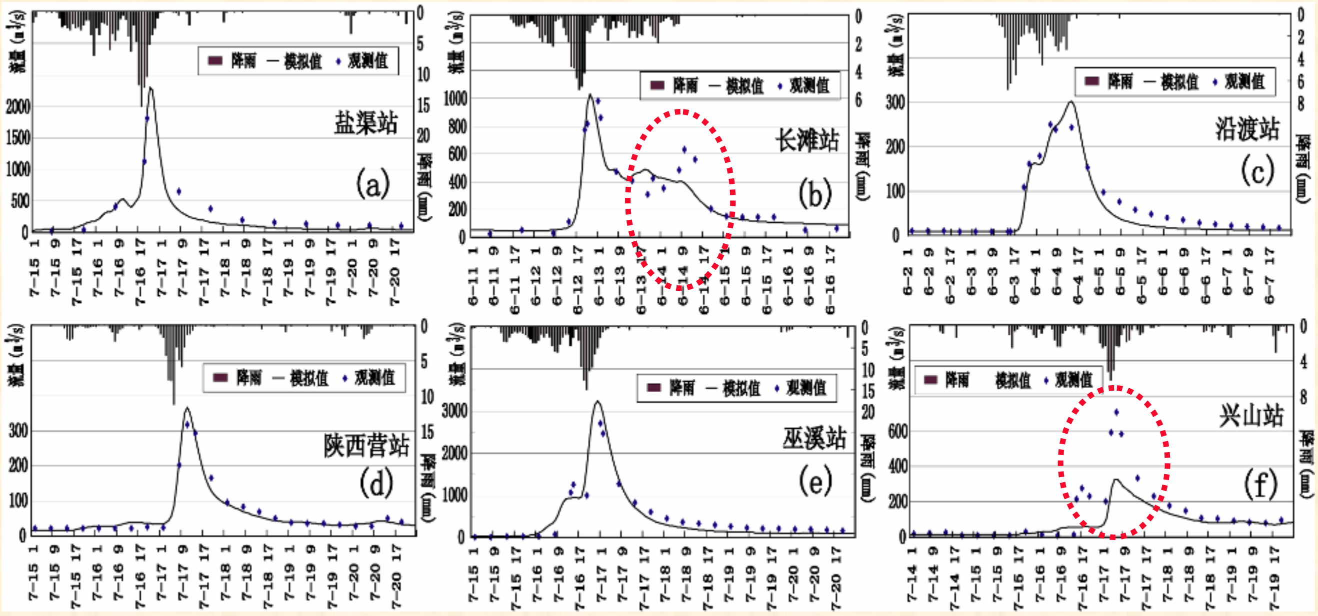
(7) Flood Forecast

Flood Simulation —— Calibration (2004)



Without Radar Measurement of Rainfall

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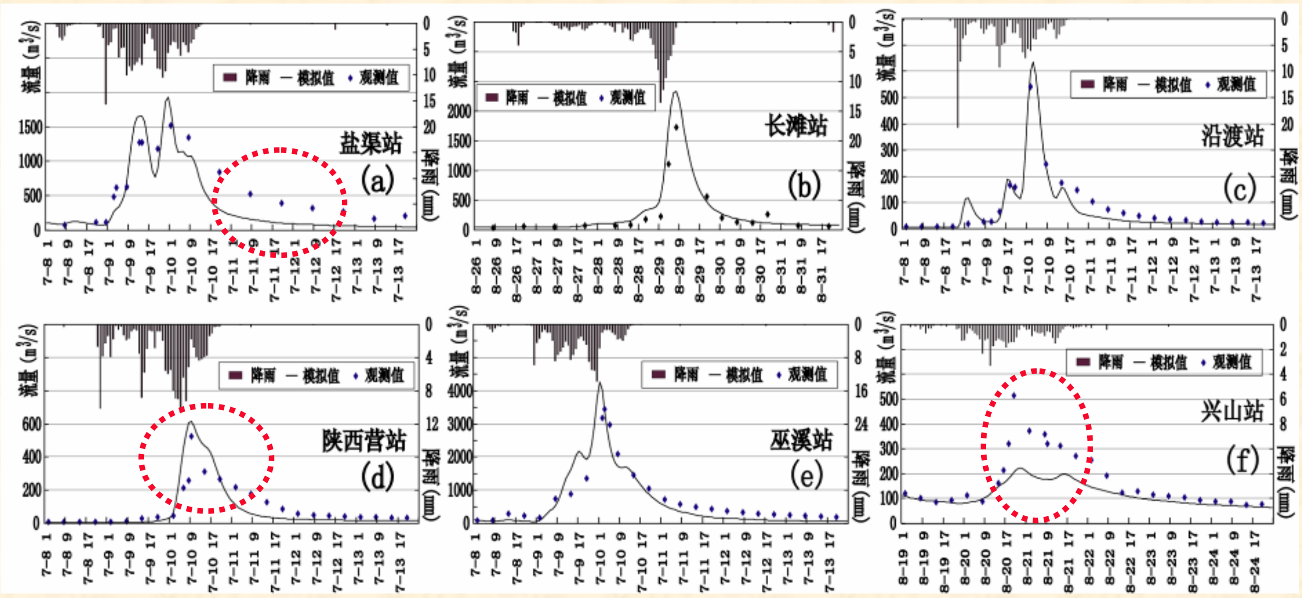
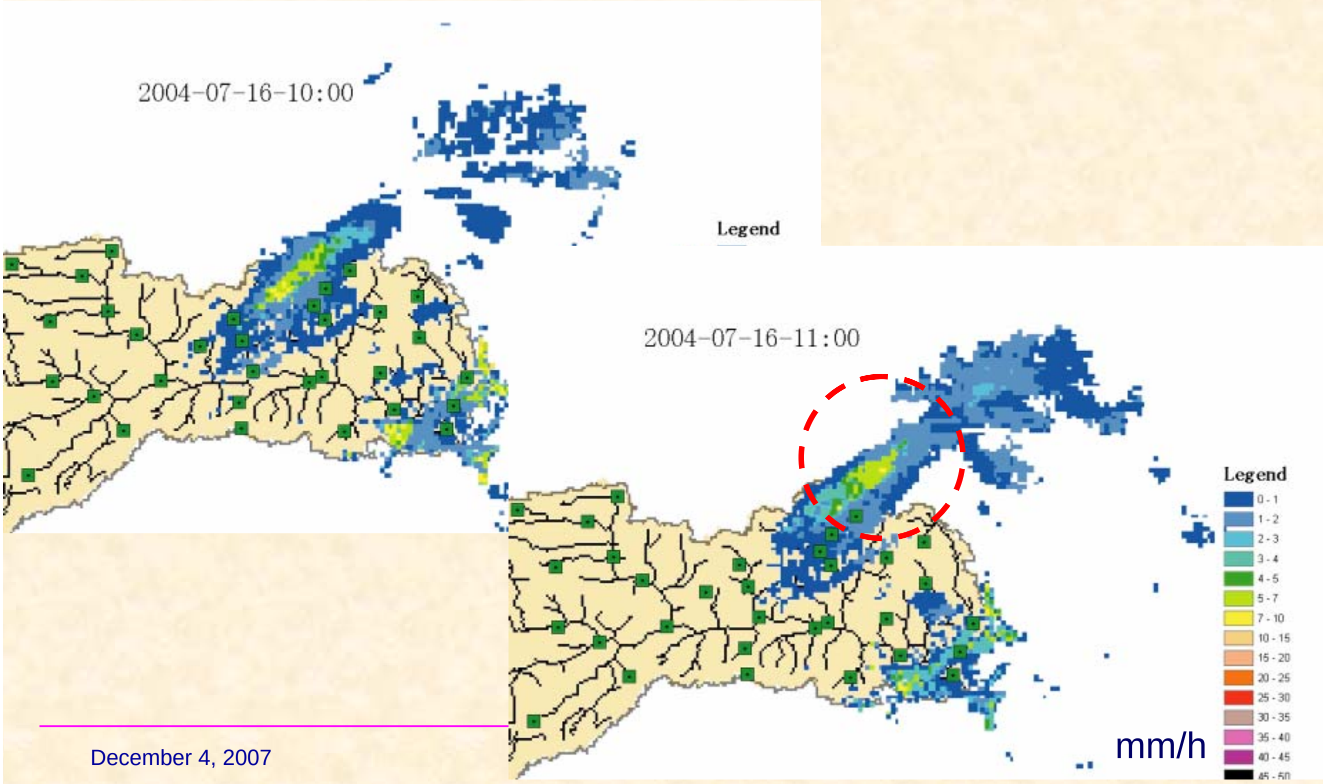
Flood Simulation —— Validation (2005)



Without Radar Measurement of Rainfall

Radar can help for capture the spatial distribution of rainfall.



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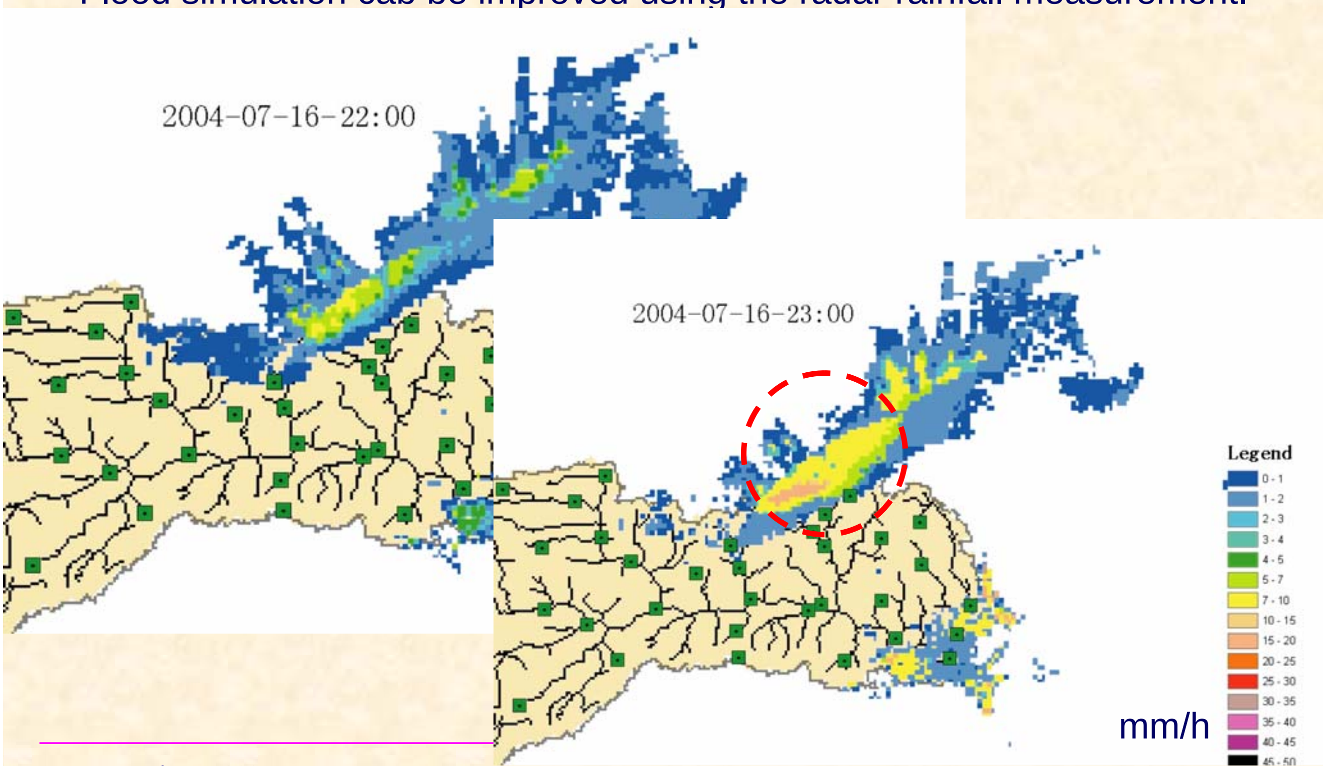
Flood simulation cab be improved using the radar rainfall measurement.



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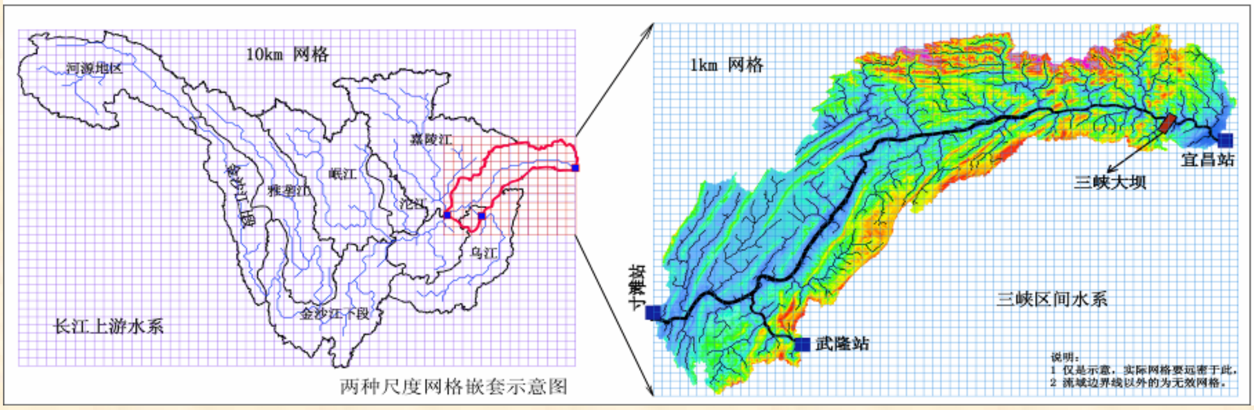
(8) Flood Routing in the Reservoir



两种尺度网格嵌套示意图

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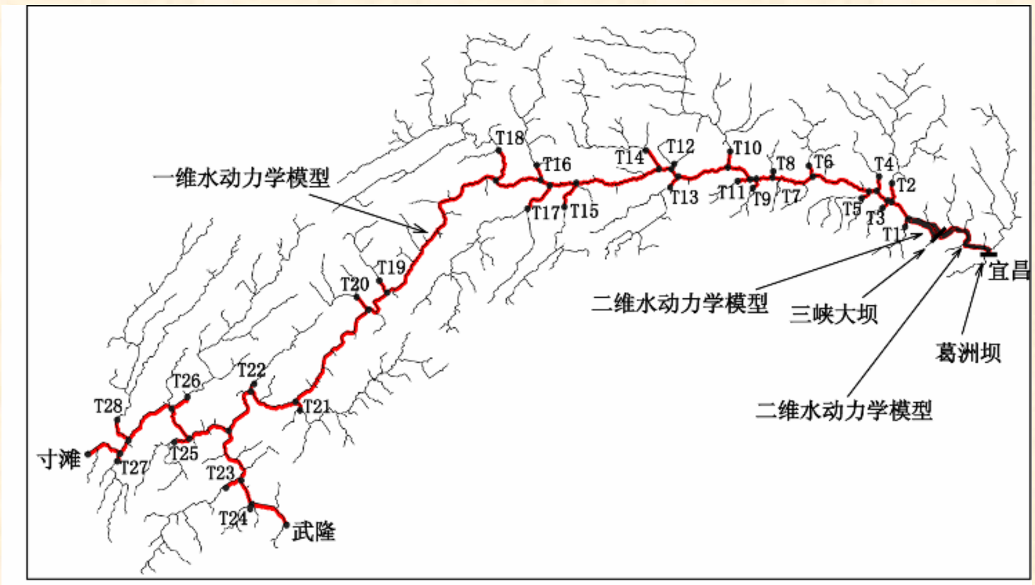
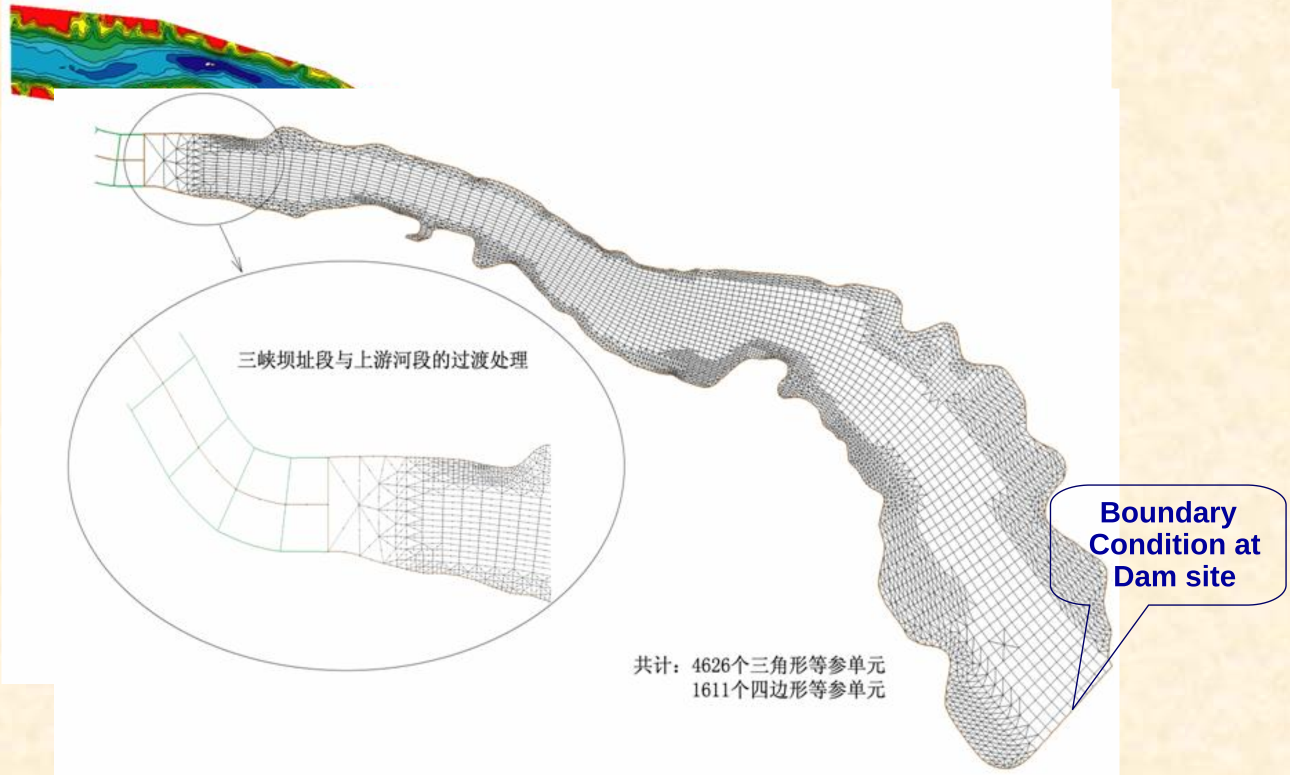


Coupling the one/two-dimensional hydraulic model with the hydrological model for simulating the regional flood and its routing in the reservoir.



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Two-dimensional hydraulic model using the Navier-Stokes equation.

$$h\frac{\partial u}{\partial t}+hu\frac{\partial u}{\partial x}+hv\frac{\partial u}{\partial y}-\frac{h}{\rho}\left(E_{xx}\frac{\partial^2 u}{\partial x^2}+E_{xy}\frac{\partial^2 u}{\partial y^2}\right)+gh\left(\frac{\partial a}{\partial x}+\frac{\partial h}{\partial x}\right)$$
$$+\frac{gun^2}{\left(1.486\,h^{1/6}\right)^2}+\left(u^2+v^2\right)^{1/2}-\xi V_a^2\cos\psi-2h\omega v\sin\phi=0$$

$$h\frac{\partial v}{\partial t}+hu\frac{\partial v}{\partial x}+hv\frac{\partial v}{\partial y}-\frac{h}{\rho}\left(E_{yx}\frac{\partial^2 v}{\partial x^2}+E_{yy}\frac{\partial^2 v}{\partial y^2}\right)+gh\left(\frac{\partial a}{\partial y}+\frac{\partial h}{\partial y}\right)$$
$$+\frac{gvn^2}{\left(1.486\,h^{1/6}\right)^2}+\left(u^2+v^2\right)^{1/2}-\xi V_a^2\sin\psi+2h\omega v\sin\phi=0$$

$$\frac{\partial h}{\partial t}+h\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)+u\frac{\partial h}{\partial x}+v\frac{\partial h}{\partial y}=0$$

The SMS（Surface Water System）developed by USACE is an available software for solving the Navier-Stokes equation.

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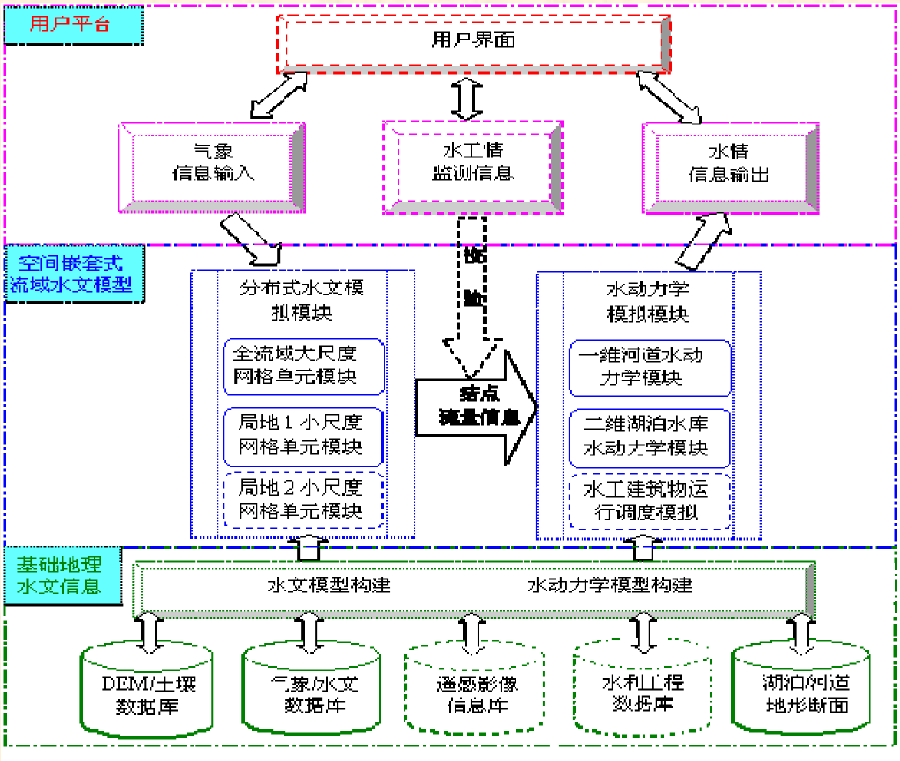
Combining the three models, we can have spatially multi-scale modeling system

User interface

Core Models

Data Base



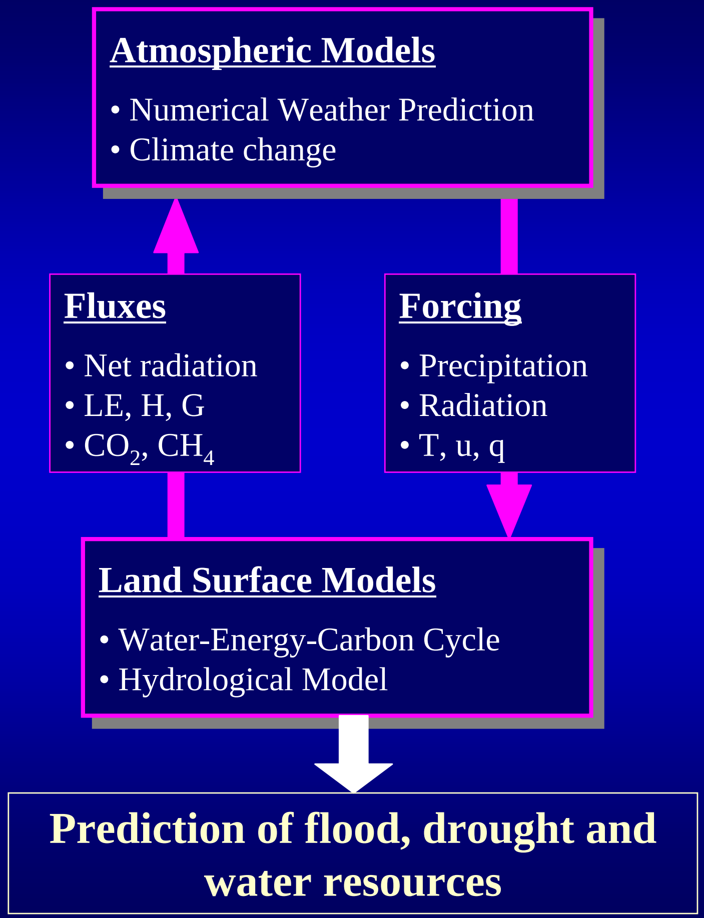
4. Summary

- There are increasing needs of hydrological models from the society.
- Hydrological model based on the available GIS information can be employed for practical applications.
- The hydrological modeling approach is facing new challenges regarding its uncertainty and non-sufficient leading time.

Future Challenge to the DHM

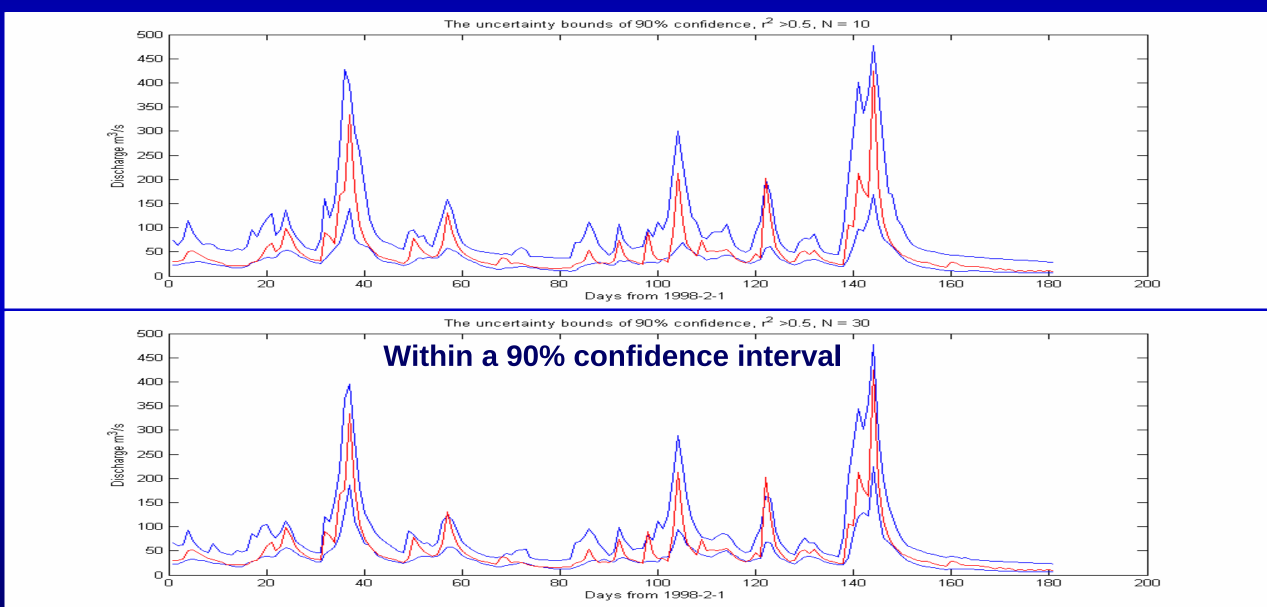
❖Coupling the Hydrological model with the Regional Atmospheric Model for increasing the leading time.

We have tested coupling of MM5 with GBHM for simulation the great floods in 1998 in the Yangtze River.



Future Challenge to the DHM

❖The Hydrological model will predict/forecast the floods in a certain extent with confidence.



We have tested the prediction uncertainty introduced by the model parameters.

Thank you for your kind attention!