



State Key Laboratory of Numerical Modelling for Atmospheric Sciences
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Institute of Atmospheric Physics Chinese Academy of Sciences

The land model with considering anthropogenic groundwater exploitation and its coupling with the Earth system model CESM

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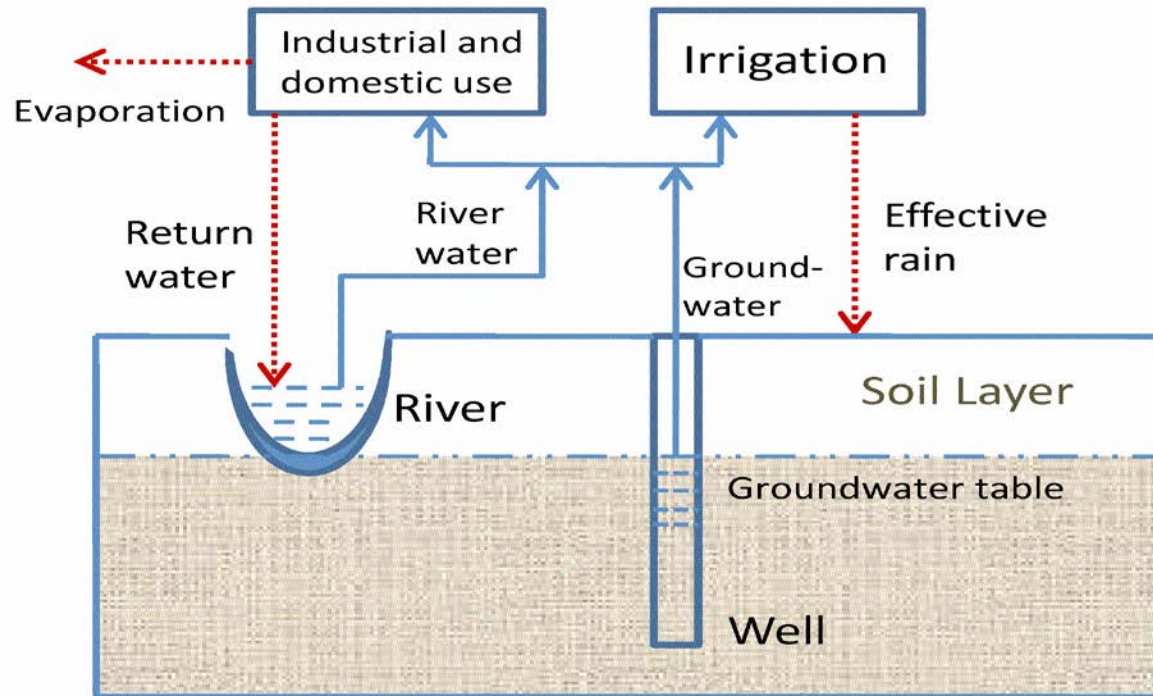


Outline

- **Motivation**
- **Model development**
- **Effects of groundwater exploitation on global climate**
- **Summary and discussion**



Water resource exploitation and consumption processes



- Groundwater was exploited widely to meet human demands for water resource, especially in regions with water shortage;
- Continually pumping groundwater for consumption causes not only local declining of groundwater table but also alters regional water cycle and energy budget.

How to affect climate for the exploitation and consumption processes?



The changes of soil moisture make changes of water and energy fluxes at the surface, and effect climate

Change the SH and LH to directly influence atmosphere

Change the vegetation to indirectly influence atmosphere

Irrigation makes soil moisture increase

Surface

Key factor: **Soil water** (How to change?)

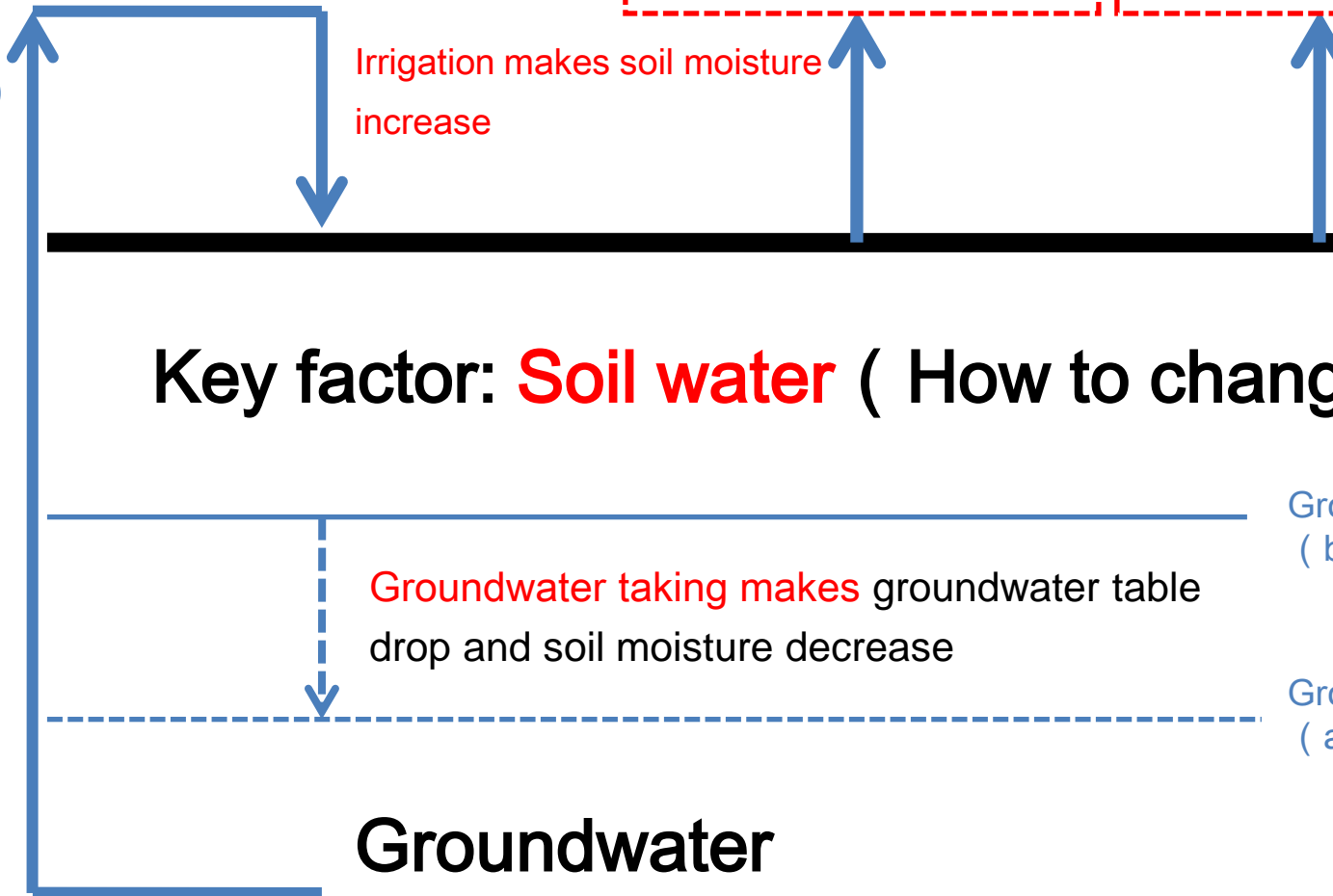
Groundwater table (before exploitation)

Groundwater taking makes groundwater table drop and soil moisture decrease

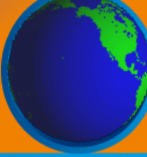
Groundwater table (after exploitation)

Groundwater withdrawal

Groundwater



Motivitation



- What are the climate response due to anthropogenic groundwater exploitation and consumption? How to express it in climate models ?
- Zou, Xie et al. (CD,2014;JH, 2015), land model, regional model; However, current GCMs do not consider;
- To represent the anthropogenic groundwater exploitation in a climate model , A scheme of groundwater exploitation and consumption was incorporated into CESM1.2.0;
- Climatic responses to anthropogenic groundwater exploitation were then investigated on global scale.

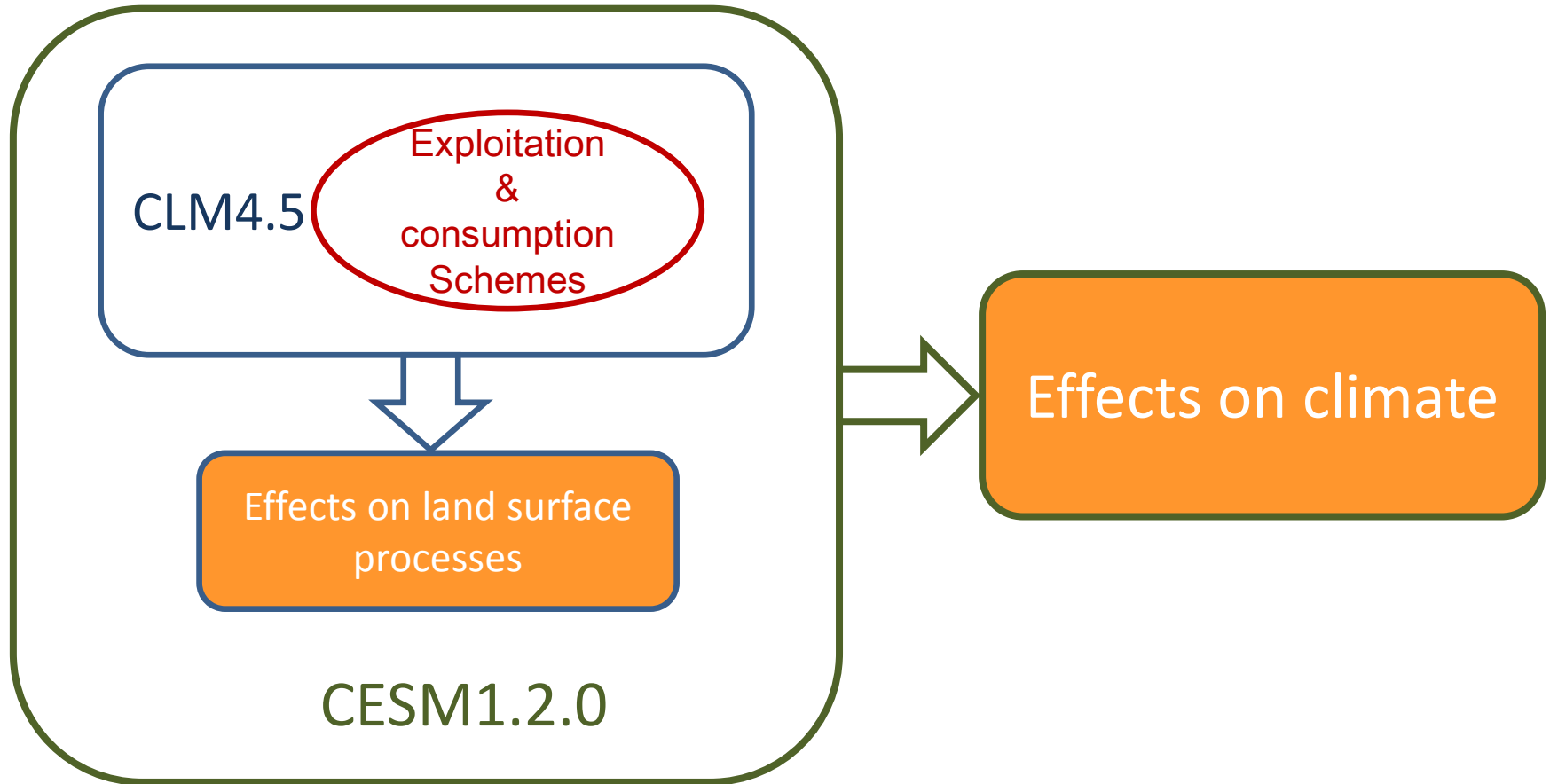


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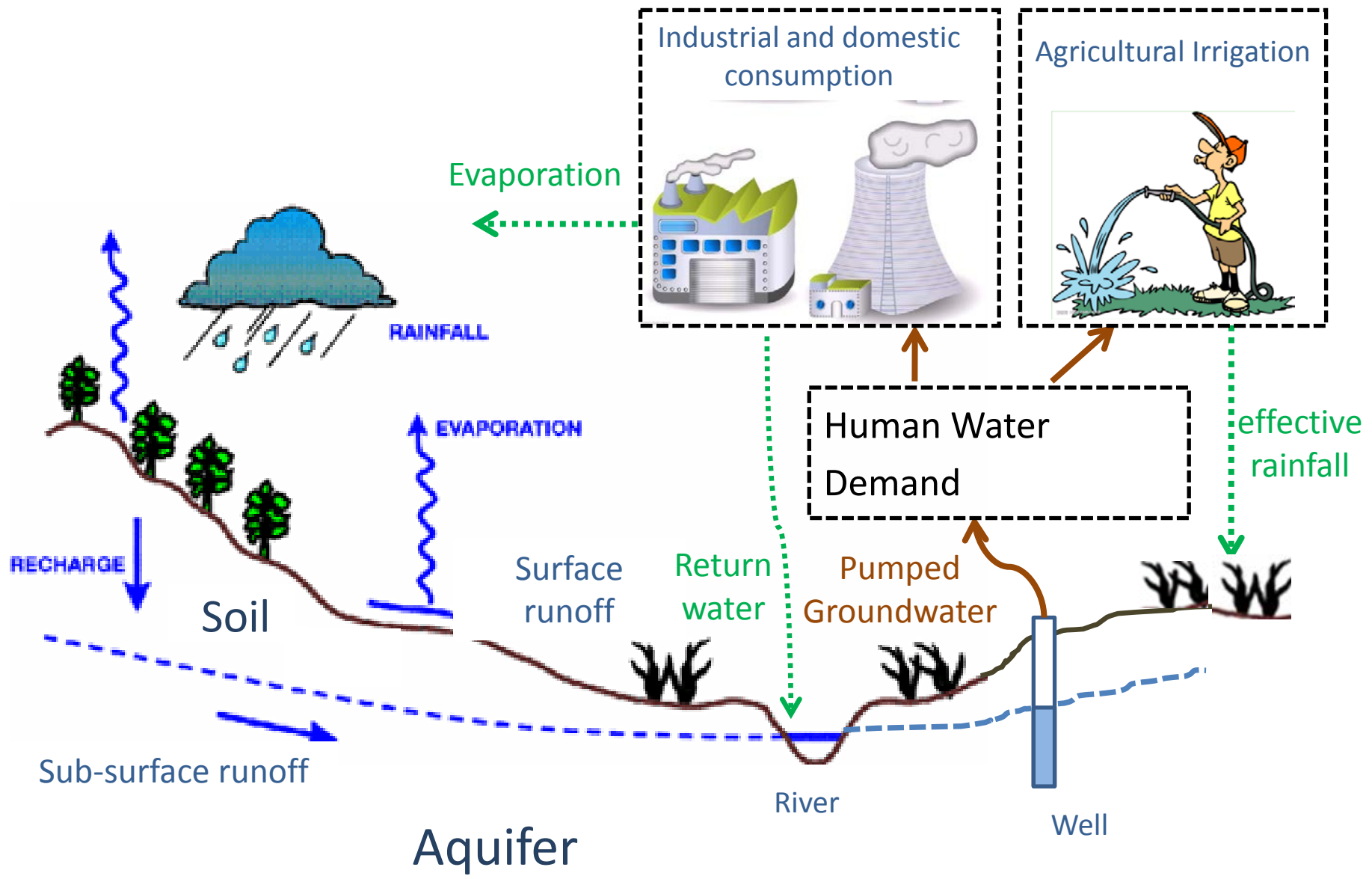


Model Development



- A scheme of groundwater exploitation and consumption was incorporated into CLM4.5, the land surface module of earth system model CESM1.2.0;
- Climatic responses to anthropogenic groundwater exploitation were investigated.

Groundwater exploitation and consumption





- The consumption of water resource exploited is divided into three parts: agricultural irrigation, industrial consumption and domestic consumption;
- The water consumed by irrigation is treated as effective rainfall reaching the topsoil;
- The industrial and domestic water consumptions are treated as being consumed through evaporation and waste water discharge into stream channels.

Groundwater exploitation representation in CLM4.5



Groundwater table in CLM4.5 is changed depend on the aquifer recharge rate, which can be expressed as follows (exploitation Q_g) :

$$Q_{aqu_new} = Q_{aqu_ori} - Q_g$$

The irrigation consumption is treated as the effective rainfall to the surface, which can be expressed as:

$$Q_{topsoil_new} = Q_{topsoil_ori} + r_{agr} Q_g$$

The groundwater consumed in industry and domestic uses is treated as waste water and evaporation respectively. The waste water which assumes to discharge into stream channels is added to the surface runoff, and the other part is treated as evaporation in CLM4.5 as:

$$Q_{runoff_new} = Q_{runoff_ori} + \alpha(r_{ind} + r_{dom})Q_g$$

$$Q_{evp_new} = Q_{evp_ori} + (1 - \alpha)(r_{ind} + r_{dom})Q_g$$



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Simulations



- **Study Region: Global**
- **Resolution: $0.9^\circ \times 1.25^\circ$**
- **Component sets: CAM4+CLM4.5 (CESM)**
- **SSTs are prescribed by monthly observation from Hadley Centre.**
- **Simulation period: 1965-2005**
- **There are two ensemble simulations with and without groundwater exploitations respectively (EXP and CTL)**
- **Each ensemble contains six runs with different initial conditions.**

Estimation of groundwater withdrawal and consumption 1965 to 2005



The municipal, industrial and agricultural water use data (FAO)

The global municipal, industrial and agricultural water withdrawal data by regional groups (in 1970, 1990 and 2009)

The Global Map of Irrigation Areas v5 (Siebert et al, 2013)

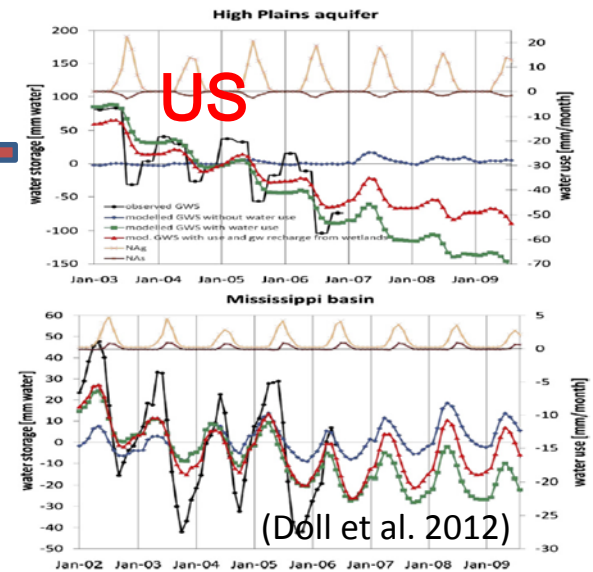
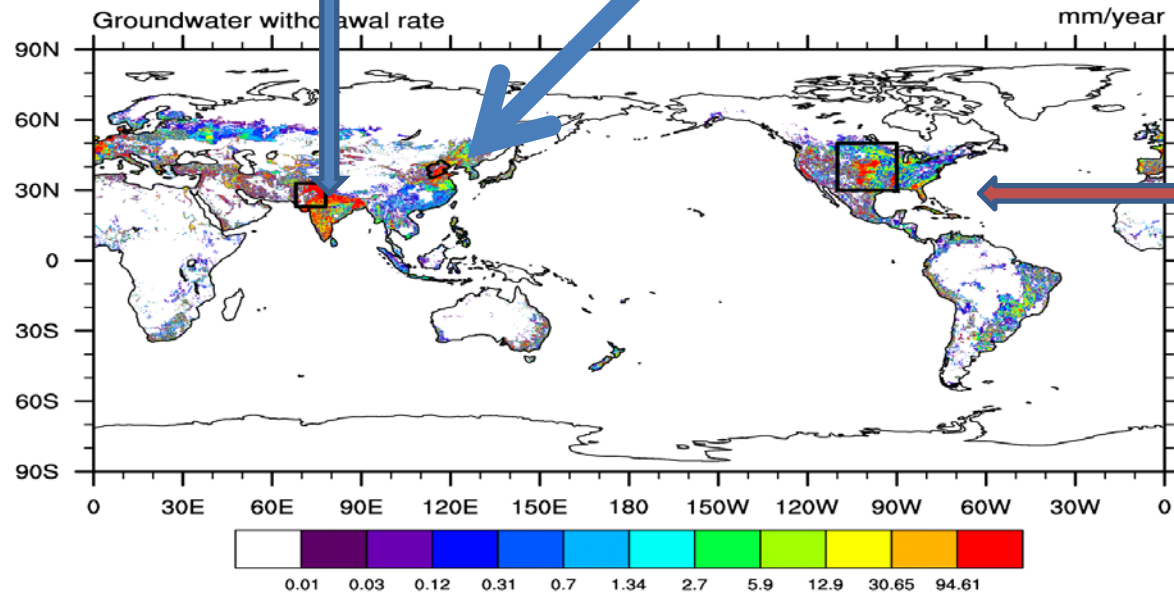
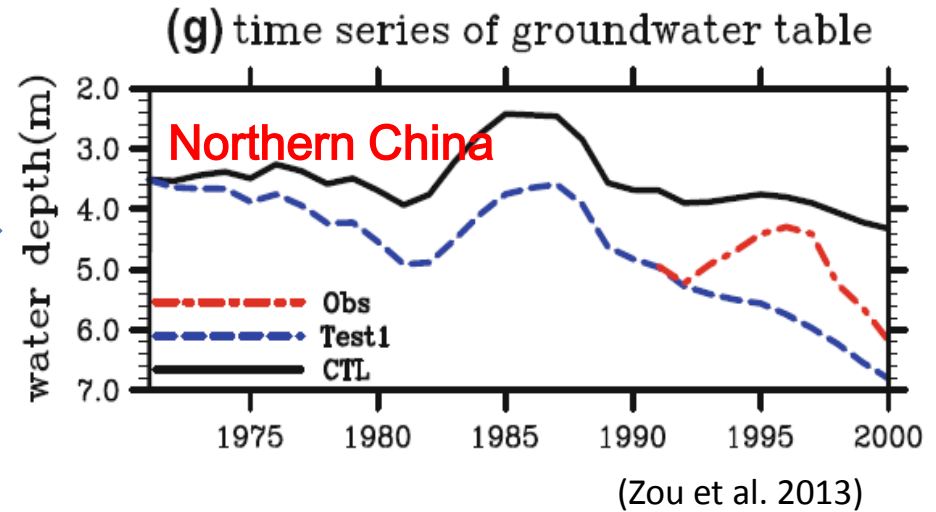
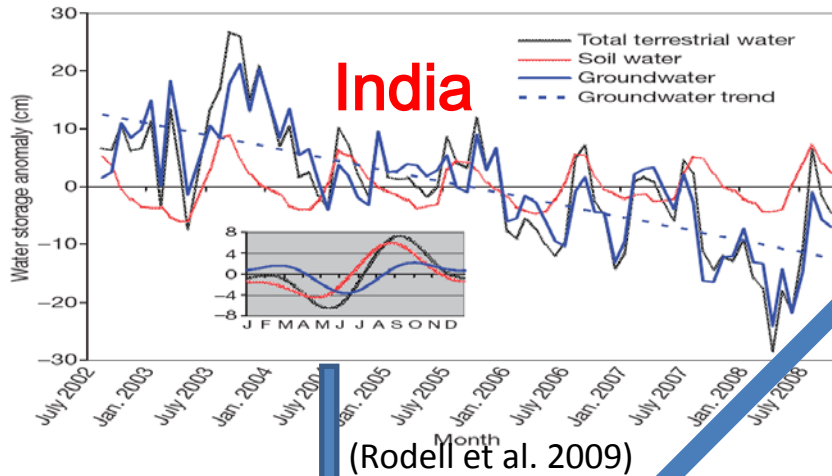
The irrigation area percentage of the total area and the groundwater irrigation percentage of the total irrigation area (grid data)

Monthly soil moisture and saturated soil moisture (by CLM4.5 offline run)

Convert area percentage to water withdrawal percentage

Groundwater withdrawal amount and its consumption in agricultural, industrial and domestic of each grid from 1965 to 2005, estimated

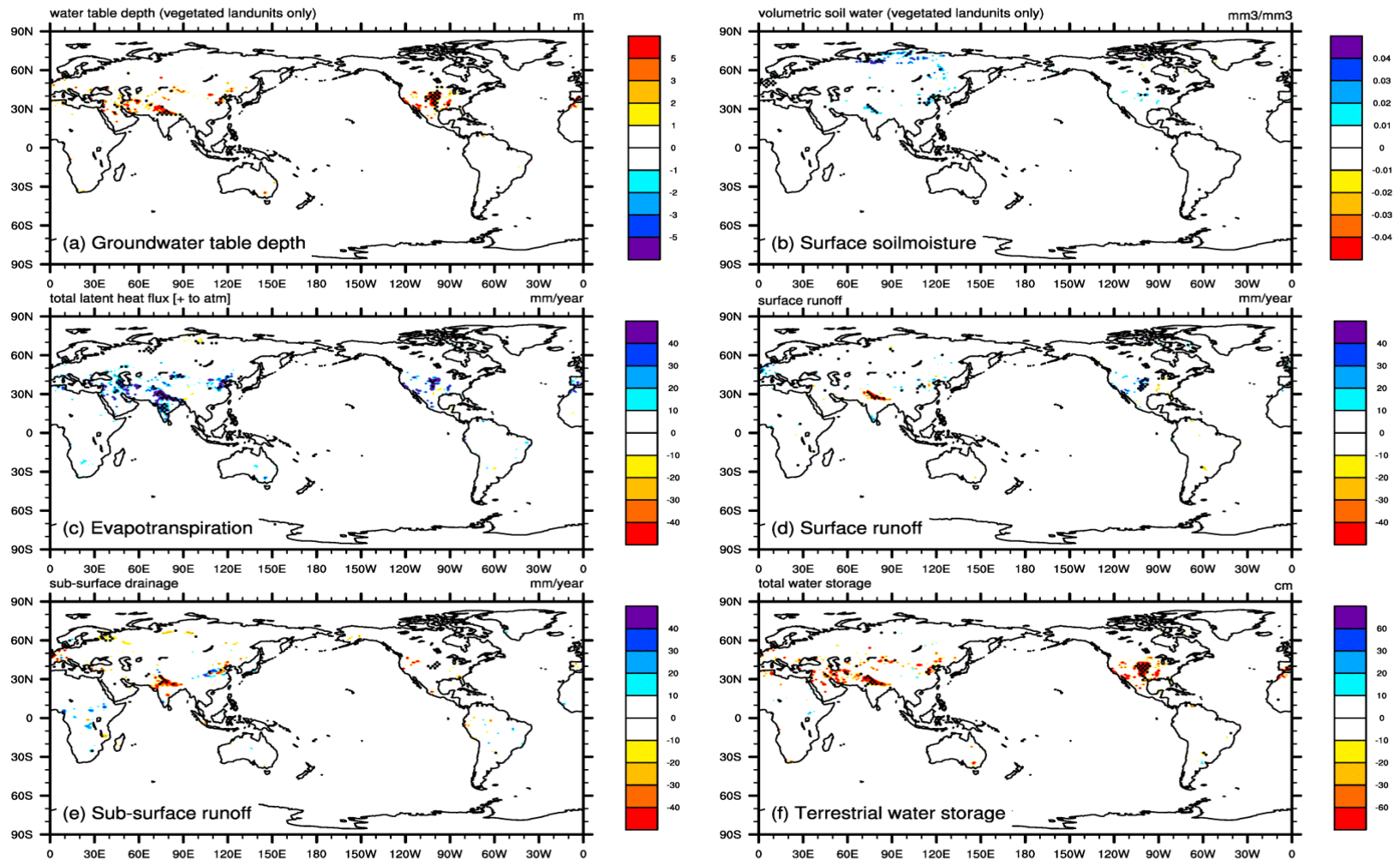
Groundwater withdrawal rate



- The three largest contiguous areas with high groundwater exploitation rate are located in **Central US**, in **Haihe River Basin in China** and in **North India and Pakistan**.

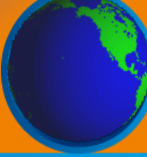
Effects of groundwater exploitation on land surface processes

Climatology EXP-CTL, ensemble averaged.

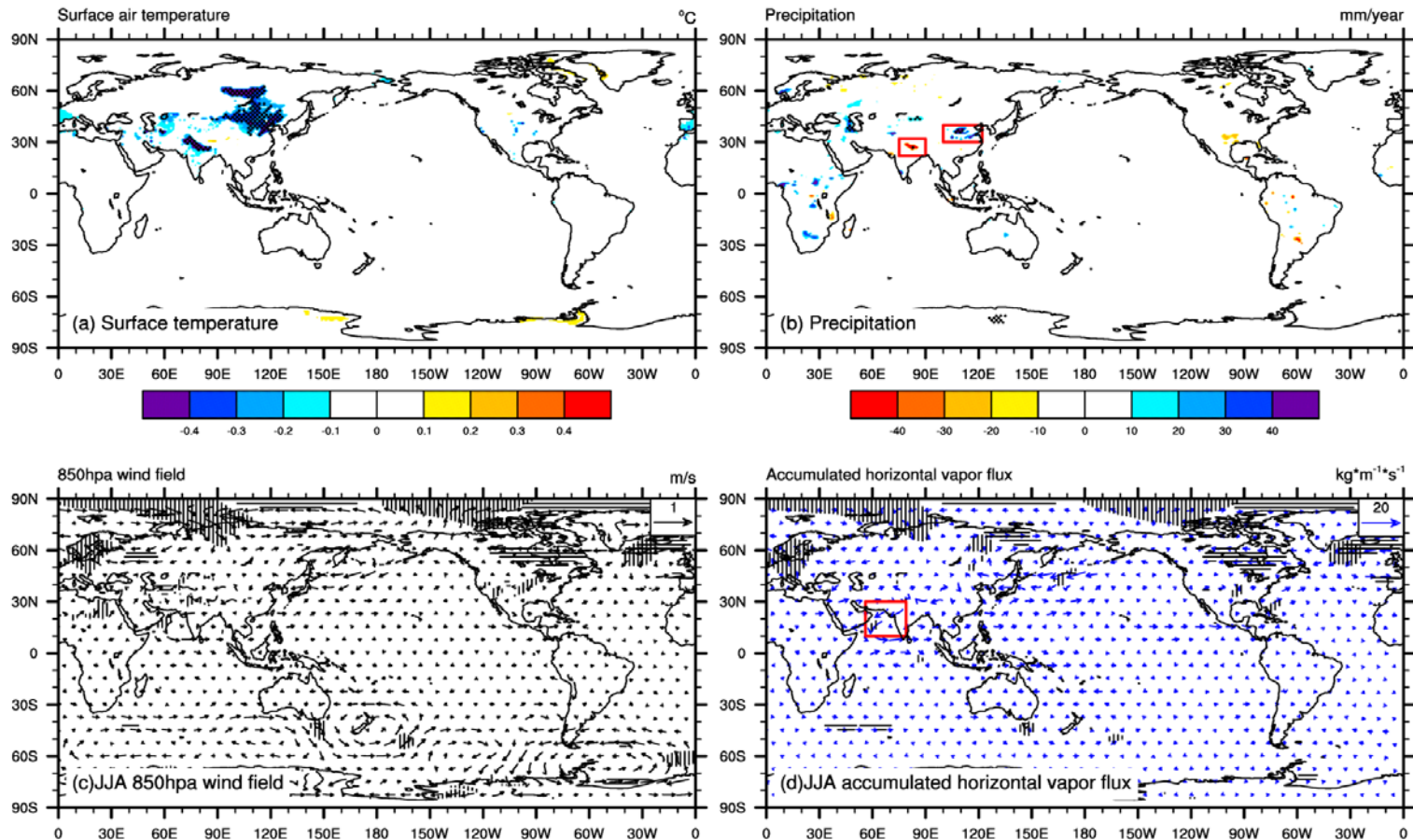


- Decreasing of runoff and terrestrial water storage, along with a rapidly declining groundwater table occurred in areas with serious groundwater exploitation.

Effects of groundwater exploitation on climate

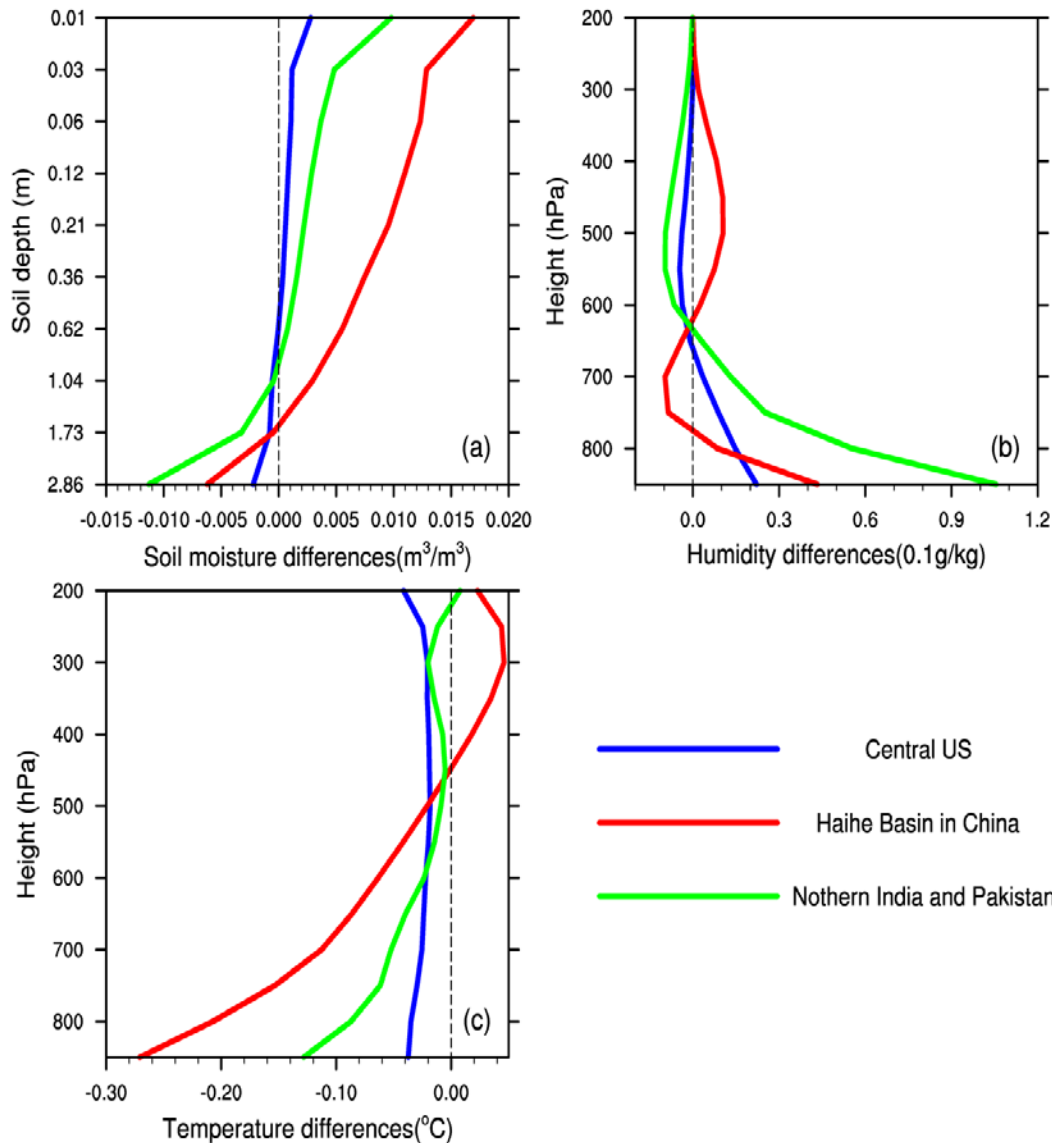


Climatology results of EXP-CTL, ensemble averaged.



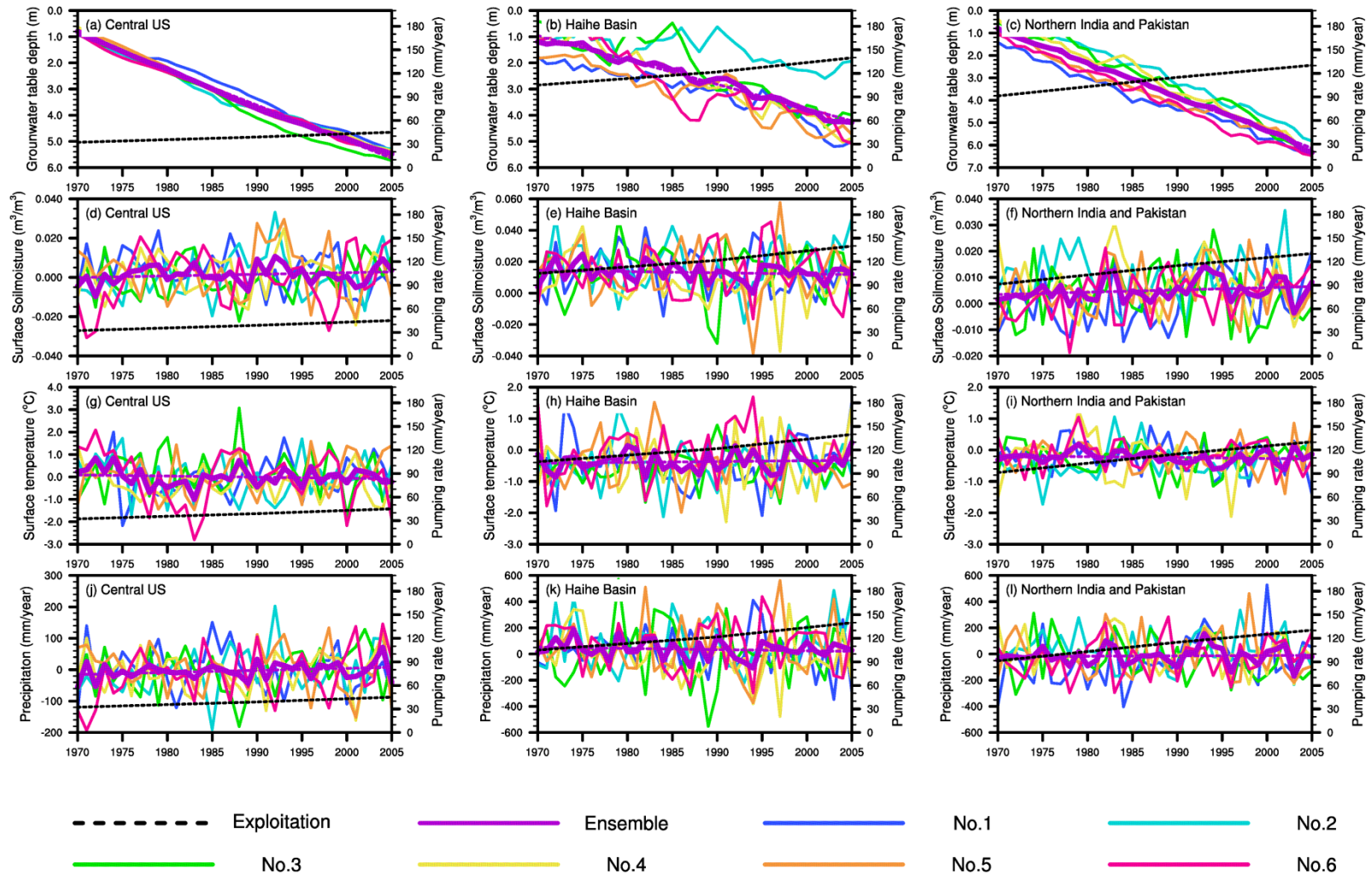
- Significantly cooling effects are occurred in Northern China, India and Pakistan.
- Precipitation is increased in North China Plain but decreased in Northern India. It maybe due to that the water vapor is taken away from India continent to ocean by atmospheric circulation anomalies induced by groundwater exploitation.

Effects of groundwater exploitation on vertical profiles



- Climatology of EXP-CTL, ensemble averaged on vertical profiles of soil moisture, air humidity and temperature;
- In all the three regions, groundwater exploitation makes the deeper soil dryer, upper soil wetter, and the lower troposphere cooler and wetter.

Groundwater table, temperature and precipitation

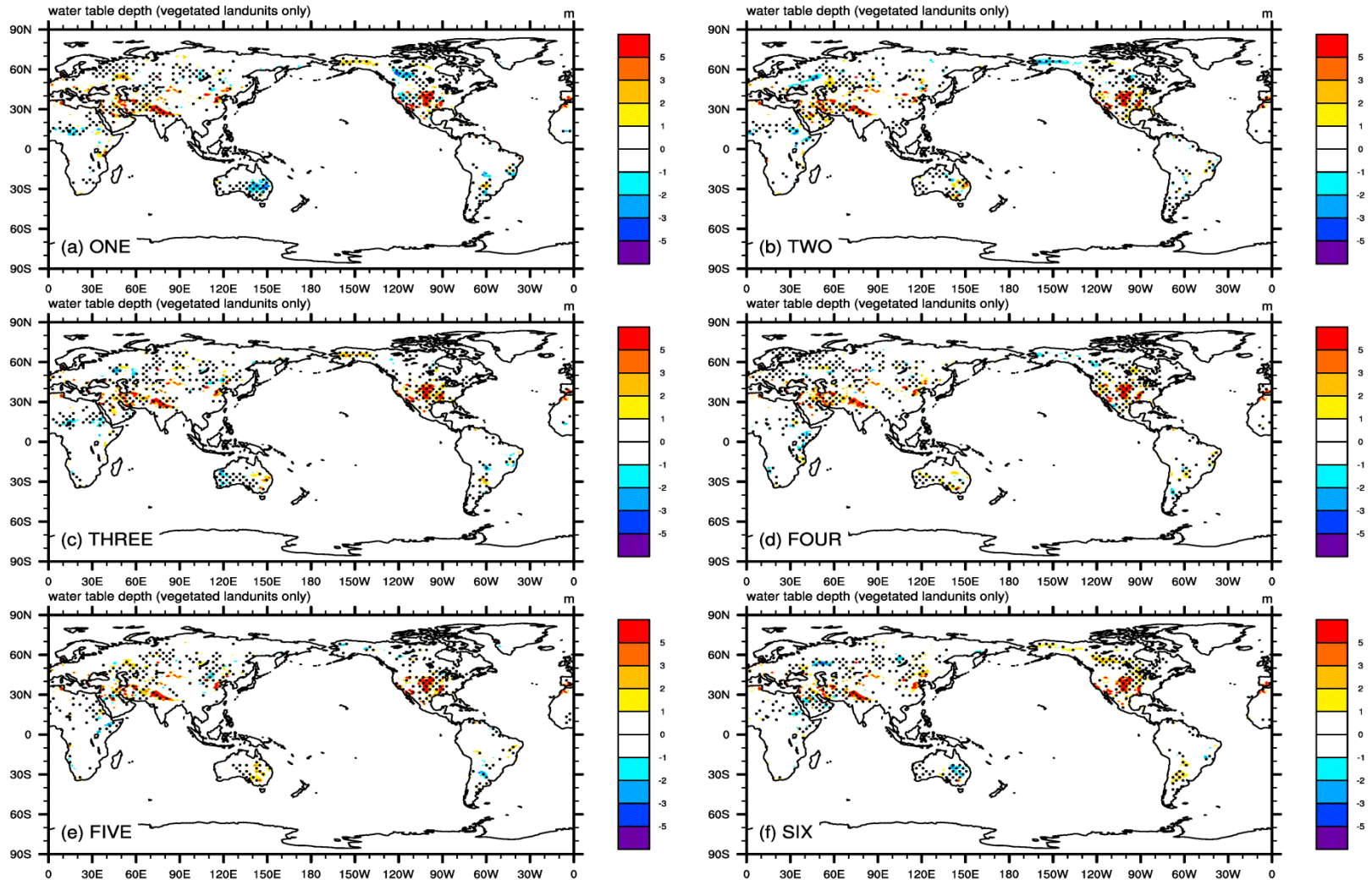


- Time series of groundwater table, 10cm soil moisture, surface temperature and precipitation of each number of EXP-CTL in Central US, Haihe Basin in China and Northern India and Pakistan;
- The groundwater table is the most sensitive variable to groundwater exploitation.

Uncertainties related to different initial conditions

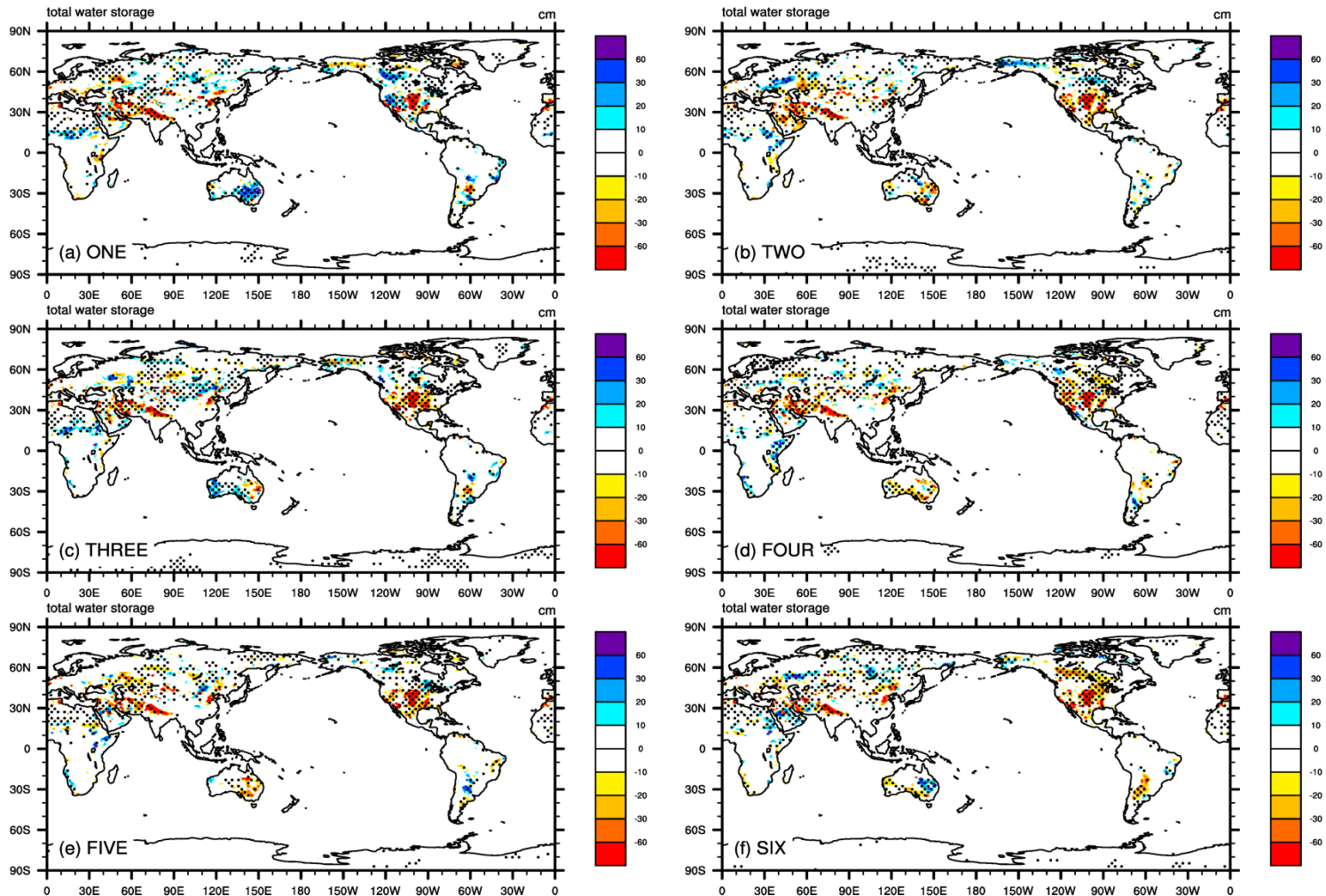


Groundwater table depth of each number with different initial conditions in EXP-CTL



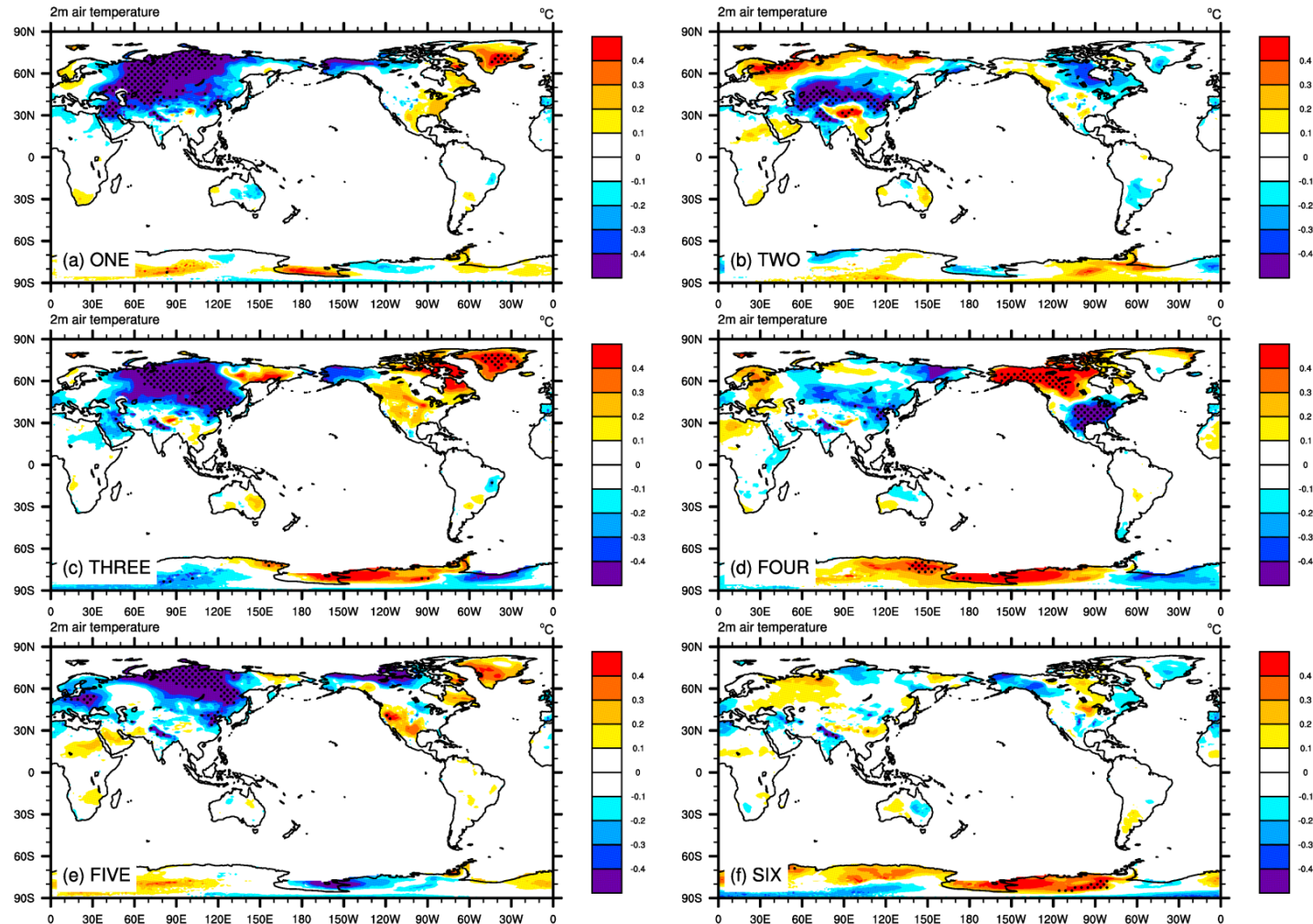
- The decline effects on groundwater table are relative stable with different initial conditions

Terrestrial water storage of each number of EXP-CTL with different initial conditions



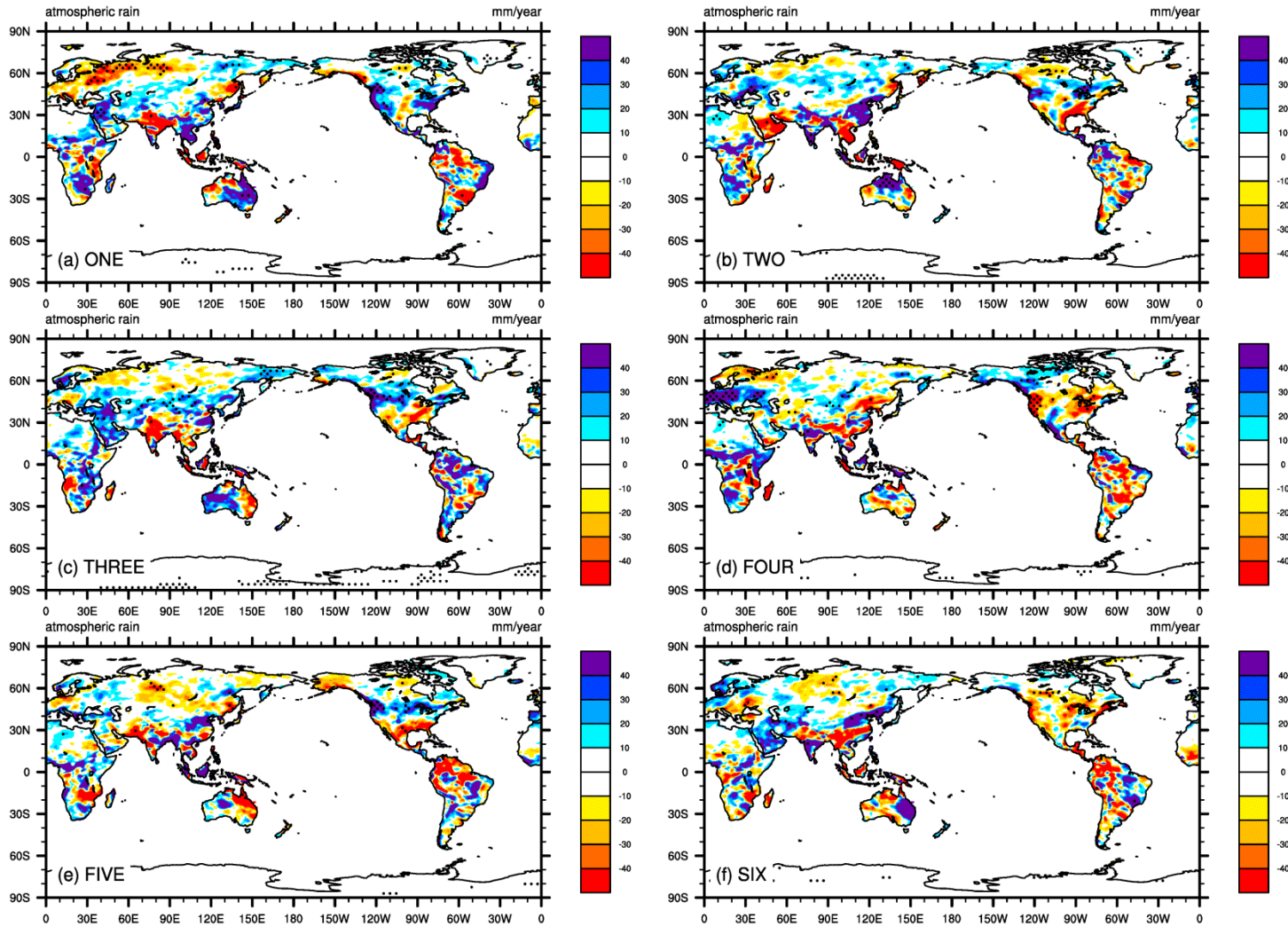
- Water storage is decreased in all the runs with different initial conditions. It determines ground water resources is unsustainable with current high groundwater pumping rate.

Surface temperature of each number with different initial conditions in EXP-CTL



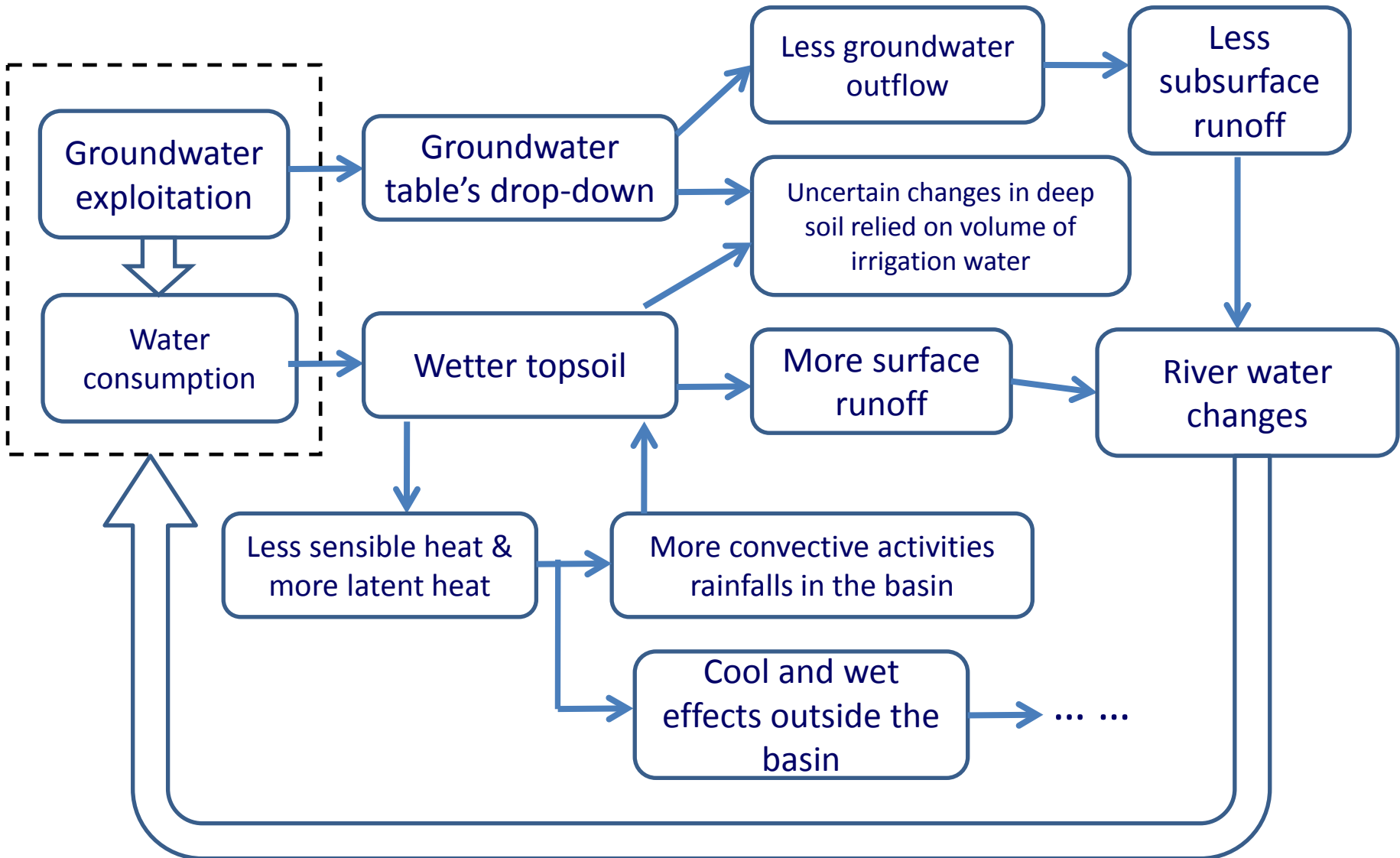
- The effects, especially the non-local effects of groundwater exploitation on temperature are not stable with different initial conditions. This may relate to land-atmosphere coupling processes.

Precipitation of each number with different initial conditions in EXP-CTL



- The effects, especially the non-local effects of groundwater exploitation on precipitation are also not stable with different initial conditions.

Possible mechanism





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Summary and Discussion



- A scheme of groundwater exploitation and consumption was incorporated into CLM4.5, and the earth system model, Community Earth System Model.
- The climatic responses to anthropogenic groundwater withdrawal are investigated on global scale.

Related papers:

- Zeng Y., Xie Z, et al., global climate responses to anthropogenic groundwater exploitation, in preparation.
- Zou J., Z. Xie et al., Climatic responses to anthropogenic groundwater exploitation, *Climate Dynamics*, 2014.
- Zou J., Z. Xie et al., Effects of anthropogenic groundwater exploitation on land surface processes, *J. Hydrology*, 2015.

Summary and Discussion



- The groundwater over-exploitation and water consumption cause drying effects on soil moisture in deep layers and wetting effects in upper layers, along with a rapidly declining groundwater table.
- The atmosphere also responds to anthropogenic groundwater exploitation. Cooling and wetting effects appear on lower troposphere.
- Increased precipitation occurs in Haihe River Basin while decreased precipitation occurs in Northern India.
- The local reducing effects on total terrestrial water storage suggest that water resource be unsustainable with the current high exploitation rate.

Thank you !

<http://web.lasg.ac.cn/staff/xie/xie.htm>



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