Irrigation-related land and water environment in China

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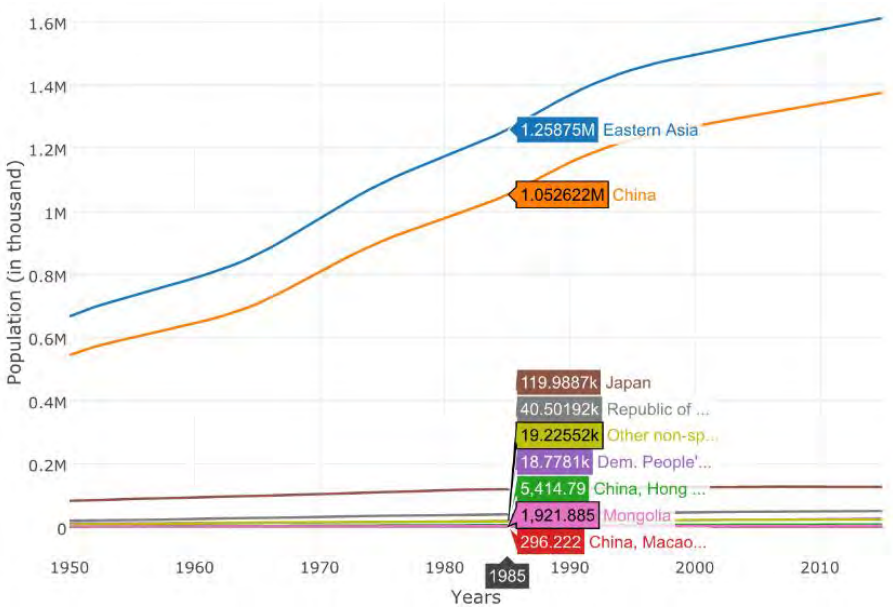
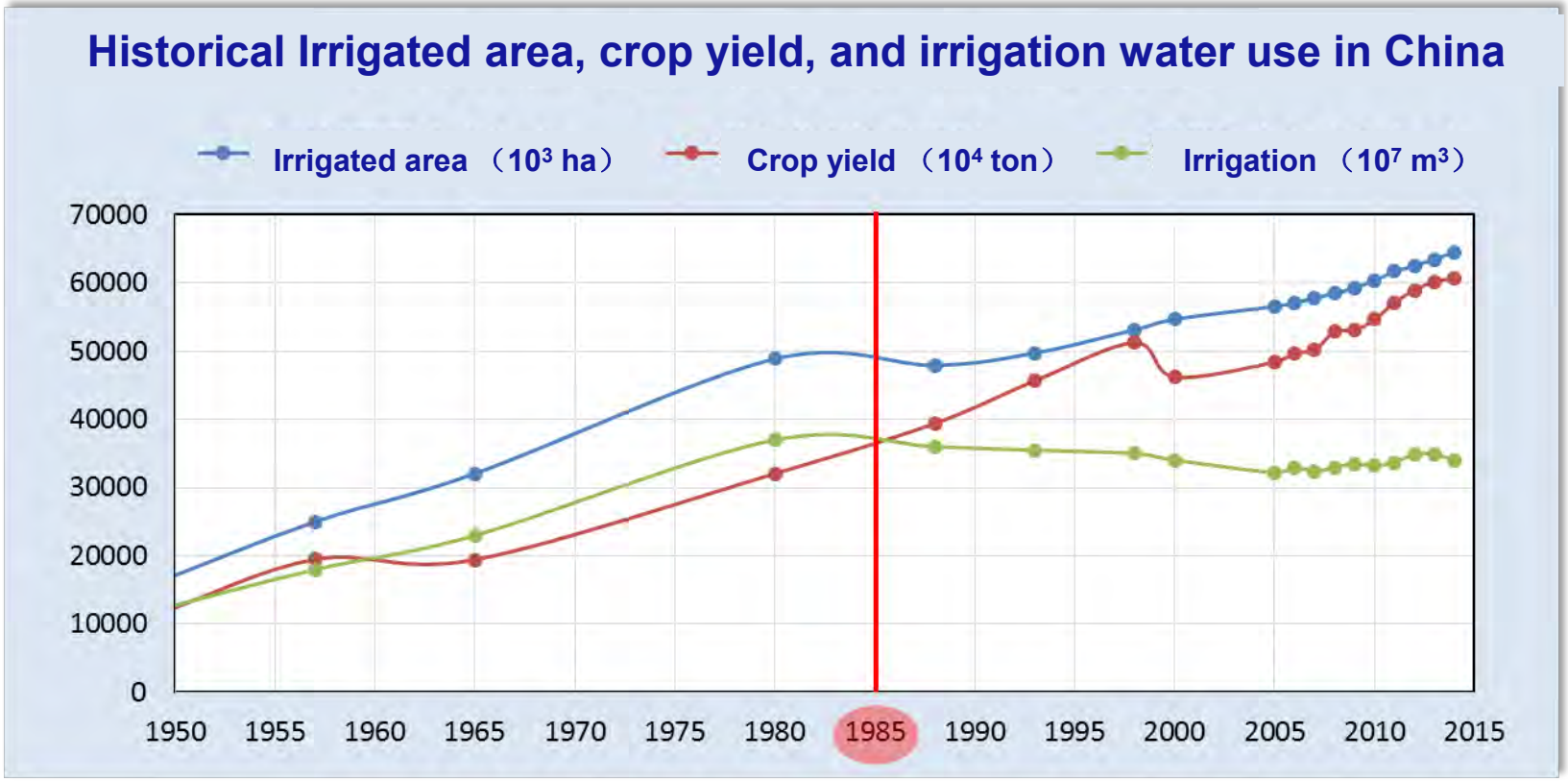
1. Background

- China is the most populous country in the world.
  (1.39 billion in 2017)
- We need to feed ourselves and we did.



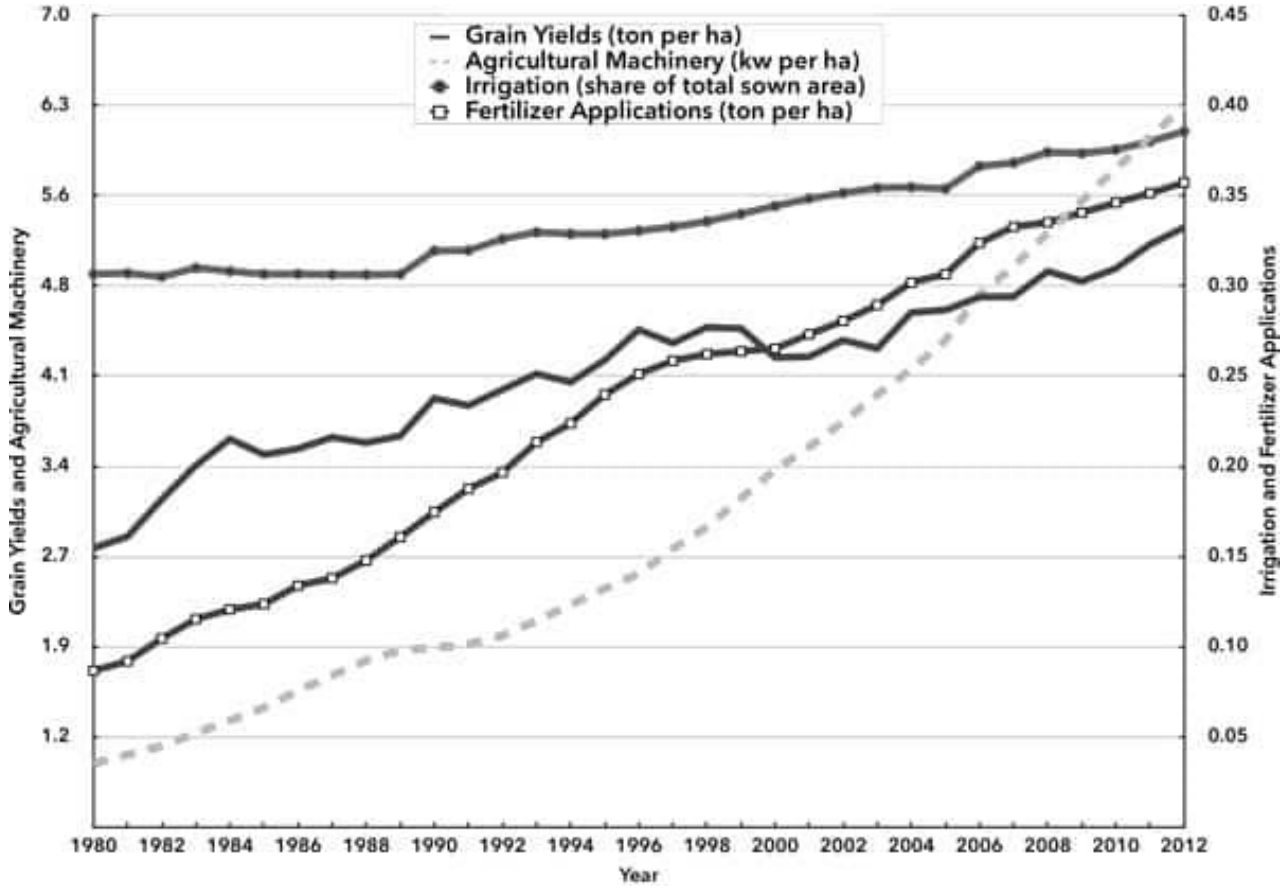
1. Background

- **Irrigation contributes a lot to food security.**
  - ✓ China has the most irrigated lands in the world.
  - ✓ >50% arable lands are irrigated.
  - ✓ Irrigation water utilization efficiency is about 50%



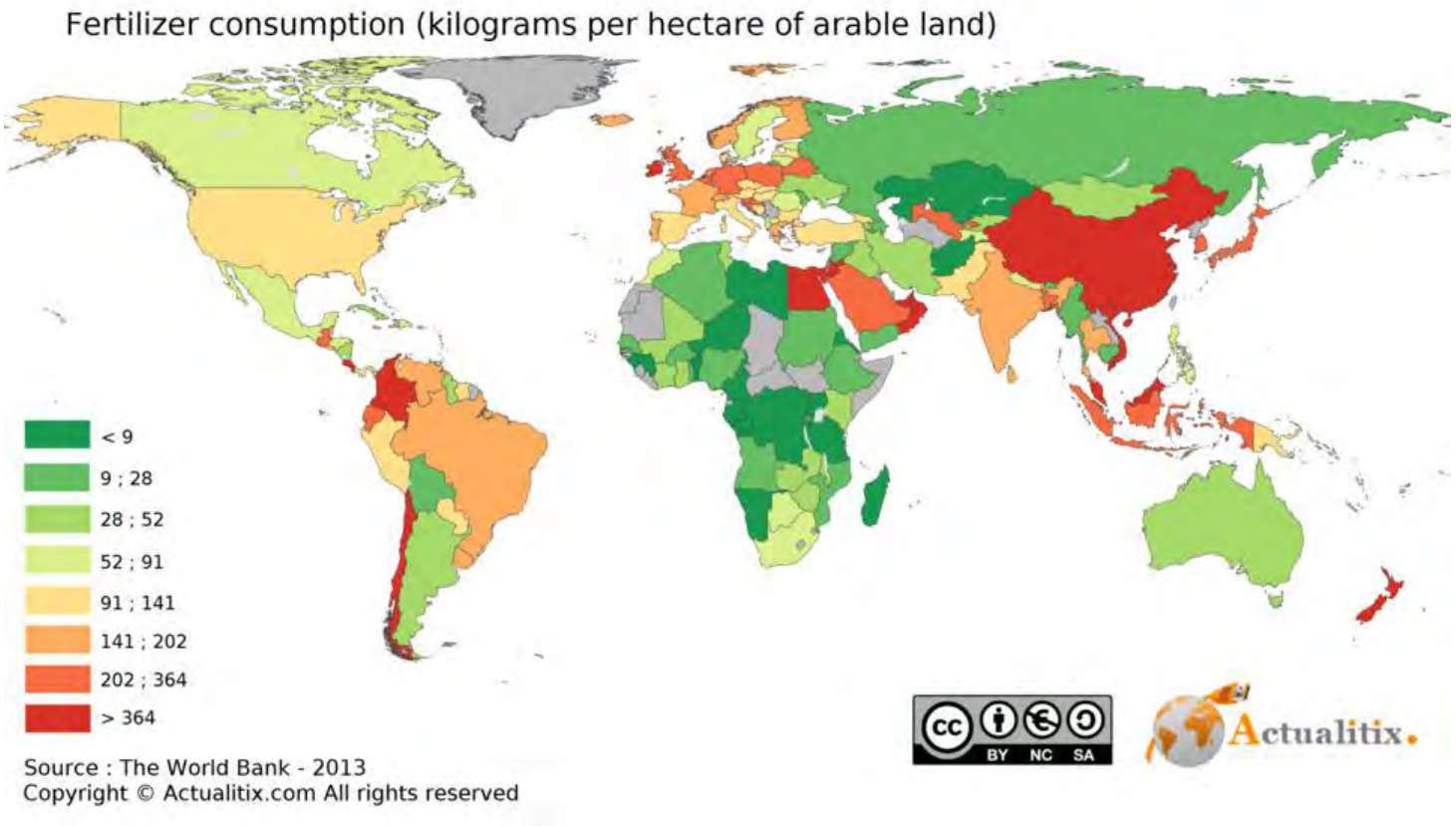
1. Background

- Fertilizer is another important factor that ensures food security in China. （Contribution rate >40%）



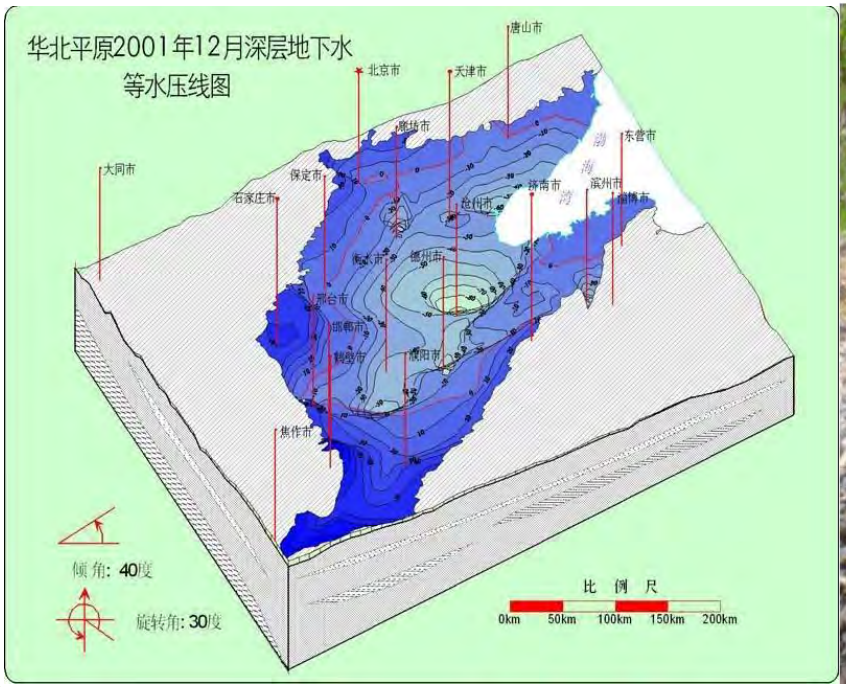
1. Background

- ✓ 7% world's arable land consume 1/3 fertilization
- ✓ Application rate is 3.7 times as the world average level
- ✓ Utilization effiency < 30%, half of the world average



1. Background

- **Overuse of water and fertilizer leads to serious environmental problems**

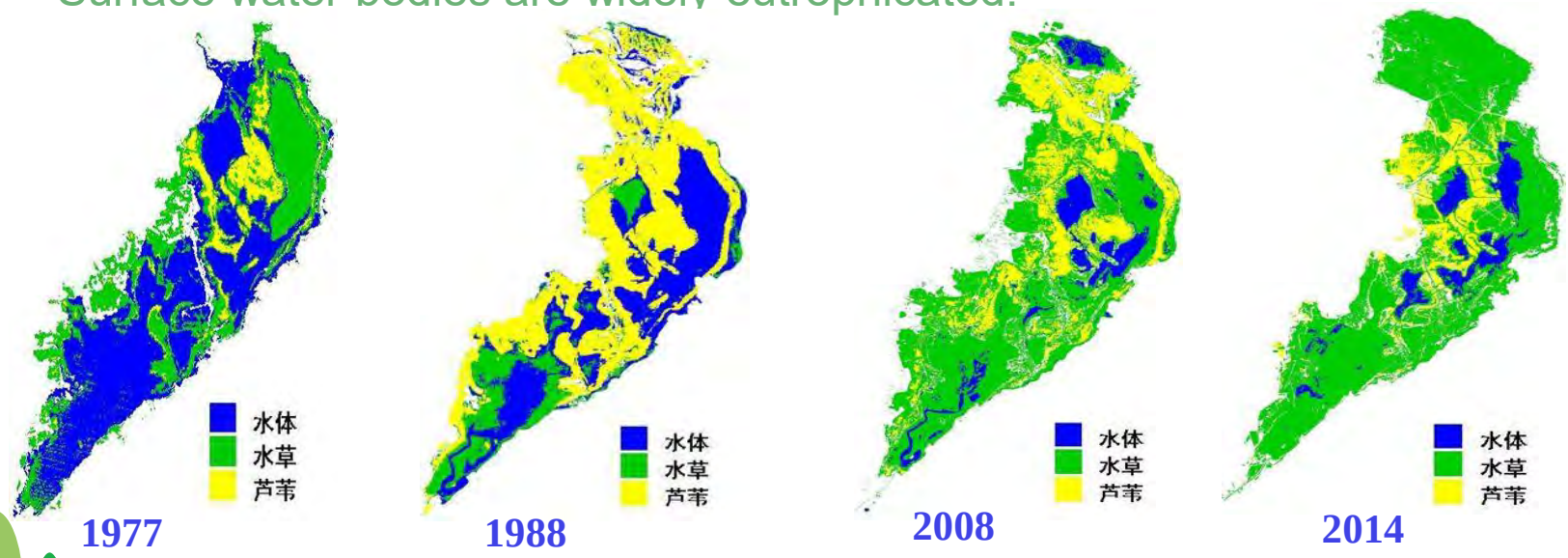


Groundwater depression

River flow cutoff or reduction

1. Background

- **Overuse of water and fertilizer leads to serious environmental problems**
  - ✓ 1/6 of China's arable land has been polluted by heavy metals.
  - ✓ 40 percent of China's land is affected by soil erosion, salinization, and desertification.
  - ✓ 80% groundwater is polluted and not qualified for drinking.
  - ✓ Surface water bodies are widely eutrophicated.



Expansion of reed in Wuliangsuhai Lake, Inner Mongolia, China

1. Background

- We want both golden, silver hill and clean water, green mountains as well.
- lucid waters and lush mountains are invaluable assets.

Contents

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2 Research interests

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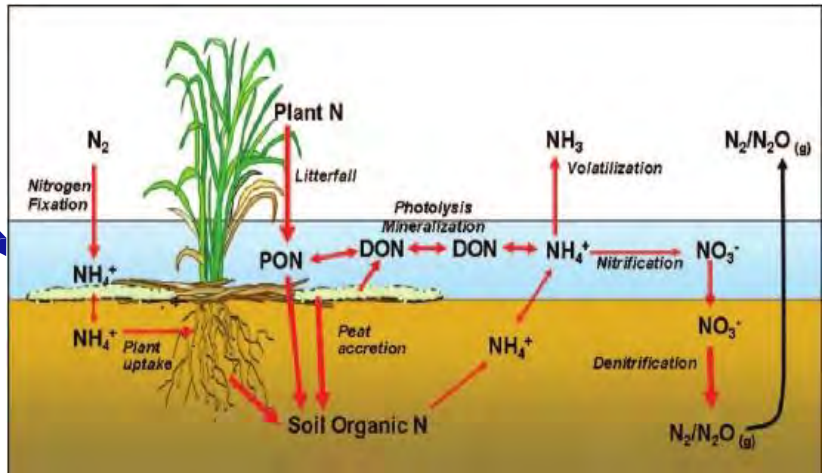
2. Research interests in agricultural land and water environment

- Issue 1: Solutes transport and transformation in agricultural system
- Issue 2: Interaction of crop, water and solutes
- Issue 3: Response of environment to irrigation & drainage and solutions to related environmental problem

2. Research interests

(1) Solutes transport and transformation

☐ Nitrogen transport in agricultural system



- ✓ Massive observation at different scales have been made to understand how nitrogen behaves under irrigation and drainage condition
- ✓ Various simulation Models have been developed for different regions

2. Research interests

(1) Solutes transport and transformation

☐ Nitrogen transport in agricultural system

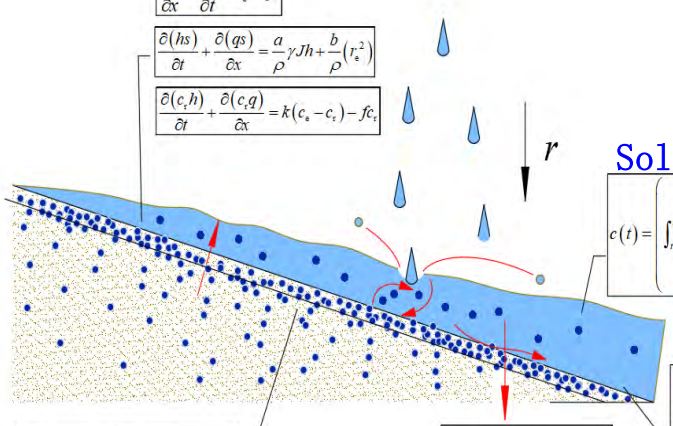
- ✓ In mountainous area, nitrogen loss is greatly linked with slope runoff and is often studied by integrating with soil erosion.

Gov. Eqs.

$$\frac{\partial q}{\partial x}+\frac{\partial h}{\partial t}=r_e-f$$

$$\frac{\partial(hs)}{\partial t}+\frac{\partial(qs)}{\partial x}=\frac{a}{\rho}\gamma Jh+\frac{b}{\rho}\left(r_e^2\right)$$

$$\frac{\partial(c_t h)}{\partial t}+\frac{\partial(c_t q)}{\partial x}=k(c_e-c_t)-fc_t$$



Solute with runoff

$$c(t)=\int_{t_p}^{t}\frac{kc_e(t)\exp\left((k+r_e)\left(\int_{t_p}^{t}\frac{\mathrm{d}t}{h(t)}\right)\right)}{h(t)}\mathrm{d}(t)\exp\left(-(k+r_e)\left(\int_{t_p}^{t}\frac{\mathrm{d}t}{h(t)}\right)\right)$$

Sediment with runoff

$$s(t)=\exp\left(\int_{t_p}^{t}\frac{f(t)-r_e}{h(t)}\mathrm{d}t\right)\left(\int_{t_p}^{t}\frac{\left(a\gamma Jh(t)+br_e^2\right)\exp\left(\int_{t_p}^{t}\frac{r_e-f(t)}{h(t)}\mathrm{d}t\right)}{\rho h(t)}\mathrm{d}t\right)$$

$$\frac{\partial Rc_s}{\partial t}=\frac{\partial}{\partial z}\left[D_s\frac{\partial c_s}{\partial z}-vc_s\right]$$

Infiltration

$$i=\frac{1}{2}S\cdot(t-\Delta t)^{-\frac{1}{2}}$$

$$c_e(t)=c_i\left(1-\frac{1}{2}erfc\left(\frac{-vt}{2\sqrt{DRt}}\right)-\frac{v+k}{2k}erfc\left(\frac{vt}{2\sqrt{DRt}}\right)+\left(1+\frac{v}{2k}\right)\exp\left(\frac{(k+v)kt}{DR}\right)erfc\left(\frac{(2k+v)t}{2\sqrt{DRt}}\right)\right)$$

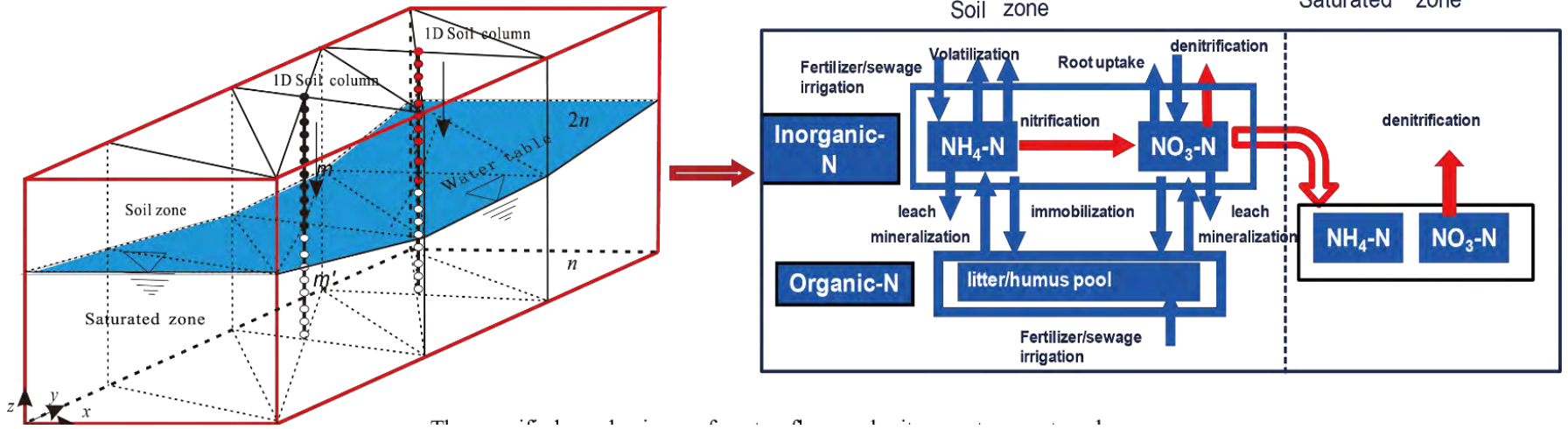
Transport in soils

2. Research interests

(1) Solutes transport and transformation

☐ Nitrogen transport in agricultural system

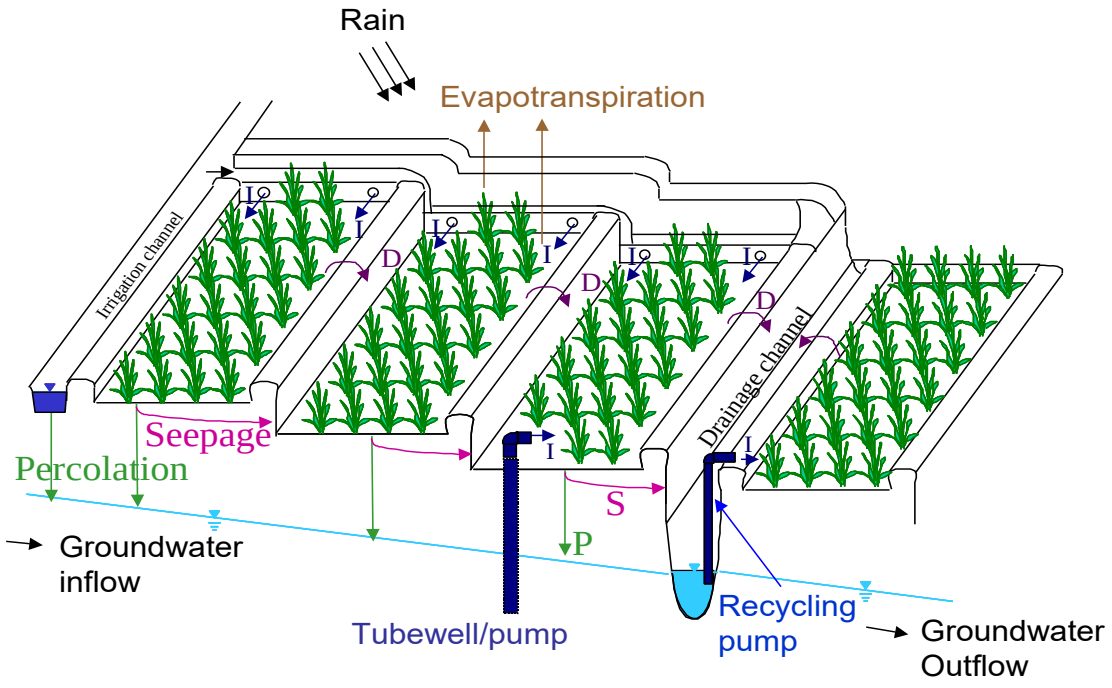
- ✓ In arid and semi-arid area where upland crop is planted, the interaction between saturated zone and unsaturated zone is significant. Nitrate leaching and groundwater pollution are generally concerned.



2. Research interests
(1) Solutes transport and transformation

☐ Nitrogen transport in agricultural system

- ✓ In paddy rice area, flood irrigation, ditch detaining and surface water body purifying are important factors in nitrogen cycle.

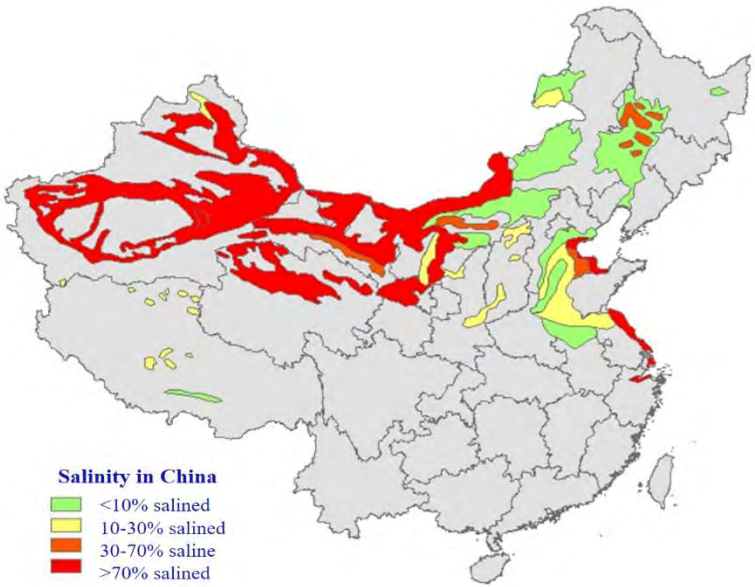


2. Research interests

(1) Solutes transport and transformation

☐ Salt transport and soil salinization

- ✓ Salt-affected area amount to 0.1 bln ha
- ✓ 7% farm land affected
- ✓ 0.25 mln ha abounded per year due to salinization



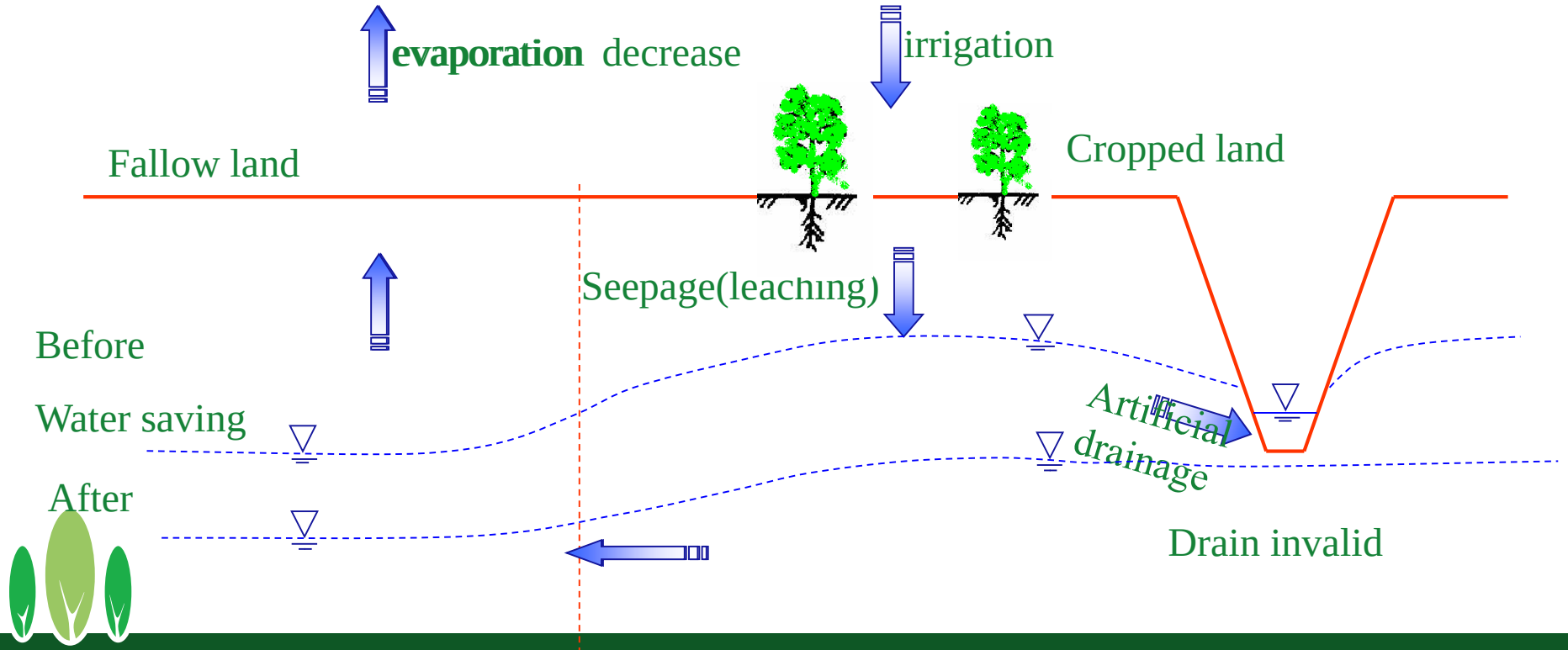
Birdview of Hetao Irrigation District, Top3 irrigation project in China

2. Research interests

(1) Solutes transport and transformation

☐ Salt transport and soil salinization

- ✓ National wide water saving practices result in the falling of groundwater table and change the salinization mechanism.
- ✓ Positive and negative impacts on salinization simultaneously

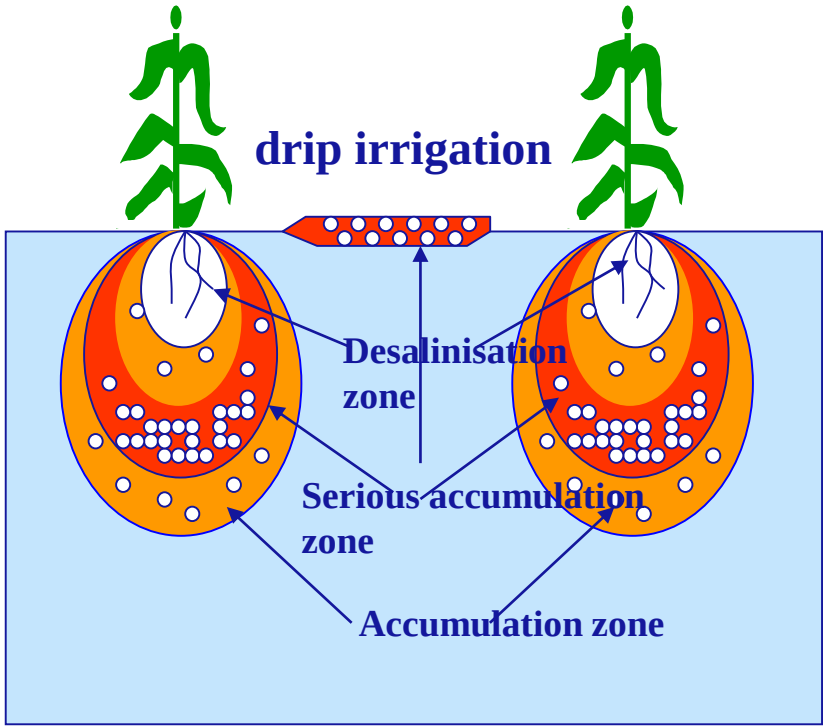


2. Research interests

(1) Solutes transport and transformation

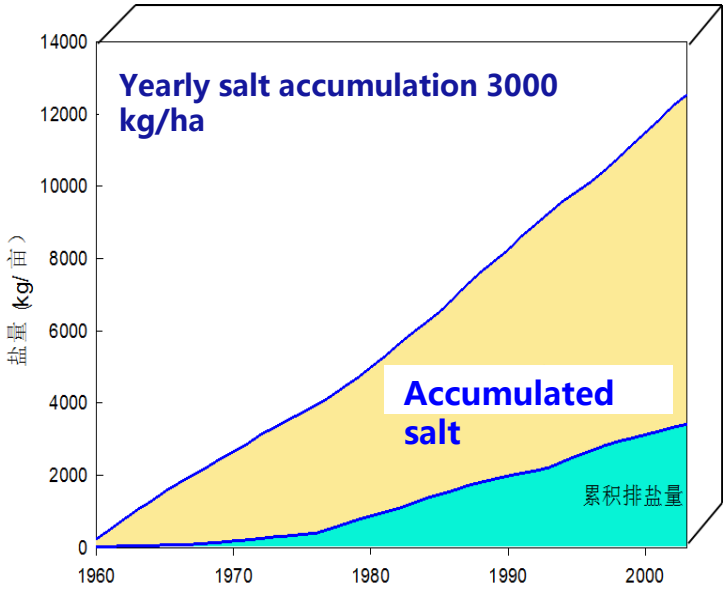
☐ Salt transport and soil salinization

- ✓ Salt built up in root zone due to the lack of leaching



Field scale

- ✓ salt accumulation inside the system due to decreasing drainage capacity

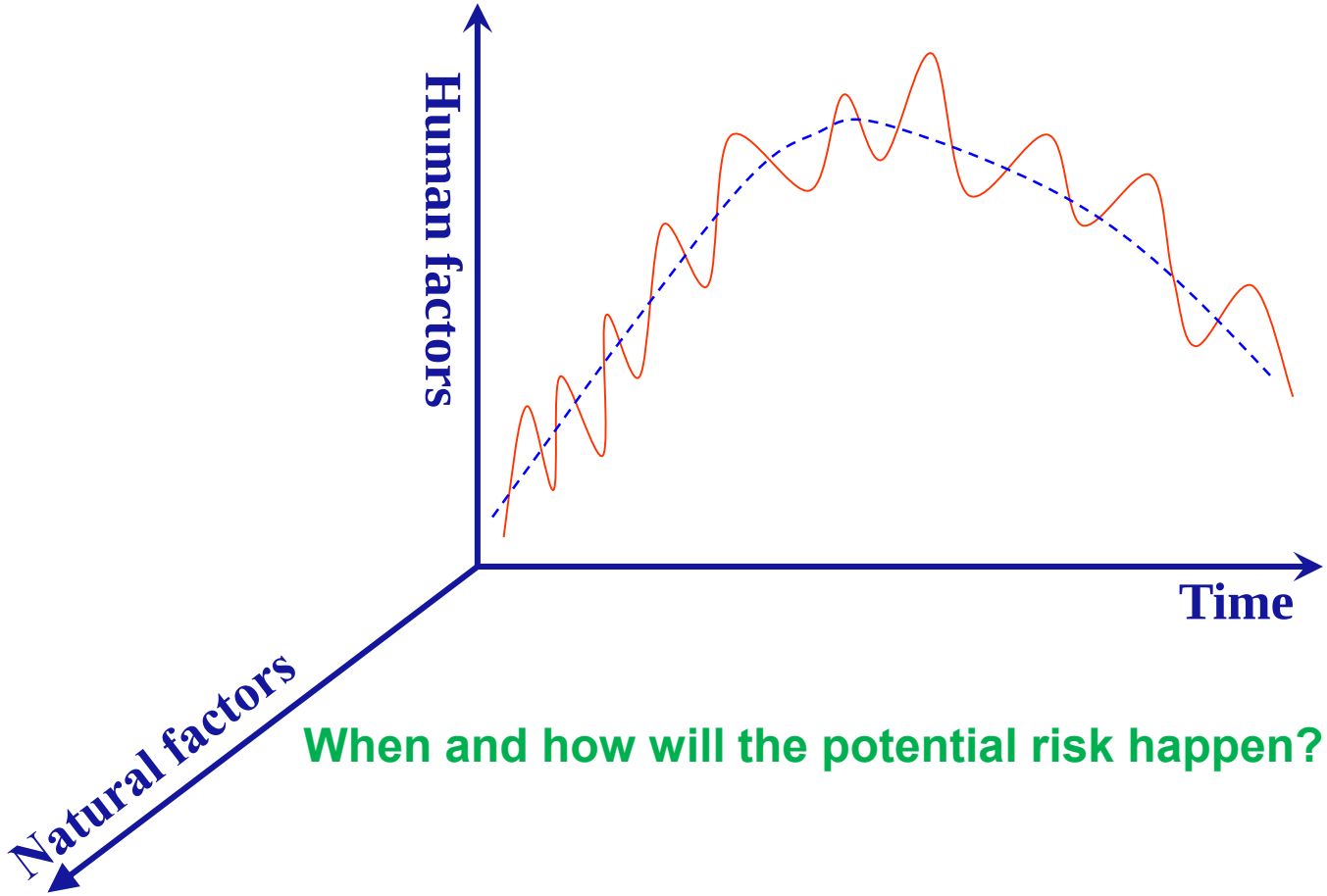


System scale

2. Research interests

(1) Solutes transport and transformation

- Salt transport and soil salinization

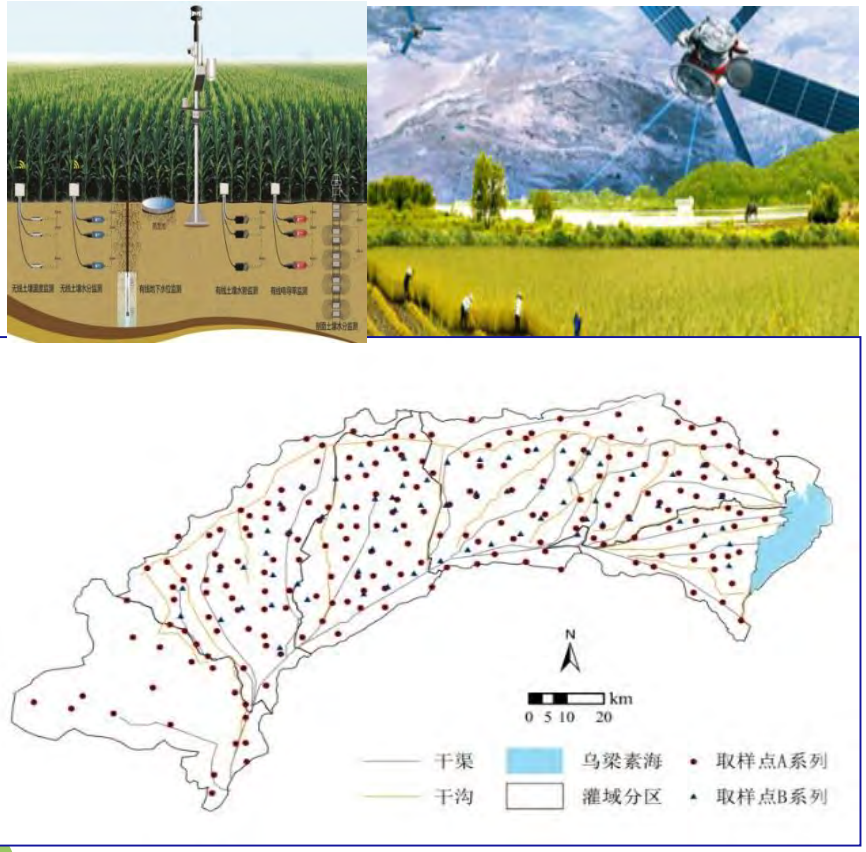


When and how will the potential risk happen?

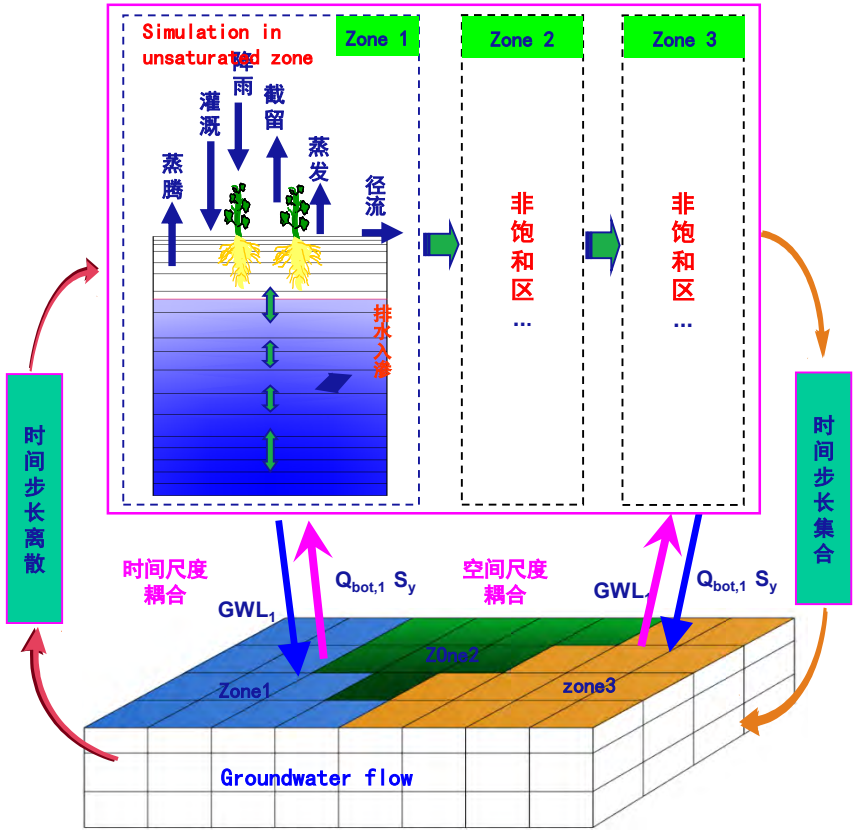
2. Research interests

(1) Solutes transport and transformation

Salt transport and soil salinization



Multi-scale Monitoring

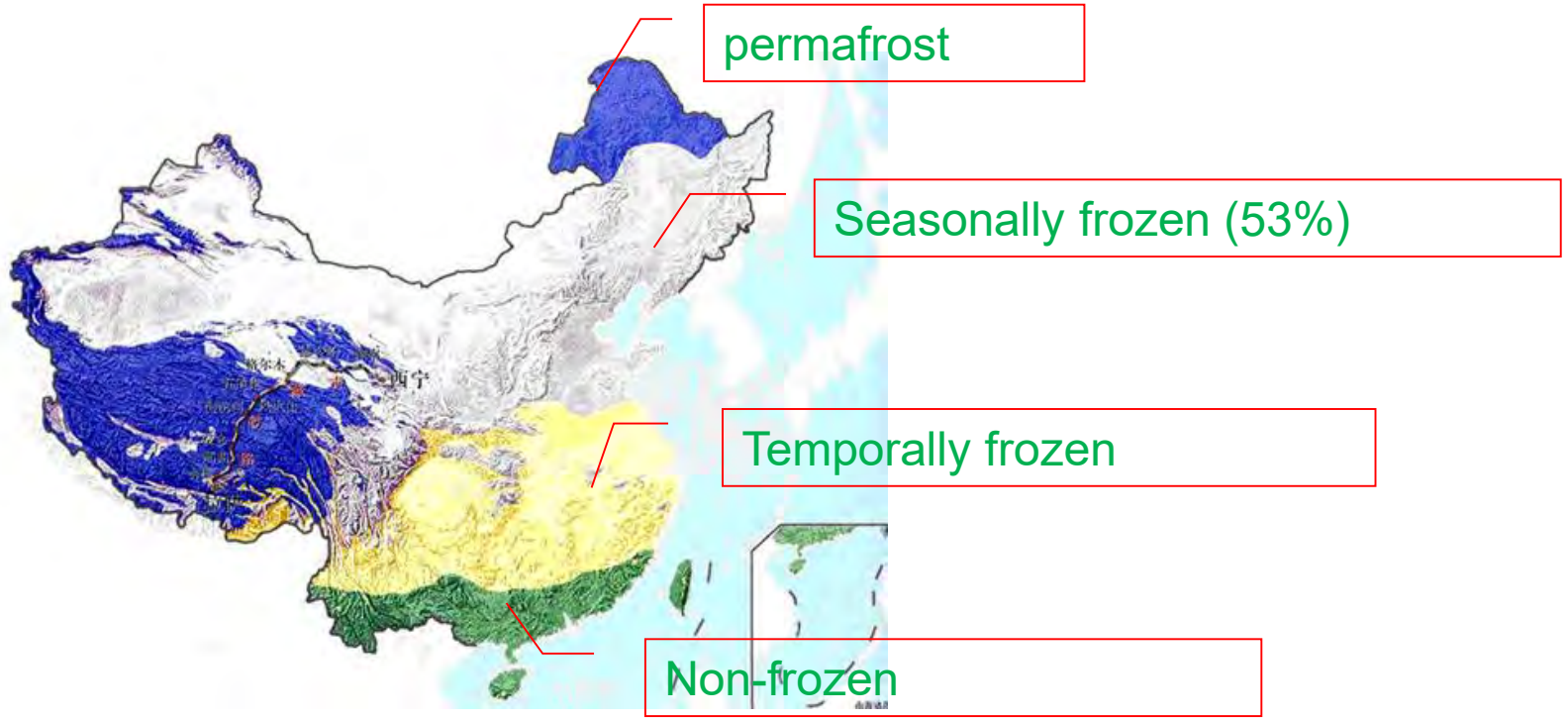


Multi-scale coupled Modeling

2. Research interests

(1) Solutes transport and transformation

- **Water/solute transport in freezing and thawing soils**

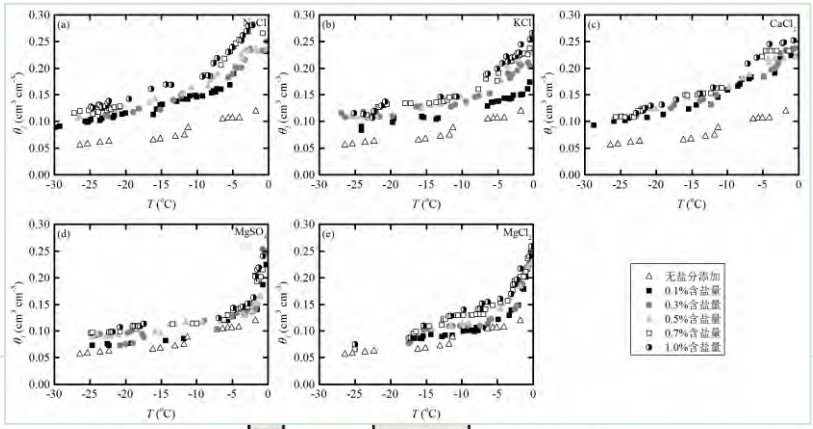


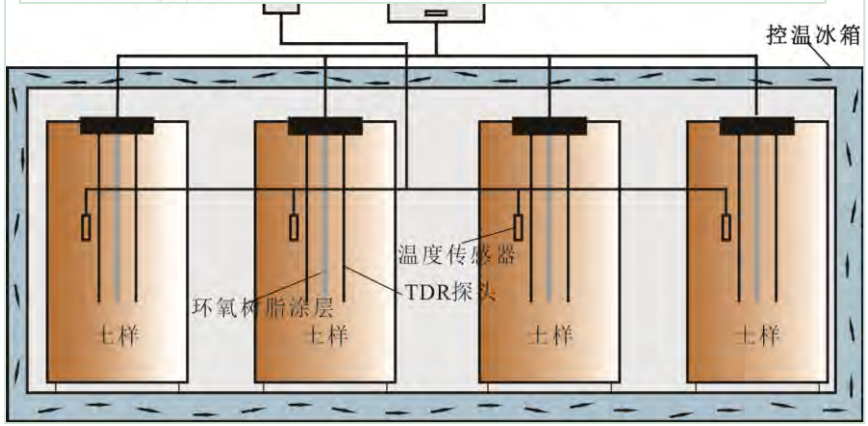
2. Research interests

(1) Solutes transport and transformation

☐ Water/solute transport in freezing and thawing soils

✓ Field and laboratory experiments have been conducted to study the dynamic of soil water and solute and migration mechanism.





2. Research interests

(1) Solutes transport and transformation

☐ Water/solute transport in freezing and thawing soils

✓ Models coupling water, solute, heat and snow cover have been developed.

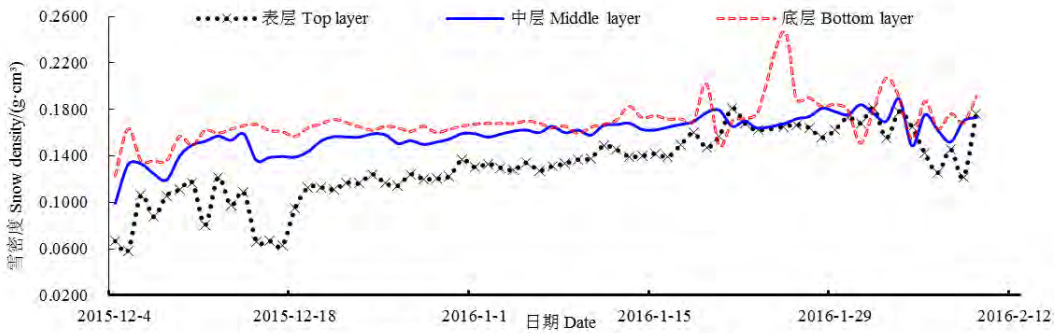
$$C_s \frac{\partial T}{\partial t} + L_f \rho_l \frac{\partial \theta_l}{\partial t} = \frac{\partial}{\partial z}(\lambda \frac{\partial T}{\partial z}) + L_f \rho_l \frac{\partial}{\partial z}[D(\theta_l)\frac{\partial \theta_l}{\partial z} - K(\theta_l)] \qquad (C_s + L_f \rho_l \frac{d\theta_m}{dT})\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}[(\lambda + L_f \rho_l D(\theta_l)\frac{d\theta_m}{dT})\frac{\partial T}{\partial z}] - L_f \rho_l \frac{\partial K(\theta_l)}{\partial z}$$

$$\frac{\partial}{\partial z}\left(\lambda_{sp}\frac{\partial T}{\partial z}\right) + S = \rho_{sp} C_{ice}\frac{\partial T}{\partial t} + \rho_l L_f \frac{\partial \theta_{sp}}{\partial t} + L_s\left(\frac{\partial \rho_v}{\partial t} + \frac{\partial q_v}{\partial z}\right)$$

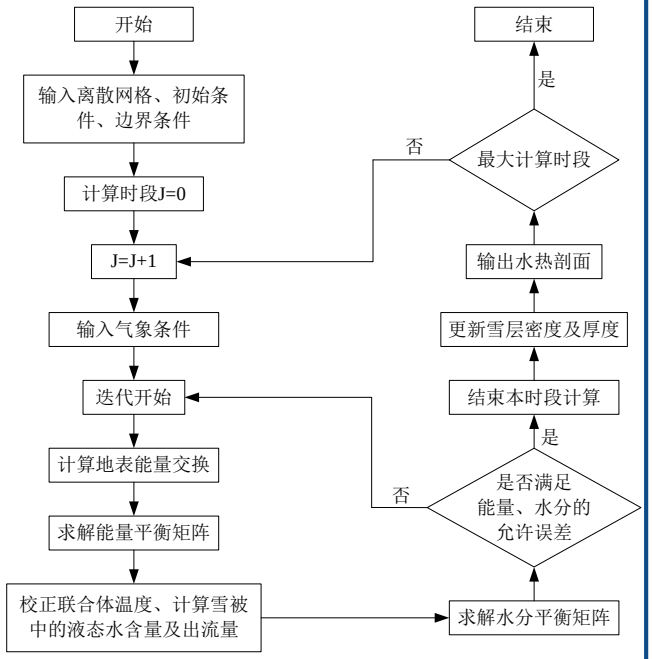
$$\frac{1}{(\Delta z_i + \Delta z_{i+1})/2}\left[\frac{\lambda_{sp,i+1/2}^{k+1}(T_{i+1}^{k+1} - T_i^{k+1})}{\Delta z_{i+1}} - \frac{\lambda_{sp,i-1/2}^{k+1}(T_i^{k+1} - T_{i-1}^{k+1})}{\Delta z_i}\right] + S_i^{k+1}$$

$$= \rho_{sp,i} C_{ice}\frac{T_i^{k+1} - T_i^k}{\Delta t} + \rho_l L_f \frac{\theta_{sp,i}^{k+1} - \theta_{sp,i}^k}{\Delta t} + L_s \frac{\partial \rho_v}{\partial T}\frac{T_i^{k+1} - T_i^k}{\Delta t}$$

$$+ L_s \frac{\partial \rho_v}{\partial T}\frac{1}{(\Delta z_i + \Delta z_{i+1})/2}\left[\frac{D_{e,i+1/2}^{k+1}(T_{i+1}^{k+1} - T_i^{k+1})}{\Delta z_{i+1}} - \frac{D_{e,i-1/2}^{k+1}(T_i^{k+1} - T_{i-1}^{k+1})}{\Delta z_i}\right]$$



积雪消融过程中各分层密度变化曲线

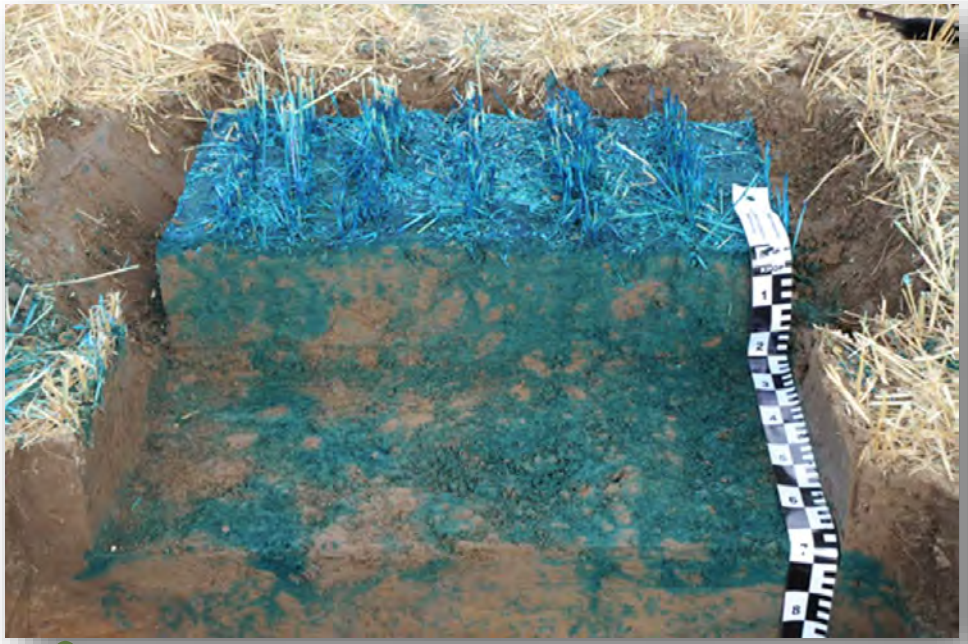


土壤水热耦合迁移方程数值模拟流程

2. Research interests

(1) Solutes transport and transformation

- **Methods to increase the accuracy in simulating solute transport and transformation**
  - ✓ Geostatistics, stochastic simulation and bayes' theorem are used to deal with the uncertainty of parameters, complex model boundary condition and improper model assumptions in simulation.



Heterogeneity

Sparse observation

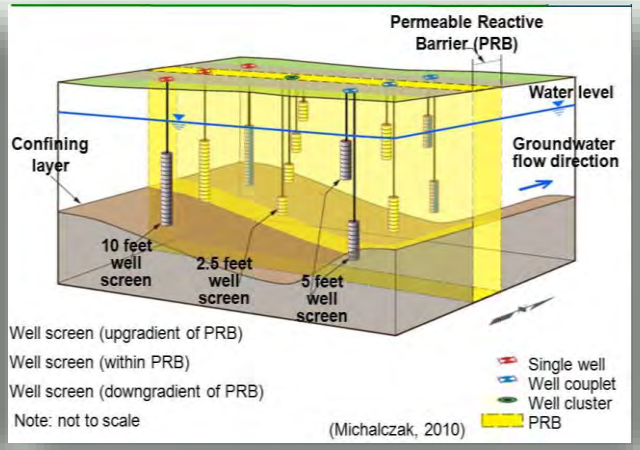
2. Research interests

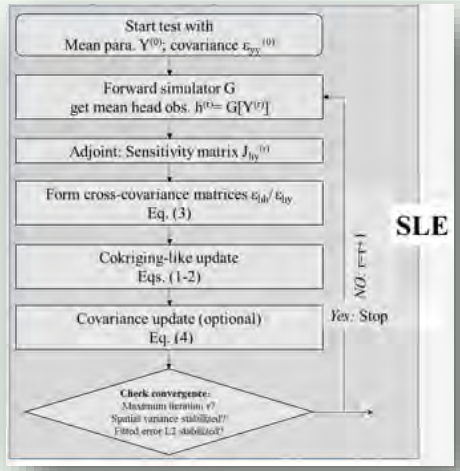
(1) Solutes transport and transformation

☐ Methods to increase the accuracy in simulating solute transport and transformation

✓ Data fusion is used to identify the soil heterogeneity based on different kinds of observations

Prior soil information + **Observation** → **Inverse algorithm**

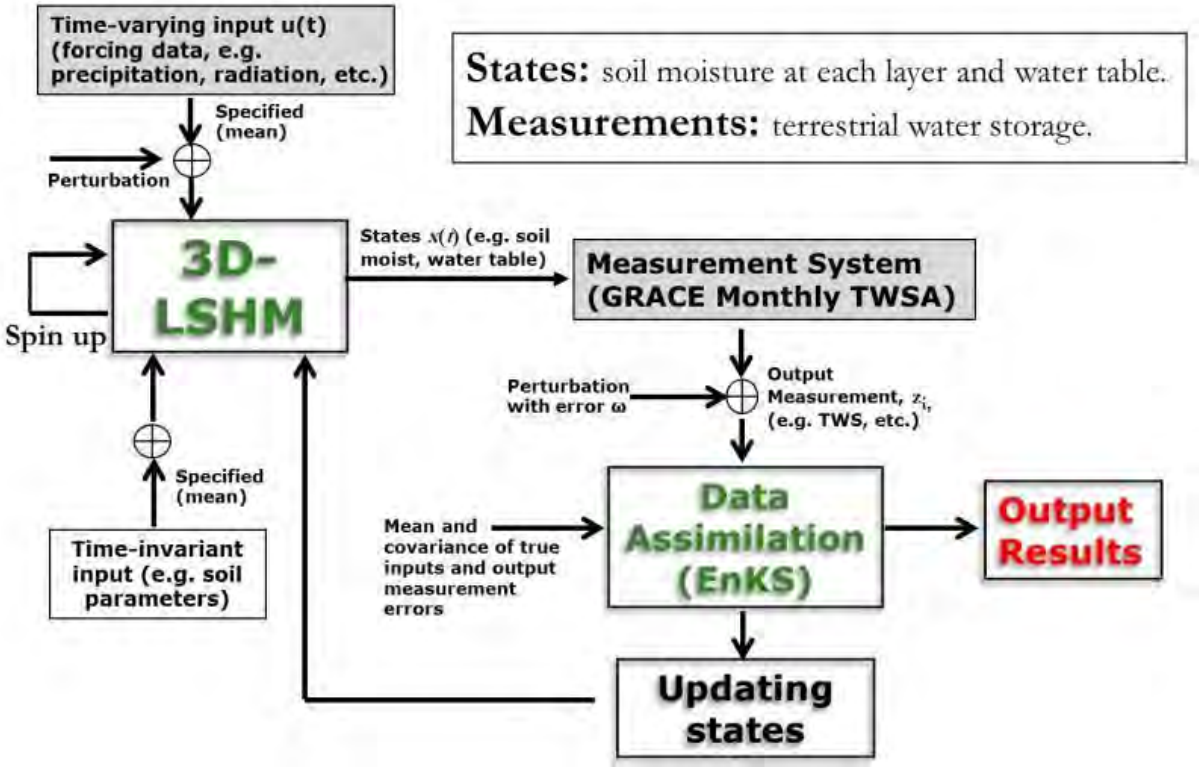




2. Research interests

(1) Solutes transport and transformation

- **Methods to increase the accuracy in simulating solute transport and transformation**
  - ✓ Data assimilation is also used to identify the soil heterogeneity based on different kinds of observations



2. Research interests
(2) Interaction of crop , water and Solutes

☐ effects of the coupling of water and fertilizer (nitrogen)

✓ Massive field experiments have been conducted to understand the effects of the coupling of water and nitrogen application on crop yield.

Consider the effects of the coupling of water and nitrogen applications on crop yield

Consider the requirement of crop quality

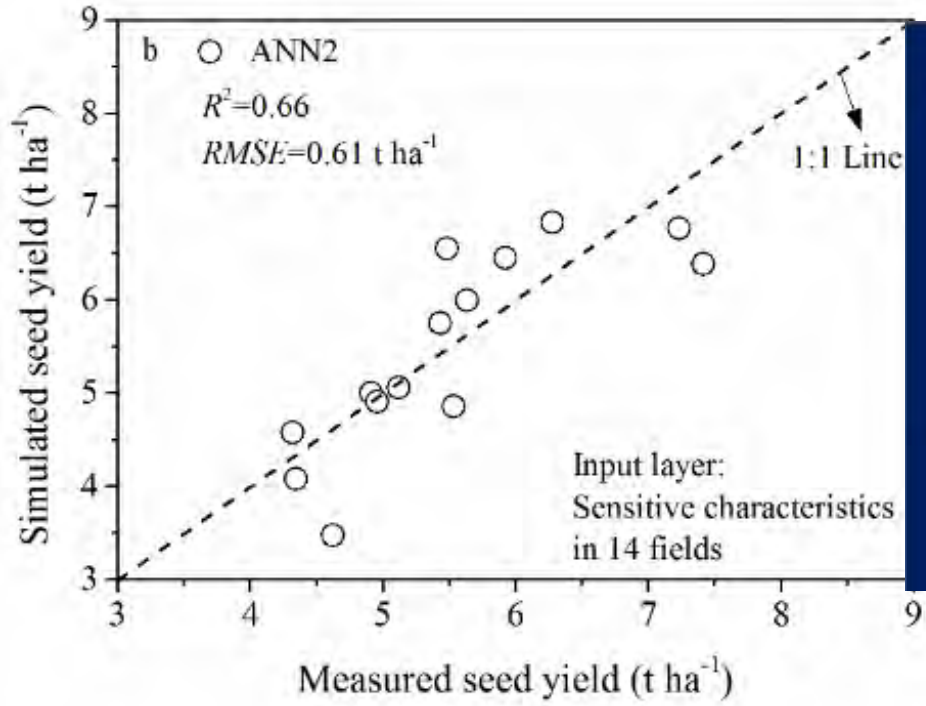
Consider the effect of soil salt

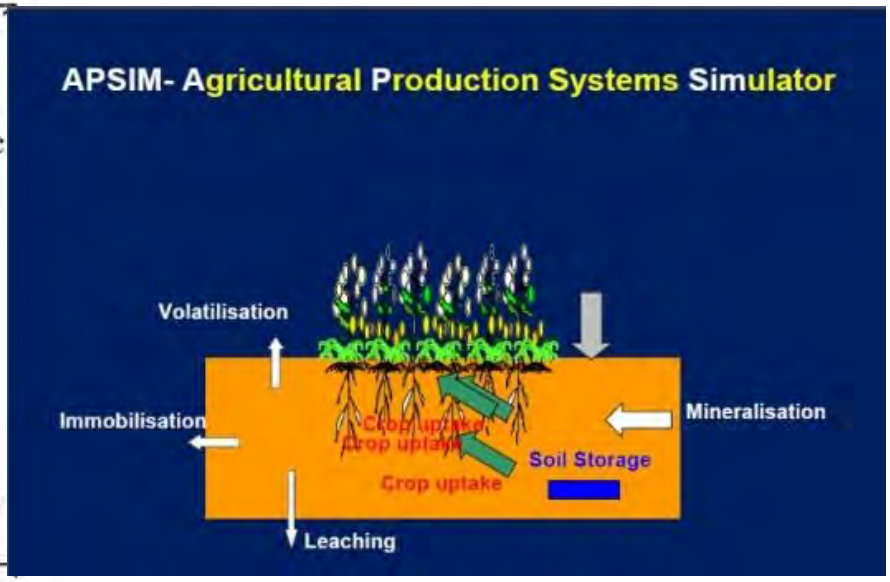
Consider the constraint of eco-environment

2. Research interests
(2) Interaction of crop , water and Solutes

☐ Modeling water-fertilizer production function

✓ Statistical Method （PLSR, ANN）， Semi-empirical method (Jense , Morgan), process-based method are widely applied to quantifying the interaction of crop, water and solution.





Process-based Method
Crop growth simulation model

2. Research interests
(2) Interaction of crop , water and Solutes

☐ Root distribution and water/fertilizer uptake

Low salinity level | Moderate salinity level | High salinity level

Root distribution under different water, nitrogen and salinity.

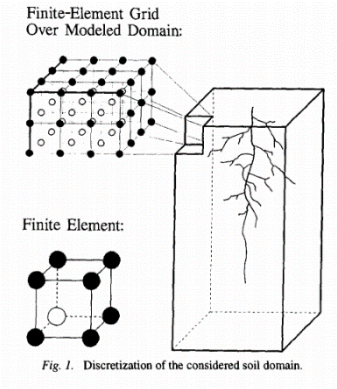
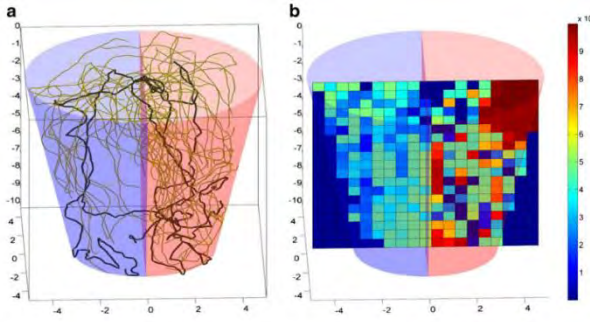


Fig. 1. Discretization of the considered soil domain.

Physical and empirical macroscopic models are used to qualifying water uptake.

$$\rho = \frac{4}{r_0^2 - a^2 r_m^2 + 2\left(r_m^2 + r_0^2\right)\ln\frac{a r_m}{r_0}}$$

$$S(z,t) = \alpha(h,\pi,z) \cdot \beta(z) \cdot T_p$$

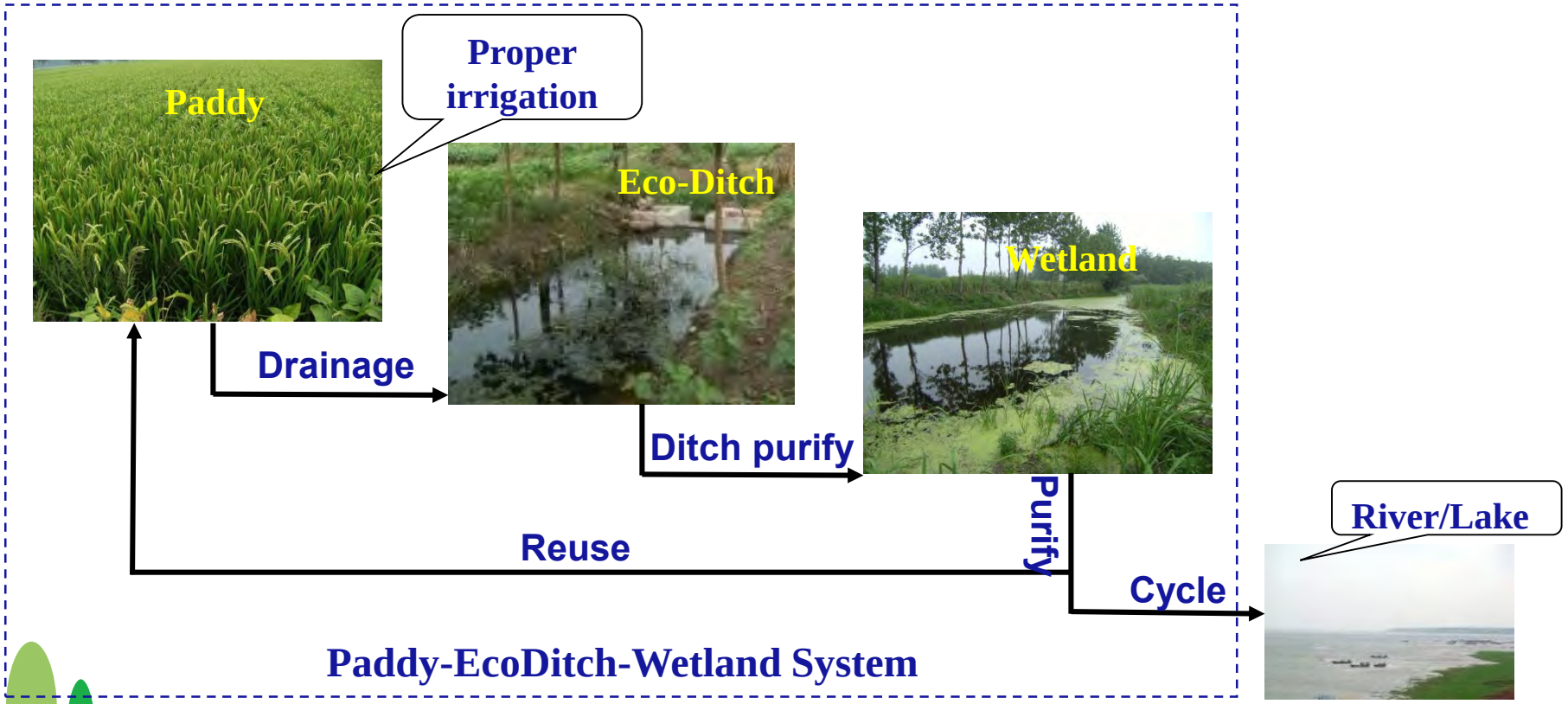


Compensatory root water uptake

2. Research interests:

(3) Interaction of Irrigation-drainage-Environment

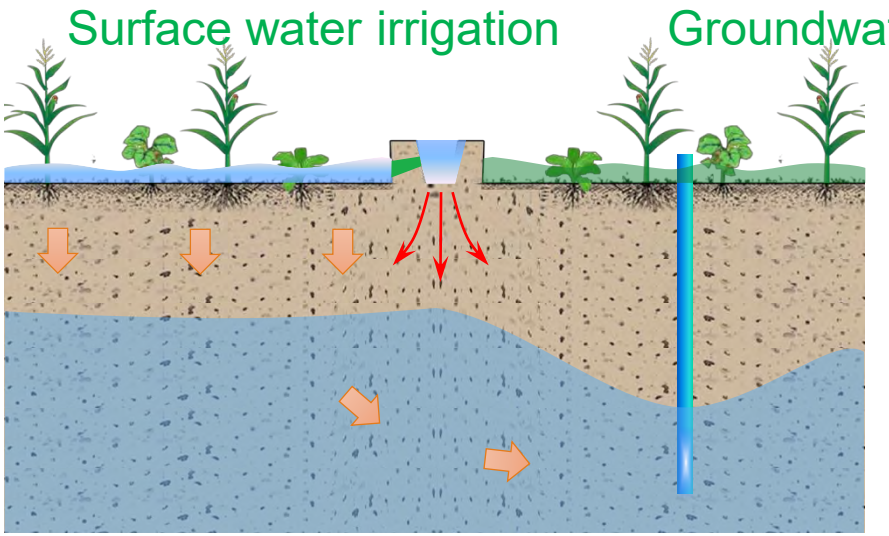
- Proper irrigation/drainage to reduce agricultural pollution.

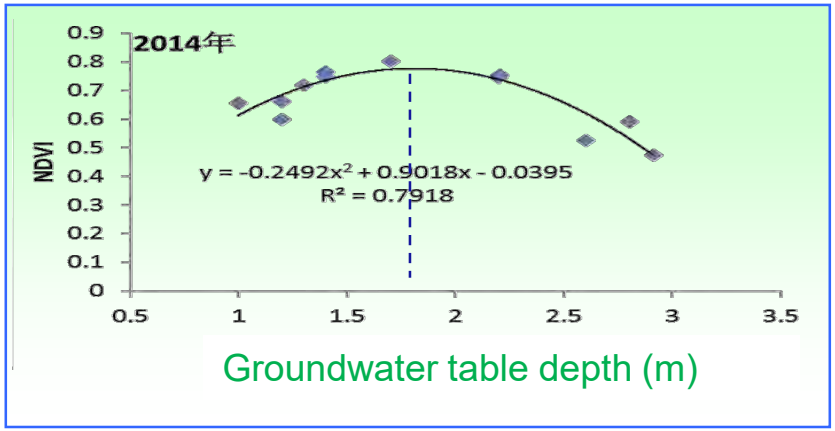


2. Research interests:

(3) Interaction of Irrigation-drainage-Environment

- **Proper conjunctive use of irrigation water resources to balance water saving and eco-environment protection**

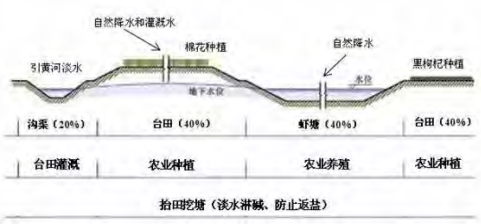


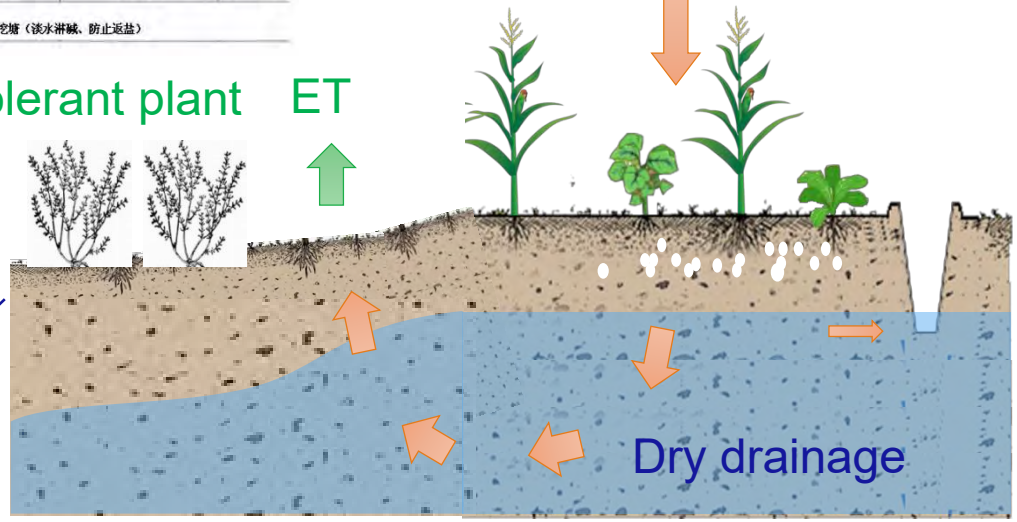


2. Research interest:

(3) Interaction of Irrigation-drainage-Environment

- Proper land-use planning to mitigate soil salinity threat and protect eco-environment.



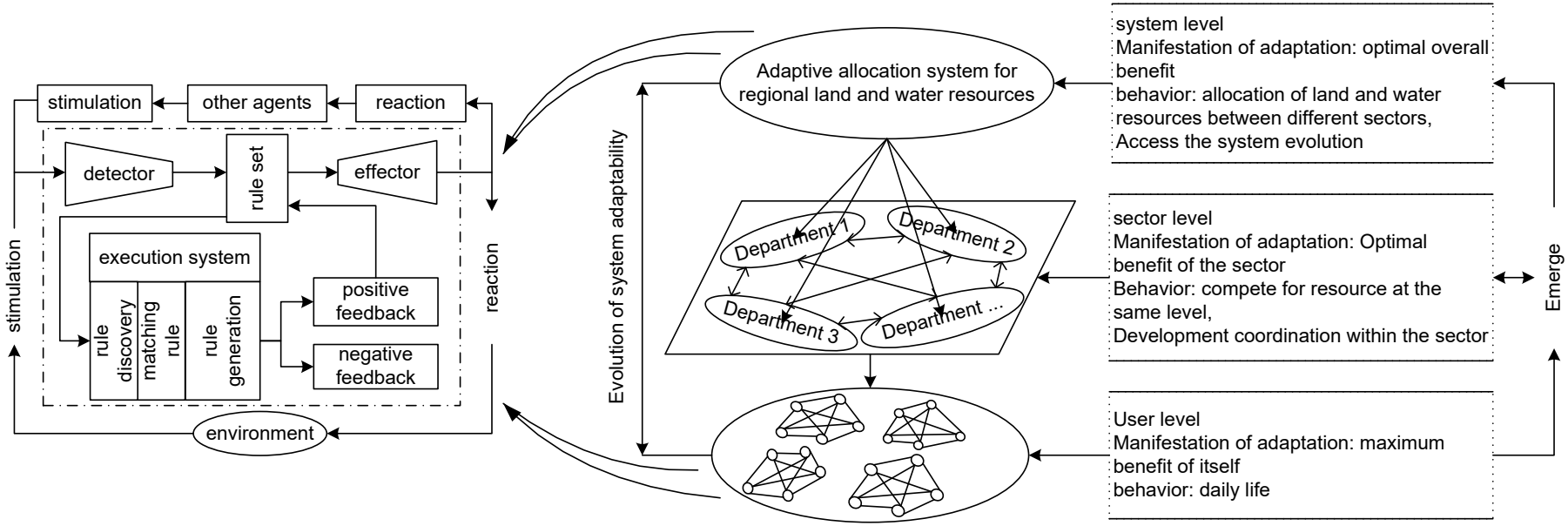


2. Research interest:

(3) Interaction of Irrigation-drainage-Environment

- **System theory is studied to explore optimum solutions to the multi-objects, multi-process problem.**

  (Food-Water-Environment-energy nexus)

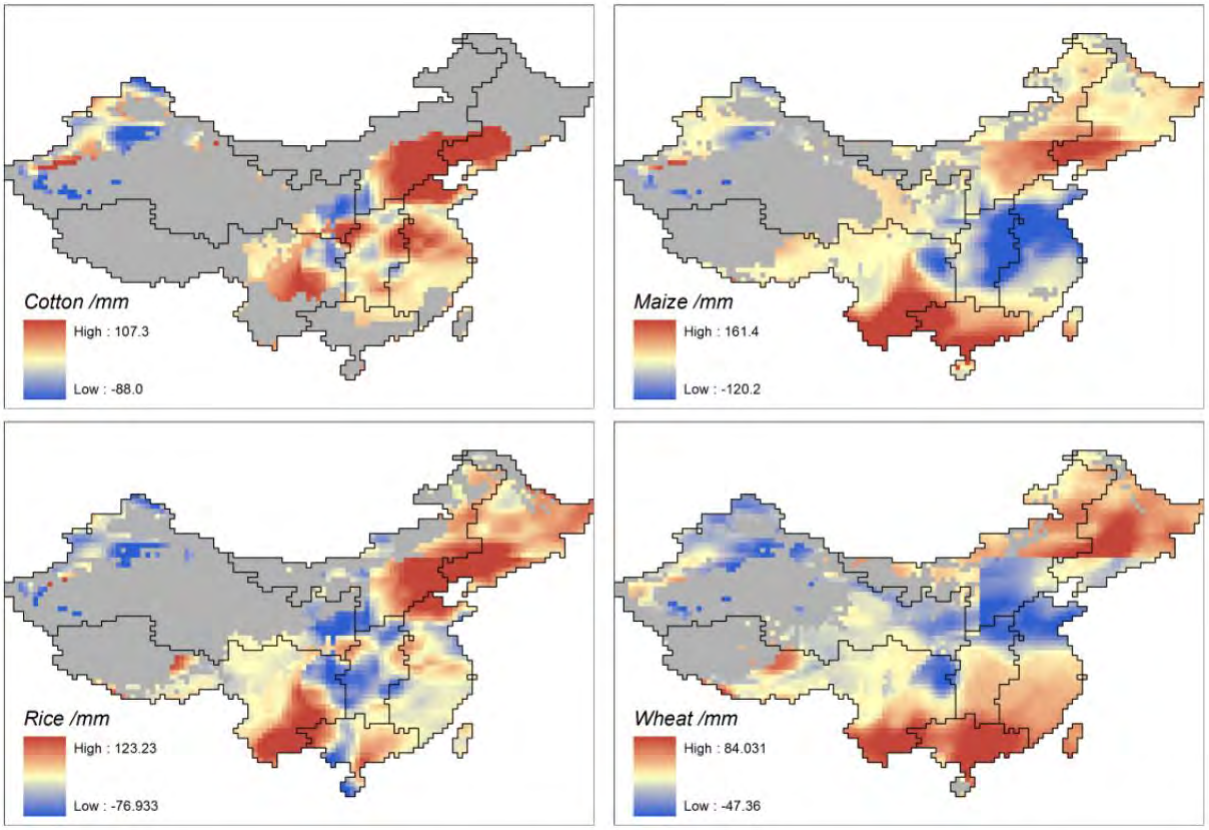


2. Research interest:

(3) Interaction of Irrigation-drainage-Environment

- **How climate change impact irrigation and corresponding adaptation**

- ✓ Water availability
- ✓ Crop Water requirement
- ✓ irrigation demand
- ✓ Variability and uncertainty
- ✓ Adapting irrigation to climate change

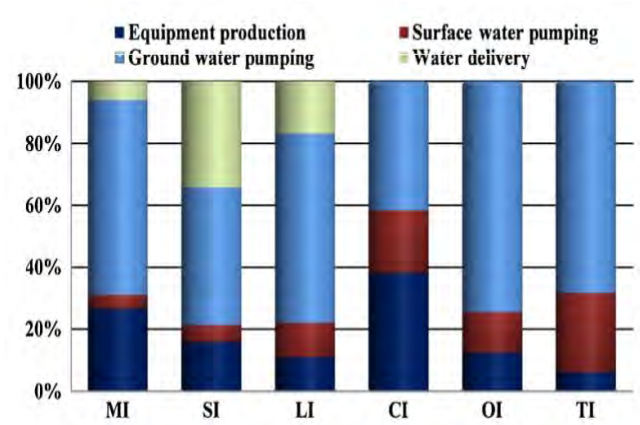


Changes in Irrigation demand for the main crops

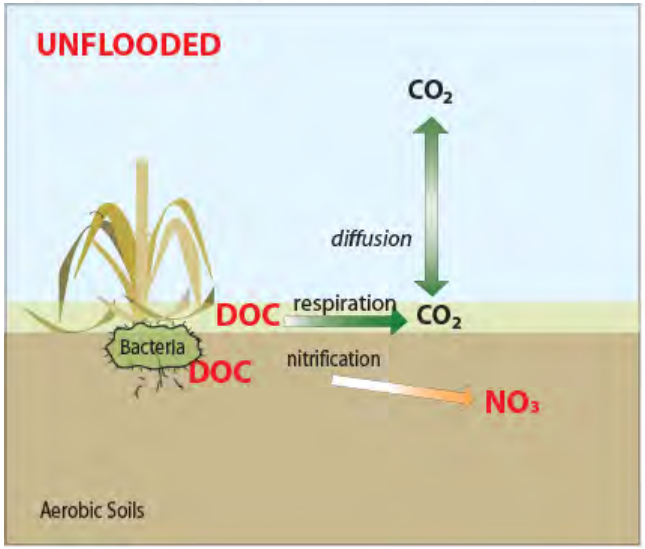
2. Research interest:
(3) Interaction of Irrigation-drainage-Environment

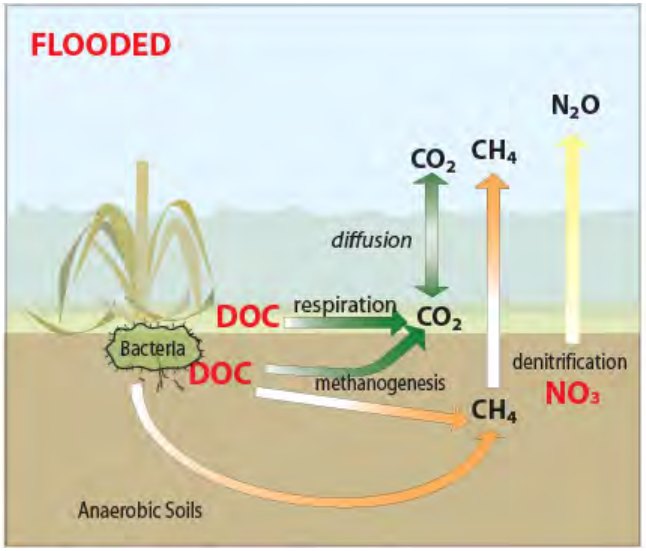
☐ Irrigation and GHG emission

- ✓ Monitoring and estimating
- ✓ Exploring mechanism and simulation
- ✓ Optimizing irrigation & drainage practices



The CO_2-e emission proportions of different irrigation process in 2010 in China





Contents

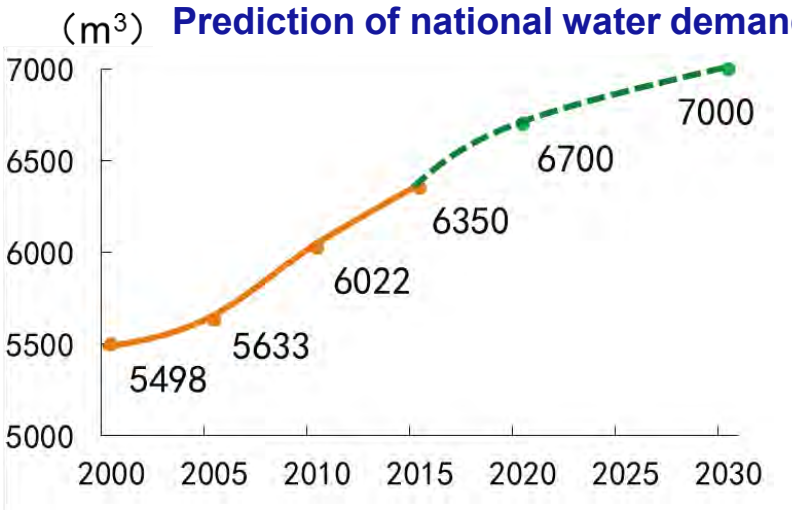
1 Background

2 Research interests

3 Outlooks

3. Outlooks

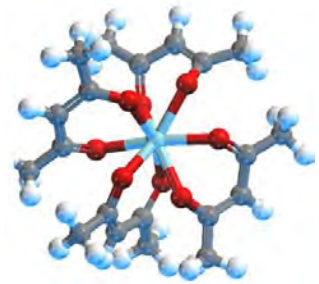
- **Outlook 1: Irrigation-related environmental issues will be highly concerned and studied.**
  - ✓ current situation
  - ✓ continuous water saving practice
  - ✓ State will

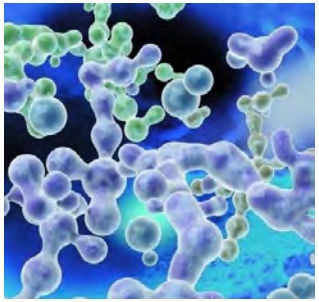


3. Outlooks

- **Outlook 2: The sciences of soil, plant physiology, environment, ecology and chemistry will be greatly integrated with irrigation science to accurate characterize the behavior of solutes and the interaction of crop-water-solute-environment.**

Interdisplines

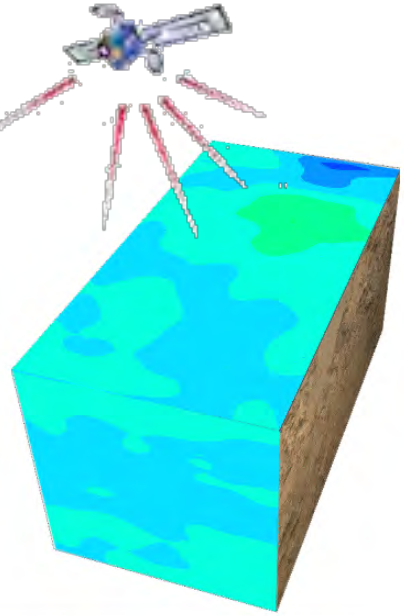






The interaction of crop-water-solute-environment

3. Outlooks

- **Outlook 3: Data and simulation models will be deeply fused to increase understanding and reduce uncertainty.**



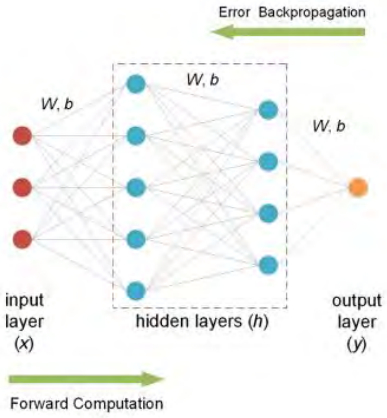
Satellite sensing

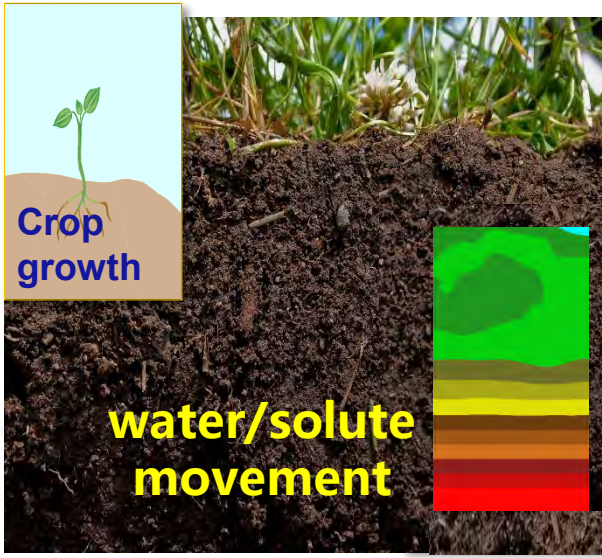
NAV monitoring

Geophysical detecting

Field monitoring

Experimental sampling

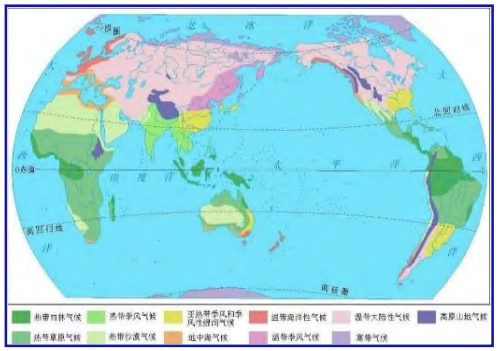




Multi-Scale observations **Deep learning** **Multi-models**

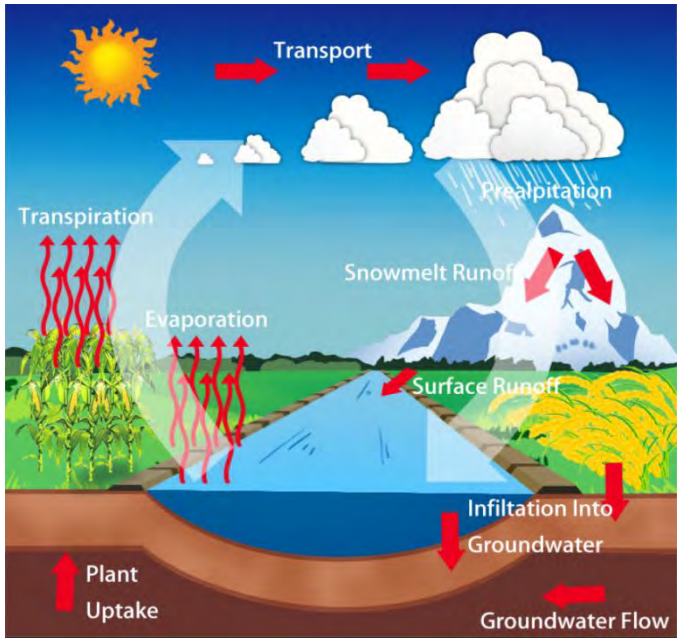
3. Outlooks

- **Outlook 4: The interaction of changing environment and irrigation practice will be studied at multi-scales to optimize irrigation & drainage management and achieve all-win.**



Climate Change

Human activity



Water and solute cycle

Data availiablity

+

simluation Uncertainty

Multi-process adaption

Thanks for attention !