CHANG'AN UNIVERSITY

XVIII World Water Congress
International Water Resources Association (IWRA)

Mechanism of soil water transfer and its ecological effect in seasonally frozen regions

Ce Zheng

Chang 'an University

XVIII WORLD WATER CONGRESS
Water for All
Harmony between Humans and Nature

第18届
世界水资源大会
水与万物:
人与自然和谐共生

XVIII World Water Congress
International Water Resources Association (IWRA)

CHANG'AN UNIVERSITY

Mechanism of soil water transfer and its ecological effect in seasonally frozen regions

Ce Zheng

Chang’an University

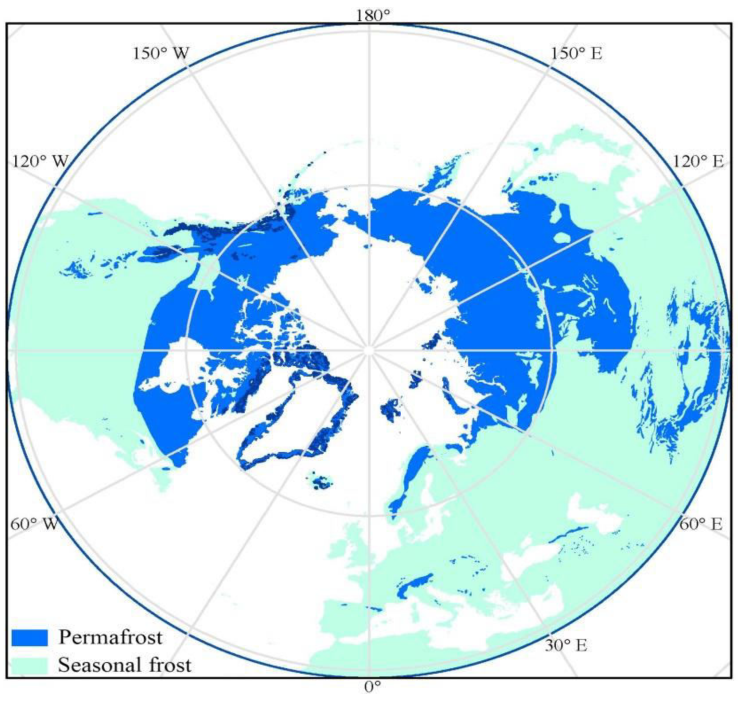
2023.09.14

CONTENTS

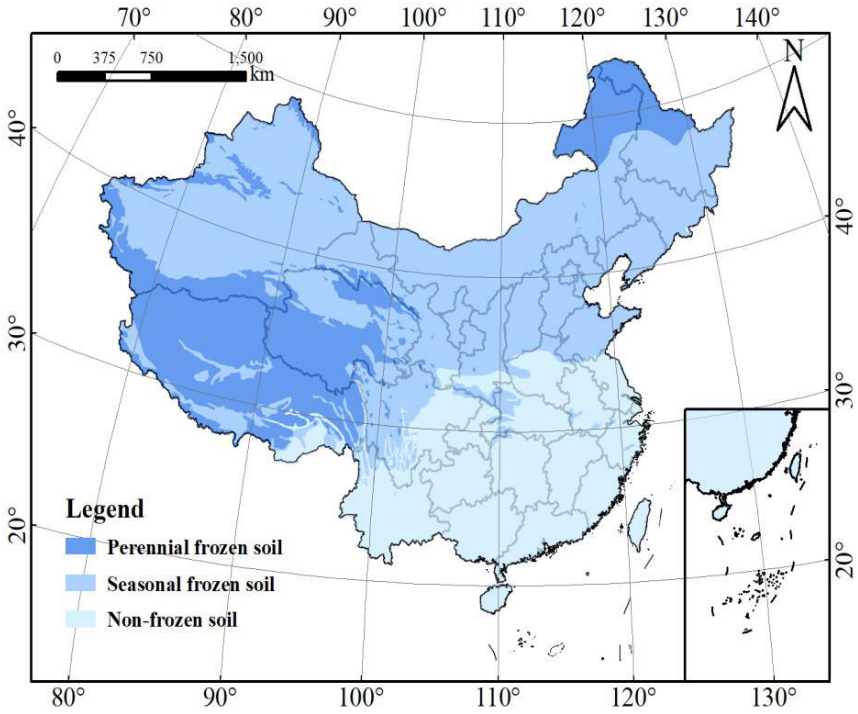
- PART 1 | Research Background
- PART 2 | Research Methodology
- PART 3 | Major Findings
- PART 4 | Future Research Plan

Research Background

CHANG'AN UNIVERSITY



Distribution of frozen soil in the Northern Hemisphere



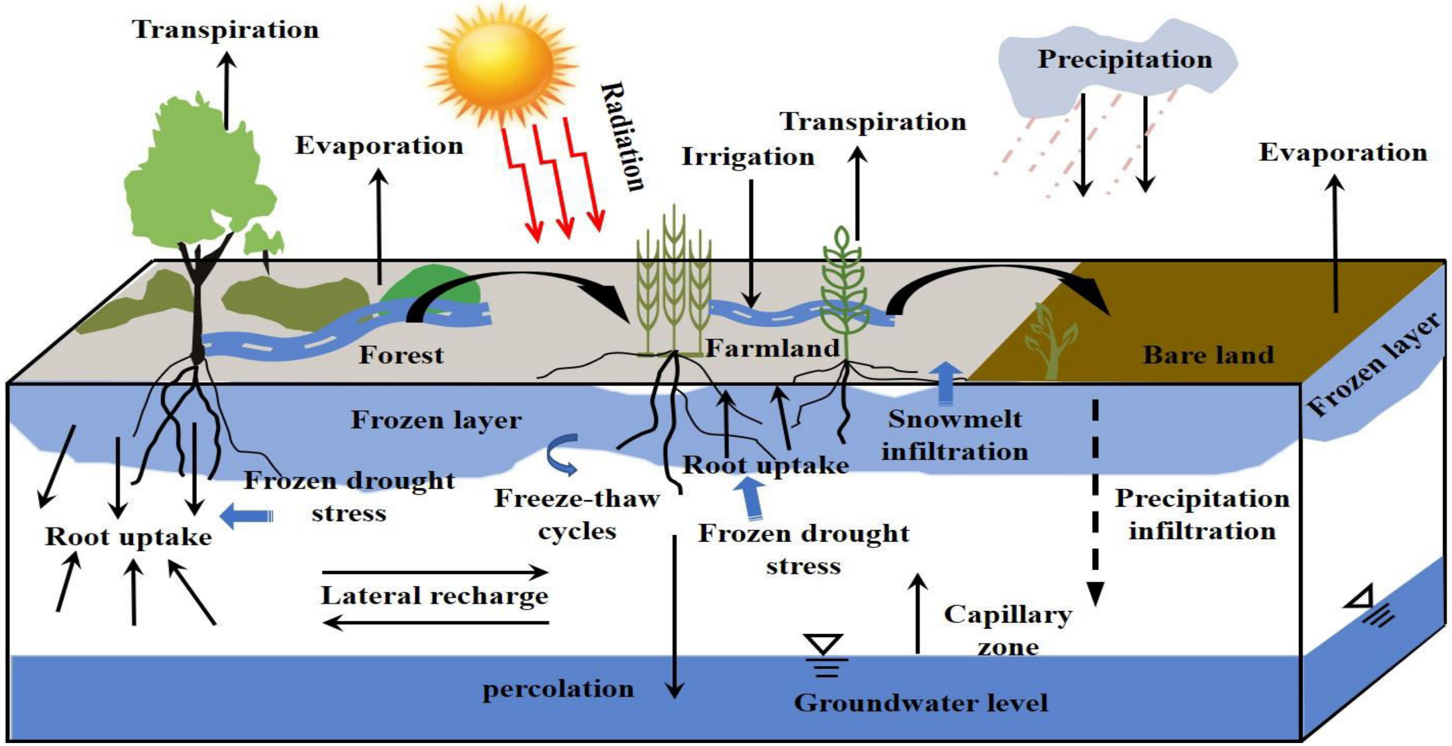
Distribution of frozen soil in China

- China has been reported as the third largest country worldwide in terms of frozen soil distribution area, of which approximately **72%** of the territory has been taken up by permafrost and seasonal frost

- The freeze-thaw process in cold regions, which lead to numerous problems in **environmental** and **engineering** areas, has been drawing increased attention and research interest

Since most of the regions with seasonally frozen soil belongs to arid and semi-arid areas, the effect of water vapor on soil water transfer should be considered

Research Background



Conceptual model of hydrological processes in frozen soil regions

When soil is frozen, liquid water, ice, and water vapor coexisted in soil pores. Under the effect of freeze-thaw process, soil water and heat transport was completely different from the non-freezing period.

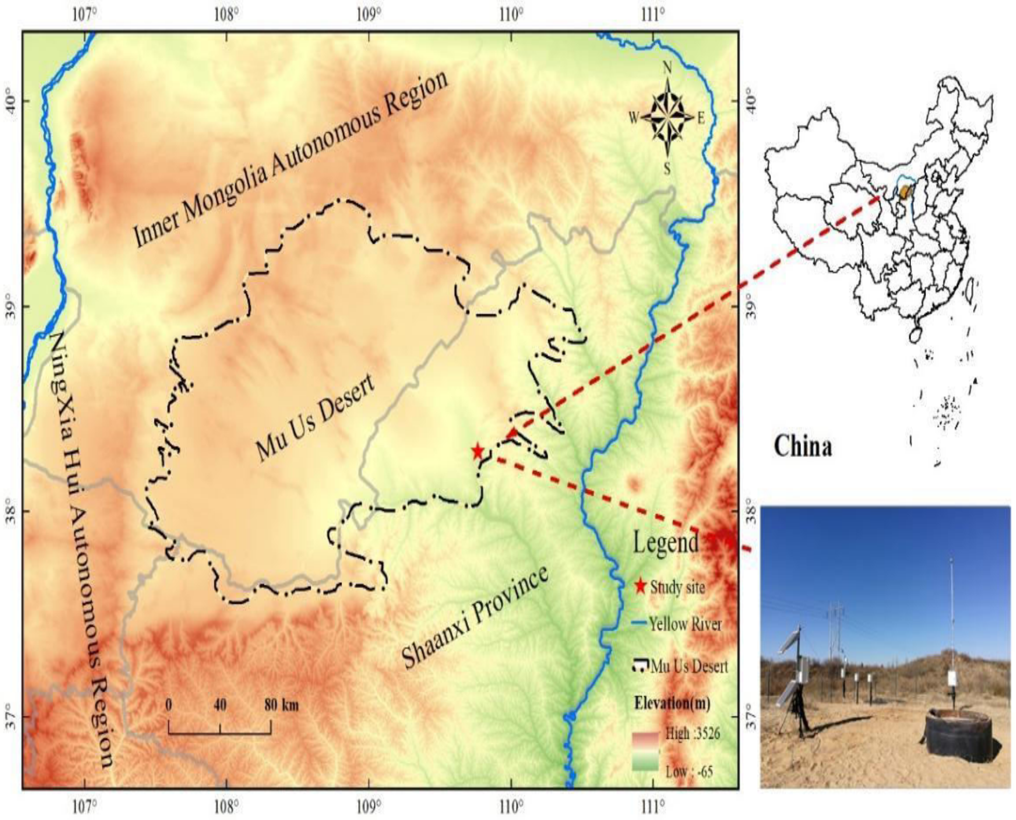
Current Research

* Stability and applicability of numerical models need to be improved

* Understanding of water vapor monitoring and its transport mechanism are insufficient

Investigating the mechanism of soil water transport in seasonally frozen soil areas not only helps to deepen water cycle theory, but also provides technological support for ecological environment protection and vegetation restoration

Research Methodology



Location of the research area

The Mu Us Sandy Land, one of the four largest sandy lands in China, locates between the Loess Plateau and Ordos Plateau and belongs to **a typical seasonally frozen region**. Climate feature of this region can be defined to be cold and dry, **with the average annual precipitation and air temperature of approximately 419 mm and 9.1 °C**. Generally, soil begins to freeze from November and lasts till March of the following year, **with a maximum frost depth of over 1 m**.

Methods:

In-situ observation, field and laboratory experiments, numerical simulation

Research Methodology

CHANG'AN UNIVERSITY

1. In-situ Observation

The in-situ observation site is selected in the southeast of the Mu Us Sandy Land, located in Yulin Desert Ecological Station of the State Forestry Administration (38°23′ N, 109°42′ E).

At the study site, a typical soil profile is set as the research object. Soil samples at different depths in this profile. The **Hydra Probe II sensors** were installed horizontally at 10, 50, 100, 200, 400, and 630 cm below the surface to observe changes in soil temperature and moisture.

Instrument layout of the study site

Research Methodology

2. Filed and Laboratory Experiments

(1) Measuring soil physical properties

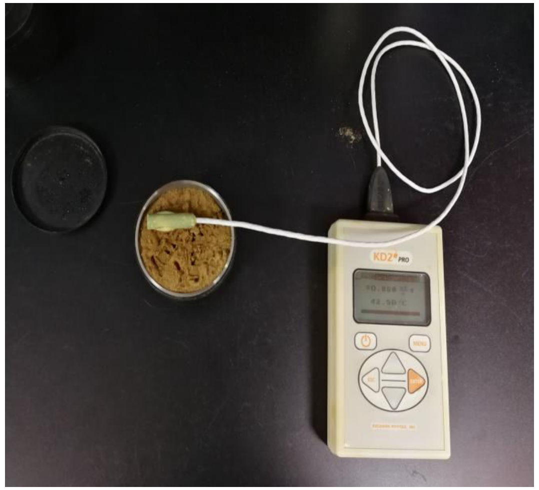
(2) Measuring soil relative humidity

(3) Calibrating sensors

(4) Measuring soil hydraulic parameters

(5) Measuring soil thermal parameters

(6) Measuring the total water content during freezing period



Research Methodology

3. Numerical Simulation (Coupled water-vapor-heat movement theory)

Water flow equation:

$$\frac{\partial\theta_l}{\partial t}+\frac{\rho_v}{\rho_l}\frac{\partial\theta_v}{\partial t}+\frac{\rho_i}{\rho_l}\frac{\partial\theta_i}{\partial t}=\frac{\partial}{\partial z}\left[K_{lh}\frac{\partial h}{\partial z}+K_{lh}+K_{lT}\frac{\partial T}{\partial z}+K_{vh}\frac{\partial h}{\partial z}+K_{vT}\frac{\partial T}{\partial z}\right]\text{-}S$$

Heat transport equation:

$$\frac{\partial C_pT}{\partial t}-L_f\rho_i\frac{\partial\theta_i}{\partial t}+L_0\frac{\partial\theta_v}{\partial t}=\frac{\partial}{\partial z}\left(\lambda\frac{\partial T}{\partial z}\right)-C_w\frac{\partial q_lT}{\partial z}-C_v\frac{\partial q_vT}{\partial z}-L_0\frac{\partial q_v}{\partial z}-C_wST$$

Soil Freezing curve:

Based on the theory of thermodynamic equilibrium, the matric potential of soil could be estimated for subfreezing temperature by using the generalized Clapeyron equation:

$$h=\frac{L_f}{g}\ln\frac{T}{T_f}$$

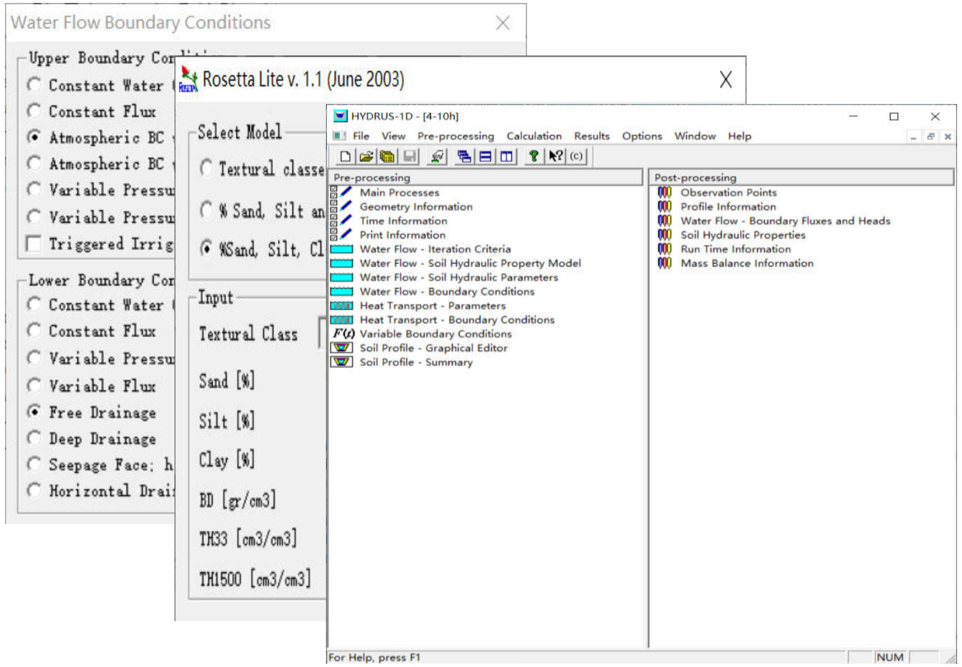
The relationship between liquid water content and temperature can be expressed as:

$$\theta_l=\theta_r+\frac{\theta_s-\theta_r}{\left[1+\left|\alpha\left(\frac{L_f}{g}\ln\frac{T}{T_f}\right)\right|^n\right]^m}$$

Research Methodology

(1) Non-freezing Period:

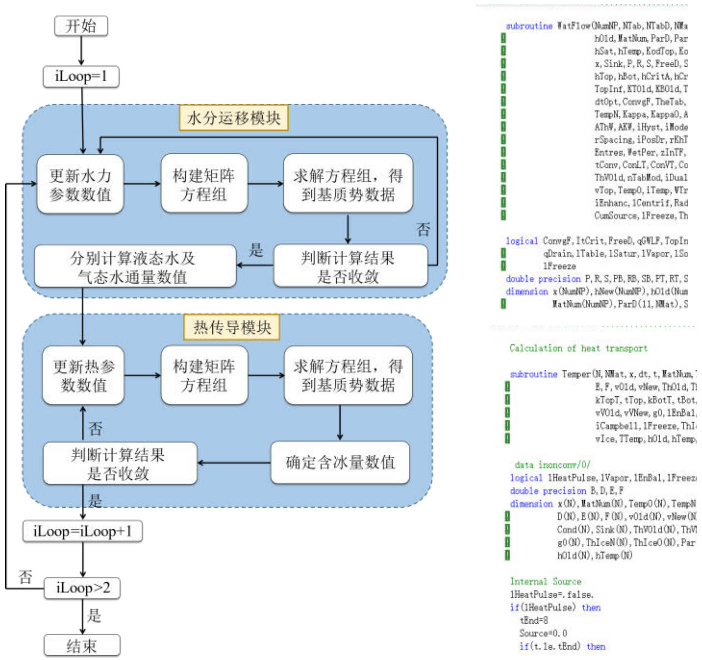
The coupled water, vapor, and heat transport model is established using the Hydrus-1D software



Interface of the Hydrus-1D software

(2) Freezing period:

Based on the theory, the code is revised in Fortran language and incorporated into the standard Hydrus-1D code.



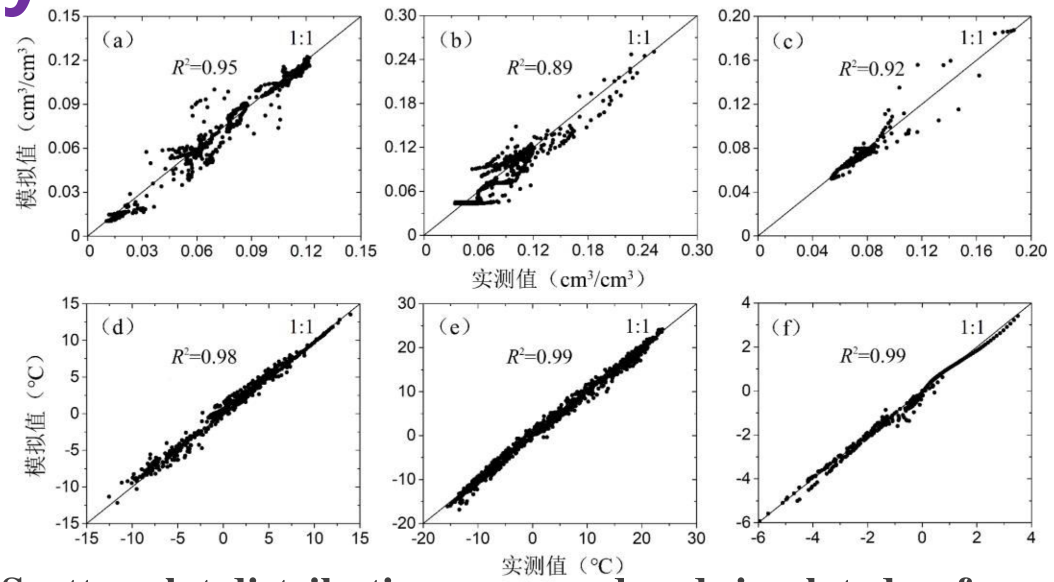
Flowchart of the revised calculation program

Major Findings

1. Model accuracy and applicability

Comparison of different sites

	榆林	锡林郭勒	玛曲
纬度	38° 23′19″ N	43° 37′50″ N	33 30′~34° 15′ N
海拔	1157 m	1250 m	3200~4200 m
气候	寒冷干燥	寒冷干燥	寒冷干燥
月最低温度	-9.5~-12 ℃	约为-20 ℃	约为-10 ℃
土壤质地	砂土	砂壤土	砂壤土
地下水位	8.5~10 m	约30 m	8.5~12 m
水分传感器	Hydra Probe II	ML2x probes	5TM ECH2O probes



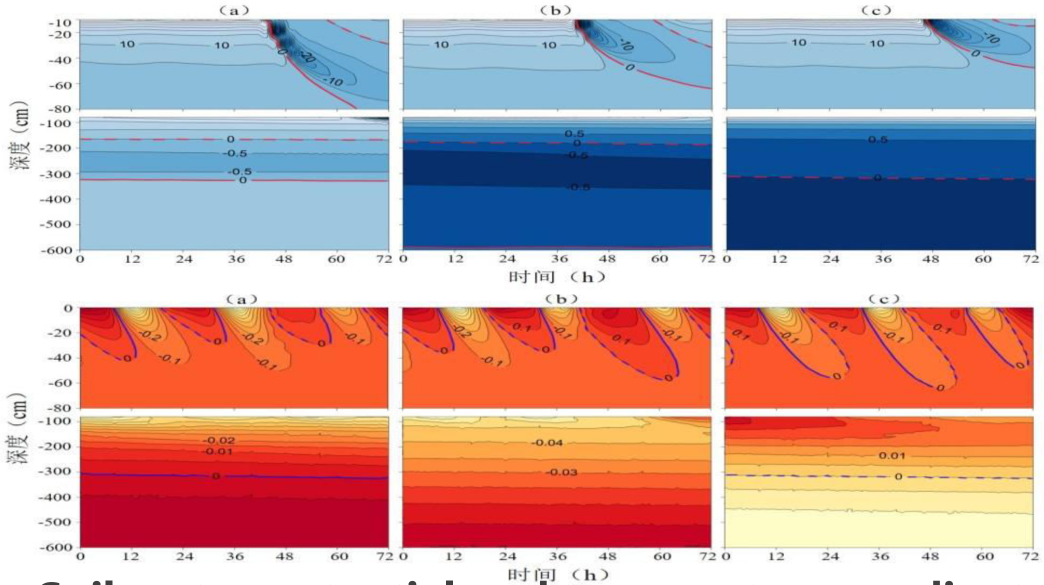
Scatter plot distribution measured and simulated unfrozen water content and soil temperature at different sites

The proposed model overcomes the numerical calculation problems caused by the phase transition process between ice and water, and can obtain stable and accurate numerical solutions. Simulation results proved that the proposed model has high accuracy and applicability.

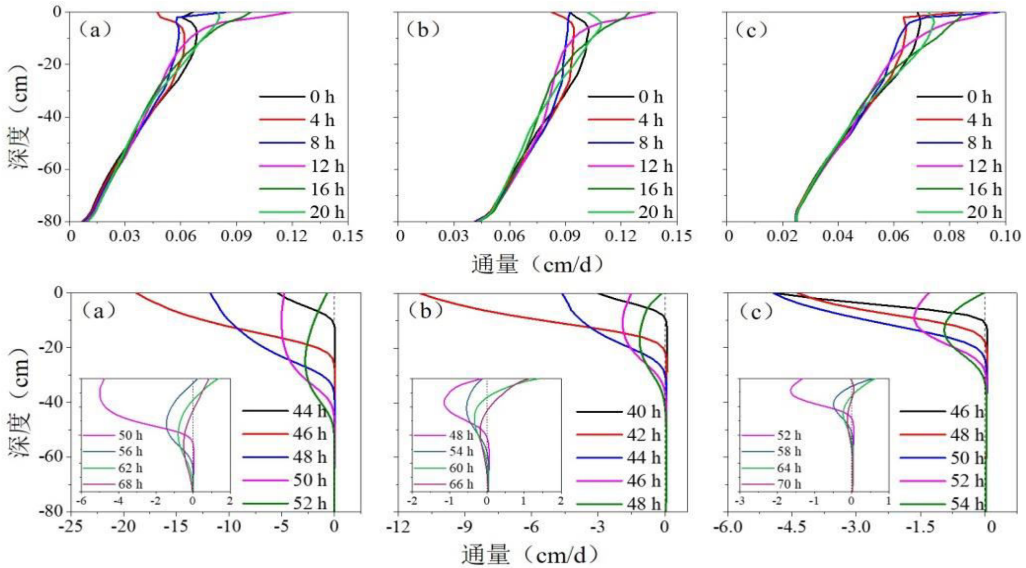
Major Findings

CHANG'AN UNIVERSITY

2. Mechanism of soil water movement



Soil water potential and temperature gradients



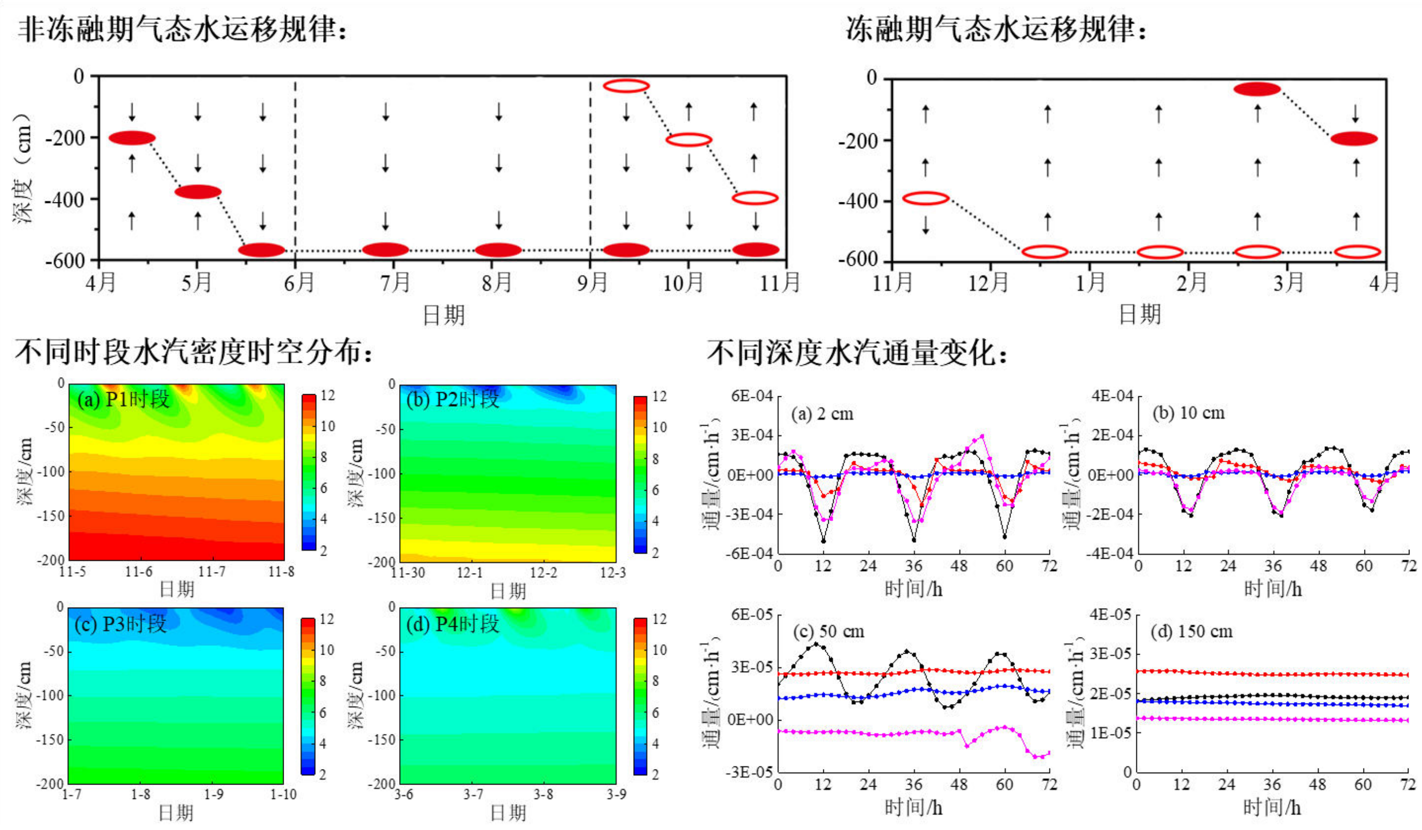
Calculated water flux under dry and wet conditions

Driven by soil water potential and temperature gradients, isothermal and thermal liquid and vapor fluxes changes greatly under different conditions. Results indicated that the model considering coupled water-vapor-heat transport is not only suitable for the field situation, but also conducive to understanding the water cycle mechanism of the vadose zone

Major Findings

CHANG'AN UNIVERSITY

3. Characteristics of water vapor and its influencing factors

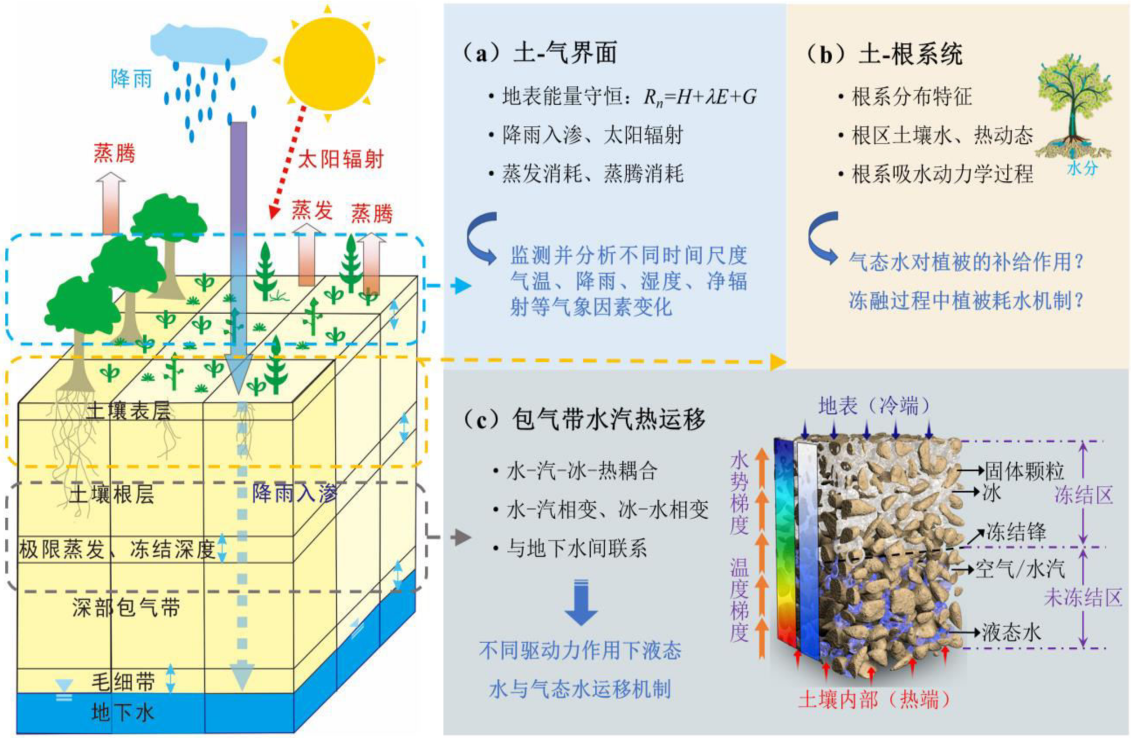


Migration of vapor transfer during different periods and the variation of vapor density and flux

By investigating the driving forces for vapor transfer, the variation pattern and importance of water vapor flux in arid sandy land under both freezing and non-freezing conditions were explored

Future Research Plan

On the basis of clarifying the soil water cycle process, we will focus on the coupling system of "soil-vegetation-atmosphere" in sandy land, and conduct research on the water cycle of typical vegetation system during both the dormancy (freeze-thaw period) and growth (non freeze-thaw period) seasons

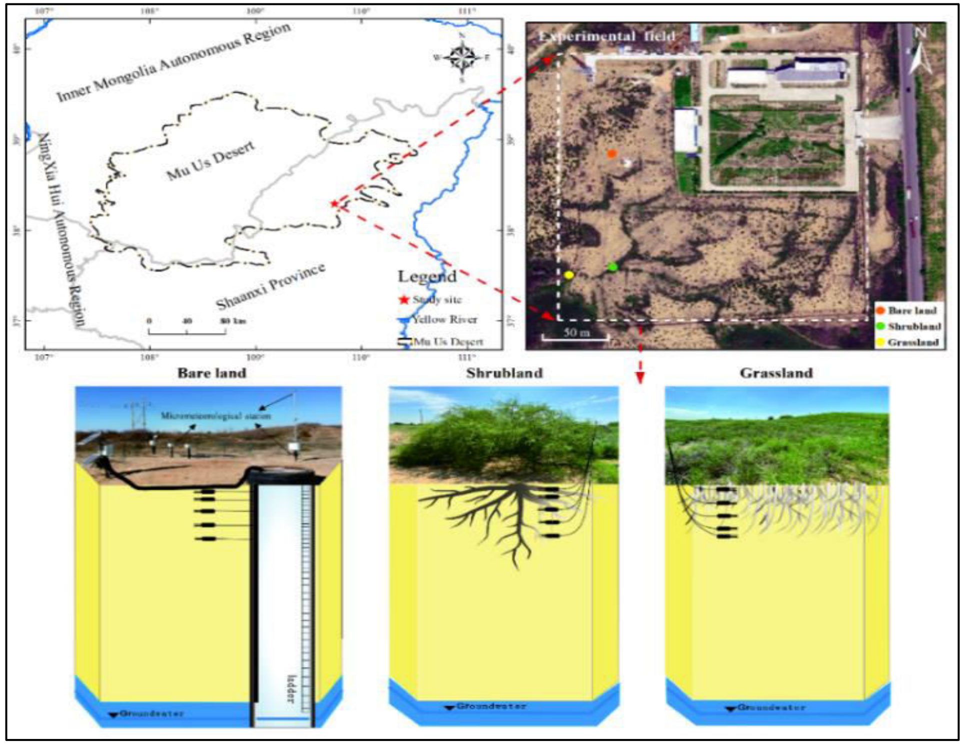


Schematic diagram of the interconnection in "soil-vegetation-atmosphere" system

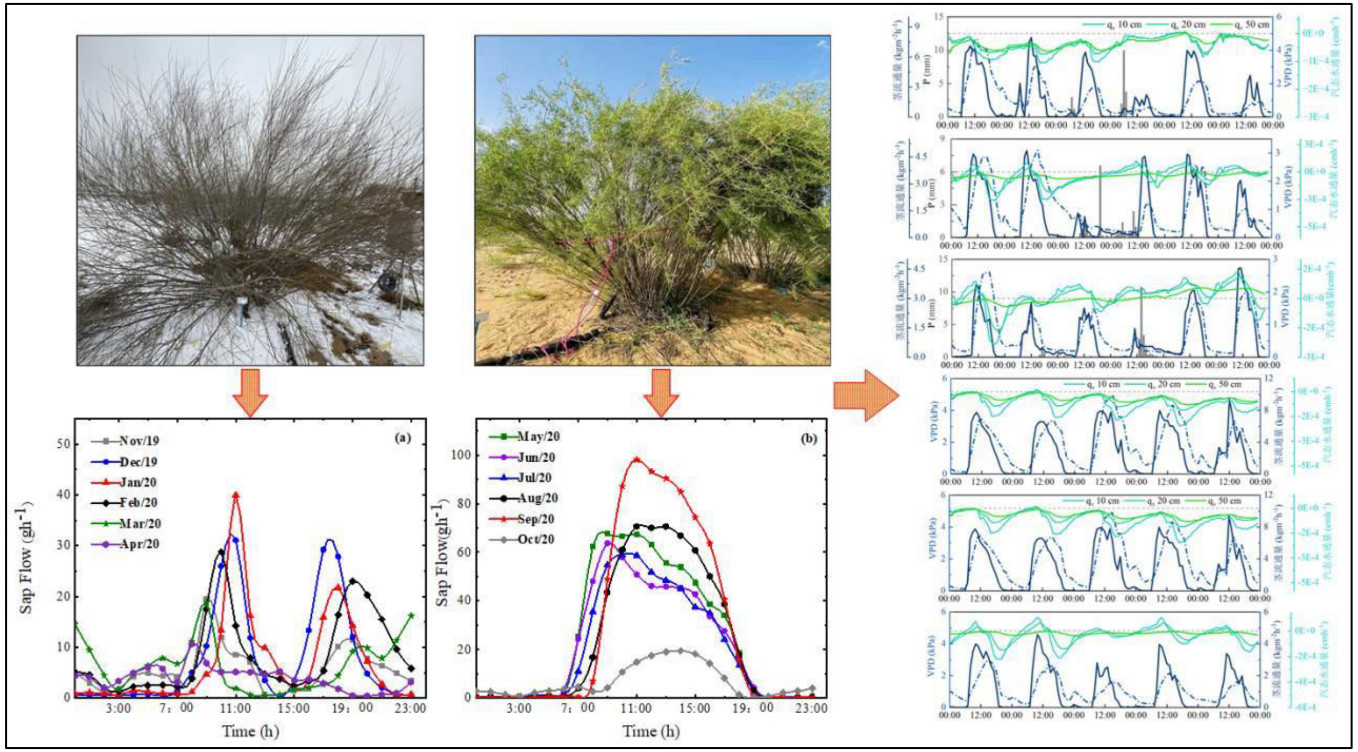
By exploring the mechanism of liquid water and vapor transfer in the vadose zone under the influence of vegetation in the seasonally frozen soil area and the ecological effect of soil water resources, the ecological carrying range of water resources is defined, and can provide scientific support for vegetation restoration in ecologically fragile areas.

Future Research Plan

By establishing in-situ monitoring sites for shrublands and grasslands, we preliminarily analyzed the water consumption characteristics of vegetation.



Location and land type of the test sites



Sap flow patterns of *Salix psammophila* during freeze-thaw and non freeze-thaw periods

Thanks for your attention!

Ce Zheng

Chang’an University

zhengce@chd.edu.cn