Monitoring and modeling of cold region hydrological process in a Third Pole high mountain river basin

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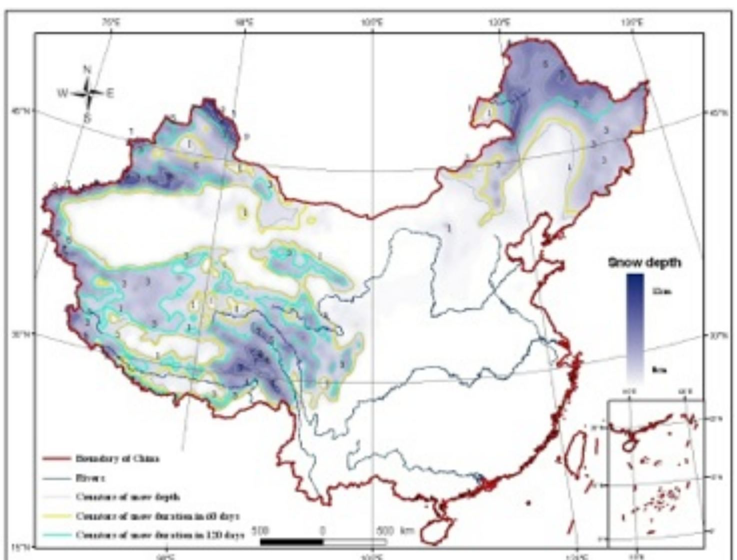
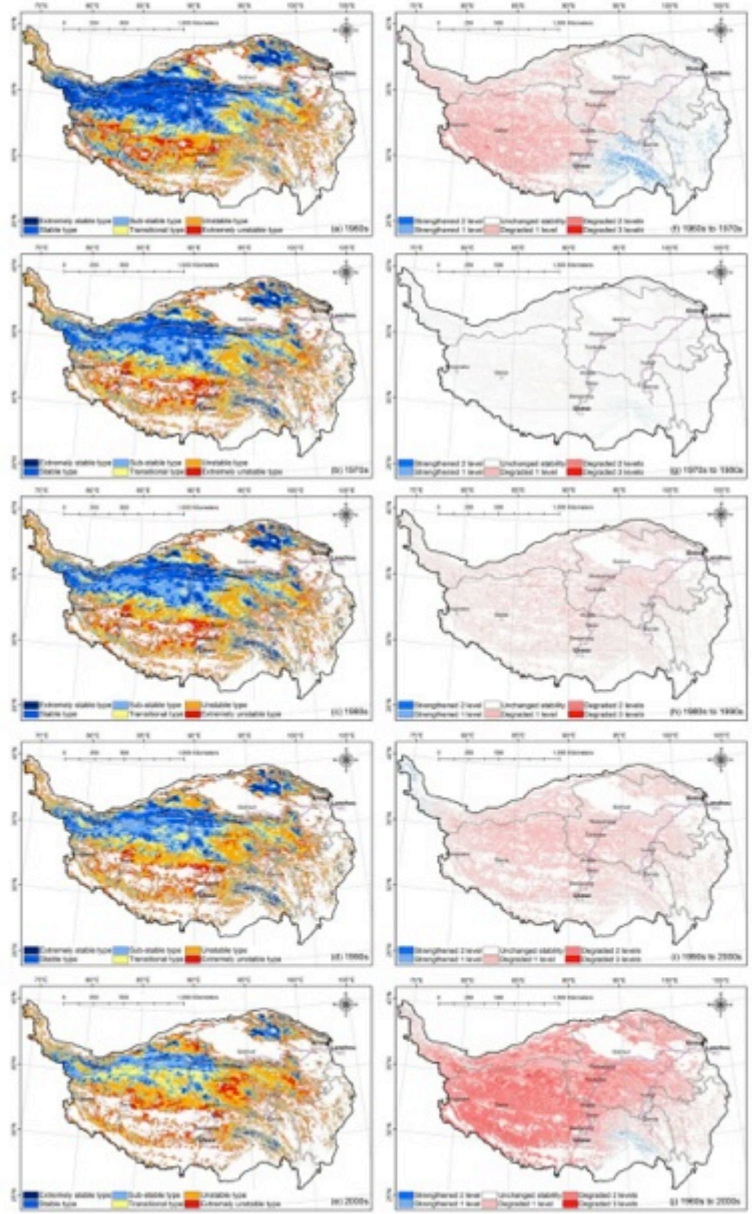
Contents

1. Background

Cryosphere change is accelerating over the Third Pole





Li et al., 2008, GPC; Che et al., 2008, Annals of Glaciology; Ran et al., 2012, PPP; Ran et al., 2017, TC

Inconsistent understanding of how climate change influences hydrological cycles (**tipping point, seasonality, attributions, future trend**) in third pole river basins □

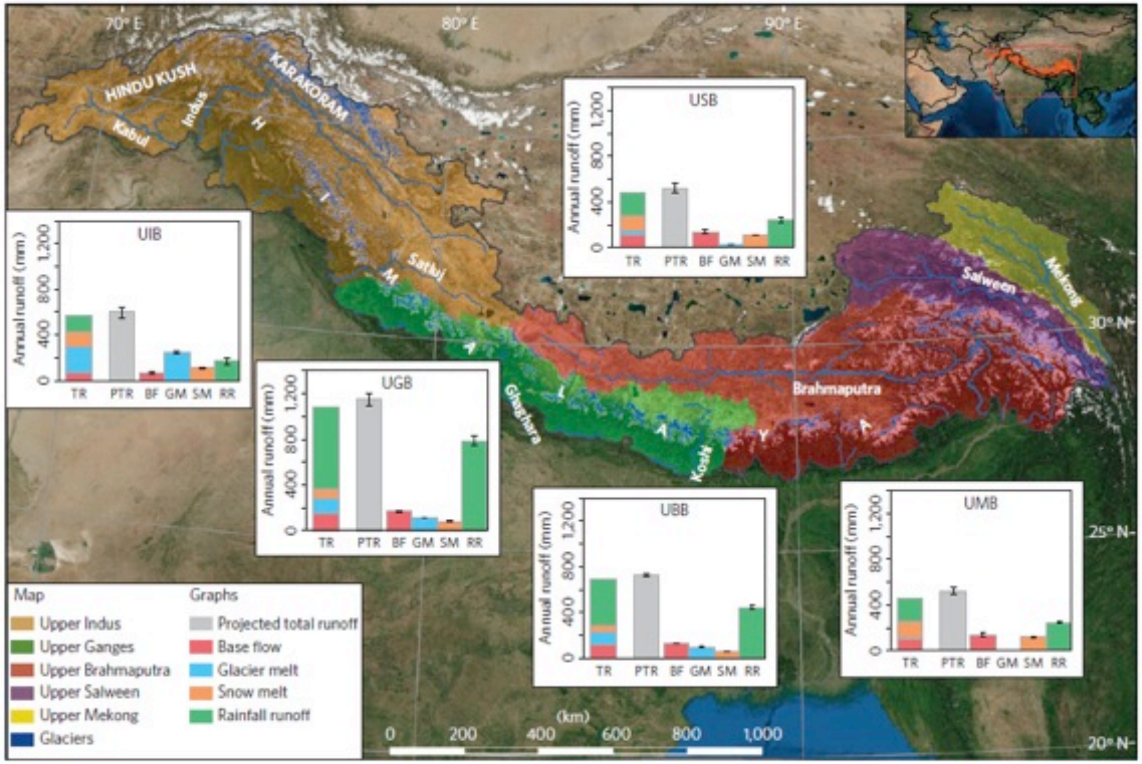
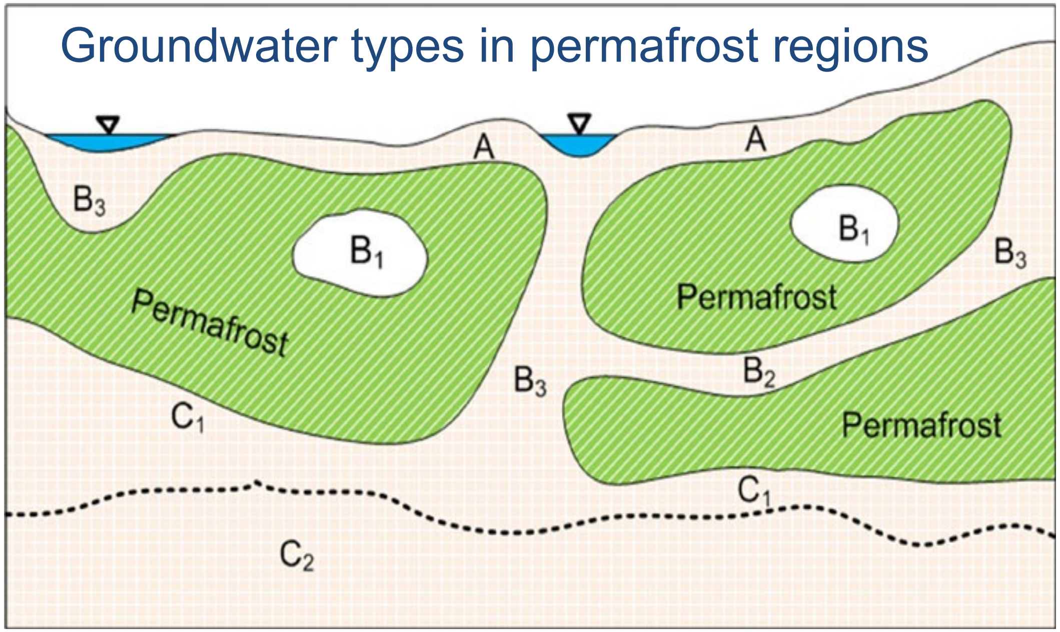


Figure 1 | The upstream basins of Indus, Ganges, Brahmaputra, Salween and Mekong. Bar plots show the average annual runoff generation (TR) for the reference period (1998–2007, REF: first column). The second column shows the mean projected annual total runoff (PTR) for the future (2041–2050 RCP4.5) when the model is forced with an ensemble of 4 GCMs. In the subsequent columns, PTR is split into four contributors (BF: baseflow, GM: glacier melt, SM: snow melt, RR: rainfall runoff). Error bars indicate the spread in model outputs for the model forced by the ensemble of 4 GCMs.

Lutz, A. F., Immerzeel, W. W., Shrestha, A. B. and Bierkens, M. Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation. Nature Climate Change 4, 587-592 (2014). □

Change of permafrost and its hydrological effects



A: supra-permafrost water, B: in-permafrost water, C: sub-permafrost water

- Deeping of active layer: more water storage
- Saturated ice: release more liquid water
- Open talik channels: Surface water percolates to deep layer
- Thermalkarst: more water storage at the surface

Cheng and Jin, 2013, Hydrogeology Journal

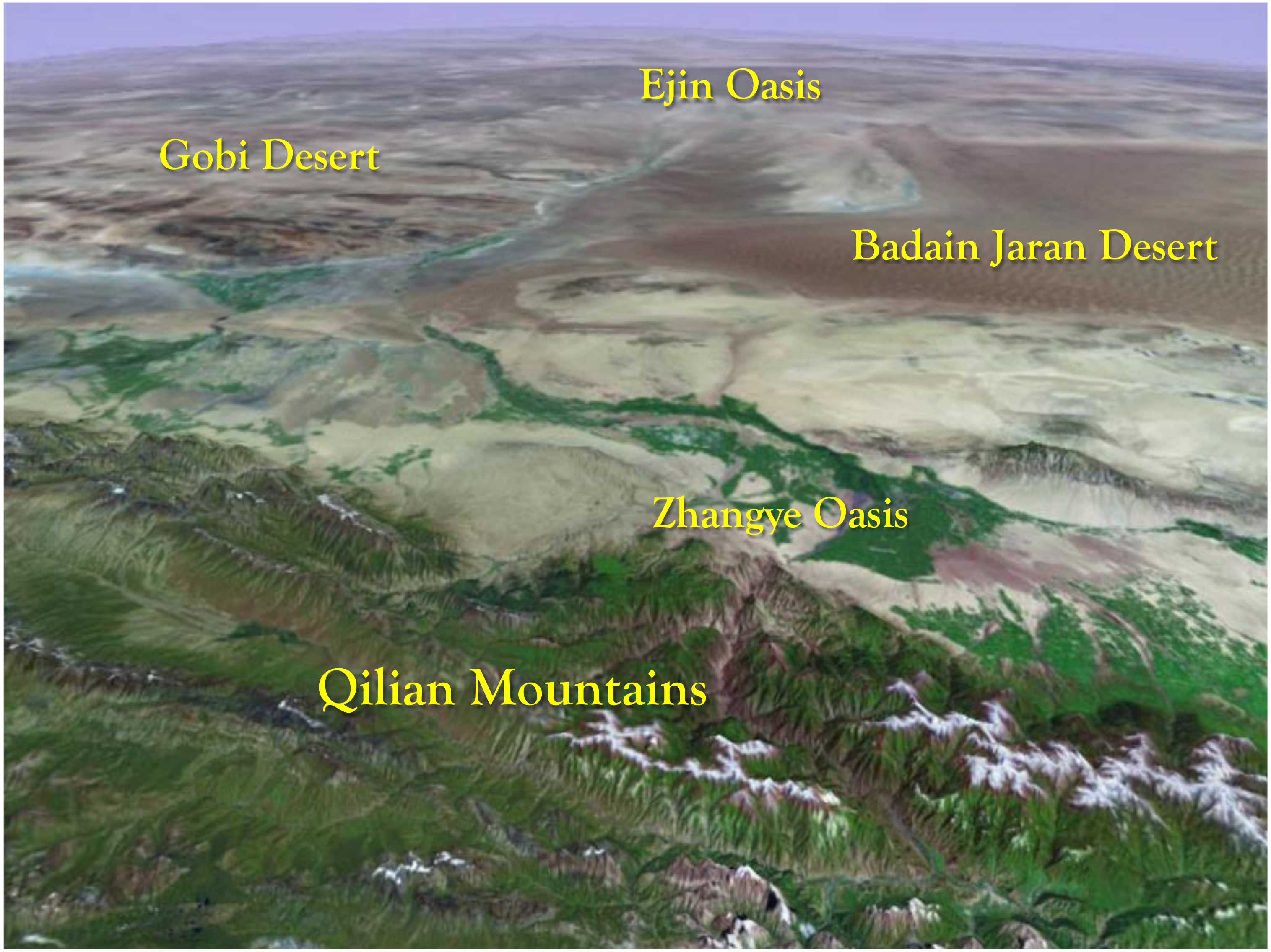
Challenges

- In situ observation of precipitation is usually underestimated by 15~30% in cold regions due to wind-induced errors; areal estimation of precipitation is also largely uncertain.
- Estimation of permafrost contribution to hydrological cycle is very difficult.
- “The volume, vulnerability and likely lifespan of the HMA ice reserve is therefore a matter of considerable speculation” (Pritchard, 2017).
- Closing water balance at river basin scale still a speculation.

Actions

- Therefore, there is an urgent requirement to carry out a synthesis of the hydrological cycle at an experimental river basin by using integrated models in combination with various high quality data including remote sensing products.
- Eventually, knowledge of the hydrological cycle obtained from the testbed river basin is expected to be transferrable to other Third Pole basins.

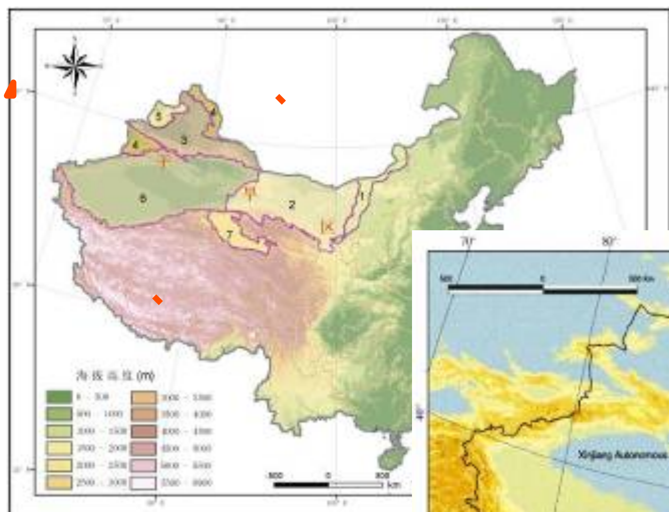
2. Geographic context of the Heihe River Basin: Mountain cryosphere, oases and deserts

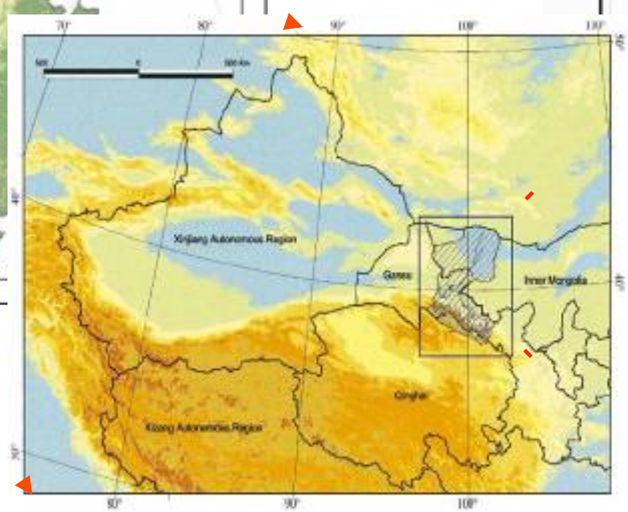


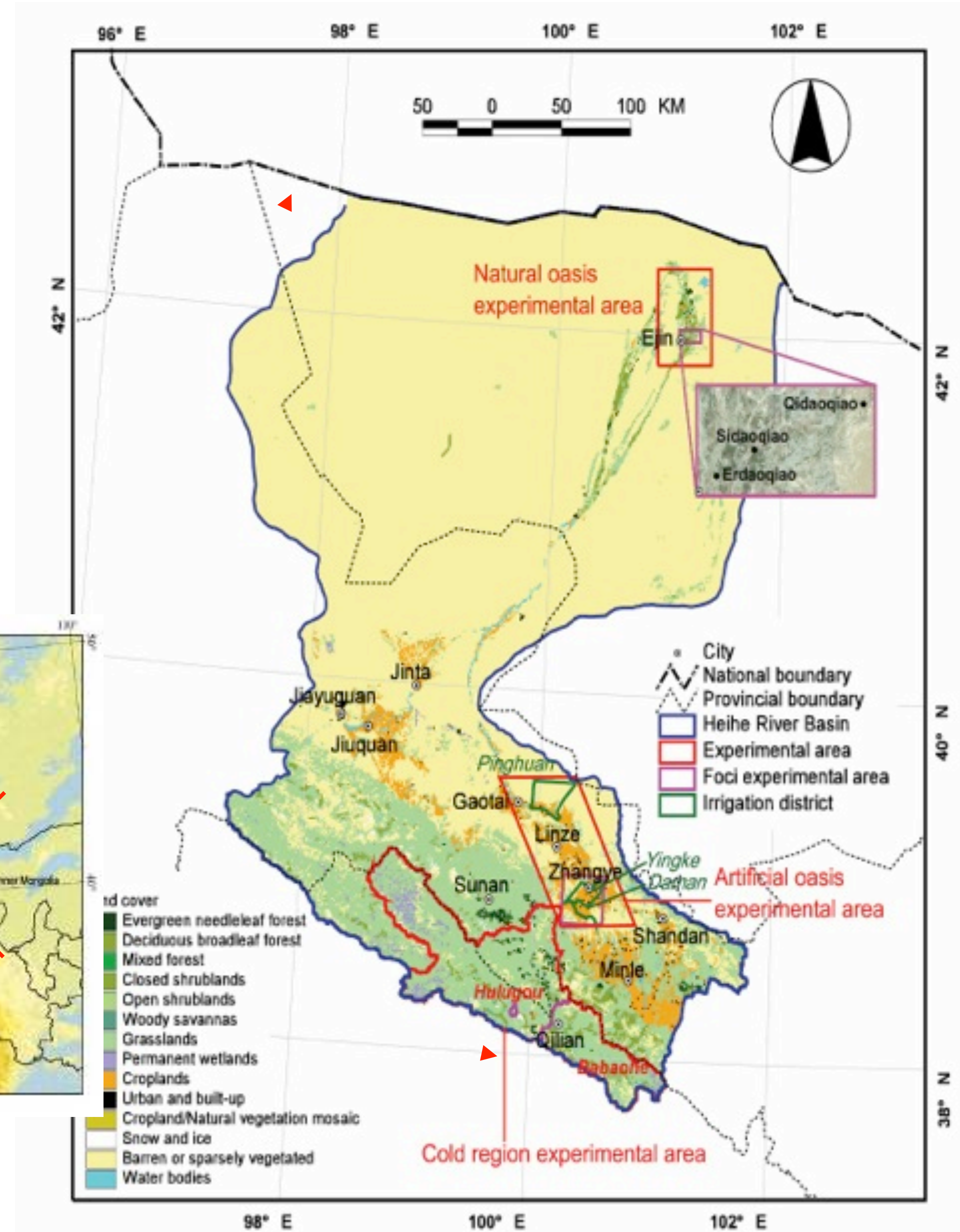
Cheng, Li, Zhao, Xu, Feng, Xiao, Xiao, National Science Review, 2014

Heihe River Basin: a test bed

HRB, a well-instrumented experimental river basin with a lot of integrated eco-hydrological modeling work.







HiWATER

Integrated study of the water-ecosystem-economy in the **Heihe River Basin**

1980s, HEIFE, comprehensive expeditions to the HRB

1990s, rescuing the Ejin oasis initiative, ecological water diversion project, digital Heihe River Basin

2004-2010, Integrated modeling initiative, WATER project, pilot project on ecosystem rehabilitation

2010, Heihe Major Research Plan launched

2014 and beyond, …

REVIEW

National Science Review
00: 1–16, 2014
doi: 10.1093/nsr/nwu017
Advance access publication 0 2014

ENVIRONMENT/ECOLOGY

Integrated study of the water–ecosystem–economy in the Heihe River Basin

Guodong Cheng, Xin Li*, Wenzhi Zhao, Zhongmin Xu, Qi Feng, Shengchun Xiao and Honglang Xiao

ABSTRACT

The ecological water diversion project in the Heihe River Basin is the first successful case in China in which the ecological systems in a river basin have been rescued. This project serves as a valuable example for the management of ecosystems in other inland river basins. This paper reviews the integrated studies of the water–ecosystem–economy relationship in the Heihe River Basin and concludes that sustainable development in inland river basins requires the basin to be considered as a whole, with the relationships between the upstream, midstream and downstream areas of the basin coordinated appropriately. Successful development in these basins will be reflected in an improved output per cubic meter of water and the implementation of integrated river basin management practices.

Keywords: Heihe River Basin, water–ecosystem–economy, integrated study, climate change, human activity, ecological water diversion

INTRODUCTION

Inland river basins in northwestern China exhibit alternating high mountains and basins. The mountainous areas usually experience much more precipitation, snowmelt and glacier melt. These mountains, usually distributed in the upstream areas of river basins, are water production areas. The mid- and downstream areas of inland river basins, where precipitation is scarce, are water consumption areas. After runoff leaves the mountains and flows into a basin, it is the determining ecological factor for the inland river basin. Without water, the oases cannot survive and become desertified. However, too much water results in salinization. For thousands of years, humans have lived in inland river basins, where sufficient water has been available to support grazing and agriculture, and people have altered the landscape to support thriving communities. However, in recent decades, many of the inland river basins in China's northwestern arid region have experienced a common challenge. With the population booming and the rapid economic development in the up- and midstream areas of the river basins, the consumption of water increases dramatically and diminishes the water available for ecological processes. The terminal lakes dry up, sandstorms become more common and the *Populus euphratica* forests die, causing a series of severe ecological disasters [1]. Similar to the Heihe River Basin (HRB), the competition for water between economy and ecosystem is also getting more intense in other inland river basins all over the world, e.g. the Aral Sea basin [2] and the Tarim River Basin [3] leading to a 'Tragedy of the Commons' problem [4]. In all of these cases, the water, the ecosystem and the economy are closely interrelated. Therefore, the solution to this problem must involve the careful and rational use of the limited water resources in such a way that not only supports economic development but also sustains the health of the ecosystems [1].

The HRB is located in the middle part of the Hexi corridor in the arid region of northwestern China (Fig. 1). The HRB is the second largest inland river basin and is representative of all of the inland river basins. At the end of the 20th century, an ecological water diversion project (EWDP) was successfully implemented by the central government of China, and as a result, the severe deterioration of ecosystems in the downstream areas of the HRB has been greatly alleviated [5]. Numerous studies on the water, atmosphere, ecology and anthropogenic

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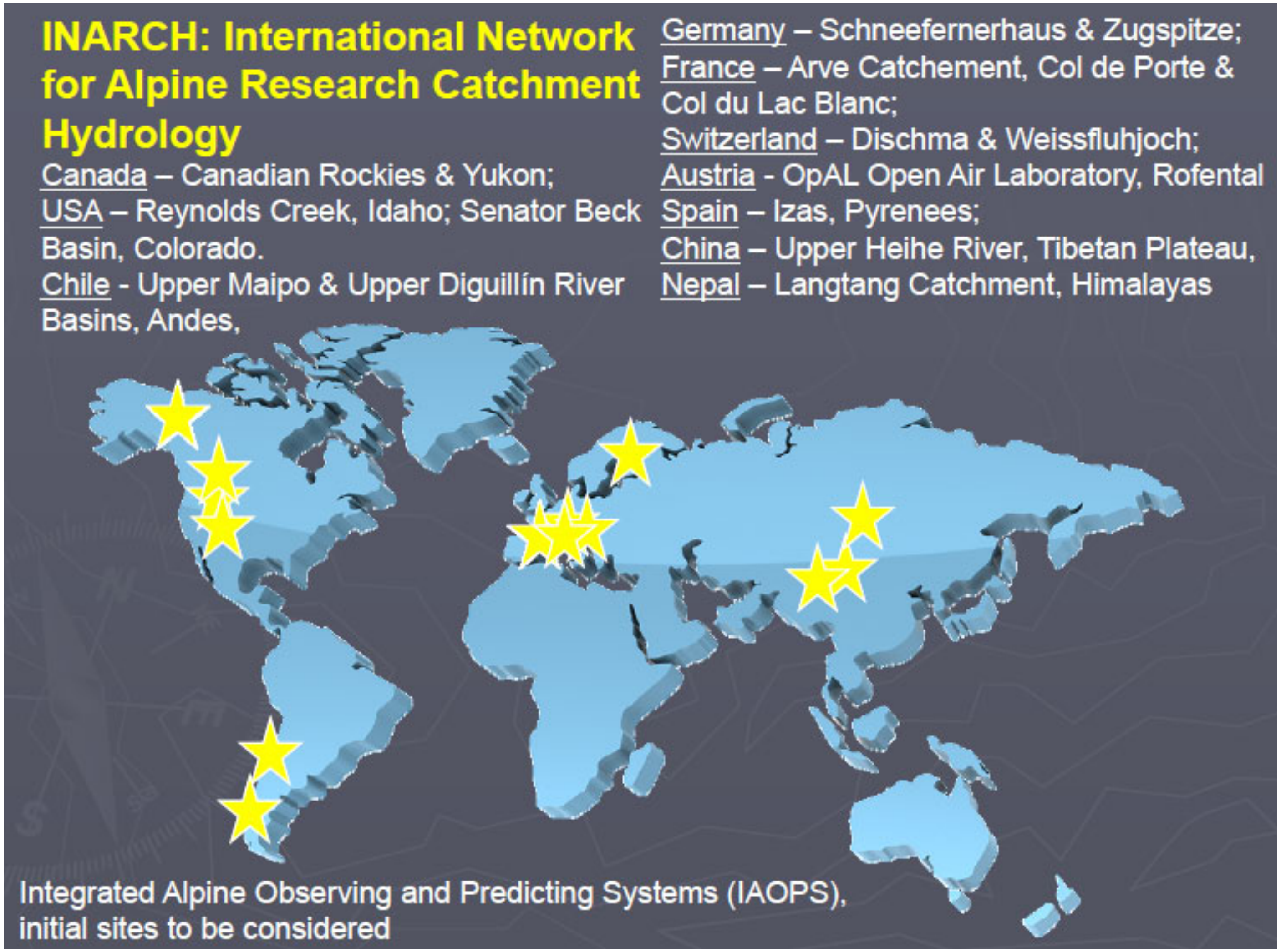
Cheng, Li, Zhao, Xu, Feng, Xiao, Xiao, National Science Review, 2014

Heihe Watershed Allied Telemetry Experimental Research (HiWATER) 2012-2016

- Flux observing matrix and an eco-hydrological wireless sensor network
- Heterogeneity, scaling, uncertainty and closing water cycle at the watershed scale.

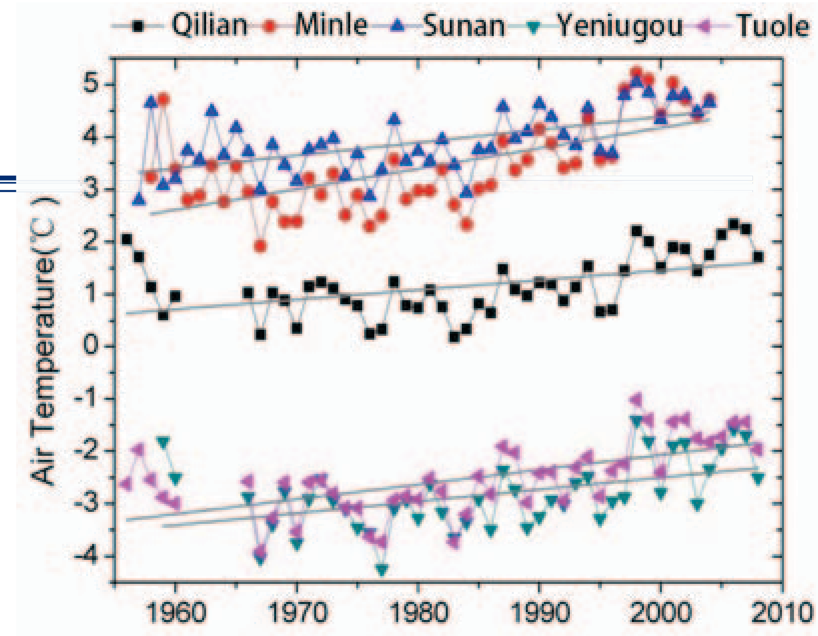
Li et al., BAMS, 2013

An INARCH catchment

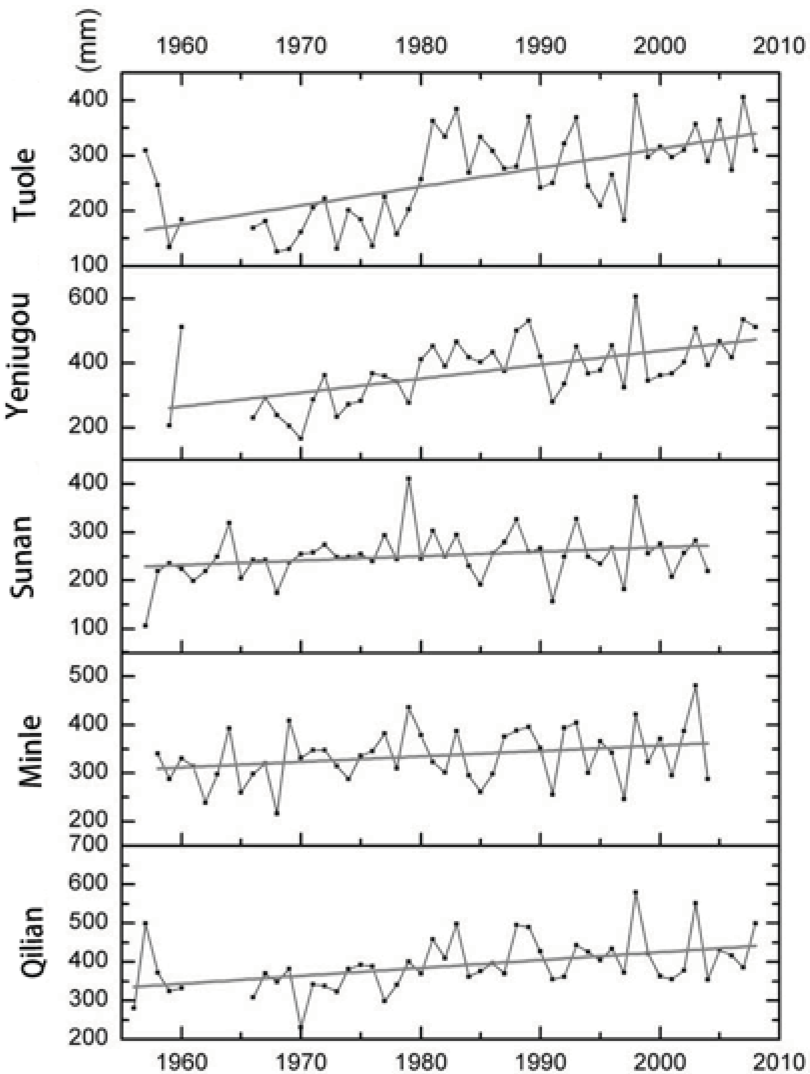


From Prof. John Pomeroy

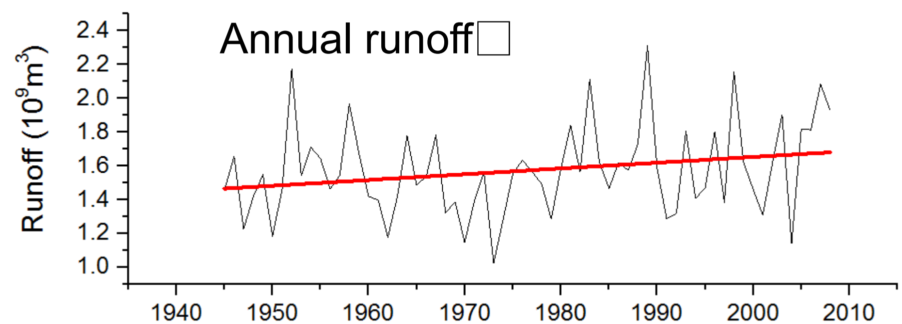
Climate change

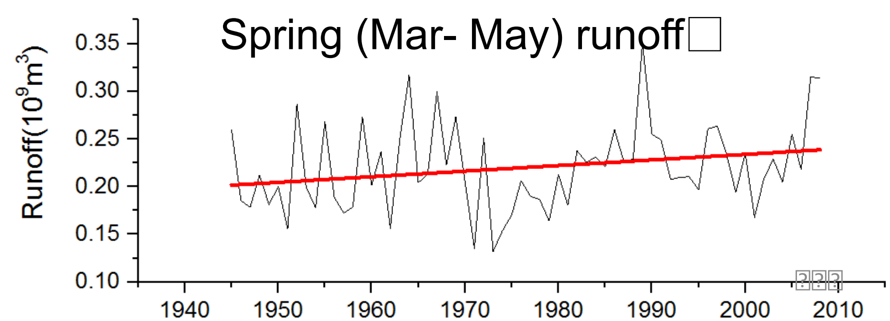


Air temperature

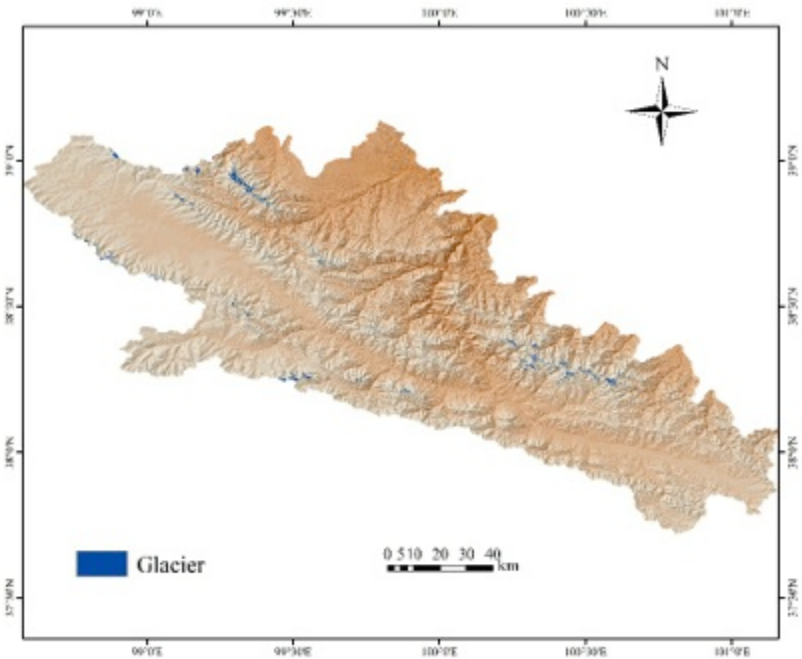


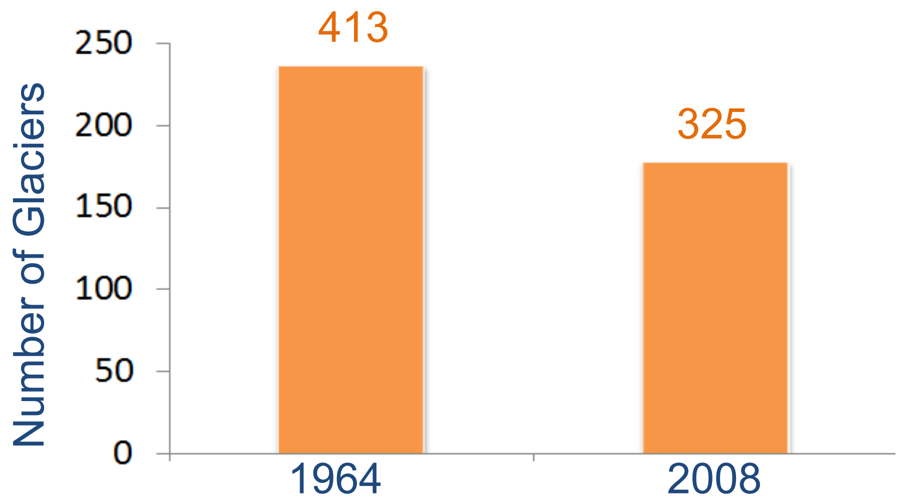
Precipitation

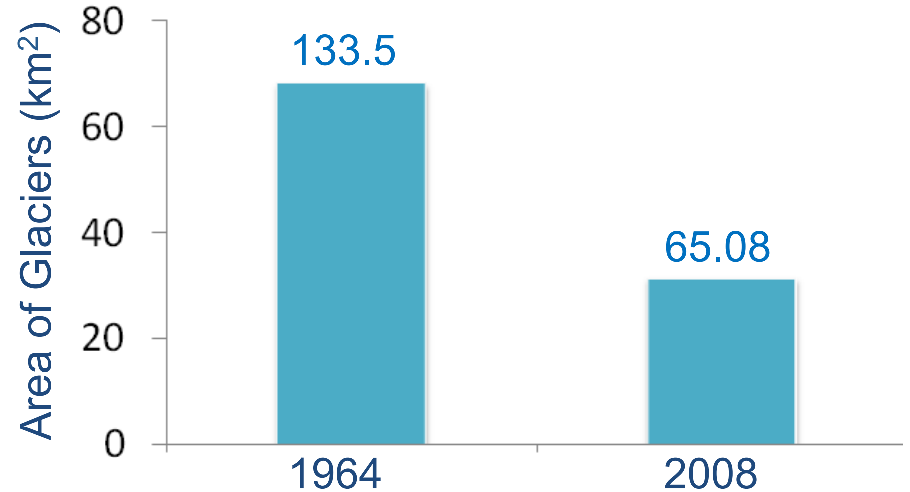




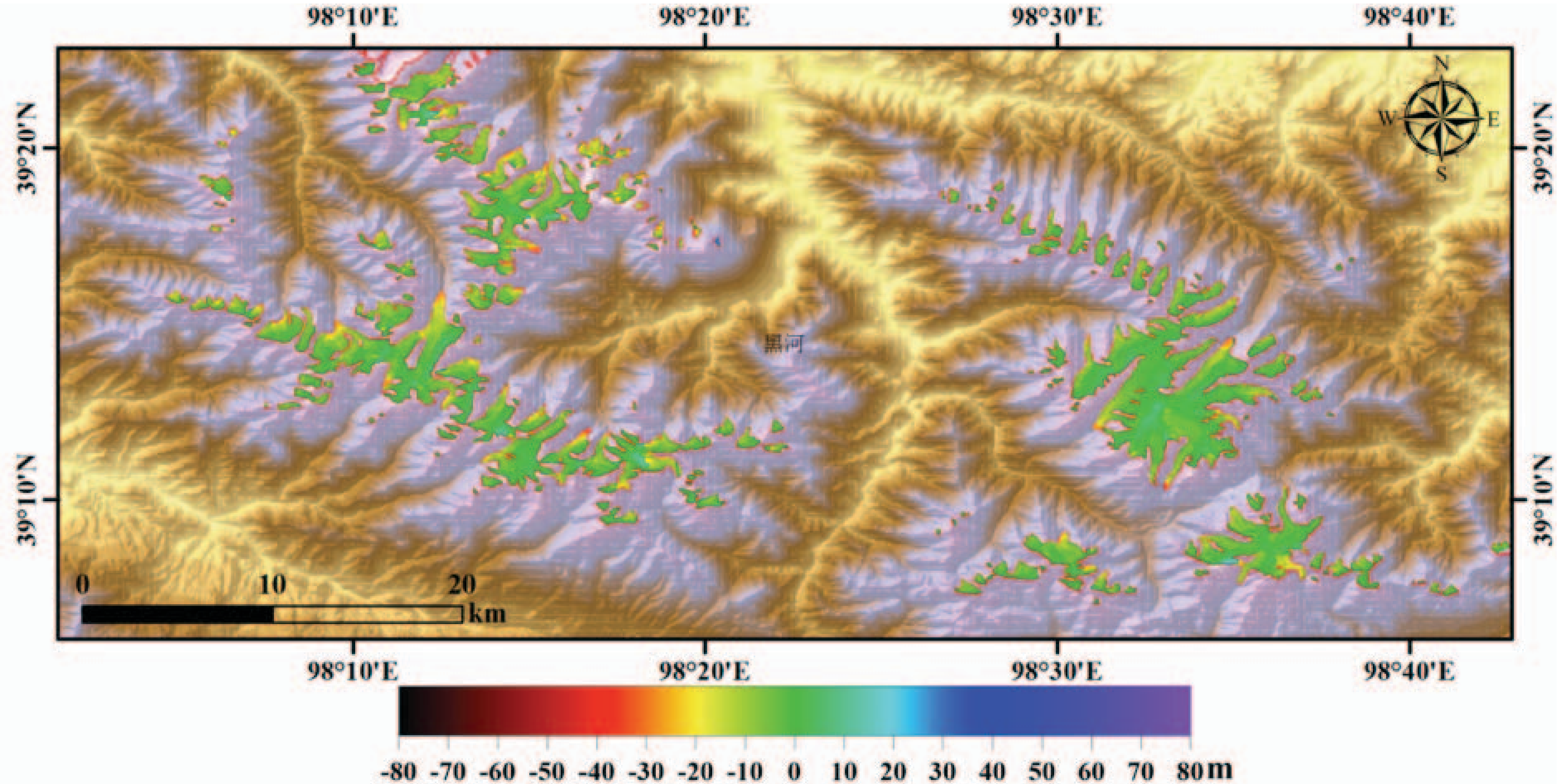
Observed cryospheric change: e.g., glaciers







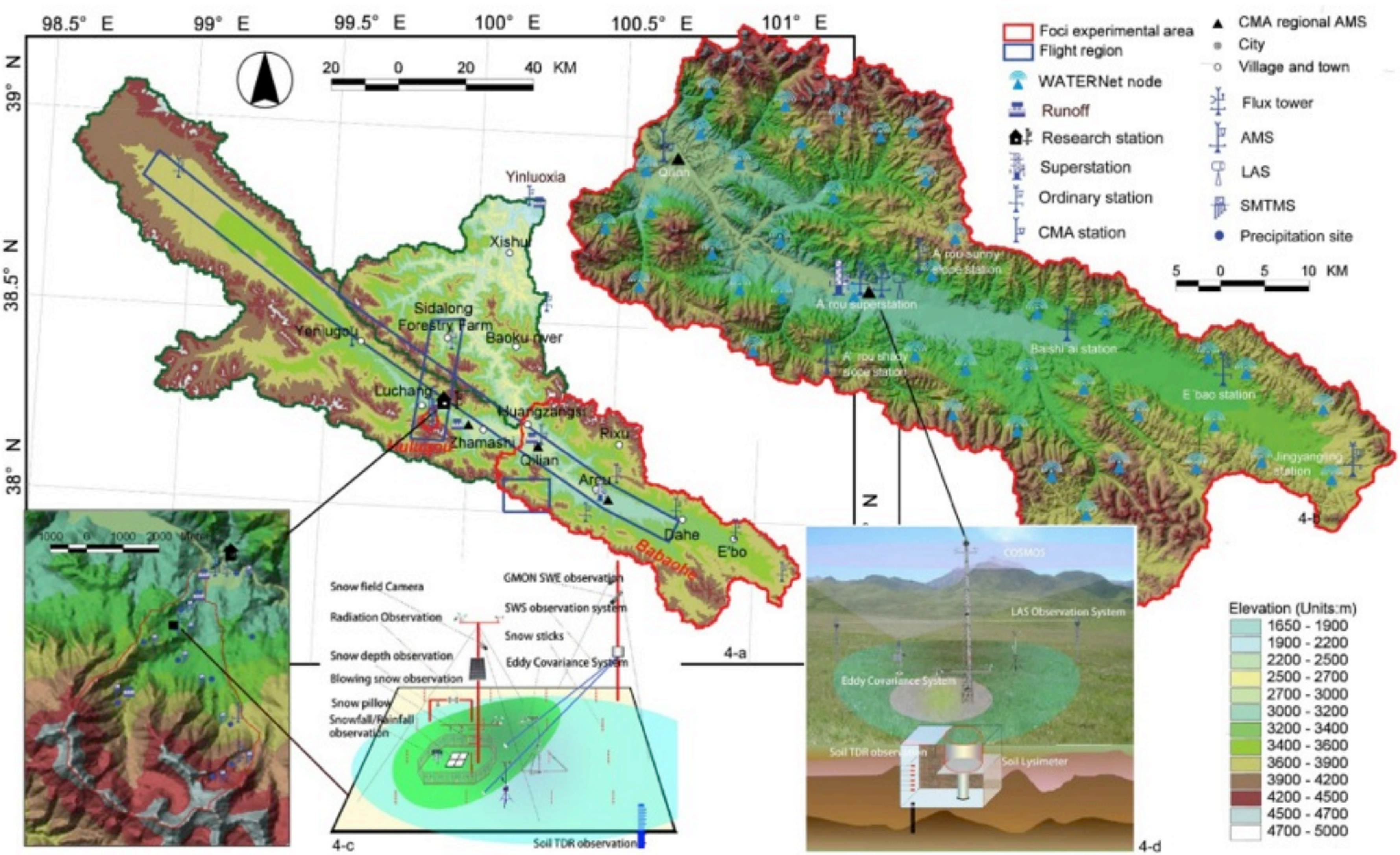
Observed glacier volume change: TanDEM-X DEMs - SRTM DEM



Thickness change is -5.07 m between 2000-2014.
The glacier area in this place is about 144.62 km^2.

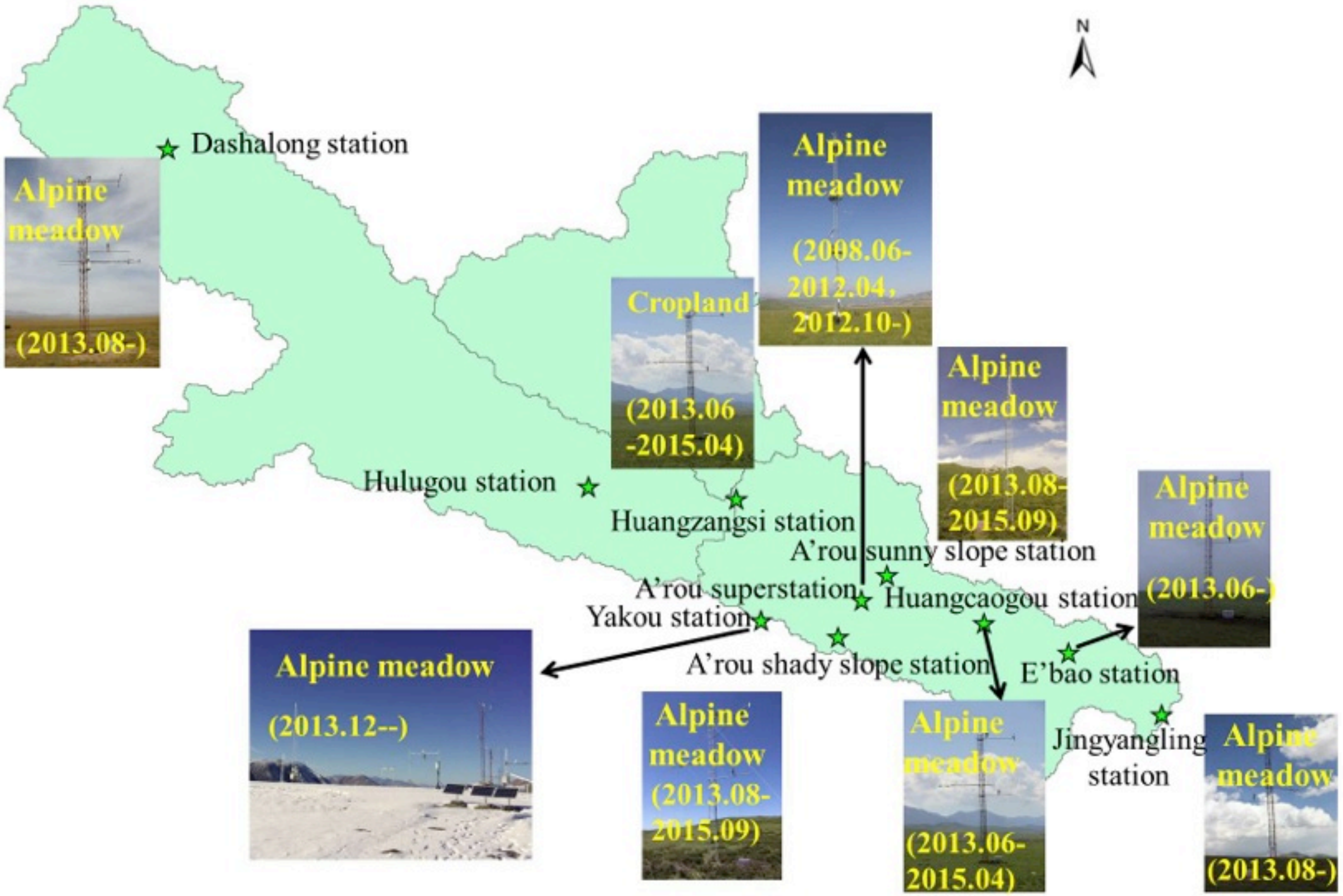
3. Multi-scale high mountain river basin observing system

Multi-scale high mountain river basin observing system

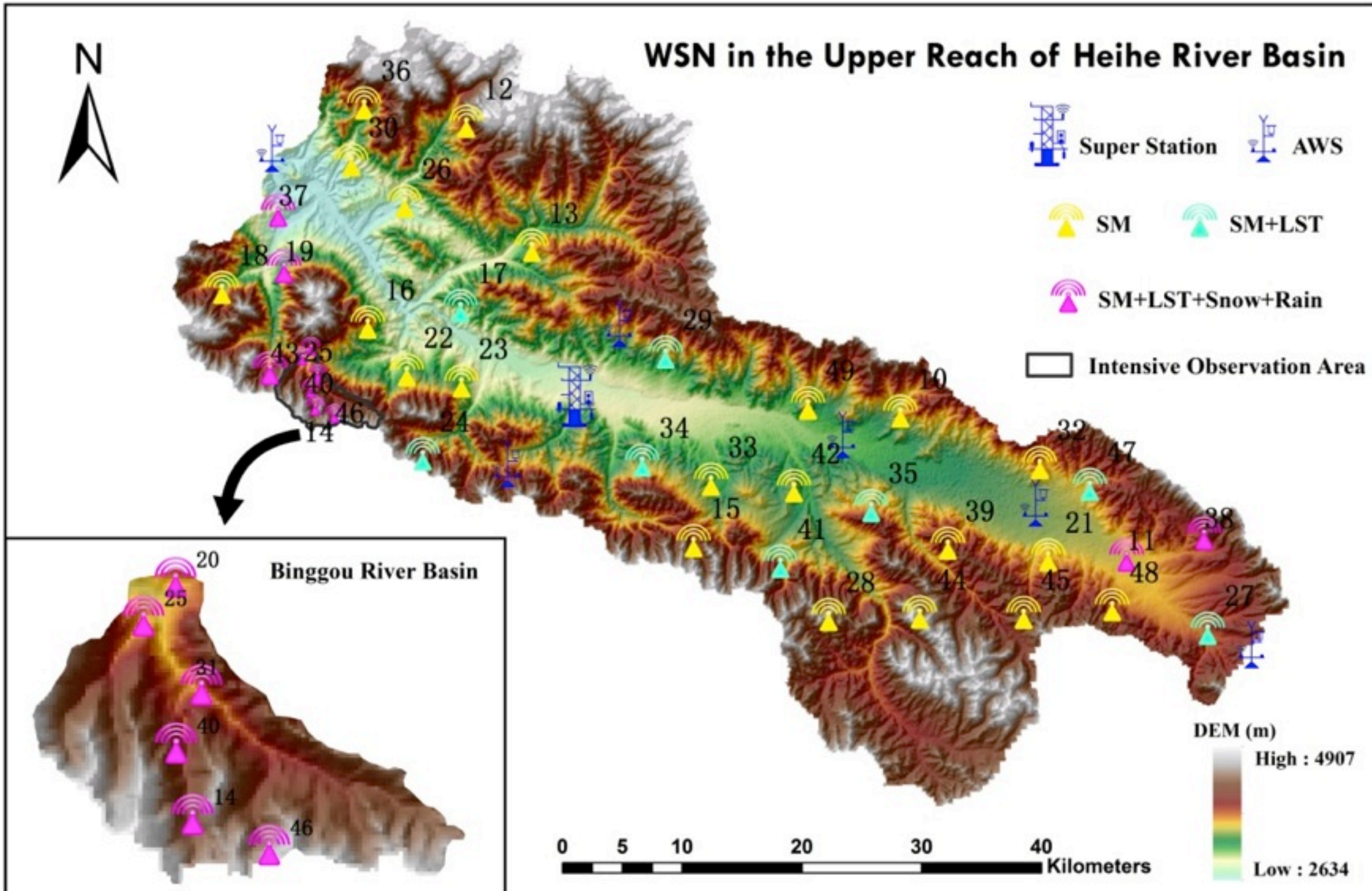


Li et al., 2013, BAMS

Network of automatic meteorological station and flux towers



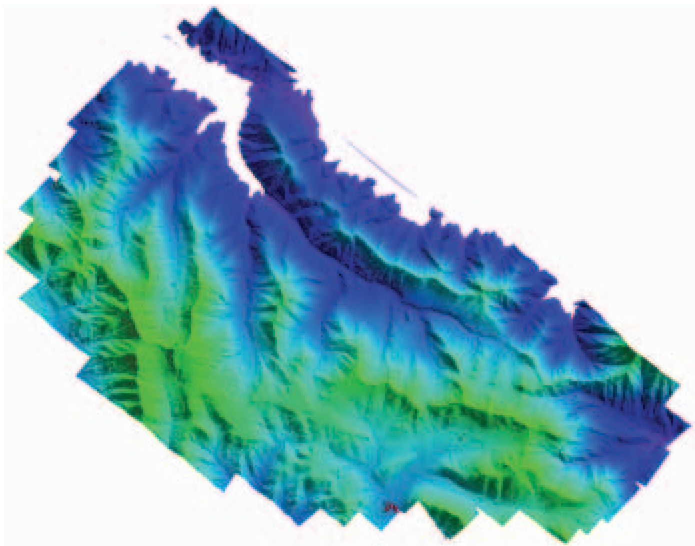
Multi-scale high mountain river basin observing system: Wireless sensor network



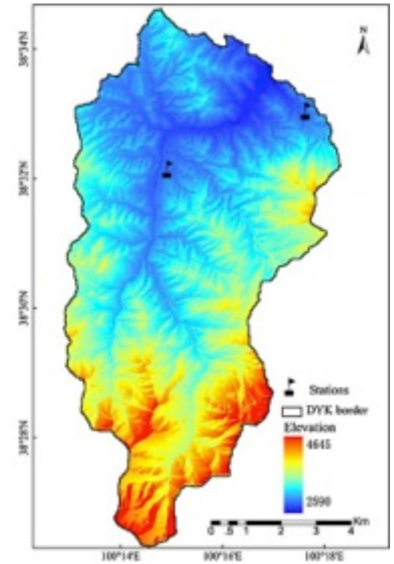
Jin et al., 2014, IEEE GRSL

Super high-resolution DEM by airborne LiDAR

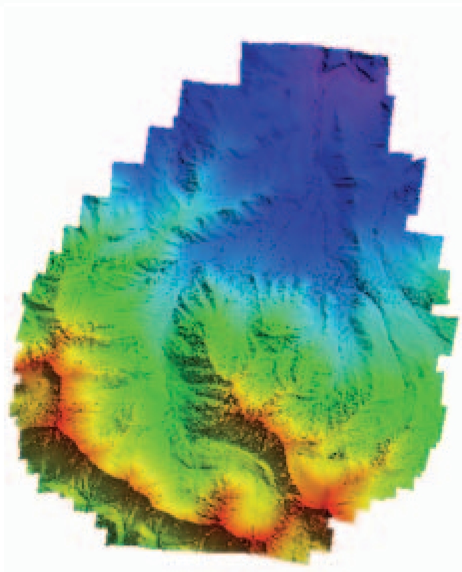
Binggou DSM



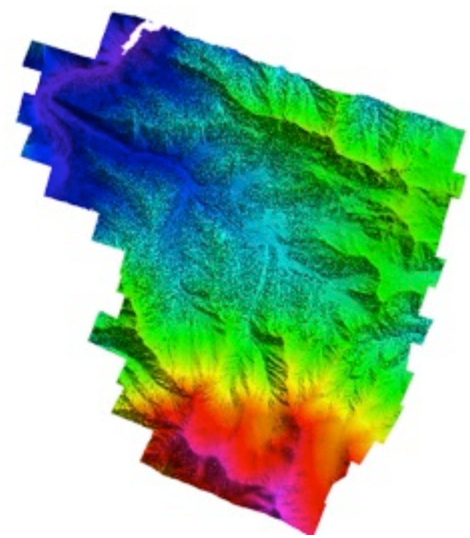
Dayekou DEM



Hulugou DSM



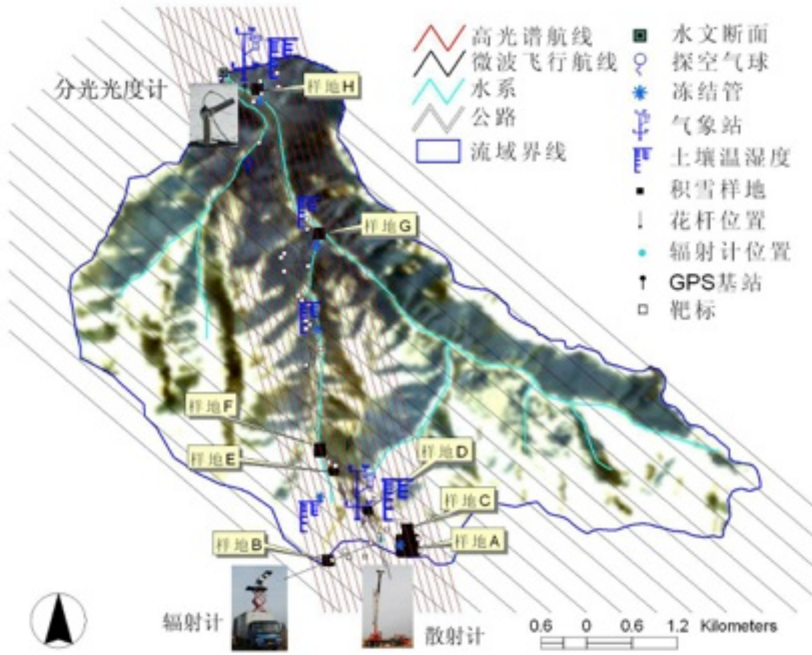
Tiannaochi DSM

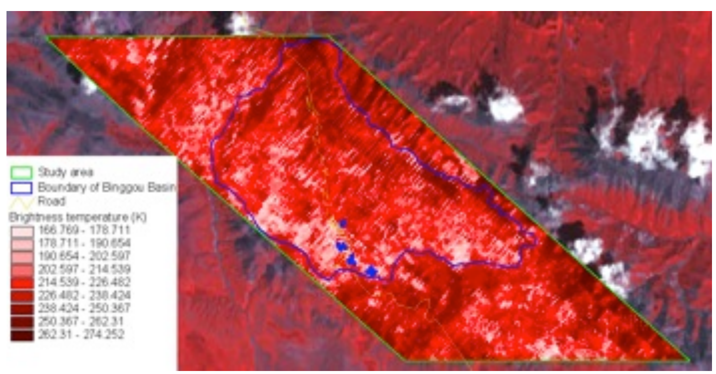


Airborne missions at Binggou watershed







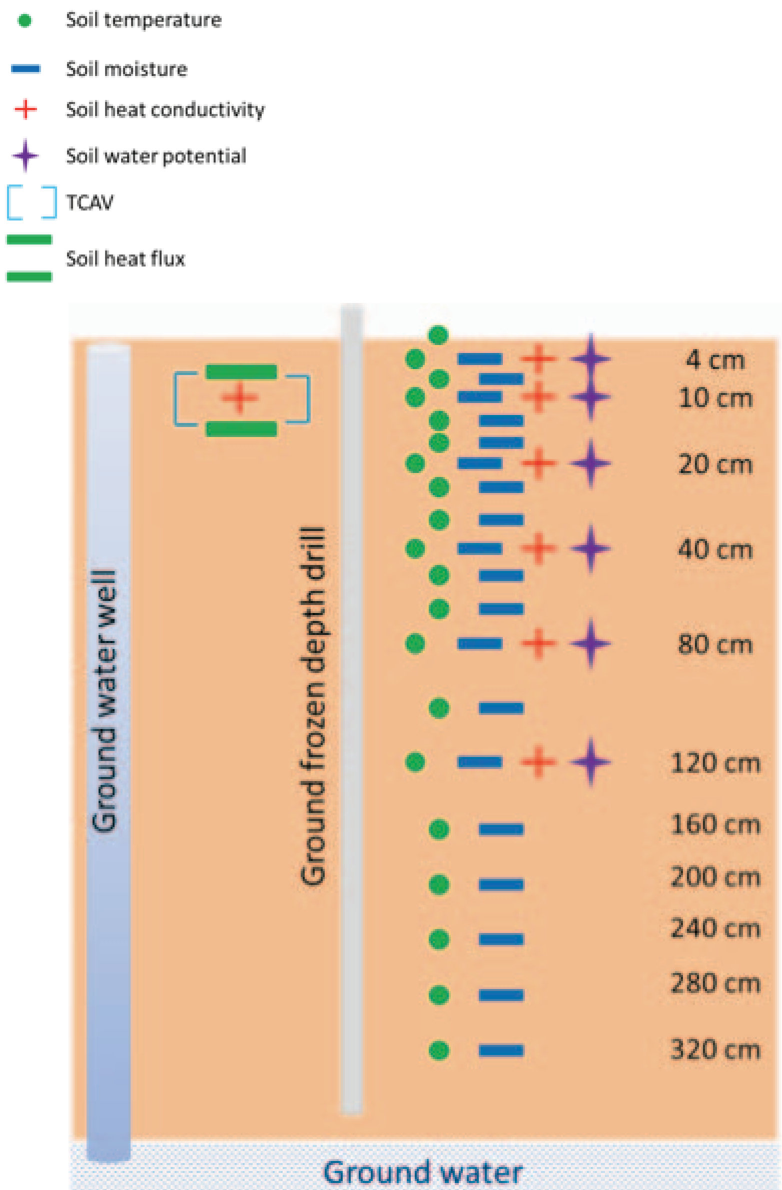






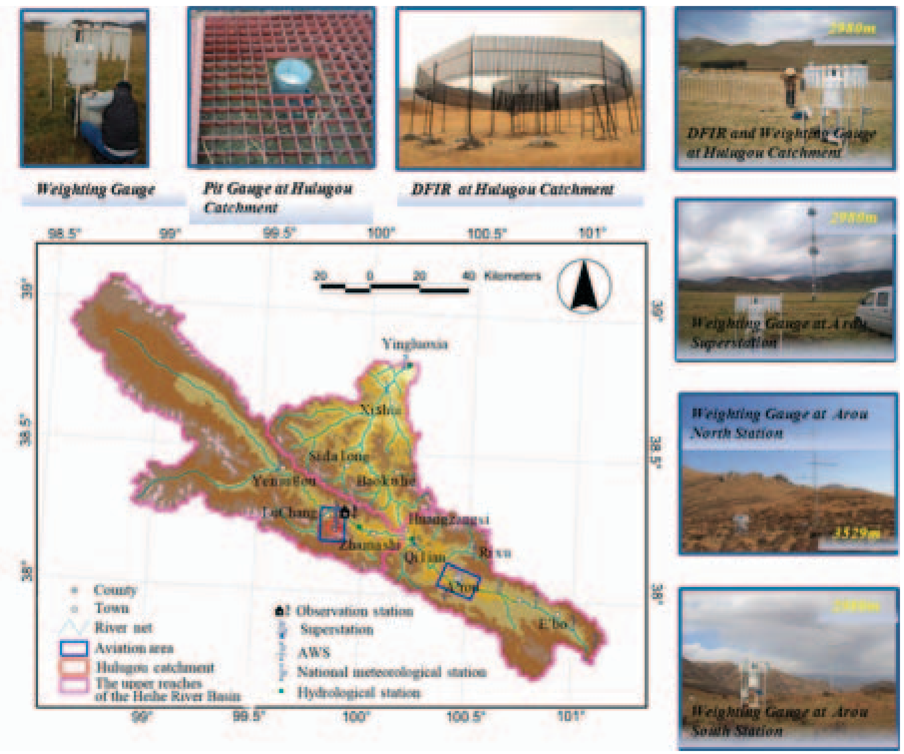
Snow observatory in the upstream area of the HRB

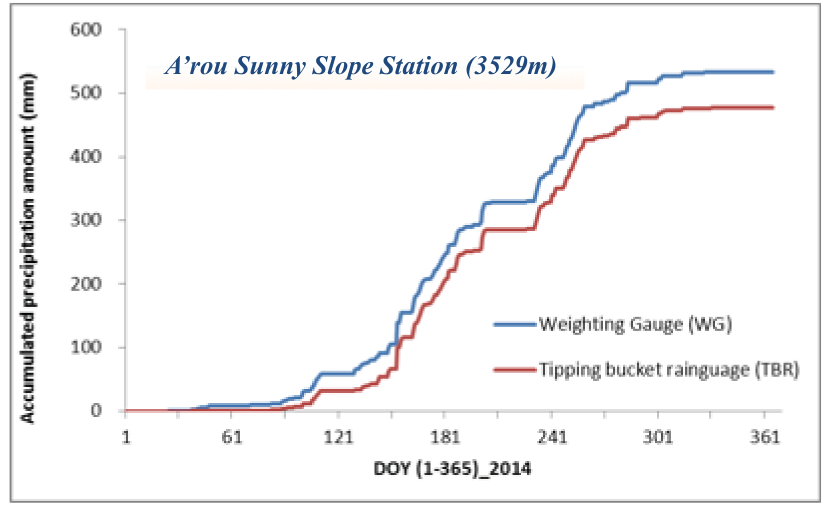
Frozen soil observatory in the upstream area of the HRB

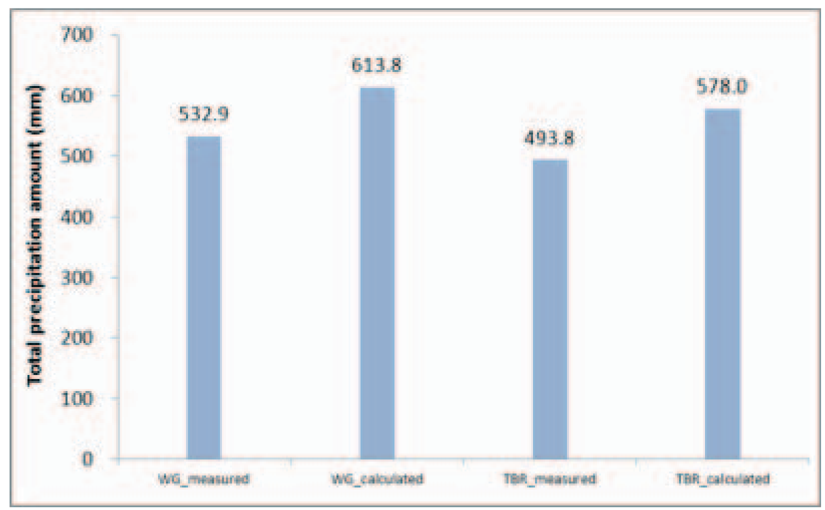


Observation item	Setting
Wind Speed	1, 2, 5, 10, 15, 25 meter
Wind Direction	2 meter
Precipitation	0, 28 meter
Air temperature	1, 2, 5, 10, 15, 25 meter
Humidity	1, 2, 5, 10, 15, 25 meter
Air pressure	1 meter
Radiation (4 components)	5 meter
LST	5 meter
Snow depth	2 meter
Eddy correlation	4 meter
LAS	10 meter
COSMOS	1.5 meter

Precipitation calibration□







Calibrated precipitation results at A'rou Sunny Slope Station (3529 m)

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  □□o o.□r□□□ck□□c□r□raBa□□□□□g□
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He et al., 2017, Hydrological Processes

Glacier observation at Hulugou watershed

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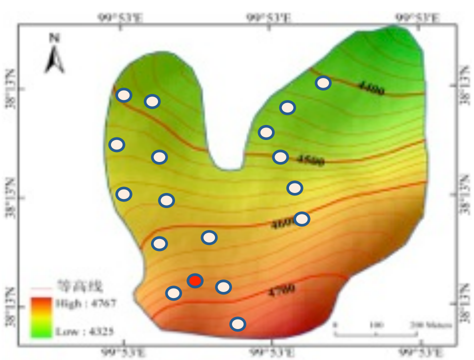

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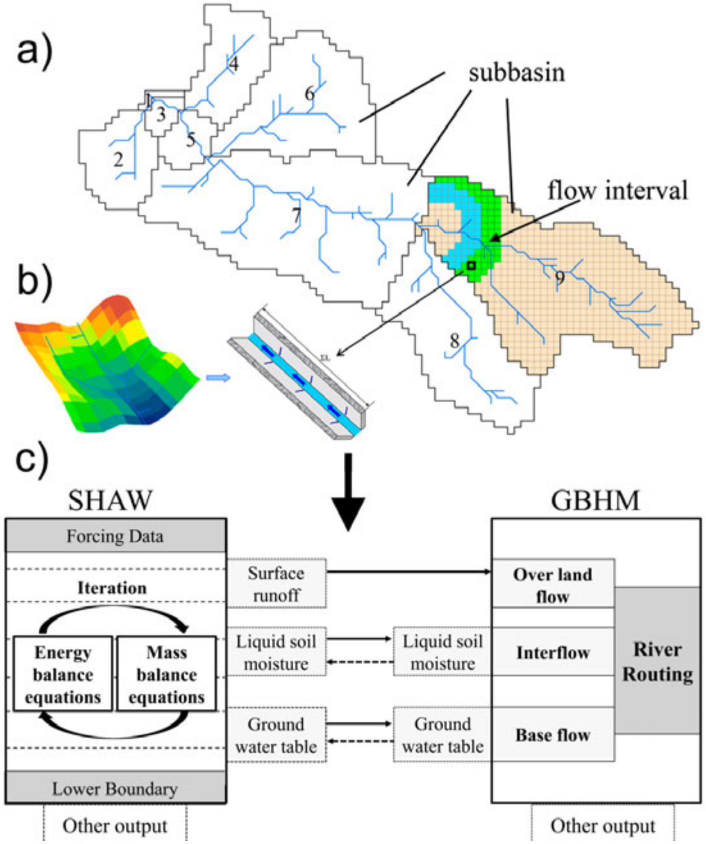
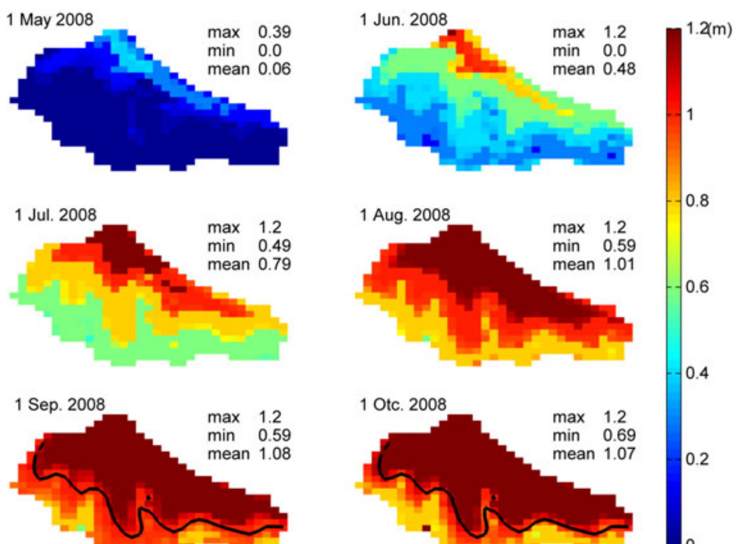
4. Cold region hydrological modeling and data assimilation

4.1 Modeling the cryospheric processes and prediction of cryospheric changes

Coupling a frozen soil model with a distributed hydrological model

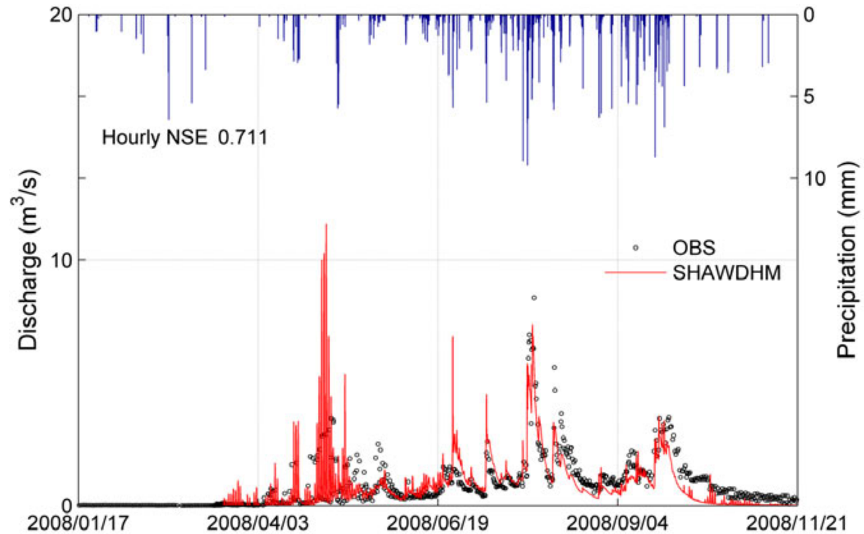


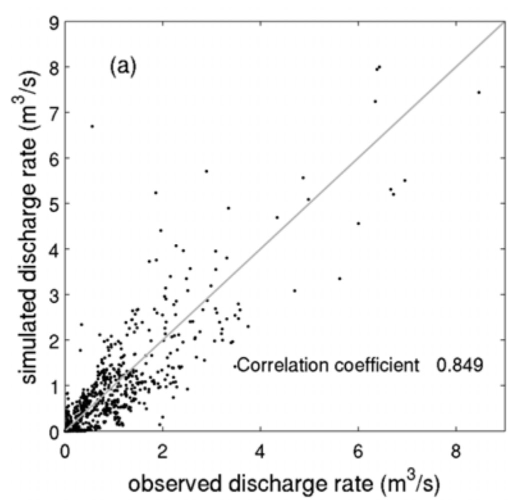


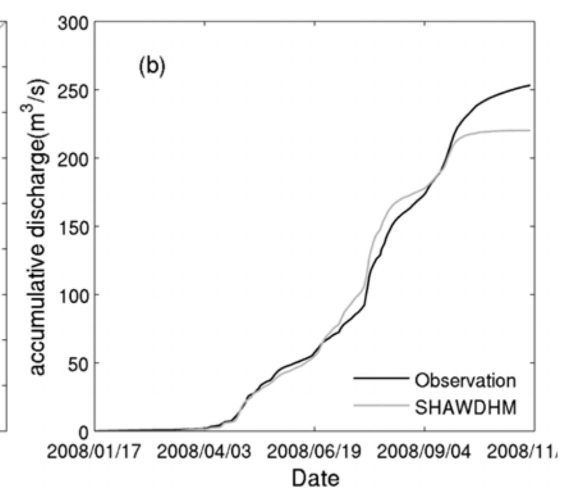
Simulated soil thawing depth

Zhang et al., 2013, Hydrological Processes

Zhang et al., 2017, PPP



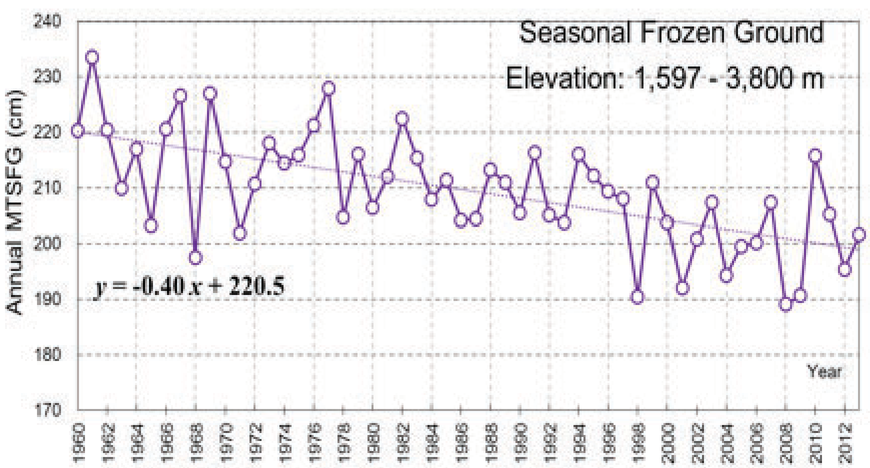




Prediction of frozen soil change□

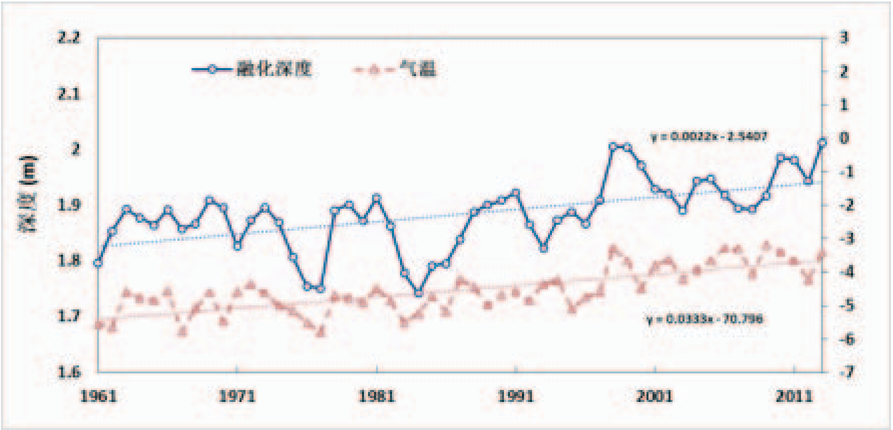
- Changes in seasonally frozen soil□

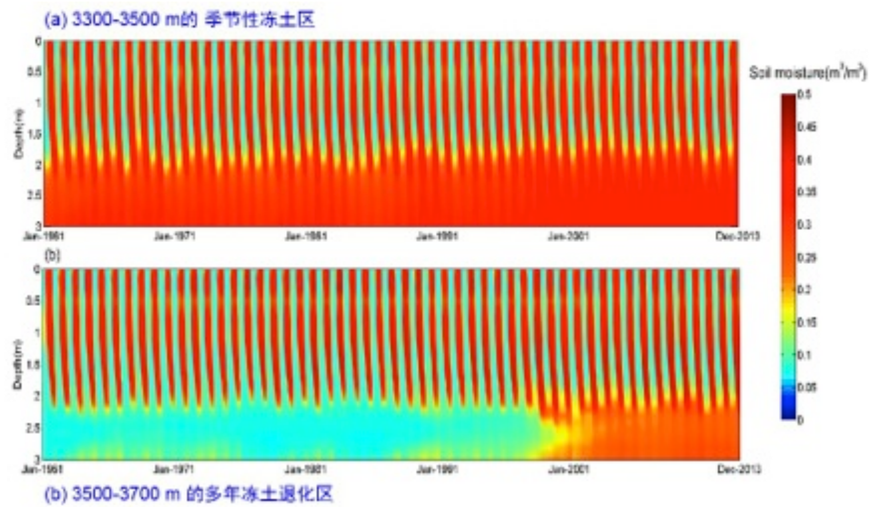
Maximum frozen depth (MTSFG) estimated by Stefan formula



Maximum frozen depth significantly decreased. Changing rate in the regions below 3800 m is 4.0 cm 10 yr^{-1}.

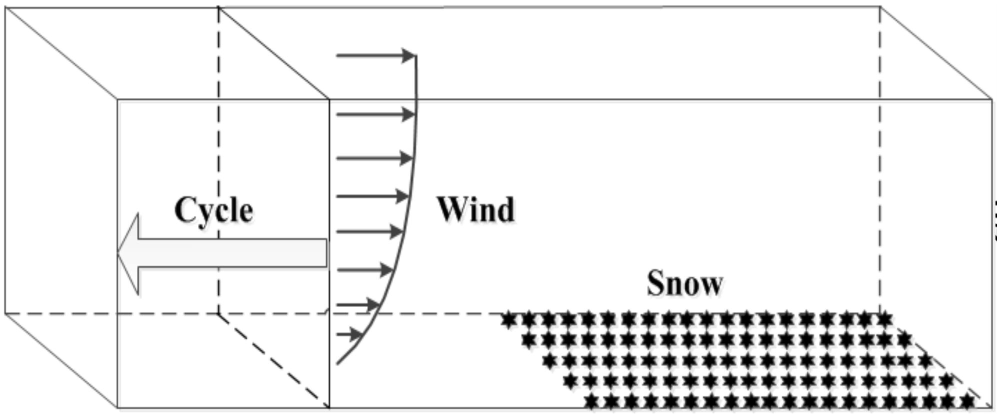
- Changes in permafrost□

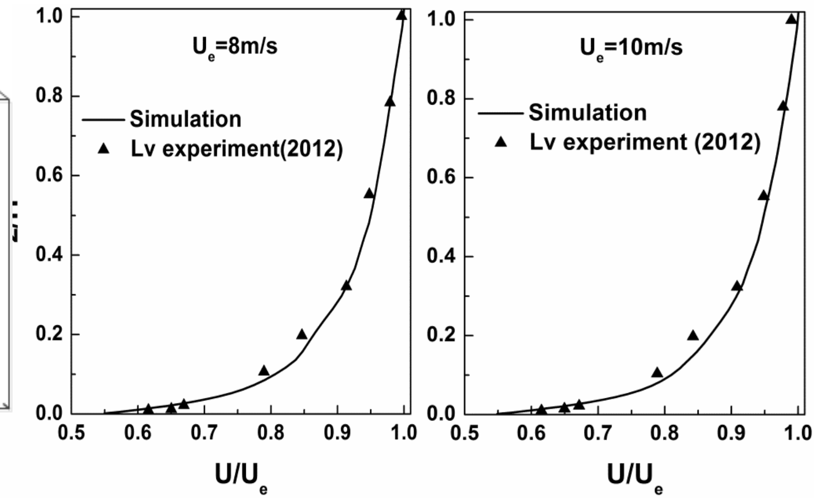




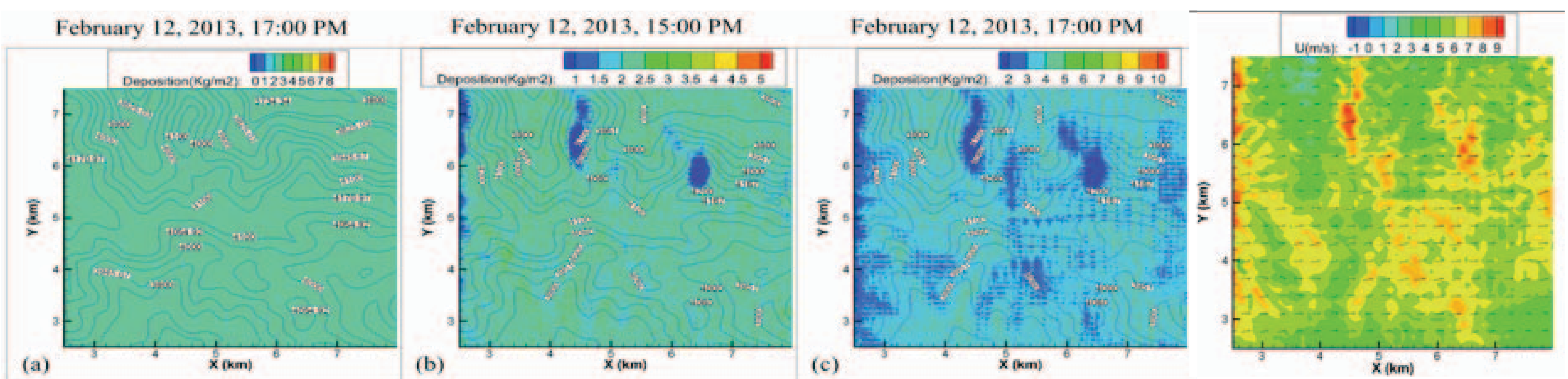
Qin et al., 2016, J. Hydrology

3-D blowing snow simulation in complex terrain based on large eddy simulation and Lagrangian particle tracking method



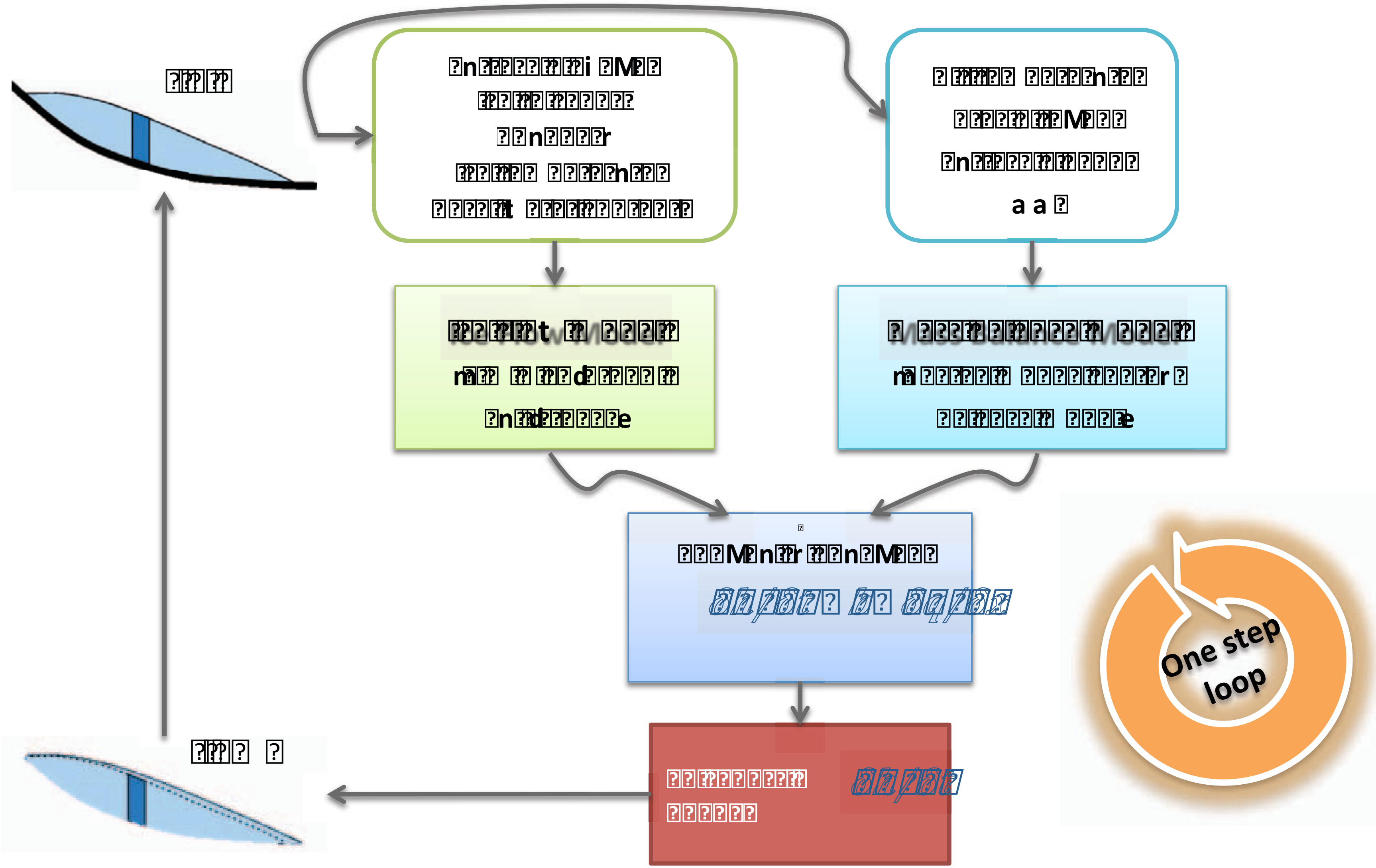


The snow deposition in real terrains due to snowfall based on typical particle tracking



The snowfall deposition cloud map at different time (a) is initialized with meteorological data; (b) and (c) are initialized with constant speed of 5m/s.

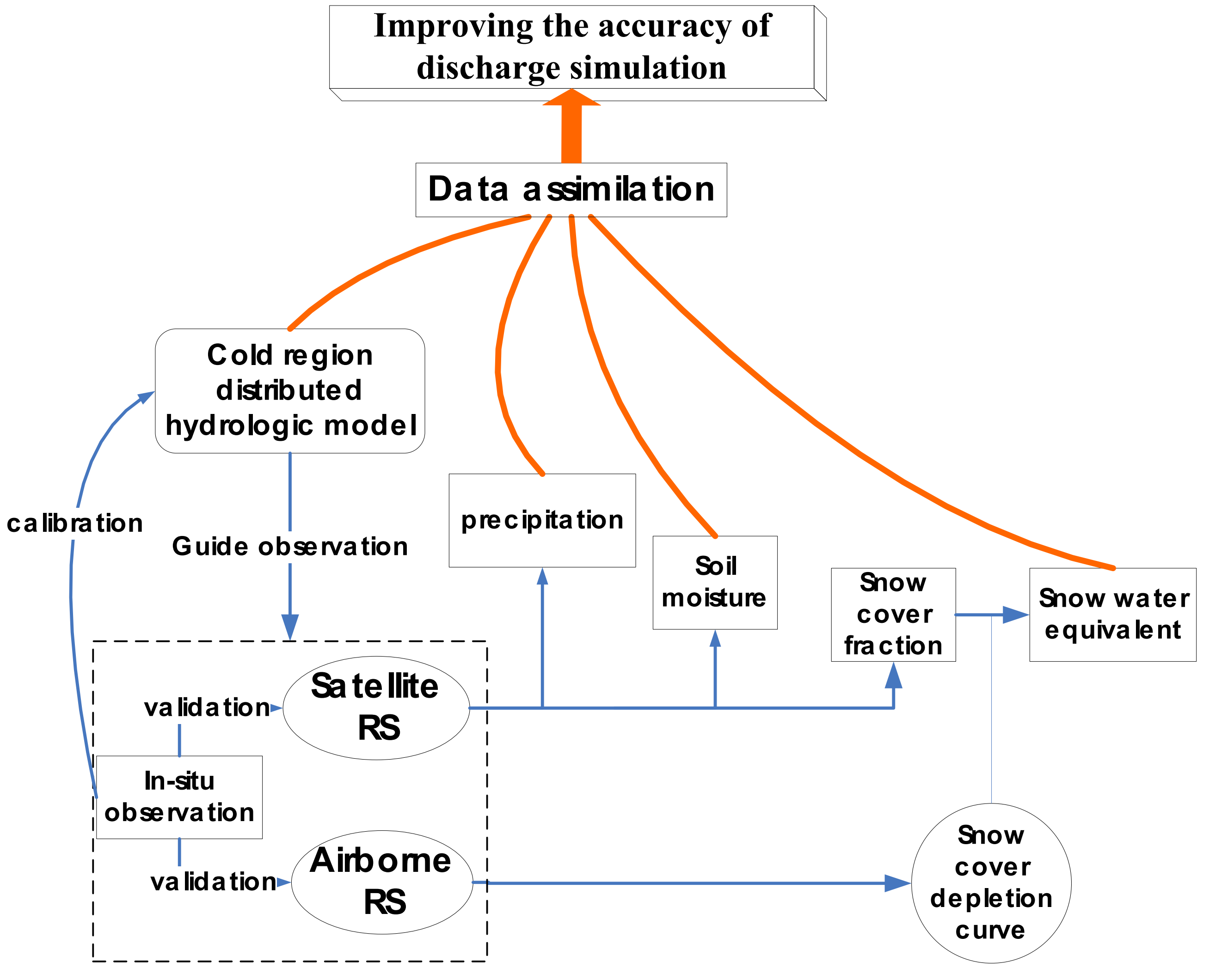
Glacier model physics



Li, H. L. et al., 2012, JGR

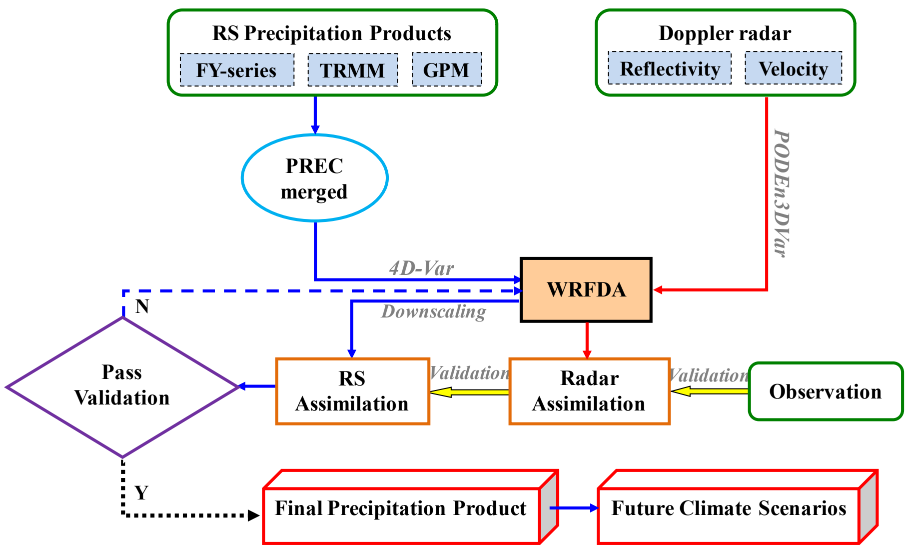
4.2 Development of a river basin scale cold region modeling and data assimilation system

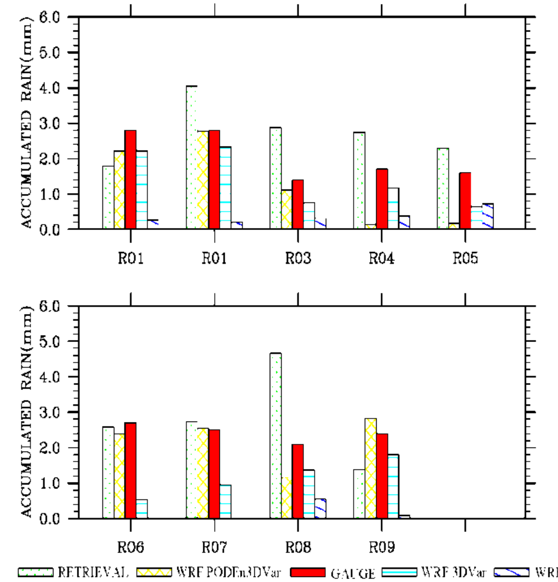
Improve the cold region hydrological predictability by using remote sensing products

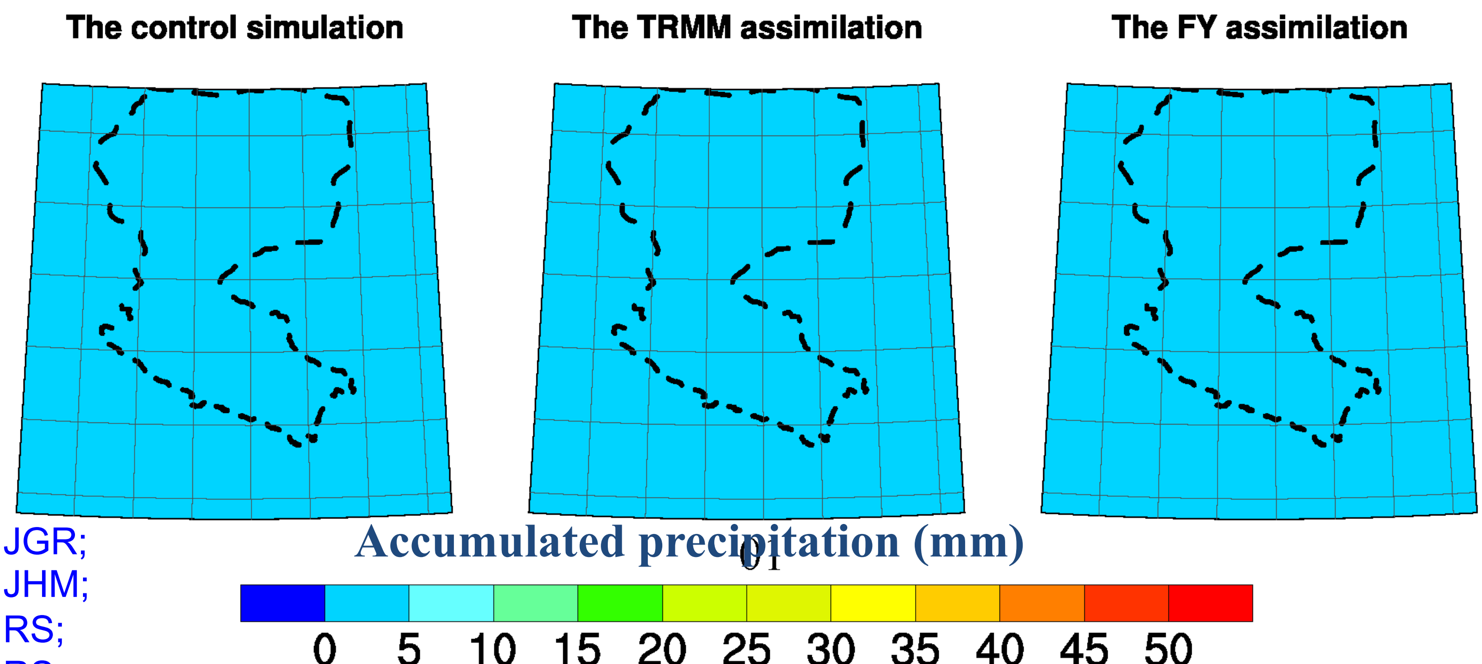


HiWATER

Daily precipitation and other forcing dataset with 5km resolution, 2000-2014
A multi-scale regional climate modeling and data assimilation system





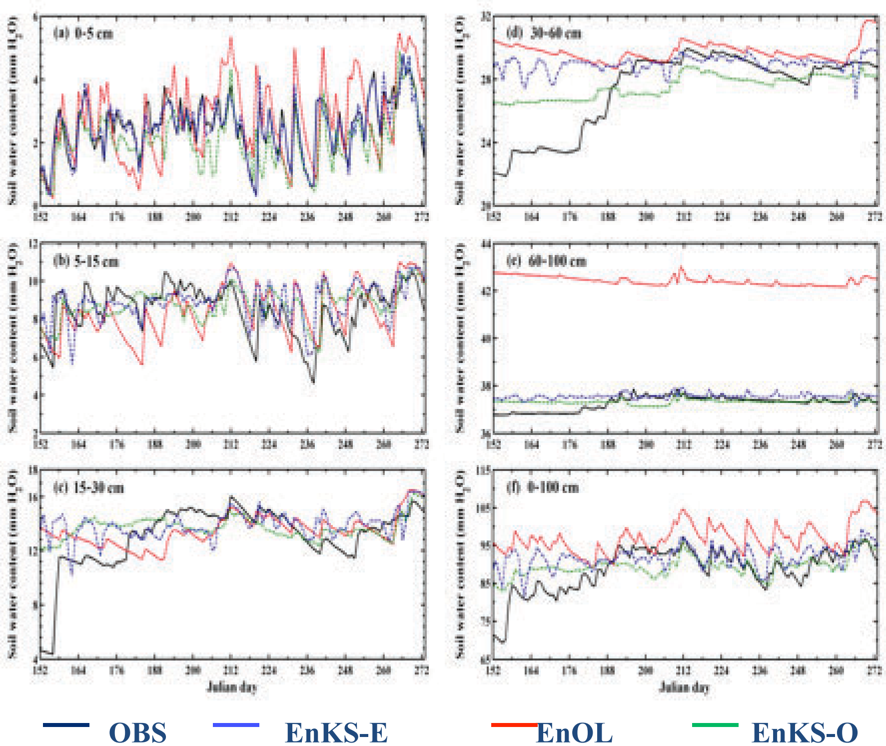


Pan et al., 2012, JGR;
Pan et al., 2014, JHM;
Pan et al., 2015, RS;
Pan et al., 2017, RS

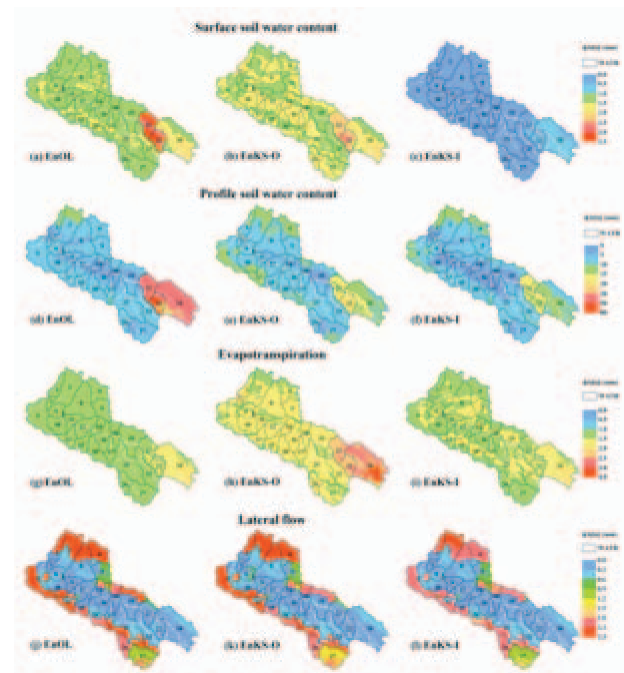
Data assimilation: Synthetic surface soil moisture data assimilation via the ensemble Kalman smoother (EnKS) method

The assimilation of surface soil moisture can moderately improve estimates of deep layer soil moisture, surface runoff and lateral flow, which reduces the negative influences of erroneous forcing and inaccurate parameters.

Assimilation results



Spatial errors (RMSE)



Lei et al., 2015, Advances in Water Resources

5. Closing water balance at the upstream high mountain watershed of the Heihe River Basin

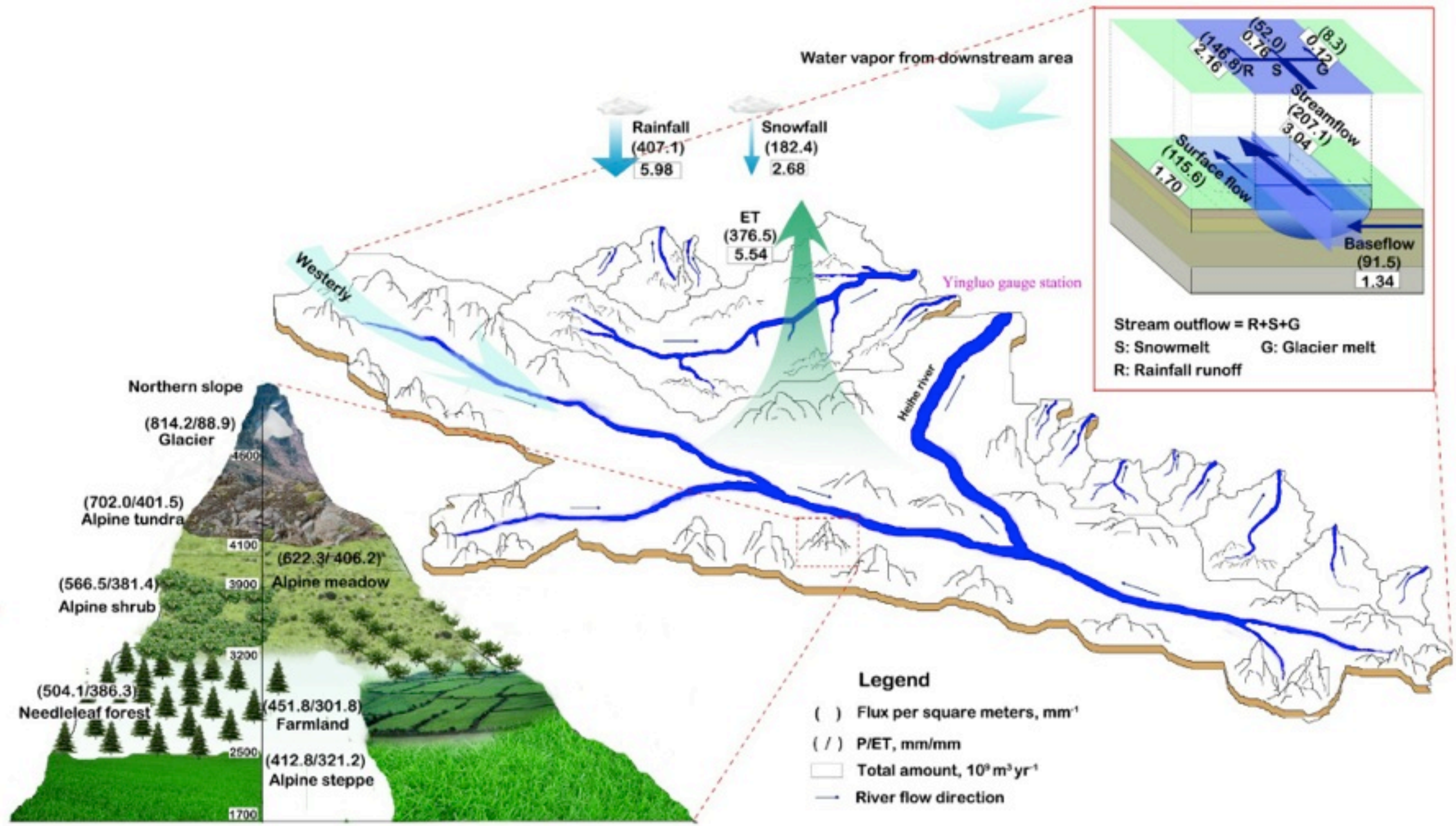
Water balance equation: upstream

$$P = ET + R + G_{out} + \Delta S + \Delta GW + \Delta C + \Delta L,$$

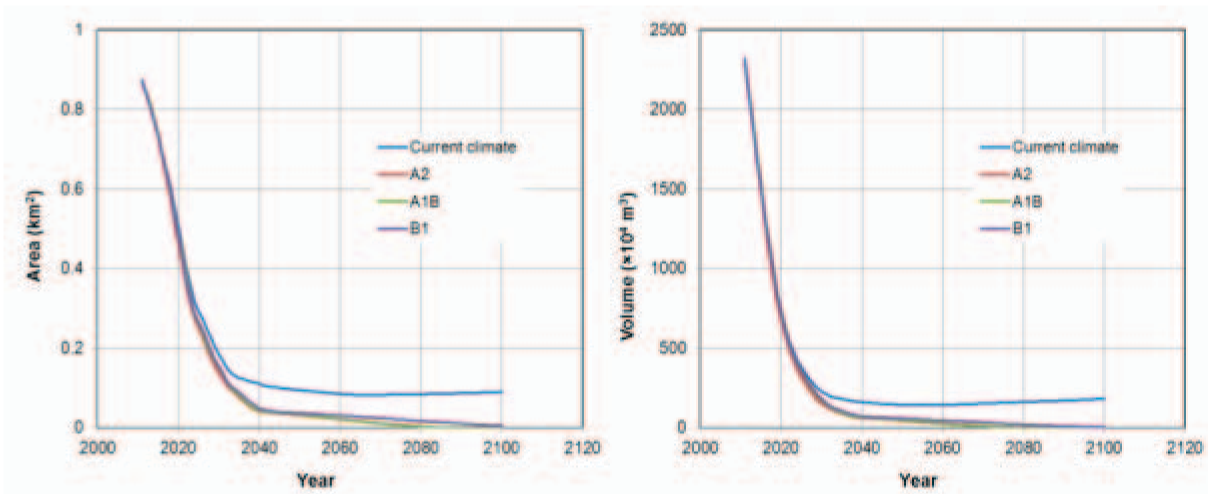
$$R = R_{s} + R_{b}$$

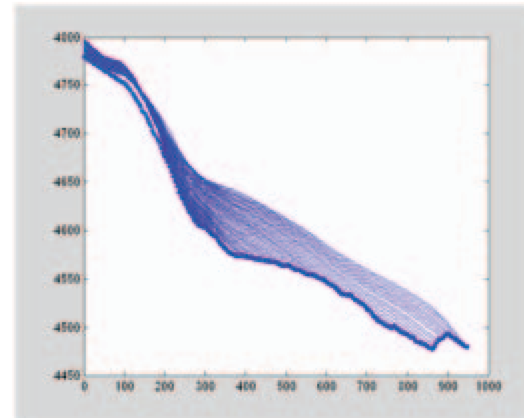
$$R = R_{rain} + R_{snow} + R_{glacier}$$

Water balance in the upstream area of the HRB

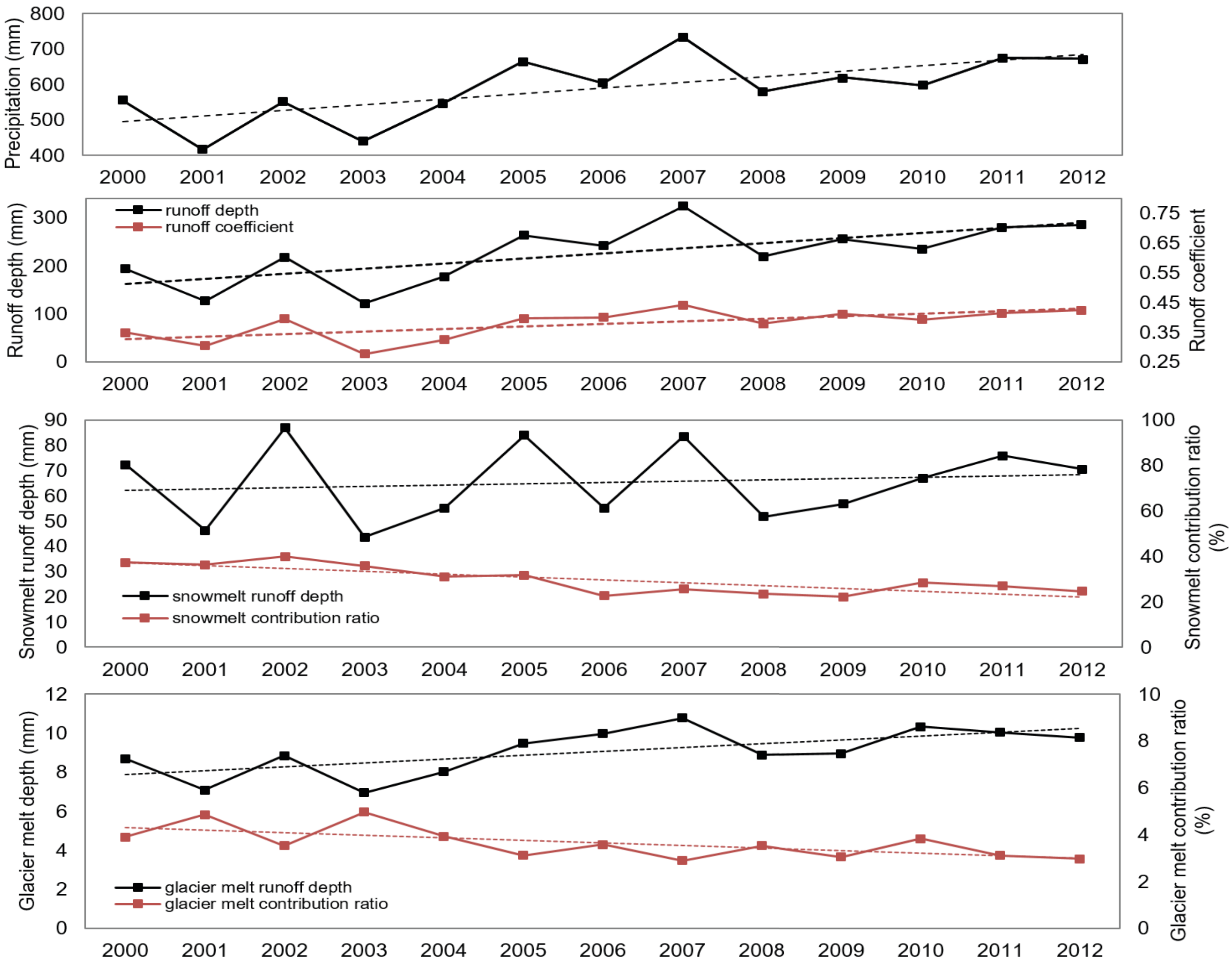


Predication of the glacier change





Changes in precipitation, runoff, snowmelt, and glacier melt in the upstream area of the Heihe River Basin from 2000 to 2012□



Hydrological Cycle in the Heihe River Basin and Its Implication for Water Resource Management in Endorheic Basins

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H076: Integrated water-ecosystem-economy studies at the river basin scale
Convener: Xin Li, Ximing Cai, Howard Wheater
Session time: December 13, 2017

6. Summary (1)

- The multi-scale high mountain river basin observing system in the upstream area of the Heihe River Basin, Qilian Mountains of China can be used as a testbed for cold region eco-hydrological process study, modeling and data assimilation.
- Cryospheric process models/modules were coupled into the distributed eco-hydrological models.
- A river basin scale hydrological DA system has been developed.

6. Summary (2)

- Cryospheric hydrological process dominates in the upstream mountainous area. Precipitation, runoff, snowmelt, and glacier melt kept increasing in the upstream area of the HRB from 2001 to 2012 under a warming climate.
- The onset of snowmelt has gone ahead. However, the contribution ratio of snowmelt to total runoff decreased. The contribution ratio of glacier melt to total runoff was slightly decrease as well. Frozen soil melt advances in time as well, it may also contributes to the increase of the portion of baseflow in total runoff.

Data sharing:

http://card.westgis.ac.cn/hiwater in English

http://heihedata.org/hiwater in Chinese

Cold and Arid Regions Science Data Center at Lanzhou

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Dataset / HiWATER

- Introduction of HiWATER
- Airborne remote sensing data +
- Airborne remote sensing data products +
- Hydrometeorological observation network +
- Calibration and validation experiment +
- Eco-hydrological wireless sensor network +
- The multi-scale observation experiment on evapotranspiration over heterogeneous land surfaces +
- Satellite remote sensing data

Heihe Watershed Allied Telemetry Experimental Research (HiWATER)

HiWATER

Heihe Watershed Allied Telemetry Experimental Research

HiWATER is designed to be a comprehensive eco-hydrological experiment in the framework of the “Integrated research on the eco-hydrological process of the Heihe River Basin” , based on the diverse needs of the interdisciplinary studies of the research plan and the existing observing infrastructures in the basin. The overall objective of HiWATER is to improve the observability of hydrological and ecological processes, to build a world-class watershed observing system and to enhance the applicability of remote sensing in integrated eco-hydrological studies and water recourse management at the basin scale. HiWATER was formally initialized in May 2012 and will last four years until 2015.

HiWATER is jointly supported by two project groups titled “Heihe Watershed Allied Telemetry Experimental Research” (grant numbers: 91125001, 91125002, 91125003, 91125004) and “Remote Sensing Data Products in the Heihe River Basin: Algorithm Development, Data Products Generation and Application Experiments” (KZCX2-XB3-15), which are funded by the NSFC and Chinese Academy of Sciences, respectively.

Li et al., 2017, Scientific Data

Thanks！