中国科学院青藏高原研究所
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Chinese Academy of Sciences

Cryosphere–Hydrometeorology Observations for a Water Tower Unit on the Tibetan Plateau Using the BeiDou-3 Navigation Satellite System

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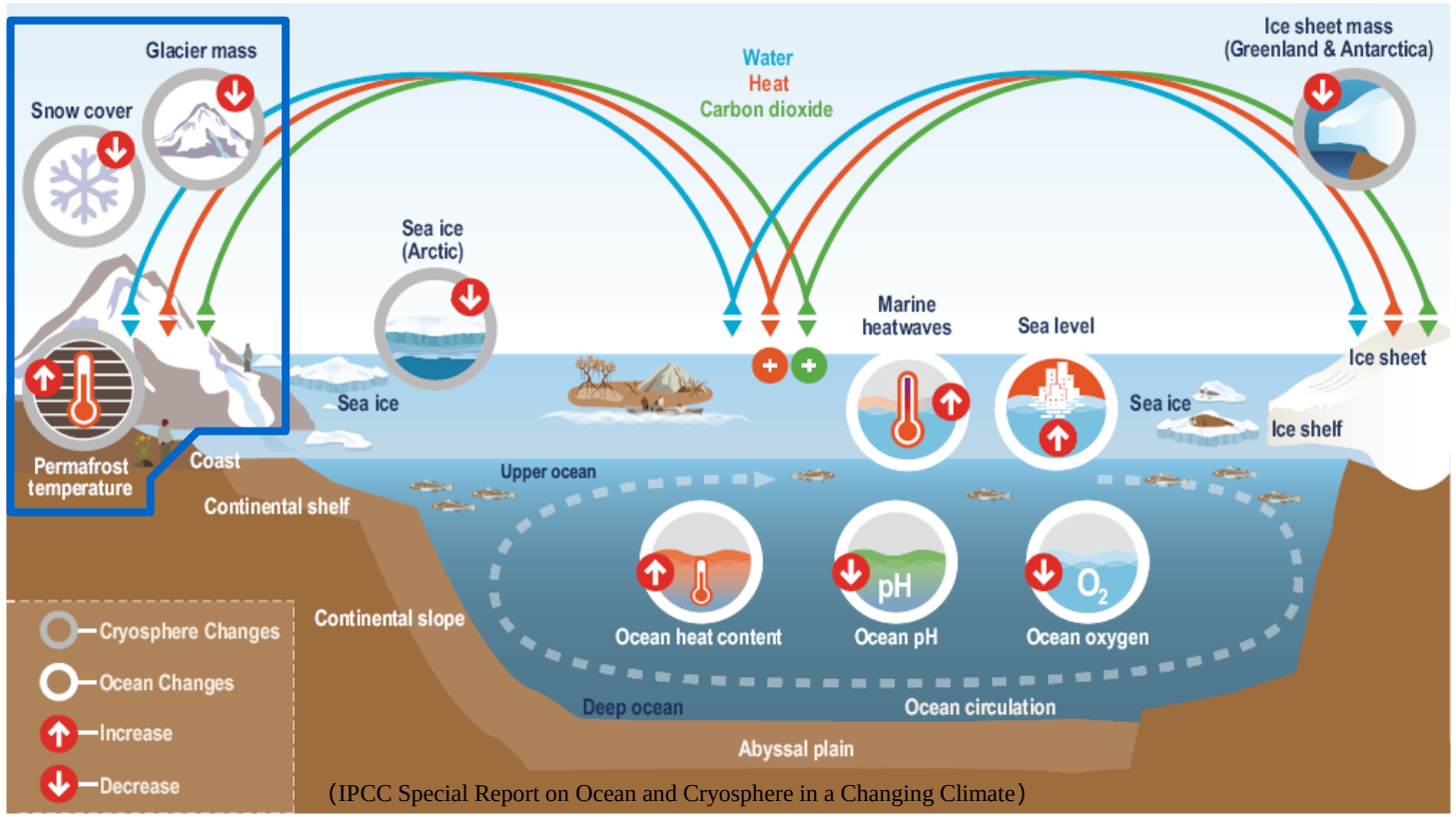
Reference: Liu R & Wang L* et al., BAMS, 2024, https://doi.org/10.1175/BAMS-D-23-0001.1

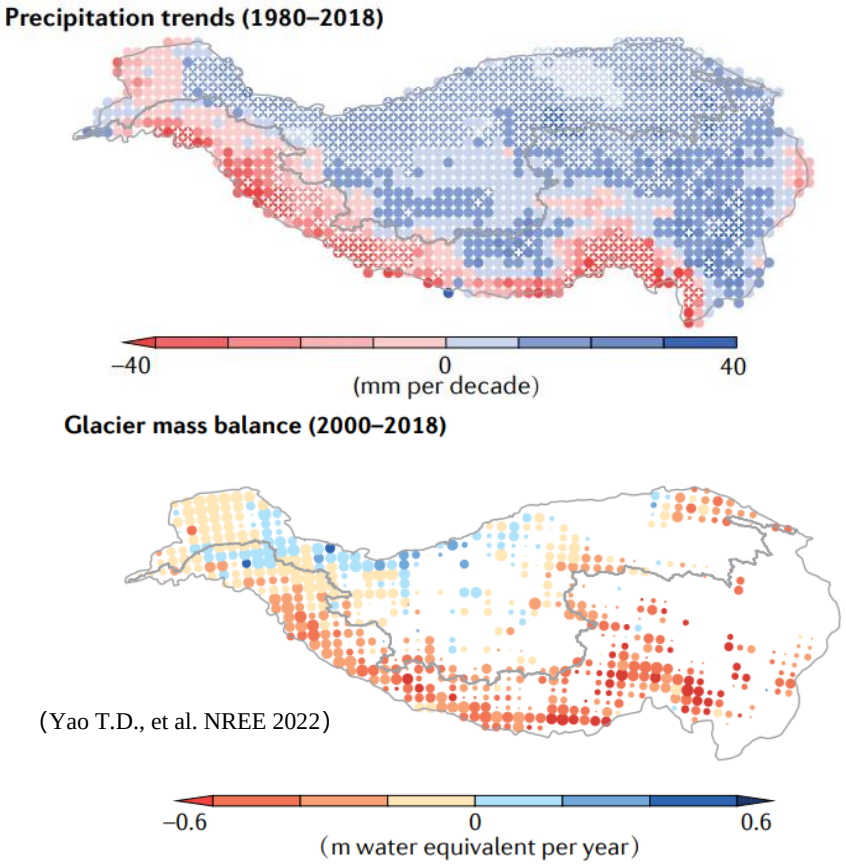
Outline

- ✓ Background and objective
- ✓ Data and methods
- ✓ Major results
- ✓ Summary

Background



(IPCC Special Report on Ocean and Cryosphere in a Changing Climate)



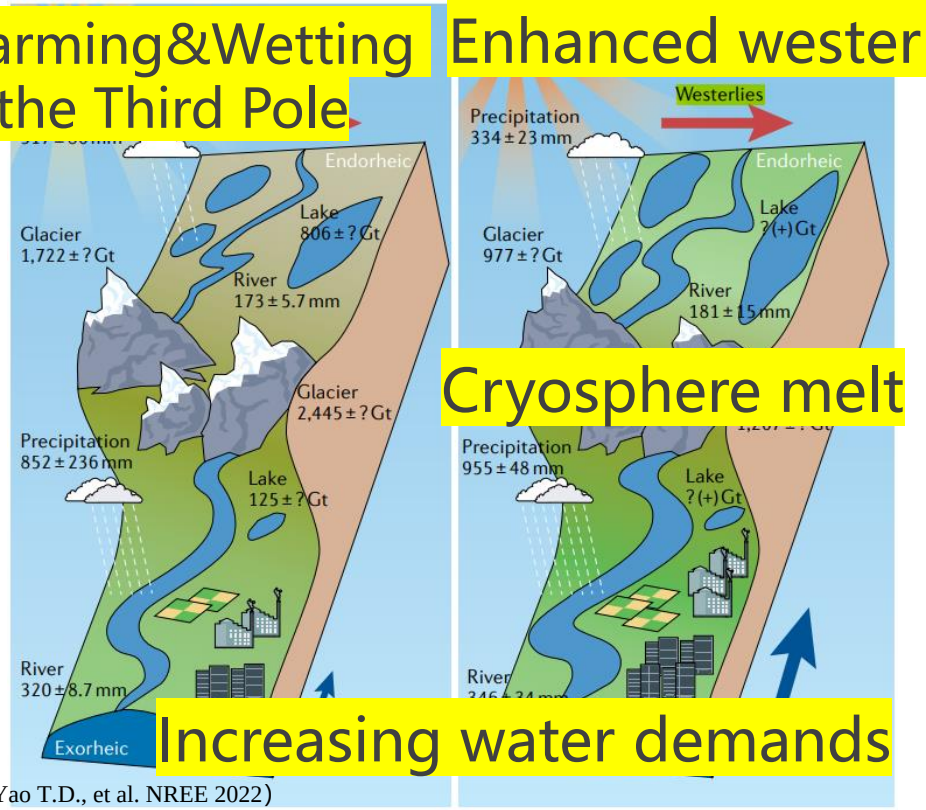
(Yao T.D., et al. NREE 2022)

Future changes in cryosphere have drawn much attention globally. In the Third Pole regions, particularly the westerlies-dominated arid/semi-arid regions, the cryosphere melting have prominent impacts on regional water cycle and ecological sustainability.

Background

Warming&Wetting in the Third Pole

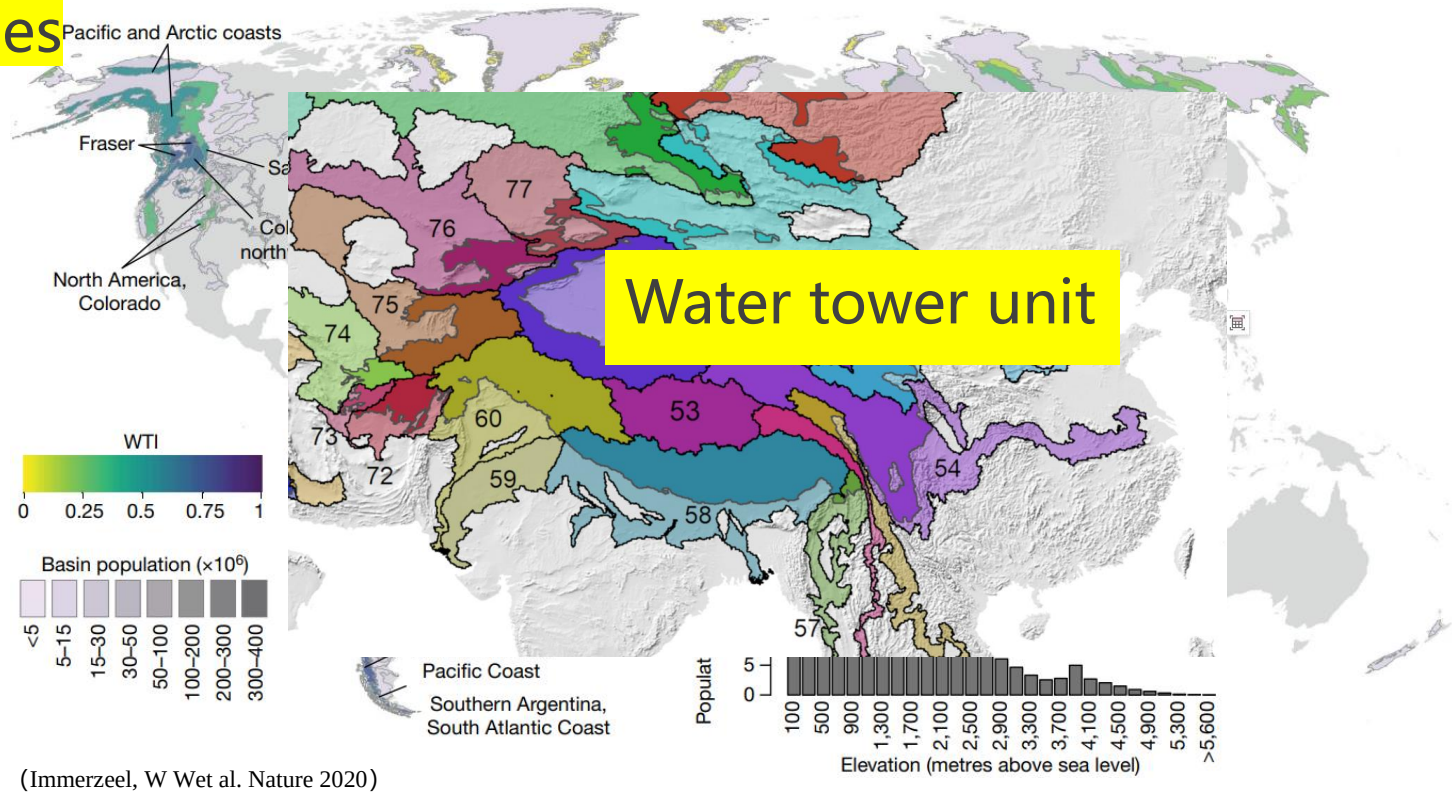
Enhanced westerlies



Cryosphere melt

Increasing water demands

(Yao T.D., et al. NREE 2022)



(Immerzeel, W Wet al. Nature 2020)

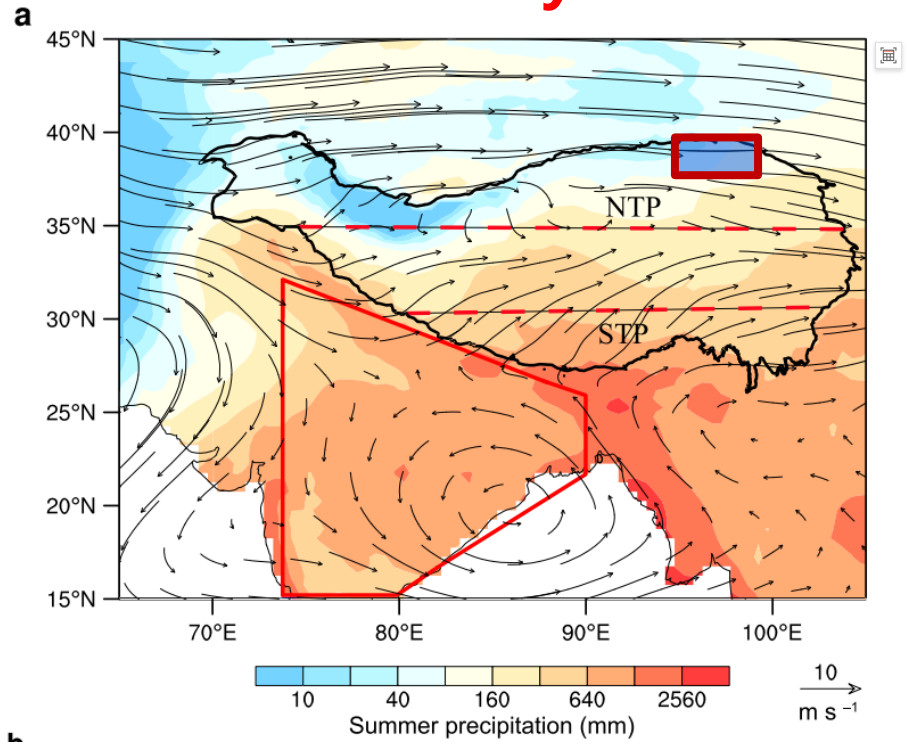
- **Arid alpine basin is often major water source of downstream oasis; uncertainty of water supply and regulation of solid/liquid water storage increases risk of regional development.**
- **A major way to reduce uncertainty of regional runoff prediction, is to elaborate response from weather process to land surface runoff process by observation and modeling.**

Dunhuang City: is famous with world cultural heritage

Dunhuang Mogao Grottoes

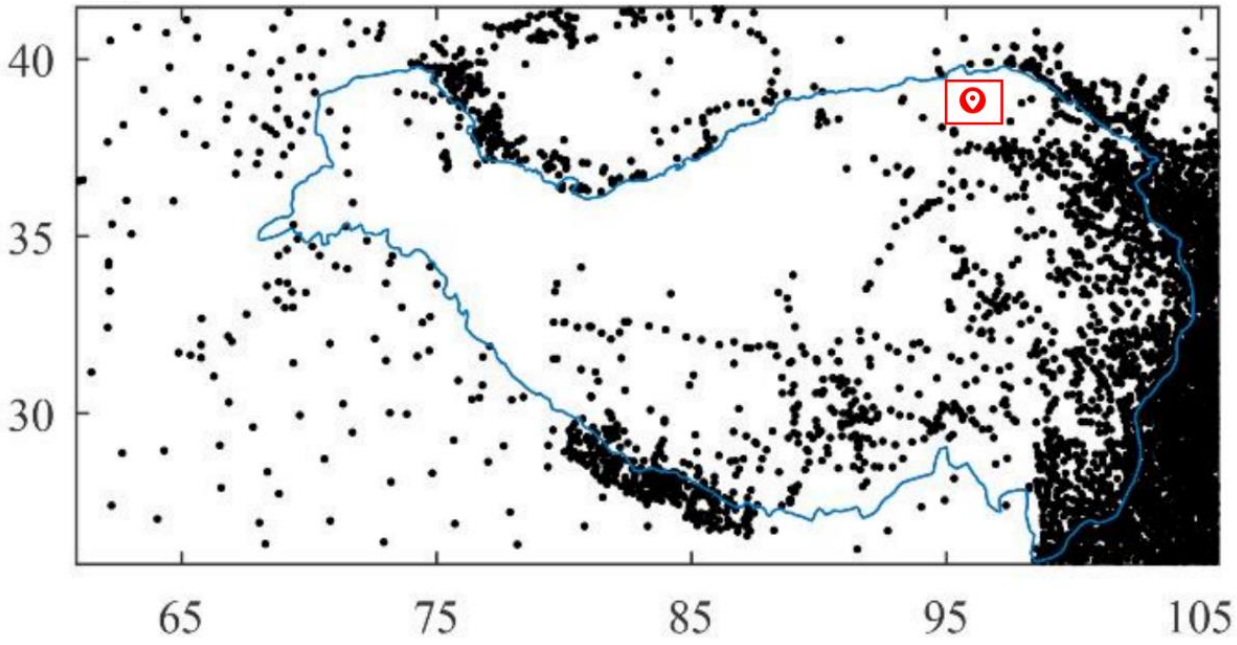
Life and civilization in arid regions depend on the availability of freshwater

Arid alpine river basins, where hydrological processes are highly sensitive to rapid warming, act as vital water towers for lowland oases. However, scientific understanding of precipitation variability and related cryosphere–hydrology processes is extremely limited because of the scarcity of in situ observations.



Westerlies-dominated

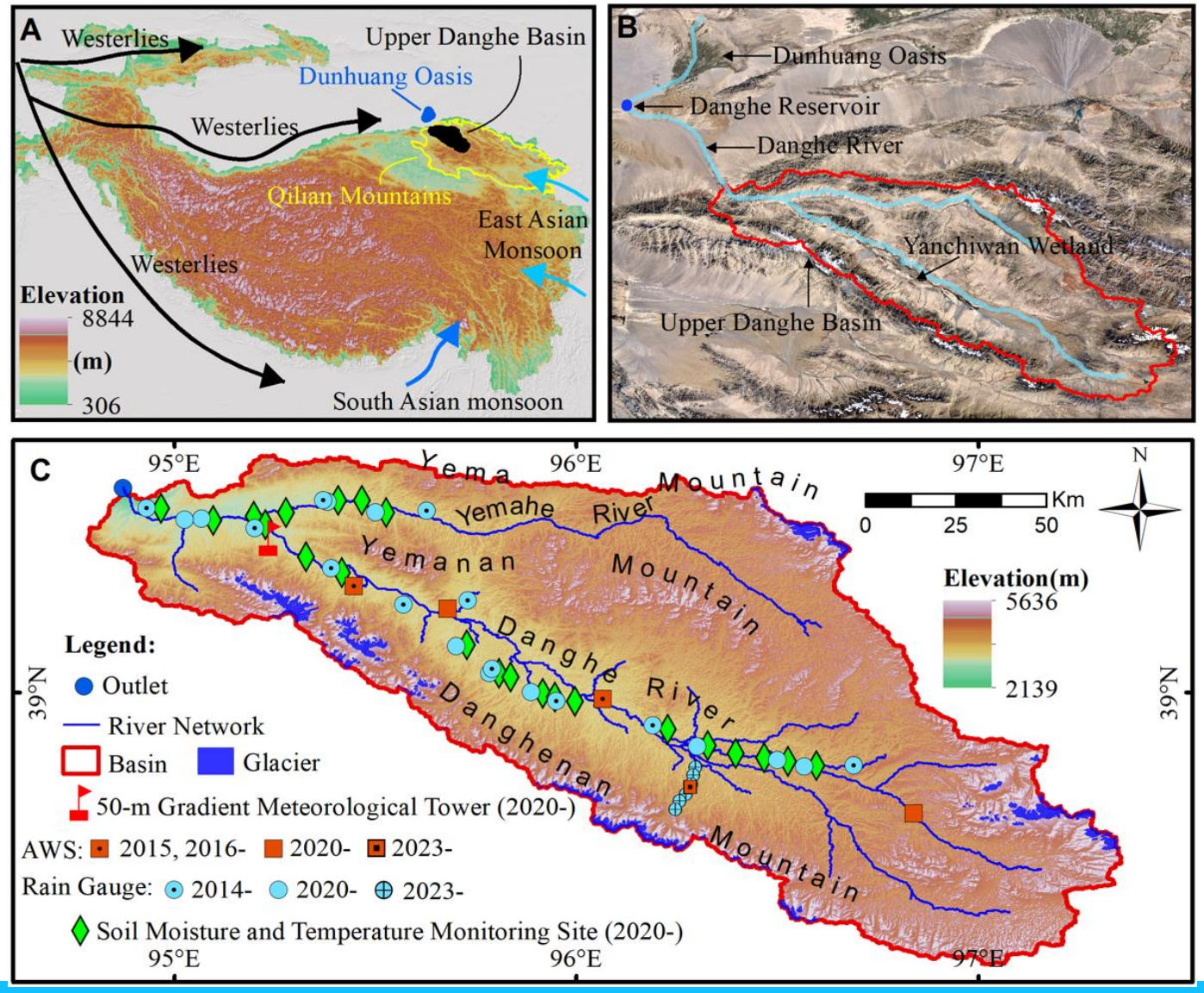
(Yang J.H., et al. NC 2022)



One rain gauge in 1983-1987, later stopped

(Jiang Y.Z., et al. ESSD 2022)

The upper Danghe River basin (UDB)



The upper Danghe River basin (UDB; ~14,000 km²) is an arid and westerly dominated basin on the northeastern Tibetan Plateau and is the water source for the Dunhuang Oasis in China.

Reference: Liu R & Wang L* et al., BAMS, 2024, https://doi.org/10.1175/BAMS-D-23-0001.1

Scientific objectives and project tasks

The UDB project is designed to enhance our understanding of cryosphere–hydrology and hydrometeorology processes, guiding integrated water resources management in an arid water tower unit within a rapidly warming global context.

This endeavor follows the technical framework of observations–data–modeling with the objectives to:

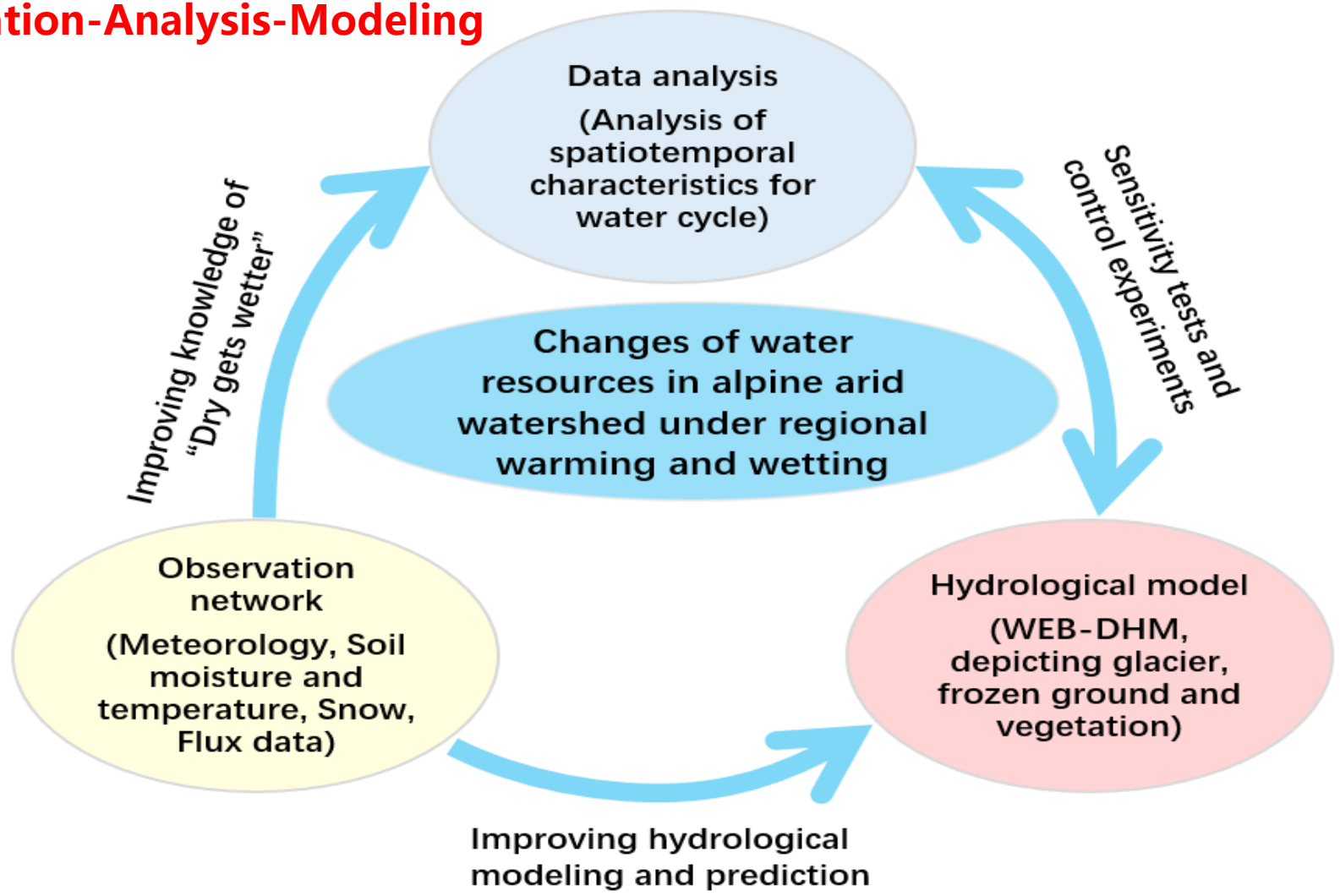
1) establish an integrated observation system,

2) elucidate the regional water cycle processes,

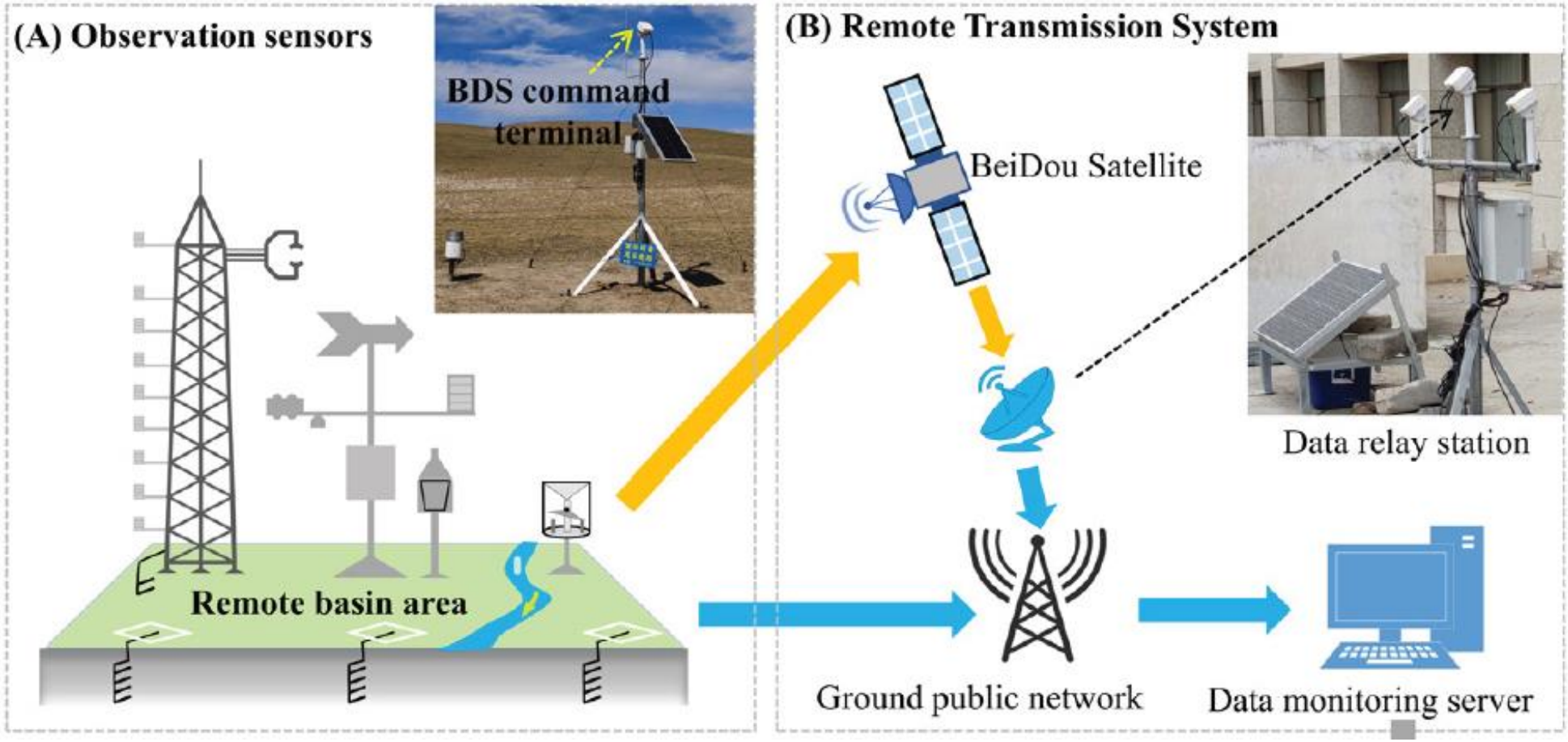
3) quantify precipitation impact and projecting discharge.

Technical framework of the UDB project

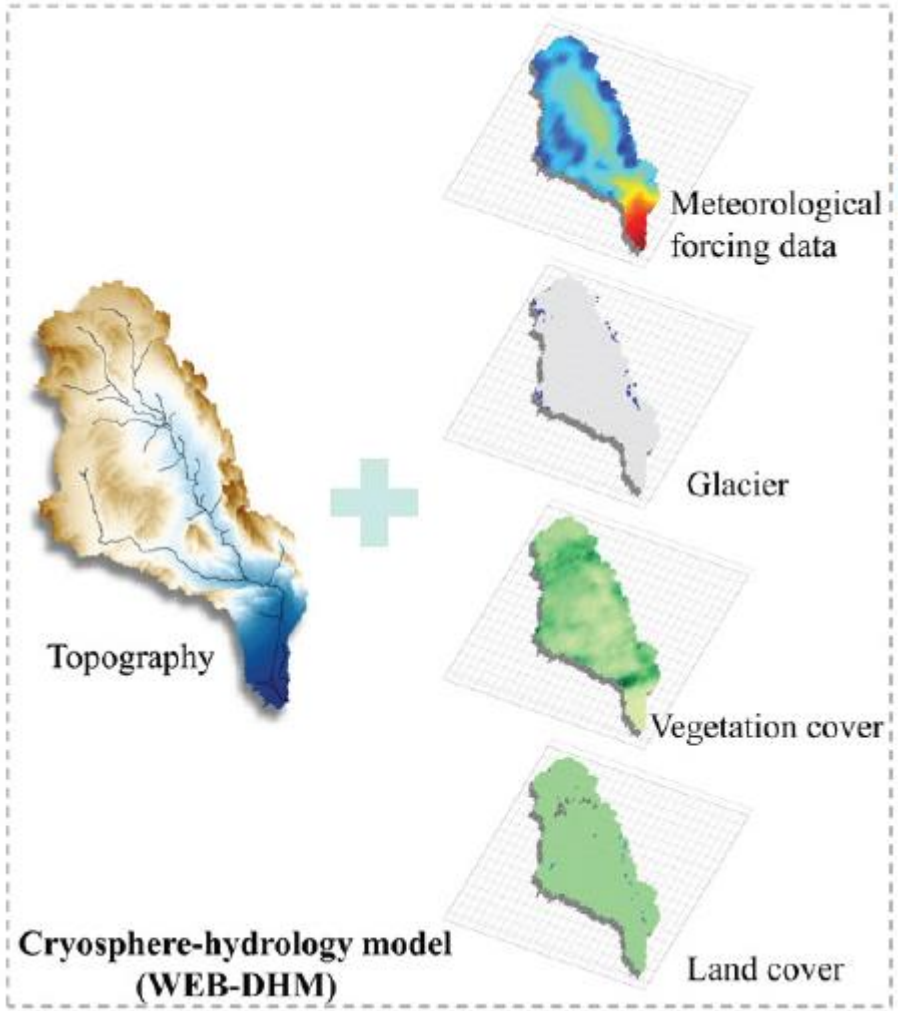
Observation-Analysis-Modeling



Observation sensors and Remote Transmission System



Road map of the runoff and components analysis



Model calibration: Multi-site discharge.

Model validation: Multi-site soil moisture; site ET, soil heat flux and CO_2 flux.

Process-based evaluation and model development

History and future of the river runoff.

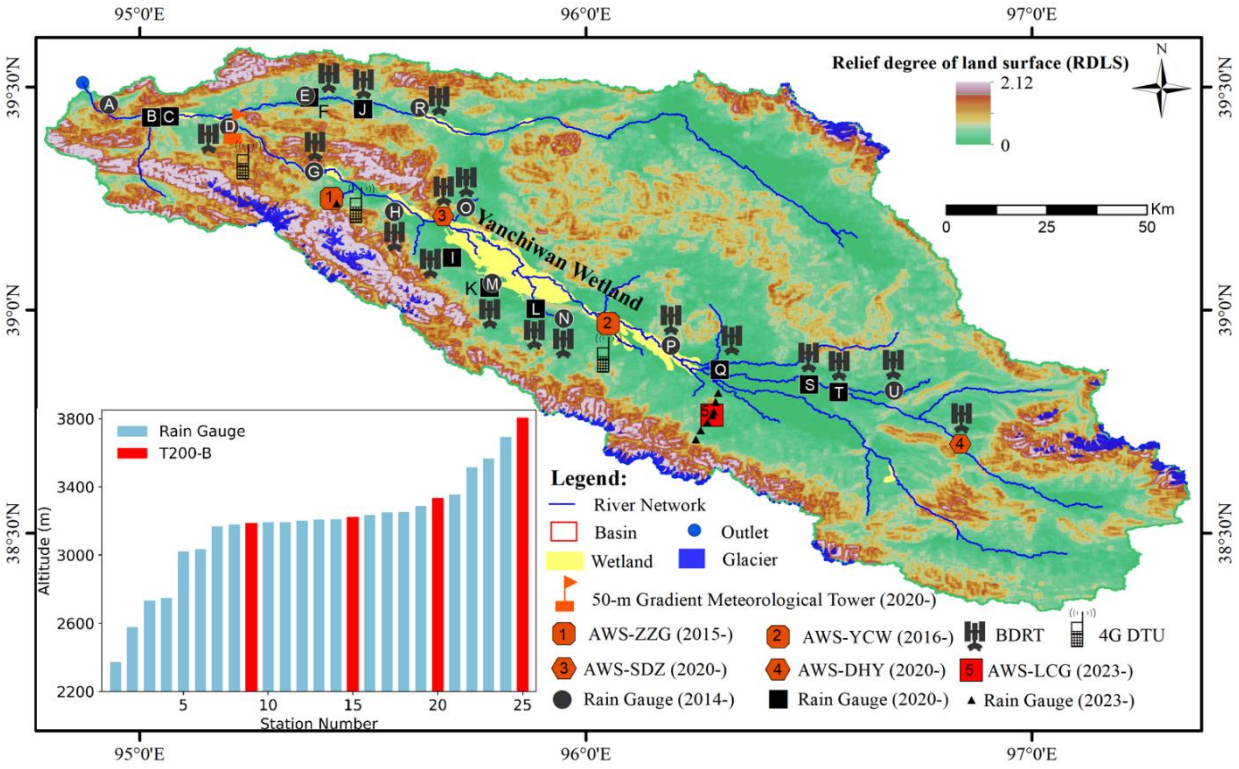
Control experiment: uncertainty analysis of various factors (glacier, frozen ground, vegetation) effects on runoff in UDB.

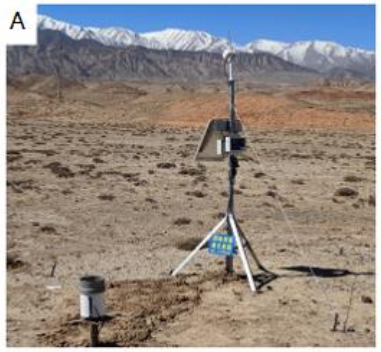
Changes of runoff components and the driving forces behind the changes.

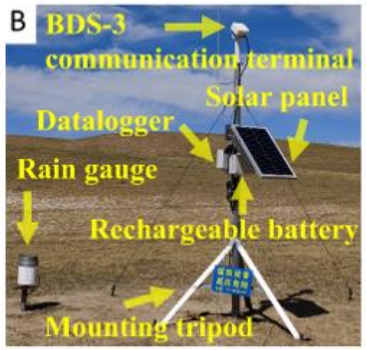
Reference: Liu R & Wang L* et al., BAMS, 2024, https://doi.org/10.1175/BAMS-D-23-0001.1

Rainfall observations and land surface process observations

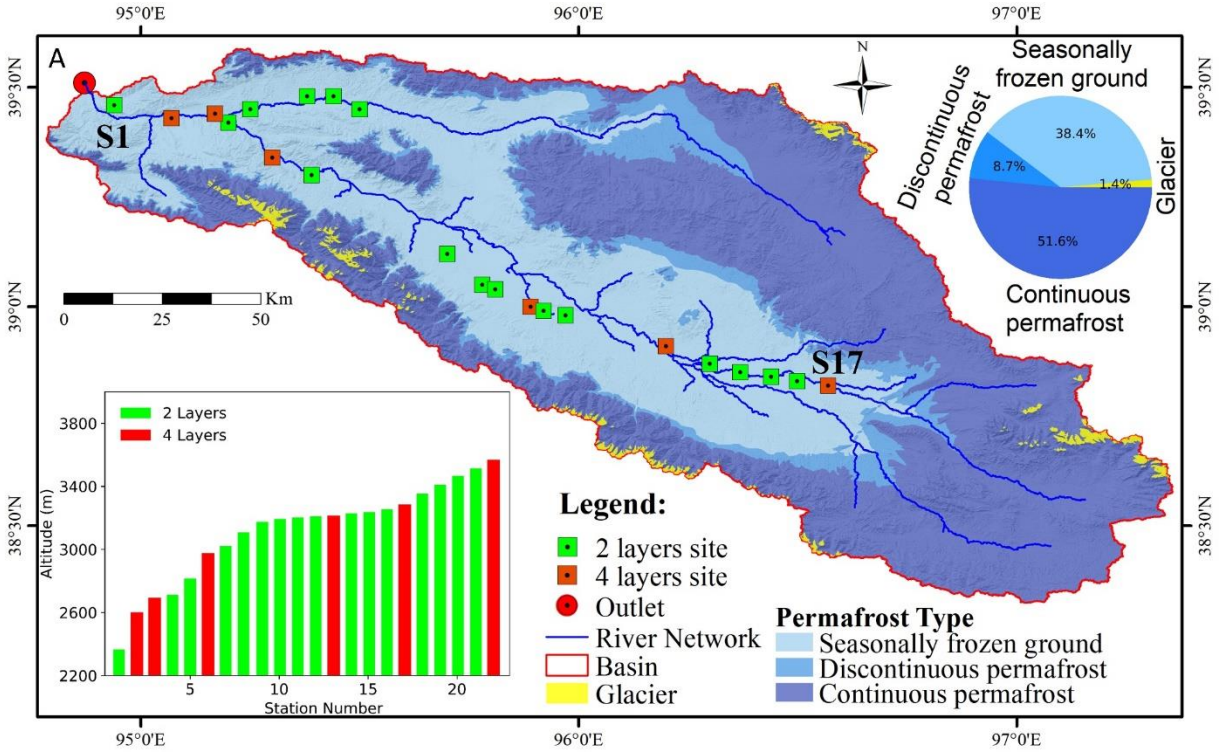
21 rain gauges; 4 AWS; the 50-m gradient meteorological tower; 18 sites with BDS-3 communication terminals (“BDRT” in the legend)

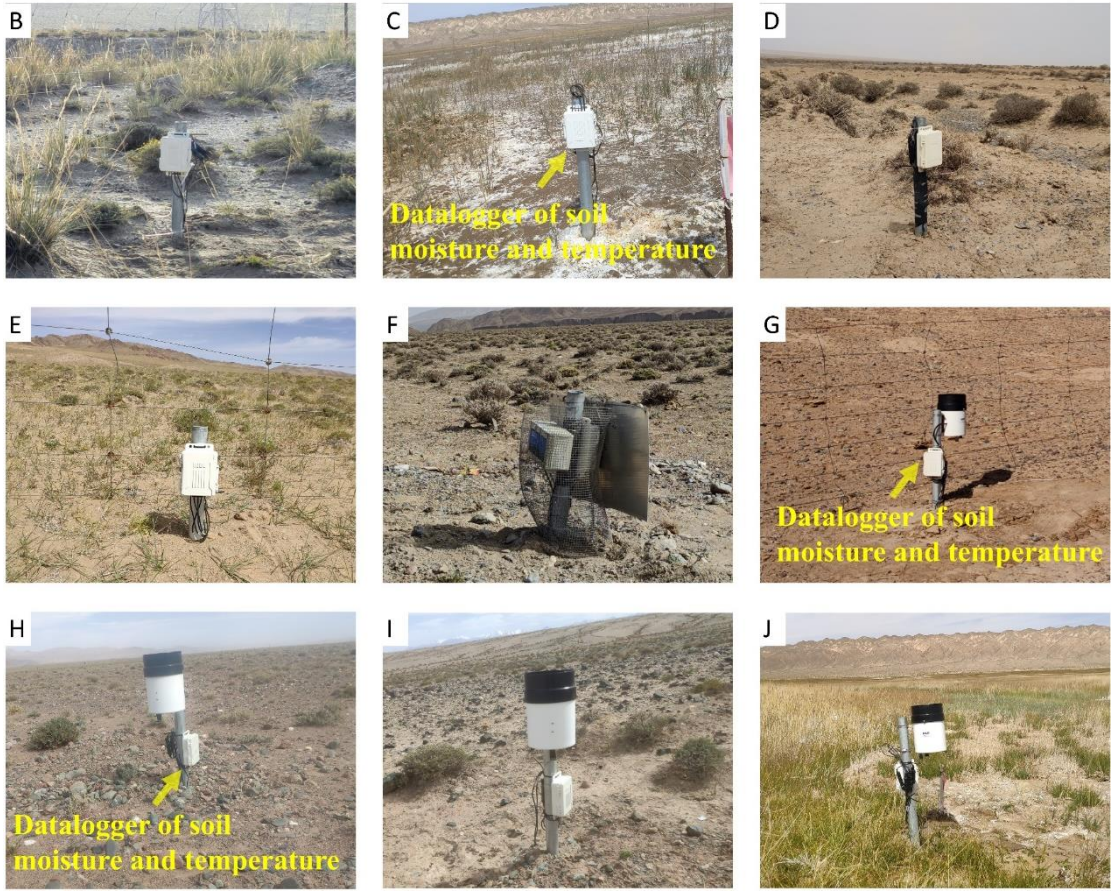






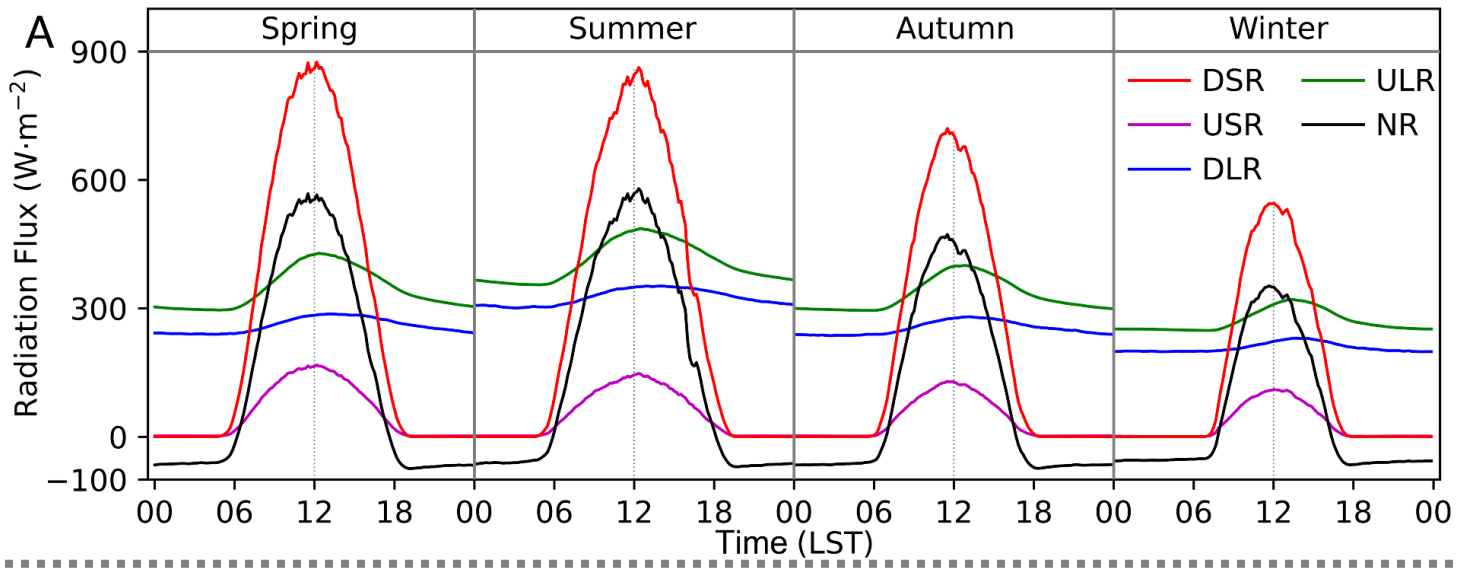
Soil moisture and temperature observation network



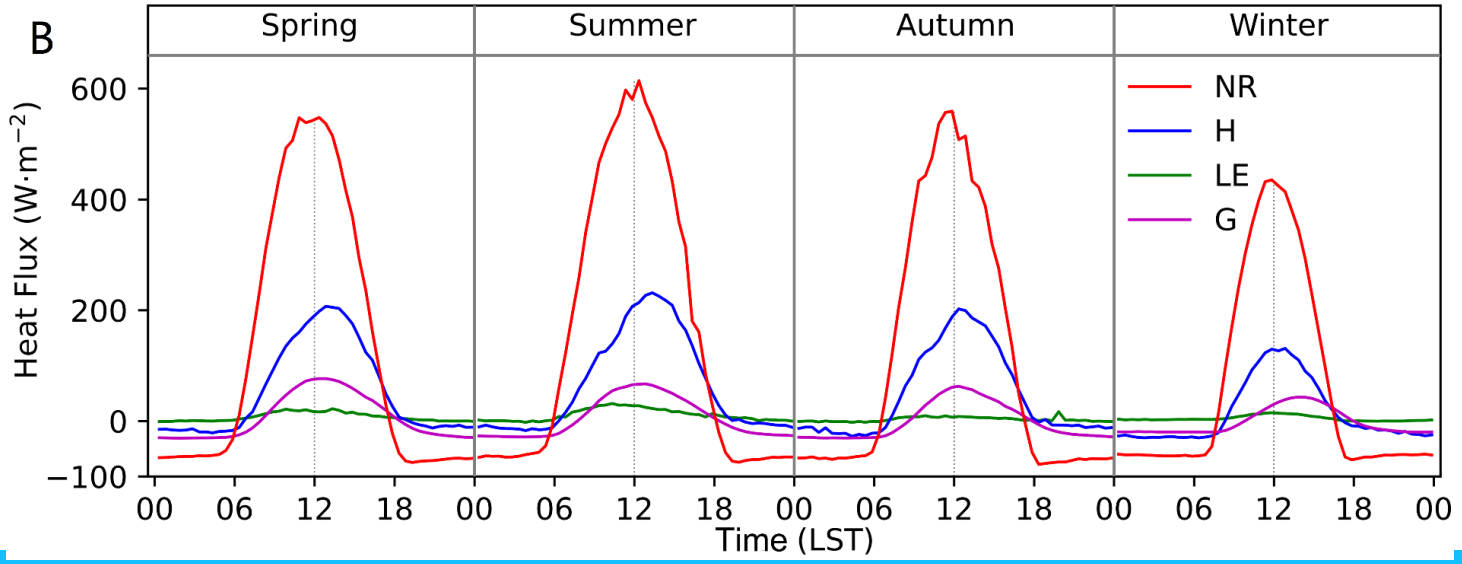


Soil moisture and temperature sensors:
Two layers (30/60 cm)
Four layers (20/30/60/80 cm)

Surface radiation and energy exchange at the 50-m gradient meteorological tower



Downward solar radiation and net radiation are higher at spring and summer. Longwave radiations are highest at summer, and lowest at winter.

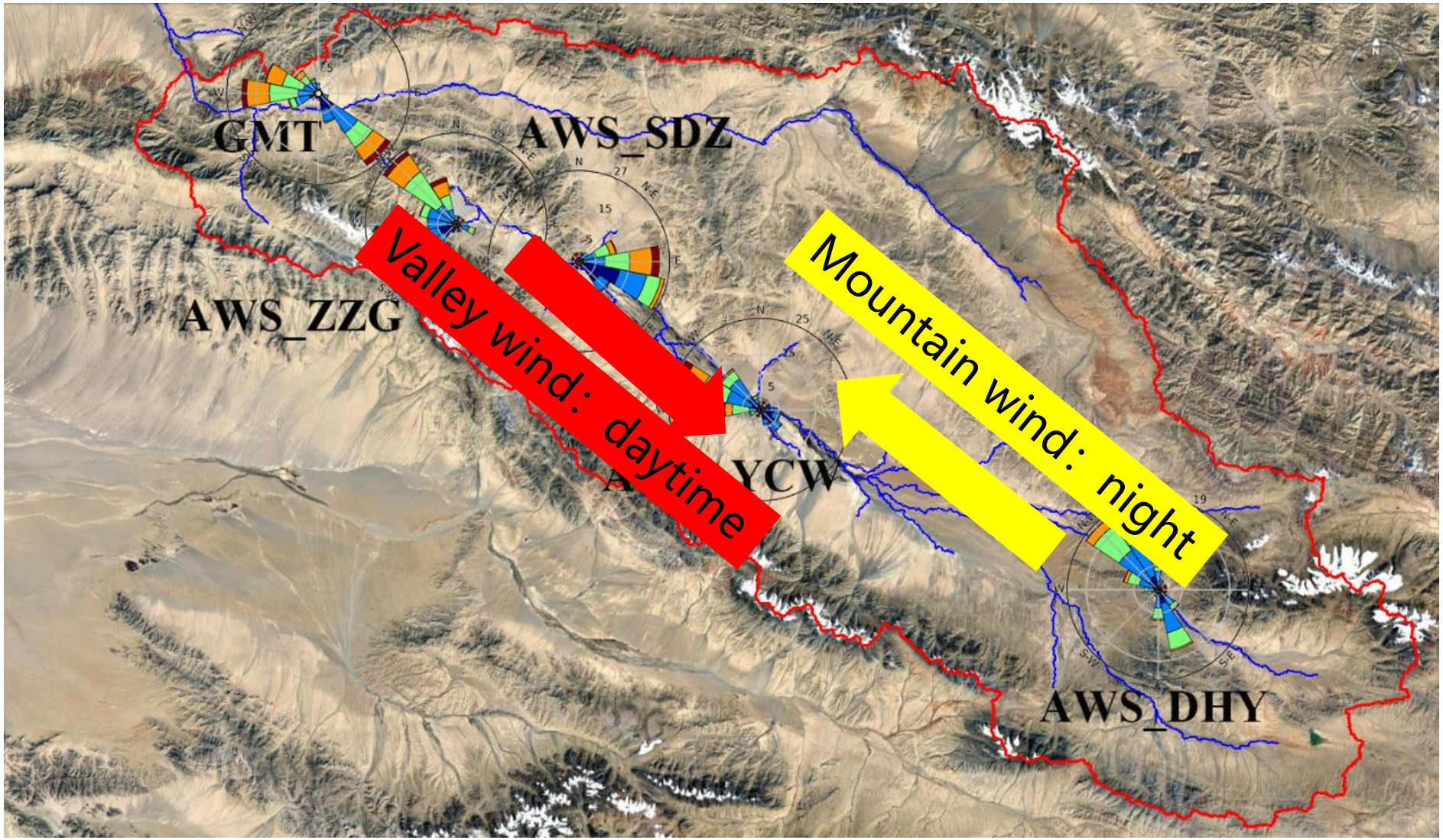


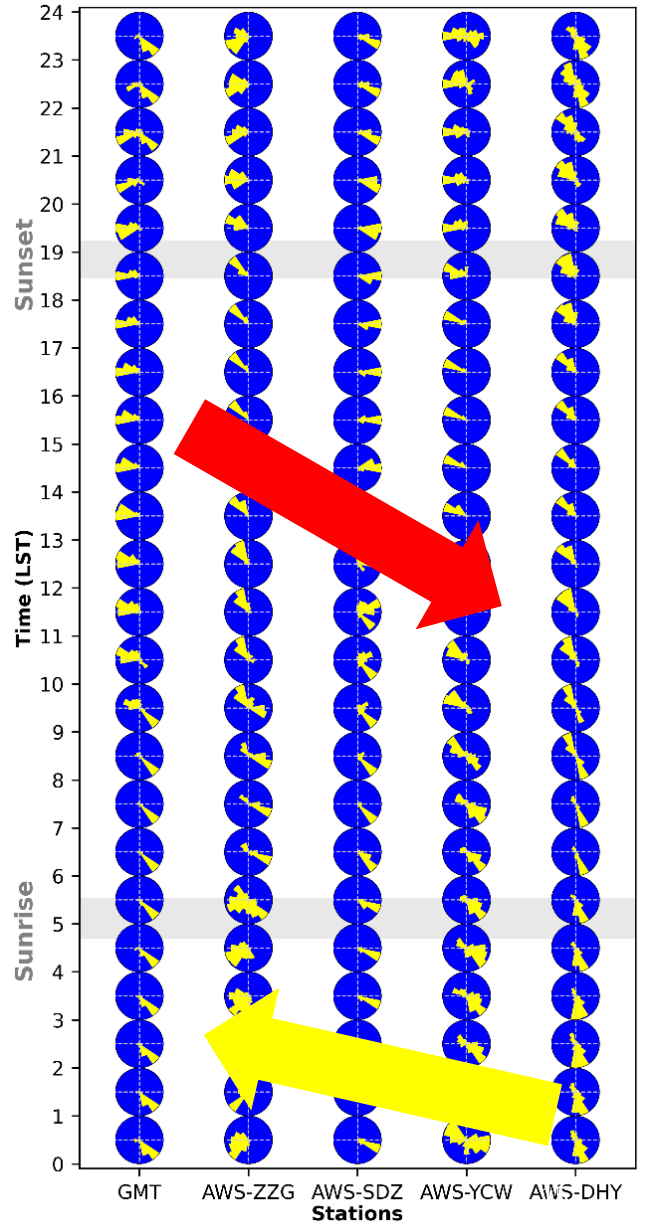
Sensible heat fluxes (H) are greater than latent heat fluxes (LE). LE is largest at summer; while H is smallest at winter.

Reference: Liu R & Wang L* et al., BAMS, 2024, https://doi.org/10.1175/BAMS-D-23-0001.1

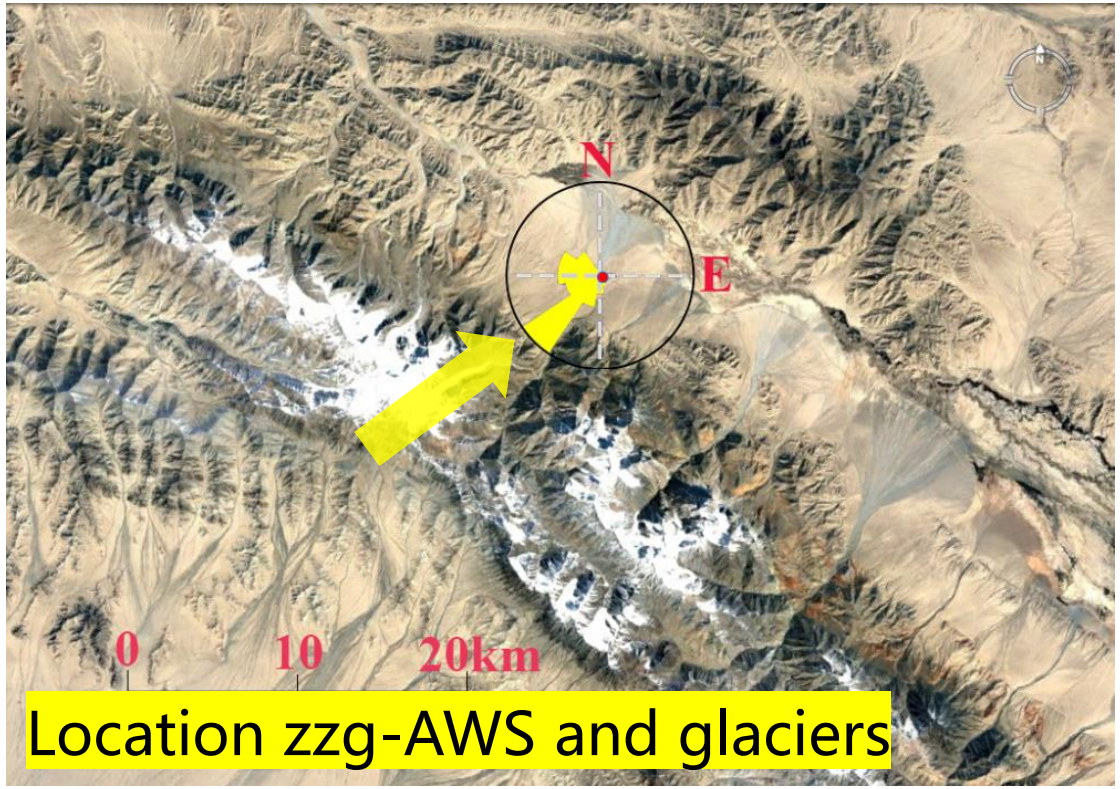
Diurnal change of local winds

局地风场日变化





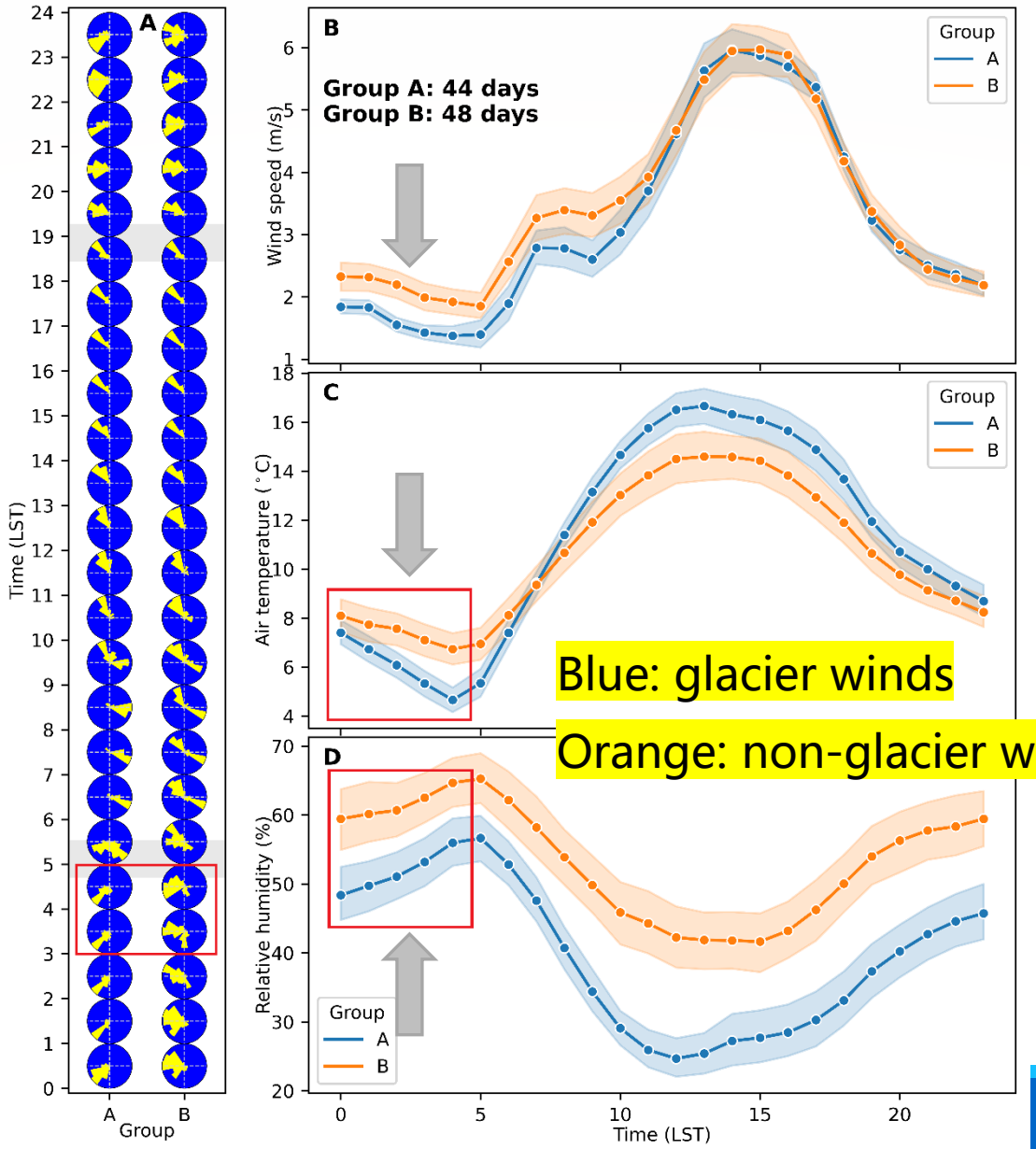
Glacier wind



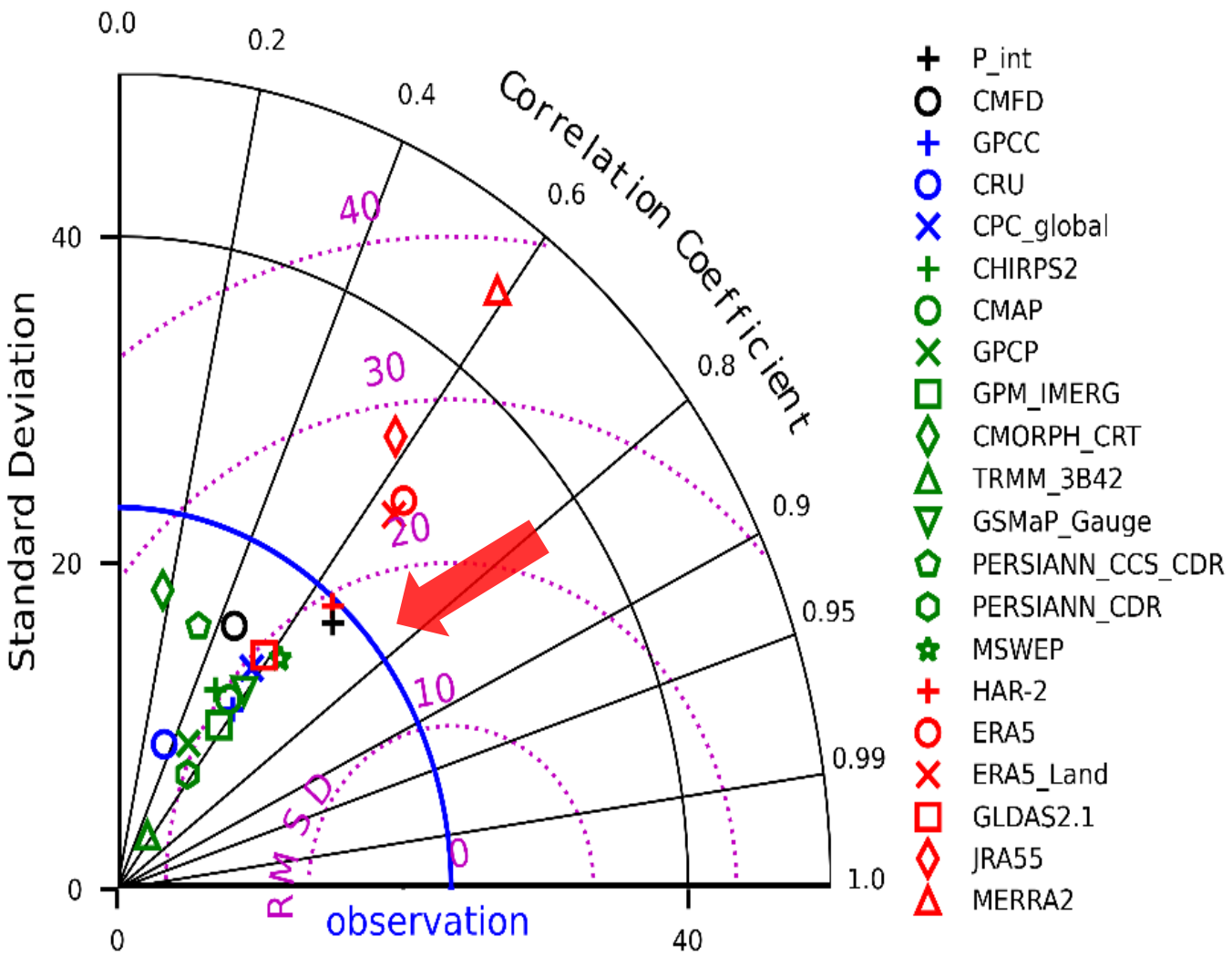
Location zzg-AWS and glaciers

By contrast experiments, we compare the wind speed, air temperature, and relative humidity for glacier winds and non-glacier winds

Glacier winds: colder and drier



Taylor diagrams used to compare the precipitation estimates across the basin (2014–2021).



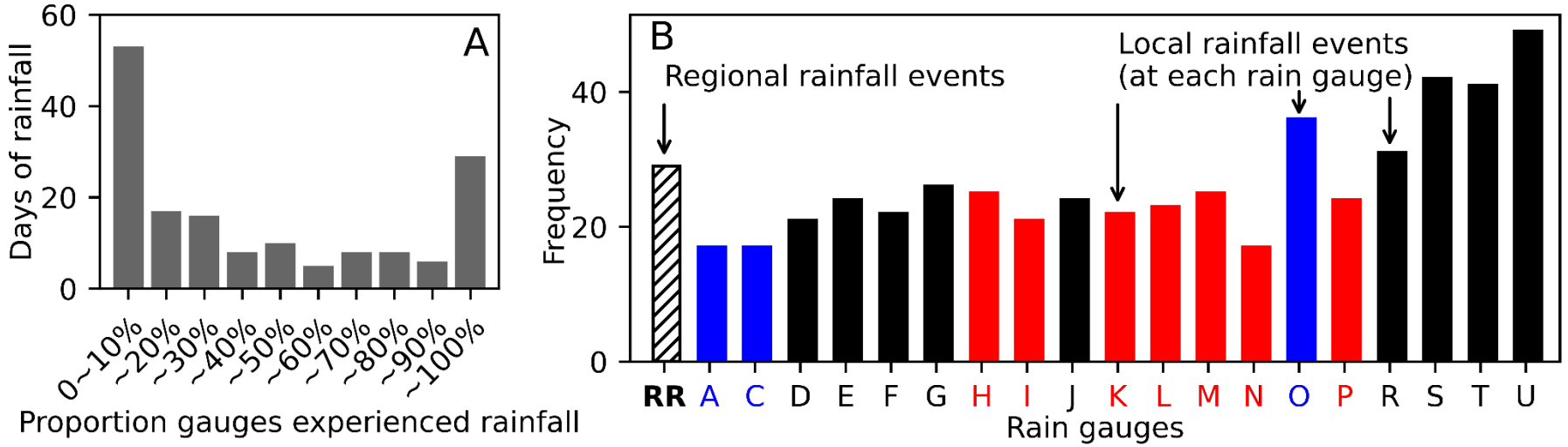
High Asia Refined analysis version 2 (HAR-2) exhibited strong agreement with observations, boasting high correlation coefficients and low RMSD. Although ERA5-Land and ERA5 also showed reasonable correlation coefficients (>0.6), their RMSD values were comparatively larger.

On the whole, gauge- and satellite-based datasets tend to underestimate rainfall, whereas reanalysis datasets tend to overestimate it in this region.

After the evaluation of existing datasets, we developed a new precipitation product (P_int) for 1995–2019 over UDB at 3h and 2km resolution for modeling.

Reference: Liu R & Wang L* et al., BAMS, 2024, https://doi.org/10.1175/BAMS-D-23-0001.1

Frequency of different types of rainfall events

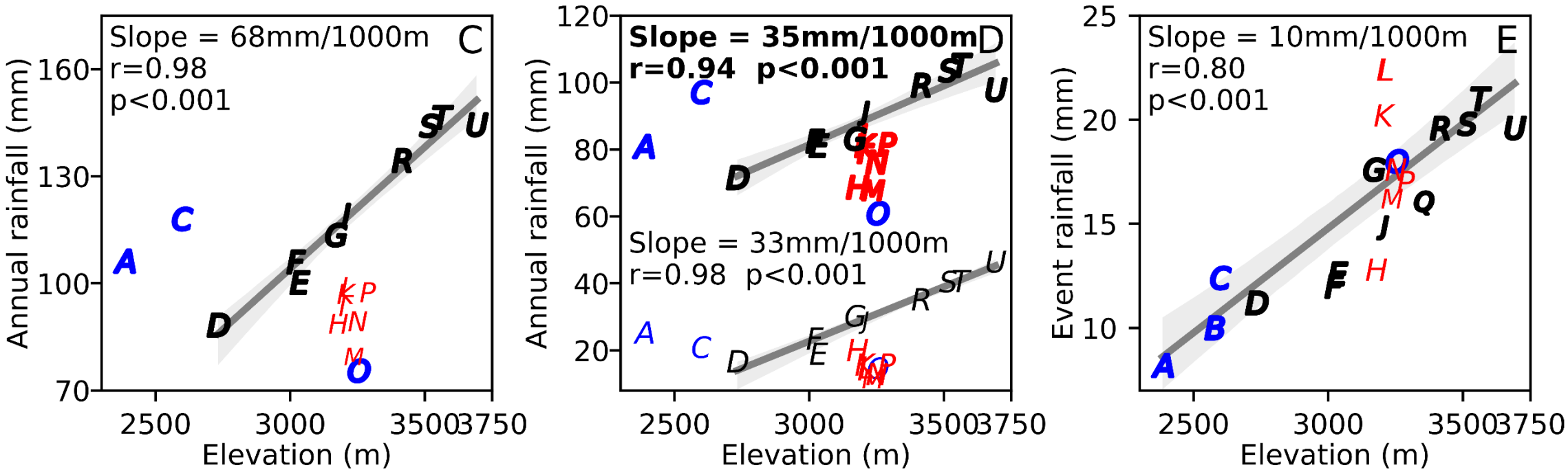


(a) The frequency of the proportion of rain gauges with rainfall events during a day in 2021/22.

(b) The frequency of different types of rainfall events in 2021/22; a regional rainfall event occurs when over 90% of the rain gauge sites measure the rainfall; otherwise, it is defined as a local rainfall event; the frequency of local rainfall events is counted site by site.

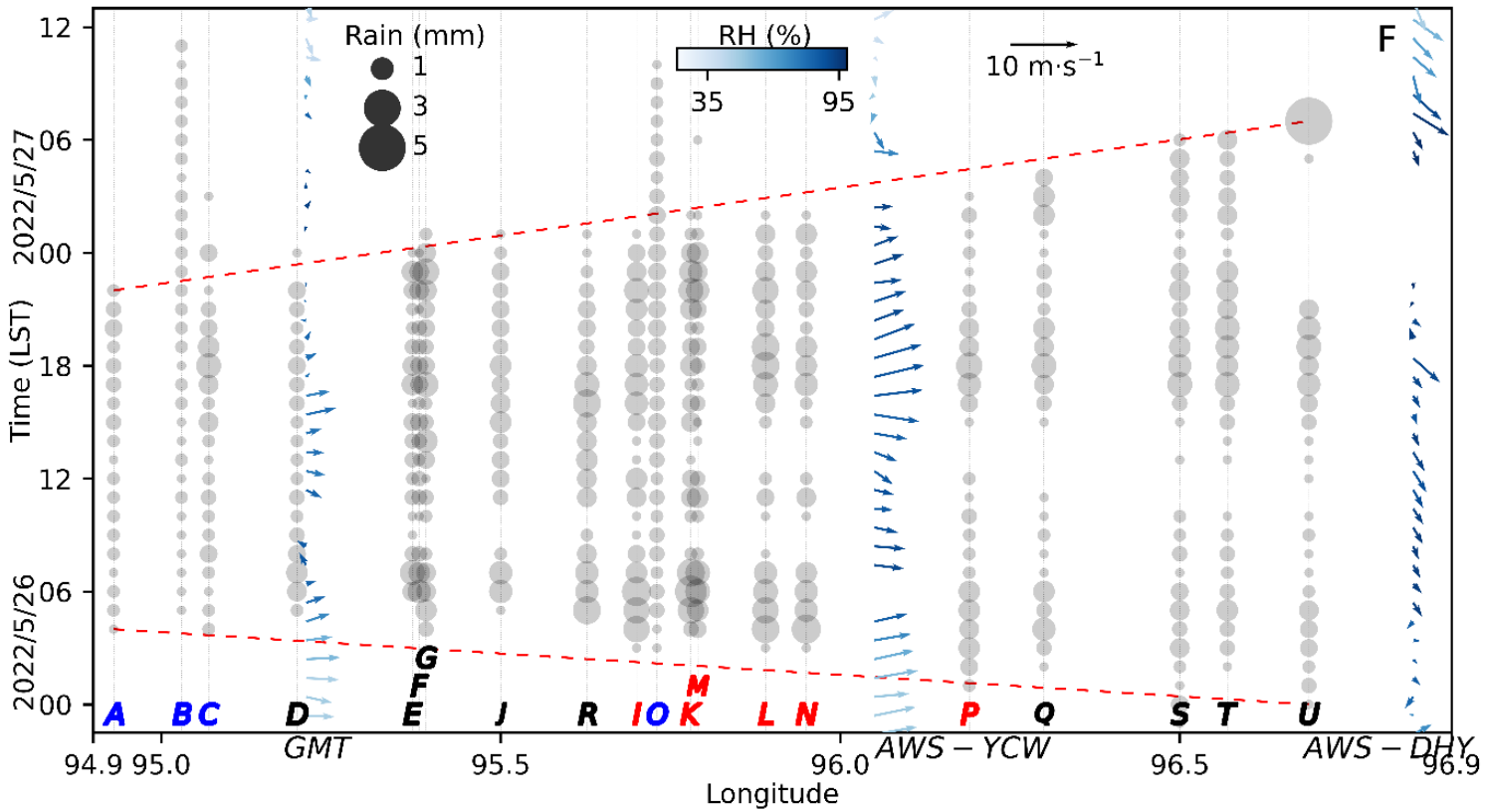
During 2021-2022, there are total 29 regional rain events, taking up about 18% of all.

Observed elevation-dependency of rainfall



(C) Relationship between average annual rainfall and elevation during 2021/22. The gray line denotes the linear regression line for the data of altitude-dominated rain gauge sites (black letters). (D) regional (boldface) and local (non-boldface) **rainfall events are displayed separately. (E) Relationship between rainfall and elevation in a regional rainfall event during 25–27 May 2022.**

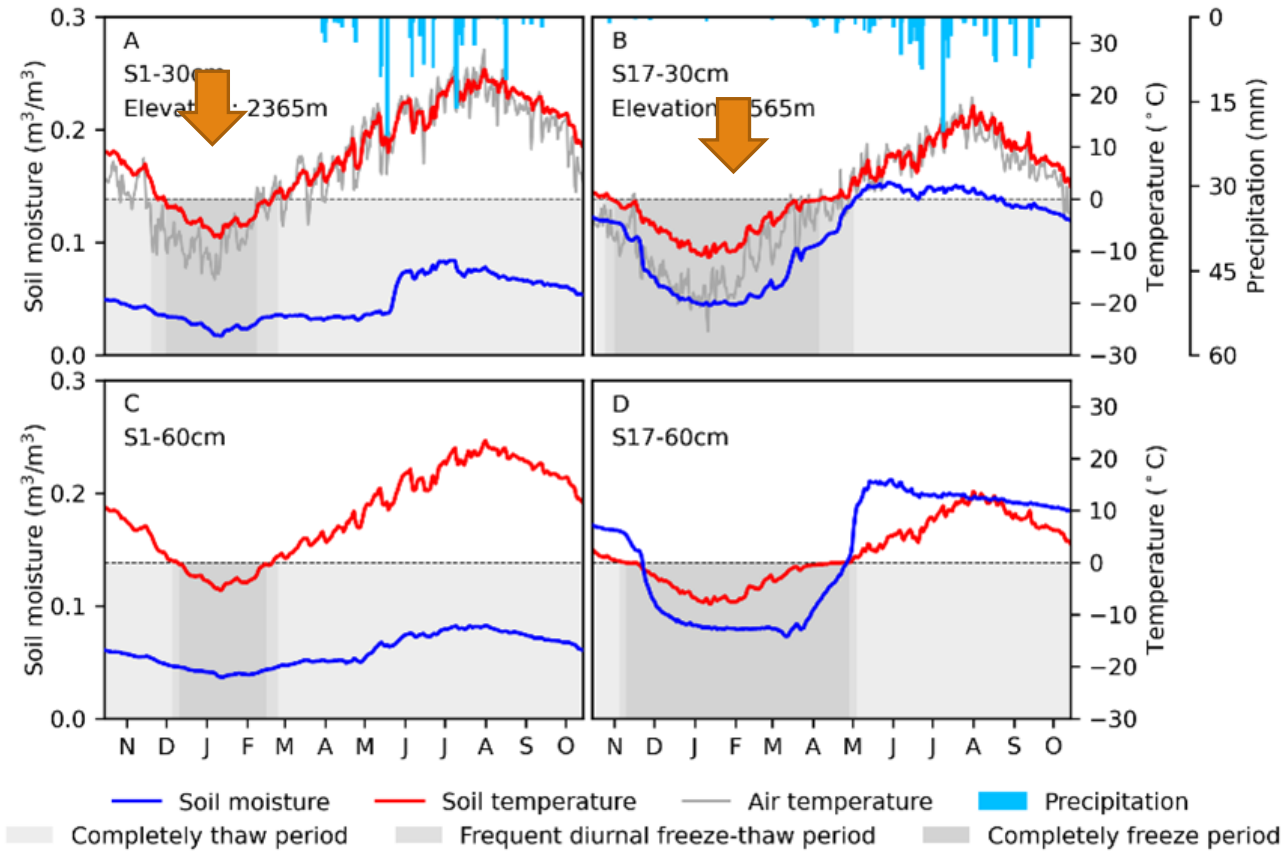
The process of regional rainfall event from 25 to 27 May 2022



Rainfall event showed obvious westward propagation

- **Wind and relative humidity (RH) are recorded by 50-m gradient meteorological tower, AWS-YCW and AWS-DHY. The red dashed line indicates the start and end of the rainfall process at each station.**
- **Blue, red, and black represent rain gauges categorized as "complex terrain site," "wetland effect site," and "altitude-dominated site," respectively.**

Observed daily soil moisture and temperature, air temperature and rainfall variations from 15 Oct 2020 to 14 Oct 2021

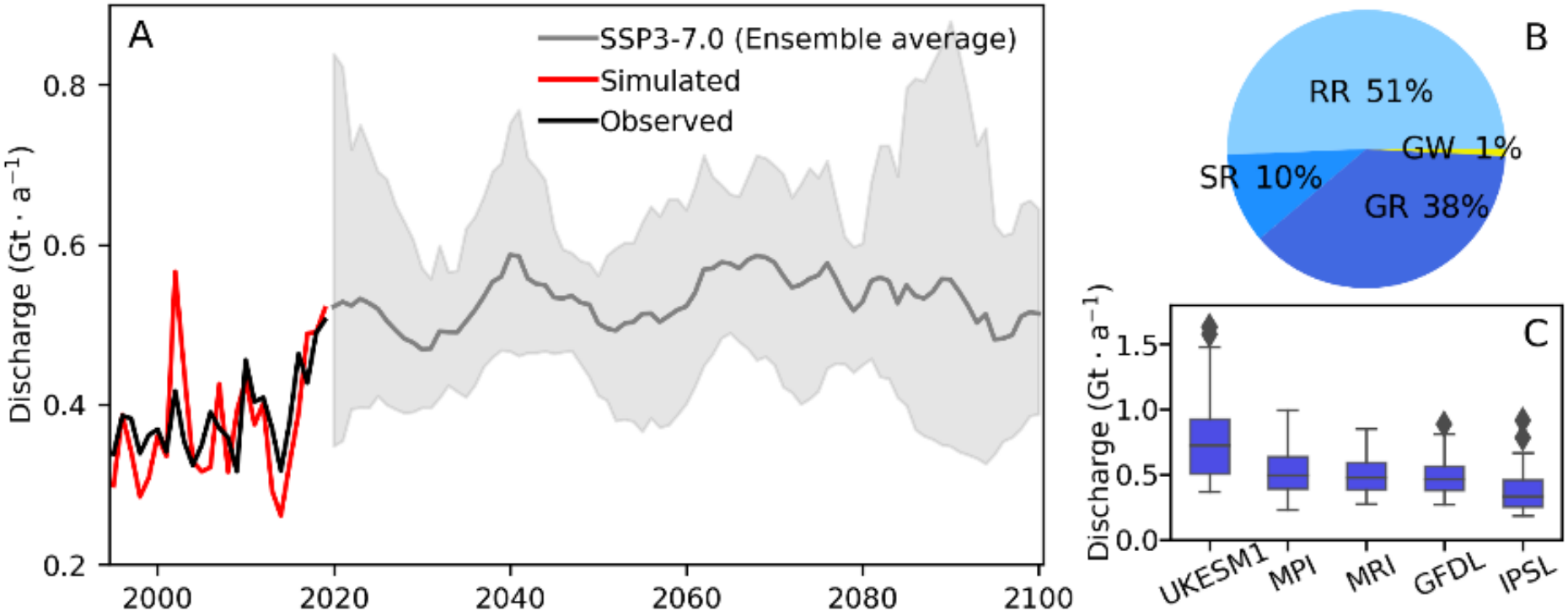


Soil freeze-thaw cycle at two sites

By comparing the freeze-thaw process of soil at two sites with similar annual rainfall, we find that the freezing period was longer in the high altitude area due to lower temperature. Evaporation is lower at higher elevations, thereby soil moisture is significantly higher.

At the beginning of freezing, soil with large water content will release a lot of latent heat when freezing, so the temperature difference between air temperature and soil temperature becomes significantly larger.

Temporal changes of discharge over 1995–2100 in the UDB



Runoff component: rain-runoff 51%, glacier melt 38%, snowmelt 10%, groundwater runoff 1%. Under the SSP370 scenario, the future runoff will increase by the projections till 2100. The UKESM1, MPI, MRI, GFDL, and IPSL represent the GCM versions UKESM1-0-LL, MPI-ESM1-2-HR, MRI-ESM2-0, GFDL-ESM4, and IPSL-CM6A-LR, respectively. Discharge is shown by annual runoff volume (Gt/a).

Summary

- The integrating cryosphere–hydrometeorology observation network with BeiDou-3 Satellite System and high-density instrumentation provides the community a unique example of studying regional water cycle processes from the perspective of both synoptic meteorology and cryosphere hydrometeorology.
- The UDB observation system holds the potential to serve as a pivotal research platform for disciplines like arid zone hydrology, mountain meteorology, cryosphere studies, and climate change sciences.

Many thanks for your kind attention!

Reference: Liu R & Wang L* et al., BAMS, 2024, https://doi.org/10.1175/BAMS-D-23-0001.1