Water cycle modeling for the Third Pole: Progress and perspective

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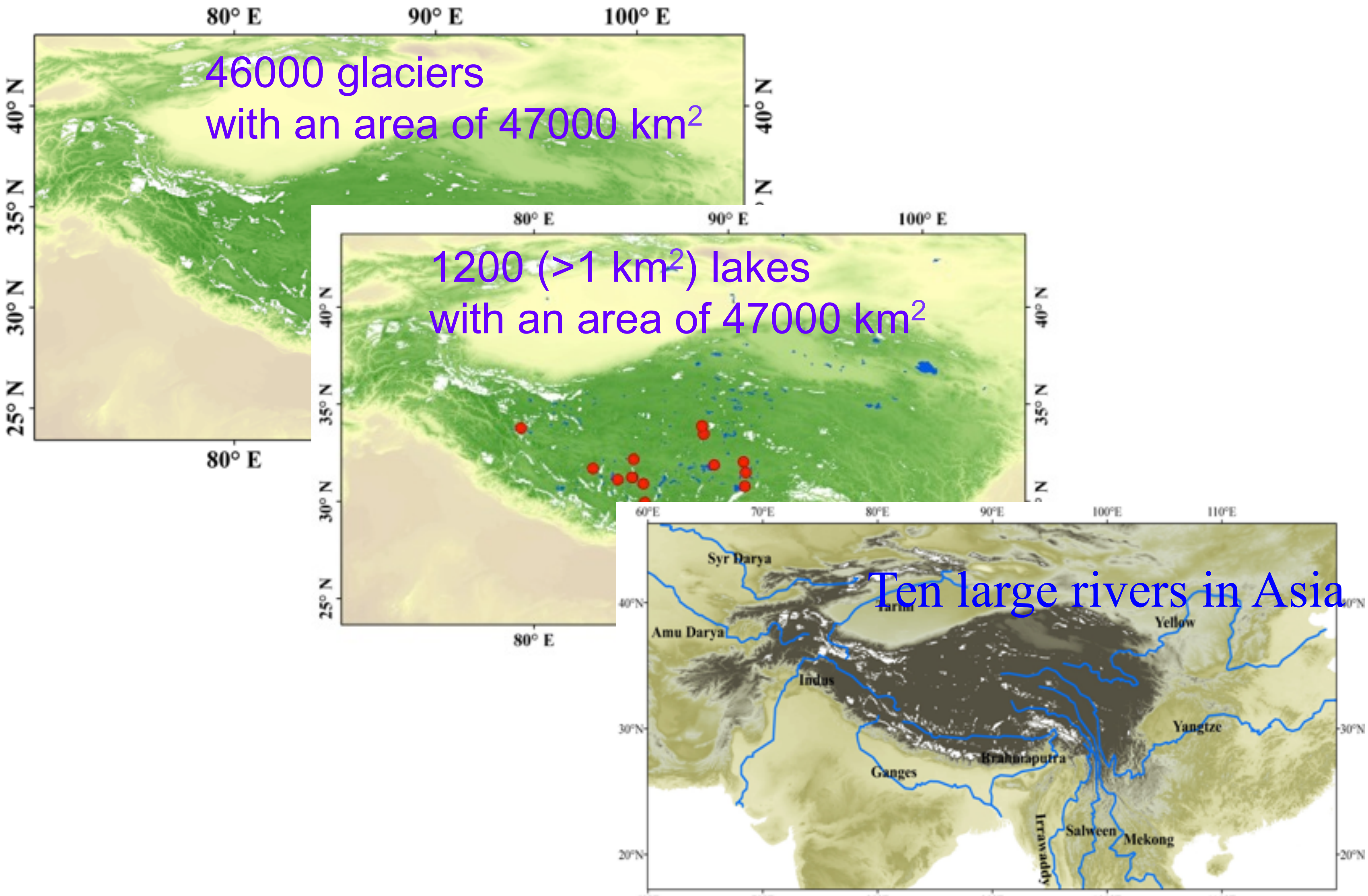
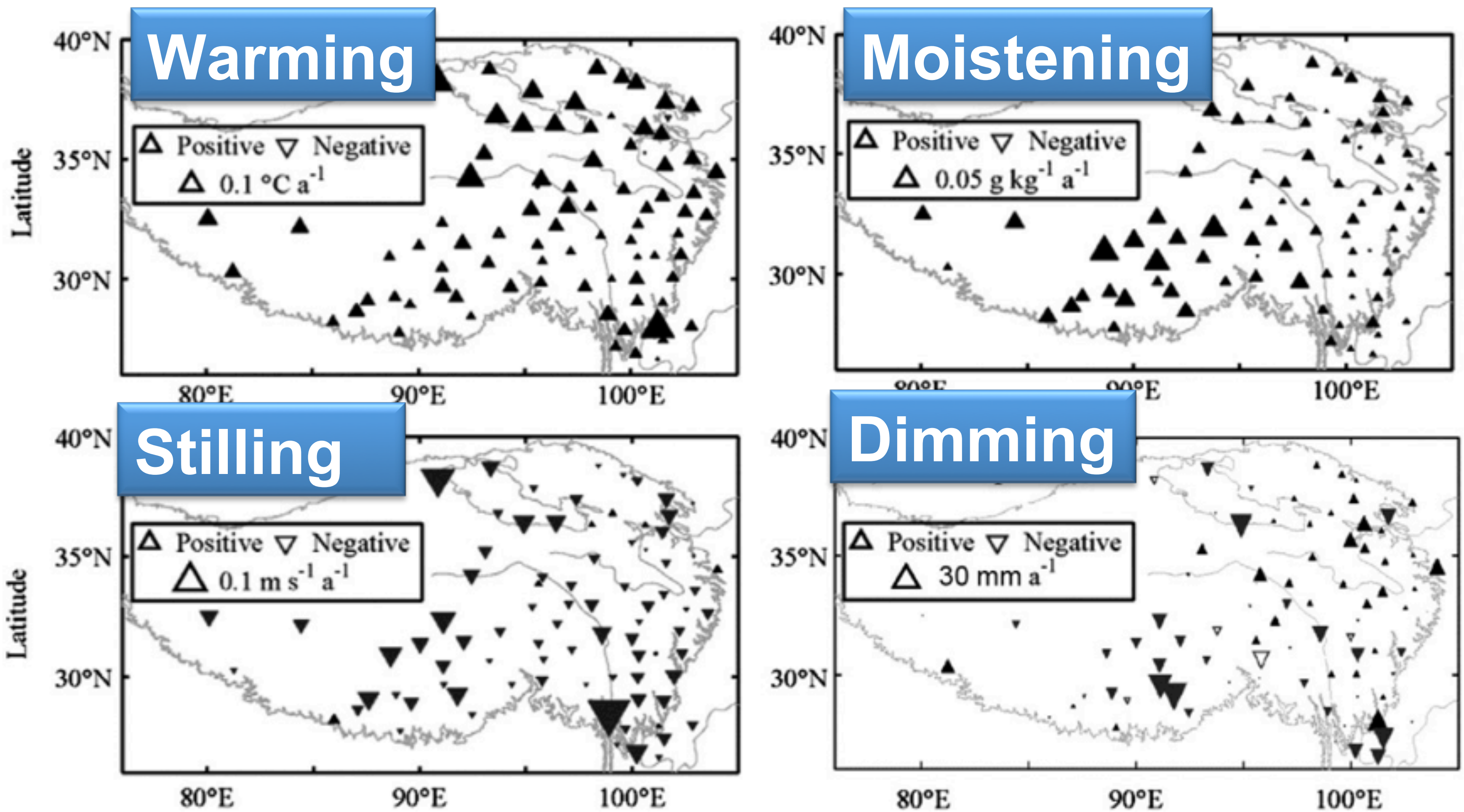
Outline

- Background
- Integrated land model development
  - Glacier model
  - Lake model
- Impact of complex-terrain on climate
- Summary and Plan

Crucial to understanding and modeling water cycle across multi-spheres in the Tibetan Plateau

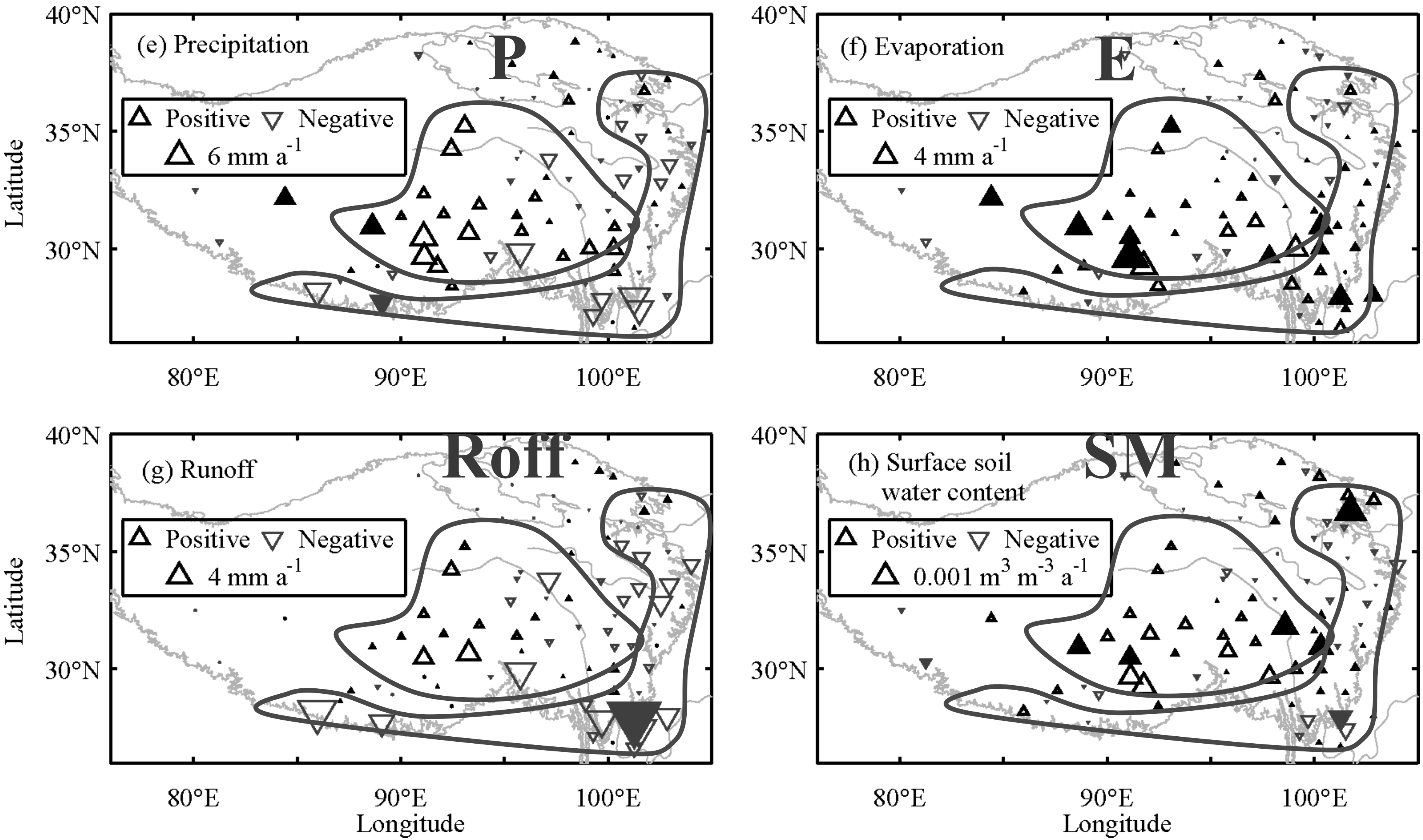


The Tibetan Plateau has been experiencing a rapid climate change since middle of 1980s: warming, moistening, wind stilling and solar dimming



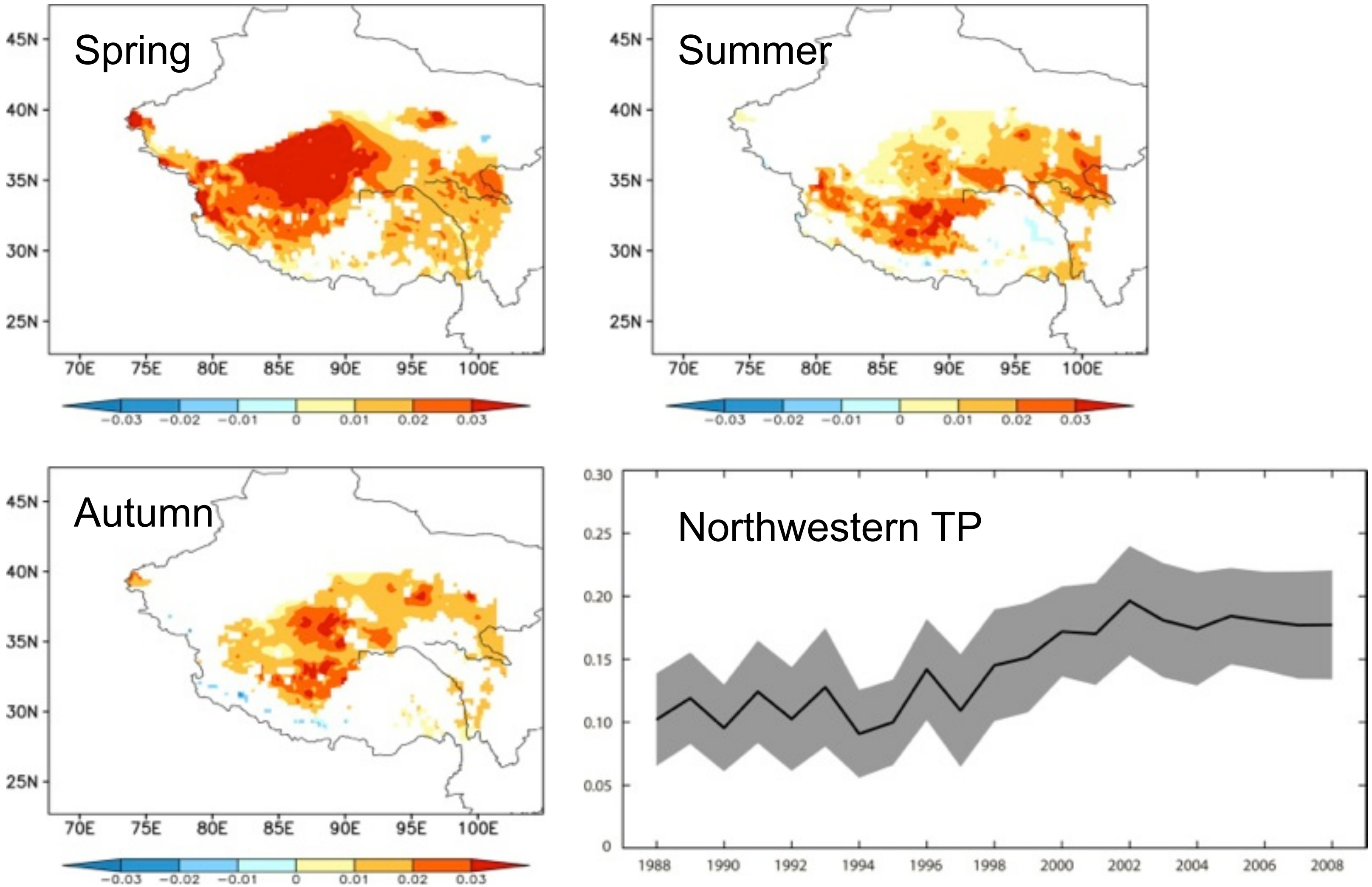
(Yang et al. 2014, GPC)

Hydrological cycle response: more runoff in central TP and less runoff in south/east TP



(Yang et al. 2014, GPC)

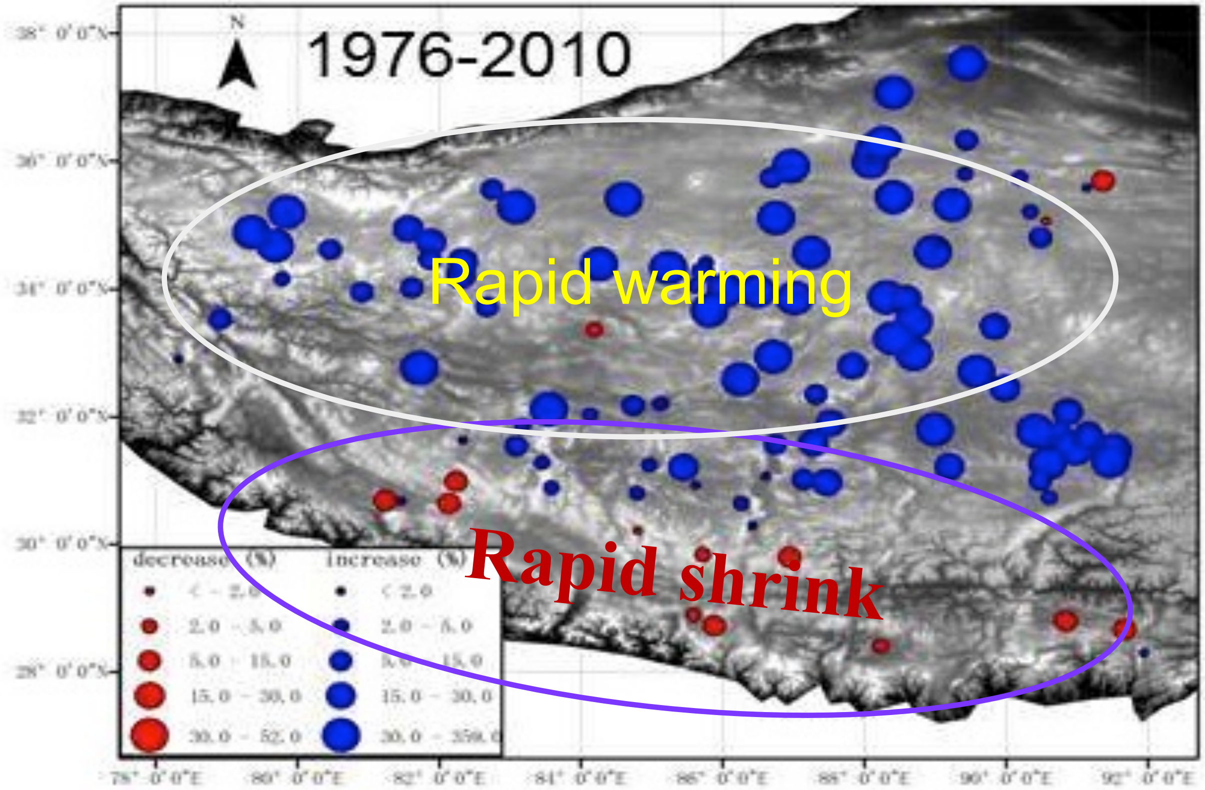
The positive trend in soil moisture derived from microwave also supports NW TP got wet ($m^3 m^{-3}$ per 10a)



(Velde et al. 2014, HESS)

Summary on regional hydrological response

Spatial pattern of water balance change: Dry (Central and Western TP) got less dry, and wet (Southern and Eastern TP) got less wet. This is consistent with the pattern of lake change



(Figure from Lei et al, 2014, Clim. Chang.)

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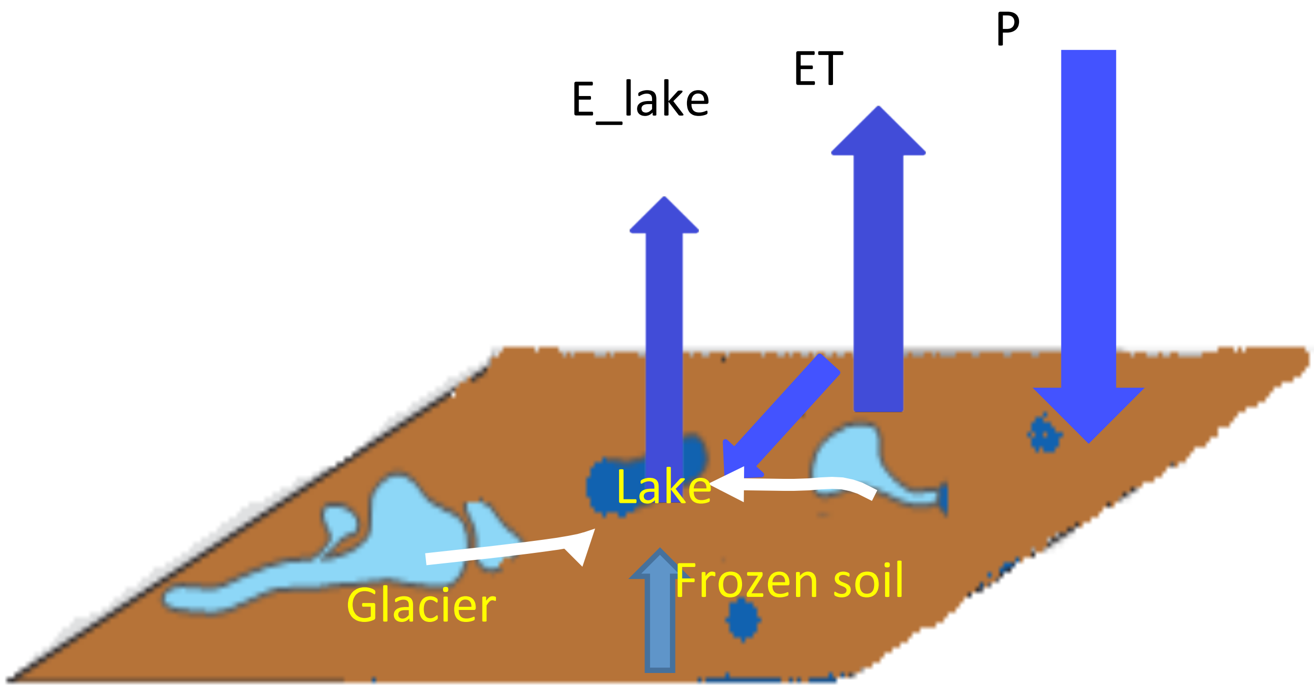
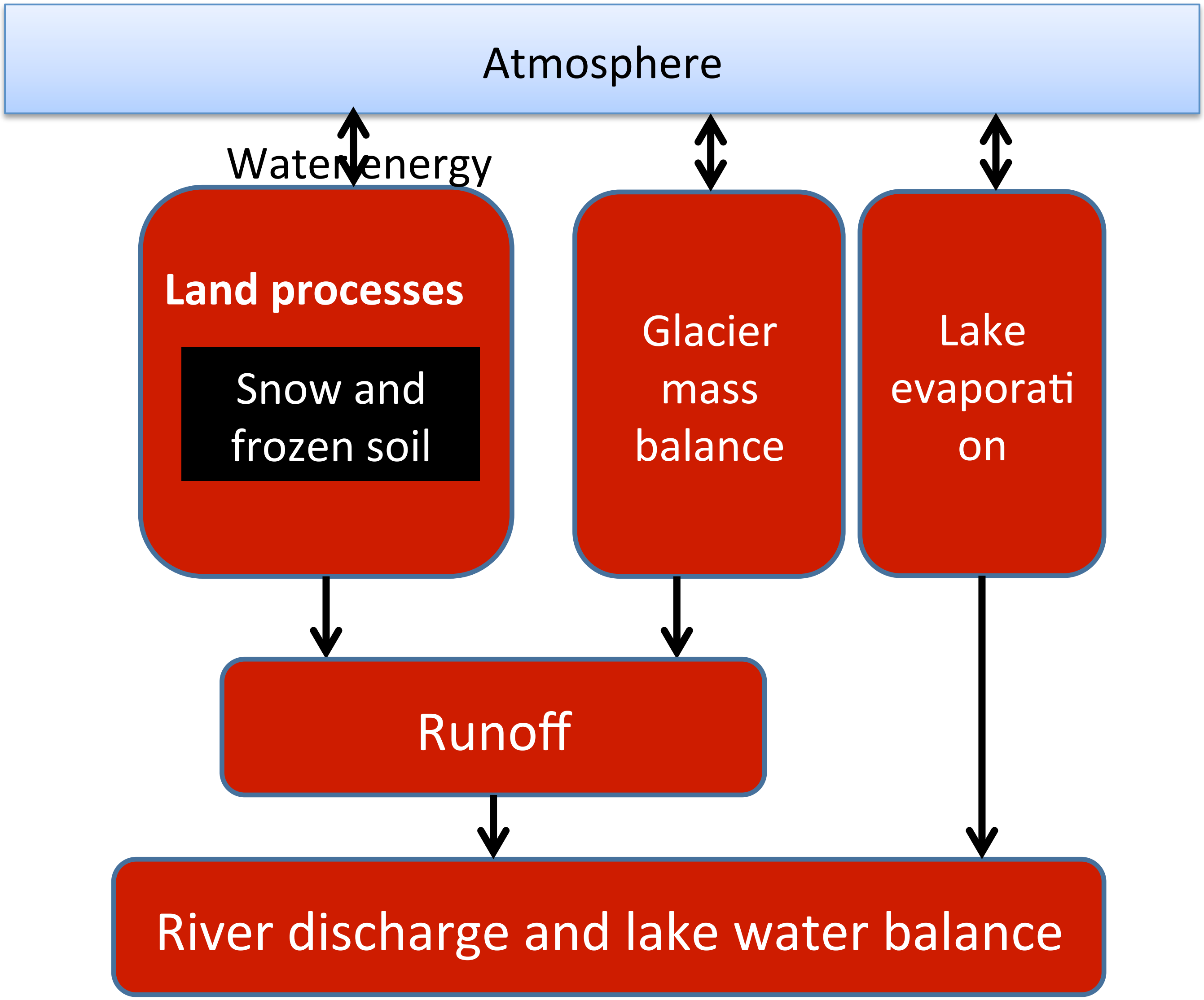
Water cycle change may be related to changes in several components (precipitation, land/lake evaporation, glacier/snow melting, frozen soil degradation)



Develop an integrated model to understand interactions among multi-spheres and quantify water cycle change (prec., land/lake evaporation, glacier melting, frozen soil)



Development of a Water and Energy Budget-based Glacier mass balance Model (WEB-GM)

AGU PUBLICATIONS

Water Resources Research

RESEARCH ARTICLE

10.1002/2016WR018865

Key Points:

- A new glacier mass balance model based on enthalpy budget was developed
- Albedo parameterization was refined to consider the impact of sleet and shallow snow
- A dynamic snow/sleet/rain identification scheme and a turbulent heat flux scheme were implemented to improve modeling

Development of a Water and Enthalpy Budget-based Glacier mass balance Model (WEB-GM) and its preliminary validation

Baohong Ding[1], Kun Yang[1,2,3], Wei Yang[1,2], Xiaobo He[4], Yingying Chen[1,2], Lazhu[1,5], Xiaofeng Guo[6], Lei Wang[1,2], Hui Wu[7], and Tandong Yao[1,2]

[1]Key Laboratory of Tibetan Environment Changes and Land Surface Processes, Institute of Tibetan Plateau Research, Chinese Academy of Sciences (CAS), Beijing, China, [2]CAS Center for Excellence in Tibetan Plateau Earth Sciences, Beijing, China, [3]Department of Earth System Science, Tsinghua University, Beijing, China, [4]State Key Laboratory of Cryospheric Sciences, Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou, China, [5]University of Chinese Academy of Sciences, Beijing, China, [6]State Key Laboratory of Atmospheric Boundary Layer Physics and Atmospheric Chemistry, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China, [7]State Key Laboratory of Severe Weather, Chinese Academy of Meteorological Sciences, Beijing, China

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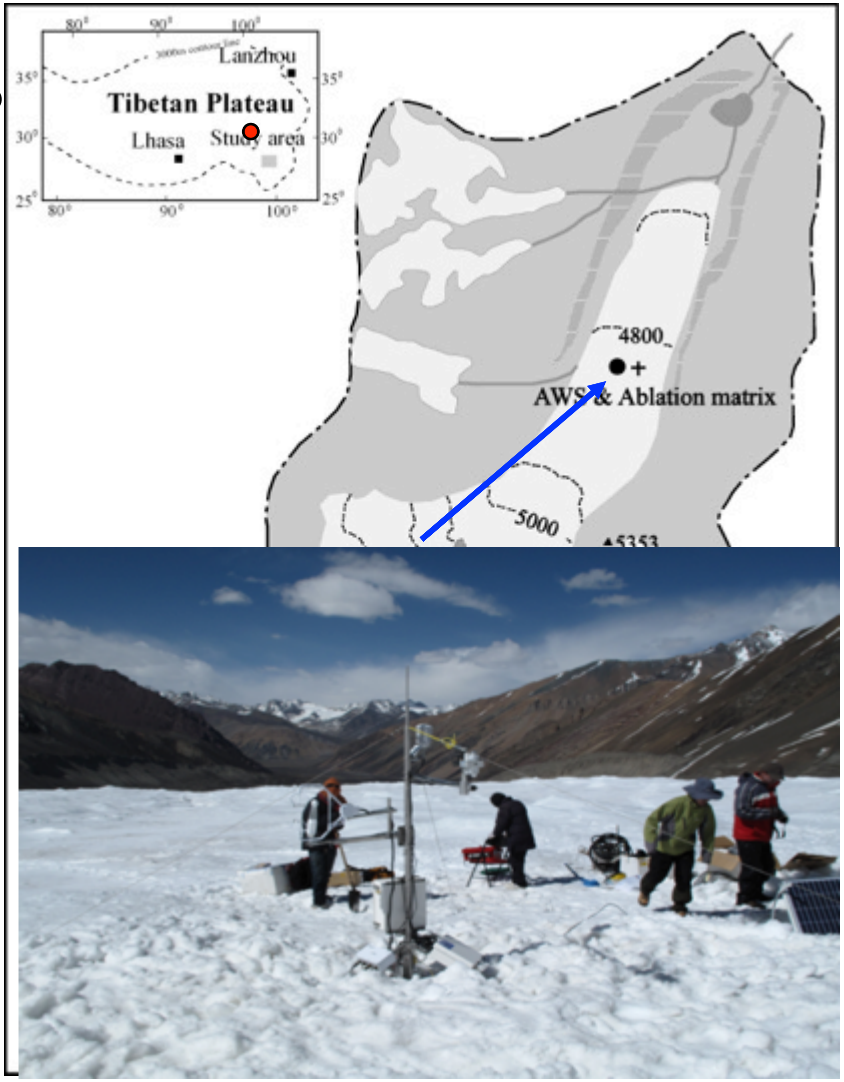
The first glacier energy budget station in China

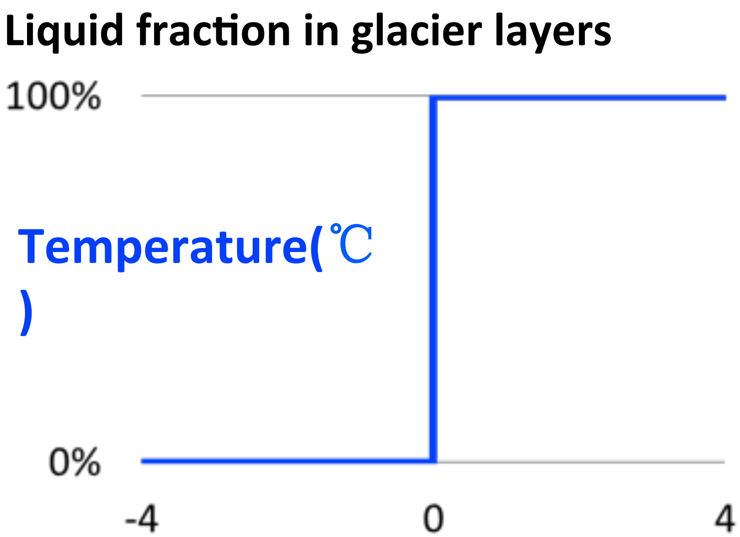
- **Parlung No.4 Glacier**
  - A typical maritime glacier in SE-TP
  - Area: ~11.7 km^2
  - Length: ~8 km
  - Elevation: 4650 m ~ 5964 m

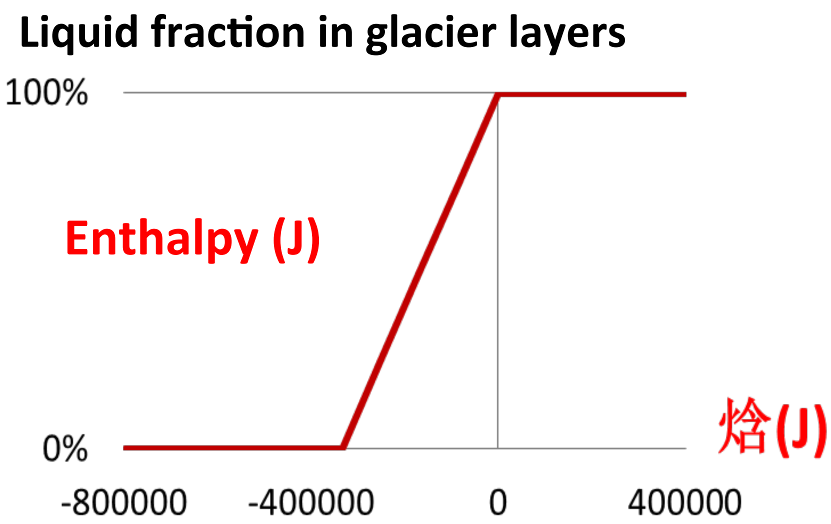
- **Observation**
  - Net radiation
  - Surface heat flux
  - Meteorological data
  - Ablation depth



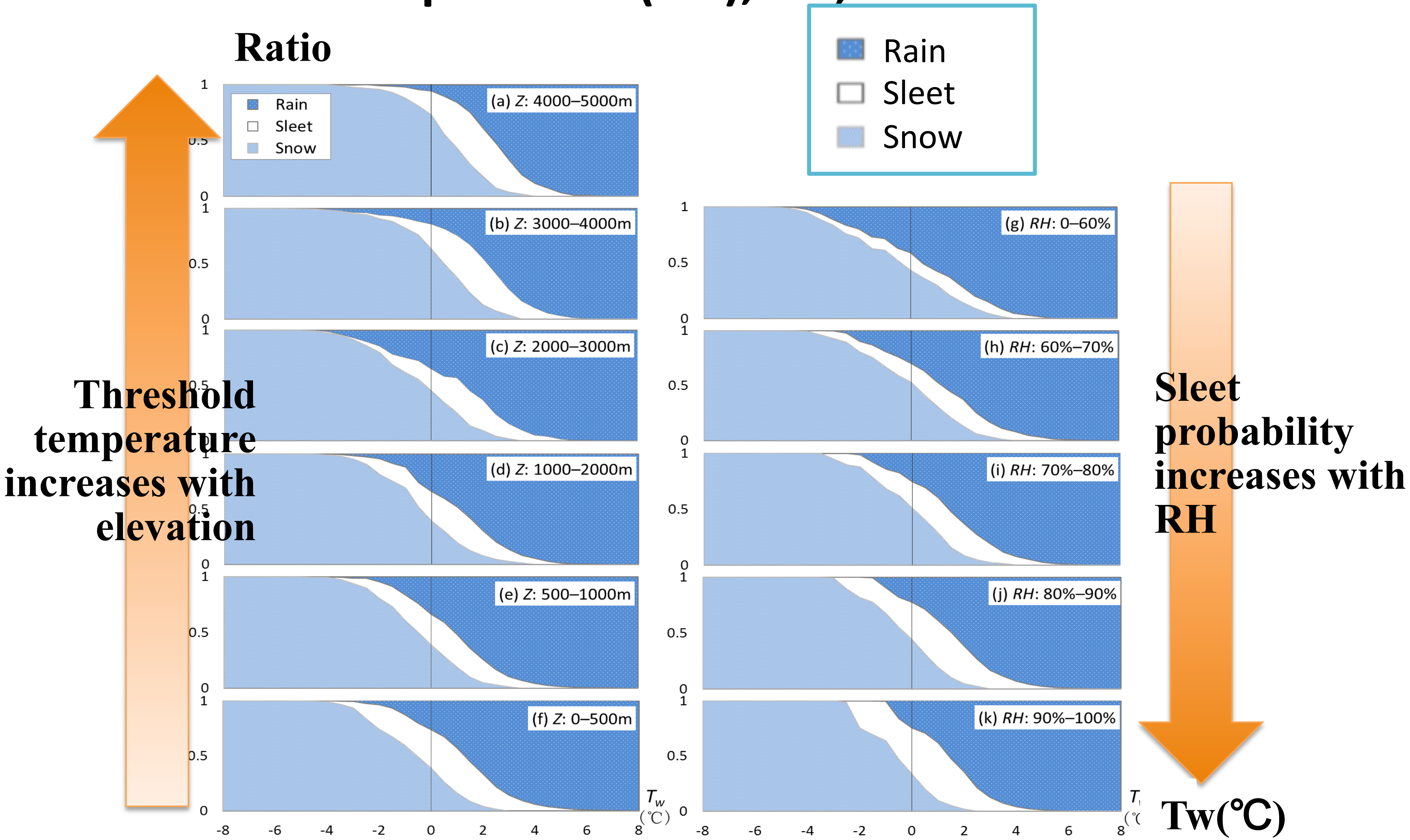
Enthalpy-based model for numerical solution

- **Deficiency:** during water phase transition, abundant energy absorption/release occurs, but surface temperatures remain at the freezing point, which often induces computational instability when temperature is used as the
- **Solution:** Enthalpy is used as the unknown to ensure computational stability. Enthalpy represents energy state that is defined to be zero for liquid water at the freezing point. Enthalpy changes with respect to the liquid fraction.



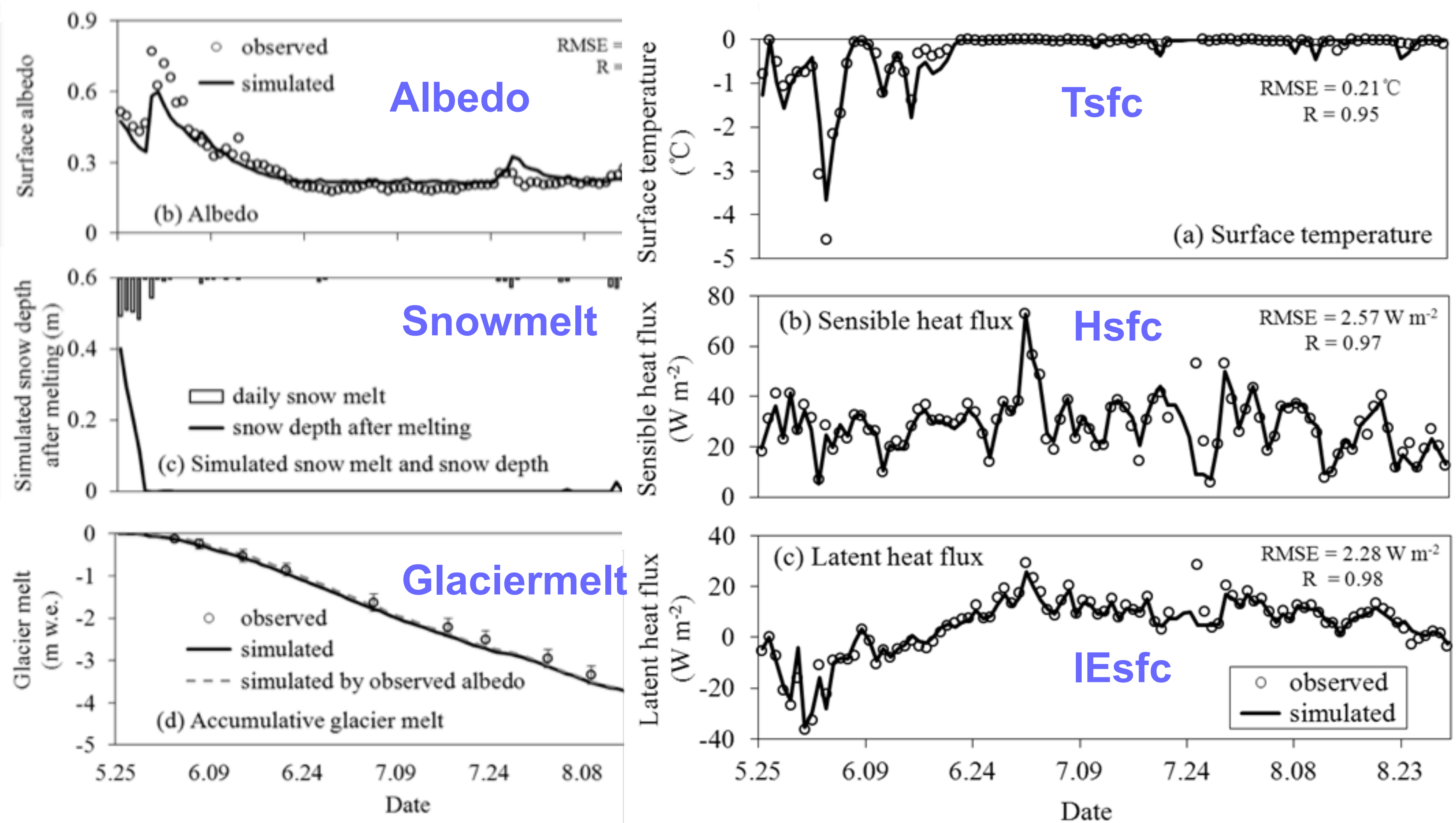


Precipitation types highly depend on wet-bulb temperature (Tw), RH, and elevation



(Ding et al., 2014, JH)

The simulation results for a SE-Tibet glacier are encouraging



(Ding et al., WRR, 2017)

Modeling evaporation from cold and deep alpine lakes in the Tibetan Plateau

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

10.1002/2015JD024523

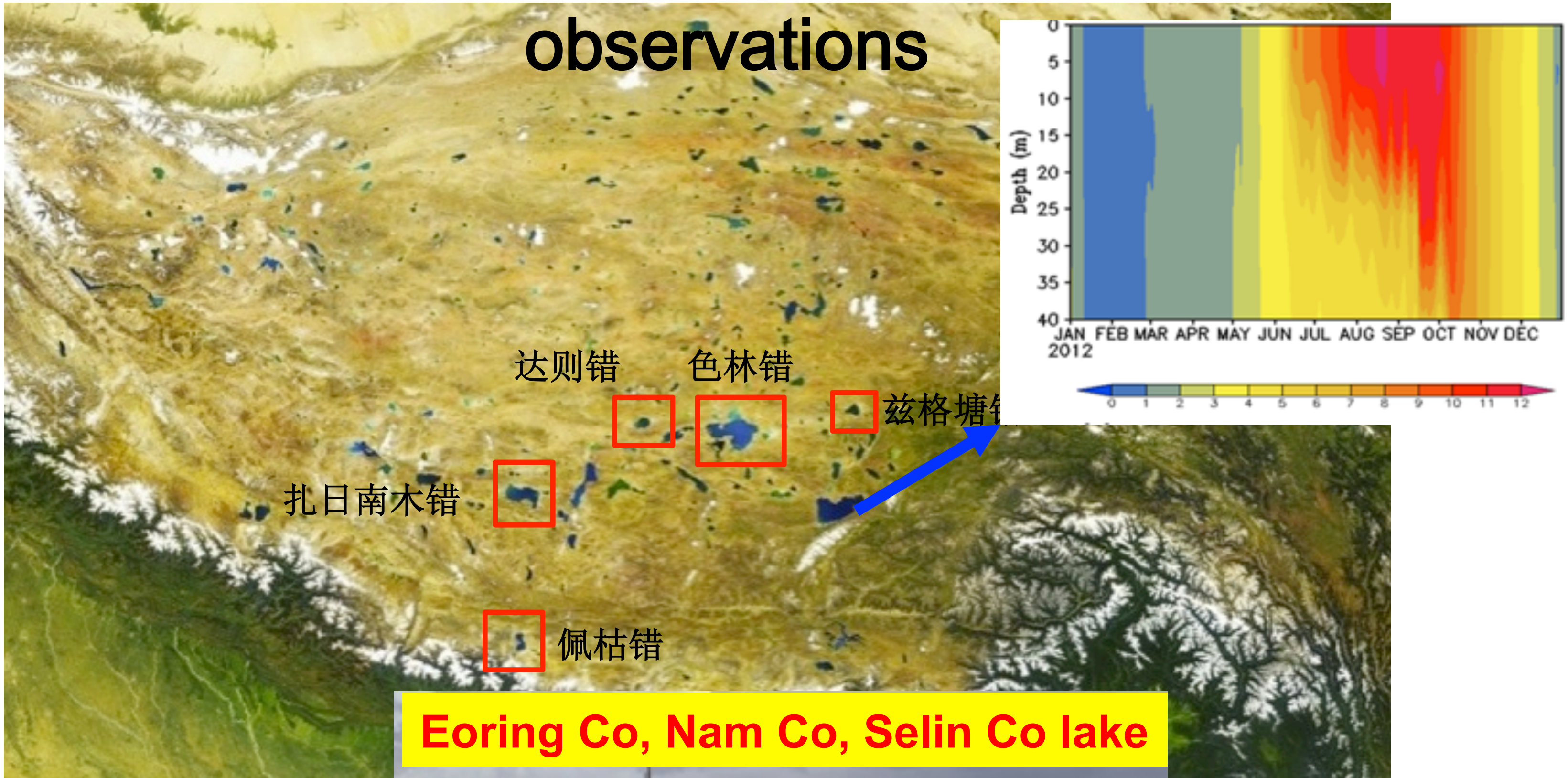
Key Points:
- Evaporation of Nam Co is simulated by Flake model with good accuracy
- Simulated evaporation is much less than Penman-equation-derived one for the deep lake
- The evaporation change played a role in suppressing the recent expansion

Quantifying evaporation and its decadal change for Lake Nam Co, central Tibetan Plateau

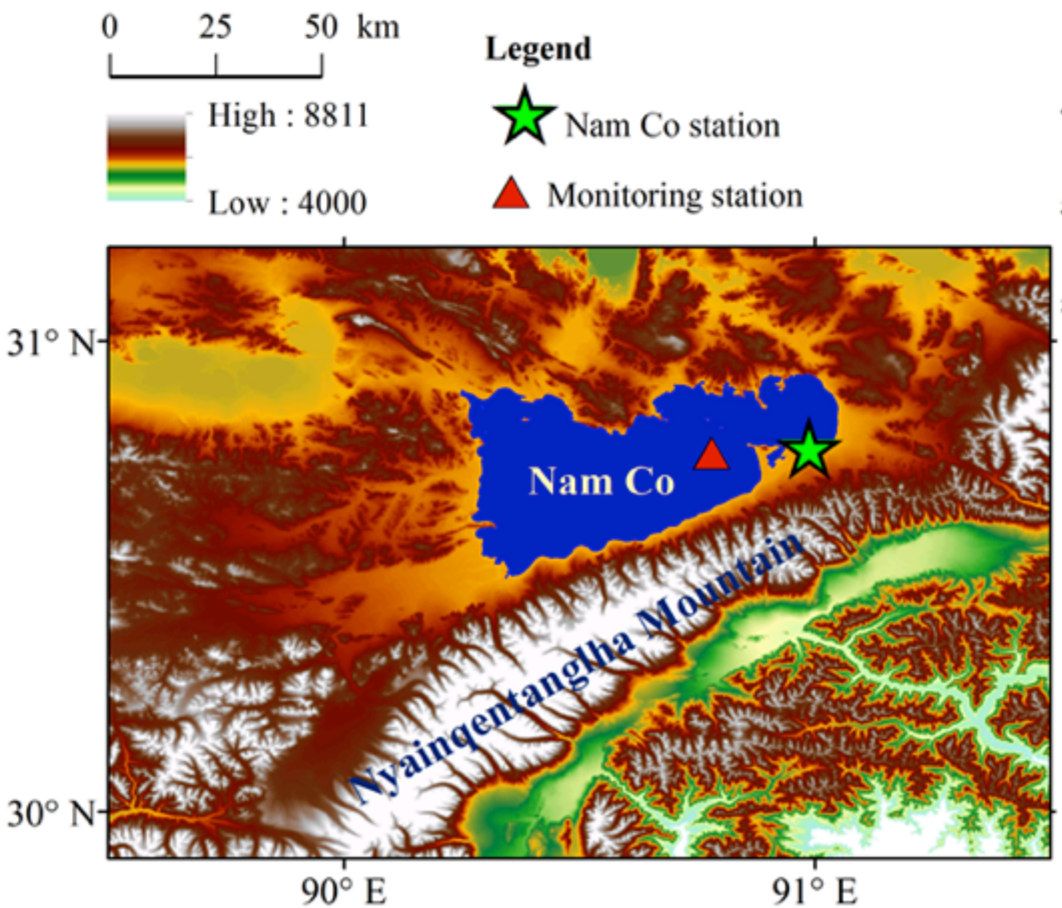
Lazhu[1,2], Kun Yang[1,3], Junbo Wang[1,3], Yanbin Lei[1,3], Yingying Chen[1,3], Liping Zhu[1,3], Baohong Ding[1], and Jun Qin[1]

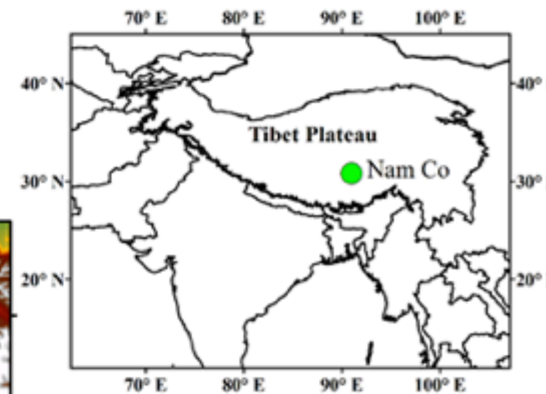
[1]Key Laboratory of Tibetan Environment Changes and Land Surface Processes, Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing, China, [2]University of Chinese Academy of Sciences, Beijing, China, [3]CAS Center for Excellence in Tibetan Plateau Earth Sciences, Beijing, China

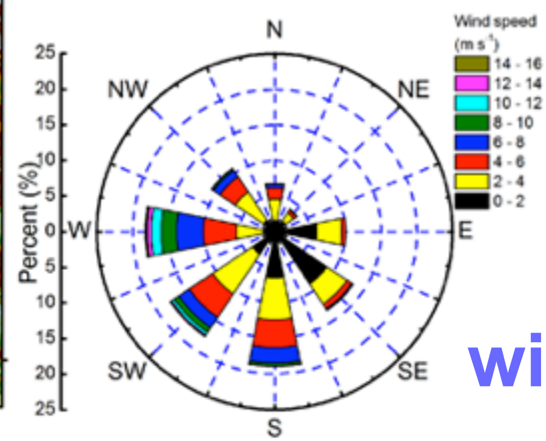
Lake temperature and turbulent fluxes observations



Lake Nam Co







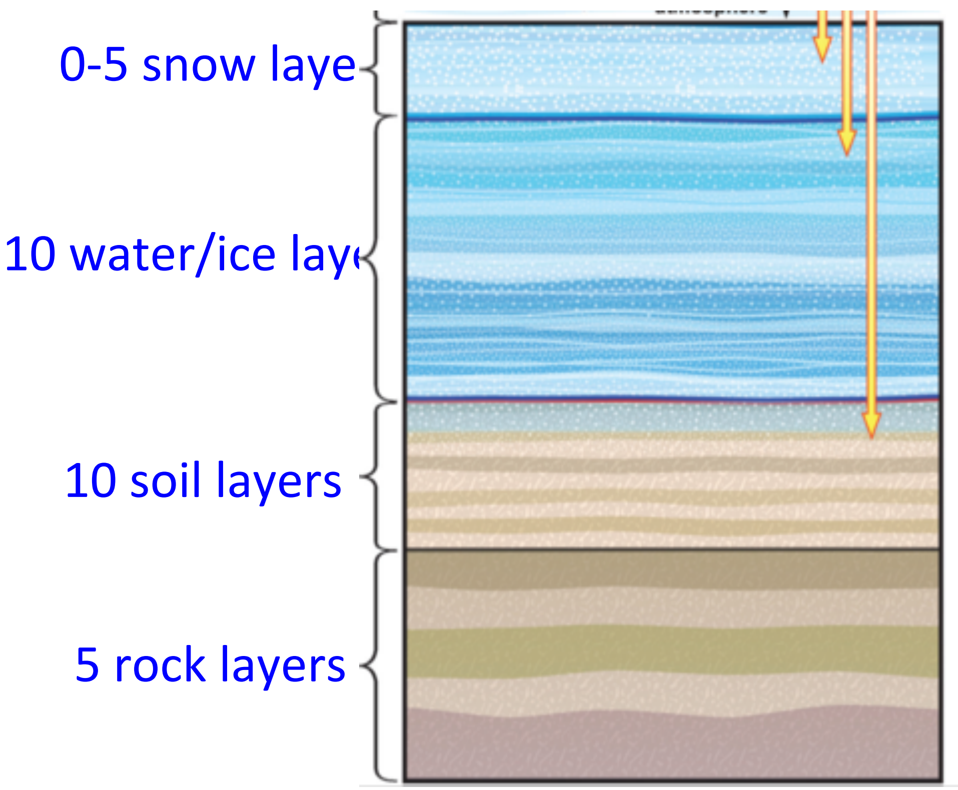
wind

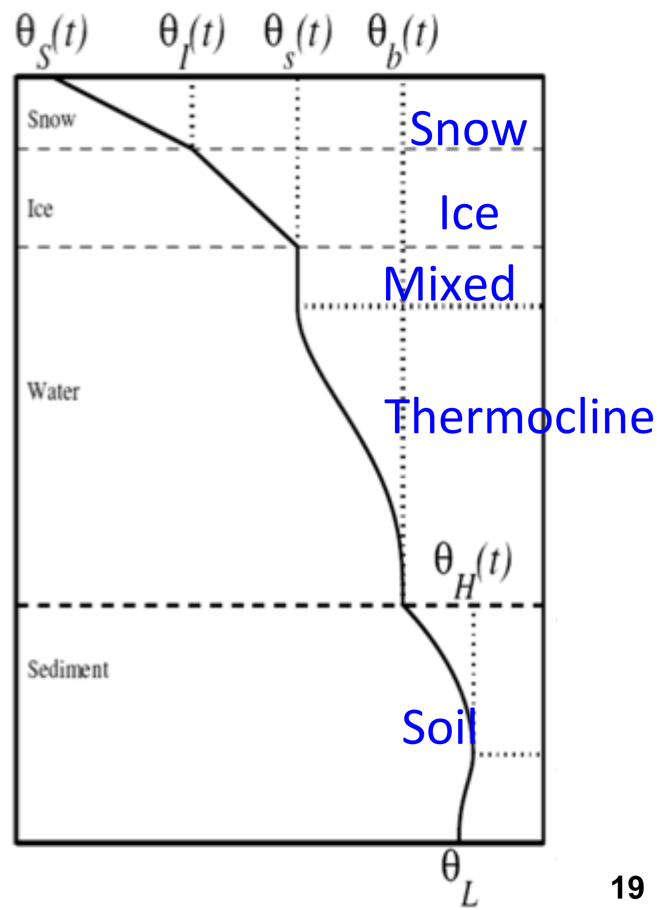
Area: 2021km^2(2010), Ele: 4725m

Depth: 40m on average

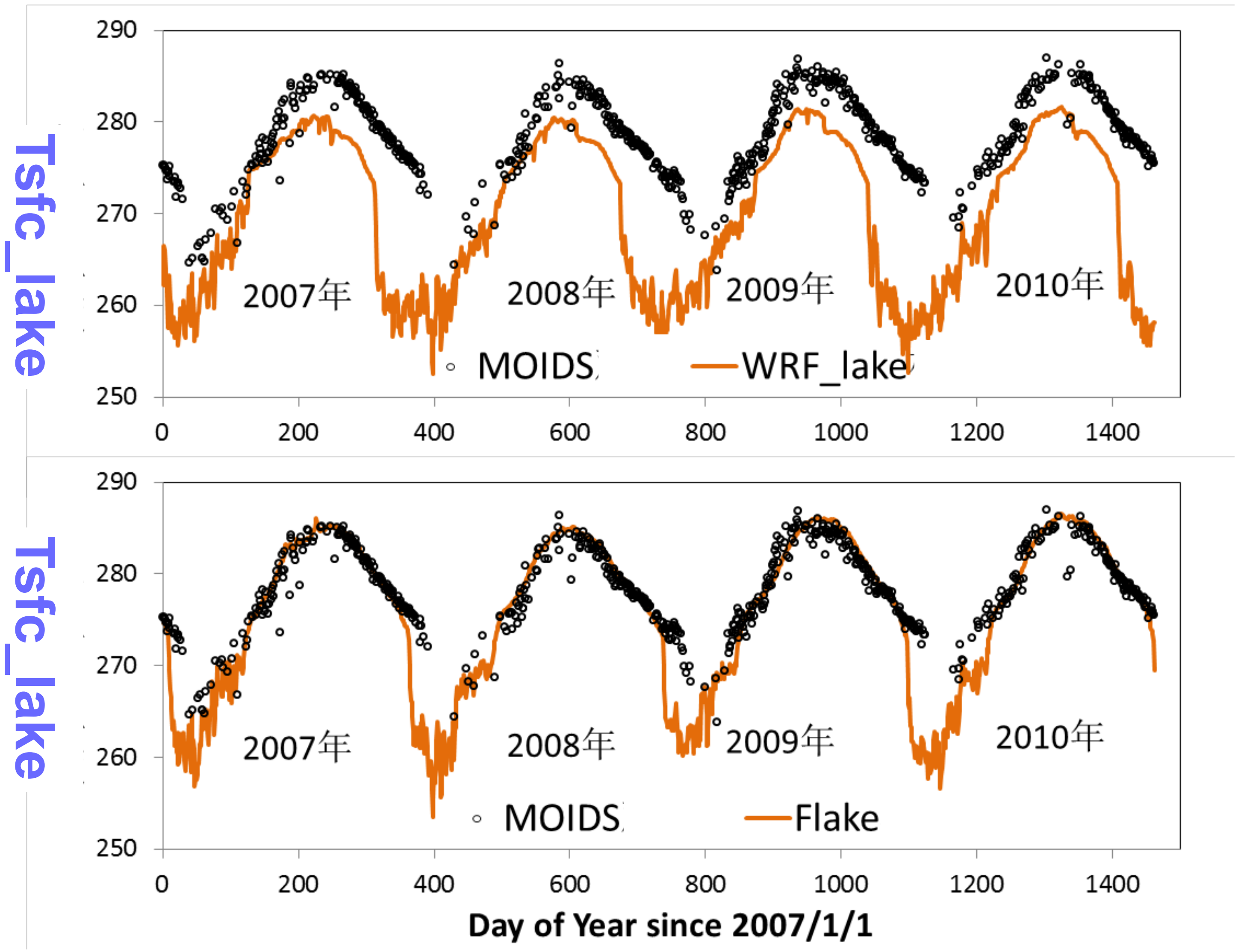
Two lake models with different complexity

	WRF-lake	ECMWF-Flake
Theory	TDE+turbulence	Self-similarity
Unknowns	25-30	4-6
Temperature	Each layer	Interpolated





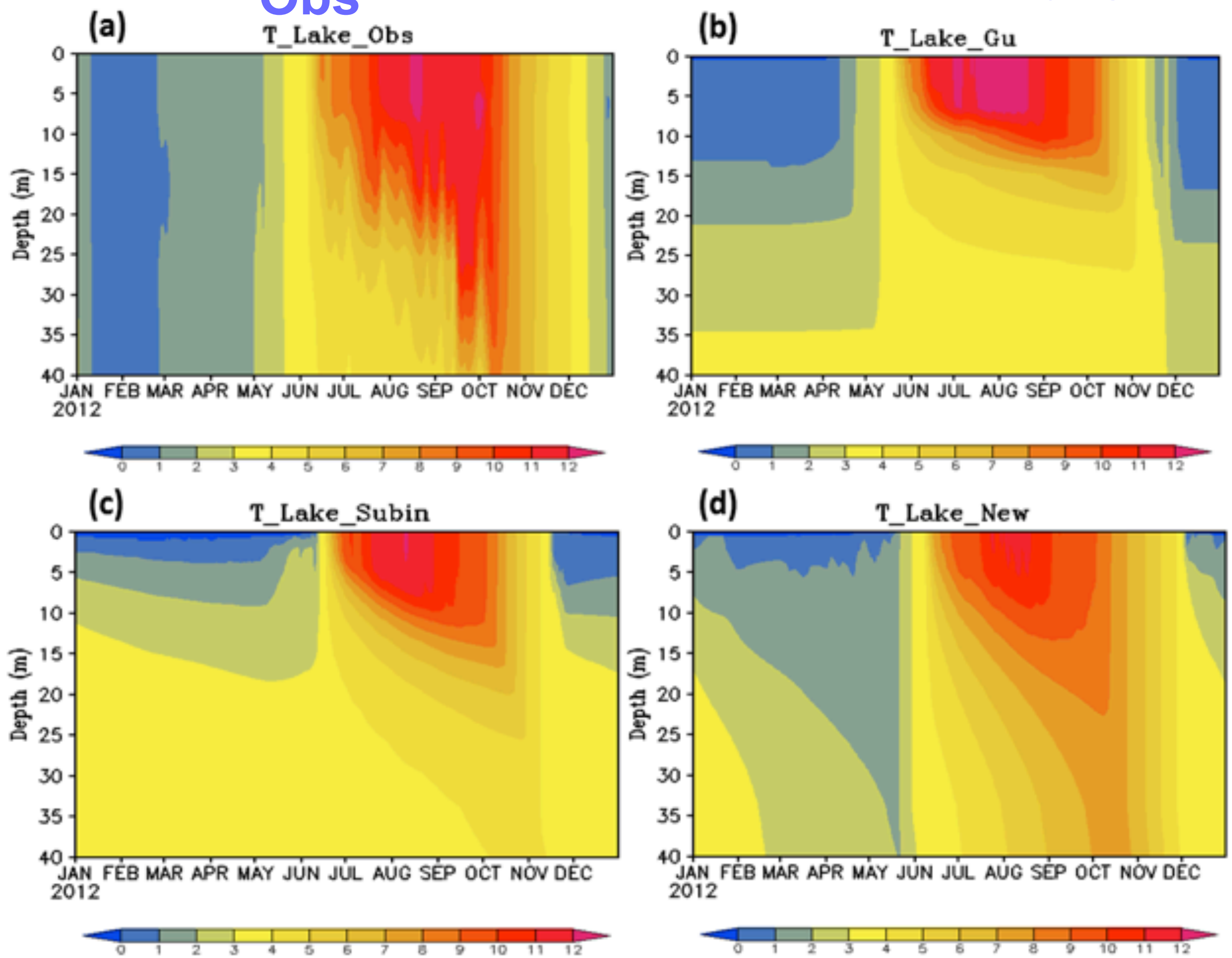
Model evaluation: WRF-lake severely underestimates MODIS-observed lake temperature, while Flake model perform better



Amplifying convective mixing coefficient may improve energy transfer in the lake

Obs

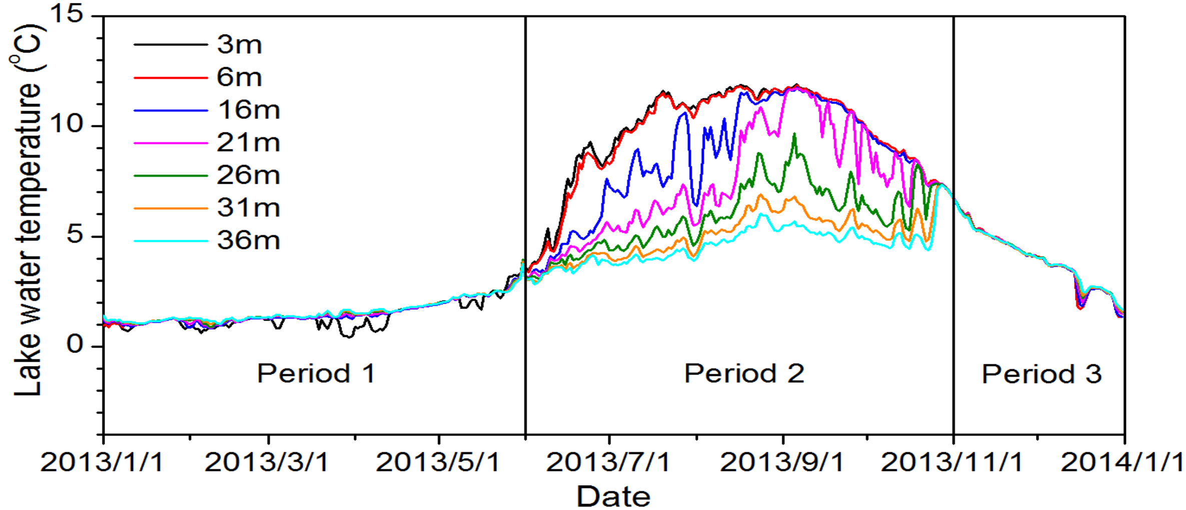
WRF-Lake

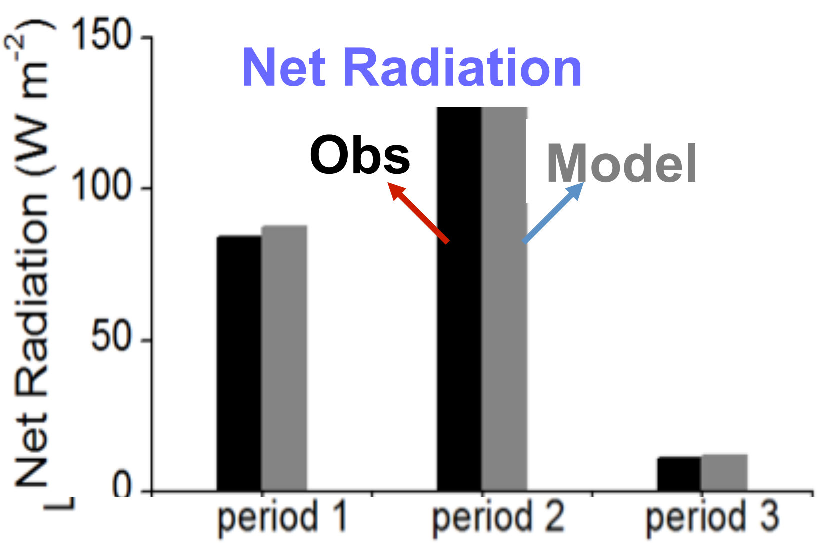


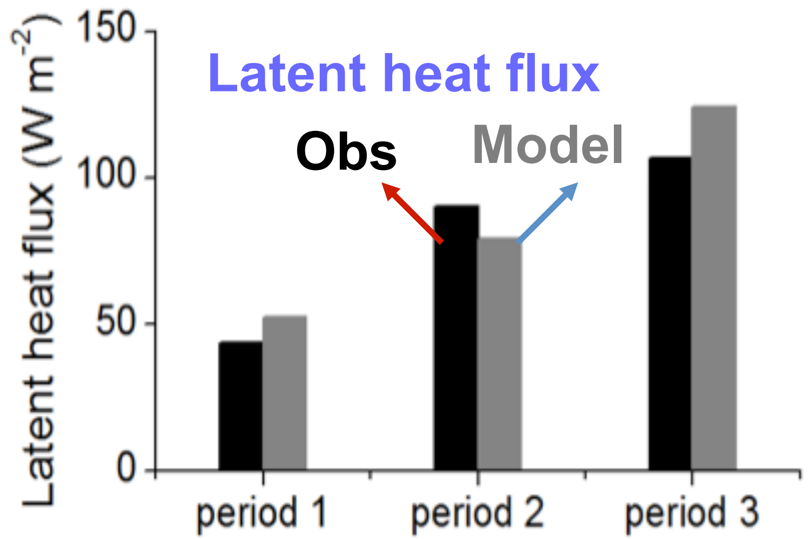
Amplify by 10 times
（Subin et al.,2012)

Amplify by 100 times

Flake evaluation： surface energy balance

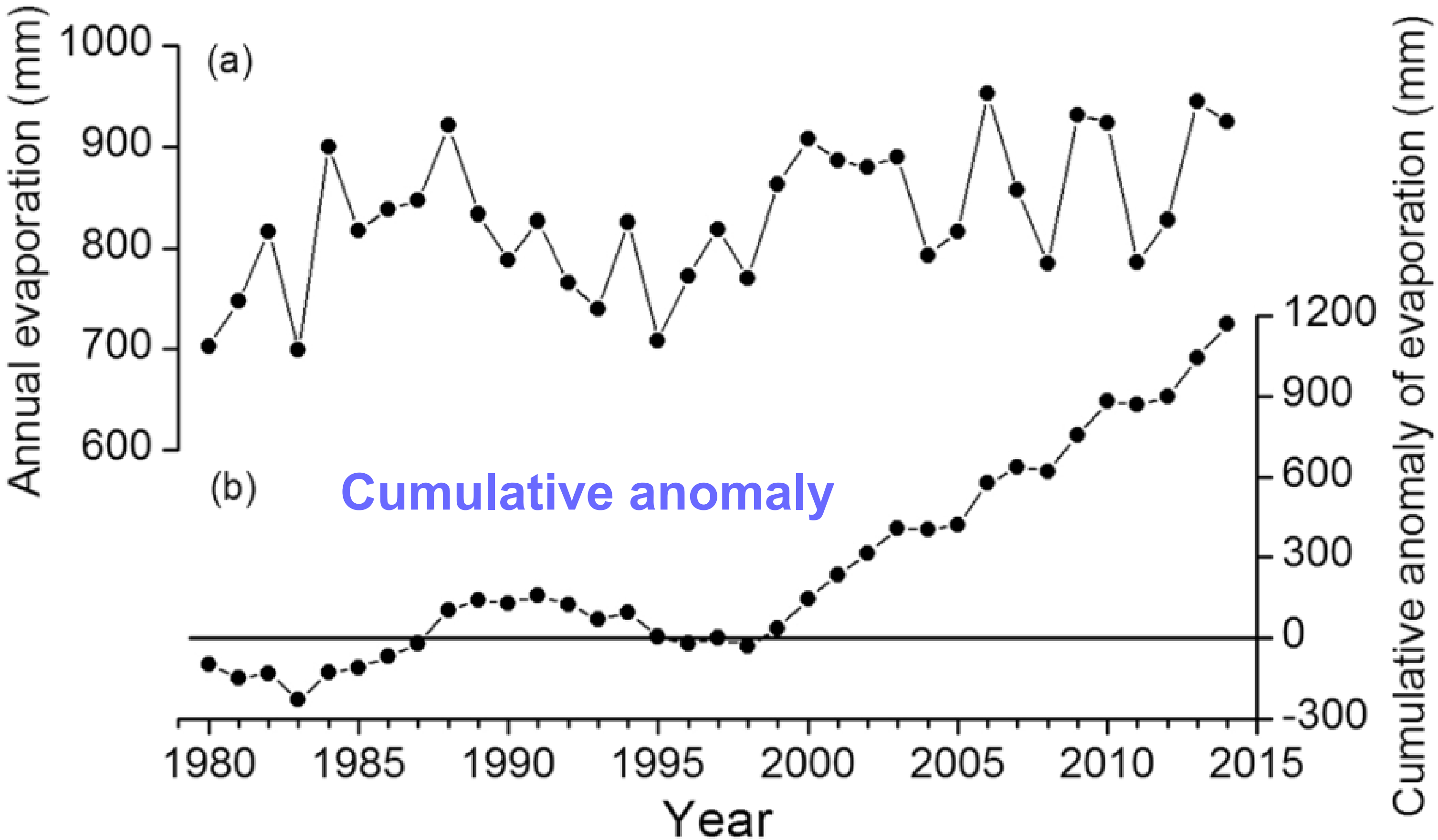






Simulated evaporation is about 830±70 mm, much less than potential evaporation

Change in lake evaporation since 1998



Lake evaporation since the late 1990s is greater than previous periods; thus, this change in evaporation has suppressed the recent expansion of Lake Nam Co.

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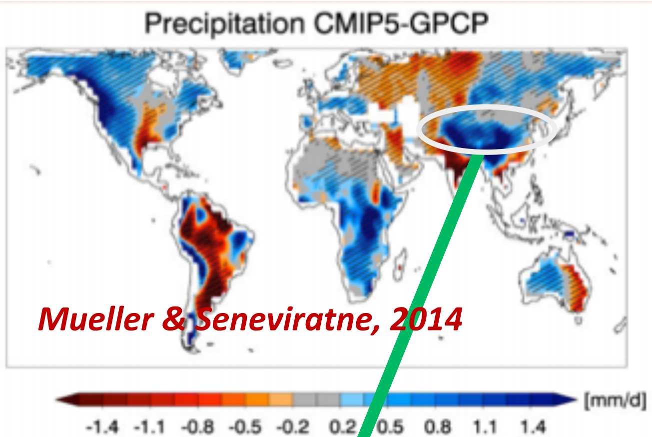
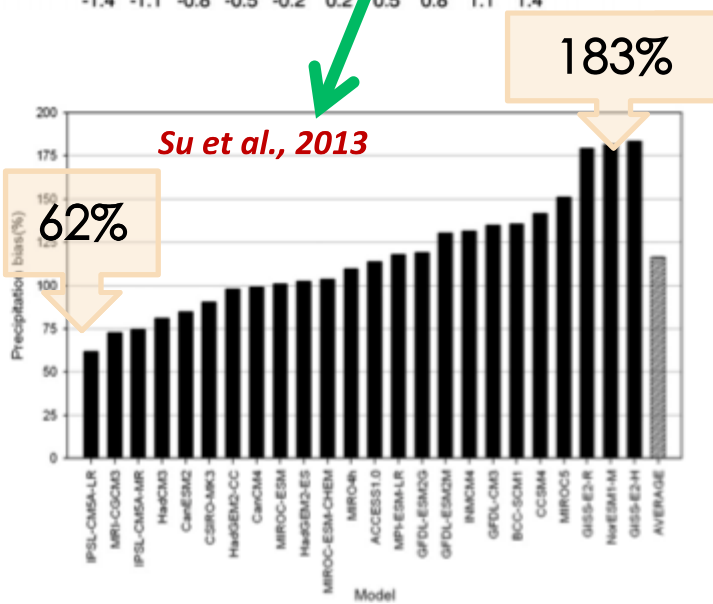
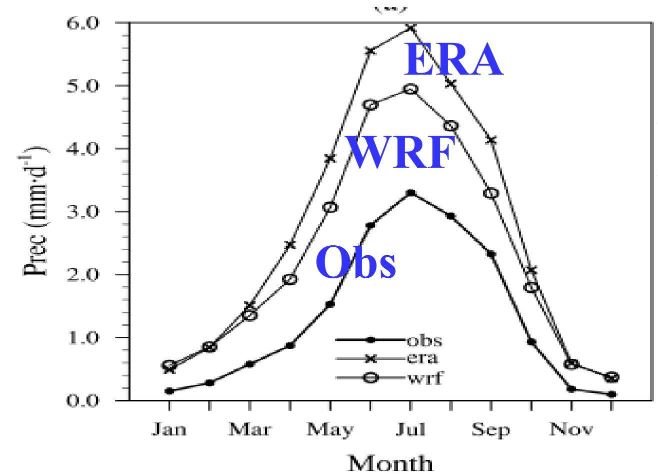
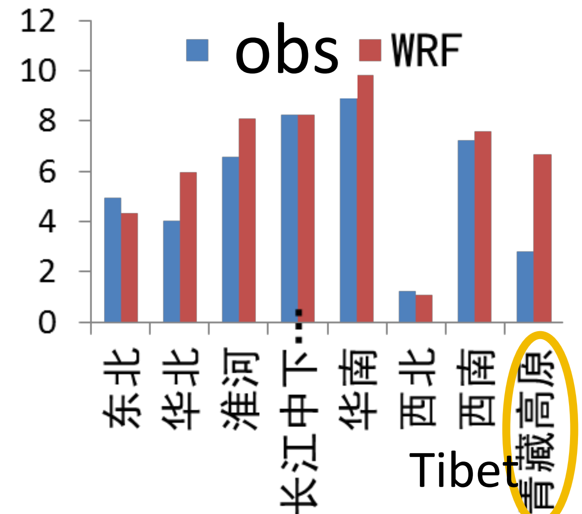
What causes distinct precipitation biases in climate models: much more in the Plateau and less in adjacent regions!





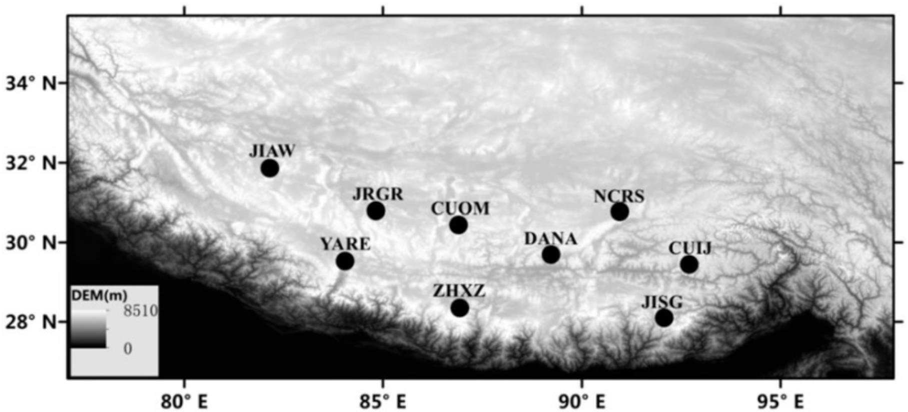


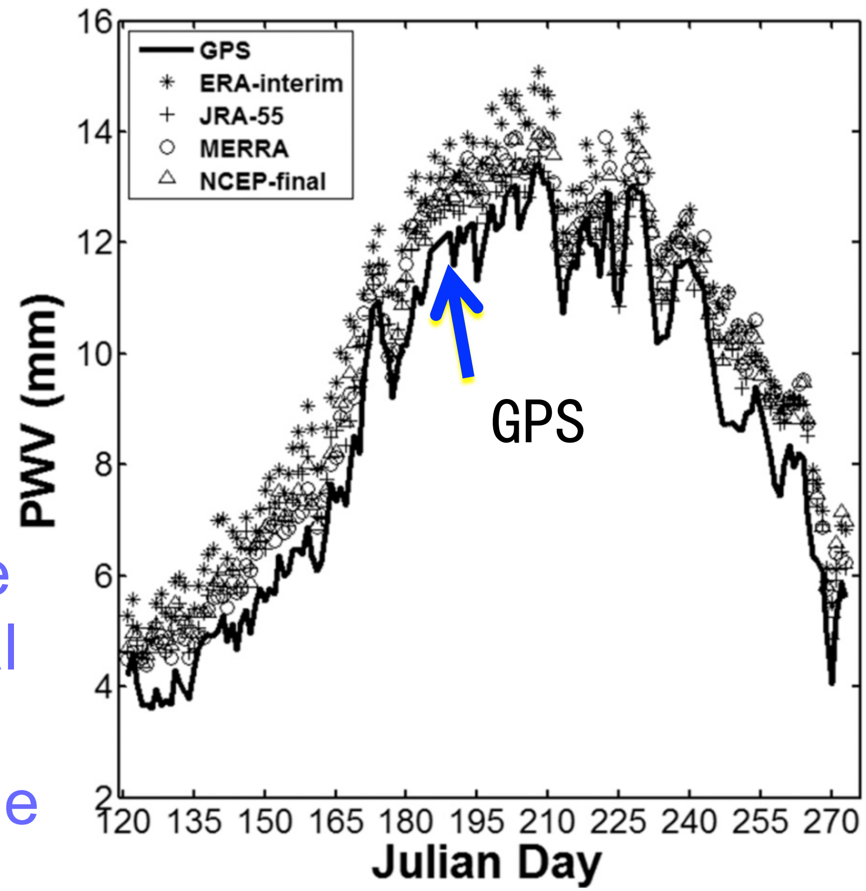
(Gao Yanhong et al., 2015)



(Ma Jiehua et al., 2015)

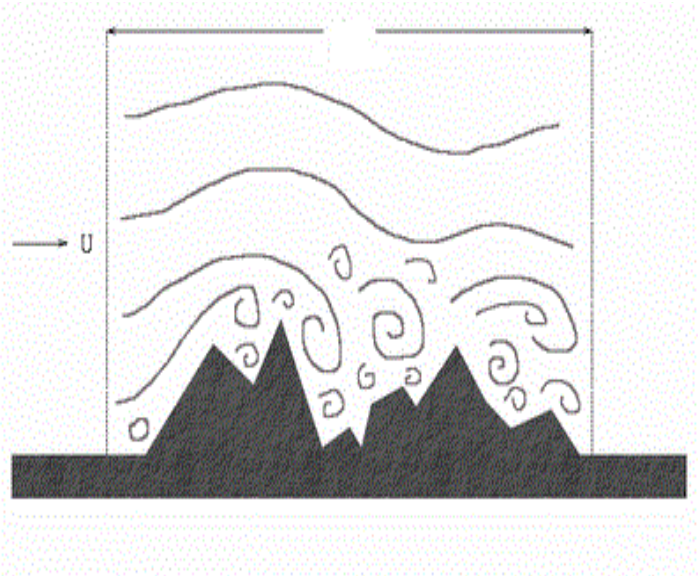
Water vapor measurement in South Tibetan Plateau

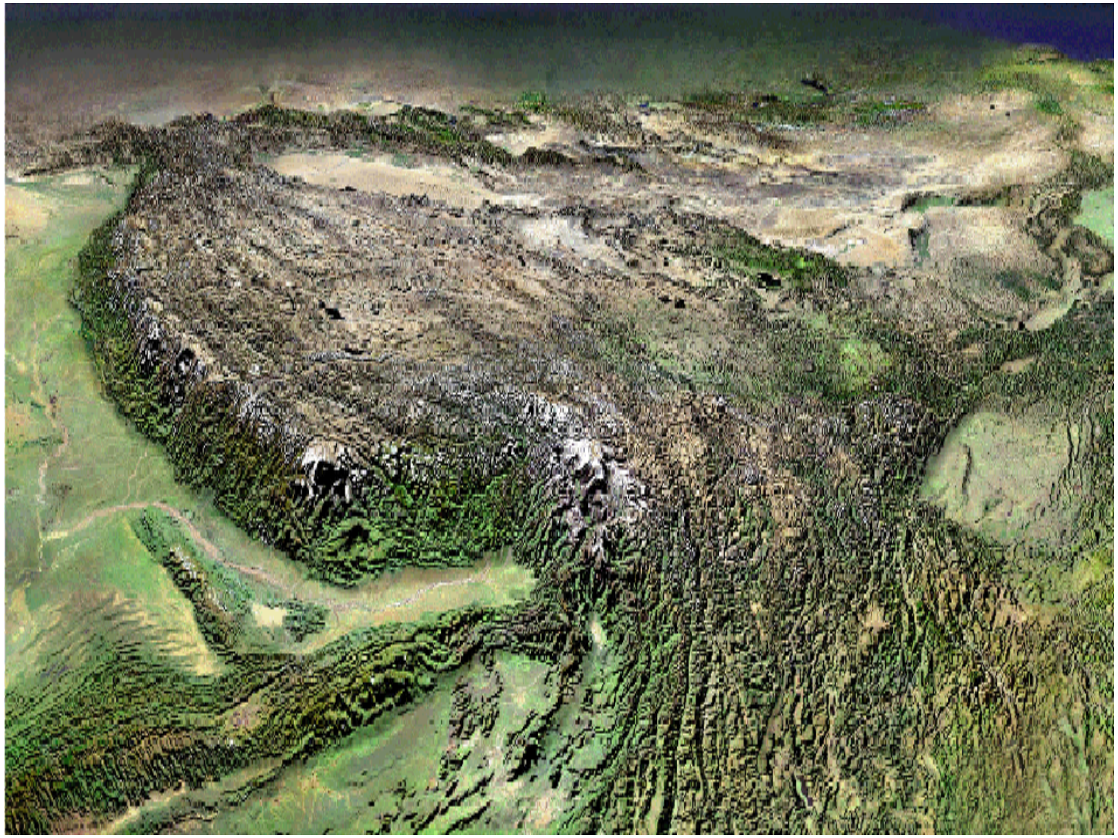




All the reanalyses have positive biases along the PWV seasonal cycle, which may be linked to the well-known wet bias over the TP in current climate models

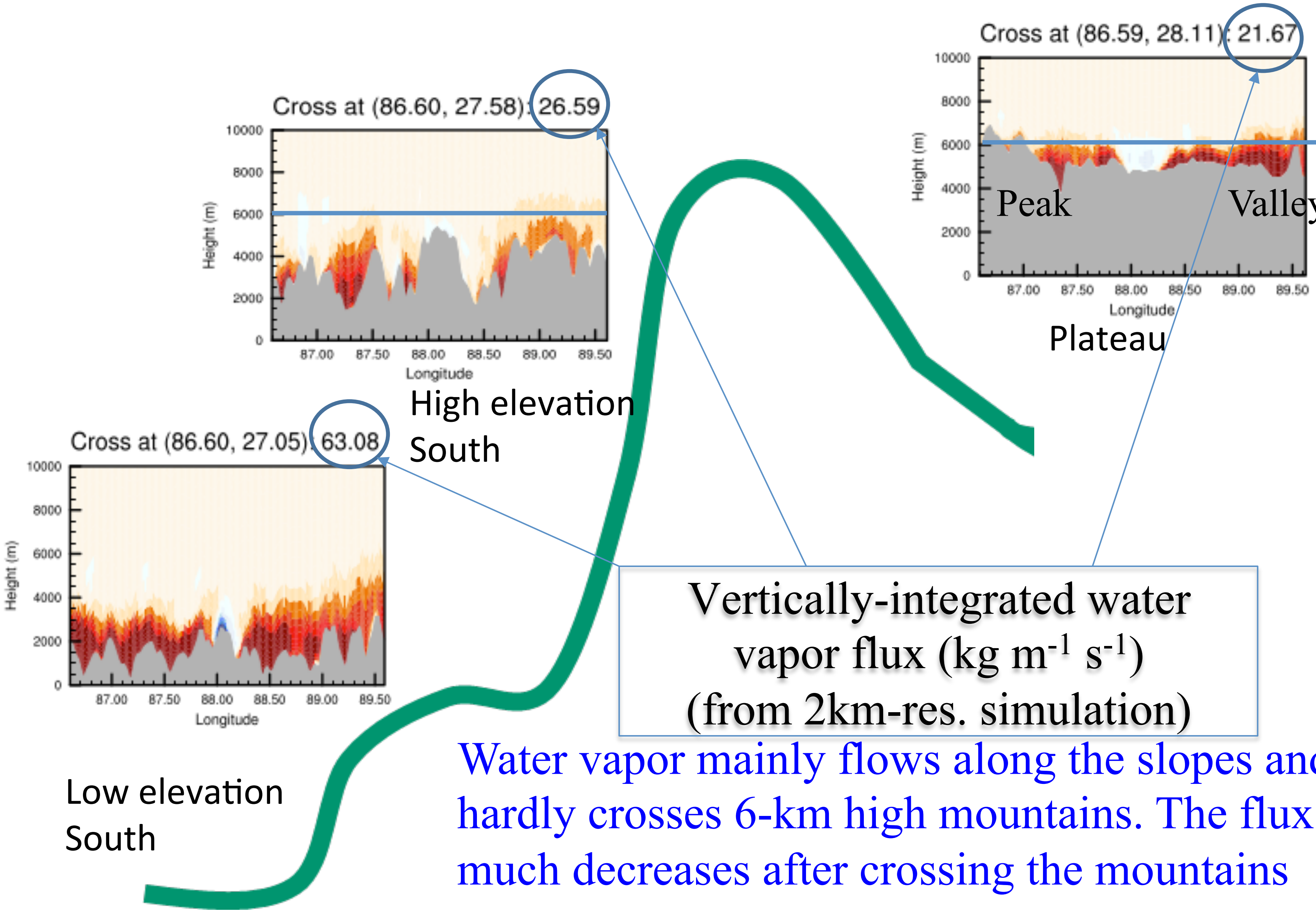
Due to orographic drag on flow?





We conducted three simulations for the south TP, with a resolution of 30km, 10km and 2km.

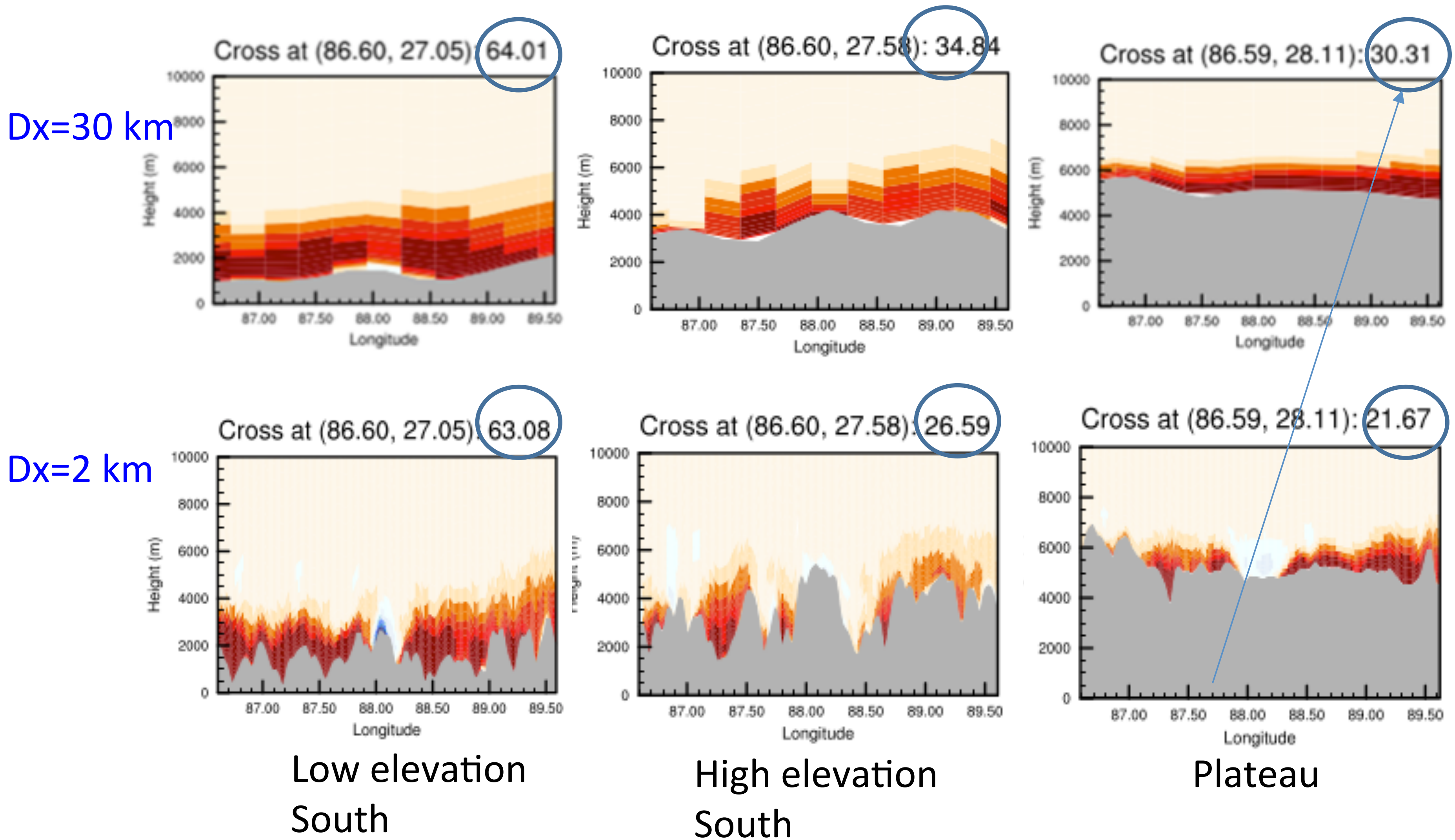
Water vapor transport simulated at dx = 2 km



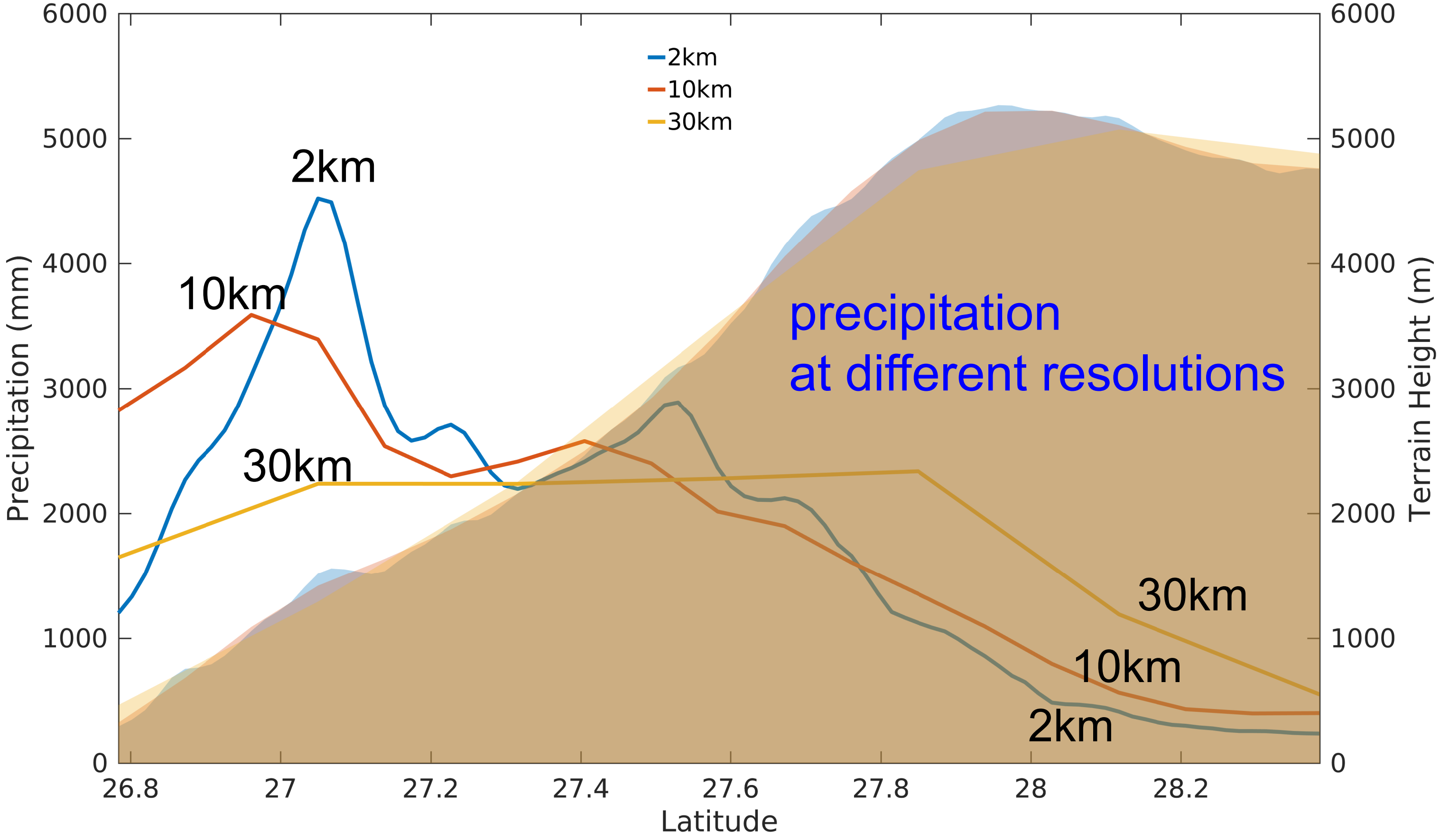
Water vapor mainly flows along the slopes and hardly crosses 6-km high mountains. The flux much decreases after crossing the mountains

Water vapor transport depends on WRF resolution

Cross-mountain water vapor flux simulated with dx=30km is 50% higher than the one with dx=2km, mainly due to wind error



Positive bias in vapor flux results in much more precipitation in the Plateau and less in south slope



Summary and Plan

- An energy-based glacier mass balance model were established for simulation and projection of glacier change
- Lake evaporation models were evaluated. There is a big space for lake modeling studies
- Current models may produce too strong water vapor transport from South Asia to South Tibet, and a possible cause is that the orographic drag of complex terrain is not well accounted.
- More studies are expected to quantify the contribution of complex terrain and snow/glacier cover to water vapor transport, and lake-air and land-air interactions to re-fill water vapor.

Look forward to cooperation!