Enhance data availability of snow depth and soil moisture in the Tibetan Plateau

- **Land surface modeling - Need precipitation data and types**
- **Satellite remote sensing**

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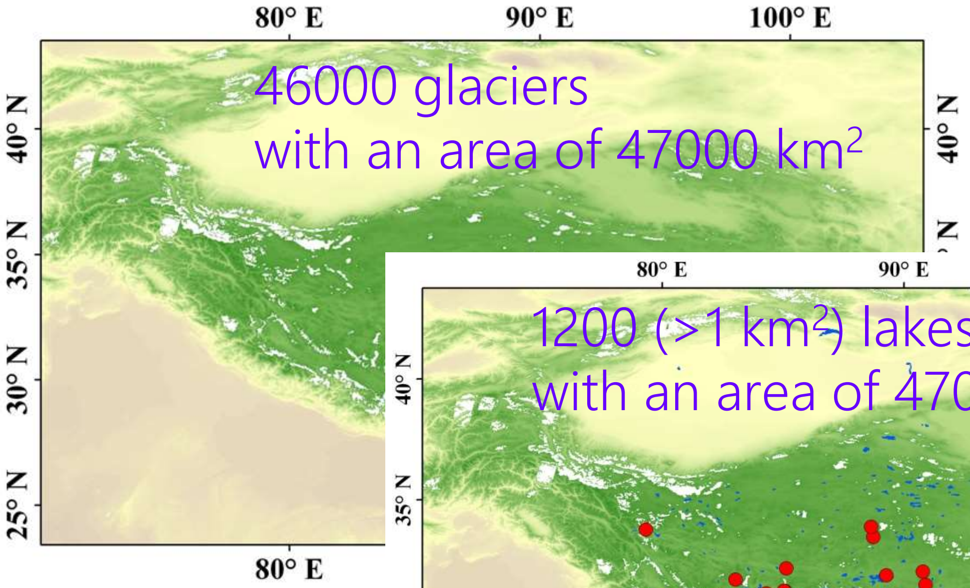
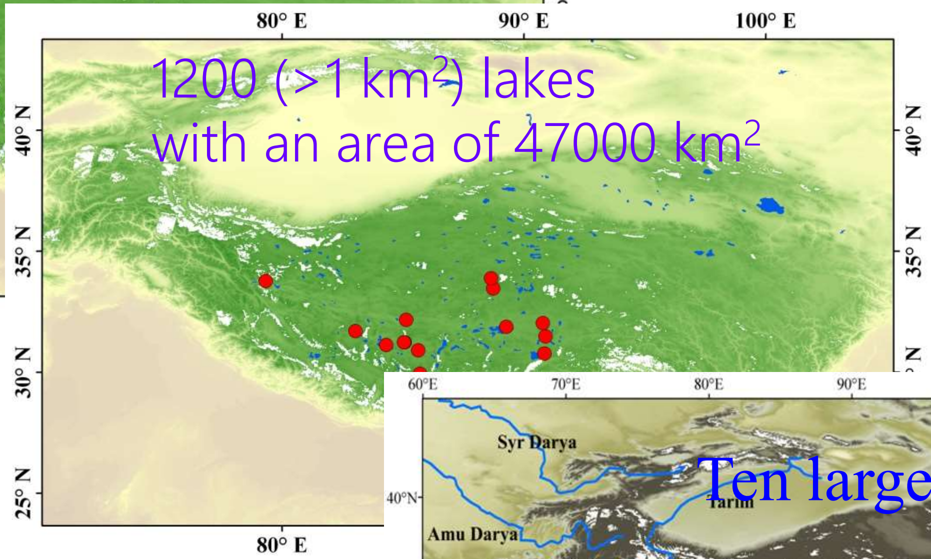
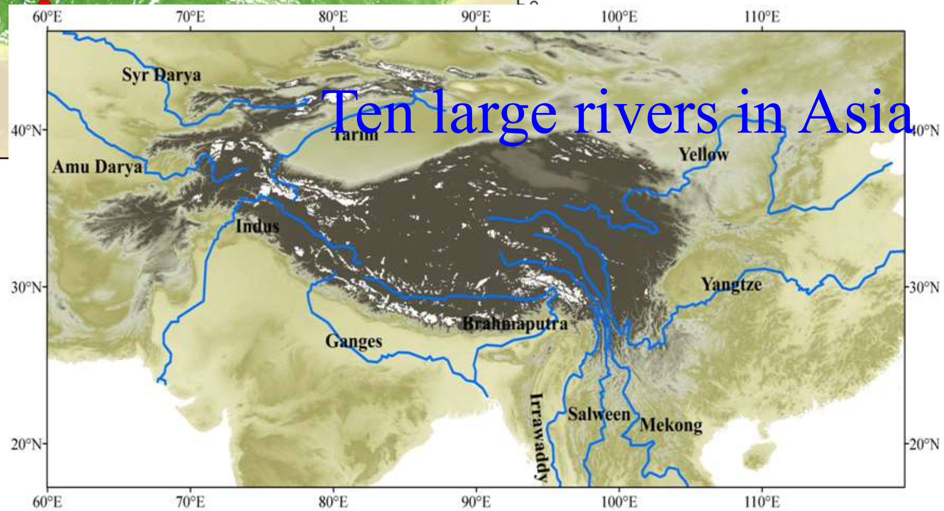
2016 International Teams in Space and Earth Sciences

ISSI-Beijng, National Space Science Center

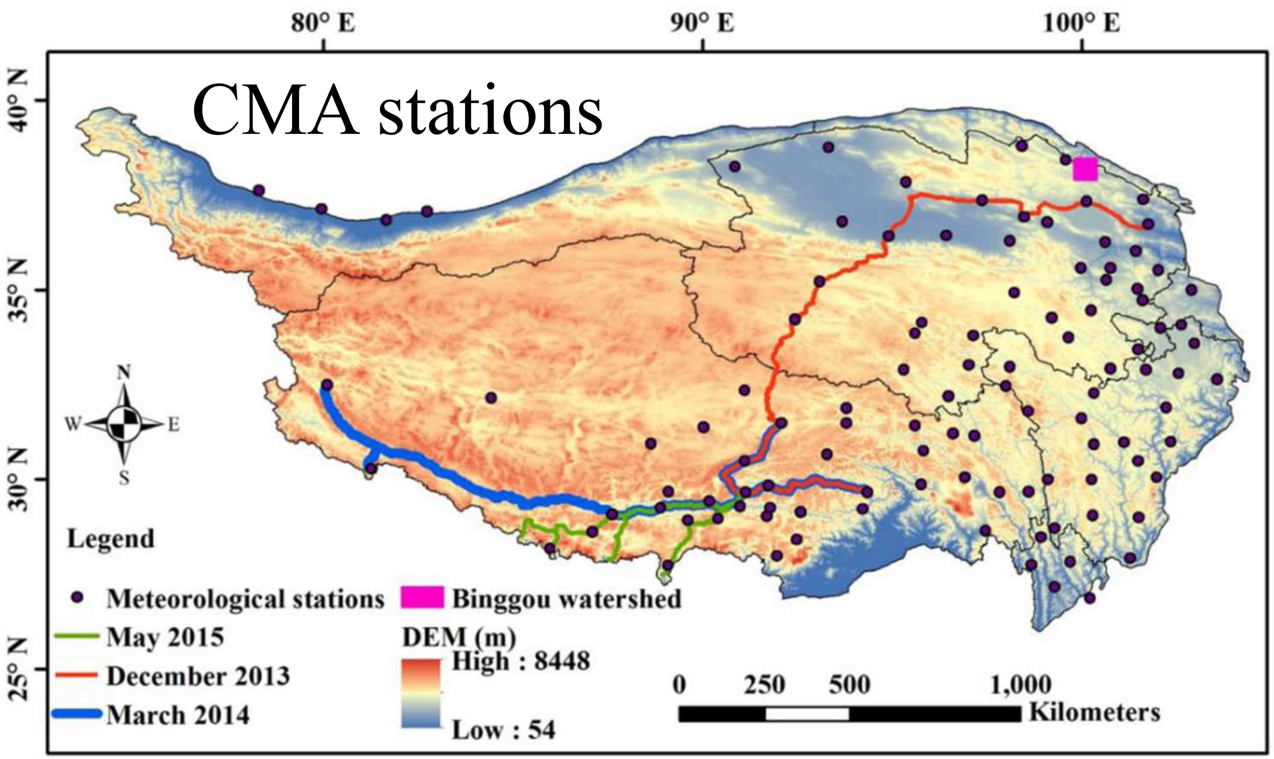
Crucial to understanding and modeling water cycle across multi-spheres in the Tibetan Plateau







GC1: Develop a high-resolution reanalysis dataset for TP



Major problems:

1. Sparseness: few data in west, high-elevation
2. Spatial representativeness: patch snow cover

GC1: Develop a high-resolution reanalysis dataset for TP
We have developed China Meteorological Forcing Dataset

Fusion

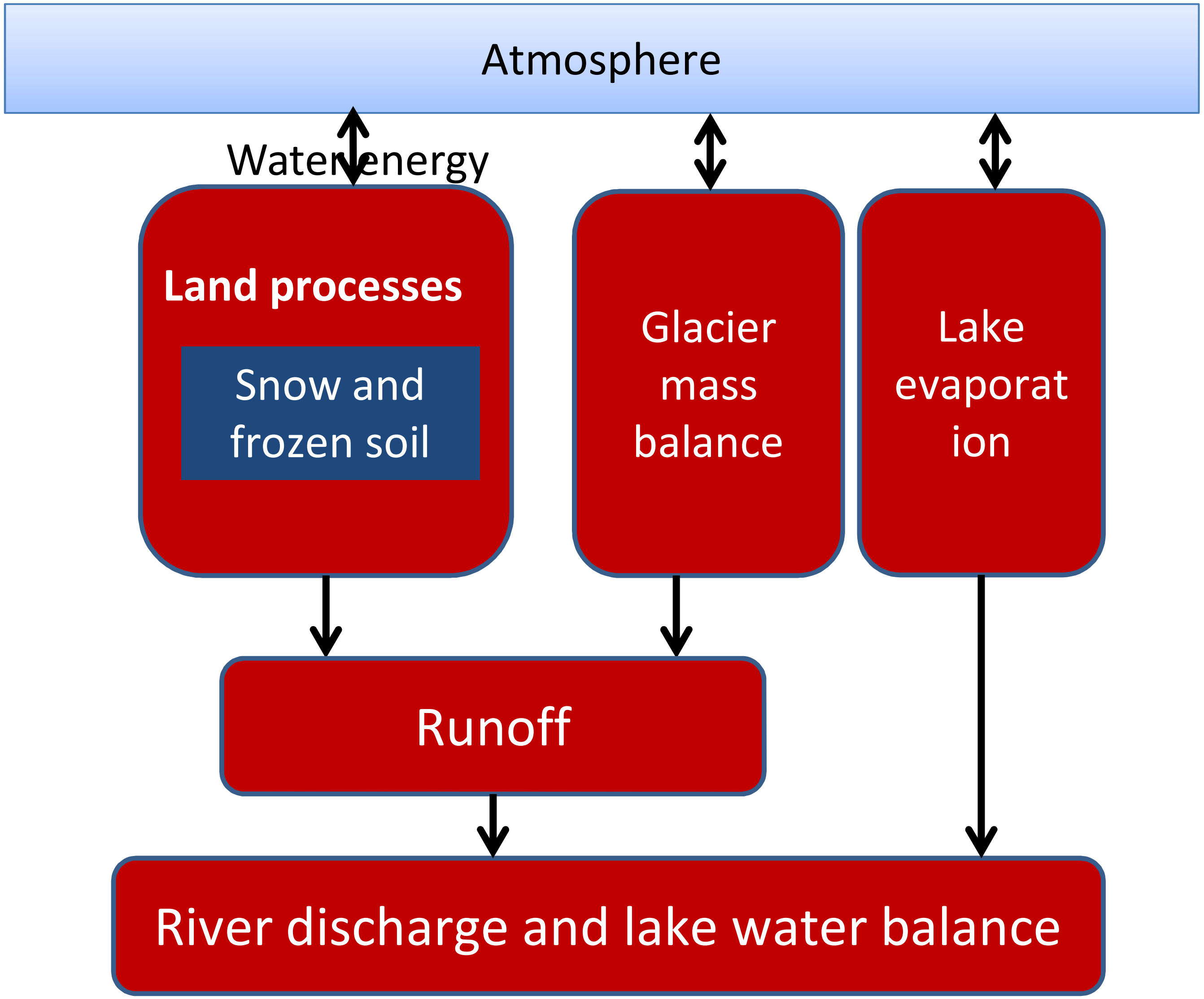
Parameters:
- Wind, Ta, qa
- Pa, Prec, Rad

Spatial coverage:
- Mainland China

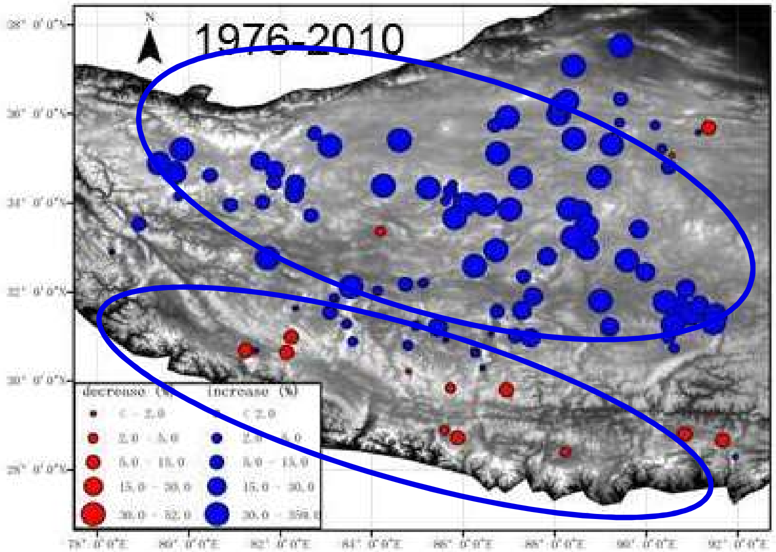
Temporal coverage:
1979-2015

Resolution:
- 0.1 deg, 3 hrs

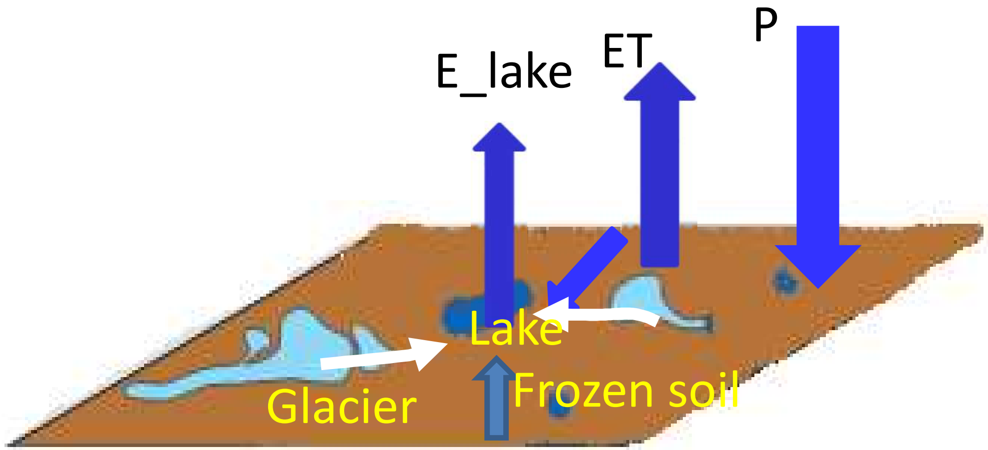
GC2: Developing an integrated model to quantify the interactions among multiple spheres



- To understand water cycle change (Precipitation, land/lake evaporation, glacier/snow melting, frozen soil degradation), such as lake expansion in central and north and shrinkage in south

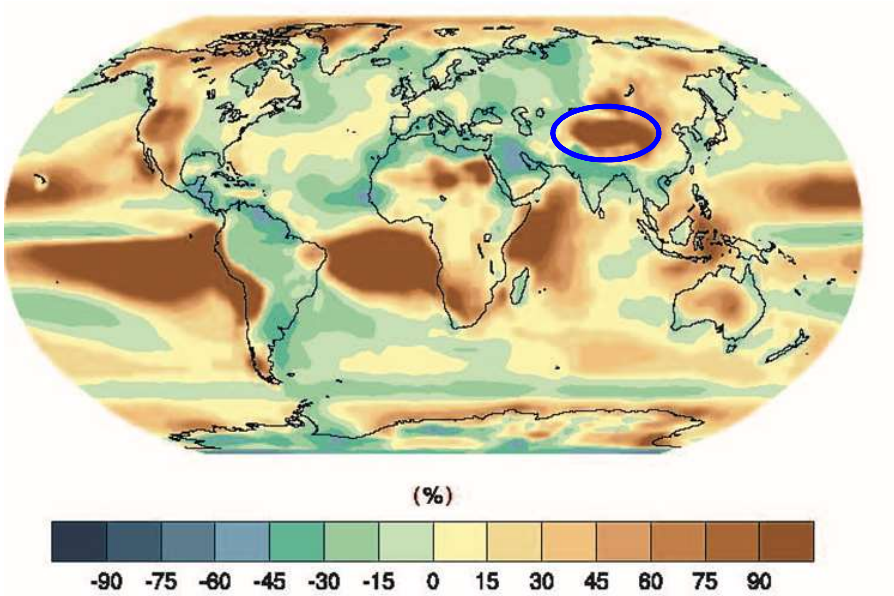


(Lei et al, 2014, Clim. Chang.)

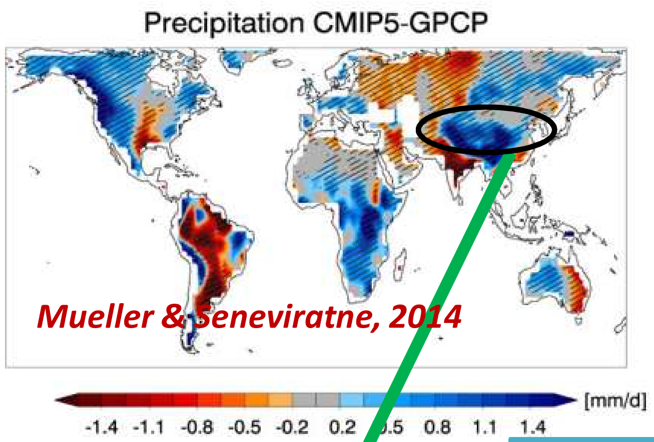


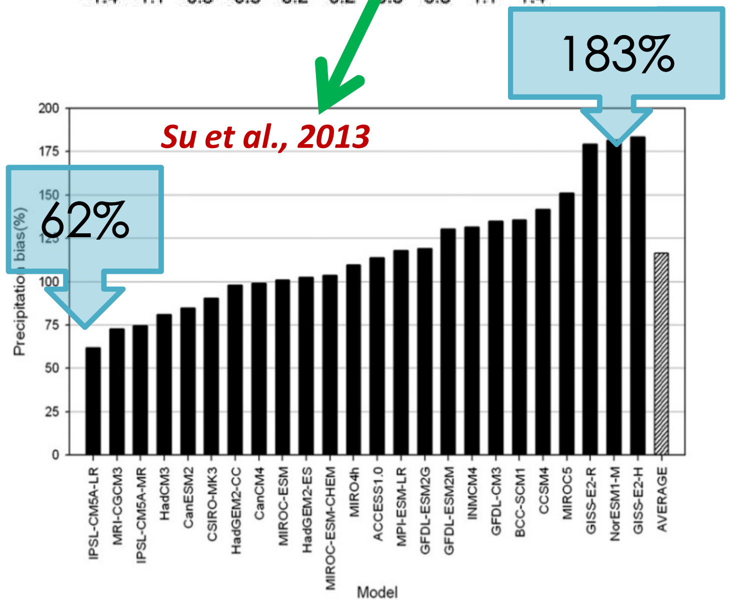
GC3: Reduce distinct precipitation biases in models: much more in the Plateau and less in adjacent regions!

The largest relative bias in GCMs over global land is on the Tibetan Plateau



(Flato et al., 2013)

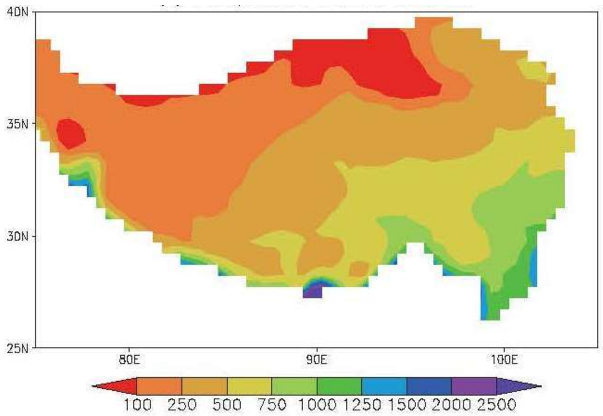




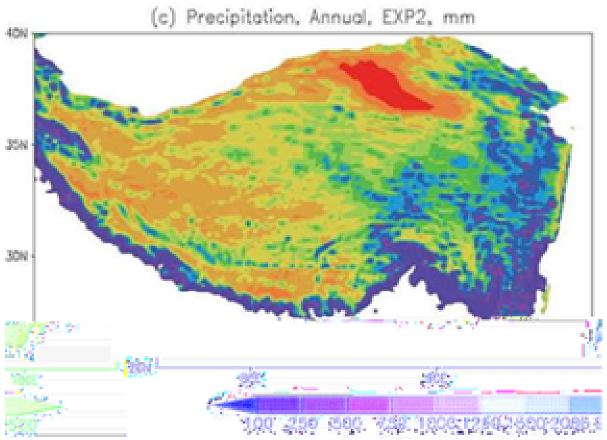
Biases across CMIP5 models

GC3：Reduce distinct precipitation biases in models: much more in the Plateau and less in adjacent regions!

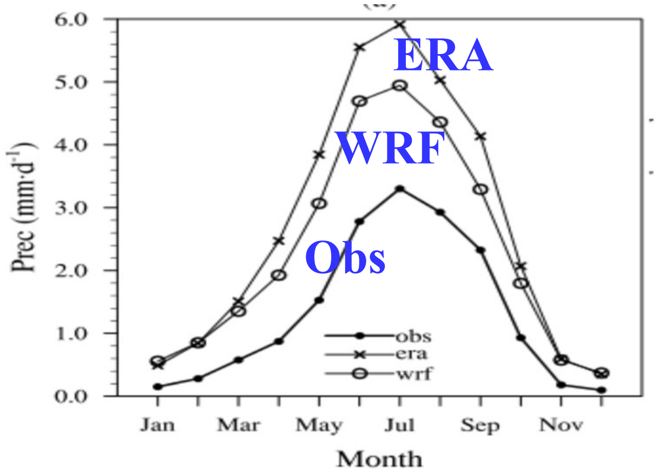
Observed



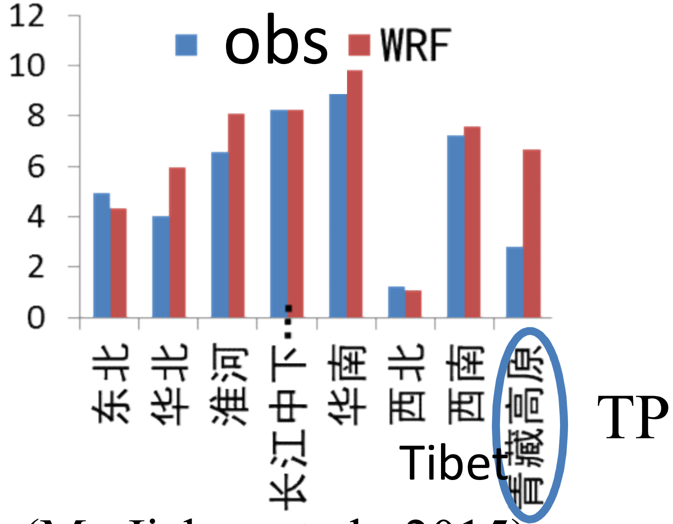
10km RegCM simulated



(Ji & Kang, 2014)



(Gao Yanhong et al., 2015)



(Ma Jiehua et al., 2015)

The dependence of precipitation types on surface elevation and meteorological conditions and its parameterization

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Outline

- Introduction
- Data
- Precipitation Type Discrimination Scheme
- Scheme Evaluation
- Summary

Introduction

- **Different precipitation types have different impacts on the land surface mass and energy balance**
  - Snowfall: accumulates at the land surface; albedo increases greatly
  - Rainfall: infiltrates into soils and converges into rivers; albedo doesn't change or decreases slightly.
- **Precipitation type is also needed for the correction of precipitation gauge data. (Yang et al., 1995)**
- **Therefore, the differentiation of precipitation types is important for land hydrological process studies.**

Rain & Snow Classification

- Common method: statistical relationship between precipitation classification and some available variations, such as temperature, relative humidity
- Generally, critical temperature method used in most distributed hydrological model
  - Single threshold method

$$P_l = \begin{cases} P & ,T \geq T_0 \\ 0 & ,T < T_0 \end{cases}$$

  - Dual-threshold method:

$$P_l = \begin{cases} P & ,T \geq T_l \\ \dfrac{T_l - T}{T_l - T_s} P & ,T_s < T < T_l \\ 0 & ,T \leq T_s \end{cases}$$

Schemes for precipitation type discrimination in the literature

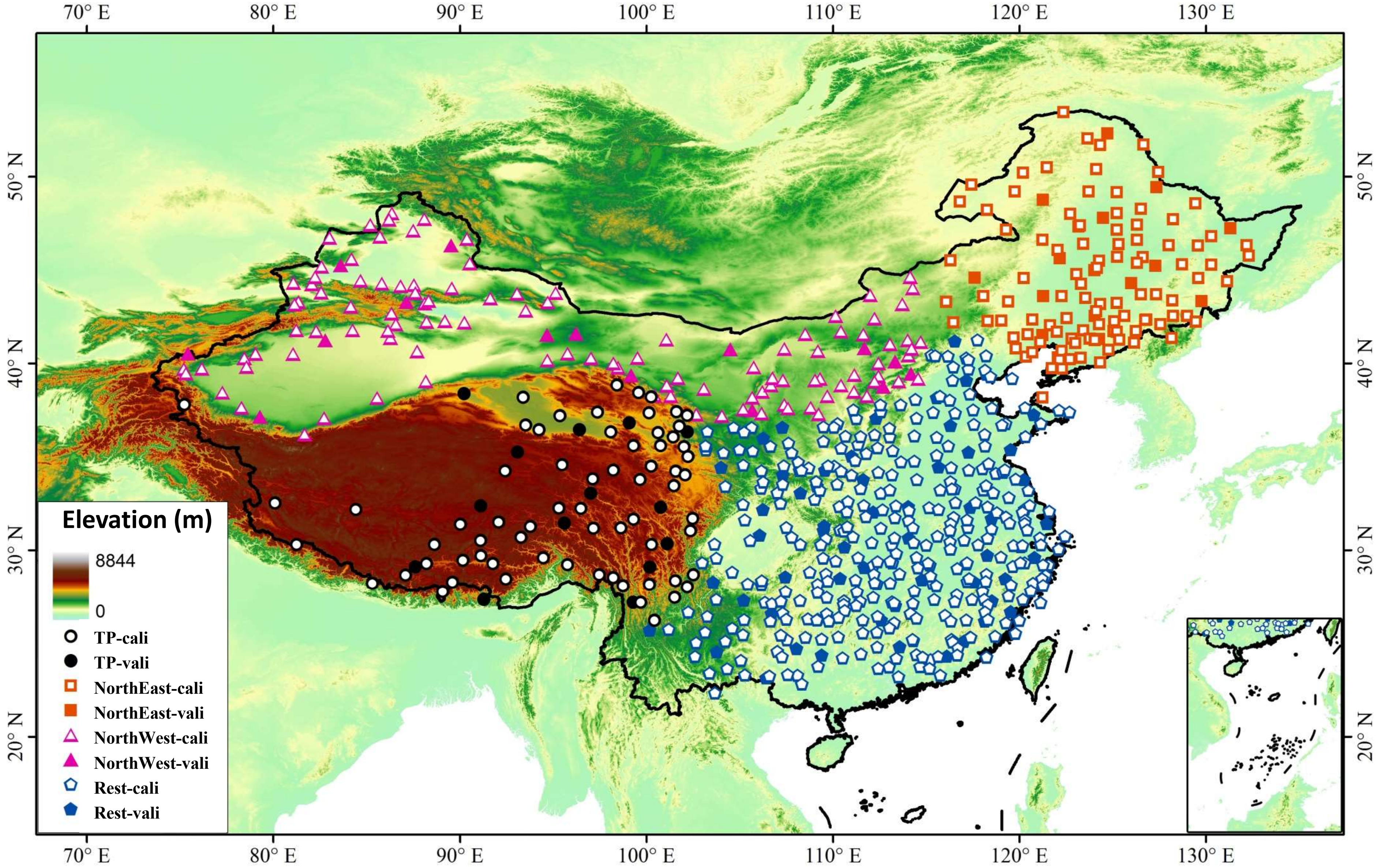
Scheme	Thresholds of T_a or snow ratio	Model	Region and Period being applied
Y97 (Yang et al., 1997)	**2.2℃**	BATS model	Yershov, Uralsk, Ogurtsovo, Kostroma, Khabarovsk and Tulun (48˚N–57˚N, 41˚E–135˚E), 1978–1983
L93 (Loth et al., 1993)	**-1℃, 4℃**	Snow cover model	German meteorological station Potsdam (52˚23’, 13˚04’), 1975–1980
W94 (Wigmosta et al., 1994)	**-1.1℃, 3.3℃**	DHSVM model	Middle Fork Flathead River basin in northwestern Montana (114˚00'W, 48˚29'N, 900m–3000m), Oct 1988–Oct 1991
K94 (Kang, 1994)	**2.8℃, 5.5℃**	Energy, Water, Mass Balance and Hydrological Discharge model	Tianshan Mountain, China (43˚06’N, 86˚50’E, 3539m–4010m), 1986–1990
L97 (Lindström et al., 1997)	**-1℃, 1℃**	HBV model	Ten basins in Sweden, 1969–1989
C04 (Collins et al., 2004)	**-5℃, 0℃**	NCAR CAM3.0	
HH05 (Hock and Holmgren, 2005)	**0.5℃, 2.5℃**	Mass Balance Model	Storglacia¨ren, Sweden (67˚55’N, 18˚35’E, 1120m–1730m), 1993–1994
G10 (Gao et al., 2010)	**-0.5℃, 2℃**	Degree-day mass balance model	Tarim River Basin, China (35˚N–43˚N, 73˚E–93˚E, 2780m–4800m), 1961–2006
W11 (Wang et al., 2011)	**0℃, 2℃**	Degree-day mass balance model	Qiyi Glacier in Qilian Mountains, China (39.5˚N, 97.5˚E, 4304m–5158.8m), Jun 30–Sep 5, 2010
Y01 (Yamazaki, 2001)	**snow ratio dependent on T_w**	One dimensional land surface model	Lena River basin in Eastern Siberia, 1986–1994
D08 (Dai, 2008)	**snow ratio dependent on T_a and p_s**		15000 land stations global and many ships, 1977–2007

Introduction

- Clearly, the critical temperature values are not unique in different regions, and all these schemes need validation in different climate regimes.
- This study aims at developing a universal scheme to discriminate rain, sleet, and snow.

Data

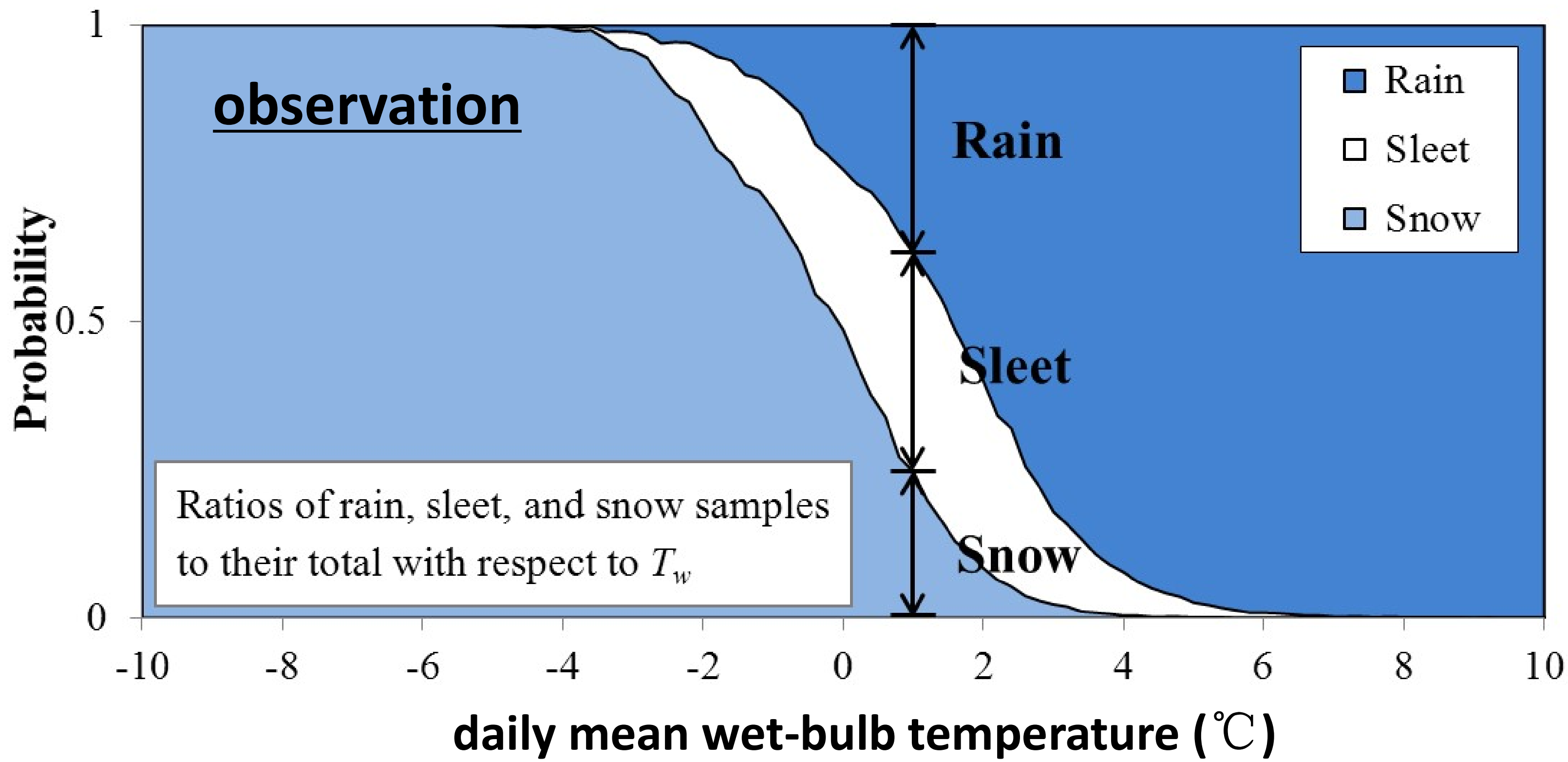
- CMA (China Meteorological Administration) station data
  - 1951-1979, daily
  - Daily mean air temperature (T_a), relative humidity (RH), surface air pressure (p_s), daily precipitation and precipitation type at 824 stations, and station elevation
  - Precipitation types (3 classes): rainfall, snowfall, and sleet
  - Total 709 stations, 459766 data, after data quality control



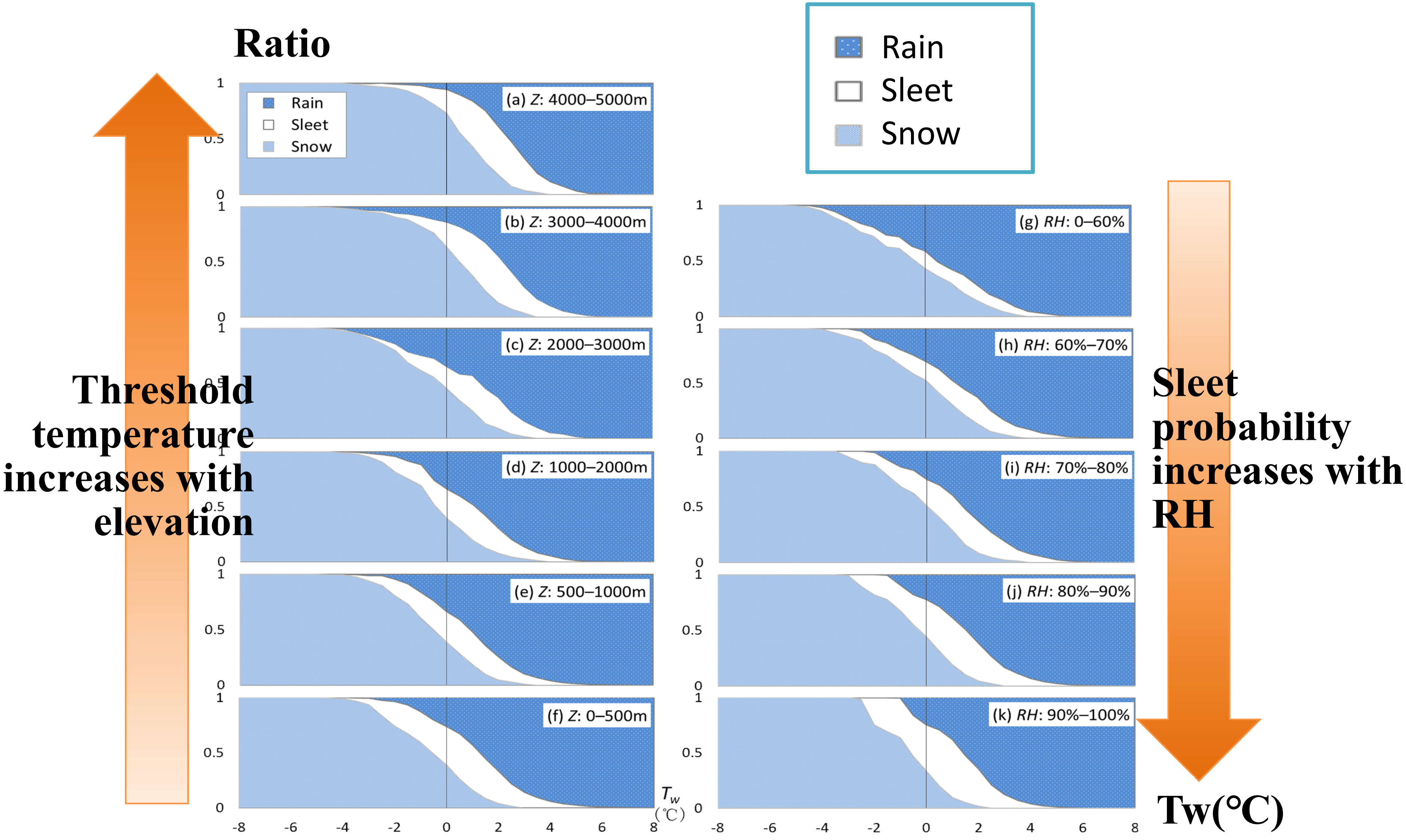
CMA daily data (1951-1979)

- **Scheme development：609 stations (hollow marks)，391380 data**
- **validation：100 stations (solid marks)，68386 data**

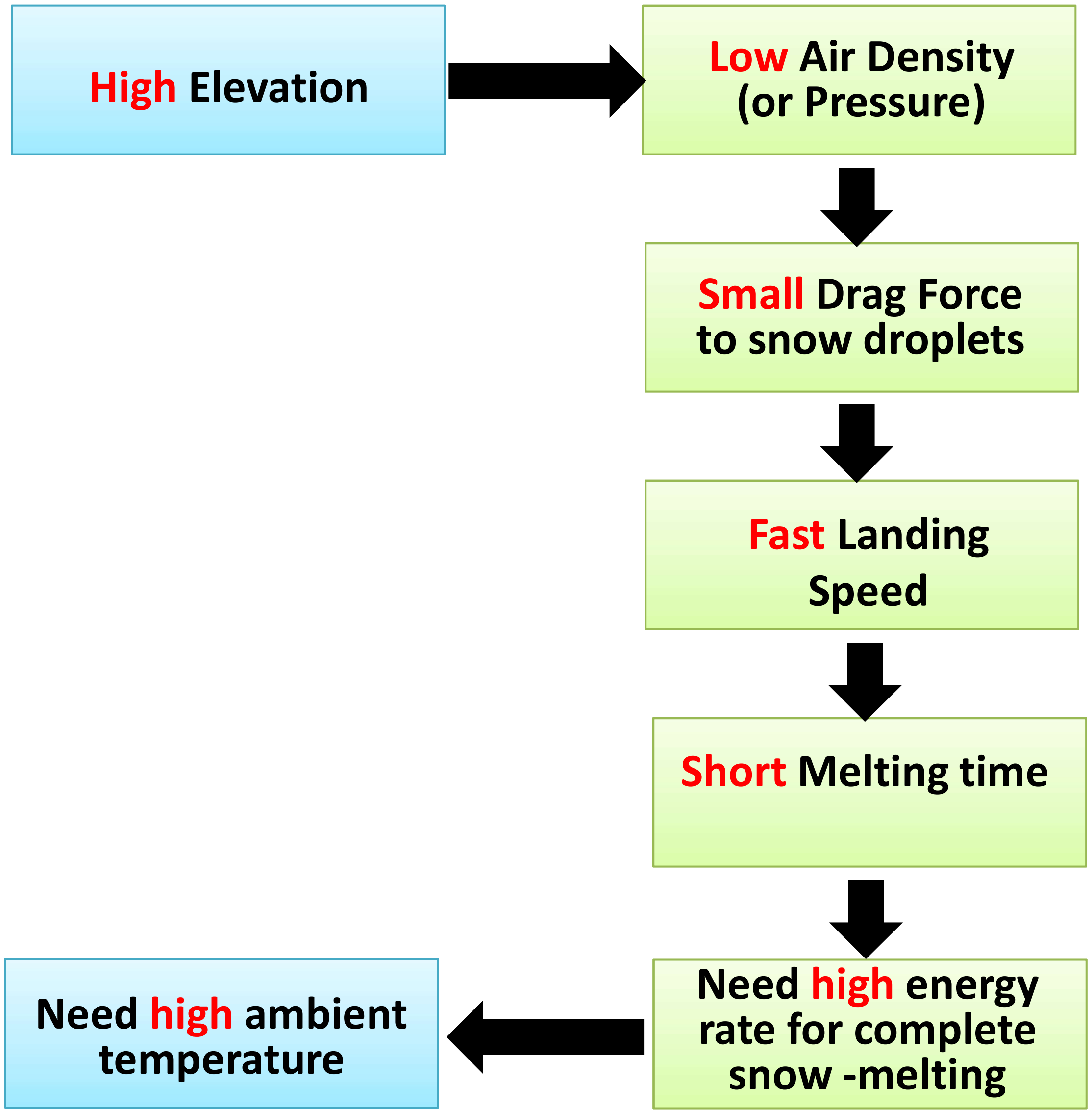
Precipitation Classification



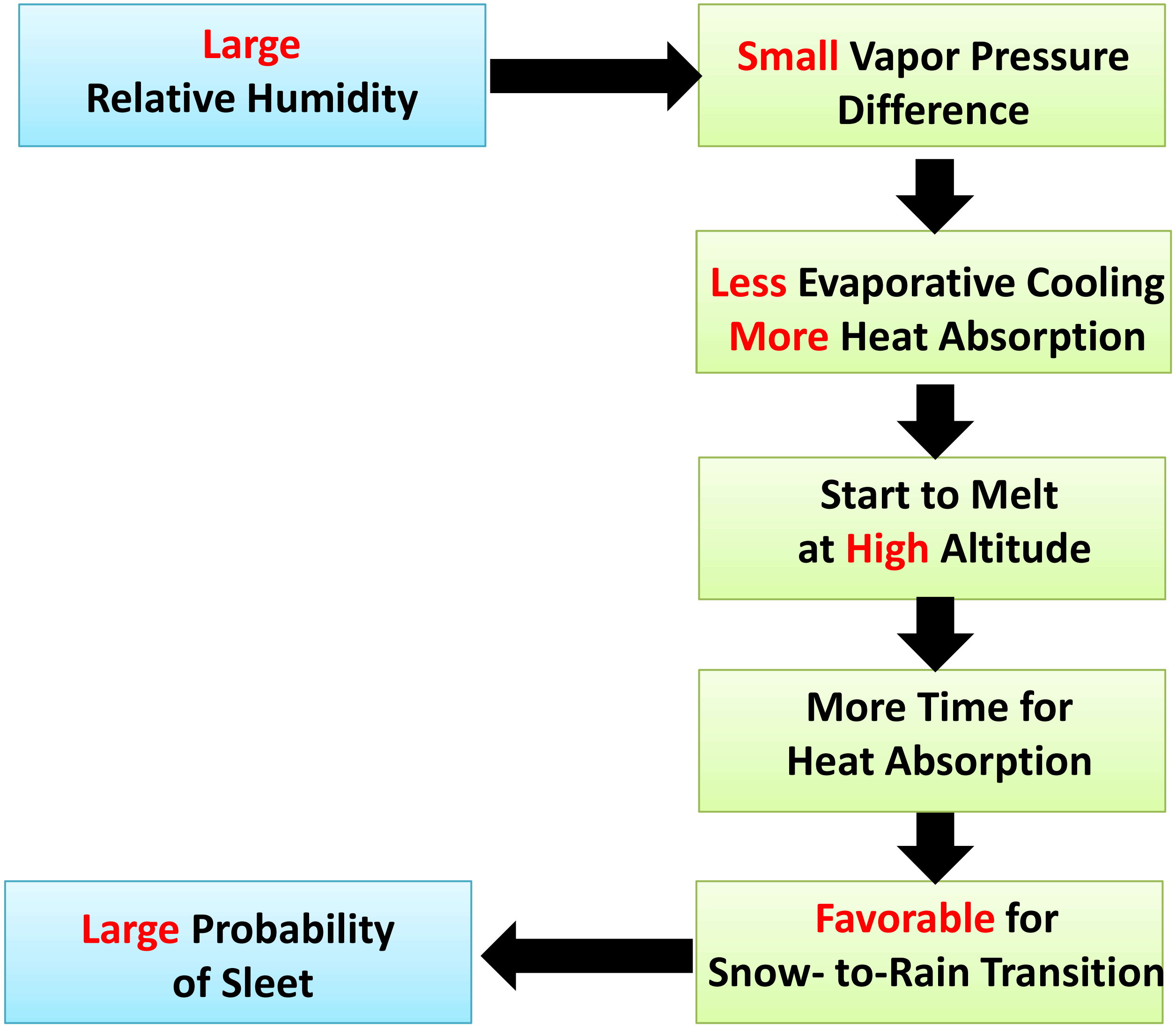
Precipitation types are highly dependent on Tw, RH, and elevation



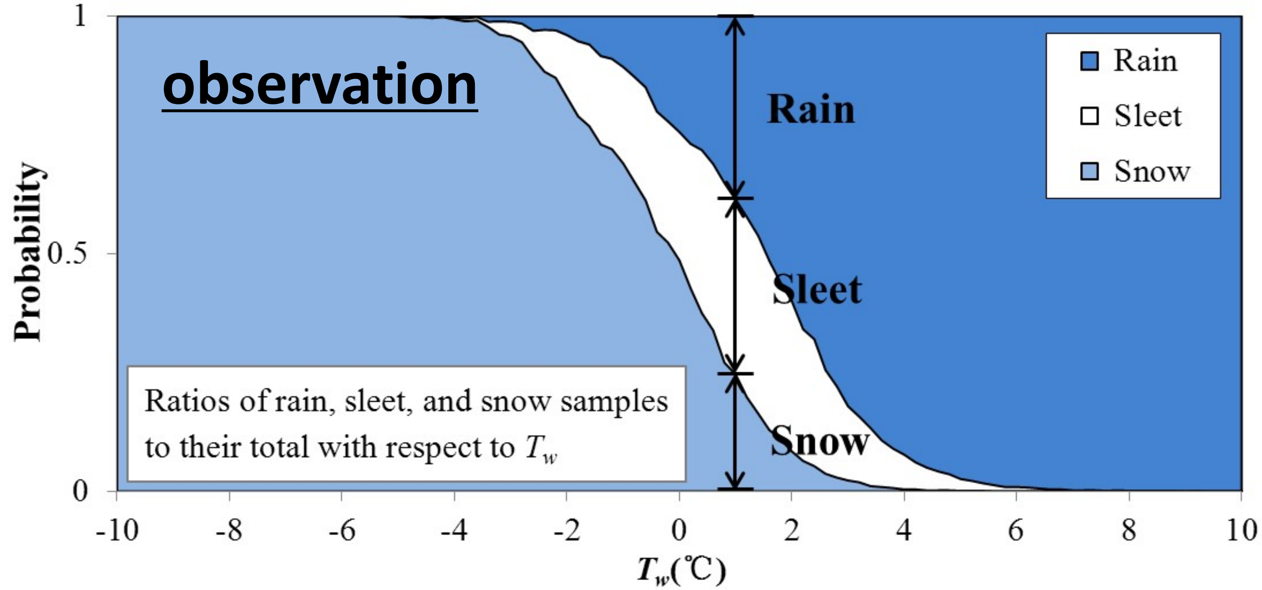
The effect of Elevation



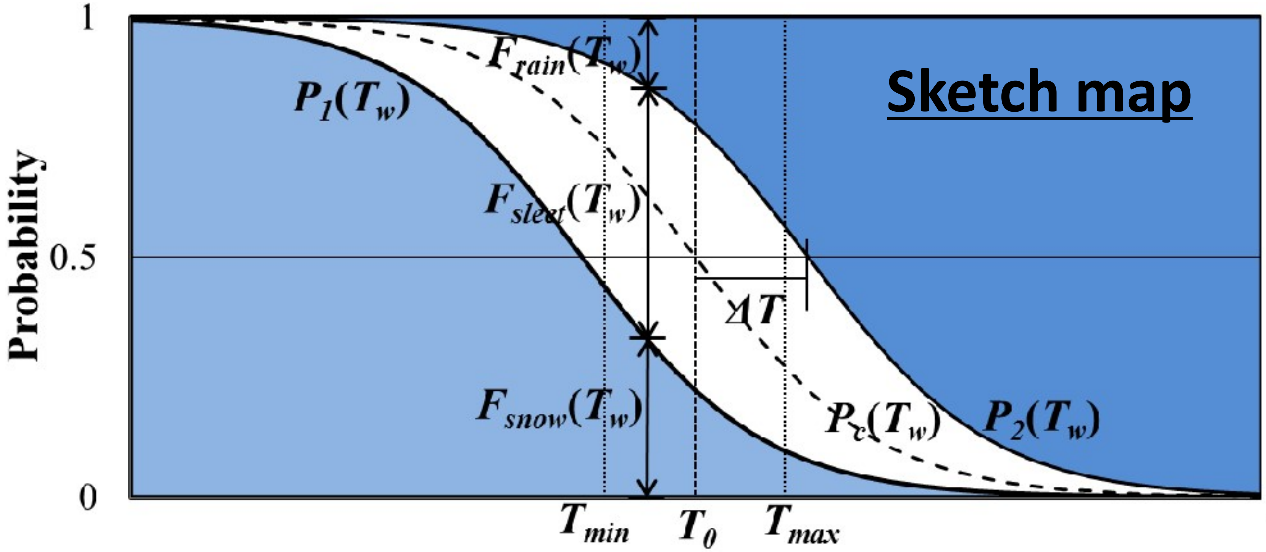
The effect of Relative Humidity



Precipitation Classification Scheme



daily mean wet-bulb temperature



$$P_1(T_w) = \frac{1}{1 + exp(\frac{T_w - T_0 + \Delta T}{\Delta S})}$$

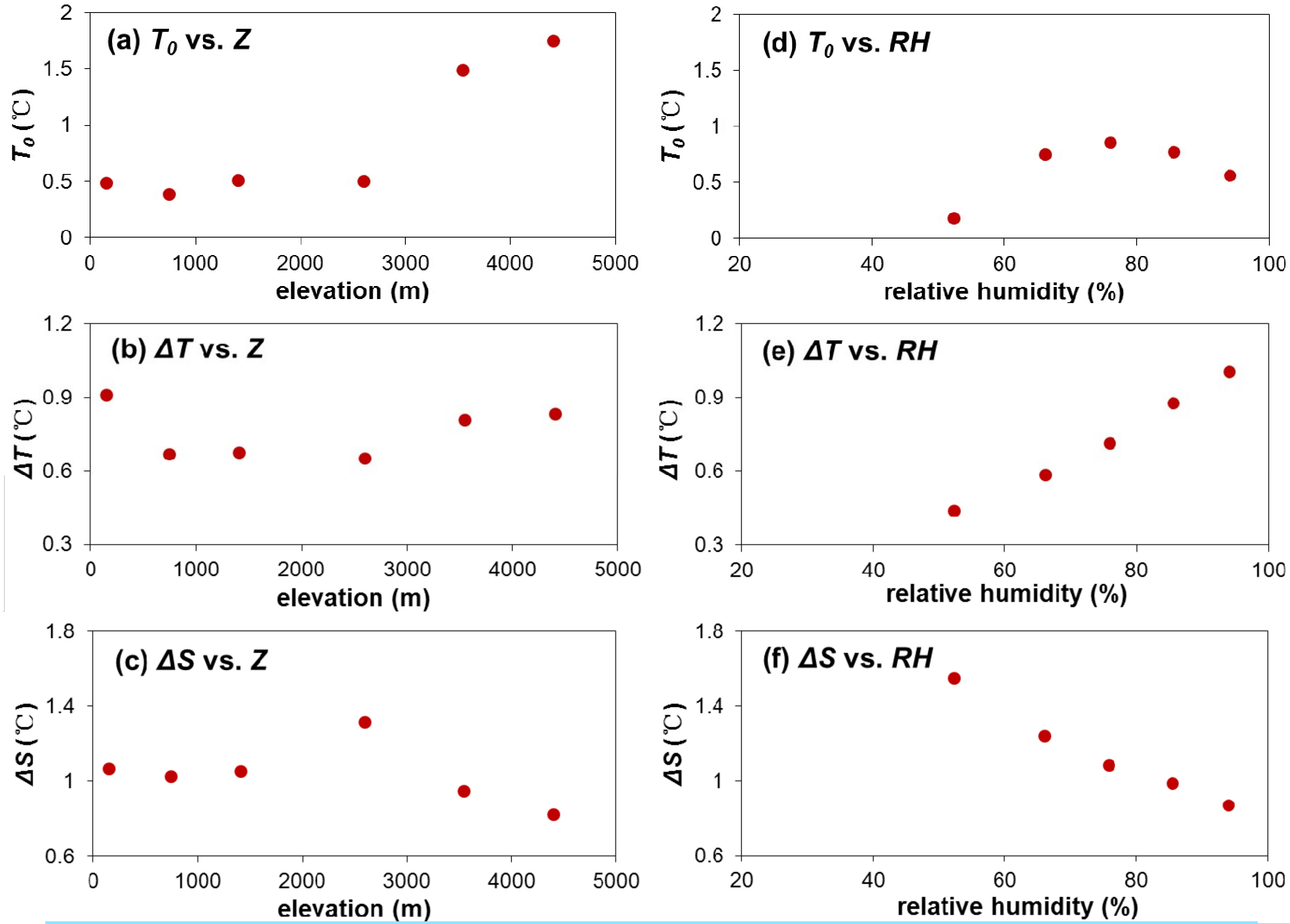
$$P_2(T_w) = \frac{1}{1 + exp(\frac{T_w - T_0 - \Delta T}{\Delta S})}$$

Three parameters:

T_0, ΔT, ΔS

daily mean wet-bulb temperature

Relationship between the parameters (T_0, ΔT, ΔS) and elevation(Z), relative humidity(RH)

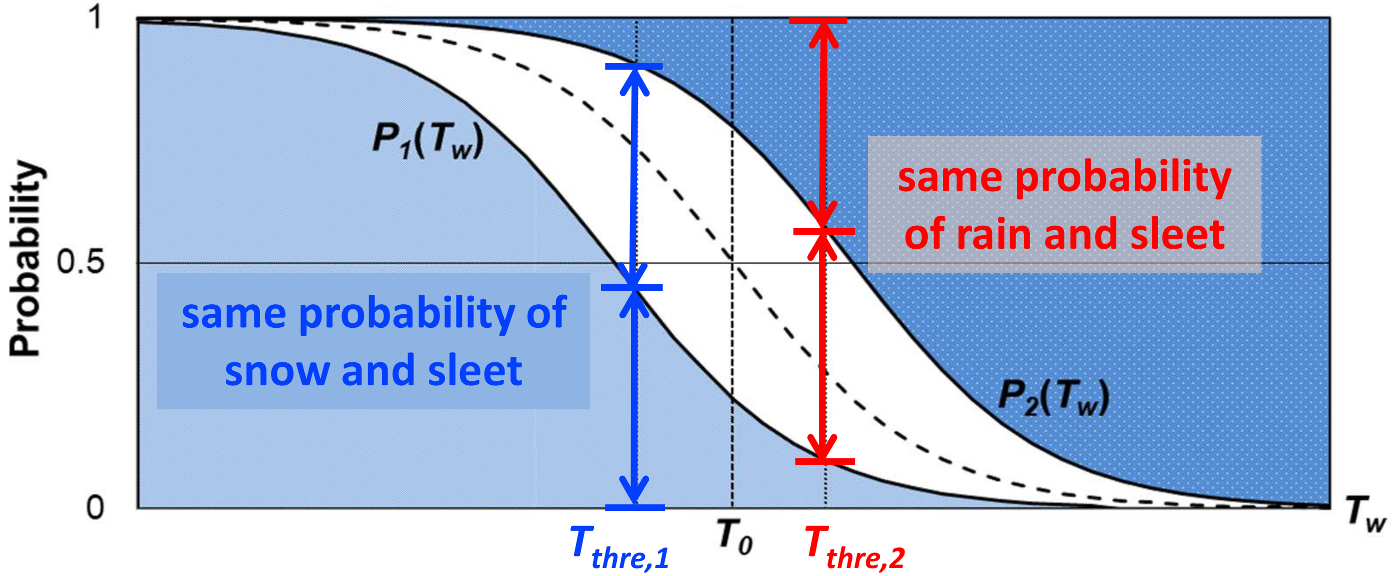


$$\Delta T = 0.215 - 0.099 \times RH + 1.018 \times RH^2$$

$$\Delta S = 2.374 - 1.634 \times RH$$

$$T_0 = -5.87 - 0.1042 \times Z + 0.0885 \times Z^2 + 16.06 \times RH - 9.614 \times RH^2$$

Determinant parameterization of precipitation types



daily mean wet-bulb temperature

$$T_{thre,1} = \begin{cases} T_0 - \Delta S * \ln\left[exp\left(\frac{\Delta T}{\Delta S}\right) - 2 * exp\left(-\frac{\Delta T}{\Delta S}\right)\right] & \frac{\Delta T}{\Delta S} > \ln 2 \\ T_0 & \frac{\Delta T}{\Delta S} \leq \ln 2 \end{cases}$$

$$T_{thre,2} = \begin{cases} 2 * T_0 - T_{thre,1} & \frac{\Delta T}{\Delta S} > \ln 2 \\ T_0 & \frac{\Delta T}{\Delta S} \leq \ln 2 \end{cases}$$

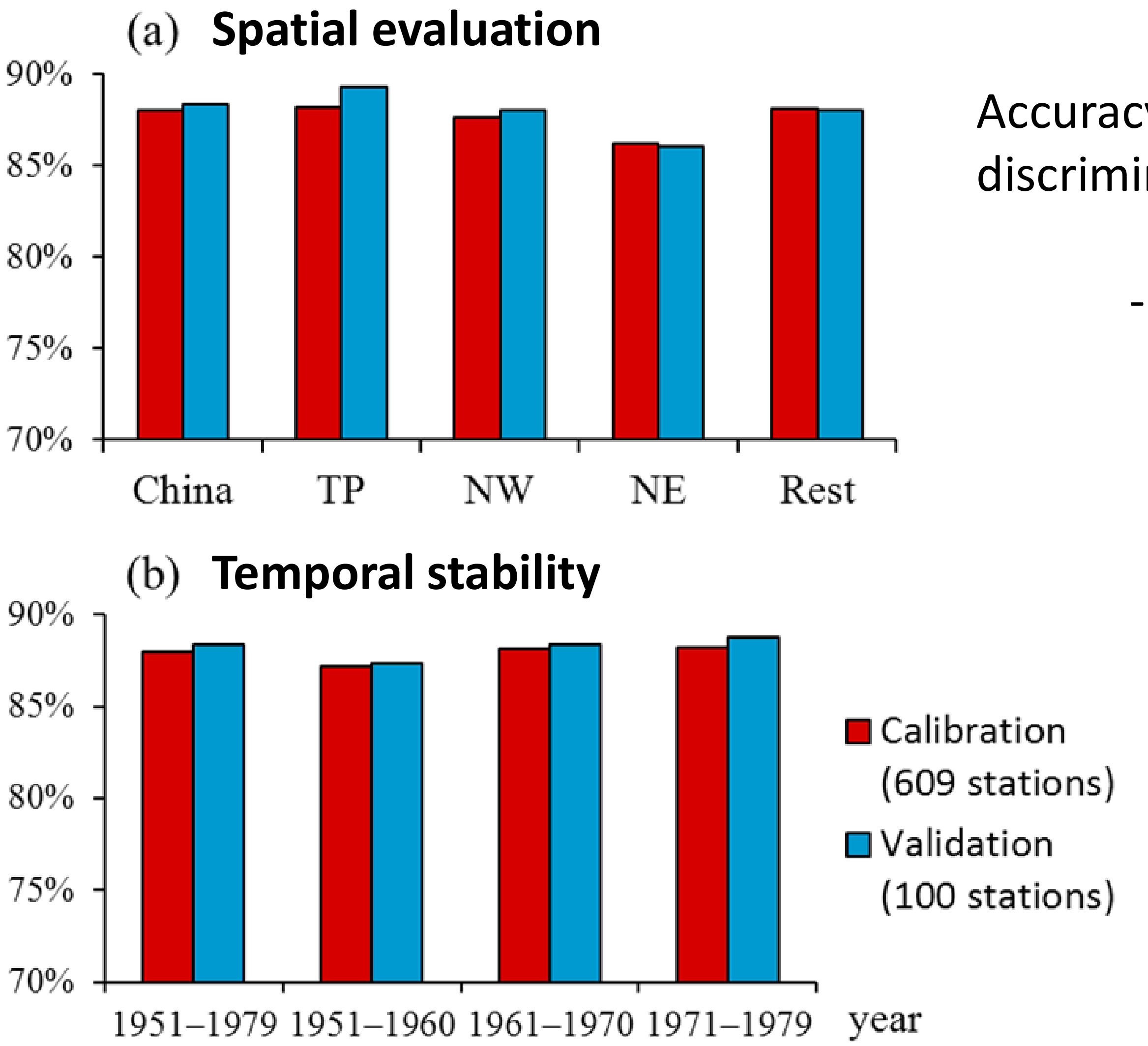
Precipitation Type

snow: $T_w \leq T_{thre,1}$

sleet: $T_{thre,1} < T_w < T_{thre,2}$

rain: $T_w \geq T_{thre,2}$

Scheme Evaluation

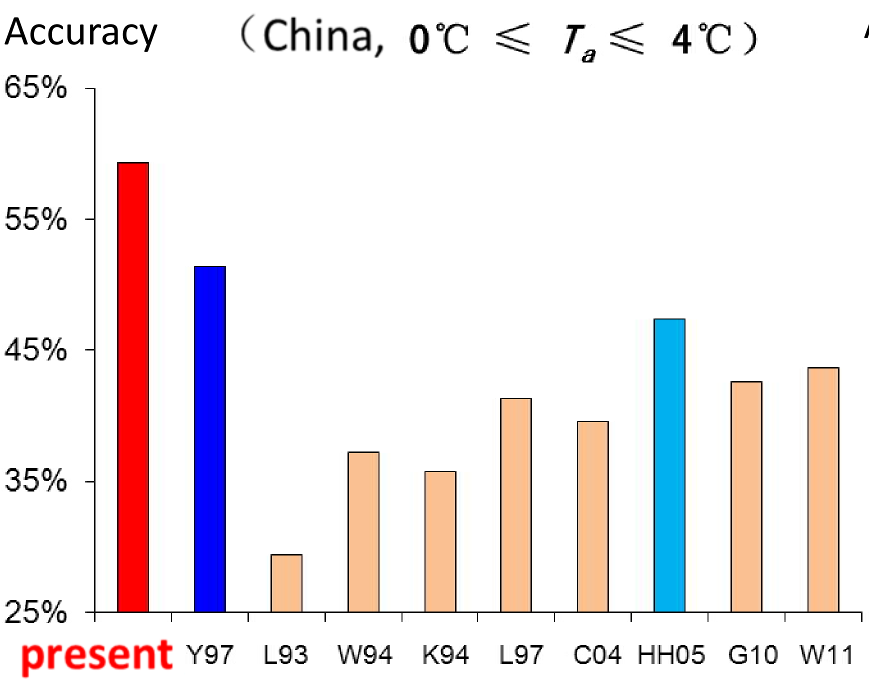


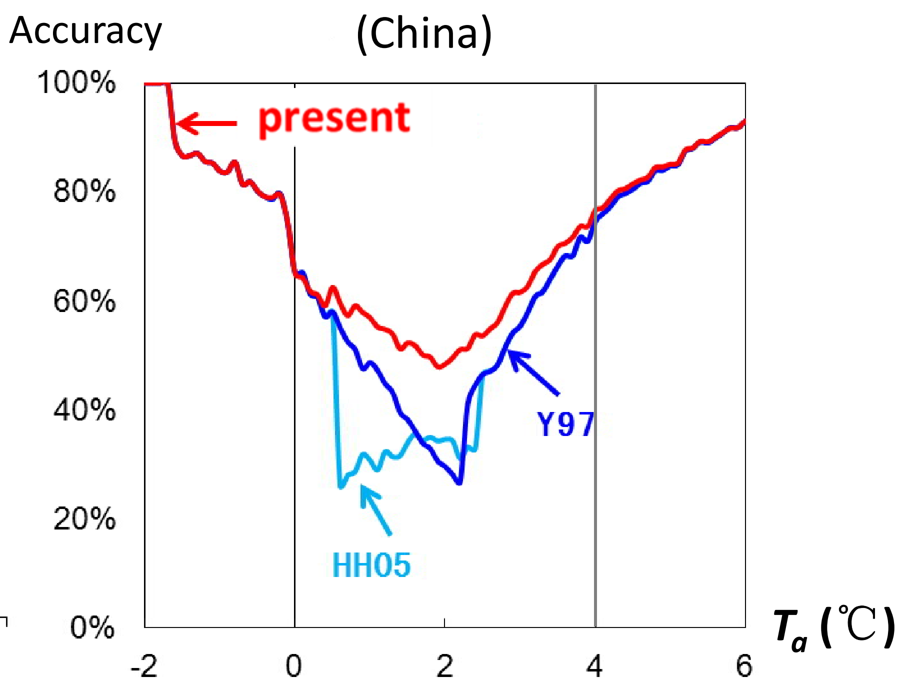
Accuracy of precipitation type discrimination of the scheme

$-10℃ \leq T_a \leq 10℃$

Comparison with other schemes

Accuracy of precipitation type discrimination





Summary

- Precipitation types highly depend on surface wet-bulb temperature, relative humidity, and elevation. A dynamic temperature threshold scheme is developed to discriminate rain, sleet, and snow. Evaluations show that the new scheme outperforms the schemes used in hydrological land surface models.

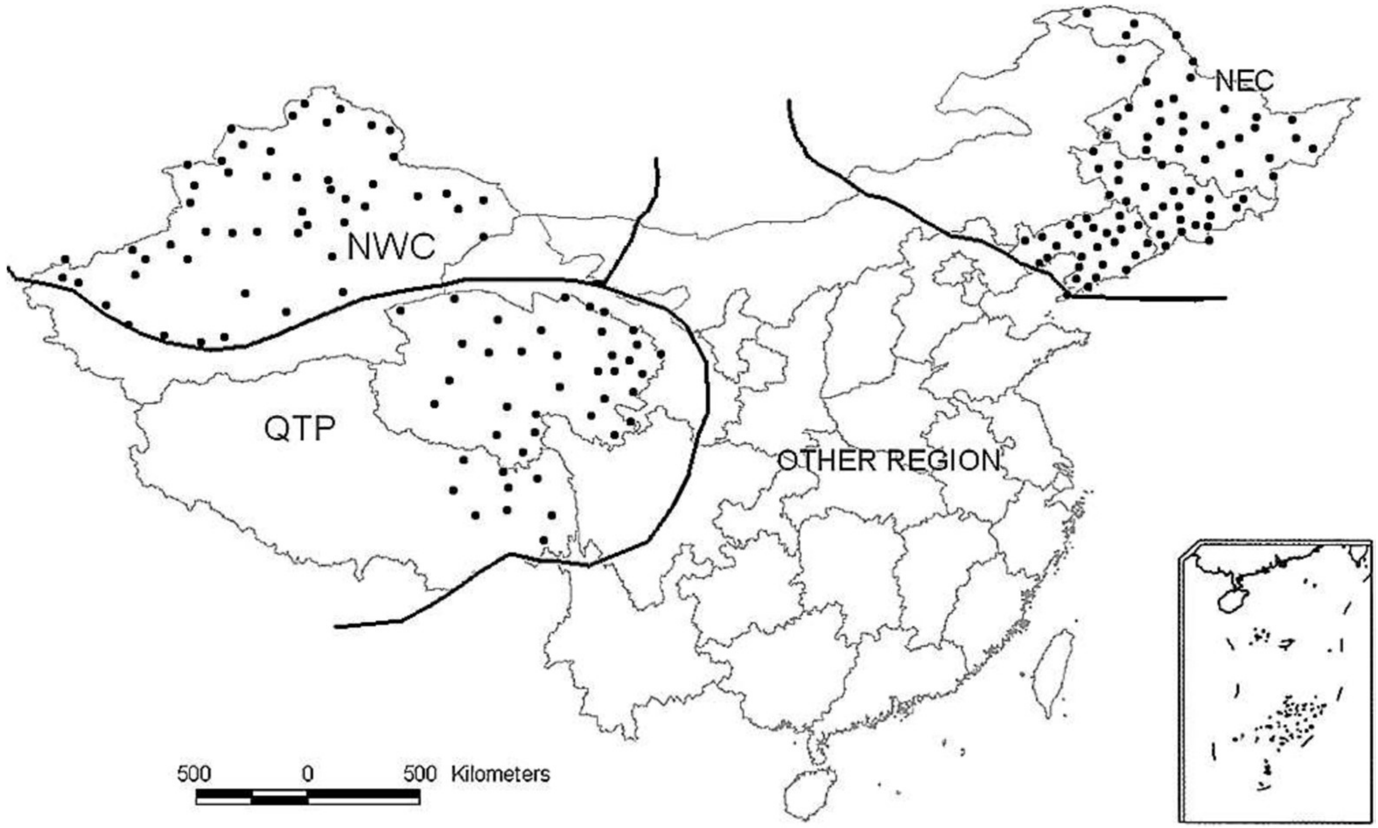
- Reference:

Ding, B., Yang, K., Qin, J., Wang, L., Chen, Y., He, X., 2014. The dependence of precipitation types on surface elevation and meteorological conditions and its parameterization. J. Hydrol. 513, 154–163.

Satellite product of snow depth in China

- **References**
  - Che T, Li X et al. , 2008: Snow depth derived from passive microwave remote-sensing data in China. Annals of Glaciology, 2008, 49: 145-154)
  - Dai L, Che T, Ding Y, et al. Evaluation of snow cover and snow depth on the Qinghai-Tibetan Plateau derived from passive microwave remote sensing. The Cryosphere Discussions. 2016, 2016: 1-31.
- **Webpage for snow depth dataset:**
  - The world data center for glaciology and geocryology, Lanzhou

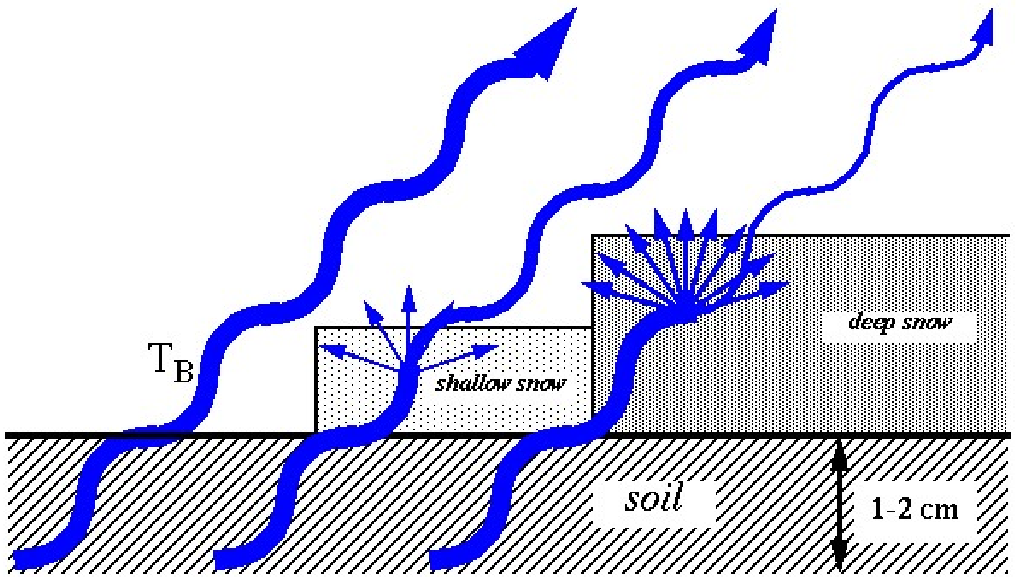
Snow-depth observations at CMA stations



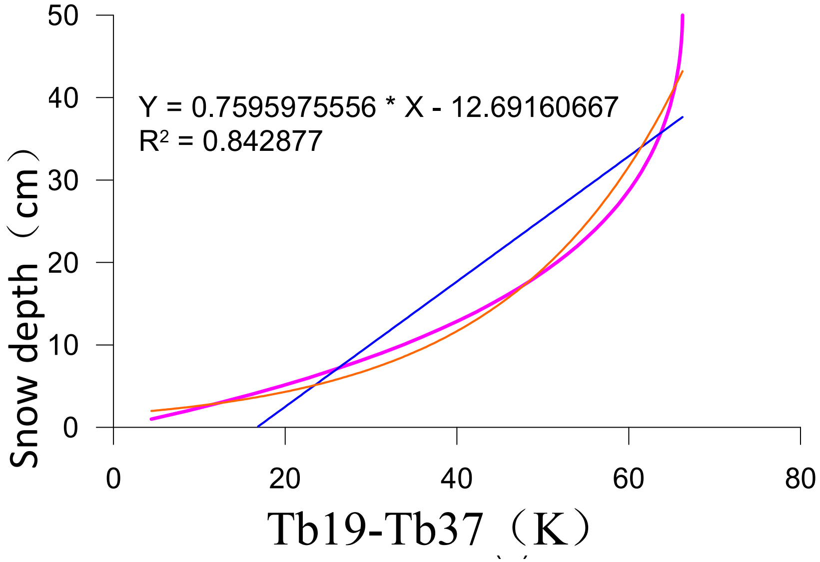
Global algorithm for snow depth retrieval

- Snow crystals are effective scatterers of microwave radiation. This scattering effect redistributes the upwelling radiation according to snow thickness and crystal size, which provides the physical basis of microwave detection of snow.
- The deeper the snowpack, the more snow crystals there are available to scatter microwave energy away from the sensor.
- Usually, the higher the microwave frequencies, the more volume scattering because the wavelength is close the snow crystal size.

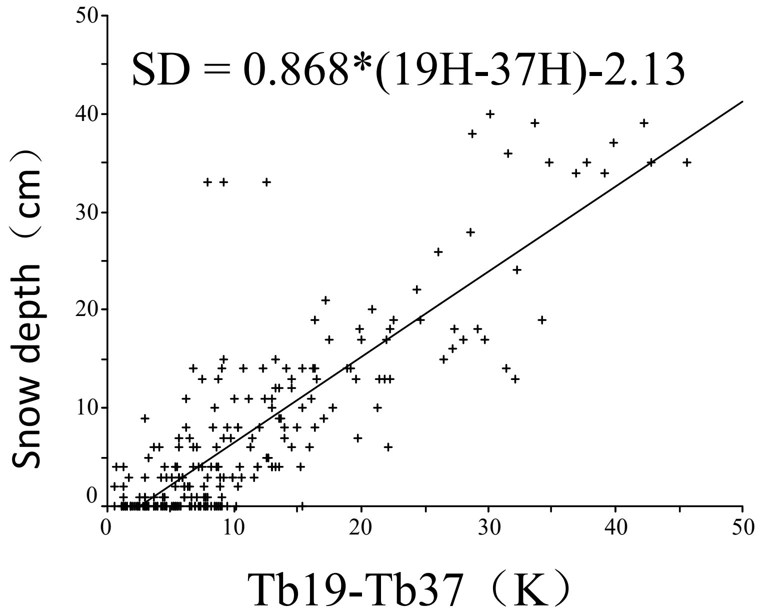
$$SD = a * (T_{b,18} - T_{b,37})$$



Retrieval algorithm



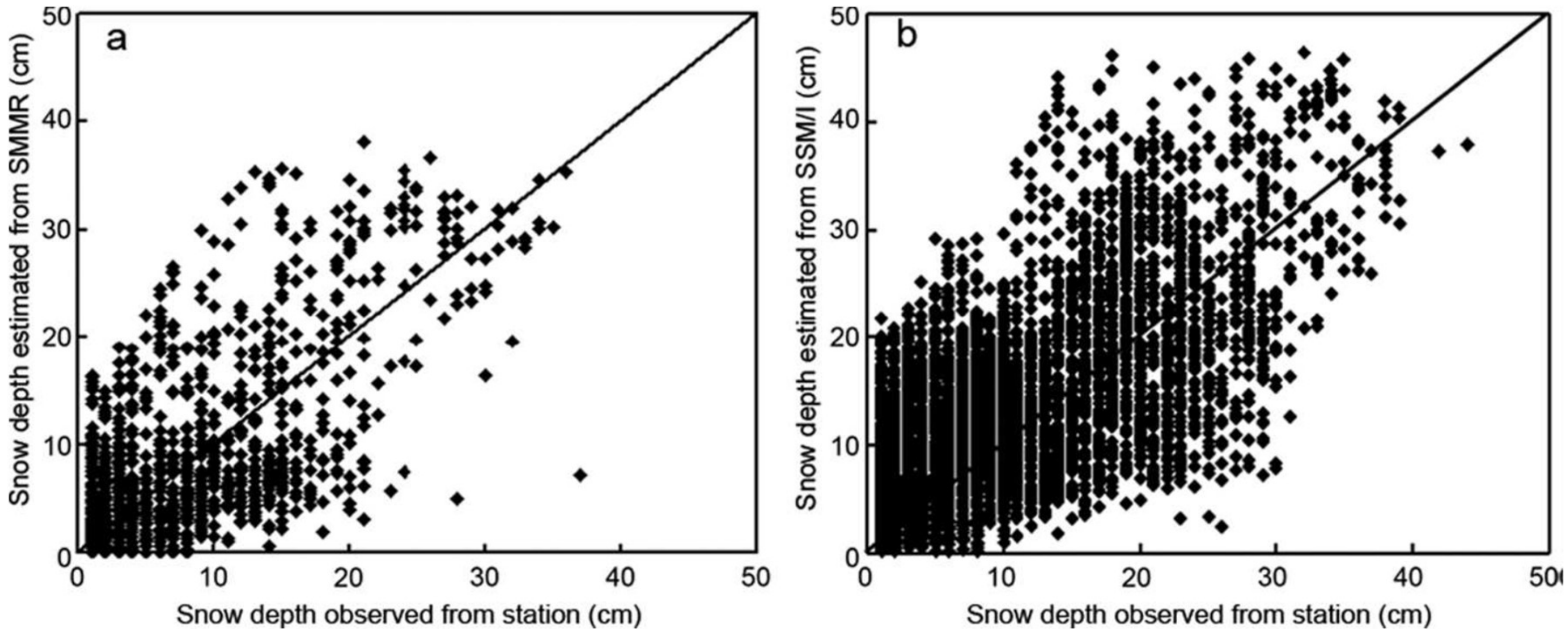
Simulation by RTM



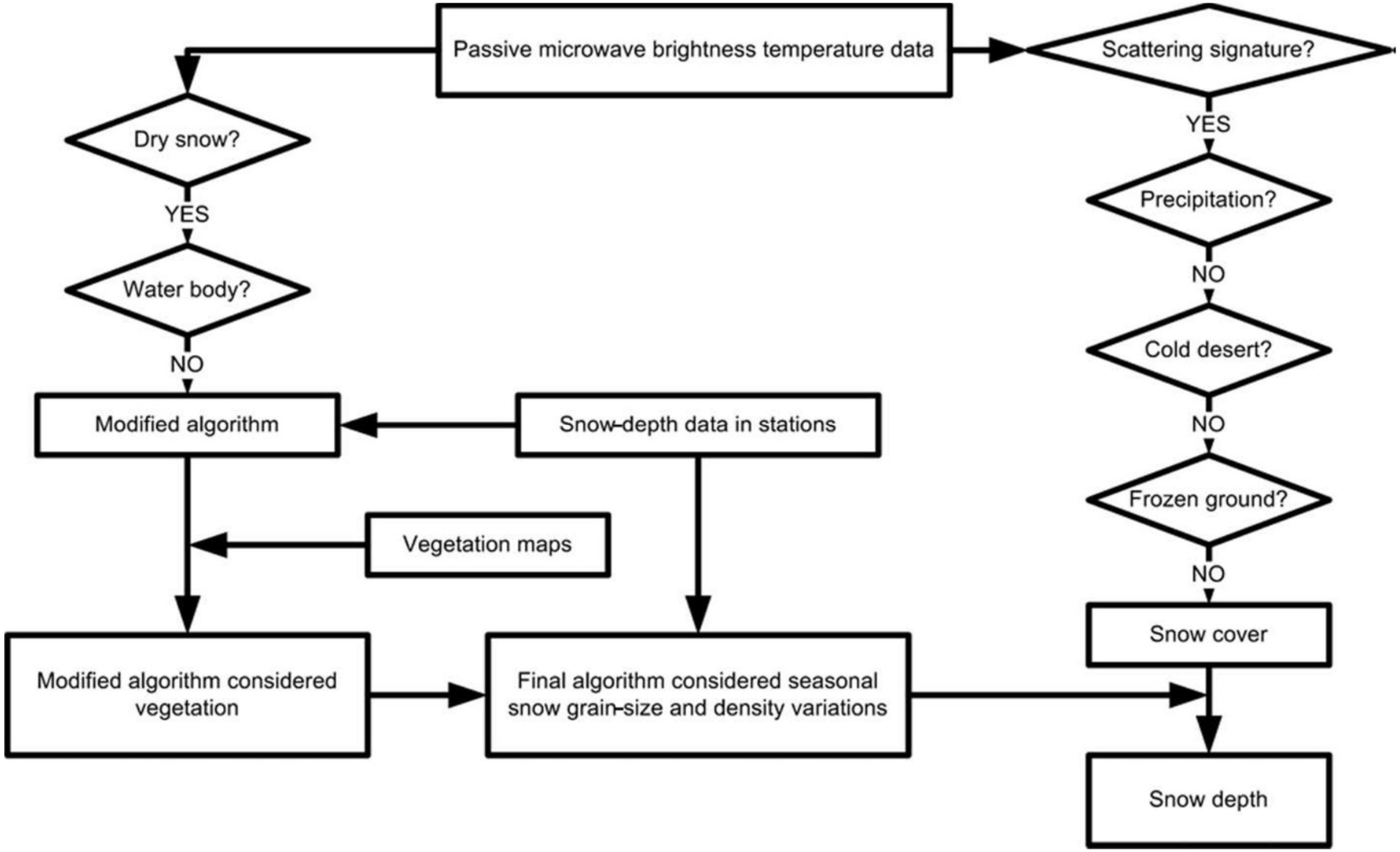
Regression by observations

Che T, Li X, Jin R, et al. Snow depth derived from passive microwave remote-sensing data in China[J]. Annals of Glaciology, 2008, 49: 145-154.

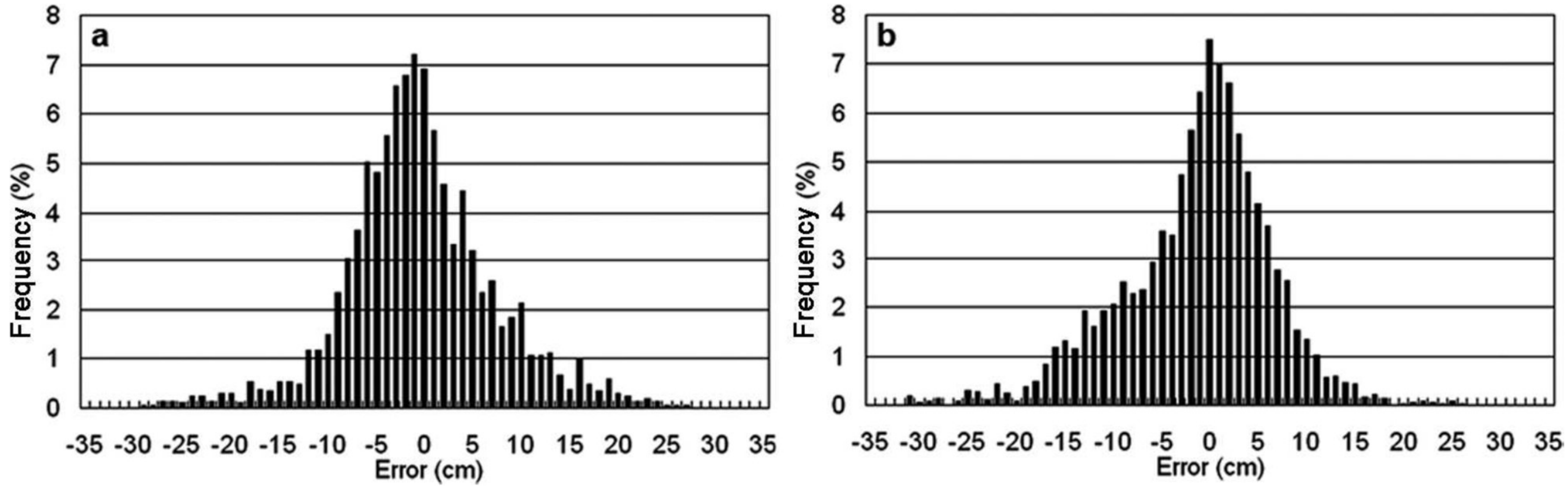
Calibration with daily observations in 1980 and 1981 for SMMR, and in 2003 for SSM/I.



Flow chart of algorithm deriving snow-depth from passive microwave brightness temperature

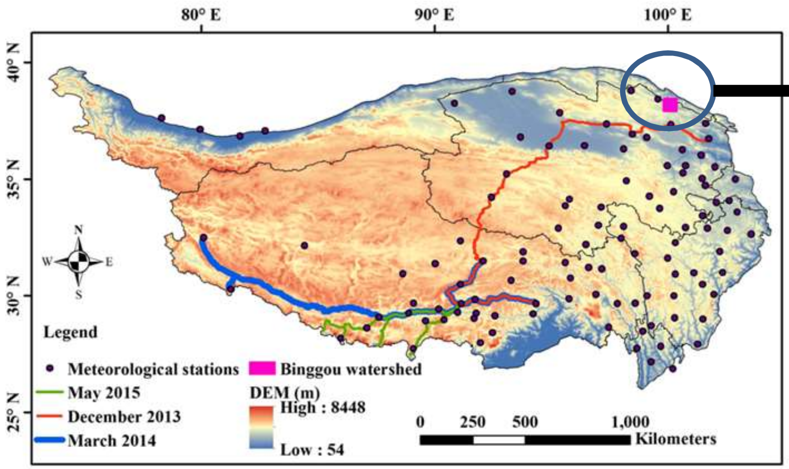


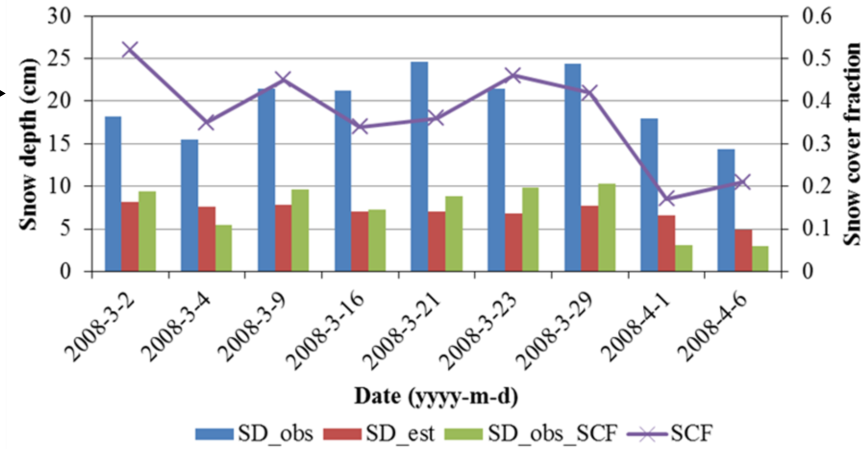
The standard deviations are 6.03cm and 5.61cm for SMMR and SSM/I, respectively.



Percentage error-frequency distribution of estimated snow-depth in (a) 1983 and 1984 (number of data = 2070) and (b) SSM/I in 1993 (number of data = 6862)

Difficulty in evaluation of snow depth products

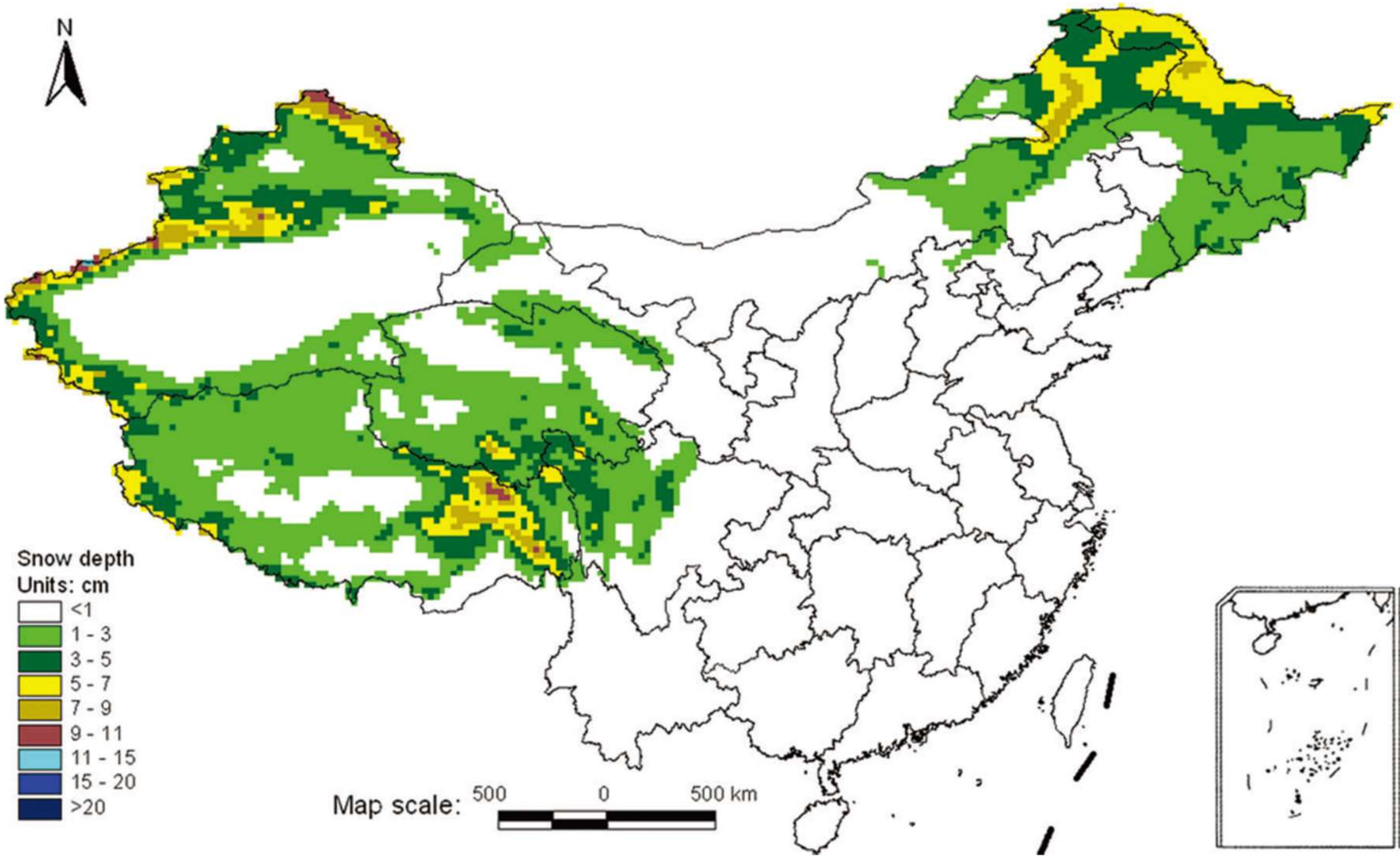




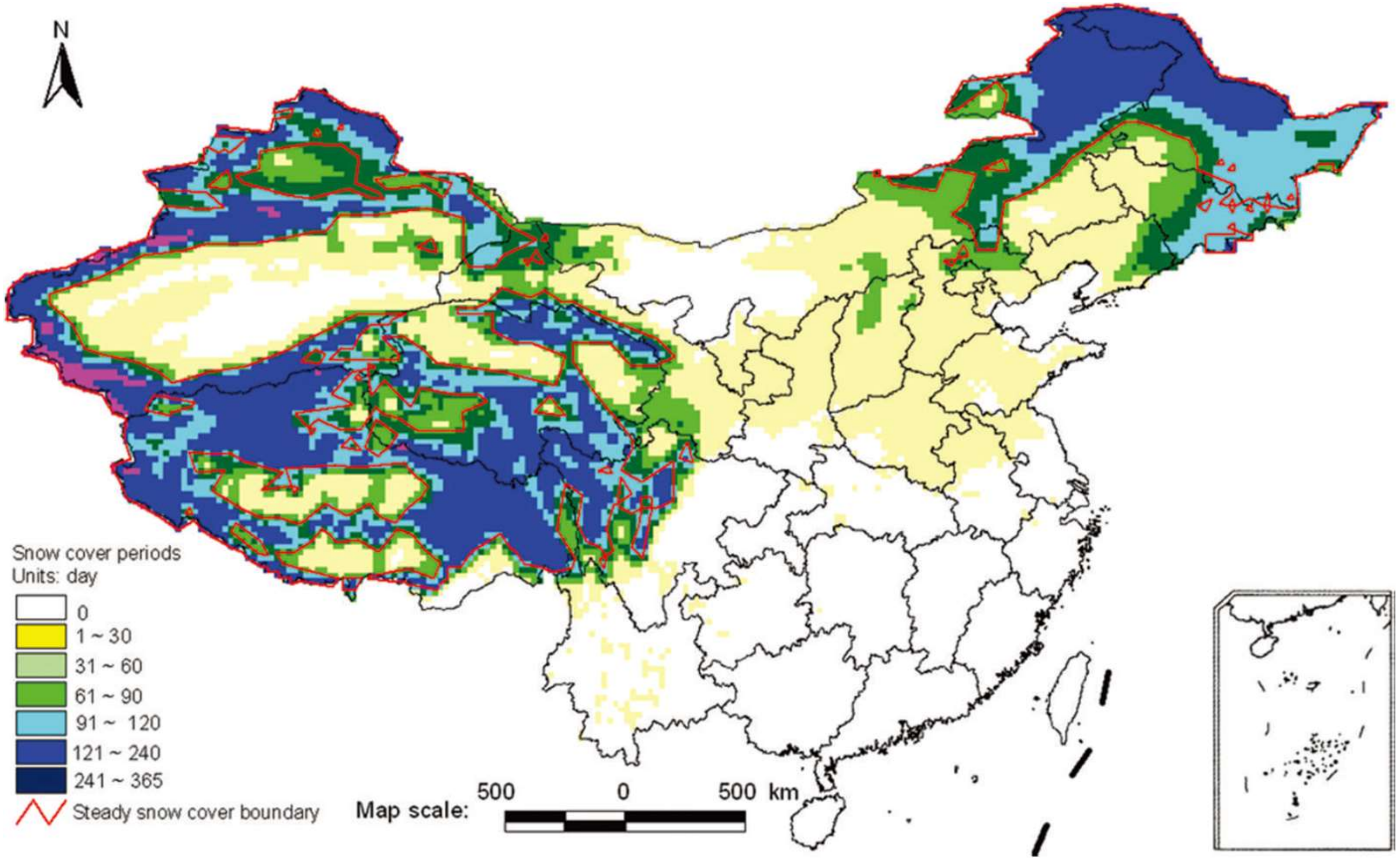
- Patch snow leads the low spatial representativeness observation in a single station on the QTP.
- The validation is still ongoing with a multi-sources data.

Dai L, Che T, Ding Y, et al. Evaluation of snow cover and snow depth on the Qinghai-Tibetan Plateau derived from passive microwave remote sensing. The Cryosphere Discussions. 2016, 2016: 1-31.

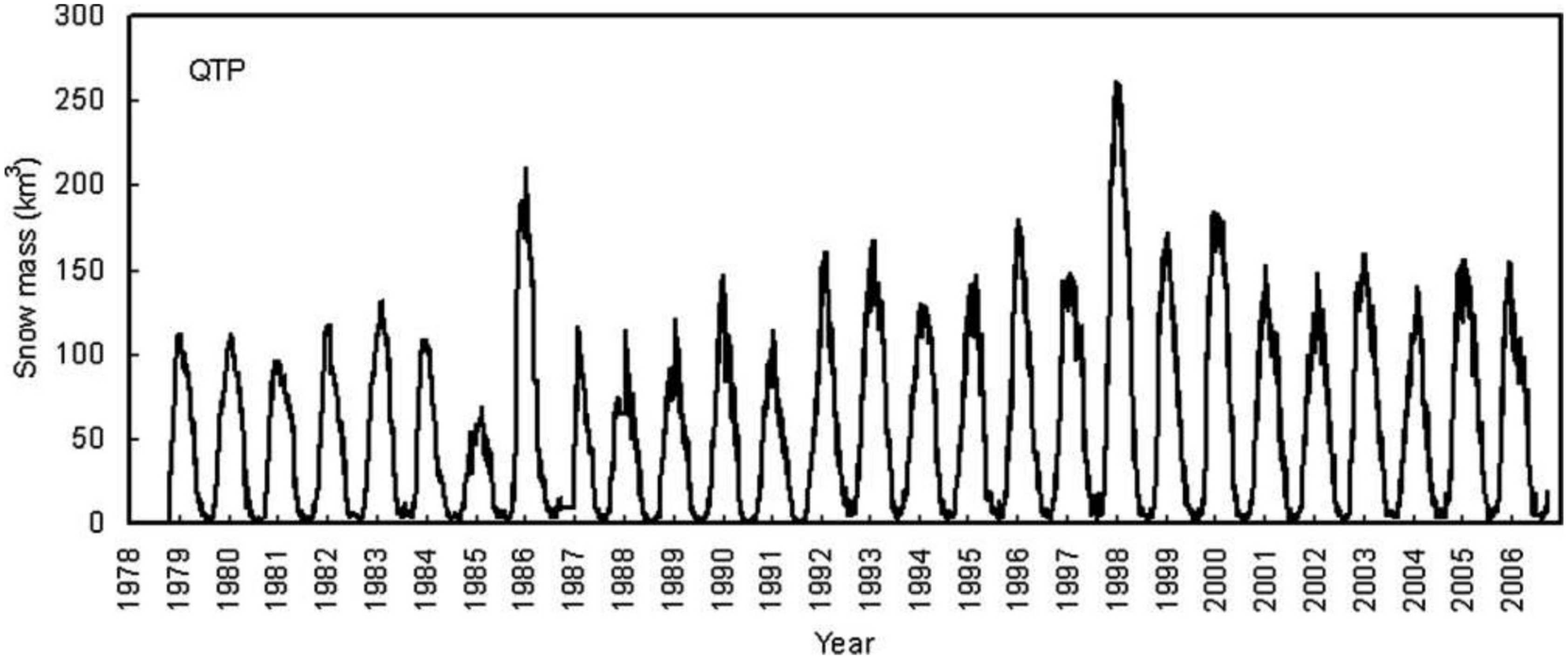
Annual average snow-depth distributions in China from 1978 to 2006 based on the SMMR and SSM/I data.



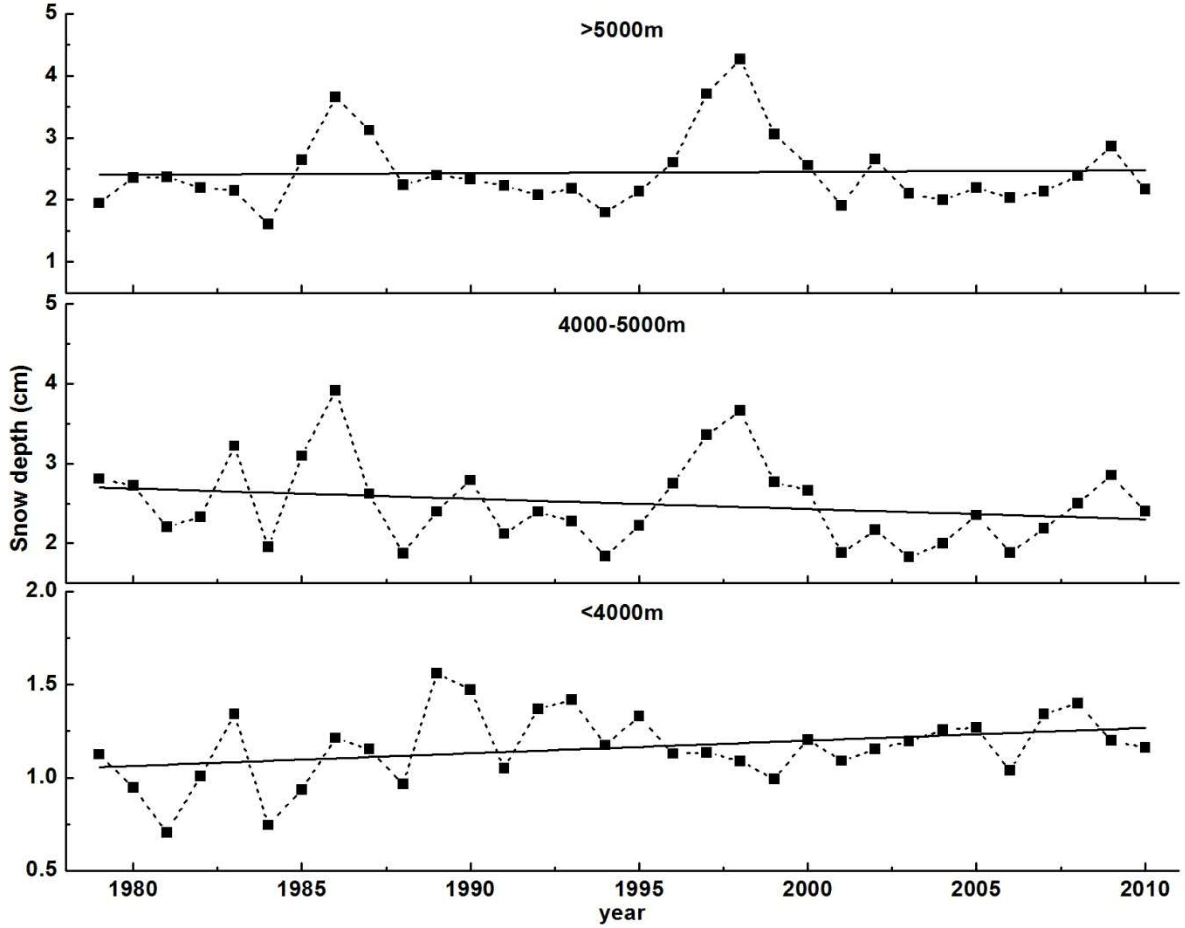
Annual average distributions of snow-cover period in China from 1978 to 2006 based on the SMMR and SSM/I data



Seasonal and inter-annual variations of snow mass on the TP from 1978 to 2006 based on the SMMR and SSM/I data.



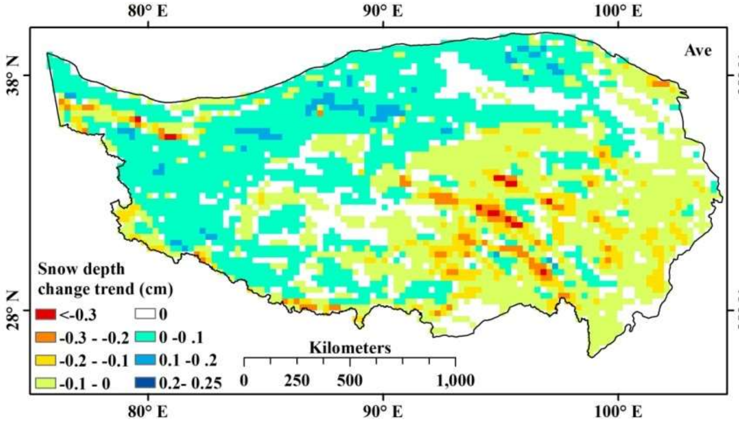
Changes in snow depth at different elevation bands

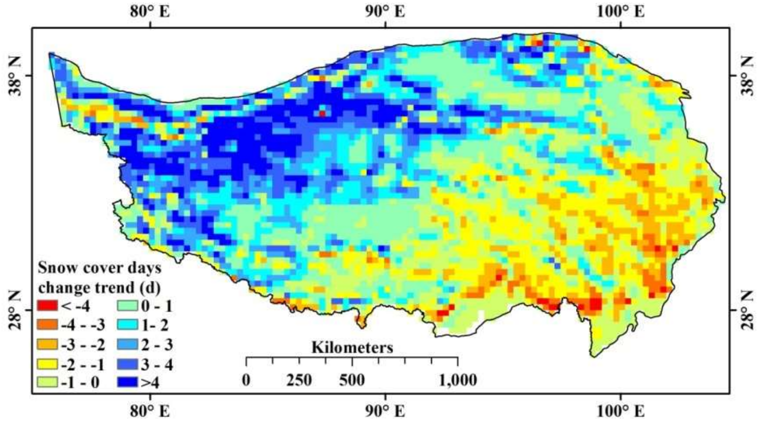


- ➢SMMR (1978-1987)
- ➢SSM/I (1987-2015)

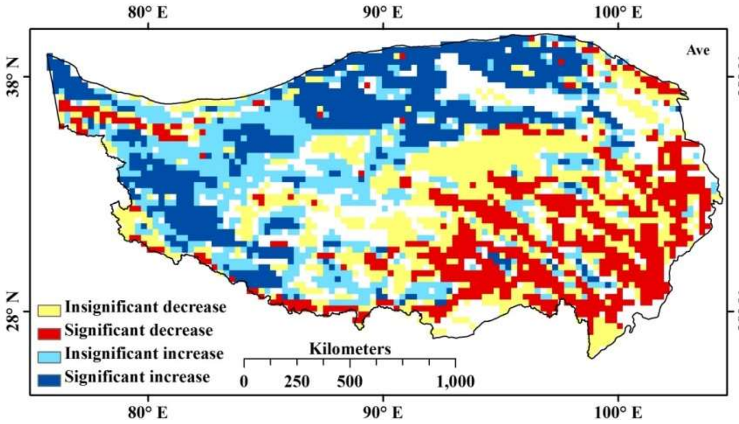
Che T et al, unpublished materials

Changes in snow depth and duration

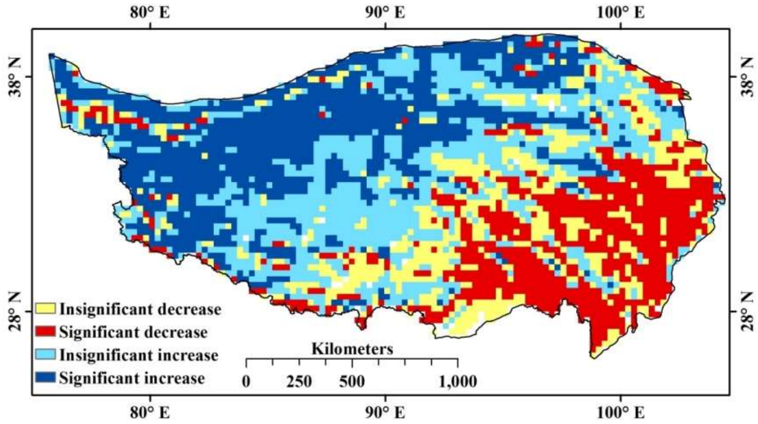




Changes in snow depth（cm/year） **Changes in snow duration（d/year）**



Significance



Significance

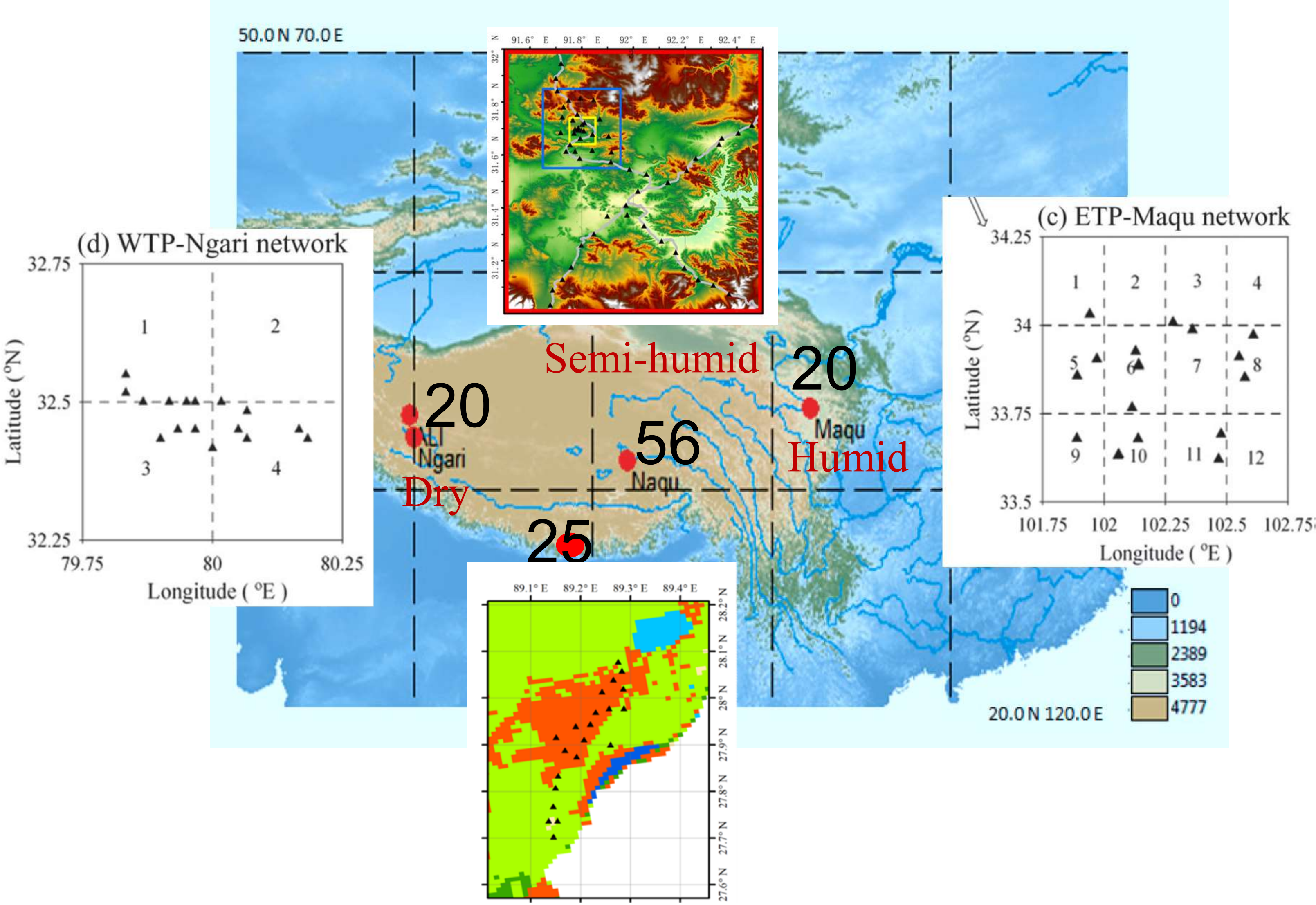
Snow depth and duration have a similar change in spatial scale.
Increases in North and West part, while decreases in Southeast part.

Summary

- A dynamic temperature threshold scheme is developed to discriminate rain, sleet, and snow. A combination of this scheme and land surface modeling may be used to re-construct snow depth data.
- Abundant snow cover and snow depth data are available from microwave remote sensing, but the validation of snow depth data is difficult.

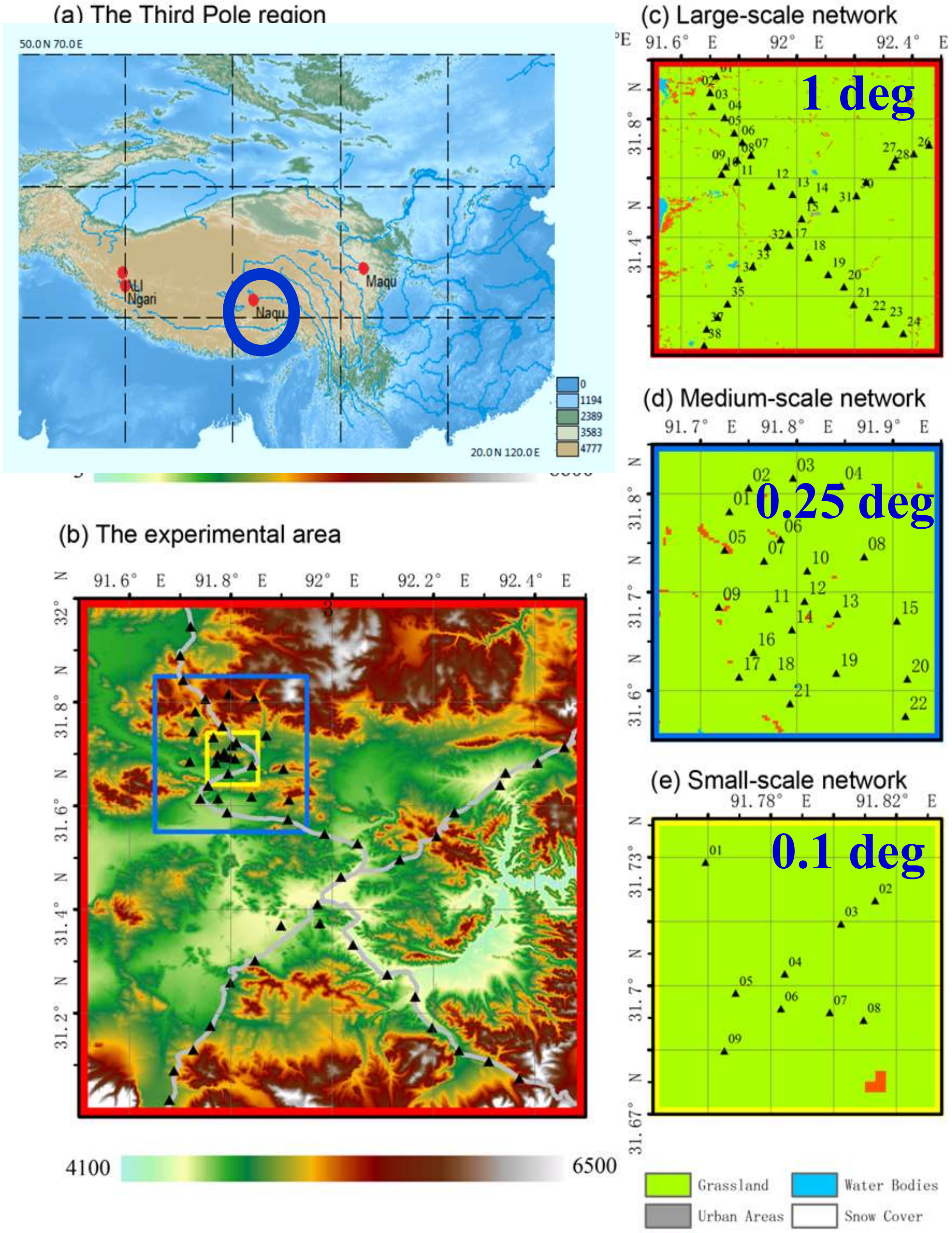
Thank you!

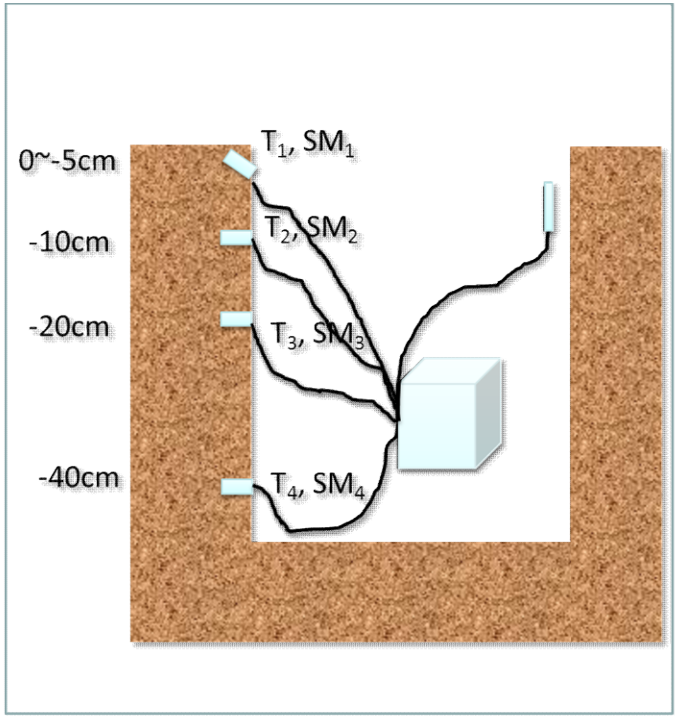
Four soil moisture and soil temperature networks are the validation basis of satellite soil moisture products



(Su et al., 2011 HESS; Yang et al., 2013)

Naqu multi-scale soil moisture and temperature network in CTP

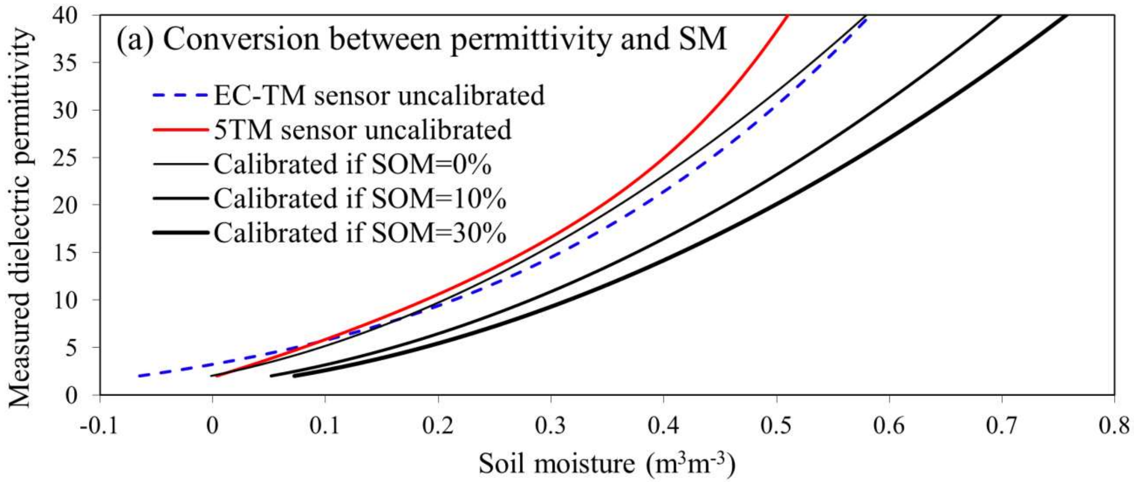


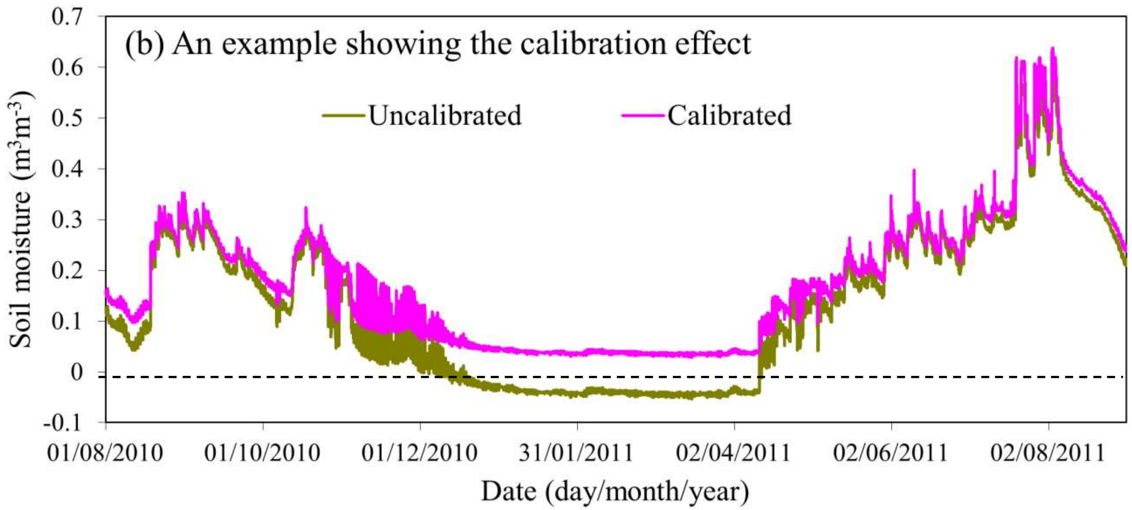


- Above 4500 m a.s.l.
- Sensor calibrated,
- Data accessible through ISMN

(Yang et al., 2013 BAMS)

Sensor calibration according to soil texture and SOC
Based on relationship established by laboratory experiments

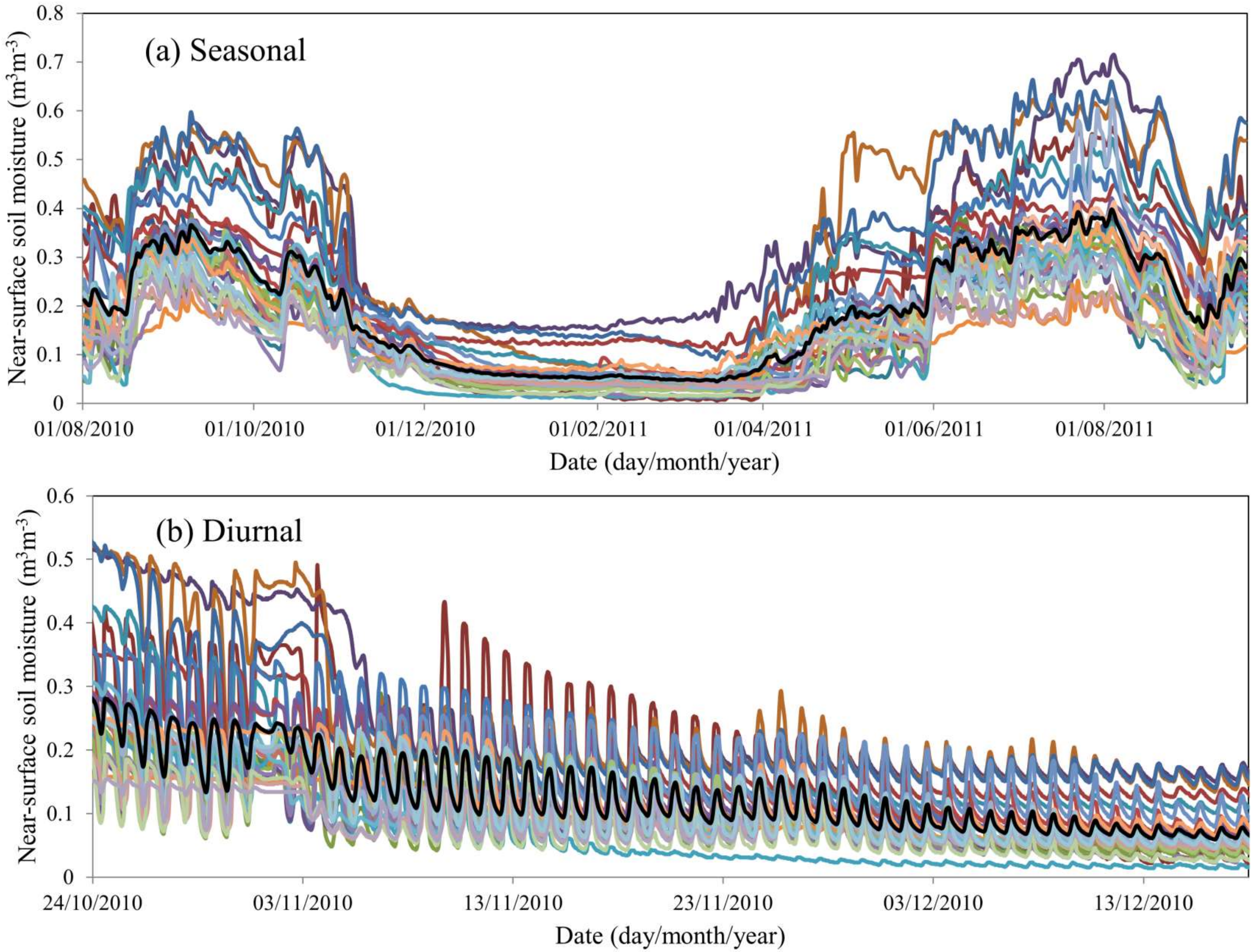




very high soil organic matters content

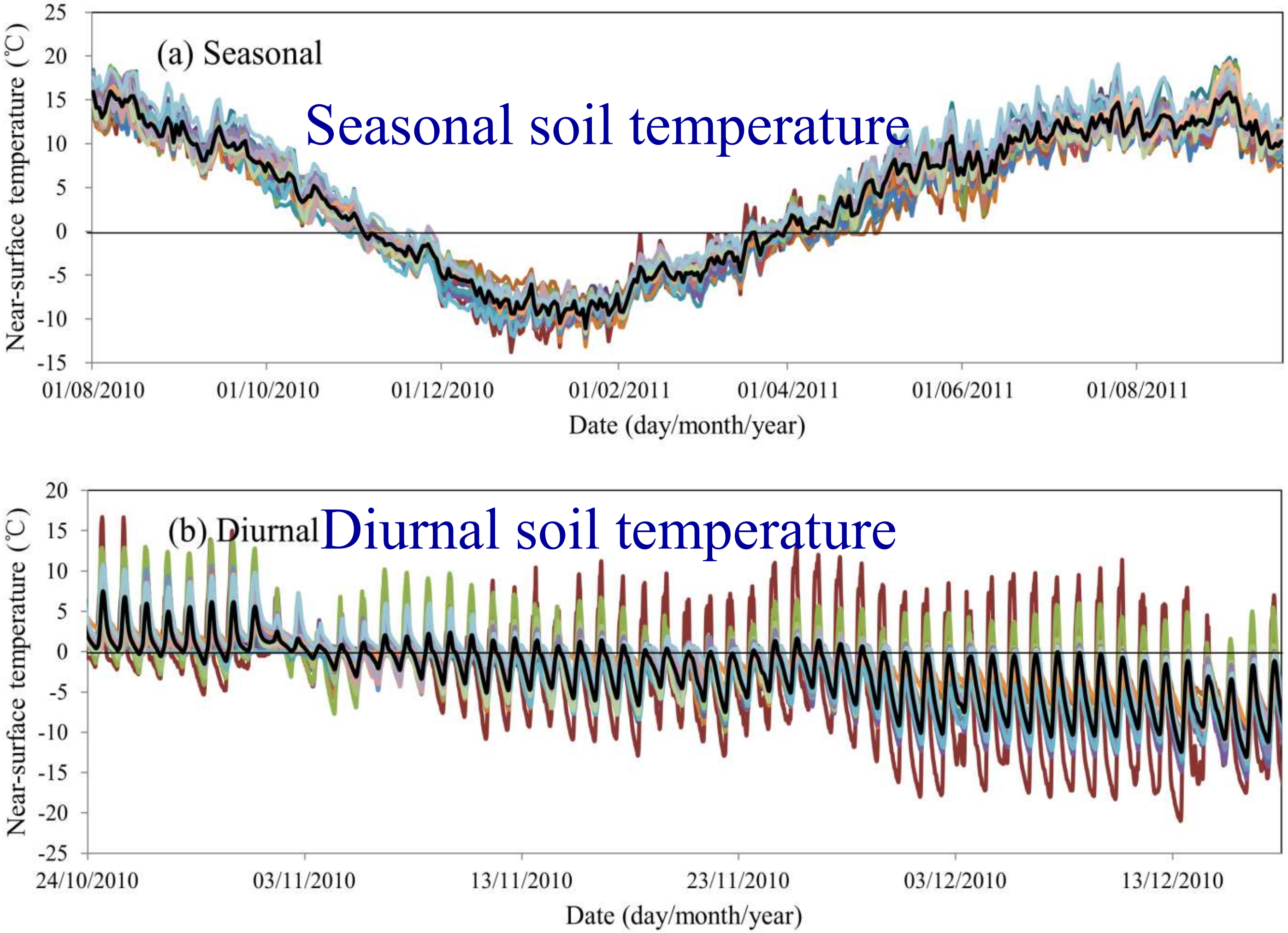
(Yang et al., 2013 BAMS)

Observed soil moisture



(Yang et al., 2013 BAMS)

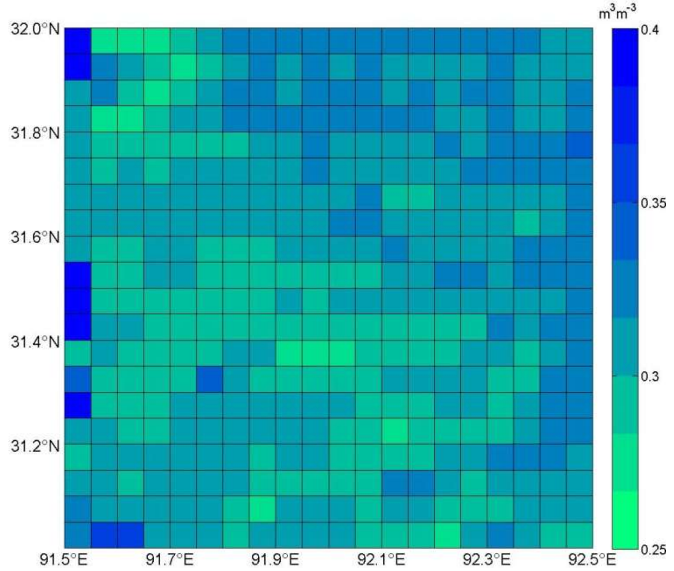
Observed seasonal soil freezing and thawing

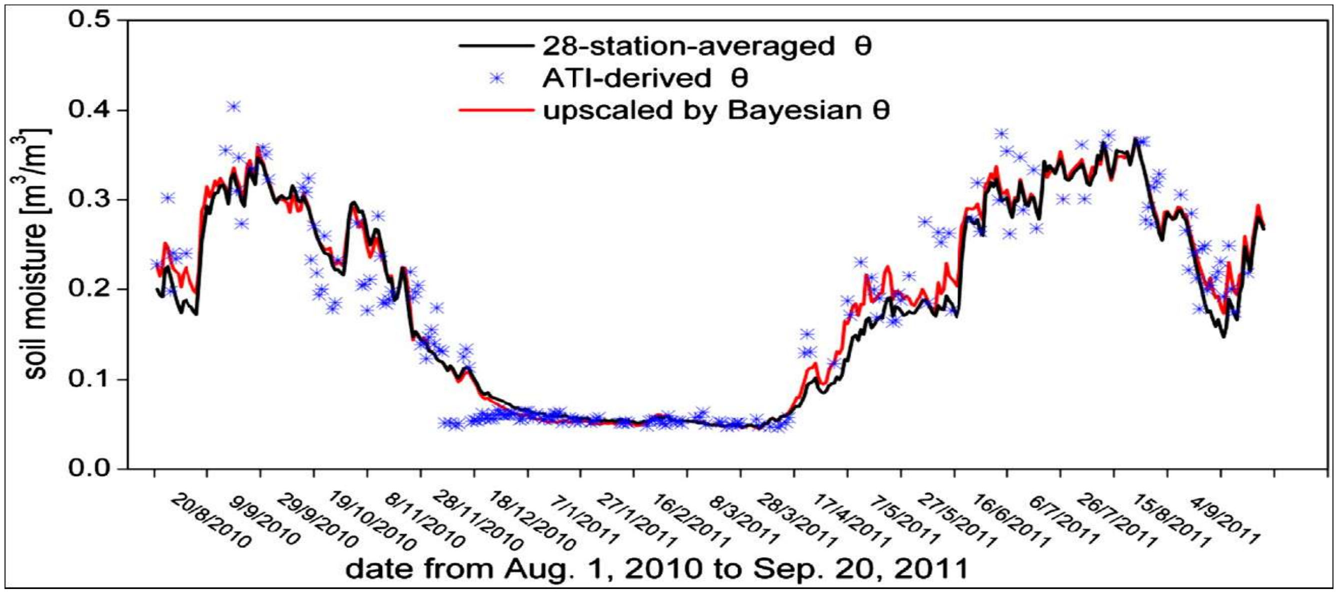


(Yang et al., 2013 BAMS)

Upscale from points to pixels by introducing MODIS LST

Soil moisture distribution obtained by upscaling



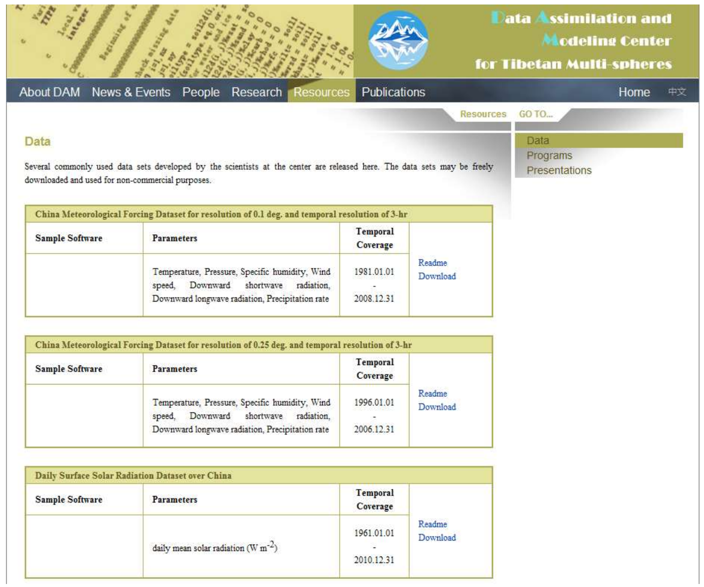


(Qin et al., 2013RSE)

Data sharing through ISMN

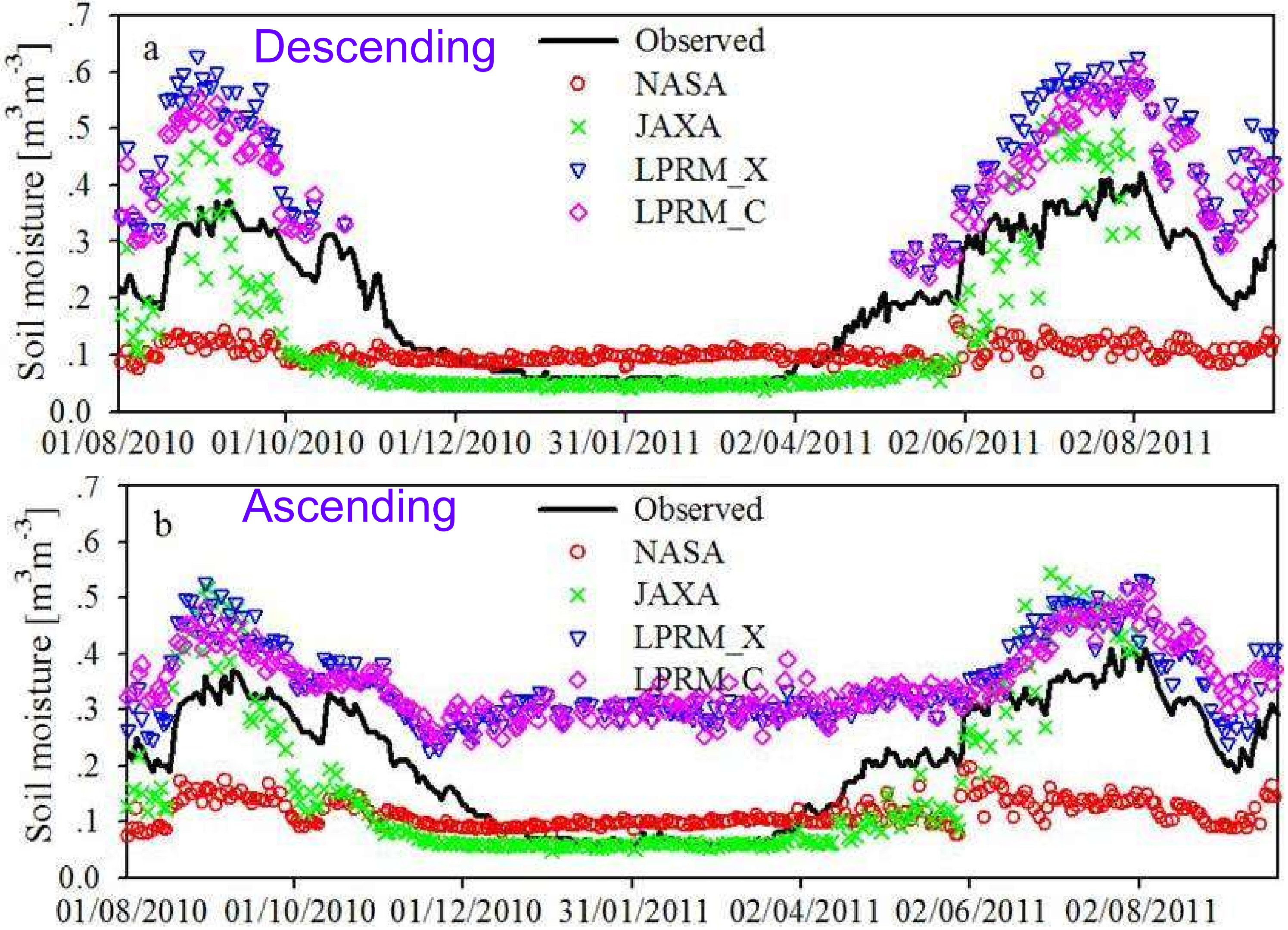
- Cooperation with ISMN Network
  - Network
    - Required: general info/contact person(s)
  - Station
    - Required: name/Lon/Lat/Ele
    - Optional: Image/photo…
  - Data
    - Required: monitoring depth(s)/sensor info/acquisition time (UTC)/
    - Optional: meteorological variables/soil properties/land cover…
  - Data sharing policy
    - Scientific use only
    - No onward distribution
    - Acknowledgement and citation (the original data provider and the ISMN)
    - Delivery may be suspended or terminated at any moment.
- Data access
  - Data portal through DAM

http://www.ipf.tuwien.ac.at/insitu/



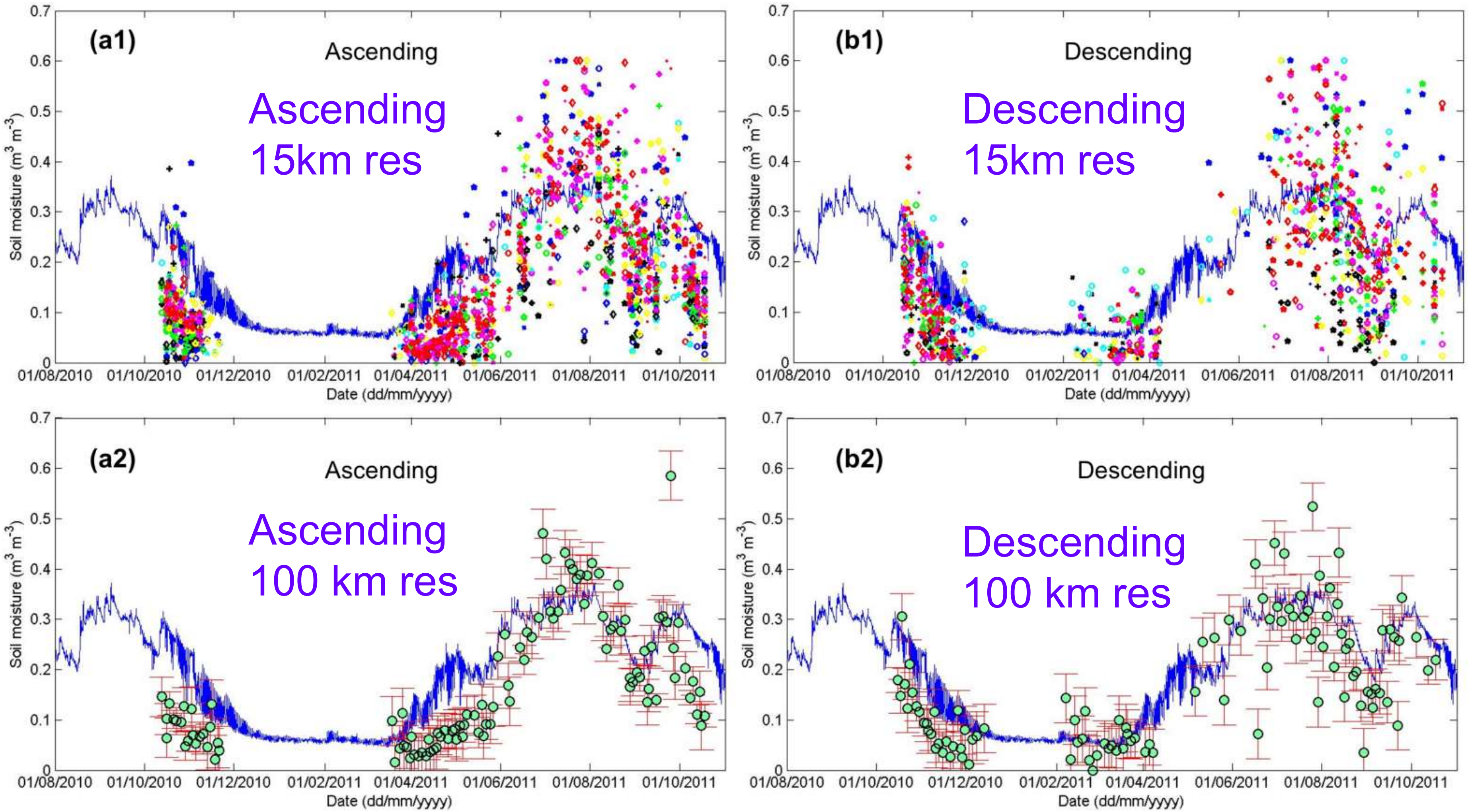
http://dam.itpcas.ac.cn/rs/?q=data

Evaluation: four AMSR-E satellite products have large biases, either underestimated or over-estimated



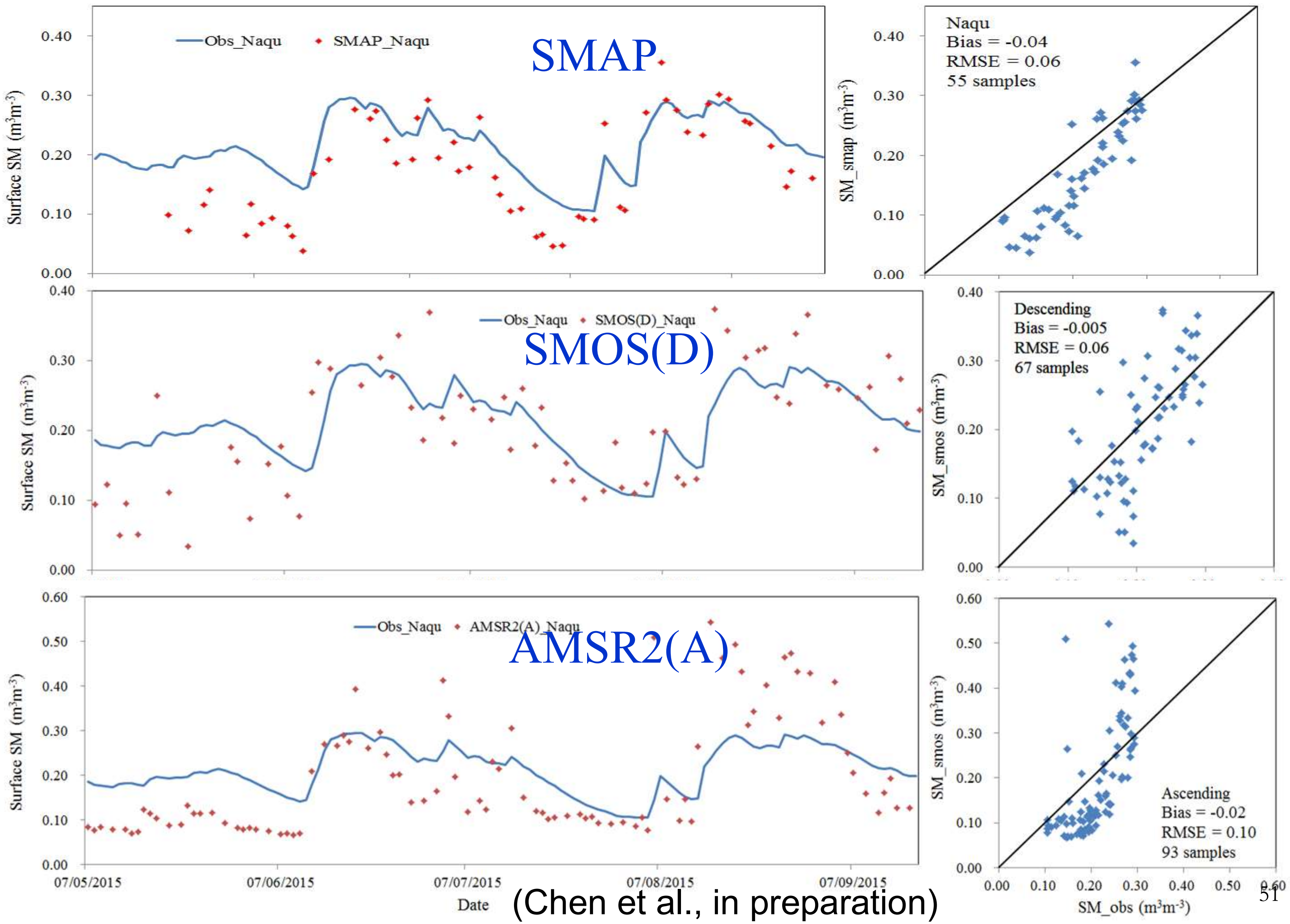
(Chen et al., 2013 JGR)

Evaluation: The accuracy of SMOS L2 SM data is scale-dependent; higher accuracy at coarser resolution



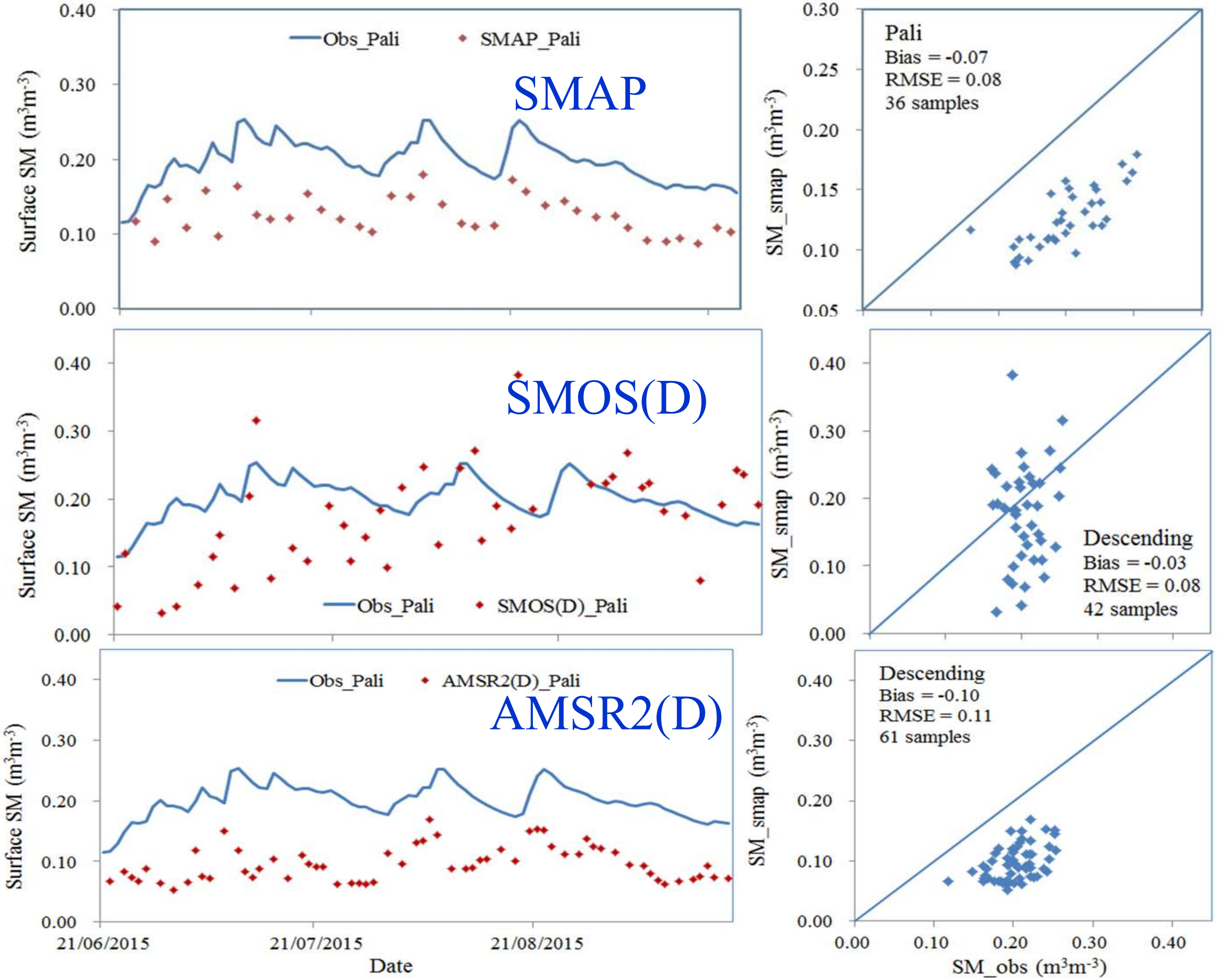
(Zhao et al., 2014 RSE)

Evaluation in CTP network



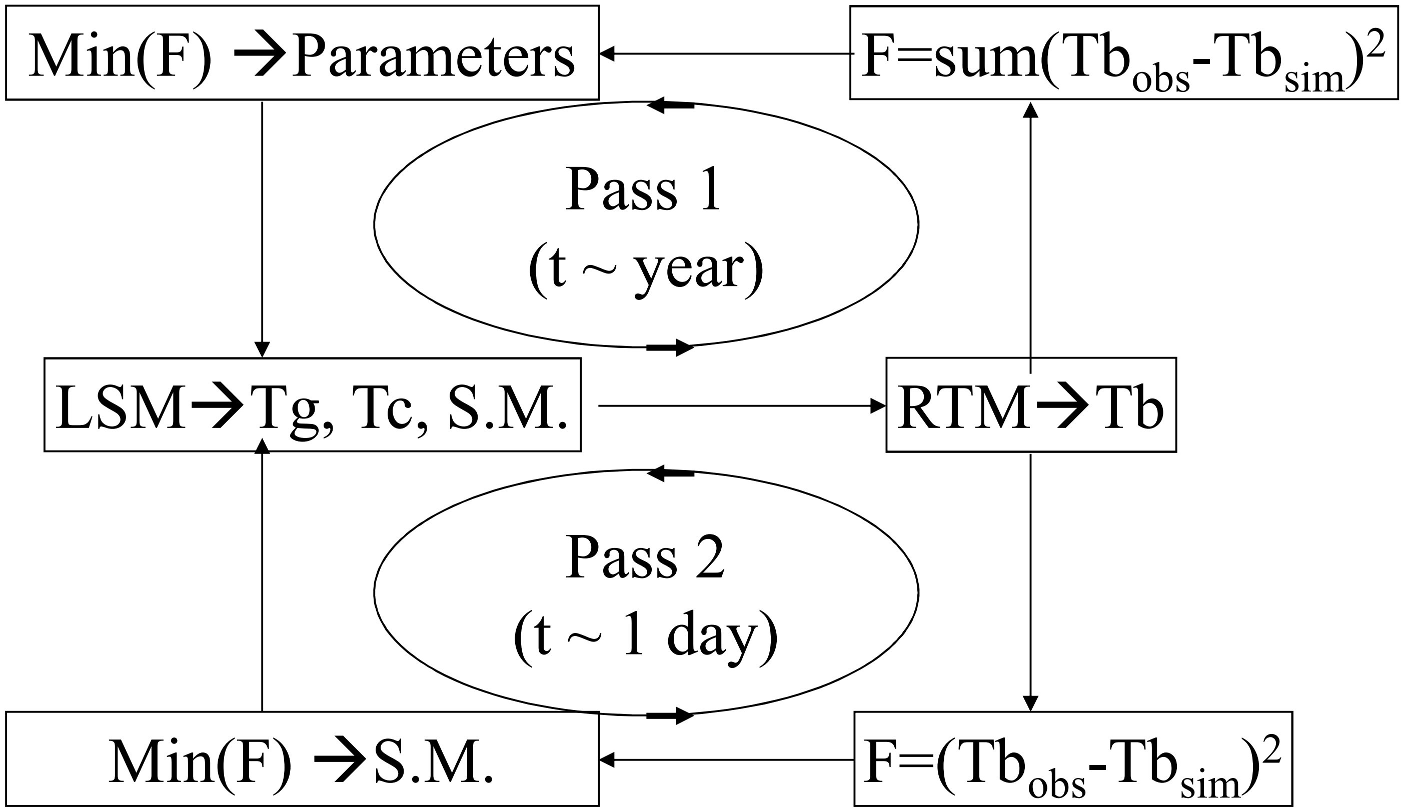
(Chen et al., in preparation)

Evaluation in STP network



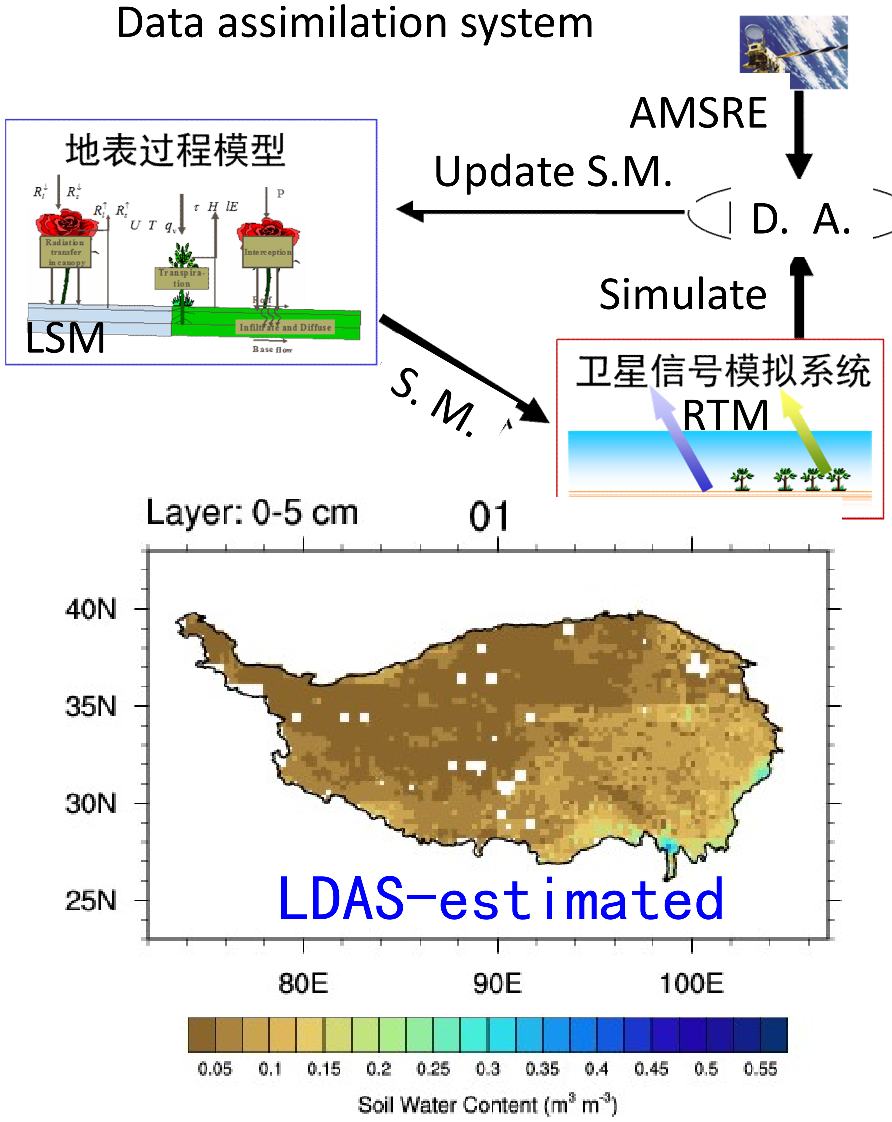
Developed a dual-pass (calibration + assimilation) data assimilation system

- Pass 1: Optimize parameter values in a long-term window (~year)
  - Tuning parameters with satellite data
  - time-consuming but only conduct once.
- Pass 2: Estimate land state in a short-term window (daily)

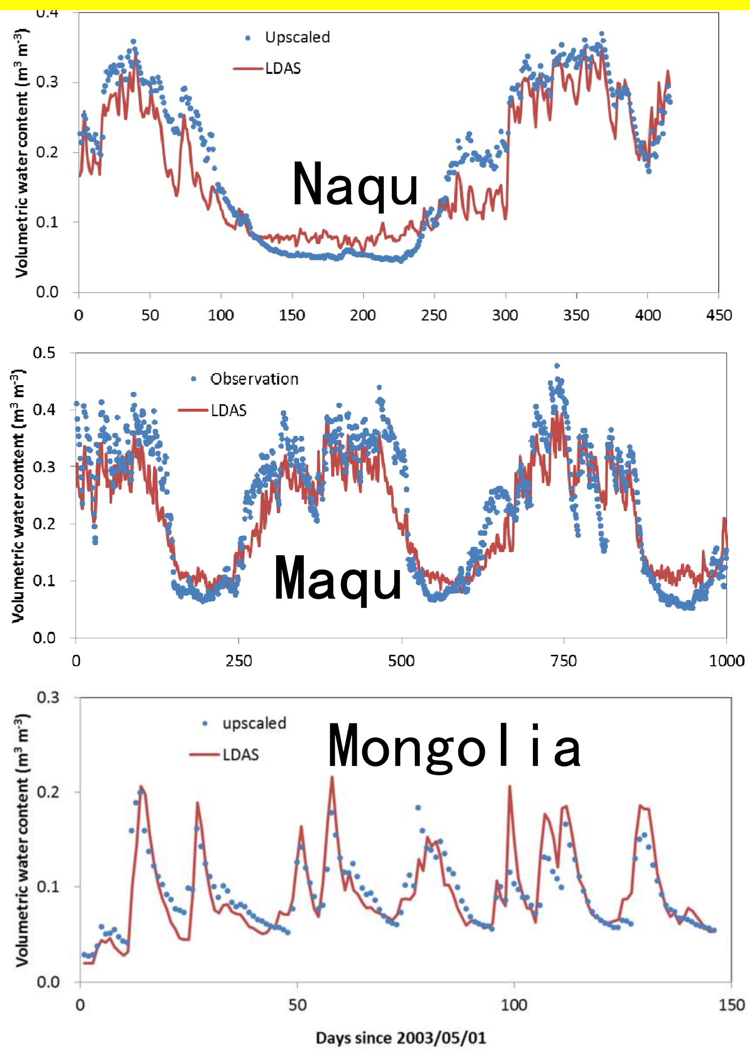


(Yang et al., 2007JMSJ; 2009 JHM)

Produced soil moisture in China during 2002-2011 by the system and validated in Tibetan and Mongolian Plateau

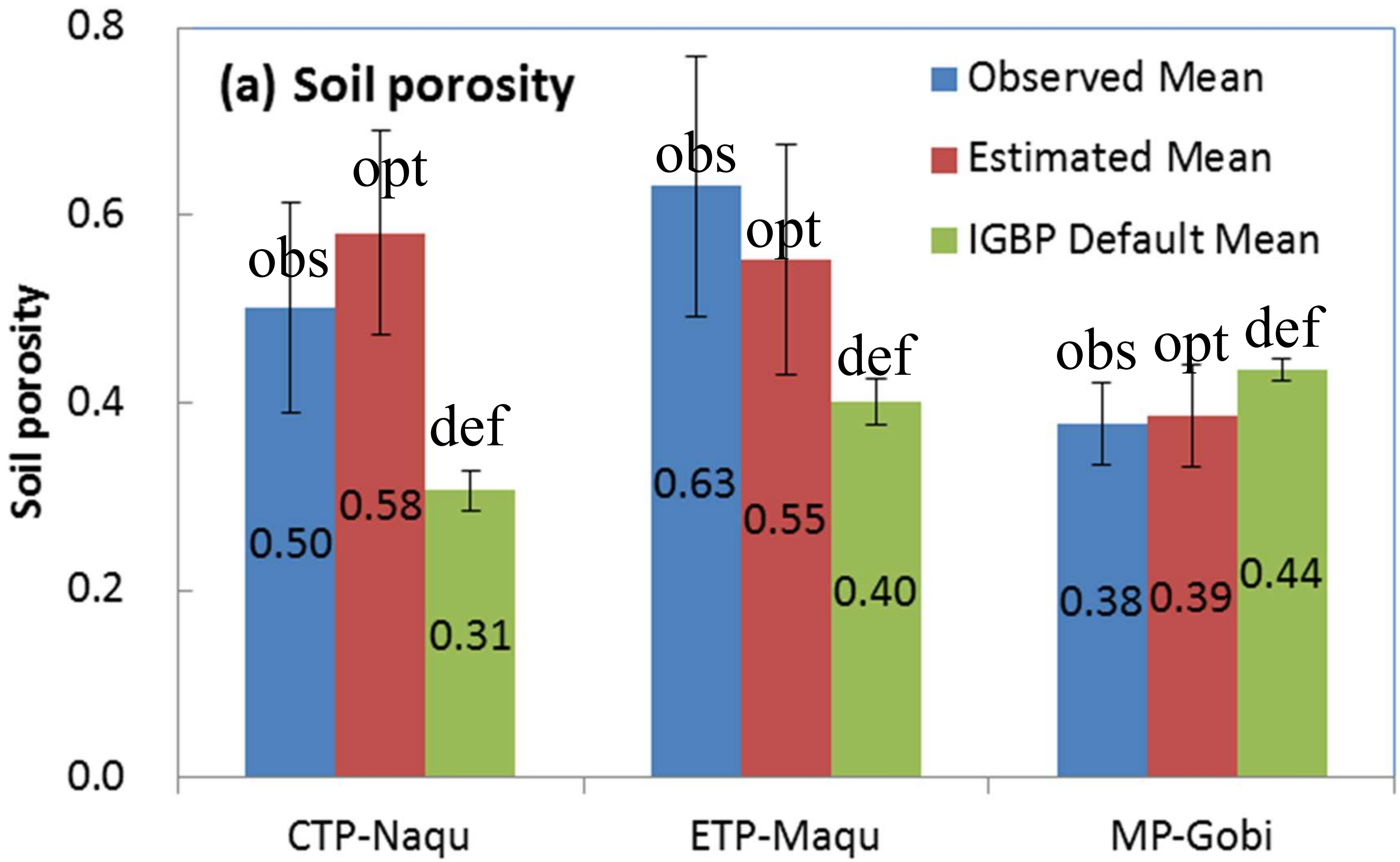


Compare LDAS and ground truth



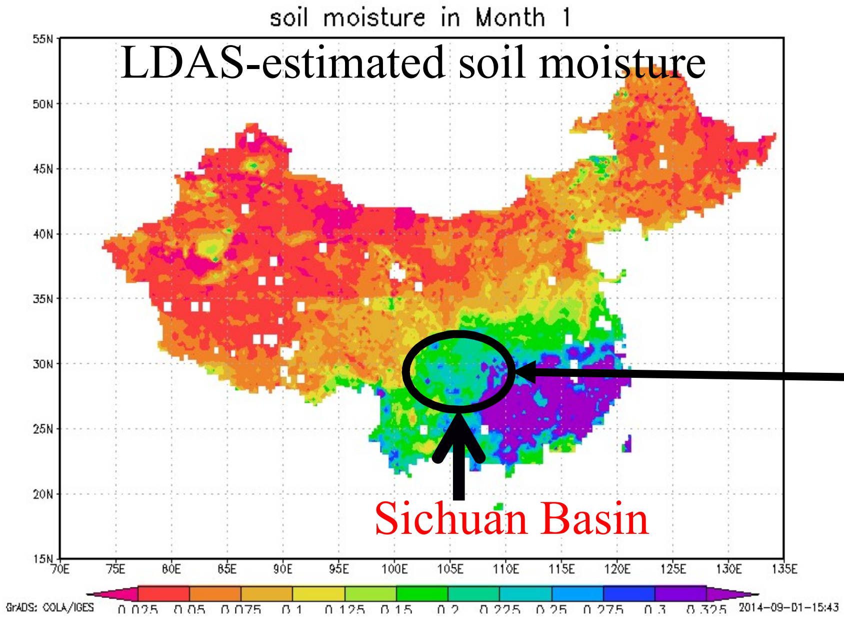
(Yang et al., 2007, 2009, 2016)

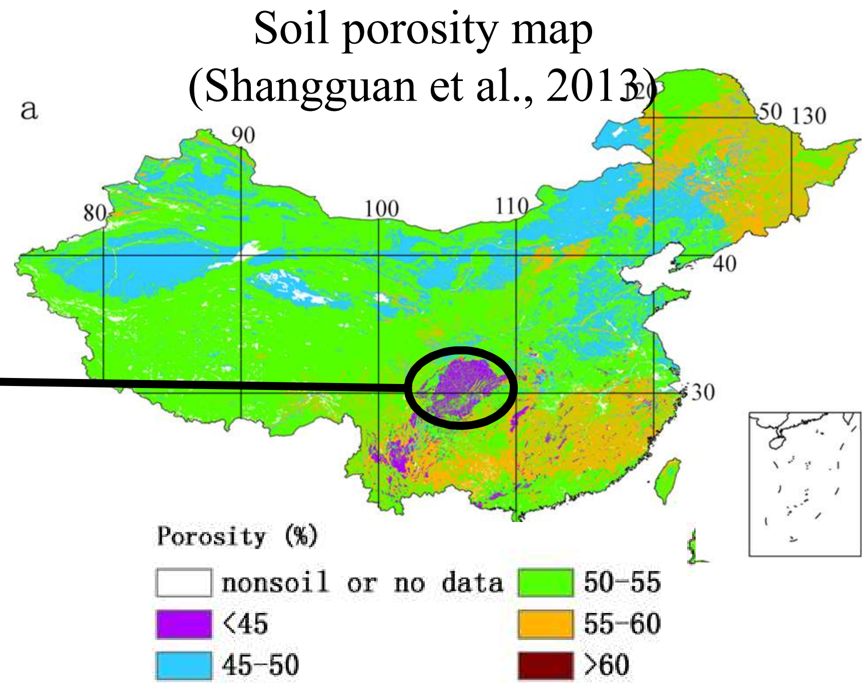
Improved soil porosity (the most important parameter for soil moisture) through the satellite data assimilation



(Yang et al., 2016 JoH)

Two independent datasets (our soil moisture product and the latest soil porosity dataset in China) are consistent at regional scale



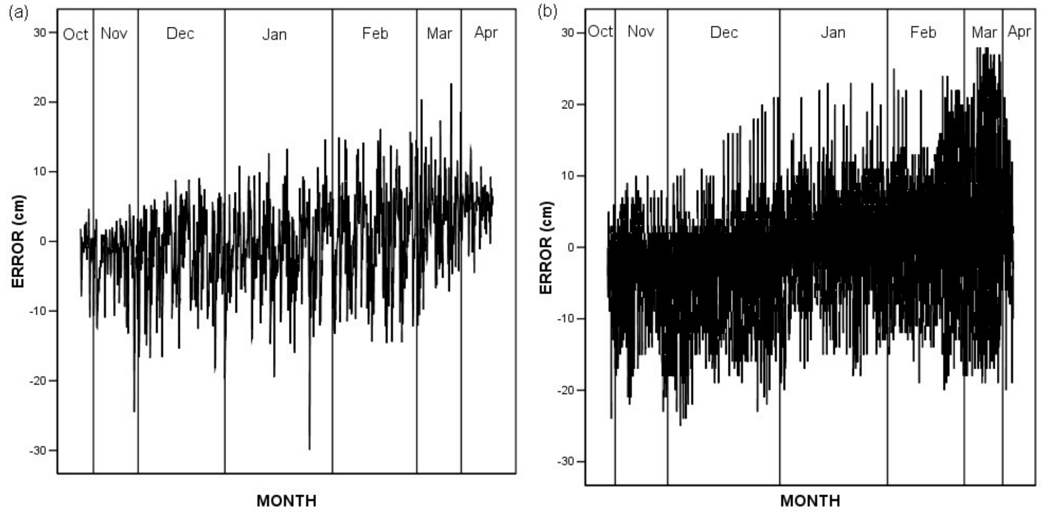


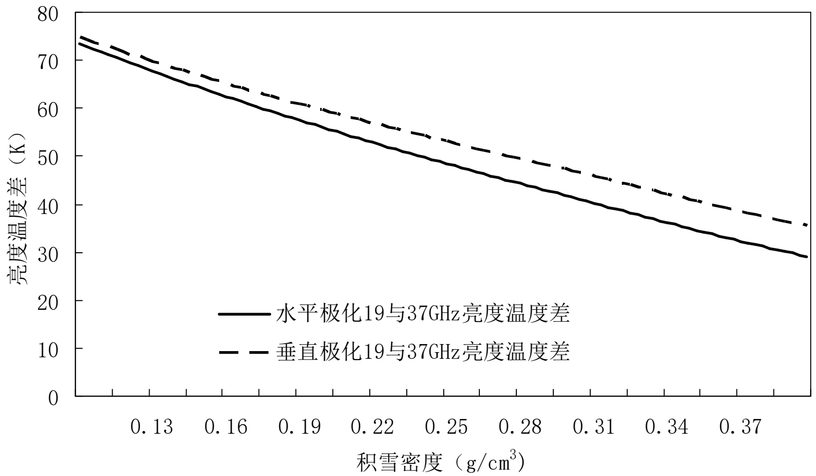
Precipitation amount is high in Sichuan Basin but LDAS yields low soil moisture values

The soil in Sichuan Basin is a kind of purple soil and has low porosity.


Welcome collaborations

Seasonal Modification of snow density and grain size





Month	Average offset (cm)	
	SMMR	SSM/I
Oct	-3.64	-4.18
Nov	-3.08	-3.58
Dec	-1.91	-1.93
Jan	-0.19	0.29
Feb	1.51	2.15
Mar	2.65	3.31
Apr	3.32	3.80