Hydrological modeling in alpine catchments on the Tibetan Plateau

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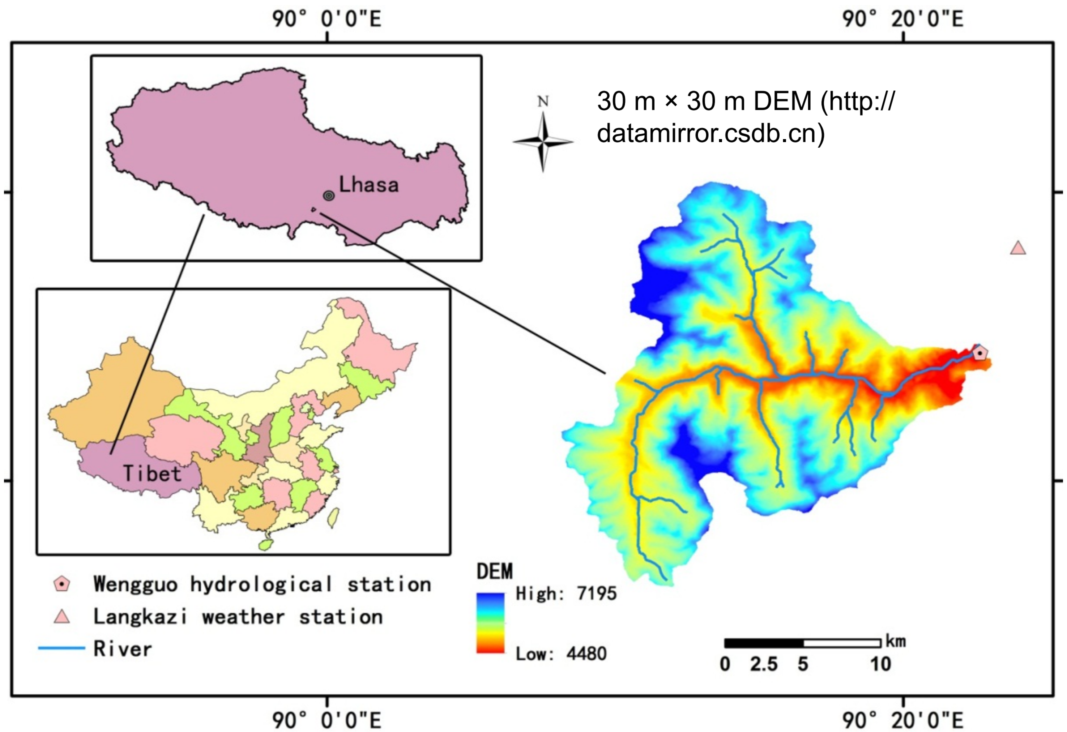
Outline

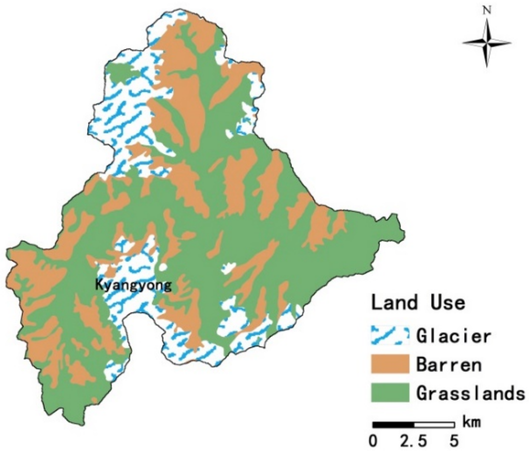
1. Effects of temperature and precipitation parameters on hydrological modelling in a high mountain catchment
2. Temperature lapse rate estimation from MODIS LST
3. Precipitation gradient based on precipitation observation

Introduction

- **Accurate runoff simulation is meaningful for water resources management and planning**
- **Hydrological modeling: challenging for alpine regions with scarce gauges**
- **Meteorological data shortage: Temperature Lapse Rate (TLR) and Precipitation Gradient (PG)**
- **To evaluate effect of precipitation parameters on snow cover area (SCA) and runoff simulation and access modeling strategies in a sparsely gauged catchment**

Study area



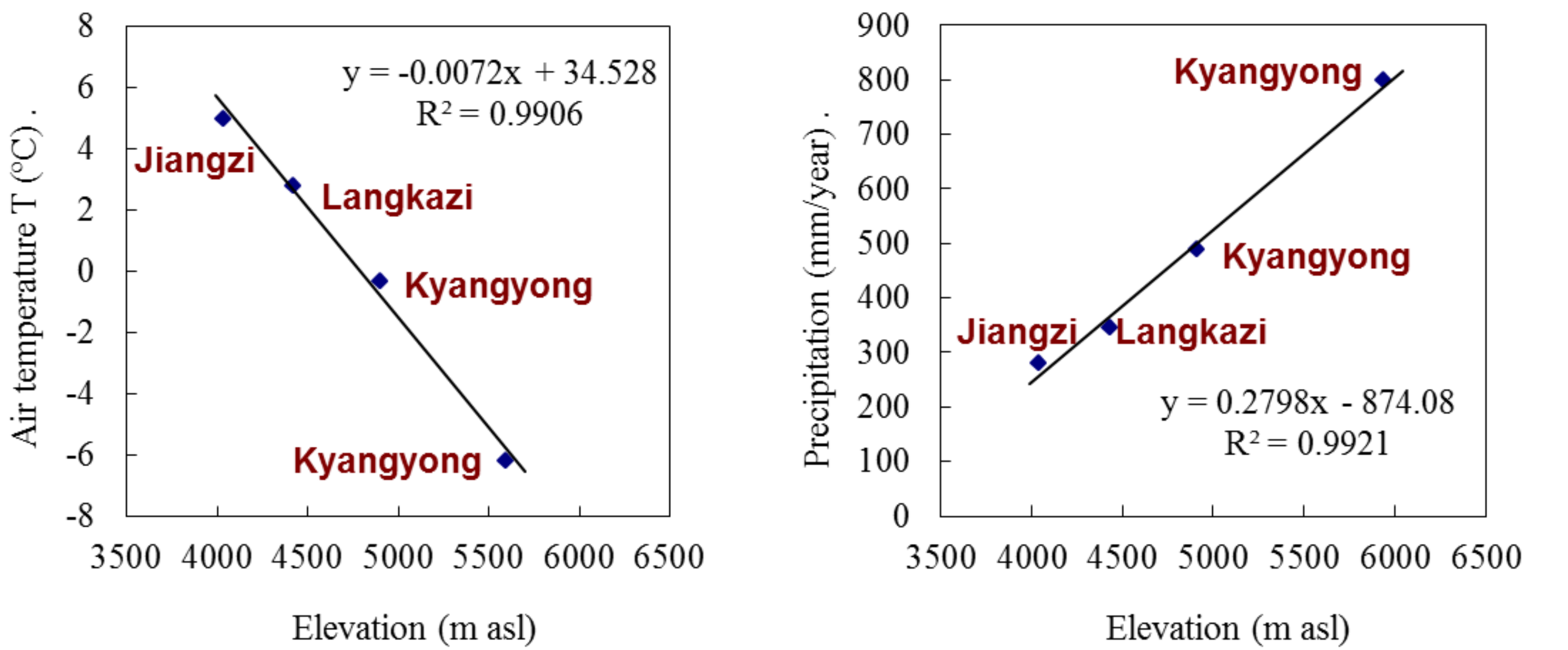


http://westdc.westgis.ac.cn

- **Karuxung River catchment : 286 km^2**
- **Fifty Glaciers: 58 km^2 (20%)**
- **Wengguo hydrological station: 4550m asl**
- **Langkazi weather station: 4432 m asl**

Estimation of TLR and PG

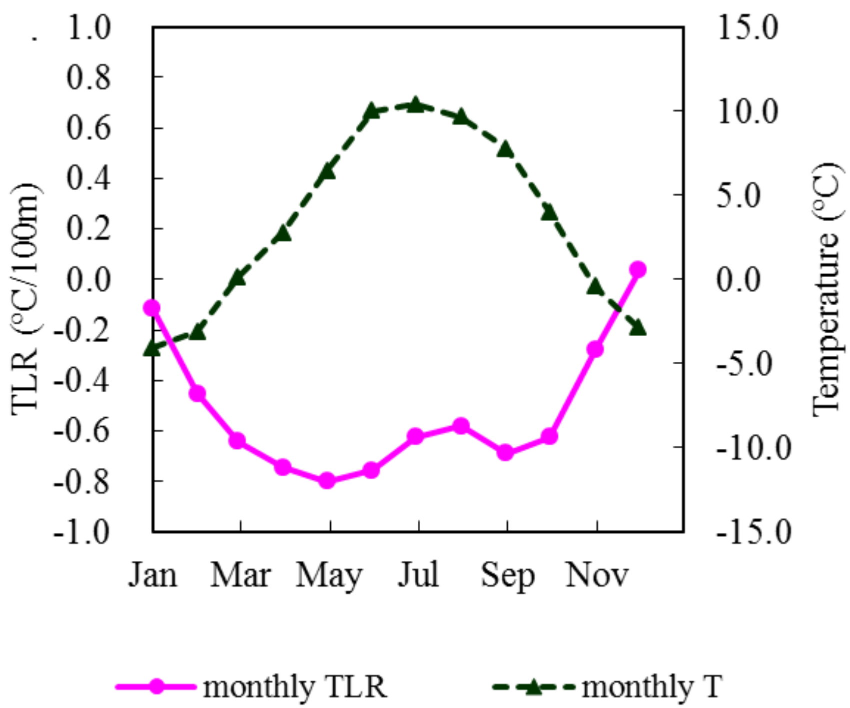
- **Available data for estimating TLR and PG are scarce**

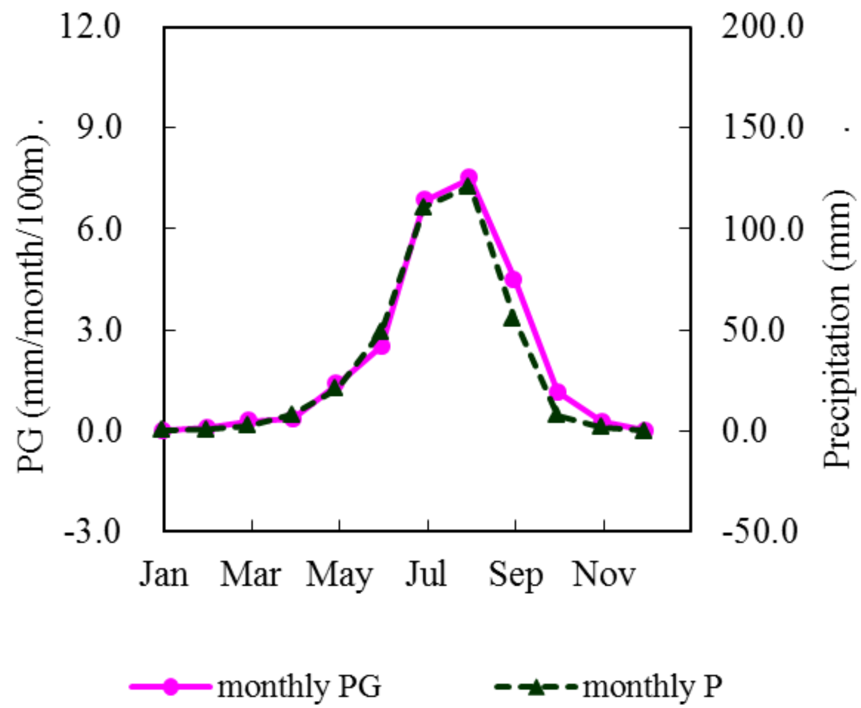


Annual mean temperature in 1975 Annual precipitation in 1975

- **T and P differences between Langkazi and Jiangzi weather stations have the potential to represent the TLR and PG in the catchment**

Estimation of TLR and PG





- **Monthly TLRs and PGs derived from the Langkazi and Jiangzi weather stations: fit scientific expectations and used as model inputs**

SCA and Runoff simulation

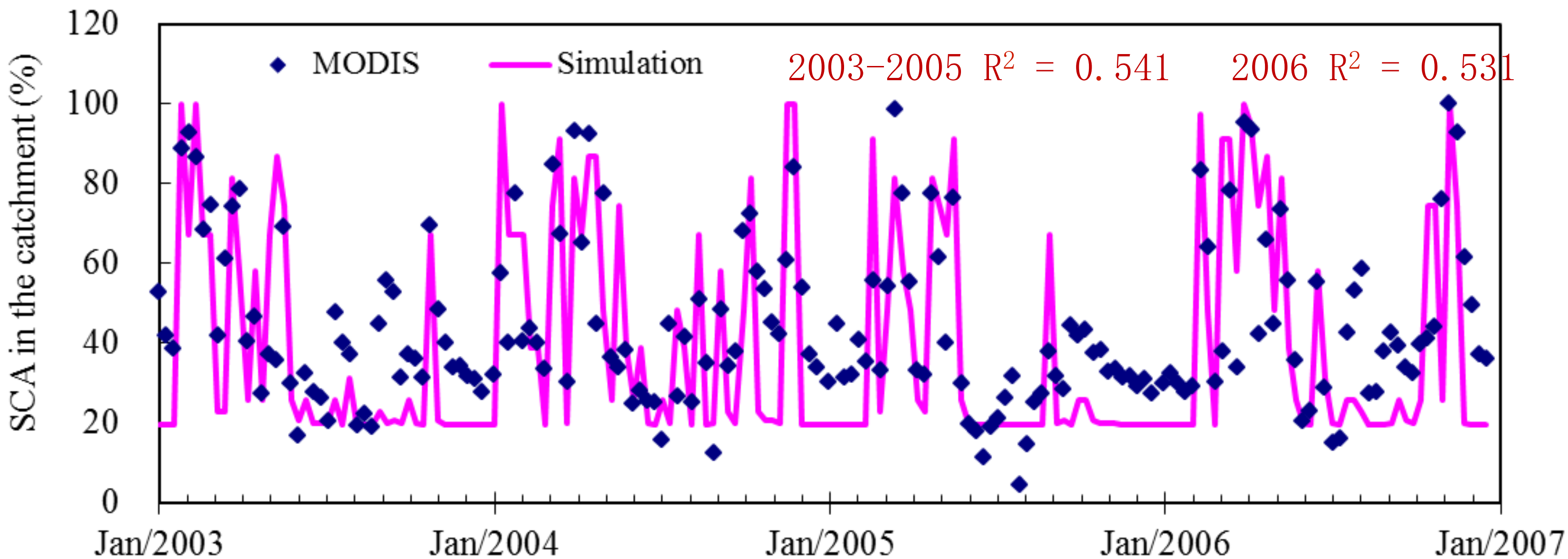
- **Semi-distributed altitude zone based temperature-index model operating on a daily time step**

- **Daily T and P at Langkazi are extrapolated to each elevation zone using TLR and PG**

- **Model calibration: MODIS 8-day maximum snow cover extent and Wengguo hydrological station runoff data during 2003-2005**

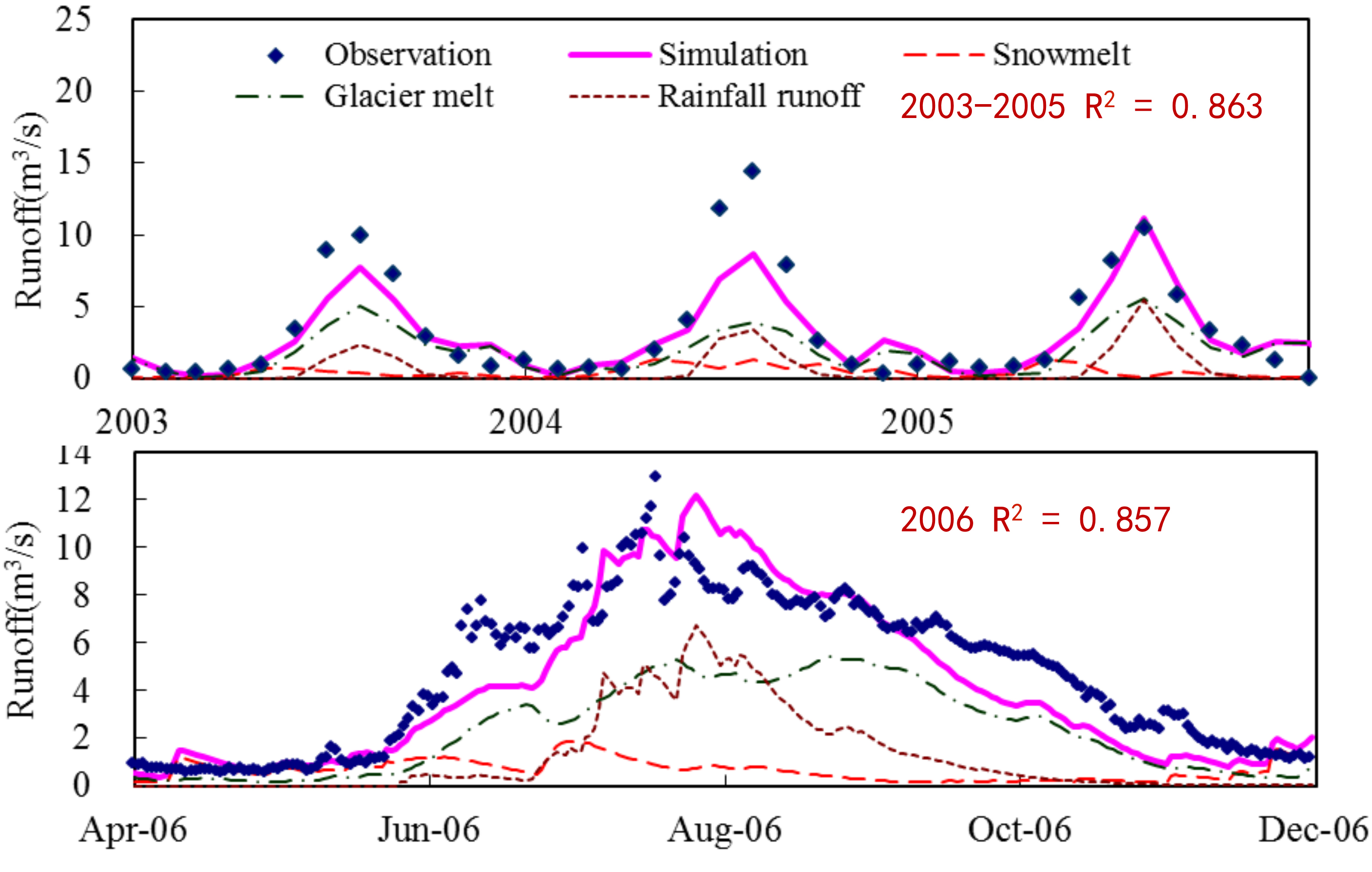
- **Model verification period: 2006**

SCA and Runoff simulation



- Snow covers the whole catchment in early spring
- Not all the snow melts during summer
- Simulation reflects seasonal SCA evolution in general

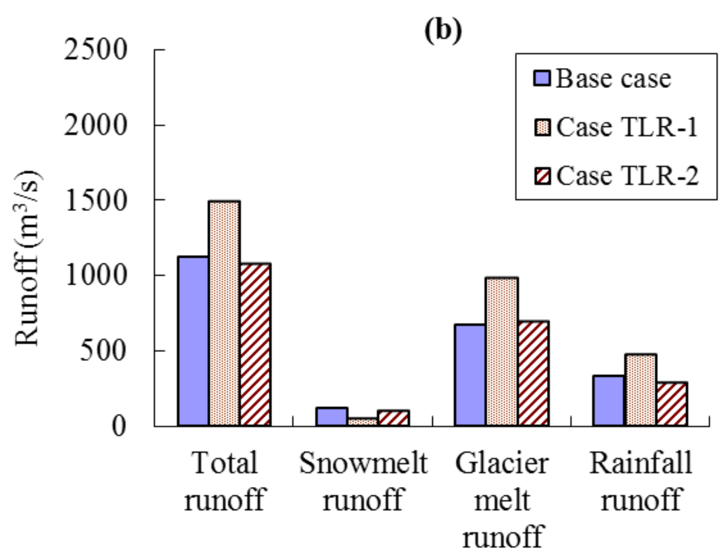
SCA and Runoff simulation

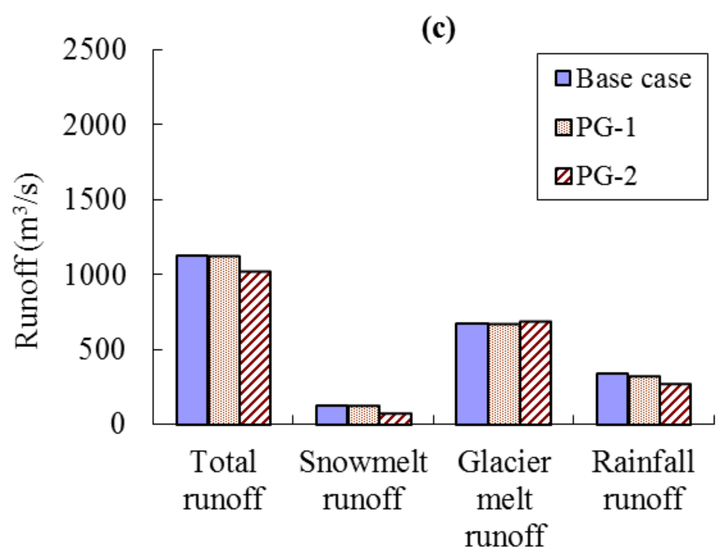


- **Good fits between runoff observation and simulation are good with R^2 reaching ~0.86 for both model calibration and validation periods.**

Sensitivity Analysis

Case TLR-1	TLR = -0.52 ºC/100m (local average)
Case TLR-2	TLR = -0.65 ºC/100m
PG-1	PG = 0.26 mm/day/100m (local average)
PG-2	PG = 0.0 mm/day/100m





The seasonal changes of TLR and PG should be considered for accurate snow cover and runoff modeling.

Key Points

- TLR and PG determine the form and amount of precipitation and spatial distribution of temperature and precipitation in hydrological modelling of the high mountain catchment.
- Seasonal patterns of both parameters should be considered in the modelling studies when meteorological observations are only available at low elevation.

Outline

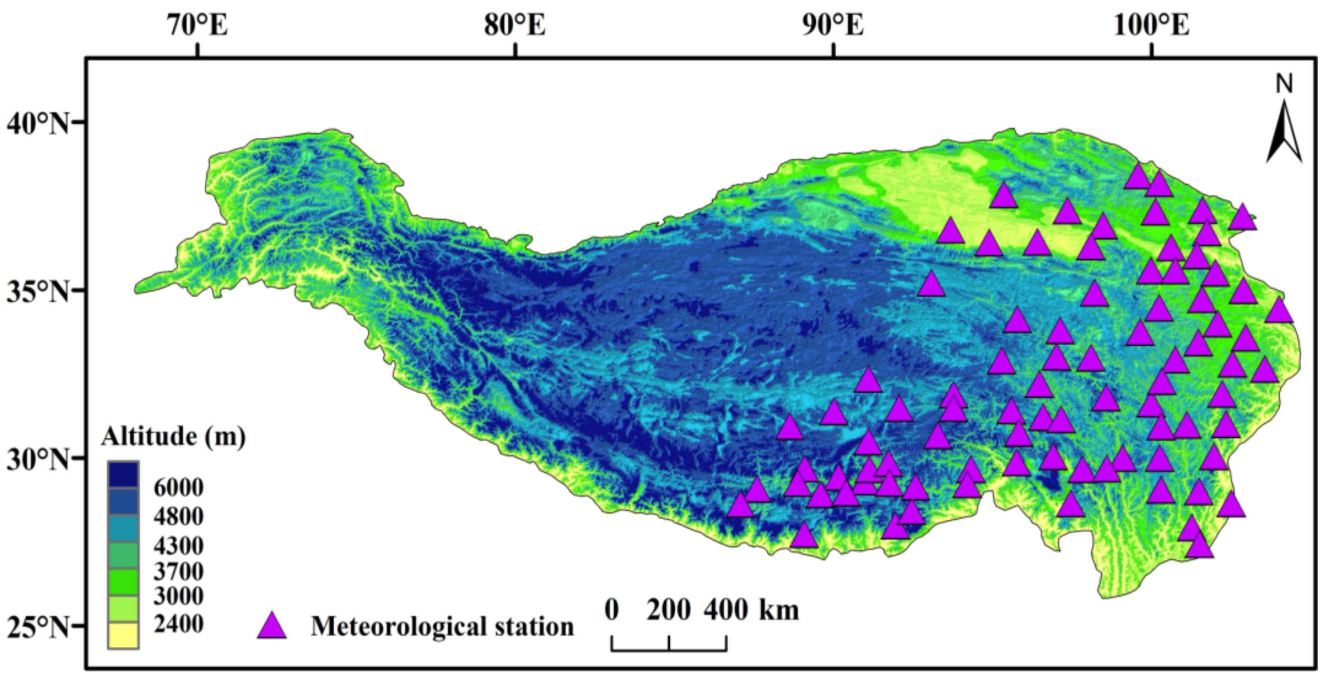
1. Effects of temperature and precipitation parameters on hydrological modelling in a high mountain catchment

2. Temperature lapse rate estimation from MODIS LST

3. Precipitation gradient based on precipitation observation

Introduction

- **The air temperature lapse rate (TLR) is commonly used for interpolating air temperature in mountainous areas**
  - **The accurate estimation of the TLR largely relies on sufficiently dense and representative observations.**
  - **The sparse distribution of stations in the west TP, especially in high-altitude regions, may lead to a large bias**

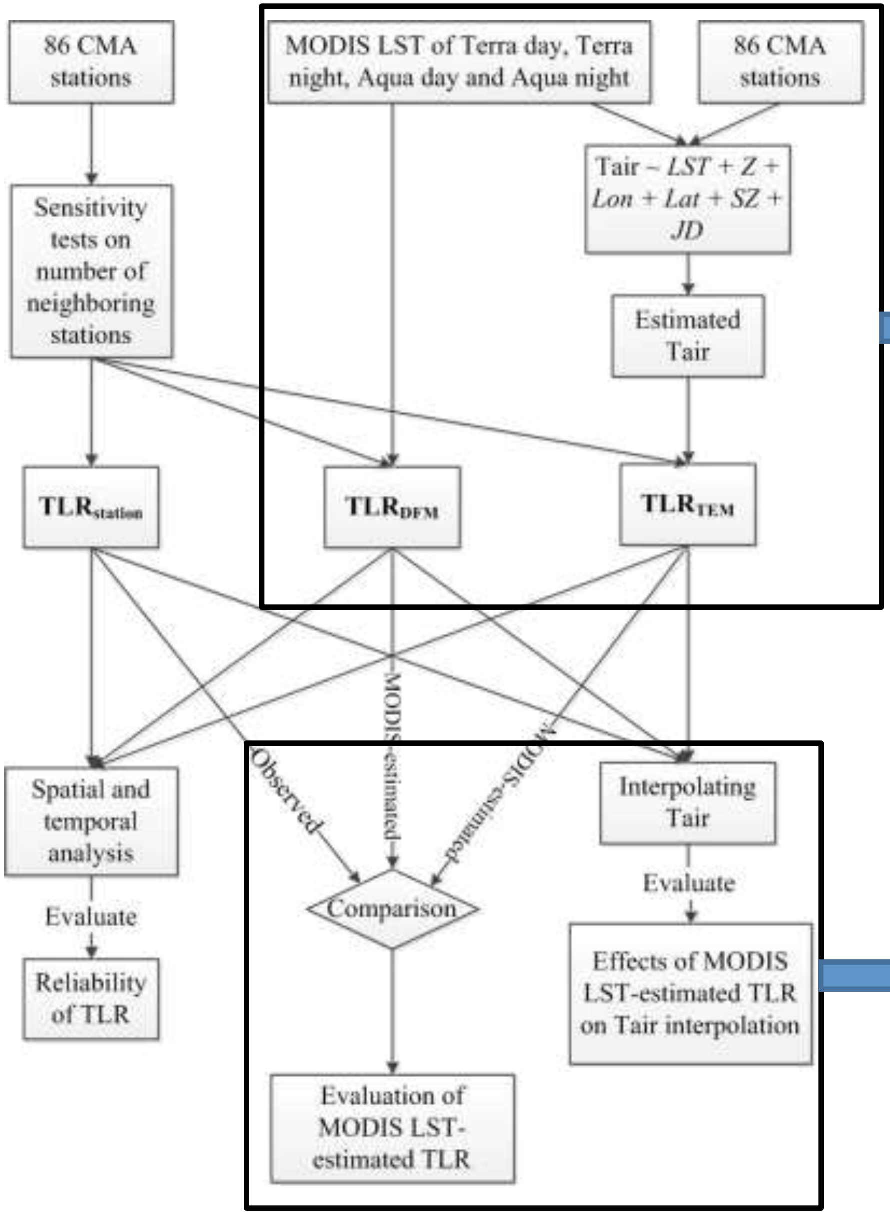


Introduction

- Remotely sensed land surface temperature (LST) can provide comprehensive temperature observations compared with the limited ground stations

  - The MODerate resolution Imaging Spectroradiometer (MODIS) LST data are generally used for air temperature estimation
  - The MODIS LST data alone have the potential to directly reflect the spatial variation of air temperature

Methods



This study employed two methods in estimating the TLR based on MODIS LSTs including:

(1)Directly computing the lapse rate From MODIS LST (DFM)

(2)based on air Temperature Estimation from MODIS LST (TEM)

The results are then compared with the "observed" TLR derived from 86 stations across the TP, to validate and evaluate the two proposed methods

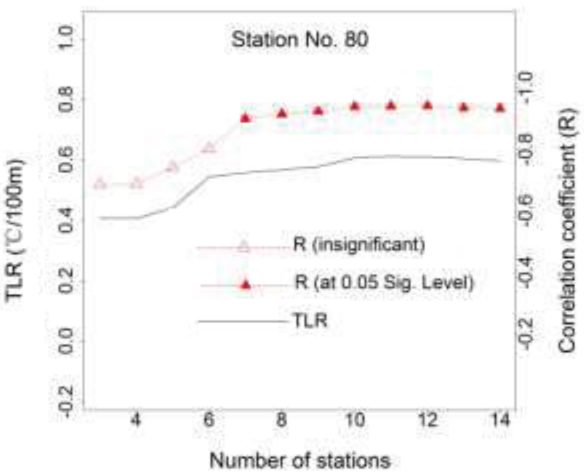
Estimation of $TLR_{station}$

- Estimating equation: Tair = a × Z + b
- Based on neighboring CMA stations

➢ For each CMA station, the nearest neighboring CMA stations were added sequentially.

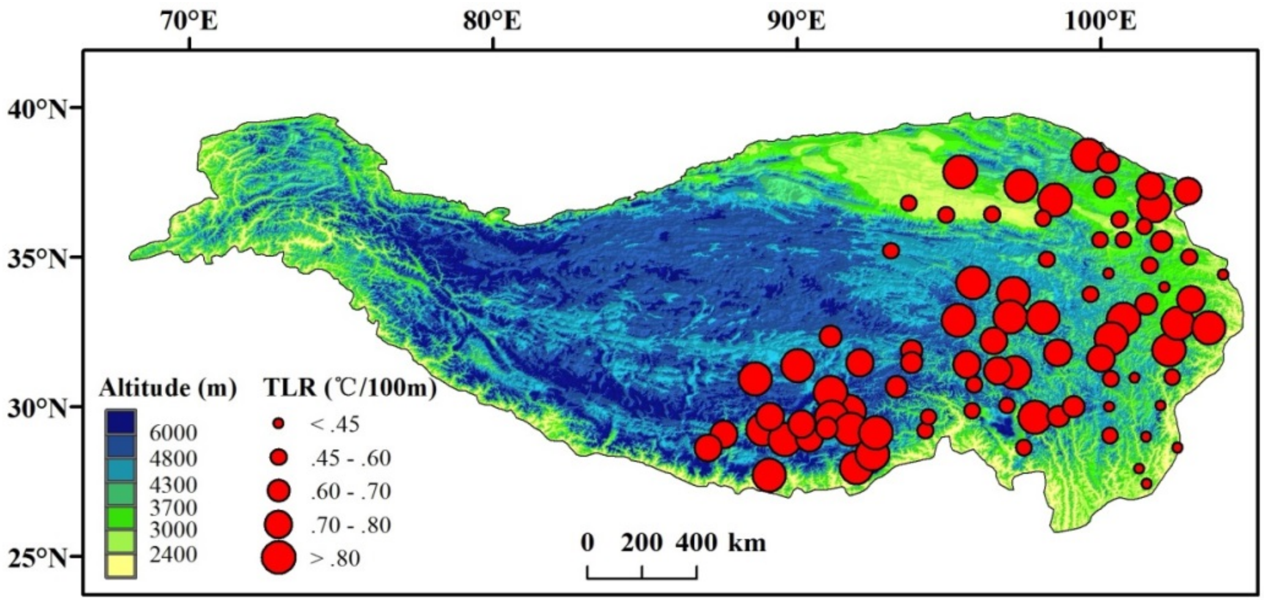
➢ The TLR as well as the correlation coefficient (R) and its significance level were computed.

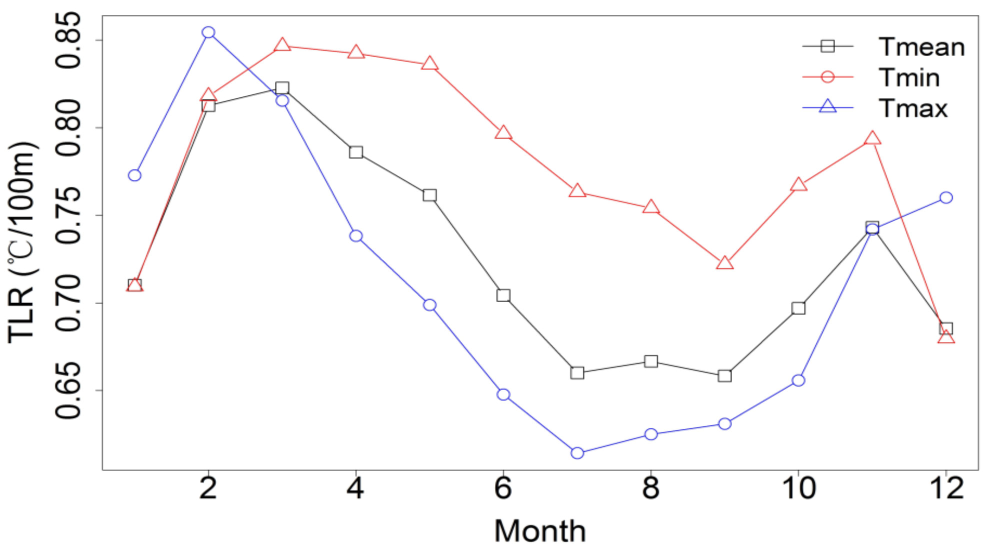
➢ The process continued until a strong negative correlation was indicated at the 0.05 significance level .



Estimation of $TLR_{station}$ → Observed

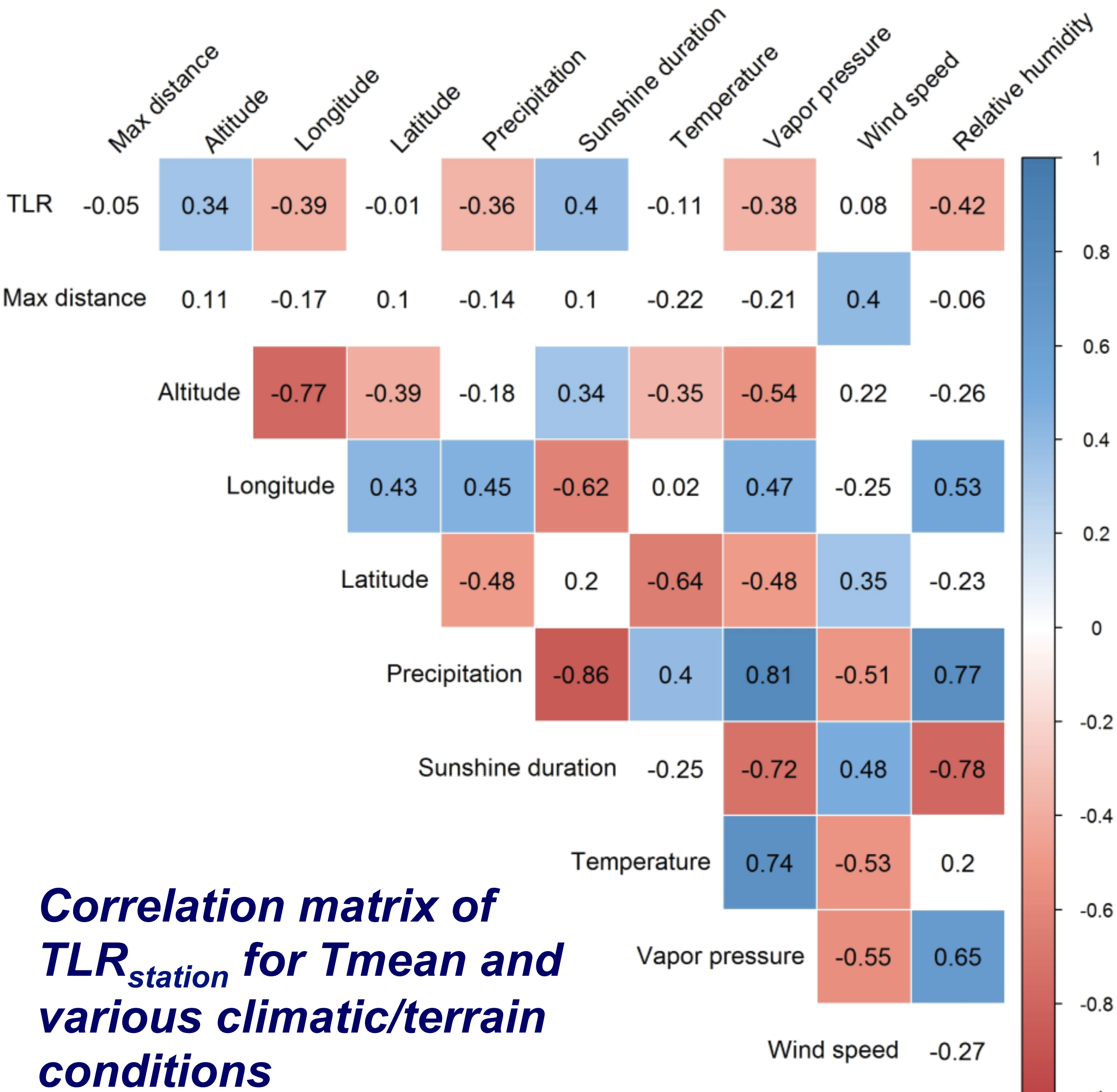
$TLR_{station}$ is highly variable in space





The average $TLR_{station}$s of all the 86 stations show strong monthly variation that it presents a double-humped pattern

Estimation of $TLR_{station}$

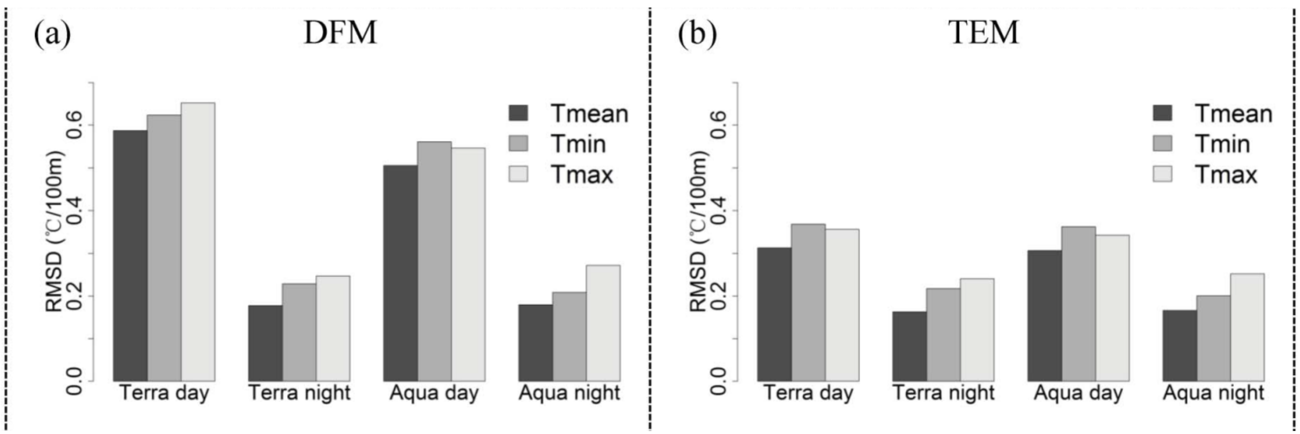


TLR may be influenced by altitude, longitude, precipitation, sunshine duration, vapor pressure and humidity in the study area

Correlation matrix of $TLR_{station}$ for Tmean and various climatic/terrain conditions

Estimation of TLR from MODIS LST

Accuracies of the DFM (a) and TEM (b) methods for TLR estimation for Tmean, Tmin and Tmax.



- **in comparison to TLRstation, MODIS LST-estimated TLR is more accurate for Tmean than for Tmin and Tmax.**
- **When using MODIS nighttime LSTs, both DFM and TEM show highly acceptable accuracies for estimating the TLR of Tmean with averaged RMSD of <0.2ºC/100m.**

Outline

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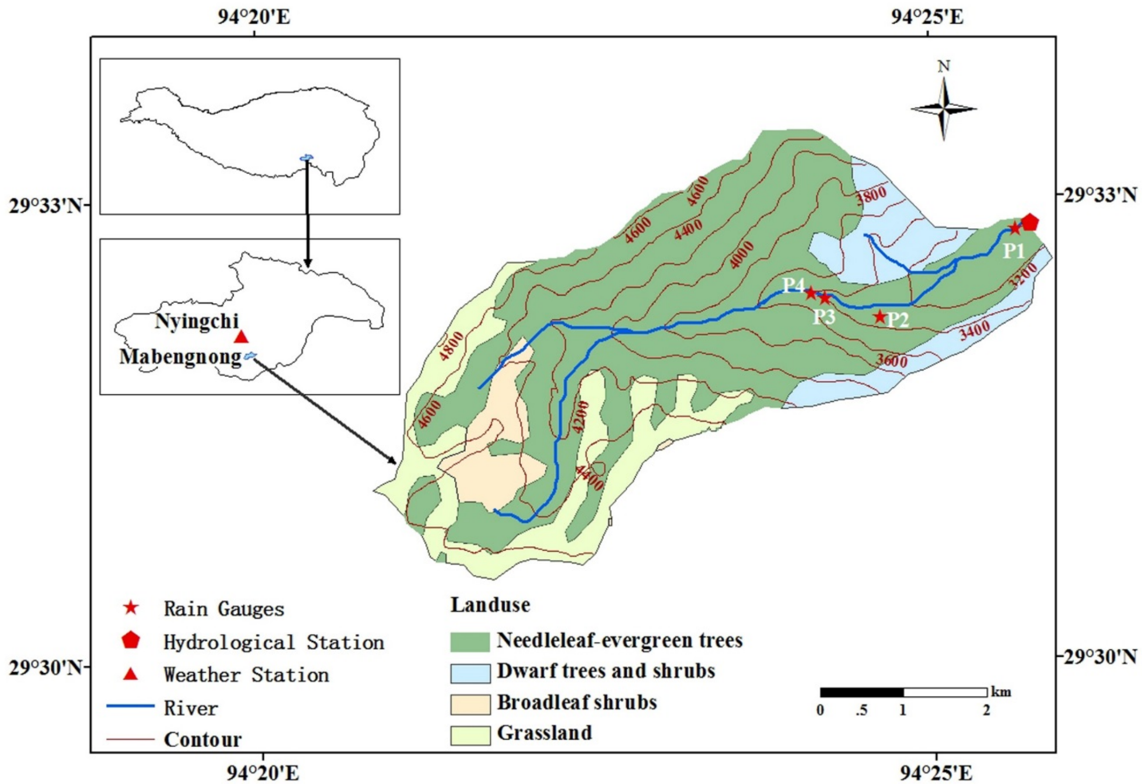
Introduction

- **Precipitation is one of the most critical model inputs for accurate hydrological simulation (Daly et al., 1994; Faurès et al., 1995; Beven, 2001).**
- **Characterization of precipitation in high altitude localities is a challenging task because the hydrometeorological data sets are extremely limited and precipitation is highly variable in mountainous areas (Buytaert et al., 2006; Immerzeel et al., 2014).**
- **Therefore, an appropriate method is needed to interpolate point observations to gridded input for distributed models (Ahrens, 2006; Tahir et al., 2011; Immerzeel et al., 2012).**

Study area



- **Mabengnong River catchment : 21 km^2**
- **Mabengnong hydrological station: 3023m asl**
- **Nyingchi weather station: 2992 m asl**

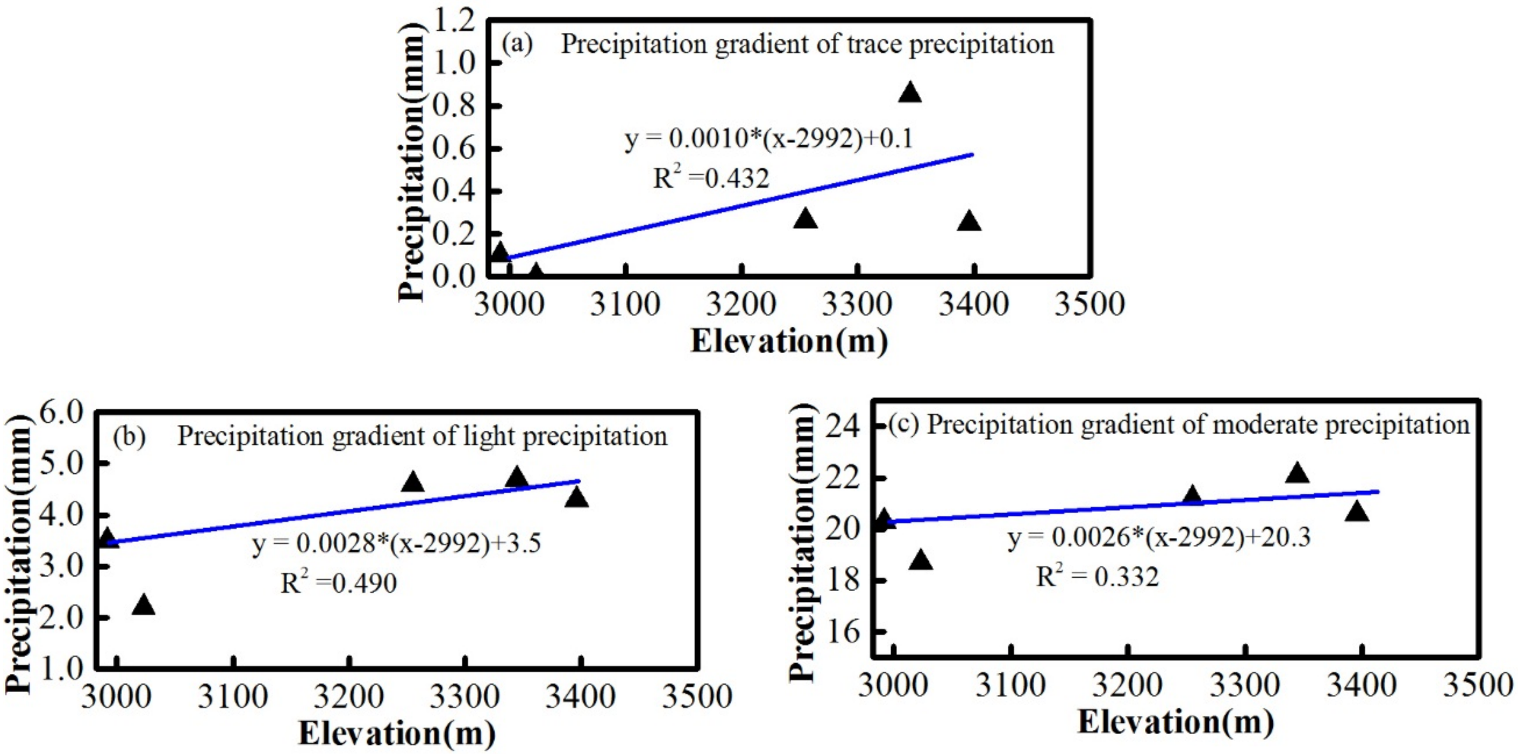
Precipitation correlation analysis

Four rain gauges (RHD-14-2, China) were set up at different altitudes, which logged the precipitation every 5 minutes during July to August 2013.

	2992m	3023m	3255m	3345m	3396m
2992m	1	0.912**	0.863**	0.863**	0.825**
3023m	0.912**	1	0.944**	0.938**	0.918**
3255m	0.863**	0.944**	1	0.995**	0.987**
3345m	0.863**	0.938**	0.995**	1	0.991**
3396m	0.825**	0.918**	0.987**	0.991**	1

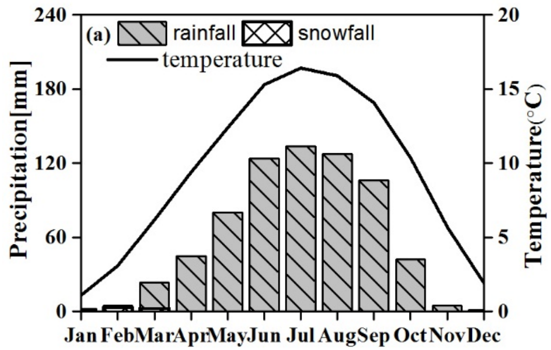
Precipitation of the Nyingchi meteorological station and observed by rain gauges installed at different altitudes within the catchment shows significant correlation.

Estimation of PG



The average daily PG for trace, light and moderate precipitation is 0.10, 0.28 and 0.26 mm/d/100m, respectively

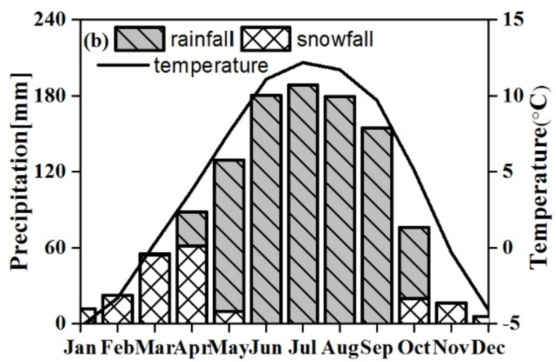
Study area



(2992 m asl)

Nyingchi meteorological station

- **Annual mean T : ~9.4℃**
- **Annual P : ~694 mm**
- **Snowfall: November to March**



(3907 m asl)

Average elevation of the catchment

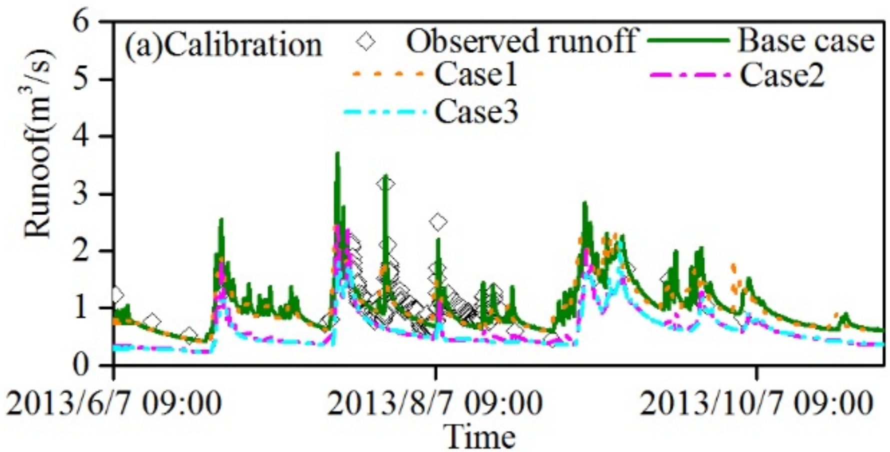
- **Annual mean T : ~3.1℃**
- **Annual P : ~1100 mm**
- **Snowfall: October to March**

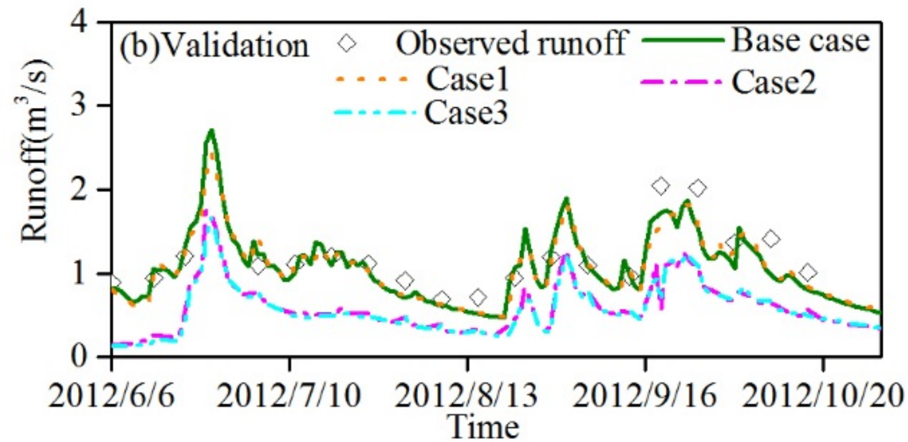
SCA , Runoff and LST simulation

- A distributed biosphere hydrological model based on water and energy budgets with improved physical process for snow (WEB-DHM-S) operating on a hourly time step
- Gridded precipitation data derived from Nyingchi station and PG characterized for the study
- Model calibration: MODIS daily snow cover area(SCA), Mabengnong hydrological station runoff data and MODIS land surface temperature (LST) during 2013
- Model validation period: 2012

Runoff, SCA and LST simulation

Periods	Runoff			SCA			LST		
	NSE	R^2	RMSE (m^3/s)	NSE	R^2	RMSE (%)	NSE	R^2	RMSE (K)
Calibration	0.619	0.674	0.191	0.73	0.775	7.5	0.876	0.903	2.83
Validation	0.652	0.718	0.209	0.665	0.718	14.2	0.701	0.832	3.56





The runoff, SCA and LST simulation results are acceptable for the base case using the PG derived based on observation.

Sensitivity analysis shows that simulated runoff is significantly underestimated without consideration of PG.

Key Points

- Gridded precipitation input obtained based on the PG and HD results enables the WEB-DHM-S model to generate accurate simulation of runoff, SCA and LST.
- Simulated runoff is significantly underestimated without consideration of PG.
- Intensive precipitation observation can improve hydrological modelling in high mountain areas with extreme topography.

Thank You!

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Estimation of TLR from MODIS LST

- **Four pass times of MODIS LST**

  Terra Night (LST_{TN}), Terra Day (LST_{TD}), Aqua Night (LST_{AN}), Aqua Day (LST_{AD})

- **Estimation of TLR_{DFM} (Directly From MODIS)**

$$\begin{aligned} LST_{TN} &= a_1 \times Z + b_1 \\ LST_{TD} &= a_2 \times Z + b_2 \\ LST_{AN} &= a_3 \times Z + b_3 \\ LST_{AD} &= a_4 \times Z + b_4 \end{aligned}$$

The TLR estimated is in fact the TLR of LST

The neighboring stations/grids used were the same as those used for $TLR_{station}$.

Estimation of TLR from MODIS LST

- **Four pass times of MODIS LST**

  Terra Night (LST_{TN}), Terra Day (LST_{TD}), Aqua Night (LST_{AN}), Aqua Day (LST_{AD})

- **Estimation of TLR_{TEM} (Temperature Estimation from MODIS)**

  ➢ **Tair estimation from MODIS LSTs in combination with auxiliary variables**

$$T_{air} = a_1 \times LST_{TN} + b_1 \times Z + c_1 \times SZ + d_1 \times Lon + e_1 \times Lat + f_1 \times JD + g_1$$
$$T_{air} = a_2 \times LST_{TD} + b_2 \times Z + c_2 \times SZ + d_2 \times Lon + e_2 \times Lat + f_2 \times JD + g_2$$
$$T_{air} = a_3 \times LST_{AN} + b_3 \times Z + c_3 \times SZ + d_3 \times Lon + e_3 \times Lat + f_3 \times JD + g_3$$
$$T_{air} = a_4 \times LST_{AD} + b_4 \times Z + c_4 \times SZ + d_4 \times Lon + e_4 \times Lat + f_4 \times JD + g_4$$

  where *SZ* is solar zenith; *Lon* is longitude; *Lat* is latitude; *JD* is Julian day

  ➢ **With the estimated Tair, four sets of TLR_{TEM} values were all derived using:**

$$T_{air} = a \times Z + b$$

  The neighboring stations/grids used were the same as those used for $TLR_{station}$.