

This discussion paper is/has been under review for the journal Hydrology and Earth System Sciences (HESS). Please refer to the corresponding final paper in HESS if available.

The influence of precipitation and temperature input schemes on hydrological simulations of a snow and glacier melt dominated basin in Northwest China

X. Ji^{1,3} and Y. Luo^{1,2}

¹State Key Laboratory of Oasis Ecology and Desert Environment, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi, Xinjiang 830011, China

²Key Laboratory of Ecosystem Network Observation and Modeling, Chinese Academy of Sciences (CAS); Institute of Geographic Sciences and Natural Resources Research, Beijing 100101, China

³Graduate University of the Chinese Academy of Sciences, Beijing 100049, China

Received: 28 December 2012 – Accepted: 9 January 2013 – Published: 18 January 2013

Correspondence to: Y. Luo (luoyi.cas@hotmail.com)

Published by Copernicus Publications on behalf of the European Geosciences Union.

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[⏪](#)

[⏩](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



Abstract

Basins with glaciers and snow provide water storage and supply for downstream irrigated farmland, but their hydrology is often poorly known because there are limited observation networks in high mountain regions. Large uncertainties in hydrological simulations also arise from errors associated with meteorological forcing data. The influence of precipitation and temperature forcing data on hydrological simulations in rain/snow dominated watershed is well documented, but less so in basins with glaciers. We analyzed the impacts and reliability of precipitation/temperature input solutions on hydrological simulations in the glacier/snow dominated Manas River Basin, showing that precipitation pattern has significant impact on snow accumulation and melt, and further impacts on simulated glacier melt behavior. The temperature inputs affect not only the timing of discharge but also the total water yield. The uncertainty associated with simple estimated input data propagates and is amplified through the modeling process. We suggest that the impacts of forcing data on hydrological simulations in basins with glaciers are more complex than in common rain/snow dominated watersheds. Glacier melt behavior may conceal uncertainties that are actually derived from input data. Assessment of hydrological model performance should include investigation of key processes involved in the hydrologic cycle individually, not just comparisons of simulated and observed discharge.

1 Introduction

Mountainous regions are often referred to as the world's natural "water towers" (Immerzeel et al., 2010; Weingartner et al., 2003; Viviroli et al., 2003). Especially in arid or semi-arid areas, such as Central Asia, the mountains provide water storage and supply for surrounding irrigated farmland, derived from the water/ice content of permafrost and glaciers (Bolch and Marchenko, 2006; Sorg et al., 2012). Hydrological modeling is required to understand dominant processes controlling the water balance in such

HESSD

10, 807–853, 2013

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



basins, to provide local authorities with science-based information to make water resource management decisions (Chaponniere et al., 2008). However, the hydrology of mountainous areas is often poorly known. Chalise (1994) qualifies it as the blackest of “black boxes” in the hydrological cycle. Observation networks in mountain regions are often limited, even though their density should be high to capture water flux variability in space and time. Hydrological models are always a simplification of the actual physical processes, and large uncertainties in simulation arise from errors associated with meteorological forcing data (Salamon and Feyen, 2009). Reducing input data uncertainty helps in identifying problems associated with model structure and parameters, thereby improving reliability and sustainability in resultant water resource management and planning decisions.

Precipitation and temperature are critical forcing variables in hydrologic modeling, impacting on various components of the water budget such as runoff, evaporation, and infiltration (Guo et al., 2004; Beven, 2001, 2002; Boyle et al., 2001; Haddeland et al., 2002). In glacier and snowmelt dominated alpine watersheds, the hydrology is best represented by simulations that rely on air temperature and precipitation (Aizen et al., 2000).

First, for precipitation, its spatial distribution strongly affects the simulated hydrographs (Michaud and Sorooshian, 1994; Sun et al., 2002), and accurate precipitation inputs are essential for reliable hydrologic prediction (Su et al., 2008). Sparse rain gage networks in mountains thus become an appealing problem for hydrological modeling applications. Remote sensing data, with wide spatial coverage, has been used to obtain precipitation estimates in such areas, and can help with this problem to a certain extent. For instance, TMPA (TRMM Multi-Satellite Precipitation Analysis) products have appeared in more and more applications in recent years, especially for hydrological research (Su et al., 2008; Hughes et al., 2006; Collischonn et al., 2008). However, because of the limited time-span (TMPA products begin in 1998), most applications only simulate over a short period (e.g., 5 to 10 yr) when using such data directly, and consequently may have greater uncertainties and instability than if simulated and

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



The influence of precipitation and temperature input schemesX. Ji and Y. Luo

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

calibrated with over longer periods. Finnerty et al. (1997) suggest that calibration requires at least 8 yr of historical input precipitation data for continuous simulation and a further 8 yr for validation. This problem may be more serious in glacier/snow runoff dominated watersheds which have complex runoff mechanisms. Actually, it is necessary to “warm-up” the model over a sufficient period to reach a dynamic equilibrium, when little is known about the initial situation. For example, Fontaine et al. (2002) conducted a 6 yr snowmelt hydrologic simulation following a 7 yr model warm-up period. Luo et al. (2013) simulated snow/glacier processes over 39 yr in the Manas River Basin which is a cold-arid inland river basin in northwest China, finding that a five year warm-up period was needed. Therefore, the available real-time satellite precipitation data seems inadequate for direct application in watersheds which need long term simulation. Nevertheless, the basic spatial distribution patterns of precipitation in these basins can be identified by satellite products. Since the distribution of precipitation is usually represented by the precipitation-elevation relationship (Smith, 1979; Daly et al., 1994), remote sensing precipitation data could, at least, be used indirectly for hydrological modeling applications.

For temperature, its spatial distribution in mountain areas is determined by many factors. For large-scale areas, latitude, longitude, and altitude are the main factors, but in small and medium-scale areas altitude becomes the most important factor and the temperature-elevation relationship is quite stable and obvious (Tabony, 1985; Livingstone et al., 1999; Aizen et al., 1996). Therefore, although temperature observations in mountain areas are also often scarce, they can be successfully estimated using the temperature-elevation relationship in a certain region and the existing observed data of a weather station located at low altitude. In fact, this approach for temperature estimation has been widely applied in hydrologic research (Rango and Martinec, 1979; Rango and Martinec, 1994; Martinec and Rango, 1986; Garen and Marks, 1996; Hartman et al., 1999).

Fontaine et al. (2002) developed a snowmelt component in SWAT to simulate the hydrology of mountainous regions, and used precipitation/temperature lapse rates

(PLAPS/TLAPS) to estimate precipitation amount and temperature at high altitudes. Until now, PLAPS and TLAPS had been adopted in SWAT. In the default situation SWAT uses a single precipitation/temperature lapse rate (SPLAPS/STLAPS) value for the whole elevation range throughout the year (Neitsch et al., 2011). In studies that used SPLAPS/STLAPS in SWAT for simulating hydrological processes in data-scarce basins (Luo et al., 2012, 2013; Yu et al., 2011) PLAPS was considered an external parameter and its value was obtained by calibration. Because of the inherent uncertainty of hydrological models constructed for such basins, the empirically calibrated value may not reflect the true precipitation distribution, and Luo et al. (2012) indicated that large differences in simulated results may be due to the use of a single precipitation lapse rate. A single TLAPS value ($-6^{\circ}\text{C km}^{-1}$, which is the typical value of the saturated adiabatic lapse rate) is also often chosen in such studies (e.g. Tabony, 1985). In reality, the altitudinal air temperature gradient is found to vary throughout the year (Glazirin, 1985; Aizen et al., 2000; Dou et al., 2011). The precipitation lapse rate also changes significantly from month to month, and more than one lapse rate may apply for different elevation ranges (Ji and Chen, 2012; Shen and Liang, 2004; Bookhagen and Burbank, 2006; Bookhagen and Strecker, 2008). Identification of the precipitation/temperature lapse rates for different seasons and elevation ranges is equivalent to improving the spatial-temporal resolution of input data, and thereby the reliability of hydrologic simulations. The question remains, how do these solutions for data-scarce problems perform when applied to simulations in glacier/snow dominated watersheds?

To answer this question we evaluated various input temperature, rainfall, and potential evapotranspiration (PET) schemes for hydrological simulations in the mountainous, data-scarce, glacier/snow dominated Manas River Basin in northwest China. Experiments were conducted to compare the performance of the schemes on key components of the modeled water cycle, and our discussion focuses on how input uncertainty influences water balance and simulation results.

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



2 Materials and methods

2.1 The study area

The Manas River Basin (MRB) originates from the Yilianhabierga Mountain located on the northern side of the mid Tianshan Mountains, Northwest China (Fig. 1). The Manas River is the largest inland river in the Dzungaria Basin. It flows 160 km to the Kenswate Hydrological Station (KHS), and continues 240 km through the oasis and desert finally merging into Manas Lake. The MRB catchment area to the KHS is 5163 km² (Luo et al., 2012), and there are only three rain gages located near KHS (Fig. 1), and only KHS itself has a long precipitation data time series, hence the designation of the basin as data-scarce.

To understanding the meteorological characteristics of the MRB accurately, we extended the area for gathering both ground observed and TRMM 3B43 data from inside the watershed to include the surrounding region. The extended study region focused mainly on the mid Tianshan Mountains, between latitudes 42°–45° N and longitudes 84°–88° E (Fig. 1). This area has markedly seasonal precipitation and very abrupt orographic variations, with altitudes ranging from 150 m to more than 5000 m within horizontal distances of only 100 km. Snow and glacial melt are important hydrologic processes in these mountains, and changes in temperature and precipitation are expected to markedly affect melt behavior.

2.2 The SWAT model with a glacier-melt module

To simulate snow and/or glacier melt dominated streamflow in rivers in arid and cold northwest China, Luo et al. (2013) developed a glacier melt module for SWAT. In addition, because of the rapidly receding high-flow and very slowly declining low-flow river discharge dynamics in the study region, Luo et al. (2012) added a slow-reacting reservoir to extend the existing one-reservoir baseflow pathway in SWAT. Both the glacier melt module and two-reservoir method were used in our simulations of MRB

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



streamflow. The basic delineation of MRB, into 27 sub-basins and 163 Hydrological Response Units (HRUs) was inherited from the two previous studies. Each sub-basin was divided into ten bands with equal elevation increments for simulating snow and glaciers. Other base data, such as observed streamflow, land use maps, soil properties, and the China Glacier Inventory (CGI), were as used by Luo et al. (2012).

2.3 The precipitation and temperature input

2.3.1 The in situ precipitation and temperature data

Precipitation data for a total of 16 stations around the MRB were collected (Fig. 1). Four of them have only monthly precipitation data from between 2000 and 2007. Daily precipitation data for the other 12 weather stations, obtained from the Climatic Data Center of the China Meteorological Administration, were summed to give monthly values. The data have passed rigorous quality assessment and quality control processes, with all extreme values being checked and validated. The data were consistent, with no missing values for the monthly time series of precipitation for all 16 stations. Of the stations around the MRB, 9 on the north slope of mid Tianshan Mountains had daily temperature data, which were used for calculating the temperature lapse rate (Fig. 1 and Table 1).

2.3.2 The TRMM 3B43 data

The Tropical Rainfall Measuring Mission (TRMM) is a satellite jointly operated by NASA (United States National Aeronautics and Space Administration) and JAXA (Japanese Aero-spatial Agency). It provides precipitation estimates at fine spatial resolution using a calibration based sequential scheme and data from multiple satellites, as well as, gage analyses (Huffman and Bolvin, 2012; Immerzeel et al., 2009). We used the TRMM 3B43 product, which provides the single best estimate of monthly precipitation spanning a global belt from 50° N to 50° S with a spatial resolution of 0.25°. The original

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



processing occurs at a time interval of 3 h. The integrated microwave precipitation estimates and infrared (IR) estimates (3B42) are combined to provide the best estimate in each grid cell. All 3-hourly combined microwave and IR estimates are then summed up over a calendar month. Finally, the monthly multi-satellite product is combined with monthly accumulated GPCC rain gage analyses (Huffman et al., 2007).

Although the TRMM 3B43 data represent the best estimate of monthly precipitation among the TMPA products, a previous study found that the product underestimated precipitation in high mountain regions (Ji and Chen, 2012). This problem also exists with other TMPA products around the world (Berg et al., 2006; Huffman et al., 2007; Barros et al., 2004). These regional biases may be caused by technical deficiencies, such as the discrete sampling frequency and the sensors' areal coverage (Condom et al., 2011). To address the inadequacy of snowfall detection in the TRMM 3B43 product, snowfall input has been assigned based on simple snowfall rate (Huffman and Bolvin, 2012), but this may lead to large biases in mountainous regions with frequent snowfall. Such biases can result in erroneous conclusions if applied directly without calibration (AghaKouchak et al., 2009; Gebremichael et al., 2010). Hence TRMM 3B43 data require area-specific adjustment and calibration to reduce such errors.

Ji and Chen (2012) used regression models to improve the accuracy of TRMM 3B43 monthly precipitation estimates in the mid Tianshan Mountains. These models were based on several terrain factors and geographic location data. The corrected TRMM 3B43 data showed better performance than before, and provided a good explanation of the spatial distribution of precipitation in the area, its also covers the MRB area and was used in our study.

2.3.3 PLAPS and TLAPS used in SWAT

In SWAT, precipitation, and maximum and minimum temperatures are calculated for each elevation band as a function of the respective lapse rate and the difference between the gage elevation and the average elevation specified for the band. For precipitation,

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



$$R_{\text{band}} = R_{\text{day}} + \frac{EL_{\text{band}} - EL_{\text{band}}}{1000} \cdot \frac{P_{\text{laps}_{\text{yr}}}}{P_{\text{days}_{\text{yr}}}}, \text{ when } R_{\text{day}} > 0.01 \quad (1)$$

For temperature,

$$T_{\text{band}} = T_{\text{day}} = \frac{EL_{\text{band}} - EL_{\text{gage}}}{1000} \cdot T_{\text{laps}_{\text{yr}}} \quad (2)$$

where R_{band} is the precipitation falling in the elevation band (mm H₂O), R_{day} is the precipitation recorded at the gage (mm H₂O), EL_{band} is the mean elevation in the elevation band (m), EL_{gage} is the elevation at the recording gage (m), $P_{\text{laps}_{\text{yr}}}$ is the precipitation lapse rate (mm H₂O km⁻¹), $P_{\text{days}_{\text{yr}}}$ is the average number of days of precipitation in a year. T_{band} is the max/min/mean daily temperature in the elevation band (°C), T_{day} is the max/min/mean daily temperature recorded at the gage (°C), $T_{\text{laps}_{\text{yr}}}$ is the temperature lapse rate (°C km⁻¹), and 1000 converts meters to kilometers (Neitsch et al., 2011).

The PLAPS and TLAPS used in SWAT assume one good linear relationship between elevation and precipitation/temperature for the whole year and watershed elevation range, hence, we called them single precipitation/temperature lapse rates (SPLAPS/STLAPS). As mentioned above, more than one significantly different PLAPS can exist in some months for the MRB (including negative values), and the altitudinal air temperature gradient varies throughout the year. Therefore, this study proposes the adoption of multiple precipitation/temperature lapse rates (MPLAPS/MTLAPS) which differ by month and elevation range. The equations become,

$$R_{\text{band}} = R_{\text{day}} + \sum_{n=1}^N \frac{\Delta EL_n \cdot P_{\text{laps}_{n,\text{mth}}}}{1000 \cdot P_{\text{days}_{n,\text{mth}}}}, \text{ when } R_{\text{day}} > 0.01 \quad (3)$$

$$T_{\text{band}} = T_{\text{day}} + \sum_{n=1}^N \frac{\Delta EL_n \cdot T_{\text{laps}_{n,\text{mth}}}}{1000} \quad (4)$$

For each of the 12 months, the PLAPS/TLAPS that should be used is determined by the current elevation range,

$$\Delta EL_n = \begin{cases} EL_{\text{band}} - EL_n, & EL_n \leq EL_{\text{band}} < EL_{n+1} \\ EL_{n+1} - EL_n, & EL_n \leq EL_{n+1} < EL_{\text{band}} \end{cases} \quad (5)$$

where N is the total number of the PLAPS/TLAPS over the entire elevation range, $P_{\text{laps}_{n,mth}}$ (mm H₂O km⁻¹) represents the n th PLAPS in the m th (calendar month, January to December), $T_{\text{laps}_{n,mth}}$ (°C km⁻¹) represents the n th TLAPS in the month, $P_{\text{days}_{mth}}$ is the average number of precipitation days in the month, EL_n (m) is the lower elevation of the n th elevation range, and EL_{n+1} (m) is the upper elevation.

2.3.4 Identification of MPLAPS and MTLAPS

The MRB spatial precipitation distribution was provided by the corrected TRMM 3B43 data of Ji and Chen (2012), and MPLAPS were based on precipitation and elevation relationships. Because of the large elevation range in the MRB (> 4000 m), a 200 m wide elevation interval was chosen for calculating the relationship between average elevation and average monthly precipitation. Temperature data are more stable and less noisy than precipitation data (Garen and Marks, 2005). The temperature elevation gradient is also usually quite stable and obvious in a medium-scale area (Tabony, 1985; Livingstone et al., 1999; Aizen et al., 1996). The temperature-elevation relationship was derived from observations at 9 stations around the MRB (Fig. 1 and Table 1) for each month.

When identifying the MPLAPS and MTLAPS, it was necessary to evaluate the stability and reliability of the relationships. Three conditions were used to evaluate the relationships; (i) R^2 , a measure of goodness of fit for linear relationships, values closer to 1 represent a better fit; (ii) the significance level, reflecting the reliability of the result; and (iii) the rational elevation range, which avoids meaningless results from a very good relationship covering a very small elevation span. In this study, MPLAPS and MTLAPS

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



considered to be valid were those results with $R^2 \geq 0.9$, significant at the 0.01 level, and with an elevation span greater than 1000 m.

2.4 PET method used in simulation

Evapotranspiration (PET), one of the major hydrologic components, is very sensitive to climatic variability (Claessens et al., 2006; Wullschleger and Hanson, 2006). There are many PET calculation methods used in hydrologic models, and the number of variables required in calculation varies according to the sophistication of the method (Fekete et al., 2003; Wu and Johnston, 2007). In SWAT, the Penman-Monteith method requires relative humidity, wind speed, and solar radiation, etc. (Neitsch et al., 2011). For data-scarce basins, such variables are unavailable or obtained by simple estimation from neighboring stations. This may lead to great uncertainty in the estimated PET. A method based on temperature, which is easily acquired or reliably estimated, is more suitable and efficient for such areas (Liu et al., 2011). Therefore, to distinguish the impacts of precipitation and temperature input on the water budget from other factors in the simulation, we tested the Hargreaves method (which only requires air temperature; Neitsch et al., 2011), against the Penman-Monteith approach.

2.5 Evaluation of the precipitation and temperature input schemes

In previous studies (Luo et al., 2012, 2013) the precipitation input to SWAT was calculated from SPLAPS and observational data from the base Shihezi weather station (SWS). This station, at elevation 444 m a.s.l., is located below the KHS outlet of the MRB (Fig. 1). We collected precipitation data at KHS (885 m a.s.l.), which is nearer to the mountains, and should have a pattern of annual precipitation closer to that of the mountainous region, than the base SWS station. In order to evaluate the MPLAPS precipitation schemes, a comparison with the previous SPLAPS scheme was necessary. For comparability, a virtual weather station (VWS) was defined at 885 m a.s.l. and data were calculated according to the previous scheme ($\text{SPLAPS} = 45 \text{ mm km}^{-1}$, with SWS

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



as the base station). Three schemes were assigned for analyzing the impact of precipitation on the hydrological simulation; (i) SPLAPS (45 mm km⁻¹) with the VWS as the base station (the same as the previous study) named “SPLAPS_SWS”; (ii) MPLAPS with the VWS (MPLAPS_SWS); and (iii) MPLAPS with the KHS (MPLAPS_KHS).

In the initial simulation, temperature lapse rate was assigned the single value (−6 °C km⁻¹) used by Luo et al. (2012, 2013). To determine the influence of temperature input on the simulation, the two schemes (STLAPS and MTLAPS) were compared using the same precipitation scheme. In addition, simulations with the two PET methods (Hargreaves and Penman-Monteith) were compared. This gave three scenarios. Scenario 1 is the combination of MPLAPS, STLAPS and Penman-Monteith PET; Scenario 2 is MPLAPS, MTLAPS and Penman-Monteith PET; and Scenario 3 is MPLAPS, MTLAPS and Hargreaves PET.

2.6 Evaluation of simulation results

We split the daily streamflow data set into calibration (1961 to 1980) and validation (1981 to 1999) periods. The simulated streamflow was compared with the measured values on a daily basis and model performance was evaluated using both the Nash-Sutcliffe efficiency (NSE) and Percent Bias (PBIAS) indices (Moriasi et al., 2007).

$$NSE = 1 - \frac{\sum_{i=1}^n (Q_i^{obs} - Q_i^{sim})^2}{\sum_{i=1}^n (Q_i^{sim} - Q^{mean})^2} \quad (6)$$

$$PBIAS = \frac{\sum_{i=1}^n (Q_i^{obs} - Q_i^{sim})}{\sum_{i=1}^n Q_i^{obs}} \times 100 \quad (7)$$

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

where Q_i^{obs} is the i -th observation for the daily flow, Q_i^{sim} is the i -th simulation value for the daily flow, mean is the mean of observed data for the daily flow, and n is the total number of the daily flow observations. Q^{mean} is the mean of observed flow data for the period being evaluated.

5 NSE is a normalized statistic that determines the relative magnitude of the residual variance compared with the measured data variance (Nash and Sutcliffe, 1970), and it indicates how well the plot of observed versus simulated data fits the 1 : 1 line. NSE ranges between -1 and 1 (1 inclusive), with $\text{NSE} = 1$ being a perfect fit. PBIAS is the deviation of the simulation from the observed data, expressed as a percentage.
10 The optimal value of PBIAS is 0 with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model over estimation bias (Morasi et al., 2007).

3 Results and discussion

3.1 The MPLAPS and MTLAPS in MRB

15 Annual precipitation at different elevations in the MRB (Table 2), calculated from corrected TRMM 3B43 data, exhibited three PLAPS at different elevation ranges (Fig. 2), and precipitation even decreased with elevation between 2500 m a.s.l. and 3700 m a.s.l. Monthly average precipitation at different elevations showed large differences between months (Fig. 3). Except for June, July, and August (in which the precipitation almost
20 always increased with elevation), at least one elevation region with negative PLAPS occurred in the other months. The PLAPS value at different elevations is also quite different within each month.

It is noteworthy that there was more precipitation at lower elevations in cold seasons than at higher elevations, as observed in another study (Han et al., 2004) in this region.
25 For such a distribution feature, SPLAPS may overestimate precipitation (snowfall) in the

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



MRB high mountains in cold seasons, which could affect the simulation of snow/glacier melt.

In short, we conclude that a SPLAPS may not represent the distribution of precipitation in the MRB well, and may lead to inaccurate precipitation estimates in some areas.

Using formulae (3) and (5), MPLAPS in the MRB were identified. These were used with the SPLAPS values in the respective precipitation schemes listed in Table 2.

The MTLAPS were identified from air temperature observations from weather stations around the MRB (Fig. 1 and Table 1). The temperature trends with elevation were quite different among months (Fig. 4). During the winter months temperature inversion was observed below about 1800 m a.s.l. on the northern slopes of the mid Tianshan Mountains (Han et al., 2002; Aizen et al., 1996). This phenomenon has been found in many mountainous regions (Garen and Marks, 2005; Livingstone et al., 1999), and if ignored may lead to uncertainties in the simulation of winter snow fall and melt. Table 3 lists the identified MTLAPS and initial STLAPS used in the comparison simulations.

3.2 The influence of precipitation on glacier and snow melt

The impact of the precipitation schemes on the hydrological response of the MRB was evaluated by comparing SWAT simulations using the three schemes defined in Sect. 2.5. The same model parameter settings were used in each case.

First, the average precipitation in the MRB, calculated in SWAT from the three schemes, demonstrated quite different patterns during the year (Fig. 5). Monthly average data from five rain gages in the mountain area was used as a reference, showing that almost half of the annual precipitation occurred in summer (June, July, August; Fig. 5), and only about 10 % occurred in winter (December to February). Thus the average precipitation during the year calculated with the SPLAPS_SWS scheme was quite different from the mountain area. This was because the base station (SWS) is located in the lowland plain where the precipitation difference during the year is small, and with SPLAPS the increase in precipitation with elevation is linear. Using MPLAPS_SWS, the annual precipitation distribution pattern is closer to that of the mountain area,

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



indicating that MPLAPS adjusted the precipitation distribution effectively. The pattern is even closer to that of the mountain area when using MPLAPS_KHS. The likely reason is that KHS lies closer to MRB than SWS, and hence has more climate similarity than SWS. The precipitation estimated with MPLAPS_SWS was much less than with MPLAPS_KHS (Fig. 5); this is because of the PLAPS value (45 mm km^{-1}), which is greatly underestimated between 444 m.a.s.l. and 885 m.a.s.l. The precipitation of the virtual weather station (VWS) at 885 m.a.s.l. (about 230 mm yr^{-1}) was also underestimated compared with observed data at KHS (about 345 mm yr^{-1}). Therefore, despite the use of MPLAPS, the MPLAPS_SWS scheme did not adequately represent the precipitation situation.

Precipitation in the cold season is often in the form of snow. For the quite different precipitation distributions estimated by the three schemes, the distribution pattern of snowfall simulated in the cold season showed unique features (Fig. 6). Using SPLAPS, the 39-yr averaged snowfall in the glacier HRU (GHRU) is greater than in the non-glacier HRU (NGHRU) in the cold season, but the opposite occurs when using MPLAPS. In the mid Tianshan Mountains, winter snowfall is less above the permanent snow line (in the glacier area) than below it (Wei et al., 2001). This result further supports the use of MPLAPS based on corrected TRMM 3B43 data, which can represent the precipitation distribution more accuracy.

Additionally, using SPLAPS, the average snowfall in the cold season is nearly 140 mm (Fig. 6), almost 42 percent of the annual simulated precipitation (334 mm). Using MPLAPS, the average winter snowfall was only 80 mm, 17% of the annual total. Wei et al. (2001) showed that for Glacier No. 1 in the headwaters of the Urumqi River, which is near to the MRB in the mid Tianshan Mountains, less than 10% of annual precipitation occurs between October and March. The 17% estimated using MPLAPS is therefore a more reasonable value than the 42% produced by the SPLAPS scheme.

These results indicate that precipitation schemes strongly impact on the spatial and temporal distribution of snowfall in hydrological simulations. Not surprisingly, further impacts on the simulation of snow and glacier melt were found. In the model glacier

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



melt module, when snow cover ablation is complete, the glaciers begin to melt. In the model simulation using MPLAPS, less snow accumulates in the cold season, this leads to decreased summer snowmelt, and rapid summer snow ablation means the glacier is exposed for longer producing more glacial melt water, than with SPLAPS (Fig. 7). This may explain why simulated glacier melt volume differences between the precipitation schemes occur mainly in the snowmelt period. Thus for the snow/glacier-dominated watershed, it is clear that the modeled precipitation input affects not only rain-runoff, snow accumulation, and melt-water volume, but also has a notable influence on the simulation of glacier melt behavior.

The above analysis suggests that, for snow and glacier melt runoff-dominated river basins, well estimated precipitation input is extremely important for accurate hydrologic simulations. Moreover, precipitation distribution characteristics in MRB, which decreases with elevation in cold seasons and falls mainly in summer, is well represented in the simulation using MPLAPS. This scheme could be considered as a more reliable method of precipitation estimation for reducing the uncertainty of hydrologic simulations in data-scarce watersheds.

The statistical results for simulations, based on the three precipitation schemes, show that with MPLAPS and Penman-Monteith, there was little difference in PET; in addition, when the annual average precipitation increased, the water yield increased correspondingly, as might be expected. The large difference in water yield between the precipitation schemes indicates that, precipitation, as the basic input of water cycle, is critical for water balance in the simulation. For the MPLAPS.KHS simulation, NSE decreased to 0.54 and the PBIAS was more than 50 percent. So despite MPLAPS_KHS being a more reasonable precipitation scheme, the efficiency and bias of simulation was worse, indicating that the initial model has large uncertainties besides precipitation input.

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



3.3 Impacts of temperature input schemes and PET method on the hydrologic simulation

Compared with the pan evaporation of three weather stations at different elevations in the mid Tianshan Mountains, the simulated annual average potential evapotranspiration (PET) for the MRB (mean elevation ca. 3000 m a.s.l.) seems too small (about 270 mm yr⁻¹; Table 5). Zhang et al. (2009) suggested that PET in the mid Tianshan Mountains should be between 500 and 900 mm. From this discrepancy between observed and simulated PET we surmise that the overestimated water yield (Table 4) may be caused by insufficient ET and PET as calculated by the Penman-Monteith method in the initial model. For the alternative Hargreaves PET method (Sect. 2.4) the availability of accurate temperature data is no doubt an important core element.

As for precipitation, the single temperature lapse rate (STLAPS, $-6\text{ }^{\circ}\text{C km}^{-1}$) used in the initial model was changed to provide multiple values (MTLAPS); one for each elevation range. Compared with STLAPS, using MTLAPS, the MRB temperature distribution decreased in May to August, and increased in other months (Table 3). When MTLAPS was used in the model (scenario 2; Fig. 8), (i) the simulated snowmelt increased significantly in spring and fall, and the melt period was correspondingly prolonged; (ii) both ET and snow sublimation (which were related to PET) had a small increase in spring and fall, but decreased in the summer months because of lower temperatures; (iii) during the main glacier melt period, lower temperatures in June, July, and August also led to decreased melt water. The change of temperature input also led to a slight slowing in the arrival of streamflow peaks (Fig. 9). Moreover, the annual average simulation outputs (Table 6) indicate that the influence of temperature on key hydrological processes, such as snowmelt, snow sublimation, and evapotranspiration, should not be neglected. However, the final water yield only decreased about 4%, which was simply because the decreased glacier melt amount was partly offset by a simultaneous decline in snow sublimation and evapotranspiration. Some studies have concluded that annual runoff is affected primarily by precipitation changes, while the seasonal distribution of runoff is

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

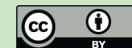
Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



affected by changes in temperature (Gleick, 1987; Aguado et al., 1992; Cayan and Rid-
dle, 1993). Our results indicate that temperature dominates the changes in snow/rain
ratio and may accelerate or delay snowmelt and thus alter the timing of runoff. This
argument is generally true for a rain and snow dominated runoff basin, because tem-
perature would not affect the total input amount in the water balance. But in a basin
containing glaciers, temperature could change the glacier melt amount which is an im-
portant water source component of the water cycle. Therefore, for a rain-snow-glacier
runoff driven basin, temperature affects not only the timing of discharge but also the
total water yield amount, and the processes and mechanisms thereof, are complex.

It is noteworthy that the STLAPS input generates a simulation which closely approx-
imates the steep narrow peak flow in the MRB. It is, however, unacceptable that this
simple estimated temperature obscures other real problems, such as parameter un-
certainty or frozen soil related issues in the model (Luo et al., 2012; Liu et al., 2011).
MTLAPS, on the contrary, represents the temperature distribution in the MRB, and a
realistic temperature input helps to reduce the uncertainty of the hydrologic simulation.

The most significant outcome of changing the PET calculation method from Penman-
Monteith (scenarios 1 and 2) to Hargreaves (scenario 3), was that ET almost doubled
(Fig. 8 and Table 6). Snow sublimation, which is closely related to PET, also doubled,
leading to less snow for melting in the summer. Glacier melt, however, was almost
unchanged by the switch of PET methods. Changing the temperature scheme from
STLAPS to MLAPS (with Penman-Monteith PET, scenarios 1 and 2) had a small im-
pact; the simulated PET was still small (Scenarios 1 and 2; Fig. 8 and Table 6). This
may be because temperature is not the most critical factor for the Penman-Monteith
method, and that other variables which are hard to obtain in data-scarce basins were
estimated inaccurately.

In Scenario 3, MPLAPS.KHS, the combined impacts of snow melt, sublimation, and
glacier melt were reflected in the final simulated discharge, which closely fits the ob-
served flow (Fig. 9). With the Hargreaves method, the annual average estimated PET
for the MRB reached 561 mm (a reasonable value), and the simulated water yield

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



decreased to 236 mm with a surprisingly small PBIAS. These results suggest that the uncertainty of simple precipitation estimates in data-scarce catchments may be propagated and amplified along the course of the modeling process. The underestimated precipitation may lead, for instance, to a choice of PET method which is unrealistically low to maintain an accurate basin water balance.

The scenario 3 simulation with its small PBIAS is not still not a good modeling result (NSE = 0.52), because the simulated streamflow is low in summer and high in spring and fall compared with the observations (Fig. 9). The simulated groundwater flow (GRND Q) in scenario 3 was significantly reduced such that the ratio to surface flow was less than a third (Table 6). This may be attributed to the greatly increased evapotranspiration, which has a large influence on the amount of soil water and root zone percolation that reaches the aquifer, and then contributes to baseflow (Liu et al., 2011). The detailed physical mechanisms of this process are not discussed in this study. The low groundwater contribution to streamflow may also explain the severe undulation of the hydrograph (Fig. 9), because surface runoff recedes more rapidly than groundwater flow. Because the simulated PET was reasonable, the low simulation efficiency with MPLAPS_KHS was probably due to the uncertainty in key model parameters, and the model needed specific recalibration for the MPLAPS_KHS scenario inputs.

3.4 Recalibration and model evaluation

To solve the problems with scenario 3, further analysis of the SWAT hydrologic model parameters was necessary. Because of the lack of site-specific data, a sensitivity analysis of the relevant parameters was carried-out, followed by manual calibration of the most sensitive parameters (Table 7), using daily KHS runoff data.

The SCS curve number (CN), a function of soil permeability, was the most sensitive parameter, and has a significant impact on the surface runoff and groundwater yield. Large CN may overestimate surface runoff leading to an undulating streamflow hydrograph. Reducing the CN generates more baseflow which has a relatively slow response to discharge, and smoothes the tiny peak of the hydrograph. ALPHA_BF and

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



ALPHA.BF_DP are the baseflow recession constant of the shallow and deep aquifer layers in the two-reservoir approach, respectively. These have a large influence on the shape of the baseflow response; high values lead to a steep response, and low values to a sluggish response. In the two-reservoir approach, RCHG_DP is the fraction of root zone percolation that reaches the deep aquifer. It has a significant impact on discharge in the cold season for slow release from the deep reservoir. GWQMN, GW_DELAY and GW_REVAP are also sensitive groundwater parameters that dictate the amount as well as the timing of water flow released from or recharged to the shallow aquifer. For snow/glacier melt components, SMFMN, SMFMX, SSBLFMX, SSBLFMN, TIMP and GMFMX were quite sensitive to discharge in melt seasons; adjustment of these would be conducive to resolving the problem that streamflow was low in summer and high in spring and fall.

While implementing the manual calibration, a comprehensive consideration of these parameters was necessary (Table 7). The calibrated average daily streamflow was obviously improved compared with the simulation in scenario 3 (Fig. 10). The peak flow in summer was closer to that observed, and the hydrograph fit was much better in spring and fall. The recalibration NSE for the whole period increased from 0.52 to 0.68 and PBIAS was less than five percent (Table 8). The NSE evaluation rates both the calibration and validation as “good”, indicating a good degree of correlation between the observed and simulated discharge. In combination with a series of previous analyzes, these were determined to be adequate for accepting the model results for the MRB.

However, the efficiency of the recalibrated simulation (NSE = 0.68, PBIAS = -2.8 %) was lower than that of the initial model (NSE = 0.72, PBIAS = -3.2 %) using SPLAPS and Penman-Monteith PET. This suggests that the influence of uncertainties in the input data may cancel each other out, or be covered up by uncertainties in other hydrologic component methods and parameters of the model. A wide range of parameter values and conditions can result in very similar model results; this is “equifinality” (Beven, 1996). In addition, it is not sufficient to evaluate hydrologic models

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



in data-scarce watersheds on the basis of comparisons between simulated and measured streamflow alone.

The recalibrated model also had limited capability in simulating complex hydrograph shapes and peak discharges (Fig. 11). This is probably a consequence of having the daily precipitation dynamics observed at KHS applied to the whole basin; the timing and magnitude of the actual precipitation in different parts of the catchment will not be the same, and hence KHS precipitation is unlikely to be representative for the whole MRB. However, there is no alternative for a data-scarce river basin. Our next research objective is to address the influence of spatial variation in daily precipitation events on streamflow simulations.

4 Conclusions

In this study, the influence of different precipitation/temperature input schemes on the simulation of hydrological processes, in a glacier/snow dominated watershed, were compared using a hydrological model.

Multiple precipitation lapse rates were identified for the MRB based on corrected TRMM 3B43 data. Compared to SPLAPS, the use of MPLAPS was equivalent to improving precipitation spatio-temporal resolution, and seasonal distribution patterns in the MRB, which is more reasonable for the mountain region. Analysis of the different precipitation schemes demonstrated a large influence on snow accumulation and melt behavior. This had further impacts on the simulated glacier melt response. The uncertainty associated with simple precipitation estimates can propagate and be amplified through the modeling process, but glacier melt behavior may also conceal uncertainty caused by the input data. These findings indicate that the effects of forcing data on hydrological simulations are more complex in basins with glaciers than in common rain/snow dominated watersheds.

We confirmed that temperature has a significant influence on glacier melt volume which is an important water cycle source component. Hence, temperature influences

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



the total water yield in basins with the three (rain, snow, and glacier) sources, unlike rain/snow driven river basins, where temperature inputs mostly affect the timing of discharge.

STLAPS is conducive to generating simulations which fit the steep and narrow peak flow in the MRB, but the use of this simple estimated temperature obscures other limitations of the model. MTLAPS as applied in this study, represents a more realistic temperature distribution and can help to reduce the uncertainty of the hydrologic simulation.

We found that PET in the MRB was underestimated by the Penman-Monteith method. A reasonable result was obtained using the Hargreaves method, indicating that the Penman-Monteith method (which needs more parameters) is of limited use for the data-scarce MRB, and that temperature based PET methods may be more appropriate.

Recalibration of the model for the improved precipitation, temperature and PET schemes increased the global NSE to 0.68, and PBIAS was -2.83% , hence an acceptable model for MRB was achieved. However, the evaluation ratings of the initial model were the same as the recalibration, indicated that the uncertainty of input data could be masked by other aspects of the model. In other words, for this high mountain watershed with complex hydrologic mechanisms (runoff derived from rain–snow–glacier sources) and less known about the hydro-climatic conditions, model evaluation should not be made on streamflow alone. The key processes involved in the hydrologic cycle need to be assessed individually. These include precipitation, snow accumulation, snow/glacier melt, evapotranspiration, and groundwater.

In general, we commenced with a scarce data input problem, gradually discussing the major aspects of the hydrological model, and finally obtained a reasonable model for the MRB. This study provides a reference for hydrologic modeling in data-scarce basins.

HESSD

10, 807–853, 2013

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Acknowledgements. This study is supported partially by the Natural Science Foundation of China (Grant No. 41130641), the 973 Program of China (Grant No. 2010CB951002), and the Project of the National Eleventh-Five Year Research Program of China (Grant No. 2012BAC19B07). We thank the Climate Data Center at the National Meteorological Information Center of the China Meteorological Administration for providing the station precipitation data used in this study.

References

- AghaKouchak, A., Nasrollahi, N., and Habib, E.: Accounting for uncertainties of the TRMM satellite estimates, *Remote Sensing*, 13, 606–619, 2009.
- Aguado, E., Cayan, D. R., Riddle, L. G., and Roos, M.: Climatic fluctuations and the timing of West Coast streamflow, *J. Climate*, 5, 1468–1483, 1992.
- Aizen, V., Aizen, E., and Melack, J. M.: Precipitation, melt and runoff in the northern Tien Shan, *J. Hydrol.*, 186, 229–251, 1996.
- Aizen, V., Aizen, E., Glazirin, G., and Loaiciga, H. A.: Simulation of daily runoff in Central Asian alpine watersheds, *J. Hydrol.*, 238, 15–34, 2000.
- Barros, A. P., Kim, G., Williams, E., and Nesbitt, S. W.: Probing orographic controls in the Himalayas during the monsoon using satellite imagery, *Nat. Hazards Earth Syst. Sci.*, 4, 29–51, doi:10.5194/nhess-4-29-2004, 2004.
- Berg, W., L'Ecuyer, T., and Kummerow, C.: Rainfall climate regimes: the relationship of regional TRMM rainfall biases to the environment, *J. Appl. Meteorol. Climatol.*, 45, 434–453, 2006.
- Beven, K.: Equifinality and uncertainty in geomorphological modelling, *The Scientific Nature of Geomorphology: Proceedings of the 27th Binghamton Symposium in Geomorphology*, 289–313, 1996.
- Beven, K.: How far can we go in distributed hydrological modelling?, *Hydrol. Earth Syst. Sci.*, 5, 1–12, doi:10.5194/hess-5-1-2001, 2001.
- Beven, K.: Towards an alternative blueprint for a physically based digitally simulated hydrologic response modeling system, *Hydrol. Process.*, 16, 189–206, 2002.
- Bolch, T. and Marchenko, S.: Significance of glaciers, rockglaciers, and ice-rich permafrost in the Northern Tien Shan as water towers under climate change conditions, *Proceedings of the workshop, "Assessment of Snow-Glacier and Water Resources in Asia"*, 199–211, 2006.

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



- Bookhagen, B. and Burbank, D. W.: Topography, relief, and TRMM-derived rainfall variations along the Himalaya, *Geophys. Res. Lett.*, 33, L08405, doi:10.1029/2006GL026037, 2006.
- Bookhagen, B. and Strecker, M. R.: Orographic barriers, high-resolution TRMM rainfall, and relief variations along the eastern Andes, *Geophys. Res. Lett.*, 35, L06403, doi:10.1029/2005WR004131, 2008.
- Boyle, D. P., Gupta, H. V., Sorooshian, S., Koren, V., Zhang, Z., and Smith, M.: Toward improved streamflow forecast: value of semi-distributed modeling, *Water Resour. Res.*, 37, 2749–2759, 2001.
- Cayan, D. R. and Riddle, L. G.: The Influence of Precipitation and Temperature on Seasonal Streamflow in California, *Water Resour. Res.*, 29, 1127–1140, 1993.
- Chalise, S. R.: High mountain hydrology in changing climates: perspectives from the Hindu Kush-Himalayas, *Developments in hydrology of mountain areas, Proceedings of the FRIEND AMHY Annual Report No.4, Technical Documents in Hydrology*, 8, 23–31, 1994.
- Chaponniere, A., Boulet, G., Chehbouni, A., and Aresmouk, M.: Understanding hydrological processes with scarce data in a mountain environment, *Hydrol. Process.*, 22, 1908–1921, 2008.
- Claessens, L., Hopkinson, C., Rastetter, E., and Vallino, J.: Effect of historical changes in land use and climate on the water budget of an urbanizing watershed, *Water Resour. Res.*, 42, W03426, doi:10.1029/2005WR004131, 2006.
- Collischonn, B., Collischonn, W., and Morelli, C.: Daily hydrological modeling in the Amazon basin using TRMM rainfall estimates, *J. Hydrol.*, 360, 207–216, 2008.
- Condom, T. R. P. and Espinoza, J. C.: Correction of TRMM 3B43 monthly precipitation data over the mountainous areas of Peru during the period 1998–2007, *Hydrol. Process.*, 25, 1924–1933, 2011.
- Daly, C., Neilson, R. P., and Phillips, D. L.: A statistical topographic model for mapping climatologically precipitation over mountainous terrain, *J. Appl. Meteorol.*, 33, 140–158, 1994.
- Dou, Y., Chen, X., Bao, A. M., and Li, L. H.: The simulation of snowmelt runoff in the ungauged Kaidu River Basin of TianShan Mountains, China, *Environ. Earth Sci.*, 62, 1039–1045, 2011.
- Fekete, B. M., Vorosmarty, C. J., Roads, J. O., and Willmott, C. J.: Uncertainties in Precipitation and Their Impacts on Runoff Estimates, *J. Climate*, 17, 294–304, 2003.
- Finnertya, B. D., Smitha, M. B., Sea, D. J., Korena, V., and Moglenb G. E.: Space-time scale sensitivity of the Sacramento model to radar-gage precipitation inputs, *J. Hydrol.*, 203, 21–38, 1997.

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Fontaine, T. A., Cruickshank, T. S., Arnold, J. G., and Hotchkiss, R. H.: Development of a snowfall–snowmelt routine for mountainous terrain for the soil water assessment tool (SWAT), *J. Hydrol.*, 262, 209–223, 2002.

Garen, D. C. and Marks, D.: Spatial distributed snow modeling in mountainous regions: Boise River application, *HydroGIS96: application of geographic information systems in hydrology and water resources management (Proceedings of the Vienna Conference, April, 1996)*, 235, 421–428, 1996.

Garen, D. C. and Marks, D.: Spatially distributed energy balance snowmelt modelling in a mountainous river basin: estimation of meteorological inputs and verification of model results, *J. Hydrol.*, 315, 126–153, 2005.

Gebremichael, M., Anagnostou, E. N., and Bitew, M. M.: Critical Steps for Continuing Advancement of Satellite Rainfall Applications for Surface Hydrology in the Nile River Basin, *J. Am. Water Resour. As.*, 46, 361–366, 2010.

Gleick, P. H.: The development and testing of a water balance model for climate impact assessment: Modeling the Sacramento Basin, *Water Resour. Res.*, 23, 1049–1061, 1987.

Guo, J., Liang, X., and Leung, L. R.: Impacts of different precipitation data sources on water budgets, *J. Hydrol.*, 298, 311–334, 2004.

Haddeland, I., Matheussen, B. V., and Lettenmaier, D. P.: Influence of spatial resolution on simulated streamflow in a macroscale hydrologic model, *Water Resour. Res.*, 38, 1124–1133, 2002.

Han, T. D., Ding, Y. J., Ye, B. S., and Xie, C. W.: Precipitation Variations on the Southern and Northern Slopes of the Tianger Range in Tianshan Mountains, *Journal of Glaciology and Geocryology*, 6, 761–766, 2004 (in Chinese).

Hartman, M. D., Baron, J. S., Lammers, R. B., Cline, D. W., Band, L. E., Liston, G. E., and Tague, C.: Simulations of snow distribution and hydrology in a mountain basin, *Water Resour. Res.*, 35, 1587–1603, 1999.

Huffman, G. J. and Bolvin, D. T.: TRMM and other data precipitation data set documentation. Laboratory for Atmospheres, NASA Goddard Space Flight Center and Science Systems and Applications, 25, available at: ftp://precip.gsfc.nasa.gov/pub/trmmdocs/3B42_3B43_doc.pdf, last access: July 2012.

Huffman, G. J., Adler, R. F., Bolvin, D. T., Gu, G., Nelkin, E. J., Bowman, K. P., Hong, Y., Stocker, E. F., and Wolff, D. B.: The TRMM multi-satellite precipitation analysis: quasi-global, multi-

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



year, combined-sensor precipitation estimates at fine scale, *J. Hydrometeorol.*, 8, 38–55, 2007.

Hughes, D., Andersson, L., Wilk, J., and Savenije, H.: Regional calibration of the Pitman model for the Okavango River, *J. Hydrol.*, 331, 30–42, 2006.

5 Immerzeel, W. W., Droogers, P., Jong, S. M., and Bierkens, M. F. P.: Large-scale monitoring of snow cover and runoff simulation in Himalayan river basins using remote sensing, *Remote Sens. Environ.*, 113, 40–49, 2009.

Immerzeel, W. W., Beek, L. P. H., and Bierkens, M. F. P.: Climate change will affect the Asian water towers, *Science*, 328, 1382–1385, 2010.

10 Ji, X. and Chen, Y. F.: Characterizing spatial patterns of precipitation based on corrected TRMM3B43 data over the mid Tianshan Mountains of China, *J. Mt. Sci.*, 9, 628–645, 2012.

Liu, T., Willems, P., Pan, X. L., Bao, An. M., Chen, X., Veroustraete, F., and Dong, Q. H.: Climate change impact on water resource extremes in a headwater region of the Tarim basin in China, *Hydrol. Earth Syst. Sci.*, 15, 3511–3527, doi:10.5194/hess-15-3511-2011, 2011.

15 Liu, T., Willems, P., Feng, X. W., Li, Q., Huang, Y., Bao, A. M., Chen, X., Veroustraete, F., and Dong, Q. H.: On the usefulness of remote sensing input data for spatially distributed hydrological modelling: case of the Tarim River basin in China, *Hydrol. Process.*, 36, 335–344, 2012.

Livingstone, D. M., Lotter, A. F., and Walkert, I. R.: The Decrease in Summer Surface Water Temperature with Altitude in Swiss Alpine Lakes: A Comparison with Air Temperature Lapse Rates, *Arct. Antarct. Alp. Res.*, 31, 341–352, 1999.

20 Luo, Y., Arnold, J., Allen, P., and Chen, X.: Baseflow simulation using SWAT model in an inland river basin in Tianshan Mountains, Northwest China, *Hydrol. Earth Syst. Sci.*, 16, 1259–1267, doi:10.5194/hess-16-1259-2012, 2012.

25 Luo, Y., Arnold, J., Liu, S. Y., Wang, X. Y., and Chen, X.: Inclusion of glacier processes for distributed hydrological modeling at basin scale in Tianshan Mountains, northwest China, *J. Hydrol.*, 477, 72–85, 2013.

Martinec, J. and Rango A.: Parameter values for snowmelt runoff models, *J. Hydrol.*, 84, 197–219, 1986.

30 Michaud, J. D. and Sorooshian, S.: Effect of rainfall-sampling errors on simulations of desert flash floods, *Water Resour. Res.*, 30, 2765–2775, 1994.

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



- Moriasi, D. N., Arnold, J., Liew, M. W., Bingner, R. L., Harmel, R. D., and Veith, T. L.: Model evaluation guidelines for systematic quantification of accuracy in watershed simulations, *T. ASABE*, 50, 885–900, 2007.
- Nash, J. and Sutcliffe, J.: River flow forecasting through conceptual models, 1. A discussion of principles, *J. Hydrol.*, 10, 282–290, 1970.
- Neitsch, S. L., Arnold, J. G., Kiniry, J. R., and Williams, J. R.: Soil and Water Assessment Tool Theoretical Documentation, Version 2009, available at: <http://twri.tamu.edu/reports/2011/tr406.pdf>, last access: July 2012.
- Rango, A. and Martinec, J.: Application of a snowmelt-runoff model using landsat data, *Nord. Hydrol.*, 10, 228–235, 1979.
- Rango, A. and Martinec, J.: Model accuracy in snowmelt runoff forecasts extending from 1 to 20 days, *J. Am. Water Resour. As.*, 30, 463–470, 1994.
- Salamon, P. and Feyen, L.: Assessing parameter, precipitation, and predictive uncertainty in a distributed hydrological model using sequential data assimilation with the particle filter, *J. Hydrol.*, 376, 428–442, 2009.
- Shen, Y. P. and Liang, H.: High Precipitation in Glacial Region of High Mountains in High Asia: Possible Cause, *Journal of Glaciology and Geocryology*, 24, 806–809, 2004 (in Chinese).
- Smith, R. B.: The influence of mountains on the atmosphere, *Advances in Geophysics*, Academic Press, 21, 87–233, 1979.
- Sorg, A., Bolch, T., Stoffel, M., Solomina, O., and Beniston, M.: Climate change impacts on glaciers and runoff in Tien Shan (Central Asia), *Nature Climate Change*, 2, 725–731, doi:10.1038/nclimate1592, 2012.
- Su, F., Hong, Y., and Lettenmaier, D. P.: Evaluation of TRMM Multisatellite Precipitation Analysis (TMPA) and Its Utility in Hydrologic Prediction in the La Plata Basin, *J. Hydrometeorol.*, 9, 622–640, 2008.
- Sun, H., Cornish, P. S., and Daniell, T. M.: Spatial variability in hydrologic modelling using rainfall runoff model and digital elevation model, *J. Hydrol. Eng.*, 7, 404–412, 2002.
- Tabony, R. C.: The variation of surface temperature with altitude, *Meteorol. Mag.*, 114, 37–48, 1985.
- Viviroli, D., Weingartner, R., and Messerli, B.: Assessing the Hydrological Significance of the World's Mountains, *Mt. Res. Dev.*, 23, 32–40, 2003.
- Wei, W. S., Qin, D. H., and Liu, M. Z.: Properties and structure of the seasonal snow cover in the northwest regions of China, *Arid Land Geography*, 24, 310–313, 2001 (in Chinese).

- Weingartner, R., Barben, M., and Spreafico M.: Floods in mountain areas – an overview based on examples from Switzerland, *J. Hydrol.*, 282, 10–24, 2003.
- Wu, K. S. and Johnston, C. A.: Hydrologic response to climatic variability in a Great Lakes Watershed: A case study with the SWAT model, *J. Hydrol.*, 337, 187– 199, 2007.
- 5 Wullschleger, S. D. and Hanson, P. J.: Sensitivity of canopy transpiration to altered precipitation in an upland oak forest: evidence from a long-term field manipulation study, *Global Change Biol.*, 12, 97–109, 2006.
- Yu, M. Y., Chen, X., Li, L. H., Bao, A. M., and Paix, M. J.: Streamflow Simulation by SWAT Using Different Precipitation Sources in Large Arid Basins with Scarce Raingauges, *Water Resour. Manage.*, 25, 2669–2681, 2011.
- 10 Zhang, M. J., Li, R. X., Jia, W. X., and Wang, X. F.: Temporal and Spatial Changes of Potential Evaporation in Tianshan Mountains from 1960 to 2006, *Acta Geographica Sinica*, 64, 798–806, 2009.

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[⏪](#)[⏩](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Table 1. The location, altitude, duration, and annual rainfall of meteorological observation stations used in this study. Stations with monthly data only in italics. *P* denotes precipitation and *T* is temperature.

Station names	Elev. (m)	Lat. (°)	Long. (°)	Prec. (mm yr ⁻¹)	Time span	Data type
<i>Bajjahu</i>	<i>1302.0</i>	<i>43.950</i>	<i>85.417</i>	<i>400.8</i>	<i>Jan 2000–Dec 2007</i>	<i>P</i>
Bayinbuluke	1738.3	42.733	86.300	210.1	Jan 1958–Dec 2009	<i>P</i>
Baluntai	2458.9	43.033	84.150	290.2	Jan 1958–Dec 2009	<i>P</i>
Caijiahu	441.0	44.200	87.533	141.2	Jan 1959–Dec 2009	<i>P & T</i>
Daxigou	3539.0	43.100	86.833	453.5	Jan 1959–Sep 2007	<i>P & T</i>
Manasi	473.1	44.317	86.200	190.9	Jan 1961–Sep 2007	<i>P & T</i>
<i>Meiyao</i>	<i>1161.0</i>	<i>43.900</i>	<i>85.850</i>	<i>417.2</i>	<i>Jan 2000–Dec 2007</i>	<i>P</i>
<i>Qingshuihezi</i>	<i>1886.0</i>	<i>43.800</i>	<i>86.217</i>	<i>495.0</i>	<i>Jan 2000–Dec 2007</i>	<i>P</i>
Shiyanzhan	1930.0	43.450	87.183	450.5	Jan 1978–Sep 2007	<i>P & T</i>
<i>Shimenzi</i>	<i>1176.0</i>	<i>43.917</i>	<i>86.050</i>	<i>445.0</i>	<i>Jan 2000–Dec 2007</i>	<i>P</i>
Shihezi	443.7	44.316	86.050	210.0	Jan 1953–Dec 2008	<i>P & T</i>
Wulanwusu	469.3	44.284	85.817	224.7	Jan 1991–Sep 2007	<i>P & T</i>
Wulumuqi	918.7	43.783	87.617	267.1	Jan 1951–Dec 2009	<i>P & T</i>
Wusu	478.3	44.433	84.667	169.1	Jan 1957–Dec 2009	<i>P & T</i>
Xiaoquzi	1871.8	43.483	87.100	552.1	Jan 1957–Sep 2007	<i>P & T</i>
Kensiwat	885.0	43.950	85.417	345.0	<i>Jan 1956–Dec 2007</i>	<i>P</i>

Table 2. The MPLAPS and SPLAPS used in this study (the SPLAPS used in the previous is 45 mm km^{-1} for year, here we convert it to corresponded value for day according to divided by the P_{days_y}). Min and Max is the minimum and maximum elevation in MRB respectively.

Month	MPLAPS		SPLAPS	
	Value ($\text{mm km}^{-1} \text{ day}$)	Elevation Range	Value ($\text{mm km}^{-1} \text{ day}$)	Elevation Range
Jan	1.0 -0.8	Min-3100 3100-Max		
Feb	1 -0.8	Min-2500 2500-Max		
Mar	1.8 -2.5 1.7	Min-2000 2000-3500 3500-Max		
Apr	1.9 -2.6 0.5	Min-2000 2000-3500 3500-Max		
May	0.4 -0.9 1.4	Min-2500 2500-3700 3700-Max	0.9	Min-Max
Jun	0.9	Min-Max		
Jul	1.6	Min-Max		
Aug	2.0	Min-Max		
Sep	2.8 -1.9 0.5	Min-2200 2200-3500 3500-Max		
Oct	1.2 -1.4	Min-2000 2000-Max		
Nov	1.2 -0.8	Min-2000 2000-Max		
Dec	-0.4	Min-Max		

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract Introduction

Conclusions References

Tables Figures

◀ ▶

◀ ▶

Back Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Table 3. The MTLAPS and STLAPS used in this study. Min and Max is the minimum and maximum elevation in MRB respectively.

Month	MTLAPS		STLAPS	
	Value ($^{\circ}$ km $^{-1}$)	Elevation Range	Value ($^{\circ}$ km $^{-1}$)	Elevation Range
Jan	4.7	Min–1800	–6	Min–Max
	–3.1	1800–Max		
Feb	2.5	Min–1800		
	–3.3	1800–Max		
Mar	–3.2	Min–Max		
Apr	–5.7	Min–Max		
May	–6.6	Min–Max		
Jun	–7.0	Min–Max		
Jul	–7.1	Min–Max		
Aug	–6.4	Min–Max		
Sep	–5.6	Min–Max		
Oct	–4.2	Min–Max		
Nov	–2.4	Min–Max		
Dec	2.8	Min–1800		
	–3.2	1800–Max		

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Table 4. The statistical results of simulation by SWAT using the three precipitation schemes.

Scheme	PRECIP (mm yr ⁻¹)	PET (mm yr ⁻¹)	WTR YLD (mm yr ⁻¹)	NSE	PBIAS (%)
SPLAPS_SWS	334.1	271.6	238.3	0.72	-3.2
MPLAPS_SWS	343.5	282.5	248.8	0.69	-7.8
MPLAPS_KHZ	473.0	275.5	365.3	0.54	-56.6

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



HESSD

10, 807–853, 2013

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Table 5. Pan-Evaporation of three weather stations at different elevation in mid Tianshan Mountains.

Station	Pan-Evaporation (mm yr ⁻¹)	Elevation (m)
SWS	1600	444
KHS	1500	885
Daxigou	950	3550

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[I◀](#)[▶I](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Table 6. The annual average outputs of simulation by SWAT using the three scenarios.

Scenario	SNOW M (mm)	SNOW S (mm)	SURF Q (mm)	GRND Q (mm)	ET (mm)	PET (mm)	WTR YLD (mm)	NSE	PBIAS (%)
Scenario1	91.4	60.9	199.9	127.5	140.3	275.5	365.3	0.54	-56.6
Scenario2	133.7	47.3	192.4	128.4	128.3	261.5	354.1	0.57	-52.3
Scenario3	103.0	86.1	164.2	53.4	258.2	561.7	236.5	0.52	0.29

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Table 7. Parameters in calibration.

Parameter	Initial value	Calibrated value	Description
CN	83–100	68–91	SCS curve number
GW_DELAY	15	7	Delay time for groundwater recharge (days)
RCHG_DP	0.4	0.3	Fraction of root zone percolation that reaches the deep aquifer
ALPHA_BF	0.4	0.6	Baseflow recession constant of shallow aquifer (days)
ALPHA_BF_DP ^a	0.05	0.02	Baseflow recession constant of deep aquifer (days)
GWQMN	250	900	The threshold water levels in shallow aquifer for baseflow (mm)
GW_REVAP	0.055	0.02	Groundwater re-evaporation coefficient
SSBLFMX ^b	0.6	0.2	Maximum snow sublimation coefficient
SSBLFMN ^b	0.2	0.1	Minimum snow sublimation coefficient
TIMP	0.005	0.04	Snow pack temperature lag factor
SMFMN	4	1	Minimum snow melt factor (mm H ₂ O day ⁻¹ °C ⁻¹)
SMFMX	6.7	3.5	Maximum snow melt factor (mm H ₂ O day ⁻¹ °C ⁻¹)
GMFMX ^b	3	3.8	Maximum glacier melt factor (mm H ₂ O day ⁻¹ °C ⁻¹)

^a indicated the parameters added in two-reservoir approach; ^b indicated parameters added in the glacier module; initial value means that used in the previous study (Luo et al., 2012, 2013) and previous simulation in this study.

HESSD

10, 807–853, 2013

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Table 8. The NSE and PBIAS for the simulation by SWAT in MRB (the rating is based on rules given by Moriasi et al., 2007).

Stage	NSE	Rating	PBIAS	Rating
calibration (1966–1980)	0.72	Good	−4.97	Very good
validation (1981–1999)	0.66	Good	−1.26	Very good
Whole Peroid	0.68	Good	−2.83	Very good

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

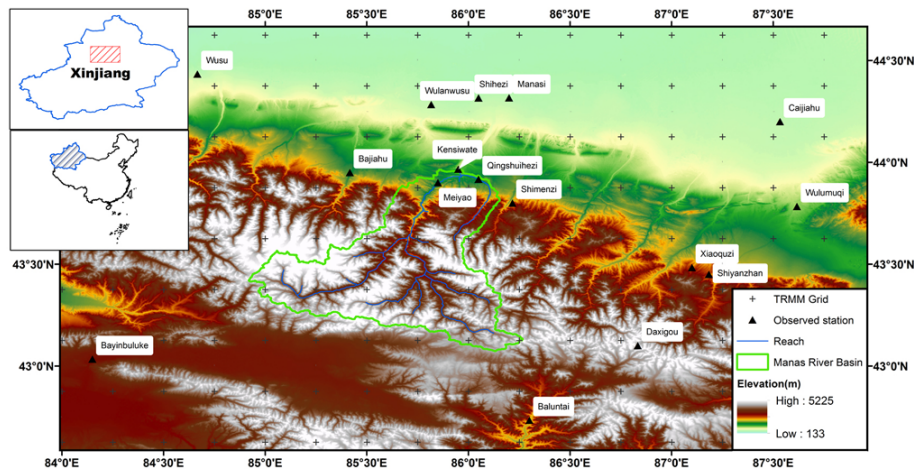


Fig. 1. The location of weather station in study area.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

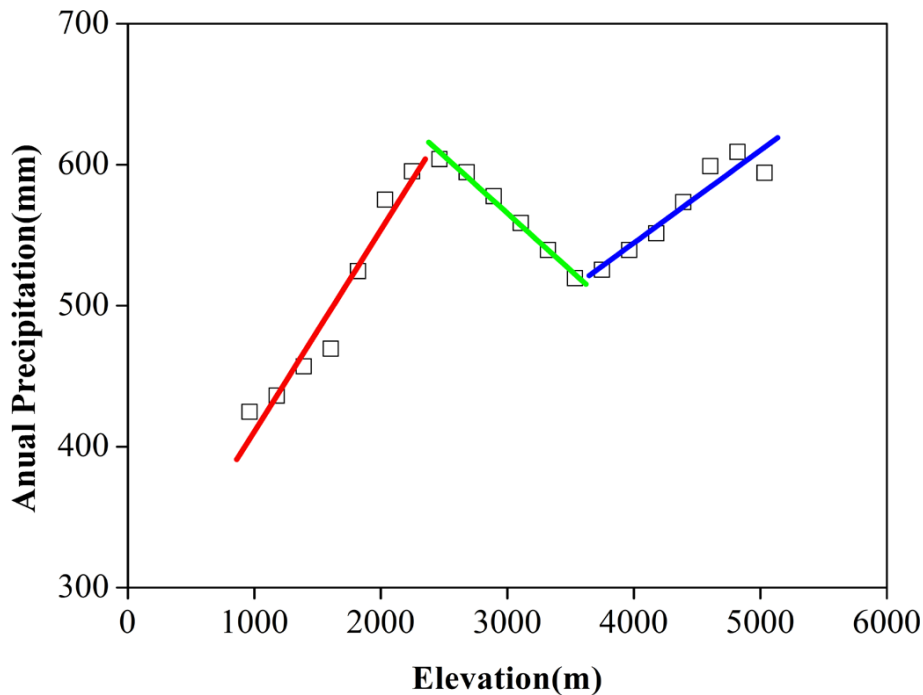


Fig. 2. Annual precipitation at different altitude by the corrected TRMM 3B43 data (1998–2009) in MRB.

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

Title Page

Abstract Introduction

Conclusions References

Tables Figures

⏪ ⏩

◀ ▶

Back Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

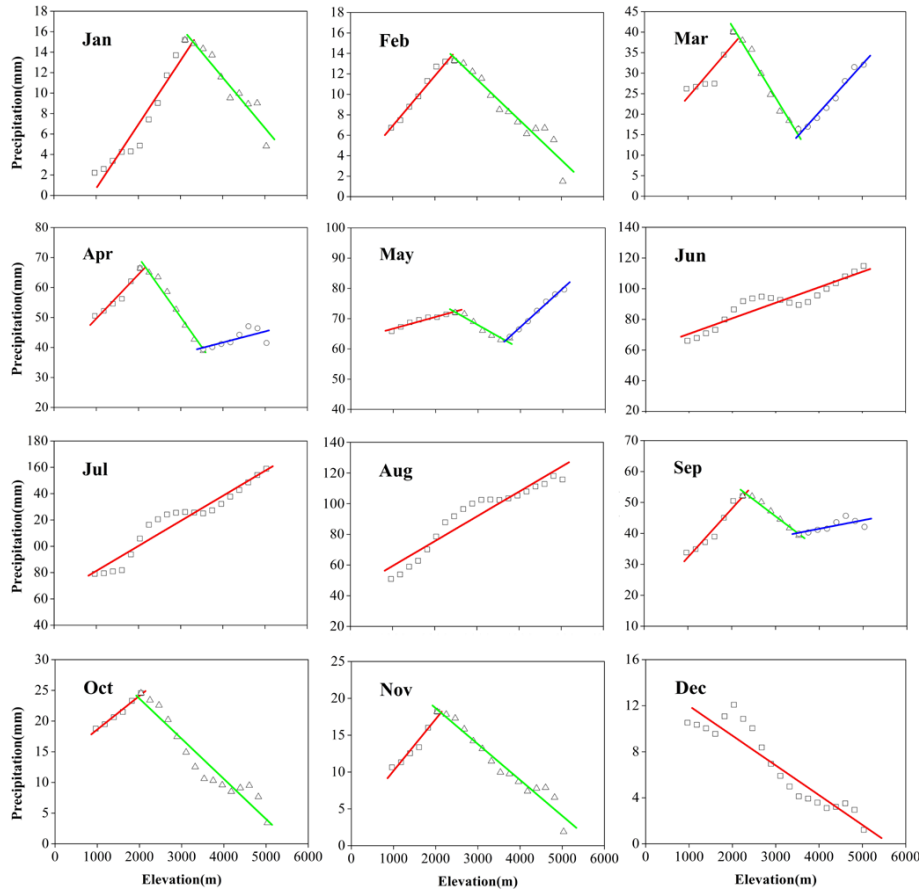


Fig. 3. Monthly average precipitation at different elevation in MRB, using the corrected TRMM 3B43 data (1998–2009), the slope of the fitting line is the precipitation lapse rate.

Title Page

Abstract Introduction

Conclusions References

Tables Figures

⏪ ⏩

◀ ▶

Back Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

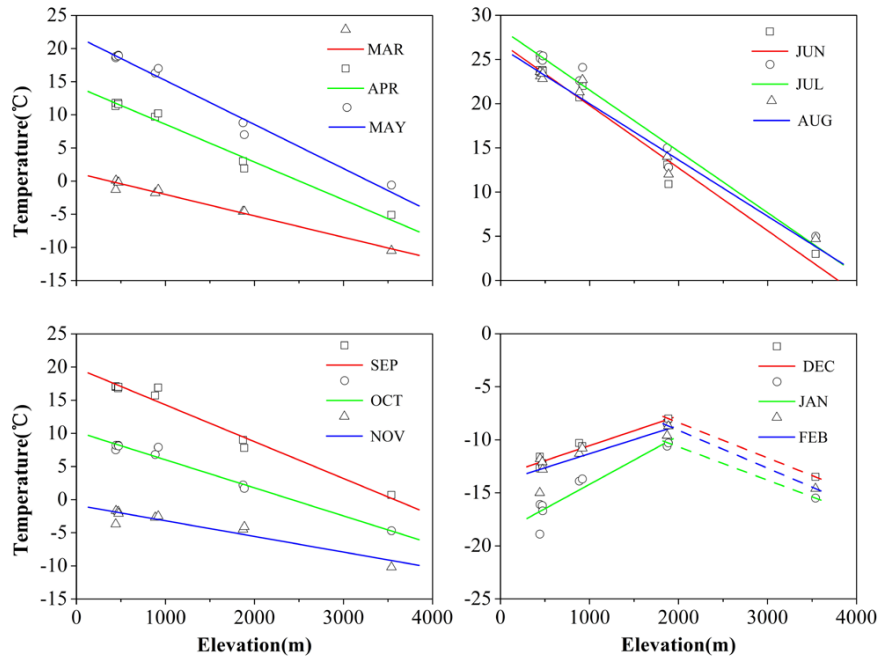


Fig. 4. The temperature-elevation relationship based on the measured data of weather stations in mid Tianshan Mountains.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

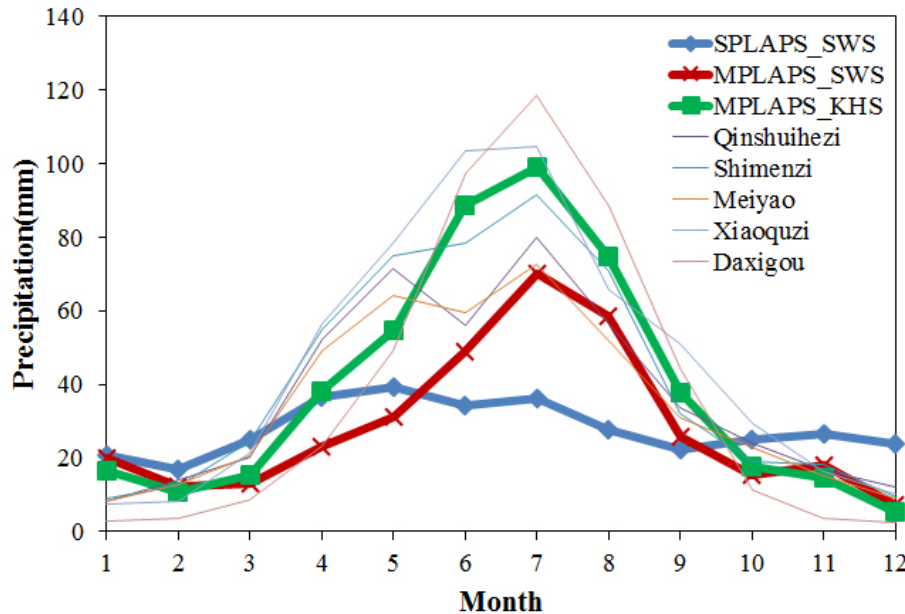


Fig. 5. Mean monthly precipitation in MRB (1961–1999, 39-yr averaged) calculated by the three schemes (SPLAPS_SWS, MPLAPS_SWS, MPLAPS_KHS) and some gauge data around MRB in mountain area (above 1100 m a.s.l.).

Title Page

Abstract Introduction

Conclusions References

Tables Figures

⏪ ⏩

◀ ▶

Back Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

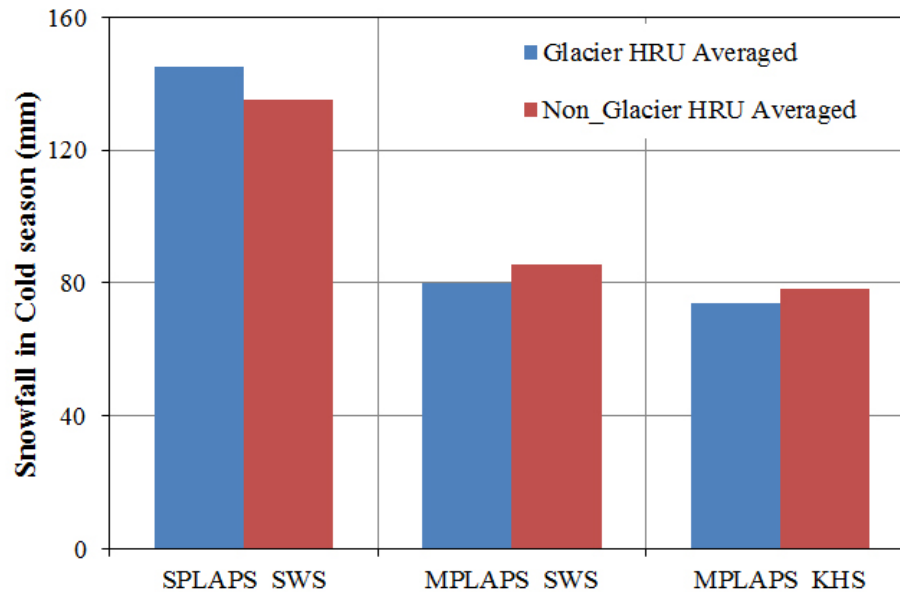


Fig. 6. Contrast of snowfall in cold season (October to March) between glacier-HRU and non-glacier-HRU.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[⏪](#)[⏩](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

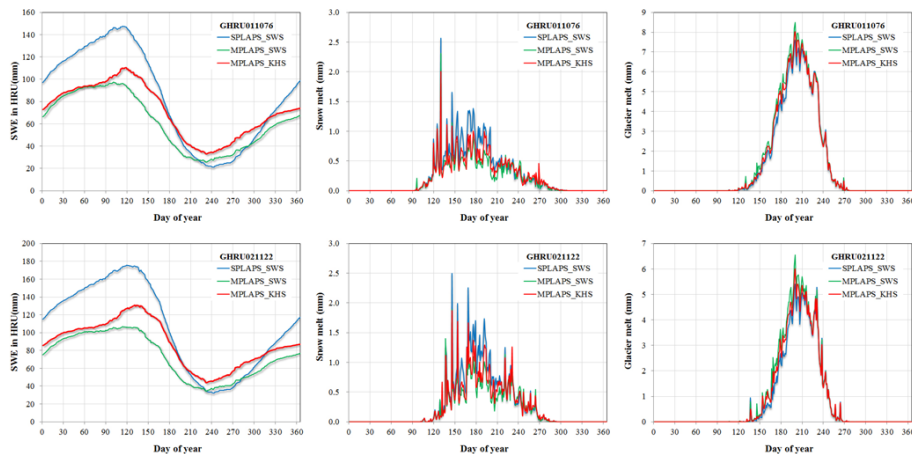


Fig. 7. The daily average water equivalent of snowpack, snowmelt and glacier melt on two typical glacier HRU (GHRU011076 = the glacier HRU is the 76th HRU and in 11th subbasin; GHRU021122 = the glacier HRU is the 122th HRU and in 21th subbasin).

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

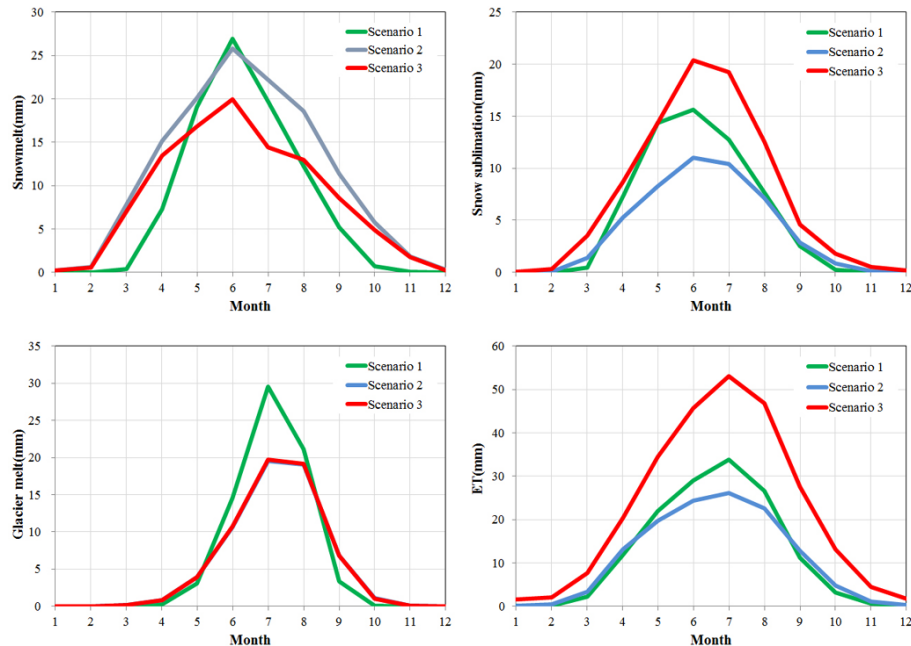


Fig. 8. The influence of temperature and PET methods on the simulation of key parts of hydrologic process (Scenario 1 represents the combination of MPLAPS, STLAPS and Penman-Monteith method; Scenario 2 changes the STLAPS to MTPLAPS; Scenario 3 further changes the calculation method of PET as Hargreaves).

[Title Page](#)
[Abstract](#)
[Introduction](#)
[Conclusions](#)
[References](#)
[Tables](#)
[Figures](#)
[⏪](#)
[⏩](#)
[◀](#)
[▶](#)
[Back](#)
[Close](#)
[Full Screen / Esc](#)
[Printer-friendly Version](#)
[Interactive Discussion](#)

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

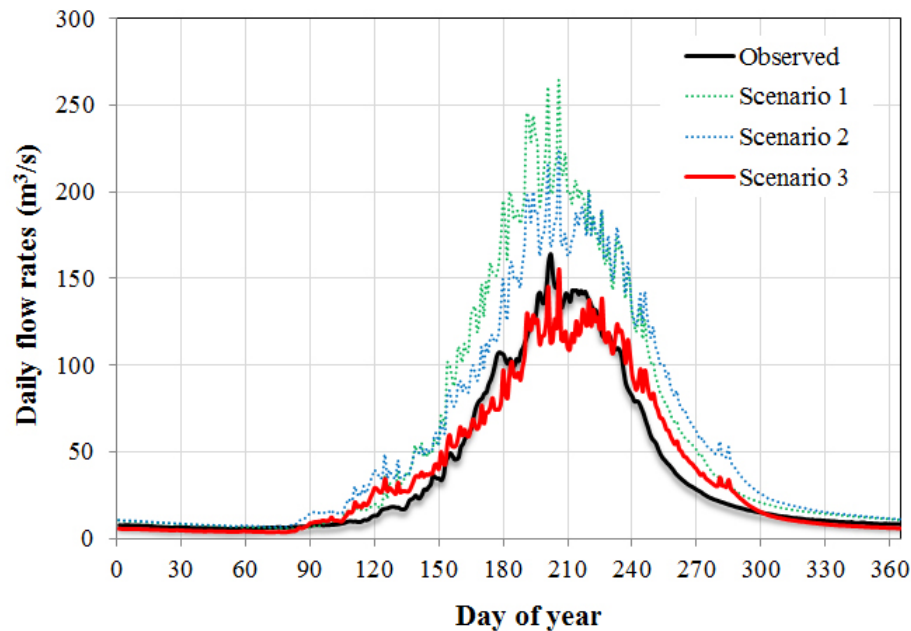


Fig. 9. Comparison of average daily streamflow simulated with different scenarios.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[⏪](#)[⏩](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

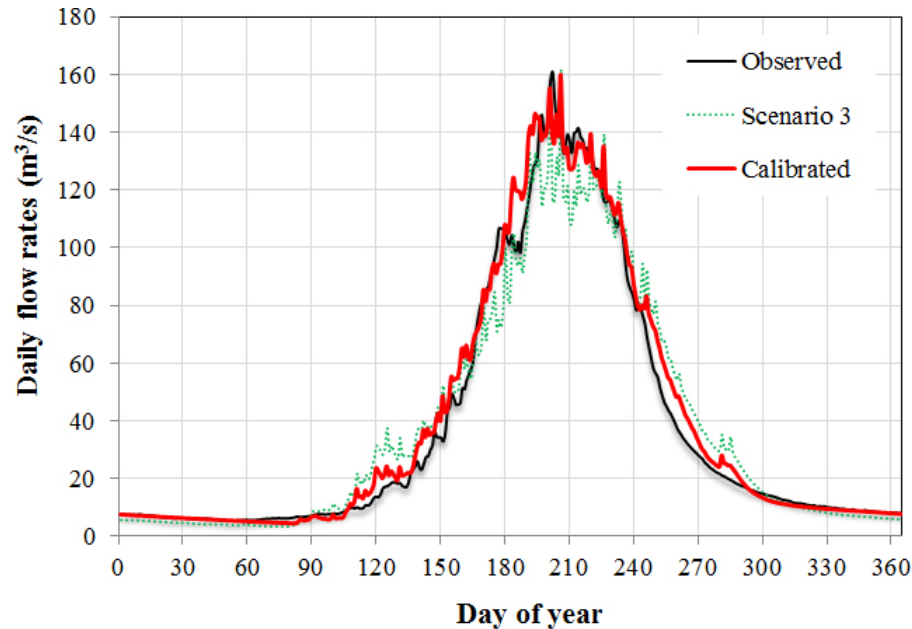


Fig. 10. Comparison of average daily streamflow of the calibrated, pre-calibrated and measured.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[⏪](#)[⏩](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

The influence of precipitation and temperature input schemes

X. Ji and Y. Luo

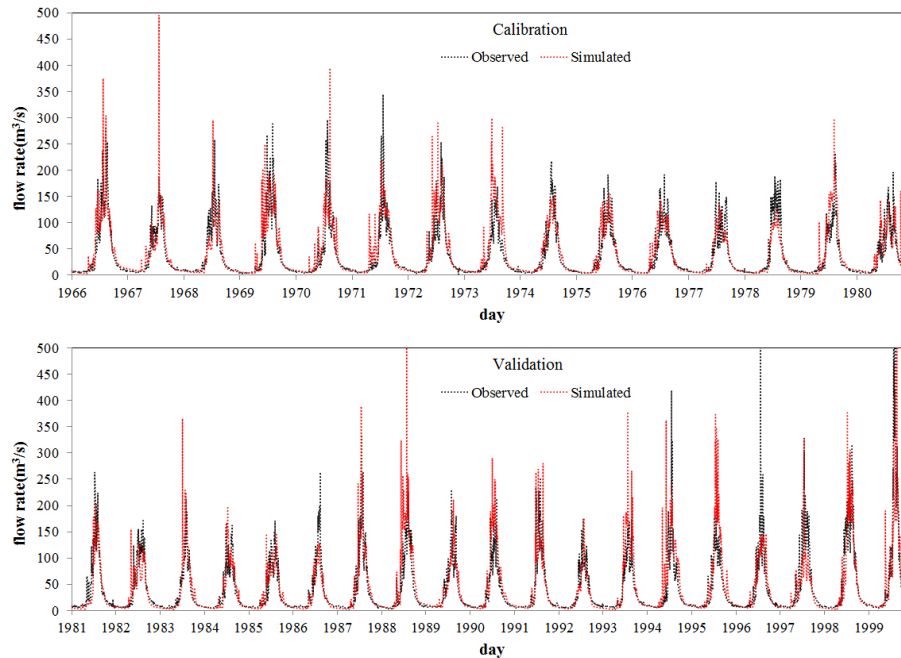


Fig. 11. Comparison of observed and simulated daily streamflow for calibration and validation periods.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[⏪](#)[⏩](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)