# Reply to Community Comments

1. How is the snowfall determined? Is the determination of snowfall for future scenarios guaranteed to be accurate?

Reply:

The WEB-DHM-sf model uses a single-temperature threshold method, in which the precipitation below the threshold is considered as snowfall (Shrestha et al., 2014). This method is widely used in hydrologic and land surface models due to its easy access to input data, such as VIC (Liang et al., 1996), SWAT (Arnold et al., 1998) and Mike SHE (Rsfsgaard et al., 1992). Meanwhile, Ding et al. (2014) (about precipitation type identification) illustrated that the single-temperature threshold method has a great applicability in areas where the relative humidity is lower than 78%, and furthermore has a very good performance in high-altitude areas, such as the Tibetan Plateau (TP). Therefore, the accuracy of air temperature and precipitation is a prerequisite for determination of snowfall.

We believe that the reliability of the projected snowfall can be improved by using reliable forcing data (precipitation and temperature), thereby reducing the uncertainty of projected results as much as possible. We need to evaluate and correct the input GCM forcing data to ensure its reliability in the historical period. On this basis, we further ensure the consistency of its future trend. Here, we used 4 bias-corrected ISIMIP 3b GCM (GFDL-ESM4, IPSL-CM6A-LR, MPI-ESM1-2-HR, MRI-ESM2-0) datasets, which have a consistent experimental protocol (historical, SSP126, and SSP585) and atmospheric climate variables (spatial and temporal resolutions of 1 day and 0.5°). To maintain the relative and absolute trends of these variables during the historical and future periods at the basin scale, we further corrected these variables on the monthly scale using the delta method. We then validate the performance of the projected forcing datasets in history periods by comparing the simulated discharges to observations (Fig. 7). With the above efforts, we reduce the uncertainty of the forcing datasets and make the trends of the future projections reasonable.

2. Have snowfall and SWE been verified? They are different from SCA.

Reply:

We didn't perform validations on snowfall and SWE due to a lack of *in-situ* observations at the USR basin. However, the spatial distribution of snow cover area and the snowmelt runoff at the basin outlet implicitly represent the integrated amount of snowfall. Satellite-derived global snow cover area (SCA) by MODIS, known as a reliable snow index for representing large-scale snow variability, is the most effective validation data in hydrologic modelling to quantify the spatial distribution of snow in poorly gauged mountainous river basin (Wang et al., 2009; Shretha et al., 2010, 2014; Zhou et al., 2021). Furthermore, the present snow module considers the attenuation of shortwave radiation penetrated in a three-layer snow pack and the snow-covered surface albedo scheme, and the enthalpy (*H*) is used as a prognostic variable instead of snow temperature in the energy balance equation, which includes the internal energy of liquid water or ice as well as the energy of the phase change. It is assumed that liquid water at its melting point has zero enthalpy so that the phase change processes can be dealt with easily. Therefore, the WEB-DHM-sf model can provide realistic simulation of complex snow physics and have the ability to integrate the measurable physical quantities (Shrestha et al., 2010, 2014; Wang et al., 2017).

3. What is the calculation of the contribution of snow to the runoff?

Reply:

The WEB-DHM-sf model adopts a three-layer energy balance snow scheme of the Simplified Simple Biosphere 3 model (SSiB3, Xue et al., 2003) and the prognostic albedo scheme of the Biosphere Atmosphere Transfer Scheme (Yang et al., 1997).

Within a given subbasin, a number of flow intervals are specified to present time lag and accumulating processes in the river network according to the distance to the outlet of the subbasin, each flow interval includes several model grids. For each model grid with one combination of land use type and soil type, the SSIB3 is used to calculate snow processes, of which the snowmelt can be calculated by the energy balance equations. The amount of snowmelt *Mg/Ms* (m w.e.) of each model grid produced over a period of time can then be expressed as,

$$M_{g/s} = \frac{Q_m}{\rho_w \times h_v} \tag{1}$$

Where $\rho_w$ is the density of liquid water, and the *hv* is the latent heat of fusion; $Q_m$ is the energy consumed by melt of snow. The energy balance for a ground snowpack or canopy snowpack can be written as:

Ground
$$Q_{Mg} = R_n + H + \lambda E + G_{pr} + G_g - \xi \tag{2}$$

Canopy
$$Q_{Mc} = R_n + H + \lambda E + G_{pr} - \xi \tag{3}$$

Where the subscripts ‘g’ and ‘c’ refers to the ground and canopy respectively, Rn (W m$^{-2}$) = $Rn_{sw}$+$Rn_{lw}$ , net radiation which is the sum of net shortwave ($Rn_{sw}$) and longwave radiation ($Rn_{lw}$), H (Wm$^{-2}$) the sensible heat flux exchanged between snow and atmosphere, $\lambda E$ (Wm$^{-2}$) the latent heat flux exchanged between snow and atmosphere, $G_{pr}$ (Wm-2) the sensible heat flux supplied by rainfall, $G_g$ (Wm$^{-2}$) the conductive heat flux exchanged between snow and soil, $\xi$ (J m$^{-2}$) is internal energy of the snowpack, and $Q_{mg}/Q_{mc}$ is the energy consumed by melt of snow. Fluxes towards the surface are considered positive and vice versa. These energy interactions are followed by the change in internal energy or the cold content of the snowpack which results change in its temperature and its phase. Melt occurs when the snowpack reaches 0°C and $Q_{mg}/Q_{mc}$ is positive. More detailed theories and formulas can be found in Shrestha et al. (2010, 2014) and Wang et al. (2017).

Here, we assume that the longest time of snowmelt flow routing in the basin is less than one month, that is, the snowmelt of all grids reaches the basin outlet within one month. Therefore, the total snowmelt is the accumulation of snowmelt from all grids in the basin (Wang et al., 2009a, b, 2017).

## Reference

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