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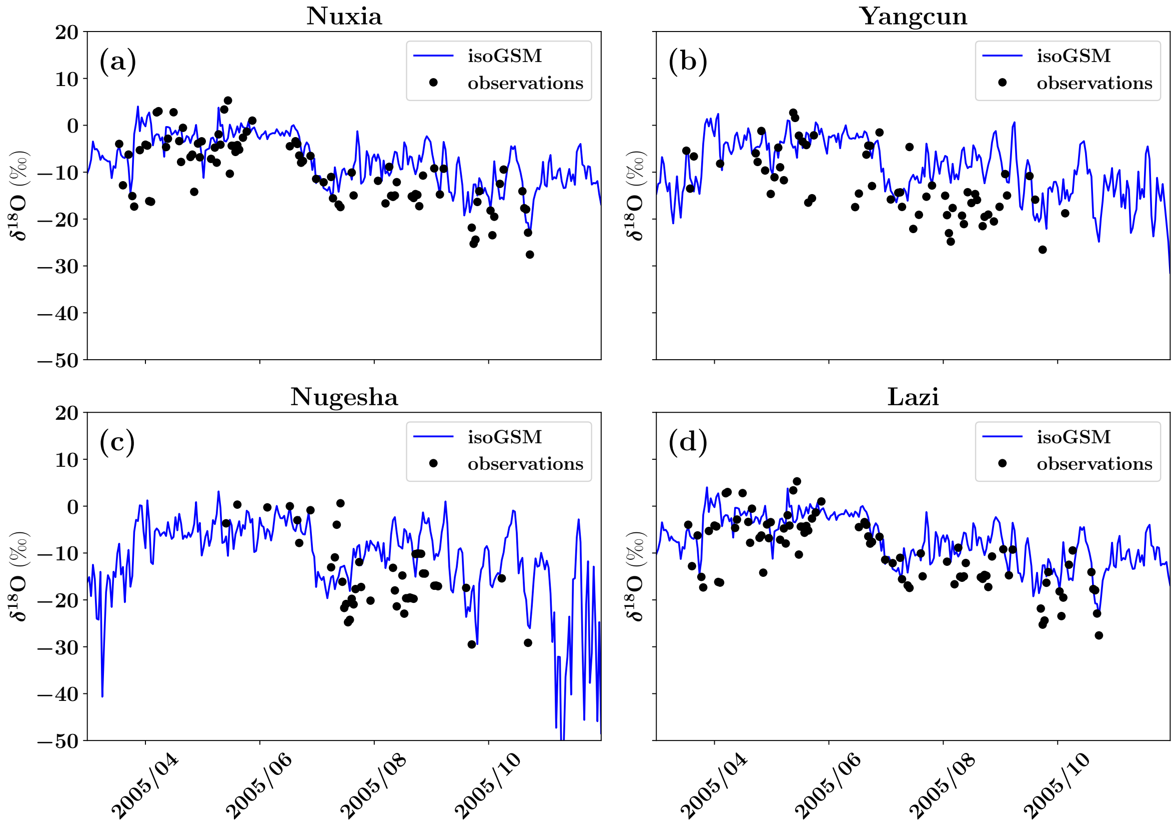
# Reducing hydrological uncertainty in large mountainous basins: the role of isotope, snow cover, and glacier dynamics in capturing streamflow seasonality

**Diego Avesani et al.**

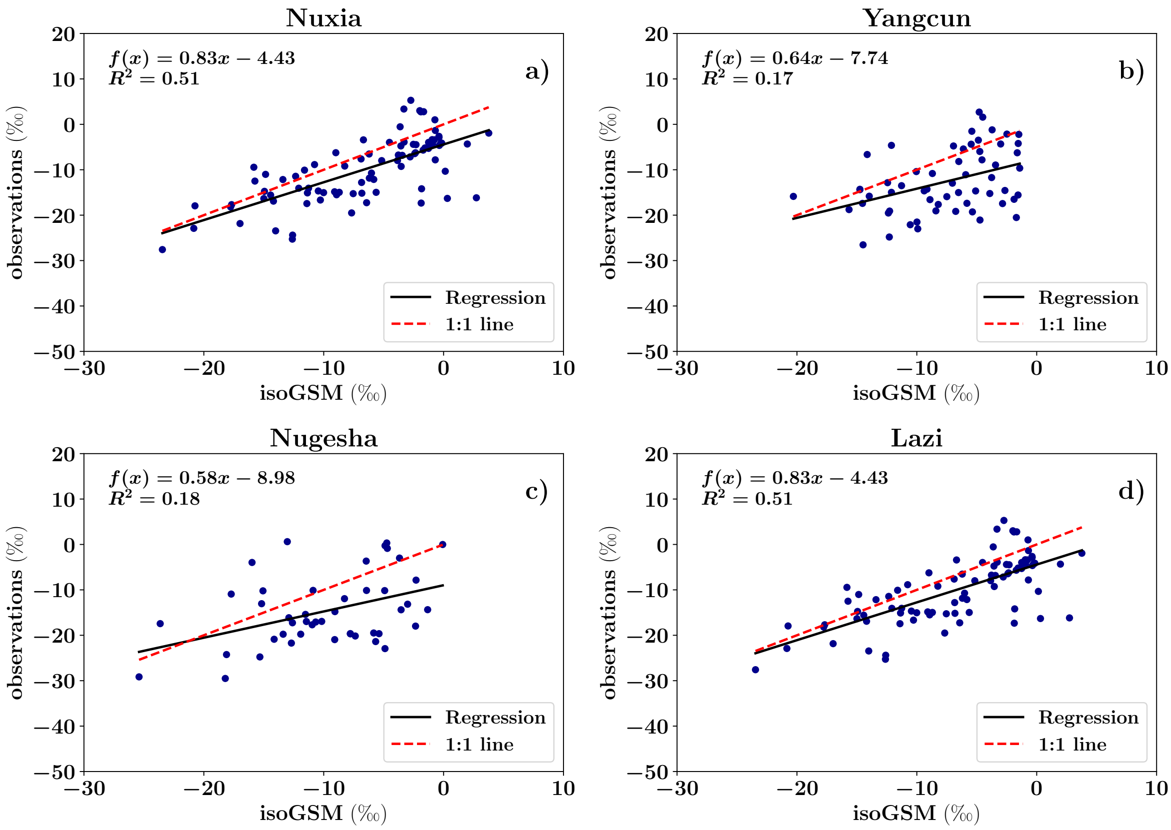
*Correspondence to:* Yi Nan (ny1209@qq.com)

**Figure S1: Precipitation $\delta^{18}O$ at four stations**



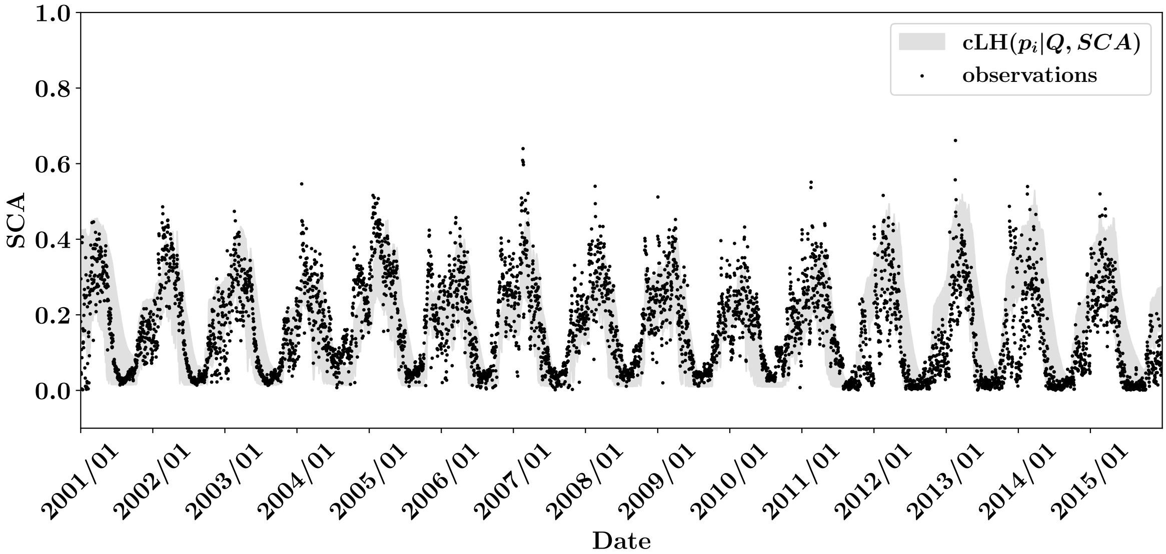

Temporal variations in the precipitation $\delta^{18}O$ (‰) derived from observation and isoGSM data at four stations.

## Figure S2: isoGSM and measured isotope data at four stations



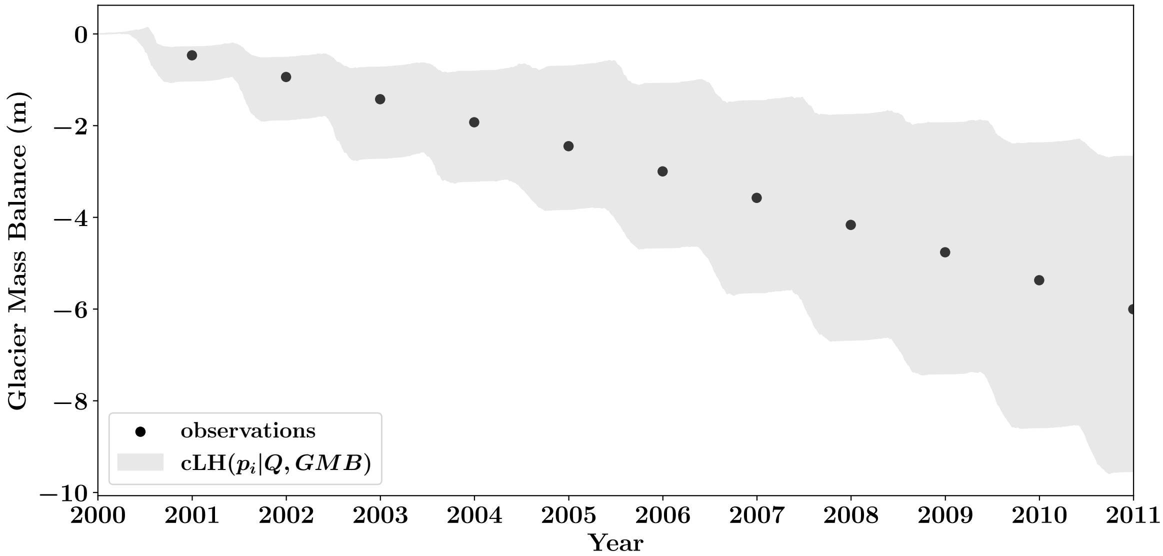

The scatter diagrams between the isoGSM and measured isotope data at four stations.

**Figure S3: Observed Snow Cover Area and posterior model ensemble**



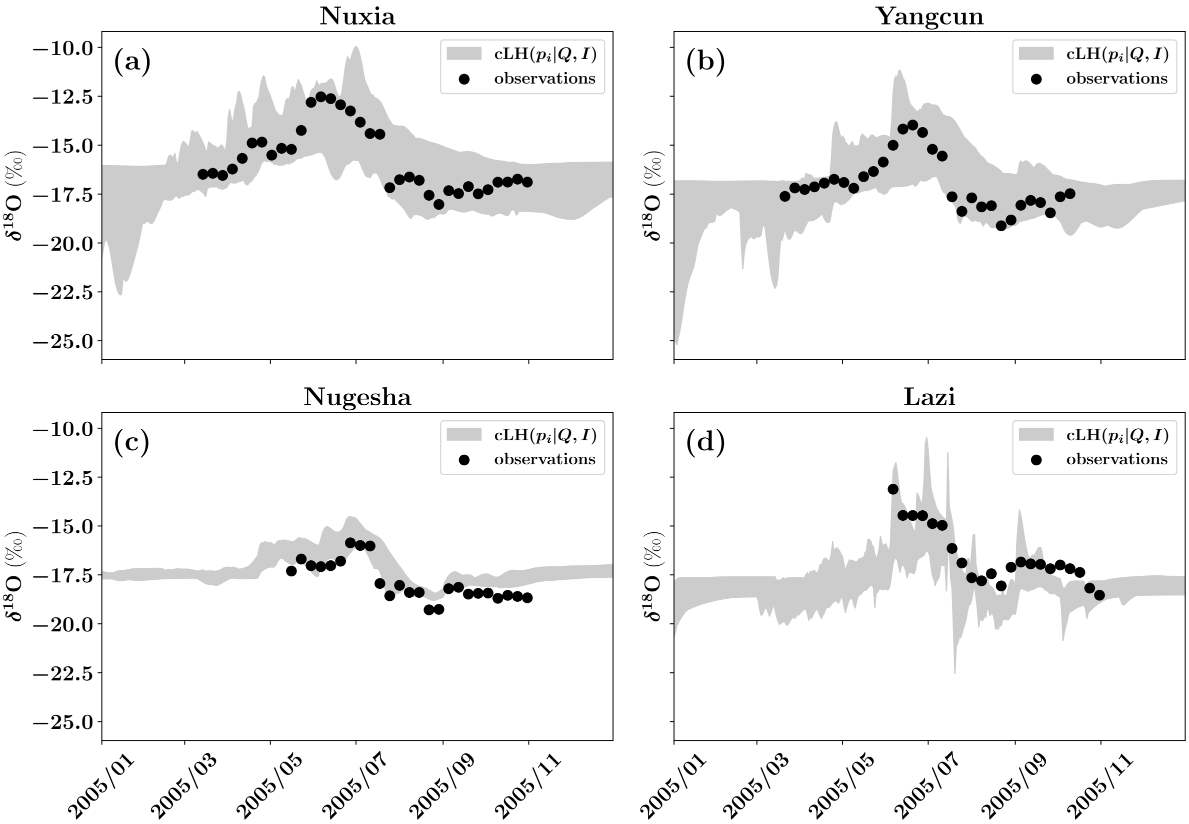

Observed snow cover area and posterior model ensemble cLH($p_i|Q, SCA$), based on joint conditioning with streamflow and snow cover area information.

**Figure S4: Observed glacier mass balance and posterior model ensemble**



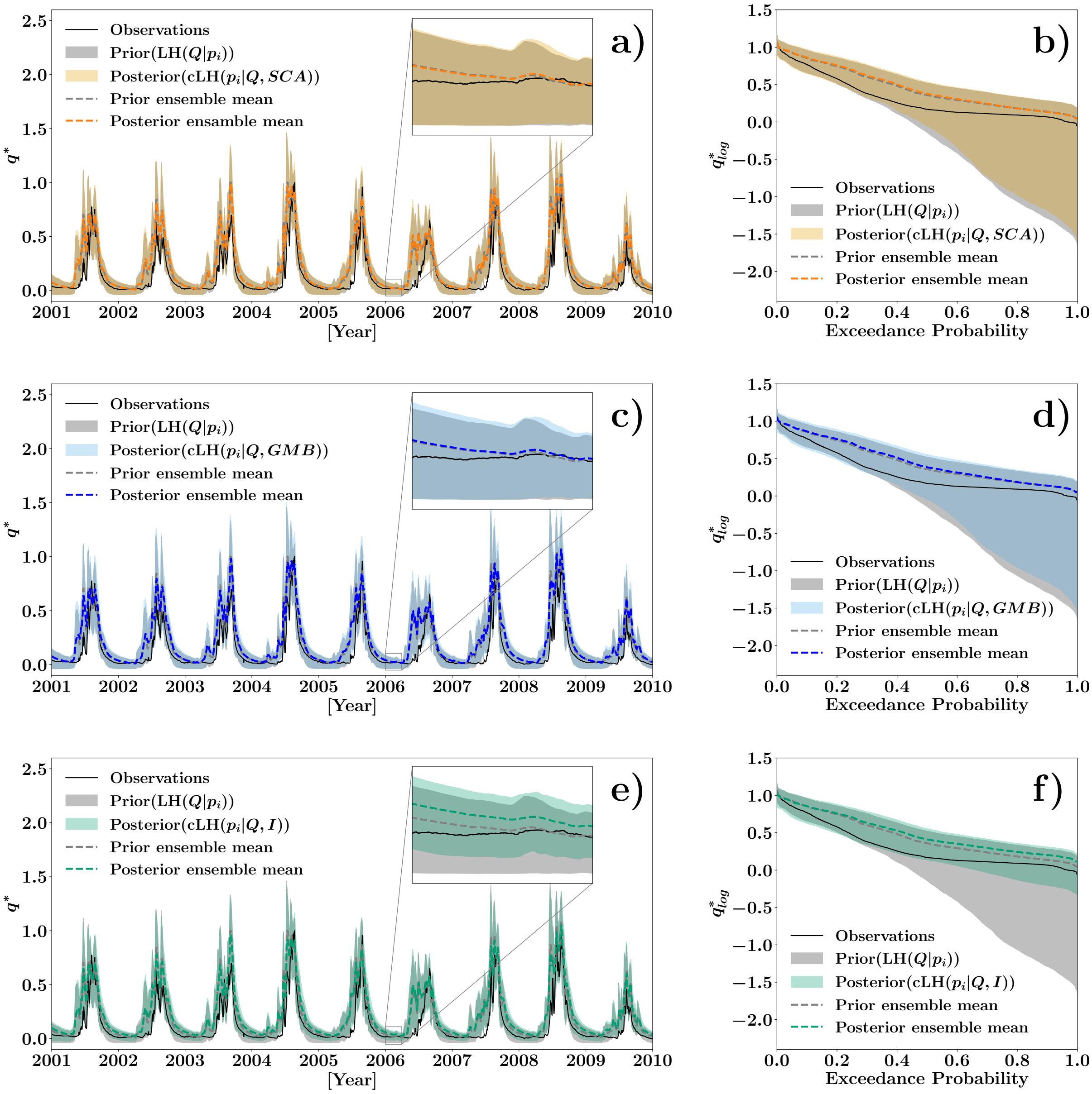

Observed glacier mass balance and posterior model ensemble cLH($p_i|Q, GMB$), based on joint conditioning with streamflow and mass balance information.

## Figure S5: Observed $\delta^{18}O$ and the model posterior ensemble



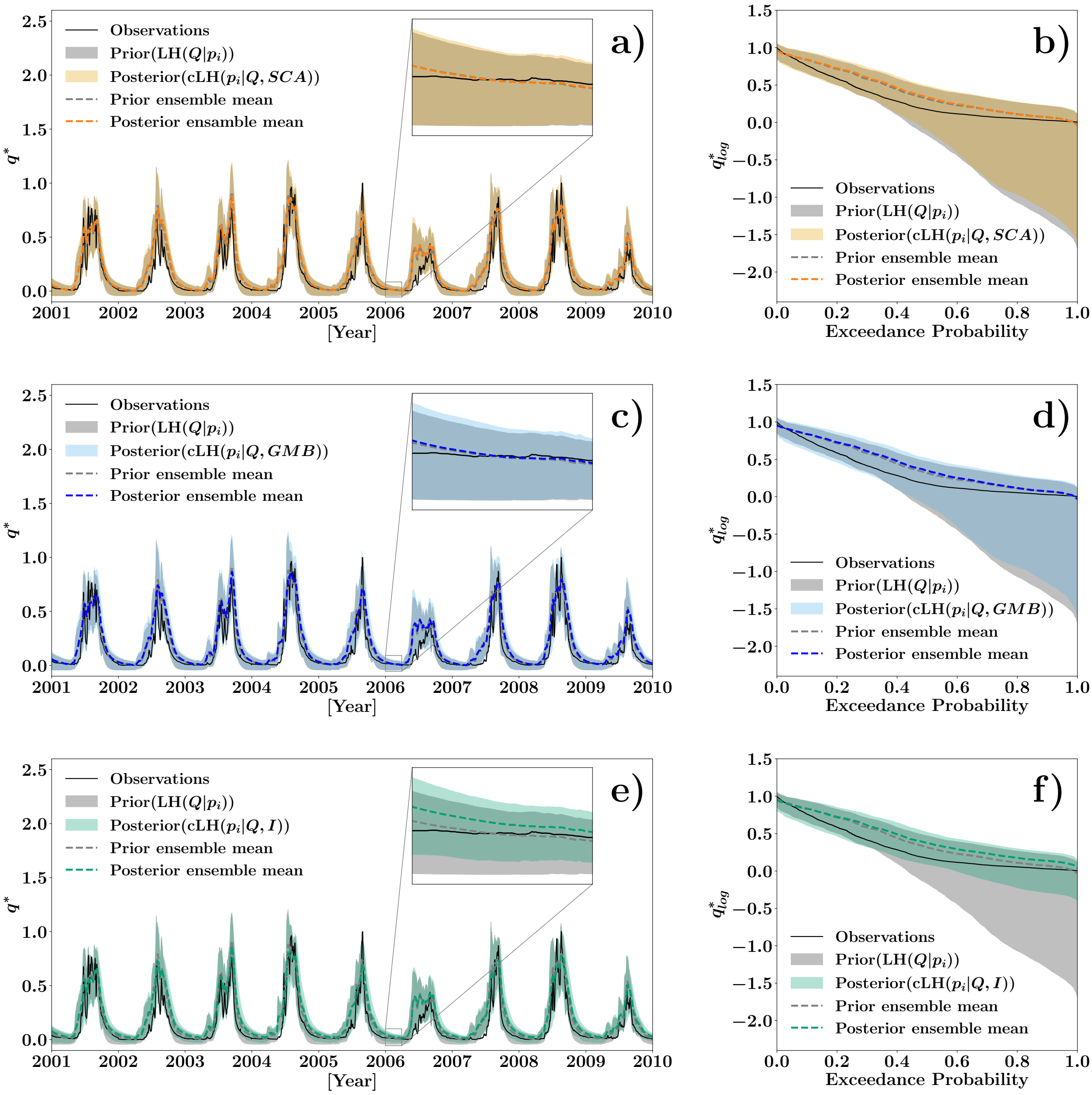

Comparison between observed $\delta^{18}O$ and the model posterior ensemble cLH$(p_i|Q,I)$, conditioned on streamflow and isotope information.

**Figure S6: Streamflow simulation uncertainty range at Nugesha station**



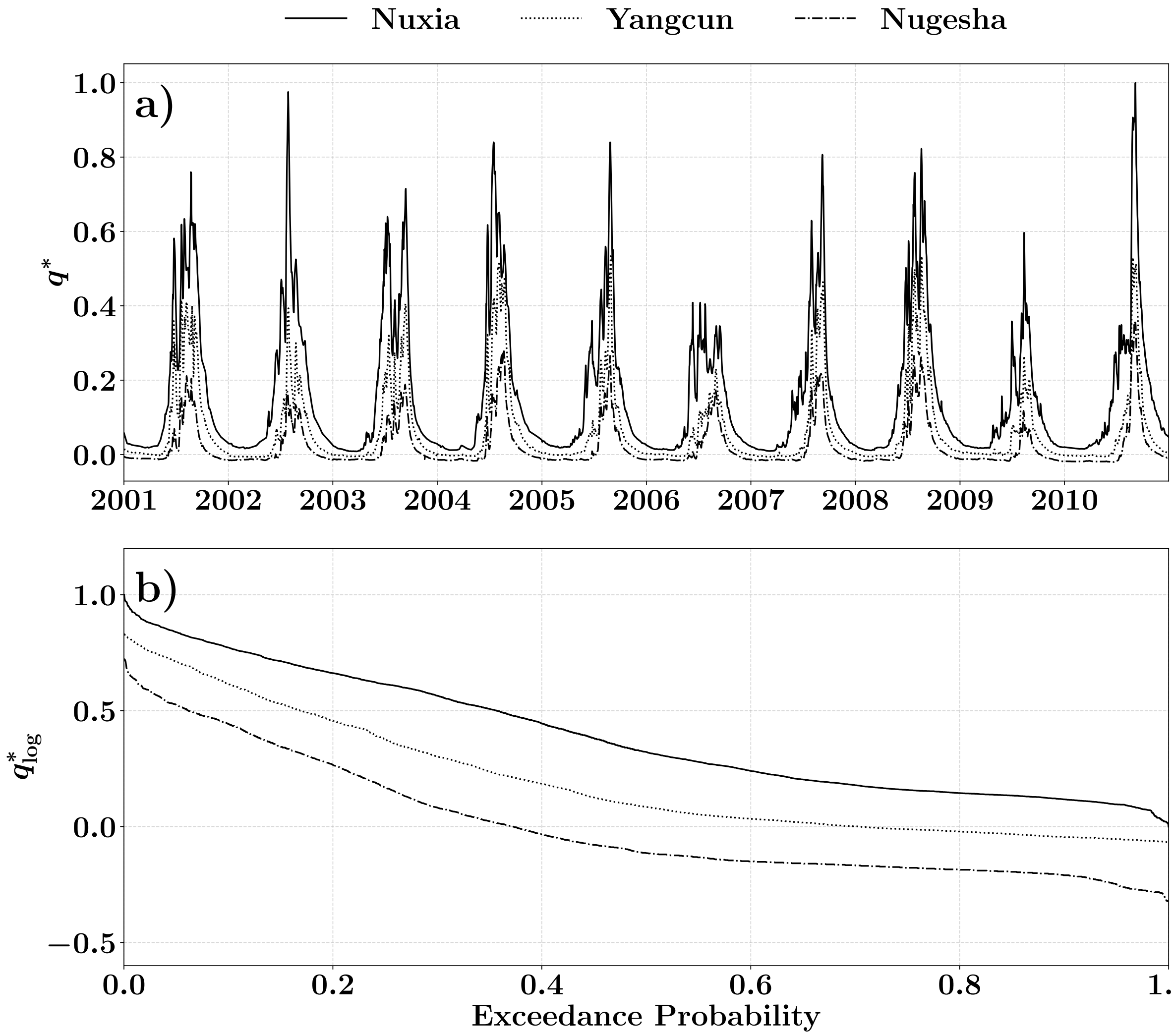

The 5–95% percentile prior, conditioned solely on streamflow, and the posterior predictive uncertainty ranges for streamflow are calculated under different conditions: snow cover area (SCA), glacier mass balance (GMB), and isotopes (I). Panels (a), (c), and (e) show daily streamflow time series for the period 2010–2015, with insets highlighting low-flow dynamics; panels (b), (d), and (f) show flow duration curves for the full period 2001–2015. Streamflow data are presented in dimensionless form due to dissemination restrictions imposed by the data provider. A linear normalization, $q^* = (Q - Q_{\min})/(Q_{\max} - Q_{\min})$, is applied to the time series (panels a, c, e) to enable relative comparison of streamflow magnitude over time. In contrast, a logarithmic normalization, $q^*_{\log} = (\log Q - \log Q_{\min})/(\log Q_{\max} - \log Q_{\min})$, is used for the flow duration curves (panels b, d, f), as is standard in FDC representation, to facilitate comparison across the full spectrum of discharges, including low-flow conditions. In both cases, $Q_{\min}$ and $Q_{\max}$ refer to the minimum and maximum observed discharges at the Nugesha station.

**Figure S7: Streamflow simulation uncertainty range at Yangcun station**




The 5–95% percentile prior, conditioned solely on streamflow, and the posterior predictive uncertainty ranges for streamflow are calculated under different conditions: snow cover area (SCA), glacier mass balance (GMB), and isotopes (I). Panels (a), (c), and (e) show daily streamflow time series for the period 2010–2015, with insets highlighting low-flow dynamics; panels (b), (d), and (f) show flow duration curves for the full period 2001–2015. Streamflow data are presented in dimensionless form due to dissemination restrictions imposed by the data provider. A linear normalization, $q^* = (Q - Q_{\min})/(Q_{\max} - Q_{\min})$, is applied to the time series (panels a, c, e) to enable relative comparison of streamflow magnitude over time. In contrast, a logarithmic normalization, $q^*_{\log} = (\log Q - \log Q_{\min})/(\log Q_{\max} - \log Q_{\min})$, is used for the flow duration curves (panels b, d, f), as is standard in FDC representation, to facilitate comparison across the full spectrum of discharges, including low-flow conditions. In both cases, $Q_{\min}$ and $Q_{\max}$ refer to the minimum and maximum observed discharges at the Yangcun station.

**Figure S8: Normalized streamflow at the Nuxia, Yangcun, and Nugesha stations**




(a) Time series of normalized streamflow between 2001 and 2010 at the Nuxia, Yangcun, and Nugesha stations. Discharge values are represented as

$$q^* = \frac{Q - Q_{\min}}{Q_{\max} - Q_{\min}}$$

where $Q_{\min}$ and $Q_{\max}$ refer to the minimum and maximum observed discharges at the calibration station (Nuxia). This normalization enables a relative comparison of streamflow magnitude across the three sites on a common scale.

(b) Flow duration curves (FDCs) for the same stations. Discharge values are shown as normalized logarithmic flow, calculated as

$$q^*_{\log} = \frac{\log(Q) - \log(Q_{\min})}{\log(Q_{\max}) - \log(Q_{\min})}$$

As is standard in FDC representation, the logarithmic scale allows for a more effective comparison across the full range of discharges, particularly improving the readability of low-flow variability.