

Dynamic Snowmelt Process in a Small Watershed of the Western Tianshan Mountains and Its Relationship with Air Temperature: Postprint

Authors: Gulmira Hanat, Heymitan Helili, Liu Qianqian, Sulitan

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Abstract

Using synchronous observations of snowfall, snowmelt, and air temperature at 30-min intervals from the snow, snowmelt, and meteorological observation stations in the Aredubai small watershed of the Western Tianshan Mountains during 2017–2018, a comparative analysis was conducted on the dynamic processes of snowmelt and its relationship with air temperature at relatively short time scales throughout the snow-covered period. The results indicate that snowfall in mountainous areas exhibits an overall characteristic of “first increasing then decreasing”. The stable snow cover period was concentrated from December 27, 2017 to March 8, 2018, with a maximum snowfall rate reaching up to $9.6 \text{ mm} \cdot \text{h}^{-1}$ (snow water equivalent value, converted to a fresh snow depth value of $96.5 \text{ mm} \cdot \text{h}^{-1}$). The variation pattern of the snowmelt process in mountainous areas was opposite to that of snowfall, showing a “first decreasing then increasing” characteristic. Snowmelt variation was divided into three stages: Stage 1: as air temperature decreased, the snowmelt rate declined, gradually decreasing from $3.24 \text{ mm} \cdot \text{h}^{-1}$ to $0 \text{ mm} \cdot \text{h}^{-1}$; Stage 2: when air temperature fell below the critical temperature for snowmelt ($-13.5 \sim -12.0 \text{ }^\circ\text{C}$), no snowmelt occurred; Stage 3: as air temperature rose, the snowmelt rate gradually increased from $0 \text{ mm} \cdot \text{h}^{-1}$ to $3.87 \text{ mm} \cdot \text{h}^{-1}$. In the big data relationship between annual snowmelt and air temperature, the correlation coefficient between snowmelt amount and air temperature was not very significant, with a correlation coefficient of 0.708; under conditions without precipitation interference, the correlation coefficient between 7-day averaged synchronous snowmelt amount and air temperature reached a significant level, with a Pearson correlation coefficient of 0.907 and $R^2=0.823$; when further considering the lag effect, the correlation coefficient between snowmelt amount and air temperature improved to an extremely significant linear relationship, with a correlation coefficient as high as 0.943 and $R^2=0.889$, both of which passed the two-tailed test at the 0.01 significance level.

In the Aredubai small watershed of the Western Tianshan Mountains, the variation process of snowmelt amount was closely correlated with the variation process of air temperature. This response relationship of snowmelt amount to air temperature changes and its analytical method have certain reference value for improving the capacity to respond to future climate change and for flood prevention and water resources management.

Full Text

Dynamic Snowmelt Process and Its Relationship with Air Temperature in a Small Watershed in the West Tianshan Mountains

Gulimire Hanati¹, Haimidan Helili², LIU Qian-qian^{3,4}, SULitan³

¹Xinjiang Institute of Water Resources and Hydropower Research, Urumqi 830049, Xinjiang, China

²Party School of Xinjiang Uyghur Autonomous Region Committee of the Communist Party of China, Urumqi 830000, Xinjiang, China

³State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, Xinjiang, China

⁴College of Resources and Environment, University of Chinese Academy of Sciences, Beijing 100049, China

Abstract

Snowfall, snowmelt, and air temperature in a small watershed named Aredubai in the West Tianshan Mountains were synchronously observed every 30 minutes from 2017 to 2018, and the relationship between snowmelt and air temperature was analyzed. The results showed that snowfall in the mountainous area first increased and then decreased. The duration of snow cover accumulation was from December 27, 2017, to March 8, 2018, and the maximum snowfall intensity was as high as $9.6 \text{ mm} \cdot \text{h}^{-1}$ (when the snow water value was converted into fresh snow depth, it was $96.5 \text{ mm} \cdot \text{h}^{-1}$). The snowmelt pattern in the mountainous area was opposite to that of snowfall; that is, snowmelt decreased first and then increased. The snowmelt process was divided into three stages. At the first stage, the snowmelt rate gradually decreased from $3.24 \text{ mm} \cdot \text{h}^{-1}$ to $0 \text{ mm} \cdot \text{h}^{-1}$ with the decrease of air temperature. At the second stage, snowmelt did not occur when the air temperature was lower than the critical temperature for snowmelt (-13.5 to -12.0°C). At the third stage, the snowmelt rate gradually increased from $0 \text{ mm} \cdot \text{h}^{-1}$ to $3.87 \text{ mm} \cdot \text{h}^{-1}$ with the increase of air temperature. In the overall relationship between snowmelt and air temperature, the correlation coefficient was not particularly significant at 0.708. Under conditions without precipitation, the correlation coefficient between the 7-day average snowmelt and air temperature was significant, with a Pearson correlation coefficient of 0.907 and $R^2 = 0.823$. When hysteresis was further considered,

the correlation coefficient between snowmelt and air temperature increased significantly to 0.943, with $R^2 = 0.889$, both passing the two-tailed test at the 0.01 significance level. There was a close correlation between the dynamic change of snowmelt and air temperature in the Aredubai watershed of the West Tianshan Mountains. The response relationship and analysis method of snowmelt to temperature change have certain reference value for improving the ability to cope with future climate change and for flood and water resources management.

Keywords: small watershed; air temperature; snow cover depth; snowfall; snowmelt rate; West Tianshan Mountains

1. Introduction

Snowmelt is a critical component of the hydrological cycle in mountainous regions, particularly in arid and semi-arid areas where it serves as a vital water resource. Understanding the dynamic relationship between snowmelt processes and air temperature is essential for accurate water resource management and flood forecasting under changing climate conditions. Previous studies have established fundamental relationships between snowmelt and climatic factors, but high-frequency synchronous observations remain limited in small mountainous watersheds.

2. Data and Methods

Observations were conducted in the Aredubai watershed, a small catchment in the West Tianshan Mountains. Snow depth, snow water equivalent, and air temperature were measured synchronously at 30-minute intervals throughout the 2017–2018 snow season. The instrumentation included an SR50A ultrasonic snow depth sensor, a T-200B precipitation gauge, and an SSG surface energy balance system. Data quality control involved removing periods of active precipitation to isolate snowmelt signals from snowfall events.

The snowmelt process was analyzed in three distinct stages based on temperature regimes and melt rates. Statistical analyses included Pearson correlation coefficients and hysteresis modeling to quantify the relationship between air temperature and snowmelt rates. Seven-day moving averages were applied to reduce short-term noise and examine sustained melt patterns.

3. Results

The snow cover accumulation period extended from December 27, 2017, to March 8, 2018. Snowfall exhibited a pattern of initial increase followed by decrease, with maximum intensity reaching $9.6 \text{ mm} \cdot \text{h}^{-1}$ (equivalent to $96.5 \text{ mm} \cdot \text{h}^{-1}$ fresh snow depth). In contrast, snowmelt displayed the opposite pattern, decreasing initially then increasing as temperatures rose.

The three-stage snowmelt process showed distinct characteristics. During the first stage, melt rates declined progressively from $3.24 \text{ mm} \cdot \text{h}^{-1}$ to $0 \text{ mm} \cdot \text{h}^{-1}$

as air temperatures decreased. The second stage represented a dormant period where no melt occurred because temperatures remained below the critical melt threshold of -13.5 to -12.0°C . In the third stage, melt rates increased from $0 \text{ mm} \cdot \text{h}^{-1}$ to $3.87 \text{ mm} \cdot \text{h}^{-1}$ with rising temperatures.

Correlation analysis revealed that the instantaneous relationship between snowmelt and air temperature was moderate ($r = 0.708$). However, when examining 7-day average values under precipitation-free conditions, the correlation strengthened significantly ($r = 0.907$, $R^2 = 0.823$). Incorporating hysteresis effects further improved the relationship ($r = 0.943$, $R^2 = 0.889$), with all correlations significant at the 0.01 level.

4. Discussion and Conclusion

The close correlation between snowmelt dynamics and air temperature in this West Tianshan watershed demonstrates the predictable nature of melt processes when appropriate temporal averaging and physical considerations are applied. The identification of a critical temperature threshold for melt initiation provides valuable information for modeling applications. The hysteresis effect, reflecting the time lag between temperature changes and melt response, proves essential for accurate predictive modeling.

These findings offer important insights for improving hydrological forecasting capabilities and water resource management strategies in snow-dominated mountainous regions, particularly under scenarios of future climate change. The methodology and relationships established here can serve as a reference for similar watersheds in arid zone mountain environments.

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