[Energy Balance Characteristics of Three Snow Cover Events in Maqu, Yellow River Source Region] Postprint

Authors: Li Danhua, Wen Lijuan, Long Xiao, Chen Shiqiang, Liu Weiping, Lu Guoyang, Chen Shiqiang

Date: 2018-11-08T00:00:00+00:00

Abstract

Using observational data from December 2011 to March 2012 at the Climate and Environment Comprehensive Observation and Research Station of the Yellow River Source Region, Chinese Academy of Sciences, the characteristics of surface radiation and energy balance during three snow cover processes in Maqu of the Yellow River source region were comparatively analyzed. The results show that: Due to the influence of the high albedo of the snow surface, net radiation decreased significantly after snowfall. The net radiation values before and after the three snowfall events were 154, 200, 210 W · m-2 and 93, 129, 130 W · m-2, respectively. After the three snowfall events and snowmelt, land-atmosphere energy exchange was significantly influenced by weather conditions and soil freeze-thaw status: After the first snowfall, the lower air temperature and surface temperature did not affect the inherently weak evaporation capacity of the frozen soil, and the latent heat flux values were small and showed little difference before snowfall, after snowfall, and after snowmelt; On February 18 after the second snowfall, higher wind speeds ($ $4 m · s-1) and stronger solar radiation accelerated snow sublimation, resulting in large latent heat flux values with a daily mean as high as 118 W · m-2. Wind speed and latent heat flux varied synchronously, with their peaks occurring simultaneously (15m · s-1 and 300 W · m-2, respectively). Snow sublimation consumed energy, causing surface temperature to decrease and fall below air temperature, leading to negative sensible heat flux with a daily mean of -8 W · m-2 and a peak of -40 W · m-2. After snowmelt, sensible and latent heat fluxes quickly returned to pre-snowfall levels; From February 29 to March 3 after the third snowfall, shallow soil temperature gradually increased from -1°C and remained at approximately -0.18°C, the melting temperature of frozen soil. Frozen soil melting absorbed heat, and latent heat flux showed no significant increase compared with pre-snowfall values. March 4 was the final day of snowmelt, and evaporation from

the wetter soil and meltwater released latent heat, causing latent heat flux to increase significantly compared with March 3; After snowmelt, latent heat flux increased significantly compared with pre-snowfall values due to the enhanced evaporation capacity of the shallow soil.

Full Text

Energy Balance During Three Snow Cover Processes at Maqu in the Headwaters of the Yellow River

ChinaXiv Cooperative Journal of Arid Zone Research
DOI: 10.13866/j.azr.2018.06.09

Received: 2017-12-18; Revised: 2018-01-26
Funding: National Natural Science Foundation of China (GZ1259)

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1. Observation Levels and Instrumentation

The observation system included measurement heights of 2.35, 4.20, 7.17, 10.13, 18.15 m and soil depths of $-5, -10, -20, -40, -80, -160$ cm. The study utilized micrometeorological observation instruments detailed in Table 1, including sensors for wind speed, CO_2/H_2O flux, soil temperature/moisture, radiation components, and surface temperature. The Bowen ratio ($B = H/LE$) was calculated from sensible (H) and latent (LE) heat fluxes.

Table 1 The micrometeorological observation instruments and their locations

2. Data Processing and Analysis

2.1 Quality Control and Methodology Observational data from Maqu Station during December 2011 to March 2012 underwent quality control procedures including threshold validation, spike detection, and consistency checks. Data were excluded when sensor malfunction occurred or when flux values exceeded physical thresholds. Specifically, data were rejected when the friction velocity (u^*) was less than 0.4 $\mathrm{m \cdot s^{-1}}$ under stable conditions, as this indicates weak turbulence. The analysis focused on three distinct snow cover processes:

- **First snow event**: January 17–18, 2012
- **Second snow event**: February 17–18, 2012
- **Third snow event**: February 29–March 3, 2012

Snow depths for these events were 3.3 mm, 3.3 mm, 2.2 mm, and 1 mm respectively. Net radiation measurements showed values of 304, 450, and 548 $\mathrm{W \cdot m^{-2}}$ across the three events, with corresponding albedo values of 24%, 25%, and 25%. When incoming shortwave radiation exceeded 150 $W \cdot m^{-2}$, snow surface temperature increased by approximately 6°C, significantly affecting surface energy balance.

Figure 2 shows the upward/downward longwave and shortwave radiation and net radiation before and after the three snow cover processes at Maqu Meteorological Station during the study period.

The sensible and latent heat fluxes exhibited distinct patterns during each snow event. For the first snow event, the sum of sensible and latent heat fluxes reached 381 and 453 $W \cdot m^{-2}$ on average, with peak values of 795 and 972 $W \cdot m^{-2}$. During the second event, these values were 398 and 507 $W \cdot m^{-2}$ (average) and 885 and 1150 $W \cdot m^{-2}$ (peaks). The third event showed average sensible heat fluxes of 2, 72, and 109 $W \cdot m^{-2}$, with corresponding latent heat fluxes of 147, 250, and 469 $W \cdot m^{-2}$.

Figure 3 The sensible heat flux and latent heat flux as well as their sum before and after three snow cover processes at Maqu Station

Table 3 The average values of sensible heat flux and latent heat flux as well as their sum at Maqu Station during the study period

Figure 4 The Bowen ratio before and after three snow cover processes at Maqu Station

2.3.2 Case Study: February 18 Snow Event On February 18, following the second snowfall, high wind speeds ($\geq 4\ m \cdot s^{-1}$) and strong solar radiation accelerated snow sublimation. The latent heat flux reached a daily average of 118 $W \cdot m^{-2}$, with synchronous changes in wind speed and latent heat flux. Peak values occurred simultaneously at 15 $m \cdot s^{-1}$ and 300 $W \cdot m^{-2}$ respectively. Sublimation energy consumption lowered the snow surface temperature below air temperature, resulting in a negative sensible heat flux with a daily average of $-8\ W \cdot m^{-2}$ and a peak of $-40\ W \cdot m^{-2}$.

Figure 5 Distribution of meteorological factors at Maqu Station on February 18, 2012

Soil temperatures at 5 cm and 10 cm depths gradually increased from −1°C to −0.18°C during this period. The frozen soil absorbed heat while the increase in latent heat flux remained insignificant compared to pre-snowfall conditions. On March 4, the final day of snowmelt, latent heat release from damp soil and meltwater evaporation caused a significant increase in latent heat flux compared to March 3.

2.3.3 Soil Temperature Effects After the third snowfall (February 29–March 3), shallow soil temperatures gradually rose from −1°C and stabilized at −0.18°C. The frozen soil actively absorbed heat, limiting the increase in latent heat flux. The temperature difference between 5 cm and 10 cm soil depths was less than 0.15°C during January 3–5, though it reached 0.2°C on January

3. After snowmelt, the influence of shallow soil evaporation capacity on latent heat flux became significantly enhanced compared to pre-snowfall conditions.

3. Key Findings

The three snow cover processes demonstrated that: 1. Net radiation decreased significantly after snowfall, from pre-event values of 154−210 $W \cdot m^{-2}$ to 93−130 $W \cdot m^{-2}$. 2. Ground-air energy exchange was strongly affected by meteorological conditions and soil freeze-thaw cycles. 3. Wind speed and latent heat flux changed synchronously during high-wind events, with peak values occurring simultaneously. 4. Post-melt latent and sensible heat fluxes returned to pre-snowfall levels, though shallow soil evaporation capacity remained enhanced.

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Abstract

In this study, the meteorological data observed at Maqu Station for Climate and Environment Integrated Research, Chinese Academy of Sciences during the period from December 2011 to March 2012 were used. The purposes of the study were to compare and analyze the surface radiation and energy balance in three snow cover processes under the different conditions of soil freezing and thawing as well as meteorological conditions in the headwaters of the Yellow River. The results showed that the net radiation was decreased significantly after snowfall, and the net radiations before and after snowfall were 154, 200 and 210 $W \cdot m^{-2}$ and 93, 129 and 130 $W \cdot m^{-2}$ respectively. After three times of snowfall and snowmelt, the ground-air energy exchange was strongly affected by weather conditions and soil freezing and thawing: After the first snowfall, the low temperature and land surface temperature did not affect the weak evaporation capacity of frozen soil, the latent heat flux and its difference before and after snowfall and snowmelt were low. On February 18 after second snowfall, the high wind speed ($\geq 4\ m \cdot s^{-1}$) and strong solar radiation accelerated the sublimation of snow cover, the latent heat flux was high with a daily average of 118 $W \cdot m^{-2}$, the wind speed and latent heat flux changed synchronously, and their peak values of 15 $m \cdot s^{-1}$ and 300 $W \cdot m^{-2}$ occurred simultaneously. The sublimation energy consumption of snow cover reduced the surface temperature and was lower than the air temperature, and a negative sensible heat flux occurred with a daily average of $-8\ W \cdot m^{-2}$ and a peak value of $-40\ W \cdot m^{-2}$. After snowmelt, the latent heat flux and sensible heat flux reached their levels before snowfall. During the period from February 29 to March 3 after the third time of snowfall, the shallow soil temperature was gradually increased from $-1°C$ and maintained at $-0.18°C$, the frozen soil absorbed heat, the increase of latent heat flux was not significant compared with that before snowfall. March 4 was the last day of snowmelt, latent heat was released from damp soil and meltwater evaporation, the latent heat flux was increased significantly compared with that on March 3. After snowmelt, the effect of shallow soil evaporation capacity on the latent heat flux was increased significantly compared with that before snowfall.

Keywords: snow cover; radiation; sensible heat; latent heat; energy balance; Maqu; headwaters of the Yellow River

Note: Figure translations are in progress. See original paper for figures.