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IMPACT OF VARIATIONS IN SNOWPACK ONSET AND DISAPPEARANCE DATES ON SURFACE ENERGY BALANCE IN THE ALASKAN ARCTIC

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1. INTRODUCTION

Seasonal snow cover, which experiences fluctuations spatially and temporally, is one of the Earth's fastest-changing land covers. It not only influences local and regional scale heat and water exchange processes, but also affects the Earth's global heat budget (Barnett et al. 1989). The existence of snow cover is a crucial issue with major implications for studies of climate change, as well as for weather forecasting (Gustafsson et al. 2001).

The onset date of the seasonal snow cover in the Alaskan Arctic varies from late September to early October, while the disappearance date of seasonal snow cover ranges from late May through middle June (Zhang et al. 1997). Variations in timing and duration of seasonal snow cover can strongly affect energy exchange between the atmosphere and the surface due to changes in surface albedo, emissivity, and roughness length. In this paper, a numerical model was used to quantify the impact of variations in snowpack onset and disappearance dates on the surface energy balance in the Alaskan Arctic. The surface temperature (snow surface temperature when snowpack was present and ground surface temperature when snowpack was absent), net short-wave and net long-wave radiation fluxes, sensible, latent, and conductive heat fluxes in 1998 at Barrow, Alaska, for different simulation cases were calculated by changing the snowpack onset date in autumn and disappearance date in spring.

2. METHODS

The numerical model used in this study is a one-dimensional heat transfer model with phase change combined with a surface energy balance equation. The surface energy balance approach is based on a lake ice evolution model (Liston and Hall, 1995) and was used to calculate the surface heat fluxes and estimate the upper boundary temperature conditions for thermal conduction calculations. The heat transfer model is based on the equations for freezing and thawing of permafrost containing unfrozen water (Osterkamp, 1987) and was solved by using a fully implicit difference scheme. This model was validated against the meteorological data and ground temperatures at different depthes at Barrow, Alaska,

This study focuses on the impact of variations in snowpack onset and disappearance dates on the surface energy balance in the winter of 1997-1998. In order to eliminate the effect of the assumed initial temperature distribution, the model was run from August 1, 1995. The basic meteorological data (Figure 1) used in this study include mean daily air temperature, dew point temperature, snow cover depth, wind speed, and atmospheric pressure measured at the National Weather Service (NWS) station at Barrow, Alaska; and the incident solar radiation measured at the NOAA Climate Monitoring and Diagnostics Laboratory (CMDL) at the Barrow site. Only the snowpack onset and disappearance dates in the winter of 1997-1998 were varied.

The stable seasonal snow cover appeared on September 22, 1997 and disappeared on May 28, 1998 at NWS at Barrow, Alaska. There were 200 days between October 25 and May 13 in which the seasonal snow depth was greater than 0.25 m (Figure 1c). In order to investigate the effect of variations in timing and duration of the seasonal snow cover, the 200 days were extended to 210 days by linear interpolation, and were also shortened to 190 days by removing 10 linearly. The snow depth for each interpolated day was derived using a six-day average snow depth of three days before and three days after the interpolated day. Five simulation cases were conducted (Table1). The mean snow density for tundra snow over at Barrow was set at a value of 352 kg m^{-3} (Jeffries et al. 1999), the effective thermal conductivity of snow was derived from a snow density dependent function (Sturm et al. 1997), and the snow albedo was estimated by using a method presented by Anderson (1976).

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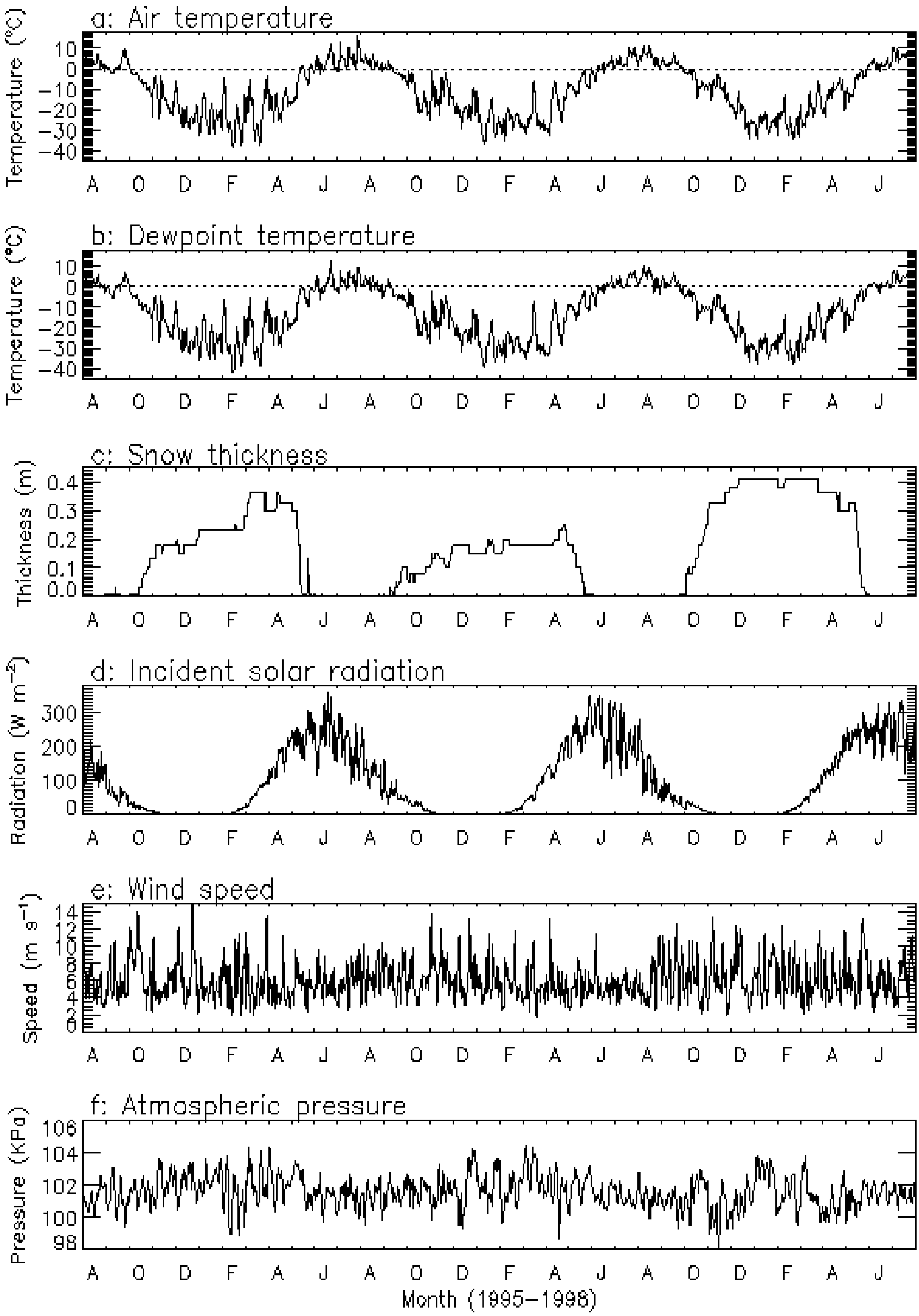

Figure 1. Variations of the mean daily meteorological values from August 1995 through July 1998 at Barrow, Alaska. These are basic input data for simulation C0.

The daily mean air temperature and dew point temperature were assumed not to change with variations of the timing and duration of snowpack. This is a reasonable assumption

Table 1. Simulation cases carried out in this study.

Simulation case	C0	C1	C2	C3	C4
Advances in appearance date (day)	0	10*	-10**	0	0
Advances in disappearance date (day)	0	0	0	10	-10

* 10 days early
** 10 days late.

because net radiation is the dominant source of energy for snowmelt at high latitudes. Previous studies show that snow melts due to radiative heating even when the air temperature is a few degrees below the freezing point (Koh and Jordan, 1995; Zhang et al. 2001). When snow cover is present and the surface temperature estimated from the surface energy balance approach is greater than 0^{o}C, energy is available for snow melting. In this case, the surface temperature was reset to 0^{o}C and the surface heat fluxes and permafrost temperatures were recalculated.

3. RESULTS

The simulated surface temperature and surface heat fluxes during September 1997 through June 1998 are displayed in Figure 2. During the period that snowpack was present, the mean daily snow surface temperature varied from 0^{o}C to as low as -39.0^{o}C (Figure 2a), with a mean temperature of -17.7^{o}C. Due to the insulating effect of snow, the mean daily snow surface temperature was lower than air temperature, with a mean temperature difference of -1.53^{o}C. Energy toward the surface are defined to be positive. The daily average net solar radiation flux had a significant decrease as the ground surface went from snow-free to snow-covered, and a significant increase as the ground surface went from snow-covered to snow-free (Figure 2b). Similarly, the daily average net longwave radiation flux has dramatic changes as the ground surface went from snow-free to snow-covered or as the ground surface went from snow-covered to snow-free (Figure 2c). This is because: 1) the incident solar radiation flux is relatively small during the period that seasonal snow cover was present (Figures 1c, 1d); 2) the peat and snow albedos were assumed to be 0.17 and 0.87, respectively; 3) the peat and snow emissivities were assumed to be 0.92 and 0.87, respectively. The sensible heat flux was positive when seasonal snow cover was present and was negative when the ground was snow free (Figure 2d). The latent heat flux was negative and small when the stable seasonal snow cover was present in November 1997 through early April 1998, and was more negative during September through October when the active layer was in freezing period and during middle April to June when the snow and permafrost were in melt period (Figure 2e). This is generally true because the evaporation increased as the frozen of active layer and the melt of snow and permafrost progressed. The conductive heat flux to the atmosphere was calculated using the thermal conditions at the bottom of the top node layer, which is at 0.1 m depth. During the period that the ground was frozen, the conductive heat flux was positive as ground temperature at the bottom of top node layer was generally greater than snow surface temperature. While during the period that the ground was freezing or thawing, the mean daily conductive heat flux could be positive, negative. or equal to zero, since ground temperature at the bottom of top node layer was strongly affected by air temperature. While in the period when seasonal snow cover was absent, due to the thermal conductivity of peat is greater than the effective thermal conductivity of snow and peat, and ground temperature at the bottom of top node layer was generally lower than ground surface temperature, the conductive heat flux was more negative (Figure 2f).

Figure 3 shows the simulated daily surface temperature difference and the surface heat flux differences between C1 and C0 (solid lines) and between C2 and C0 (dotted lines). As can be seen, setting the snowpack onset date 10 days earlier in autumn results in surface temperature decreasing (Figure 3a), the net solar radiation flux decreasing (Figure 3b), and the net longwave rediation flux generally becoming more negative (Figure 3c). And setting the snowpack onset date 10 days later in autumn leads to surface temperature and the net solar radiation flux slightly increasing, and the net longwave radiation flux becoming less negative. Due to the incident solar radiation flux is small in September (Figure 1d), the net radiation flux change is relatively small with variations in the snowpack onset date. A snowpack onset date 10 days earlier in autumn results in the sensible heat flux becoming more positive (Figure 3d) and the latent heat flux generally becoming less negative (Figure 3e). While a snowpack onset date 10 days later in autumn leads to the Sensible heat flux becoming less positive and the latent heat flux becoming more negative. Variations in the snowpack onset date not only change surface temperature and ground temperature at the bottom of the top node layer, but also change the effective thermal

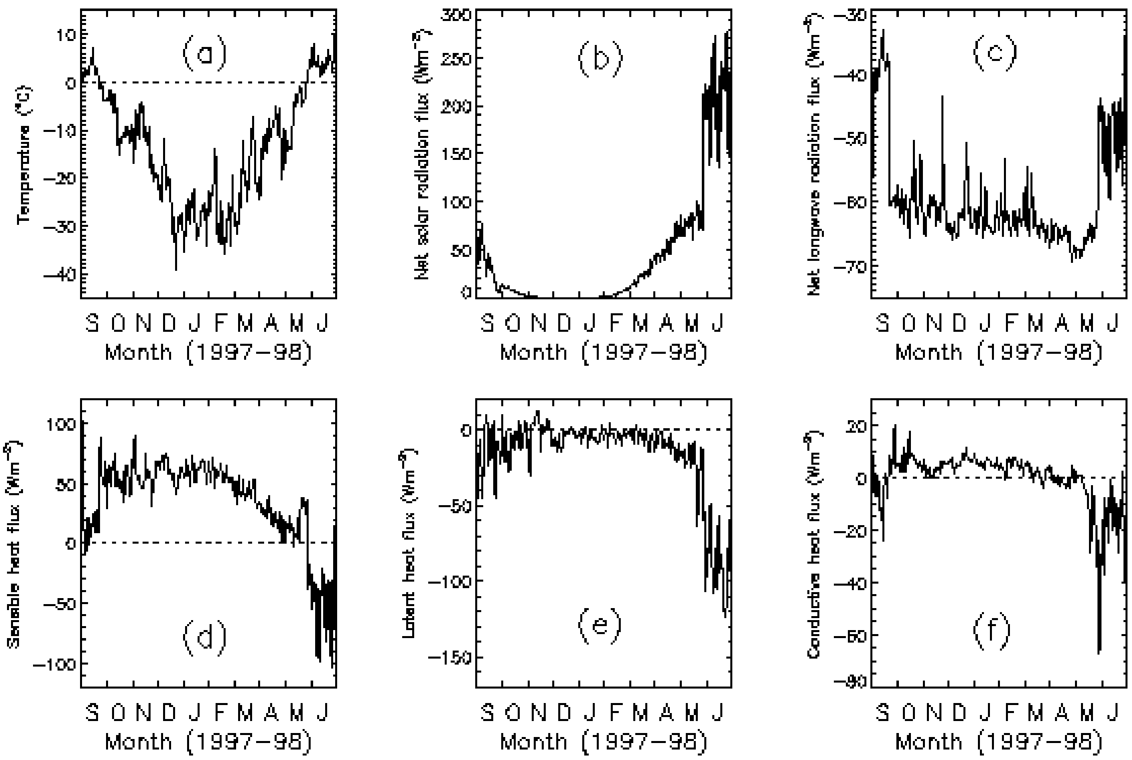

Figure 2. Simulated daily (a) surface temperature (snow surface temperature when seasonal snow cover was present and ground surface temperature when seasonal snow cover was absent); (b) net solar radiation flux; (c) net longwave radiation flux; (d) sensible heat flux; (e) latent heat flux; and (f) conductive heat flux by using the mean daily meteorological values in Figure 1. Energy fluxes toward the surface are defined to be positive.

Conductivity of the snow and peat matrix, As a result, the magnitude of conductive heat flux can increase or decrease, and the heat flux can go upward or downward, depending on the day to day air temperature.

Figure 4 is the simulated daily surface temperature difference and surface heat flux differences between C3 and C0 (solid lines) and between C4 and C0 (dotted lines). Setting the snowpack disappearance date 10 days earlier in spring results in surface temperature and the net solar radiation flux generally increasing (Figures 4a and 4b), and the net longwave rediation flux becoming less negative (Figure 4c). Setting the snowpack disappearance date 10 days later in spring leads to surface temperature and the net solar radiation flux decreasing, and the net longwave radiation flux generally fluctuation. A snowpack disappearance date 10 days earlier in spring results in the sensible heat flux becoming more negative (Figure 4d) and the latent heat flux generally becoming more negative (Figure 4e). While a snowpack disappearance date 10 days later in spring leads to the sensible heat flux becoming less positive and the latent heat flux becoming less negative. Advancing or delaying the snowpack disappearance date 10 days in spring can strongly affect the conductive heat flux. The conductive heat flux difference can be negative or positive (Figure 4f). The obvious conductive heat flux difference between Ck and C0 existed not only during the periods that the snowpack onset date was set 10 days early or late, where k =1, 2, 3, and 4. but also during the several days before and after the 10 changed days (Figures 3f and 4f). This is because of the changes in snow depth.

The mean differences of the calculated surface temperature and heat fluxes between simulation cases Ck and C0 during the 10 days that the snowpack onset date or disappearance date was varied are summarized in Table 2.

4. SUMMARY

A surface energy balance approach based one-dimensional heat transfer model with phase change was used to quantify the impact of variations in timing and duration of seasonal snow cover on the surface energy balance. The model was driven with observed mean daily air temperature, dew point temperature, snow cover

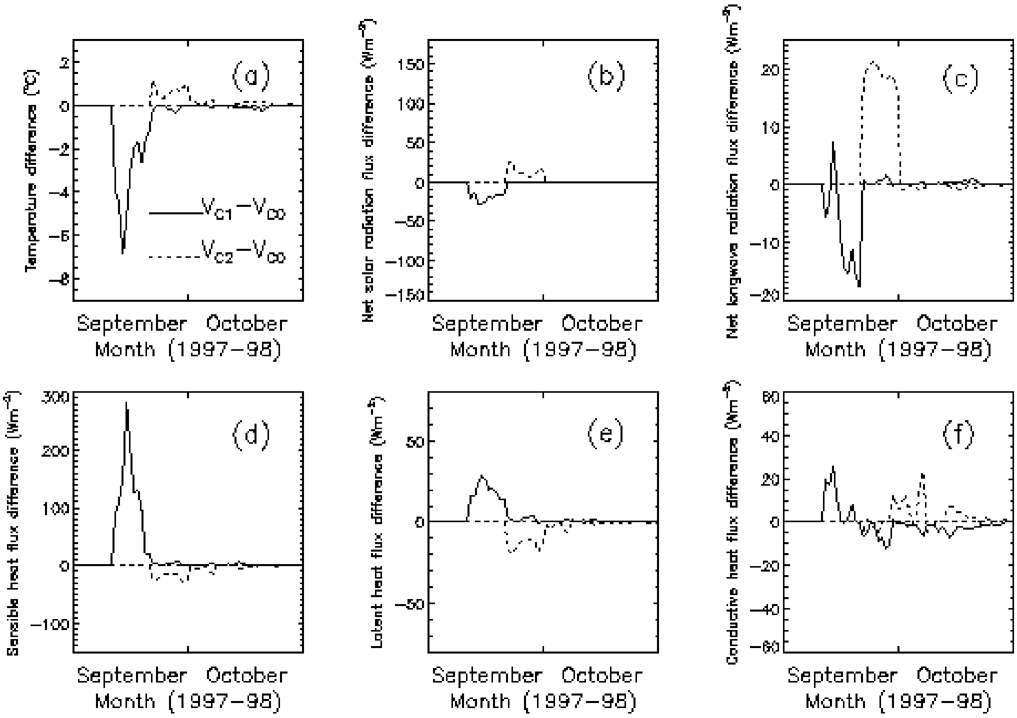

Figure 3. Simulated daily (a) surface temperature difference; (b) net solar radiation flux difference; (c) net longwave radiation flux difference; (d) sensible heat flux difference; (e) latent heat flux difference; and (f) conductive heat flux difference between C1 and C0 (solid lines) and between C2 and C0 (dotted lines) in the winter of 1997-1998. Where V is surface temperature or surface heat flux.

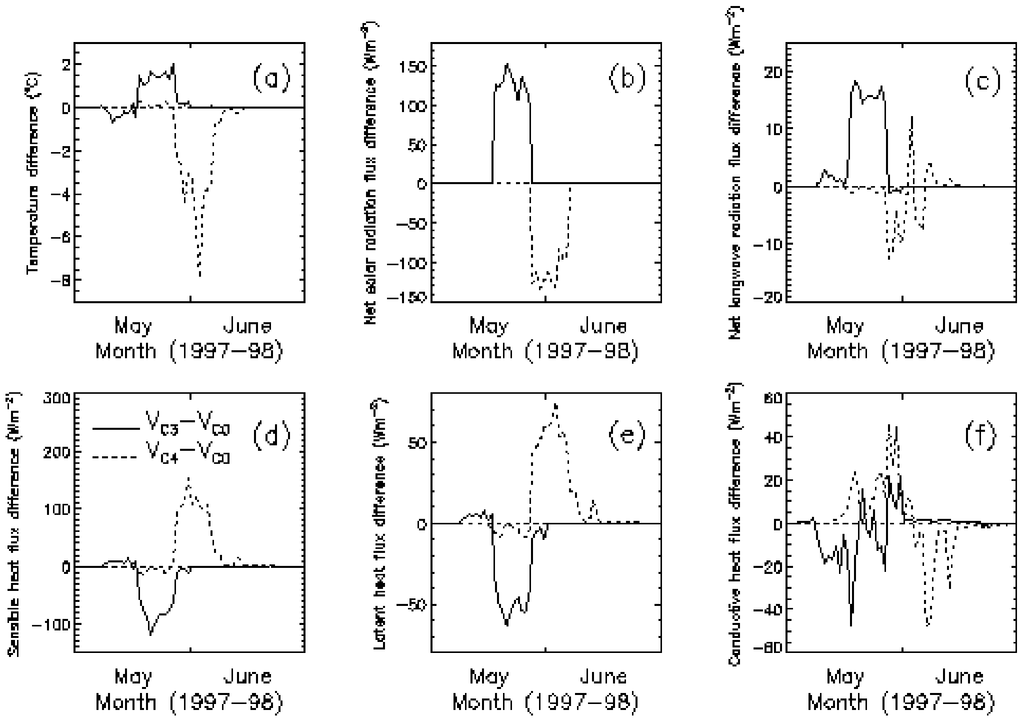

Figure 4. Simulated daily (a) surface temperature difference; (b) net solar radiation flux difference; (c) net longwave radiation flux difference; (d) sensible heat flux difference; (e) latent heat flux difference; and (f) conductive heat flux difference between C3 and C0 (solid lines) and between C4 and C0 (dotted lines) in the winter of 1997-1998. Where V is surface temperature or surface heat flux.

Table 2. The mean differences of the calculated surface temperature (^{o}C) and heat fluxes (W m^{-2}) between simulation cases Ck and C0, where *k* = 1, 2, 3, 4.

Simulated components	Simulation cases			
	C1	C2	C3	C4
Surface temperature	-3.27	0.68	1.45	4.04
Net solar radiation flux	-20.08	14.49	127.47	113.26
Net longwave radiation flux	-8.65	19.15	15.96	5.31
Sensible heat flux	122.49	-20.60	-83.18	106.10
Latent heat flux	19.61	-14.36	50.88	55.46
Conductive heat flux	8.38	.1.32	-10.14	13.46

collected at Barrow, Alaska. Five simulation cases were conducted by using the measured snow data, and by changing the snowpack onset date by 10 days in autumn and the disappearance date by 10 days in spring in the winter of 1997-1998 at Barrow, Alaska. The results indicate that the surface temperature, net solar radiation flux, net longwave radiation flux, sensible heat flux, latent heat flux, and conductive heat flux all are sensitive to variations in snowpack onset date in autumn and disappearance date in spring.

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