Modulation of snow on the daily evolution of surface heating over the Tibetan Plateau during winter: Observational analyses

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Abstract

Studying the daily evolution of turbulent fluxes modulated by snowfall over the Tibetan Plateau (TP) is of importance to understand the features of the change in the TP heat source/sink. Based on observations from 4 sites of the Third TP Atmospheric Scientific Experiment, the process of surface energy balance impacted by snow is investigated. The results show that the surface albedo increases on the first day of snow and then slowly decreases. Correspondingly, the sensible heat (H) flux sharply decreases after snow and then recovers to the original level during the following approximately 10 days. The latent heat (LE) flux becomes more active and stronger after snowfall and persists for a longer period than H, since the soil moisture may still contribute to a high LE after snowmelt. As the synergistic result of H and LE modulated by snow, the surface turbulent heating (i.e., the sum H and LE) of the TP decreases at the early period of snow events and then even enhances to a higher level after the snowmelt than before snow. Comparison analyses reveal that the impact of snow on the H and LE over the TP is much stronger than over similar latitude low-altitude regions in North America and Europe, which may be partly attributed to the larger and more drastic change of the surface net solar radiation associated with snow processes in the TP. This study may help further understand the detailed physical processes of modulation of snow events on Asian weather processes during winter.

Modulation of snow on the daily evolution of surface heating over the Tibetan Plateau during winter: Observational analyses

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Abstract: Studying the daily evolution of turbulent fluxes modulated by snowfall over the Tibetan Plateau (TP) is of great importance to understand the features of the change in the TP heat source/sink and its contribution to Asian atmospheric circulation and weather processes. However, the lack of data over the TP restricts the detailed studies. Based on observations from 4 sites of the Third TP Atmospheric Scientific Experiment, the process of surface energy balance impacted by snow is investigated. The results show that the surface albedo largely increases on the first day of snow and then slowly decreases. Correspondingly, the sensible heat (H) flux sharply decreases after snow and then gradually recovers to the original level during the following approximately 10 days. The latent heat (LE) flux becomes more active and stronger after snowfall and persists for a longer period than H, since the soil moisture may still contribute to a high LE after snowmelt. As the synergistic result of H and LE modulated by snow, the surface turbulent heating (i.e., the sum H and LE) of the TP decreases at the early period of snow events and then even enhances to a higher level after the snowmelt than before snow. Comparison analyses reveal that the impact of snow on the H and LE over the TP is much stronger than over similar latitude low-altitude regions in North America and Europe, which may be partly attributed to the larger and more drastic change of the surface net solar radiation associated with snow processes in the TP. The ERA5 and CFS reanalysis datasets fail to reproduce the modulation of snow on the heat fluxes, which suggests that the physical schemes of the models should be further improved based on the observational analyses over TP. This study may help further understand the detailed physical processes of modulation of snow events on Asian weather processes during winter and is also conducive to the improvement of surface parameterization schemes of models.

Key words: Tibetan Plateau snow, eddy-covariance heat flux, ERA5 reanalysis, CFS reanalysis.

1. Introduction

The Tibetan Plateau (TP), located at the subtropical central and eastern Eurasian continent, is the highest in the world, with a mean elevation higher than 4000 m above sea level. The TP generally acts as an elevated atmospheric heat source during summer but a heat sink during winter (Flohn, 1957; Yeh et al. 1957). The heat source/sink plays an important part in modulating weather and climate over the TP adjacent and even broader regions. The elevated heat source of the TP should be considered as one of the most important factors that drive the South and East Asian summer monsoons (Yin et al., 1949; Flohn, 1957; Yeh et al. 1957). Based on different datasets and numerical experiments, the contribution of the TP thermal anomaly to the seasonal transition of atmospheric circulation and the associated onset of the Asian monsoon has been revealed by many studies (Yeh and Gao 1979; Shen et al. 1984; Nitta, 1983; Luo and Yanai, 1983, 1984; Tao and Chen, 1987; He et al. 1987; Yanai et al. 1992, 2006; Yanai and Li, 1994; Wu et al. 1997, 2003, 2004; Liu et al. 2001, 2002; Duan and Wu 2005). Recent studies have argued that the thermal anomaly of the TP may adjust the atmospheric circulation and associated climate variability over East Asia, the Pacific, Europe, and even Africa (Duan et al., 2013; Duan and Wu, 2005; Liu et al., 2017, 2015; Wu et al., 2016; Lu et al., 2018; Chen et al., 2020; Nan et al., 2019, 2020), showing a broader effect during summer.

In earlier research, the TP was regarded as a large-scale topography that blocks and modulates the atmospheric circulation (Queney 1948, Charney and Eliassen 1949, Bolin 1950, Yeh 1950). Such an effect of dynamical blocking is more crucial in winter (Ma et al. 2014). Besides, many studies that reported the cross-season relationship between the winter snow cover anomaly in the TP and summer monsoon and associated rainfall anomalies over India (Dey and Bhanukumar 1983; Dey et al. 1985; Dey and Kathuria 1986), and East Asia (Tao and Chen, 1987; Xu et al. 1994; Wei and Luo, 1994; Zhai and Zhou, 1997; Wu and Qian, 2000; Chen et al. 2000; Wu et al. 2003). However, fewer studies focus on the winter snow and the related heating effect of the TP on the simultaneous weather and climate variability. Nan et al. (2012) revealed that the atmospheric cold source around the TP can result in atmospheric circulation and associated precipitation anomalies over central-eastern China during January. Li et al. (2018) found that through modulating the sensible (H) and latent (LE) heat fluxes, the TP snow cover has a significant influence on the Asian atmospheric circulation and weather on medium-range time scales during winter.

Obviously, investigating the short-time (e.g., daily) evolution of the H and LE modulated by the TP snowfall is of great benefit to further understand the effect of the heat source/sink of the TP and its potential contribution to Asian atmospheric circulation and weather processes. However, the lack of data over the TP restricts detailed studies. In recent years, through the Third Tibetan Plateau Atmospheric Scientific Experiment (TIPEX-III; Zhao et al., 2016b, Xin et al. 2018), updated observational eddy-covariance and planetary boundary layer data have been obtained. The observational data provide a possibility to further study this snowfall-related daily evolution of H and LE.

This rest of the paper is organized as follows. The data are described in Section 2. The results are presented in Section 3. Finally, a summary and related discussions are provided in Section 4.

2. Study Area and Data

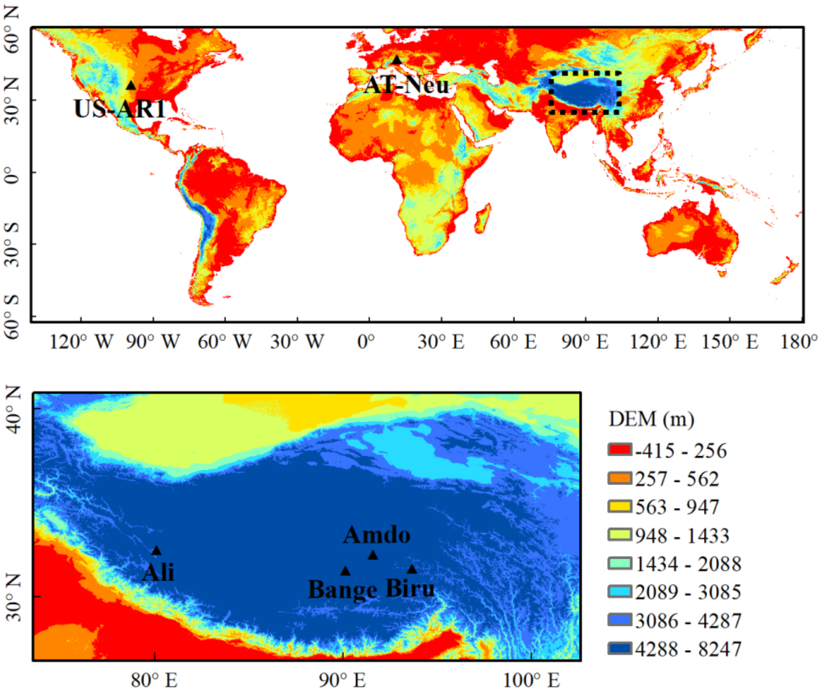

Figure 1 The locations of the observation sites, including US-AR1 and CA-NS7 in North America, AT-Neu in Europe, Ali (AL), Bange (BG), Amdo (AD), and Biru (BR) in the TP. The TP domain is shown in the bottom amplificatory figure. The color shadings denote the altitude of topography.

The geographic information and land surface characteristics of the observation sites are shown in Table 1. Figure 1 presents the locations of these sites, including four sites in the TP and two low-altitude grassland sites in Europe and North America, respectively. The observational data from four sites at the TP were obtained from the TIPEX-III (Zhao et al. 2016) that started in the summer of 2014 and continues to be conducted. There are ten sites that are involved in the land-atmospheric interaction mission of TIPEX-III (Xin et al. 2018). However, only the data from the four sites were used in this study since most of the winter observational data from the other six sites are missing or fail to pass the quality control test. The shortwave (SW) radiation, longwave (LW) radiation, air temperature, amount of precipitation, and the other variables at a temporal resolution of 30 min were obtained from the slow-response sensor for the atmospheric gradient and solar radiation. The turbulent fluxes, which were obtained from fast-response sensors for sonic anemometers and gas analyzers, have been processed by flux correction from raw eddy-covariance data (Xin et al., 2018). The data for the two sites in low-altitude Europe and North America (Figure 1) were acquired from the FLUXNET dataset (https://fluxnet.fluxdata.org/). Similar to the four sites in the TP, the two low-altitude sites are also covered by grassland or bare soil and possess snow cover in winter. Moreover, the latitudes of the two sites are as close to the TP sites as possible. The Woodward Switchgrass 1 site (US-AR1), obtained from the U.S. Department of Agriculture Southern Plains Range Research Station in Woodward, Oklahoma, has 4 years of data, beginning at 0:00 on January 1, 2009 (2002) and ending at 23:30 on December 31, 2012 (2005). The Neustift site (AT-Neu), owned by the University of Innsbruck, has 7 years of data from 0:00 on January 1, 2006, to 23:30 on December 31, 2012. Additionally, the National Centers for Environmental Prediction (CFS) 4-time daily reanalysis dataset (Kanamitsu et al., 2002) and the ERA5 24-time daily reanalysis dataset (Sabater et al., 2019) from European Centre for Medium-Range Weather Forecasts (ECMWF) were used in this study.

Table 1. Information of observational sites in this study

Site	***Geographical information***			***Land cover type***
	Lat.(°N)	***Lon.(°E)***	***Elevation(m)***	
Amdo (AD)	32.24	91.62	4695	alpine steppe
Ali (AL)	32.49	80.10	4350	bare soil
Bange (BG)	31.40	90.14	4700	alpine steppe

Biru (BR)	31.48	93.68	4408	alpine steppe
US-AR1	36.42	-99.42	611	grassland
AT-Neu	47.12	11.32	970	grassland

3. Results

3.1 The impact of snow on the surface albedo at the TP sites

To investigate the impact of snow events on the surface energy balance over the TP, we gathered 13 snow cases during the period from winter 2014 to spring 2016 from the four observation sites in the TP (Table 2). Although there are snow water equivalent (SWE) data measured by rain gauges at these sites, the data may be severely underestimated. The underestimation is mainly due to the trajectory of the falling snowflakes disturbed by strong winds and to the evaporation induced by heating devices (Sevruk et al., 1989; Rasmussen et al., 2012; Grossi et al., 2017). In particular, both the heating and wind speed are high over the TP. As an alternative, we used land surface albedo to judge whether snow cover exists or not, since the land surface albedo can be changed by snow cover (Warren 1982; Cline 1997). All 13 cases at the four TP sites capture the response of the land surface albedo to snow processes (Figure 2) lthough the accumulation of the snow-water equivalent (SWE) and snow cover duration are different from each other. Before snowfall, the monthly mean albedo at Amdo (AD), Biru (BR), Bange (BG), and Ali (AL) are 0.3, 0.2, 0.3, and 0.2, respectively. After a snowfall, the albedo clearly increases. The albedo on the first day after snow is almost 0.99 and then decreases daily (e.g., Case #1 and Case #4 at the AD site and Case #4 at the BR site). The time series of the albedo generally show gradual decreases for almost all snow cases, although with different rates of decrease.

Table 2. Snow cases from the four observation sites in the TP, in which snow cover duration means the time from the beginning of snowfall to the time when the snow is melted

Site		*Snow cover duration*
AD	Case1	Dec. 15, 2014 – Dec. 23, 2014
	Case2	Dec. 24, 2014 – Jan. 3, 2015
	Case3	Jan. 4, 2015 – Feb. 3, 2015
	Case4	Jan. 20, 2016 – Jan. 27, 2016
	Case5	Jan. 30, 2016 – Feb. 15, 2016
BR	Case1	Dec. 18, 2014 – Dec. 25, 2014
	Case2	Dec. 26, 2014 – Jan. 2, 2015
	Case3	Jan. 7, 2015 – Feb. 6, 2015
	Case4	Jan. 7, 2016 – Jan. 20, 2016
	Case5	Jan. 21, 2016 – Feb. 8, 2016
BG	Case1	Dec. 17, 2014 – Dec. 30, 2014
	Case2	Jan. 6, 2015 – Jan. 20, 2015
AL	Case1	Mar. 3, 2015 – Mar. 8, 2015

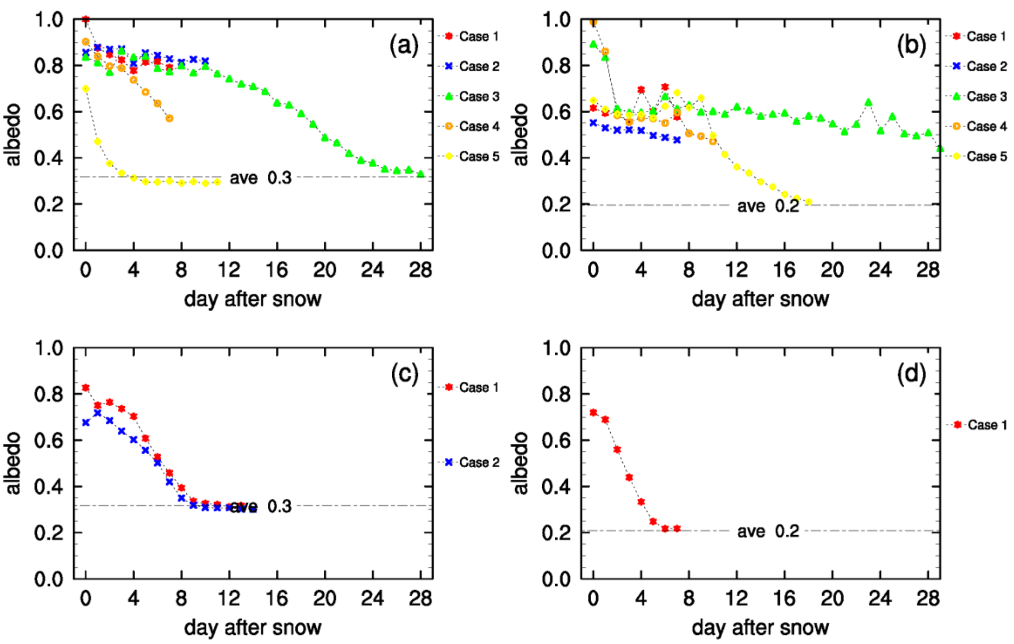

Figure 2 Evolution of the albedo after snow for the snow cases at the four TP sites: (a) AD; (b)

BR; (c) BG; (d) AL. The dash-dotted line is the monthly mean albedo before snow.

3.2 Quantitative analysis of the impact of snow on the turbulent fluxes at the TP sites

The effect of snow on H is presented in Table 3 and Figure 3. The daily maximum Hs before (after) snow are 239.5 (137.3), 164.1 (77.4), 167.2 (96.1), 158.1 (124.0) W m^{-2} at the AD, BR, BG, and AL sites, respectively (Table 3). Furthermore, the standard deviation (σ) of H after snow is smaller than that before snow (Table 3). The above results clearly indicate that the value and varying magnitude of H after snow is smaller than that before snow for the TP sites. Clearly, the snow reduces the transfer of H from the land surface to the atmosphere.

Table 3 The daily maximum value and standard deviation (σ) of H (W m^{-2}) and LE (W m^{-2}) before (monthly mean value) and after (case-averaged value) snow for the four TP sites

Site	H				LE			
	Daily max (W m^{-2})		σ (W m^{-2})		Daily max (W m^{-2})		σ(W m^{-2})	
	Before	After	Before	After	Before	After	Before	After
AD	239.5	137.3	87.0	49.0	29.8	98.5	9.3	30.9
BR	164.1	77.4	53.9	27.6	30.5	68.1	8.6	20.0
BG	167.2	96.1	59.8	41.8	25.0	34.4	7.3	10.4
AL	158.1	124.0	51.9	35.7	24.3	73.6	6.9	18.9

Figure 3 further presents the daily evolution of H during the snow cover duration. On the first day after snow, sharp decreases in H occur, with the case-averaged Hs decreasing to −1.0, −1.7, 0.4, and 6.9 W m^{-2} at the AD, BR, BG, and AL sites, respectively. These Hs are much lower than those (approximately 35.1, 24.6, 30.1, and 27.7 W m^{-2}, respectively) before snow at the four sites. During the following days, the Hs gradually recover (Figure 3). The mean H of all cases at the four TP sites (Figure

5a) further confirms the begining decrease and the following slow recovery of the H. This process of evolution of H maintains for almost two weeks. The recovery process of H mainly depends on the terrain and weather conditions (e.g., the amount of snow, air temperature, solar radiation, and wind speed). For the AD, BR, BG, and AL sites, the case-average recovery periods of H are approximately 11, 15, 10, and 5 days, respectively. The average recovery period of all 13 cases is approximately 13 days (Figure 5a).

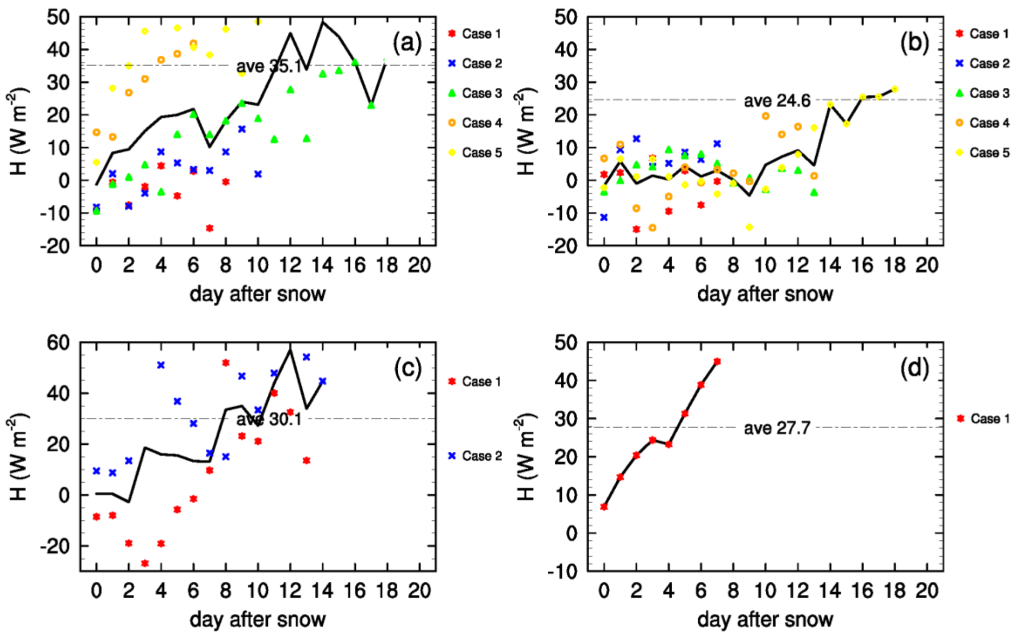

Figure 3. Time series of the daily mean H (units: W m^{-2}) after snowfall for the snow cases at the four TP sites: (a) AD; (b) BR; (c) BG; (d) AL. The dash-dotted line is the monthly mean value before snow, and the solid line is the case-average value.

Different from H, the daily maximum and mean values and standard deviation (σ) of LE are smaller before snow than after snow (Table 3 and Figure 4). This signifies that the LE becomes stronger and more active after snowfall, suggesting that the snow enhances the transfer of LE from the land surface to the atmosphere.

The peak of the LE increased by snow is not on the first day but in the next few days (Figures 4 and 5). The reason is probably that the time when the LE reaches the peak mainly depends on the time of the maximum snowmelt. When the LE reaches the peak, its value is approximately 500% of that before snow (Figure 5). Additionally, the evolution process of LE persists for a longer period than the recovery period of H, since the soil moisture content may still contribute to a high LE after the disappearance of snow cover (Figure 4).

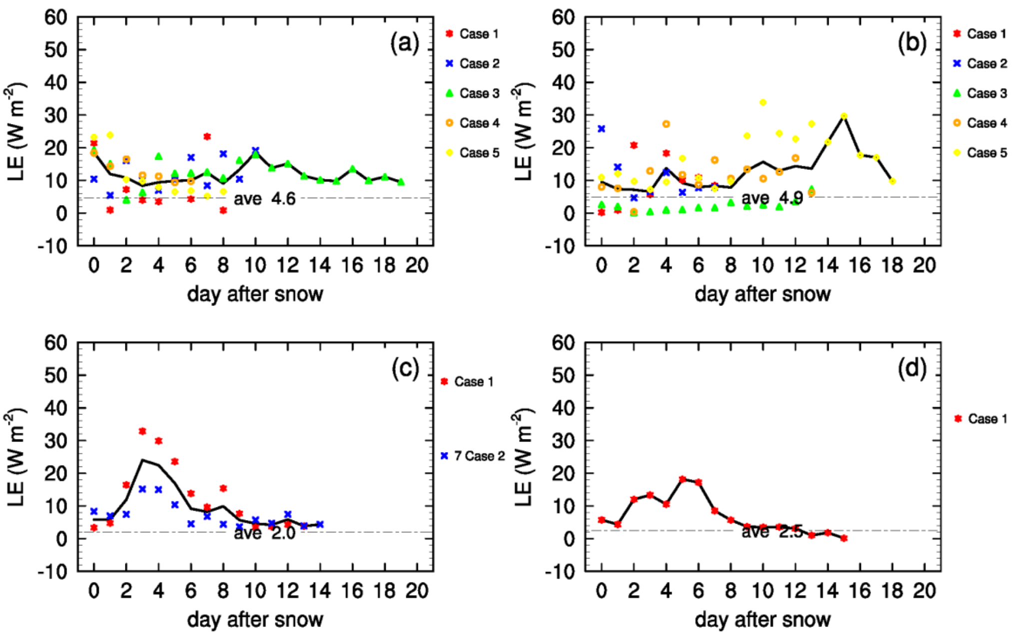

Figure 4. As in Figure 3, but for the LE

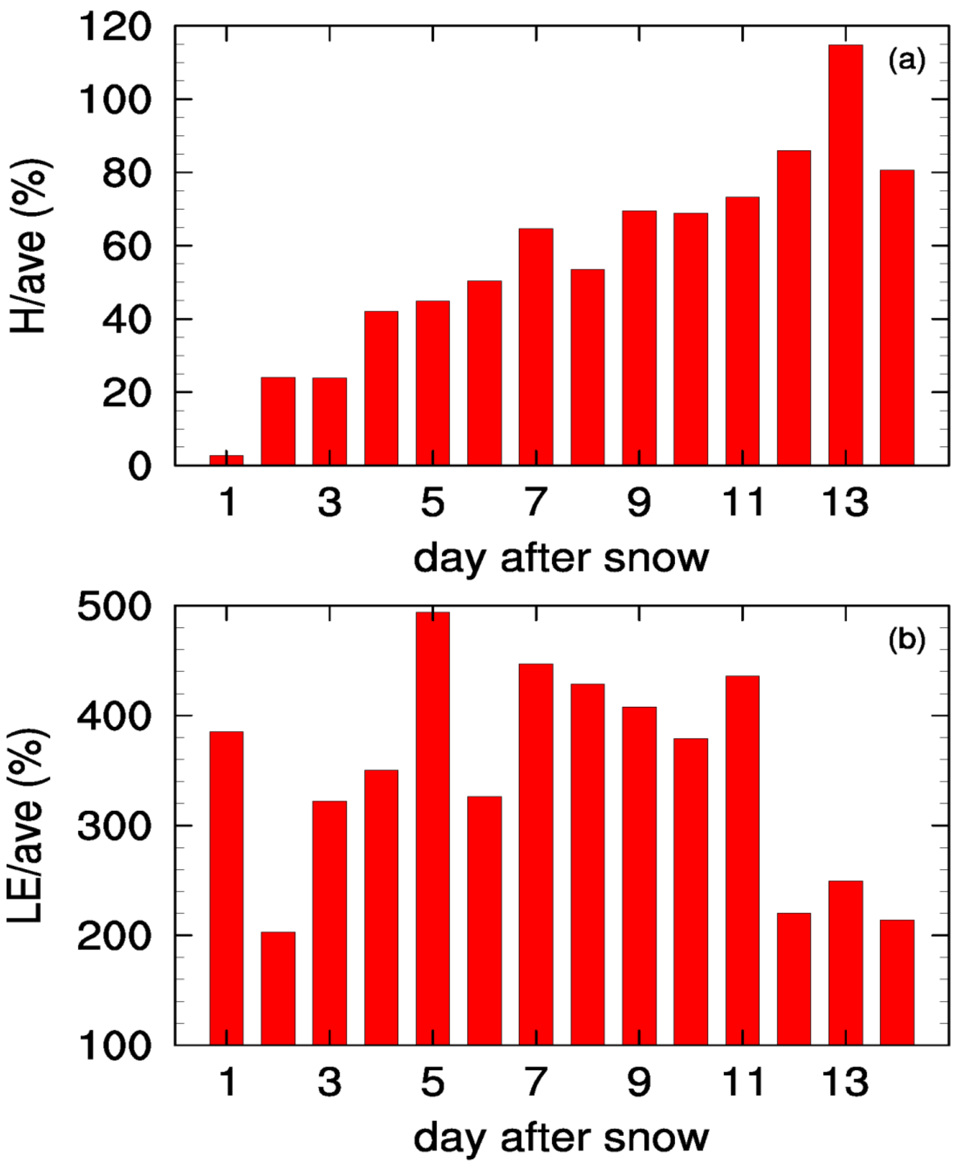

Figure 5 The histograms of the ratio of daily mean H (a) and LE (b) after snow to the average value before snow

3.3 Impact on the TP surface heating

As indicated above, snow reduces H but increases LE, and meanwhile results in different evolution processes of H and LE. Several studies have documented the importance of land surface heating in modulating weather and climate changes over the TP (Wu et al., 1998; Hsu and Li, 2003; Rajagopalan et al., 2013; Wang et al., 2019). Certainly, it is also important to further explore the total effect of snow on the surface turbulent flux (i.e., the sum of H and LE), which is regarded as a crucial component of the heat source of the TP.

On the first day after snow, the surface turbulent flux rapidly decreases to approximately 39% of that before snow (Figure 6), from 36.7 W m^{-2} to 13.6 W m^{-2}. This causes a weaker surface heating of the TP. This heating maintains a weaker level than before snow for approximately 10 days, although gradually increasing, and then recovers to the magnitude before snow after 10 days. As shown in Section 3.2, the H recovers to the original level after the snowmelt, but the LE still maintains and even increases to a higher level because of the soil moisture anomalies caused by the snowmelt. Thus, the joint effect of H and LE seems to result in the even larger heating of the TP after the snowmelt than before snow; that is, the stronger heating tends to appear after the process of snowfall (Figure 6). The remarkable fluctuation of the surface heating of the TP associated with snow events may exert a pronounced influence on local and downstream weather processes.

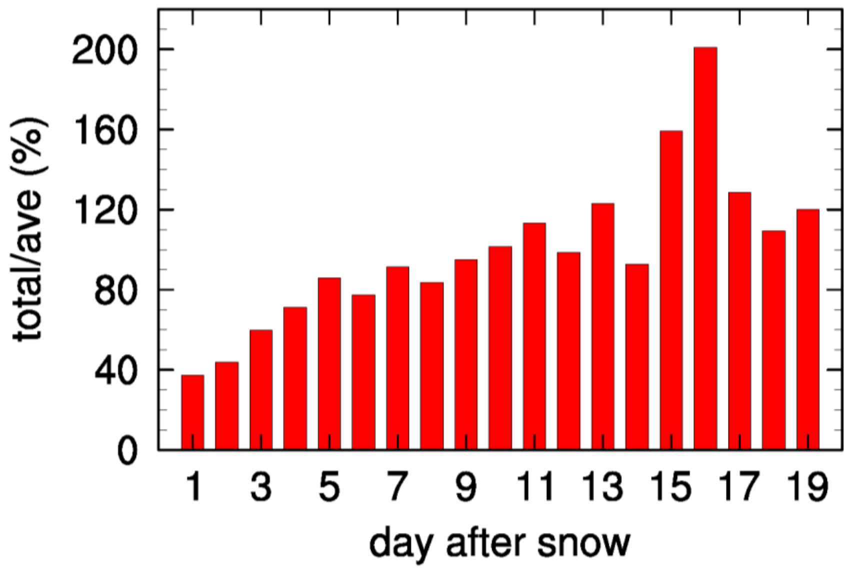

Figure 6 The histogram of the ratio of the daily mean of the turbulent heat flux (i.e., the sum of H and LE) after snow to the average turbulent heat flux before snow

3.4 Comparison between the surface heat fluxes over the TP and over the low-altitude regions.

The surface heat fluxes (H and LE) over the TP are considerably affected by snow, as shown in the previous subsections. We wonder whether the impact of snow is different between the TP and low-altitude regions. To more clearly and detailly demonstrate the differences of the surface heat fluxes affected by snow between different regions, the multi-winter-averaged diurnal cycles for the four sites in the TP and the two sites in the low regions are presented in Figures 7 and 8. As shown in Figure 7a-d, the H with snow cover (red line) is much lower than that without snow cover (blue line) at the four TP sites. The maximum value (59.7 W m^{-2}) of the site-averaged H during the snow cover period, which generally appears at noon and afternoon, is much lower than that (131.5W m^{-2}) during the non-snow cover period. In contrast, at the two low-altitude sites, the difference between the H with snow cover and that without snow cover is very small (Figure 7e, f). The maximum value (35.5 W m^{-2}) of the site-averaged H during the snow cover period does not show a large decrease relative to that (46.7 W m^{-2}) during the non-snow cover period. The results revealed that H is largely decreased by snow cover over the TP, whereas the effect of snow cover in reducing the H is much weaker over the low-altitude regions. The mean absolute difference (MAD) further shows that at noon and afternoon of local time, the differences between the H with snow cover and that without snow cover at the four

TP sites (see black curves in Figures 10a–d) are clearly larger than those at the two low-altitude sites (see black curves in Figures 10e–f). Similarly, the LE is remarkably increased by snow cover over the TP, and the effect of snow cover on the LE is also weaker over the low-altitude regions (Figure 8; the figure of MADs in LE is not shown).

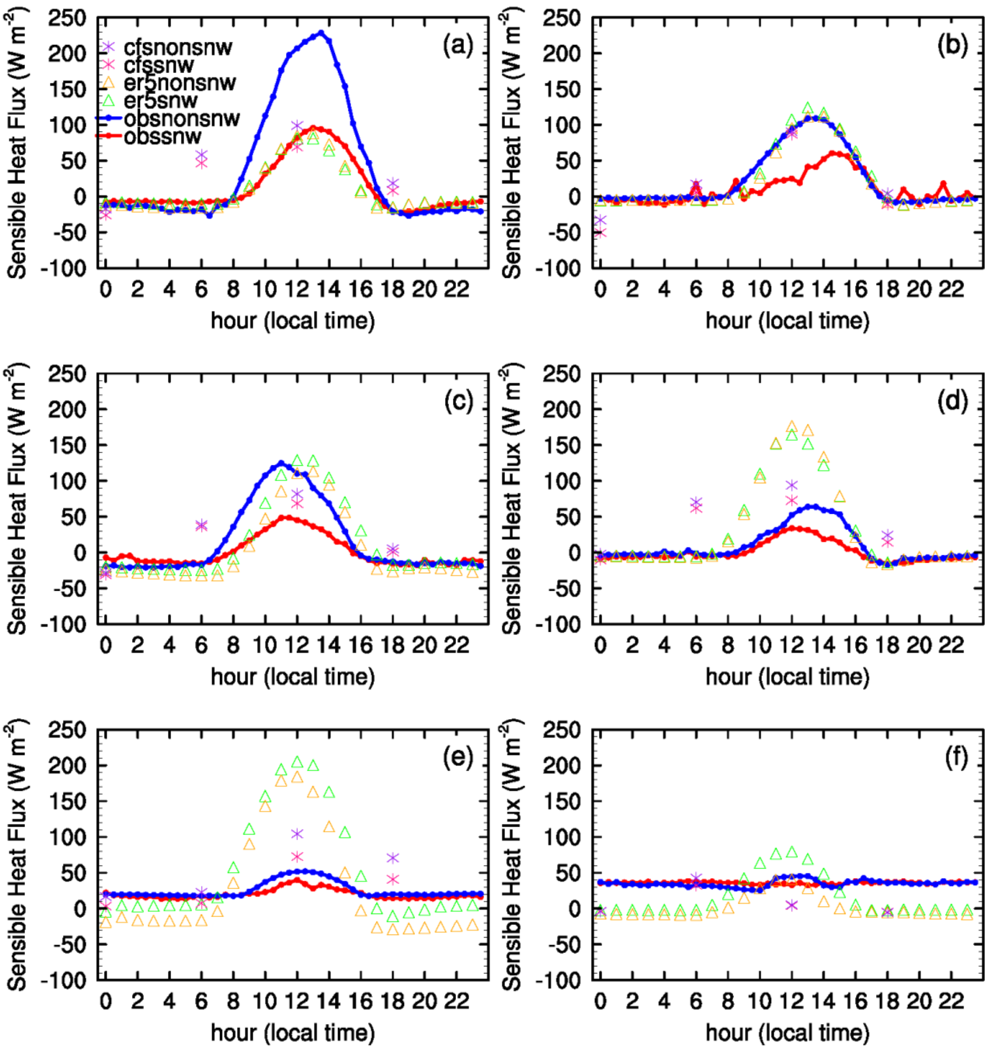

Figure 7 Multiwinter-averaged diurnal cycle of H for snow cover and non-snow cover conditions at (a) Amdo, (b) Ali, (c) Bange, (d) Biru, (e) US-AR1, and (f) AT-Neu. “cfs” means CFS; “er5” means ERA5; “obs” means observation; “nonsnw” means non-snow cover; “snw” means snow cover

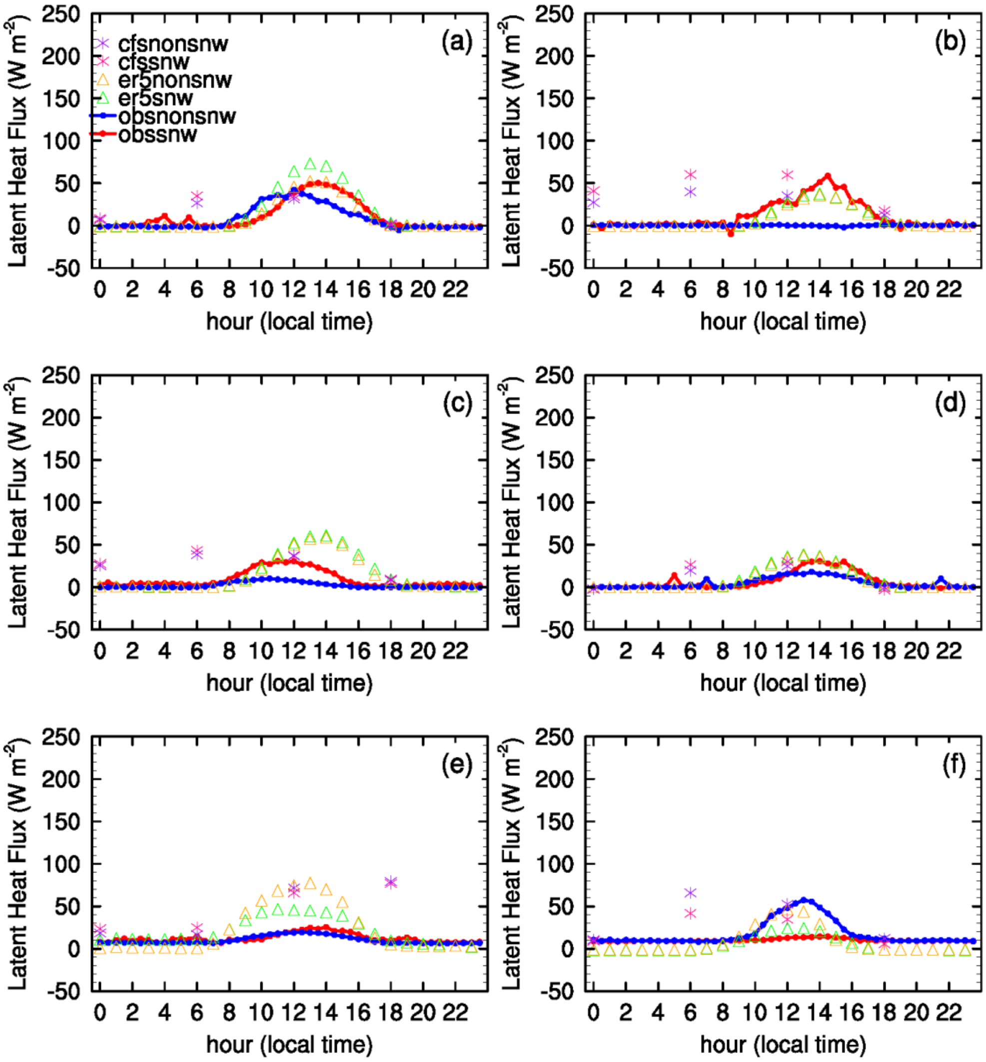

Figure 8 As in Figure 7, but for the LE

The difference in the surface heat flux between the snow cover and non-snow cover conditions is larger at noon and afternoon. This implies that the solar radiation may be responsible for, at least partly, such a difference. Relative to that at the low-altitude sites, the surface net solar radiation (R_n) at the TP sites shows larger differences between the snow cover and non-snow cover conditions (Figure 9). The daily maximum R_n with (without) snow cover is 102.2 W m^{-2} (369.7 W m^{-2}) at the TP sites, whereas that with (without) snow cover is 58.5 W m^{-2} (134.0 W m^{-2}) at the low-altitude sites. The results imply that the stronger modulation of the H and LE by snow over the TP may be partly attributed to the larger and more drastic change of the R_n associated with snow processes in this high-altitude region.

By calculating bias error (BE) and mean absolute error (MAE), we further compared the ERA5 and CFS reanalysis datasets (Table 4). The results show that relative to the CFS, the ERA5 has smaller MAEs for H, LE, and R_n at the TP sites, but larger MAEs for H at the low-altitude sites (Table 4). Generally speaking, the heat fluxes of the ERA5 reanalysis seem more reliable than those of the CFS reanalysis. However, the ERA5 reanalysis severely underestimates the difference between the H with snow cover and that without snow cover (red stars in Figures 10a–d), although it shows a higher reliability of the heat fluxes than the CFS reanalysis over the TP. Different from the results over the TP, the ERA5 reanalysis overestimates the difference between the H with snow cover and that without snow cover at the low-altitdue sites (red stars in Figures 10e–f). The CFS reanalysis is worse, since it even cannot capture the basic diurnal cycle of the fluxes (Figures 7 and 8) and certainly cannot reproduce the observational difference between the H with snow cover that without snow cover (triangles in Figure 10). In summary, both the ERA5 and CFS reanalysis datasets fail to reproduce the modulation of snow on the heat fluxes. Therefore, the physical schemes of the models, particularly the snow scheme, should be further improved based on the observational analysis over TP.

Table 4 Bias error (BE, W m^{-2}) and mean absolute error (MAE,W m^{-2}) of H, LE and R_n between the reanalyses (ERA5 and CFS) and observation at the six sites

site	ERA5	CFS

	H		LE		R_n		H		LE		R_n	
	BE	MAE	BE	MAE	BE	MAE	BE	MAE	BE	MAE	BE	MAE
AD	-10.4	16.3	4.5	6.5	18.1	39.3	9.8	36.6	9.0	12.8	-18.2	60.9
AL	-1.6	5.3	6.7	7.8	0.1	39.4	-1.0	17.1	28.9	28.9	-33.2	132.2
BG	2.1	22.3	9.3	11.9	1.7	36.2	13.2	28.5	22.5	22.4	-32.8	101.6
BR	31.1	31.9	3.0	4.7	6.7	37.6	34.6	35.8	6.9	11.7	-37.1	87.8
US	3.2	47.9	16.5	20.0	33.6	42.3	26.5	27.8	33.6	36.4	28.4	74.1
AT	-25.3	33.0	-7.0	9.5	22.1	25.4	-28.5	30.8	13.9	14.9	-8.0	43.1

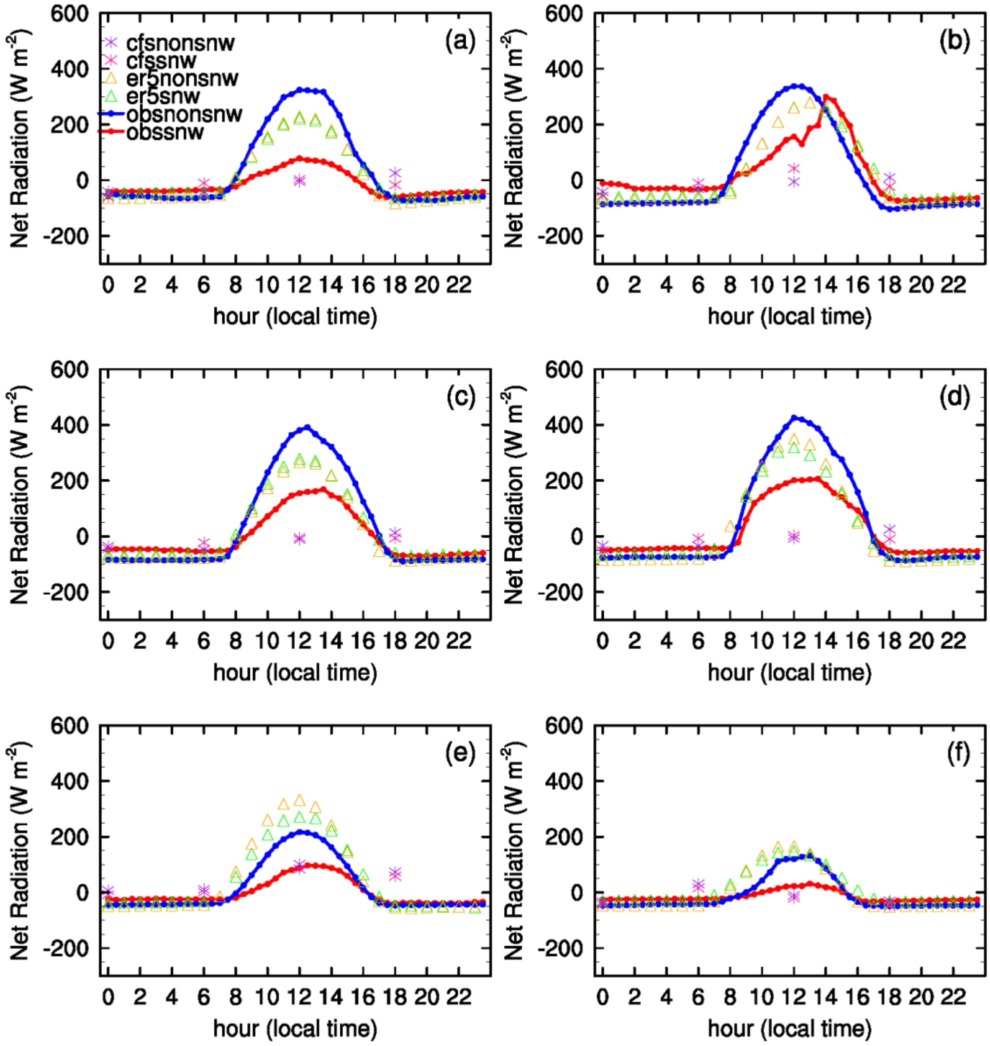

Figure 9 As in Figure 7, but for the R_n

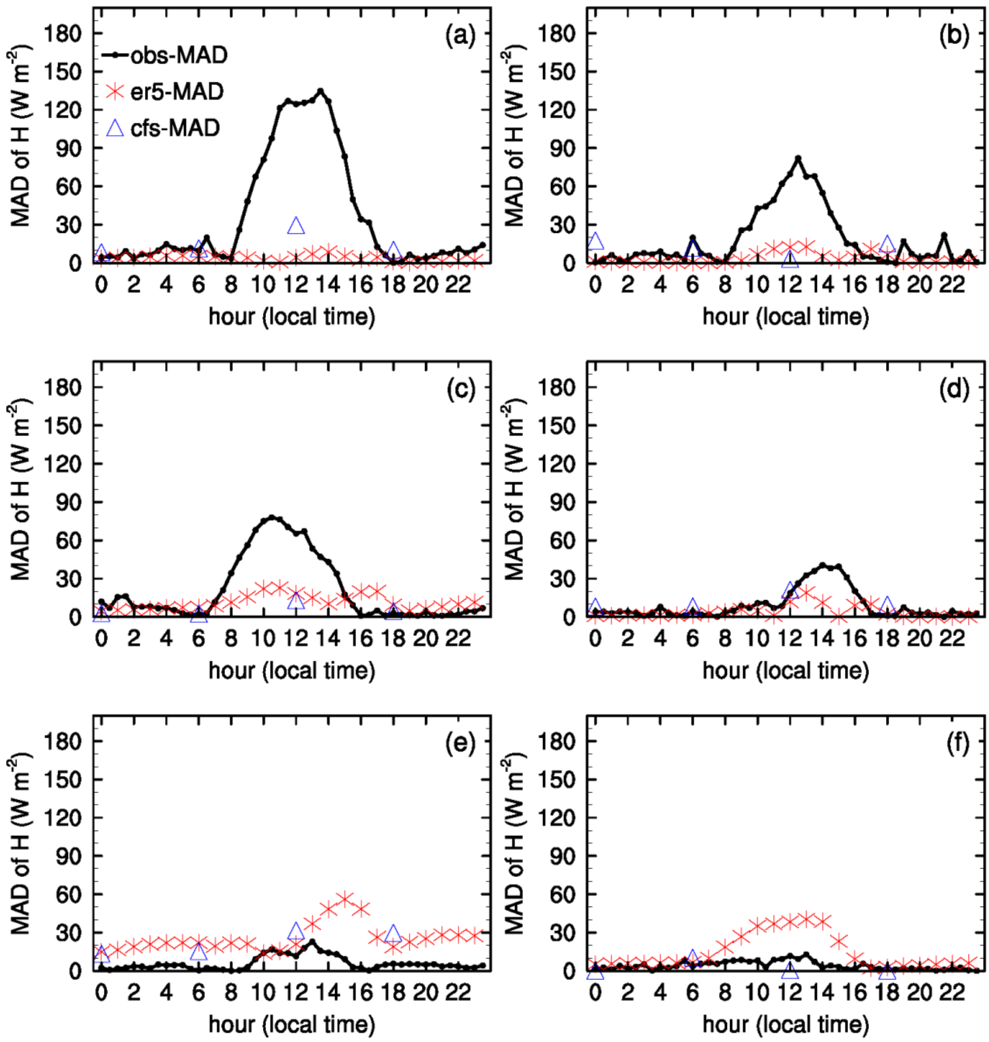

Figure 10 Diurnal cycle of the mean absolute difference (MAD, W m^{-2}) of H between snow and no snow for observation, ERA5 and CFS at at (a) Amdo, (b) Ali, (c) Bange, (d) Biru, (e) US-AR1, and (f) AT-Neu. “obs”,“cfs”, and “er5” denote observation, CFS, and ERA5.

4. Conclusions and Discussion

Through modulating surface heating, the snow cover over the TP has an influence on the Asian atmospheric circulation and weather during winter (Li et al., 2018). However, a key issue—how and by how much is the surface heating of the TP modulated by snow? —remains unclear, in particular, the daily evolution of surface heating of the TP adjusted by snow has not been revealed because of the lack of observational data. Using the eddy-covariance, atmospheric gradient, and solar radiation measurements from the 4 sites in the TP obtained from the TIPEX-III, the snowfall-related daily evolution of the surface turbulent heating (i.e, H and LE) is investigated. The results show that the surface albedo sharply increases to almost 1 on the first day of snow and then gradually decreases. Correspondingly, the H flux sharply decreases after snow, with a smaller value and varying magnitude than that before snow. That is, the snow can suppress the transfer of H from the land surface to the atmosphere. During the following approximately 10 days after snow, H gradually recovers to the original level. In contrast to H, the LE becomes stronger and more active after snowfall, indicating that the snow can enhance the transfer of LE from the land surface to the atmosphere. The fluctuation of LE resulted from snow can persist for a longer period than H, since the soil moisture may still contribute to a high LE after snowmelt. Although the effect of snow on the H and that on the LE are opposite to each other, the joint effect on the total turbulent flux (i.e, the sum of H and LE) is clear: the surface turbulent heating of the TP decreases at the early period of snow events and then even enhances to a higher level after the snowmelt than before snow. The severe fluctuation resulted from snowfall may affect local and downstream atmospheric circulation and weather processes during winter, which deserves further study in the future.

Comparison analyses preliminarily reveal that the impact of snow on the H and LE over the TP is much stronger than over similar latitude low-altitude regions in

North America and Europe. This difference may be partly attributable to the larger and more drastic change of the surface net solar radiation associated with snow processes in the TP. However, the detailed processes should be explored in future research. For example, the solar radiation-snowmelt surface heating link and evolution processes in different latitude regions require further investigation.

The ERA5 and CFS reanalysis datasets fail to reproduce the effect of snow on the surface heat fluxes over the TP and low-altitude regions. This indicates caution should be taken when using the reanalysis surface heat fluxes to diagnose the TP heating-related synoptic processes. After obtaining more flux observations in the TP, we will continue to verify the daily fluctuation of the surface heating of the TP associated with snow events. This is conducive to understand the detailed physical processes of modulation of snow events on Asian weather processes during winter and the improvement of surface parameterization schemes of the surface energy balance in the land surface models.

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Data Availability Statement

The in-situ data of six sites can be found at https://doi.org/10.6084/m9.figshare.14471283; The ERA5 reanalysis dataset were publicly provided by European Centre for Medium-Range Weather Forecasts (https://cds.climate.copernicus.eu/cdsapp#!/dataset/10.24381/cds.e2161bac?tab=overview, DOI:10.24381/cds.e2161bac); The CFS reanalysis datasets were publicly provided by National Oceanic and Atmospheric Adiministration (https://rda.ucar.edu/datasets/ds094.1/, DOI: 10.5065/D6N877VB).

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