ADVANCES IN ATMOSPHERIC SCIENCES, VOL. 26, NO. 4, 2009, 701–706

Variability of Northeast China River Break-up Date

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(Received 19 December 2008; revised 4 February 2009)

ABSTRACT

This paper investigates the variability of the break-up dates of the rivers in Northeast China from their icebound states for the period of 1957–2005 and explores some potential explanatory mechanisms. Results show that the break-up of the two major rivers (the Heilongjiang River and Songhuajiang River) was about four days earlier, and their freeze-up was about 4–7 days delayed, during 1989–2005 as compared to 1971–1987. This interdecadal variation is evidently associated with the warming trend over the past 50 years. In addition, the break-up and freeze-up dates have large interannual variability, with a standard deviation of about 10–15 days. The break-up date is primarily determined by the January–February–March mean surface air temperature over the Siberian-Northeast China region via changes in the melting rate, ice thickness, and snow cover over the ice cover. The interannual variability of the break-up date is also significantly connected with the Northern Annular Mode (NAM), with a correlation coefficient of 0.35–0.55 based on the data from four stations along the two rivers. This relationship is attributed to the fact that the NAM can modulate the East Asian winter monsoon circulation and Siberian-Northeast China surface air temperature in January–February–March.

Key words: river icebound season, interdecadal variation, interannual variability, northern annular mode

Citation: Wang, H. J., and J. Q. Sun, 2009: Variability of Northeast China river break-up date. *Adv. Atmos. Sci.*, **26**(4), 701–706, doi: 10.1007/s00376-009-9035-1.

1. Introduction

The climate in China has become warmer over the most recent 50 years and is projected to undergo further warming in the next hundred years (Zhou and Li, 2008; Li, 2008; Lu and Dong, 2008). The changing climate results in many potential impacts on the environment and the society, including river icebound state, in particular. The rivers in the Heilongjiang Province of Northeast China remain in an icebound state during the winter season, largely because the average winter surface air temperature (SAT) is far below zero, normally at −16°C to −17°C. The average thickness of the ice cover over the rivers is about 0.7–1.5 meters, depending on surface meteorological conditions such as temperature, snow amount, wind, etc. (Wang et al., 2006). The rivers' icebound state in Northeast China normally starts in October and ends in April of the following year, with year-to-year fluctuations (Yu et al., 2005).

Since there is quite a lot of vehicle transport and human activity over the river ice cover during the icebound season, information about the start and end dates, as well as the duration of the icebound state, is important. In addition, the fragmentation of the river ice cover before the ice break-up may cause damage to human life and interfere with economic activities. Thus, a reliable forecast of the dates related to the icebound state is of value to the local public.

The dates related to the rivers' icebound state are closely associated with climate variability on interannual, interdecadal, and even longer time scales. Signals of climate change can be found in many aspects of the earth system, including the variability of river freezing (Magnuson et al., 2000). Therefore, an improved understanding of the mechanistic factors and the predictability of the dates related to the icebound state is of scientific merit. In this paper, we will focus on the variability of the start and end dates of the rivers' icebound conditions (with emphasis on the end

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date) on the interannual to interdecadal scales, and try to identify local and remote factors that modulate the end date of the icebound state of the rivers in the Heilongjiang Province.

2. Data

The dates for break-up and freeze-up of the Heilongjiang and Songhuajiang Rivers in Northeast China (1957–2005) were provided by the Meteorological Office of the Heilongjiang Province. The monthly atmospheric reanalysis data employed were provided by the National Centers for Environmental Prediction and the National Centers for Atmospheric Research, with 2.5° × 2.5° horizontal resolution (Kistler et al., 2001). The index of the northern annular mode (NAM), computed as the leading empirical orthogonal functions of the Northern Hemisphere (20°–90°N) sea-level pressure monthly anomaly, was provided by the Joint Institute for the Study of the Atmospheric and Ocean of University of Washington (http://www.jisao.washington.edu/data/). The monthly land surface air temperature and precipitation data were obtained from the Climate Research Unit (CRU, Norwich, U.K., dataset: CRU TS 2.1) for January 1957–December 2002 (Mitchell and Jones, 2005), which covered the global land surface at 0.5-degree resolution.

3. Results

In the Heilongjiang Province of Northeast China, there are two major rivers (Heilongjiang, Songhuajiang), which are primarily located in the domain of (42°–55°N, 110°–140°E). The rivers are icebound for half a year (normally from mid-October to the next mid-April or early May), with an ice thickness of about 0.7–1.5 meters. In this paper, the river break-up date (BUD) is defined as the day when the river ice begins to break up and drifts with the river flow. The river freeze-up date (FUD) is defined as the first day when the river is fully covered by ice. The averaged FUD and BUD are, respectively, 18 October and 26 April for the period of 1957–2005 for the Heilongjiang River, and 23 October and 13 April for the Songhuajiang River. In this paper, we defined the BUD and FUD indices as the numbers of days after 31 March and 30 September, respectively. Therefore, a larger (smaller) BUD means that the river icebound state ended later (earlier).

For each river, we selected two stations: these were located at Heihe (50.22°N, 127.53°E) and Qike (49.6°N, 128.6°E) for the Heilongjiang River, and at Jiamusi (46.83°N, 130.25°E) and Tonghe (45.98°N, 128.7°E) for the Songhuajiang River. Our preliminary analysis indicated that the BUD has shifted earlier over the last two decades. As shown in Table 1, the BUD is about 3.3–4.2 days earlier at these four stations over the period of 1989–2005 as compared to 1971–1987. The FUD was 4.4–7.3 days delayed in the same period (table not shown). These interdecadal changes are apparently related to the warming trend of the last five decades, since the surface air temperature in the latter period was significantly higher than for the former period. Figure 1 depicts the BUD of Qike station in Heilongjiang River and the mean January–February–March (JFM) SAT, averaged for the region (47.5°–52.5°N, 125°–130°E). Figure 1 clearly shows the upward and downward trends in the two time series; they are correlated at levels of −0.68 and −0.67 for the un-detrended and detrended series during 1957–2002. We obtained similar results for the other three stations. Therefore, the BUDs of the rivers in Heilongjiang Province of Northeast China are substantially modulated by the local SAT in JFM. A higher (lower) JFM SAT caused decreased (increased) thickening of the ice cover, and the ice cover melted faster (slower), thus corresponding to an earlier (later) BUD. The local SAT in JFM could explain roughly 40% of the total variance of the BUD. Thus, the BUD is greatly influenced by the local SAT.

The spatial distribution of the regressed SAT against the JFM BUD at Qike is plotted in Fig. 2. It shows that the positive phase of the BUD at Qike was associated with negative temperature anomalies over a large area spanning Siberia and Northeast China. The associated temperature anomalies are centered in the region to the north of Lake Baikal in Siberia, not Northeast China. A possible reason for this displacement is that the winter monsoon circulation dominates the SAT in Northeast China, and the monsoon surge primarily originates from the Lake Baikal region. The winter monsoon circulation is characterized by low-level northerly winds.

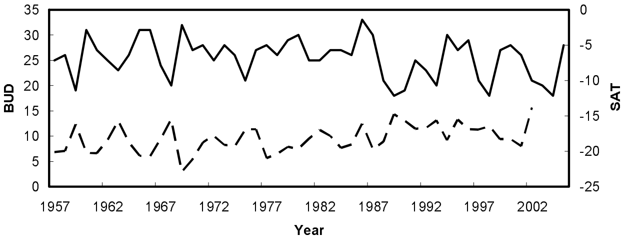

Fig. 1. Time series for the BUD (days after 31 March) of Qike during 1957–2005 (solid line) and the mean JFM SAT (°C) averaged for the region 47.25°–52.25°N, 125.25°–130.25°E during 1957–2002 (dashed line).

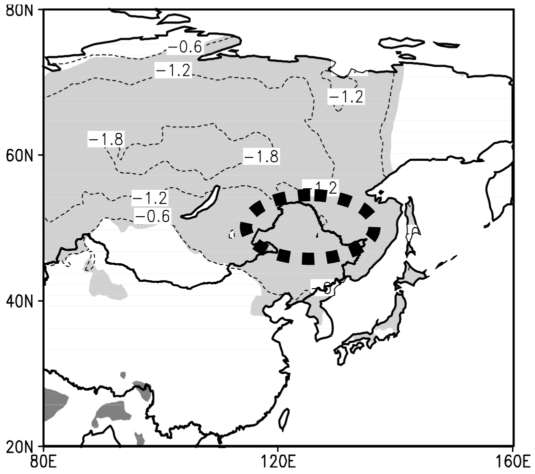

Fig. 2. The JFM SAT regressed against the BUD of the Qike region for the period of 1957–2002. Shaded areas indicate confidence level greater than 95%. The circle in the figure indicates the region where the rivers are located.

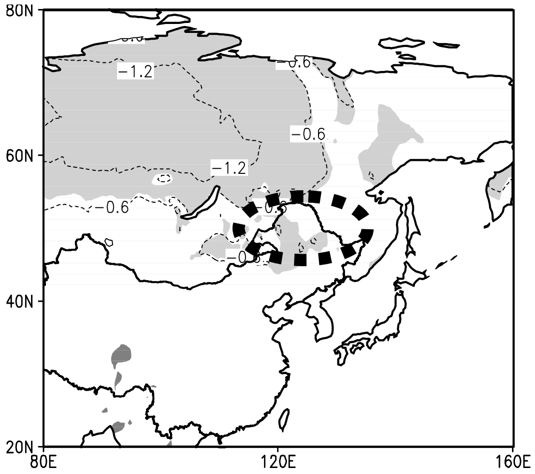

Fig. 3. The JFM SAT regressed against the precipitation of the Qike region, averaged across (47.25°–52.25°N, 125.25°–130.25°E) for the period of 1957–2002. Shaded areas indicate confidence level greater than 95%. The circle in the figure indicates the region where the rivers are located.

Another potential reason is that the BUD of the river is not only determined by the SAT, but also by dynamic conditions. A stronger winter monsoon circulation favors increased precipitation during JFM (snowfall), snowfall being the main phase of precipitation during JFM. Figure 3 shows the connection between the local JFM snowfall and the SAT over the Siberian-Northeast China region via regression analysis. A clear negative correlation is presented, indicating that a large area of negative SAT anomalies

Table 1. BUDs of the Heilongjiang River at Heihe (HH) and Qike (QK), and the Songhuajiang River at Jiamusi (JM) and Tonghe (TH) during 1957–2005. The first numeral of the figure denotes the month and the last two numerals denote the date (e.g., "425" denotes the 25th of April).

Year	HH	QK	JM	TH
1957	425	425	421	418
1958	427	426	413	405
1959	425	419	405	403
1960	501	501	423	419
1961	426	427	419	418
1962	427	425	421	419
1963	426	423	411	413
1964	426	426	416	416
1965	428	501	415	416
1966	430	501	418	420
1967	425	424	414	412
1968	411	420	409	403
1969	504	502	416	412
1970	427	427	419	417
1971	501	428	419	415
1972	425	425	414	412
1973	427	428	420	420
1974	426	426	419	419
1975	420	421	413	411
1976	430	427	416	413
1977	507	428	413	414
1978	426	426	412	408
1979	501	429	417	413
1980	502	430	419	417
1981	430	425	413	409
1982	426	425	412	412
1983	428	427	409	407
1984	429	427	417	418
1985	426	426	417	416
1986	429	503	415	413
1987	501	430	418	417
1988	421	421	416	416
1989	422	418	406	406
1990	420	419	411	406
1991	427	425	409	414
1992	423	423	408	403
1993	420	420	405	408
1994	501	430	416	412
1995	503	427	418	414
1996	425	429	416	414
1997	421	421	407	410
1998	418	418	406	405
1999	428	427	419	421
2000	427	428	417	415
2001	429	426	416	414
2002	422	421	404	402
2003	418	420	410	410
2004	417	418	407	406
2005	422	428	412	409

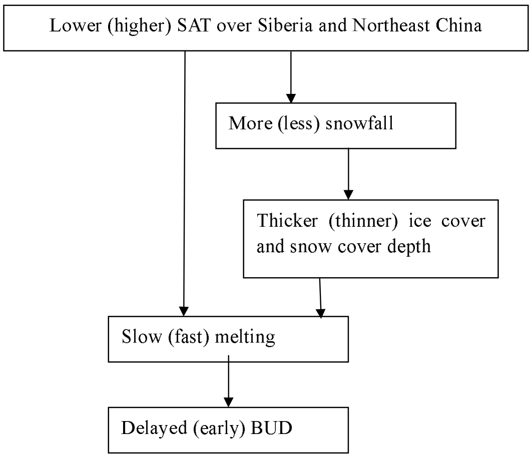

Fig. 4. Schematic diagram showing the effect of the JFM SAT on the BUD.

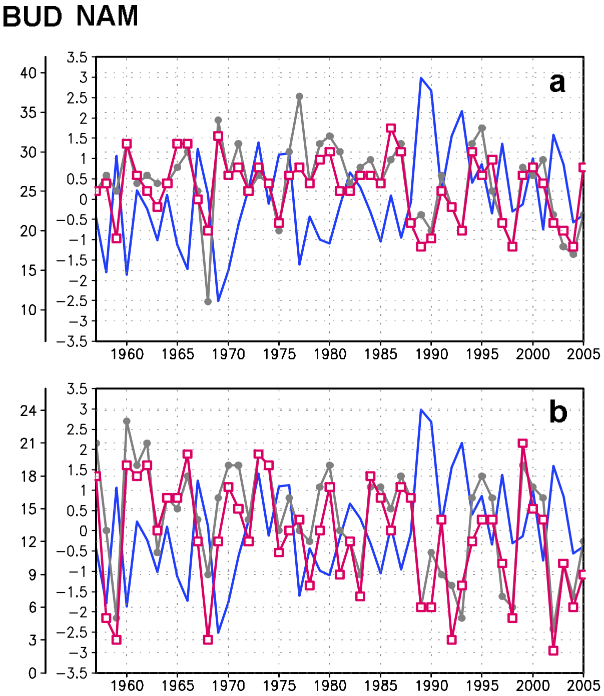

Fig. 5. Time series for the NAM and BUD (days after 31 March) in 1957–2005. (a) for the NAM (blue) and BUD at Heihe (grey) and Qike (pink), (b) for the NAM (blue) and BUD at Jiamusi (grey) and Tonghe (pink).

(stronger winter monsoon) normally correspond to increased snowfall in Northeast China, and vice versa. Therefore, a lower SAT and the associated increased snowfall in Northeast China would result in thicker ice cover and more snow cover during the winter season. Therefore, the BUD would be postponed.

To summarize, the BUD is essentially controlled by the SAT over the Siberian-Northeast China region in two ways: firstly, the lower (higher) SAT corresponds to slower (faster) melting and delayed (early) BUD. Secondly, a lower (higher) SAT corresponds indirectly with increased (decreased) snowfall, thicker (thinner) ice covers and snow cover depth, slower (faster) melting and delayed (early) BUD. A schematic diagram for the SAT-BUD linkage is depicted in Fig. 4.

It is important to recognize the large-scale factors of atmospheric circulation that are associated with the variability of the BUD. The northern annular mode (NAM) is a major influence of interannual variability in the middle and high latitudes of the Northern Hemisphere (Thompson and Wallace, 1998, 2000). The NAM has been documented to have in-phase relationships with the winter SAT and the East Asian winter monsoon (Gong et al., 2001; Wu and Wang, 2002). In this study, the role of the NAM in the variability of the BUD was addressed. It was found that the NAM was negatively correlated with the BUD at all four selected stations during the period of 1957–2005. The correlation coefficients between the JFM NAM and the BUD at the Heihe, Qike, Jiamusi, and Tonghe were respectively −0.48, −0.59, −0.49, −0.41 before removal of the linear trend, and −0.43, −0.55, −0.41, −0.35 after removal of the linear trend. The linear trend was removed by linear regression. All of the correlation coefficients listed were above the 95% confidence level, as estimated by the student t-test. Therefore, the correlation between the NAM and the BUD at the four stations was quite consistent, a finding that can also be seen in Fig. 5, which shows the time series of the NAM and the BUD at the four stations for the period of 1957–2005.

The key factor in the NAM-BUD relationship is the SAT over the Siberian-Northeast China region. Figure 6 depicts the regression of the SAT against the NAM for JFM. It is clearly shown that the NAM was positively correlated with the SAT over the Siberian-Northeast China region, confirming its role as a major controller of the BUD in Northeast China. The pattern of the regressed SAT was quite similar to that of the regressed BUD at Qike, shown in Fig. 2, with the opposite sign.

Since the SAT during JFM is an indicator for the winter East Asian monsoon, anticyclonic anomalies of velocity at 850 hPa were identified over the region of Siberia-Northeast China, centered in Northeast China. The velocity pattern at 850 hPa evidently indicated a weaker winter East Asian monsoon. Again, the spatial pattern of the velocity at 850 hPa against the NAM (Fig. 7) was quite similar to that of the regressed velocity at 850 hPa against the BUD at Qike, the only difference being that the regressed velocity at 850 hPa against the BUD at Qike was cyclonic (figures not

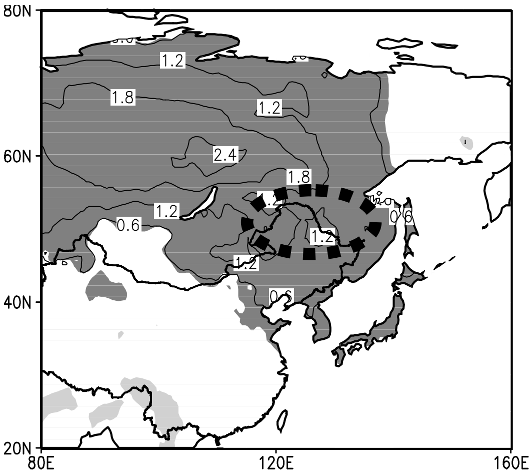

Fig. 6. The SAT regressed against the NAM index during JFM for the period of 1957–2002. The shaded area indicates greater than 95% confidence level.

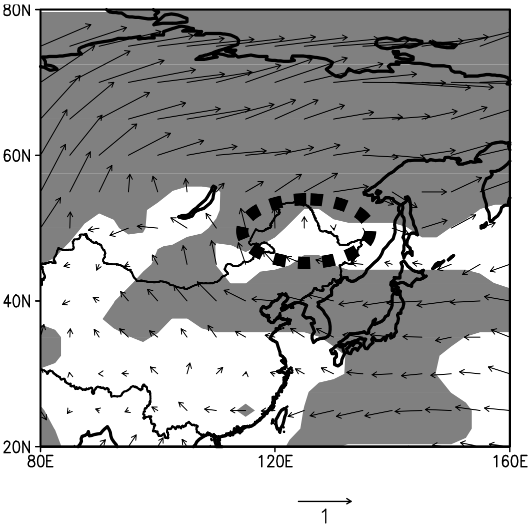

Fig. 7. The velocity at 850 hPa regressed against the NAM index in JFM for the period of 1957–2002. Shaded areas indicate greater than 95% confidence level.

shown).

4. Concluding remarks

The variability of the icebound season for the rivers in the Heilongjiang Province of Northeast China was investigated. The results showed that an interdecadal variation occurred in the late 1980s as a result of the long-term warming trend. The icebound state of the two rivers ended about four days earlier in 1989–2005 than in 1971–1987. The interannual variability of the BUD is primarily controlled by the JFM SAT over the Siberian-Northeast China region centered over the Lake Baikal area, with a correlation coefficient of -0.67. The SAT over this region can alter the BUD in direct and indirect ways by changing the thickness of the ice cover and snow cover, and by changing the melting rate during the melting period before the BUD. The melting rate is evidently influenced by the SAT, as well as the thickness of the ice cover and snow cover. In addition, the Northern Annular Mode during JFM was identified as affecting the interannual variability of the BUD. The explanation for this linkage between the NAM and the BUD is that the NAM can modulate the SAT across the region of Siberia-Northeast China. Therefore, variability of the icebound season not only indicates changes in the global and regional climate, but also the variability of atmospheric circulation.

Better understanding of the interannual variability of the river icebound state may lead to reasonable prediction of the river break-up date and the freeze-up date, which will benefit the local people and society by better planning transportation on the frozen rivers or in relation to melting rivers, and by directing recreational activities on icebound rivers, and preventing possible damage caused by the rivers' break-up. However, the study in this paper needs to be continued to further realize the mechanisms of the BUD (FUD) variability by using more stations' data, by considering the impacts of the upstream river runoff, and by employing climate simulation approaches.

Acknowledgements. The authors would like to thank Mr. Gao Yuzhong from the Heilongjiang Meteorological Office for providing the data pertaining to the river icebound state. The research was jointly supported by National Basic Research Program of China (973 Program) under Grant No. 2009CB421406, the Chinese Academy of Sciences under Grant KZCX2-YW-Q1-02, and the National Natural Science Foundation of China under Grant No. 40631005.

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