Yukon River hydrological and climatic changes, 1977–2006

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Abstract This paper analyses long-term hydrology and climate data over the Yukon River basin. It uses regression analysis to define the relationship between the climate and discharge data over the basin. Discharge at the outlet of the basin shows low runoff in the cold season (November to April), with small variations. Flow is high (28 483–177 000 ft^3/s; 807–5012 m^3/s) with high fluctuations in the warm season (May to October). The discharge in May has a positive trend (177 000 ft^3/s; 5012 m^3/s). The mean annual flow is about 227 912 ft^3/s (6454 m^3/s), with high fluctuations; it has increased by 18 213 ft^3/s (or 8%) during the study period. Basin air temperature from 1977 to 2006 increased by 3.9°F (2.2°C) in June and decreased by 10.5°F (5.8°C) in January. Basin precipitation has negative trend in June (0.6 inch; 15.2 mm) with a confidence over 93%. Regression analysis shows a strong and positive correlation between temperature and discharge in May, and a strong and negative correlation between May temperature and June discharge. Precipitation in August and September has strong and positive correlations with basin discharge in September and October.

Key words cold region hydrology; Arctic climate; Yukon River basin; correlation analysis

1 INTRODUCTION

During the last several decades, climate over the Arctic region has experienced significant changes, such as warmer winters (Serreze *et al*., 2000; Houghton *et al*., 2002), increasing winter and autumn precipitation in northern Eurasia (Wang & Cho, 1997), greater winter snow depth and enhanced thawing of permafrost in the Arctic and subarctic Russia (Pavlov, 1994). River runoff in the high latitude regions is a critical source of freshwater to the Arctic Ocean. Freshwater systems in arctic and subarctic regions are undergoing profound changes (IPCC, 2001; ACIA, 2005). Freshwater discharge from the northern rivers plays an important role in regulating the thermohaline circulation of the world's oceans (Aagaard & Carmack, 1989). Studies show that both the amount and the timing of freshwater inflow to the ocean systems affect ocean circulation, salinity, sea ice dynamics, and climate (Aagaard & Carmack, 1989; Macdonald, 2000). Therefore, it is of critical importance to understand and quantify the hydrological regimes and changes over large rivers in the northern regions.

Significant climate change has occurred in the Yukon River Basin. Shulski & Wendler (2007) have detected a slight increase in the average annual temperature over the last 30 years in Alaska. Zhao (2004) detected significant warming trends in the northern river basins, including the Yukon River. Yang *et al*. (2009) identified a clear correspondence of river discharge to seasonal snow cover change for the Yukon basin. Brabets *et al*. (2009) found that annual discharge had remained relatively unchanged during 1944–2005, but a few glacier-fed rivers demonstrate positive trends due to enhanced glacier melt. The Yukon River is very important to the Bering Sea ecosystem because it provides most of the freshwater runoff, sediments, and dissolved solutes in the eastern part of the Bering Sea (Lisitsysn, 1969). Therefore, it is necessary to analyse the hydrological regime and its response to climate change over the Yukon River.

2 BASIN DESCRIPTION, DATA SETS AND METHODS

The Yukon River basin (Fig. 1) is located in northwestern Canada and central Alaska. It is the fourth largest river in the North America, with a drainage area of 331 005 sq. miles (857 299 km^2) and average annual discharge of 226 014 ft^3/s (6400 m^3/s) (Brabets *et al*., 2002, 2009). The discharge data for 1977–2006 (US Geological Survey, http://www.waterdata.usgs.gov/nwis) are from the Pilot station near the basin outlet (Fig. 1). Temperature and precipitation data are from the Alaska Climate Research Center (ACRC, http://climate.gi.alaska.edu) at University of Alaska

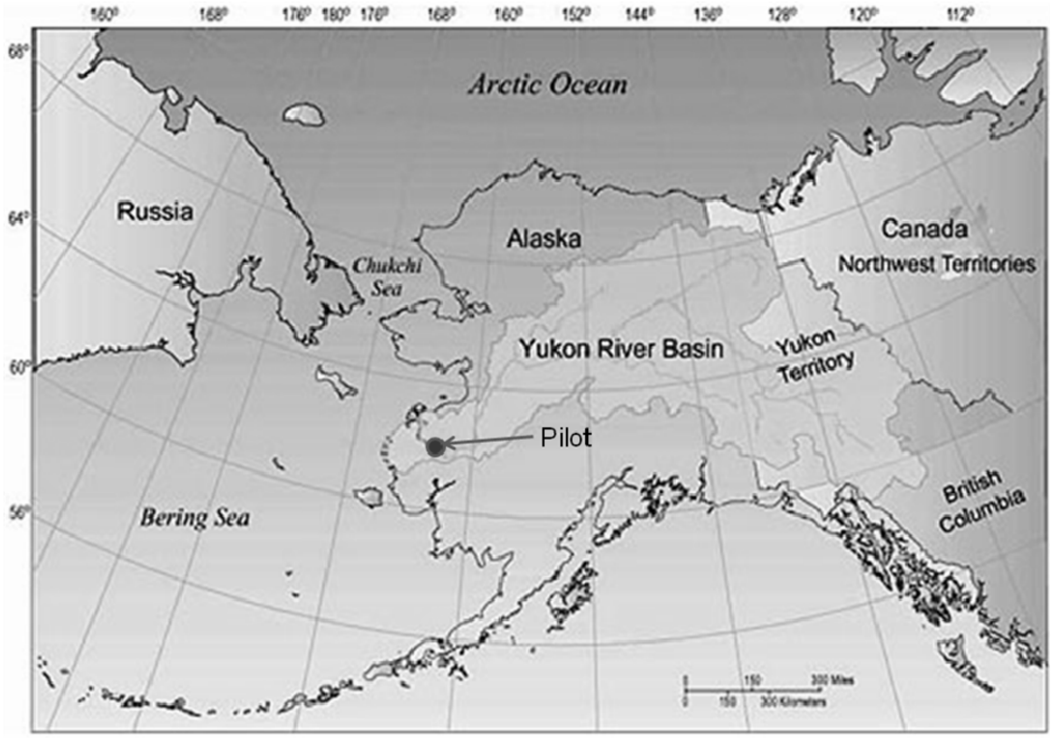

Fig. 1 The Yukon River watershed and location of the Pilot station near the basin outlet (USGS, 2001).

Fairbanks. The monthly temperature and precipitation data from five stations within (and closest to) the Yukon River basin have an overlapping time period (1977–2006) with discharge data.

Monthly mean and standard deviation for monthly discharge, temperature, and precipitation have been calculated to define the hydrological and climatic regimes over the basin. The long-term hydro-climatic changes have been determined by a linear trend analysis. Statistical significance tests are conducted for the trends. Correlation analysis and statistical significance tests are used to assess the associations among climatic and hydrological variables. Based on these analyses, the consistency in flow changes over the basin is examined.

3 DISCHARGE REGIME AND CHANGE

The statistical analysis of monthly flow records at the Pilot station (Fig. 2) shows a low flow period (46 639–125 587 ft^3/s; 1321–3556 m^3/s) during November to April, and a high flow period (252 087–579 747 ft^3/s; 7138–16 417 m^3/s) from May to October, with the maximum flow (579 747 ft^3/s; 16 417 m^3/s) occurring usually in June due to snowmelt floods and ice jams. Trend analyses show an obvious increase by 177 000 ft^3/s (5012 m^3/s) in May, which is significant at 97%; the increase of 4 586 ft^3/s (130 m^3/s) in April is significant at over 85%; the other months have small changes with low confidence levels.

The annual discharge of the Yukon River from 1977 to 2006 is given in Fig. 3. Trend analysis indicates an increase of mean annual flow by 18 213 ft^3/s (516 m^3/s, 8.0%) over 1977–2006. This change is probably caused by the high discharge event in 2005. The peak flow (784 400 ft^3/s; 22 211 m^3/s) in May 2005 has pulled the trend up, as this high flood event caused the higher mean annual flow for this year.

Daily flow data (Fig. 4) show that the flow in the cold season (November to April) is very low and does not change much. This is because the flow in the cold season is dominated by groundwater, which does not change much in winter. But for the warm season (May to October), flow variations are quite large due to rainfall variations. The timing of peak flow at the Pilot Station shifted to an earlier date due to a warmer spring.

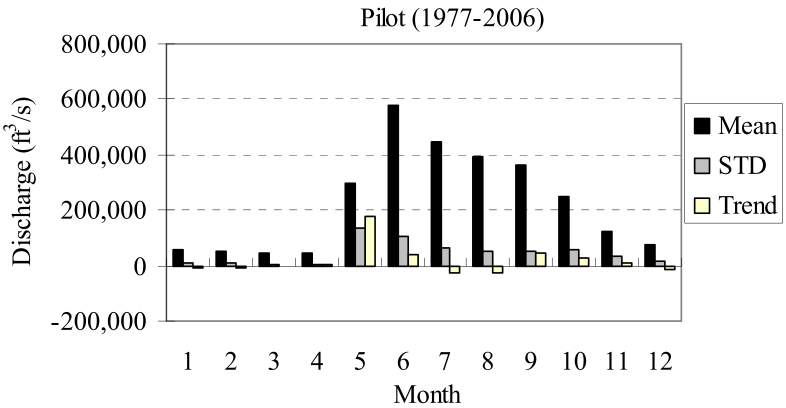

Fig. 2 Mean monthly discharge, standard deviation, and trend at the Pilot Station during 1977–2006.

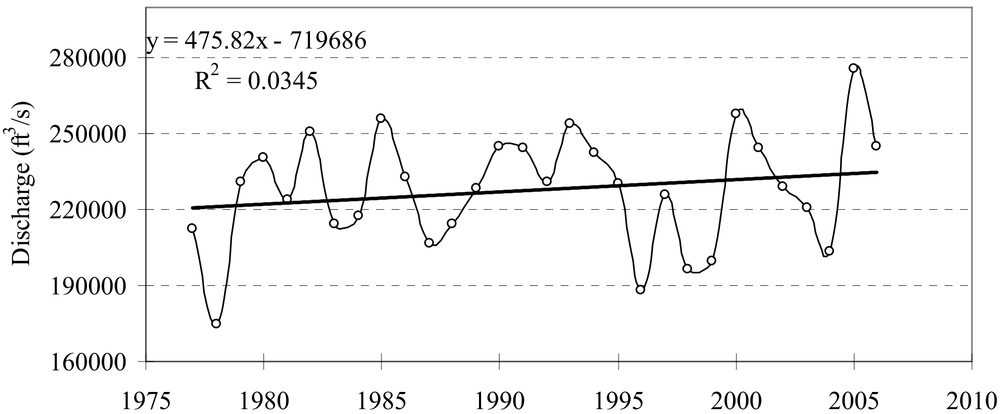

Fig. 3 Yearly discharge record at the Pilot Station during 1977–2006.

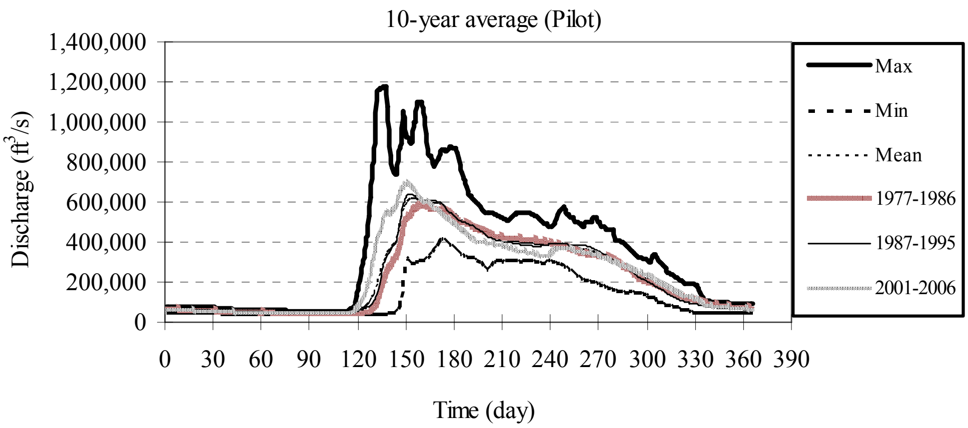

Fig. 4 The 10-year average of daily discharge at the Pilot Station.

4 BASIN TEMPERATURE AND CORRELATION WITH DISCHARGE

Figure 5 shows the monthly mean air temperature over the Yukon River Basin during 1977–2006. The warm season is from May to September (43.9–59.6°F; 6.6–15.3°C) with the maximum temperature in July (59.6°F; 15.3°C); while the cold season is from October to April (–2.3°F to 28.8°F; –19.1°C to –1.8°C). Trend analyses suggest an increase by 3.9°F (2.2°C) in June

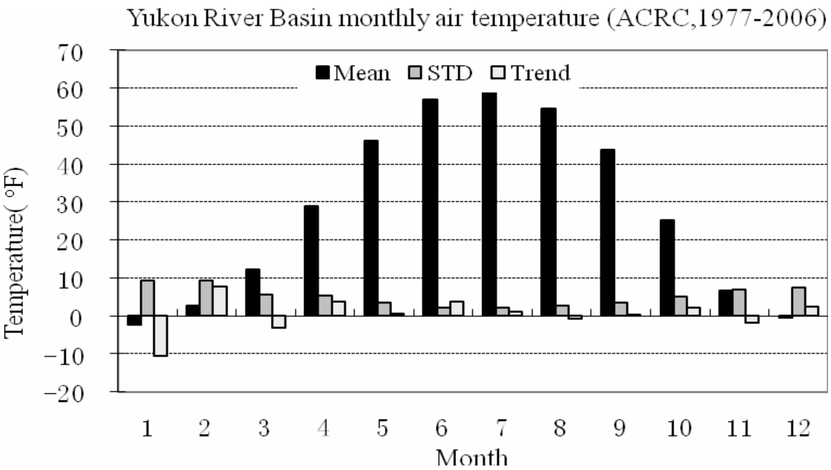

Fig. 5 Mean monthly temperature, standard deviation, and trend over the Yukon River basin (1977–2006).

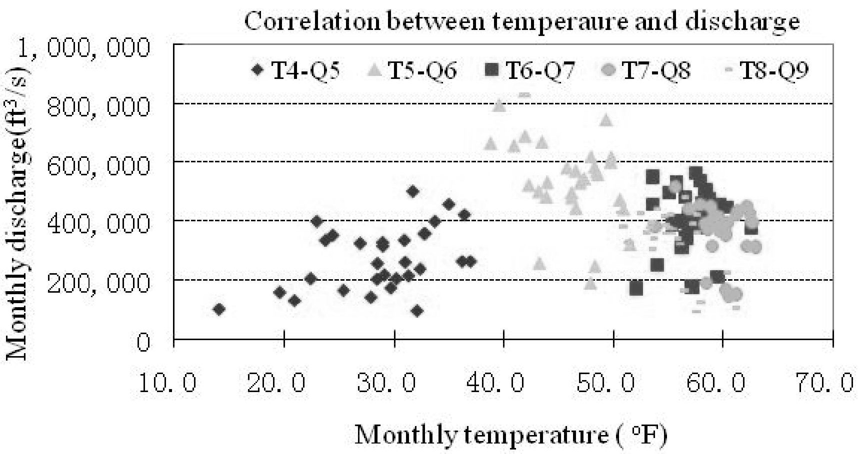

Fig. 6 Correlation between monthly discharge at the Pilot Station and basin mean temperature, with a time lag of one month.

(confidence level at 99.7%); there is a slight decrease of 0.8°F (0.4°C) in August but the confidence level is below 60%; weak positive trends (statistically insignificant) are detected in May (0.6°F; 0.3°C), July (1.0°F; 0.6°C), and September (0.4°F; 0.2°C). During the winter season, the temperature decreased by 10.5°F (5.8°C) in January with a confidence level of 92.3%. It increased in February (7.7°F; 4.3°C), April (3.7°F; 2.1°C), October (2.2°F; 1.2°C), and December (2.6°F; 1.4°C). The positive trends in these months are not statistically significant. The negative trends in March (3.2°F; 1.8°C) and November (1.8°F; 1°C) have confidence levels below 60%. Mean annual temperature during 1977–2006 increased by 0.5°F (0.3°C). Brabets *et al.* (2002) found that the warming rate over the Yukon River during 1949–1996 has been about 0.4°F (0.2°C) per hundred years.

Correlation analyses between basin air temperature and discharge at the Pilot Station (Fig. 6) show a strong positive relation in May. This is probably caused by a stronger and faster snowmelt in warmer springs. Temperature in May has a strong negative correlation with the discharge in June. It is likely that the increased temperature in May causes more snowmelt in May, and subsequently reduces discharge in June.

5 BASIN PRECIPITATION AND CORRELATION WITH DISCHARGE

Figure 7 displays results of statistical analyses for monthly precipitation from 1977 to 2006. It indicates high precipitation period (1.7–2.5 inch; 43.2–63.5 mm) from June to September, with the maximum value in August (2.5 inches; 63.5 mm). The low precipitation period (0.5–1.1 inch; 12.7–27.9 mm) is from October to May. An obvious negative trend is observed in June (0.6 inch; 15.2 mm) with a confidence level over 93%. Precipitation decreased by 0.4 inch (10.2 mm) in December, but with a confidence level lower than 80%. Weak precipitation decreases are detected in March (0.1 inch; 2.5 mm), April (0.1 inch; 2.5 mm), and November (0.1 inch; 2.5 mm). Positive trends are observed in February (0.5 inch; 12.7 mm) with a confidence level greater than 87%, and in January (0.2 inch; 5.1 mm), May (0.3 inch; 7.6 mm), July (0.3 inch; 7.6 mm), August (0.6 inch; 15.2 mm), September (0.3 inch; 7.6 mm), and October (0.1 inch; 2.5 mm), with confidence levels less than 80%. Annual precipitation during 1977–2006 shows an increase by 1.1 inch (27.9 mm).

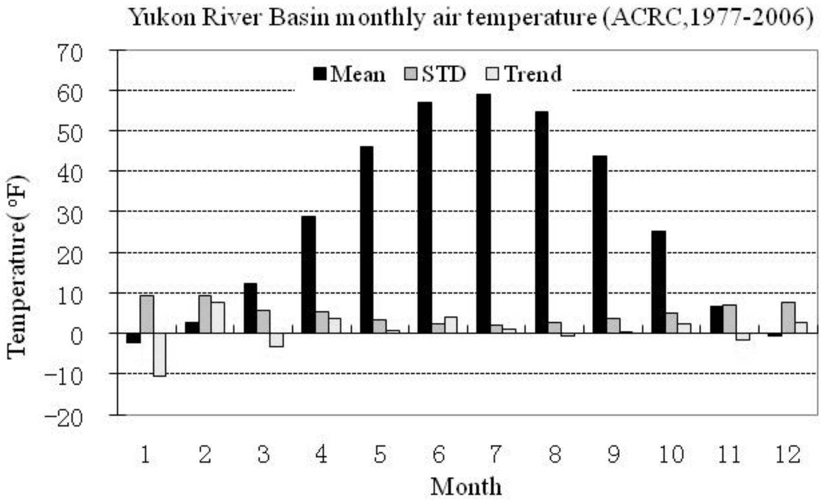

Fig. 7 Mean monthly precipitation, standard deviation, and trend for the Yukon River basin (1977–2006).

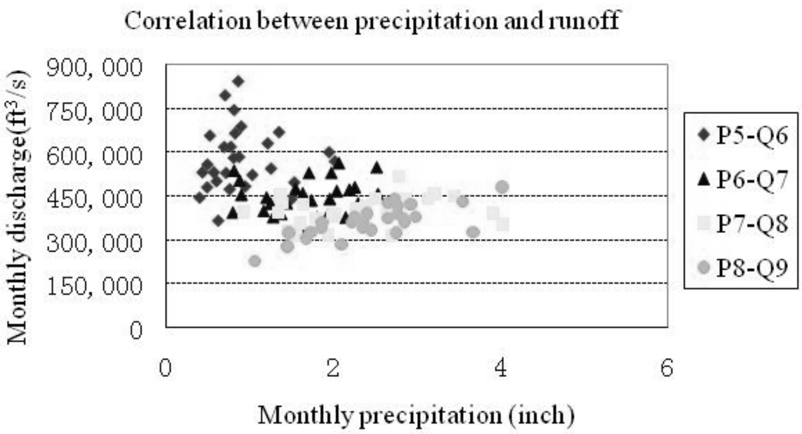

Fig. 8 Correlation between monthly discharge at the Pilot Station and basin mean precipitation, with time lag of one month.

Correlation analyses between basin precipitation and discharge at the Pilot Station (Fig. 8) reveal that the precipitation in August has a strong positive relation with runoff in September. Precipitation in April and May weakly and positively correlates with runoff in May and June, respectively.

6 CONCLUSION

The Yukon River has low flow with small variations in the cold season (November to April) and high flow with large variations in warm season (May to October). Monthly discharge at the Pilot Station increased significantly by 177 000 ft^3/s (5012 m^3/s) or 59% in May and 42 303 ft^3/s (1198 m^3/s) or 7% in June due to a warm spring. Daily discharge analyses show that the peak flow at the Pilot station increased by 67 400 ft^3/s (1909 m^3/s), with timing shifting to an earlier date due to early warming in spring. The annual discharge at the Pilot station has large fluctuations and an increase trend of 18 213 ft^3/s (516 m^3/s, 8.0%) during 1977–2006.

Basin temperature during 1977–2006 strongly increased in winter (December to February) and spring (March to May) by 2.2 to 7.7°F (1.2–4.3°C). The warming is especially significant (3.7°F; 2.1°C) in April, which caused earlier snowmelt over the basin. The basin temperature in April has a strong positive correlation with discharge in May. From 1977 to 2006, the basin precipitation during June–August increased by 0.3 to 0.6 inch (7.6–15.2 mm); and during September to November increased by 0.1 to 0.3 inch (2.5–7.6 mm). Precipitation in August has a strong positive correlation with discharge in September. The total precipitation increase (1.0 inch; 25.4 mm) during May to September contributes to the flow increase in September at the Pilot Station.

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7 REFERENCES

Aagaard, K. & Carmack, E. C. (1989) The role of sea ice and other fresh water in the arctic circulation. *J. Geophys. Res.* **94**(C10), 14,485– 14,498.

ACIA (2005) *Arctic Climate Impact Assessment.* Cambridge Univ. Press, New York, USA. 1042 pp.

Brabets, T. P. & Walvoord, M. A. (2009) Trends in streamflow in the Yukon River Basin from 1944 to 2005 and the influence of the Pacific Decadal Oscillation. *J. Hydrol.* **371**(1-4), 108–119.

Brabets, T. P., Wang, B. & Meade, R. H. (2000) Environmental and hydrologic overview of the Yukon River Basin, Alaska and Canada. *US Geological Survey Water-Resources Investigations Report 99-4204*, 106 pp.

Houghton, J. T., Ding, Y., Griggs, D. J., Noguer, M., van der Linden, P. J., Dai, X., Maskell, K. &. Johnson, C. A. (2002) *Climate Change 2001: The Scientific Basis.* Cambridge University Press, Cambridge, UK.

IPCC (2001) *Climate Change 2001: Impacts, Adaptation and Vulnerability - Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)*, 801–824, Cambridge Univ. Press.

Lisitsysn, A. P. (1969) *Recent Sedimentation in the Bering Sea*. Washington, D.C., National Science Foundation, The Israel Program for Scientific Translations (translated from Russian).

Macdonald, R. W. (2000) Arctic estuaries and ice: A positive-negative estuarine couple. In: *The Freshwater Budget of the Arctic Ocean: Proceedings of the NATO Advanced Research Workshop*, edited by E. L. Lewis *et al*., 383–407, Kluwer Acad., Norwell, Massachusetts, USA.

Pavlov, A. V. (1994) Current change of climate and permafrost in the Arctic and subarctic of Russia, *Permafrost and Periglacial Processes* **5**, 101–110.

Serreze, M. C., Walsh, J. E., Chapin, E. C., Osterkamp, T., Dyugerov, M., Romanovsky, V., Oechel, W. C., Morison, J., Zhang, T. & Barry, R. G. (2000) Observation evidence of recent change in the northern high-latitude environment. *Climate Change* **46**, 159–207.

Shulski, M. & Wendler, G. (2007) *The Climate of Alaska.* University of Alaska Press, Fairbanks, USA. 143 pp.

Wang, X. L. & Cho, H.-R. (1997) Spatial-temporal structures of trend and oscillatory variabilities of precipitation over Northern Eurasia. *J. Clim.* **10**, 2285–2298.

Yang, D., Zhao, Y., Armstrong, R. & Robinson, D. (2009) Yukon River streamflow response to seasonal snow cover changes, *Hydrol. Processes* **23**, 109–121.

Zhao, Y. (2004) Snow cover runoff assessment in five large northern watersheds, Master Thesis. University of Alaska Fairbanks, Fairbanks, Alaska, USA.