



Supplement of

Asymmetric shifts in seasonal transition timing in a sub-Arctic river system under climate warming

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Table S1 Intra-variable Intervals (IVI) and their definitions for each variable used in the analysis.

Intra-variable Interval (IVI)	Legacy period	Definition	Variable
DSP (Discharge Stability Period)	Ice cover	Period between DSO and DSE	Discharge
DVP (Discharge Variability Period)	Open water	Complementary period to DSP	Discharge
CSP (Continuous Snow Period)	Snow cover	Period between CSO and CSE	Snow depth
NSP (Non-Continuous Snow Period)	No-snow	Complementary period to CSP	Snow depth
CDP (Cooling-Dominant Period)	Cold season	Period between CCT and CWT	Temperature
WDP (Warming-Dominant Period)	Warm season	Complementary period to CDP	Temperature

Table S2 Cross-variable intervals (CVI) and their definitions for each variable used in the analysis. Note. For each row A–B, $\Delta t_{A \rightarrow B} = t(B) - t(A)$ (days), with t the calendar day of the PCT within the WY. When $\Delta t_{A \rightarrow B} > 0$, event A precedes B; when $\Delta t_{A \rightarrow B} < 0$, B precedes A.

Cross-variable intervals (CVI)	Definition	Variables	Phase
DSO–CSO	Signed timing offset between discharge stabilization onset and continuous snow onset	Discharge–Snow	Onset-group
DSO–CCT	Signed timing offset between discharge stabilization onset and cumulative cooling transition	Discharge–Temperature	Onset-group
CSO–CCT	Signed timing offset between continuous snow onset and cumulative cooling transition	Snow–Temperature	Onset-group
DSE–CSE	Signed timing offset between discharge stabilization end and continuous snow end	Discharge–Snow	Release-group
DSE–CWT	Signed timing offset between discharge stabilization end and cumulative warming transition	Discharge–Temperature	Release-group
CSE–CWT	Signed timing offset between continuous snow end and cumulative warming transition	Snow–Temperature	Release-group

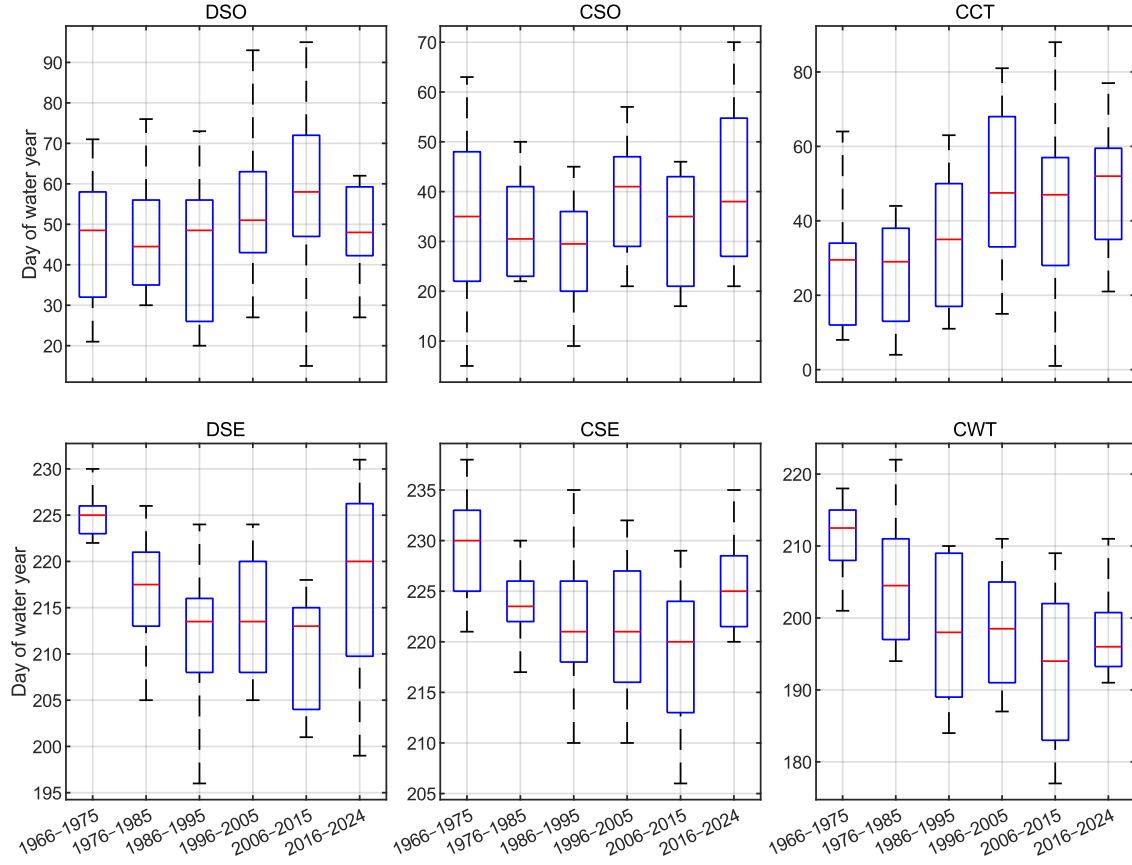


Figure S1 Decadal-scale distributions of PCT timings (day of WY) across the full record (WY1966–WY2024), for consecutive 10-year blocks (last block 9 years, WY2016–WY2024). (Top row) Onset-group PCTs (Bottom row) Release-group PCTs. (Left column) discharge PCTs, (Middle column) snow-depth PCTs, and (Right column) air temperature PCTs.

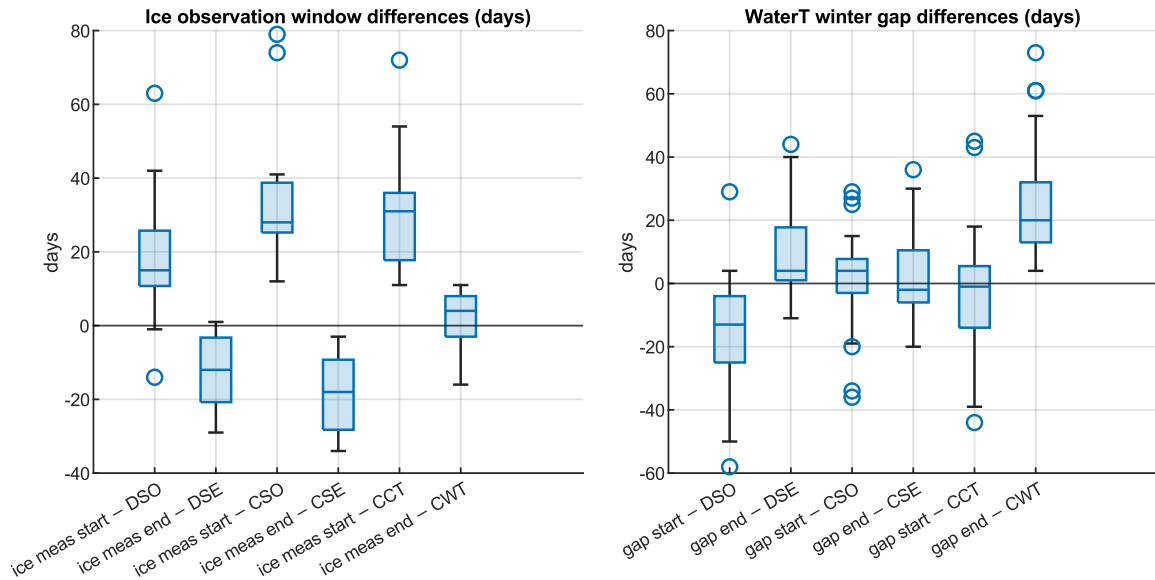
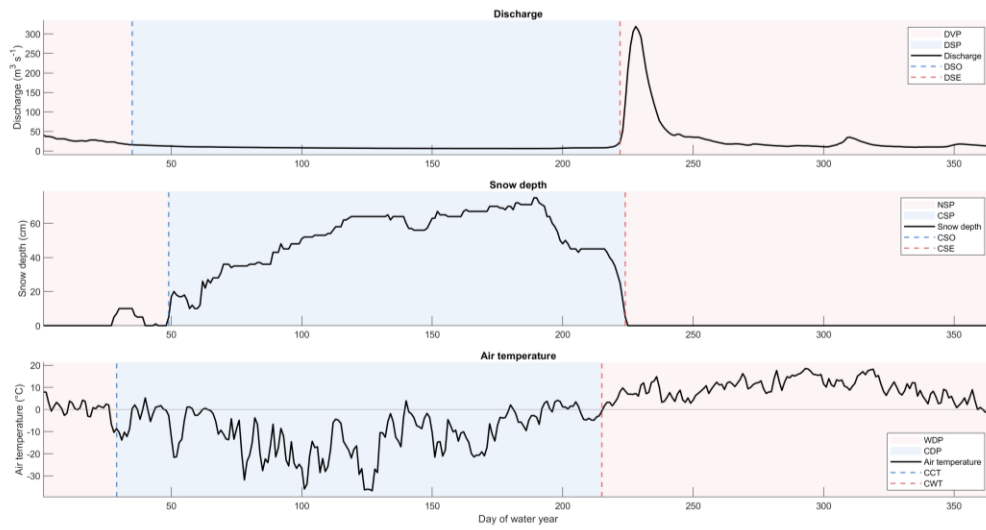


Figure S2 Ice observation timing and water-temperature data gaps relative to RiTiCE proxy transition dates (WY1966–WY2024). (A) Differences between the start/end of the ice-thickness measurement window and the corresponding PCT dates. (B) Differences between the start/end of the largest winter gap in WaterT observations and the corresponding PCT dates. The zero line indicates perfect agreement; positive values mean the observation/gap endpoint occurs after the proxy date and negative values mean it occurs before. These records provide operational context only and are not a validation of the detected PCTs.

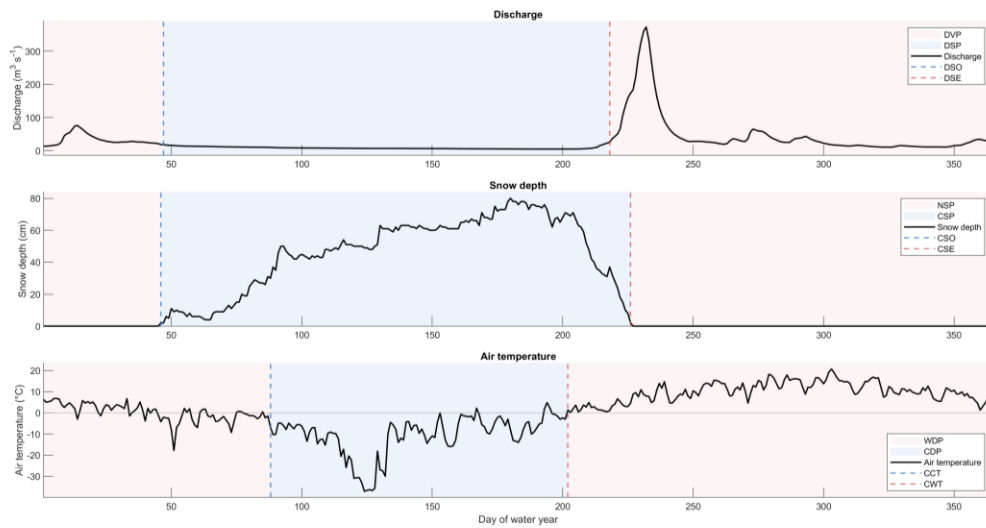
(a)

Water year 1975 – PCT & IVI



(b)

Water year 2011 – PCT & IVI



(c)

Water year 2020 – PCT & IVI

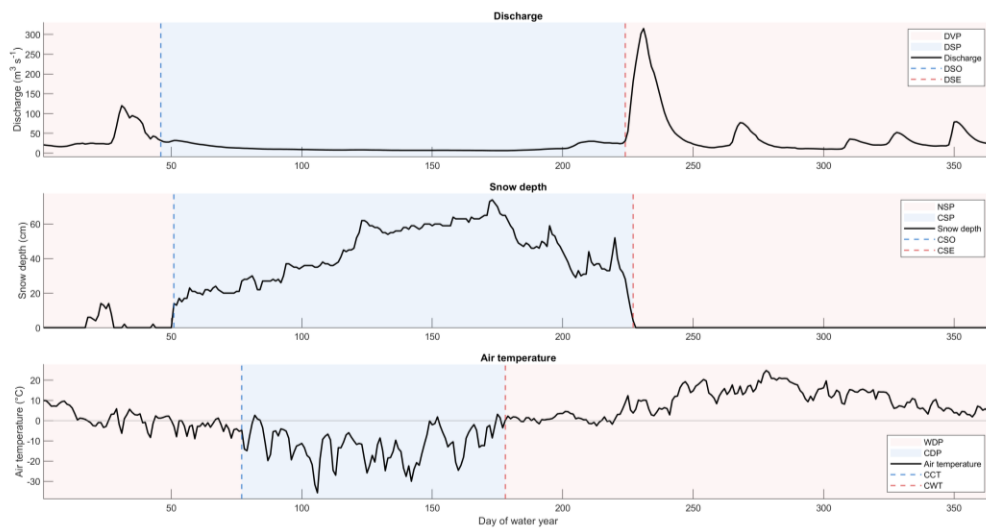


Figure S3 Example water years illustrating onset-group ordering reversals. For each year, daily discharge, snow depth, and air temperature are shown together with the detected onset-group PCTs (DSO, CSO, CCT) and the shaded intra-variable intervals. (a) WY1975: a short early snow spell falls outside the longest continuous snow segment, so CSO is set later and the order is CCT, DSO, CSO. (b) WY2011: discharge stabilizes while the cumulative cooling transition is delayed, giving CSO, DSO, CCT. (c) WY2020: discharge stabilizes early and the initial snow record falls outside the continuous segment, giving DSO, CSO, CCT.