Impacts of convective storms on runoff, erosion, and carbon export in a continuous permafrost landscape

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ABSTRACT

Permafrost holds more than twice the amount of carbon currently in the atmosphere, but this large carbon reservoir is vulnerable to thaw and erosion under a rapidly changing Arctic climate. Convective storms are becoming increasingly common during Arctic summers and can amplify runoff and erosion. These extreme events, in concert with active layer deepening, may accelerate carbon loss from the Arctic landscape. However, we lack measurements of carbon fluxes during these events.

Rivers are sensitive to physical, chemical, and hydrological perturbations, and thus are excellent systems for studying landscape responses to thunderstorms. We present observations from the Canning River, Alaska, which drains the northern Brooks Range and flows across a continuous permafrost landscape to the Beaufort Sea. During summer 2022 and 2023 field campaigns, we opportunistically monitored river discharge, sediment, and organic carbon fluxes during several thunderstorms. During one notable storm, river discharge nearly doubled from ~130 m^3/s to ~240 m^3/s, suspended sediment flux increased 70-fold, and the particulate organic carbon (POC) flux increased 90-fold relative to non-storm conditions. Taken together, the river exported ~16 metric tons of POC over one hour of this sustained event, not including the additional flux of woody debris. Furthermore, the dissolved organic carbon (DOC) flux nearly doubled. Although these thunderstorm-driven fluxes are short-lived (hours to days), they play an outsized role in exporting organic carbon from Arctic rivers. Understanding how these extreme events impact river water, sediment, and carbon dynamics will help predict how Arctic climate change will modify the global carbon cycle.

1 INTRODUCTION

Permafrost soils hold more than twice the amount of carbon currently in our atmosphere (Schuur et al. 2013). The Arctic is warming four times faster than the rest of the world (Rantanen et al. 2022), causing this carbon-bearing permafrost to thaw. Along with warming air temperatures, convective storms may be occurring more frequently now than in the past and the fraction of annual precipitation from convective storms is projected to increase in the future (Bennett and Walsh 2015; Poujol et al. 2020; Bieniek et al. 2022). Increases in the amount of precipitation delivered by extreme events are predicted to be greater than increases in mean annual precipitation over the next 80 years (Bennett and Walsh 2015; Bieniek et al. 2022). Earlier sea ice retreat and a lengthening open water season increases the probability of precipitation during the Arctic summer (Galley et al. 2016; Broadman et al. 2020; Blaskey et al. 2023). Increased runoff generated by these thunderstorms may accelerate erosion of the landscape, such that the carbon stored in previously frozen soil is now being removed from the landscape and transported down rivers to the Arctic Ocean. We hypothesize that intense convective storms are causing Arctic watersheds to lose more carbon now than in the past, but we lack evidence of how these extreme events affect the amount of organic carbon exported by Arctic rivers. Here we aim to understand how the Arctic landscape is physically changing in response to thunderstorms and how much carbon is lost from the landscape as permafrost soils thaw and runoff increases.

Rivers are profoundly sensitive to changes in runoff and erosion across the landscape, as they are conduits for water, solutes, and sediment from the surrounding landscape. Catchments underlain by permafrost have limited subsurface water storage capacity, and thus generate runoff more rapidly than in non-permafrost catchments (McNamara et al. 1998; Kane et al. 2003; Koch et al. 2013). Even in spongy, organic-rich soils, water tracks on hillslopes appear to be efficient conduits for runoff, generating a rapid response in Arctic rivers (Evans et al. 2020). Early season (May–June) rain-on-snow events are effective at enhancing runoff, however intense rain storms in July and August can also generate a large and rapid runoff response. Individual rain events in the Arctic summer season can generate peak discharges that rival peaks generated by spring snowmelt runoff (Kane et al. 2003; Arp and Whitman 2022). Observations from the Upper Kuparuk River catchment in July 1999 showed that the runoff response from a single thunderstorm was three times larger than any river discharge recorded over the preceding eight years (Kane et al. 2003). The geomorphic effects of this runoff in permafrost river catchments are poorly understood, as we lack observational data of river turbidity and sediment fluxes during these events and few rivers have long-term discharge gauging stations.

In addition to potential geomorphic change associated with high intensity rainfall events, increases in river discharge may amplify the fluxes of organic carbon exported from the Artic landscape to the ocean. There are two possible mechanisms for storm runoff to enhance river organic carbon fluxes. Active river corridors store organic carbon

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from both allochthonous sources (i.e., transported from upstream in the catchment) and autochthonous sources (soils and biomass accumulating on fluvial sediment deposits). Increases in river stage and discharge generate bed shear stresses sufficient to entrain the POC stored within the channel belt, thereby removing this carbon from the floodplain and transferring it downstream. To a lesser extent, active layer soils, which contain ~61% of the total soil organic carbon stock of Alaska (Mishra and Riley 2012), can be mobilized by riverbank erosion and thermokarst gulley erosion across tundra hillslopes. Riverbank and gulley erosion can cut deeply into frozen soils, causing rapid thaw and potential mobilization of deep permafrost carbon during runoff events. Determining which mechanism of organic carbon export is dominant in Arctic watersheds is challenging due to the lack of long-term carbon flux monitoring data.

Several studies have investigated the temporal variability in dissolved organic carbon (DOC) export in Arctic rivers using both field-based (Finlay et al. 2006; Holmes et al. 2012; Koch et al. 2013, 2021; Shogren et al. 2021), and remote sensing methods (Griffin et al. 2018; Huang et al. 2019; El Kassar et al. 2023). These studies show that DOC concentrations increase with increasing river discharge in Arctic rivers, with the highest DOC fluxes in May–June during the spring freshet and more modest peaks throughout the summer. This suggests that storms have an important impact on export of labile organic matter from Arctic rivers but does not indicate when and how sensitive particulate organic carbon fluxes are to storm runoff.

Due to the challenge of monitoring and sampling suspended sediment in Arctic rivers, few studies have evaluated the temporal variability of particulate organic carbon (POC) export from Arctic rivers. Together, the six largest pan-Arctic rivers (Lena, Kolyma, Ob’, Mackenzie, Yenisey, and Yukon) export ~$3x10^{12}$ gC/yr (McClelland et al. 2016), but this estimate does not account for the temporal variability in river suspended sediment and POC concentrations across the summer season. Furthermore, smaller watersheds may have a stronger river runoff response than these continental-scale river systems which have greater land surface area for water to infiltrate, dampening the river runoff response. Given the flashy behavior of Arctic rivers (Mcnamara et al. 1998; Stuefer et al. 2017), we hypothesize that summer thunderstorms exert an outsized impact on suspended sediment and particulate organic matter export from Arctic watersheds. However, existing discharge-POC rating curves for Arctic rivers do not capture the effects of intense rainfall events, and thus likely underestimate POC export from these catchments.

Here we report observations of an Arctic river responding to thunderstorms that occurred in July 2022 on the North Slope of the Brooks Range in northern Alaska. We opportunistically collected measurements of river discharge, suspended sediment concentration, organic carbon content, and dissolved chemistry before, during, and after thunderstorm-driven runoff events to understand how much sediment and carbon is mobilized and exported to the Arctic Ocean during these extreme events. Over the course of two thunderstorms during this field campaign, we were able to measure changes in river discharge, POC, and DOC. Although thunderstorm-driven changes in river discharge are typically short-lived (hours), our work shows that they have an outsized impact on organic carbon export from Arctic rivers.

2 STUDY AREA AND METHODS

2.1 The Canning River, Alaska

We studied the effects of thunderstorms on river discharge and particulate organic carbon fluxes in the Canning River on the North Slope of Alaska (Figure 1). The Canning River drains the northern flank of the Brooks Range between -146.5° and -145° longitude and flows for ~200 km across the Coastal Plain to the Beaufort Sea. With a catchment area of 7,142 km^2, it is the largest river basin on the North Slope east of the Sagavanirktok River. The Canning is a braided, gravel-bed river with several narrow, single-thread sections. Active layer depths across the Coastal Plain and Brooks Range foothills range from ~35 to 80 cm (Wang et al. 2018), offering very limited storage capacity for rain water delivered to these hillslopes during high intensity convective storms. Combined with steep hillslope gradients > 30° in the headwaters, runoff may rapidly increase river water discharge.

The US Geological Survey (USGS) maintained a river discharge gauging station on the Canning River near the Staines airstrip (69.881523, -146.388850) from June 2008 until October 2012 (US Geological Survey, 2021). This gauging record shows that the river is frozen during the winter, and thus water flows predominantly during the summer season. From 1 May to 31 October, the average river discharge at Staines is 90.44 m^3/s. Precipitation records are not available for the Canning River catchment, making it difficult to directly link river runoff to extreme precipitation events.

We rafted down the Canning River from 28 June to 10 July 2022, from the upper Canning within the headwaters to the mouth at the Beaufort Sea coast. During this field campaign, we selected five locations along the active channel to conduct Acoustic Doppler Current Profiler (ADCP) surveys for river discharge measurement and collect river water samples for suspended sediment and POC (Repasch et al. 2024). T1 is the farthest upstream transect and T5 is the farthest downstream (Figure 1). There are nine notable tributaries between T1 and T3, which could deliver sediment to the mainstem during storms. T4 is 25 km downstream of T3, and over this distance, there are approximately eight small ephemeral streams, which were inactive at the time of our sampling campaign. Due to this lack of notable tributaries, water discharge at T3 and T4 should be similar. Just downstream of T4 is the delta apex, where the river becomes a distributary delta system and water discharge is partitioned between two main channels. Based on our summer 2023 ADCP surveys at T4 and T5 (Repasch et al. 2024), the Staines branch (west) and Canning branch (east) convey roughly 68% and 32% of the river discharge, respectively.

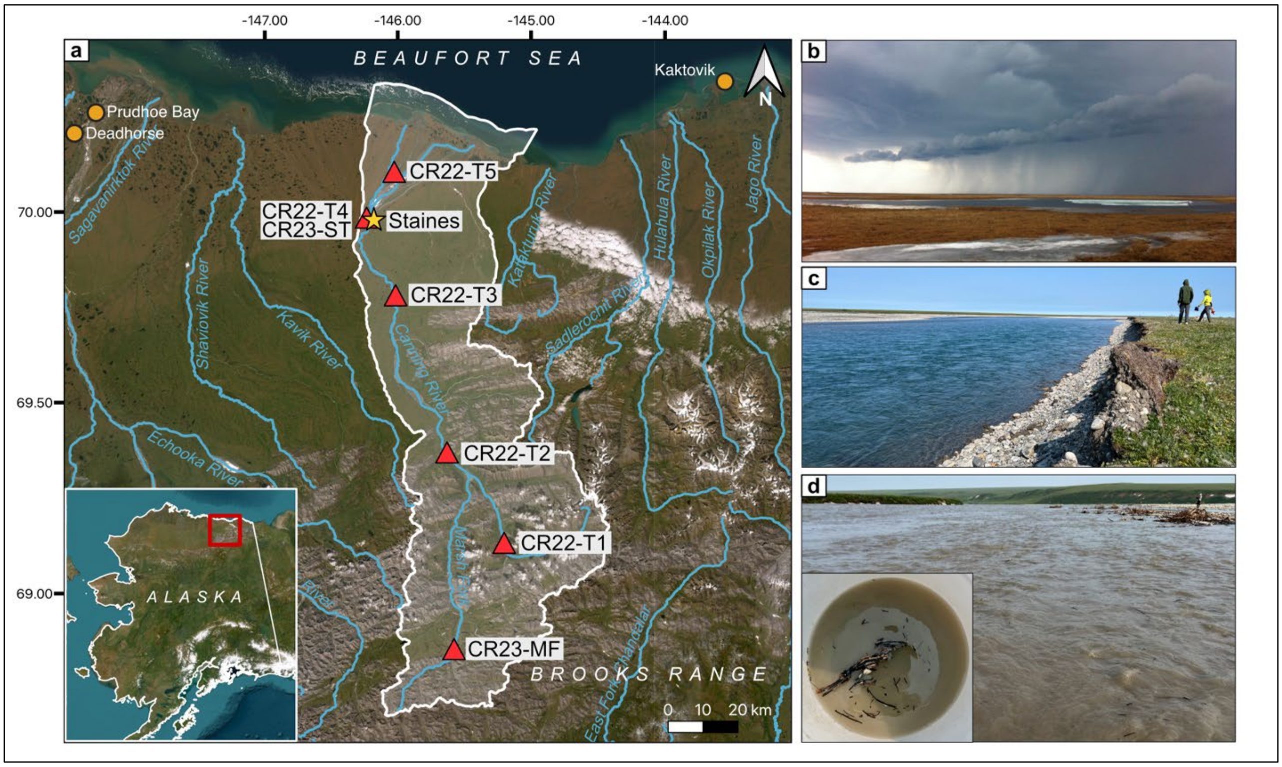

Figure 1. a) Esri satellite image of the study area in the eastern part of Alaska's North Slope (Esri 2023). The Canning River catchment (white shaded area) extends from the Brooks Range to the Beaufort Sea. Red triangles denote locations of ADCP surveys and suspended sediment sampling activities in 2022 (CR22) and 2023 (CR23). Yellow star shows the location of the historic USGS gauging station at Staines, which was operated June 2008–October 2012 (US Geological Survey 2021). Inset map is a satellite image of Alaska, with the red box showing the study area extent. b) Photo of convective storm clouds and precipitation over the north slope near the Chipp River, AK on 13 June 2013. Photo by J. Koch, USGS. c) Photo of clear water in the Canning River at Staines on 26 July 2023. Photo by M. Repasch, University of Colorado Boulder. d) Photo of turbid water in the Canning River at site CR22-T3 during a thunderstorm-triggered high flow event on 5 July 2022. Inset shows buoyant woody debris and organic matter in surface water collected during this event. Photos by M. Repasch, University of Colorado Boulder.

2.2 River discharge analysis

We measured river discharge and channel geometry during our summer 2022 and 2023 field campaigns using a Sontek RiverSurveyor ADCP (Repasch et al. 2024). These ADCP surveys were conducted where the river narrows and nearly all discharge flows within a single thread. The ADCP was towed across the channel on a SonTek HydroBoard attached to a packraft. We measured discharge across a minimum of 6 transects and calculated the discharge as the mean of the highest quality transects.

In addition to field measurements and observations, we analyzed the summer river runoff response in the historic USGS gauging record, which spanned June 2008 to September 2012 (US Geological Survey, 2021). This station was located on the Canning River at the Staines airstrip, where the river is confined to a single thread with a cross-section width up to 400 m under bank-full conditions. This is the same location as our "CR22-T4" and "CR23-ST" sample and ADCP transect location. The USGS surveyed this section of the river channel by ADCP thirty times over the period of gauging, ensuring a well-calibrated dataset.

Using this nearly 5-year discharge record, we identified peak flows and determined how often the river discharge exceeds 200 m^3/s. This threshold value was chosen based on a discharge-suspended sediment rating curve constructed with our field observations.

2.3 Sediment and carbon fluxes

At each river discharge measurement site, we collected river water samples from the channel thalweg using a 2.2-liter van Dorn style horizontal sampling bottle (Wildco Beta Plus Bottle). Sampled water was temporarily stored in clean 10-liter LDPE cubitainers and then filtered through 0.45 µm polyethersulfone (PES) filter membranes using a Geotech barrel filter. Filtered sediment was stored in a cooler until returning to the laboratory for processing. We measured the flux of coarse particulate organic matter (CPOM), or woody debris, transported at the water surface by holding a bucket (opening diameter = 0.3 m) at the water surface for a fixed time interval to collect material. We separated the solid material from the river water using a net and returned the CPOM samples to the lab for processing.

We rinsed sediment off the filters into clean evaporating dishes using ultrapure water, and then dried at 50 °C until desiccated. We calculated suspended sediment concentrations (SSC) by weighing the dry sample mass and dividing by the volume of water filtered. Instantaneous suspended sediment fluxes were then calculated by multiplying the sediment concentration by the total water discharge at the corresponding sampling site. We calculated the CPOM/woody debris carbon flux by drying and weighing the samples, dividing the dry mass by time, then multiplying by 0.49, as woody biomass is estimated to contain ~49% organic carbon (Martin et al. 2021).

We used 0.5 g aliquots of sediment for total organic total organic carbon (TOC) measurement. Samples were ground to a fine powder and decarbonated using repeated treatments with 7% HCl in an 80 °C water bath (Galy et al. 2007). TOC was measured on an elemental analyzer. POC concentrations were determined by correcting the weight percent TOC for mass lost during carbonate removal, and then multiplying by the suspended sediment concentration.

3 Results

3.1 Observed changes in river discharge, suspended load, and organic carbon fluxes

In early July 2022, we observed several thunderstorms in the Canning River headwaters, two of which had notable effects on the river discharge and turbidity. While at site T2 in the foothills (Figure 1a), we deployed a pressure transducer to monitor water level changes. Here we observed a dramatic increase in water level from 2 July to 3 July, which equates to a 30% increase in instantaneous river discharge (from ~75 m^3/s on 2 July to ~98 m^3/s on 3 July). During the rising stage, we observed a rapid increase in turbidity, with a measured suspended sediment concentration of 148 mg/L (sample T2-W1). Three hours later, we measured a suspended sediment concentration of 91 mg/L (sample T2-W2), despite no change in water level over this period. This suggests that more sediment is entrained and transported during the initial rise in water discharge and this sediment supply may become depleted over the duration of the high flow event. We measured a similar decrease in the POC concentration and flux over this three-hour period, reducing from 1.22 to 0.85 mgC/L and 119.7 to 83.5 gPOC/s, respectively. The DOC concentration and flux did not change appreciably during the event, decreasing only slightly from 0.66 to 0.62 mgC/L and 64.5 to 60.6 gDOC/s, respectively. Due to our limited time at site T2, we were not able to collect a systematic timeseries of water samples to determine how this 30% increase in discharge impacted the suspended sediment and POC fluxes.

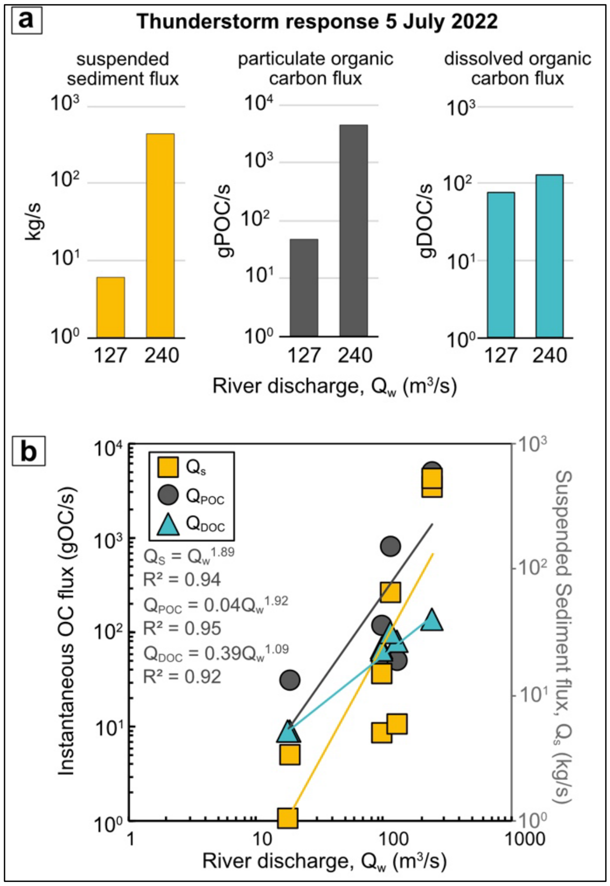

Figure 2. a) Bar chart showing the response of suspended sediment flux, POC flux, and DOC flux to the 5 July 2022 thunderstorm-triggered high flow event at site T3 (240 m^3/s) compared with non-storm flow (127 m^3/s) measured at site T4. b) River discharge (Q_W) versus instantaneous particulate organic carbon flux (Q_{POC}), dissolved organic carbon flux ($Q_{DOC;}$ y-axis left), and suspended sediment flux ($Q_{S;}$ y-axis right) at all Canning River locations in 2022. The trendlines represent the power-law relationships between Q_W and Q_S, Q_{POC}, and Q_{DOC}, expressed by the equations on the plot (Repasch et al. 2024).

Downstream at site T3, we observed a second thunderstorm during the night from 4 July to 5 July 2022. This site is ~127 km downstream from the headwaters, at the transition from the foothills to the coastal plain (Figure 1). This thunderstorm caused a significant increase in water level and turbidity (Figure 1d). ADCP measurements show that discharge increased to 240 m^3/s during this high flow event, representing a 90% increase in water discharge relative to non-storm conditions (127 m^3/s measured at Staines (site T4) on 7 July 2022; Figure 1c). The suspended sediment concentration increased from ~50 mg/L to ~1800 mg/L, resulting in an increase in suspended sediment flux from ~8 kg/s to ~440 kg/s. The POC concentration increased from ~0.5 mgC/L to ~19 mgC/L, resulting in an increase in POC flux from ~0.05 to 4.5 kgC/s (Figure 2a; Repasch et al. 2024). Despite relatively low DOC concentrations during this high flow event (0.54 mgC/L), the DOC flux nearly doubled due to the substantial increase in discharge (Figure 2a), increasing from ~75 gDOC/s to ~130 gDOC/s (Repasch et al. 2024).

We also measured the flux of CPOM/woody debris, transported at the water surface during this high flow event, which averaged 4 kgC/s. (Repasch et al. 2024). Taken together, the river exported ~31 metric tons of POC and CPOM, and an additional ~0.5 metric tons DOC over approximately one hour of this sustained sediment flux. This thunderstorm-driven 240 m^3/s discharge event at site T3 (transition from foothills to coastal plain) had a much larger impact on the Canning River carbon fluxes than the ~100 m^3/s discharge event observed at site T2 (foothills) described above. This difference is likely due to higher carbon stocks in the tundra soils of the foothills and coastal plain compared to the bedrock hillslopes dominating the catchment area upstream of site T2 (Figure 1a).

3.2 Peak flows in the river discharge gauging record

Based on these observations, we propose that flows exceeding 200 m^3/s, or roughly double the mean summer flow of 90 m^3/s, account for the majority of POC export throughout the summer. To test this hypothesis, we analyzed the long-term discharge record at Staines from 2009 to 2012 (US Geological Survey, 2021; Figure 3).

This record shows that the highest flows occur during late May to early June, with the highest recorded discharges exceeding 800 m^3/s. Sporadic rainstorms generate high flow events from June to August, with peak flows ranging from 250 to 650 m^3/s. On average, there are 5–6 discharge peaks per year exceeding 200 m^3/s (Figure 3), and this discharge is exceeded only ~6%, or ~22 days of the year. Based on POC flux measurements from summer 2022 (Repasch e al. 2024), it is likely that most of the annual POC load is transported during these events, although, some of these high flows occur during river ice breakup when we have no data on suspended sediment or POC fluxes.

3.3 Storm contributions to annual POC fluxes

Using our ADCP measurements and suspended sediment (SS), POC, and DOC data (Repasch et al. 2024), we were able to construct a rudimentary rating curve to describe the relationship between river discharge and SS, POC, and DOC fluxes (Figure 2b). SS, POC, and DOC have strong positive correlations with river discharge, following power-law functions. SS and POC scale with discharge to the powers of 1.89 and 1.92, respectively, while DOC scales with discharge to the power of 1.09.

Because this discharge-POC scaling relationship is based on a very small dataset, we cannot confidently apply this rating curve to the long-term daily mean discharge record to calculate the average annual POC export from the Canning River. Our measurements from early July 2022 do not account for the discharge peaks that occur during spring freshet, nor do they account for the late summer runoff that may occur after the sediment and POC supplies have diminished.

4 Discussion and Conclusions

4.1 Storm-triggered organic carbon export

The goal of this study is to demonstrate that summer thunderstorms in continuous permafrost watersheds are effective generators of runoff, leading to mobilization and transport of sediment and organic carbon that were once stored in the Arctic landscape. We found strong power-law relationships between discharge and suspended

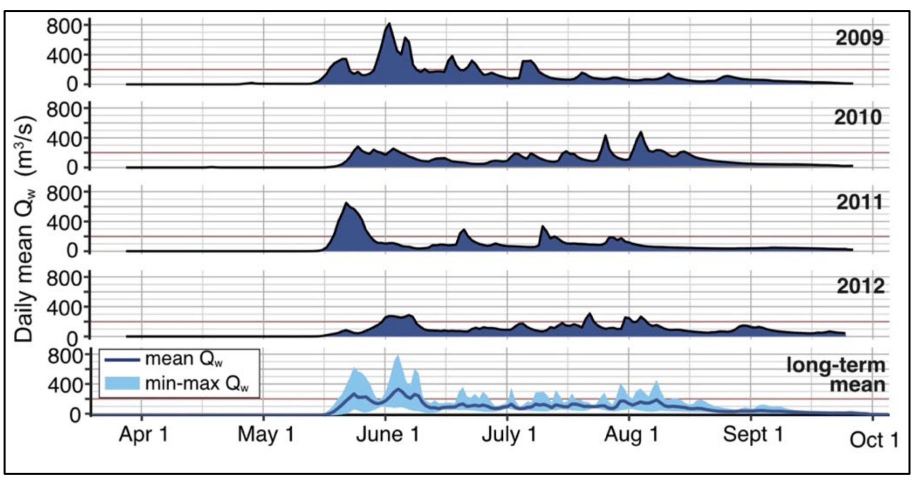

Figure 3. Continuous record of river water discharge at USGS gauging station 15955000 (Canning River at Staines near Deadhorse, AK) measured from 2009 to 2012 (US Geological Survey 2021). This gauging station was active from June 2008 until September 2012. The red lines indicate 200 m^3/s river discharge, which was exceeded during the thunderstorm-driven high flow events we observed in the field. The bottom panel shows the long-term daily mean, minimum, and maximum daily discharge over this four-year record.

sediment, POC, and DOC fluxes in the Canning River. During summer, the POC flux increases by a power of two for every unit increase in river water discharge, suggesting that POC fluxes are highly sensitive to runoff generated during thunderstorms. There are two possible mechanisms that could drive the increase in POC export during these high flow conditions: 1) new erosion of organic-rich soils via runoff and bank erosion, and 2) remobilization of organic matter stored transiently within the active channel belt.

We observed very few abrupt thaw hillslope erosion features in the Canning watershed, suggesting it is unlikely that storm-generated runoff events trigger enough hillslope soil erosion to elevate river SS and POC fluxes. More commonly observed are freshly cut stream and riverbanks, where thawed permafrost soil has collapsed upon loss of its pore ice. This soil slumps into the margins of the river channel, providing a supply of unconsolidated fine sediment and organic carbon for the river to entrain during high flows. It is possible that riverbank erosion is most active during peak flows associated with river ice breakup, generating a supply of sediment and organic matter on the banks. Each subsequent high flow event would mobilize some of this riverbank material, causing this supply to dwindle over the summer season. As such, the SS and POC fluxes associated with large runoff events would decrease throughout the summer.

Gravel braid bars in the active floodplain trap sand and silt, uprooted willows and tundra vegetation, and other forms of particulate organic matter eroded during river ice break-up and transported with early season flows. As water levels rapidly increase with storm runoff, this material becomes entrained, increasing the river suspended load. In July 2022, we observed uprooted willows and tundra vegetative mats tumbling downstream in these high flows at site T5 (downstream distributary system), where the channel was deeper and narrower due to river aufeis still occupying the left side of the channel. This observation highlights the elevated transport capacity of the river during storm-driven peak flows. It is likely that this supply of sediment and organic carbon on the active floodplain dwindles throughout the summer. However, the short duration of these high flow events may result in deposition of entrained organic matter further downstream on the floodplain, requiring multiple years for this material to be transported out of the system. Future measurements of the radiocarbon content of these samples may help to identify whether relatively young organic carbon is flushed out of the channel, or if riverbank and runoff channels are eroding into aged permafrost soil carbon stocks.

During a second field campaign in August 2023, we observed one thunderstorm-triggered runoff event at Staines (CR23-ST). This event caused river discharge to increase from 150 to 228 m^3/s over a period of ~16 hours (Repasch et al. 2024). Although samples are still being processed for POC, we measured a more than seven-fold increase in suspended sediment concentration (from 73.4 mg/L to 511 mg/L), resulting in a ten-fold increase in suspended sediment flux (from 11.0 kg/s to 116 kg/s). The DOC concentration also increased from 0.66 to 0.82 during this rise in discharge, resulting in a DOC flux increase from 96 gC/s to 187 gC/s. Compared to the early July 2022 event, this August 2023 storm generated a much smaller increase in suspended load, but comparable increase in DOC load. We observed less buoyant woody debris in transport during the August 2023 event than in the July 2022 event. One hypothesis is that the available POC in the active channel had been flushed from the river system earlier in the summer. If this is true, then the power-law relationship between discharge and POC would weaken over the duration of the summer. Alternatively, the location of the upstream thunderstorm may impact how much organic carbon is delivered to the river. More suspended sediment sampling efforts could fill in these data gaps.

This flushing of POC from within the active channel belt limits the carbon storage capacity of the floodplain and increases export of POC to the Canning River delta, and ultimately the Arctic Ocean. As summer thunderstorms continue to increase in frequency and intensity, the ability of river gravel bars to store organic carbon will diminish. Alternatively, increasing active layer depths across the Arctic may increase subsurface water storage capacity, thereby progressively dampening the runoff response to extreme precipitation events over time.

We acknowledge that our data are insufficient to develop robust discharge-SS and POC rating curves, prohibiting us from modeling future POC export with predicted increases in thunderstorm frequency. A longer-term and more systematic sampling approach could result in a robust discharge-POC flux rating curve and determine the contribution of thunderstorm runoff to carbon export from Arctic rivers. Further research efforts are needed to capture the high temporal variability in these fluxes during river ice breakup, snowmelt, permafrost thaw, and sediment and carbon supply. While some of the largest peak flows are associated with early season river ice breakup, the thawed layer is quite shallow during this time, suggesting that mobilization and transport of ancient permafrost carbon should be limited. Future efforts should aim to monitor, measure, and sample river water, sediment, and carbon fluxes in Arctic rivers, in conjunction with rain gauge data, over several years may help to understand how the rainfall-runoff response changes over time and determine the mechanisms driving organic carbon export from Arctic rivers.

4.2 Future predictions of Arctic carbon export

Increasing thunderstorm frequency and river discharge across the high Arctic (Poujol et al. 2020; Feng et al. 2021; Blaskey et al. 2023) competes with a deepening active layer. If subsurface water storage capacity increases over time, the river runoff response to high intensity rain events may be significantly dampened, thereby reducing river sediment transport capacity and the rate at which carbon is exported to the Arctic Ocean. Future predictions of dissolved and particulate nutrient fluxes in Arctic rivers will depend on this balance between enhanced convective storm activity and changing water storage capacity within the active layer. Another consideration is Arctic shrubification, which may stabilize river banks (Ielpi et al. 2023), preventing accelerated bank erosion during these high flow events. Monitoring long-term trends in river runoff response to summer rain events and trends in active-layer water storage capacity may constrain the sign and magnitude of these feedbacks.

5 CONCLUSIONS

Climate change in the Arctic is causing profound changes in the Arctic environment. One such change is an increase in convective storm activity, which can trigger a strong rainfall-runoff response in continuous permafrost river catchments. We investigated the response of river discharge, suspended sediment, and particulate and dissolved organic carbon fluxes in the Canning River, which drains a continuous permafrost watershed in the northern Brooks Range of Alaska. We show that thunderstorm runoff can more than double river discharge and drive nearly 70-fold and 90-fold increases in suspended sediment and particulate organic carbon fluxes, respectively. While these events are short in duration, there are more than 22 days every summer when high flows have been recorded, suggesting that these events could contribute most of the annual organic carbon export from the Canning River. Given the projected increase in thunderstorms in a warmer future Arctic (Bennett and Walsh 2015; Poujol et al. 2020; Bieniek et al. 2022), these storm-triggered fluxes could flip the carbon balance of Arctic watersheds, by eroding soil and river banks containing aged permafrost soil carbon and limiting carbon storage within the floodplain. Long-term monitoring and sampling efforts could allow development of rating curves required to predict future changes in carbon export from Arctic permafrost landscapes.

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