Thaw Season Constituent Fluxes Through Arctic Rivers to Alaskan North Slope Coastal Waters

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Background and Objectives

Regional changes in climate on the North Slope of Alaska, like other high latitude locations, have led to enhanced physical disturbance and thermal perturbation of permafrost, terrain degradation, changing weather patterns, and altered hydrogeologic processes (**Fig. 1**). These changes can alter surface water chemistry in stream and river systems and constituent fluxes to the coastal Arctic Ocean. The Alaska North Slope Material Flux Study (AKMFS) is a 4-year field research study to investigate how landscape-specific source contributions change surface water chemistry in and material and heat fluxes through rivers on the North Slope of Alaska on seasonal-to-interannual scales (**Fig. 1a**). An objective of this study is to show that ***integrated inputs from tundra streams and drainage pathways during the summer thaw season, specifically during episodic periods of extreme precipitation and high stream-river discharge, significantly alter surface water chemistry in and constituent fluxes through Arctic rivers like the Sagavanirktok River***. If summertime extreme precipitation and high discharge events become more frequent (**Fig. 2**), thaw season constituent fluxes through the Sagavanirktok River and other Arctic Rivers may be more variable and increase under future warming scenarios.

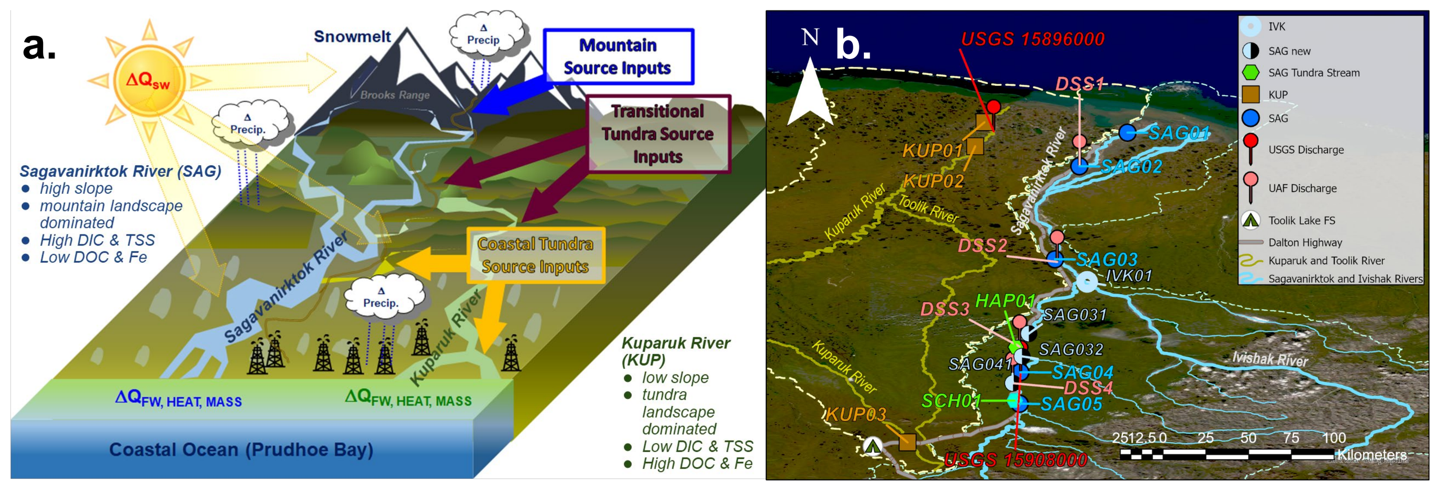

Figure 1. (**a**) The AKMFS concept and (**b**) study area on the North Slope of Alaska with sampling sites on the Sagavanirktok River and transitional tundra streams that feed the Sagavanirktok River. Also shown are the locations of the Sagavanirktok River USGS discharge gaging station (15908000) and University of Alaska-Alaska Department of Transportation discharge gaging stations (DSS1-4; *Toniolo et al. (2019)*.

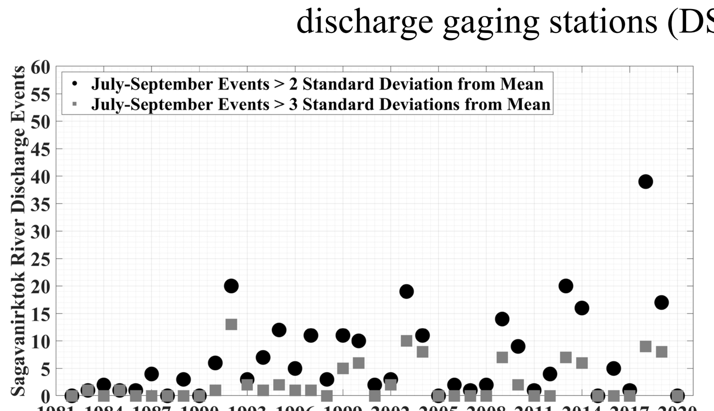

Figure 2. Number of extreme July-September Sagavanirktok River discharge events (> 2-3 x the standard deviation of the daily mean) from 1981-2020 (USGS station 15908000: https://waterdata.usgs.gov/nwis/inventory/?site_no=15908000).

Discharge data and surface water samples were collected from 5 sites on the Sagavanirktok River (SAG01-05) and 2 transitional tundra streams (Schuyler Creek (SCH01) and Happy Valley Creek (HAP01)) during four 2019 open water season sampling events: 03-13 June, 31 July – 07 August, 10-12 September, and 08-11 October 2019. Data and samples were collected from the same sites and three additional sites on the Sagavanirktok River (SAG031, 032, 041) during three sampling events in 2021: 04-13 June, 30 July – 08 August, and 13-16 September 2021 (**Fig. 1b**). Methods are shown and described in **Figure 3**.

Surface Water Parameter(s)	Analytical Method(s)
River/Stream Discharge	RiverRay Acoustic Doppler Current Profiler (ADCP), Sontek Flow Tracker 2 Acoustic Doppler Velocimeter (ADV), Flow Meter, USGS gaging stations
Minor and Trace Elements	Thermo-Fisher Element XR Double-focusing Inductively Coupled Plasma Mass Spectrometer (ICPMS)
Dissolved Inorganic & Organic Carbon (DIC & DOC) and Stable Carbon Isotope Analysis ($\delta^{13}C$)	OI Analytical 1030D Total Organic Carbon Analyzer in-line with Thermo Delta V Isotope Ratio Mass Spectrometer (IRMS)
Particulate Organic Carbon (POC) and Stable Carbon Isotope Analysis ($\delta^{13}C$, $\delta^{15}N$)	CHN Analyzer in-line with Thermo Delta V IRMS

Figure 3. Sample and discharge data collection and methods used for analysis of surface waters. Surface waters were collected using in-field syringe filtration techniques described in *Smith et al., 2022* (in preparation).

***Acknowledgements**: This project was supported by the Strategic Environmental Research and Development Program (SERDP; RC19-1382, PI: Gallaher). The 2019 and 2021 Alaska North Slope Material Flux Study (AKMFS) Teams included: Dragos Vas, Stephanie Saari, Kate Liddle Broberg, Patricia Nelsen, Lauren Bosche and Taylor Sullivan (CRREL); USNA Midshipman and USMA and USCGA Cadets. Thanks to Horatio Toniolo, University of Alaska, Fairbanks (UAF), and the NSF-sponsored support staff at Toolik Field Station (https://toolik.alaska.edu/). Special thanks to Alan Schiller (USM) and Chris Osburn (NCSU) for sample analysis; Jerry Lucas and Luis Rodriguez (USNA) for logistical support; and the many people at BP Exploration Alaska, ConocoPhillips Alaska, Hilcorp, and Alaska Clean Seas who helped facilitate this work.*

a. 2019 Results

b. 2021 Results

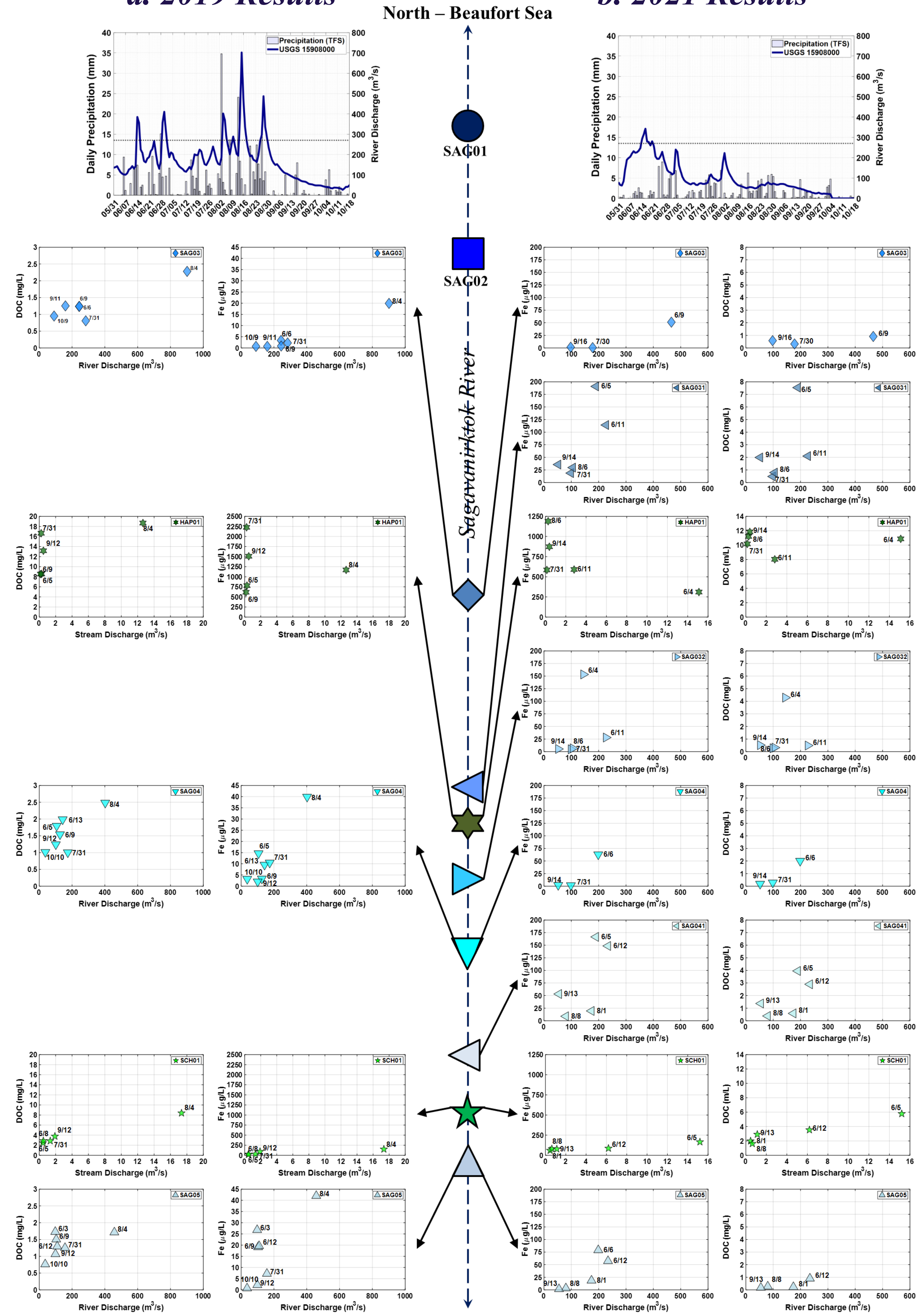

Figure 4. Daily precipitation (*EDC, 2021*) ,averaged Sagavanirktok River discharge (USGS gaging station 15908000) and concentration-discharge plots of surface water DOC and dissolved Fe from (**a**) June – October 2019 and (**b**) June – October 2021. Sampling sites in 2019 were: SAG01 and SAG02 (results not shown), SAG03, HAP01, SAG04, SCH01, and SAG05. Sampling in 2021 was expanded to include sites SAG031, SAG032, and SAG041. *The dashed horizontal line on the daily precipitation plots indicates extreme daily precipitation (3x the standard deviation of the median June-October daily precipitation from 2008-2018).*

In 2019, the spring freshet in the Sagavanirktok River occurred in mid-May. An extreme open water thaw season precipitation event on 03 August was followed by high river discharge on 04 August and high discharge from SCH01 and HAP01, transitional tundra streams characterized by high DOC and dissolved Fe. Concentration-discharge plots at the main-stem SAG sites all show elevated DOC and dissolved Fe concentrations on 04 August (**Fig. 4a**). In 2021, the spring freshet and peak flow in the Sagavanirktok River occurred in early June and precipitation and river discharge remained low throughout the open water thaw season. Dissolved Fe and DOC concentrations at the main-stem SAG sites and at SCH01 and HAP01 was generally highest during peak-flow discharge conditions in early June consistent with high constituent export during the spring freshet noted by others (*Rember and Trefry, 2004*; **Fig. 4b**).

Discussion

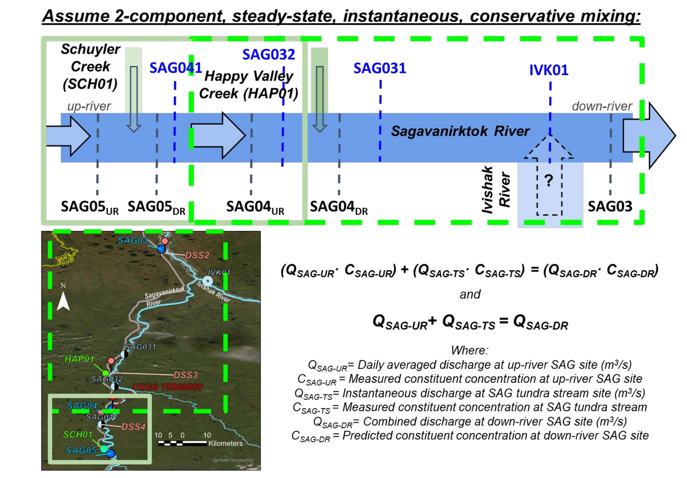

Figure 5. 2-component, steady-state, instantaneous, conservative mixing model (results **Table 1**) for the main-stem Sagavanirktok River between SAG05 and SAG03 and transitional tundra streams SCH01 and HAP01.

Table 1. Measured constituent (DOC, Fe, and DIC) concentrations before and after SCH01 and HAP01 discharge into the main-stem Sagavanirktok River down-river from sites SAG05 and SAG04, respectively. Results are shown for a 04 August 2019 extreme precipitation and high-discharge event and for 11-12 June 2021 near peak flow at the spring freshet. Estimated down-river constituent concentrations from SAG05 (***$SAG05_{DR}$***) and SAG04 (***$SAG04_{DR}$***) based on an instantaneous, two-component conservative mix of tundra stream waters and river waters are shown in parentheses. In 2019, concentrations for the Ivishak River, a major tributary of the Sagavanirktok River, were estimated using the SAG04 predicted concentrations and the measured values at SAG03.

2019						2021					
Schuyler Creek						***Schuyler Creek***					
Site	Date	Flow (m^3/s)	DOC (mg/L)	Fe (μg/L)	DIC (mg/L)	Site	Date	Flow (m^3/s)	DOC (mg/L)	Fe (μg/L)	DIC (mg/L)
SAG05	08/04	458	1.7	42	19.7	SAG05	06/12	234	0.9	57	15.5
SCH01	08/04	17.3	8.4	151	10.5	SCH01	06/12	6.2	3.5	86	10.5
SAG04 (***$SAG05_{DR}$***)	08/04	402 (***475***)	2.5 (***2.0***)	40 (***46***)	18.7 (***18.4***)	SAG041 (***$SAG05_{DR}$***)	06/12	234 (***240***)	2.9 (***1.0***)	149 (***58***)	11.2 (***15.4***)
Happy Valley Creek						***Happy Valley Creek***					
Site	Date	Flow (m^3/s)	DOC (mg/L)	Fe (μg/L)	DIC (mg/L)	Site	Date	Flow (m^3/s)	DOC (mg/L)	Fe (μg/L)	DIC (mg/L)
SAG04	08/04	402	2.5	40	18.7	SAG032	06/11	227	0.5	28	16.7
HAP01	08/04	12.6	18.7	1170	1.8	HAP01	06/11	2.8	8.0	590	3.3
SAG03 (***$SAG04_{DR}$***)	08/04	901 (***415***)	2.3 (**3.0**)	20 (**74**)	22.3 (**18.2**)	SAG031 (***$SAG04_{DR}$***)	06/11	227 (***230***)	2.1 (***0.6***)	114 (***35***)	14.6 (***16.5***)
Ivishak?	08/04	***486***	***1.7***	***~ 0***	***25.8***						

A simple mixing model (**Fig. 5**) provides an estimate as to whether DOC and dissolved Fe inputs at SCH01 and HAP01 can significantly alter surface water chemistry in the main-stem Sagavanirktok River during high discharge. The model approach provides only a first order estimate since DOC and dissolved Fe do not behave conservatively and there are multiple potential sources for DOC and dissolved Fe inputs to the system. The 2019 modeled results (**Table 1**) suggest inputs of tundra-sourced DOC from discrete sources like SCH01 and HAP01 coincident with extreme precipitation, higher hydrologic connectivity, and higher discharge (*Shogren et al, 2019*). Physical disturbance and thermal perturbations of tundra landscapes underlain by permafrost can enhance solute transport and introduce new hydrologic pathways during high precipitation events (*Lafrenière and Lamoureux, 2019*; **Fig. 6a**). Unmanned aerial system (UAS) surveys in 2021 revealed physical disturbance and enhanced drainage pathways in the Happy Valley area (**Fig. 6b**). Results from 2021 show that tundra stream sources may be less significant during peak flow at the spring freshet when constituent concentrations and subsequent riverine fluxes are normally at their highest. At this time, diffuse sources may be more important. Based on river discharge at sites near the river mouth (SAG02 and SAG01) and measured DOC and dissolved Fe concentrations, constituent fluxes through the Sagavanirktok River and export to the coastal mixing zone were 99.5-100.0 t·C and 729-845 kg·Fe on 07 August 2019 after the extreme precipitation and high discharge event as compared to 34.1-46.7 t·C and 1511 – 2437 kg·Fe on 09 June 2021 during the spring freshet.

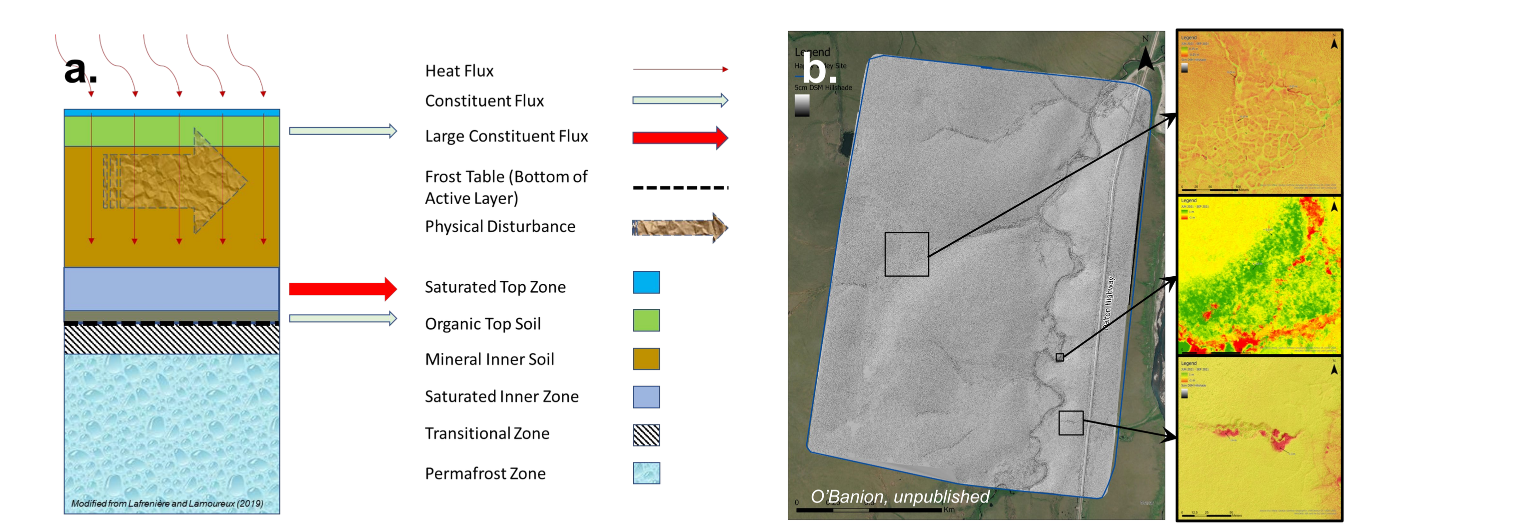

Figure 6. (**a**) Conceptual model of physical disturbance and thermal perturbation of tundra landscapes and (**b**) 2021 UAS vertical landscape change detection survey results (+/- 1m) from Happy Valley sub-watershed.

Conclusion

As Arctic climate and Alaska North Slope landscapes change, integrated solute inputs from tundra streams and drainage pathways during the summer thaw season during episodic periods of extreme precipitation and high stream-river discharge may result in pulsed DOC and dissolved Fe fluxes through the Sagavanirktok River that rival those during the spring freshet.

Future Work (Summer 2022)

- Collect additional data and samples during the 2022 open water summer thaw season; include rare earth element analysis
- Investigate the interaction of precipitation, soil saturation, hydrologic residence time, and biogeochemical processes within the soil active layer in determining dissolved carbon and inorganic constituent inputs from sub-watersheds to larger Arctic rivers

References: Environmental Data Center Team (2021), Toolik Field Station (https://toolik.alaska.edu/edc/monitoring/abiotic/met-data-query.php);.Lafrenière, M. J. and Lamoureux, S. F. (2019), *Earth-Science Reviews* 191: 212-223; Rember, R. D. and R. H. Trefry (2004), *Geochim. Cosmochim. Acta*, 68(3), 477–489; Shogren, A.J. et al., (2019), *Sci Rep* 9, 12894; Smith et al., (2022), Water (in preparation); Toniolo, H. (2019), University of Alaska Fairbanks, Water and Environmental Research Center (http://ine.uaf.edu/werc/research Fairbanks).