

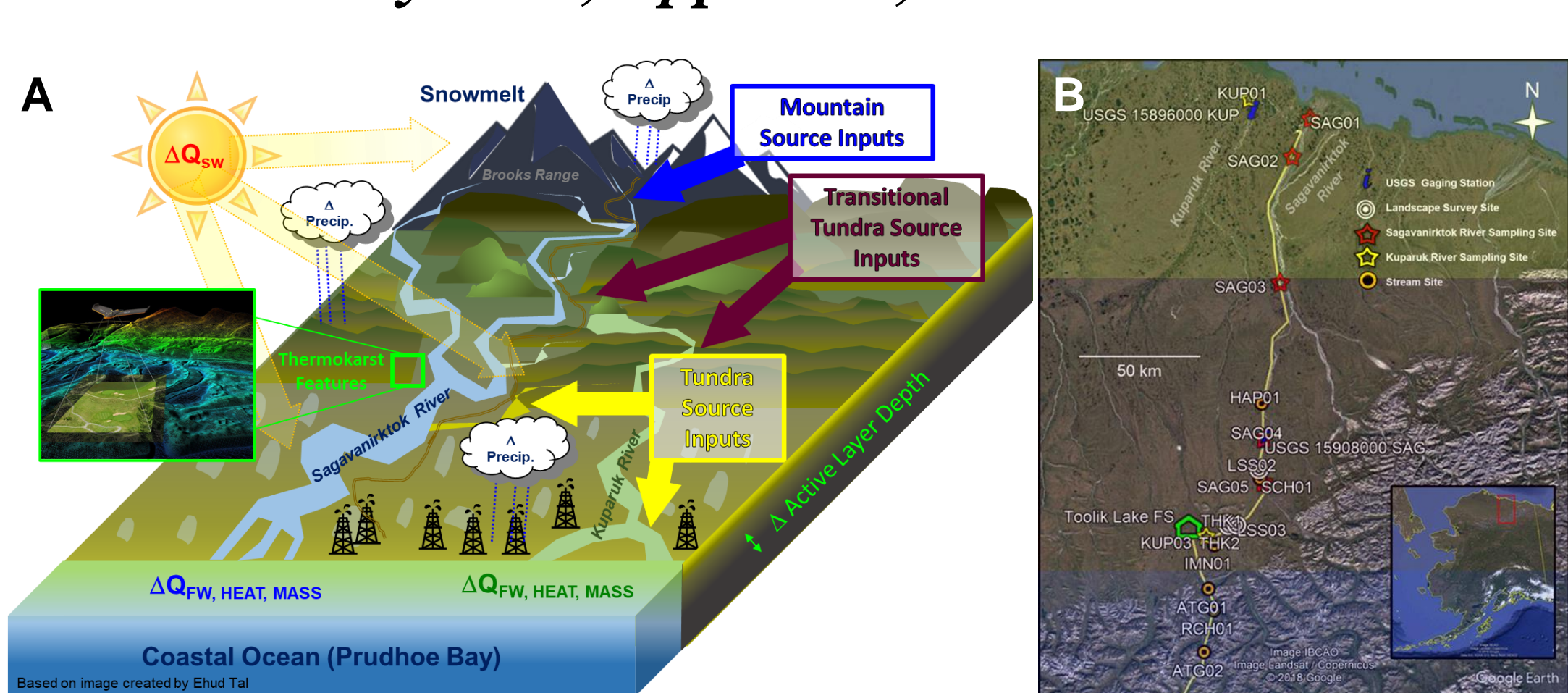
# The U.S. Naval Academy Polar Science & Technology Program 2019 Alaska North Slope Material Flux Study (AKMFS): Spring-to-Late Summer Variability in Iron and Carbon Fluxes Through Small Rivers

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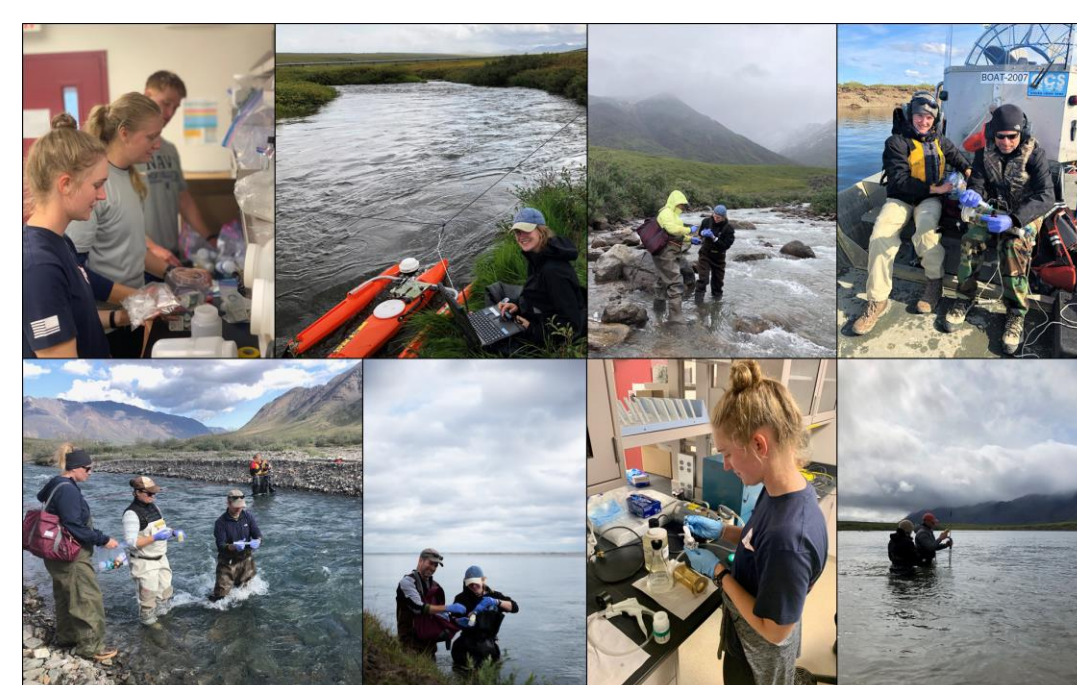
The U.S. Naval Academy Polar Science & Technology Program (USNA-PS&TP), the U.S. Army Corps of Engineers, Engineer Research & Development Center, Cold Regions Research & Engineering Laboratory (CRREL), Fairbanks, AK, the U.S. Military Academy (USMA), and the U.S. Coast Guard Academy (USCGA) are collaborating on a 3-year field research study to investigate how seasonal-to-interannual variability in landscape-specific source contributions changes surface water chemistry in small rivers on the North Slope of Alaska and how material and heat fluxes through these rivers change as they flow from the Brooks Range to the Beaufort Sea. Freshwater flow data, physiochemical data, and surface water samples were collected from sites on the Sagavanirktok River and Kuparuk River and from smaller streams feeding these rivers during four sampling events from June – October 2019. Results of the biogeochemical analysis of these surface waters are presented to provide an assessment of the variability of the dissolved iron and carbon pools in and flux of dissolved iron and inorganic and organic carbon through the Sagavanirktok River and Kuparuk River from spring-to-late summer 2019.

## Study Area, Approach, and Methods



**Figure 1.** (A) Diagram of the AKMFS concept and (B) Map of study area on the North Slope of Alaska with sites on the Sagavanirktok River (red stars; SAG01 – SAG05) and Kuparuk River (yellow stars; KUP01 & KUP03) for repeat sampling and data collection (seasonal-to-annual). The yellow line indicates the Dalton Highway (AK pipeline “haul” road). Also shown are: mountain stream sites (Atigun River (ATG01 & 02) and Roche Moutonnee Creek (RCH01)) and transitional tundra streams that feed both the Sagavanirktok River and Kuparuk River (Imnavait Creek (IMN01), Oksrukuyuk Creek (OKS01), Schuyler Creek (SCH01), and Happy Valley Creek (HAP01)); Toolik Lake Field Station (THK01, THK02, LSS02, LSS03). Stream sample site OKS01 is coincident with site LSS03. Not shown are sample sites on the Toolik River (TLK01) near KUP 03 and site KUP02 20-30 km upstream on the Kuparuk River from site KUP01.

The objective of the AKMFS (Fig. 1A) is to investigate how seasonal-to-interannual variability in landscape-specific freshwater and material source contributions changes surface water chemistry in and material and heat fluxes through the Sagavanirktok (SAG) and Kuparuk (KUP) Rivers on the AK North Slope as they flow from Atigun Pass, north of the Brooks Range to Deadhorse, AK and Prudhoe Bay (Fig. 1B). The SAG has a downward slope of ~29° and drains a watershed of ~13500 km<sup>2</sup> with a that is ~50% Brooks Range, ~30% transitional tundra, and ~20% coastal plain tundra. The KUP has a downward slope of ~2.5° and drains a watershed of ~8,100 km<sup>2</sup> that is ~62% transitional tundra and ~28% coastal plain tundra (Kane et al. 2014; McClelland et al., 2014; Toniolo et al. 2015, 2017).

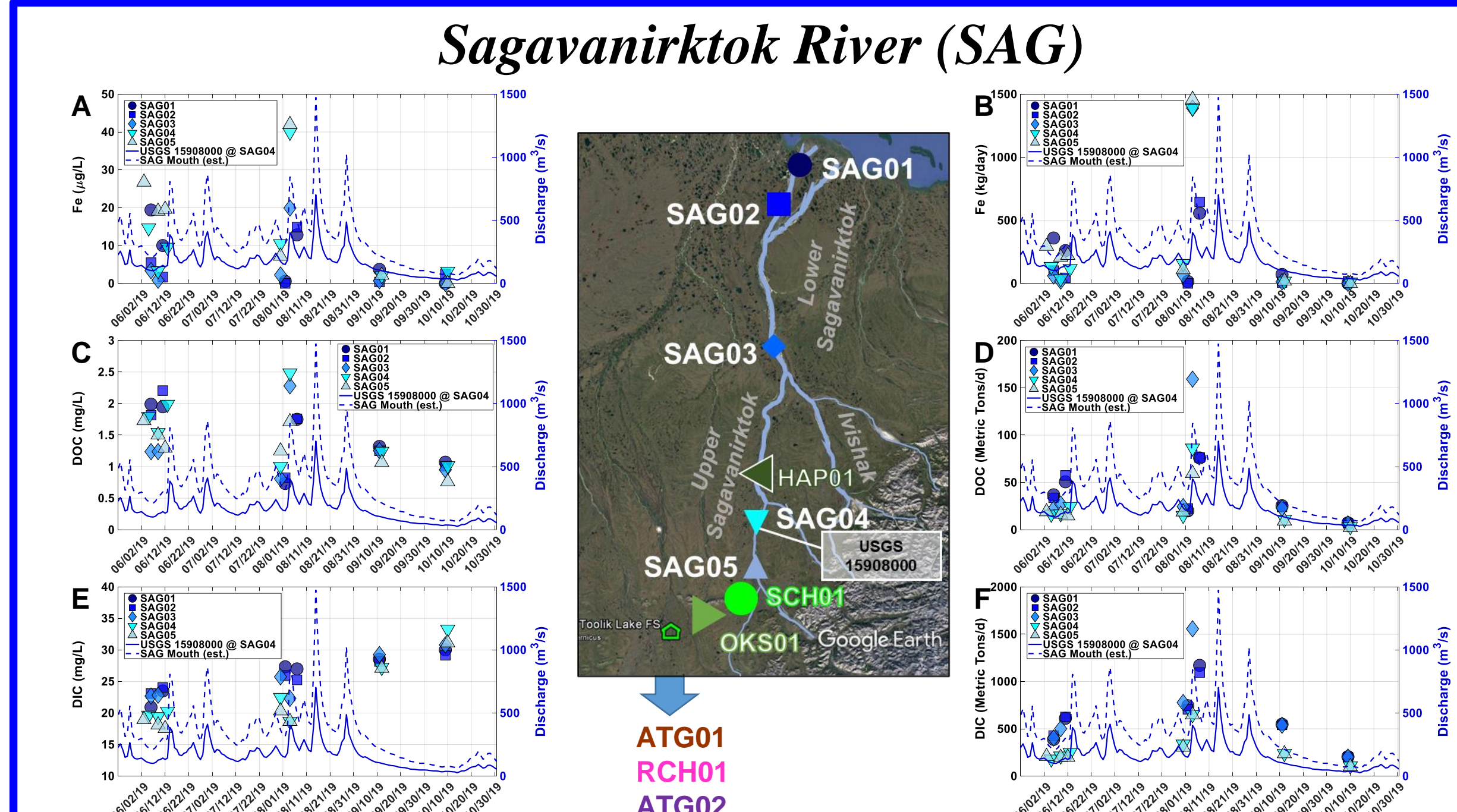


**Figure 2.** Midshipman 1/C Emily Doyle and the AKMFS Team collecting data and surface water samples during the 2019 field campaign (03-13 June, 31 July – 07 August, 10-12 September, 08-11 October 2019). Surface waters were collected by filtering directly from the upper 10 cm into pre-cleaned collection bottles. When possible, streamflow data was collected using a RDI Teledyne RiverRay Acoustic Doppler Current Profiler (ADCP), a Sontek FlowTracker 2 Acoustic Doppler Velocimeter (ADV). Samples processing was performed at Toolik Field Station ([toolik.alaska.edu/](http://toolik.alaska.edu/)) and stored cold (<4°C) prior to laboratory analysis.

The AKMFS data collection plan includes a wide variety of physical and physiochemical parameters and biogeochemical analyses including: alkalinity, dissolved minor and trace elements, major ions, dissolved inorganic and organic carbon (DIC and DOC), stable isotopes, particulate organic carbon, chromophoric dissolved organic matter, and total suspended solids. This work is focused on presenting results of the analysis of iron (Fe), DIC, DOC, and the stable carbon isotope composition ( $\delta^{13}\text{C}$ ) of the DOC and DIC pool ( $\delta^{13}\text{C}$ -DOC and  $\delta^{13}\text{C}$ -DIC) in surface waters collected during the 2019 AKMFS field campaign (Fig. 2; Table 1).

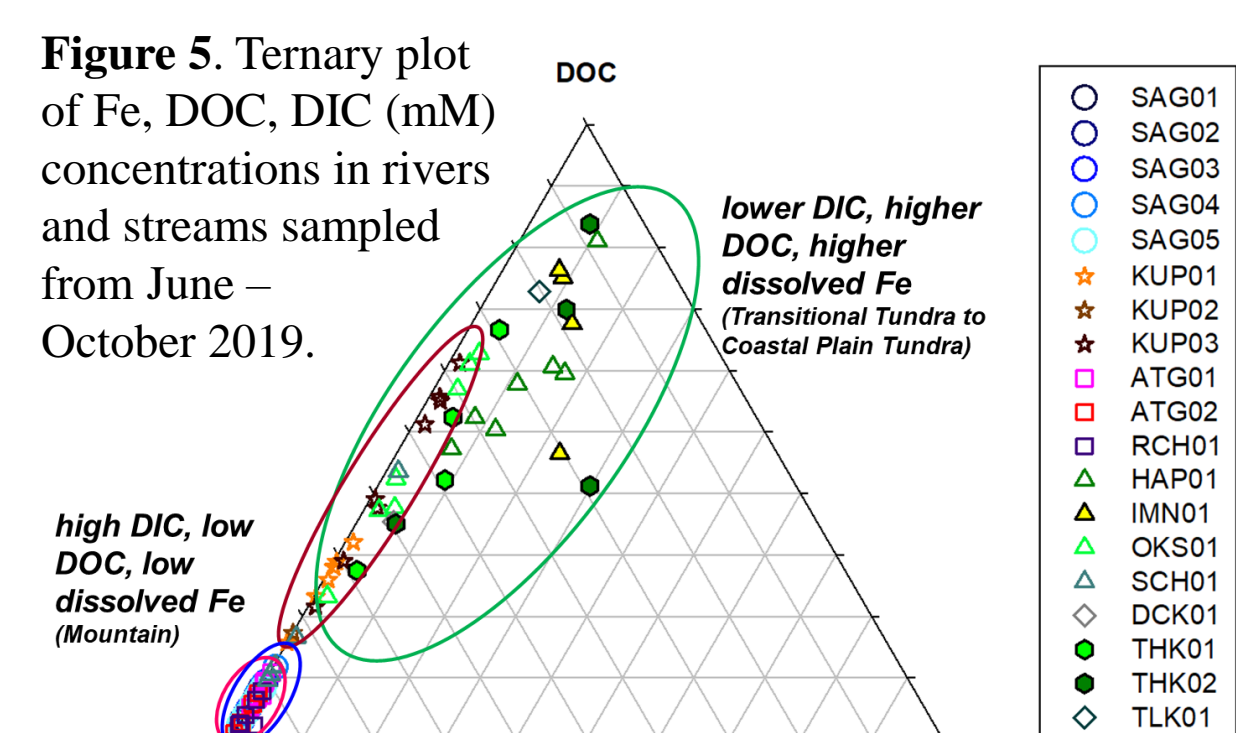
**Table 1.** Biogeochemical analysis and physiochemical data collected during the 2019 AKMFS.

Parameter	Method(s)
Stream Flow	RiverRay ADCP, Flow Tracker 2, Flow Meter, USGS gaging stations
Minor and Trace Elements (Al, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Mo, Cd, Sn, Ba, La, Ce*, Pr, Nd, Sm, Eu*, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Au, Tl, Pb)	125 ml bulk surface water syringe filtered through 0.45 $\mu\text{m}$ filter tip into pre-cleaned HDPE bottle; Thermo-Fisher Element XR Double-focusing Inductively Coupled Plasma Mass Spectrometer (HR-ICPMS; Shiller, USM)
Dissolved Inorganic Carbon (DIC), Dissolved Organic Carbon (DOC), Dissolved Stable Isotope Analysis ( $\delta^{13}\text{C}$ )	40 ml bulk surface water syringe filtered through 0.2 $\mu\text{m}$ filter tip into pre-cleaned glass amber vial; OI Analytical 1030D Total Organic Carbon Analyzer in-line with Thermo Delta V Isotope Ratio Mass Spectrometer (IRMS; Osburn, NCSU)

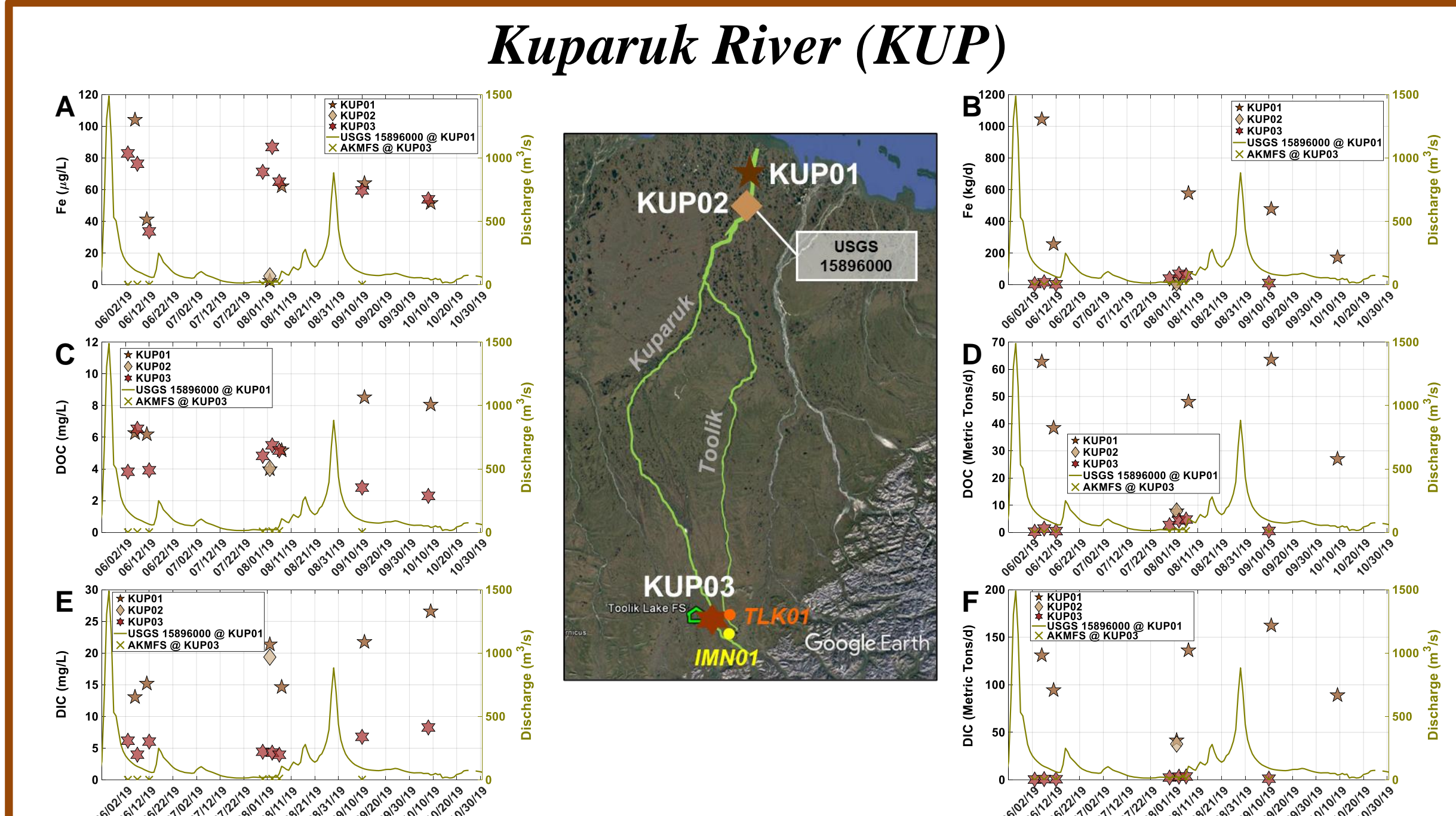


**Figure 3.** Measured Sagavanirktok River (SAG01-05) surface water (A) Fe concentrations ( $\mu\text{g/L}$ ); (B) Fe flux (kg/day); (C) DOC concentrations (mg/L); (D) DOC flux (metric tons/day); (E) DIC concentrations (mg/L); and (F) DIC flux (metric tons/day) in the from June – October 2019. Secondary y-axis shows Sagavanirktok River discharge measured at USGS gaging station 15908000 near AK pipeline pump station #3 (<https://waterdata.usgs.gov/ak/nwis/>) and discharge at the mouth of the Sagavanirktok River estimated using a weighting factor from Toniolo et al. (2017).

Surface waters at SAG sites (SAG01-05) generally had low dissolved Fe, low DOC, and high DIC concentrations (Fig. 3). This is consistent with SAG waters fed primarily from the Brooks Range (Kane et al. 2014; McClelland et al., 2014; Toniolo et al. 2015, 2017; Lehm et al., 2017). Dissolved Fe concentrations decreased landward to seaward and were < 20  $\mu\text{g/L}$  at SAG sites at all sampling times except at SAG04 & 05 during a high discharge event in early August (Fig. 3A). Dissolved Fe flux was generally low (<< 500 kg/d) except during the high discharge event in August when Fe flux was > 1300 kg/d at SAG03-05 (Fig. 3B). DOC concentrations were low (< 2.5 mg/L) at SAG sites at all sampling times, but were especially low during September and October (Fig. 3C). Consequently, DOC flux through the SAG was also low, reaching only ~160 metric tons/d at SAG03 during the early August discharge event and as low as < 10 metric tons/d during low discharge in October (Fig. 3D). DIC concentrations were high at SAG sites and increased from ~20 mg/L in June to > 30 mg/L in October (Fig. 3E). DIC fluxes varied from 200 – 600 metric tons/d in June to a peak of > 1500 metric tons/d at SAG03 during the high discharge event in August, eventually decreasing to < 200 metric tons/d during low discharge in October (Fig. 3F).



**Figure 5.** Ternary plot of Fe, DOC, DIC (mM) concentrations in rivers and streams sampled from June – October 2019. Although freshwater flow plays a large role in determining dissolved Fe, DOC, and DIC fluxes through Sagavanirktok and Kuparuk Rivers, material source contributions from different watershed landscapes are also important. Rivers and streams on the North Slope of AK sampled during the AKMFS can be grouped into four general categories (Fig. 5). Looking at  $\delta^{13}\text{C}$ -DOC vs. DOC at the SAG sites and the mountain streams (Fig. 6A) and the transitional tundra streams (Fig. 6C) that feed the Sagavanirktok River, the DOC pool in the Sagavanirktok River is a mix of DOC sources. The  $\delta^{13}\text{C}$ -DIC vs. DIC values at SAG sites show a DIC pool dominated by a geogenic source from the Brooks Range (Fig. 6B) with biogenic contributions that vary seasonally (Fig. 6D). The  $\delta^{13}\text{C}$ -DOC (‰) vs. DOC (mg/L) values at KUP sites and transitional tundra streams that feed the Kuparuk River point to a DOC pool dominated by organic matter from terrestrial C3 plants (Fig. 6E) and  $\delta^{13}\text{C}$ -DIC vs. DIC values indicate a seasonal biogenic influence (Fig. 6F). In-and-between stream variability in the DIC and DOC pools in both rivers reflects discrete and diffuse sourcing, biogeochemical cycling, and changes in discharge and hydrogeology (Lambert et al., 2011; Campeau et al., 2017; Lehm et al., 2017; Shogren et al., 2019).



**Figure 4.** Measured Kuparuk River (KUP01-03) surface water (A) Fe concentrations ( $\mu\text{g/L}$ ); (B) Fe flux (kg/day); (C) DOC concentrations (mg/L); (D) DOC flux (metric tons/day); (E) DIC concentrations (mg/L); and (F) DIC flux (metric tons/day) in the from June – October 2019. Secondary y-axis shows Kuparuk River discharge measured at USGS gaging station 15896000 near Deadhorse AK (<https://waterdata.usgs.gov/ak/nwis/>) and point streamflow measurements at KUP-03 collected with a Sontek FlowTracker2 ADV. Flow at KUP03 is ~2 orders of magnitude lower than flow at KUP01.

Surface waters at KUP sites (KUP01-03) generally had higher dissolved Fe, higher DOC, and lower concentrations than SAG sites (Fig. 4). This is consistent with waters fed from transitional and coastal plain tundra (McClelland et al., 2014; Barker et al., 2014; Shogren et al., 2019). Dissolved Fe concentrations were variable at KUP sites, ranging from > 100  $\mu\text{g/L}$  at KUP01 in early June to < 10  $\mu\text{g/L}$  at KUP01&02 in late July. The highest dissolved Fe concentrations were measured at KUP01 in early June, the sampling event closest to peak Kuparuk River discharge (Fig. 4A); this is also the time with the highest dissolved Fe flux (> 1000 kg/d) measured at KUP01. By the end of the fall, Fe flux decreased to < 200 kg/d (Fig. 4B). DOC concentrations at KUP01-03 varied from 2-9 mg/L (Fig. 4C). DOC fluxes were also variable at KUP01, ranging from 25-85 metric tons/d, with no clear correlation to flow although DOC flux was lowest in October during low discharge (Fig. 4D). DIC concentrations were < 30 mg/L at KUP sites and increased from ~12 mg/L in June to ~27 mg/L in October at KUP01 (Fig. 4E). DIC fluxes at KUP01 varied from 40-60 metric tons/d, again, with no clear correlation to flow (Fig. 4F). Tundra source contributions may be more important to material fluxes in the Kuparuk River as compared to the Sagavanirktok River.

