

Integrating Remote Sensing, Field Measurements, and Numerical Modeling to Investigate the Influence of Riverine Exports on Coastal Biogeochemistry in Northern Alaska

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Abstract

Arctic rivers transport large quantities of freshwater and constituents to coastal areas composed of a diverse array of bays, deltas and lagoons. In northern Alaska half of the Beaufort Sea coastline is skirted by discontinuous barrier islands that enclose numerous shallow lagoon ecosystems. These ecosystems host productive, biologically complex assemblages of biota that are inherently shaped by the extreme seasonal variations in physical-chemical conditions and increasingly challenged by alterations in river discharge and chemistry driven by climate change.

Advances in remote sensing observations and a growing collection of measurements from river sampling provide a wealth of key data to integrate with numerical models to yield spatially and temporally extensive estimates of river exports and, in turn, advance knowledge of the dynamics driving coastal water biogeochemistry. We describe the observations, measurements and models being used to quantify freshwater and dissolved organic carbon (DOC) fluxes to the Beaufort Sea coast over the past four decades. Remote sensing and other geospatial data from the NASA ABoVE and other regional studies and monitoring networks are being leveraged for soil freeze-thaw state, surface water extent, and coastal water DOC concentration, with the latter derived from platforms including satellite retrievals, aircraft overflights, and handheld spectroradiometers. River measurements span sampling sites from headwater streams in the Brooks Range to river mainstems near the coast. Simulations with a permafrost-hydrology model for the period 1980-2022 provide estimates of freshwater and DOC exports, capture alterations occurring on land, reveal watershed spatio-temporal patterns in surface runoff and DOC leaching/loading, and point to changes in the chemistry, biology, and circulation of the lagoons and adjacent coastal waters of northern Alaska.

Synthesis of observations and modeling is crucial for understanding how shifts in seasonality, permafrost thaw and water cycle intensification in the rapidly warming Arctic are affecting aquatic biogeochemistry and the food webs that inhabit coastal zones.

Watershed DOC Gradient and Model Validation

DOC measurements from the Canning River watershed in northeastern Alaska, 2012-2023, were used for model validation. DOC was sampled from the river mainstem and contributing streams across a latitudinal gradient from the Brooks Range to the coastal plain to capture spatial variability associated with catchment changes in topography, soil organic matter, and hydrology (Figure 3). DOC was sampled from late-June to early-August to capture temporal variability associated with precipitation and seasonal active layer thaw (Figure 4).

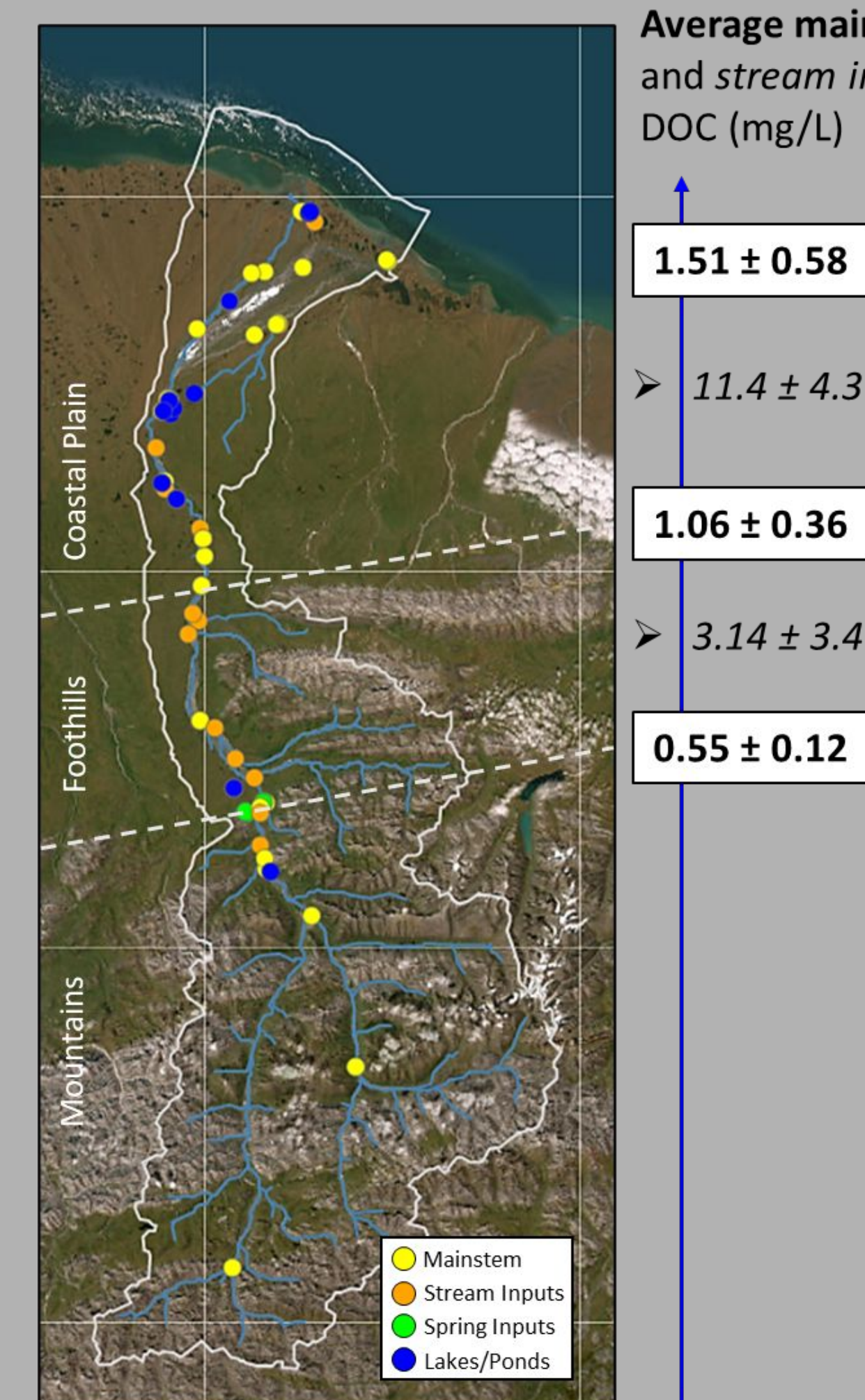


Figure 3. (left) Map showing the locations of DOC measurements from the Canning River along a latitudinal gradient from the Brooks Range to the coastal plain/river delta. (right) Average concentrations of DOC (mg/L) from field samples collected during the summer thaw period along the river mainstem (in bold) and from stream inputs (in italics). DOC was averaged by geographic position in the watershed, downstream of (i) the Brooks Mountain Range, (ii) the foothills of the Brooks Range, and (iii) the coastal plain. The relative proportion of the watershed that makes of these landscape domains are divided by the white dashed line.

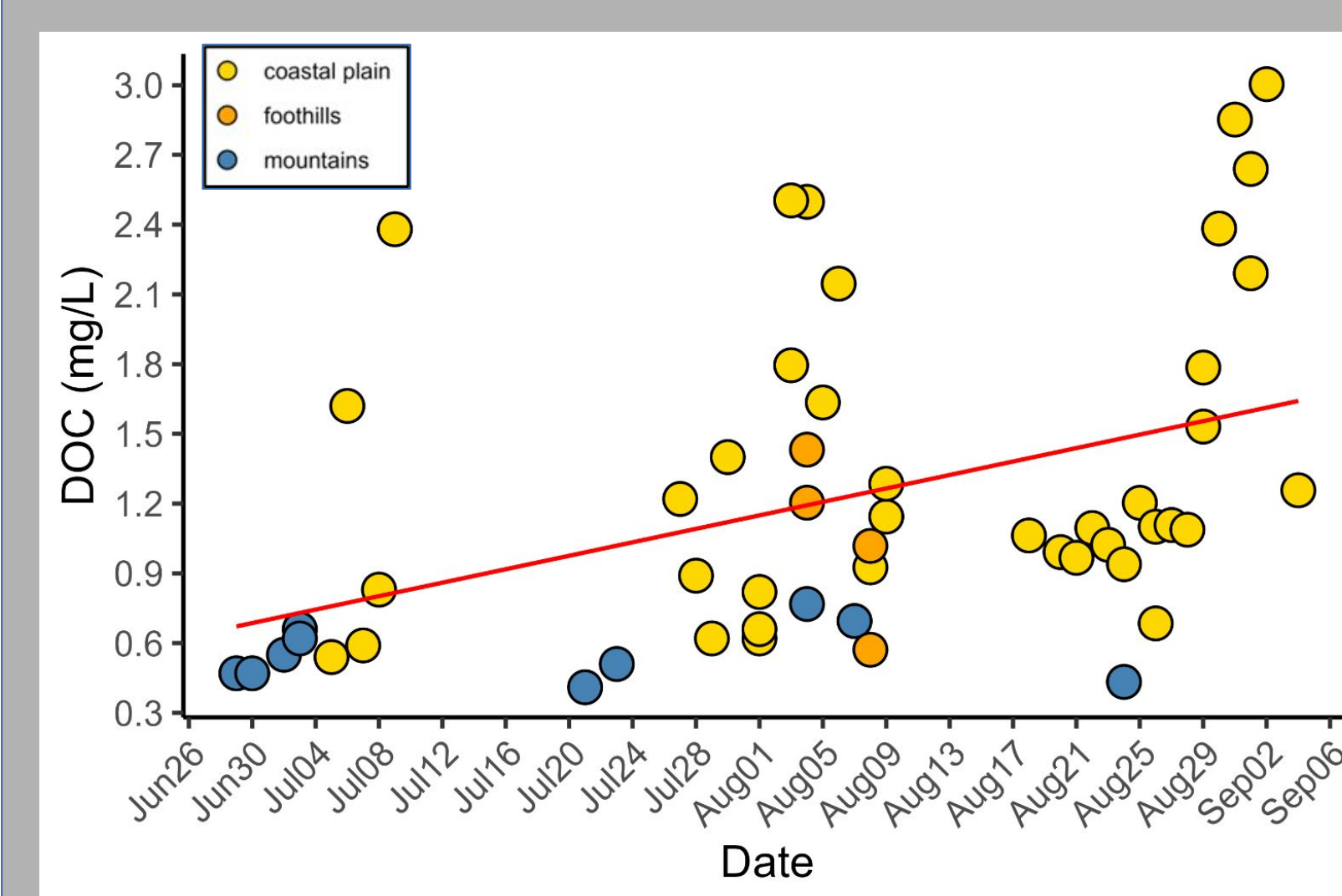


Figure 4. Scatter plot of river mainstem DOC (mg/L) on the month/day sampled. Circles are colored by their sampled geographic location: mountains (blue), foothills (orange), and coastal plain (gold). Trendline indicated in red. DOC values capture a seasonal pattern with geographic separation and evidence of DOC response to summer storm events.

Remote Sensing of Active Layer Thickness and Thawing Timing

Figure 7. Permafrost Dynamics Observatory (PDO) active layer thickness (ALT), (b) PDO soil moisture (depth-averaged over the active layer), and (c) National Land Cover Database (NLCD) land cover maps of the Deadhorse transect (Chen et al., 2022). The PDO soil moisture corresponds to the P-band data acquired on 13 August 2017. (d) Histograms of PDO ALT retrievals and Circumpolar Active Layer Monitoring in-situ ALT data (circles) in the sedge (NLCD 72: sedge/herbaceous) and tussock (NLCD 51: dwarf scrub) tundra areas.

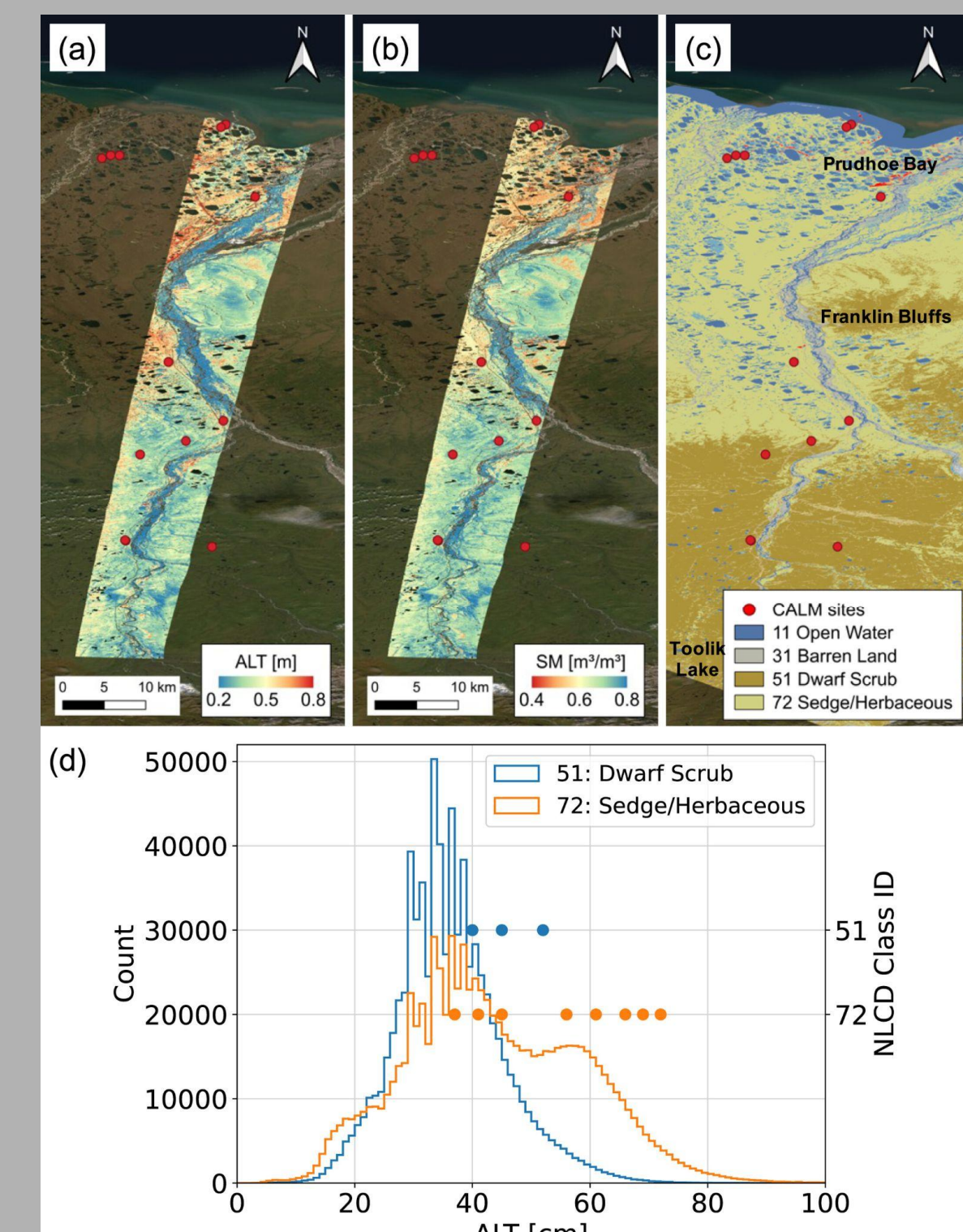


Figure 8. Spring thaw onset derived from Soil Moisture Active Passive (SMAP) daily 9 km freeze-thaw retrievals for 2016 and 2017 (Kim et al., 2019). The data capture this critical landscape transition and are useful in assessing modeled snowmelt runoff and freshet temporal dynamics.

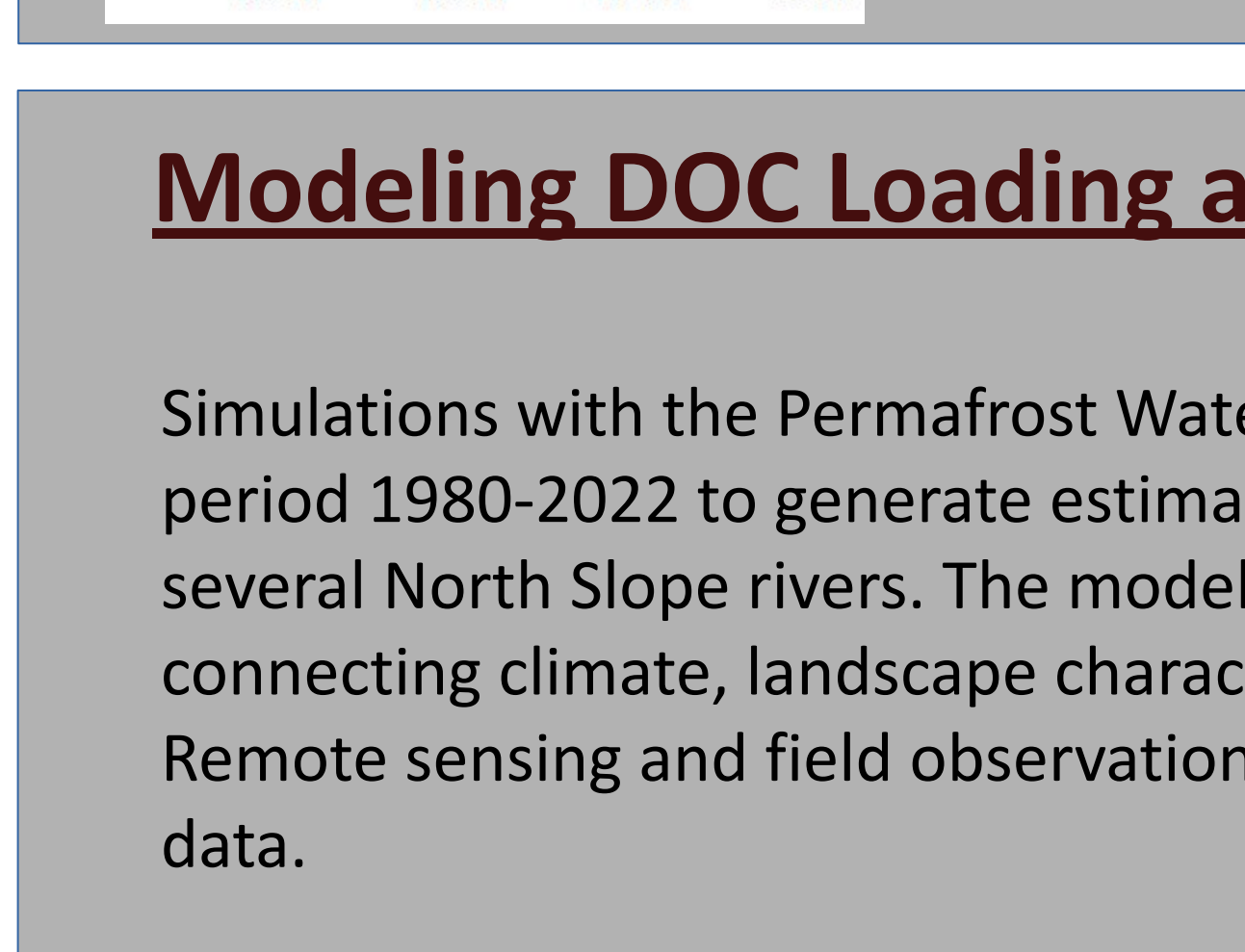
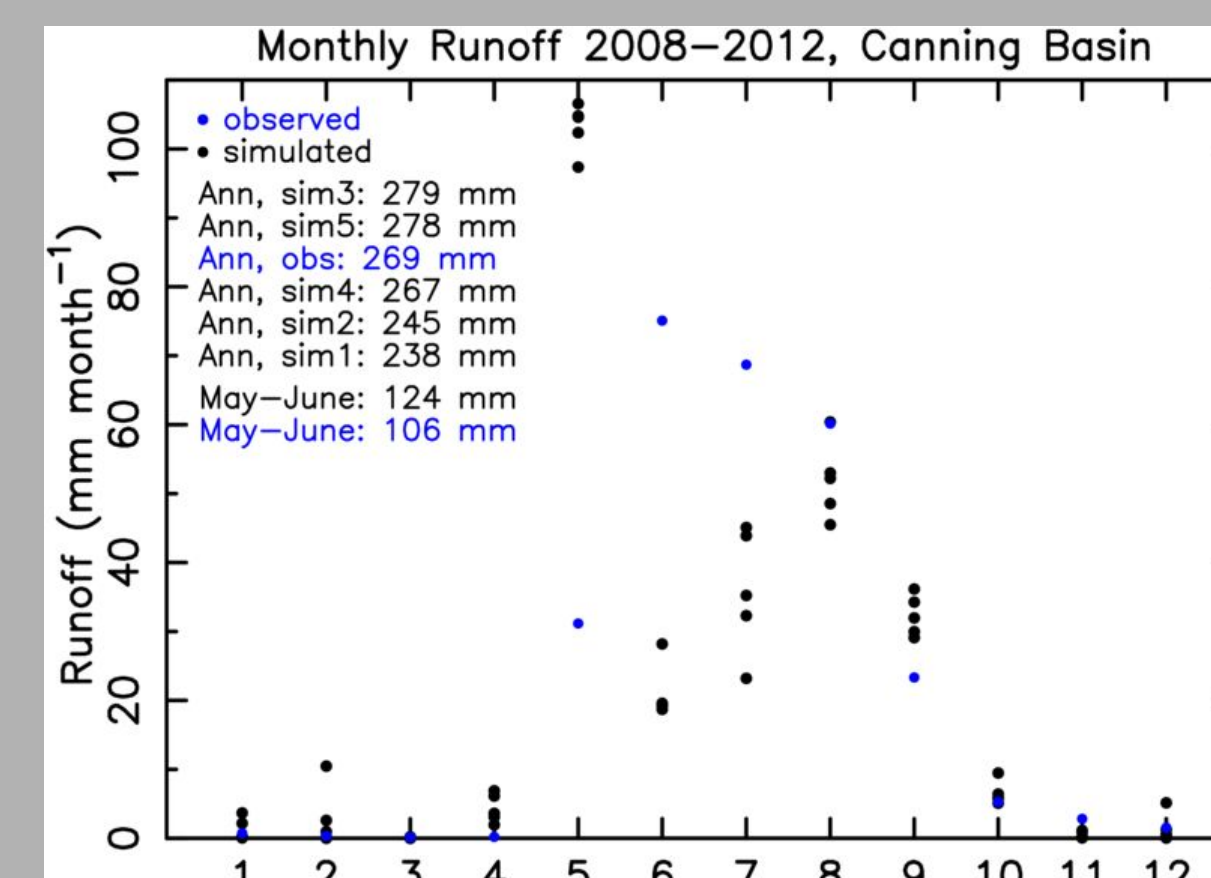


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Modeling DOC Loading and Export – Canning Basin

Simulations with the Permafrost Water Balance Model were run for the period 1980-2022 to generate estimates of freshwater and DOC export for several North Slope rivers. The modeling captures key physical processes connecting climate, landscape characteristics and river biogeochemistry. Remote sensing and field observations provide key calibration and validation data.

Figure 9. Monthly (climatological) total runoff from five ensemble model simulations and the USGS observations. Annual totals in the simulations bracket the observed estimate. Peak simulated runoff in late May leads the peak in observed runoff in early June by ~2 weeks.



Remote Sensing of CDOM and DOC

Spatiotemporal patterns in CDOM and DOC along Alaska's North Slope were examined using remote sensing from airborne and satellite sensors. A regionally optimized multiple linear regression (MLR) algorithm (Cao and Tzortziou, 2024) was applied to multiple airborne and satellite remote sensing platforms including AVIRIS-NG, Sentinel 3A/B OLCI, Sentinel 2A/B MSI and Landsat OLI. The combination of sensors provide a breadth of spatial and temporal resolutions with which to observe the region and help negate the difficulties in monitoring this region due to the high cloud and ice cover, low solar elevations, and optically complex waters.

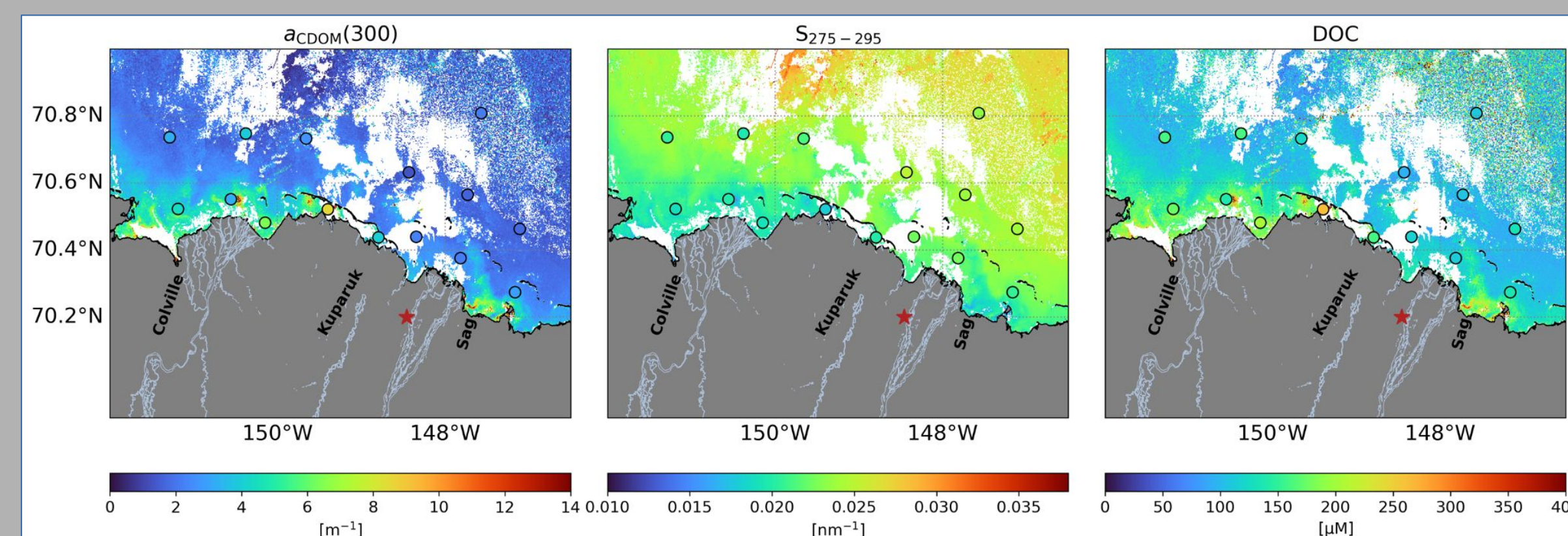


Figure 1. $a_{CDOM}(300)$, $S_{275-295}$, and DOC retrieved by OLCI between August 20-24 2022. Circles denote the in situ samples collected on August 20, 21, 23 and 24. OLCI L2 scenes processed with L2gen atmospheric correction.

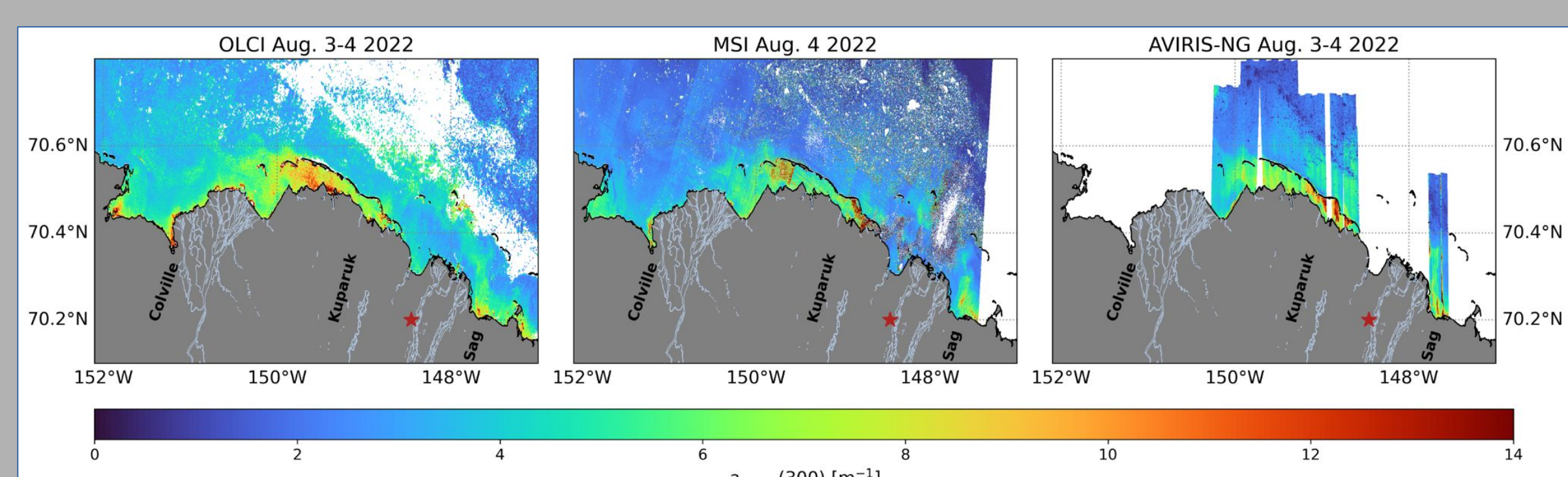


Figure 2. Comparison of $a_{CDOM}(300)$ retrievals from OLCI, MSI and AVIRIS-NG between Aug 3-4 2022.

Spatial and Seasonal Variability of DOC in Coastal Waters of the Alaska Beaufort Sea

Data from the Beaufort Lagoon Ecosystems Long Term Ecological Research (BLE LTER) program collected between 2018 and 2023 show how DOC concentrations vary spatially and seasonally in nearshore waters of the Alaska Beaufort Sea.

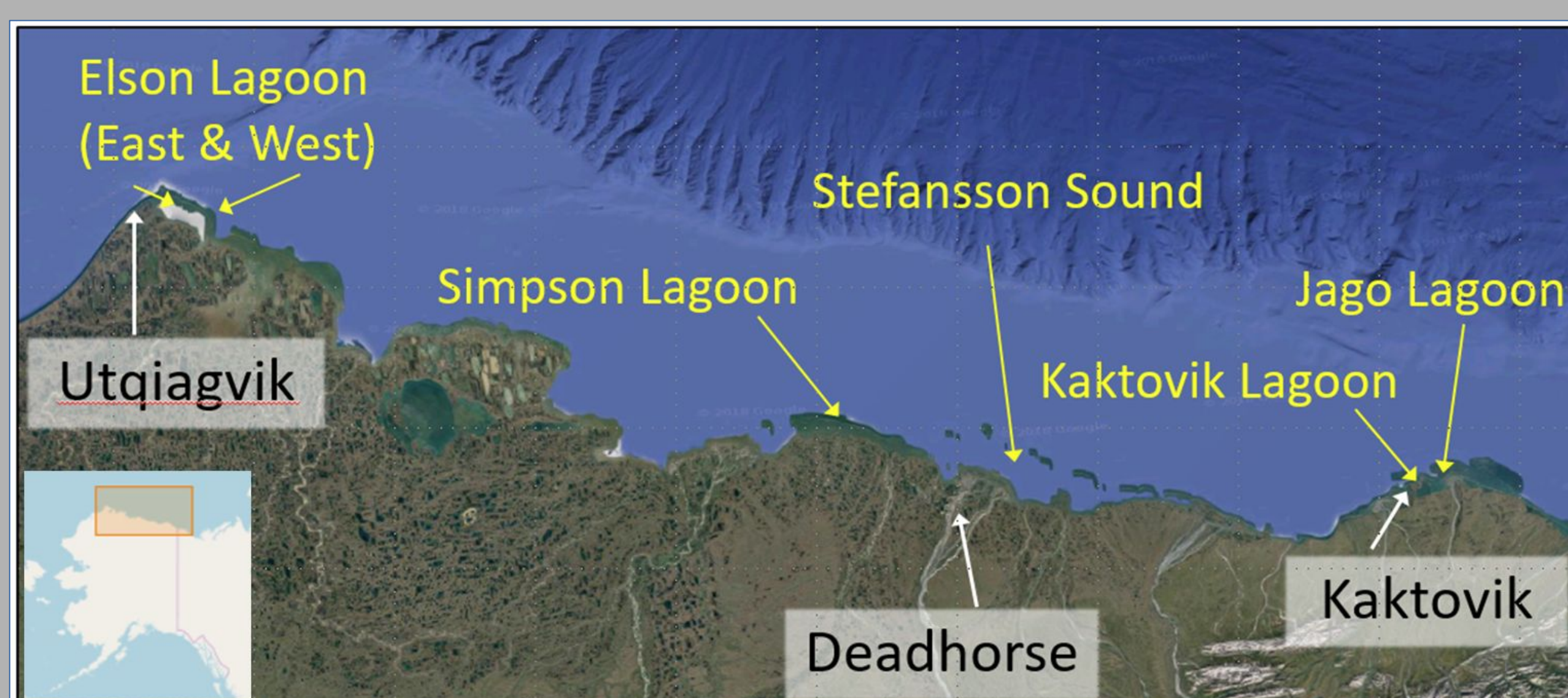


Figure 5. Sampling locations along the Alaska Beaufort Sea coast. Black text identifies bases of field operations and yellow text identifies major water bodies routinely sampled by the BLE LTER.

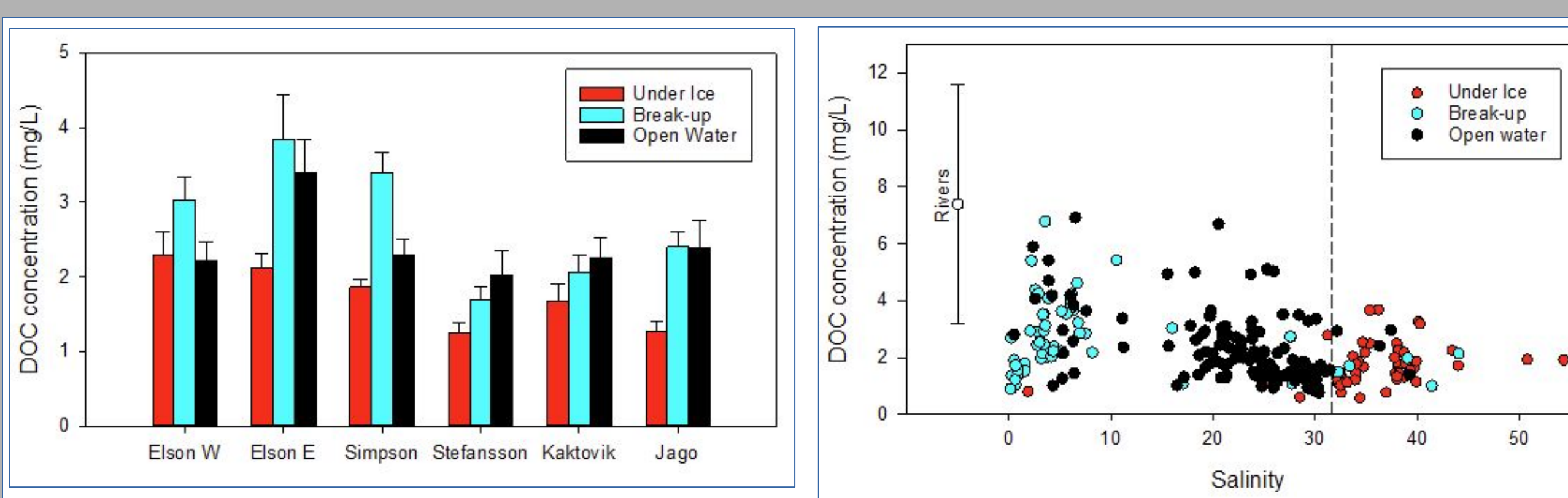


Figure 6. Site-specific DOC concentrations during different seasons (left), and combined data from all sites vs. salinity (right). Data from under ice, break up, and open water sampling are from April, late June – early July, and late July – August respectively. Open circle in the right-hand plot is mean (± 1 standard deviation) for inflowing river water (Mayoek, No-Name, Avak, Separuk, Put, and Sagavanirktok rivers). Dashed line marks salinity of the Beaufort Sea Polar Mixed Layer.

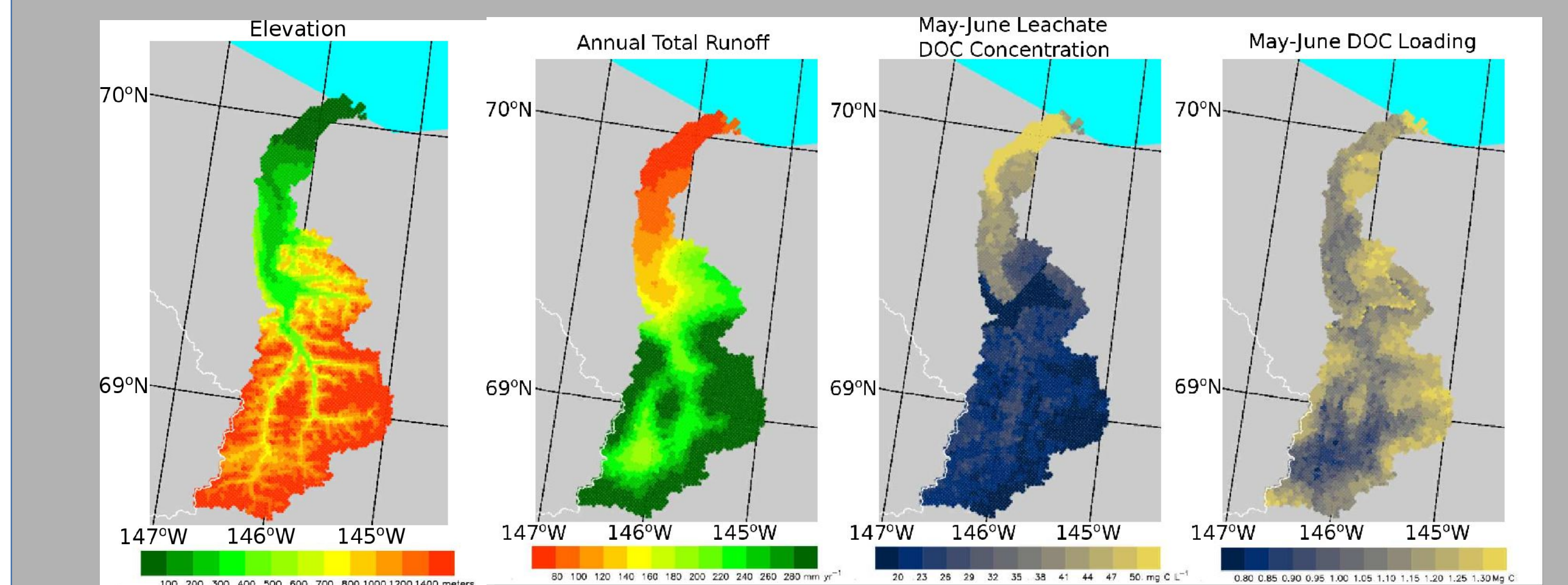


Figure 10. Streamflow in the Canning River basin is dominated by runoff from higher elevations of the Brooks Range. Leachate DOC concentrations are greater closer to the coast where soil carbon storage is higher. In turn, stream DOC loading during the May-June freshet period is relatively more spatially uniform across basin.

Acknowledgments and References

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