Arctic DOM and POM in Optically Complex Waters

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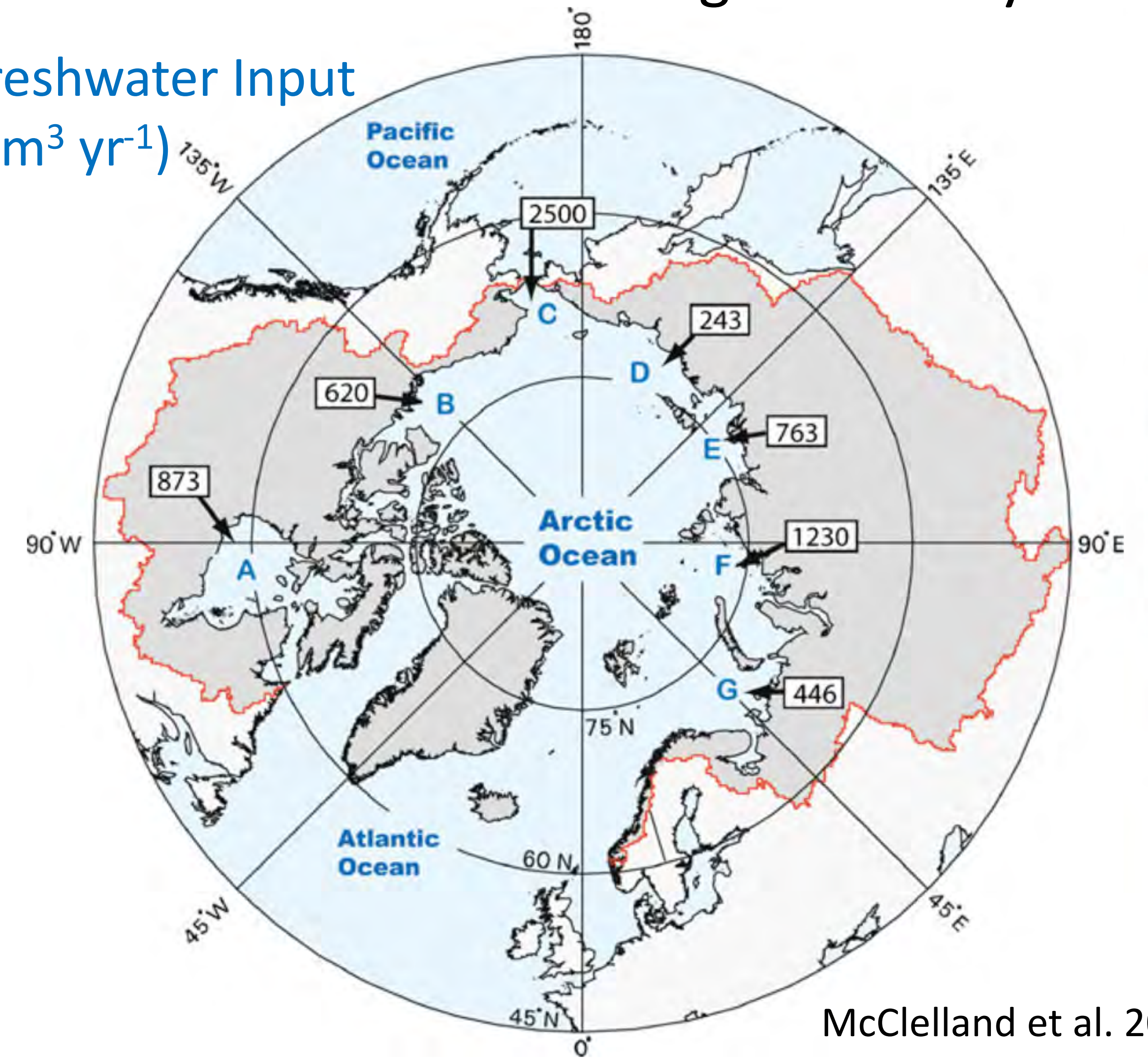
Outline

- Background on the coastal Arctic and sources of optical complexity
- Global warming impacts on the Arctic that affect present and future optical complexity
- DOM characteristics of rivers and coastal Arctic
- POM characteristics of rivers and coastal Arctic
- Remote sensing of DOC, CDOM, and SPM
- Remote sensing challenges
- Logistical challenges in collection of *in situ* measurements

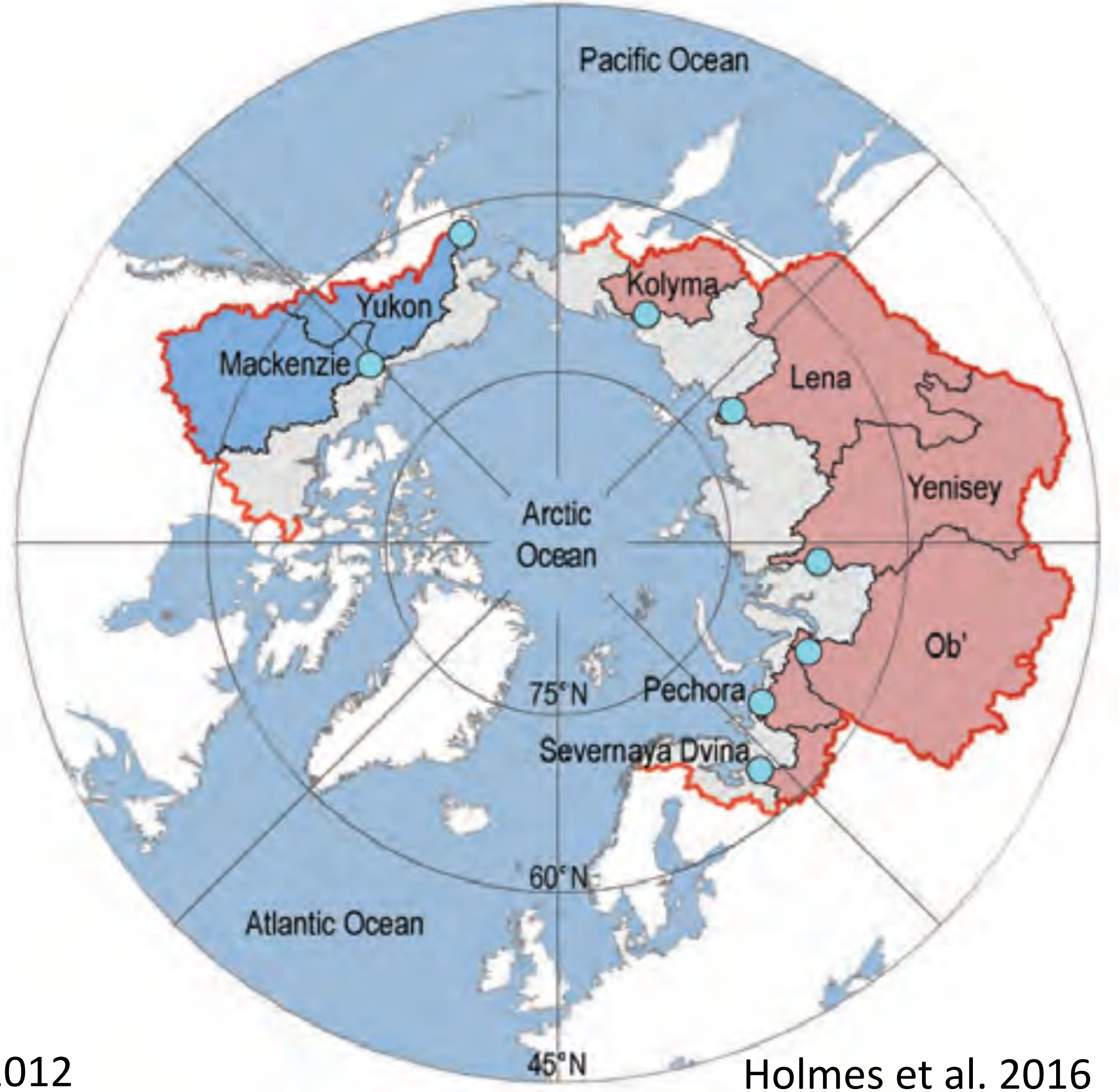
Background – Arctic Rivers as source of coastal complexity

- Coastal Arctic as a large relatively contiguous estuary

Freshwater Input
($km^3\ yr^{-1}$)



McClelland et al. 2012



Holmes et al. 2016

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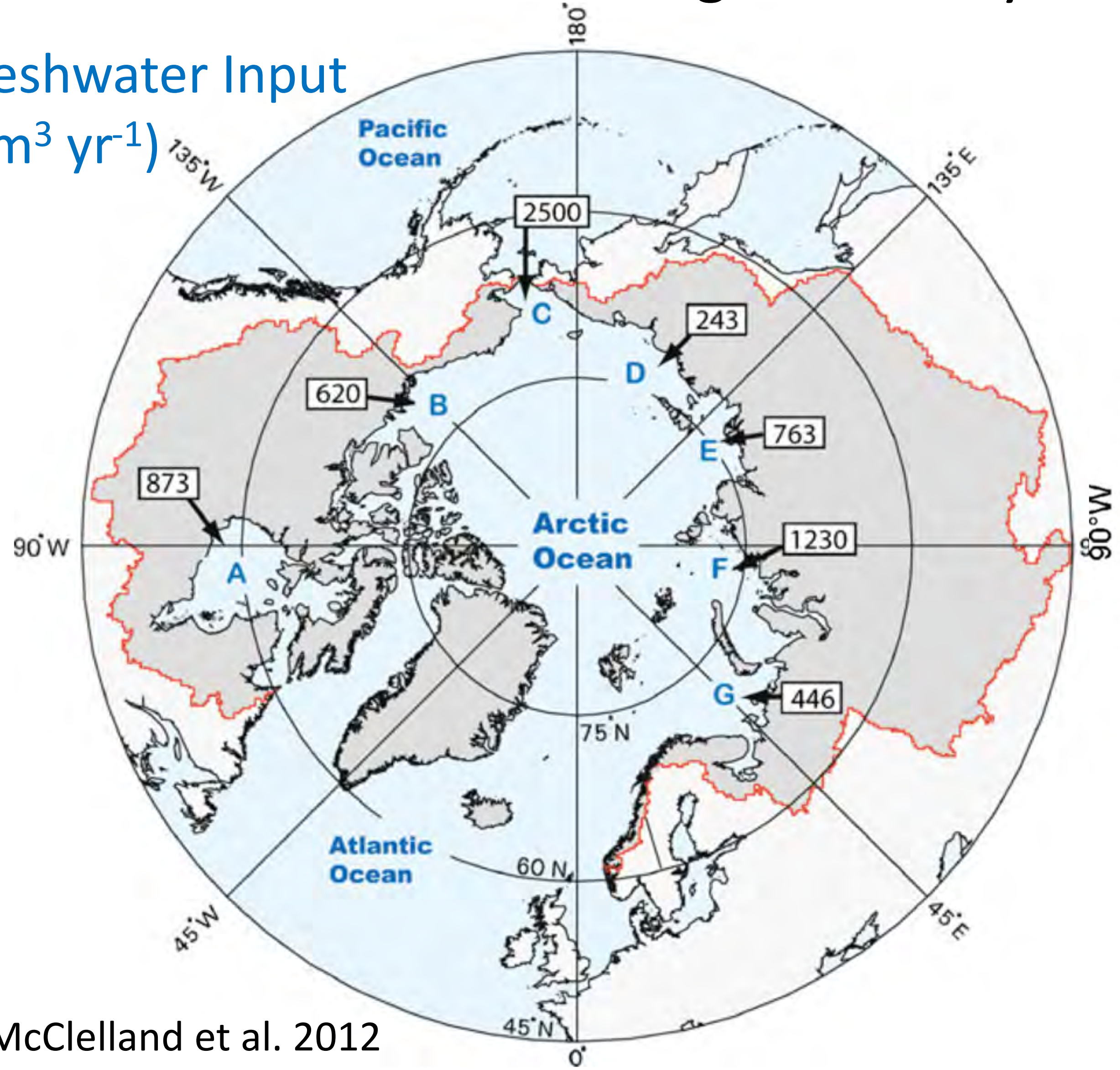

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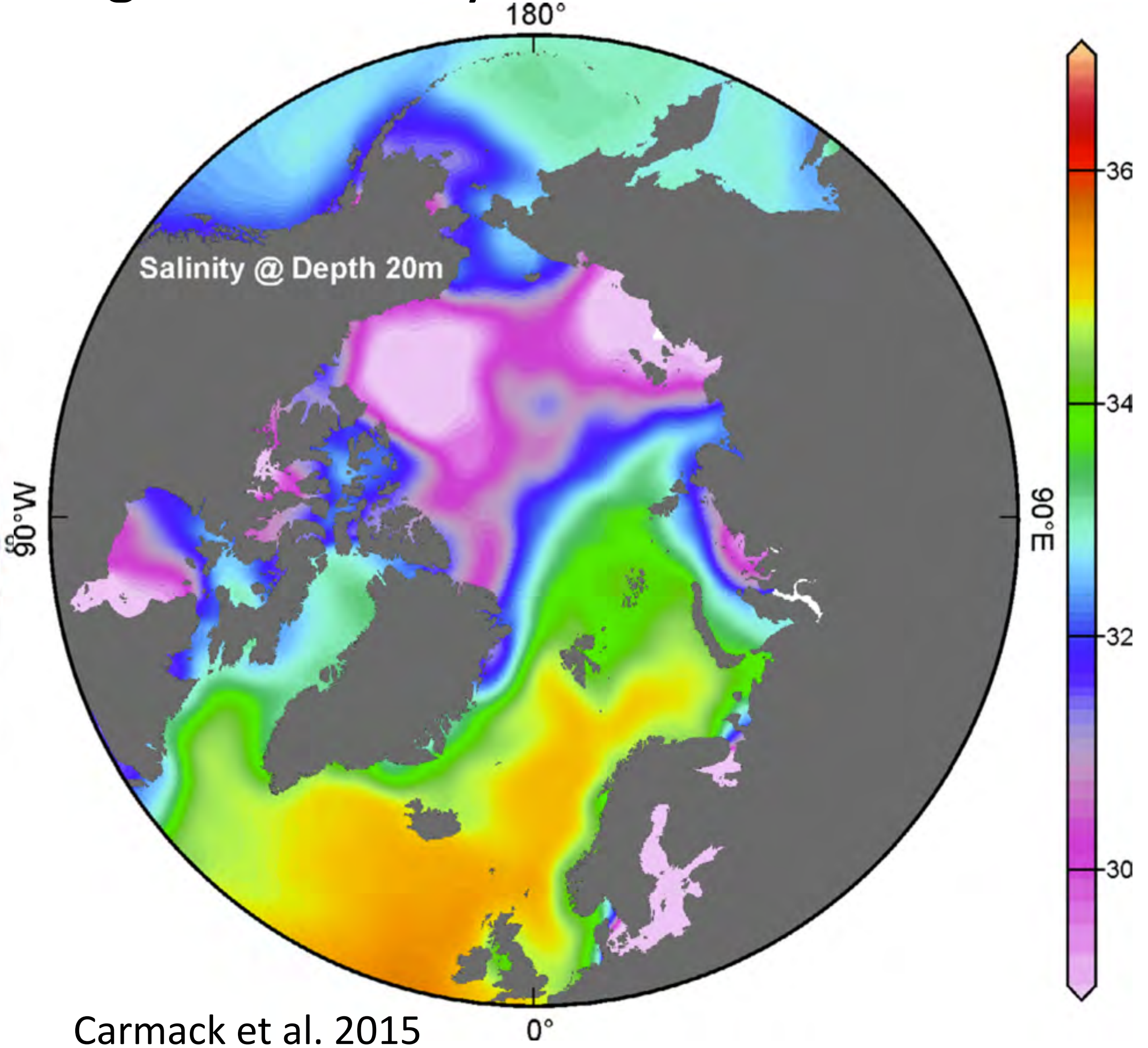
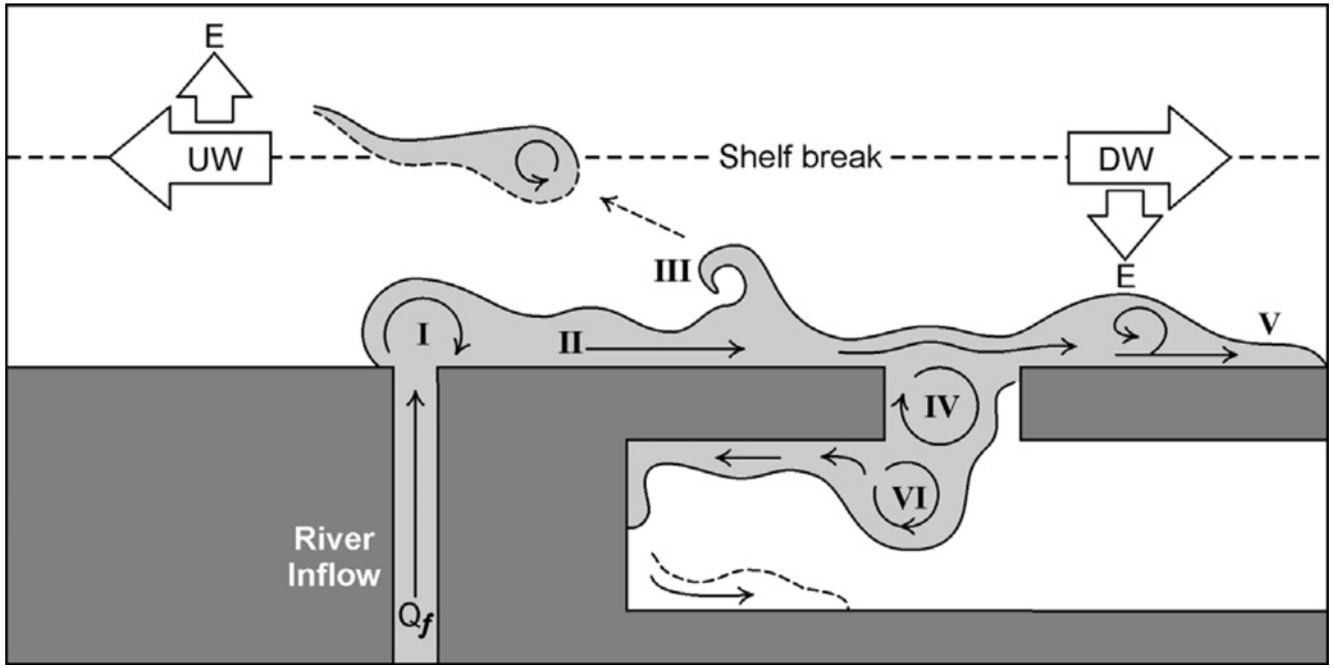


Carmack et al. 2015

Background - Arctic Rivers as source of coastal complexity

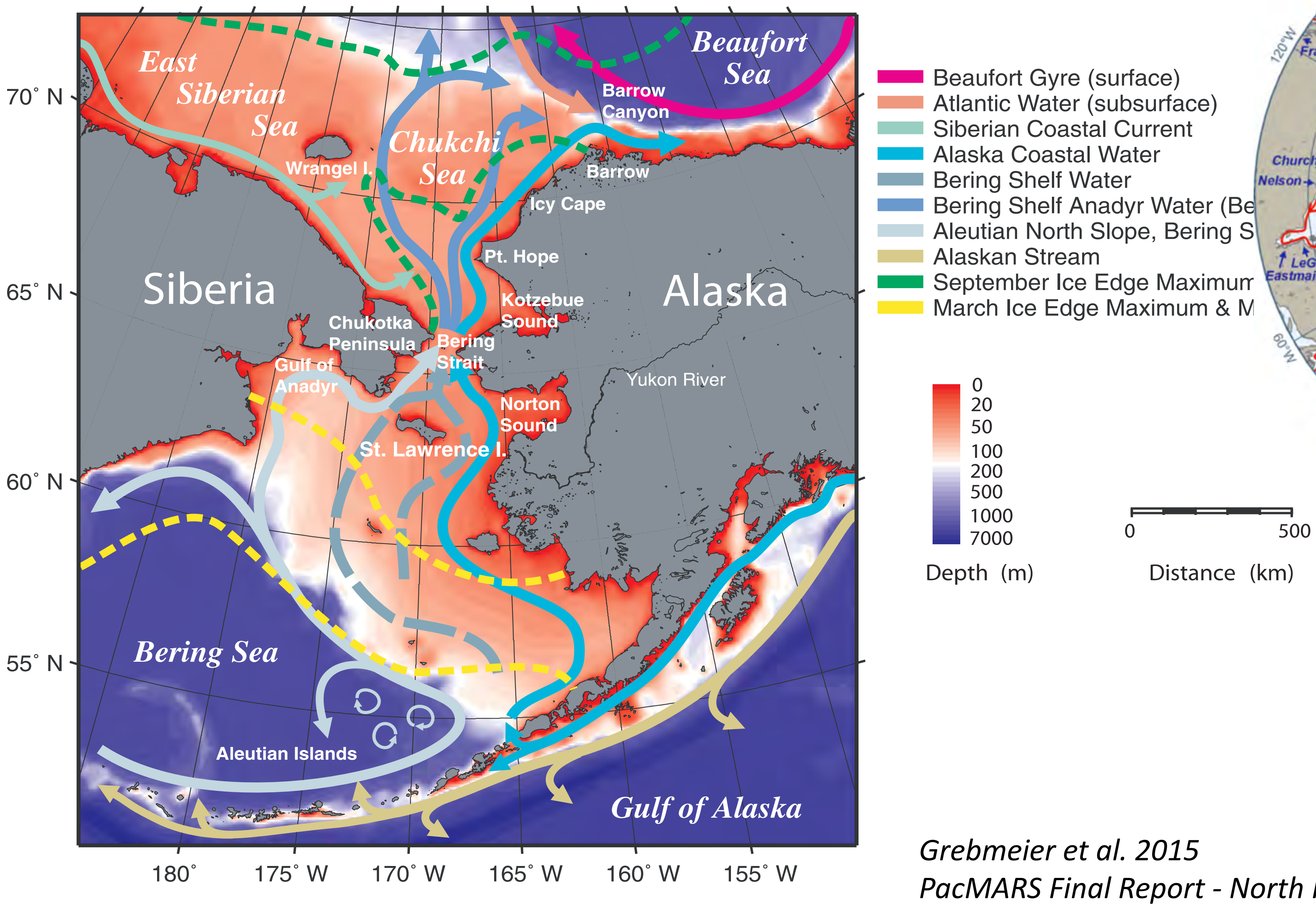
Along Coast Circulation

Contiguous flow of a narrow stream of “freshwater” flowing along the coast from the Bering Sea to the Chukchi Sea and to the Beaufort Sea (suggested as a Pan-Arctic phenomena)



Carmack et al. 2015

Background - Shallow coastal waters

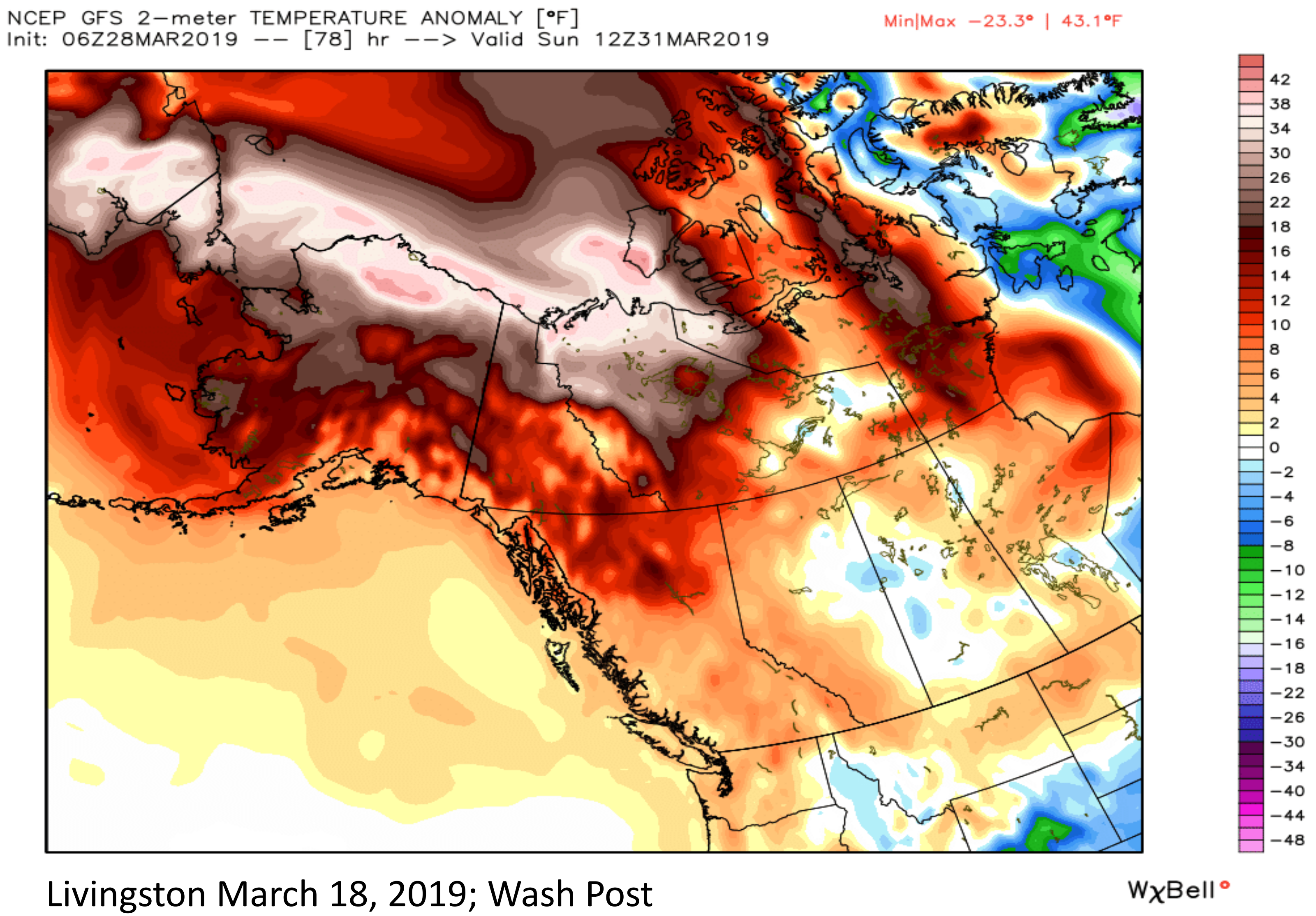


Grebmeier et al. 2015

PacMARS Final Report - North Pacific Research Board

Background – Rapid Changes in the Arctic

- Land north of 60º increase in 1.2ºC by 2015 since 1981-2010, 2.8ºC increase since 1900.[1]



Livingston March 18, 2019; Wash Post

[1] Richter-Menge & Mathis 2016

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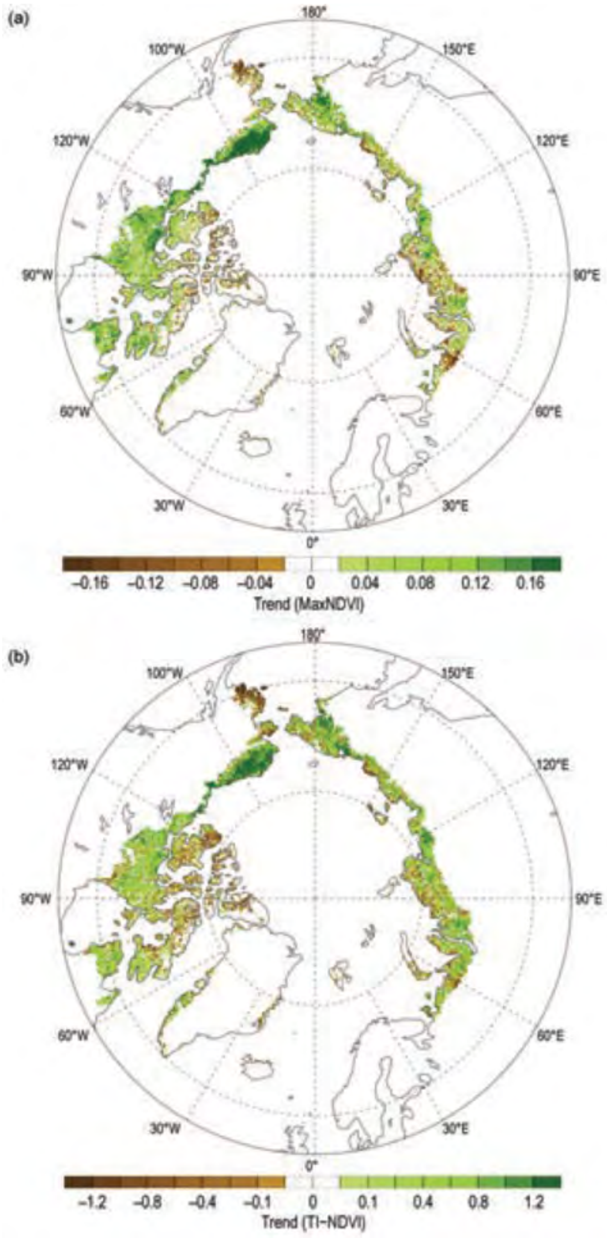

- Land north of 60^{o} increase in $1.2^{o}C$ by 2015 since 1981-2010, $2.8^{o}C$ increase since 1900. [1]
- Record high temps in permafrost at 20 m depth [1]
- Increase in Tundra greenness & productivity [2]
- Declines in snow cover extent in May and June combined with continuing early spring snowmelt [1]
- 15% Increase in River Discharge between 2015 and 1980-1989 average for the 6 largest Euro-Asian rivers.
- Peak river discharge shifting earlier in spring
- Record extent of sea ice retreat in late summer
- 0.5 C SST increase per decade in Chukchi Sea & eastern Baffin Bay since 1982.

[1] Richter-Menge & Mathis 2016
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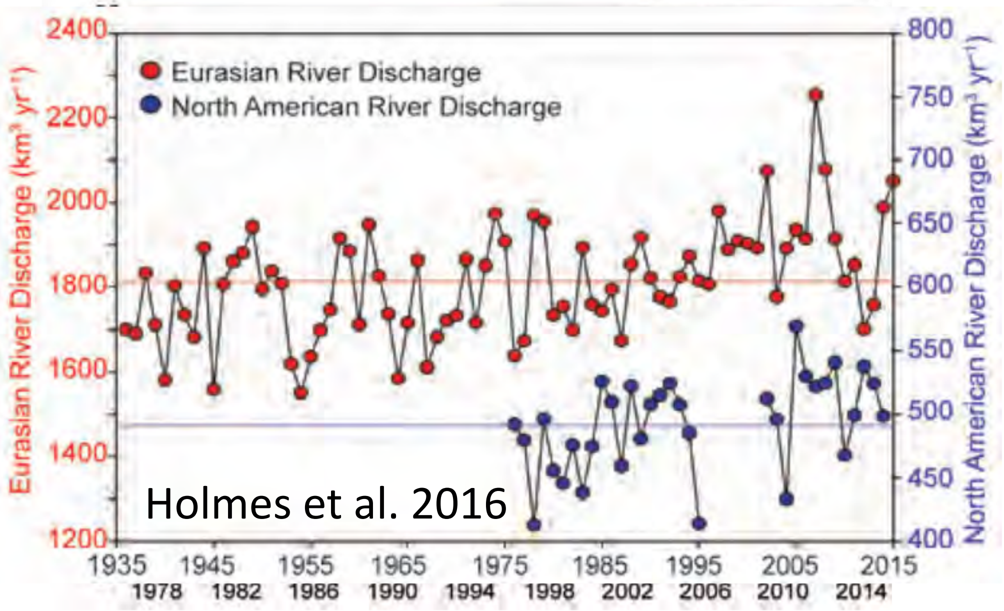

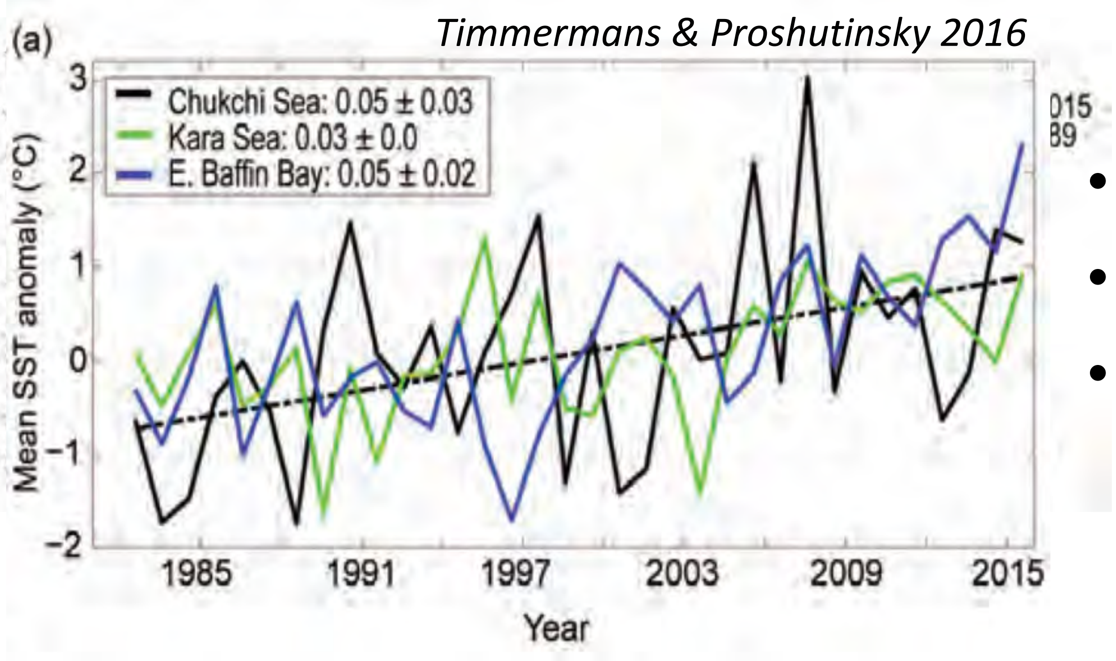

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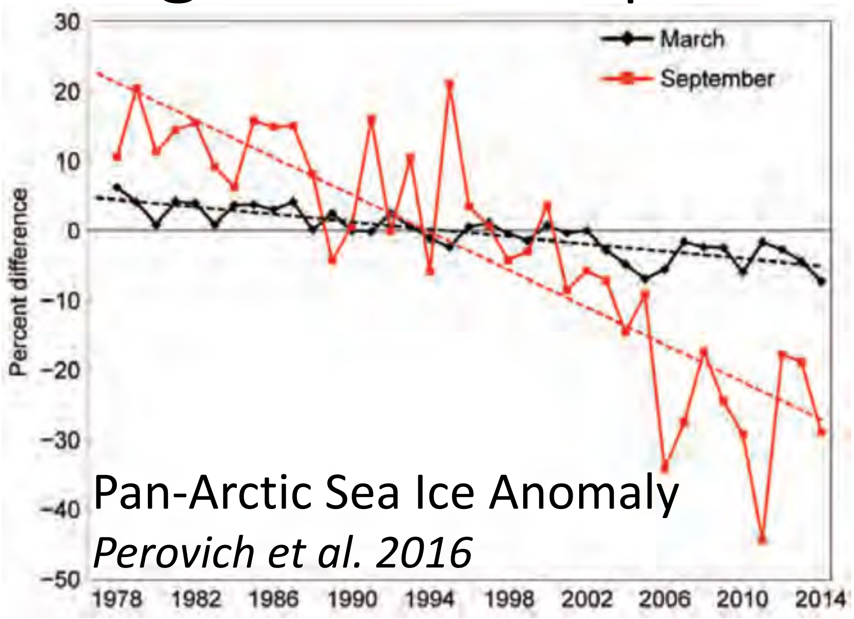

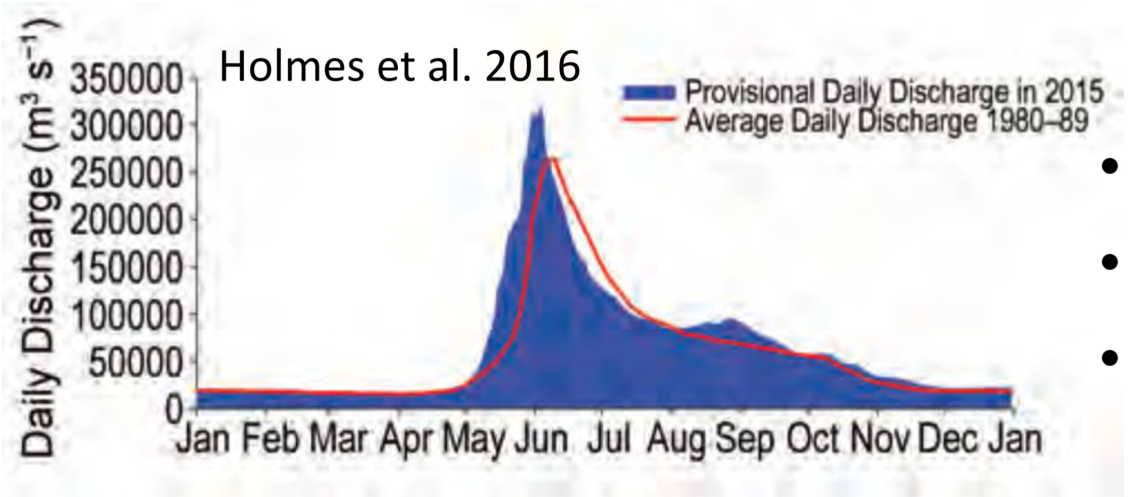

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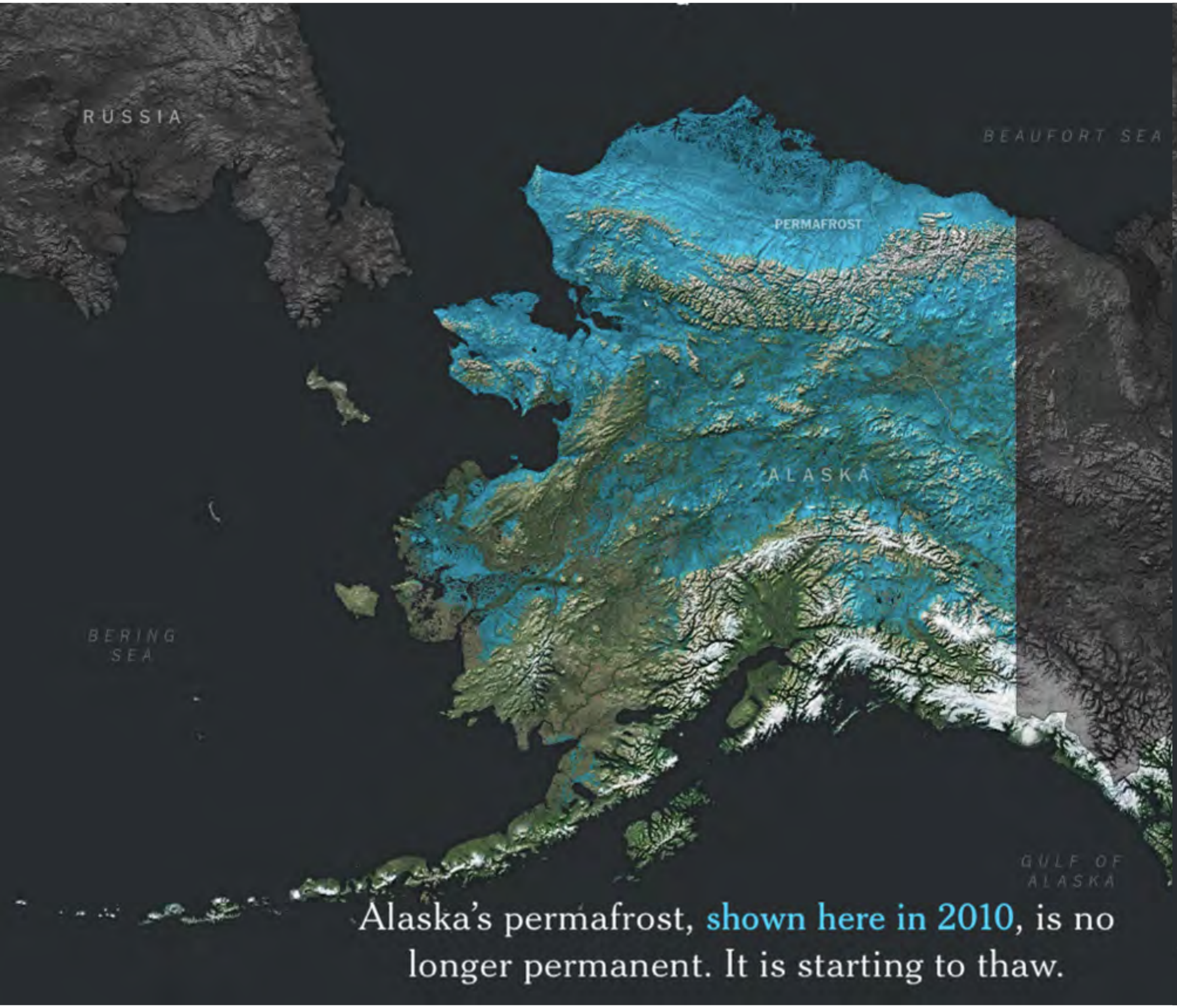
Predicted Loss in Permafrost in Alaska by 2050



Fountain Aug. 23, 2017; NY Times

Climate Change Impacts

- Thawing permafrost along with changing vegetation will undoubtedly alter the composition and fluxes of nutrients, organic matter and sediments entering nearshore waters and coastal seas.
- >50% increase in mean transport across Bering Strait (2001-2011) - could contribute to initiating earlier/further sea ice retreat.
- Sea ice loss during summer (50% by area; 75% by volume)
- Light penetration has increased
    - Higher NPP (1998-2012) esp. within interior shelves (Beaufort and East Siberian; less in Chukchi)
    - Surface sea layer experiencing more warming (e.g., CDOM absorption)
    - Delay in autumn freeze-up
    - Accelerates sea-ice retreat
- All the above resulting in shift in ecosystem structure and function

Carmack et al. 2015; Moore & Stabeno 2015; Wood et al. 2015

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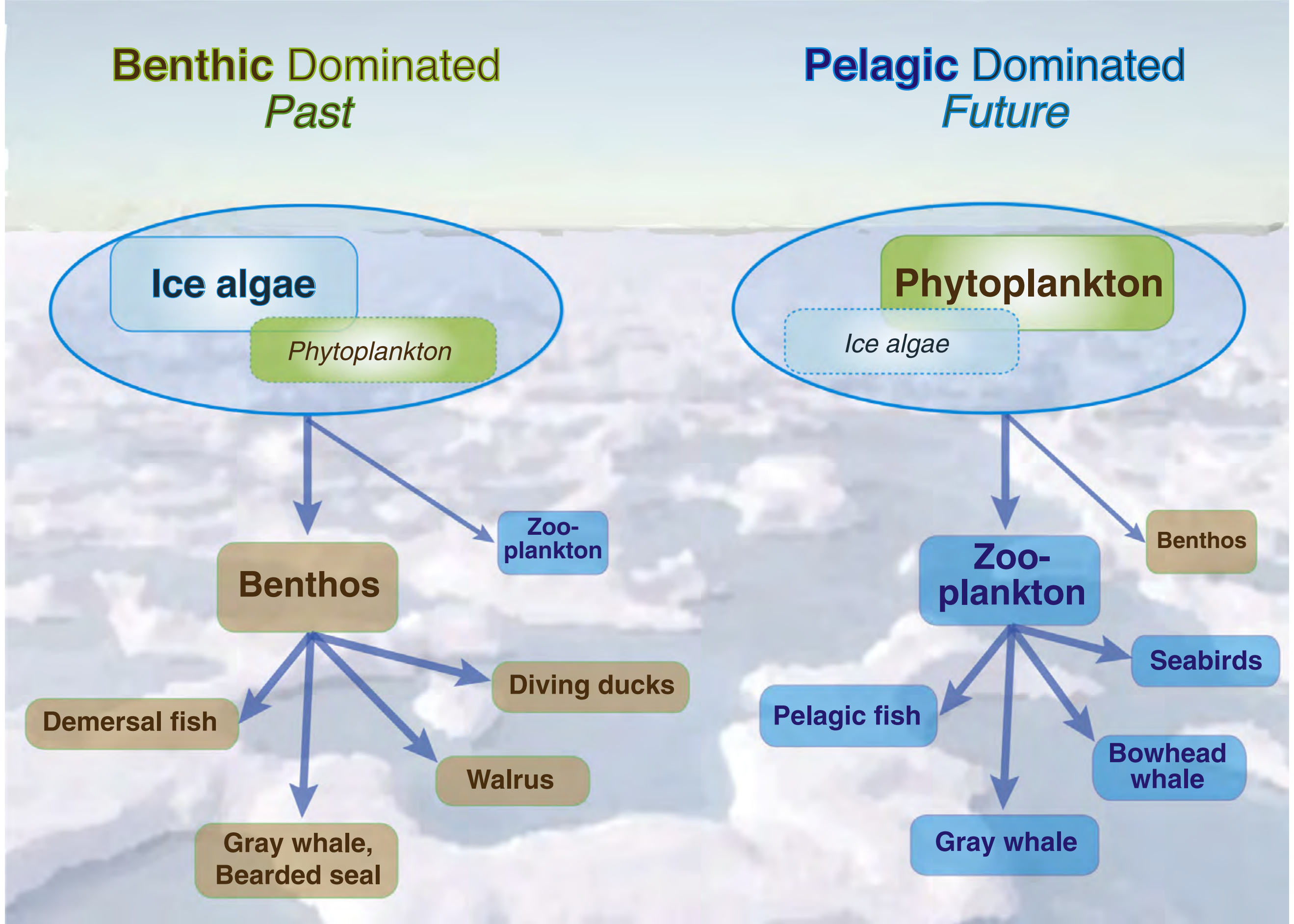


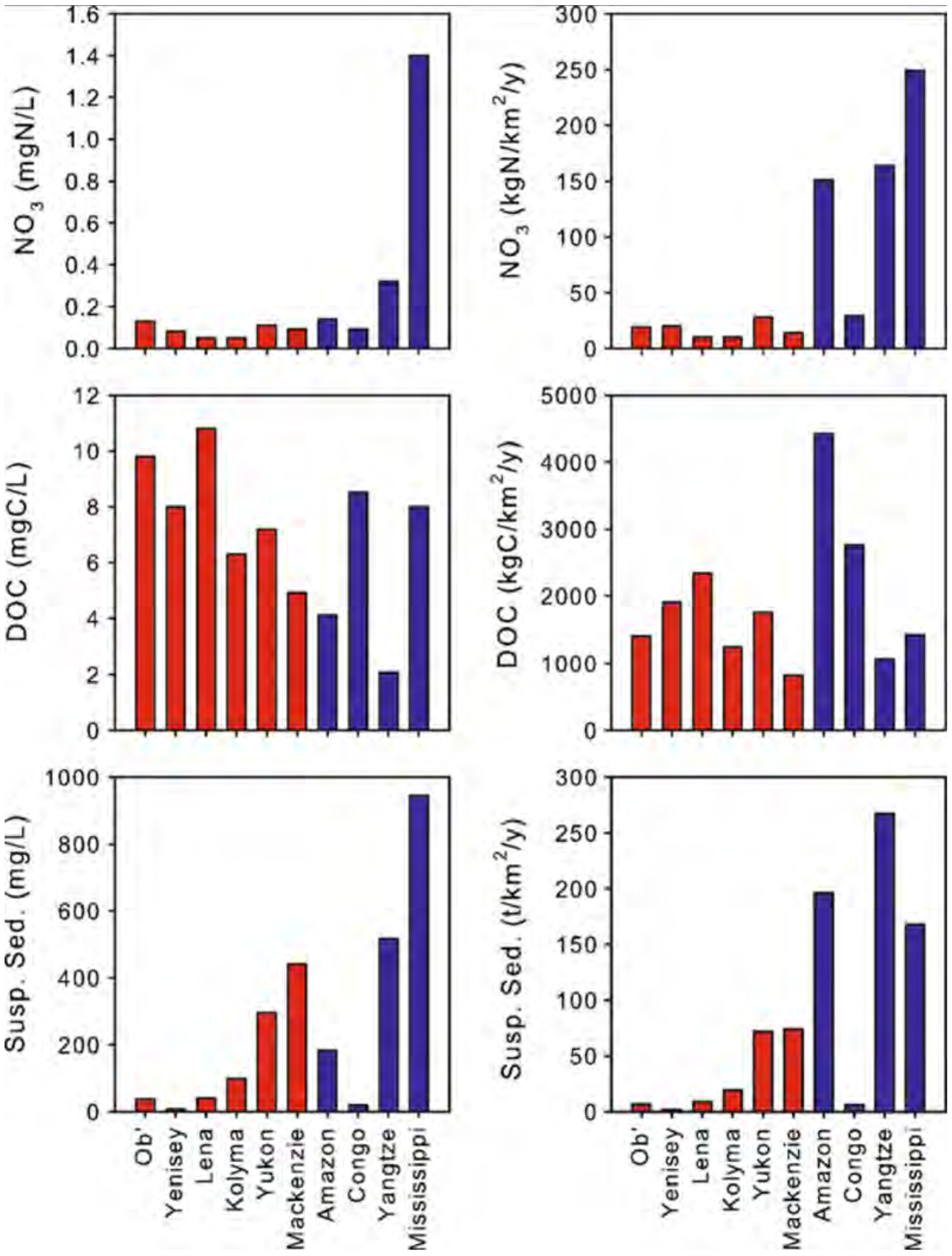
Moore & Stabeno 2015

- All the above resulting in shift in ecosystem structure and function

Carmack et al. 2015; Moore & Stabeno 2015; Wood et al. 2015

Arctic Rivers compared to other Major Rivers

- Arctic rivers are lower in nitrate,
- higher in DOC,
- both low to high in suspended sediments (Euro-Asian vs North American)
- Rivers dilute Arctic Ocean wrt nitrate and phosphate but enrich in DOC and silicate



McClelland et al. 2012

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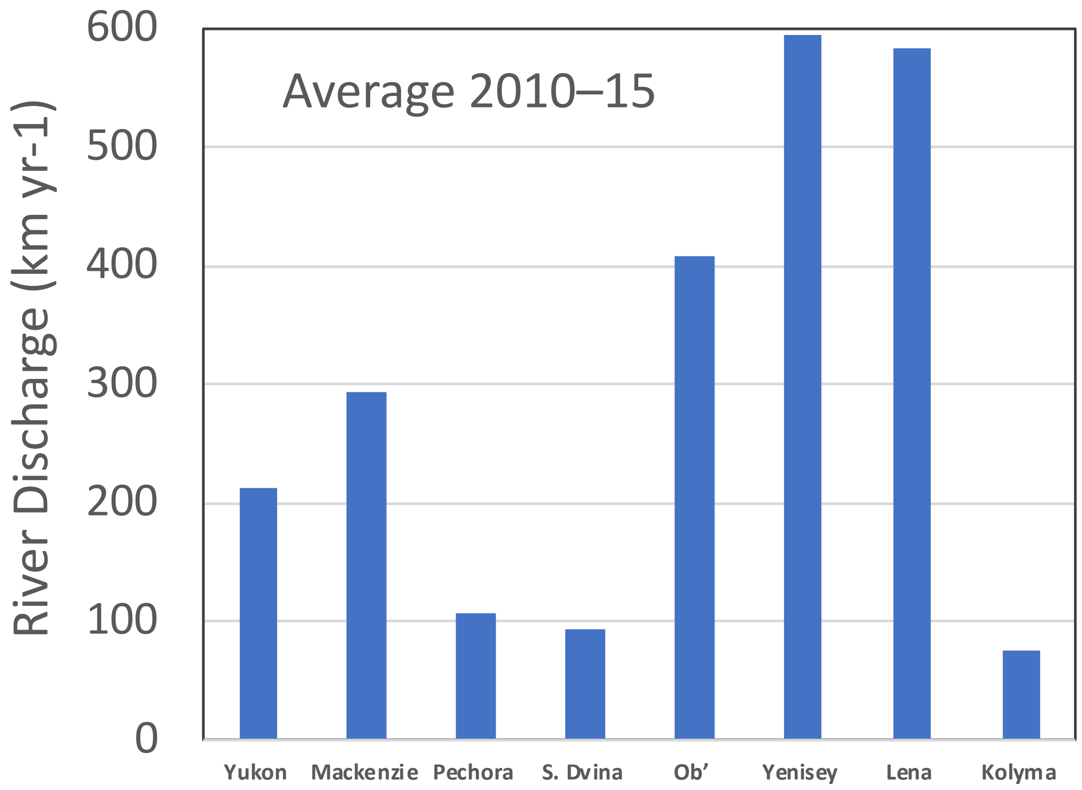
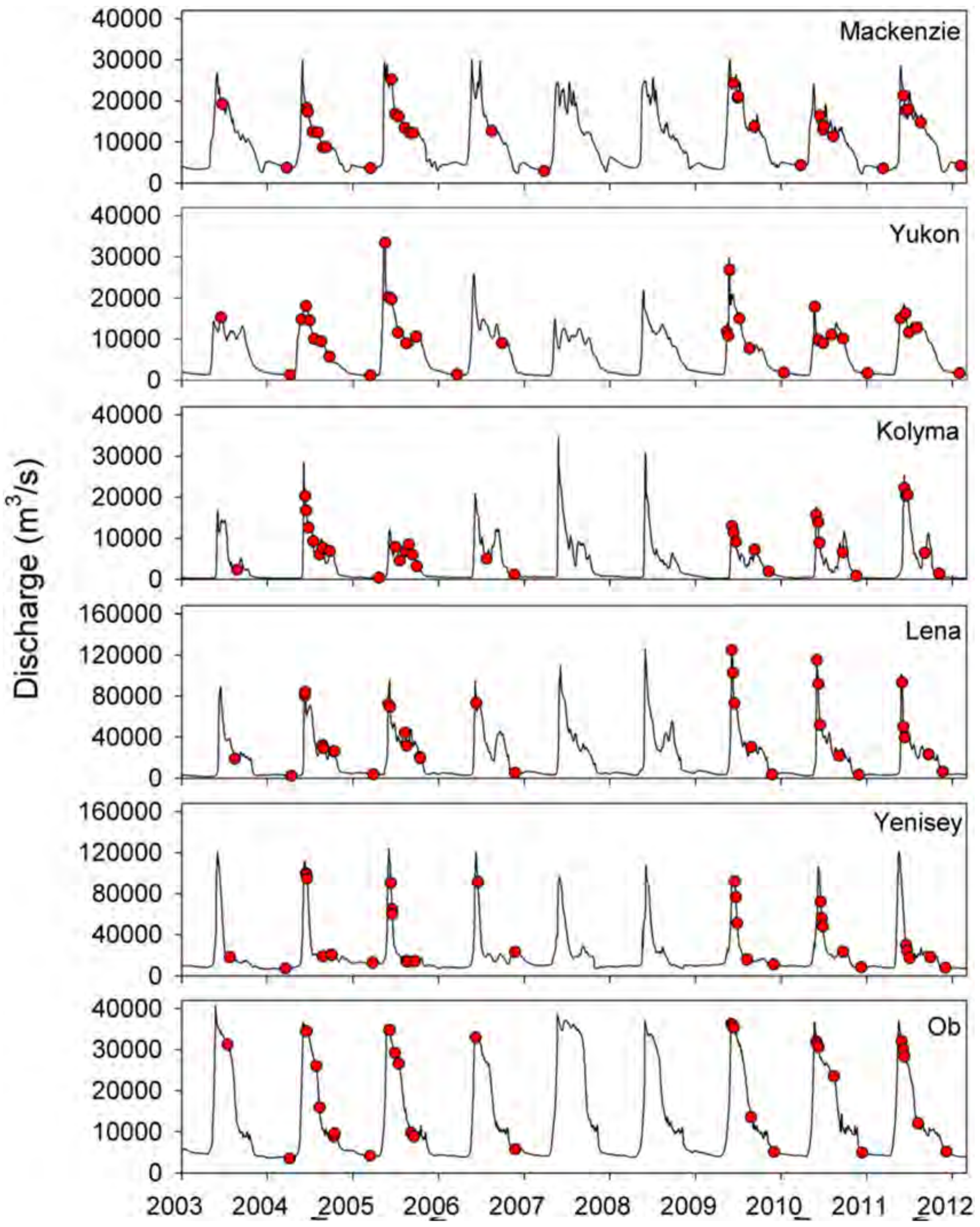


- Phenology of river discharge dominated by sharp peak discharge event once ice breaks in rivers in late spring

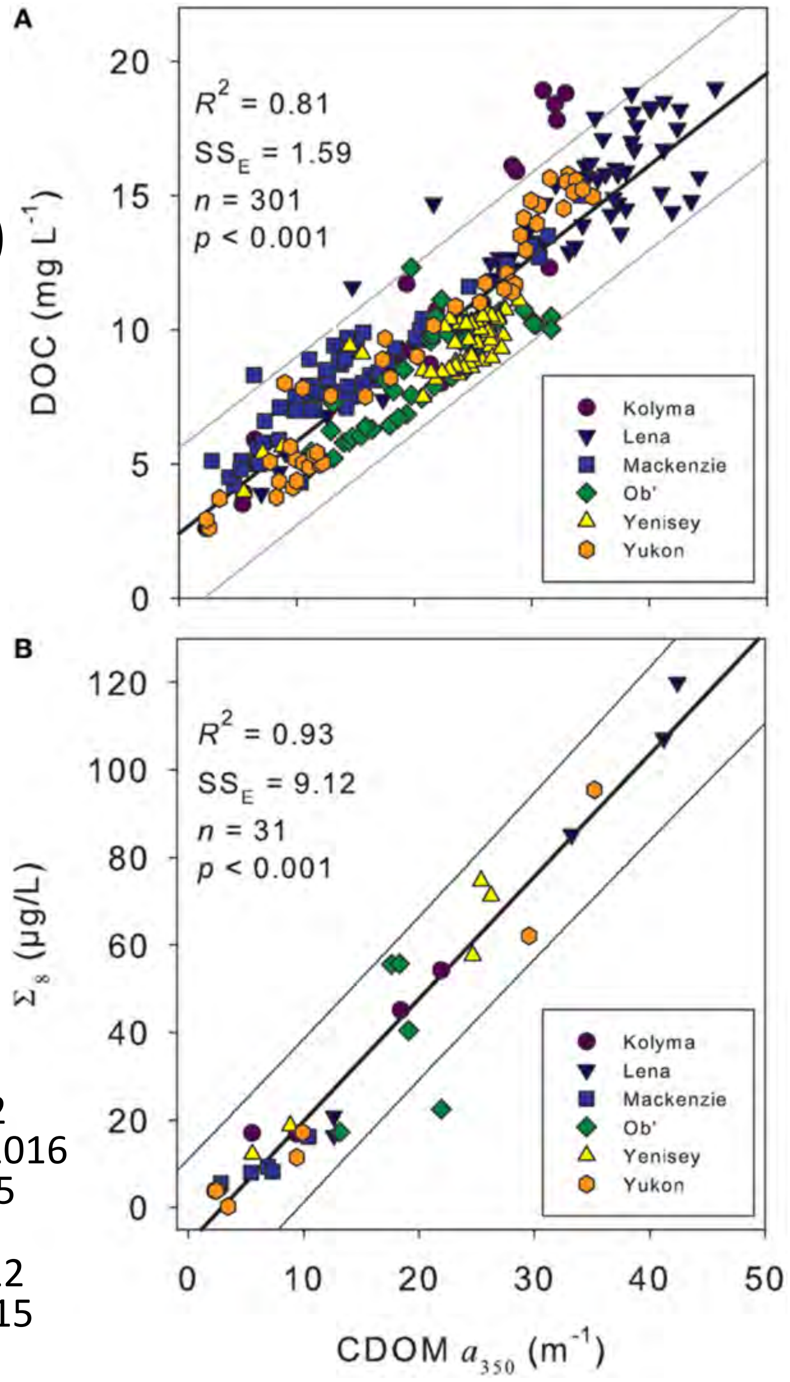
McClelland et al. 2012



McClelland et al. 2016

DOM Characteristics

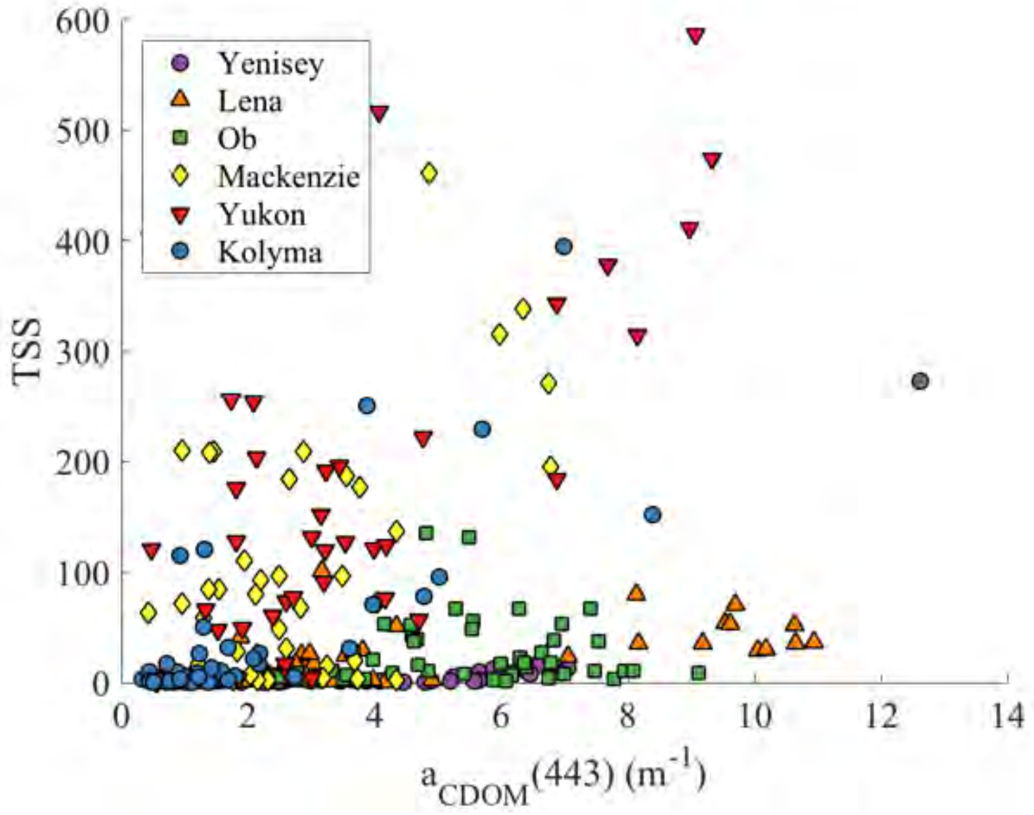
- DOC in North American (Yukon & Mackenzie rivers; ~625 and 415 uM) is on lower end of Euro-Asian rivers (~500 to 915 uM)
- Pan-Arctic DOC loads of 16.6 Tg C yr^{-1} (POC = 3.0) [1,2]
- DOC (CDOM) highest in Ob, Yenisey & Lena
- DOC yields vary by river from 820 (Mackenzie R.) to 2338 kg m^{-2} yr^{-1} (Lena R.; Yukon=1771). [1]
- DOC exported from major rivers appears largely modern.[3]
- Ancient permafrost DOC (>20k yr) microbially degrades quickly (50% in 7 days) with decay rates ~30-200% greater than river DOC. [3]
- Six major rivers export Biodegradable DOC (2.3 Tg C yr^{-1} equivalent to 12-18% of annual DOC export) [5]
- Sea ice melting decreases a_{CDOM} and increases scattering in surrounding seawater; high CDOM terrestrial origin yields 50-60% heat flux into surface Arctic Ocean layer compared to clear waters. [6]



[1] Holmes et al. 2012
[2] McClelland et al. 2016
[3] Spencer et al. 2015
[4] Mann et al. 2016
[5] Wickland et al 2012
[6] Granskog et al. 2015

POM Characteristics in the Arctic Rivers-to-Sea

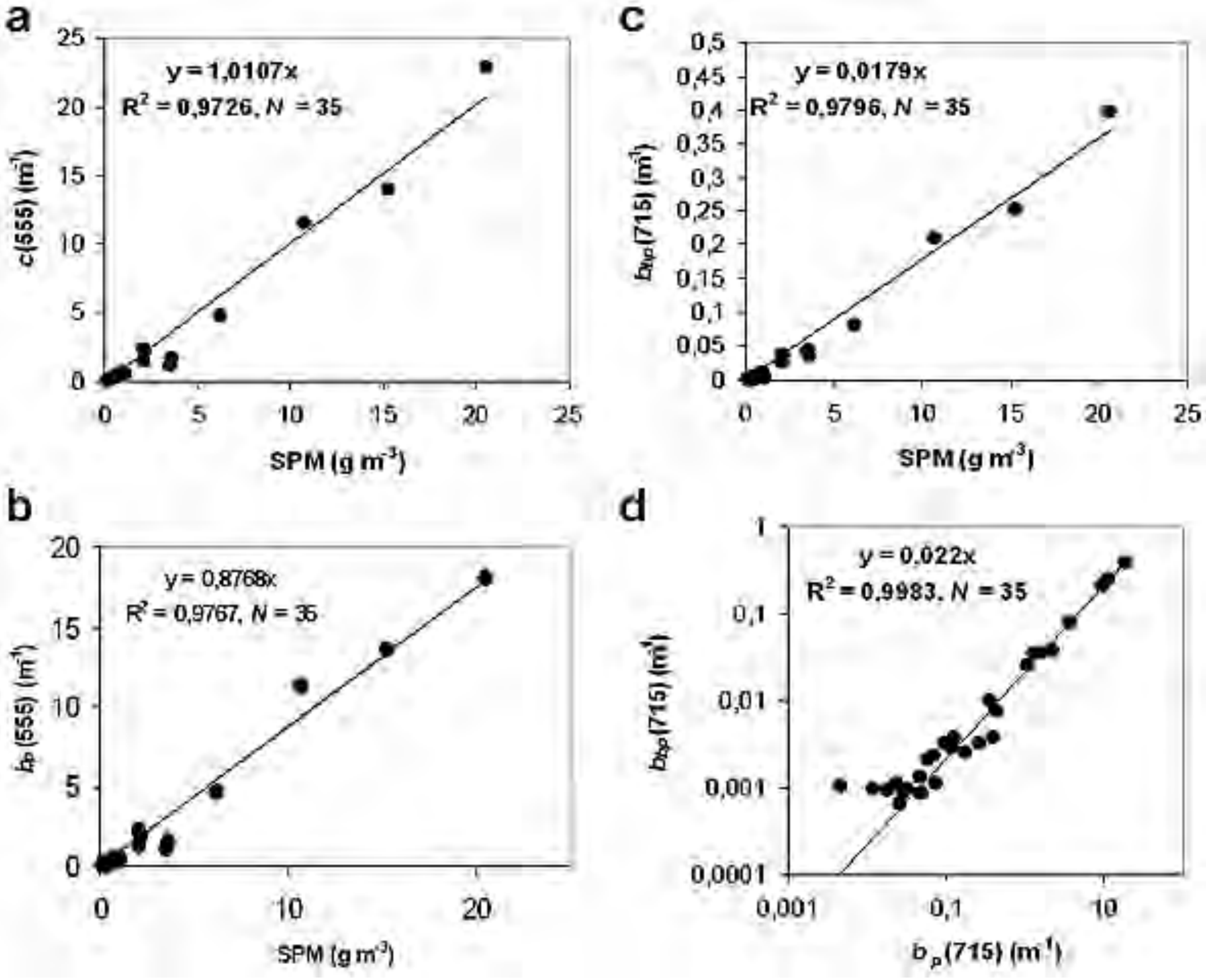
- POC in North American (Yukon & Mackenzie rivers; 145 and 126 uM) is much higher than Euro-Asian rivers (26 to 97 uM) (217 and 201 discharge-normalized compared to 32 to 122).
- PN in Yukon & Mackenzie (13.1 & 10.4 uM) is higher than Euro-Asian rivers (3.3 to 11.5 uM) (19.7 and 16.3 discharge-normalized compared to 3.9 to 16.1).
- Pan-Arctic POC fluxes: 3.0 Tg C yr^{-1}
- Pan-Arctic PN fluxes: 0.33 Tg N yr^{-1}
- Suspended sediments low in Ob, Yenisey, and Lena and very high in Yukon and Mackenzie
- SPM (TSS) not related to CDOM

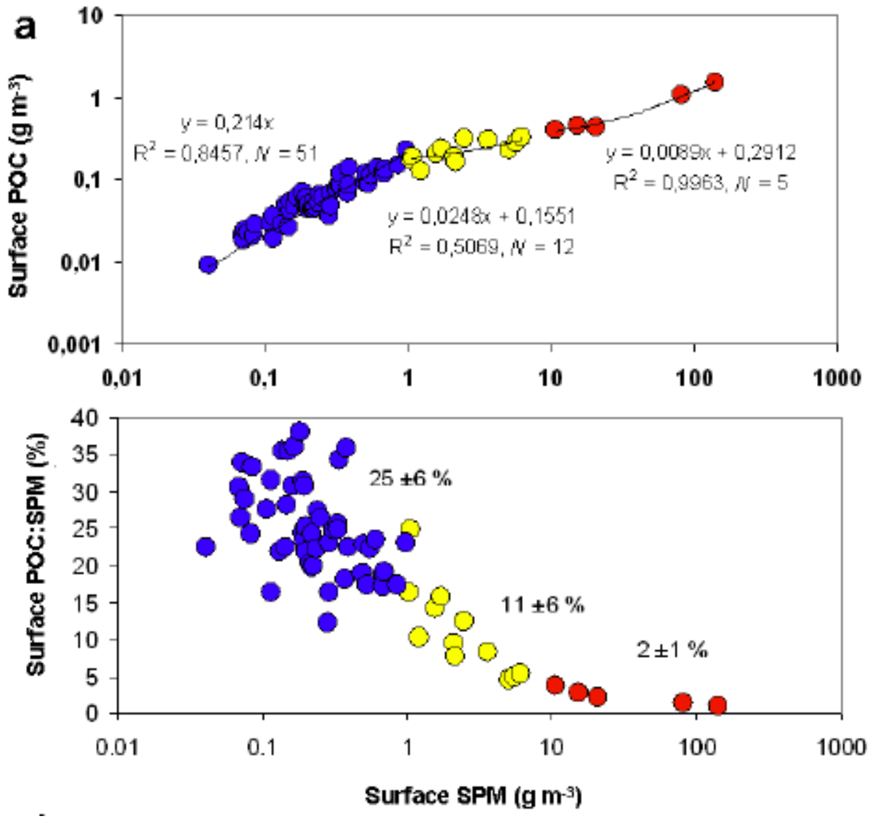


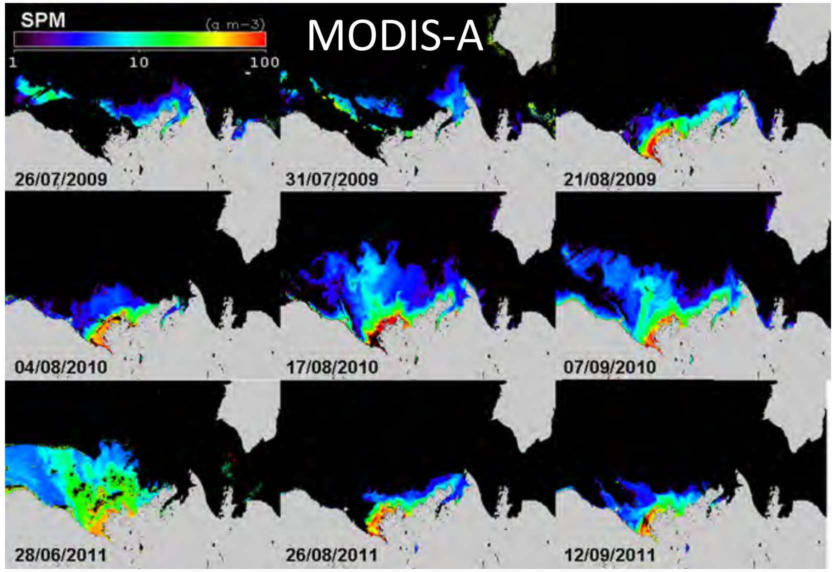
McClelland et al. 2016

SPM & POC – Mackenzie-Beaufort system

- SPM flux for 2010: 29 Tg yr^{-1} (0.6 Tg POC yr^{-1})

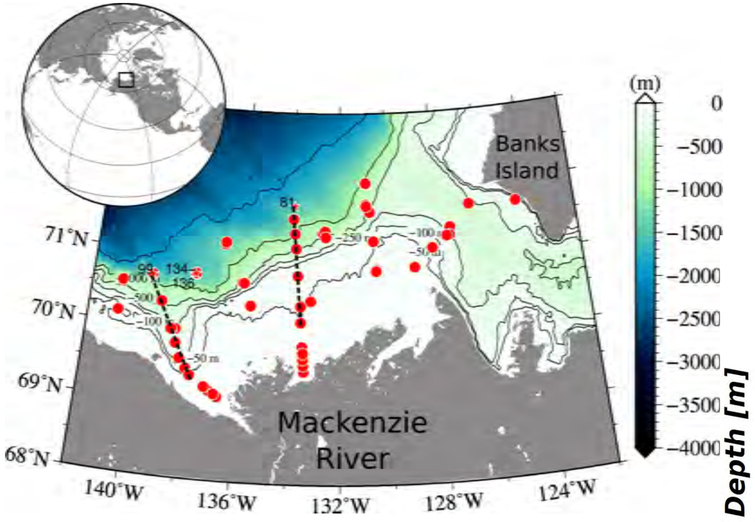


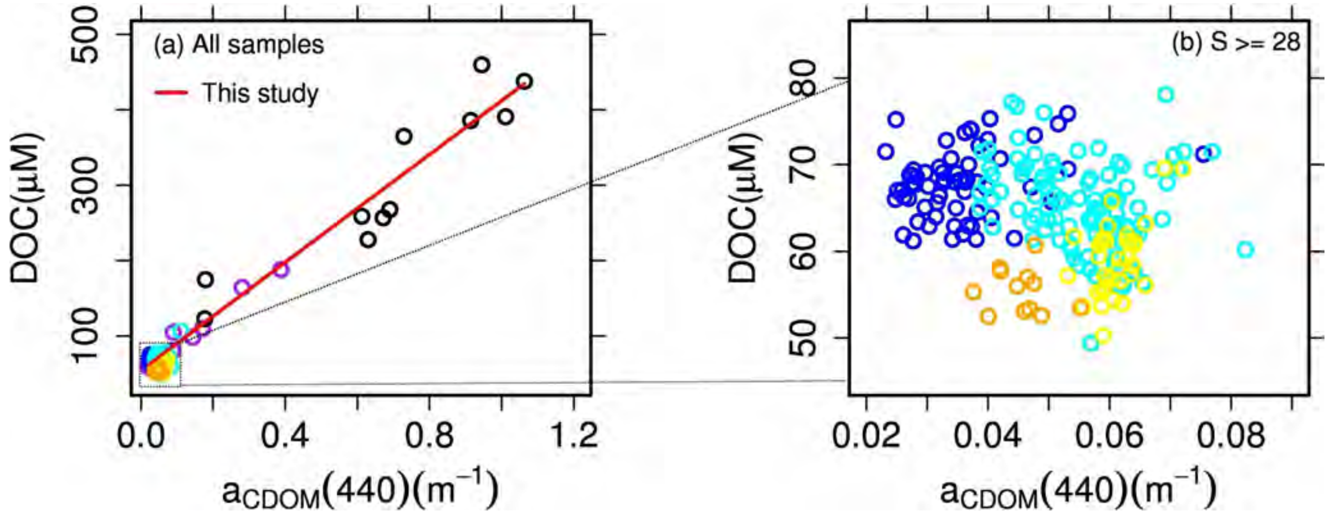


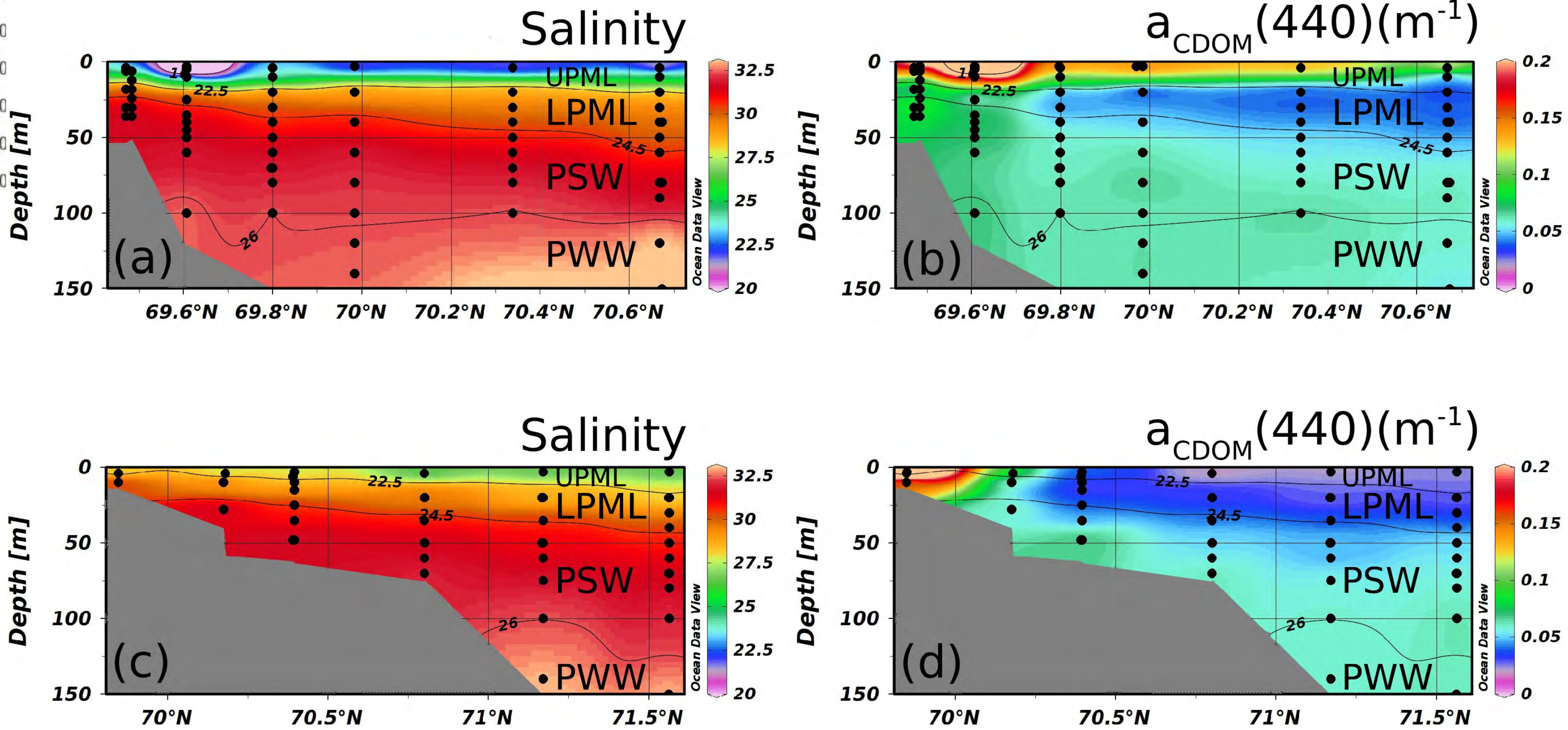


Doxaran et al. 2012

DOM in Mackenzie Plume

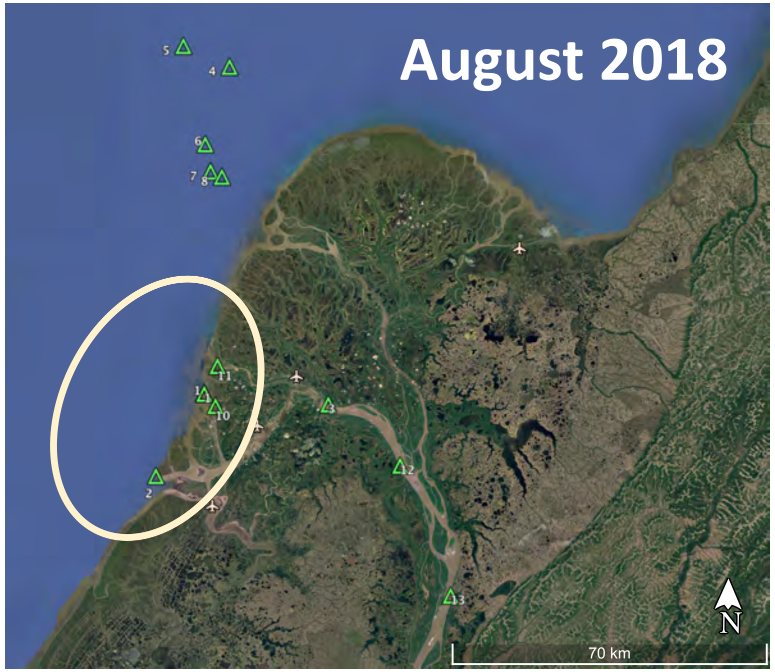




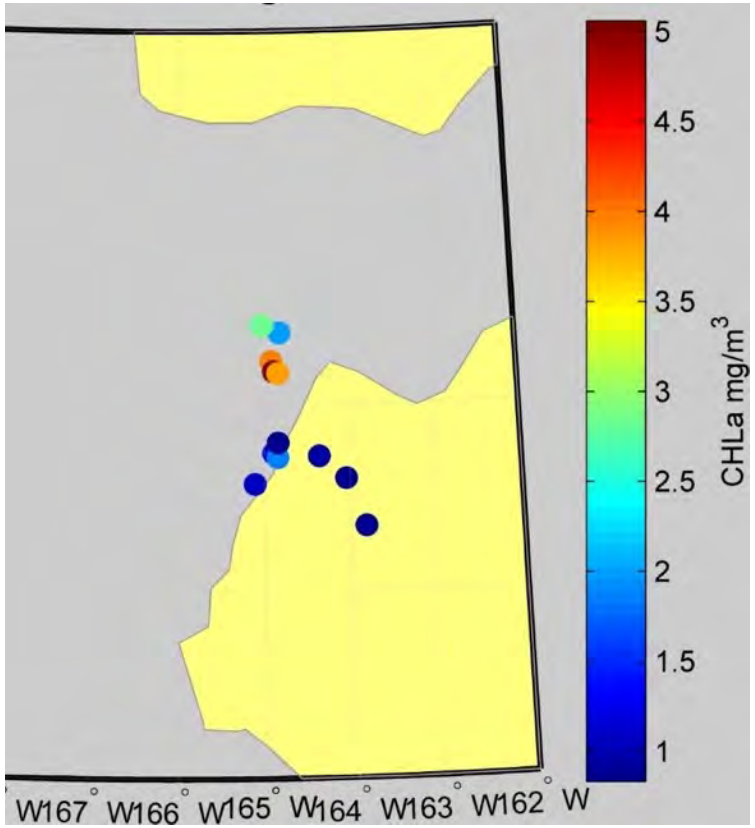


Matsuoka et al. 2012

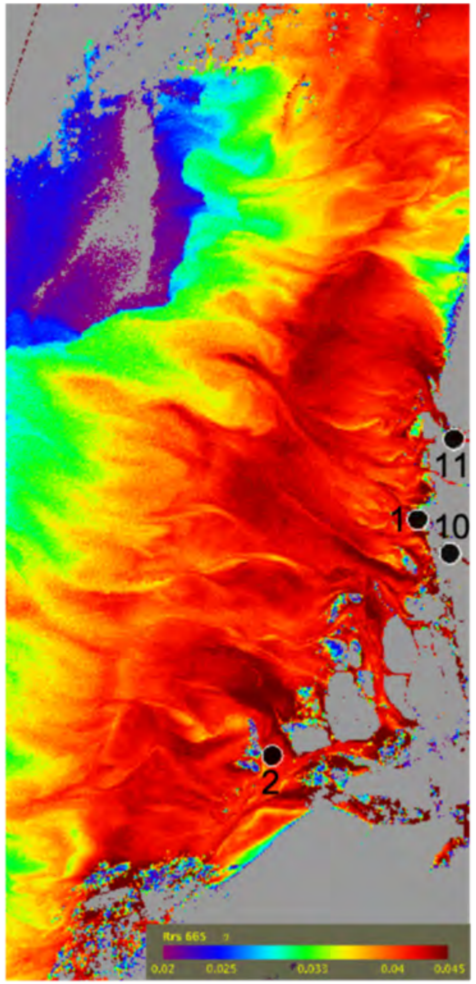
Results from Yukon-Norton Sound System



- DOC correlates very well with a_{CDOM}
- POC correlates very will with SPM
- SPM exceeds 550 g m^{-3} within the Yukon River delta; compared to the ~300 g m^{-3} measured far upstream at Pilot Station by Arctic-GRO.



Sentinel 2B - Rrs665
August 2018

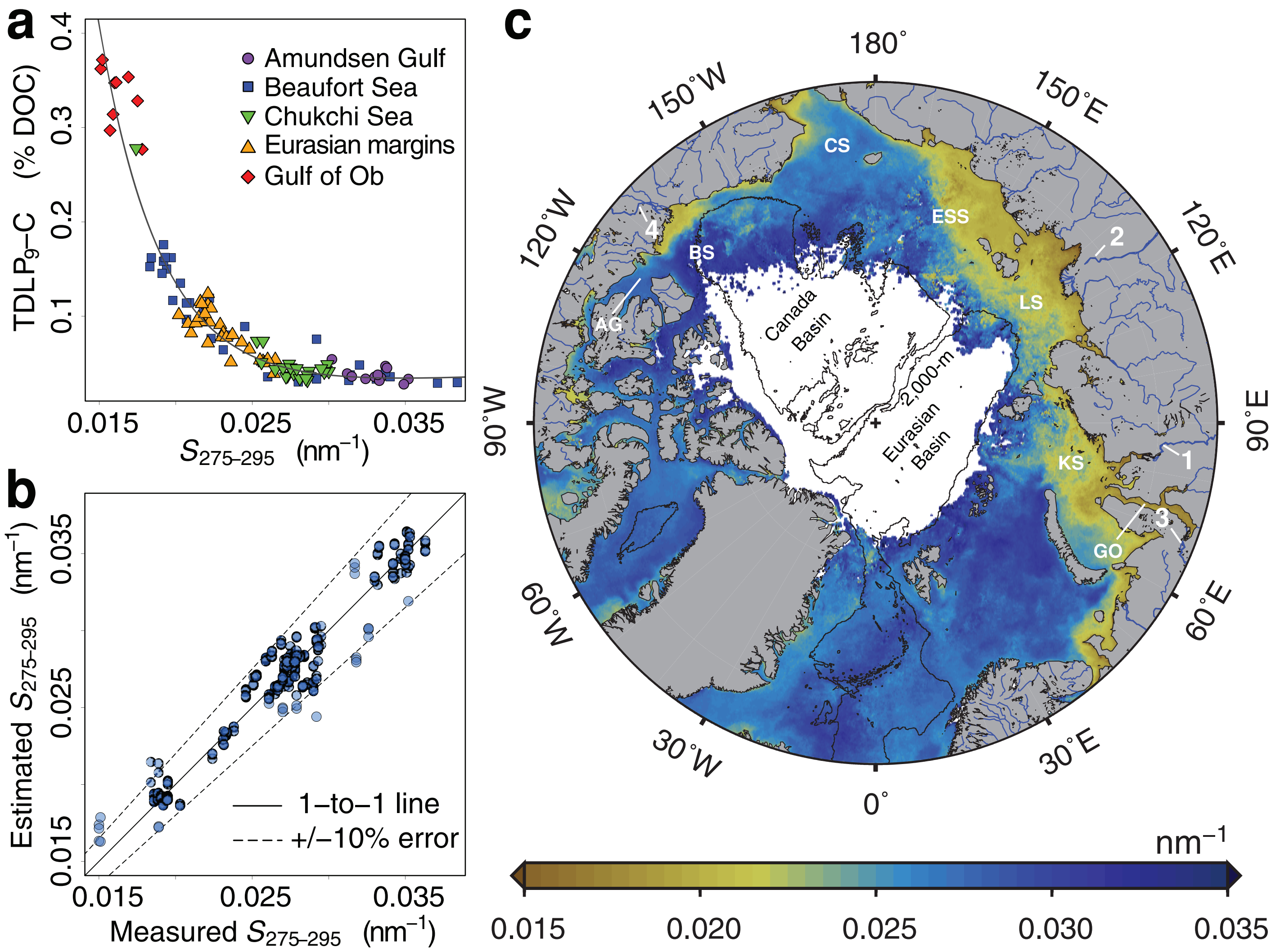


NASA Arctic RSWQ project: Hernes, Mannino, Spencer, Tzortziou, Aurin, Grunert, Clark, Novak, Freeman

MODIS-Aqua CDOM spectral slope and link to lignin

- Lignin correlates with CDOM spectral slope ($S_{275-295}$)
- Inter-annual changes in routing of Mackenzie River discharge from eastward to the northwest

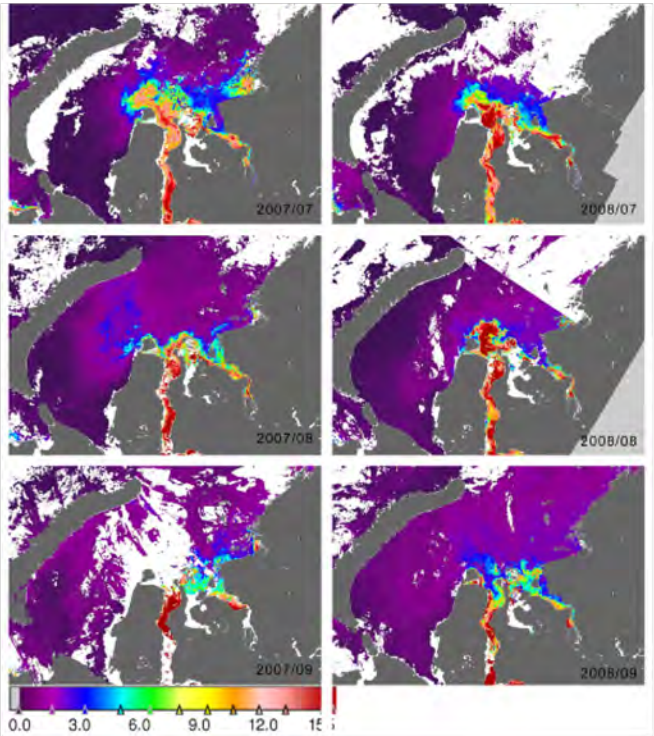
$S_{275:295}$ derived from multiple linear regression formulation with Rrs bands



Fichot et al. 2013

Satellite Retrievals of DOC and CDOM

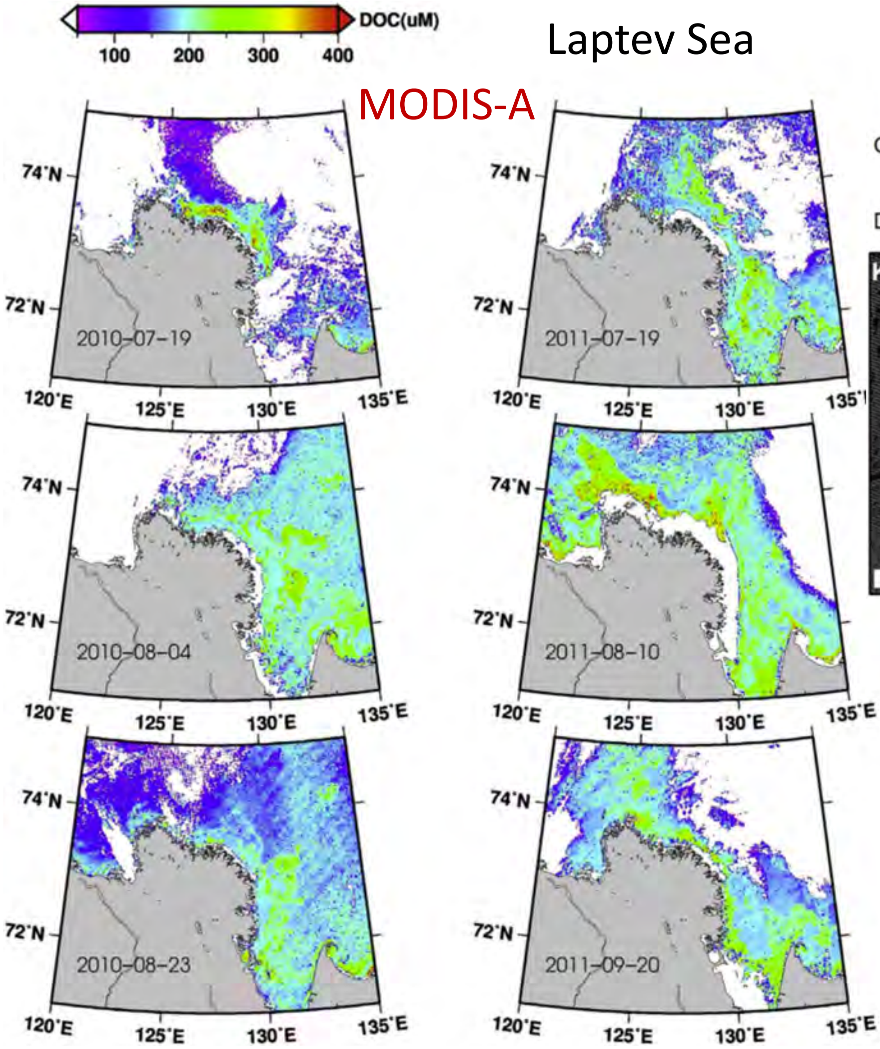
MERIS monthly DOC for Kara Sea and contributing Ob & Yenisey Rivers



Korosov et al. 2012

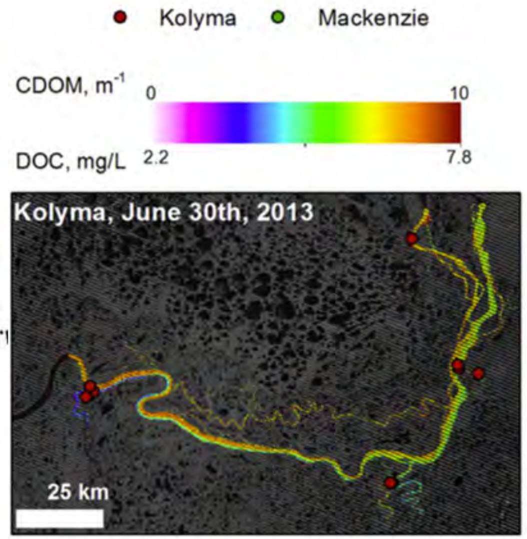
Laptev Sea

MODIS-A

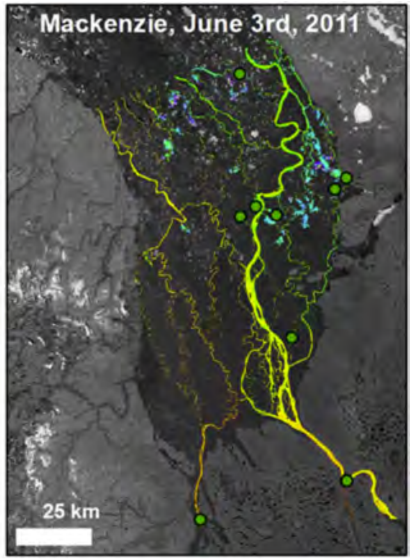


Matsuoka et al. 2017

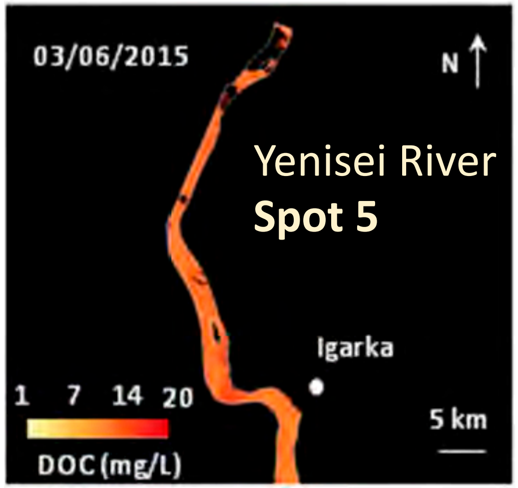
Griffin et al. 2018



Landsat-8



Herrault et al. 2018



Challenges in Remote Sensing – some unique to the Coastal Arctic

- Low sun angles (higher air masses and lower signal)
  - Small errors in atmospheric correction magnified at high solar zenith angles
  - Lw comprise <1 to 4.5% of L_t at >70° N (default ac processing set to <70°)

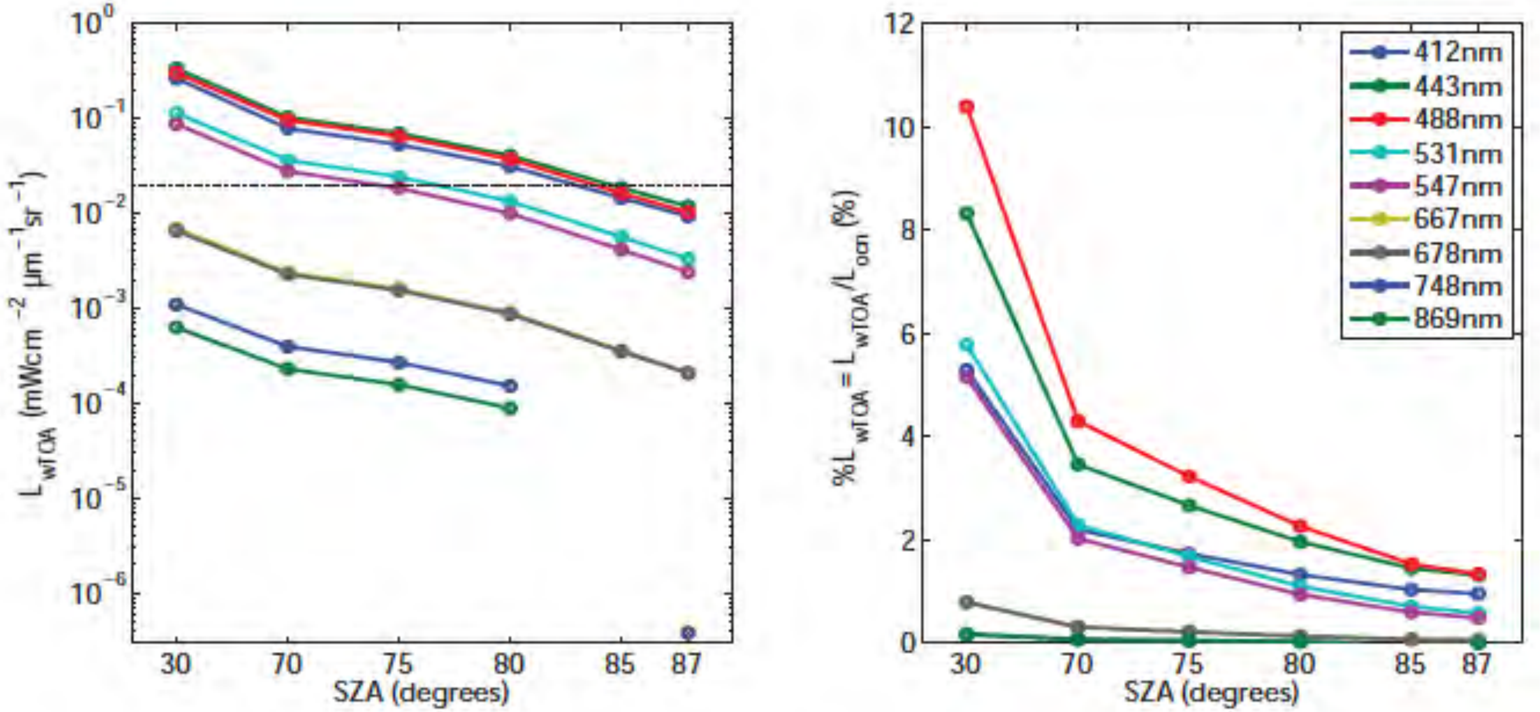


Figure 3.5 Radiance emerging from the sea that reaches the TOA, as defined by Equation 3.10, for several values of the solar zenith angle from 30° to 87°, and b) the percentage contribution of water signature to the TOA. The dashed line in a) is the accepted atmospheric correction algorithm uncertainty.

IOCCG Report No. 16 2015

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  - Lw comprise <1 to 4.5% of L_t at >70° N (default ac processing set to <70°)
- Complexity of high constituent loading
  - High CDOM and SPM; moderate chlorophylls as turbidity decreases offshore
- Adjacency effects from land and ice
- Pixel contamination from sea ice (and clouds)
- Arctic haze – strong absorbing aerosols in April to June
- Forest fires in summer contribute absorbing aerosols to the Beaufort and elsewhere
- Need for high spatial resolution at high SNR along the coast and inland
- Cloud cover – "on average ~80% at 60°N during spring, summer, and fall, remains about the same between 60 and 80°N during summer, and decreases to 60% and 70% at 80°N during spring and fall"
- Presence of ice cover from late fall to early spring (cannot see under ice blooms)
- Pigment packaging differs for Arctic phytoplankton; standard algorithms not adequate
- Arctic-specific or regionally tuned algorithms
- Obtain adequate in situ measurements along the coast for algorithm development and for validation

IOCCG Report No. 16 2015

Challenges in Collection of Field Observations

- Remoteness – access to sites, resources, wildlife hazards; Ice conditions
- IOP sensors designed/tuned to highly absorbing and scattering waters
  - Shorter pathlengths, higher dynamic range
- Radiometers designed with higher sensitivity for measurements at low sun angles (lower Lw) and for highly absorbing and scattering waters
- Small volume filtration of turbid samples require extra care
  - To homogenize and for accurate volume
- Sampling at peak discharge by boat is dangerous due to high water velocity and presence of ice chunks
  - Helicopters enable water sampling collection and potentially optics
- Shallow waters prevents direct access by larger boats/ships
  - Use of small local boats; large ships/boats that carry small crafts
- River flow gauges (if they exist) are far upstream from the river mouth
- Those working in the coastal Arctic today are overcoming many of these challenges (new/refined optical sensors needed!)

Arctic COLORS

Arctic - Coastal Land Ocean Interactions

Poster # 69