Changing Freshwater Fluxes in the Arctic: A Tale of Melted Ice, River Runoff and the Bering Strait

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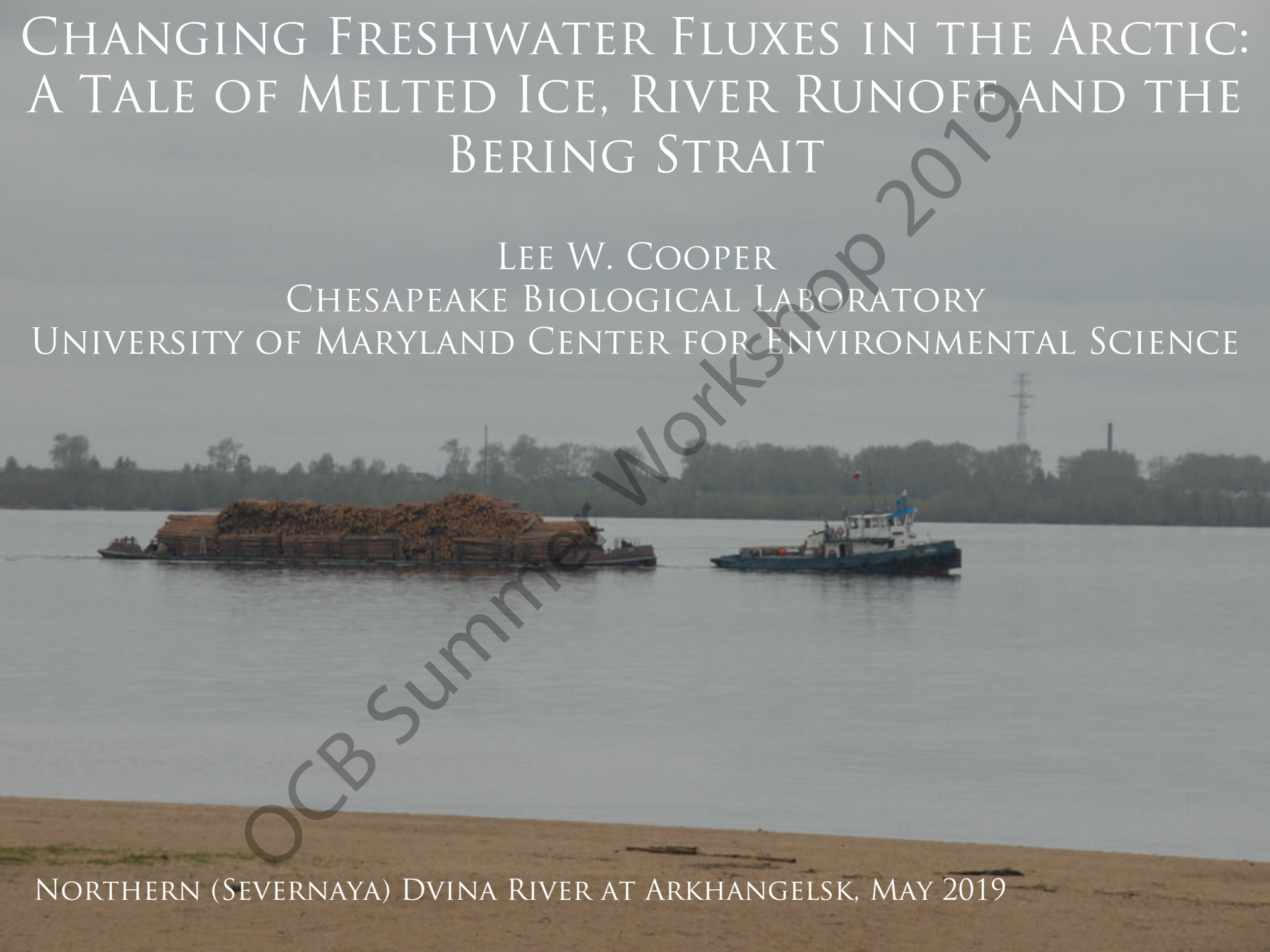
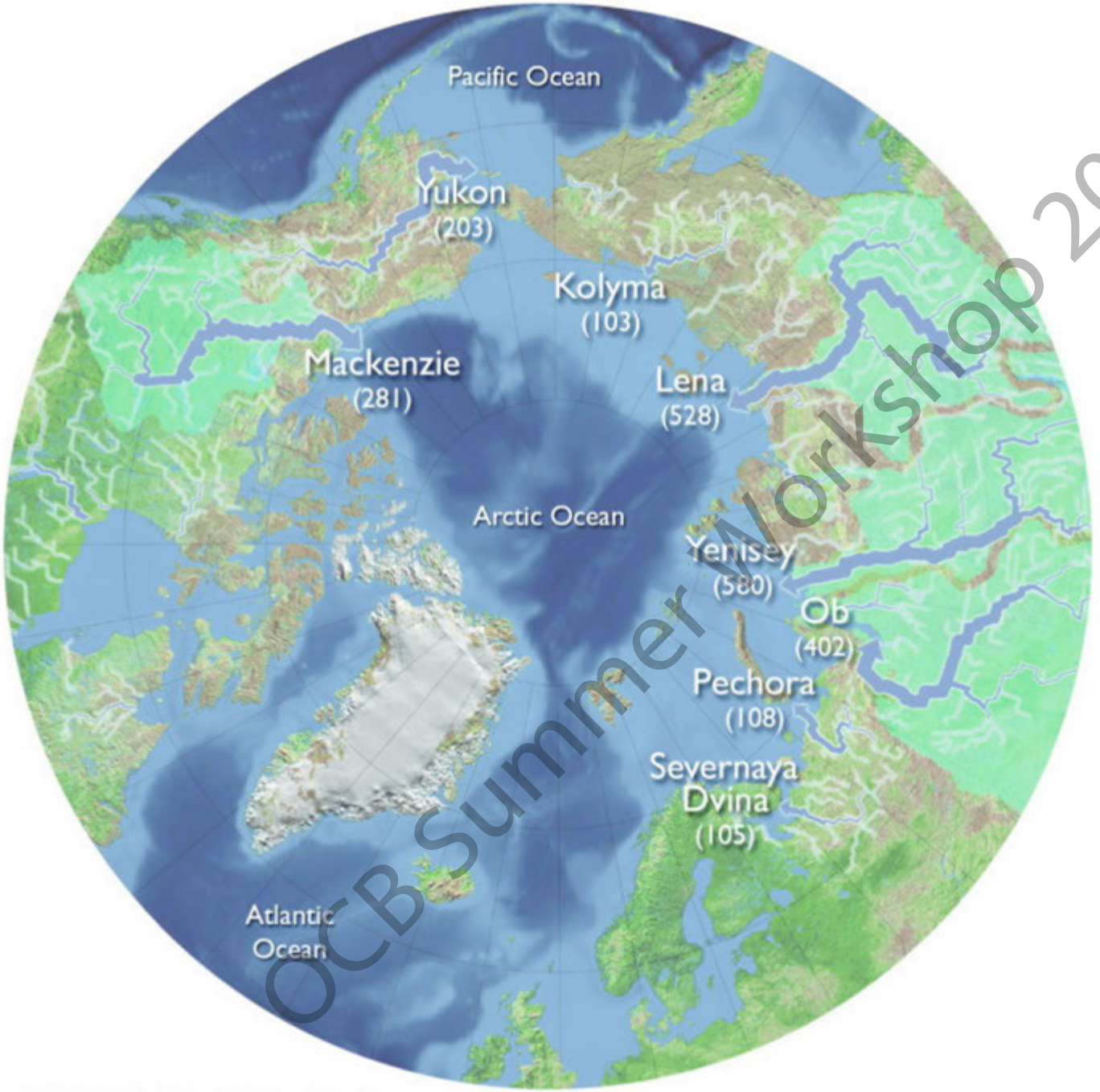


Northern (Severnaya) Dvina River at Arkhangelsk, May 2019



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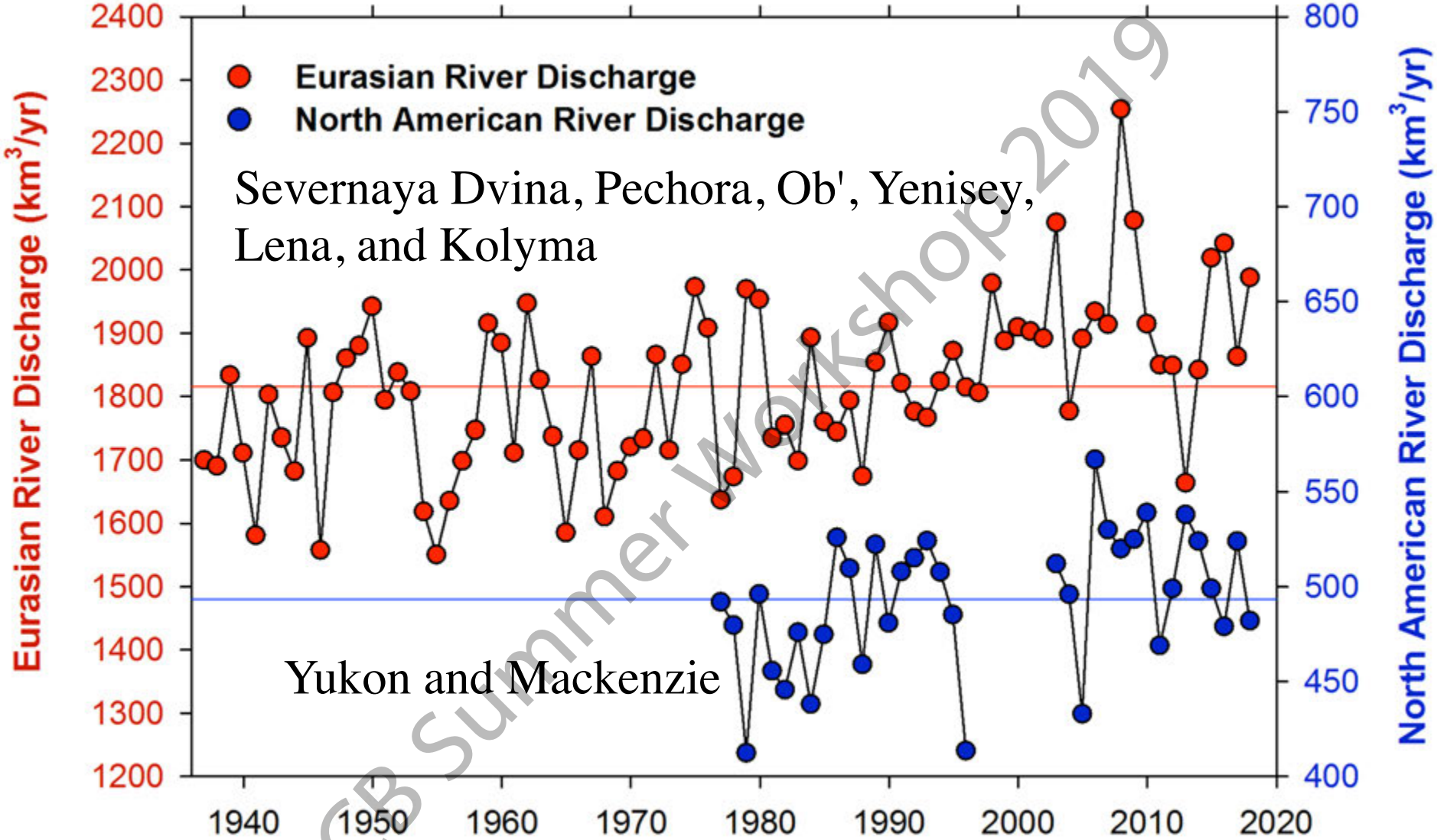
Major Arctic Rivers Numbers are Annual Discharge in km^3



Source: Arctic Report Card, 2018 (R. M. Holmes, A. I. Shiklomanov, A, Suslova, M. Tretiakov, J. W. McClelland, R.G.M. Spencer, S. E. Tank, authors)

Freshwater flow through Bering Strait ~2300 km^3 (2001) to ~3500 km^3 (2014) (Based upon deep Atlantic salinity of 34.8)

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Increases in the Pacific inflow to the Arctic from 1990 to 2015, and insights into seasonal trends and driving mechanisms from year-round Bering Strait mooring data

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ABSTRACT

Year-round *in situ* Bering Strait mooring data (1990–2015) document a long-term increase (~0.01 Sv/yr) in the annual mean transport of Pacific waters into the Arctic. Between 2002 and 2015, all annual mean transports (except 2005 and 2012) are greater than the previously accepted climatology (~0.8 Sv). The record-length maximum (2014: 1.2 ± 0.1 Sv) is 70% higher than the record-length minimum (2001: 0.7 ± 0.1 Sv), corresponding to a reduction in the flushing time of the Chukchi Sea (to ~4.5 months from ~7.5 months). The transport increase results from stronger northward flows (not fewer southward flow events), yielding a 150% increase in kinetic energy, presumably with impacts on bottom suspension, mixing, and erosion. Curiously, we find no significant trends in annual mean flow in the Alaskan Coastal Current (ACC), although note that these data are only available 2002–2015.

Record-length trends in annually integrated heat and freshwater fluxes (primarily driven by volume flux trends) are large (0.06 ± 0.05 × 10^{20} J/yr; 30 ± 20 km^3/yr; relative to −1.9 °C and 34.8 psu), with heat flux lows in 2001 and 2012 (~3 × 10^{20} J) and highs in 2007 and 2015 (~5.5 × 10^{20} J), and a freshwater range of ~2300 km^3 (2001) to ~3500 km^3 (2014). High-flow year 2015 (volume transport ~1.1 Sv) has the highest annual mean temperature recorded, ~0.7 °C, astoundingly warmer than the record-length mean of 0.0 ± 0.2 °C, while low-flow year 2012 (~0.8 Sv) is also remarkably cold (~−0.6 °C), likely due to anomalously weak northward flow in January–March, partly driven by anomalously strong southward winds in March.

A seasonal decomposition of properties of the main flow shows significant freshening in winter (~0.03 psu/yr, January–March) likely due to source changes, but no trend (or perhaps salinization) in the rest of the year. A seasonal warming trend in the strait proper in May and June (~0.04 °C/yr) is reflected in a trend to earlier arrival (0.9 ± 0.8 days/yr) of waters warmer than 0 °C. Counterintuitively, no significant trend is found in the time of cooling of the strait. The strait's seasonal increasing transport trends (~0.02 Sv/yr) are largest from May–November, likely due to the large wind-driven variability masking the signal in other months.

We show that Ekman wind-driven transport of waters along the coasts in the strait can explain the strong correlation of the water velocity with along-strait winds (as opposed to across-strait winds). We highlight the strong seasonality of this relationship (r ~ 0.8 in winter, but only ~0.4 in summer), which reflects the weak influence of the (seasonally weak) winds in summer. By separating the flow into portions driven by (a) the local wind and (b) a far-field (Pacific–Arctic "pressure-head") forcing, we find the increase in the Bering Strait throughflow is primarily due to a strong increase in the far-field forcing, not changes in the wind. We propose a higher annual mean transport for the strait for the 2000s (1.0 ± 0.5 Sv) based on recent flow increases, and present estimated seasonal climatologies for properties and fluxes for the strait and for the ACC. Heat and freshwater seasonalities are strongly influenced by the ACC and stratification.

Finally we conclude that year-round *in situ* mooring are still the only currently viable way of obtaining accurate quantifications of the properties of the Pacific input to the Arctic.

1. Introduction to the Bering Strait throughflow

The flow through the Bering Strait is the only oceanic input from the Pacific to the Arctic Ocean. In addition to driving most of the oceanic properties in the Chukchi Sea (Woodgate et al., 2005a), the Bering Strait throughflow, although comparatively small in volume (~0.8 Sv,

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0079-6611/

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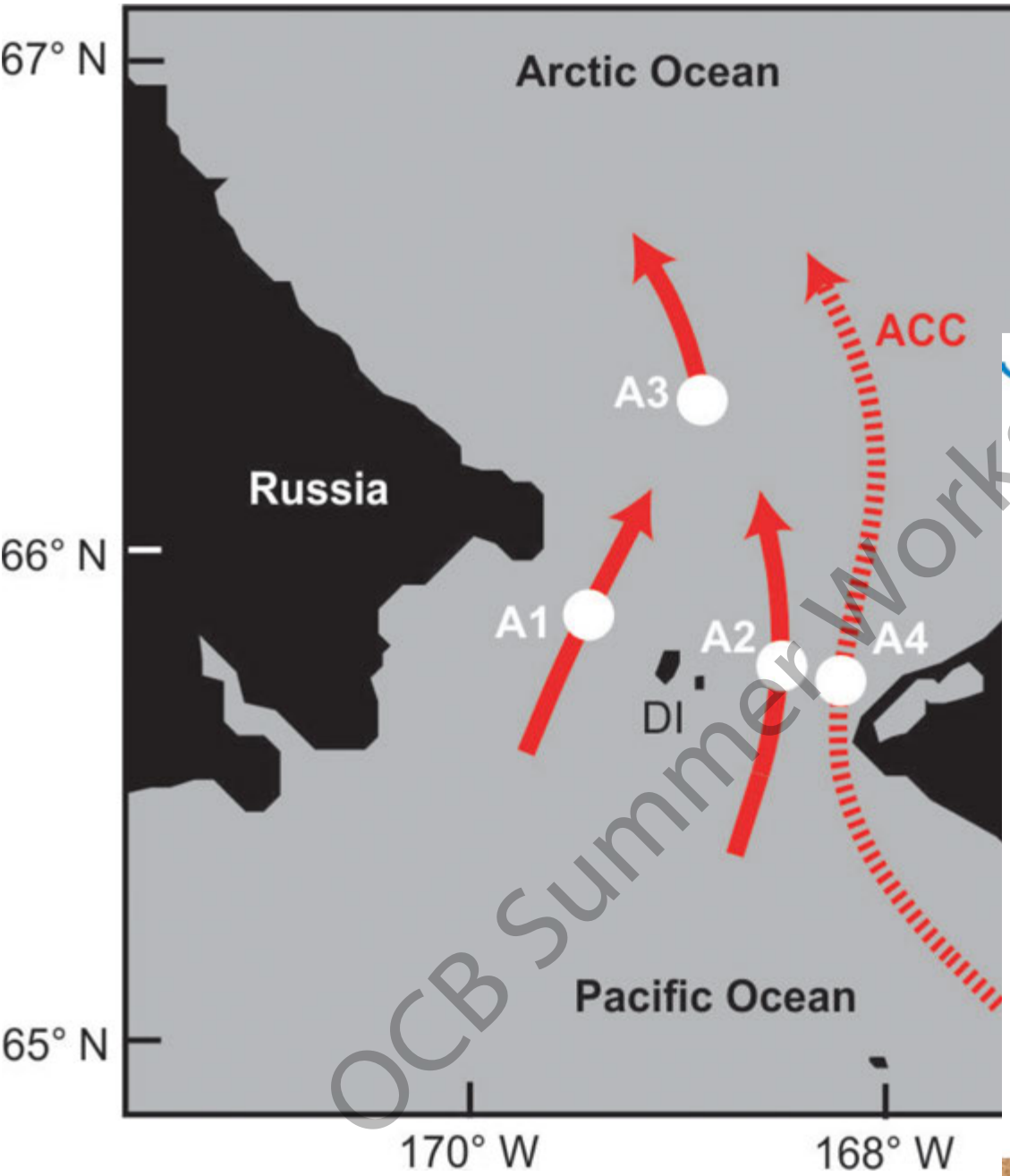
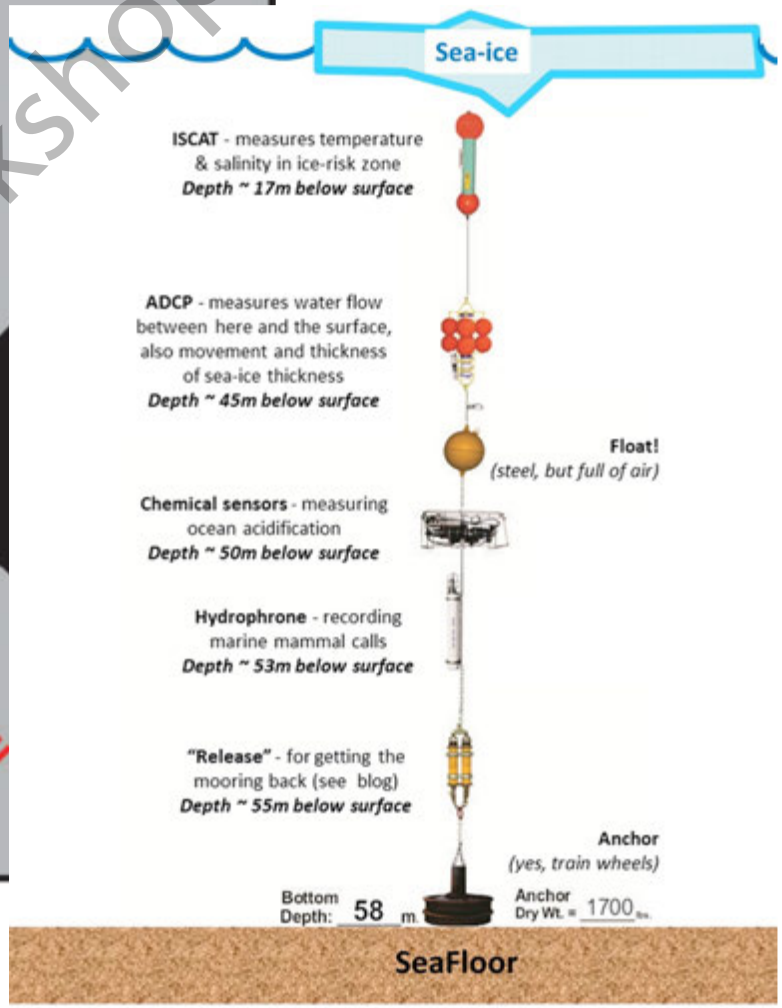
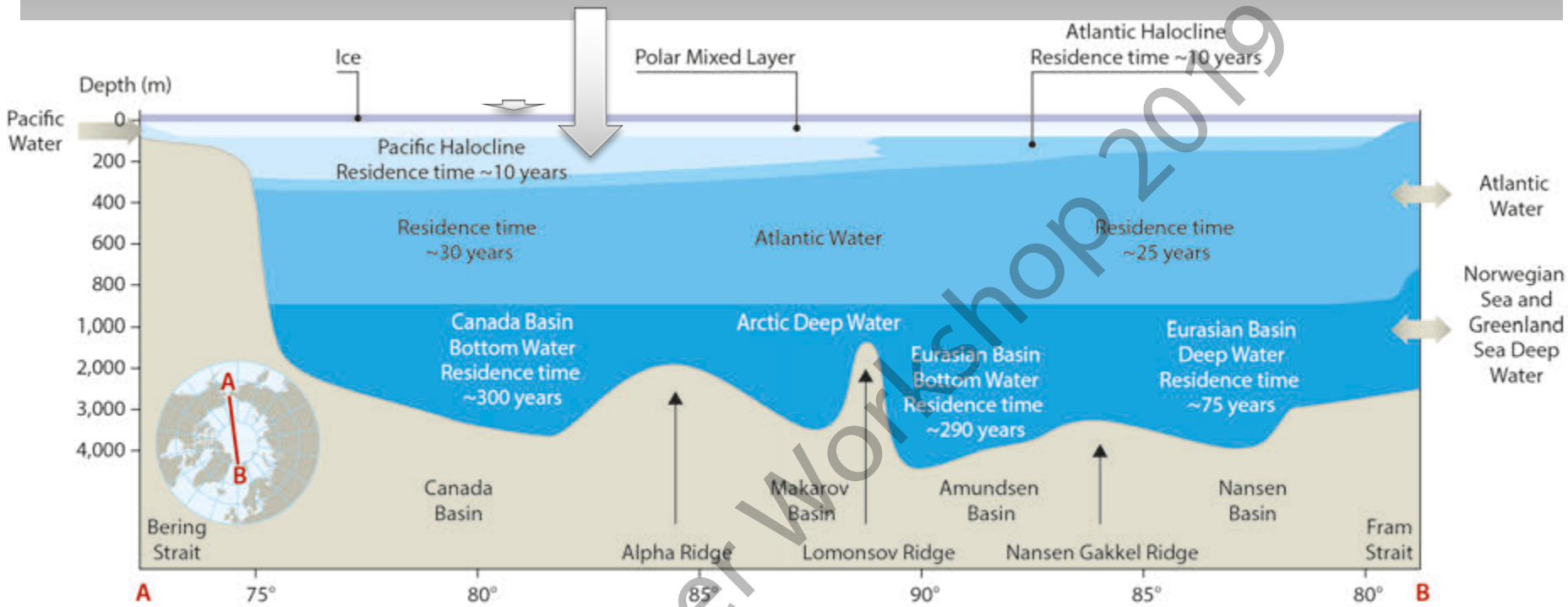


Ocean Sci., 15, 379–399, 2019

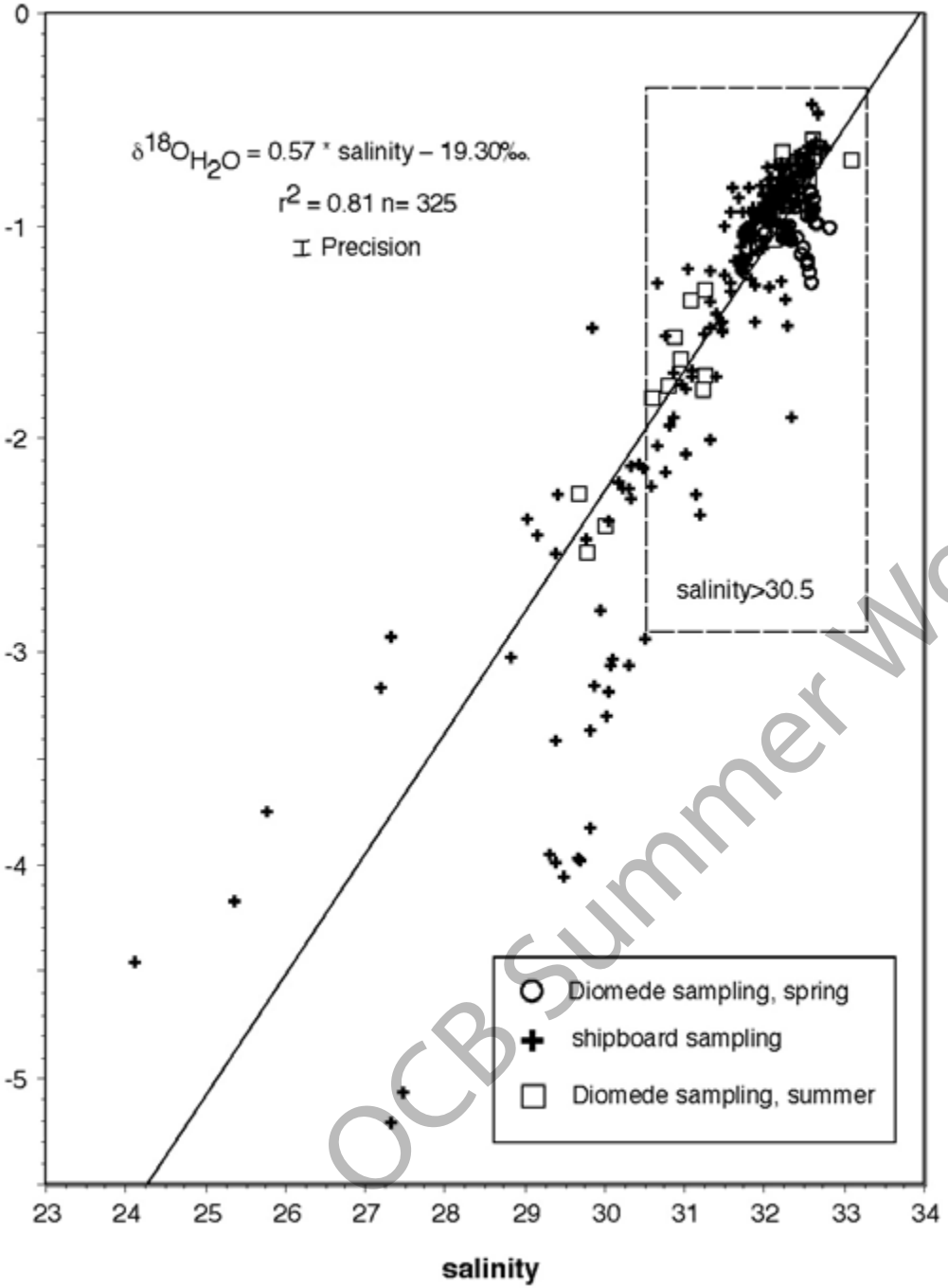


Nutrient maximum associated with the Bering Strait inflow.



Meltofte, H. (ed.) 2013. Arctic Biodiversity Assessment. Status and trends in Arctic biodiversity. Conservation of Arctic Flora and Fauna, Akureyri.

The $\delta^{18}O$ value of the upper Arctic Ocean halocline was estimated to be ~-1.1 ‰ in the late 1980's (Macdonald et al. 1989; Ekwurzel et al. 2001); Salinity = 33.1



Freshwater end-member in Bering Strait $\delta^{18}O$ = ~-19‰ (similar to Mackenzie River)

← Melted sea ice

→ Brine injection

Arctic
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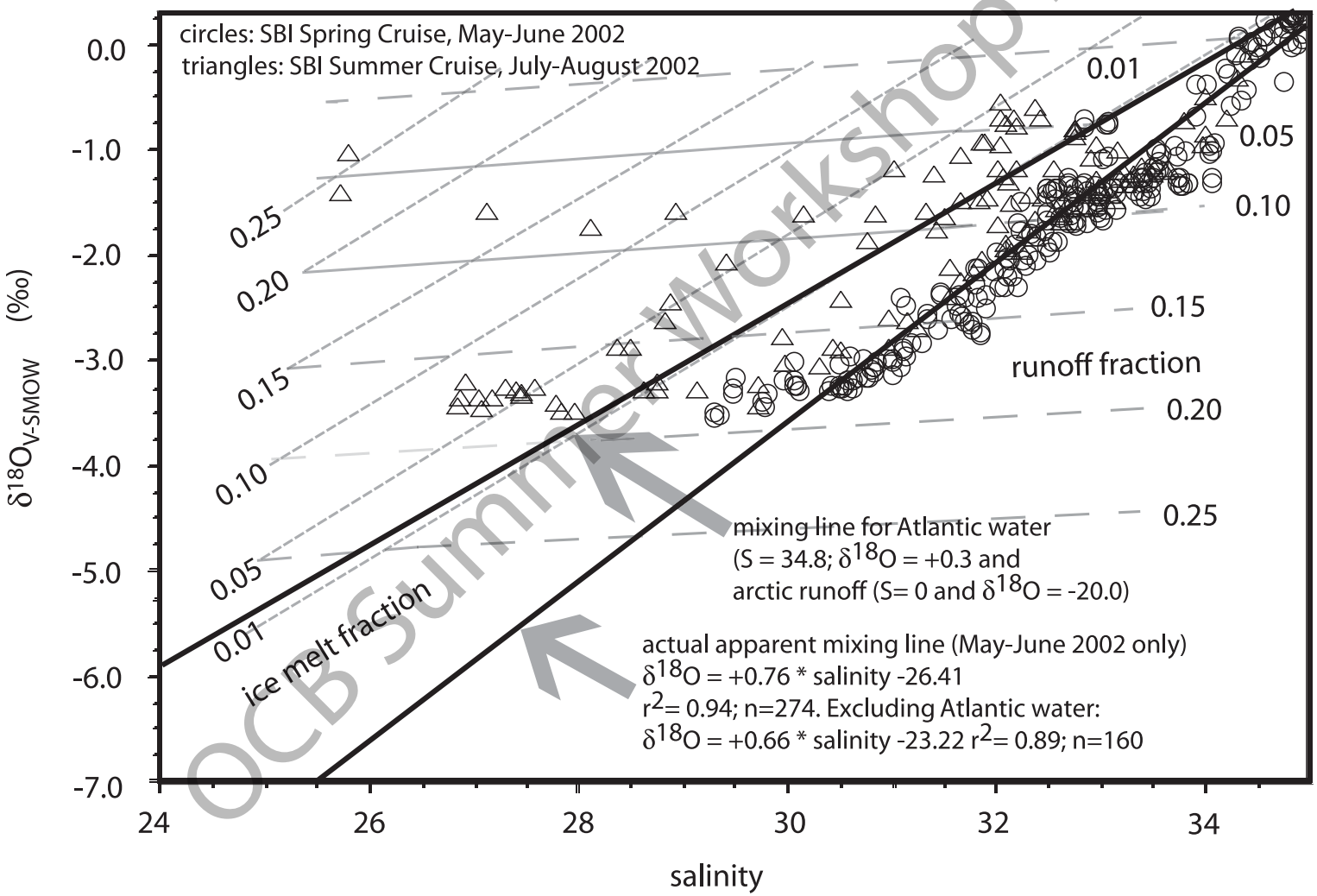
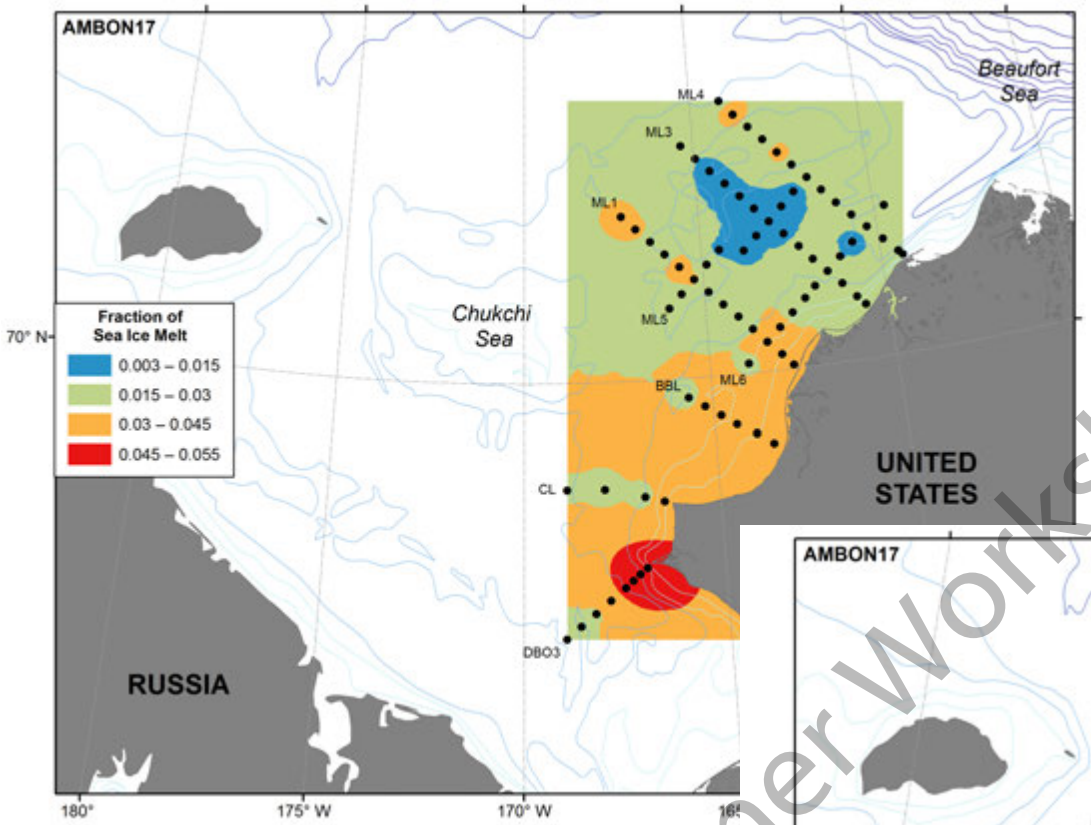
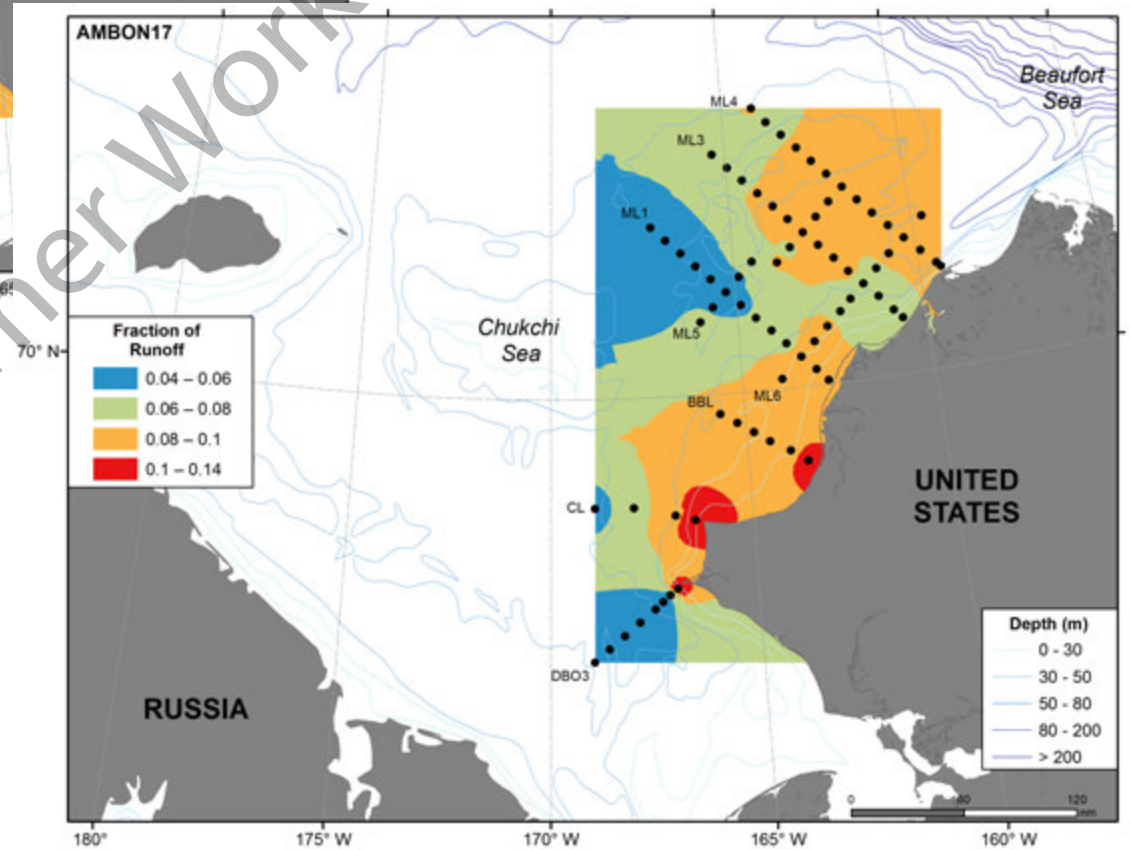




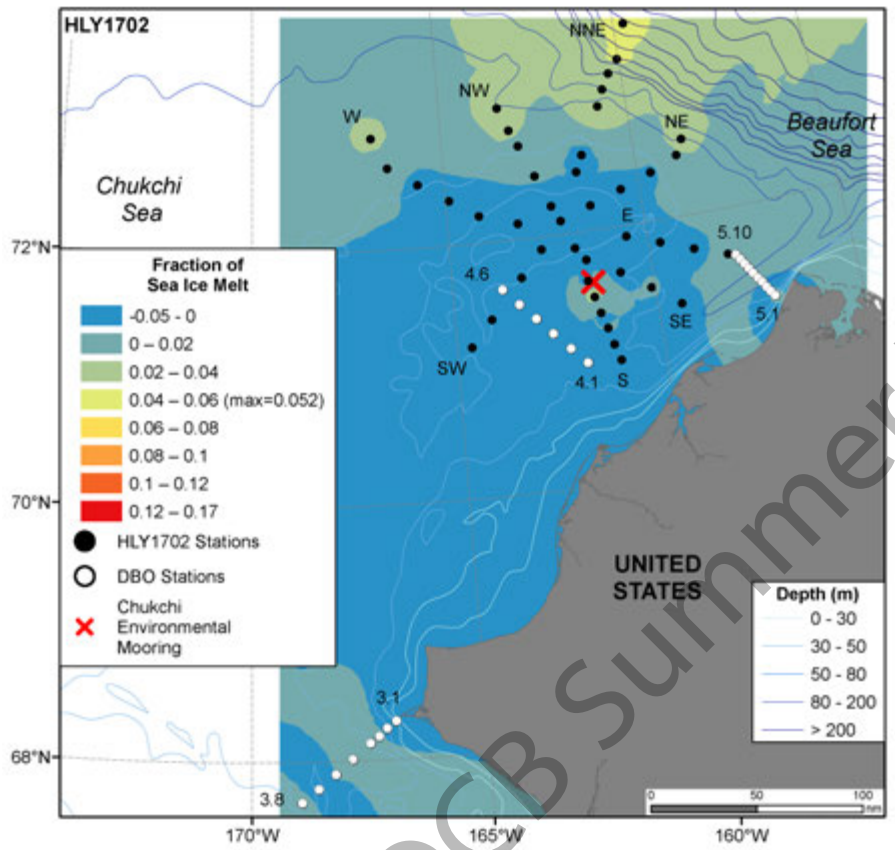
Melted sea ice <1% to 5.5% of surface water

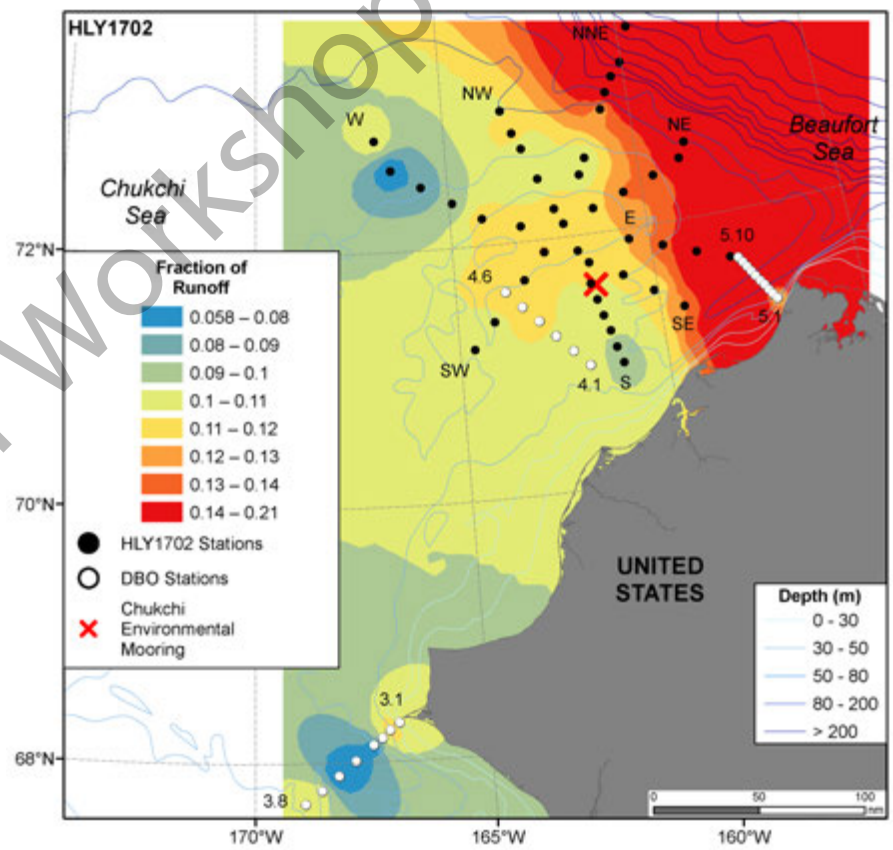


Runoff (up to 14% of surface water)

Cooper, unpublished

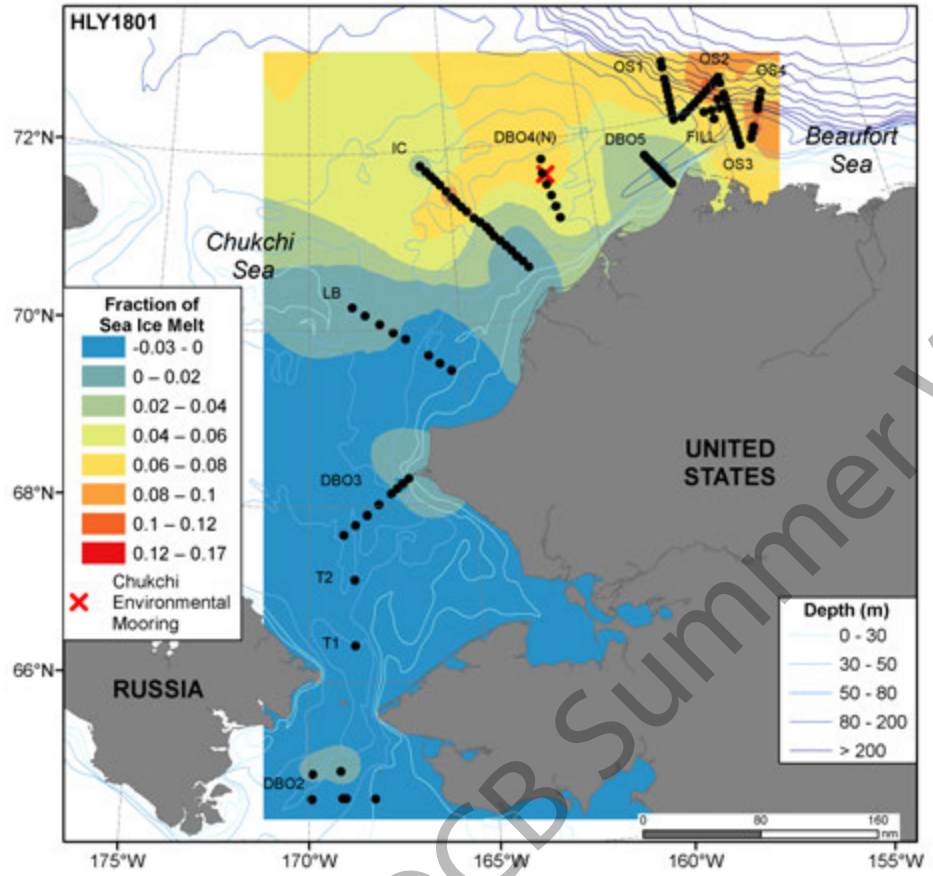
Fractions of melted sea ice and runoff in surface waters (Low ice year – 2017)

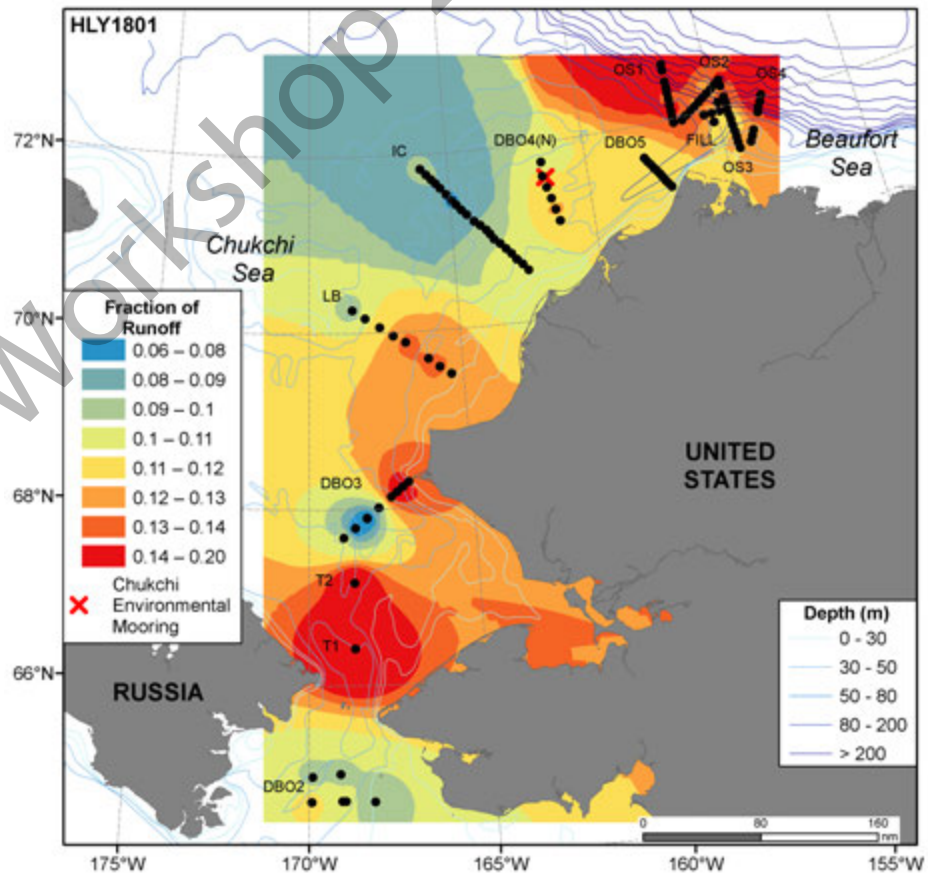




Cooper, unpublished

Fractions of melted sea ice and runoff in surface waters

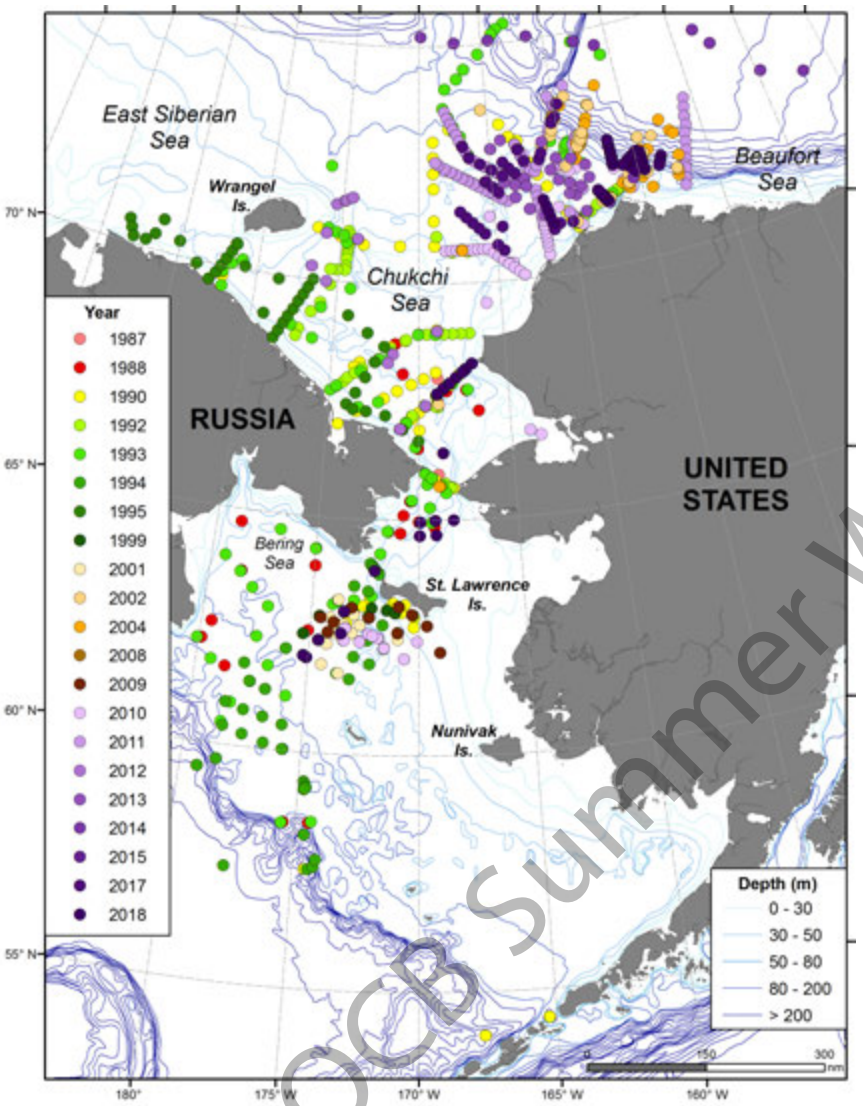


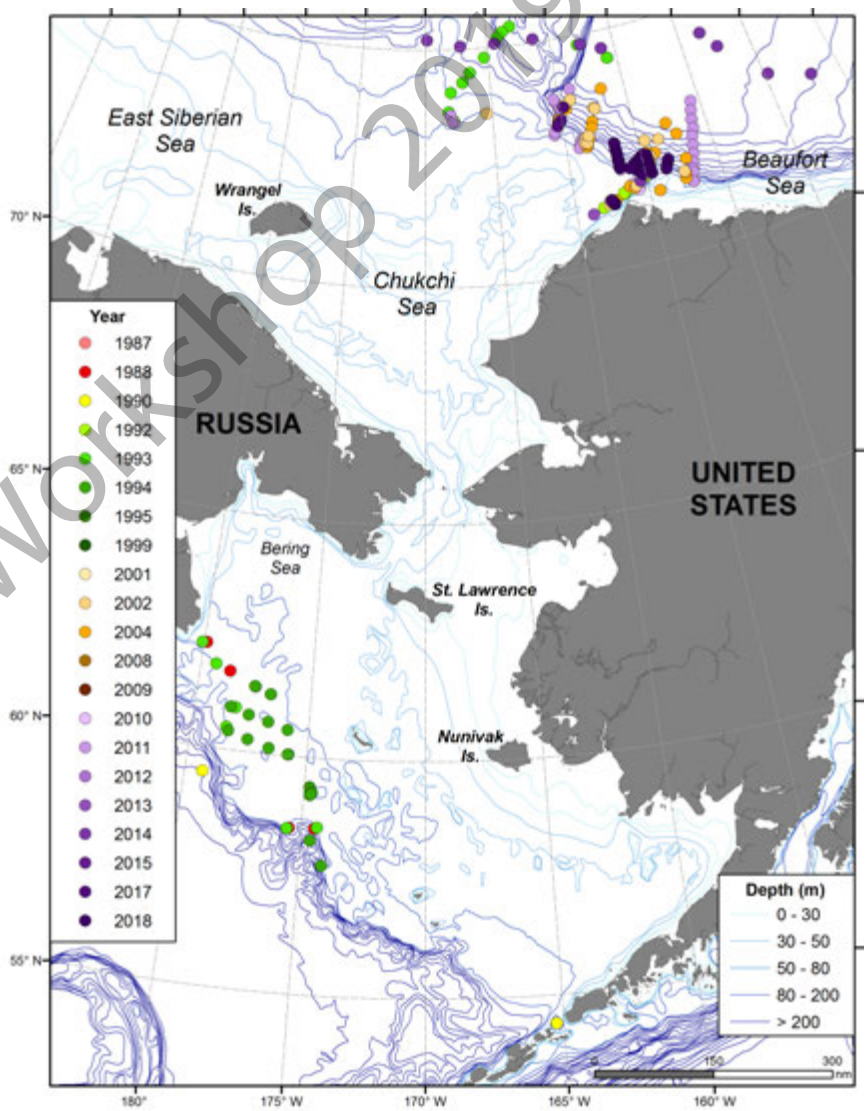


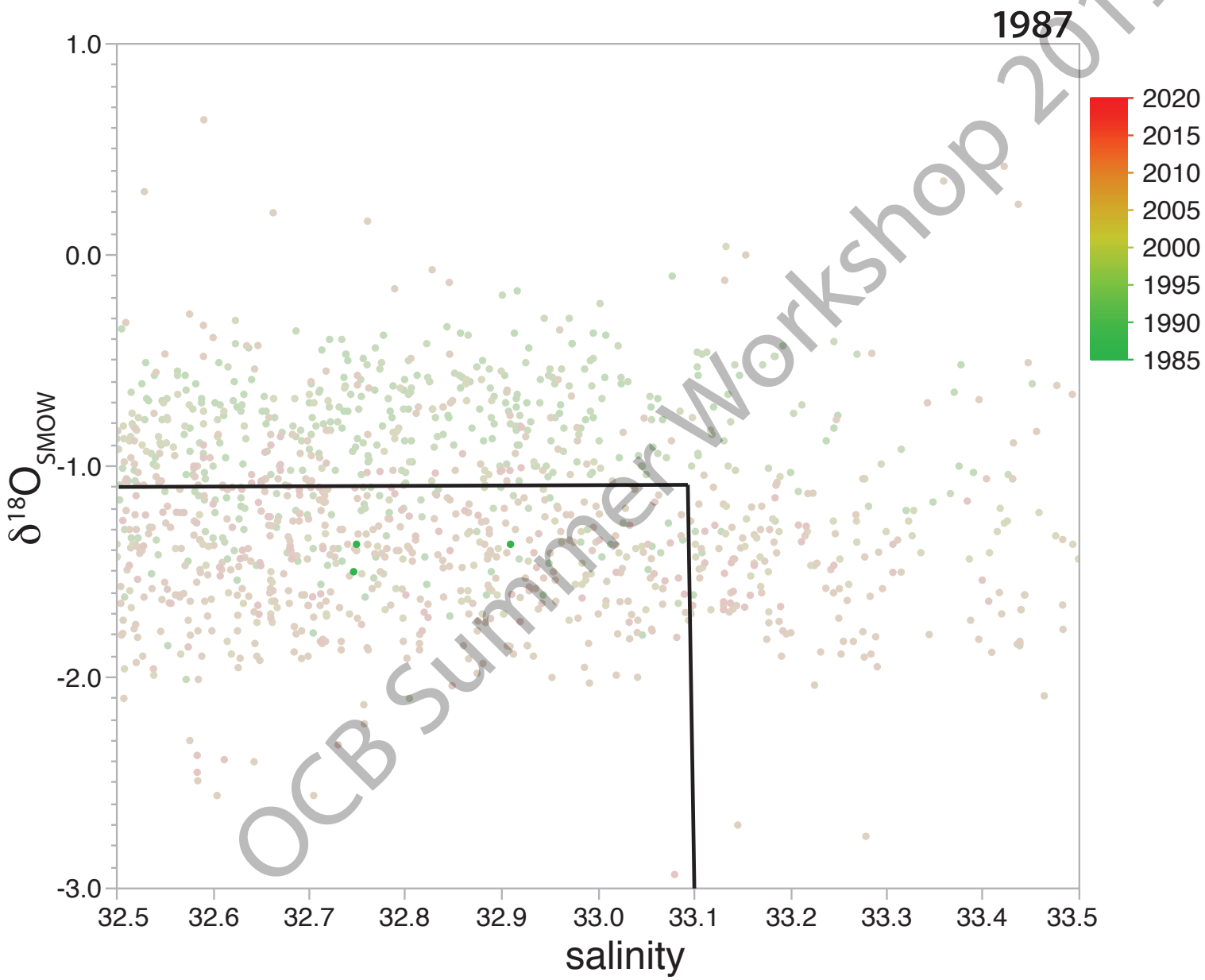
Cooper, unpublished

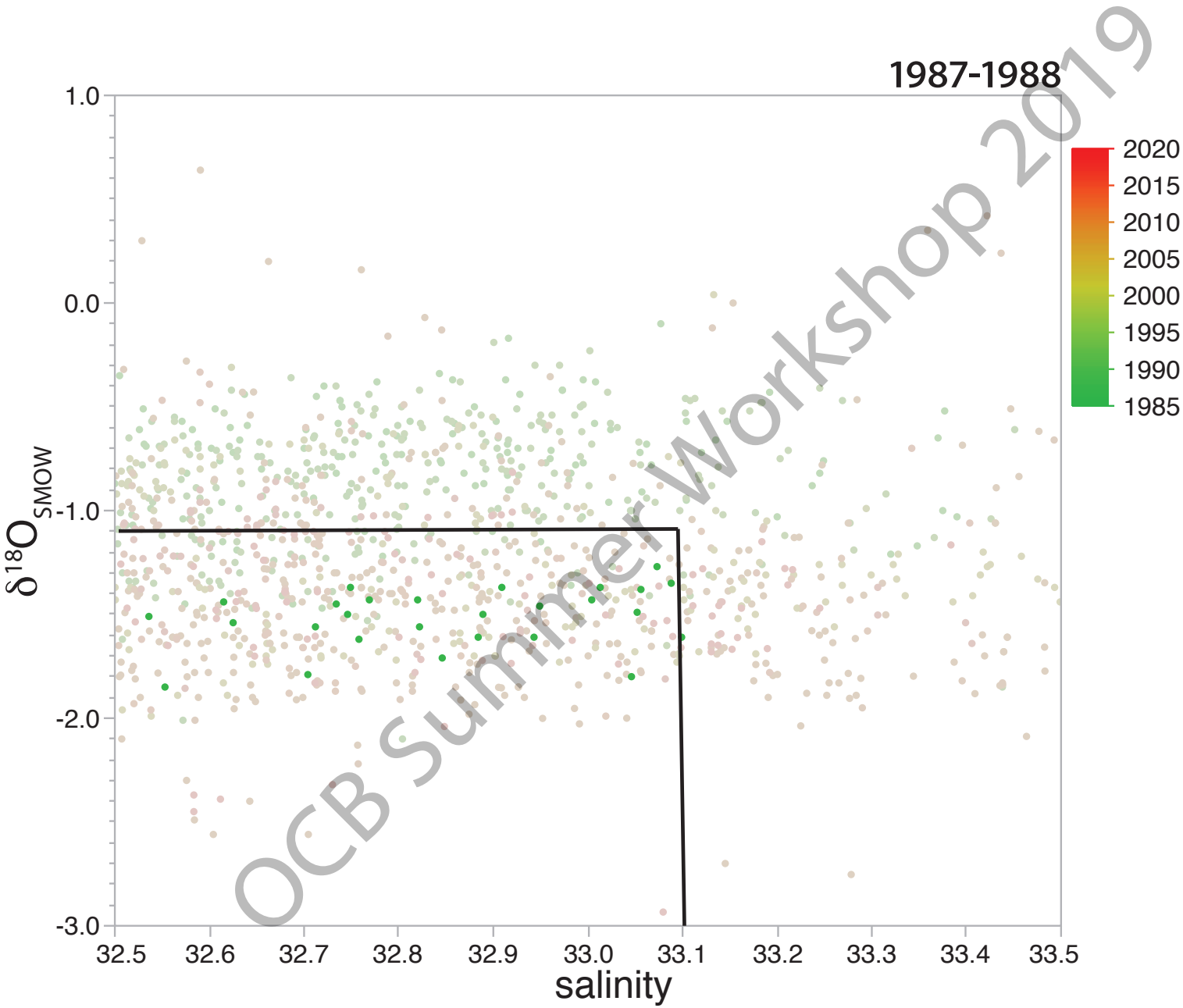
Salinity between 32.5 and 33.5

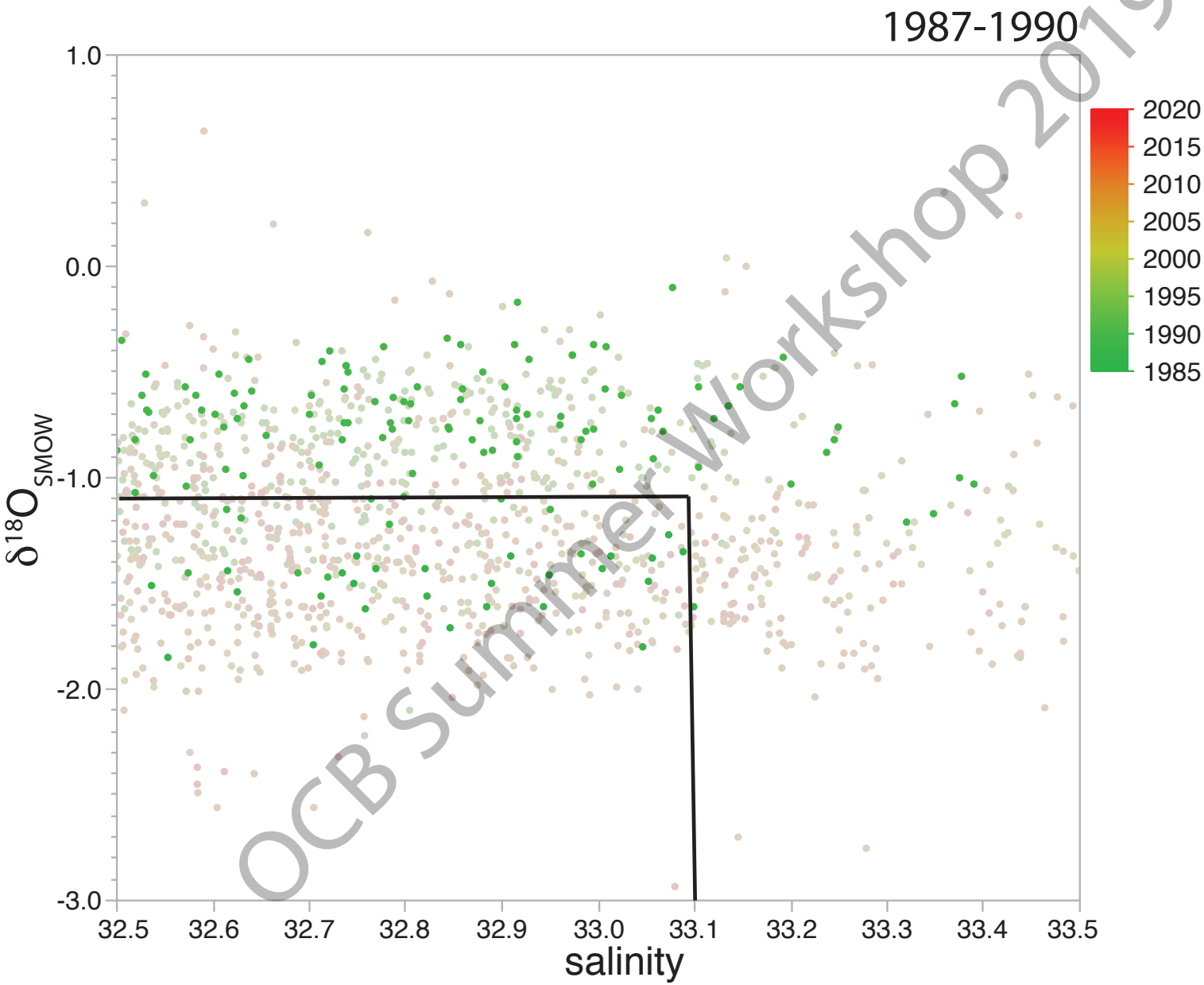
Depth >100 m

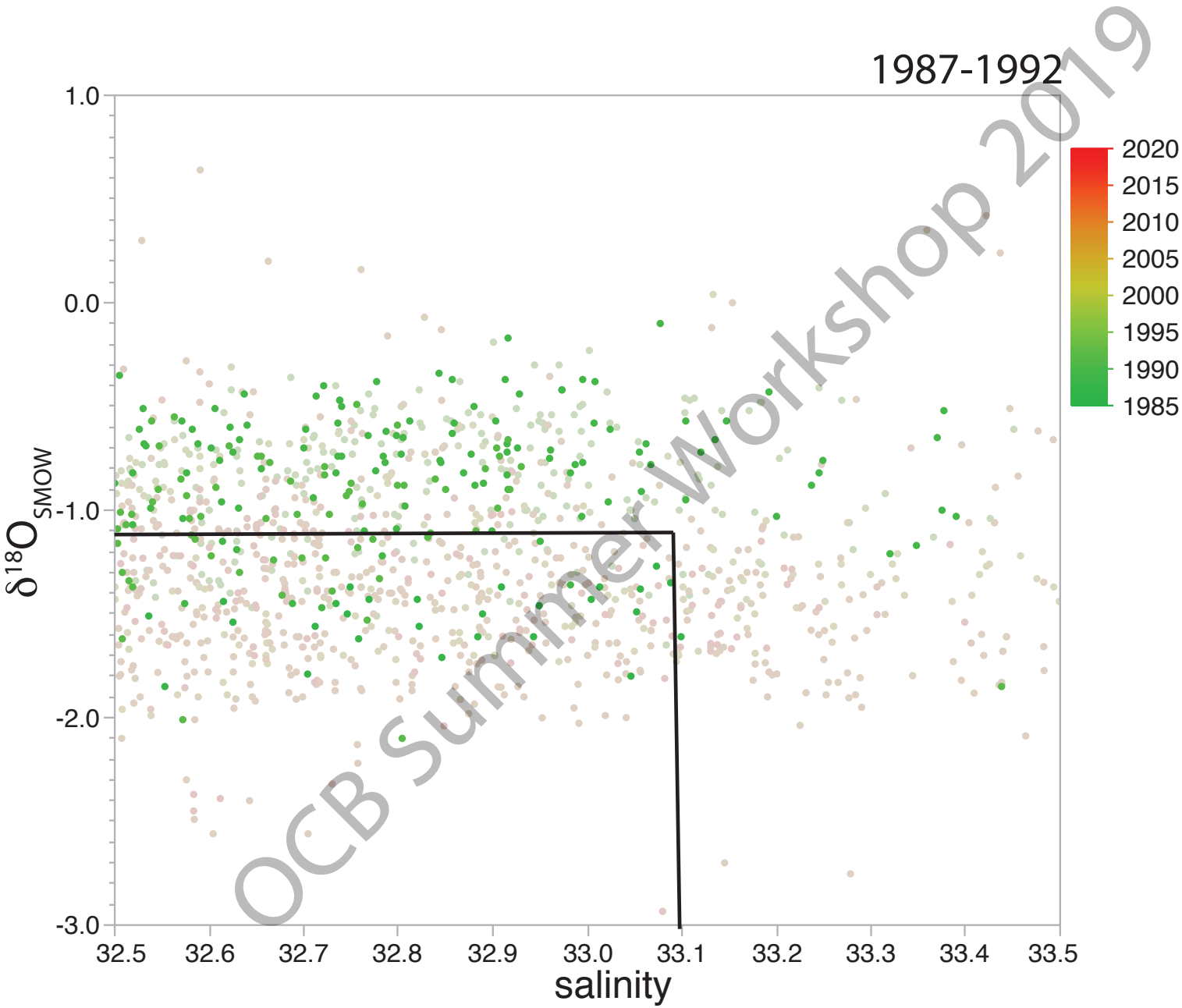


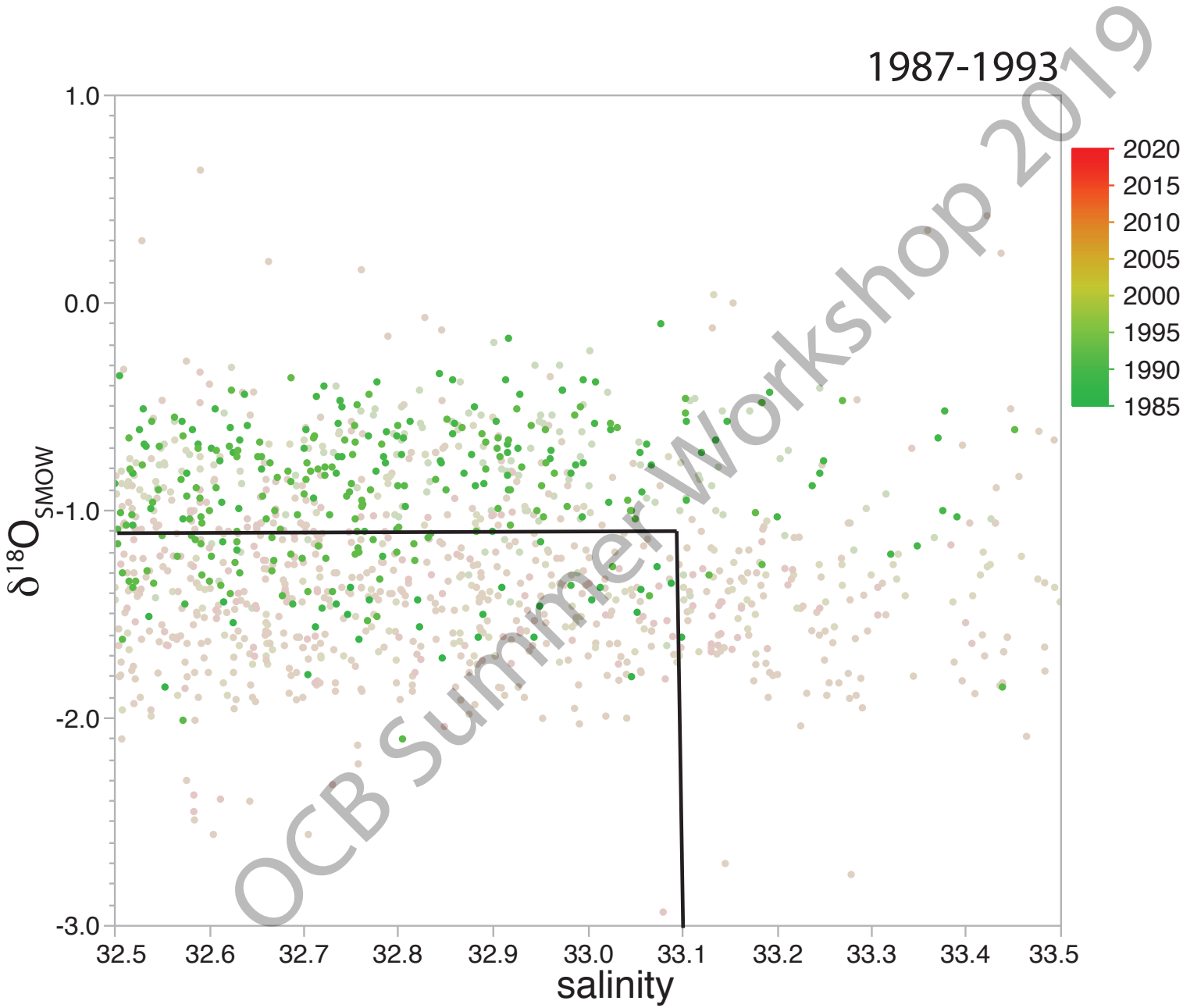


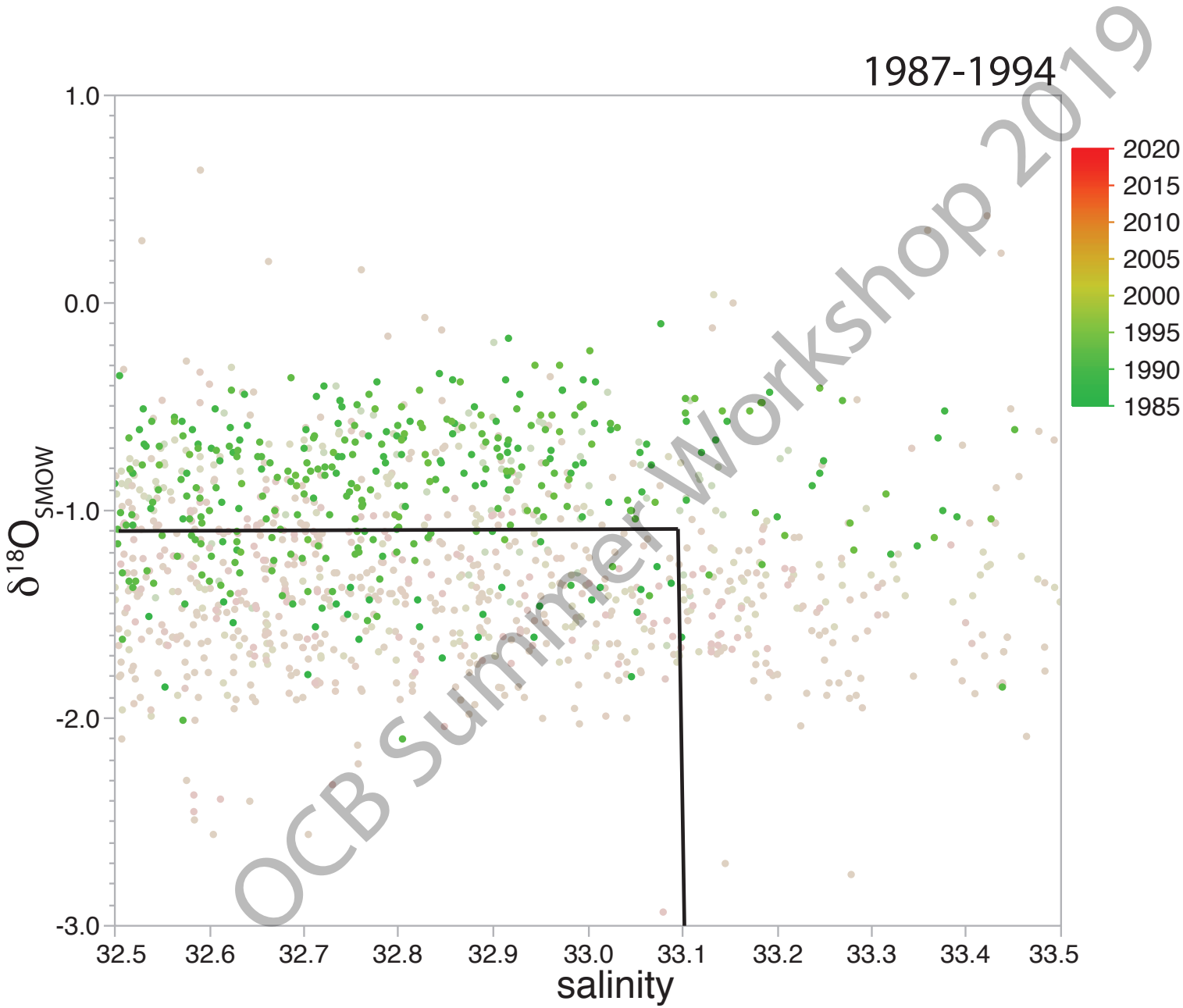


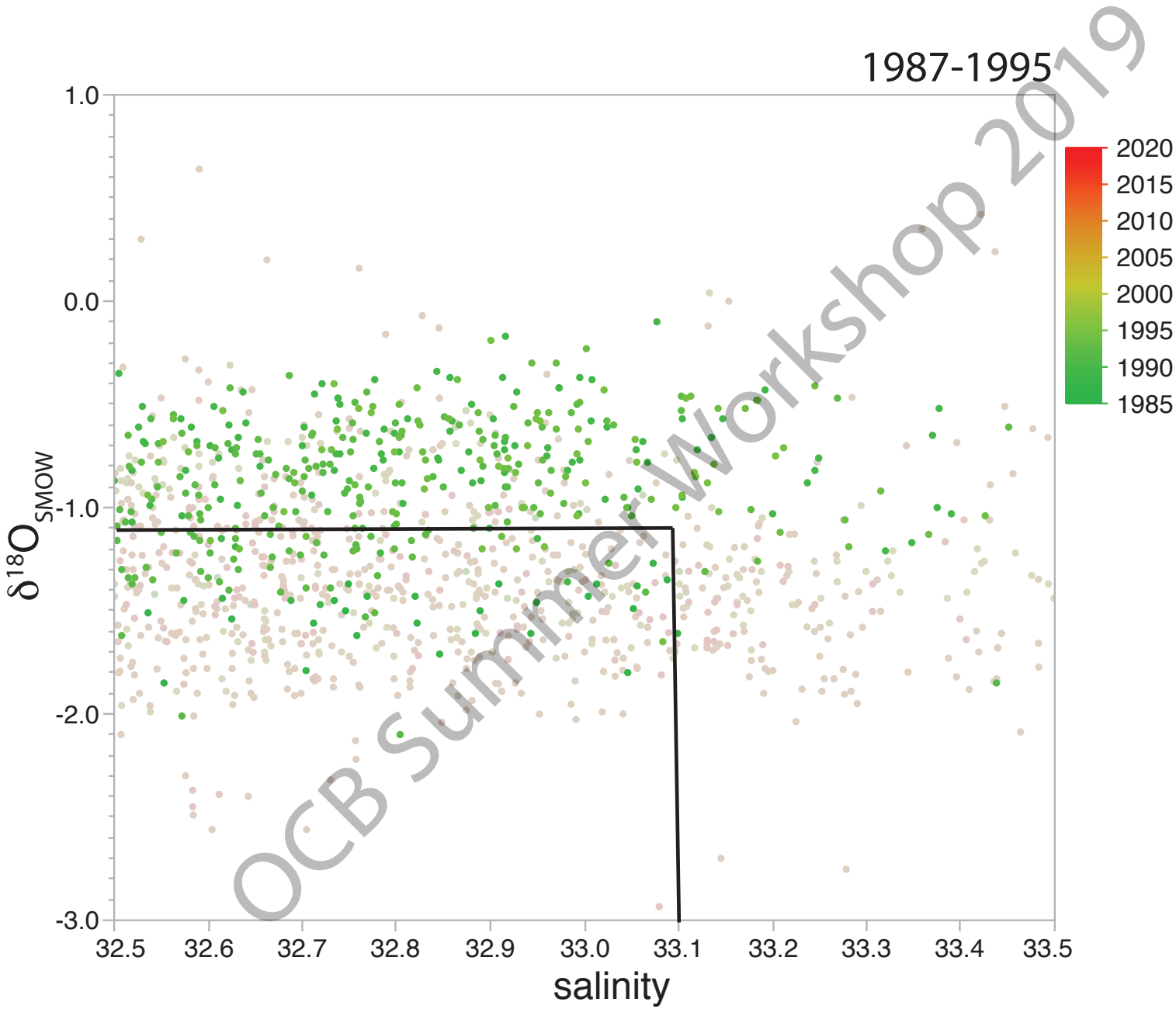


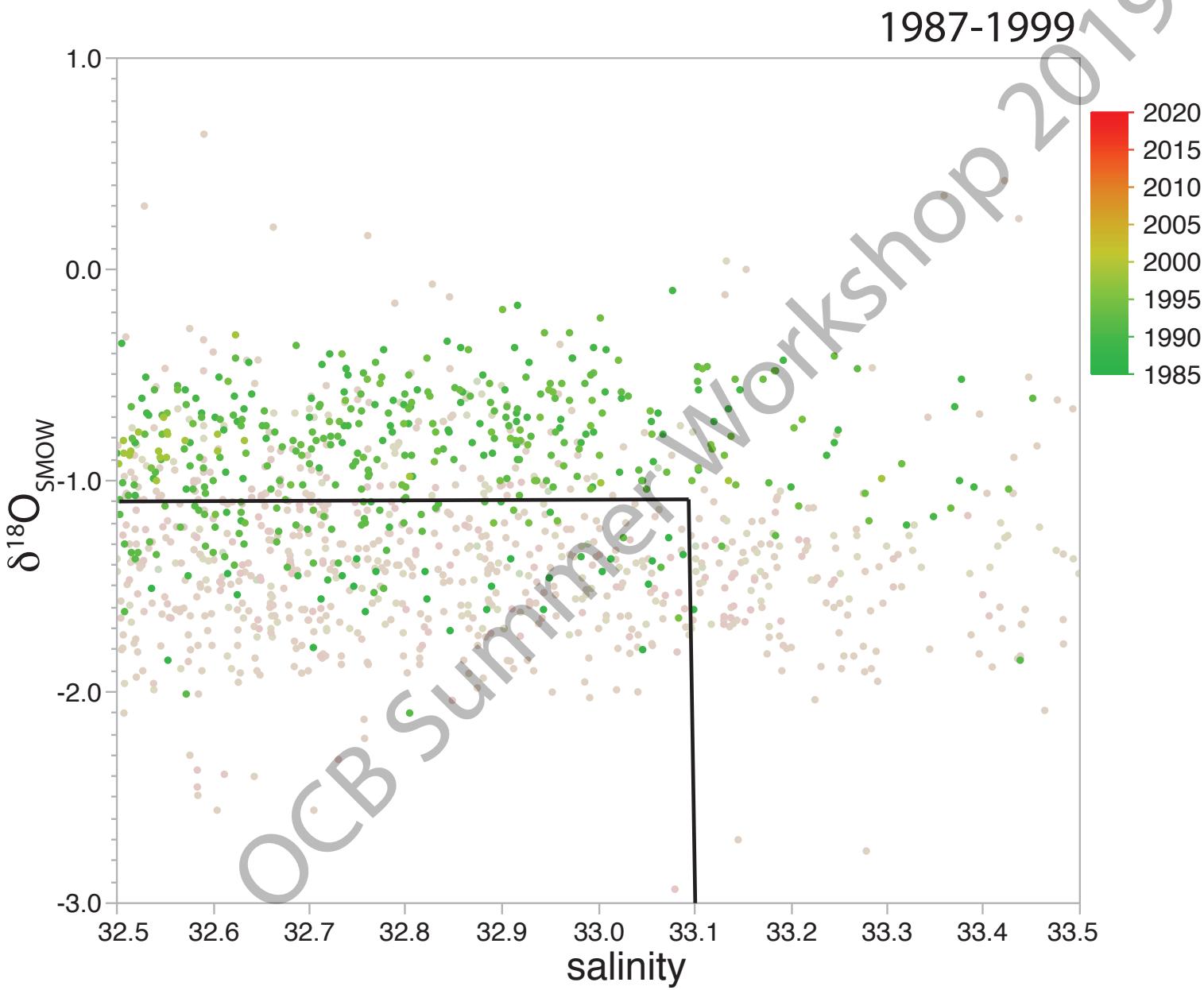


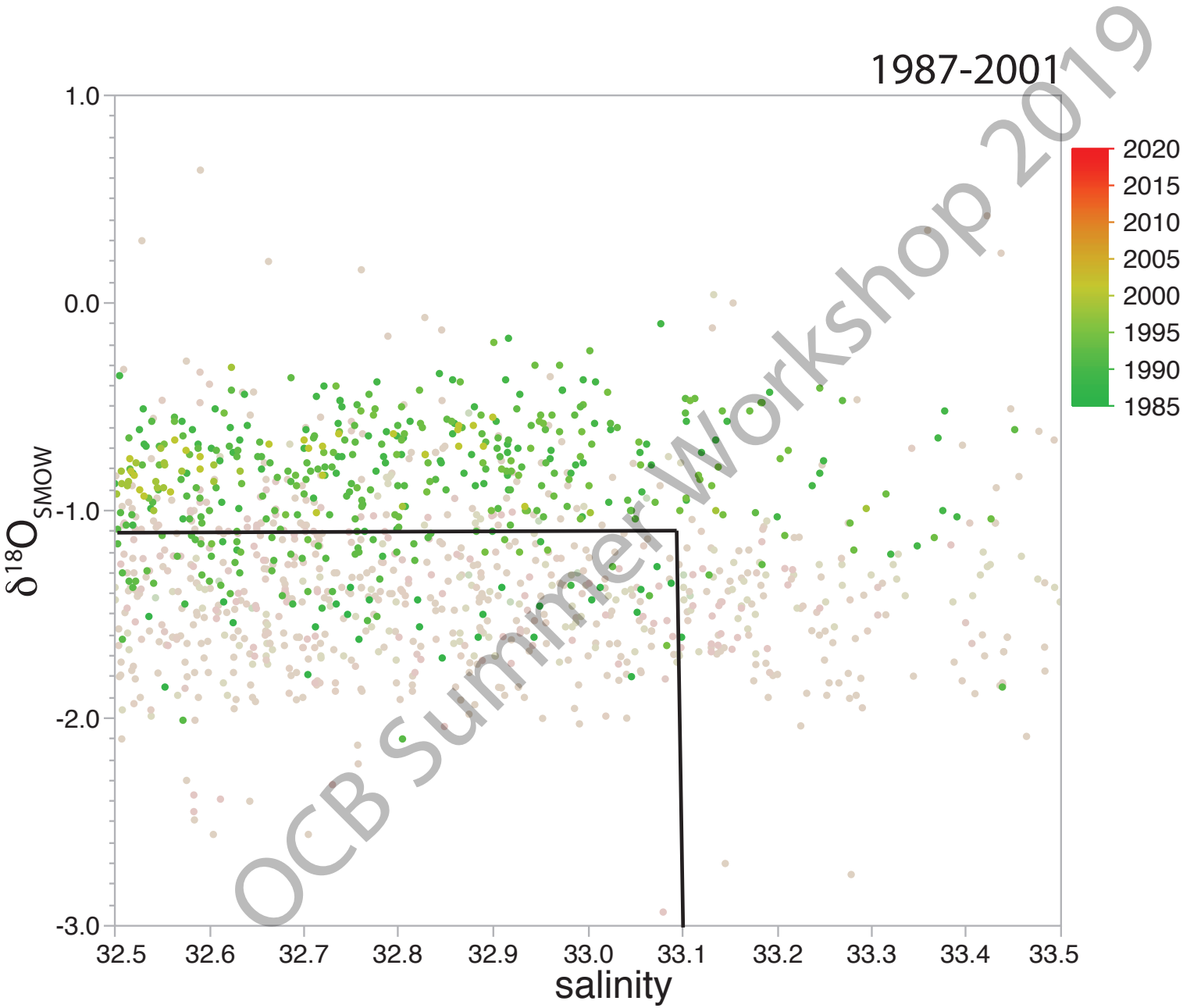


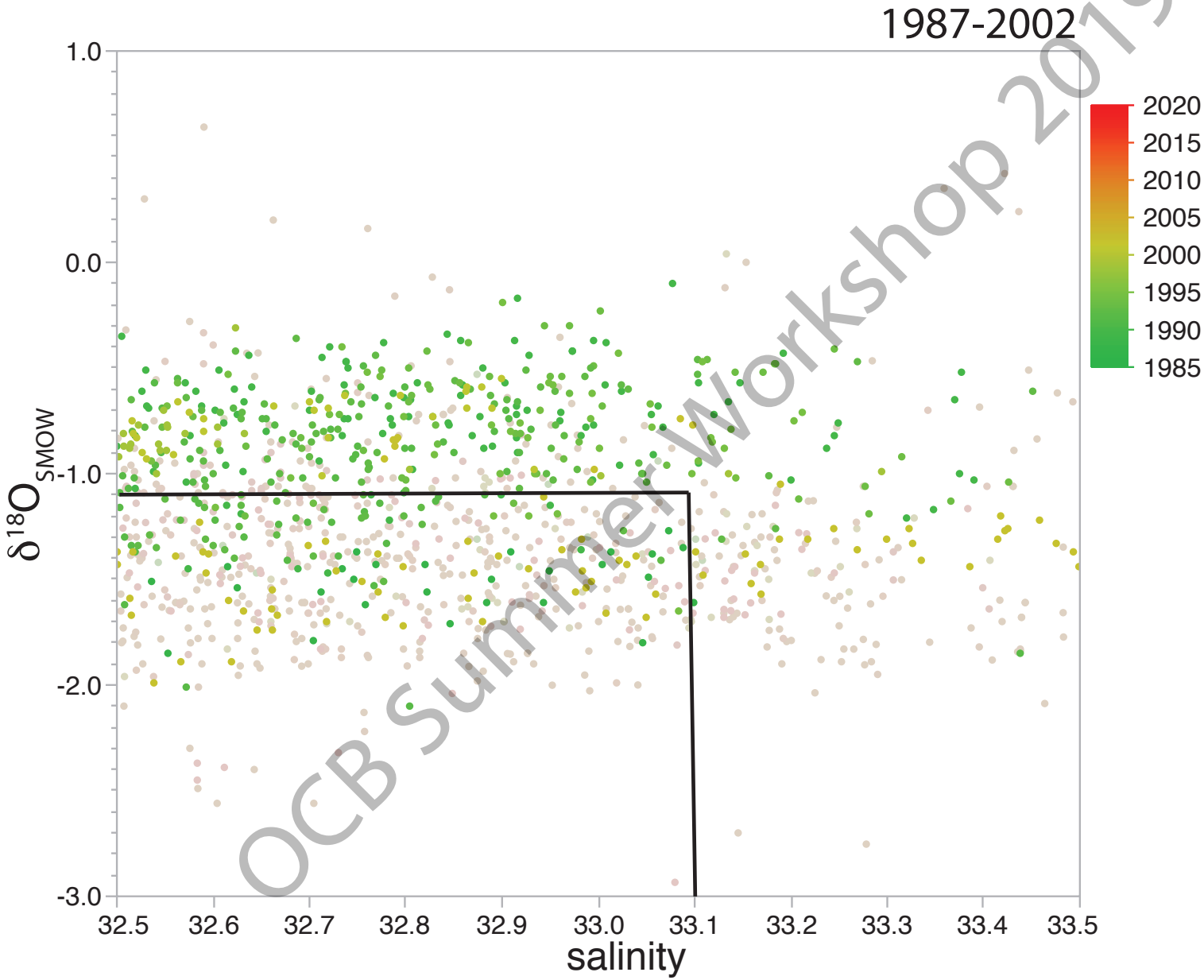


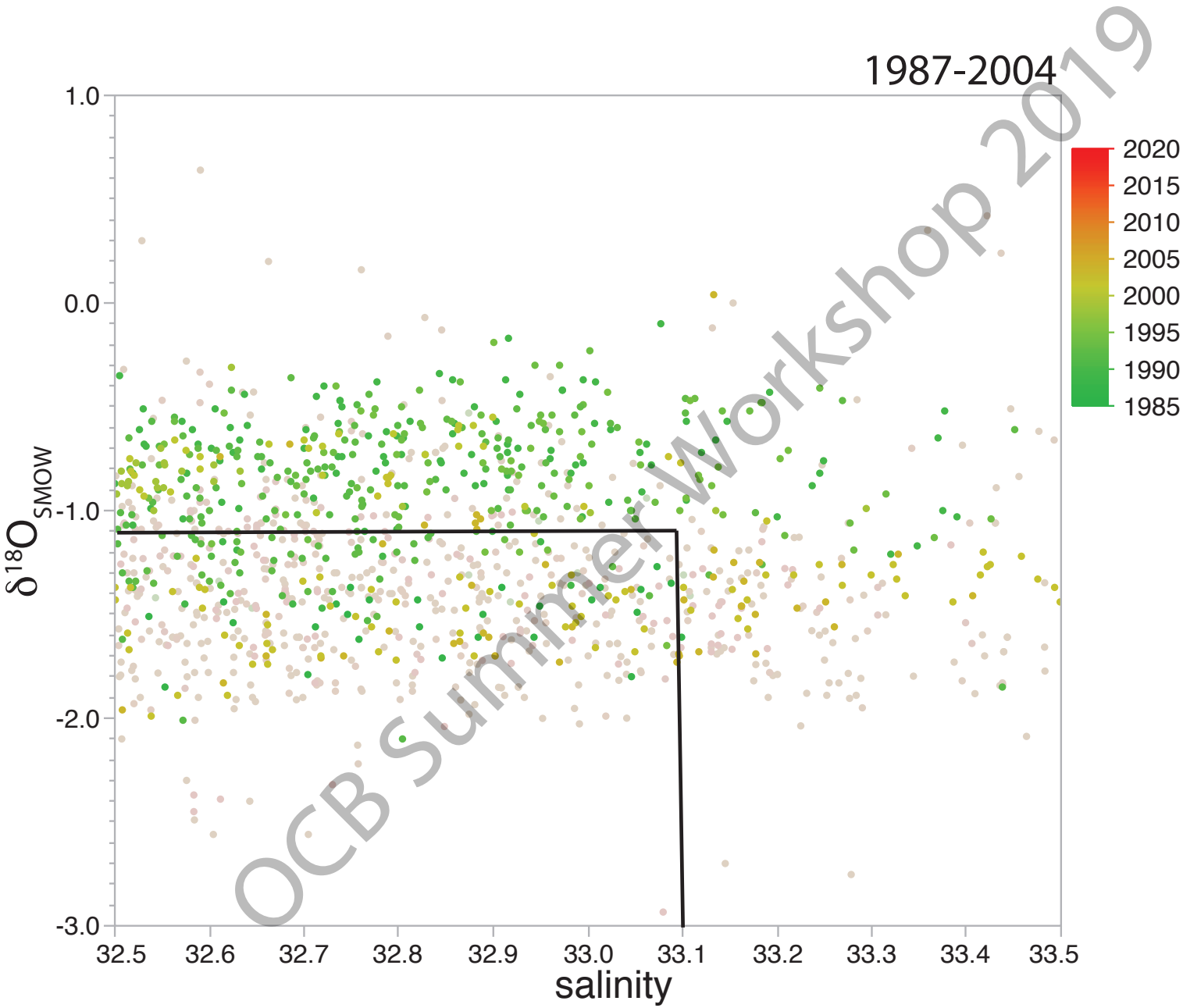


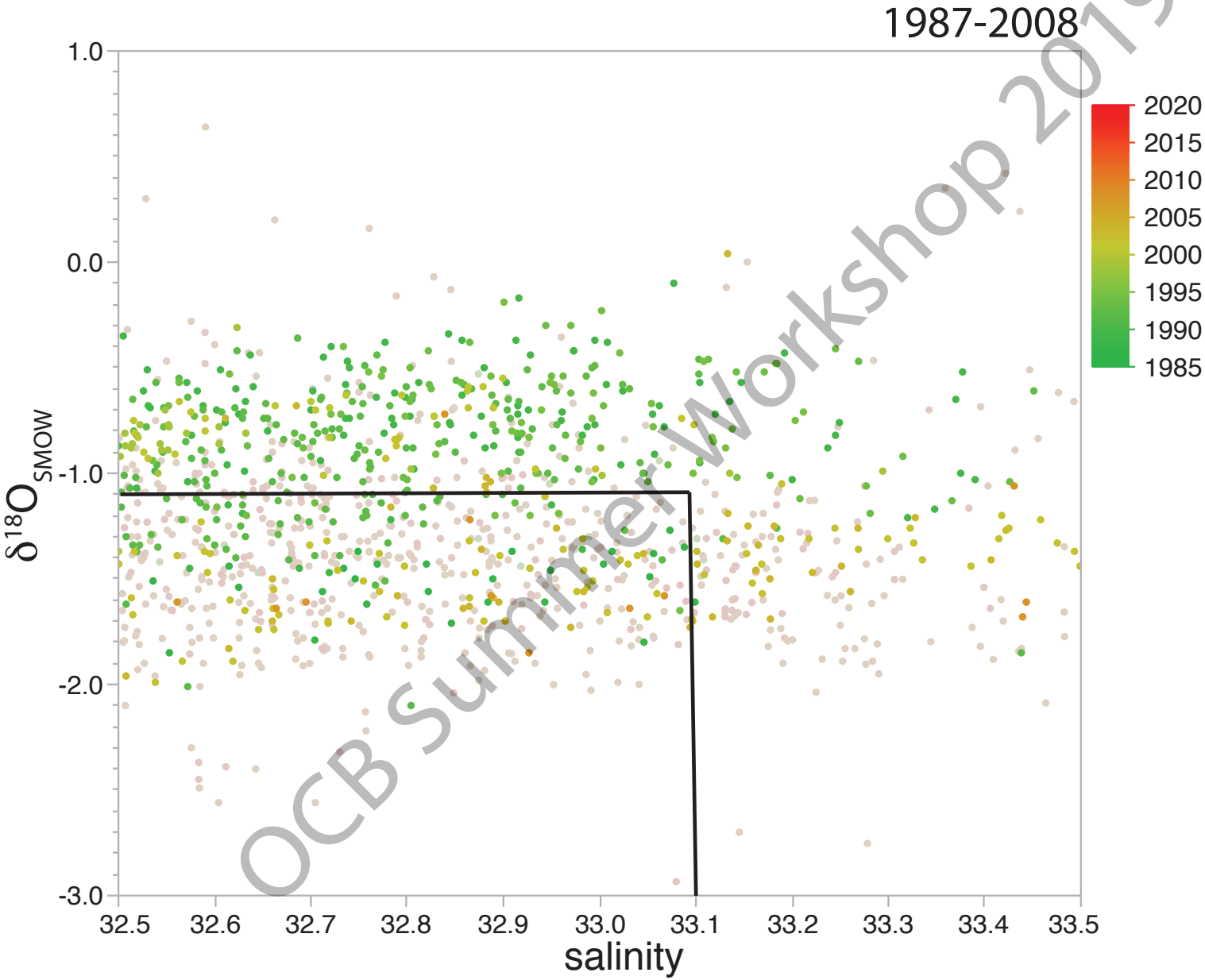


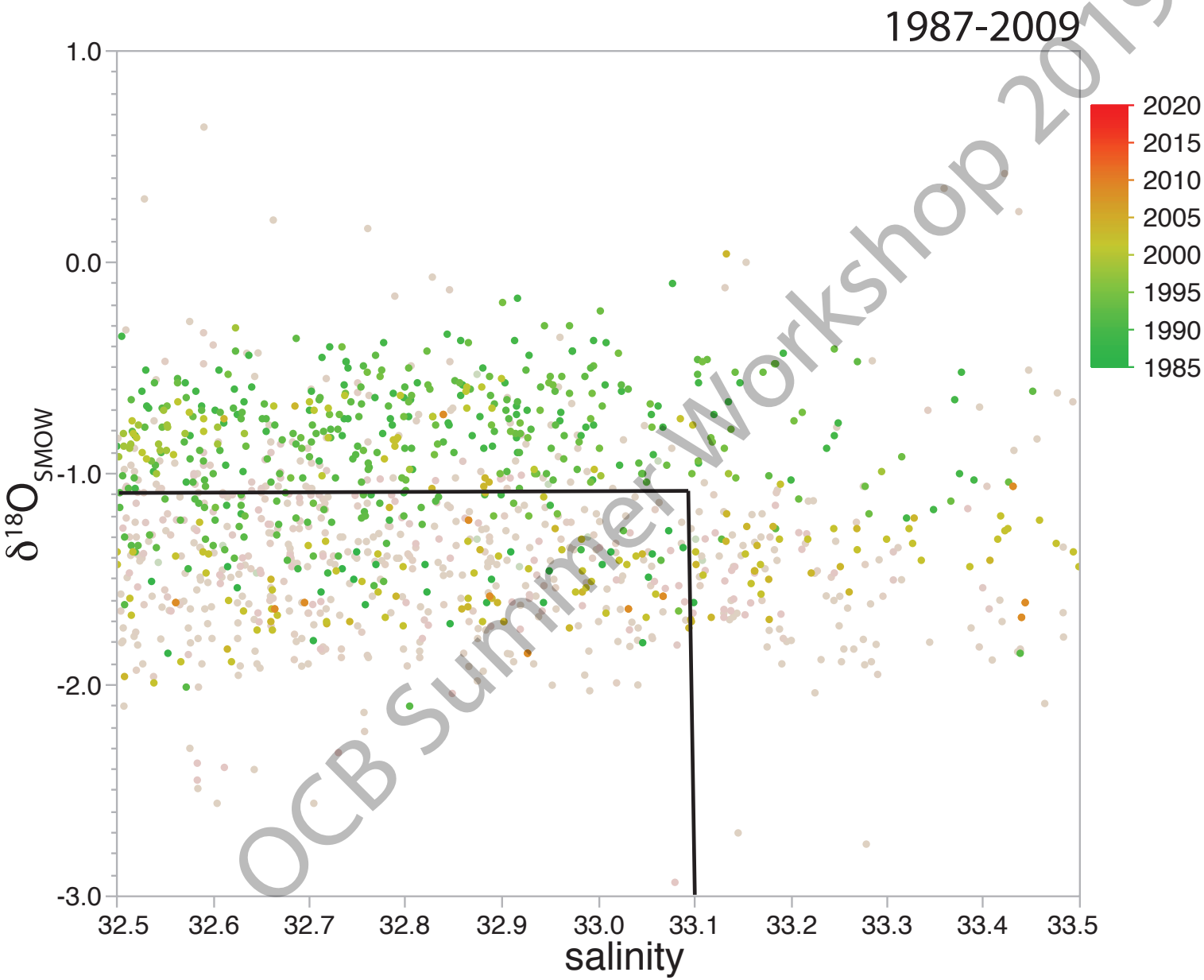


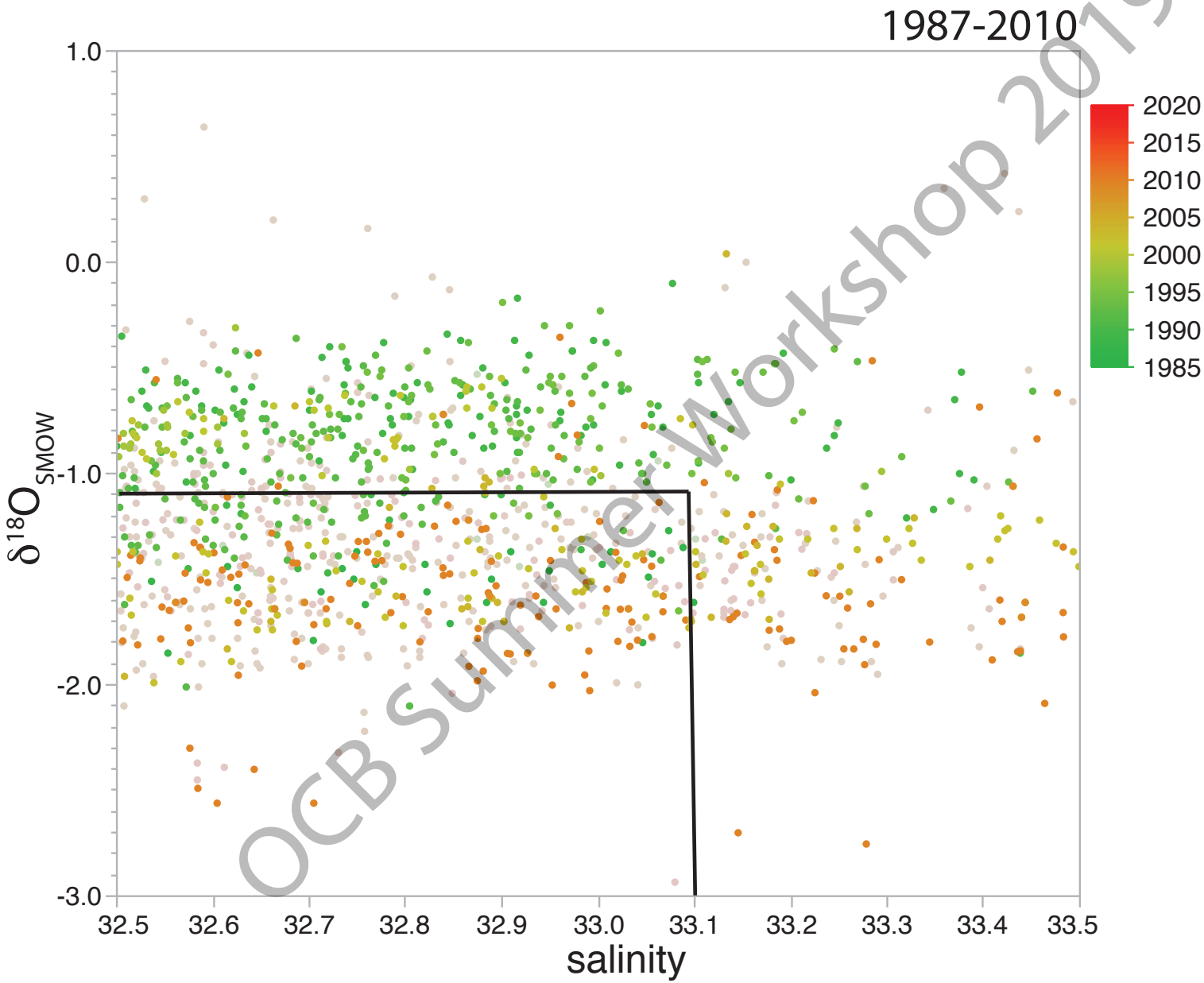


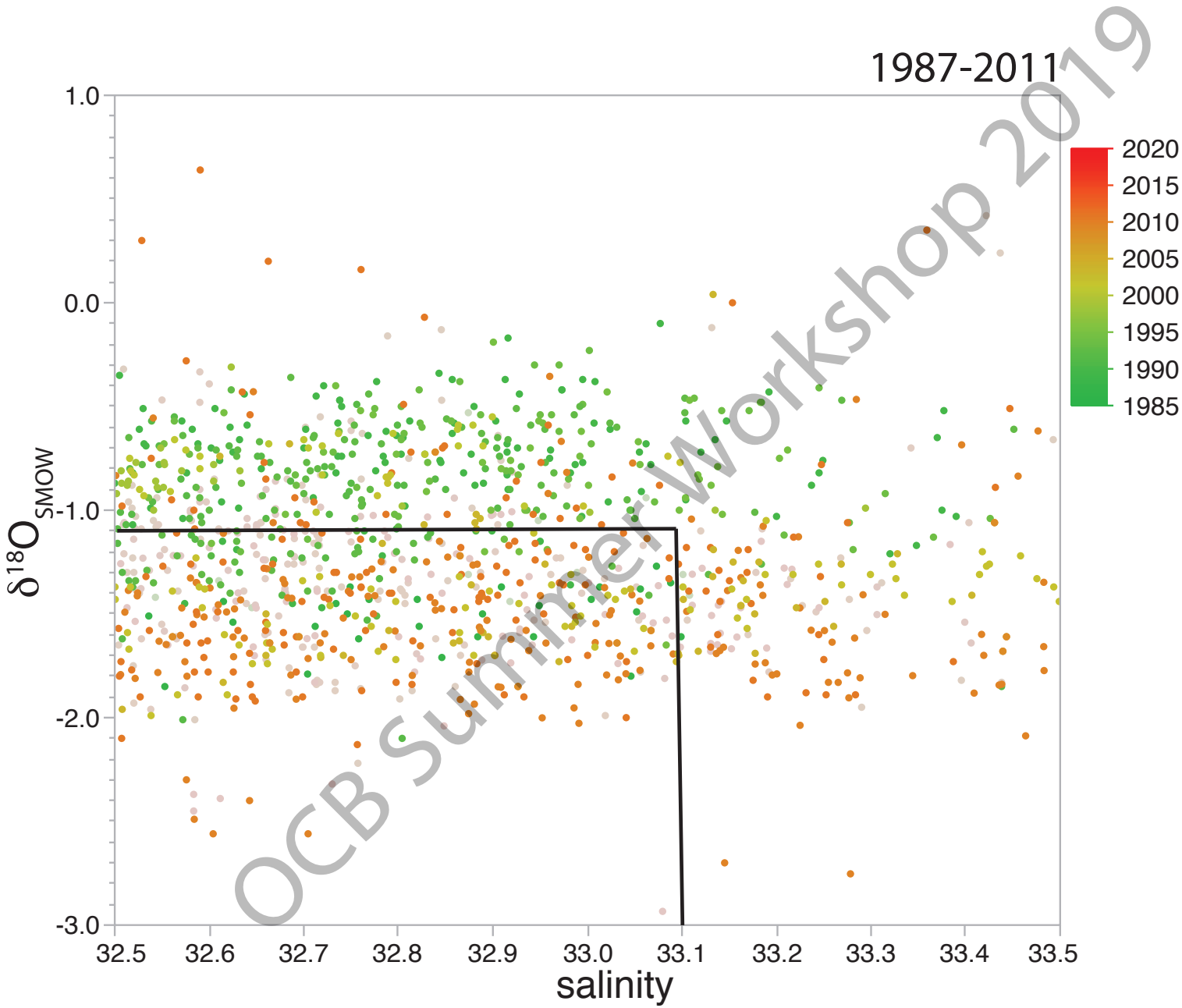


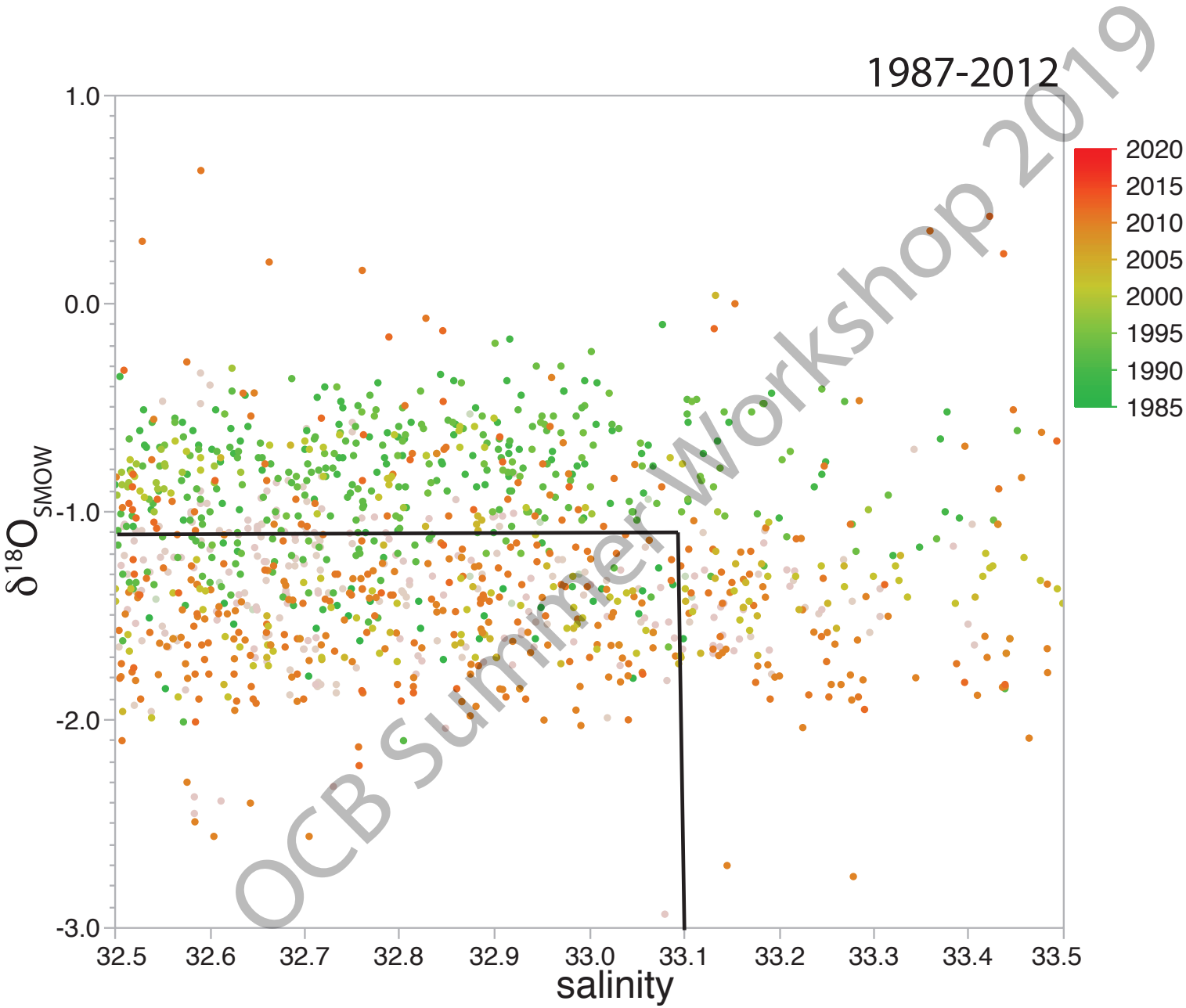


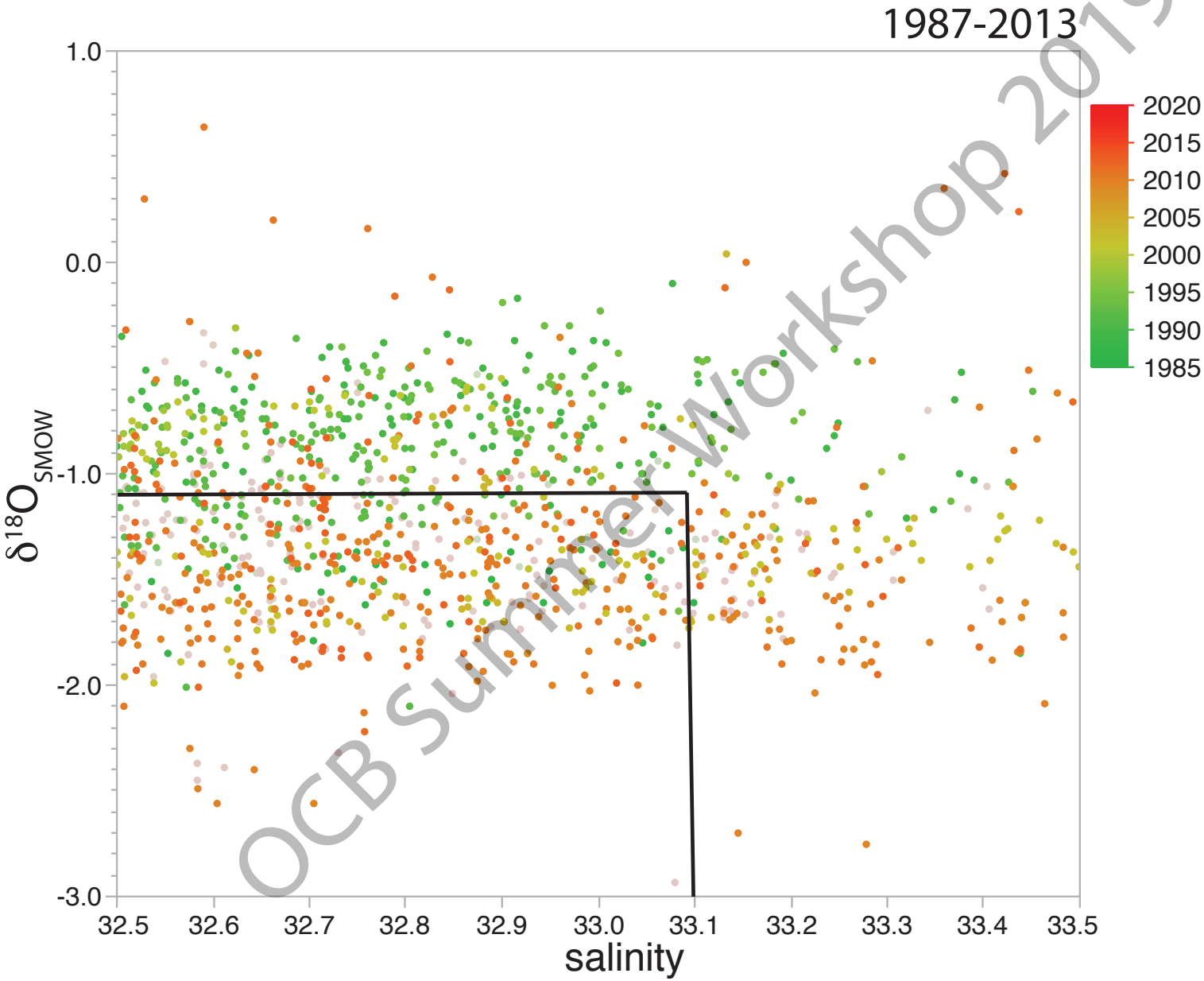


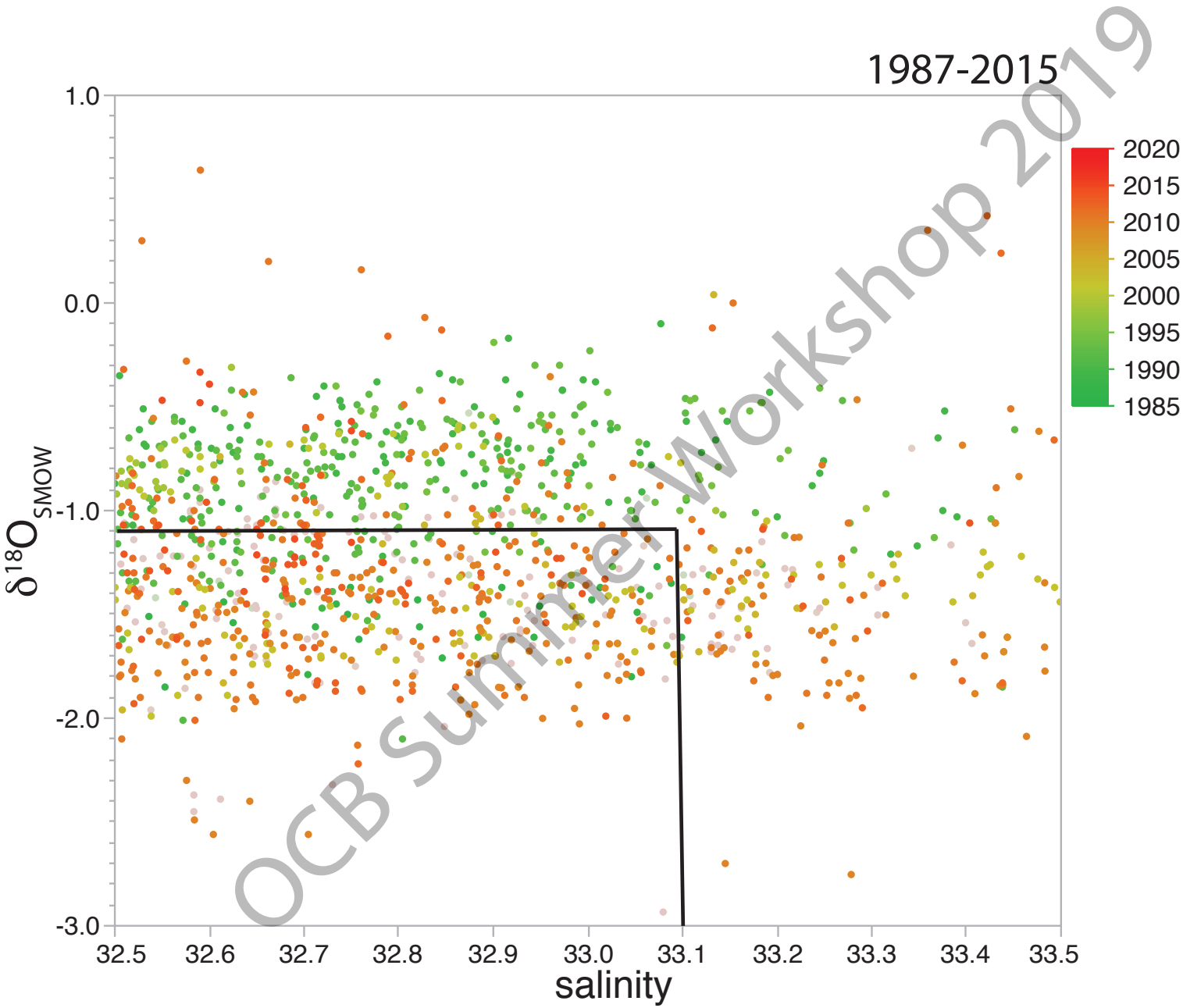


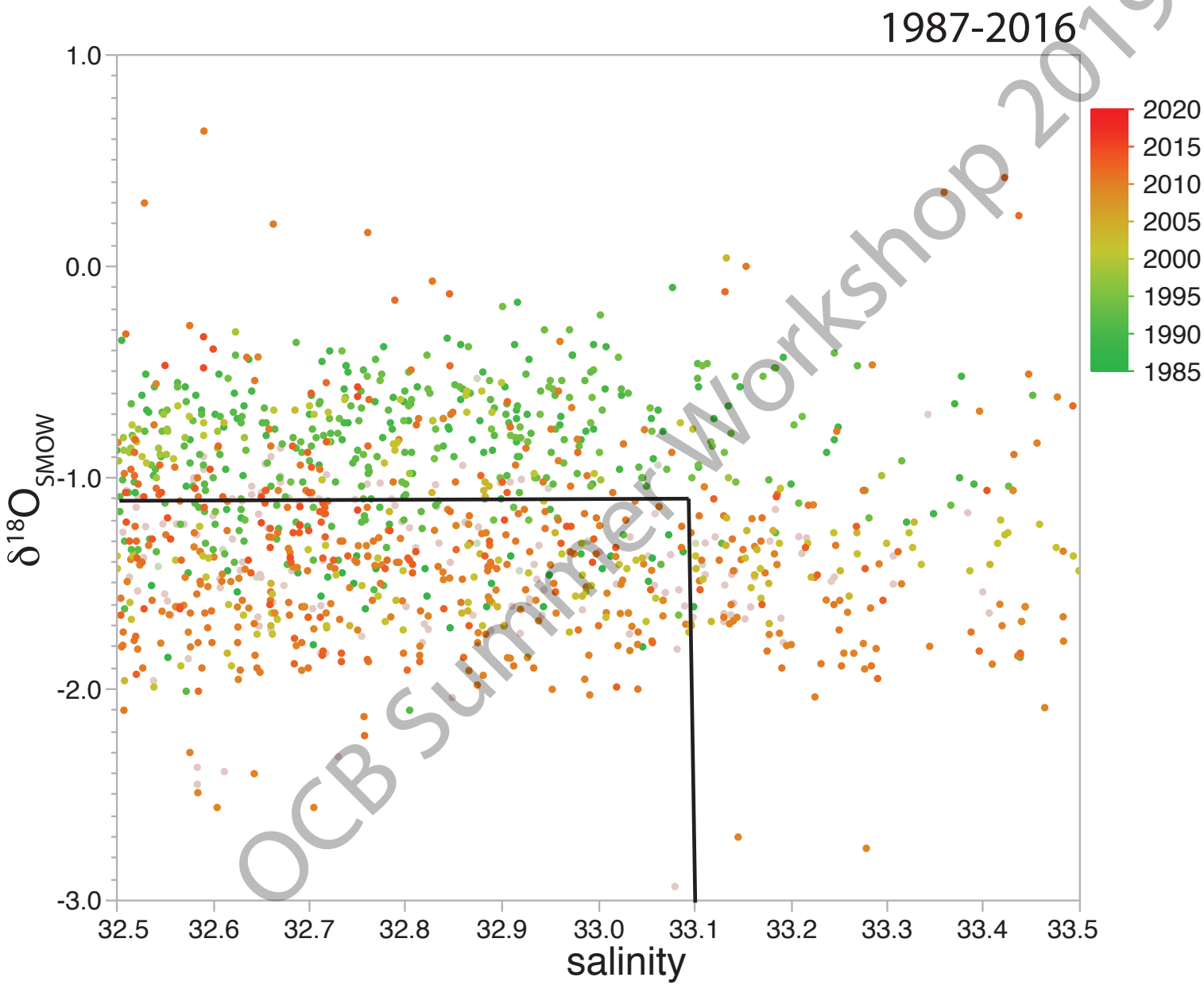


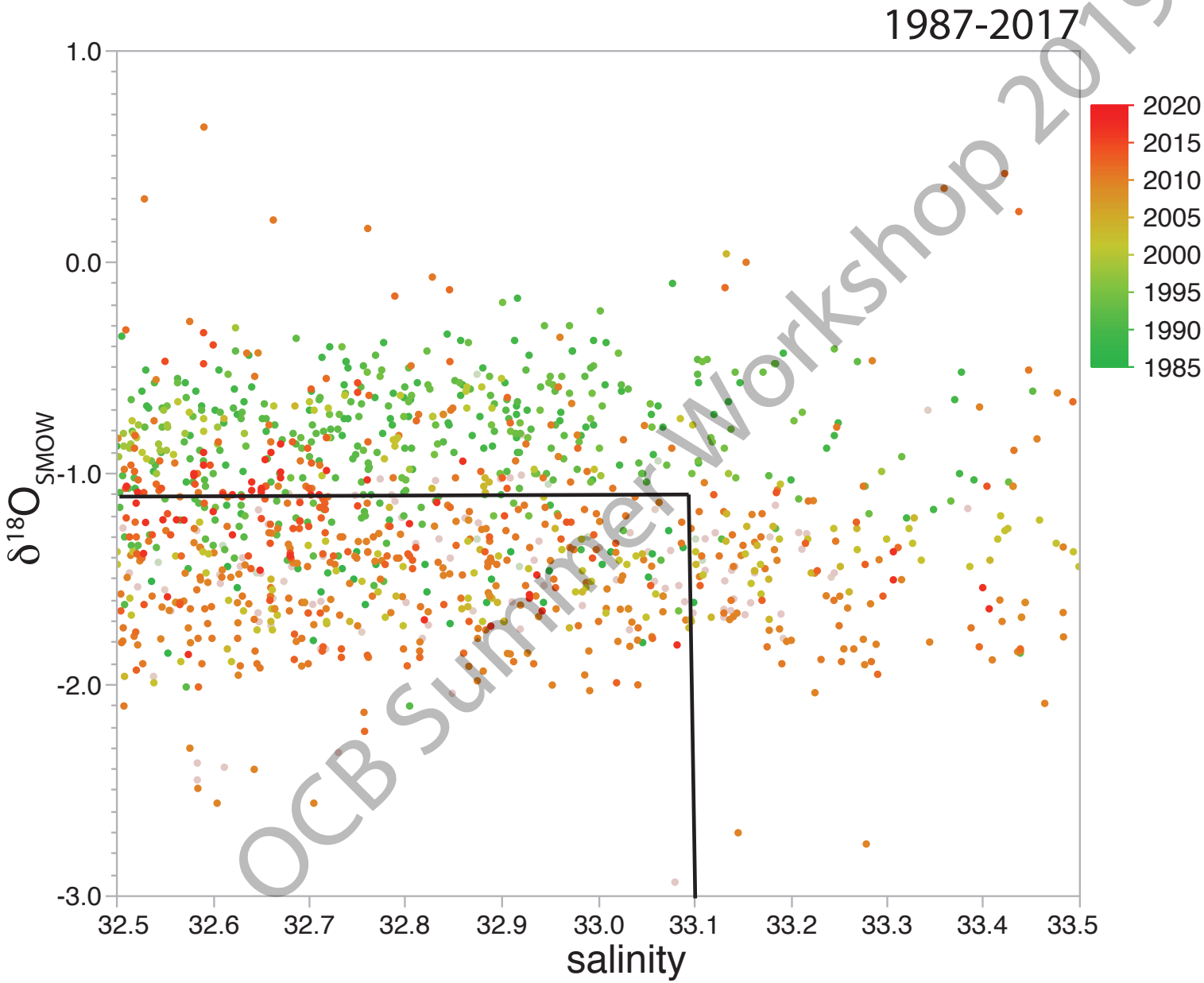


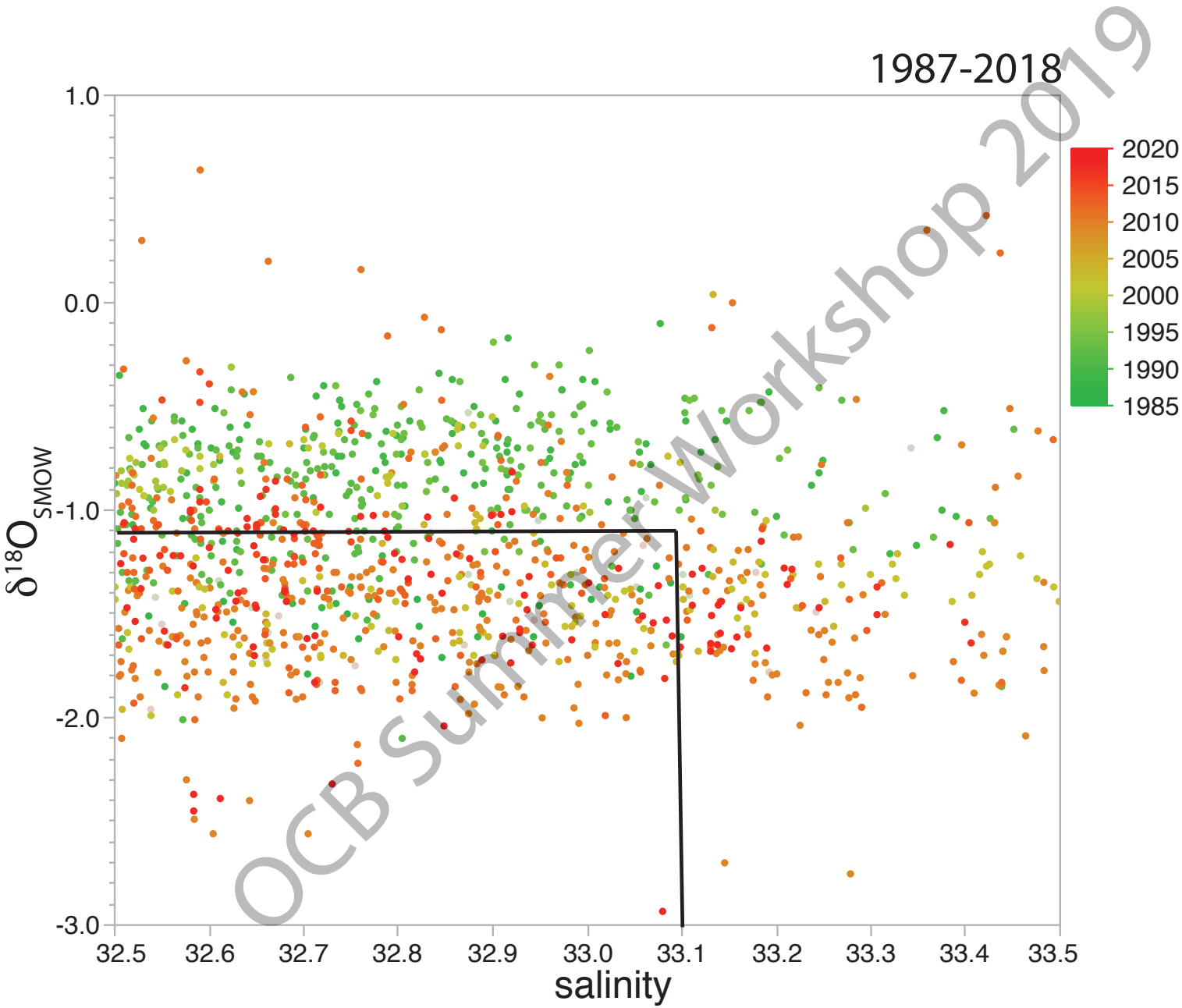












Assumptions

$\delta^{18}O_{end\text{-}member}$ of freshwater in Bering Strait inflow remains ~-19.3‰

Salinity of upper halocline remains 33.1

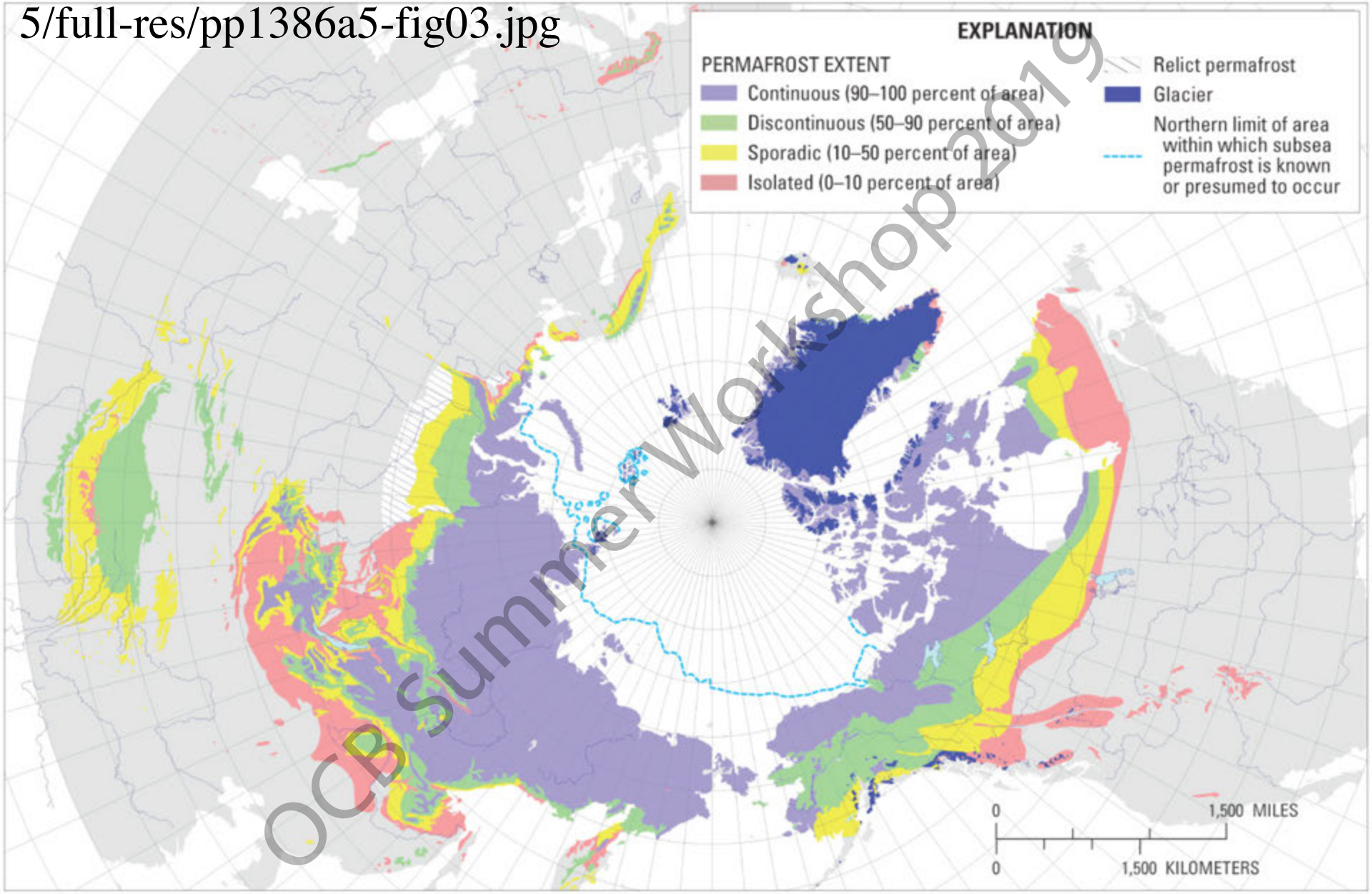
change in freshwater volume is proportional to

$(\delta^{18}O_{end\text{-}member})(X)$ = [(33.1) * original $\delta^{18}O$ value of upper halocline)] relative to:

$(\delta^{18}O_{end\text{-}member})(X)$ = [(33.1) * new $\delta^{18}O$ value of Upper halocline)]

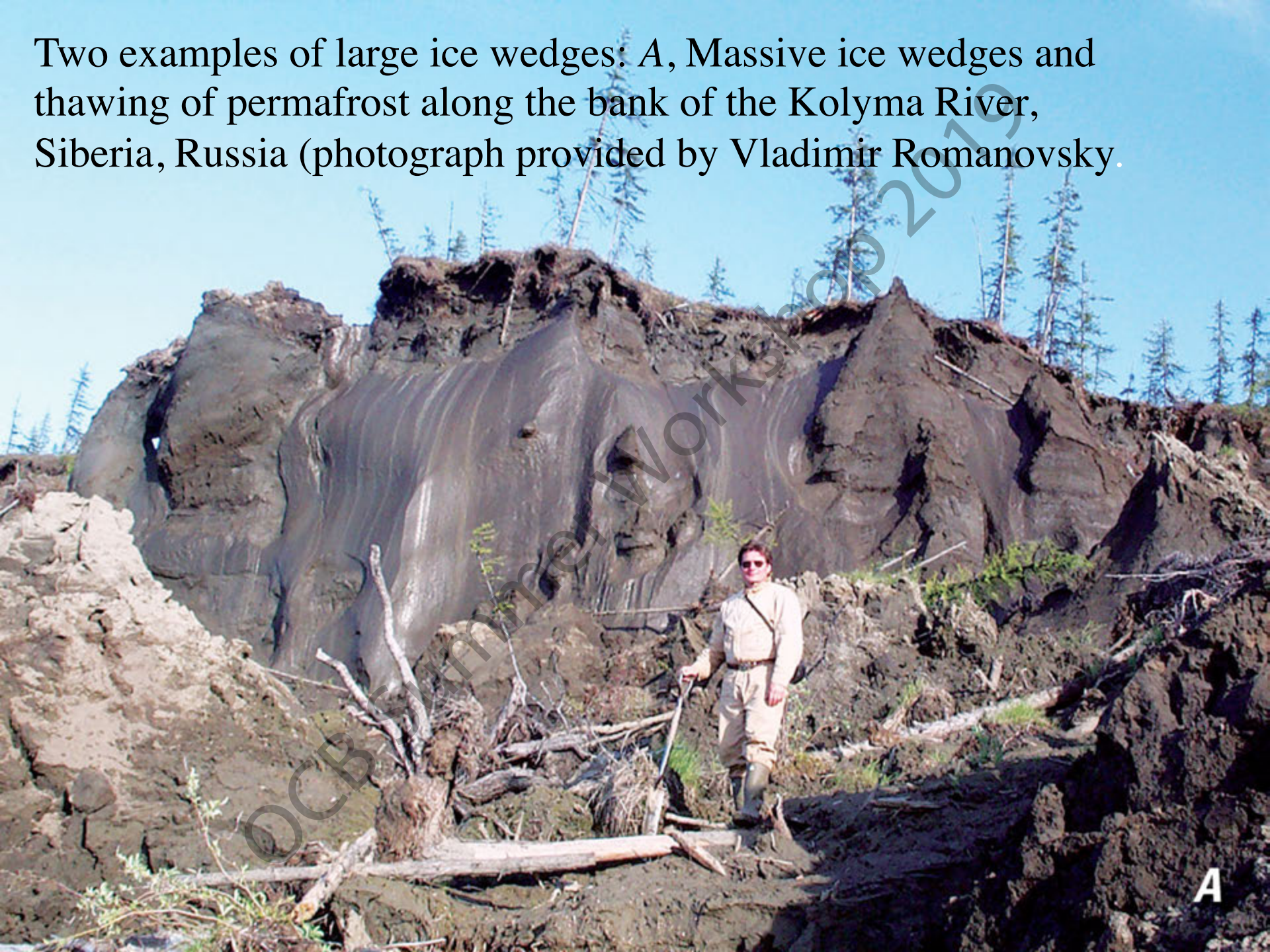
Change from -1.1 to -1.6‰ corresponds to 45% increase in freshwater flow

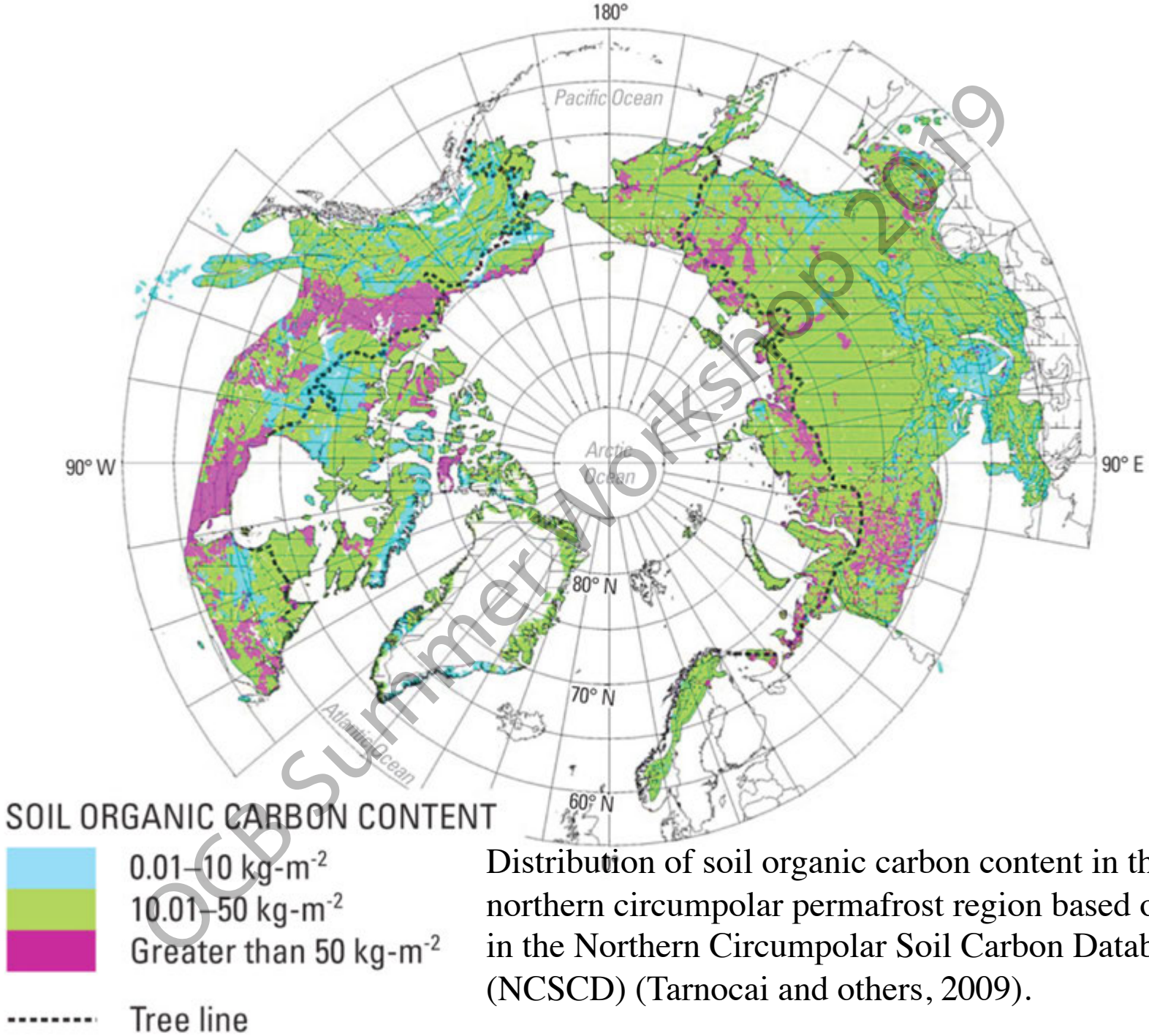
http://pubs.usgs.gov/pp/p1386a/images/gallery-5/full-res/pp1386a5-fig03.jpg



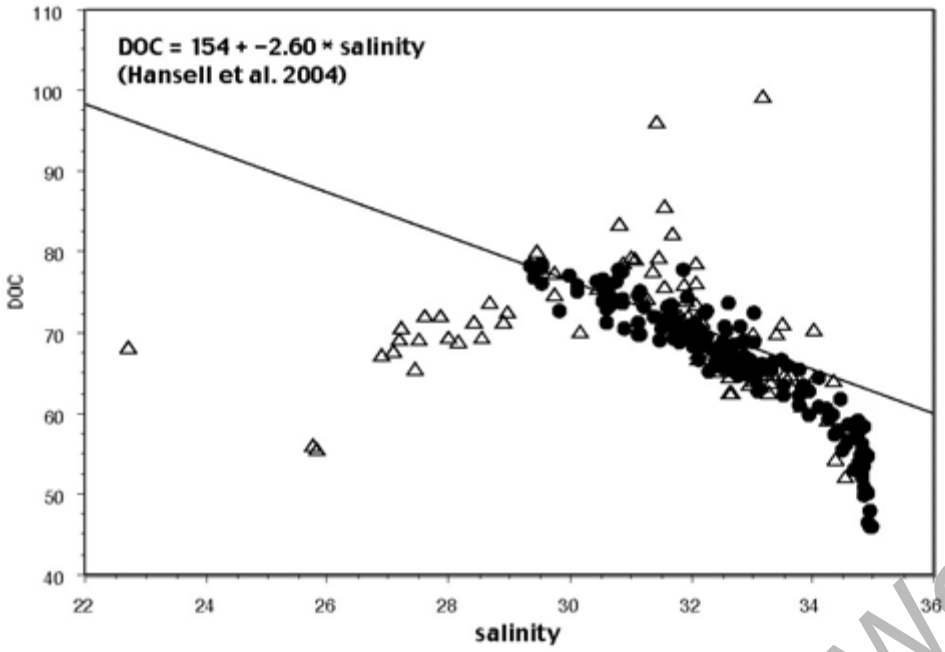
Selawik slump, northwestern Alaska
http://pubs.usgs.gov/pp/p1386a/gallery5-fig27.html
photograph by Kenji Yoshikawa, University of Alaska Fairbanks

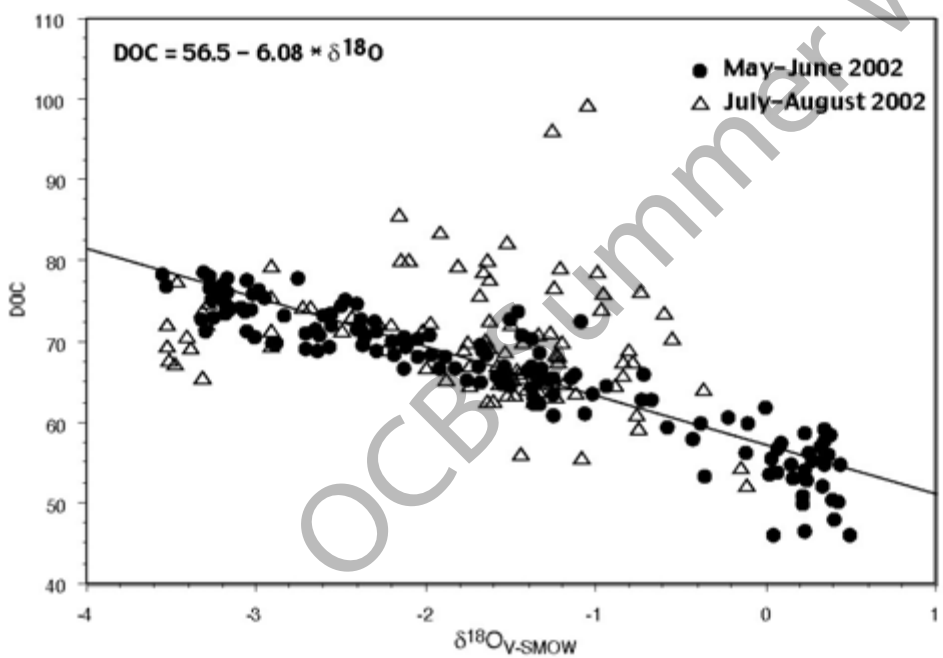
Two examples of large ice wedges: *A*, Massive ice wedges and thawing of permafrost along the bank of the Kolyma River, Siberia, Russia (photograph provided by Vladimir Romanovsky.





Distribution of soil organic carbon content in the northern circumpolar permafrost region based on data in the Northern Circumpolar Soil Carbon Database (NCSCD) (Tarnocai and others, 2009).





JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 110, G02013, doi:10.1029/2005JG000031, 2005

Linkages among runoff, dissolved organic carbon, and the stable oxygen isotope composition of seawater and other water mass indicators in the Arctic Ocean

Lee W. Cooper,[1] Ronald Benner,[2] James W. McClelland,[3] Bruce J. Peterson,[3] Robert M. Holmes,[4] Peter A. Raymond,[5] Dennis A. Hansell,[6] Jacqueline M. Grebmeier,[1] and Louis A. Codispoti[7]

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[1] Flow-weighted dissolved organic carbon (DOC) concentrations and $\delta^{18}O$ values were determined from major arctic rivers, specifically the Ob, Yenisey, Lena, Kolyma, Mackenzie, and Yukon during 2003–2004. These data were considered in conjunction with marine data for DOC, $\delta^{18}O$ values, nutrients, salinity, and fluorometric indicators of DOC obtained during sampling at the shelf-basin boundary of the Chukchi and Beaufort seas. On the basis of these data, freshwater in the sampled marine waters is likely derived from regional sources, such as the Mackenzie, the Bering Strait inflow, and possibly eastern Siberian rivers, including the Kolyma, or the Lena, but not rivers farther west in the Eurasian arctic. Freshwater from melted sea ice is insignificant over annual cycles, although melted sea ice was a locally dominant freshwater component following summer sea-ice retreat in 2002. DOC concentrations were correlated with the runoff fraction, with an apparent meteoric water DOC concentration of 174 mM. This is lower than the flow-weighted concentrations measured at river mouths of the five largest Arctic rivers (358 to 917 mM), indicating removal of DOC during transport through estuaries, shelves and in the deep basin. Flow-weighted DOC concentrations in the two largest North American arctic rivers, the Yukon (625 mM) and the Mackenzie (358 mM), are lower than in the three largest Eurasian arctic rivers, the Ob (825 mM), the Yenesey (858 mM), and the Lena (917 mM). A fluorometer responding to chromophoric dissolved organic matter (CDOM) was not correlated with DOC concentrations in Pacific-influenced surface waters unlike previous observations in the Atlantic layer. Nutrient distributions, concentrations, and derived ratios suggest the CDOM fluorometer may be responding to the release of chromophoric materials from shelf sediments. Shipboard incubations of undisturbed sediment cores indicate that sediments on the Bering and Chukchi Sea shelves are a net source of DOC to the Arctic Ocean.

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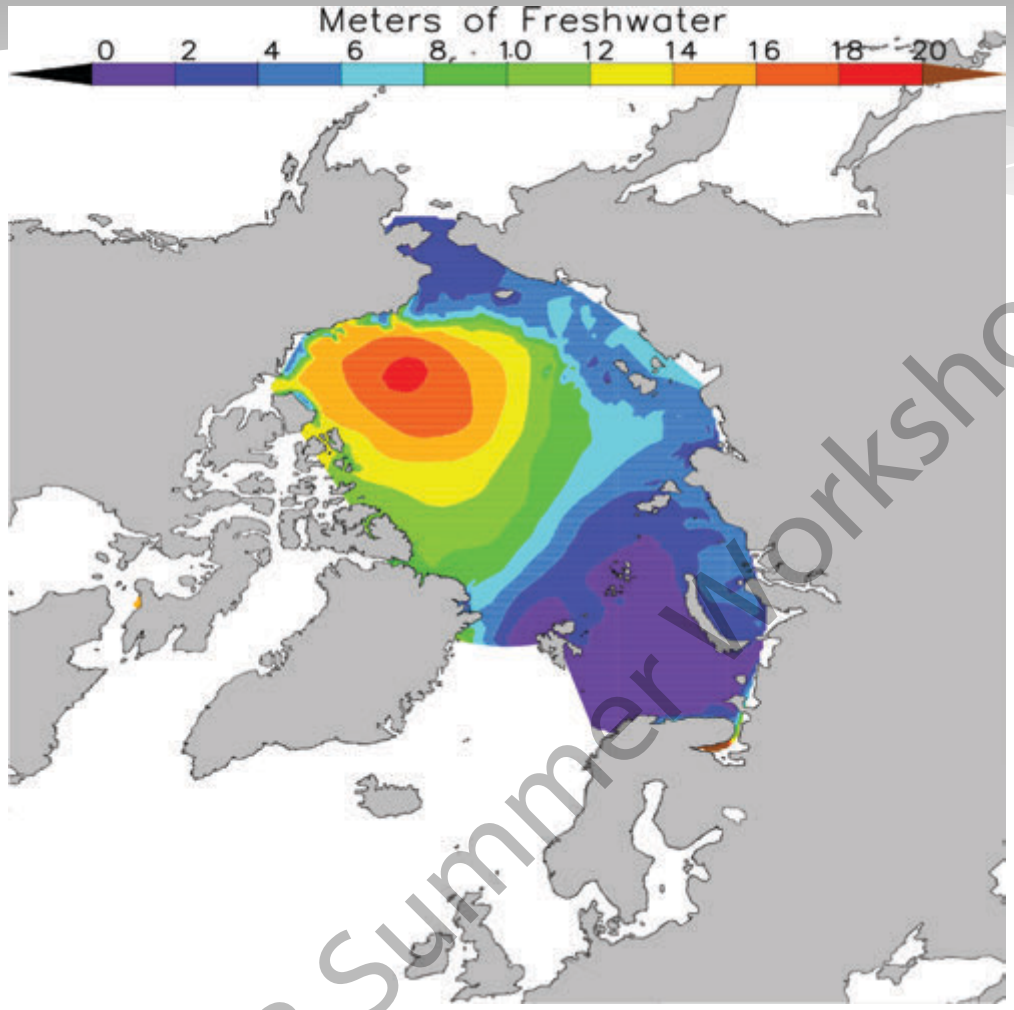
1. Introduction

[2] A number of previous studies in the Arctic Ocean have documented strong linear correlations between salinity and marine dissolved organic carbon (DOC) concentrations [Dittmar and Kattner, 2003, and references therein]. These apparently conservative relationships suggest that terrestrial allochthonous DOC entering the Arctic marine environment is resistant to degradation. Labile, autochthonous DOC by contrast is rapidly recycled in the upper water column [e.g., Wheeler et al., 1996]. Much of the work leading to the conclusion that allochthonous DOC is conserved during transport through the Arctic Ocean, however, has focused on the Eurasian side of the basin. In this study we examined new North American marine data from the Shelf-Basin Interactions (SBI) program and pan-Arctic river data from



Serreze, M. C., A. P. Barrett, A. G. Slater, R. A. Woodgate, K. Aagaard, R. B. Lammers, M. Steele, R. Moritz, M. Meredith, and C. M. Lee (2006), The large-scale freshwater cycle of the Arctic, J. Geophys. Res., 111, C11010, doi:10.1029/2005JC003424.

Figure 3. Mean annual freshwater content of the Arctic Ocean (excluding sea ice) based on the University of Washington Polar Science Center Hydrographic Climatology (PHC). The scale is in meters offreshwater, computed using a reference salinity of 34.8 (http://psc.apl.washington.edu/Climatology.html).

Conclusions

Freshwater in the Arctic Ocean is increasing

Both from Rivers & Bering Strait

Sea ice melt is likely a modest freshwater component

Potential for impacts on North Atlantic

Increasing dissolved organic carbon and nutrient fluxes likely

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