Exploring Spatial and Temporal Variations of Arctic Circulation Using Oxygen Isotopes of Seawater

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Introduction

Water isotopes (^{16}O and ^{18}O, see *) are tracers of the hydrologic cycle. Heavy isotopes are more common in liquid form; when water changes phase, heavy isotopes tend to remain in the liquid form. This 'fractionation' yields a correlation between the amount of rainout in an air parcel and the depletion of the heavy isotope (Rayleigh Distillation). The provenance of meteoric water sources can be inferred through samples of stable isotopes of ocean water. The abundance and distribution of these isotopes are also linked to the temperature at which water vapor condenses and precipitates (Dansgaard, 1964).

For the ocean, freshwater processes impact the heavier ^{18}O as they impact salinity, yielding a regional linear relationship (Craig and Gordon, 1965). The relationship breaks down on larger scales because water is evaporated and transported between ocean regions. Water isotopes are also important because they are preserved in archives like ice cores and thus can provide a proxy for climates of the past.

Observations from the past sixty years of $\delta^{18}O_{seawater}$ were compiled into a database by Schmidt et al. (1999), and subsequently used to calculate a three-dimensional 1°x1° $\delta^{18}O$ global gridded dataset by LeGrande and Schmidt (2006; LS06). Although the Schmidt et al. (1999) Global Seawater Oxygen-18 Database ($\delta^{18}O_{obs}$) contains 25,514 measurements used to calculate the global gridded dataset, *LS06 point out that, "d*ata coverage varies greatly from region to region," with seasonal variability creating biases in areas where sea ice is present.

Methods

- Imported data from 2,942 new samples into the Global Seawater Oxygen-18 Database (Schmidt, et al., 1999) via Python.
- Organized database into Arctic melt-season (May-September) and frozen season (October-April) via Python pandas (figs. 2b,c).
- Applied LS06 method to update global gridded dataset (LeGrande and Schmidt, 2006). Quantified and visualized discrepancies via Python matplotlib (fig. 1).
- Defined ten water masses using observed clusters and Arctic surface circulation patterns (fig. 3a).
- Explored data sets, including and jackknife analysis of $\delta^{18}O$ - Salinity relationship to identify outliers within each of the ten previously defined water masses via R and Python (fig. 3b).
- Removed outliers in each of the ten previously defined water masses and recalculated $\delta^{18}O$ - Salinity relationships (fig. 3b). Reconsidered boundaries of the ten water masses.

Results

Figure 1 Global Gridded Data Set (Left), arctic estimated-calculated discrepancy(right).

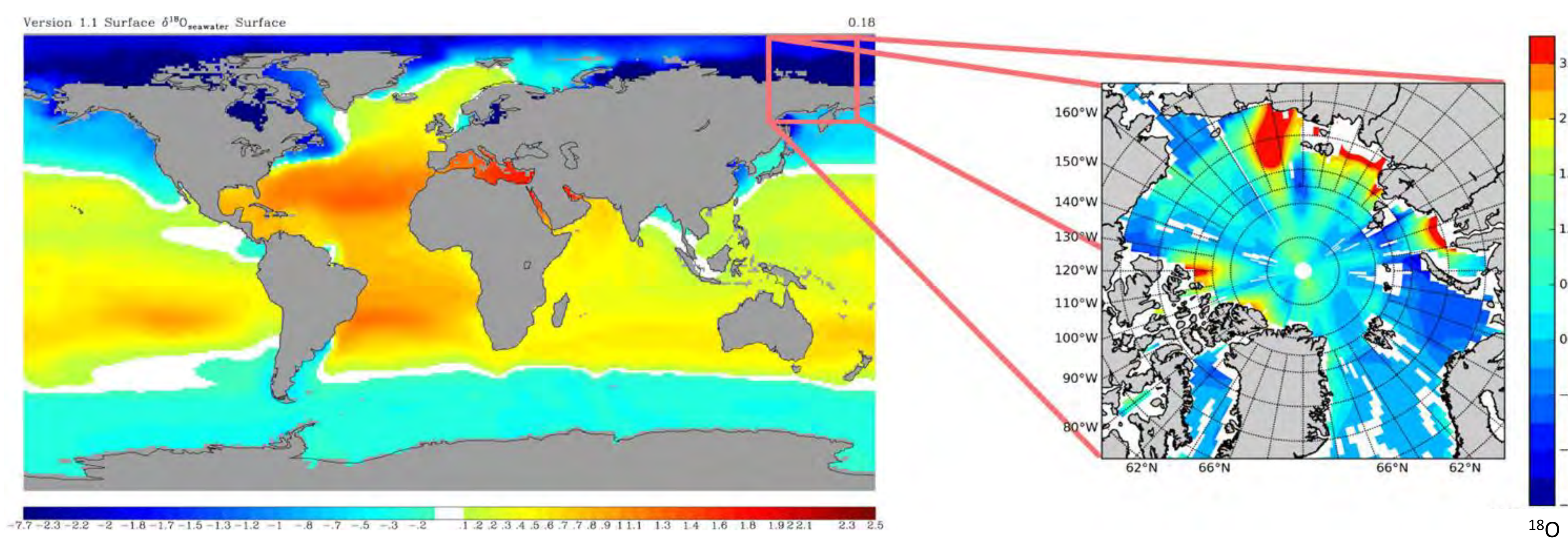


Figure 2a, b, c. Arctic Spatial & Temporal Distribution

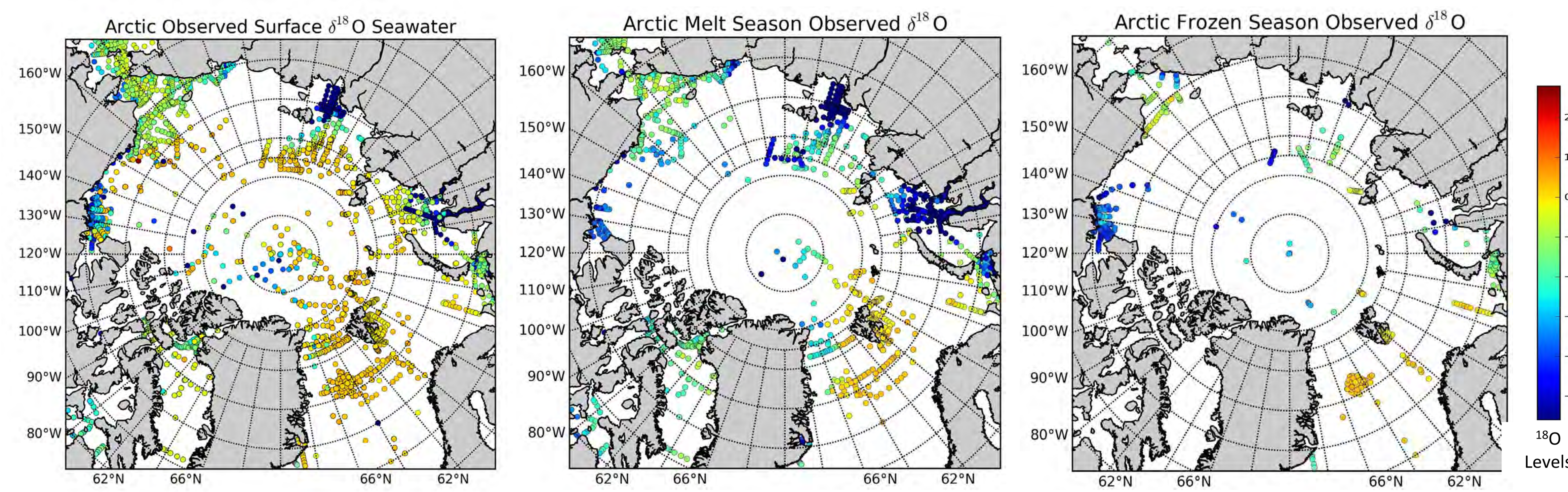
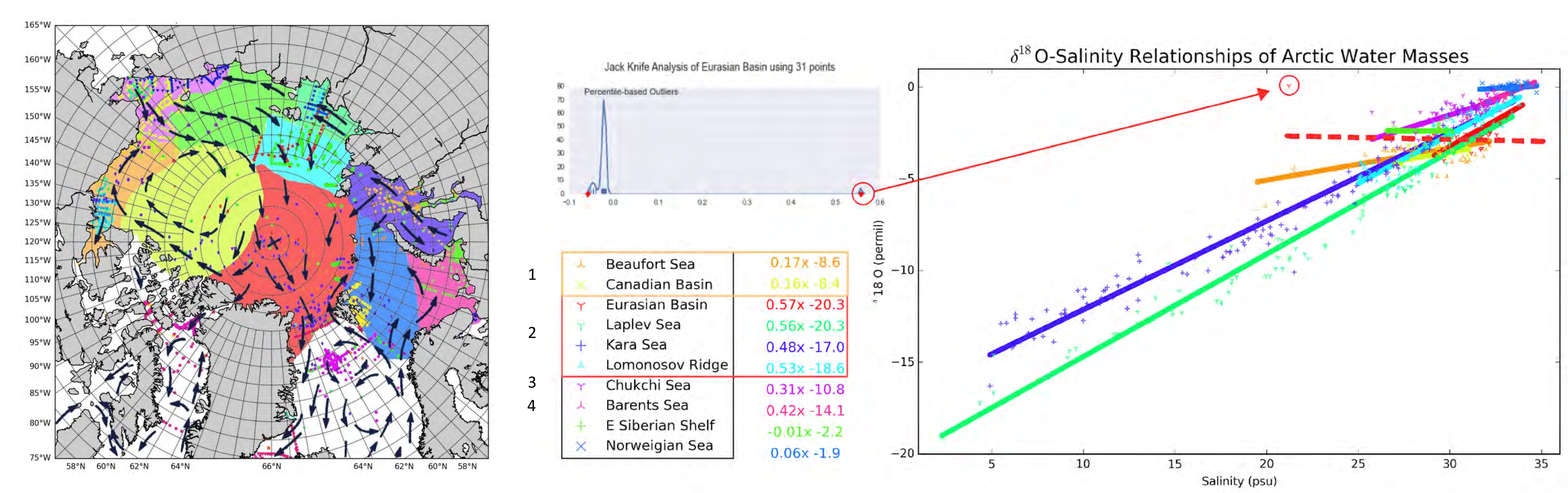


Figure 3a, b Arctic Water Mass Definition & Analysis



Conclusion

After updating the Global Seawater Oxygen-18 Database, examining the calculated-estimated discrepancies, and noting the spatial and temporal distribution of ^{18}O, the complexity of the Arctic Ocean circulation was realized in ten, later condensed into four newly defined Arctic water masses.

Future Work:

- Representation of ocean components along isopycnals.
- Characterization of freshwater impact on halocline.
- Application of Jackknife slope analysis to improve regional $\delta^{18}O$-Salinity relationships that better define water masses and track their sources, pathways, and interactions in global ocean circulation.

Discussion

Discrepancies between the estimated and calculated global gridded sets that are in the Arctic (fig. 1) appear correlated by two variables:

Spatial Distribution

^{18}O of the rivers is highly depleted because the rivers are sourced at high latitudes and far from the coast line, the precipitation source. The Arctic Ocean is a small body of water where river impact extends beyond the coast (figs. 1, 2a).

Temporal Distribution

Data are collected primarily during melt season (May-September), when river discharge creates gradients of fresh $\delta^{18}O$-depleted coastal water and salty $\delta^{18}O$-enriched ocean water (figs. 2b, 2c). These gradients yield steep $\delta^{18}O$-S relationships, while sea ice has similar $\delta^{18}O$ to seawater and thus has a shallow gradient (fig. 3b). Based on freshwater end members (where salinity=0, at the y-intercept) and Jackknife eliminations of outliers, we can condense the initial ten water masses into four water masses with distinct $\delta^{18}O$-Salinity relationships (figs. 3a, b).

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* The concentration of water isotopes is often presented using 'delta' notation, which is presented in 'permil' ‰ units and defined as where R is concentration $d^{18}O$ defined as (R sample/R standard - 1)*1000. (R standard is standard mean ocean water, where for each 1,000,000 molecules of $H_2{}^{16}O$, there are roughly 2005 $H_2{}^{18}O$ molecules.)