Supporting Information

This section contains text, three additional figures and one table, as well as references.

Detailed procedure for the determination of $\delta^{18}O$ (addendum to Section 3.2.2.)

Just prior to analysis, subsamples for oxygen isotope analysis were pipetted from 20 mL vials into sealable 2 mL vials. The oxygen isotopic composition was measured by a Picarro Cavity Ring-Down Spectroscopy High Precision Isotopic Water Analyzer (CRDS model L2130-i) at the University of Manitoba (U of M). Three reference standards, Standard Light Antarctic Precipitation (-55.50 ‰), an in-house artificial seawater standard created at the University of Manitoba Sea Ice Research Facility (SERF) (-16.50‰), and Vienna Standard Mean Ocean water (V-SMOW) (0‰), were run before and after each set of 10 samples to recalibrate the instrument, reduce drift, and maintain precision. Six measurements were made in total for each 2 mL sample and the latter three values used to calculate the average $\delta^{18}O$ (‰) for that sample. Although the analysis of seawater causes a salt build-up inside the instrument (cf., Walker et al. 2016), proper maintenance and routine flushing was practiced to ensure there was no influence on the quality or integrity of the measurements. Over the course of several months, between June and August 2015, the overall precision obtained for duplicate samples and standards was ±0.10‰ (n=53). This precision is similar to that reported in previous studies of coastal Hudson Bay waters (Granskog et al. 2011; Kuzyk et al. 2008). The average difference for a set of 20 samples analyzed both at the U of M and the lab used in previous studies (G.G. Hatch Isotope Laboratory, University of Ottawa) was 0.29‰. The U of M results showed a slight positive bias, which implies that the data used in this study will slightly underestimate the fractional contribution of river water relative to previous work.

References

Granskog, M., Z.A. Kuzyk, K. Azetsu-Scott, and R.W. Macdonald. 2011. Distributions of runoff, sea-ice melt and brine using δ18O and salinity data - a new view on freshwater cycling in Hudson Bay Journal of Marine Systems 88: 362-374.

Kuzyk, Z.A., R.W. Macdonald, M.A. Granskog, R.K. Scharien, R.J. Galley, C. Michel, D. Barber, and G. Stern. 2008. Sea ice, hydrological, and biological processes in the Churchill River estuary region, Hudson Bay. Estuarine, Coastal and Shelf Science 77: 369-384.

Walker, S.A., Azetsu-Scott, K., Normandeau, C., Kelley, D.E., Friedrich, R., Newton, R., Schlosser, P., McKay, J.L., Abdi, W., Kerrigan, E., Craig, S.E., Wallace, D.W.R., 2016. Oxygen isotope measurements of seawater (18O/ 16O): A comparison of cavity ring-down spectroscopy (CRDS) and isotope ratio mass spectrometry (IRMS). Limnology and Oceanography: Methods 14, 31-38.

Detailed procedure for converting depth in ice cores to time of freezing (addendum to Section 3.4.2)

A time scale for each ice core was constrained by at least two known dates: The date of freeze-up, estimated from MODIS satellite imagery (NASA, EODIS Worldview) of the study region, and the date of core collection (Table 2). Freeze-up fell within the second week of December (5-17 December 2014) at most stations (Table 2). The later freeze-up dates for several stations off the southeast coast (cf., SK 23, Table 2) reflect the fact that although ice began to form there in December, a permanent platform did not persist until after 5-16 January 2015. All ice cores were collected under winter conditions (i.e., freezing temperatures prevailed) and before spring thaw commenced as confirmed by the freezing-degree day record at Sanikiluaq (Fig. 3). To confirm ice growth rates, ice thicknesses were measured 35-53 days into the period of ice growth at ten stations (Table 2). Observed ice thicknesses and age of the ice determined from freeze-up date showed a strong relationship of the form expected for thermodynamic ice growth, i.e., a second order polynomial (Fig. 3b, R^2=0.94, $p<0.001$).

The start of freezing, the date at the bottom of the ice, and any additional dates on which ice thicknesses were measured (see Fig. 3b) were used together to relate depth in the core to time using Stefan's equation for ice growth (Anderson 1961; Stefan 1889), which is an analytical solution for thermodynamic ice growth as a function of freezing-degree days (t): $H = d\ t^{0.5}$, where H is the thickness of the sea ice. Knowing the length of the ice core (H) at one or more time points, and the cumulative freezing-degree days of growth determined up to that point from the air temperature record, we determined the constant (d) for each ice core. We then applied the equation (4) to estimate the time of formation (days) for each depth corresponding to the midpoints of the extracted 5-cm ice core sections. The uncertainty in this method of dating the cores was evaluated by comparing the ice thicknesses predicted using equation (4) with the ice thicknesses measured 35-53 days into the period of ice growth (Table 2). For the 10 stations where ice thicknesses were observed, the predicted ice thicknesses exceeded the observed thicknesses by on average 5.6 (±3.3) cm, implying that the dates assigned to sections in the middle of the cores could be in error by one week. The derived dates must be used with this caution in mind. The positive bias in the predicted ice thicknesses suggests that ocean heat flux or snow cover had slowed the in situ growth of ice compared to the thermodynamic model predictions. When ice thickness observations were made in January, 2015, about 5±5 cm of snow had accumulated on the ice at the sampling stations.

References

Anderson, D.L. 1961. Growth rate of sea-ice. Journal of Glaciology 3: 1170-1172.

Stefan, J. 1889. Über die Theorie der Eisbildung. Sitzungsberichte deT Kais. Akademie der Wissenschaften in Wien. Math Naturwiss. Abt. 2a: 965.

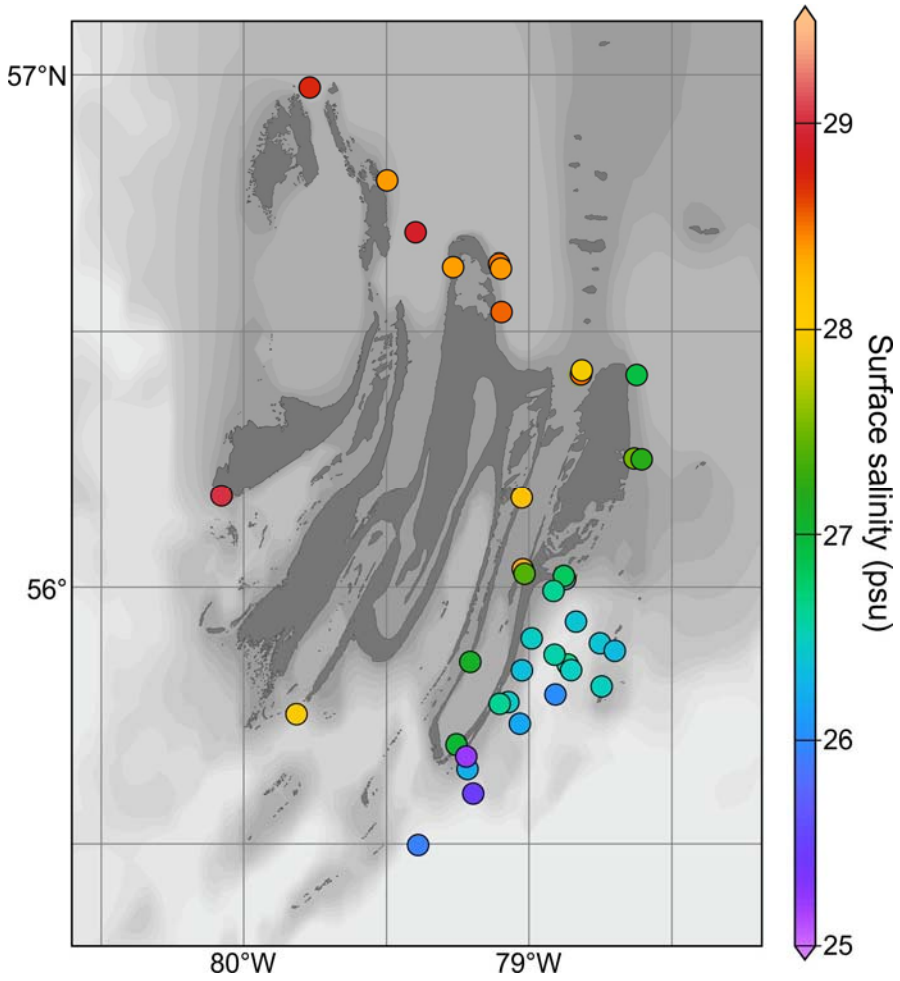

Figure SI-1. Surface salinity distribution during winter 2015 showing the fresher surface layer (salinity ~ 26) observed at most stations south/southeast of the Belchers.

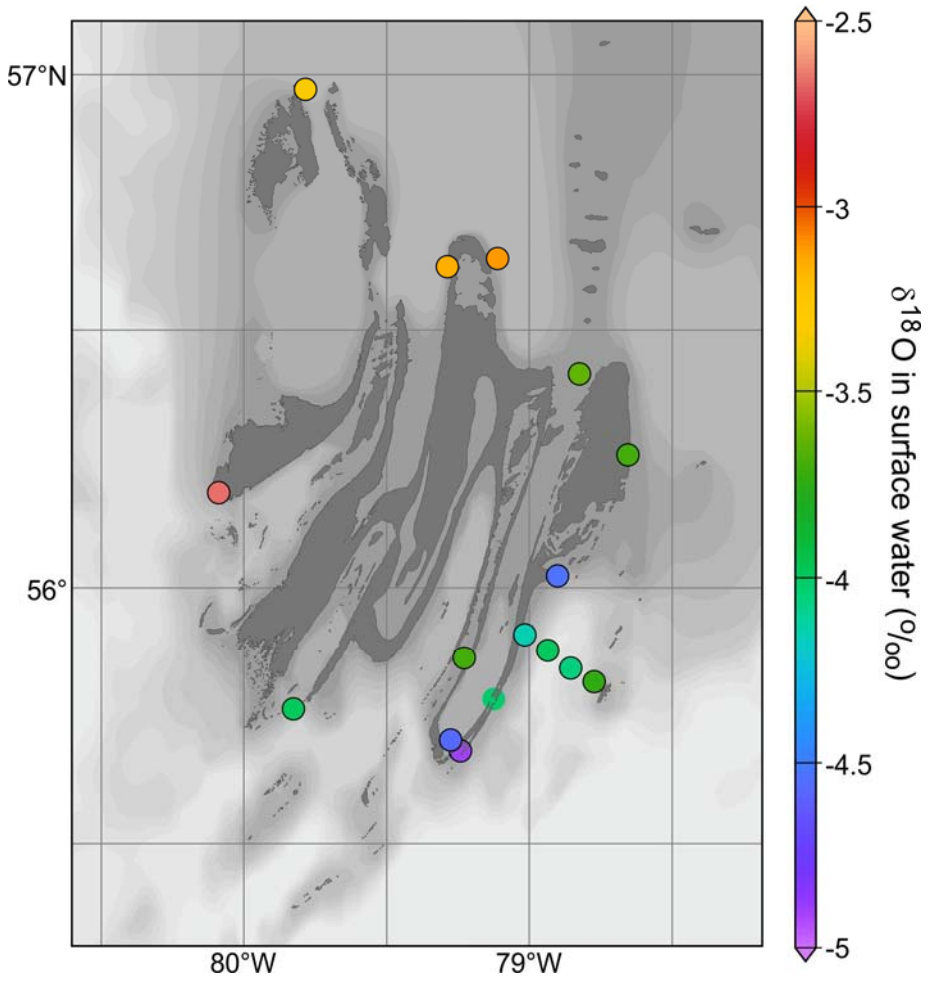

Figure SI-2. Surface water $\delta^{18}O$ data during winter 2015 showing lowest $\delta^{18}O$ values (below -4‰) southeast of the Belchers where fresher surface layer was observed and highest values to the north and west of the islands.

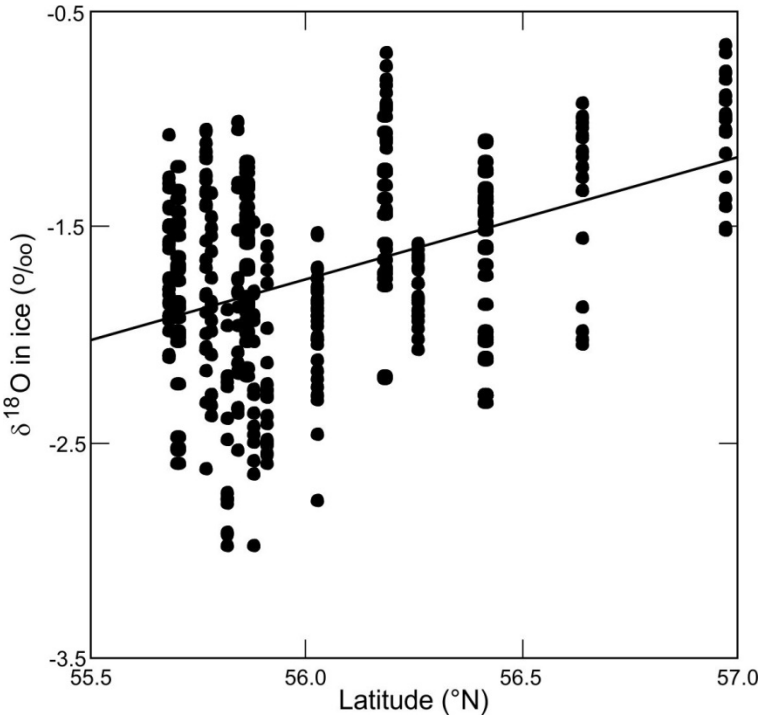

Figure SI-3. $\delta^{18}O$ data for sea-ice samples from both years, showing significant increase with increasing latitude (r^2=0.18, $p<0.001$, n=330). Thus, the spatial pattern in $\delta^{18}O$ in sea ice roughly reflects the spatial pattern in $\delta^{18}O$ in sea water.

Table SI-1. Salinity and $\delta^{18}O$ data obtained during the four field campaigns around the Belcher Islands.

Field Campaign	Station	Latitude	Longitude	Date	Btm Depth [m]	Depth [m]	Salinity [psu]	$\delta^{18}O$ [‰]
1	SK-1	55.681	-79.2401	01/21/2014	65	0	27.21	-5.01
1	SK-1	55.6810	-79.2401	01/21/2014	65	1	26.95	-4.88
1	SK-1	55.6810	-79.2401	01/21/2014	65	5	27.00	-4.98
1	SK-1	55.6810	-79.2401	01/21/2014	65	10	27.30	-4.73
1	SK-1	55.6810	-79.2401	01/21/2014	65	20	28.13	-4.44
1	SK-2	55.7022	-79.2752	01/21/2014	65	1	27.54	-4.77
1	SK-2	55.7022	-79.2752	01/21/2014	65	5	27.80	-4.50
1	SK-2	55.7022	-79.2752	01/21/2014	65	10	27.55	-4.58
1	SK-2	55.7022	-79.2752	01/21/2014	65	20	28.59	-3.76
1	SK-2	55.7022	-79.2752	01/21/2014	65	60	29.08	-4.02
1	SK-3	56.0246	-78.9059	01/22/2014	32	1	26.74	-5.18
1	SK-3	56.0246	-78.9059	01/22/2014	32	2	26.74	-4.77
1	SK-3	56.0246	-78.9059	01/22/2014	32	5	26.99	-4.76
1	SK-3	56.0246	-78.9059	01/22/2014	32	10	27.74	-4.66
1	SK-3	56.0246	-78.9059	01/22/2014	32	20	28.88	-3.20
1	SK-3	56.0246	-78.9059	01/22/2014	32	30	N/A	N/A
1	SK-4	56.9818	-79.7672	01/25/2014	52	1	29.66	-3.98
1	SK-4	56.9818	-79.7672	01/25/2014	52	2	29.65	-4.15
1	SK-4	56.9818	-79.7672	01/25/2014	52	5	29.65	-4.14
1	SK-4	56.9818	-79.7672	01/25/2014	52	10	29.66	-4.69
1	SK-4	56.9818	-79.7672	01/25/2014	52	20	29.68	-4.48
1	SK-4	56.9818	-79.7672	01/25/2014	52	50	29.92	-4.29
1	SK-8	55.7689	-79.7874	02/08/2014	13	0	29.28	-4.26
1	SK-8	55.7689	-79.7874	02/08/2014	13	5	29.18	-4.41
1	SK-8	55.7689	-79.7874	02/08/2014	13	10	29.36	-3.98
1	SK-8	55.7689	-79.7874	02/08/2014	13	13	29.72	-4.01
1	SK-9	55.8540	-79.2670	02/14/2014	67	0	N/A	N/A
1	SK-9	55.8540	-79.2670	02/14/2014	67	5	N/A	N/A
1	SK-9	55.8540	-79.2670	02/14/2014	67	10	N/A	N/A
1	SK-9	55.8540	-79.2670	02/14/2014	67	20	N/A	N/A
1	SK-9	55.8540	-79.2670	02/14/2014	67	60	N/A	N/A
1	SK-10	56.4150	-78.8246	02/14/2014	28	0	28.87	-4.52
1	SK-10	56.4150	-78.8246	02/14/2014	28	2	28.16	-4.28
1	SK-10	56.4150	-78.8246	02/14/2014	28	5	28.98	-3.81
1	SK-10	56.4150	-78.8246	02/14/2014	28	10	29.06	-4.34
1	SK-10	56.4150	-78.8246	02/14/2014	28	28	29.17	-3.78

Field Campaign	Station	Latitude	Longitude	Date	Btm Depth [m]	Depth [m]	Salinity [psu]	$\delta^{18}O$ [‰]
1	SK-14	56.1815	-80.0943	02/19/2014	60	0	30.17	-3.49
1	SK-14	56.1815	-80.0943	02/19/2014	60	2	30.18	-3.09
1	SK-14	56.1815	-80.0943	02/19/2014	60	5	30.18	-4.18
1	SK-14	56.1815	-80.0943	02/19/2014	60	10	30.18	-3.55
1	SK-14	56.1815	-80.0943	02/19/2014	60	20	30.17	-4.06
1	SK-14	56.1815	-80.0943	02/19/2014	60	60	30.24	-3.36
2	SK-1	55.6810	-79.2400	10/27/2014	60	1	27.70	-3.32
2	SK-1	55.6810	-79.2400	10/27/2014	60	5	27.75	-2.99
2	SK-1	55.6810	-79.2400	10/27/2014	60	10	27.76	-3.40
2	SK-1	55.6810	-79.2400	10/27/2014	60	20	27.95	-3.17
2	SK-1	55.6810	-79.2400	10/27/2014	60	60	28.95	-2.75
2	SK-9	55.8540	-79.2670	10/27/2014	60	0	27.03	-3.21
2	SK-9	55.8540	-79.2670	10/27/2014	60	5	27.03	-3.41
2	SK-9	55.8540	-79.2670	10/27/2014	60	10	27.08	-3.35
2	SK-9	55.8540	-79.2670	10/27/2014	60	20	27.06	-3.03
2	SK-9	55.8540	-79.2670	10/27/2014	60	60	29.20	-2.72
2	SK-3	56.0250	-78.9060	10/27/2014	30	0	28.03	-3.25
2	SK-3	56.0250	-78.9060	10/27/2014	30	5	28.02	-3.13
2	SK-3	56.0250	-78.9060	10/27/2014	30	10	28.06	-3.07
2	SK-3	56.0250	-78.9060	10/27/2014	30	30	28.08	-2.72
2	SK-10	56.4150	-78.8237	10/27/2014	30	0	28.08	-3.24
2	SK-10	56.4150	-78.8237	10/27/2014	30	5	28.02	-3.21
2	SK-10	56.4150	-78.8237	10/27/2014	30	10	28.05	-3.22
2	SK-10	56.4150	-78.8237	10/27/2014	30	30	28.06	-3.28
3	SK 1	55.6808	-79.2426	01/14/2015	57.3	1	25.86	-4.26
3	SK 1	55.6808	-79.2426	01/14/2015	57.3	5	25.95	-4.04
3	SK 1	55.6808	-79.2426	01/14/2015	57.3	10	26.96	-3.58
3	SK 1	55.6808	-79.2426	01/14/2015	57.3	20	27.44	-3.27
3	SK 1	55.6808	-79.2426	01/15/2015	57.3	50	29.63	-2.34
3	SK 2	55.7024	-79.2763	01/26/2015	60	1	27.48	-3.51
3	SK 2	55.7024	-79.2763	01/26/2015	60	5	27.89	-3.44
3	SK 2	55.7024	-79.2763	01/26/2015	60	10	28.22	-3.30
3	SK 2	55.7024	-79.2763	01/26/2015	60	20	28.56	-3.35
3	SK 2	55.7024	-79.2763	01/26/2015	60	60	29.08	-2.98
3	SK 3	56.0231	-78.9010	01/15/2015	47.7	1	26.15	-4.24
3	SK 3	56.0231	-78.9010	01/15/2015	47.7	5	26.23	-4.11
3	SK 3	56.0231	-78.9010	01/15/2015	47.7	10	26.75	-4.04
3	SK 3	56.0231	-78.9010	01/15/2015	47.7	20	27.20	-3.86

Field Campaign	Station	Latitude	Longitude	Date	Btm Depth [m]	Depth [m]	Salinity [psu]	$\delta^{18}O$ [‰]
3	SK 3	56.0231	-78.9010	01/15/2015	47.7	32	28.57	-3.24
3	SK 4	56.9719	-79.7839	01/20/2015	41.6	1	28.96	-2.89
3	SK 4	56.9719	-79.7839	01/20/2015	41.6	5	29.03	-3.04
3	SK 4	56.9719	-79.7839	01/20/2015	41.6	10	29.09	-2.66
3	SK 4	56.9719	-79.7839	01/20/2015	41.6	20	29.14	-2.84
3	SK 4	56.9719	-79.7839	01/20/2015	41.6	40	29.21	-2.83
3	SK 8	55.7690	-79.8276	01/17/2015	8.3	1	28.84	-3.12
3	SK 8	55.7690	-79.8276	01/17/2015	8.3	5	28.84	-3.29
3	SK 8	55.7690	-79.8276	01/17/2015	8.3	8	28.85	-2.85
3	SK 9	55.8620	-79.2285	01/29/2015	60	1	27.44	-3.45
3	SK 9	55.8620	-79.2285	01/29/2015	60	5	27.54	-3.37
3	SK 9	55.8620	-79.2285	01/29/2015	60	10	27.70	-3.13
3	SK 9	55.8620	-79.2285	01/29/2015	60	20	28.06	-3.22
3	SK 9	55.8620	-79.2285	01/29/2015	60	60	29.88	-2.43
3	SK 10	56.4150	-78.8246	01/29/2015	12	1	29.04	-3.08
3	SK 10	56.4150	-78.8246	01/29/2015	12	5	29.07	-2.85
3	SK 10	56.4150	-78.8246	01/29/2015	12	10	29.03	-2.86
3	SK 12	56.6260	-79.2870	01/24/2015	20	1	28.80	-2.95
3	SK 12	56.6260	-79.2870	01/24/2015	20	5	28.80	-2.79
3	SK 12	56.6260	-79.2870	01/24/2015	20	10	28.79	-2.84
3	SK 12	56.6260	-79.2870	01/24/2015	20	15	28.79	-3.02
3	SK 14	56.1847	-80.0881	01/21/2015	25.5	1	29.38	-2.87
3	SK 14	56.1847	-80.0881	01/21/2015	25.5	5	29.39	-2.85
3	SK 14	56.1847	-80.0881	01/21/2015	25.5	10	29.38	-2.77
3	SK 14	56.1847	-80.0881	01/21/2015	25.5	20	29.41	-2.68
3	SK 15	56.6420	-79.1110	01/25/2015	24.7	1	28.94	-3.14
3	SK 15	56.6420	-79.1110	01/25/2015	24.7	5	28.92	-3.46
3	SK 15	56.6420	-79.1110	01/25/2015	24.7	10	28.92	-3.55
3	SK 15	56.6420	-79.1110	01/25/2015	24.7	20	28.92	-3.41
3	SK 21	55.7815	-79.1249	01/26/2015	22.4	1	26.59	-4.22
3	SK 21	55.7815	-79.1249	01/26/2015	22.4	5	26.81	-4.18
3	SK 21	55.7815	-79.1249	01/26/2015	22.4	10	27.85	-3.69
3	SK 21	55.7815	-79.1249	01/26/2015	22.4	20	28.53	-3.47
3	SK 23	56.2585	-78.6547	01/23/2015	30	1	27.91	-3.97
3	SK 23	56.2585	-78.6547	01/23/2015	30	5	27.96	-3.84
3	SK 23	56.2585	-78.6547	01/23/2015	30	10	28.06	-3.90
4	SK 3	56.0231	-78.9010	02/17/2015	45	1	27.25	-4.54
4	SK 3	56.0231	-78.9010	02/17/2015	45	5	27.25	-4.44

Field Campaign	Station	Latitude	Longitude	Date	Btm Depth [m]	Depth [m]	Salinity [psu]	$\delta^{18}O$ [‰]
4	SK 3	56.0231	-78.9010	02/17/2015	45	10	27.55	-4.32
4	SK 3	56.0231	-78.9010	02/17/2015	45	20	27.81	-4.26
4	SK 3	56.0231	-78.9010	02/17/2015	45	30	28.01	-4.14
4	SK 21	55.7815	-79.1249	02/28/2015	78	1	27.04	-4.02
4	SK 21	55.7815	-79.1249	02/28/2015	78	5	27.26	-3.97
4	SK 21	55.7815	-79.1249	02/28/2015	78	10	27.47	-3.94
4	SK 21	55.7815	-79.1249	02/28/2015	78	20	28.31	-3.40
4	SK 22	55.9079	-79.0154	02/26/2015	85	1	27.65	-4.14
4	SK 22	55.9079	-79.0154	02/26/2015	85	5	26.88	-4.08
4	SK 22	55.9079	-79.0154	02/26/2015	85	10	27.03	-4.01
4	SK 22	55.9079	-79.0154	02/26/2015	85	20	27.78	-3.59
4	SK 22	55.9079	-79.0154	02/26/2015	85	60	30.19	-2.61
4	SK 23	56.2585	-78.6547	02/25/2015	30	1	27.70	-3.68
4	SK 23	56.2585	-78.6547	02/25/2015	30	5	27.72	-3.72
4	SK 23	56.2585	-78.6547	02/25/2015	30	10	27.70	-3.46
4	SK 23	56.2585	-78.6547	02/25/2015	30	20	27.71	-3.68
4	T1A	55.8155	-78.7728	02/20/2015	54	1	26.90	-3.75
4	T1A	55.8155	-78.7728	02/20/2015	54	5	26.90	-3.85
4	T1A	55.8155	-78.7728	02/20/2015	54	10	26.91	-3.66
4	T1A	55.8155	-78.7728	02/20/2015	54	20	26.95	-3.55
4	T1A	55.8155	-78.7728	02/20/2015	54	50	29.88	-2.53
4	T1B	55.8424	-78.8555	02/22/2015	85	1	26.82	-4.05
4	T1B	55.8424	-78.8555	02/22/2015	85	5	26.84	-4.20
4	T1B	55.8424	-78.8555	02/22/2015	85	10	26.85	-4.12
4	T1B	55.8424	-78.8555	02/22/2015	85	20	27.73	-3.55
4	T1B	55.8424	-78.8555	02/22/2015	85	60	30.03	-2.72
4	T1C	55.8775	-78.9359	02/22/2015	85	1	26.94	-3.99
4	T1C	55.8775	-78.9359	02/22/2015	85	5	26.94	-4.11
4	T1C	55.8775	-78.9359	02/22/2015	85	10	26.97	-3.91
4	T1C	55.8775	-78.9359	02/22/2015	85	20	27.72	-3.26
4	T1C	55.8775	-78.9359	02/22/2015	85	60	29.95	-2.51
4	SK 1	55.6808	-79.2426	03/14/2015	56	1	27.06	-4.91
4	SK 1	55.6808	-79.2426	03/14/2015	56	5	27.25	-4.73
4	SK 1	55.6808	-79.2426	03/14/2015	56	10	27.46	-4.59
4	SK 1	55.6808	-79.2426	03/14/2015	56	20	27.08	-4.91
4	SK 1	55.6808	-79.2426	03/14/2015	56	50	29.90	-3.49
4	SK 2	55.7024	-79.2763	03/12/2015	80	1	27.58	-4.56
4	SK 2	55.7024	-79.2763	03/12/2015	80	5	27.65	-4.32

Field Campaign	Station	Latitude	Longitude	Date	Btm Depth [m]	Depth [m]	Salinity [psu]	$\delta^{18}O$ [‰]
4	SK 2	55.7024	-79.2763	03/12/2015	80	10	27.67	-4.08
4	SK 2	55.7024	-79.2763	03/12/2015	80	20	28.25	-3.84
4	SK 2	55.7024	-79.2763	03/12/2015	80	60	28.98	-3.61
4	SK 4	56.9719	-79.7839	03/06/2015	40	1	29.23	-3.32
4	SK 4	56.9719	-79.7839	03/06/2015	40	5	29.24	-3.72
4	SK 4	56.9719	-79.7839	03/06/2015	40	10	29.27	-3.50
4	SK 4	56.9719	-79.7839	03/06/2015	40	20	29.37	-3.48
4	SK 4	56.9719	-79.7839	03/06/2015	40	40	29.78	-3.38
4	SK 8	55.7690	-79.8276	03/09/2015	8.4	1	28.33	-3.99
4	SK 8	55.7690	-79.8276	03/09/2015	8.4	5	28.42	-3.44
4	SK 8	55.7690	-79.8276	03/09/2015	8.4	8	28.27	-3.32
4	SK 9	55.8620	-79.2285	03/12/2015	80	1	27.62	-3.68
4	SK 9	55.8620	-79.2285	03/12/2015	80	5	28.21	-3.67
4	SK 9	55.8620	-79.2285	03/12/2015	80	10	27.86	-3.48
4	SK 9	55.8620	-79.2285	03/12/2015	80	20	28.06	-3.45
4	SK 9	55.8620	-79.2285	03/12/2015	80	60	30.09	-2.63
4	SK 10	56.4150	-78.8246	03/01/2015	13	1	28.26	-3.62
4	SK 10	56.4150	-78.8246	03/01/2015	13	5	28.26	-3.64
4	SK 10	56.4150	-78.8246	03/01/2015	13	10	28.34	-3.54
4	SK 12	56.6260	-79.2870	03/12/2015	27.5	1	29.35	-3.16
4	SK 12	56.6260	-79.2870	03/12/2015	27.5	5	29.35	-3.07
4	SK 12	56.6260	-79.2870	03/12/2015	27.5	10	29.37	-3.07
4	SK 12	56.6260	-79.2870	03/12/2015	27.5	15	29.36	-2.77
4	SK 14	56.1847	-80.0881	03/09/2014	25.3	1	29.72	-2.64
4	SK 14	56.1847	-80.0881	03/09/2014	25.3	5	29.84	-2.76
4	SK 14	56.1847	-80.0881	03/09/2014	25.3	10	29.74	-2.45
4	SK 14	56.1847	-80.0881	03/09/2014	25.3	15	29.76	-2.73
4	SK 14	56.1847	-80.0881	03/09/2014	25.3	20	29.77	-2.32
4	SK 14	56.1847	-80.0881	03/09/2014	25.3	25	29.80	-2.69
4	SK 15	56.6420	-79.1110	03/01/2015	19	1	28.82	-3.25
4	SK 15	56.6420	-79.1110	03/01/2015	19	5	28.80	-2.69
4	SK 15	56.6420	-79.1110	03/01/2015	19	10	28.88	-3.24
4	SK 15	56.6420	-79.1110	03/01/2015	60	15	28.82	-2.93