Chapter 16
Is the Global Conveyor Belt Threatened by Arctic Ocean Fresh Water Outflow?

E. Peter Jones[1] and Leif G. Anderson[2]

16.1 Introduction

Understanding climate and climate change is a main motive for determining fresh water budget of the Arctic Ocean, specifically the sources, distributions and pathways of fresh water. Most fresh water within the Arctic Ocean occurs as a result of there being more evaporation than precipitation in the Atlantic Ocean. Much of the excess evaporation from the Atlantic Ocean falls as rain into the Pacific Ocean and into river drainage basins that feed into both the Pacific and Arctic Oceans. The climate change concern is that, in returning to evaporation sites in the Atlantic Ocean, the fresh water passes through regions of deep convection in the Nordic and Labrador seas, the "headwaters" of the Global Conveyor Belt (Fig. 16.1). To quote Aagaard and Carmack (1989), "We find that the present-day Greenland and Iceland seas, and probably also the Labrador Sea, are rather delicately poised with respect to their ability to sustain convection." Under climate change, we can anticipate changes in fresh water fluxes from the Arctic Ocean. A main motive for trying to determine Arctic Ocean fresh water sources and their distributions is to try to assess the vulnerability of the Atlantic thermohaline circulation to such changes. How the fresh water sources are redistributed within the Arctic Ocean together with the place and timing of their exit from the Arctic Ocean are of direct relevance to the development of models giving scenarios of changes, possibly abrupt, in the Atlantic thermohaline circulation (e.g., Rahmstorf 1996). Fortunately, tracers allow us to distinguish among the different sources of fresh water being exported from the Arctic Ocean thereby allowing changes in each to be separately accommodated in climate change model scenarios.

Fresh water in the Arctic Ocean, whose sources are sea ice meltwater, river water, and Pacific water (Pacific water entering the Arctic Ocean is fresher, S ~32,

[1]Bedford Institute of Oceanography, Dartmouth, NS, B2Y 4A2, Canada,
e-mail: jonesp@mar.dfo-mpo.gc.ca

[2]Department of Chemistry, Göteborg University, SE-412 96 Göteborg, Sweden,
e-mail: leifand@chem.gu.se

R.R. Dickson et al. (eds.), *Arctic–Subarctic Ocean Fluxes*, 385–404

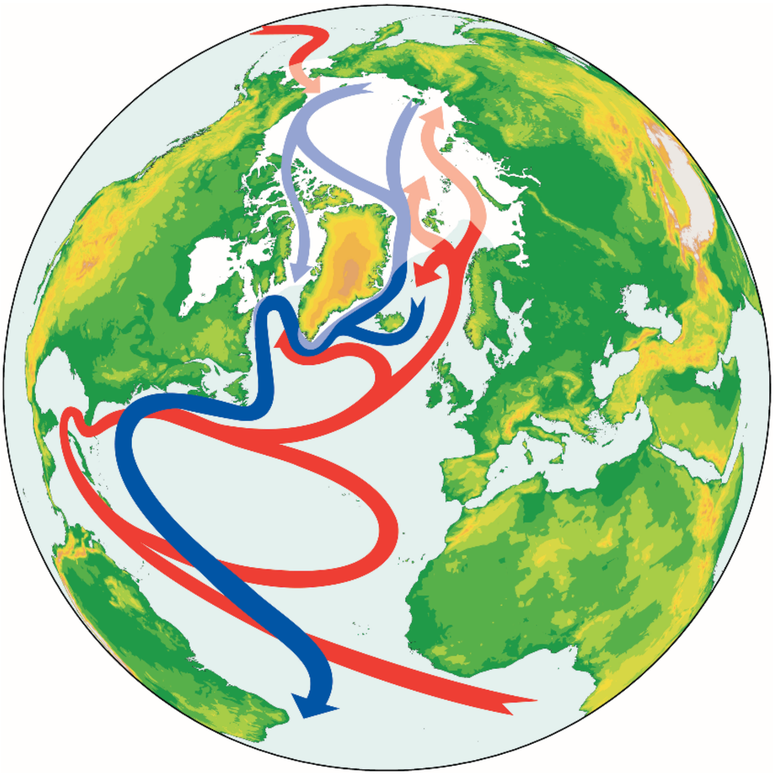

Fig. 16.1 The Global Conveyor Belt emphasizing the Arctic Ocean and the return of fresh water from the Pacific Ocean to the Atlantic Ocean. (After Holloway and Proshutinsky 2007.) Dark red traces the northward flow of warm relatively salty and into the Arctic Ocean. Dark blue traces the deep flow south. Light shades illustrate the flow from the Arctic Ocean and hint at a possible influence on thermohaline circulation

than Atlantic water, S ~34.85), is exported from the Arctic Ocean through Fram Strait and through the Canadian Arctic Archipelago. Each of these fresh water sources will likely respond differently under climate change. While sea ice is also a significant component of the total fresh water export, only the liquid form of fresh water is discussed here.

16.2 Approach

Salinity, alkalinity, and nutrients (nitrate and phosphate) can distinguish among Pacific water, Atlantic water, river water, and sea ice meltwater (Jones et al. 2003, 2006a; Taylor et al. 2003). Three equations using salinity and alkalinity relate the relative fractions of Atlantic water, Pacific water, sea ice meltwater, and river water:

$$f^{AW}+f^{PW}+f^{si}+f^{r}=1 \tag{16.1}$$

$$A_T^{AW}f^{AW}+A_T^{PW}f^{pw}+A_T^{si}f^{si}+A_T^{r}f^{r}=A_T^{m} \tag{16.2}$$

$$S^{AW}f^{AW}+S^{PW}f^{PW}+S^{si}f^{si}=S^{m} \tag{16.3}$$

A_T is alkalinity, f is a water fraction, and the superscripts, *PW, AW, si* and *r*, designate end-members respectively of Pacific water, Atlantic water, sea ice meltwater and river water, and *m* indicates measured values.

A fourth independent equation is required to determine the fractions f. Nutrient relationships distinguish the relative fraction of Pacific water from the other three components. In the Arctic Ocean, waters of Pacific and Atlantic origin have their own linear phosphate (PO_4) vs. nitrate (NO_3) relationship (Equations 16.4 and 16.5). From limited data, we presume that river water and sea ice meltwater have nitrate-phosphate relationships similar to those of Atlantic source water (Jones et al. 1998, 2003). Thus the fraction of Pacific water, f^{PW}, in a sample with particular nitrate and phosphate concentrations can be determined using the nitrate phosphate relationships:

$$PO_4^{PW}=PW_{slope}\times NO_3^{PW}+PW_{intercept} \tag{16.4}$$

$$PO_4^{AW*}=AW^{*}_{slope}\times NO_3^{AW*}+AW^{*}_{intercept} \tag{16.5}$$

$$f^{PW}=\frac{PO_4^{m}-PO_4^{AW*}}{PO_4^{PW}-PO_4^{AW*}} \tag{16.6}$$

*AW** represents Atlantic water together with river water and sea ice meltwater. Once the Pacific water fraction is determined, salinity and alkalinity can distinguish the other three component fractions (Equations 16.1–16.3). The method gives the net sea ice formation or melt, i.e., the fresh water not otherwise accounted for. A "negative" sea ice meltwater value represents sea ice formation.

The total fresh water fraction is the amount of fresh water that must be mixed with Atlantic water to give the measured salinity values and the Pacific fresh water fraction is the fraction of the total fresh water carried by Pacific water, i.e., the amount of fresh water referenced to end-members S^{PW} = 32.0 and S^{AW} = 34.85:

$$f_{fresh}^{total}=1-S^{m}/S^{AW} \tag{16.7}$$

$$f_{fresh}^{PW}=f^{PW}(1-S^{PW}/S^{AW}) \tag{16.8}$$

The end-member slopes and intercepts of the nitrate–phosphate relationships (Equations 16.4 and 16.5) as well as the salinity and alkalinity end-members (Equations 16.1–16.3) are determined from regions of the Arctic Ocean where the water type is well determined, i.e., from data inside the Arctic Ocean not far from

Bering Strait at depths where no Atlantic water is present, and from north of St. Anna Trough where no Pacific water is present. Pacific water entering the Arctic Ocean follows two paths (Jones et al. 1998; Shimada et al. 2001; Steele et al. 2004) with slightly different slopes and intercepts of the nitrate–phosphate relationship for each path (Jones et al. 2003). The slightly different relationships give results within the expected precision of this approach.

Uncertainties in calculated fractions can result from uncertainties in end-member values as source waters are defined by a range of values. We believe that the chosen salinity, nutrient, and alkalinity end-member values reasonably well represent Pacific and Atlantic waters, but the different rivers entering the Arctic Ocean can have fairly different alkalinity values. River alkalinity values vary from river to river and season to season (PARTNERS http://ecosystems.mbl.edu/partners/data.html). A recently published representative average river alkalinity value for the Arctic Ocean of 831 ± 100 μmol kg^{-1} (Yamamoto-Kawai and Tanaka 2005) is lower than that appearing in some publications (e.g., Anderson et al. 2004) and lower than the average (~1,100 μmol kg^{-1}) reported in PARTNERS. In an attempt to choose the single alkalinity value best representing river water in the Arctic Ocean, we compared estimates of river water fractions from both the Eurasian and Canadian basins for which both alkalinity and oxygen-18 data are available. We used the approach outlined above but with oxygen-18 end-members (Ekwurzel et al. 2001; Macdonald et al. 1999) in place of alkalinity values. By comparing calculated results using data from three expeditions (Ekwurzel et al. 2001; Macdonald et al. 1999) we found representative alkalinity river water values of 1,000 μmol kg^{-1} give consistent results with oxygen-18 results, the value we chose for this work. With the uncertainties in end-members the computed source water concentrations should be considered somewhat approximate, likely no better than ±0.02. Also ascertaining uncertainties in the calculation of fresh water fractions is not straight-forward as the calculated fractions are interdependent and uncertainties vary according to the magnitude of the calculated fractions (Jones et al. 1998; Ekwurzel et al. 2001; Taylor et al. 2003). We consider the absolute values of higher water fractions, >0.03, to be reasonably valid with uncertainties of ±0.01, while lower fractions, <0.01, may not be reliable.

16.3 Results

Measurements in the Arctic Ocean were made on several expeditions from 1991 through 2005, while those in the Canadian Arctic Archipelago and in the East Greenland Current were made in 1997 and 2002 respectively (Fig. 16.2). All data except those from the East Greenland Current were collected under summer conditions, typically from late July to mid-September. Data from the East Greenland Current were collected in early spring when winter conditions persisted.

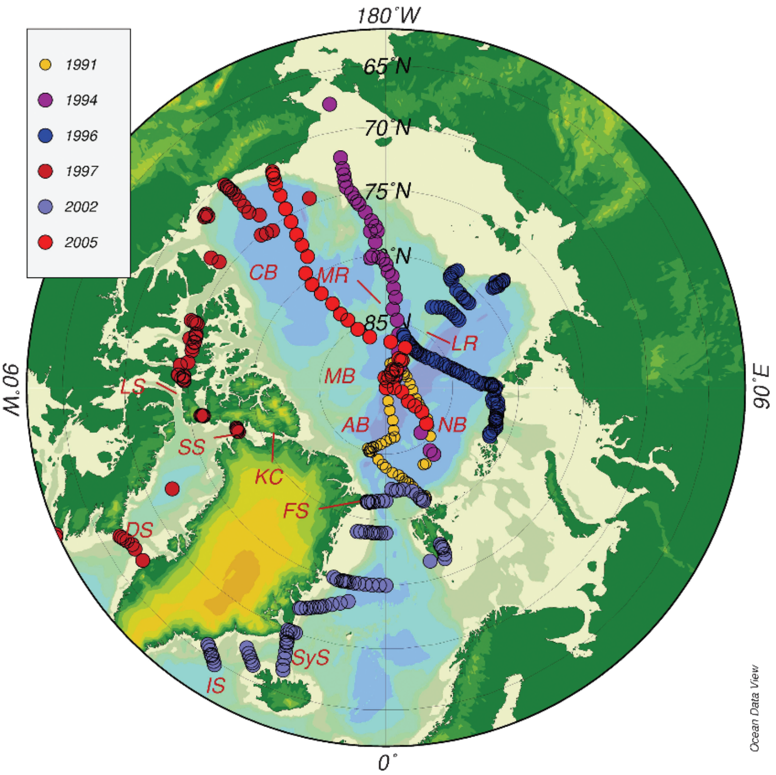

Fig. 16.2 Map showing all stations of this study. Labels indicate Canada Basin (CB), Makarov Basin (MB), Amundsen Basin (AB), Nansen Basin (NB) Mendeleyev Ridge (MR), Lomonosov Ridge (LR), Smith Sound (SS), Davis Strait (DS), Lancaster Sound (LS), Kennedy Channel (KC), Fram Strait (FS), Scoresby Sound (SyS), and Irminger Sea (IS)

We present sections showing vertical distributions of the fresh water components in the Eurasian Basin (1996) and Canadian Basin (2005) (Fig. 16.3a, b) as representative of the Arctic Ocean, in the Canadian Arctic Archipelago (1997) as representative of fresh water exiting through that region (Figs. 16.3c–d), and in the East Greenland Current (2002) as representative of fresh water exiting through Fram Strait (Figs. 16.3e–g). All data are presented in fresh water inventory plots (Fig. 16.4). It should be noted that these data span several years, and, because of variability in water mass distributions (e.g., Anderson et al. 2004; Falck et al. 2005), the results do not give a synoptic view of conditions of fresh water in the Arctic Ocean and exiting from it.

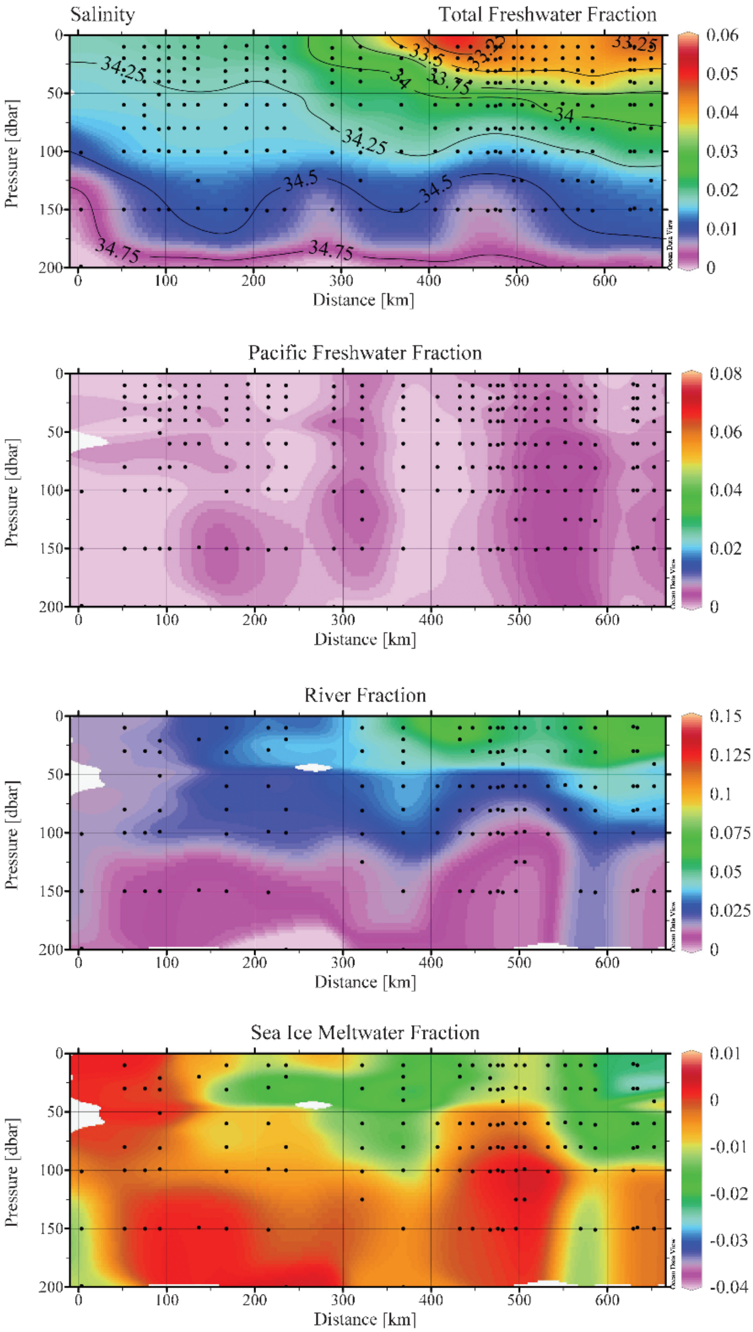

Fig. 16.3 These sections illustrate fresh water components in selected regions. Contours in Total Fresh Water sections represent salinity. See Fig. 16.4 for inventories at stations shown in Fig. 16.2. (a) Eastern Eurasian Basin Section (1996). The section begins on the slope north of the Barents and Kara seas, crosses the Eurasian Basin, and extends into the Makarov Basin

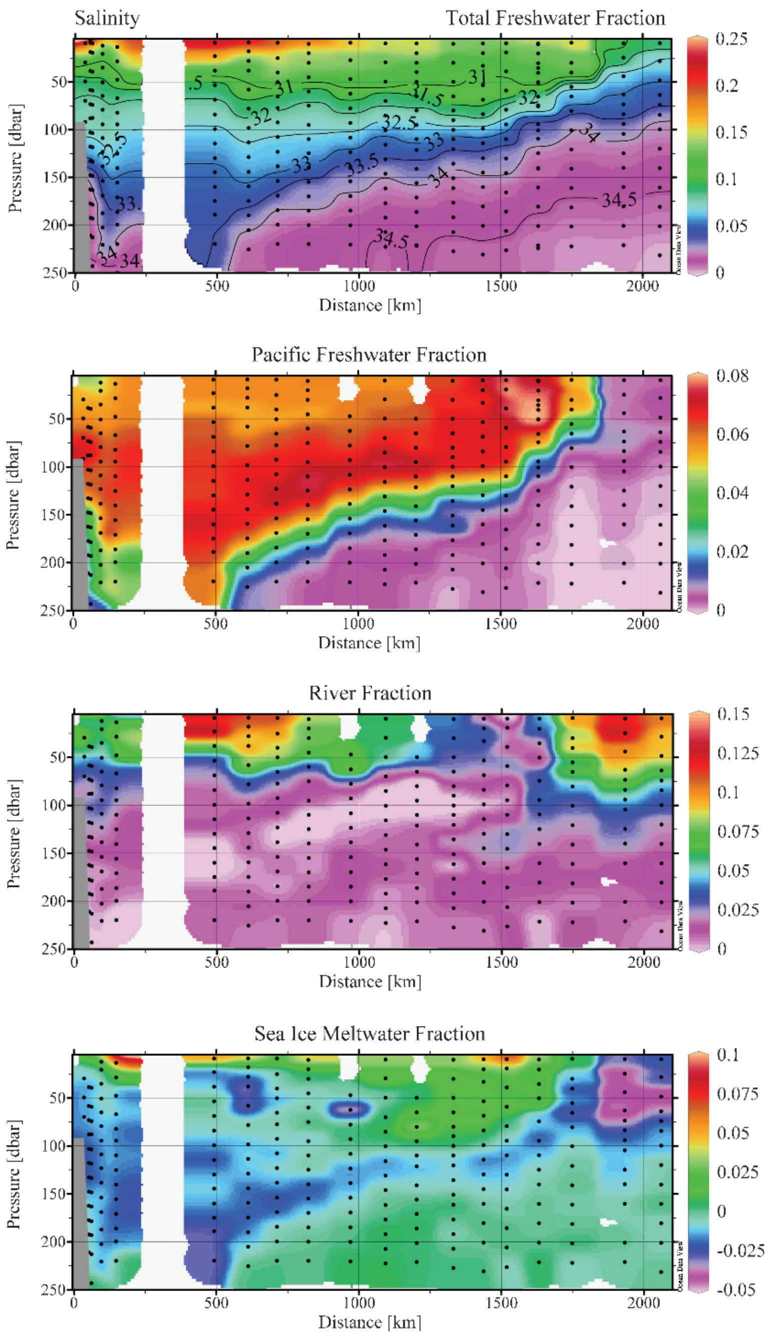

Fig. 16.3 (continued) (b) Canadian Basin Section (2005). The section begins north of Barrow, Alaska, crosses the Canada and Makarov basins, and ends at the Lomonosov Ridge

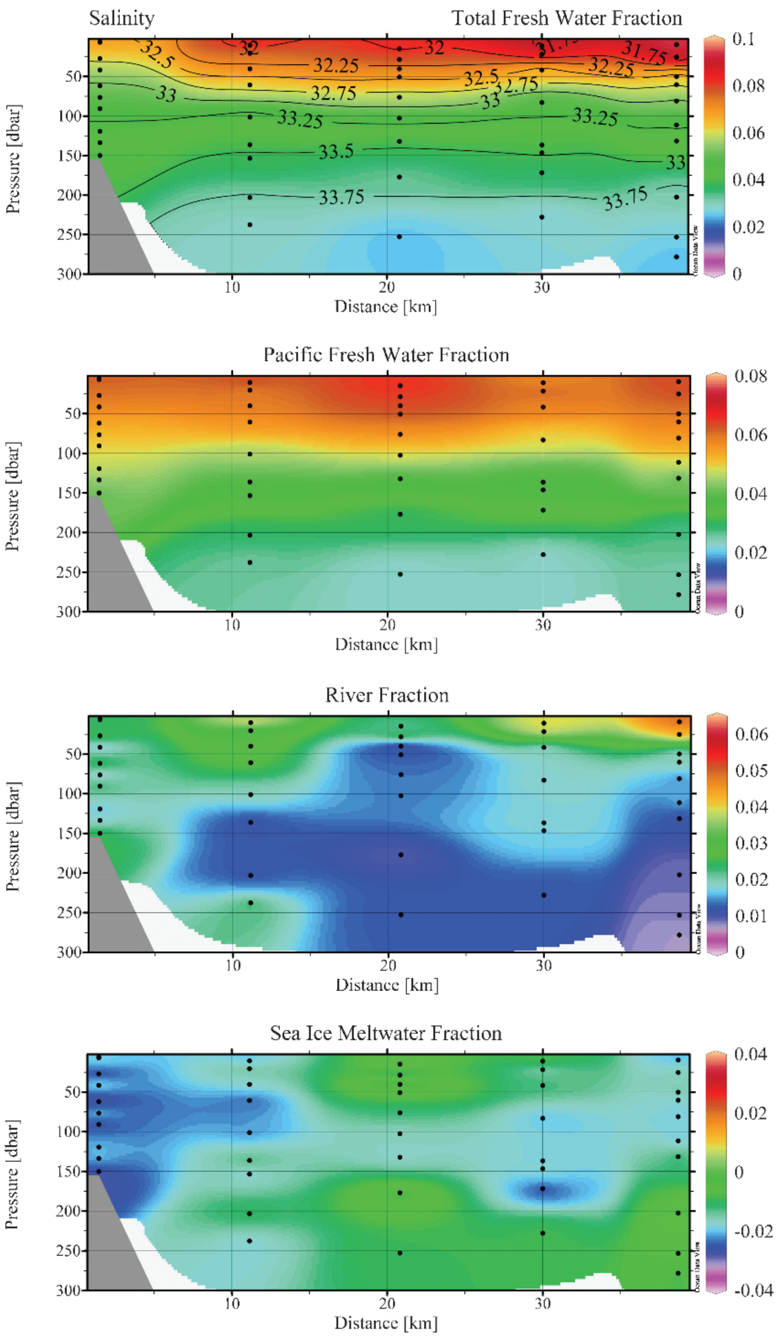

Fig. 16.3 (continued) (c) Smith Sound Section (1997). The section extends across southern Nares Strait

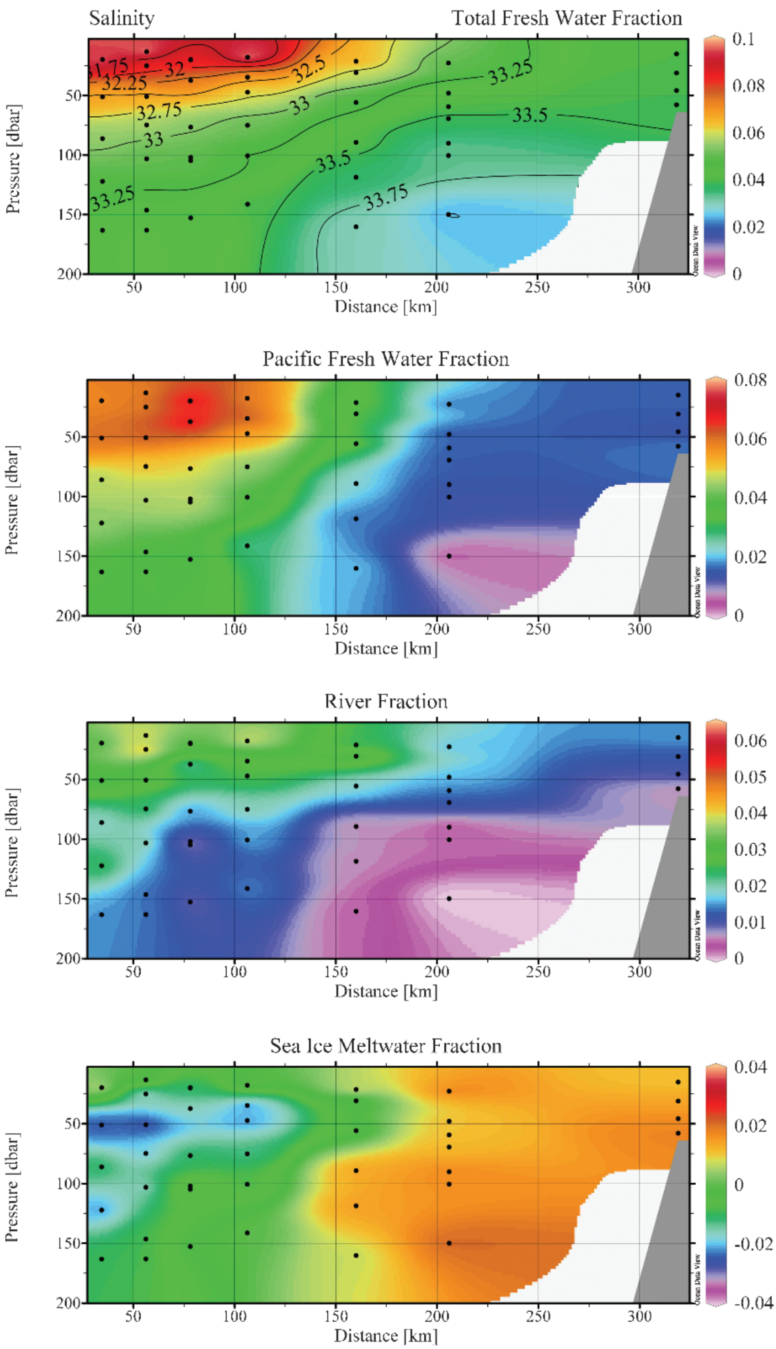

Fig. 16.3 (continued) (d) Davis Strait Section (1997). The section extends across Davis Strait just north of the sill between Baffin Bay and the Labrador Sea

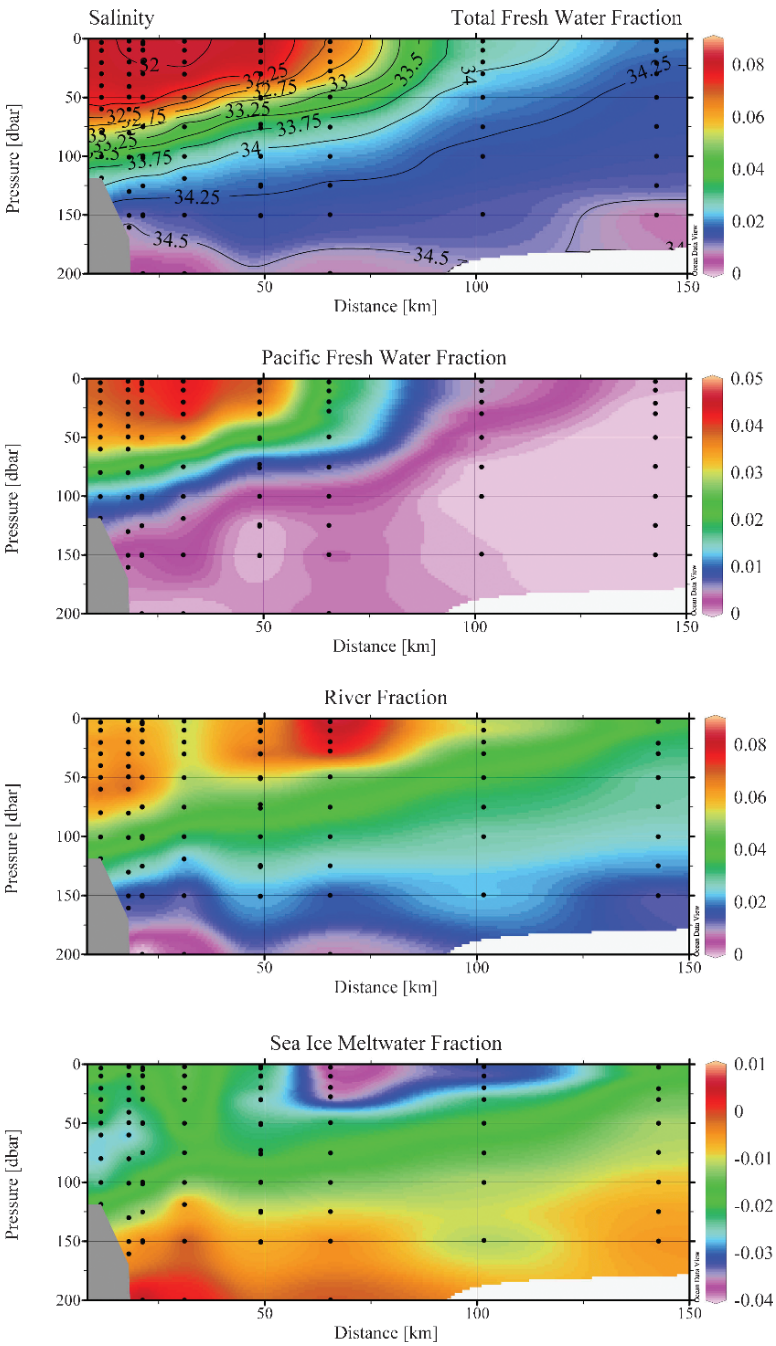

Fig. 16.3 (continued) (e) Fram Strait Section (2002). The section extends into Fram Strait from Greenland at 82° N

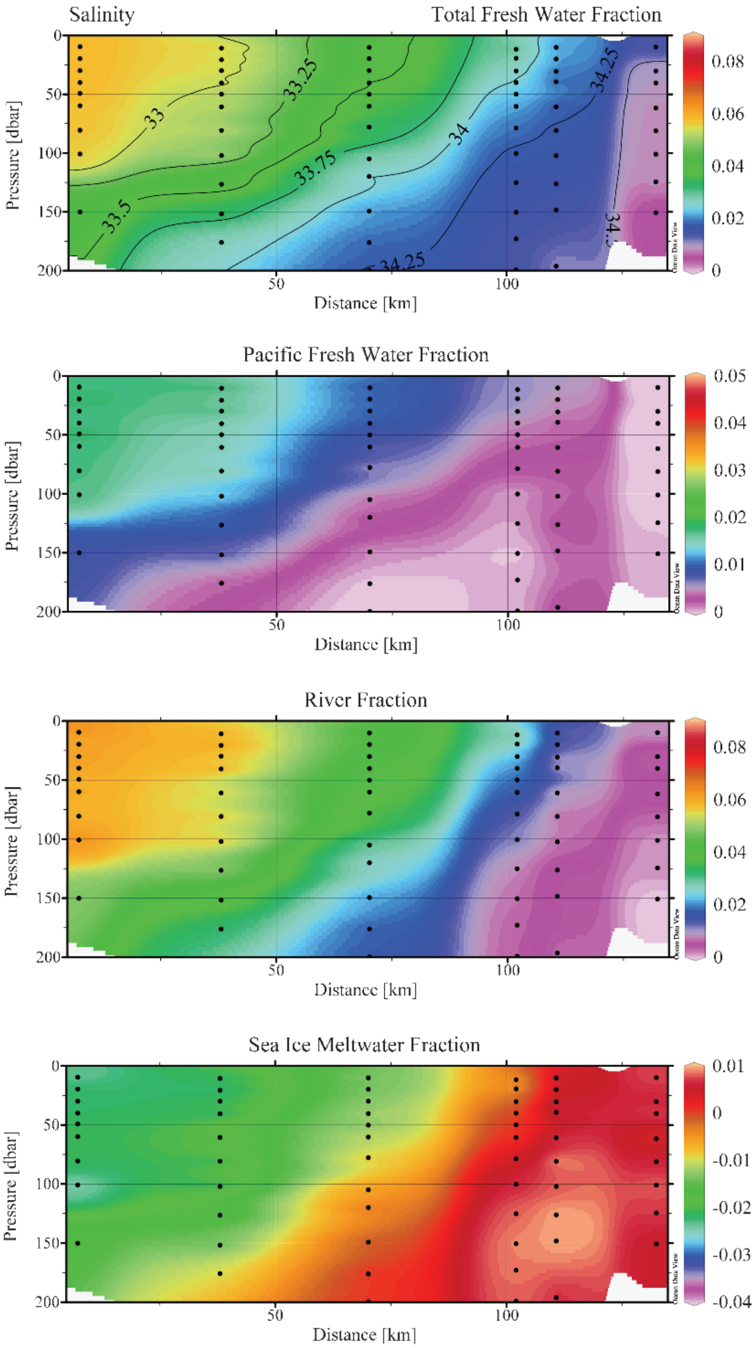

Fig. 16.3 (continued) (f) Scoresby Sound (2002). The section extends from Greenland between 67° N and 65° N

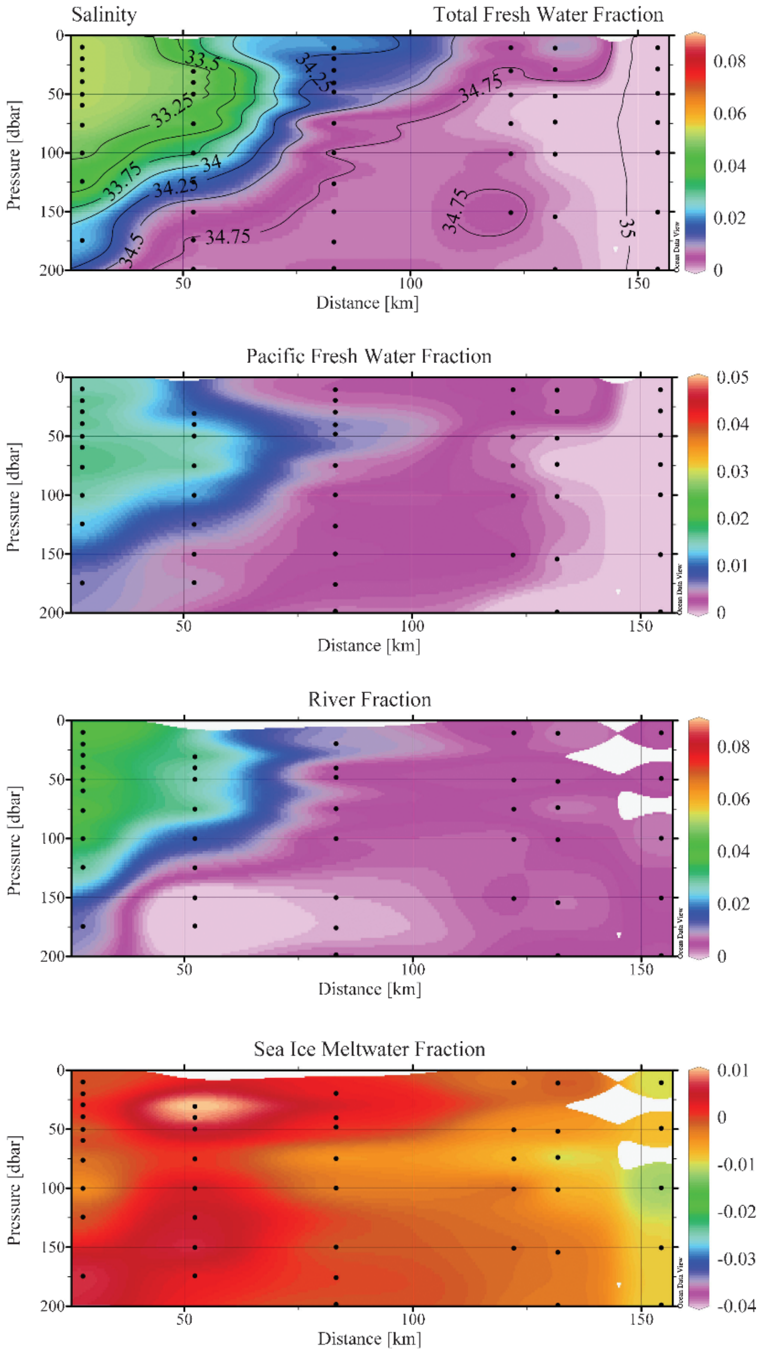

Fig. 16.3 (continued) (g) Northern Irminger Sea. The section extends between 66° N and 65° N

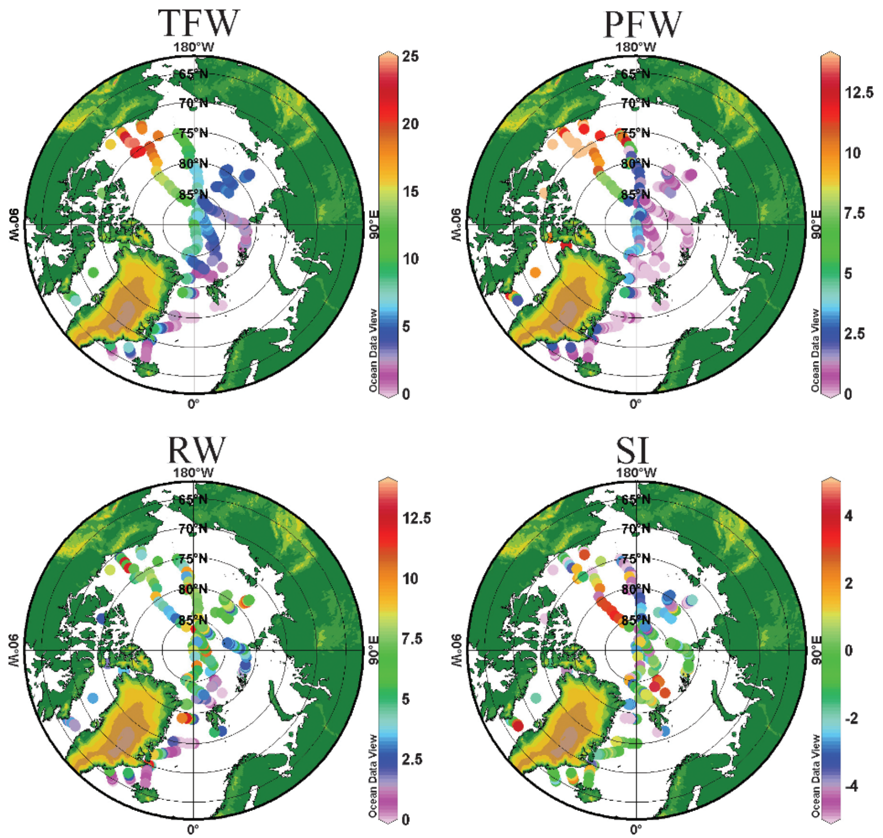

Fig. 16.4 Fresh water inventories: Total Fresh Water (TFW), Pacific Fresh Water (PFW), River Water (RW), and Sea Ice Meltwater (SI), within the Arctic Ocean, the East Greenland Current and the Canadian Arctic Archipelago. The units of the color bars are meters

16.3.1 Arctic Ocean Sections

We chose two sections in the Arctic Ocean to illustrate the fresh water components in the general regions of Atlantic water inflow (Eurasian Basin) and Pacific water inflow (Canadian Basin).

16.3.1.1 Eurasian Basin (1996)

This section begins at the shelf north of the Barents and Kara seas, crosses the Eurasian Basin and enters into the Makarov Basin (Fig. 16.3a). It is the region where Atlantic water dominates. The total fresh water fraction is relatively small throughout the Eurasian Basin, ~0.02, except near the Lomonosov Ridge. Pacific fresh water is essentially non-existent. River water fractions are small, between 0.01 and 0.04, with the higher values near the coast and in the vicinity of the Lomonosov Ridge. And while some sea ice meltwater is found near the coast, sea ice formation is present in most locations, particularly in the vicinity of the Lomonosov Ridge, and is roughly coincident with river water.

16.3.1.2 Canadian Basin (2005)

This section begins in the Canada Basin north of Barrow, Alaska, crosses the Canada and Makarov basins, and ends at the Lomonosov Ridge (Fig. 16.3b). The total fresh water fraction is greatest in the Canada Basin, with highest amounts in the southern part of the section, where near surface salinities are as low as 27. Pacific water concentrations in near surface water were high in the central Canadian Basin, a region where earlier only speculations on their concentrations existed (Jones et al. 1998). Pacific fresh water is most abundant in the southern Canada Basin, where near surface fractions approach 0.07. The high concentrations extend over the Mendeleyev Ridge into the Makarov Basin.

River water distributions differ somewhat from Pacific fresh water. River water extends across the Canada Basin and is most abundant from about the middle of the southern Canada Basin to offshore from the Chukchi Cap. River water is generally confined to the top 50 m, whereas Pacific fresh water generally extends to depths of nearly 300 m in the southern Canada Basin. River water displaces some Pacific fresh water above about 50 m in this region. The highest river water fractions, up to 0.12, are about double the highest Pacific fresh water concentrations. There is very little river water in the general vicinity of the Mendeleyev Ridge. River water concentrations increase in the Makarov Basin, with maxima in the Canada Basin and in the central Makarov Basin and decrease towards the Lomonosov Ridge. The high concentrations of river water in the Canada Basin coincide with fresh water pool in the central Beaufort Gyre. The high concentrations in the Makarov Basin are likely outside the gyre.

Sea ice meltwater with fractions up to 0.1 is found over much of the Canada Basin and generally coincides with Pacific fresh water. Lower concentrations extend to depths near 50 m. Sea ice formation is evident in the Amundsen Basin to depths approaching 100 m except near the North Pole, where there is some sea ice meltwater and Pacific fresh water.

16.3.2 Canadian Arctic Archipelago

Sections across Smith Sound, at the southern end of Nares Strait, and across Davis Strait at the southern end of Baffin Bay were chosen to represent waters flowing through the Canadian Arctic Archipelago.

16.3.2.1 Smith Sound (1997)

The Smith Sound section (78.3° N) is in the southern part of Nares Strait, south of the sill near 81° N in Kennedy Channel (Fig. 16.3c). Pacific fresh water is the dominant source of fresh water in this section. Pacific fresh water and river water distributions more or less overlap and are fairly uniform across the section. The highest concentrations of Pacific fresh water and river water are comparable (0.06) but higher river water concentrations are confined to very near the surface. Sea ice meltwater is mostly negative. Its distribution is also roughly coincident with Pacific fresh water and river water suggesting that it reflects sea ice formation that has occurred in the Arctic Ocean. Distributions of total fresh water and Pacific fresh water in Kennedy Channel in 2001 (Jones and Eert 2006b) are similar to those in Smith Sound in 1997. From this we infer that there is not much change in near surface waters traversing from the Arctic Ocean through Kennedy Channel to Smith Sound.

16.3.2.2 Davis Strait (1997)

The Davis Strait section is at the southern end of Baffin Bay just north of the sill between Baffin Bay and the Labrador Sea (Fig. 16.3d). Fresh water from the Arctic Ocean in the Baffin Island Current on the west side extends nearly half way across the strait. The near surface water is slightly fresher than that in Nares Strait. Pacific fresh water and river water distributions roughly overlap, and concentrations are comparable to those in Nares Strait thus indicating little dilution of the Arctic Ocean water flowing south. As in Nares Strait, sea ice formation is seen at depth coinciding with the Pacific fresh water and river water, again suggesting that this is reflecting sea ice formation in the Arctic Ocean. The slightly fresher surface water may be reflecting a contribution of fresh water passing through the other several Canadian Arctic Archipelago channels into Lancaster Sound as well as possibly some local melting as indicated by the lesser amount of sea ice formation near the surface.

16.3.3 East Greenland Current

Three sections were chosen to illustrate the fresh water constituents in the East Greenland Current from the Arctic Ocean to south of Iceland: the most northerly at 82° N, one near the entrance to Denmark Strait at 70–67° N, and the most southerly in the northern Irminger Sea at 66–65° N. The data were collected under winter conditions with surface freezing apparent almost everywhere. Because of ice conditions not all of the sections reached close enough to the coast to capture the inshore Polar Surface Water flowing from the Arctic Ocean (Rudels et al. 2005). The same concentration scales are maintained for all East Greenland Current section plots.

16.3.3.1 Fram Strait (2002)

This section is just at the boundary of Fram Strait and the Arctic Ocean (Fig. 16.3e). Most of the fresh water exiting the Arctic Ocean lies above 100 m. As in the Canadian Arctic Archipelago, Pacific fresh water and river water distributions roughly overlap, with river water extending deeper and somewhat farther offshore. In contrast to the Canadian Arctic Archipelago, here river water concentrations are nearly twice that of Pacific fresh water. In this section, as in Smith Sound, sea ice meltwater is essentially non-existent. Sea ice formation, likely having occurred within the Arctic Ocean, is clearly present.

16.3.3.2 Scoresby Sound (2002)

This section north of Denmark Strait covers much of the Greenland shelf and likely captures most of the fresh water in the East Greenland Current (Fig. 16.3f). Surface salinities are higher than in Fram Strait and the fresh water extends to greater depths. River water and Pacific fresh water concentrations are lower than in Fram Strait; however both river water and Pacific fresh water are found at depths greater than those in Fram Strait, with the concentrations and extent of river water relative to Pacific fresh water being similar to what is seen in Fram Strait. Sea ice meltwater is non-existent.

16.3.3.3 Northern Irminger Sea (2002)

The Irminger Sea section was not close enough to the coast to capture all of the East Greenland Current fresh water (Fig. 16.3g). The trends of increasing surface salinities and deeper penetration of fresh water toward the south continued in this section and the relative distributions of river water and Pacific fresh water were maintained. Although possibly within the uncertainty of the measurements, there was an indication of sea ice meltwater at the surface. This could be a result of local melting rather than sea ice meltwater exported from the Arctic Ocean.

16.3.4 Fresh Water Inventories

Another way to describe fresh water distributions is by water column inventories of fresh water. The fresh water inventories represent integrated fractions of each fresh water component from the surface to a depth of 200 m (Fig. 16.4).

In the Arctic Ocean all but sea ice meltwater inventories are highest in the Canada Basin north of Alaska. The total fresh water inventory is more than 20 m with river water reaching nearly 20 m in some locations and Pacific fresh water values nearly 10 m over a large region of the Canada Basin. Values for these sources are generally low in most of the Amundsen and Nansen basins. Sea ice meltwater inventories can be as much as 4 m, though inventories are generally negative (representing sea ice formation) over most of the Arctic Ocean.

In the Canadian Arctic Archipelago, Pacific and river fresh water inventories are roughly the same in Lancaster Sound and Nares Strait. In the East Greenland Current, river water inventories are up to 10 m, typically three times greater than in the Canadian Arctic Archipelago. This is likely a reflection of significant Pacific water draining off through the Canadian Arctic Archipelago (Rudels et al. 2005). In the near surface waters of the Arctic Ocean along the North American coast, river water tends to be farther offshore than Pacific water, likely a sign of their dominant Eurasian source. The relatively greater amounts of river water in the East Greenland Current may be reflecting this.

16.4 Summary

The data span a significant time period over which changes in fresh water distributions have been reported (e.g., Schlosser et al. 2002; Anderson et al. 2004). Nevertheless, a general picture of distributions does emerge. Pacific fresh water and river water are the two main contributors to the total fresh water within the Arctic Ocean and in near surface waters exiting from it. The greatest amount of Pacific fresh water is in the Canada Basin. High concentrations in the near surface in Makarov Basin diminish to very little in the Amundsen Basin. River water distributions, at least in 2005, suggest two pathways of Eurasian rivers, one into the central Canada Basin as part of the Beaufort Gyre and another into the central Amundsen Basin likely associated with the Transpolar Drift. This is consistent with two paths of near surface flow suggested in earlier work (Jones et al. 1998; Steele et al. 2004). The lesser amounts of river water near the North American coast in 2005 (near 152° W) and relatively large amounts farther east in 1997 (near 141° W) (Macdonald et al. 1999 and satellite observations referred to in this paper) may suggest that these larger amounts being of North American origin.

There is a distinct difference between relative amounts of Pacific fresh water and river water exiting the Arctic Ocean via the Canadian Arctic Archipelago and those exiting via the East Greenland Current, with Pacific fresh water fractions being much more dominant in the former and river water much more dominant in the latter. Based on the relative Pacific halocline depths north of the Canadian Arctic Archipelago and in Fram Strait, Rudels et al. (2004) suggested that much of Pacific water exits through the Canadian Arctic Archipelago. Also, this may be reflecting two paths for Eurasian rivers, one toward the east into the Beaufort Sea and one headed more directly to the north and west towards Fram Strait. This is consistent with the finding that, at least in 1998, North American river water was not present in Fram Strait (Taylor et al. 2003).

Sea ice meltwater is the least abundant of the fresh water sources in the Arctic Ocean, where it was present in the near surface waters of the Canada Basin in 1994 and 2005 as well as in the Makarov Basin in 2005. It was consistently observed north of Svalbard, where inflowing relatively warm Atlantic water entered the Arctic Ocean, in 1991, 1994, 2002 and 2005. Sea ice formation was evident in most other locations.

Sea ice meltwater is essentially absent from out flowing Arctic Ocean water. Most regions outside the Arctic Ocean show evidence of sea ice formation that probably has occurred both locally and in the Arctic Ocean. Within the East Greenland Current the negative sea ice meltwater values are likely reflecting sea ice formation in the Arctic Ocean and possibly also the freezing conditions in the East Greenland Current when the data were obtained with the implication that no residual sea ice meltwater is flowing from the Arctic Ocean.

16.5 Implications

Is a change in fresh water flux from the Arctic Ocean a threat to the Global Conveyor Belt, i.e., is fresh water from the Arctic Ocean controlling deep convection in the Nordic and Labrador seas? The usual thinking stemming from the analysis of Aagaard and Carmack (1989) is that an increase in the fresh water outflow from the Arctic Ocean could have a major impact on deep convection in the Nordic and Labrador seas. This scenario may need further investigation, however. In 2002, the salinity of near surface waters of the Greenland Sea was much higher than that of the Polar Surface Water in the East Greenland Current, thereby precluding the possibility of Arctic Ocean fresh water reaching the Greenland Sea region of deep convection (Rudels et al. 2005). Further, Rudels et al. (2005) point out that there was no apparent diminishment of the fresh water in the East Greenland Current as it progressed to south of Denmark Strait. This could suggest that liquid fresh water from the Arctic Ocean may have little influence on deep convection in these regions. If so, ice export (~0.1 Sv, Vinje 2001) and precipitation remain the only possible Arctic Ocean contributions to surface freshening.

A similar situation seems to exist for the Labrador Sea, where polar waters from the Canadian Arctic Archipelago also seem to be strongly constrained to near the shelf and away from where deep convection takes place. A recent model simulation (Myers 2005) also suggests that fresh water export from the Arctic Ocean has little impact on Labrador Sea deep convection. Here precipitation, sea ice meltwater from Baffin Bay, and perhaps fresh water from the East Greenland Current entering via the West Greenland Current would more likely be influencing deep convection.

This and other similar work make clear that climate change scenarios dealing with fresh water budgets of the Arctic Ocean should not use a single parameter representation of fresh water since the fresh water has different sources and distributions, all subject to different forcing. The differing geographical sources of fresh water components and their potentially differing response to climate change requires that each be separately considered in climate change scenarios. Of the three components that affect thermohaline circulation, the inflow of Pacific fresh water might seem to be the least open to change, though what fraction of it exits through Fram Strait can change dramatically (Falck et al. 2005; Steele et al. 2004). River water and sea ice meltwater may be the components that change most in climate change scenarios because of changes in precipitation in the large river drainage basins feeding into the Arctic Ocean and because of the changes in sea ice meltwater arising from ice-free Arctic Ocean summers.

Acknowledgements Many people on several expeditions helped to collect relevant data. Their contributions are greatly appreciated. This work presented here was supported in part by the Canadian Panel on Energy Research and Development and the National Centre for Arctic Aquatic Research Excellence (EPJ) and by the Swedish Natural Research Council (LGA). Most figures were produced using Ocean Data View (Schlitzer 2006).

References

Aagaard K, Carmack EC (1989) The role of sea ice and other fresh water in the Arctic circulation. J Geophys Res 94: 14485–14498

Anderson LG, Jutterström S, Kaltin S, Jones EP, Björk G (2004) Variability in river runoff distribution in the Eurasian Basin of the Arctic Ocean. J Geophys Res 109: C01016, doi:10.1029/2003JC001773

Ekwurzel B, Schlosser P, Mortlock RA, Fairbanks RG (2001) River runoff, sea ice meltwater, and Pacific water distribution and mean residence times in the Arctic Ocean. J Geophys Res 106: 9075–9092

Falck E, Kattner G, Budéus G (2005) Disappearance of Pacific Water in the northwestern Fram Strait. Geophys Res Lett 32: L14619, doi:10.1029/2005GL023400

Holloway G, Proshutinsky A (2007) Role of tides in Arctic ocean/ice climate. J Geophys Res 112: C04S06, doi:10.1029/2006JC003643

Jones EP, Anderson LG, Swift JH (1998) Distribution of Atlantic and Pacific waters in the upper Arctic Ocean: Implications for circulation. Geophys Res Lett 25: 765–768

Jones EP, Swift JH, Anderson LG, Lipizer M, Civitarese G, Falkner KK, Kattner G, McLaughlin FA (2003) Tracing Pacific water in the North Atlantic Ocean. J Geophys Res 108 (C4): 3116, doi:10.1029/2001JC001141

Jones EP, Anderson LG, Jutterström S, Swift JH (2006a) Sources and distribution of fresh water in the East Greenland Current. Submitted to Progress in Oceanography

Jones EP, Eert AJ (2006b) Waters of Nares Strait in 2001. Polarforschung 74: 185–189

Macdonald, RW, Carmack EC, McLaughlin FA, Falkner KK, Swift JH (1999) Connections among ice, runoff and atmospheric forcing in the Beaufort Gyre. Geophys Res Lett 26: 2223–2226

Myers PG (2005) Impact of freshwater from the Canadian Arctic Archipelago on Labrador Sea Water formation. Geophys Res Lett 32, L06605, doi:10.1029/2004GL022082

Holloway, G, Proshutinsky, A (2007) Role of tides in Arctic ocean/ice climate. J Geophys Res 112: C04S06, doi:10.1029/2006JC003643

Rahmstorf, S (1996) On the freshwater forcing and transport of the Atlantic thermohaline circulation. Climate Dyn 12: 799–811

Rudels B, Jones EP, Schauer U, Eriksson P (2004) Atlantic sources of the Arctic Ocean surface and halocline waters. Polar Research 23: 181–208

Rudels B, Björk G, Nilsson J, Winsor P, Lake I, Nohr C (2005) The interaction between water from the Arctic Ocean and the Nordic Seas north of Fram Strait and along the East Greenland Current: Results from the Arctic Ocean-02 Oden Expedition. J Mar Sys 55: 1–30

Schlitzer R (2006) Ocean Data View, http://www.awi-bremerhaven.de/GEO/ODV

Shimada K, Carmack EC, Hatakeyama K, Takizawa T (2001) Varieties of shallow temperature maximum waters in the western Canadian Basin of the Arctic Ocean. Geophys Res Lett 28: 3441–3444

Schlosser P, Newton R, Ekwurzel B, Khatiwala S, Mortlock R, Fairbanks R (2002) Decrease of river runoff in the upper waters of the Eurasian Basin, Arctic Ocean, between 1991 and 1996: Evidence from $\delta^{18}O$ data. Geophys Res Lett 29 (9), 1289: doi:10.1029/2001GL013135

Steele M, Morison J, Ermold W, Rigor I, Ortmeyer M, Shimada K (2004) Circulation of summer Pacific halocline water in the Arctic Ocean. J Geophys Res 109: C10003, doi:10.1029/2003JC002009

Taylor J R, Falkner KK, Schauer U, Meredith M (2003) Quantitative consideration of dissolved barium as a tracer in the Arctic Ocean. J Geophys Res 108: C12, 3374, doi:10.1029/2002JC001635

Vinje T (2001) Fram Strait ice fluxes and the atmospheric circulation: 1950–2000. J Clim 14: 3508–3517

Yamamoto-Kawai M, Tanaka N (2005) Freshwater and brine behaviors in the Arctic Ocean deduced from historical data of D18O and alkalinity (1929–2002 A.D.). J Geophys Res 110: C10003, doi:10.1029/2004JC002793