Chapter 10
The Arctic–Subarctic Exchange Through Hudson Strait

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10.1 Introduction: The Hudson Bay System: An Extensive Arctic Basin

One major export of (fresh) water from the Arctic region to the North Atlantic is due to surface-intensified currents that flow along the topographic margins. These enter the North Atlantic through three major straits – Fram, Davis and Hudson – which therefore provide ideal gateways for monitoring the exchange. Of these straits, the first two link the North Atlantic Ocean with the Arctic Ocean while the third, Hudson Strait, connects it to an extensive Arctic region, the Hudson Bay System (HBS), which, in its northwest corner, is also connected to the Arctic Ocean (via Fury and Hecla Strait – Fig. 10.1). The lack of a direct connection with the Arctic Ocean is, likely, the reason why Hudson Strait's contribution to the Arctic/North Atlantic exchange has, until recently, been overlooked. In this chapter, we present estimates for the net, as well as the inflow and outflow transports, of volume, heat and freshwater through Hudson Strait. These are based both on a review of the inputs into the basin and on the first year-long measurements of the outflow from Hudson Strait to the Labrador Sea. This analysis shows not only that the HBS provides a substantial net input of Arctic (fresh) water to the North Atlantic but, also, that a significant fraction of the export through Davis Strait is recirculated in the HBS before it effectively flows into the Labrador Sea.

The outflow from Hudson Strait emerges as a highly stratified flow, even after transiting the turbulent region at the mouth of the Strait (LeBlond et al. 1981), along the Labrador coast. Here it merges with the 'direct' Davis Strait outflow and the offshore continuation of the West Greenland Current into the Labrador Current (Mertz et al. 1993) – a freshwater laden current which flows close to the Labrador Sea's deepest convection region (Clarke and Gascard 1983; Pickart et al. 2002). This current is recognized as an important source for the freshwater that rapidly re-stratifies the convection region in the spring (Lazier et al. 2002; Straneo 2006).

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Freshwater anomalies in the flow, which make their way to the interior, can thus [Au1] have a significant impact on the extent of convection (Lazier 1980; Straneo 2006) and hence of the large-scale ocean circulation. Further downstream, the outflow from Hudson Strait is thought to have a profound influence on the highly productive regions of the Labrador and Newfoundland shelves (Sutcliffe et al. 1983).

The Hudson Bay System (HBS) is a large inland sea that includes Hudson Bay, James Bay, Foxe Basin, Ungava Bay and Hudson Strait (Fig. 10.1). Though its meridional extension spans roughly 20° of latitude across the Arctic Circle (roughly 52–70° N), the entire basin is characterized by typical Arctic (oceanic and atmospheric) conditions and, as such, is the southernmost extension of the Arctic region as defined, for example, by the Arctic Monitoring and Assessment Programme (AMAP; http:/ www.amap.no). One typical Arctic feature of the basin is its complete seasonal ice-cover, which makes it the largest inland body of water in the world (1 million square kilometers, one fifth of the size of the Arctic Ocean) to seasonally freezes over and

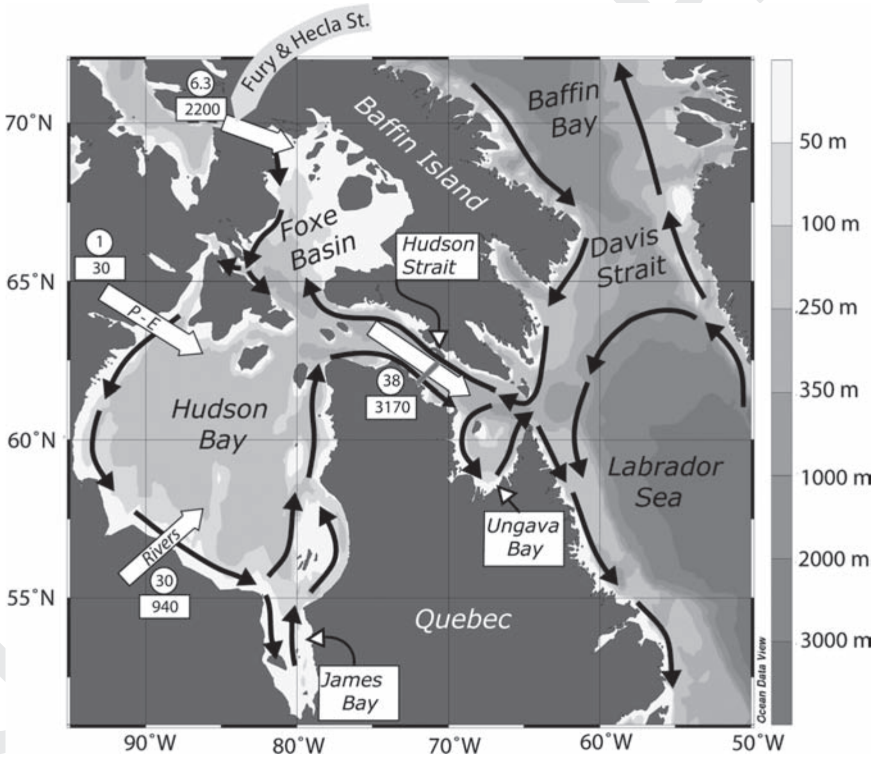

Fig. 10.1 Topography and schematic circulation of the Hudson Bay System, Labrador Sea and Baffin Bay region. White arrows overalaid show the net volume (rectangles, in km³/year) and freshwater (circles, in mSv referenced to a salinity of 34.8) transports due to the input of rivers, precipitation minus evaporation and Fury and Hecla Strait into the HBS. The resulting estimated net transports out of the system, through Hudson Strait, are also shown

then be virtually ice-free in the summer (Prinsenberg 1988). This southern extension of Arctic conditions, well beyond the Arctic Circle, has a large impact on the climate of the surrounding land masses and oceanic basins as indicated, for example, by the southern displacement of the tree line due to the HBS (United Nations Environment Program 2006, http://maps.grida.no/go/graphic/treeline_in_the_arctic).

The large size of the HBS, alone, makes it a likely significant contributor to the Arctic/North Atlantic exchange. Its contribution, furthermore, is greatly enhanced by its considerably larger watershed. Indeed, the HBS' drainage basin occupies an area roughly four times larger than HBS itself, which extends from Alberta to Quebec and from Baffin Island to south of the Canada/USA border (roughly 4 million square kilometers; Déry et al. 2005). This large catchment area drains approximately 900 km^3/year of freshwater into the HBS (McClelland et al. 2006; Déry et al. 2005) which, for comparison, is approximately one fifth of the river discharge into the Arctic Ocean (Déry et al. 2005).

The exchange between the HBS and the North Atlantic or more specifically the Labrador Sea, occurs through Hudson Strait, a narrow (~100 km) and long (~400 km) channel, with depths ranging from 900 m (east) to 200 m (west), and HBS' primary opening. Water flows through the strait in two opposite directions. Along its northern shores, the Baffin Island Current flows *into* the HBS from the Labrador Sea. Along its southern shores, buoyant (fresh) waters flow *towards* the Labrador Sea (Fig. 10.1; LeBlond et al. 1981; Drinkwater 1988). Both flows participate in the exchange between the HBS and the Labrador Sea, and the *net* transports out of Hudson Strait (into the North Atlantic) must be calculated as the difference between the *outflow* (the flow towards the Labrador Sea, on the southern side) and the *inflow* (the flow along Baffin Island).

If observations of the fluxes on either side of the strait were available, along with their variability, the estimate of the net transports through Hudson Strait would be straightforward. In practice, data in the strait are scarce and the only simultaneous measurements of the flow on *both* sides of the strait are due to a moored array deployed for 2 months, in the summer of 1984, which measured the volume flux alone (Drinkwater 1988). Also, the strong seasonality of the high-latitudes and the lack of direct current measurements do not allow one to estimate the mean annual transports from the limited available summer hydgrographic surveys.

In order to estimate the net transports through Hudson Strait, an alternate approach is to assume the HBS in steady state. Given that the system has only two open-boundaries (Fury and Hecla and Hudson Straits), it follows that if one knows the air–sea fluxes (heat, evaporation, precipitation), the river input and the exchange through one of the straits, then one can estimate what flows through the other. Here, we use this approach to infer the net transports out of Hudson Strait. These estimates are then compared with the observed transports in the outflow, on the southern side of the strait, obtained by deploying a moored array from August 2004 to August 2005 (Straneo and Saucier 2007). The difference between the net and the inflow gives us a measure of the inflow into the HBS.

This analysis reveals that the net exchange of volume is typically one order of magnitude smaller than the inflow/outflow transports, and that care must be taken in using them to characterize an exchange. For freshwater, this analysis shows that much more freshwater is outflowing than is input by rivers, air–sea fluxes, or the direct exchange with the Arctic Ocean (through Fury and Hecla Strait). The implication is that a significant portion of the Davis Strait outflow recirculates into the HBS instead of flowing directly towards the Labrador shelf. This is a new result that suggests re-drawing the Arctic export pathways west of Greenland since this recirculation can, potentially, add a significant lag to the emergence of anomalies from the Arctic Ocean. A discussion of these results is presented in the last part of this chapter.

10.2 Volume, Heat and Freshwater Budgets for the Hudson Bay System

Estimates for the input of volume, heat and freshwater into the HBS from all external sources (rivers, air–sea fluxes) and from Fury and Hecla Strait, based on published data are presented below.

10.2.1 River Discharge

The most recent assessment of river discharge into the HBS can be found in Déry et al. (2005). They used data from 42 rivers draining into Hudson, James, Ungava Bays and Hudson Strait from 1964 to 2000, compiled in Environment Canada's Hydrometric Database (HYDAT), to assess the mean discharge rates and their interannual variability. The observed mean annual discharge is 714 km^3/year. Since these rivers occupy roughly 80% of the overall drainage area of this region, and assuming the same rate of discharge per unit area, this implies that the net annual discharge is 892 km^3/year. This number is reasonably close to a previous estimate
[Au2] by Shikolmanov and Shiklomanov (2003) who report a mean of 938 km^3/year from 1966 to 1999. In either case, these contributions are likely underestimated since they do not include the contribution from the islands (including Baffin Island) that surround the HBS (where no data are available). In this review we thus assume that a reasonable estimate of the river input is 940 km^3/year. This is equivalent to a volume transport of 0.03 Sv (1 Sv = 10^6 m^3/s) and to a freshwater flux of 30 mSv (milli Sverdrup).

We did not find, in the literature, any reference to the rivers' contribution to the heat budget of the region. While this is unlikely to be large, it may still play a role. If we assume, for example, that the river water has a mean inflow temperature of 1.5 °C, then it would contribute 0.15 TW of heat to the HBS. As shown below, this input is of the same order of magnitude (indeed it offsets it) of the negative heat transport that we estimate through Fury and Hecla Strait.

10.2.2 Air–Sea Fluxes

Air–sea fluxes contribute to the volume and freshwater budget of the HBS through the difference between evaporation and precipitation. Overall direct measurements of precipitation over the entire system are poor, and evaporation estimates depend on the algorithm used – making the difference between the two quite uncertain. Earlier estimates suggested that the Hudson/James Bay region is characterized by a net evaporative loss over precipitation except for James Bay, where the two balance (Prinsenberg 1977). A more quantitative assessment, by the same author, suggests that the mean annual freshwater loss over Hudson Bay and Foxe Basin is of the order of 6 mSv (Prinsenberg 1980).

More recent estimates, on the other hand, suggest that precipitation exceeds evaporation in the region (Saucier et al. 2004). These are based on the operational analyses (NOWCAST) and 12-h forecast cycles issued from the Canadian Meteorological Centre using the Global Environmental Multiscale Model (GEM) from 1997 to 1999. These estimate the net precipitation to be of the order of 10 to 50 km^3/year. Clearly, there is some discrepancy between these estimates and, still, a large uncertainty associated with these fluxes. At the same time, the estimated volume (and freshwater) contribution from the air–sea exchange appears to be an order of magnitude smaller than the river input. Below, we make use of the estimate based on reanalyses data, as the most recent, in the volume and freshwater budgets for the region.

Similar discrepancies are found in the literature for estimates of the annual heat loss over the HBS. Prinsenberg (1983) claims that Hudson Bay gains heat from the atmosphere (in an annual mean sense) and estimates the annual gain to be 1.8 W/m^2 – equivalent to a net input of 1.8 TW. The same re-analyses products described above (see Saucier et al. 2004) suggest, on the other hand, that the region including HS and FB undergoes a net heat loss on the order of 10 W/m^2. Much of this heat loss, however, occurs to the east of the mooring section where warmer waters are recirculating at the mouth the strait. Given their uncertainty, we feel that one cannot rely on these numbers to infer, for example, the inflow of heat into the HBS. Instead, as discussed below, we will do the opposite (only for heat) and use an estimated inflow mean temperature, combined with the estimated transport of the inflow to infer the net heat flux into the HBS.

10.2.3 Transports via Fury and Hecla Strait

Fury and Hecla is a narrow, shallow strait that connects the Gulf of Boothia, in the Arctic Ocean, to Foxe Basin, the northern extension of the HBS. Its width varies from approximately 15 to 30 km, and it is approximately 120 km long and 170 m deep. Observations in the strait are limited to current meter data collected in April–May 1976 (Sadler 1982) and in the summer of 1960 (Barber 1965) yielding mean residual transports, towards Foxe Basin, of 0.04 Sv and 0.1 Sv respectively.

These transports are associated with typical Arctic Ocean temperatures of −1.7 °C and salinities of 32.0–32.1, in late winter, and of 0.5–0.75 °C and 31.0–32.0, in summer (Ingram and Prinsenberg 1998). If we take the late winter conditions to be representative of the period from December to May, and the summer conditions of the remaining 6 months, the estimated volume and freshwater (relative to 34.8) transports are of 0.07 Sv (2,200 km^3/year) and 6.3 mSv, respectively. The heat transport, relative to 0 °C, is −0.15 TW into the HBS.

10.2.4 Summary

The estimates of volume and freshwater transports out of HBS are summarized in Table 10.1 and shown schematically in Fig. 10.1. The heat flux contribution is omitted given its large uncertainty. For volume and freshwater the sum of the contributions, listed in Table 10.1, must be balanced by the net transports through Hudson Strait. It is interesting to note that the volume and freshwater balances are maintained by two different input terms. For volume, the net flux through Hudson Strait mostly offsets the inflow via Fury and Hecla Strait. For freshwater, the balance is between the river input and the export through Hudson Strait.

10.3 Transports Through Hudson Strait

The estimated contributions listed in Table 10.1, to the volume and freshwater budgets for the HBS imply that there must be a net volume transport out of Hudson Strait (towards the Labrador Sea) of approximately 3,200 km^3/year (or equivalently 0.1 Sv) and a freshwater transport of 38 mSv (relative to a salinity of 34.8). The net volume transport out compares well with the measurements of Drinkwater (1988) who found a mean residual northwestward transport of 0.82 Sv (along Baffin Island) and of 0.93 Sv towards the Labrador Sea (along the Quebec shore), even if these measurements were based on a 2-month survey only.

Next, we compare these estimated net transports with those observed in the outflow alone by Straneo and Saucier (2007). The outflow transports were obtained from a three mooring array, deployed across the southern portion of the strait, roughly mid-strait (Fig. 10.1) from August 2004 to August 2005 as part of a collaboration

Table 10.1 Mean annual inputs of volume and freshwater (relative to a salinity of 34.8) due to air–sea interaction, to rivers and to Fury and Hecla Strait

Input to HBS	Volume (km^3/year) (Sv)	Freshwater (mSv rel 34.8)
River	940 (0.03)	30
Air–sea	30 (0.001)	1.0
Fury and Hecla St.	2,200 (0.07)	6.3
Total	3,170 (0.1)	38

between the Woods Hole Oceanographic Institution (WHOI) and Fisheries and Oceans Canada (the Canadian MERICA program for the monitoring of the HBS). The section occupied by the array was only slightly more inland of the one occupied by Drinkwater in 1984. This location was chosen over the mouth of the strait for a number of practical and scientific reasons. The mouth of the strait is characterized by strong, turbulent flow and persistent eddies, associated with the interaction of tides with numerous channels and islands (LeBlond et al. 1981). Such strong circulation makes mooring deployment difficult and hazardous, and makes defining the mean flow more problematic. Similarly, the region extending west of the of the mouth of the strait to the section is characterized by a strong recirculation (Ingram and Prinsenberg 1998) which would not only affect the measurements but also threaten the moorings since it carries numerous icebergs (Drinkwater 1986). Finally, it should be noted that the section chosen is upstream of the river input from Ungava Bay. Because these are relatively small compared to the total input to HBS, and given the uncertainty on the input, we have not attempted to factor this into our calculations.

The moorings were positioned across the fresh outflow current that is characteristic on this side of the strait (Fig. 10.2). They consisted of a combination of profiling salinity and temperature recorders, acoustic Doppler current profilers and fixed depth instruments. The most difficult problem, typical when attempting to estimate freshwater transports, was to reconstruct properties in the upper part of the water column, over a layer of about 40 m, where no measurements were made. Instead of simply using a mixed layer approach for these upper 40 m, the authors made use of the observed dynamic characteristics of the flow to infer the density (and hence the salinity) distribution. This method and, in general, the transport calculations are described in detail in Straneo and Saucier (2007).

The section shown in Fig. 10.2 is representative of summer conditions across the strait. It shows the fresher, and strongly stratified, outflow wedged across the sloping topography on the southern side of the strait and a much more weakly stratified,

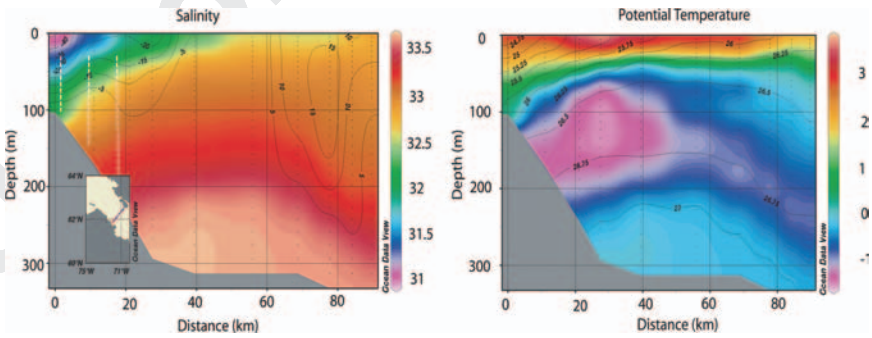

Fig. 10.2 Hydrographic section across Hudson Strait collected in August 2005. Left panel: Salinity and geostrophic velocity contours overlaid (black lines), distance is from the coast of Quebec. Also shown are the mooring locations of Straneo and Saucier (2007). Right panel: Potential temperature and potential density contours overlaid

barotropic and saltier inflow along the coast of Baffin Island. The geostrophic velocity overlaid was calculated assuming zero flow at the bottom and should, therefore, be regarded as the baroclinic portion of the flow only. The outflow was characterized by a marked seasonal variability in properties with the freshest waters transiting from June to March, with salinities as low as 28.8 observed at the uppermost instrument of the most onshore mooring (Fig. 10.3). The along-strait flow was found to increase (at least in the surface layers) during the passage of the freshest waters. The temperature of the water flowing past the moorings was close to freezing for much of the year, except during a short period between July and November when it reached about 2 °C (Fig. 10.3).

The flow is dominated by the tidal cycle due to mostly barotropic, semi-diurnal tides with speeds in excess of 1 m/s and tidal ranges of the order of 8 m. Once the tides are removed, the mean flow is aligned with the strait and has the characteristics of a buoyant, gravity current over a sloping bottom with a depth of 150 m and

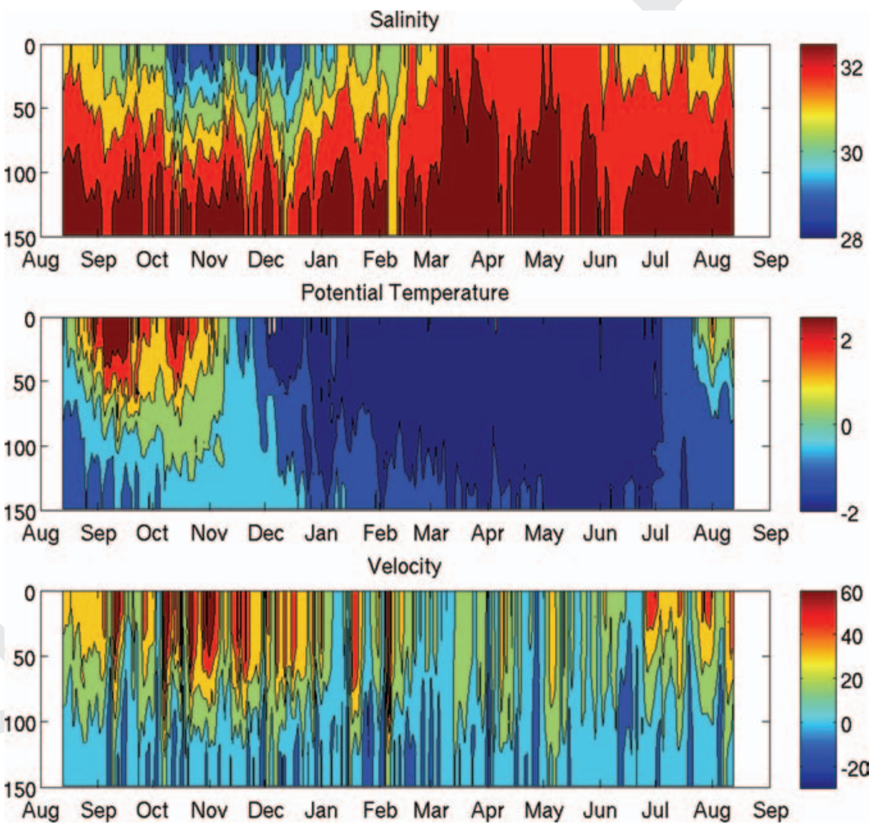

Fig. 10.3 Reconstructed Salinity, Potential Temperature and Along-strait Velocity (cm/s) at the central mooring of the array of shown in Fig. 10.2, details of the data analysis can be found in Straneo and Saucier (2007)

a horizontal width of 30 km. Superimposed on the seasonal variability, temperature, salinity, and especially velocity are characterized by strong variations over several days. These appear to be mostly barotropic and not determined by changes in the density field (Fig. 10.3; Straneo and Saucier 2007). The outflow exhibits very high lateral coherence and the time series of salinity, temperature and currents from the other two moorings are qualitatively very similar to those shown in Fig. 10.3. The salinity decreases onshore, as shown in the hydrographic section, while the maximum flow in the surface layers occurs more offshore (Straneo and Saucier 2007).

The mean annual transports of volume, heat and freshwater in the outflow calculated from these data are of 0.94 Sv (~30,000 km^3/year), −2.2 TW and 79 mSv, respectively. Details of how they were determined can be found in Straneo and Saucier (2007). We note that the observed freshwater transport is due to the liquid portion of the outflow since no sea-ice thickness data were available. Model simulations suggest that when included the sea-ice portion may contribute a net additional 6 mSv (Saucier et al. 2004).

These transports can be used, in combination with the net transports derived from the volume and freshwater budget of the HBS, to infer the inflow transports into HBS, for which we have no measurements. To balance volume, the inflow volume transport must be on the order of 0.84 Sv (26,800 km^3/year) which agrees with Drinkwater's 1984 measurements. To balance freshwater, we need a freshwater transport, along the coast of Baffin Island, of 41 mSv and likely more if we had taken into account the freshwater transport due to sea-ice in the outflow. This means that as much freshwater (relative to a salinity of 34.8) is carried into the HBS through Hudson Strait by the inflow as is input by the rivers throughout. Given that both the freshwater outflow and the river discharge are obtained from direct observations, this estimate is likely fairly reliable (excluding the missing sea-ice contribution and the interannual variability). For the inflow volume transport (0.84 Sv) to contribute 41 mSv of freshwater, the mean salinity of the inflowing water must be of the order of 33.1. This is well within the range of what is observed in the summer hydrographic section shown in Fig. 10.2. It is also in agreement with the mean salinity of the waters flowing out of Davis Strait ($32.5 < S < 33.5$; Cuny et al. 2005).

Given the uncertainty on the annual mean net heat flux estimates for HBS, we use a different approach to estimate the heat transports through Hudson Strait. First we ask what the mean temperature of the inflow waters must be in order to balance what comes out – assuming that the HBS' net annual heat loss is small. Given the inflowing transport of 0.84 Sv, such condition can be maintained with a mean inflow temperature of −0.65 °C. Next, from a review of the historical data found in the World Ocean Atlas 1998 (http://www.nodc.noaa.gov/OCL/woa1998.html),we find that the temperature at the mouth of HS is around 1.2 °C between 500 and 900 m, cooling to −0.7 °C at 150 m. On the other hand, from the few historical profiles we have, waters are colder (0.8 °C in August, −1.7 °C during winter) throughout the water column in the narrow strait 100 m deep (Annapolia and Gabriel Straits) just north of the mouth of HS. Across the wider section at the mouth of HS, these profiles show the temperature at depths over 500 m is also colder, from −0.4 °C in the north to −0.9 °C in the south, warming as we move up from 500 to 110 m to reach −0.4 in the north to 0.1 °C in the south. We note that while the core of the fresh outflow

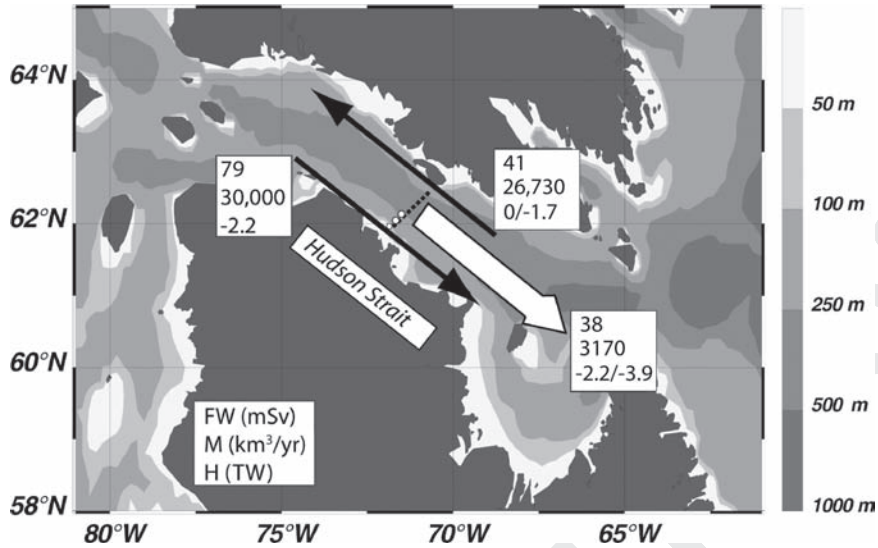

Fig. 10.4 Freshwater, volume and heat transports for the inflow and outflow through Hudson Strait (black arrows) and for the net (white arrow). Units are shown in the key. Also shown are the mooring locations (white circles) and the location of the section shown in Fig. 10.2 (dashed line)

from Davis Strait is cold (−1.5 °C; Cuny et al. 2005), its heat content is likely to modified as it mixes with warmer waters of the Labrador Sea at the entrance of Hudson Strait. Finally, if we look at the hydrographic section in Fig. 10.3, this shows that the mean inflow temperature is on the order of 0–0.5 °C, which would, in turn, yield a heat flux of 0–1.7 TW. If we assume that this is a reasonable estimate for the heat flux into the system it would result in a net heat transport out of Hudson Strait in the range of −2.2 to −3.9 TW. These numbers, in turn, imply that the HBS (west of the section) is a region of net heat loss with a mean annual heat flux out of −2 to −3.9 W/m^2. Clearly, these numbers are highly uncertain and should only be viewed as a preliminary attempt.

The transports of volume, freshwater and heat for the inflow, outflow and net flow through Hudson Strait are represented schematically in Fig. 10.4. Not surprisingly, the net transports are a poor indicator of the flow through the strait – especially for volume where they are an order of magnitude less than the actual circulation. For freshwater, the amount that flows out is equally due to the inputs into the HBS as to the inflow on the northern side.

10.4 Summary and Discussion

In this chapter, we have provided estimates for the net transports of heat, volume and freshwater through Hudson Strait as well as the respective contributions of the inflow and outflow. These are summarized in Fig. 10.4. While the estimates for the heat transports (except for measured outflow) remain strongly uncertain, we believe the remaining numbers to be reasonable.

The transports shown in Fig. 10.4 support the statement made in the introductory paragraph: that the HBS is an important contributor to the Arctic/North Atlantic exchange. They also show, however, that care must be taken in how one assesses the size of a contribution. If we look at the net contribution alone, the volume transport through Hudson Strait is small compared with the net 2–3 Sv that flow through Davis Strait (Cuny et al. 2005). This reflects the fact that the HBS is essentially an enclosed basin in contrast to the Arctic Ocean which has a net exchange both via Bering and Fram Straits. Yet, in terms of freshwater, the net freshwater flux through Hudson Strait is non-negligible and of the order of one third of the Davis Strait contribution (130 mSv according to Cuny et al. 2005).

As is obvious from Fig. 10.4, however, the net transports alone are a limited indicator of the pathways of Arctic water. The volume outflow from Hudson Strait is one order of magnitude larger than the net and about a third of that from Davis Strait (3–4 Sv according to Cuny et al. 2005 and Loder et al. 1998). The freshwater outflow is about two thirds of that flowing out of Davis Strait (120–150 mSv according to the same studies). Care must clearly be taken in interpreting these numbers since, in reality, what these results suggest is that approximately 1/3 (according to both freshwater and volume estimates) of the Davis Strait outflow recirculates into Hudson Strait instead of directly joining the Labrador Current further downstream. This recirculation must be taken into consideration when we list the contributors to the volume or freshwater flux of the Labrador Current – clearly the two outflows cannot be simply summed.

Why should we care if some of the Davis Strait outflow is recirculated through Hudson Strait? First, this implies re-drawing the Arctic export routes and adding a time lag for at least a portion of the Davis Strait outflow between the time it exits Davis Strait and when it merges into the Labrador Current. Second, the passage through the mouth of Hudson Strait will change the characteristics of the transiting water masses given the intense, tidally driven, mixing that occurs there. Third, and perhaps most important, the recirculation that is being discussed here has made its way to about the middle of Hudson Strait and is, possibly, on the way to Foxe Basin and Hudson Bay. If this is the case it will then participate in the water mass transformation processes of the HBS and re-emerge, transformed, several years later. At a time when we are seeking to understand how the variability observed in the Arctic region will propagate to the North Atlantic, and potentially impact global climate, the transit through Hudson Strait may modify the signal in a non-linear and, hence, non-trivial way.

The transports derived in this chapter represent our best estimates to this day. This analysis, however, highlights the chronic lack of data in a region and the imperative need to make additional measurements. The most important gap is due to the lack of measurements that cover a full seasonal cycle on the northern side of the strait. The second biggest gap is the lack of simultaneous flux measurements on both sides of Hudson Strait. Given the considerable interannual variability observed in the river outflow (Déry et al. 2005), for example, the sea-ice cover (Parkinson and Cavalieri 2002), or the atmospheric forcing (Saucier et al. 2004) – it is clear that observing both sides of the strait simultaneously is important. Hudson Strait is a rough working environment due to the strong tides, the large sea-ice ridges and, in general, its inaccesibility for much of the year. But, as the 2004–2005 measurements show, we now have the adequate technology (through moored, profiling instrumentation) to measure these transports.

Finally, like much of the Arctic Ocean, the HBS is undergoing rapid change. The river discharge into the HBS is decreasing (Déry et al. 2005) thus offsetting approximately 50% of the increased river discharge into the Arctic Ocean (McClelland et al. [Au3] 2006). The sea-ice cover has been steadily decreasing (Laine 2004) and, in general, models show that this region is likely to undergo accelerated change towards ice-free conditions (Gagnon and Gough 2005a, b). The Intergovernmental Panel on Climate Change (IPCC 2001) identified the HBS as one particulary prone to climate change with important consequences for the indigeneous populations which depend on the stability of the region's ecosystem. Thus, not only is it important to assess the mean transports through this Arctic gateway but, also, we need to monitor its variability.

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Author Queries:

[Au1]: Lazier (1980) not in Reference List.
[Au2]: Changed to match Reference List.
[Au3]: Laine et al. (2002) changed to (2004) to match Reference List.