Ice and Ocean Mooring Data Statistics from Barrow Strait, the Central Section of the NW Passage in the Canadian Arctic Archipelago

Simon Prinsenberg and Roger Pettipas

Bedford Institute of Oceanography, Department of Fisheries & Oceans,

Dartmouth, Nova Scotia, Canada

ABSTRACT

Since August 1998, personnel from the Bedford Institute of Oceanography have deployed year-long moorings in Barrow Strait of the Canadian Arctic Archipelago (CAA) to monitor the seasonal and inter-annual variabilities of ocean and pack ice parameters. Data from these moorings provide statistics on ice drafts and on ocean and ice velocities. This statistical information is presented here for bi-monthly subsets of the total eight year time series. Maximum ocean and ice velocities of 150 cm/sec were observed and ice drafts of up to 22 m. The 8-yr bi-monthly mean currents were stronger along the southern shore (15 cm/sec) where most of Arctic surface waters pass eastwards through the Barrow Strait.

KEY WORDS: ADCP and ULS mooring data, Canadian Arctic Archipelago, NW Passage, ice velocities, ocean velocities and ice drafts.

INTRODUCTION

It is generally accepted now that due to climate change, the polar ice caps are melting (ACIA, 2004, 2005 and IPCC, 2007) and indeed, the Arctic Ocean ice extent of September 2007 was the smallest observed over the past 30 years when satellite imagery was available to document accurately its extent (National Snow and Ice Data Centre, www://nsidc.org.). In addition, all three NW Passage routes through the Canadian Arctic Archipelago (CAA) were ice free for the first time for the 30-yr satellite observation period. Normally the eastern part of the NW Passage within the CAA, consisting of Barrow Strait and Lancaster Sound (Fig. 1), becomes ice free and is used by Canada's domestic shipping to re-supply eastern northern communities. In contrast, the western section (M'Clure Strait and Viscount Melville Sound) remains mostly filled with ice and is re-filled with multiyear (MY) ice from the Beaufort Sea Gyre through M'Clure Strait (Howell et al., 2008). Models (Lindsay and Zhang, 2005) have suggested that if the polar pack ice retreats north past the entrance of the M'Clure Strait as it has in 2007, the flux of MY ice to the region would stop, thus improving navigation through the entire NW Passage. This is contrary to the speculation based on available data sets prior to 2007 that improved shipping was not expected to be happening in the near future (Melling 2002, Wilson et al., 2004 and Howell et al., 2008) as Arctic MY ice would come into the CAA from the north and east. Only data sets from future years will tell us what will happen but the ice conditions that occurred in the Arctic and the NW Passage in 2007 had never been seen before (www://nsidc.org).

As part of the international Arctic-Sub-Arctic Ocean Flux (ASOF) program, moorings have been monitoring the volume, heat and freshwater fluxes passing through Barrow Strait of the Canadian Arctic Archipelago since August 1998 (ASOF, 2004). The aim of the program is to better understand the oceanographic and pack ice fluxes passing through the Archipelago and their relationship to the heat and freshwater budgets of the Arctic Ocean and the CAA, to the circulation and vertical ventilation of the North Atlantic Ocean, and to the global meridional overturning circulation (MOC).

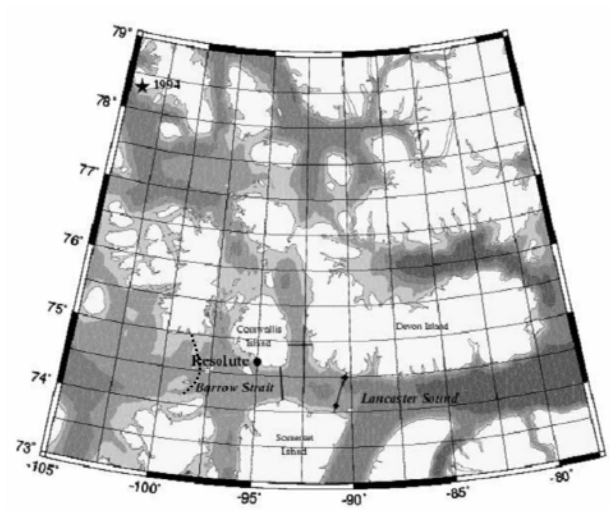

Fig.1 Map of the eastern CAA section of the NW Passage showing the CTD transects as solid lines, mooring sites (dots) in is eastern Barrow Strait, the sill (dotted line) in western Barrow Strait and the north magnetic pole location (1994) which is moving northwards.

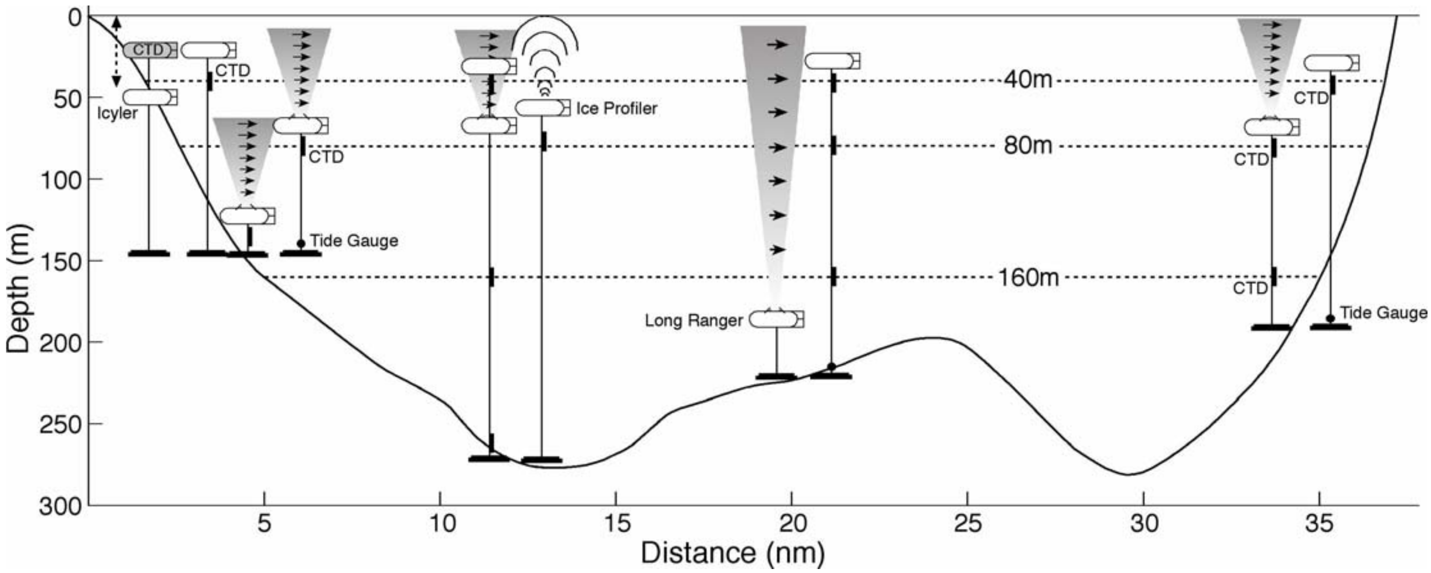

Fig. 2 Barrow Strait array for 2003-04 looking upstream to the Arctic with the south shore on the left of the figure (37 nm equals 65 km).

The same data sets can be used to answer engineering questions being asked by shippers and regulators managing Canada's domestic shipping in the NW Passage. These regulatory programs have supported the mooring program in Barrow Strait to obtain statistics on the seasonal and inter-annual variability and possibly on long-term trends of ocean currents, ice velocities, and ice drafts. The object of this manuscript is to present this statistical navigation information covering eight years of mooring data.

MOORING INSTRUMENTATION

Barrow Strait is 65 km (37 nm) wide at the mooring site and reaches depths of 285 m. Both mobile and land-fast pack ice conditions occur for 10 months of the year. Ice ridge keels within the pack ice are a threat to moorings which, for this reason, were designed not to extend into the top 25 m of the water column. Instrumentation of the yearly arrays have varied, but use Acoustic Doppler Current Profilers (ADCPs) to monitor ocean and ice velocities, Upward Looking Sonars (ULSs) to monitor ice drafts and CTD units (MicroCats) to monitor water column properties at various depths. Fig. 2 shows the array used for 2003-2004 deployment, which also used Tide Gauges and a CTD profiler called ICYCLER. Further descriptions of the instrumentation and data analysis can be found in Prinsenberg and Hamilton (2005).

For this manuscript we will concentrate on data from the two shore sites as they have the longest time series (8 years). Ice and ocean velocities (at 10 m depths) were collected with ADCPs at 2hr intervals and ice drafts with ULSs at 2-3 s intervals.

ICE VELOCITIES and ICE DRAFTS

The bi-hourly ice velocity data for the 8 yr period were divided into two month sections for which the along-strait velocity was used to derive the bi-monthly vector mean velocities, the standard deviations (Std) and maximum east and west velocities.

Fig. 3 shows the results from the southern site of Barrow Strait where most of the eastwards flowing Arctic surface waters occurs (Prinsenberg and Hamilton, 2005). Fig. 4 shows results for the northern site. Land-fast ice conditions occur normally in March and April and in some severe winters during the months of May and June. In 2003, the ice was mobile for at least part of each 2 month period and land-fast ice conditions did not occur for the total two month period (March-April). During mobile ice conditions, the bi-monthly mean velocities are up to 50 cm/sec and directed towards Baffin Bay moving along with the Arctic surface waters passing through Barrow Strait. Maximum ice velocities can reach 150 cm/sec when tidal, bi-monthly mean and wind forced ice drift components all act in the same direction. Maximum ice velocities towards Baffin Bay are generally larger than those towards the Arctic as they move along with the eastward bi-monthly mean ocean currents.

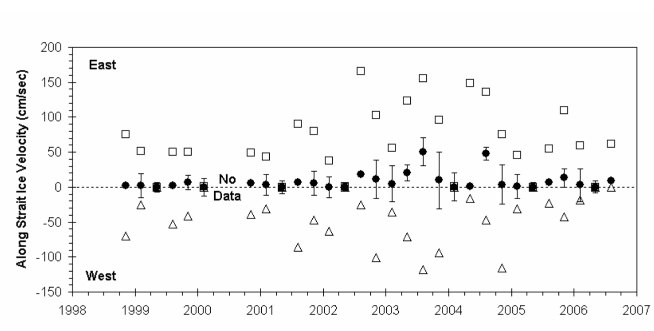

Fig. 3 Eight years of ice velocity data observed in Barrow Strait located at a site 5 nm from the southern shore (Fig. 2). Bi-monthly means are shown as solid circles, with ±1 standard deviation illustrated with the bars. Maximum eastward velocities to Baffin Bay over each bi-monthly interval are shown as open squares and maximum westward velocities to the Arctic by open triangles.

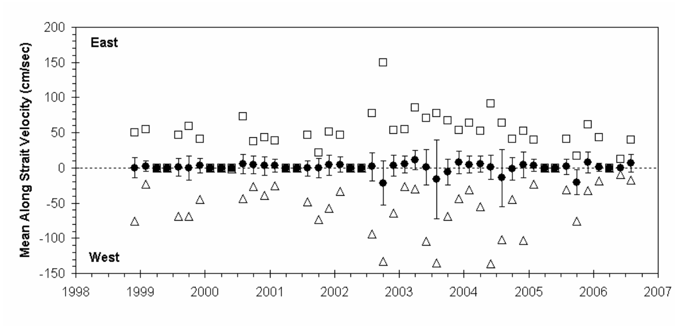

Fig. 4 Same as Fig. 3 but for site 3 nm from the northern shore in Barrow Strait (Fig. 2).

At the northern site, land-fast ice conditions persisted for the months of March and April for all years except in 2003 and 2004 (Fig. 4). Bi-monthly vector mean ice velocities are smaller along the northern shore and have no preferred direction as was the case for southern site. Maximums are again large, up to 150 cm/sec but now equally distributed in both directions.

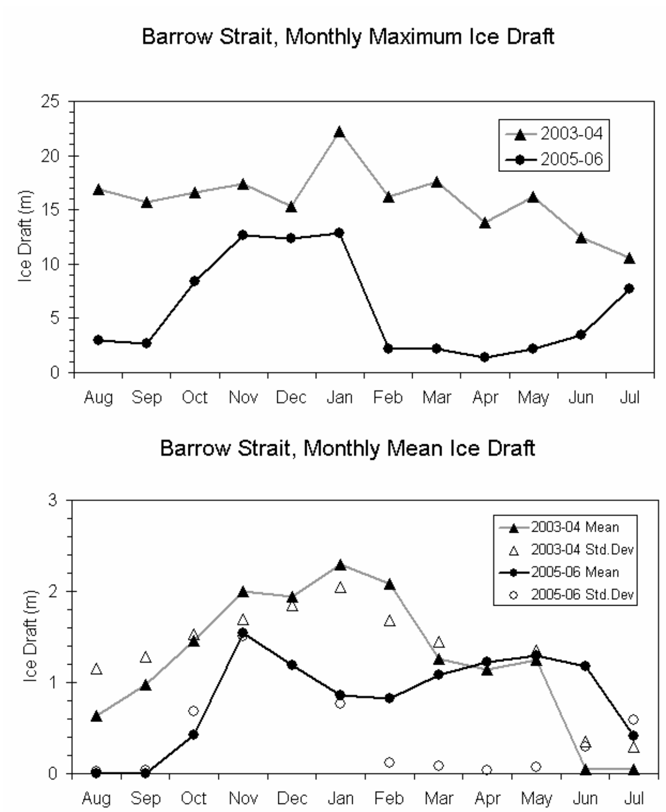

Fig. 5 Two years of ice draft data from the southern site of the Barrow Strait array. Shown are monthly maxima ice draft (top panel) and monthly means and standard deviations in the bottom panel.

Fig. 5 shows two years of ice draft data from the ice season of 2003-04 when the pack ice remained mobile throughout the winter and from the ice season 2005-06 when land-fast ice conditions occurred and thus reflect a more normal ice season. With global warming, however, mobile ice conditions such as those of 2003-04 may become more prevalent. During mobile ice conditions, ice ridges passing the mooring site reach up to 24 m but as a norm were up to 16 m for the 2003-04 winter. In 2005-06 the maximum ice draft was 13 m. The larger monthly maximum ridges attained in the 2003-04 season probably reflect the increased ridging that can occur when the mobile pack area to the west of the site is larger and can generate more and larger compression forces. From ice charts, it can be seen that the ice arch separating land-fast ice from mobile ice occurred in western Barrow Strait in 2003-04 (95 deg West), 120 km west of the mooring site while it established itself at the mooring site in the 2005-06 winter (Can. Ice Service, http://ice-glace.ec.ca). Once land-fast ice conditions were established at the mooring site on February of 2006, the sonar monitors the same ice that grows slowly thermodynamically. For the 2005-06 winter the land-fast ice above the sonar was not ridged and thus low monthly maxima were detected. The small variability detected in the monthly mean is probably due to mooring motion that causes the sonar to monitor ice in a small area and not just one specific location of the pack ice.

In the bottom panel of Fig. 5, the monthly mean draft and the standard deviation are shown for the 2003-04 and 2005-06 winters. Relative to the 2003-04 winter, the 2005-06 winter started and ended two months later. During mobile ice conditions the monthly Std of ice drafts and the monthly mean ice drafts vary similarly; meaning that the variability about the mean and the mean itself increase and decrease proportionally. During land-fast ice conditions the Std approaches zero and the mean values vary as expected under thermodynamic ice growth. Once the land-fast ice breaks up in June, 2006 ridges start to appear and increase the monthly maximum.

OCEAN VELOCITIES

Ocean currents vary hourly due to tidal components, vary daily due to atmospheric forcing and vary seasonally due to long-term variability in sea level pressure gradients. In addition to these temporal variabilities at each location, there are large horizontal and vertical spatial variabilities. Statistics presented in this manuscript should thus be considered as values for the specific locations and for the specific time periods and not be taken as general values for the entire CAA's NW Passage nor for all past and future time periods.

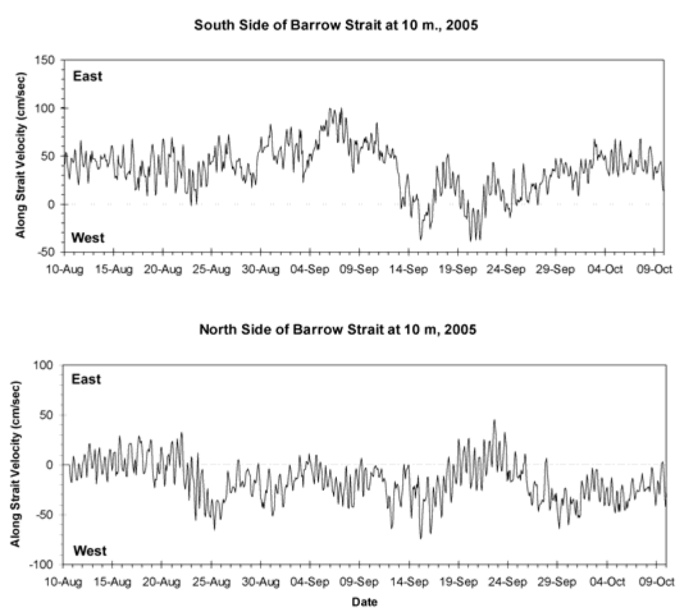

Fig. 6 Along-shore ocean surface velocities (10 m depth) from the southern and northern mooring sites in Barrow Strait. Bi-hourly data are from August 10 to October 9, 2005.

Fig. 6 shows a 2 month section of the bi-hourly along-shore currents at 10 m depth from the southern and northern sites in Barrow Strait. These small sections of the total 8-yr records show the temporal variability that exists throughout the 8-yr time series. Tidal currents vary on a 12-hr cycle by up to 35 cm/sec when the sun and moon tidal constituents generated in the Atlantic Ocean reinforce or oppose each other. The contribution from the Arctic Ocean tide is weaker as the Arctic tides are smaller and reflected back to the Arctic from the sill located in western Barrow Strait at 96 deg W longitude (Fig. 1).

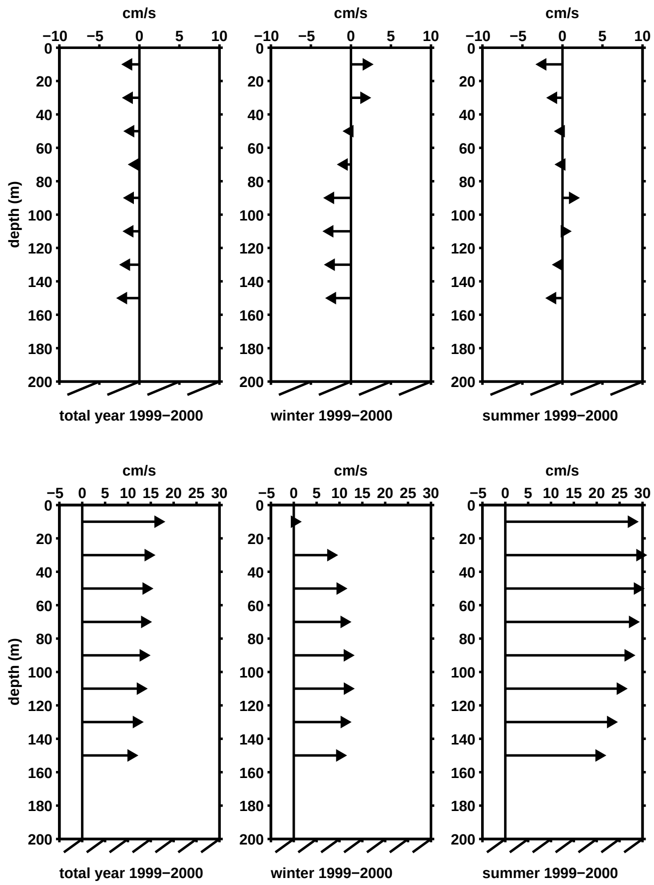

Fig. 7 Along-shore current profiles for the northern (top) and southern (bottom) sites in Barrow Strait. Profiles are for year-long deployment of August 1999 to August 2000, the winter 2000 (January to April) and the summer 2000 (June to mid August).

The largest long-term mean velocity components, driven by atmospheric and sea level pressure gradient along the NW Passage are found along the southern shore where daily mean values of the exiting Arctic surface waters reach 50 cm/sec and set towards Baffin Bay. Along the northern shore, the long-term currents are smaller and do not have a persistent preferred direction (Fig. 7). In the summer they generally are directed towards the west (Arctic Ocean) and in the winter towards the east (Baffin Bay).
Currents normally decrease with depth in response to surface atmospheric forcing and bottom friction. The exception being that during land-fast ice conditions, the ice isolates the ocean surface from wind forcing and acts as a friction boundary thereby reducing the surface currents in winter relative to mid-depths values (Fig. 7). The seasonal and yearly mean currents (Fig. 7) vary inter-annually in response to large scale atmospheric forcing and in particular to the sea surface level set-up due to surface winds at the western entrance of the NW Passage section in the CAA (Peterson, 2008).

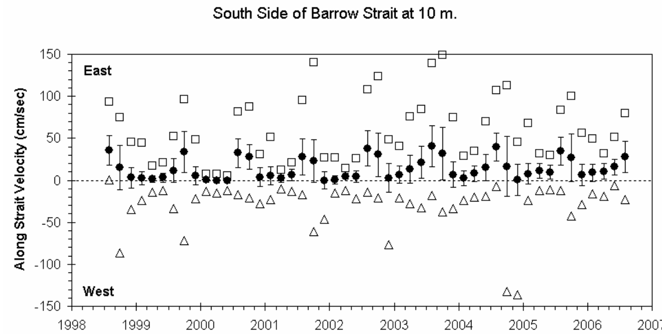

Fig. 8 Eight years of bi-monthly ocean velocity data observed at 10m depth at the southern site in Barrow Strait. Shown are bi-monthly vector velocity means (solid circles), standard deviations (bars), and the maximum east (squares) and maximum west velocities (triangles) for each bi-monthly section.

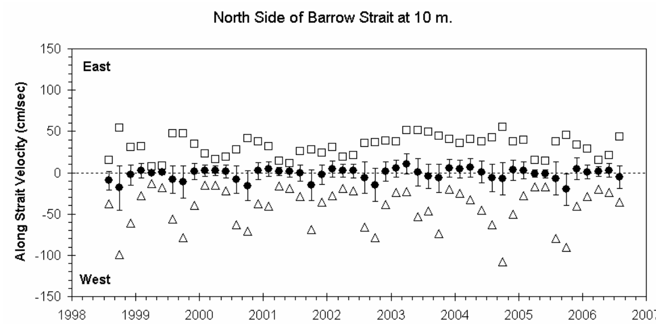

Fig. 9 Same as Fig. 8 but for the northern site in Barrow Strait.

Similarly to the ice drift data, Figs. 8 and 9 show the bi-hourly ocean along-shore current data for the 8-yr period as bi-monthly values. The bi-monthly mean velocities (solid dots) and magnitude of the Std about the mean show that at both sites the mean currents are lower and are less variable during the winter months than the summer months when additional far-field and local wind forcing occur. In the summer months the mean currents and variability about the means are larger for the southern site and are setting to Baffin Bay (eastwards). For the northern site, the summer means are small but generally setting to the west. The maximum velocities are similarly largest in the southern site, occur during the open water period and are in the direction of Baffin Bay. The maximum velocities towards the west are less as they oppose the mean currents flowing to Baffin Bay. In contrast, the largest summer maximum velocities along the northern shore are directed towards the west (Arctic) in the direction of summer mean currents.

CONCLUSIONS

The 8-yr mooring data from eastern Barrow Strait in the central part of the NW Passage show large seasonal and inter-annual variabilities in ice drafts and in ocean and ice velocities. Statistics derived from the 8-yr time series, shown as figures and listed in Table 1, should not be taken as general values for the entire NW Passage nor for all past and future time periods. The numbers of data points used in the analysis, plots and Table 1 are in units of 1000 s (k). They are derived from a specific time period and specific location. However they can be used as a guide on expected temporal and spatial variability for other locations and time periods.

Ocean velocity (cm/sec)		#pts/yrs	Mean	Std	max-W	max-E
	S-10m	28.6k/8	15.3	21.5	136.6	149.3
	N-10m	31.3k/8	-2.2	15.0	108.1	55.6
Ice drift (cm/sec)	South	22.9k/8	4.6	15.0	117.4	166.0
	North	24.1k/8	1.7	11.8	136.2	149.7
Ice draft (m)	2003-04	15544k/1	1.27	1.59	22.3*	----
	2005-06	10196k/1	0.86	0.82	12.8*	----

* maximum value for the entire record

Table 1 Statistical parameters for the ocean velocity, ice drift and ice draft for the mooring array in eastern Barrow Strait shown in Figures 3, 4, 8 and 9. Positive ocean velocities and ice drifts are directed to the east while negative values are directed to the west.

Due to the eastwards setting Arctic surface waters found along the southern shore, the mean currents there are large (15.3 cm/sec) as compared to smaller west setting mean currents of 2.2 cm/sec along the northern shore. Standard deviation about the 8-yr mean are 21.5 and 15.0 cm/sec respectively for the southern and northern shore, while maximum values can reach up to 150 cm/sec. Mean ice drifts are smaller because of the long period of land-fast ice conditions but can reach maximum speeds of 150 cm/sec as well. Ice draft measurements were available for only two years and show that the mean, standard deviation and maximum keel depth depend on the distance the observation is taken relative to a stable ice arch. The more distance there is for the ice ridging process, the larger the mean, Std and maximum ice draft. The maximum ice draft seen was 22.3 m.

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REFERENCES

ACIA (2004). "Impacts of a Warming Arctic: Arctic Climate Impact Assessment", Cambridge University Press.

ACIA (2005). "Arctic Climate Impact Assessment", Cambridge University Press, 1042 pp.

ASOF (2004). "Arctic/Subarctic Ocean Fluxes, Newsletter No 2". http:asof.npolar.no.

Howell, S.E.L, T. Adrienne, J.J. Yackel and S. McCourt (2008). "Multi-Year Sea Ice Conditions in the Western Canadian Arctic Archipelago Region of the NW Passage: 1968-2006". Atmosphere-Ocean 46(2): 229-242.

IPCC (2007). "IPCC fourth Assessment report (AR-4)", Twenty-Seventh Session of the International Panel on Climate Change, Valencia Spain, Nov, 12-17, 2007.

Lindsay, R.W., and J. Zhang (2005). "The thinning of Arctic sea ice, 1988-2003: have we reached a tipping point?" Journal of Climate, 18, 4879-4984.

Melling, H. (2002). "Sea ice of the northern Canadian Arctic Archipelago". J. of Geophys. Research-Oceans, Vol. 1007, No. C11, 3181 doi:10.1029/2001JC001102.

Peterson, I. K. (2008). "Beaufort Sea wind forcing of the flow through the Northwest Passage", Geophysical Research Letters, submitted.

Prinsenberg, S. J. and J. Hamilton (2005). "Monitoring the volume, freshwater and heat fluxes passing through Lancaster Sound in the Canadian Arctic Archipelago", Atmosphere-Ocean 43(1): 1-23.

Wilson, K.J., J. Falkingham, H. Melling and R.A. DeAbreu (2004). "Shipping in the Canadian Arctic: Other Possible Climate Change Scenarios". 2004 Int. Geoscience and Remote Sensing Symposium (IGARSS'04), Anchorage, Alaska, Conf. Proceedings, 4pp.