REPORT ON ESTIMATING SEA-ICE TRANSPORT INTO THE NORTH ATLANTIC USING THE ADVANCED MICROWAVE SCANNING RADIOMETER (AMSR-E)

T. A. Agnew[1] and J. Vandeweghe[2]
[1] Meteorological Service of Canada, Canada
[2] Engineering Department
University of Toronto, Toronto, Canada

Abstract

Using the Advanced Microwave Scanning Radiometer sensor (AMSR-E), winter (October to May) sea ice area flux is estimated for the main channels of the Canadian Arctic Archipelago, Baffin Bay and Fram Strait. The transport through Fram Strait is estimated at 533,000 km^2 and 635,000 km^2 for the winter of 2002/03 and 2003/04 which is below the 24-year average of 754,000 km^2 obtained by Kwok et al. (2004) using earlier satellite microwave sensors. The error estimate using AMSR-E is 7300 km^2 which is a considerable improvement over for the earlier SSMI and SMMR sensors and is due to the improved resolution of the AMSR-E sensor. The average winter sea ice area flux over these two years for Baffin Bay, Davis Strait, Hudson Strait, Barrow Strait, and Lancaster Sound in the Canadian Arctic Archipelago is 687,000, 605,000, 69,000, 39,000 and 16,000 km^2 respectively. Smaller channels such as Nares Strait, Smith Sound and Jones Sound could not be reliably estimated using AMSR-E sensor because these channels are too narrow.

1. INTRODUCTION

Sea ice plays a critical role in air-sea interaction in Arctic regions. The growth, melt, and transport of sea ice have a strong influence on the exchange of heat, freshwater, salt, and momentum between the atmosphere and the ocean and on albedo. The southward extent of sea ice also lies near the main storm track in the north Atlantic and affects and is affected by the location and intensity of storms which shape the regional climate. It is also an important component of the freshwater exported into the north Atlantic either through Fram Strait into the Greenland Sea or through the Canadian Arctic Archipelago (CAA) into Baffin Bay (Carmack, 2000). Much of the Meridional Overturning Circulation (MOC) occurs within or near the marginal sea ice zone of the north Atlantic and so the transport of sea ice into the north Atlantic has a direct and/or indirect control on deep water formation.

Sea ice export through Fram Strait into the Greenland Sea has been estimated by Kwok et al. (1999, 2004a) and Vinje (2001) using the earlier Special Sensor Microwave Imager (SSM/I) and Scanning Multichannel Microwave Radiometer (SMMR) and ocean mooring data. Much less is known about the transport of sea ice and freshwater through the channels of the CAA. Prinsenberg and Hamilton (2005) have estimated freshwater export through Lancaster Sound and Melling (2000) has summarized current knowledge of the flux of freshwater through the smaller channels of the CAA. The main objective for this work is to quantify the sea ice export using the latest all-weather Advance Microwave Scanning Radiometer (AMSR-E). Daily repeat coverage and all-weather capability of AMSR-E allow daily estimates of sea ice area transport in this region which has a high frequency of cloud and stratus.

This work is part of the Canadian Archipelago Through-flow Study (CATS) which is a five-year international study bringing together Canadian and American Arctic scientists to study the first-ever simultaneous tracking of sea ice and freshwater out of the Arctic Ocean through Canadian Arctic Archipelago (CAA) into the North Atlantic (http://newark.cms.udel.edu/~cats/index.html). CATS is also an element of the international Arctic-Subarctic Ocean Flux (ASOF) program. The approach is to combine moored ocean instruments, satellite remote sensing, chemical analysis and atmospheric modeling to determine the amount and origin of this freshwater. The 2003 expedition to Nares Strait (between northern Ellesmere Island and Greenland) set up much of the oceanographic instrumentation which can be used to compare sea ice motion and sea ice transport estimates obtained using the AMSR-E sensor.

The work is funded in part by a US National Science Foundation grant OPP-0230236, the Canadian Panel on Energy Research and Development (PERD) and Environment Canada and the Department of Fisheries and Oceans of Canadian Government. The work contributes to the Canadian and US Global Climate Change Program, the international Arctic-SubArctic Ocean Flux Program (ASOF) and the Climate and Cryosphere Program (CLiC) of the World Climate Research Program (WCRP).

2. DATA AND METHODOLOGY

The AMSR-E data was obtained from the National Snow and Ice Data Center (NSIDC). The data product used to estimate sea ice motion was the 89 Ghz horizontally polarized daily average of all descending orbits projected onto the polar grid with 6.25 km grid spacing. The 18.7 and 36.5 GHz channels of the AMSR projected onto the polar grid at 12.5 km resolution were used to estimate sea ice concentration using the NASA Team algorithm. Sea ice motions were compared to Arctic drifting buoy data obtained from the International Arctic Buoy Program (IABP).

A maximum cross correlation method is used to estimate sea ice motion between satellite images (Agnew et al.,1997; Kwok et al., 1998). The technique uses the cross correlation between two sub-regions or patches in the two images. The size of the patch is 6 x 6 pixels or 37.5 km square and results in an independent estimate of ice motion at approximately every 37.5 km in the image. The sea ice motion vectors are then interpolated to a 25 km regular grid. Sea ice concentrations, estimated from the 18.7 and 36.5 GHz channels of the AMSR sensor, are interpolated on the 25 km regular grid as well. The daily average of only descending orbits was used to estimate ice motion. This ensures that overlapping orbits for the CAA occur within 4 to 5 hour of each other which reduces the time average of overlapping orbits and improved the estimates of ice motion. These data products had occasional missing pixels due to binning of swath data onto the polar grid. These missing pixels were filled in using the median of the nearest 8 neighbors.

The accuracy of the ice motion estimates is determined by comparing results with Arctic drifting buoy data. The drifting buoy locations are accurate to within 100 m. This is much finer than the AMSR-E image resolution which is approximately one half a pixel size (3 km) and so the buoys were considered to be ground truth. For buoys within 1000 km of Fram Strait, ice motion estimates are interpolated to the buoy location and then compared to the ice drift estimated from the drifting buoys. Table 1 shows the results of the comparison using 1-day separation between AMSR-E images. The average of the mean difference (AMSR minus buoy motion) is -0.49 km/day indicating that the AMSR underestimates motion compared to the buoys by about 5%. This underestimation is most likely a result of the relatively coarse resolution of the AMSR-E sensor. The standard deviation of the differences is 4.64 km/day. This is about half the mean motion of all the buoys (9.74 km/day). A comparison was also made using individual overlapping orbital data separated by approximately one day. No improvement in sea ice motions was found. Combining sea ice motion and sea ice concentration, the sea ice area transport can be calculated.

The sea ice area transport across a flux gate is estimated following a method similar to Kwok and Rothrock (1999) and Kwok et al. (2004a). Those studies estimated the winter (October to May) sea ice area flux through Fram Strait using the earlier SMMR and SSM/I sensors. The more recent sensor AMSR-E has increased spatial resolution at 89 Ghz of approximately 6 km. This increased resolution provides an opportunity to estimate sea ice transport in smaller regions such as the main channels of the Canadian Archipelago and Baffin Bay/Labrador Sea and to improve estimates of sea ice transport through Fram Strait over those obtained using these earlier passive microwave sensors. In this study the AMSR data is used to estimate sea ice area transport in these regions for the 2002/03 and 2003/04 winter seasons.

The location of all the flux gates used in this study is shown in Figure 1. These locations were selected based on the location of ocean moorings set up during the CATS 2003 summer ocean campaign and other observation programs. Fram Strait (gate 1) is the location of the main export of sea ice into the North Atlantic. Several ocean moorings are in this vicinity and previous studies by Vinje (2001) and Kwok (1999, 2004a) have used this flux gate location. Baffin Bay (gate 2) is a strategic location at the widest part of Baffin Bay. No moorings however are at this location. Davis Strait gate (gate 3) is near measurements taken as part of the Davis Strait freshwater flux investigation (Dr. C. Lee, University of Washington, Applied Physics Laboratory) which is using automated submarines to measure salinity and current profiles across the strait. Gates 5 to 11 are located at strategic locations in the Canadian Archipelago and for several of these locations ocean moorings have been set up during the 2003 CATS ocean campaign and earlier by other researchers.

3. ESTIMATION OF SEA ICE AREA FLUX

The sea ice area flux across each gate is calculated as follows:

$$F = \sum c_i u_i \Delta x$$

where Δx is the spacing of flux estimates along the gate, u_i is the ice motion normal to the flux gate at the ith location, and c_i is the sea ice concentration. Occasional missing days or missing data in the AMSR-E images resulted in no daily flux estimate. These missing days were estimated using the average daily flux for that month. This occurred two to four times in the months of October, November and December.

The error in estimating sea ice area flux depends on the accuracy of ice motion and sea ice concentration estimates. The comparison of AMSR ice motions with drifting buoys suggests an ice motion error of 4.64 km/day (Table 1) and the accuracy in estimating sea ice concentration is 10% (Cavalieri et al 1999). Assuming these two sources of error are uncorrelated, the error (σ_e) in estimating the ice area flux element $c_i u_i$ across a one km wide gate is 4.74 km^2 /day.

The number of independent ice flux estimates along the gate is determined by the size of the patch used to obtain independent ice motion estimates (37.5 km) and how far the sea ice extends across the gate on average (L). For Baffin Bay, it is estimated that there are about 680 km/(37.5 km) ~ 18 independent estimates of ice flux (Ns). We assume that the errors in the individual fluxes sampled are additive, unbiased, uncorrelated, and normally distributed. Then, the uncertainty in the daily ice motion across the gate is

$$\sigma_f = \sigma_e L/(N_s)^{1/2}$$

where L is the effective extent of sea ice across the gate. If the daily flux errors are additive, unbiased, uncorrelated and normally distributed then uncertainty in the average monthly flux is

$$\sigma_T = \sigma_f (N_d)^{1/2}$$

where N_d is the number of days in the month. A similar formula can be used for the error in winter flux estimates. For each gate the monthly error estimate using 30 days and the winter season error estimate assuming 240 days are summarized in Table 2. For Fram Strait, the error estimate over the season is 7300 km^2 which is a considerable improvement over error estimates from previous SSM/I and SMMR sensors estimated by Kwok and Rothrock (1999) to be 17,000 km^2 for the SSM/I sensor and 25,000 km^2 for the SMMR. Improved resolution of the AMSR-E sensor is the main reason. No correction was made for the 5% bias in 1-day ice motion estimates compared to drifting buoys.

4. RESULTS

4.1 Sea Ice Area Flux in Fram Strait, Baffin Bay, Davis Strait and Hudson Strait

Flux gate 1 across Fram Strait, extends from latitude 81°N on the Greenland coast to roughly latitude 80°N on the Svalbard coast and is about 460 km across (Figure 1). Sea ice does not usually extend right across to the Svalbard coast so the effective length used in Table 2 is estimated to be 400 km. Flux gate 2, across the widest part of Baffin Bay, runs roughly from 72°N and is about 680 km across. Sea ice usually extends completely across the Bay at this location during February, March and April. The flux gate across Davis Strait (gate 3) runs roughly from 67 °N just north of Cape Dyer. Sea ice does not usually extend completely across Davis Strait. The effective length used for estimating the error was 400 km.

Sea ice motion is estimated every day from AMSR 89 GHz horizontal polarization data over the 2002/03 and 2003/04 winters (October-May). Figure 2 and 3 show the daily ice area flux across Fram Strait and Baffin Bay for the 2003/04 winter. Negative sea ice flux means transport north. There is considerable variability from day-to-day through both gates caused mainly by the variability in sea ice motion. For example, the change from positive (southward) transport of sea ice at the mid-December 2004 to negative (northward) transport for several days (Figure 3) was caused by an intense storm which moved up from northern Quebec and Labrador into Foxe Basin and produced very strong southerly winds over the Baffin Bay region. The standard deviation of daily flux for Fram Strait and Baffin Bay gates is approximately 2600 km^2 and 3600 km^2 respectively. Both these values are considerably larger than the estimated error in daily fluxes of 570 km^2 and 760 km^2 (Table 2).

Table 3 summarizes the monthly average sea ice area transport for Fram Strait, Baffin Bay and Davis Strait for both winters and Figure 4 plots the average monthly flux over the two winters. For the winter of 2002/03 and 2003/04, sea ice area flux for Fram Strait is 533,000 and 656,000 km^2 respectively. The 2002/03 value in particular is well below the average transport found by Kwok et al. (2004a) of 754,000 km^2 for the 1978 to 2002 period. This very low value for the 2002/03 winter was confirmed by Kwok et al. (2004b) using SSMI data and he attributes it to anomalous atmospheric circulation which redirected the export of sea ice through the passage between Svalbard and Franz-Josef Land.

Baffin Bay winter average sea ice area flux is 687,000 km^2. Monthly values are about 15% higher than the value for Fram Strait except for October and May when there is little to no sea ice present. The average winter sea ice transport further south in Davis Strait is 605,000 km^2 but is delayed by about a month with maximum transport occurring in February. Peak values however are as high as Baffin Bay. Although the sea ice area flux is higher than Fram Strait for these two locations, Baffin Bay and Davis Strait are mainly first year ice and therefore thinner than sea ice exported through Fram Strait. Maximum thickness of level ice for Baffin Bay ranges from 1 to 1.5 m (Prinsenberg and Petersen,

1992) during the coldest months of February and March. Ridging would increase the average thickness appreciably to perhaps 2.0 m (Melling, 1996). Winter sea ice thickness estimates for Fram Strait are about 3.5 m based on ULS estimates of underwater sea ice draft (Kwok et al., 2004a). Using these ice thickness values the sea ice volume flux through Fram Strait is 2100 km^3 compared to 1370 km^3 for the Baffin Bay gate.

The Hudson Strait gate (gate 4) is a strategic location to monitor the export of sea ice from Hudson Bay. Monthly sea ice area flux is summarized in Table 4 and plotted in Figure 5. Positive ice flux through this gate means ice transport towards the Labrador Sea. The average winter ice area flux was 39,000 km^2 over these two winters. This is an order of magnitude less Baffin Bay and Davis Strait. The standard deviation of daily fluxes is 920 km^2 /day which is twice the estimated daily error (Table 2). Monthly error bars are shown in Figure 5. The sea ice area flux shows a reversal (negative) in sea ice transport northwestward towards Foxe Basin in January. This reversal in the ice transport occurred in 2002/03 when persistent lows pressure in northern Quebec and Labrador reversed the transport of sea ice in Hudson Strait most of January, 2003.

4.2 Sea Ice Transport through the Parry Channel of the Archipelago

The Parry Channel is one of the main channels that passes through the Canadian Archipelago. From west to east, it includes: M'Clure Strait, Melville Sound, Barrow Strait and Lancaster Sound. Starting at the eastern end, the Lancaster Sound gate (gate 8) is a strategic location to monitor the export of sea ice into Baffin Bay. Monthly sea ice area flux is summarized in Table 4 and plotted in Figure 5. The standard deviation of daily fluxes is 620 km/day. This is three times larger than the estimated daily error (Table 2). The error bars in Figure 5 are small compared to the monthly fluxes. Positive values of ice flux mean ice transport eastward towards Baffin Bay. The average winter ice area flux into Baffin Bay was 69,000 km^2 over these two winters. At this location, sea ice remains mobile all winter with positive ice flux each month except in October when there is little of no ice. Maximum sea ice flux occurs in February.

Moving further west, the Barrow Strait gate (gate 7) is located just below where sea ice consolidated during both these winters and is near where ocean mooring sites set up by Prinsenberg and Hamilton (2005). Even further west, the Griffith Island flux gate (gate 6) is in the ice consolidation zone upstream from where the ice bridge formed each winter. Table 5 and Figure 6 summarize the monthly fluxes. The estimated daily error (Table 2) and the standard deviation of the daily flux (200 km^2/day) are comparable for both these flux gates. However by averaging over the month, it is possible to come up with a reliable estimate of monthly ice transport even although the error bars are large. The average winter sea ice area transport for Griffith Island gate and Barrow Strait gate are 16,100 km^2 and 27,560 km^2 respectively and is less than Lancaster Sound. In October there is little or no ice for both locations. During November, sea ice is new and unconsolidated resulting in similar sea ice flux at both locations. For the rest of the winter, the monthly ice transport at Griffith Island gate is low reflecting the fact that the sea ice has consolidated in the region while further down the channel at Barrow Strait gate, ice remains mobile all winter and monthly sea ice transports are higher. The timing of sea ice consolidation and the formation of the ice bridge affects the monthly ice transport at the Griffith Island gate. In 2002/03, sea ice consolidated early and the ice bridge formed in November near Griffith Island gate (Figure 7). In 2003/04 the sea ice consolidated later in early December and further to the west so that ice flux remained high from December to March. This resulted in considerable difference in the ice transport at Griffith Island for the winter of 2002/03 and 2003/04.

M’Lure Strait gate (gate 5) borders on the Arctic Ocean at the western end of this central passage. The estimated daily error is 345 km^2/day (Table 1) and the standard deviation of the daily flux is 330 km^2/day which are comparable. Mean monthly motion is quite variable for October and November (Figure 8). From December on sea ice has consolidated and net mean motion is small essentially distinguishable from zero. Net mean flux over the two winters is only - 152 km^2/day (Table 5)indicating little or no net transport in the winter months.

The Jones Sound, Smith Sound and Nares Strait (gate 9, 10, 11) have ice transports that are too small to be reliably estimated using the AMSR-E sensor. The Nares Strait gate (gate 11) is even too narrow to get one independent estimate of sea ice motion.

5. CONCLUSIONS

Using AMSR-E, sea ice area transport through the main channels of the CAA has been estimated for the 2002/03 and 2003/04 winters. A comparison is also made of the sea ice transport through Fram Strait and Baffin Bay. Although the monthly sea ice area flux through Baffin Bay was found to be about 15% higher than Fram Strait for the 2002/03 and 2003/04 winters, sea ice passing through Fram Strait is at least twice as thick as that of Baffin Bay sea ice. The low sea ice area flux for Fram Strait in 2002/03 was exceptionally low due to anomalous atmospheric circulation which redirected the export of sea ice through the passage between Svalbard and Franz-Josef Land (Kwok et al., 2004b). Further south, the transport through Davis Strait is comparable to Baffin Bay but the maximum sea ice transport occurs one month later in February. The average winter sea ice area transport in Hudson Strait was 39,000 km^2 towards the Davis Strait/Labrador Sea.

Sea ice flux through through the Parry Channel increases steadily from zero to 16,100 to 27,560 to 69,000 km^2 for M'Lure Strait, Griffith Island, Barrow Strait, and Lancaster Sound as you move east. This increase in sea ice transport from west to east reflects the pattern of freeze-up in the CAA over the winter.

The lack of validation of these sea ice flux estimates using in-situ observations is a major deficiency in these results. In the future, ice motion comparisons will be made with in-situ mooring data in the Barrow Strait, Davis Strait and Nares Strait and in-situ upward looking sonar at these locations will be used to estimate thickness and sea ice volume flux. Also, satellite systems such as IceSat and in the future CryoSat show promise in estimating sea ice thickness from space and will helpfully be used in the future. The use of EnviSat ASAR global monitoring mode will also be investigated to estimate ice motion in the smaller channels of Jones Sound, Smith Sound and Nares Strait which could not be resolved by the AMSR-E sensor.

6. ACKNOWLEDGEMENTS

The authors acknowledge the National Snow and Ice Data Center for providing the AMSR-E data products and the International Arctic Buoy Program for providing the Arctic buoy data. This work is partially funded by the Canadian Panel on Energy Research and Development (PERD). The CATS study is supported by the US National Science Foundation grant OPP-0230236 and is an element of the Arctic-Subarctic Ocean Flux (ASOF) program supported by the NSF Office of Polar Programs grant OPP-0230382.

7. REFERENCES

Agnew, T. A. , H. Le, and T. Hirose, 1997. Estimation of Large Scale Sea Ice Motion from SSM/I 85.5 GHz Imagery, *Annals of Glaciology*, 25, 305-311.

Cavalieri,D., C.Parkinson, P. Gloersen, 1999. Deriving long-term time series of sea ice cover from satellite.microeave multisensor data sets, *J. of Geophy. Res*., 104,C7,15803-15814

Carmack, E., 2000, The Arctic Ocean's Freshwater Budget: Sources, Storage and Export, In: The Freshwater Budget of the Arctic Ocean, ed. E. L. Lewis, Kluwer Acad., Norwell, Mass. pp. 91-126.

Kwok,R, G.F. Cunningham and S.S. Pang, 2004a. Fram Strait sea ice outflow. *J. of Geophy. Res*., 109, C01009, doi:10.1029/2003JC001785.

Kwok, R., S. Laxon, and W. Maslowski, 2004b. On the large outflow of Arctic sea ice into the Barents Sea, EOS Trans 85(47), 2004 Fall AGU Suppl. Abstract.

Kwok, R. and D. A. Rothrock, 1999. Variability of Fram Strait ice flux and North Atlantic Oscillation, *J. Geophy. Res.*, 104, C3, 5177-5189.

Kwok, R., A. Schweiger, D. A. Rothrock, S. Pang, and C. Kottmeier, 1998. Sea Ice motion from satellite passive microwave imagery assess with ERS SAR and buoy motions, *J. Geophy. Res.,* 103, C4, 8191-8214.

Melling, H., 2000. Exchanges of freshwater through the shallow straits of the North American Arctic, In: The Freshwater Budget of the Arctic Ocean, ed. E. L. Lewis,, Kluwer Acad., Norwell, Mass. pp 479-502.

Melling,H. and D.A.Reidel, 1996. Development of seasonal pack ice in the Beaufort Sea during the winter of 1991-1992: A view from below, *J. Geophys. Res.*, 101, No. C5, 11,975-11,992 (96JC00284).

Prinsenberg, S. and J. Hamilton, 2004. Monitoring the volume, freshwater and heat fluxes passing through Lancaster Sound in the Canadian Arctic Archipelago, *Atmosphere-Ocean*, 43(1), 2005, 1-22.

Prinsenberg,S. and I. Petersen, 1992. Sea Ice properties off Labrador and Newfoundland during LIMEX'89, *Atmosphere-Ocean*, 30, 2, 207-222.

Vinje, T., 2001. Fram Strait Ice Fluxes and Atmospheric Circulation : 1950-2000, *J. of Cl.*, 14,3508-3517.

Separation	Observations	Mean Difference	Standard Deviation	Mean Motion
1-day	198	-0.49	4.64	9.74

Table 1 Difference between AMSR-E and drifting buoys (km/day)

Gate Number	Gate Name	Effective L (km)	$\sigma_{f(day)}$ (km^2)	$\sigma_{f\ (month)}$ (km^2)	$\sigma_{f\ (winter)}$ (km^2)
1	Fram Strait	400	570	3130	7300
2	Baffin Bay	680	760	3800	10800
3	Davis Strait	400	570	3130	7300
4	Hudson Strait	140	345	1890	5350
5	M’Clure Strait	140	345	1890	5350
6	Griffith Island	50	205	1220	3180
7	Barrow Strait	60	226	1240	3500
8	Lancaster Sound	70	240	1330	3770
9	Jones Sound	45	195	1070	3020
10	Smith Sound	45	195	1070	3020
11	Nares Strait	30	-	-	-

Table 2 Effective length and sea ice area flux error estimates for each flux gate.

Fram Strait (gate 1)											
Winter	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total	Mean	Std. Dev.
2002/03	31	15	22	124	61	151	88	61	553	69	49
2003/04	31	44	123	140	120	72	45	59	635	79	42
Mean	31	30	73	132	91	112	67	60	594		
Baffin Bay (gate 2)											
2002/03	0	57	113	129	139	145	134	29	746	93	56
2003/04	1	61	82	172	129	100	65	17	627	78	56
Mean	0	59	97	150	134	123	99	23	687		
Davis Strait (gate 3)											
2002/03	0	22	24	92	162	120	117	18	554	69	61
2003/04	1	20	48	156	149	143	84	53	655	82	61
Mean	0	21	36	124	156	132	100	36	605		

Table 3. Monthly sea ice area flux in 10^3 km^2 for 2002/03 and 2003/04 winters

Hudson Strait (gate 4)											
Winter	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total	Mean	Std. Dev.
2002/03	-1046	443	6828	-14964	18459	19670	13576	1311	44277	5535	11591
2003/04	-926	-945	7565	843	11263	4195	13717	-2770	32942	4118	6145
Mean	-986	-251	7196	-7061	14861	11933	13647	-730	38609		
Lancaster Sound (gate 8)											
2002/03	-113	4499	7018	4706	16425	14814	13928	3206	64484	8060	6157
2003/04	-663	6907	8394	19322	19632	13147	1691	5567	73996	9249	7556
Mean	-388	5703	7706	12014	18029	13981	7810	4386	69240		
M'Clure Strait (gate 5)											
2002/03	4028	-8839	-5138	2069	4081	2617	1307	116	240	30	4633
2003/04	-2908	4563	-3942	1260	350	2006	-927	-946	-545	-68	2733
Mean	560	-2138	-4540	1665	2216	2312	190	-415	-152		
Barrow Strait (gate 7)											
2002/03	475	2235	2435	3157	5286	5210	4349	1475	24621	3078	1753
2003/04	299	4027	5571	7262	4775	3604	3431	1524	30492	3812	2195
Mean	387	3131	4003	5210	5031	4407	3890	1499	27557		
Griffith Island (gate 6)											
2002/03	1748	3408	2036	594	2096	1	1185	1032	12101	1513	1051
2003/04	-898	3356	3981	5867	3547	3268	450	541	20113	2514	2253
Mean	425	3382	3009	3231	2822	1635	818	787	16107		

Table 4. Monthly sea ice area flux in km^2 for 2002/03 and 2003/04 winters.

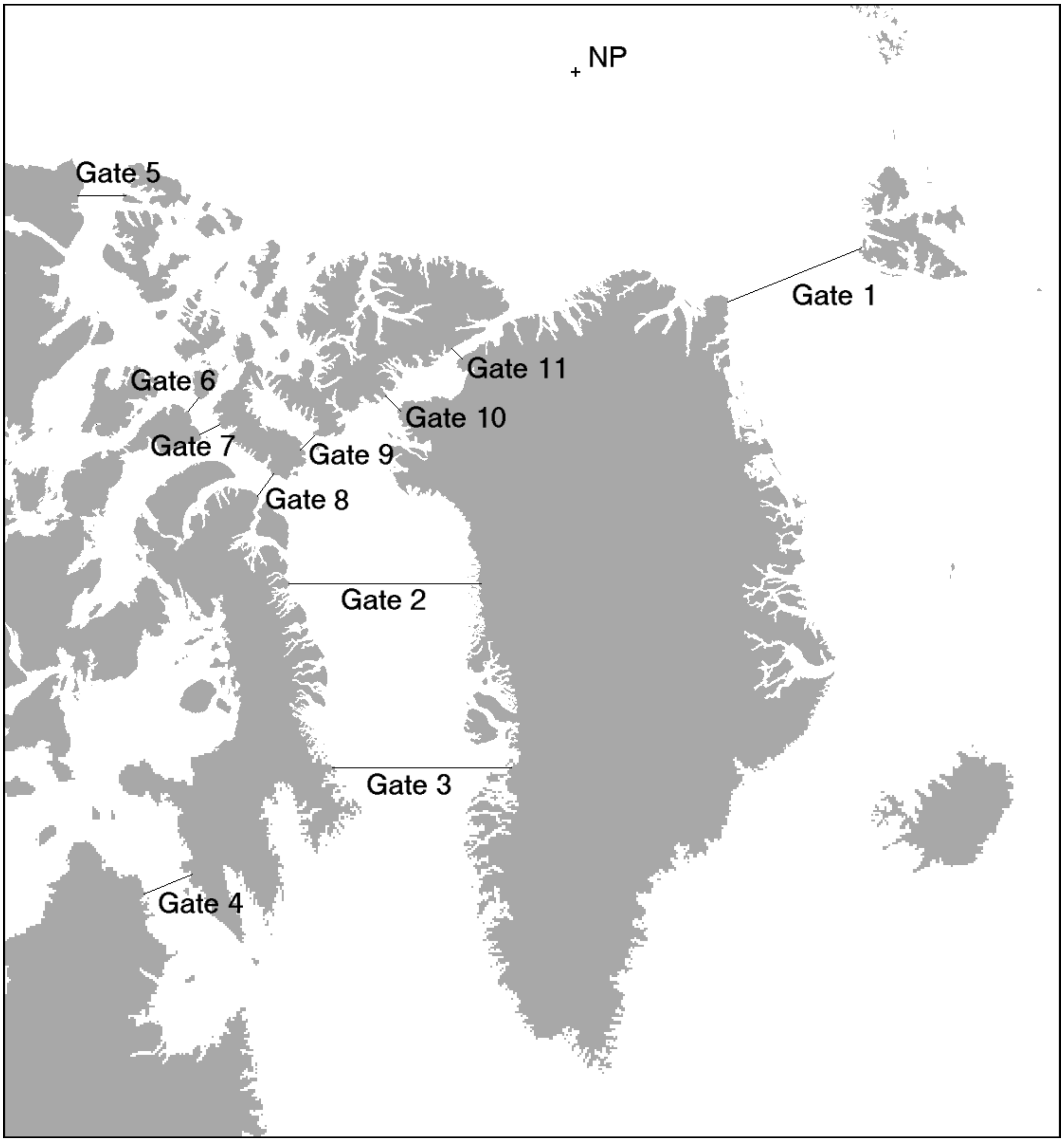

Figure 1 Location and names of flux gates: 1- Fram Strait, 2- Baffin Bay, 3- Davis Strait, 4- Hudson Strait, 5- M'Lure Strait, 6- Griffith Island, 7- Barrow Strait, 8- Lancaster Sound, 9- Jones Sound, 10- Smith Sound, 11- Nares Strait.

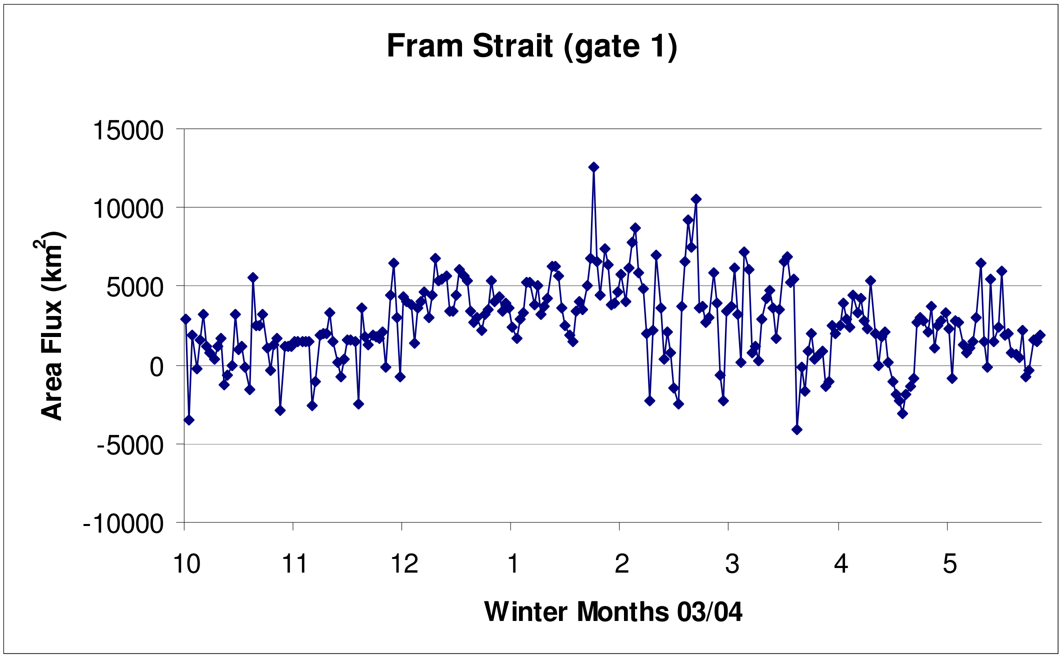

Figure 2 Daily sea ice area transport for Fram Strait.

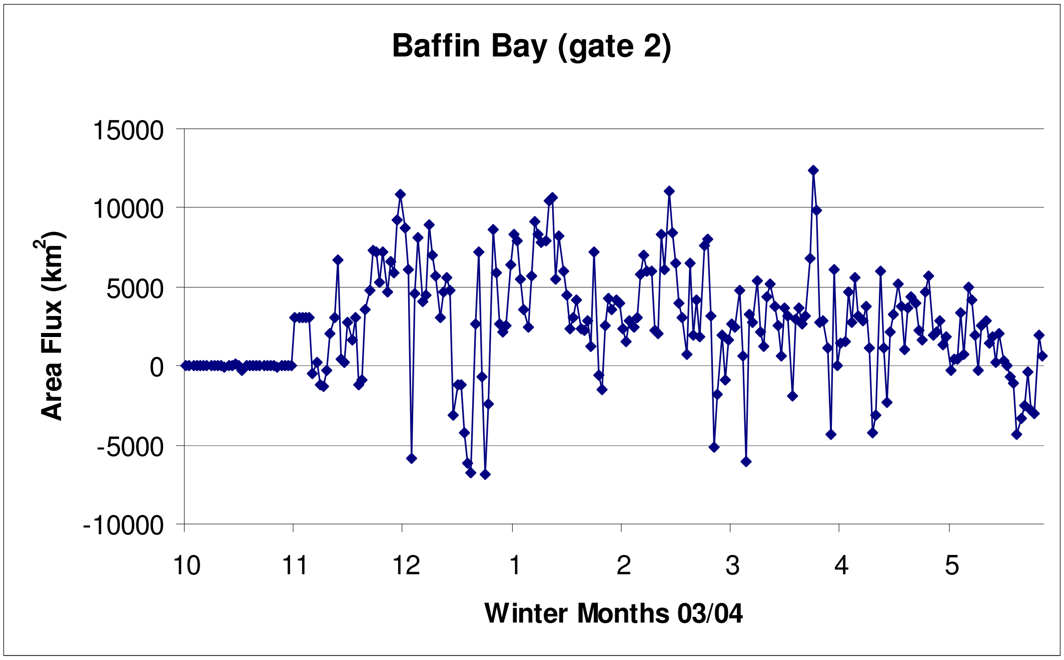

Figure 3 Daily sea ice area transport for Baffin Bay.

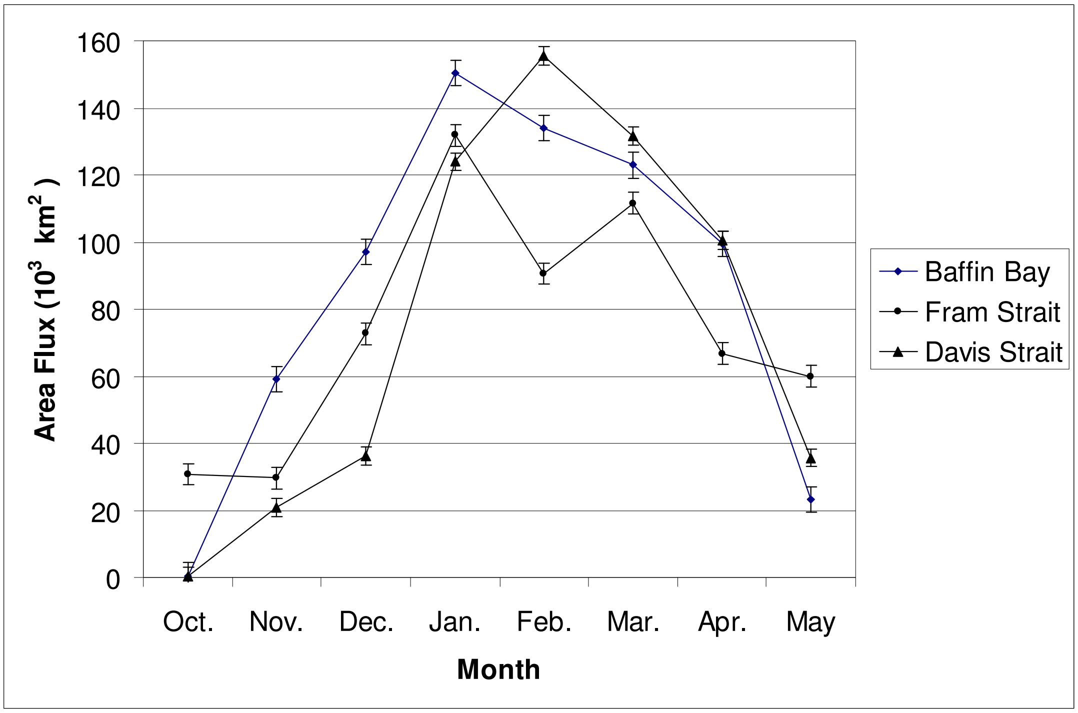

Figure 4 Mean monthly sea ice area flux for Fram Strait, Baffin Bay and Davis Strait for 2002/3 and 2003/04.

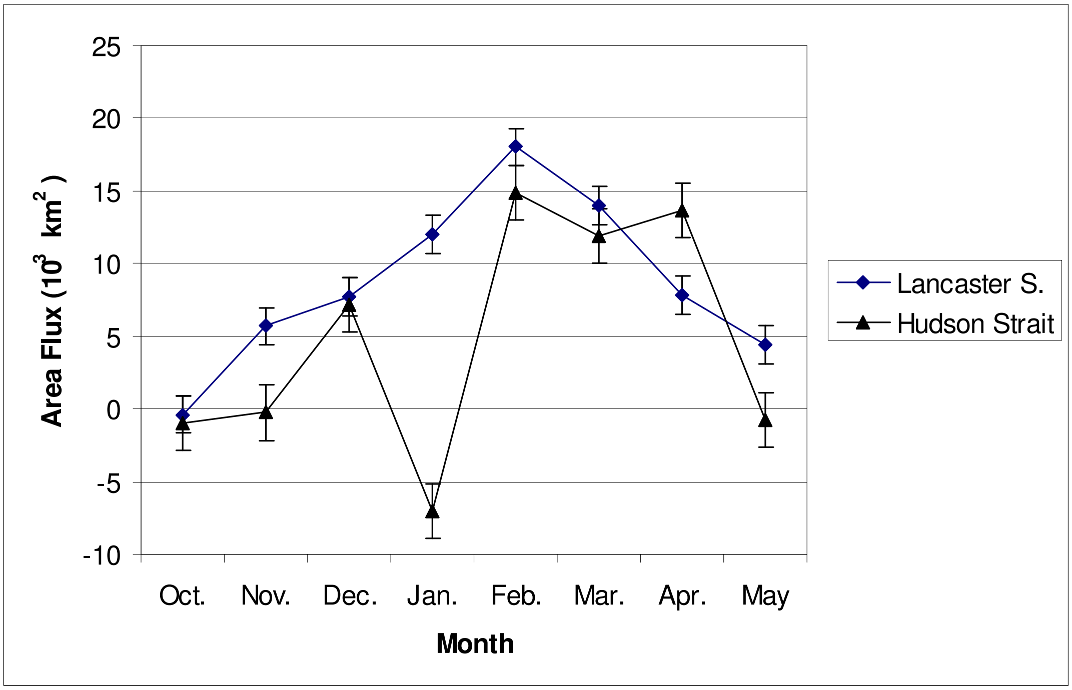

Figure 5 Mean monthly sea ice area flux for Lancaster Sound and Hudson Strait for 2002/3 and 2003/04.

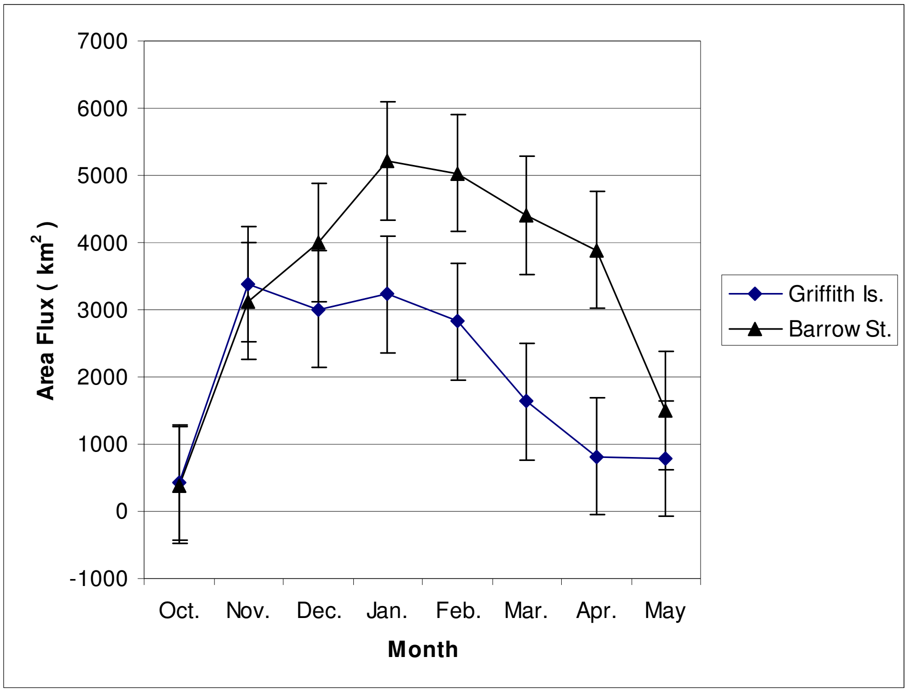

Figure 6 Two-year Average sea ice area flux for Griffith Island gate and Barrow Strait gate for 2002/3 and 2003/04.

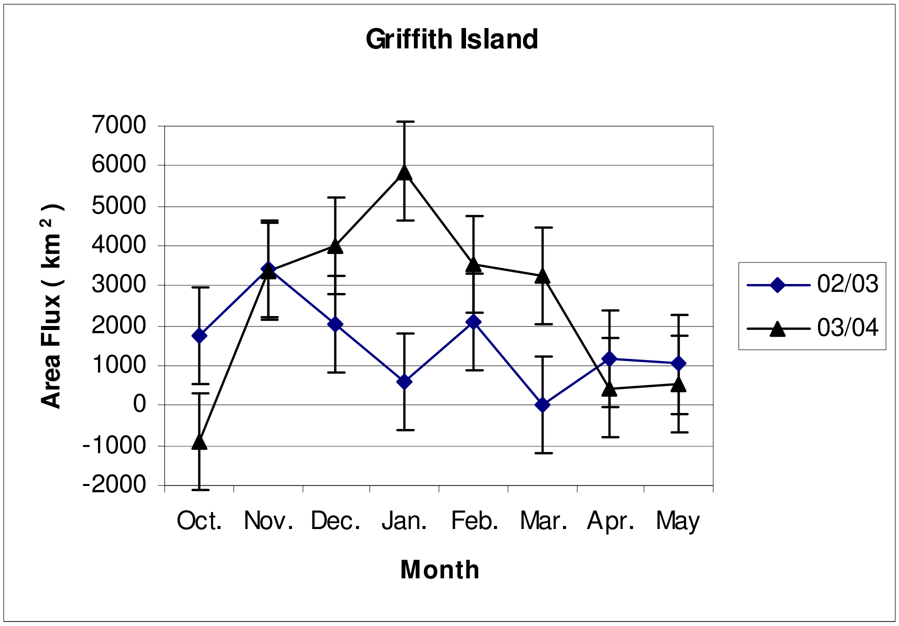

Figure 7 Mean monthly sea ice are flux for winter of 2002/03 and 2003/04.

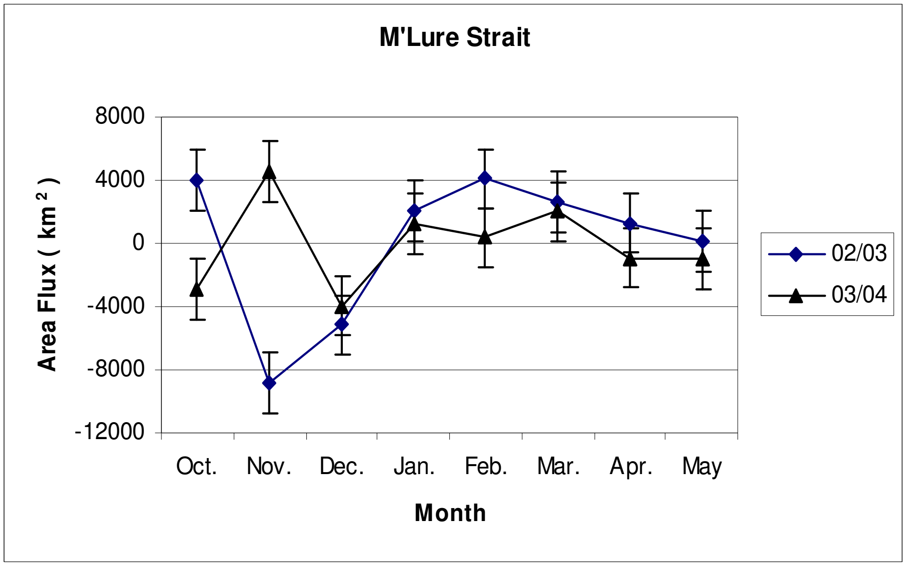

Figure 8 Mean monthly sea ice are flux for winter of 2002/03 and 2003/04.