HUDSON BAY AND UNGAVA BAY
RUNOFF AND ICE-MELT
1963-1992

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1995

Canadian Contractor Report of Hydrography and Ocean Sciences 45

Fisheries and Oceans
Pêches et Océans

Canada

Canadian Contractor Report of Hydrography and Ocean Sciences

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*Prepared under contract through DSS Contract No. FP953-4-0832/01-HAL. Published by the Department of Fisheries and Oceans for the sea-ice program at Bedford Institute of Oceanography through funds of the Federal Panel of Energy Research and Development.

Cat. No. FS 97-17/45E ISSN 0711-6748

Correct Citation:

Loucks, R.H. and R.E. Smith. 1995. Hudson Bay and Ungava Bay runoff and ice-melt 1963-1992. Can. Contract. Rep. Hydrogr. Ocean Sci. 45:x + 73 pp.

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ABSTRACT

Loucks, R.H. and R.E. Smith. 1995. Hudson Bay and Ungava Bay runoff and ice-melt 1963-1992. Can. Contract. Rep. Hydrogr. Ocean Sci. 45:x + 73 pp.

Freshwater from runoff and ice melt leaving Hudson Bay and Foxe Basin through Hudson Strait amounts to approximately 0.2 Sverdrup and has the potential to significantly affect the oceanographic properties of not only the Hudson Bay area itself but also regions downstream along the Labrador shelf. In this report, the third of a series, the runoff and ice melt monthly data are extended to a thirty-year period (1963-1993) and are presented in tables and plots, together with estimated uncertainties.

RÉSUMÉ

Loucks, R.H. and R.E. Smith. 1995. Hudson Bay and Ungava Bay runoff and ice-melt 1963-1992. Can. Contract. Rep. Hydrogr. Ocean Sci. 45:x + 73 pp.

Le débit d'eau douce prevenant du ruissellement et de la fonte des glaces sortant de la baie d'Hudson et du bassin Foxe par le détroit d'Hudson est d'environ 0.2 Sverdrup et peux affecter d'une facon significative les propriétées non seulement de la baie d'Hudson mais aussi des régions en aval de long de la côte du Labrador. Ce rapport, le troisième d'une série, contient les données mensuelles pour l'eau de ruissellement et de la fonte des glaces pour une période de trente ans (1963-1993). Elles sont presentées sous forme de tables et de graphiques avec un estime des erreurs.

Acknowledgements

This work was supported by the Federal Panel on Energy Research and Development (PERD).

Dr. Simon J. Prinsenberg, Fisheries and Oceans, Bedford Institute of Oceanography, was the Scientific Authority and provided valuable guidance and advice.

We are indebted to several data sources: Philip Cote of the Ice Centre, Environment Canada for digital ice and snow data, to Roger Couture, Direction du Milieu Hydrique, Ministere de L'Environnement et de la Faune, Quebec, and to Water Survey of Canada for monthly means of gauged river discharge data, and to Mike Webb, Climate Information Branch, Atmospheric Environment Service for daily mean temperature data for Churchill.

Executive Summary

Freshwater from runoff and ice melt dilutes the surface layer of Hudson Bay and surrounding water bodies and produces a surface outflow through Hudson Strait. Seasonal variability in runoff and ice melt are of interest because this freshwater flux affects the circulation and density structure of the Bay itself and of the waters overlying the Labrador and Newfoundland Shelves.

Previous work on seasonal variability of runoff and ice melt upstream of Hudson Strait documented the period 1963-83. This report extended that work from 1984 to 1992 using the same analysis techniques to provide a 30-year monthly mean climate variable. Run-off and ice melt time series were combined for the 30-year period into single freshwater flux signals exiting Hudson Strait, corresponding to three ocean drift speed scenarios.

River runoff and ice melt data were organized into the eight drainage regions previously identified: five regions for Hudson Bay and regions for James Bay, Foxe Basin and Ungava Bay/Hudson Strait. In cases where data were unavailable, documentation is provided for the use of surrogate data.

For the 1963-92 period, the measurement and extrapolation uncertainties, assuming all contributions are random, amount to ±18% in combined runoff and ice melt monthly effluxes at Hudson Strait; these arise mainly from ice melt. The Base Drift annual cycles of river and ice melt discharges at Hudson Strait indicate the months of peak efflux are August and September, that ice melt is a much stronger source on average than river runoff, and that ice melt is much more variable between months than runoff. The Zero Lag annual cycle peaks in June, and the Fast Drift annual cycle peaks in July. There is obvious inter-annual variability in the June peak (Zero Lag time series), a variability somewhat reduced by river regulation after 1980.

1. Introduction

Freshwater from runoff and ice melt entering Hudson Bay and surrounding water bodies dilutes the surface layer of the bay and produces a surface outflow through Hudson Strait. The freshwater flux leaving Hudson Strait affects the circulation and density structure of the waters overlying the Labrador and Newfoundland Shelves. Seasonal variability in ice growth and decay and runoff will affect the density structure in the bay directly and indirectly through its effect on circulation.

Previous work on the seasonal variability of runoff and ice melt upstream of Hudson Strait entrance has been documented for the twenty-one year period, 1963-83. Monthly mean runoff rates for eight drainage areas of Hudson Bay and Ungava Bay (Figure 1.1) were compiled in Prinsenberg et al. (1987), hereafter designated (P) and similarly ice melt cycles for Hudson Bay and Ungava Bay (Figure 1.2) were compiled for the same period in Loucks and Smith, (1989), hereafter designated (L). Using three ocean drift scenarios, runoff and ice melt time series were separately compiled to provide freshwater flux due to runoff and ice melt exiting Hudson Strait. It was found that ice melt dominates river runoff.

The purpose of this report is to extend this work from 1984 to 1992 using the same analysis techniques and thus to provide a 30-year monthly mean climate variable useable for east coast long term variability analysis of the ice cover and ocean environment. Runoff and ice melt time series are combined for the 30-year period into a single freshwater flux signal exiting Hudson Strait, using three ocean drift speed scenarios.

2. Data Collection

2.1 1984-92 Runoff Data

River runoff data for the period 1984-92 were organized into the eight drainage regions used in P: five regions for Hudson Bay and one region each for James Bay, Foxe Basin and Ungava Bay (Figure 1.1; Table 2.1).

Gauged records containing monthly runoff averages were supplied by Water Survey of Canada.

Since 1963, several gauging stations have been moved or discontinued, particularly in the latter part of the period of interest (Table 2.2). In addition, not all of the rivers were gauged, so a great deal of runoff data had to be generated using neighbouring river runoff data as estimators. The best estimator under the different circumstances was used to minimize uncertainties. As a result, the estimators for a given region may vary for different time periods. Surrogate data from rivers in neighbouring drainage areas were prorated using monthly discharge factors for each river set to fill significant data gaps (Appendix A). On the other hand, small random data gaps occurring in several records were filled by interpolating from monthly means of adjacent rivers.

Lack of data for coastal areas (where the gauge is typically located upstream of the mouth of the river) and for ungauged watersheds was accounted for by prorating surrogate gauged data by the ratio of total ungauged area to gauged area.

Individual treatment of each river drainage area is documented in Appendix A.

As in P, uncertainties are assessed at ± 5% for gauged runoff, ±15% for an ungauged segment of an otherwise gauged watershed area e.g. coastal areas, and ±25% for ungauged watersheds where signals from neighbouring watersheds are used as surrogates.

2.2 1984-92 Ice Melt Data

Data from the same eleven stations selected to represent the ice-volume areas in L were used (Figure 1.2, Table 2.3).

Observations as frequent as once per week of ice and snow thickness data were supplied by Ice Climatology Services, Ice Centre, Environment Canada.

The maximum thickness of ice (plus 10% of the snow depth) in centimetres and the corresponding time in Julian days as well as the time of open water were identified for each year. These are plotted and recorded in Appendix B.

The maximum thickness of ice and snow were readily identified for most stations during the period of interest (1984-92). The time of open water was often missing, and an average value from the entire record (1963-92) was used although this sacrificed some interannual variability.

To identify the month end thickness throughout the melt season, linear interpolation was used on data plotted in time series for each year and each station (e.g. Figure 2.1). Where data was scarce, the exponential decay model (Billelo, 1980) for melt was least-squares fitted to determine ice thickness values for the last day of each month, as had been previously applied in L. The model requires that a representative time constant be calculated from years with plentiful data for the particular station.

Individual treatment of each station is documented in Appendix B.

Using the same regional division as for runoff, the Hudson Strait - Ungava Bay region (Figure 1.2) is the only region which has data for more than one ice station. The month-end thickness data for the four stations representing Hudson Strait and Ungava Bay (Cape Dorset, Quaqtaq, Iqaluit and Kuujjuak) were averaged.

Month-end thickness data were converted to monthly volume discharge data for each region (Table 2.4) as described in L.

Incomplete records were filled by regressing maximum thickness and corresponding time from a neighbouring station when it was possible to hindcast for a period when data were available for both stations and when resulting correlation coefficients were satisfactory. The average value was used in cases where the time of open water was not available. The average time constant already calculated for each station was then used in the exponential model to determine month-end ice volumes between the time of maximum thickness and the time of open water.

Uncertainties for the period 1984-1992 are assessed at ±15% where ice thickness measurements were available, ±25% where they were not available and where surrogates were used.

2.3 1963-1992 Runoff and Ice Melt Data

The 1963-83 runoff data (P) and the 1984-1992 runoff data for the eight regions (§2.1.1) were merged to form a 30-year time series for runoff. The 1963-83 ice melt values, multiplied by 0.9 to convert volume of ice to mass of ice, were merged with 1984-92 ice melt data to form a second 30-year time series.

Runoff data and ice melt data from the regions were merged using three sets of lags to simulate a single freshwater efflux from Hudson Strait. For the Zero Lag scenario all lags are set to zero. This scenario shows the availability of fresh water locally. Table 2.4 shows the lags used for ice melt in the Base Drift and Fast Drift scenarios. For the Base Drift scenario the lags are chosen to reflect the best information available on ocean drift speeds along the pathways to Hudson Strait. For the Fast Drift scenario, lags are deliberately chosen with a bias toward overestimated drift speeds.

3. Results

3.1 1984-92 Runoff and Ice Melt Data

Estimated monthly runoff discharges were compiled by region as defined in Figure 1.1. These estimates are tabulated in Tables 3.1 to 3.8. In all regions, within-year variability is larger than interannual variability. The discharges in the spring are largest followed by a secondary peak in the fall.

Uncertainties for these estimates are derived as in P and L and are shown in Table 3.9.

Ice thickness results are shown in Appendix Figures A.1 to A.11. They are characteristically highly variable year to year. Ice melt estimates by region are given in Tables 3.10 to 3.17.

Uncertainties for total ice melt for the period 1963-1983 are evaluated at ±17%; for 1984-1992, at ±18% (Table 3.18).

Runoff discharges from all regions were added, using three sets of lags (Table 2.4), to form estimates of total runoff leaving Hudson Strait. The spring peaks of runoff occur locally (Zero Lag) almost simultaneously with the ice melt peaks (Figure 3.1; Table 3.19). The runoff series displays a secondary peak not seen in the ice melt series. Occasionally when a partial melt is followed by a new thickening of ice cover, ice melt for a particular month is shown as negative. Comparison between the runoff and ice melt curves show that ice melt volume per year is larger (2x) than runoff volume.

Similar to the Zero Lag time series, in the Fast Drift scenario the peaks of runoff and ice melt tend to occur simultaneously (Figure 3.2; Table 3.20).

For the Base Drift, deemed the scenario best simulating the circulation pattern, the ice melt and runoff peaks tend not to arrive at Hudson Strait simultaneously; the former dominates (Figure 3.3; Table 3.21). It should be noted that the base drift is based on summer observations; possibly the spring circulation is faster and a better scenario to simulate the freshwater flux exiting Hudson Strait.

3.2 1963-92 Runoff and Ice Melt Data

The Base Drift annual cycles of river and ice melt discharges at Hudson Strait (Figure 3.4) indicate that the months of peak efflux are August and September, that ice melt is a much stronger source on average than river runoff, and that, in this scenario, ice melt is also much more variable between months than runoff. Myers et al (1990) suggest that November is the month of minimum surface salinity at 50 m depth in Hudson Strait. Depending on the tidal mixing strength the minimum at the surface will be earlier by several months but hard to verify due to lack of data.

The Base Drift annual cycle of combined freshwater efflux (Figure 3.5) peaks in August/September at approx 0.2 Sverdrup. The between-years standard deviation for a particular month varies approximately proportionally with the mean.

The Zero Lag annual cycle (Figure 3.6) peaks in June, i.e. the largest amount of liquid freshwater is 'available' in the system in June. The Fast Drift annual cycle (Figure 3.7) peaks in July.

Interpreting the Zero Lag scenario (Figure 3.8) as representing the freshwater (liquid state) available in the Hudson Bay system, it is apparent that there is an enormous pulse (as high as 0.5 Sverdrup) of available fresh water in June each year. The inter-annual variability in this June peak is also evident. This variability is somewhat reduced by river regulation/hydro dams after 1980.

The Fast Drift time series (Figure 3.9) is similar in peak amplitude to that for the Zero Lag time series (Figure 3.8), but the years exhibiting extreme discharges are not the same.

In the Base Drift scenario (Figure 3.10) peak discharges are considerably lower than in the other scenarios, relatively high frequency variability is evident, and interannual variability in the summer peaks is strong.

3.3 Variability and Uncertainties

The annual mean freshwater discharge (Zero Lag) (Figure 3.11) shows peaks in 1972 and 1983, and troughs in 1977 and 1981. The graph for Fast Drift (Figure 3.12) shows similar features. The Base Drift graph (Figure 3.13) shows additional peaks and troughs. These Base Drift annual mean discharges have been tested with ANOVA and do not show statistically significant interannual variability.

These standardized anomalies are differences between actual estimated monthly freshwater discharges at Hudson Strait and the average for that month, divided by the standard deviation for that month.

All three scenarios exhibit log-normal behaviour, i.e. larger anomalies positive than negative. The Base Drift scenario (Figure 3.14) shows more high frequency variability than the other scenarios (Figures 3.15 & 3.16).

Uncertainties were estimated as in P and L. The measurement and extrapolation uncertainties, assuming all contributions are random, amount to ±18% in combined runoff and ice melt monthly effluxes at Hudson Strait. These uncertainties arise mainly from the ice melt, both because ice melt is the largest contributor to efflux and the least certain.

One uncertainty not yet discussed is the relationship between the local landfast ice thicknesses used in this report and the actual offshore ice thickness. As seen in Prinsenberg (1988) the amount of ice volume in offshore ice ridges can be substantial. For Hudson Bay an extra 20% of ice may be present in ice ridges increasing to 90% for the rough ice cover of Foxe Basin.

Errors in assigning lags can, as in P and L and because of strong seasonal variability, lead to substantial errors in estimates of combined efflux. For months of peak efflux in the Base Drift scenario, the assumption of one month errors in lags leads to variations of as much as 35% in estimates. This large uncertainty will not be encountered if observations in Hudson Strait confirm that the timing for the Base Drift peak efflux corresponds to that of the observed peak.

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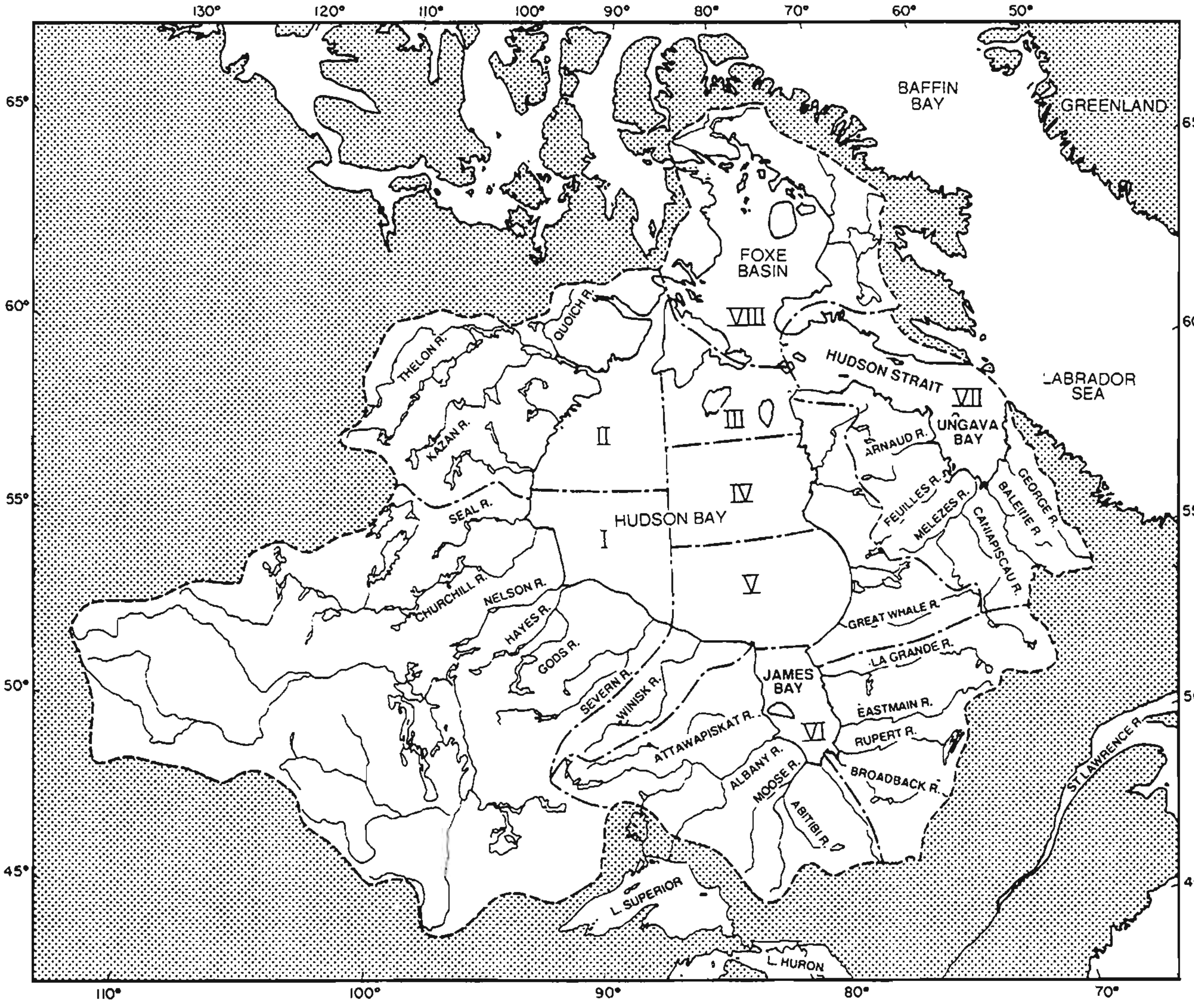

Figure 1.1 Map of Hudson Bay drainage areas and receiving seawater regions.

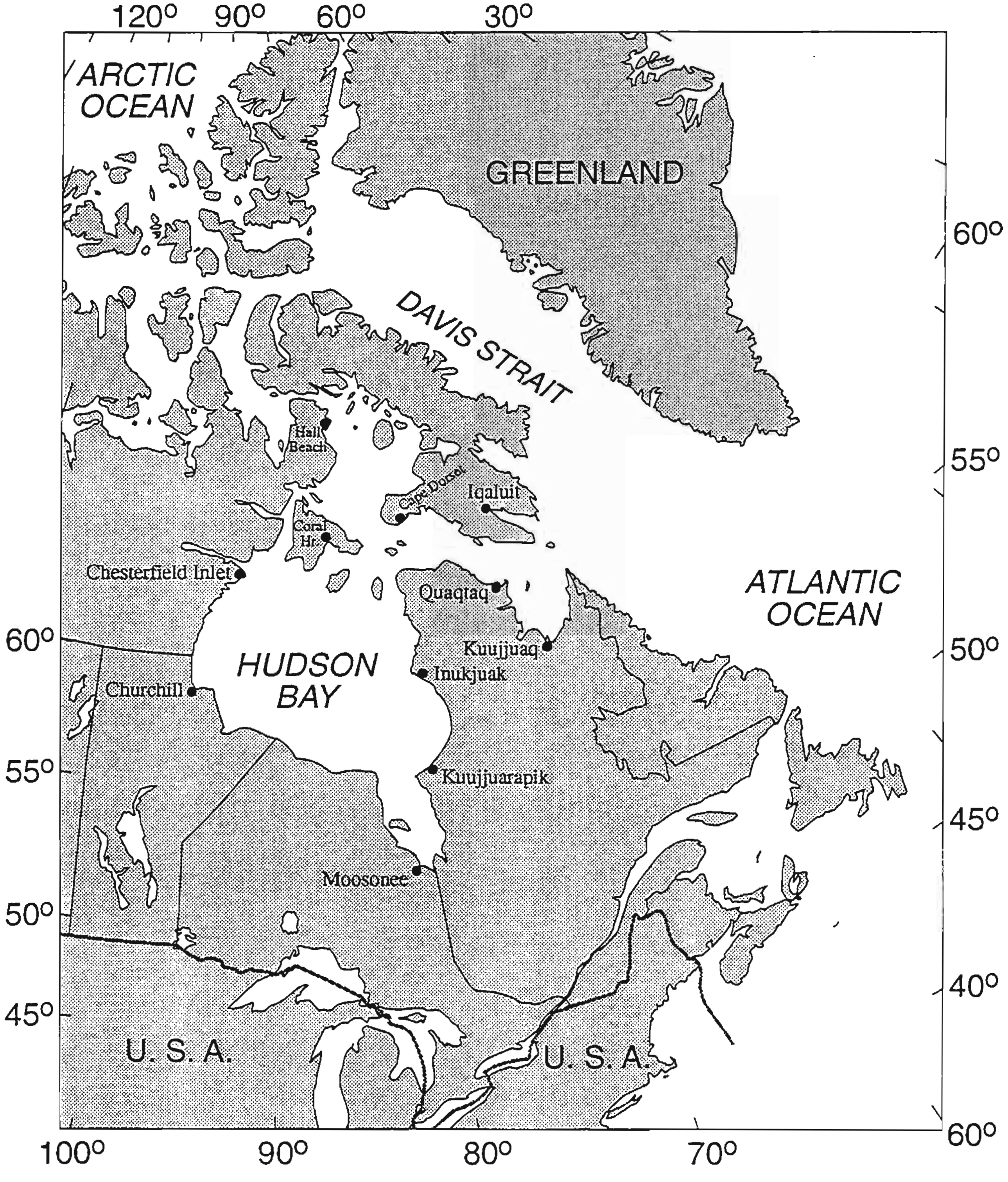

Figure 1.2 Ice thickness monitoring stations.

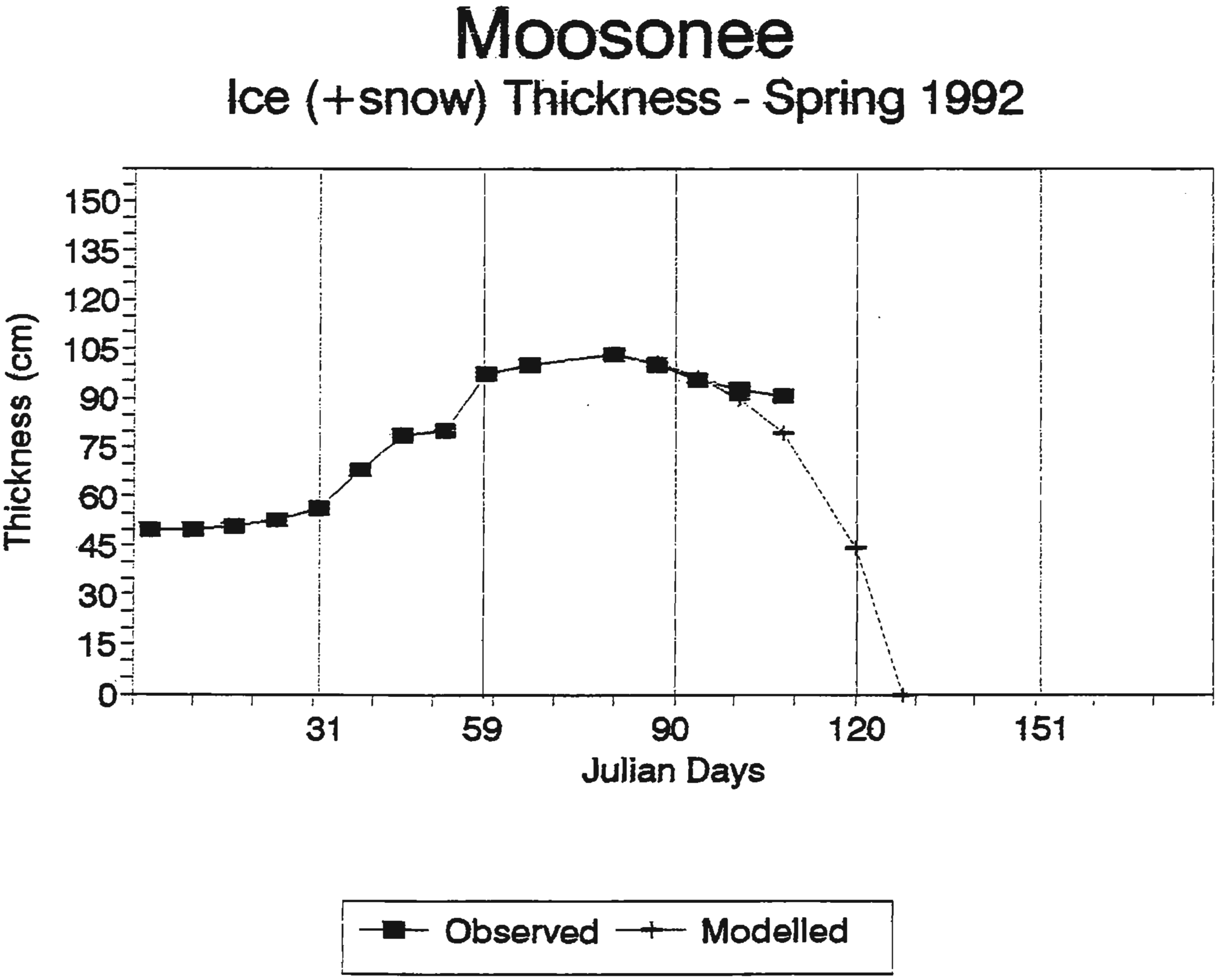

Figure 2.1 Time series of ice and snow thickness measurements - Moosonee, 1992.

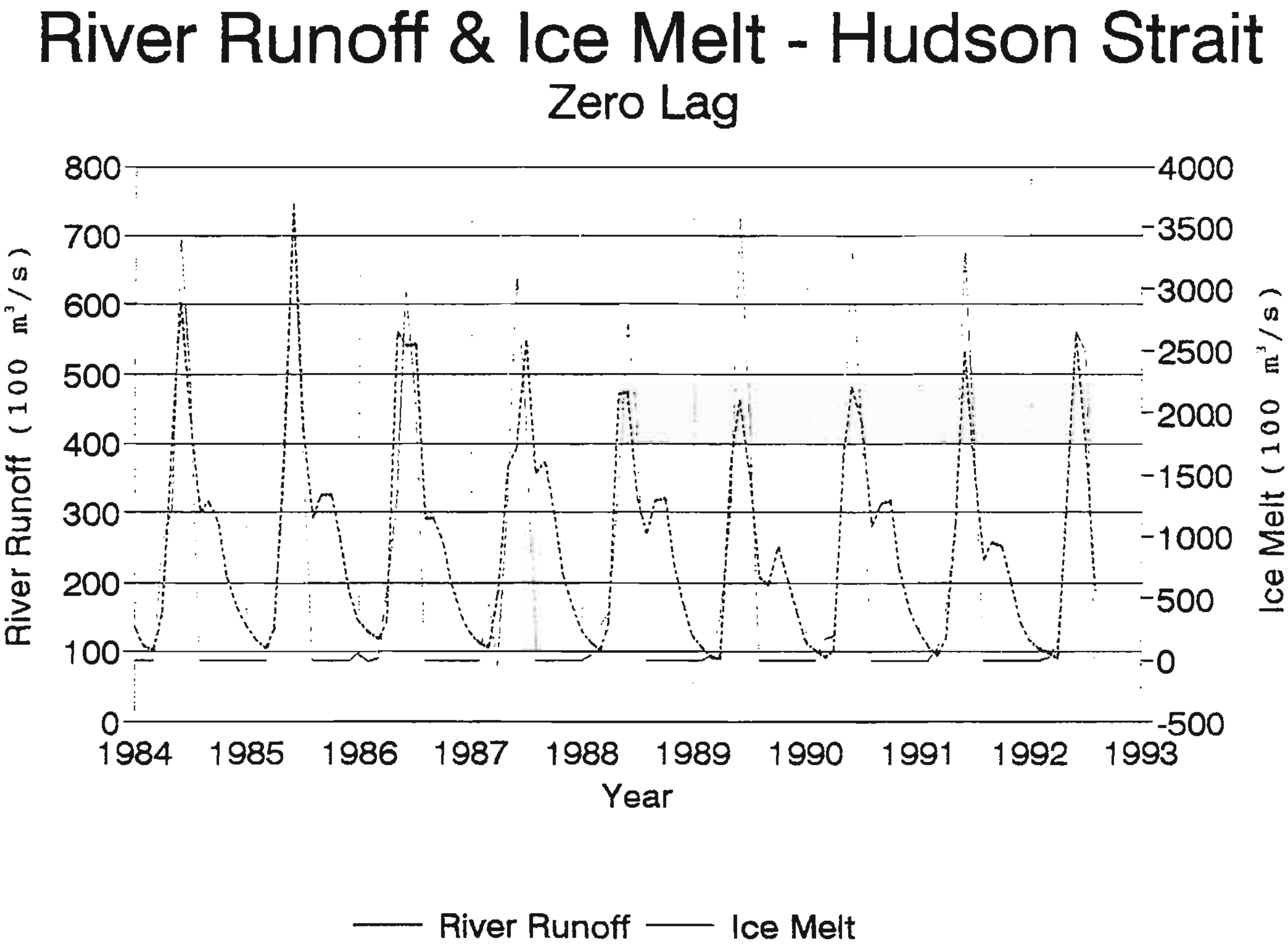

Figure 3.1 Time series plot of river runoff and ice melt (m^3s^{-1}), Hudson Strait, zero lag case, 1984-92.

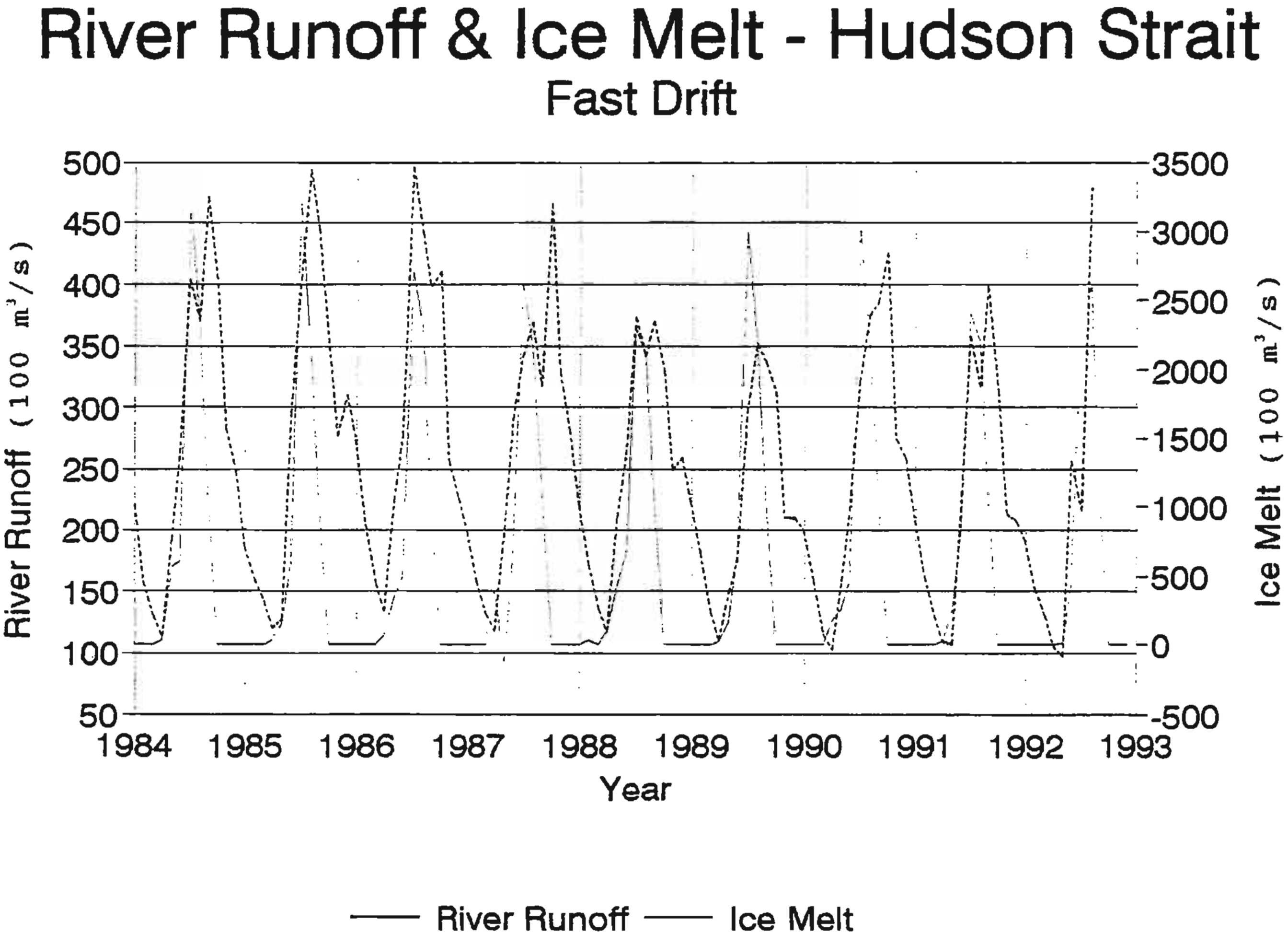

Figure 3.2 Time series plot of river runoff and ice melt (m^3s^{-1}), Hudson Strait, fast drift case, 1984-92.

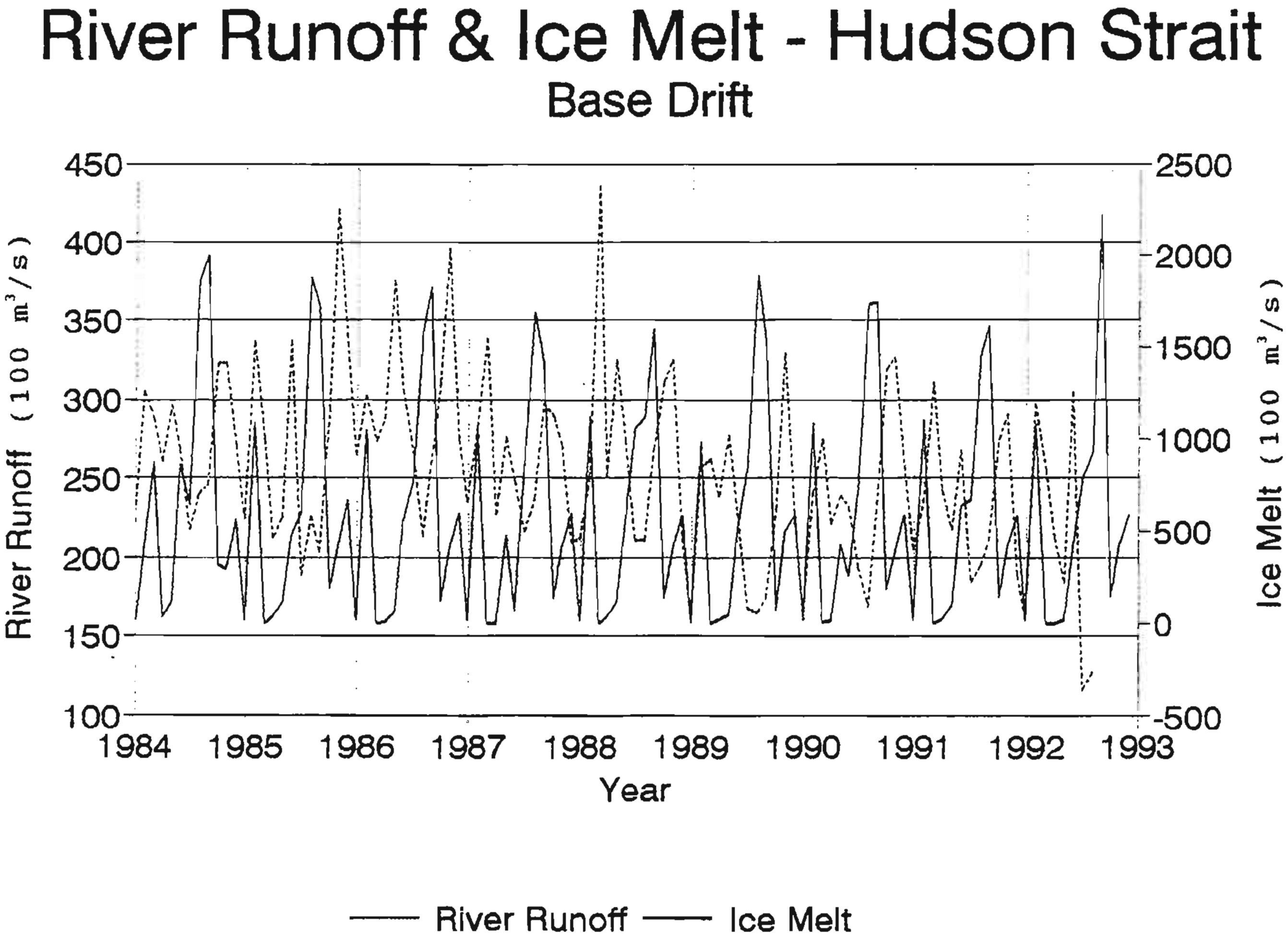

Figure 3.3 Time series plot of river runoff and ice melt (m^3s^{-1}), Hudson Strait, base drift case, 1984-92.

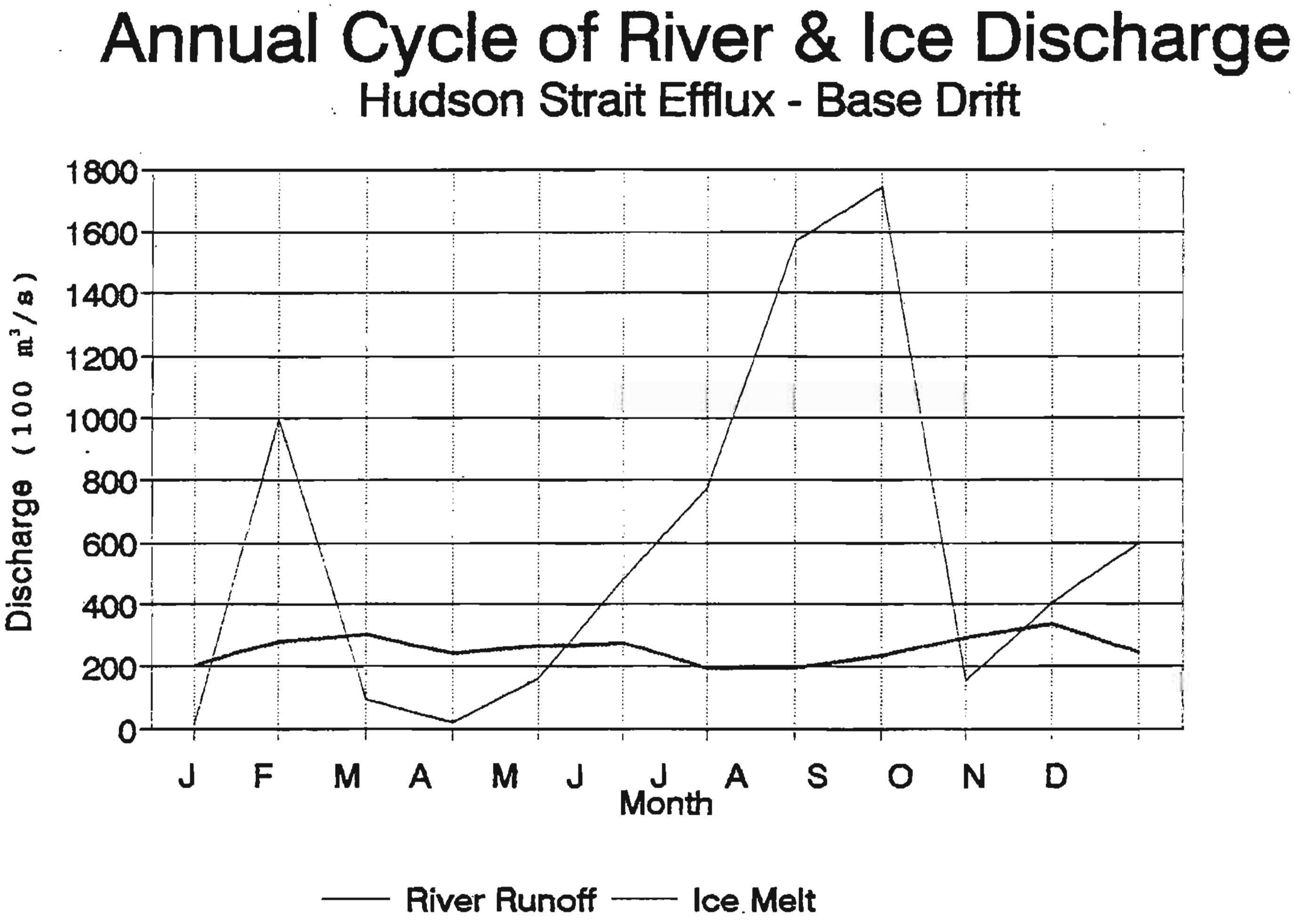

Figure 3.4 Annual cycle of river and ice discharge (m^3s^{-1}) - Hudson Strait efflux, base drift 1963-92.

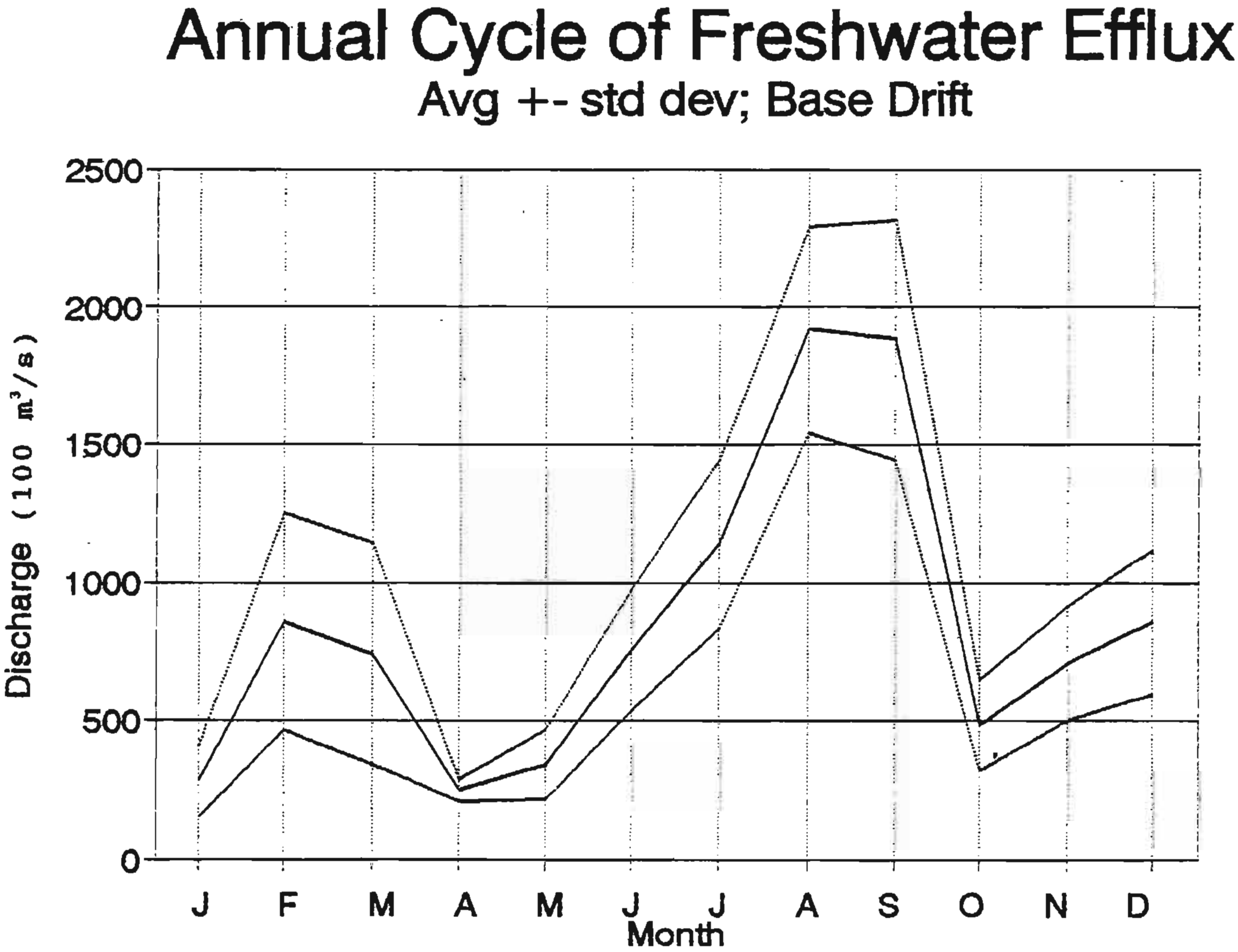

Figure 3.5 Annual cycle of freshwater (runoff plus ice melt) efflux (m^3s^{-1}) - average ± standard deviation - from Hudson Strait, Base Drift, 1963-92.

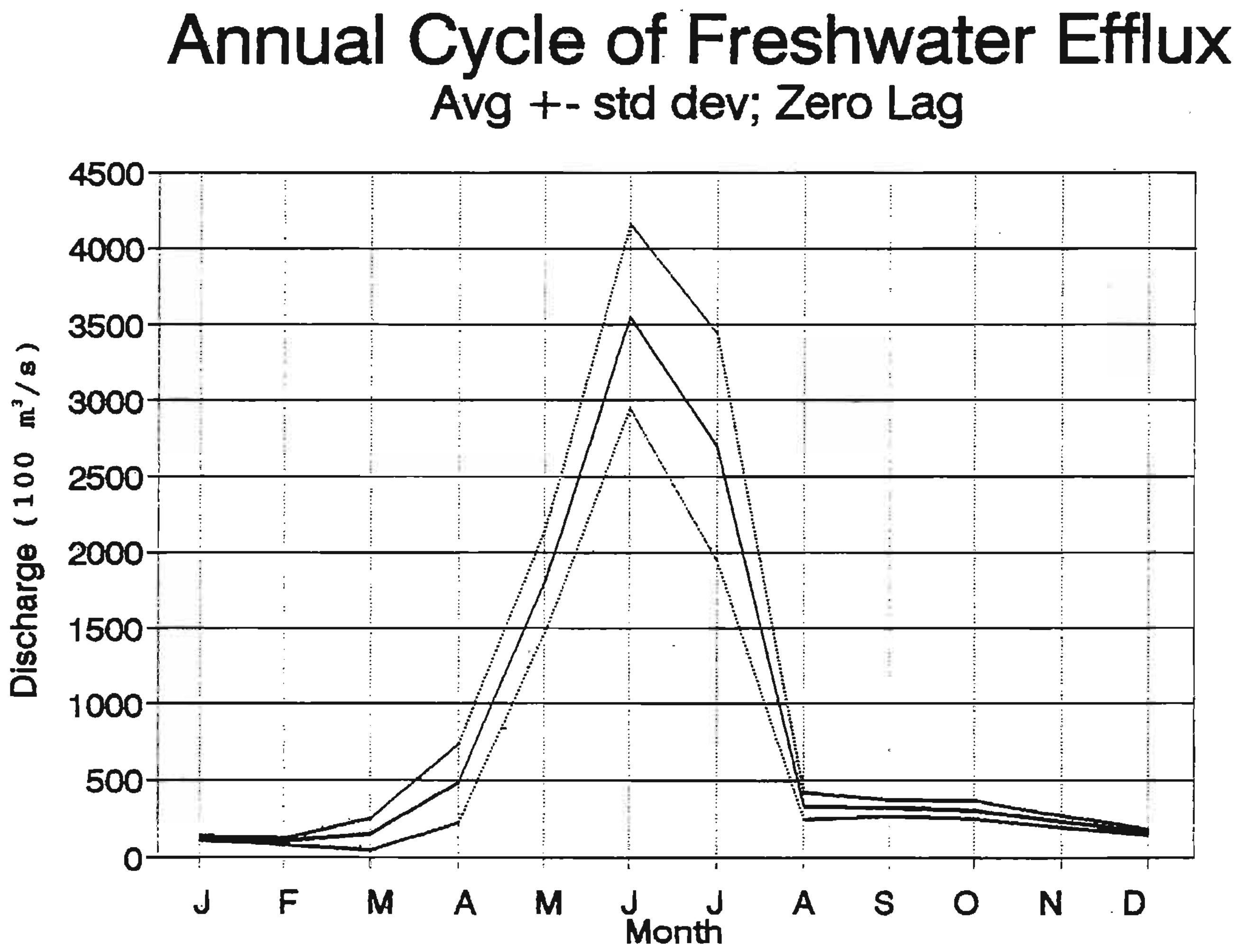

Figure 3.6 Annual cycle of freshwater efflux (m^3s^{-1}) - average ± standard deviation - from Hudson Strait, Zero Lag, 1963-92.

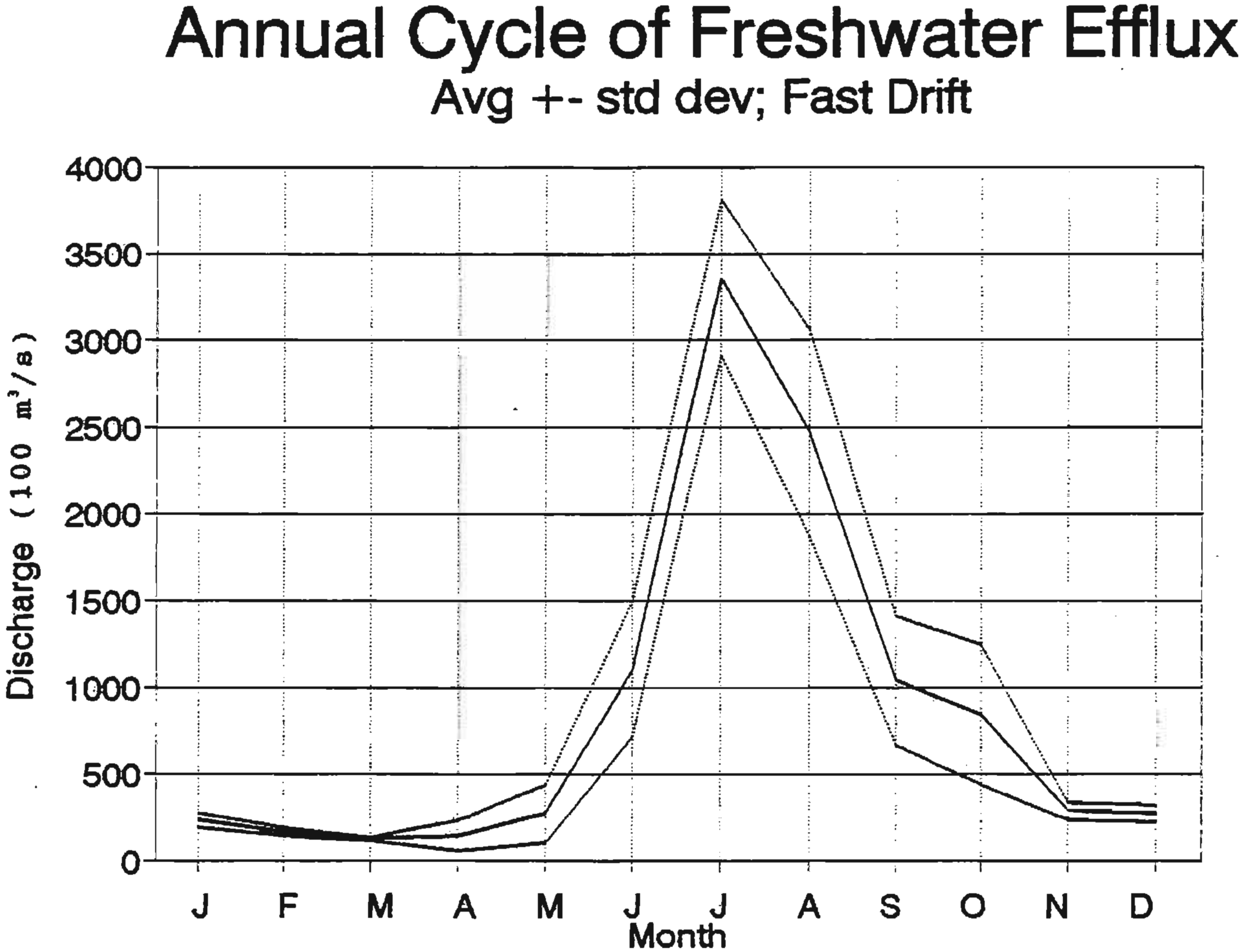

Figure 3.7 Annual cycle of freshwater efflux (m^3s^{-1}) - average ± standard deviation - from Hudson Strait, Fast Drift, 1963-92.

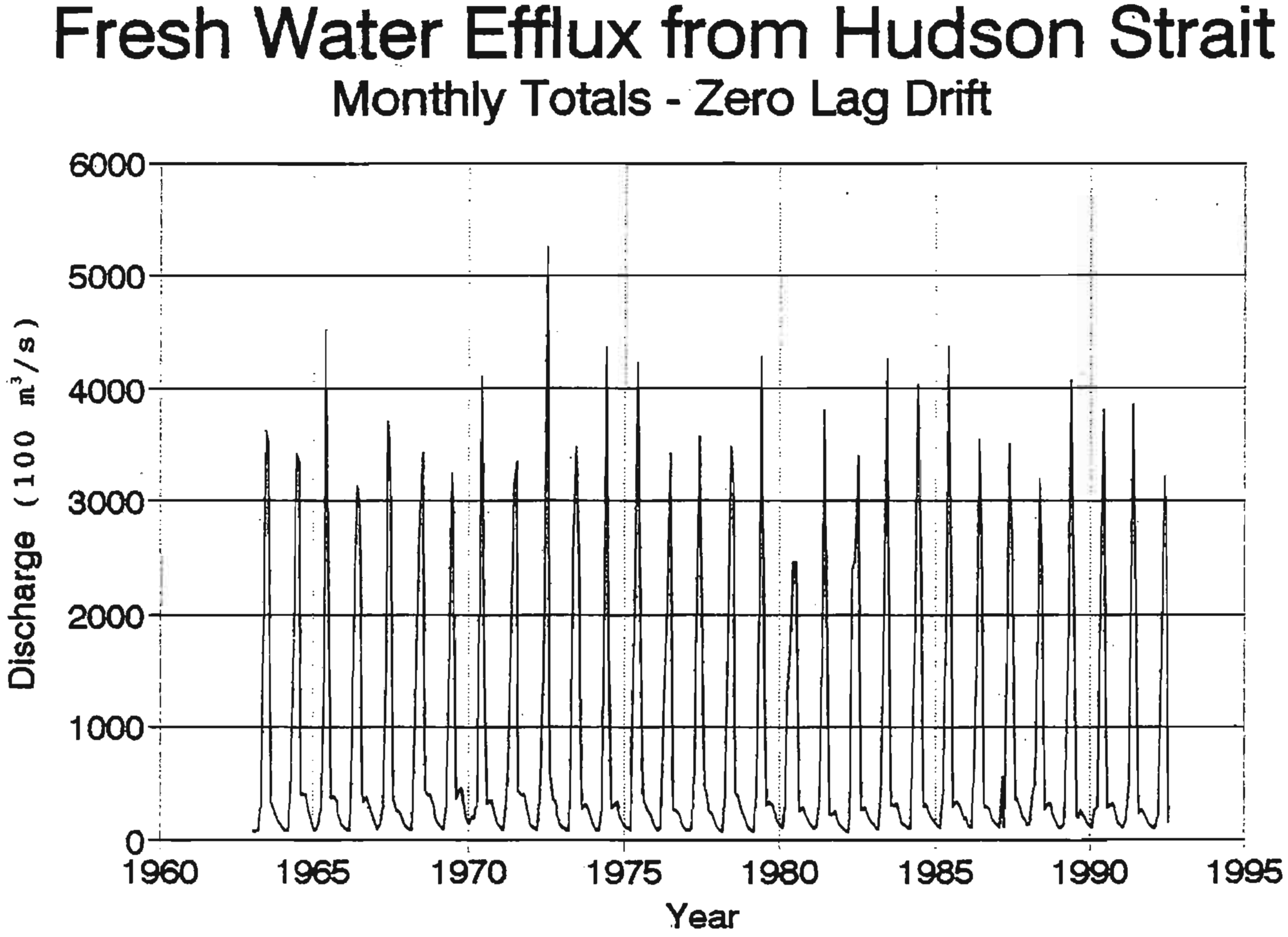

Figure 3.8 Monthly totals of fresh water efflux (m^3s^{-1}) from Hudson Strait, Zero Lag drift, 1963-92.

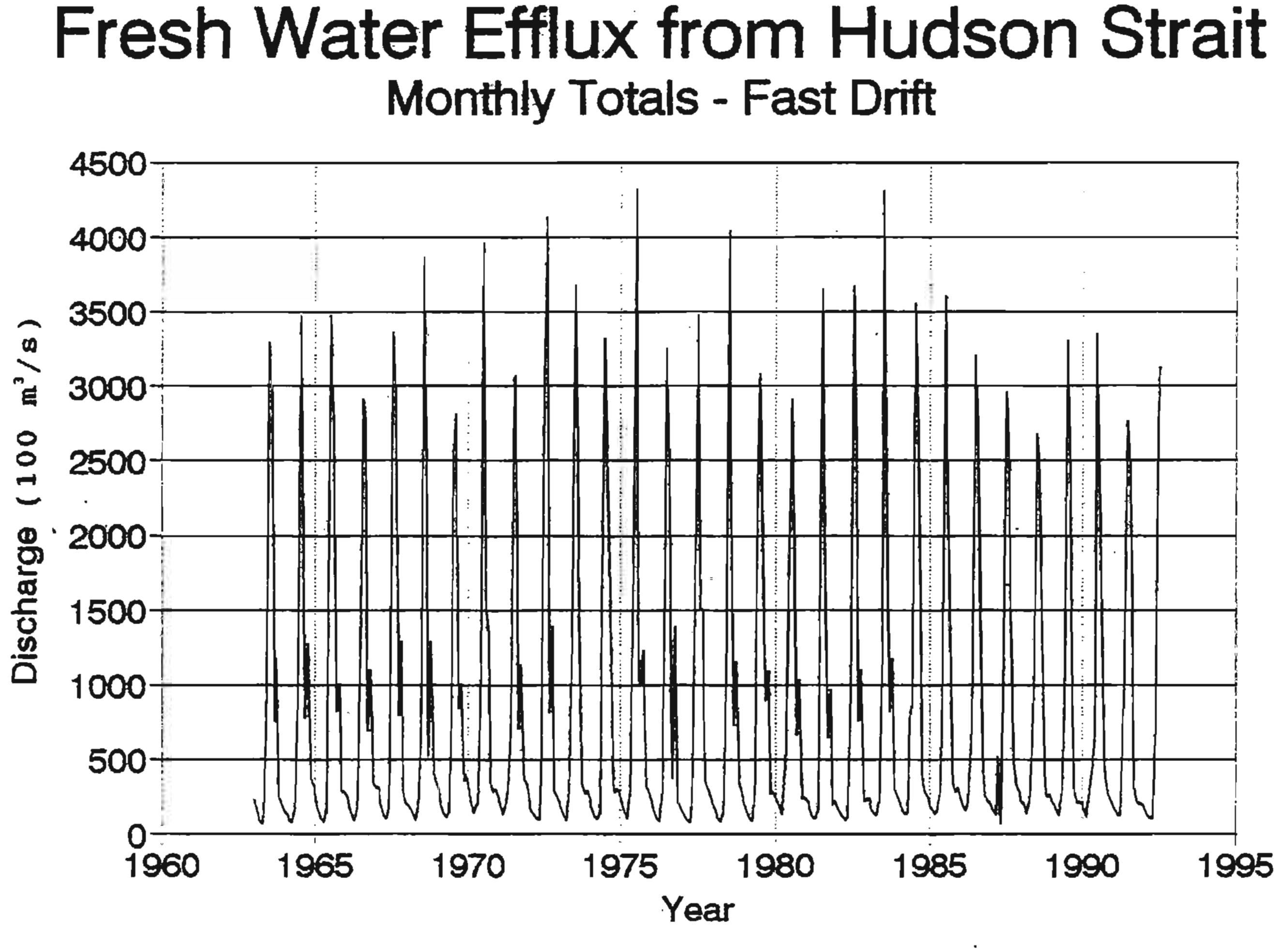

Figure 3.9 Monthly totals of fresh water efflux (m^3s^{-1}) from Hudson Strait, Fast Drift, 1963-92.

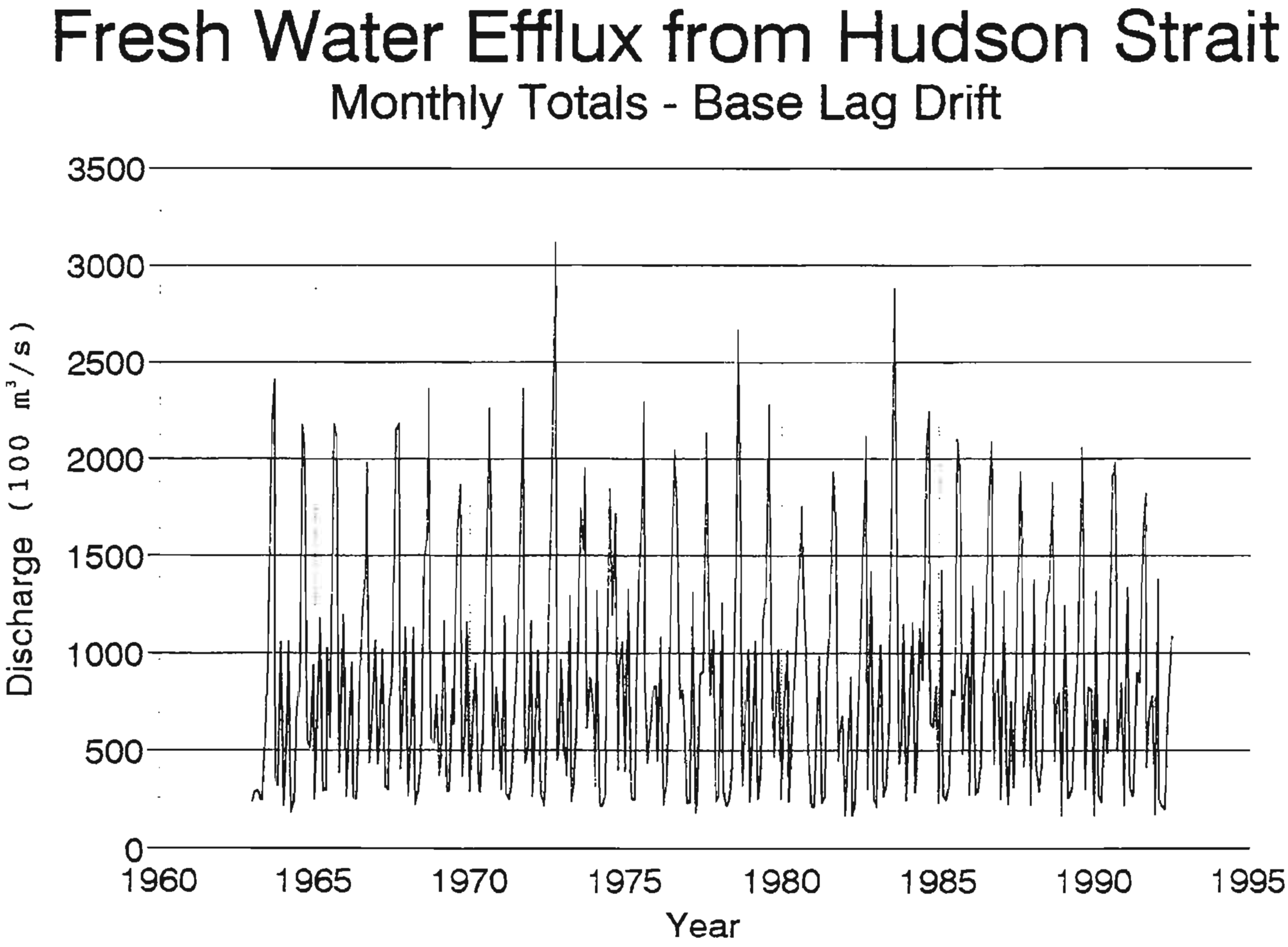

Figure 3.10 Monthly totals of fresh water efflux (m^3s^{-1}) from Hudson Strait, Base Drift, 1963-92.

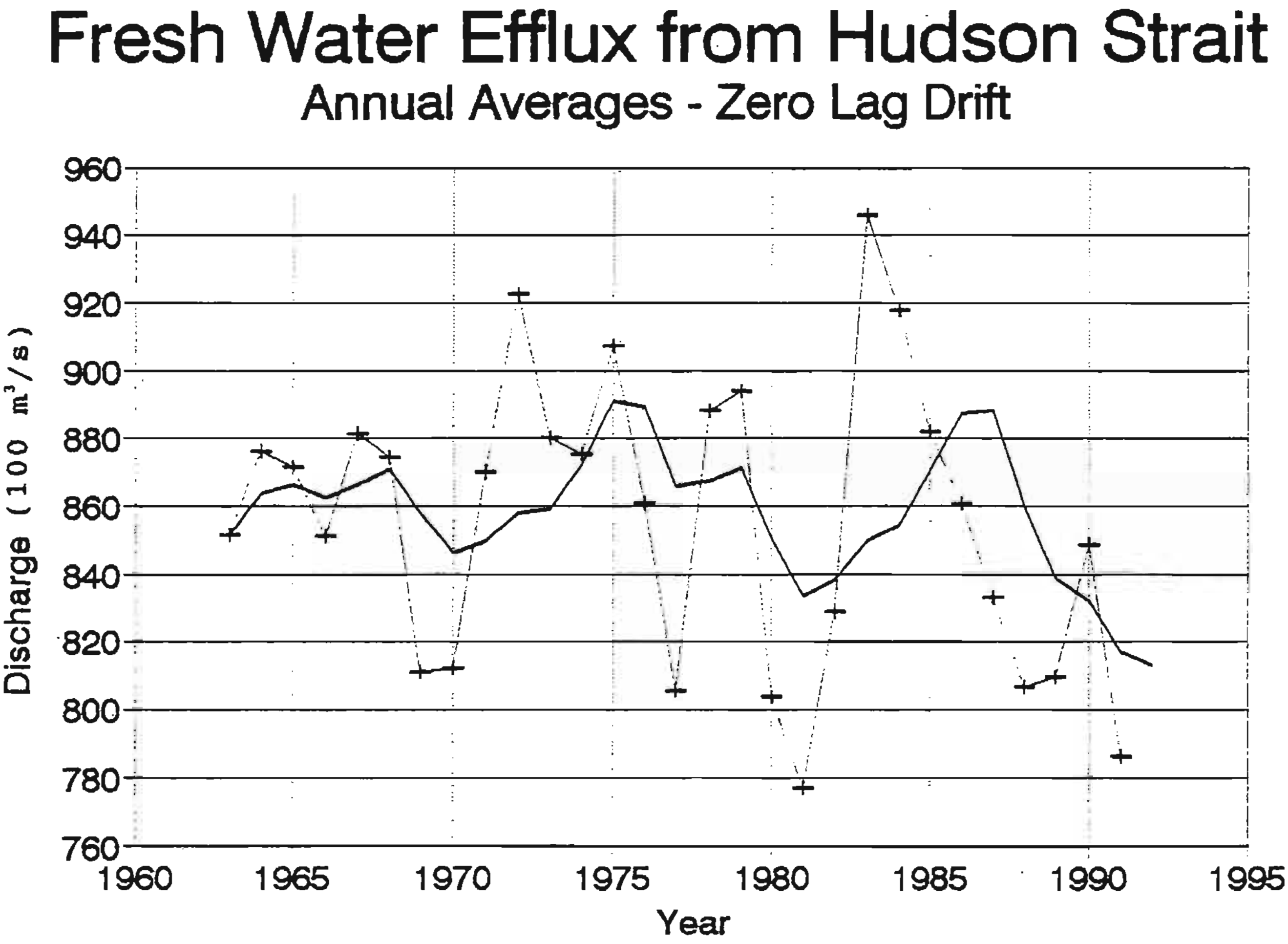

Figure 3.11 Time series of annual means of efflux from Hudson Strait with 5-year smoothing, Zero Lag.

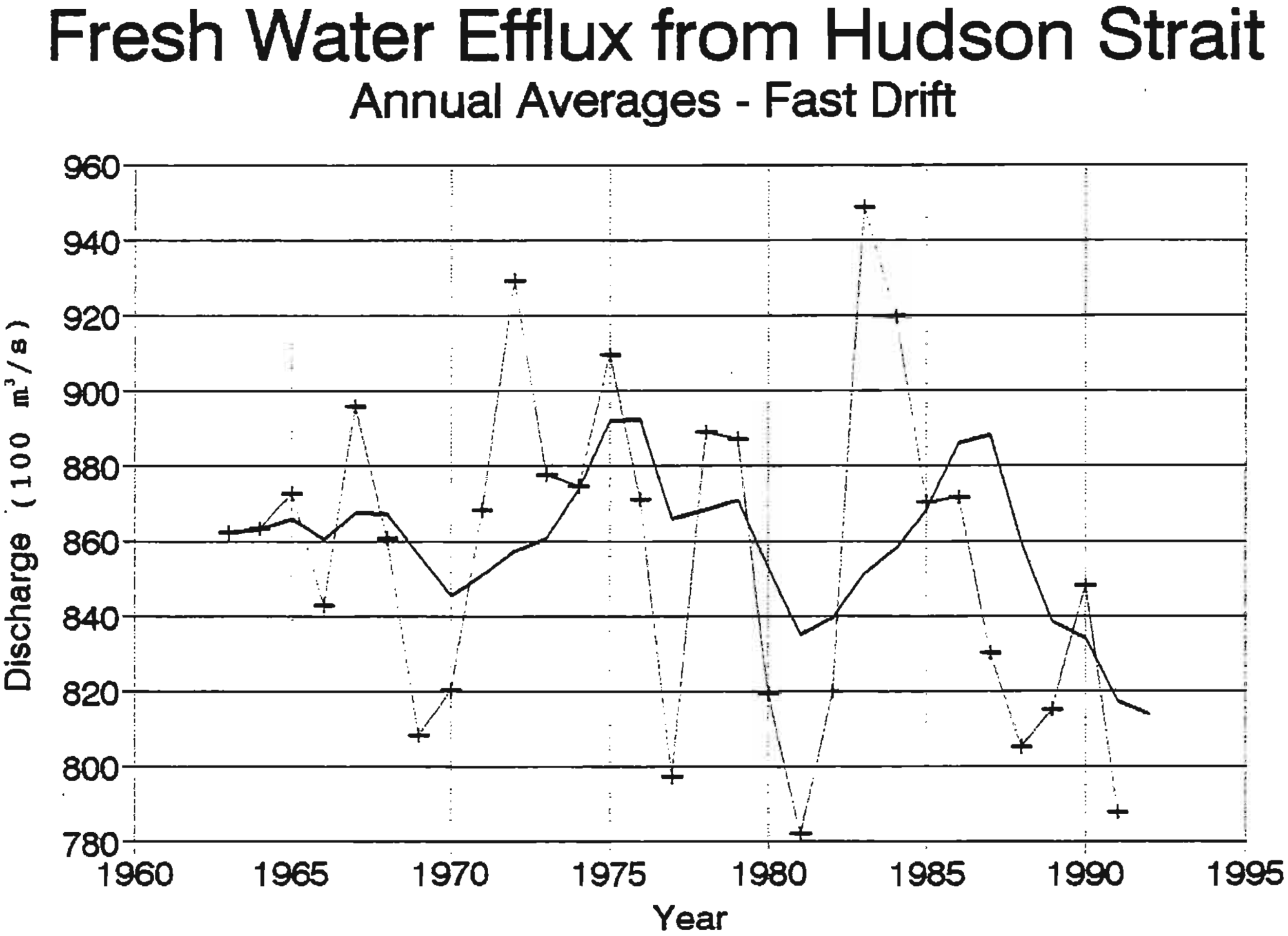

Figure 3.12 Time series of annual means of efflux from Hudson Strait with 5-year smoothing, Fast Drift.

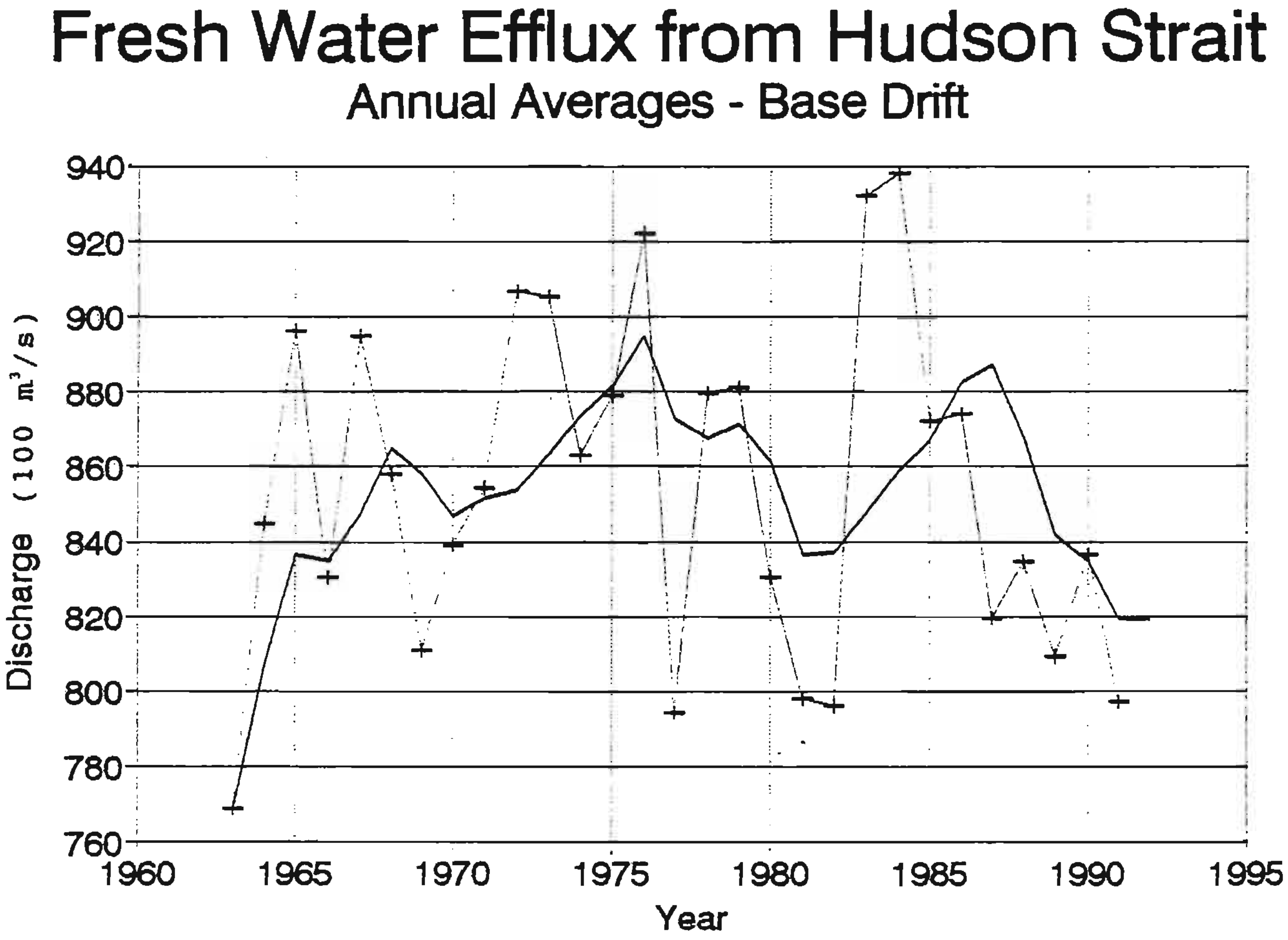

Figure 3.13 Time series of annual means of efflux from Hudson Strait with 5-year smoothing, Base Drift.

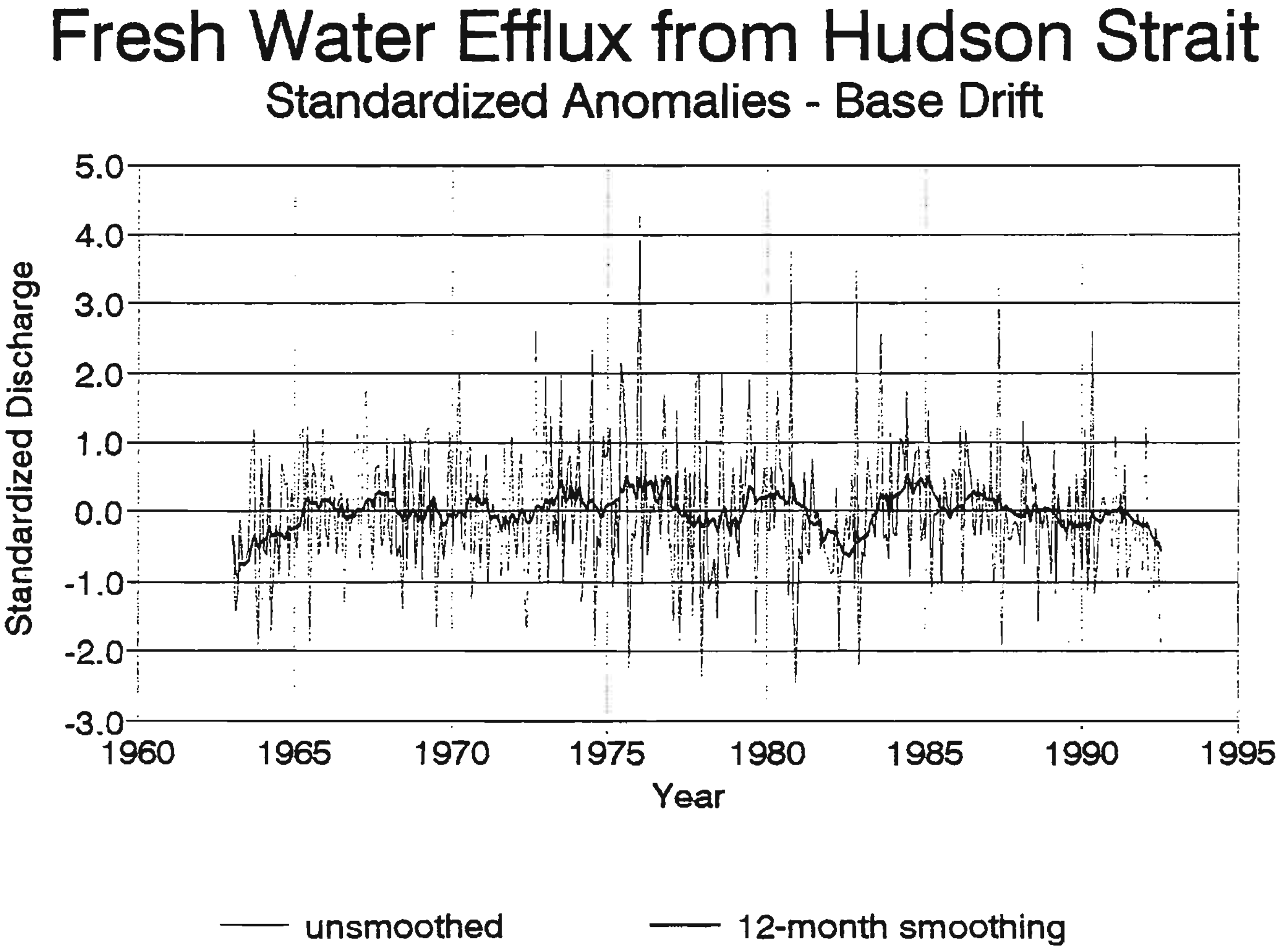

Figure 3.14 Time series of standardized monthly anomalies of efflux with 12-month smoothing, Base Drift.

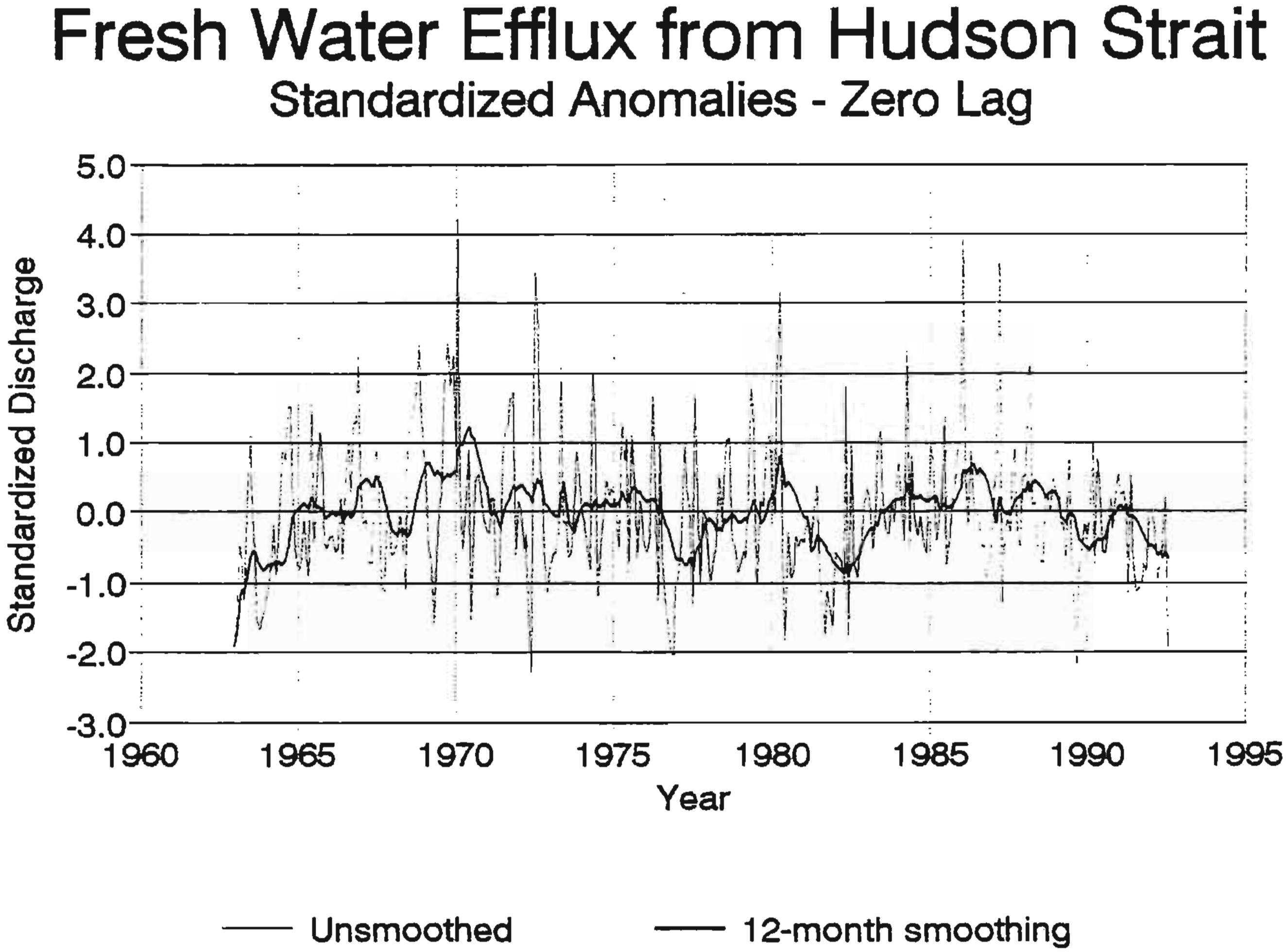

Figure 3.15 Time series of standardized monthly anomalies of efflux with 12-month smoothing, Zero Lag.

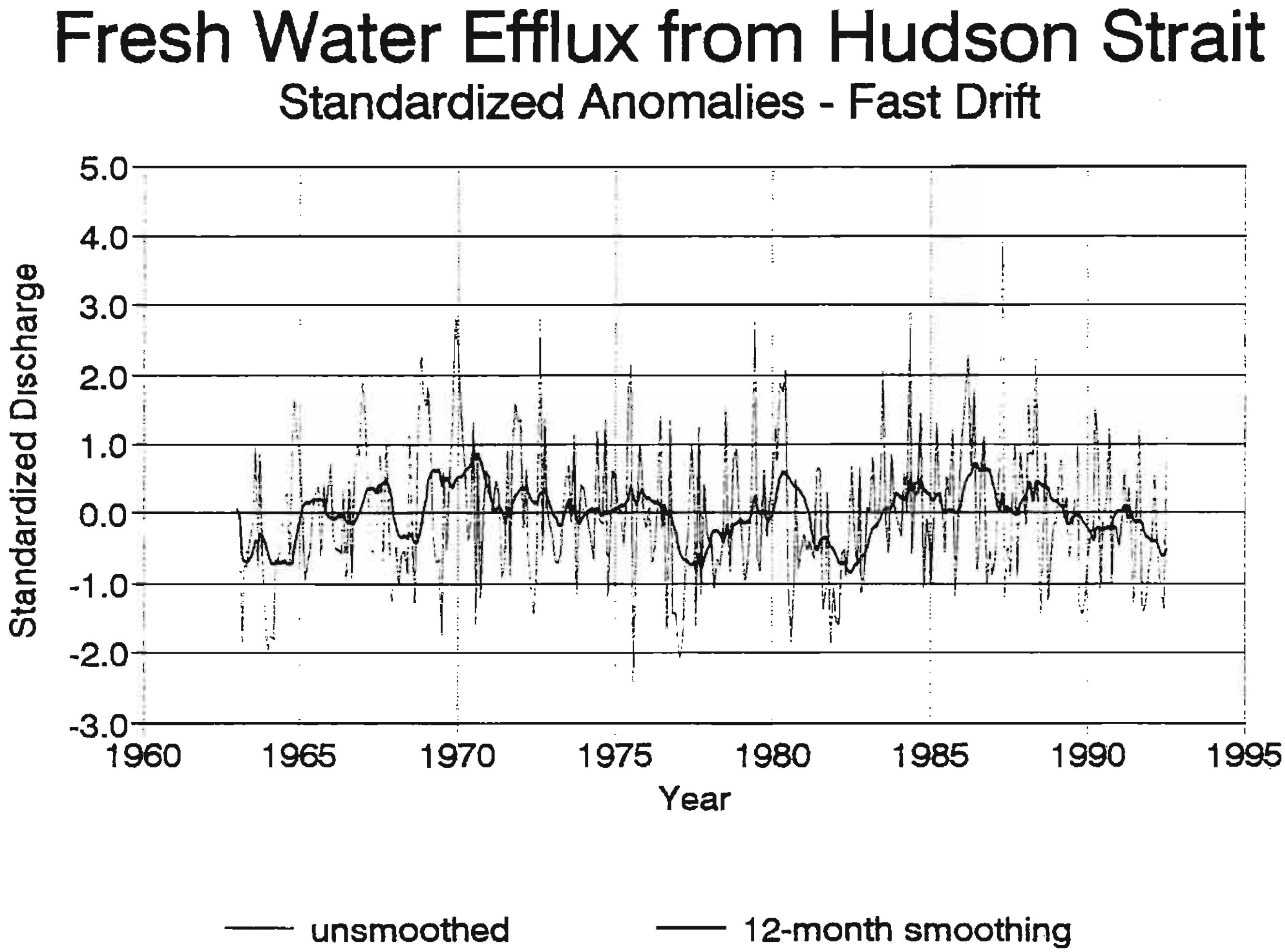

Figure 3.16 Time series of standardized monthly anomalies of efflux with 12-month smoothing, Fast Drift.

Table 2.1. Gauged and ungauged drainage areas (in 1000 km ^{2}) of the eight subregions of the Hudson Bay - Ungava Bay Region, 1984-92

Region	Discharge Gauged	Discharge Estimated	Area Subtotal	Cumulative Total	% of Total
I (Prairies & NW Ont.)	1542.5	166.6	1709.1	1709.1	46.9
II (NW Territories)	253.0	242.0	495.0	2204.1	13.6
III & IV (N Que.)	0.0	80.0	80.0	2284.1	2.2
V (Mid-Que./NE Ont.)	101.4	77.0	178.4	2462.5	4.9
VIa (W. James Bay)	252.0	111.5	363.5	2826.0	10.0
VIb (E James Bay)	168.7	131.8	300.5	3126.5	8.3
VII (Ungava/Hudson St.)	236.2	123.2	359.4	3485.9	9.9
VIII (Foxe Basin)	0.0	155.0	155.0	3640.9	4.2

Table 2.2 Gauged and ungauged drainage areas and period of gauging for individual rivers.

River and Region	Gauged Drainage Area $[10^3 \text{ km}^2]$	Ungauged Drainage Area $[10^3 \text{ km}^2]$	Gauged Period [years]
			84 86 88 90 92
REGION I [Man.+N.Ont.]			
Seal	48.2	41.93	***************
Nelson	1010.0		***************
Churchill	287.0	98.25	***************
Hayes	103.0		***************
Gods	65.5		***************
Severn	94.3	26.40	***************
TOTAL	1542.5	166.60	
REGION II [N.W.T.]			
Thelon	152.0		** ***********
Kazan	72.3	242.00	***************
Quoich	28.7		***************
TOTAL	253.0	242.00	
Region III/IV [N.Que.]			
Innuksuak	-	16.50	Not Gauged
Kogaluk	-	13.00	
Povungnituk	-	27.50	
Kovik	-	10.00	
Others	-	13.00	
TOTAL	0.0	80.00	

Table 2.2 (continued). Gauged and ungauged drainage areas and period of gauging for individual rivers

River and Region	Gauged Drainage Area [10^3 km^2]	Ungauged Drainage Area [10^3 km^2]	Gauged Period [years]
			84 86 88 90 92
REGION V [Mid. Que.]			
Denys	4.7	3.5	***************
Great Whale	36.3	5.9	***************
Little Whale	10.4	6.3	***************
Nastapoca	-	20.0	
Winisk	50.0	29.0	***************
TOTAL	101.4	77.0 *	
REGION VIa [James Bay-West]			
Ekwan	10.4	14.4	***************
Attawapiskat	36.0	27.5	***************
Albany	118.0	15.0	***************
Moose	60.1	15.9	*********
Abitibi	27.5	38.7	***************
TOTAL	252.0	111.5	
REGION VIb [James Bay-East]			
Nottaway	0	65.5	
Broadback	9.8	10.9	***************
Rupert	40.9	9.0	***************
Eastmain	21.4	34.4	***************
Castor	-	12.0	
LaGrande [LG2]	96.6	1.3	***********
Roggan	-	11.1	
TOTAL	168.7	131.8 *	

*12.3 x 10 km of Region VIb accounted for in Region V

Table 2.2 (continued) Gauged and ungauged drainage areas and period of qauging for individual rivers

River and Region	Gauged Drainage Area [$10^3 km^2$]	Ungauged Drainage Area [$10^3 km^2$]	Gauged Period [years]
			84 86 88 90 92
REGION VII [Ungava Bay and Hudson Strait]			
Baleine	29.8	10.2	**************
Arnaud	0.0	49.9	
Melezes	42.7	12.3	**************
George	35.2	12.8	*******
Caniapiscau	86.8	—	**************
Feuilles	41.7	14.0	******
Hudson Strait	—	24.0	
TOTAL	236.2	123.2	
REGION VIII [Foxe Basin]			
No rivers	—	155.0	

Table 2.3 Period of Record for Selected Ice Thickness Monitoring Stations

STATION	PERIOD OF RECORD (years) 84 85 86 87 88 89 90 91 92
HUDSON BAY	
Chesterfield Inlet	
Churchill	*************
Kuujjuarapik	****************************
Inukjuac	************************** *******
Coral Harbour	*******************************
JAMES BAY	
Moosonee	**********************************
HUDSON STRAIT	
Cape Dorset	**********************************
Quaqtaq	********
Iqaluit	**********************************
UNGAVA BAY	
Kuujjuaq	**********************************
FOXE BASIN	
Hall Beach	************ ********** *******

Table 2.4 Area and Time Lag Estimates Used in Synthesizing an Ice-melt Discharge Signal

REGION	STATION	AREA $[10^3 \ km^2]$	HUDSON STRAIT TIME LAG [months]		
			Base	Fast	Zero
NW Hudson Bay	Chesterfield Inlet	1.625	8	3	0
SW Hudson Bay	Churchill	1.557	6	2	0
SE Hudson Bay	Kuujjuarapik	1.746	4	2	0
E Hudson Bay	Inukjuac	1.447	2	1	0
NE Hudson Bay	Coral Harbour	1.098	1	1	0
James Bay	Moosonee	0.670	6	3	0
Hudson Strait	Cape Dorset Quaqtaq Iqaluit	1.780	0	0	0
Ungava Bay	Kuujjuaq				
Foxe Basin	Hall Beach	1.780	2	1	0

Yr\Month	J	F	M	A	M	J	J	A	S	O	N	D	AVG	StdDev
1984	3932	3540	3391	4267	7368	6882	5324	3917	4233	4438	4065	3796	4596	1228
1985	3452	3219	2760	3433	8195	12259	9300	5768	5416	6485	5311	4479	5840	2728
1986	4248	4026	3755	3481	12760	10344	8447	6507	5761	5452	4670	4207	6138	2803
1987	3669	3368	3196	5307	5823	4902	5364	4631	4698	3929	3927	3381	4368	859
1988	2909	2709	2427	2063	7674	5543	3572	2876	2388	2524	2658	2471	3318	1574
1989	2227	2012	1866	1684	7405	5425	4829	3879	4102	4492	3890	3229	3737	1619
1990	2902	2610	2398	2198	4958	5939	5101	4143	3999	4322	4149	3646	3864	1114
1991	3077	2620	2326	2291	6339	4598	4659	3632	3536	4260	3580	3020	3661	1115
1992	2816	2694	2481	2378	6446	6087	6066	4562	5337	6833	5558	3908	4681	1800
Avg	3248	2977	2733	3011	7441	7109	5740	4435	4408	4748	4179	3571	4467	
Std Dev	595	575	566	1130	2106	2491	1760	1047	1005	1250	844	584	920	

Table 3.1 Monthly discharge estimates (m^3s^{-1}) for runoff - Region I.

Yr\Month	J	F	M	A	M	J	J	A	S	O	N	D	AVG	StdDev
1984	717	584	529	561	722	16237	11797	6191	6480	2504	1518	1184	4092	4954
1985	790	592	508	519	738	10680	7430	4965	8156	3251	1567	1163	3366	3429
1986	831	663	661	666	1025	9309	16330	4639	3594	1919	1104	772	3459	4589
1987	639	571	535	553	617	3985	22404	7576	6077	3343	1368	983	4054	5991
1988	694	523	445	502	630	10275	9176	6458	6417	3231	1507	1132	3416	3615
1989	665	728	695	727	602	10377	11560	4743	3103	2104	1293	904	3160	3691
1990	760	658	626	653	749	7196	13720	7423	5935	2490	1181	844	3519	4004
1991	658	549	532	562	697	14704	11091	4605	3965	2011	1239	919	3461	4478
1992	730	625	583	629	760	2834	19740	5001	4569	1738	1099	738	3254	5192
Avg	745	610	568	597	749	9511	13694	5738	5368	2519	1320	982	3531	
Std Dev	76	60	76	71	113	4158	4642	1132	1657	589	170	161	308	

Table 3.2 Monthly discharge estimates (m^3s^{-1}) for runoff - Region II.

Yr\Month	J	F	M	A	M	J	J	A	S	O	N	D	AVG	StdDev
1984	188	131	111	121	2775	2423	1623	1112	1527	2000	836	402	1104	917
1985	232	168	137	124	789	5151	762	600	1223	1347	879	334	979	1320
1986	202	149	122	132	3304	2210	1448	1215	2090	1035	569	273	1082	990
1987	176	137	118	168	3222	3840	1079	1103	1604	1292	647	323	1142	1180
1988	204	165	131	137	3791	2709	1025	1523	1408	1574	654	355	1139	1104
1989	214	142	101	87	1305	1785	857	444	660	1114	621	209	626	518
1990	170	113	83	72	2471	2034	1014	738	1814	1763	761	440	956	820
1991	265	202	152	126	604	1897	852	1464	1520	798	420	291	717	579
1992	187	120	88	76	287	2231	1310	1671						
Avg	206	146	116	116	2061	2698	1108	1096	1481	1365	661	338	966	
Std Dev	33	25	22	30	1248	1042	276	403	395	371	148	55	182	

Table 3.3 Monthly discharge estimates (m^3s^{-1}) for runoff - Region III-IV.

Yr\Month	J	F	M	A	M	J	J	A	S	O	N	D	AVG	StdDev
1984	1062	800	610	1316	3802	3243	2438	1986	2568	2902	2288	1768	2057	936
1985	1209	889	668	643	5103	7011	3998	2297	2132	2480	2258	1477	2515	1664
1986	971	899	657	516	3981	3572	2930	2361	3101	2477	1699	1129	1999	1180
1987	851	874	654	1221	3145	2809	2158	2014	3424	2647	2021	1400	1910	934
1988	941	708	584	849	4273	3065	1827	1352	1895	2686	2092	1385	1786	1071
1989	947	892	525	443	2143	3385	1931	1128	1176	1876	1896	1252	1449	804
1990	760	527	413	371	2525	3944	2419	1768	2066	2196	1766	1131	1657	1025
1991	756	569	480	434	2437	3157	2130	1784	2118	2856	1867	1189	1648	908
1992	821	612	489	409	1591	5716								
Avg	924	685	540	667	3209	3989	2479	1836	2310	2516	1986	1344	1878	
Std Dev	139	105	70	335	1073	1340	658	401	663	321	203	207	306	

Table 3.4 Monthly discharge estimates (m^3s^{-1}) for runoff - Region V.

Yr\Month	J	F	M	A	M	J	J	A	S	O	N	D	AVG	StdDev
1984	1242	975	864	4008	8128	6934	4823	2496	1276	1621	1979	1676	3083	2392
1985	1262	1053	978	3881	13487	7945	5900	4579	4322	7448	5581	2714	4929	3423
1986	1489	1027	897	3780	10058	3870	2550	1745	1527	3143	2511	1553	2846	2376
1987	1148	983	941	2985	4273	3075	2844	3308	3415	3220	2488	1708	2530	1044
1988	1112	844	791	3580	9231	3898	2817	2757	3849	4897	4899	2714	3416	2218
1989	1488	1120	939	1279	10861	6242	2902	1969	1839	2543	2168	1273	2885	2761
1990	883	752	920	2442	9340	7287	4055	1843	1381	2284	2463	1605	2919	2599
1991	1152	938	802	3417	6600	3552	1694	1088	1103	3031	3108	1781	2355	1818
1992	965	768	782	1279	16244	9509	965	768	782	1279	16244	9509	4928	5950
Avg	1193	940	879	3070	9802	5812	3150	2264	2141	3274	4604	2726	3321	
Std Dev	194	117	69	1156	3340	2157	1448	1108	1220	1775	4283	2445	905	

Table 3.5 Monthly discharge estimates (m^3s^{-1}) for runoff - Region VIa.

Yr\Month	J	F	M	A	M	J	J	A	S	O	N	D	AVG	StdDev
1984	5130	4016	4021	3731	8784	7000	6331	6628	6671	6830	6269	5782	5933	1421
1985	5693	5041	4594	3992	8445	9357	6820	6098	5320	6826	7463	6238	6324	1501
1986	5645	5478	5017	4984	13619	8384	7708	6868	7165	7716	7301	6101	7164	2226
1987	5538	4926	4698	6999	9740	8781	6990	7243	9358	10021	8193	7609	7508	1729
1988	6325	5748	5259	6592	10051	7062	5791	5282	5931	6017	7640	6847	6729	1322
1989	5566	5281	4582	4265	8768	6043	5613	4950	4826	7303	8400	7017	6218	1535
1990	4850	4737	4252	3872	10703	8617	5972	6377	6794	9122	8364	6538	6683	2047
1991	5868	5058	4383	4343	9958	8503	5844	6359	6307	6534	7375	5705	6269	1584
1992	5378	4751	4189	3845	7835	9171	5378	4751	4189	3845	7835	9171	5828	2001
Avg	5554	5004	4553	4714	9769	8322	6271	5950	6285	7335	7671	6779	6517	
Std Dev	398	469	376	1178	1607	784	716	844	1422	1693	630	1024	525	

Table 3.6 Monthly discharge estimates (m^3s^{-1}) for runoff - Region VIb.

Yr\Month	J	F	M	A	M	J	J	A	S	O	N	D	AVG	StdDev
1984	693	649	656	569	9339	12545	7630	5768	6053	7353	3265	1561	4762	3692
1985	964	698	676	525	2772	18885	5858	3494	3671	3824	2626	1444	3795	4815
1986	908	675	570	566	10988	13492	9731	4394	4839	3262	1659	939	4335	4386
1987	632	500	454	762	9610	10593	6768	7516	6729	4070	2058	1070	4230	3660
1988	653	473	423	463	11215	11624	5438	4756	8161	8212	2687	1522	4652	4073
1989	642	520	375	331	5722	7805	4195	2240	2829	6176	2469	1323	2819	2324
1990	769	542	412	373	6962	10874	6545	3671	7563	8964	3063	1706	4268	3574
1991	1065	731	552	441	1623	12289	6617	3845	6145	5122	2234	1168	3486	3402
1992	743	559	998	484	912	17309	743	559	998	484	912	17309	3501	6178
Avg	832	594	546	501	6571	12824	5947	4029	5321	5162	2377	3118	3985	
Std Dev	134	90	175	119	3798	3218	2334	1874	2287	2516	711	5023	596	

Table 3.7 Monthly discharge estimates (m^3s^{-1}) for runoff - Region VII.

Yr\Month	J	F	M	A	M	J	J	A	S	O	N	D	AVG	StdDev
1984	222	181	164	174	224	5033	3657	1919	2009	801	471	367	1268	1536
1985	245	183	157	161	229	3311	2303	1545	2628	1008	488	367	1044	1063
1986	257	206	205	207	318	2886	5062	1438	1114	595	342	239	1072	1423
1987	198	177	166	171	191	1235	6945	2349	1884	1036	424	305	1257	1857
1988	215	162	138	158	195	3165	2845	2002	1989	1001	467	351	1059	1090
1989	274	225	216	225	249	3217	3584	1470	962	652	401	280	980	1144
1990	238	204	194	203	232	2231	4253	2301	1840	772	368	261	1091	1241
1991	204	170	165	174	216	4558	3438	1427	1229	623	384	265	1073	1388
1992	226	194	181	195	238	878	8119	1550	1416	539	341	226	1009	1810
Avg	231	189	178	185	232	2948	4245	1778	1663	761	409	298	1095	
Std Dev	23	19	23	22	36	1288	1439	351	483	183	53	60	95	

Table 3.8 Monthly discharge estimates (m^3s^{-1}) for runoff - Region VIII.

Table 3.9 Estimated standard deviation measurement uncertainties in regional time series of runoff

Region	% of Total Runoff	Fraction of Area Gauged	Estimated Uncertainty
I 84-92	17	.90	3.2
II 84	14	.51	7.5
II 85		.20	8.7
II 86-92		.51	7.5
III/IV 84-92	4	.00	25.0
V 84-92	7	.64	3.7
VIa 84-88	13	.69	3.0
VIa 89-92		.62	5.2
VIb 84-91	25	.56	6.1
VIb 92		.24	10.0
VII 84-87	16	.66	4.2
VII 88-92		.44	6.8
VIII 84	4	.00	25.0
VIII 85		.00	25.0
VIII 86-92		.00	25.0

Yr\Month	J	F	M	A	M	J	J	A	S	O	N	D	Avg	Std Dev
1984	0	0	0	0	10	1093	0	0	0	0	0	0	92	302
1985	0	0	0	0	9	1044	0	0	0	0	0	0	88	288
1986	0	0	0	0	9	1044	0	0	0	0	0	0	88	288
1987	0	0	0	0	10	1093	0	0	0	0	0	0	92	302
1988	0	0	0	0	9	989	0	0	0	0	0	0	83	273
1989	0	0	0	0	9	1082	0	0	0	0	0	0	91	299
1990	0	0	0	0	10	1104	0	0	0	0	0	0	93	305
1991	0	0	0	0	9	1076	0	0	0	0	0	0	90	297
1992	0	0	0	0	9	1065	0	0	0	0	0	0	90	294
Avg	0	0	0	0	9	1065	0	0	0	0	0	0	90	
Std Dev	0	0	0	0	0	34	0	0	0	0	0	0	3	

Table 3.10 Monthly ice melt discharges (100 m^3s^{-1}) from NW Hudson Bay, Region II, 1984-92,

Yr\Month	J	F	M	A	M	J	J	A	S	O	N	D	Avg	Std Dev
1984	0	0	0	21	207	563	0	0	0	0	0	0	73	168
1985	0	0	0	20	351	664	0	0	0	0	0	0	86	199
1986	0	0	0	0	310	597	0	0	0	0	0	0	76	179
1987	0	0	0	25	314	595	0	0	0	0	0	0	78	178
1988	0	0	0	20	312	591	0	0	0	0	0	0	77	177
1989	0	0	0	20	312	591	0	0	0	0	0	0	77	177
1990	0	0	0	20	312	591	0	0	0	0	0	0	77	177
1991	0	0	0	20	312	591	0	0	0	0	0	0	77	177
1992	0	0	0	20	312	591	0	0	0	0	0	0	77	177
Avg	0	0	0	19	315	597	0	0	0	0	0	0	78	
Std Dev	0	0	0	7	14	25	0	0	0	0	0	0	3	

Table 3.11 Monthly ice melt discharges (100 m^3s^{-1}) from SW Hudson Bay, Region I, 1984-92.

Yr\Month	J	F	M	A	M	J	J	A	S	O	N	D	Avg	Std Dev
1984	0	0	0	143	762	0	0	0	0	0	0	0	75	211
1985	0	0	0	54	839	0	0	0	0	0	0	0	74	231
1986	0	0	0	143	702	0	0	0	0	0	0	0	70	195
1987	0	0	42	60	583	0	0	0	0	0	0	0	57	160
1988	0	0	196	18	655	0	0	0	0	0	0	0	72	184
1989	0	0	24	161	607	0	0	0	0	0	0	0	66	169
1990	0	0	0	0	833	0	0	0	0	0	0	0	69	230
1991	0	0	63	119	554	0	0	0	0	0	0	0	63	153
1992	0	0	0	0	821	0	0	0	0	0	0	0	68	227
Avg	0	0	38	77	706	0	0	0	0	0	0	0	69	
Std Dev	0	0	62	61	106	0	0	0	0	0	0	0	5	

Table 3.12 Monthly ice melt discharges (100 m^3s^{-1}) from SE Hudson Bay, Region V, 1984-92.

Yr\Month	J	F	M	A	M	J	J	A	S	O	N	D	Avg	Std Dev
1984	0	0	0	64	64	1075	0	0	0	0	0	0	104	295
1985	0	0	0	0	118	1076	0	0	0	0	0	0	99	296
1986	0	0	0	69	64	644	0	0	0	0	0	0	81	231
1987	0	0	0	0	94	937	0	0	0	0	0	0	86	258
1988	0	0	64	183	113	493	0	0	0	0	0	0	71	139
1989	0	0	0	64	64	987	0	0	0	0	0	0	93	271
1990	0	0	0	0	301	923	0	0	0	0	0	0	102	261
1991	0	0	0	49	69	597	0	0	0	0	0	0	60	164
1992	0	0	0	0	0	158	543	0	0	0	0	0	58	152
Avg	0	0	7	50	101	766	60	0	0	0	0	0	84	
Std Dev	0	0	20	57	78	292	171	0	0	0	0	0	17	

Table 3.13 Monthly ice melt discharges (100 m^3s^{-1}) from E Hudson Bay, Region IV, 1984-92.

Yr\Month	J	F	M	A	M	J	J	A	S	O	N	D	Avg	Std Dev
1984	0	0	0	0	19	195	539	0	0	0	0	0	63	153
1985	0	0	0	0	15	180	494	0	0	0	0	0	57	141
1986	0	0	0	0	19	172	502	0	0	0	0	0	58	142
1987	0	0	0	0	7	112	636	0	0	0	0	0	63	176
1988	0	0	0	0	0	150	466	0	0	0	0	0	51	132
1989	0	0	0	0	0	270	472	0	0	0	0	0	62	144
1990	0	0	0	0	0	202	569	0	0	0	0	0	64	162
1991	0	0	0	62	45	210	431	0	0	0	0	0	61	125
1992	0	0	0	0	0	191	517	0	0	0	0	0	59	148
Avg	0	0	0	6	12	187	514	0	0	0	0	0	60	
Std Dev	0	0	0	16	14	41	58	0	0	0	0	0	4	

Table 3.14 Monthly ice melt discharges (100 m^3s^{-1}) from NE Hudson Bay, Region III, 1984-92.

Yr\Month	J	F	M	A	M	J	J	A	S	O	N	D	Avg	Std Dev
1984	0	0	0	295	0	0	0	0	0	0	0	0	25	81
1985	0	0	0	164	64	0	0	0	0	0	0	0	19	47
1986	50	-16	5	119	82	0	0	0	0	0	0	0	20	40
1987	0	0	16	110	94	0	0	0	0	0	0	0	18	38
1988	0	0	14	112	89	0	0	0	0	0	0	0	18	37
1989	0	0	14	53	180	0	0	0	0	0	0	0	21	50
1990	0	0	0	160	75	0	0	0	0	0	0	0	20	47
1991	0	0	0	119	101	0	0	0	0	0	0	0	18	41
1992	0	0	11	123	101	0	0	0	0	0	0	0	20	42
Avg	8	-2	7	139	87	0	0	0	0	0	0	0	20	
Std Dev	16	5	7	63	44	0	0	0	0	0	0	0	2	

Table 3.15 Monthly ice melt discharges (100 m^3s^{-1}) from James Bay, Region VI, 1984-92.

Yr\Month	J	F	M	A	M	J	J	A	S	O	N	D	Avg	Std Dev
1984	0	0	0	30	115	405	425	0	0	0	0	0	81	153
1985	0	0	0	36	109	411	332	0	0	0	0	0	74	137
1986	0	0	0	8	56	237	457	0	0	0	0	0	63	135
1987	0	0	0	0	85	313	498	0	0	0	0	0	75	154
1988	0	30	-2	36	46	366	443	0	0	0	0	0	77	148
1989	0	0	0	21	42	410	496	0	0	0	0	0	81	168
1990	0	0	3	9	264	259	355	0	0	0	0	0	74	128
1991	0	0	0	20	42	543	300	0	0	0	0	0	75	163
1992	0	0	0	0	11	402	578	0	0	0	0	0	83	186
Avg	0	3	0	18	86	372	432	0	0	0	0	0	76	
Std Dev	0	10	1	14	71	87	84	0	0	0	0	0	5	

Table 3.16 Monthly ice melt discharges (100 m^3s^{-1}) from Hudson Strait and Ungava Bay, Region VII, 1984-92.

Yr\Month	J	F	M	A	M	J	J	A	S	O	N	D	Avg	Std Dev
1984	0	0	0	358	-61	97	1238	0	0	0	0	0	136	348
1985	0	0	0	49	-30	255	880	0	0	0	0	0	98	247
1986	0	0	0	231	30	103	1123	0	0	0	0	0	124	308
1987	0	0	394	-255	121	61	813	0	0	0	0	0	95	257
1988	0	0	0	0	152	140	935	0	0	0	0	0	102	257
1989	0	0	0	30	-6	273	916	0	0	0	0	0	101	257
1990	0	0	164	0	-121	243	910	0	0	0	0	0	100	260
1991	0	0	0	0	0	310	1062	0	0	0	0	0	114	298
1992	0	0	6	0	18	249	837	0	0	0	0	0	93	235
Avg	0	0	63	46	11	192	968	0	0	0	0	0	107	
Std Dev	0	0	128	160	80	86	134	0	0	0	0	0	14	

Table 3.17 Monthly ice melt discharges (100 m^3s^{-1}) from Foxe Basin, Region VIII, 1984-92.

Table 3.18 Areas and uncertainties in ice-melt estimated for each region.

Ice Regions	Area	% Uncertainty		Weighted Uncertainty	
		1963-83	1984-92	1963-83	1984-92
NW Hudson Bay	1.625	15	25		
SW Hudson Bay	1.557	15	25		
SE Hudson Bay	1.746	25	15		
E Hudson Bay	1.447	15	15		
NE Hudson Bay	1.098	15	15		
James Bay	0.67	15	15		
Hudson Strait	1.78	15	15		
& Ungava Bay		25	15		
Foxe Basin	1.78	15	15		
TOTAL	11.703	(1000 km^2)		17%	18%

Yr\Month	J	F	M	A	M	J	J	A	S	O	N	D	Avg	Std Dev
1984	134	109	102	1088	1636	4031	2638	300	317	285	207	166	918	1202
1985	138	118	104	456	1873	4375	2130	294	328	327	327	182	888	1239
1986	198	113	122	712	1634	3537	2623	292	292	256	199	152	861	1108
1987	129	113	559	121	1675	3503	2493	357	374	296	211	168	833	1070
1988	131	144	375	510	1846	3202	2168	270	318	321	230	168	807	972
1989	124	107	130	439	1583	4075	2239	208	195	253	208	156	810	1180
1990	113	101	260	291	2054	3803	2265	281	314	319	221	162	849	1144
1991	131	108	177	497	1417	3860	2156	232	259	252	202	144	788	1106
1992	119	103	115	234	1616	3214	2668	189	173	145	320	409	792	1083
Avg	135	113	216	483	1728	3733	2398	269	268	273	236	189	838	
Std Dev	23	12	148	269	181	377	250	49	82	53	47	78	42	

Table 3.19 Combined runoff and ice melt monthly estimates of discharge (100 m^3s^{-1}) at Hudson Strait, Zero Lag.

Yr\Month	J	F	M	A	M	J	J	A	S	O	N	D	Avg	Std Dev
1984	220	157	130	142	749	874	3551	2720	1565	400	282	248	920	1081
1985	188	160	141	157	285	883	3602	2605	1489	351	351	311	877	1083
1986	273	205	157	192	563	774	3204	2758	1441	411	257	228	872	1008
1987	199	159	132	512	71	926	2958	2517	1410	467	330	282	830	931
1988	220	202	135	218	638	944	2679	2433	1359	329	249	259	805	859
1989	223	181	133	131	309	838	3293	2521	1419	312	211	209	815	1014
1990	200	159	117	275	421	676	3349	2531	1490	427	275	258	848	1013
1991	208	162	131	128	334	1011	2759	2511	1478	314	213	207	788	916
1992	192	152	130	111	108	708	2649	3078	1338	319	168	335	774	997
Avg	213	171	134	207	368	848	3116	2630	1443	370	259	259	836	
Std Dev	25	19	10	118	217	105	346	188	67	54	55	41	44	

Table 3.20 Combined runoff and ice melt monthly estimates of discharge (100 m^3s^{-1}) at Hudson Strait, Fast Drift.

Yr\Month	J	F	M	A	M	J	J	A	S	O	N	D	Avg	Std Dev
1984	244	723	1160	290	412	1133	860	2095	2246	639	620	833	938	617
1985	233	1430	275	248	335	813	788	2105	1923	476	478	1000	842	626
1986	274	1346	273	295	432	881	1041	1768	2068	429	789	873	874	579
1987	244	1328	339	227	756	313	1083	1930	1709	424	879	804	820	555
1988	222	1374	434	287	435	822	1266	1330	1871	442	727	803	834	496
1989	168	1248	262	259	321	732	1015	2057	1711	302	823	813	809	586
1990	173	1322	278	230	668	491	931	1903	1977	499	715	850	836	583
1991	215	1338	310	263	313	905	846	1851	1828	413	704	781	797	528
1992	170	1374	255	213	200	708	902	1050	2390	359	761	1008	782	617
Avg	216	1275	399	257	430	753	970	1768	1971	443	699	863	837	
Std Dev	36	201	274	28	167	224	139	345	220	89	98	79	44	

Table 3.21 Combined runoff and ice melt monthly estimates of discharge (100 m^3s^{-1}) at Hudson Strait, Base Drift.

APPENDIX A. Runoff

A.1 Description of Runoff Calculations

A.1.1 Region I, the SW sector of Hudson Bay

Gauged data exists for the period of interest (1984-92) for the major rivers; the Seal, Nelson, Churchill, Hayes and Gods. Data from the Severn River was added to this region's total because it discharges into Region I of Hudson Bay even though it originates from another major drainage basin located in northern Ontario (Figure 1.1).

The Churchill River has been regulated since 1928 and the Nelson River since 1960. It was necessary to estimate data to fill random data gaps for the Seal, Churchill, Hayes and Gods Rivers. The Severn River was used to calculate substitution ratios for a small number of data gaps in the Seal River record (Table A.8). The complete record of the Nelson River was used to calculate monthly discharge ratios for substituting missing Churchill River data. The more complete record of the Gods River was used to calculate ratios to fill data gaps in the Hayes River record. Where Gods and Hayes River data gaps coincided, the Severn River record was used as the reference.

Coastal drainage estimates for the northern section (principally, the Seal River) were obtained by using a factor of 0.87 on the Seal River data. The factor was derived from drainage area estimates for the Caribou, North and South Knife and lower Churchill Rivers.

Coastal drainage estimates for the southern section were derived by using a factor of 1.5 on the Gods River data. (The Gods River is a tributary of the Hayes River). The sum of estimated drainage areas of several smaller rivers (i.e. Burntwood, Grass, Limestone, Kettle, upper Nelson, lower Nelson, lower Hayes, Kaskattawan and Owl Rivers) is 1.5 times the published (WSC) drainage of the Gods River (Table 2.2).

The runoff into the southwestern sector of Hudson Bay (Region I) was obtained by the following equation whose values are listed in Table 3.1.

$$\begin{aligned}\text{Region I Runoff} = {} & \text{Nelson} + 1.87(\text{Seal}) + \text{Churchill} \\ & + \text{Hayes} + 1.5(\text{Gods}) + 1.28(\text{Severn})\end{aligned}$$

A.1.2 Region II, the NW sector of Hudson Bay

The Thelon, Kazan and Quoich Rivers are the major contributors to this region (Chesterfield Inlet) and gauged data exists for the period of interest (1984-92). It was necessary to fill a 1985 data gap for the Thelon River by calculating monthly discharge ratios from the Kazan River (Table A.8).

Estimates of discharge values for the coastal region were obtained by using the Quoich River data corrected by a factor of 8.43 (Table 2.2). This factor differs slightly from that used for the 1963-83 period because the Thelon River gauge was moved inland in 1983. The Kazan River was not used as a surrogate for the coastal region because it lies too far inland and to the south of the area in question.

The runoff into the northwestern sector of Hudson Bay was obtained by the following equation whose values are listed in Table 3.2:

$$\text{Region II Runoff} = \text{Thelon} + \text{Kazan} + 9.43(\text{Quoich})$$

A.1.3 Region III and IV, the NE sector of Hudson Bay

The Innuksuac, Kogaluk, Povungnituk, Kovik and other smaller rivers in Northern Quebec which drain into the northeast sector of Hudson Bay are not gauged.

The drainage area of these rivers is equivalent to the gauged drainage areas of the Melezes and Little Whale Rivers corrected by a factor of 1.5 (Table 2.2). (The Little Whale is an adjacent northern river in Middle Quebec and the Melezes is a river in the northern Ungava Bay region).

The runoff into the northeast sector of Hudson Bay was estimated by the following equation whose values are listed in Table 3.3):

$$\text{Region III/IV Runoff} = 1.5(\text{Melezes} + \text{Little Whale})$$

A.1.4 Region V, the SE sector of Hudson Bay

This drainage sector of Hudson Bay includes the Denys, Great Whale, Little Whale and Nastapoca Rivers. The Winisk River from northern Ontario is included in this middle Quebec region because its discharge quickly drifts into Region V of Hudson Bay. The coastal area north of the LaGrande River including the Roggan River of northern James Bay is also included.

Gauged records for the 1984-92 period exist for the Denys, Great Whale, Little Whale and Winisk Rivers. The Nastapoca River is not gauged. The coastal regions are accounted for by including two additional gauged Denys units and a factor of 1.6 on each unit of river data (Table 2.2).

The runoff into the southeast sector of Hudson Bay was estimated by the following equation whose values are listed in Table 3.4.

$$\text{Region V Runoff} = 1.6[3.0(\text{Denys}) + \text{Great Whale} + \text{Little Whale} + \text{Winisk}]$$

A.1.5 Region VIa, James Bay (Ontario)

Runoff into James Bay from Ontario comes principally from the Ekwan, Attawapiskat, Albany, Moose and Abitibi Rivers. Gauged data for the entire period of interest (1984-92) were available for all but the Moose River. The Albany has been regulated since 1939, and the Moose and Abitibi since 1963.

The Moose River record was discontinued at the end of 1988. The Albany River was used to calculate monthly discharge ratios for substituting 1989-92 Moose River data (Table A.8).

The coastal area for all of these gauged rivers equals the Attawapiskat drainage area multiplied by a factor of 3.1 (Table 2.2).

The runoff into western James Bay was estimated by the following equation whose values are listed in Appendix B (Table 3.5):

$$\text{Region VIa Runoff} = \text{Ekwan} + 4.1(\text{Attawapiskat}) + \text{Albany} + \text{Moose} + \text{Abitibi}$$

A.1.6 Region VIb, James Bay (Quebec)

Quebec's runoff into James Bay is derived from three river systems: the Nottaway,Broadback and Rupert; the Eastmain and Castor; and the LaGrande and Roggan Rivers. Gauging of the Nottaway River was discontinued in 1983. The Castor and Roggan Rivers are not gauged. The LaGrande and Eastmain Rivers are subject to hydroelectric development with the Eastmain being diverted into the LaGrande complex (LG2) during 1980. There is a complete record for the Rupert, Eastmain and Broadback Rivers during the period of interest (1984-92).

The Broadback River was used to calculate ratios for substituting 1983-92 Nottaway River data (Table A.8).

The LG2 record was unavailable from February 1991 onward. The remainder of this record was created by repeating LG2 1990-91 data.

The coastal area for the first two river systems was accounted for by using correction factors for each of the rivers. The ungauged Castor River was included in the Eastmain correction factor of 3.2. For simplification, the coastal area north of the LaGrande River was transferred to Region V (Table 2.2).

The runoff into eastern James Bay was estimated by the following equation whose values are listed in Table 3.6:

$$\begin{aligned}\text{Region VIb Runoff} = {} & 1.14(\text{Nottaway}) + 2.1(\text{Broadback}) + 1.2(\text{Rupert}) \\ & + 3.2(\text{Eastmain}) + \text{LG2}\end{aligned}$$

A.1.7 Region VII, Ungava and Hudson Strait

This drainage area includes the Arnaud, Feuilles, Melezes, Koksoak, Caniapiscau, Baleine and George Rivers. All are gauged. The Koksoak and the Caniapiscau Rivers were partially diverted into the Caniapiscau Reservoir as part of the LaGrande Complex during 1983. The Koksoak is gauged where the Melezes River enters.

Reasonably complete records for the period of interest (1984-92) exist for the Baleine, Melezes and Caniapiscau Rivers. The Arnaud record was discontinued after 1983 and the Baleine River was used to calculate monthly discharge ratios to estimate the Arnaud record. (Table A.8). The George River record stops during 1988 and the remainder of the period was estimated using calculated monthly discharge ratios from the Baleine River. The Feuilles River record stops during 1987 and the Melezes River was used to calculate monthly discharge ratios to complete the Feuilles record. The Caniapiscau record was used as a reference to fill isolated data gaps in the Melezes and Feuilles records, in the latter case when Melezes and Feuilles records contained coincidental data gaps.

The Ungava coastal region was taken to be 1.3 times the combined gauged drainage areas of the Arnaud and Baleine Rivers. The coastal drainage of Hudson Strait was prorated on the basis of Region II data (5%) with widened uncertainties. (Table 2.2).

The runoff into Hudson Strait and Ungava Bay was estimated by the following equation whose values are listed in Table 3.7:

$$\begin{aligned}\text{Region VII Runoff} = {} & 2.3(\text{Arnaud}+\text{Baleine}) + \text{Feuilles} + \text{Melezes} \\ & + \text{Caniapiscau} + \text{George} + \text{Hudson Strait coast}\end{aligned}$$

A.1.8 Region VIII, Foxe Basin

Since gauged data are unavailable, estimates were made by prorating Region II data by an areal factor of 0.31 and appropriately widening the estimates of uncertainty (Tables, 2.2., 3.8).

Table A.1. Monthly standard deviation uncertainties (%) of rivers or their substitutes contributing to runoff of Region I. The second uncertainty refers to ungauged area.

	1984-92
Nelson	5
Seal	5/15
Churchill	5
Hayes	5
Gods	5/15
Severn	5/15
Total (Table 3.9)	3.2

Table A.2. Monthly standard deviation uncertainties (%) of rivers or their substitutes contributing to runoff of Region II. The second uncertainty refers to ungauged area.

	1984	1985	1986-92
Thelon	5	25/Kazan	5
Kazan	5	5	5
Quoich	5/15	5/15	5/15
Total (Table 3.9)	7.5	8.7	7.5

Table A.3. Monthly standard deviation uncertainties (%) of rivers or their substitutes contributing to runoff of Region III-IV. The second uncertainty refers to ungauged area.

	1984-92
Northern Rivers	25/Arnaud
Southern Rivers	25/Little Whale
Total (Table 3.9)	25

Table A.4. Monthly standard deviation uncertainties (%) of rivers or their substitutes contributing to runoff of Region V. The second uncertainty refers to ungauged area.

	1984-92
Denys	5/15
Great Whale	5/15
Little Whale	5/15
Winisk	5/15
Total (Table 3.9)	3.7

Table A.5. Monthly standard deviation uncertainties (%) of rivers or their substitutes contributing to runoff of Region VIa. The second uncertainty refers to ungauged area.

	1984-88	89-92
Ekwan	5	5
Attawapiskat	5/15	5/15
Albany	5	5
Moose	5	25/Albany
Abitibi	5	5
Total (Table 3.9)	3	5.2

Table A.6. Monthly standard deviation uncertainties (%) of rivers or their substitutes contributing to runoff of Region VIb. The second uncertainty refers to ungauged area.

	1984-91	92
Nottaway	25/Broad-back	25/Broad-back
Broadback	5/15	5/15
Rupert	5/15	5/15
Eastmain	5/15	5/15
LaGrande (LG2)	5	25/LG2
Total (Table 3.9)	6.1	10

Table A.7. Monthly standard deviation uncertainties (%) of rivers or their substitutes contributing to runoff of Region VII. The second uncertainty refers to ungauged area.

	1984-87	88-92
Baleine	5/15	5/15
Arnaud	25/Baleine	25/Baleine
Melezes	5	5
George	5	25/Baleine
Caniapiscau	5	5
Feuilles	5	25/Melezes
Hudson Strait	25	25
Total (Table 3.9)	4.2	6.8

Table A. 8 Monthly discharge ratios for river substitutions

Month	Region I			Region II	Region VIA
	Nelson for Churchill	Gods for Hayes	Severn for Seal	Kazan for Thelon	Albany for Moose
Jan.	0.08	1.39		3.02	1.06
Feb.	0.07	1.36		3.35	1.24
Mar.	0.06	1.36		3.54	1.75
Apr.	0.06	1.30		3.43	1.37
May	0.33	1.69	0.39	2.85	0.88
Jun.	0.36	1.51		2.55	0.63
Jul.	0.25	1.53		1.93	0.52
Aug.	0.17	1.40		1.45	0.57
Sept.	0.14	1.39		1.69	0.68
Oct.	0.16	1.40		2.16	0.56
Nov.	0.12	1.43		2.22	0.80
Dec.	0.10	1.37	0.61	2.64	0.95

Month	Region VIB	Region VII			
	Broadback for Nottaway	Baleine for George	Melezes for Feuilles	Baleine for Arnaud	Caniapiscau for Feuilles
Jan.	2.75	0.17	1.74	0.71	
Feb.	2.75	0.16	1.67	0.80	0.53
Mar.	2.85	0.15	1.71	0.92	
Apr.	4.20	0.43	1.36	0.98	
May	4.59	0.29	0.66	0.18	
Jun.	3.79	0.15	0.96	0.49	
Jul.	3.22	0.20	1.36	1.30	
Aug.	2.91	0.23	1.30	1.31	
Sept.	3.10	0.21	1.08	1.14	
Oct.	3.27	0.23	1.14	0.78	
Nov.	3.22	0.20	1.20	0.68	
Dec.	2.95	0.18	1.64	0.68	0.63

APPENDIX B. Ice Melt

B.1 Description of Ice-Thickness Calculations

B.1.1 Chesterfield Inlet

The Chesterfield Inlet station was discontinued in 1980. Data from Baker Lake, a neighbouring station located more inland than the Chesterfield Inlet station, did not provide an acceptable correlation when 1963-80 records from both stations were compared.

Maximum ice thickness for Chesterfield Inlet was estimated for 1984-92 by regressing from Coral Harbour data. The corresponding date of occurrence was estimated by calculating the mean for Chesterfield Inlet over 18 years from 1963-80. The mean is 139 (in Julian days) and the range is 57 days.

The date of open water was estimated by calculating the mean for Chesterfield Inlet over 16 years during 1963-80. The mean is 191 (in Julian days) and the range is 32 days (Table B.1).

These values were used together with the representative time constant from 1964-72 in the exponential decay model with least squares fitted to predict month-end melt values.

A time series plot of maximum ice thickness observations from 1963-80 is shown in Figure B.1.

B.1.2 Churchill

Ice observations have been discontinued since 1987 at Churchill because of danger to observers from polar bears. (Table 2.3). Maximum thickness of ice and corresponding time were readily identified for 1984-87. Dates of open water were not recorded. The mean time of open water from the 1959-83 record over 19 years was used for 1984-92. The mean is 164 (in Julian days) and the range is 78 days (Table B.1).

To attempt to capture the interannual variability from this important ice station, regressions were investigated using Churchill air temperatures as monthly freezing-degree-days, Coral Harbour and Moosonee ice signals and regional river signals. Best combinations were obtained using step-wise multiple regression. However, the highest correlation achieved was 0.65. This was not considered high enough to be acceptable as a surrogate for interannual variability.

Therefore, for 1988-92, the maximum ice thickness and time of maximum thickness for each year were predicted using mean values from 1963-87.

The exponential decay model was least-squares fitted to derive month-end melt values for 1984-92.

A time series plot of maximum ice thickness observations from 1963-87 is shown in Figure B.2.

B.1.3 Kuujjuarapik

The Kuujjuarapik record is continuous to 1991 (Table 2.3). Maximum thickness of ice and corresponding time were readily identified between 1984-91. Dates of open water were recorded only in 1990-91. The mean time of open water was calculated from 7 years in the 1963-84 record and from 2 years of the 1984-91 record. The mean is 147 (in Julian days) and the range is 13 days. This mean was used for 1984-89,92 (Table B.1)

Linear interpolation was used to derive month-end melt values for 1991 and portions of 1984-90.

For 1992, maximum ice thickness and corresponding date of occurrence were predicted by regressing maximum ice thickness and day from Inukjuak data. This value is used together with Kuujjuarapik's average time of open water.

The exponential ice decay model with least squares fitted was used to predict month-end melt values for the remainder of the record.

A time series plot of maximum ice thickness observations from 1973-91 is shown in Figure B.3.

B.1.4 Inukjuac

The Inukjuac record is continuous between 1984-92 (Table 2.3). Maximum thickness of ice and corresponding date of occurrence were readily identified. No dates of open water were recorded. The mean time of open water over 17 years from the 1963-83 record was used. This mean is 171 (in Julian days) and the range is 33 days (Table B.1).

Linear interpolation was used to derive month-end ice melt values for 1988,89,91 and portions of 1984-87,90. The exponential decay model was least-squares fitted to predict month-end thickness values for 1992 and the remaining portions of 1984-87,90.

A time series plot of maximum ice thickness observations from 1963-91 is shown in Figure B.4.

B.1.5 Coral Harbour

The Coral Harbour record is continuous between 1984 and 1991 (Table 2.3). Maximum ice thickness and corresponding time were readily identified. No dates of open water were recorded. The mean time of open water over 17 years from the 1963-83 record was used. The mean is 196 (in Julian days) and the range is 30 days (Table B.1).

Linear interpolation was used to derive month-end melt values for portions of 1984,86,89,90 and 91 and the exponential decay model was least squares fitted to predict month-end melt values for the remainder of the record.

For 1992, maximum ice thickness and corresponding date of occurrence were predicted by regressing from Cape Dorset data. These values were used together with Coral Harbour's mean time of open water.

A time series plot of maximum ice thickness observations from 1963-91 is shown in Figure B.5.

B.1.6 Moosonee

The Moosonee record is continuous for the period of interest, 1984-92 (Table 2.3). Maximum ice thickness and date of occurrence were readily identified. Dates of open water were recorded except for 1986-88 and 1992 where the mean time of open water over 25 years during 1963-92 was used. The mean is 128 (in Julian days) and the range is 28 days (Table B.1).

Linear interpolation was used to derive month-end melt values except for portions of 1986-88,92 where the exponential decay model was least squares fitted.

A time series plot of maximum ice thickness observations from 1963-92 is shown in Figure B.6.

B.1.7 Cape Dorset

The Cape Dorset record is continuous between 1984 and 1992 (Table 2.3). Maximum ice thickness and corresponding time were readily identified. Dates of open water were recorded only for 1990 and 1992. The mean time of open water over 4 years during 1963-92 was used for 1984-89 and 1991. The mean is 201 (in Julian days) and the range is 18 days (Table B.1).

Linear interpolation was used to derive month-end melt values except for portions of 1984-89,91 where the exponential decay model was least squares fitted.

A time series plot of maximum ice thickness observations from 1972-92 is shown in Figure B.7.

B.1.8 Quaqtaq

The Quaqtaq record exists for 1985-86 (Table 2.3). Maximum ice thickness and date of occurrence were identified. The date of open water was recorded for 1985. The mean time of open water over 9 years during 1963-83,85 was used for 1984,86-92. The mean is 197.

For 1984,87-92, maximum ice thickness data and corresponding date of occurrence were predicted by regressing from Cape Dorset data. These values were used together with Quaqtaq's mean time of open water.(in Julian days) and the range is 35 days (Table B.1).

Linear interpolation was used to derive month-end melt values for 1985. The exponential decay model was least squares fitted to derive month-end melt values for 1986 and the remainder of the record.

A time series plot of maximum ice thickness observations from 1972-86 is shown in Figure B.8.

B.1.9 Iqaluit

The Iqaluit record is continuous from 1984 to 1992 (Table 2.3). Maximum ice thickness and corresponding time were readily identified. The date of open water was recorded for 1990-91. The mean time of open water over 17 years during 1963-83 and 1990-91 was used for 1984-89 and 1992. The mean is 198 (in Julian days) and the range is 40 days (Table B.1).

Linear interpolation was used to derive month-end melt values for 1984,88,90,91 and portions of 1985,89. The exponential decay model was least squares fitted to predict month-end melt values for the remainder of the record.

A time series plot of maximum ice thickness observations from 1963-92 is shown in Figure B.9.

B.1.10 Kuujjuak

The Kuujjuak record is continuous between 1984 and 1992 (Table 2.3). Maximum ice thickness and date of occurrence were readily identified. The date of open water was recorded for 1990-92. The mean time of open water over 8 years during 1963-83 and 1990-92 was used for 1984-89. The mean is 162 (in Julian days) and the range is 47 days (Table B.1).

Linear interpolation was used to drive month-end melt values for 1991-92 and portions of 1984-89, and the exponential decay model was least squares fitted to predict month-end melt values for the remainder of the record.

A time series plot of maximum ice thickness observations from 1973-92 is shown in Figure B.10.

B.1.11 Hall Beach

The Hall Beach record exists for 1984-86,88-89,91-92 (Table 2.3). Maximum ice thickness and corresponding time were readily identified. The mean maximum ice thickness and mean corresponding time from 18 years during 1963-92 was used for 1987 and 1990. The means are 214 and 130, and the ranges are 90 (cm) and 103 (in Julian days), respectively. The time of open water was not recorded. The mean time of open water over 9 years in the 1963-83 record was used. The mean is 198 (in Julian days) and the range is 40 days (Table B.1).

Linear interpolation was used to derive month-end melt values for portions of 1984-86,88-89,91,92. The exponential decay model was least squares fitted to predict month-end melt values for the remainder of the record.

A time series plot of maximum ice thickness observations from 1963-92 is shown in Figure B.11.

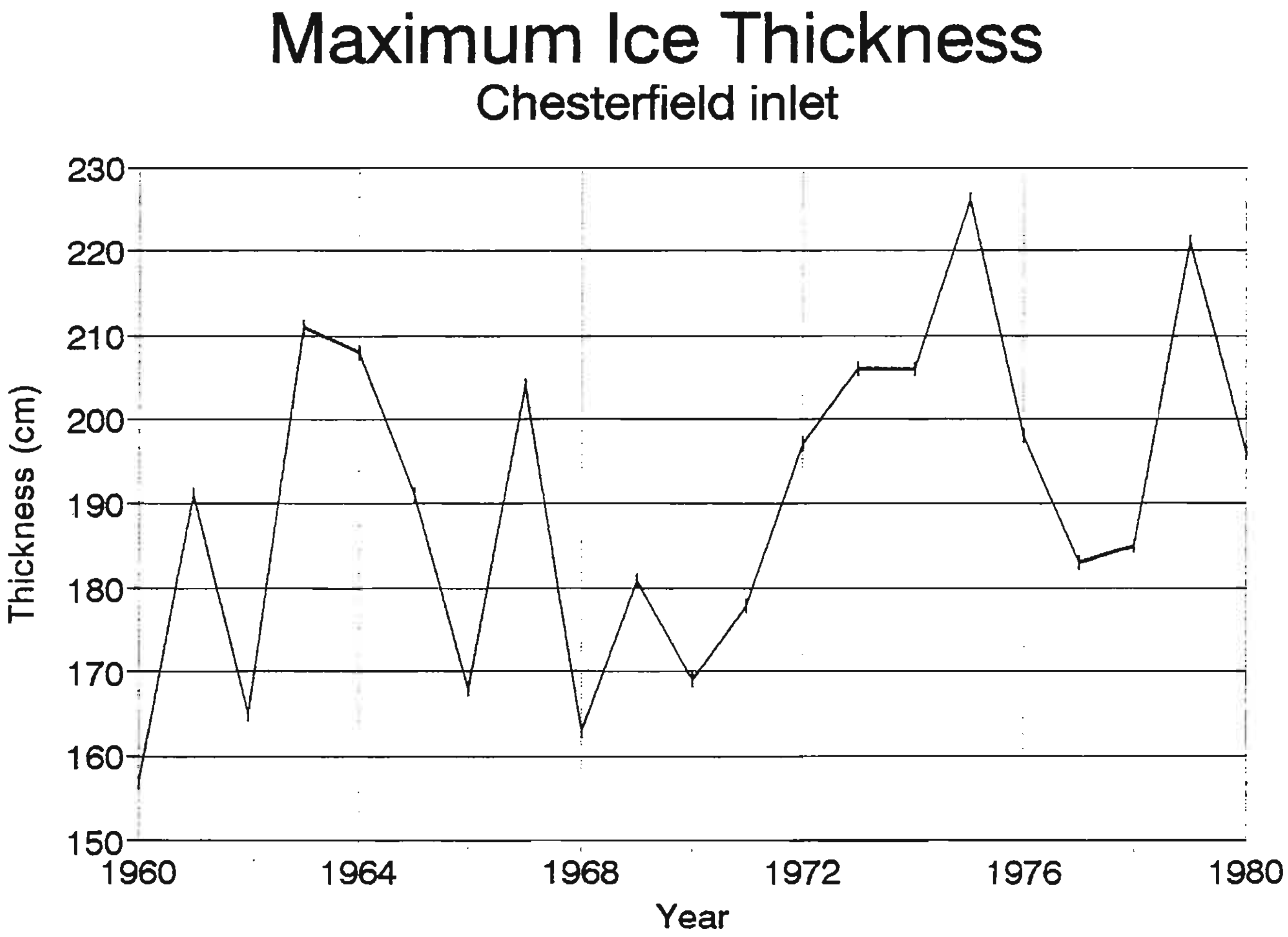

Figure B.1 Time series plot of maximum ice thickness observations, 1963-92, Chesterfield Inlet.

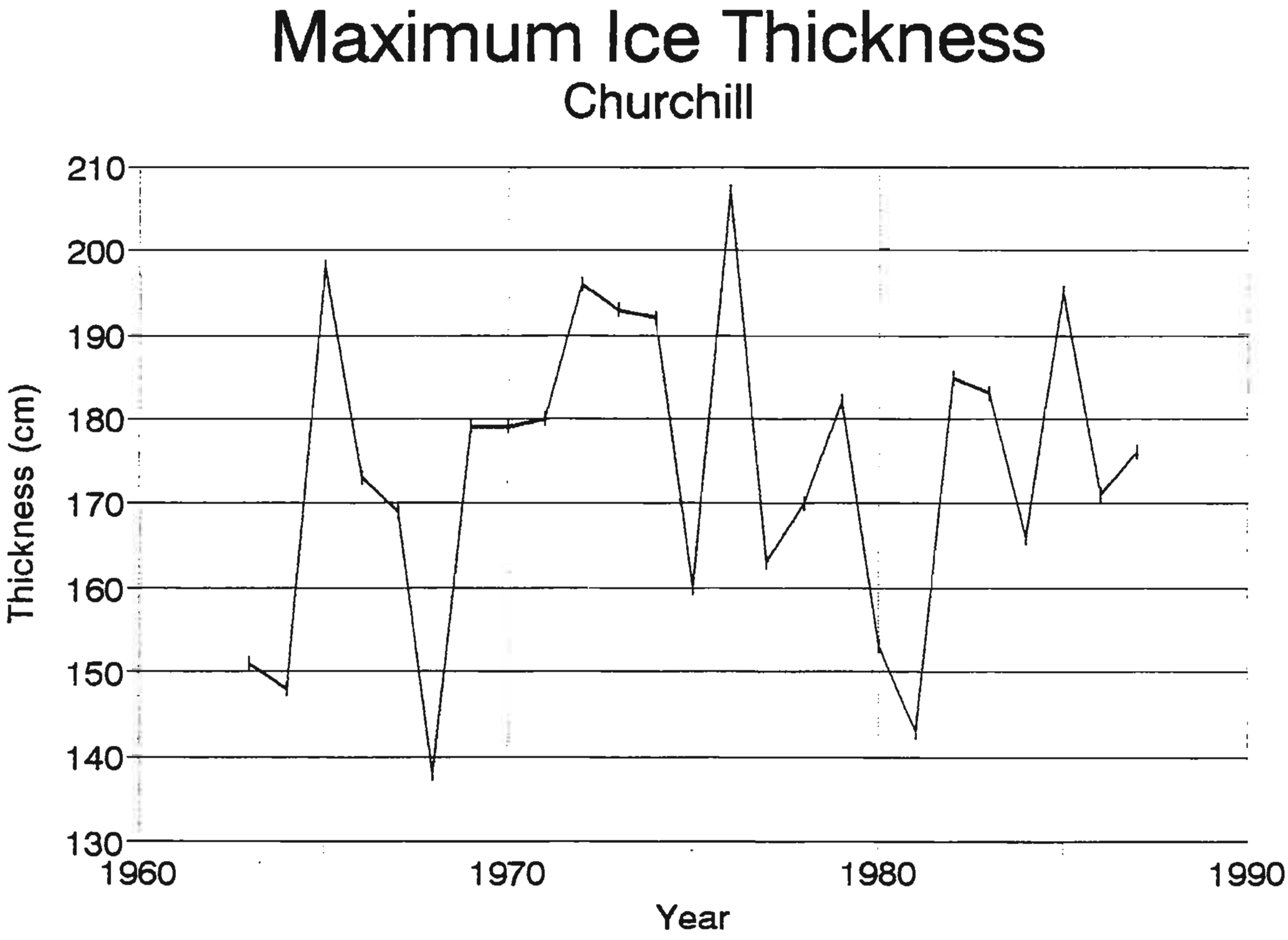

Figure B.2 Time series plot of maximum ice thickness observations, 1963-92, Churchill.

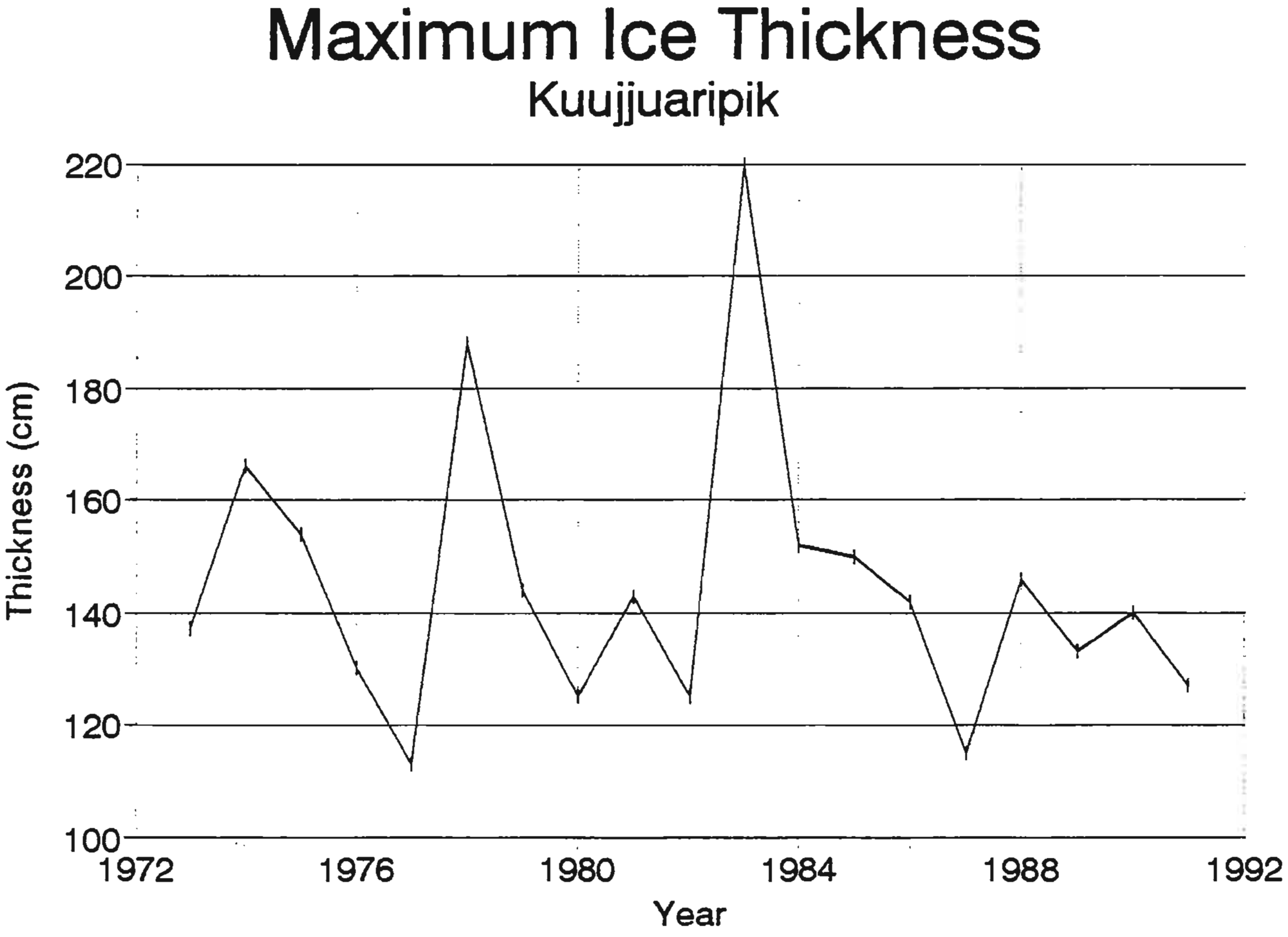

Figure B.3 Time series plot of maximum ice thickness observations, 1963-92, Kuujjuarapik.

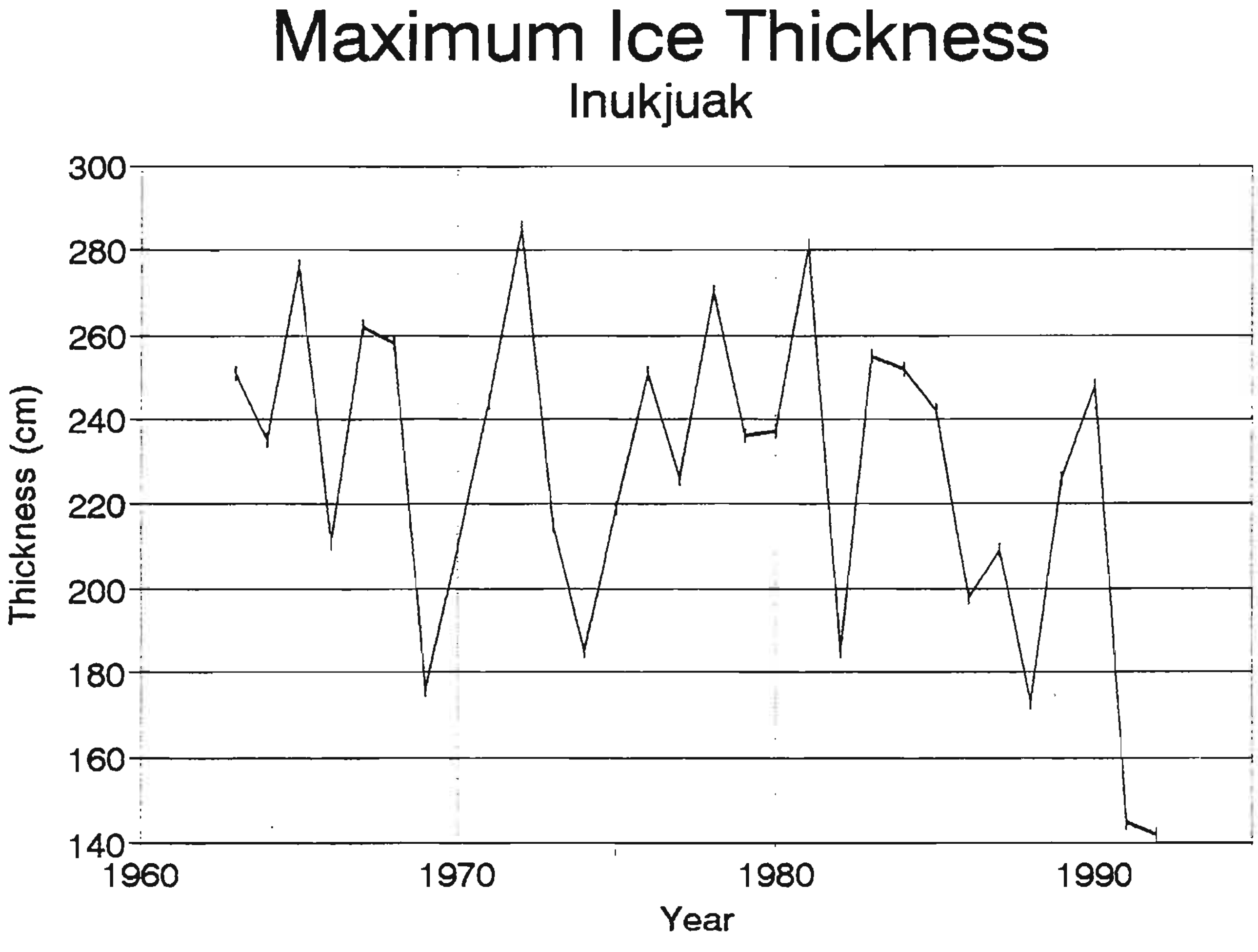

Figure B.4 Time series plot of maximum ice thickness observations, 1963-92, Inukjuak.

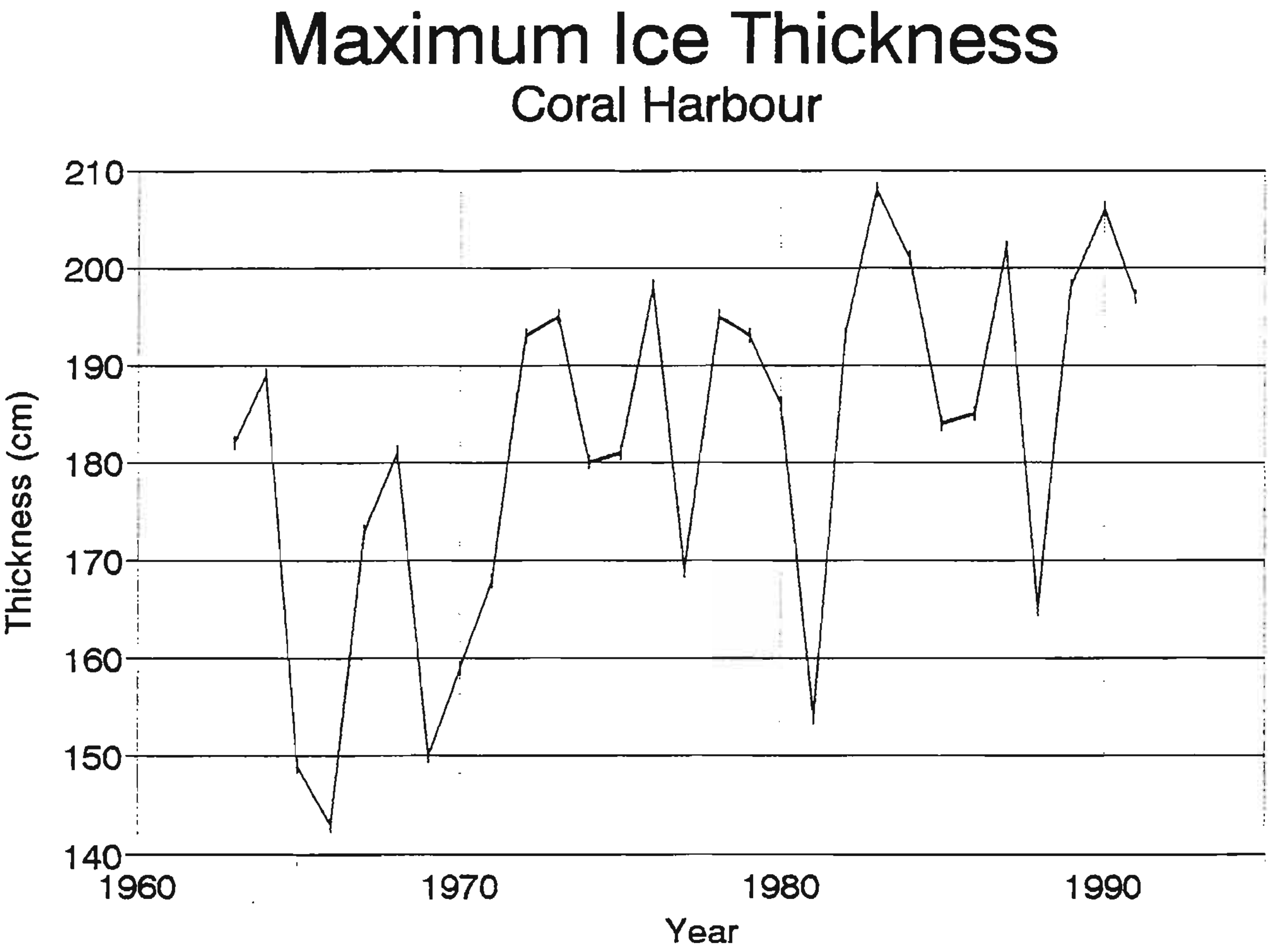

Figure B.5 Time series plot of maximum ice thickness observations, 1963-92, Coral Harbour.

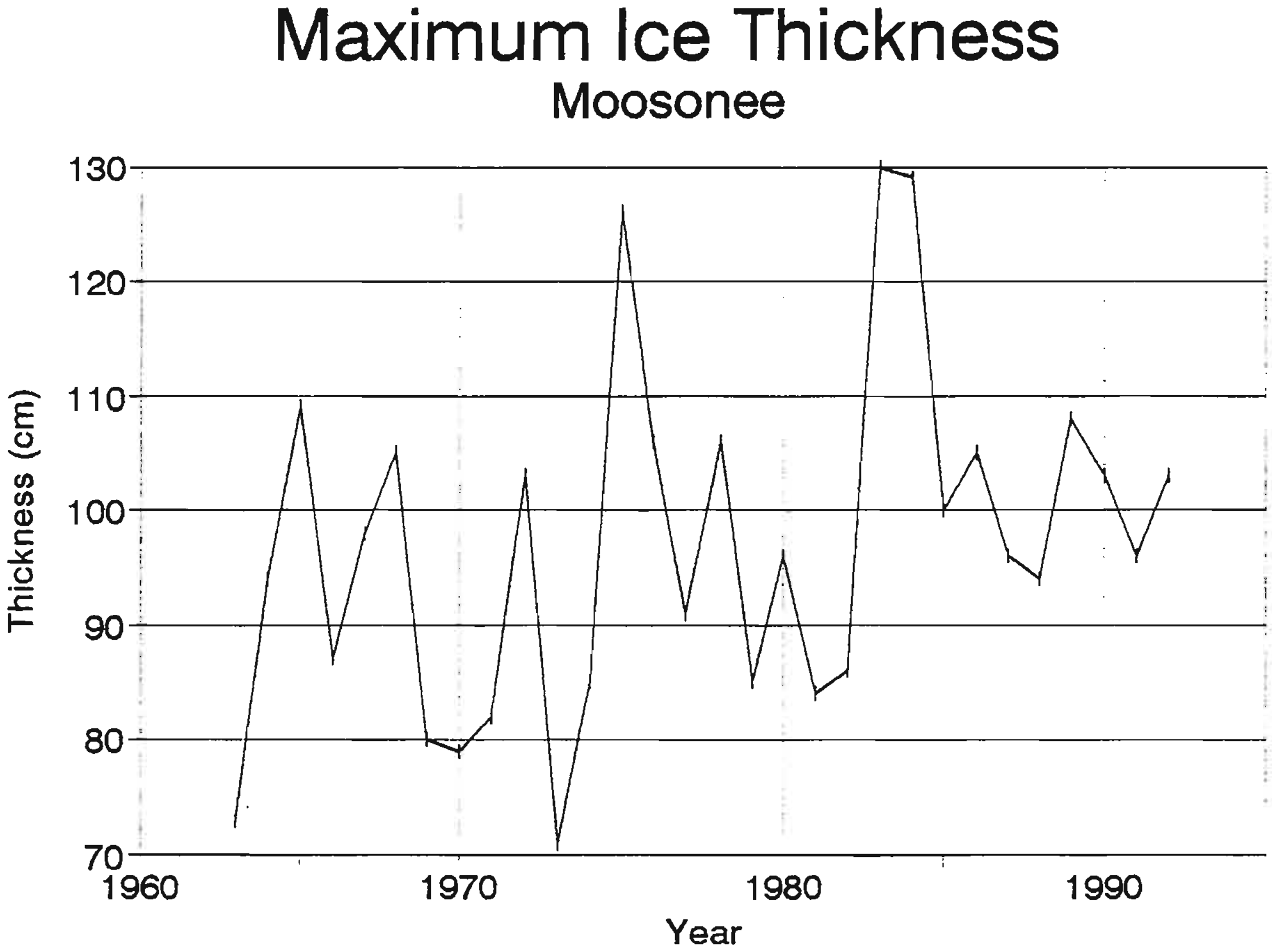

Figure B.6 Time series plot of maximum ice thickness observations, 1963-92, Moosonee.

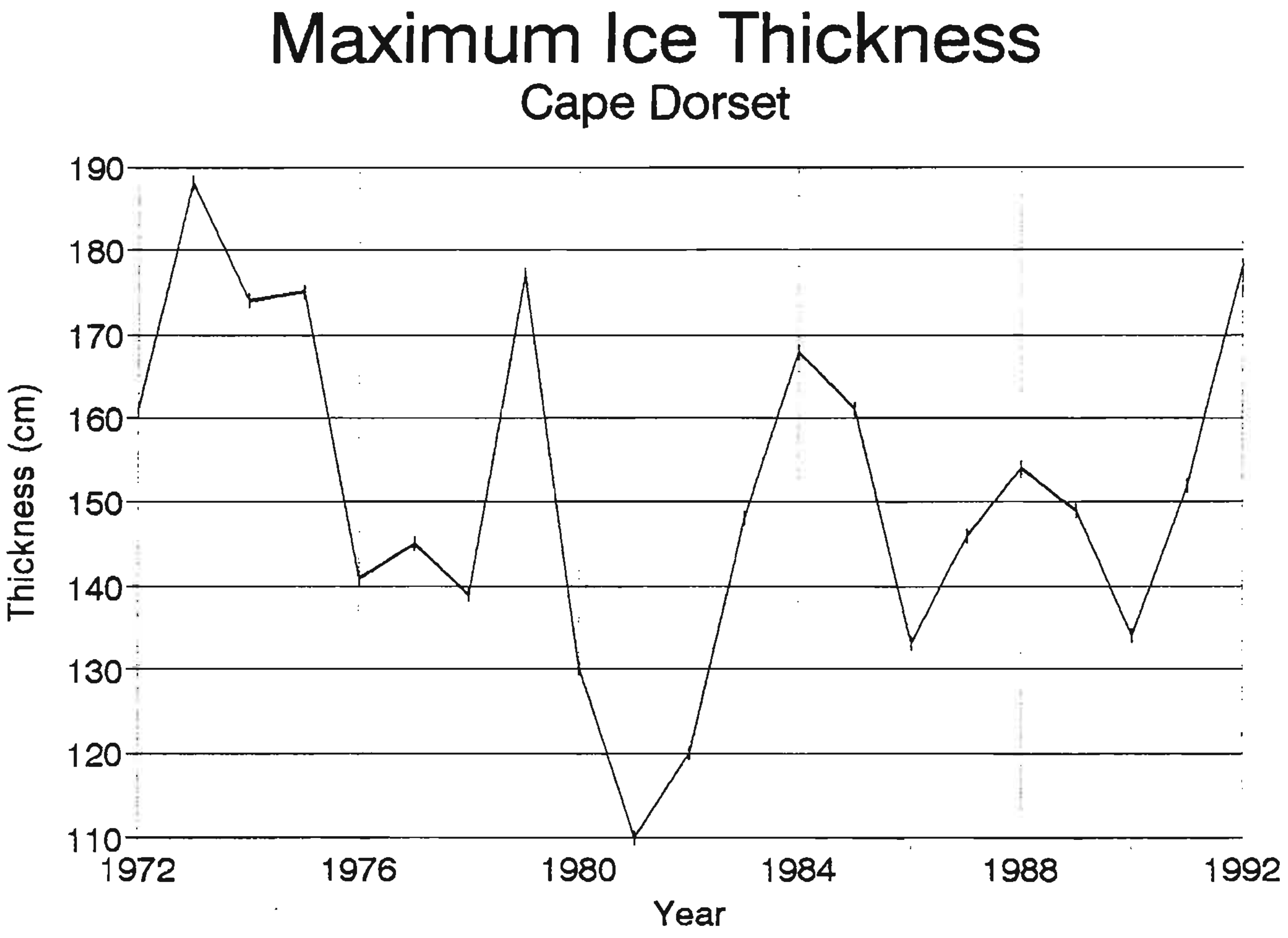

Figure B.7 Time series plot of maximum ice thickness observations, 1963-92, Cape Dorset.

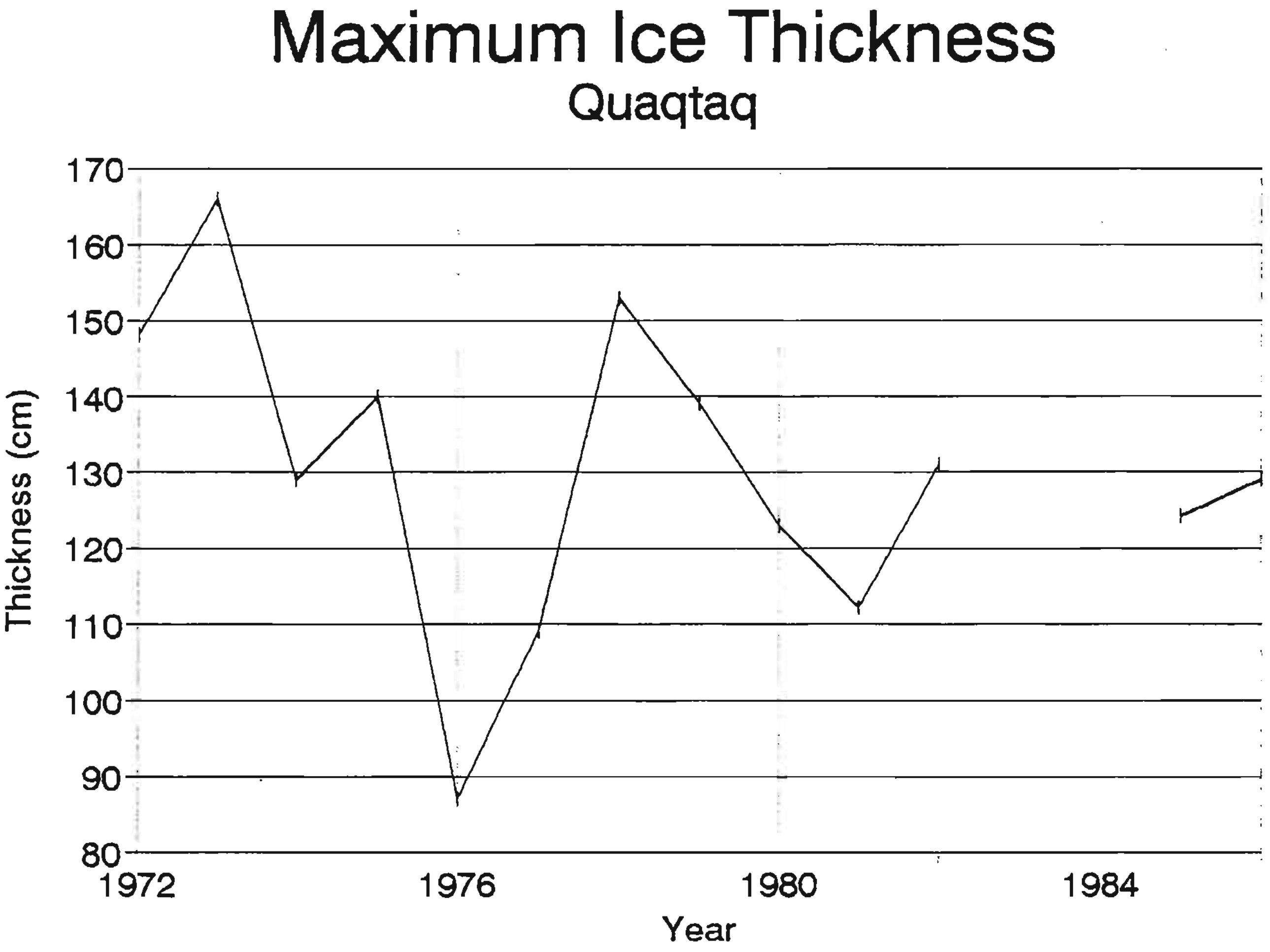

Figure B.8 Time series plot of maximum ice thickness observations, 1963-92, Quaqtaq.

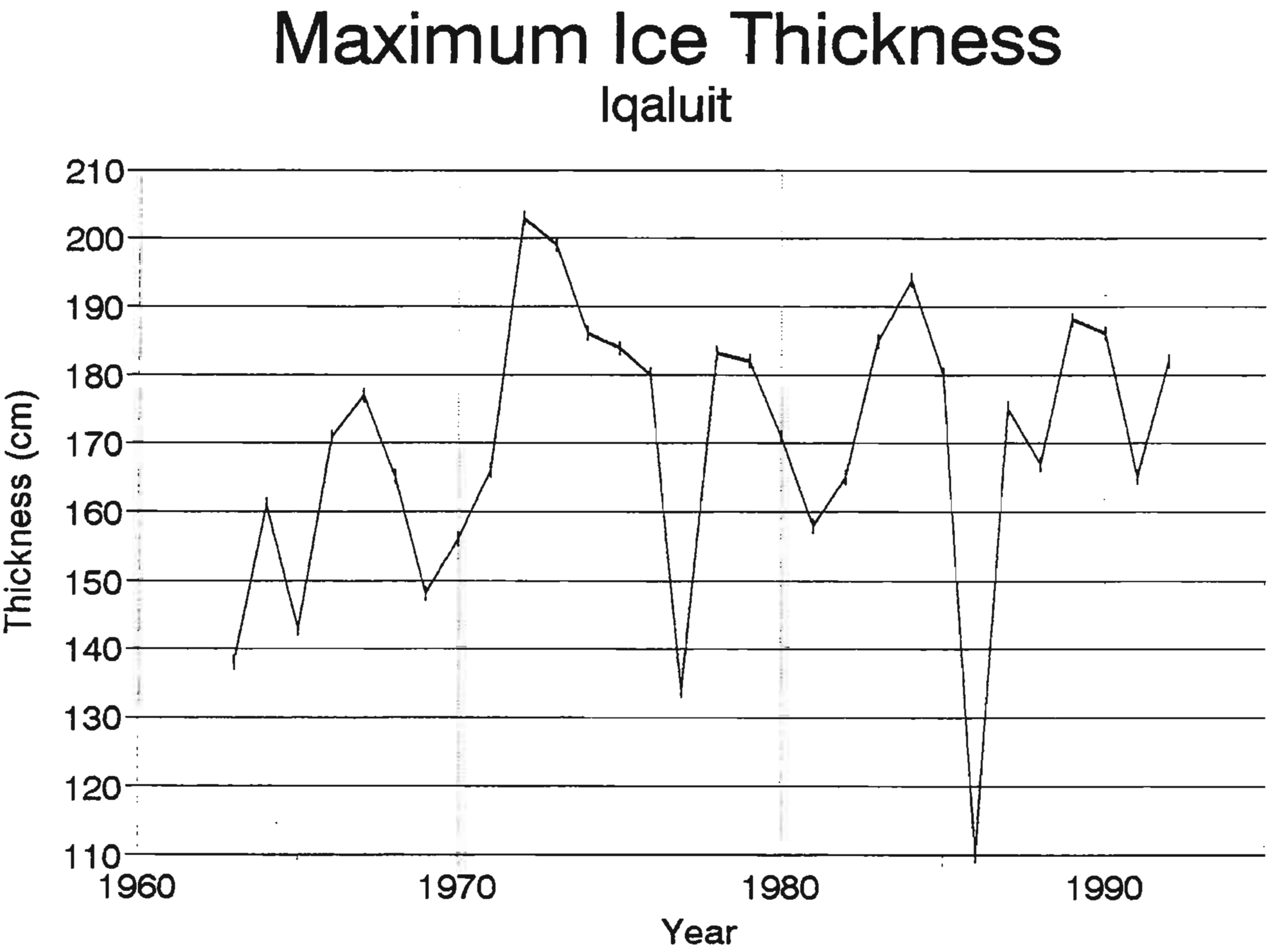

Figure B.9 Time series plot of maximum ice thickness observations, 1963-92, Iqaluit.

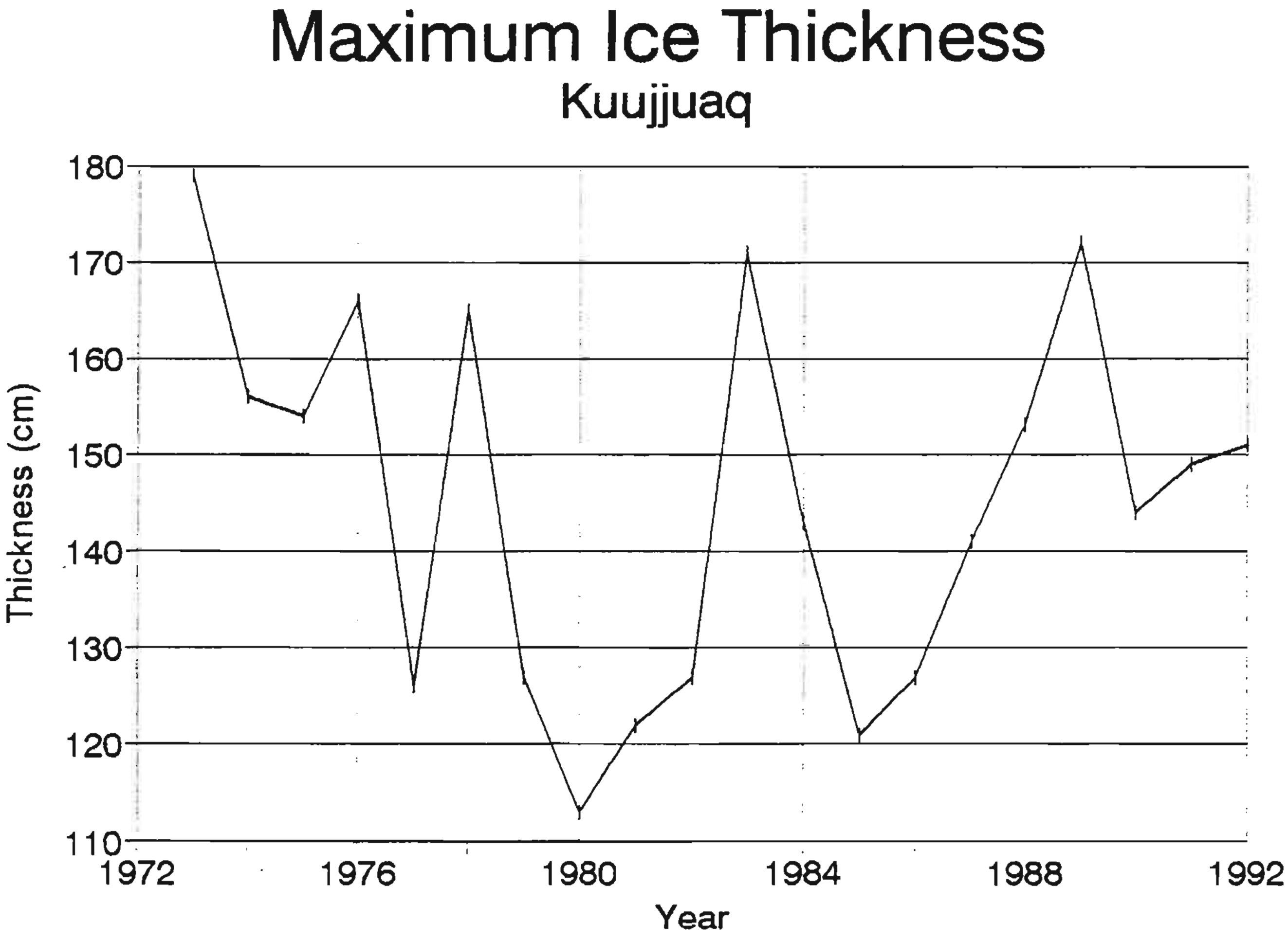

Figure B.10 Time series plot of maximum ice thickness observations, 1963-92, Kuujjuaq.

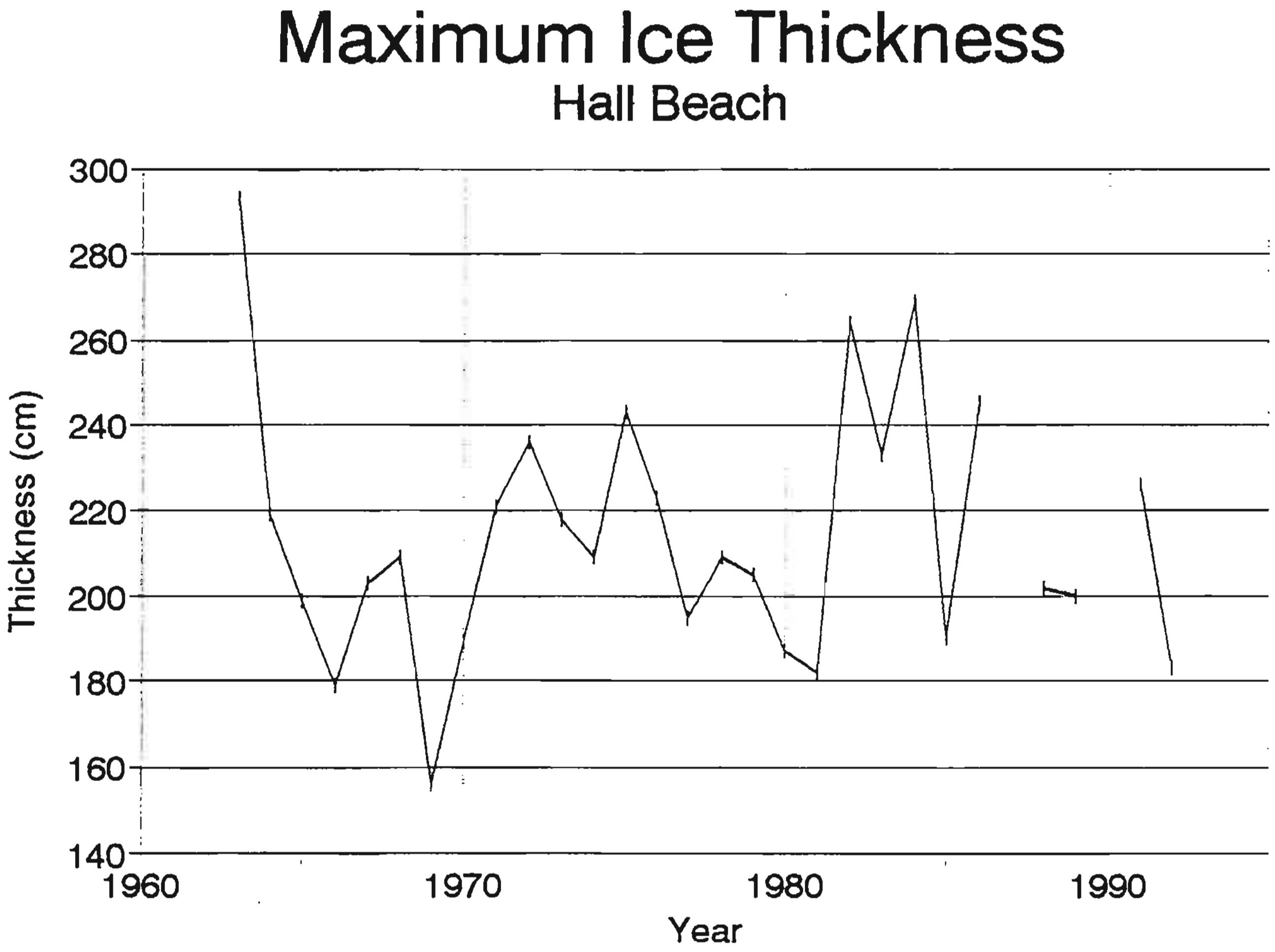

Figure B.11 Time series plot of maximum ice thickness observations, 1963-92, Hall Beach.

Table B.1 Maximum ice thickness (augmented by 10% of snow cover), date of maximum thickness, date of open water, and representative decay time constants. (**=mean value;*=regressed value)

STATION	YEAR	MAXIMUM THICKNESS (cm)	DATE (Julian days)	DATE OF OPEN WATER (Julian days)	TIME CONSTANT (days)
CHESTERFIELD INLET	1984	199 *	139 **	191 **	9
	1985	190 *	139 **	191 **	
	1986	190 *	139 **	191 **	
	1987	199 *	139 **	191 **	
	1988	180 *	139 **	191 **	
	1989	197 *	139 **	191 **	
	1990	201 *	139 **	191 **	
	1991	196 *	139 **	191 **	
	1992	194 *	139 **	191 **	
					13
CHURCHILL	1984	166	104	164 **	13
	1985	195	109	164 **	
	1986	171	122	164 **	
	1987	176	100	164 **	
	1988	174 **	107 **	164 **	
	1989	174 **	107 **	164 **	
	1990	174 **	107 **	164 **	
	1991	174 **	107 **	164 **	
	1992	174 **	107 **	164 **	
KUUJJUARAPIK	1984	152	97	147 **	
	1985	150	109	147 **	
	1986	142	94	147 **	
	1987	115	86	147 **	
	1988	146	78	147 **	
	1989	133	76	147 **	
	1990	140	124	145	
	1991	127	67	145	17
	1992	138 **	125 *	147 **	

STATION	YEAR	MAXIMUM THICKNESS (cm)	DATE (Julian days)	DATE OF OPEN WATER (Julian days)	TIME CONSTANT (days)
INUKJUAK	1984	252	104	171 **	
	1985	242	137	171 **	
	1986	198	101	171 **	
	1987	209	121	171 **	
	1988	173	85	171 **	
	1989	226	111	171 **	
	1990	248	131	171 **	
	1991	145	102	171 **	
	1992	142	157	171 **	
CORAL HARBOUR	1984	201	125	196 **	
	1985	184	123	196 **	
	1986	185	143	196 **	
	1987	202	135	196 **	
	1988	165	162	196 **	
	1989	198	153	196 **	
	1990	206	152	196 **	
	1991	197	116	196 **	
	1992	192 **	139 **	196 **	
MOOSONEE	1984	129	90	119	
	1985	100	102	125	
	1986	105	23	128 **	
	1987	96	72	128 **	
	1988	94	64	128 **	
	1989	108	83	136	13
	1990	103	96	123	12
	1991	96	95	137	
	1992	103	80	128 **	

STATION	YEAR	MAXIMUM THICKNESS (cm)	DATE (Julian days)	DATE OF OPEN WATER (Julian days)	TIME CONSTANT (days)
CAPE DORSET	1984	168	160	201 **	
	1985	161	102	201 **	
	1986	133	164	201 **	
	1987	146	121	201 **	
	1988	154	58	201 **	
	1989	149	132	201 **	
	1990	134	75	194	29
	1991	152	137	201 **	
	1992	178	166	209	16
QUAQTAQ	1984	138 *	146 *	197 **	
	1985	124	102	180	20
	1986	129	150	197 **	
	1987	128 *	127 *	197 **	
	1988	132 *	97 *	197 **	
	1989	130 *	132 *	197 **	
	1990	123 *	105 *	197 **	
	1991	131 *	135 *	197 **	
	1992	142 *	149 *	197 **	
IQALUIT	1984	194	125	198 **	
	1985	180	137	198 **	
	1986	110	157	198 **	
	1987	175	163	198 **	
	1988	167	99	198 **	
	1989	188	153	198 **	
	1990	186	159	204	
	1991	165	109	180	10
	1992	182	158	198 **	
KUUJJUAK	1984	143	104	162 **	
	1985	121	130	162 **	
	1986	127	108	162 **	
	1987	141	135	162 **	
	1988	153	92	162 **	
	1989	172	104	162 **	
	1990	144	131	148	3
	1991	149	123	160	
	1992	151	143	169	
HALL BEACH	1984	269	91	198 **	
	1985	190	90	198 **	
	1986	245	115	198 **	
	1987	214 **	139 **	198 **	
	1988	202	134	198 **	
	1989	200	118	198 **	
	1990	214 **	139 **	198 **	
	1991	226	152	198 **	
	1992	183	80	198 **	