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Tidal Currents and Inertial Oscillations in Northwestern Baffin Bay

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ABSTRACT. From moored current meter data obtained in 1978 and 1979 in western Baffin Bay and Lancaster Sound, a preliminary analysis was made of the tidal currents and inertial oscillations in the area. The tidal currents are relatively small through much of the study area. Offshore, the largest of both the diurnal and the semi-diurnal tidal currents were in all cases less than 8 cm/s in amplitude. In nearshore locations, the tidal currents can be considerably stronger due to internal tides; for example, off Cape Hay on Bylot Island, the K_1 tidal currents near the surface were determined to have an amplitude of 15 cm/s. Evidence of inertial oscillations was present in the records from the uppermost current meters on all moorings located at a nominal depth of 35 m. Typical amplitudes were 10 to 20 cm/s, with speeds as high as 35 cm/s being observed. The magnitude of inertial oscillations decreases rapidly with depth; at 250 m, they are greatly reduced in amplitude and are difficult to resolve from the semi-diurnal tidal currents. The inertial oscillations resulted, in large part, from changes in the local surface wind; at times of solid ice cover, their amplitudes were markedly reduced.

Key words: Baffin Bay, tidal currents, inertial oscillations, circulation

RÉSUMÉ. Une analyse préliminaire des courants de marée et des oscillations inertièlles dans la région a été effectuée à partir des données, enregistrées en 1978 et 1979, par les compteurs de courants mouillés dans la partie ouest de la baie de Baffin et du détroit de Lancaster. Une analyse préliminaire a été effectuée sur les courants de marée et les oscillations inertielles dans la région. Les courants de marée étaient relativement faibles à l'intérieur du territoire à l'étude. Au large, les plus importants courants de marée diurne et semi-diurne étaient dans tous les cas d'une amplitude inférieure a 8 cm/s. Aux endroits près de la côte, les courants de marée peuvent être considérablement plus forts dûs aux marées intérieures: par exemple, au large du cap Hay sur l'ile Bylot, l'amplitude des courants de marée K_1 près de la surface, a été déterminée à 15 cm/s. L'évidence des oscillations inertielles était presente dans les registres des compteurs de courants les plus hauts sur tous les sites de mouillage à une profondeur nominale de 35 m. Les amplitudes caracteristiques étaient de 10 à 20 cm/s, avec des vitesses aussi élevées que 35 cm/s. L'ampleur des oscillations inertièlles dimunuait rapidement selon la profondeur: à 250 m elles étaient grandement réduites en amplitude et étaient difficiles à distinguer des courants de marée semi-diurne. Les oscillations inertielles resultent, en majeure partie, du changement des vents locaux de surface: lorsque la surface était recouverte de glaces solides, l'amplitude était nettement réduite.

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INTRODUCTION

Tidal currents and inertial oscillations account for much of the oceanic variability occurring within the mesoscale frequency band, encompassing periods of one hour to one day (Monin *et al.*, 1977). In Baffin Bay, the study of these phenomena has been hampered by the lack of time series measurements of sufficient duration (several days or longer).

Previous studies of the tides in Baffin Bay have been made using information on sea level variations of tidal frequencies obtained from coastal tide gauge stations. Godin (1966) numerically modelled the M_2 tide in Baffin Bay, Davis Strait and the Labrador Sea. The model results were in reasonably good agreement with the observed tidal ranges. The M_2 tidal currents derived from Godin's model for Baffin Bay are rectilinear, being aligned with the NW-SE axis of the bay. They decrease in amplitude as one approaches the closed northern boundary of the bay. Typical amplitudes of M_2 tidal currents were calculated as 24 cm/s in northern Baffin Bay and 40 cm/s in central and southern Baffin Bay over the assumed constant depth of 800 m. Current meter data obtained in Smith Sound, near the northern boundary of Godin's model, have been analyzed by Avis and Coachman (1971). From these data of 11 days duration in September 1968, they determined that the M_2 tidal currents had amplitudes of 8 and 12 cm/s, respectively, at the two sites and were rectilinear, being oriented at 332 and 345 degrees true. The K_1 tidal currents were negligibly small at the two measurement sites.

Inertial oscillations are a common circulation feature, having been observed at many locations in other parts of the world's oceans (Webster, 1968). They are usually strongest near the surface, where they are primarily generated by changes in the wind (Pollard, 1970, 1980; Kundu, 1976). In their simplest form, inertial oscillations are circular motions with the sense of rotation being clockwise in the northern hemisphere. They occur intermittently, as a response to individual wind events, and decay rapidly within a few cycles. With the subsurface current meter data obtained in northwestern Baffin Bay during the course of the Eastern Arctic Marine Environmental Studies (EAMES) Program in 1978 and 1979, the data base now exists from which a quantitative description of tidal currents and inertial oscillations can be derived. The results of a preliminary analysis of these data are presented in this paper.

METHODS

Data Collection

Time series measurements of subsurface currents were obtained at 14 locations in the summer of 1978 (31 July - 5 October), and 18 locations in the summer of 1979 (23 July -2 October) in northwestern Baffin Bay and eastern Lancaster Sound (Fig. 1). Also, five moorings which had been in place since the end of summer 1978 were recovered at the beginning of the summer 1979 studies. At these latter locations, the currents were sampled at hourly intervals;

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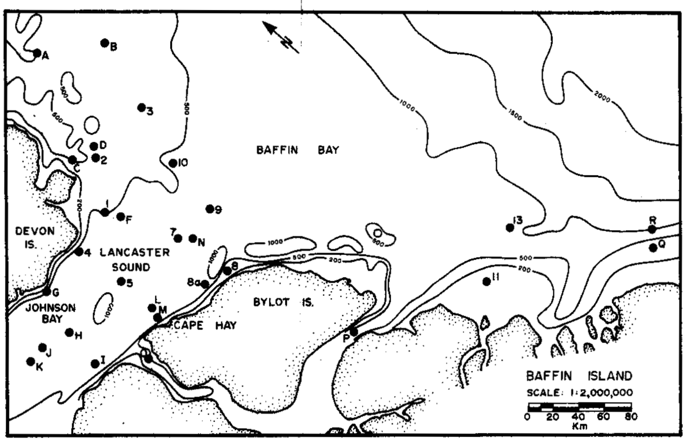

FIG. 1. The positions of the current meter moorings in relation to the bathymetry.

the summer currents were sampled every ten minutes. The current meters were placed at nominal depths of 35, 125, 250, 500 and 750 m. All moorings contained one meter at 35 m depth; the depths of the other current meters varied with location, with each mooring having from two to five meters. A more detailed description of the locations and operational periods can be found in Fissel *et al.* (1982) or Fissel *et al.* (1980).

All of the time series current data were obtained with Aanderaa RCM-4 model current meters, modified to provide improved directional sensitivity. These modifications, described by Fissel and Wilton (1980), include increasing the separation between the compass and the internal sources of magnetic disturbances in the instrument and clamping the compass immediately upon commencement of a recording cycle in order to eliminate errors due to encoder magnetization as described by Keenan (1979). According to the manufacturer's specifications, the current speeds are accurate to within ±2 cm/s for speeds up to 100 cm/s. The accuracy of directional measurements is reduced in the study area due to the proximity of the north magnetic pole. The directional accuracy varies according to the local horizontal field strength, calibration history of the meter, and mooring design. Fissel and Wilton (1980) estimate that the directional accuracies range from ±5 degrees to ±18 degrees for this study.

Included in the present study are time series measurements obtained in eastern Lancaster Sound in the summer of 1977 by Fissel and Wilton (1978). They also used Aanderaa RCM-4 current meters having the same measurement uncertainties in speed and estimated ±20 degree uncertainties in direction.

Analysis Procedures

Following verification of the current meter timing and the removal of obvious errors (Fissel and Wilton, 1980), the current meter data was decimated to hourly values using a three pass moving average filter of Godin (1972) designated as $A_6A_6A_7$. (For the data obtained over the winter, the original data were recorded hourly so that no decimation of the data was required.) A harmonic analysis was then carried out on each hourly time series using the computer programs of Foreman (1978) based upon the methods of Godin (1972). The program compensates for the reduction in the amplitude of tidal constituents due to digital filtering. In the present study, tidal analysis results are presented only for the largest constituent of the diurnal and semi-diurnal tides; the K_1 and the M_2 tidal currents, respectively.

Errors in the tidal current analysis can result from three major sources. These are measurement errors in the current meter data, the presence of variations at harmonic constituent frequencies due to movements of the subsurface moorings, and contamination of the harmonic analysis results due to phenomena other than tidal oscillations. As discussed above, the measurement errors are ±2 cm/s for speeds and up to ±20 degrees for directions. Since these errors are random in nature rather than systematic, their effect on the harmonic analysis results should be substantially reduced over the typical record lengths (50 days) used in the analysis. One manifestation of the random measurement errors will be evident in the background levels of variations at frequencies near the diurnal and semi-diurnal frequencies. These, as determined from autospectral estimates of the current meter time series, have maximum values of 1.2 cm/s at a nominal depth of 35 m, decreasing to 0.8 cm/s or less at depths of 250 to 500 m.

Errors resulting from mooring motion take two forms. First, there is the motion of the mooring itself. The amplitude of this motion was simulated from the pressure data recorded by the uppermost current meter at station 6, a site of strong currents where vertical excursions of up to 45 m were observed. Using the pressure data to compute the vertical excursions and from this, the angle of mooring tilt, the horizontal velocities due to mooring motion were calculated and subjected to harmonic analysis. The resulting magnitude of the computed currents was 0.2 cm/s or less for both the diurnal and semi-diurnal tidal constituent frequencies. In addition to the currents induced directly from the mooring motion, errors could arise from changes in the currents due to the effect of vertical movement of the current meter through zones of vertical current shear. Again, the apparent currents resulting from this effect were estimated by deriving the vertical movements of the instrument from the recorded pressure data and using the instantaneous mean shears between the levels of the uppermost and middle current meters at station six (nominal depths of 35 m and 250 m). For this simulation, the amplitude of the computed currents at the diurnal and semi-diurnal constituent frequencies was 0.7 cm/s or less.

Variations of the currents due to phenomena other than tidal currents can result in erroneous tidal analysis results. One very important such phenomenon is inertial oscillation, which at the latitudes of the study area occurs at a frequency which lies among the semi-diurnal tidal constituents. The amplitude of the inertial oscillations varies markedly with depth and is driven largely by fluctuations in the surface wind. At 35 m, the magnitude of currents due to inertial oscillations is typically 20 cm/s during wind events off the east coast of Baffin Island; at 250 m depth these currents are reduced to magnitudes of 3 to 4 cm/s as discussed below. Because individual events have a relatively short duration and occur at random phase with one another, the effect on the tidal current analysis is reduced. Comparisons of harmonic analysis results for station 13, a location of relatively strong inertial oscillations, over periods of summer open-water conditions and winter solid-ice conditions when inertial oscillations are greatly reduced, suggest that the contribution of inertial oscillations to the semi-diurnal frequency band is reduced by a factor of approximately two to four from their actual magnitudes over a 50-day record of currents during open-water conditions.

To summarize, the accuracy of the tidal analysis is limited by measurement errors, contamination due to mooring motion, and other oceanic phenomena, particularly inertial oscillations (Table 1). At 35 m depth, the errors due to mooring motion and background variations $[(0.2^2 + 0.7^2 + 1.2^2)^{0.5}]$ result in cumulative errors of 1.4 cm/s or less. For depths of 250 m or greater, the corresponding computation yields a value of 1.0 cm/s or less. The effect of inertial oscillations is more serious; at 35 m depth, the errors due to these oscillations can be so large as to render the results of the tidal analysis invalid. In this study, semi-diurnal tidal analysis results exclude depths of 35 m. At greater depth, the effect of inertial oscillations is reduced to levels of 2 cm/s or less.

RESULTS AND DISCUSSION

Tidal Currents

Godin (1966) compiled a map of the spatial variations of the M_2 and K_1 tidal height constituents based on sea-level data collected at coastal measurement sites. These maps have been updated (Fig. 2) using harmonic analyses of sea-level data measured since the time of Godin's paper. These additional data are confined to locations in the eastern Canadian Arctic Islands and included a ten-month-long record of sea level variations measured in Johnson Bay on Devon Island, which was obtained during the EAMES study (Birch, 1980).

The M_2 tidal heights are largest in the northern end of Baffin Bay with amplitudes of 80 cm, decreasing to approximately 60 cm in Lancaster Sound, further decreasing in the central and southern portions of Baffin Bay to effectively zero amplitude in the vicinity of an amphidromic point located off southeastern Baffin Island. The K_1 tidal heights are more spatially uniform throughout Baffin Bay with amplitudes of 25 to 30 cm, tending to decrease from north to south.

TABLE 1. Summary of the maximum amplitude of errors and uncertainties in the tidal analysis results

	Uncertainties (cm/s)			
	Semi-Diurnal		Diurnal	
Cause of Uncertainties[1]	35 m	250 m	35 m	250 m
1) random measurement errors	1.2	0.8	1.2	0.8
2) direct mooring motion	0.2	0.2	0.2	0.2
3) mooring motion through vertical velocity shears	0.7	0.7	0.7	0.7
Root-Mean-Square value of 1), 2), & 3)	1.4	1.1	1.4	1.1
4) contamination due to inertial oscillations	4.0 - 10.0	1.0 - 2.0	n/a[2]	

[1]Refer to the text for an explanation of each type of uncertainty.
[2]Not applicable.

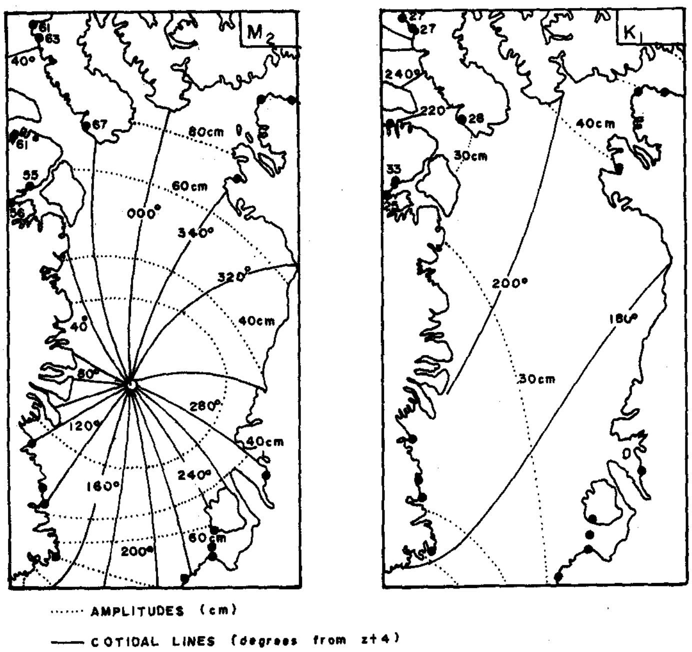

FIG. 2. Tidal heights of M_2 and K_1 constituents in Baffin Bay, inferred from coastal water level data collected in various years (after Godin, 1966).

As a first approach to examining the spatial variations of the M_2 tidal currents, a map of the results of the harmonic analyses is presented in Figure 3. The station locations, record length used for the analyses, and measurement depth are provided in Table 2. For the sake of uniformity, the harmonic analysis results used to construct Figure 3 are computed where possible from data obtained at 250 m depth. If suitable data were not available at 250 m depth, the harmonic analysis results for other depths (125 m or 500 m) were submitted, with the exception of 35 m depth data which could be seriously contaminated by the effect of inertial oscillations, as discussed previously. The pro-

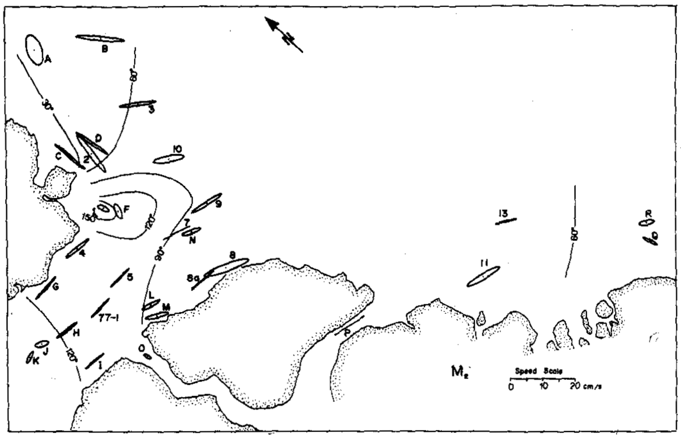

FIG. 3. The M_2 tidal current ellipses and the contours of the phase for the current meter data.

gram used for the harmonic analysis presents the results in the form of tidal current ellipses which are traced out as the sum of two oppositely rotating vectors. The semi-major axis of the ellipse represents the maximum amplitude of the tidal current constituent, while the inclination denotes the angle between the direction of maximum tidal flow and true east, in degrees counterclockwise. Also included is the Greenwich phase angle, expressed in constituent degrees, which relates the time of maximum instantaneous current to the tidal potential; the definitions of these parameters are described in detail by Foreman (1978).

The amplitude of the M_2 tidal currents varies markedly over the study area, ranging from 7.2 cm/s to the east of Devon Island to less than 2.5 cm/s in the central portion of Lancaster Sound, in Navy Board Inlet and off the east

TABLE 2. Parameters of the K_1 and M_2 tidal current ellipses along with the location and duration of each current meter data set

							K_1 TIDAL CURRENT				M_2 TIDAL CURRENT			
Station Id.	Lat.	Long.	Period Start	Stop	No. of Days	Depth (M)	Semi Maj. (cm/s)	Min.	Inclination Deg.	Phase Deg.	Semi Maj. (cm/s)	Min.	Inclination Deg.	Phase Deg.
A	75°42'	77°52'	26/ 7/79	24/ 9/79	60	125	1.85	-.73	16.	110.	4.40	1.88	119.	36.
B	75 26	76 21	27/ 7/79	26/ 9/79	61	125	1.63	-1.02	11.	95.	7.30	-.63	129.	43.
C	75 00	79 09	25/ 7/79	18/ 9/79	55	250	2.37	-.05	91.	109.	5.93	-.35	97.	23.
2	74 55	78 41	4/ 8/78	21/ 7/79	351	250	3.64	-.44	58	113.	7.08	-.79	84.	36.
D	74 58	78 29	25/ 7/79	25/ 9/79	62	125	2.40	-.20	65	117.	5.85	-.41	102.	32.
E	74 59	77 52	25/ 7/79	25/ 9/79	62	35	2.86	-1.52	47.	109.	—	—	—	—
3	74 56	76 53	3/ 8/78	21/ 9/78	50	250	2.96	-1.51	21.	118.	5.57	.47	143.	62.
I	74 35	79 26	4/ 8/78	21/ 7/79	343	250	4.68	-.46	23.	183.	1.89	.68	112.	172.
F	74 30	79 12	4/ 8/79	18/ 9.79	45	125	3.53	-.01	33	125.	2.45	.85	72.	149.
10	74 31	77 19	3/ 8/78	28/ 9/78	57	250	2.85	-1.39	25.	121.	4.74	.94	146.	69.
4	74 30	80 38	5/ 8/78	17/ 9/78	43	250	7.01	.15	25.	146.	4.50	-.49	179.	93.
5	74 09	80 19	6/ 8/78	29/ 8/78	23	250	5.61	.69	1.	134.	3.97	.19	4.	103.
G	74 26	81 55	1/ 8/79	22/ 9/79	52	250	8.03	.22	5.	134.	4.58	.26	10.	113.
77-1	74 05	81 11	29/ 7/79	29/ 9/79	62	250	4.76	.14	1.	133.	3.98	-.21	5.	100.
H	74 07	82 11	1/ 8/79	22/ 9/79	52	250	5.56	.31	177.	140.	3.94	-.33	177.	119.
J	74 09	82 54	2/ 8/79	20/ 9/79	49	500	5.86	.30	177.	140.	2.10	.78	159.	87.
K	74 08	83 21	3/ 8/79	20/ 9/79	48	500	5.45	.34	10.	146.	1.86	.48	24.	127.
I	73 50	82 08	2/ 8/79	22/ 9.79	51	500	6.59	-.01	4.	136.	3.64	.15	179.	109.
O	73.37	81 05	12/ 8/79	12/ 9/79	31	250	2.25	.27	115.	134.	1.21	.46	112.	118.
L	73 52	80 11	29/ 7/79	18/ 9/79	51	500	4.06	-.56	160.	151.	3.08	.52	167.	88.
M	73 47	80 15	29/ 7/79	21/ 9/79	54	250	7.64	-.82	158.	139.	3.54	.60	152.	73.
8A	73 45	78 47	29/ 9/78	28/ 7/79	302	250	3.36	.01	178.	125.	4.86	-.10	177.	92.
8	73 42	78 11	1/ 8/78	27/ 9/78	58	250	4.84	.60	168.	176.	7.22	-1.10	157.	71.
7	74 07	78 29	2/ 8/78	16/ 9/78	45	250	3.53	-.29	3.	134.	4.53	.01	164.	86.
N	74 03	78 12	5/ 8/79	26/ 9/79	52	250	2.70	-.41	6.	134.	3.02	.58	156.	84.
9	74 07	77 25	2/ 8/78	28/ 9/78	57	250	2.43	-.55	179.	131.	5.41	-.53	168.	82.
P	72 49	77 02	2/ 8/79	1/10/79	50	35	1.47	-.79	2.	269.	5.22	-.01	168.	65.
11	72 23	74 04	11/ 8/78	26/ 9/78	47	125	1.25	-.31	109.	302.	5.75	-.83	163.	81.
13	72 31	72 46	11/ 8/78	8/ 8/79	362	250	.51	.10	125.	344.	3.49	.13	145.	71.
Q	71 40	71 01	10/ 8/79	1/10/79	53	125	.48	.04	179.	260.	2.47	-.39	102.	174.
R	71 46	70 45	9/ 8/79	1/10/79	53	250	.32	-.18	79.	232.	2.33	.72	139.	38.

coast of central Baffin Island. In these latter regions, the accuracy of the analysis of the M_2 tidal currents is questionable, because the amplitudes are comparable to the uncertainties described above. The M_2 tidal currents decrease from north to south on the western side of Baffin Bay and decrease from east to west in eastern and central Lancaster Sound. At measurement sites near the coast of Baffin Bay, the tidal currents tend to be more or less aligned with the overall orientation of the coastline in contrast to offshore locations; this is most evident at stations A, C, D and 2 located nearer the east coast of Devon Island in comparison to stations B and 3, located further offshore.

The M_2 tidal currents off the southeastern corner of Devon Island (stations 1 and F) have anomalous values of both amplitude and phase when compared to nearby stations both to the east of Devon Island and in eastern Lancaster Sound (stations C and 4), with the phases exceeding by 50 degrees those at other nearby measurement sites. These anomalies may result from a transition in the barotropic tide between the tidal current regimes of Baffin Bay and Lancaster Sound or, alternatively, from internal tides.

The tidal analysis results for the K_1 tidal currents are compiled in Table 2 and displayed in Figure 4. For the K_1 results, analyses from current meter data at 35m depth are included if no other measurements are available, because inertial oscillations do not contaminate the K_1 tidal currents. As was the case for the M_2 tidal currents, the orientation of the K_1 tidal currents tends to parallel the shoreline at coastal locations. For example, in northern Baffin Bay off Philpots Island, which is located on the east coast of Devon Island, the K_1 tidal currents are oriented north-south near the coast but become more east-west in orientation further offshore.

The K_1 tidal currents, in contrast to the M_2 tidal currents, are larger in Lancaster Sound than in northwestern Baffin Bay. Typical amplitudes of 2.5 to 3.5 cm/s are found off the east coast of Devon Island and the mouth of the sound, as compared to amplitudes of 5 to 8 cm/s in eastern Lancaster Sound. The K_1 tidal currents decrease from north to south along the western side of northern Baffin Bay; off the east coast of the central portion of Baffin Island the magnitude of the current is extremely small, being less than 1.5 cm/s, and cannot reliably be resolved from background noise levels.

Some of the spatial variability in the tidal currents may result from internal tides which are characterized by variations in the currents with no corresponding sea level variations. Because of the high latitude of the study area, all of the internal tidal constituents in the diurnal group of frequencies, and some of those in the semi-diurnal group, will be poleward of the inertial latitude. As a result, freely travelling internal waves cannot occur at the frequency of these constituents. However, internal tides can occur locally as trapped waves over the varying bottom bathymetry.

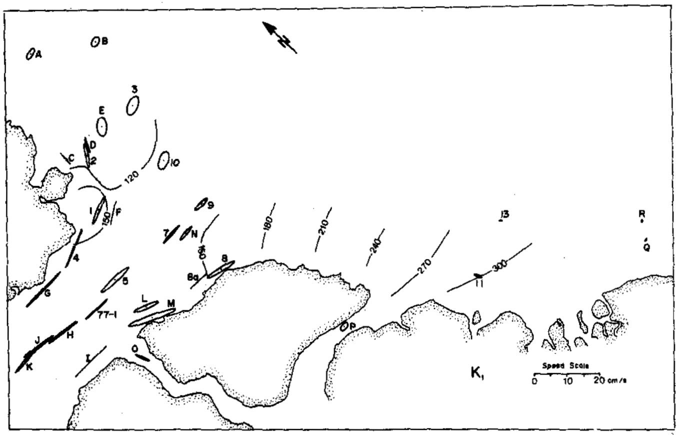

FIG. 4. The K_1 tidal current ellipses and the contours of the phase for the current meter data.

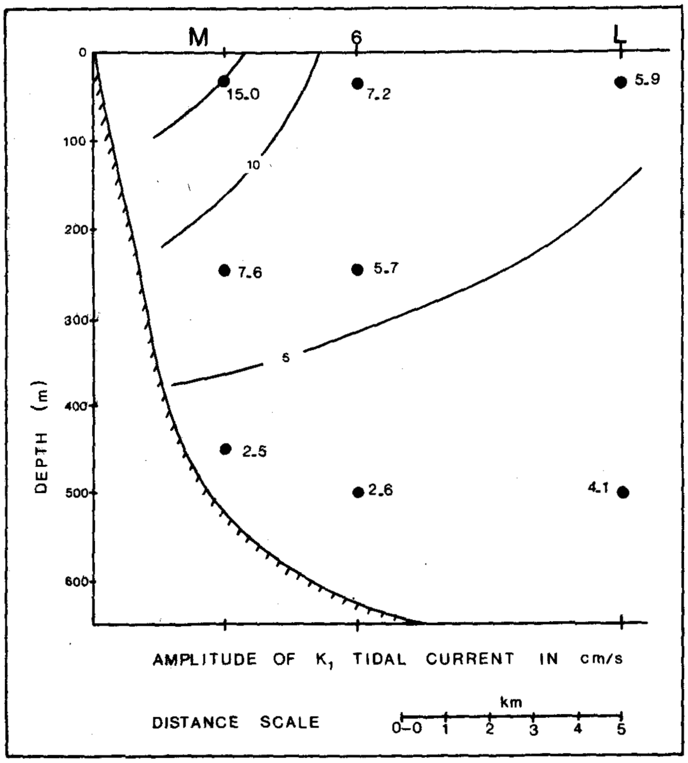

FIG. 5. Variations of the amplitude of the K_1 tidal currents with depth and distance offshore of northwestern Bylot Island. The larger amplitudes near the coastline are indicative of internal tidal currents.

Detection of internal M_2 tides is made difficult due to the contamination of the tidal analysis by inertial oscillations in the upper portion of the water column. However, the K_1 tidal currents are more conducive to searching for internal tides. At locations in Lancaster Sound, the magnitude of the K_1 tidal currents are relatively uniform with depth (within 38% at stations 77-1, 77-3, G, H, I and J). In northwestern Baffin Bay, the reduced levels of the K_1 tidal currents make meaningful comparisons with depth difficult. However, a large vertical variation of the K_1 tidal currents is evident at locations off the NW coast of Bylot Island, in the vicinity of Cape Hay (see Fig. 5). The changes with depth decrease with distance offshore, as measured at stations 6 and L, but remain significant. Thus internal K_1 tides may be of considerable importance in local areas; however, they do not appear to be significant in much of the offshore study area.

The tidal currents through most of the study area have relatively small amplitudes of <8.0 cm/s for both the K_1 and M_2 constituents. Since the areas of large K_1 and M_2 tidal currents did not coincide, the largest offshore tidal currents represented as the sum of the two major constituents are typically 8-10 cm/s in amplitude and do not exceed 12 cm/s. In nearshore locations, the tidal currents can be considerably larger. Off Cape Hay, Bylot Island, the K_1 tidal currents amplitude was 15 cm/s near the surface, several times the corresponding value at depth, apparently due to an internal tide.

Inertial Oscillations

To resolve the inertial oscillations from tidal variations requires a long record of current observations to attain the necessary frequency resolution. However, because the inertial oscillations occur as individual events, with the phase of the events being unrelated to one another, the oscillations are best examined over a record length comparable to the duration of individual events. These intermittent characteristics make it difficult to resolve inertial oscillations from tidal currents even when extended time series data are available.

We begin our examination of inertial oscillations with the data from station 13 located about 75 km off the east coast of Baffin Island in a water depth of 840 m. At this site, current measurements of 362 days duration are available at nominal depths of 35, 250 and 500 m and the M_2 tidal currents are relatively small with an amplitude of 3.5 cm/s.

Starting with the decimated hourly data, a finite-impulse recursive digital filter was applied which passed all current variations with periods between 1.5 and 2.5 cycles per day, (hereafter referred to as the SD filter [see Fissel *et al.*, 1980]). A plot of the band-passed current revealed a striking difference in the amplitude of semi-diurnal variations before and after November 1978 (see Fig. 6). During the period from November 1978 to June 1979, the semi-diurnal variations were reduced by a factor of two or more due to the presence of a solid ice cover at the surface (freeze-up began in mid-October and was well underway in November 1978). Because of the sea ice cover, the surface wind apparently became less effective in generating inertial oscillations.

It is possible that the changes in the surface wind could generate inertial oscillations in the ice cover which in turn could induce inertial oscillations in the upper water layers. Inertial oscillations have been observed elsewhere in pack ice (Hunkins, 1967; McPhee, 1980). However, the markedly reduced amplitudes of the inertial oscillations at 35 m depth observed in the present study suggest that this mechanism is much less effective in generating inertial oscillations than direct forcing due to surface wind, for the winter ice conditions of northwestern Baffin Bay.

In order better to delineate the inertial oscillations, a harmonic analysis was made of the SD band-passed current over the period 15 November 1978 to 30 June 1979, when the analysis is least likely to be contaminated by inertial oscillations. From this analysis, predictions of the semi-diurnal tidal currents were produced for the entire 362-day period of the SD band-passed time series (Fig. 6(B)). After subtracting the predicted tidal currents from the band-passed currents, the resultant time series contains inertial oscillations along with other semi-diurnal variations due to measurement errors. In addition, internal tidal currents which vary in phase over the record length will also be present in the resultant time series.

Inertial oscillations are readily apparent in the time series plot for the period prior to freeze-up. These oscillations occur as individual events of, typically, five to seven days duration. An example of one such event from 9-14 September 1978 is shown in Figure 7, in the form of a progressive vector diagram as computed from the band-passed currents, following removal of the tidal currents.

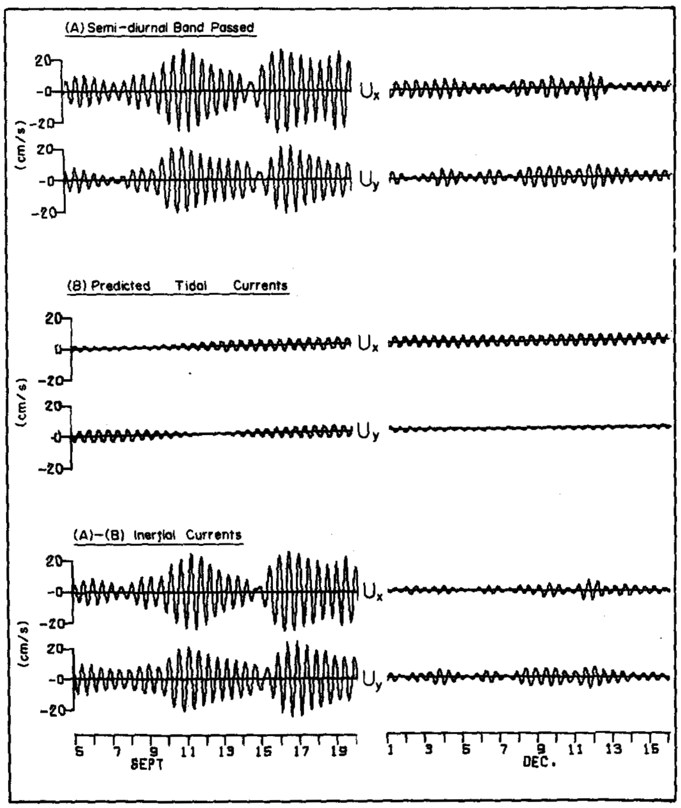

FIG. 6. For the current meter time series data at station 13, 35 m depth, (A) the semi-diurnal passed data; (B) the predicted semi-diurnal tidal current; and (C) the difference between (A) and (B) dominated by inertial oscillations. Note the marked reduction of inertial activity in the ice-covered December period.

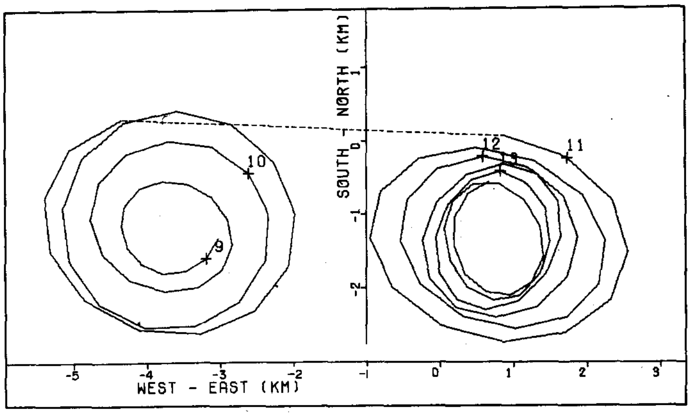

FIG. 7. Progressive vector diagram of the inertial oscillations computed for station 13, 35 m depth, from 9-14 September 1978. The period of decay (11-14 Sept.) is displaced from the time of growth of the oscillations (9-10 Sept.).

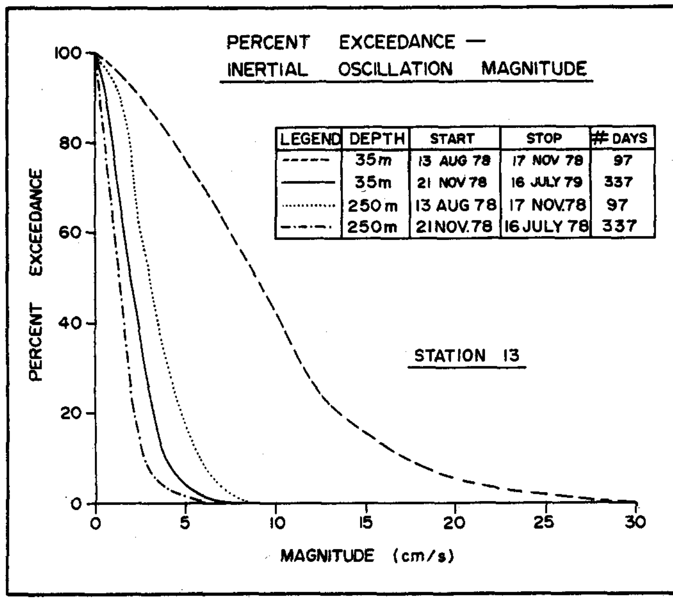

FIG. 8. The percent exceedance of inertial oscillation magnitudes at station 13, 35 m depth and 250 m depth.

The inertial oscillations trace out clockwise circulation motions, as expected, beginning with a period of growth (9-10 September) followed by a period of decay (11-14 September). The diameter of the inertial oscillations is typically 2 km and occasionally approaches 4 km during the peak oscillations of a strong event, corresponding to typical and maximum velocities of 14 and 28 cm/s, respectively.

In Figure 8, the per cent exceedance is presented for the speeds of the band-passed current after removal of the tidal currents. At 35 m depth, the maximum speed is 30 cm/s with 10% of the values exceeding 17 cm/s. In contrast, the speeds calculated during the periods of ice cover are much reduced: the maximum speed is 8 cm/s and the 10% level is only 4 cm/s. The magnitude of the band-passed currents at 250 m depth, following removal of the tidal currents, is markedly reduced with a maximum calculated speed of only 12 cm/s (Fig. 8).

There is no apparent correspondence between inertial oscillation events at 35 m and 250 m. Nevertheless, a portion of the inertial oscillations at 250 m appears to be related to surface processes because significantly larger amplitudes were found under open-water conditions as compared to periods of ice cover (Fig. 8).

We have examined the inertial oscillations at station 13 in some detail. To extend the description over a larger area and to study the horizontal coherence of inertial oscillations, we consider the current measurements at four sites located east of Baffin Island in the summer of 1978: stations 11, 14, and 15 along with station 13. For these data, however, the tidal currents cannot be effectively removed since the current meter records are of shorter duration (50 days) and limited to periods of open water. Instead, the northerly component of the band-passed current is presented in Figure 9. Based on the harmonic analysis at station 13, the root-mean-square value of the northerly component of the semi-diurnal tidal currents is only 1.5 cm/s with a maximum value over 362 days of 4.7 cm/s.

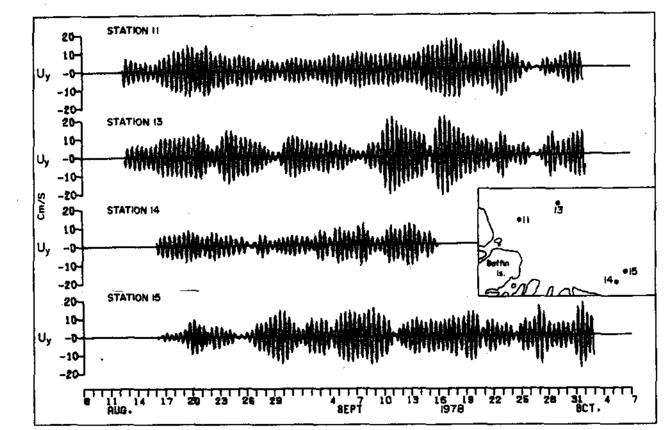

FIG. 9. The semi-diurnal band-passed northerly components at 35 m depth of stations 11, 13, 14 and 15 in 1978.

Inertial oscillations are clearly evident in the band-passed currents at each measurement site off Baffin Island (Fig. 9). The inertial oscillations can be distinguished from tidal currents by the relatively large magnitudes of the northerly components as compared to the expected tidal currents, and from the irregular bursts of activity in the semi-diurnal variations.

A visual scan of the time series plots reveals little horizontal coherence in the level of inertial oscillations among the four sites. Large inertial oscillations will often occur at one location with only low to moderate levels at the other locations over the same time period. One example of such an occurrence is found 9-14 September when strong inertial oscillations were measured at Station 13 (Fig. 7) while the levels of inertial oscillations at the other three stations were relatively low. This lack of any evident coherence applied to all pairs of stations, including stations 14 and 15 which were separated by only 14.5 km.

At both pairs of stations (11 and 13; 14 and 15), markedly higher levels of inertial oscillations occurred at the offshore location. The total standard deviation of the band-passed currents at station 13 is 47% larger than that at station 11; the corresponding difference between station 14 and 15 is 39%. The cause of these differences is not clear. One possible explanation could be reduced winds at the inshore locations, due to topographic effects; however, the inshore stations are still a considerable distance from the coastline. Another possible cause could be a difference in the density structure of the water column. Because of the southward currents in the area, combined with the lower-density water from ice melt and land run-off in nearshore areas, the stratification is greater for inshore waters than for offshore waters (Fissel *et al.*, 1982). One consequence of this is that the mixed-layer depth is reduced at inshore stations: 8 ± 9 m (mean ± standard deviation) as compared to 17 ± 9 m offshore. The decreased mixed-layer depth and increased stratification inshore will tend to limit the inertial oscillations to the upper mixed layer because of the amount of energy required to penetrate the more stratified waters below the mixed layer. This explanation suggests that reduced inertial oscillations at the nominal depth of 35 m of the upper current meter for inshore areas would occur at inshore sites, as compared to offshore sites, in agreement with the comparisons for station pairs 11 and 13, and 14 and 15.

At station 13, inertial oscillations were found to be greatly reduced at 250 m depth as compared to 35 m depth. At stations 11 and 14, both located closer to shore in shallower water of depths 158 m and 260 m, respectively, current meter data were obtained at depths of 125 m and 35 m. The amplitude of the inertial oscillations at 125 m is markedly reduced from the levels observed at 35 m (Fig. 10), having a standard deviation of <0.5 that observed at 35 m. Because of the reduced levels, the semi-diurnal band-passed northerly current component cannot be taken as a reliable indicator of inertial oscillations, being only 50% above the amplitude of the tidal currents in terms of standard deviation. This may explain, in part, the fact that no vertical coherence is visually apparent between the band-passed currents at 35 m and 125 m. The inertial oscillations at 125 m depth at stations 11 and 14 appear to be only marginally larger than those observed at 250 m depth at station 13.

A similar analysis was made of inertial oscillations in the waters to the east of Devon Island, some 350 km north of the region discussed previously. The semi-diurnal tidal currents in this area are nearly twice as large, with the M_2 constituent being typically 5 to 7 cm/s in amplitude and oriented north-south, making the extraction of inertial oscillations more difficult. In other respects, the regions are similar: considerable wind fetches are found for winds from north to southeast and the dominant current flows to the south.

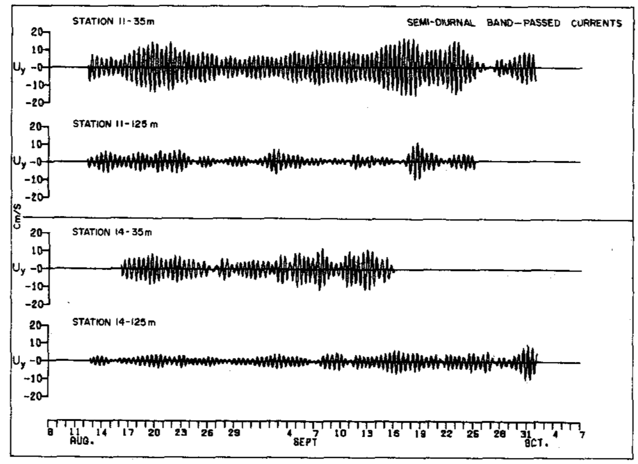

FIG. 10. The semi-diurnal band-passed northerly components at 35 m and 125 m depths for stations 11 and 14 in 1978.

At one location, station D, it was possible to remove the semi-diurnal tidal fluctuations by subtracting the predicted tidal currents as analysed from nearby (10 km separation) station 2, where current data were available for the ice-covered period of autumn 1978 to summer 1979. The inertial oscillations occur over periods of several days with typical amplitudes of 10 cm/s. The largest inertial oscillations at station D (peak amplitudes of 20 cm/s) occurred from 19 to 23 August 1979 as a result of the passage of an intense cyclonic weather disturbance through Baffin Bay.

The magnitude of the inertial oscillations observed in 1979, to the east of Devon Island, appears to be lower than that observed east of Baffin Island in 1978. This does not necessarily imply that the amplitude is significantly different between the two areas since the winds may have differed significantly between the two years. Indirect evidence for this latter possibility is provided by the currents at two locations east of Baffin Island which were separated by only three km: station 15 occupied in the summer of 1978 and station R occupied in the summer of 1979. The level of the inertial oscillations as indicated by the semi-diurnal variations in the northerly component was significantly lower in 1979, with a standard deviation of 3.5 cm/s, as compared to 6.3 cm/s in 1978 for a similar period of measurements.

In eastern Lancaster Sound, the 35 m time series at station J, obtained in the summer of 1979, was examined for inertial oscillations. While no long-period current meter records are available from which to determine the semi-diurnal tidal currents, the northerly current components should provide a good indicator of the level of activity of inertial oscillations since the M_2 tidal currents are nearly rectilinear and aligned east-west with the coastline of the sound. From the northerly component of SD band-passed time series, the magnitude of the inertial oscillations at 35 m depth is strikingly low compared to the magnitudes measured in Baffin Bay, having a typical amplitude of

4 cm/s and a maximum value of 11 cm/s. It seems unlikely that the difference can be attributed to lower wind speeds in Lancaster Sound. While suitable data for a comparison of offshore winds in the summer of 1979 are not available, recent climatological studies (Maxwell *et al.*, 1980) suggest that the surface winds are normally stronger in Lancaster Sound. However, since the vertical stratification in the vicinity of station J is generally larger than that of offshore locations in western Baffin Bay, due to the low surface salinities resulting from ice melt, the inertial oscillations may be more closely confined to levels above that of the current meter depth (35 m) than would be the case in western Baffin Bay.

Inertial oscillations, being primarily forced by surface winds, are present at the surface as well as at depths throughout the upper portion of the ocean. Inertial oscillations were observed near the surface in the tracks of two satellite-tracked drifters during the cyclonic weather disturbance of 19-20 August (Fig. 11). Prior to the wind event, one drifter (1975) was travelling to the northwest at approximately 15 cm/s while the other drifter (1979), separated by less than 15 km from the first, was moving slowly with no apparent net motion. As the winds began to increase, no response was apparent on the first day (18 August) when northerly to northwesterly winds of 5 m/s were blowing. The winds increased and peaked on 19 August at speeds of 17 m/s. On this day, inertial oscillations were identifiable in the tracks of both drifters. Early on 20 August the winds declined rapidly and by midday they were weak and variable, a condition which persisted for the next five days. The inertial oscillations, once they began on 19 August, continued to be apparent in the tracks of drifters 1975 and 1979 until 23 August and 21 August, respectively. The circular pathlines of the drifters measured 3 to 5 km in diameter, corresponding to oscillatory speeds of 21 to 36 cm/s. Simultaneous measurements of the inertial oscillations were obtained at current meter station N (35 m depth) located about 50 km to the southwest. Here, the inertial oscillations had peak speeds of approximately 15 cm/s and persisted with reduced magnitudes until August 23.

Inertial oscillations in the uppermost 35 m of the water column are at times considerably stronger than the local semi-diurnal tidal oscillations. Their typical amplitudes are 10 to 20 cm/s with speeds as large as 35 cm/s being observed. Inertial oscillations are clearly observed at depths of 4-11 m from drifter data and at 35 m from current meter records; at depths of 250 m or more, they are so greatly reduced in amplitude as to be difficult to separate from the tidal variations. Thus, large inertial oscillations appear to be confined to the Arctic Water mass and concentrated in and immediately below the upper pycnocline.

The properties of inertial oscillations observed over this depth range suggest that they are clearly linked to changes in the local surface wind. They occur intermittently near the synoptic period of wind variations (3-10 days). For particularly strong wind events such as that of 19 August

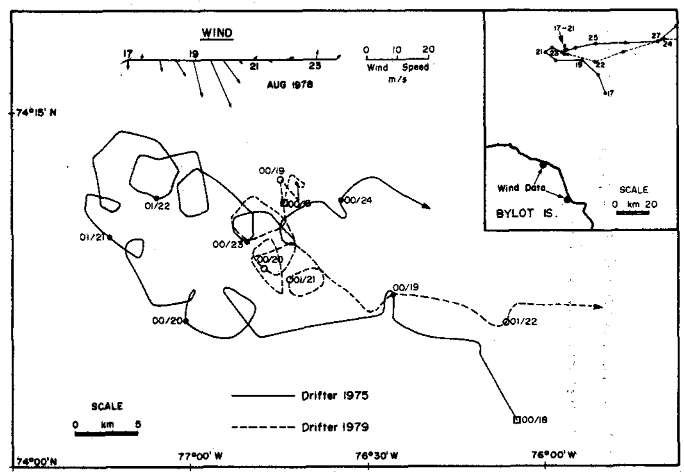

FIG. 11. The tracks of two satellite-tracked drifters during and immediately after a strong wind event on 18-26 August 1979. Inertial oscillations are evident in the tracks of both drifters.

1979 inertial oscillations are generated at a wide range of locations. Once started, inertial oscillations typically persist for a period of four to seven days.

In the results, some uncertainty arises due to the difficulty of adequately separating inertial oscillations from semi-diurnal tidal currents, which occur at nearly the same frequency. Removal of the barotropic tidal currents, along with phase-invariant internal tidal currents, was possible. However, internal tidal currents which vary in phase over the length of the available time series data could be misinterpreted as apparent inertial oscillations.

Given the observed nature of the inertial oscillations and their clear relationship to wind variability, uncertainties arising from possible contamination by internal tidal currents are not expected to alter the largely qualitative conclusions of this study. Nevertheless, this source of uncertainty illustrates the need for further investigation of internal tidal activity in the area. In particular, further tidal analyses of the present data sets, computed for different times times of the year corresponding to the seasonal changes in stratification, may provide insight into internal tidal activity.

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