SECOND INTERNATIONAL CONFERENCE ON
PORT AND OCEAN ENGINEERING UNDER ARCTIC CONDITIONS
UNIVERSITY OF ICELAND
DEPARTMENT OF ENGINEERING AND SCIENCE

AN ASSESSMENT OF ICE TRANSPORT IN THE HUDSON BAY REGION

T.S. Murty
and
F.G. Barber

Marine Sciences Directorate Ottawa, Canada.

INTRODUCTION

One of the least known parameters of many of our northern marine areas is the annual average of the net of export and import of ice. It is generally recognized that errors in estimate of the value can seriously upset interpretation of regional heat budgets, but as yet no significantly useful data or interpretations of data have become available except perhaps those of Lindsay (1) with respect to the waters of the Canadian arctic archipelago. On the other hand, many estimates are available for the Polar Ocean and some for Baffin Bay, but as those vary widely the parameter is of uncertain significance. Recently, it has been shown that in the Gulf of St. Lawrence the value of the ice export can be significant in the heat budget (2); the method used in that work, i.e. the application of a box model to estimates of ice growth and of changes in ice distributions, is utilized here.

Box models are gaining popularity because of their ability to incorporate a large amount of observed data as input and with little computational effort yield numbers on the transports of the parameter under study through the various boundaries of the boxes. We estimated that to obtain similar results through a finite-difference numerical model, one has to necessarily use three-dimensional models with a computational effort at least two orders of magnitude higher. However, it is true that finite-difference models yield detailed and accurate output with little input because the equations contain the physics of the problem. With the box model the physics is contained explicitly in the continuity equation and implicitly in the empirical relations that are used to prescribe the functional dependence of the parameter under study upon other parameters.

BOX MODEL OF ICE TRANSPORT FOR HUDSON BAY

The box model for the area under study was developed to include Hudson Bay, Hudson Strait, Foxe Basin, Ungava Bay and James Bay (Fig. 1). The area was divided into eight regions as shown in this diagram, while figure 2 shows schematically the resulting box model. The division into these eight boxes is unfortunately not made from strict considerations of the physics alone (i.e. homogeneity in a given region etc.), but more for mathematical convenience in inverting the matrix of equations of the model. If the boxes are placed in parallel, difficulties might arise due to singular matrices as noted by Murty and Smith (2).

This box model is considered to have only one opening to the ocean, i.e. through Hudson Strait. The net transport through this opening comes out as part of the solution and this could be used as a check (by comparing with any other independent estimates of the net transport) for the model itself. Although V_9 (Fig. 2) indicates a transport from (or to) the north through Foxe Basin, this was ignored as it is small.

Let $(VP)_i$ represent the volume of ice produced in region i due to meteorological cause and $(VM)_i$ the volume of ice dissipated. Let V_i denote the volume of ice transported across a boundary. In figure 2 the different V's are shown, out of these V_9 is prescribed to be zero; the rest of the V's except V_6 denote transports across the boundaries of various regions while V_6 represents the net transport into the ocean through Hudson Strait.

Let $(\Delta V)_i$ denote observed change in the volume of ice in a given period (taken here as 2 weeks). The equations which express the conservation of ice in the eight regions (with respect to figure 2) are:

$$(VP)_1 - (VM)_1 - V_1 = (\Delta V)_1$$

$$(VP)_2 - (VM)_2 - V_2 = (\Delta V)_2$$

$$(VP)_3 - (VM)_3 + V_1 + V_2 - V_3 = (\Delta V)_3$$

$$(VP)_4 - (VM)_4 - V_4 = (\Delta V)_4$$

$$(VP)_5 - (VM)_5 + V_3 + V_4 - V_5 = (\Delta V)_5$$

$$(VP)_6 - (VM)_6 + V_5 - V_6 + V_7 + V_8 = (\Delta V)_6$$

$$(VP)_7 - (VM)_7 - V_7 = (\Delta V)_7$$

$$(VP)_8 - (VM)_8 - V_8 + V_9 = (\Delta V)_8.$$

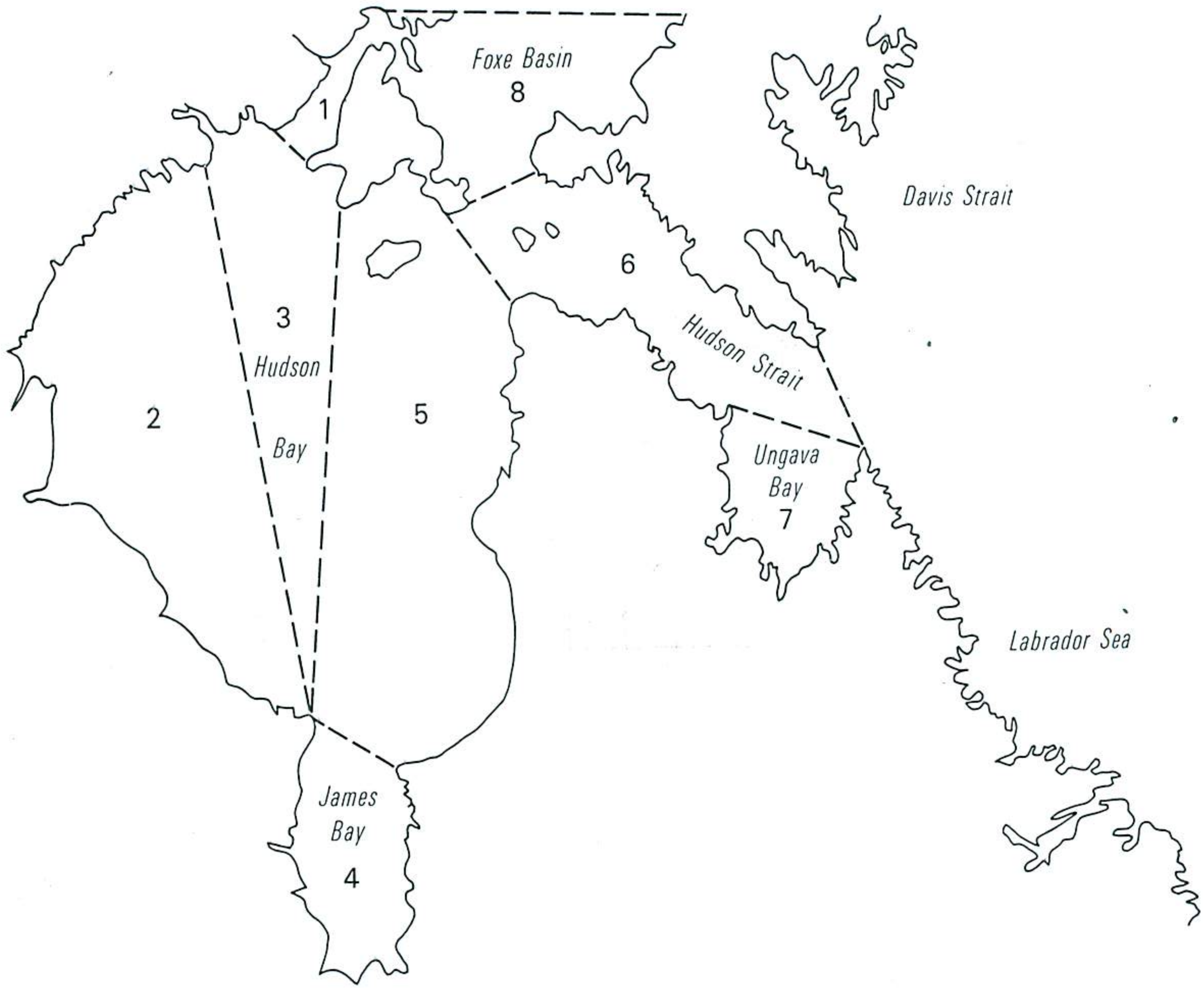

Figure 1. The study area showing the eight regions and the boundaries across which the ice transports were computed in the box model.

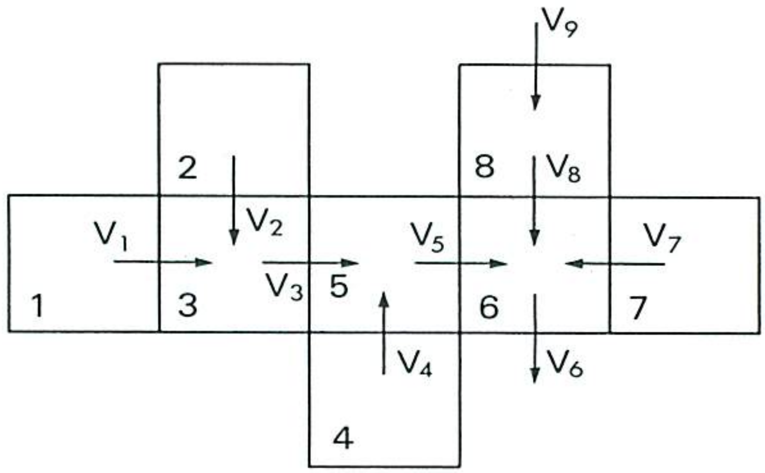

Figure 2. A schematic representation of the box model along with the signs for the transports across the boundaries.

These equations contain 4 different sets of variables. The (ΔV)'s which are the observed changes in ice volumes during two week periods are prescribed through the data contained in the annual ice summaries prepared by the Ice Central Analysis Office of the Atmospheric Environment Service of Canada for Hudson Bay and approaches. Specifically the data for the 5 years 1966 to 1970 were used after averaging the data.

The (VP)'s which are the volumes of ice produced and the (VM)'s which are the volumes of ice melted, are prescribed through an empirical relation involving the concept of degree days. Zubov (3) gave the following relation,

$$(\Delta I)^2 + 50\,\Delta I = 8 \sum_{1}^{n} (T_f - T)$$

where ΔI (in centimeters) is the growth of ice thickness due to local freezing or melting during an n day period and T is the daily mean air temperature (°C) and T_f is the freezing temperature of sea water (which is - 1.8°C). Here we have ignored the effects on T_f of the different salinities in the various regions.

Experience has shown that Zubov's formula probably over-estimates the rate of melting (4). There are other formulae available, e.g. Kolesnikov (5), but as our model is rather crude, it was felt that the extra effort would not prove worthwhile.

Zubov's formula was intended to be representative for average conditions of wind and snow cover in the arctic. In the present box model some provision was made to account for open water in the ice cover by adjusting the areas of the regions by means of a factor. Air temperature data from eleven weather stations (6) were used to prescribe T in Zubov's formula.

After prescribing the (ΔV)'s, (VP)'s and (VM)'s, the matrix is inverted to determine the V's during each of the following two week intervals:

1) May 21 to June 3
2) June 4 to June 17
3) June 18 to July 1
4) July 2 to July 15
5) July 16 to July 29
6) July 30 to Aug. 12
7) Aug. 13 to Aug. 26
8) Aug. 27 to Sept. 9
9) Sept. 10 to Sept. 23
10) Sept. 24 to Oct. 7
11) Oct. 8 to Oct. 21
12) Oct. 22 to Nov. 4

Table. Transports of Ice Across Various Boundaries -- Transport in $cm^2\ sec^{-1}$

Period	Eastern Hudson Bay to Hudson Strait	Foxe Basin to Hudson Strait	Hudson Strait to Ungava Bay	Eastern Hudson Bay to James Bay
May 21 to June 3	1125	900	0	140
June 4 to June 17	0	200	150	375
June 18 to July 1	188	-140	150	335
July 2 to July 15	150	-200	150	-170
July 16 to July 29	-470	0	-240	-140
July 30 to Aug. 12	-188	0	0	0
Aug. 13 to Aug. 26	500	-564	0	0
Aug. 27 to Sept. 9	150	-200	0	0
Sept 10 to Sept 23	0	400	0	0
Sept. 24 to Oct. 7	0	450	0	0
Oct. 8 to Oct. 21	520	-140	0	0
Oct. 22 to Nov. 4	1034	0	0	0
Nov. 5 to Nov. 18	450	-1222	-150	-140

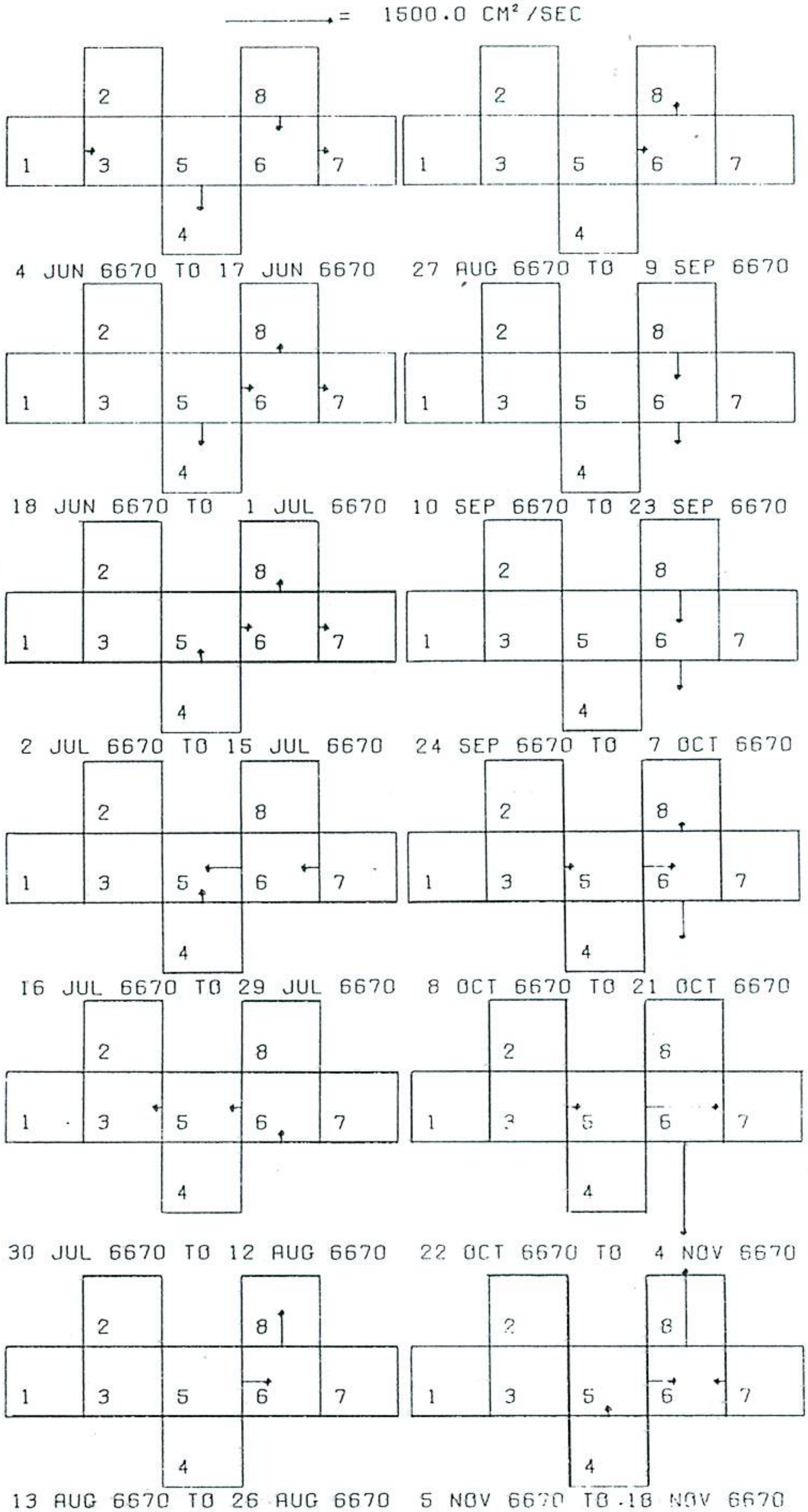

Figure 3. Ice transports during twelve of the thirteen periods.

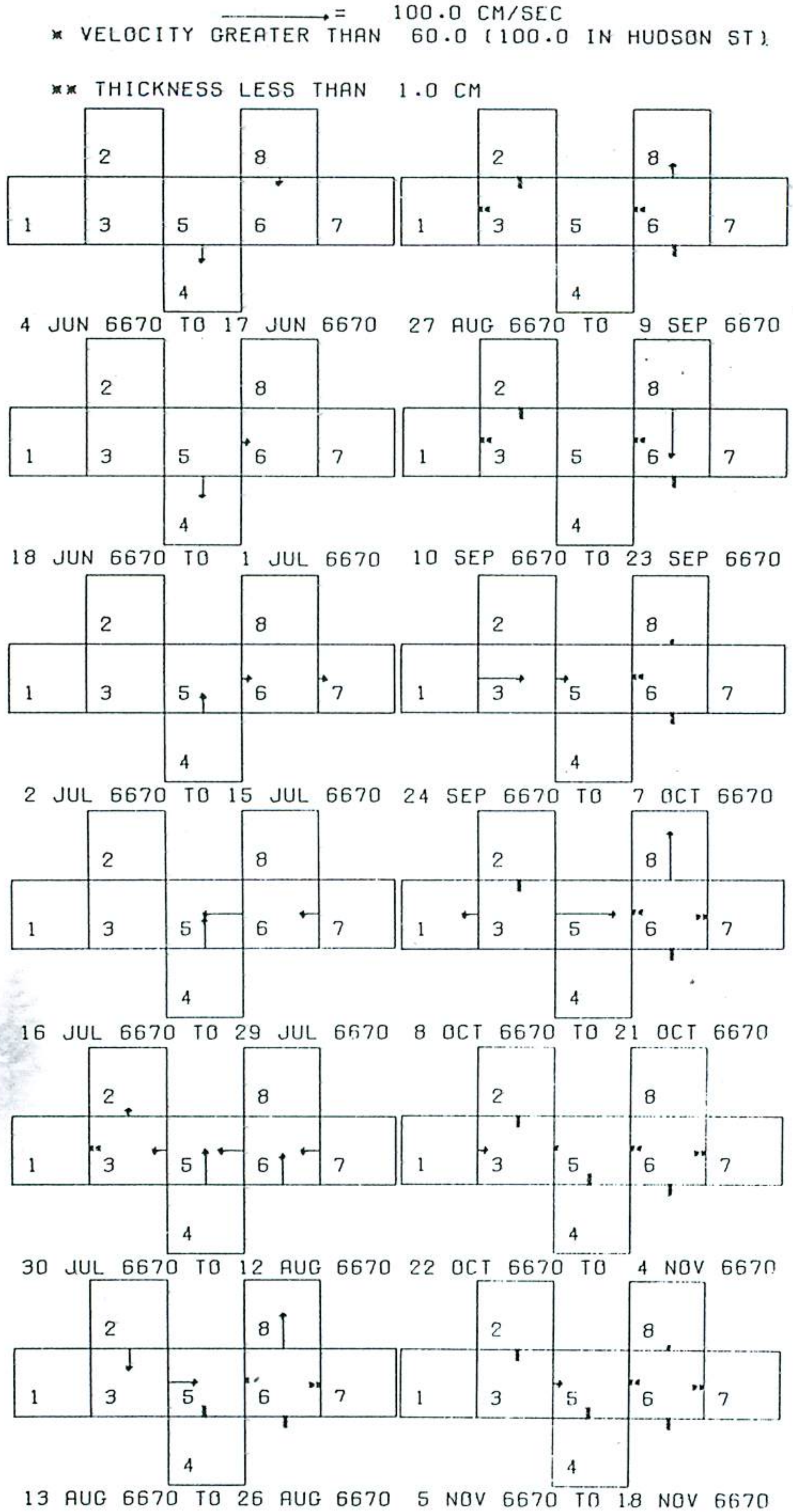

Figure 4. Ice velocities during twelve of the thirteen periods.

13) Nov. 5 to Nov. 18.

The ice drift was not computed during the period November 18 to May 21 mainly because, Hudson Bay proper is solidly packed with ice and very little motion occurs.

RESULTS AND DISCUSSIONS

Figures 3 and 4 respectively show the ice transports and velocities during 12 of the 13 periods as obtained from the application of the model and a listing of some transports for 13 periods is given in the Table . It may be noted that one could obtain unreasonably large velocities if the ice thickness is small, because the velocities are derived as a ratio of the transports to the ice thickness values.

In general, the transports and velocities between the various boxes accord with present understanding of the circulation of the region. The marked time-dependence would be expected in a region of annual ice cover, but the frequent transports into Foxe Basin were not expected. Also unexpected, and perhaps related, is the lack of a persistent transport out of Hudson Strait to the ocean; nevertheless, the general result is in accord with an earlier assessment, i.e. that the Hudson Bay system did not "benefit" to large extent from an excess of export over import of ice (7).

Within the system, the transports between boxes 1, 2 and 3 appear negligible, but there is a pattern of movement between eastern Hudson Bay (box 5) and James Bay (box 4) which annually would contribute 10^{10} m^3 of ice to James Bay. The loss of heat associated with the melting of the ice is about 7×10^{17} g cal, which over the area of James Bay would cool a 10 metre layer by 1C°. During a short period, late May through June, a persistent transport into James Bay of about 2×10^{10} m^3 of ice is indicated. It seems likely that this ice would result in the known persistence of the annual ice cover there to beyond the end of July and, as ice has a higher albedo than water, would further limit the seasonal heat storage. Thus the box model has provided the first quantitative value for the ice moved into the southern part of Hudson Bay in summer, an estimate which is much smaller than implied elsewhere (8).

REFERENCES AND NOTES

(1) Lindsay, D.G., 1968. Ice distribution in the Queen Elizabeth Islands. Paper presented at the Ice Seminar. Petroleum Soc. Can. Inst. Mining and Metallurgy and the American Petroleum Institute. Calgary May 6 - 7. 47 pages.

(2) Murty, T.S. and S.D. Smith, 1973. A box model of ice transport in the Gulf of St. Lawrence. Unpublished Manuscript. Bedford Institute of Oceanography. Report Series BI - R - 73.

(3) Zubov, N.N., 1943. Arctic ice. Translation by U.S.N. Oceanographic Office and American Meteorological Society. U.S.N. Electronics Laboratory Publication, 491 pages.

(4) personal communication from W.E. Markham.

(5) See Callaway, E.B., 1954. An analysis of environmental factors affecting ice growth. U.S.N. Hydrographic Office. 31 pages.

(6) The eleven stations are located at Hall Beach, Chesterfield, Churchill, Coral Harbour, Moosonee, Fort George, Port Harrison, Deception Bay, Cape Hopes Advance, Nottingham Island and Fort Chimo.

(7) Barber, F.G., 1967. A contribution to the oceanography of Hudson Bay. Department Energy, Mines and Resources, Marine Sciences Branch Manuscript Report Series No. 4. 69 pages.

(8) for example see Danielson, Eric W., 1971. Hudson Bay ice conditions. Arctic 24 (2): 90 - 107.