Papers

Evaluation of North Water Spring Ice Cover from Satellite Photographs

P. G. ABER[1] and E. VOWINCKEL[2]

ABSTRACT. Satellite photographs for 2 years (March-September) have been used to study ice cover in the polynia called "North Water", and to determine whether reliable ice maps could be made from satellite data without computer analysis.

After early July the clouds become opaque and distinction between cloud and ice is impossible. It was concluded that ice distribution for short periods could best be obtained by careful photograph interpretation. The most persistent open water is found at the northern edge, at about 78°N. The southern ice edge is diffuse.

The changes in ice cover in the North are mainly caused by freezing and melting, whereas ice transport is important in the southern area.

RÉSUMÉ. *Evaluation de la couverture glacielle printanière de la polynia "North Water" à l'aide de la photographie par satellite.* Les auteurs se sont servi de photographies par satellite pour les mois de mai à septembre de deux années, pour étudier la couverture glacielle de la polynia appelée "North Water" et pour ainsi déterminer si l'on peut établir des cartes glacielles sûres à partir de ces photos et sans analyse par ordinateur. Dès après le début de juillet, les nuages deviennent opaques et la distinction entre nuage et glace devient impossible. Les auteurs concluent qu'une interprétation soignée des photos permet d'obtenir la meilleure distribution des glaces pour de courtes périodes. L'eau libre la plus persistante se trouve à la limite nord, vers 78° N., alors que la limite sud de la glace est diffuse. Dans le Nord, les changements dans la couverture glacielle sont surtout liés à l'engel et à la fonte, alors que dans le Sud, c'est le transport de la glace qui est important.

РЕЗЮМЕ. *Оценка весенней ледовитости полыньи «Норт Вотер» по фотосъемке со спутников.* Материалы повторных фотосъёмок, выполненных со спутников в течение 2 лет (в периоды с марта по сентябрь), были использованы для оценок ледовитости в полынье «Норт Вотер» и выяснения возможности составления надежных ледовых карт по спутниковым данным, не прибегая к помощи анализа на ЭВМ.

Установлено, что с начала июля, когда облачный покров теряет прозрачность, морской лёд становится неотличимым от облаков. Для остального времени дешифрирование фотографий, полученных со спутников, оказалось наилучшим источником информации о распределении морских льдов. Выяснено также, что наиболее постоянный участок открытой воды приурочен к северной части полыньи (около 78° с.ш.), тогда как кромка льдов на её юге является значительно более изменчивой.

Главный фактор колебаний ледовитости северной части полыньи — процессы замерзания и таяния; те же колебания на юге обусловлены меняющимися условиями дрейфа льдов.

INTRODUCTION

The literature describing average monthly variations in ice cover of the North Water polynia was recently summarized by Dunbar (1969). The main sources of

[1]Atmospheric Environment Service, Toronto, Canada.
[2]Department of Meteorology, McGill University, Montreal, Canada.

information for the evaluation of ice distribution have been observations from aircraft reconnaissance flights. Such observations involve difficulties; for example, North Water is observed only at irregular intervals because flights are few, and the area generally considered to encompass North Water is large — twice the size of Lake Superior, i.e., about 6.5 x 10^4 sq. miles compared with 3.2 x 10^4 sq. miles. Since aircraft observations usually evaluate the ice cover over a 60-mile-wide strip along the flight path, the complete area of North Water is rarely observed in a single day. For instance, the records of the "Birds Eye" ice reconnaissance flights for 1958, 1959, and 1961, show that there were only 6 days when complete coverage of the North Water area was possible. This lack of continuity could have influenced the monthly mean distributions obtained, depending on changes in ice cover caused by melting and freezing, and on the mobility of the ice. It is thus apparent that synoptic ice maps are required on a regular basis if the ice cover and its changes are to be evaluated. Furthermore, to understand the processes that determine the polynia, a knowledge of short-term fluctuations is desirable.

Experiments were made with satellite photographs which constituted the only available regular synoptic information for the area. However, as the photographs represented the optical wavelengths only, conditions could not be observed during the polar night or when the sun's elevation was less than 10 degrees. The most useful records were of the period *c.* 20 March to 20 September.

According to data published by Dunbar (1969) and the U.S. Navy Hydrographic Office (1958) conditions in March seem to represent nearly maximum ice concentrations and by mid-September the ice cover has passed its minimum extent. Although only the melting period can be examined by optical pictures, the maximum change in ice extent will be evaluated.

PHOTO INTERPRETATION

The great difficulty in determining ice cover from satellite photographs when clouds cover the area proved least formidable in the early part of the year when a large proportion of the clouds is thin owing to the low water content of the air. Vowinckel and Orvig (1962) have reported on the transparent clouds of late winter in the Arctic. Even under rather cloudy conditions it is then possible to distinguish between ice-covered and open or partially open water.

Another difficulty is that of differentiating between the grey shade resulting from thin cloud over open water and the grey shade of thin or patchy ice on water. Unless there is a large expanse of ice-free water nearby, where the cloud cover can be identified, it is impossible from one picture alone to distinguish between cloud and ice.

Until about the middle of May and after the end of July, such distinction is made easier by the presence of noticeable cloud shadows. These are enhanced by the low elevation of the sun and give structure to middle and low-cloud fields and occasionally even to layers of cirrus.

Adequate viewing conditions lasted until about the beginning of July in both 1969 and 1970. Later, the cloud cover over the area was almost always opaque. The transition from thin to opaque cloud layers was gradual, progressing through the month of June. First the opacity of cloud shields associated with migratory cyclones increased while unorganized strati remained transparent, but by the end of June even the unorganized layers were becoming opaque.

The ice distribution could be determined definitively only under clear sky conditions, which rarely occur after the beginning of July. By that time there are connections of open water to the south making North Water progressively less distinct as a unit so it was decided to end the analysis.

The following figures show the number of daily photographs that were reasonably free from electronic or other technical interference in the area of interest during the 118 days from 20 March to 15 July; those that could be used to determine at least in part the ice cover of the North Water area are also given.

No. of pictures with little interference			*Pictures used*	
1969	101	(85%)	72	(61%)
1970	88	(75%)	74	(63%)

It is apparent from these figures that the surveillance via satellite is far more frequent than aircraft reports from this area.

In evaluating the ice cover and its changes from these photographs, two approaches were taken: 1) individual picture evaluation where, in case of doubt, cross reference was made to previous and subsequent pictures, thus distinguishing between ice and cloud from the persistence of the images; 2) historical evaluation which began with a day when the whole area was cloud free. The ice distribution found on the starting date was assumed valid until contradicted by positive evidence of ice cover change in subsequent pictures. If there was no completely clear day at the beginning of a period, the initial ice distribution was constructed as a composite from fairly clear pictures taken a few days earlier or later.

Disregarding the question of resolution of the camera system, the investigation showed that ice concentrations in a given locality were too variable to allow for distinguishing gradations as fine as one-tenth of ice in the individual satellite photographs. Furthermore, the historical approach, superimposing the previously determined ice outline on each picture, does not permit the drawing of maps that locate such fine variability of ice cover. It was therefore decided to use only 2 boundary lines to indicate gradations in ice cover: open water greater than 75 per cent and open water greater than 25 per cent.

Observations of complete or no ice cover do not require a reference that relates the ice cover to the size of the area being observed. All other ice concentrations are ambiguous, since a particular point is either covered or open. Thus ice cover values may differ vastly, depending on the area over which the average is taken.

This problem is not a difficulty when observations are taken from land stations or ships, since the area which is averaged is determined by the height of the observer and remains fairly constant. With the advent of aircraft, the area which can be viewed has increased by at least 1 magnitude and with the satellite by another 2 or 3 magnitudes. In both cases the averaging is done over only part of the viewing field. Since no accepted reference area exists, the present authors arbitrarily chose an area of approximately 1 mm.^{2} on the photographs, which is approximately equal to 70 sq. naut. miles (1 mm. ~ 8.3 naut. miles). Fig. 1 shows the area considered in this study; it consists of 673 units of 1 mm.^{2} on the pictures. This is equal to about 46,500 sq. miles.

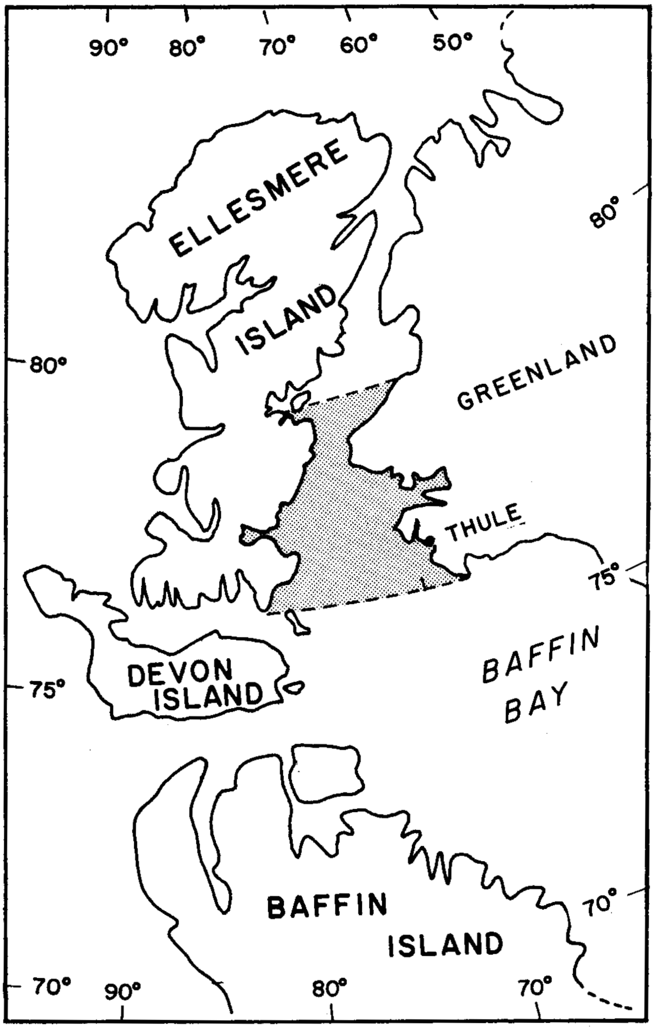

FIG. 1. Area studied.

RESULTS

Technical

One of the objectives of the investigation was to determine whether reliable ice maps for short time intervals could be produced without using a computer. Experimental ice mapping, involving computer analysis of satellite data, has been described by McClain and Baker (1969). Basically, the approach is a computer variation of the "historical evaluation" described above. Video data from the satellite are digitized, rectified and arranged as a meso-scale data array. The meso-scale is about 40 km. on a side. The brightness information is then manipulated, and a composite is formed of the minimum average brightness for each meso-scale spot. Non-persisting features such as transient clouds are filtered out through this compositing process. Geographic features, permanent ice fields, open water and any other persisting features are retained.

Excellent results have been achieved by this computer method, but some serious drawbacks remain. The major ones are, first, the inability to deal with persistent cloud fields, transient ice flows, and short-term melting or freezing; second, positioning errors of as much as 60 naut. miles and, third, the inability to take into account different patterns and nuances over large areas.

The last difficulty is inherent in all photo analysis performed by computer methods. The human photo interpreter, when analysing a photograph, examines patterns, size, shape, shadow, tone and texture for the area or point in question and, simultaneously, for adjacent areas or points and even for the entire photograph. He also brings to bear his related experience in the field of the analysis. For the computer to apply this same level of judgement, it would require a core size of phenomenal capacity. Not the least problem would be the difficulty of writing the program for such computer analysis.

The conclusion reached, therefore, is that the ice distribution on a short-term basis can best be obtained by careful human photo interpretation, and the results will depend critically on the experience and skill of the interpreter.

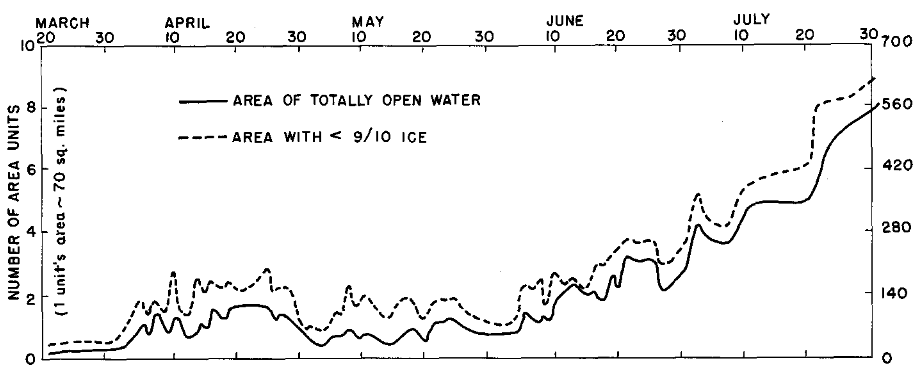

FIG. 2. Ice cover and open water in 1969.

Ice distribution

An attempt was first made to estimate the ice cover in tenths, using the method of individual picture evaluation. Fig. 2 shows the results for 1969, with the lower curve giving the area of totally open water and the upper curve the area with less than nine tenths of ice. Both curves display marked short-term variations. Reevaluation of these variations showed that they might have resulted from difficulty in attributing an ice density value to individual areas. It is evident that such detailed interpretation goes beyond the limit of information which can easily be extracted from the satellite pictures.

But the longer term variations proved beyond doubt to be real, at least qualitatively. Notable examples were the marked increase in open water in April and the subsequent decrease in May.

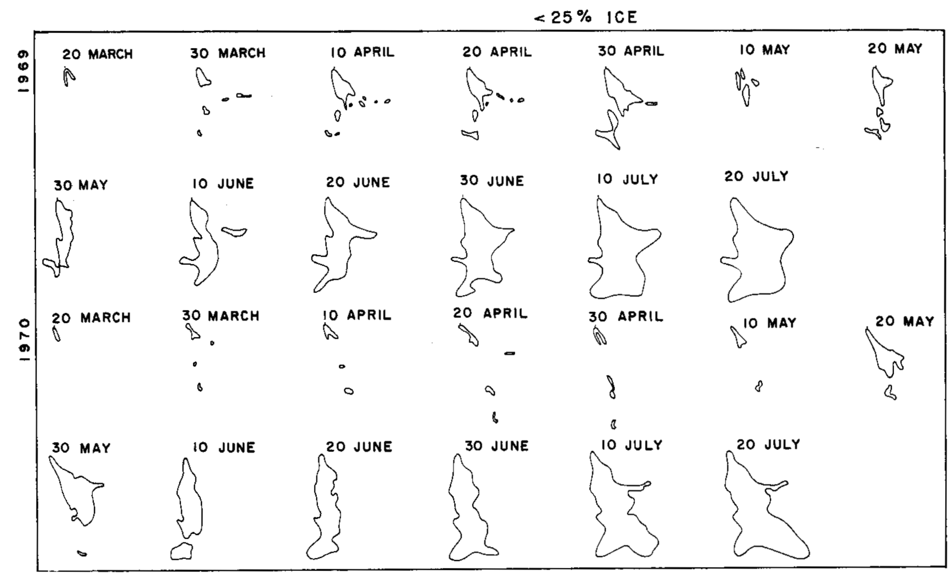

FIG. 3. Examples of areal maps.

The results of the historical evaluation are given in Figs. 3 and 4. It is the opinion of the present authors that these are about the most detailed statements of ice distribution which can be obtained from satellite pictures, on a regular basis. On certain days, with especially good viewing conditions, considerably better detail could be obtained; even the individual picture evaluation would work satisfactorily; but such continuous record could not be kept.

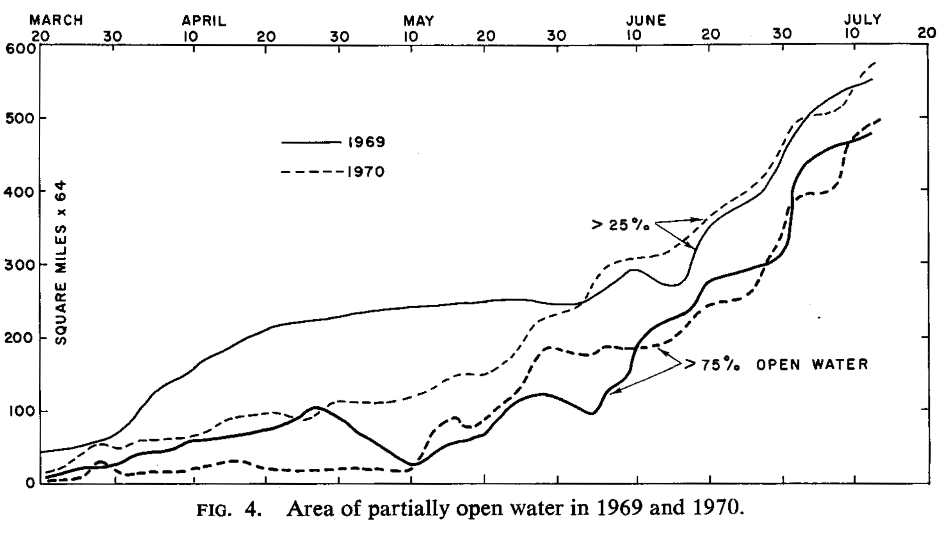

FIG. 4. Area of partially open water in 1969 and 1970.

The ice cover showed rather similar characteristics in the two seasons. Some of these features are mentioned below.

The northern edge of the open water, indicated by the area shown in Fig. 3 for 20 March 1969, saw very little shift in position during the season or from year to year. Thus this area is the most persistent open water in the North Water polynia. The increase in open water area, therefore, does not spread uniformly from a focal point in all directions but essentially only southwards, from a focal point at about 78°N. in Smith Sound.

Ice edges generally seem to be sharply defined in the North, East and West. The southern ice edge, at least before June, is diffuse with pack ice areas of varying extent forming a belt between the semi-open or open water areas in the north and the solid or nearly solid ice fields in the south. Along the western side there seem to be several places which open much earlier than other areas (see Fig. 3).

In the northern portion of the polynia, melting rather than ice export appears to be the important method of reducing ice cover. Similarly, increase in ice seems to be the result of freezing. In the southern area, advection and export play a much larger role.

The curve for water area greater than 75 per cent in Fig. 4 indicates no smooth increase of open water, but prolonged occurrence of stability or even decrease in the open area. This curve by itself, and even in conjunction with the curve for >25 per cent, does not give a value for the total open water area, since ice cover may vary between wide limits within both boundaries. However, considering also the curves in Fig. 2, a genuine reversal of the seasonal trend towards more open water has to be accepted for 1969. It is also of interest to note that the onset of rapid increase in open water seems to start at nearly the same time in both years.

When comparing the sequence of increases in size of the polynia in the 2 years (Figs. 3 and 4), it is apparent that there is a sharp variation in the progression. In 1970 the open water was concentrated more in the west and south of the North Water region than it was in 1969.

Ice movement

The ice, as seen from the satellite, does not display uniform characteristics of brightness. The features which can be differentiated are generally distinguishable for 1 or 2 days and only in exceptional cases for up to 6 days. However, the similarity in features on days 1 and 6 could never be established by direct comparison, but only historically through a day-to-day comparison. This is a result of the rapid melting and merging of features which occur even when the motion of the object is very slight.

Distinguishable features were used to determine the general ice drift in the area. Table 1 gives the values obtained.

All values are derived from average motions for 48 hours. Unfortunately, the sampling is not distributed evenly in time or space. The requirement of clear skies over the area, at least at the beginning and end of the 48-hour period, restricts sharply the number of useful pictures. Furthermore, not all pictures show sufficient structure to make an identification feasible in subsequent pictures. Areally, the southern portion of the polynia shows many more identifiable objects than the northern part. Accordingly, the data are not sufficiently numerous to permit a separation of the observations according to area. In general, the tendency is for ice movement towards the north and west along the eastern side of the polynia, and to the south along the western side. However, in several cases where nearby objects could be observed, their direction and speed of movement were found to differ. This was particularly noticeable in the southeast.

TABLE 1. a) Ice drift speed; b) Frequency distribution of drift speeds

a)	1969		1970	
	No. of Cases	Mean Speed miles/day	No. of Cases	Mean Speed miles/day
April	10	5.12	6	5.67
May	4	3.40	7	6.17
June	5	13.36	4	7.70

b)										
Speed miles/day	1.9	2–3	4–5	6–7	8–9	10–11	12–13	14–15	16–17	18–19
No. of Cases	3	7	11	4	1	3	2	1	3	1

The evaluation requirement of clear sky results in an over-representation of anticyclonic and low wind speed situations. The speeds in Table 1 will therefore represent a lower limit of the ice motion actually taking place.

CONCLUSION

The investigation has shown that it is possible to obtain a reasonably detailed picture of ice distribution, and its changes in time, from an interpretation of a series of good satellite pictures. Furthermore, motions of the ice fields can be observed, and the accuracy of these measurements would improve with more sophisticated techniques and equipment.

The results show that there are periods within the general melting cycle when the ice cover actually increases. The dates and durations of these periods differed markedly in the two years examined. The investigation of these reversals, and their variations from year to year, may shed light on the mechanisms responsible for the existence and behaviour of the polynia. It is therefore desirable that such investigations be continued for at least a 2 or 3 year period, to accumulate sufficient observational data upon which conclusions may be based.

ACKNOWLEDGEMENTS

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