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GROWTH AND DECAY OF "KATIE'S FLOEBERG"

BY

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ABSTRACT

The growth and decay of the grounded ice feature, located at approximately 160°W 72°N, labeled variously as "Katie's Floeberg", a "berg field", and an "island of grounded ice", has been analysed in relation to the prevailing surface winds and surface temperature measurements taken at nearby Barrow, Alaska. The primary source of data were Landsat I and II imagery obtained between 1973 and 1976. Three major factors were found to influence the growth and decay of the feature: 1) ice uniformity, 2) surface windspeed and direction, and 3) surface temperatures. Of these, the wind appears to be the dominating factor. The typical growth pattern was found to be the formation of a cone-shaped projection of fractured ice pointing into the oncoming ice. The permanence of the new addition was found to be dependent upon wind and temperature conditions. Remains of these growth patterns can be sometimes seen in the interior of the feature on the satellite imagery. The feature-was found to undergo decay throughout the summer, starting in June, until early fall when the growth pattern resumes. However, some years it may disappear altogether by fall and be rebuilt over the winter and spring.

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Growth and Decay of "Katie's Floeberg"

I. INTRODUCTION

The grounded ice feature located at 162°W 72"N on Hanna's Shoal in the Chukchi Sea approximately 160 km off the coast of Alaska (Figure 1) has been variously termed a "bergfield," (Toimil and Grantz, 1976) an "island of grounded sea ice" (Kovacs, Gow, and Dehn, 1976) and "Katie's Floeberg" (Stringer and Barrett, 1975a). All of these labels imply something about the structure and composition of the feature. To avoid making any such implications in this paper, the ice structure on Hanna's Shoal will be referred to as "the feature" or "the grounded ice feature."

In a previous paper (Stringer and Barrett, 1975b) the effects of the grounded ice feature on the pack ice moving past Hanna's Shoal were described. It was found that at times, the pack ice moved past the feature in a uniform sheet, with only a polynya on the lee side of the feature to indicate its presence. At other times, the pack ice was seen to be divided into zones of ice moving at different velocities, separated by shear lines. In addition, no significant divergence of the pack ice around the feature was observed as the ice was forced past, indicating that the ice must have been undergoing significant piling in the vicinity of the feature. This piling was deduced to be the primary mechanism of growth of the feature. A correlation is shown between the ice piling, the weather and the growth and decay of the feature.

II. DATA SOURCES

The primary data source for studying the feature has been 1:1,000,000 and 1:500,000 scale imagery obtained from NASA's satellites, Landsat I

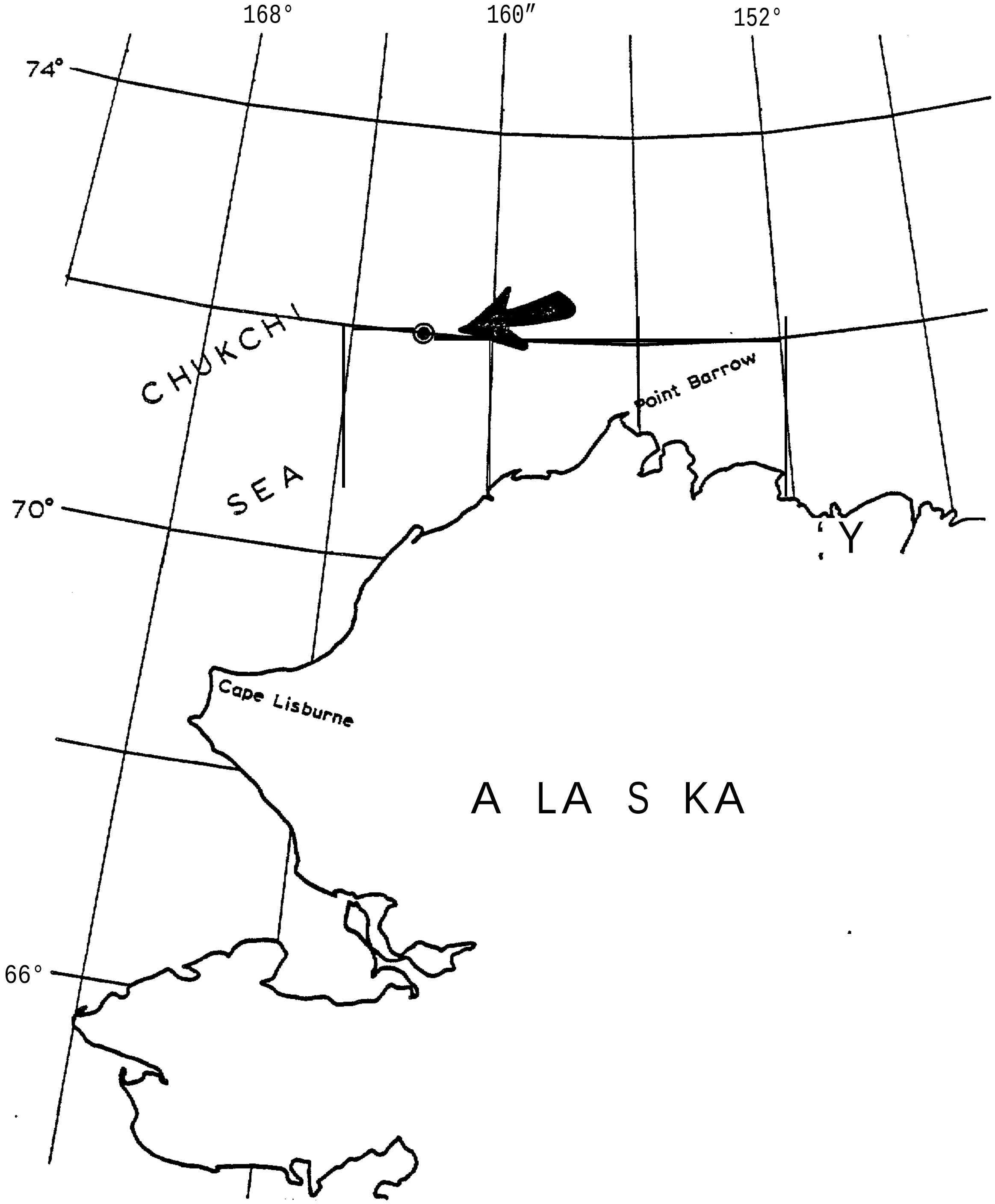


Figure 1. Location of ice feature grounded on Hanna's Shoal in the Chukchi Sea. Arrow shows predominant direction of ice motion.

and II. Landsat I (formerly ERTS-1) was launched on 25 July 1972, and the first cloud-free image of the feature on Hanna's Shoal was acquired by the satellite on 7 March 1973. The Landsat orbit is such that the general area of the feature is imaged once every 18 days. However, the overlap of succeeding days' images due to the nature of the satellites orbit allows the feature to be observed up to four days in succession. A second satellite, Landsat II, was launched on 22 January 1975, resulting in increased coverage. A total of more than 40 images have been obtained to date for the area, with the latest available image acquired on 28 August 1976. Thus four years of Landsat coverage was available.

Another major source of data was the NOAA-3 and NOAA-4 weather satellites, which daily obtain small-scale (approximately 1:5 million) images of the Arctic Ocean. The scale of these images was so small that their usefulness was restricted to determining if the feature was still in existence at any particular time. However, this was an especially important source of information for late fall because, normally, few Landsat images are obtained during this time due to cloud cover. Landsat imagery was not available for December and January because the sun was below the horizon throughout these months.

A third source of data was photography obtained by various investigators both on the feature itself and from low-flying aircraft, These data include both color and black-and-white oblique photographs.

III. GROWTH AND DECAY CYCLES

The grounded ice feature on Hanna's Shoal has been observed on satellite imagery dating as far back as 1966 (Kovacs, Gow, and Dehn, 1976) and undergoes yearly growth and decay cycles. For the purpose of observing the detailed growth and decay cycles of the feature over long periods of time, Landsat imagery appears to be the best source of data due to its high resolution capability. For that reason Landsat imagery was considered to be the principal data source and thus, the growth and decay cycle of the feature beyond dates of Landsat data availability was not followed in detail.

1972 (See Figure 2)

The first Landsat image available of the area of Hanna's Shoal was acquired on 2 August 1972 (scene 1010-22133]. This scene shows old pack ice covering approximately 60 percent of the area, including Hanna's Shoal. The remnants of what may be the feature can be seen, although it may just be remnants of old ice ridges in the pack. There are similar pieces seen elsewhere in the pack ice. An image obtained on 26 September, (scene 1065-221 92) although partially obscured by clouds, also shows the area where the feature should have been. But the feature cannot be seen, so it seems to have completely disappeared in 1972 although it was observed earlier that year by Kovacs, et al. (1976).

1973 (See Figure 3)

The first available Landsat image showing the feature was obtained on 7 March 1973 (scene 1227-22203). It shows pack ice completely covering the ocean surface with the exception of a small polynya on the southeast side of the feature indicating. ice movement in that direction. A plume of fog extending from the polynya southeastward suggests that the wind was responsible for the movement of the ice. The area just "upstream", on the northwest side, of the feature appeared to have been repeatedly broken up and refrozen and was in the form of a wedge. The feature at

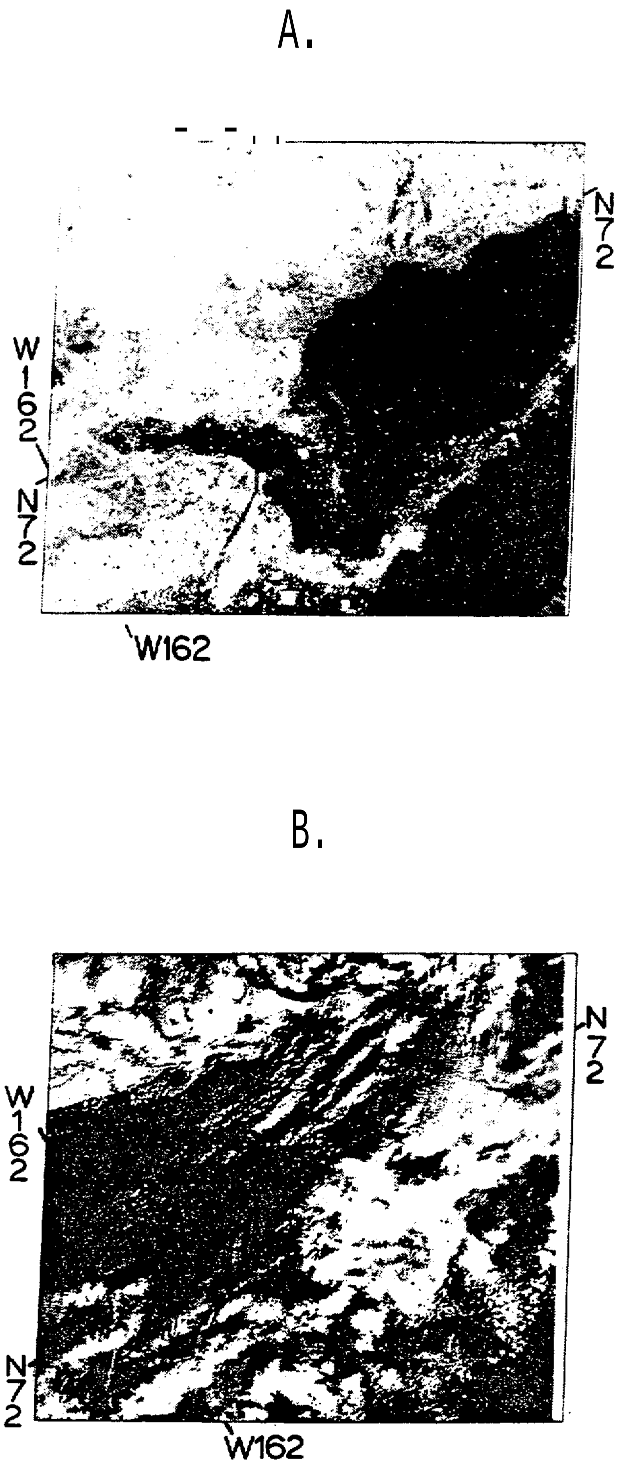


Figure 2. **1972 Landsat scenes of vicinity of Hanna's Shoal: a) scene 1010-22133, 2 August 1972, b) scene 1065-22192, 26 September 1972.**

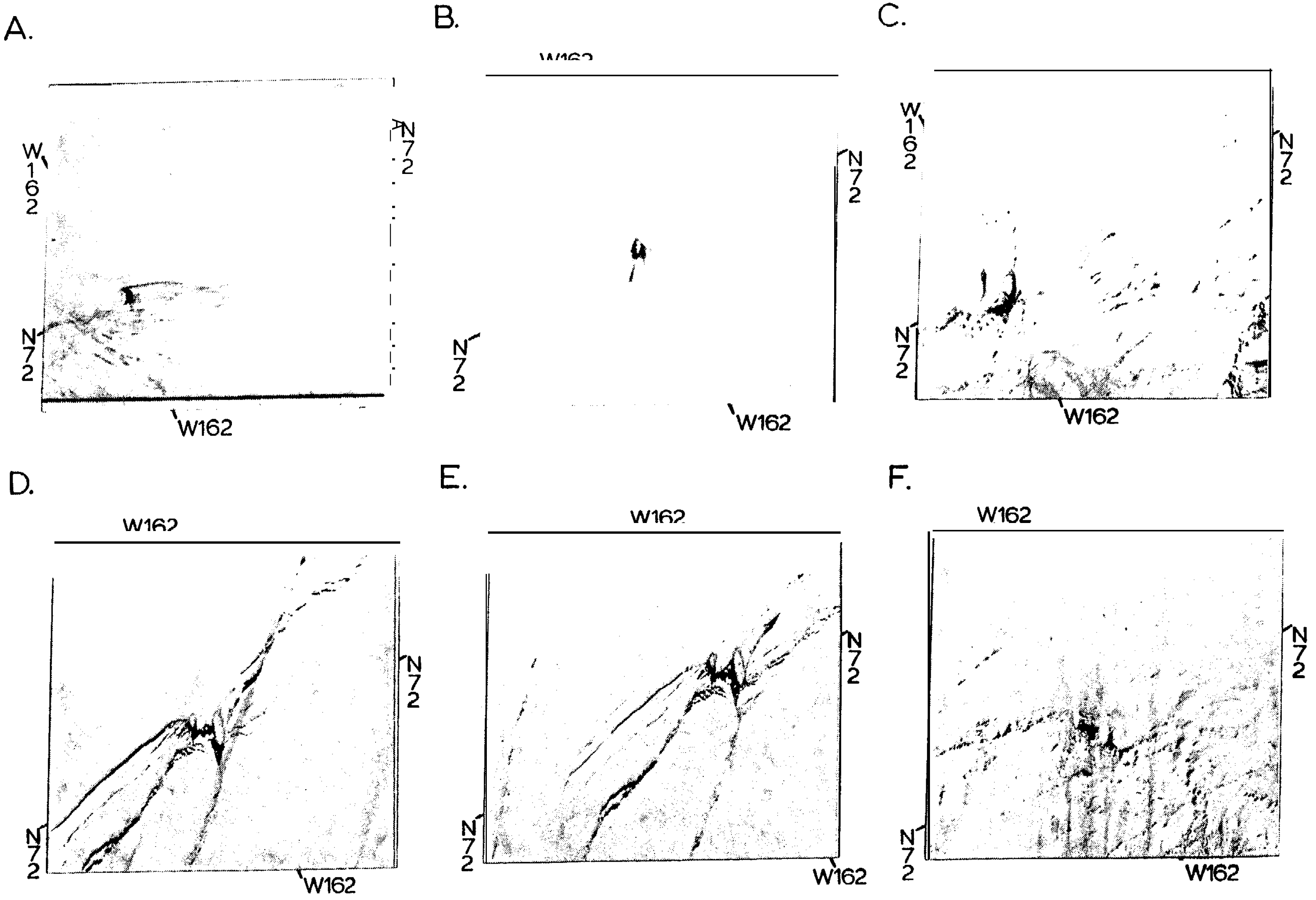


Figure 3. 1973 Landsat scenes of vicinity of Hanna's Shoal: a) scene 1227-22203, 7 March, b) scene 1228-22261, 8 March, c) scene 1263-22203, 12 April, d) scene 1282-22261, 1 May, e) scene 1283-22315, 2 May, f) scene 1300-22260, 19 May.

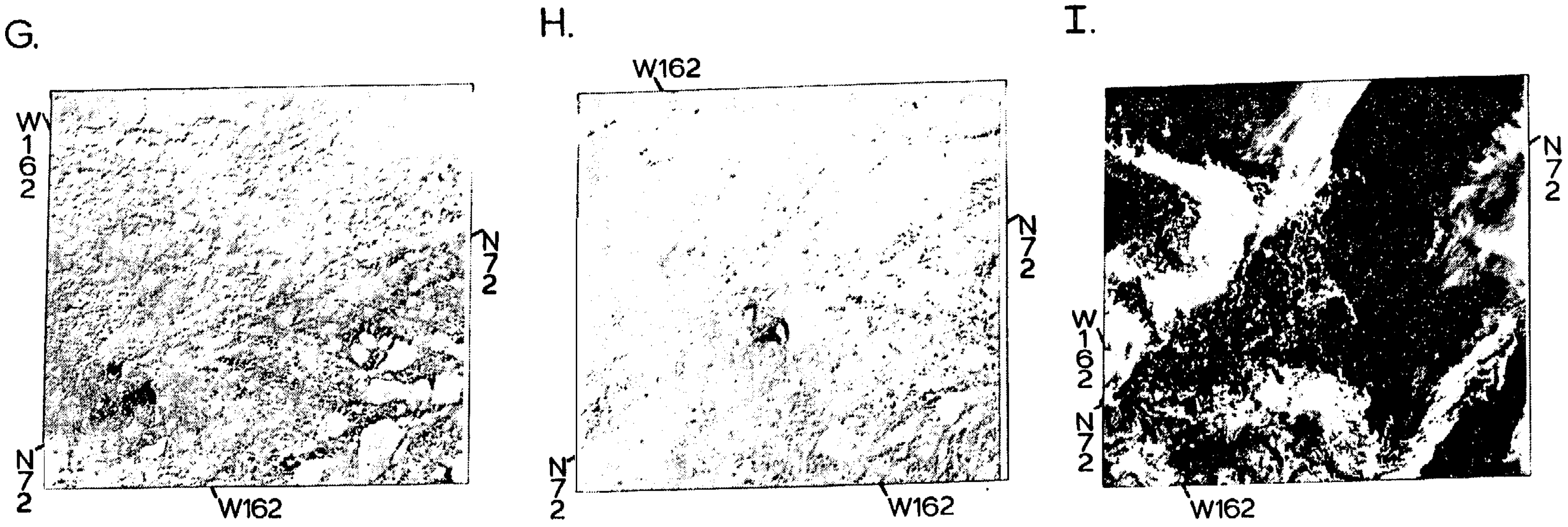


Figure 3. g) scene 1318-22255, 6 June, h) scene 1317-22200, 5 June, i) scene 1406-22131, 2 September

that time had a semi-elliptical shape approximately 9 km by 3 km with the major axis oriented approximately northeast-southwest (the feature was always observed to be oriented in this approximate direction throughout the years 1973-1976).

An image obtained the following day (scene 1228-22261) shows both the direction of ice motion and wind direction to have shifted, with the wind out of the northeast and ice moving to the southwest. The previous polynya had frozen and a new one formed. The wedge observed the previous day to be attached to the feature had broken loose. The feature did not change in size *or* shape between March 7 and 8.

However, by 12 April (scene 1263-?.2203] the feature had nearly doubled in size, being 14.8 km long by 5.6 kmwide, still oriented roughly northeast-southwest. The outline of the feature as it appeared on 8 March was still visible and indicated that most of the growth had occurred on the north and northeast sides of the feature. A fracture pattern differing in appearance from the wedge could be seen “upstream” from the feature. A second, much smaller (5.1 x 1.9 km) grounded feature appeared to the north of the larger one. It had the same general shape and orientation that the larger one did on 8 March. The polynyas on the southwest side of the features indicate ice movement from northeast to southwest. Trails of fresh ice in the pack indicate previous directions of ice movement.

Both features had grown larger by 1 May (scene 1282-22261) - the larger one 20.4 km by 5.6 km and the smaller one 7.4 km by 3.7 km. The ice motion was from the northeast to the southwest. On 2 May (scene 1283-22315), the direction of ice motion had shifted to an east-to-west movement. The wedge-shaped extensions could again be seen in this scene.

One Landsat cycle later, on 19 May 1973 (scene 1300-22260), the pack ice, which was well-consolidated on 2 May, appeared fractured and broken. The direction of pack ice movement was approximately from the northeast, but was difficult to determine because little movement could be detected on the image; there were no open leads or polynyas large enough to make a positive determination. The northeastern end of the larger of the two features had broken off and thus the major dimension was decreased to ?3.0 km but the minor dimension appeared to be 6.5 km wide, nearly a kilometer wider than in the previous image. The smaller feature was actually somewhat longer in this image then on 2 May, 9.3 km long by 3.7 km wide.

By 6 June (scene 1318-22255), the larger feature had decayed further. At that time, both features were nearly the same size, the 'larger' one '3.3 km by 5.1 km and the 'smaller' one 9.3 km by 4.6 km. The pack ice was even more decayed. A polynya on the western side of the features on 5 June (scene 1317-22200) indicated ice motion had been in that direction, but on 6 June open water on the eastern side indicated that. the direction of ice motion had shifted 180° and was moving west to east. On 6 June the clouds cleared enough to reveal a small wedge of ice that had previously formed to the east but had broken off as the wind changed.

The last available image of 1973 was obtained on 2 September (scene 1406-22131) showing the feature much reduced in size: 2.8 km long by 1.9 km wide. The location of the smaller companion feature was off of the Landsat scene so that the existence of the smaller feature was not determined. The pack ice was a loose swirl pattern of unconsolidated ice. The direction of ice motion was indeterminate.

The feature may or may not have disappeared completely in 1973. This will be discussed more fully below.

1974 (See Figure 4)

The first available Landsat imagery in 1974 was an overlapping series from 19-23 March (scenes 1604-22090, 1605-22145, 1606-22203, and 1608-22320). On 19 March, the pack ice can be seen to have moved northwest to southeast creating a polynya on the southeast side of the feature. On 20 March the direction of ice motion shifted to the southwest as shown by the opening leads. The ice motion again shifted direction and on 21 March the ice was moving east to west as evidenced by the large polyna. It continued moving west through 23 March. The ice traveled, from 20 March to 23 March, approximately 15 km in a westerly direction. Adding to this the southwesterly movement from 19 to 20 March gives a total ice movement of approximately 18 km west southwest. The ice in the immediate northeast vicinity of the feature was very broken, consisting of old floes of varying size in a matrix of young and new ice.

One Landsat cycle later, 7 and 8 April, the feature appeared unchanged. However, close comparison of the 7 April and 8 April images (scenes 1623-22142 and 1624-22201, respective y) showed that the ice in the wedge adjacent to the eastern side of the feature had not moved whereas the rest of the ice had moved westward 2 to 5 km. Ice north of the shear line which was visible to the north of the feature had moved even more (Stringer and Barrett, 1975). The wedge had in fact consolidated with the rest of the feature, as can be seen on 27 April (scene 1643-22252). The point of the wedge had been rounded off; close examination showed the faint outline of the feature as it appeared in earlier images. The open and refreezing leads in this scene indicate that the ice motion had been to the north, then shifted to the northwest. The feature was 14 km long by 6 km wide.

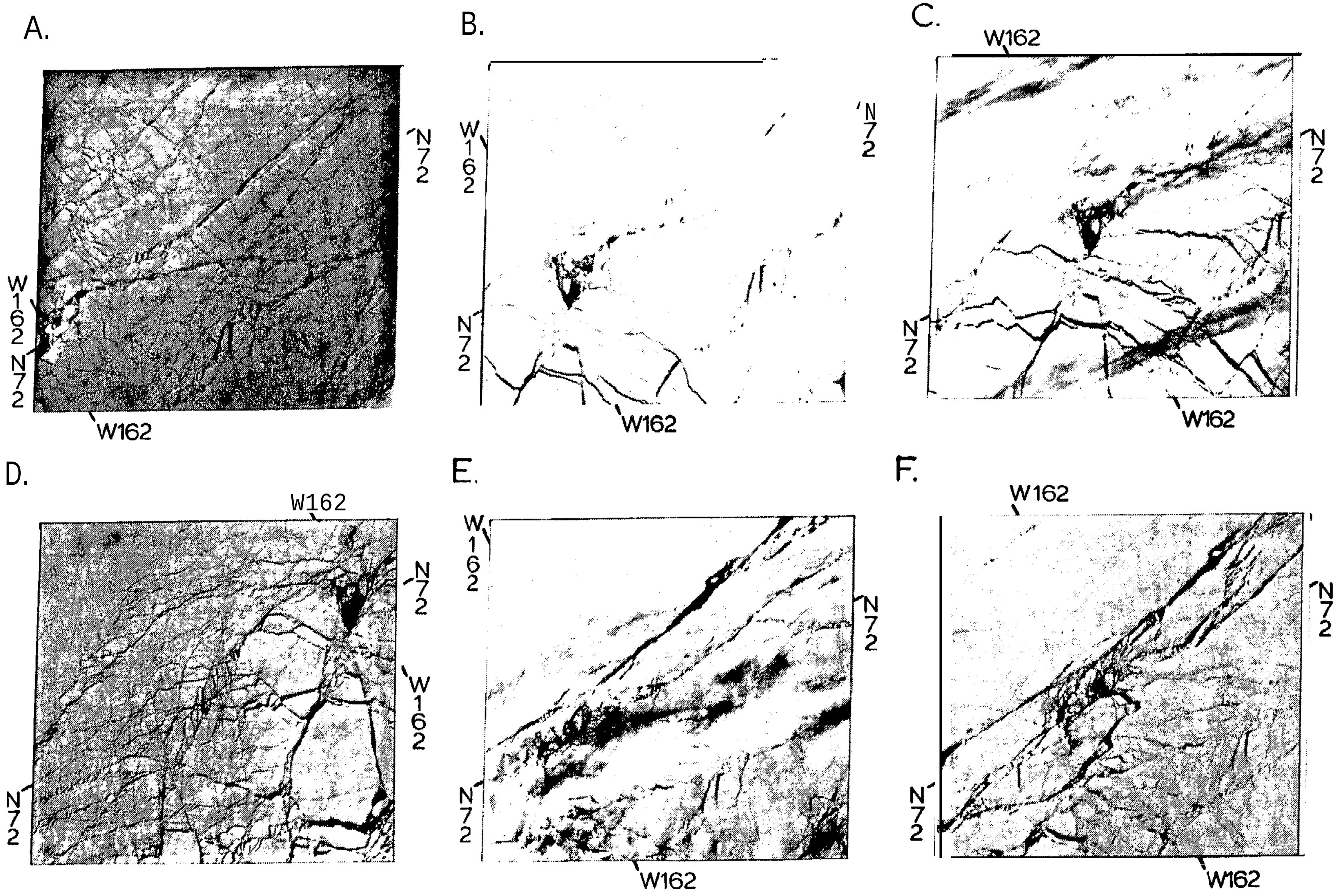


Figure 4. 1974 Landsat scenes of vicinity of Hanna's Shoal: a) scene 1604-22090, 19 March, b) scene 16uj-22145, 20 March, c) scene 1606-22203, 21 March, d) scene 1608-22320, 23 March, e) scene 1623-22142, 7 April, f) scene 1624-22201, 8 April.

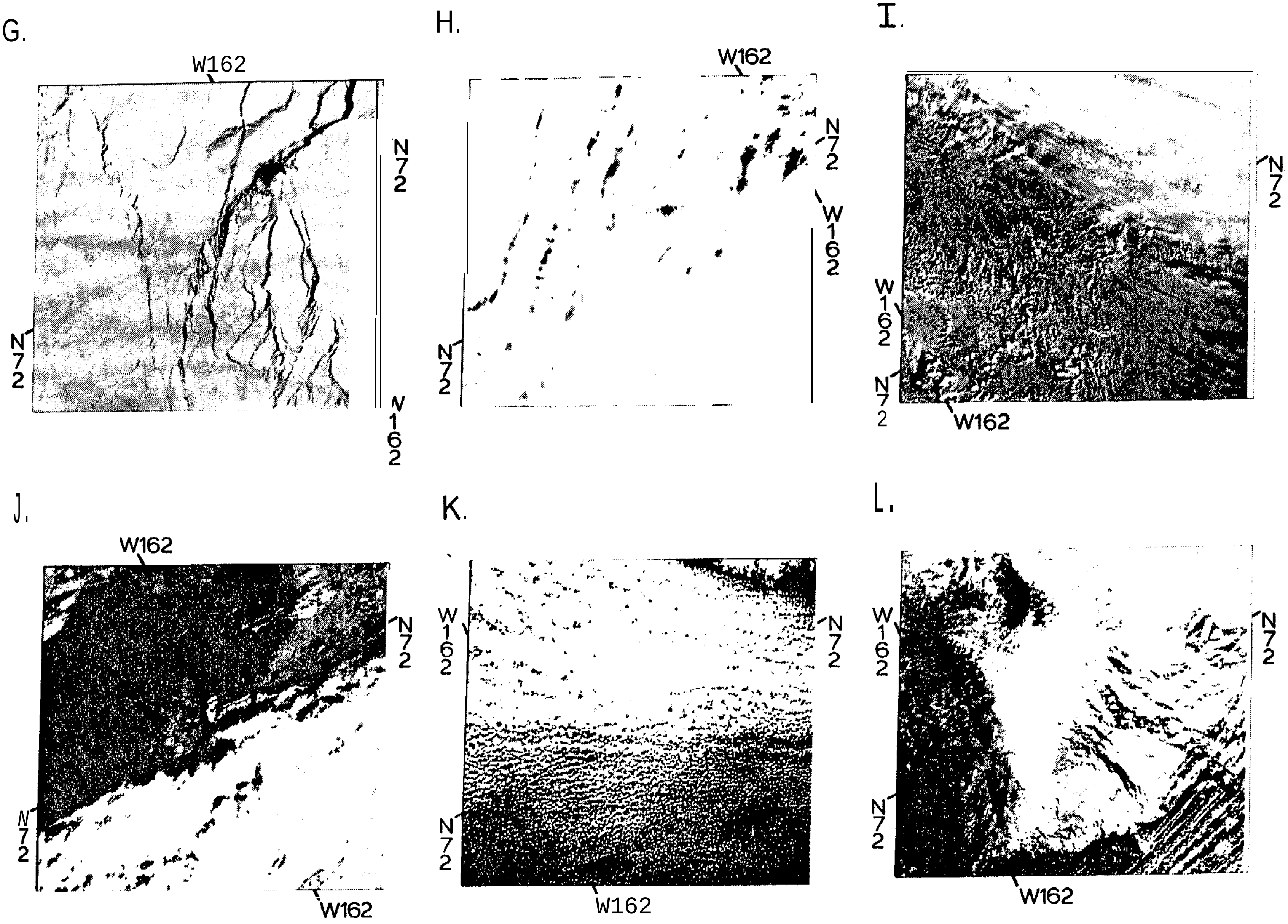


Figure 4. g) scene 1643-22252, 27 April, h) scene 1662-22304, 16 May, i) scene 1712-22061, 5 July, j) scene 1750-22161, 12 August, k) scene 1803-22083, 4 October, I)- scene 1821-22082, 22 October.

The 16 May scene (1662-22304) was almost completely covered by clouds, but the outline of the feature could be seen. Its dimensions at that time were 17 km by 7 km. The surrounding ice conditions were obscured by clouds.

The dimensions of the grounded ice feature did not significantly change through 5 July (scene 1712-22061], being 17 km long by 6 kmwide on that date. Throughout the summer, the pack ice steadily decayed and was thin and broken and/or puddled by 5 July.

The 12 August image (scene 1750-22161) was the last image in 1974 in which the feature was visible on Landsat imagery. The feature was clearly visible, partially surrounded by remnants of unconsolidated pack ice and open water. The feature was 15 km long by 5.5 km wide, not having decayed or changed shape much since 16 May.

An image obtained on 4 October 1974 (scene 1803-22083) showed no trace of the feature. Although the scene was partially obscured by clouds, the area where the feature should have been was obscured by small cumulus clouds on the order of a kilometer in diameter. If the feature was *still* in existence, it would have to have been less than that size in order to be hidden under the clouds. The area appeared to be totally free of pack ice. The limit of the pack ice can be seen in the eastern corner of the image. On 22 October (scene 1821-22082) the pack ice covered the area, but no polynya (the most distinguishable characteristic of the feature) could be observed.

In an effort to pinpoint the day that the feature disappeared and to determine when it reappeared in 1974, NOAA 3 images acquired from September to November were examined. There were few available images due to cloud conditions.

The feature was still visible on the 6 September NOAA 3 image (Figure 5a). The pack ice was more than 100 km to the north, although a

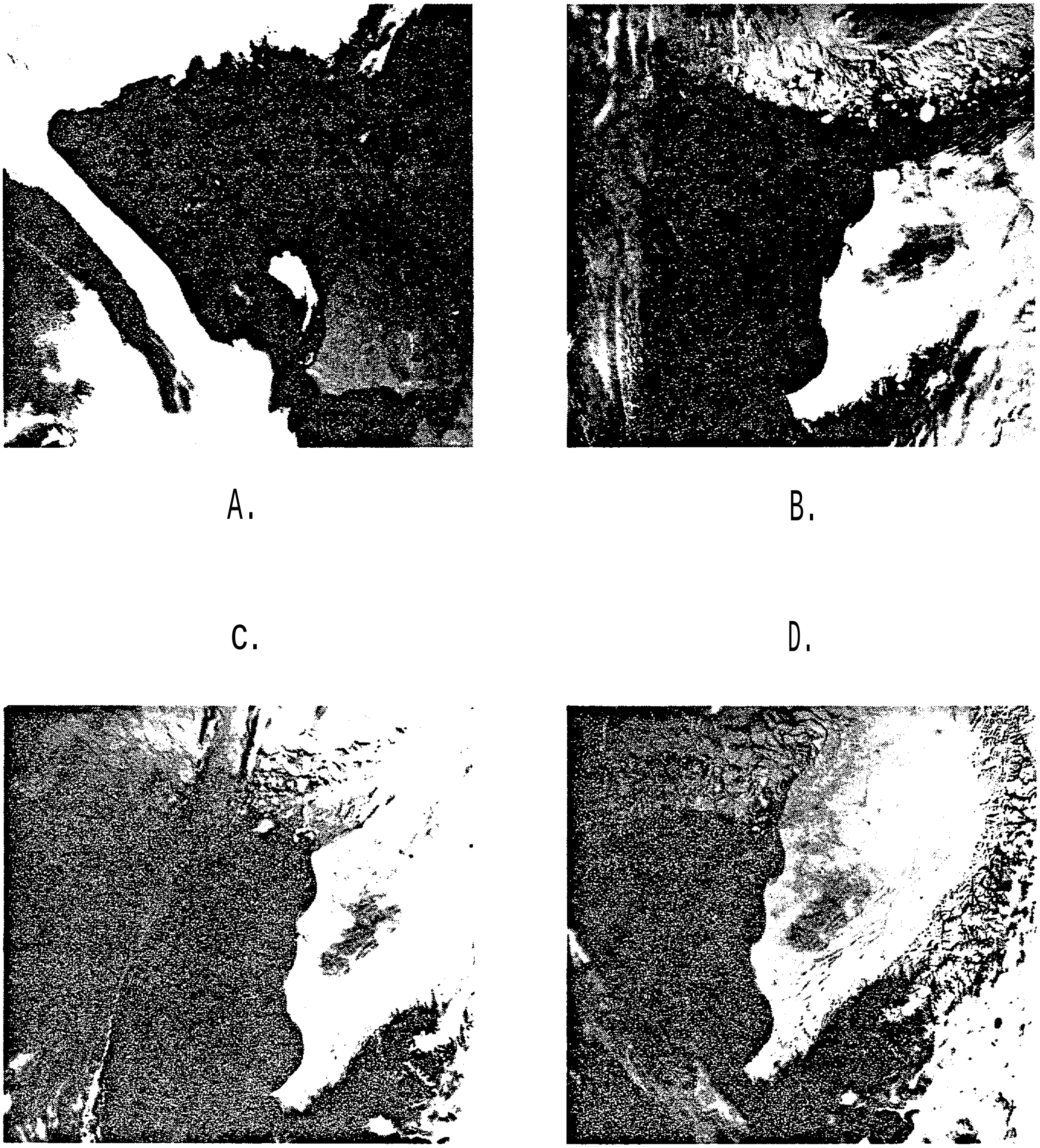
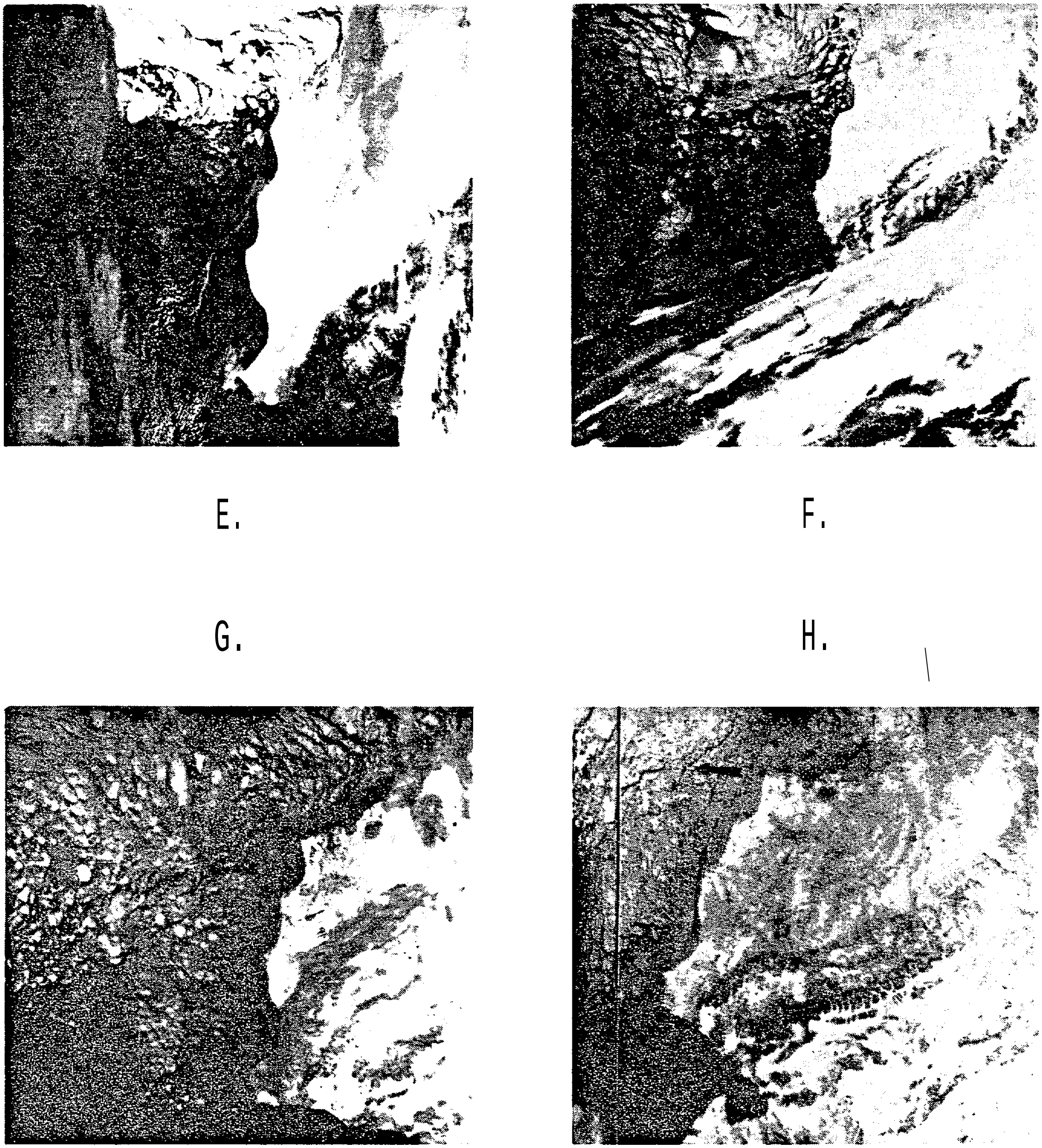


Figure 5. Fall NOAA images of the vicinity of Hanna's Shoal: a) image 3808, 6 September 1974, b) image 4117, 4 October 1974, c) image 4229, 13 October 1974, d) image 4291, 18 October 1974.



E. F.

G. H.

Figure 5. e) image 4353, 23 October 1974, f) image 4576, 10 November 1974, g) image 4737, 23 November 1974, h) image 4761, 25 November 1974.

few floes were observed in the area of the feature. The next clear NOAA 3 image of the area was obtained on 4 October (Figure 5b). That image concurred with the Landsat image of the same date; the feature seemed to have disappeared. NOAA images obtained on 6 October and 13 October (Figure 5c) also revealed no feature. By 18 October (Figure 5d) thin pack ice seemed to be forming in the area. The 23 October NOAA 3 image (Figure 5e) and the 22 October Landsat image both showed newly formed ice in the area.

On 10 November, the date of the next NOAA 3 image (Figure 5f}, a small polynya appeared at approximately 162° W latitude 72° N longitude. The pack ice in the area was quite dense. A lead which opened along the Chukchi Sea coastline indicated that the ice was in motion. The lead was about the same width as the apparent polynya and so seemed to confirm the existence of the polynya. Two NOAA images, 23 November (Figure 5g) and 25 November (Figure 5h), showed the polynya more clearly. Apparently the feature had started to reform by 10 November after disappearing sometime between 9 September and 4 October.

<u>1975</u> (See Figure 6)

The earliest 1975 Landsat image of the area of the feature was acquired 25 February (scene 1947-22031). At that time, the feature was already well-developed, being 21 km long by 9 km wide and oriented northeast-southwest, the same as for the previous two years. A polynya had formed on the eastern side of the feature but had refrozen by the time the image was acquired, indicating that the ice had moved approximately 10 km east. The characteristic wedge pattern was again seen on the west side of the feature.

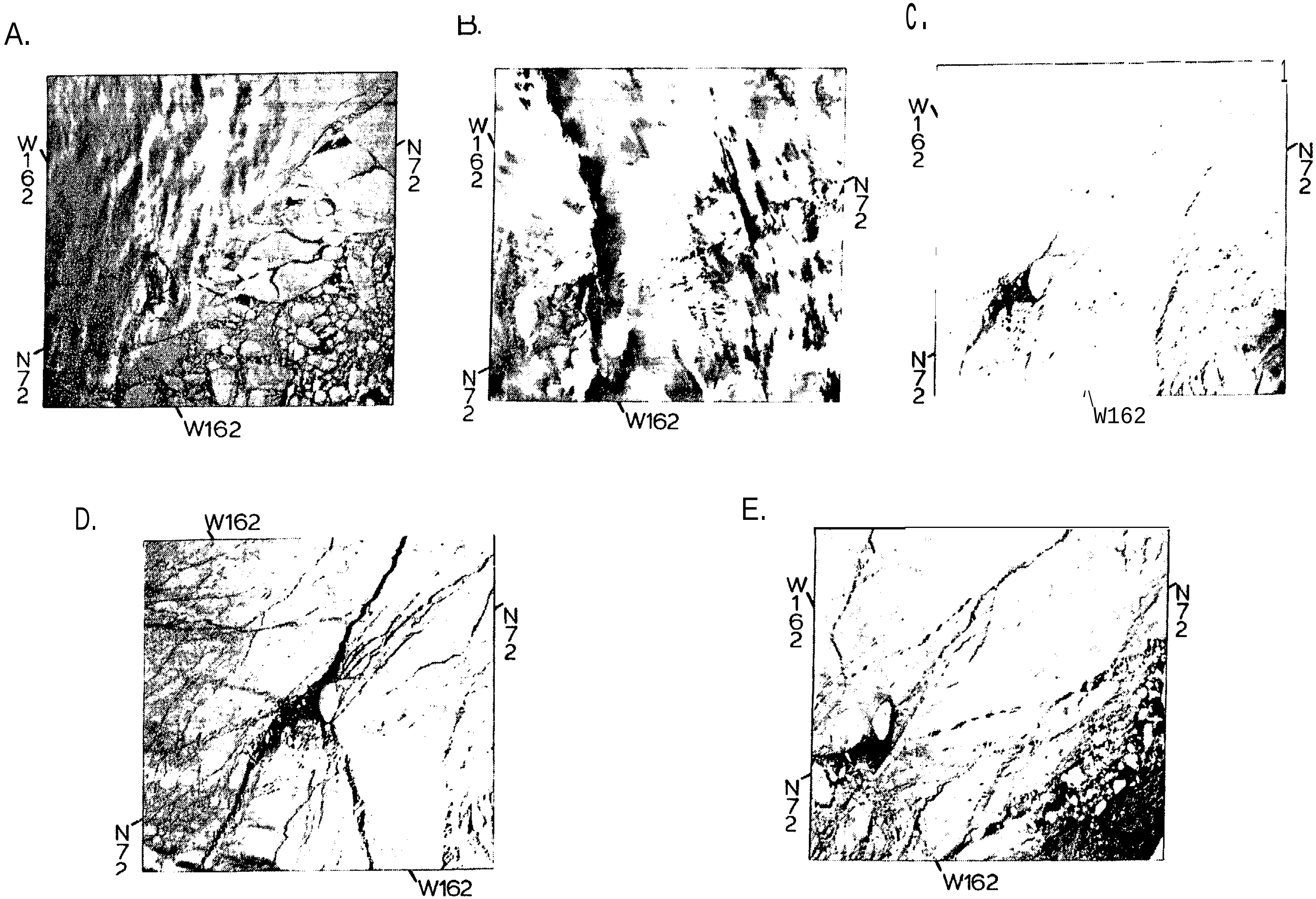


Figure 6. 1975 Landsat scenes of vicinity of Hanna's Shoal: a) scene 1947-22031, 25 February, b) scene 1965-22022, 15 March, c) scene 1983-22013, 2 April, d) scene 1984-22071, 3 April, e) scene 2079-22082, 11 April.

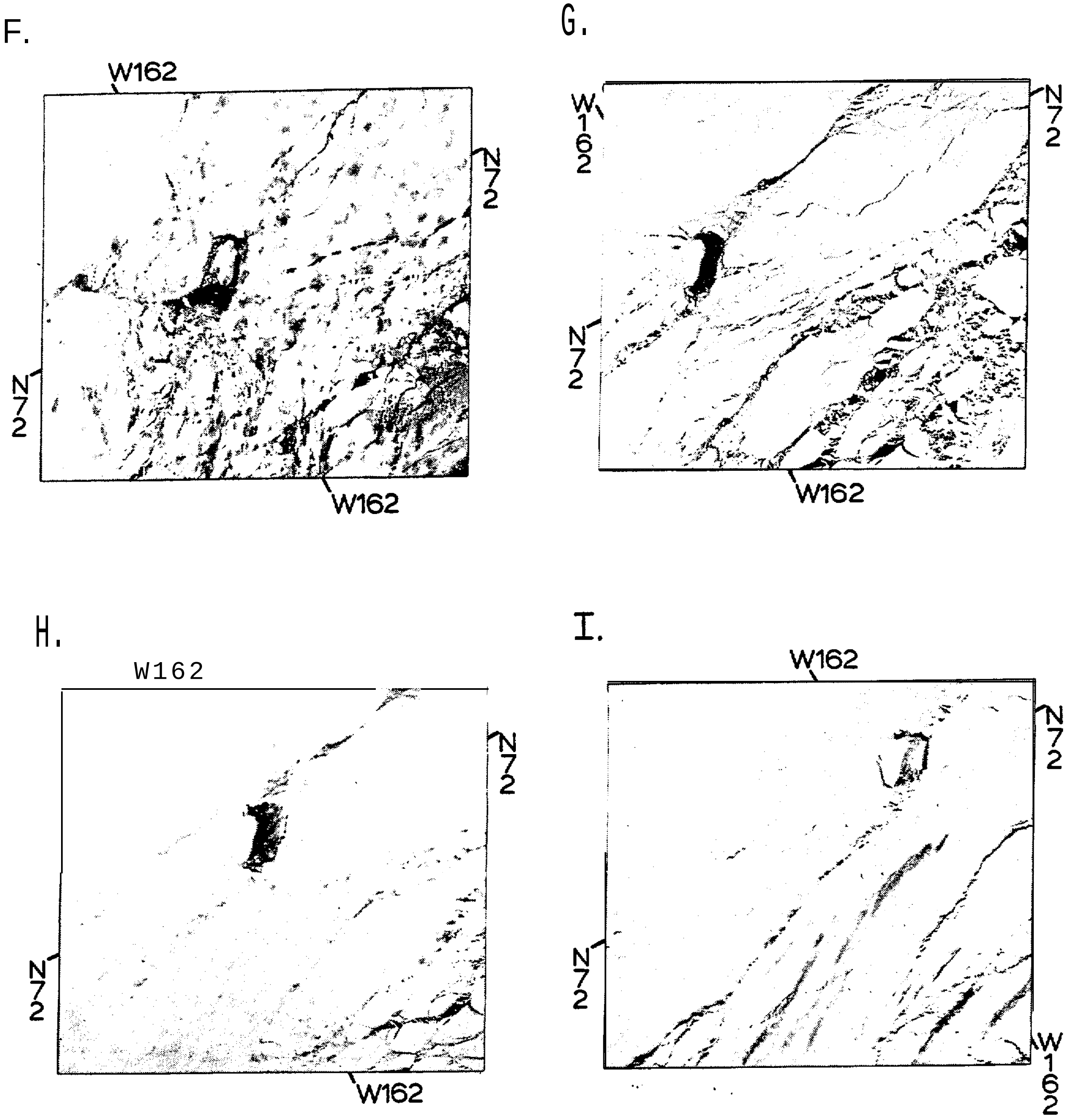


Figure 6. f) scene 2080-22140, 12 April, g) scene 2097-22081, 29 April, h) scene 2098-22135, 30 April, i) scene 2099-22194, 1 May.

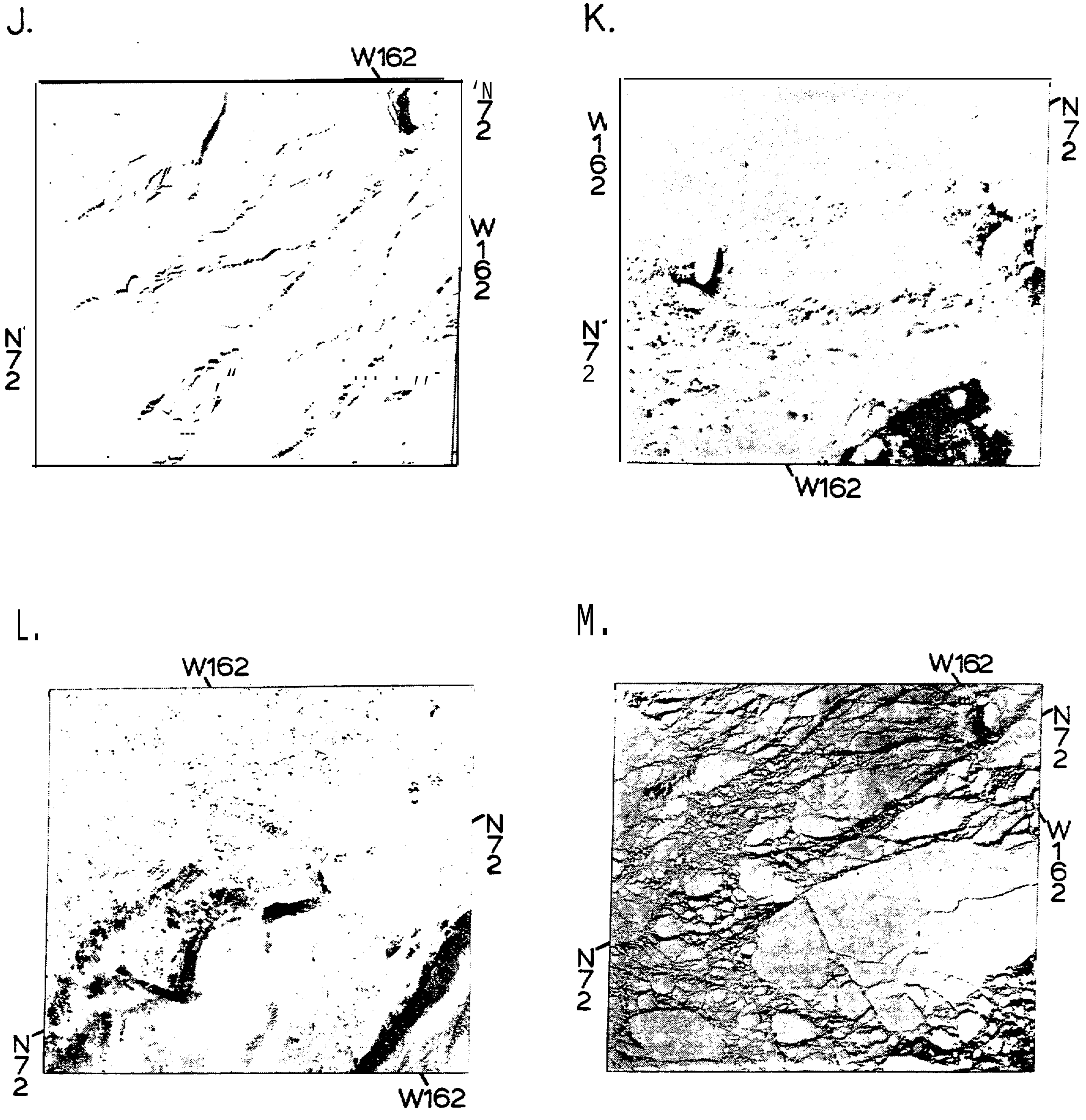


Figure 6. j) scene 2100-22252, 2 May, k) scene 2115-22075, 17 May, l) scene 2207-22184, 17 August, m) scene 2262-22240, 11 October.

On 15 March (scene 1965-22022) the ice was moving in a north-northwest direction, as shown by the open polynya on that side of the feature. The edge of the feature showed the jagged remains of the ice wedge seen on 25 February that had broken off as the pack ice moved away. These remains enlarged the feature to 23 km by 12 km.

The 2 April Landsat image (scene 1983-22013} showed a very pronounced wedge of fractured and ridged ice on the eastern side of the feature and a large polynya, mostly frozen over, on the western side, indicating ice motion was from east to west. However, at the time the image was acquired, a lead system had started to open to the north of the feature, with the ice to the north moving approximately northwest. On 3 April (scene 1984-22071) the major lead had widened considerably and a large pattern of fracture leads had opened. However, the wedge of piled ice was still intact. The feature remained the same size on both days, 21.5 km by 11 km.

Scene 2079-22082 obtained on 11 April showed the wedge of ice on the eastern side of the feature to have broken off, due to the change in direction of motion of the pack ice from an east to west movement to a northeast to southwest movement. The size and shape of the feature remained nearly unchanged (22 km by 10 km). The next day, scene 2080-22140, showed the ice motion to have shifted again, this time to a southwest to northeast movement, a shift of nearly 180°. The amount of movement in that direction was 1.0 to 1.5 kilometers.

Beginning on 29 April a *four* day series of overlapping images of the area of the feature was obtained. On 29 April (scene 2097-22081), the feature appeared essentially unchanged from the 12 April image with the exception of a narrow addition of ice on the northwest corner of the feature. A wedge of ice was seen forming again on the northwest side of the feature, with a corresponding polynya to the southeast, both the result of ice motion to the southeast. . The ice had moved very little between this scene and the one obtained on 30 April (scene 2098-22135) with the result that the polynya had partially frozen. Some ice movement formed cracks in the polynya. Twenty-four hours later, the polynya had completely frozen, but a small lead on the west side of the feature indicated that the ice motion had changed to that direction (scene 2099-22194} . On 2 May (scene 2100-22252) the ice had indeed moved west, opening a large polynya on that side of the feature.

The 17 May image (scene 2115-22075) showed little change in the dimensions of the feature. The pack ice was broken and decayed by this time.

The next available image, 17 August 1975 (scene 2207-22184), showed the feature very decayed and somewhat smaller in size, 20 km long but only 4 km wide. The pack ice was very decayed and had been moving from approximately northeast to southwest.

The next available image of the area was a NOAA 4 image acquired on 23 September 1975 (Figure 7) which showed new pack ice covering the area and a large polynya to the southwest of the feature. On 11 October, a Landsat scene (scene 2262-22240) showed the feature much reduced in size, 14 km by 7.5 km, but similar in shape to that seen in the early part of the summer. A refrozen polynya to the west indicated ice motion in that direction. The 11 October image was the last Landsat image for 1975. The feature apparently did not disappear in 1975.

<u>1976</u> (See Figure 8)

The first available Landsat imagery of the area in 1976 was a series of four images acquired on 17, 18, 19 and 21 March {scenes 2420-

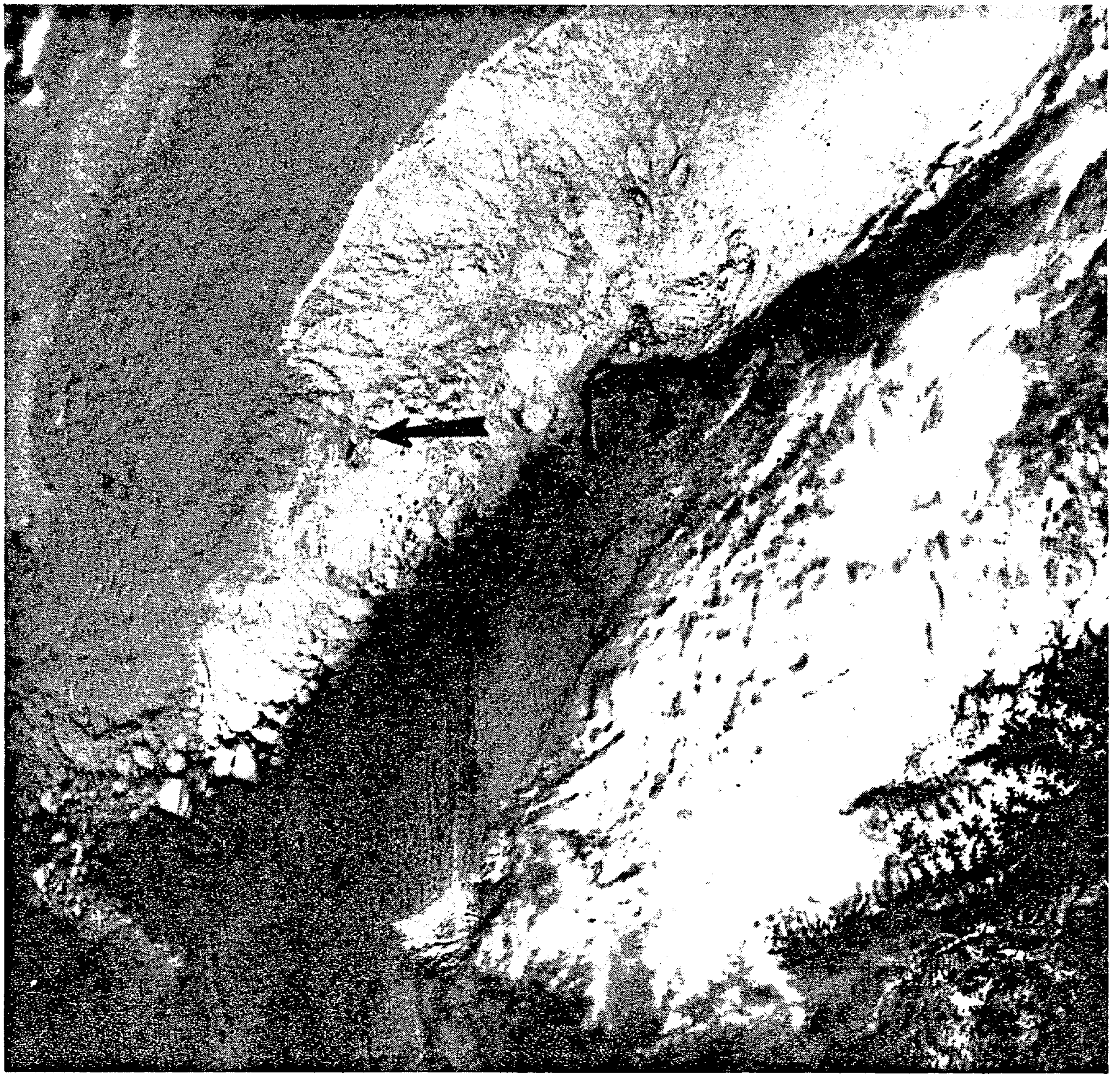


Figure 7. NOAA image 3909, 23 September 1975, of vicinity of Hanna's Shoal.

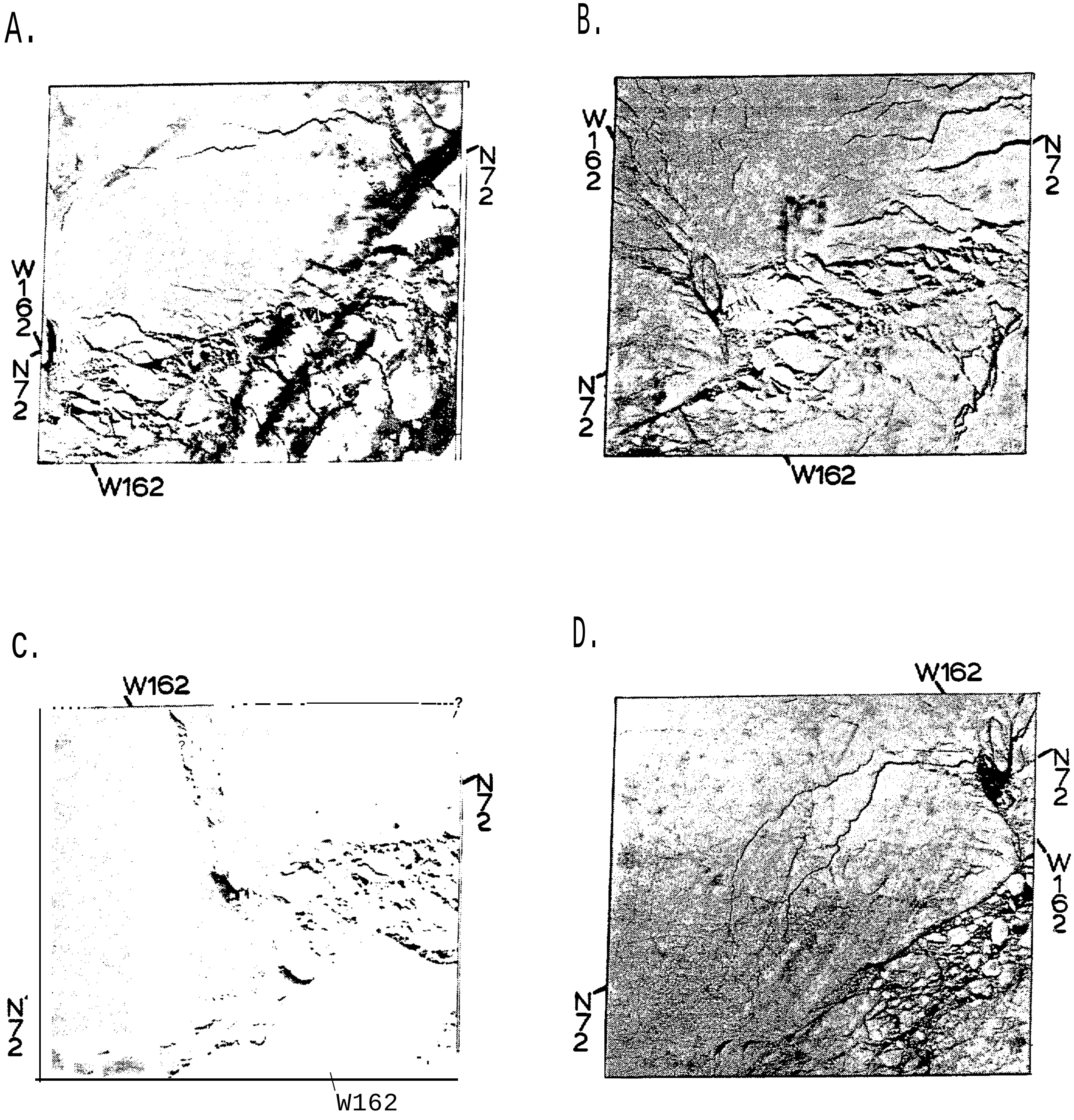


Figure 8. 1976 Landsat scenes of vicinity of Hanna's Shoal: a) scene 2420-21583, 17 March, b) scene 2421-22042, 18 March, c) scene 2422-22100, 19 March, d) scene 2424-22212, 21 March.

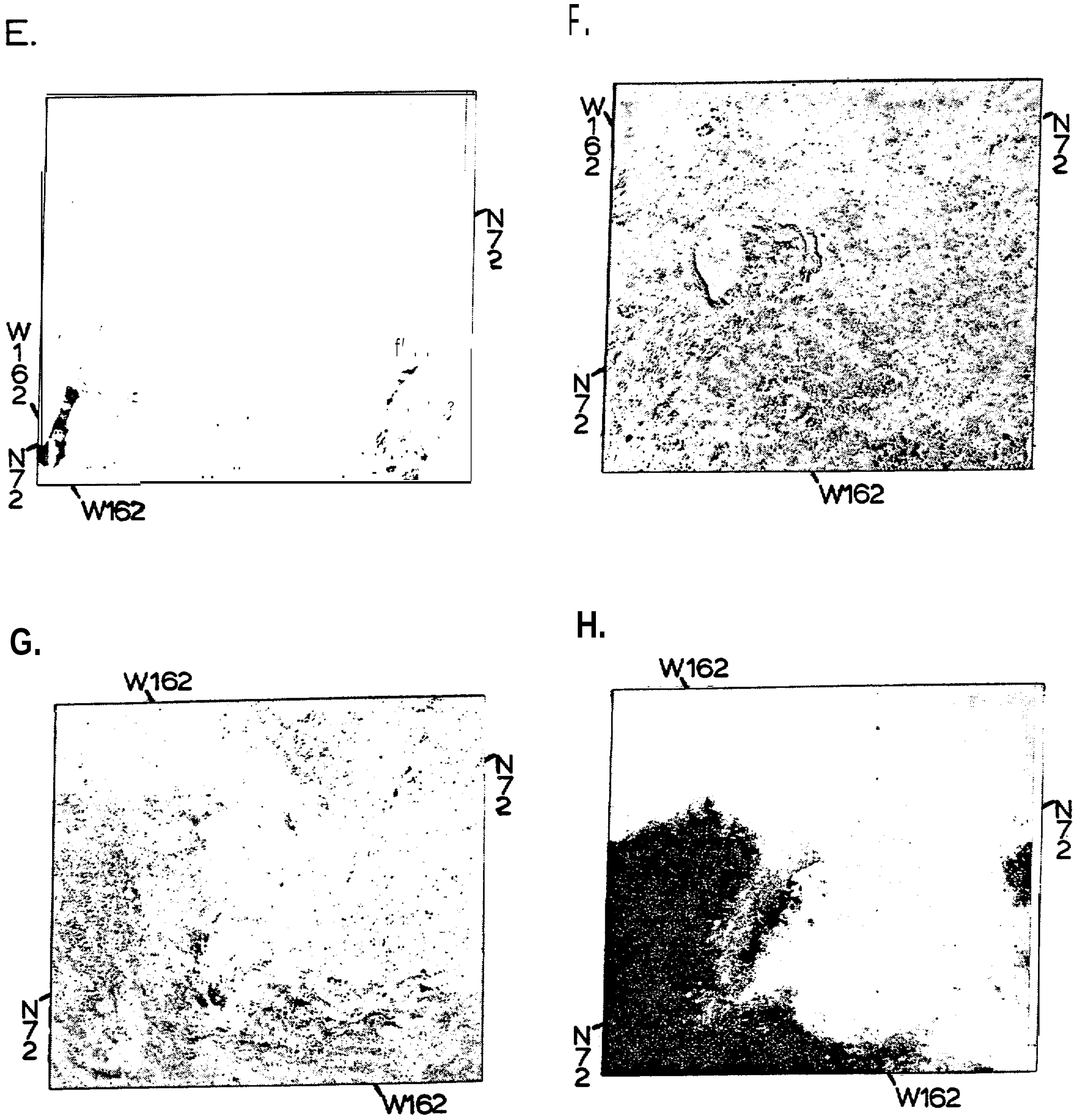


Figure 8. e) scene 2472-21570, 10 May, f) scene 2511-22015, 16 June, g) scene 2548-22063, 23 July, h) scene 2584-22053, 28 August.

21583, 2421-22042, 2422-22100 and 2424-22212, respectively). The feature had undergone considerable decay since 11 October 1975 but had grown to its largest observed size yet, 27 km by 10 km. A small round core could be seen on the southwest tip of the feature, with large growth features to the north and east. A wedge shaped fracture pattern could be seen forming to the northwest on 18 March but the wedge had detached and moved southwest on the 19th indicating ice motion *in* that direction. By the 21st the ice had moved even farther southwest, but a new lead had opened up to the south indicating a change of direction of ice movement.

On the 10 May Landsat image (scene 2474-21570], the feature was half out of the picture so its size could not be determined, but it was at least as large as in March. A polynya on the south side indicated ice motion in that direction.

On 16 June (Landsat scene 2511-22015) the feature was 30 km by 25 km in size in the shape of a teardrop, with the tip to the southwest. The pack ice was very decayed, with about 5 percent of the pack consisting of open water due to small holes in the ice. No ice motion was detectable.

On 23 July (Landsat scene 2548-22063) the feature was approximately 6 km narrower than on 16 June, being 31 km long by 19 km wide. The pack ice consisted of decayed and loosely consolidated small floes. No ice motion was detectable: no polynyas or leads were seen.

By 28 August (Landsat scene 2584-22053) the feature had decayed considerably, losing much of its material on the northwest and southeast sides. The long axis, as usual, was oriented approximately northeast-southwest. The feature itself was in the shape of a ‘T’, with the length of the top of the ‘T’ approximately 20 km, while the narrow part

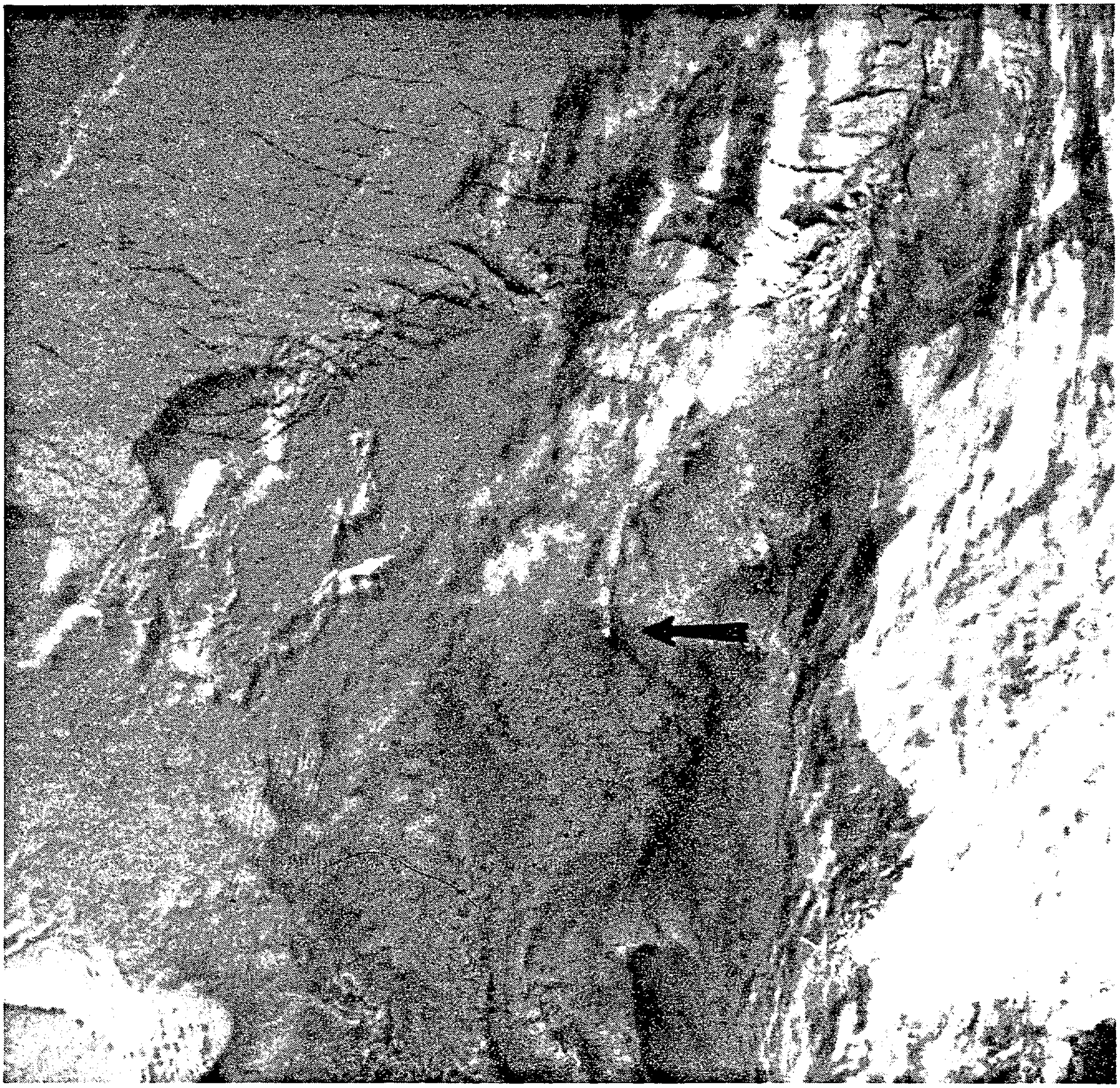


Figure 9. NOAA image 956, 14 October 1976, of the vicinity of Hanna's Shoal.

was only 10 km wide. The northwest-southeast dimension was 31 km with the top of the ‘T’ contributing 8 km. The pack ice was mostly loose, small floes, with open water to the west.

The feature apparently did not disappear in 1976. NOAA 4 imagery showed its existence at least as late as 7 November (Figure 9). At that time pack ice covered the entire area surrounding the feature, but a large polynya several kilometers long revealed the feature’s presence. The last NOAA image that showed the feature clearly was acquired on 28 October and showed the feature nearly the same size as on the 28 August Landsat scene.

Summary

The above sequences of NOAA and Landsat images show that the feature undergoes yearly growth and decay cycles. In March of 1973, it was shown that the direction of ice motion was in the same direction that the wind was blowing; hence winds were likely the major cause of ice motion, at least in the winter. Some years the feature seems to disappear completely.

IV. BARROW WEATHER VERSUS ICE MOTION

It is an hypothesis of this study that the process of growth and decay of the grounded ice feature is mostly dependent upon the weather conditions, especially the direction of the wind movement, at the location of the feature. The closest reliable and complete records of the weather in the area are collected at Barrow, Alaska. Since Barrow is over 100 km southeast of the location of the feature, the wind and weather conditions may not be the same at both locations.

Figure 10 was made in an attempt to correlate the direction of ice motion in the area surrounding the ice feature with the direction of the winds at Barrow. The direction of the ice motion was derived by observing polynyas and open leads on Landsat imagery on the dates shown.

Figure 10 shows that the direction of the ice motion was usually to the right of the wind vector. The average angle between the wind and the ice motion directions of all the values in Figure 10,' with the exception of those of 10 and 11 April 1975 which were anomalous, was calculated to be 20°, with an average deviation of ± 19°. When only the angles of ice motion measured to the right of the wind direction are considered, the average value is 29° , with an average deviation of + 13°. The latter situation may be more valid because the ice vectors to the left of the wind vectors occurred when the winds were low to moderately low in speed while the winds which occurred to the right of the ice motion were generally of higher speeds. Therefore, the ice vector at the grounded ice feature is usually approximately 29 degrees to the right of the wind vector at Barrow. In support of this, it has been found that the Coriolis acceleration causes the direction of ice motion to curve approximately 30° to the right of the wind direction (Zubov, 1945). Nansen observed (Zubov, 1945, p. 358), while drifting aboard a ship in the Arctic Ocean, that loose ice floes tended to move at an angle of 28° to the right of the wind direction. This is very close to the 29° observed on the Landsat images. Also, two Landsat images, 7 and 8 March 1973 (Figure 3a and 3b), show condensation trails extending from open polynyas, showing the direction of ice and wind motion simultaneously. The ice motion in these cases is 25° to 30° to the right of the wind direction.

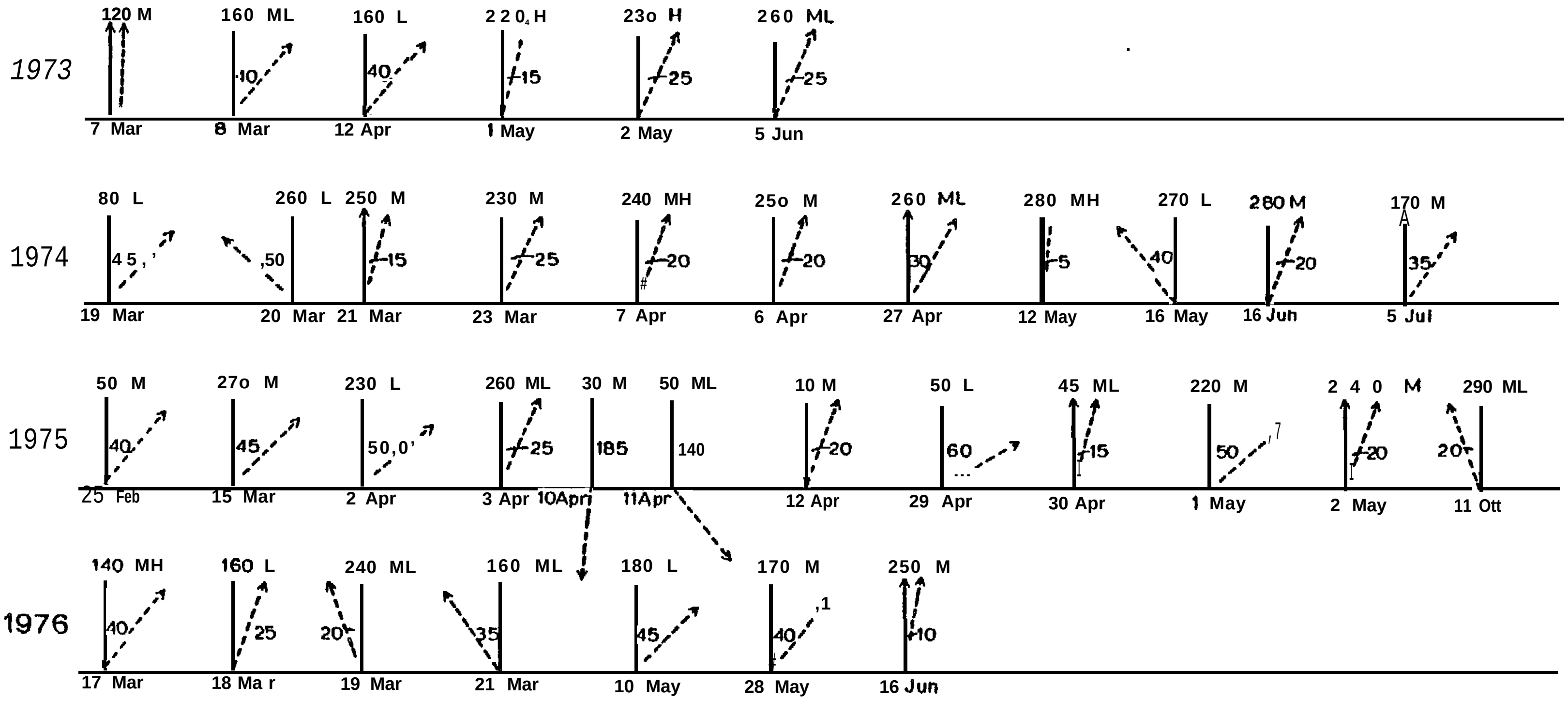


Figure 10.

Barrow wind directions (solid arrows) and pack ice directions (dashed arrows). Number above wind gives direction from which the wind was blowing in degrees east of north. Angle between solid and dashed arrows gives direction of pack ice motion relative to the wind. The date is given beneath the arrows as well as the wind speed: L = low, 0-6 km/hr; ML = moderately low, 7-13 km/hr; M = moderate, 14-19 km/hr; MH = moderately high, 20-26 km/hr; H = high, over 26 km/hr.

The only amomalies are the vectors on the 10th and 11th of April 1975. On 10 April, the wind at Barrow was out of the southwest, pointing N 30° E. But the direction of ice motion was to the southwest, pointing N 215° E. On 11 April the situation was similar, with the wind vector pointing N 50° E and the ice vector N 190° E. The wind speeds on these two days were moderate (14-19 km/hr) and moderately low (7-13 km/hr), respectively. The polynya used to determine the direction of ice motion may have formed prior to the time the wind was blowing northeast, which would have put its formation time back on the 7th of April. But this seems unlikely, as the surface temperatures were *in* the range of -23°C to -26°C at the time, which would have meant that the polynya should have been frozen evermore than it appears to be on 11 April. Except for this unexplained anomaly, the wind direction at Barrow is correlatable with the ice motion at the feature, which means that the wind direction at the feature is generally the same as at Barrow and probably determines the direction of motion of the pack ice at the feature.

Since it is assumed that the winds are the major cause of ice motion and that the wind direction at Barrow is usually the same as at the feature, the wind speed at Barrow may be correlatable with the velocity of the ice moving past the feature. The rate of ice movement at the feature is calculated by measuring the flow vectors at the feature and dividing by the time interval. Figure 11 shows the pack ice velocity at the ice feature plotted against the windspeed at Barrow for 1973 through 1976. The symbol numbers are the same as those in Table 1.

When the types of ice motion are delineated, a pattern begins to emerge. The motion of ice that is free-floating and loose, such as loose floes or pack ice that is apparently free of coastal effects

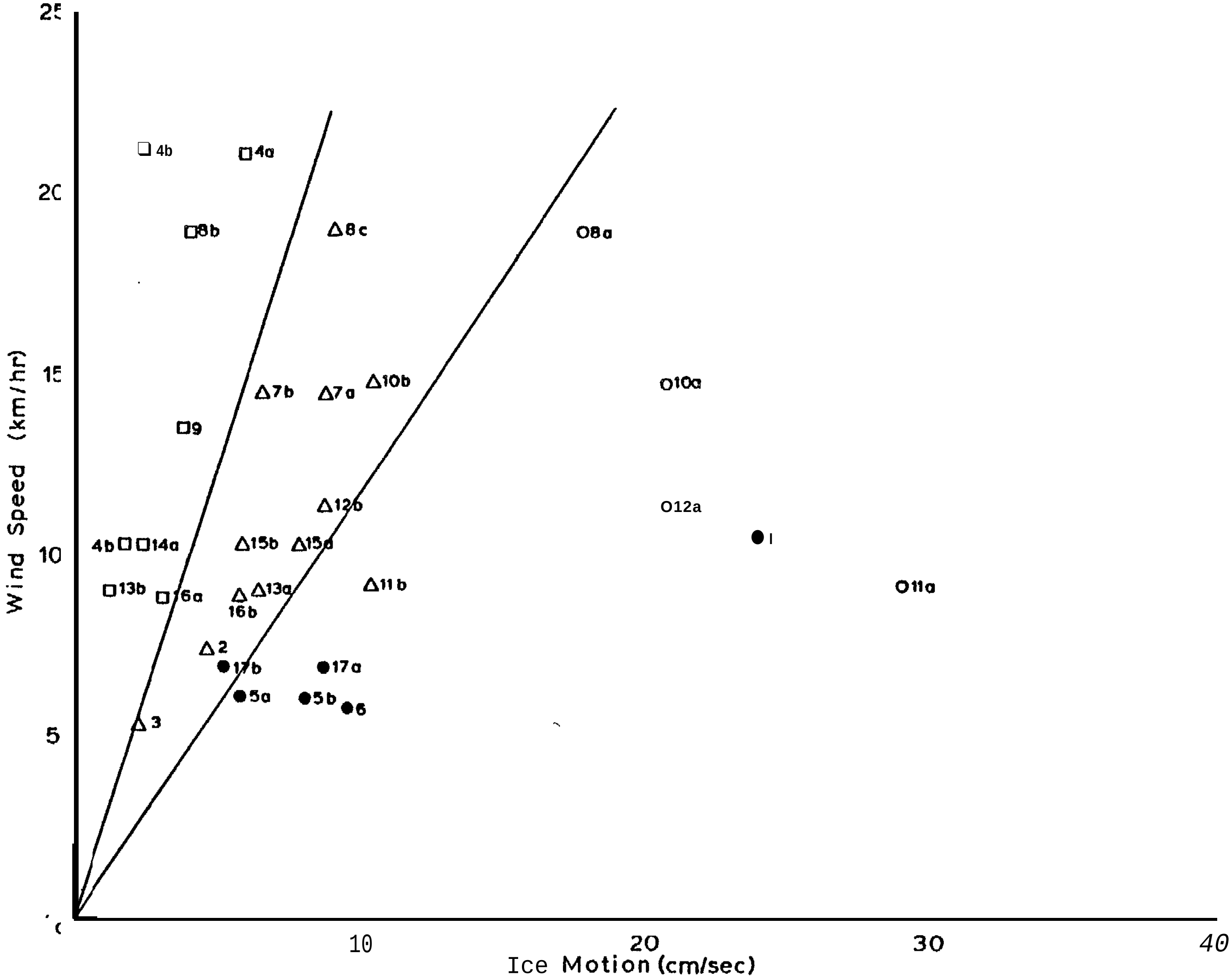


Figure 11. **Wind speeds measured at Barrow versus pack ice motion as determined** from Landsat imagery. Solid symbols indicate summer data (post ice-decay, usually after May 1). Open symbols indicate data for periods when the pack ice was observed to be mostly intact. Type I motion is indicated by circles, Type II is indicated by triangles, and Type III is indicated by squares. Reference numbers correspond to those in Table 1.

because of an intervening shear line or lead, is Type I. Pack ice motion of this nature may have gained momentum previously or may be part of the Pacific Gyre. Type II is ice motion that is apparently affected by coastal friction and may be heading towards Bering Strait. This type of motion is predominant, and is generally slower than Type I. Type III motion is very slow, apparently because the ice is partially attached to the shore or otherwise impeded. In some cases, the ice moved only a few kilometers per day, despite winds averaging 10 to 15 knots for 24 hours or longer.

All three types of motion may be present at the same time. For example, during the period 7 to 8 April 1974, a shear line existed to the north of the feature. The ice north of the shear line moved at a rate of 17.8 cm/see, the ice south of the feature, nearest the shore, moved only 3.9 cm/see, while the ice between these two zones and obstructed by the feature, moved approximately 9.0 cm/sec. These form three zones with distinct boundaries, as indicated by the ice vectors in Figure 12.

Due to this complex relationship, measuring the windspeed at Barrow will not give the magnitude of ice drift at the feature. Other factors to be considered are coastal friction, ice surface roughness, and amount of open water *or* thin ice.

The ambient air temperature at the feature appears to be a major factor in determining the strength, and therefore the permanence, of *new* additions to the feature (discussed below). There is no satisfactory way to correlate the temperature at Barrow with the temperature at the feature. However, since Barrow is on a point of land extending into the Arctic Ocean and the land surface to the south and east of Barrow has very little surface relief, and Barrow is at nearly the same latitude as the feature (Barrow

Table 1. ICE VECTORS

Point No.	Date	Ice Speed (cm/see)	Ice Motion Direction	Average Wind Speed (km/hr)
1	21-22 August 72	24	SE to NW	10.4
2	7-8 March 73	4.6	N to S	7.4
3	11-12 April 73	2.3	N to S	5.3
4a b	1-2 May 73	5.8 2.3	E to W	21.1
5a b	5-6 June 73	5.8 8.1	E to W	6.1
6	30 May - 2 June 74	9.6	SE to NW	5.8
7a b	20-21 March 74	6.5 8.7	E to W	14.4
8a b c	7-8 April 74	17.8 3.9 9.0	E to W	18.9
9	21 March-7 April 74	3.7	E to W	13.4
10a b	17-18 March 76	20.8 10.4	NNW to SSE	14.7
11a b	18-19 March 76	29.0 10.4	E to W	9.1
12a b	19-21 March 76	20.8 8.7	ENE to WSW	11.4
13a b	2-3 April 75	6.4 1.2	SE to NW	9.0
14a b	11-12 April 75	2.3 1.7	SW to NE	10.2
15a b	29-30 April 75	7.8 5.8	WSW to ENE	10.2
16a b	30 April-1 May 75	3.1 5.8	E to W	8.8
17a b	17-18 May 75	8.7 5.2	NE to SW	6.9

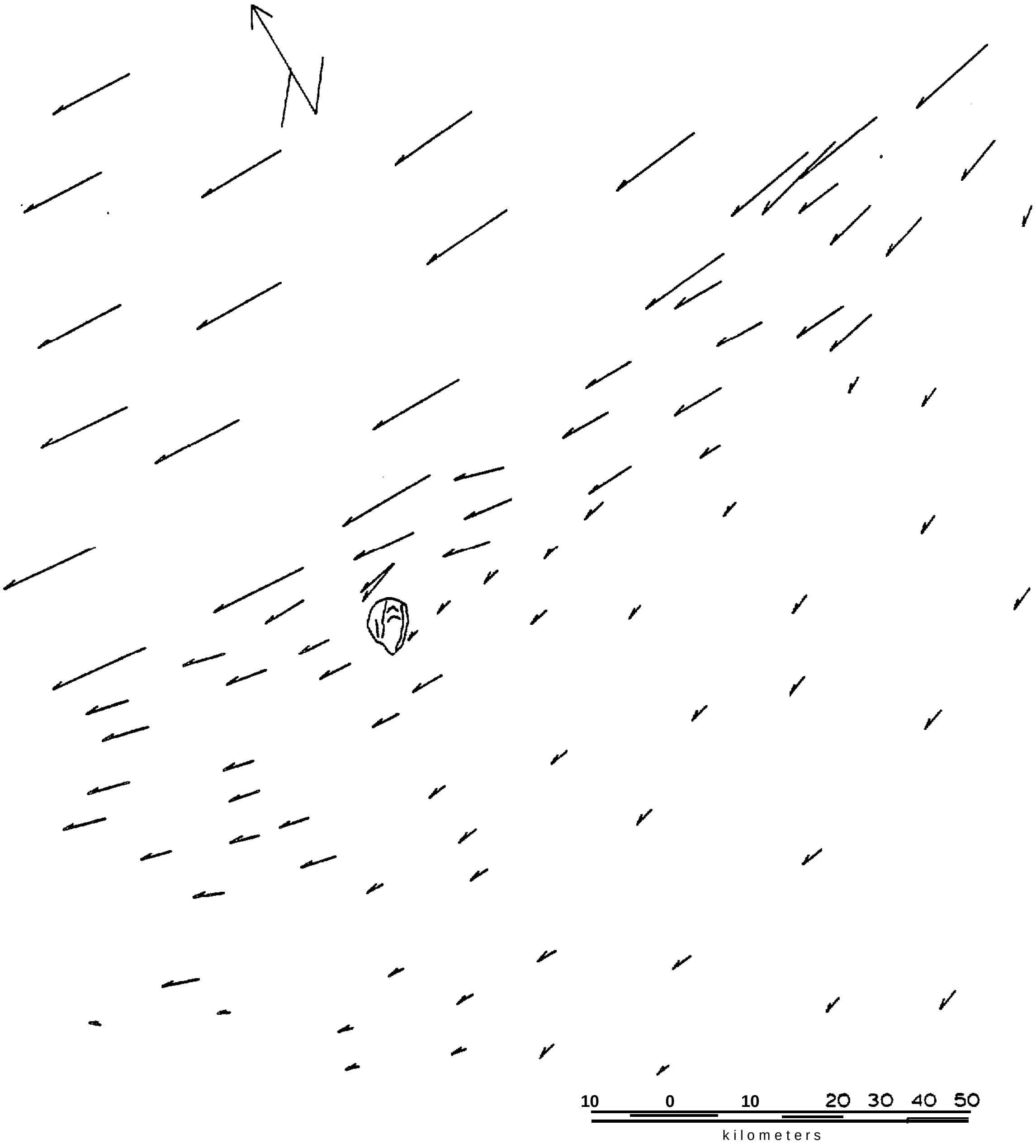


Figure 12. Ice vectors around the grounded ice feature during the 24-hour period, 7 April - 8 April 1974. Note the distinct shear line north of the feature.

is at 70020’; the feature is at 72000’), the temperatures at the two locations may be similar.

V. GROWTH MECHANISMS

In the section on growth and decay cycles, mention was made of wedges of ice that appeared to consist of pack ice that had fractured. and then reconsolidated by freezing. It is now postulated that the formation of these wedges constitutes the principal growth mechanism of the feature.

The mechanism of formation of the wedges is more complex than simple fracturing and reconsolidation by freezing, and is illustrated in Figure 13. As the ice is forced past the feature, it piles up behind, i.e., “upstream” (with respect to the ice motion) of the feature (Stage I). Initially, the piled ice forms ridges approximately parallel to the edge of the feature. As the ice piling continues, the ice pile expands upstream in a direction perpendicular to the effective cross section of the feature, where the effective *cross* section, X, is equal to Y tan ϕ, where X and Y are as shown in Figure 13, and ϕ is the angle between Y_and the side of the wedge. The 12 April 1973 image (Figure 3c) shows this process. Long fracture lines extend upstream and piled ice can be seen adjacent to the feature.

At some point in the process of piling, shear ridges develop, extending upstream from the sides of the feature to a point where the ridges intersect, forming a wedge shape which effectively encloses the piled ice. In an attempt to determine when this occurs, the ratio, R, of the length, Y, (Figure 13) of the wedge to the cross section, X, of the feature was computed for those scenes for which the measurements could be made. Table 2 gives the dimensions and ratios for those “

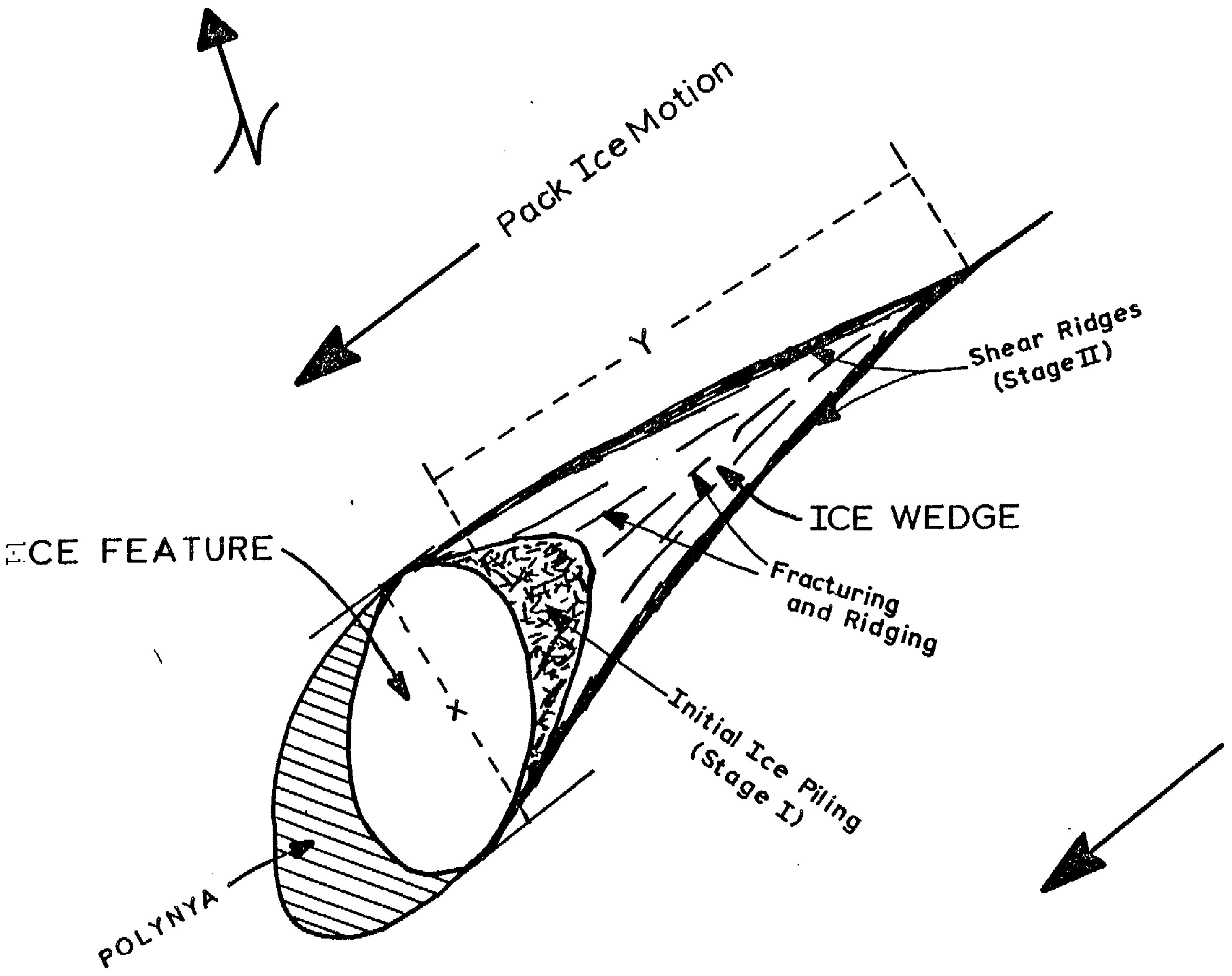


Figure 1. Idealized model of growth mechanism of grounded ice feature. The main body of the feature may be 5 to 25 kilometers wide.

TABLE 2. ICE WEDGE DIMENSIONS

Year	Date	Cross Section X (km)	Length Y (km)	Y/X
1973	7 March	8	13	1.6
	1 May	9	22	2.4
	1 May	8	8	1.0
	2 May	9	21	2.3
	6 June	5	10	2.()
1974	8 April	9	18	2.0
	27 April	9	18	2.0
1975	2 April	15	28	1.9
	29 April	15	38	2.6
	11 October	13	10	0.77
1976	18 March	8	30	3*7
	18 March	14	38	2.7

scenes used. The minimum observed ratio was 0.77, which occurred on 11 October 1975. This ratio indicates that the shear ridge formation occurs not long after the piling begins.

The development of the shear ridges does not halt the growth of the wedge. A previous study of the ice motion around the feature (Stringer and Barrett, 1975b) showed that the feature did not cause the pack ice to diverge significantly around it as the pack ice was forced past. Therefore compaction of the pack ice must occur in an amount proportional to the area of the polynya formed downstream of the feature. The total volume of ice compacted would be equal to the area of the polynya times the thickness of the pack ice. Some of the compaction would occur in the pack ice in the immediate vicinity of the wedge, depending upon the ice thickness, amount of open water, etc., while the remainder would occur along the shear ridges, resulting in piling and subsequent expansion of the wedge. This is Stage II of the growth mechanism.
An illustration of Stage II is contained in the sequence of images obtained during the late winter and spring of 1973 (Figure 3). The feature was comparatively small on 8 March 1973, but by 12 April had more than quadrupled in area.

It is unclear at this time whether Stage I or Stage II accounts for the majority of the feature's growth. The wedge seems *to* form soon after the ice movement commences; there are no sequences of images within a sufficiently short time frame to determine how much ice is piled before the wedge forms. The speed with which the ice moves past the feature is the primary factor affecting how soon the wedge forms since the amount of ice piling is proportional to the amount of ice moving past the feature. In the sequence of Landsat images obtained on 18, 19 and 21 March 1976, the ice was moving moderately fast, 20 to 30 cm/sec. In the 18 March scene, the ice had just started moving northeast to southwest. No wedge had formed by 19 March but ice piling was evident. By 21 March, however, a wedge had formed and substantial growth of the feature could be seen. The time between the 19 and 21 March images was too long to determine when the wedge formed. A close examination of the surface of the feature on the 12 April Landsat image revealed a concentric wedge-shaped pattern of growth. On the northeast end of the feature, Stage I fracture patterns and concomitant piling could be seen, indicated by the darker gray area. No definite wedges had yet formed.

By 1 May 1973, the length of the feature had nearly doubled. Again, the wedge pattern can be seen in the newly added ice. The direction of ice *motion* had changed by approximately 45°, from northeast on 12 April to almost due east on 1 May. A new, much larger growth wedge had formed on the eastern side of the feature.

Another example of the wedge forming process is illustrated on the 18 March 1976 image (scene 2421-22042). Three separate periods of growth can be seen here. The feature was originally a small oval of ice approximately 6 km in diameter. It was probably a remnant of the previous year's feature last seen on 11 October 1975 (see 1975 growth and decay cycle). Extending north-northeast of this oval core was a wedge pattern approximately 8 km long, the result of the first period of growth. The second period of growth was to the northeast, during which the feature doubled in length but did not change in width. During the third period of growth the feature increased in width but not in length. The third period of growth, towards the north and northwest, was still in progress at the time the image was obtained.

The building process probably does not continue indefinitely. At some point (Stage III), if the direction of ice motion has remained constant, the wedge would cease to grow and the ratio R would reach a maximum value R_{max}. This cessation of growth would be the result of the angle ϕ becoming small enough that the predominant process would change from a combination of shear and pressure ridging to a simple shearing motion. The value of R_{max} is a function of the ice conditions, such as thickness, uniformity, temperature and brittleness. R_{max} is probably also dependent on grounding of the newly formed shear ridges. The maximum R measured on the Landsat scenes was 3.7 on 18 March 1976. However, it is not clear that the ice formation measured was a true growth wedge. Another wedge measured on the same image gave an R of 2.7. A similar value of 2.6 was obtained for a wedge on 29 April 1975. The sequence of images of 1 and 2 May 1973 showed the length of the wedge actually decreasing. On 1 May the wedge had a ratio of 2.4 with pronounced shear boundaries. On the next day's image, the ratio was 2.3, yet the direction of ice motion had changed less than 20°. Therefore, it seems that the wedge had reached an R_{max} of 2.4, and a slight change in the direction of motion of the pack ice resulted in pieces of the wedge breaking off.

A somewhat different example of the Stage I and II processes is illustrated in the images obtained of the feature in the late winter and spring of 1974. The 20 March image showed the ice to have moved from east to west. There were numerous floes of various sizes frozen into a matrix of new ice immediately to the east and northeast of the feature. The ice movement towards the west caused that portion of the frozen matrix to the east of and in line with the feature to pile up on the eastern side. Some of the floes maintained their integrity, not breaking and piling. Despite the fact that the ratio of the length of the piled ice to the effective cross section of the feature was $R = 1.0$ (which is greater than the minimum of 0.77 observed above) no wedge formation was observed at that time. The 23 March image showed the piled ice to have consolidated and the wedge shape was finally apparent.

Comparing this sequence with that of 11 and 12 April 1973 shows the absence of the initial fracture patterns in 1974. Possibly the ice upstream of the feature in 1974 was much newer ice (except for the floes), and may have rafted and piled immediately around the older floes and ridge remnants and then reconsolidated without breaking them up. In 1973, the ice was thicker and more uniform upstream. This would account for the observation by Toimil and Grantz (in press) of the irregular and older appearance of the ridges in the feature in 1974 rather than the expected newer appearance of ridges formed that ice season.

The growth wedge does not always become permanently that affixed to the feature. Many of the images show the wedge forming and then later breaking loose due to shifts in the direction of the ice motion. The attachment of the growth wedge to the feature depends upon the winds, the temperature, and the length of time the direction of ice motion had remained constant. For example, during the 1974 sequence, the ice motion was from east to west consistently from 21 March until 8 April. Consequently, the wedge that had formed by 23 March was still in existence on 8 April and, despite a change in direction of motion, the wedge remained nearly intact on 27 April.

This is in contrast to several other examples, such as that of April 1975. On 2 April a large wedge had formed on the eastern edge of the feature. But by 12 April the wedge had broken loose and the ice motion had changed direction more than once. In this *case,* the ice motion changed from an easterly to a northeasterly direction, resulting in the shearing off of the wedge at the previous edge of the feature.

The above proposed method of growth is the major but not the only possible method. In order for this process to occur, relatively deep draft ice (thicker than first year sheet ice) must first become grounded on the shoal. Thus, the initial core of the feature would consist of remnants of multi-year ridges, floebergs, and possibly some ice islands, frozen to one another in a matrix of first year ice. Such deep draft objects have been observed within the feature (Toimil and Grantz, in press; Kovacs, Gow, and Dehn, 1976). This type of growth probably accounts for only a small percentage of the total.

Another minor growth mechanism can be observed in the 15 March 1975 image (Figure 6b). In this scene, a polynya had frozen over prior to 15 March. When the ice resumed movement, a new polynya formed; but a narrow shelf of the new ice that had covered the older polynya remained attached to the feature, adding to the area of the feature. On 2 April 1975, only a small portion of this shelf still existed. This method, which adds only a small percentage of material to the feature, is of minor importance.

VI GROWTH AND DECAY AND THE MEATHER

Barrow Weather Data

As previously shown, the weather at Barrow is correlatable to ice motion at the feature and thus provides an approximation of the conditions at the feature. The primary source of weather data for Barrow was obtained by personnel at the National Weather Service Office' located at the Wiley Post-Will Rogers Airport at Barrow, Alaska. These data are published monthly by the NOAA Environmental Data Service, Asheville, North Carolina. The data pertinent to this study, (wind speed, wind direction, and temperature) were recorded at three-hour intervals and compiled into daily averages. The wind speed and direction values are the vector sums of the eight daily three-hour observations, while the temperature values are averages of the eight daily observations and the wind direction is the direction from which the wind is coming.

In order to compare the weather data of the four years for which Landsat imagery of the feature was available, 1973 through 1976, the data for each year were plotted beginning approximately one month previous to the date of the first Landsat image to just after the last Landsat image of each year. Figures 14 through 17 show the weather data for the years 1973 through 1976, respectively.

Another source of weather data taken at Barrow, but compiled differently, was obtained from the USAF Air Weather Service headquartered in Asheville, N. C. The data give the percentage frequency of wind direction and speed from hourly observations. These data averaged over all months for the years 1945 through 1968 are plotted in Figure 18. Figure 18a shows the percentage frequency of wind direction, Figure 18b shows the mean wind speed versus direction and Figure 18c shows the percentage frequency of wind speed.

As shown in Figure 18a, the winds at Barrow are predominantly out of the east and east-northeast. The numbers on the rose diagram give the percentages of the winds that occur within each of sixteen 22 1/2° divisions. The sum of east and east-northeast winds accounts for more than 30 percent of the total. A secondary peak occurs in the west with 5.6 percent of the winds from that direction.

Figure 18b shows that more than 60 percent of the wind speeds are in the range of 11 to 26 km/hr. Figure 18c compares the wind speeds

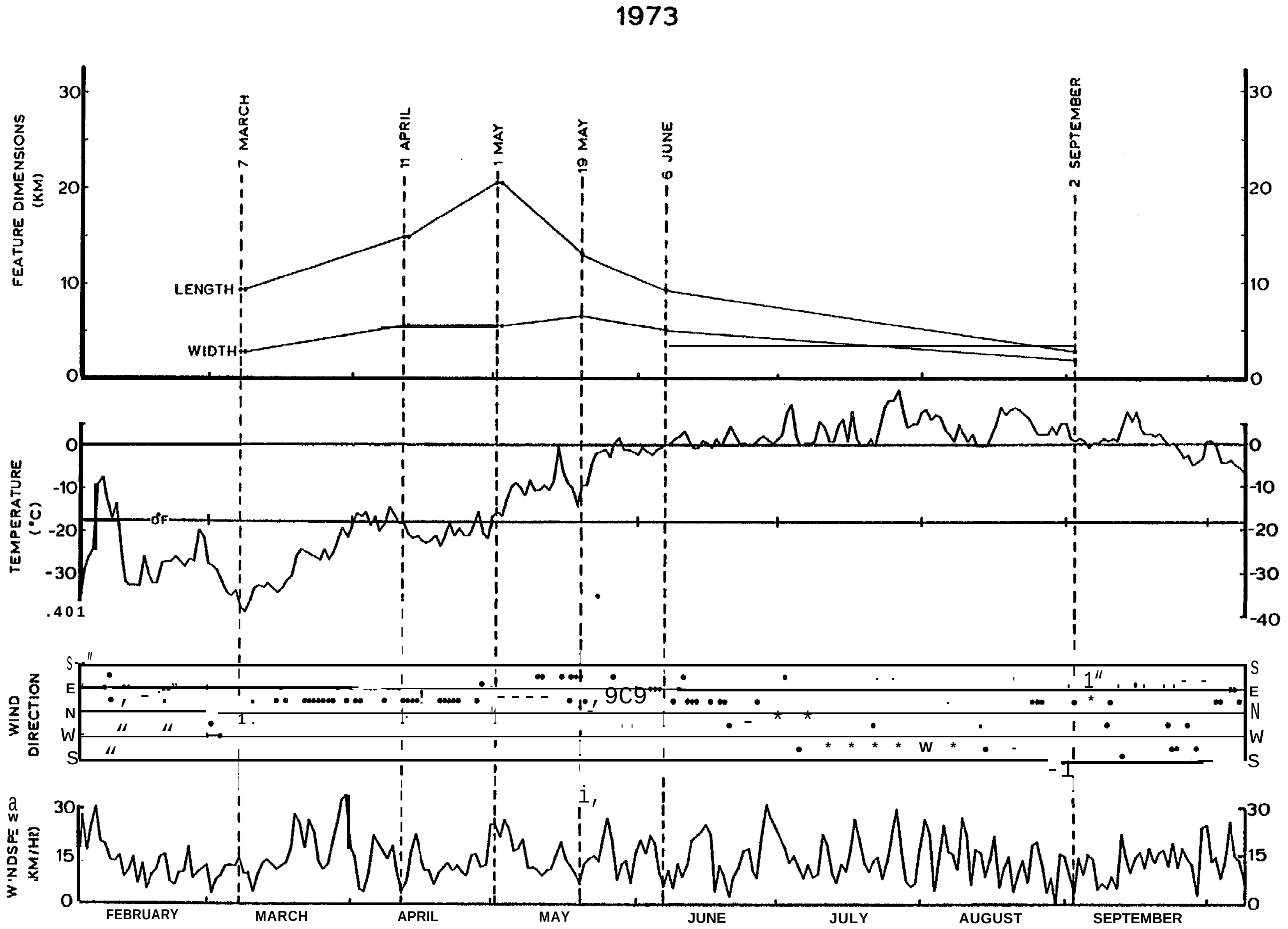


Figure 14. 1973 Barrow weather data and concurrent dimensions of the grounded ice feature. Dates shown are dates of Landsat images.

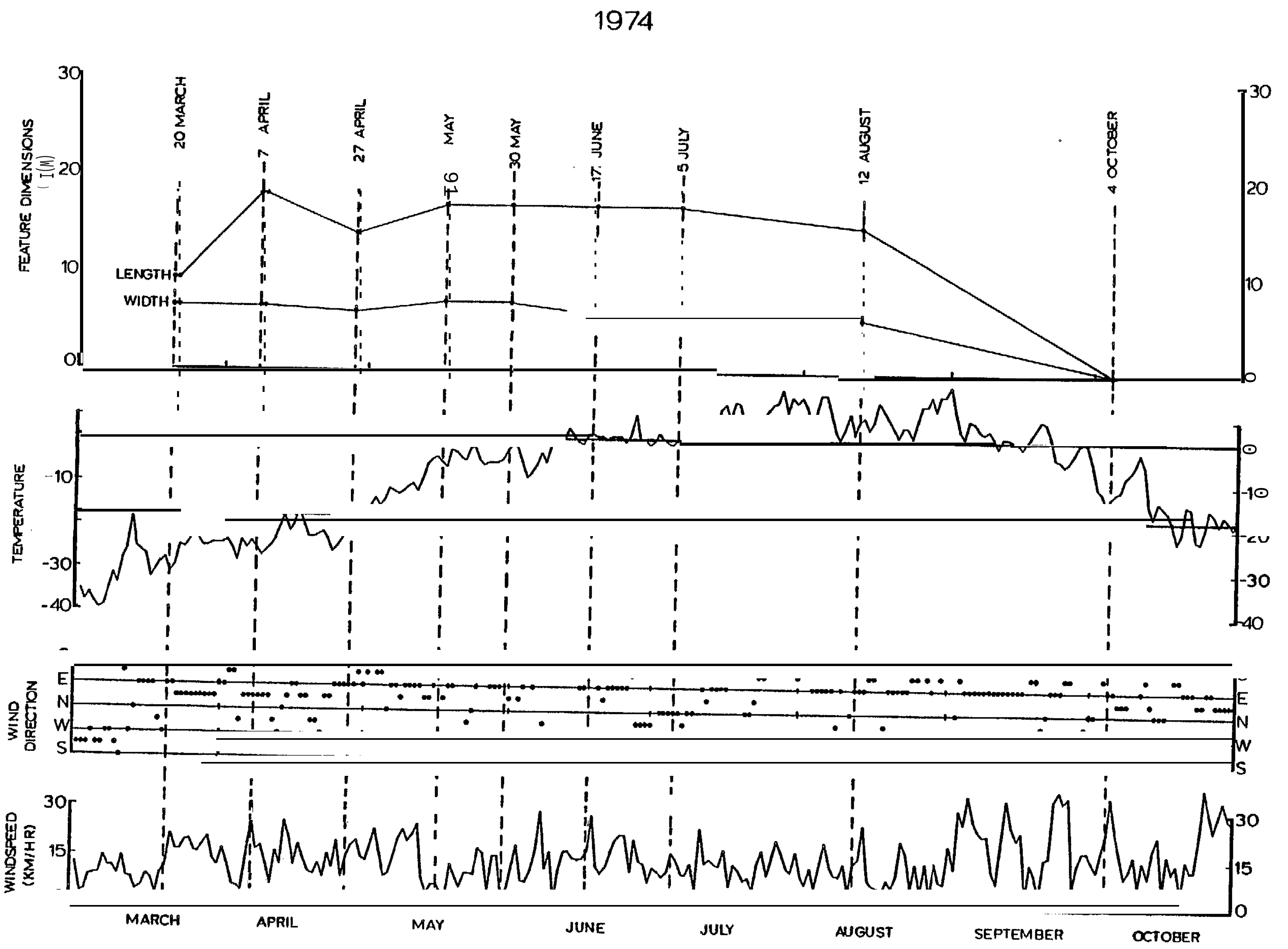


Figure 15. 1974 Barrow weather data and concurrent dimensions of the grounded ice feature. Dates shown are dates of Landsat images.

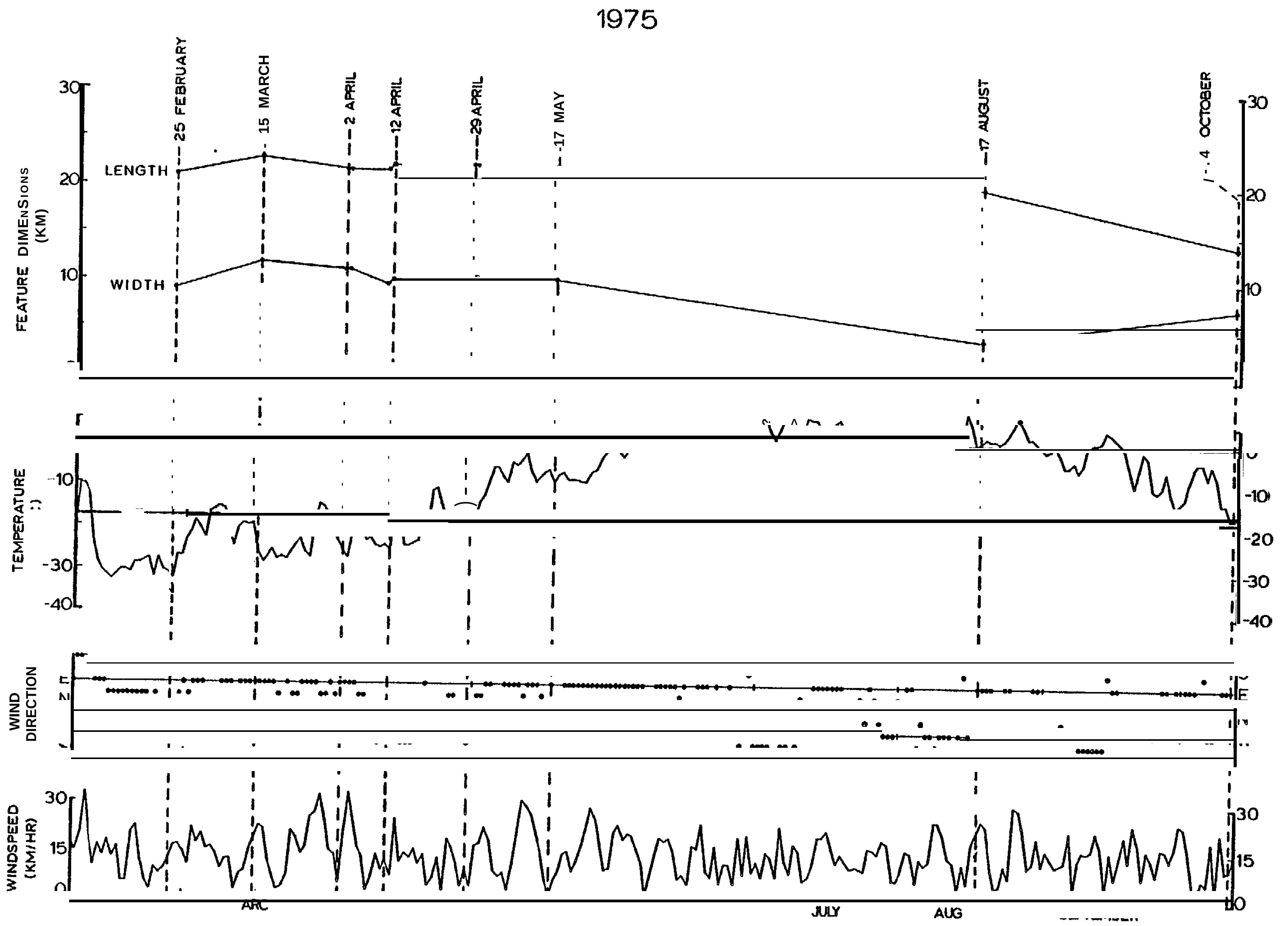


Figure 16. 1975 Barrow weather data and concurrent dimensions of the grounded ice feature. Dates shown are dates of Landsat images.

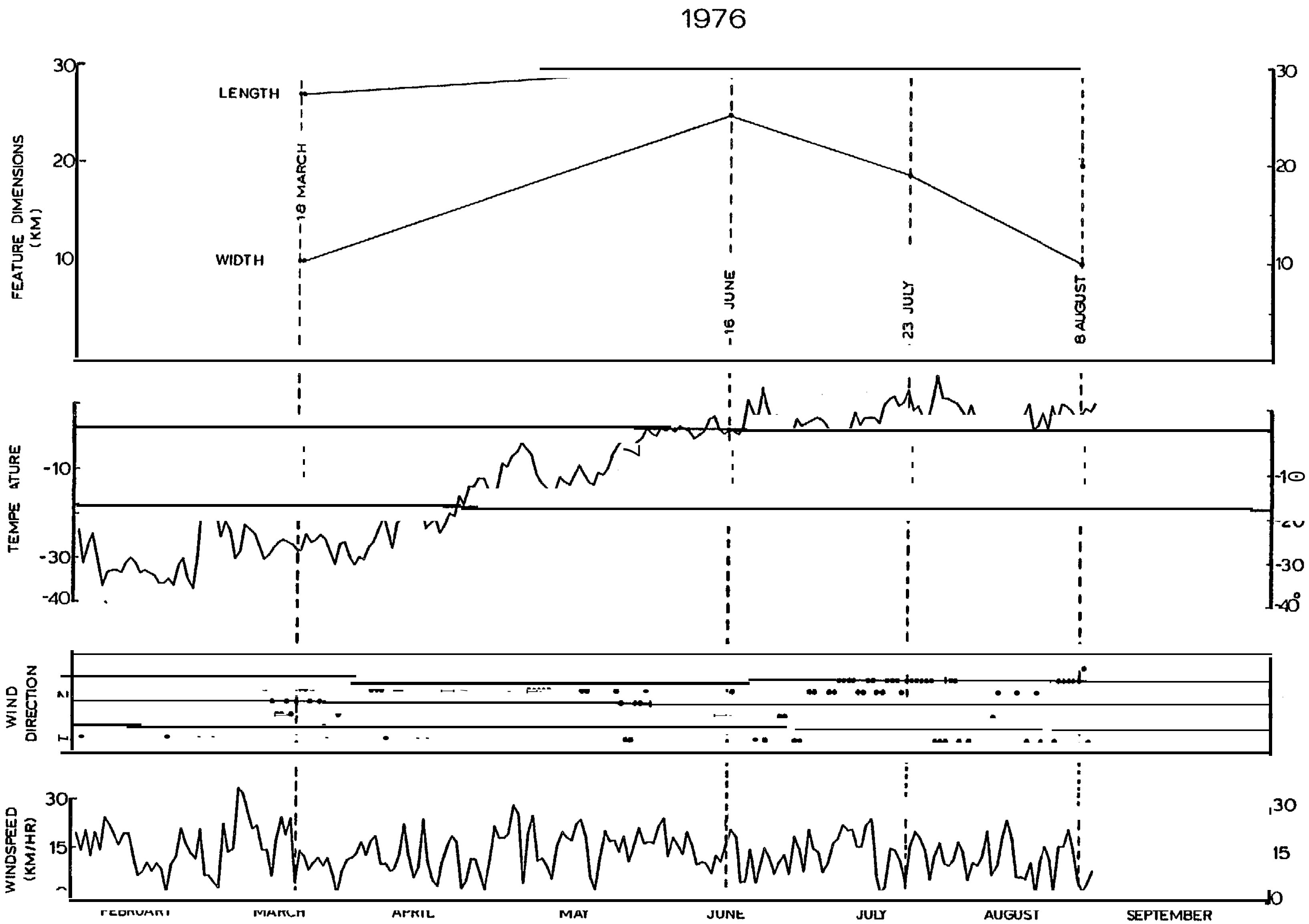


Figure 17. 1976 Barrow weather data and concurrent dimensions of the grounded ice feature. Dates shown are dates of Landsat images.

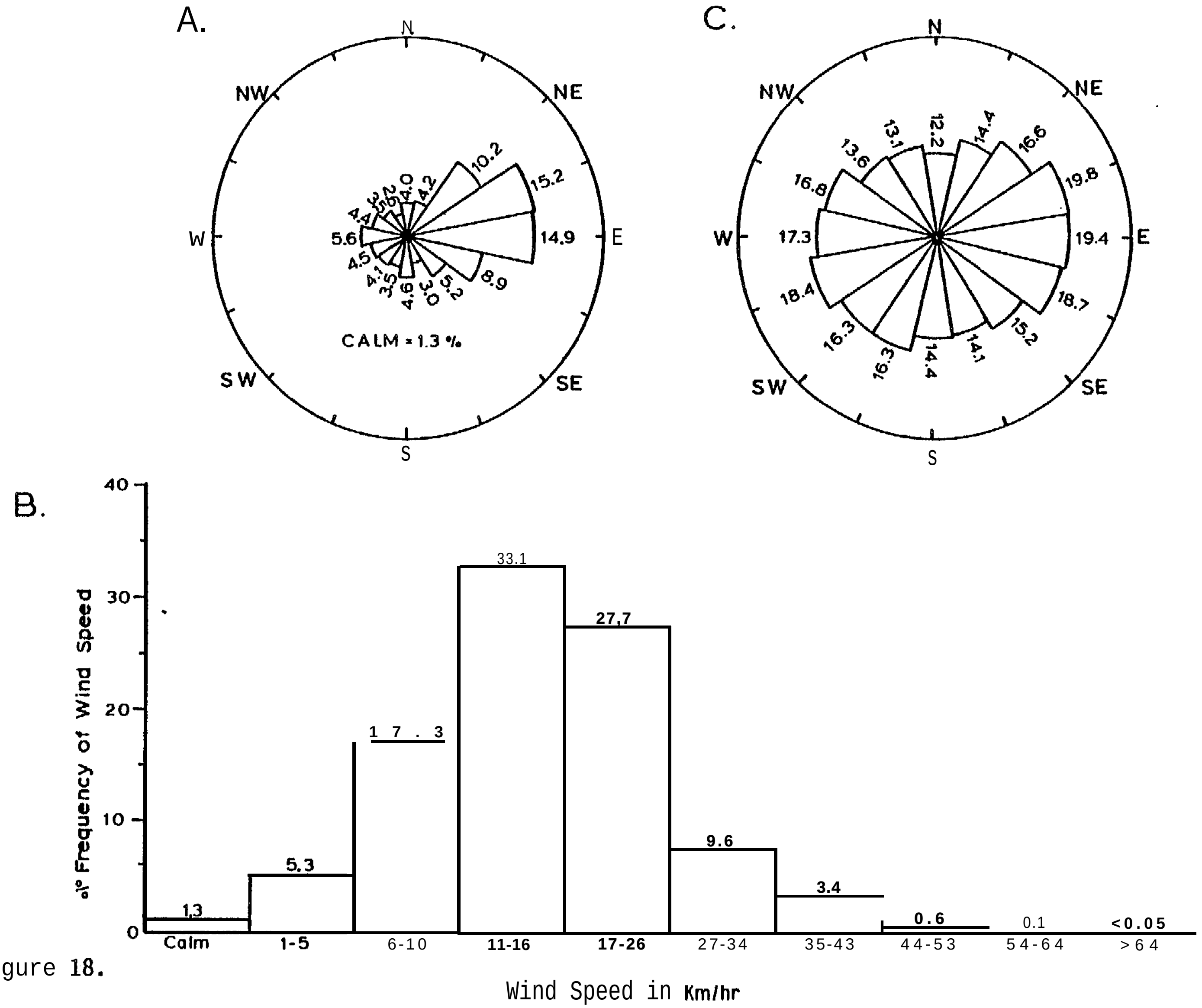


Figure 18.

a) Rose diagram of percent wind direction at Barrow - numbers are the percent wind direction,
b) Histogram showing percent frequency of wind speed versus the actual wind speed at Barrow,
c) Rose diagram of average wind speed versus wind direction - numbers are the wind speeds in km/hr.

and directions. The maximums and minimums in the wind speed frequency approximately correspond to the maximums and minimums in the wind direction frequency.

The data plotted in Figures 14 through 17 show the same distribution of maximums and minimums on a yearly basis. The predominant wind directions are east to northeast, and the winds are steady from these " directions for periods of days at a time. The highest wind speeds are generally associated with these.periods, although occasional high winds may come from other directions. The lowest wind speeds are generally associated with winds from other than the predominant directions.

General Features of Growth

Several. general conclusions can be drawn regarding the location and orientation of the growth patterns of the feature. First, growth always starts very near 162°00'W 72°00'N, indicating that this is probably the shallowest point on Hanna's Shoal. Thus the ice would ground here first and form the "core" for further grounding and growth. 'In 1973, the first available images (7 and 8 March) showed the feature to be very small and located almost precisely at 162°00'W 72°00'N. Later images of 1973 showed the feature to have expanded from this point. First available images for-1974, 1975 and 1976 showed the feature already past the grounding stage of growth, but the "core" could be seen clearly, This core was most vividly seen in the ?7 thru 21 March 1976 series of images.

Another general characteristic of the growth pattern of the feature is that growth by the "ice wedge" mechanism detailed above always occurs within a narrow zone on the northeast side of the original core. This zone generally varies no more than from north-northeast to east-northeast, approximately 45 degrees. The narrow growth zone is largely due to the weather conditions, mostly the wind direction. However, there is another reason for part of this behaviour. On the 12 April 1973 image of the feature, a large section of ice on the southwest tip of the feature can be seen to have broken off. This breaking off seems to indicate that growth cannot occur on the southwest side of the feature. Possibly the water is too deep to ground any ice that may pile there, and any shelf of ice that forms there would break off rather easily.

Correlation of Barrow Weather and Growth of the Feature

Figures 14 through 17 show the weather conditions at Barrow and the dimensions of the grounded ice feature during the period from approximately one month prior to the first available Landsat scene of each year to just after the last available scene of that year for the years 1973 through 1976, respectively. These intervals encompass approximately eight months of each year.

'The first available Landsat scene of the feature in 1973 was acquired on 7 March. At that time, the feature (Figure 14) was 9.3 km long, extending northeast-southwest, and 2.8 km wide. The preceding February was characterized by cold temperatures and winds averaging less than 16 km/hr from varying directions. The next available Landsat image was obtained on 11 April and showed the feature to be much larger -- 14.8 km by 5.6 km (only the larger feature is considered here). The temperatures during the period 7 March to 11 April warmed to near -18°C from a low near -40°C. The winds were almost steadily from the northeast to east at speeds sometimes greater than 30 km/hr. The feature continued to increase in size through 1 May, when it reached its maximum observed size of 20.4 km by 5.6 km. Again the winds were mostly from the northeast, with some from the north and east. The wind speeds averaged near 16 km/hr while the temperatures were -15°C to -23°C. The feature had decreased in size by the 19th of May, to 13 km by 6.5 km. The winds during this time were more variable in direction and the temperatures were much warmer than earlier in the year.

The first clear Landsat scene of the feature in 1974 was obtained on 20 March. The length of the feature (oriented northeast-southwest) was 9.3 km and the width was 6.5 km (Figure 15), During the preceding three weeks the winds at Barrow shifted slowly from the southwest to the east and then to the northeast. The wind speed during this time varied from 3 to 15 km/hr and the temperatures ranged from -40°C to -19°C. Growth of the feature was slow. However, the next image on 7 April shows a dramatic growth. The feature had increased to 18 km in length with no apparent change in width. The winds during the interval 20 March to 7 April were mostly from the northeast and averaged greater than 15 km/hr. A drop in wind speed occurred for a few days when the winds shifted and became light and variable. The predominance of winds from the northeast at moderate speeds resulted in a northeastward extension of the feature. The temperatures during this period were near -20°C.

In 1975 the first Landsat scene of the feature was obtained on 25 February. At that time (Figure 16), the feature was already quite large, 21 km long by 9 kmwide (same orientation as previous years). Since 9 February, the winds had been predominantly from the northeast with wind speeds averaging approximately 15 km/hr. The temperature hovered near -30°C. These conditions resulted in significant growth of the feature. By 15 March, the feature had increased to 23 km by 12 km, not a large increase considering that the weather conditions appeared to be favorable for growth. However, the exact size of the feature could not be determined because clouds partially obscured the scene. Between 15 March and 17 May, several images of the feature were acquired which showed little change in the feature. Growth wedges formed several times, only to become detached from the feature by a shift in the wind direction. These shifts, usually of 30 degrees or more, occurred only occasionally up through 2 April, but the windspeed was sufficient to cause the wedges to break loose. After 2 April, the shifts in wind direction occurred more frequently. Thus, conditions were not favorable for growth after 15 March, and little growth occurred. The temperatures were quite low in 1975, being around -20°C to -30°C most of the time tip until the end of April.

The feature did not disappear in 1975. On 11 October 1975 it could still be seen to measure 14 km by 7.5 km. By 18 March 1976 the part of the feature remaining from 1975 had shrunk to a small, nearly circular core, upon which the feature had rebuilt. Three distinct phases of growth could be seen, the first phase apparently building the feature toward the north, the second phase extending it more toward the east, and the third stage, still in progress, building the feature toward the north. The initial stage of building to the north required winds from the north-northwest since the direction of ice motion is generally 30° to the right of the wind direction. These winds are not seen in the weather data (Figure 17). More likely, winds from the northeast and east in late February built the initial ice wedge only to have it modified by a sudden shift in the winds to the south and southwest. No evidence of building is seen that could be attributed to the steady west winds in early February. In early March . the wind's were *out* of *the* northeast and east and built the second extension of the feature. The winds shifted *to* the north to northwest for approximately a week resulting in the third building stage during which the feature grew to 27 km by 10 km. Building of the feature continued and by 16 June 1976 it was 30 km by 25 km. During this time, the winds were predominantly from the east and northeast at speeds from 3 to 30 km/hr. The temperature gradually rose from -30°C to O″C.

In summary, growth of the feature appears to occur when the winds are steady and of moderate speed, and the temperature is below -18°C. In addition, it was observed that growth via ice wedge formation never occurred in directions ranging from southeast to south to west. Apparently the shoals *are* too deep to allow grounding of the ice in these directions. When the winds were predominantly out of the east to north and averaging 11 to 16 km/hr, growth of the feature occurred in directions ranging from east to north. The resulting feature was always seen to be oriented with its long axis in a northeast-southwest direction, with the southeast tip of the feature at 162°00'W 72°00'N.

It is uncertain at what time during the winter the feature begins to grow. In 1973 and 1974, it was quite small in March, with much growth taking place later. In 1976, the core of the feature could be seen' in mid-March with recent growth appearing to have occurred in February. However, in 1975, the feature was quite large by 25 February. Thus, growth probably begins in January or February, but may begin earlier. By the second week in May of each year, growth has virtually ceased. From that time until mid-Autumn, the feature decays.

Summer Decay of the Feature

The decay of the feature is a relatively simple process which consists of melting and fracturing of the ice with large and small pieces of ice being broken off and carried away by wind and pack ice action. As shown by Figures 14 through 17, the decay process starts almost immediately after growth ceases, usually in mid-May, when the temperatures average -5°C to -10″C with the winds variable. In 1973, there was a sharp decline in length of the feature between 1 May and 19 May, with a gradual decrease in the decay rate after that. For the other three years, decay proceeded more slowly until July or August. In 1974, the feature is believed to have disappeared completely, and may have done so in 1973 as well. In 1975, it did not disappear completely, and in 1976 the last available image, acquired on 28 August, showed the feature to be quite large but definitely decayed.

The winds during the summer and early autumn are generally of moderate speeds but with varying directions when compared to winds of winter and spring. With temperatures generally above freezing until mid-September, the feature steadily decays. Then the pack ice, which is usually gone from the area in late August and September, returns and begins to rebuild the feature. The feature being extant throughout the fall in 1975 may have been the result of the pack ice remaining in the area that year (see Figure 6m).

VIII SUMMARY AND CONCLUSIONS

The growth of the grounded ice feature that recurs each year on Hanna's Shoal appears to be almost totally dependent on the wind direction, wind speed, and the temperature at that location. The wind directions as measured at Barrow seemed to correlate very well with the direction of ice motion at Hanna's Shoal, the ice moving in a direction approximately 30° to the right of the prevailing winds at Barrow (which were usually from the east or northeast). A slight correlation was seen between the wind speed and the amount of ice movement.

It is hypothesized that the primary mechanism of growth of the ice feature is the formation of wedges of-piled ice bounded by shear ridges which consolidate with the main body of the feature. The growth occurred in three stages. Stage I-consists of the piling of ice on the upstream side of the feature. After the ice pile has reached a maximum size, distinct shear ridges form, extending from the sides of the ice feature upstream where they come together, forming a wedge-shaped extension to the feature. Stage II continues with ice piling, with the shear ridges growing in length and breadth until the length of the wedge reaches a maximum. During Stage III the wedge becomes consolidated to the feature by freezing and grounding of the piled ice. If the-duration of Stage III is not sufficient to consolidate the growth wedge before the direction of ice motion changes, then the wedge breaks free and no resultant growth occurrs.

Finally, a correlation has been shown between the weather, especially the wind direction, and the formation of the growth wedges. When the winds are predominantly from the east and northeast the feature builds up in those directions resulting in an ellipse shape oriented with the long axis northeast-southwest. The southwest tip of the feature always occurrs very near 162°00'W 72°00'N, indicating deep water and thus no ice grounding on the southwest side of the shoal. The feature generally continues to undergo growth until mid-May, when it begins to decay. The decay of the feature is due to melting and fracturing with the loose pieces moved away by wind, ice and water currents. The feature decays until it either disappears or until mid-autumn when the temperatures drop and the pack ice once more moves into the area. The mid-winter characteristics of the growth of the feature are not known due to the lack of data.

Thus, a typical cycle of growth and decay of the grounded ice feature may proceed as follows. If the feature is non-existent in the early-autumn, pack ice moving into the area of Hanna's Shoal carries in deep-draft ice objects such as ice islands, floebergs, multi-year pressure ridges, etc. which become grounded on the shoals. Other ice becomes piled around these grounded pieces and freezes to them. As the pack ice becomes thicker, pressure ridges and hummock fields form upstream of this nucleus and growth commences. Ice wedges form, and either consolidate to the feature and thus enlarge it, or break free and drift away. The time at which ice wedges first form is not known, but it is probably as soon as the pack ice becomes a uniform sheet. The ice wedges continue to form until the pack ice becomes too fractured to form shear ridges, sometime in mid-spring. Then the feature begins to decay. The warming temperatures cause the ice to melt and weaken and the moving pack ice breaks off pieces of ice and carries them away. This ablation probably occurs until the feature either completely disappears or the pack ice reforms, sometime in mid-autumn. The cycle then begins again.

The correlation between ice motion at Hanna's Shoal and the winds at Barrow seems quite good. The observed average deviation of the ice motion 30” to the right of the wind direction has been observed by others in pack ice. However, the correlation of wind speed with ice velocity is not very good because too many unknown factors enter in, such as the density, strength, and uniformity of the pack ice and the ambient air temperature. These factors cannot be determined from Landsat imagery.

The correlation of growth (not amount of growth) with wind direction, speed and stability, as well as temperature, appears to be quite good. When the winds are steady out of the east to north directions, in the range of 7 to 25 km/hr in speed, and the temperatures are below -18°C, formation of the ice wedges are seen to occur. Growth is not observed to the southwest. In addition, growth is inhibited by variable winds, and decay is seen to occur once the temperatures rose above -5°C.

Finally, in the introduction various terms used by different authors to describe the feature were discussed. As a result of this study, none of these terms seem adequate. The feature is not a floeberg, it is not an island of grounded sea ice, and it is not a berg field. The feature is a composite of all of the above. It has been seen to consist of floebergs, ice islands, pressure and shear ridges, hummock fields and very small areas of flat ice (Kovacs, et al., 1976; Toimil and Grantz, 1976). Thus the terms "grounded ice feature" or "island of grounded ice" seem more appropriate.

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