Observations of Arctic Sea Ice Dynamics Using the Earth Resources Technology Satellite (ERTS-1)

This study shows that ERTS-1, launched by the U.S. National Aeronautics and Space Administration in July 1972, can be used to make synoptic observations of dynamic changes in arctic sea ice and also to locate areas of sea ice that are actively melting and therefore probably likely to break up early. Such observations will be extremely useful for predicting the availability of shipping routes in the polar regions.

Each data swath of ERTS-1 is 185 kilometres wide at the surface and is repeated once every 18 days. This provides a day-to-day orbital sidelap of 14 per cent at the equator. Because of a near-polar orbit, this sidelap increases to over 80 per cent at arctic latitudes. As a consequence of this large sidelap, the tracking of individual ice features for periods up to 5 or 6 days is permitted.

The ERTS-1 Multispectral Scanner Subsystem (MSS) records data by simultaneously scanning across the satellite track in 4 spectral bands. The wavelength limits of the 4 bands are: green (0.5-0.6 μm), red (0.6-0.7 μm), and two near infrared bands (0.7-0.8 μm and 0.8-1.1 μm). The nominal spatial resolution for all 4 bands is 80 metres. A standard ERTS-1 photographic format has an image scale of nearly 1:1,000,000, which is convenient for direct comparison with available maps.

Hendriksen Strait, the passage between Amund Ringnes Island and Cornwall Island at about 77°45′N. and 95°00′W. constituted the study area; it is in the Queen Elizabeth Islands of Arctic Canada, and is one of the most enticing and promising areas of recent oil and gas strikes[1]. The distance across Hendriksen Strait averages 13 kilometres. To the northwest is the average summer minimum limit of polar pack ice. As shown in Fig. 1, during a 6-day period from 23 to 28 August, ERTS-1 provided 5 days of coverage of Hendriksen Strait.

Various types of sea ice can be identified in the ERTS-1 imagery (0.6-0.7 μm band) in Fig. 1. Shore-fast ice is found in Hendriksen

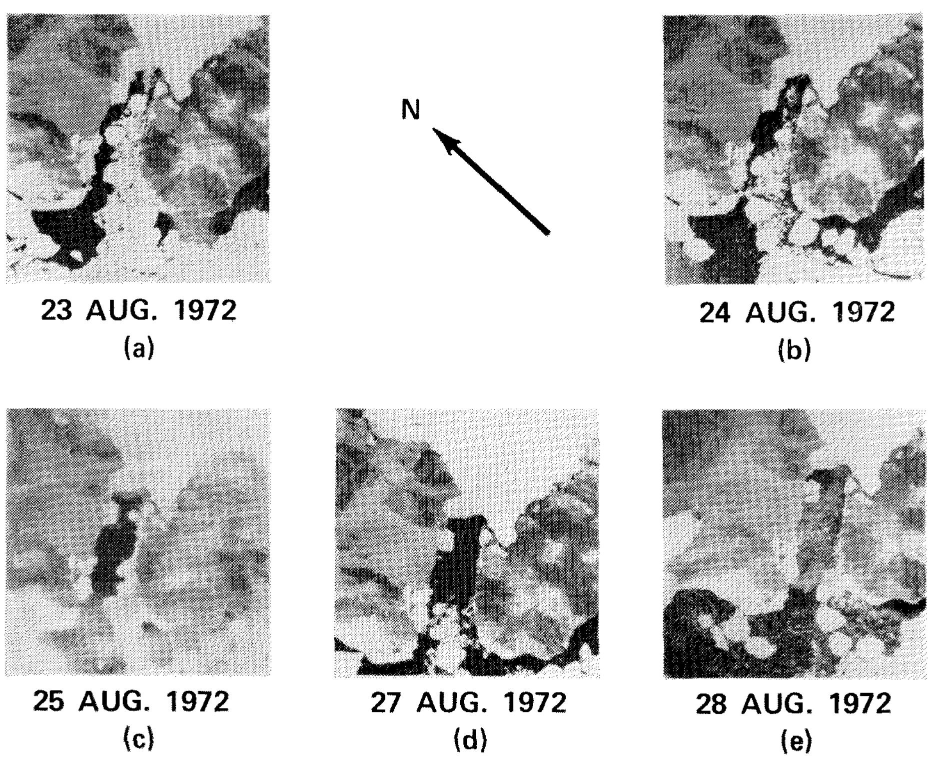


FIG. 1. ERTS-1 observations (0.6-0.7 μm) of arctic sea ice in Hendriksen Strait, 77°45′N., 95°00′W.

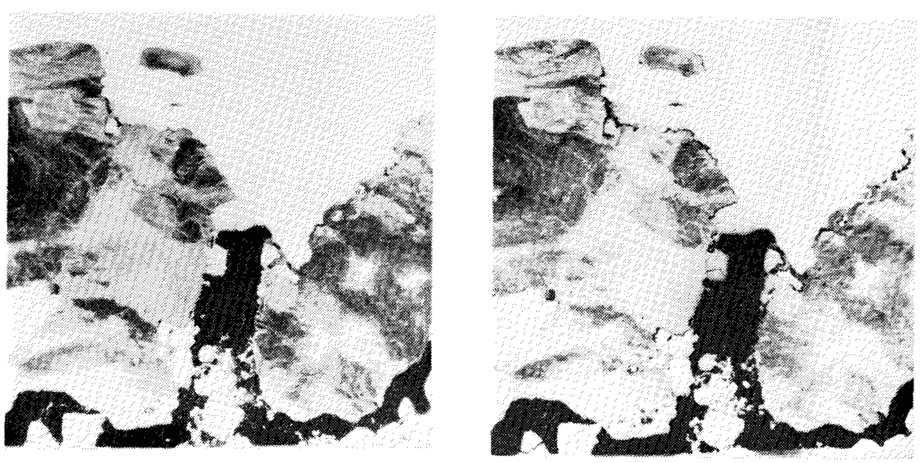
Strait; ice floes are numerous throughout the Strait and in the general area; and finally pack ice, which consists of many individual ice floes, is present. It was observed that the pack ice drifted out of the Strait over the 5-day period, and some shore-fast ice broke away from the land and also left the Strait. Correlation of the side to side movement of the pack ice as it left the Strait with surface wind direction (obtained from surface weather maps) was generally found to be good. On 23 and 24 August the pack ice was in the middle of the Strait; on the 25th it had moved to the southern shore; on the 27th it was back in the centre of the channel; and on the 28th it had moved back towards the south.

In such a sequence of observations, a number of sea ice changes with time are detectable. Changes in position of individual ice floes can easily be translated to velocity. A number of ice floes were tracked over the 5-day period and their velocities calculated. The average velocity for ice floe movement was 8.5 kilometres/day which seems reasonable when compared to a figure of 4.4 kilometres/day given by Mellor[2] for the average drift rate of large ice islands in the Arctic Ocean circulation. Recently, Campbell *et al.*[3] have demonstrated that ERTS-1 can be used to study ice floe morphology and dynamics in the Beaufort Sea at time scales of several days to months.

Repeated observations of individual ice floes such as those available here will also allow calculation of the ablation of the ice mass, in this case the decrease of surface area with time. Over a 4-day period individual ice floe surface areas were measured. The average 4-day decrease in surface area for the measured ice floes was approximately 10 per cent.

The ice cover, i.e. the relative amount of sea ice present in a given area, is important for shipping purposes and air-sea interaction processes. The ice cover in Hendriksen Strait on 23 August was approximately 7/10, decreasing to 2/10 by 28 August. This type of sea ice change is easily observed from ERTS-1 and combined with possible identification of navigation routes through sea ice could be quite useful to shipping interests.

In regard to the delineation of navigation routes through sea ice, the detection of active melting on the surface of the ice would indicate areas likely to be ice free in the near future. ERTS-1 has the ability to do this through observations of reflectance variability both temporally and spectrally. Comparison of Figs. 1a and 1d shows that several areas of the ice exhibit a pronounced variation of reflectance with time. The areas that show a lower reflectance in Fig. 1d probably indicate the location of the most rapid melting of the surface of the sea ice. Puddling on the ice surface has reached a sufficient amount significantly to reduce the reflected radiation measured at the spacecraft. Areas of sea ice which will probably break up early may thus be determined by observing sequential imagery in order to locate areas of most rapid melting.



0.6–0.7 μm BAND

(a)

0.8–1.1 μm BAND

(b)

FIG. 2. Simultaneous observations of Hendriksen Strait from ERTS-1 in two separate spectral bands, 27 August 1972.

The second method of observing the sea ice reflectance change is provided by comparing two separate images made at the same time but in different spectral bands. Fig. 2, taken 27 August 1972, shows such a comparison using the 0.6-0.7 μm band in Fig. 2a and the 0.8-1.1 μm band in Fig. 2b. The near infrared band (0.8-1.1 μm) shows a much lower reflectance than the red band (0.6-0.7 μm) in some sections of the simultaneous imagery. Because the absorption of solar radiation by water is much greater in the near infrared than in the visible portion of the spectrum, the lower reflectance is again probably due to the presence of meltwater on the surface of the ice. Thus sea ice with water on it, even in very thin layers, will show a considerable difference in reflectance between these spectral bands of observation. Similar observations have been reported by Strong *et al.*[4]

The areas in Fig. 2 that have the lowest reflectance are in the vicinity of the recent breakup and along the nearby shore. This perhaps indicates areas that will be next to break up because they are experiencing the greatest solar heating. Many of the floes have markedly lower reflectances than ice elsewhere in the images, indicating that the darker floes have relatively large amounts of meltwater on their surfaces. Temporal and spectral observations of reflectance variations afforded by ERTS-1 thus make it possible to locate areas of sea ice that are in varying stages of melting and breakup.

The results presented here demonstrate that for high latitudes, ERTS-1 will provide overlapping coverage on sequential days that will allow observation of dynamic changes in the polar regions. In addition, route planning for shipping in the Arctic should benefit from frequent observations of sea ice movement and reflectance variations of the type obtainable from ERTS-1. Projected further, sea ice observations from ERTS-1 over a period of years in the Arctic Islands should aid in the placement of offshore oil-drilling structures. Reflectance measurements over this period will also increase our understanding of the heat balance in the polar regions. Finally, ERTS-1 observations of the amount of ice cover versus the amount of open water will be important in determining boundary conditions for future use in models of the global heat balance.

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