APPENDIX IX

ICE MOVEMENT IN THE NEARSHORE REGION OF THE EASTERN BEAUFORT SEA AS MEASURED FROM LANDSAT IMAGERY

by

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Introduction. The movement of ice in the nearshore region (up to 100 km from the coast) of the eastern Beaufort Sea is of interest from two standpoints:

1. This region is the "shear zone," the transition region between the relatively stable fast ice and the pack ice associated with the clockwise-rotating Beaufort Gyre. Measurements of ice velocities in this region should help in understanding the nature of the transition occurring here.
2. The trajectory and residence time of spilled petroleum during the ice season is determined to a large measure by the motion of the ice.

This report describes the results of an effort to measure ice motions from sequential Landsat images obtained during the period 1973 through 1982 in the eastern U.S. portion of the nearshore Beaufort Sea.

Background. The maps of ice floe vector fields contained here were compiled by means of superimposition of Landsat imagery. This is possible at arctic latitudes because Landsat is a polar-orbiting satellite with orbits designed to provide a 10% overlap between adjacent images taken one day apart at the equator. The orbit paths must converge with increasing latitude and as a consequence, a given location at the latitude of this study area will be imaged on three successive days. Hence, it is at least theoretically possible that trajectories representing up to 48 hours of motion may be recorded. In addition, since successive satellite orbit paths move westward," it was occasionally possible to monitor a westward traveling floe for 72 hours. Occasionally, it was possible to monitor floe motion between successive Landsat cycles, a period of 18 days.

Obviously, the determination of floe trajectories depends not only on the acquisition of reasonably cloud-free imagery, but also on the ability to recognize specific floes from one image to the next. It is possible that satisfying the first requirement might possibly cause a significantly skewed selection of data. As a result of this, careful testing must be done before performing detailed statistical analyses on results from this data set.

Satisfaction of the floe identification requirement could be expected to limit observations at times when floes were undergoing destruction or being compacted to such a degree that floe boundaries were no longer recognizable. This potential problem did not impose a serious limitation to the compilation of a comprehensive data set, although it was apparent from time to time.

The displacements reported here were measured by sequentially projecting successive Landsat multispectral (MSS) images onto a translucent screen so that individual pieces of ice could be tracked. The device used is called a "color-additive viewer" and is manufactured by 12s, Inc. The Landsat images were projected to 1:500,000 scale from 70 mm positive transparencies. Registration of images was provided by superimposing geographical features on the sequential Landsat images. Colvocoresses and McEwen (1973) have shown that the random distortions on a Landsat MSS image have a root mean square value on the order of 200 m. This is the average error to be expected from the instrumentation. However, the results reported here were based on a visual best fit of two projected images. At the scale used (1:500,000) 1 km is 2 mm. Some transparencies appeared to superimpose uniformly over the whole Landsat image to well within 1 mm (500 m) while others would show apparent displacements of geographical features of 2 km on one side of a pair of images made to coincide on the opposite side. In these latter cases, a best average fit was obtained. Since the geographical features used are located at. the southern edge of the study area, this technique tended to minimize the errors in that area, while errors undoubtable increased to the north. Therefore, the uncertainty placed on the daily floe displacement reported here has been placed at 1 km along the southern portions of the maps and two to three km along their northern border.

Data. Thirty-six maps are presented (figures 1-36) which show ice displacements in the eastern Beaufort Sea for the region from Tigvariak Island to Demarcation Point. Individual vectors on these maps show 24 hour displacement. In several instances displacements were measurable for more than a 24 hour period. In these cases the 24 hour vectors are connected head to tail. Four maps were made of ice movement over 18 day periods.

Each map was examined for the minimum and maximum displacement occurring in a 24 hour period. These measurements and the direction of movement were arranged according to date and location. Location of the measurements (east/west axis) is identified by the path of Landsat imagery used. In addition, the minimum/maximum data were grouped into three categories reflecting distance from shore. The boundaries of these categories were placed 50 km and 100 km from the average shoreline. This was done to identify any change in ice floe behavior with distance from shore. The minimum/maximum data is summarized on Table I.

Results. Table II shows direction, frequency, magnitude, and the percent of occurrence of minimum and maximum displacements grouped by month. Mean magnitude of minimum and maximum movement is given for each direction and month. It is apparent from this information that the prevalent direction of ice floe movement is west. The magnitude of westward movements are several times the nonwest magnitudes for all months of the ice season. The magnitude of displacements for both minimum and. maximum do not appear to be influenced by location east to west.

While the most frequently occurring direction of movement overall is west, eastward motion is most common in March. However, even here the westward motions are significantly greater than other motions with the result that the net motion is westward.

Table 3 is based on the mean displacements with distance from shore taken from the right side of Table I. This table also includes frequency and magnitude by direction for the three distance categories by month. Thus, Table 3 evaluates how frequently magnitudes of displacements increase or decrease with increased distance from shore; there are several conditions possible when analyzing the three distance categories. There can be a consistent increase across the three categories, a consistent decrease, a mixed condition when the middle category is either less than or greater than the other *two,* or in the case where only one category has a displacement measurement for the time period, a change in magnitude cannot be determined. Likewise, when only two categories contain a measurement, a mixed response is not possible. The total frequency and percent of occurrence indicate that decreased magnitude occurs as frequently as increased magnitude. Of the mixed conditions, with only one exception, the middle category contained the greatest of the 3 magnitude measures.

The tendency for the 50-100 km category to contain the greatest magnitude is further supported by the summary of statistics at the bottom of Table 3. The"mean magnitude for the entire season for both west and nonwest motion is greatest in the 50-100 km category, although the difference in values is very slight ($\bar{x}$= 16.5, 17.2, and 11.6 km for 0-50, 50-100, and >100 km from shore respectively). The magnitude of westward motion for the ice season remains significantly greater than nonwest motion for all 3 distance categories. The direction of movement does not appear to be greatly affected by distance from shore. Northern motion is more frequent in the 0-50 km category than further offshore.

Southern motion is also frequent at this distance, although not as frequent as the extreme offshore category. Lack of movement is more closely associated with the nearshore category. The "other" directions (NE, SE, NW, SW) were not observed in the nearshore category. It is not immediately apparent why the intermediate directions would only be observed further offshore. As the season progresses, westward displacements become dominant in number as well as overall magnitude. Understandably, the magnitude of both west and nonwest movement increases.

Detailed examination of the data reveal that anomalously large westward displacements (5.5 km/day) were recorded for March, 1975. These results agree with 'observations of large openings of the Cape Bathurst Polynya at the eastern side of the Beaufort Sea in March of that year. (Stringer and Groves, 1975).

Conclusions. Measurements-of individual floe movements in the Beaufort Sea show net westward ice motions for all seasons. However, the frequency of eastward motions appears to be. greater than westward motions during March (while their magnitudes are much less than the westward motions). These results support the concept that the Beaufort Gyre turns clockwise and extend the concept to include ice even less than 50 km from shore. However, the data also show that other directions of motion are possible as well, although they are likely to be smaller in magnitude than the westward motions.