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APPENDIX VI

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by

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OBSERVATIONS OF DOUBLE ARCH FORMATION IN THE BERING STRAIT

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Abstract. During the time that ice is present in the Bering Strait, it is constantly moving, both northward and southward, subject to wind and current stresses. There were, however, several times in the last decade when the ice was prevented from traveling through the Strait. The blockage of ice was due to the formation of fairly stable double arches that extended across the Strait.

Six episodes of double arch formation, resulting in ice blockage in the Bering Strait, were recorded on NOAA satellite imagery spanning the last eleven years; one additional episode was seen on Landsat imagery. All of the incidence of double arching occurred between February and May. In the most extreme case the arches prevented the southward flow of ice through the Strait for at least 27 days during April and May 1980.

Introduction

When ice is forced from the north through the Bering Strait, an arch can be formed with its base extending from the Seward Peninsula to the Chukchi Peninsula--approximately 86 km. Thorough analysis of satellite imagery from 1974 to 1985 showed that these single arches were formed many times during the course of each winter season, and in each case seen, the single arch failed within 24 hours. The magnitude of forcing required to collapse the single arch is apparently not great and quickly achieved. This type of arching has been investigated by Shapiro and Burns [1973], Pritchard, Reimer, and Coon [1979], and Sodhi [1977].

A smaller double arch, that withstood southward forcing and prevented the flow of ice through the Strait for more than one day, was first seen on satellite imagery from March 1979. In the double arch structure one arch spans the western channel of the Bering Strait, while the other spans the eastern channel. The axes of the arches extend toward the northeast with arch heights ranging from 7 km to 30 km above their bases. The two arches have a common footing on the Diomede Islands in the center of the Strait (Figure 1), giving each arch a base width of approximately 40 km.

This paper will focus on six episodes of double arch formation, seen on NOAA satellite imagery, that halted the flow of ice through the Bering Strait. These episodes lasted from three to twenty-seven days.

Methods

The data used were NOAA VHRR and AVHRR (Very High and Advanced Very High Resolution Radiometer) visual and infrared satellite imagery in transparency format at a scale of approximately 1:7,000,000. The nominal spatial resolution at the nadir of the satellite is 1.1 km [Stringer, Barnett, and Godin, 1984], which is sufficient for distinguishing individual floes and lead systems.

To observe the double arches in the Bering Strait it is necessary to distinguish only two ice types:

New ice - all ice which has formed in leads and polynyas, and
Drift ice - any area of sea ice other than fast ice, regardless of its form or arrangement

[Stringer et al., 1984]. As viewed on NOAA imagery open water appears black, new ice is represented by gray tones, and drift ice appears white or light gray.

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Observations

On 18 March 1979, after the ice had been moving south into the Bering Sea for at least eight days, two very shallow arches formed in the Strait. During the following three days the ice south of the Strait continued to travel in a southwesterly direction. Consequently, a polynya formed to the south of the double arch (Figure 2). Between 18-21 March 1979 the double arch held back ice in the Chukchi Sea, while ice in the northern Bering Sea moved southward as much as 14 km/day. Clouds obscured the Bering Strait region between 22-24 March; when the weather cleared the arches were no longer present. A polynya, located on the northern side of the Diomede Islands, indicated a recent northward movement of ice.

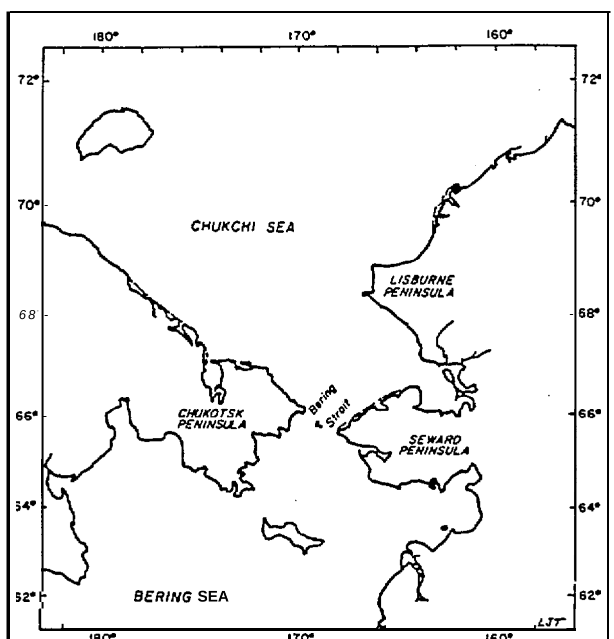

Fig. 1. Bering Strait and adjacent area.

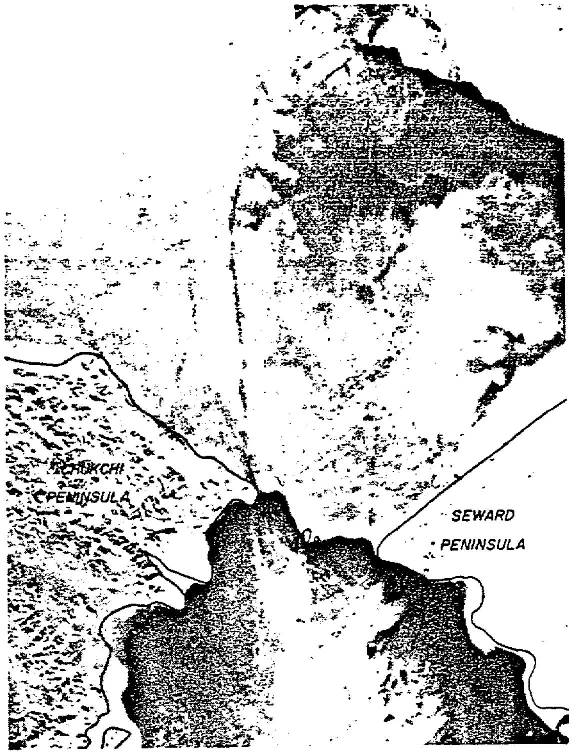

Fig. 2. NOAA AVHRR image of Bering Strait on 20 March 1979. The Alaskan and Siberian coastlines have been drawn on this image to help orient the viewer.

Fig. 4. NOAA AVHRR image of Bering Strait on 16 March 1983.

A double arch was next seen forming on 13 April 1980. It restricted ice movement through the Strait for at least 27 days. Drift ice south of the Strait moved south until the 15th. Then the direction of ice motion reversed for two days the drift ice travelled back into the polynya south of the arches. During the next 21 days ice continually formed in the enlarging polyn south of the arches, as drift ice once again travelled southward (Figure 3). The peak sou

Fig. 3. NOAA AVHRR image of Bering Strait on 5 May 1980.

Fig. 5. NOAA AVHRR image of Bering Strait o 1 March 1984.

Fig. 6. NOAA AVHRR image of Bering Strait on 7 April 1984.

ward speed of the drift ice during this period was 30 km/day. On 9 May drift ice in the northern Bering Sea changed direction and started to move northward. On the same day a fracture in the central pillar of the double arch was seen. The northward motion continued, causing fractures in the ice which weakened the arches. The arches were seen until the Strait was obscured by clouds on 12 May. When the Strait became clear again the arches had failed,

A short-term double arch occurred between 13-15 March 1983 (Figure 4). After forming on the 13th, the arches withstood two days of southward forcing before the Strait became obscured by clouds. Despite the clouds, drift ice located north and south of the Strait was still visible. On the 16th the drift ice reversed its direction and travelled to the north. When the Strait cleared on the 18th, the arches had broken up and a long polynya was seen north of the Diomede Islands. The presence of the polynya indicated that northward ice motion had continued while the Strait was cloudy.

After nearly two weeks of constant southward motion through the Strait, a double arch started to form on 16 February 1984. The outline of the arches became clear on the 17th, but on the 18th, the ice reversed its direction of motion. During the next four days the ice travelled a short distance to the north. On the 22nd the ice began to move southward again and a new double arch was formed on the 23rd. The arches remained fixed for 12 days, while drift ice south of the Strait continued to travel southward, leaving a large polynya (Figure 5). The highest daily southward motion during this period was 23 km. On 8 March, after two days when there were no images of the Strait, a polynya, indicating northward motion, was seen north of the Diomede Islands. Also, linear fractures had formed through the double arch. The next visible image of the Strait on 12 March showed that drift ice had continued to travel northward. The outline of the double arch was still visible, but it was fractured to a great extent. On 13 March the ice reversed direction and the arches failed.

On 22 March 1984 ice fractured and moved southward, away from a double arch in the Bering Strait. The western arch was very high--approximately 70 km. Over the next two days, however, the broken floes travelled down toward the base of the western arch where they jammed together. A very asymmetric arch, with its axis extending just further than that of the eastern arch, was then formed lower in the jammed ice. The frozen polynya from the high arch is the light gray area above the western arch in the satellite image from 7 April 1984 (Figure 6). On 5 April a large floe broke away from the apex of the western arch leaving a more symmetric arch. The floe can be seen south of the Strait in Figure 6. Drift ice south of the Strait continued moving southward until 10 April when it reversed direction. The peak speed attained during the southward motion was 45 km/day. As the drift ice moved northward toward the Strait, linear fractures formed through the double arch. The northward forcing and fracturing continued through the 20th. On the 21st the direction of forcing reversed and the arches failed.

A small arch was seen forming on the western side of the Strait on 11 April 1985; the rest of the Strait was obscured by clouds. On the 12th the Strait became clear and the double arch was visible (Figure 7). The forcing slowly changed from a southward direction and began to push northward on the 14th. The northward motion fractured the double arch.

One other episode of double arching was ob-

Fig. 7. NOAA AVHRR image of Bering Strait on 12 April 1985.

served, this time on Landsat imagery. This episode could not be followed on NOAA imagery due to the cloudy conditions in the Bering Strait. On 5 April 1976, under partly cloudy skies, a newly formed double arch was seen in the Strait. By the time the weather cleared on the 7th, the arches had apparently already been fractured by northward ice motion, as evidenced by a polynya formed on northern side of the Diomede Islands.

Discussion

The formation of a double arch does not appear to be a frequent occurrence. Only seven incidences of double arch formation have been seen on imagery that spans the last eleven years. There is a good possibility that there have been more episodes of double arching that were not recorded due to cloudy conditions. On the average, clouds obscured the Bering Strait on 44 percent of the days during the winter months of the study period. The double arches that were seen formed only after there had been southward forcing for several days. In six out of the seven episodes the ice in the Bering Strait had been moving southward for at least one week prior to arch formation. The double arches were also seen to form only between the months of February and May.

Contrasted to a single arch, which extends across the entire Strait and fails consistently under the influence of southward forcing, the double arch was seen to fail only after the direction of ice forcing reversed. The failure of the double arch was directly observed in four cases. In these cases there is direct observational evidence of a northward push before the failure of the double arch. In the other three cases drift ice north and south of the strait was seen to travel northward and a polynya was formed on the northern side of the Diomede Islands, indicating northward movement, before failure of the arches.

Worldwide there are a number of straits, principally Davis Strait between Greenland and Baffin Island, Denmark Strait between Greenland and Iceland, Fram Strait between Spitsbergen and Greenland, Robeson Channel between Greenland and Ellesmere Island and Bering Strait, where ice flux or the absence of it plays a major role in determining regional ice budgets. The width of these straits--along with other parameters such as ice thickness and forcing mechanisms--appears to be a major factor influencing ice motion. Because these straits occur at locations with widely varying values for these parameters, it is difficult to separate their individual influences.

These results show that Bering Strait arch formation is at least hi-modal: the first and more common mode being a single arch spanning the entire strait and the second mode being the double arch reported here. While the single arch has been observed to fail continuously under southward forcing, the double arch was only observed to fail after a period of northward forcing; southward forcing alone was not observed to be associated with double arch failure. Thus, other factors being equal, the double arch formation would appear to be "stronger" than the single arch. Since it is possible that forcing mechanics and ice thickness may be reasonably repeatable at Bering Strait, the double arching reported here affords an opportunity to examine the influence of strait width on the motion of ice through straits independently from other factors.

The phenomenon of double arching may play a role in determining when migrating whales can pass through Bering Strait during their springtime return to the Chukchi and Beaufort seas. Since the strait appears to be totally obstructed during these events, it would seem likely that whales would not be able to make passage during these times. Thus, double arching would serve as a modulator to whale migration.

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References

Pritchard, R.S., R.W. Reimer, and M.D. Coon, Ice flow through straits, Proc. POAC 79, 3, 61, Norwegian Institute of Technology, University of Trondheim, Trondheim, Norway N7034, 1979.

Pritchard, R.S., R.W. Reimer, and M.D. Coon, Beaufort and Chukchi sea ice motion Part 2. Onset of large scale Chukchi sea ice breakout, Flow Research Co. Report No. 133, Flow, Inc., 21414 68th Ave. South, Kent, Washington 98031, 1979.

Reimer, R.W., J.C. Schedvin, and R.S. Pritchard, Chukchi sea ice motion, Proc. POAC 81, 2, 1038, Dep. de genie civil, University Laval, Cite Universitaire, Quebec, Canada G1K 7P4, 1981.

Shapiro, L. H., and J. J. Burns, Satellite observations of sea ice movement in the Bering Strait region, in Climate of the Arctic, edited by G. Weller and S.A. Bowling, Geophysical Institute, University of Alaska, Fairbanks, Alaska 99775-0800, pp. 379-386, 1973.

Sodhi, D.S., Ice arching and the drift of pack ice through restricted channels, CRREL Report 77-18, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire 03775-1290, 1977.

Stringer, W.J., D.G. Bamett, and R.H. Godin, Handbook for Sea Ice Analysis and Forecasting, 324 pp., Naval Environmental Prediction Research Facility, Monterey, California 93943, 1984.

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