ARCTIC SEA ICE PROCESSES

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LONG TERM GOALS

The goal of the proposed research is to use the scale-invariant (or fractal) nature of sea ice to identify some objective parameter or set of parameters derivable from AVHRR satellite imagery that will aid in the development of a description of the sea–ice rheology that is valid for spatial scales of 1–20 km.

OBJECTIVES

Develop temporal and spatial statistics of large-scale lead patterns over the Beaufort Sea during a winter season so that these statistics can be related to atmospheric deformation fields and sea ice motion fields.

APPROACH

A technique developed by Banfield (1992) for skeletonizing lead patterns provides an ideal way both to handle the large amount of information involved in studying lead pattern information for a whole winter season, and to also quantify the changes that take place in the lead patterns. The method of Banfield (1992) is based on modeling ice leads using skeletons, a tool from mathematical morphology, which provide a useful structural description of the shape of an ice lead. Skeletons also provide a means to quantify aspects of the leads that are difficult, if not impossible, to measure directly from the original image. Characteristics such as orientation, length, number of branches, the distribution of branch lengths, and the distribution of the angles between branches can be calculated more easily from the skeletons than from the original image. The skeletonizing procedure allows us to study both the spatial and temporal variations of these objective measures of lead characteristics.

The extension of the time period considered to a full winter season together with the application of the skeletonizing technique will allow us to quantify the persistence of certain lead patterns, assess the role of ice mechanical history in how the ice field responds to specific wind forcing events and investigate the existence of scale invariant features in lead patterns (ie, the fractal nature of sea ice).

ACCOMPLISHMENTS

The lead pattern changes seen in the AVHRR time series over the Beaufort Sea for the winter season from Oct, 1992 to Apr, 1993 were analyzed. The large fraction of time that cloud cover was present in the imagery made it nearly impossible to use the automated

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skeletonizing software for characterizing the leads over the Beaufort Sea as was originally intended. The bulk of the analysis therefore had to be done manually which was extremely time consuming.

SCIENTIFIC/TECHNICAL RESULTS

The start of the AVHRR time series (Oct 12) began with large scale (100's km) diamond-shaped NE-SW oriented lead patterns (with imbedded 10-20 km scale diamonds) across the northern and central Beaufort Sea and disorganized circular floes in the southern Beaufort. There was considerable open water along the Alaska coast. Northerly winds during Oct 20-25 created a pattern of N-S oriented leads which met these E-W oriented diamond patterns at a latitude of 76 deg N at what appeared to be a slip line as described by Walter and Overland (1993).

A strong storm (979 mb low) moved across the Beaufort on Oct 29-30 and totally destroyed the diamond -shaped lead patterns. After the storm the central and southern Beaufort was populated by large circular floes with diameters of order 50 km. Diamond shaped lead patterns were still present north of 76 deg N.

Another strong storm passed across the Beaufort during Nov 4-5 with strong southerly prefrontal winds and northerly winds behind the front. On Nov 9-11 there was another storm passage. Nov 17 is the next date when useful AVHRR imagery is available. Unorganized circular floes were still present over the central and southern Beaufort and even into the northern Beaufort and this was the case until Nov 22. During November there were no periods when winds were from a given direction for a long enough period of time to establish a particular lead pattern orientation. On Nov 22 persistent northerly winds broke up the diamond shaped pattern over the northern Beaufort (78-81 deg N) present since Oct 12. There were long N-S oriented leads into the southern Beaufort but no geometric pattern present.

After Nov 27 a series of lows moved across the Beaufort. Northwesterly winds commenced on Dec 6 with high pressure dominating on Dec 8 when northeasterly winds blew across the Beaufort. At this time there was the start of large-scale (100's km) N-S oriented diamond patterns over the Beaufort. The NE winds continued through Dec 13. The response of the ice was different than that reported by Overland et al (1995) because the ice was not initially compacted against the Alaska coast. Here there was considerable open water along the coast and to the west. There was a tendency for some large crescent-shaped leads to form across the Beaufort, but the overall result was for a large-scale rotation of the Beaufort Sea ice pack in response to the anticyclonic atmospheric forcing and the opening of large leads along the eastern border of the basin as well as in the northern Beaufort. It was as if the entire Beaufort ice pack calved off from the coast and shorefast ice.

On Dec 15 the wind direction reversed briefly and the ice began to move eastward. On Dec the winds were again easterly and the ice again moved westward. On Dec 21winds became very strong from the west with attendant large ice movement to the east. By Jan 1-5 there was evidence of large-scale diamond lead patterns in the northern Beaufort but disorganized floes elsewhere. On Jan 6 there were storm clouds present. On Jan 11-13 there were strong southerly winds changing to westerly to southwesterly during Jan 14-23. Brief glances through the cloud cover showed no particular lead pattern organization.

Northerly winds began on Jan 24 and persisted through Jan 27 compacting the ice against the Alaska coast. Then on Jan 29-30 an easterly wind regime began to open up large N-S oriented diamond-shaped lead patterns across the Beaufort from the Alaska coast to 78 deg N. These large diamond-shaped lead patterns persisted until Jan 31 - Feb 1. This wind regime scenario (northerly then easterly) was nearly exactly the same as that discussed in Overland et al (1995) and the ice response was the same. Overland et al (1995) hypothesized that the northerly winds compact the ice against the Alaska coast and generate latent large-scale diamond-shaped lead patterns that only become visible in the satellite imagery when the easterly wind regime begins and opens up the leads.

On Feb 3 NW winds closed up the diamond-shaped pattern in the western Beaufort. Winds were again easterly on Feb 6-8 and the diamond lead patterns reopened. During Feb 10-27 there were clouds present over the Beaufort with storms moving across the Beaufort every few days producing alternating NW and SE wind regimes. During Feb 27-28 an easterly wind regime started and continued through Mar 5.

The next possible view of the ice was Mar 3 and at this time the whole character of the lead patterns had changed. There were irregular floes in the northern Beaufort and long parallel NW-SE oriented leads in the central and southern Beaufort. These leads evolved into diamond shaped patterns in the southwest and central Beaufort with scales of order 100 km. From Mar 14-20 there were strong westerly winds (from NW to SW) switching Mar 18-21 to winds with a southerly component. There was cloud cover during Mar 11-18 with the next view of the ice on Mar 21 through thin cloud cover.

At this point there were large-scale lead patterns nearly identical to those described by Walter and Overland (1993) after a similar wind-forcing scenario. A slip line was present extending across the Beaufort from SW to NE. This slip line moved northward during Mar 20-22 as winds got a more southerly component. North of the slip line there were 100 km scale diamond shaped lead patterns with leads intersecting the slip line at an angle of about 30 deg as reported by Walter and Overland(1993).

Winds were northerly during Mar 23-25 (cloudy) with a storm passing Mar 26. An easterly wind regime began Apr 3 with a high pressure area over the northern Beaufort. Winds over the Beaufort maintained an easterly component until Apr 13 when the time series of AVHRR images ended. The images from Apr 3-6 showed large-scale N-S oriented diamond-shaped patterns similar to those described above at the end of January and by Overland et al (1995) but were not as dramatic because the easterly winds were weaker and did not extend clear across the Beaufort Sea.

The significance of the above results is that the sea ice in the Beaufort Sea responds similarly to similar regional wind forcing scenarios as shown by the comparisons with the results from Walter and Overland (1993) and Overland et al (1995).

IMPACT FOR SCIENCE/SYSTEM APPLICATIONS

Knowledge of how large-scale lead patterns change with respect to different wind forcing regimes over a basin such as the Beaufort Sea is important to the development and verification of large-scale sea ice prediction models. Overland et al (1992) suggested that: in regional models it may be important to keep track of principal directions and orientations of fracture lines and that there may be other state variables necessary for a regional description of sea ice. Since sea ice appears quasi-self similar based on the spatial scales of floes and lead patterns and the angular relationships between leads, the degree of self similarity may be quantified by a fractal dimension. It may be that this fractal dimension could become a state variable of a sea ice model which would allow the aggregate properties of sea ice to be represented as an effective property.

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