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OBSERVING THE POLAR OCEANS WITH SPACEBORNE RADAR

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In this brief presentation, I would like to explore the application of spaceborne imaging radar data to polar oceanography and sea ice. Several problems come to mind which are presently ripe with ideas and models, but are in need of new data--SAR data--for any progress to be made. These are the study of the ice mass balance, the ice momentum balance, and the circulation of the Arctic Ocean. We will describe these problems and the data which is applicable to them and can be extracted from SAR imagery. Finally, we will discuss some uses of these data to explore mesoscale processes which affect the oceans and ice cover.

The ice cover undergoes advances and retreats on a range of time scales, but predominantly over the annual cycle. To understand the balance which determines ice extent, we must observe where ice is produced and where it melts. To do this at the most simple level--to describe the balance of ice covered area, we need to observe ice velocity and ice concentration. To describe the mass balance requires additional observations of ice thickness, which are presently beyond the direct reach of remote sensing, but can be estimated from continuous observations of the field of ice motion (Thorndike et al, 1975).

Consider recent studies of ice balance. Walsh et al (1985, Figure 14) analyze model output and find a strong net sink of ice mass in the northern Greenland Sea. Moritz (personal communication) analyzes buoy motions and concentrations from ice charts and finds the northern Greenland Sea to be a weak source of ice area. These results are not incompatible; the ice grown in the region is thin whereas the ice melted there is presumably older thick ice advected down from the Arctic Ocean. The point is that the first result is based on model output rather than direct observations of ice thickness, concentration or motion, and the second result is based on a very modest data set. Much stronger results on this description of the ice mass balance will be derived with kinematic data from SAR and with concentration data from SAR and passive microwave.

Another problem susceptible to SAR data is the circulation of the Arctic Ocean. We have the potential to observe the surface velocity of this ocean (that is, the motion of its ice cover) better than any other, and to prescribe its surface buoyancy flux by virtue of ice motion, ice concentration and air temperature observations. The thermohaline structure of the ocean is determined by advected Atlantic Water, and by the formation of dense waters at the surface in the Greenland and Iceland Seas and over the Siberian continental shelves (e.g., Aagaard et al, 1985). Good SAR observations of ice velocity and ice deformation would add enormously to our ability to simulate this circulation and compare results to oceanographic observations from buoy-mounted thermistor and conductivity chains, and from SOFAR floats.

A third appetizing problem is that of ice momentum balance, approximated most simply as a balance between air stress and water stress $U = A*G + C$, where U is ice velocity, A is a matrix involving ratios of wind and water drag coefficients, G is the geostrophic wind, and C is the current at the base of the ocean mixed layer. An investigation using surface pressure and ice velocity data from buoys showed that through this relationship, the wind explained about 70% of the variance of the ice motion (Thorndike and Colony, 1982). Spaceborne SAR would allow the study of this relationship in the seasonal ice zones where buoys cannot survive and where ice stress may add a term to the momentum equation. Ice stress depends on ice deformation which can be measured by SAR, but not by the coarse buoy network.

To apply SAR data to these problems, we must develop a suitable sampling strategy for use of data from ERS-1 and subsequent satellite radars. The requirement is to settle on an area over which to average deformation and concentration, and then verify how these averages vary spatially. Can we interpolate these mean quantities between SAR ground swaths several hundred kilometers apart?

An observational program based on SAR images will require automated algorithms for extracting geophysical data. What variables can be extracted, and to what extent are the necessary algorithms in hand? The most promising variables appear to me to be ice velocity and deformation, ice concentration, and floe size and lead size and spacing statistics. The latter group concerning the fragmentation of the ice cover has as yet received little effort towards automation, but techniques for extracting these data are available, and automating them should not be difficult. Floe and lead geometrics are of interest more to operations than to the issues of mass and heat balance being focussed on here.

Ice drift and deformation, on the other hand, are central to the problems outlined above, and are ideally suited to measurement from SAR imagery, whose high resolution makes it possible to follow a dense set of ice features—each grid intersection in Figure 1. (See Curlander et al, 1985, and Fily and Rothrock, 1985.) Such dense data allow a far more useful and reproducible estimate of mean deformation than just three or four data points from imagery or from buoys. This data extraction problem is clearly defined, is receiving attention at several institutions, and will yield, it appears, to further development before ERS-1 is launched. Ice motion measurement is facilitated by two facts: feature recognition depends on relative not absolute brightness, and the accuracy of deformation estimates can be estimated by applying the technique to (non-deforming) land.

Ice concentration (areal fraction of ice coverage) has been estimated from SAR imagery by several investigators, with techniques that tend to be operator dependent (e.g., Shuchman, this volume). The problem is more difficult than motion measurement because both absolute backscatter and field corroboration are crucial to identifying ice types correctly from imagery. Concentrations of several types of ice—multiyear ice, first year ice, grease ice, and open water—have been estimated from SIR-B imagery by supervised classification by Holt and Carsey (personal communication). Comparisons with SMMR concentration estimates have been within one percent for some scenes, and within five to ten percent for others.

These types of observations can unravel some of the puzzles about processes which occur on scales of one to one hundred kilometers. For instance, the detailed measurements in Figure 1 suggest replacing the traditional continuum velocity assumption with a model consisting of a set of random cracks with velocity discontinuities along those cracks (Thorndike, 1981). They can also allow us to pin down the relation between mean deformation of a large area and the production of new open water where ice grows rapidly and salt flux to the ocean is intense. (Fily and Rothrock, 1985).

SAR is an excellent tool for observing ice covered oceans. To realize its promise, we must develop firm sampling requirements and strategies, and automated algorithms for extracting ice kinematics, ice concentrations, and floe and lead statistics. Challenging problems await this new data.

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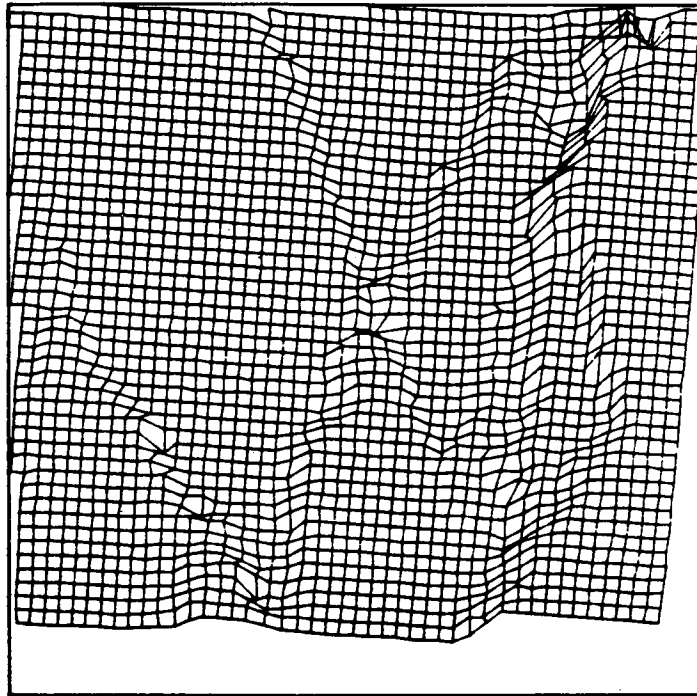
Figure 1. The deformation of a grid embedded in the ice. The grid was
          undeformed three days earlier. The displacement of each grid
          vertex was tracked automatically by cross-correlating small
          sections of two sequential SEASAT SAR scenes, first at highly
          degraded resolution, but iterating through scenes with
          increasing resolution (Fily and Rothrock, 1985). No role was
          played by an operator. The figure is 100 km on each side.
          Note the large rigid floes separated by narrow zones of intense
          deformation. The figure is 100 km on each side.