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ESTIMATING ARCTIC SEA-ICE DEFORMATION USING DATA ASSIMILATION

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1. INTRODCUTION

In response to changes in large-scale atmospheric circulation in mid- to high-latitudes sea-ice motion over the Arctic Ocean exhibits strong interannual to decadal variability. In particular, observations suggest that an anomalous pattern in sea ice motion appears in association with a spatially dominant mode found in the Northern Hemispheric sea-level pressure field, referred to as the Northern Hemisphere annular mode (Rigor et al., 2002). The question then arises as to the extent to which this anomalous sea-ice motion would modulate the mass balance of sea-ice. Of course, both thermodynamical and dynamical processes can contribute to act to influence the mass balance. Thermodynamically, changes in poleward heat and moisture fluxes associated with changes in large-scale atmospheric circulation would likely exert influences on the mass balance. On the other hand, dynamically changes in ice motion would likely be accompanied by some changes in an ice deformation field, thereby affecting the mass balance by ridge and lead formations, a process referred to as redistribution mechanism (Thorndike, et al, 1975).

An underlying notion is that convergent (divergent) ice motion is responsible for the formation of ridges (leads), respectively (Ukita and Moritz, 1995). Yet, a simple analysis reveals that it is a uniaxial contraction-extension that is more relevant to the ridge and lead formations. Previous observations suggest that this is a rather rare class of deformation events since on the average the Arctic sea-ice motion is nearly non-divergent. To gain an insight into this process and ultimately to understand its role in the mass balance we have conducted a pilot study to examine sea-ice deformation over the Arctic Ocean. In this presentation we shall show results regarding spatial and temporal characteristics of the uniaxial contraction-extension based on our analysis on the merged sea-ice motion data.

2. DATA

We base our analysis on a merged sea-ice motion data set composed of the Defense Meteorological Satellite Program's Special Sensor Microwave/Imager (SSM/I), NASA scatterometer (NSCAT), buoy ice motion data. In order to allow a comparison with other data sets in a later stage our focus at present is on the winter of 1996-1997, a subset of a larger body of data. A 2-D Gaussian wavelet transform was first applied to the SSM/I radiance and NSCAT backscattering measurements to obtain daily estimates on sea-ice drift (Liu et al., 1999). They were merged with Arctic buoy drift data from the International Arctic Buoy Program (Rigor and Heiberg, 1997). Strain rate components and invariants were calculated using a center-difference scheme for the domain covering the Arctic Ocean at a 100km resolution.

3. RESULTS

Fundamental to our analysis is a notation that parameterizes two-dimensional deformation characteristics (Thorndike et al., 1975). Let us define θ by the arctangent of the ratio of maximum shear to divergence. The values of $\theta = 0, \pi/4, \pi/2, 3\pi/4, \pi$ correspond to pure divergence, uniaxial extension, pure shear, uniaxial contraction, pure convergence, respectively. Fig**.** 1 shows spatial distributions of the probability (a total number of days for a particular class of events over 121 days covering the December –March period) that ice deformations are in near divergence (θ=22.5±11.25°) to near convergence (θ=157.5±11.25°) for seven different categories. These maps clearly support a notion that the sea-ice motion over the Arctic is nearly non-divergent, e.g. Fig. 1D dominates others. In regard to our question, Fig. 1 B and F present two cases where ice deformations are in nearly uniaxial-extension (θ=45±11.25°) and uniaxial-contraction (θ=135±11.25°). These maps reveal that relatively speaking the uniaxial extension is more homogeneous than the uniaxial contraction, except a few spots in the Russian coastal region. On the other hand, there is a strong indication that the frequency of

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the uniaxial-contraction events is significantly higher in the region north of the Canadian Archipelago and Greenland, which extends approximately 500–700 km from the coast.

Of course the above results are still preliminary, and in-depth error analyses are necessary. Nonetheless, this particular spatial pattern is consistent with our longstanding view that in the climatological sense sea-ice is thicker in the region north of the Canadian Archipelago and Greenland compared with the rest of the Arctic Ocean due to the redistribution mechanism. While we cannot yet provide quantitative information on the extent to which this spatial pattern reflects the redistribution mechanism (e.g. note that this is also the region with low surface air temperatures, Overland et al., 1997) the above results provide evidence for the presence of the mechanism.

4. REMARKS

There emerge issues and implications from the above analysis. A first point is that, because of complementary strengths and weaknesses inherited in different sea-ice motion data sets, a composition of different data sets such as the one employed here would significantly enhance our ability to assess otherwise difficult-to-observe sea-ice deformation. This point becomes particularly relevant in light of an ongoing controversy on relative importance of the redistribution as oppose to ice thinning to the question of the sea-ice mass balance (Holloway and Sou, 2002). Our results also indicate that relevant, or at least apparent, temporal scales for the redistribution mechanism would fall in a range of days to a week. Spatially a 100-km resolution is sufficiently small, although still quite noisy in the current form, to resolve the details of the mechanism.

Second, our results provide supporting evidence for an underlying assumption on the redistribution mechanism, which is regarded as a source of uncertainty in the sea-ice models. A development of a means to estimate ice-deformation at a sufficiently high accuracy would seem to open up a possibility of using such information to improve a parameterization on this mechanism. Finally, a thrust for this research is a construction of a sea-ice data assimilation method to address the sea-ice mass balance question. The present results, although preliminary, seem to be promising toward achieving this goal.

5. ACKNOWLEDGMENTS

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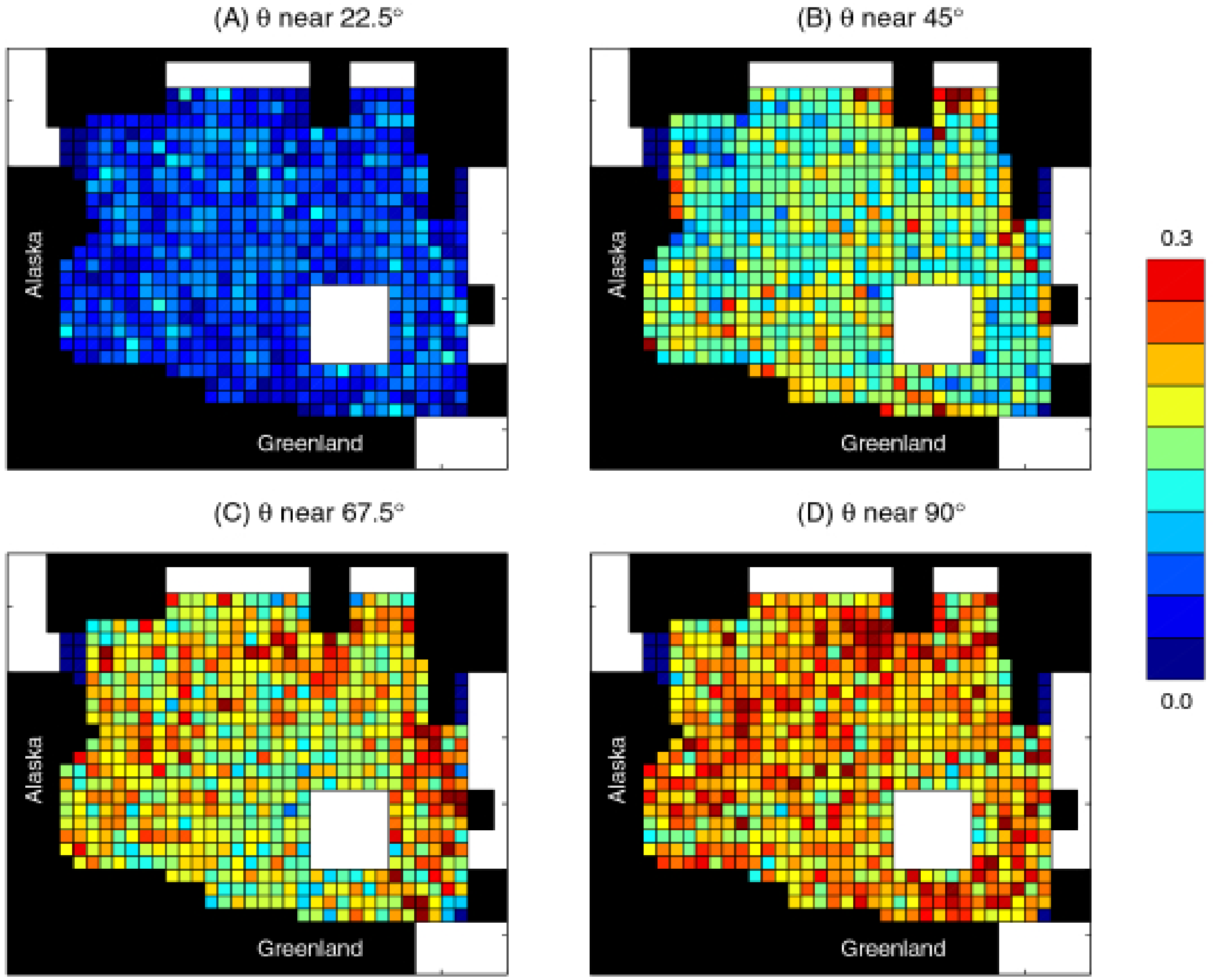
Fig. 1 Probability

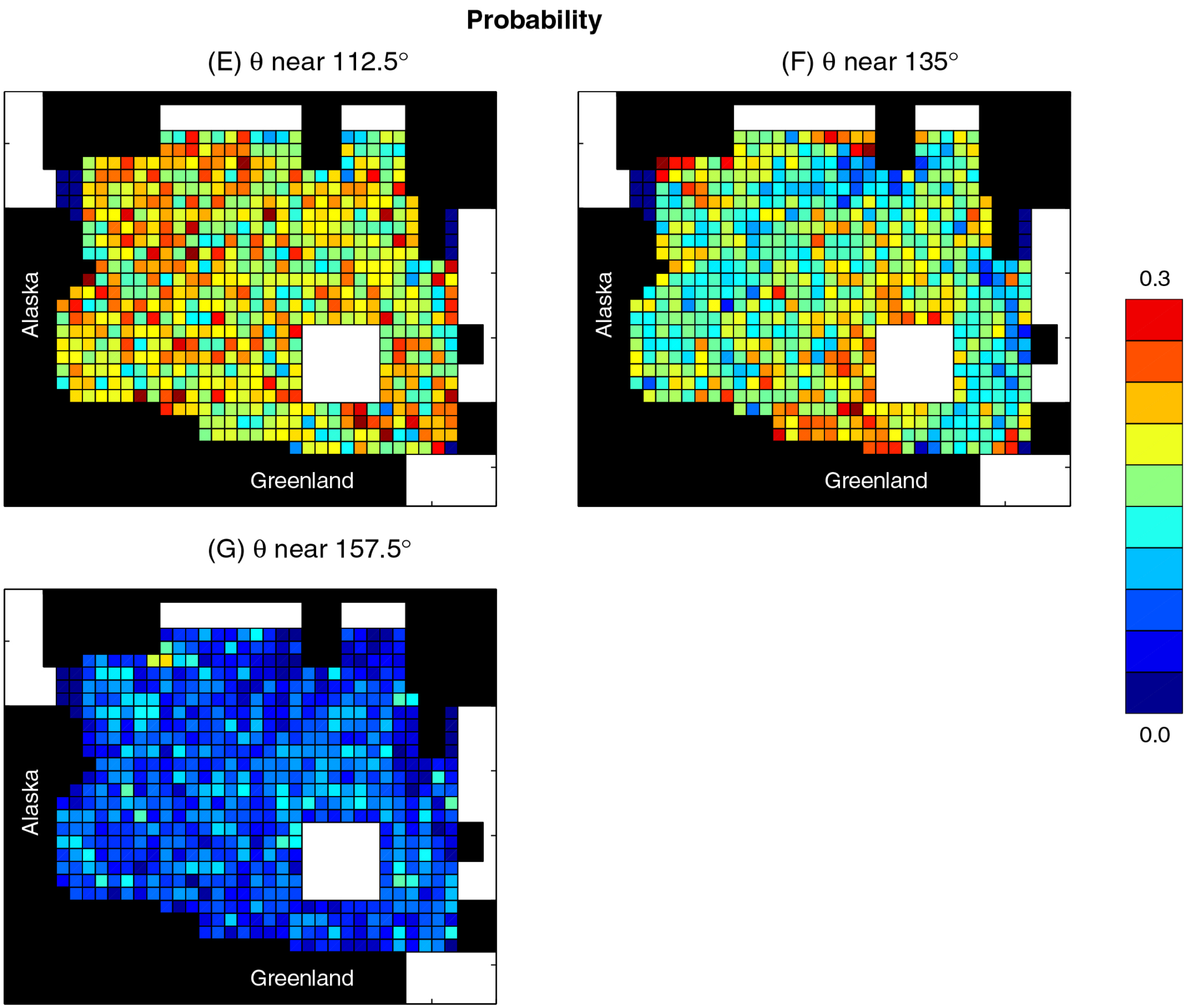


(A) θ near 22.5°

(B) θ near 45°

(C) θ near 67.5°

(D) θ near 90°


Probability
(E) θ near 112.5°
Alaska
Greenland
(F) θ near 135°
Alaska
Greenland
(G) θ near 157.5°
Alaska
Greenland
0.3
0.0