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POTENTIAL OF AMSR-E DERIVED SEA ICE MOTIONS FOR ASSIMILATION INTO SEA ICE MODELS

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1. INTRODUCTION

Sea ice motion has been one of the most common parameters used for assimilation into sea ice models. The assimilated ice motions have been shown to improve model estimates of motion and other related parameters, such as ice thickness. Observations from in situ buoys or Radarsat imagery, provide detailed high-resolution ice motion information. However, their utility for data assimilation is limited due their sparse spatial or temporal coverage. Imagery from passive microwave sensors has provided a long history (since 1979) of daily, basin-scale motion estimates, but at a coarse spatial resolution. The new Advanced Microwave Scanning Radiometer for EOS (AMSR-E) sensor on the Aqua platform has more than double the spatial resolution of its predecessor, the Special Sensor Microwave/Imager. This allows it to obtain much more accurate and more detailed ice motion estimates, but at the same daily intervals as SSM/I. With more detailed and frequent motion information, important smaller-scale processes, such as lead formation and ridging, can be better characterized. Sea ice models are becoming more sophisticated (e.g., improved rheologies, higher resolution) and new modeling approaches (e.g., Lagrangian particle models) are being developed. The improved sea ice observations from AMSR-E will be particularly beneficial for such models. Here, we demonstrate the potential of AMSR-E to yield detailed ice motion circulation as well as estimates of divergence and other parameters useful for assimilation into sea ice models.

2. AMSR-E ICE MOTIONS

The NASA Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E) is a six frequency, dual-polarized passive microwave sensor. It represents an advancement over its predecessor, the Special Sensor Microwave/Imager (SSM/I). It contains more channels and, most relevant for ice motion, higher spatial resolution. For example, the AMSR-E 89 GHz instantaneous field of view is 6 x 4 km versus 16 x 14 km for SSM/I's comparable 85 GHz channels. Gridded spatial resolution for AMSR-E is twice that of SSM/I (e.g., 6.25 km for AMSR-E 89 GHz versus 12.5 km for SSM/I 85 GHz).

Sea ice motions are derived from the AMSR-E imagery using a maximum cross-correlation scheme (Emery et al., 1991). Features are matched between two coincident images separated by a period of time. The displacement of features are computed by finding correlation peaks between the two images and the velocity is computed by dividing the distance between the features by the time separation between the images. An oversampling technique is used to obtain subpixel velocity resolution.

The higher resolution and oversampling allow AMSR-E to track ice that moves less than 2 km/day, a substantial improvement over SSM/I. While this resolution is still fairly coarse compared to visible/infrared (e.g., MODIS) and synthetic aperture radar (e.g., Radarsat) sensors, it can provide near-complete fields over the entire Arctic at daily intervals. MODIS is limited to clear sky regions and Radarsat is limited by sensor capabilities to a 3-6 day interval.

3. BEAUFORT SEA EXAMPLE

To demonstrate the potential of AMSR-E motions, a short case study is presented in the Beaufort Sea north of Alaska in early March 2004. A strong divergence event occurs between the 2nd and 3rd of March, opening a large lead (Figure 1). The divergence is clearly reflected in the derived ice motions (Figure 2). In Figure 1, several other linear fracture patterns are noticeable. At the lower resolution of SSM/I, features such as these have not been resolved.

This is a large lead, several kilometers across, but AMSR-E has also been found to detect reasonably small leads (~1-2 km across). Divergence fields computed from the ice motions may be able to detect regions of formation of even smaller leads. The lead remained open until 8 March when convergent motion closed the lead. During that time, ice growth commenced. Using a simple Lebedev ice growth model based on freezing degree days, an estimate of 16 cm of new ice growth was computed.

The Geoscience Laser Altimeter System (GLAS) on the Ice, Cloud, and land Elevation Satellite (ICESat) is a new satellite technology that can be used to obtain sea ice thickness estimates. By measuring the freeboard (height of the ice above the unfrozen ocean surface) and estimating an ice density, the thickness can be calculated (Kwok et al., 2004). On 7 March, an overflight of the lead by ICESat/GLAS occurred. The observed ice thickness was 15-20 cm, which encompasses the estimate derived from the AMSR-E motions. Thus, AMSR-E has the potential to track thin ice production, as well as related quantities such as salinity fluxes into the ocean and heat/moisture fluxes into the atmosphere with appropriate ancillary data (e.g, meteorological fields).

4. IMPLICATIONS FOR DATA ASSIMILATION

Assimilation is a method to combine observations and model in a statistically optimal manner to reduce errors and improve model estimates. This has the potential to produce more complete and more accurate estimates of important sea ice parameters, such as ice thickness, and improve our understanding of sea ice processes.

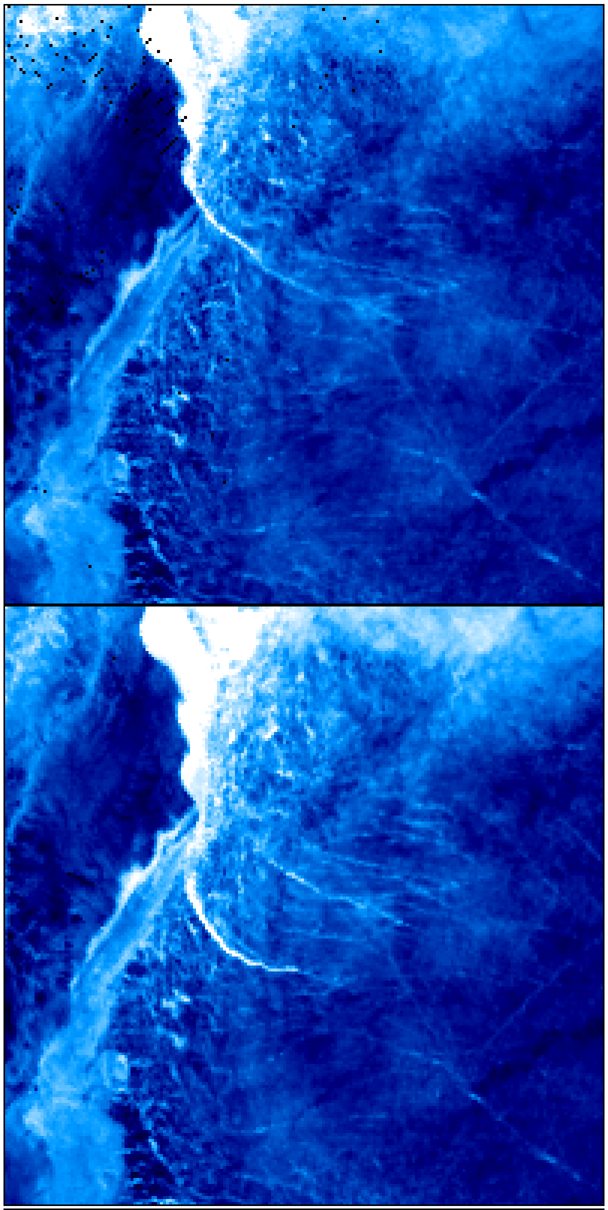

Figure 1: AMSR-E 89 GHz brightness temperatures for 2 March (top) and 3 March (bottom). North is to the right in the images. The north coast of Alaska, including Point Barrow is on the left. The color scale goes from dark blue for cold temperatures (160K) to white for warm temperatures (240K). The lead that opens between 2-3 March can be seen as a white linear feature in the middle of the 3 March image.

The AMSR-E ice motions can be assimilated into sea ice models as has been done previously with SSM/I (e.g., Thomas and Rothrock, 1989; Meier et al., 2000; Zhang et al., 2003). With the higher resolution ice motions, more accurate and more detailed motion information can be obtained from assimilated products. Such higher resolution also has the potential to investigate smaller scale processes within models, such as lead formation and ridging.

In addition, through assimilation the model can act as a data integrator by combining data from different sources in a consistent manner. For example, ice motions from passive microwave, visible/infrared, SAR, and in situ buoys can all be combined to obtain complete, accurate estimates on a consistent spatial grid at a consistent temporal sampling.

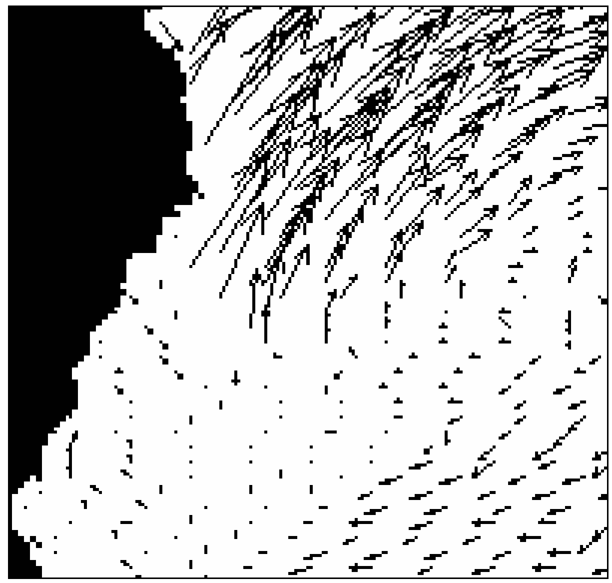

Figure 2: Sea ice motion for 2-3 March derived from AMSR-E 89 GHz brightness temperatures. The region is the same as in Figure 1. Very strong divergence is noticeable in the region where the lead opens in the 89 GHz imagery of Figure 1. The high velocities east of the lead correspond to ~20 km/day ice motion.

By assimilating observations, the model can extrapolate the observations to new data products that cannot be observed. The most salient example for sea ice is ice thickness. Basin-scale ice thickness measurements have not been possible until the adaptation of altimeters, such as the recent ICESat/GLAS and the imminent launch of Cryosat, and observations will continue to be sparse. By using the surface ice motions to influence the model dynamics, observation-based ice thickness fields can be obtained that are more physically-based and likely more accurate than those obtained from only models. Such improvements via data assimilation have already been demonstrated in comparisons with submarine upward looking sonar observations (Zhang et al., 2003).

AMSR-E has the potential to be particularly beneficial for ice motion assimilation. Because of its combination of high spatial and temporal resolution and its all-sky capabilities, AMSR-E is able to detect relatively small-scale ephemeral processes, such as the thin ice growth (and related parameters) discussed above. These processes are important in the evolution of the ice cover but are currently not well-parameterized within sea ice models. Other sensors have greater spatial resolution and can resolve smaller leads (Kwok et al., 1999; Yu and Lindsay, 2003), but due to sensor limitations and/or clouds, they generally cannot capture the high frequency (1 day or less) changes in the ice cover over the entire basin.

These high frequency variations in the ice cover can be important. Short period ice deformation that occurs on sub-daily scales, due to tides and inertial forcing, has been found to be potentially crucial in properly simulating the evolution of the ice cover (Kwok et al., 2003). While the standard AMSR-E products are daily composites, swath data can be employed to obtain sub-daily ice motion.

Incorporating accurate high frequency sea ice motion information into sea ice models will improve model estimates of ice deformation, heat/moisture fluxes, and other small-scale processes. Such processes can have substantial effects on the local, regional, and basin-scale environment.

5. SUMMARY AND CONCLUSIONS

Because of its frequent coverage and all-sky capabilities, passive microwave sensors have significant advantages over visible/infrared and SAR sensors. AMSR-E represents the most advanced passive microwave satellite sensor and is a substantial improvement over its predecessors. It combines the general advantages of passive microwave sensors with much higher spatial resolution.

The basin scale, daily observations of important sea ice parameters at reasonably high spatial resolutions are potentially valuable for assimilation in sea ice models. The observations will provide improved information on small-scale processes that currently cannot be explicitly resolved by standard sea ice models.

6. REFERENCES

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