"The Seasonal Evolution of Sea Ice Floe Size Distribution"

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LONG-TERM GOALS

This work is motivated by the desire to improve the understanding of processes governing the evolution of the marginal ice zone that forms seasonally in the southern Beaufort and Chukchi Seas region.

OBJECTIVES

The objective of this work is to determine the seasonal evolution of the floe size distribution (Figure 1), paying particular attention to the role of winter preconditioning of the ice on summer floe breakup. To achieve this objective we will:

1. Develop a mathematical framework for the floe size distribution.
2. Calculate the evolution of floe size distribution during spring and summer.
3. Determine the floe breaking function by tracking individual floes using high resolution imagery.
4. Estimate lateral melt rates from high resolution imagery.
5. Investigate the roles of wave action and ice preconditioning in floe breakup.
6. Assess the relative contributions of dynamics and thermodynamics to changes in the floe size distribution

APPROACH

We plan to address the evolution of the floe size distribution by acquiring a library of high resolution images following the same groups of floes from early spring through late summer. This will include the imagery acquired as part of the ONR MIZ DRI, which is expected to include images from the MEDEA/National Security and Climate Change Research Program and the Center for Southeastern Tropical Advanced Remote Sensing (CSTARS). The high resolution imagery will allow us to follow flaws formed in winter and spring and assess their impact on the summer breakup of the ice cover. Large-scale, lower resolution imagery from MODIS and other platforms will also be analyzed to determine changes in floe size distribution.

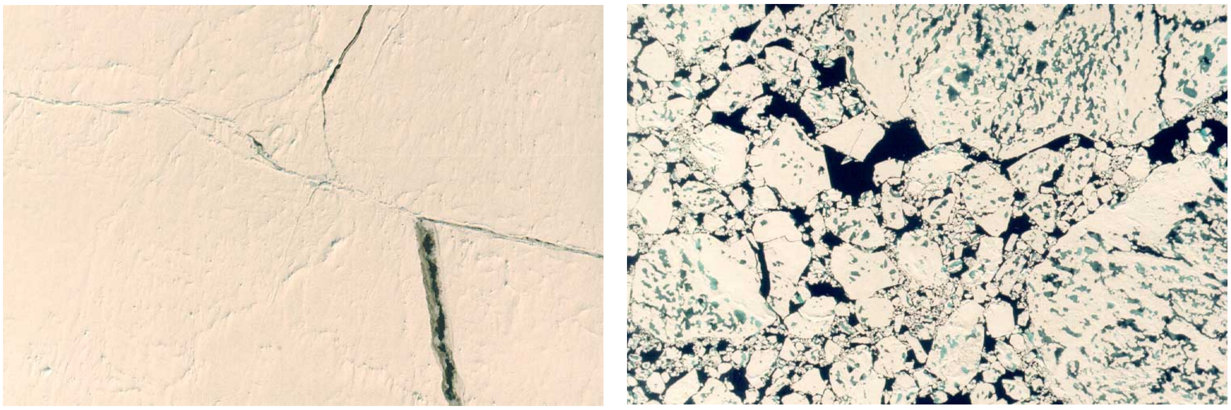

Figure 1. Aerial photographs illustrating the of the profound changes that occur in the appearance and morphology of the Arctic sea ice cover over and annual cycle. These photos were taken over the pack ice near SHEBA in May (left) and August (right) taken at an altitude of 1800 m. The scale is the same in both images.

After obtaining the imagery we will first use image processing software to partition the high resolution images into ice and ocean. The next step will be to compute floe parameters including area, perimeter, and shape factor from the partitioned images. Individual floes will be tracked to investigate how floes break. A central focus will be examining the impact of preconditioning of the floes during winter and spring to the breakup observed in summer. This information will contribute to determining the breaking function and to assessing the role of wave action in breakup. Key issues concerning breakup include; what floes are likely to break, when do they break, and what causes them to break. Estimates of solar heat input to the ice – ocean system will be calculated and used to determine lateral melt rates. A time dependent floe size distribution governed by lateral melting and a breaking function will be determined.

WORK COMPLETED

Now in the second year of this project and with significant involvement from the graduate student funded by the project, we have:

(1) Completed a journal article accepted for publication, which uses the aerial photography from the Surface Heat Budget of the Arctic Ocean (SHEBA) field campaign to develop a mathematical framework for the evolution of floe size distribution (Perovich and Jones, 2014).

(2) Obtained additional high resolution visible imagery from the MEDEA/National Security Climate Change Research Program and SAR imagery from the Center for Southeastern Tropical Advanced Remote Sensing (CSTARS).

(3) Presented the poster “Satellite and in situ observations of Arctic sea ice floe breakup and melt” at 2013 Fall AGU

(4) Created a library of images tracking a cluster of drifting ice-based buoys located in the southern Beaufort Sea during summer 2013 using the imagery from (2), .

(5) Developed an image processing technique to analyze floe size distribution during the summer melt season using (4),. The technique allows for the direct observation of lateral melt and the

calculation of changes in floe perimeter, and the ability to track the detailed evolution of flaw formation.

(6) Outlined a plan to use the results of (5) to evaluate the utility of the discrete element method (DEM) in (a) advancing the understanding of the dynamic and thermodynamic processes governing the seasonal evolution of the marginal ice zone (MIZ) and (b) forecasting conditions in the MIZ in support of an anticipated increase in operational requirements.

RESULTS

Using aerial photographs from the SHEBA field experiment, we examined the seasonal evolution of the floe size distribution. We assumed the floe size distribution could be represented by a two-parameter power law where the number of floes per unit area N_{tot} and the power α are determined from measurements of total ice area and perimeter.

The seasonal evolution of the floe size distribution from spring through summer exhibits several characteristics. Over the course of the summer there is a general trend of floes breaking resulting in more floes and smaller floe diameters, increasing the exponent of the power law floe size distribution. Changes in floe size distribution were small for much of the summer until a major ice motion, breaking, and melting event in late July. Associated with this event was extensive floe breaking resulting in a decrease in the size of floes, an increase in the number of floes, and an increase in the total floe perimeter. There were also several meters of lateral melting. The combination of increased floe perimeter and increased lateral melt rates resulted in large ice losses due to lateral melting, and a significant decrease in ice concentration. We found that a simple breaking function that has larger floes breaking into more pieces than smaller floes represented the significant transition in floe size distribution that occurred in late July/early August (Figure 2). This breaking function maintained the power law form of the floe size distribution. The quantitative representation produced a dramatic increase in the number of floes and the total floe perimeter per unit area, along with a decrease in the relative number of large floes. Lateral melting of 2.6 m along the enhanced perimeter provided area and perimeter concentrations consistent with the image analysis from 7 August.

These results confirm that changes in the floe size distribution are due to a combination of thermodynamic and dynamic processes. Lateral melting decreases floe size and perimeter and may reduce the number of floes by eliminating smaller floes. Lateral melting also causes the floe size distribution to deviate from a power law for small floe sizes. Dynamics breaks floes, decreasing the floe size and increasing the total floe perimeter and the number of floes. An increase in total floe perimeter tends to increases the total amount of lateral melting.

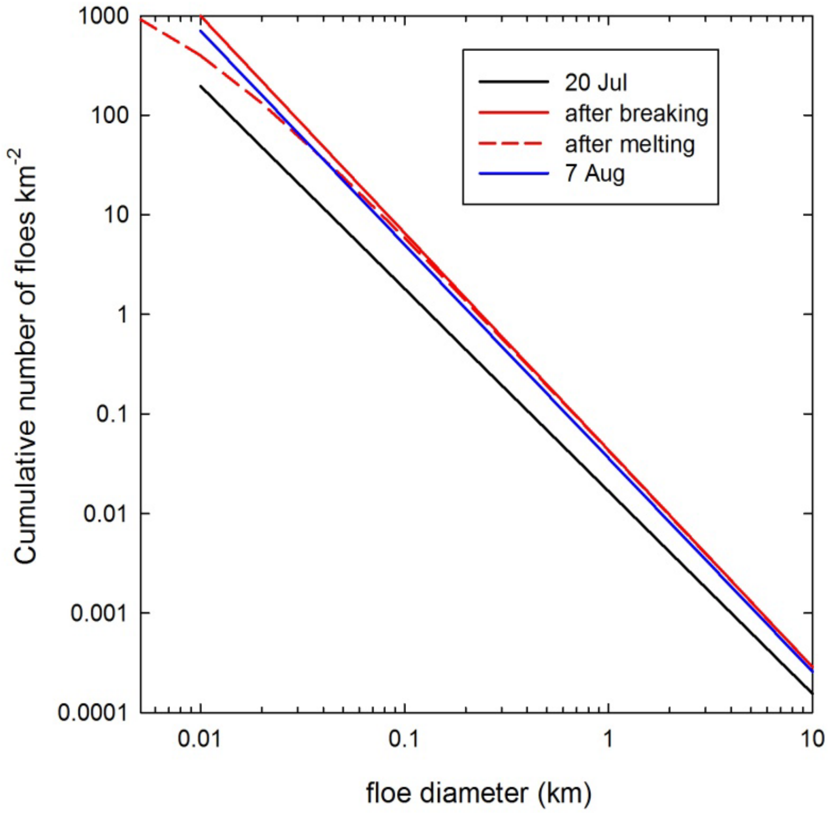

Figure 2. SHEBA major breaking event beginning 20 July (black), analyzed as breaking (solid red) followed by melting (dashed red). The smallest floes post-melting on 7 August have diameters slightly less than 5 m. The power law fit on 7 August (blue) is also shown.

IMPACT/APPLICATIONS

Identifying the processes that govern the evolution of the floe size distribution is a key to understanding the evolution of the marginal ice zone that forms seasonally in the southern Beaufort and Chukchi Sea region. The floe size distribution directly impacts the partitioning of the solar radiation absorbed in the upper ocean. The absorbed sunlight contributes to warming the water, melting on the underside of the ice and melting at the lateral edges of the floes. The warming water and melting ice leads to a significant positive feedback, causing more open water, a thinner ice cover and more solar energy absorbed. These changes, in turn, affect the arctic ecosystem. The improved understanding of the evolution of the floe size distribution will ultimately contribute to improvements in the ability to model the future condition of the sea ice cover on both the seasonal and decadal time scales.

Results from this work will also be used to evaluate the CRREL sea ice discrete element model's (DEM) ability to simulate the observed evolution of the seasonal MIZ. We hypothesize that the DEM, a model designed to capture detailed ice interaction at the floe scale, would be an effective tool for investigating the processes governing the floe size distribution and forecasting ice conditions. To test this hypothesis, we will make a qualitative comparison of the model results against a time series of the satellite images used as part of this project. Image analysis from the project will provide a more detailed and quantitative comparison of the evolution of floe properties, to include floe size, area fraction and floe perimeter.

RELATED PROJECTS

- ONR Marginal Ice Zone Departmental Research Initiative:

http://www.onr.navy.mil/en/Science-Technology/Departments/Code-32/All-Programs/Atmosphere-Research-322/Arctic-Global-Prediction/Marginal-Ice-Zone-DRI.aspx

The goal of this five-year DRI, (FY12-FY16) is to improve the knowledge and understanding of the physics of the retreating summer ice edge and Marginal Ice Zone (MIZ) in the Beaufort and Chukchi seas. The approach will be to integrate data from *in situ* sensing platforms, remotely-sensed observations, and integrated process models to develop a comprehensive, quantitative picture of open-ocean, ice edge and MIZ processes, interactions and feedbacks as the ice retreats.

- CRREL: We will be coordinating with the following projects to obtain, process and apply satellite imagery to provide information about the initial configuration and condition of the ice cover for the DEM model and to evaluate the performance of the DEM in the modeling the evolution of the MIZ.
    - Song: “Evaluating the Discrete Element Method as a Tool for Predicting the Seasonal Evolution of the MIZ”, Office of Naval Research Grant # N0001414MP20126.
    - Polashenski: “Remote Sensing of Meter-Scale Sea Ice Properties”, Office of Naval Research Grant # N0001414WX20362.

PUBLICATIONS

Perovich, D.K and K.F. Jones (2014) The sSeasonal evolution of sea ice floe size distribution, *J. Geophys. Res.* [accepted for publication, referred]