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LARGE-EDDY SIMULATION OF TURBULENT PROCESSES IN SUMMERTIME LEADS

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1. INTRODUCTION

Accurate prediction of sea ice coverage is crucial for realistic climate simulation. Sea ice provides an insulative cap on the polar ocean, reducing outgoing heat flux in the winter and incoming solar radiation during the summer. If in response to climate change sea ice declines during the summer months, then solar radiation normally reflected back to space by the ice will instead be absorbed by the upper ocean. Consequently, understanding how open water or leads are created in pack ice is critically important in assessing the polar ocean heat budget and changes in the earth's climate system.

Most leads are formed by dynamic motion of the pack ice forced by winter storms. These leads refreeze, but have an ice draft less than the surrounding ice and typically are the first to open during the summer melt period. We know that lateral melting at the lead edge is usually larger than melting under the ice pack because sea water in leads directly absorbs sunlight. What's not well understood is how heat stored in the middle of the lead is transported to the lead edge and under the ice.

One of the primary goals of Surface Heat and Energy Budget Experiment (SHEBA) was to determine the processes that transport heat in the upper ocean and control ice melting. Observations taken from a small boat (Pegau and Paulson 2003) show that water within leads exhibits consistent patterns with the warmest water near the middle of the lead and strong temperature gradients near the ice edge depending on the wind direction.

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Here, we apply an ocean turbulence model to examine how turbulent circulations are forced in leads. The model is based on the technique of large-eddy simulation (LES), which resolves the largest turbulent scales of motion associated with shear and convectively forced turbulence. Ice in the model is imposed by setting grid cell velocities to zero and defining a fixed lead opening. Heat and salinity fluxes between the ice grid cells and the ocean are determined using exchange coefficients defined in McPhee et al. (1987). A more complete description of the ice-LES model is presented in Skyllingstad et al. (2003).

2. EXPERIMENT DESIGN

Domain size is set to 448 x 448 grid points in the horizontal with 40 vertical levels. Grid spacing of 0.1 m is used, yielding a horizontal domain of 44.8 m with a depth of 4 m. Ice thickness is set to 1.5 m, with a 16 m square lead located in the center of the domain. Solar forcing of 224 W m^{-2} is applied using a depth dependent absorption from Pegau and Paulson (2003). Surface heat loss from the open lead is set to 30 W m^{-2}, representing the total sensible, latent, and radiative loss. Constant wind stress of 0.075 N m^{-2} and ice motion of 0.05 m s^{-1} are applied, representing typical summer conditions. Sea water with salinity of 4 psu and a temperature of -0.2 ^{o}C is initialized in the top 0.4 m of the lead. Below this depth, linear profiles of temperature and salinity are applied with values changing to -1.44 ^{o}C and 31 psu, respectively at a depth of 1 m.

3. RESULTS

The importance of wind forcing and ice motion on the lead circulation is clearly shown by plots of the temperature and surface currents (Figure 1). WIthout wind and ice motion, we would

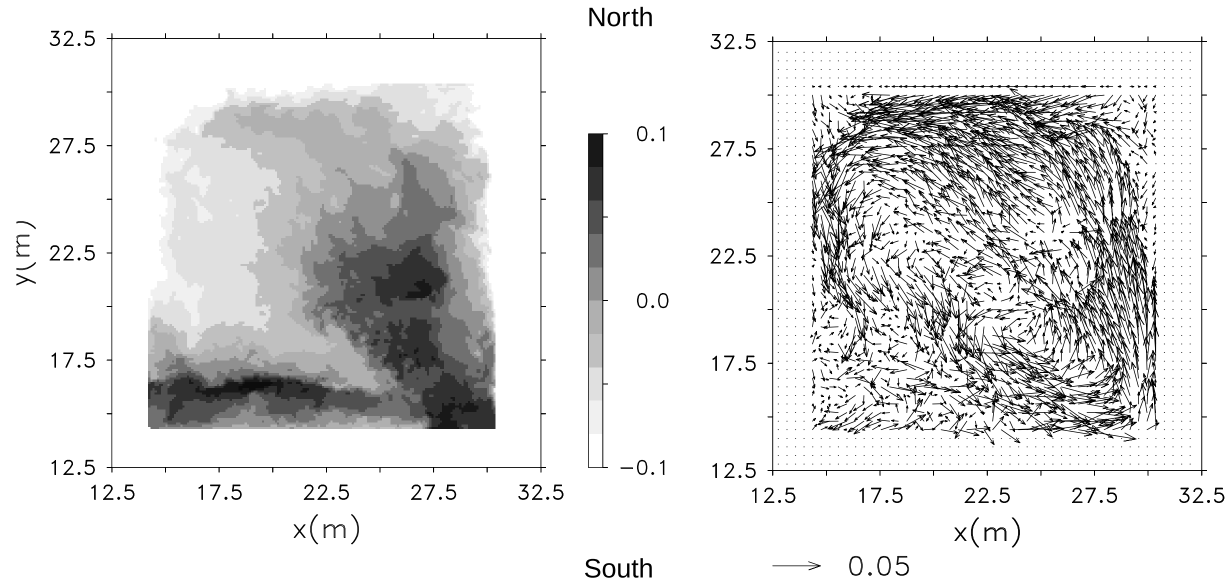

Figure 1. Horizontal cross section of potential temperature taken from a depth of 0.2 m after 3 hours.

expect the near surface lead temperature to be a maximum in the middle of the lead, with a gradual decrease to the lead edge where ice melting cools the water. Here, we find that wind forcing sets up a cyclonic circulation that is asymmetric with warm water concentrated along the southern and eastern ice edges. Preliminary analysis suggests that the circulation within the lead results from Coriolis turning of the currents. Future experiments are planned to test this hypothesis.

Melting heat flux estimates from the model show a broad range from about 15 W m^{-2} on the ice bottom to values as high as ~350 W m^{-2} on the southern ice edge. The highest values are near the surface on the south edge, as expected given the surface heating. However, along the eastern edge values are higher at a depth of ~0.5 m. Submerged flux maxima indicate that the wind forced circulation is either transporting warm water downward, or forcing a stronger ice edge current just above the halocline. Melting is controlled by both the current speed (increased ice edge turbulent fluxes) and the ice-water freezing temperature difference. These two processes will be examined as our work continues.

Comparison of these results with heat budget estimate reported in Pegau and Paulson (2003) show very good agreement. In Pegau and Paulson, ice edge melt flux was calculated as a residual from the heat balance equation, which yielded a value of ~67 W m^{-2}. Here, we compute an average of the lateral edge melting flux, yielding a value of ~60 W m^{-2}. Considering the difference in lead size, orientation, and our idealized approach, these results are very encouraging and suggest that our simulation is correctly modeling the distribution of solar heat throughout the water column below the lead.

4. SUMMARY

Using a coupled ice-ocean LES model with an idealized lead, we were able to calculate lateral melt rates that are very consistent with estimates made during the SHEBA experiment. Future research will focus on the sensitivity of melt rates to currents, surface wind and heat forcing, and lead orientation.

5. REFERENCES

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