The Role of Summer Leads in Melting Sea Ice

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LONG-TERM GOALS

The long-term goal of this study is to understand and quantify the processes which control the input of solar energy into summer leads and the disposition of this energy into lateral melting, bottom melting, and heat storage.

OBJECTIVES

The objectives of this study are to:

- Determine the albedo of lead surfaces as a function of solar altitude, surface roughness (wind speed and fetch), and clouds (transmittance).
- Determine optical properties of leads and their effect on the absorption and penetration of solar radiation.
- Determine salt and temperature stratification within leads and their dependence on melt rate, air-sea heat exchanges and turbulent mixing forced by the wind and ice-ocean velocity difference.
- Balance the heat and freshwater budgets of leads and assess the effects of atmospheric, ice, and oceanic forcing on components of the balances.

APPROACH

We participated in the Surface Heat Budget of the Arctic (SHEBA) field experiment in the Beaufort Sea. Measurements were made from lead edges and from a small boat during the summer of 1998 (Figure 1). Measurements included: 1) incoming and outgoing solar radiation over leads; 2) vertical profiles of temperature, salinity and optical properties on vertical sections across and around the perimeter of leads; and 3) velocity from drogued drifters. We will analyze the data that we collected and we will collaborate with other SHEBA investigators who have complementary data to achieve the stated objectives. Measurements of lead dimensions, albedo , wind speed, and cloud cover will be analyzed to achieve our first objective. The inherent and apparent optical properties within leads were measured directly. These properties will be used in the equation of radiative transfer to determine the deposition of solar energy

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within the water column. Our measurements of temperature and salinity will be combined with ice mass, atmospheric, and current measurements to investigate the dependence of salt and temperature stratification on external forcing conditions. The heat and salinity balance will be determined in a similar manner.

WORK COMPLETED

We participated in the summer portion of the SHEBA field campaign between June 2, 1998 and August 11, 1998. We collected near-surface temperature and salinity data as a function of position within the lead. We collected temperature, salinity, and optical data as a function of depth along transect paths across leads and time series at fixed locations. When possible, we sampled remote leads by use of snow machine or helicopter. When traveling to remote leads was not possible, we sampled a nearby lead. Measurements in this lead resulted in a time series of the summer evolution of a single lead. The lead remained open during the entire sampling period with occasional changes in geometry due to ice motion and melting. The perimeter of the lead was mapped by the use of two GPS units, one on the boat and the second on an adjacent ice floe.

Prior to the field experiment we assembled and tested the equipment used in the field experiment. Instruments were calibrated prior to the experiment. Preliminary data processing was carried out in the field to verify proper sampling techniques and equipment operation. Data processing will continue after the instruments return and post-calibration has been completed. We have participated in SHEBA coordination/planning meetings.

RESULTS

Preliminary results indicate that the addition of fresh water by snow and ice melt has a dramatic influence on the vertical density profile within a lead. Observations made in the lead near the SHEBA ice camp (Nanook lead) show the summertime variation in temperature (T) and salinity (S) in the upper 20 m of the lead. The geometry of the lead on 11 July is shown in Figure 2. The area of the lead is 12,000 m^2, the length of the perimeter is 700 m and the maximum distance across the lead is 200 m. The length of the perimeter is underestimated because small-scale irregularities in the boundary were not resolved by the navigation.

The summer cycle is illustrated in Figure 3. At the beginning of the summer season T and S were nearly uniform within an upper mixed layer approximately 30 m in depth with T close to the freezing point. This mixed layer formed during the previous winter under the influence of wind-forced ice motion, surface cooling, and brine rejection associated with ice formation. As solar insolation increased during the summer, the total surface heat flux into leads changed from net cooling to net heating which melted ice. The meltwater formed a salt-stratified surface layer with temperature above freezing. The near-surface temperature of Nanook lead was consistently above freezing after 21 June. By 11 July the average temperature of Nanook lead at a depth of 15 cm ranged from 0.9 to 2.2 C with a mean of 1.6 C (Figure 2). The thickness of this warm, fresh layer was approximately 0.5 m and surface salinity was about 4 psu (Figure 3). As summer progressed, the modified layer deepened to 1.3 m and salinity decreased to a uniform 2 psu in the upper 0.9 m (Figure 3). On 28 July winds increased to 15 m/s and remained near this level during most of the following day. The wind stress caused ice motion and turbulent mixing which was sufficiently energetic to deepen the surface mixed layer to 15 m as observed on 1 August. Following this date, the melt rate was not sufficient to reestablish a persistent, low-salinity layer at the surface.

Preliminary results will be presented at the Fifth Conference on Polar Meteorology and Oceanography sponsored by the American Meteorological Society (Pegau and Paulson, 1999).

Figure 1. Sampling system used to obtain our measurements. A SBE-19 CTD is suspended off the bow so that it samples T and S ahead of the boat. A GPS unit is located on the blue tarp on the port side of the boat. The difference between the position recorded on the boat and that at a second GPS on the ice was used to determine location at any given time. The profiling CTD and optics sensors were deployed from the davit on the aft-port corner of the boat. An electric motor powers the boat for surface mapping. During most profiling transects across the lead we would start at the upwind edge and drift while profiling.

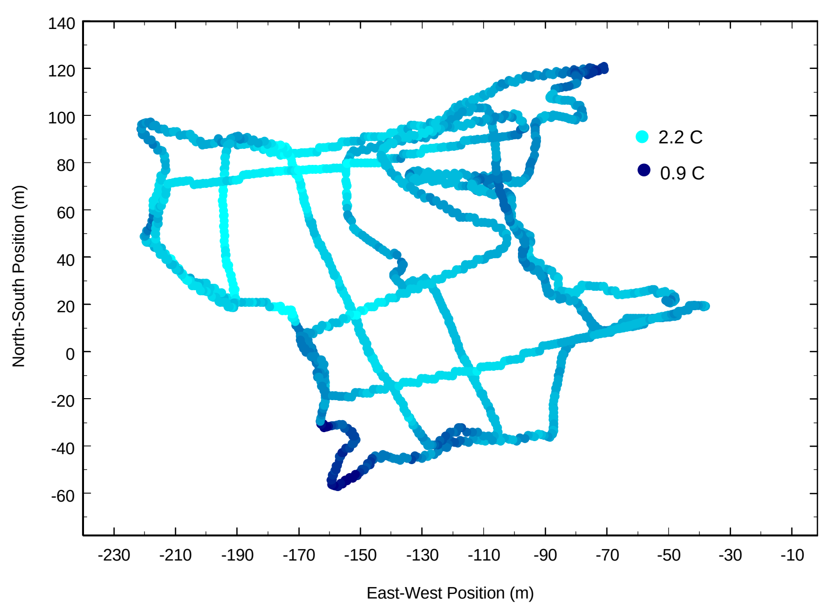

Figure 2. Boat track around the perimeter and across Nanook lead on 11 July 1998 together with temperature measured at a depth of 15 cm.

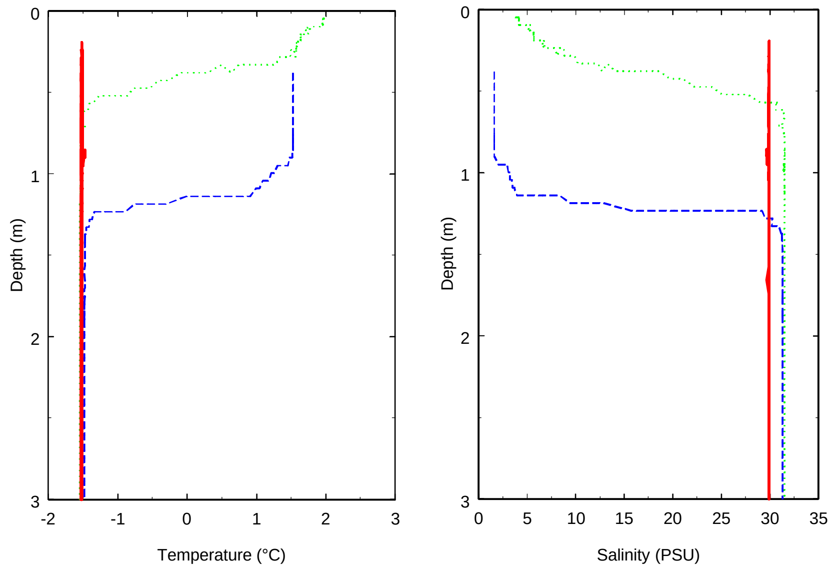

Figure 3. Temperature and salinity profiles in Nanook lead on 11 July (dots), 22 July (dashed) and 1 August (solid).

IMPACT/APPLICATIONS

The summer cycle observed in Nanook lead illustrates the establishment of a fresh, warm, surface layer with very low surface salinity (2 psu) and temperature well above freezing (2 C). The strong vertical stratification associated with this layer inhibited mixing until near the end of July when a passing storm generated enough ice motion and turbulence to vertically mix the 1-m thick surface layer down to a depth of 15 m. The stratified surface layer may have limited the vertical transfer of heat to melt bottom ice, especially in the first part of the summer when the depth of the surface layer was less than the draft of surrounding ice floes. Hence the role of stratified surface layers in leads may be to apportion more heat to melting the sides of ice floes than to their bottoms.

TRANSITIONS

The preliminary data has been used by Dr. Grenfell to establish plausible lead temperature ranges to check the performance of IR temperature measurements being made during helicopter surveys of the surrounding regions.

RELATED PROJECTS

We are not currently working on related projects.

PUBLICATIONS

Pegau, W. S., and C. A. Paulson, 1999. The role of summer leads in the heat and mass balance of the upper Arctic Ocean, accepted in the Preprint Volume of the Fifth Conference on Polar Meteorology and Oceanography sponsored by the American Meteorological Society.