4A.4 EARLY SUMMER HEATING OF THE UPPER OCEAN IN THE VICINITY OF SHEBA

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1. INTRODUCTION

Summertime solar heating of the upper ocean, and subsequent basal melting, are important factors in the ice mass and energy balance, as well as in the seasonal evolution of the Arctic mixed layer. At the SHEBA site in June, 1998, a steady increase in elevation of mixed-layer temperature above freezing ($\delta T = T - T_f(S)$) indicated that heat loss to basal melting could not keep pace with insolation. During June, the areal coverage of leads in the vicinity of the station remained less than 5% with no open water near the “Ocean City” measurement site (D. Perovich, pers. comm). Transmission of solar energy through the ice cover is not well understood, hence ocean heating during a time of large ice fraction is of special interest.

This work focuses on a particular period just prior to summer solstice, 16-20 Jun 1998, when there were continuous records of mean properties and turbulent fluxes from two instrument clusters in the upper 10 m of the mixed layer, along with extensive coverage by the SHEBA profiling CTD. Over the four days, the mixed layer was moderately turbulent, with little stratification in the upper 15-20 m. We observed a continuous warming trend (absolute as well as relative to freezing), along with a superimposed diurnal signal, with temperature maxima lagging maximum solar angle by 4-6 h (Fig. 1). A diurnal cycle was also present in turbulent heat flux ($H_f = \rho c_p \langle w'T' \rangle$) measured 4.2 and 8.2 m below the interface. At midday, this flux was negative, as turbulence transported solar energy deposited in the upper part of the water column downward. At low sun angle, the sign reversed at the upper instrument cluster, as melting at the interface extracted heat from the water column.

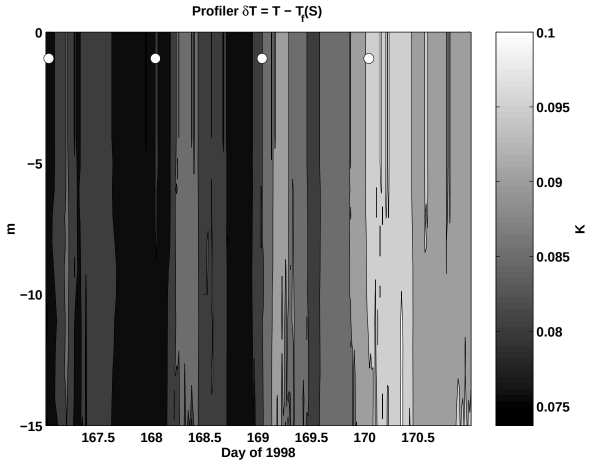

FIGURE 1. Temperature elevation above freezing in the upper 15 m of the water column under the SHEBA floe, from the SHEBA ocean profiler. White circles indicate local solar noon.

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The upper ocean data, combined with measurements of downwelling shortwave radiation at the upper ice surface, provide a rare opportunity to test modeling parameterizations.

2. MODELING

A one-dimensional, time-dependent upper ocean model (McPhee 1999) was used to simulate mixed-layer response during the period 1998:167-171. Model temperature/salinity structure was initialized to observed conditions at time 167.0 (i.e., 0000UTC on 16 Jun 1998), then allowed to evolve in response to (i) interfacial stress determined from current measurements 4.2 m below the ice; (ii) a fixed percentage of the downwelling short wave radiation as measured at the SHEBA Project Office installation; and (iii) interfacial heat and salinity flux associated with melting at the interface.

The short-wave radiative flux is distributed as a source term in the model heat equation:

$$Q = \frac{c_{SW} F_{SW}}{\lambda_{SW}} \exp\left(\frac{-|z|}{\lambda_{SW}}\right)$$

where F_{SW} is the measured downwelling shortwave radiative flux at the ice surface; c_{SW} is a constant transmission factor for local sea ice; and λ_{SW} is the "e-folding" shortwave attenuation length in the water.

Ocean-to-ice (basal) heat flux is parameterized in the model as

$$H_{mod} = \rho c_p u_{*0} c_h \delta T$$

where u_{*0} is friction velocity at the interface and c_h is a constant heat transfer coefficient. Interfacial salinity flux ($\langle w'S' \rangle_0$) follows from the enthalpy balance assuming no upward heat conduction within the ice cover.

Eddy viscosity and diffusivity depend on local friction velocity (square root of Reynolds stress) and a buoyancy-flux dependent mixing length, following the algorithm suggested by McPhee (1994). The mixing length in the well mixed layer is sensitive to buoyancy flux at the interface, primarily dependent on $\langle w'S' \rangle_0$.

3. RESULTS

The primary adjustable parameters in the model, along with values used for model comparisons below are summarized in Table 1.

TABLE 1. Model Parameters

Undersurface Roughness, z_0	0.01 m
Heat tranfer coefficient, c_h	0.006
Solar Transmission Factor, c_{SW}	0.08
Ocean Solar Attenuation Length, λ_{SW}	4 m

Figure 2 compares the thermal structure observed in the upper ocean with modeled response. By passing 8% of the solar energy through the ice cover, the model reproduces both the trend and the dirurnal variation reasonably well, including the phase lag between the radiative maximum and temperature maximum.

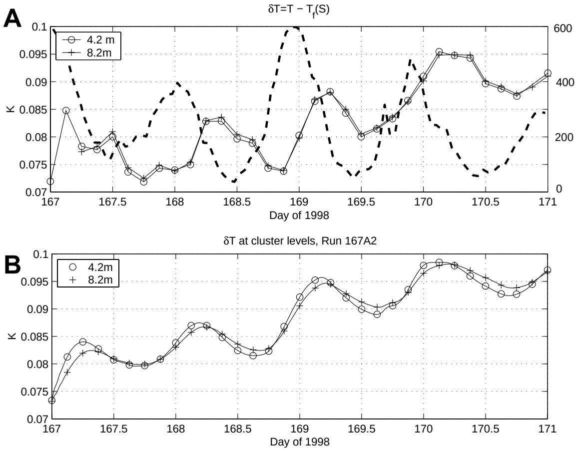

FIGURE 2. A. Observed temperature elevation above freezing at two turbulence instrument clusters (solid curves with symbols, left ordinate label). Also shown is the downwelling shortwave radiation (dashed curve , right ordinate label in W m^{-2}). B. Modeled temperature elevation at the instrument levels.

A second test of the model is illustrated in Fig. 3, where measured turbulent heat flux is again reason-

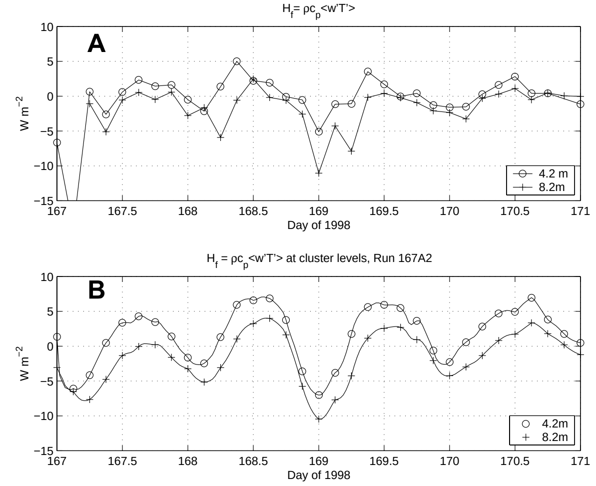

FIGURE 3. A. Observed turbulent heat flux at two turbulence instrument clusters. Positive flux is upward. B. Modeled heat flux at the instrument levels.

ably well reproduced by the model. Note that at 4.2 m, the diurnal cycle in heat flux is nearly phase locked with the solar cycle, and that there is perceptible phase lag between the upper and lower clusters, in both the observations and model.

4. DISCUSSION

Since the mixed layer is always above freezing there is continuous melting and heat loss at the ice/ocean interface. At 4.2 m below the ice, there is rough balance between the downward turbulent heat flux at midday and the upward flux centered around the time of minimum sun angle. Four meters lower, the net flux is downward, illustrating the means by which the mixed layer warms during summer— essentially, the rate of heat loss to melting is less than the influx of solar energy, which is distributed through the mixed layer by turbulence.

What is perhaps most surprising about the June period is that the heating occurs during a time of relatively high ice concentration. Aerial photographs (courtesy of D. Perovich) on days 1998: 166 and 173 show virtually no open water in the vicinity of the turbulence mast, and the estimate of open water in an area of 100-200 km^2 around the ship was 3-4% (D. Perovich pers. comm). The model was run again with identical forcing except with the solar radiation transmission factor halved. Results (Fig. 4) show that in this case, insolation cannot keep pace with melting and the modeled mixed layer cools. Thus the modeling, combined with the fact that the measured heat flux cycle is so closely locked with the solar cycle (implying that the heat could not have been deposited in open leads some distance “upstream”), suggests that as much as 8% of the incoming shortwave is making its way through the solid ice cover to heat the upper ocean in the period just before summer solstice.

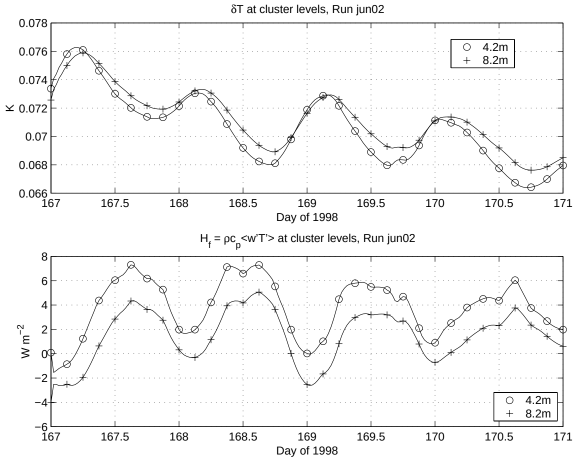

FIGURE 4. Model results with $c_{SW} = 0.04$ instead of 0.08. Upper: model ocean temperature at instrument levels; Lower: model turbulent heat flux.

5. REFERENCES

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