**P1.26** HORIZONTAL VARIATIONS IN THE NET HEAT FLUX OF A SPRINGTIME FREEZING LEAD

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## 1. INTRODUCTION

Leads or cracks in the sea ice, play an important role in determining the energy budget of the Arctic ice pack. The components of the surface energy budget over the snow covered multiyear ice pack and freezing leads differ markedly, particularly in spring. In spring, air temperatures are cold enough to support large fluxes of sensible and latent heat into the atmosphere. The relatively warm ocean waters and ice surface lead to a large upwelling longwave radiative flux. In addition, the surface albedo in leads is drastically reduced compared with the surrounding ice pack.

In detailed thermodynamic sea ice models, leads are assumed to freeze over uniformly based on the net heat flux for the lead surface (e.g., *Ebert and Curry*, 1993). In this study, we determine the affect that across-lead variations in the surface properties have on the lead-average net heat flux using observations made during the Surface Heat Budget of the Arctic (SHEBA) field experiment and a modified version of the ice growth/surface flux model of *Alam and Curry* (1998).

## 2. OBSERVATIONS OF A FREEZING LEAD

Observations of a freezing lead were made on 28 April 1998 during SHEBA. The lead began to form at 1815 UTC and grew to a width of 400+ m after 6 hours. Cold surface air temperatures and an across-lead fetch resulted in the rapid buildup of frazil ice on the downwind edge of the lead. Between 1.5 and 5 hours, surface conditions varied across the lead from nilus near lead edge, to frazil and open water near the center of the lead. The lead was nearly covered with new ice after less than 6 hours.

Observations of skin temperature and upwelling shortwave flux were obtained at lead edge using a Mobile Radiometric Platform (MRP). This platform is described in some detail by *Maslanik et al.* (1999). Data was collected with the MRP from 1946 UTC on 28 April to 1908 UTC on April 29. Downwelling radiative fluxes were observed by the flux-PAM stations using a Kipp and Zonen CM21 pyranometer and an NCAR-modified Eppley pyrgeometer, respectively. The upwind surface layer humidity and temperature were obtained from a remote flux-PAM station. Wind speed at 10 m was obtained from data collected at the Atmospheric Surface Flux Group (ASFG) 20-m tower.

## 3. SURFACE ENERGY BUDGET CALCULATION

The surface energy budget of a freezing lead is determined by combining data collected by the MRP and a nearby flux-PAM station. The surface energy budget over the open water and ice portions of a freezing lead is given by:

$$F_n = a(1-\alpha)S_d + \varepsilon(F_d - \sigma T_s^4) - H_S - H_L + F_c \quad (1)$$

where $F_n$ is the net heat flux, $S_d$ is the downward shortwave flux, $F_d$ is the downward longwave flux, $T_s$ is the surface skin temperature, $\alpha$ is the broadband albedo, *a* is the solar absorptivity, $\varepsilon$ the broadband emissivity (0.98 is assumed for open water and sea ice) and $F_c$ is the conductive flux. The storage term has been neglected in this equation.

The sensible and latent heat fluxes are determined from observations using the bulk aerodynamic formula given by:

$$H_S = \rho c_p C_H U(T_s - T_a) \quad (2)$$

$$H_L = \rho L_v C_H U(q_s - q_a) \quad (3)$$

where $\rho$ is the air density, $C_H$ is the heat exchange coefficient, U is the mean wind speed, $T_a$ and $q_a$ are the surface air temperature and specific humidity (nominally at 2 m), U is the 10-m wind speed and $T_s$ and $q_s$ are the surface temperature and specific humidity, respectively. The heat exchange coefficients for open water and ice were determined using the fetch dependent parameterization of *Andreas and Murphy* (1986). The fetch across the lead is assumed to increase with time at a rate of 3 m min$^{-1}$ until reaching 400 m.

The components of the SEB are calculated assuming the surface of the lead is either open water or new ice. A solar absorptivity of 45% is used for ice, 60% for water after *Ebert and Curry* (1993). These calculations give an indication of the potential horizontal variation of surface fluxes across a freezing lead. The net shortwave, net longwave radiative, sensible and latent heat, and net fluxes estimated for sea ice and open water from the observations are shown in Figure 1.

The difference between open water and sea ice is quite large for each term of the SEB. The absorbed shortwave flux is up to 70 W m$^{-2}$ greater over open water owing to a much lower solar absorptivity. The difference in the net longwave flux increases with time as the ice surface cools while the sea water temperature is fixed. The sensible heat flux over water tends to be more than 100 W m$^{-2}$ greater than the open water values. Smaller variations are seen in the latent heat fluxes. The difference between the net heat flux over water and that over ice is largest at night when ice surface is coolest influ-

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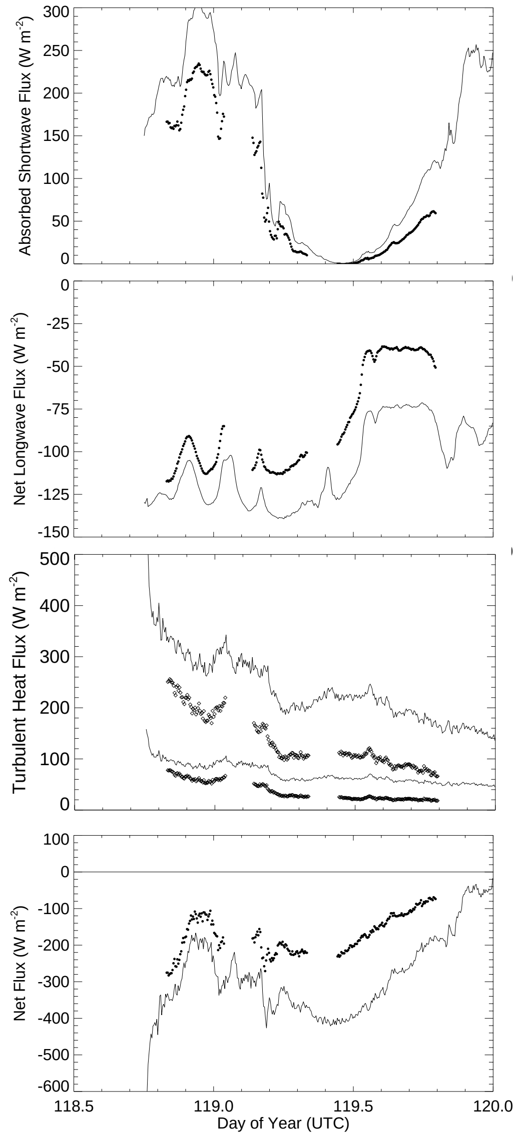


*Fig. 1. Evolution of surface energy budget components assuming lead is either open water (solid lines) or ice-covered (dots) for the lead observed on 28-29 April 1998 at SHEBA. .*

encing both the turbulent and net longwave fluxes. The difference between the net flux over open water and ice can be as large as 200 W m$^{-2}$.

## 4. MODEL RESULTS

The ice growth/surface turbulent flux model of *Alam and Curry* (1998) has been modified to simulate the surface conditions in a dynamically opening lead. Downwelling radiative fluxes and upwind temperature and moisture are obtained from the observations. The model treats both frazil ice processes and congelation ice growth. The turbulent flux calculations account for variations in surface roughness associated with different ice growth regimes and account for the modification of surface air temperature and moisture as air flows across the lead.

Several simulations of the springtime lead observed at SHEBA were performed. Generally, across lead variations in components of the surface energy budget were greatest during the first 5 hours of the lead's existence. Horizontal variations in surface temperature shown in Figure 2a result in variations in the upwelling longwave flux of as much as 20 W m$^{-2}$. Variations in surface albedo alone caused the net shortwave radiation at the surface to vary by as much as 30 W m$^{-2}$. Differences in the solar absorption by different surface types significantly increases this number. The sensible heat fluxes shown in Figure 2c vary by as much as a factor of 3 across the lead and are clearly the dominant source of variability in the net heat flux across the lead.

Assuming the same solar absorptivities as those used to calculate the observed SEB, the net heat flux across the lead varies from between -600 and -200 W m$^{-2}$ at hour 1 to -260 and -220 W m$^{-2}$ at hour 6 when the lead is ice covered. These results indicate that significant variations exist in the net heat flux across freezing leads even when covered with ice. These results imply that bulk treatments of the net heat flux of a lead will underestimate the ice growth rate.

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## 5. REFERENCES

Alam, A., and J. A. Curry, 1998: Evolution of new ice and turbulent fluxes over freezing winter leads, *J. Geophys. Res.*, 103, 15,783-15,802.

Andreas, E. L., and B. Murphy, 1986: Bulk transfer coefficients for heat and momentum over leads and polynya. *J. Phys. Oceanogr.*, 16, 1875-1883.

Ebert, E. E., and J. A. Curry, 1993: An intermediate one-dimensional thermodynamic sea ice model for investigating ice-atmosphere interactions, *J. Geophys. Res.*, 10085-10109.

Maslanik, J. A., R. S. Stone, J. O. Pinto, C. Fowler, 1999: Mobile-platform observations of surface energy budget parameters at the SHEBA site. 5th Conf. on Polar Met. and Ocean., Dallas, TX.

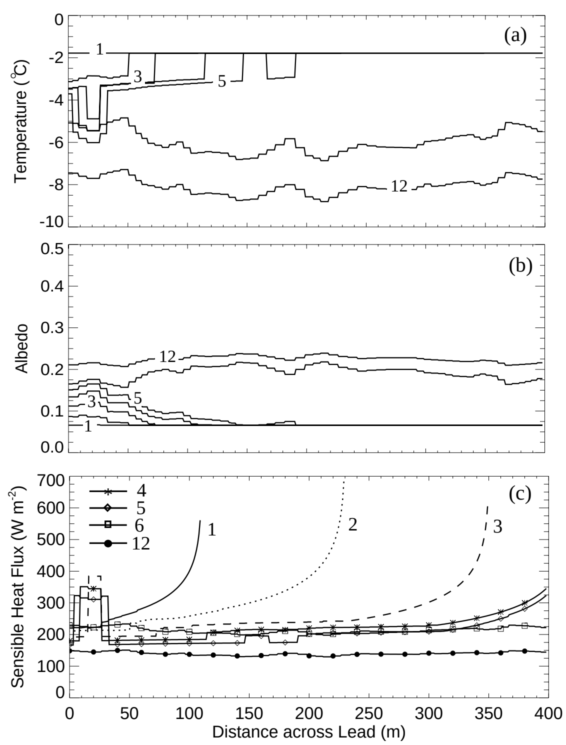


*Fig. 2. Simulated across lead variations in (a) surface temperature, (b) surface albedo, and (c) sensible heat flux for hours 1 through 6 and 12 (odd hours labeled). Hour 1 corresponds with 118.85 UTC in Figure 1. The downwind edge of the lead is at distance 0.*