THE TURBULENT HEAT FLUX FROM ARCTIC LEADS

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Abstract. The turbulent transfer of heat from Arctic leads in winter is one of the largest terms in the Arctic heat budget. Results from the AIDJEX Lead Experiment (ALEX) suggest that the sensible component of this turbulent heat flux can be predicted from bulk quantities. Both the exponential relation

\[ N = 0.14R_s^{0.72} \]

and the linear relation

\[ N = 1.6 \times 10^{-3}R_s + 1400 \]

fit our data well. In these, \( N \) is the Nusselt number formed with the integrated surface heat flux, and \( R_s \) is the Reynolds number based on fetch across the lead. Because of the similarity between heat and moisture transfer, these equations also predict the latent heat flux. Over leads in winter, the sensible heat flux is two to four times larger than the latent heat flux.

The internal boundary layer (IBL) that develops when cold air encounters the relatively warm lead is most evident in the modified downwind temperature profiles. The height of this boundary layer, \( \delta \), depends on the fetch, \( x \), on the surface roughness of the lead, \( z_0 \), and on both downwind and upwind stability. A tentative, empirical model for boundary layer growth is

\[ \frac{\delta}{z_0} = \beta \left( \frac{z_0}{L} \right)^{0.8} \left( \frac{x}{z_0} \right)^{0.4}, \]

where \( L \) is the Obukhov length based on the values of the momentum and sensible heat fluxes at the surface of the lead, and \( \beta \) is a constant reflecting upwind stability.

Velocity profiles over leads are also affected by the surface nonhomogeneity. Besides being warmer than the upwind ice, the surface of the lead is usually somewhat rougher. The velocity profiles therefore tend to decelerate near the surface, accelerate in the mid-region of the IBL because of the intense mixing driven by the upward heat flux, and rejoin the upwind profiles above the boundary layer. The profiles thus have distinctly different shapes for stable and unstable upwind conditions.

1. Introduction

Although in winter the temperature difference between the upper Arctic Ocean and the near-surface atmosphere can be 40°C, the Arctic pack ice generally keeps the two thermally separated. Therefore, when leads – linear areas of open water or very thin ice – occasionally break the continuity of the insulating ice, the heat exchange is

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intense: the rate of turbulent heat transfer from ocean to atmosphere over open
water may be two orders of magnitude larger than the transfer rate through mature
ice (Badgley, 1966; Maykut, 1978). If leads covered 1% of the Arctic Ocean in
winter (Untersteiner, 1964; Badgley, 1966; Coachman, 1966) with the remainder
covered by thick ice, the heat exchange through them would, thus, account for
roughly half of the total turbulent heat transfer between the ocean and the Arctic
atmosphere (Vowinckel and Taylor, 1965; Badgley, 1966). Using a more realistic ice
thickness distribution, Maykut (1978) shows that the substantial transfer through
thin ice alters this proportion: in his model, 20% to 30% of the total turbulent heat
exchange occurs over open water.

Miyake (1965) and Badgley (1966) have tried to measure the magnitude of the
turbulent exchange over leads, and several wind tunnel studies have investigated the
transfer of sensible and latent heat from warm water to cooler air (e.g., Mangarella et
al., 1971, 1973; Coantic and Favre, 1974). Nonetheless, because of the unique
environmental conditions in the Arctic and the difficulties of an in situ measurement,
the turbulent heat flux from leads in winter has remained one of the least-known
terms in the Arctic heat budget.

The AIDJEX Lead Experiment (ALEX; AIDJEX is Arctic Ice Dynamics Joint
Experiment) was organized to define the heat exchange between ocean and atmos-
phere through leads (Paulson and Smith, 1974). During ALEX, Holmgren and
Weller (1974) measured radiative fluxes. This paper discusses the turbulent transfer
of sensible and latent heat. The velocity and temperature profiles above leads – from
which these turbulent fluxes are derived – are interesting by themselves: never have
so many profiles been collected in such nonhomogeneous conditions. Therefore, in
the course of establishing the fluxes, we present 76 pairs of velocity and temperature
profiles over leads, discuss the development of their shapes, and model the height of
the internal boundary-layer (IBL).

2. The Experiment

To determine the turbulent heat flux, it is essential to sample simultaneously the air
flow both upwind and downwind of the leads. Lindsay (1976) gives a full account of
the upwind measurements during ALEX; Andreas (1977) discusses the downwind
measurements; and Heiberg (1974) chronicles all phases of the experiment. In this
section, therefore, we summarize only the more important aspects of the experimen-
tal procedure.

Both upwind and downwind sites had a hut, for housing personnel and electronics,
and two instrument towers, a profile tower and a flux tower (Figure 1). The profile
tower supported one set of sensors which moved from near the surface to a height of
about 4 m sampling velocity, temperature, and humidity profiles. The flux tower
supported velocity and temperature sensors at two fixed heights. The data yielded
spectra and cospectra and so provided a direct determination of momentum and
sensible heat fluxes.