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WHAT IS THE ROLE OF THE SENSIBLE HEAT FLUX ON THE SURFACE HEAT BUDGET OF MULTI-YEAR SEA ICE?

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1.0 INTRODUCTION

The authors carried out a comprehensive measurement program to determine the surface energy budget at the SHEBA site. This paper will focus on the characteristics of the air-ice sensible heat flux and its role in the surface energy budget. The results discussed here are based on covariance measurements at the main tower site. We continuously sampled the sensible heat flux for almost an entire year at nominal levels of 2 m, 3 m, 5 m, 8 m and 18 m.

2.0 GENERAL CHARACTERISTICS

The monthly means (averaging all levels) of the turbulent sensible heat flux ranged from a minimum of -8.0 Wm^{-2} (negative downward, i.e. surface heating) in February to a maximum of 2.4 Wm^{-2} in August (Figure 1.) The pattern of monthly means compares fairly well with the climatological values determined by Lindsay (1998), the latter based on several years of data from the Russian drifting stations. However the magnitudes were smaller. The annual mean was also smaller, -2.1 Wm^{-2}, compared to Lindsay's -3.0 Wm^{-2}. Standard deviations of hourly averages ranged from about 11 Wm^{-2} in winter to 6 Wm^{-2} in summer. Although these values may seem insignificant compared to typical radiative fluxes of 100's of Wm^{-2}, the sensible heat flux over thick ice is nonetheless an important parameter for several reasons. The value of the mean sensible heat flux can make the difference between a net loss or gain of ice in a yearly cycle because the radiative fluxes tend to cancel in the mean. For example, the SHEBA annual mean net surface radiation value was only 2.6 Wm^{-2}. Hourly

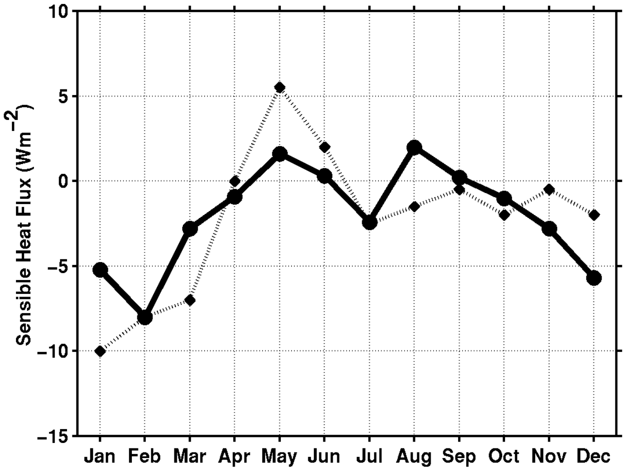

Figure 1. The mean monthly values of sensible heat flux from the SHEBA tower (thick, circles) and Lindsay (1998) (dotted, diamonds).

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fluctuations in sensible heat flux often partially negate surface cooling or heating by radiation; in April over 30% of the hourly surface net radiation was counteracted by surface sensible heat fluxes. The sensible heat flux is a key parameter in terms of lower atmospheric dynamics and stability because it represents the primary means of heat transfer between the surface and the air just above.

3.0 HEAT FLUX REGIMES

Sensible heat flux "events" can be divided into two types: advective and radiative. During "advective" events, temperature changes in the air above the surface lead temperature changes of the surface proper. These events are generally caused by temperature advection in the atmospheric boundary layer but could also be caused by radiative cooling or entrainment at the top of the boundary layer. During radiative events, the surface temperature leads; these are usually a result of changes in cloud cover or diurnal changes in solar radiation.

During the winter, the sensible heat flux is usually downward and switches between radiative and advective events. Cloud clearing induces cooling radiative events and these are counteracted by warm advective events. This is indicative of the main energy transfer process in polar winters: heat is lost by longwave radiation to space and replaced by warm advection from lower latitudes, as seen in the example from SHEBA (Figure 2). When solar radiation becomes important in the spring, the sensible heat fluxes go up and down and radiative events dominate, see the SHEBA example for April (Figure 3). During this period and to a lesser extent in the early fall, the air temperature is characterized by diurnal cycles. In mid-summer the surface starts to melt and remains near 0°C at all times; advection and radiation events change the water phase instead of the air temperature. Thus we see the Arctic is characterized by three sensible heat flux regimes: (1) a winter radiational cooling - advective heating regime dominated by changes in cloud cover, (2) a spring and fall diurnal radiative regime and (3) a summer melt regime.

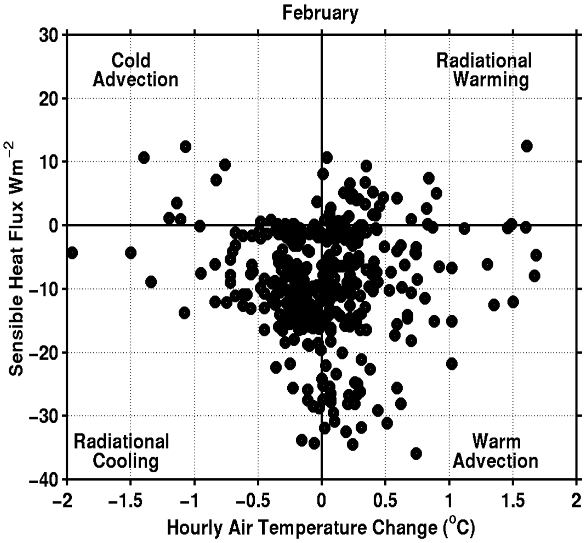

Figure 2. Scatter plot of hourly air temperature change vs. average sensible heat flux for the month of February at the 2-meter main tower level.

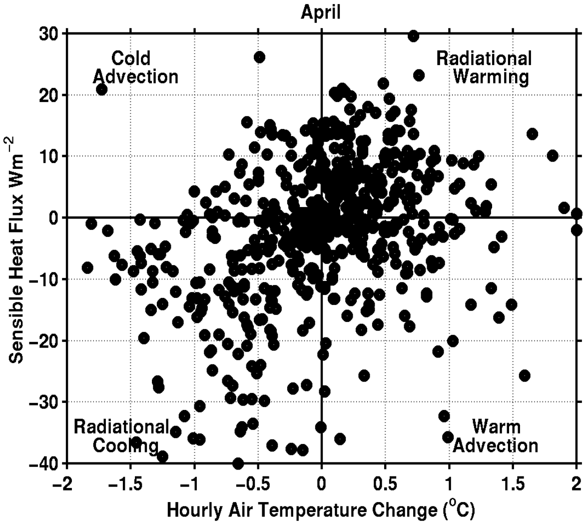

Figure 3. Same as Figure 2 for the month of April.

4.0 PARAMETERIZING THE SENSIBLE HEAT FLUX

The key parameter related to representations of sensible heat flux, H_s, in numerical models is the sensible heat transfer coefficient, C_H

$$C_H = H_s/U(T_o-T)\rho c_p \qquad (1)$$

where U is the wind speed, T_o and T are the surface and air temperatures and ρ and c_p are the air density and the air heat capacity. The sensible heat transfer coefficient can be expressed as a function of the momentum and temperature roughness scales z_o and z_{ot} and the integrated stability functions for momentum and temperature ψ_u and ψ_t.

$$C_{H10} = \frac{k^2}{[\ln(10/z_o) - \psi_u][\ln(10/z_{ot}) - \psi_t]} \qquad (2)$$

where C_{H10} is C_H referenced to 10 meters and k is von Karmen's constant.

The temperature roughness scale, z_{ot}, is more difficult to measure than z_o for three main reasons. First, it requires an accurate measurement of surface temperature. Second, it cannot be done in neutral conditions because there is no heat flux. Third, because it must be measured in non-neutral conditions, the derived value depends on the form of the stability functions that are used. Figure 4 shows the effects of stability on the value of C_{H10} during SHEBA. In this case, we found that the simple stability function $\psi_u = \psi_t = -7(z/L)$ provided a reasonable fit to the data in stable cases (z/L > 0) where L is the Obukhov length scale, although more work is required to before this result is confirmed. This function is represented by the thick curved line in Figure 7.

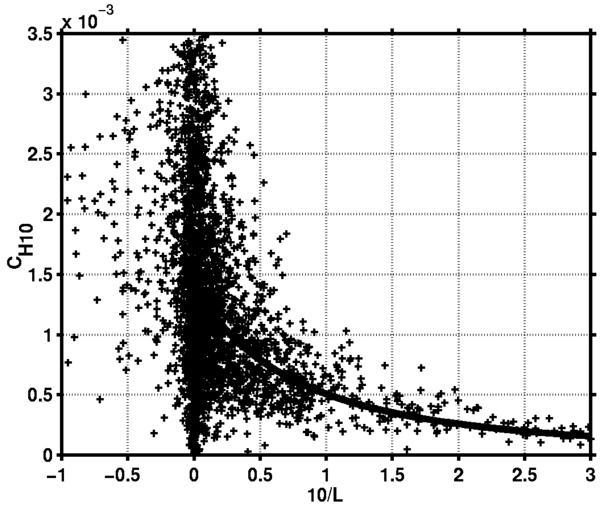

Figure 4 Sensible heat flux transfer coefficient referenced to 10 meters as a function of the stability parameter 10/L for all available data from the 8 meter tower level.

The difficulty in determining the value of z_{ot} is demonstrated in Table 1, which shows the median value of the near neutral heat transfer coefficient for 10 meters, C_{H10}, and the roughness parameters based on all usable data from the SHEBA project for all the tower levels.

Table 1. Sensible Heat Transfer Parameters

Nominal Tower Level Height (m)	z_o x 1000 (m)	z_{ot} x 1000 (m)	C_{HN10} x 1000
2	0.291	0.531	1.53
3	0.355	0.252	1.48
5	0.701	0.162	1.53
8	0.614	0.093	1.43
18	0.524	0.058	1.36

Note: The values in Table 1 have not been subjected to quality control; they are for demonstration purposes only and should not be used at this time.

Notice that the temperature roughness parameter, and to a lesser degree C_H, are a function of tower height, contrary to standard Monin-Obukhov surface layer theory. This is probably because the surface temperature used to determine these parameters was based on measurements on the ice floe near the tower and did not take into account lead effects. Heat (cooling) from nearby leads in winter (summer) caused a divergence (convergence) of heat between the lower and upper portions of the tower. The values in Table 1 are strongly dependent on the type of editing procedure used to process the data and further work is required to determine how the sensible heat flux should be parameterized in numerical models.

5. CONCLUSIONS

The value of the data from the HEBA sensible heat flux measurements is not so much that they represent an Arctic climatology, but rather because they represent an opportunity to understand the details of the physics of the heat transfer process. In conjunction with other measurements at the SHEBA camp, these measurements should helps scientists untangle the complicated processes that must understood in order to develop accurate geophysical model of the Arctic and its role in the global climate system.

6. ACKNOWLEDGEMENT

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7. REFERENCE

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