11.8 # Field Observations of the Influence of Pack Ice Cover on Surface Heat Fluxes

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1. BACKGROUND

The development of extensive pack ice fields on the Great Lakes influences the degree to which the atmosphere is modified locally and on a larger-scale. It is important to understand the atmospheric response to variations in the concentration and arrangement of pack ice on the Great Lakes; however past investigations have lacked observations needed to quantify this over-lake interaction. This paper describes the Great Lakes Ice Content – Atmospheric Flux (GLICAF) experiment, which was conducted to examine the influences of pack ice on atmospheric exchanges with the surface.

The majority of the ice on the Great Lakes is pack ice, which is not attached to the shore. Pack ice is classified by size (*ice field*: collection of ice floes at least 8 km; *ice floe*: single piece of pack ice; *ice cake*: ice fragments up to 11 m across; *brash ice*: fragments up to 2 m across), age, arrangement, and concentration. The pack ice cover can be very transitory during the winter, particularly in mid-lake areas where freeze-up and break-up events, snowfalls, and winds can alter the ice cover. Figure 1 shows an aerial photo of pack ice fields over Lake Erie, illustrating some of the variability of arrangements and concentrations of pack ice observed over Lake Erie during GLICAF.

Investigations of boundary layer development and the magnitude of surface heat fluxes over ice-covered water have been predominantly conducted in high-latitude oceanic regions where meltponds, leads, polynyas, and a multiyear ice pack exist. Several of these studies have focused on examining the atmospheric circulations, surface heat fluxes, and convective plumes associated with Arctic leads (e.g., Alam and Curry 1995, Lavelle 1997, Pinto et al. 1995, Uttal et al. 2002) and their contribution to the surface energy budget (Pinto et al. 2001). While the Great Lakes annual ice fields have some structural similarities to Arctic multiyear ice fields, such as fractures separating ice floes, the more temporally and spatially variable Great Lakes ice fields limit the applicability of results from Arctic boundary layer studies to this lower latitude region.

Meteorological field projects in the Great Lakes have focused on boundary layer responses to the

Figure 1. Photograph of the surface of Lake Erie taken from the University of Wyoming King Air on 25 February 2004, 1120 UTC. Photo courtesy of Michael Spinar.

surface diabatic forcing over ice-free regions. For example, recent studies using data from the Lake-Induced Convection Experiment (Lake-ICE, Kristovich et al. 2000) detailed the over-lake evolution of the atmospheric boundary layer and mesoscale circulations above ice-free areas (Young et al. 2000, Mayor 2001, Miles 2002, Schroeder 2002, Kristovich et al. 2003). Great Lakes ice research investigations have focused on ice extent, thickness, characteristics, and processes (e.g., Bolsenga 1992). More recent investigations of Great Lakes ice fields have used satellite-based instrumentation to identify ice extent and surface properties, such as roughness scales and motion dynamics (e.g., Pilant and Agarwal 1998). Several Great Lakes studies have examined the relationship between the extent of ice cover and large-scale weather patterns (e.g., Rodionov et al. 2001, Assel et al. 1985, 1996); however, interactions between the atmospheric boundary layer and ice fields with varied ice concentrations have not been investigated.

The GLICAF field experiment sought to collect data to allow for an improved understanding of over-lake surface exchange processes between ice concentration and surface heat fluxes.

2. GLICAF FIELD EXPERIMENT

In order to achieve the primary goal of the Great Lakes Ice Cover – Atmospheric Flux (GLICAF) field experiment, data were concurrently collected on surface pack ice concentration and turbulent surface heat fluxes (latent and sensible) over a range of ice concentrations.

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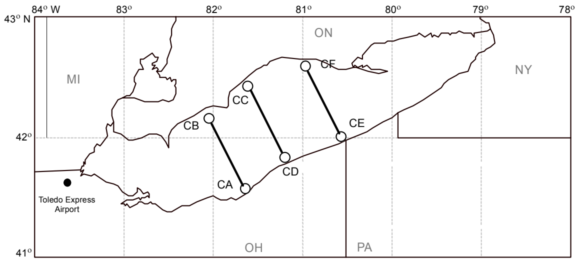

Figure 2. Approximate flight pattern on 26 February 2004. Solid lines denote locations of the flight stacks. Circles denote locations of spiral soundings.

Data were collected by the University of Wyoming King Air in February 2004 over Lake Erie.

The King Air was equipped with standard sensors for measuring atmospheric state, motion, radiation, and microphysical properties (standard instrumentation can be found at http://flights.uwyo.edu/). Vertical heat fluxes were determined using eddy correlation techniques from observations of vertical motions, potential temperature, and atmospheric moisture. Observations of these parameters were averaged to 20 Hz, or about 4 m flight distance. Estimates of the magnitudes of surface heat fluxes, and other boundary layer parameters, will be presented.

Observations of ice cover were obtained through the use of a downward viewing digital video camera. The video gave continuous observations of visible surface conditions from flight altitudes of 500 m. Supplemental data were obtained through a Heimann downward-pointing radiometer (Heimann KT-19.85), with a nominal accuracy of 0.5 °C. Intercomparisons between the video and Heimann data are discussed below.

The King Air conducted research flights on five days, three of which exhibited positive heat fluxes over Lake Erie. The research flights on these three days consisted of a series of two-altitude flight stacks and spiral soundings to heights of about 2 km above the lake surface (ALS) conducted at the beginning and end of the flight stack. An example flight pattern is shown in Figure 2. The first flight leg in each flight stack was conducted at approximately 500 m ALS in order to obtain observations of the surface ice cover. Two subsequent flight legs in each stack were flown at approximately 50 m ALS (lowest possible flight altitude)

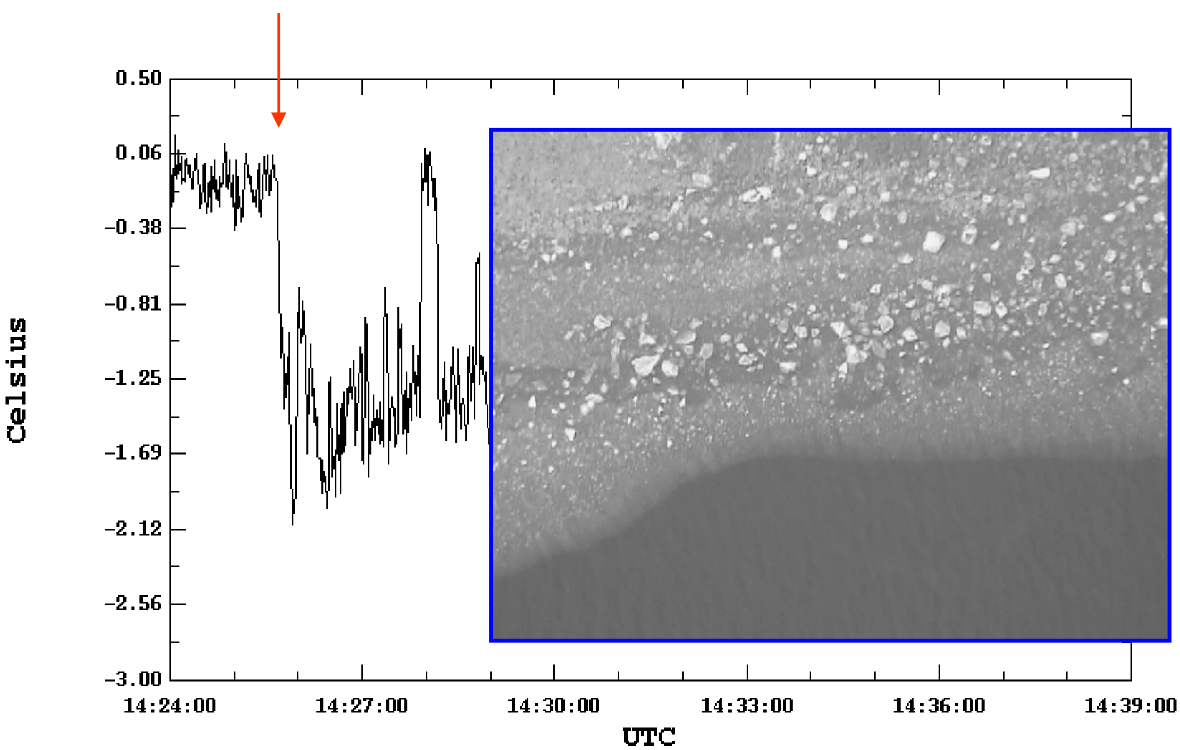

Figure 3. Example of changes in Heimann radiometric temperature when the aircraft flew over a water-ice boundary. The plot is of Heimann radiometric temperature as a function of time on 26 February 2004. The red arrow shows the time of the inset video image. In the video image, the aircraft is flying from bottom to top.

to measure surface heat flux variations. Flight legs were oriented approximately perpendicular to the mean boundary layer wind direction.

3. ICE COVER AND HEAT FLUX OBSERVATIONS

The primary dataset used to determine ice cover was obtained by a downward-pointing digital video camera taken at passes approximately 500 m above the lake surface. Since it may be difficult to differentiate open water from thin ice in some of the video images, observations from the Heimann radiometer, which gives data on surface temperature, were also examined. Figure 3 illustrates the correspondence between the video and Heimann observations during a portion of flight on 26 February 2004. Note that the surface temperatures abruptly fell from near 0°C to -1.5°C as the aircraft flew from open water to ice conditions. Many smaller-scale features are also evident in both the video and Heimann observations. Additional work will be shown demonstrating the correspondence between these two observational techniques.

On most dates in this study, Lake Erie was largely covered with ice (estimates from the National Ice Center suggested ice cover 70- 90% over most of the lake). On 26 February, video imagery, Heimann observations, and satellite data confirm this result. Despite the ice cover, small differences between air temperatures (generally 0° to -3°C) and lake surface temperatures (near 0° to 1°C in areas of open water), and light wind speeds, positive heat fluxes were clearly evident in many of the 50-m flights conducted on 25, 26, and 27 February 2004. This is illustrated in Figure 4, which shows evidence of positive fluxes in the one-minute time series on 26 February over pack ice cover.

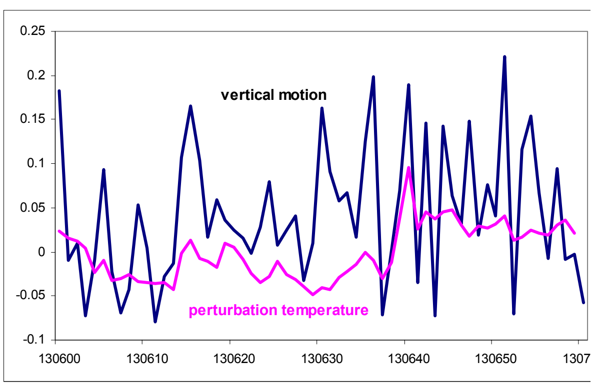

Figure 4. Time series of vertical motion and perturbation temperature (pass-mean temperature removed) on 26 February 2004. Data were collected by the University of Wyoming King Air at an altitude of approximately 50 m.

Further investigations will quantify the estimated fluxes and develop relationships between the fluxes and variations in surface pack ice cover.

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