7.17 SPATIAL VARIATIONS OF SURFACE TEMPERATURES AND HEAT FLUXES OVER LAKE MICHIGAN

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1. INTRODUCTION

Surface heat and moisture fluxes are a fundamental driving force for the development of convective boundary layers and lake-effect snow storms over the Great Lakes (e.g., Lenschow 1973, Eichenlaub 1979). For example, Chang and Braham (1991) found that surface fluxes accounted for much of the heat and moisture budgets of a lake-effect boundary layer over Lake Michigan. Variations in lake surface temperatures and surface fluxes might therefore be expected to result in variations in the boundary layer structure. Indeed, Kristovich and Laird (1998) found that mesoscale variations in lake surface temperature, as derived from satellite observations, resulted in significant changes in the location of the upwind cloud edge in several lake-effect events. Hjelmfelt (1990), using numerical sensitivity tests, found that surface heat and moisture fluxes played an important role on mesoscale convective structures.

Currently, satellite-derived analyses of lake surface temperature distributions, provided by the National Oceanic and Atmospheric Administration Great Lakes CoastWatch program (Schwab et al. 1992), are the best available operational dataset of water surface temperature fields. Schwab et al. (1999) showed that data provided through CoastWatch had a mean difference of less than 0.5^{o}C with coincident in-situ observations from buoys. *However, frequent cloudiness over the Great Lakes region in winter can result in long time periods where satellite estimates of surface temperature are not available for large portions of the lake. This, in turn, can result in derived temperature analyses of the Great Lakes that become less representative of actual water temperature distributions with time, potentially producing significant uncertainty in the results of scientific investigations of resultant mesoscale atmospheric circulations.*

This presentation will outline initial results of two efforts to: 1) compare Lake Michigan surface temperature analyses derived from AVHRR satellite observations with those obtained by low-flying aircraft during the Lake-Induced Convection Experiment (Lake-ICE), and (2) examination of resultant over-lake variations of heat and moisture fluxes.

2. ANALYSIS METHODOLOGY

Satellite-derived lake surface temperature observations were derived using a method described in Schwab et al. (1992) and provided for this study by the CoastWatch program. In short, CoastWatch composites lake surface temperature observations from cloud-free portions of the lake using several techniques into a daily lake surface temperature map. During cloudy time periods, the temperature maps may represent conditions observed days earlier. Example lake surface temperature maps are given in Figure 1.

Aircraft data were collected by the National Center for Atmos. Res. Electra and the Univ. of Wyo. King Air. These aircraft observed the vertical, horizontal, and temporal evolution of lake-effect boundary layer phenomena (see Kristovich *et al*. (2000) for details). As part of these research flights, the aircraft were often at altitudes appropriate for remote sensing of the lake surface temperature and estimation of heat fluxes using eddy correlation techniques.

Lake surface temperatures were obtained from both aircraft with Heimann KT 19.85 pyrometers. Because of the strong effects of liquid water and atmospheric vapor content on these observations, the following criteria were met for all aircraft data used in this study: 1) flight altitude was less than 250 m above the lake, 2) the roll and pitch angles of the aircraft were less than 3.5^{o}, and 3) in situ instrumentation did not detect more than 50 cm^{-3} cloud particles (as measured by FSSP). Flight altitudes were somewhat high for surface heat flux estimates, but should be adequate for determination of their spatial variations.

A comparison of pyrometer observations from the two aircraft was carried out for the 5 Dec. 1997 case, when the aircraft flew side by side across portions of Lake Michigan. These pyrometer observations generally indicated cloud top temperatures. Temporal (spatial) variations were in excellent agreement. However, the Electra observations had to be corrected by +3.1^{o} C to account for an offset between the aircraft and to bring these observations more inline with aircraft and sounding observations of cloud-top temperatures. Further intercomparisons on other days of the project gave results consistent with this analysis.

Dates for this study were chosen based on availability of adequate aircraft data. The lake was covered by clouds during much of December 1997 and January 1998, limiting satellite observations of the lake surface. Weak lake-effect convective patterns were observed on 20 December 1997 with relatively cool air flowing from northwest-to-southeast across Lake Michigan in the vicinity of the aircraft observations. Lake-effect convection on the 19-20 January cases

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was more complex, with organized convective bands in several locations and with different orientations over the Lake. Since there were no notable changes in satellite lake surface temperatures from 19 to 20 January, these dates were combined for this study.

3. SURFACE TEMPERATURE COMPARISON

Figure 1 gives AVHRR-derived lake surface temperatures (left panels, from CoastWatch) and aircraft-derived lake surface temperatures from both aircraft (right panels), for December 20, 1997, and combined data from January 19-20, 1998. Despite the presence of clouds over the lakes during most of December 1997 and January 1998, limiting updates of satellite-derived lake surface temperatures, surface temperature observations agreed quite well. Generally, aircraft-observed surface temperatures were within about 2^oC of those from satellite.

Despite the good statistical agreement in temperature observations, however, significant regional differences were visible. For example, on the 19-20 January case, satellite-derived temperatures were $2\text{-}3^oC$ warmer in the southeastern-most and northern-most portions of the aircraft observations. Time series animations of CoastWatch data revealed that this region was largely cloud covered or otherwise unavailable for over 10 days before, and over 5 days after, the aircraft operations. Once clear skies were present over that portion of the lake, the satellite-derived surface temperatures dropped quickly in this region, possibly explaining the difference. Other regions of differences in estimated surface temperatures over 1.5^oC were noted on both dates.

From a boundary layer standpoint, regional variations in lake surface temperature may be more important to mesoscale circulation patterns than random temperature differences throughout the observation region. For example, Hjelmfelt (1990) found that relatively minor lake surface temperature variations could significantly influence the primary mesoscale circulation that develops. Kristovich and Laird (1998) found that lake-effect cloud patterns responded to minor mesoscale variations in lake surface temperature. On 20 December 1997, for example, lake surface – air temperature differences generally ranged from $6\text{-}7^oC$. A $1\text{-}2^oC$ error in lake surface temperature can give rise to as much as a 20-30% difference in estimated regional surface heat and moisture fluxes on 20 December.

4. SURFACE FLUX OBSERVATIONS

The 20 December 1997 case was chosen for a detailed examination of heat flux measurements from aircraft due to the relatively simple west-to-east growth of the convective boundary layer in the locations of aircraft flights on this day. Figure 2 gives lake-air temperature differences, sensible heat fluxes, lake-air mixing ratio differences, and latent heat fluxes along the NW-SE flight passes shown in Figure 1b. These data were taken at a single height level, about 195 m above the lake surface.

Across most of Lake Michigan, there is a general decrease in air-lake temperature and mixing ratio differences from NW to SE. This is due primarily to increasing atmospheric temperature and moisture across the lake (not shown), since lake surface temperatures were nearly steady or increasing across the lake. Local variations in lake surface temperature gave rise to lower lake-air temperature differences near the upwind end of the flight leg, and locally higher differences near the downwind end.

Correspondingly, surface sensible and latent heat fluxes decreased slowly from NW to SE along the flight path by approximately 20-40% and 10-30% for sensible and latent heat fluxes, respectively. These trends are similar to those observed in the lake-effect event studied in Chang and Braham (1991). Increases in wind speed from about 5 to 8 m s^{-1} across the lake (not shown) may have partially offset the effects of the large cross-lake decreases in lake-air temperature and mixing ratio differences.

5. SUMMARY AND CONCLUSIONS

CoastWatch Great Lakes surface temperature distribution analyses are the best dataset available operationally. However, scientific analyses must cautiously use these data, because they cannot be updated when clouds cover the lakes, leading to potentially significant uncertainty in temperature fields. Aircraft observations of lake surface temperatures were compared to CoastWatch satellite-derived lake surface temperature fields for three cases of wintertime lake-effect snow storm events. Despite the large number of days with cloud cover limiting satellite observations, the overall agreement was quite good (generally within about 2^oC). However, mesoscale regions of surface temperature differences above 1.5^oC were noted. Such differences on weak lake-effect dates may influence boundary layer structure and mesoscale circulations. Aircraft-observed sensible and latent heat fluxes, derived by eddy-correlation techniques, showed the expected cross-lake decreases. However, these observations indicated regional variations in fluxes partially accounted for by lake surface temperature variations.

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6. REFERENCES

Hjelmfelt, M. R., 1990: *Mon. Wea. Rev.*, **118**, 138-150.

Lenschow, D.H., 1973: J. Atmos. Sci., 30, 568-581.

Kristovich, D.A.R., and N.F. Laird, 1998: Wea. Forecasting, 13, 541-551.

Kristovich, D.A.R., and co-authors, 2000: Bull. Amer. Meteor. Soc., 81, 519-542.

Schwab, D.J., G.A. Leshkevich, and G.C. Muhr, 1999: J. Great Lakes Res., 25, 468-481.

Schwab, D.J., G.A. Leshkevich, and G.C. Muhr, 1992: J. Great Lakes Res., 18, 247-258.

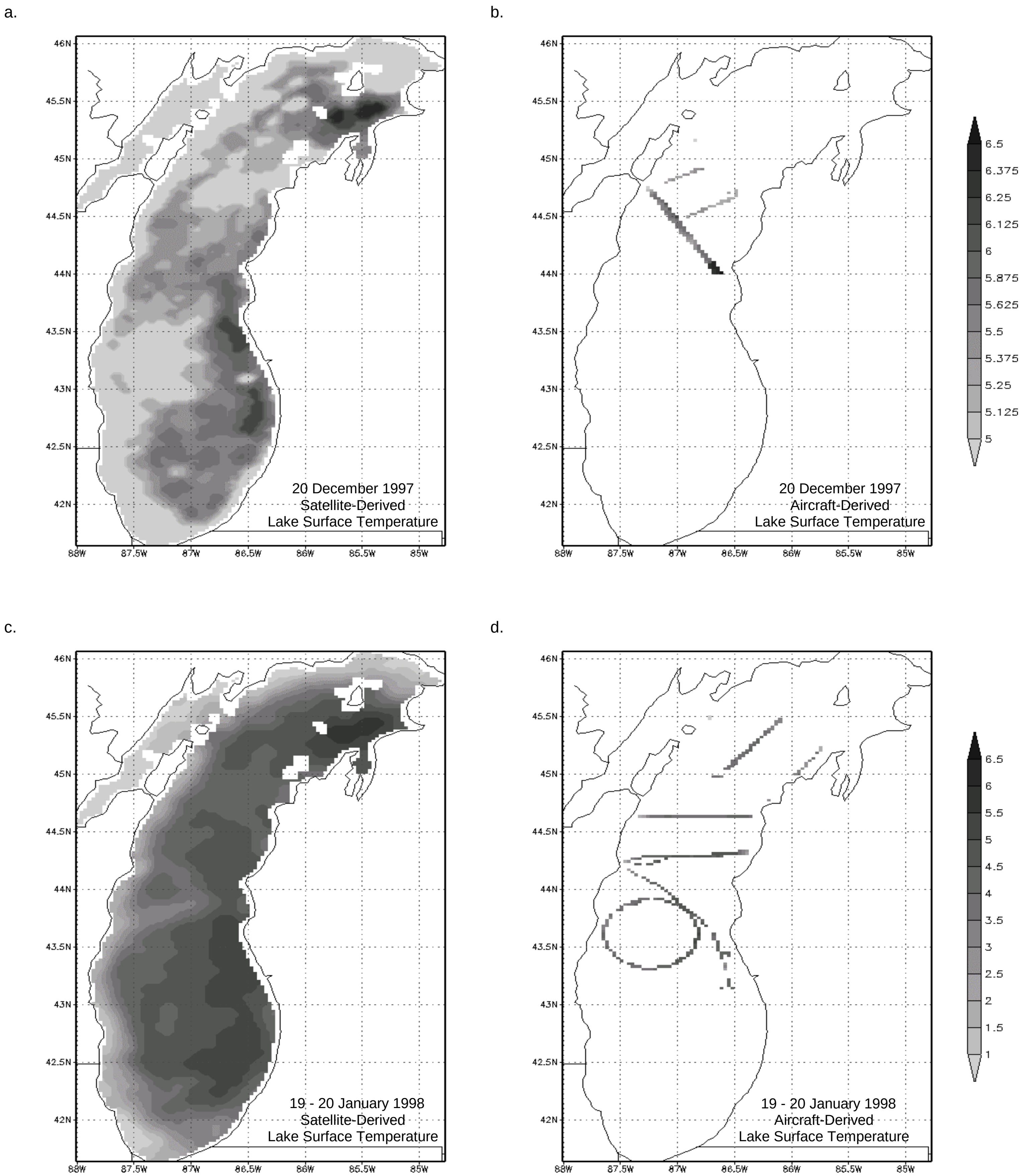

Figure 1. Lake surface temperatures from satellite (CoastWatch, panels 1a and c) and aircraft (Lake-ICE, panels 1b and d) observations.

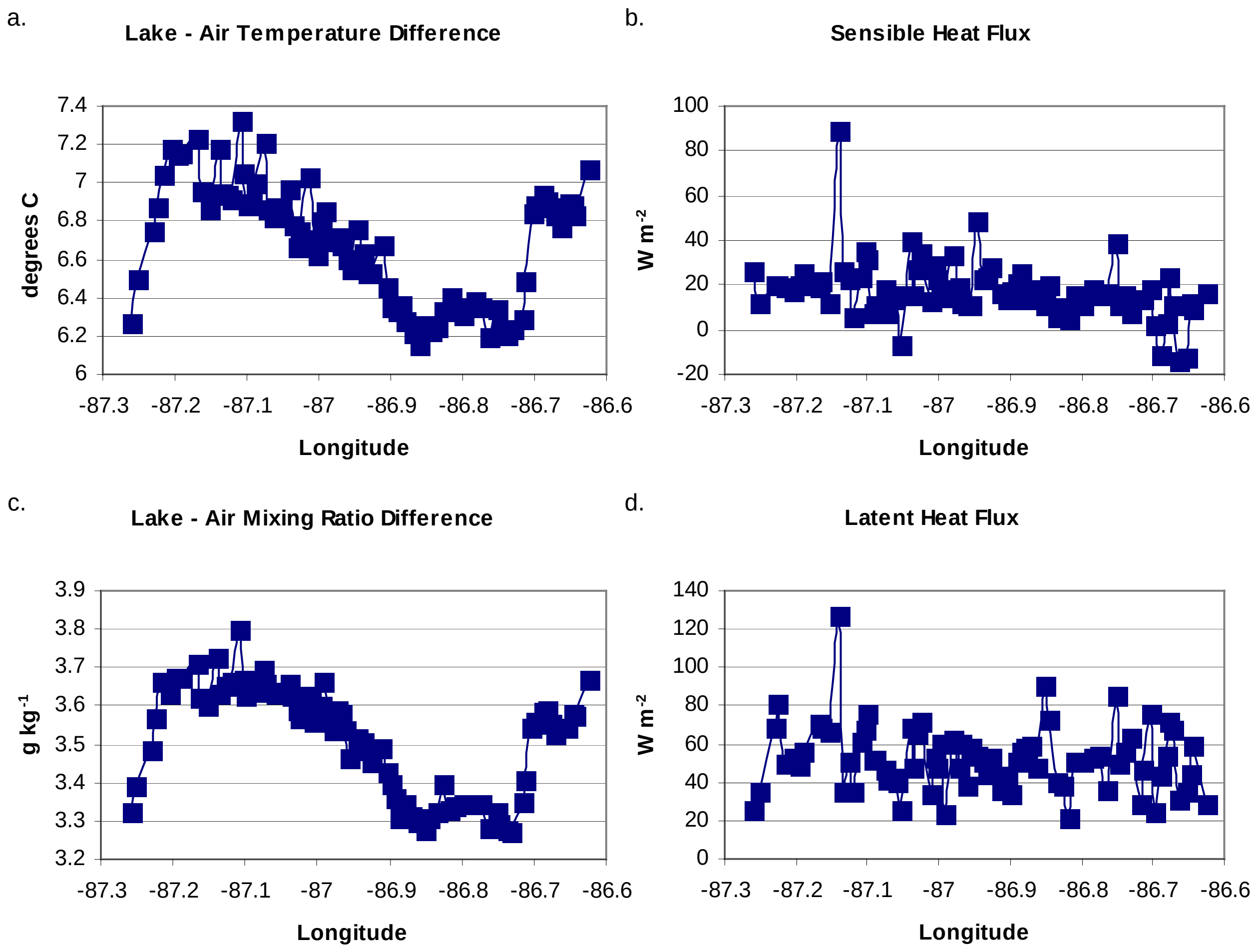

Figure 2. 20 December 1997 observations of lake-air temperature differences (panel 2a), sensible heat fluxes (panel 2b), lake-air mixing ratio differences (panel 2c), and latent heat fluxes (panel 2d). These data were taken along a Northwest-to-Southeast oriented flight track.