Final Project Report – 15 August 2011

Pilot Field Observations of Lake Michigan Atmospheric Boundary Layers: Seed Project Proposal

Funded by Illinois-Indiana Sea Grant Program

David Kristovich, Ph.D.
ISWS, Prairie Research Institute, University of Illinois
Champaign, IL

The objective of this project was to take pilot observations using a new mobile sounding system, to add support to a future proposal to determine processes by which deep convective systems reaching Lake Michigan are modified by interactions with the lake. Specifically, the goals of the project were to A) test the ability of a mobile atmospheric sounding system, and best deployment methods, to observe marine boundary layer (MBL) structure and evolution across Lake Michigan, B) Compare observations from this sounding system to nearby standard NOAA National Weather Service (NWS) sounding data in the Great Lakes region, C) Conduct initial tests of theories by Workoff (2010) on cross-lake changes in marine boundary layer vertical stability and wind structure, and D) Use pilot data gathered during these field tests to develop a more complete observational field study of interactions between Lake Michigan marine boundary layers and deep convective storm systems.

1. Mobile Sounding System and Field Operations in 2010 *(Goal A)*

Funds from this grant supported deployment of our mobile sounding system on nine dates during the warm season in 2010, summarized in Table 1. Soundings were taken at a number of locations and atmospheric conditions primarily to test the rawinsonde system's ability to observe shallow, stable marine boundary layers (MBLs) over and near the lake. In addition, we conducted three special launches (31 July, 4 August, and 17 November) to test the rawinsonde under different large-scale weather regimes, compare with operational soundings taken by the NWS and provide test and educational opportunities for students.

Dates	Location	Launch Times (LT*)	Goals
31 July 2010	Homer, IL	1606	Test launch
4 August 2010	Mahomet, IL	1403	Comparison with NWS sounding; severe storm conditions
8 August 2010	Muskegon, MI	0825, 1136, 1409, 1648	MBL air advection case
9 August 2010	Muskegon, MI	1118, 1406	MBL air advection case
12 August 2010	Ludington, MI	1716	Lake breeze circulation
13 August 2010	Ludington, MI to Manitowac, WI	1103, 1240, 1619, 1752	Over-lake (Badger ferry) MBL
21-22 September 2010	Whitehall, MI	1114, 1246, 1319, 1519, 1720, 1838, 2027	MBL, pre- and during squall line
17 November 2010	New Brunswick, IN	2019, 2219	Cyclone, comparison with research radar

* *LT denotes local time at the location that the soundings were initiated.*

As will be discussed below, the operations were quite useful. The new mobile sounding system showed an ability to observe MBLs that was better than expected, but with

some realistic limitations. In terms of operations, we learned that ideally, launches should be conducted no more frequently than once every 1.5 to 2.0 hours. For study of low-level features, such as MBLs, rise rates of 200-300 m/min appear to be an ideal balance between giving high vertical resolution observations, limiting horizontal movement of the rising balloon, and ensuring adequate ventilation of the rawinsonde sensors. Such practical understanding of the system's capabilities will prove very useful in developing and proposing future field operations.

2. Comparison with Rawinsonde Test Case – Mahomet, IL *(Goal B)*

A scheduled launch to train graduate students the proper methods for obtaining sounding observations, at 1400 UTC on 4 August 2010, turned out to be an ideal opportunity to compare our observations with those of a standard NWS sounding. Due to anticipated severe weather, the NWS Forecast Office in Lincoln, IL, conducted a launch at approximately 1300 UTC, one hour and about 70 km west of our launch at Mahomet, IL. Figure 1 gives a "skew-T" plot of data taken by our and the NWS. These soundings preceded the development of a line of severe thunderstorms over Illinois and Indiana, ultimately producing more than 200 reports of severe winds and damage from Indiana to Virginia.

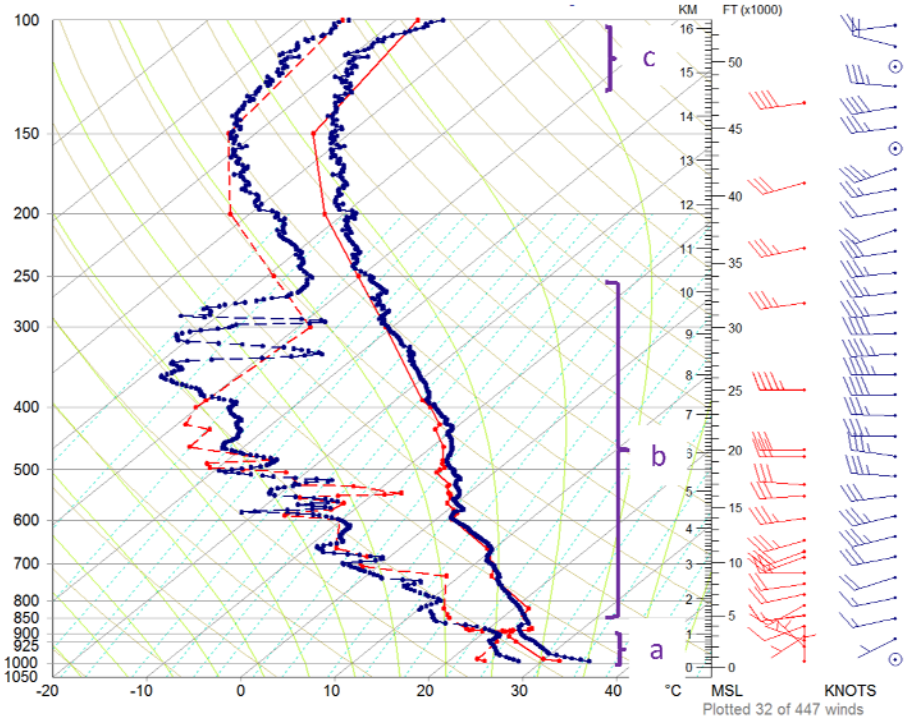

Figure 1. "Skew-T" plot of sounding observations taken by the NWSFO in Lincoln, IL (approximately 1700 UTC, red) and by our project team at Mahomet, IL (1802 UTC, blue). The vertical axes are height measured in length units (right axis) or atmospheric pressure (left axis). Data points reflect temperature (right-most series of points) and dew point temperature (left-most series of points). Wind velocities, shown at the right, include compass direction from which the wind was blowing (north is upward) and speed (full flags denote 2.5 m s^{-1}, half-flags denote 5 m s^{-1}). Note that the temperature axis is skewed upward from left to right, to make sounding features more visible. See text regarding labeled layers.

There is strong correspondence between the two soundings. Most features seen in the NWS sounding were present in the mobile sounding system observations: 1) Low-level mixed boundary layer, capped by an inversion, b) increasingly dry air above the boundary layer up to near the top of the troposphere, a relatively moist tropopause, and similar wind profiles. There was a tendency for the NWS sounding to

be cooler by up to 1-2°C, perhaps reflecting the warming atmosphere over the hour between launches. This consistency adds confidence in the efficacy of our observations. Note the much greater vertical resolution available from our sounding, allowing for detection of more fine-scale features.

3. Ability to Observe Marine Boundary Layers over and Near Lake Michigan *(Goal A)*

Several examples of observations taken during the project illustrate the usefulness of the soundings for future field experiments.

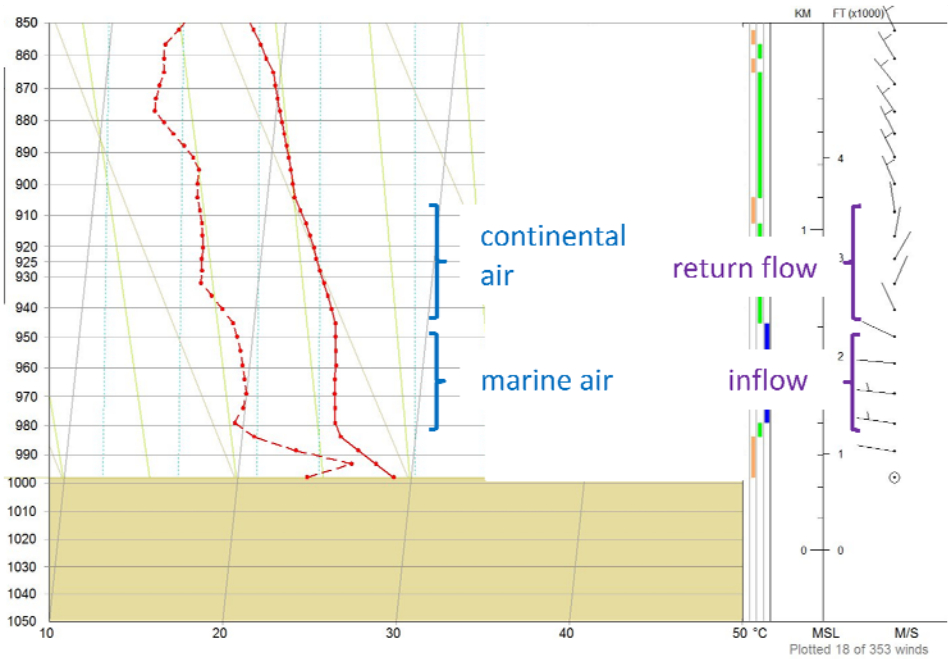

Figure 2. "Skew-T" plot of sounding taken at Ludington, MI on 12 August 2010.

a. Lake breeze case

Atmospheric conditions were warm with light winds, ideal for the development of lake breezes on 12 August. Such circulations are generated by temperature differences between the land and lake surface. A launch on this day allowed us to compare our observations with the well-known MBL circulations to test this mobile sounding system's ability to observe such shallow layers. Figure 2 shows the observations within the lowest 2 km of the atmosphere. Wind, temperature, and dew point profiles were observed to have very similar features to those seen in previous observational and modeling studies of lake breezes, further supporting the use of this mobile sounding system for studies of low-level MBL.

Figure 3. The PI launching a rawinsonde system from the top of the SS Badger on 13 August 2010.

b. Over-lake observations (Goal C)

We received permission to launch soundings from the SS Badger as the ferry crossed Lake Michigan from Ludington, MI, to Manitowac, WI and back on Friday, 13 August. This provided a unique opportunity to observe over-lake conditions on a day when warm air was blowing across a relatively-cool lake surface. Four successful launches were conducted from the top of the ship in rather windy conditions (Figure 3), with extraordinary help from the Badger crew. The soundings (not shown) indicate the clear presence of a cool, stable MBL over the lake, distinctly different than the overlying airmass, further indicating the system's capabilities.

Initial comparisons between these observations and theoretical MBL characteristics by Workoff (2010) were conducted. In general, the depth of the MBL was similar to those predicted. However, due to the cross-ferry-track (southerly) direction of the winds and changing wind conditions throughout the day, a much more detailed analysis than possible under this funding must be conducted to produce a thorough comparison.

c. Observations preceding, and within, a thunderstorm squall line

A unique opportunity arose on 21 September. Warm air moved from the southwest over the relatively cool lake waters, as a thunderstorm squall line developed over Wisconsin. This allowed us to take sounding observations of the airmass ahead of the thunderstorm throughout the day, a weather situation very similar to that described in Workoff (2010) and one motivation for the present study. The final balloon launched on that day, approximately 30 min before the time period shown in Figure 4, entered the storm. The upward motion of the balloon ended abruptly at about 4.5 km height, nearly coincident with a nearby lightning strike, after which observations taken as the sonde sank back to the surface.

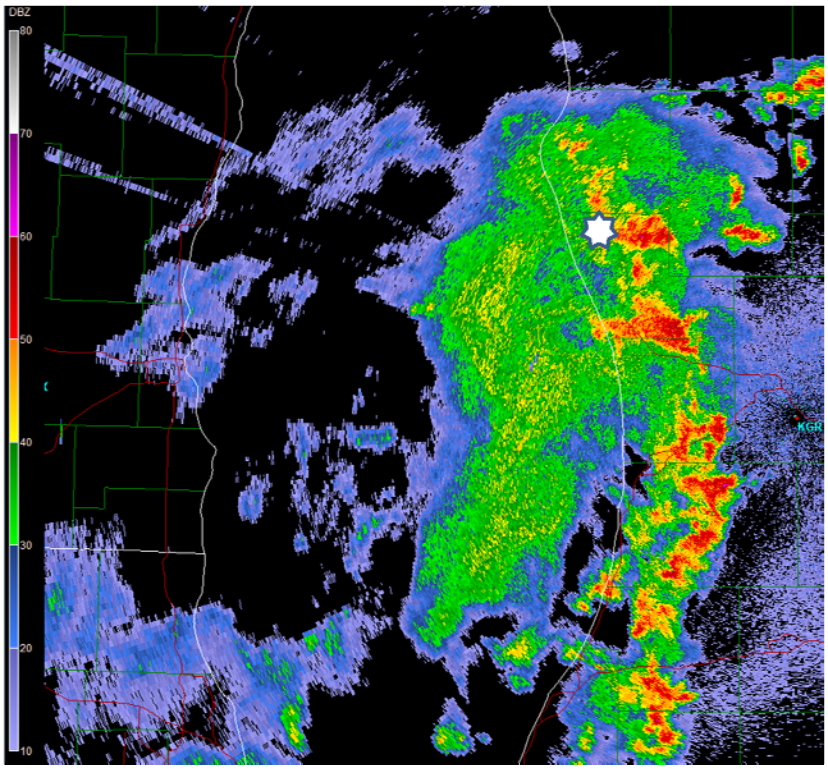

Figure 4. Plan-view observations of a thunderstorm squall line that had crossed Lake Michigan, taken by the NWS WSR-88D radar at 0055 UTC on 21 September 2010 .The approximate location of the rawinsonde launches on this day is shown by the white star.

Soundings taken during the day showed a very interesting evolution of the MBL, which formed as air flowed from the southern end of the lake to the launch site. Cool layers near the surface, indicated by sounding temperatures

increasing with height, reached depths of approximately 500-600 m (estimated as the above-surface height of maximum temperature). In the later soundings, the depth of the cool layers only reached about 100 m. While surprising, the increasingly shallow cool layer appears reasonable physically. We hypothesize that as the air upwind of the lake warmed during the day, the difference in temperature with the relatively cool lake surface increased. Downward heat transfer would tend to cool the lowest portions of the atmosphere more rapidly as the air above the lake

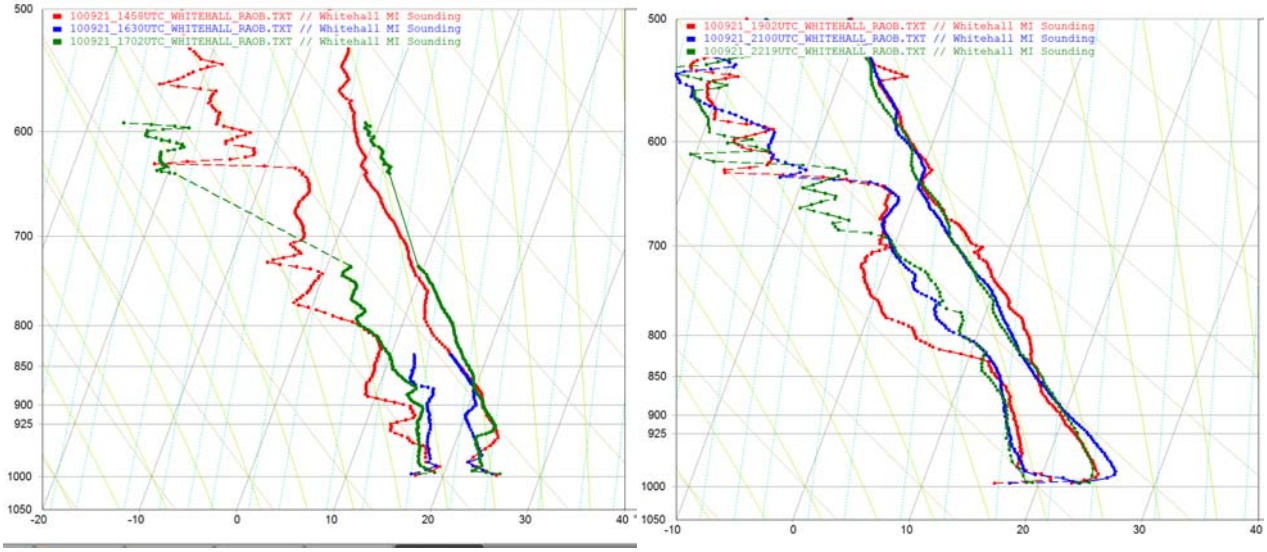

Figure 5. Skew-T plot of sounding data taken on 21 September 2010 from Whitehall, MI, during six launches ahead of a thunderstorm squall line. Soundings taken from 1058-1302 UTC are shown on the left and 1502-1819UTC are shown on the right.

warmed. Since the cool layer would become increasingly stable, the ability to mix the lake-cooled air vertically would be sharply decreased, resulting in the increasingly cool and shallow near-surface MBL.

The findings on data collected on this date could play an important role in the development of a field experiment to understand thunderstorm-MBL interactions. An undergraduate student in the Dept. Atmospheric Sciences, Amanda Jones, is planning to conduct a study of this case as part of her senior year capstone research project.

4. Use of Pilot Data in Development of Further Funding *(Goal D)*

An important goal of this research was to conduct pilot observations that would lead to new funding opportunities and stronger proposals using our new mobile sounding system. This project has aided, and is aiding, in the development of several prospective experiments.

- An opportunity to utilize our sounding system and give graduate students experience in the field has led to our potential involvement in the AgI Seeding of Clouds Impact Investigation (ASCII) this coming winter. While it is still unclear whether we will be able to take soundings, this has led to a proposal to the National Science Foundation, led by the University of Wyoming, to seek funds for our involvement.

- The success of this rawinsonde system has led to important changes and improvements in a field project to be proposed for winter 2014. The Ontario Winter Lake-effect Snow (OWLeS) project seeks to use up to five such sounding systems, including the University of Illinois System, to document and understand the boundary layer dynamics associated with intense lake-effect snow storms. The research group currently includes faculty and scientists from the University of Illinois, Pennsylvania State University, State University of New York (Oswego), University of Utah, Hobart and William Smith Colleges, and Millersville University. The next deadlines for proposals of wintertime deployments are in July 2012.

- We are in the process of developing plans for a field project to be submitted this coming year. The field project would focus on Lake Michigan and seek to understand interactions between thunderstorm systems and the MBL. The project would be funded by the National Science Foundation and the University Corporation for Atmospheric Research. We plan to submit the two linked proposals by the December 2011 due date for a possible deployment during the summer 2013.

5. Presentations and Student Education

Results of this pilot project have been presented in the following forums:

- Encounters Between Thunderstorms and the Great Lakes. *Department of Geophysical Sciences, Hobart and William Smith Colleges* (2010)

- Coastal Urban Heat Islands. *Workshop, Illinois-Indiana Sea Grant Program*. (2010)

- Thunderstorm encounters with Lake Erie. *National Weather Service Forecast Office – Cleveland, OH*. (2011)

Five graduate students were given experience taking research observations, planning a field research project and/or participating in forecasting for a research project (Luke Bard, Tom Workoff, Jason Keeler, Paul Gesicki, and Joseph Wegman).

6. Grant Financial Summary

Approximate as of 8/12/11	**Budget amount**	**Expended**
Supplies	$ 5,712	$ 5,712.00
Travel (incl oper. of auto)	$ 1,216	$ 1,204.19
Indirect Costs (F/A)	$ 3,062	$ 3,057.10
TOTAL	$ 9,990	$ 9,973.29