Annual Report

The Use of 4-Dimensional Lidar Data to Evaluate Large Eddy Simulations: A Lake-ICE Project

UW 144-GW37

NSF ATM-9707165

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1 Sheboygan Deployment

The University of Wisconsin Lidar Volume Imaging Lidar (VIL) was deployed on the shore of Lake Michigan as part of the Lake-ICE experiment. Approximately 40 giga-bytes of data were acquired during 45 hours of operation on 9 days between December 5, 1997 and January 19, 1998. The VIL performed well and only minor difficulties with the laser cooling unit and the beam steering unit were experienced until optical damage to a laser rod required us to terminate operation one day before the end of Lake-ICE.

The VIL depicts atmospheric sturcture by sensing spatial inhomogeneities in aerosol backscattering. Prior to the experiment we were concerned that the aerosol content might be very low during Lake-ICE making it difficult to detect structure. These fears proved groundless and good conditions were present thoughout the experiment. Nearly every day provided new and interesting data.

The winter of 1997-98 was one of the warmest on record. However, the mild cold-air outbreaks provided sufficient temperature contrast with the lake to form internal boundary layers in the offshore flow. Preliminary analysis of our lidar observations suggest that these cases are suitable for evaluating the performance of Large-Eddy-Simulations. In addition to the expected internal boundary layer cases, the data set includes observations of a land-breeze circulation, complex gravity wave fields, and patterns of snow fall from thin lake-generated stratus clouds. Additional information on the VIL observations is provided in conference abstracts attached to this report.

The only major disappointment of the experiment, was our failure to acquire data from surface heat flux data bouys. This data would have been very useful in our LES modeling effort. The research group working on this project anchored two bouys in our scan area. Both stopped transmitting shortly after deployment. Attempts to recover the bouys were unsucessful and these valuable instruments were lost. It appeared that the bouys had either broken loose from their anchors or sunk.

2 Preliminary Data Analysis

We have documented observation times and scan geometries for all VIL Lake-ICE data. In addition, MPEG annimations have been created for all lidar scans. The data catalog and the MPEG annimations are posted on our web page (http://lidar.ssec.wisc.edu, *see, Results from Lake-ICE*). This web site also includes MPEG animations of visible, infrared and water vapour imagery from the GOES satellite. Background information and photos depicting our participation in Lake-ICE are also presented. Time-resolved 2-d wind fields have been generated for the land-breeze case observed on December 21, 1997. Animations of these winds are also posted on our web page.

3 Prelimnaray LES modeling

The resolution of Large-Eddy-Simulations are typically limited by computer speed and memory capacity. Our computer resources have recently been improved with the support of the IBM corporation Shared University Research program. IBM has given us an 8-processor model J50 computer for use in this program. This provides approximately twice the processing speed of our previous computer and it also increases the memory capacity from 1 Gb to 2 Gb.

Greg Tripoli has substantially restructured the University of Wisconsin Numerical Modeling System code to allow efficient operation on Symmetric Multi-Processor computers. We have taken this code, which was written for a Silicon Graphics computer, and modified it to run on our IBM system. Identical model runs have been performed on the SGI and IBM machines to confirm that that the model operation has not been affected by changing computers and operating systems.

4 Conference Presentations

Our Lake-ICE work has been presented in two conference papers at the 19th International Laser Radar Conference held in Baltimore, MD, July 6-10, 1998. Extended abstracts for these papers are appended to this report. The second of these papers (Mayor et al) received a prize for the best presentation amoung the 165 posters displayed at the conference.

A paper has been accepted for presentation at the Tropospheric Profiling Symposium to be held in Snowmass, CO, Sept 21-25, 1998 and two papers have been accepted for presentation at the American Meteorlogical Society Conference on Boundary Layers and Turbulence to be held in Dallas, TX, January 10-15, 1999. Preliminary abstracts of these papers are also appended to this report.

5 Extended abstracts:
19th-International Laser Radar Conference
Annapolis, MD
July, 1998

Lidar Observations of a Land-Breeze Circulation

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Abstract

Observations of a wintertime land-breeze along the shoreline of Lake Michigan are presented. Sequences of RHI, PPI, and three-dimensional scans with the University of Wisconsin Volume Imaging Lidar provide a detailed description of the flow of cold dense air out over the water in the face of an on-shore synoptic flow. Animations of the lidar data showing the surface outflow, the elevated return flow, gravity waves on the return flow boundary, the fluctuating frontal boundary and the eventual collapse of the front will be presented.

1 Background

The University of Wisconsin Volume Imaging Lidar (VIL) is designed to provide high spatial and temporal resolution images of atmospheric structure. It employs a Nd:YAG laser operating at a repetition rate of 100 Hz. 0.5-m diameter scanning optics, and a fast data acquisition system to generate two- and three-dimensional images. In typical operation the system records data to a range of 18 km with a range resolution of 15 m. The data system records profiles without averaging. Approximately 1 G-byte of data is recorded per hour of operation.

The VIL was operated as part of the Lake Induced Convection Experiment (Lake-ICE) at a site on the western shore of Lake Michigan from December 5, 1997 to January 19, 1998. Our lidar observations were designed to provide data on convective structures which develop over the lake when cold winter air flows over the unfrozen lake. The strong surface heat flux caused by the air-water temperature difference and the uniform lake surface provide a natural 'laboratory' setting which can be used to test computer models of convection in the atmospheric boundary layer. This paper presents lidar observations of a land-breeze circulation observed between 12:43 UT and 17:12 UT on December 21, 1997. A more complete description of VIL operations during the Lake-ICE experiment is contained in a paper by Mayor *et al.* (these proceedings).

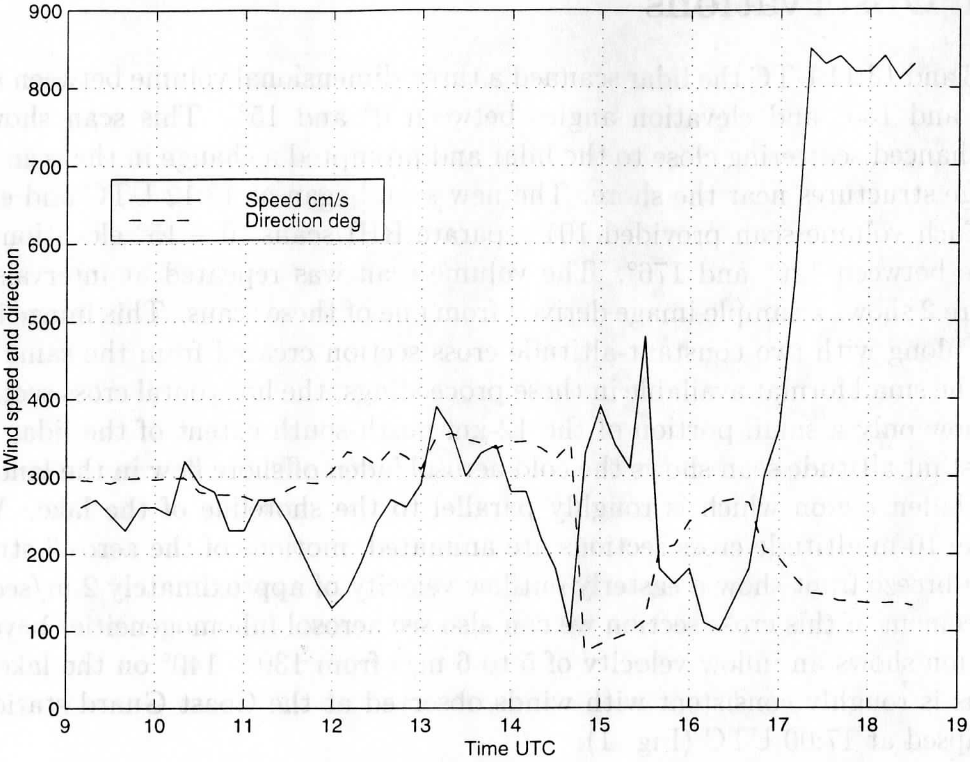

Figure 1: Wind speed and direction measured at the Sheboygan Coast Guard station between 9:00 and 18:30 UTC. The Coast Guard station is located 3/4-km North of the lidar site. Notice that the land-breeze front breaks down at 17:00 UTC under the influence of a weakening land-water temperature differential.

2 Synoptic Conditions

A large high-pressure system centered northeast of Lake Huron moved slowly eastward during the observation period. The resulting pressure gradient supported a weak southeasterly (on shore) synoptic flow. Figure 1 shows the wind speed and direction measured at the Coast Guard station.

Except for a short period around 15:00 UTC, the offshore flow of the land-breeze is evident from 9:00 to 17:00 UTC. After 17:00 the onshore flow overwhelms the land-breeze flow.

The morning low temperature at the Sheboygan airport ($\sim$ 10 km inland from the lidar) was $-6°$ C and it occurred at 14:00 UTC. The airport temperature rose slowly to $-1°$ C by 17:00 UTC. The morning low temperature at the Sheboygan Coast Guard station (3/4 km north of the lidar on the shore line) was $-3.4°$ C at 11 UTC and the temperature rose to $1.6°$ C at 18 UTC. NOAA-satellite derived temperatures for the water offshore from the lidar were between $4°$ and $5°$ C.

3 Lidar Observations

Between 12:43 and 13:11 UTC the lidar scanned a three-dimensional volume between azimuth angles of 85° and 135° and elevation angles between 0° and 15°. This scan showed the presence of enhanced scattering close to the lidar and prompted a change in the scan pattern to better image structures near the shore. The new scan began at 13:12 UTC and ended at 15:21 UTC. Each volume scan provided 101 separate RHI scans (0 – 15° elevation) in the azimuth range between 126° and 176°. The volume scan was repeated at intervals of 187 seconds. Figure 2 shows a sample image derived from one of these scans. This image includes one RHI scan along with two constant-altitude cross section created from the same volume scan. Due to the small format available in these proceedings, the horizontal cross sections are enlarged to show only a small portion of the 12-km north-south extent of the lidar images. The 10-m constant altitude scan shows the cold aerosol laden offshore flow in the land-breeze as an aerosol laden region which is roughly parallel to the shoreline of the lake. When a sequence of the 10-m altitude cross sections are animated, motions of the aerosol structures inside the lake-breeze front show a easterly outflow velocity of approximately 2 m/sec. With careful enhancement of this cross section we can also see aerosol inhomogeneities beyond the front. Animation shows an inflow velocity of 5 to 6 m/s from 130 – 140° on the lake-side of the front. This is roughly consistent with winds observed at the Coast Guard station after the front collapsed at 17:00 UTC (Fig. 1).

The RHI image shows that the front decreases in depth with distance from the shore. It also shows the thin bright land-breeze outflow layer within ~ 20 m of the surface; this is the cold layer of air sliding out over the water against the synoptic flow. Animation of the RHI cross section shows that the land-breeze outflow is confined to a thin layer near the surface. This air appears to flow along the surface to the front where it rises in a strong convergence zone and is then swept back inland in the layer above the outflow. This return flow appears to undergo strong mixing with the marine boundary layer as it is forced up over the land-breeze front. This mixing is evident in the decreased brightness of the upper part of the front near the shore. This decrease of brightness can also be seen in the 110-m cross section which is brightest at the outer edge for the front where air from the surface outflow is being lofted in the convergence zone. Animations show the presence of gravity-wave crests running parallel to the shoreline in the upper part of the front. Point-target-echos also indicate the presence of sea gulls soaring in the air lifted over the front.

Between 15:24 and 16:46 UTC the lidar was scanned back-and-forth to produce PPI scans at an elevation of 0.06° between an azimuth of 85° and 176°. These were acquired with an angular separation between profiles of 0.08° providing a scan time of 12 seconds. Animations of these scans show the position of the land breeze fluctuating in a series of surges and regressions. The outflow wind is made clearly evident by the motion of aerosol inhomogeneities. The signal strength was sufficient to provide usable images of the front out to a range of approximately 12 km south of the lidar. Visual observations during this period showed the lake to be calm without capillary waves near the shore. Offshore, at a distance which appeared consistent with the lidar imaged front, the water surface turned dark and

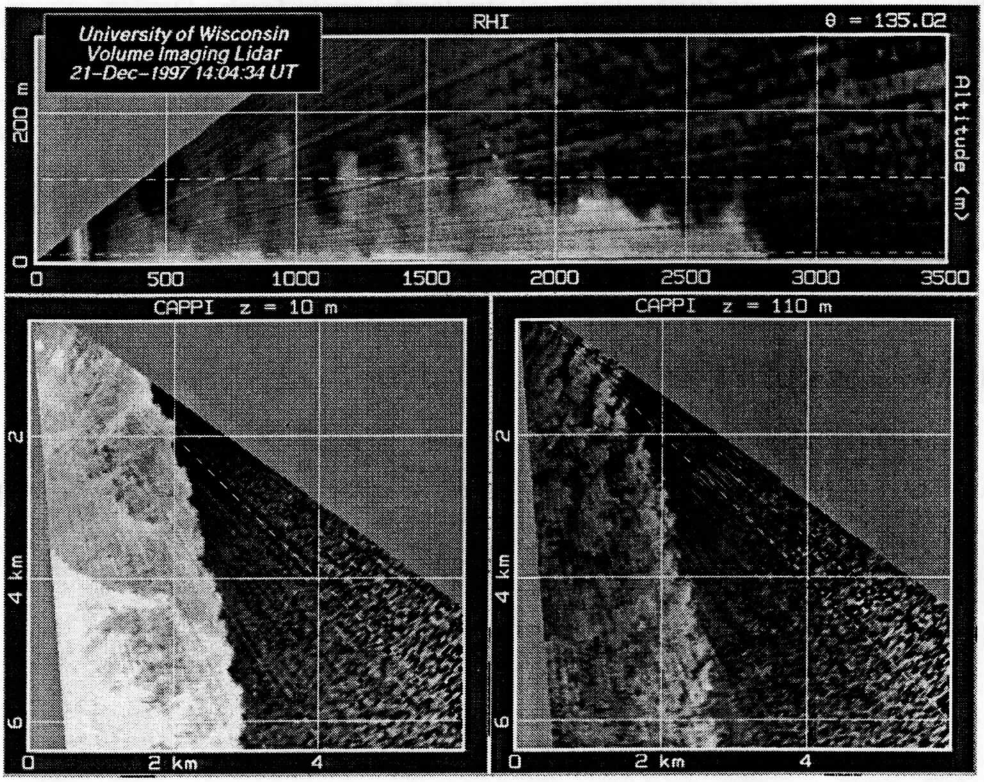

Figure 2: The land-breeze front observed at 14:04 UTC on December 21, 1997. The top panel shows a RHI cross section extending from the surface to an altitude of 300 m and a maximum horizontal range of 3500 m. The RHI is oriented at a compass heading of 134 degrees. The bottom panels show horizontal cross sections over a 6- by 6-km square area at altitudes of 10 m (left) and 110 m (right). North is at the top of the horizontal cross sections and the shoreline runs roughly along the left edge of the images.

disturbed by the on shore flow.

Between 16:51 and 17:12 UTC the lidar was programmed to repeatedly repeat an RHI scan between elevations of 0 and 15° with the azimuth held at 165°. The azimuth was selected from visual observations of the cloud motion; the lidar azimuth was set opposite to the wind direction in a newly formed stratocumulus cloud layer. This animation provides vivid images of the return flow even though the images are made more complex by the presence of extremely light snow showers which had begun to fall from an advancing stratocumulus cloud layer. This sequence documents the collapse of the land-breeze front. During the sequence, the frontal surface continuously retreats until it passes over the lidar's shoreline location. Small capillary waves began to build on the water near the shoreline as the front approached. After the frontal passage at 17:00 UTC the water became disturbed. Shortly afterward waves of approximately 30-cm height formed all along the previously calm shoreline.

This presentation will include animations of the lidar observed structure. We also hope to present lidar derived wind profiles in the frontal zone.

4 Acknowledgments

This research was supported under NSF Grant ATM-9707165 and Army Research Office Grant DAAH04-94-G-0195. Assistance in data acquisition and analysis was provided by P. Ponsardin, J. Hedrick and G. Tubal.

Summary of Volume Imaging Lidar (VIL) Preliminary Results from the Lake-Induced Convection Experiment (Lake-ICE)

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1 Introduction

The University of Wisconsin's Volume Imaging Lidar (UW-VIL) was deployed in Sheboygan, Wisconsin, for the Lake-Induced Convection Experiment (Lake-ICE) during December of 1997 and January of 1998. The site (43°44′N, 87°42′W, 176 m ASL) was located within 10 m of the western shore of Lake Michigan for the purpose of measuring the 4-dimensional (space and time) structure of the upwind edge of the unstable thermal internal boundary layer (TIBL) that forms over the relatively warm lake during cold air outbreaks (CAOs).

Figure 1: Map of the region. For Lake-ICE, the VIL was located in Sheboygan, WI.

During CAOs, the air temperature typically drops to -15 to -30° C while the temperature of the lake water remains a few degrees above freezing. This temperature difference generates large surface heat fluxes which creates a convective boundary layer over the lake. Because the large-scale air flow is from the land to the lake and considering the diffusive nature of turbulence, the TIBL becomes deeper with increasing offshore distance. Stratocumulus clouds form offshore, and steam fog often forms over the lake surface. Futher downwind, the convection can become intense enough to produce lake-effect snow.

Despite the 1997-1998 midwest US winter being one of the mildest on record, we still experienced a few CAOs that were strong enough to enable us to meet our objective. Furthermore, in addition to the TIBLs we observed, we gathered VIL data on many other very interesting phenemona at the edge of the lake, including a land-breeze (see Eloranta *et al.*, this conference), microscale linear and cellular patterns in shallow convection, steam-fog, steam-devils, and gravity waves.

We collected data on 9 days during Lake-ICE, which took place from December 5 until December 22, 1997, and from January 9 until January 22, 1998. The experiment included flights of the NCAR Electra and the University-of-Wyoming King-Air aircraft for in situ boundary layer measurements. Three NCAR integrated sounding systems (ISS) stations and five fixed and one mobile cross-chain loran atmospheric sounding system (CLASS) stations provided additional wind and thermodymanic soundings in the surrounding states. The only ISS in Wisconsin was located about 10 km west of the VIL. Measurements of wind and temperature mentioned here are from the National Data Buoy Center's SGNW3 weather station which was located about 750 m north of the VIL. The air temperature and wind were measured at 15.5 m and 19.2 m above the site elevation, respectively.

2 Motivation

Large eddy simulations (LESs) provide an attractive way of developing parameterizations for large-scale models such as global climate and weather forecast models. This is because they provide 4-D information which can potentially be used to compute fluxes with sampling errors that are much smaller than those made from in situ measurements. LESs, however, are only viable if we have confidence in their solutions. In particular, high resolution 4-D measurements are needed to test the LES.

The UW-VIL is uniquely suited to measure the 4-D structure of aerosol backscatter in the atmospheric boundary layer. By rapidly moving the laser beam in a series of RHIs, each with a slightly increased azimuth angle, we can measure the 3-D structure within a few minutes. For example, a volume which spans 40° in azimuth and 15° in elevation angle requires about 2 minutes and contains about 80 RHIs. The change in elevation angle between two laser pulses during an RHI is 0.23°. By repeating such volume scans, we can also monitor the temporal evolution of the structures. This is possible because the lifetimes of the individual thermals and large-eddies within the boundary layer are long compared to the time it takes to complete one volume scan.

In addition to volume-scans, we also repeated RHI scans at constant azimuths and PPI scans at constant elevations to obtain high temporal resolution 2-D animations of the boundary layer. For example, RHIs (between 0° and 15° elevation) at a constant azimuth direction allow us to produce animations of a vertical slice of the atmosphere with new frames every 2 s. The configuration of the VIL used in Lake-ICE allowed us to transmit 400 mJ/pulse at 100 Hz, and record backscatter intensity at 15-m intervals out to a range of 18 km.

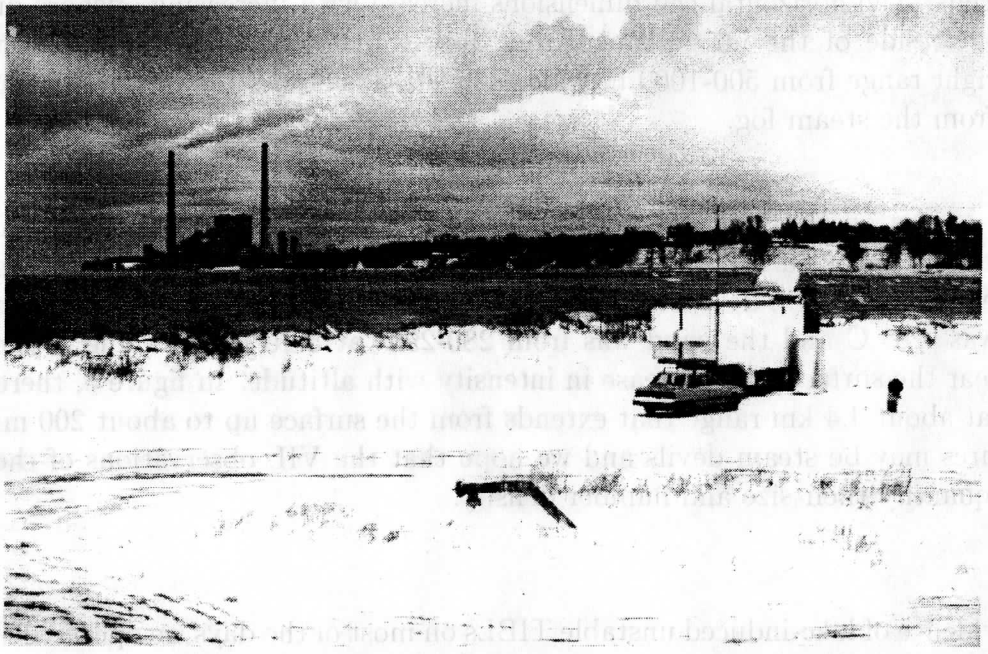

Figure 2: Photograph (looking south) showing the UW-VIL trailer in the foreground on the right and the Edgewater electric power plant in the background on the left. Stack plumes in this photo are blowing to the west.

3 Interesting observations

Perhaps the most interesting VIL observation during Lake-ICE was open-cell convection patterns in the steam-fog about 5 meters above the surface of the lake on 10 and 13 January 1998. Cold air advection was occurring on both of these days and visual observations confirmed clear skies over the lidar site and steam fog on the surface of the lake. On 10 January the minimum temperature reached -16.7° C at 14 UTC with the wind from 236° at 6.5 m s^{-1}.

The VIL's beam-steering-unit (the point at which lidar beam is transmitted from) was located approximately 5 m above the lake surface. Thus, PPI scans at 0° elevation allowed us to map the horizontal distribution of steam-fog in a plane approximately 5 m above and parallel to the surface of the lake. Figures 3 and 4 are PPI scans of this type. In figure 3, the data range from 5 to 10 km offshore. RHI scans within an hour of this image show that the steam-fog did not rise above ~50 m on this day.

The narrow walls of the cells, where the steam is concentrated, is probably a region of convergence and upward motion with weaker compensating sinking motion in the larger clear interior of the cell. The cells appear to be slightly elongated in the direction of the wind. Their somewhat hexagonal shape allows any one cell to share most of its walls with neighboring cells. The horizontal cell dimensions increase with increasing offshore distance. Cells on the left side of the image range from approximately 200-500 m wide while the cells on the right range from 500-1000 m wide. The streaks across the image are caused by attenuation from the steam fog.

While the steam on the 10th did not appear to rise more than about 50 m above the lake, RHI scans from 13 January reveal narrow rising columns of steam which sometimes extend to the top of a 400-m deep mixed-layer. The minimum temperature on the morning of the 13th was -20° C and the wind was from 280-290° at 5-10 m s^{-1}. The columns are very bright near the surface and decrease in intensity with altitude. In figure 5, there is one such feature at about 4.4 km range that extends from the surface up to about 200 m. Some of these features may be steam devils and we hope that the VIL observations of them will enable us to quantify their size and number density.

We saw evidence of lake-induced unstable TIBLs on most of the days we operated the VIL at Lake-ICE. Our first operational day, 5 December 1997, showed a complex boundary layer in which snow caused the air above the TIBL to be higher in scattering than the thermals with origins over the lake.

Figure 6 shows the vertical structure of the lower atmosphere over the lake on 19 January 1998. A shallow mixed layer can be seen from the surface up to about 100 m. A residual layer, or mixed layer produced from the land, which is lower in scattering, can be seen from 100 to 200 m. Gravity waves can be seen between 500 and 600 m above the lake. The waves have an amplitude of approximately 50 m and a wavelength of about 500 m.

On 14 December 1997, we observed a "criss-cross" pattern of waves, or waves and linear convective features, within a 100-km^2 area on PPI displays. The linear features (or waves) with crests that were oriented north-south were moving toward the east and the linear features with crests oriented approximately west-east were moving to the north. The result is a pattern which resembles a "waffle" and is shown in figure 7. The coherent structures are much more obvious in animated color images. The wavelength of both features is 400-500 m. The animation also reveals some counter-clockwise turning of the flow field which may be related to the terrain causing a coastal eddy.

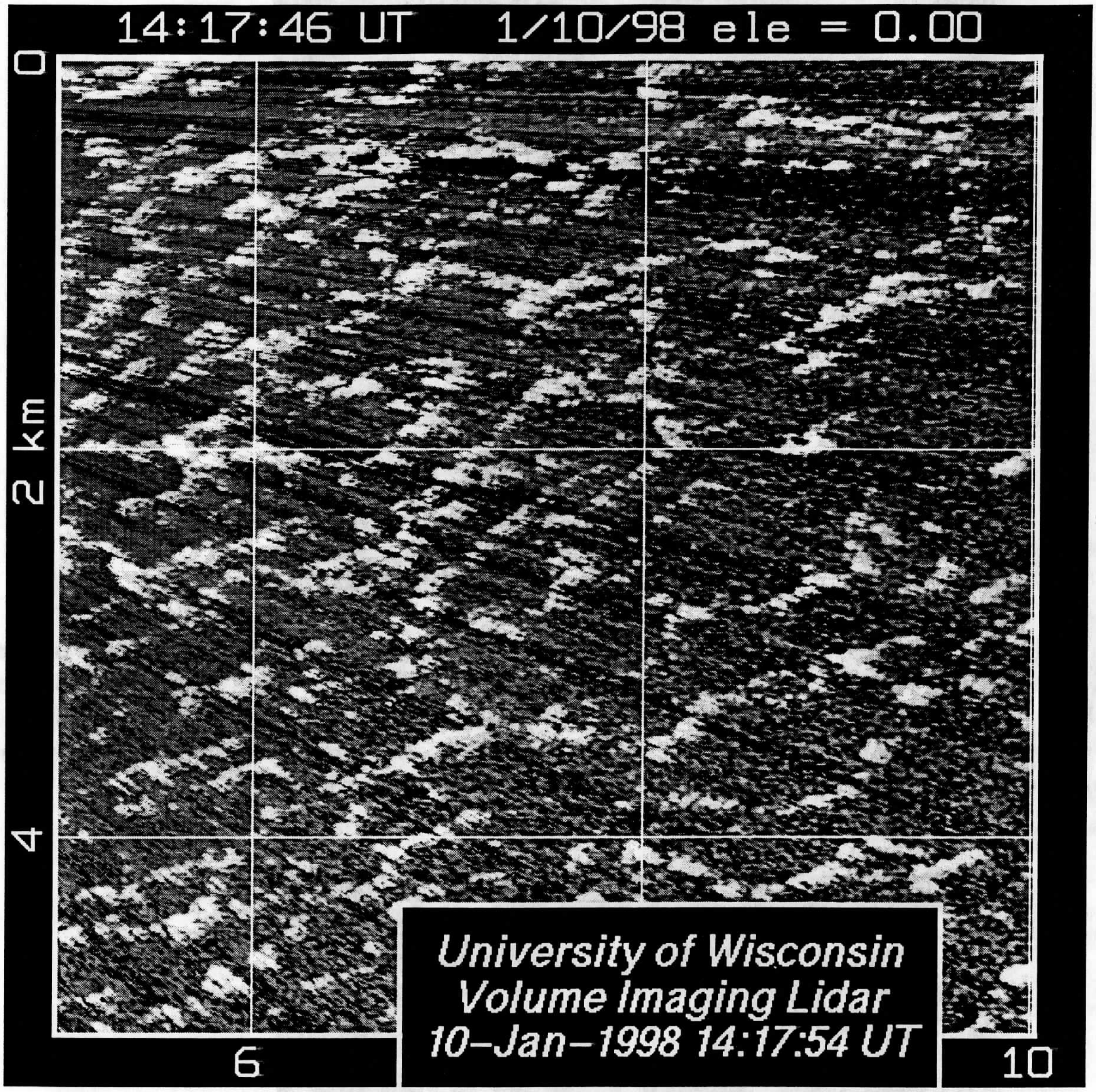

Figure 3: Enlargement of a 25-km^2 region 5-10 km offshore from a PPI image of range-corrected backscatter intensity. The image shows open-cell organization of convection in the steam-fog over the lake during a cold air outbreak on 10 January 1998. Note the approximately hexagonal shape of the cells. At the shore, the mean wind during this time was from 236° at 6.5 m s^{-1} and the air temperature was -16.7° C. The streaks across the image are caused by attenuation from the steam fog.

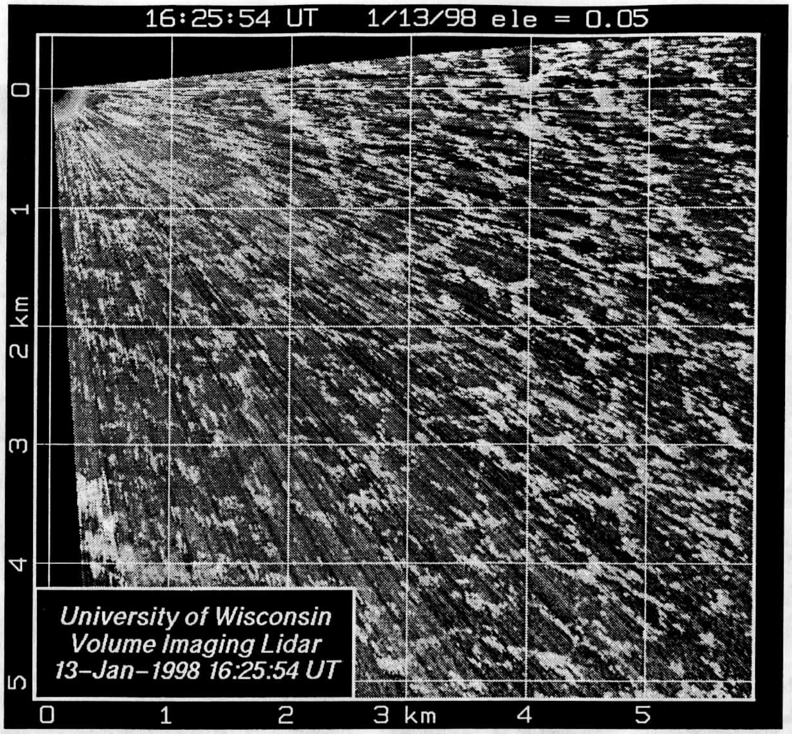

Figure 4: **PPI of range-corrected backscatter intensity showing the open-cell organization of the steam fog on 13 January 1998 from a few hundred meters to 5.9 km offshore. At the shore the mean wind during this time was from 280-290° at 5-10 m s^{-1} and the air temperature was -20° C.The open-cells range in horizontal size from about 100 m at 1 km offshore to about 500 m at 5.9 km offshore.**

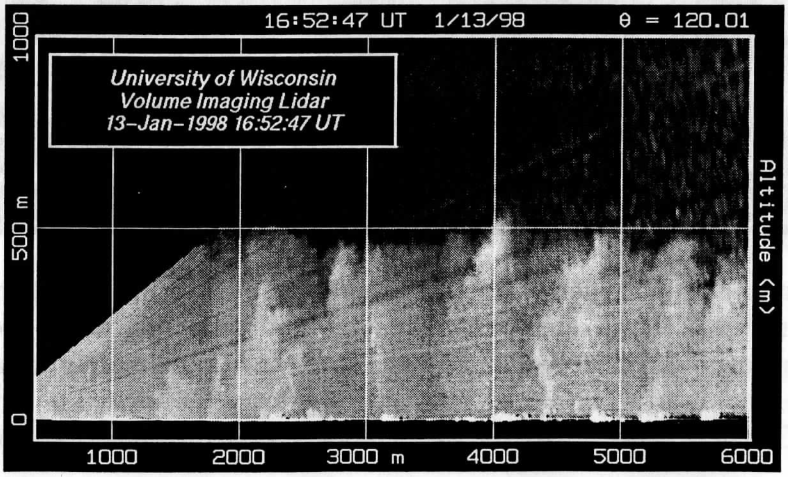

Figure 5: RHI of range-corrected backscatter intensity showing the vertical structure of the steam fog and TIBL over the lake on 13 January 1998.

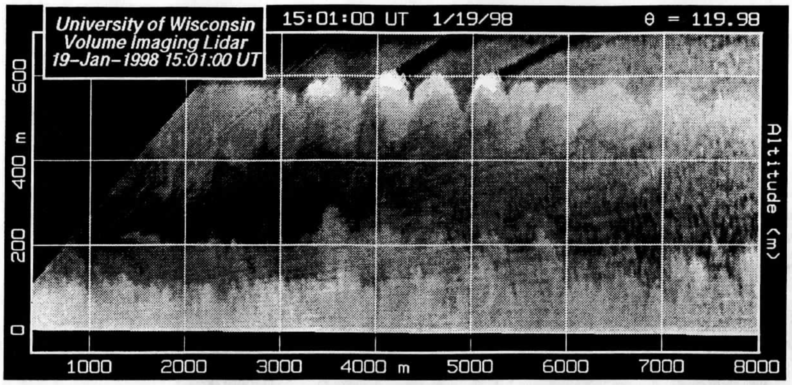

Figure 6: RHI aligned downwind (120° azimuth). This vertical cross-section of the atmosphere over the lake on 19 January 1998 shows gravity waves above a shallow mixed layer.

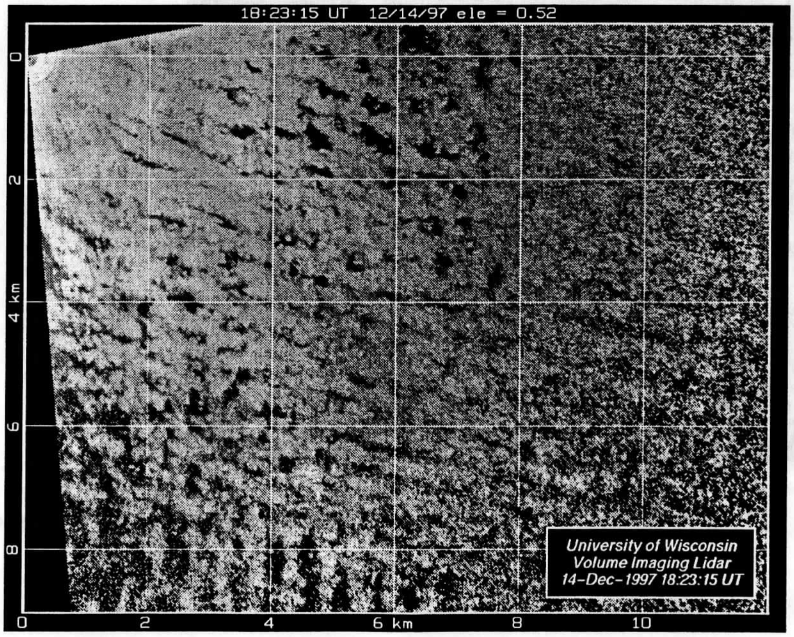

Figure 7: PPI of range-corrected backscatter intensity showing a "criss-cross" of waves or waves and linear coherent structures over the lake on 14 December 1997.

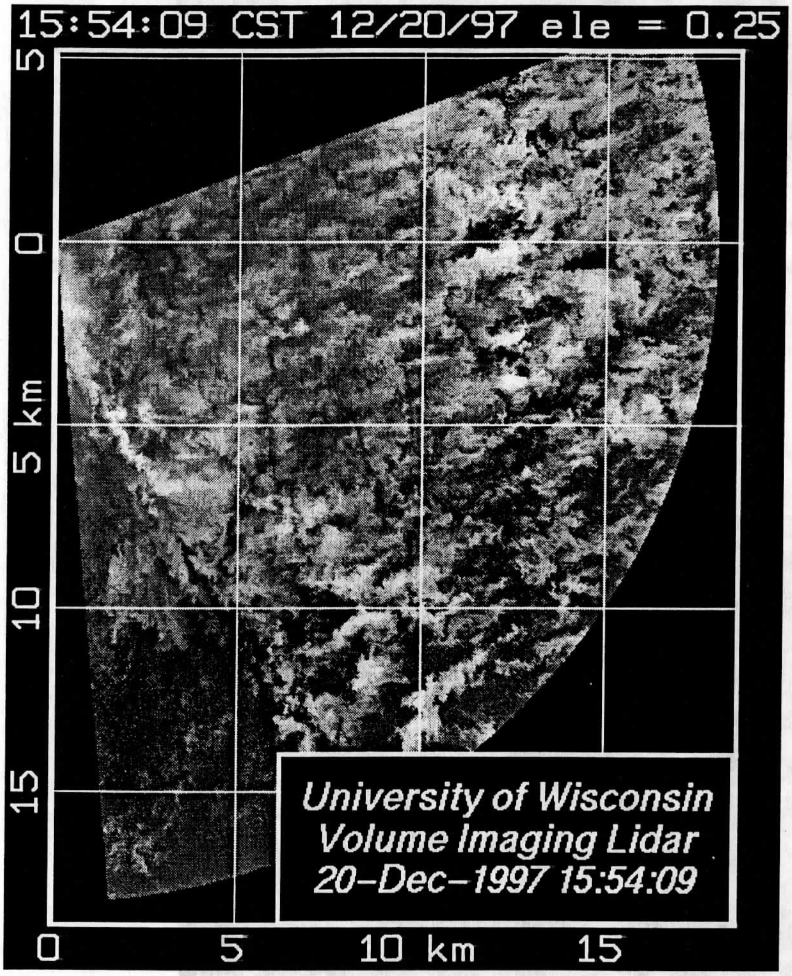

Figure 8: Snow acting as a tracer as it falls into the mixed layer over the lake.

Figure 8 shows patterns in a light snowfall on 20 December 1997. Surface measurements indicated the wind was from 310° at 3-5 m s^{-1} and the air temperature was near 0° C. Animations of the lidar data show structures flowing from the north and a convergence band along a line from approximately 3 km south of the lidar site to a point 5 km east and 10 km south of the lidar. This case was particularly impressive because the signal-to-noise ratio at 18 km was still very high.

While light snow acted as a tracer on a few days, we found the coastal environment near Sheboygan to offer high contrast in the aerosol scattering. Even on days with very high visibility, there was abundant scattering to resolve boundary layer structure. Steam-fog over the lake also provided a high scattering tracer in extremely shallow convection.

All the images shown here are frames extracted from high-resolution color animations. These MPEG movies can be downloaded from our website at http://lidar.ssec.wisc.edu.

3.1 Summary

Deployment of the UW-VIL in Lake-ICE during the winter of 97-98 allowed us to collect a rich set of unique measurements of atmospheric boundary layer structures. Our next steps include using the VIL data to quantitatively estimate the shapes of the structures and to compute wind profiles as a function of offshore distance. We also plan to compare these measurements with LES of intense cold-air advection over warm water.

4 Acknowledgments

This work was made possible by NSF grant number ATM9707165 and ARO grant number ARO DAAH-04-94-G-0195. Thanks to Jim Hedrick and Toby Schwalbe for preparation and maintance of the lidar.

8 Preliminary abstracts: American Meteorlogical Society Conference on Turbulence and Diffusion Dallas, TX, Jan 1999

Near-Shore, Boundary Layer Structure over Lake Michigan in Winter

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The wintertime flow of cold air over warm water produces a vigorous growing convective boundary layer along the upwind shore of Lake Michigan. This boundary layer, which increases in depth with distance from the upwind shore, provides an attractive setting in which to observe the development of convective structures. The water surface provides a lower boundary with nearly uniform temperature and flat topography to facilitate model calculations.

This paper presents observations gathered by the University of Wisconsin Volume Imaging Lidar (VIL). The lidar was deployed on the lake shore at Sheboygan, WI, as part of the Lake Induced Convection Experiment (Lake-ICE). Data were acquired on 9 days between December 5, 1997 and Jan 22, 1998. Supplementary local data were collected by an NCAR integrated sounding system (ISS) located 10-km west of the lidar and by the National Data Buoy Center's SGNW3 weather station located 3/4-km north of the lidar.

The lidar observations were designed to acquire data to test Large Eddy Simulation (LES) models. Azimuthal scans with the lidar aimmed horizontally over the lake provided high resolution images of structures with 15-m spatial and approximately 15-second temporal resolution. These were analyzed to provide the horizontal wind field and its temporal evolution. Typically, winds could be derived with 1-km or better spatial resolution and 2-minute or shorter temporal resolution. At times, the signal to noise ratio was sufficient to provide wind measurements over the entire 250-square-km scan area. Time-lapse animations of these scans also show the horizontal structure of the convective field and its evolution with distance from the shore. Of particular interest are images showing open cells with downward motion in the center, upward motion in narrow cell walls, and approximately hexagonal cross sections. Vivid images of a land-breeze front and its temporal evolution were also recorded.

Volume scans provided information on both the 3-dimensional structure and temporal evolution of the boundary layer. These data were also analyzed to provide vertical profiles of the horizontal wind speed and direction. A typical scan recorded over 10 million data points in a volume bounded by a 50-degree azimuth sector and a maximum elevation angle of 15 degrees. Signals were recorded to a maximum range of 18 km and the scans were repeated at intervals of approximate 2 minutes. Volume scans recorded during a land-breeze are of particular interest. These data provide a detailed description of the flow of cold dense air out

over the water in the face of an on-shore synoptic flow. Animations of the lidar data showing the surface outflow, the elevated return flow, gravity waves on the return flow boundary, the fluctuating frontal boundary and the eventual collapse of the front were recorded.

Microscale Convection Patterns Observed by Lake-ICE Lidar

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The University of Wisconsin Volume Imaging LIDAR (VIL) was deployed during the recent Lake-ICE (Lake Induced Convection Experiment) for the purpose of observing the early growth of the unstable boundary layer. The lake effect storms of Lake Michigan provide an ideal laboratory for this type of observation. There, following cold outbreaks, relatively homogenous arctic air passes over a relatively warm lake forming a vibrant growing unstable boundary layer just off shore and within the relatively modest range of LIDAR coverage. Steam and fog rising with the thermals from the lake provide a optimal medium for LIDAR observations to depict the evolution and structure of resulting thermals. Large eddy simulations are usually limited by the computationally feasible scale of their domain and the need for periodic lateral boundary conditions in order to capture the long term evolution of the boundary layer in a situation of mean air flow.

The region just off the windward shore of the lake-effect convective boundary layer also provides an ideal laboratory for large eddy simulation. There, one finds the potential for simulating the entire evolution of the convective boundary layer using open lateral boundary conditions, predictable surface forcing and a domain consistent with the limitations of computational resources. With local LIDAR observations of the actual boundary layer evolution available, this ideal atmospheric laboratory for Large Eddy Simulation is complete, enabling direct comparison of simulated to observed large eddy structures.

The LIDAR observations made on 13 January, 1998 were found to be of particular interest. On that day a system of apparently open-cell convection confined below 50 m was observed. The mean wind was from the west-northwest at 5-10 m/s. The lower atmospheric temperature was measured at -20 C, while the lake temperature was at 4C, measured just off shore. This provided an exceptionally strong surface moisture and heat fluxes.

The UW-NMS (University of Wisconsin Nonhydrostatic Modeling System) was run at a maximum horizontal grid spacing of 100 m and a vertical spacing of 10-50 m to simulate the evolution of the convective layer in the first 10 km off shore. The structures simulated by the LES will be compared to the LIDAR observations at the oral presentation. Model sensitivities to simulated surface fluxes and initial stable boundary layer structure will be examined as possible explanations for the cellular structure