Fine-scale Airborne Doppler Radar Measurements of Vertical Air Motions within Lake-effect Systems

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Introduction

Communities near the Great Lakes are frequently inundated with substantial lake-effect snowfalls each winter, which can cripple aviation, ground transportation, industry, and result in injuries, deaths, and significant damage to property (Kristovich et al. 2000). The Ontario Winter Lake-effect Systems (OWLeS) Project collected a comprehensive dataset on several lake-effect systems during the winter of 2013/14.

This work is the foundation of an analysis which will examine the evolution of vertical air motions and the vertical structure of long lake-axis-parallel (LLAP) bands as they move over Lake Ontario and the adjacent topography east of the lake.

Previous research by Minder et al. (2015) suggests that as lake-effect convection moves inland, it weakens and transitions to a stratiform morphology, becoming less intense, shallower in depth, more spatially uniform, and less turbulent. Moreover, their findings contradicted their initial hypothesis that the inland intensification of lake-effect snowfall is caused by orographic invigoration of convection.

Data and Methods

15-m resolution Doppler radar data were collected by the Wyoming Cloud Radar (WCR) aboard the Wyoming King Air (WKA) aircraft within 7 LLAP bands near Lake Ontario during OWLeS. An example case from IOP4 15/16 December 2013 is presented. The flight path of the WKA within the LLAP band is shown in Fig. 1.

Corrections were made to the vertical radial velocity data to account for the roll, pitch, and yaw of the aircraft and to eliminate ambient wind contamination within the beam during times when the beam was tilted from nadir due to turbulence. This eliminated significant noise within the vertical radial velocity dataset (not shown).

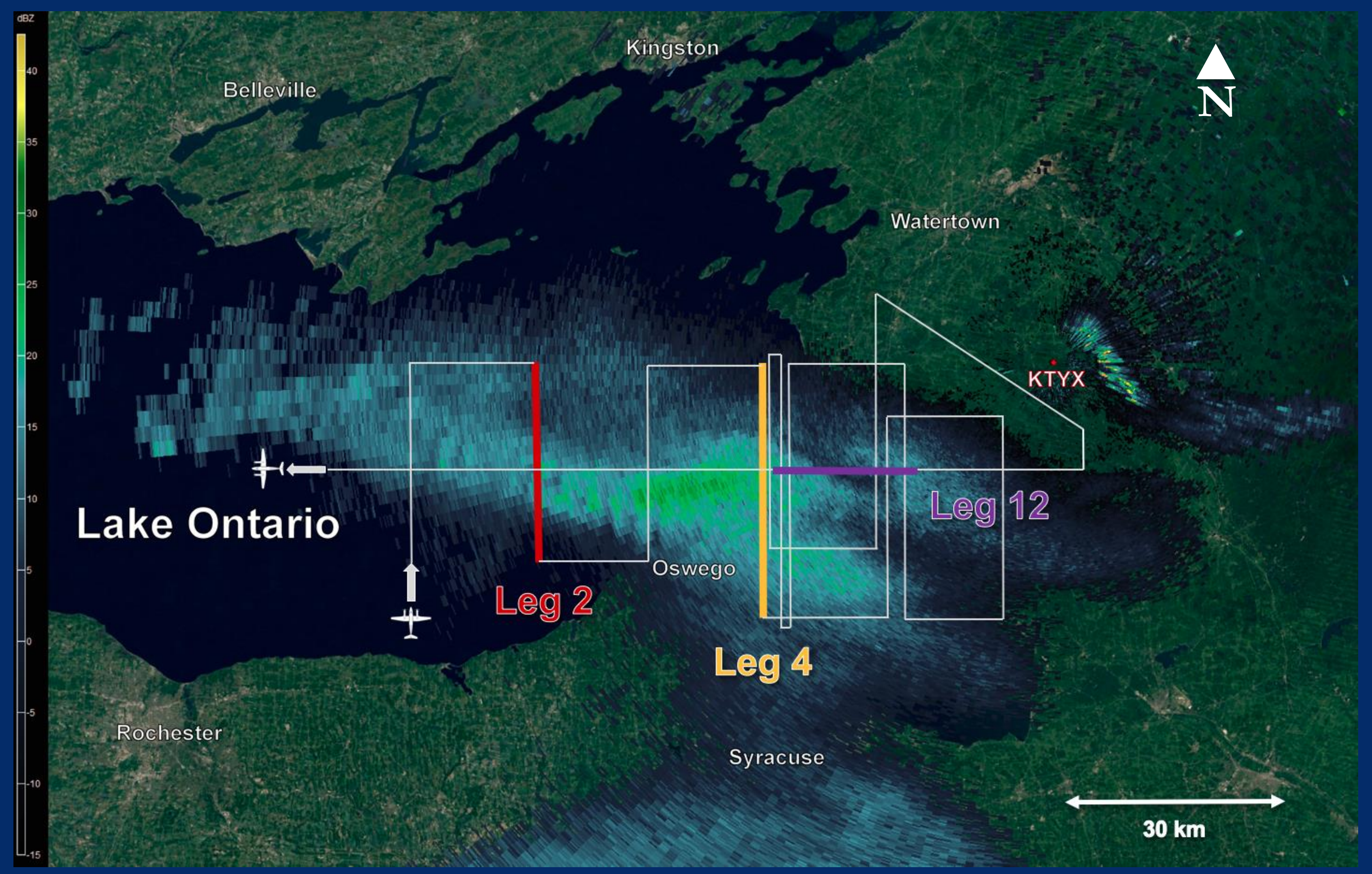

Fig. 1. Equivalent reflectivity factor (hereafter reflectivity) at 0.5° from the KTYX WSR-88D at 2343 UTC 15 December 2013. WKA flight path (white line), leg 2 of flight (red line), leg 4 of flight (orange line), and leg 12 of flight (purple line) are indicated. Note: Ground clutter from wind turbines and other sources are present to the northeast of the radar site.

Wyoming Cloud Radar Data

Generating Cells and Surface-based Convection: Leg 2

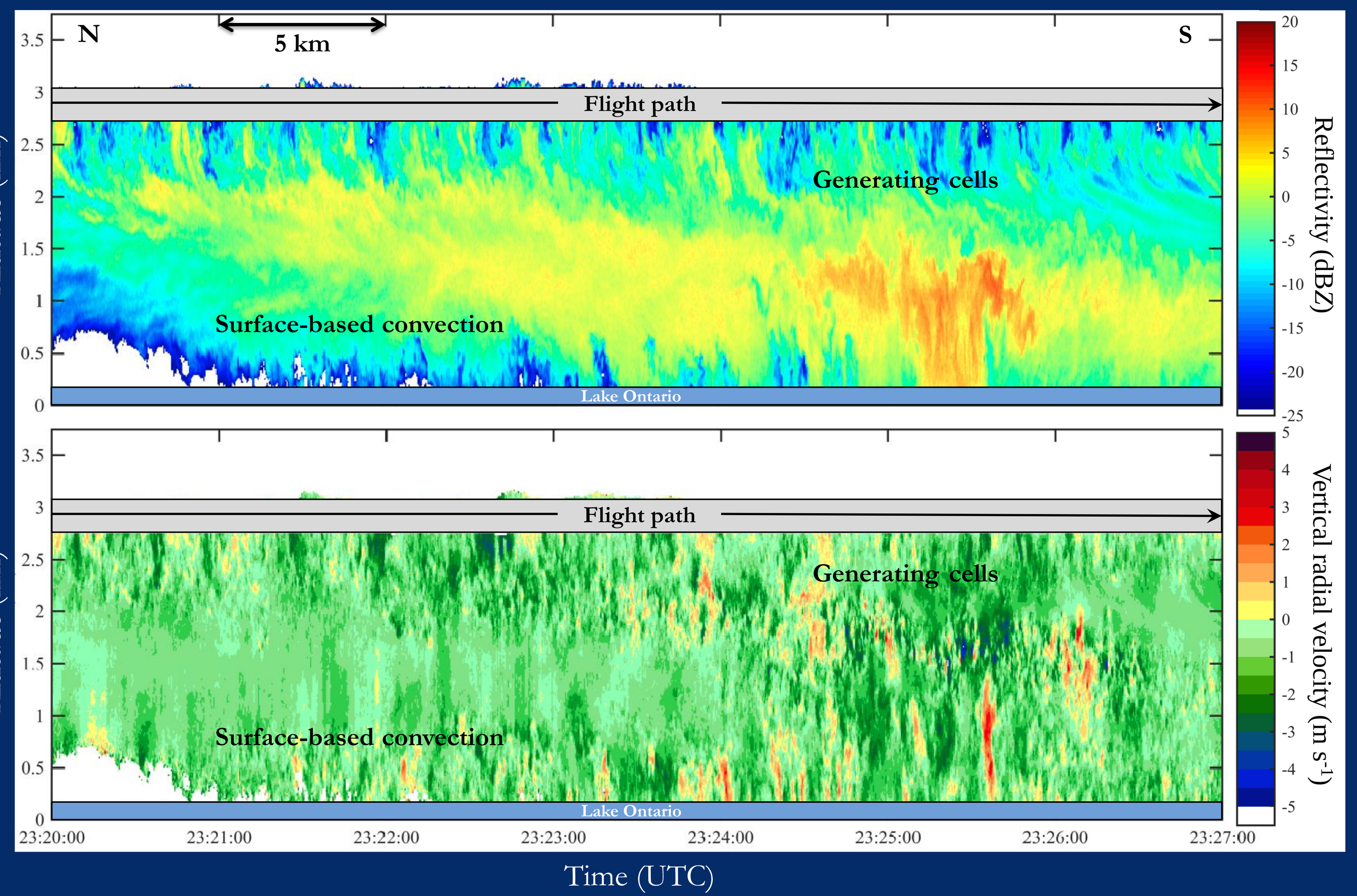

Fig. 2. WCR reflectivity cross-section through the LLAP band. Flight path is shown at an altitude of ~2.8 km mean sea level (MSL). Cloud top generating cells (GCs) are ubiquitous along this leg. The width of the GCs range from 500-1000 m. The vertical extent of the GCs are ~1000 m. Surface-based convection is also present particularly below 1 km MSL. Attenuation near the surface is most likely caused by supercooled water embedded in surface-based convection.

Fig. 3. WCR corrected vertical radial velocity cross-section through the LLAP band. The updraft speeds within the GCs are on the order of of 1-2 m s^{-1}, while the surrounding downdraft speeds are on the order of 1-3 m s^{-1}. Significant surface-based convection with updraft speeds of around 3 m s^{-1} are also present near the center of the band. Surface-based updrafts reach as high as ~2 km MSL, just below the GC level.

Lake-to-land Transition: Leg 4

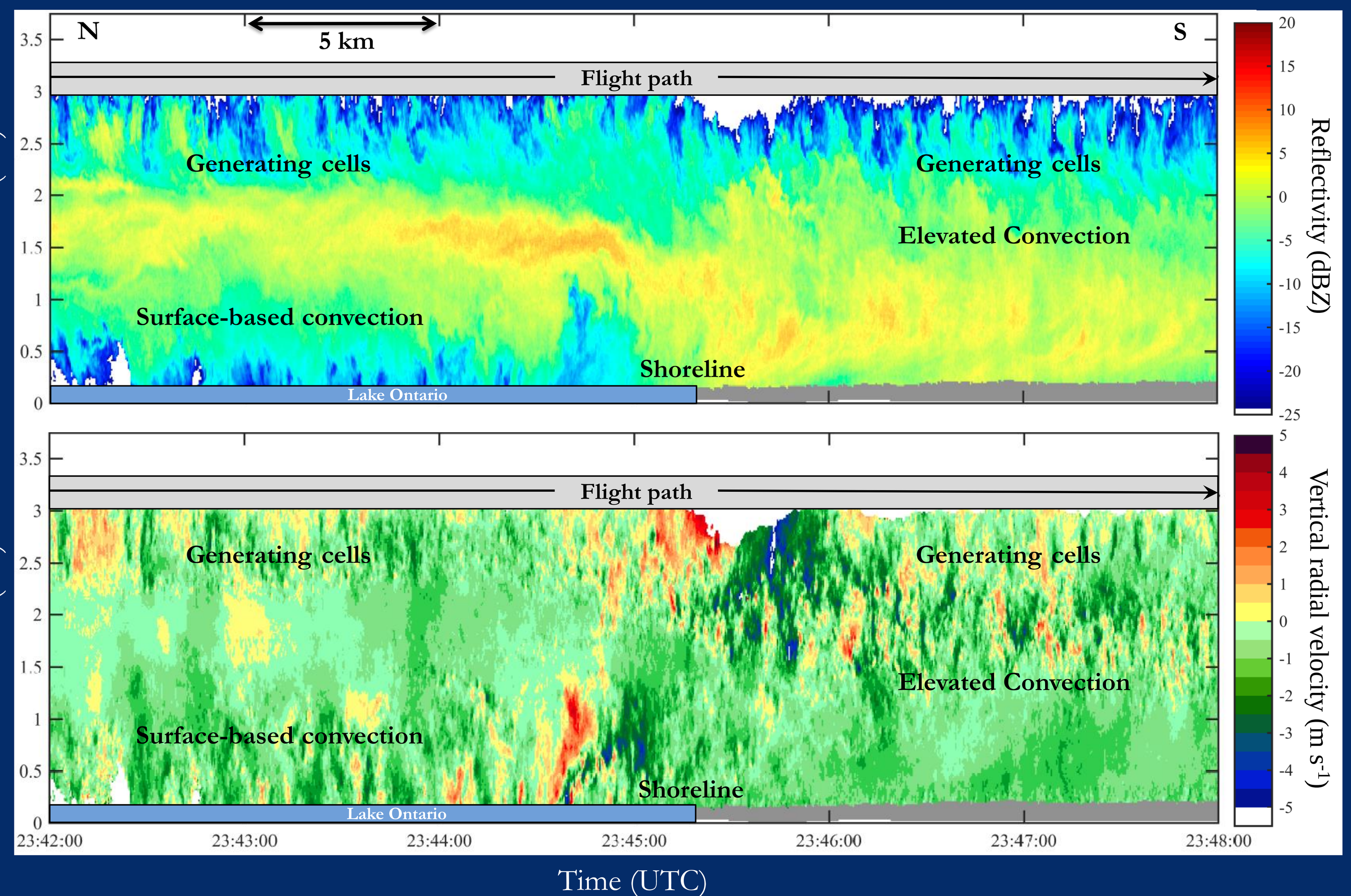

Fig. 4. WCR reflectivity cross-section through the LLAP band. Flight path is indicated at an altitude of 3.2 km MSL. GCs are also ubiquitous along this flight track and are of similar size as those in leg 2. Surface-based convection transitions to a stratiform morphology as the band progresses inland. Moreover, the height at which elevated convection occurs decreases from 2.5 km to 1.5 km MSL.

Fig. 5. WCR corrected vertical radial velocity cross-section through the LLAP band. The updrafts within the GCs and the downdrafts surrounding the GCs are of the same magnitude as those in leg 2. Updrafts within the surface-based convection over the lake reach an altitude of 1.5 km MSL and speeds near 4 m s^{-1}. A gravity wave is seen at 2.75 km MSL over the shoreline, which could be due to frictional convergence at the shoreline.

Gravity Waves and Elevated Convection: Leg 12

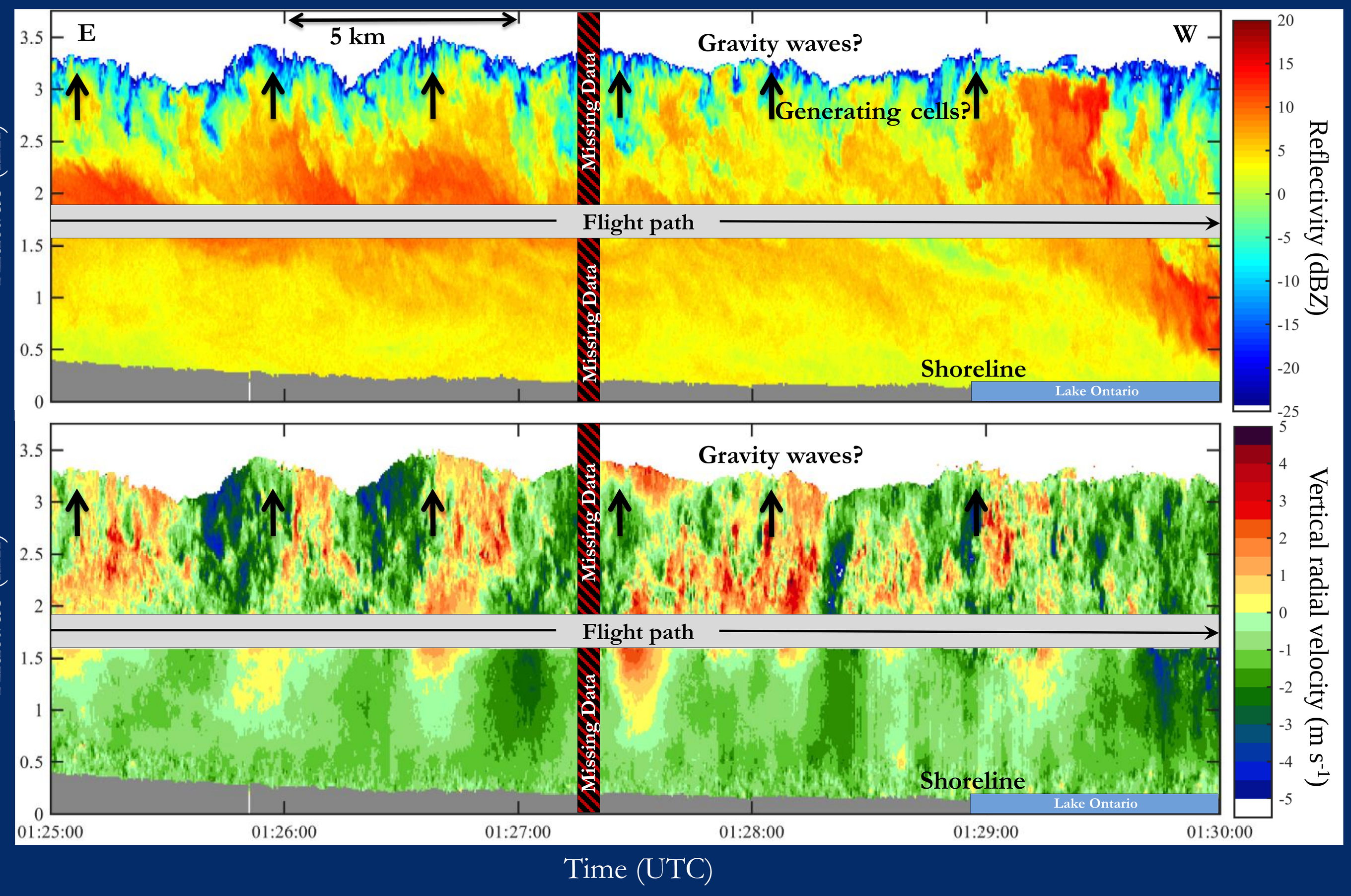

Fig. 6. WCR reflectivity along-band cross-section. Flight path is shown at an altitude of 1.75 km MSL. Reflectivity increases above 1.5 km MSL, likely due to elevated convection which is embedded within possible gravity waves at ~3 km MSL. Generating cells may also be present at cloud top.

Fig. 7. WCR corrected vertical radial velocity along-band cross-section. Possible gravity waves are seen above 2 km MSL. The updraft speeds and downdraft speeds inside these features are on the order of 1-5 m s^{-1}. Only weak shallow surface-based convection is seen over land.

Generating Cell Analysis

IOP	GCs Present?	Horizontal Extent	Vertical Extent	Updraft Speed	Day/ Night	Synoptic Conditions	Archetype of Convection
1	Yes	~250-1000 m	~500-1500 m	~0.5-2 m s^{-1}	Day	Post frontal	Cellular
2b	No	--	--	--	Day	Pre frontal	Large mesoscale band
3	Yes	~100-1000 m	~250-1000 m	~0.5-2 m s^{-1}	Night	Pre frontal	Large mesoscale band
4	Yes	~100-1000 m	~500-1500m	~0.5-2 m s^{-1}	Night	Post frontal	Large mesoscale band
7a	No	--	--	--	Day	Post frontal	Large mesoscale band
7b	No	--	--	--	Day/ Night	Post frontal	Multiple mesoscale bands
9	Yes	~100-500 m	~500 m	~0.5-1 m s^{-1}	Day	Post frontal	Small mesoscale band

Table 1. Selected physical characteristics of generating cells seen in LLAP bands.

Conclusions

- Several different archetypes of vertical motion are present in LLAP bands, including generating cells, deep and shallow surface-based convection, elevated convection, and possible gravity waves.
- GCs are not ubiquitous atop the LLAP bands and occur equally during the day and night.
- The horizontal extent of GCs are 100-1000 m and their vertical extent is ~250-1500 m, while the updraft speed within them is 0.5-2 m s^{-1}. These characteristics are similar to those observed by other studies (e.g., Rosenow et al. 2014; Kumjian et al. 2014).

Future Work

- Construct contoured frequency by altitude diagrams (CFADs) to examine the distributions of vertical radial velocity and reflectivity within LLAP bands and to associate the measured vertical radial velocities to vertical air motions within the bands.
- Analyze the thermodynamic characteristics of GC environments.
- Create a conceptual model of LLAP bands based upon CFAD analysis.

Acknowledgements

We are grateful to all of the volunteers who assisted with the data collection and to Dr. Bart Geerts and Phillip Bergmaier at the University of Wyoming for their help with data post processing. Support from NSF Grant No. AGS 12-59257 is also acknowledged.

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