Ontario Winter Lake-effect Systems (OWLeS) Project
Working Document: Science and Experiment Design Overview
December 2013 – January 2014

Summary

The OWLeS project examines the formation mechanisms, cloud microphysics, boundary layer processes and dynamics of lake-effect systems (LeS) using new observational tools capable of detailing LeS characteristics not observed in previous LeS field experiments. Lake-effect systems form through surface-air interactions as a cold air mass is advected over relatively warm (at least partially) ice-free mesoscale bodies of water. The OWLeS project focuses on Lake Ontario because of its geometry and size, frequency of LeS, nearby orography, and proximity to several participating universities with a strong record of undergraduate research. We distinguish between short-fetch LeS (those oriented at large angles to the long axis of the lake) and long-fetch LeS (those more aligned with the lake's long axis). The overarching objectives of the OWLeS project are to:

a) describe the upwind surface and atmospheric factors determining the three-dimensional structure of short-fetch LeS convective bands that develop over a relatively-warm, open water surface;

b) understand the development of, and interactions between, internal planetary boundary layers (PBL) and residual layers resulting from advection over multiple mesoscale water bodies and intervening land surfaces;

c) examine how organized, initially convective LeS structures in short-fetch conditions persist far downstream over land, long after leaving the buoyancy source (i.e., the ice-free water);

d) examine how surface fluxes, lake-scale circulations, cloud microphysics and radiative processes affect the formation and structure of long-fetch LeS;

e) understand dynamical and microphysical processes controlling the fine-scale kinematic structures and lightning characteristics of intense long-fetch LeS;

f) provide *in situ* validation of operational (S-band) and research (X-band) dual-polarization hydrometeor type classification and lake-effect snowfall QPE; and

g) understand the influence of downwind topography on LeS generated over Lake Ontario.

Facilities requested from the NSF Lower Atmosphere Observing Facility (LAOF) pool are:

- the University of Wyoming King Air (UWKA), with the Wyoming Cloud Radar (WCR) and Lidar (WCL) systems; and
- three Center for Severe Weather Research (CSWR) Doppler on Wheels (DOW) radar systems.

In addition, several PI-supported mobile and stationary flux, surface, and sounding systems will be deployed. These non-LAOF systems will enhance the ability to observe mesoscale surface and PBL conditions and will facilitate student learning opportunities.

Intellectual merit: Building on previous LeS field campaigns, OWLeS provides a unique opportunity to broaden the understanding of LeS by deploying new remote sensing instrumentation, documenting the growth and evolution of LeS at unprecedented fine scales, and by expanding the location in which experimental observations are collected. Fundamental understanding of internal PBL evolution in response to spatially-variable surface conditions will be gained.

Broader impacts. Lake-effect snow remains a major weather hazard, especially downwind of the eastern Great Lakes. While current operational numerical weather prediction (NWP) models sufficiently capture LeS locations and timing, the predicatability of snowfall intensity and inland extent of convection remains poor. Likely causes of poor QPF include unresolved variations in upwind and over-lake PBL structure, downwind circulations within residual layers, inadequate coupling between buoyantly-driven PBL turbulence and cloud microphysics. Thus, the mesoscale NWP community will benefit from the results of OWLeS. The main benefit of the national WSR-88D dual-pol radar upgrade is believed to be improved QPE, yet this outcome is largely untested in lake-effect snowfall. OWLeS would fill in this

information void. An improved understanding of processes driving LeS becomes more urgent in a warming global climate. Climatological trends and recent trend changes in LeS snowfall and related atmospheric and lake properties are not well understood, and improved understanding of LeS will allow for investigations of possible impacts on regional ecology and communities. In addition, boreal lakes and the Arctic coastal waters are expected to remain ice-free for longer periods in the cold season, possibly resulting in complex internal PBL interactions and substantial increases in PBL moisture and snowfall.

1. Collaborative Efforts and Proposal Organization:

The OWLeS project is a collaborative effort between several institutions. The Principal Investigators (PIs) intend to maintain this cooperation for both the field project operations and subsequent research activities. Many of the project objectives connect in a natural manner. Therefore, the PIs will submit two collaborative research proposals that focus on connected areas of research: (i) surface and atmospheric influences on lake-effect convection when the winds are at large angles to the long axis of the lake ("short-fetch", related to objectives a, b, and c from Summary) and (ii) convective snow bands oriented parallel to the long axis of Lake Ontario ("long-fetch", related to objectives d, e, and f). A single, coordinated field campaign such as OWLeS is much preferred over single-PI efforts given the synergy of instruments and superior data density.

Table 1: Research proposals and PIs linked to the OWLeS project.

OWLeS – SAIL **(Surface and Atmospheric Influences on Lake-effect convection)** **Short-Fetch LeS** **Mainly objectives a, b, c**	**OWLeS – BIC** **(Bands of Intense Convection)** **Long-Fetch LeS** **Mainly objectives d, e, f**	**Independent proposals** **Mainly objective g** **and other** **collaborators and participants**
Richard Clark, MU	Jeffrey Frame, UIUC	* James Steenburgh, UU
* David Kristovich, UIUC	* Bart Geerts, UW	
Neil Laird, HWS	Kevin Knupp, UAH	Michael Evans, NWS-BGM
Nicholas Metz, HWS	Karen Kosiba, CSWR	David Zaff, NWS-BUF
Todd Sikora, MU	Scott Steiger, SUNY-O	
George Young, PSU	Joshua Wurman, CSWR	

* Lead PI; CSWR-Center for Severe Weather Research; HWS-Hobart and William Smith Colleges; MU-Millersville University; NWS-BUF-National Weather Service Forecast Office (NWSFO) – Buffalo, NY; NWS-BGM-NWSFO-Binghamton, NY; PSU-Pennsylvania State University; SUNY-O-State University of New York – Oswego; UAH-University of Alabama in Huntsville; UIUC-University of Illinois in Urbana-Champaign; UU-University of Utah; UW-University of Wyoming. Proposed objectives are identified by the letters used in the Summary.

2. Background:

Over the last three decades, several field experiments have focused on understanding processes involved in the development of lake-effect snow storms. For example, the Lake-Induced Convection Experiment was conducted over Lake Michigan in the winter of 1997/98 (Kristovich et al. 2000) and the Lake Ontario Winter Storms project occurred in early 1990 (Reinking et al. 1993). Most recently, a small NSF EAGER-supported project, conducted downwind of Lake Ontario in late 2010 and early 2011, documented some remarkable shear-driven convective structures in intense snow bands, including multiple vortices less than 1 km in diameter, vertical wave patterns, and bounded weak echo regions (Cermak et al. 2012). This observation motivates the need for high-resolution three-dimensional wind data to better characterize and understand the development of these structures. Observational and associated NWP studies have revealed much about the complex evolution of LeS and examined the broader issues of atmospheric convective PBL responses, mesoscale circulations, and cloud-microphysical processes which are associated with variations in surface properties (e.g., Agee and Hart 1990, Braham 1990, Hjelmfelt 1990, Chang and Braham 1991, Rao and Agee 1996, Braham and Kristovich 1996, Grim et al. 2004, Kristovich and Braham 1998, Kristovich and Laird 1998, Kristovich et al. 1999, Young et al. 2000, Laird et al. 2001, Young et al. 2002, Kristovich et al. 2003, Laird et al. 2003, Miles and Verlinde 2005, Schroeder et al. 2006, Yang and Geerts 2006, Cordeira and Laird 2008, Steiger et al. 2009, Laird et al. 2009, Alcott et al. 2012). This extensive work has raised a number of important scientific questions. These include:

- How do multiple internal boundary layers develop and interact as an air mass progresses over mesoscale stretches of open water and intervening land?
- What role does the variation in these multiple internal boundary layers have on the circulation patterns, longevity, and intensity of LeS?
- How does the interplay between dynamics and mixed-phase cloud processes produce long-lived LeS persisting far downwind of open water?
- How do lake-scale circulations and surface and convective processes control the formation of intense long-fetch LeS snowbands?
- What is the fine-scale kinematic, dynamic and microphysical structure of intense LeS bands, which may contain cells with all characteristics of thunderstorms except for their depth in a highly-sheared low-CAPE environment?
- What processes lead to lightning production in intense LeS?
- What processes control snow production over and downwind of a lake?
- How are PBL circulations and lake-effect intensity affected by coastal transitions and downwind orographic effects?

To develop a better understanding of such LeS processes, the proposed OWLeS (Ontario Winter Lake-effect Systems) project will collect measurements during the peak months of lake-effect snows (December and January) in the vicinity of Lake Ontario.

On a broader scientific scale, improved understanding of processes in LeS is expected to become more important in a changing global climate. In particular, a recent study identified a reversal in the long-term increasing trend in lake-effect snow over the last century over a portion of the Great Lakes (Bard and Kristovich 2012). In addition, boreal lakes and the Arctic coastal waters are expected to remain ice-free for longer periods in the cold season (Stroeve et al. 2012), likely resulting in substantial increases in atmospheric modification and precipitation (especially snowfall) potential (Brown and Duguay 2010), resulting from interactions of multiple internal PBL generated by such lakes.

3. **OWLeS Scientific Hypotheses:**

The following hypotheses will be tested using measurements collected during OWLeS:

I. Effect of Upwind Land/Lake Variations: Spatial variations in PBL structure and, in turn, short-fetch LeS, critically depend upwind PBL characteristics developed over alternating mesoscale land/water surfaces, modified by the combined influences of above-PBL stability and internal PBL circulations. (mainly objectives a and b)

II. Small Lakes: Mesoscale circulations, PBL evolution, and snowfall distribution are altered and enhanced through downstream interactions of residual boundary layers with internal layers generated by smaller water bodies (such as individual Finger Lakes in New York). Additional enhancement comes from changes in downstream orography through channeling convergence and topographic lift. (mainly objectives a, b, and c)

III. Downwind Persistence: LeS bands are sustained over downwind land by one of three mechanisms: solenoidal circulations driven by weak moist convection in a decoupled mixed layer, ducted gravity waves, or continued coupling of lake-initiated convection to the surface due to overland instability created by differential temperature advection and solar heating. (mainly objective c)

IV. Dynamics of long-fetch LeS: Depending on wind, upwind temperature and stability, lake-parallel LeS may become sufficiently strong to produce lightning, vortical band structures (such as line-echo wave patterns), and heavy snowfall downwind, through a combination of lake-scale solenoidal flow, enhanced surface heat fluxes, and convective dynamics. (mainly objectives d and e)

V. Electrification of LeS: Long-fetch lake-effect system electrification is supported by microphysical and kinematic characteristics that include relatively deep convection (up to about 4 km, cloud top temperature down to about -30°C) with moderate updrafts (≈3-5 m s^{-1}). (mainly objective e)

VI. Hydrometeor Particle Types and QPE: LeS contain a variety of particles (dry snow, rimed snow, graupel, wet snow …), which can be revealed by means of DOW and WSR-88D dual-pol fields (especially differential reflectivity ZDR and differential propagation phase K_{DP}) and can be identified using the WSR-88D dual-pol algorithms. The WSR-88D dual-pol snow rate estimation is superior to reflectivity-based snow rate estimation. (mainly objectives e and f)

VII. Orographic enhancement: Enhanced snowfall occurs as lake-modified air ascends over downwind elevated terrain, such as the Tug Hill Plateau east of Lake Ontario. Orographic convection and boundary layer turbulence contribute to this enhancement, with hydrometeor advection and fall speed also affecting the intensity and distribution of snowfall upwind and over the Plateau. Variations in PBL structure, height and strength of the capping inversion, and storm morphology (e.g., shoreline bands, widespread coverage) produce intra- and inter-storm variations in these orographic effects and snowfall rates from the Lake Ontario coast across the Tug Hill Plateau. (mainly objective g)

4. Observational facilities and priorities:

Facilities requested from the NSF Lower Atmosphere Observing Facility (LAOF) pool are:

- the University of Wyoming King Air (UWKA), with the WCR and WCL systems; and
- three CSWR Doppler on Wheels (DOW) radar systems.

The following instruments and platforms are PI-supported:

- A total of five mobile sounding systems will be deployed, from UIUC, MU, SUNY-O, HWS, and one from UU (see Table 1 for abbreviations).
- The *Millersville University Profiling System* (MUPS) includes a surface flux tower, a sodar & RASS, and a tethersonde with probes measuring standard meteorological variables and the turbulence structure function (CT^2) and energy dissipation rate, up to a height of ~1000 m AGL.
- The *Mobile Integrated Profiling System* (MIPS) includes a 915 MHz wind profiler, a CL51 ceilometer, a microwave profiling radiometer, a vertically pointing X-band Doppler radar, Parsivel disdrometer, a hot plate precipitation gage, and an electric field mill.
- The UWKA team plans to bring a Yankee hot plate (precipitation rate), a WXT520 weather station, and GPS receiver station, to be mounted during the duration of OWLeS at a site (such as the home of a CoCoRaHS volunteer) near Sandy Point on the east end of Lake Ontario. The DOWS team plans to deploy up to ~20 "tornado" pods in each IOP, as detailed in the deployment plans. These pods are rapidly deployable weather stations measuring T, RH, and wind direction & speed at 1 Hz frequency. The data storage currently limits these pods to 17 hours of data collection. These pods will be deployed by means of 2 DOW support vehicles,

which themselves measure all basic meteorological variables, but are otherwise not used to collect transect data along roads.

- Additional observations: snow photography and surface snow board measurements at 4 sites along a transect from the coast to Tug Hill Plateau.

A summary of the relative importance of the facilities (LAOF and non-LAOF) for the seven OWLeS hypotheses is given below. Nearly all requested facilities will be at least useful for each of the hypotheses.

Table 2. Relative importance of the facilities for OWLeS hypotheses, rated as follows: 1=essential, 2=important, 3=useful, 4=not needed.

Hypotheses	I effect of upwind	II small lakes downwind	III downwind persistence	IV dyn. LeS	V Electrify-cation	VI Hydromete-ors and QPE	VII orography
NSF LAOF							
UWKA in situ probes	1	3	1	1	2	1	1
UWKA WCR	2	3	1	1	2	1	1
UWKA WCL	1	3	2	3	2	2	2
single DOW (Z, V, dual-pol variables)	2	2	2	1	1	1	1
DOW dual-Doppler winds	2	4	3	1	2	1	1
PI- instruments							
mobile radiosondes	1	1	2	1	1	1	2
MUPS	1	1	2	4	4	4	4
MIPS profiling sensors	2	1	3	1	1	1	1
MIPS in situ microphysics & field mill	4	2	3	2	1	1	1

5. OWLeS Field Operations:

LeS to be examined during OWLeS are either generated or augmented by Lake Ontario. It is convenient to organize our conceptualization of Lake Ontario convective systems as those generated when the winds are at large angles to the long axis of the lake (short-fetch, such as northerly or northwesterly winds) and those generated with winds nearly parallel to the long axis of the lake (long-fetch, usually westerly to southwesterly winds, but occasionally winds from opposite direction, ENE). The two main proposals (see Table 1) generally follow the same partitioning (i.e., OWLeS-SAIL focuses mainly on short-fetch LeS, OWLeS-BIC focuses on long-fetch LeS). Thus, the operations of OWLeS will vary with the predicted organization of the LeS convective structures, as illustrated below.

a. **Experiment Plan 1** (Figure 1) is designed for conditions giving rise to short-fetch LeS. The internal lake-effect PBL structure develops in response to heat, moisture, and momentum fluxes from the lake surface. The atmospheric response to these fluxes may be controlled by such factors as the stability of the atmosphere, spatial variations in land cover, shoreline shape, upwind lakes, and internal PBL circulations. The most common convective structure in these conditions is multiple wind-parallel bands originating over Lake Ontario. Such bands occasionally extend far downwind of the lake. With this wind regime, convective bands also frequently develop within the PBL over the Finger Lakes within air modified by Lake Ontario.

   Plan 1 primarily serves hypotheses I through III (objectives a through c). In this experiment, observational platforms focus on obtaining information on either the spatial evolution of the PBL north of and over Lake Ontario or the spatial evolution of convective bands over and south of Lake Ontario, depending on the objective chosen for that day. Observational platforms can be deployed to determine:

1) PBL and environmental conditions near the upwind shore of Lake Ontario (objectives a, b)
2) Surface fluxes, PBL evolution, and LeS development over Lake Ontario (objectives a, b)
3) PBL structure and convective precipitation structures near the downwind shore of the lake (objectives a, b, c)
4) PBL and convective structures between Lake Ontario and the Finger Lakes (objectives b, c)
5) PBL and convective structure over the Finger Lakes (objective c)
6) Convective and microphysical structure within convective bands extending long distances downwind from their convective source regions. (objective c)

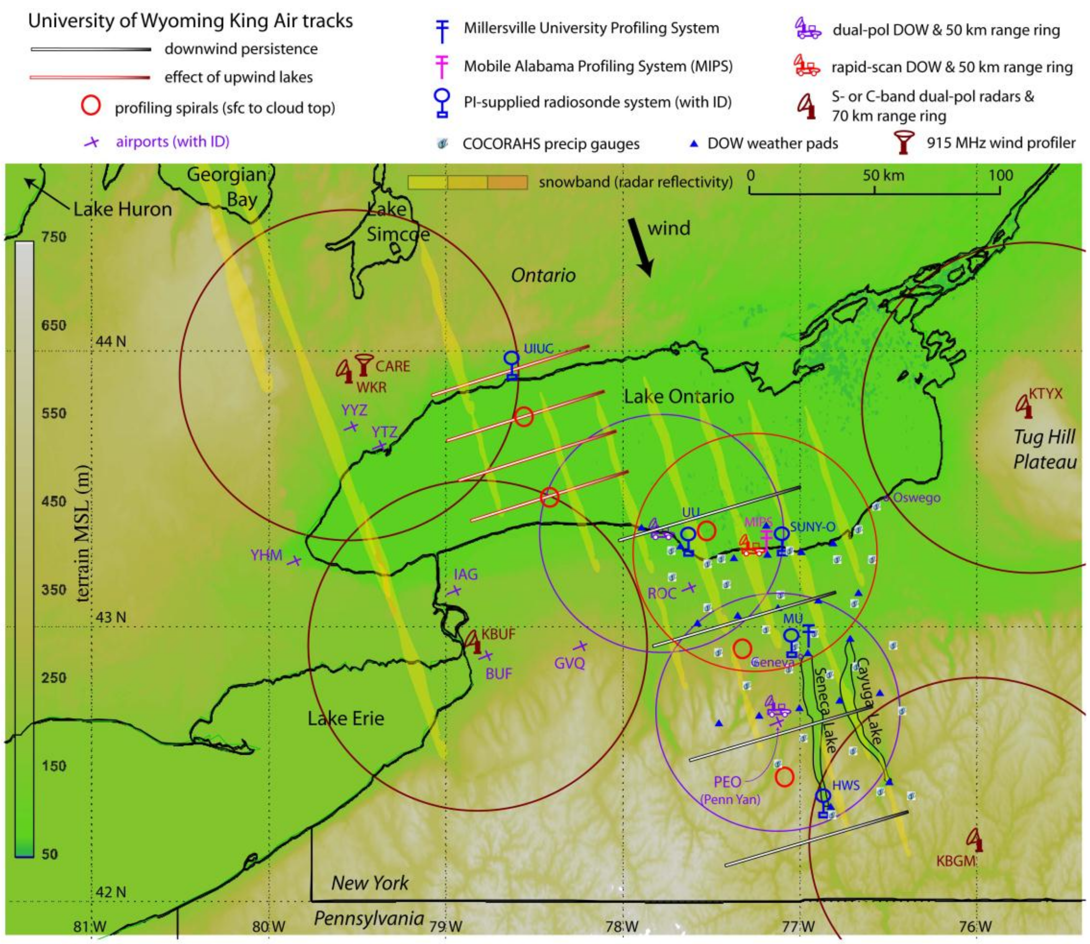

Fig. 1: Map showing schematic location of UWKA flight patterns, the OWLeS facilities, and relevant operational facilities in Experimental Plan 1 during conditions with short-fetch LeS bands. Light-colored regions oriented NW-SE illustrate the types of multiple convective bands frequently seen in these conditions. The colored UWKA flight tracks serve hypotheses I and III. All OWLeS facilities are mobile but are designed remain stationary during the duration of short-fetch IOPs. The two largest Finger Lakes in New York, Cayuga and Seneca, are highlighted.

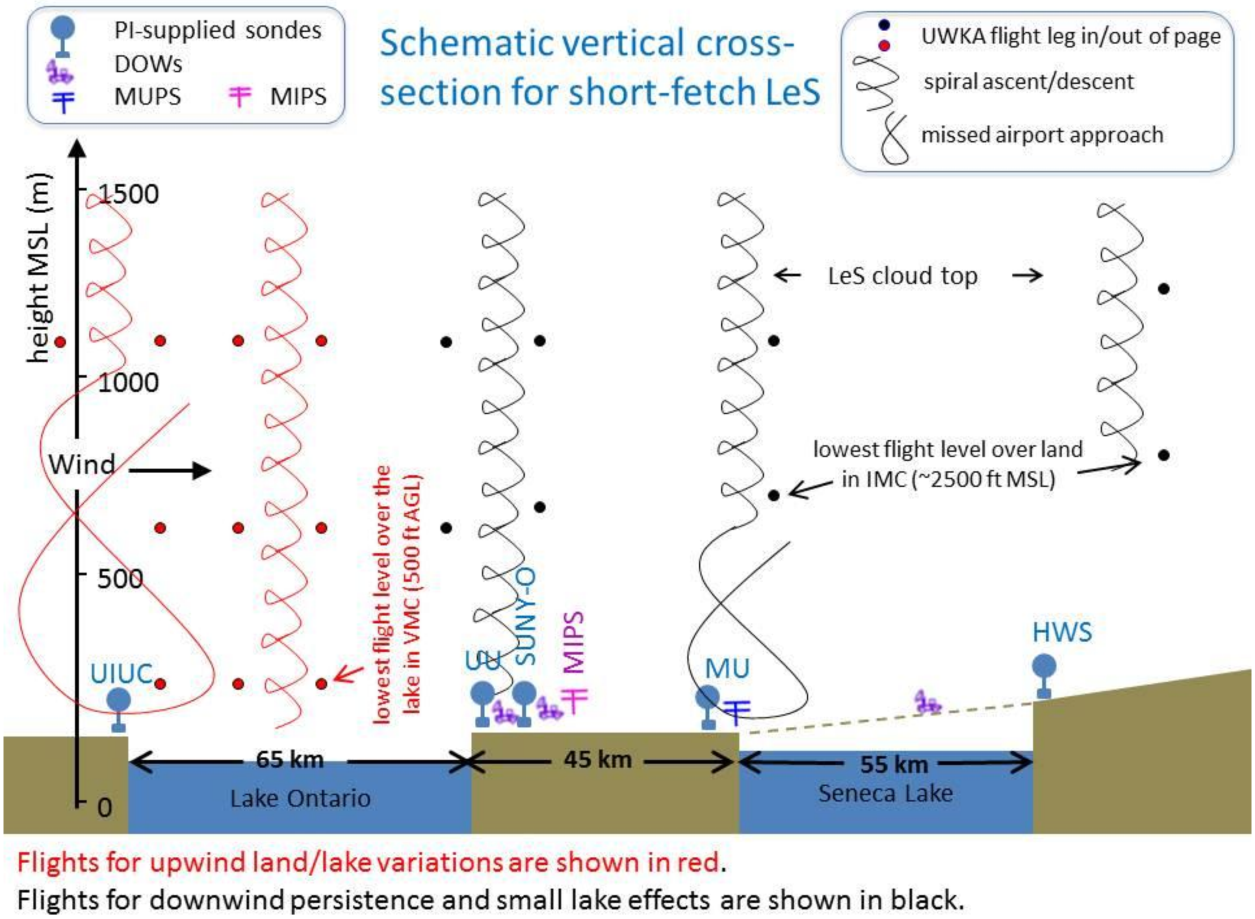

Fig. 2*: Schematic vertical cross-section showing schematic location of UWKA flight patterns, the five sites with OWLeS facilities, and mobile sites in Experimental Plan 1.*

b. **Experiment Plan 2** (Figure 3) is designed for conditions giving rise to long-fetch LeS. The most common LeS structures in these conditions are single or multiple bands, generated over Lake Ontario and extending over higher terrain east of the lake. Plan 2 primarily serves hypotheses IV through VII. In this experiment, observational platforms focus on obtaining information on the spatial evolution of the LeS over and east of Lake Ontario.

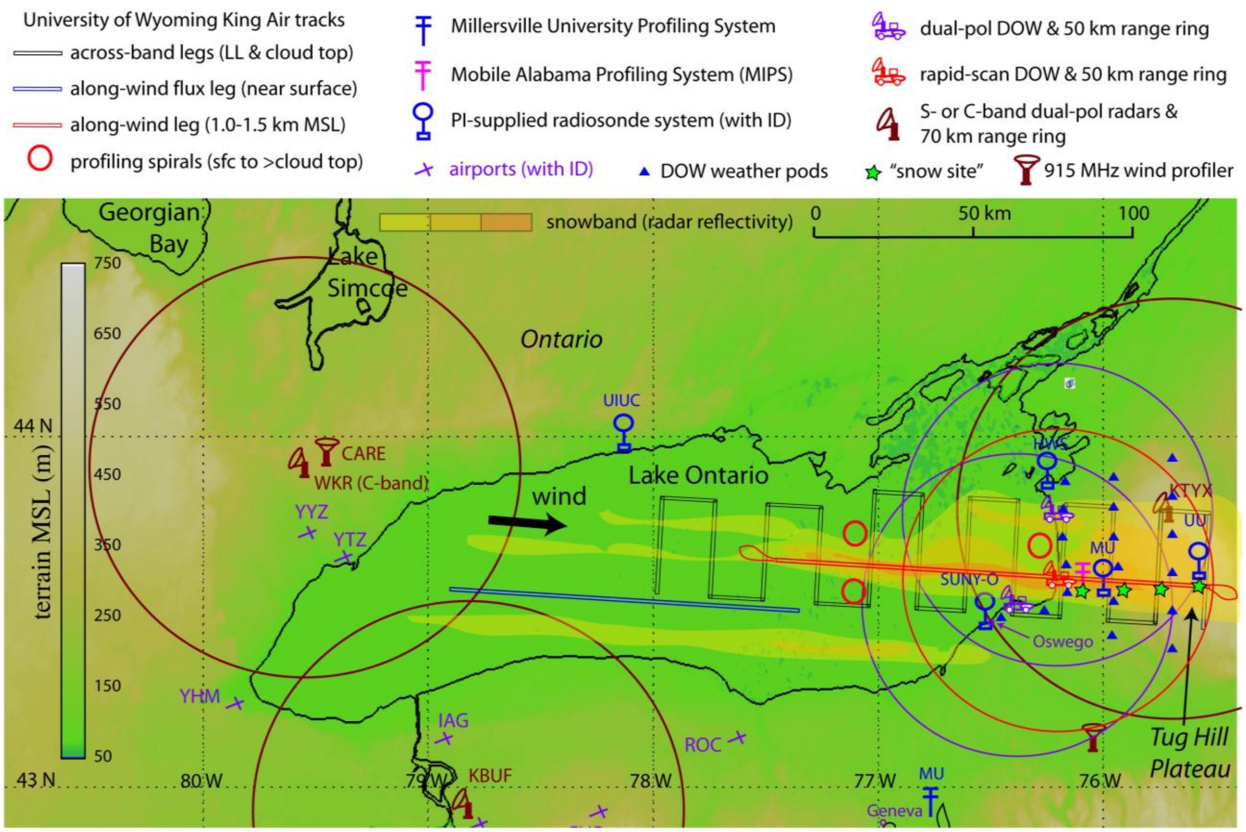

***Fig. 3**: Terrain map showing schematic location of UWKA flight patterns, OWLeS facilities, mobile sites and relevant operational facilities in Experimental Plan 2 during conditions with LeS oriented approximately parallel to the long axis of Lake Ontario. Sounding sites, MIPS and MUPS are designed to remain stationary during the duration of the long-fetch IOPs, but one or more DOWs may be moved between pre-selected sites during an IOP, if road conditions allow.*

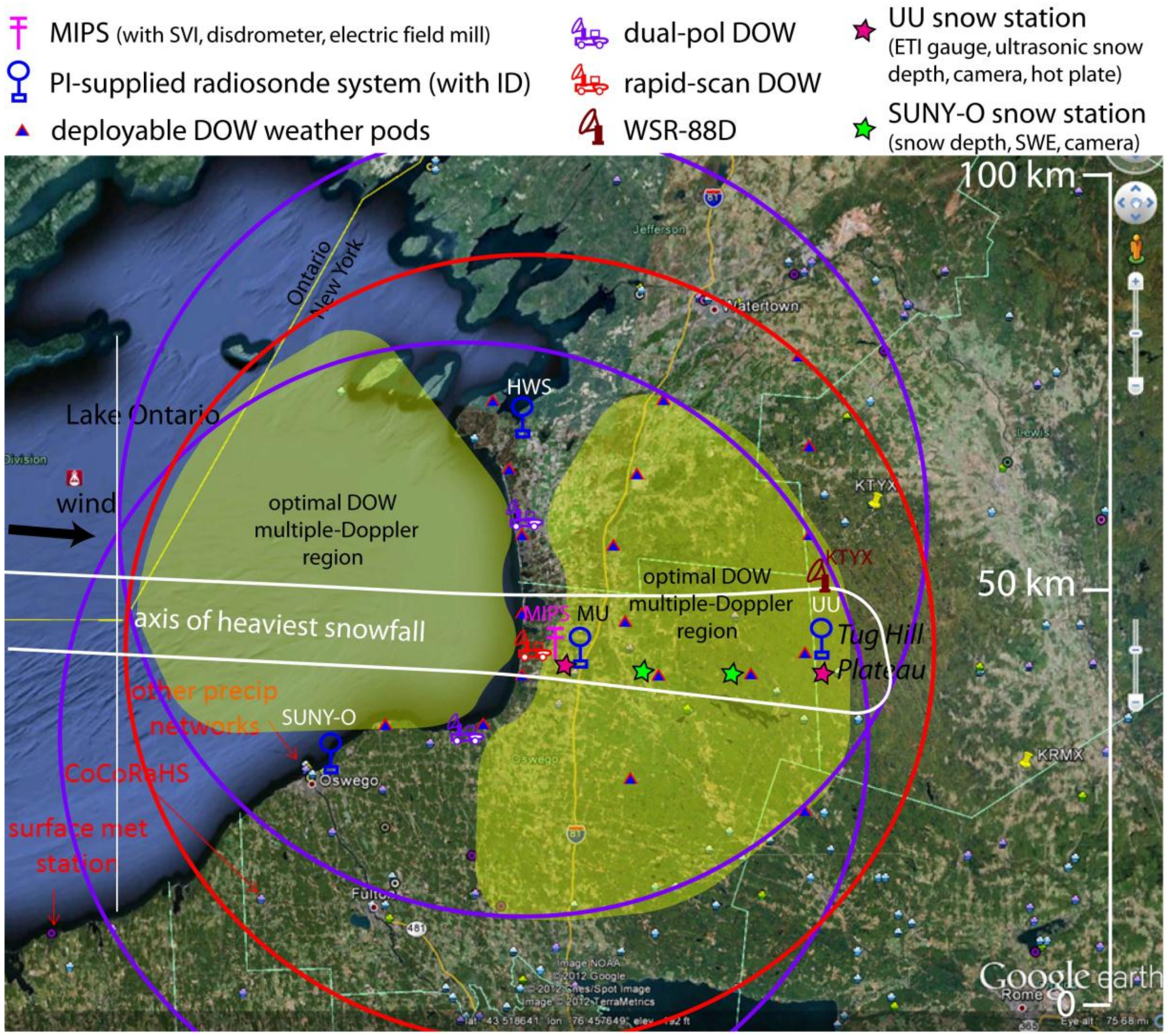

***Fig. 4**: Zoom-in map from eastern Lake Ontario to the Tug Hill Plateau, showing the same platforms as in Fig. 3 (except the UWKA), plus the DOW dual- to triple-Doppler regions, the transect of manual snow observations (photograph & snow board), and all operational weather stations including hourly to daily precipitation networks.*

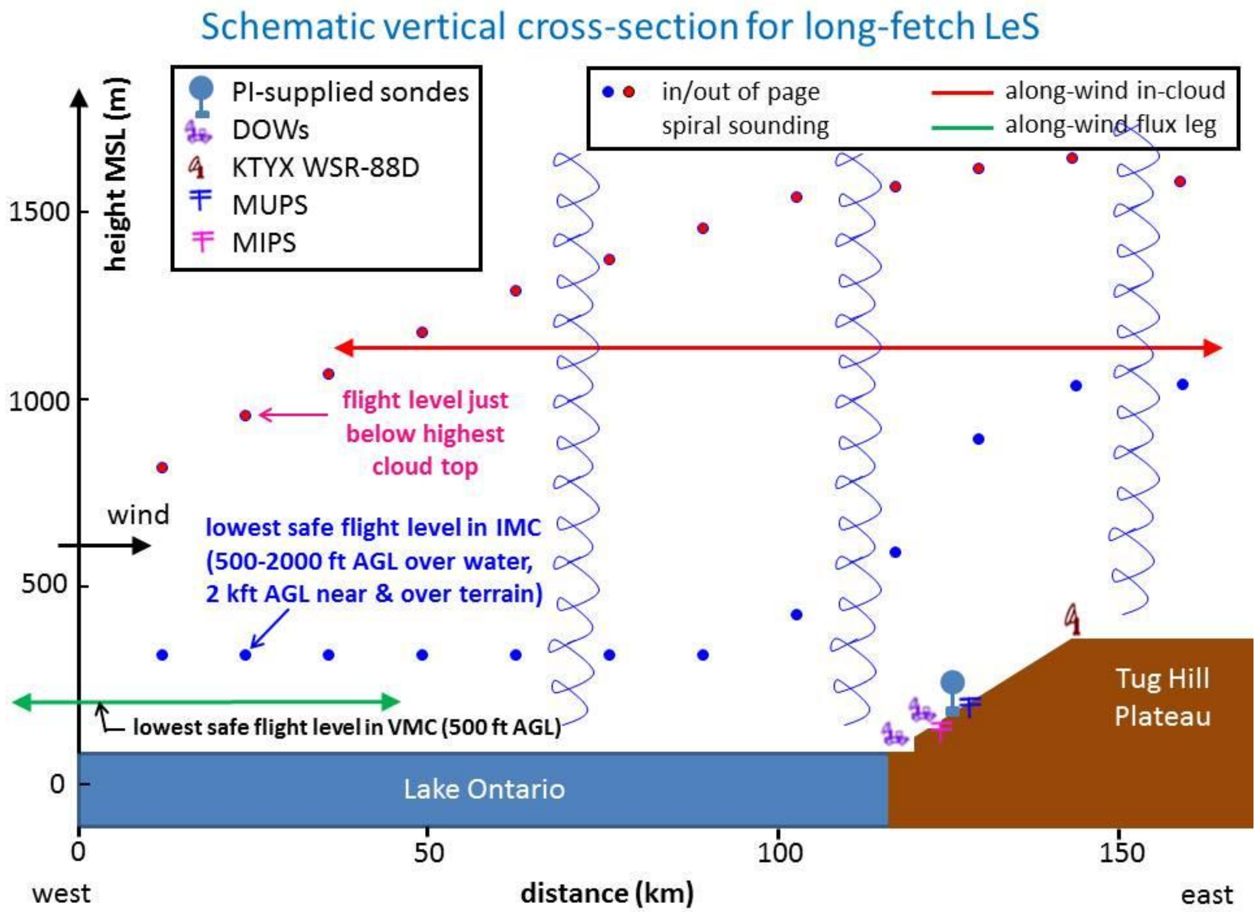

***Fig. 5**: Schematic vertical cross-section showing schematic location of UWKA flight patterns and OWLeS facilities, in Experimental Plan 2.*

6. <u>**OWLeS timing and duration:**</u>

The field phase is planned to coincide with the peak frequency of LeS near Lake Ontario. Specifically, the field operations are planned for 1-21 December 2013 and 3-24 January 2014, a 43-day period.

The duration of the field campaign is planned to be sufficient to capture approximately eight LeS events. Climatological analyses have shown that a six-week period spanning late November through early January typically yields about 10 LeS events (Table 3). Note that techniques available to Rodriguez et al. (2008) enabled them to identify weaker events than Kristovich and Steve (1995), and thus may be more representative of appropriate conditions for OWLeS. Of these events, typically about 5 are short-fetch LeS under northwesterly flow (Experimental Plan 1) some of which may extend between upwind lakes and Lake Ontario, and extend far downwind from Lake Ontario. Long-fetch LeS events (Experimental Plan 2) are less common (typically 1-3 during the time period), although they tend to last longer (Table 4). Note that since Kristovich and Steve (1995) and Rodriguez et al. (2008) based their LeS classification on visible satellite imagery, roughly half of the lake-effect cases could not be clearly categorized into one of these two types. In addition, weaker cases of PBL modification that do not produce significant clouds/snow over Lake Ontario but are useful for studying the influence of upwind lake and land variations, are thought to occur more frequently than reported by these previous studies. During the LLAP project, 7 long-fetch lake-effect wind cases were observed by Cermak et al. (2012). At least a third of the cases during a typical year last longer than a day (Table 4), allowing for multiple operational periods.

Table 3*. Climatic frequency (in # days) over Lake Ontario in a 43 day period in late November-early January, based on visible satellite imagery.*

Number of days with …	Kristovich & Steve (JAM, 1995)	Rodriguez et al. (MWR, 2008)
Lake-effect snow	5-12	10-12
Widespread snow or multiple bands (rolls, usually oriented NW-SE)	2-6	5-6
Long lake axis parallel bands (W-E)	< 2	2-3

Table 4*. Duration (in # days) of lake-effect snows over Lake Ontario.*

Percentage of	Based on data compiled by Kristovich and Steve 1995 and Rodriguez et al. 2008)	Based on LeS events listed by NWS Forecast Office, Buffalo, NY, 2009 (http://www.erh.noaa.gov/buf/)
1-day events	66%	18%
2-day events	23%	46%
Both 1- and 2-day events	89%	64%

7. Educational efforts:

a. *Training opportunities for OWLeS participants*

The NSF LAOF Users Workshop held at NCAR in September 2007 highlighted the importance of the training of future observational scientists through participation in field work (Serafin et al. 2008), not just in data analysis, but also in campaign planning, instrument preparation, and data collection. We intend to bring several graduate students and a larger number of undergraduates into the field (Table 5). The positions to be assigned to these students are listed in Table 6. The student participation in the DOW operations is important as it will reduce the facility deployment cost. The preparation and release of radiosonde balloons requires two people. For safety, at least two people will be at any one site, and IOP-related travel requires two people per vehicle (the buddy system).

Table 5. Student participation in OWLeS. Rotations are anticipated.

University	# undergraduate students	# graduate students
Hobart and William Smith Colleges	~5	-
Millersville University	~12	-
Pennsylvania State University	-	1-2
State University of New York – Oswego	~10 or more	-
University of Alabama in Huntsville	-	1-2
University of Illinois Urbana-Champaign	4	2-3
University of Utah	-	1-2
University of Wyoming	-	1-2

Table 6. Student assignments in OWLeS. These are full-time positions; rotations are anticipated.

Instrument	# positions
DOWs (3 positions per DOW)	9
mobile sounding systems – 6 total (1 from HWS, 1 from MU, 1 from UIUC, 1 from SUNY-O, and 2 from UU)	12
Millersville University Profiling System (MUPS)	2
Mobile Integrated Profiling System (MIPS)	2
Snow photography	8
Forecasting, IOP nowcasting	2
total	35

Students will be involved in all aspects of the project. This includes logistics, deployment and data collection, real-time running of WRF, with an inner domain centered over Lake Ontario, daily weather briefings, interaction with the NWS WFOs at Buffalo and Binghamton, and nowcasting during IOPs in support of the operations director who coordinates the crews in the field. A smaller number of students will conduct OWLeS research as part of their degree program (BSc to PhD).

In addition, we plan to take advantage of many non-IOP days between cold-air outbreaks. A for-credit *OWLeS seminar series* will be organized, on both the science of lake-effect snowfall and on field instrumentation, which will include visits to the facilities (radar polarimetry and Doppler synthesis; passive microwave atmospheric profiling; airborne and ground-based flux measurements …). Students register at their home institutions. The seminar sequence will be determined in advance; the exact timing depends on the IOP sequence. Most seminars will be open to anyone. One seminar will be dedicated to the planning of an IOP, whereby the students decide on the UWKA flight plan, the schedule of GAUS sonde releases, and the deployment of participants in the field. This seminar, aimed at participating graduate and undergraduate students, will be modeled after the seminar held as part of RICO (Rauber et al. 2007). The richness and breadth of instrumentation deployed in OWLeS will ensure that students participating in the seminar will be exposed to in-situ ground-based and airborne platforms and remote observing facilities, with sensors operating at several different frequencies, capturing multiple spatial scales, with each sensor dedicated to a specific measurement while serving as a component of a coordinated project-scale observing system.

b. *Outreach:*

Several universities in the vicinity offer undergraduate degree programs in meteorology or related fields (SUNY Brockport, SUNY Oswego, HWS Colleges, Cornell …). We plan to arrange events for students to see the UWKA, the DOWs, MIPS and MUPS at the UWKA's base airport. We may be able to release and track a weather balloon with the visitors. We may also develop a web-based OWLeS Outreach Program similar to the program at Millersville University where teachers from local high schools, community colleges, and universities can request an on-site visit to the facilities.

"*Most scientists today began their careers as children, chasing bugs, collecting spiders,* [observing weather], *and feeling awe in the presence of nature. Since such untidy activities are fast disappearing, how, then, will our future scientists learn about nature?* (Richard Louv, *Last Child in the Woods: Saving our children from nature deficit disorder.* Algonquin Books of Chapel Hill, 2008 p.144.) OWLeS activities are replete with opportunities for students to learn about winter weather, meet the scientists that endeavor to understand the atmosphere, and visit exciting facilities such as the DOWs and the UWKA.

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