PROJECT SUMMARY:

Collaborative Research: Ontario Winter Lake-effect Systems – Surface and Atmospheric Influences on Lake-effect Convection (OWLeS – SAIL)

This collaborative proposal is one of three proposing research associated with the Ontario Winter (OW) Lake-effect Systems (LeS) field project, scheduled for Dec 2013 - Jan 2014. The OWLeS project aims to document dynamical and cloud microphysical processes of planetary boundary-layer (PBL) convection over and downstream of relatively warm, mesoscale open-water surfaces at unprecedented detail, using X-band and S-band dual-polarization (dual-pol) radars, an aircraft instrumented with particle probes and profiling cloud radar and lidar, and a network of profiling systems and surface precipitation instruments. The OWLeS project focuses on the Lake Ontario and Finger Lakes regions because of the varied size and orientation of lakes, the climatological frequency of LeS events, the nearby moderate orography, the impact of Lake Ontario LeS hazards on public safety and commerce, and the proximity of several universities and colleges with atmospheric science programs. The OWLeS project is comprised of two complimentary modes, each related to the prevailing wind direction: 1) short-fetch LeS (those oriented at large angles to the long axis of the lake) are the main topic of this proposal; and, 2) long-fetch LeS (those more aligned with the lake's long axis). The PIs of OWLeS proposals are committed to coordinated field operations, the sharing of all OWLeS data and analysis products, and collaborative research.

This proposal and the OWLeS project stand out mainly for two reasons: 1) the focus on physical processes in the context of a prime example of interactions between the PBL, the surface, and cloud & precipitation, interactions that current operational numerical weather prediction (NWP) and climate models cannot resolve because the processes are separately parameterized; and 2) the unique collaboration with undergraduate programs at several institutions and the extensive opportunities for undergraduate students to participate in cutting-edge research, from data collection in the field to co-authoring peer-reviewed publications.

The key objectives of this proposal are to describe and understand: 1) 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; 2) the development of, and interactions between, internal planetary boundary layers (PBL) and residual layers resulting from advection over multiple mesoscale water bodies, including smaller lakes, and intervening land surfaces; 3) how organized, initially convective LeS structures in short-fetch conditions persist far downstream over land, long after leaving the original buoyancy source (i.e., the ice-free water).

Intellectual Merit: While current operational NWP models reasonably capture LeS timing, there remain significant gaps in our understanding of fine-scale thermodynamic and kinematic structure of LeS; the interaction between and evolution of multiple internal boundary layers as an air mass progresses over multiple stretches of open water and intervening land; the role that variation in multiple internal boundary layers have on the morphology of mesoscale precipitation; and how the interplay between dynamics and mixed-phase cloud processes produce long-lived snow bands persisting far downstream of open water. Building on previous LeS field campaigns, OWLeS provides a unique opportunity to not only document the fine-scale thermodynamic, kinematic, and cloud microphysical structure of LeS, but also to further our understanding of key processes in LeS by deploying a mesoscale network of new, high-resolution *in situ* and remote sensors. This observational network is well suited to capture the structure, evolution, and spatio-temporal variability of the PBL and will provide unprecedented evaluation of short-fetch LeS.

Broader Impacts: Lake-effect snow events create major weather hazards downwind of the Great Lakes, especially considering the region includes several well-traveled interstate highway systems. An understanding of the structure and processes leading to intensified downwind LeS will better inform road management agencies of weather situations having large impacts on winter travel. This research becomes more urgent in a warming global climate, as boreal lakes and the Arctic coastal waters are expected to remain ice-free for longer periods. This may lead to substantial increases in boundary-layer heat, moisture and snow growth, and, as a result, an increase in coastal erosion, precipitation, and ecosystem impacts. Finally, the proximity to several institutions with participating PIs gives us the opportunity to inexpensively train many students (~ 35), mostly undergraduates, in authentic hands-on instrument-based end-to-end (data-to-papers) research in atmospheric science, and to reach out to numerous K-20 students across the region.

RESULTS FROM PRIOR NSF SUPPORT

ATM-05-12954 (Kristovich) & ATM-05-12233 (Laird) 9/2005–9/2010
Collaborative Research: Effects of Non-Uniform Surface Conditions on Lake-Effect Systems

Description of Results: The current proposal builds on scientific findings and expertise developed during our previous investigations using a variety of approaches to understand fundamental planetary boundary layer (PBL) processes and lake-effect (LE) systems. Below we present results from an NSF Collaborative Research grant which focused on LE systems during the last five years. Emphasis is placed on studies which relate to the proposed research.

Barthold and Kristovich (2011) provided a detailed investigation of cloud and snow growth across Lake Michigan during a LE snowstorm with southwesterly winds. As anticipated, both liquid and ice water contents increased steadily across the lake. However, snow particle concentrations decreased over the downwind half of the lake as aggregation became more prominent. Surprisingly, snow particles were observed 3-7 km upstream of the LE cloud deck. One of the potential causes of this is snow blowing from the upwind shore; a process targeted for observation during the proposed OWLeS project with planned research to examine its linkage to over-lake snow development.

Our research revealed several cases of variations in LE boundary layer conditions related to processes outside of the typically-considered LE system, such as "seeding" of LE clouds by non-LE snow particles or PBL modification by upwind lakes. Perhaps the most visible manner by which an upwind lake can influence LE over a downwind lake is the development of lake-to-lake cloud bands. In a study examining such bands throughout the Great Lakes region, Rodriguez et al. (2007) found that approximately 30% of all LE cases that develop over Lake Huron produce a cloud band that extends to Lake Ontario, the study region for the proposed OWLeS project. Such lake-to-lake cloud bands result in important spatial variations in LE PBL clouds and snow and, presumably, PBL depth and other thermodynamic processes. This study also builds on a previous case study by Schroeder et al. (2006), who found that the depth of the well-mixed boundary layer and snowfall rates in LE systems can be very sensitive to variations in environmental stability and pre-existing snow. Despite modest surface heat fluxes of 100–200 W m^{-2} over Lake Michigan, cross-lake boundary layer growth was twice that previously reported as the LE convection merged with an overlying reduced-stability layer caused by a nearby cyclone. In addition, snowfall rates were increased by an order of magnitude where cyclone-generated snow "seeded" the shallower LE clouds and boundary layer depth increased by about 10% compared to nearby non-seeded areas. These studies demonstrate the sensitivity of convective PBLs to the environments in which they develop and the significant roles that upwind lakes and synoptic systems can have in LE development and intensification.

Laird et al. (2009a, 2009b, 2010) provided climatological analyses of LE precipitation events which developed in association with lakes smaller than the Great Lakes. The frequency, characteristics, and environmental conditions favorable for LE precipitation were examined for nine winters (October-March) for Lake Champlain (Laird et al. 2009a) and eleven winters for the New York State (NYS) Finger Lakes (Laird et al. 2009b, 2010). WSR-88D radar data from Burlington, VT (for Lake Champlain) and Binghamton, NY (for the Finger Lakes) were used to identify 67 and 125 LE events, respectively. Laird et al. (2009b) showed that all of the eastern and central NYS Finger Lakes can produce LE precipitation bands. These LE events had an average duration of 9.4 hrs and exhibited an evident diurnal signal in the timing of their initiation and dissipation – a result consistent with Great Lakes LE snowfall (Kristovich and Spinar 2005). Additionally, Laird et al. (2010) showed that LE precipitation events originating from the Finger Lakes, rather than an enhancement to Lake Ontario LE or synoptic precipitation, developed with the: (a) coldest temperatures, (b) largest lake-air temperature differences, (c) weakest wind speeds, (d) highest sea-level pressure, and (e) lowest base height of the stable layer. The characteristics of and transitions between LE events in the Finger Lakes region strongly suggested links to variability of the Lake Ontario boundary layer – an interaction targeted during the proposed OWLeS project.

Additional studies conducted under these grants focused on understanding the atmospheric processes that influence LE systems. These include an investigation of the influence of pack ice concentration on surface heat exchanges using measurements from the Great Lakes Ice Cover - Atmospheric Flux (GLICAF) project (Gerbush et al. 2008) and a study examining the influence of extensive ice cover on two Lake Erie LE snowstorms (Cordeira and Laird 2008).

Published Research: Since 2006, research under this collaborative grant resulted in 9 published journal articles and more than 40 conference presentations given by the PIs or graduate and undergraduate students. Also, 16 undergraduate students have participated in the summer research program at Hobart & William Smith Colleges and one graduate thesis was completed at the University of Illinois.

<u>Journal Articles</u>:

1. Rodriguez, Kristovich and Hjelmfelt, 2007: Lake-to-lake cloud bands: Frequencies and locations. *Mon. Wea. Rev*., **135**, 4202-4213.
2. Payer, Desrochers and Laird, 2007: A lake-effect snow band over Lake Champlain. *Mon. Wea. Rev.*, **135**, 3895-3900.
3. Cordeira and Laird, 2008: The influence of ice cover on two lake-effect snow events over Lake Erie. *Mon. Wea. Rev.*, **136**, 2747-2763.
4. Gerbush, Kristovich and Laird, 2008: Aircraft observations of surface heat fluxes over pack ice-covered Lake Erie., *J. Appl. Meteor. Climatol.*, **47**, 668-682.
5. Laird, Desrochers and Payer, 2009a: Climatology of lake-effect precipitation events over Lake Champlain. *J. Appl. Meteor. Climatol.*, **48**, 232-250.
6. Laird, Sobash and Hodas, 2009b: The frequency and characteristics of lake-effect precipitation events associated with the New York State Finger Lakes. *J. Appl. Meteor. Climatol.*, **48**, 873-886.
7. Laird, Sobash and Hodas, 2010: Climatological conditions of lake-effect precipitation events associated with the New York State Finger Lakes. *J. Appl. Meteor. Climatol*., **49**, 1052-1062.
8. Barthold and Kristovich, 2011: Observations of the cross-lake cloud and snow evolution in a lake-effect snow event. *Mon. Wea. Rev.*, **139**, 2386-2398.
9. Bard, L. and D.A.R. Kristovich, 2012: Trend Reversal in Lake Michigan Contribution to Snowfall. *J. Appl. Meteor. and Climatol*. In press.

<u>Masters Degree Thesis</u>:

1. Barthold, 2008: *The spatial evolution of clouds and snow in a lake-effect boundary layer.* M. S. Thesis, Dept. of Atmospheric Sciences, Univ. of Illinois, 119 pp. Advised by Dr. Kristovich.

For more than 15 years, Drs. Kristovich and Laird have taken a leading role in research on physical processes that govern the development, intensity, and locations of LE snow storms. This effort has led to a better understanding of LE systems by examining related boundary layer processes (Kristovich 1993, Kristovich et al. 2003, Gerbush et al. 2008), microphysical evolution of clouds and snow (Kristovich and Laird 1998, Kristovich and Spinar 2005, Schroeder et al. 2006, Barthold and Kristovich 2011), mesoscale circulations (Laird 1999, Laird et al. 2001, Grim et al. 2004, Laird and Kristovich 2004, Laird et al. 2003a, b, Payer et al. 2007, Cordeira and Laird 2008), and climatological characteristics and conditions (Kristovich and Steve 1995, Rodriguez et al. 2007, Laird et al. 2009a, b, Laird et al. 2010, Bard and Kristovich 2012). In addition to the work that has been published in scientific journals, close interactions with numerous National Weather Service Forecast Offices have allowed for the results from many of these efforts to be more efficiently incorporated into an operational setting. Knowledge from our previous and ongoing research has provided us the understanding and experience to address remaining important scientific issues related to the fundamental thermodynamic and dynamic forcing necessary for LE events; the focus of the current proposal. The proposed research will provide new insights through unprecedented observations collected during the OWLeS project and numerical model simulations.

PROJECT DESCRIPTION OF THE PROPOSED RESEARCH

Collaborative Research: Ontario Winter Lake-effect Systems – Surface and Atmospheric Influences on Lake-effect Convection (OWLeS – SAIL)

1. Introduction: The Ontario Winter Lake-effect Systems (OWLeS) project examines the formation mechanisms, the cloud microphysics, boundary layer processes and the dynamics of snow bands; more broadly, lake-effect systems (LeS). LeS are particularly well-suited for developing an understanding of fundamental, complex interactions between the surface, multiple internal boundary layers, and surface-based mesoscale systems. LeS form when a cold air mass is advected over relatively warm mesoscale bodies of water, such as the Great Lakes. The OWLeS project focuses on Lake Ontario because of its (a) size and orientation in relation to the low-level wind direction, giving rise to two dominant LeS modes, (b) frequency of LeS events, (c) upwind variability in surface land and water bodies, (d) nearby orography, and (e) the impact of Lake Ontario LeS hazards on public safety and commerce. In addition, proximity to several participating universities with a strong record of undergraduate and graduate research aids in both project logistics and learning opportunities. It is convenient to organize Lake Ontario LeS for planning of operations during OWLeS into two dominant LeS modes: (1) when winds are at large angles to the long axis of the lake (short-fetch, such as northerly or northwesterly winds) and (2) when winds are nearly parallel to the long axis of the lake (long-fetch, such as westerly to southwesterly winds).

This proposal describes the research efforts associated with short-fetch LeS. It is thought that such systems are strongly influenced by upwind mesoscale water bodies (such as Georgian Bay), produce highly variable snowfall rates over a wide region near the downwind shore of the lake, can produce cloud and snow bands extending many hundreds of km downwind and regularly contributes to LE snow storms over the NYS Finger Lakes.

2. Background: Over the last three decades, a few field experiments have focused on understanding processes involved in the development of LeS. 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 was conducted downwind of Lake Ontario in the winter of 2010/11. Observational and associated numerical weather prediction (NWP) studies have revealed much about the complex evolution of LeS and examined the broader issues of atmospheric convective planetary boundary layer (PBL) responses, mesoscale circulations, and cloud-microphysical processes that 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, 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 previous work has raised a number of important scientific questions, including:

- How do multiple internal boundary layers develop and interact as an air mass progresses over multiple 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 are PBL circulations and LE intensity affected by coastal transitions?

To develop a better understanding of these processes, the proposed OWLeS project will collect measurements during the peak months for LE snows (December and January) in the vicinity of Lake Ontario and throughout the NYS Finger Lakes region.

2.1 *Boundary-layer circulations over a complex area of mesoscale open lakes and land*

The evolution of the PBL in response to variations in surface properties is a topic of intense scientific interest and has important impacts on the environment and society (e.g., atmospheric dispersion, precipitation development and evolution, wind power production, etc.). In a recent review of the state of knowledge about the PBL, Baklanov et al. (2011) indicated that interacting internal PBLs caused by variations in surface roughness and temperature plays an important, not well understood, role on weather, climate, and air quality. They emphasized the need for additional observations of such complex PBL environments. The Great Lakes region is ideal for investigations of these processes, since most cold-air outbreaks result in flow over multiple mesoscale regions of land and open water surfaces. Due to intense surface-air exchanges, internal PBLs often exhibit conditions far different than those upwind of the lakes. For example, pre-modification of the atmosphere by upwind lakes has been shown to increase LE snow intensity and influence snow band locations over downwind lakes (Agee and Gilbert 1989; Schroeder et al. 2006; Niziol et al. 1995; Rose 2000; Mann et al. 2002; Rodriguez et al. 2007). However, the relative roles of radiative processes, mesoscale circulations, and alterations in the PBL stability profile have not been determined (e.g., Byrd et al. 1991, Kristovich and Laird 1998).

While upwind lakes have large influences on LE convection over downwind lakes, more subtle variability in upwind land and lake surface conditions are also thought to affect the downwind evolution of the LE PBL. Meso-β variations in the cross-wind depth of the PBL and snowfall have been observed in a number of detailed case studies (e.g., Agee and Gilbert 1989, Rodriguez et al. 2007). Kristovich and Laird (1998) found that such changes in cross-wind boundary layer depth could be due to subtle variations in lake-surface temperatures and upwind stability. Barthold and Kristovich (2011) found clear correlations between variations in PBL depth and snowfall intensity. The reasons for these meso-β variations in PBL depth and structure were not examined in detail. On a smaller scale, Tripoli (2005), using numerical simulations, found that meso-γ-scale roll-like structures could be generated by variations in the shape of the upwind coast in LE situations and that these structures persist downstream across the entire lake. These previous studies focused on Lake Michigan LeS, with few impacts from upwind lakes.

The proposed OWLeS measurements will take place in a region with multiple upwind mesoscale water bodies in conditions allowing for strong LE PBL convection. New observational platforms and the unique upwind conditions in Lake Ontario LeS allow for an unprecedented opportunity to address fundamental aspects of internal boundary layer interactions and mesoscale LE PBL variations.

2.2 *Downwind persistence of lake-effect circulations*

In certain situations LE and similar circulations, and their associated cloud and precipitation bands, persist for hundreds of kilometers downwind of their original surface buoyancy source (e.g., Young and Sikora 2003; McFarlane et al. 2005) and may ultimately result in snowfall well removed from the lakes (i.e., Keighton et al. 2009). It is well understood that snow bands developing during cold-air outbreaks over relatively warm water consist of convective cells driven by surface heat and moisture fluxes (e.g., Yang and Geerts 2006). Furthermore it is widely believed that the circulations supporting long-lived snow bands over land decouple rapidly from the surface once the air mass crosses a shoreline.

But it is not clear whether long-lived snow bands over land remain as solenoidal circulations driven by residual buoyancy release in a decoupled internal boundary layer. In particular, it is unknown how a conditionally unstable lapse rate can be maintained under turbulent mixing and radiative flux divergence, nor how moist convection can be sustained in a non-replenishing water vapor reservoir. Slow isentropic ascent of the moist layer above an increasingly deep stable boundary layer over land, especially at night or over snow cover, may explain sustained condensation/deposition and very light snowfall. However, the strongest overland snowfall is often observed during the afternoon in conjunction with towering cumulus, suggesting a surface-forced convective component related to solar heating. Cellular convection aligned in bands occurs as far downstream of the eastern Great Lakes as central Pennsylvania. If convective forcing does cease rapidly upon landfall, one wonders whether frictional dissipation can be slow enough to allow such circulations to continue for hours. Alternatively, long-lived snow bands may result from gravity waves triggered in the capping layer above the BL by linear convection over the upstream lake and ducted under a suitable wind shear and stratification profile (e.g., Wang and Lin 1999). Yet in several cases singular (not wave-like) persistent snow bands have been observed.

Thus, the existing observations suggest the existence of one or more mechanisms for continued destabilization (such as differential temperature advection) in support of convection in the overland regions downstream of the lakes. Observations taken during OWLeS will allow quantification of these potential processes to develop a better understanding of the downwind longevity of LE mesoscale circulations. We believe highly resolved thermodynamic, kinematic, and flux profiles using surface observations, profiling capabilities and aircraft during OWLeS will help to improve understanding of the connection between the boundary layer forcing and the downwind evolution of these circulations.

2.3 *Lake-effect precipitation events associated with lakes smaller than the Great Lakes*

Investigations of LE snowstorms and the conditions leading to their development have typically focused on events associated with large lakes, such as the Great Lakes. Investigations of LeS over smaller lakes, such as the Great Salt Lake (GSL) (Carpenter 1993, Steenburgh et al. 2000, Steenburgh and Onton 2001, Onton and Steenburgh 2001, Alcott et al. 2012), Lake Champlain (Payer et al. 2007, Laird et al. 2009a), NYS Finger Lakes (Laird et al. 2009b, 2010), and small lakes in the Western and Midwestern U.S. (Huggins et al. 2001, Cairns et al. 2001, Schultz et al. 2004), have resulted in an increased understanding of LE processes and the differences between large and smaller lake systems; however, limited observations are available to examine the influence of upstream conditions on the convective development over smaller lakes. The Finger Lakes region within central NYS includes 11 lakes of varying sizes and orientations approximately 50 km south of Lake Ontario making the region ideal for investigating the influence of Lake Ontario boundary layers on the development and evolution of mesoscale circulations and precipitation that develop in association with smaller lakes.

Laird et al. (2009b) presented the duration, timing, and frequency of LE events which occurred in the NYS Finger Lakes region during an 11-winter time period. LE events were found to occur over all of the eastern Finger Lakes as: (a) isolated Finger Lakes LE bands, (b) an enhancement of Lake Ontario LE bands, or (c) an enhancement of synoptic-scale precipitation (Figure 1). In a related article, Laird et al. (2010) provided a climatological analysis of 125 LE events in the Finger Lakes region and found a mean lake-to-850 hPa temperature difference of 18.9 ºC – a value notably larger than the dry adiabatic lapse rate criteria of 13 °C that has been identified for Great Lakes LE events (e.g., Niziol et al. 1995). Important differences between LE event types in the Finger Lakes region were found demonstrating varied downstream interaction with Lake Ontario boundary layers. For example, isolated Finger Lakes LE band events had the coldest air temperatures, the largest values of lake-air temperature difference, and the lowest base height of an elevated stable layer.

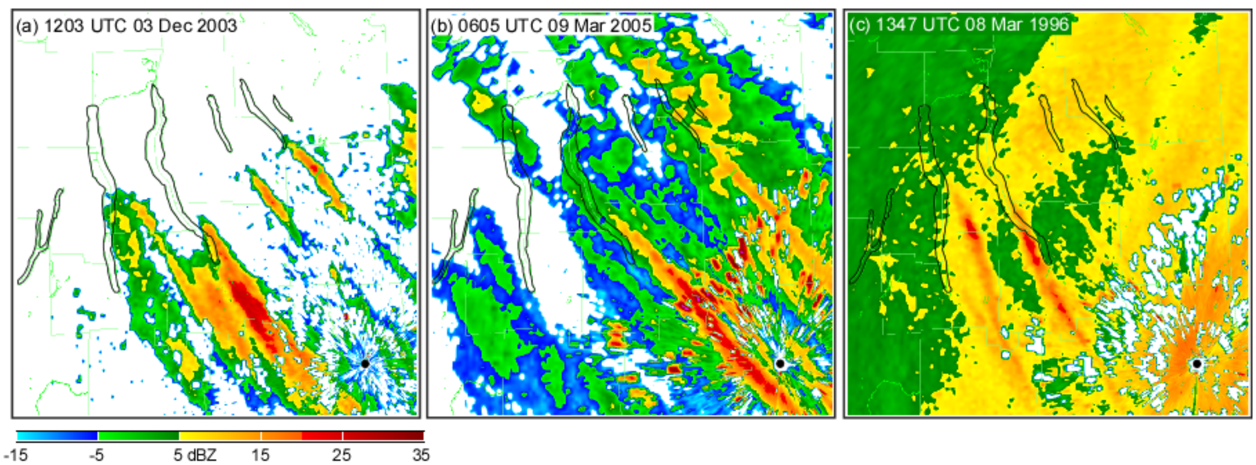

Fig.1. *Examples of Binghamton, New York WSR-88D (KBGM) radar reflectivity fields at 0.5° elevation for LE event types of (a) isolated Finger Lakes bands, (b) Lake Ontario Enhanced, and (c) Synoptic-Enhanced. The six eastern-most Finger Lakes are shown on base map.*

Recent results from LE studies over the NYS Finger Lakes, Lake Champlain, and the GSL have raised several questions related to understanding fundamental PBL processes. For example, observations from past LE events show a greater amount of upstream low-level moisture is typically available and smaller values of lake-air temperature difference necessary for the higher frequency of events which occur on the smaller NYS Finger Lakes as compared to the lower frequency of LE events that occur over the larger Lake Champlain. How does the upstream presence of Lake Ontario influence the development and evolution of Finger Lake LE snow bands? What are the limitations of surface heat source dimensions (defined by wind-normal lake width and lake fetch) and topographic variation on the development of coherent solenoidal circulations? We propose to use case study analyses and mesoscale model simulations of LE precipitation events that occur during the OWLeS project to examine the interaction of convective boundary layers, specifically the influence of large-lake boundary layers on the downstream evolution of convection over smaller lakes.

3. Proposed Research: The overarching objectives of the OWLeS research in this collaborative proposal are to:

1. describe the upwind surface and atmospheric factors determining the three-dimensional structure of the short-fetch convective LeS PBL that develops over a relatively-warm, open water surface;
2. 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);
3. understand the development of, and interactions between, internal PBL and residual layers resulting from advection over multiple mesoscale water bodies and intervening land surfaces.

3.1 The OWLeS Field Project

3.1.1 Collaborative Efforts:

The OWLeS project is a collaborative effort between several institutions. The Principal Investigators 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, Principal Investigators from several institutions are involved with the submission of two collaborative research proposals that focus on connected areas of research. The two multi-investigator collaborative research proposals target objectives related to (i) surface and atmospheric influences on LeS when the winds are at large angles to the long axis of the lake ("short-fetch") and (ii) convective snow bands oriented parallel to the long axis of Lake Ontario ("long-fetch", called OWLeS-BIC in this proposal). A third independent proposal, referred to as OWLeS-orography, is being submitted by James Steenburgh (University of Utah). That proposal also examines lake-mountain interactions around the Great Salt Lake. A single, coordinated field campaign such as OWLeS is much preferred over a fragmented collection of single-PI field efforts given the synergy of instruments and superior data density planned for OWLeS.

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

OWLeS – SAIL (Surface and Atmospheric Influences on LeS) **Short-Fetch LeS**	**OWLeS – BIC (Bands of Intense Convection)** **Long-Fetch LeS**	**OWLeS-Orography * and other 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.

3.1.2 OWLeS-SAIL 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 on upwind PBL characteristics developed over alternating mesoscale land/water surfaces, modified by the combined influences of above-PBL stability and internal PBL circulations. (research objectives 1 and 3)

II. 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. (research objective 2)

III. 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. (research objectives 1, 2 and 3)

3.1.3 Observational facilities and priorities:

The OWLeS project will collect observations with the University of Wyoming King Air (UWKA) (with the Wyoming Cloud Radar and Lidar systems) and Doppler on Wheels systems from the NSF Lower Atmospheric Observing Facility pool and the following PI-supported instruments and platforms:

- A total of six mobile sounding systems will be deployed, from UIUC, MU, SUNY-O, HWS, and two 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, the turbulence structure function (C_T^2) and energy dissipation rate, up to about 1000 m AGL.
- The *UAH Mobile Integrated Profiling System* (MIPS) includes an eye-safe Doppler Lidar (10 m resolution), 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 four sites along a transect from the Lake Ontario eastern shoreline to the Tug Hill Plateau.

3.1.4 OWLeS Field Operations:

The two main proposals (see Collaborative Efforts) generally follow the same partitioning of LeS discussed in the Introduction (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 orientation of the LeS convective structures. The information below pertains primarily to the short-fetch LeS efforts.

The experimental plan illustrated in Figure 2 is designed for conditions giving rise to short-fetch LeS. The internal LE PBL structure develops in response to heat, moisture, and momentum fluxes from the lake surface. The atmospheric responses to these fluxes are 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 in association with the PBL over the Finger Lakes within air modified by Lake Ontario.

Figure 2 shows facility locations that serve the three hypotheses and three objectives of OWLeS-SAIL. In this experiment, observational platforms focus on obtaining information on either the spatial evolution of the PBL north of and over Lake Ontario and /or the spatial evolution of convective bands over and south of Lake Ontario, depending on the day's chosen objective . Platforms will be deployed to determine:

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

3.1.5 **OWLeS timing and duration:**

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 period spanning December through January typically yields about 16 LeS events (Table 2). 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 5-8 are short-fetch LeS under northwesterly flow and extend into the NYS Finger Lakes region or further downstream. Some of these events may have an established cloud/snow band extending from an upwind lake to Lake Ontario. 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. Long-fetch LeS events (the focus of the westerly-wind LeS proposal) are less common (typically 4-5 during the time period), although they tend to last longer. Roughly half of the LE cases in the climatological studies by Kristovich and Steve (1995) and Rodriguez et al. (2008) could not be clearly identified as one of these two types. Note that during the LLAP project, 7 long-fetch LE wind cases were observed by Cermak et al. (2012). At least 1/3 of LE cases should last longer than a day, allowing for multiple operational periods.

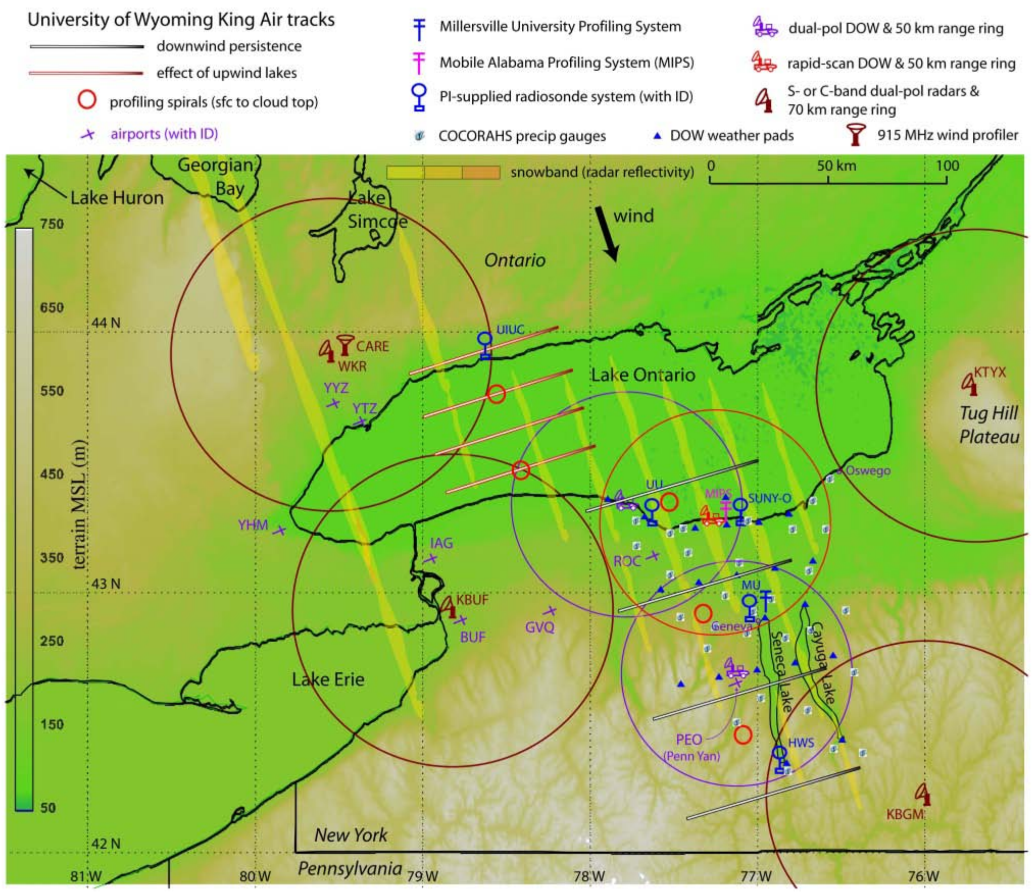

***Fig. 2**: Map showing schematic location of UWKA flight patterns, the OWLeS facilities, and relevant operational facilities during conditions with short-fetch LeS bands. Light-colored regions oriented NW-SE illustrate the types of multiple convective bands frequently seen in these conditions. The colored lines oriented WSW-ENE represent locations of stacks of UWKA flight legs. Each stack consists of three flight legs; at lowest allowable height, one at about 700m (within the PBL mixed layer near the downwind shore), and one at about 1200 m (near the top of the PBL near the downwind shore). Red hollow circles denote locations of spiral soundings conducted by the UWKA. All OWLeS facilities are mobile but are designed remain stationary during the duration of short-fetch IOPs.*

***Table 2**. Lake-effect frequency over Lake Ontario in December and January.*

Number of days with …	Kristovich & Steve(JAM, 1995)	Rodriguez et al.(MWR, 2008)
Lake-effect systems	14-16	16-18
Widespread clouds or multiple bands (oriented NW-SE): Short-Fetch	4-5	8-10
Long lake axis parallel bands (oriented W-E): Long-Fetch	4-5	4-5

3.1.6 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 3). The student participation in the DOW operations is important as it will reduce the facility deployment cost. The preparation and release of rawinsonde balloons requires two people. For safety, at least two people will be at all OWLeS sites, and IOP-related travel will require two people per vehicle (the buddy system).

***Table 3.** Student participation in OWLeS. Rotations are anticipated.*

University	# undergraduate students	# graduate students
Hobart and William Smith Colleges	6	-
Millersville University	~12	-
Pennsylvania State University	-	1
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
Total	31 or more	6-11

Students will be involved in all aspects of the project. A total of 35 student positions are needed for the OWLeS project: DOWs (needs 9 full-time positions), mobile sounding systems (12), MUPS (2), MIPS (2), snow photography (8), and Forecasting/IOP nowcasting (2). A smaller number of students will do OWLeS research as part of their degree program (BSc to PhD).

In addition, we plan to take advantage of non-IOP days between cold-air outbreaks. A for-credit *OWLeS seminar series* will be organized on both the science of LE 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 …). Most students will 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 Univ…). 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. 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.

3.2 Research Plan: ***Boundary-layer circulations over a complex area of open lakes and land***

OWLeS offers a unique opportunity to understand the influence of multiple internal boundary layers formed upwind of Lake Ontario, on the convective LeS over and downwind of the lake. There are two major steps that will be taken to examine boundary layer circulations over a complex area of open lakes and land: (1) collection and analysis of PBL and above-PBL observations during OWLeS; (2) determination of relationships between upwind surface conditions, LeS PBL characteristics and mesoscale PBL circulations. If possible, idealized numerical modeling efforts will be used to help determine the relative importance of influences of surface and environmental factors on LeS PBL evolution using factor separation techniques. The primary observations for this research will be taken by the UWKA, the Wyoming Cloud Radar and Lidar systems, upwind and downwind rawinsonde sites, as well as DOW radars downwind of the lake (Figure 2). The University of Illinois Mesoscale/Boundary Layer research group has a great deal of experience collecting and analyzing *in situ* observations obtained in LeS. Use of novel observational platforms (such as the Wyoming Cloud Radar and Lidar systems and the DOW radars) will allow for determination of the LE PBL evolution and its relationship to more complex upwind surface and environmental conditions than previously examined – an important need emphasized in the review of boundary layer research by Baklanov et al. (2011). UWKA *in situ* and remote observations of PBL conditions will be taken in stacks of cross-wind, relatively straight, level flight legs (Figure 2).

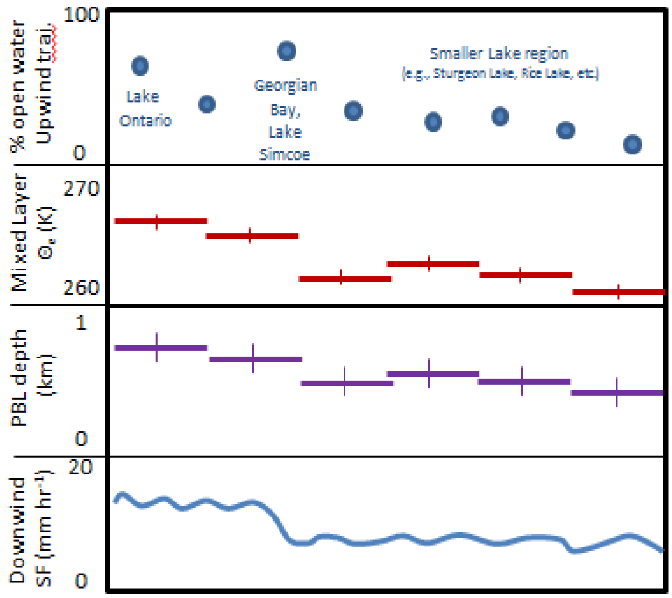

***Fig. 3**: Schematic example of some proposed mesoscale PBL analyses. Horizontal axis is distance along flight track and along the north shore of Lake Ontario. Snowfall rate (SF) would be estimated from DOW polarimetric observations.*

Analyses comparing PBL characteristics to those of the upwind surface variations will provide information on its importance relative to upwind atmospheric conditions (esp. stability) and internal PBL processes (such as boundary layer roll circulations or cloud glaciation). Our initial plan will utilize backward trajectories calculated by the Air Resources Laboratory Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model (http://ready.arl.noaa.gov/HYSPLIT.php) to determine the relation of airflow and upwind surface variations. Such trajectories have been extensively used in atmospheric transport studies but not, to our knowledge, to understand PBL spatial variations. We expect that the relatively stable upwind conditions will be ideal to estimate the air's trajectory using HYSPLIT. Back trajectories would be initialized at points along the cross-wind UWKA flight stack near the northern shoreline and determined to -12 hr, half the time scale of the observed LE snow durations reported in Kristovich and Spinar (2005). Other backward time periods will also be tried. Three-dimensional coordinates generated by the HYSPLIT model will be ingested into ARC GIS (Version 10) for plotting and analysis of surface characteristics, such as percentage of the upwind trajectories are over water bodies (Figure 3). Other surface characteristics, such as ice cover on Lake Huron and Georgian Bay (US National Ice Center http://www.natice.noaa.gov/, Canadian Ice Service http://www.ec.gc.ca/glaces-ice/) and surface snow cover (US National Snow & Ice Data Center (http://nsidc.org/) will also be considered. The University of Illinois Mesoscale/Boundary Layer research group has considerable resources for utilization of ARC GIS, including programs and staff that have used GIS since 1982.

Estimates of LeS PBL top can be difficult to determine, so several techniques will be utilized, based on the local conditions. As an initial working approach, we will define the mean PBL top as the height at which approximately equal amounts of the air have characteristics of the LeS PBL and have characteristics of the stable air above the PBL (with areas of mixed air parcels between). Past experience has shown that the PBL top usually coincides with LeS cloud top (e.g., Chang and Braham 1991, Kristovich 1993, Schroeder et al. 1996). Remote sensing observations from the WCR will provide a "mapping" of the variable cloud top, and thus the PBL top. It is anticipated that the WCL will also provide exceptional information on the PBL top over Lake Ontario, and may be useful upwind of the LeS clouds (e.g., Mayor et al. 2003). In situ observations will also be highly beneficial in PBL top determination. PBL top will be estimated using profiles of mean and variance of thermodynamic variables (such as turbulence magnitudes), conserved variable analysis (e.g., Kristovich 1991), and buoyancy of convective elements (especially updrafts, Braham and Kristovich 1996, Schroeder et al. 2006). These techniques have been successfully employed during our previous studies.

In addition to PBL top analyses, mesoscale variations in UWKA-observed thermodynamic characteristics within the LeS PBL will be related to upwind conditions. Mesoscale PBL variations along cross-wind flight legs will be separated from smaller-scale features through linear trend analyses (Kristovich 1993, Kristovich and Braham 1998), running-means (Gerbush et al. 2008), means over blocks of time (Figure 3, Gerbush et al. 2008), or low-pass filtering techniques (Chang and Braham 1991). While running means and means over blocks of time do not satisfy Reynolds averaging criteria, Sun et al. (1996) found that the method was very useful in cases with highly nonlinear trends of state variables, which are likely to be found in OWLeS. Spatial variations in mean LeS PBL conditions determined by these techniques will be compared to the upwind surface conditions (Figure 3). In addition, snowfall rate and LeS convective band characteristics determined by the DOW radars (Figure 2) near the downwind shore of Lake Ontario will also be compared with potential upwind influences.

PBL characteristics can also vary due to processes other than upwind surface conditions (e.g., upwind stability variations, and internal PBL circulations (e.g., rolls). Similar comparisons to that shown in Figure 3 will be made comparing over-lake LeS PBL variations to upwind stability (as determined by the UWKA flight stack near the upwind shore) and upwind convective bands such as from Georgian Bay (determined by the WCL and WCR systems, satellite imagery, etc.). Such comparisons will provide important information on the relative importance of various types of upwind surface and atmospheric conditions.

If possible, our graduate student or staff member will use the WRF model and factor separation techniques to give additional insight into the processes involved in the evolution of an idealized Lake Ontario LeS situation. Numerical modeling expertise at the University of Illinois (including a new PBL modeler in the lead PI's department), co-PIs on this project, and gained through UCAR WRF user workshops will be critical to design appropriate simulations for this effort. While this is a new effort for the current University of Illinois team, we are encouraged by the intense PBL responses as cold air crosses much warmer surface water areas, which can be more readily simulated (c.f., our collaborative effort in Cooper et al. 2000).

3.3 Research Plan: *Downwind persistence of lake-effect circulations*

The work plan for this component of OWLeS-SAIL represents a three-year collaborative effort between Millersville University (MU) and Penn State University (PSU) beginning 1 OCT 2013 with preparation for the year-1 field campaign in DEC 2013 – JAN 2014. Individual investigators will take responsibility for specific data acquisition and QA/QC tasks while all investigators will collaborate on the quantitative analysis and interpretation of results. This sharing of the analysis and interpretation effort takes advantage of the broad expertise of the team and the synergy between our differing perspectives.

The field campaign is the primary focus in year-1 of the MU-PSU effort. With the deployment of many ground-based and airborne platforms in support of multiple scientific objectives under the collective umbrella of OWLeS, pre-experiment planning and coordination, including conducting ground-based site surveys and establishing base operations are paramount to a successful field campaign. The PIs will work with NCAR/EOL for selecting base operations, as well as their own ground-based sites, with special attention given to the site location and land owner permissions for acoustic sodar and the RASS unit. The Millersville group (Clark, Sikora, and students) will begin preparations for moving equipment in late summer 2013 (before the funding period) and will take part in the site survey for MUPS (see Figure 2).

Millersville will also seek the necessary FAA waivers for tethered balloon operations at the MUPS site. The OWLeS-SAIL team will develop climatology of each type of downwind persistent LeS using the Penn State GOES and NEXRAD image archive (Young and Sikora have considerable experience in this area).

Young, Clark, and Sikora along with undergraduates from MU will be fully engaged in the measurement program throughout the campaign. Young will serve as UWKA mission scientist for the downwind persistence flights and support the other IOPs. Clark and Sikora will direct MUPS and its mobile rawinsonde operations on all IOPs. On non-IOP days project team members will gather at base operations to de-brief, critique, and if necessary, modify operations. In addition to the collective OWLeS effort, Young will work with the University of Wyoming group to QA/QC the UWKA data; and Clark and Sikora will have responsibility for the QA/QC on the data collected by MUPS.

Analysis of the OWLeS-SAIL Downwind Persistent (DP) data sets will continue following the field campaign. Data reduction and analysis will commence and data sets will be shared for the more detailed analysis in year-2. Post-experiment organizational meetings among OWLeS PIs and students will take place in summer 2014. We anticipate several abstracts and extended manuscripts to emerge from these meetings describing the OWLeS project, field campaign, and preliminary results.

The year-2 effort of MU and PSU will focus on the analysis and synthesis of data from all platforms that provide data relevant to addressing the scientific objectives and hypotheses of OWLeS-SAIL DP research. Data collected by the UWKA and the array of instruments downstream of Lake Ontario (see Figure 2) will be used to analyze buoyancy/stability profiles, differential temperature advection, and gravity wave signatures, characterizing the connection of each to the structure and evolution of DP events. The complete suite of DP measurement facilities, as well as satellite and radar imagery, is required to analyze the buoyancy forcing associated with DP convective structures. We will begin to synthesize these analyses into a fuller description of the forcing of OWLeS-SAIL DP. Also in year-2, Sikora will work with meteorologists at the regional NWS WFOs to determine their preferred form of forecast guidance in preparation for transitioning our research to operations. We anticipate several papers to begin to emerge from the year-2 analysis and synthesis of OWLeS-SAIL DP observations.

Year-3 will extend the year-2 effort, synthesizing the observations to address hypothesis 3 and integrating DP observations with other project teams in support of their scientific objectives. In addition, during the final year we will focus more of our efforts on the implications of the results on operational forecasting, and with cooperation from the NWS WFOs, will begin the transition of this research and forecasting tools to the regional NWS WFOs. In particular, we will investigate the relationship between DP morphology, surface gustiness, and reductions to visibility during blowing snow events. We expect that the results will lead to an improved conceptual model of hazardous gusts and snow squalls associated with DP LeS. We anticipate several DP papers submitted for publication in year-3.

3.4 Research Plan: ***Thermodynamic, dynamic, and topographic forcing of small-lake LE events***

Recent climatological studies of LE events for lakes smaller than the Great Lakes have strongly suggested these events are influenced by upstream moisture sources and complex terrain surrounding the lakes. The OWLeS deployment of observational facilities, specifically the DOW radars, atmospheric profiling/sounding systems, UWKA, and WSR-88D radars, will provide measurements of the thermodynamic and dynamic environment upstream, over, and downstream of the Lake Ontario and NYS Finger Lake regions. This will provide unprecedented observations of the temporal and spatial interaction of the Lake Ontario BL with the intervening land surface upstream of the Finger Lakes and the evolving BL associated with individual Finger Lakes. The radar and profiling systems will be most useful in determining the factors controlling the development, transition between, and dissipation of specific types of Finger Lakes LeS (Figure 1). The utilization of the DOW radars during OWLeS will allow collection of radar data in a region south of Lake Ontario and north of the Finger Lakes that is typically under-sampled by the WSR-88D radars during LE events (Brown et al. 2007). Data from the sounding systems and the UWKA will provide measurements useful for constructing high spatial and temporal resolution vertical thermodynamic cross-sections to examine the structure and evolution of the Lake Ontario and Finger Lakes BLs. The evolution of the individual or merged BLs will then be examined in relation to the development, evolution (with perhaps transitions in type of convection over the Finger Lakes region), and dissipation of precipitation bands downstream of Lake Ontario.

We plan to use analysis of at least three OWLeS Lake Ontario short-fetch LE IOP events along with several arrays of Weather Research and Forecast (WRF) mesoscale model simulations to investigate the thermodynamic, dynamic, and topographic forcing of small-lake LE events. Specific focus of this research will be on understanding the interaction of Lake Ontario and Finger Lakes BLs and the role of those interactions on the development of snow bands over the smaller Finger Lakes.

Several studies have utilized numerical modeling of case studies or idealized experiments to examine multiple lake connections in the Great Lakes region (e.g., Rose 2000, Mann et al. 2002), the influence of lake shape and size (e.g., Laird et al. 2003a,b), and the influence of topography on LeS. For example, Mann et al. (2002) investigated the influence of individual lakes or combinations of lakes, which built on a series of numerical modeling studies examining the multiscale atmospheric responses to the Great Lakes (Sousounis and Fritsch 1994; Sousounis 1997, 1998; Weiss and Sousounis 1999, Sousounis et al. 1999; Sousounis and Mann 2000). Rose (2000) pointed out that while some authors indicated that a minimum of 80-km fetch over open lake waters is typically needed for formation of significant LE precipitation (e.g., Lavoie 1972; Niziol 1987), preconditioning of the atmosphere by upwind lakes can allow for much more rapid development. Rose (2000) used idealized model simulations to find that thermal preconditioning from Lake Michigan led to deeper, more intense, and more persistent LE circulations over Lake Erie. Cosgrove et al. (1996), using a series of simplified model simulations, found that the larger NYS Finger Lakes (i.e., Seneca and Cayuga Lakes) could substantially enhance LE precipitation originally initiated over Lake Ontario. Far fewer studies have examined the influence of topography on LE events; however, these studies found that topography plays an important role. Two more recent studies of Great Salt Lake (GSL) LeS determined that (a) orographic effects resulting from the complex terrain surrounding the GSL were not responsible for LE snow band generation, but did affect the distribution and intensity of precipitation in regions where the snow band interacted with the downstream terrain (Onton and Steenburgh 2001) and (b) terrain upstream of the GSL was important to establishing the moisture and low-level dynamic conditions for over-lake LE snow band development (Alcott 2012).

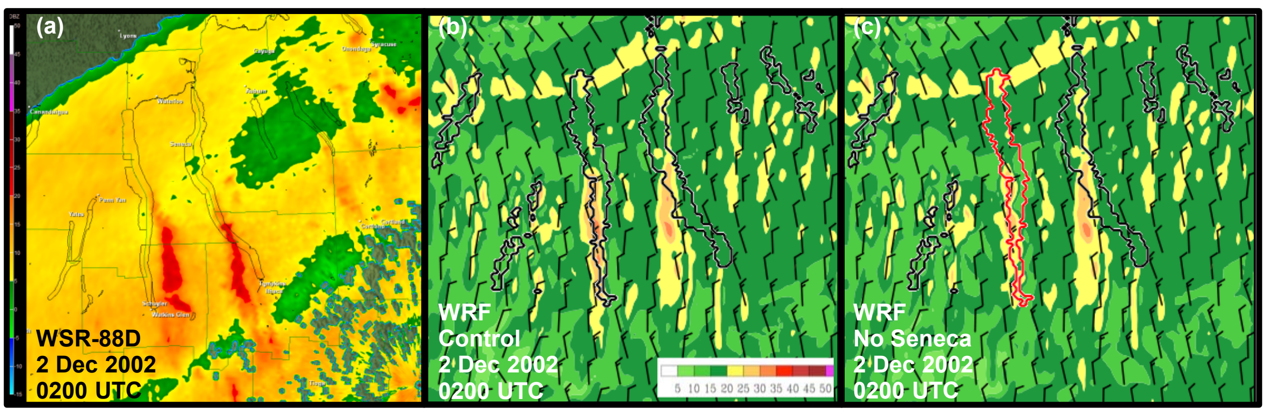

Fig. 4. *(a) WSR-88D radar reflectivity (0.5° elevation) at 0200 on 3 Dec. 2002. WRF model simulations showing (b) real-case (control) simulated reflectivity and 10-m wind field at same time on panel and (c) WRF model simulation with Seneca Lake removed. Reflectivity color scales are different for WSR-88D and simulated radar reflectivity. Finger Lakes are represented by black lines. Seneca Lake shown with red line for simulation with lake removed.*

For purposes of the proposed research, preliminary simulations of a Finger Lakes snow band event on 3 Dec. 2002 were performed to demonstrate the capability of the WRF model in simulating LE events on small lakes. The WRF model version 3 (e.g., Skamarock et al. 2008) was formulated with the ARW core, the Noah land surface model (Skamarock et al. 2005), and the 32-km North American Regional Reanalysis (NARR) for boundary conditions. The horizontal grid spacing of the WRF was 750 m, with 45 vertical levels specified. Other model options included the MYJ boundary-layer scheme (Janjić 2001), WSM6 6-class graupel scheme (Hong and Lim 2006), and explicit convection. The first simulation was a control run utilizing the aforementioned specifications (Figure 4b) that could be directly compared with the observed case (Figure 4a). The second has an identical setup; however, Seneca Lake was removed (Figure 4c) by converting all model grid points that comprised Seneca Lake to land surface with characteristics of the surrounding land grid points – an approach similar to that used by Sousounis and

Mann (2000) and Metz (2011). The results show that the WRF is capable of simulating the Finger Lakes LeS reasonably well, even in the presence of widespread synoptic snowfall (Figure 4b). Additionally, the surface fluxes from individual Finger Lakes seem to significantly contribute to snow bands downstream of Lake Ontario – note the reduction in precipitation intensity in the vicinity of Seneca Lake when the lake is removed (Figure 4c). To obtain the best possible WRF control simulations, we plan to investigate the different parameterizations in WRF, the setup of nesting grids and horizontal grid spacing, and alternative initialization times and data sets. We plan to identify at least three Lake Ontario short-fetch events to first perform thorough case study analyses using OWLeS project measurements and then conduct an array of WRF simulations for each.

We propose to implement the factor separation technique first presented by Stein and Alpert (1993) and used for several subsequent model sensitivity studies to understand the influence of individual factors, as well as interactions of factors. Sousounis and Mann (2000) and Mann et al. (2002) used factor separation techniques to examine interaction between multiple lakes in the Great Lakes region during LE conditions. Stein and Alpert (1993) demonstrated that 2n simulations are required for n factors to be isolated. The use of the factor separation technique for the proposed research will provide a more complete analysis of the role of each individual factor (e.g., topography, over-lake fluxes, presence of upstream or nearby lakes – such as in the NYS Finger Lakes region) and combined interactions.

These analyses will allow us to answer several critical questions concerning the influence of thermodynamics, dynamics, and topography on the development and evolution of LE events associated with small lakes. For example, what role does the moisture, boundary layer structure, and mesoscale circulations from Lake Ontario LE play in the development or enhancement of downstream NYS Finger Lakes LE events? Do neighboring NYS Finger Lakes influence LE band development and evolution? What influence does terrain have on the development of LE precipitation? Do terrain-induced channeled flows significantly contribute to over-lake convergence and LE snow band development? How do variations in lake surface fluxes influence the development of LE over small lakes?

4. Collaboration and Timeline: Drs. Kristovich, Clark, Sikora, Laird, Metz, and Young each provide expertise that is central to the proposed project and all will be involved in planning and conducting the proposed research. While we will collaborate on all efforts, it is most efficient for each PI to lead different aspects of the research. The timeline below gives the proposed research goals and highlights which group(s) will lead each aspect of the research. In support of our close collaborative efforts, we have requested travel funds for research visits among groups. Our efforts in the past using this approach have been highly successful, resulting in the advancement of understanding on complex mesoscale systems.

Topic	Year 1 (2013-2014)	Year 2 (2014-2015)	Year 3 (2015-2016)
Boundary-layers over a complex of open lakes and land (UIUC)	• OWLeS field operations • Determine mesoscale variations in PBL conditions	• Determine relationship of upwind conditions on LeS. Publish results.	• Numerical analyses • Publish results of all remaining analyses
Downwind persistence of lake-effect circulations (MU, PSU)	• QC data and make it available for other users • OWLeS field operations • Analyze diurnal and downstream evolution of stability profile	• Analyze structure of LeS downwind of Lake Ontario • Publish results of stability and structure analyses	• Analyze the processes responsible for LeS downwind of Lake Ontario • Publish results of all remaining analyses
Thermodynamic, dynamic, and topographic forcing of small-lake LE events (HWS)	• OWLeS field operations • Perform WRF real-case simulations and observational analyses of selected OWLeS events	• Complete obs. analyses of selected OWLeS events • Perform WRF sensitivity simulations of specific factors and combinations using factor separation	• Complete analysis of WRF sensitivity simulations • Publish results of case studies and WRF simulations

5. Broader Impacts: OWLeS will provide an unprecedented dataset and insight on convective PBL characteristics under varying surface and atmospheric conditions, a critical need in the PBL research community (Baklanov and Grisogono 2007, Baklanov et al. 2011). LE snow remains a major weather hazard, extending downwind of the Great Lakes. While current operational NWP models sufficiently capture LeS locations and timing, the predictability of snowfall intensity and inland extent of convection remains poor. Likely causes for poor QPF include unresolved variations in upwind PBL structure, downwind circulations within PBL or residual layers, lack of coupling between parameterized buoyantly-driven PBL turbulence and cloud microphysics. Thus, the mesoscale NWP community, and those depending on them for timely warnings, would benefit from the results of OWLeS. To develop a better understanding of LeS processes, the proposed OWLeS (Ontario Winter Lake-effect Systems) project will collect measurements during the peak months for LeS (December and January) in the vicinity of Lake Ontario and the NYS Finger Lakes. 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 LE snow during 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, IPCC AR4 2007), likely resulting in substantial increases in atmospheric modification and precipitation (especially snowfall) potential (Brown and Duguay 2010, Walsh 2008). Rapid climatological trends and 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.

Research results will be communicated to the scientific community through journal articles and conference presentations. All groups have previously forged close relationships with the operational community and will continue these interactions through regional workshops, presentations, and direct collaborations. Based on our experiences with previous projects, such direct collaborations are beneficial to all and introduce research results into an operational setting more rapidly. The next generation of scientists will benefit through a wide range of undergraduate and graduate education and training activities, both during the OWLeS field campaign and during subsequent research. Lastly, exposure to OWLeS field measurements and observational facilities, along with research results from OWLeS, will be incorporated into classroom lessons at both the undergraduate and graduate levels.

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a. Professional Preparation:

Rutgers University, New Brunswick, NJ	Meteorology	1985	B.S
University of Chicago, Chicago, IL	Meteorology	1988	S.M.
University of Chicago, Chicago, IL	Meteorology	1991	Ph.D.
University of Chicago, Chicago, IL	Meteorology postdoctoral	1991-1992	

b. Appointments:

2008-present	*Center Head,* Center for Atmospheric Sciences, Illinois State Water Survey, Prairie Research Institute, University of Illinois at Urbana- Champaign
2012-present	*Editor-in-Chief,* American Meteorological Soc. Journal of Applied Meteorology and Climatology.
2000-present	*Adjunct Associate Professor*, Dept. of Atmospheric Sciences, Univ. of Illinois.
2001-2007	*Senior Scientist*, *Acting Center Director* (occasional), *Scientific Leader* for Boundary Layer/Mesoscale Meteorology, Center for Atmospheric Sciences, Illinois State Water Survey
2001-2011	*Editor*, American Meteorological Society Journal of Applied Meteorology and Climatology.
2001	*Associate Editor*, American Meteorological Society Monthly Weather Review.
1998-2000	*Visiting Associate Professor*, Department of Geography, Univ. of Illinois at Urbana-Champaign.
1998-2001	*Professional Scientist*, Illinois State Water Survey
1995-1998	*Associate Professional Scientist*, Illinois State Water Survey
1993-1995	*Assistant Professional Scientist*, Illinois State Water Survey
1992	*Visiting Lecturer*, Physics of Weather, University of Illinois at Chicago, Department of Physics.

c. Publications:

(i) Most relevant to this proposal:

Barthold, F. E., and D. A. R. Kristovich, 2011: Observations of the cross-lake cloud and snow evolution in a lake-effect snow event. *Mon. Wea. Rev.* **139**, 2386-2398.

Gerbush, M. R., D. A. R. Kristovich, and N. F. Laird, 2008: Mesoscale Boundary Layer and Heat Flux Variations over Pack Ice-Covered Lake Erie. *J. Appl. Meteor. and Climatol.*, **47**, 668-682.

Rodriguez, Y., D. A. R. Kristovich, and M. R. Hjelmfelt, 2007: Lake-to-Lake Cloud Bands: Frequencies and Locations. *Mon. Wea. Rev.*, **135**, 4202-4213.

Schroeder, J.J., D.A.R. Kristovich, and M.R. Hjelmfelt, 2006: Boundary layer and microphysical influences of natural cloud seeding on a lake-effect snow storm. *Mon. Wea. Rev.*, **134**, 1842-1858.

Kristovich, D.A.R., N.F. Laird, and M.R. Hjelmfelt, 2003: Convective evolution across Lake Michigan in a lake-effect snow event. *Mon. Wea. Rev.*, **131**, 643-655.

(ii) Five other significant publications:

Workoff, T. E., D.A.R. Kristovich, N. F. Laird, R. LaPlante, and D. Leins, 2012: A climatological analysis of deep convective interaction with the Lake Erie marine boundary layer. *Wea. Forecasting*. In press.

Markus, M., D. J. Wuebbles, X.-Z. Liang, K. Hayhoe, and D. A. R. Kristovich, 2012: Diagnostic analysis of future climate scenarios applied to urban flooding in the Chicago metropolitan area. *Climatic Change*. **11**, 879-902. DOI 10.1007/s10584-011-0172-z.

Kunkel, K.E., D. R. Easterling, D.A.R. Kristovich, B. Gleason, L. Stoecker, and R. Smith, 2010: Trends in U.S. Heavy Precipitation Caused by Tropical Cyclones. *Geophysical Research Letters*. **37**, L24706.

Kristovich, D. A. R., 2009: *Climate Sensitivity of Great Lakes – Generated Weather Systems*. In *Climatology, Variability, and Change in the Midwest*, S. C. Pryor, Editor. Indiana University Press, 236-250.

Westcott, N. E., and D. A. R. Kristovich, 2009: A climatology and case study of continental cold season dense fogs associated with low clouds. *J. Appl. Meteor. and Climatol.*, **48**, 2201-2214.

d. Synergistic activities:

Dr. Kristovich has given invited training sessions, based on our and others' research, on lake-effect snow storms and Great Lakes meteorology for forecasters at the National Weather Service Offices in Chicago, IL, and Cleveland, OH.

Dr. Kristovich is Editor-in-Chief of the American Meteorological Society *Journal of Applied Meteorology and Climatology* and Assoc. Editor of *National Weather Dig.* He was Assoc. Editor of *Monthly Weather Review.*

Dr. Kristovich was the lead scientist for the Lake-ICE field project (1997/1998), with participants from 22 research institutions) and a lead PI for the Great Lakes Ice Cover – Atmospheric Flux Experiment (GLICAF, 2004). Usages of these datasets include not only research, but graduate and undergraduate activities. Several graduate students have received (are receiving) research training using these and other datasets. In teaching undergraduate and graduate courses Mesoscale Meteorology and Boundary Layer Meteorology, Dr. Kristovich used data collected during Lake-ICE and GLICAF to illustrate important points and for homework assignments. This is a direct benefit of this research to educational activities.

In 1992, Dr. Kristovich wrote "*Discover Weather*" (Publications International, Ltd.), directed at high school students, which describes physical processes in the atmosphere - nominated for AMS L. J. Battan award in 1994.

e. Collaborators & other Affiliations:

(i) Collaborators:

Dr. E. Andreas	NorthWest Resrch. Assoc., Inc.	Mr. J. Keeler	University of Illinois
Dr. S. Baidya Roy	University of Illinois	Dr. K. Kunkel	National Clim. Data Center
Dr. P. Bajcsy	University of Illinois	Dr. N. Laird	Hobart & William Smith Coll.
Mr. L. Bard	University of Illinois	Mr. R. LaPlante	NWS Forecast Office, Cleveland
Ms. F. Barthold	NOAA Hydrol. Pred. Center	Mr. D. Leins	NWS Forecast Office, Cleveland
Dr. A. Bartosova	University of Illinois	Dr. X.-Z. Liang	University of Maryland
Dr. K. Baylis	University of Illinois	Dr. M. Markus	University of Illinois
Dr. C. Bernacchi	US Geologic Society	Dr. G. McIsaac	University of Illinois
Dr. D. Breed	Nat. Ctr. Atmos. Research	Dr. N. Metz	Hobart & William Smith Coll.
Dr. X. Cai	University of Illinois	Dr. B. Minsker	University of Illinois
Dr. M. Caughey	University of Illinois	Dr. T. Overbye	University of Illinois
Dr. R. Clark	Millersville University	Dr. D. Park	University of Illinois
Dr. G. Czapar	University of Illinois	Dr. N. Paulson	University of Illinois
Dr. T. Deshler	University of Wyoming	Dr. S. C. Pryor	Indiana University
Dr. D. Easterling	National Clim. Data Center	Dr. R. Rasmussen	Nat. Ctr. Atmos. Research
Dr. F. Fernandez	University of Illinois	Dr. G. Schnitkey	University of Illinois
Dr. K. Friedrich	University of Colorado	Dr. T. Sikora	Millersville University
Dr. J. Frame	University of Illinois	Ms. R. Smith	Colorado State University
Dr. D. Gay	University of Illinois	Dr. J. Steenburgh	University of Utah
Dr. B. Geerts	University of Wyoming	Dr. S. Steiger	State Univ. New York - Oswego
Mr. B. Gleason	National Clim. Data Center	Ms. L. Stoecker	University of Illinois
Dr. K. Hayhoe	Texas Tech. University	Dr. C. Sweet	University of Illinois
Dr. W. Jarrell	University of Illinois	Dr. N. Westcott	University of Illinois
Dr. E. Jeffery	University of Illinois	Mr. T. Workoff	University of Illinois
Ms. A. Jones	University of Illinois	Dr. D. Wuebbles	University of Illinois
Dr. M. Hjelmfelt	South Dakota Sc. Mines & Tech	Dr. G. Young	Pennsylvania State University

(ii) Graduate and Postdoctoral Advisor: R.R. Braham, Jr. (University of Chicago, North Carolina State University)

(iii) Thesis Advisor and Postgraduate-Scholar Sponsor: R. Steve (M.S., 1996), B. Rose (Ph.D., 2000), N. Laird (Ph.D. 2001), J. Schroeder (M.S. 2002), Y. Rodriguez (M.S. 2005), M. Gerbush (M.S. 2005), S. Jackman (M.S. 2005), Faye Barthold (M.S., 2008), Thomas Workoff (M.S., 2010), Jason Keeler (M.S., 2010), Luke Bard (M.S., 2012), Paul Gesicki (M.S., current) (10 M.S., 2 Ph.D., 0 Postdocs)

BIOGRAPHICAL SKETCH

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a. Professional Preparation:

University of Illinois, Urbana-Champaign	Atmospheric Sciences	2001	Ph.D.
University of Illinois, Urbana-Champaign	Atmospheric Sciences	1992	M.S.
State University of New York, Oswego College	Meteorology	1990	B.S.

b. Appointments:

2009-present *Associate Professor*, Department of Geoscience, Hobart & William Smith Colleges, Geneva, New York

2004-2009 *Assistant Professor*, Department of Geoscience, Hobart & William Smith Colleges, Geneva, New York

2002-2004 *Research Assistant Professor*, Department of Atmospheric Sciences, University of Illinois, Urbana-Champaign, Illinois

2001-2002 *Postdoctoral Research Associate*, Department of Atmospheric Sciences, University of Illinois, Urbana-Champaign, Illinois

2001-2002 *Visiting Assistant Professor*, Department of Geoscience, Hobart & William Smith Colleges, Geneva, New York

1997-2001 *Associate Professional Scientist,* Illinois State Water Survey, Champaign, Illinois

2000 *Graduate Teaching Assistant*, Department of Atmospheric Sciences, University of Illinois, Urbana-Champaign, Illinois

1992-1997 *Assistant Professional Scientist*, Illinois State Water Survey, Champaign, Illinois

1990-1992 *Graduate Research & Teaching Assistant*, Department of Atmospheric Sciences, University of Illinois, Urbana-Champaign, Illinois

1990 *Principal Assistant*, National Lightning Detection Network, Power Technologies, Inc., Schenectady, NY

c. Publications:

(i) Most relevant to this proposal:

Alcott, Steenburgh, and Laird, 2012: Great Salt Lake-effect precipitation: Observed frequency, characteristics and associated environmental factors. *Wea. Forecasting*, (in press)

Laird, Sobash, and Hodas, 2010: Climatological conditions associated with lake-effect precipitation events in the New York State Finger Lakes region. *J. Appl. Meteor. Climatol.*, **49**, 1052-1062

Laird, Desrochers, and Payer, 2009a: Climatology of lake-effect precipitation events over Lake Champlain. *J. Appl. Meteor. Climatol.*, **48**, 232–250.

Laird, Sobash, and Hodas, 2009b: The frequency and characteristics of lake-effect precipitation events associated with the New York State Finger Lakes. *J. Appl. Meteor. Climatol.*, **48**, 873–886.

Laird, Kristovich, and Walsh, 2003: Idealized model simulations examining the mesoscale structure of winter lake-effect circulations. *Mon. Wea. Rev.*, **131**, 206-221.

(ii) Other significant publications:

Payer, Desrochers, and Laird, 2007: A lake-effect snowband over Lake Champlain. *Mon. Wea. Rev.*, **135**, 3895-3900.

Cordeira and Laird, 2008: The influence of ice cover on two lake-effect snow events over Lake Erie. *Mon. Wea. Rev.*, **136**, 2747-2763.

Laird, Walsh, and Kristovich, 2003: Model simulations examining the relationship of lake-effect morphology to lake shape, wind direction, and wind speed. *Mon. Wea. Rev.*, **131**, 2102-2111.

Laird, Miller, and Kristovich, 2001: Synthetic dual-Doppler analysis of a winter mesoscale vortex. *Mon. Wea. Rev*., **129**, 312-33..

Kristovich and Laird, 1998: Observations of widespread lake effect cloudiness: Influences of lake surface temperature and upwind conditions. *Wea. Forecasting*, **13**, 811-821.

d. Synergistic activities:

Development of Curricular Materials: Laird contributed research results and analyses of lake-effect snowstorms to the widely-used college introductory textbook *Severe and Hazardous Weather* by Rauber, Walsh, and Charlevoix. Additionally, Laird has been central in the revision of the HWS Geoscience curriculum to now offer a program of study in Atmospheric Sciences. This has been possible with the new tenure-track faculty line in Atmospheric Sciences and the recent hire of Dr. Nicholas Metz to the HWS faculty.

Geoscience Seminar & Field Courses: Laird has developed two interdisciplinary undergraduate courses that incorporate weather and climate materials. The first is a seminar course for HWS first-year students on the science and communication of weather. The seminar focuses on improving the writing and oral communication skills of undergraduate students entering college during the fall semester. The second is a hands-on field studies course offered by the HWS Department of Geoscience in Hawaii which will explore the Weather, Climate, and Geology of the Big Island. The field course is structured to offer students an intensive experience examining things such as; volcanoes and lava flow fields, historical Tsunami deposits, sea-breeze development, tropical weather systems and rainfall, and biodiversity across a variety of microclimate regions.

Development of Databases for Research and Education: Laird has participated in 8 major meteorological field experiments. During these field campaigns, he has collaborated with national and international scientists from many institutions to use national facilities (research aircraft, Doppler radars, and surface and upper air observing systems) in concentrated efforts targeted at collecting unique data sets and addressing key unresolved scientific issues.

Transfer of Knowledge to the Next Generation of Scholars: Laird collaborates with undergraduate students through numerous independent study projects, summer internships and senior honors research. Since joining HWS in 2004, he has advised 9 academic year student research projects and 32 summer internships. These collaborations have resulted in 6 peer-reviewed manuscripts and over 40 student presentations at regional and national conferences. Many of these students have entered graduate school, careers in K-12 education, or environmental consulting.

Professional Service to the Scientific Community: During 2010-2011, Laird was an editor of the *Journal of Applied Meteorology and Climatology*. Prior to his service as editor, he contributed as an associate editor for JAMC for nearly six years. Additionally, he maintains active membership in the AGU, CUR, AMS, Sigma Xi and reviews journal manuscripts and funding-agency proposals regularly.

e. Collaborators & other Affiliations:

(i) Collaborators:

Dr. S. Colucci	Cornell Univ.	Dr. D. Kristovich	ISWS / Univ. of Illinois
Dr. A. DeGaetano	Cornell Univ.	Dr. J. Lenters	Univ. of Nebraska
Mr. M. Evans	NWSFO Binghamton, NY	Dr. N. Metz	HWS
Dr. J. Frame	Univ. of Illinois	Dr. S. Robeson	Indiana Univ.
Dr. M. Hjelmfelt	S. Dakota Sch. Mines & Tech.	Dr. J. Steenburgh	Univ. of Utah
Dr. J. Horel	Univ. of Utah	Dr. S. Steiger	Oswego State Univ.
Dr. E. Hoffman	Plymouth State Univ.	Mr. D. Zaff	NWSFO Buffalo, NY

(ii) Graduate and Postdoctoral Advisors:

Kenneth Beard	MSc. advisor,	University of Illinois
John Walsh	Ph.D. co-advisor,	University of Illinois
David Kristovich	Ph.D. co-advisor,	Illinois State Water Survey / University of Illinois

BIOGRAPHICAL SKETCH

Nicholas D. Metz
Department of Geoscience
Hobart & William Smith Colleges
Geneva, NY 14456
Tel: 315-781-3615
Fax: 315-781-3860
Email: nmetz@hws.edu

a. Professional Preparation:

University at Albany	Atmospheric Sciences	2011	Ph.D.
University at Albany	Atmospheric Sciences	2008	M.S.
Valparaiso University	Meteorology	2004	B.S.

b. Appointments:

2012-present *Assistant Professor*, Department of Geoscience, Hobart and William Smith Colleges, Geneva, New York

2010-2011 *Research Assistant,* Department of Atmospheric and Environmental Sciences, University at Albany, Albany, New York

2010 *Instructor,* Department of Atmospheric and Environmental Sciences, University at Albany, Albany, New York

2009-2010 *Teaching Assistant Instructor*, Department of Atmospheric and Environmental Sciences, University at Albany, Albany, New York

2007-2009 *Research Assistant,* Department of Atmospheric and Environmental Sciences, University at Albany, Albany, New York

2006 *Instructor,* Department of Atmospheric and Environmental Sciences, University at Albany, Albany, New York

2004-2007 *Teaching Assistant*, Department of Atmospheric and Environmental Sciences, University at Albany, Albany, New York

2003 *Research Experience for Undergraduates Research Assistant,* National Weather Center, National Severe Storm Laboratory and University at Oklahoma, Norman, OK

2002-2004 *Undergraduate Teaching Assistant,* Department of Meteorology, Valparaiso University, Valparaiso, IN

c. Publications:

(i) Most relevant to this proposal

Metz, Archambault, Galarneau, Srock, and Bosart, 2012: A comparison of South American and African preferential pathways for extreme cold events. *Mon. Wea. Rev.,* submitted.

(ii) Other significant publications

Metz and Bosart, 2010: Derecho and MCS development, evolution, and multiscale interactions during 3–5 July 2003. *Mon. Wea. Rev.,* **138**, 3048–3070.

Metz, Schultz, and Johns, 2004: Extratropical cyclones with multiple warm-front-like baroclinic zones and their relationship to severe convective storms. *Wea. Forecasting*., **19**, 907–926.

d. Synergistic activities:

Participating in HEOP summer institute program at HWS: Metz participated in a five-week institute as part of the Higher Education Opportunity Program (HEOP) at HWS during the summer of 2012. The HEOP program at HWS supports incoming freshmen, typically from first-generation, underrepresented populations. In the summer institute, Metz taught twenty students a 5-week course entitled Exploring Weather and Climate Change. In additional to learning about weather and climate, students developed scientific and mathematical thinking skills that will be used during their collegiate careers.

Knowledge Transfer to the Next Generation of Scholars: Metz joined HWS in the fall of 2011 and has already had multiple opportunities to work with undergraduate students on research endeavors. In the spring of 2012 he advised an academic year research project and in the summer of 2012 he mentored two students in eight weeks of intense research. This follows from Metz's time as a graduate student at the University at Albany where he mentored two motivated undergraduate students as they prepared well-received conference presentations at a regional conference. Both students subsequently decided that the research experience offered them was extremely positive and are currently pursuing their doctoral degrees.

Development of course materials: Since joining HWS, Metz as taken a central role, along with Dr. Neil Laird in developing a concentration of study in atmospheric science within the Department of Geoscience. In addition to laying out a program consistent with American Meteorological Society recommendations, Metz has developed course materials for five separate courses to date. Metz spent an extensive amount of time developing active-learning exercises, and laboratory activities to be utilized in many of these courses. As a graduate student at The University at Albany, Metz developed notes for a Synoptic Meteorology course that subsequent instructors have utilized heavily. For his work in Synoptic Meteorology, Metz won the Vonnegut award, named after Dr. Bernie Vonnegut, for outstanding work as a graduate teaching instructor.

Development of Pedagogical Methods: Metz has taken an interest in the scholarship of teaching and learning. In the summer of 2012 he attended the Lilly Conference on Brain-Based Learning and Teaching where numerous discussions and ideas were shared and fostered on a wide variety of classroom techniques. Previously, as part of his graduate education, Metz attended a bi-weekly seminar course on preparing to be a future faculty member. Much of this course was focused on developing teaching pedagogy, and explored learning styles that were appropriate for a variety of students. Since such knowledge was not readily disseminated in the Department of Atmospheric and Environmental Sciences at The University at Albany. Metz has shared the information he learned with others, and continuously allows the information to shape his and colleagues teaching styles.

Professional Service to the Scientific Community: Metz maintains active membership in the professional societies of the American Meteorological Society, American Geophysical Union, National Weather Association, and the New York Academy of Sciences and has served as a conference session chair.

e. Collaborators & other Affiliations:

(i) Collaborators:

Dr. H. Archambault	Naval Postgraduate School
Dr. L. Bosart	The University at Albany
Dr. J. Cordeira	The University at Albany
Dr. T. Galarneau	National Center for Atmospheric Research
Dr. E. Hoffman	Plymouth State University
Dr. D. Keyser	The University at Albany
Dr. D. Kristovich	ISWS / Univ. of Illinois
Dr. N. Laird	Hobart and William Smith Colleges
Dr. A. Srock	Michigan State University
Dr. M. Weisman	National Center for Atmospheric Research

(ii) Graduate and Postdoctoral Advisors:

Lance Bosart	M.S. advisor,	University at Albany
Lance Bosart	Ph.D. advisor,	University at Albany

Biographical sketch: George S. Young

Professional Preparation (education)
B.S. Florida State University, Meteorology, 1979
M.S. Florida State University, Meteorology, 1982
Ph.D. Colorado State University, Atmospheric Science, 1986

Appointments
2000-present Professor, The Pennsylvania State University (Meteorology)
1992-2000 Associate Professor, The Pennsylvania State University (Meteorology)
1986-1992 Assistant Professor, The Pennsylvania State University (Meteorology)
1982-1986 Graduate Research Associate, Colorado State University (Atmospheric Science)
1979-1982 Graduate Research Assistant, Florida State University (Meteorology)
1975-1979 Undergraduate Research Assistant, Florida State University (Oceanography)

Publications

Related to proposal

Sousounis, P.J., G. Mann, G.S. Young, B. Hoggatt, W. Bandini, R. Wagenmaker, 2000: Forecasting during the Lake-ICE/SNOWBANDS Field Experiment. Weather and Forecasting, 14, 955{975.

Kristovich, D.A.R., G.S. Young, J. Verlinde, P.J, Sousounis, P. Mourad, D. Lenschow, R.M. Rauber, M.K. Ramamurthy, B.F. Jewett, K. Beard, E. Cutrim, P.J. DeMott, E.W. Eloranta, M.R. Hjelmfelt, S.M. Kreidenweis, J. Martin, J. Moore, H.T. Ochs III, D.C. Rogers, J. Scala, G. Tripoli, J. Young, 2000: the lake-Induced Convection Experiment and the Snowband Dynamics Project. Bulletin of the American Meteorological Society 81, 519-542.

Young, G.S., 2008: Implementing a neural network emulation of a satellite retrieval algorithm, Arti_cial Intelligence Methods in the Environmental Sciences, Haupt, S.E., C. Marzban, and A. Pasini, eds., Springer, 424 pp.

Haupt, S.E., R.L. Haupt, and G.S. Young, 2009: A mixed integer genetic algorithm used in chem-bio defense applications, Journal of Soft Computing. invited paper, DOI 10.1007/s00500-009-0516-z.

Kuroko, Y., G.S. Young, and S.E. Haupt, 2010: UAV Navigation by an Expert System for Contaminant Mapping with a Genetic Algorithm. Expert Systems with Applications, 37, 4687-4697. (doi:10.1016/j.eswa.2009.12.039).

Other Significant Publications

Young, G.S., D.A.R. Kristovich, M.R. Hjelmfelt, R.C. Foster, 2002: Rolls, streets, waves, and more: A review of quasi-two dimensional structures in the atmospheric boundary layer. Bulletin of the American Meteorological Society, 83, 997{1001. Also, an extended electronic supplement.

Nicholls, S.D., and G.S. Young, 2007: Dendritic patterns in tropical cumulus: An observational analysis. Monthly Weather Review, 135, 1994{2005.

Young, G.S., 2007: Development of empirical Weather Forecasting techniques for soaring flight. Technical Soaring, 31, 62-67.

Young, G.S., T.D. Sikora, and N.S. Winstead, 2008: Mesoscale near-surface wind speed variability mapping with synthetic aperture radar. Sensors, 8, 7012-7034.

Young, G.S., 2008: Implementing a neural network emulation of a satellite retrieval algorithm, Artificial Intelligence Methods in the Environmental Sciences, Haupt, S.E., C. Marzban, and A. Pasini, eds., Springer, 424 pp.

Synergistic Activities

- Published 1 book, 3 book chapters, 79 journal papers and 82 conference papers, making a total of 161 publications. Presented 22 invited talks. Editorial Positions: Associate Editor, Journal of Applied Meteorology (2001{2003); Associate Editor, Monthly Weather Review (2009-present)
- Over $12,415,000 received whilst at the Pennsylvania State University, from various bodies (some of which is jointly held with other researchers) including for research into satellite remote sensing of mesoscale and synoptic meteorology.
- Chair National Science Foundation / University Corporation for Atmospheric Research Observing Facilities Advisory Panel (2000), vice-chair (1999).
- Conference Committees: 6th (1992) and 7th (1995) American Meteorological Society Mountain Meteorology Conferences. 14th American Meteorological Society Symposium on Boundary Layers and Turbulence (2000).
- Professional Committees: American Meteorological Society Mountain Meteorology Committee (1992-1995), American Meteorological Society Committee on Boundary Layers and Turbulence (1999-2002), Observing Facilities Advisory Panel (1997-2000, Chair 1999-2000). National Oceanic and Atmospheric Administration Ocean Observer Satellite team (2000). National Weather Association Information Technology Committee (2007-2009), National Weather Association Information Membership Committee (2011-present)

Collaborators & Other Affiliations

Collaborators (past 48 months) and co-editors (past 24 months): C. Allen (Computer Sciences Corporation), A. Annunzio (Penn State), M. Bettwy (Millersville), A. Beyer-Lout (Cermak Peterka Petersen), J. Dutton (Prescient), C. Fisher (ITT Space Systems), W. Frank (Retired), M. Fritch (Retired), F. Germi (Independent), S. Greybush (Maryland), R. Grumm (NOAA), J. Haqq-Misra (Penn State), S.E. Haupt (NCAR), J. Hilliker (West Chester), R. Holmes (NOAA), P. Knight (Penn State), Y. Kuroki (National Defense Academy of Japan), J. Lee (Penn State) L. Lei (NCAR), K. Long (Penn State), R. Manion (unknown) T. McCandless (Centaurus), S. Nichols (Rutgers), L. Rodriquez (Penn State), B. Root (Oklahoma), J. Ross (Prescient), T. Sikora (Millersville), D. Stauffer (Penn State), N. Winstead (Johns Hopkins)

M.S. advisor: William Mach (deceased)
Ph.D. advisor: Richard Johnson (Colorado State U)   Post-doctoral advisor: N/A

Thesis and post-graduate advisees (past 5 years): Daniel Alexander, Andrew Annunzio, Chris Allen, Anke Beyer, Matthew Colman, Caren Fisher, Marikate Ellis, Yuki Kuroki, Jared Lee, Kerrie Long, Michael Lowe, Robert Manion, Luna Rodriguez, Benjamin Root, Addison Sears-Collins, Dustin Swales
Total number of graduate students advised: 44 (all time)
Total number of postdoctoral scholars sponsored: 0 (all time)

Biographical Sketch: Richard D. Clark, Ph.D.

Professional Preparation:

University of Wyoming, Laramie, WY	Atmospheric Science	Ph.D., 1987
University of Wyoming, Laramie, WY	Atmospheric Science	M.S., 1985
Point Park College, Pittsburgh, PA	Chemistry and Mathematics	B.S., 1975
Penn State University, State College, PA	Astronomy (grad. level, 1976)	no degree

Academic and Professional Appointments:

- Chair (third term), Department of Earth Sciences, Millersville University, May 2002 - present
- Professor of Meteorology, Dept of Earth Sciences, Millersville University, August 1997-present
- Program Coordinator, M.S. in Integrated Scientific Applications, July 2011-present
- Director, Millersville University Environmental Institute, Millersville University, Fall 99-Spring 04
- Associate Professor of Meteorology, Dept of Earth Sciences, Millersville University, 1992-1997
- Assistant Professor of Meteorology, Dept of Earth Sciences, Millersville University, 1987-1992

Recent Publications and Presentations:

Stauffer, R. M., A. M. Thompson, D. K. Martins, R. D. Clark, C. P. Loughner, R. Delgado, T. A. Berkoff, E. C. Gluth, R. R. Dickerson, J. W. Stehr, M. A. Tzortziou, and A. J. Weinheimer, Submitted to *J. of Applied Meteorology and Climatology*, 2012.

Illari, L., J. Marshall, P. Bannon, J. Botella, R. Clark, T. Haine, A. Kumar, S. Lee, K. J. Mackin, G. A. McKinley, M. Morgan, R. Najjar, T. Sikora, and A. Tandon, 2009: WEATHER IN A TANK—Exploiting Laboratory Experiments in the Teaching of Meteorology, Oceanography, and Climate. *Bull. Amer. Meteor. Soc.*, **90** (11), pp. 1619-1632.

Clark, R. D., S. Marru, M. Christie, T. Baltzer, K. Droegemeier, E. Joseph, and B. Illston, 2008: The LEAD-WxChallenge Pilot Project: The Potential of Grid-Enabled Learning. TeraGrid 2008, Las Vegas, NV. (Peer-reviewed presentation.)

Plale, B., D. Gannon, J. Brotzge, K. Droegemeier, J. Kurose, D. McLaughlin, R. Wilhelmson, S. Graves, M. Ramamurthy, R. Clark, S. Yalda, D. Reed, E. Joseph, V. Chandrasekar, 2006: CASA and LEAD: Adaptive cyberinfrastructure for real-time multiscale weather forecasting. *Computing: IEEE Transactions on Parallel and Distributed Systems.* IEEE Computer Society. **38**, (11), pp. 56-64.

Droegemeier, K., T. Baltzer, K. Brewster, R. Clark, B. Domenico, D. Gannon, S. Graves, E. Joseph, V. Morris, D. Murray, B. Plale, R. Ramachandran, M. Ramamurthy, L. Ramakrishnan, D. Reed, J. Rushing, D. Weber, R. Wilhelmson, A. Wilson, M. Xue, and S. Yalda, 2005: Service-oriented environments in research and education for dynamically interacting with mesoscale weather. *Grid Computing: Computing in Science and Engineering*, IEEE Computer Society and Amer. Inst. of Physics. Nov/Dec 2005.

Yalda, S., R. D. Clark, and E. Joseph, 2006: LEAD Educational Initiatives. Preprints, 15th Symposium on Education. American Meteorological Society, Atlanta, GA, January 2006.

Clark, R. D., D. Fitzgerald, T. Baltzer, E. Joseph, R. Ramachandran, and S. Chiao, 2006: EarlyLEAD: A WRF ensemble demonstrating a data mining capability. Preprints, 22nd International Conference on Interactive Information Processing Systems for Meteorology, Oceanography, and Hydrology. 86th Annual Meeting, Amer. Meteor. Soc., Altanta, GA.

Droegemeier, K. K., V. Chandrasekar, R. Clark, D. Gannon, S. Graves, E. Joseph, M. Ramamurthy, R. Wilhelmson, K. Brewster, B. Domenico, T. Leyton, V. R. Morris, D. Murray, B. Plale, R. Ramachandran, D. Reed, J. Rushing, D. Weber, A. Wilson, M. Xue, and S. Yalda, 2005: Linked Environments for Atmospheric Discovery (LEAD): Architecture, Technology Road Map and Deployment Strategy. Preprints, *Joint 21 IIPS and 14 Education.* American Meteorological Society, San Diego, CA.

Yalda, S., R. D. Clark, E. Joseph, J. Alameda, T. Baltzer, K. Droegemeier, D. Bender**, and W. Yarnell**, 2005: LEAD Learning Communities. Preprints, *Joint 21 IIPS and 14 Education.* American Meteorological Society, San Diego, CA.

Clark, R. D., D. Brewer*, E. Lowery*, D. Rabatin*, J. Yorks*, K. Howett*, A. Rowe*, C. Hanna*, and M. Maiuri,* 2005: Surface and aloft measurements of aerosol concentrations in a wintertime boundary layer at a mid-Atlantic site. Preprints, *7th Conference on Atmospheric Chemistry*, American Meteorological Society, San Diego, CA.

Clark, R. D., D. M. O'Donnell*, A. K. Rowe*, K. L. Howett,* 2004: A detailed characterization of the wintertime boundary layer using tethered balloons. Preprints, *16th Conference on Boundary Layers and Turbulence*, American Meteorological Society, Portland, ME.

Clark, R. D., D. M. O'Donnell*, K. N. Berberich*, C. J. Homan*, D. T. Brewer*, E. M. Lowery*, J. E. Bunting*, C. L. Hanna*, M. T. Maiuri*, and J. E. Yorks,* 2004: Preprints, Wintertime tethered balloon measurements of meteorological variables and aerosol characterization in support of MANE-VU. *13th Joint Conference on the Applications of Air Pollution Meteorology with the Air and Waste Management Association*. American Meteorological Society, Vancouver, BC.

* Denotes undergraduate students; ** Denotes high school teachers

Recent Grants and Contracts:

Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ), NASA, $117K, 2011-12

GALACTICA, DARPA, $79K, 2011-12

Geosciences Probe of Discovery, National Science Foundation, IIS-ALT. $350K, 2009-2012.

Acquisition of remote sensing systems for lower atmospheric research and undergraduate research training at Millersville University. National Science Foundation, MRI. $280K. 2006-2009.

Exploiting laboratory experiments in the teaching of meteorology, oceanography, and climate: Phase II. NSF, contract with Massachusetts Institute of Technology. $26K. 2006-2009.

Atmospheric Sensing Technology. Contract with Penn State University. $15K. 2004-2005.

Wintertime Particle Study. NESCAUM (MANE-VU). $55K, 2003-2004.

Linked Environments for Atmospheric Discovery. NSF-ITR (Large) Collaborative. $691.9K, 2003-2008.

Investigations of Source-Receptor relationships during NARTSO-NE-OPS. DEP, $42K, 2003.

Instrumentation and Equipment for air chemistry/meteorology undergraduate research and education at Millersville University. NSF-DUE: CCLI-A&I, $62K, 2000-2003

Investigation of factors determining the occurrence of ozone and fine particles in the Northeast USA. US-EPA. $244.5K. 1998-2001

Professional and Synergistic Activities:

- Unidata Policy Committee (member, 2006-09)
- 2006 Unidata Users Workshop, "Expanding the Use of Models as Educational Tools in the Atmospheric & Related Sciences," LEAD Session participant
- Partner in a NSF-ITR (Large) Collaborative, LEAD education and outreach
- Chair, Vice-Chair, Member NSF-NCAR Observing Facilities Advisory Panel, 2003-2006
- UCAR Unidata Users Committee, served two terms as chair, 2000-2004

Membership and Awards:

- University Corporation for Atmospheric Research (2nd term Board of Directors (2012-15)
- American Meteorological Society Council (elected member, 2008-2011)
- American Meteorological Society (member since 1987)
- American Geophysical Union (member since 1996)
- Sigma Xi (member since 1996)
- Recipient of the 2006 Russell L. DeSouza Award for Outstanding Contributions to the Unidata Community
- Recipient of the 2008 American Meteorological Society Teaching Award

Biographical Sketch: Todd D. Sikora

Professional Preparation:

The Pennsylvania State University,	Meteorology,	B.S.,	1990
The Pennsylvania State University,	Meteorology,	M.S.,	1992
The Pennsylvania State University,	Meteorology,	Ph.D.,	1996

The Johns Hopkins University Applied Physics Laboratory, Ocean Remote Sensing, Post-doc, 1996-1997

Appointments:

2011-Present:	Professor, Millersville University, Department of Earth Sciences
2008-2011:	Associate Professor, Millersville University, Department of Earth Sciences
2005-2008:	Assistant Professor, Millersville University, Department of Earth Sciences
2003-2005:	Associate Professor, United States Naval Academy, Oceanography Department
1997-2003:	Assistant Professor, United States Naval Academy, Oceanography Department
1996-1997:	Adjunct Assistant Professor, United States Naval Academy, Oceanography Department

Related Publications:

Sikora, T. D., and G. S. Young, 1993: Observations of planview flux patterns within convective structures of the marine atmospheric surface layer. *Boundary-Layer Meteor.*, 65, 273-288.

Winstead, N. S., T. D. Sikora, D. R. Thompson, and P. D. Mourad, 2002: Direct influence of gravity waves on surface-layer stress during a cold air outbreak, as shown by synthetic aperture radar. *Mon. Wea. Rev.*, 130, 2764-2776.

Sikora, T. D., and D. M. Halverson, 2002: Multiyear observations of cloud lines associated with the Chesapeake and Delaware Bays. *J. Appl. Meteor.*, 41, 825-831

Young, G. S., and T. D. Sikora, 2003: Mesoscale stratocumulus bands caused by Gulf Stream meanders. *Mon. Wea. Rev.*, 131, 2177-2191.

Sikora, T. D., G. S. Young, M. D. Stepp, and C. M. Fisher, 2011: A synthetic aperture radar-based climatology of open cell convection over the Northeast Pacific Ocean. *J. Appl. Meteor. Climatol.*, 50, 594-603.

Significant Publications:

Sikora, T. D., G. S. Young, R. C. Beal, and J. B. Edson, 1995: Use of spaceborne synthetic aperture radar imagery of the sea surface in detecting the presence and structure of the convective marine atmospheric boundary layer. *Mon. Wea. Rev.*, 123, 3623-3632.

Monaldo, F. M., T. D. Sikora, S. M. Babin, and R. E. Sterner, 1997: Satellite imagery of sea surface temperature cooling in the wake of Hurricane Edouard (1996). *Mon. Wea. Rev.*, 125, 2716-2721.

Sikora, T. D., K. S. Friedman, W. G. Pichel, and P. Clemente-Colon, 2000: Synthetic aperture radar as a tool for investigating polar mesoscale cyclones. *Wea. Forecasting*, 15, 745-758.

Young, G. S., T. D. Sikora, and N. S. Winstead, 2005: Use of synthetic aperture radar in fine-scale surface analysis of synoptic-scale fronts at sea. *Wea. Forecasting*, 20, 311-327.

Jones, C. T., T. D. Sikora, P. W. Vachon, and J. Wolfe, 2012: Towards automated identification of sea surface temperature front signatures in Radarsat-2 images. *J. Atmos. Oceanic Technol.*, 29, 89-102.

Synergistic Activities:

Scholarly: Dr. Sikora has been continually funded by the Office of Naval Research (ONR) since 1997 to investigate the use of synthetic aperture radar (SAR) as a marine meteorological tool. Recently, Dr.

Sikora contracted with Canadian agencies on a related project known as the Spaceborne Ocean Intelligence Network (SOIN). The following is the text of a letter from Dr. Sikora's former SOIN program manager (Wayne Renaud) to Dr. Sikora's ONR program manager (Ronald Ferek) describing the synergy of Dr. Sikora's efforts:

I'm writing to you to acknowledge Code 322MM research that has benefited SOIN. Dr. Todd Sikora is serving as a SOIN project consultant and has thus facilitated the integration of research from his group (with Dr. George Young and Dr. Pete Winstead) into SOIN. We are particularly grateful for your supporting research that culminated in the following recent references:

Young, G. S., T. D. Sikora, and N. S. Winstead, 2008: Mesoscale near-surface wind speed variability mapping with synthetic aperture radar. Sensors, 8, 7012-7034.

Young, G. S., T. D. Sikora, and N. S. Winstead, 2007: Manual and semi-automated wind direction editing for use in the generation of synthetic aperture radar wind speed imagery. J. Appl. Meteor. Climatol., 46, 776-790.

Sikora, T. D., G. S. Young and N. S. Winstead, 2006: A novel approach to marine wind speed assessment using synthetic aperture radar. Wea. Forecasting, 21, 109-115.

The contributions made by Dr. Sikora and his group have greatly benefitted the SOIN project, and the professional relationships we've established will undoubtedly continue to serve the Department of National Defense and ONR well into the future.

Service: Dr. Sikora served as Chairperson of the AMS Air-Sea Interaction Committee (2006-2009). It is the purpose of this Committee to promote the increase and exchange of knowledge and understanding in the field of air–sea interactions, broadly interpreted. The Committee is charged with making efforts to reduce disciplinary barriers, which tend to restrict the flow of information between people in different specialties. This is done by assuring that there will be opportunities for meteorologists, oceanographers, and others to share information and opinions through joint meetings and via the written word, especially before and after field programs of national and international scope. During Dr. Sikora's tenure as Chairperson, meetings were held in conjunction with the Sixteenth and Fifteenth Conferences on Air-Sea Interaction.

Currently, Dr. Sikora is an associate editor for the Journal of Applied Meteorology and Climatology, is a member of the UCAR Membership Committee, and is a member of COMET's Dynamic Meteorology Faculty Advisory Panel.

Collaborators & Other Affiliations:

Collaborators and Co-Editors: Michael Bettwy (National Weather Service); Alex DeCaria (Millersville University); Caren Fisher (ITT Space Systems Division); Chris Jones (Dalhousie University); Hampton Shirer (Penn State); Matthew Stepp (Information Technology and Innovation Foundation); Dustin Swales (University of Colorado); Paris Vachon (Defense Research and Development Canada); Nathaniel Winstead (Johns Hopkins University Applied Physics Laboratory); John Wolfe (Defense Research and Development Canada); George Young (Penn State).

Graduate and Postdoctoral Advisors:
George Young (Penn State, Graduate); Donald Thompson (Johns Hopkins University Applied Physics Laboratory, Postdoctoral)

Thesis Advisor and Postgraduate-Scholar Sponsor: Dustin Swales (Penn State M.S. thesis committee); Brian Kerschner (University of Delaware M.S. thesis committee)