**The Collaborative Science, Technology, and Applied Research (CSTAR) Program**

# *Development of Improved Diagnostics, Numerical Models, and Situational Awareness of High-Impact Cyclones and Convective Weather Events*

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**National Oceanic and Atmospheric Administration (NOAA) Award #:** NA16NWS4680005

**Date:** 21 July 2020

## 1. SUMMARY OF RESEARCH ACTIVITIES

### a) Forecast and model diagnostics for severe convective weather events in complex terrain

*Students: William Flamholtz and Luke LeBel*
*PI and co-PIs: Brian Tang, Lance Bosart, and Kristen Corbosiero*
*NWS focal points: Thomas Wasula (ALY), Michael Evans (ALY), and Matthew Kramar (PIT)*

**Research summary:**

Several goals were accomplished to better understand and help forecast severe convective weather events in complex terrain. First, we updated the low-predictive skill severe weather events database developed by Vaughan et al. (2017) to include events that have occurred since 2013. Second, we simulated select events, using the WRF model with HRRR-like physics, to better understand terrain-induced inhomogeneities in the convective environment and their effects on convection. Third, we conducted idealized WRF simulations (containing homogeneous, initial environments and idealized north-south oriented valleys) in order to fundamentally understand how terrain affects the evolution of convection.

The main findings of the project can be summarized as:

- Terrain channeling of warm, moist air up north–south oriented valleys locally increases instability and vertical wind shear.
- Local increases in vertical wind shear and storm-relative helicity due to terrain channeling may be more important for increasing severity of convection in high-CAPE, moderate/high-shear environments (versus high-CAPE, low-shear environments; Fig. 1)

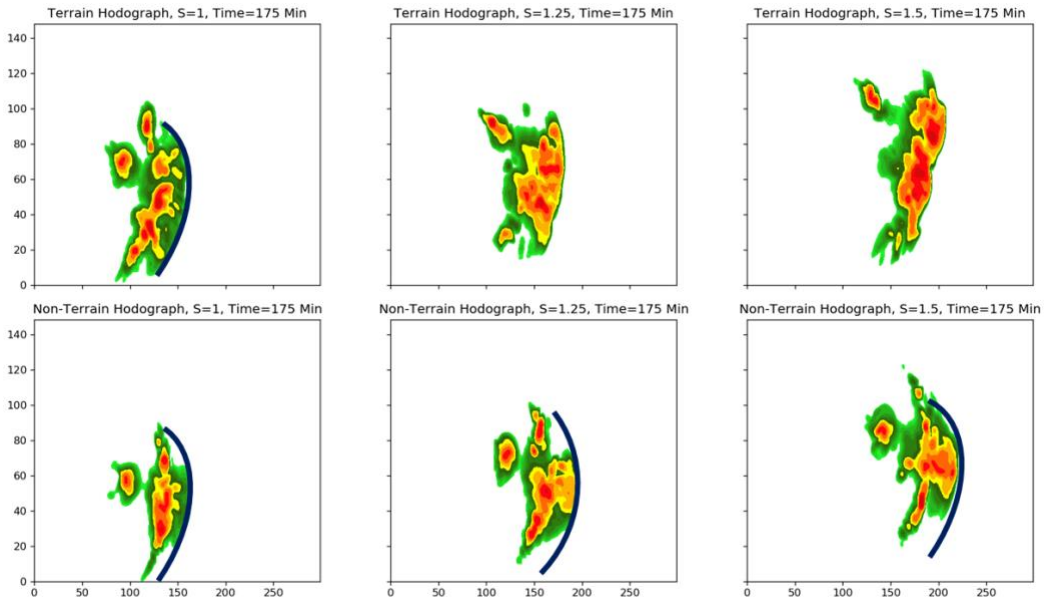


***Figure 1.*** *Simulated radar reflectivity for high-CAPE, low- (first column), medium- (second column), and high- (third column) shear simulations. The top (bottom) row of simulations has a low-level wind profile that is representative of channeled (non-channeled) flow. Blue curves represent approximate location for the front edge of the cold pool. Note the robust QLCS structure in the upper-right simulation. This simulation has the strongest severe weather proxies (maximum 10-m wind speed, maximum 2–5-km updraft helicity, and maximum vertical velocity).*

- Upslope flow and terrain-induced horizontal convergence/boundaries can cause an increase in the updraft velocity, reflectivity, and low-level vorticity of supercells (Fig. 2).

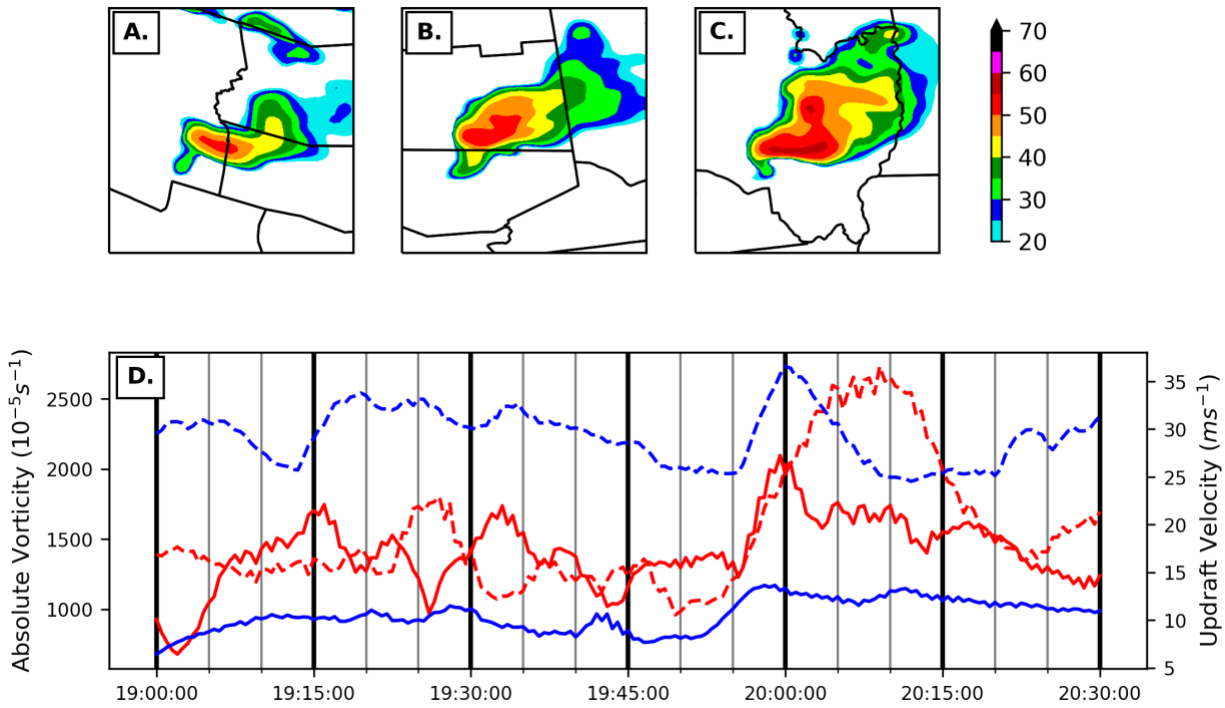


***Figure 2.*** *Simulated radar reflectivity (dBZ) for the Mechanicville supercell at (a) 1900, (b) 1930, and (c) 2000 UTC 31 May 1998. (d) Maximum 1-km updraft (blue, solid), 5-km updraft (blue, dashed), 1-km absolute vorticity (red, solid), and 5-km absolute vorticity (red, dashed). The supercell crosses a terrain-induced boundary around 1945 UTC and intensifies shortly after.*

- Cold-pool interactions with sloping terrain can cause changes in convective mode (e.g., supercell to bow echo; Fig. 3).

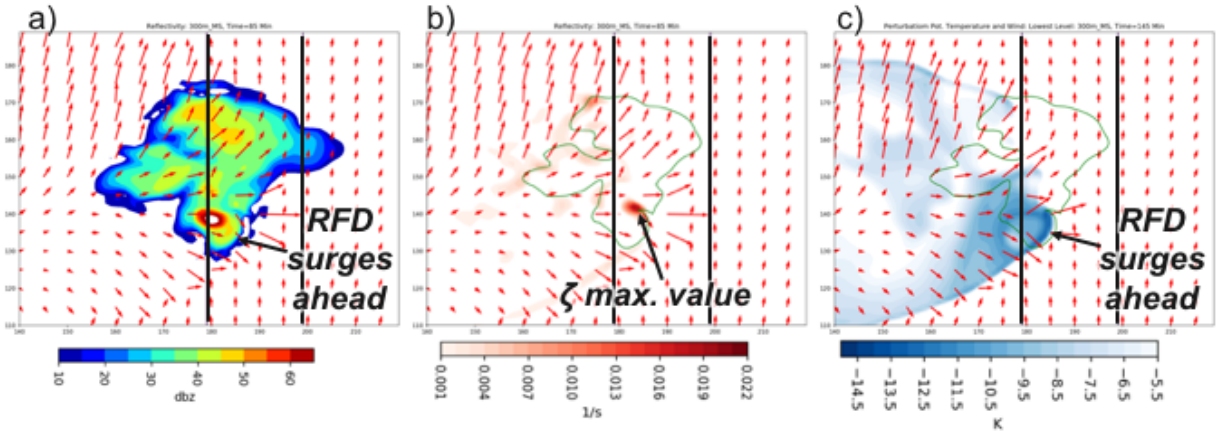


***Figure 3.*** *(a) Simulated reflectivity (dBZ), (b) 1-km relative vorticity ($s^{-1}$), (c) perturbation potential temperature (K). Red arrows are near-surface wind. Black lines denote the edges of the valley. As the rear-flank downdraft surges ahead, the low-level mesocyclone occludes and the supercell transforms into a bow echo. In contrast, a control simulation without the valley has a quasi-steady supercell through the whole simulation (not shown).*

These findings can provide for improved situational awareness when forecasting and nowcasting severe convection:

- Provided the environment is marginal or supportive for severe convection, the risk of severe hazards may be enhanced in valley areas where convection can take advantage of the more favorable, local environment. In particular, forecasters should be alert for the potential for terrain channeling to enhance convection in high-CAPE and moderate/high-shear environments.
- Forecasters should be alert for convection to become severe shortly after intersecting areas of upslope flow or low-level boundaries, provided the overall environment is supportive for severe weather. A prominent low-level boundary can exist at the confluence of the Mohawk and Hudson valleys. The New York State Mesonet is a great tool for identifying these boundaries and other local inhomogeneities in the convective environment.
- Expect convective mode changes, and associated changes in potential severe hazards, as cold pools interact with the underlying terrain and channeled flow.

**NWS Interactions:**

A number of NOAA and NWS interactions occurred at both the local weather forecast office level to the national level. At the local level, research updates were given twice a year at CSTAR meetings at the NWS Albany office. William Flamholtz and Brian Tang gave overview presentations and then discussion between the students, co-PIs, and NWS focal points provided valuable feedback and future directions for the project. At the regional to national level, William Flamholtz, Luke LeBel, Brian Tang, and Lance Bosart gave presentations on this work at workshops and conferences, including the Northeast Regional Operational Workshop, the Northeastern Storms Conference, the Severe Local Storms Conference, and the American Meteorological Society Annual Meeting. Additionally, Lance Bosart attended the Hazardous Weather Testbed Spring Forecast Experiment in multiple years to discuss this work with National Severe Storms Laboratory and Storm Prediction Center scientists and forecasters.

In order to enhance the research-to-operations transfer of knowledge from these subprojects, Ross Lazear will work with William Flamholtz to develop summary points and conceptual diagrams of the operationally-relevant portions of their research to incorporate into the NOAA Virtual Laboratory. Luke LeBel is working with Brian Tang and Ross Lazear to publish research on how terrain influenced the 1998 Mechanicville supercell.

**b) High-resolution numerical forecasts of lake-effect snowstorms: model performance, physics sensitivities, and synoptic predictability**

*Graduate student: Massey Bartolini*
*PI and co-PIs: Justin Minder, Daniel Keyser, and Ryan Torn*
*NWS focal points: Joseph Villani (ALY) and David Zaff (BUF)*

**Research summary:**

Lake-effect snow (LeS) presents a substantial forecast challenge for convection-permitting numerical weather prediction (NWP) models, due in part to uncertainties in the parameterization of microphysical (MP) and planetary boundary layer/surface layer (PBL/SL) processes and to uncertainties in mesoscale and synoptic-scale initial and boundary conditions (ICs/BCs). This research focused on understanding these uncertainties through the study of an LeS event that

occurred during 10–12 December 2013 during the Ontario Winter Lake-effect Systems (OWLeS) field campaign. Throughout this event, long-lake-axis-parallel snowbands persisted downwind of the eastern shore of Lake Ontario, leading to snowfall accumulations as high as 105 cm (liquid precipitation equivalent of 64.5 mm) on the Tug Hill Plateau. We ran nested simulations of the 10–12 December 2013 LeS event at 12-, 4-, and 1.33-km horizontal grid spacing using the Weather Research and Forecasting (WRF) model configured similarly to the operational High-Resolution Rapid Refresh (HRRR) model. Two suites of physics sensitivity experiments were conducted for the event, first, with nine different MP schemes, and second, with eleven different PBL/SL schemes. A suite of IC/BC experiments was also run, using a twenty-member ensemble.

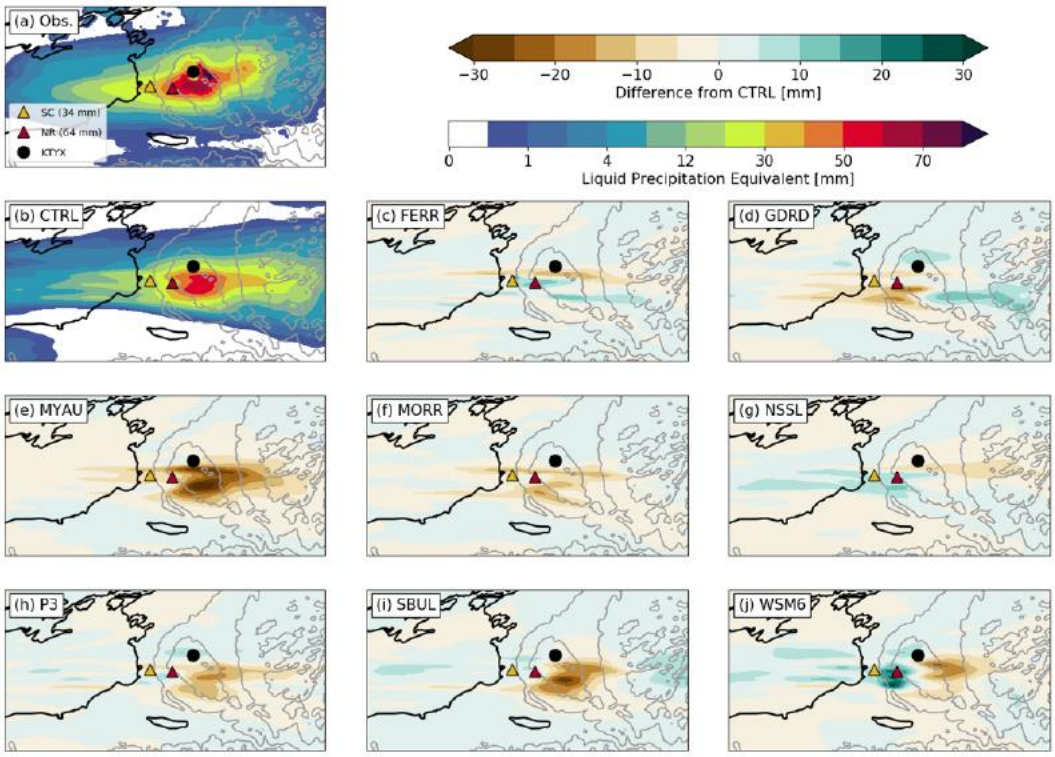


***Figure 4.*** *Observed and WRF-simulated 24-h accumulated precipitation ending at 0000 UTC 12 December 2013. (a) Precipitation measured by OWLeS manual observations (filled triangles) and estimated by KTYX radar (shading). (b) WRF quantitative precipitation forecast (QPF) over the same 24-h period for HRRR-like control member (CTRL). (c)-(j) QPE differences, relative to CTRL for remaining MP ensemble members. Taken from Bartolini (2019).*

The main results of the MP experiments are summarized in the MS thesis Bartolini (2019) and are being prepared for a future publication in an academic journal. The remainder of this paragraph is adapted from the abstract of Bartolini (2019) to summarize this work. Large differences between the MP experiments were found in the LeS band intensity and precipitation type, with smaller differences in the band timing, position, and morphology. Maximum storm-total liquid precipitation equivalent amounts among MP ensemble members ranged from 35 to 62 mm. Differences in storm-total precipitation are documented in Figure 4. Results from the WRF simulations were compared to detailed observations from OWLeS, including scanning and profiling radar data and surface snowfall and crystal habit observations. Additionally,

measurements from the University of Wyoming King Air aircraft, including vertically pointing cloud radars and in-situ flight-level thermodynamic and microphysical observations, were used to compare modeled and observed cloud structures. By analyzing cloud microphysics, such as supercooled liquid water content, hydrometeor size distributions, and precipitation fall speed, we compared modeled and observed lake-effect cloud properties and assessed which MP schemes most accurately simulated cloud processes during this LeS event. Motivated by substantial differences in the model-observational comparisons, we also performed several sensitivity experiments with the aerosol-aware Thompson MP scheme used in the HRRR, modifying the snow size distribution and fall speed within WRF to quantify single scheme precipitation uncertainty. These sensitivity experiments varied maximum liquid precipitation equivalent amounts over the Tug Hill Plateau by 5 to 15 mm relative to the Thompson control simulation.

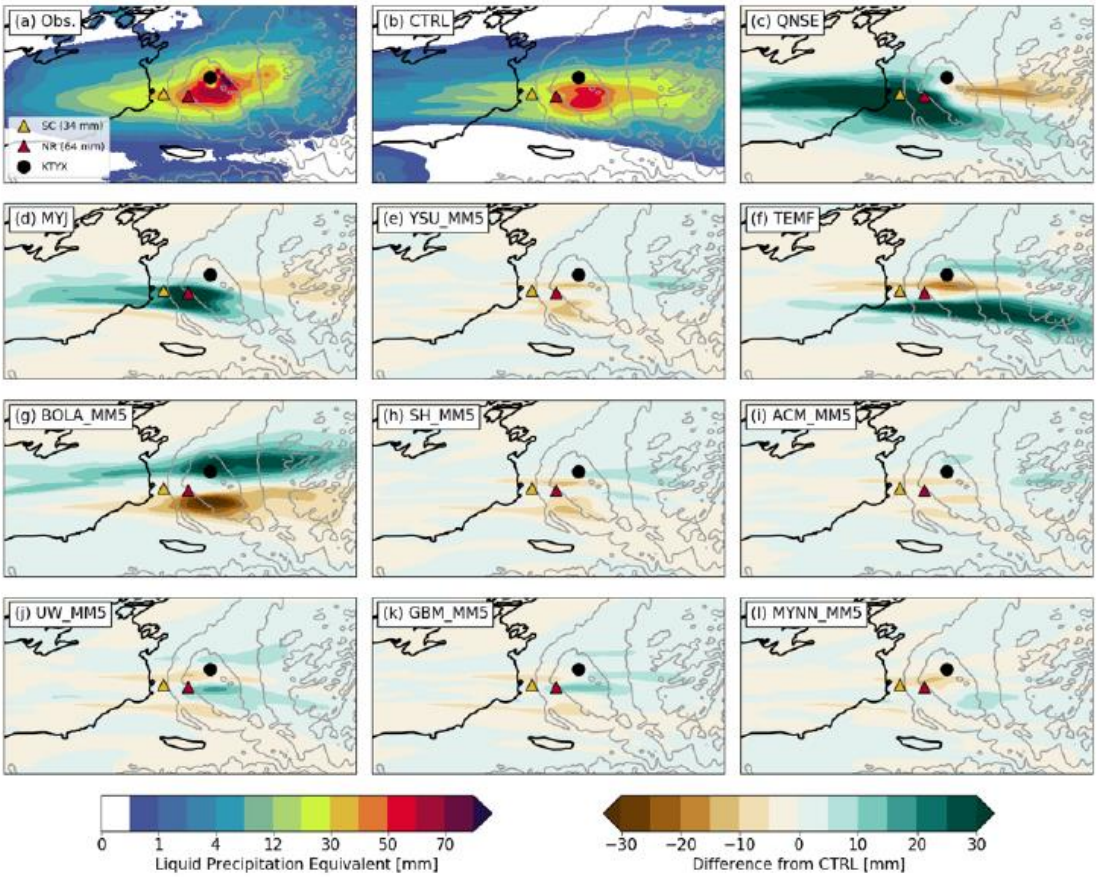


***Figure 5.*** *As for Figure 4, but for PBL/SL experiment suite. Taken from Bartolini (2019).*

The main results of the PBL/SL experiments are summarized in the publication Minder et al. (2020). The remainder of this paragraph adapts the abstract of that paper to summarize this work. Two cases were simulated, the above-described December 2013 OWLeS event and a 2016 event downwind of Lake Superior. Measurements of over-lake fluxes and downwind snowfall were used to evaluate the simulations. Consistent with previous studies, LeS was found to be strongly sensitive to SL and PBL parameterization choices. Simulated precipitation accumulations differed by up to a factor of two depending on the schemes used. Differences in storm-total precipitation for the December 2013 OWLeS case are documented in Figure 5. Differences

between SL schemes were the dominant source of this sensitivity. Parameterized surface fluxes of sensible and latent heat each varied by over 100 W $m^{-2}$ between SL schemes. The magnitude of these fluxes was correlated with the amount of downwind precipitation. Differences between PBL schemes played a secondary role but had notable impacts on storm morphology. Most schemes produced credible simulations of over-lake fluxes and downwind snowfall. However, the schemes that produced the largest surface fluxes produce fluxes and precipitation accumulations were biased high relative to observations. For two SL schemes studied in detail via parameter sensitivity experiments (MYJ and QNSE), unrealistically large fluxes were attributed to specific parameter choices: the neutral stability turbulent Prandtl number and the threshold friction velocity used for defining regimes in the overwater surface roughness calculation.

Additional research was conducted to examine the role of IC/BC uncertainty using an ensemble of simulations with varied ICs and BCs in collaboration with Craig Schwartz of NCAR. Mr. Schwartz ran a series of ensemble simulations with varied ICs/BCs for IOP2b. Each limited-area, 20 member WRF ensemble uses boundary conditions from the GEFS. At each of three different lead times (36-, 24-, and 12 h before LeS precipitation onset), two ensembles were initialized. One ensemble had ICs from the GEFS and another had ICs generated using WRF-DART Ensemble Kalman filter data assimilation, the same approach used in the 2015–2017 real-time NCAR. These two initial condition systems, GEFS and EnKF, were chosen to investigate the influence of synoptic-scale and mesoscale ICs, respectively, on LeS forecasts. Results from these IC/BC ensemble simulations for IOP2b were used to quantify the increase of forecast uncertainty with increasing forecast lead-time. However, this uncertainty was not uniform across the OWLeS study area and is concentrated on the edges of the axis of heaviest precipitation especially at close lead times. This uncertainty is further modulated by precipitation regimes within the event, with more forecast spread during the onset and end of LeS precipitation and during forecast times with oscillations in the mean low-level wind flow across Lake Ontario. Analysis of synoptic flow in ensemble members was used to trace some of the forecast uncertainty to specific mesoscale and synoptic-scale features in the flow, such as shortwave troughs. These initial results were presented in multiple conference presentations but have not yet been incorporated into any published work.

The above-summarized results, showing strong sensitivity of LeS to uncertainties in model physics, have helped to motivate additional research that extends beyond or CSTAR project. In particular, Dr. Minder and Mr. Bartolini have begun investigating the utility of stochastic parameter perturbations (SPP) in convection-permitting probabilistic forecasting of high-impact winter precipitation events. The perturbed parameter sensitivity experiments conducted for OWLeS cases as part of our CSTAR serve as a foundation that we are building on for this work, which is funded as part of NOAA grant: NA19OAR4590137.

Finally, as a side-project, Mr. Bartolini developed a situational awareness tool that summarizes model forecasts of key lake-effect ingredients and compares current and forecasted conditions to seasonal climatologies. This tool is available (during the cold season) in real time at: *http://www.atmos.albany.edu/student/mbartolini/les.php*.

**NWS Interactions:**

Throughout the project, in-person and virtual meetings were held between UAlbany researchers, NWS WFO staff (at ALY and BUF), and HRRR-model developers (at NOAA-ESRL) to receive feedback and communicate results. Results were also conveyed to the operational community during CSTAR meetings and the Northeast Regional Operational Workshop. Additionally, the research has been made available to the operational community through the

NOAA Virtual Lab (VLab), where a copy of Bartolini (2019) is posted, a link to the above-described situational awareness tool is given, and a "quick reference" guide that summarizes key operationally relevant results (Figure 6) is available.

## Summary of Key Results from OWLeS Case IOP2b*

| Microphys. Scheme (HREFv2.1 Model) | Band Intensity | Total Band Area | Precipitation Types | QPF Relative to Control (THOM) | Heat/Moisture Fluxes |
|---|---|---|---|---|---|
| THOM (**HRRR**) | Similar to observed | Too small | >95% SN, very little GR | | |
| WSM6 (**HRW ARW, HRW NSSL**) | Too high | Too small | 30% GR windward of Tug Hill, SN elsewhere | More QPF windward of Tug Hill, less leeward | |
| **PBL/Surface layer Scheme (HREFv2.1)** | **Band Intensity** | **Total Band Area** | **Precipitation Types** | **QPF Relative to Control (MYNN)** | **Heat/Moisture Fluxes** |
| MYNN/MYNN (**HRRR**) | Similar to observed | Too small | >95% SN | | |
| YSU/revMM5 (**HRW ARW**) | Similar to observed | Too small | >95% SN | Similar to MYNN | Similar to MYNN |
| MYJ/MYJ (**HRW NSSL, HRW NMMB, NAM Nest**) | Too high | Too small | >95% SN | More QPF windward of Tug Hill, similar elsewhere | Higher than MYNN |

Notes: ***All results are specific to OWLeS IOP2b, may not be representative of other LeS cases,** experiments based off physics options in WRF-ARWv3.9 (released April 2017), configured similarly to HRRRv3 (implemented July 2018)
MP = microphysical parameterization, PBL/SL = planetary boundary layer / surface layer parameterizations

***Figure 6.*** *"Quick reference" guide summarizing key results available on NOAA-VLab at: https://vlab.ncep.noaa.gov/web/albany-cstar/numerical-forecasts-of-lake-effect-snowstorms.*

**Training:**

This funding supported the studies of Mr. Massey Bartolini. He completed a MS thesis based on this research in December 2019 (Bartolini 2019). Additional professional development for Mr. Bartolini included a visit to the NWS BUF WFO, where he learned about operational LeS forecasting. He also traveled to Boulder, CO, during June 2017 to collaborate with Craig Schwartz (NCAR) on IC/BC sensitivities of lake-effect forecasts and again during June 2018 to attend the NCAR Advanced Study Program (ASP) Summer Colloquium focused on comparing modeled and observed cloud properties, where he learned model diagnostic skills that directly contributed to his research progress. During this trip he also presented project updates to the ESRL-HRRR development team and to Craig Schwartz. Mr. Bartolini is continuing his graduate studies at UAlbany, focusing on evaluating and improving stochastic physics parameterizations for convection-permitting NWP forecasts of winter precipitation.

**c) Applying forecast track and intensity diagnostics to high-impact Northeast winter storms**

*Graduate student: Tomer Burg*
*PI and co-PIs: Andrea Lang, Ryan Torn, and Kristen Corbosiero*
*NWS focal points: Neil Stuart (ALY), Joseph Dellicarpini (BOX), and Justin Arnott (GYX)*

**Research summary:**

Northeastern winter storms can have significant impacts, ranging from heavy snowfall to damaging winds and coastal flooding. Forecasting such cyclones can be a challenge, especially in the medium range (e.g., three to five-day lead time), where significant spatial and temporal variability in skill of NWP models exists. The goal of this project was to identify and quantify systematic biases with forecasts of high-impact Northeast U.S. winter cyclones to improve situational awareness during the forecast process.

Over the course of the project period, work consisted of the development of an objective cyclone identification and tracking algorithm suitable for use in medium-range ensemble forecast models, and incorporating forecast cyclone position ellipses representing ensemble spread of cyclone positions identified following the methodology of Hamill et al. (2011). The first part of the analysis was the creation of a climatology (1985–2015) of ensemble forecasts of high-impact Northeast winter storms initialized from 0 to 5-day lead times was constructed using the Global Ensemble Forecast System (GEFS) Reforecast version 2. Cases included in this climatology were those identified within 750 km of the 40ºN/70ºW benchmark from an ERA-I based cyclone track dataset created by Sprenger et al. (2017), but also could be tracked with Climate Forecast System Reanalysis (CFSR) data using the 925-hPa area-averaged vorticity maxima and height minima-based tracking algorithm developed for this project. The verification of the ensemble forecasts at 0 through 5-day lead times was computed against the CFSR verification track, and the analysis quantified the GEFS climatological forecast track and intensity errors and biases.

The second part of the analysis consisted of an examination of the biases and errors for the 517 East Coast winter cyclones that were identified and tracked within the CFSR. While the CFSR verification tracks consistent with prior climatologies of East Coast cyclones, the analysis showed an underdispersive bias in the GEFS for both position and intensity forecasts. In addition, the GEFS position errors exhibited predominantly along-track position variability. The results did not find a systematic right of track bias in the forecasts of East Coast winter cyclones; for most of the reforecast lead times, cyclones tended to exhibit a slightly left of track bias on average, while the 12–66-hour lead time range shows a prominent slow bias for most cases (Figure 7). The forecasts exhibit a negative correlation between across-track bias and intensity bias, peaking at day 3 forecast lead-time (Figure 8). This negative correlation results motivated further analysis in assessing synoptic composites of left vs. right of track bias and weak vs. strong intensity bias.

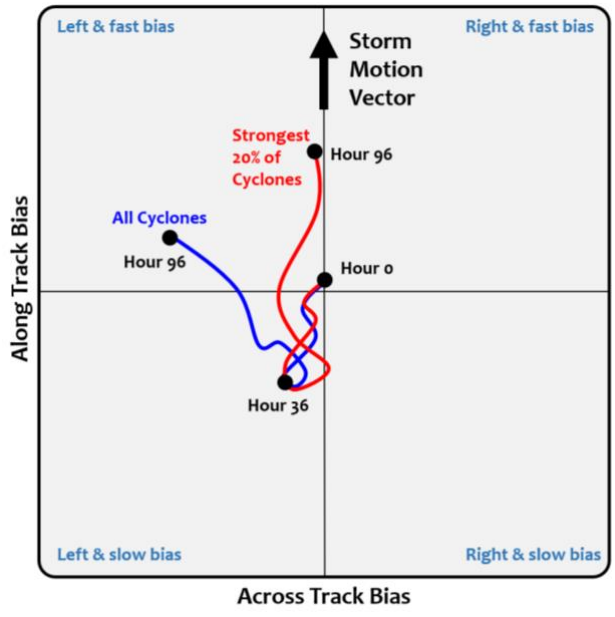


***Figure 7.*** *A schematic representation of the along-track and across-track biases for all 517 Northeastern cyclones (blue) and the strongest 20% of cyclones (red) at GEFSRv2 forecast lead-time from 0 to 96 hours.*

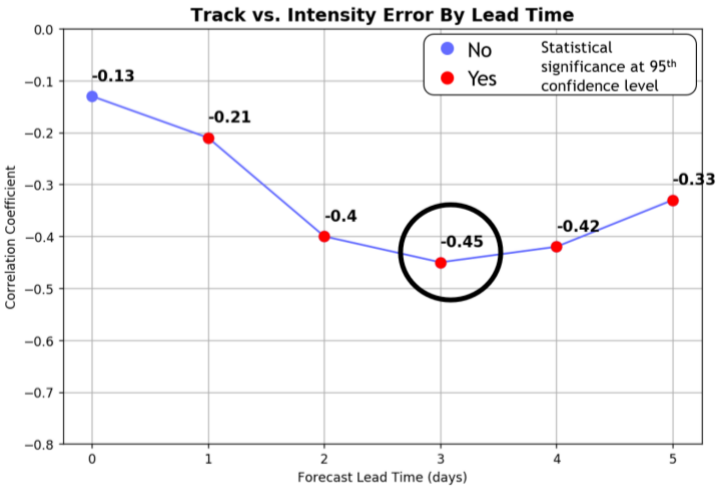


***Figure 8.*** *A time series of the track versus intensity error correlation coefficient by forecast lead-time. A negative correlation implies that left of track biases are correlated with strong intensity bias and right*

More amplified flow over the United States was found in the right of track and weak bias composites compared to the left of track and strong bias composites, respectively. The flow amplified flow included a stronger downstream polar jet streak and upstream subtropical jet streak relative to the mean cyclone location. Assessing the synoptic composite differences of small vs. large across-track variability found a tendency for higher mean sea level pressure and upper level heights across western North America in the small across-track variability composite, which along with a significantly more negative temperature anomaly in the eastern two thirds of the U.S. suggests a higher likelihood of cold air outbreaks than large across-track variability. The synoptic situations for the biases development was further explored by considering the large-scale flow variability indices that projected on to the bias-composite anomalous flow. We found that cases with small across-track variability on averaged exhibit, more positive PNA and negative AO, while cases with large across-track variability tended to exhibit positive EPO and positive NAO (Figure 9). These results were compiled for the NWS–University at Albany CSTAR VLab page.

The thesis summarizing this work was submitted by Tomer Burg, who successfully presented and defended his master's thesis research on 1 May 2019 Several NWS employees were in attendance. Tomer graduated with his Masters this May 2019. It is anticipated that these thesis results will be submitted to an AMS journal.

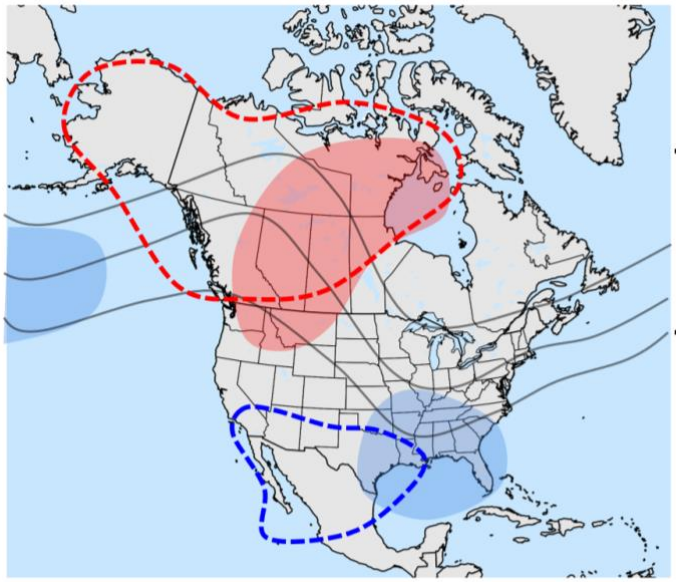

***Figure 9.*** *Composite of the 500-hPa geopotential height (black) in the subset of cases with small across-track variability. The positive and negative 500-hPa height anomalies associated with small across-track variability are shaded red and blue, respectively. The locations where the 500-hPa geopotential heights are higher or lower for small across-track bias cases compared to large-across track bias cases are within the red and blue dashed regions, respectively.*

## 2. CSTAR VI PROJECT THESES, PRESENTATIONS, AND PUBLICATIONS

### a) Theses completed

Bartolini, W. M., 2019: Convection-permitting ensemble forecasts of the 10–12 December 2013 lake-effect snow event: sensitivity to microphysical, planetary boundary layer, and surface layer parameterizations, University at Albany/SUNY, 103 pp.

Burg, T., 2019: Applying forecast track and intensity diagnostics to high-impact Northeast winter storms. Master of Science Thesis, Dept. of Atmospheric and Environmental Sciences, University at Albany/SUNY, 77 pp.

### b) Presentations

Bartolini, W. M., J. R. Minder, R. D. Torn, D. Keyser, 2017: An analysis of microphysics scheme performance in numerical simulations of the lake-effect snow event of 10–12 December 2013 during the Ontario Winter Lake-effect Systems Field Campaign. Poster presentation at the *42nd Northeastern Storm Conference*, 11 March, Saratoga Springs, NY.

Bartolini, W. M., J. R. Minder, R. D. Torn, and D. Keyser, 2017: An analysis of microphysics scheme performance in numerical simulations of the lake-effect snow event of 10–12 December 2013 during the OWLeS Field Campaign. Poster presentation at the *17th American Meteorological Society Conference on Mesoscale Processes*, 25 July, San Diego, CA.

Bartolini, W. M., J. R. Minder, R. D. Torn, and D. Keyser, 2017: Convection-permitting ensemble forecasts of the 10–12 December 2013 lake-effect snow event: Sensitivity to initial and boundary conditions. Oral presentation at the *18th Northeast Regional Operational Workshop*, 2 November, Albany, NY.

Bartolini, W. M., J. R. Minder, C. S. Schwartz, R. D. Torn, and D. Keyser, 2018: Convection-permitting ensemble forecasts of the 10–12 December 2013 lake-effect snow event: Snowband and land-breeze front predictability. Oral presentation at the *43rd Northeastern Storm Conference*, 11 March, Saratoga Springs, NY.

Bartolini, W. M., J. R. Minder, C. S. Schwartz, D. Keyser, and R. D. Torn, 2018: Multiscale frontal circulations during the 6–8 January 2014 lake-effect snow event: Understanding their superposition and predictability using convection-permitting ensemble forecasts. Poster presentation at the *29th Conference on Weather Analysis and Forecasting/25th Conference on Numerical Weather Prediction,* 5 June, Denver, CO.

Bartolini, W. M., and J. R. Minder, 2018: Convection-permitting ensemble forecasts of the 10–12 December 2013 lake-effect snow event: Sensitivity to initial and boundary conditions. Oral presentation at the *19th Northeast Regional Operational Workshop,* 7 November, Albany, NY.

Bartolini, W. M., and J. R. Minder, 2019: Convection-permitting ensemble forecasts of the 10–12 December 2013 lake-effect snow event: Sensitivity to microphysical parameterizations. Oral presentation at the *99thAMS Annual Meeting,* 7 January, Phoenix, AZ.

Bartolini, W. M., and J. R. Minder, 2019: Convection-permitting ensemble forecasts of the 10–12 December 2013 lake-effect snow event: Sensitivity to microphysical parameterizations. Oral presentation at the *44th Annual Northeastern Storm Conference,* 11 March, Saratoga Springs, NY.

Bartolini, W. M., and J. R. Minder, 2019: Convection-permitting ensemble Forecasts of the 10–12 December 2013 lake-effect snow event: Sensitivity to microphysical parameterizations. Oral presentation at the *18th Conference on Mesoscale Processes*, 30 July, Savannah, GA.

Bartolini, W. M., and J. R. Minder, 2019: Single-parameter perturbations: Quantifying microphysical parameterization uncertainty in convection-permitting forecasts of the 10–12 December 2013 lake-effect snow event. Oral presentation at the *20th Northeast Regional Operational Workshop,* Albany, NY.

Bartolini, W. M., and J. R. Minder, 2020: Quantifying microphysical parameterization uncertainty in convection-permitting forecasts of the 10–12 December 2013 lake-effect snow event. *100th AMS Annual Meeting / 30th Conference on Weather Analysis and Forecasting / 26th Conference on Numerical Weather Prediction,* Boston, MA.

Bosart, L. F., 2017: Modern weather analysis and forecasting: challenges and opportunities. Oral presentation at the *Ohio University Eighth Annual Meteorological Symposium*, 25 March, Athens, OH.

Bosart, L. F., A. M. Bentley, T. Burg, and A. C. Winters, 2018: The "Pi-Day" coastal storm of 14 March 2017. Oral presentation at the *43rd Northeastern Storm Conference*, 10 March, Saratoga Springs, NY.

Bosart, L. F., A. M. Bentley, T. Burg, and A. C. Winters, 2018: The "Pi-Day" coastal storm of 14 March 2017. Oral presentation at the University of Utah, 26 March, Salt Lake City, UT.

Burg, T., A. L. Lang, K. L. Corbosiero, and R. D. Torn, 2017: Applying forecast track diagnostics to high-impact Northeast winter storms. Oral presentation at the 18th Cyclone Workshop, 5 October, Sainte-Adele, Quebec, Canada.

Burg, T., A. L. Lang, K. L. Corbosiero, and R. D. Torn, 2017: Applying forecast track and intensity diagnostics to two high-impact Northeast winter storms. Poster presentation at the *42nd Northeastern Storm Conference*, 11 March, Saratoga Springs, NY.

Burg, T., A. L. Lang, K. L. Corbosiero, and R. D. Torn, 2017: Applying forecast track diagnostics in high-impact Northeast winter storms: Climatology and case analysis. Oral presentation at the *18th Northeast Regional Operational Workshop*, 1 November, Albany, NY.

Burg, T., A. L. Lang, K. L. Corbosiero, and R. D. Torn, 2018: Applying forecast track diagnostics in high-impact Northeast winter storms: Climatology and case analysis. Oral presentation at the *43rd Northeastern Storm Conference*, 10 March, Saratoga Springs, NY.

Burg, T., A. L. Lang, K. L. Corbosiero, and R. D. Torn, 2018: Applying forecast track diagnostics in high-impact Northeast winter storms: Climatology and case analysis. Oral presentation at the *29th Conference on Weather Analysis and Forecasting/25th Conference on Numerical Weather Prediction*, 4 June, Denver, CO.

Burg, T., A. L. Lang, K. L. Corbosiero, and R. D. Torn, 2018: Applying forecast track diagnostics to high-impact Northeast winter storms. Oral presentation at the *19th Northeast Regional Operational Workshop,* 7 November, Albany, NY.

Burg, T., A. L. Lang, K. L. Corbosiero, and R. D. Torn, 2019: Applying forecast track diagnostics to high-impact Northeast winter storms. Oral presentation at the *44th Northeastern Storm Conference*, 10 March, Saratoga Springs, NY.

Ekster, M. L., 2018: The 1 July 2017 Maine tornadoes: A mesoscale and radar analysis. Oral presentation at the *43rd Northeastern Storm Conference*, 10 March, Saratoga Springs, NY.

Flamholtz, W., B. Tang, and L. Bosart, 2018: Terrain effects on the convective environment of the 13–14 August 2016 northeastern U.S. severe weather event. Poster presentation at the *43rd Northeastern Storm Conference,* 10 March, Saratoga Springs, NY.

Flamholtz, W., B. Tang, and L. Bosart, 2018: Evaluating the effects of terrain-channeled, low-level flow on convective organization. Oral presentation at the *29th AMS Severe Local Storms Conference*, 23 October, Stowe, VT.

Flamholtz, W., B. Tang, and L. Bosart, 2018: Evaluating the effects of terrain-channeled, low-level flow on convective organization. Oral presentation at the *19th Northeast Regional Operational Workshop,* 8 November Albany, NY.

Flamholtz, W., B. Tang, and L. Bosart, 2019: Simulating the effects of terrain-induced perturbations on severe convection using an idealized valley. Oral presentation at the *44th Northeastern Storm Conference*, 10 March, Saratoga Springs, NY.

Frugis, B. J., 2017: Examining methods to accurately predict significant severe thunderstorm wind damage across the Northeastern U.S.. Poster presentation at the *42nd National Weather Association Annual Meeting*, 18 September, Garden Grove, CA.

Frugis, B. J., 2018: Using specific differential phase to predict significant severe thunderstorm wind damage across the Northeastern United States. Poster presentation at the *29th AMS Severe Local Storms Conference*, 22 October, Stowe, VT.

LeBel, L., B. Tang, and R. Lazear, 2018: Examining terrain effects on the 31 May 1998 Mechanicville, New York supercell and tornado. Poster presentation at the *29th AMS Severe Local Storms Conference*, 23 October, Stowe, VT.

LeBel, L., B. Tang, and R. Lazear, 2019: The Mohawk–Hudson dryline: The effects of a terrain-influenced boundary on three severe weather events. Oral presentation at the *44th Northeastern Storm Conference*, 10 March, Saratoga Springs, NY.

LeBel, L., B. Tang, and R. Lazear, 2020: Examining the variable impact of terrain on Upstate New York severe weather events. Oral presentation at the *45th Northeastern Storm Conference*, Saratoga Springs, NY.

Main, M. E., R. A. Lazear, and L. F. Bosart, 2018: Differences between high-shear/low-CAPE environments favoring tornadoes versus straight-line damaging winds in the Northeast U.S.. Oral presentation at the *43rd Northeastern Storm Conference*, 10 March, Saratoga Springs, NY.

Minder, J. R., W. M. Bartolini, R. D. Torn, and D. Keyser, 2017: Convection-permitting ensemble forecasts of the 10–12 December 2013 lake-effect snow event: Sensitivity to microphysical and surface-layer parameterizations. Oral presentation at the *18th Northeast Regional Operational Workshop,* 2 November, Albany, NY.

Minder, J. R., and W. M. Bartolini, 2018: Characterizing and constraining uncertainties in convection permitting simulations lake-effect snowfall associated with parameterization of surface fluxes. Poster presentation at the *8th GEWEX Open Science Conference*, 8 May, Canmore, Alberta, Canada.

Minder, J. R., and W. M. Bartolini, 2018: Convection-permitting simulations lake-effect snowfall response to climate change: Understanding and constraining uncertainties associated with surface and boundary layer turbulence. Oral presentation at the *GEWEX Convection-Permitting Climate Modeling Workshop II,* 5 September, National Center for Atmospheric Research, Boulder, CO.

Minder, J. R., and W. M. Bartolini, 2018: Convection-permitting simulations lake-effect snowfall response to climate change: Understanding and constraining uncertainties associated with surface and boundary layer turbulence. Oral presentation *GEWEX Convection-Permitting Climate Modeling Workshop II,* 5 September, National Center for Atmospheric Research, Boulder, CO.

Minder, J. R., W. M. Bartolini, 2018: Convection-permitting ensemble forecasts of the 10–12 December 2013 lake-effect snow event: Sensitivity to microphysical and surface-layer parameterizations. Oral presentation at the *19th Northeast Regional Operational Workshop*, 7 November, Albany, NY.

Minder, J. R., and W. M. Bartolini, 2019: Towards improved understanding and prediction of intense lake-effect snowstorms. Oral presentation at the *Atmospheric and Oceanic Sciences Department Seminar*, McGill University, 26 November, Montreal, QC, Canada.

Minder, J. R., and W. M. Bartolini, 2020: Characterizing and constraining uncertainty associated with surface and boundary layer turbulent fluxes in simulations of lake-effect snowfall. *I* Oral presentation at the *100th AMS Annual Meeting / 30th Conference on Weather Analysis and Forecasting / 26th Conference on Numerical Weather Prediction,* Boston, MA.

Rocque, M., and J. Minder, 2018: Understanding variations in WSR-88D dual-polarization radar parameters from the Ontario Winter Lake-Effect Systems Field Campaign. Poster presentation at the *43rd Northeastern Storm Conference,* 10 March, Saratoga Springs, NY.

Stuart, N. A., 2017: Utilizing partnerships between state departments of health, universities, and the National Weather Service to improve public preparation and response to extreme heat. Oral presentation at the *12th Symposium on Societal Applications: Policy Research and Applications at the 97th American Meteorological Society Annual Meeting*, 22–26 January, Seattle, WA.

Stuart, N. A., T. A. Wasula, A. Wasula, K. L. Corbosiero, A. L. Lang, and B. Tang, 2017: Lance Bosart's 20 years of contributions to operational meteorology, Part II: Impacts in the operational forecasting community and beyond. Poster presentation at the *Lance Bosart Symposium at the 97th American Meteorological Society Annual Meeting*, 22–26 January, Seattle, WA.

Tang, B., W. Flamholtz, and L. Bosart, 2019: Simulating the effects of terrain-induced perturbations on severe convection using an idealized valley. Oral presentation at the *20th Northeast Regional Operational Workshop*, Albany, NY.

Villani, J. P., 2017: Using GAZPACHO to create forecast snowfall bias/error maps stratified by flow regime. Oral presentation at the *18th Northeast Regional Operational Workshop,* 2 November, Albany, NY.

Wasula, T. A., and B. J. Frugis, 2018: Albany forecast area significant hail climatology and case studies. Poster presentation at the *29th AMS Severe Local Storms Conference*, 22 October, Stowe, VT.

Wasula, T. A., B. J. Frugis, and M. S. Evans, 2018: A multiscale analysis of the 18 May 2017 severe weather event across eastern New York and western New England. Poster presentation at the *29th AMS Severe Local Storms Conference*, 25 October, Stowe, VT.

Wasula, T. A., and B. J. Frugis, 2018: Albany forecast area significant hail climatology and case studies. Oral presentation at the *19th Northeast Regional Operational Workshop,* 8 November Albany, NY.

Wasula, T. A., 2019: The 4 August 2018 severe weather event across east-central New York. Oral presentation at the *44th Northeastern Storm Conference*, 11 March, Saratoga Springs, NY.

Wasula, T. A., and B. J. Frugis, 2017: A multiscale analysis of the 1 July 2016 null tornado watch across eastern New York and western New England. Oral presentation at the 42nd Northeastern Storm Conference, 12 March, Saratoga Springs, NY.

Wasula, T. A., B. J. Frugis, and M. S. Evans, 2019: The Multi-Hazard Severe Weather Event of 21 August 2019 across eastern New York and western New England. Oral presentation at the *20th Northeast Regional Operational Workshop*, Albany, NY.

Wasula, T. A., 2020: The 4 August 2018 severe Weather Event across east central New York. Oral presentation for the *New York State Mesonet Forum*, Albany, NY.

Wasula, T. A., and M. S. Evans, 2020: Application of recent northeast cool-season CSTAR conceptual models to three March 2018 snowstorms impacting eastern New York and western New England. Oral presentation at the *100th AMS Annual Meeting / 30th Conference on Weather Analysis and Forecasting / 26th Conference on Numerical Weather Prediction,* Boston, MA.

Wasula, T. A., B. J. Frugis and M. S. Evans, 2020: The multi-Hazard severe weather event of 21 August 2019 across eastern New York and western New England. *45th Northeastern Storm Conference*, Saratoga Springs, NY.

**c) Refereed publications**

Minder, J. R., W. M. Bartolini, C. Spence, N. R. Hedstrom, P. D. Blanken, and J. D. Lenters, 2020: Characterizing and constraining uncertainty in simulations of lake-effect snowfall associated with surface and boundary layer turbulence. *Wea. Forecasting*, **35**, 467–488.

Villani, J. P., M. Jurewicz, and K. Reinhold, 2017: Forecasting the inland extent of lake effect snow bands downwind of Lake Ontario. *J. Operational Meteor.*, **5**, 53–70.

## 3. RESEARCH TO OPERATIONS

Significant progress was made on the Albany CSTAR Virtual Lab (VLab) community page, a publicly viewable repository for past and current CSTAR research projects. The page contains a list of ongoing projects, recent CSTAR reports, M.S. theses, CSTAR project-related web tools, operational training modules, and quick references—concise reports of student-led CSTAR projects which contain only the portions of the results that are most operationally relevant. These quick references are easily viewed by operational forecasters through the use of keywords within the AWIPS Interactive Reference (AIR) tool. Finally, the VLab community page also hosts past proceedings from the Northeast Regional Operational Workshop, held annually in Albany each fall.

In addition to adding quick references from CSTAR V, the following projects were completed and operationally relevant results were made into quick references, as outlined below:

- Massey Bartolini created a table highlighting key differences in lake-effect snow band intensity, position, and graupel content when adjusting microphysics and boundary layer parameterization schemes for a lake-effect snow case from the Ontario Winter Lake-effect Systems (OWLeS) project. The table clearly depicts which parameterizations are used in current operational convection-allowing models.

- Tomer Burg created a phase-space diagram representing along- and across-track biases for Northeast cyclone tracks. Tomer also created a conceptual diagram showing longwave upper-tropospheric patterns conducive for large and small across-track variability, as well as biases expected for various teleconnection patterns.

Two web-based tools were made, and are viewable on the VLab community page:

- Massey Bartolini's lake-effect forecasting webpage (operational only in-season): *http://www.atmos.albany.edu/student/mbartolini/les.php*
- Tomer Burg's GEFS reforecast cyclone tracking page: *http://www.atmos.albany.edu/student/tburg/research/cases.php*

Finally, the legacy CSTAR website now directs all web traffic to the VLab community page, and the page is being monitored through Google Analytics in order to more easily track traffic to each page, both via the web and through the AIR.

**4. NWS PERSPECTIVE ON CSTAR VI** *(Michael Evans, SOO WFO ALY)*

The National Weather Service continues to benefit greatly from our relationship with UAlbany including collaborations done through CSTAR research grants, including CSTAR VI. During the past several years, the National Weather Service has been transitioning its operations towards an increased emphasis on decision support services for our partners within the emergency management community. This emphasis requires that NWS meteorologists focus less on the manual production of gridded forecasts of routine weather, and more on the application of the latest science to forecasts and warnings of high-impact weather events. The collaboration between NWS Albany and UAlbany has positioned our office to excel in this area by helping us to maintain a culture that emphasizes the benefits of applying science to our forecasts and warnings. In particular, the emphasis on high-impact weather events in CSTAR VI was the key to ensuring the operational relevance of this project to the NWS.

Benefits realized by the NWS Forecast office in Albany include the opportunities for professional growth provided by direct interactions with students and faculty during the execution of the projects. In addition, research associated with CSTAR VI consistently provides much of the material for presentations at our annual Northeast Regional Operational Workshop (NROW), which in turn provides excellent opportunities for professional growth for both presenters and attendees. Along with benefits realized by the forecast office in Albany, activities associated with CSTAR VI have provided opportunities for professional enhancement across the entire National Weather Service, and especially at offices over the northeast U.S. Findings from CSTAR VI have been placed on the National Weather Service's Virtual Laboratory so that they can be accessed by all offices within the NWS. Collaborative research projects motivated by research associated with CSTAR VI were undertaken by staff from several northeastern NWS offices including at Albany, and meteorologists from many northeastern forecast offices have attended and presented at NROW.

Research has been completed on the three Major Foci projects of CSTAR VI, and work to transition this research to operations is ongoing. As was stated above, the emphasis on high-impact weather was critical to ensuring the operational relevance of this work to the NWS. The first major project with Tomer Burg was titled "Applying forecast track and intensity diagnostics to major northeast winter storms". NWS focal points for this project were Neil Stuart from NWS Albany,

Joe Dellicarpini from NWS Taunton, and Justin Arnott from NWS Gray. The goal of this research was to compare observed low pressure tracks to GEFS forecast tracks for a large number of storms, in an effort to identify patterns that may help forecasters to better utilize the ensemble data to determine the most likely storm tracks within ensemble track envelopes. Tomer developed a diagnostic tool that will aid forecasters with this effort. The tool is available to forecasters on the VLab page and our local google sites page. The three focal points are working with Mike Evans to modify Tomer's Master's thesis PowerPoint presentation into a presentation that could be presented to operational staff prior to the beginning of the winter of 2020–2021. A webinar will be presented to operational staff in late fall, 2020.

Findings from Tomer's work are highly relevant to operational forecasters. There is a belief among forecasters that the operational forecast models have a "right-of-track" bias for eastern CONUS cyclones. The results from Tomer's work indicate that that no such bias exists when a comprehensive collection of eastern CONUS surface cyclones is examined; however, there may be synoptic patterns that are favorable for a right of track bias. In particular, Tomer has demonstrated that amplified midlevel flow patterns with strong western CONUS ridges may be favorable for a right of track bias. Tomer has also demonstrated that the GEFS is under-dispersive with tracks of cyclones regarding both positioning and timing. Note that a major effort to increase the dispersion of the GEFS has been accomplished with the latest version of the GEFS, which will become operational later this year. The NWS focal points for this project are examining the results from Tomer's project, and are working to organize it in a format that will be easy for forecasters to interpret. Once this is done, his findings should result in improved forecasts for East Coast winter storms.

The second major project completed by Massey Bartolini was titled "Predictability and variability of lake effect snow events". This study was under the guidance of PIs Dr. Justin Minder, Dr. Daniel Keyser, and Dr. Ryan Torn. NWS focal points were David Zaff (BUF) and Joe Villani (ALY). Massey looked at how well high-resolution models simulate severe lake-effect storms. In particular investigated model physics sensitivity, multi-scale predictability, and ultimately model performance. He has used observational datasets gathered during OWLeS.

As part of the project, Joe Villani and Mike Evans have been working on conducting a local study comparing high-resolution model output (from the NAMNest and HRRR) to detailed observations of terrain-induced snowfall, including lake effect snow bands. This is an extension of Joe's prior lake effect snow research mentioned in the Future Work section of the NWA JOM paper, *https://member.nwas.org/sites/default/files/nwa_pubs/2017-JOM5.pdf*.

Findings from Massey's work are useful for operational meteorologists forecasting lake effect snow over the eastern Great Lakes. Massey's work shows that large differences in intensity and timing of lake effect snow can occur in high resolution forecast models when changes are made to microphysics schemes. Importantly, there has been a long-held belief by forecasters that operational models have a southward bias in their forecasts of lake effect snow. It appears that, in the case that Massey studied, this bias was not evident. This is an indication that high-resolution modelling may finally be overcoming this southward bias. This would be a major advancement for operational forecasters, as forecasting the southward extent of lake effect snow has been a consistently difficult challenge for decades.

The third major project was from William Flamholtz, which advanced Pamela's Eck's CSTAR V research, on "The effects of mesoscale inhomogeneities on severe convection in complex terrain". The PI on the project was Dr. Brian Tang, with NWS focal points Tom Wasula,

Michael Evans, and Matt Kramer. Kat Hawley from NESDIS also worked with William on the project and supplied some satellite imagery to William for a case that he worked on.

This study appears to set the foundation for work that will ultimately be useful for operations and additional work in this area is ongoing in CSTAR VII. The work that William has done has been mostly theoretical. For maximum use in operations, that work now should be transitioned to develop conceptual models that operational forecasters can apply to help anticipate where and when convection may intensify or change its structure, which could be most useful during the gap between issuance of watches, and issuance of warnings, allowing forecasters to highlight areas where intensification is likely, prior to the actual occurrence of severe weather. For example, highlighting environments that would be favorable for intensification of convection as it moves off of higher terrain and down into heavily populated valleys. There seem to be some days when convection intensifies as it moves off of higher terrain down to the Hudson Valley, while on other days this fails to occur. Brennan Stutsrim's initial work in CSTAR VII appears to be a good step in that direction, as he has been analyzing and modelling an event that intensified and became more linear as it moved into the Hudson Valley from the west. A conceptual model including maps highlighting favored areas would be very helpful for forecasters.

Research has been completed, or is ongoing, on several collaborative projects related to the work completed in CSTAR VI. Benefits of these projects have been or will be realized by the several NWS offices participating in the research. A few highlights from these collaborative projects are below:

- A collaborative project was completed on polygon-based lake effect snow warnings, led by staff from the forecast office in Buffalo. This project resulted in implementation of lake effect snow warnings at several offices in the eastern and central Great Lakes region. Findings from this project will be utilized to expand polygon-based methodologies to other winter weather warnings.
- Heat waves and extreme heat events in the northeast U.S., led by staff at the forecast office in Albany. Findings from this study have led to changes in criteria for heat advisories in the Northeast U.S.
- Development of improved WSR-88D warning criteria using dual pol data sets, led by staff at the forecast office in Albany. Techniques have been developed utilizing a variety of data types to improve forecasts of severe wind gusts and large hail.
- Expanding decision support services, led by staff at the forecast office in Albany. Findings from this research were included in a course provided to all NWS meteorologists on decision support services as part of the effort to improve our support services.