A 2011 Comparison of Models, Soundings, and Radar at Valparaiso University

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ABSTRACT

This paper focuses on a comparative analysis of models, soundings, and radar data in order to potentially quantify a better method of forecasting lake effect events over southern Lake Michigan. Selected cases throughout 2011 were analyzed in order to determine a correlation between numerical weather prediction and local nowcasting forecast tools. Forecast soundings from the Rapid Update Cycle (RUC) as well as the local Valparaiso University Weather Research and Forecasting Model (VU-WRF) are compared with actual soundings from radiosonde launches at Valparaiso University in Valparaiso, Indiana. Three-hour Storm Total Precipitation (STP) data from the Valparaiso University Dual-Polarization radar is also compared with the VU-WRF quantitative precipitation forecasts (QPF). An analysis of radar imagery as well as simulated radar reflectivity from the VU-WRF is also explored. Analysis and comparisons of the aforementioned data show that there is a strong correlation between local Valparaiso University nowcasting tools and local and regional model forecast output. However, errors in rainfall estimation, primarily a result of the atmospheric thermodynamic profile, are evident as well.

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1. Introduction

Since the advent of a meteorology major at Valparaiso University in 1991, hundreds of undergraduate students have utilized meteorological tools and methods to forecast and predict various synoptic and mesoscale events that impact the Valparaiso, Indiana metropolitan area. As the years have progressed since the establishment of a meteorology major at Valparaiso University, the Department of Geography and Meteorology has acquired a plethora of cutting edge technology. This technology has enabled undergraduate meteorology students to effectively utilize meteorological tools and analysis techniques to forecast the atmosphere.

Within the last decade, a series of grants and generous donations from past Valparaiso University alumni have helped establish the university's undergraduate meteorology program

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as one of the premier programs in the field of atmospheric science. With the installation of a 5 cm dual-polarization radar in the fall of 2006, Valparaiso University became one of but a handful of institutions to have access to radar capabilities. The use of the Valparaiso University Dual-Polarization radar (VU-Dual Pol) as a research tool along with radiosonde launches performed in conjunction with the Massachusetts Institute of Technology's Lincoln Laboratories has resulted in the creation and development of algorithms that are designed to increase the effectiveness of winter weather products for the Federal Aviation Administration. The implementation of a local numerical weather prediction model, the Valparaiso University Weather Researching and Forecasting Model (VU-WRF), has also helped to expand meteorological research at Valparaiso University.

By comparing various numerical weather prediction and nowcasting tools, the goal of this paper will be to determine if there is a beneficial correlation between these meteorological tools in the forecasting and research of synoptic and mesoscale events at Valparaiso University. The remainder of this paper is organized in the following manner: Section 2 outlines the motivation behind our research. Section 3 examines the data used during the research process. Sections 4 and 5 explore the results of our research. 1-2 February 2011 focuses on the "Groundhog Day Blizzard," with emphasis placed on the synoptic features of the system. 8 February 2011 focuses on multiple mesolows that developed over Lake Michigan during the late morning hours, dumping nearly half a foot of snow over portions of northwest Indiana. 18 February 2011 will be used as a "control case," in which dry and calm conditions prevailed. Finally, Section 6 provides overarching conclusions regarding the findings of this research.

2. Motivation

Motivation for this research primarily stems from the mesoscale interactions between Lake Michigan and the various topographical features of northwest Indiana. Of these mesoscale interactions, lake-effect snow is perhaps the most crippling to the infrastructure of the Valparaiso metropolitan area.

By comparing local nowcasting tools and model data with regional models, this research hopes to find a correlation that either verifies or nullifies current forecasting techniques being undertaken by undergraduate meteorology students at Valparaiso University. While not targeting the forecasting process itself, this research hopes to shed new light on the effectiveness of the meteorological tools and technology used by Valparaiso University to forecast and research various synoptic and mesoscale events.

3. Data

An array of informational tools is available to the students of Valparaiso University. The Department of Geography and Meteorology runs its own Weather Research and Forecasting Model, known as the VU-WRF. Updating every six hours, the VU-WRF allows for students and faculty to isolate

specific variables of the atmosphere to study, interpret, and research.

For *in situ* data, Valparaiso University also owns and operates a 5 cm, Dual-Polarization Doppler radar. Using radar manipulation software known as Edge, students can employ various algorithms to further analyze the state of atmosphere. Employing these tools, we were able to compare the VU-WRF simulated reflectivity with actual corrected base reflectivity produced by the VU-Dual Pol.

The discovery of the Gauge algorithm in Edge also lead to the evaluation of the Rapid Update Cycle's (RUC) quantitative precipitation forecast (QPF). By isolating a three-hour time frame in the radar data, the Gauge algorithm produces a Storm Total Precipitation (STP) for the VU-Dual Pol range in those three hours. *In situ* data was also available via radiosonde launches, performed by various undergraduate meteorology students and professors. Using the software package RAOB, accurate soundings of these radiosonde launches were available for analysis with RUC forecast soundings.

4. Cases

4.1 1-2 February 2011

The "Groundhog Day Blizzard" of 1-2 February 2011 impacted a large area of the United States, affecting enough people to validate the need for a scientific study. The snowstorm affected over 100 million people across an area stretching from the Rockies to the New England states creating widespread power outages and forcing traffic to a standstill for nearly three days. Many were also stranded in their homes for days having to dig out of one to two feet of snow.

Perhaps the most impacted by the "Groundhog Day Blizzard" was the Chicago, Illinois metropolitan area. Blizzard conditions here including heavy snowfall, near-zero visibilities and fierce winds stranded motorists for several hours during the peak intensity of the system. In terms of snowfall, Chicago received the third-highest snowfall total in recorded history for a single storm with 20.2 inches.

The peak intensity of this powerful synoptic system for the Valparaiso metropolitan area occurred between 0000 UTC and 1200 UTC 2 February (Figure 1). Although primarily a synoptic-scale system, lake-effect snow did produce additional accumulations late into the overnight hours of 3 February. Our research and accompanying analysis will focus primarily on the 0000 UTC-1200 UTC 2 February timeframe including a radiosonde launch performed at 2200 UTC 1 February.

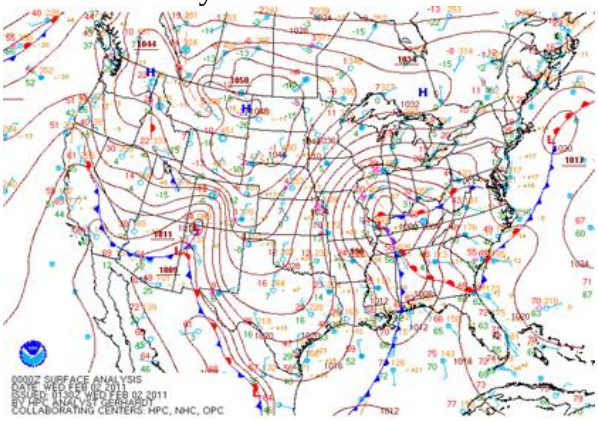

Figure 1. Hydrometeorological Prediction Center (HPC) surface analysis from 00 UTC 2 Feb. 2011.

4.2 8 February 2011

During the late morning hours of 8 February 2011, synoptic-scale northerly flow over Lake Michigan enabled a lake-effect band to set up virtually north of the Valparaiso metropolitan area. Strong low-level lapse rates, including superadiabatic lapse rates near the immediate lake surface, coupled with an inversion height of around 700 hPa, produced a thermodynamic profile conducive for moderate to heavy lake-effect snow.

By 1500 UTC, the lake-effect band had propagated southward to lower Lake Michigan, where the low-level wind profile produced a more favorable convergent pattern. More notable though was the development of an upper-level impulse that moved across Lake Michigan in response to a thermal 850 hPa trough-ridge pattern resembling a Rex Block (Figure 2). We hypothesize that this low-level thermal field which instigated the upper-level impulse was caused by diabatic processes in and around the lake-effect band.

The upper-level impulse altered the low-level wind profile in such a way that produced backing near the inversion level, a profile favorable for mesolow development. Between 1500 UTC and 1700 UTC, multiple mesolows intensified the lake-effect band causing near half a foot of snow to fall in portions of northwest Indiana.

A radiosonde launch was conducted at 1700 UTC just as the last mesolow passed overhead Valparaiso University. Therefore, our research will focus on the 1500 UTC-1800 UTC timeframe, when the bulk of the snowfall and multiple mesolows impacted the Valparaiso metropolitan area.

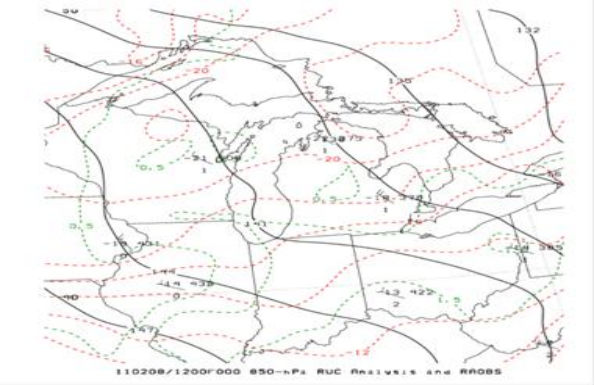

Figure 2. RUC 850 hPa GEMPAK analysis.

4.3 18 February 2011

18 February 2011 was used as a "control case" with the previous two cases. The purpose of this "control case" was to identify sources of error with the two cases in which precipitation occurred against a case in which there was no precipitation. The "control case" was also implemented to determine if there would be any noticeable differences in boundary layer representation between actual and model soundings.

With surface high pressure and upper-level ridging aloft under northwest flow, dry and fair conditions were in place over much of the lower Midwest. These conditions made 18 February 2011 an ideal choice for a control case.

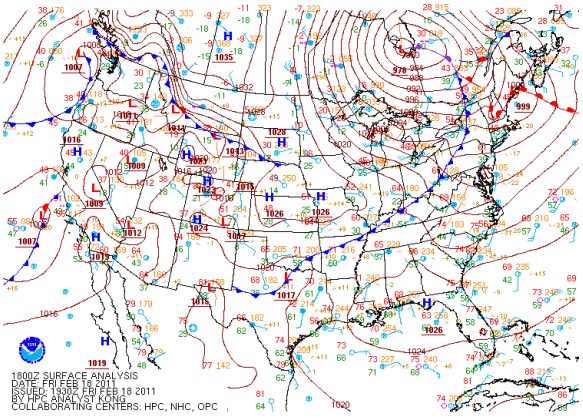

Figure 3. 18 February 2011 1800Z surface analysis.

5. Results

5.1 1-2 February 2011

Analysis of the data from the "Groundhog Day Blizzard" centered on a radiosonde launch conducted at 2200 UTC 1 February 2011. This launch was performed as part of a request by the Massachusetts Institute of Technology's Lincoln Laboratories research of aviation icing. The goal of a 2200 UTC launch was to intercept the onset of the synoptic precipitation.

The actual sounding revealed a strong near-surface inversion with rather impressive mid-level lapse rates for early February above it. Also of note was the presence of strong low-level warm air advection, conducive to rising motion through quasi-geostrophic theory.

The RUC 2100 UTC 1 February 2011 initialization run showed a nearly identical thermodynamic profile, with a strong inversion coupled with strong lapse rates above it (Figure 4). The wind profile also resembled the actual sounding, once again showing strong low-level warm air advection. Of interesting note though was the height of the inversion layer in the model

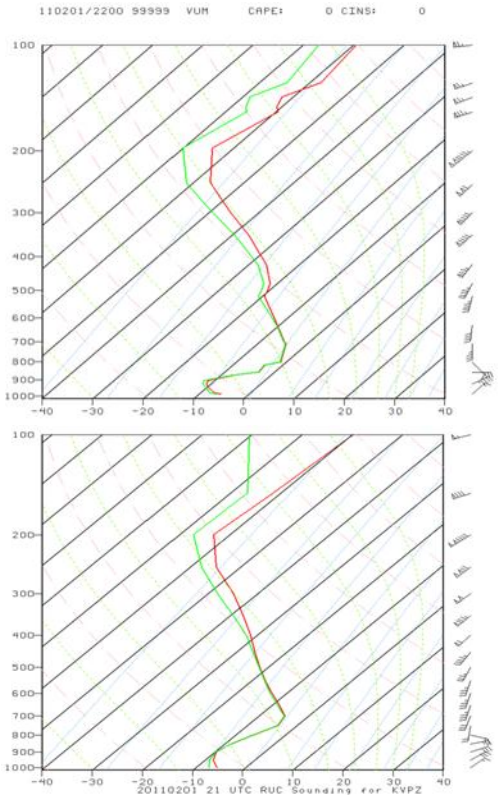

Figure 4. Valparaiso University 2200 UTC 1 Feb. 2011 sounding (top) and RUC 2100 UTC 1 Feb. 2011 sounding (bottom).

sounding being higher than the actual sounding. We hypothesize these inversion height indifferences are a result of an inaccurate representation of the boundary layer, which is often times difficult to parameterize in numerical weather prediction.

VU-Dual Pol corrected base reflectivity from 2200 UTC depicted returns of around 20 dBZ near the Valparaiso metropolitan area. However, about 75 miles south was an area of significantly higher returns ranging from 30-40 dBZ. Compared to the VU-WRF simulated reflectivity from the 1800 UTC 1 February 2011 run valid at 2100 UTC 1 February 2011, model reflectivity was significantly lower over this same region. While the

VU-Dual Pol and VU-WRF reflectivities verified over the Valparaiso metropolitan area, just 75 miles south produced different results. We hypothesize that this error is attributable to bright banding that was occurring during this time, as both the actual and model soundings indicated 850 hPa temperatures near 0°C. Temperatures near 0°C are favorable for the partial melting of ice crystals that often lead to radar bright banding.

Although bright banding was occurring, the VU-Dual Pol three-hour STP (2100 UTC 1 Feb. – 0000 UTC 2 Feb.) still verified with the RUC QPF forecast using the same timeframe (Figure 5). Whereas the

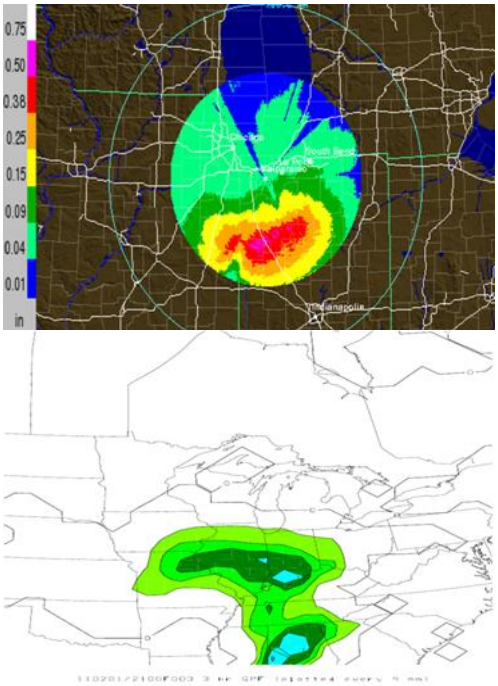

Figure 5. VU-Dual Pol three-hour STP (2100 UTC 1 Feb.- 0000 UTC 2 Feb.) (top) and RUC QPF at same timeframe (bottom).

VU-Dual Pol estimated a range of 0.15-0.60 inches, the RUC QPF forecasted a comparable 4-8 millimeters, or roughly 0.25-0.50 inches. Further analysis of the thermodynamic environment during this time may shed light in future research as to the relationships associated with the actual reflectivity and rainfall estimates compared to the model reflectivity and rainfall estimates.

5.2 8 February 2011

While the "Groundhog Day Blizzard" of 1-2 February 2011 should have been easier to verify actual data with model data due to the fact that the system was primarily synoptic in nature, 8 February 2011 presented an opportunity to test whether models could accurately forecast a mesoscale event. On this day, multiple mesolows over Lake Michigan developed in conjunction with a lake-effect snow band that progressed southward through the late morning hours and reached the Valparaiso metropolitan area around 1700 UTC.

Once again, a radiosonde launch was conducted at Valparaiso University producing a "classic mesolow" sounding indicative of backing low-level winds with height and steep low-level lapse rates underneath an elevated inversion layer. The 1500 UTC RUC initialization run model sounding depicted nearly identical conditions in both the wind and thermodynamic profiles. The only major difference was in the boundary layer, where parameterization schemes produced a coarser instability profile.

Perhaps the most revealing of data was the comparison of the VU-Dual Pol corrected base reflectivity and simulated model reflectivity (Figure 6). Both reflectivities

captured a primary lake-effect band with a notch at the southern edge of the band where the southernmost mesolow was located. Also, both reflectivities were able to capture a secondary band that formed to the southeast as a result of convergence produced by the mesolow.

The rainfall estimates, however, did not verify as well as the actual and model reflectivities. The VU-Dual Pol three-hour STP (1200 UTC-1500 UTC 8 Feb.) depicted rates of 0.04-0.15 inches over lower Lake Michigan in conjunction with the primary lake-effect band, while also producing the same estimates

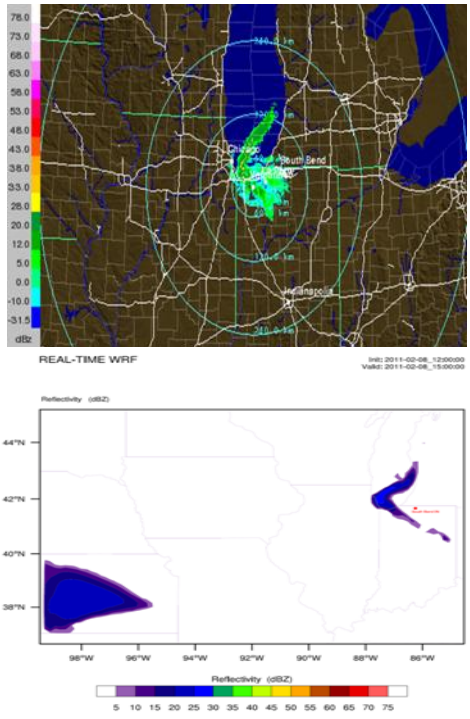

Figure 6. VU-Dual Pol corrected base reflectivity valid at 1500 UTC 8 Feb. (top) and VU-WRF simulated model reflectivity at same timeframe (bottom).

for the secondary band. The 1200 RUC initialization run forecast valid at 1500 UTC picked up nearly identical QPF for the secondary band; however missing the primary band, where stronger returns were visible on the VU-Dual Pol. These differences in rainfall estimation are hypothesized to be attributed to mesoscale effects that could not be resolved by the RUC model resolution.

5.3 18 February 2011

The comparison of the VU-WRF simulated corrected base reflectivity with the VU-Dual Pol radar proved to be very conclusive. The 1800 UTC VU-Dual Pol image plots minor ground clutter and anomalous propagation around the Valparaiso metropolitan area. Though this minor error in the radar existed, the VU-WRF 1200 UTC initialization run forecast valid at 1800 UTC accurately predicted the clear and dry day, verifying the model run.

Due to the presence of ground clutter, the 1800 UTC three-hour STP also plotted minor returns surrounding Valparaiso; however, this effect can be ignored when compared to the larger synoptic-scale setup.

A look at actual versus model soundings showed little variability verifying the atmospheric conditions. The only notable difference in soundings involves the resolution of the RUC model in portraying the subtle changes in the thermodynamic profile.

5.4 Potential Errors

Multiple sources of error arose within this research. The most consequential of these miscalculations included various types of radar data acquisition errors. Especially prominent in the 1-2 February 2011 case, bright banding

occurred in the midst of the snowstorm. These higher reflectivities led to higher than expected VU-Dual-Pol three-hour STP estimates for the blizzard. This error may have also been attributable to incorrect Z-R relationships. Research has been conducted over the last couple of decades to determine an appropriate Z-R relationship for liquid precipitation (i.e. rain) versus frozen precipitation (i.e. snow) (Fujiyoshi et al. 1990). Determination of appropriate Z-R relationships used in the VU-Dual Pol precipitation algorithms will be explored in future research.

An additional source of precipitation error occurred due to ground clutter and anomalous propagation. Most notable in the "control case," ground clutter led to higher VU-Dual Pol three-hour STP than expected due to the initial erroneous returns.

These errors in STP by the VU-Dual Pol radar may be an effect of the algorithms themselves. Further research and data collection is needed to determine this hypothesis.

6. Conclusions

By performing analyses on three case studies involving comparisons of radar and model reflectivity, rainfall estimation, and soundings, we have found the following conclusions:

1) Actual and model soundings verified in terms of both the thermodynamic and wind profiles, though model soundings produced coarser representations of the boundary layer.
2) Actual and model reflectivities verified both on the synoptic-scales and mesoscales, reaffirming the accuracy of the VU-Dual Pol and VU-WRF as reliable and advanced meteorological tools.
3) The Gauge function used within the Edge software needs further exploration into its effectiveness as a STP substitute.

Our findings suggest that the meteorological forecasting tools and technology incorporated by the Department of Geography and Meteorology verify with *in situ* weather data and observations, as well as with larger, regional models.

Acknowledgements

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