FINAL REPORT SUBAWD001611

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Project Title: "Development of operational products from the New York State Mesonet to aid forecasts of high-impact weather events by National Weather Service Forecast Offices"
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Section 1: Summary of Project Objectives

The overall goal of this project was to create potential new uses for NYS Mesonet data for New York (or adjacent) NWS offices for high impact events. The NYS Mesonet is a recently installed state-of-the-art observing system in NY consisting of 126 standard stations measuring a variety of atmospheric and soil variables. To accomplish this goal, forecasters at these offices selected three sub-topics for which it was thought NYS Mesonet data may prove useful:

a) **Flash Flooding**: The NYS Mesonet measures soil moisture at three levels. Unlike air temperatures, values cannot easily be related across sites due to differences in moisture capacity from differing soil types. This portion of the project sought to better relate flood products to these soil moisture variables.
b) **Freezing Rain**: NYS Mesonet sites also measure soil temperature, and several sites also estimate skin temperature via outgoing longwave radiation. This sub-project aimed to use this data (and other data) to create possible benchmarks for freezing rain.
c) **Severe Convection**: While temperature, humidity, and wind speeds and direction were already widely used NYS Mesonet observations, this portion of the project sought to relate equivalent potential temperature (theta-e), the gradient of theta-e, 3 hour pressure changes, and other severe weather parameters to severe storm reports.

Although these three projects had little in common, the idea was to increase the potential to create useable results and products, and to also create the seeds of more in-depth future work while getting students involved in the research process. Each subproject would have a dedicated undergraduate working on only that project, and thus there would be three total student researchers working on this overall project. Upon completion, each subproject would inspire the creation of real-time products available for NWS forecasters to use during these events to increase situational awareness and/or forecast skill.

Section 2: Project Accomplishments and Findings

Project outcomes and products are broken down by subproject, and each subproject inspired the creation of a dedicated webpage for that project:

a) **Flash Flooding (student: Andrew Lunavictoria):** NYS Mesonet sites observe volumetric soil moisture at three levels across all 126 sites in NY, but unlike conventional variables like temperature or precipitation that are easily comparable across sites, soil moisture varies strongly by soil type, and thus raw data is not easily comparable (real-time example here). Therefore, in order to properly relate soil moisture to precipitation and flash flood products, we first transformed all soil moisture data into percentile-space, considering each site and each level individually, which then allowed for easier comparisons across sites (since now all values vary relatively uniformly between 0-100).

Andrew then identified every flash flood warning issued for NY during 2018 and 2019 and subjectively identified the event on radar as a "Thunderstorm" or "Widespread rain" type of event to aid in analysis, and then assigned the most relevant NYS Mesonet site(s) to that each flash flood warning. Once this was done, Andrew was able to easily relate changes in soil moisture levels to precipitation during flash flood events. A variety of relationships were examined, such as time to peak soil moisture vs. precipitation, total soil moisture change, starting soil moisture values, and many more. General conclusions are that thunderstorm events reach peak soil moisture values faster due to more intense rainfall rates, and these events also require less precipitation on average to reach maximum soil moisture values (1" vs. 1.7" respectively). Further analysis was conducted on soil type, though it was determined more data was needed to better classify these. Finally, it was shown that either total column moisture or 5 cm soil moisture was a better metric to use than either 25 or 50 cm soil moisture.

The primary outcome of this sub-project was the creation of a dedicated hydrology page[1], viewable here. This site provides a variety of NY-area maps relating radar estimated precipitation (or flash flood guidance) for various time ranges to actual NYS Mesonet observations of rainfall on the left, with a site-by-site soil moisture breakdown on the right, with sites chosen by selecting the appropriate dot on the map at left. These soil moisture analyses denote soil moisture in the percentile-space described above for easy comparison. Where either 5 cm or total column soil moisture exceed the 99th percentile, that time range is highlighted.

b) **Freezing Rain (student: Alex Kellman):** The NYS Mesonet does not directly observe freezing rain nor surface (skin) temperature, so a primary goal of this subproject was to examine ways to use other NYS Mesonet data to better evaluate or predict freezing rain events. NWS provided us a list of all freezing rain products in NY over a 2 year period, and also provided a list of all METAR observations from NY-based ASOS observations that observed freezing rain during this same time. For every site and every event, Alex determined the event onset and nearest NYS Mesonet site(s), as well as the difference in elevation and distance between sites. Based in part on input from NWS forecasters, we examined seven initial variables: 24 hour average irradiance, 24 hour average 2 m temperature, 24 hour average 5 cm soil temperature, latest 2 m temperature, latest 2 m wet-bulb temperature, latest 5 cm soil temperature, and latest irradiance. Alex determined each of these values for all freezing rain events at the appropriate NYS Mesonet site.

After some amount of analysis, it was determined that soil temperature varies on a lengthy timescale, so 24 hour average soil moisture was determined redundant with the latest soil temperature, and thus removed from evaluation. In its place we substituted an skin temperature estimate created prior to this project, derived largely from upwelling longwave radiation from 18 NYS Mesonet flux sites and extrapolated to all sites. For all

[1] https://operations.nysmesonet.org/~nbassill/comet/FLOOD/

variables, Alex determined an observed range for all variables. Some key findings include: Two-thirds of all 24 hour average 2 m temperatures and average irradiance were below 32F and 52W/m^2, respectively. Two-thirds of all latest wet-bulb values, irradiance, and estimated surface temperatures were 31F, 24 W/m^2, and 33F respectively. Several outliers are likely due to subtle but important differences in station conditions (such as elevation or frontal passages) between the ASOS and NYS Mesonet sites.

The primary products[2] derived from this project were a series of spatial maps that relate the current equivalent NYS Mesonet site value for the above parameters to the historical event values created by Alex, so that an NWS forecaster can easily see if current conditions are within a recent historical climatology. All parameters' are shown by the percent of historical cases that had a value **below** the current value, shown here. In this way, if a variable has a value of 100 or 0, that indicates the current value is outside of the historical climatology of freezing rain events for that site, suggesting freezing rain is unlikely. A summary map of how many variables are outside climatology was also created, viewable here. Finally, the raw 24 hour averages values, latest values, and latest surface temperature estimate were all mapped here, here, and here, respectively.

c) **Severe Convection (Student: Megan Schiede):** This project's goal was to relate surface weather parameters such as theta-e and pressure changes to severe storm reports from severe convection. NWS provided a list of severe weather cases over three years, for which Megan noted the total storm reports (wind, hail, or tornado) for each case, and broken up according to the region of New York which was subjectively created by Megan. These regions would then be used to determine values from a list of potential severe weather parameters such as the theta-e gradient, lifted condensation level, and pressure trend derived from NYS Mesonet observations. The rationale behind regions rather than sites was to identify the most extreme (or average, depending on the variable) value in the general area where thunderstorms were observed, to limit the chance a specific station was closest to a thunderstorm, yet missed the event by avoiding thunderstorm impacts.

Once all of this data was gathered, Megan analyzed the averages and standard deviations of these parameters, and also correlated them with total storm reports for that event. Megan also created a number of scatter plots relating total storm reports to values of these variables to evaluate potential relationships. One significant issue encountered during this sub-project was the extreme variability and non-linearity of severe weather reports, which hampered clean results despite the best of intentions. To attempt to ameliorate these effects, we segregated results according to season (summertime vs. shoulder season) as well as report totals (breaking up events by terciles of event totals). Although this did not necessarily simplify results, it did help to demonstrate relationships that were robust across season and event magnitude.

One primary result was that the strength of the theta-e gradient was strongly correlated with total storm reports. A secondary, and somewhat surprising, result was that the minimum value of lifted condensation value was strongly negatively correlated with total storm reports in shoulder seasons but not summertime. We hypothesize that shoulder seasons are more likely to feature evaporative cooling driven wind events. Finally, three hour pressure change was difficult to interpret, primarily because strong

[2] https://operations.nysmesonet.org/~nbassill/comet/ICING/

pressure rises may signal cold pools and strong winds, while strong pressure falls may signal environments promoting rising air and the initiation of thunderstorms, which made correlations difficult. Based on NWS input, a future project could instead relate the difference between peak pressure fall and peak pressure rise. In an effort to relate the above surface parameters and event totals to a measure of instability, Megan used the same process to denote values of most unstable CAPE (MUCAPE). Somewhat counterintuitively, MUCAPE was not found to have a strong relationship to storm report totals. We hypothesize this relationship was complicated by several very dynamically driven shoulder season events with high report totals and low MUCAPE values and also by several isolated summertime events with low totals but high MUCAPE.

The primary outcome of this project was a dedicated website compiling the severe weather parameters on a single webpage[3] (except for MUCAPE, which is not calculable by NYS Mesonet observations). A new theta-e gradient map and animation were created as a result of this work, viewable here. Existing lifted condensation level and three hour pressure change maps were slightly improved and added to the site, viewable here and here respectively.

For all subprojects, it was agreed that more years of data would improve the robustness of results. Final detailed presentations to NWS for all subprojects can be seen by going to the page denoted in the footnote for each subproject, and scrolling to the bottom.

Section 3: Benefits and Lessons Learned: Operational Partner Perspective

[note: this section was compiled by NWS from a variety of NWS points of contact on the three projects]

The equivalent potential temperature gradient product has only been available since late April, with two severe weather events in our forecast area since the introduction of the product. During a severe weather event on 21 April 2021, there were consistent signals in the equivalent potential temperature gradient, which supported the hypothesis that localized gradients exceeding 60 Kelvin/100 km signaled thermal moisture boundaries that can support severe thunderstorms. Another example with the usage of the product was a strong gust front that moved through the Capital Region and KALB, where a 44 knot gust occurred on 26 May 2021. A Special Weather Statement was issued with winds gusts around 45 knots, as the peak equivalent potential temperature gradient with wind vectors overlaid was 83K/100 km over eastern Albany into western Rensselaer Counties in eastern NY. This product will be evaluated further during the 2021 severe weather season. Coordinating with the students was very limited due to COVID. However, communication by E-mail and Zoom meetings occurred periodically through the study.

Regarding the freezing rain study, we found that using the NYS Mesonet observations from sites that had a wet-bulb temperature at or below 34F as input for the FRAM model produced flat ice amounts that were very similar to the ASOS flat ice accretion amounts. The output results are plotted in a map of New York and proved very useful from a verification standpoint. In fact, this type of map wThe equivalent potential temperature gradient product has only been available since late April, with two severe weather events in our forecast area since the introduction of the product. During a severe weather event on 21 April 2021, there were consistent signals in the equivalent potential temperature gradient, which supported the

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hypothesis that localized gradients exceeding 60 Kelvin/100 km signaled thermal moisture boundaries that can support severe thunderstorms. Another example with the usage of the product was a strong gust front that moved through the Capital Region and KALB, where a 44 knot gust occurred on 26 May 2021. An Special Weather Statement was issued with winds gusts around 45 knots, as the peak equivalent potential temperature gradient with wind vectors overlaid was 83K/100 km over eastern Albany into western Rensselaer Counties in eastern NY. This product will be evaluated further during the 2021 severe weather season.

Coordinating with the students was very limited due to COVID. However, communication byas produced for the February 15 - 17, 2021 freezing rain and the ASOS flat ice amounts ended up being very close to the FRAM model output. Given the challenges involved for NWS forecasters to receive reliable ice accretion amounts during an event and when verifying winter storm and ice warnings, this product proved to be a time saver and a great way to gain situational awareness, especially across less populated areas.

As far as the flash flooding study, this research was a good foundation for future research and collaboration on how to best analyze and report the soil moisture data. The use of the website developed for the project will allow NWS forecasters to make better use of the previously difficult to decipher soil moisture data.

Section 4: Benefits and Lessons Learned: University Partner Perspective

The benefits from this project have been exceptional. Three talented undergraduates gained useful skills and hands-on research experience. The projects themselves lent themselves to analyzing data that may not commonly be analyzed in this level of detail (such as soil moisture), and thus it has helped myself and the NYS Mesonet better understand aspects of the network. Finally, an already-close relationship with NWS has become a bit closer. One lesson learned would be to always have contingency options (see below).

The primary problem (by far) was the impact of COVID-19. These projects were just beginning around February or March of 2020 – mere weeks before the COVID-19 pandemic began in earnest and forced classes, teaching, and research to go remote. Since a majority of this project entails poring over data, analyzing plots, and making presentations, being able to be "hands on" drastically improved the student experience. For two undergraduates who were not seniors, we decided to halt our work with the intention/hope of resuming in-person in fall 2020. The third was a senior, and for that person we continued the work remotely by Zoom or Teams over spring and summer of 2020. For the other two students, unfortunately UAlbany remained largely remote in 2020 and thus we reluctantly resumed as fully remote with them as well, again using Zoom or Teams. Student camaraderie wasn't possible given the remote environment and differing schedules. This situation was less than ideal for all parties – one-on-one interaction was made much more difficult, conversing with NWS partners about the projects was more difficult, and ultimately there were no in-person visits between any students and NWS offices. However, each subproject maintained an option email chain with the NWS partners, and also provided semi-regular (roughly monthly) updates. Final presentations were either presented live or recorded for NWS viewing at their leisure. Unfortunately, COVID-19 also impacted students' abilities to speak at professional conferences, since many were canceled or postponed. However, all three students presented their work to a larger operational or academic audience upon completion of their projects, and I will continue to encourage them to pursue these opportunities as conferences resume. I have encourage them to submit abstracts to the upcoming first NYS Mesonet Annual Symposium.

Section 5: Publications and Presentations

a) Flash Flooding:

Lunavictoria, A. 2020: Diagnosing the Relationship between Flash Flooding and NYSM Soil Moisture. Oral presentation at the 21st Northeast Regional Operational Workshop, 4 November, Albany, NY. Viewable: https://youtu.be/tv212qhDV5k?t=10841

b) Freezing Rain:

Kellman, I. 2021: Analysis Of Freezing Rain Events From 2017-2019 In New York State. Oral presentation at the New York State Mesonet Forum, 12 February, Albany NY. Viewable after minute twenty-six here.

c) Severe Convection:

Schiede, M. 2021: An Investigation of Variables Favorable For The Development Of Severe Weather Events Across New York State. Oral presentation at the New York State Mesonet Forum, 12 February, Albany NY. Viewable at minute six here.

Section 6: Summary of University/Operational Partner Interactions and Roles

At UAlbany, the PI, primary mentor, and author of most of this report was Dr. Nick Bassill. Nick helped guide each subproject, coordinated outreach to NWS, and developed products. Andrew Lunavictoria, Alex Kellman, and Megan Schiede were students assigned to work each subproject. These students conducted most of the research and created presentations to communicate that research, with guidance from Nick. Nathan Bain and Dr. June Wang of the NYS Mesonet collectively helped make data available, troubleshoot data problems, and provide feedback where able. The product webpages are hosted on a NYS Mesonet server.

Mike Evans, SOO at NWS Albany, was my counterpart at NWS and helped coordinate NWS engagement and provide project guidance where able. A lengthy list of NWS representatives from WFOs around New York contributed to this project.

Describe the responsibilities of the various project participants over the course of the entire project.