Semi-Annual Report

# Better Use of Ensembles in the Forecast Process: Scenario-Based Tools for Predictability Studies and Hazardous Weather Communication

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

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

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**1. Background**

Our project addresses CSTAR objectives to: "Improving the lead-time and accuracy of forecasts and warnings for high impact weather -- Improving the use of ensemble predictions systems in order to enable more effective forecaster assessment of uncertainty"; "Improving Impact-Based Decision Support Services"; and "Improving water resource information (precipitation) for decision support and situational awareness" Our focus area is the Eastern U.S. for high impact weather during the cool season; however, our approach can be expanded to other parts of the country and phenomena. The primary goals are: (1) To extend our newly developed fuzzy clustering approach to high impact weather events including precipitation, freezing level (2-m temperature), and 10-m wind for days 1-7 using the short-range and global ensembles; (2) Expand our new spread-anomaly ensemble tool; (3) Use these tools to verify these phenomena in the ensembles and understand the large-scale flows attached to the less predictable events; and (4) Integrate the Alan Alda Center for Communicating Science (www.aldacenter.org) into our CSTAR to help forecasters better communicate probabilistic information through a series of three workshops, some of which involving stakeholders.

**2. Scientific Objectives and Accomplishments**

During the past six months we focused on further development of the fuzzy clustering approach, worked with our partners to make our tools more operational and for testbed activities (e.g., Winter Weather Workshop at WPC), and the development of a forecaster uncertainty workshop, which was unfortunately was cancelled in September 2018 because of hurricane Florence and then cancelled again in January 2019 because of the government shutdown. We are planning another one in early spring 2019.

*a. Fuzzy-Clustering Tool*

The CSTAR student has been expanding the fuzzy clustering tool to include other variables and approaches. The existing version online (http://breezy.somas.stonybrook.edu/CSTAR/Ensemble_Sensitivity/FC_Main.html) focuses the clusters around sea level pressure. A goal of this project is to develop the clustering around other variables using the global ensembles (GEFS, CMC, and EC – 90 members). For the last report the CSTAR student got the clustering to work for 24-h accumulated precipitation and 2-m temperature.

However, during winter storms one serious concern of forecasters is whether the precipitation will fall as snow, rain, or mixed phase. One useful guidance is the location of the zero degree Celsius contour within the planetary boundary layer, such as at 925 hPa level. Proximity to this line may indicate the transition region between snow and rain. We have experimented with a new clustering tool to highlight the uncertainty of this location. Clustering based on the 925 hPa temperature (T925) directly is not expected to highlight this region, since temperature variability can be large over regions with temperature far from freezing, and using temperature directly mainly highlights those regions with the largest temperature variability that are not necessarily close to the freezing contour. Instead, the zero degree contour is highlighted by a novel transformation, as follows: For each ensemble member, grid boxes where T925 is above freezing is assigned a value of 1, while grid boxes where T925 is below freezing is assigned a value of 0. For any forecast ensemble member (or the analysis), the entire field will be either 0 or 1. However, when averaging the entire forecast ensemble, regions where all ensemble members have temperature above 0 will show an ensemble mean of 1, while regions where all members have below freezing temperature will have a mean of 0. Over regions where some of the members have above freezing temperature and some below, the ensemble average is between 0 and 1, and corresponds to the fraction of ensemble members that have temperature above freezing.

To illustrate this new tool, we have applied it to analyze the winter storm that affected the US Northeast coastal area on November 15, 2018. This storm brought several inches of snow to the tri-state area, and generated evening rush-hour traffic gridlock over New Jersey and New York due to more widespread snow accumulation than expected during the evening commute. Here, we examine the 1.5-day ensemble forecast valid at 00Z November 16, 2018. The ensemble consists of 50-member ECMWF ensemble, 20-member NCEP GEFS ensemble, and 20-member CMC ensemble, with a total of 90 ensemble members. Figure 1a shows the ensemble mean and spread of T925. The ensemble-mean zero degree contour extends from just south of Long Island west-southwestward towards central New Jersey into southern Pennsylvania, and then southwestward into Maryland and Virginia. The shades in the figure shows the ensemble spread. Clearly, the largest spread occurs south of the zero degree ensemble mean contour. Thus by examining the ensemble mean and spread of T925, it is not clear how much uncertainty there is in the location of the zero degree contour, with the largest uncertainties highlighted over regions where T925 is well above freezing.

The situation is very different after our transformation is applied. The ensemble mean and spread of the transformed T925 field is shown in Fig. 1b. The ensemble spread (shades) now highlights the region around the ensemble mean zero degree contour, which is very close to the location where the ensemble mean of the transformed field has a value of 0.5. As expected, the ensemble spread is basically bounded by the ensemble mean contours of 0.01 and 0.99. North of the 0.01 contour, all members have below freezing temperature, while south of the 0.99 contour, all members have above freezing temperature. In between, some members forecast above freezing while others forecast below freezing, thus highlighting a region of potential transition between rain and snow. Figure 1b shows that even 1.5-day prior to the event, there is still significant uncertainty in the location of the zero degree contour, with the full ensemble indicating an uncertainty of around 150 km in its location. Such large uncertainties are not clear from the inspection of T925 directly (Fig. 1a).

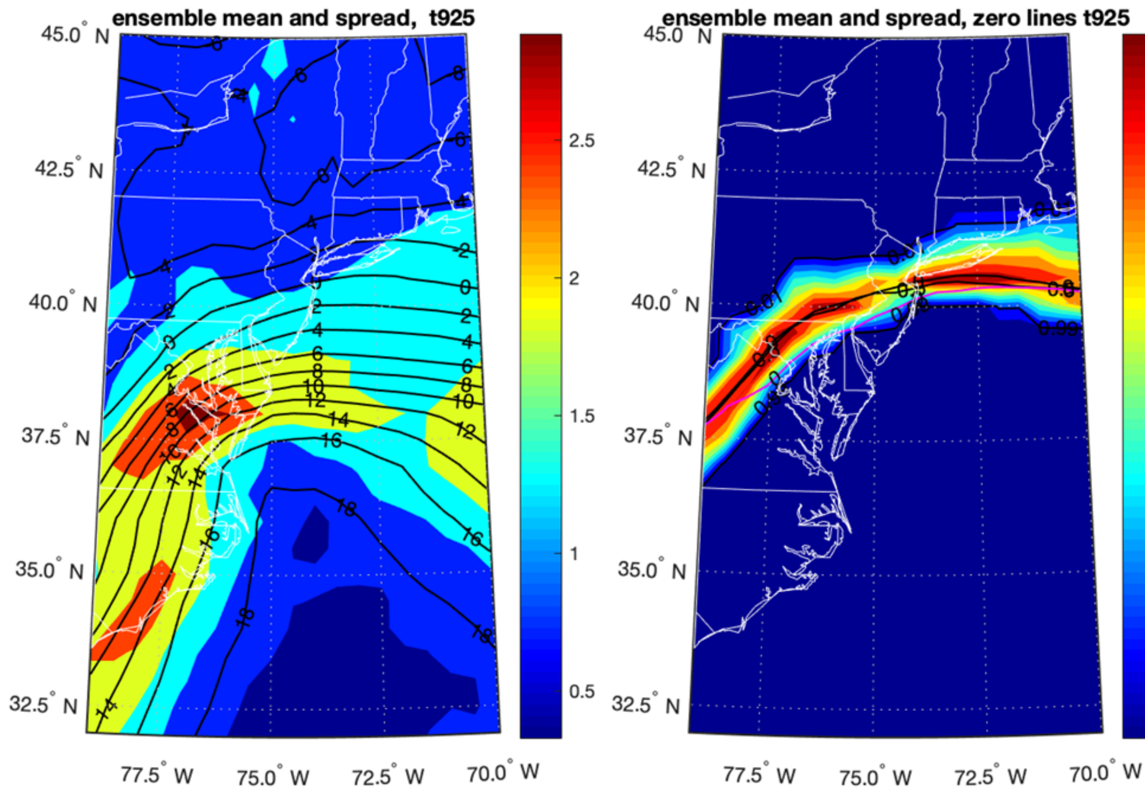


*Figure 1. Left (a) Contours: Ensemble mean T925 (in $^{o}C$) valid at 00Z 16 November 2018; Shades: Ensemble spread. Right (b) Shades Ensemble spread of transformed T925 (see discussions in text). Black contours: Ensemble mean of transformed T925 at values of 0.01, 0.50, and 0.99. The ensemble mean zero degree contour is also shown. The zero degree contour from the analysis is shown as the magenta line.*

The zero degree contour from the analysis is plotted as the magenta line on Fig. 1b. Over most regions it lies south of the ensemble mean zero degree contour, indicating colder temperature than predicted by the ensemble mean. Nevertheless, Fig. 1b shows that the analysis lies within the ensemble and is not out of ensemble. Over southern New Jersey, northern Delaware and northeastern Maryland, the analysis lies close to the edge of the ensemble, but close to or below freezing temperature over these regions should not have been unexpected if the full ensemble is considered, since the analysis does lie within the full ensemble.

Clustering is performed using the two leading EOFs of the transformed T925 field. The leading EOFs are shown in Fig. 2. Positive EOF1 (Fig. 2a) shows negative values on both sides of the ensemble mean zero degree contour, indicating colder temperature over those regions, translating to a more southward location of the zero degree contour. Positive EOF2 (Fig. 2b) shows negative values to the southwest and positive values to the northeast, suggesting colder T925 over Virginia and warmer to the east of Long Island, or a slight counter-clockwise rotation of the zero degree contour. Clustering is performed using the two PCs, and the results of the clustering is shown in Fig. 3a.

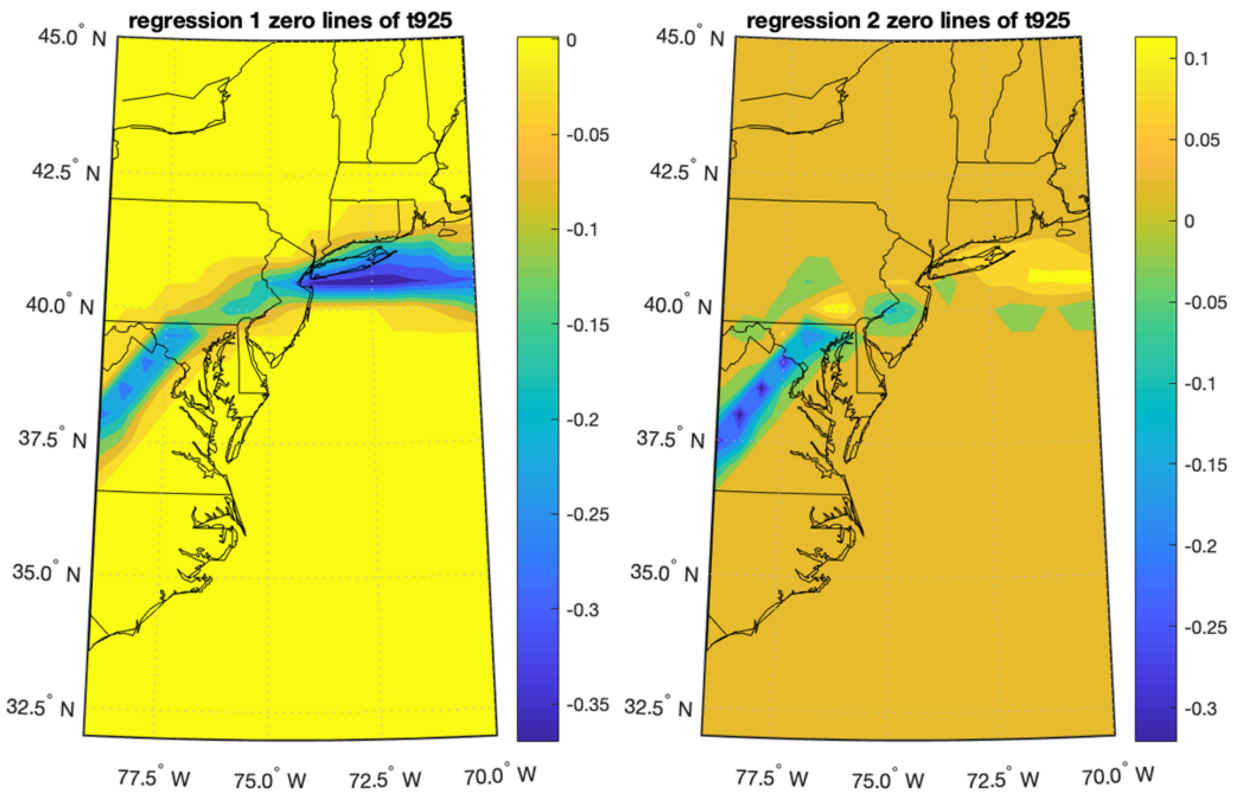


*Figure 2. Left (a) Leading EOF of transformed T925. Right (b) Second leading EOF.*

Figure 3a shows that all members with large negative PC2 (corresponding to more northward location of the zero degree contour) are from CMC, and this ensemble clearly has a warm bias for this case. Note that the analysis projected onto PC1 and PC2 is shown as the magenta cross on Fig. 3a. The analysis has positive PC1, indicating a more southward location of the zero degree contour than the ensemble mean as discussed above. Nevertheless, Fig. 3a shows that the analysis is located inside the full ensemble in PC1-PC2 space, consistent with the discussions above. The group mean zero degree contours for the five groups are shown in Fig. 3b. This also highlights the large spread in the predicted location of the zero degree contour. While none of the groups shows as far south a location as the analysis (yellow) over southern New Jersey and northern Delaware, the large spread displayed by the five groups as well as the spread shown in Figure 1b would serve as indicators that there is significant uncertainty in the location of the T925 zero degree contour.

One complication that we encountered relates to the fact that the main interest in the location of the zero degree contour lies over regions with significant precipitation. That is the reason why we restricted the analysis to the region shown in the figures. We have experimented with larger domains, but since the zero degree contour extends into regions without precipitation, the leading EOFs could be dominated by variability over those regions and thus become less useful. This is different from clustering based on MSLP or precipitation, in which the variance is always dominated by regions around cyclones and thus areas with large variance are always of interest. More testing and fine-tuning will be needed to perfect this tool. We are currently coding up a new package to be run daily at EMC by our NCEP/EMC CSTAR collaborators, with the results to be posted on a new web page (password protected due to inclusion of ECMWF data) on the Stony Brook CSTAR site, to further test and evaluate this tool. We will also examine historical cases from the TIGGE archive and use this tool as a verification tool to evaluate the performance of the 90-member ensemble using the methodology described in Zheng et al. (2017).

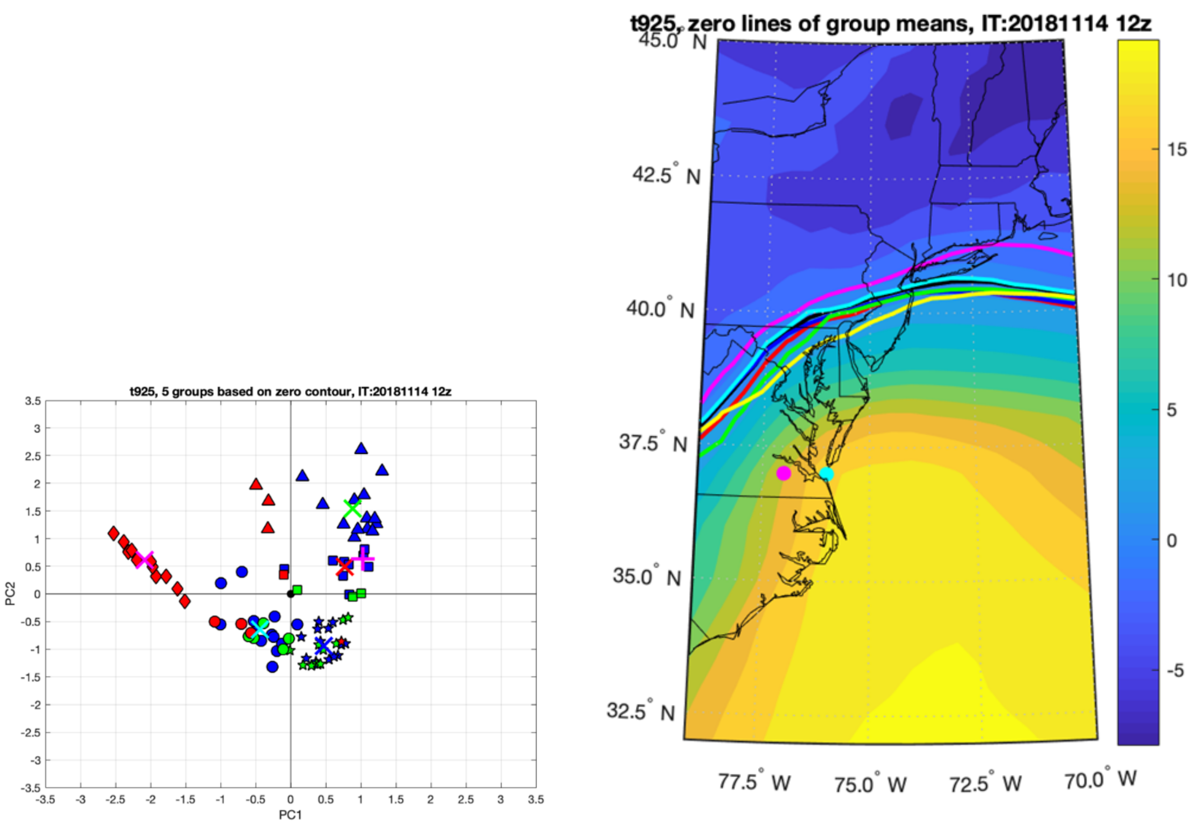


*Figure 3. a) Projection of each ensemble member (filled colored symbols), group means from clustering analysis (X), and the analysis (magenta +) onto PC1-PC2 space. Red symbols indicate CMC members, green NCEP GEFS, and blue ECMWF. b) Zero degree contours from the 5 groups, together with that from the analysis (yellow).*

*b. Communication Uncertainty Workshop*

The first Communication Uncertainty Workshop was developed for 15-20 forecasters from NWS offices and some of the NCEP Operational Centers (e.g., Weather Prediction Center), as well as our social science collaborators at NCEP involved in the project. The original plan was to have the workshop from July 24-25th 2018 at Stony Brook University; however, because of forecaster summer vacations and office staff shortages limiting attendance (only 7-8 could attend) we have delayed the meeting until 11-12 September 2018. However, because of hurricane Florence travel and staff issues, this date was cancelled as well and re-scheduled for 15-16 January 2019. However, because of the government shutdown this workshop was cancelled as well. We hope to have this workshop in late winter or early spring 2019. We have slowed spending for this CSTAR project, so we can have a no-cost extension to still get 2-3 workshops completed. Meanwhile, as shown below, we developed an abstract, a thought-experiment/questionnaire to send a week before the workshop, and a draft agenda for the meeting.

<u>Abstract:</u>

**Hazardous Weather Communication Workshop**

Stony Brook University

Communicating uncertainty for high impact weather event, especially to the public and decision makers, can be formidable, especially since the information expectations from users has grown dramatically. As a result, there is an increased emphasis within the National Weather Service (NWS) for "impact-based decision support." It is important to learn how to engage in a variety of non-specialized audiences about the forecast storm evolution and risk and uncertainty. Led by Christine O'Connell, Ph.D., from the Alan Alda Center for Communicating Science at Stony Brook University, this interactive workshop will focus on helping NWS forecasters learn how to distill their message and effectively engage their colleagues, potential collaborators, decision makers, media, and the general public about the uncertainties associated with the various issues with winter storms.

Through discussion and improvisation exercises, the first day will first discuss some of the challenges in forecasting high impact winter storm events, which will lay out the motivation and foundation for the subsequent messaging and engagement exercises. This will be done by introducing participants to general principles in how to craft short, clear, conversational statements, find common ground, engage your audience, and speak at different levels of complexity for different audiences without jargon or "dumbing it down." The second day you will get to practice and get feedback in the presentation of a given hazardous weather event in the context of the uncertainties associated with the range of high-impact scenarios.

Document Sent to Prepare for Your Workshop

The Alda Center team is looking forward to working with you, and we have assembled some resources to help you prepare for your upcoming workshop.

Please see below for your Pre-workshop Assignments and Agenda.

Thought Assignment #1: What Do You Do?

Imagine you're at a party with local business and civic leaders, including some legislators. Someone you really want to talk with (you decide who that is) comes up and asks you what you do. In only a minute, you want to tell this person about your forecasting work (focusing on a specific event or other aspect, such as modeling) and why it matters. Your goal should be to interest this person enough so he/she asks you friendly questions.

Some things to think about:

- What problem are you trying to solve?
- How would solving it make a difference?
- How are you trying to solve it?

Thought Assignment #2: Your 3-minute Briefing

Be prepared to give a 3-minute briefing on an extreme weather event of your choosing for a public audience (including some policy and decision makers present too). This about how you would talk about the uncertainties associated with a range of high-impact scenarios. You can prepare some slide or data in advance, but you will be allowed no more than 3 slides. Please focus on the communication aspect of the problem, not the challenge the models had in predicting the event.

Workshop Draft Agenda:

Day 1:

**9:00-9:15:** Welcome and Intro to the Alda Center and Science Communication

**9:15-10:15:** Forecaster examples of challenging storms

**10:30-12:00** See & Be Seen: Improvisation exercises that build focus and connection

**12:00-1:00** Lunch

**1:00-2:30** Designing a Vivid Message

**2:45-4:45** Just a Minute (JAM) Practice Session: Practice distilling your message and talking clearly and vividly about science in a 1-minute talk about climate or weather research or a related science topic of your choosing.

**4:45-5:00** Reflection Routine & Wrap Up

Day 2:

9:00-9:30: Warm-up

9:30:00-12:30: Practice giving talks (3 min on an extreme weather event) and getting feedback

12:30-1:00: Discussion and Wrap Up

Flyer:

### 3. Recent Interaction with Operational CSTAR Partners

a. *Spread-Anomaly Tool*

We have developed a web page for our Spread-Anomaly tool (http://blue.somas.stonybrook.edu/ssa/ssa.html) that was shared with our CSTAR partners. The tool itself has been described in in detail in previous reports. The latest version of the software is on github (https://github.com/aaTman/SpreadAnomaly). Basically, at each point it determines how anomalous the SLP spread is relative to other events with a similar SLP and lead time using the Global Ensemble Forecast System Reanalysis (GEFS-R) ensemble for the historical events. The web page was highlighted in the last report. The page for the GEFS has the standard mean/spread, probability matched mean, and standardized spread anomaly (SSA). The mean/spread are for SLP, 500Z, integrated water vapor (PWAT), 850 hPa temperatures, and 6-h surface precipitation. The SSA is currently only available for SLP. During the last six months we have been writing code to give to our CSTAR partners so they can run locally on their machines. Also, we have been writing a paper outlining the spread-error relationships for East coast storms as highlighted in the last report.

*b. Fuzzy Clustering Tool*

As noted above we have expanded the tool to include the freezing line at 925 hPa, and we have shared this code with EMC, so they can generate the graphics in real-time for our CSTAR webpage.

Meanwhile, WPC has implemented our clustering approach for their 2018-2019 Winter Weather Experiment (WWE). They developed a webpage for the clusters: https://www.wpc.ncep.noaa.gov/hmt/wwe2019/clusters/view.php (Fig. 4). The 90 members from the CMC, EC, and GEFS global ensembles for the 0000 and 1200 UTC cycles are used in the clusters as on our CSTAR website. The first two EOFs are calculated using the 500-hPa heights for the selected lead-time day and then clustered using the PC1 versus PC2 phase space (Fig. 5), which are color coded by ensemble system. Figure 5 highlights the issue of clustering of members by ensemble system (EC versus GEFS+CMC). Figure 6 shows the 5 different clusters valid at 3 for the ensembles initialized at 0000 UTC 25 January 2019. Cluster4 has a stronger with the East Coast trough comprised mainly of GEFS members, while cluster2 is weaker with the trough with mainly EC members.

WPC uses the members from each of these 500 hPa clusters to generate clusters of several other variables, such as 24-h precipitation, 24-h snowfall, MSLP, 850 hPa temperature, 700 hPa temperature, 6-h precipitation, and 6-h snowfall. For example, figure 7 shows the 5 clusters and ensemble mean for 24-h precipitation using the same members as the five 500 hPa clusters.

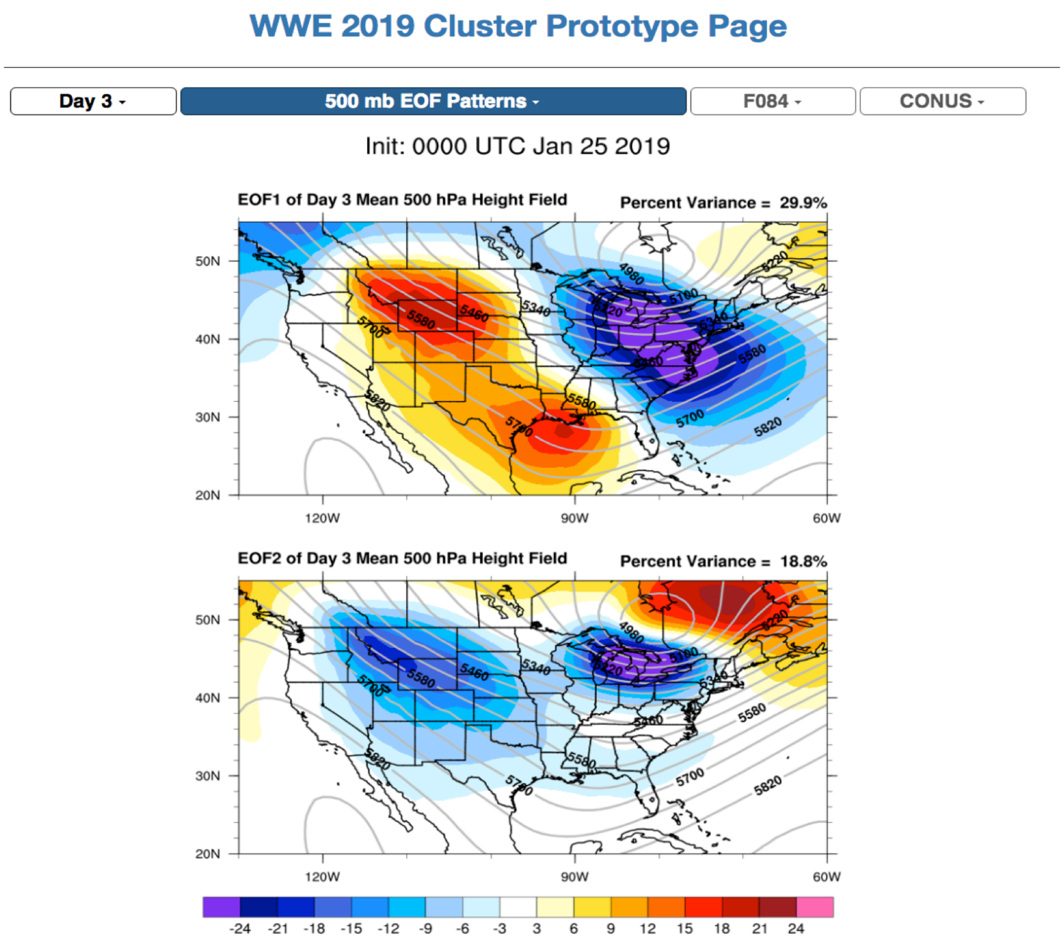


*Figure 4. Snapshot of the front page of the WPC fuzzy cluster website (https://www.wpc.ncep.noaa.gov/hmt/wwe2019/clusters/view.php.) showing an example of the two leadings EOFs of 500 hPa heights used to create the 5 PC clusters.*

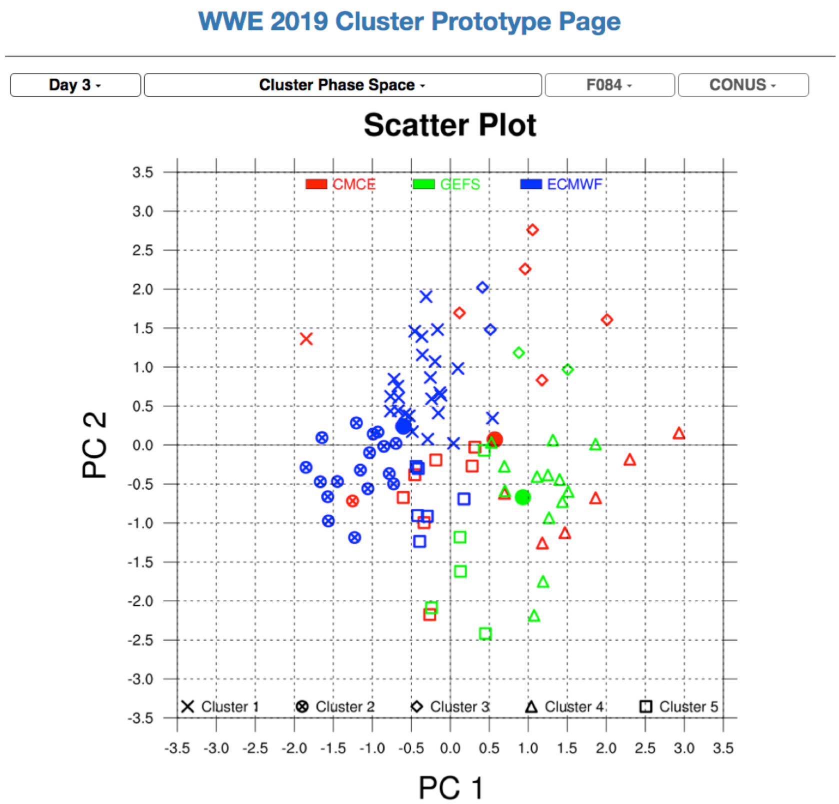


*Figure 5. Scatter plot of the 90 ensemble members (EC blue, GEFS, green, and CMC red) on the PC1 versus PC2 phase space. The center of the 5 clusters are shown using the black symbols highlighted at the bottom.*

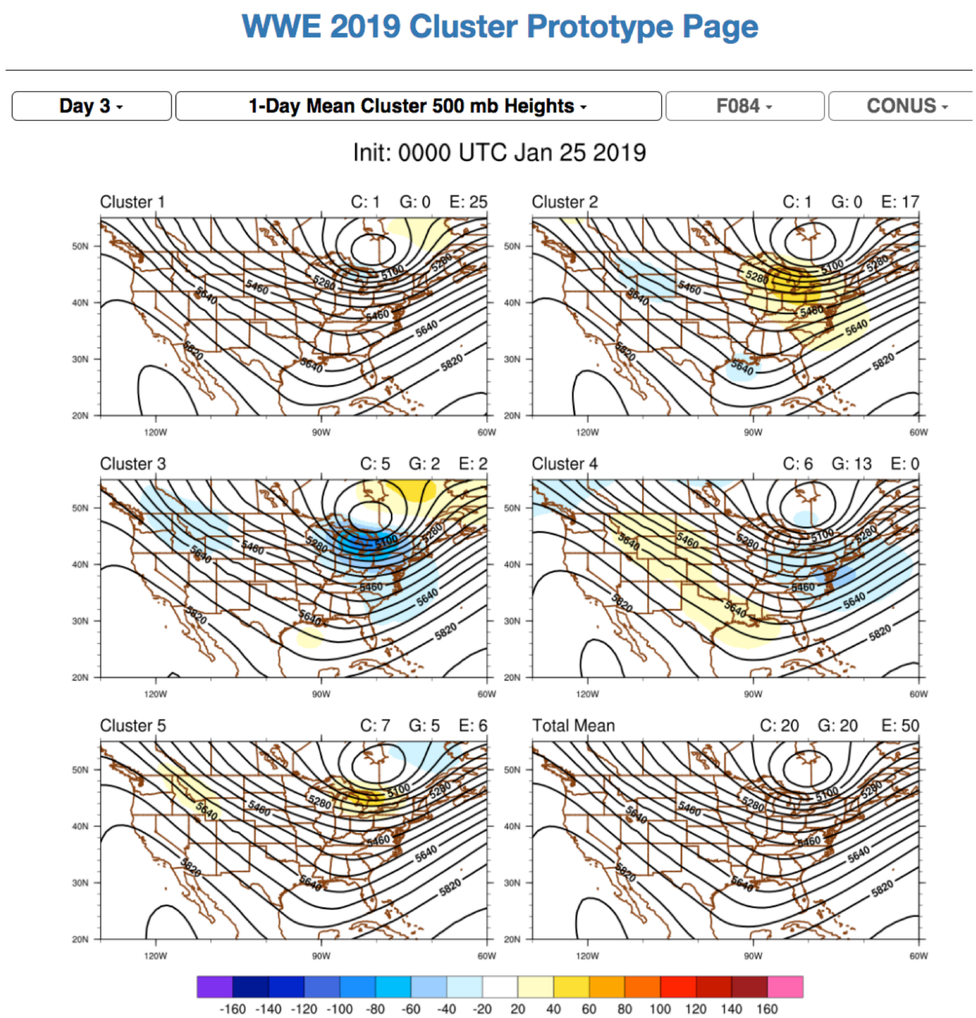


*Figure 6. The 5 clusters and ensemble mean for the day 3 forecasts initialized at 0000 UTC 25 January 2019, with the number of members from each ensemble system shown in the upper right.*

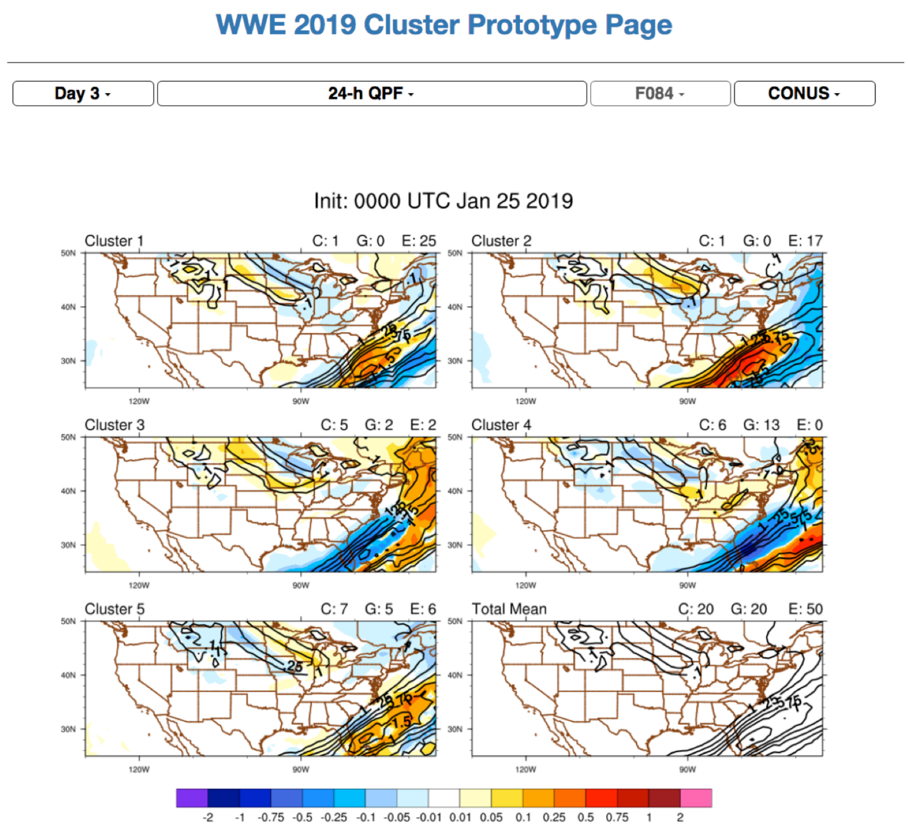


*Figure 7. Same as Fig. 6 but for 24-h precipitation (contoured in inches and shaded difference from the ensemble mean in inches) using the same clusters and members as the 500 hPa height.*

### *c. Communication Uncertainty Workshop*

The Stony Brook team had a conference call with NWS Eastern Region (Bohemia, NY) as well as the social science team at NCEP (Vankita Brown and Leticia Williams) on 31 August 2018 to discuss the uncertainty workshop. The content of the workshop was discussed as well as some of the potential logistics. This meeting was followed up with several phone calls with Eastern Region to discuss more of the workshop content, forecaster recruitment, and logistics.

Meanwhile, NWS forecast office partners and Eastern Region forwarded to Stony Brook University the weather briefings for a few coastal storms. These powerpoint briefings are shared with emergency managers and others online, and thus represent the challenge in communicating uncertainty. The goal is to take material from these briefings to use a discussion points during the workshop.

## 4. Products and Presentations

*a. Ensemble Spread Tool*

A web page has been developed the past six months for the spread anomaly tool (*(http://blue.somas.stonybrook.edu/ssa/ssa.html)*. The code has been shared with NCEP-WPC and it is on github, so the output can eventually be combined with the Situational Awareness Table (SAT) online for forecasters.

*b. Fuzzy Clustering and other Ensemble Tool*

The fuzzy clustering and other ensembles tools (ensemble sensitivity, wave packets, cyclone tracks, etc) are currently maintained and accessible from our CSTAR page:

http://breezy.somas.stonybrook.edu/CSTAR/Models.html

*c. Theses, Papers, and Presentations*

*Formal papers published or in preparation:*

Zheng, M., Chang, E.K., Colle, B. A., Luo, Y., & Zhu, Y., 2019: Evaluating U.S. East Coast Winter Storms in a Multi-Model Ensemble Using EOF and Clustering Approaches. In revision to *Mon. Wea. Rev.*

Wirth, V., M. Riemer, E. K. M. Chang, and O. Martius, 2018: Rossby wave packets on the mid-latitude Rossby waveguide, *Mon. Wea. Rev*., **146**, 1965-2001.

Mandelbaum T., B.A. Colle, 2019: Assessing the spread-error relationship for East Coast winter storms. To be submitted to *Wea. Forecasting*.

Zheng, M., Chang, E.K., & Colle, B. A., 2018: Impacts of upper level Rossby wave packets on medium-range forecast errors and uncertainties. In preparation.

Zheng, et al, 2018: Ensemble sensitivity of U.S. East Coast winter storms: the multi-model climatology and paths of forecast uncertainty in medium range. In preparation.

*Presentation at 25th Northeast Regional Operational Workshop , Albany NY (7-8 November 2018)*

Brian Colle, "CSTAR Update: Better Use of Ensembles in the Forecast Process: Scenario-Based Tools for Predictability Studies and Hazardous Weather Communication."

*Presentation at 25th Conference on Numerical Weather Prediction, Denver CO (4-7 June 2018)*

Taylor Mandelbaum, Brian Colle, and Trevor Alcott: "Assessing the Spread/Error Relationship for East Coast Winter Cyclones."

*d. Stony Brook CSTAR graduates (alum)/students:*

*David Stark (M.S., 2012) – NWS General Forecaster at Upton, NY*

*Matthew Souders (M.S., 2013) –Weather Analytics, New Hampshire*

*Michael Layer (M.S., 2014) – Weatherworks, Hackettstown, NJ*

*Michael Erickson (Ph.D., 2015) – NOAA Contractor (Weather Prediction Center)*

*Minghua Zheng (Ph.D. -2016, Post-doc at Scripps)*

*Nathan Korfe (M.S. 2016) – Research Meteorologist at WindLogics, MN)*

*Taylor Mandelbaum (M.S. 2018)—Meteorologist and Data Analyst at NY Power Authority*

*Rui Zhang – current Ph.D. CSTAR student*

*d. CSTAR Group Meetings and List Serve*

There are over 50 participants on the list serve: cstar_stony_brook@infolist.nws.noaa.gov.

**5. Problems and Difficulties**

The rescheduled workshop for September 2018 was cancelled because of hurricane Florence, and the meeting was cancelled again in January 2019 because of the government shutdown. As a result, we are 6 months behind with the workshops planned for this project. We plan to have a no cost extension to makeup these efforts.