Development and Analysis of Operational Forecast Tools at the Weather Prediction Center

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Performance Improvements = Errors + Insights HydroMeteorology Testbed (HMT)

Klein 2013: "Seeing what others don't"

Who we are

We are Scientists who bridge the gaps between research & operations, to improve forecasts of precipitation extremes, in a human centered way. We generate Discussion through Experiments, Seminars, Training, and Focus Groups. We explore observations and models (NWP/UFS, AI/ML and statistical models) in order to evaluate and verify NWP models, tools, and techniques.

HMT is a:

- Naturalistic decision-making environment,
- Physical & virtual space,
- Insight-generating collaboration,
- A Boundary Object: sitting at the intersection between Research and Operations.

We host immersive experiments:

- Flash Flood & Intense Rainfall (Summer)
- Winter Weather Experiments (Winter)
- Extended Range Forecasts (Year round)

Activities We Conduct and Support

- Forecast Exercises focused on *Extremes*
- Models & Ensembles: RRFS, NBM, HRRR
- AI/ML: ERO 1st guess, snow, precip
- *Probabilistic* Forecasting Techniques
- Subjective and Objective *Verification*

What we aspire to:

- Improve forecasters' expertise via a robust ecosystem of tools and knowledge
- Generate Insight on challenges of Forecasting & Impact-based Decision Support Services
- Improve the state of the science with real-world testing & evaluation
- Be People (not technology) Centered

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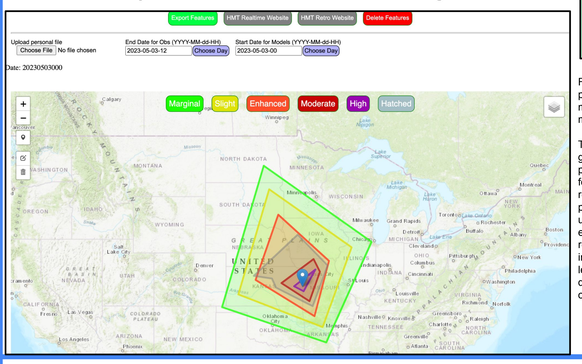
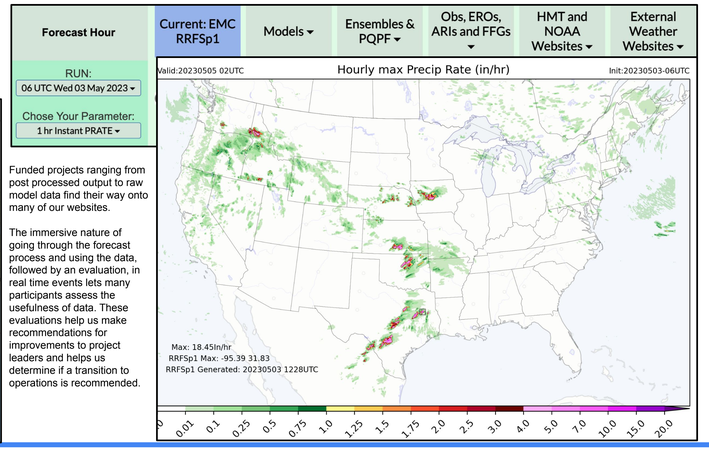
Make your own Forecast with our drawing tools



Display multiple project datasets in realtime or case study mode



Funded projects ranging from post processed output to raw model data find their way onto many of our websites.

The immersive nature of going through the forecast process and using the data, followed by an evaluation, in real time events lets many participants assess the usefulness of data. These evaluations help us make recommendations for improvements to project leaders and helps us determine if a transition to operations is recommended.

Winter Storm Severity Index (WSSI)

The Winter Storm Severity Index (WSSI) combines official NWS forecast data with climatological and non-meteorological information using geographical information system (GIS) software to spatially depict the severity of potential societal impacts. It is an impact-based decision support tool designed to help forecasters, stakeholders, and the general public maintain situational awareness of forecasted winter impacts. The product output scales with the severity of the impact to daily life, including, but not limited to: traffic disruptions; closures of roads, schools or businesses; power or other utility service disruptions or outages; downed tree limbs or overhead utility lines; and structural integrity issues and collapses from the weight of snow or ice.

There is now a "suite" of WSSI products at various stages of development:

- **Deterministic WSSI** – Operational
- Probabilistic WSSI (**ProbWSSI**) – Experimental
- Hourly WSSI (**WSSI Travel**) – Prototype
- **WSSI for Alaska** – In Development

CIRES employees working on the WSSI suite of products work alongside federal developers and partners, professional stakeholders, and a team of social scientists to aid in development and continually improve the product.

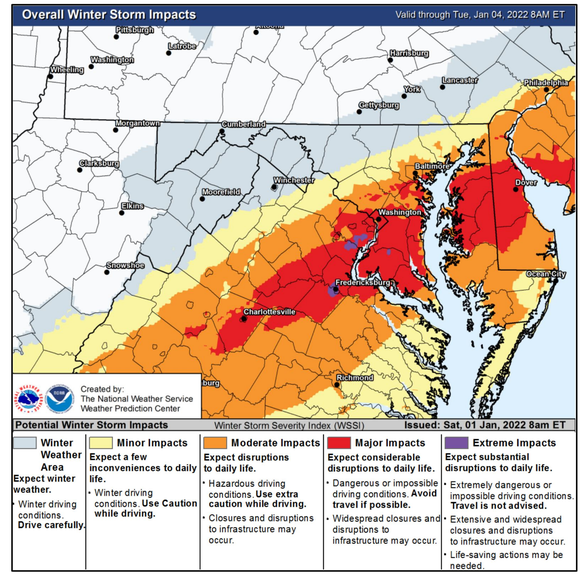


Figure 1: Output from the operational deterministic WSSI product from 1 January 2022, valid over the 72 hour period ending at 8:00 AM on 4 January. Impact severity levels are color-coded according to the legend, alongside definitions for each impact level. Definitions were recently overhauled for the 2022-23 winter season in response to feedback from a study led by social scientists alongside the WSSI Development Team.

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Ensemble Clustering Techniques

Motivation

As technology improves and NWS responsibilities expand, forecasters have access to more data with simultaneously less time to interrogate those data. Viewing the mean of an ensemble dataset can wash out important nuance amongst membership. Alternatively, viewing each ensemble member is unrealistic when working with many members.

Solution? Use a clustering approach to break down the ensemble forecast into its most prevalent scenarios!

How does clustering work?

- Empirical orthogonal function (EOF) analysis (traditionally known as Principal Component Analysis) collapses the ensemble forecast into its leading modes of variability
- Use k-means clustering to group together similar scenarios based on the first two modes (Principal Components or PCs) of the forecast

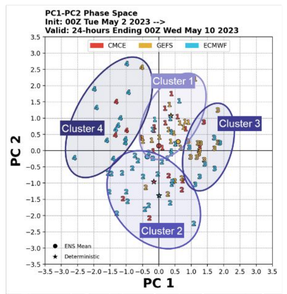

Figure 1. Depiction of 7-day forecasts from the CMCE, GEFS, and ECMWF ensemble systems in PC1-PC2 phase space along with their cluster assignments.

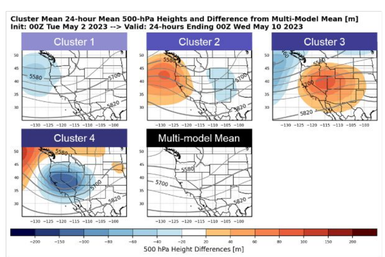

Figure 2. Forecast means of 500-hPa heights from each cluster valid at forecast day 7. Shading indicates differences from the multi-model ensemble mean.

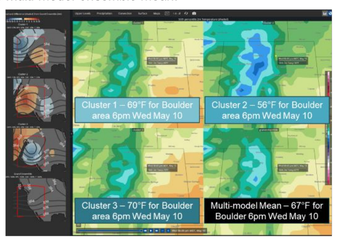

Figure 3. DESI cluster forecasts valid for Boulder on the afternoon of May 10 range from 56°F to 70°F depending on the nearby trough's location and magnitude in the forecast!

How does it perform?

- In addition to the WPC webpage, clustering is the centerpiece of the Dynamic Ensemble-based Scenarios for IDSS (DESI), an experimental application to visualize and interrogate ensemble data in a scenario-based framework
- Best-performing cluster forecast outperforms best deterministic forecast and best ensemble system mean forecast for Days 3-7 (Lamberson et al. 2023)

Ensemble clustering has proven itself a more useful and accurate forecasting/communication tool than traditional ensemble post-processing approaches!

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Object-Based Verification Development

Goal: Transition object-based forecast and verification tools to operations through calibration analysis and web development.

Object-based analysis: Product suite designed to assist forecasters for short-range heavy rainfall events and heavy snowband events. They indicate uncertainty for areas of enhanced concern during events by providing historical context from both the model and observations.

Data: All of the products under development currently utilize HRRRv4 model output and Multi-Radar Multi-Sensor (MRMS) observations.

Method: These products were developed and prototyped using NCAR's Model Evaluation Tools (MET) Method for Object-Based Diagnostic Evaluation Time Domain (MODE-TD).

Calibration Techniques: Experiments will be conducted to improve the reliability of the forecast products. These experiments will take two approaches:

1) Sensitivity studies performed on the parameters and smoothing metrics used to define precipitation objects.
2) Machine Learning algorithms will cluster objects based on their forecasted precipitation mode, aiming to gather more appropriate historical data used to inform the probabilistic products.

Web Development: New web-based interface(s) are being developed to improve the way these products are communicated & displayed. In particular, a new interface for displaying data related to verification of the Excessive Rainfall Outlook (ERO) (Figure 2) replaces a difficult to navigate internal page displaying static images. The new interface allows for more in-depth investigation of the data through the use of an interactive map in addition to the static plots. Similar interface(s) will be developed for the object-based analysis products.

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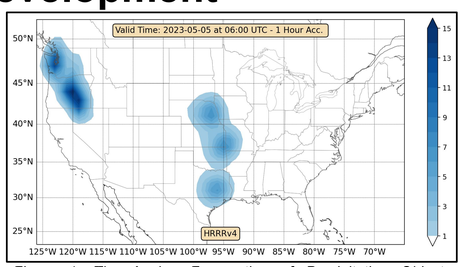

Figure 1: The Analog Forecasting of Precipitation Objects (AnaPrO) is a probabilistic forecast of the rainfall object centroids using historical HRRRv4 and MRMS observations.

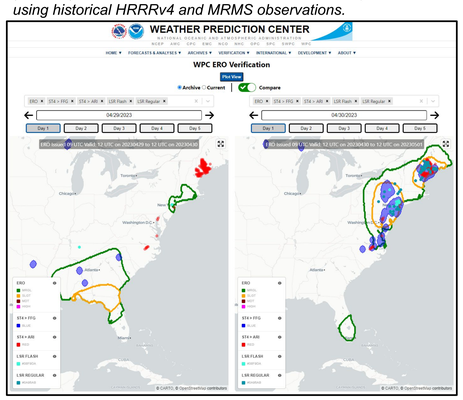

Figure 2: Updated Excessive Rainfall Outlook (ERO) interactive webpage, capable of further investigation of ERO verification and event statistics.