State of the Science FACT SHEET

Forecast Uncertainty

Uncertainty is … a fundamental characteristic of weather, seasonal climate, and hydrological prediction, and no forecast is complete without a description of its uncertainty (National Research Council, 2006).

Uncertainty is an inherent part of all forecasts, and understanding this uncertainty enables emergency managers to strengthen their decision making. Forecast users and industry partners now look to NOAA to regularly characterize and convey forecast confidence and uncertainty. As a result NOAA is: (1) quantifying forecast uncertainty; (2) providing uncertainty information visually and verbally in decision support services~~;~~ and (3) assessing the benefits and challenges of using uncertainty information to continue to enhance the decision making environment. Building relationships with our partners and understanding their needs and risk preferences enables us to evolve our science and services and provide better ways to communicate risk to decision makers.

Sources of Forecast Uncertainty

The National Research Council wrote in 2006 "no forecast is complete without a description of its uncertainty." All prediction is inherently uncertain and effective communication of this uncertainty about weather, climate, and hydrological forecasts benefits users' decisions. While NOAA continues to reduce forecast uncertainty through improved observations, including the most recent suite of NOAA satellites, data assimilation and numerical modeling techniques, some forecast uncertainty will remain because our atmosphere and oceans are inherently chaotic. Small errors in the estimation of the atmosphere's initial state grow with increasing forecast lead time. In addition, the atmosphere does not evolve in reality in quite the same way as a simplified model predicts. To decrease uncertainty and improve model accuracy and reliability, NOAA continues to improve ensemble prediction methods, and statistical techniques to calibrate this output. Still, estimating and communicating forecast uncertainty throughout the NOAA product suite in a way that supports the decision making environment is an ongoing challenge.

How NOAA Communicates Forecast Uncertainty

Deterministic, or single-value forecasts (*e.g. the temperature will be 75 degrees*), are easier to convey, but leave out the uncertainty information which gives the user a full picture of a forecast. NOAA communicates the uncertainty of its forecasts in several ways. Range predictions *(e.g. the temperature will be between 70-78 degrees*) quantify possible uncertainty values in a forecast. Using words such as "chance" or "likely" express the probability of an event like precipitation, tropical cyclone development, or severe weather. Values and categories (e.g. 20% Moderate) indicate a range of uncertainty (Figure 1). While all of these methods deliver value to decision makers, they can fall short. Capturing the probability of an event does not always provide the specific information most critical to a decision maker. For instance, citrus growers see impacts at specific temperatures. Highway maintenance crews care most about specific temperatures, snowfall amounts and timing. Others, such as emergency managers or residents may best use a combination of probabilities and thresholds to prepare for the specific impacts of tropical storms, such as wind (Figure 2) or storm surge, and other severe weather events. NOAA continues to develop and communicate probabilistic information to provide a spectrum of possibilities that allows users to assess their risk using their respective criteria and thresholds.

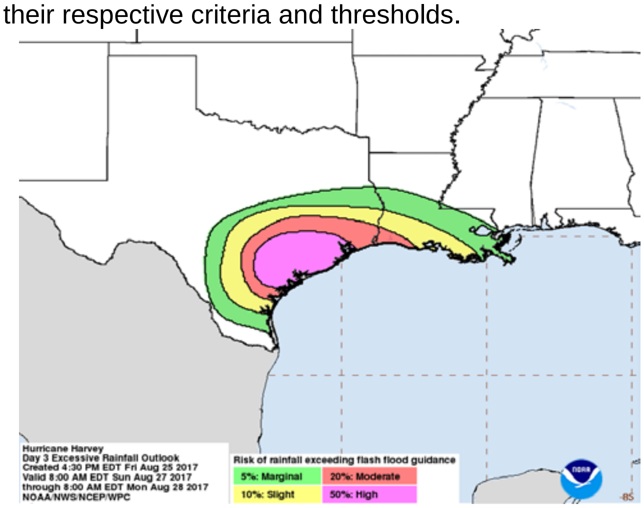

Figure 1. The risk of rainfall exceeding flash flood guidance expresses the uncertainty both probabilistically and categorically during Hurricane Harvey

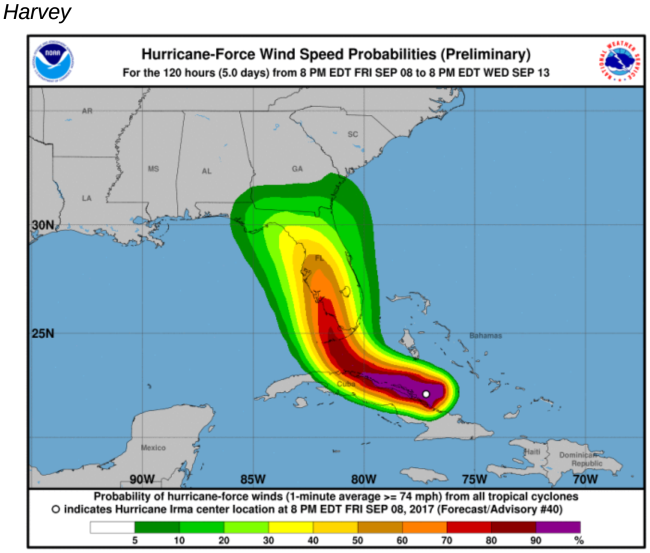

Figure 2. Range of probability of hurricane force surface winds during Hurricane Irma indicating the range of uncertainty

Decision Making with Forecast Uncertainty

Forecasts possess no intrinsic value. They acquire value through their ability to influence the decisions made by users of the forecasts (Murphy, 1993)

In response to the needs of decision makers, NOAA continues to research and develop innovative ways to quantify the uncertainty of our forecasts and effectively communicate it to our users and partners. Forecasts are increasingly based on a set of numerical weather prediction models (known as ensembles) to predict a range of possible future atmospheric states to convey the forecast. NOAA's constituents request and use probabilistic forecast information to make more data-informed, risk-based decisions.

Here are a few examples of decision making with forecast uncertainty:

- Providing areas of potential thunderstorms allows the FAA to reroute aircraft when thunderstorm probabilities exceed a pre-defined threshold, thus reducing fuel costs and increasing efficiency.
- State and local highway authorities improve road safety due to informed decisions on road surface treatments during winter weather.
- Providing probabilistic information allows FEMA to respond well in advance of possible high impact events, increasing efficiency in deploying response and recovery resources to locations.
- Probabilistic wind direction forecasts enable the U.S. Forest Service to improve fire suppression efforts by deploying resources to guard against dangerous wind shifts.
- NOAA-generated uncertainty forecasts provide opportunities to assist weather-dependent industries, such as utilities, to reduce operating costs.

Key Research Goals for Forecast Uncertainty

NOAA is advancing its research efforts to provide a more comprehensive suite of products and decision support services to continue to meet user needs. NOAA's research will:

- Use social and behavioral science to understand what motivates people to prepare and take action, and help us improve the way we communicate risk and its associated uncertainty.
- Build an end-to-end forecasting and messaging framework designed to manage and clearly convey hazardous weather information and forecast uncertainty through an approach known as Forecasting a Continuum of Environmental Threats (FACETs) http://www.nssl.noaa.gov/projects/facets/ (Figure 3)
- Improve ensemble prediction techniques by: (a) using improved data assimilation and forecast systems; (b) more accurately quantifying uncertainty in the initial estimate of the atmospheric state, (c) employing improved, more physically based methods for quantifying the growth of forecast uncertainty due to model imperfections and (d) utilizing statistical post-processing methods to improve the skillfulness and reliability of the ensemble model output.
- Provide high-quality real-time and retrospective ensemble forecast and analysis data and post-processed probabilistic guidance to the weather enterprise partners enabling them to develop their own decision-support tools.
- Develop probability-based decision-support tools to facilitate the delivery of data, products, and services for key customers.
- Improve ensemble model visualization capabilities to convey uncertainty information to weather forecasters and users.

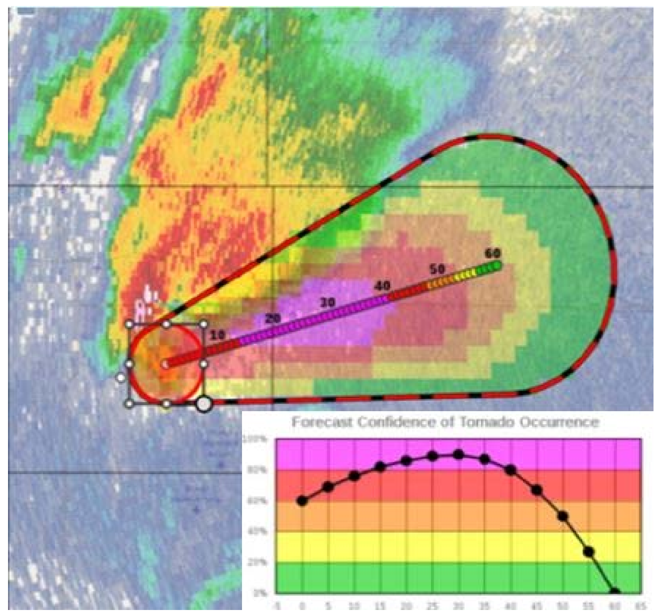

Figure 3. Probability of a Tornado occurrence in the next 0-60 minutes quantitatively expresses the uncertainty in the forecast.

Recommended Reading

Hirschberg, P.A. and Coauthors, 2011: A Weather and Climate Enterprise Strategic Implementation Plan for Generating and Communicating Forecast Uncertainty Information, *Bull. Amer. Meteor. Soc*., **92**, 1651-1666.,

Murphy, Allan H. 1993: What is a Good Forecast? An Essay on the Nature of Goodness in Weather Forecasting. *Wea. Forecast*., **8**, 281-293

National Research Council (NRC), 2006: Completing the Forecast: Characterizing and Communicating Uncertainty for Better Decisions Using Weather and Climate Forecasts. National Academies Press, 124 pp