State of the Science FACT SHEET

Weather Forecast Uncertainty

This document represents the state of the science of quantifying and communicating weather forecast uncertainty. Decisions can be improved by better understanding the uncertainties in the weather forecasts. NOAA seeks to help users of its forecasts by: (1) quantifying uncertainty applying statistical techniques to ensemble model output; (2) providing decision support services (DSS) to core partners; and (3) educating customers on how to benefit from the use of uncertainty information in decision-making.

Why is Forecast Uncertainty Information Needed?

Our knowledge about the future state of the weather (the science of weather forecasting including water and climate conditions) is inexact because the atmosphere, as it interacts with the oceans and land, is not perfectly predictable, especially at longer lead times. It follows that uncertainty is an essential component of any forecast affected or driven by the atmosphere. Diagnosing and communicating forecast uncertainty in a way that allows people to make better daily decisions regarding the weather is a challenge for NOAA.

Weather forecasts are typically communicated as single values, such as “the low temperature tomorrow night will be 38 degrees.” Sometimes forecasts are expressed as a range of values, such as 35 to 41 degrees, implying a single number could not be given with certainty. By having additional information in the form of probabilistic forecasts, i.e., the likelihood of a forecast scenario happening, people can better understand the uncertainty of an event and weigh this information against inherent risks to make better decisions.

For example, with the temperature range cited above, the probability of the temperature dropping to 30 degrees or lower may be 20 percent. Knowing this probability, citrus growers might consider taking action to protect their crops from a freeze. Similarly, a mountain hiker, hearing a forecast of cloudy and a chance of snow might feel safe enough to start his climb. However, if the forecast included the probability of heavy snow as 10 percent, the hiker might decide not to risk potential disaster and postpone the trip.

How can forecast uncertainty best be understood?

Most weather forecasts beyond a few hours are based on the results of numerical weather prediction models. A model predicts atmospheric variables such as temperature, pressure, moisture, and wind above the earth’s surface. Errors in models arise primarily from two sources: (a) the current state of the atmosphere on which the forecast is based is not completely known and (b) the model itself is not perfect.

Forecast error can be assessed by running the model a number of times, with slightly different, but still plausible, initial conditions, and sometimes with different formulations of the model. These various model runs are together called an “ensemble.” Ensembles form basic building blocks for probabilistic forecasts.

To date, forecasts from ensembles exhibit certain biases and the results do not reliably cover all of the possible outcomes; however, forecasters apply their skills and training to account for biases and, using this information, produce a full suite of probabilistic forecasts for a wide variety of uses.

NOAA is actively pursuing the necessary research and development to employ ensembles to quantify uncertainty as a paradigm shift in forecasting, as shown in figure 1.

Old Paradigm	vs.	New Uncertainty Paradigm
Focus only on reducing uncertainty	→	Focus on reducing & quantifying uncertainty
Single value “most likely” forecast	→	Most likely value and probabilities of other values
Decisions based only on “most likely” scenario	→	Decisions based by weighing costs and impacts of each possible scenario
Status quo socio-economic losses due to forecast error	→	Risk mitigation, socio-economic enhancements due to factoring forecast error in decision making

Figure 1. Risk reduction and socio-economic improvements result from applying uncertainty information into decision-making process.

What are the Benefits of Communicating Forecast Uncertainty?

NOAA's constituents are now requesting uncertainty information for weather, water, and climate scenarios for better risk-based decision making. Here are a few examples of how forecast uncertainty information provided by NOAA can benefit the nation:

- Federal Aviation Administration (FAA) can reroute aircraft to avoid areas of potential thunderstorms when their probability exceeds a pre-defined threshold, thus reducing fuel costs and increasing efficiency.
- Federal Highway Administration can improve road safety due to better decisions on road surface treatments during winter weather.
- Dept. of Homeland Security can gain greater efficiency in deployment of response and recovery resources to locations well in advance of possible high impact events.
- U.S. Forest Service can improve fire suppression efforts by deploying resources based on probabilistic wind direction forecasts to guard against dangerous wind shifts.
- Private weather companies can rely on NOAA-generated uncertainty forecasts to assist weather-dependent industries, such as utilities, to reduce operating costs.

What are the Key Research Goals for Forecast Uncertainty?

NOAA is pursuing a number of research goals to provide a more comprehensive suite of uncertainty products and decision support services. Through research NOAA will:

- Improve ensemble techniques through better representations of baseline atmospheric conditions and model physics to produce an accurate dispersion of ensemble solutions (http://www.nco.ncep.noaa.gov/pmb/products/sref/ and http://www.wmo.int/thorpex).
- Develop "high impact event" ensemble system to quantify the probability of extreme weather, water, and climate events (http://ewp.nssl.noaa.gov/)
- Develop probability-based decision support tools to facilitate the delivery of data, products, and services (http://esrl.noaa.gov/).
- Develop ensemble model visualization capabilities for forecasters to optimize the value of ensemble data (http://esrl.noaa.gov/).
- Produce skillful probabilistic forecasts and verification statistics (http://www.weather.gov/mdl/).
- Collaborate with NOAA partners to express forecast uncertainty using social science principles to ensure correct application of uncertainty information (http://www.sip.ucar.edu/wasis/).

NOAA Resources and Capabilities

In addition to NOAA research efforts listed above, there are currently over 100 probabilistic NOAA products that are operational, experimental, or under development. Some probabilistic product examples include wind speed for tropical cyclones, severe weather (i.e., tornadoes, hail), and river stage levels. An example of a probabilistic forecast is given in figure 2. Probabilities of storm surge levels can be used by emergency managers and local authorities to determine how far inland to evacuate, where to pre-deploy disaster relief resources, and what is the best way to mitigate property damage.

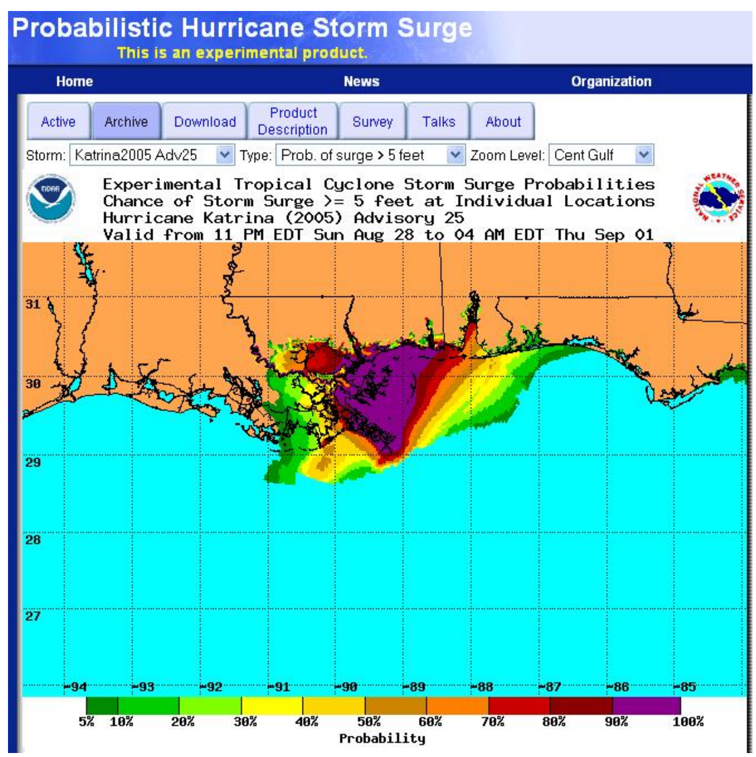

Figure 2. Probabilistic storm surge product is shown for Hurricane Katrina for August 28th to September 1st 2005. Probabilities of >5 feet storm surge are provided for coastal waters from Louisiana to Florida. Better evacuation, coastal resilience, and risk mitigation decisions can be made using probabilistic forecasts rather than solely relying on the "most likely" forecast.

For more information on the NOAA Forecast Uncertainty program go to: http://www.nws.noaa.gov/ost/nfuseindex.htm.