

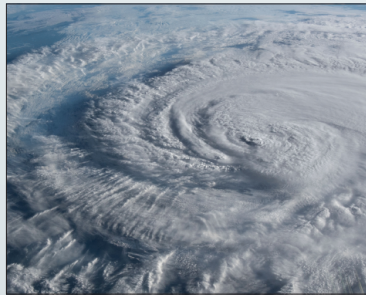
# Mathematics and Statistics of Weather Forecasting

Accurate weather forecasting is vital to many sectors of the economy, such as the airline industry and agriculture. And lives can depend on the accuracy of predictions for hurricanes and major storms. Mathematical weather forecasting combines equations that define physical laws of atmospheric events with current weather observations. Weather forecasting has improved significantly over the past decades because of mathematical and statistical advances, innovations in mathematical modeling, better integration of weather monitoring data, more efficient computing, and progress in quantifying uncertainty of predictions.

Putting all these pieces together ensures that the best weather estimates are available when we need them most.

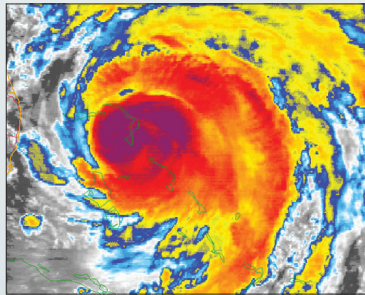
## Forecasting methods and understanding uncertainty

### Innovative models



Forecasting models typically treat the atmosphere as if it were a fluid with eddies and currents, just like water. These complex models continue to improve over time with the help of mathematical and statistical advances.

### Data integration



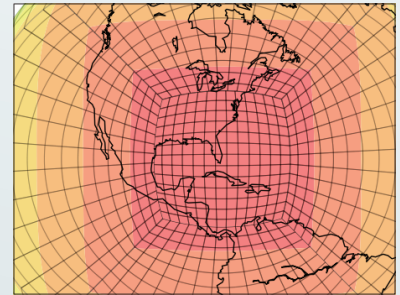
Weather data from multiple sources — spanning different physical and time scales, and collecting different types of information like wind speed, rainfall or temperature — are combined into forecast models.

### Efficient computing



These models are computationally intensive, and depend on efficient numerical methods and powerful computers to deliver fast results.

### Uncertainty quantification



Accounting for uncertainty in model predictions is difficult due to disparate data, varying methods for modeling, and other data science-related challenges. Innovation in this space requires advanced mathematical and statistical approaches.



**Satellites** collect digital images of the Earth at a variety of scales and time frequencies.



**Aircraft** carry instruments that automatically report air pressure, temperature and wind speed.



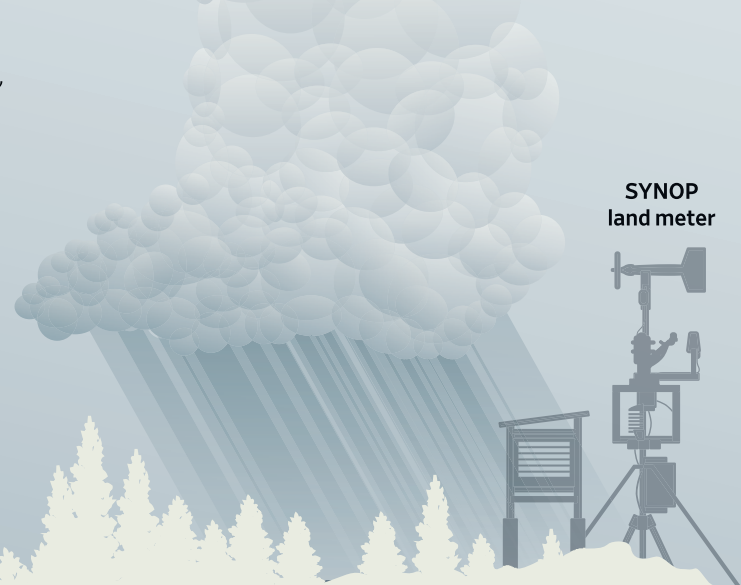
**Dropsondes**, expendable weather reconnaissance devices, are dropped from an aircraft to measure and track storm conditions as the device falls to the surface.



**Radar** uses radio waves that are deflected back by precipitation to infer information about rain and snow.



**Surface synoptic observations (SYNOP)** are updates from thousands of manned and automated weather systems on land or sea that report observations at a fixed time interval.



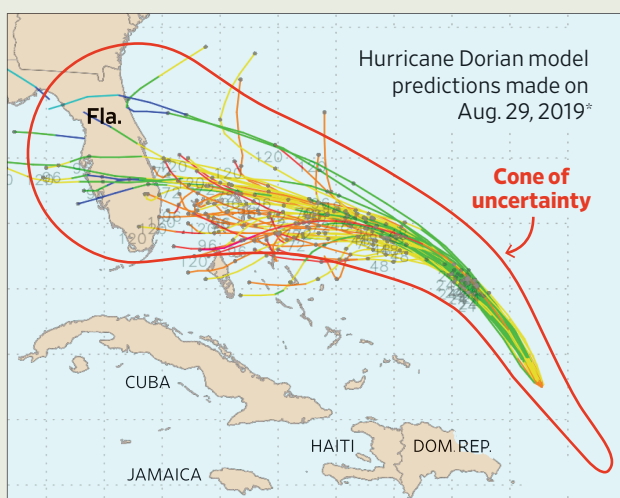
SYNOP land meter

## Cone of uncertainty

In the case of modeling the path of a hurricane, the variability of predictions can be understood by running the model multiple times while changing the inputs — like wind speed and direction, pressure, temperature, and moisture — that affect the prediction at given locations and times.

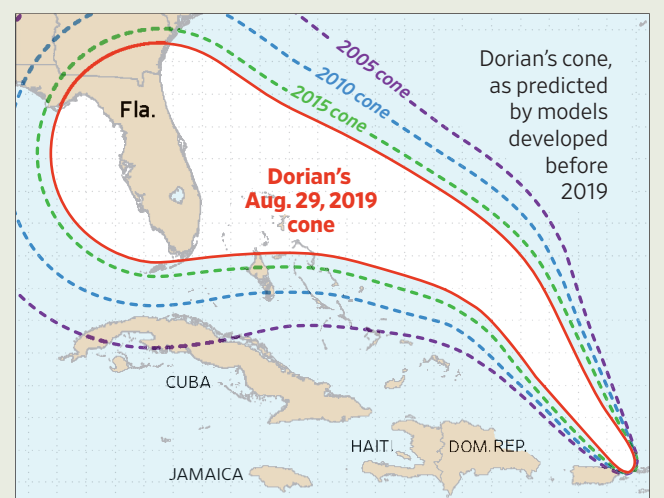
The probable track of a hurricane is represented by incorporating individual predictions into a “cone of uncertainty,” which shows the likely path of the storm’s center but not the size of the storm.

Typically, the near-term path of a hurricane — the base of the cone — is predicted with a high level of confidence. However, as models predict where the center of the storm will be days in advance, the uncertainty increases and the cone widens.



Over recent decades, mathematical, statistical, and computing advances have helped to decrease the uncertainty, and thus narrow the cone. This has enabled a more accurate estimate of areas likely to be impacted.

More reliable forecasts help communities prepare for and respond to weather events.



Dorian's cone, as predicted by models developed before 2019

[ BETTER MATH. BETTER INSTRUMENTS. PARTNERS FOR PREDICTION. ]

\*Hurricane Dorian is the most recent example of a Category 5 hurricane to hit the U.S. as of Aug. 2, 2022.

Sources: Images courtesy of NASA and NOAA