Microsoft

AI for Earth Grantee Profile

Scripps Institution of Oceanography / CW3E
Atmospheric river forecasting

Summary

Atmospheric rivers are a weather phenomenon that cause much of the precipitation in the western coasts of continents but aren't well represented in current forecasting models. The Center for Western Weather and Water Extremes (CW3E), a project of the Scripps Institution of Oceanography at UC San Diego, was established to better understand and predict atmospheric rivers and other phenomena affecting the western US. By applying machine learning and other AI tools to existing decades of weather data, CW3E hopes to improve the accuracy of forecasts and provide better tools and processes for managing flooding and drought conditions.

Improving weather forecasting for the western US with AI

Weather forecasting is a vital tool at all levels of modern society, from mundane daily activities to critical long-term planning at regional or even national levels. Predicting precipitation is important for agriculture, reservoir and water supply management, flood control, and many other areas. However, long-term forecasting is notoriously difficult to do. As popularly illustrated by the "butterfly effect"—more technically called *sensitive dependence on initial conditions*—a small change at one point in time and location can eventually grow to have large consequences. And so, a chance of a partly cloudy day in a week becomes a rained-out picnic—or a reservoir threatening to overflow its dam.

> Five days out from landfall, the best forecast model had a margin of error of over 600 kilometers, the distance between Los Angeles and San Francisco.

A primary forecasting model implemented across the US is the National Center for Environmental Prediction's Global Forecast System (NCEP GFS). This model uses four daily initialization times and builds predictions at three-hour increments out for the next 16 days, with a grid resolution of 0.5 degrees (approximately 55 miles east to west). Although the physics are constrained well, it's still subject to the same sensitive dependence on initial conditions: a small difference in the data used for modeling can mean a hundred-mile difference between the forecast and where a storm actually hits.

One additional wrinkle in weather forecasting affects the western US. The west coast receives much of its moisture in a form that has been little studied until recently: atmospheric rivers. Atmospheric rivers are long, narrow bands of water vapor originating in the tropics that develop into storm systems and deliver massive quantities of water when they reach land. These intense storms are a major cause of flooding in the west, but also are major contributors to the snow pack and water supply—and thus also a major factor in droughts, when they don't arrive when or where expected.

Predicting that arrival under the current forecast models can be very uncertain. A 2013 study published by NOAA's Earth System Research Laboratory showed that five days out from landfall, the best model had a margin of error of over 600 kilometers, the distance between Los Angeles and San Francisco. That much uncertainty in so little time makes it highly difficult for water managers and flood controllers to prepare for major rainfall.

Monitoring and predicting atmospheric rivers

However, because atmospheric rivers are such massive structures—by definition, over 2,000 km in length—and arise even further distances away from the coast, they offer an opportunity to use modern technology for more precise forecasting. In response to a formal recommendation from the Western States Water Council for forecasting research and practices tailored to the western US, the Scripps Institution of Oceanography at the University of California San Diego established the Center for Western Weather and Water Extremes (CW3E). CW3E's mission is to apply modern scientific research and technology to help address the impacts of extreme weather and water events on the environment, people, and economy of western North America.

> The AR Landfall tool provides guidance on the intensity, duration, orientation, and timing of atmospheric rivers up to 16 days in advance.

CW3E is developing several tools to help support forecasting of atmospheric rivers. These start with forecast maps derived from NOAA's numerical weather prediction model data, as well as forecast plume diagrams that show possible variations in timing and intensity at landfall. The AR Landfall tool provides guidance on the intensity, duration, orientation, and timing of landfalling atmospheric rivers up to 16 days in advance. And watershed forecast tools provide guidance on the impacts of precipitation from the atmospheric rivers, including how it is likely to divide between rain and snow, which helps to assess flood and water supply risks. Along with these tools, CW3E developed an atmospheric river category (AR CAT) scale that rates the intensity and duration of an atmospheric river event, to help communicate the balance between hazardous and beneficial.

Applying machine learning to improve forecasting

CW3E's aim with this project is not to replace existing forecast models, but to augment them by using machine learning algorithms to reduce the landfall location error in predictions. The goal is to create a deep learning model that accurately corrects for bias and error in operational ensemble forecasts. This model will also help identify physical features of atmospheric river weather systems that can further improve the current weather forecast models' ability to predict landfall.

Training the algorithms requires a massive amount of data—they will be using NASA's MERRA2 dataset, covering the years 1980 to 2015 in three-hour increments in a grid of approximately 0.5 degrees latitude by 0.625 degrees longitude (the same resolution used by the NCEP GFS predictive model). That's over 100,000 records just in terms of time segments alone, and millions of data points in total.

> CW3E's deep learning model will augment existing forecasts by correcting for bias, reducing the landfall location error in predictions.

With their AI for Earth grant, CW3E is using Microsoft Azure storage and virtual machines for the massive amounts of data and intensive training that deep learning models require. Azure provides the computational resources that would not be cost-effective for CW3E to purchase as hardware for itself. The code is processed through Azure Machine Learning packages. Each model takes about seven hours per training session, but once deployed can produce a forecast within a few minutes.

Going forward

CW3E currently has a pilot project called Forecast Informed Reservoir Operations (FIRO) underway at California's Lake Mendocino reservoir. Like most other reservoirs, Lake Mendocino's operations manual, developed decades ago, uses a simple seasonally based measurement curve to maintain water levels in the reservoir. Excess rainfall during the historically dry months may lead the reservoir managers to release water even if the reservoir has capacity at that time, in order to maintain the reservoir's level as set in the manual and avoid flooding during the anticipated rainy months.

However, if that anticipated precipitation never arrives in the rainy months, unplanned drought conditions would ensue. Likewise, flooding and damage may occur if unpredicted atmospheric rivers bring heavy rains during the wet months—as occurred at California's Oroville Dam in 2017. Through FIRO, CW3E is working to apply better atmospheric river modeling and forecasting tools to enable more proactive, flexible reservoir operations that account for increased variation in weather patterns and allow more responsiveness to current conditions. The goal is to not only improve operations at Lake Mendocino but also document a process that can be replicated at other reservoirs in the western US.

About CW3E

The Center for Western Weather and Water Extremes (CW3E) was established by the Scripps Institution of Oceanography at the University of California San Diego in response to a recommendation by the Western States Water Council for focused weather research, monitoring, and prediction tailored to the Western US. The Center's mission is to provide 21st-century water cycle science, technology, and outreach to support effective policies and practices that address the impacts of extreme weather and water events on the environment, people, and economy of western North America. CW3E works in partnership with the California Department of Water Resources, NOAA ESRL/Physical Sciences Division and National Weather Service, NASA/Jet Propulsion Laboratory, Orange County Water District, Sonoma County Water Agency, U.S. Army Corps of Engineers, and the U.S. Bureau of Reclamation. The team consists of faculty, research PhDs, and graduate students at the Center.

About Scripps

A department of UC San Diego, Scripps Institution of Oceanography is one of the oldest, largest, and most important centers for ocean, earth, and atmospheric science research, education, and public service in the world. Research at Scripps encompasses physical, chemical, biological, geological, and geophysical studies of the oceans, Earth, and planets. Scripps undergraduate and graduate programs provide transformative educational and research opportunities in ocean, earth, and atmospheric sciences, as well as degrees in climate science and policy and marine biodiversity and conservation.

Resources

Websites

Center for Western Weather and Water Extremes (CW3E) site
Scripps Institution of Oceanography at UC San Diego site
AI for Earth

Publications

Wick, G. A., Neiman, P. J., Ralph, F. M. & Hamill, T. M. "Evaluation of Forecasts of the Water Vapor Signature of Atmospheric Rivers in Operational Numerical Weather Prediction Models." *Weather Forecast*. 28, 1337–1352 (2013). https://journals.ametsoc.org/doi/full/10.1175/WAF-D-13-00025.1

Documentation

"What are atmospheric rivers?" National Oceanic and Atmospheric Administration (NOAA). December 2015. https://www.noaa.gov/stories/what-are-atmospheric-rivers