Pair Use Neural Network to Predict Hurricane Waves

Hurricane waves pose a significant threat to recreational, commercial, and military vessels, and can inflict massive damage to beaches and beach-front property.

VIMS researchers Dr. Jerome Maa and graduate student Jun-Young Kim are now testing whether a new type of computer model can improve wave forecasts and thus help mariners better withstand a windstorm's fury. As a lieutenant commander in the South Korean Navy, Kim takes both an academic and professional interest in his work.

The new model, called an artificial neural network or ANN, is designed like the human brain to learn from its experiences and to recognize patterns. "ANN models are simpler and require much less computing time than traditional numerical models," says Kim. Their ability to quickly forecast a wave field makes them particularly promising for vessels at sea.

The National Hurricane Center and other U.S. forecasting agencies currently predict waves using a state-of-the-art numerical model known as WAVEWATCH III. But "even these third-generation wave models aren't perfect," says Kim.

Most importantly, traditional numerical models require prohibitive computing time and power. This drawback is particularly vexing for naval vessels, which would prefer wave forecasts on a real-time basis.

Kim estimates that a 2,000-times increase in computational power would be required to meet the forecasting needs of the navy; an increase that is unlikely to occur any time soon.

Current numerical models also suffer from the scientific community's imperfect knowledge of the complex processes involved in wave formation, a deficiency well appreciated by anyone who has looked out at the wind-driven cauldron of spray and white caps generated by a hurricane or nor'easter.

"Wind-wave generation is a complicated non-linear process that we don't yet fully understand," says Kim. Maa notes that interactions among waves, transfer of momentum from wind to waves, and dissipation of energy from white capping and bottom friction are the processes that are understood least.

Attempts to improve traditional numerical models by incorporating additional equations, for instance to account for wave-to-wave interactions, further increases computing time.

Maa and Kim are trying to sidestep these problems by using an ANN model instead.

Unlike current numerical models that use physically based equations to calculate wave height, frequency, and direction, ANNs "simply find the difference in patterns between observed inputs and outputs," says Kim.

Maa uses an automotive analogy to describe the difference between the two model types. "If you want to predict how fast a car can go, you can stand on the street and watch the cars go by. With practice, just by looking at a car's shape you can recognize what kind it is. If it's a BMW 850, you know it can go really fast. That's ANN modeling, which is based on pattern recognition. With a numerical model, you'd have to know the processes by which the car works: how its internal

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Graduate student Jun-Young Kim and Dr. Jerome Maa (seated) are testing whether an artificial neural network can accurately forecast ocean waves.

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combustion engine operates, the rate at which it burns gas, the thermodynamic transfer of energy from gas to wheels."

In recognizing patterns, ANNs resemble the human brain. "An ANN is designed to imitate the brain to learn from past experiences," says Kim, "much like a child learns to recognize dogs from examples of dogs." After these early learning processes, a child can generalize beyond the family pet by recognizing other dogs, even an unfamiliar breed.

In order to teach an ANN to predict wave height and frequency, Kim first trains it by entering wind-speed data for specific storms, like 1999's Hurricane Floyd, and corresponding wave data as measured by a set of five NOAA buoys along the U.S. East Coast. Once the ANN has "learned" the height and frequency of waves generated by Floyd's unique wind field, Kim repeats this "training" process with similar data sets from other Atlantic hurricanes or winter storms.

As the training continues, the ANN's circuits begin to recognize the characteristic wave pattern that results from a particular wind field. Once the ANN "recognizes" this pattern, it can begin to predict the wave field that is likely to result from an ongoing or future storm.

To date, Kim's ANN model has shown mixed success. "So far, we are lucky with winter storms, we can get a correlation of 80-85% between predicted and observed waves," says Maa. For hurricanes we are not that lucky yet." He estimates the correlation between predicted and observed hurricane waves at about 70%.

The disparity in forecast accuracy is partly due to differences between the storms. Whereas winter storms tend to be large and slow moving, with evenly distributed winds, "A hurricane's wind speed and direction change drastically with time and distance to the eye," says Kim. "That's why hurricane prediction is much more difficult than storm-wave prediction."

The main problem, though, is a lack of data. "The performance of an ANN model depends on how good your data are," says Maa. "We are very lucky in this country because we don't have too many hurricanes, but because of that we also don't have enough data to fully observe the pattern."

Whereas the northwest Pacific experiences an average of 16 typhoons a year, the Atlantic basin averages only 5 hurricanes annually. "In Taiwan, where I come from, we have 1 or 2 typhoons each year," says Maa. "If you had a good wave-monitoring program there for 20-30 years, you'd get enough data."

In the meantime, Kim is examining ways to interpolate between the 10 existing points for which wind data are available in the western Atlantic. "There should be a way to use some type of interpolation to find the waves at other places," says Maa. "But what kind of interpolation we don't know yet."

Despite the drawbacks of ANN modeling, Maa still thinks Kim's approach provides significant value. "This is one of the first studies using an ANN model to predict wave height using the correct wind input," he says. "ANN is a technique that can be applied in many, many areas. We have the tool now, and a good example to show how we can use it. Now we would like to see other people build on this study."

VIMS By the Numbers.....

- **64.6** Water temperature off VIMS' Ferry Pier on June 1. Normal water temperature for June 1 is 72.7° F.
- **$37,810,402** Monetary value of VIMS research grants active during the 2002 fiscal year (416 multi-year awards).
- **$5,000** Biennial budget of the Virginia Fisheries Laboratory (VIMS' predecessor) for 1939-1940.
- **150** Commercial watermen who collaborate in VIMS' bounty program for the invasive marine snail *Rapana venosa*. The program, which started with 35 watermen in 1998, pays $5 for a live Rapa whelk and $2 for a dead one. To date, bounty hunters have turned in more than 5,000 specimens, and more whelks are collected each year.
- **36** Number of research vessels in the VIMS fleet.
- **7,400,000** Number of bibliographic records available for query by users of VIMS' new on-line library database.
- **12** Percentage of VIMS graduate students who hail from outside the U.S.
- **40** Number of VIMS faculty and students certified for scientific diving.
- **300** Approximate number of sea turtles that strand within Virginia's waters each year, mostly juvenile loggerheads and Kemp's ridleys.