Research

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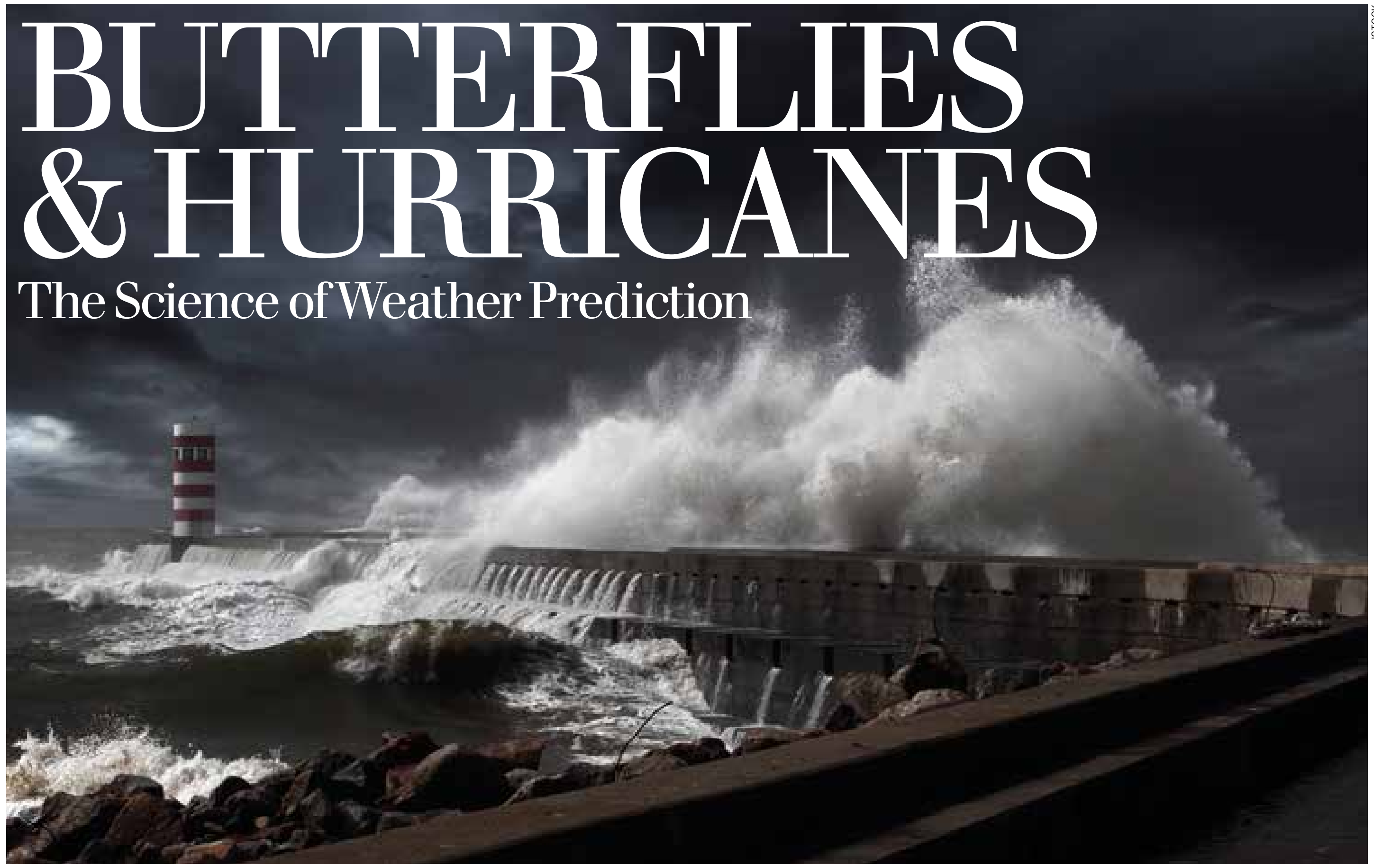
BUTTERFLIES & HURRICANES

The Science of Weather Prediction



ISTOCK

HANNAH ARNOLD

ABOVE: Dr Hannah Arnold prepares for all weathers

From the dawn of time, people have been interested in knowing tomorrow's weather. But how exactly do we make a weather prediction? As late as the mid 20th century, it was thought that the best way to predict the future was to look to the past. The movement of weather systems over the globe should be recorded over many decades, building up a large historical dataset. Then it would simply be the case of looking back over the record for a day which looks very similar to today, and issuing the historical evolution of the atmosphere as today's forecast for the coming week. However attractive this method sounds, it does not work in practice. This is because the atmosphere is *chaotic* – the evolution of the weather over days to weeks is very sensitive to small details in the state of the atmosphere on the first day, the 'butterfly effect', but these details may be too small for us to detect using the limited satellite and weather balloon data available. The forecasting method described above is doomed to fail as it is impossible to find a historical match to today's weather with high enough accuracy.

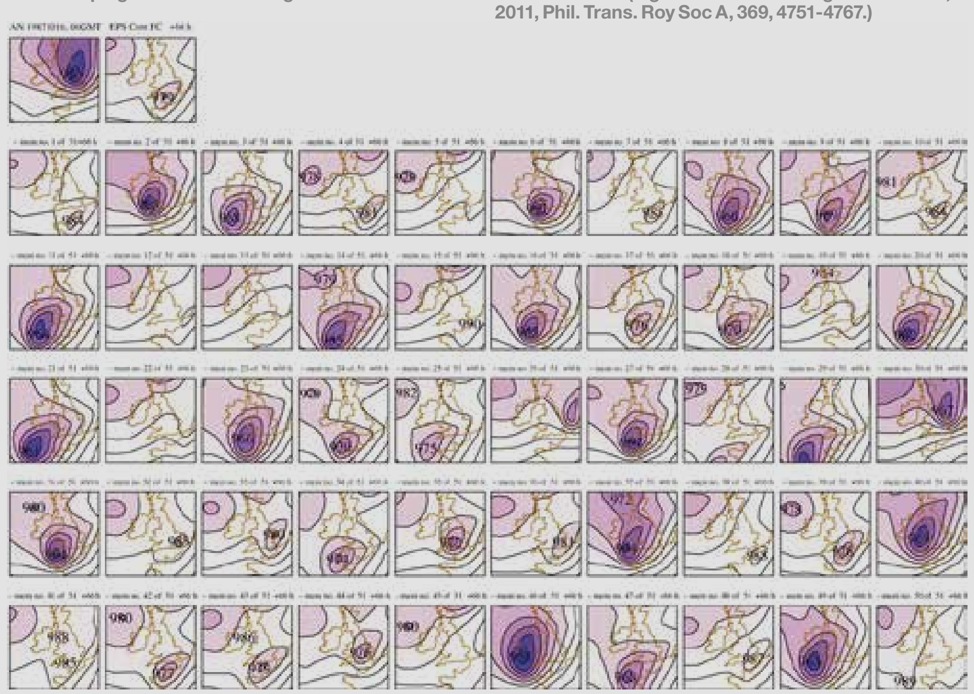
Instead of looking to the past, we make a forecast by using the mathematical equations which describe the weather to build a complex computer simulator of the atmosphere. We know the equations which describe the atmosphere, such as the large scale relationship between wind, pressure and temperature – these are included in our simulator. We also know the equations which describe processes at smaller scales – the interaction between wind and waves, how clouds and rain form, and how the landscape affects the local weather. However, we only have limited computer resources, so must make simplifications while building the simulator. In particular, small scale processes (such as clouds) are usually represented using approximate equations, called *parametrisation schemes*, which then act as a large source of uncertainty in weather forecasts.

WEATHER PATTERNS

We are now able to produce useful probabilistic forecasts which include a reliable estimate of the uncertainty in the prediction. Importantly, it has been found that certain weather patterns are very predictable – the errors due to the starting conditions and model simplifications stay small as we look to the future.

The Great Storm of '87 is an excellent example of very unpredictable weather. Figure 1 shows the results of applying a modern probabilistic weather forecasting system to that situation. The single 'best guess' forecast, similar to that which Michael Fish would have had access to, gives no indication of the storm. However, if we consider 50 alternative forecasts, all equally likely, we see that some do predict the storm, while others indicate very calm conditions. It is only by representing uncertainty in the forecast that the highly unpredictable nature of that night's weather is revealed, and the public can be alerted to the possibility of a big storm.

BELOW: A probabilistic forecast of pressure for 15-16 October 1987 using starting conditions from 66 hours previously. Top left shows the observed 'Great Storm' – a deep low-pressure system with very strong winds. Top right shows the best guess forecast made using a modern deterministic weather forecasting model. The other fifty panels show equally likely outcomes from a modern probabilistic weather forecasting system, indicating substantial uncertainty in the forecast. (Figure taken from Slingo and Palmer, 2011, Phil. Trans. Roy Soc A, 369, 4751-4767.)



> 10% chance of rain? I'd probably risk it. But if the forecast were 50-50, I'd be packing my umbrella.

As we all know, weather forecasts are not always correct – predicting the future weather is challenging, and forecasts can be drastically wrong! Michael Fish's infamous forecast of the Great Storm of October 1987 is an extreme example: hours before the storm hit, he is quoted as saying "Earlier on today, apparently, a woman rang the BBC and said she heard there was a hurricane on the way. Well, if you're watching, don't worry, there isn't!". Why was his forecast so far out? There are two main sources of error in weather forecasts. The first is from estimating the starting conditions for the forecast. As I have just explained, the evolution of the weather is very sensitive to small details in the state of the atmosphere at the start of the forecast. A second source of forecast error is from the simplifications and approximations made when developing our atmospheric simulator. A single best-guess forecast for the weather next week is not very useful, as it doesn't indicate how sure we are in our forecast. It would be more useful to make a probabilistic forecast for the weather next week, using our knowledge of these sources of error to indicate how certain we are that, for example, the day in question will be dry, calm and storm-free.

My research focuses on predicting uncertainty in weather forecasts. I work with a new technique which has been proposed for representing those uncertainties that arise from simplifications in the model. The parametrisation schemes representing small scale processes such as clouds are made stochastic. This means that random numbers are included into the equations to represent different possible small scale effects – instead of calculating only the most likely clouds over Oxford, for example, we calculate the effect of many different possible clouds on the large scale weather patterns to see how this affects the forecast. Now, instead of making a single, best-guess forecast, a set of forecasts are made for the weather next week. The different forecasts start from different, but equally likely, starting conditions estimated from our measurements of the atmosphere. Each forecast also uses different random numbers in the stochastic parametrisation schemes indicating different possible effects of the small scale processes.

It is impossible to predict exactly what the future will hold, including the weather next week. However by acknowledging that this is the case, and instead striving to accurately indicate the uncertainty in our prediction, we can provide honest weather forecasts to the public who can then choose how to use the extra information. 10% chance of rain? I'd probably risk it. But if the forecast were 50-50, I'd be packing my umbrella.