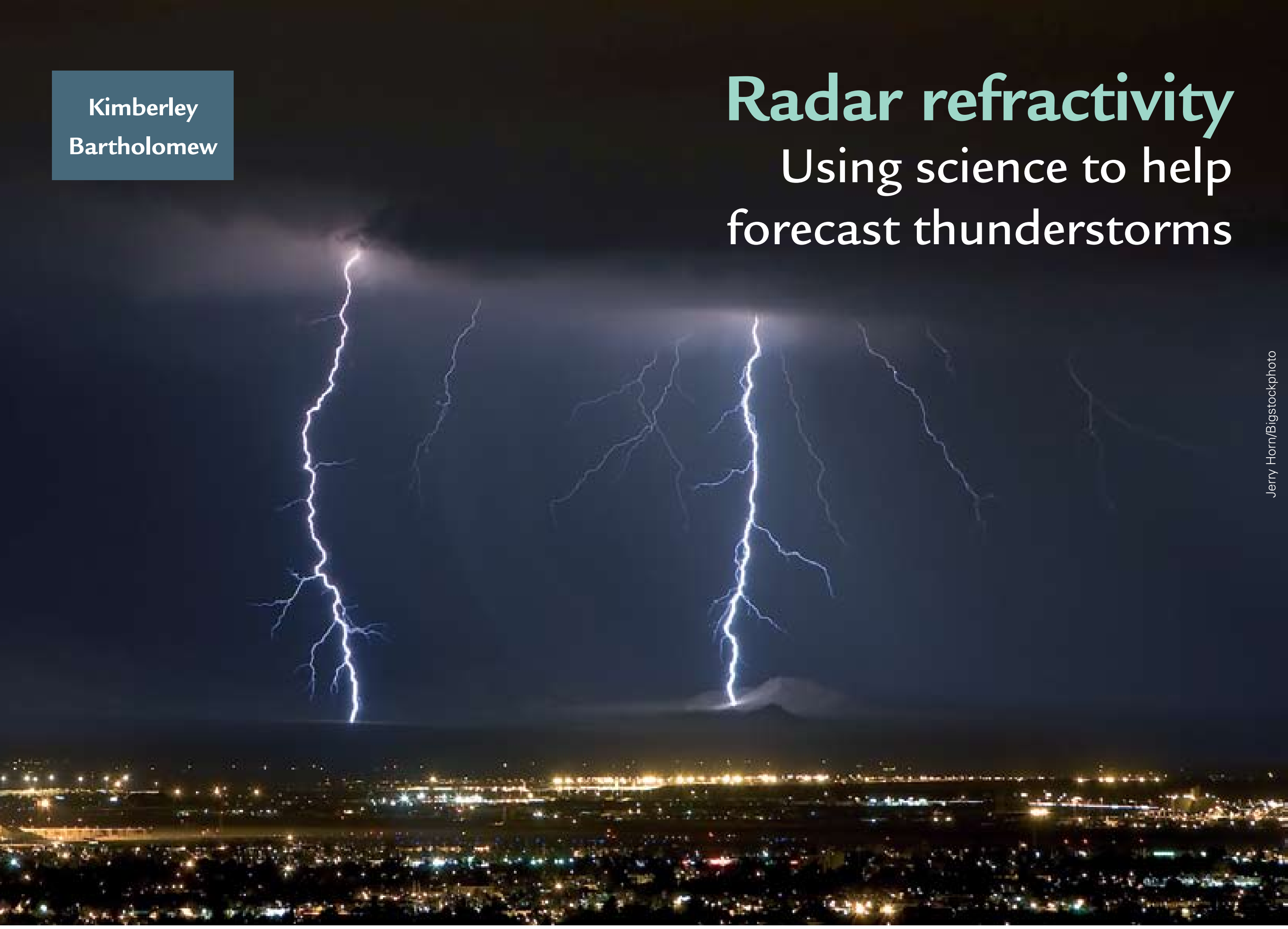
Radar refractivity

Using science to help forecast thunderstorms

Kimberley Bartholomew



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Weather forecasts can help keep the public safe in extreme situations by providing advance warnings: for example, airline pilots rely on accurate information about the development of thunderstorms to help them decide which routes might be at risk from lightning or violent downbursts of air. Likewise, people on the ground need timely forecasts of such events as they are vulnerable to flash flooding and hail. Kimberley Bartholomew describes how meteorologists measure the humidity of the atmosphere.

Simulating the atmosphere

From TV forecasts, you will be aware that we can predict general changes in the weather up to about a week in advance. This is far from guesswork: behind smart presenters and studio lights we are harnessing the power of mathematics to tell us about the state of the weather and how it might change. Computer models, which incorporate most known physical laws that govern the atmosphere, are run 24 hours a day on powerful supercomputers, giving us exclusive insight into how the real weather might behave.

So if we can simulate the atmosphere in a model, then why can we not forecast the weather a year, or ten years, in advance, with perfect accuracy? Firstly, we do not fully understand the physics which drives the atmosphere and so we have to use an imperfect set of equations to run our simulations of the weather. Secondly, chaos theory tells us that very different end conditions can be given from similar starting points, so that a model which is run a long way into the future will start to drift from reality.

Atmospheric scientists, including us here in Reading, are striving to deepen our understanding of the atmosphere and to feed this new understanding into forecast models. Indeed, UK Met Office statistics show that the accuracy of forecasts has improved (for example, a three-day forecast now has the accuracy of a one-day forecast 20 years ago) and this is expected to increase further.

Using real observations

Thunder clouds form when a convection current is set up in the atmosphere (see Figure 1). Convective showers and thunderstorms are hard to predict since models are generally unable to capture the small-scale changes in atmospheric variables which influence their behaviour. We know that the timing and position of individual thunderstorms is sensitive to the horizontal distribution of humidity (water vapour in the air), because even on a hot day, clouds cannot form without moisture. Additionally, since water loses energy as it condenses from vapour into cloud droplets (exactly like steam condensing onto a cold window), this extra energy is available to heat up the atmosphere even more, thus strengthening the convection.

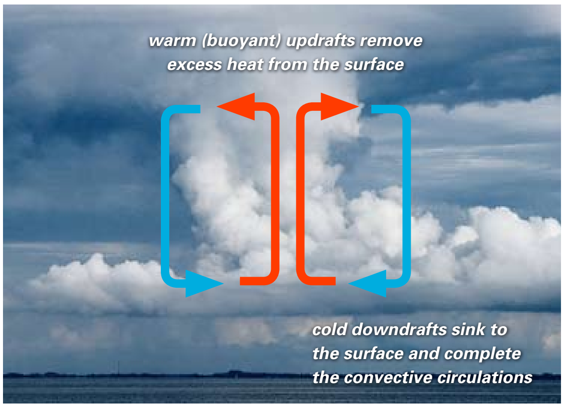

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Figure 1 *Convection currents are set up as warm air rises.*

If we could obtain a dense network of observations which told us where the humidity is greatest on a local scale, we could use this to tell a model about the true state of the atmosphere, which will act to 'update' the model and pull it closer to the real picture (a process called data assimilation). When used at a very high resolution, this could greatly improve the accuracy of forecasts of convection and thunderstorms.

Measuring phase changes

Here at Reading, we are developing a technique designed to achieve high-resolution humidity measurements using radar, combined with some simple scientific principles. Radar is used routinely in meteorology to detect rainfall (see Box 1).

Currently we use a 3m radar dish located in pretty North Devon, surrounded by rolling hills and trees. When we detect a returned radar signal, we can measure its phase (the particular point in the wave cycle); if the phase changes, we then deduce that the time taken for the wave to return to the radar has changed. There can be two reasons for this:

Normally, a phase change tells us that the reflecting object's distance from the radar has changed (see Figure 2a). This is how planes are tracked by an air traffic control tower using a giant rotating dish near the runway, or how an area of rainfall is tracked by meteorologists.

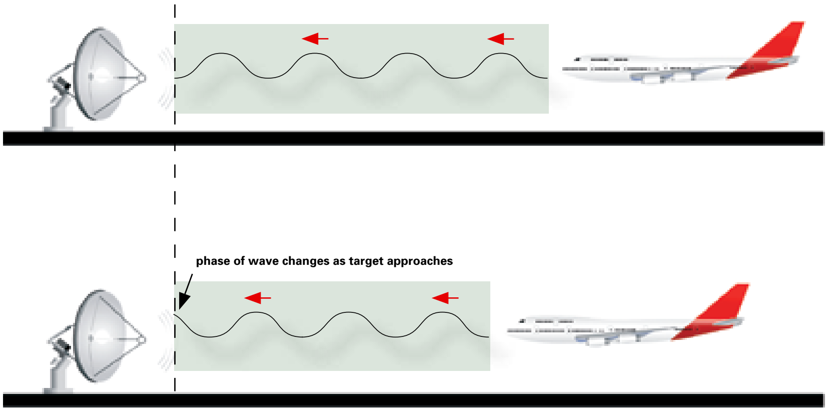

Figure 2a *A moving target produces a phase change in the reflected radar wave.*

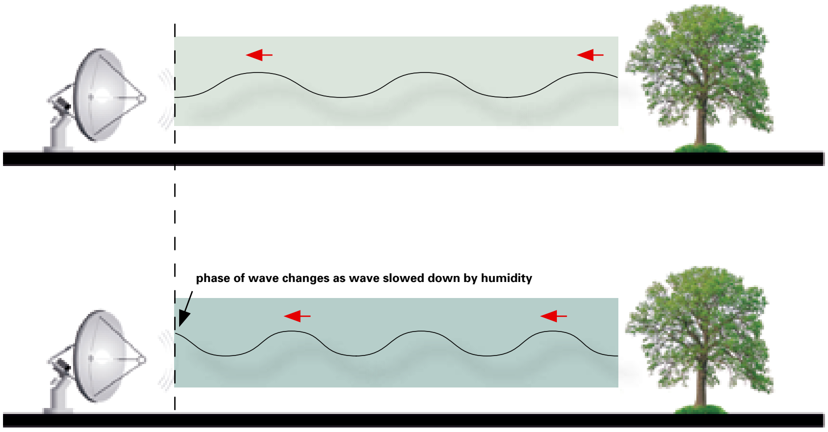

Figure 2b *Alternatively, the radar waves may have been slowed down by humidity in the atmosphere. On its way to and from a target, a wave will encounter air molecules within the atmosphere and interact with them. This slows them down, causing the radar waves to be refracted.*

The amount of refraction depends on the condition of the atmosphere at the time. For example, if the air is colder (and therefore denser), or there is more water vapour in the air (higher humidity) a radar wave will propagate more slowly. We say that the refractivity has increased (see Figure 2b). This increases the time it takes the wave to return to the radar, which will generate the phase shift that we can use to determine the amount by which the wave has slowed down, and therefore by how much the refractivity has increased. It turns out that refractivity is most sensitive to humidity (especially in the summer) and so changes in refractivity tell us about changes in humidity.

Making a map of humidity

By doing some simple sums, we can work out the changes in humidity between lots of different targets along a path and by doing this for all angles, build a 2D map of local changes in humidity. This is where our radar in Devon comes into its own: with so many hills and trees everywhere to bounce the wave back, we can build up a really detailed map showing all the fine structure that conventional methods can miss.

A familiar effect of **refraction** is the apparent bending of a drinking straw where it emerges from a glass of water. This occurs because electromagnetic waves travel at different speeds depending on the material they are travelling through. For instance, in the lower atmosphere they travel at around 99.97% of the speed they would through a vacuum and at just 75% of this speed through water.