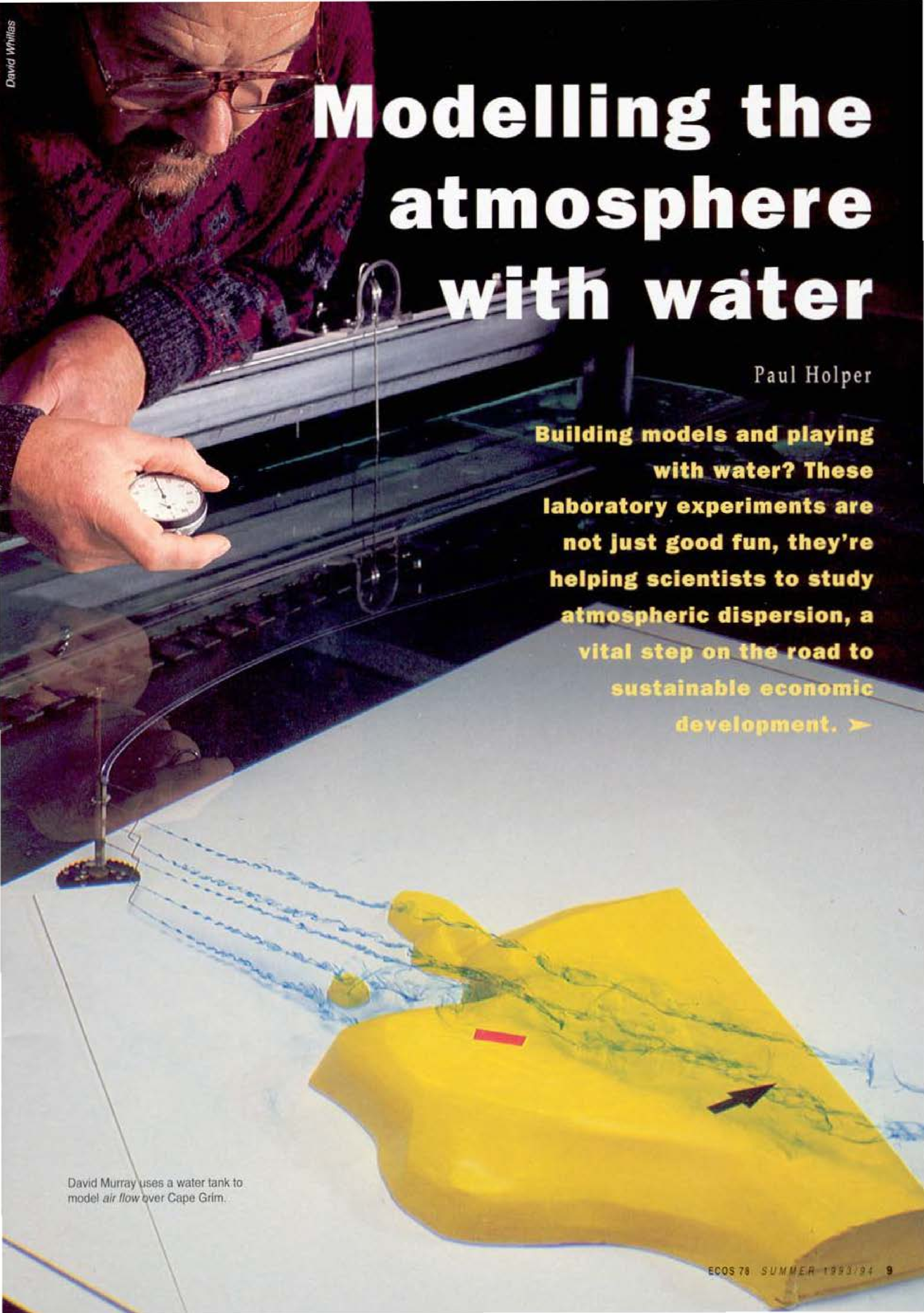
Modelling the atmosphere with water

Paul Holper

Building models and playing with water? These laboratory experiments are not just good fun, they're helping scientists to study atmospheric dispersion, a vital step on the road to sustainable economic development. ➤



David Whillas

David Murray uses a water tank to model *air flow* over Cape Grim.

Above every square metre of the earth's surface is 10 tonnes of air. Air keeps our planet at habitable temperatures. It brings us our weather patterns, and provides us with a gigantic reservoir for our waste gases.

Air is a fluid. It ebbs and flows, swirls and surges. But its movement is difficult to study.

However, the behaviour of another fluid, water, can be readily examined in laboratory tanks. Tank experiments have many applications. They are used for simulating flow in rivers, harbours and estuaries. Rotating tanks allow scientists to study large-scale ocean circulation patterns. Australia's successful 1983 America's Cup challenge had its origins in a Dutch tank facility. The Bond Syndicate fine-tuned Australia II's now famous winged-keel design during a series of towing experiments with a one-third scale wooden model.

Water tank experiments can also tell us a lot about air flow. Scientists use water to learn more about the behaviour of our atmosphere.

Air flow over a cape

Perched 90 metres above the sea on Cape Grim in remote north-western Tasmania is the Australian Baseline Air Pollution Station. For the past 15 years, the station has provided detailed information about the rise in atmospheric greenhouse-gas levels.

Overshadowing the station is a giant telecommunications tower. The tower lends little beauty to the scientific complex, but it does allow scientists a choice of heights at which to sample air that has journeyed thousands of kilometres across the Southern Ocean.

The station inlet is 10 m above the ground; the tower inlet is 70 m high.

CSIRO Division of Atmospheric Research chief, Dr Graeme Pearman, and senior principal research scientist, Dr Roger Francey, decided to investigate whether they could use these two inlets to measure differences between the composition of air close to the ocean surface and air slightly higher in the atmosphere. Any difference could tell them whether Cape Grim air samples are contaminated by the station's local surroundings. Knowledge of any contamination is essential if the data from the collected air is to improve our understanding of the global carbon budget.

Pearman sought to detect tiny variations in carbon dioxide concentrations in air collected at the two inlets. Francey was interested in the measurement of any carbon isotope differences.

For several years a carbon dioxide analyser was dedicated to the comparison of air at the two inlet levels. Throughout the period, on selected days, alternate air samples were collected for 10-minute periods, first from the 70 m inlet, and then from the 10 m inlet.

Results from analyses soon showed that there were differences in carbon dioxide levels between air collected close to the ground and air higher up. Small, but significant differences. On average, during the daytime in spring, the lower air samples contained 0.1 ppm (part per million) less carbon dioxide than the higher samples. Even though this difference is small compared with the background concentration of carbon

Cape Grim station with the Telecom tower in the background. The model (below) helped scientists to investigate variations in air composition. The dye streams represent air flow at 20 metres, 50 m, 80 m, 110 m, and 140 m above sea level.

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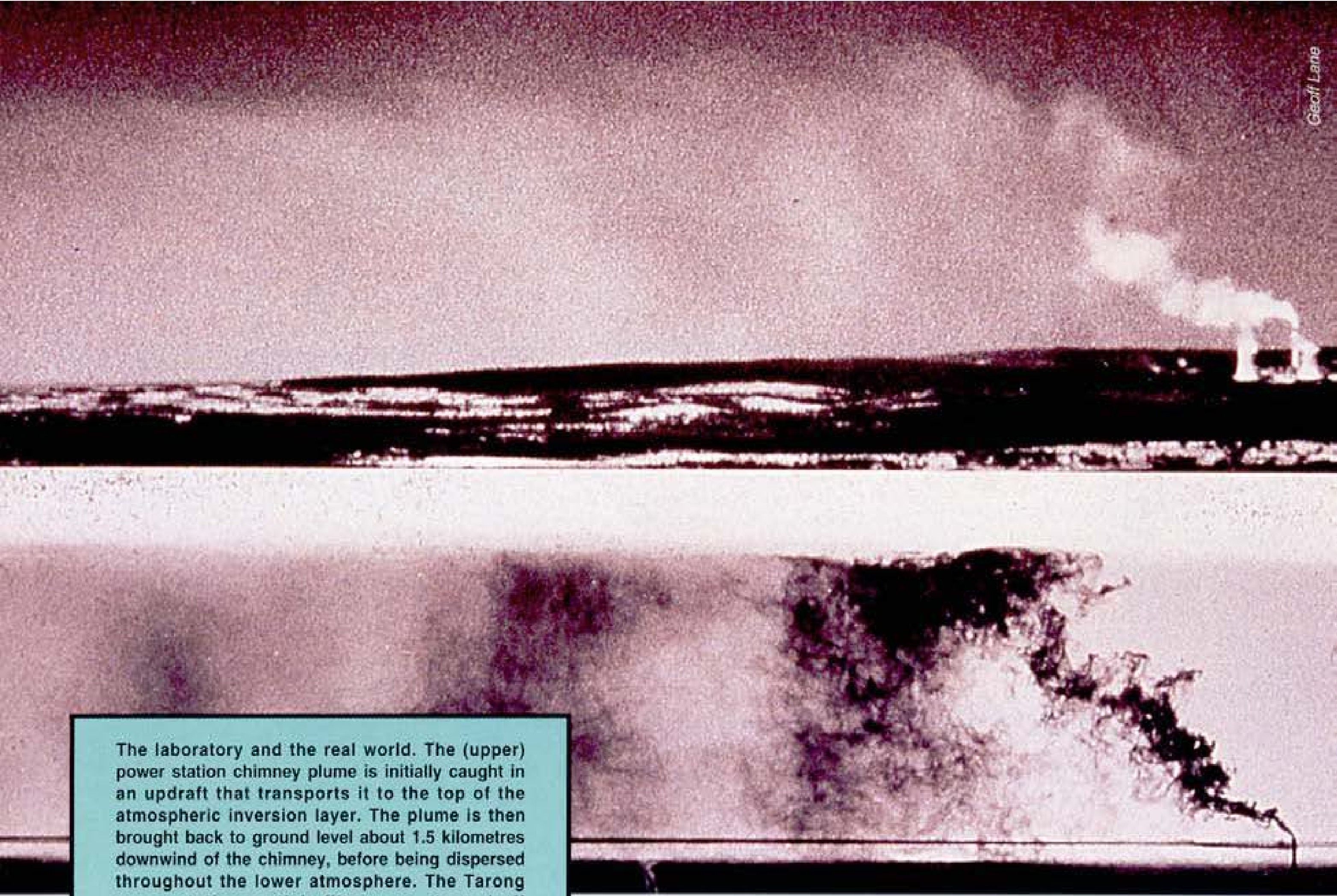
The Baseline Air Pollution Station at Cape Grim in north-western Tasmania.



The laboratory and the real world. The (upper) power station chimney plume is initially caught in an updraft that transports it to the top of the atmospheric inversion layer. The plume is then brought back to ground level about 1.5 kilometres downwind of the chimney, before being dispersed throughout the lower atmosphere. The Tarong power station particle filters were turned off specially for this experiment, to help scientists track the plume. The (lower) laboratory photograph has been inverted and is from the Division of Atmospheric Research saline convection tank, which models similar behaviour using a 1:5000 scale model.

dioxide in air (355 ppm), it was far greater than what would be expected due to atmospheric diffusion alone.

The most likely explanation for the concentration differences was that the lower air was being robbed of carbon dioxide by photosynthesising plants close to the station.

Measurements of carbon-12 and carbon-13 isotopes in the air samples were consistent with local interference from plants. Terrestrial plants favour carbon dioxide containing the lighter carbon-12 isotope. Air collected at the lower inlet suggested that this form of carbon dioxide was less abundant than in samples collected from high up the tower.

These results raised an interesting question. How could local plants contaminate low-level air samples?

The Cape Grim station's baseline sampling takes place only when wind comes from across the ocean at more than 30 kilometres per hour. At this speed, air would not be in contact with local vegetation for long enough for carbon dioxide levels to be altered. To solve the problem, Pearman and Francey needed to know more about air flow patterns close to the ground.

Tracking the progress of rapidly moving air as it passes over an obstacle presents a major scientific challenge. Often, the easiest approach is to simulate the conditions in a laboratory.

The Division of Atmospheric Research's Geophysical Fluid Dynamics Laboratory is ideal for this sort of experiment. The laboratory houses a number of tanks designed to study atmospheric phenomena.

Dr Peter Baines, a senior principal research scientist, set to work with senior technical officer David Murray. They built a 90-millimetre high perspex model of Cape Grim and towed it under water through a 4 m by 1.5 m modelling tank.

Movement is relative. In Tasmania, air passes over Cape Grim. In the tank, the Cape Grim model moves underneath the water. In both cases, fluid is moving relative to land. Although water is far more viscous than air, appropriately-scaled modelling experiments clearly show all the important features of atmospheric flow.

Baines released dye upstream of the model at various heights to build up a complete picture of air flow as it passed Cape Grim and the baseline station.

High level flow was straightforward. The dye simply moved upward, and sometimes to the left and right, as it passed over the cape. Baines found that, regardless of wind direction, air sampled at the upper inlet, 160 m above sea level, comes from about 125 m above the sea.

Low level flow was more complex. At the base of the cliff, Baines discovered vertical vortices of swirling dye. Higher up the cliff the dye formed eddies. At some places it was completely stationary.

Converting his model results to the real world, Baines estimated that it takes air at higher levels about 10 seconds to pass from the ocean over the cape to the 70 m inlet. In contrast, by the time the lower level air has negotiated its way up the cliff face, more than 60 seconds may have elapsed. This is easily enough time for vegetation to affect carbon dioxide levels.

Emissions from industry

In the same laboratory, senior research scientist Dr Mark Hibberd, operates a 3.2 x 1.6 x 0.8 m convection tank. The tank, largely paid for by Victoria's State Electricity Commission, is designed to model the behaviour of power station plumes.

On sunny days with light winds, air warmed by the ground rises. At the same time, parcels of cooler air sink. Plumes released from tall chimney stacks can be brought down to the ground by the cooler air, in a process known as looping. Pollution problems are at their worst if looping happens close to the stack, before the plume has time to disperse.

Plume looping causes some of the highest ground-level concentrations of sulfur dioxide and nitrogen oxides in industrial regions such as the Latrobe Valley in Victoria, the New South Wales Hunter Valley, and Mount Isa in Queensland. Looping also creates large fluctuations in pollutant concentrations downwind of chimneys.

Hibberd uses his tank to identify conditions that are likely to lead to pollution problems for people living and working close to emission sources.

The tank presents an upside down view of the world. A layer of fresh water on top of a layer of salty water simulates the way in which cold air is often trapped close to the ground. Pollutants are trapped within this layer, unable to break through into the warmer air above.

Upward movements of warm air, which transport smoke away from the ground, are simulated by allowing a concentrated saline solution to diffuse downwards through a sintered polythene membrane into the tank. The salty water sinks through the fresh water, mimicking the way in which warm air rises in the real world.

The smoke plume is simulated by a solution of salt and dye injected into the top of the tank though a fine tube. Towing the tube through the tank models the effect of wind.

The 4000-litre convection tank allows Hibberd to model atmospheric smoke plumes for distances of up to 15 km from their source.

Plume dispersion in the tank shows striking resemblance to the behaviour of plumes from Queensland's Tarong power station, which was the subject of extensive field work in 1988 and 1989.

Typically, low buoyancy, cooler plumes show moderate looping, meandering some kilometres through the lower atmosphere before striking the ground.

The greater buoyancy of warmer plumes (simulated with concentrated coloured saline solutions) enables them to climb higher, becoming more diffuse. Ground strikes happen further from the source and pollutant concentrations are lower.

A laboratory is a controlled environment. Instead of scientists having to cope with a host of continuously varying conditions, they can isolate and study individual processes.

Just as distances are scaled down in laboratory tanks, so is time. Dispersion of a plume that would take several hours in the real world takes just minutes in a tank.

Often, a tank experiment will reveal the essential features of flow. Armed with this information, scientists can repeat measurements, either in the laboratory or in the field, knowing the best location to examine in depth.

Laboratory experiments provide a link between field measurements and computer-based numerical models. Knowledge gained from tank experiments improves the accuracy of numerical models' represention of atmospheric dispersion.

Where should a new power station be built to minimise pollution problems? How high does a smelter chimney need to be to ensure that pollutants disperse rapidly? Why do gases released in one part of a city affect residents hours later elsewhere in the city? Where should air pollution monitoring stations be located? Laboratory experiments help provide atmospheric scientists with information to answer questions like these.

Increasingly, we are recognizing the need for environmentally sustainable development. Improved understanding of atmospheric dispersion underpins our quest for cleaner air.

David Whillas

Dr Mark Hibberd and George Scott prepare their convection tank for studies of power station plume behaviour.