Tracking *plumes* in the sunshine

IMAGINE watching puffs of smoke as they snake away from an industrial chimney. Our eyes tell us that the smoke plume widens and disperses soon after emerging, eventually to disappear from view.

But where has it gone? Up or down, to the left or right? Will it come to ground nearby, or hundreds of kilometres away? How concentrated will the pollutants be when this grounding occurs, and how long will they remain there?

Gases and fine particles from power stations may travel some distance before their concentrations merge into the background, depending on the type and strength of emission, the natural features over which the plume passes, and the prevailing weather conditions.

In stable conditions, which often occur at night, plumes spread little in the vertical because there is little turbulence in the atmosphere. As a result, pollutants are transported far from their source of emission and when there are no hills around are unlikely to come to ground. But during daytime, heating of the sun causes that atmosphere to behave like a giant mix-master, mixing the air in large eddies.


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Top: In stable conditions, plumes spread very little in the vertical because there is little turbulence in the atmosphere. As a result, pollutants are transported far from their source of emission and when there are no hills around are unlikely to come to ground.

Above: In convective conditions, the atmosphere behaves like a giant mix-master, mixing the air in large eddies. With an appropriate understanding of convection and plume dispersion under different climates and terrains, models can be produced that predict the best site for new power stations or industries.

If plumes are caught in the grip of strong, descending convection currents, they may reach the ground too soon, causing the plume to ground just a few kilometres from the chimney, before the emissions have mixed with the atmosphere. Local pollutant concentrations may then exceed desirable levels, sparking the need for costly 'add on' emission controls. Whether or not this occurs at a particular site depends on local factors.

Convective air movement is common in Australia's warm climates, and can give rise to high concentrations of pollutants at ground level. We must understand this process, because it affects the quality of the air we breathe.

With an understanding of convection and plume dispersion under different climates and terrains, models can be produced that predict with greater accuracy the best site for new power stations or industries.

Scientists from CSIRO have for a number of years assisted power-generating authorities by carrying out research into the dispersion of chimney plumes, their fate and their environmental impact.

John Carras and David Williams from the Division of Coal and Energy Technology at North Ryde in New South Wales use specially-equipped aircraft to measure plumes over distances of up to 120 kilometres from power stations.

Sulfur dioxide, nitrogen oxides and fine particulates are measured and predictions made as to the rates of chemical transformations that might occur (such as nitric oxide to nitrogen dioxide and sulfur dioxide to sulfate). Concurrently, time-lapse photography records the horizontal and vertical movement of the visible plume.

Carras, a physicist, and Williams, an atmospheric chemist, teamed up in the late 1970s to study sulfur dioxide oxidation and plume dispersion from Mt Isa's copper and lead smelters. Since then they have spent countless hours measuring and interpreting the behaviour of plume emissions.

Work in the Hunter Valley and Central Coast region of New South Wales, a major power-generating site, has shown how plumes from power stations merge and behave as a single plume, and how coastal weather conditions can significantly affect plume behaviour.

Carras says the atmosphere is 'a complex animal'. A description of one of their field studies to track plume dispersion indicates just how difficult this 'animal' can be to characterise.

At the coalface

Carras and Williams joined scientists from the CSIRO Division of Atmospheric Research and Centre for Environmental Mechanics, the Queensland Electricity Commission and Flinders University to collect a set of data on plume dispersion under convective conditions at Queensland's Tarong Power Station.

A wide range of measuring techniques was employed during the two-week field experiment. The field measurements were made during the spring of 1989, a period expected to have clear-sky conditions with strong convection.

Dr Brian Sawford and his team from the Division of Atmospheric Research set up their equipment and caravan laboratory on a hill about 3.7 km east-north-east of the power station. Their task was to scan the early dispersion of the plume with an instrument called Lidar (Light Detection and Ranging).

The Lidar system fires a short pulse of light which is scattered and absorbed by air molecules and particles in the atmosphere. A small fraction of the laser beam scatters back to the Lidar. The concentration of particles in the atmosphere can be calculated from the intensity of the backscattered signal.

The Tarong plume was scanned repeatedly throughout the experiment at a number of different heights and distances from the chimney, with the operation of LIDAR, from aiming and firing the laser to storing the digital data, controlled by a personal computer.

Carras and Williams took charge of the cross-wind plume measurements. They must have felt like rally drivers as they traversed at right angles to the plume direction in a vehicle equipped to detect emissions such as sulfur dioxide and nitrogen oxides.

A compass and distance-measuring devices were used to record their location in relation to the power station. (The Global Positioning System is now used for this task.) Their choice of roads had to be carefully planned beforehand to make sure they didn't come upon a 'dead-end' at a vital moment.

These ground measurements were taken to help plot the location and size of the plume 'footprint'. That is, the kind of impression the plume would leave on the ground if it were the muddy foot of a giant.

But plumes don't leave muddy footprints. Rather, they alter the constituents and chemistry of the atmosphere. To detect these changes at ground level, 10 stationary monitors each day were placed in an arc about 5-7 km from the power station and about 0.5 km from each other. Fortunately, the 'footprint' was expected to come to ground in a rural area. The rugged, portable monitoring units attracted little interest from passing cattle.

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Above: A comprehensive set of data on plume dispersion under convective conditions was gathered during a two-week field experiment downwind of Queensland's Tarong Power Station.

Upper right: Ground measurements were taken to plot the location and size of the plume 'footprint'. Ten stationary monitors were placed in an arc about 5-7 km from the power station. The concentrations of various emissions (as a function of time) were recorded every 10 seconds by an inbuilt data logger.

Lower right: Cross-wind plume measurements were taken from a four-wheel-drive vehicle travelling at right angles to the plume direction. The concentrations of emissions such as sulfur dioxide and nitrogen oxides were recorded.

The monitors were made by the Division of Coal and Energy Technology and Flinders University and were powered by motor cycle batteries. They ran for four to five hours a day and were calibrated (checked for accuracy) at least twice daily and recharged each night.

The concentrations of various emissions (as a function of time) were recorded every 10 seconds by an inbuilt data logger. At the end of the day the data stored in each logger was downloaded into a personal computer for later analysis.

Time-exposure photographs of the plume were taken from elevated points on a line at right angles to, and about 20 km away from, the plume. These photographs are then processed using contrast-enhancing techniques to provide a measure of the vertical structure of the plume.

What about the weather?

Tracking the Tarong plume would have been pointless without the simultaneous recording of local weather conditions. By comparing both sets of data, the scientists can see how pollutant dispersion is affected by local wind and temperature fluctuations.

CSIRO's Centre for Environmental Mechanics made the meteorological measurements. A 60 m lattice tower was erected on a ridge east of the power station. This was equipped with profile and turbulence instruments and sonic anemometers to measure wind fluctuation and momentum and heat fluxes.

Considering the logistics of the Convective Atmospheric Dispersion Study, it's no surprise that scientists have developed laboratory techniques for simulating plume dispersion. But real measurements will always be needed to validate laboratory experiments and computer models.

With knowledge gleaned from all these techniques, Carras and Williams have developed a model for predicting plume dispersion that accounts for the influence of convective conditions. The model is empirical in that it uses the field measurements of plume rise and spreading rates to predict ground level concentrations to be expected for a given emission strength.

The Tarong study has provided a large set of data which is still being analysed and interpreted. No doubt it will add significantly to our understanding of, and ability to predict, the behaviour of chimney plumes in convective conditions.

More about plumes and modelling

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