Australia's monsoon

Darwin's summer rains are brought by the same weather system that causes Asian monsoons.

Last July and August, as much of Australia prepared for a dry, dusty spring during one of the most severe droughts on record, the River Ganges, swollen by the monsoon rains, burst its banks.

In India's most populous State, Uttar Pradesh, already ravaged by floods, the death toll passed 1000.

At such times the two countries seem worlds apart, yet the Indian monsoon is part of a weather system that also brings Australia its cyclones — like Tracy, which devastated Darwin at Christmas 1974, and Kerry, whose destructive and wayward behaviour is described on page 17.

There is little we can do to change the weather, but people living in both hemispheres would benefit enormously from accurate forecasting of both the violent storms that flatten homes and the vital rains on which much of south-eastern Asia's rice crops, and therefore its human populations, depend.

The meteorologist trying to predict weather is like a zoologist studying a species of wild animal. He begins in the field, watching, recording, and making countless observations. Back at his desk he sifts his accumulated information, looking for recurring patterns that will transform shapeless heaps of unrelated facts into orderly ranks governed by relatively few major ideas.

Once he is familiar with the patterns, the scientist can predict how an animal or a monsoon will behave, provided he knows its detailed circumstances: a well-fed lion will ignore potential prey, and a monsoon will bring rain only on certain days.

The quantity of information required to understand weather systems is enormous, but some of the key ideas date back centuries. In 1686 the British scientist Edmund Halley, who gave his name to the well-known comet, contributed a paper to the *Philosophical Transactions of the Royal Society* under the title 'An Historical Account of the Trade Winds, and Monsoons, observable in the Sea between and near the Tropicks, with an attempt to assign the Physical cause of the same Winds'.

The 'physical cause' proposed by Halley was essentially the difference between the surface temperatures of land and ocean, coupled with the spin of the earth. Winds, he suggested, were caused by air rising over hot land in summer, and their direction was influenced by the planet's rotation — the Coriolis effect.

Halley's ideas still hold good, and they account for perhaps 90% of a monsoon's structure. Unfortunately, they are much too generalized to explain winds and rains in detail. Even now, hundreds of years and millions of research dollars later, meteorologists are just beginning to work out the fine tuning that determines monsoon weather day by day.

Seasonal weather

The word 'monsoon' is used in several ways. It possibly comes from an Arab word meaning 'season', and it can be defined as a period of heavy summer rainfall in a country with dry winters. Another definition hinges on a reversal of wind direction through about 180° twice a year.

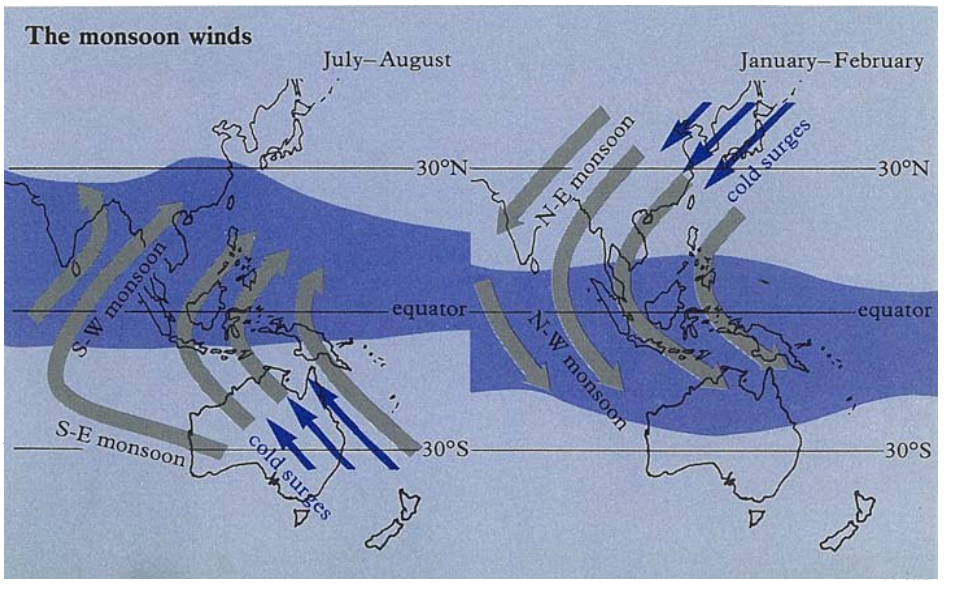
Both definitions fail to describe the particular idiosyncracies of classic monsoons; seasonal wind reversals even occur in Melbourne! It seems best to restrict the word to weather patterns that satisfy both definitions. These form two major monsoon systems: the African and the Asian–Australasian.

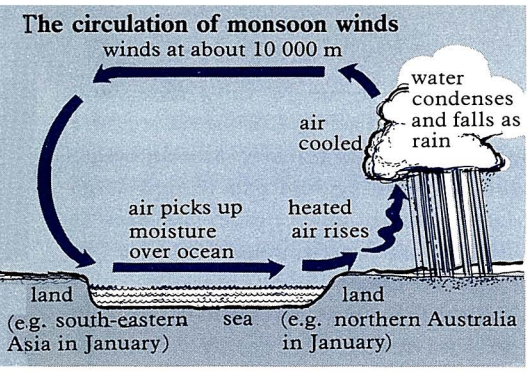
In summer, the sun warms both land and sea, but the land surface becomes hotter than the surface of the ocean. This is because heat diffuses down through the land only slowly, but it is carried below the surface of the sea by vertical currents.

In winter, the ocean's stored heat prevents the water cooling as rapidly as the land, and so it is the sea that is the warmer.

The sea's slow temperature changes have another effect: they delay the seasonal weather cycle, putting it 6–8 weeks

The summer weather in each hemisphere is greatly influenced by winds from the other hemisphere. As they cross the equator these winds turn through about 90°. The shaded area is the region of monsoonal rains.





In January, moisture-laden winds bring rain to northern Australia. In July the circulation is reversed and air descends over northern Australia, warming up as it does so and therefore inhibiting rain.

behind the solar cycle. This is why the climax of the summer 'wet' in northern Australia comes not at the solstice on about December 21, but in January and February. There is a similar time lag in the Northern Hemisphere: south-eastern Asia experiences its heaviest monsoon rains in late July and August.

Why does the monsoon bring rain? As the land heats up in summer, it heats the air above it, which becomes less dense and therefore rises.

Then, as Halley put it, 'it is necessary that the cooler and more dense air should run thither to restore the equilibrium'. So an onshore wind, which may have a fetch of many thousands of kilometres, develops up to an altitude of about 1000 m.

This air, bringing water vapour that has evaporated from the sea, in turn rises over the land. As it rises, it cools and its water-holding capacity drops. The excess water condenses and falls as rain. The atmospheric circuit is completed by air returning to the winter hemisphere at about 12 000 m.

During the Australian winter, air is rising, and unloading its water, over south-eastern Asia. The air sinks over Australia; as it does so, it usually warms up and can comfortably hold all the water vapour it meets.

This is why winter rains are rare in tropical Australia. Cold fronts may bring rain to the south and centre of the continent, but the north stays dry.

Reverse cycle

The whole huge cycle of air revolves in the opposite direction in our summer. Now the winds blow towards northern Australia at low level. The Australian monsoon is not an exact mirror-image of the Indian one, however, and a map suggests why. In the Northern Hemisphere most of the monsoon rain falls between latitudes 30° and 40°, but the southern monsoon chiefly drenches the region within 20° of the equator.

Scientists debate the reason for this difference. One likely explanation is that the Southern Hemisphere lacks a land mass the size of Asia, which draws air farther from the equator. Another, more contentious, hypothesis is that the northern monsoon is partly influenced by the Himalayas, which act as an elevated source of heat. This huge mountain range has no southern counterpart.

Australia's 'top end' is famous for its summer rains, but these amount, in a sense, to other countries' left-overs. In particular, the high mountains and warm seas of Indonesia interrupt the monsoon on its journey south, trapping most of the rain.

In any case, the Australian monsoon delivers less rain than does the Asian monsoon blowing in the other half of the year. This is because the northern monsoon crosses larger expanses of ocean on its journey to south-eastern Asia.

Indian monsoons and summer rains in northern Australia both belong, therefore, to one vast system of air currents straddling the equator and linking whole continents and oceans. For accurate forecasting, scientists need information about weather details over as much as possible of the monsoon's range — horizontal and vertical.

International research

Several countries are collaborating to collect such information, and CSIRO's contribution is a tropical meteorology program involving the Division of Atmospheric Physics, which concentrates on theoretical work, and the Australian Numerical Meteorology Research Centre (ANMRC), which carries out analyses of collected observations. The ANMRC is run jointly by CSIRO and the Department of Science and Technology.

The program, whose aim is the development of forecasting techniques for Australia's tropical north, is co-ordinated by Dr Peter Webster of the Division of Atmospheric Physics. He spends much of his time building and testing mathematical models of monsoons — models that incorporate his ideas on the underlying recurrent patterns and that, if successful, could eventually help achieve accurate forecasting.

Just as zoologists make expeditions to observe their subjects in the wild, so Dr Webster enjoys monsoon-watching in the field. He participated in and helped to organize two international monsoon experiments (MONEX for short), one in December 1978 to February 1979 centred on the South China Sea, and the other the following July studying the northwards monsoon in the Bay of Bengal.

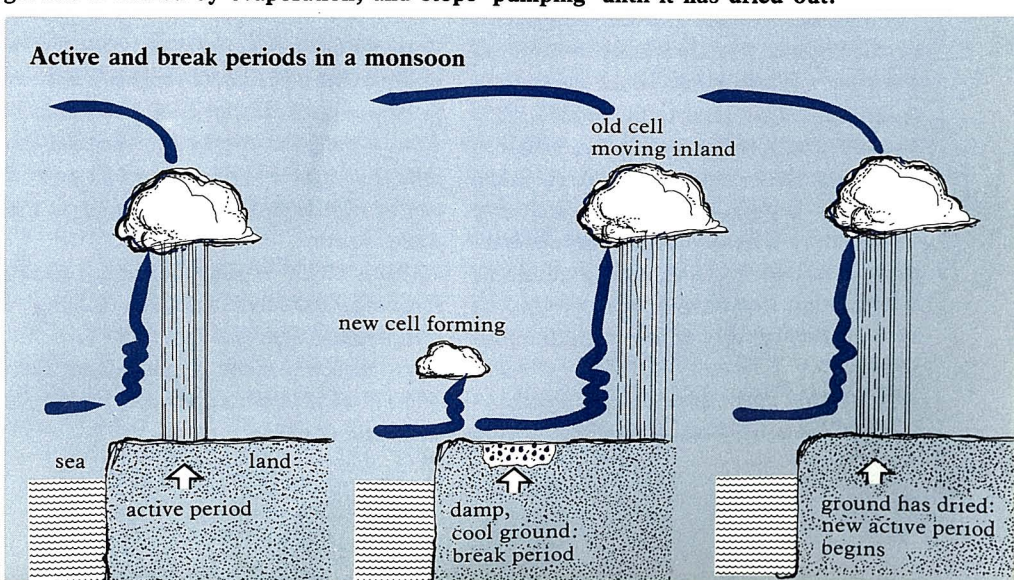
Both these research efforts formed part of the Global Weather Experiment (see *Ecos* 18) and involved co-ordinated measurements using aircraft, buoys, ships, and radar contributed by various nations, including the United States of America and the Soviet Union.

The vast body of information from these two intensive field exercises and from other sources, including the geostationary meteorological satellites (see page 16), is grist to the modelling mill.

When he began his study of monsoons, Dr Webster set about understanding the large-scale phenomena, and particularly the timing of the rains. In their studies of the interactions between land and sea, Halley and subsequent monsoon modellers had considered only the influence of the oceans south of Asia, but Dr Webster found the ocean to the east (the northern Pacific) to be an equally important cause of the observed lag between solstice and monsoon.

He then tackled the mystery of the 'active' and 'break' periods within a monsoon. An active period lasts for perhaps a fortnight and includes a cluster of about

In summer hot land 'pumps' air upwards, where it cools and drops rain. The soaked ground is cooled by evaporation, and stops 'pumping' until it has dried out.



Australia's monsoon brings a summer storm to the South Alligator River region, Northern Territory.

three or four 'disturbances', each of which brings rain. A break is a dry spell between active monsoon periods.

Why the rains are intermittent

It occurred to Dr Webster that when rain falls the wet ground below gradually cools as water evaporates from its surface. A monsoon is like a current of air being pumped by hot land, and as the land cools so the pump slows down. For a while there is a break in the rains, until the land has dried out sufficiently to raise its temperature and restart the pump.

Dr Webster developed a mathematical model for the south-eastern Asian monsoon incorporating this idea, and a computer told him what rain pattern the model would create. The answer was a series of active periods about 10–20 days apart, separated by dry breaks.

Each active period was caused by a northwards-moving, rain-bearing cell of air, which gradually weakened as it travelled farther inland and crossed increasingly cooler land at higher latitudes. The land soaked by a cell's rain gradually dried and warmed up, heating the lower atmosphere and creating a fresh surge of moist air from the ocean. This wind developed into a new northwards-moving cell.

While Dr Webster and Dr Lang Chou of the Naval Post-graduate School at Monterey, California, were writing a technical paper about the model, they heard of a detailed study of air circulation during the Asian monsoon by Dr K. Sikka and Dr S. Gadgil, of the Indian Institute of Science. These on-the-spot observations matched the computer predictions well enough to satisfy Dr Webster and Dr Chou that they were on the right theoretical lines.

Using the principles of the Webster–Chou model, meteorologists should find it easier to predict the onset and end of active periods than to say whether rain will fall on any particular day within an active period. In practice this is not too important; it is the 2-week forecasts that matter to farmers, not the 24-hour ones. Germinating rice can tolerate short intervals between downpours, but if the crop is sown just before a break period it may well fail.

The Australian monsoon is more complex than the Asian. The mountains, forests, and warm seas of Indonesia complicate what would otherwise be a straightforward cross-equatorial flow of air, and tropical Australia is downwind of Indonesia. Dr Webster needs a substantial body of meteorological information, including analyses of satellite records, before he can construct a model of northern Australia's summer weather.

Such a model would benefit forecasting in other parts of Australia, too. The northern 'wet' extends well south in some years, such as 1974, when the centre of the continent received torrential rains that filled Lake Eyre.

What's more, the monsoon influences weather patterns in the southern coastal districts where most Australians live, and some of the unpredicted rains in this region seem to be associated with the rapid movement of moist air out of the tropics.

The Siberian connection

Our weather is further affected by phenomena called cold surges. These are pulses of cool air that enter the monsoon flow; during the Australian summer they take the form of bursts of cool air pouring out of northern Asia, weakening as they travel south.

Hong Kong experiences about four or five cold surges a mouth, each causing the temperature to drop by up to 10°C for 1–2 days, but only some of the surges reach Australia, where they usually have a less dramatic effect.

Scientists do not yet fully understand cold surges. It seems that the air pressure gradually builds up over Siberia before suddenly falling and expelling a huge cool southerly gust. Surges are hard to predict, and at present scientists use two main clues.

A surge is always preceded by a rise in pressure over Siberia, and by the passage of a trough from Europe or another mid-latitude region. Forecasters in Hong Kong know that a surge will reach them 3–4 days after a trough arrives over Lake Baikal.

During our winter, similar (but weaker) cold surges head northwards, and Chinese meteorologists use Australian surges to help predict rainfall in their monsoon. Dr Webster thinks Australian forecasters may eventually be able to use Siberian surges to predict at least some of our summer rainfall.

Information collected during the MONEX field work gave him the idea for a model of surge formation, in which an incoming trough interacts with a jet stream between the Himalayas and Japan at about 10 000 m. The trough shifts and accelerates the jet stream eastwards until it is so positioned that it expels from over Siberia cold air that has slowly built up in the preceding days.

Cold surges form part of the 'macro-scale' pattern of monsoon weather that has so great an influence on agriculture, and this is why scientists are keen to develop a technique for forecasting them. There is another reason for wanting to understand surges: they seem to be connected with the formation of tropical cyclones. Dr John McBride of ANMRC is using statistical analysis to test the strength of this connection.

What triggers a cyclone?

Australia lies in one of the world's four major tropical cyclone regions, the others being the north-western Pacific, areas of the Indian Ocean, and the North Atlantic.

Clouds over the South China Sea during the MONEX study.

Most tropical cyclones form within about 10° of the equator, and the activity of Australian cyclones is concentrated on two areas: in the Coral Sea and off the north-west shelf.

As yet meteorologists cannot explain what triggers a cyclone but, as Dr Webster puts it, 'the monsoon is the envelope in which cyclones reside', and so we must understand the monsoon if we are to predict cyclones.

Dr McBride's studies of a large number of Northern Hemisphere cyclones suggest that certain configurations of the large-scale tropical flow of air seem to increase their likelihood. If the analysis of Southern Hemisphere cyclones confirms this idea, then accurate forecasting of the Australian monsoon will become extremely important — the monsoon determines these configurations.

Weather forecasting is based on mathematical models that embody past experience. The computer analyses the current meteorological situation in the light of the model. Why, then, are forecasts sometimes inaccurate? Was Halley right when he wrote nearly 300 years ago 'there is no general rule but admits of some exceptions'?

In a sense he was, but scientists believe the exceptions can be explained too. The model must be refined. Australian weather-forecasting models ignore events north of the equator.

This approach reflects the former belief that the equator was a barrier between two independent weather systems. Studying monsoons has changed all that. In the world's monsoon regions, one of which embraces Australia, the weather is considerably determined by events the other side of the equator. 'We need', Dr Webster urges, 'a global model.'

If such a model is to improve weather forecasting in Australia's temperate regions and sort out the day-to-day vagaries of the Australian monsoon, it must be both carefully built and thoroughly 'fed' with meteorological observations. Scientists hope that satellites will help to provide the large body of information they need. The other requirement, careful construction of the model, is the main aim of the tropical meteorology program.

John Seymour

More about the topic

Mechanisms affecting the state, evolution, and transition of the planetary scale monsoon. P.J. Webster, Lang Chou, and Ka Ming Lau. *Pure and Applied Geophysics*, 1977, 1463–91.