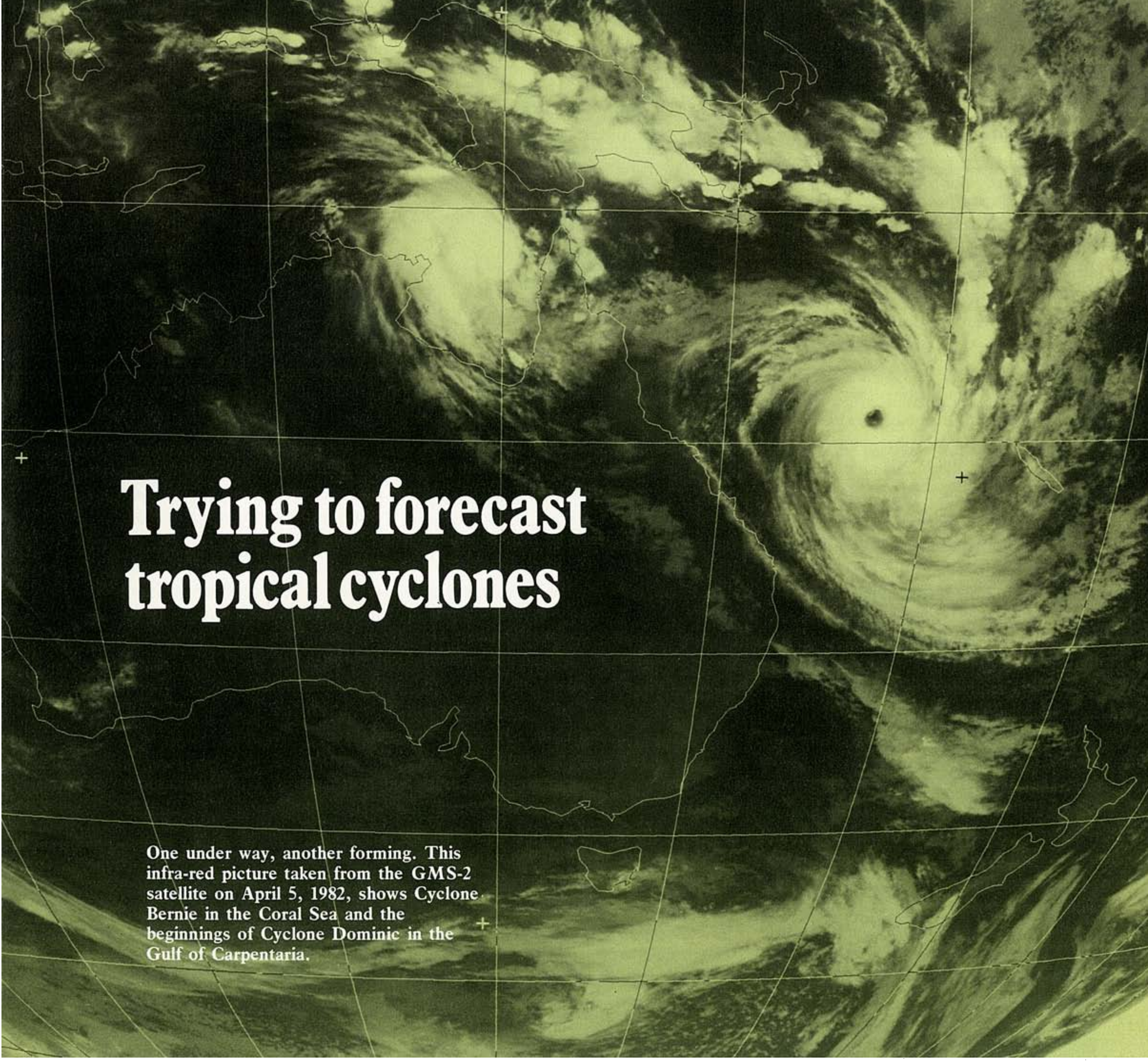


Trying to forecast tropical cyclones

One under way, another forming. This infra-red picture taken from the GMS-2 satellite on April 5, 1982, shows Cyclone Bernie in the Coral Sea and the beginnings of Cyclone Dominic in the Gulf of Carpentaria.

Tropical cyclones are great whirlwinds, dangerously destructive in their ferocity. In the Australian region, about a dozen of them manifest every year, and residents of our tropical coast live in a state of preparedness, ready to seek cover and batten the storm windows whenever the radio indicates that a cyclone is on the loose nearby.

A cyclone behaves like a vehicle of fate, drifting in first one direction, then another. Weather forecasters wish they could predict its motion accurately, so that they could issue precise, timely warnings. Unfortunately, they are a long way from achieving this, as a recent paper by Dr Tom Keenan of the Bureau of Meteorology makes plain.

He analysed the accuracy of tropical cyclone forecasts for a recent 7-year period, and found these to have 'considerable' error, both in direction and speed of movement and in intensity.

The big problem is that nobody knows fully what causes and directs the cyclones. We are aware of a number of predisposing factors, and some of the dynamics, but why one should form at a particular time and place is not completely understood. Similarly, all the forces that steer it on its fateful course are not yet known.

Many thousands of cloud clusters pass over the tropical oceans every year. Only a very small number are destined to become cyclones. What is the difference between those that intensify into cyclones and those that don't? Is there a meteorological equivalent of the plug-hole that sets the bath-water circling into a whirlpool, or is it an inevitable consequence of large-scale circulation patterns — the shape of the bath itself?

Dr John McBride of the Australian Numerical Meteorology Research Centre has set himself the task of finding out what's behind the spawning of tropical cyclones. Studies over the past few years have allowed him to elucidate a number of the factors at work, apart from those already known.

For example, although the importance of adding to the spiralling motion of the developing cyclone was known, Dr

Is there a meteorological equivalent of the plug-hole?

McBride has shown that high-level winds spiralling outwards in an anticlockwise direction contribute as much as clockwise winds spiralling inwards near the surface.

More recently, Dr McBride has teamed up with Dr Keenan to look at the climatic influences on Australian cyclones. From what they have found, they now think they can answer the question: 'bath or plug-hole'. It seems it's the bath. In other words, the large-scale atmospheric circulation — in particular, the monsoon circulation — gives rise to cyclones, although the energy is channelled to a central focus.

This conclusion, albeit still tentative, encourages them to think that prospects for improving the success of cyclone forecasting are good. That should come as welcome news for forecasters at the three Australian Tropical Cyclone Warning Centres operated by the Bureau of Meteorology at Perth, Darwin, and Brisbane.

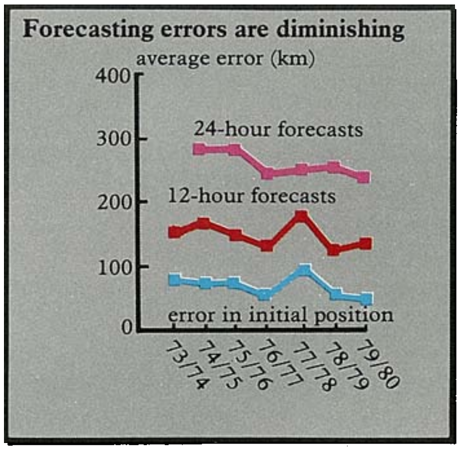
A difficult task

The daunting task facing them at the moment is to produce, quickly, accurate forecasts of the position, direction of movement, and intensity of a tropical cyclone and of the peak tides and rainfall it will produce. The better their forecasts, the better will be the chance of undertaking the most appropriate protective measures.

Dr Keenan's analysis shows how difficult this task is. He analysed the position forecasts for cyclones in the Australian region (80°E to 160°E) from the 1973/74 season to that of 1979/80. He compared the initially advised position and the 12-hour and 24-hour forecasts with data derived by careful analysis after the event.

The difference between where the storm centre was first thought to be and where, with hindsight, Dr Keenan found it really was averaged out at 69 km. This 'initial position' error is about twice that typical for the major Northern Hemisphere cyclone forecast centres because of the better observational data (satellite and aircraft) there. In particular, all tropical cyclones in the Caribbean–West Atlantic area are routinely monitored by the United States Air Force, and aircraft fly through each cyclone every 6 hours to give an up-to-date fix on its intensity and location.

In Australia, no such data are available. The Bureau's Tropical Cyclone Warning

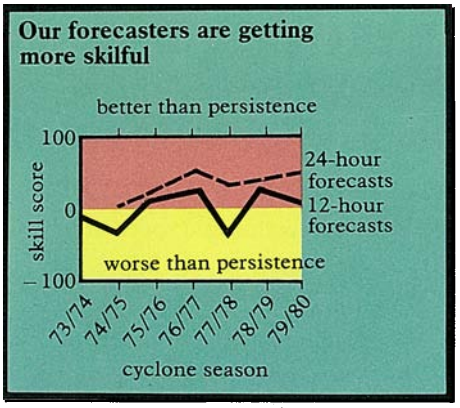


With increased data-gathering, Australian cyclone forecasts are becoming more accurate.

Centres have to rely on the skilled interpretation of other data sources. Significantly, the error here is decreasing, thanks to the advent of the Japanese Geostationary Meteorological Satellites GMS-1 and GMS-2, the first of which came into operation in 1978, and to improved coastal radar coverage. Dr Keenan estimates that recent forecasts of the positions where cyclones make landfall (at least those near population centres) are probably no worse than equivalent forecasts for the Atlantic and Caribbean areas. Radar fixes are good to about 30 km, he found.

The 12- and 24-hour forecasts for the seven-season period were out by an average of 150 km and 263 km respectively. The yardstick for measuring skill in such exercises is the 'persistence' forecast. This predicts the position the cyclone will move to if its speed and direction remain constant (obviously demanding minimal skill of the meteorologist).

Taking into account the error due to ignorance of the precise positions of cyclones to begin with, Dr Keenan found that, on average, actual forecasts were



A measure of the cyclone forecaster's skill — the extent to which the forecast betters a 'persistence' forecast (one assuming a cyclone's speed and direction remain constant). On average, forecasters have done slightly better, and they're improving.

slightly better than persistence forecasts. Also, as shown in the diagram, their accuracy does seem to be steadily improving as modern technology comes to our aid.

A cyclone's intensity is even more difficult to forecast than its position. Large errors are made, mainly because of unreliable initial-pressure estimates (the central pressure can be translated into that all-important measure of storm intensity, the maximum wind speed).

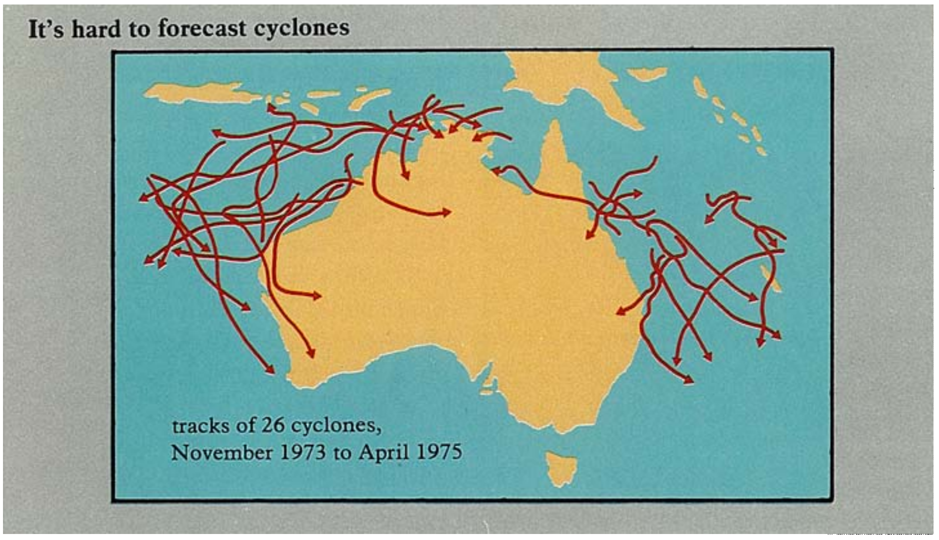
Dr Keenan found that forecasts of maximum wind speed erred by an average of about 65% for weak storms and 10% for very intense storms. He concluded that these forecasts, even allowing for initial erroneous values, were not significantly different from persistence ones. Better observational networks are obviously needed to improve their accuracy. Since, as one study has shown, cyclone damage can vary as the fourth power of the wind speed, this need is of some consequence.

How much better could cyclone forecasts be? Perhaps they could be perfect, given masses of data and powerful computers running numerical models of the weather (at least, that's an article of belief among some meteorologists). But, in practice, broadly how much improvement could we expect?

A cyclone's intensity is even more difficult to forecast than its position.

Dr Keenan attempted to go some way to answering this by analysing the average movement and surrounding atmospheric pressure patterns of 856 cyclones (from 1970 to 1980). (He did not tackle the question of potential improvement in intensity forecasting.) From a statistical viewpoint, how well did climatological and weather patterns correlate with cyclone movements, and did they provide better correlations than persistence alone?

The short answer is that persistence is our single most important forecasting tool, even in cases where cyclone motion becomes less well behaved. However, in the environment in which actual forecasts must be made — where cyclone positions are less well known — the weather map component is extremely important. Here correlations do emerge (most strongly between westerly movement and a 500-mb ridge to the south) that are vital to increasing the forecast accuracy beyond that provided by persistence.



Tortuous tracks make forecasting difficult. Nevertheless, 'persistence' (assuming a straight track) is the best starting point for making a forecast.

Dr Keenan stresses that his analysis shows how important it is for the forecaster to obtain accurate cyclone locations. Also he believes that, because of their often erratic behaviour, Australian cyclones are inherently more difficult to predict than those occurring elsewhere in the world. At least we should be grateful that cyclones persist in their tracks as strongly as they do: on average, 80% of all cyclones change their speed by less than 1·8 m per second over 24 hours, and alter their heading by less than 55°.

Despite the large element of error they have found in Australian tropical cyclone forecasts, Dr Keenan and Dr McBride are full of praise for the competence and efficiency of the Bureau's Tropical Cyclone Warning Centres. Even a persistence forecast can't be carried out unless the cyclone's current position and intensity, and its movements over the previous 12 hours, are accurately known.

Since cyclones always occur over the tropical oceans, where direct pressure and wind observations are scarce, the location and intensity of the central core of the cyclone must be inferred indirectly from surrounding scattered large-scale weather observations and from remote-sensing devices such as satellites and radar. The interpretation of such data depends critically on the training and experience of the meteorologist on duty.

Where and why

Tropical cyclones form over warm oceans in the tropics, but rarely within 5° of the equator, as the pressure gradients at very low latitudes are insufficient. In the Southern Hemisphere they usually fail to form more than 20° south of the equator because the sea surface temperature isn't high enough (it needs to be more than about 27°C) to feed sufficient moisture and heat energy into the system.

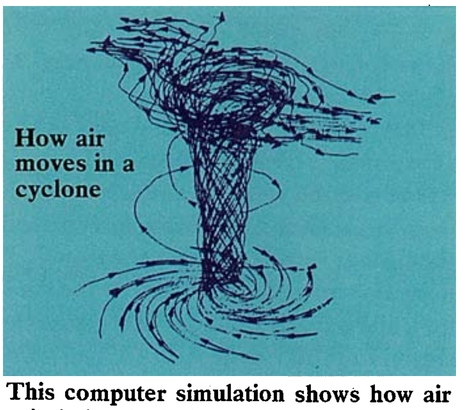
Other prerequisites for cyclone formation are known. Dr McBride, from his analysis of cyclones, sees the following as being the most important.

- An uplift of air of more than about 1000 metres per day is necessary near the surface. This comes about by air spiralling in towards the eye — from there it can only go up. The same behaviour occurs higher up too. About half of the air mass flows in from above 1 km altitude.
- The most easily measured quantity separating a cyclone from just another cloud cluster is the speed of tangential winds. Values for cyclone precursors — of 4–5 metres per second at a radius of 500 km — are more than double those found in other systems that don't develop into cyclones.
- At some stage, the incipient cyclone must develop an anticyclone at high altitude. Stacking an anticyclone (spiralling anticlockwise) on top of a cyclone (going clockwise) leads to large amounts of shear — although near the eye, where moisture and heat energy build up, a continuous column remains. The shear patterns can extend over a 10° latitude radius, indicating that cyclones are brought into being by large-scale flow patterns. Small cloud clusters around which the cyclone intensifies act merely as the trigger, Dr McBride believes.
- Cyclones have a warm, moist core, but in the early developing stage the temperature differs by only 1°C between centre and outside — a difference difficult to detect on an individual weather chart. Nevertheless, over hundreds of square kilometres, a large quantity of latent heat energy is stored as water vapour, and is released when rain falls.
- The situation outlined above means that cyclones can maintain themselves only through energy received from the ocean. And so cyclones weaken or die when this source of energy is cut off, as happens when they cross the coast.

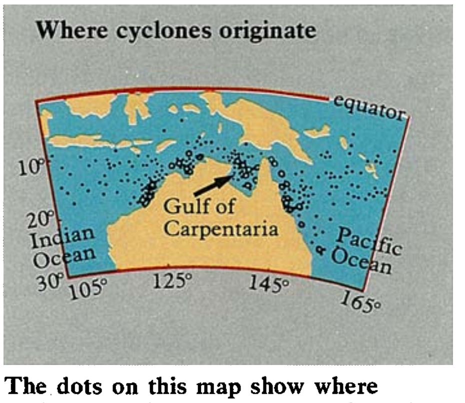
Australian cyclones

While Australian cyclones show all these general characteristics, recent studies by Dr McBride and Dr Keenan have revealed some further interesting and unusual features. In particular, our cyclones prefer to form near the coastline (about half originate within 300 km of it) and, surprisingly, often begin life over land. Sometimes a cyclone crosses the coast and loses intensity over land, but then instead of dying 'regenerates' by going back over the ocean.

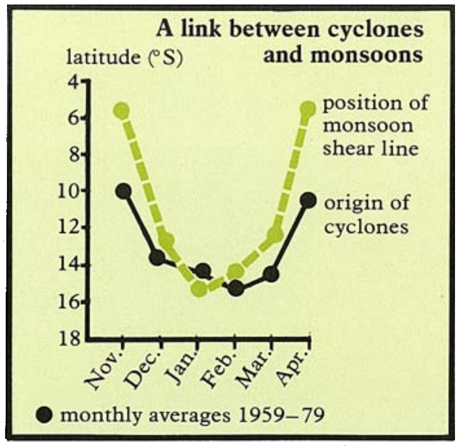
Although some such cases can be found outside the Australian region, they are certainly more common here, with 12% of Australian tropical cyclones forming from previously existing ones.



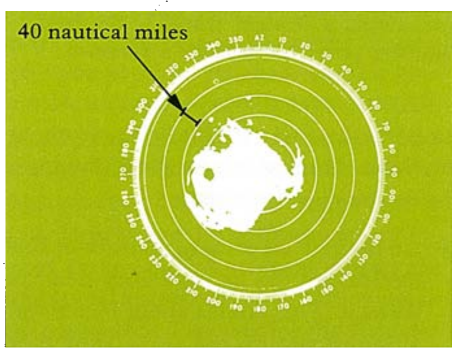
This computer simulation shows how air spirals in clockwise at the bottom, rises, and leaves in an anticlockwise spiral at high altitude.



The dots on this map show where cyclones originated between 1959 and 1979. About half originated within 300 km of the coast. Circles show where a cyclone sprang back to life after waning over land.



The graph shows a strong connection between the latitude of cyclone origins and that of the monsoon shear line (the line separating the easterly trade winds and the westerly equatorial winds).



Radar allows cyclones to be accurately tracked, which improves the reliability of subsequent forecasts. The eye of Cyclone Hazel (March 1979) appears here on the radar screen of Learmonth Meteorological Office.

Persistence is our single most important forecasting tool.

One striking case was Cyclone Madge in 1973. It was initially classified as a tropical cyclone in the Pacific Ocean, crossed land and was reclassified as a cyclone in the Gulf of Carpentaria, made landfall once more, and later was classified as a tropical cyclone over the Indian Ocean.

A map prepared by the research pair shows points of origin for all the cyclones in the Australian region over the 20 years 1959–79. A striking feature is the clustering of points around four highly preferred locations. The maximum number of cyclones in a season was 19 in 1962/63; the minimum was seven (including three cases of regeneration) in 1978/79.

Further analysis of the data revealed another striking feature: of 38 cyclones that developed between 1974/75 and 1978/79, more than half of those making their preliminary appearance in the western region of the continent (west of 125°E) did so over land.

As yet, the researchers are unable to offer an explanation, but one big clue to emerge from their analysis is that cyclones appear to be strongly linked to the Australian monsoon. In 84% of cases (32 of the 38), their precursors first appeared when they were on the 'monsoon shear line'. At the point at which they were actually classified as tropical cyclones, 37 of the 38 were on this line.

The monsoon shear line — the line of separation between the easterly trade winds and the westerly equatorial winds — is the most easily identified feature on the surface weather chart in the tropics. It is present every day throughout the summer, and usually extends right across the region from 105° to 165°E.

The graph shows the seasonal movement in latitude of this line, and of cyclone points of origin. They follow each other closely.

A ray of hope

The close connection between cyclones and monsoon systems rekindles hope that cyclones may be amenable to forecasting after all, according to Dr McBride. However, as Dr Keenan's analysis showed, it is unlikely that simple synoptic models will be of much help. Rather, the hope lies in computer models.

A computer by itself doesn't guarantee success, as an earlier paper by Dr Keenan showed. Indeed, some computer programs are available to assist in cyclone forecasting, but again, they can perform poorly. They are usually statistical schemes, comparing the cyclone at hand with a multitude of more or less similar past cyclones. None, Dr Keenan found, performed better than persistence.

However, as alluded to earlier, numerical models simulating the day-to-day changes of the large-scale flow of the atmosphere may do the trick. In Australia at present, these aren't used for cyclone forecasting, but no doubt they're coming. Already the first step has been taken, and a computer program has been developed that could draw the weather maps at the Darwin weather office.

The computer method, currently undergoing testing before routine use, was developed by Mr Noel Davidson and Dr Bryant McAvaney, of the Australian Numerical Meteorology Research Centre. Its main feature, valuable in the tropics, is its ability to extend its analysis into areas with no data. It does this by searching its data banks for yesterday's and past seasons' values, and comparing these with the values of neighbouring stations to come up with a first guess.

Refining of all the data then takes place until the most consistent set of meteorological data is produced. Assessment of the scheme's performance by Darwin forecasters has convinced them of its skill.

Satellites and computers are raising our hopes that tropical cyclones will become more predictable. Dr McBride and Dr Keenan both agree, however, that improved data resources and more advanced technology can go only part of the way towards the production of accurate tropical cyclone forecasts. A factor of at least equal importance is the need for greater physical understanding of how tropical cyclones work.

For this reason they stress that research effort should aim at elucidating the fundamental physical mechanisms governing a cyclone's change in position and intensity. Once the physical mechanisms are known, they argue, improved forecasts will follow automatically; 'you can't hope to forecast it if you don't know what's making it go', runs their adage.

Whether the improvements come from more data, powerful computers, better physical understanding, or a combination of all factors, more-accurate forecasts will help to reduce the annual world-wide cyclone damage bill of $6000 million.

Andrew Bell

More about the topic

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