‘Eye’ing the cyclone

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Figure 1: Hurricane Rita in full fury

On an average, about 80 tropical cyclones form every year over the seven major oceanic basins in the world. As many as one-third of these form in the northwest Pacific Ocean. Over the Arabian Sea and Bay of Bengal, we get an average of only 4 to 6 cyclones per year, but historically some of them have been the world's deadliest. Over the south Atlantic Ocean, cyclones are the rarest, with the solitary exception of the one that hit Brazil in March 2004.

Not all cyclones have devastating effects. Those that form close to the coastline and have no scope for intensification may even turn out to be beneficial providing the coastal regions with the much needed precipitation. Some systems move into colder waters and dissipate there without making landfall. There are storms which recurve and move away from the coast. As a result, full-blown killer storms are, thankfully, not that common.

Tropical cyclones grow out of existing weakly organised low pressure areas in tropical oceans. They thrive on the ocean's energy and usually there is a distinct storm season in which the ocean is warm enough for their formation. In the early stages of development, they are known by various names such as depression, deep depression, cyclonic storm, tropical disturbance or tropical storm, depending upon the practice prevailing in different countries.

When the winds in a tropical cyclone exceed 64 knots (118 kmph), the system is categorised as a "very severe cyclonic storm" in our region. In eastern and central Pacific Ocean and north Atlantic Ocean, it is called a "hurricane" and in the northwest Pacific Ocean, it is termed a "typhoon". These differences are only in the nomenclature and not in the characteristics of the storm. Crossing the 64 knots threshold marks out the system as a major storm, and it is at this stage that it gets a name like Katrina or Rita as per naming conventions.

In the United States, hurricanes are further ranked on the 5-point Saffir-Simpson scale ranging from Category 1 which has the lowest damage potential to Category 5 which denotes the most powerful hurricane. In India, we use the term "Super-Cyclone" for cyclones in which the wind speeds are higher than 119 knots (221 kmph). This roughly corresponds to a Category 4 hurricane.

Satellite monitoring of tropical cyclones

After the launch of the world's first weather satellite on 1 April 1960, meteorologists got their first glimpse of tropical cyclones from space. Until then, whatever was known about them had been based upon ship logs and special observations from daredevil aircraft reconnaissance missions flown into tropical cyclones. Initially, only one satellite image of a tropical cyclone was available in a day and night-time observations became possible later. Subsequently, with geostationary satellites like GOES, Meteosat and GMS and since 1982 with INSAT, tropical cyclones came under a global round-the-clock surveillance right from their genesis up to landfall.

In 1975, Vern Dvorak developed a technique on the principle that certain patterns or features identifiable in satellite pictures of tropical cyclones were indicators of their intensity. The satellite view of a mature tropical cyclone shows many distinct features like the eye, which is a 30-60 km wide circular area having the lowest pressure and light winds at the earth's surface. Around the eye is the ring-like eyewall, which has the strongest winds. Then there are the long, narrow bands of organised convection and heavy rain, which appear to spiral into the centre of the tropical cyclone, and hence called spiral bands. Between the eyewall and the outer bands is the central dense overcast or CDO, which is a shield of cirrus clouds.

Dvorak's technique was initially calibrated with reference to aircraft observations over the Atlantic and Pacific Oceans but has gained acceptance worldwide. However, it has many limitations particularly when using night-time infra-red images which have a poorer resolution than visible channel images

In Dvorak's technique, the current satellite picture of a tropical cyclone is matched with a number of standard pattern types. The size and characteristics of the banding, CDO, eye and other features are analysed. A decision tree is then used to arrive at what is known a T-number which is a measure of the intensity of the storm and is associated with increasing wind speed and decreasing sea level pressure. The T-number is T1 for a nascent disturbance, T2.5 for a marginal tropical cyclone and is T6 or higher for a very severe cyclonic storm.

Dvorak's technique was initially calibrated with reference to aircraft observations over the Atlantic and Pacific Oceans but has gained acceptance worldwide. However, it has many limitations particularly when using night-time infra-red images which have poorer resolutions than the visible channel images. Secondly, thin cirrus clouds which are transparent to visible radiation show up prominently in infra-red pictures and obscure the view of lower level clouds. Further, the low level cloud lines which help locate the system centre are not seen in infrared imagery.

Tracking cyclones and disaster management

While a tropical cyclone is characterised by strong winds of the order of 100 to 200 km per hour, the cloud system as a whole moves only at about 20 km per hour along with the large-scale atmospheric flow around it. Usually, the system moves towards the west, but has some northward movement as well. This is because of the existence of an east-west axis of high pressure called the subtropical ridge to the north. However, if the subtropical ridge is weak, the system turns northward rather than westward, and as a result, away from the coastline. Ultimately, it may turn fully eastward. This behaviour is called recurvature. It is the cause of many tropical cyclones over the Bay of Bengal first heading towards Andhra Pradesh, then turning towards Orissa and finally making landfall over Bangladesh or Myanmar. Occasionally, a cyclone may even perform a loop in its path.

An accurate and early prediction of the cyclone track is of crucial importance in cyclone warning and disaster management. The easiest method of satellite-based cyclone track prediction is to generate an animation sequence of satellite images and to extrapolate the apparent motion of the cloud system over the next 12 or 24 hours. This simplistic approach often fails as it cannot envisage the possible recurvature of the storm. With water vapour channel imagery, changes in the upper level moisture patterns can be used as an indicator of the motion of the storm. U.S. meteorological satellites have the capability of observing hurricanes at 1-minute interval, from which rapid scan cloud motion winds can be derived.

New advances in satellite technology

In the last few years, there have been some major strides in satellite technology, particularly in the area of microwave remote sensing, which have helped cyclone forecasters to overcome many of the limitations that they had been living with.

The Tropical Rainfall Mapping Mission (TRMM) satellite was launched in 1997 as a joint U.S.-Japan enterprise. This was the first satellite to carry a precipitation radar that could measure the rain rate in tropical weather systems. TRMM has, during its 8-year lifetime, yielded invaluable information on the rainfall associated with tropical cyclones, which could not have been obtained by any other means.

An instrument known as the Advanced Microwave Sounding Unit (AMSU) has been flying on U.S. NOAA satellites since 1998. This can measure the energy emitted by the earth and its atmosphere in 20 microwave channels, from which the vertical profiles of temperature and many other parameters like precipitable water vapour and rain rate are being derived globally. Some AMSU channels can be used to estimate the central pressure in tropical cyclones.

Another very advanced instrument, modestly named as the Moderate Resolution Spectroradiometer (MODIS) was launched on two NASA satellites, Terra in 1999 and Aqua in 2002. It views the earth and the atmosphere over areas as small as a quarter of a kilometre in 36 spectral channels. MODIS data has a wide variety of applications but is particularly useful because it provides extremely clear views of the cloud structure of tropical cyclones. See the MODIS image of Hurricane Rita taken on 21 September 2005, when the storm was out at sea and in its full fury (Source: NASA web site: earthobservatory.nasa.gov)

By following the drifting motion of clouds over successive satellite images obtained from geostationary satellites, it is possible to derive the winds at various levels in the atmosphere. This derivation cannot be carried out over areas where appropriate cloud tracers do not exist or when clouds are totally absent. The method cannot be used for extracting winds right at the sea surface, which are important in the case of tropical cyclones. This limitation has been overcome by an instrument known as scatterometer, which is a space-borne radar that measures the microwave backscatter from the sea surface. This payload is currently being flown on many satellites, and the proposed Indian

NOMENCLATURE OF TROPICAL WEATHER SYSTEMS USED IN INDIA

System Category	Wind Speed in knots	Wind Speed in kmph
Low Pressure Area	Less than 17	Less than 31
Depression	17-27	31-51
Deep Depression	28-33	52-61
Cyclonic Storm	34-47	62-87
Severe Cyclonic Storm	48-63	88-117
Very Severe Cyclonic Storm	64-90	118-167
-do-	91-119	168-221
Super-Cyclone	Greater than 119	Greater than 221

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satellite, Oceansat-2 is also going to have one. Since microwave energy can travel through clouds, scatterometers are providing an accurate picture of the surface wind field of tropical cyclones.

Cyclone track prediction

In order to forecast what path a tropical cyclone will traverse over the ocean, it is necessary to first predict the steering current, or the environmental flow, in which the tropical cyclone is embedded, and how the cyclone will interact with it. Because of the wealth of data that the new generation of satellites are making available, the ability of meteorologists to make predictions of cyclone tracks has been consistently improving.

Numerical weather prediction models require appropriate data on the initial conditions of the atmosphere. Even the most advanced models run on the fastest computers are constrained by the availability of initial data about the cyclone's internal structure and its external environment. The accuracy of cyclone track prediction by operational numerical weather prediction centres has steadily improved over the past ten years. However, even now, track predictions made five days in advance can be wrong by as much as 600 km and the three-day predictions by more than 300 km. Even the 24-hour predictions could be in error by up to 150 km. The CLIPER technique, which is a statistical combination of climatology and persistence of cyclone motion, shows higher skills than 48-hour numerical model forecasts. This is what makes it necessary to play it safe and order massive evacuations of populations over hundreds of kilometres of the coastal belt on both sides of the likely landfall point.

Influence of global warming

As mentioned at the beginning of this article, the annual global average number of tropical cyclones is about 80 and not many of them intensify to hurricane strength. As we are dealing with very small numbers, it is difficult to determine statistically significant trends which may reveal a clear influence of global warming on the intensity and frequency of tropical cyclones. The Intergovernmental Panel on Climate Change in its Third Assessment Report issued four years ago (IPCC, 2001), said that there was no compelling evidence to indicate that the characteristics of tropical and extratropical storms had changed and the observed variations in their intensity and frequency showed no clear trends, although intra-decadal and multi-decadal variations were apparent.

On the other hand, logically speaking, if a sea surface temperature of 27°C is a requirement for tropical cyclogenesis, and if the earth is warming, more oceanic areas should become favourable for the formation of tropical cyclones, and warmer oceans should produce more intense storms. The question of the possible influence of global warming on cyclones therefore keeps coming up, particularly when there is a disastrous storm like Hurricane Katrina or Hurricane Rita.

Three research papers written on this subject by leading scientists have appeared very recently in three renowned scientific journals. Emanuel (2005) found evidence that global warming in the last 30 years was producing more intense cyclones. Webster et al (2005) have concluded that against a background of increasing SST, no global trend has yet emerged in the number of tropical storms and hurricanes with the exception of the North Atlantic, which shows a statistically significant increasing trend from 1995 onwards that has also been noticed earlier (WMO, 2004). Webster et al found that the most intense storms are not getting stronger, but that the number of intense storms shows an increasing trend globally. However, Pielke et al (2005) who reviewed recent research on tropical cyclones and climate change from the perspective of event risk, concluded that the relationship between human-caused climate change and hurricane impacts is and will be insignificant.

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