

VARIATIONS IN WEATHER PATTERNS ON THE ITCZ

The inter-tropical convergence zone (ITCZ) is an area of low pressure found around the equator, characterised by rapidly rising, warm, moist air which produces huge cumulo-nimbus clouds and frequent afternoon thunderstorms. These are clearly visible on satellite photos as a band of swirling white clouds circling the globe (Figure 1). Sometimes described as the ‘power-house of the general global circulation’, the ITCZ is the first stage in the mechanism that distributes solar energy around the world. The area was once notorious to sailors as the ‘doldrums’ – the rising air leaves only very gentle, variable winds at ground level which, in the days before ships were powered by engines, made sailing through the area very difficult and time-consuming.

The ITCZ forms between the two Hadley Cells that control weather patterns around the equator as part of the tricellular model of atmospheric circulation that operates on a global scale (Figure 2). This model explains how the huge amount of incoming solar radiation (known as insolation) received at the equator causes a deep low pressure area to form. Rising air reaches to the top of the troposphere (the lowermost section of the atmosphere) and then flows northwards and southwards, away from the equator. Together with the Ferrel Cell and the Polar Cell, the Hadley Cell is responsible for transferring solar energy from those areas that have an excess (the tropics) to those areas, such as the poles, where much less insolation is received. This ensures that atmospheric energy is kept in balance and is essential for life on earth.

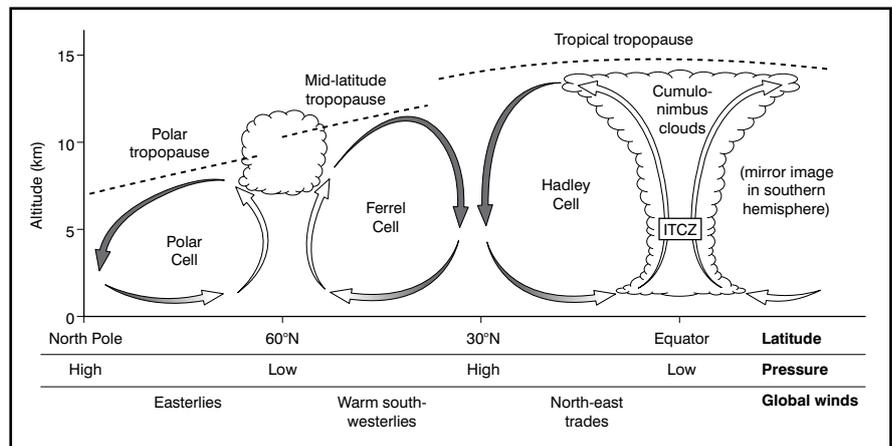
The surface winds that blow towards the equator from the descending arms of the two Hadley Cells meet at the ITCZ. They are called the trade winds and come together in an area known as the ‘thermal equator’. This is the area of most intense heating of the earth’s surface by the sun. The thermal equator is not stationary, but follows the overhead sun, migrating between the tropic of Cancer and the tropic of Capricorn as the sun tilts on its axis through the year. In July (summer in the northern hemisphere), the thermal

Figure 1: Bands of cloud associated with the ITCZ



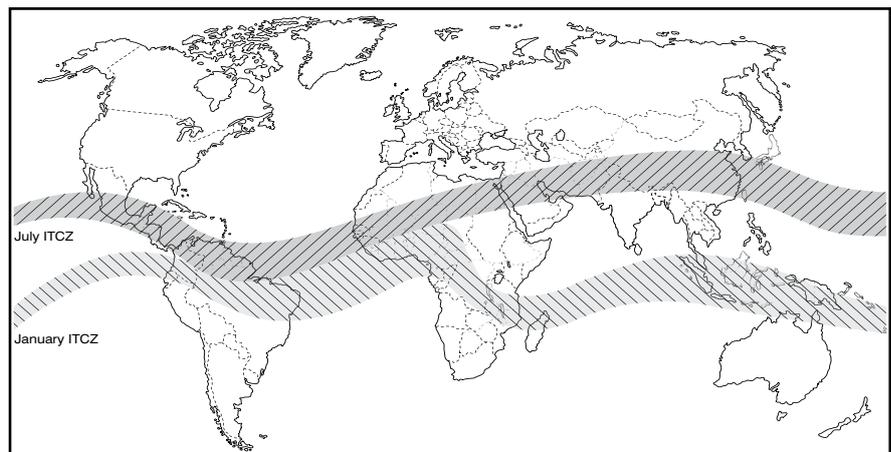
Source: NASA

Figure 2: The tricellular model of atmospheric circulation



Source: Waugh (2009)

Figure 3: Average location of the ITCZ in January and July



Source: Mats Halldin

equator is at its most northerly point– in Africa, for instance, it is over the Sahara desert, which receives maximum incoming solar radiation at this time of the year. The thermal equator then migrates southward

to reach its most southerly point in January, when it is summer time in the southern hemisphere.

Figure 3, however, shows that the ITCZ does not form a straight line

around the globe. This is due to differential heating between the sea and the land. The land heats up and cools down much more quickly so, in areas where the ITCZ lies over large land masses, there is much greater variation in the latitudinal difference between its average northern and southern extent. This difference is, therefore, especially pronounced over eastern Africa and the main Asian land mass.

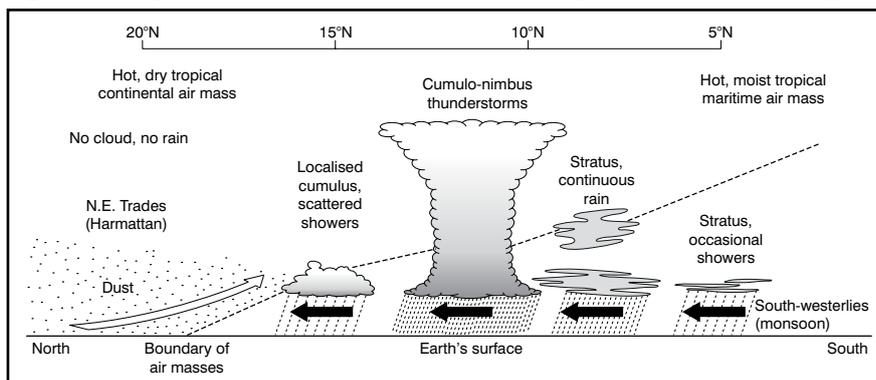
While important on a global scale, the migration of the ITCZ is also a huge influence on local weather patterns. As the low pressure zone moves northwards across the equator, the winds which blow into it change direction because of the Coriolis effect imparted by the rotation of the earth. The south-east trade winds, for instance, are drawn to the right as they cross the equator, to become the moisture-laden south-west monsoon over the Bay of Bengal and off the western coast of central Africa. Here, and in many other cases, the ITCZ determines the levels of rainfall over tropical areas. As we shall see in the following examples, the position of the ITCZ can be a matter of life and death over West Africa and is instrumental in creating the seasonal monsoon in south-east Asia.

The ITCZ over West Africa

The trade winds which blow towards the ITCZ over West Africa originate in two vastly different air masses – large, stable bodies of air that take on the characteristics of their source areas. Located over the Sahara is the tropical continental air mass. Unsurprisingly, this is very hot and dry, and gives rise to the dusty and desiccating Harmattan winds that affect many countries in southern Central Africa for large parts of the year. From the south come the wet south-easterly trade winds, blowing from the tropical maritime air mass formed over the warm waters of the equatorial Atlantic Ocean. As these winds cross the equator they are deflected to the right by Coriolis and become the south-westerly monsoon.

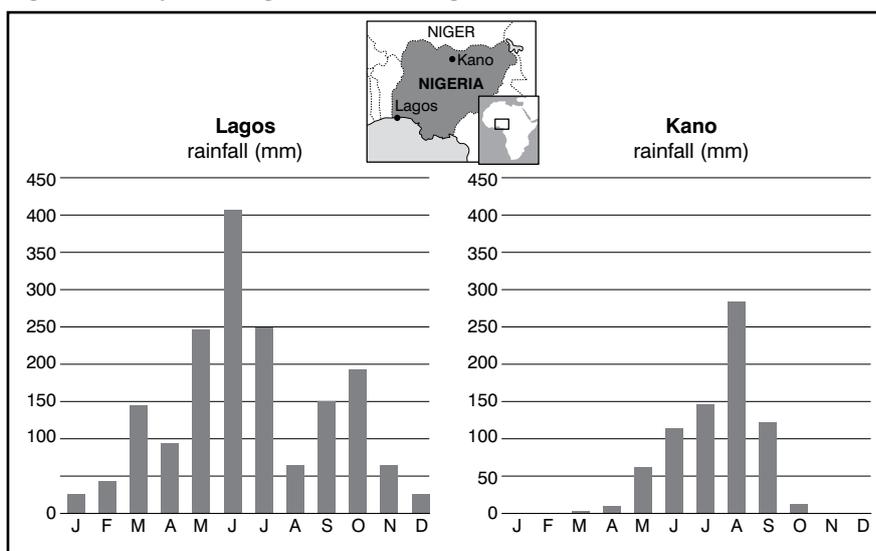
These monsoon winds bring warm and wet weather as they travel north. Areas lying to the north of the ITCZ only ever receive the hot and dry Harmattan winds, and it may not rain here for long periods of time, often months on end. As the ITCZ follows the thermal equator north, however, the Harmattan is replaced by bands of rain clouds of

Figure 4: Rainfall bands on a south-north transect through the ITCZ over West Africa



Source: MacLean and Thomson (2005)

Figure 5: Rainfall in Lagos and Kano, Nigeria



Source: http://www.rmtbristol.org.uk/nigeria_lagos_kano.gif

differing intensity. A general cross-section showing the formation of these bands of rain in a south-north transect is shown in Figure 4.

Obviously it follows that the position of a town or city relative to the northward passage of the ITCZ will influence the amount of rain it receives each year. Figure 5 shows rainfall information for the cities of Kano and Lagos in Nigeria. Lagos is always south of the ITCZ and, therefore, receives some rainfall all year round. By imagining the migration northwards of the rain bands in Figure 4 it can be seen that the weather conditions over Lagos will consist of scattered showers, replaced by thunderstorms, replaced by continuous rain and then occasional showers. As the ITCZ reaches its northern limit and then retreats southwards the pattern is reversed and, because of this, Lagos has two rainfall peaks (June and October), coinciding with the maximum rainfall bands shown in the diagram.

In contrast, for the months from November to February, Kano lies north of the ITCZ, is affected by Harmattan winds and receives no rainfall at all. This dry season comes to an end as the ITCZ migrates to a position north of Kano and the rains begin. The rainfall totals are much lower than those experienced by Lagos and there is only one peak as the bands of maximum rainfall reach Kano, stop and then retreat southwards.

Case study: rainfall variability in West Africa

The generalised pattern described above should, perhaps, mean that local people can plan their year's harvests around the times of maximum rainfall. Unfortunately, however, there is considerable variation in the annual northern limit of the ITCZ and also in the exact timing of the onset of the rainy season from year to year. This makes life very difficult for farmers living in the marginal lands towards the

southern edge of the Sahara. Some years, the ITCZ may bring adequate amounts of rainfall to carry out agriculture but, sometimes, it stops short of these regions, the farmers receive no rainfall, crops fail, and survival is very difficult indeed.

This is the situation in the Sahelian countries such as Mali, Niger and Sudan, where rainfall is increasingly variable as you travel further north. Years of particularly high rainfall in the countries bordering the southern edge of the Sahara during the 1950s and 1960s coincided with a period when the ITCZ migrated further north than its average. Many subsistence and pastoral farmers moved into more marginal areas, grew crops and bred cattle in the benign climatic conditions.

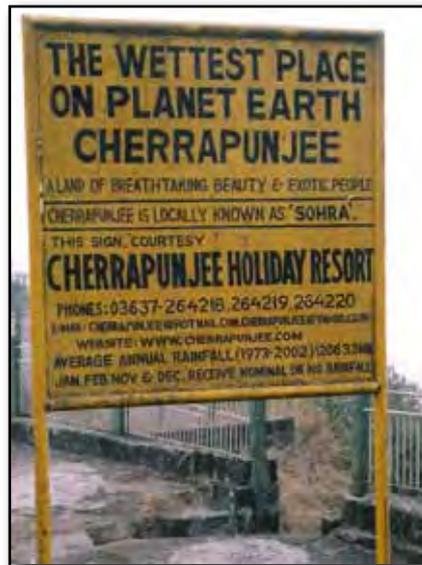
Subsequent years were, however, less beneficial to farming. The late 1970s and early 1980s brought years with much lower rainfall than had been expected. Researchers have shown a correlation between these events and the failure of the ITCZ to reach its long-term average northerly limit. There is also evidence that when the migration of the ITCZ occurred earlier in the year, a relatively bad rainy season followed some months later. During these periods croplands dried up and animals had no grazing land to feed on. Drought and famine resulted in starvation and mass migration, often to already overcrowded cities, leading to an increase in urban population problems.

The same patterns in the ITCZ have been cited as causing the recent widespread drought affecting countries including Kenya and Sudan in East Africa. The problems have been exacerbated by human factors. As population has increased over the last 30 years, farmers have been forced onto land that has little hope of sustaining agriculture, using semi-desert patches of land where crops will only grow when rainfall totals are relatively high. It seems likely that this combination of an unreliable ITCZ and human changes to the natural system will result in continuing and, perhaps, more extreme droughts in the region in the future.

The ITCZ and the south-east Asian monsoon

Further east, the ITCZ is a major influence on the monsoon – the

Figure 6: Cherrapunjee has around 12 metres of rainfall a year



Source: R Mehra

seasonal reversal of wind direction that brings huge amounts of rain to countries including India and Bangladesh. As the thermal equator, and the ITCZ, move northwards towards the tropic of Cancer in June, the high level of solar radiation creates a low-pressure zone that draws in warm moist equatorial maritime and tropical maritime air from over the Indian Ocean. Initially travelling in a northwards direction, Coriolis once again deflects the wind to the north-east so that it rises over the mountain range of the Western Ghats (on the western side of India) and around the windward slopes of the Himalaya. Intense rainfall results from the very humid airstreams. Mumbai, on the western coast of India, receives 2000mm during the four summer months alone (compared with London's annual total of around 600mm), while Cherrapunjee in the foothills of the Himalaya in north-eastern India has a massive 12,000mm during the same period, making it one of the wettest inhabited places on Earth (Figure 6).

As the ITCZ migrates southwards over the equator during the northern winter, it draws down very dry winds from the high pressure area located over central Asia (where the source is a semi-desert region). These winds become even drier as they pass over the Himalaya so that, for the remaining eight months of the year, Mumbai receives an average of a mere 100mm rainfall.

The monsoon affects the lives of one-quarter of the world's population and has helped rice – the world's most important staple food – become the predominant crop in the region. However, as in West Africa, the rainfall brought by the ITCZ is not completely reliable. Variations in the northward extent of the convergence zone means the rains can fail. Drought and famine are the result. From the late 1970s to the 1980s there were nine years when the monsoon failed in north-west India. At the other extreme the variations in the ITCZ can also mean even more extreme rainfall, such as that which brought excessive flooding to Bangladesh in 1987, 1988 and 1998.

South America and the Pacific, the ITCZ and El Niño

Rainfall patterns associated with the ITCZ over South America are similar to those experienced in the other parts of the world already mentioned. However, as can be seen in Figure 3, the northward and southward migration of the convergence zone is much more restricted due to the greater influence of the surrounding oceans. Even so, the effects can be quite dramatic on a local scale, and the ITCZ has to be treated with respect. The rising winds have an influence on the devastating hurricanes that affect both the Pacific and the tropical Atlantic oceans. The fast rising air can also cause other problems. On 31 May 2009, for instance, thunderstorms along the ITCZ played a key role in the loss of Air France flight 447 flying from Rio de Janeiro to Paris. The aircraft crashed with no survivors and, although the exact cause is still not known, theories include the influence of extreme turbulence caused by dramatic updraughts of air, a lightning strike setting off an electrical fault or rapidly forming ice affecting the aircraft's sensors – all being a direct consequence of flying through the towering clouds formed by the ITCZ.

On a continent-wide scale the influence of the ITCZ is also important, given its short-term impact on El Niño Southern Oscillation (ENSO) events. ENSO events occur every three to four

years and involve a reversal in weather patterns found over the Pacific Ocean. Normally pressure rises over the eastern Pacific and falls over the western side, giving clear, dry conditions over western South America and heavy rainfall over Indonesia. In contrast, during ENSO events pressure rises over the western Pacific and falls in the east, with a direct effect on the ITCZ. The northward migration of the ITCZ is inhibited and it may migrate southwards instead. The trade winds weaken in strength and their direction can be reversed. The collapse of the trade wind system causes air to descend over Indonesia and Australia, leading to much drier conditions than normal and even the possibility of drought. In the 1998 ENSO event the dry conditions led to forest fires over parts of Indonesia and a widespread smoke haze that covered a number of nearby countries. Meanwhile, in the eastern Pacific, ascending air brings heavy rainfall in Peru and neighbouring countries that normally stay dry. Again, in the 1998 event, areas of Peru received the equivalent of six months of rainfall every day for a 12-day period. The extensive flash flooding that followed caused several hundred deaths and injuries to more than 16,000 people.

The breakdown in normal climatic conditions brought on by ENSO and the disruption to the ITCZ have effects much further afield and can cause extraordinary conditions on a global scale, including temperatures just above freezing in Bangladesh and extremely mild winters in the Canadian Rockies.

Climate change and the ITCZ

Recent research has begun to show the effects that any possible future climate change could have on the weather in countries affected by the ITCZ. Some of these have the potential to be very worrying. Investigations into past climates have shown that the position of the ITCZ is very sensitive to changes in the temperature of the atmosphere and to amounts of incoming solar radiation. These results have been used to make projections about what will happen towards the year 2100 if levels of greenhouse gases in the atmosphere continue to rise. Some scientists think this may result in

the ITCZ moving around 5 degrees of latitude further north than its current average northern maximum, between 3 and 10 degrees north of the equator, to between 8 and 15 degrees north. Some of the potential effects include:

- wet areas in northern Indonesia, Malaysia and the Philippines receiving less ITCZ rain than at present, with effects on the potential to grow crops such as coffee
- southern Central America, Ecuador and Colombia would be drier and, again, crops such as coffee and banana (which need large amounts of rainfall) may prove impossible to cultivate
- subsistence agriculture would be affected in all these regions and, even if there is a mass migration to the cities from rural areas to compensate, regional food shortages could cause severe problems
- there may be droughts in northern Mexico and the southern United States
- some countries, including El Salvador, would lie in the ITCZ rainfall belt for the first time and would become more humid.

There are further concerns from scientists that a northward shift in the ITCZ would affect the frequency of hurricanes, monsoons and the patterns of ENSO events. More research is needed to determine any possible future scenarios. What is obvious is the present and future importance of the inter-tropical convergence zone and its influence on weather patterns both within the tropics and around the rest of the planet.

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Much of the internet information available on the ITCZ is quite technical although <http://en.wikipedia.org>, www.guardian.co.uk, www.bbc.co.uk and erpz.net all have more accessible data. For those requiring more in-depth research, www.srh.noaa.gov, orca.rsmas.miami.edu and www.cpc.ncep.noaa.gov all have research papers and detailed information on atmospheric processes.

The best place to find an animated overview of the ITCZ and some fantastic detail on how it changes through the year, affects the weather and is influenced by the tricellular model of atmospheric circulation can be found at http://daphne.palomar.edu/pdeen/animations/23_weatherpat.swf.

FOCUS QUESTIONS

1. (a) Describe the reasons behind the formation of the inter-tropical convergence zone.
(b) Explain why the ITCZ moves northwards and southwards throughout the year.
2. With reference to specific examples from around the world, describe the rainfall associated with the passage of the inter-tropical convergence zone.
3. Outline the influence of El Niño Southern Oscillation events on the migration of the ITCZ and associated weather conditions over South America and the Pacific Ocean.
4. Give examples from specific countries of the possible impacts of climate change on weather patterns associated with the inter-tropical convergence zone.