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REVIEW ARTICLE

Mutual interactions and Inter-relationships between "Weather" and "Weather Systems"

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ABSTRACT

The study relates to mutual interactions and inter-relationships between weather systems such as the Indian Ocean Dipole (IOD), Equatorial Pacific El Nino-Southern Oscillation (ENSO), Global General Circulation Patterns (GGCP), Indian South-west Monsoon (ISM), Indian North-east Monsoon (INM), and cyclones/hurricanes which deal with the wind, pressure, temperature, and rainfall. IOD has three phases, namely, positive, negative, and neutral. It relates to India and some parts including East Africa, Southern Australia, Southern China, and Indonesia. ENSO also has three phases within a 3–7-year cycle namely, warm-dry El Nino, cold-wet/rainfall La Nina, and neutral. They relate to global events. Under neutral conditions, this includes both the El Nino and La Nino conditions. In 126 years, the Indian rainfall under El Nino ranged from normal to deficit, and in the case of La Nina, it ranged from normal to surplus, and under neutral, it varied from deficit to surplus. Thus, around 50% of the occasions, it is normal. These are generalized observations, and in real situations, they might be counteracted by other weather systems. IOD and ENSO present interactions positively and negatively based on combination scenarios. GGCP covers not only global impacts but also localized impacts such as Western disturbances (WDs) in North-west India and jet stream in the USA in terms of temperature, primarily–secondarily with rainfall. WDs are a wave from the North-west Mediterranean zone – around this zone, a subtropical jet stream passes over the foothills of the Himalayan Mountains. Summer causes heat waves, and winter causes rainfall and cold waves. Cyclonic systems in the Arabian Sea and Bay of Bengal play an important role in WDs south-to-north movements of warm and cold waves in summer and winter, respectively. The jet stream in the USA causes the same way as WDs in India. It stops cold waves moving to the south in summer and allows cold wave movement to the south in winter. The jet stream is influenced by systems in the Pacific Ocean on the north-central west coast of the USA. IOD and ENSO play important roles in ISM both positively and negatively. El Nino plays a role in INM similar to La Nino on ISM. Ocean surface temperatures present cyclic patterns, for example, the Atlantic Multi-Decadal Oscillation (AMO) presented a 60-year cycle and a 132-year cycle in the South Atlantic Ocean. The same is the case with the Pacific Ocean – Pacific Decadal Oscillation (PDO) presenting a 60-year cycle in the north and a 132-year cycle in the south Pacific zones. Such cyclic variations are not given much importance while dealing the weather systems. These factors are influenced by cyclic variations in rainfall, temperatures, and cyclones in India/hurricanes in the USA over different parts of the globe, a principal component of climate change, that is beyond human control but we need to adapt to them. The Bay of Bengal cyclones followed the cyclic variation. ENSO and IOD have no systematic consistent variations. The heat generated from these factors is generally attributed to global warming which is hypothetical in nature. Discussed the interactions between IOD (positive, negative, and neutral) and ENSO (El

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Nino, La Nina, and neutral), also, discussed the impact of these on Australian, Indonesia, East African, and South China Rainfall and also, presented the inter-relation between AMO and PDO and ENSO.

Key words: AMO, climate change, cyclic variations, ENSO, GGCP, IOD, PDO, precipitation, temperature, WD, weather systems

INTRODUCTION

General

Global warming is a component of climate change by definition, a part of human-induced changes is a hot topic as it involves millions of dollars to share. In evaluating it greenhouse gases such as carbon dioxide, methane, and nitrous oxide are the principal components used by researchers, global average annual temperature (adjusted in the starting part of the data series as the data during that time was sparse in terms of met network and the number of years data available) presented 60-year cycle and the global warming part of the trend is 0.45°C for 1951–2100 with the amplitude of sine curve of 0.60°C/60-years. This is basically related to the manipulation of the starting data series and sparse data network under the rural-cold-island-effect part and oceans part. The IPCC defined 1951 as the starting year of the global warming.

The natural variability in rainfall, temperatures, and cyclones/hurricanes contribute to increases and decreases in water vapor content in the atmosphere that increases or decreases the incoming and outgoing radiation from the Sun and the Earth. In some parts of the globe, this is affected by volcanic eruptions, dust storms, and as well as earthquakes. Forest fires, wars, etc. also contribute the same impact.

The USA "raw" temperature data from a well-distributed network presented a 60-year cycle with no trend. The adjusted data series presented a trend as the data available during the early part of the data series [with sparse met network and in terms of number of years] have been adjusted downward to show a steep rise. IPCC identified 1951 as the starting year of global warming. This was not adhered. For the study of identifying cycles in the data, one can start from the start of the data series. The satellite data superposed at the later stage of the data series on ground data showed no trend;[1] however, this was deleted from the Internet and added new data. Since 2000, this showed a steep abnormal rise and carbon dioxide presented a linear increase. This is the most absurd pattern.

To understand these issues presented Figure 1a, it relates to the global land and ocean areas distribution. The ratio of land to water for the whole of the Earth is approximately 1:2 (Land: Oceans) and 2:3 in the Northern Hemisphere (Land: Ocean). The ratio of land to ocean in the Southern Hemisphere is 1:3. Thus, the Northern Hemisphere must be more than the Southern Hemisphere in terms of temperature. Rainfall is influenced by global, regional, and local factors based on the local climate systems in addition to the natural variability part of climate change. The Southern Hemisphere contains Antarctica, Australia, some Asian islands, one-third of Africa, and most of South America. The Northern Hemisphere contains the northern two-thirds of Africa, the northern part of South America, North America, and Europe [Figure 1a].

Global Thermocline Circulation

Global thermocline circulation [Figure 1b] transports and mixes the water of the oceans. In the process, it transports heat, which influences regional climate patterns. The density of seawater is determined by the temperature and salinity of a volume of seawater at a particular location. The difference in density between one location and another drives the thermohaline circulation.

The top surface layer of the ocean is called the epipelagic zone and is sometimes referred to as the "ocean skin" or "sunlight zone." This layer interacts with the wind and the waves, which mix the water and distribute the warmth. At the base of this layer, it is the thermocline. A thermocline is the transition layer between the warmer mixed water at the surface and the cooler deep water below. It is relatively easy to tell when you have reached the thermocline in a body of water because there is a sudden change in temperature. In the thermocline, the temperature decreases rapidly from the mixed layer temperature to the much colder deep water temperature.

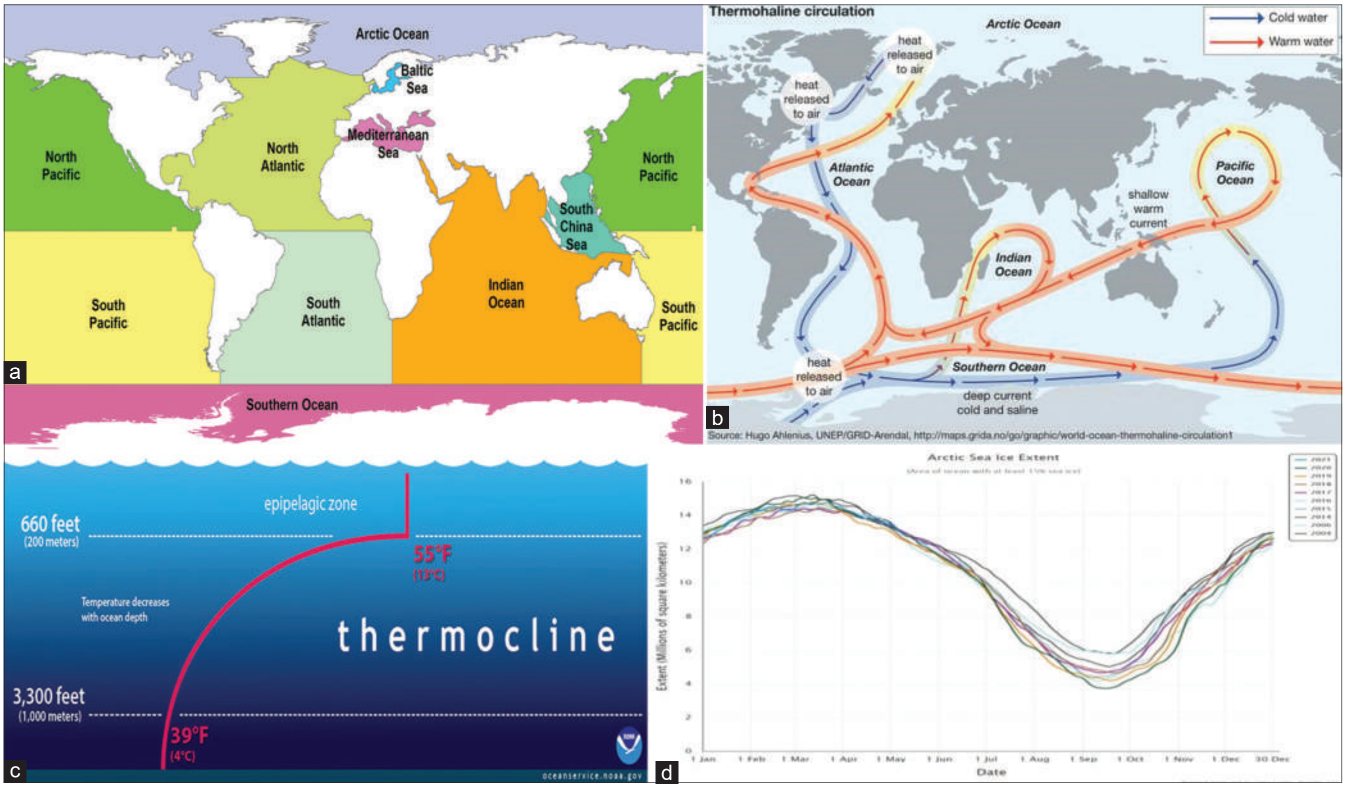

Figure 1: (a) Distribution of global land-ocean areas. (b) Global Thermocline Circulation Pattern. (c) The red line in this illustration shows a typical seawater temperature profile. (d) Seasonal March of "Arctic Sea Ice Extent in millions of sq. km."

The thermocline varies in depth. It is semi-permanent in the tropics, variable in temperate regions, and shallow to non-existent in the Polar Regions, where the water column is cold from the surface to the bottom. A layer of sea ice will act as an insulation blanket. The first accurate global measurements were made during the oceanographic expedition of HMS challenger. In the ocean, the depth and strength of the thermocline vary from season to season and year-to-year. It is semi-permanent in the tropics, variable in temperate regions (often deepest during the summer), and shallow to non-existent in the Polar Regions, where the water column is cold from the surface to the bottom. Thermoclines [Figure 1d] also play a role in meteorological forecasting. For example, hurricane forecasters must consider not just the temperature of the ocean's skin (the sea surface temperature [SSTs]), but also the depth of warm water above the thermocline. Water vapor evaporated from the ocean is a hurricane's primary fuel. The depth of the thermocline is the measure of the size of the "fuel tank" and helps to predict the risk of hurricane formation.

Most of the heat energy of the sunlight that strikes the Earth is absorbed in the first few centimeters at the ocean's surface, which heats during the day and cools at night as heat energy is lost to space by radiation. Waves mix the water near the surface layer and distribute heat to deeper water such that the temperature may be relatively uniform in the upper 100 m (330 ft), depending on wave strength and the existence of surface turbulence caused by currents. Below this mixed layer, the temperature remains relatively stable over day/night cycles. The temperature of the deep ocean drops gradually with depth. As saline water does not freeze until it reaches −2.3°C (27.9°F) (colder as depth and pressure increase), the temperature well below the surface is usually not far from zero degrees.

In the open ocean, the thermocline is characterized by a negative sound speed gradient, making the thermocline important in submarine warfare because it can reflect active sonar and other acoustic signals. This stems from a discontinuity in the acoustic impedance of water created by the sudden change in density.

The thermocline in the ocean can vary in depth and strength seasonally and annually (the same is the case with the Arctic Sea Ice Extent). The total solar radiation from the Sun and net radiation (balance) from the Earth also follow the seasonal and annual according to the location in terms of latitude and longitude. This is particularly noticeable in mid-latitudes with a thicker mixed layer in the winter and thinner mixed layer in summer. The cooler winter temperatures cause the thermocline to drop to further depths and warmed summer temperatures bring the thermocline back to the upper layer. In areas around the tropics and subtropics, the thermocline may become even thinner in the summer than in other locations. At higher latitudes, around the poles, there is more of a seasonal thermocline than a permanent one with warmer surface waters. This is where there is a dichothermal layer instead. In the Northern Hemisphere, the maximum temperatures at the surface occur through August and September and minimum temperatures occur through February and March with total heat content being lowest in March. This is when the seasonal thermocline starts to build back up after being broken down through the colder months. A similar pattern is also seen in the Arctic Sea Ice Extent [Figure 1c]. A permanent thermocline is one that is not affected by season and lies below the yearly mixed layer maximum depth.

What is Weather System?

Weather systems comprise several systems that are confined to local, regional, or global contexts. There are three basic weather systems, namely:

- Indian Ocean Dipole (IOD) which has three phases, namely, positive, negative, and neutral. This is primarily related to temperature – warm, cool, and neutral. The term Dipole means two poles or two areas of difference. The IOD measures the difference in SSTs between the Arabian Sea (western pole) and the Eastern Indian South of Indonesia (eastern pole). Both these poles are situated within the equatorial belt of the Indian Ocean (between 10°N and 10°S)
- El Nino-Southern Oscillation (ENSO) is a global climate phenomenon that emerges from variations in winds and SSTs over the tropical Pacific Ocean. Those variations have an irregular pattern but do have some semblance of cycles (3–7 years). It affects the climate of much of the tropics and has links to higher-latitude regions of the world. Here, temperature and winds play a prominent role. This follows the cyclic pattern in three phases, namely, El Nino, La Nina, and neutral
- Global General Circulation Patterns (GGCP) relate to global weather parameters such as wind, pressure, and temperature. This includes WDs in India and jet stream in the USA.

What is a Cyclone/Hurricane/Typhoon?

Every year during the late summer months (July–September in the Northern Hemisphere and January–March in the Southern Hemisphere), cyclones strike regions as far apart as the Gulf Coast of North America, North-west Australia, and Eastern India. Tropical cyclones (TCs) can last for days or even weeks and have irregular trajectories. It passes over land or cooler waters, a cyclone will dissipate. Depending on where they originate in the world, TCs are referred to by various names, in the Caribbean Sea and North Atlantic Ocean, it is known as hurricanes, whereas in the Western North Pacific, it is known as typhoons. It is referred to as a TC or just a cyclone in the Indian Ocean Region and the South Pacific Ocean. Since they are virtually invariably formed between Tropic of Cancer and Capricorn (between the latitudes 23.5°N and 23.5°S), all these storms are classified as TCs that form over water that is warmer than 26.5°C. TCs typically do not form within 5° north and south of the equator because of Coriolis effect is less pronounced along the equator. Some introduced global warming causes an increase in the proportion of severe TCs. Global warming (hypothetical in nature) is a global average that has no impact on local or regional systems.

Cyclone is a general term for a low-pressure system over tropical and subtropical waters that have organized convection (i.e., thunderstorm activity) and winds at low levels that circulate either clockwise or anti-clockwise, in the Northern Hemisphere or Southern Hemisphere, respectively. They usually develop when the SST is higher than 26.5°C.

Centuries ago European explorers learned the indigenous word hurakan, signifying evil spirits and weather gods, to describe the storms that battered their ships in the Caribbean. Today, “hurricane” is one of three names for giant spiraling tropical storms with winds of at least 119 km (74 miles) an hour. Called hurricanes when they develop over the North Atlantic, central North Pacific, and eastern North Pacific, these rotating storms are known as cyclones when they form over the South Pacific and Indian Ocean, and typhoons when they develop in the Northwest Pacific. Whatever the moniker, TCs can annihilate coastal areas and cause massive death tolls. Rated on the five-point Saffir–Simpson Scale [Table 1] based on the wind speed, hurricanes are considered major when they reach category 3. A category 5 storm can deliver wind speeds of more than 253 km (157 miles) an hour.

Cyclones are given many names in different regions of the world. They are known as typhoons in the China Sea and Pacific Ocean; hurricanes in the West Indian islands in the Caribbean Sea and Atlantic Ocean; tornados in the Guinea lands of West Africa and southern USA; willy-willies in North-western Australia, etc. [Figure 1a]. A typhoon with maximum sustained surface winds greater than or equal to 130 knots (approximately category 5) is called a "super typhoon," and a hurricane of category 3 and above is called a "major hurricane." A TCs weaker than category 1 is not a "typhoon" by the international standard.

As a cyclone approaches, the wind and rain gradually increase over several hours. A cyclone will sound such as a roaring train or jet engine and the skies will darken, turning the day into night. You could be inside for many hours. There may be strong winds and horizontal rain. These winds are powerful enough to break large trees, roll over sea containers, and blow away unsecured caravans, garden sheds, and poorly constructed roofed patios. They can cause extensive property damage and turn loose items into wind-borne debris that causes further building damage. Slow-moving cyclones can take many hours to move past a particular location, and extreme wind and rain can last up to 12 h. As the cyclone moves over the coastline, those in the direct path will experience the eye of the cyclone, and it is lighter winds and clear skies. The eye can be from 10–100 km wide. When the eye passes over, the returning winds are faster, more intense, and can return without any warning. Table 1 presents the Saffir–Simson Scale under different categories.

Table 1: Saffir–Simpson Scale: 1-min maximum sustained winds

Category	M/s	knots	Mph	km/h
5	>0 70	>137	>157	>252
4	58–70	113–136	130–156	209–251
3	50–58	96–112	111–129	178–206
2	043–949	083–095	096–110	154–177
1.	033–042	064–082	074–095	119–153
TS	018–032	034–063	039–073	063–118
TD	<017	<033	<038	<062

TS: Tropical storm, TD: Tropical depression

TC is an intense circular storm that originates over warm tropical oceans and it is characterized by low atmospheric pressure, high winds, and heavy rain. Drawing energy from the sea surface and maintaining its strength as long as it remains over warm water, a weaker TC (such as a tropical depression or a tropical storm) can mature to become a much stronger TC (known as a hurricane, typhoon, cyclone, or other name depending on the region in which it occurs) when its winds exceed 119 km (74 miles) per hour [Table 1].

The weakest TCs are called *tropical depressions*. If a depression intensifies such that its' maximum sustained winds reach 39 miles per hour, the TC becomes a *tropical storm.* Once a TC reaches maximum sustained winds of 74 miles per hour or higher, it is then classified as a hurricane, typhoon, or TC, depending upon where the storm originates in the world. In the North Atlantic, Central North Pacific, and Eastern North Pacific, the term *hurricane* is used. The same type of disturbance in the North-west Pacific is called a *typhoon*. Meanwhile, in the South Pacific and Indian Ocean, the generic term TC is used, regardless of the strength of the wind associated with the weather system.

In extreme cases, winds may exceed 240 km (150 miles) per hour, and gusts may surpass 320 km (200 miles) per hour. Accompanying these strong winds are torrential rains and a devastating phenomenon known as the storm surge, an elevation of the sea surface that can reach 6 m (20 feet) above normal levels [Figure 2a]. Such a combination of high winds and water makes cyclones a serious hazard for coastal areas in tropical and subtropical areas of the world.

A rare phenomenon occurred in the Pacific Ocean on Monday [Figure 2b]. Four named tropical storms were churning in the ocean at the same time: Carlotta, Daniel, Emilia, and Fabio. The last time

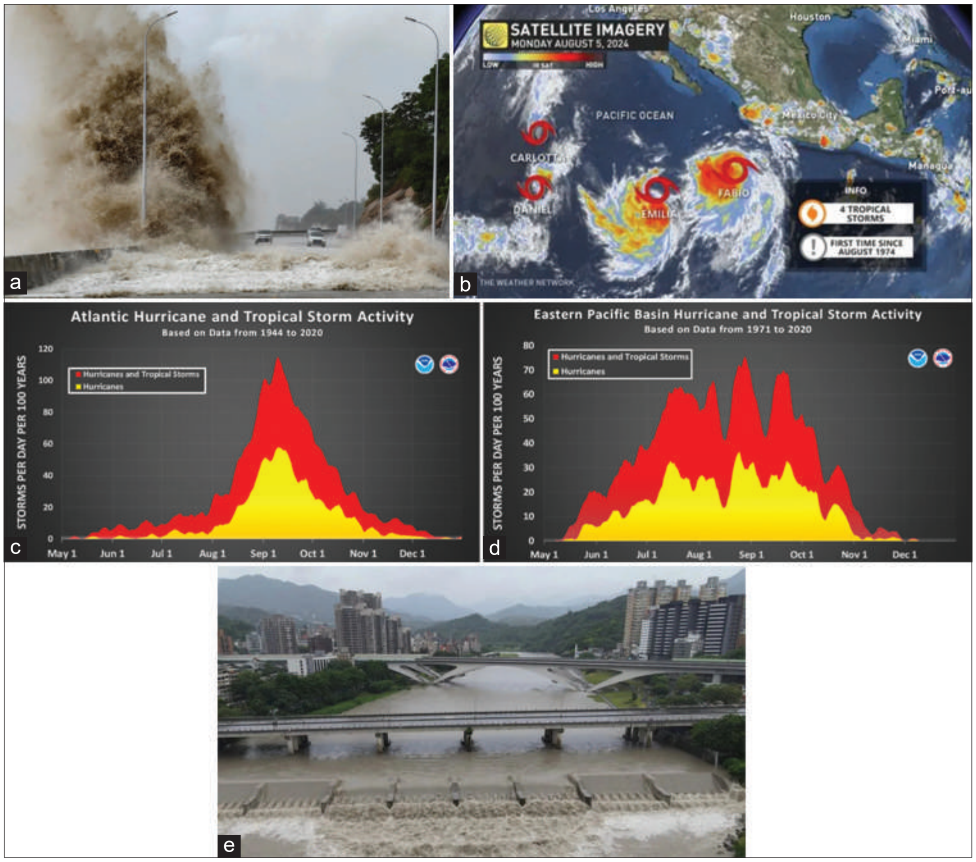

Figure 2: (a) Waves crash on the coast of Sansha town, Fujian Province, as Typhoon Gemi approaches (Reuters). (b) Satellite imagery Pacific Ocean Aug. 5, 2024 (four storms). (c) Atlantic Hurricanes and Tropical Storm Activity. (d) Eastern Pacific Basin Hurricanes and Tropical Storm Activity. (e) Taiwan's Xindian River rises in New Taipei City as Typhoon Gemi barrels over Taiwan on July 25, 2024. - Sam Yeh/AFP/Getty Images

that happened was 50 years ago, in August 1974. On other occasions, notably in 2018, several cyclones churned up the warm waters of the Pacific at the same time, but they were not in the entire same category.

The Atlantic Ocean's hurricane season peaks from mid-August to late October [Figure 2c] but Figure 2d presents a break between August and September and the count is less than in Figure 2c and spread over a wider period of time – similar to India rainfall – and averages 5–6 hurricanes per year. While the cyclones on the Northern Indian Ocean, typically form between April and December, with peak storm activity around May and November. Figure 2e presents a scene of flooding, as an example.

SYSTEMS OF OPERATION

IOD

The IOD, also known as the Indian Niño (El Nino), is an irregular oscillation of SSTs in which the Western Indian Ocean becomes alternatively warmer positive phase, Figure 3a and then colder [negative phase, Figure 3b]. These figures also present the pattern of sea breeze and land breeze systems; whereas the IOD refers to western and eastern parts of the Indian Ocean.

The IOD Index is defined as the difference between SST anomalies of the Western (50–70°E) and eastern (90–110°E) longitude belts. – tropical Indian Ocean. This is specific to regional issues only. The IOD is a climate pattern affecting the Indian Ocean. During a positive phase, warm waters are pushed to the Western part of the Indian Ocean, whereas cold deep waters are brought up to the surface in the Eastern Indian Ocean [Figure 3a and b]. When it is reversed, the impact is also reversed.

The IOD is characterized by the difference in SST between two regions of the Indian Ocean [Figures 3a and b], namely (i) the Western Indian Ocean (near the coast of East Africa) and (ii) the Eastern Indian Ocean (near the eastern Pacific Ocean

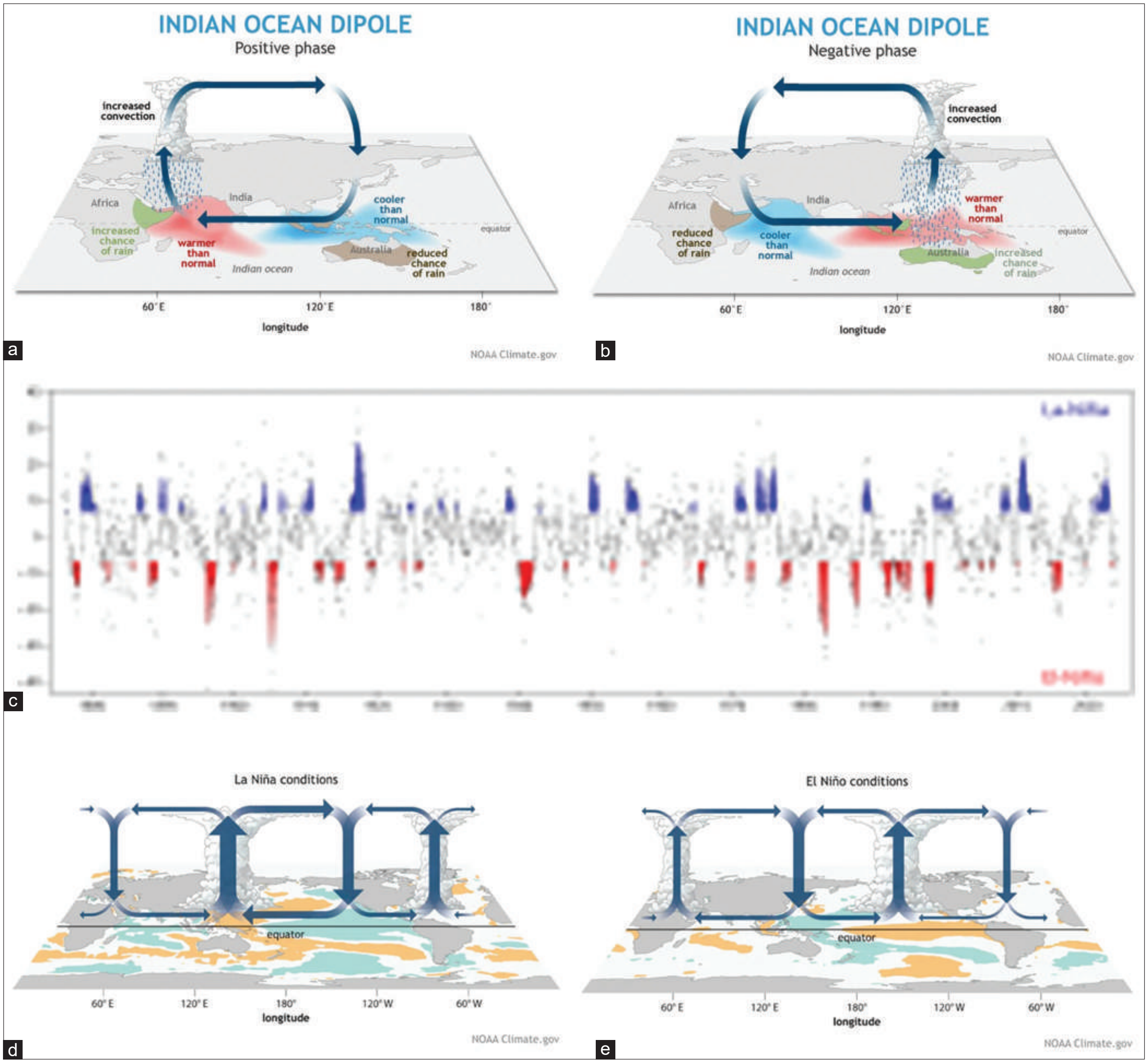

Figure 3: (a) Indian Ocean Dipole (Positive Phase). (b) Indian Ocean Dipole (negative Phase). (c) Southern Oscillation Index time series from 1876 to 2024 – It shows the average temperature anomaly between La Nina (blue) and El Nino (red)-Source: Internet. (d) During La Niña, the Walker circulation intensifies, triggering stronger storms where the air rises. Fiona Martin, NOAA Climate.gov. (e) During El Nino, the Walker circulation weakens, where the air falls. Fiona Martin, NOAA Climate.gov

Coast of Indonesia). It has three phases, namely, positive, negative, and neutral. Positive IOD causes the warm SST in the Western Indian Ocean and cooler temperatures in the Eastern Indian Ocean; on the contrary negative IOD causes the reverse of positive IOD; neutral IOD causes the average SSTs in both the regions without significant anomalies.

It is reported that the positive IOD causes a significant influence on weather patterns, especially the Indian Monsoon Season (IMS), namely enhanced monsoon leads to increased rainfall over the Indian subcontinent resulting in a stronger monsoon season and dry conditions in southern parts of Australia due to reduced rainfall. The negative IOD causes weaker monsoons resulting in below-the-average rainfall over India, potentially leading to drought conditions; and wet conditions in southern parts of Australia cause increased rainfall**.** The neutral IOD causes normal monsoons resulting in typical monsoons without significant deviations from the average – which can be linked to positive IOD. These are generalized factors but in the presence of several other such systems, it may be strengthened or weakened. When we are talking of the Indian Northeast Monsoon (INM) and associated cyclonic activity in the Bay of Bengal negative IOD plays a positive.

ENSO

Introduction

The ENSO is a single climate phenomenon that periodically fluctuates between three phases: Neutral, La Niña, and El Niño that occur in opposite phases in the oscillation which are deemed to occur when Pacific Ocean and atmospheric conditions are reached or exceeded similar to cyclic patterns of above and below the averages and at inflection year neutral condition-the periodic fluctuation is not sinusoidal form such as cyclic pattern and also the period of the cycle varies. An early recorded mention of the term "El Niño" ("The Boy" in Spanish) and the term "La Niña" ("The Girl" in Spanish) is the colder counterpart of El Niño, as part of the broader ENSO climate pattern.

The warming phase of the SST is known as *El Niño* and the cooling phase as *La Niña*. La Niña is defined as the periodic cooling of the central Pacific Ocean. When this occurs, the variable polar jet stream is forced north. This usually leads to wetter and colder winters in the Pacific North-west and warmer and drier winters in the South-west.

A report suggests that the La Niña is the opposite of El Niño. Trade winds are even stronger than usual during La Niña events, pushing warm water toward Asia. Off the west coast of the US upwelling increases and brings cold, nutrient-rich water to the surface. These cold waters in the Pacific push the jet stream northward. Hurricane activity tends to increase under La Niña due to its effects on wind shear and atmospheric conditions over the Atlantic. There is a reduction in wind shear in the tropics when La Niña occurs, which can encourage hurricane development. Wind shear means a change in wind speed and direction with height in the atmosphere. La Niña also favors greater hurricane activity by decreasing atmospheric stability and reducing the amount of sinking motion in the atmosphere.

The Southern Oscillation (SO) is the atmospheric component of El Niño. This component is an oscillation in surface air pressure between the tropical eastern and the western Pacific Ocean waters; a negative phase exists when atmospheric pressure over Indonesia and the west Pacific is abnormally high and pressure over the east Pacific is abnormally low, during El Niño episodes.

That is, *El Niño* is associated with higher than normal air-sea level pressure over Indonesia, Australia, and across the Indian Ocean to the Atlantic; A positive phase is when the opposite occurs during La Niña episodes, and pressure over Indonesia is low and over the west Pacific is high; *La Niña* has roughly the reverse pattern: high pressure over the central and eastern Pacific and lower pressure through much of the rest of the tropics and subtropics; neutral periods of lower intensity interspersed *El Niño* events can be more intense but *La Niña* events may repeat and last longer; The two phenomena last a year or so each and typically occur every 2–7 years with varying intensity. Figure 3c presents the SO Index time series from 1876 to 2024. For several years, the index is not associated with La Nina or El Nino conditions.

Weaker easterly trade winds result in a surge of warm surface waters to the east and reduced ocean upwelling on the equator. In turn, this leads to warmer SSTs (called El Niño), a weaker Walker circulation an east-west overturning circulation in the atmosphere, and even weaker trade winds (called La Nino). Ultimately the warm waters in the western tropical Pacific are depleted enough so that conditions return to normal.

Each country that monitors the ENSO has a different threshold for what constitutes an El Niño or La Niña event, which is tailored to their specific interests. El Niño and La Niña affect the global climate and disrupt normal weather patterns, which as a result can lead to intense storms in some places and droughts in others. Natural variability in rainfall must be taken into account before coming to a conclusion or a theory.

El Niño events cause a short-term (approximately 1 year in length) rise in global average surface temperature; *La Niña* events cause a short-term surface fall in global average surface temperature; this means a major part of the ocean is not accounted for like in IOD. Therefore, the relative frequency of *El Niño* compared to *La Niña* events can affect global temperature trends on timescales of around 10 years; the countries most affected by ENSO are developing countries that border the Pacific Ocean and are dependent on agriculture and fishing. The tropics have an atmospheric circulation pattern called the Walker circulation, named after Sir Gilbert Walker, an English physicist in the early 20th century-first director of the India Meteorological Department (IMD) and who introduced the long-range rainfall forecasting method. The Walker circulation is basically giant loops of air rising and descending in different parts of the tropics [Figure 3d and e].

During La Niña, those loops intensify, generating stormier conditions where they rise; and drier conditions where they descend [Figure 3d]. During El Niño, ocean heat in the eastern Pacific instead shifts those loops, so the eastern Pacific gets stormier [Figure 3e]. During El Niño, the Walker circulation shifts eastward, so more storms form off California as warm air rises over the warmer waters of the Eastern Pacific. (Fiona Martin, NOAA Climate.gov). This is a generalized inference. Here, hurricanes presented a natural 60-year cycle with an increasing trend.[2-4]

El Niño and La Niña also affect the jet stream, a strong current of air that blows from west to east across the U.S. and other mid-latitude regions; During El Niño, the jet stream tends to push storms toward the subtropics, making these typically dry areas wetter; Conversely, mid-latitude regions that normally would get the storms become drier because storms shift away.

El Nino is the warming of sea waters in the Central-east Equatorial Pacific that occurs every few years (Warm phase off the coast of Peru). Over India, the El Nino has the impact of suppressing monsoon rainfall like negative IOD – however this has not happened in 2024 but on the contrary, a cyclone formed in the Bay of Bengal and reached to Bangladesh. La Nina sees cooler than average SSTs in the equatorial Pacific region (Cool phase). In the Indian context, La Nina is associated with good rainfall during the southwest monsoon season (IMS) like positive IOD. Both these conditions, together called ENSO, affect weather events across the world. Neutral IOD is similar to neutral conditions in ENSO for the Indian Monsoon. Table 2 presents the SO versus Indian South-west Monsoon (ISM) rainfall (78.2% of the annual average rainfall) from 1880 to 2006.

In 126 years, 18 years observed El Nino conditions and only in 7 years deficit rainfall occurred and 1-year excess rainfall, 5 years each under below the normal and normal conditions. Twenty-four years were under the La Nina with excess rainfall in 10 years and 7 years each under above normal and normal conditions. 84 years under neutral conditions with deficit to excess rainfall conditions. Total 49 years were under normal conditions.[1]

Table 2: Southern Oscillation versus Indian South-west Monsoon Rainfall (1880–2006) – s.j.reddy

Events	SO			Number of Years		
	D	BN	N	AN	E	Total
El Nino	7	5	5	0	1	18
Neutral	14	13	37	14	6	84
La Nina	0	0	7	7	10	24
Total	21	18	49	21	17	126

D: Deficit, BN: Below normal, N: Normal, AN: Above normal, E: Excess rainfall years

It is seen from Figure 4 that during below the average 30-year period cycle of all-India annual average rainfall (1897–1926 and 1957–1986) El Nino presented drought conditions in 12 years and a similar pattern with La Nina is not seen and it only presented in 7 years observed flood conditions. Although the above-normal condition in rainfall is seen but they are not under La Nina system and the same is the case with El Nino. Neutral conditions, respectively, were 11 and 12 years above the average and below the average. The annual average rainfall of India during 1871–1872 to 2014–2015 of January to December period presented a 60-year cycle but the last period data showed doubtful data – the data of CWC for June to May for 1985–86 to 2016-17 presented a correct pattern[5] – above the average.

Impact of ENSO on Southern Hemisphere

The impacts of El Niño and La Niña are almost a mirror image in the Southern Hemisphere. Chile and Argentina tend to get droughts during La Niña, while the same phase leads to more rain in the Amazon [northeast Brazil presents a 52-year cycle with sub-multiples of 26, 13, and 6.5 years in rainfall.[6] This is similar to the onset dates of the south-west monsoon over the Kerala Coast. Southern Australia had severe flooding during the last La Niña. Positive IOD also favors the Indian monsoon, meaning above-average rainfall. The effects are not immediate, however. In South Asia,

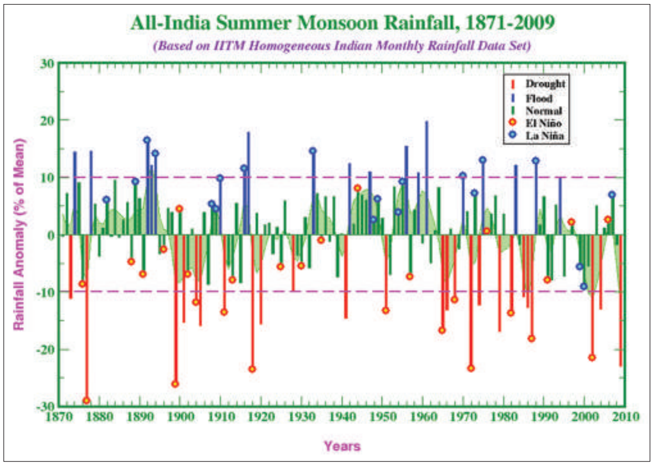

Figure 4: During below the average 30-year period cycle [1897-1926; 1957-1986] – El Nino presents drought conditions and a similar pattern with La Nina and floods are not seen: Source: IITM

for example, the changes tend to show up a few months after La Niña has officially appeared.

La Niña is quite bad for eastern Africa, where vulnerable communities are already in a long-term drought. IOD showed India and Eastern Africa presenting a similar pattern but La Nina showed the opposite phenomenon – a good Indian monsoon during La Nina period but a bad period for Eastern Africa. However, both Indian rainfall and eastern African rainfall presented cyclic patterns.[6]

Impact of La Nina on climate change

Natural variability is the main component of climate change that is beyond human control except that we need to adapt to it, and the other component is a human-induced part that has two major divisions. People use global warming as climate change but it is only one part of the human-induced component. That forms a greenhouse gas component.

However, so far scientists have not achieved the goal of quantitative form for the "Climate Sensitive Factor" that links greenhouse gases to global warming. Furthermore, recent reports brought out several other components of greenhouse gases that were not included in greenhouse gases (carbon dioxide, methane, and nitrous oxide). The major part of carbon dioxide forms humans release is not considered greenhouse gas instead entire carbon dioxide in the atmosphere is considered a greenhouse gas. Global Warming thus is a hypothetical parameter to collect millions of dollars.

Reports say that the El Niño and La Niña are now happening on top of the effects of global warming. That can exacerbate temperatures, as the world saw in 2023, and precipitation can go off the charts. Since the summer of 2023, the world has had 10 straight months of record-breaking global temperatures. This is a hypothetical postulation only. The abnormal increases in summer and abnormal decreases in winter temperatures are caused by localized systems associated with heat waves and cold waves. In India caused by WDs (region of influence is regulated by cyclonic storms occurring in the Bay of Bengal and Arabian Sea); in the USA Jet stream regulates this.

A lot of that warmth is coming from the Oceans, which are still at record-high temperatures; however, ocean temperatures follow natural cyclic variations in temperature like 60-year cycle in Atlantic Ocean Multi-decadal Oscillation (AMO) and 132-year cycle in Australian SST with zero trends and thus zero global warming component except the 132-year cycle has an amplitude of 0.85 [from −0.425 to +0.425°C]/132 years.

La Niña should cool things a bit, but greenhouse gas emissions that drive global warming are still rising in the background – it is insignificant and also it is an average of the global temperature it is like an average of rich man plus poor man by two. Hence, fluctuations between El Niño and La Niña can cause short-term temperature swings.

The arrival of El Niño or La Niña in the tropical Pacific Ocean triggers a cascade of changes in tropical rainfall and wind patterns that echo around the globe. For the US, the most significant impact is a shift in the path of the mid-latitude jet streams. These swifts and high-level winds play a major role in separating warm and cool air masses and steering storms from the Pacific across the U.S. – see Figure 5a.

- In summer, the jet stream has a tendency to be farther north, causing drier and warmer conditions in the southern USA
- In winter, the jet stream has a tendency to push to the south causing cooler/wetter conditions in the Southern USA.

A report states that one or more of these climate patterns have occurred during many El Niño and La Niña events in the past. That does not mean that all of these impacts happen during every episode. Every event is somewhat different. In other words,

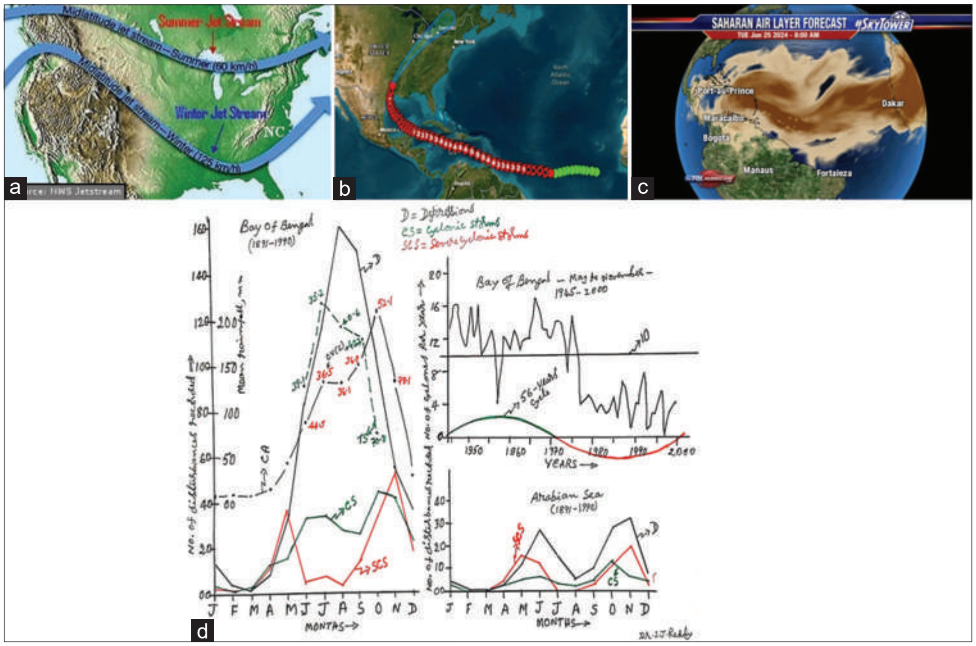

Figure 5: (a) During La Niña, the jet stream tends to be farther north, causing drier conditions across the U.S. [Source: Internet]. (b) Track Beryl as it made its way across the Atlantic, into the Caribbean, then the Gulf of Mexico, and into the USA. (c) NASA-NOAA satellite captures Saharan dust Cloud extending up to Maracalbo]. (d) Andhra Pradesh Weather at a Glance including cyclones

the influence of El Niño on the US winter climate is a matter of probability, not certainty. Natural variability and trends in Hurricanes show special circumstances.

El Niño and La Niña are opposite phases of a natural climate pattern across the tropical Pacific Ocean that swings back and forth every 3–7 years on average. El Niño and La Niña alternately warm and cool large areas of the tropical Pacific-the world's largest ocean-which significantly influences where and how much it rains there.

Like a boulder dropped into a stream, this shift in the location of tropical rainfall disrupts the atmospheric circulation patterns that connect the tropics with the middle latitudes, which in turn modifies the mid-latitude jet streams. By modifying the jet streams, El Niño and La Niña can affect temperature and precipitation across the United States and other parts of the world. The influence on the U.S. is strongest during the winter (December-February), but it may linger into early spring.

Dust storm's role on Hurricane forming: Beryl becomes hurricane farthest east in Atlantic since 1933 [Figure 5b]: A report states that "Hurricane Beryl [Figure 5b] was one for the record books. Here is why and how it impacted so many. The storm that started in the Atlantic on June 28 grew to a monster Category 5 storm, made three landfalls, and killed at least 11 as it carved a path of destruction across the Caribbean and at least four in Texas after coming ashore as the season's first hurricane. On Monday, July 8, just over 12 h after making landfall in Texas as a Category 1 hurricane, Beryl was a tropical depression. While the National Hurricane Centre issued its last advisory on the system early July 9, Beryl still is not done making its presence felt. It is expected to bring heavy rainfall and possibly flash flooding from the lower and mid-Mississippi Valley to the Great Lakes on Tuesday, July 9, and Wednesday, according to the final advisory from the National Hurricane Center. Storms could also bring a risk for tornadoes as Beryl moves north. Here is how many records Beryl set over its life, as provided by Dr. Philip Klotzbach, a meteorologist at Colorado State University specializing in Atlantic basin seasonal hurricane forecasts.

Dust is making it hard for hurricanes to form for now [Figure 5c]: One reason for the lull over the next couple of weeks will be the dry, dusty air spreading across the Atlantic Ocean from the Sahara Desert in Northern Africa: "Although the water temperatures are warm enough to support tropical development and further intensification, dry air and dust are suppressors for storm development," Banks said. "Basically, the dust acts like a lid and storms struggle to form."

Impact of La Niña on hurricanes

Temperatures in the tropical Pacific also control wind shear over large parts of the Atlantic Ocean. Wind shear is a difference in wind speeds at different heights or directions**.** Hurricanes have a harder time holding their column structure during strong wind shear because stronger winds higher up push the column apart. La Niña produces less wind shear, removing a brake on hurricanes.

That warmth affects the atmosphere, causing more atmospheric motion over the Atlantic, fuelling hurricanes. Here, we must remember the fact that hurricanes presented a 60-year cycle – with the current period under the above average 30-year hurricanes period – with increasing trend and presented 1 and 5 as the lowest and 50 and 51 as the highest.[2] Even according to this, this period comes under above the average 60-year cycle with the increasing trend.

INTERACTION AND INTER-RELATION BETWEEN IOD ON ENSO

Impact of IOD on ENSO

Cyclones in the Arabian Sea and Bay of Bengal

Both the Bay of Bengal and the Arabian Sea experience cyclonic events due to their proximity to the Indian Ocean [Figure 5d], where cyclones are a common phenomenon. However, when the two are compared, the Bay of Bengal sees approximately five times as many cyclones as its Western counterpart, the Arabian Sea. In addition, cyclones in the Bay of Bengal are stronger and deadlier.[7] Moreover, what is more, nearly 58% of cyclones formed in the Bay of Bengal reach the coast as compared to only 25% of those formed in the Arabian Sea.

TCs-also called typhoons or hurricanes – are intense water-rotating systems formed by strong winds (of speeds at least 62 km/h) around low-pressure areas. They have a spiral, anticlockwise movement. Additional weather conditions like high SSTs, vertical changes in wind speed inside the spiral, and high relative humidity help cyclones form and intensify.

Since SSTs and humidity both directly correlate with chances of cyclone formation, the Bay of Bengal is a more likely target because it gets higher rainfall, and because the sluggish winds around it keep temperatures relatively high: about 28° around the years. Warm air currents enhance this surface temperature and aid the formation of cyclones.

In addition, the Bay of Bengal receives higher rainfall and a constant inflow of fresh water from the Ganga and Brahmaputra rivers. This means that the Bay of Bengal's surface water keeps getting refreshed, making it impossible for the warm water to mix with the cooler water below, making it ideal for a depression. On the other hand, the Arabian Sea receives stronger winds that help dissipate the heat, and the lack of constant fresh water supply helps the warm water mix with the cool water, reducing the temperature.

However, not all cyclones are formed in the Bay of Bengal. The basin is also host to cyclones that are formed elsewhere but move toward the water body, especially those formed in the Pacific Ocean. Cyclones usually weaken if they encounter a large landmass. However, due to the lack of any such presence between the Pacific and the Bay of Bengal, cyclonic winds easily move into the Bay of Bengal. Once here, the winds encounter the Western Ghats and the Himalayas, either becoming weak or getting blocked in the Bay of Bengal, but never reaching the Arabian Sea.

Since high water and air temperatures are crucial to the formation and intensification of cyclones, they are most commonly reported, or expected, in summer. However, both the Arabian Sea and the Bay of Bengal witnessed cyclones in both pre-monsoon (summer) and post-monsoon (winter). The post-monsoon (winter) period sees a higher number of cyclones than the pre-monsoon (summer) period.[6] It can be seen in Figure 5d.

This is because summers and pre-monsoons see dry and hot air moving from north-western India toward the Bay of Bengal. This blocks the rise of air from the water, and the subsequent formation of clouds, preventing cyclone-friendly conditions. However, the absence of this air movement in the post-monsoon phase increases the chances of cyclones. it is not a factual scenario that always only lesser in summer over winter: For example, in 2024 May cyclone formed with these warmer conditions, and on land temperature was reduced by 10°C moved to Bangladesh, and again temperatures have gone up and again gone down with the onset of the southwest monsoon on May 30th, 2024. All these factors make the Bay of Bengal one of the most sensitive areas in the world when it comes to cyclones. It also explains why people in the coastal states along the Bay of Bengal live in perpetual risk of this destructive weather phenomenon.

The impacts of ENSO and IOD on TC activity (intensity, frequency, genesis location, track, and average lifetime) in the Bay of Bengal are studied by scientists for the period 1891–2007 using cyclone e-Atlas of IMD. TCs include cyclones with a maximum sustainable wind (MSW) of 34 knots (referred to as cyclonic storms) and severe cyclonic storms with an MSW of 48 knots. The study shows a total of 502 TCs over the Bay of Bengal occurred during the 117-year study period at the rate of 4.29 TC per year. The seven-year running mean of TCs for the period 1891–2007 shows a decreasing trend [Figure 6a]. However, this can be divided into two parts, namely, the 5 cyclones/year followed by the four cyclones/year – average line at 4.5 cyclones/year. The former is followed by a "W" or "M" shape like in the case of Durban (after integrating the 66 and 22-year cycles) [Figure 6b] and later by an inverted "V" followed by a "V" shape. After this, again this started the first "W" pattern.

Figure 6a is not matching with Figure 5d (right-top) as in the case of the former 1945 to 1972 is below the average and in the latter, it is above the average. Figure 5d is following Figure 6c AMO. Figures 6e is not match with Figures 5d and 6c that followed the 56 (60?) cycle.

In Figure 6d, the top curve presents the 10-year running mean of north-east monsoon season rainfall in the coastal Andhra and the bottom curve presents the 10-year running mean of south-west monsoon. They appear to be following a similar pattern-56-year cycle. By turning the top figure from left to right, it forms a mirror image of the bottom figure.

Figure 6a presents the step-wise decreasing trend. It is a mirror image of Figure 6d. In Figure 6a, the storms are above the average before around 1945 and below the average after around 1945, similar to Figure 5d.

Figure 6e presents the undivided Andhra Pradesh average annual rainfall, a combined pattern of south-west and north-east monsoons showed below the average 66 years followed by above the average 66-year period-top curve. The bottom curve presents water flows in the Krishna River. In Figure 6e, it is reversed, before 1945, it is below the average rainfall, and after 1945 above the average – the same is the case with the water flow in Krishna River [below figure of Figure 6e].

Figure 6e is in line with Figure 6d SWM (top figure) (10-year moving average) wherein both presented a 56-year cycle.

Reports suggest that the maximum frequency of TCs occurred during the La Nina years, negative IOD years; and also when La Nina co-occurred with negative IOD; more severe cyclones were formed this issue is discussed later. Genesis location of TCs indicates that during the La Nina (El Nino) years, the TCs are oriented in the south-east to north-west (south-west to north-east) direction. TCs in neutral IOD and negative IOD years more (less) in the Northern Bay of Bengal (north of 15°N), while in the Southern Bay of Bengal (south of 15°N), TCs are more (less) during neutral (negative) IOD conditions.

However, Figure 5d presented no such pattern. During the above, the average number of cyclones/year was around 16 except 1 year and during the below part, there were around 4–5 cyclones/year except 1 year. This pattern is for individual years with 1972 as inflection year.

Another report presented that the Bay of Bengal is divided into four quadrants and the number of TCs in each quadrant is computed under different ENSO–IOD events. The peak direction of track movement is observed as northeast followed by North–North–West which is corroborated by the dissipation of TCs in the specific quadrant. Total TC tracks in the peak direction of track movements are maximum during El Nino and neutral IOD years. The study reveals that TCs with shorter lifetimes are observed during El Nino and negative IOD years, while TCs with longer lifetimes are observed during La Nina, neutral ENSO, and neutral IOD years.

South-east Asian and Australian droughts

The IOD involves an aperiodic oscillation of SST, between "positive," "neutral" and "negative" phases. A positive phase sees greater-than-average sea-

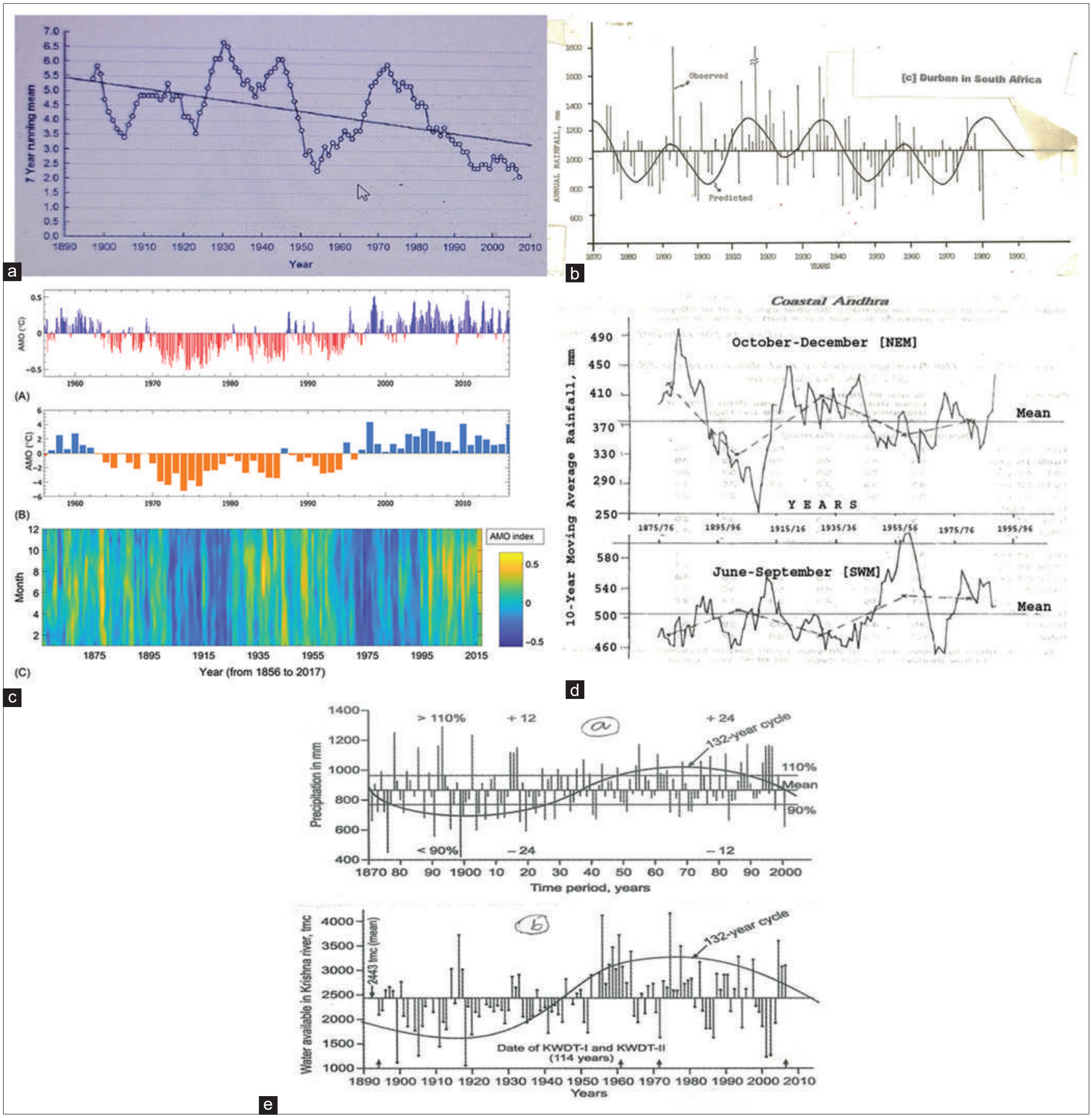

Figure 6: (a) Seven-year running means for the total yearly number of TCs – the solid line represents the linear trend. (b) Observed and predicted the pattern of Durban rainfall [Source: Reddy, 1986]. (c) AMO data chart, the Kaplan SST datasets from NOAA. (A) Monthly Atlantic Multi-decadal Oscillation Index. (B) Annual Atlantic Multi-decadal Oscillation Index. (c) Year-month chart of AMO index. (d) Coastal Andhra Met Sub-division SWM and NEM Rainfall: Observed (10-year moving averages) and predicted 56-year patterns. (e) Top figure: (a) AP rainfall and bottom figure (b) Krishna River Water Flows

surface temperatures and greater precipitation in the Western Indian Ocean region with a corresponding cooling of waters in the Eastern Indian Ocean – which tends to cause droughts in adjacent land areas of Indonesia and Australia [Table 3]. That is, the negative phase of the IOD brings about the opposite conditions, with warmer water and greater precipitation in the Eastern Indian Ocean, and cooler and drier conditions in the west. Will this postulation work under cyclic patterns in cyclones time series, a big question. The IOD also affects the strength of monsoons over the Indian subcontinent. The IOD is one aspect of the general cycle of global climate, interacting with similar phenomena like the

Table 3: IOD impact

Impact of IOD	
Positive/Neutral	**Negative**
West-warm-good Indian monsoon	East-cool-dry in South-east Asia
(Wet: East Africa and India)	Indonesia and Southern Australia
West-cool-poor Indian monsoon	East-Warm-wetter conditions
(Dry: East Africa and India)	Southern Asia/Indonesia and Southern Australia

ENSO in the Pacific Ocean. The IOD phenomenon was first identified by climate researchers in 1999.
A report says that "A positive IOD is associated with droughts in South-east Asia and Australia – here also presented 132-year cycle with high year-to-year variations in surface air temperature. The SST also presented year-to-year variation with less amplitude.
A study in 2009 has demonstrated a significant correlation between the IOD and drought in the southern half of Australia, in particular the south-east. Every major southern drought since 1889 has coincided with positive-neutral IOD fluctuations including the 1895–1902, 1937–1945, and the 1995–2009 droughts. That is 7, 7, and 14 years.
The research shows that when the IOD is in its negative phase, with cool western Indian Ocean water and warm water off North-west Australia (Timor Sea), winds are generated that pick up moisture from the ocean and then sweep down toward southern Australia to deliver higher rainfall. In the IOD-positive phase, the pattern of ocean temperatures is reversed, weakening the winds and reducing the amount of moisture picked up and transported across Australia. The consequence is that rainfall in Southern Australia is well below average during periods of a positive IOD. The study also shows that the IOD has a much more significant effect on the rainfall patterns in Southern Australia than the ENSO in the Pacific Ocean. The IOD is one of the key drivers of Australia's climate and can have a significant impact on agriculture. This is because events generally coincide with the winter crop growing season. Events usually start around May or June, peak between August and October, and then rapidly decay when the monsoon arrives in the southern hemisphere around the end of spring.

Rainfall across East Africa

A positive IOD is linked to higher than average rainfall during the East African Short Rains (EASR) between October and December. Higher rainfall during the EASR is associated with warm sea-surface temperatures (SST) in the Western Indian Ocean and low-level westerlies across the equatorial region of the ocean which brings moisture over the East African region. The increased rainfall associated with a positive IOD has been found to result in increased flooding over East Africa during the East Africa Short Rainfall (EASR period). That means it is the opposite pattern to Australia discussed above.
During a particularly strong positive IOD at the end of 2019, average rainfall over East Africa was 300% higher than normal. The higher than average rainfall has resulted in high flooding in the countries of Djibouti, Ethiopia, Kenya, Uganda, Tanzania, Somalia, and South Sudan. Torrential rainfall and increased risk of landslides over the region during this period often result in widespread destruction and loss of life. Studies by the author showed[6-8] natural variability in rainfall over Ethiopia in Northern Africa, Mozambique, in Southern Africa, and as well in North-east Brazil and India.
IOD positive cycle: A positive IOD cycle is related to multiple cyclones that ravaged East Africa in 2019, killing thousands. The unusually active 2018-2019 South–West Indian Ocean cyclone season was aided by warmer than normal waters offshore (starting with Cyclone Idai and continuing to the subsequent cyclone season). Additionally, the positive IOD contributed to Australian drought and bushfires (convective IOD cycle brings dry air down on Australia) and the 2020 Jakarta floods (convective IOD cycle prevents moist air from going south, thus concentrating it in the tropics), and more recently the 2019–21 East Africa locust infestation took place. This cannot be attributed to the IOD phenomenon.
Important Issue: When we attribute something to something else, it is essential to look into the natural variability in temperature, rainfall, and cyclones/hurricanes (systematic/cyclic variations component of climate change).

Rainfall across Islands of Indonesia-Australia-East Africa

The water from the Pacific flows between the islands of Indonesia by keeping seas to Australia's North-west warm. Air rises above this area and falls over the western half of the Indian Ocean basin, blowing westerly winds along the equator. Temperatures are close to normal across the tropical Indian Ocean, and hence, the neutral IOD results in little change to Australia's climate.

IOD develops in boreal summer (January to August) while peaks in fall (September to November). In recent decades two extremely positive IOD occurred, one during 1997 (it falls under above the average part of the 30-year cycle-1987-88-2016-17) and the other in 2019. During 1997, extreme IOD resulted in drought and bushfires in Indonesia and Australia, whereas flooding in the Eastern part of Africa. Another extreme IOD happened in 2019 and it is believed that it has relevance to widespread Australian bush fire during that year. ISM in 2019, June through September was an excess monsoon (110% of the long-period average), whereas the previous excess monsoon was during 1994. All-India Annual average rainfall presented above the average part of 30 years during 1987-88–2016-17 in the majority of the years that followed rivers water flows in northwest, northeast, and central India. There is a positive skewness of the IOD, where positive events tend to be stronger in amplitude than negative events.

Australia's millennium drought may be explained in light of tendencies of IOD events not only IOD but IOD-ENSO combined behavior is also important and can influence regional rainfall patterns. It also showed opposite impacts during some seasons. ENSO and IOD exert an offsetting impact on ISM with El Niño tend to lower ISM rainfall, whereas a positive IOD tends to increase that. However, the major factor here in terms of rainfall is natural variability in rainfall as the ENSO and IOD are not effective processes for the occurrence and non-occurrence of rainfall. IOD and ENSO only help the natural variability condition positive or negative way.

A few years back scientists submitted a report to Parliament on Indian rainfall saying that Indian rainfall is decreasing. They used above the average part of the 60-year cycle and that followed below the average and thus showed a decreasing trend. If they would have selected below the average to above the average 60-year cycle, the inference would be that Indian rainfall is increasing. This is a fallacy cyclic variation.[5] This fact I brought to the notice of the concerned ministry (MoEF and CC).

Important conclusion: The study by the author relating to cyclic patterns in SST and surface air temperature of Australia presented a 132-year cycle. The below-average 66-year temperature series between 1907 and 1972 in association with the rainfall of southwest of WA presented above the average; and above the average temperature cyclic pattern of 1972–2037 presented below the average rainfall pattern with the inflection year of 1972 that changes the sign.

Rainfall across South China

The following are a few research summaries. They suggest both IOD and ENSO presented an impact on South China rainfall. For example:

A study presented that the difference in China summer rainfall (CS rainfall) between the years with IOD occurring independently and those with IOD occurring along with ENSO showed that CS rainfall will be more than normal in South China (centered in Hunan province) and the CS rainfall will be less than normal in North China, and more than normal in Southeast China in the years of positive IOD occurring together with ENSO**.** The effect of ENSO is offsetting the relationship between IOD and summer rainfall in Southwest China, the region joining the Yangtze River basin with the Huaihe River basin ("Yangtze-Huaihe basin") and North China and enhancing in Southeast China.

Another study showed that the seasonal responses of precipitation in China to El Niño and positive IOD events, and their relationship with the large-scale atmospheric circulations, differ from one season to another. For the pure El Niño years, there is a seasonal reversal of precipitation over South-east and North-west China, with deficient precipitation occurring in these two regions before the onset of anomalous wet conditions in the developing autumn. Meanwhile, North China, tends to be drier than normal in the developing seasons, but wetter than normal in the decaying seasons.

For the pure positive IOD events, Southern China suffers a precipitation deficit in the developing spring and a surplus in summer and autumn. Furthermore, both North China and north-west China experience excessive precipitation in the developing autumn and decaying summer. In addition, there is reduced precipitation in North-east China during both the developing and decaying summers, whereas increased precipitation occurs in the developing autumn and decaying winter. For the combined years, Southern China experienced enhanced moisture supply and suffered from increased precipitation from the developing summer through the subsequent spring, but reduced precipitation in the developing spring and decaying summer. Similar to the pure El Niño, north-west (North) China becomes wetter than normal after the developing summer (autumn) in the combined years. In general, the ENSO/IOD-related precipitation variability could be explained by the associated anomaly circulations.

Another study inferred that during the warm phase of the Pacific Decadal Oscillation (PDO), the IOD of the previous autumn can cause abnormal summer precipitation in south China by strengthening or weakening the Western Pacific subtropical high of the following summer, but there is no significant effect in the cold phase of PDO. Rainfall anomalies over south China are found to be asymmetrically influenced by the IOD with far stronger Indian IOD with far stronger influence with positive IOD events. The IOD, characterized by colder SST anomalies over the tropical western Indian Ocean and warmer SST anomalies over the tropical South-east Indian Ocean during the positive phases, shows a remarkable inter-annual variation. The IOD, characterized by warmer SST anomalies over the tropical western Indian Ocean and colder SST anomalies over the tropical South-east Indian Ocean during the negative phases, shows a remarkable inter-annual variation.

The IOD affects not only the climate of the countries surrounding the Indian Ocean rim, such as Kenya, India, Indonesia, and Australia, but also the western tropical Pacific Ocean, East Asia, South America, and even Antarctica through atmospheric teleconnection, causing extreme weather or climate events with severe socioeconomic repercussions. Previous studies have indicated that a positive (negative) IOD generally corresponds to El Niño (La Niña), suggesting that ENSO is the dominant factor controlling the interannual variation of the IOD; however, not all IOD events coexist with the ENSO. This indicates that other external factors influence the evolution of the IOD. Based on long-term simulations excluding ENSO, forcing fluctuations observed in the north-west Pacific monsoon could be a significant control on the IOD during boreal summer (June–August [JJA]); and indicated that IOD growth may also be impacted by the significant inter-annual variability of the South China Sea summer monsoon (SCSSM) over the western North Pacific Ocean.

Another study reports that seasonal precipitation variation over eastern China is associated with IOD forcing and emphasizes the distinction of such responses to preceding IOD events compared with responses to ENSO. Precipitation evolution patterns in response to the IOD from autumn to the ensuing summer are derived from singular value decomposition analysis, revealing that the IOD causes a large portion of the seasonal variation in precipitation over eastern China in the simultaneous autumn and time-lagged summer. The difference in the impacts associated with the IOD and ENSO revealed by multiple linear regression and partial correlation analysis is that the IOD contributes mainly to abnormal precipitation in South China during autumn and in the region between the Yangtze River and Yellow River during the ensuing summer; while ENSO primarily boosts precipitation over eastern China during winter and spring. The distinctive effects of the IOD on the ensuing summer precipitation contrast with the less significant signals related to ENSO during the ensuing summer. Such precipitation responses correspond to an anomalous anticyclonic circulation pattern around the South China Sea, which is sustained by direct IOD forcing during autumn and winter and an SST cooling pattern triggered by the IOD over the central equatorial Pacific during the ensuing spring and summer. The calculation of wave activity flux and anomalous AGCM model experiments further confirm the importance of the direct heating of the IOD during autumn and winter and the indirect heating sink over the Central Pacific during the ensuing spring and summer for modulating the seasonal variation in precipitation over Eastern China.

GGCP

Basics of GGCP

The third phenomenon is the GGCP related to wind patterns [Figure 7a] and IOD relates to temperature

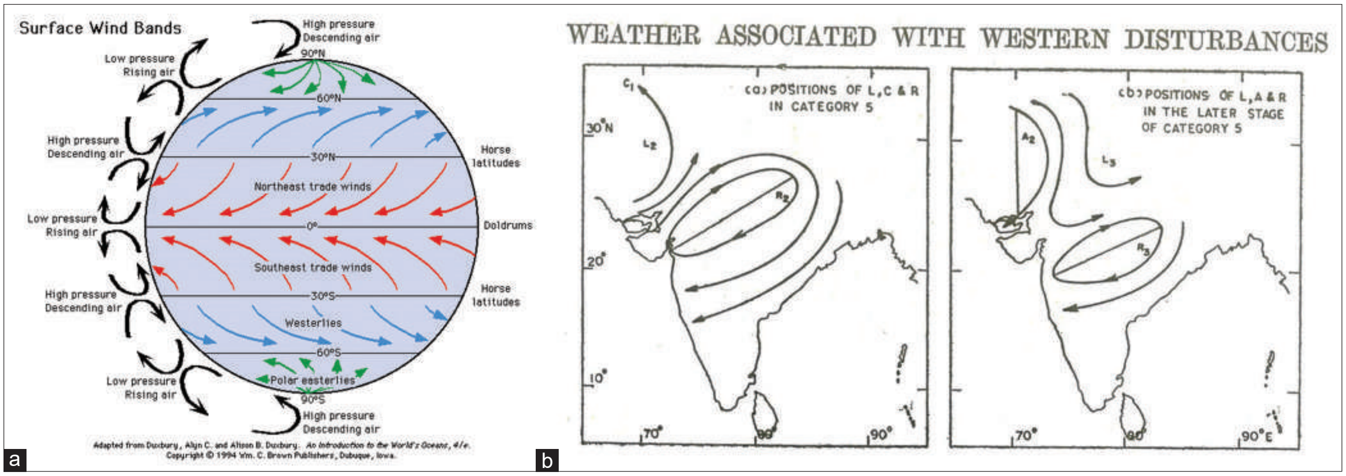

Figure 7: (a) General Circulation Patterns. (b) Weather associated with Western Disturbances in northwest India

(warm and cold) and ENSO relates to pressure and temperature patterns. That is, in ENSO pressure plays an important role.

Figure 7b presents the weather associated with the WD in north-west India (wind, temperature, and rainfall) that cause heat waves in summer and cold waves and rainfall in winter.[9]

However, circulation patterns in the Bay of Bengal and the Arabian Sea wind patterns regulate the heat and cold wave movement to southern parts of the country (east and west coast regions). Figure 5a presents the Position of the jet stream act as a break for the movement of cold and warm weather to further southern regions in the USA. Both systems are part of GGCP.

Heatwaves are not unusual in the USA and they are nothing to do with global warming [Table 4] – with the passing of time growth in the urban system, urban heat island component adds to the urban temperature – but they vary with the local circulation patterns, for example in USA 100°F reached the month of June in Allentown as back as 1923 on June 20 and 21, Willington in June 19, 1994; Atlantic City on June 22, 1988; Philadelphia on June 19, 1994, and June 22, 1988. This includes the urban heat island effect in both the summer and the winter months. In Russia even below this temperature declared as heatwaves this year. These are nothing to do with global warming but relate to general circulation patterns at that movement. This is the same all over the world. They follow general circulation patterns. They are localized weather aberrations. They could not be attributed to some system, particularly to global warming without proof from the air.

Table 4: High-temperature records at few climate sites in the USA – day in June and year

Climate Site	High Temperature Records				
	Tuesday June 18	Wednesday June 19	Thursday June 20	Friday June 21	Saturday June 22
Allentown	95°/2018	96°/1994	100°/1923	100°/1923	95°/1941
Atlantic City Airport	95°/2014	96°/1994	95°/2012	97°/1988	100°/1988
Atlantic City Marina	94°/2014	93°/1952	90°/1908	94°/2012	92°/1949
Georgetown	97°/2014	96°/1952	98°/2012	99°/2012	97°/2012
Mount Pocono	88°/1957	86°/1929	89°/2012	90°/1953	90°/1908
Philadelphia	96°/1957	100°/1994	98°/1931	99°/1923	100°/1988
Reading	97°/1957	95°/1929	101°/1923	99°/1923	96°/1921
Trenton	96°/1957	96°/1994	98°/1923	97°/1923	99°/1988
Wilmington	95°/1957	100°/1994	97°/2012	98°/2012	98°/1988

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OCEANIC AND ATMOSPHERIC ADMINISTRATION
Philadelphia Mount Holly

However, the current projection is not far from the hottest temperature ever recorded in Utah – it is natural as the urban heat island effect increases with the growth of the city – which remains 117°. The temperature was first recorded in St. George exactly 39 years ago on Friday and then matched in July 2021. The incoming heat wave is tied to a strong high-pressure system set up over the California coast on Friday, says KSL meteorologist Matt Johnson. This pattern is expected to create a heat dome. A heat dome is created when the air below the high-pressure system sinks and compresses, raising ground temperatures and creating a "bulging dome." Johnson says systems like this that form over the Pacific are typically hotter than those generated from the Gulf of Mexico because there is less moisture near it. In this case, the system is large enough that excessive heat warnings, watches, and heat advisories are in place throughout most of

California, Oregon, and Washington, as well as the western halves of Arizona, Idaho, and Nevada. "It is an expansive high-pressure system definitely large in size and it is also packing a lot of hot air in it," Johnson said.

One of the warnings says that temperatures may reach 129 degrees at Furnace Creek within Death Valley National Park over the weekend, which puts it within range of potentially matching or topping a major record. As KTLA points out, 130° is the highest "reliably measured temperature" ever recorded on the Earth. The outlet notes that there have been hotter temperatures beyond 130°, but many experts are skeptical about those readings over the quality of instruments used in the past. Meteorologists from the National Weather Service's Las Vegas office told USA Today on Thursday that there is about a 20% probability that temperatures will reach 130° at Furnace Creek on Monday and Tuesday as the high-pressure system lingers in the region. Even IMD questioned the temperature recording of more than 55°C in the current summer.

Nearly a quarter of a million people were evacuated in eastern China as rainstorms lashed swathes of the country and caused the Yangtze [Figure 8] and other rivers to swell, state media reported Wednesday. China has been enduring extreme weather conditions in recent months, from torrential rainfall to searing heat waves. The country is the leading emitter of greenhouse gases, which scientists say drive climate change and make extreme weather events more frequent and intense. State news agency Xinhua said the storms had affected 991,000 residents in Anhui province and forced the evacuation of 242,000 people by Tuesday afternoon. "As of 4 pm Tuesday, rainstorms had wreaked havoc in 36 counties and districts in seven prefecture-level cities in Anhui," Xinhua reported, citing the provincial emergency-management department. It said the Yangtze, China's longest river, has seen water levels in its Anhui section exceed warning marks and continue to rise. Torrential rains have also pushed waters above their alert levels in another 20 rivers and six lakes in the province.

Figure 8: An arial view of flooded buildings and streets in central China's Hunan province following heavy rains this week (STR)

As airflow poleward in the upper branch of the Hadley Cell [Figure 9a], eventually it curves toward the east (in the Northern Hemisphere). The end result is that air parcels in the upper branches of the Hadley Cells end up circling the Earth during their lofty treks from equatorial regions to the subtropics. This poleward spiral culminates in the subtropical jet stream ("STJ," for short) near 30° latitude. Figure 9b presents the long-term average wind speeds over Asia and the Western Pacific Ocean during meteorological winter (December, January, February)-Credit ESRL.

In fact, the STJ is stronger over the western Pacific region, on average, than any other place in the world. That is primarily because the Himalayan and Tibetan high ground interrupt and divert the generally westerly flow of air in the upper troposphere. Farther east diverted branches of airflow back together and accelerated near Japan. The overall mechanism for maintaining the STJ near 30° latitude, however, is the tendency for air parcels to conserve their angular momentum in the upper branches of the Hadley Cells. The conservation of angular momentum is the concept that explains how figure skaters spin so much faster (link is external) when it turns out that the STJ is stronger during winter than summer, despite a greater poleward extent of the upper branch of the summer hemisphere's Hadley circulation. That might seem odd, given that the main driving mechanism of the STJ is the tendency for parcels to conserve angular momentum (which would result in faster speeds when the STJ is at higher latitudes).

WD in Winter and Summer

Basics of WDs

WD has its origin in the Mediterranean Sea as extra-TCs. A high pressure is exhibited area over the areas like Ukraine and neighboring countries causing the intrusion of cold air from Polar Regions toward an area of relatively warmer air with high moisture. This change in pressure from cold air to warm air generates favorable conditions for cyclogenesis in the upper layer of the atmosphere that promotes the formation of eastward-moving extratropical depression in the sea. Then, these gradually travel across the Middle East from Iran, Afghanistan, and Pakistan to finally enter the Indian subcontinent [Figure 10a].

The extratropical Storms that originate in the Mediterranean region which bring sudden winter rain to the north-west parts of the Indian subcontinent are known as WD. It is a non-monsoonal precipitation pattern which is driven by the westerlies [Figure 7b]. In summer, the system is different[9] causing heatwaves – Figures 7b. WDs [Figure 7b], are also known as Extra-TCs or Mid-Latitude Cyclones, are low-pressure systems that originate in the Mediterranean region and move eastward across central Asia. As they traverse, they bring significant changes to the weather in India, particularly in the northern and north-west regions. These disturbances typically occur during the winter months, from November to March, with their frequency peaking in January and February.

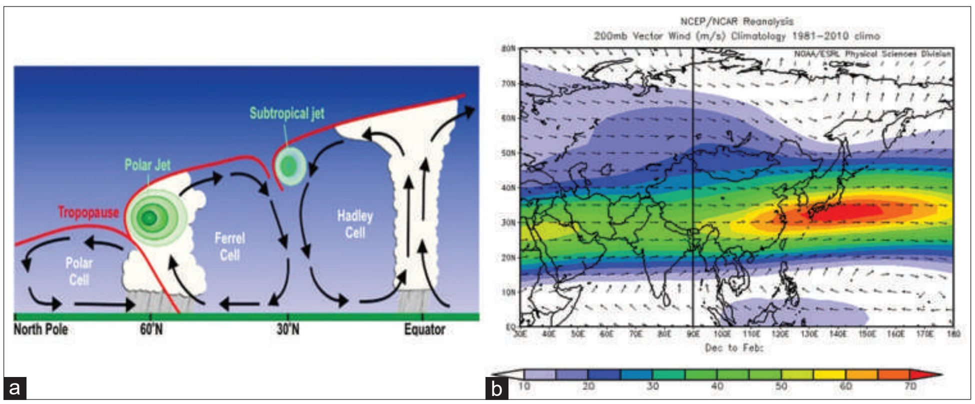

Figure 9: (a) This explains why the polar jet stream is the world's most powerful. Jet streams move seasonally just as the angle of the Sun in the sky migrates north and south. The polar jet stream known as "the jet stream," moves south in the winter and north in the summer. (b) The long-term average wind speeds over Asia and the Western Pacific Ocean during meteorological winter (December, January, and February) – Credit ESRL

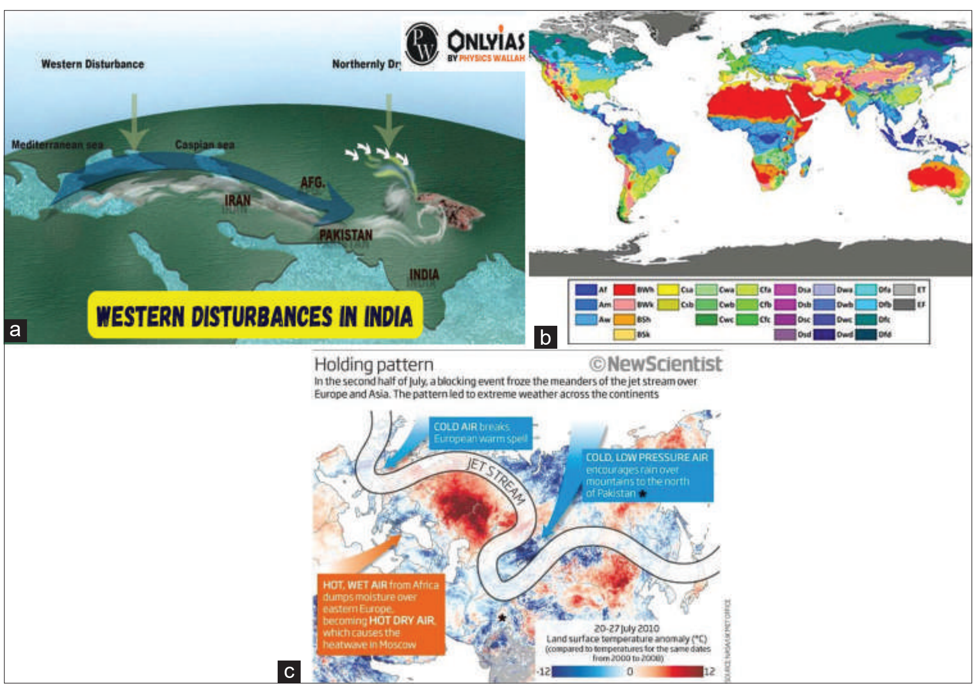

Figure 10: (a) Western disturbances in India-winter. (b) Koppen's Classification of Climate. (c) Role of Jet Stream on WD – July 20-27, 2010

During its journey, a WD collects moisture from the Mediterranean Sea, Black Sea, and Caspian Sea and traverses over Iran and Afghanistan before hitting the Western Himalayas. Strong WD reaches the central and eastern Himalayas and causes rain and snow in Nepal and North-east India. WDs are cyclonic storms that travel along the sub-tropical jet, bringing the majority of seasonal and extreme precipitation to the Hindu Kush, Karakoram, and Western Himalayas in the winter months.

They are a vital component of the region's water security. For the rest of the year, the jet stream travels from above the Himalayas to the Tibetan Plateau and China. The trajectory of the jet stream changes as per the position of the Sun. The High-Pressure Belt (near Nagpur) defines the path of the Westerlies. "The jet stream appears over northern India in October after the withdrawal of monsoon and shifts progressively southward in the winter months. It reaches its southern-most position in February and moves out of the sub-continent after May," says V S Prasad, head, the National Centre for Medium-Range Weather Forecasting under the Union Ministry of Earth Sciences. During the Northeast Monsoon season (October to December) cyclones in the Bay of Bengal and as well Arabian Sea with less frequently influence the WD.

The term "Mediterranean" is derived from the Latin word Mediterranean, where Medius means middle/between and Terra means land/earth. The sea was named Mare Magnum or Mare Internum by the ancient Romans. The Mediterranean Sea is also often referred to as the "Eurafrican Mediterranean Sea" by oceanographers due to its location between the continents of Asia and Europe. Mediterranean climate, the major climate type of the Köppen characterized by hot, dry summers and cool, wet winters and is located between about 30° and 45° latitude north and south of the Equator and on the western sides of the continents [Figure 10b]-desert belts are located in this zone. Poleward extension and expansion of the subtropical anticyclone over the oceans bring subsiding air to the region in summer, with clear skies and high temperatures. When the anticyclone moves Equator-ward in winter, it is replaced by traveling, frontal cyclones with their attendant precipitation.

Annual temperature ranges are generally smaller than those found in marine west coast climates since locations on the western sides of continents are not well positioned to receive the coldest polar air, which develops over land rather than over the ocean. Mediterranean climates also tend to be drier than humid subtropical ones, with precipitation totals ranging from 35 to 90 cm (14–35 inches); the lowest amounts occur in interior regions adjacent to the semiarid steppe climates.

Impact of ENSO and IOD on WDs

"WDs are generally weaker during the La Niña, which produces a drier winter. During El Niño, they are more intense," says Raghu Murtugudde, climate scientist at the University of Maryland, US, and the Indian Institute of Technology, Mumbai. WDs are also influenced by the North Atlantic Oscillation, a random fluctuation of air pressure over the North Atlantic Ocean due to a high-pressure region above the Azores Islands in the central North Atlantic and a low-pressure region over Iceland. The weather system is currently in a negative phase, as both low and high-pressure systems are weak, and it makes WDs 20% less frequent and 7% less intense than a positive phase, according to a research paper published in the journal *Climate Dynamics* in August 2022. For the past three years, the world has been in a La Niña phase, which refers to the cooling of ocean surface temperature in the Pacific Ocean. It weakened the temperature gradient for the formation of WD as it reduced the temperature of the hot tropical air.

Role of jet streams in winter and summer

WDs are cyclonic storms that form over land, and they occur mostly in the Mediterranean region due to a temperature gradient caused by the mixing of warm air from the tropics and cold air from the northern Polar Regions. While the storm systems occur throughout the year, they travel to India mostly between December and April/May because the trajectory of the subtropical westerly jet stream, which transports them, shifts during the winter months to the rim of the Himalayas. For the rest of the year, the jet stream travels from above the Himalayas to the Tibetan Plateau and China. The trajectory of the jet stream changes as per the position of the Sun. "The jet stream [Figure 10c] appears over northern India in October after the withdrawal of the monsoon and shifts progressively southward in the winter months. It reaches its southern-most position in February and moves out of the subcontinent after May," says V S Prasad, head, of the National Centre for Medium-Range Weather Forecasting under the Union Ministry of Earth Sciences.

When we use the term "extra-tropical storm," it refers to a low-pressure system that is outside the tropical regions. WDs are classified as extra-tropical since they originate outside the tropics. After forming in the Mediterranean Sea, these disturbances progress eastward, eventually crossing the Middle East through Iran, Afghanistan, and Pakistan before reaching the Indian subcontinent. The WDs significantly impact the winter weather in regions up to Patna (Bihar), occasionally resulting in beneficial rainfall for the existing Rabi crops like wheat, barley, mustard, gram, and lentils. During winter in the Indian Sub-continent, the mountains experience considerable snowfall, while low-lying areas receive moderate to heavy rain primarily due to WD. These disturbances play a major role in bringing post-monsoon and winter precipitation, especially in northwest India. Precipitation during the winter months is crucial for the success of Rabi crops.

The upward movement of the sub-tropical westerly jet stream in the winter season happens when it merges with the polar front jet. During the summer months of April and May, they move across North India and at times help in the activation of monsoon in certain parts of northwest India. During the monsoon season, WDs may occasionally cause dense clouding and heavy precipitation. However, this system causes heatwaves.

Forecasting of WDs

Reddy[9] "presented a method of forecasting the weather associated with WDs. There are several weather systems that cause over Indian region. Among these WD are of particular importance for the Rabi crop in India. They also cause thunderstorm activity, widespread fog, and cold wave conditions. Fog and thunderstorms are hazardous for transport and aviation while the cold wave conditions adversely affect human life and crops." The same causes heatwaves in summer (April to May/June). When there are several consecutive days with sparse data over Pakistan, Afghanistan, and adjoining areas, it becomes a major problem for a forecast to detect WD. Though WD is a lower tropospheric phenomenon, both upper and lower tropospheric wind flow patterns over the Indian region, the lower tropospheric wind flow patterns is found to be closely associated with WD [Figure 7b].

Normally in winter, an anticyclonic flow pattern is seen up to 0.9 km level over northwest India. When an active western disturbance (associated with weather like rainfall, etc.) approaches North-west India is replaced by a cyclonic circulation. In addition to this, another significant feature observed is that the extension of weather to lower latitudes is associated with a shift of the ridge line at 850 mb level to lower latitude. In this study, the features of the lower tropospheric flow patterns in association with the WD and resulting weather are presented [example Figure 7b].

An active tropical disturbance in the Bay of Bengal north of 5°N latitude inhibits the western disturbance activity over the Indian region, but an active disturbance in the Arabian Sea north of 5°N latitude will be favorable for increased rainfall over north India". This is the same with heat wave conditions. If no system is present in the Bay of Bengal the cold wave in winter and the heat wave in summer extend to south eastern parts but the presence of a system cold wave or heat wave moves to northwards. An example is in 2024 May when the temperature reached above 45–49°C with a cyclone system in the Bay of Bengal the temperature dropped down to around 33–36°C.

INTERPLAY BETWEEN ENSO, IOD, GGCP, ISM, INS, AMO AND PDO

Between ENSO and IOD

A few aspects of the interplay between the El Nino of ENSO and IOD are given as:

- ENSO events, specifically El Nino, can trigger the development of a positive IOD in the Indian Ocean
- While external factors such as ENSO can initiate IOD events in some cases, there is evidence to suggest that IOD events can also occur due to local circulation or surface processes within the equatorial Indian Ocean

- IOD events largely develop and mature through internal dynamics, even when triggered by external drivers. They have the potential to exhibit independent existence and can impact weather patterns in the Indian Ocean region
- During El Nino the Pacific side of Indonesia tends to be cooler than normal, which influences the Indian Ocean side, leading to the development of a positive IOD
- The circulation patterns of IOD and ENSO can impact each other when both events are strong. The interaction between the two phenomena can influence the intensity and duration of each event
- Positive IOD events are often associated with El Nino, while negative IOD events are sometimes linked to La Nina. However, this association is not absolute, and IOD events can occur independently to have different associations depending on the specific conditions – this combination causes failure of the model predictions of ISM
- Strong IOD and ENSO events can have combined effects on weather patterns, also circulation patterns can interact and influence each other
- While the IOD's ability to counterbalance the effects of El Nino is limited, there is hope that a positive IOD event may be reverted in the coming months. Past instances, such as strong IOD events in 2019, have demonstrated the potential of IOD in compensating for monsoon rainfall deficits.

Here, the major components that interplay a key role in droughts and floods are the cyclic patterns and if any trends in rainfall, temperature, cyclones, hurricanes, etc. These are rarely accounted for while discussing IOD and ENSO factors. They are principally related to temperature at regional and global levels.

Between ENSO, IOD and GGCP

The general circulation patterns present an independent impact on weather events like heat waves in summer and cold waves in winter conditions like WD in North-West India and Jet Stream in the USA. However, their impact is controlled by cyclonic storms in India (the Arabian Sea and the Bay of Bengal) and cyclonic/hurricane activities in the Southern and Eastern parts of the USA.

Between ENSO, IOD, and Cyclones and Hurricanes

In 2014, Biranchi Kumar Mahela and co-authors presented an article "Impact of ENSO, and IOD on TCs activity in the Bay of Bengal." The study says that "The analysis showed that the total number of TCs formed during the El Nino years are more than those during the La Nina and the Neutral ENSO years, that is, during INM and vice-versa is the case with the ISM. The frequency of TCs in the Northern Bay of Bengal is the maximum during negative IOD years. The frequency of TCs in the Southern Bay of Bengal is the maximum during positive IOD years.

The cyclones in the Bay of Bengal [Figure 5d] presented the first 28 years (1945–1972) above the average part of the 56-year cycle. The 2nd 28 years part (1973–2000) is presented below the average part of the 56-year cycle[2-4,7] – here the author has no data before the year 1945 and after the year 2000. However, Figure 6a with a longer period of data presented a different pattern from Figure 5d. Irrespective of the El Nino and IOD, cyclones per year during 1945–2000 (May to November) in the Bay of Bengal Region as reported by the Joint Typhoon Warning Centre showed a 56-year cycle [Figure 5d] (maybe a 60-year cycle or 132-year cycle) with an average of 10 cyclones/year. From 1945 to 1972 presented above the average reaching as high as 16 cyclones per year with the exception of one year (below the average of 10 cyclones) and 1972–2000 with the exception of 1 year above the average of 10 cyclones presented around 4–5 cyclones/year.

The study also reveals that TCs with shorter lifetimes are observed during El Nino and negative IOD years, while TCs with relatively longer lifetimes during La Nina/neutral ENSO and positive IOD years. The intensity of the IOD is represented by an anomalous SST gradient between the western equatorial Indian Ocean (50E-70E and 10S-10N) and the Southeast equatorial Indian Ocean (90E-110E and 10S-0N). This gradient is named as Dipole Mode Index (DMI). When the DMI is positive then, the phenomenon is referred to as the positive IOD and when it is negative, it is referred to as the negative IOD.

A report presented that during 1925–1960 DMI mean was +δ and for 1960–1995 the mean was–δ-it appears it is 66 years. TC pattern showed a decreasing trend with cyclic variation for 1900 to 1985 with a 40-year cycle – 1905 to 1925 (negative); 1925–1945 (positive), 1945–1965 (positive), 1965–1985 (negative) – 7 yearly running mean for the total yearly number of TCs. This is an 80-year cycle in which central 40 years present positive and two negative periods present 40 years (20+20).

Table 5 presents ENSO, IOD, and TC activity in the Bay of Bengal at decadal intervals for the period 1891–2007. However, there is no consistency in terms of IOD and ENSO with TCs. With the negative IOD and La Nina during 1891–1900, 50 TCs were recorded; with negative IOD and La Nina during 1951–1960 recorded 31 TCs; with the negative IOD and El Nino during 1931–40 recorded 52 TCs; with positive IOD and El Nino during 1921–30 recorded 60 TCs and during 1961–70 recoded 51 TCs; etc. These results suggest that the IOD and ENSO link is a mismatch.

A report states that depending upon the time of the year their impact is felt. For example, in the Southwest monsoon (ISM) period, it weakens the system; and enhances the system in the Northeast monsoon (INMI) season. Maximum numbers of TCs are observed during both the El Nino and La Nina years; and also when La Nina co-occurred with negative IOD more severe cyclones are formed. Genesis location of TCs indicates that during La Nina (El Nino) years, the TCs are oriented in the south-east–north-west (south-west–north-east) direction. The study reveals that TCs with shorter lifetimes are observed during El Nino and negative IOD years, while TCs with longer lifetimes are observed during La Nina, Neutral ENSO, and neutral IOD years. The decade with maximum TC formation is observed as 1921–1930, and the impacts of ENSO and IOD on decadal variability are distinctly observed. It is seen from Table 5 that:

1. IOD +ve with El Nino 51 TC/decade
2. IOD +ve with El Nino 60 TC/decade
3. IOD +ve with El Nino 15 TC/decade
4. IOD –ve with El Nino 28/TC/decade
5. IOD –ve with El Nino 35 TC/decade
6. IOD -ve with El Nino 52 TC/decade
7. IOD +ve with La Nina 45 TC/decade
8. IOD -ve with La Nina 50 TC/decade
9. IOD -ve with La Nina 31 TC/decade

These groups suggest that there are no consistent variations with TCs under IOD negative (– ve) and positive (+ ve) and El Nino and La Nina combinations. For example, the first three presented IOD +ve with El Nino wherein TCs varied from 60 to 15. The 2nd three IOD –ve with El Nino showed 52–28. In the 3rd three with La Nina IOD –ve varied from 31 to 50 and with IOD +ve presented 45. These show no systematic impact on TCs in terms of number with IOD and ENSO. Maybe present some type of system for individual years as the present data refers to decadal value?

1. Total TCs in 12 decades (117 years) during 1891–2007 presented 499 storms with a mean of 43 storms per decade. Let us see three patterns of decadal TC patterns:
   a. During the 1891–1950 presented 294 storms and during 1951–2007 presented 205 storms with the 132-year cyclic. The first six decades part of a 66-year cycle observed three each in positive and negative IODs, and two La Nina and four El Nino years, respectively;
      i. During the first six decades, the deviations from the mean storms are +7, +0, +1, +17, +9, +2, and next six decades, they are −12, +8, +2, −8, −15, −28
      ii. This is with reference to the first six decades above the average and the last six decades below the average of a 132-year cycle.

Table 5: Decadal variability in IOD, ENSO, and Number of TCs

Decadal		Variability of TCs	
IOD	Period in 10 years	ENSO of first	Number of TCs
Negative	1891-1900	La Nina	50
Negative	1901-1910	La Nina	43
Positive	1911-1920	El Nino	44
Positive	1921-1930	El Nino	60
Negative	1931-1940	El Nino	52
Negative	1941-1950	La Nina	45
Negative	1951-1960	La Nina	31
Positive	1961-1970	El Nino	51
Positive	1971-1980	La Nina	45
Negative	1981-1990	El Nino	35
Negative	1991-2000	El Nino	28
Positive	2001-2007	El Nino	15

b. The six decades of 1921–1980 presented 66-year above the average part of the 132-year cycle have 284 storms; and during below the average part of the 132-year cycle 66-year part, 1981–1920 plus bottoms 1981 to 2007 presented 215 storms for 57 years.
   i. The deviations per decade from the mean are: with above the average 6 decades, they are + 17, + 9, + 2, -12, + 8, + 2; and with below the average 6 decades, they are + 7, −0, + 1, −8, −15, −28.
c. This is with reference to six central decades in the above-average part of a 132-year cycle and three decades each in the start and end part of the 132-year cycle During the six decades of 911–1970 taken as above the average part of the 132-year cycle 283 storms. During below the average six decades of 1891–1910 plus 1971–2007 taken as below the average part of the 132-year cycle have 216 storms in 57 years. Above the average part of six decades present 4 negative and 2 positive IODs and 4 La Nina and 2 El Nino.
   i. The deviation per decade from the mean are: with above the average 6 decades, they are + 1, + 17, + 9, + 2, - 9, + 8; and with below the average 6 decades, they are + 7, −3, + 2, −8, −15, −28.
   ii. This is with reference to the 3rd to 8th decades in the above average and 1st to 2nd plus 9th to 12th on the two sides [six decades] presented 132-year cycle [Table 5].

Among these three (a, b, and c) which has the right pattern of a 132-year cycle is counter-checked:

- In (a) +6 and -4 with the inflection year of 1951; in (b) +5 and -4 with the inflection year 1981; and (c) +5 and -4 with the inflection year 1971. In a and b, only the inflection year is different by three decades
- (c) is closer to the Bay of Bengal Cyclones pattern: This fits into the inflection year 1972 [Figure 11a] and Australian SST and surface air temperature [Figures 11b] presents a mirror image with above-average storms to below-average temperature (surface air and sea surface);
- (c) is closer to the Australian SST/surface air temperature 132-year cycle with 1972 as the inflection year. The patterns of the central six decades appear to be appropriate and present a mirror image of below-average temperature versus above-average storms [Figure 11b].

Figure 11a presents three cyclic patterns:

The following are numbers referred to in Figure 11a:

1. The top one (A/R) refers to the winter rainfall of Southwest Western Australia Rainfall [Figure 11b].
2. The Middle one (A/T) refers to Australian surface air and SST [Figure 11c(i)] presented a mirror image of the top rainfall pattern.[1] – Figure 11c(ii) presents the Sydney, Australia January Hottest Daily Maximum Temperature (1896-2016). It presented a W and M pattern in the main cycle similar to Durban rainfall.[4]
3. The bottom pattern presents the undivided Andhra Pradesh annual average rainfall of the 132-year cycle [Figure 6e-top pattern]. This presented a shift of 33 years to the top curve (1). However, A/T and I/R followed that when A/T is below the average I/R presented a better rainfall with a 33-year lag. This is in line with the Western Pacific Ocean-reverse pattern [Figure 11b].

Explanation

1. The Australian SST and surface air temperature with the below the average (−) 66-year part followed by above the average (+) 66-year part with the inflection year of 1972 is followed by Bay of Bengal cyclonic storms wherein the negative temperature followed by positive temperature in 66 years each but it is reverse for cyclones above the average followed by below the average
2. Table 5 data followed a 132-year cycle of cyclones with above the average (+) 66 years and below the average (−) 66 (=22 + 44) years with the inflection year of 1972;
3. AMO and Bay of Bengal cyclones followed the same pattern in the 1972 inflection year.

Cyclones and hurricanes

There is no difference with few exceptions between (1) Atlantic basin storms including subTCs and (2) North Atlantic Ocean TCs. They are all organized storm systems that form over warm ocean waters,

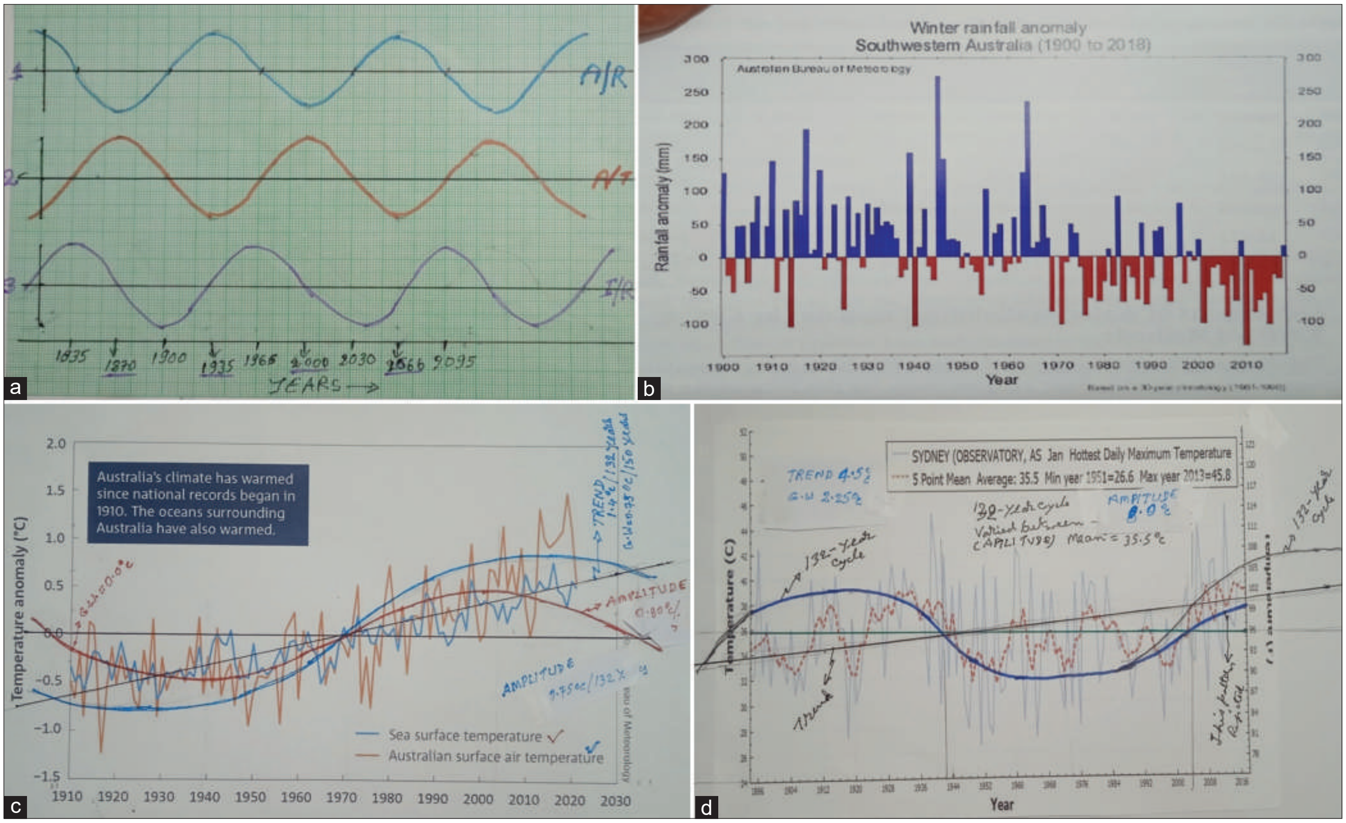

Figure 11: (a) Cyclic patterns in undivided AP [I/R – 3] and Southwest WA winter rainfall [A/R – 1] and Australian surface air & sea surface temperature [A/T – 2] [Dr. S.J.Reddy]. (b) Winter Rainfall of Southwest WA [1900 to 2018]. (c(i)) The cyclonic pattern of Australian surface air and sea surface. (c(ii)) Sydney, Australia January Hottest Daily Maximum Temperature [1896-2016]

rotate around areas of low pressure, and have wind speeds of at least 74 mph (119 km/h).

The reason for the three names is that these storms are called different things in different places (cyclones, hurricanes, and typhoons) wherein a TC with maximum sustained winds of 39–73 mph (34–63 knots) and Hurricanes are also called TC with maximum sustained winds of 74 mph (64 knots) or higher. In the Western North Pacific, hurricanes are called typhoons; similar storms in the Indian Ocean and South Pacific Ocean are called cyclones.

Scientists often use "TC" as a generic term, while "hurricane," "typhoon," and "cyclone" are regional terms. The season officially starts on June 1st and ends on November 30th. Hurricanes are technically TCs, which form due to warm, moist air temperatures, which means that the warmer and wetter the climate, the better the chance of a hurricane of some type forming.

The Atlantic basin includes the Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico**.** The Atlantic Hurricane Season starts on June 1 and continues through November 30.

Figure 12a presents the Atlantic Basin storm count including sub TCs and Figure 12b presents Atlantic Basin non-major hurricanes and major hurricanes along with the trend – this follows the AMO pattern of the 60-year cycle. Figure 12b indicates the increase in short-duration Atlantic storms, which are responsible for much of the trend. Figure 12a also shows that there has been no significant change in moderate-duration storms from 1880 to 2010 after accounting for the long-missed storms. These results show that the increase in Atlantic storms is an artifact of the way we have observed storms, rather than a real climate change toward more Atlantic hurricanes. This was sown that it follows AMO. Here is the inflection year 1972. This is seen in Figures 6c and 13a.

The author studied in continuation to an earlier study in 2008[1] that North Atlantic Ocean Historical TCs and Atlantic Basin Storms including sub-TCs to understand the natural variability expressed as cyclic patterns and increasing or decreasing trend if any. For this purpose, the data series were collected from the Internet and estimated 14-year totals in the case of Atlantic Basin Storms (with two starting point years: 1851 and 1856 like the moving average technique) and presented in Figure 13a. The "average" of North Atlantic Ocean storms + Atlantic Basin storms at 10-year totals are estimated and presented in Figure 13b.

Figure 13a presents the Atlantic Basin Storms count including sub-TCs for 14-year totals as: The 14-year totals from the starting point the lowest value is 160 storms and the highest is 377 storms per 14 years; that is 11–27 storms per year with the mean as 19 storms; The data series presented increasing trend; It presented increasing trend from a 14-year total of 160 storms to 300 storms; that is 11–22 storms per year with the mean of 16 storms; It presented "60-year cycle"-two cycles completed and the third cycle of above the average started.

Figure 13b presents the average of North Atlantic Ocean historical TCs + Atlantic Basin storms wherein totals including sub-tropical cyclones for 10-year totals. For the 10-year totals from the starting point, the lowest value is 111 storms and the highest is 277 storms; that is 11–28 storms per year with a mean of 19 storms per year; The data series presented an increasing trend. It presented increasing from a 10-year total of 120 storms to 220 storms; that is 12–22 storms per year with a mean of 17 storms per year storms; it presented a "60-year cycle" – two cycles completed and the third cycle of above the average started.

Figures 13a and b presented a 60-year cycle with the trend. In Figures 12b and 11c present below the average followed by 30 years above the average pattern with 1972 as the inflection year; but Figures 13a and b presented the same pattern with the inflection year 1960-may be due to 14- and 10-year totals.

Figures 13a and b presented similar to the AMO cycle in terms of a 60-year cycle but AMO has not

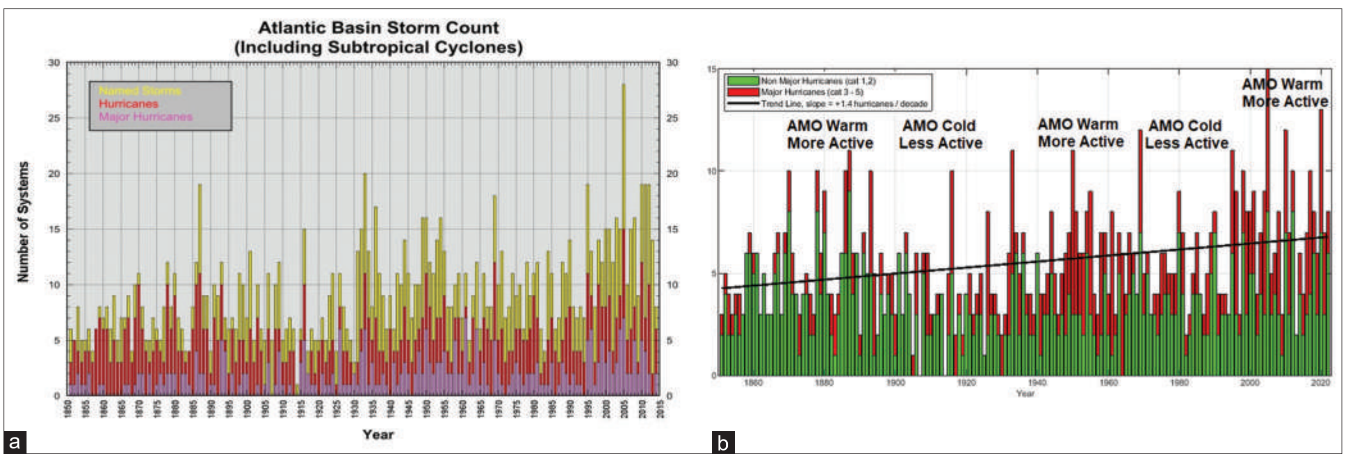

Figure 12: (a) Atlantic Basin storm count including subtropical cyclones. (b) Atlantic Basin – major hurricanes and major hurricanes along with the trend

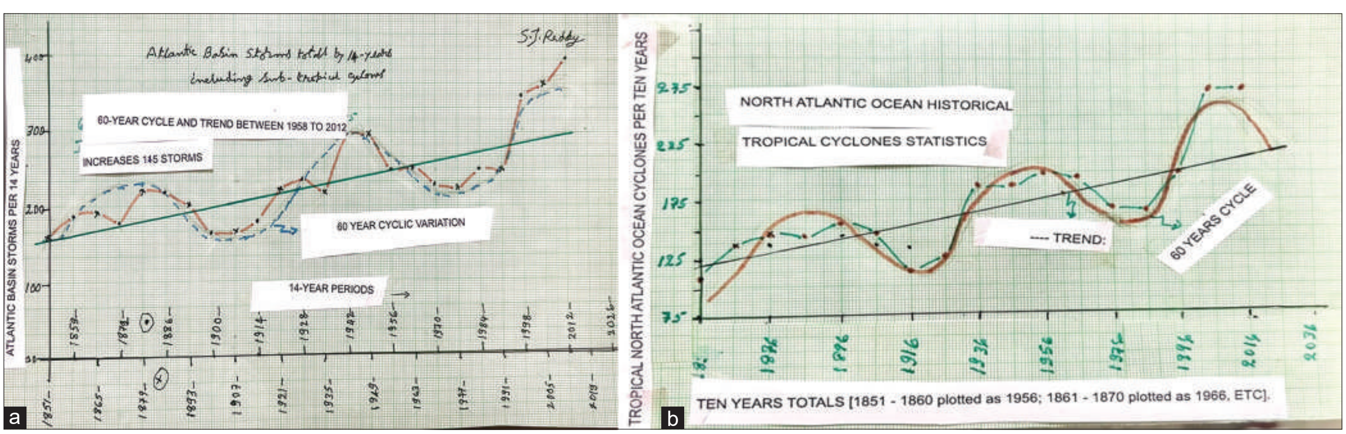

Figure 13: (a) 14-year total Atlantic Basin storms wherein totals include subtropical cyclones presented a 60-year cycle and trend of 160 to 300 storms of 14-year totals. (b) 10-year totals of the North Atlantic Ocean + Atlantic Basin average presented a 60-year cycle and trend of 120 to 220 storms

shown any increase or decreasing trend. Therefore we cannot attribute the trend observed in Figures 13a and b to ocean heating by fictitious global warming. Australian SST also has not shown the trend but presented a 132-year cycle. The trend is a linear increase from 1850 while the global warming trend starts from 1951 with a steep rise from 1980 onwards. Figure 11c(i) presents the Australian surface air and SST. They followed the 132-year cycle. Surface Air temperature presented an amplitude of 0.75°C/132 years and a trend of 1.40°C/132 years (i.e., global warming component of 0.75°C/150 years, i.e., 1951–2100). This is a mirror image of the average annual rainfall of winter southwest WA [Figure 11b] to Australian surface air and ocean surface temperature [Figure 11c(i)]. Figure 12e presents Sydney, Australia's January Hottest Daily Maximum Temperature from 1896–2016. Similarly, Australia's Surface Air Temperature presented a 132-year cycle but the inflection year shifts to 1940 instead of 1972 (backward) and to 2004 (forward). It presented an amplitude of 8.0°C/132 years and a trend of 4.5°C/132 years (i.e., global warming [?] of 2.50°C). Australian average annual surface air temperature presented high year-to-year variations when compared to global temperature. This has led to high amplitude and higher trend. It also followed the "W" and "M" patterns that were seen in the average annual rainfall of Durban in South Africa after integrating 66 and 22-year cycles with trigonometric functions.[2-4]

Between IOD, ENSO, ISM and INM

A study reports that Figure 14 presents a schematic depiction of the observed IOD-ENSO and IOD-ISM relationships (taken from the Internet). Variability in the tropical IO has also been found to be strongly connected with the phases of both ENSO and IOD. Studies also suggested that decadal variability in tropical IO SST influences the monsoon dynamics that involve Hadley and Walker circulation and modulates ISM. From the observed record, the ENSO–IOD correlation has been found positive and significant since the later decades of the 20th century which may correspond with either a weak/strong monsoon–ENSO relationship or a strong/weak monsoon–IOD relationship. It is consistent with the fact that over the same time, the teleconnection between ISM–ENSO weakened, whereas the relationship strengthened for ISM–IOD. There are hypothetical inferences the real factor relates to natural variability cycles in the majority of the years that include river water flows, Table 6 presents the list of La Nina, El Nino, positive IOD, and negative IOD years.

Between AMO, PDO and ENSO

AMO

Reddy:[1] Analysis of the record-breaking 2005 hurricane season also reveals that higher than usual global SST was responsible for the majority. However, hurricanes in the Atlantic Ocean presented an increasing trend that contradicts the postulation. AMO is a basic phenomenon of SST Anomalies in the North Atlantic Ocean [Figure 6c]; is

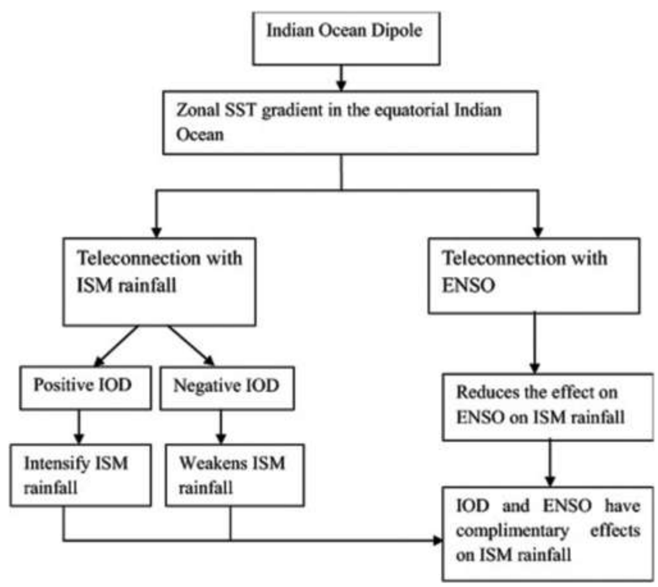

Figure 14: A schematic IOD-ENSO and IOD-ISM relationships ["ENSO, El Niño southern oscillation; *IOD*, Indian Ocean Dipole; *ISM*, Indian summer monsoon"]

Table 6: List of La Nina, El Nino, negative, and positive IOD years

ENSO/IOD	Years
El Nino	1951 1957 1963 1965 1968 1969 1972 1978 1977 1982 1986 1987 1991 1994 1997 2002
La Nina	1949 1950 1954 1955 1956 1964 1967 1970 1971 1973 1975 1984 1988 1995 1998 1999 2000
Positive IOD	1961 1964 1967 1972 1982 1987 1991 1994 1997 2002
Negative IOD	1956 1958 1960 1964 1968 1974 1975 1992 1996 1998

Source: Internet

characterized by a slow change in SST over a period of approximately 60 years. It is closely linked to variation in the Atlantic overturning circulation, that is, AMO is SST changes in the North Atlantic Ocean from 0 to 70°N with multi-decadal variability. In general, AMO has a 60-year cycle with 0.40°C range between extremes (amplitude) for 60 years – for Australia's SST presented a 132-year cycle with 0.75°C amplitude for 132 years. The overall physical mechanism that drives the variability in AMO is less understood. In fact[1-3] observed increasing hurricanes with time but presented a 60-year cycle. The Australian SST presented zero trends but presented amplitude. Australia surface Air and SST data series presented a 132-year cycle.

On the contrary, the history of cyclones/typhoons/hurricanes presents a system in their occurrence patterns of severity and frequency. In the USA according to NASA data, Hurricanes were severe in intensity during the 1940s, 1950s, and 1960s, and they were less severe in intensity during the 1970s, 1980s, and 1990s – a similar pattern is seen in Bay of Bengal cyclones with more and less cyclones per year during 1945 to 2000 data series.[1,7] Now again they are severe in intensity similar to the period 1940, 1950, and 1960s with 1972 year as the inflection year [Figure 9b in Reddy.[1]]. This pattern is similar to the pattern observed in the All-India South-west Monsoon Rainfall.[5,10] The all-India Southwest Monsoon 60-year cyclic pattern [Figure 6-Reddy[1]] is presented by a sine curve along the horizontal axis in Figure 9b of Reddy.[1]

Figure 6c presents the AMO data chart and the Kaplan SST datasets from NOAA. (a) Monthly AMO Index. (b) Annual AMO Index. (c) Year-month chart of AMO index. This presents the clear-cut 60-year cyclic pattern. From Figure 6c, it is clear that the inflection year is similar to the Bay of Bengal cyclones shown in Figure 11d. However, both present mirror images. That is a 30-year lag. Before 1972 (inflection year) the AMO presented below the average while Bay of Bengal storms showed above the average.

Rajeevan *et al*.[11] observed in 1959–1991, a significant inverse relation between Northwest Pacific activity as measured by typhoon days during summer months (June to September) and ISM Rainfall [Table 12] in Reddy.[1] That means the cyclonic activity in the Northwest Pacific is in opposition to the Hurricane activity. A similar but opposite pattern of Hurricane pattern is evident in the case of frequency of the cyclonic storms and depressions during the North-east Monsoon season (October to December) in India during 1951–1981[12] (it is in fact 1957/58–1986/87[5]) – the frequency is <6 in the 1940s–1960s and more than 6 in the 70s–90s. This is not in line with Figure 13a. The frequency of occurrence of cyclones per year in the Bay of Bengal during 1945–2000 (May to November) as presented by the joint Typhoon Warming Center shows a drastic reduction around 1975 – Figure 9c in Reddy.[1] This followed the South-west Monsoon rainfall pattern of undivided Andhra Pradesh – The Southwest Monsoon rainfall 56-year cyclic pattern is presented by a sign curve along the horizontal curve in Figure 9c in Reddy.[1]

Srivastava *et al*.[13] also presented this trend in the annual frequency of cyclonic storms over the Arabian Sea and Bay of Bengal for the period 1961–2002. Bay of Bengal storm activities presented a decreasing trend – in association with this, the Orissa rainfall presented a decreasing trend. This period coincides with the below-average rainfall cycle of the Southwest Monsoon Season of undivided Andhra Pradesh (1973–2001). Undivided Andhra Pradesh rainfall is more associated with the frequency of occurrence of depressions/storms in the Bay of Bengal.

Jadhav[14] computed the total number of low-pressure systems and depressions/storms for the monsoon months June to September for the period 1891-2000-Kumar[15] data also followed this pattern. However, the low-pressure systems are not confined to Undivided Andhra Pradesh alone but are spread all over India while the majority of depressions/storms influence the undivided Andhra Pradesh rainfall. Though low-pressure systems do not present a systematic variation [but followed the rainfall pattern of undivided Andhra Pradesh Southwest Monsoon Season wherein-see Figure 2a in Reddy[7] [Figure 13a] – during the 1973–2001 presented lower number compared to the previous 28-year period. Though during 1973–2001 depressions/cyclone storms presented a steep fall,[13] the total number of low-pressure systems presented no such fall. The steep fall in storms/depressions presents a fall in rainfall during the East Coast because of low-pressure systems the rainfall over other parts has not sown such a fall.

These clearly point out one thing there is a significant relationship among cyclonic activity over different oceans-seas and rainfall patterns. There is a need to look into this aspect by taking into account the solar-planetary system.

PDO

The PDO is a naturally occurring phenomenon that shifts between warm and cool phases. Here one important point to be noted is in the case of Northern Hemisphere PDO presents a 60-year cyclic pattern similar to Atlantic Hurricanes. In the Southern Hemisphere, PDO is similar to Australian surface air and SST follows a 132-year cycle**.** The PDO can strongly impact global weather and is important in long-range weather forecasting.

PDO is an SST climate cycle describing SST anomalies over the Northern Pacific Ocean. The PDO can influence the weather conditions across North America and the Pacific Ocean basin with characteristic patterns occurring at different times of the year. The PDO oscillates between positive and negative phases. The Positive phase is characterized by cool SSTs north of Hawaii and warmer-than-normal SSTs along the western coast of North America. The negative phase is a mirror image with warm ocean temperatures in the Central North Pacific and cooler than normal waters along the western coast of North America, During the positive phase of the PDO in the Northern Hemisphere wintertime, the Southern and Eastern USA is more likely in the West and the Northwest. At the same time, the Northern Rockies and the Midwest are likely to be drier than normal, whereas Texas, the Gulf States, and the East are likely to be wetter than normal. During the positive phase of the PDO in the Northern Hemisphere winter time, much of Asia is usually cooler than normal, with above-the-normal temperatures more likely over India. At the same time, China and Japan are likely to be drier than normal, while India often has a winter that is wetter than normal.

During the negative phase of the PDO in wintertime, much of the lower 48°N Latitude is usually warmer than normal. The West Coast and the North-west are normally colder than normal. At the same time, many parts of the USA will see drier than normal weather, but there are some notable exceptions. During the negative PDO, winter rainfall is usually above normal in the Ohio and Tennessee Valleys as well as the Northern Rockies and Plains. During the negative phase of PDO, in the Northern Hemisphere's winter time, much of India and China is usually cooler than normal. However, Japan has warmer than normal weather, especially in the north. At the same time, Japan and northwest China are usually wetter than normal whereas southwest China and much of India are usually wetter than normal.

Both ENSO and PDO are important sea surface-based phenomena that influence weather conditions in the Pacific basin. When ENSO is in El Nino phase (positive MEI) the PDO is also positive. This has occurred 32% of the times of the time since 1941. Likewise, when ENSO is in the La Nino phase (negative MEI) the PDO tends to be negative and has occurred approximately 35% of the time.

The PDO typically remains in a given phase for many years or even decades, but there can be some variation within a given decadal phase. The PDO is a cyclic variation of the SST anomalies over the North Pacific Ocean that influences the weather patterns across large parts of Asia and North America. The PDO phases Persist for many years which makes the PDO a prime consideration in seasonal forecasting.– Source: Internet "World Climate Services".

Figure 15a-c presents the ENSO, PDO, and AMO data series.

Figure 15a presents (bottom figure) central 66 years are below the average and on either side above over it shifted by 33 years forward, the below the average part of inflection year is 1972.

Figure 15b presents (bottom figure) the time structure of the PDO; the time series of the amplitude of the spatial pattern in units of standard deviations. PDO followed the AMO pattern – 1943-1972.

Figure 15c presents the (bottom figure) time structure of the AMO; time series of the amplitude of the spatial pattern in units of standard deviations. The AMO cycle [Figure 2 and 11e] above the average 30-year period is 1935–1965 and below the average is 1965–1995.

ENSO presented a 132-year cycle with the central 66 years presenting below the average. AMO and PDO presented 60-year cycles but in a mirror-image pattern. That is AMO below the average coincides with the average of PDO.

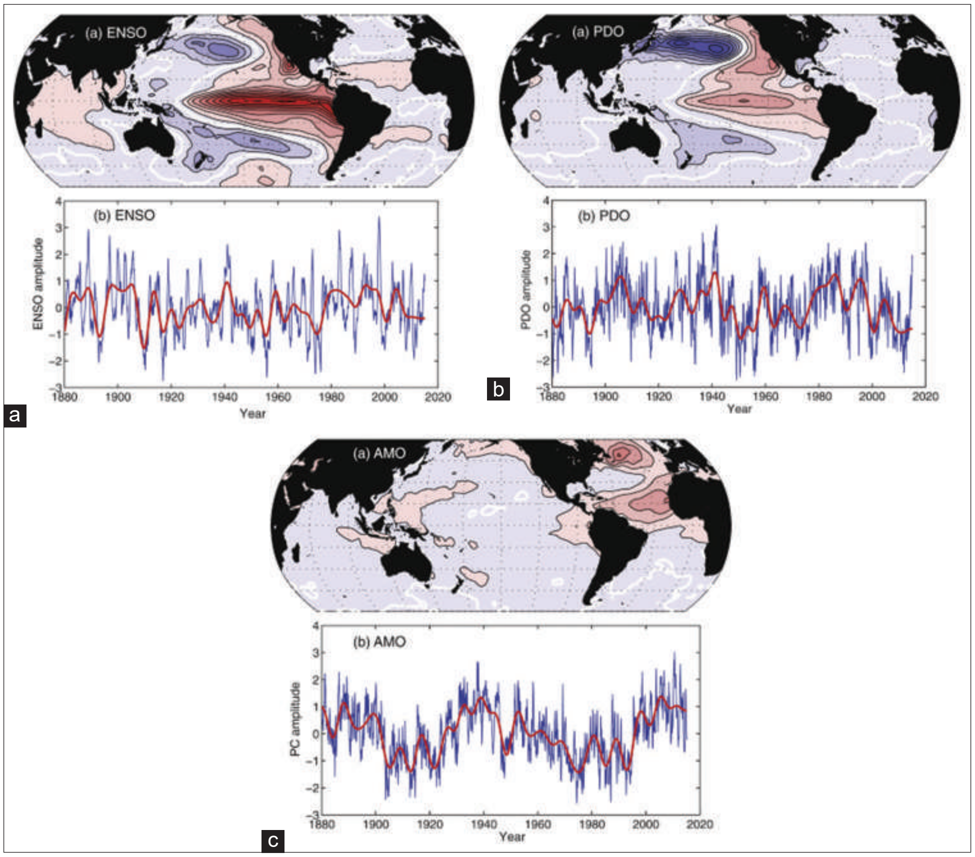

Figure 15: (a) The temporal pattern of ENSO time series from 1880 to 2020 [Source: Internet]. (b) The temporal pattern of PDO [Source: Internet]. (c) The temporal pattern of AMO [Source: Internet]

SUMMARY AND CONCLUSIONS

There are several systems that impact temperature, rainfall, and cyclones at global, regional, and local levels. Among these, some of them are IOD, ENSO, GGPC, AMO, PDO, IMS, INS, TCs, and hurricanes. However, natural variability in temperature and rainfall under climate change plays a dominant role. Sometimes, times data series used can give conflicting results.

IOD has three parts, namely positive, negative, and neutral. Positive IOD causes the warm SST in the Western Indian Ocean that affects positively on IMS; on the contrary causes cooler SST in the Eastern Indian Ocean causing dry conditions in South-eastern Australia and Eastern Indonesia. It negates these with negative IOD and under neutral conditions it is normal in both regions.

Summer rainfall in between the years with IOD occurring independently and those with IOD occurring along ENSO showed more than normal in South China. For the pure El Nino years, there is a seasonal reversal of precipitation over Southwestern and northwestern China suffers a precipitation deficit (surplus) in the developing spring (summer and autumn). It was also inferred that during the warm phase of PDO and IOD, the previous autumn can cause abnormal summer precipitation in South China.

Both IOD and ENSO play important role in Indian monsoon rainfall. IOD is confined to one cell within the eastern longitude near the equator – a local phenomenon. And. while ENSO spread over western and eastern longitude with multiple cells – a global phenomenon. The countries most affected by ENSO are developing countries that are bordering the Pacific Ocean and are dependent on agriculture and fishing. However, the IOD is considerably less powerful compared to El Nino, resulting in relatively minimal impacts.

ENSO and IOD positively impact IMS and cyclones in the Bay of Bengal. However, one must be cautious about these inferences as some other systems play major roles like natural variabilities in rainfall and temperature. Some reports suggest maximum TCs occurred during La Nina years and negative IOD years. More severe TCs occurred during La Nina with neutral IOD years. A positive IOD is linked to higher than average rainfall during EASR between October and December due to warm SST in the Western Indian Ocean.

The positive and negative IOD and El Nino and La Nina presented poor correlation with Bay of Bengal TCs.

ENSO is a global climate phenomenon that emerges from variations in winds and SSTs over the tropical Pacific Ocean. Those variations have an irregular pattern but do have some semblance of cycles. It affects the climate of much of the tropics and subtropics and has links to higher-latitude regions of the world. The warming phase of the SST is known as *El Niño* and the cooling phase as *La Niña*.

Warming of SSTs in the central and eastern equatorial Pacific Ocean and Ocean-atmosphere interaction takes place in the Indian Ocean. Due to weakening or reversal of trade winds (These winds are mainly caused due to the Coriolis Effect and Ferrel's law). They blow as North-eastern trade winds in the Northern Hemisphere and as South-eastern trade winds in the Southern Hemisphere. La Nina forms when surface temperature in the tropical Pacific Ocean is below normal by 0.5°C for 3 months and El Nino is the reverse with the temperature warmer than normal temperature.

The temperature difference takes place between the western and eastern parts of the Indian Ocean along the equator. Disrupts the atmospheric circulation patterns globally, leading to droughts, floods, and changes in temperature and precipitation patterns, and influences regional patterns in the Indian Ocean Basin and its surrounding landmasses. This suppresses rainfall, leading to drought conditions in some regions, and positive IOD enhances rainfall along the East African coastline and over the Indian subcontinent; negative IOD suppresses rainfall in affected regions. La Nina causes cooling of the SST in the central and eastern equatorial Pacific. Opposite effects are based on the temperature gradient between the western and eastern parts of the Indian Ocean. Significantly affects global weather patterns – weather compact compared to El Nino, but still influences local weather patterns.

The positive IOD has a significant influence on weather patterns, especially during the IMS, namely enhanced monsoon leads to increased rainfall over the Indian sub-continent resulting in a stronger monsoon season and dry conditions in parts of Australia due to reduced rainfall. Negative IOD causes weakened monsoons resulting in below-the-average rainfall over India, potentially leading to drought conditions; and wet conditions in Australia cause increased rainfall in parts of Australia. Neutral IOD causes normal monsoons resulting in typical monsoons without significant deviations from the average.

These are briefly given as:

- ENSO is a global phenomenon and IOD is a regional phenomenon;
- IOD is a weaker system over that of ENSO system
- Positive IOD favorable for good monsoon in India and East Africa and
    - Weakens the rain system in the Pacific side of Indonesia and parts of Southern Australia
    - El Nino presents further weakening of the positive IOD, but La Nina enhances the IOD impact on Indian Monsoon conditions and weakens the Pacific Indonesia and southern Australia's rainfall
- Negative IOD weaken monsoon system in India and East Africa
    - Strengthen the rain system in the Pacific side of Indonesia and parts of Pacific southern Australia
    - El Nino enhances weak monsoon systems but La Nina favors good monsoon; La Nina weakened by the negative IOD on the Indian Monsoon and strengthened the rain system over Pacific side Indonesia and Pacific Southern Australia;
- A positive IOD event is often seen developing at times of an El Nino-counter interaction on rainfall/Indian monsoon and it is opposite to Australia and Indonesia, while a negative IOD is sometimes associated with La Nina-counter interaction on rainfall/Indian Monsoon in India and it is opposite to Australia and Indonesia;
- During El Nino, the Pacific side of Indonesia is cooler than normal because of which the Indian Ocean side also gets cooler; and that helps the development of a positive IOD;
- If both IOD and ENSO are strong their circulation can impact each other.

The IOD is in its negative phase, with cool Western Indian Ocean water and warm water off northwest Australia (Timor Sea), winds are generated that pick up moisture from the ocean and then sweep down toward Southern Australia to deliver higher rainfall. In the IOD positive phase, the pattern of ocean temperatures is reversed, weakening the winds and reducing the amount of moisture picked up and transported across Australia. The consequence is that rainfall in the south is well below average during periods of a positive IOD. The study also shows that the IOD has a much more significant effect on the rainfall patterns in Southern Australia than the ENSO in the Pacific Ocean.

The increased rainfall associated with a positive IOD has been found to result in increased flooding over East Africa during the EASR period. Our studies[5,6,8,16,17] showed natural variability in rainfall over Ethiopia in northern Africa, Mozambique, Zimbabwe, Malawi, and South Africa, Botswana in Southern Africa, North-east Brazil, and India.

Important Issue: When we attribute something to something else, it is essential to look into the natural variability in rainfall and cyclones/hurricanes (systematic/cyclic variations component of climate change).

However, the major factor here is natural variability in rainfall as the ENSO and IOD are not effective processes for the occurrence and non-occurrence of rainfall. IOD and ENSO only help the natural variability condition either positive or negative sides.

A Western disturbance is an extratropical storm originating in the Mediterranean region that brings sudden winter rain to the North-west parts of the Indian sub-continent, which extends as east as up to northern parts of Bangladesh and Southeastern Nepal. It is a non-monsoonal precipitation pattern driven by the westerlies.

WD is formally defined by the IMD as: "*[A] cyclonic circulation/trough in the mid and lower tropospheric levels or as a low-pressure area on the surface, which occurs in middle latitude westerlies and originates over the Mediterranean Sea, Caspian Sea and Black Sea and moves eastwards across North India*." They are often associated with extreme rainfall events in the Karakoram and Hindu Kush regions of Pakistan. Despite the abundant interest in these systems, little headway has been made in developing a systematic understanding of them.

- The main cause of the Mediterranean, or dry summer, climate is the subtropical ridge, which extends towards the pole of the hemisphere in question during the summer and migrates towards the equator during the winter. This is due to the seasonal poleward-equator ward variations of temperatures
- WD is the cause of the most winter and pre-monsoon season rainfall across North-West India. This phenomenon is usually associated with a cloudy sky, higher night temperatures, and unusual rain. It is estimated that India gets close to 5–10% of its total annual rainfall from WD. They also cause cold waves and heat waves and cyclonic activity in the Bay of Bengal and Arabian Sea modify the circulation patterns of heat and cold waves
- The total number of TCs formed during El Nino years is more than those during La Nina and Neutral ENSO years
- The frequency of TCs in the northern (southern) Bay of Bengal is Maximum during negative (positive) IOD years
- WD is generally weakened during La Nina and during El Nino, they are more intensive

The other two AMO and PDO present natural variability (cyclic variation in SST) of 60-year cycle and 60 and 132-year cycles, respectively. Australia presented a 132-year cycle in surface air temperature and SST. In the Atlantic Ocean, hurricanes presented a 60-year cycle similar to AMO but they showed an increasing trend but the cause is not known. AMO's 60-year cycle presented a similar pattern with cyclonic storms in the Bay of Bengal. However, other data on cyclones in the Bay of Bengal presented a 132-year cycle similar to the Australian sea surface and surface air temperature cycle. The 66-year above-average pattern of the 132-year cycle of cyclones matches with the average temperature part of 66 years.

Australian surface air and SST presented a 132-year cycle (as the earlier value the 120-year cycle is not matching with the other data as the two ends do not match with 120 years but are well matched with a 132-year cycle.) No trend in SST was noted but noted trend in surface air temperature (global warming 0.75°C/150 years [1951–2100]). This is basically because after 1970 satellite data series were introduced in place of ground data series. It is a most inappropriate data series as the satellite data should be in reality must be lower than the surface data as it is the average of sparse data from ocean/sea surface and rural-cold-island parts. In real terms, Satellite data takes into account the sea/ocean surface temperature, urban-heat-island and rural-cold-island effects, and also carbon dioxide should not be linearly related to satellite temperature data after 1970. This serves to show they are near to 1.5°C of global warming. However, modelers put it at 2.5–4.5°C. Furthermore, they attributed the 2024 summer heat waves to global warming. In fact, this is not so for India and the USA they are associated with localized conditions (summer heat waves and winter cold waves) associated with WD in India and Jet Stream in the USA. The Atlantic Ocean and Pacific Oceans presented cyclic patterns and presented no trend. Sea/Oceans cover two-thirds of the data series with natural variability, the weather systems influence year-to-year variations within the cyclic pattern in temperature rainfall and cyclones/hurricanes. Under systematic variation components, cyclic variation and irregular variations are present. However, the weather systems have no capacity to modify the cyclic pattern. That means they represent the irregular variations in the systematic variations. PDO and AMO follow similar patterns but in opposite farms with a short shift in a 60-year cycle below the average PDO starts around 1945–1975 and above the average AMO starts around 1965–1995 with a lag of 20 years.

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