Hurricanes and Climate Change

There have been some dramatic statements emerging this week about the coming hurricane season (June-November).

[2024 Atlantic hurricane season could be among most active on record, experts predict]

Hurricane Fran. Image made from GOES satellite data.

[CSU early forecast call for above-average hurricane season | Miami Herald]

A satellite image of Hurricane Idalia, a Category 3, headed toward Florida in 2023. NOAA

Steamy ocean means 'a very, very busy season' for hurricanes, early forecasts says NOAA.

The upcoming hurricane season is shaping up to be another extremely active one, powered by the Atlantic's record-breaking run of high temperatures. The early season forecast from Colorado State University — a key pioneer of preseason hurricane forecasting — calls for another above-average season. BY ALEX HARRIS UPDATED APRIL 04, 2024 11:28 AM.

maclankford@gmail.com

Approximate "Cheat Sheet":

1 meter → 3 feet **1 degree Celsius (°C)** → 2 degree Fahrenheit (°F)
ppm = parts per million **CO_2** = Carbon Dioxide
1 tonne = 1000 kilograms = 2205 pounds **1 gigatonne (1 Gt)** = 1 billion tonnes
1 trillion tonnes (1Tt) = 1000 gigatons

Hurricanes and Climate Change

Let's get handle on how hurricanes work:

1. **A small disturbance** (...in the Force? …because of the Butterfly Effect?) appears in the atmosphere, with a local low pressure (which means rising warm air). With respect to North Atlantic Hurricanes, these disturbances almost always occur in the Eastern Sahara and **move as Waves across the continent to hit the Atlantic**.

2. **Once over the ocean**, the warm air picks up moisture (the warmer the water, the better!). The rising, warm moist air reaches cooler altitudes, condensing the water and releasing its heat. This heat continues to lift the air even higher, pulling even more warm moist air behind it and dumping a bucket load of precipitation. **This results in heavy thunderstorms**.

3. If the thunderstorms coalesce, the region becomes more coherent, pumping ever more air upwards. This draws (warm, moist) **surface air <u>in from all directions</u>, resulting in a counterclockwise rotation of the storm** from the Coriolis Effect.

4. If this pattern is continuously fed by warm seas below, **the storm can increase in size, strength, and wind speeds into a hurricane**.

5. If there are strong winds high in the Troposphere, these can rip off the tops of the hurricane and disrupt them. They are called vertical wind shears. Such wind shears are **often suppressed by La Nina conditions and increased by El Nino conditions**.

6. **The storm is propelled across the Atlantic from Africa by the prevailing Trade Winds**. In addition, there **usually is a persistent high pressure region further north** in the Atlantic from the descending air of the Hadley cell. This falling air has to go somewhere, so it **<u>flows outward</u>** at sea level, this time causing a clockwise rotation from the Coriolis Effect. The rotating cell serves to move the storm more quickly on its way to the Americas. **But even more importantly, the size of the high pressure region forces the storm path in certain directions.** These can be up the Atlantic coast of North America, directly into Florida, over Cuba, down through the Caribbean, and upwards through the Gulf regions.

7. **The greatest destructive power comes, not from the winds, but from the Storm Surge.** The extremely low atmospheric pressure below the storm lifts the sea level like a vacuum cleaner. As the storm hits land, the surge can bring sea levels up far above any protections.

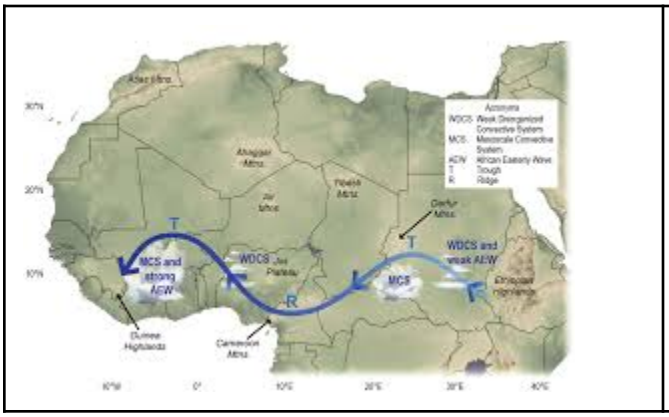
8. **So how does the warming of the planet affect hurricanes**? Warmer water can dramatically increase the energy released by the rising air as it condenses. This increases the inflowing air, speeds up the rotation of the cell, delivers higher seas to the coasts, and makes it more destructive.

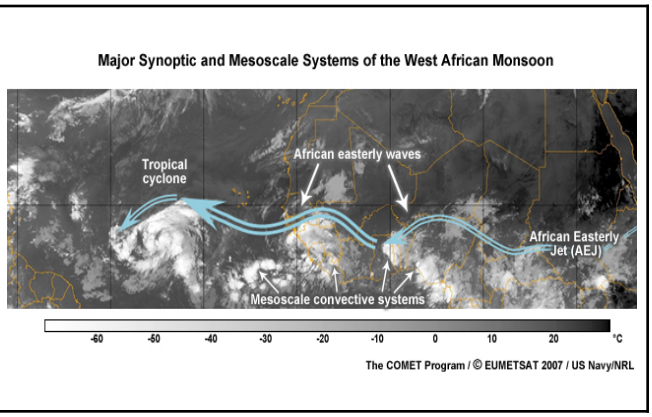
Hurricanes and Climate Change

Let's take these one at a time:

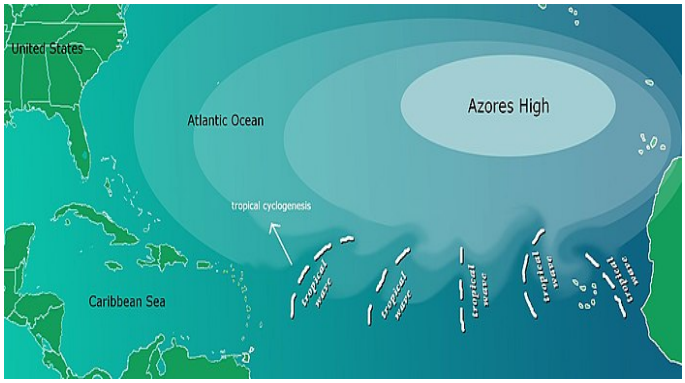
1. ***A small disturbance*** *(...in the Force? …because of the Butterfly Effect?) appears in the atmosphere, with a local low pressure (which means rising warm air). With respect to North Atlantic Hurricanes, these disturbances almost always occur in the <u>Eastern</u> Sahara and* ***move as Waves across the continent to hit the Atlantic****.*

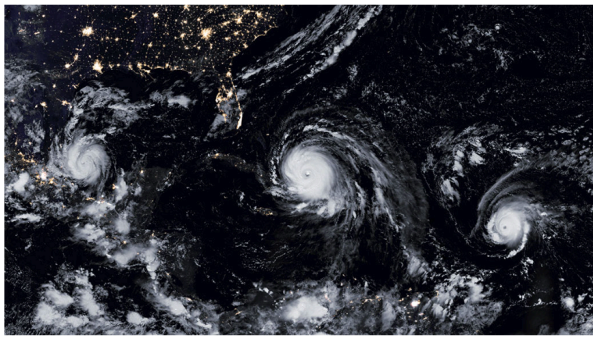
Most Atlantic hurricanes begin to form over Africa, where hot, dry desert air meets cool, wet air. In the seam between these high- and low-pressure air systems, a powerful westward stream known as the African Easterly Jet forms. Atmospheric disturbances that break off from the swerving jet can trigger hurricanes. (Natalie Renier, WHOI Graphic Services)





Hurricanes and Climate Change





Each white swirl in this image is a hurricane that formed in the Atlantic in 2017 and then headed toward the night lights of North America (upper left).

NASA EARTH OBSERVATORY IMAGES BY JOSHUA STEVENS AND JESSE ALLEN, USING VIIRS DAY-NIGHT BAND DATA FROM THE SUOMI NATIONAL POLAR-ORBITING PARTNERSHIP AND TERRA MODIS DATA FROM THE LAND ATMOSPHERE NEAR REAL-TIME CAPABILITY FOR EOS (LANCE)

Tropical waves are the origin of approximately 60% of Atlantic tropical cyclones and of approximately 85% of intense Atlantic hurricanes (Category 3 and greater).[5][6]

Tropical cyclones can sometimes degenerate back into a tropical wave. This normally occurs if upper-level wind shear is too strong. The storm can redevelop if the upper-level shear abates.

https://en.wikipedia.org/wiki/Tropical_wave#:~:text=Tropical%20waves%20in%20the%20Atlantic,by%20the%20African%20Easterly%20Jet.

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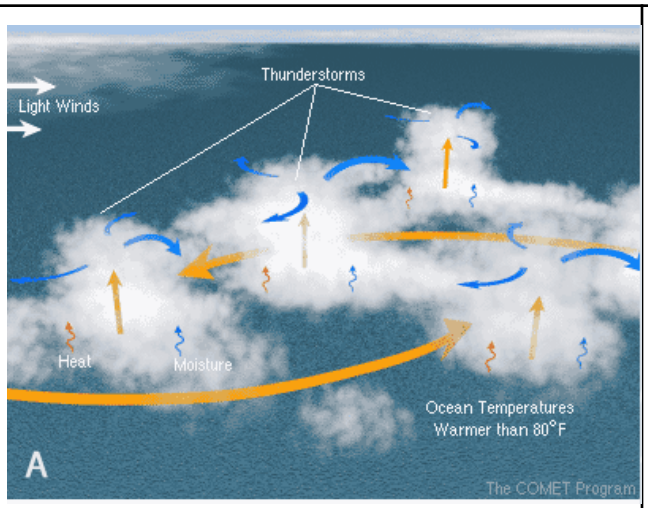
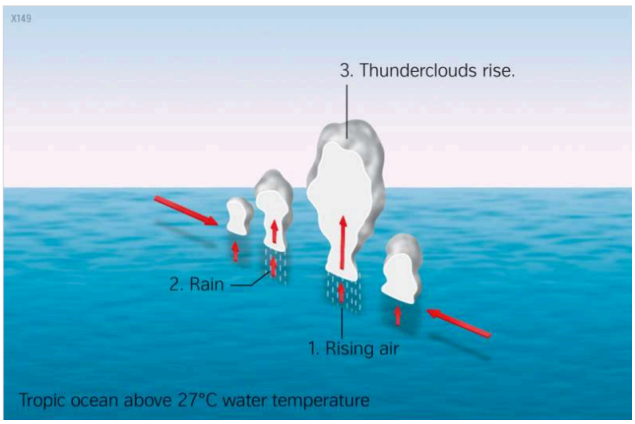
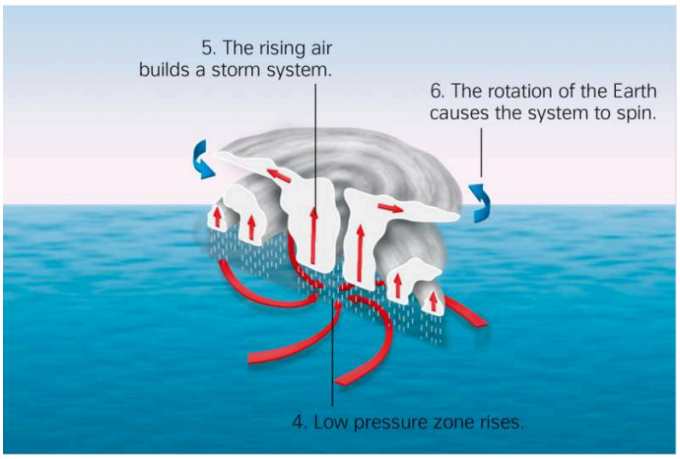
2. ***Once over the ocean****, the warm air picks up moisture (the warmer the water, the better!). The rising, warm moist air reaches cooler altitudes, condensing the water and releasing its heat. This heat continues to lift the air even higher, pulling even more warm moist air behind it and dumping a bucket load of precipitation.* ***This results in heavy thunderstorms****.*





3. *If the thunderstorms coalesce, the region becomes more coherent, pumping ever more air upwards. This draws (warm, moist)* ***surface air <u>in from all directions</u>, resulting in a counterclockwise rotation of the storm*** *from the Coriolis Effect.*



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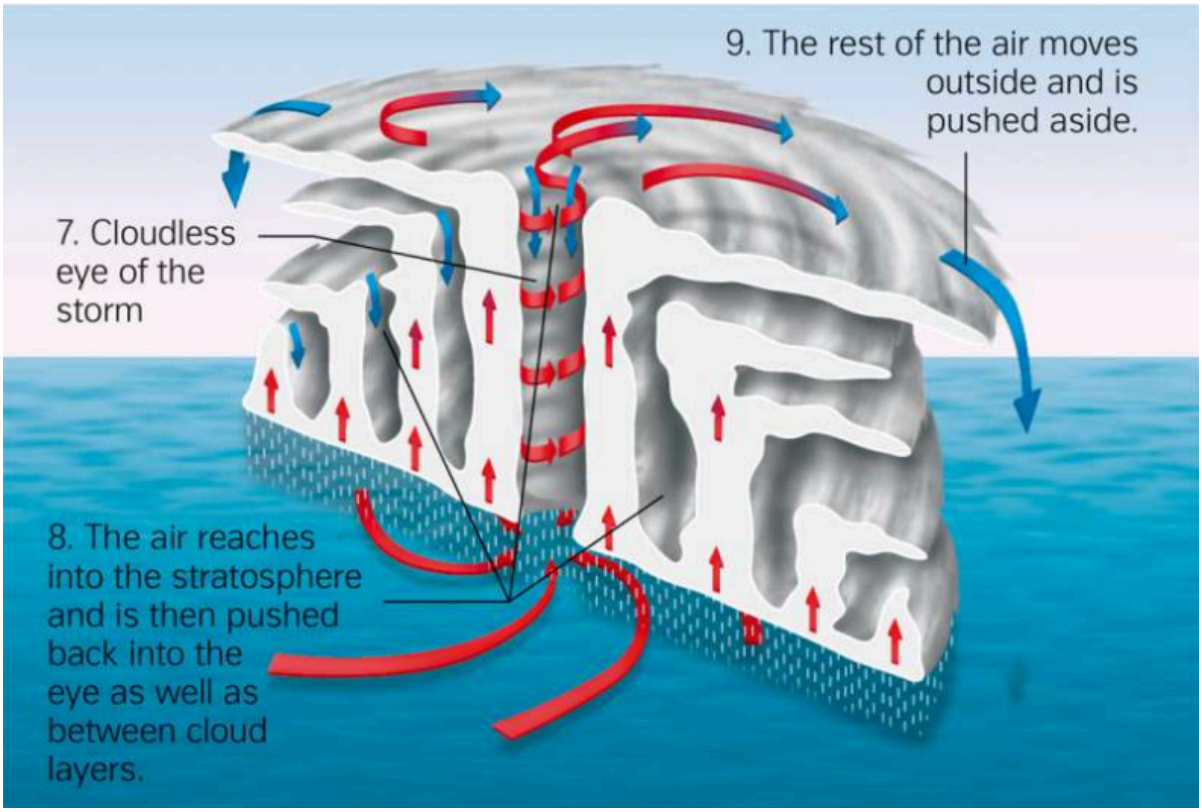
4. *If this pattern is continuously fed by warm seas below, and **unless it is disrupted by higher-up wind shear** (which would disperse the rising air), **the storm can increase in size, strength, and wind speeds into a hurricane**.*



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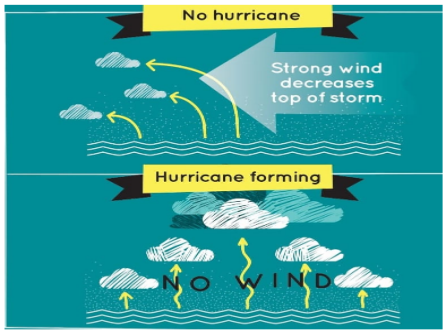
5. *If there are strong winds high in the Troposphere, these can rip off the tops of the hurricane and disrupt them. They are called vertical wind shears. Such wind shears are* ***often suppressed by La Nina conditions and increased by El Nino conditions****.*



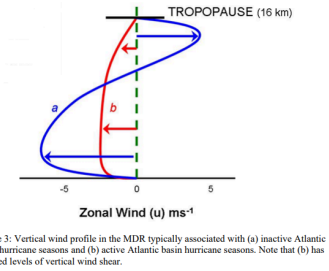
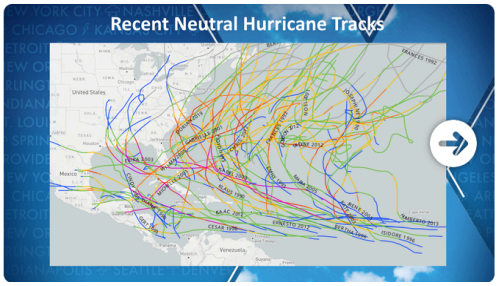
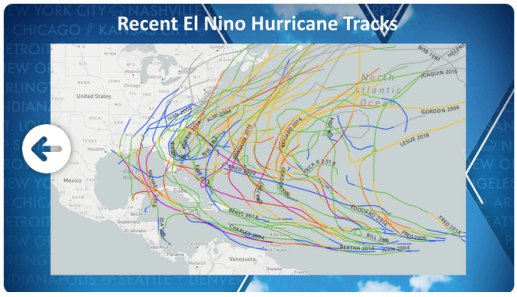
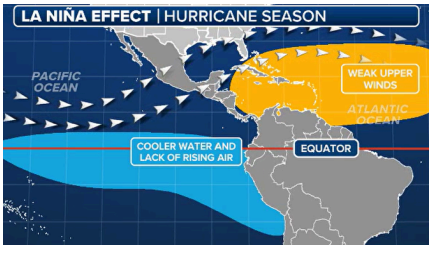


Figure 3: Vertical wind profile in the MDR typically associated with (a) inactive Atlantic basin hurricane seasons and (b) active Atlantic basin hurricane seasons. Note that (b) has reduced levels of vertical wind shear.





La Nina conditions give the most active hurricane season, because its cool waters send less air aloft near the equator. This lessens the high flow North at the top of the Hadley Cell.



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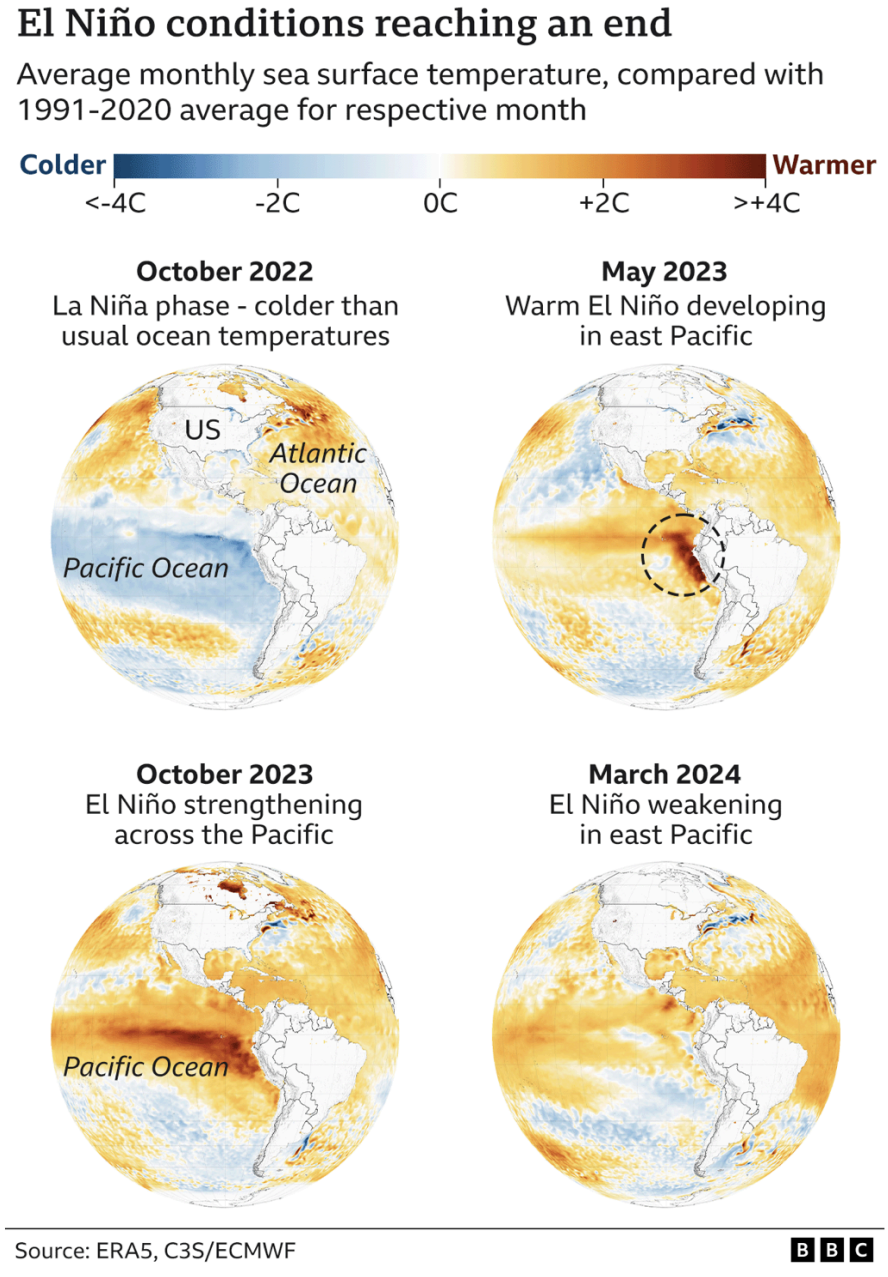
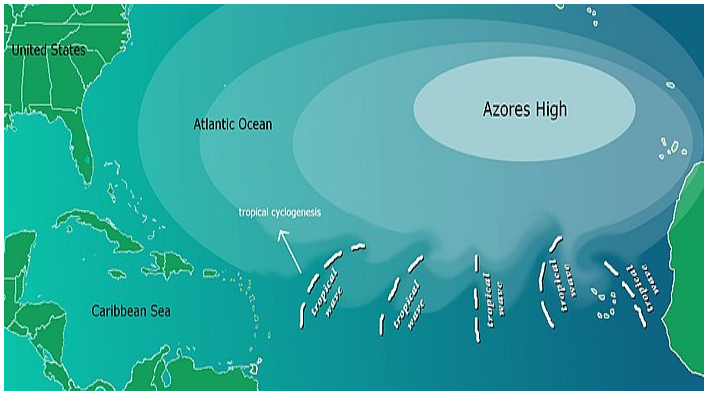
And the El Nino phase is now ending and <u>La Nina is expected to arise right at Hurricane Season</u>:



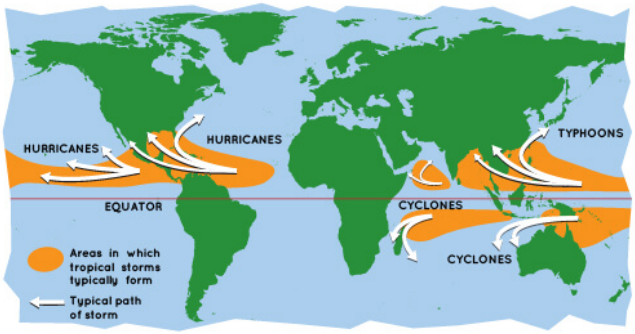
Hurricanes and Climate Change

6. ***The storm is propelled across the Atlantic from Africa by the prevailing Trade Winds***. *In addition, there* ***usually is a persistent high pressure region further north*** *in the Atlantic from the descending air of the Hadley cell. This falling air has to go somewhere, so it* ***flows outward*** *at sea level, this time causing a clockwise rotation from the Coriolis Effect. The rotating cell serves to move the storm more quickly on its way to the Americas.* ***But even more importantly, the size of the high pressure region forces the storm path in certain directions.*** *These can be up the Atlantic coast of North America, directly into Florida, over Cuba, down through the Caribbean, and upwards through the Gulf regions.*

Hot and dry winds hit the Atlantic waters, picking up moisture and generating storm clouds as they rise up. The low pressure fronts are wavelike and are moved across the atlantic by the clockwise rotation of a reasonably stable high pressure area further north.

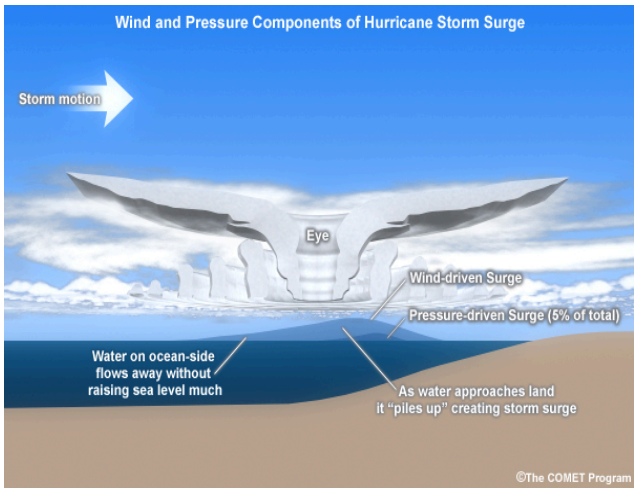


Similar action occurs around the planet.

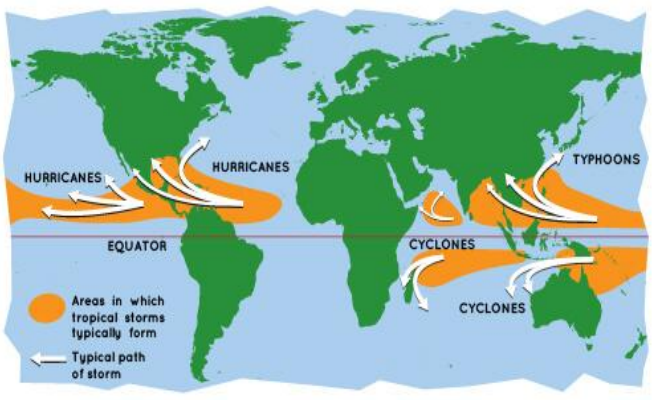


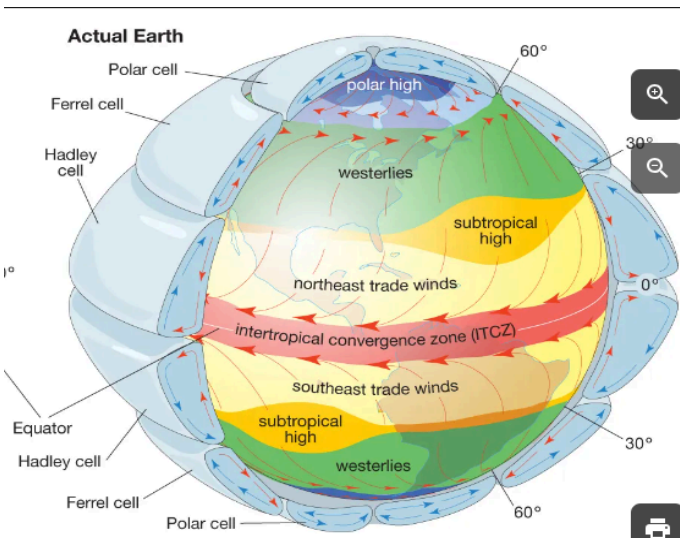
Hurricanes and Climate Change

7. ***The greatest destructive power comes, not from the winds, but from the Storm Surge.*** *The extremely low atmospheric pressure below the storm lifts the sea level like a vacuum cleaner. As the storm hits land, the surge can bring sea levels up far above any protections.*



When it is a matter of physics, Tropical Cyclones = Hurricanes = Typhoons = Cyclones





Hurricanes and Climate Change

8. ***So how does the warming of the planet affect hurricanes?***
   Warmer water can dramatically increase the energy *released by the rising air as it condenses. This increases the inflowing air, speeds up the rotation of the cell, delivers higher seas to the coasts, and makes it more destructive.*

The materials below are excerpted from a Yale study:

https://yaleclimateconnections.org/2019/07/how-climate-change-is-making-hurricanes-more-dangerous/?gad_source=1&gclid=Cj0KCQjwztOwBhD7ARIsAPDKnkBCA6i8SVGRyRLkauhgTWzN71skncVSoO8DnaE56QsravCUt4jpL8AaAiNGEALw_wcB

Indicators to date:

Are hurricanes becoming more frequent? In terms of frequency, studies have consistently shown "no discernible trend in the global number of tropical cyclones." In addition, authors of a 2013 study found no human-caused signal in annual global tropical cyclone or hurricane frequencies.

Are hurricanes getting stronger? "We conclude that since 1975 there has been a substantial and observable regional and global increase in the proportion of Cat 4-5 hurricanes of 25-30 *ver miss a story.*

Are hurricanes intensifying more rapidly? So while the team cannot attribute the rapid intensification gains to human-caused warming, they do say human-caused warming significantly increases extreme tropical cyclone intensification rates in the HiFLOR model.

Are hurricanes producing more rain? When it comes to the link between a warming world and weather, one of the most well-understood and robust connections is increased rainfall. Simply put, the warmer the air is, the more moisture it can hold and the more rain it produces. Generally, the increase in rainfall follows the Clausius-Clapeyron equation, which dictates that for every one degree Celsius (1.8 degrees Fahrenheit) increase, the atmosphere can hold 7% more moisture.

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Does climate change affect the forward speed of hurricanes? But a 2018 study by NOAA's James Kossin discovered a 10% global reduction in forward speed of tropical cyclones since 1949. Even more concerning – because of the impact on flooding – is the heightened **slowdown detected over land areas**: 21% in the western north Pacific and 16% in the North Atlantic. Authors of another study support these concerns, finding a significant positive trend over the past several decades in coastal rainfall from tropical cyclones that stall. That study does not, however, reach a conclusion on the reason for the increased stalling.

Projections into the Future:

Will hurricanes become more common in the future? When asked about the conflicting research findings on cyclone frequency, Emanuel said by email: "My own view is that we really do not know at this point whether the overall global frequency of [tropical cyclones] will increase, decrease, or stay the same. It is an area of active research."

But Emanuel stresses that the frequency metric is dominated by weak storms that typically do not do much damage, making frequency much less consequential than nailing down future intensity and rainfall.

"There is a strong consensus in the tropical cyclone climate community that the incidence of high-category events will increase, and that storms will precipitate more," Emanuel said.

Will hurricanes become more intense in the future? According to NOAA, 85% of all damages from hurricanes come from category 3, 4, and 5 storms. That's the case in part because of their intense winds. Incredibly, a hurricane with 150-mph wind speed has 256 times the damage potential of a hurricane with 75-mph winds.

In a 2015 paper using future model simulations, Knutson found an "increase in average cyclone intensity, precipitation rates, and the number and occurrence days of very intense category 4 and 5 storms." The numbers really spike when isolating just category 5 storms, with an 85% global jump and 136% Atlantic basin leap.

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How will hurricane rainfall change in the future? Projections of future rainfall increases in tropical cyclones are also notable. Knutson's study finds a **global rain rate increase of 14% by the end of the 21st century**.

Emanuel's 2017 study of Hurricane Harvey calculates that hurricane rains of 20 inches in Texas will **evolve from a once-in-100-year event at the end of the 20th century to a once-in-5.5-year occurrence by 2100**. Given that the vast majority of damage from storms like Hurricanes Harvey and Florence come from rainfall, these findings raise concerns.

Will hurricanes intensify more rapidly in the future? "**the incidence of storms that intensify rapidly just before landfall increases substantially as a result of global warming.**" To illustrate just how large the changes are, Emanuel quantifies them: "These results suggest that a storm that intensifies 70 mph in the 24 hours just before landfall, occurring on average once per century in the climate of the late twentieth century, may occur every 5-10 years by the end of this century."

Is there a danger to people or property? **Storm surge** is one the deadliest aspects of landfalling tropical systems, responsible for nearly 50% of deaths since 1963. Experts estimate that global sea-level will rise between a couple to a few feet by the end of the century. In itself, **even without stronger cyclones, sea-level rise will cause exponential damages and exposures**.

Using 21st-century climate model projections, Columbia University concludes that human-caused warming may lead to a weakening of disruptive vertical wind shear during active Atlantic hurricane cycles... **This weakening of wind shear is likely to result in more rapid intensification of storms as they near landfall.** On a massively populated coast with a heavily built environment, this combination will be dangerous and destructive.

[The following is mainly from: https://spaceplace.nasa.gov/hurricanes/en/]

https://scied.ucar.edu/learning-zone/storms/how-hurricanes-form

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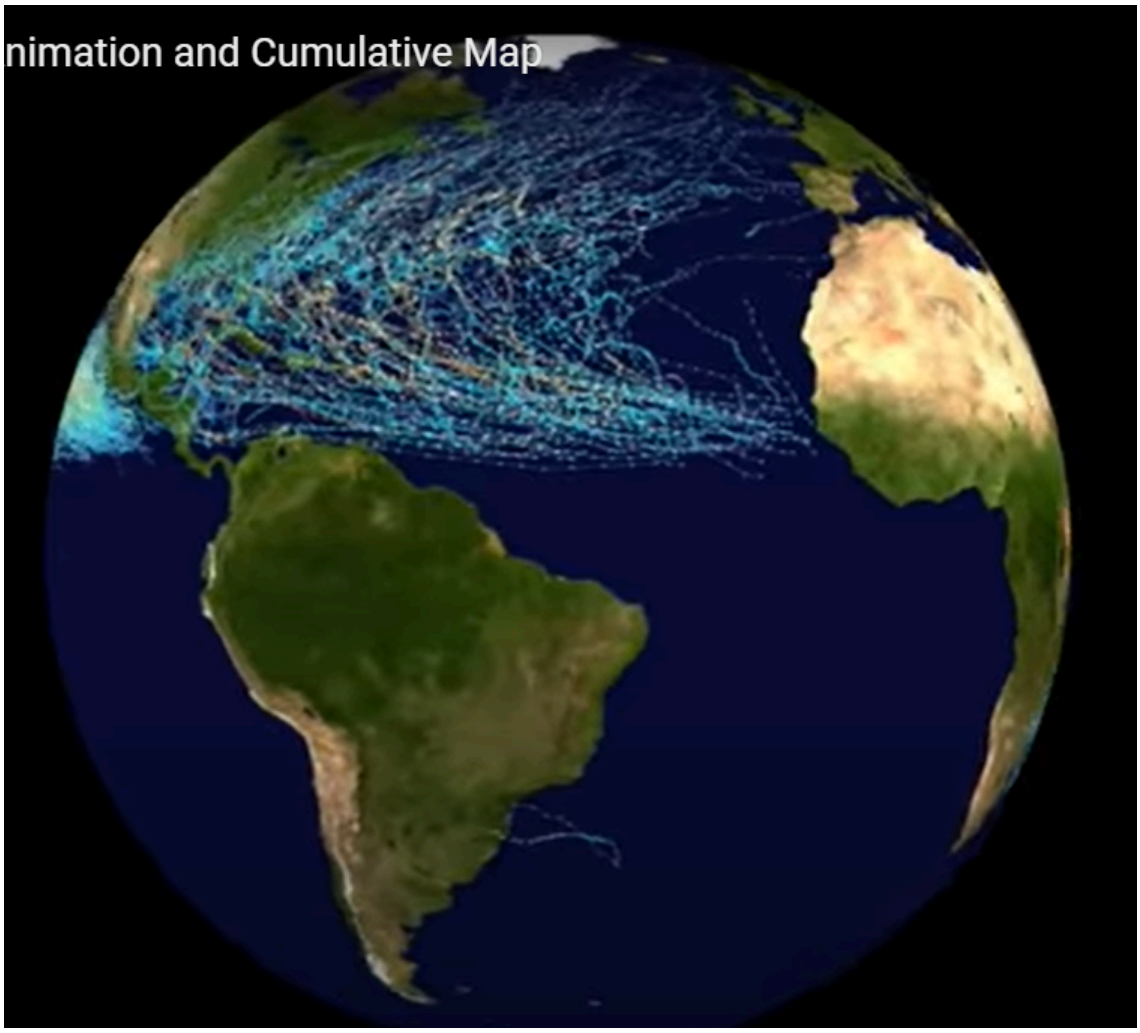

https://youtu.be/moctSQF-fH4

https://tropical.colostate.edu/Forecast/2024-04.pdf

Read more at: https://www.miamiherald.com/news/weather/hurricane/article287378610.html#storylink=cpy