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Earth's Dynamic Systems: Hurricanes and Cyclones

Nature's Most Powerful Storms

Aira Astralis

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Contents

Introduction

Chapter 1: The Discovery of Hurricanes and Cyclones

Chapter 2: Key Characteristics of Hurricanes and Cyclones

Chapter 3: The Science Behind Hurricanes and Cyclones

Chapter 4: Observation and Measurement of Hurricanes and Cyclones

Chapter 5: Important Features of Hurricanes and Cyclones

Chapter 6: Hurricanes and Cyclones in Context

Chapter 7: Research and Exploration of Hurricanes and Cyclones

Chapter 8: Significant Discoveries About Hurricanes and Cyclones

Chapter 9: Challenges and Mysteries of Hurricanes and Cyclones

Chapter 10: Future Directions in Hurricanes and Cyclones Research

Chapter 11: Fun Facts and Trivia About Hurricanes and Cyclones

Chapter 12: Conclusion: The Significance of Hurricanes and Cyclones

Conclusion

This free sample contains the Introduction and Chapter 1. The complete book contains the full contents above.

Introduction

Few forces in nature concentrate violence the way a tropical cyclone does. A single mature hurricane releases energy at a rate comparable to humanity's entire electricity production, not through any chemical or nuclear process but simply by moving heat: it is, at heart, a machine for converting the warmth of a tropical ocean into wind, and the ocean's warmth is its only fuel. Cut off from water warmer than about 26 °C (79 °F), the machine stalls; pointed back at such water, it rebuilds. The storm this book follows goes by different names — hurricane in the Atlantic and the eastern Pacific, typhoon in the western Pacific, tropical cyclone in the Indian Ocean and around Australia — but it is the same creature everywhere: a rotating system of thunderstorms organized around a calm eye, spanning hundreds of kilometers, capable of rewriting coastlines and, in a bad season, the economies of whole regions.

Its full life runs from a disorganized cluster of showers through tropical depression and tropical storm status to hurricane strength, measured on the familiar five-category Saffir-Simpson scale by the speed of its one-minute sustained winds. Three numbers sketch the scale of the phenomenon. Around 80 to 90 of these storms earn names each year worldwide. The Atlantic basin, the best-watched of them all, now averages 14 named storms a season, of which roughly half reach hurricane strength. And one Atlantic season — 2020 — produced thirty named storms, so many that the alphabet of planned names ran out and Greek letters had to be drafted.

What follows is organized the way the subject itself grew. The early chapters cover how the storms were discovered, described and finally measured, from ship logs and weather kites to dedicated satellites and hunter aircraft that fly straight through the eyewall. The middle chapters explain the physics: where the energy comes from, why the storm rotates, what the eye actually is, and how forecasters read the ocean and atmosphere to say where a storm will go. Later chapters take up forecasting's remaining failures — the erratic rapid intensification that still surprises coastal cities, the connections to climate, and the engineering and social questions of living beside the strongest winds on Earth.

A note on scope: this book treats the storm as a global phenomenon and draws its examples from every basin — the Atlantic's hurricanes, the western Pacific's typhoons, the Indian Ocean's cyclones — because the physics is shared while the record-keeping is not. Where a statistic refers to one basin, it says so. Where the science is genuinely unsettled, it says that too.

Chapter 1: The Discovery of Hurricanes and Cyclones

The United States National Hurricane Center (NHC) monitors tropical weather systems for the North Atlantic Basin and issues reports, watches, and warnings; it is considered to be one of the Regional Specialized Meteorological Centers for tropical cyclones, as defined by the World Meteorological Organization. Tropical cyclones are steered by flows surrounding them throughout the depth of the troposphere (the atmospheric layer ranging from the ground to about eight miles (13 km) high).

Neil Frank, former director of the United States National Hurricane Center, used analogies such as "a leaf carried along in a stream" or a "brick moving through a river of air" to describe the way atmospheric flow affects the path of a hurricane across the ocean. Specifically, airflow around high-pressure systems and toward low-pressure areas influences hurricane tracks.

In the tropical latitudes, tropical storms and hurricanes generally move westward with a slight tendency toward the north due to being under the influence of the subtropical ridge, a high-pressure system that usually extends east-west across the subtropics. South of the subtropical ridge, surface easterly winds (blowing from east to west) prevail.

If the subtropical ridge is weakened by an upper trough, a tropical cyclone may turn poleward (north) and then recurve (curve back toward the northeast into the main belt of the westerlies).

Poleward of the subtropical ridge, westerly winds prevail and generally move tropical cyclones that reach northern latitudes toward the east. Tropical cyclones can be categorized by intensity. The intensity of a tropical cyclone is generally determined by either a storm's maximum sustained winds or its lowest barometric pressure. The following table lists the most intense Atlantic hurricanes in terms of their lowest barometric pressure.

In terms of wind speed, Hurricane Allen and Hurricane Melissa were the strongest Atlantic tropical cyclones on record, with maximum sustained winds of 165 knots (190 mph; 305 km/h). However, Allen's measurements are suspect, since instrumentation used to document wind speeds at the time was likely to succumb to winds of such intensity. Nonetheless, their central pressures are low enough to rank them among the strongest recorded Atlantic hurricanes.

Owing to their intensity, the strongest Atlantic hurricanes have all attained Category 5 classification.

Hurricane Opal, the strongest Category 4 hurricane recorded, reached a minimum pressure of 916 hPa (27.05 inHg), a pressure typical of Category 5 hurricanes. Hurricane Wilma became the strongest Atlantic hurricane recorded after reaching an intensity of 882 mbar (26.05 inHg) in October 2005. Preceding Wilma is Hurricane Gilbert, which held the record for the most intense Atlantic hurricane for 17 years.

The 1935 Labor Day hurricane, tied with Melissa, with a pressure of 892 mbar (hPa; 26.34 inHg), is the third strongest Atlantic hurricane and the strongest documented tropical cyclone before 1950. Since the measurements taken during Wilma and Gilbert were documented using dropsonde, this pressure remains the lowest measured over land.

Hurricanes Rita and Milton share the spot as the fifth strongest Atlantic hurricane on record, each with a barometric pressure reading of 895 hPa (26.43 inHg).

Both hurricanes are also the strongest tropical cyclones ever recorded in the Gulf of Mexico. Rita is one of the three tropical cyclones from 2005 on the list, with the others being Wilma and Katrina at first and seventh respectively. Hurricanes Mitch and Dean share intensities for the ninth strongest Atlantic hurricane at 905 mbar (26.72 inHg).

Many of the strongest recorded tropical cyclones weakened before their eventual landfall or demise.

However, five of the storms remained intense enough at landfall to be considered some of the strongest, most powerful land falling hurricanes - five of the ten hurricanes on the list constitute the five most intense Atlantic landfalls in recorded history. The 1935 Labor Day hurricane made landfall at peak intensity, making it the most intense Atlantic landfall.

Hurricane Melissa made landfall shortly after peak intensity with a pressure of 897 hPa, making it the second strongest.

Though it weakened slightly before its eventual landfall on the Yucatán Peninsula, Hurricane Gilbert maintained a pressure of 900 hPa at landfall, as did Camille, making their landfalls tied as the third strongest. Hurricane Dean also made landfall on the peninsula, but it did so at peak intensity and with a higher barometric pressure; its landfall marked the fifth strongest in Atlantic hurricane history.

Climatology serves to characterize the general properties of an average season and can be used for making forecasts.

Most storms form from tropical waves in warm waters several hundred miles

north of the equator near the Intertropical Convergence Zone from tropical waves. The Coriolis force is usually too weak to initiate sufficient rotation near the equator. Storms frequently form in the waters of the Gulf of Mexico, the Caribbean, the tropical Atlantic Ocean, and in areas as far east as the Cape Verde Islands, forming Cape Verde hurricanes.

Systems may also strengthen over the Gulf Stream off the coast of the eastern United States wherever water temperatures exceed 26.5 °C (79.7 °F). Although most storms are found within tropical latitudes, occasionally storms will form further north and east due to disturbances other than tropical waves such as cold fronts and upper-level lows. These are known as baroclinically induced tropical cyclones.

Atlantic hurricane activity tracks the Pacific's ENSO state closely. El Niño years add wind shear over the Atlantic basin and so suppress storm formation there, while La Niña trims the shear away and lets activity expand.

Such a displacement of the Azores High is consistent with paleoclimatic evidence that shows an abrupt onset of a drier climate in Haiti around 3200 14C years BP, and a change towards more humid conditions in the Great Plains during the late-Holocene as more moisture was pumped up the Mississippi Valley through the Gulf coast. Preliminary data from the northern Atlantic coast seem to support the Azores High hypothesis.

Approximately 97 percent of tropical cyclones that form in the North Atlantic develop between June 1 and November 30, which delimit the modern-day Atlantic hurricane season.

The climatological peak of activity is typically around mid-September. Though the beginning of the annual hurricane season has historically remained the same, the official end of the hurricane season has shifted from its initial date of October 31. Regardless, on an average of every few years, a tropical cyclone develops outside the limits of the season.

As of September 2021, there have been 88 tropical cyclones in the off-season, with the most recent being Tropical Storm Ana in May 2021.

The first tropical cyclone of the 1938 Atlantic hurricane season, which formed on January 3, became the earliest-forming tropical storm, as post-hurricane reanalysis concluded about the storm in December 2012.

Hurricane Able in 1951 was initially thought to be the earliest forming major hurricane - a tropical cyclone with winds exceeding 115 mph (185 km/h) - however, following post-storm analysis, it was determined that Able only reached Category 1 strength, which made Hurricane Alma of 1966 the new

record holder, as it became a major hurricane on June 8.

Though it developed within the bounds of the Atlantic hurricane season, Hurricane Audrey in 1957 became the earliest developing Category 4 hurricane on record after it reached 115 mph on June 27. However, reanalysis from 1956 to 1960 by NOAA downgraded Audrey to a Category 3, making Hurricane Dennis of 2005 the earliest Category 4 on record on July 8, 2005.

The earliest-forming Category 5 hurricane, Beryl, reached the highest intensity on the Saffir-Simpson hurricane wind scale on July 2, 2024.

Though the official end of the Atlantic hurricane season occurs on November 30, the dates of October 31 and November 15 have also historically marked the end date for the hurricane season. December, the only month of the year after the hurricane season, has featured the cyclogenesis of fourteen tropical cyclones.

Tropical Storm Zeta in 2005 was the latest tropical cyclone to attain tropical storm intensity, as it did so on December 30.

However, the second Hurricane Alice in 1954 was the latest forming tropical cyclone to attain hurricane intensity. Both Zeta and Alice were the only two storms to exist in two calendar years - the former from 1954 to 1955 and the latter from 2005 to 2006. No storms have been recorded to exceed Category 1 hurricane intensity in December.

In 1999, Hurricane Lenny reached Category 4 intensity on November 17 as it took an unprecedented west-to-east track across the Caribbean; its intensity made it the latest developing Category 4 hurricane, though this was well within the bounds of the hurricane season.

Hurricane Hattie (October 27 - November 1, 1961) was initially thought to have been the latest forming Category 5 hurricane ever documented, as was 2020's Hurricane Iota, but both were later downgraded during subsequent reanalysis.

In the North Atlantic and the Eastern Pacific, the term "hurricane" is used, whereas "typhoon" is used in the Western Pacific near Asia. The more general term "cyclone" is used in the rest of the ocean basins, namely the South Pacific and Indian Ocean.

The earliest systematic watchers were the people with the most to lose. Caribbean islanders tracked the season's signs — swells arriving before clouds, seabirds fleeing inland, a unnatural stillness in the trade winds — and passed that knowledge through generations, while shipmasters compiled the first true storm climatology from the logs of vessels that survived. What science later formalized, coastal memory had already organized.

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ABOUT THE AUTHOR

Aira Astralis is a science writer specializing in astronomy and space exploration. Her work spans the full breadth of humanity's relationship with the cosmos -- from the earliest naked-eye observations to the engineering marvels of modern space missions.

Her books are built on a foundation of primary sources: peer-reviewed research, mission archives, and direct engagement with the scientific community. She writes for readers who want to understand not just what we know about the universe, but how we came to know it.

She believes that the most important frontier is not out there but in the gap between what scientists discover and what the public understands. Her books exist to close that gap.