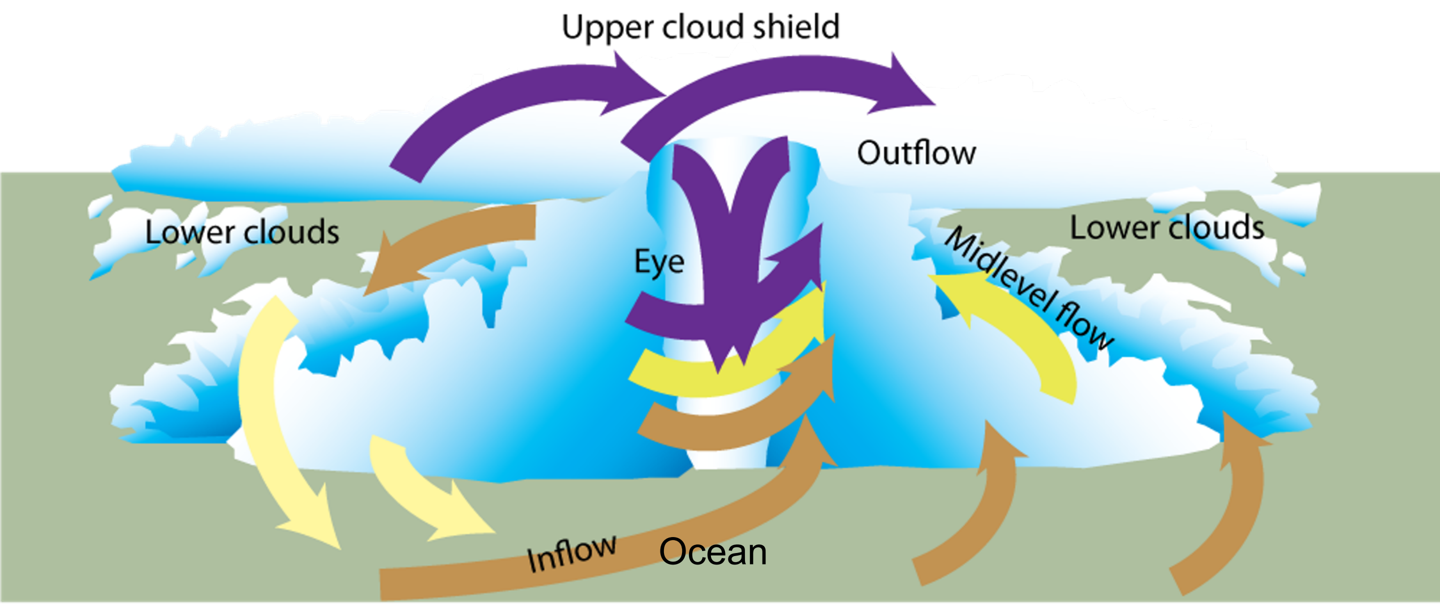
Today I Learned About Hurricanes

"Hurricanes are enormous heat engines. They convert heat that they extract from the ocean into wind energy, and the faster they can extract heat from the sea, the more powerful they can become... [T]he wind starts to blow harder over the ocean and that evaporates more water."
Professor Kerry Emanuel, MIT Department of Earth, Atmospheric and Planetary Science
TILclimate podcast: Today I Learned About Hurricanes



Conceptual diagram illustrating how hurricanes are structured and formed.
Diagram courtesy of the Integration and Application Network (ian.umces.edu), University of Maryland Center for Environmental Science. Source: Kruczynski, W.L. and P.J. Fletcher (eds.). 2012. Tropical Connections: South Florida's marine environment. IAN Press, University of Maryland Center for Environmental Science, Cambridge, Maryland. 492 pp.

Model a Hurricane

1. Visit https://scied.ucar.edu/interactive/make-hurricane
2. Move the red hurricane symbol to a circle on the map and read what happens.
3. Switch between the Sea Surface Temperature, Moisture, and Wind maps to see the data for each circle.
4. Which circles create the strongest hurricanes? Why?
5. In your own words, explain how sea surface temperature, moisture, and wind interact to create strong hurricanes – or weaken them.

As we burn fossil fuels like coal, oil, and natural gas and cut down forests, we release carbon dioxide (CO_2) into the atmosphere. This CO_2 acts like a blanket, trapping heat. While we need some blanket to maintain life on Earth, too much CO_2 traps too much heat. This heat is warming our ocean, Earth, and air.

6. How do warming ocean and air temperatures affect hurricane formation?

Graphic courtesy of Kate Bentsen, Integration and Application Network (https://ian.umces.edu/media-library)

Today I Learned About Hurricanes

"[T]he vocabulary is terrible! In the science world everything you know as a hurricane is called a tropical cyclone no matter where it occurs in the world… And tropical storm is also used in this region for tropical cyclones that aren't of hurricane strength. Super storm is not in our vocabulary. That's a … broadcast meteorologist type of thing. It's a very informal thing.

Professor Kerry Emanuel, MIT Department of Earth, Atmospheric and Planetary Science
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What's in a Word?

In the US, many of us are familiar with the term *tropical storm* and then *hurricanes* in categories 1-5. Depending on where you are in the world, the words for identical storms are different – even when everyone is using the same language. Below are three of the five classification systems recognized by the World Meteorological Organization (WMO.)

<table>
<tr><th>Knots</th><th>North Atlantic & Northeast Pacific</th><th>Southwest Indian Ocean</th><th>Northwest Pacific</th></tr>
<tr><td>17</td><td rowspan="2">Tropical Depression</td><td>Tropical Disturbance</td><td rowspan="2">Tropical Depression</td></tr>
<tr><td>28</td><td>Tropical Depression</td></tr>
<tr><td>34</td><td rowspan="2">Tropical Storm</td><td>Moderate Tropical Storm</td><td>Tropical Storm</td></tr>
<tr><td>48</td><td>Severe Tropical Storm</td><td>Severe Tropical Storm</td></tr>
<tr><td>64</td><td>Category 1 Hurricane</td><td rowspan="2">Tropical Cyclone</td><td rowspan="6">Typhoon</td></tr>
<tr><td>83</td><td rowspan="2">Category 2 Hurricane</td></tr>
<tr><td>90</td><td rowspan="2">Intense Tropical Cyclone</td></tr>
<tr><td>96</td><td>Category 3 Hurricane</td></tr>
<tr><td>113</td><td>Category 4 Hurricane (Major Hurricane)</td><td rowspan="2">Very Intense Tropical Cyclone</td></tr>
<tr><td>137</td><td>Category 5 Hurricane (Major Hurricane)</td></tr>
</table>

1 knot = 1 nautical mile per hour, 1.150779mph, 1.852km/h

Data from https://public.wmo.int/en/our-mandate/focus-areas/natural-hazards-and-disaster-risk-reduction/tropical-cyclones

Today I Learned About Hurricanes

What's in a Name?

For centuries after European colonization, hurricanes in the Caribbean were named after the Catholic saints' day on which they made landfall. Then, in the late 1800s and early 1900s, they were named for their latitude and longitude. During World War II, US military meteorologists began using first names traditionally associated with women. After the formation of the National Hurricane Center, an alphabetical list of names was developed.

Today, storms in the North Atlantic, Caribbean, and Gulf of Mexico are named from alphabetical lists maintained by the World Meteorological Organization, alternating between names traditionally associated with women and those with men. There are now six lists of 21 names each, which are used in a six-year cycle. (No storm names begin with Q, U, X, Y, or Z.) Names are removed ("retired") from the list if a storm is particularly damaging or deadly.

Before 2021, if more than 21 named storms occurred in a year, the list moved on to the Greek alphabet. This list was used for the first time in 2005. In 2020, a record-breaking storm season required the Greek alphabet again, and the World Meteorological Organization (WMO) decided to change their protocol. Beginning in 2021, there is a supplemental list of 21 names for busy hurricane seasons.

This list is only for storms within the North Atlantic region. The WMO also has lists of names for the other ocean areas (Southwest Indian Ocean, Northwest Pacific, etc.) Storms that cross from one area to another keep their original name, unless remnants from one storm reform into a new storm in the second area.

For all six lists, plus lists for other areas of the world, visit https://public.wmo.int/en/our-mandate/focus-areas/natural-hazards-and-disaster-risk-reduction/tropical-cyclones/Naming

Questions

1. Why do you think the different meteorological agencies use different terms for similar wind speeds?
2. What are some challenges that might arise from using different words for the same type of storm? (Consider multi-national corporations or international aid organizations.)
3. What are some other terms you have heard related to large storms? What do they mean, and who is using them?
4. Why do you think the National Hurricane Center switched to names instead of latitude and longitude for hurricanes?
5. What are some challenges that might arise from using human names for storms, especially across areas that include many countries?
6. Why do you think the WMO decided to create the supplemental lists instead of using the Greek alphabet?

Today I Learned About Hurricanes

"We don't really understand what sets the frequency of hurricanes even in the current climate very well... The two things I'd say we're confident about... the storms will be more intense. The storms will have stronger winds. When you put greenhouse gases in the atmosphere, the ocean not only warms up, but the rate of evaporation of seawater increases. The other thing we're completely confident of is that a given storm will rain more, because that's very simple physics: the warmer the air, the more water vapor it can hold. "

Professor Kerry Emanuel, MIT Department of Earth, Atmospheric and Planetary Science
TILclimate podcast: Today I Learned About Hurricanes

Historical Data

Since the mid-1800s, we have been adding large amounts of carbon dioxide (CO_2) to the atmosphere from the burning of fossil fuels such as coal, oil, and natural gas and cutting down of forests. This CO_2 acts like a blanket, trapping heat. Heat is absorbed by the land, ocean, and air. We know that warmer sea temperatures can lead to stronger storms.

As climatologists and meteorologists look to model future hurricane seasons, they look to the past to see how patterns have changed since the start of the industrial revolution and the dramatic increase in CO_2 emissions to the atmosphere. Consider the following data for Atlantic hurricane seasons from 1851-2020.

Interpretation

1. Using the data on the following pages, graph the pattern of storms since 1851.
2. What patterns do you notice?
3. Have the total number of storms changed over time?
4. Have the number of major storms (defined as categories 3, 4, or 5) changed over time?
5. Given the patterns that you identified, what would you expect the next decade's hurricane seasons to look like?
6. What other questions do you have about hurricanes? Where might you look for that information?

Today I Learned About Hurricanes

Year	Total Tropical Storms	Total Hurricanes	Major Hurricanes (Cat. 4&5)
1851	6	3	1
1852	5	5	1
1853	8	4	2
1854	5	3	1
1855	5	4	1
1856	6	4	2
1857	4	3	0
1858	6	6	0
1859	8	7	1
1860	7	6	1
1861	8	6	0
1862	6	3	0
1863	9	5	0
1864	5	3	0
1865	7	3	0
1866	7	6	1
1867	9	7	1
1868	4	3	0
1869	10	7	1
1870	11	10	2
1871	8	6	2
1872	5	4	0
1873	5	3	2
1874	7	4	0
1875	6	5	1
1876	5	4	2
1877	8	3	1
1878	12	10	2
1879	8	6	2
1880	11	9	2
1881	7	4	0
1882	6	4	2
1883	4	3	2
1884	4	4	1
1885	8	6	0
1886	12	10	4
1887	19	11	2
1888	9	6	2
1889	9	6	0
1890	4	2	1
1891	10	7	1
1892	9	5	0
1893	12	10	5
1894	7	5	4

Year	Total Tropical Storms	Total Hurricanes	Major Hurricanes (Cat. 4&5)
1895	6	2	0
1896	7	6	2
1897	6	3	0
1898	11	5	1
1899	10	5	2
1900	7	3	2
1901	13	6	0
1902	5	3	0
1903	10	7	1
1904	6	4	0
1905	5	1	1
1906	11	6	3
1907	5	0	0
1908	10	6	1
1909	12	6	4
1910	5	3	1
1911	6	3	0
1912	7	4	1
1913	6	4	0
1914	1	0	0
1915	6	5	3
1916	15	10	5
1917	4	2	2
1918	6	4	1
1919	5	2	1
1920	5	4	0
1921	7	5	2
1922	5	3	1
1923	9	4	1
1924	11	5	2
1925	4	1	0
1926	11	8	6
1927	8	4	1
1928	6	4	1
1929	5	3	1
1930	3	2	2
1931	13	3	1
1932	15	6	4
1933	20	11	6
1934	13	7	1
1935	8	5	3
1936	17	7	1
1937	11	4	1
1938	9	4	2

Data from the National Hurricane Center, https://www.nhc.noaa.gov/climo/images/AtlanticStormTotalsTable.pdf

Today I Learned About Hurricanes

Year	Total Tropical Storms	Total Hurricanes	Major Hurricanes (Cat. 4&5)
1939	6	3	1
1940	9	6	0
1941	6	4	3
1942	11	4	1
1943	10	5	2
1944	14	8	3
1945	11	5	2
1946	6	3	1
1947	9	5	2
1948	9	6	4
1949	13	7	3
1950	13	11	8
1951	10	8	5
1952	7	6	3
1953	14	6	4
1954	11	8	2
1955	12	9	6
1956	8	4	2
1957	8	3	2
1958	10	7	5
1959	11	7	2
1960	7	4	2
1961	11	8	7
1962	5	3	1
1963	9	7	2
1964	12	6	6
1965	6	4	1
1966	11	7	3
1967	8	6	1
1968	8	4	0
1969	18	12	5
1970	10	5	2
1971	13	6	1
1972	7	3	0
1973	8	4	1
1974	11	4	2
1975	9	6	3
1976	10	6	2
1977	6	5	1
1978	12	5	2
1979	9	5	2
1980	11	9	2
1981	12	7	3
1982	6	2	1

Year	Total Tropical Storms	Total Hurricanes	Major Hurricanes (Cat. 4&5)
1983	4	3	1
1984	13	5	1
1985	11	7	3
1986	6	4	0
1987	7	3	1
1988	12	5	3
1989	11	7	2
1990	14	8	1
1991	8	4	2
1992	7	4	1
1993	8	4	1
1994	7	3	0
1995	19	11	5
1996	13	9	6
1997	8	3	1
1998	14	10	3
1999	12	8	5
2000	15	8	3
2001	15	9	4
2002	12	4	2
2003	16	7	3
2004	15	9	6
2005	28	15	7
2006	10	5	2
2007	15	6	2
2008	16	8	5
2009	9	3	2
2010	19	12	5
2011	19	7	4
2012	19	10	2
2013	14	2	0
2014	8	6	2
2015	11	4	2
2016	15	7	4
2017	17	10	6
2018	15	8	2
2019	18	6	3
2020	30	14	7

Total Tropical Storms = All named storms in a year. Some become hurricanes.
Total Hurricanes = All hurricanes, categories 1-5.
Major Hurricanes = Hurricane categories 3-5.

Data from the National Hurricane Center, https://www.nhc.noaa.gov/climo/images/AtlanticStormTotalsTable.pdf

Today I Learned About Hurricanes

Decade	Tropical Storm	Category 1	Category 2	Category 3	Category 4	Category 5
1851-1860	15	8	5	5	1	0
1861-1870	23	8	6	1	0	0
1871-1880	21	7	6	7	0	0
1881-1890	26	8	9	4	1	0
1891-1900	34	8	5	5	3	0
1901-1910	40	10	4	4	0	0
1911-1920	23	10	4	4	3	0
1921-1930	31	5	3	3	2	0
1931-1940	65	4	7	6	1	1
1941-1950	44	8	6	9	1	0
1951-1960	36	8	1	5	3	0
1961-1970	36	3	5	4	1	1
1971-1980	43	6	2	4	0	0
1981-1990	45	9	1	4	1	0
1991-2000	47	3	6	4	0	1
2001-2010	77	8	4	6	1	0
2011-2020	92	30	12	13	13	6
Wind Speeds	*39-73mph*	*74-95mph*	*96-110mph*	*111-129mph*	*130-156mph*	*>157mph*

Data from NOAA Technical Memorandum NWS NHC-6, 2011 https://www.nhc.noaa.gov/pdf/nws-nhc-6.pdf

Today I Learned About Hurricanes

"Creating hurricane-proof buildings and infrastructure is one option. There's also work to reinforce nature's ability to break storm surges or to absorb water, like with expanding wetlands."
Laur Hesse Fisher, MIT Environmental Solutions Initiative
TILclimate podcast: Today I Learned About Hurricanes

What Is Resilience?

When people talk about *climate resilience*, they usually mean a combination of three things:

1. Preparation: Building and adapting buildings, roads, and other infrastructure that can handle predicted extreme weather (high winds, rainfall, storm surge, etc.) and making sure that residents know what to do in case of a natural hazard.
2. Adaptation: Making zoning laws, insurance policies, etc. flexible enough to handle changes to patterns of natural hazards.
3. Recovery: Rapid response after a natural hazard to restore roads, buildings, and livelihoods so that residents' lives can return to normal.

In the case of hurricanes, resilience planning must include high winds, heavy rainfall, and flooding from rain and ocean storm surge. Engineers, ecologists, architects, and designers are working all over the world to protect their communities through natural systems, building design, and infrastructure development.

Design for the World We Want

On the following pages, find some ideas that communities around the world are using to make themselves more resilient in the face of hurricanes and other storms. With your group, discuss how you could design a hurricane-resilient community that you would want to live in.

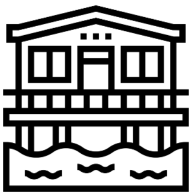
Consider:

- Does this design solve more than one problem, or give residents a benefit outside of hurricane season? (These solutions are often called *multisolving*.)
- Can this idea be applied to buildings that already exist, or does it need to be built new?
- Do you like how this design looks? Would you enjoy having it in your community?
- How does this design make a community resilient to the wind, rain, or storm surge of a hurricane?
- Communities are also resilient when they have the support and information they need to shelter in place, evacuate, return, clean up, and care for their members. What systems would help people in your imagined community get the information they need?

Today I Learned About Hurricanes

Solutions for Hurricane Resilience

Communities all over the world are developing and building solutions to protect people and places from the effects of increasing hurricane strength. The following examples are just a small selection of the innovative ideas that are improving resilience.



Rise Above Both storm surge (waves pushed by wind) and heavy rain can cause flooding. Buildings can be lifted (as on stilts) or have a first floor that can flood with limited damage.

Example: Spaulding Rehabilitation Hospital in Boston, MA
https://www.resilientdesign.org/how-to-make-a-hospital-resilient-a-tour-of-spaulding-rehabilitation-center/ or https://bit.ly/3yOBAiQ

Absorb Natural wetlands, such as salt marshes and mangrove swamps, slow down storm surge and absorb flooding. Communities can protect and restore these vital ecosystems.

Example: Mangrove restoration in Ft. Lauderdale, Florida
https://ocean.si.edu/ocean-life/plants-algae/mangrove-restoration-letting-mother-nature-do-work or https://s.si.edu/3H0mb1P

Slow Down Natural and artificial coral reefs, oyster reefs, and other ocean-bottom structures act like a speed bump for waves. People can protect and restore these underwater communities.

Example: Coral reef restoration in the Florida Keys
https://www.wbur.org/hereandnow/2020/09/18/saving-coral-florida-keys or https://wbur.fm/3eb8AIT

Hold Back Seawalls, hurricane gates, and levees can be a barrier to storm surge, protecting the spaces behind them.

Example: Seawalls in the National Parks
https://www.nps.gov/articles/seawalls-bulkheads-and-revetments.htm or https://bit.ly/3slZml9

Live With Water Parks and other public spaces can be designed to hold flood water until it can naturally seep into the groundwater.

Example: Moakley Park in Boston, MA
https://dirt.asla.org/2021/05/20/moakley-park-the-inclusive-resilient-park-of-the-future/ or https://bit.ly/3J7DHTI

Build for Wind Roofs, windows, and buildings can be designed or protected to resist, move with, or deflect wind.

Example: Affordable hurricane-resistant housing in Immokalee, Florida
https://www.naplesnews.com/story/news/local/2021/11/11/immokalee-florida-fair-housing-alliance-affordable-housing-project-underway/6181222001/ or https://bit.ly/3GWzyjE

Images from The Noun Project by Smalllike, Dan Hetteix, Coloripop, IronSV, Kmg Design, and Hanna Vernydub