Earth's Biggest Storm
Tropical Cyclones

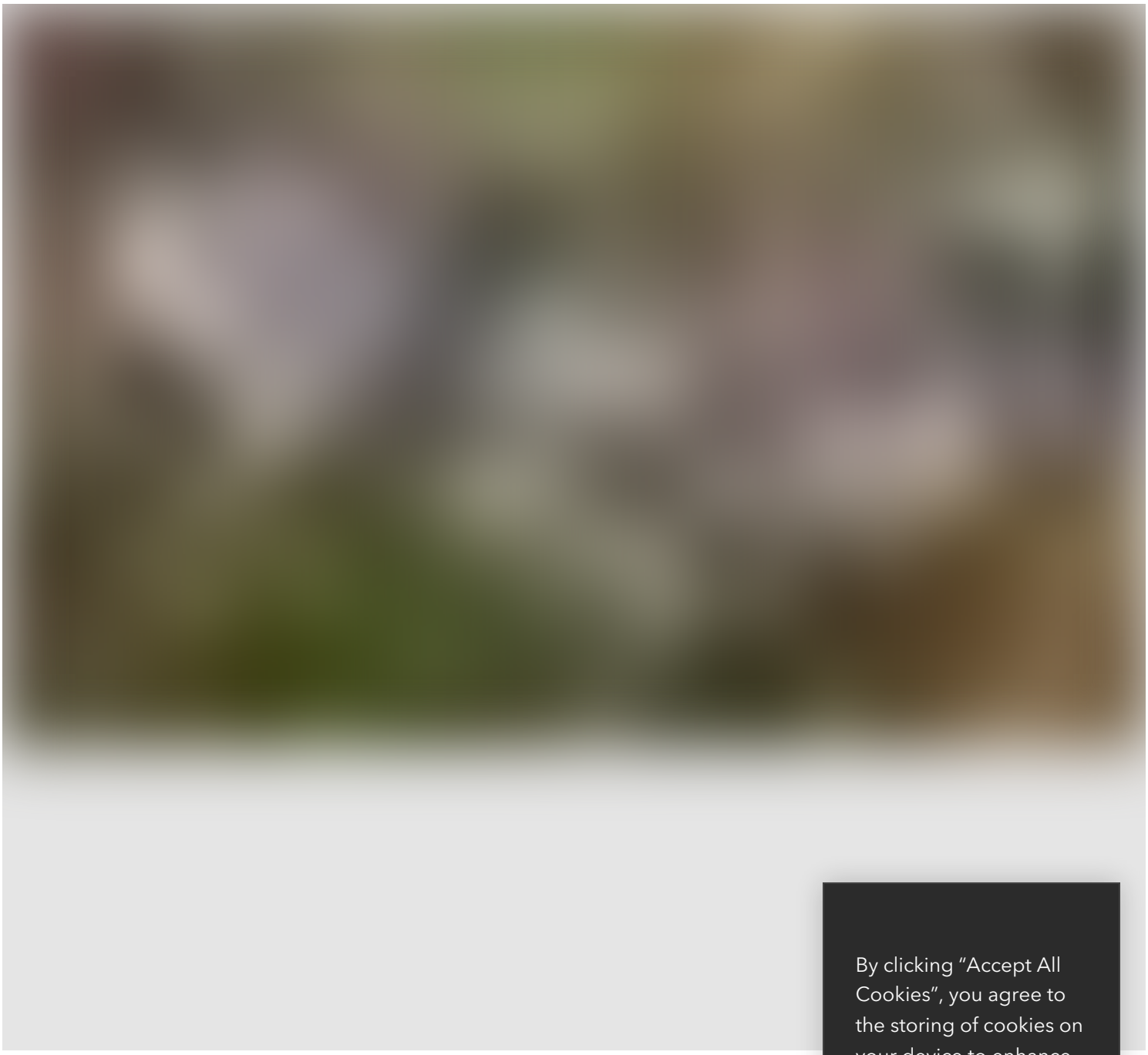
Called hurricanes by some, these spinning m
have catastrophic impacts across the globe

On September 5th, 2017, Hurricane Irma made landfall in the Caribbean Islands. The National Hurricane Center reported sustained winds of up to **185 mph (298 km/h)** making it one of the most powerful storms on record to hit the Atlantic.

Two weeks later Hurricane Maria made landfall in Puerto Rico, resulting in one the worst natural disasters in the island's history. The storm resulted in 3,000 fatalities, and incurred millions of dollars in damage to infrastructure.

The environmental impact of Maria was also devastating. Thousands of trees were uprooted or damaged; sand dunes and shorelines shifted, changing the geography of the island. The fragile island ecosystems suffered significant loss of biodiversity.

As Earth's temperatures rise, scientists predict an increase in the intensity of storm events, including cyclones like Hurricanes Irma and Maria. Read on to learn about these dynamic storms, and how they affect the people and environments in their paths.



While conducting search and rescue in Puerto Rico after Hurricane Maria, a US C
helicopter located this home (US Customs and Border Prot

UNDERSTANDING CYCLONES

Cyclones, also called hurricanes or typhoons, are intense storms tha
subtropical waters. These high-energy storms typically form in warr
Tropics of Cancer and Capricorn, which are located at 23.5° latitude
equator. They don't, however, form directly over the equator.

In order for a cyclone to form, several environmental conditions must be met. Among the catalysts is a low-pressure system that may accompany rain or a thunderstorm, water warmer than 80° F (27° C), and water depths of at least 150 ft (46 m).

Another key ingredient is wind. As the storm moves over warm surface water, some of that water evaporates into the air. Winds accelerate the evaporation process and push warm, moist air upward, where it begins to cool. The moisture condenses into clouds, eventually forming a thunderstorm. As these winds gain energy, the storm syst
low altitudes in a circular motion. According to the National Hurrica
sustained wind speeds reach 74 mph (119 km/h) for over one minut
considered a cyclone. While cyclones can vary wildly in size, a typic
averages 300 miles (186 km) in diameter and can reach 10 miles (16
atmosphere.

ANATOMY OF A CYCLONE

As a cyclone moves it displaces massive quantities of water. This causes storm surges and flooding when it makes landfall.

As a cyclone hits land, it loses its main source of energy, and eventu
However, the storm will continue to release significant amounts of r
within the weather system, often causing flooding.

Data on hurricanes has been recorded since the mid-1800s, allowing
meteorologists to study and understand where and how powerful th
The map below shows the frequency of hurricane events around the

Historical cyclone tracks (1842–2019) provide insights into their frequency and intensity. The tracks in red show the most severe storms; blue tracks are the least intense. The ocean is broken into six basins, each of which has unique monitoring agencies.

Cyclones are seasonal, meaning that regions of the world experience
of the year. From June to November cyclones are most active in the
April to November they're more active in the Pacific and Indian Bas
shows when and where cyclones occur over the course of an annual

TROPICAL CYCLONE BASIN TERMINOLOGY

The ocean is divided into six regional basins, with the responsibility for handling oceanic storm event warnings assumed by regional centers. Each regional center has its own slightly different category and classification scales, as shown in the table below.

Earth's average temperatures have been increasing over the last century. As ocean temperatures also continue to rise, a study published by the National Oceanic & Atmospheric Administration predicts that, among other effects, cyclones will have greater levels of intensity.

Galveston Island, Texas after Category 4 Hurricane Ike on September 13, 2

HUMAN IMPACT

House on Avenue N after the Great Galveston Hurricane of 1900. (Library of Congress)

People have always made their homes along coastlines. Cities, towns, and communities inevitably deal with severe storms and their effects with every cyclone season.

"The street railway trestle was carried squarely against the side of the house like a huge battering ram; the house creaked and was carried over in the surging waters and torn to pieces." *—Galveston Weather Station Chief Isaac M. Cline, 1900*

How a cyclone affects an area depends on many factors: where it hits, the intensity at landfall, the tidal cycle, the speed the storm is traveling, and the population density of the area.

Every storm behaves differently. Some sidle up to coastlines, moving along slowly or "sitting" and wreaking havoc for extended periods. Other storms come in quickly and move through areas with erratic and rapidly-changing trajectories and intensities. Whether a storm moves quickly or slowly, the people who live in coastal areas experience a dangerous mixture of storm surges, heav
even tornadoes.

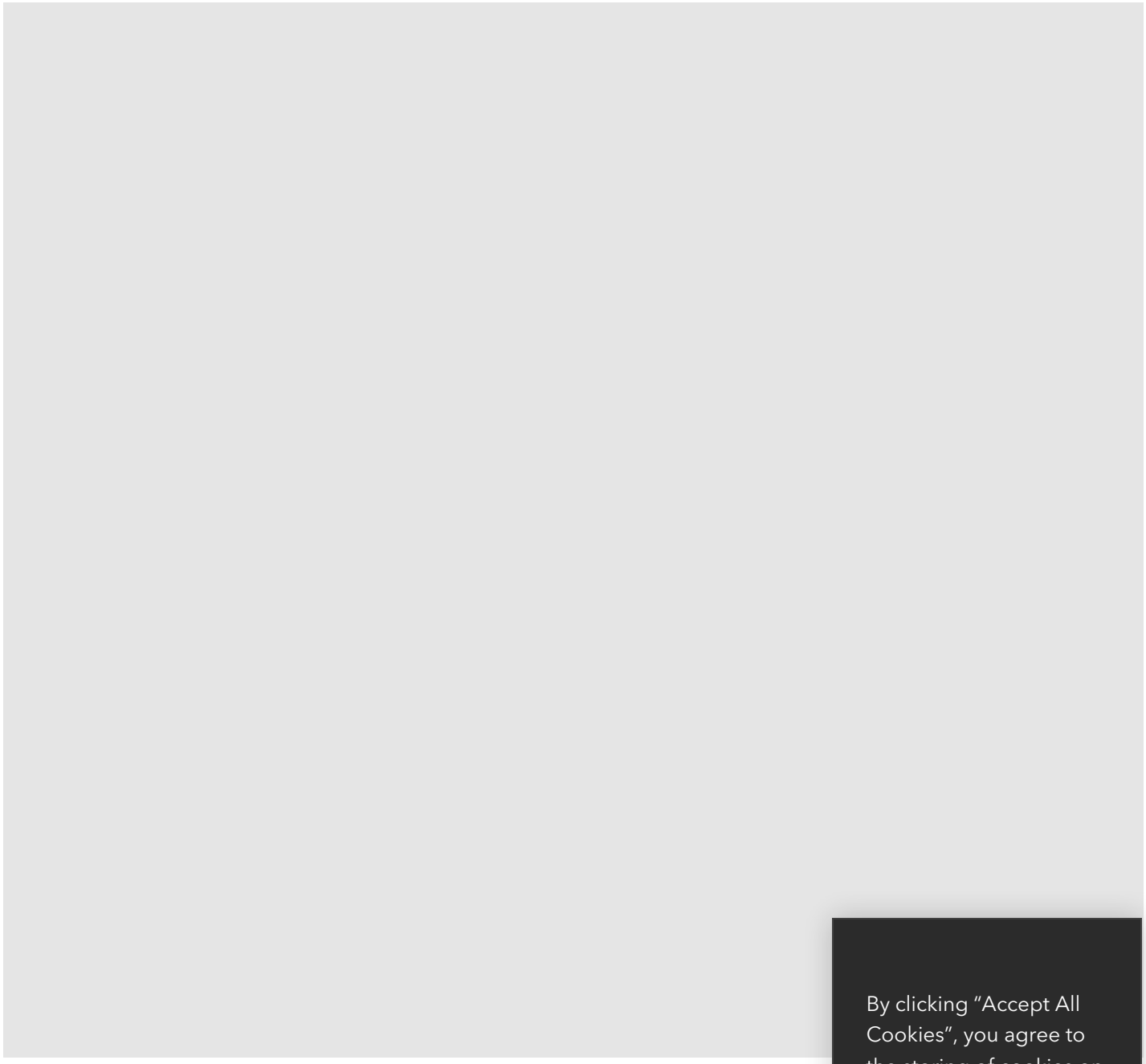
What are the major impacts for humans?

Storm Surge	Heavy Rain	Flooding	High Wind
Abnormal rise of water due to a cyclone's winds can reach heights in excess of 6 meters (20 feet)	Rainfall amounts are related to the local geography and the speed and size of the storm rather than to its strength.	Floods are dangerous and destructive and are the major threat to people from cyclones.	Sheltering or evacuating before the onset of cyclone-level winds is critical for survival.
These surges can travel several miles inland and span hundreds of miles of coastline.	Slow-moving large storms produce more rain.	Flash floods happen when significant rainfall raises water levels rapidly.	These strong winds can
A storm tide can happen when there is a combination	Mountainous terrain also enhances a storm's rainfall.	Longer-term flooding of rivers and streams can inundate	

Storm Surge	Heavy Rain	Flooding	High Wind
of a storm surge and the astronomical tide.		areas for extended periods after the storm.	turn into flying missiles when cyclone force winds arrive.

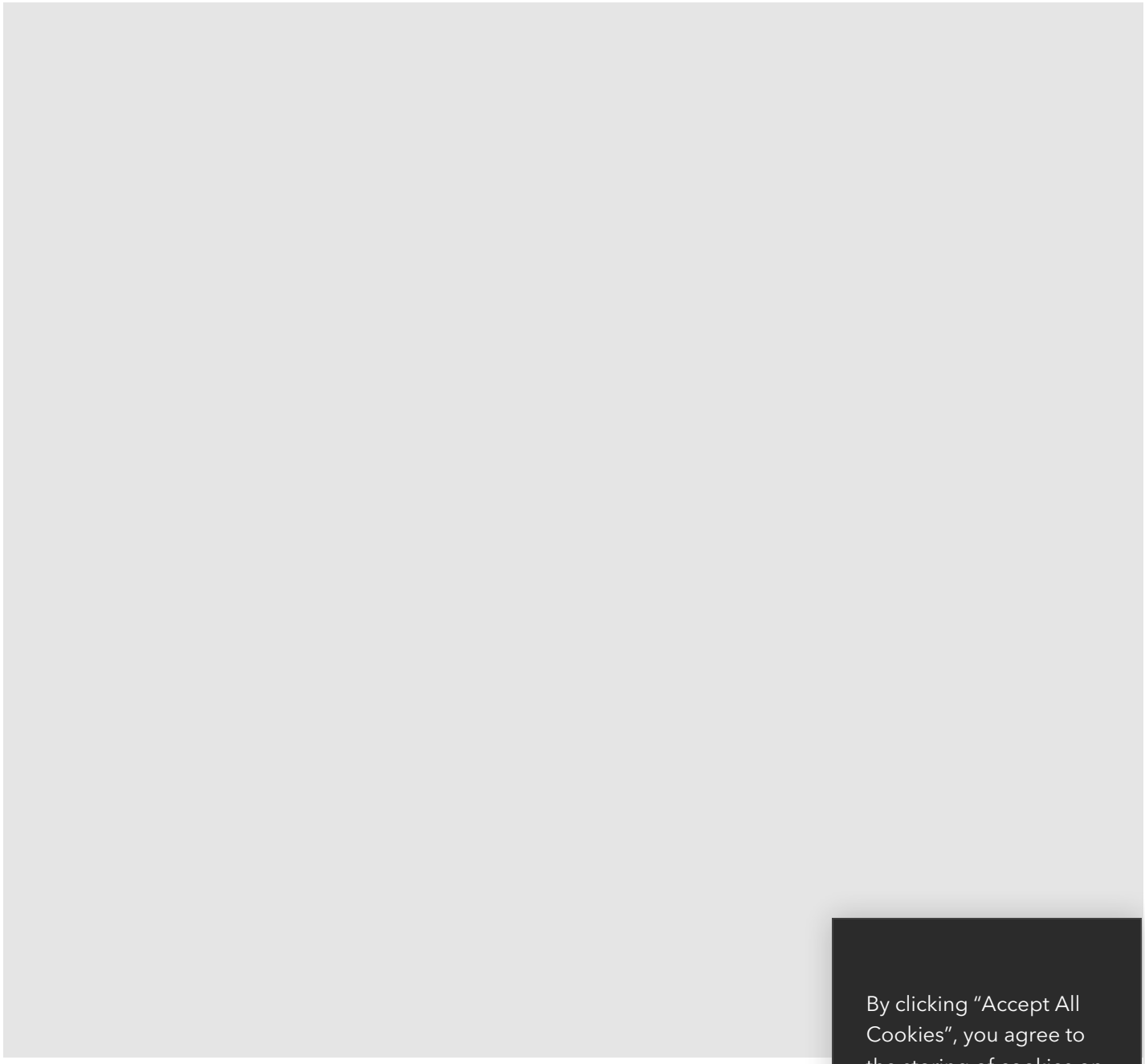
Flooding destroys levees and communities in low-lying areas, while storm surges and strong waves demolish buildings, roads, and beaches. Extreme rains destroy agricultural areas while high winds topple trees and devastate critical infrastructure, crippling areas for extended periods of time. Tornadoes are also fairly common when hurricanes make landfall, causing intense damage to areas that are directly hit.

While landfall removes the energy source of the storm, causing it to lose strength, people inland may still suffer from high winds and heavy rains that create [illegible] rivers that can wash out bridges and cause deadly mudslides.



Local crews clear streets of sand from Hurricane Sandy (

From 1998 to 2017 storms caused **233,000 deaths** globally, second or
terms of fatalities caused by natural disasters. During the same peri
were directly affected through injuries, homelessness, displacement
the emergency phases of storms.



A World Food Programme helicopter delivers humanitarian aid to Bebedo, Mozan
(U.S. Air Force photo by Staff Sgt. Corban Lundborg)

EXCEPTIONAL STORMS

Within the last 15 years E
series of exceptional stor
particularly catastrophic

The following maps show individual cyclone tracks observed at three-hour intervals. Height and color indicate wind speed and category, as shown in the graphic on the left.

NORTH INDIAN BASIN - CYCLONE SIDR

November 10–16, 2007

Cyclone Sidr devasted the Bay of Bengal, where officials evacuated up to 650,000 people from the coast of Bangladesh before it hit land. The 6-meter (20 ft) storm surges seriously affected at least 1 million households, left at least 55,000 injured or missing, and around 3,400 dead. Cyclone Sidr also destroyed fields, damaged infrastructure, and contaminated water.

WESTERN PACIFIC BASIN - TYPHOON HAIYAN (SUPER TYPHOON YOLANDA)

November 2–11, 2013

Typhoon Haiyan swept over areas of the Philippine Islands, causing catastrophic damage after winds

reached over 190 mph (305 km), and storm surges six meters (20 ft) high inundated low-lying areas. Over 7,000 people lost their lives, over a million people lost their homes, and 6 million people lost their source of income.

ATLANTIC BASIN - CATEGORY 5 HURRICANES MARIA & IRMA

Hurricane Irma – August 30 – September 13, 2017 and Hurricane Maria – September 16–30, 2017

Two devastating hurricanes crossed the Caribbean Islands within a month of each other in 2017. On Puerto Rico alone, 3.4 million people were affected by power outages, contaminated water, and damaged infrastructure. In the following months at least 3,000 Puerto Ricans were counted as victims of these storm events, though the final number may be higher.

ECOSYSTEM IMPACT

Tropical regions, where cyclones are most common, are also known for their biodiversity. Biodiverse ecosystems are home large numbers of species. Scientist think many factors contribute to the biodiversity of the tropics, including their warm, humid climates and relatively stable temperatures. These happen to be the same atmospheric conditions that produce tropical storms.

Combining historical cyclone data with biodiversity information clearly illustrates that some of the regions with the highest biodiversity also experience a high frequency of cyclones.

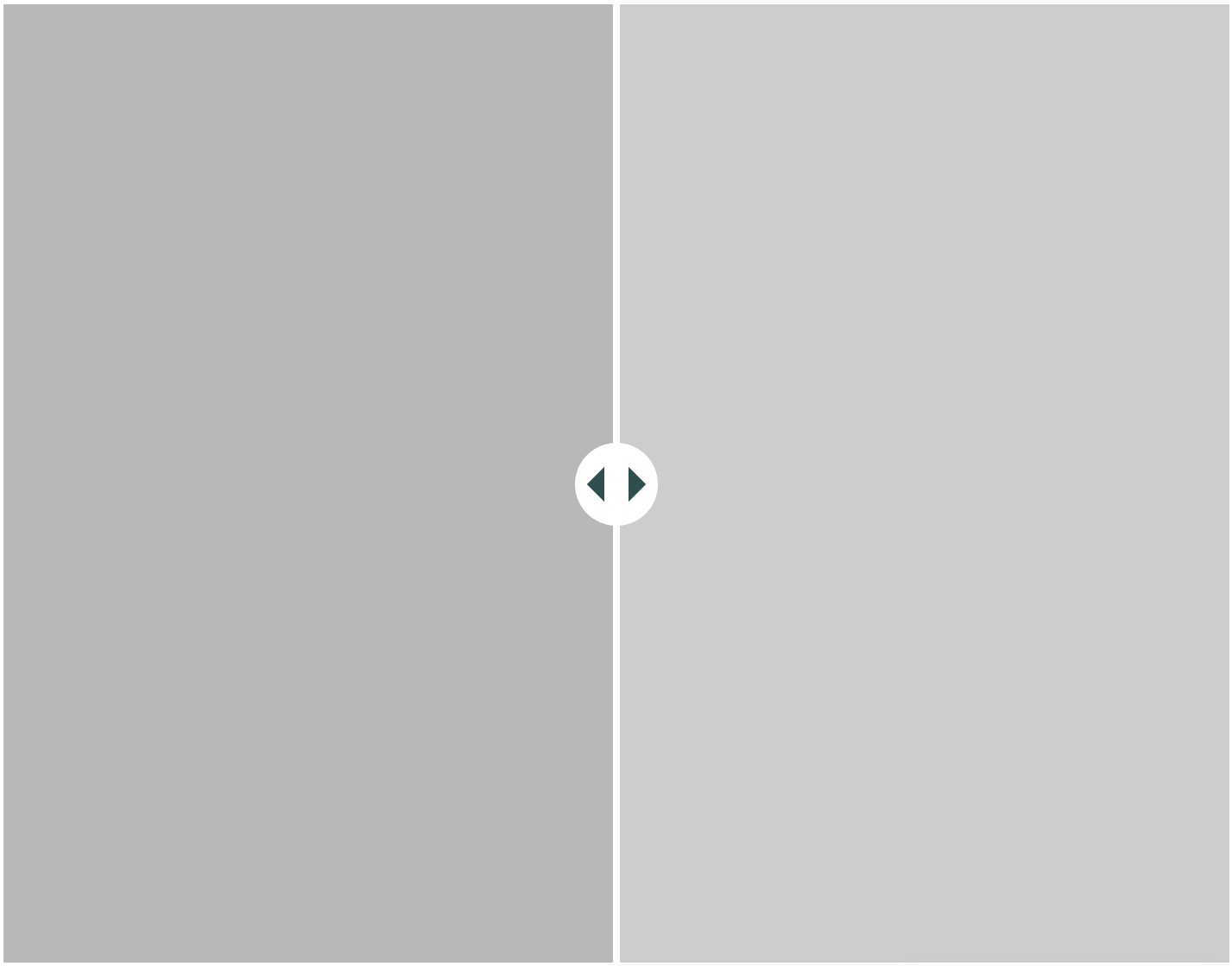
Regardless of its strength or where it makes landfall, a cyclone alters the ecosystems in its path. From coral reefs to tropical rainforests, life is constantly moving, adapting, and evolving. One of the many evolutionary pressures in these areas are caused by cyclones.

The environmental impacts that Puerto Rico and the other islands in the Caribbean Sea experienced affected humans and many plant and animal species. When hurricanes Maria and Irma hit the region in the fall of 2017, they changed local ecosys
in astounding ways.

Islands once teeming with life were completely devastated. The tran
occurred over the course of the two storms altered the landscape so
areas were almost unrecognizable.

LOST SAND DUNES

Cyclones can move massive quantities of sand due to heavy rain, sto
and widespread flooding. These can transform entire shorelines, mo
redistributing sediment into the ocean.



Swipe to see satellite images from NOAA's Remote Sensing Division of the North
Dorado before hurricanes Maria and Irma, and in the aftermath of Irma o

During Hurricanes Maria and Irma, areas occupied by dunes on the
Rico were flattened and eroded, washing away sand that was redep
dunes are important to humans, protecting man-made infrastructu
homes, and businesses by providing buffer zones between human-p
ocean.

The dunes protected low-lying areas from flooding during non-catas
dunes were critical for wildlife, providing beach habitat for several
endangered sea turtles that nested on the shore.

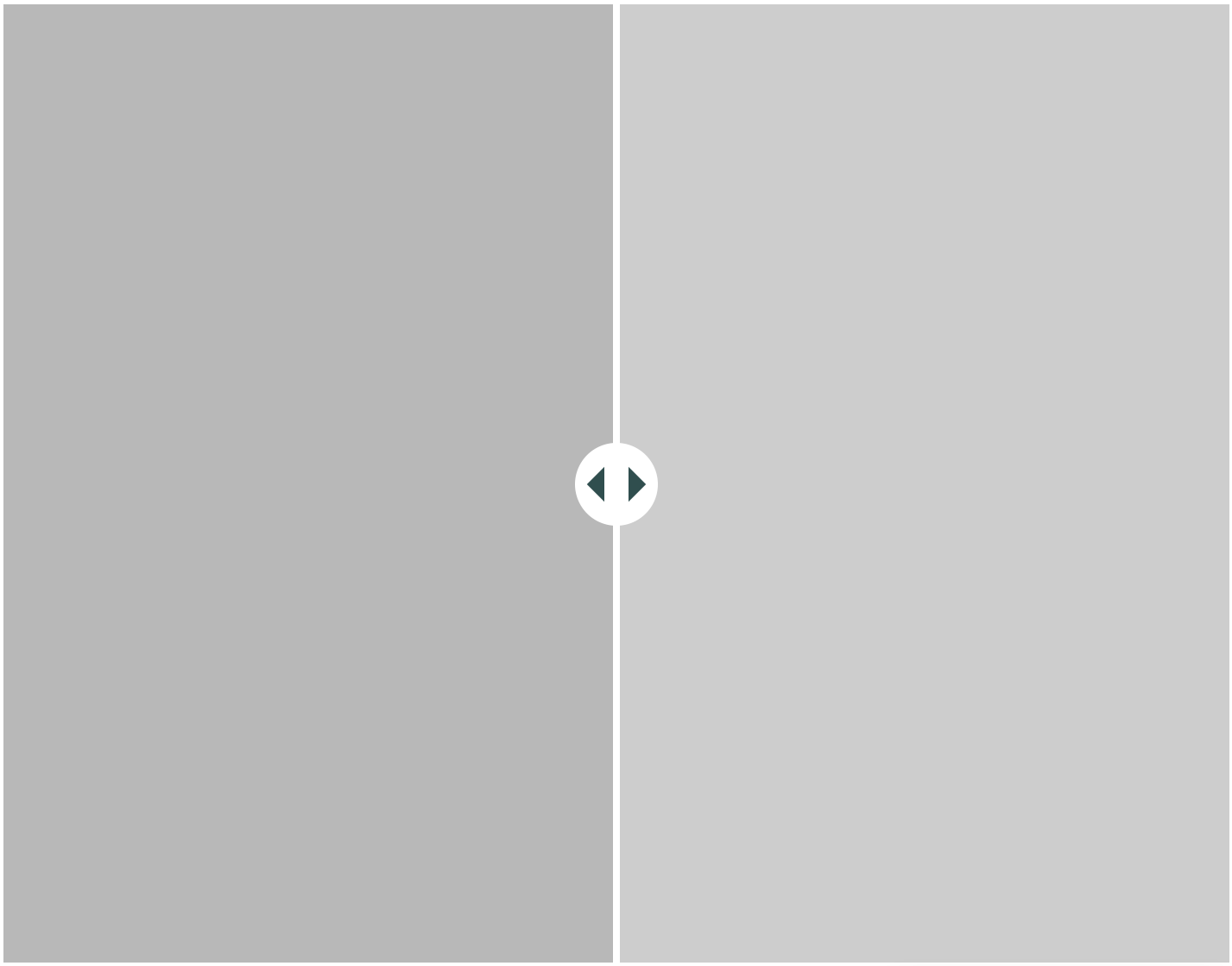
EL YUNQUE TROPICAL RAINFOREST

Nearly 31 million trees were damaged or destroyed after hurricanes Irma and Maria hit Puerto Rico. In El Yunque National Forest, the only tropical forest in the U.S. Forest Service's system, high-speed winds wreaked havoc. A lush, green old-growth rainforest teeming with life morphed into a brown, muddy mess in just under a month's time.

El Yunque National Forest in Puerto Rico

The devastating force of Irma and Maria tore through forests, destroying twice as many trees as an average hurricane.

When the winds died down and the skies cleared, roughly 30% of the trees in El Yunque were strewn across the forest floor—a devastating setback for the old-growth forest that had been recovering from logging and the impacts of other storm events.



Swipe between a satellite image from NOAA's Remote Sensing Division of El Yu
Maria and Irma and a satellite image from NASA Earth Observatory from after th
2017. Defoliation was so extreme that topography previously hidden by a vibrant
in detail. (NASA Earth Observatory image by Lauren Dau

El Yunque will take years, if not decades, to fully recover from the h
incurred by Hurricanes Irma and Maria. As the magnitude of hurric
wonder if the forest, and the habitat it provides, will ever be the sam

COMPARING TWO SPECIES

El Yunque National Forest is also the only remaining natural habitat
Rican Parrot (*Amazona vittata*), the only parrot species native to the
parrot relies on rainforest trees for food, and nests in hollow cavitie
in rainforests. In 1989 Hurricane Hugo wiped out roughly half of the

population, leaving just 20 birds. Conservation efforts since 1989 increased the wild population of the parrots; however, the severity of recent cyclones is a cause for concern for this species.

An endangered Puerto Rican Parrot and a Caribbean anole lizard. ("Puerto Rican parrot 1" Altered version of photo by Tom MacKenzie, USFWS is licensed under CC BY 2.0, and Caribbean anole by Colin Donihue)

Natural life on impacted i
evolving as better-adapte
these storm events in gre
some species are fighting
others, like the Caribbean
(*Anolis scriptus*), are adap
surprising ways.

Evolutionary ecologist Co
studying Caribbean anole
Caicos Islands, near Puert
before Hurricanes Irma a

High speed video of a lizard experiencing hurricane-force winds, and then landing safely in a safety net. (Colin Donihue)

He returned to the islands shortly after Hurricane Maria and made some interesting discoveries. He found that Caribbean anole lizards that live in locations that experience frequent extreme weather events, such as hurricanes, respond more rapidly to the than those in more sheltered locations.

After Hurricanes Irma and Maria, Donihue's survey sample of the anoles that survived the hurricane showed the lizards had larger toe pads, longer front legs, and shorter hind legs than their less climate-vulnerable counterparts.

On the end of their fingers and toes, *Anolis scriptus* lizards have adhesive lamellae that help them cling to surfaces. (Colin Donihue)

This means that the anoles that survived the storms were able to cling to trees more effectively than anoles with smaller toe pads and longer rear legs that got caught in the wind.

Species with rapid reproductive rates, such as anole lizards, can experie
trajectory that holds relat
forces of hurricanes. The
population of anoles surv
will likely continue to be
offspring.

MOVING FORWARD

Living things affected by storm events are constantly evolving to ad
conditions—as does technology. We can mitigate storm event damag
advances in our technology.

Conservation efforts to save the Puerto Rican Parrot started decades ago. The ongoing support provided by the people of Puerto Rico improves the odds that this species will make a recovery.

Scientists have been able to use geographic information systems, or GIS, to track parrot populations and the health of their habitat in order to determine the greatest threats to these birds. By analyzing data, biologists are reducing threats, managing conservation efforts and captive breeding programs, and helping to increase parrot populations. The parrots that hatch in protected facilities can then be released into the wild with increased odds of survival.

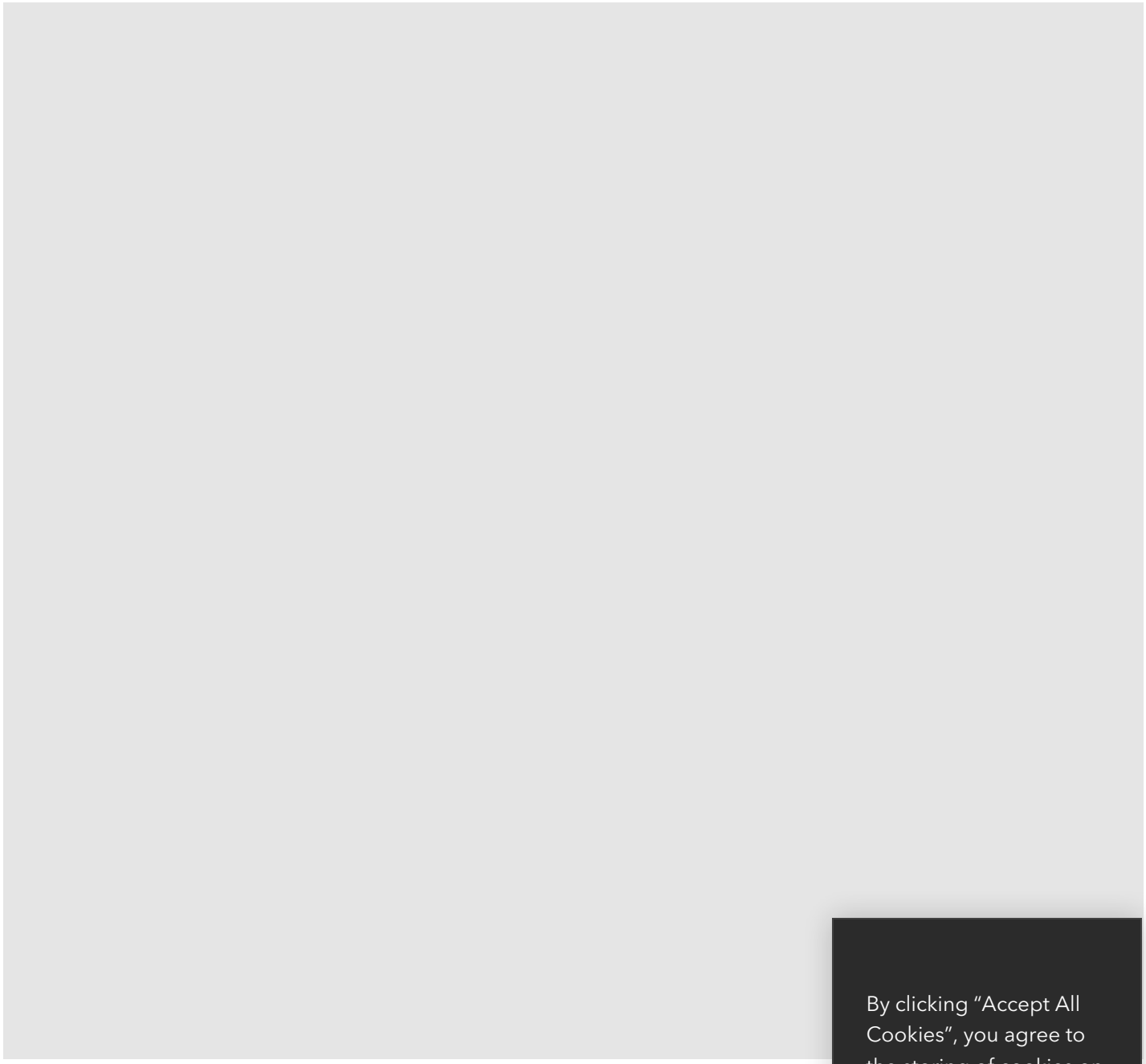
Progress is being made in the rainforest as well. New plants and trees are returning to storm-scarred areas, turning the forests verdant again.

A Caribbean anole drinks water from a leaf. (Colin Donihue)

The abundant Caribbean anole lizards will continue to be of interest to scientists. Anole lizards are able to adapt rapidly to changing environmental conditions caused by cyclones. As anoles reproduce quickly, their populations are not at risk of extinction. However, the anoles are providing clues to biologists who are studying how these lizards adapt. These clues may be able to help us learn how better to support other species in the aftermath of natural disasters.

HUMAN RESILIENCY

As for human impacts in cyclone-affected areas, we can also be hope
evolving technology, humans are able to help other people, sometim
of miles away.



Residents of Loíza, Puerto Rico, attending an event to prepare the community fo
(FEMA/Eduardo Martínez)

If you live in a cyclone-prone area, the best time to prepare is now. P
ahead of time will help ensure your safety in the event that you nee
parts of your home, or take other actions.

TECHNICAL ADVANCEMENTS

Weather forecasters and s
continue to advance their
improve the accuracy of s
example, these models in
maximum extent of storm
resulting flooding, the cau
cyclones.

These early warnings can
human life by providing r
prepare their homes and

Collecting storm data in r
that GIS is being used. Tra
storms are happening allo

Two USGS hydrologic technicians install rapid water gauge devices to measure water levels in preparation for storms. (Chris Henry, USGS)

management officials to redirect resources and, if necessary, update warnings.

After Hurricane Maria, a homeowner in Puerto Rico used hurricane-resistant materials to rebuild their house. (FEMA/Andrea Bajandas)

GIS software also offers opportunities for urban planners to incorporate mitigation plans to minimize and prevent damage from future storms. By using storm-resistant techniques and materials to rebuild homes, businesses, and infrastructure, we can decrease the economic and human costs of future storm events.

The National Weather Service has developed projections for where the most significant damage is likely to happen. Community leaders are now equipped to plan optimal evacuation routes, as well as locate emergency shelters where they will be needed the most.

Hurricanes Irma and Maria have also exposed weaknesses in existi
infrastructure. Many places, especially rural areas in the Caribbean,
before the hurricanes. In order to provide supplies and assistance, r
accurate maps. When word spread about inadequate maps via medi
citizen volunteers from all over the world answered the call for help
satellite imagery and mapping software to add building locations, ev
villages to maps using Humanitarian OpenStreetMaps.

Despite the fact that volu
of miles away from the lo
disasters, their contributi
invaluable. Through tech
determination, these volu
hope to areas overwhelm

Esri's Disaster Response Program helps communities during the emergency stages and recovery from a cyclones hit.

Esri's Disaster Response Program (DRP) assists organizations responding to disasters and crises worldwide as part of its corporate citizenship efforts. The program helps ensure that communities get the help they need to understand current conditions, make better decisions, and respond more effectively during a crisis.

GET INVOLVED

One of the best ways you can help is by directly supporting land and habitat conservation organizations. Other ways to help include advocating for reducing greenhouse gas emissions—and minimizing your carbon footprint—to reduce the rate of climate change.

People interested in volunteering to help map areas affected by disasters can go to the Humanitarian OpenStreetMaps site or support the work the Red Cross Hurricane Relief efforts.

Humanitarian OpenStreetMap

HOT is an international team dedicated to humanitarian action and community development through open mapping.

https://www.hotosm.org

Climate change and tropical cyclones

Climate change is probably fuelling more powerful tropical cyclones (hurricane flooding by tropical cyclones is amplified by rising sea level.

https://news.sciencebrief.org

Hurricane Relief

When a hurricane or tropical storm strikes, your donation helps the Red Cross provide shelter, food and comfort to families. When a hurricane or tropical storm strikes, your...

https://www.redcross.org

Hurricane Aware

The Hurricane Aware app is intended to provide information about the potential impacts of tropical storms in the United States. The data shown here from the Living Atlas are...

https://livingatlas.arcgis.com

ArcGIS Living Atlas - Indicators of the Planet (Beta)

In partnership with Microsoft, National Geographic, and the United Nations Sustainable Development Solutions Network, Esri is gathering these and other topics into the ArcGI...

https://experience.arcgis.com

About this story

This story was created by Esri's Living Atlas Environment team and the StoryMap

Before & after satellite images	NOAA Remote Sens
East Pacific & North Atlantic Basin	National Hurricane Central Pacific Hur
West Pacific Basin	Joint Typhoon War Japan Meteorologic

North Indian Ocean Basin	India Meteorological Department
South Indian Ocean Basin	Météo-France
Australia & South Pacific Basin	Bureau of Meteorology & Fiji Meteorological Service