

# Monitoring Tropical Storms for Emergency Preparedness

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May 3, 2018

# Training Objectives

- Identify remote sensing data and tools relevant to tropical storms
- Monitor conditions before, during, and after a storm using remote sensing data
- Understand how remote sensing data can be used in decision-making activities



# Course Outline

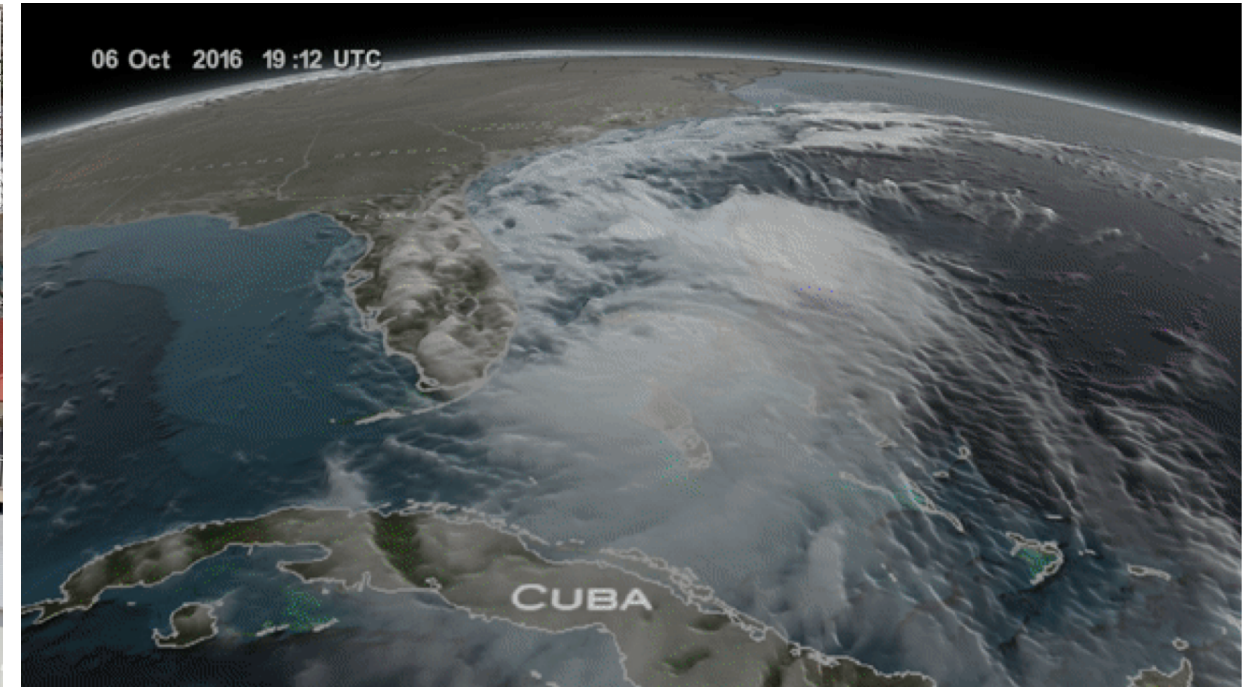
**May 3**

Overview of Tropical Storms and Their Impacts



**May 10**

Monitoring Tropical Storm Conditions During and After Storms



In this animation Hurricane Matthew travels up the east coast from Florida to the Carolinas. On October 8, 2016 Matthew (still a category 2 hurricane) dumps massive amounts of rain throughout the southeast dousing North and South Carolina.



# Homework and Certificates

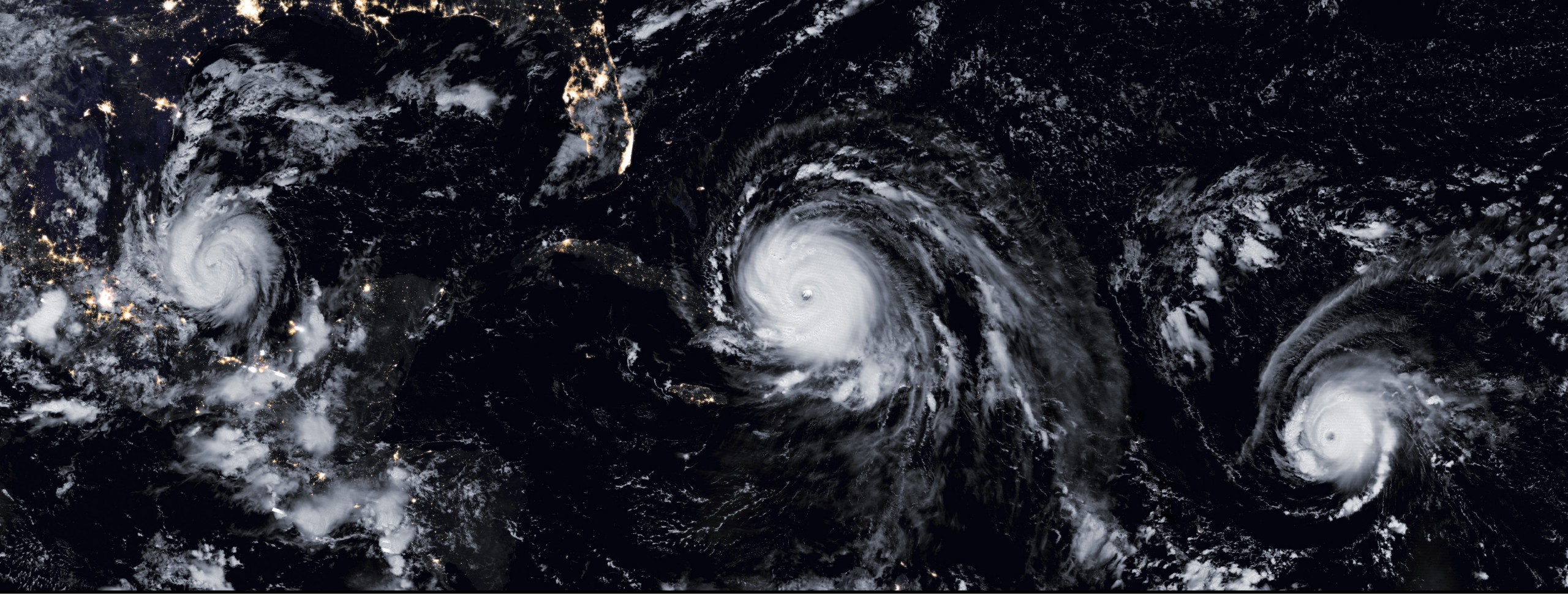
- Homework will be available after Session-1 and Session-2 from <https://arset.gsfc.nasa.gov/water/webinars/>
- **Answers must be submitted via Google Form**
- Certificate of Completion:
  - Attend both webinars
  - Complete homework assignment by the deadline (31 May 2018)
  - You will receive certificates approx. two months after the completion of the course from: [marines.martins@ssaihq.com](mailto:marines.martins@ssaihq.com)



# Outline for Session 1

- About ARSET
- About Tropical Storms
- Tropical Storm Impacts
- Pre-Storm Emergency Preparedness
- Monitor Approaching Storms With NASA Remote Sensing and Earth System Model Data and Tools
  - Data: sea level pressure, wind speed forecast, precipitation, soil moisture, terrain, population, and infrastructure
  - Tools: Worldview, Giovanni, GDACS
- Exercise: Monitor a Storm





About ARSET

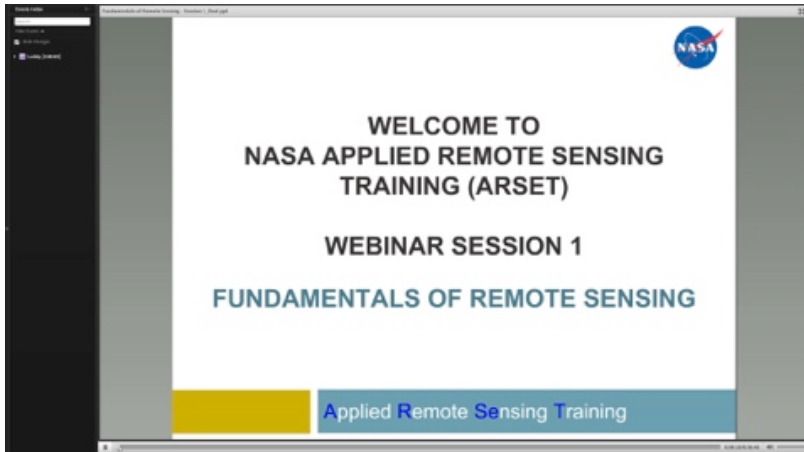
# NASA's Applied Remote Sensing Training Program (ARSET)

<http://arset.gsfc.nasa.gov/>

- **Mission: To empower the global community through remote sensing training**
- Team of 15 NASA scientists, students and other support staff at 3 NASA centers
- Part of NASA's Applied Sciences/Capacity Building Program
- Target audience: policy makers and environmental professionals in the public and private sectors



# ARSET Training Formats



## Online

- Live and recorded
- 4-6 hours of instruction
- Advanced training includes image processing

## In-Person

- 2-7 days in length
- Held in a computer lab
- Mixture of lectures and exercises
- Locally relevant case studies

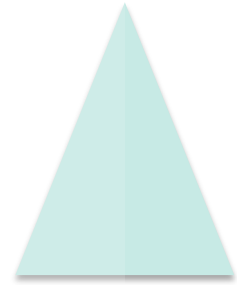
## Train the Trainers

- Online training and manuals
- For organizations seeking to develop a remote sensing training program





# ARSET Training Levels



## **Advanced (Level 2)**

Requires level 1 training or equivalent knowledge

In-depth and highly focused topics

*Advanced Webinar: Remote Sensing of Drought*

## **Basic (Level 1)**

Requires level 0 training or equivalent knowledge

Covers specific applications

*Water Resource Management Using NASA Earth Science Data*

## **Fundamentals (Level 0)**

Assumes no prior knowledge of remote sensing

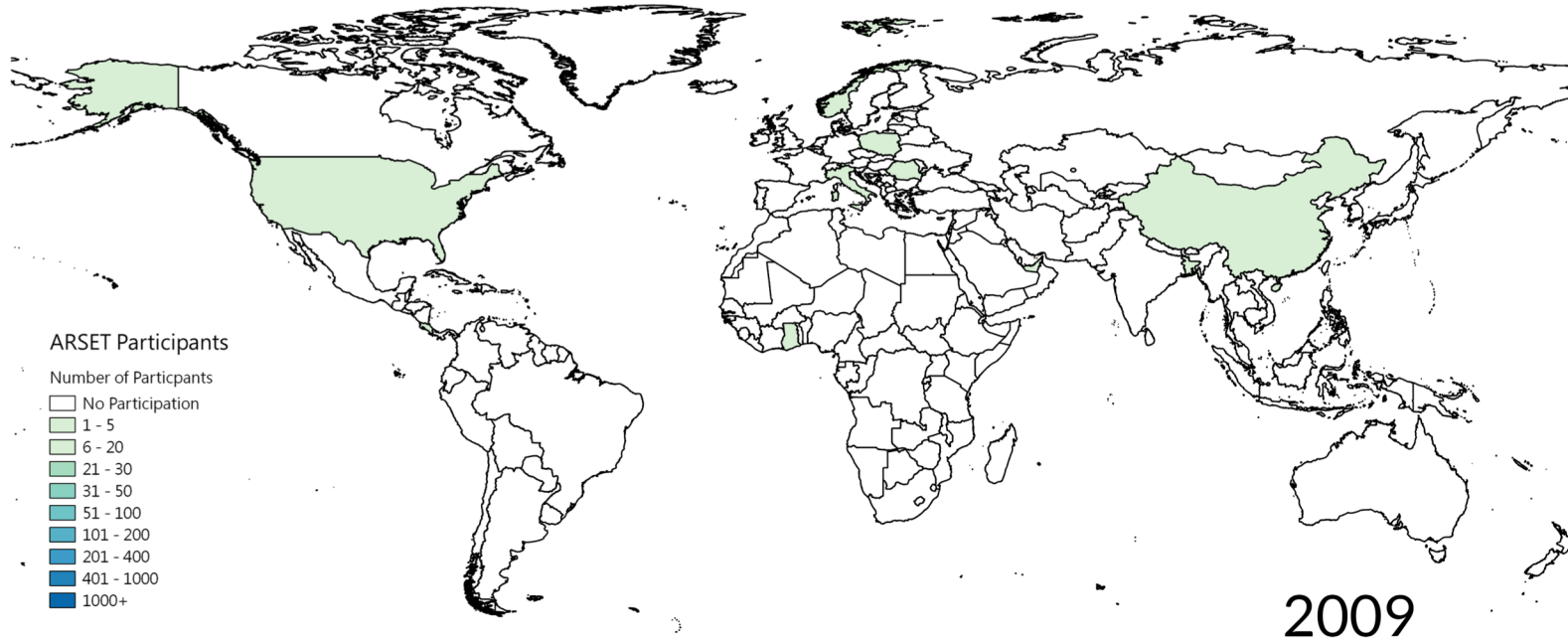
*Fundamentals of Remote Sensing*

**All presentations and exercises are freely available in English & Spanish**  
**Some recordings are delivered in both languages**



# Global Participation

## Number of participants (2009-2017)



104 total trainings



13,000+ participants



160 countries



3,700+ organizations

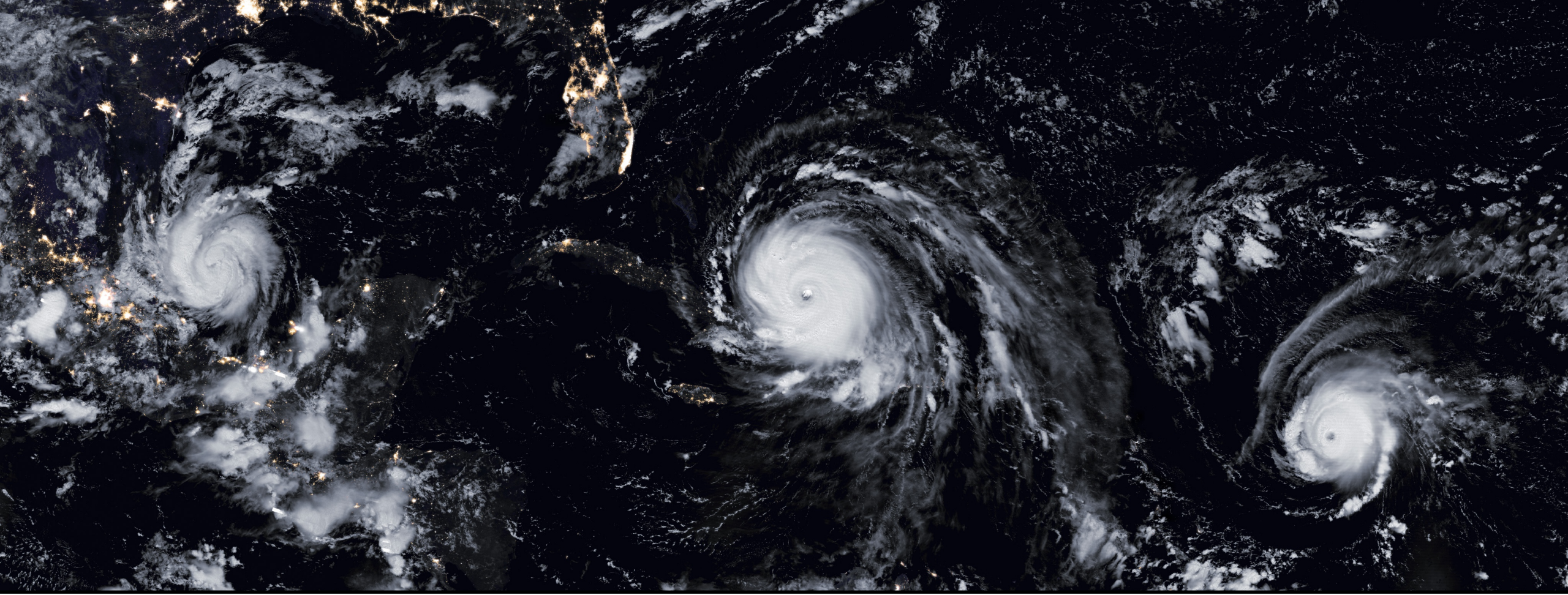


# ARSET Website and ListServ

<http://arset.gsfc.nasa.gov/>

The screenshot displays the ARSET website interface. At the top, the NASA logo and 'ARSET Applied Remote Sensing Training' are visible, along with navigation links for 'Earth Sciences Division', 'Applied Sciences', and 'ASP Water Resources'. A search bar and a Twitter icon are also present. The main navigation menu includes 'Home', 'About', and 'Trainings'. The 'Trainings' dropdown menu is open, showing categories: 'Fundamentals', 'Disasters', 'Health & Air Quality', 'Land', and 'Water Resources'. A featured training announcement for 'Introduction to Remote Sensing of Harmful Algal Blooms' is displayed, including the dates 'Tuesdays, Sep 5-26, 2017' and a 'Register Now' button. The sidebar on the right contains a list of links: 'ARSET', 'Online Trainings', 'In-Person Trainings', 'Sign up for the Listserv' (highlighted with a blue arrow), 'Tools Covered', 'Suggest a Training', 'Personnel', and 'Resources'. Below this is a section for 'Upcoming Training' with a sub-section for 'Water' and a link for 'Satellite Observations of Water Quality for'.



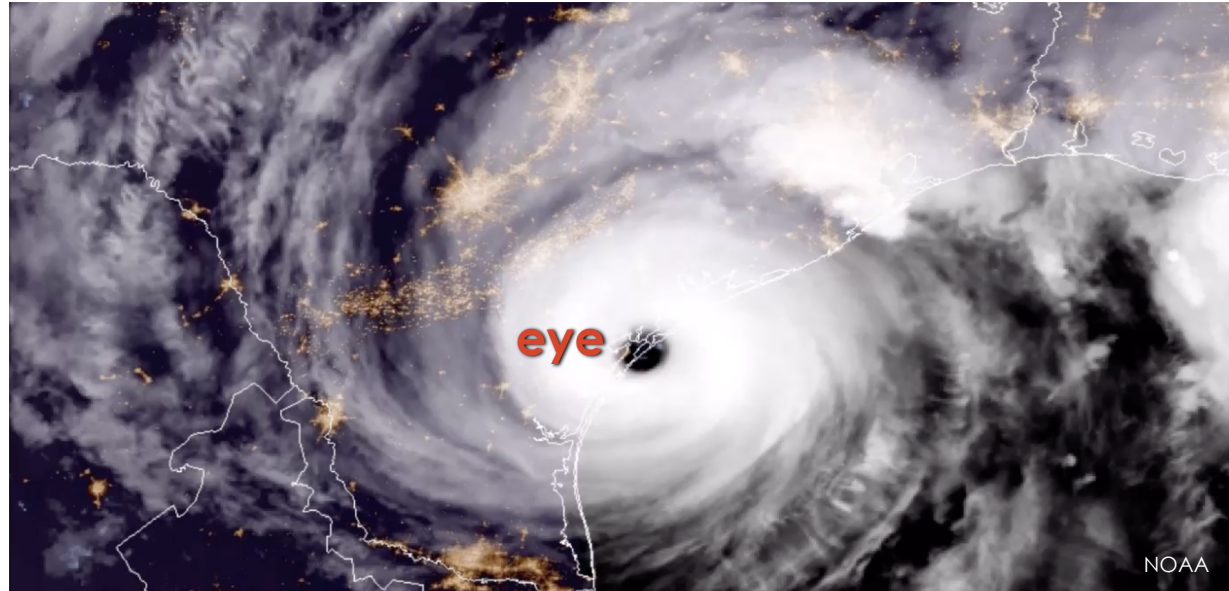


# About Tropical Storms

# What Are Tropical Storms?

- Low pressure systems that form over warm, tropical oceans
  - temperature  $> 26.5\text{ }^{\circ}\text{C}$
- Circular 'eye' in the center with a cloud free region and light winds
  - counterclockwise (cyclonic) winds around the center
- Have very high, sustained winds ( $\geq 39\text{ mph}$ ,  $\geq 60\text{ km/h}$ ,  $\geq 32\text{ kt}$ ) at the eyewall
- Sustained heavy winds, clouds, and rain extend hundreds of km from the center
- Technically different than mid-latitude storms forming over land along weather fronts

Hurricane Harvey, Aug 26, 2017



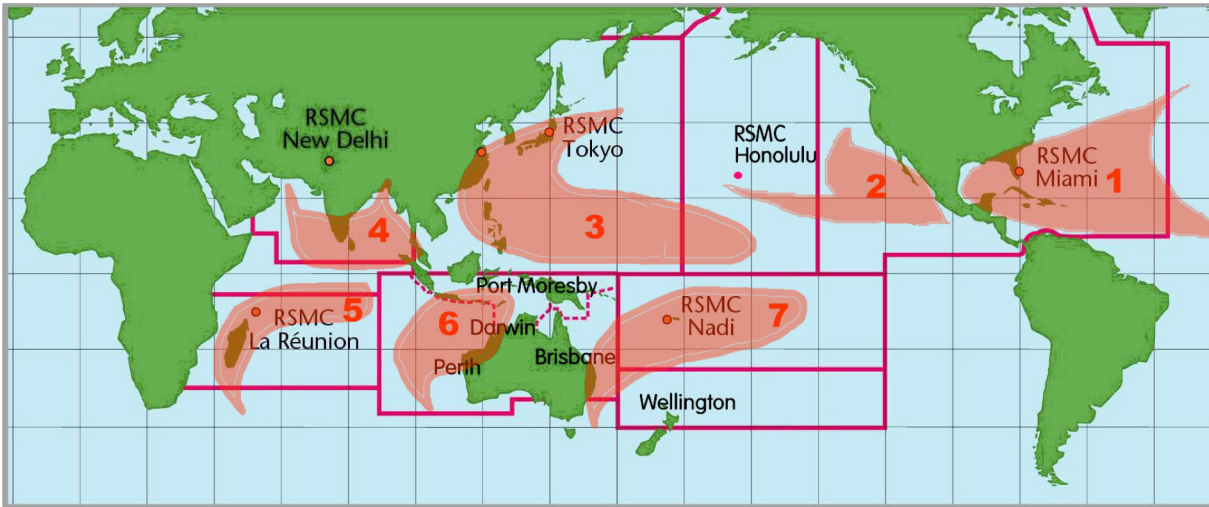
Known as:

- **Hurricanes** in the Atlantic & Northeast Pacific Oceans
- **Cyclones** in the Indian Ocean
- **Typhoons** in the Northwest Pacific Ocean



# Tropical Cyclone Regions and Seasons

<https://public.wmo.int/en/About-us/FAQs/faqs-tropical-cyclones>

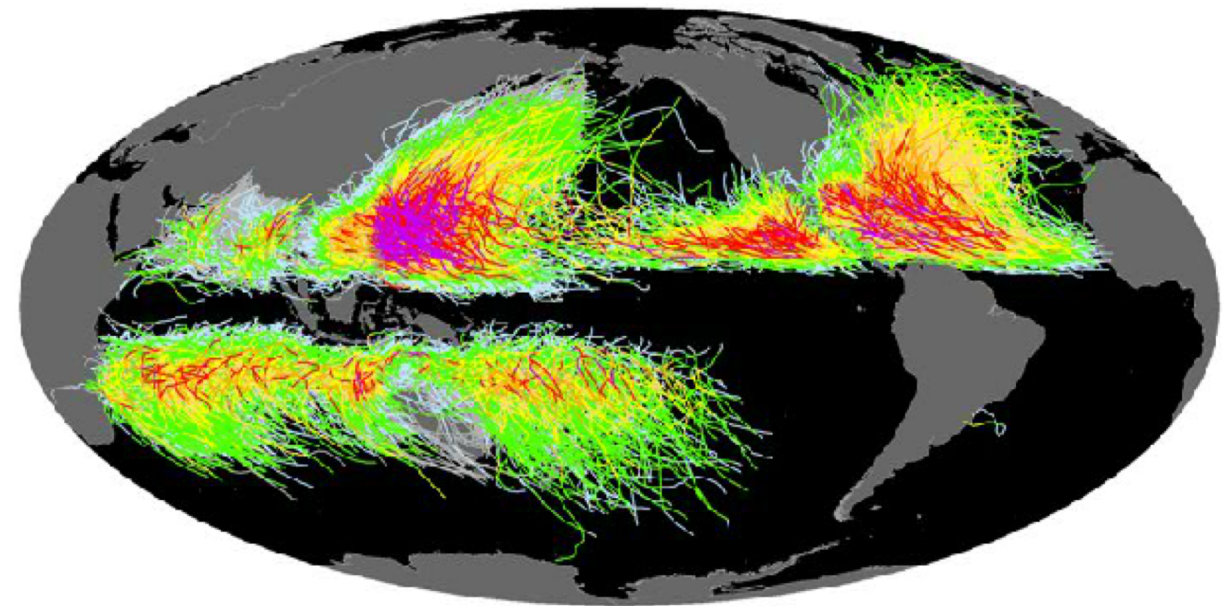
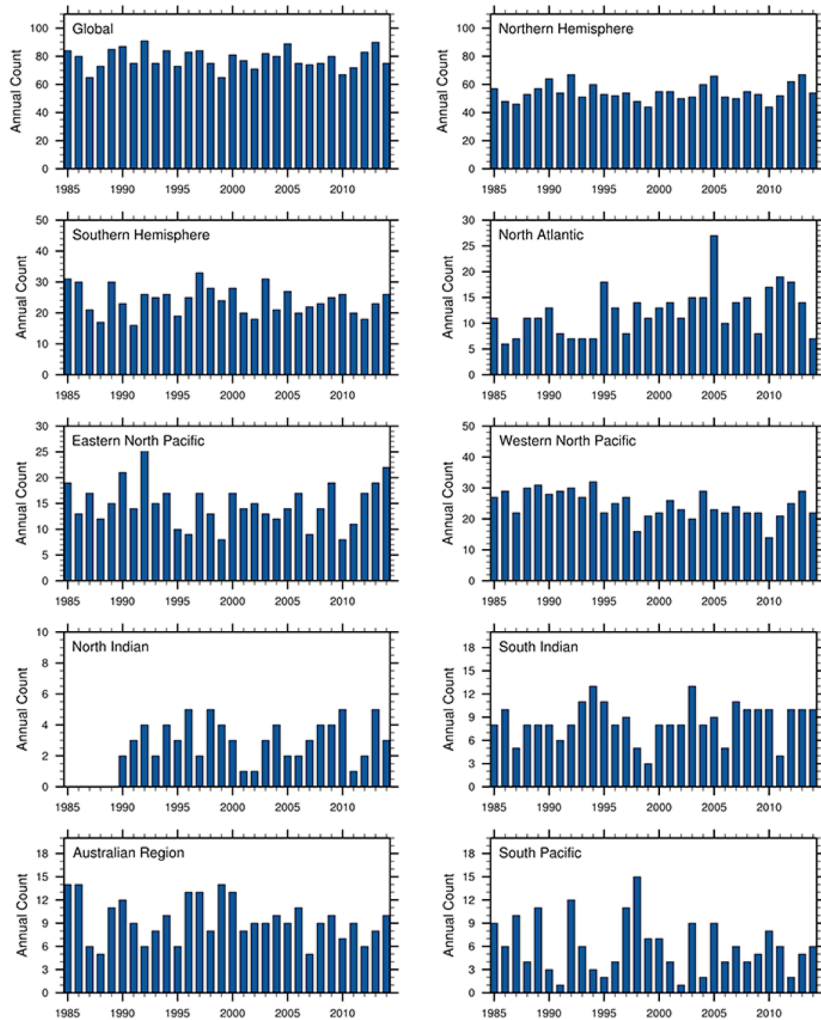


- Hurricane Season: June – November
- Typhoon Season: May – November
- Cyclone Season in South Pacific and Australia: November – April
- Cyclone Season in Indian Ocean, Bay of Bengal, and Arabian Sea:
  - April – June
  - September – November
- Cyclone Season Along East Coast of Africa: November – April

Image Credit: WMO/NHC



# Tropical Cyclone Frequency and Tracks



All 1851 1945 1970 2008 Next

The International Best Track Archive for Climate Stewardship (IBTrACS) stores global tropical cyclone information.

Saffir-Simpson Hurricane Wind Scale



Image Credits: (Left) Ramsay, H. (2017). The Global Climatology of Tropical Cyclones. Oxford Research Encyclopedia of Natural Hazard Science. doi:10.1093/acrefore/9780199389407.013.79. (Right) NOAA/climate.gov



# Tropical Cyclone Naming

<https://public.wmo.int/en/About-us/FAQs/faqs-tropical-cyclones/tropical-cyclone-naming>

- The World Meteorological Organization (WMO) maintains a rotating list of cyclone names appropriate for each ocean basin
- The U.S. National Hurricane Center (NHC) compiles names of hurricanes in the Atlantic and Caribbean regions
- Cyclone names are given alphabetically seasonally, alternating female and male names, starting with a female name
- Some names are retired if the storms were greatly destructive ([more info](#))

The six lists are used in rotation and the 2017 list will be used again in 2023.

Caribbean Sea, Gulf of Mexico and the North Atlantic Names					
2017	2018	2019	2020	2021	2022
Arlene	Alberto	Andrea	Arthur	Ana	Alex
Bret	Beryl	Barry	Bertha	Bill	Bonnie
Cindy	Chris	Chantal	Cristobal	Claudette	Colin
Don	Debby	Dorian	Dolly	Danny	Danielle
Emily	Ernesto	Erin	Edouard	Elsa	Earl
Franklin	Florence	Fernand	Fay	Fred	Fiona
Gert	Gordon	Gabrielle	Gonzalo	Grace	Gaston
Harvey	Helene	Humberto	Hanna	Henri	Hermine
Irma	Isaac	Imelda	Isaias	Ida	Ian
Jose	Joyce	Jerry	Josephine	Julian	Julia
Katia	Kirk	Karen	Kyle	Kate	Karl
Lee	Leslie	Lorenzo	Laura	Larry	Lisa
Maria	Michael	Melissa	Marco	Mindy	Martin
Nate	Nadine	Nestor	Nana	Nicholas	Nicole
Ophelia	Oscar	Olga	Omar	Odette	Owen
Phillippe	Patty	Pablo	Paulette	Peter	Paula
Rina	Rafael	Rebekah	Rene	Rose	Richard
Sean	Sara	Sebastien	Sally	Sam	Shary
Tammy	Tony	Tanya	Teddy	Teresa	Tobias
Vince	Valerie	Van	Vicky	Victor	Virginie
Whitney	William	Wendy	Wilfred	Wanda	Walter

Image Credit: [WMO](#)





# Tropical Cyclone Intensity

<https://www.nhc.noaa.gov/climo/>

- **Tropical Depression**

- tropical cyclone with maximum sustained winds of 38 mph (61 km/h, 33 kt) or less

- **Tropical Storm**

- tropical cyclone with maximum sustained winds of 39 to 73 mph (62-117 km/h, 34-63 kt)

- **Hurricane or Typhoon**

- tropical cyclone with maximum sustained winds of 74 mph (119 km/h, 64 kt) or higher
- in the western North Pacific, hurricanes are called typhoons – similar storms in the Indian Ocean and South Pacific Ocean are called cyclones

- **Major Hurricane**

- tropical cyclone with maximum sustained winds of 111 mph (178 km/h, 96 kt) or higher



# Hurricane Category

[https://www.nhc.noaa.gov/pdf/sshws\\_2012rev.pdf](https://www.nhc.noaa.gov/pdf/sshws_2012rev.pdf)

Hurricane Category	Saffir-Simpson Wind Scale
1	74-95 mph (119-153 km/h, 64-82 kt)
2	96-110 mph (154-177 km/h, 83-95 kt)
3	111-129 mph (178-209 km/h, 96-112 kt)
4	130-156 mph (209-251 km/h, 113-136 kt)
5	≥ 157 mph (≥ 252 km/h, ≥ 137 kt)

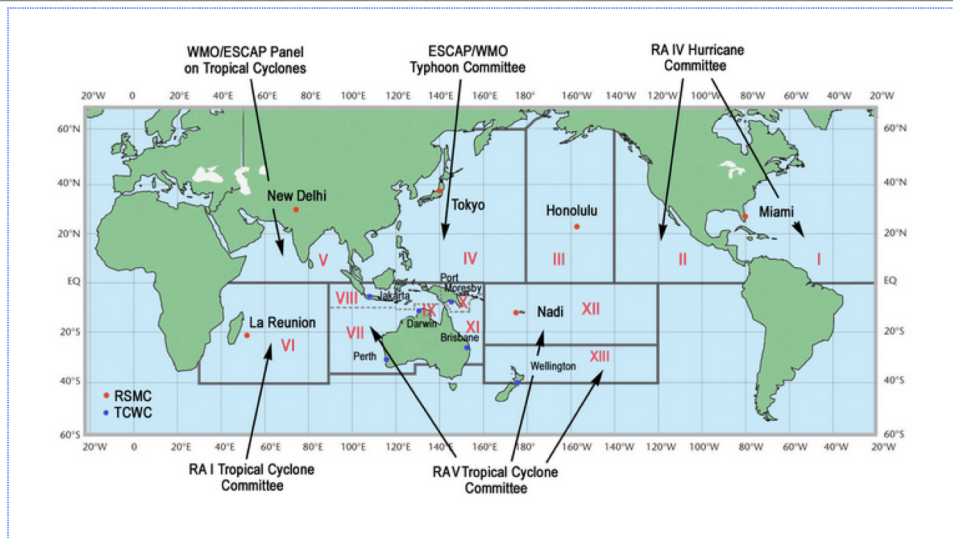
In the western North Pacific, a super typhoon is  
≥ 150 mph (≥ 241 km/h, ≥ 130 kt)



# Tropical Cyclone Information Portals

<https://www.nhc.noaa.gov/aboutrsmc.shtml>

Worldwide Tropical Cyclone Centers



Tropical Cyclone Centers and their Regions  
(click to enlarge)

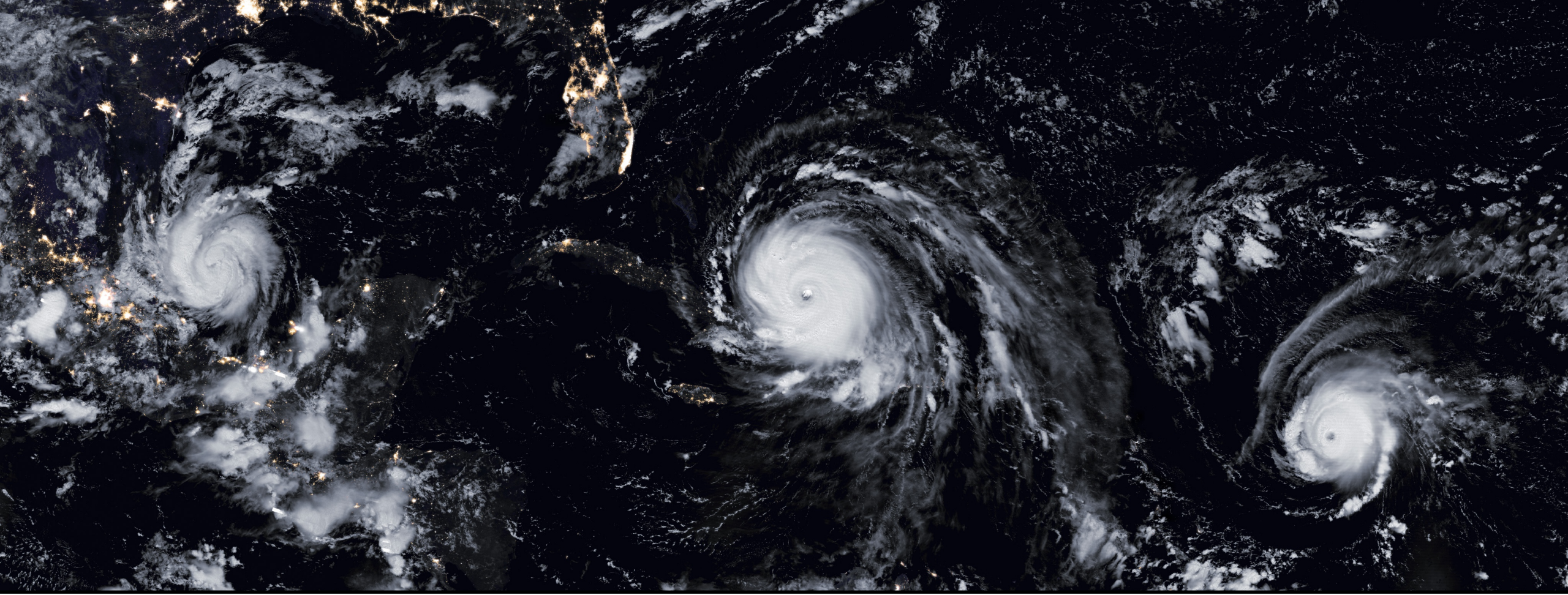
(Image courtesy of the [World Meteorological Organization](#))

The World Meteorological Organization [Tropical Cyclone Programme](#) is tasked to establish national and regionally coordinated systems to ensure that the loss of life and damage caused by tropical cyclones are reduced to a minimum.

The following table is a list of the Regional Specialized Meteorology Centers (RSMC) and Tropical Cyclone Warning Centers (TCWC) participating in the WMO Tropical Cyclone Programme.

Region	Description	Links to Centers (RSMC and TCWC)
I-II	Atlantic and Eastern Pacific	<a href="#">U.S. National Hurricane Center</a> (RSMC Miami)
III	Central Pacific	<a href="#">U.S. Central Pacific Hurricane Center</a> (RSMC Honolulu)
IV	Northwest Pacific	<a href="#">Japan Meteorological Agency</a> (RSMC Tokyo)
V	North Indian Ocean	<a href="#">India Meteorological Department</a> (RSMC New Delhi)
VI	Southwest Indian Ocean	<a href="#">Météo France</a> (RSMC La Réunion)
VII-XI	Southwest Pacific and Southeast Indian Ocean	VII: <a href="#">Australian Bureau of Meteorology</a> (TCWC Perth) VIII: <a href="#">Indonesian Agency for Meteorology</a> (TCWC Jakarta) IX: <a href="#">Australian Bureau of Meteorology</a> (TCWC Darwin) X: <a href="#">Papua New Guinea</a> (TCWC Port Moresby) XI: <a href="#">Australian Bureau of Meteorology</a> (TCWC Brisbane)
XII-XIII	South Pacific	XII: <a href="#">Fiji Meteorological Service</a> (RSMC Nadi) XIII: <a href="#">Meteorological Service of New Zealand, Ltd.</a> (TCWC Wellington)



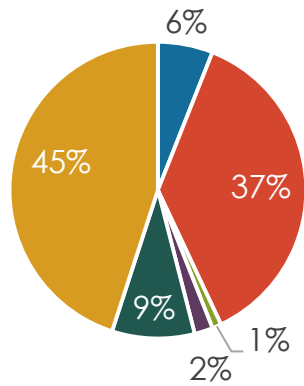


# Tropical Storm Impacts

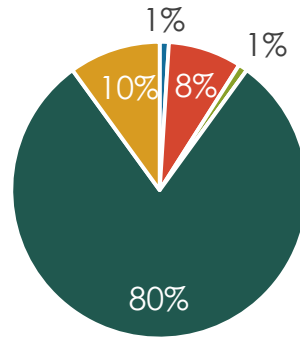
# Cyclone Impacts

## Impacts of Tropical Storms (1980-2009)

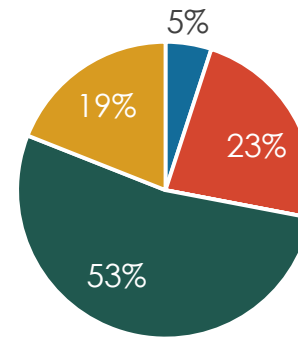
Frequency by Region  
(n=1,080)



Deaths by Region  
(n=393,201)



Affected Population by Region  
(n=151,425,74)



### WHO Regions

- AFRO = African Region
- AMRO = Region of the Americas
- EURO = European Region
- EMRO = Eastern Mediterranean Region
- SEARO = Southeast Asia Region
- WRPRO = Western Pacific Region

- Southeast Asia, the Western Pacific, and regions of America are impacted substantially
- The Western Pacific and American regions have high storm frequency but the Southeast Asian region has the highest number of storm-related deaths

Image Credit: Doocy S, et al. The Human Impact of Tropical Cyclones: a Historical Review of Events 1980-2009 and Systematic Literature Review. PLOS Currents Disasters. 2013 Apr 16 . Edition 1. doi: 10.1371/currents.dis.2664354a5571512063ed29d25ffbce74.



# Cyclone Impacts

<https://www.nhc.noaa.gov/prepare/hazards.php>

Major Causes For Damage, Destruction, Loss of Lives:

- Storm Surge and Coastal Flooding
- Heavy Rainfall and Inland Flooding
- High Sustained Winds and Gusts
- Tornadoes
- Rip Currents

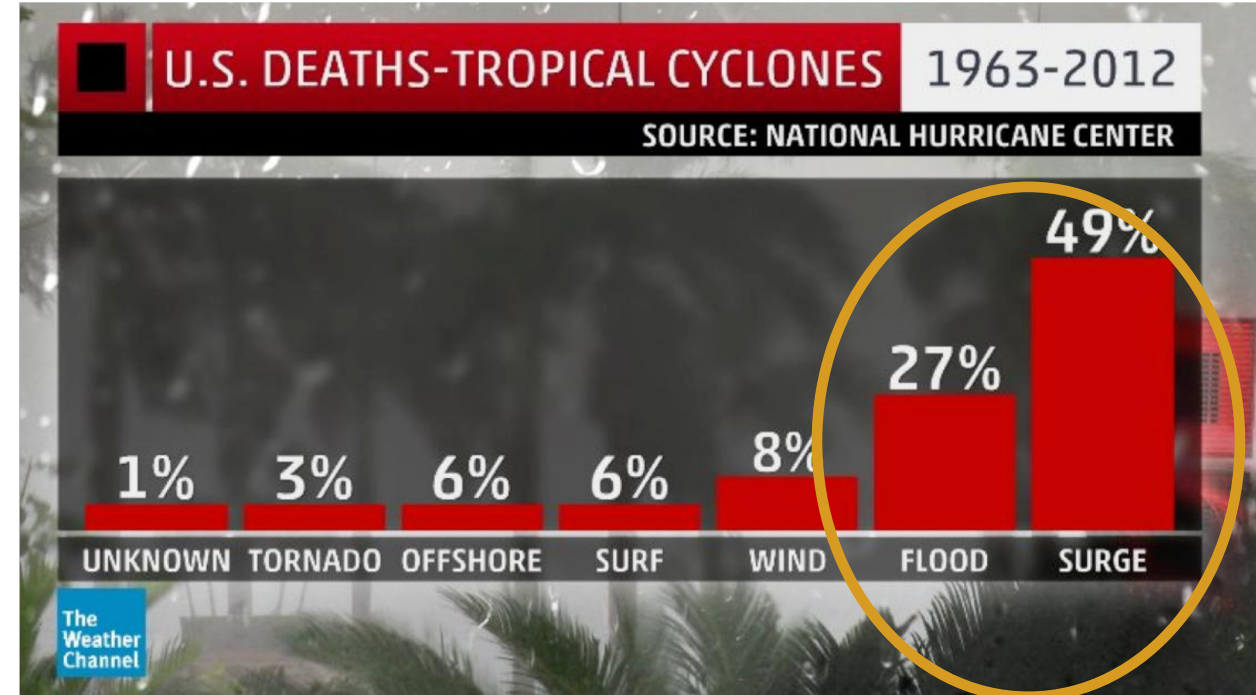


Image Credit: The Weather Channel



# Cyclone Impacts

[https://www.nature.com/articles/nclimate2975?WT.feed\\_name=subjects\\_climate-sciences](https://www.nature.com/articles/nclimate2975?WT.feed_name=subjects_climate-sciences)

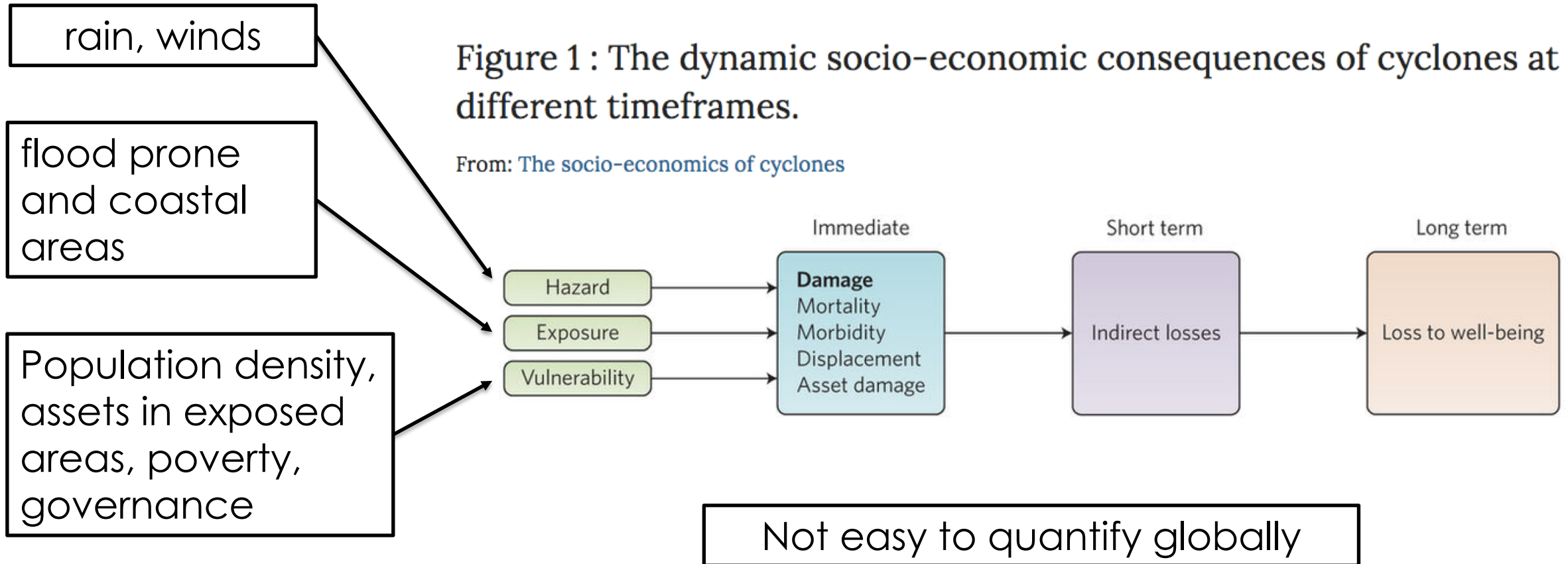


Figure 1 : The dynamic socio-economic consequences of cyclones at different timeframes.

From: *The socio-economics of cyclones*

Figure Credit: Noy, I. (2016). The socio-economics of cyclones. Nature Climate Change, 6(4), 343-345. doi:10.1038/nclimate2975



# Economic Impacts of Cyclones in the U.S.

<https://www.ncdc.noaa.gov/billions/time-series>

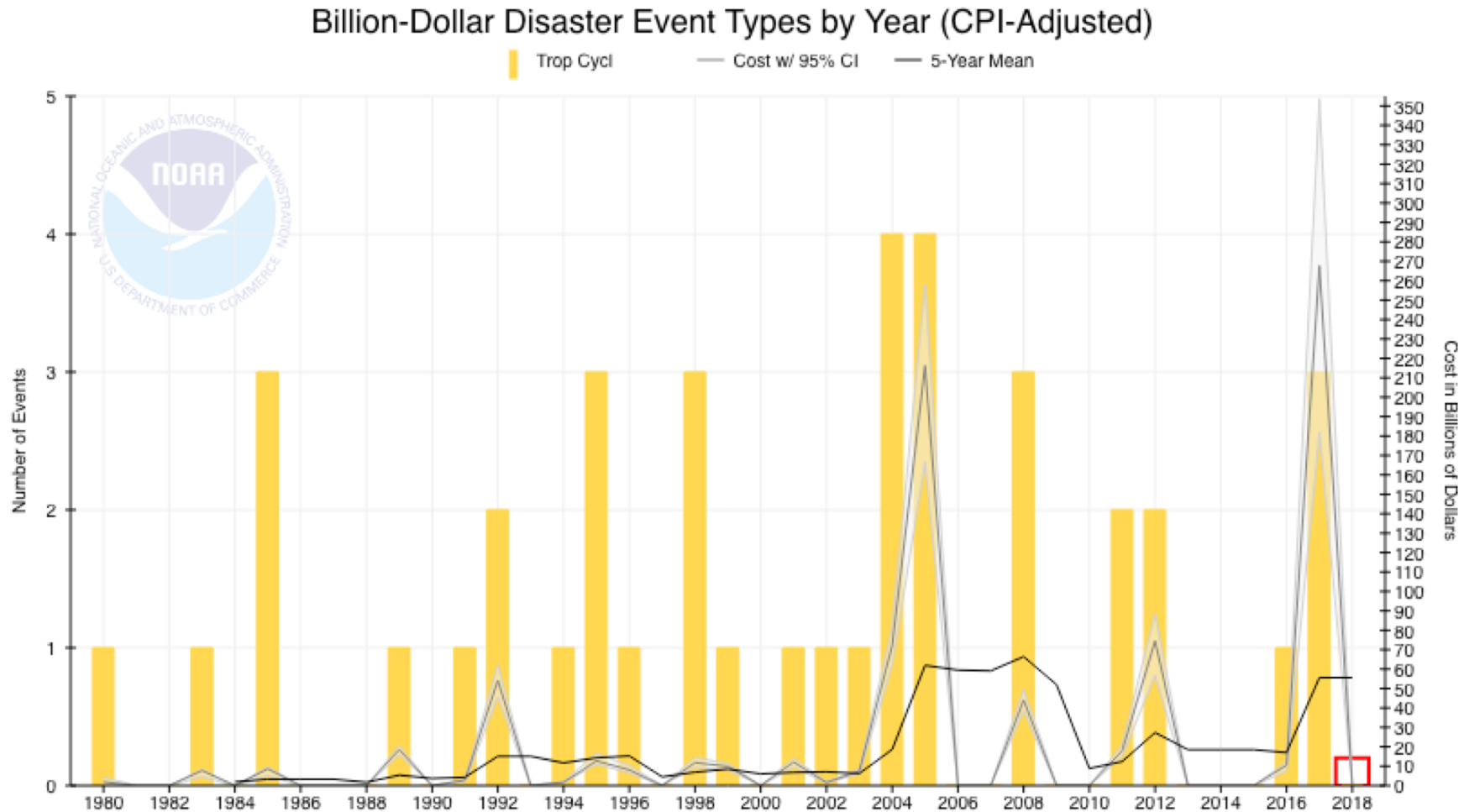


Image Credit: NOAA

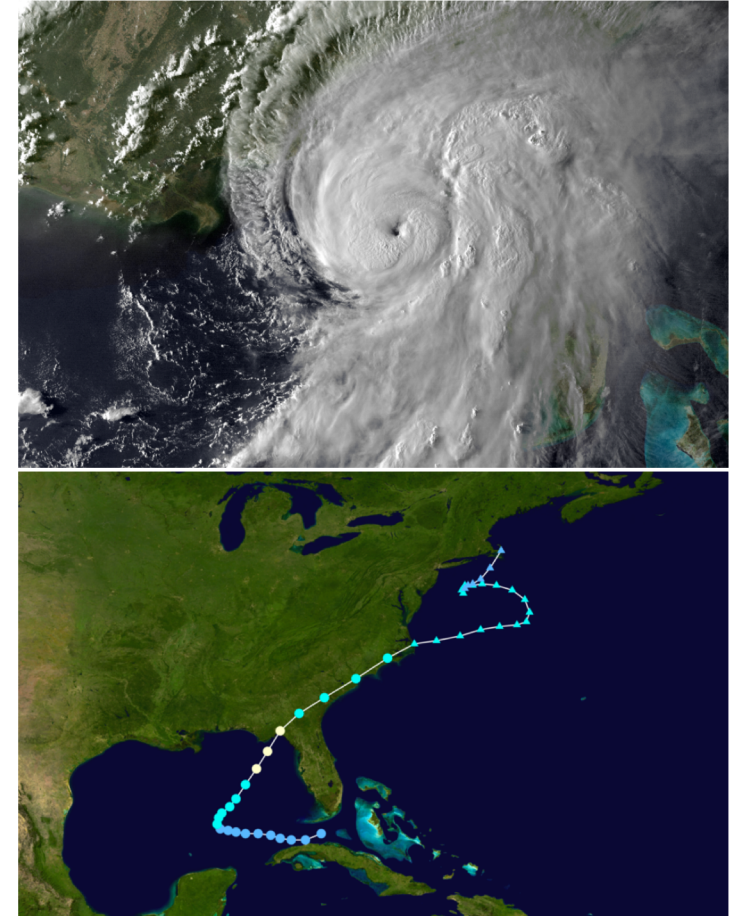
Number of events as of April 6, 2018





# Tropical Cyclone Damages: Category 1 - Minimal

- Storm Surge: 4-5 feet above normal
- Likely Damages:
  - Primarily restricted to shrubbery, trees, and unanchored mobile homes
  - No substantial damage to other structures
  - Some damage to poorly constructed signs
  - Some coastal road flooding and minor pier damage

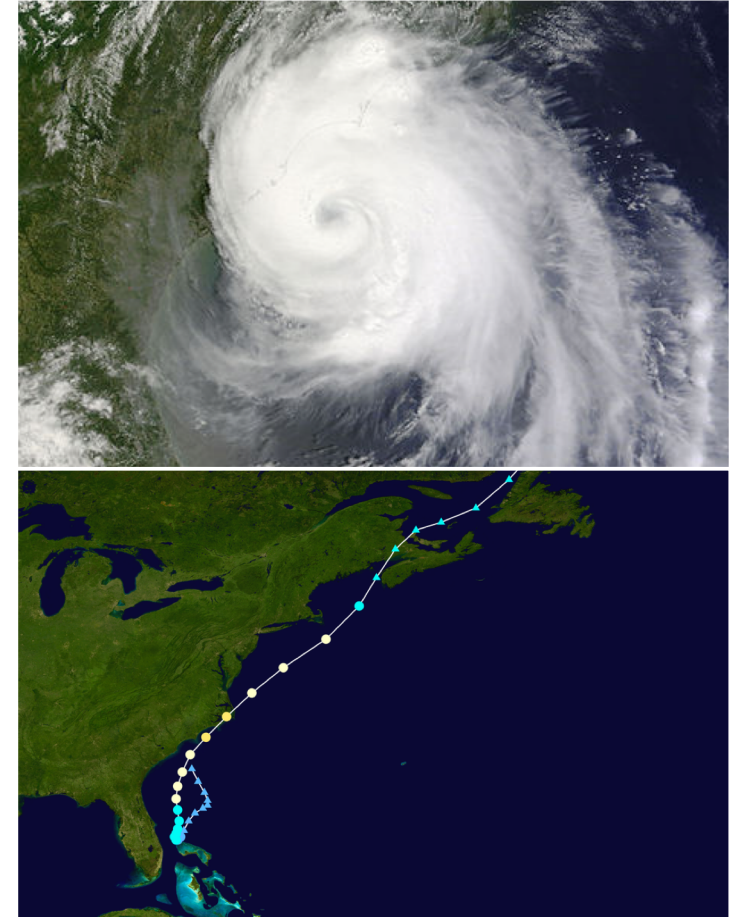


Hurricane Hermine (2016), Category 1  
Top: NOAA image, Bottom: Hurricane track



# Tropical Cyclone Damages: Category 2 - Moderate

- Storm Surge: 6-8 feet above normal
- Likely Damages:
  - Considerable damage to shrubbery and tree foliage, some trees blown down
  - Major damage to exposed mobile homes
  - Extensive damage to poorly constructed signs
  - Some damage to windows, doors, and roofing materials of buildings; no major destruction to buildings
  - Coastal roads and low-lying escape routes inland cut off by rising water about 2-4 hours before landfall
  - Considerable damage to piers, marinas flooded
  - Small craft in protected anchorage torn from mooring

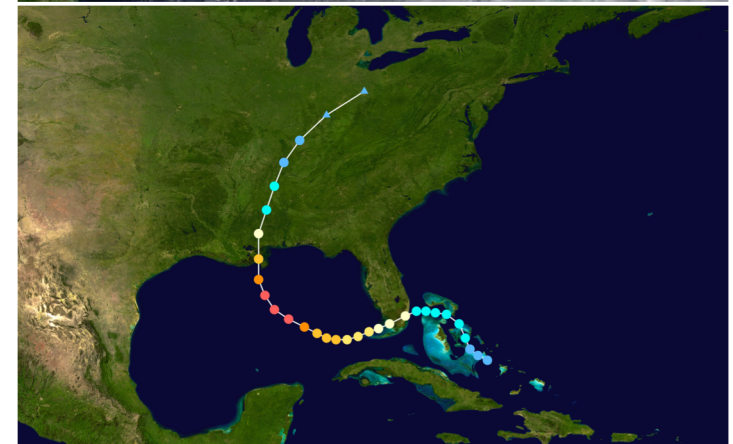


Hurricane Arthur (2014), Category 2  
Top: NOAA image, Bottom: Hurricane track



# Tropical Cyclone Damages: Category 3 – Extensive

- Storm Surge: 9-12 feet above normal
- Likely Damages:
  - Foliage torn from trees, large trees blown down
  - Poorly constructed signs blown down
  - Some damage to roofing, windows, and doors
  - Some structural damage to small buildings
  - Mobile homes destroyed
  - Serious flooding along the coast
  - Many small structures near the coast destroyed
  - Larger coastal structures damaged by battering waves and floating debris
  - Low-lying escape routes inland cut off by rising water about three to five hours before landfall
  - Flat terrain 5 feet or less above sea level flooded up to 8 or more miles inland
  - Evacuation of low-lying residences within several blocks of shoreline may be required

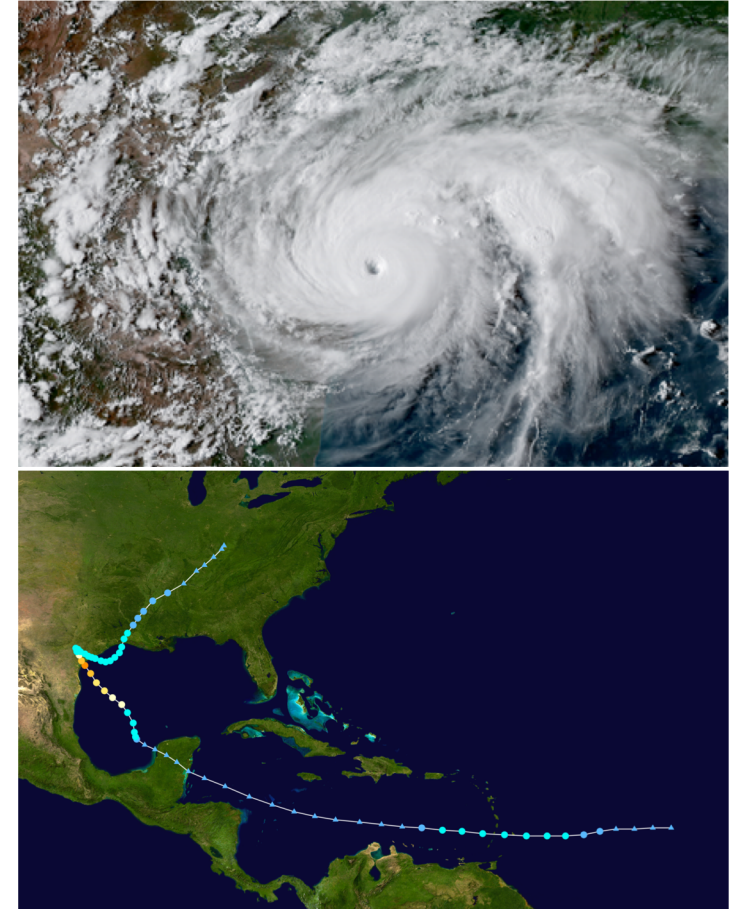


Hurricane Katrina (2005) made landfall as a Category 3 Hurricane.  
Top: NOAA image, Bottom: Hurricane track



# Tropical Cyclone Damages: Category 4 - Extreme

- Storm Surge: 13-18 feet above normal
- Likely Damages:
  - Shrubs, trees, and all signs blown down
  - Extensive damage to roofs, windows, and doors, with complete failure of roofs on many smaller residences
  - Mobile homes demolished
  - Flat terrain 10 feet or less above sea level flooded inland as far as 6 miles
  - Flooding and battering by waves and floating debris cause major damage to lower floors of structures near the shore
  - Low-lying escape routes inland cut off by rising water about three to five hours before landfall
  - Major erosion of beaches
  - Massive evacuation of inland residences as far inland as 6 miles may be required

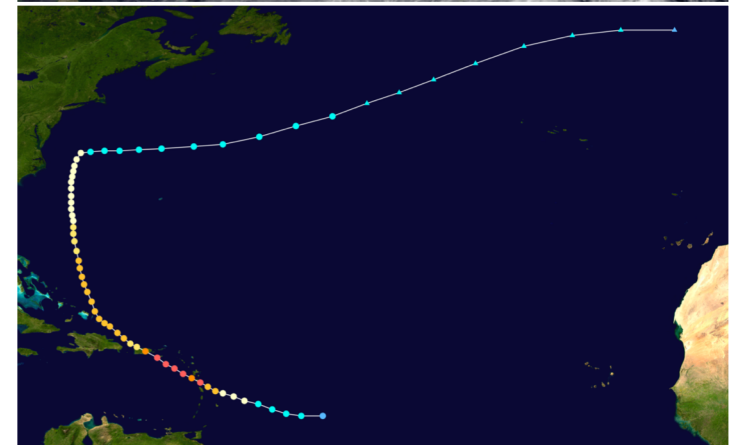
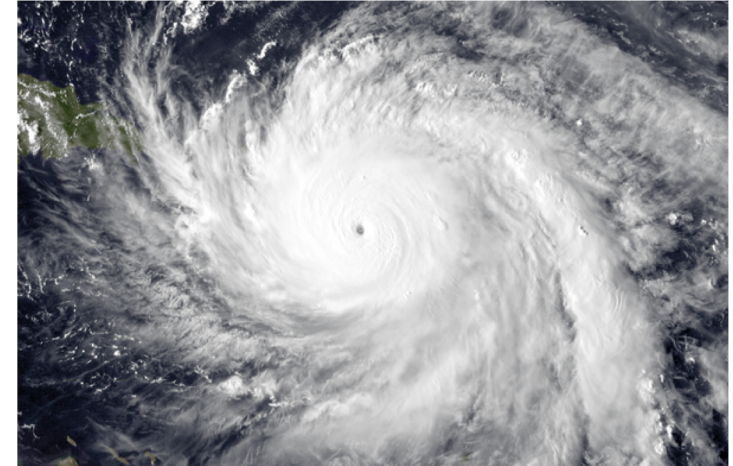


Hurricane Harvey (2017), Category 4.  
Top: NOAA image, Bottom: Hurricane track



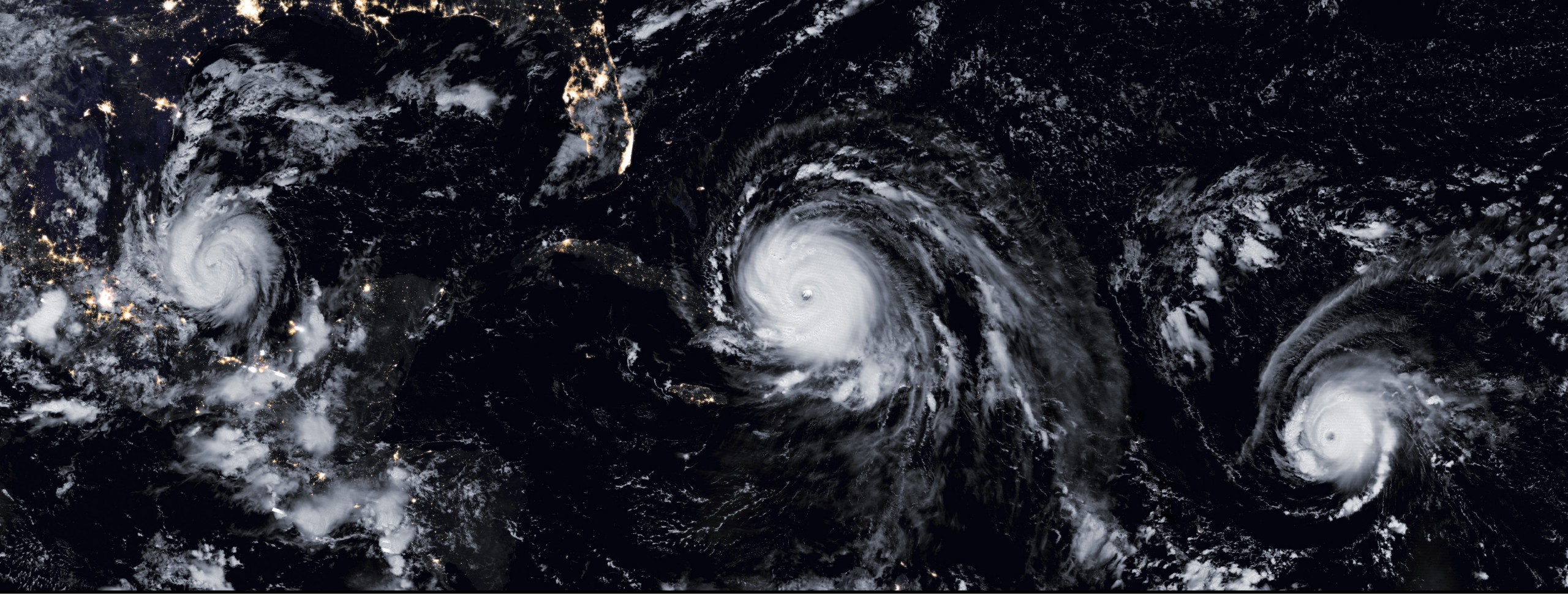
# Tropical Cyclone Damages: Category 5 - Catastrophic

- Storm Surge: >18 feet above normal
- Likely Damages:
  - Trees, shrubs, and all signs blown down
  - Considerable damage to roofs of buildings, with very severe and extensive damage to windows and doors
  - Complete failure on many roofs of residences and industrial buildings
  - Extensive shattering of glass in windows and doors; complete buildings destroyed
  - Small buildings overturned or blown away
  - Mobile homes demolished
  - Major damage to lower floors of all structures less than 15 feet above sea level within 1,500 feet of the shore
  - Low-lying escape routes inland cut off by rising water about three to five hours before landfall
  - Major erosion of beaches
  - Massive evacuation of residential areas on low ground as far inland as 10 miles may be required



Hurricane Maria (2017), Category 5  
Top: NOAA image, Bottom: Hurricane track





Pre-Storm Emergency Preparedness

# Tropical Cyclone Preparedness

[https://www.fema.gov/media-library-data/20130726-1715-25045-9324/hurricane\\_mitigation\\_handbook\\_for\\_public\\_facilities.pdf](https://www.fema.gov/media-library-data/20130726-1715-25045-9324/hurricane_mitigation_handbook_for_public_facilities.pdf)

**Plan ahead** if you are situated in a region where tropical cyclones occur!

- Reduce vulnerability of infrastructure and properties including:
  - Roads and Bridges
  - Water Control Facilities Buildings
  - Utilities
  - Other Public and Private properties
- Reduce excessive losses by taking mitigation measures for **storm surge, high winds, torrential rain and flooding**



Image Credit: FEMA



# Tropical Cyclone Preparedness

<https://www.osha.gov/dts/weather/hurricane/preparedness.html>

**Plan ahead** if you are situated in a region where tropical cyclones occur!

- Conditions that will activate the plan
- Chain of command
- Emergency functions and who will perform them
- Specific evacuation procedures, including routes and exits
- Procedures for accounting for personnel, customers and visitors
- Equipment for personnel

**How Can Remote Sensing Help?**





# Tropical Cyclone Preparedness (T-48 Hours)

[https://www.fema.gov/media-library-data/1494007144395-b0e215ae1ba6ac1b556f084e190e5862/FEMA\\_2017\\_Hurricane\\_HTP\\_FINAL.pdf](https://www.fema.gov/media-library-data/1494007144395-b0e215ae1ba6ac1b556f084e190e5862/FEMA_2017_Hurricane_HTP_FINAL.pdf)

- Monitor local news and weather reports
- Prepare to evacuate by testing your emergency communication plans, learning evacuation routes, having a place to stay, and packing a “go bag”
- Stock emergency supplies
- Protect your property by installing sewer backflow valves, anchoring fuel tanks, reviewing insurance policies, and cataloging belongings
- Collect and safeguard critical financial, medical, educational, and legal documents and records

## How Can Remote Sensing Help?



# Data Needs for Preparedness

## Planning Mitigation

- Historical/climatological data of:
  - storm frequency, track, sea level pressure, size, and wind speed
  - precipitation and flood extent
  - storm surge and coastal flooding

## Planning For Upcoming Storms

- Near real-time and forecast data of:
  - storm track, sea level pressure, size, and wind speed
  - precipitation and flood monitoring
  - storm surge monitoring

## Other Data

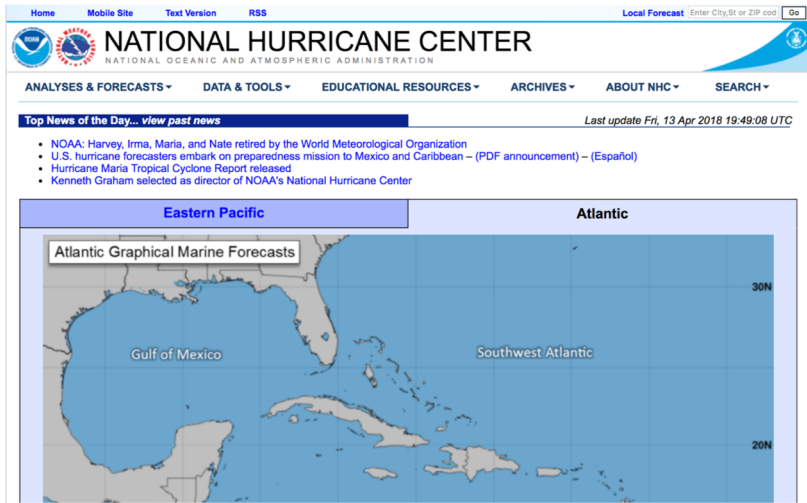
- terrain
- population and infrastructure
- damage and destruction in situ information

### Most of these data are available from:

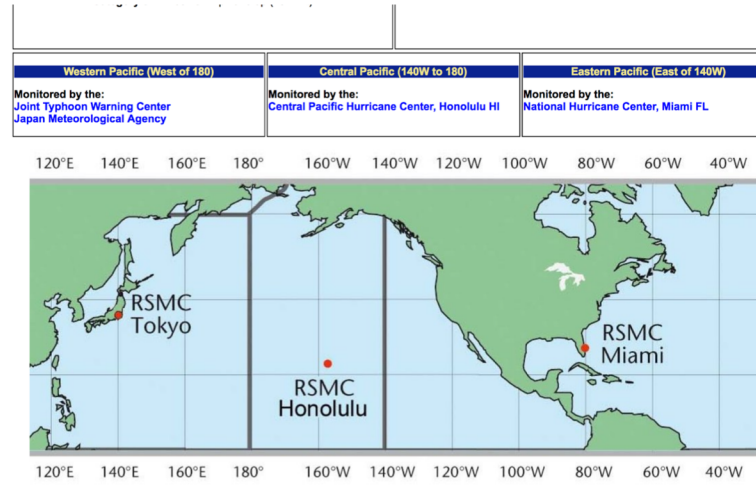
- **NASA remote sensing and Earth system models**
- National Hurricane Center (NHC)
- Central Pacific Hurricane Center (CPHC)
- Joint Typhoon Warning Center (JTWC)
- Global Disasters and Alert Coordination System (GDACS)



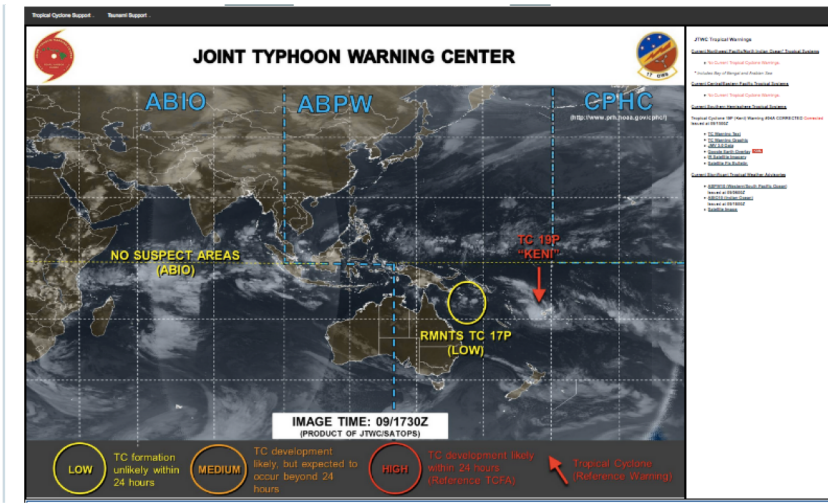
# Tropical Cyclone Operational Information Portals



<https://www.nhc.noaa.gov/>



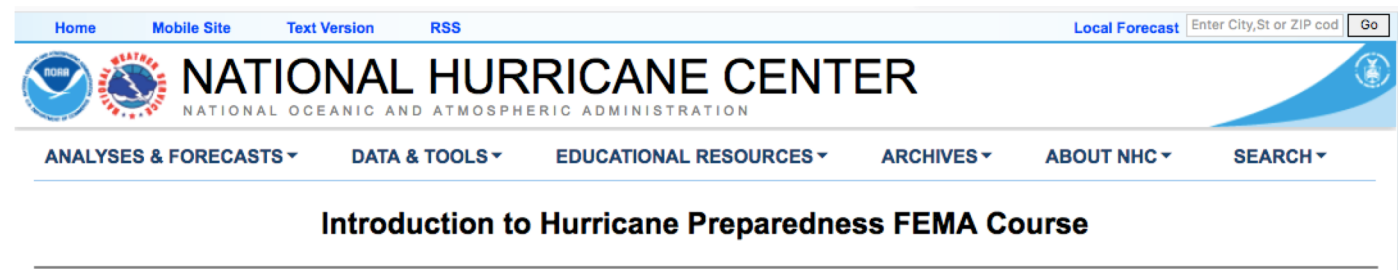
<http://www.prh.noaa.gov/cphc/>

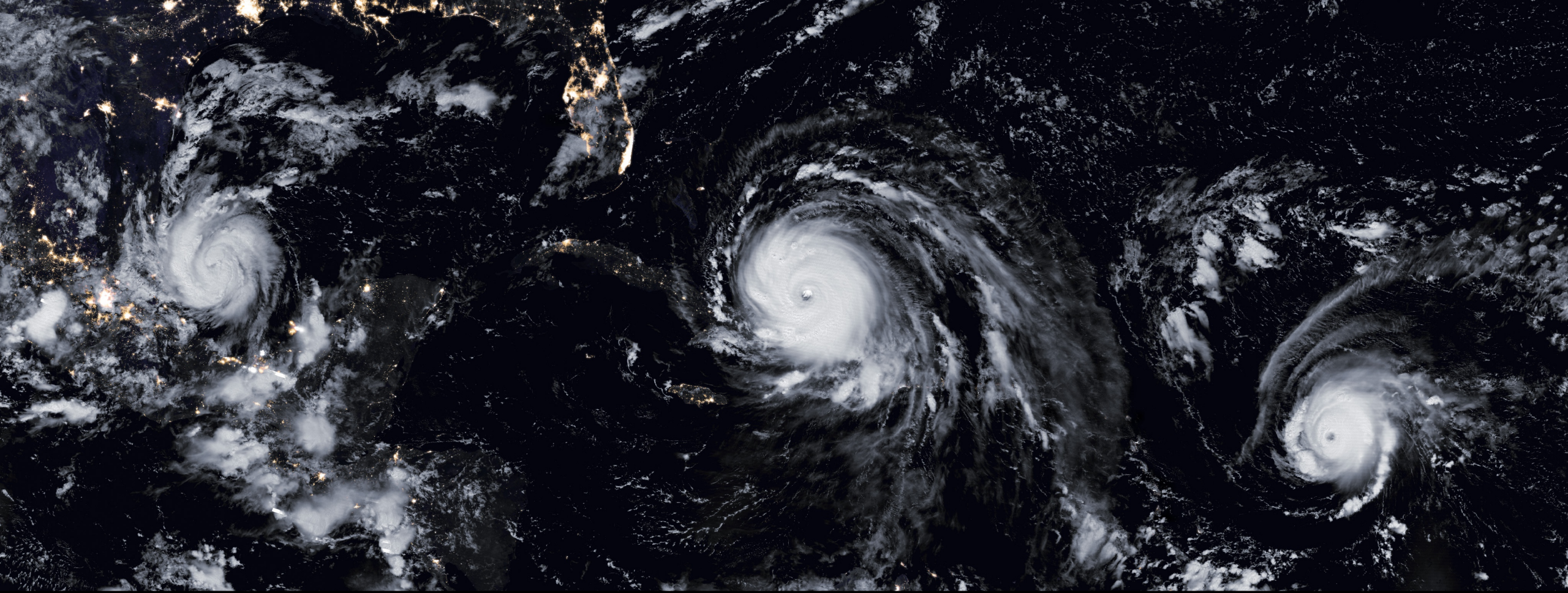


<http://www.usno.navy.mil/NOOC/nmfc-ph/RSS/jtwc/jtwc.html>

NHC provides an emergency preparedness course for FEMA:

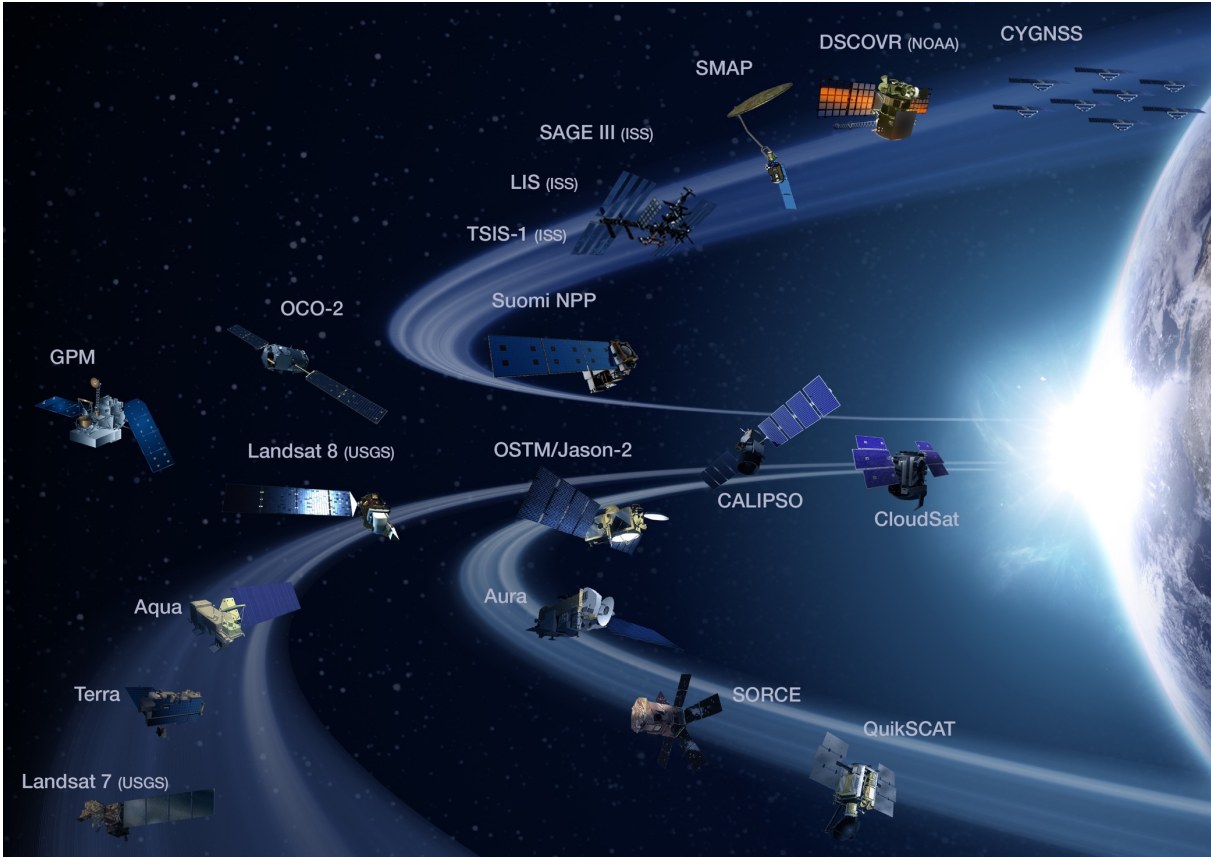
<https://www.nhc.noaa.gov/outreach/femacourse.php>





Monitor Approaching Storms With NASA  
Remote Sensing, Earth System  
Model Data, and Tools

# NASA Satellites for Monitoring Tropical Cyclones



- Tropical Rainfall Measuring Mission (TRMM): 11/1997 – 04/2015
- Global Precipitation Measurement mission (GPM): 02/2014 – present
- Terra: 12/1999 – present
- Aqua: 05/2002 – present
- Suomi National Polar-Orbiting Partnership (SNPP): 11/2011-Present



# NASA Satellites and Sensors for Monitoring Tropical Cyclones

Satellites	Sensors	Spectral Measurements	Parameter
TRMM & GPM	TMI, PR & GMI, DPR	Microwave Radiometer and Radar (Ku and Ka)	Precipitation
Terra & Aqua	MODIS	Visible, Near IR, Middle IR	Reflectance/True Color Image
SNPP	VIIRS		Day/Night Imagery

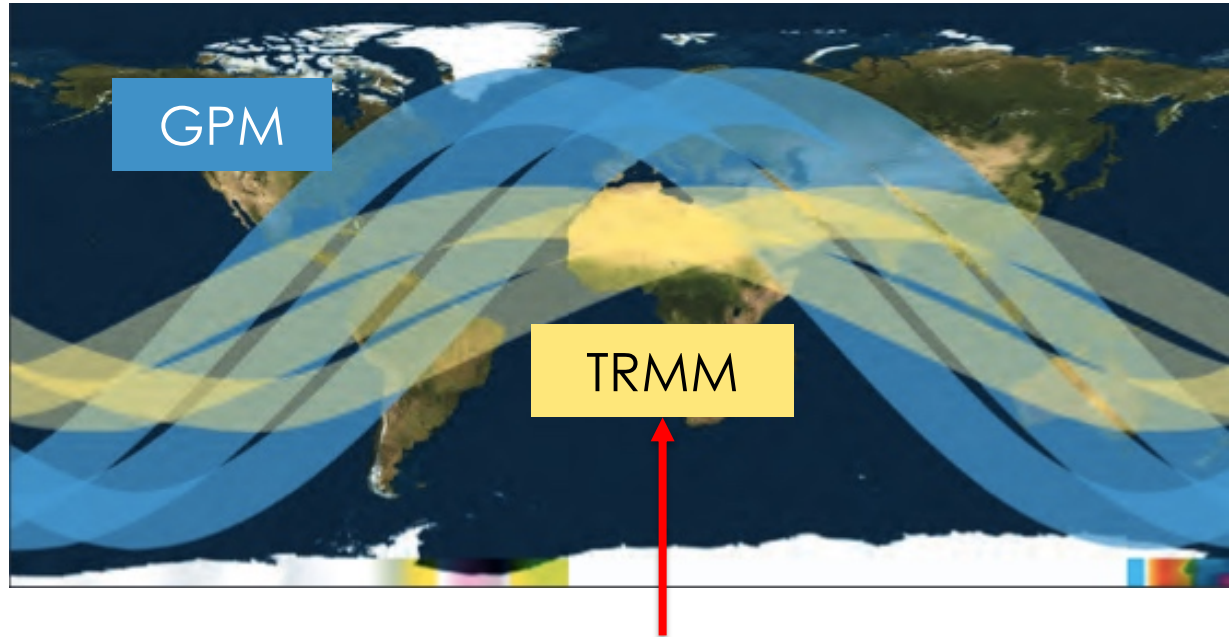
DPR	Dual-frequency Precipitation Radar
GMI	GPM Microwave Imager
IR	Infrared Radiation
MODIS	MODerate Resolution Imaging Spectroradiometer
NIR	Near-Infrared Radiation
PR	Precipitation Radar
TMI	TRMM Microwave Imager
VIIRS	Visible Infrared Imaging Radiometer Suite



# Global Precipitation Measurement (GPM) Mission

<http://pmm.nasa.gov/GPM/>

- Core satellite launched Feb 27, 2014
  - non-polar, low-inclination orbit
    - Altitude: 407 km
- Spatial Coverage
  - 16 day orbits a day, covering global area between 65°S – 65°N
- Along with constellation of satellites, GPM has a revisit time of 2-4 hrs over land
- Sensors:
  - GMI (GPM Microwave Imager)
  - DPR (Dual Precipitation Radar)



Tropical Rainfall Measurement Mission



# Multi-Satellite Algorithms for TRMM and GPM

<http://pmm.nasa.gov/science/precipitation-algorithms>

- TRMM & GPM Core satellites are used to calibrate microwave observations from a constellation of national and international satellites
- Allow improved spatial and temporal coverage of precipitation data
- TRMM Multi-satellite Precipitation Analysis (**TMPA**)
- Widely used for applications
- TMPA will be extended to match Integrated Multi-satellitE Retrievals for GPM (**IMERG**)

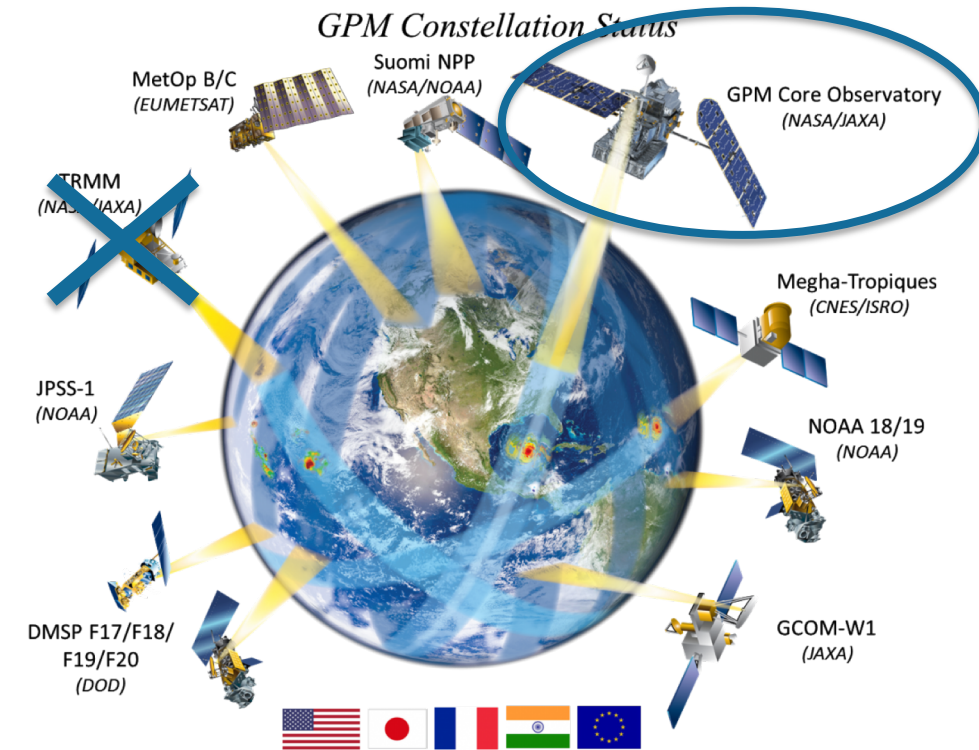




# Integrated Multi-satellite Retrievals for GPM (IMERG)

[http://pmm.nasa.gov/sites/default/files/document\\_files/IMERG\\_ATBD\\_V4.5.pdf](http://pmm.nasa.gov/sites/default/files/document_files/IMERG_ATBD_V4.5.pdf)

- GPM Core satellite data (GMI & DPR) are used to calibrate and combine microwave data from GPM constellation satellites
- GPM constellation satellites include:
  - GCOM-W
  - DMSP
  - Megha-Tropiques
  - MetOp-B
  - NOAA-N'
  - NPP
  - NPOESS
- Final rain product is calibrated with rain gauge analyses on monthly time scale



# Integrated Multi-satellite Retrievals for GPM (IMERG)

[http://pmm.nasa.gov/sites/default/files/document\\_files/IMERG\\_ATBD\\_V4.5.pdf](http://pmm.nasa.gov/sites/default/files/document_files/IMERG_ATBD_V4.5.pdf)

- Multiple runs accommodate different user requirements for latency and accuracy
  - “Early” – now 5 hours (flash flooding) – will be 4 hours
  - “Late” – now 15 hours (crop forecasting) – will be 12 hours
  - “Final” – 3 months (research data)
- Native time intervals are half-hourly and monthly (final only)
  - Value-added products at 3 hrs, 1, 3, and 7 days are available
  - Initial release covers 60°N-60°S – will be 90°N-90°S



# TMPA and IMERG

	TMPA	IMERG
Spatial Resolution	0.25° x 0.25°	0.1° x 0.1°
Spatial Coverage	Global, 50° S-50°N	Global, 60°S-60°N (will be extended from pole to pole)
Temporal Resolution	3 hours	30 minutes
Temporal Coverage	12/1997 – Present*	2/27/2014 – Present <sup>+</sup>

\* After April 8, 2015, TRMM climatological calibration is being used to generate TMPA

<sup>+</sup> TMPA and IMERG combined data will be available in early 2018 at IMERG data resolution

TMPA is widely used for flood modeling and IMERG will replace it in near future



# GPM IMERG Data Access

<https://pmm.nasa.gov/data-access>

**Data Access**

- Extreme Weather News
- ▼ Data Downloads & Documentation
  - TRMM
  - GPM
  - Ground Validation
- Data Sources
- Data Recipes
- Data News
- Google Earth
- NASA Worldview
- Using the PPS FTP
- Training
- Data FAQ

**Connect With Us**

- Twitter
- Facebook
- Youtube

**Need Help?**

- View Frequently Asked Questions
- View the PMM Glossary

**How to Access TRMM & GPM Precipitation Data**

Precipitation data from the GPM and TRMM missions is made available free to the public in a variety of formats from several sources at [NASA](#) Goddard Space Flight Center. This section outlines the different types of data available, the levels of processing, the sources to download the data, and some helpful tips for utilizing precipitation data in your research.

- **GPM Data Downloads & Documentation**
- TRMM Data Downloads & Documentation
- Explanation of GPM & TRMM Data Sources
- Data Processing "Recipes"
- Precipitation Data in Google Earth
- Frequency Asked Questions (FAQ)

**GET DATA**  
GLOBAL PRECIPITATION MEASUREMENT  
New Users Start Here

Use of the **PPS FTP** and **STORM** requires you to first register your email address. [Click here to register.](#)

- All about GPM data
  - Including updates, news, and FAQ
- Quick data access links and user registration
- For more information about GPM and about data access visit:

<https://pmm.nasa.gov/training>



# Precipitation Data Access and Analysis

<https://giovanni.gsfc.nasa.gov/giovanni/>

The screenshot shows the GIOVANNI web interface with several key sections and annotations:

- Navigation:** NASA EARTHDATA logo, Data Discovery, DAACs, Community, Science Disciplines, and a search icon.
- Header:** GIOVANNI The Bridge Between Data and Science v 4.24. Includes links for Release Notes, Browser Compatibility, and a data Login.
- Select Plot:** A row of radio buttons for plot types: Maps: Time Averaged Map (selected), Comparisons: Select..., Vertical: Select..., Time Series: Select..., and Miscellaneous: Select....
- Select Date Range (UTC):** Fields for YYYY-MM-DD and HH:mm, with a 'Valid Range: 1948-01-01 to 2018-04-16' note.
- Select Region (Bounding Box or Shape):** A text input field with a format guide: 'Format: West, South, East, North'.
- Select Variables:** A list of disciplines and measurements with checkboxes. Disciplines include Aerosols (187), Atmospheric Chemistry (75), Atmospheric Dynamics (418), Cryosphere (13), Hydrology (1115), Ocean Biology (59), Oceanography (61), and Water and Energy Cycle (1199). Measurements include Aerosol Index (5), Aerosol Optical Depth (87), Air Pressure Anomaly (1), Air Pressure (57), Air Temperature Anomaly (2), Air Temperature (101), and Albedo (25).
- Search:** A box with the text 'Number of matching Variables: 0 of 1901' and 'Total Variable(s) included in Plot: 0'. It includes a 'Keyword:' input field, 'Search', and 'Clear' buttons.
- Buttons:** 'Help', 'Reset', 'Feedback', and a prominent green 'Plot Data' button.

Annotations in red boxes with arrows point to specific features:

- Analysis and Plot Options:** Points to the 'Select Plot' section.
- Temporal and Spatial Search Map & shapefile selection for various countries or the U.S.:** Points to the 'Select Date Range' and 'Select Region' sections.
- Search data by keyword:** Points to the search box.
- Plot Data:** Points to the 'Plot Data' button.

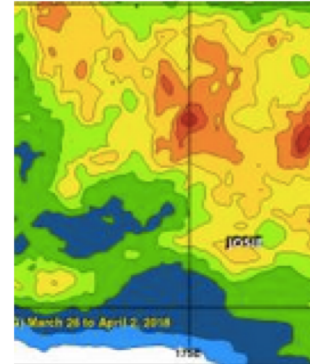


# GPM Tropical Cyclone Portal

<https://pmm.nasa.gov/applications/tropical-cyclones>

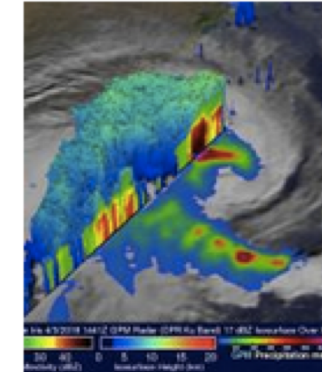
The screenshot shows the NASA Precipitation Measurement (PMM) website. At the top, it features the NASA logo and the text "NATIONAL AERONAUTICS AND SPACE ADMINISTRATION" and "GODDARD SPACE FLIGHT CENTER". Below this is the main heading "PRECIPITATION MEASUREMENT". A navigation bar includes links for "Home", "GPM", "TRMM", "Science", "Applications", "Meetings", and "Data Access". On the left, there is a sidebar with "Applications" and "Connect With Us" (Twitter, Facebook, YouTube). The main content area is titled "Tropical Cyclones" and features a video player with the title "NASA | GPM: The Trouble with Irene". Below the video, there is a paragraph of text describing the GPM mission and its role in monitoring tropical cyclones like Irene.

Monday, April 2, 2018



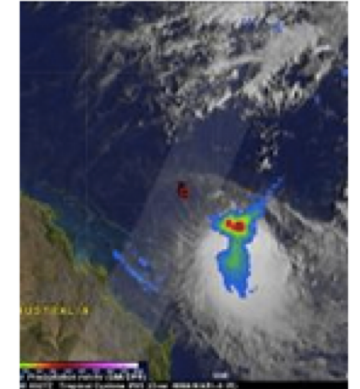
**Tropical Cyclone Josie's Deadly Flooding Rainfall Examined With IMERG**

Wednesday, April 4, 2018



**GPM Satellite Probes Tropical Cyclone Iris Near Australian Coast**

Friday, April 6, 2018



**GPM Shows Rainfall Southeast Of Sheared Tropical Cyclone Iris**



# Terra and Aqua Satellites and MODIS Sensor

## Terra

<http://terra.nasa.gov>

- Polar orbit, 10:30 a.m. equator crossing time
- Global Coverage
- December 18, 1999 – Present
- 1-2 observations per day

## Aqua

<http://aqua.nasa.gov/>

- Polar orbit, 1:30 p.m. equator crossing time
- Global Coverage
- May 4, 2002 – Present
- 1-2 observations per day



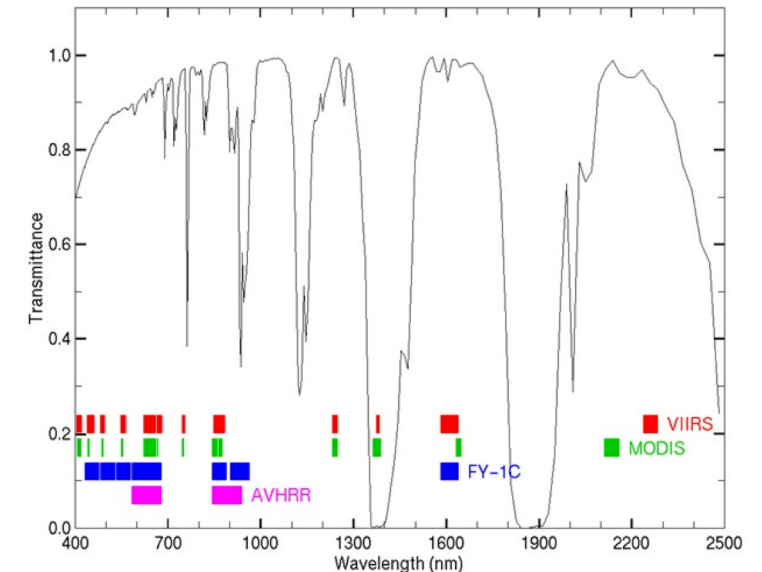
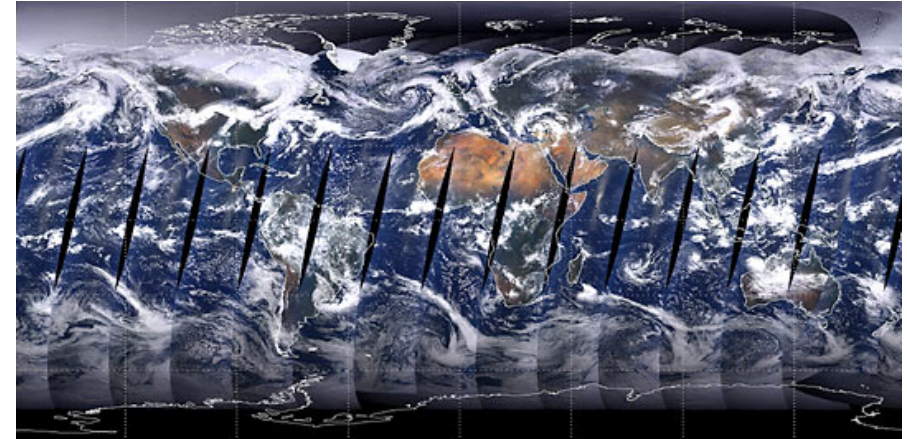
# MODerate Resolution Imaging Spectroradiometer (MODIS)

<http://modis.gsfc.nasa.gov/>

- Spectral Bands
  - 36 bands (red, blue, IR, NIR, Middle-IR)
- Spatial Resolution
  - Global, swath: 2,330 km
  - 250 m, 500 m, 1 km
- Temporal Resolution
  - Daily, 8 day, 16 day, monthly, quarterly, yearly
  - 2000 – present
- Data Access:

Land Processing Distributed Active Archive Center

[http://lpdaac.usgs.gov/dataset\\_discovery/modis/](http://lpdaac.usgs.gov/dataset_discovery/modis/)

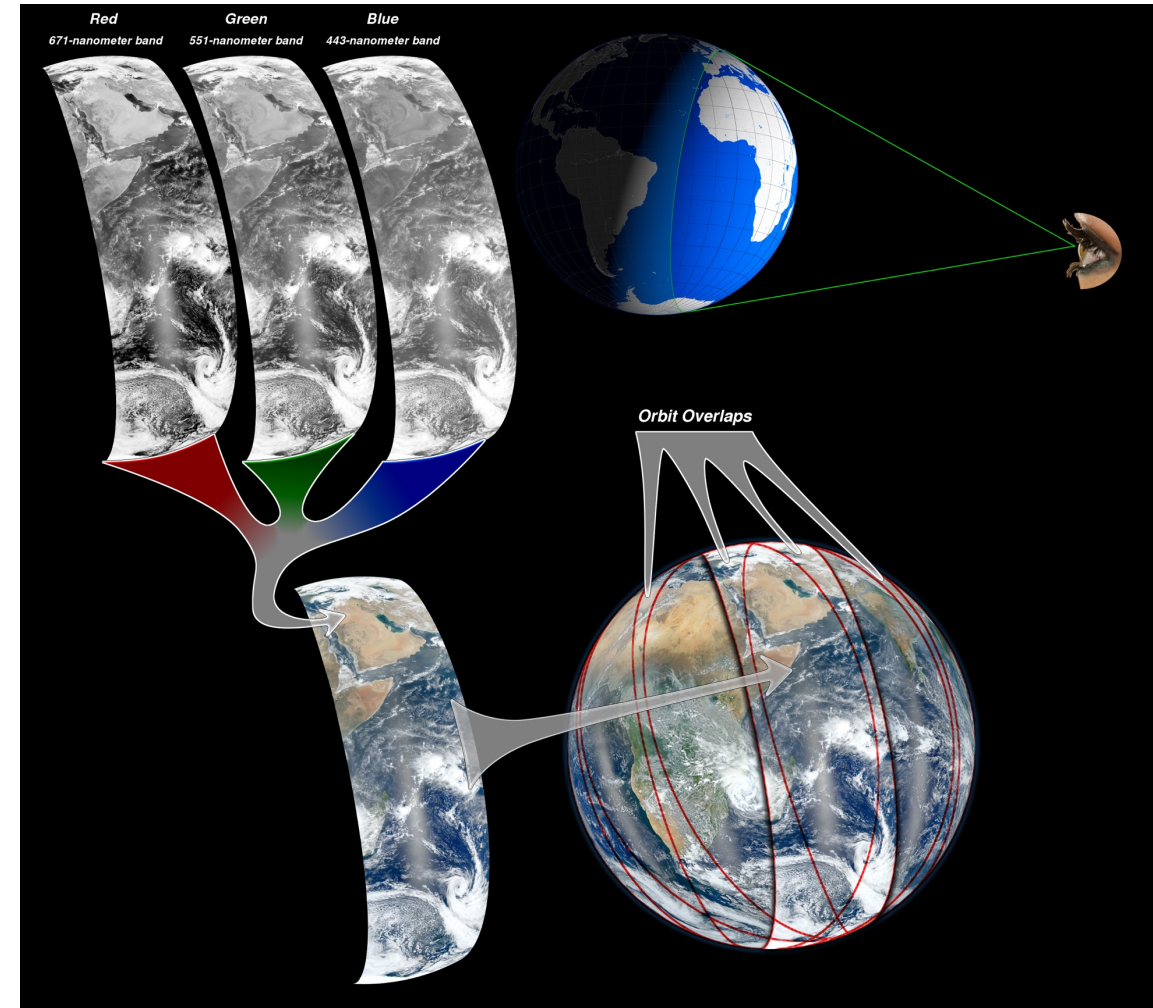




# Suomi National Polar Partnership (SNPP)

[http://nasa.gov/mission\\_pages/NPP/](http://nasa.gov/mission_pages/NPP/)

- Polar orbit, 1:30 p.m. equator crossing time
- Global coverage
- November 21, 2011 – present
- Sensors:
  - VIIRS, ATMS, CrIS, OMPS, CERES



# Visible Infrared Imaging Radiometer Suite (VIIRS)

<http://jointmission.gsfc.nasa.gov/viirs.html>

- Functionality similar to MODIS
- Spectral Bands
  - 22 bands (Visible, IR, NIR, Middle-IR, day/night band)
- Spatial Coverage and Resolution:
  - Global, Swath Width: 3,040 km
  - Spatial Resolution: 375 – 750 m
- Temporal Coverage and Resolution:
  - Oct 2011 – present
  - 1-2 times per day
  - Data Access:
    - Land Processing Distributed Active Archive Center
- [http://lpdaac.usgs.gov/dataset\\_discovery/viirs/](http://lpdaac.usgs.gov/dataset_discovery/viirs/)



DNB image of Spain showing lights in urban centers and clouds over the Atlantic Ocean. Image courtesy of NASA's Direct Readout Laboratory.

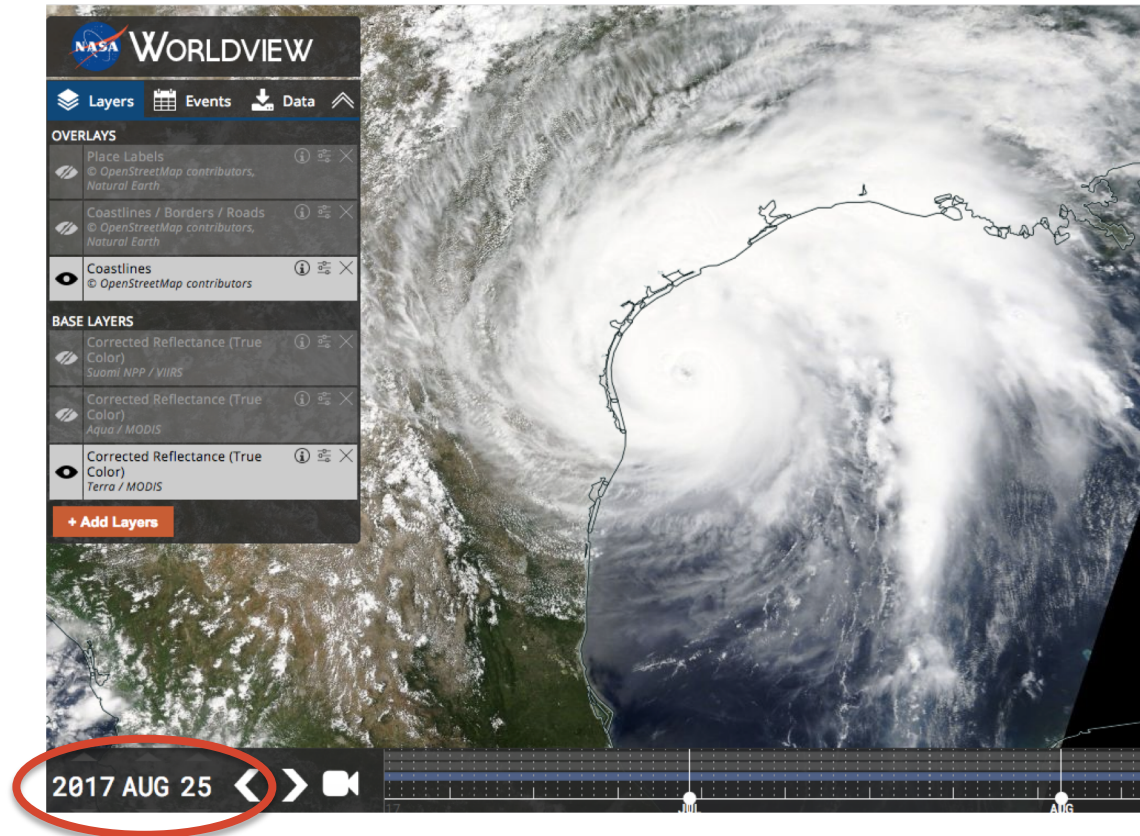


# MODIS and VIIRS Image Access

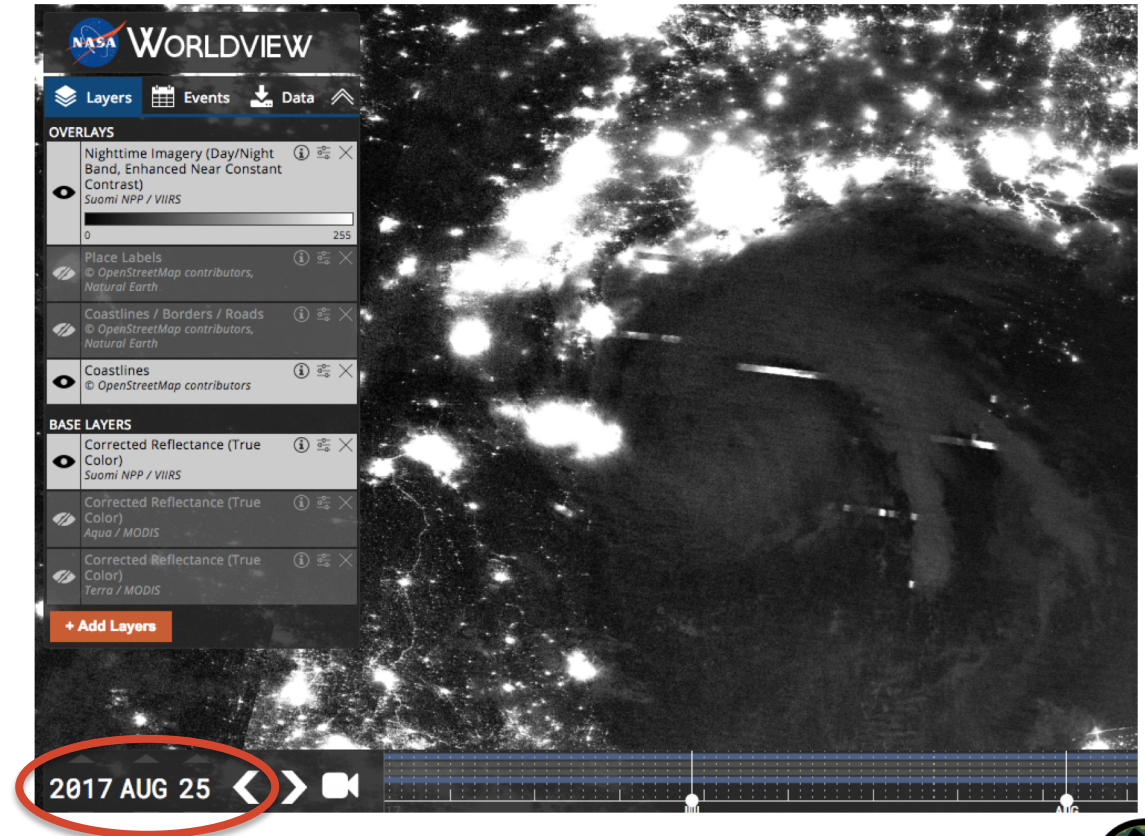
<https://worldview.earthdata.nasa.gov/>

## Hurricane Harvey Images

Terra MODIS



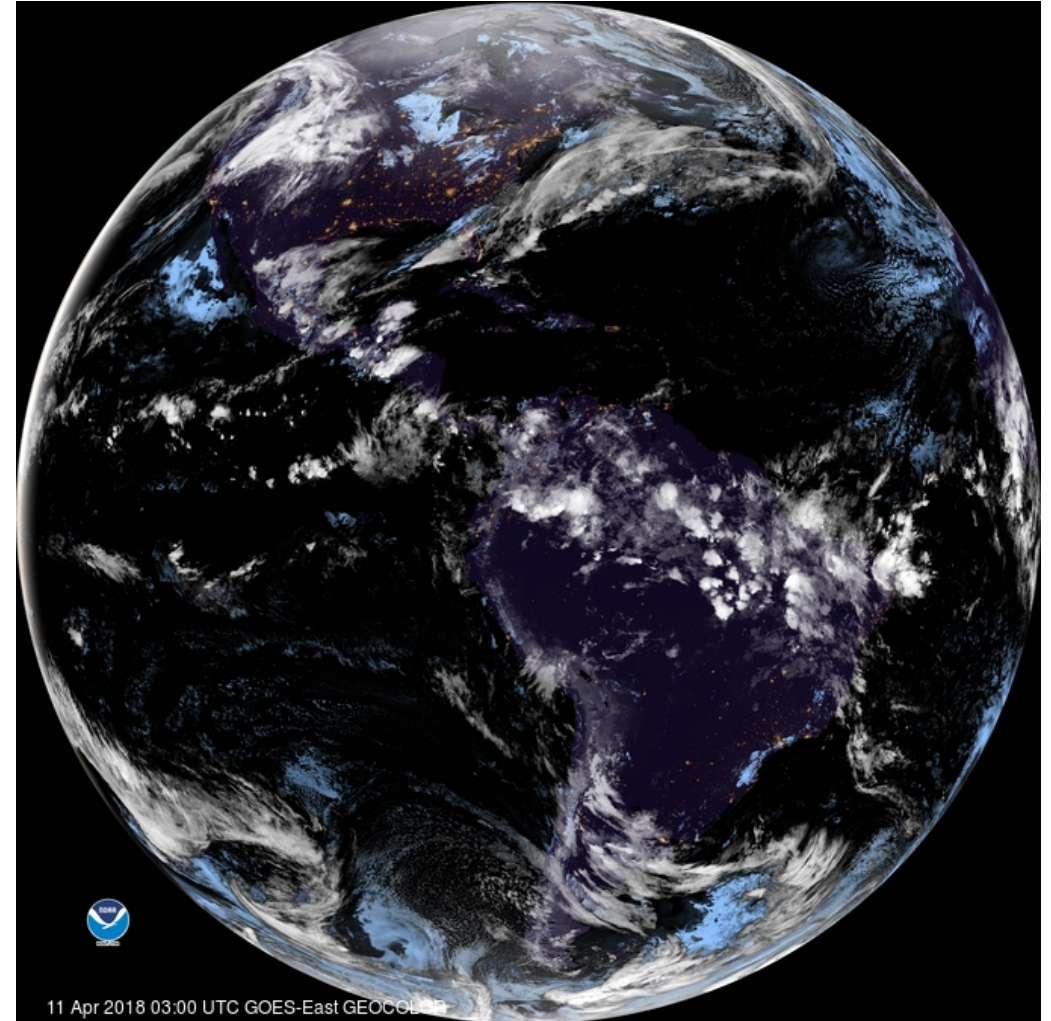
SNPP VIIRS Night Imagery



# Operational Satellite Images for Tropical Cyclones

<https://www.nhc.noaa.gov/satellite.php>

- Available from NOAA
- Images from Geostationary Satellites
  - GOES East & West
  - METEOSAT
  - HIMAWARI-8

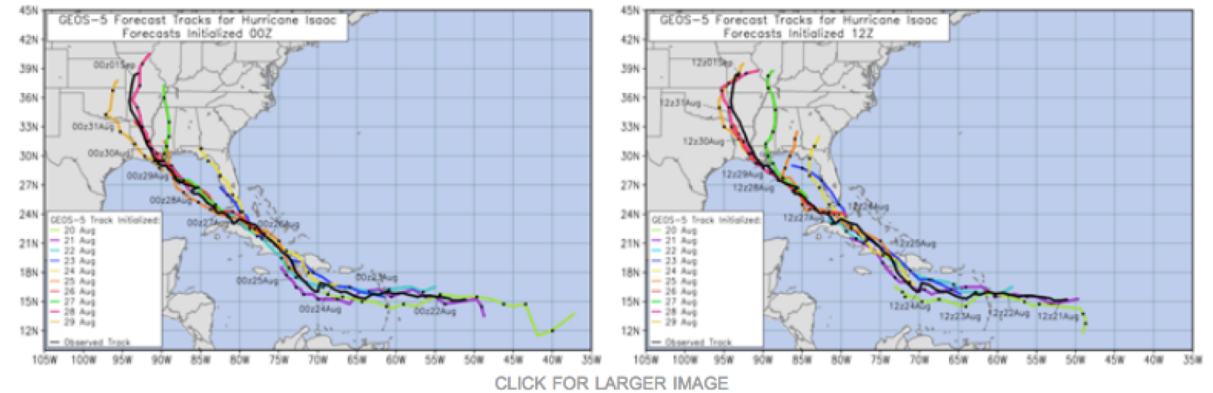


# NASA Earth System Model Forecast

[https://gmao.gsfc.nasa.gov/GEOS\\_systems/](https://gmao.gsfc.nasa.gov/GEOS_systems/)

- Goddard Earth Observing System (GEOS)-5 provides near real time data and forecast data
- Data available at 5/16 x 1/4 degree lon-lat grid, 42 vertical level.
- Surface data available every hour
- Atmospheric (A), Oceanic (O) and Coupled A-O General Circulation Model configuration options
- Chemistry-Climate and Chemistry-Transport models available

## Hurricane Isaac Track (2012)



**Figure 1.** GEOS-5 0000 UTC (left) and 1200 UTC (right) forecast tracks for Hurricane Isaac, from August 20 to August 29. Forecast positions of the low pressure center of Isaac are depicted in color, with black dots indicating the center's forecast position at 12 hour intervals (at 0000 UTC and 1200 UTC). The observed track is shown in black, with the center's position at 0000 UTC (left) and 1200 UTC (right) labeled.

Image Credit: NASA GMAO



# GEOS-5 Weather Data Maps – NRT and Forecast

<https://fluid.nccs.nasa.gov/weather/wxmaps/>

**VARIABLES**

Abs EPV	Humidity
<b>Precip &amp; SLP</b>	Temperature
Vorticity	Vert Velocity
Wind Speed	

**REGIONS**

Atlantic	Australia
Global	Mid Atlantic
<b>North America</b>	N Polar
Pacific	Seven Seas
S Polar	

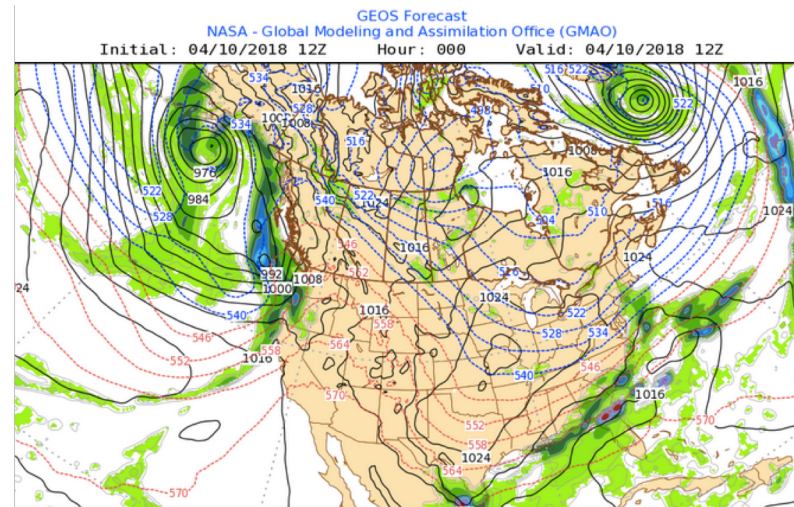
**FORECAST INITIAL TIME**

◀ 10Apr2018 12z ▶

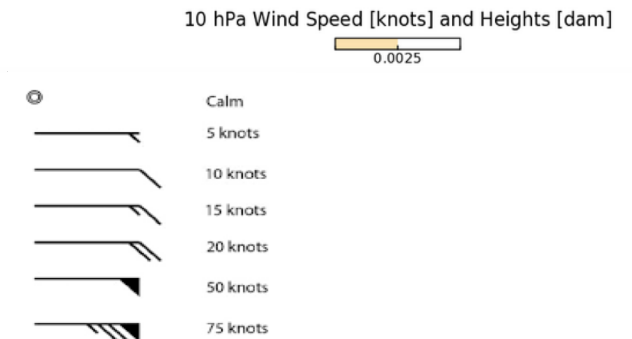
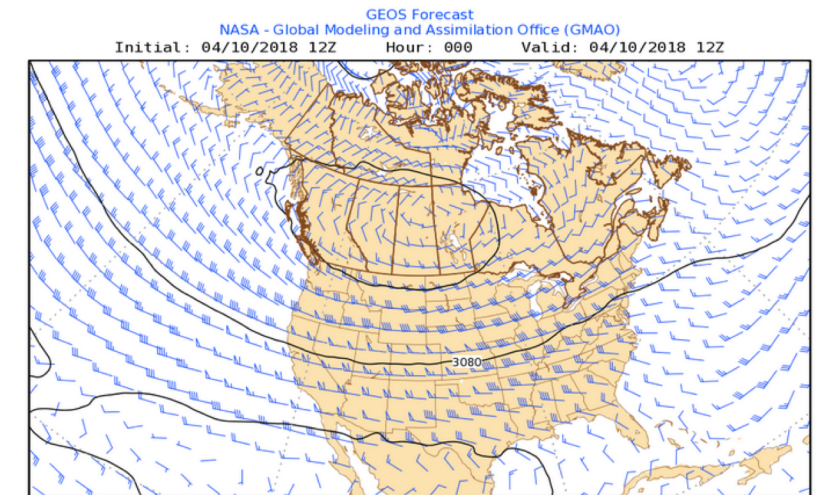
**FORECAST LEAD HOUR**

000 10Apr2018 12z

## Precipitation Sea Level Pressure



## Wind Speed & Direction

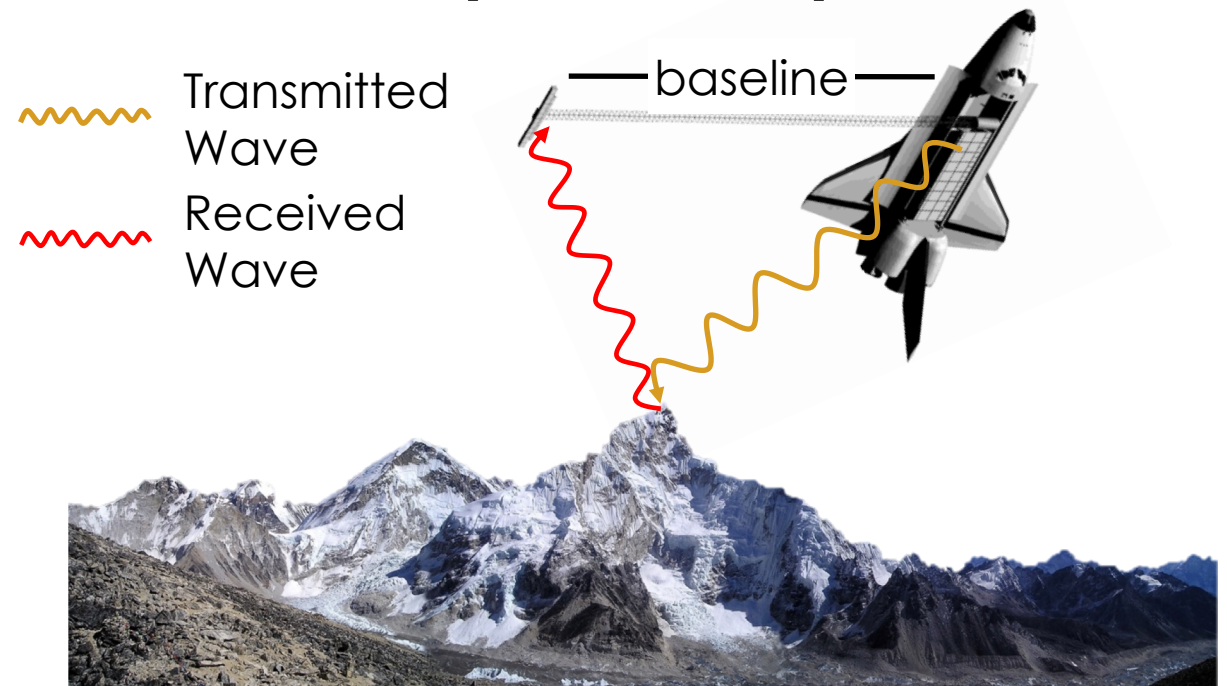


# Terrain Data From Shuttle Radar Topography Mission (SRTM)

<https://www2.jpl.nasa.gov/srtm/mission.htm>

- A C-band (5.6 cm) radar mission
- On NASA Space Shuttle Endeavor
- Completed February 2000
- 176 orbits around Earth in 11 days
- Acquired digital terrain elevation data of all land between 60°N- 56°S latitude
- ~80% of Earth's total land mass
- SRTM used interferometry to gather topographic (elevation) data
- For detailed information see: [https://arset.gsfc.nasa.gov/sites/default/files/water/Brazil\\_2017/Day3/S6P2.pdf](https://arset.gsfc.nasa.gov/sites/default/files/water/Brazil_2017/Day3/S6P2.pdf)

**Radar signals being transmitted and received on the SRTM mission (not to scale)**



Spatial Resolution: 30 m



# SRTM Elevation Data Access From Global Data Explorer (GDEx)

<http://gdex.cr.usgs.gov/>

The screenshot displays the Global Data Explorer (GDEx) interface. At the top, there are navigation menus for 'EARTHDATA', 'Data Discovery', 'DAACs', 'Community', and 'Science Disciplines'. The main header features the USGS logo and 'LP DAAC'. A toolbar contains various map navigation icons: a magnifying glass with a plus sign (Zoom), a magnifying glass with a minus sign, a hand icon, a red bounding box icon, a globe icon, a US flag icon, a 'XY' icon, a yellow rectangle icon, a yellow rectangle with a red border icon, a yellow rectangle with a red border and a plus sign icon, and a folder icon with a plus sign (Download). A white box labeled 'Zoom' points to the magnifying glass with a plus sign. A larger white box labeled 'Define region of interest by bounding box, state, country, or lat/long' encompasses the globe, US flag, 'XY', and yellow rectangle icons. A white box labeled 'Refresh' points to the yellow rectangle with a red border icon. A white box labeled 'Download' points to the folder icon with a plus sign. The main map area shows a topographic map of the United States and Mexico. On the right side, there is a 'Map Layers' panel with a list of layers: 'Background Image', 'ASTER Global DEM', 'NASA Blue Marble', 'Data Coverage', 'ASTER Global DEM V2', 'NGA SRTM 1 arcsec', 'NGA SRTM 3 arcsec', 'NASA SRTM 1 arcsec', 'NASA SRTM 3 arcsec', 'World Boundaries', 'Country', and 'State/Province'. A 'Legend' panel is also visible at the bottom right. The footer contains links for 'Accessibility', 'FOIA', 'Privacy', and 'Policies and Notices', along with contact information for the U.S. Department of the Interior and U.S. Geological Survey.





# Socioeconomic Data

<http://sedac.ciesin.columbia.edu/>

**SOCIOECONOMIC DATA AND APPLICATIONS CENTER (SEDAC)**  
A Data Center in NASA's Earth Observing System Data and Information System (EOSDIS) — Hosted by CIESIN at Columbia University

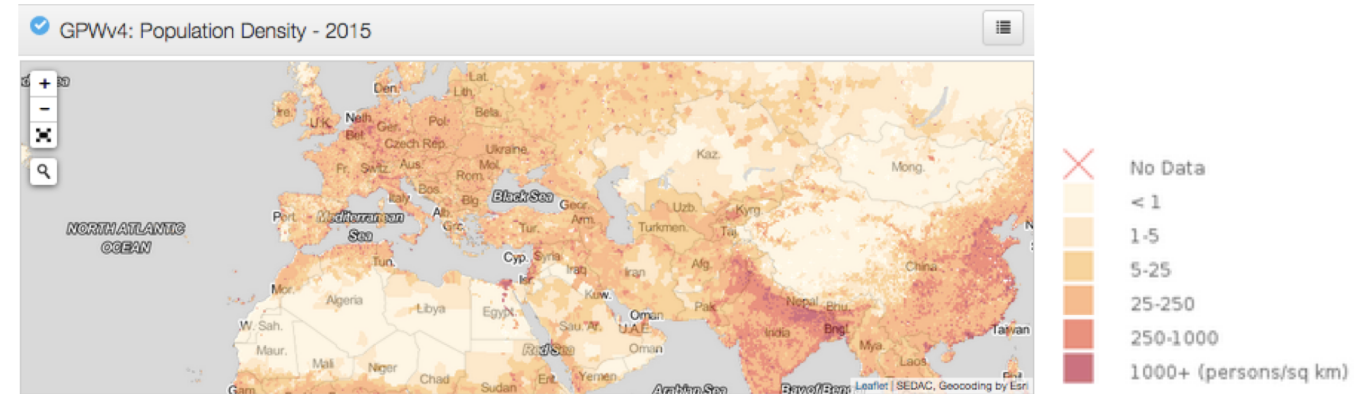
DATA ▾ MAPS ▾ THEMES ▾ RESOURCES ▾ SOCIAL MEDIA ▾ ABOUT ▾ HELP

### Data Collections (41)

1 of 2  
Prev | Next

- Anthropogenic Biomes**  
Describes 21 global anthropogenic biomes based on population density, land use, and vegetation cover, grouped into six categories—dense settlements, villages, croplands, rangeland, forested, and wildlands.
- Archive of Census Related Products (ACRP)**  
A collection of value-added georeferenced data files derived from the 1990 U.S. Census, spanning the United States and its territories.
- China Dimensions**  
A wide range of data from circa 1990, including administrative boundaries, population and agricultural census data, and other statistics, covering the administrative regions of China.
- Climate Effects on Food Supply**  
Assessments of potential climate change impacts of temperature and precipitation on global staple crop production (wheat, rice, and maize), with a focus on quantitative estimates of yield changes based on multiple climate scenarios.
- Compendium of Environmental Sustainability Indicators**  
A compilation of sustainability indicators from multiple sources incorporating multiple country codes. Methodological summaries are contained in an accompanying metadata database.
- Energy Infrastructure**  
Data on the locations and status of nuclear power facilities along with estimates of the population residing near locations with at least one operating reactor.
- Environmental Performance Index (EPI)**  
Released every two years since 2006, the EPI groups performance indicators into two policy categories, environmental health and ecosystem vitality, in order to gauge how close countries are to reaching established environmental policy goals.
- Environmental Sustainability Index (ESI)**  
Released four times between 2000 and 2005, and based on a compilation of indicators derived from underlying data sets, the ESI measures overall progress towards environmental sustainability for 146 countries.
- Environmental Treaties and Resource Indicators (ENTRI)**  
Information on treaty participation by country, environmental treaty texts, and a Conference of Party (COP) decision search tool for major multilateral environmental agreements.
- Georeferenced Population Data sets of Mexico**  
Administrative boundaries, settlement locations and populations, and gridded population data for Mexico circa 1990. Includes place names, geographic coordinates of more than 30,000 urban and metropolitan places, and elevation data for
- Global Agricultural Lands**  
Combines satellite data with agricultural inventory data to estimate the proportion of land area in cropland and pasture for the year 2000.
- Global Fertilizer and Manure, v1**  
Global gridded data sets of fertilizer application rates and manure production of nitrogen and phosphorus for circa 2000.

## Global Population Density



- Other Useful Datasets:
  - Global urban data from the Landsat satellite
  - Global reservoir and dam
  - Low elevation coastal zones
  - Global roads
  - Energy infrastructure
  - Global agricultural land



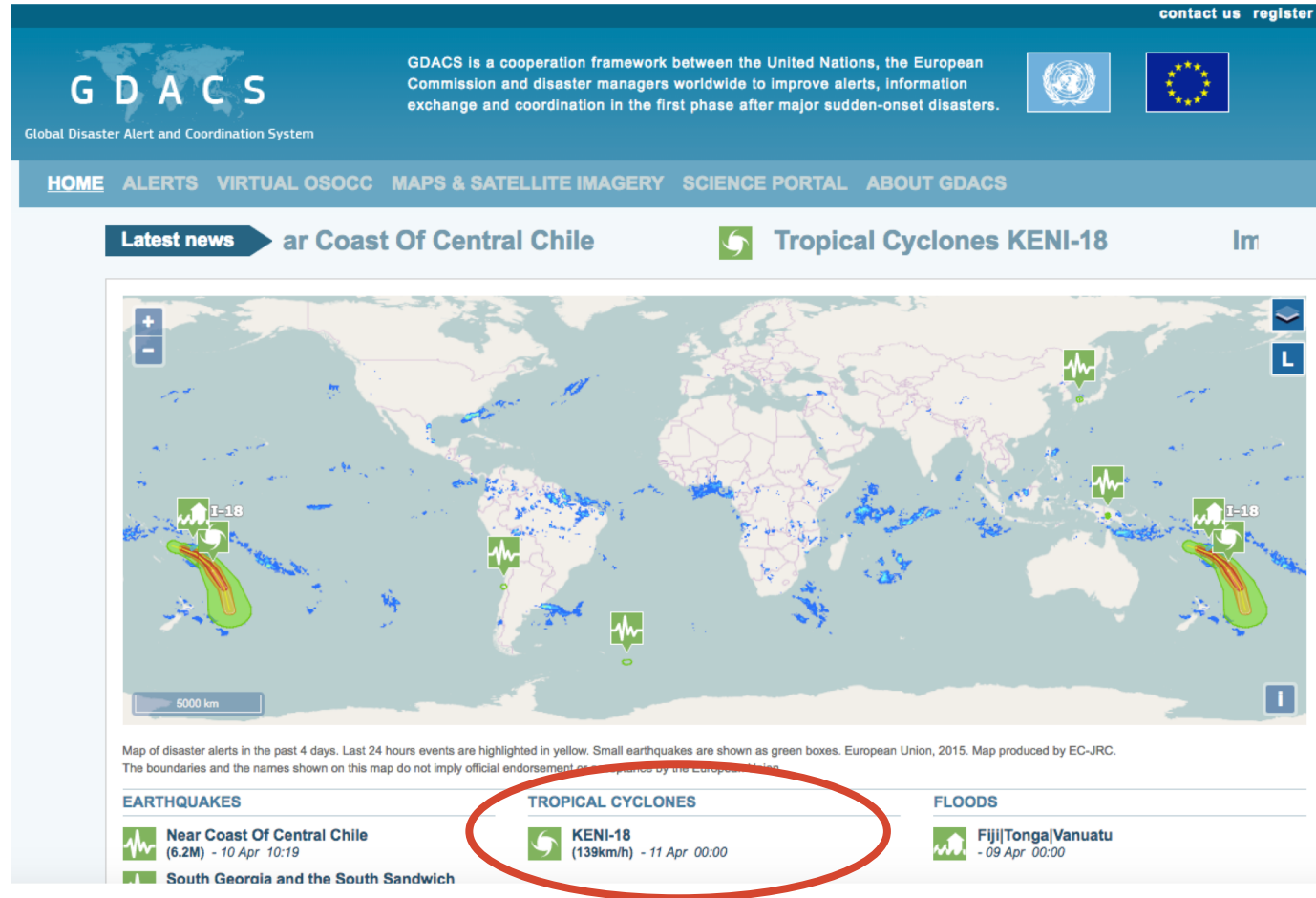
# Global Disaster Alert and Coordination System

<http://www.gdacs.org/>

## Integrated Data and Information Portal





Include

- near real-time and past storm information
- Data and maps from models and satellites
- Media reports and impacts

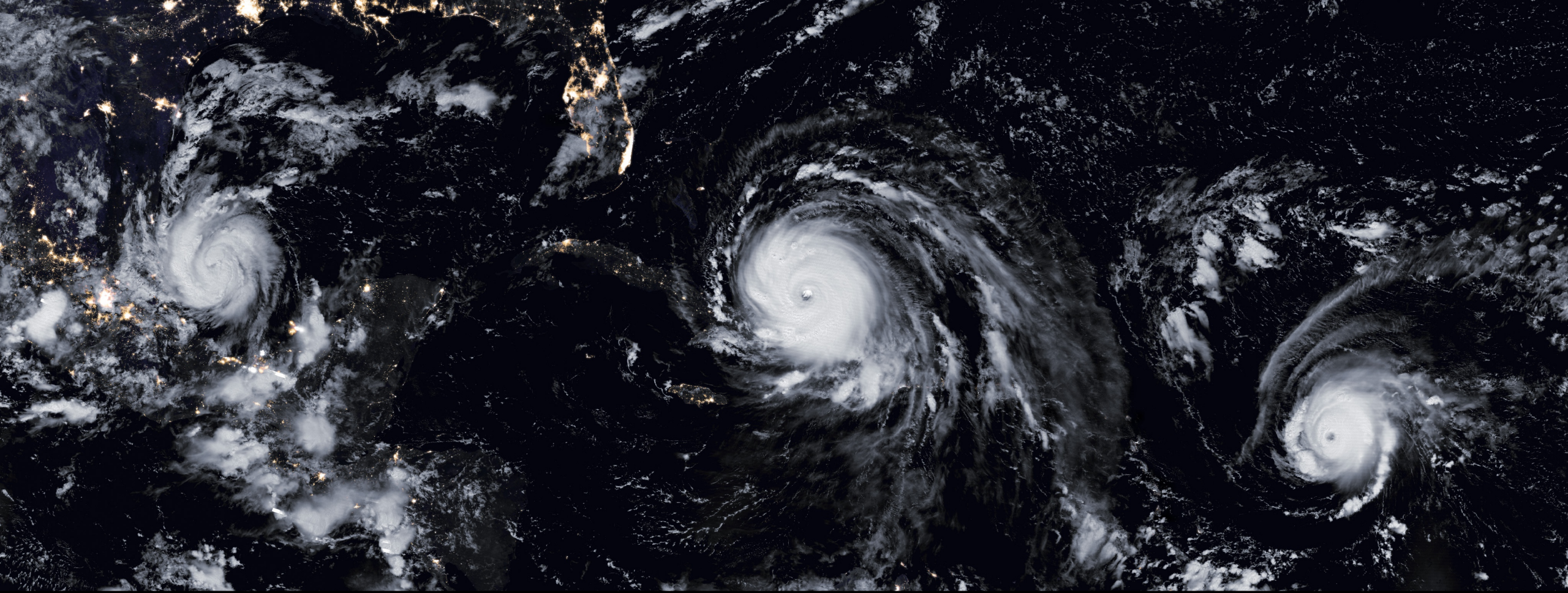


The screenshot shows the GDACS website interface. At the top, there is a blue header with the GDACS logo and the text: "GDACS is a cooperation framework between the United Nations, the European Commission and disaster managers worldwide to improve alerts, information exchange and coordination in the first phase after major sudden-onset disasters." Below the header is a navigation bar with links: HOME, ALERTS, VIRTUAL OSOCC, MAPS & SATELLITE IMAGERY, SCIENCE PORTAL, ABOUT GDACS. The main content area features a "Latest news" section with a dropdown menu showing "ar Coast Of Central Chile" and "Tropical Cyclones KENI-18". Below this is a world map displaying disaster alerts in the past 4 days, with the last 24 hours highlighted in yellow. The map shows several alerts, including tropical cyclones and earthquakes. Below the map is a list of events under three categories: EARTHQUAKES, TROPICAL CYCLONES, and FLOODS. The "TROPICAL CYCLONES" category is circled in red, showing "KENI-18 (139km/h) - 11 Apr 00:00".

Map of disaster alerts in the past 4 days. Last 24 hours events are highlighted in yellow. Small earthquakes are shown as green boxes. European Union, 2015. Map produced by EC-JRC. The boundaries and the names shown on this map do not imply official endorsement or acceptance by the European Union.

EARTHQUAKES	TROPICAL CYCLONES	FLOODS
 Near Coast Of Central Chile (6.2M) - 10 Apr 10:19	 KENI-18 (139km/h) - 11 Apr 00:00	 Fiji Tonga Vanuatu - 09 Apr 00:00
 South Georgia and the South Sandwich		





Demonstration:

NASA Worldview, Giovanni

Hurricane Harvey, Atlantic Ocean and Gulf of Mexico (8/17-9/3/2017)

Cyclone Marcus, Southern Indian Ocean (3/16-24/2018)

# Hurricane Harvey

[https://www.nhc.noaa.gov/data/tcr/AL092017\\_Harvey.pdf](https://www.nhc.noaa.gov/data/tcr/AL092017_Harvey.pdf)



Hurricane Harvey

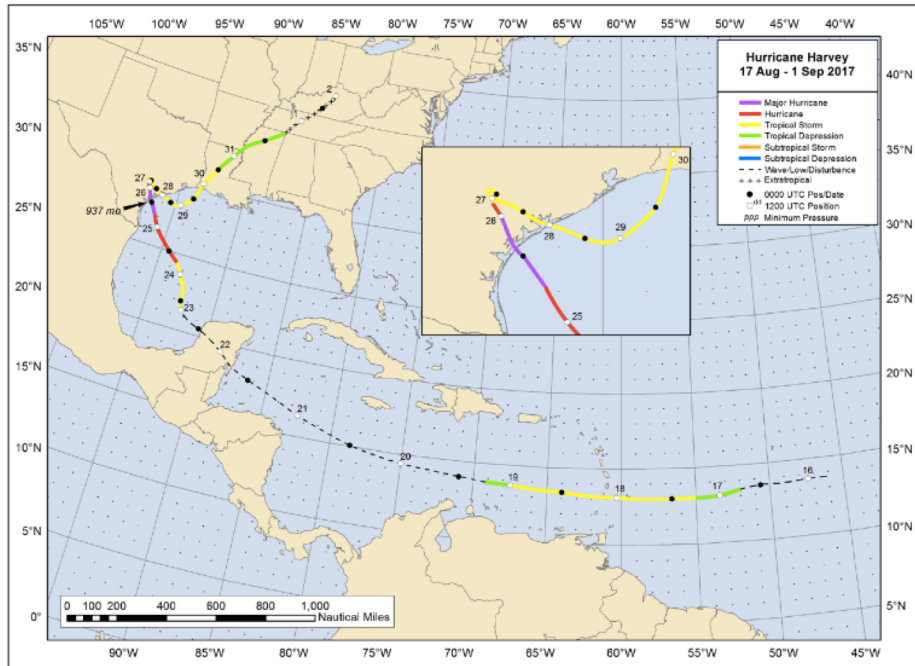


Figure 2. Best track positions for Hurricane Harvey, 17 August – 1 September 2017.



The scope of Harvey's destruction is incomprehensible. See how it stacked up to Hurricanes Katrina and Sandy and made history. USA TODAY



(Photo: USA TODAY NETWORK)

CONNECT TWEET LINKEDIN COMMENT 16 EMAIL MORE

The initial estimates from Hurricane Harvey are in, and they dwarf most other hurricanes and tropical storms.

More than 30,000 people have fled to Houston shelters while an untold number of other people have been displaced since it came ashore Friday night as

a Category 4 hurricane.

Here's a look at the storm's massive size and the destruction it has wrought:

## \$190 BILLION

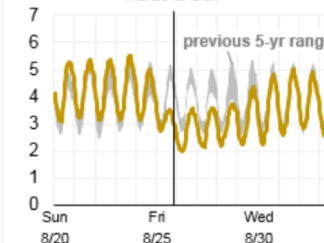
Hurricane Harvey's price tag could dwarf previous natural disasters in the U.S., according to an estimate from weather firm AccuWeather (in billions):

Hurricane Harvey caused electric system outages and affected wind generation in Texas

Hourly electricity load in ERCOT southern and coastal regions thousand megawatts (MW)

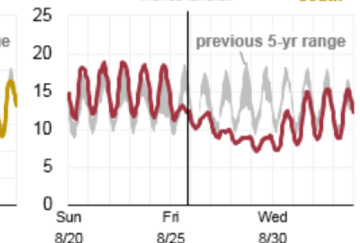
South region

Friday 8/25/17 10:00 p.m.  
Hurricane Harvey makes landfall



Coastal region

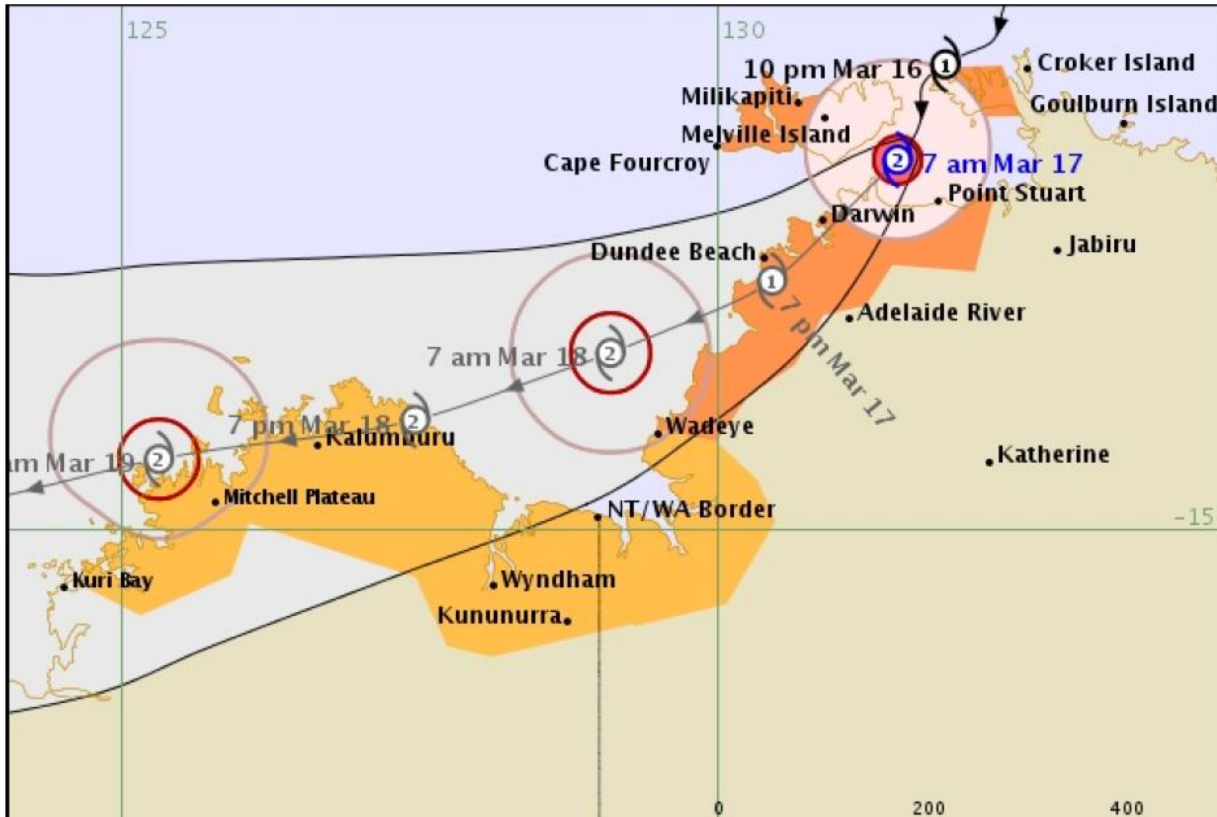
Friday 8/25/17 10:00 p.m.  
Hurricane Harvey makes landfall



Left: [FEMA](#), Middle: [USA Today](#), Right: [U.S. EIA](#)



# Tropical Cyclone Marcus



## Tropical Cyclone Marcus hits Darwin with 130km/h winds

Power is out in several areas and the storm has also affected the city's water supply

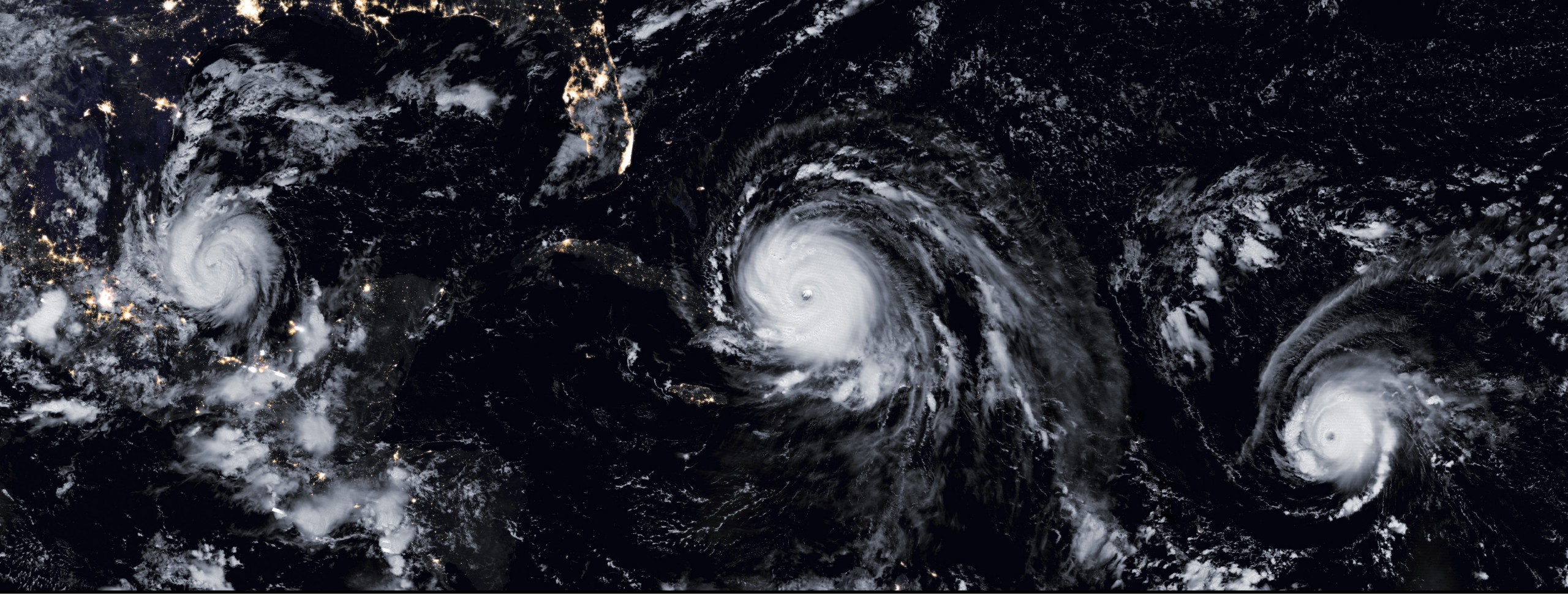


▲ Winds cause destruction as Tropical Cyclone Marcus bears down on Darwin. Photograph: Glenn Campbell/AAP

Darwin is being battered by 130km/h winds and heavy rain as Tropical Cyclone Marcus hits the city, bringing down trees and power lines and shutting down the local water supply in parts.

Left: [ABC News Australia](#), Right: [The Guardian](#)





Exercise: Monitor a Storm

# Monitoring and Preparing for an Upcoming Storm

- National Weather Service Announcement and News
- NSC/CPHC Forecast
- Cyclone Watch/Warning

## Monitor Satellite Images

- MODIS and VIIRS (Worldview)
- Geostationary Images (NHC)
- GPM Precipitation (Giovanni and GPM Hurricane Portal)
- Winds and SLP (GEOS-5)

Assess the situation in your area for 48, 24, 12 hours

- Stock emergency supplies
- Protect your property
- Are you in a low elevation area?
- Should you plan to evacuate?

Follow FEMA Guidelines





Thank you!

**Next Week:** Monitoring During & After a Cyclone:  
Precipitation, Winds, Storm Surge Flooding