Disasters Scenarios: Tropical Storms

Erika Podest, Elizabeth Hook, Sean McCartney, and Amita Mehta

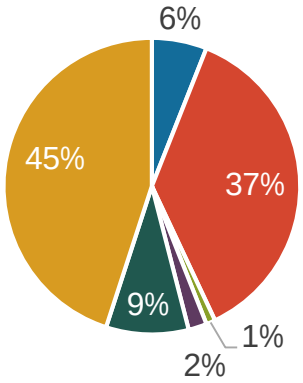
Training Objectives

- Identify remote sensing data 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

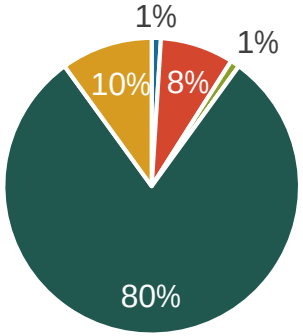
Impacts of Tropical Storms

Impacts of Tropical Storms (1980-2009)

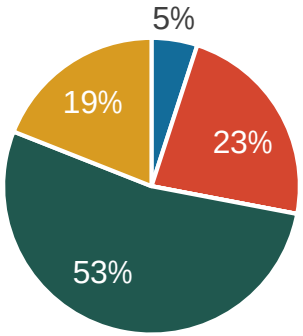
Frequency by Region (n=1,080)



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
- WPRO = 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.

Impacts of Tropical Storms

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

U.S. Deaths Directly Attributable to Hurricanes (1963-2012)

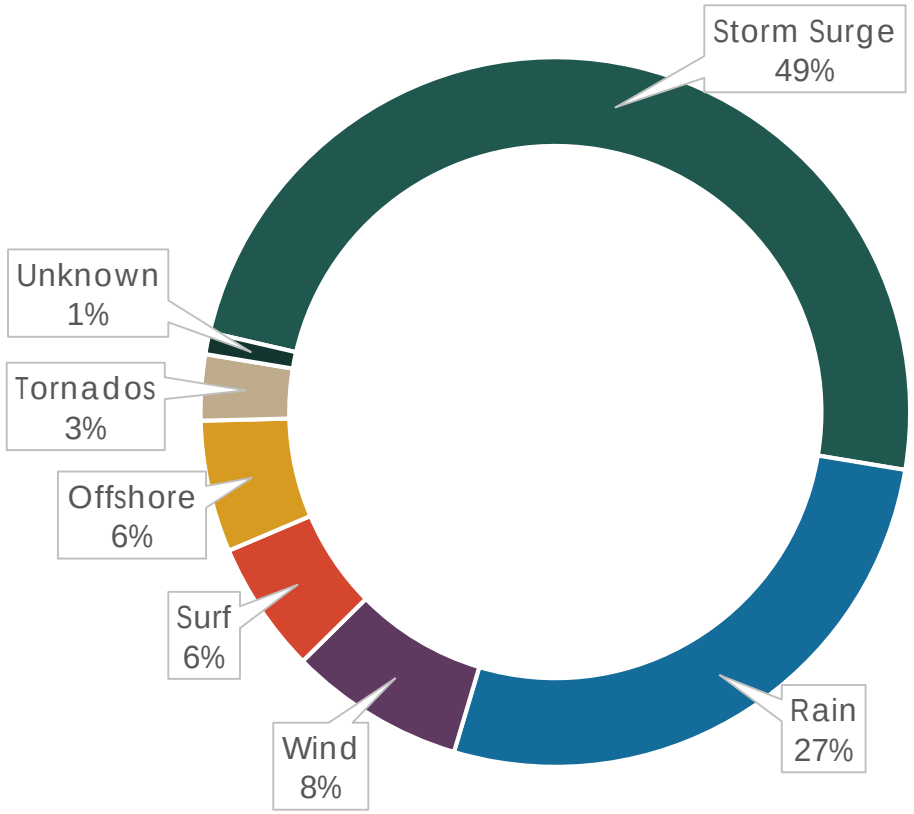


Chart Data Source: National Hurricane Center

Monitoring Tropical Storms for Emergency Preparedness

- ARSET offered an introductory training in May 2018 focused entirely on monitoring tropical storms
- The four-hour training goes into more detail on some of the information presented in this session, if you would like more details
- Available at: https://arset.gsfc.nasa.gov/disasters/webinars/18-tropical-storms

Potential Problems to Address Before/During/After a Tropical Storm

Before Making Landfall

- Where is the storm now, what is its wind speed, and how much rain is it producing?
- Where is the storm going, is it going to make landfall? When and where?
- When it makes landfall what is its projected wind speed, rainfall, and storm surge?
- What are the areas at risk for flooding?

During Landfall

- How much rain is the storm producing and what is its wind speed?
- What is its projected path, rain, and wind speed?
- What areas are flooded and what areas are most likely to flood?
- What is the current storm surge and what is it projected to be?

After the Event

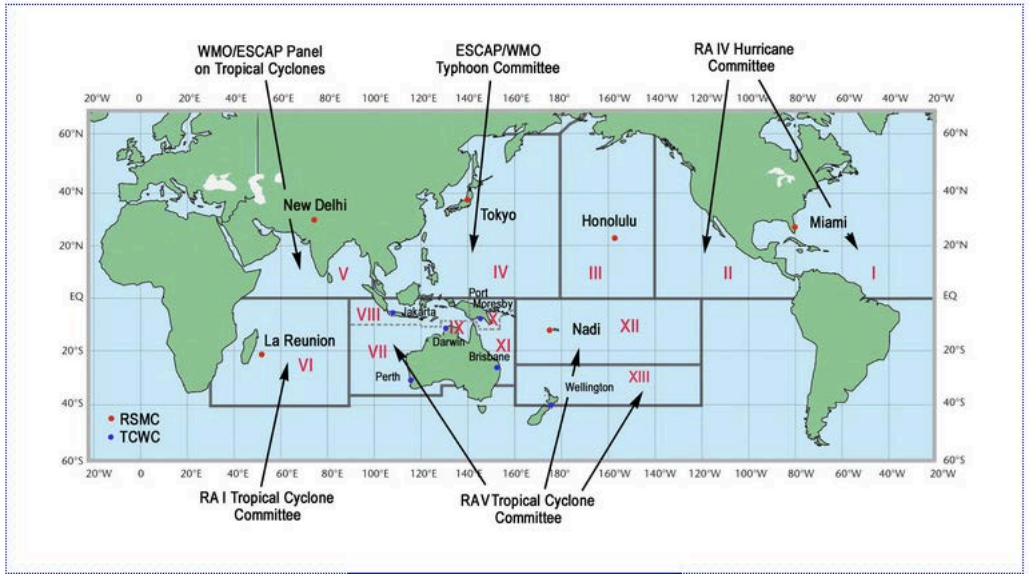
- What is the extent of flooding and how fast is it receding?
- What is the extent of the damage?

Monitoring the Storm

Tropical Storm 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	U.S. National Hurricane Center (RSMC Miami)
III	Central Pacific	U.S. Central Pacific Hurricane Center (RSMC Honolulu)
IV	Northwest Pacific	Japan Meteorological Agency (RSMC Tokyo)
V	North Indian Ocean	India Meteorological Department (RSMC New Delhi)
VI	Southwest Indian Ocean	Météo France (RSMC La Réunion)
VII-XI	Southwest Pacific and Southeast Indian Ocean	VII: Australian Bureau of Meteorology (TCWC Perth) VIII: Indonesian Agency for Meteorology (TCWC Jakarta) IX: Australian Bureau of Meteorology (TCWC Darwin) X: Papua New Guinea (TCWC Port Moresby) XI: Australian Bureau of Meteorology (TCWC Brisbane)
XII-XIII	South Pacific	XII: Fiji Meteorological Service (RSMC Nadi) XIII: Meteorological Service of New Zealand, Ltd. (TCWC Wellington)

Tropical Cyclone Operational Information Portals

Western/South Pacific and Indian Oceans (West of 180)
Monitored by the:

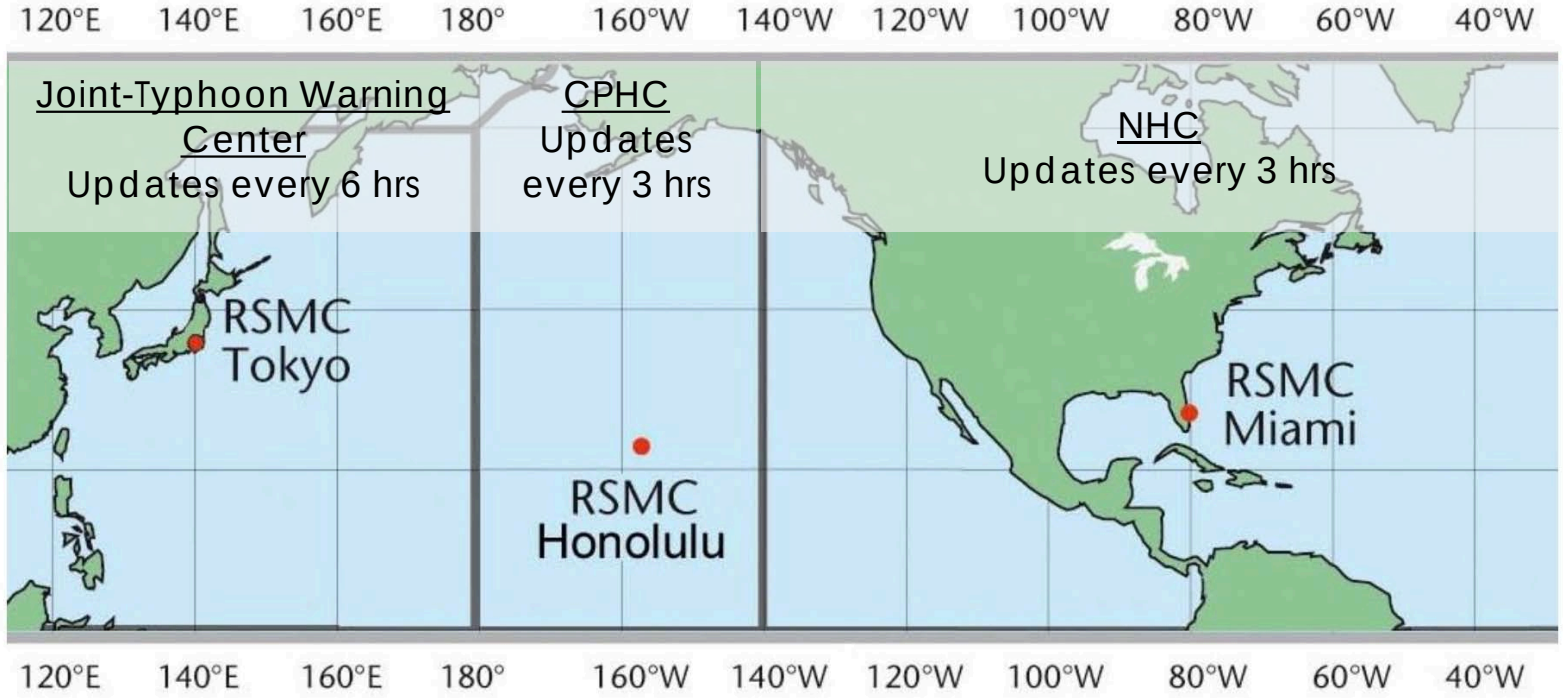
- Joint Typhoon Warning Center: http://www.metoc.navy.mil/jtwc/jtwc.html
- Japan Meteorological Agency

Central Pacific (140W to 180)
Monitored by the:

- Central Pacific Hurricane Center, Honolulu, HI: https://www.prh.noaa.gov/cphc/

Eastern Pacific & North Atlantic (East of 140W)
Monitored by the:

- National Hurricane Center, Miami, FL: https://www.nhc.noaa.gov/



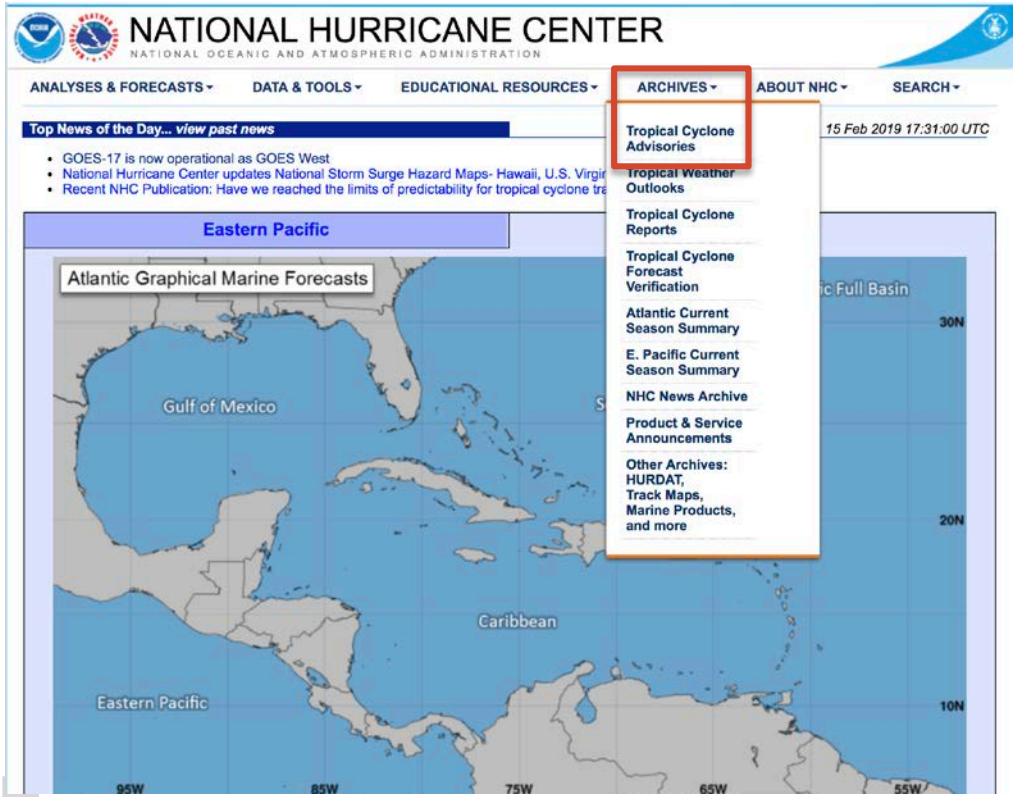
Accessing Storm Tracking Information (Atlantic and Eastern Pacific)

- The National Hurricane Center (NOAA) is the portal for hurricane tracking in the Atlantic and Eastern Pacific: https://www.nhc.noaa.gov/
- You can access current information and forecasts during the North American hurricane season (June 1 - November 30)
- We will use Hurricane Harvey (August 2017) as a case study for accessing archived information from the National Hurricane Center (NHC) and interpreting the 5-day forecast for hurricane path and wind speed
- Hurricane Harvey caused more than 100 confirmed deaths with total damage estimated at $125 billion (USD), making it one of the costliest hurricanes in US history*
- NOAA uses GOES-E and GOES-W geostationary satellites
  - Provide full-disk images of the Earth every 15 minutes, with a spatial resolution of 0.5 – 2 km (0.31–1.24 mi)

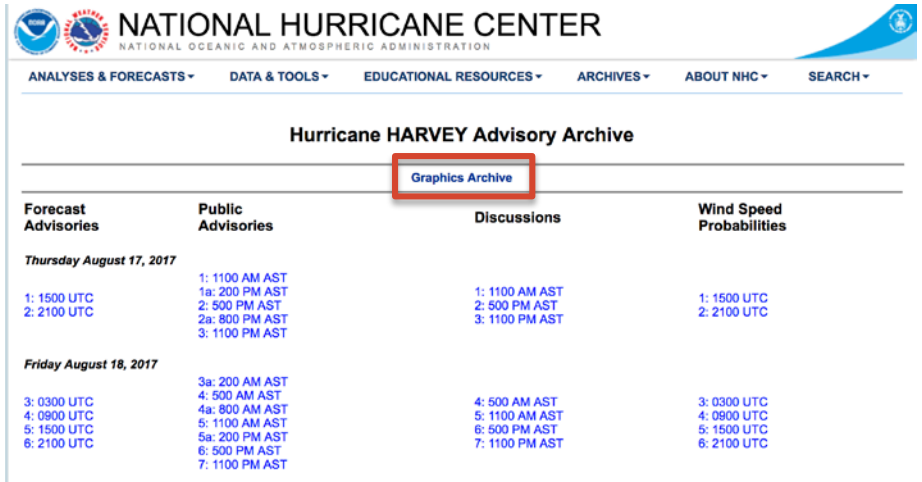
*https://www.nhc.noaa.gov/data/tcr/AL092017_Harvey.pdf

Accessing Storm Tracking Information (Atlantic and Eastern Pacific)

- Go to NHC https://www.nhc.noaa.gov/
- At the top of the page go to ARCHIVES → Tropical Cyclone Advisories

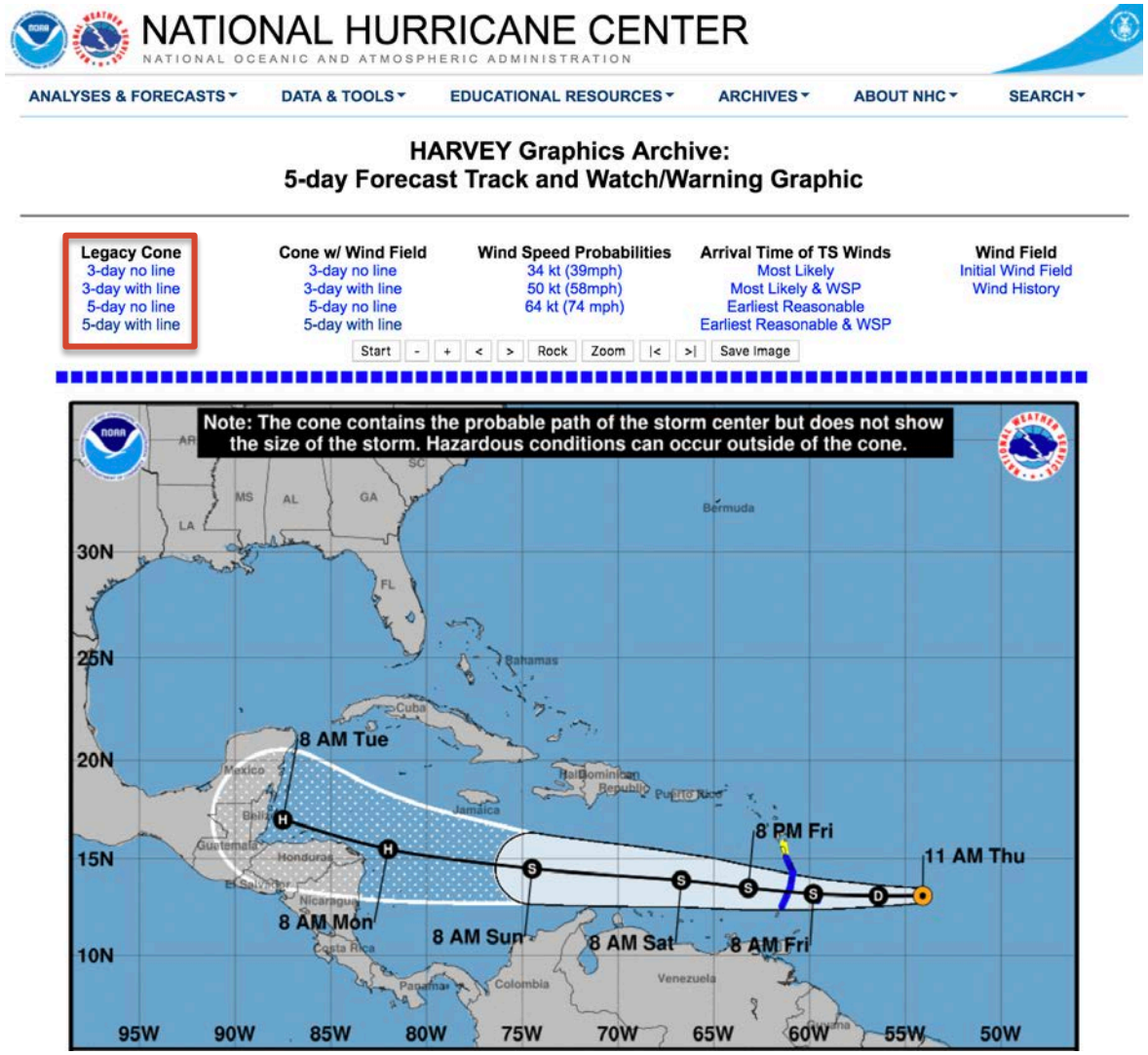


- Once the page has loaded, click on "2017"
- At the left of the page click on "Hurricane HARVEY"
- This page displays all advisories and wind speed probabilities for Hurricane Harvey from Aug 17-31
- Click on "Graphics Archive" in the top-center of the page



Accessing Storm Tracking Information (Atlantic and Eastern Pacific)

- Once directed to the Graphics Archive, at the top left of the page click on “Legacy Cone → 5-day with line”



Storm Tracking (Atlantic and Eastern Pacific)

Hurricane Harvey, August 17 – 30, 2017

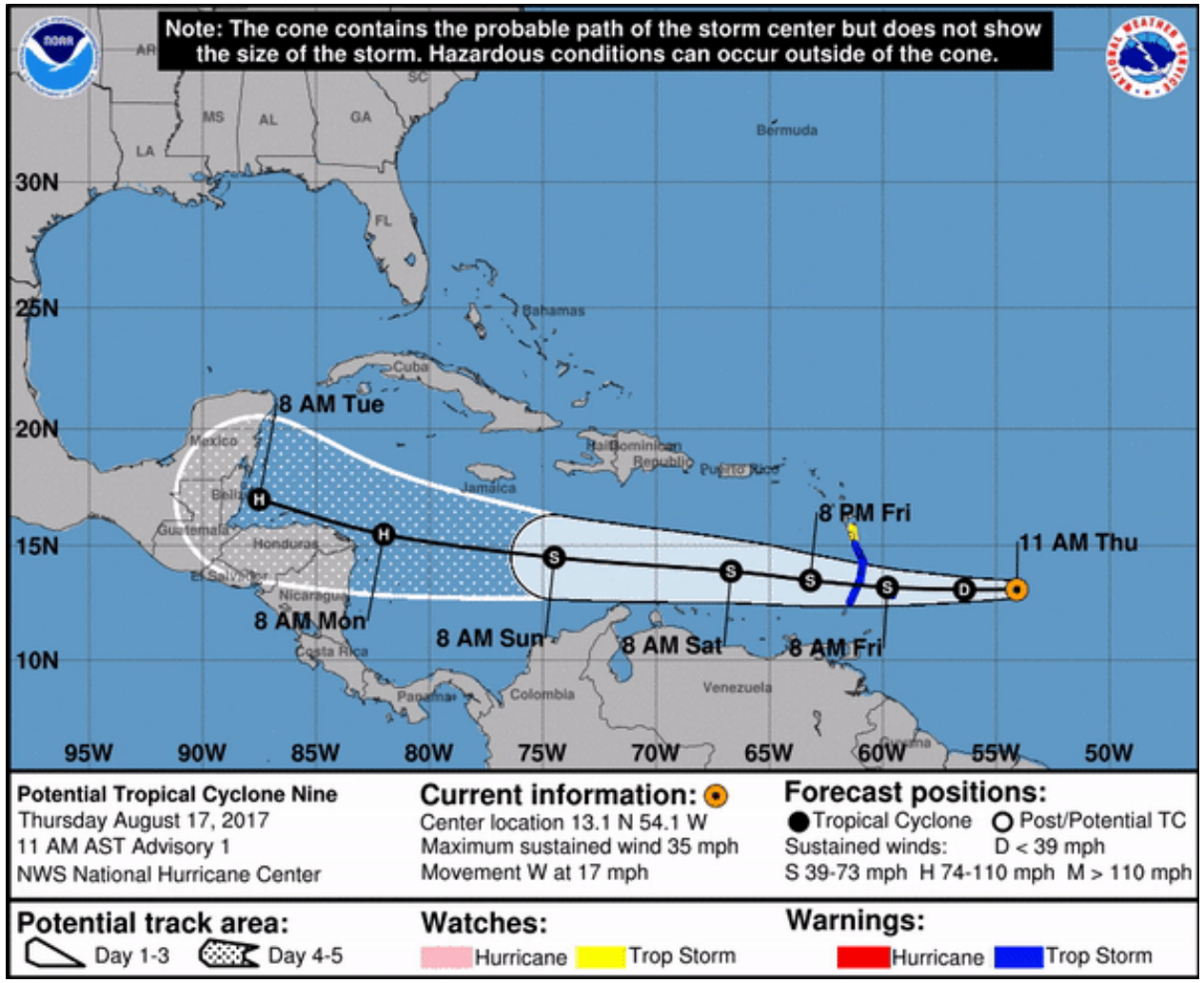


Image Credit: NHC

Accessing Storm Tracking Information (Atlantic and Eastern Pacific)

- The HARVEY Graphics Archive shows the 5-day Forecast Track and associated watches and warnings
- The series of images show the location of the hurricane and its potential track, updated every 3 hours from August 17-31
- The orange dot indicates the hurricane's present location while the cone indicates its projected path. The white area of the cone is the projected path for the next 3 days, and the dotted cone is the projected path 4-5 days out.
- The black circles in the middle of the cone forecast sustained wind speeds
  - D: < 39 mph
  - S: 39 - 73 mph
  - H: 74 - 110 mph
  - M: > 110 mph

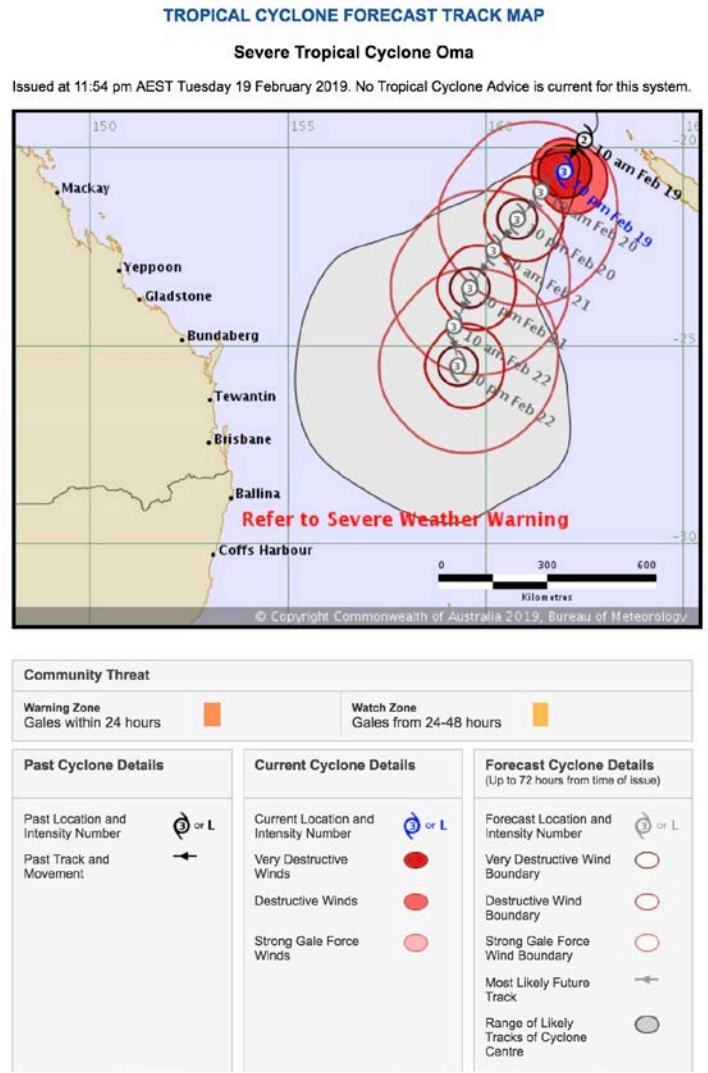
Accessing Storm Tracking Information (Southwest Pacific and Southeast Indian Ocean)

- The Australian Bureau of Meteorology (BOM) is the portal for hurricane tracking in the Southwest Pacific and Southeast Indian Ocean: http://www.bom.gov.au/cyclone/?ref=ftr
- You can access current information and forecasts during the Australian cyclone season (November – April)
- A tropical cyclone forecast map will be issued every six hours, increasing to every three hours when cyclone warnings are required
- BOM uses Japan's Himawari-8 geostationary satellite
  - Provides full-disk imagery every 10 minutes http://www.jma-net.go.jp/msc/en/

Storm Tracking (Southwest Pacific and Southeast Indian Ocean)

BOM forecast map contains:

- A quick update on the tropical cyclone
- Recent track of the cyclone and forecast track up to 72 hours after
- The latest position with a graphical representation of the current and forecast extent of gale-force (62 km/h), storm-force (89 km/h) and hurricane-force (117 km/h) winds
- The intensity category of the cyclone (1-weak to 5-strong)
- A grey uncertainty zone depicting the likely range of movement of the cyclone

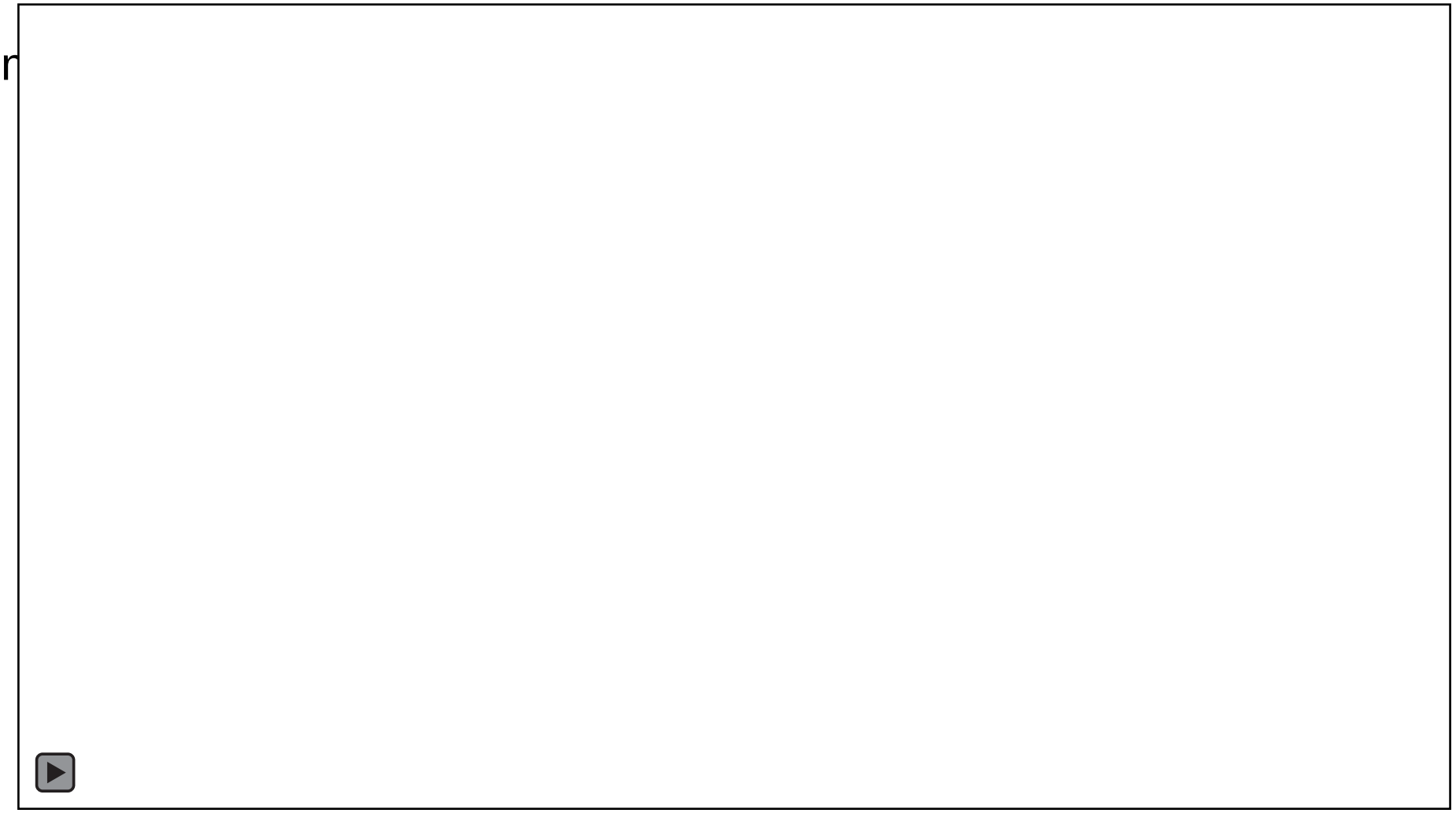


Monitoring Rainfall

Near Real Time Visualization of IMERG

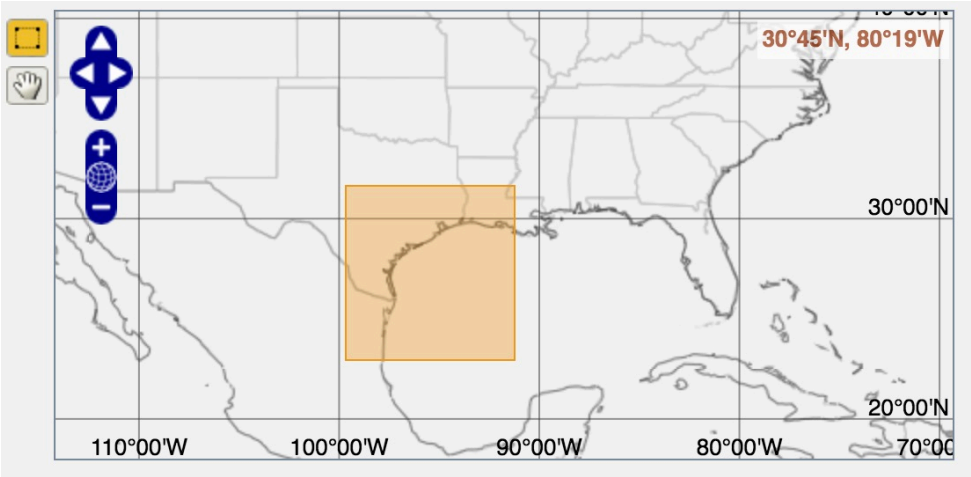
https://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=4285

IMERG fron



Monitoring Rainfall with the Integrated Multi-satellitE Retrievals for GPM (IMERG) Precipitation Product

- Can provide daily precipitation, accumulated precipitation, and half-hour rain rates
- Global Coverage from 60°S-60°N
- Available through NASA's Giovanni portal: https://giovanni.gsfc.nasa.gov/giovanni/
- Specify the dates Aug. 25-29, 2017 in the top left
- Draw your area of interest, which in this case is the Gulf Coast of the United States: -99.668,22.9395,-91.2305,31.6406

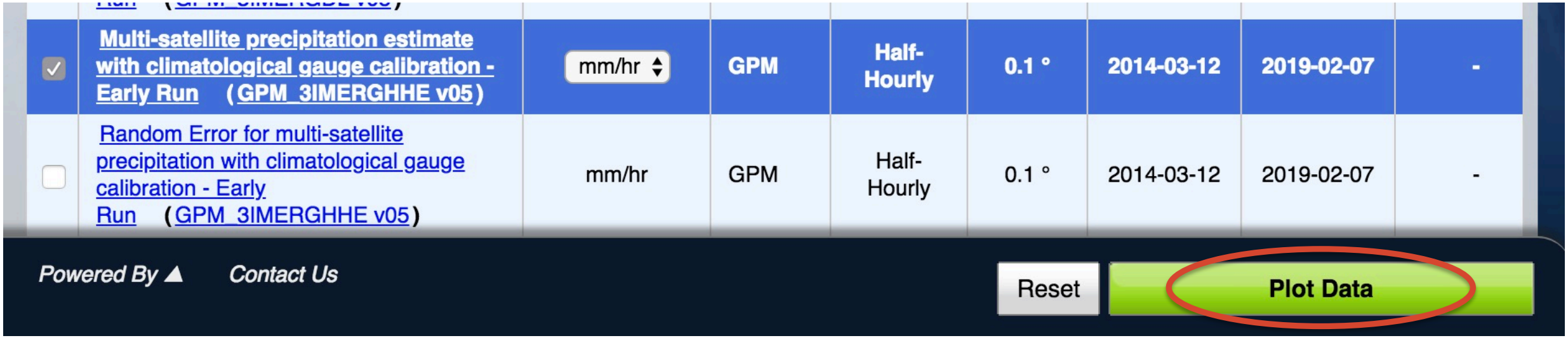


Monitoring Rainfall with the GPM (IMERG) Precipitation Product

- Select “Maps: Animation” in the top left
- Select ”Precipitation” on the left column (this will result in over 100 precipitation products)
- We are interested in the GPM IMERG Precipitation product. It is an operational product and there are several options:
  - “Early” run – now 5 hours (for flash flooding) – will be 4 hours
  - “Late” run – now 15 hours (for crop forecasting) – will be 12 hours
  - “Final” run – 3 months (for research data)
- Native time intervals are half-hourly and monthly (final only)

Monitoring Rainfall with the GPM (IMERG) Precipitation Product

- Select:
  - "Multi-satellite precipitation estimate with climatological gauge calibration - Early Run (GPM_3IMERGHHE v05)" from the list. It is a half hourly product at 0.1 degree spatial resolution. Units are in mm/hr.
  - Then "Plot Data" at the bottom

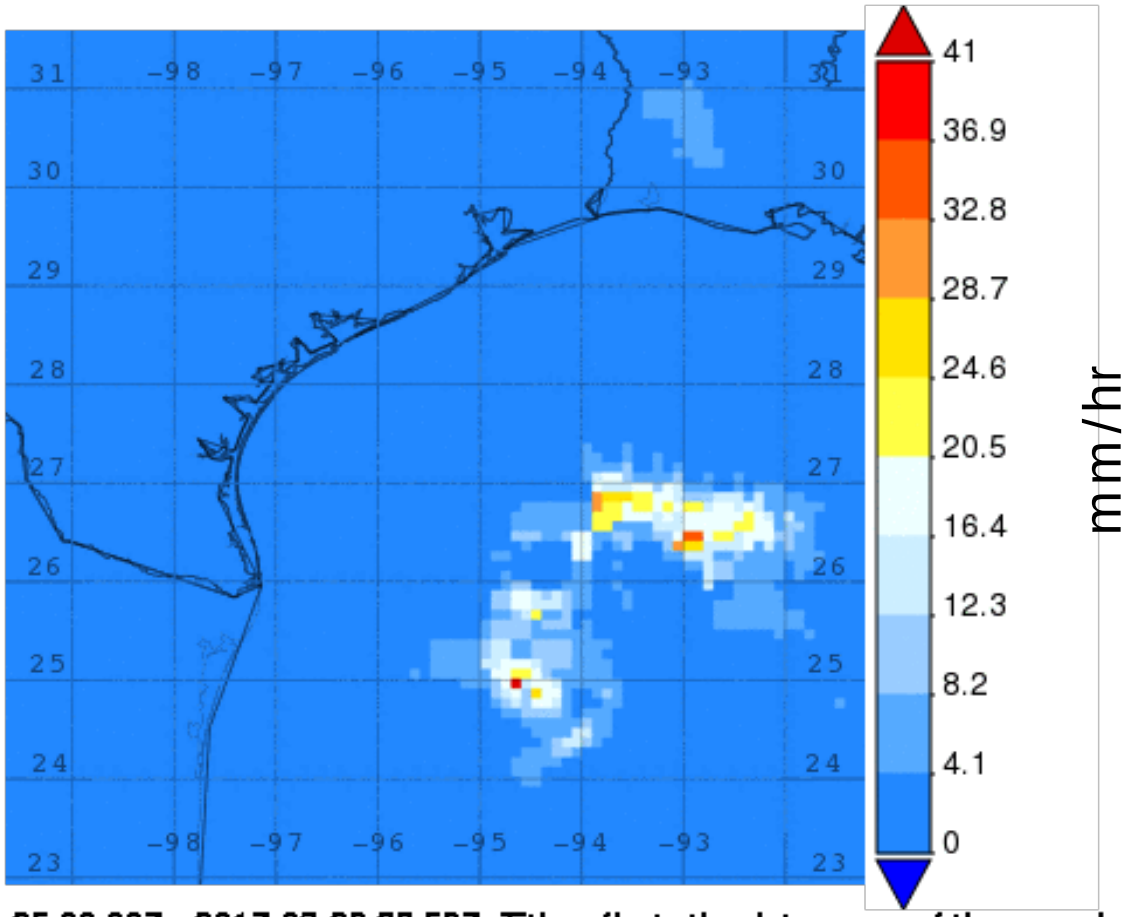


Example: GPM IMERG Precipitation During Hurricane Harvey

Half-Hourly Precipitation, August 25-29, 2017

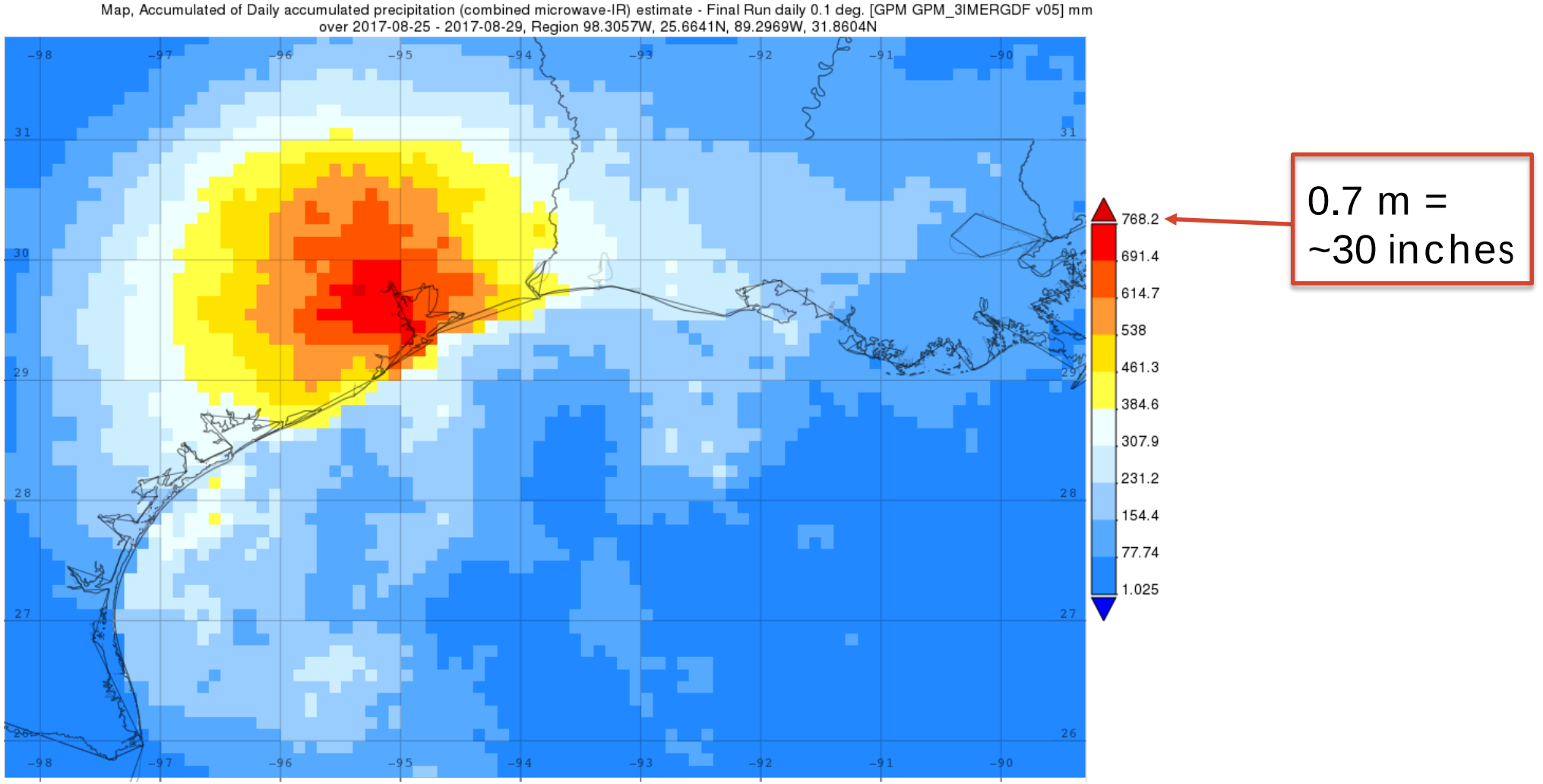
Analyses and visualizations were produced with the Giovanni online data system, developed and maintained by the NASA GES DISC:

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



Example: GPM IMERG Precipitation During Hurricane Harvey

Accumulated Precipitation, August 25-29, 2017



Example: GPM IMERG Precipitation During Hurricane Harvey

Half-Hour Rain Rate, August 25-30, 2017

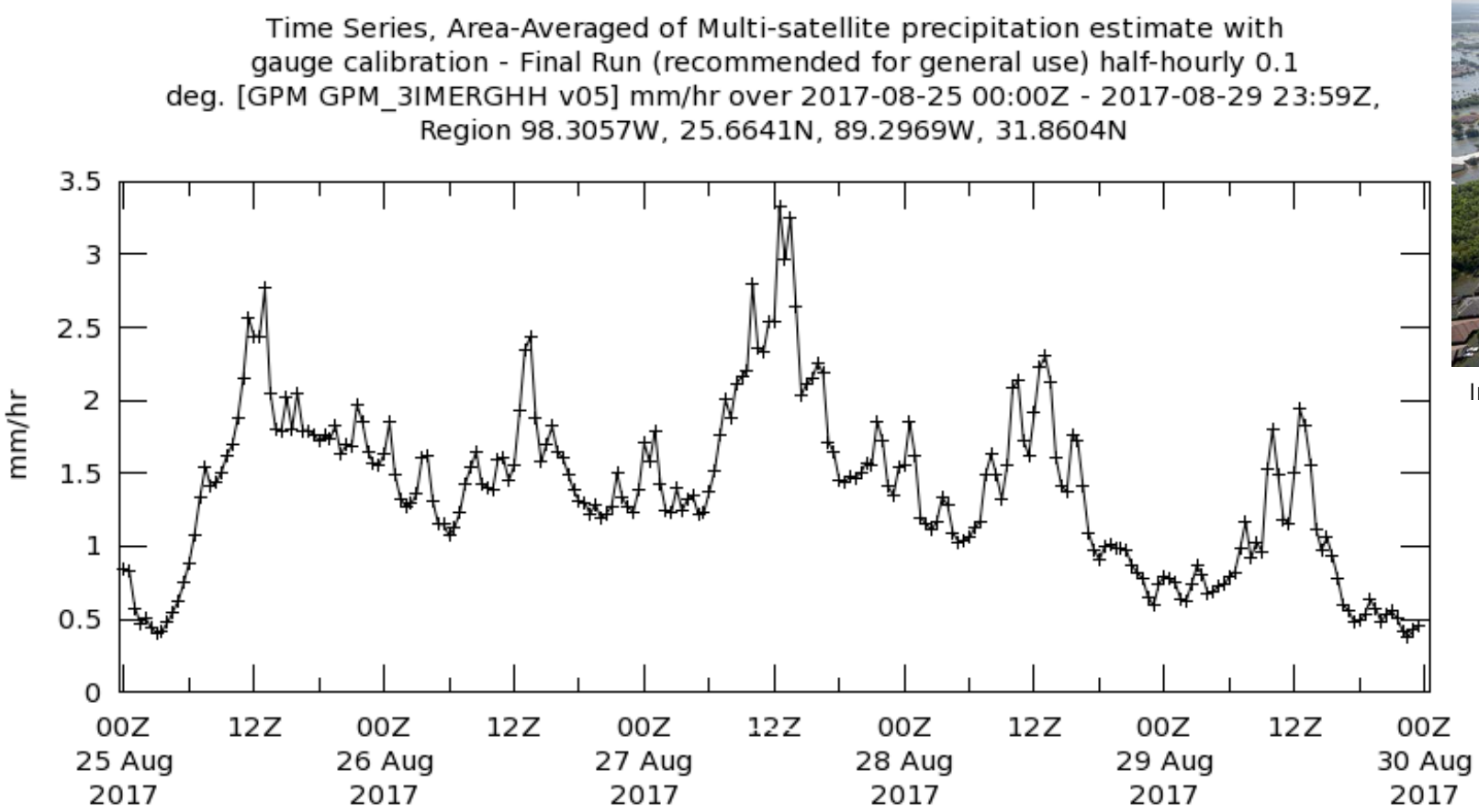


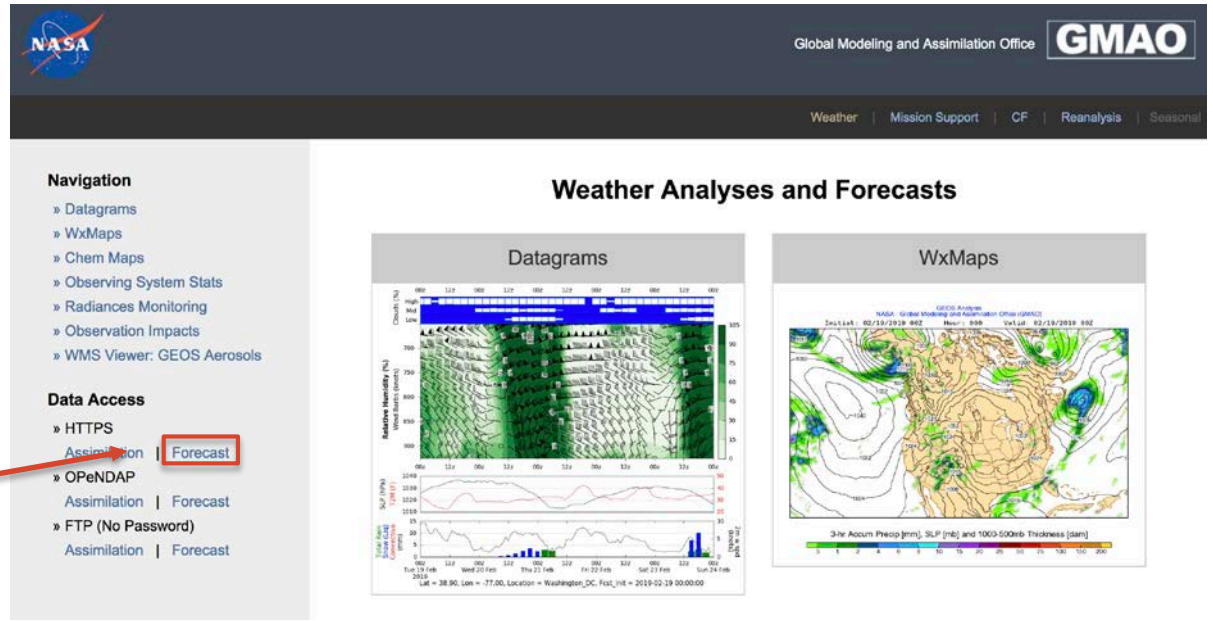
Image Credit: SC National Guard

- The user-selected region was defined by 98.3057W, 25.6641N, 89.2969W, 31.8604N. The data grid also limits the analyzable region to the following bounding points: 98.25W, 25.75N, 89.35W, 31.85N. This analyzable region indicates the spatial limits of the subsetted granules that went into making this visualization result.

Projected Rainfall

NASA's Global Modeling and Assimilation Office (GMAO)

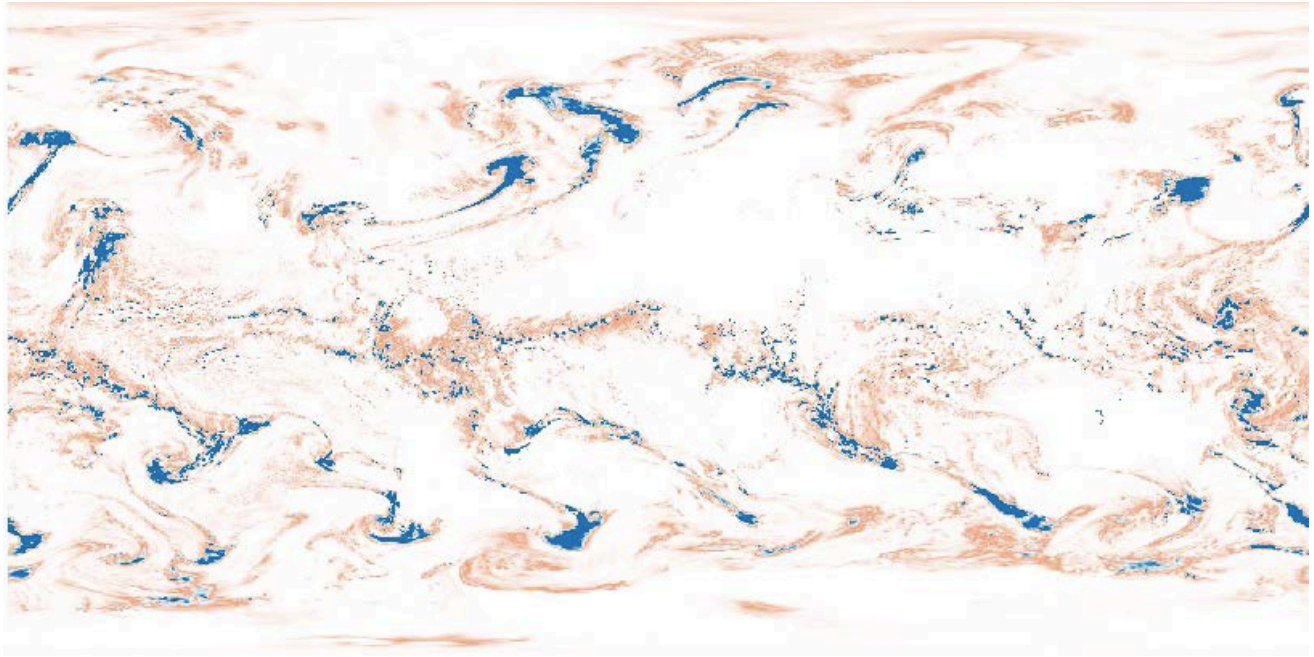
- **The Goddard Earth Observing System (GEOS-5)** model is being developed by the GMAO to support NASA's Earth science research in data analysis, observing system modeling and design, climate and weather prediction, and basic research
- **GEOS Forward Processing (GEOS FP)** are analyses and forecasts produced in real time, using the most recent validated GEOS system
- Forecasts can be downloaded in NetCDF file format as **time-averaged, hourly** data forecast up to 10 days
- Data is output as total surface precipitation flux in kg $m^{-2}s^{-1}$
- Forecast data can be accessed using: https://fluid.nccs.nasa.gov/weather/



Projected Rainfall

NASA's Global Modeling and Assimilation Office (GMAO)

- Products are saved in a geographic coordinate system (longitude-latitude grid) at a horizontal resolution of 0.3125-degree longitude by vertical resolution of 0.25-degree latitude
- Data products are shared via the NASA Center for Climate Simulation (NCCS) portal hosted at NASA Goddard Space Flight Center



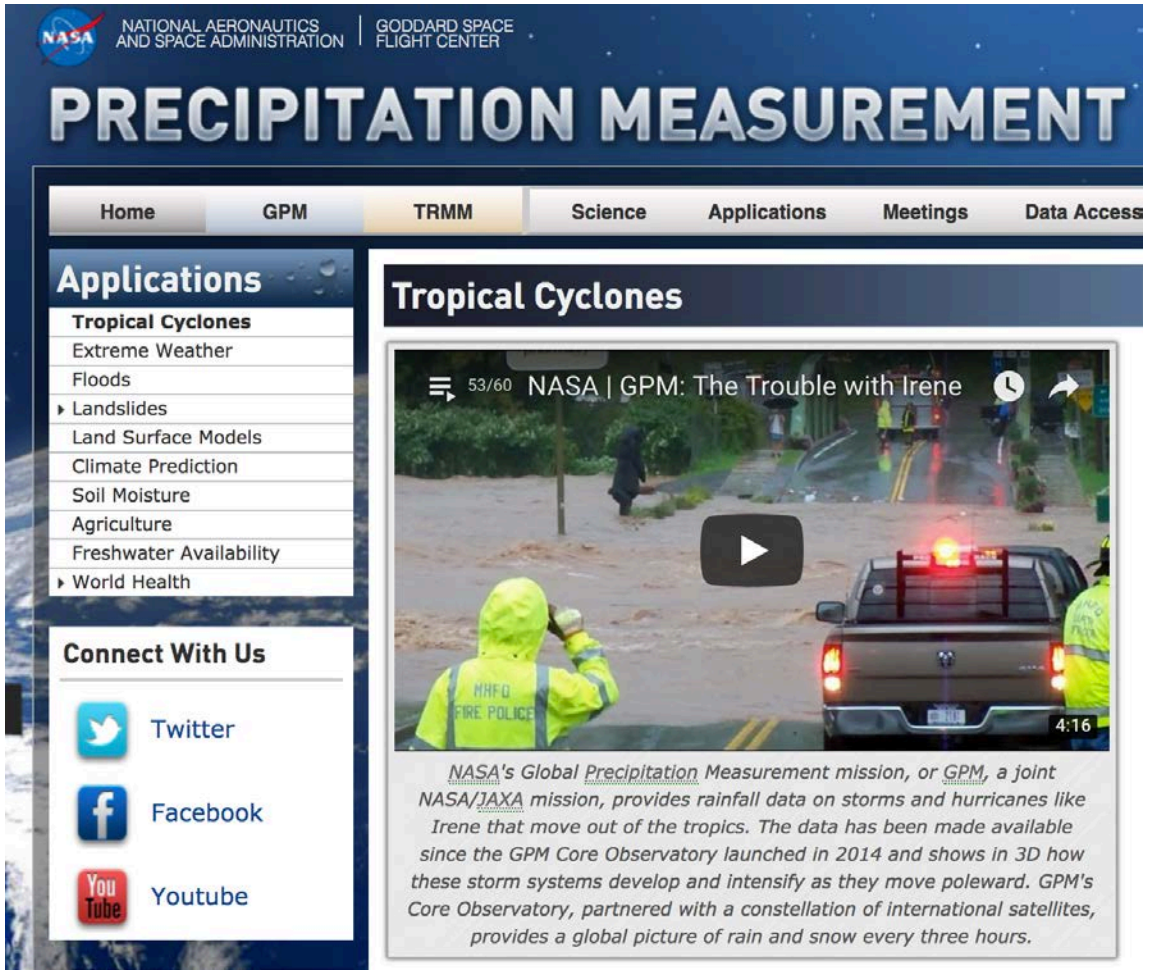
Projected Rainfall

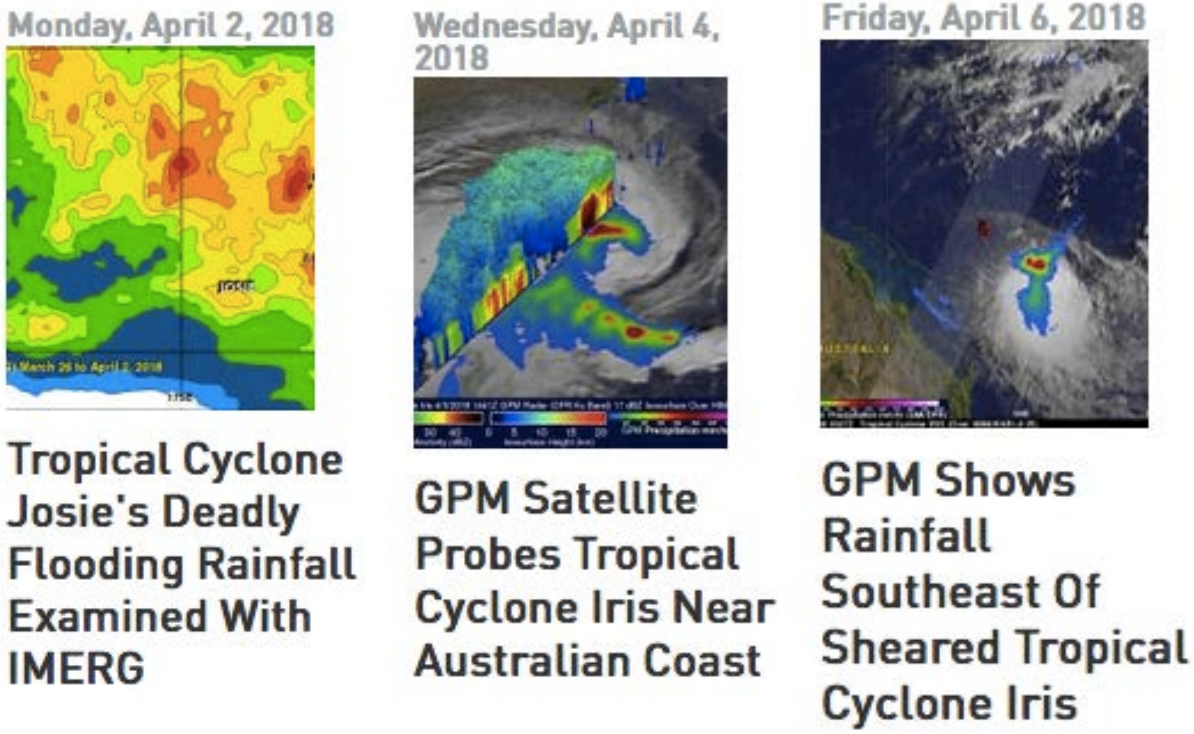
NASA's Global Modeling and Assimilation Office (GMAO)

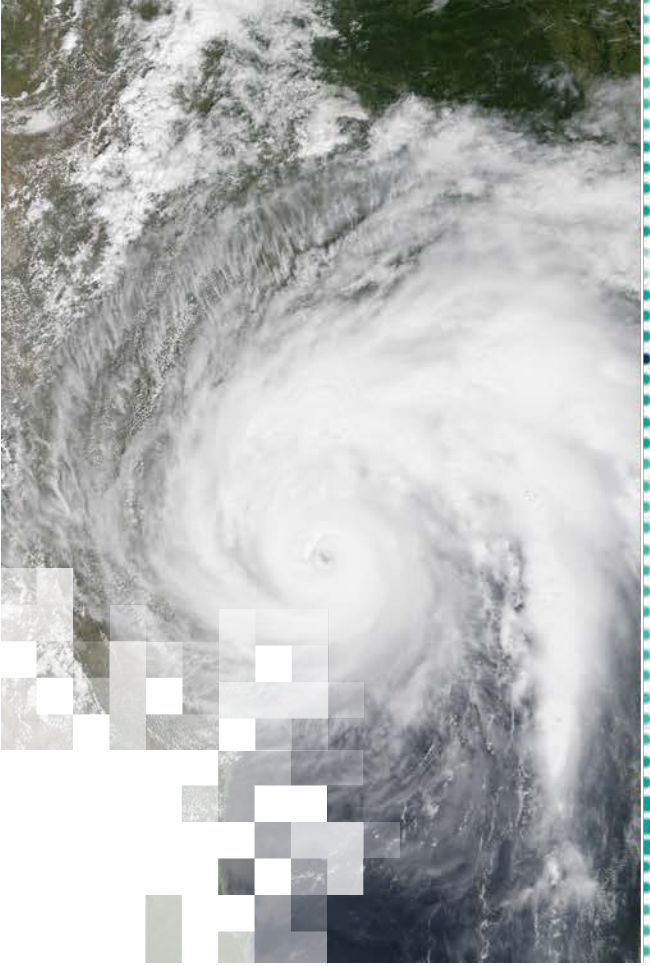
- When accessing the HTTPS site, you will go through subsequent folders starting at the year → month → day → forecast images: https://fluid.nccs.nasa.gov/weather/
- H00/ folder is the 10-day forecast
- H12/ is the 5-day forecast
- For surface precipitation forecast you should download files from: GEOS.fp.fcst.tavg1_2d_lnd_Nx_[timestamp]
- For more information on GEOS-5 refer to the document on "File Specification for GEOS FP" https://gmao.gsfc.nasa.gov/GMAO_products/documents/GEOS_5_FP_File_Specification_ON4v1_2.pdf

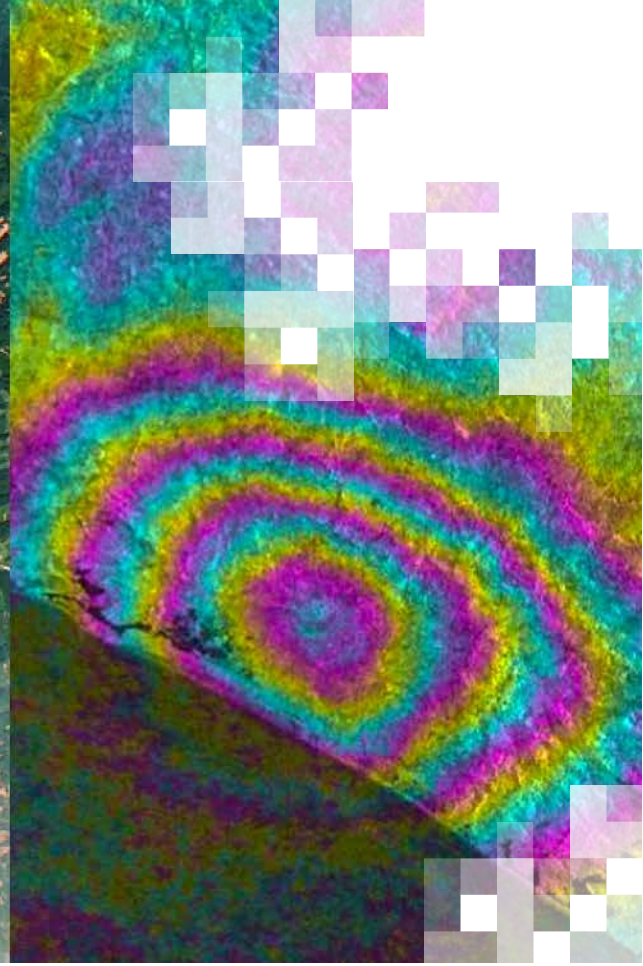
GPM Tropical Cyclone Portal

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





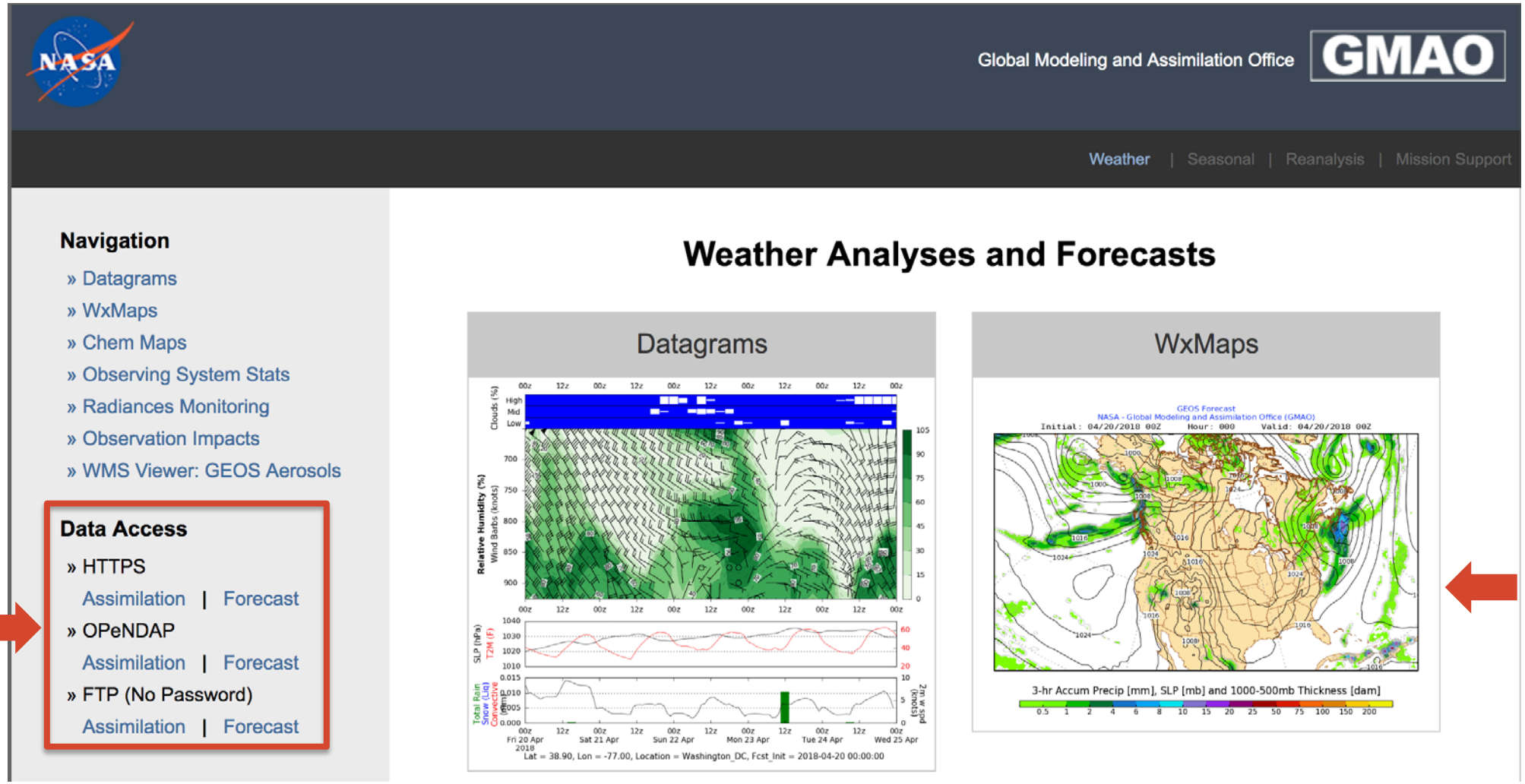




Monitoring Windspeed

GEOS-5 Winds

https://fluid.nccs.nasa.gov/weather/



Data

Maps

GEOS-5 Winds

https://portal.nccs.nasa.gov/datashare/gmao_ops/pub/fp/das/

Data Access

» HTTPS

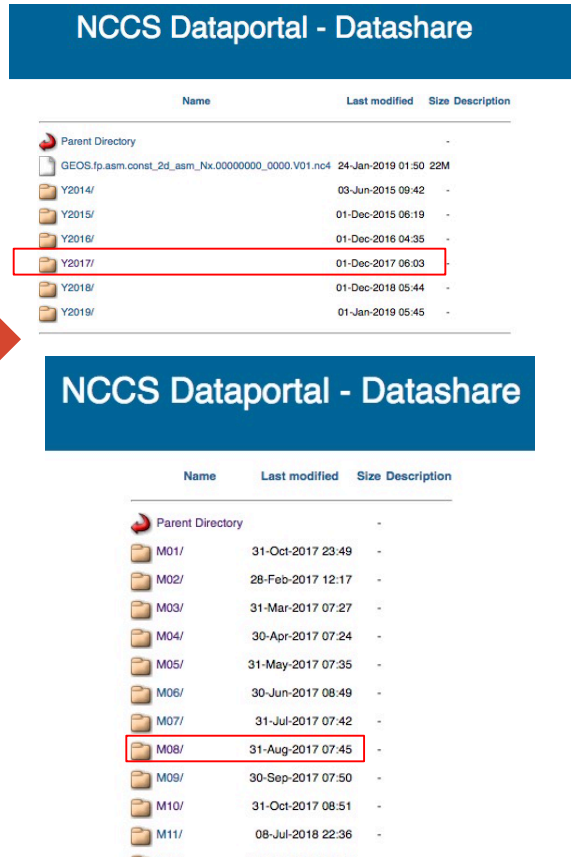
Assimilation | Forecast

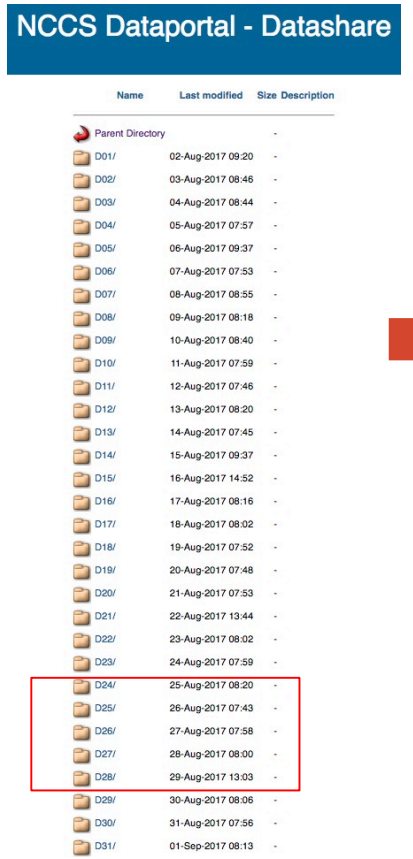
» OPeNDAP

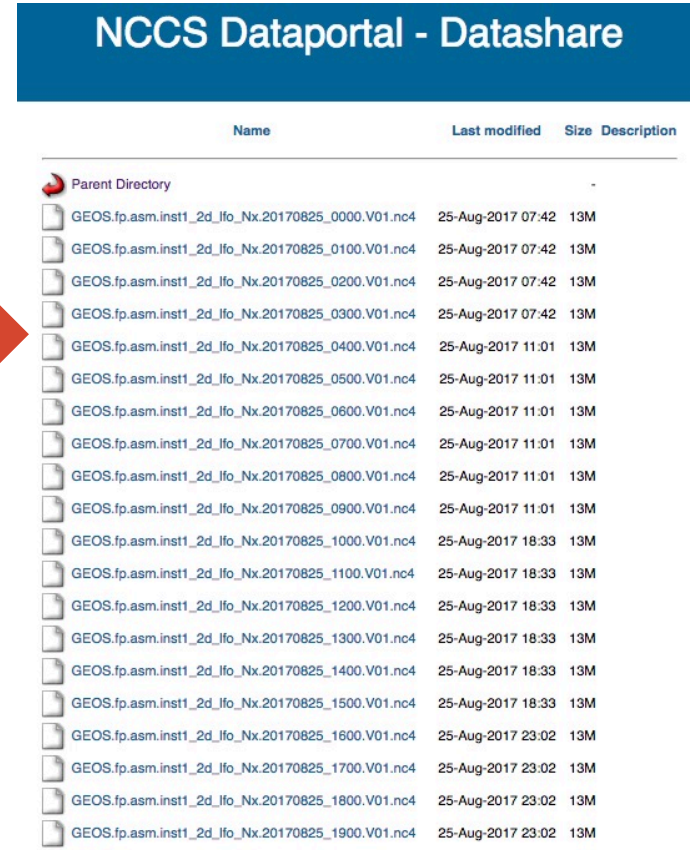
Assimilation | Forecast

» FTP (No Password)

Assimilation | Forecast







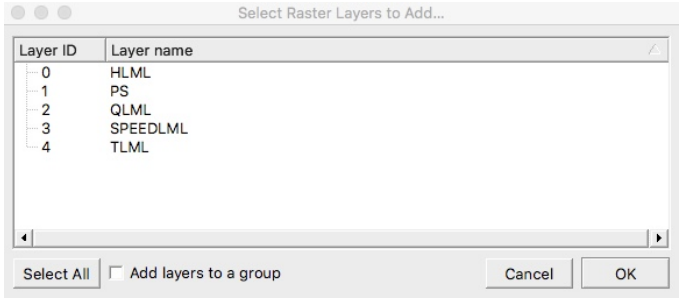
HTTP Files | Year & Month | Day | Hourly File Name*

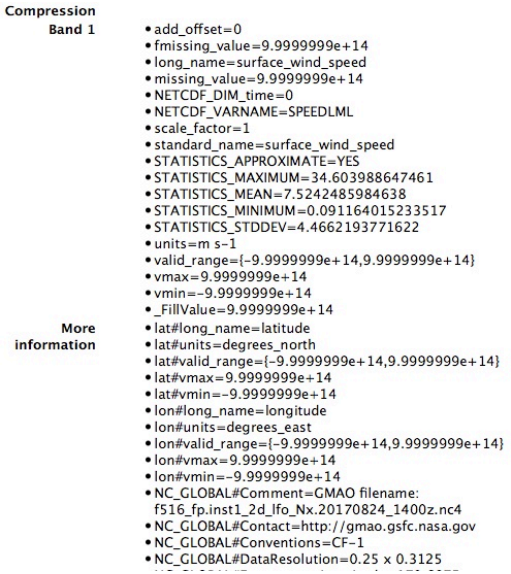
*Refer to document below for filename convention: https://gmao.gsfc.nasa.gov/products/documents/GEOS_5_FP_File_Specification_ON4v1_1.pdf

GEOS-5 Winds During a Cyclone

https://portal.nccs.nasa.gov/datashare/gmao_ops/pub/fp/das/

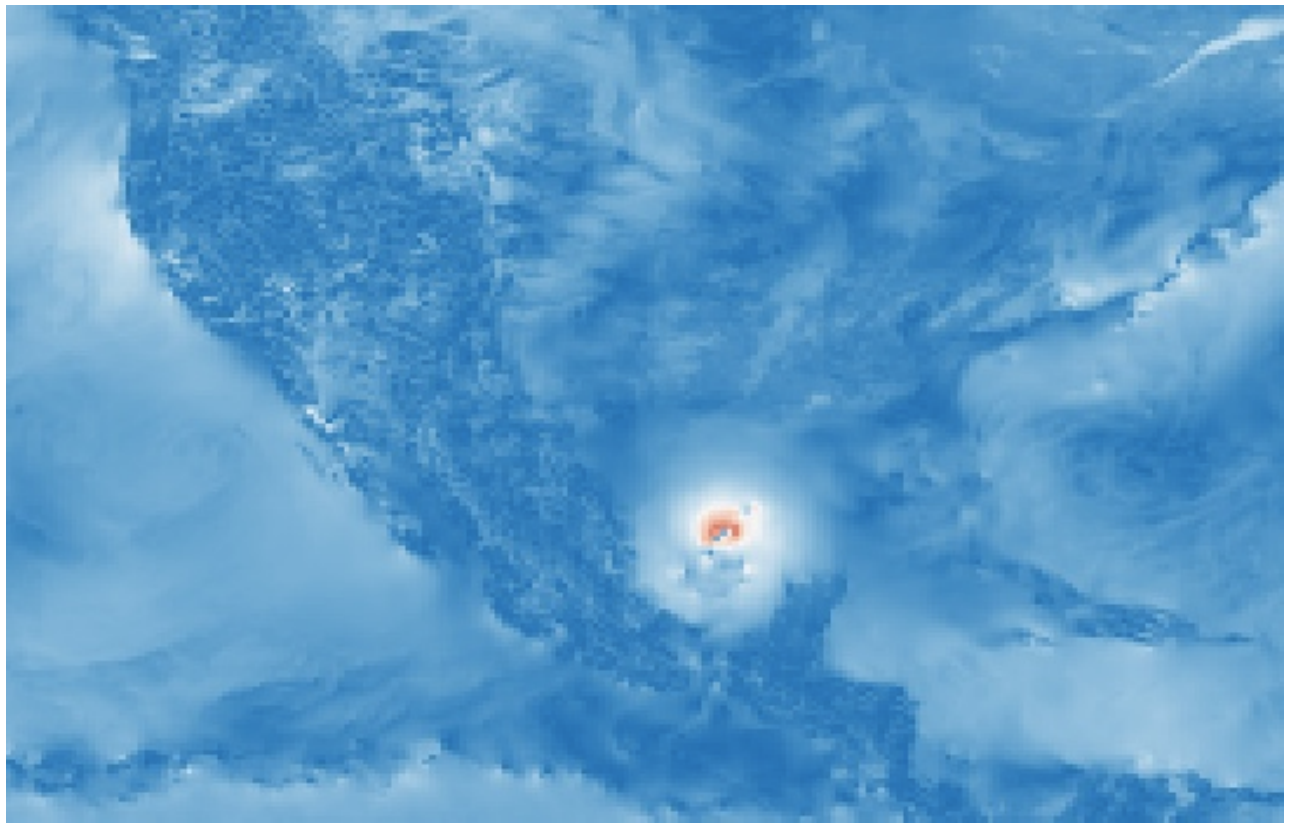
- Download wind data following instructions from the previous slide
- Refer to document below for filename convention: https://gmao.gsfc.nasa.gov/products/documents/GEOS_5_FP_File_Specification_ON4v1_1.pdf
- Download and install QGIS (open source analysis and visualization application)
  - Instructions: https://www.qgis.org/en/site/
  - Open the NetCDF-4 file using QGIS
- NetCDF-4 file for Aug. 24, 2017
- Opened in QGIS





Example: GEOS-5 Winds During Hurricane Harvey

- All data from GEOS-5 are **global**, use **Coordinated Universal Time** (UTC), and are in a **geographic coordinate system**
- The area in red shows high wind speeds (m s^{-1}) from Hurricane Harvey in the Gulf of Mexico
- Date: August 24, 2017 – 1400 UTC
- Spatial resolution:
  - 0.3125-degree longitude
  - 0.25-degree latitude
- Temporal resolution:
  - Hourly, daily



GEOS-5 Winds - Forecast

https://fluid.nccs.nasa.gov/weather/

Data Access

» HTTPS

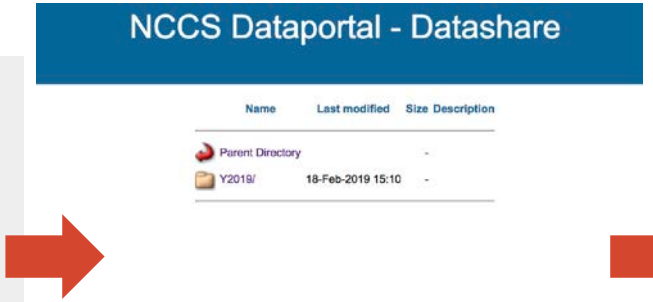
Assimilation | Forecast

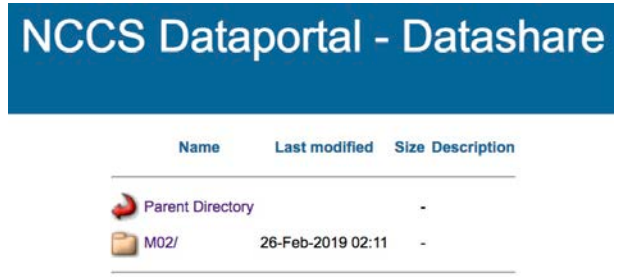
» OPeNDAP

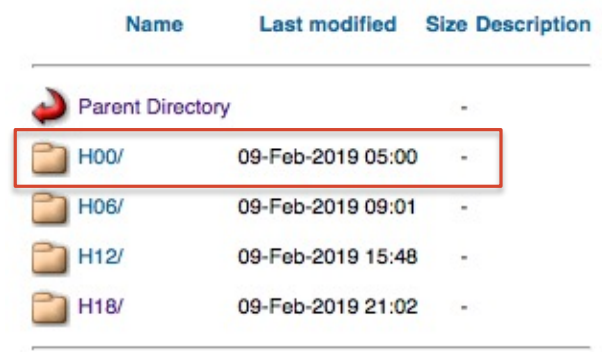
Assimilation | Forecast

» FTP (No Password)

Assimilation | Forecast

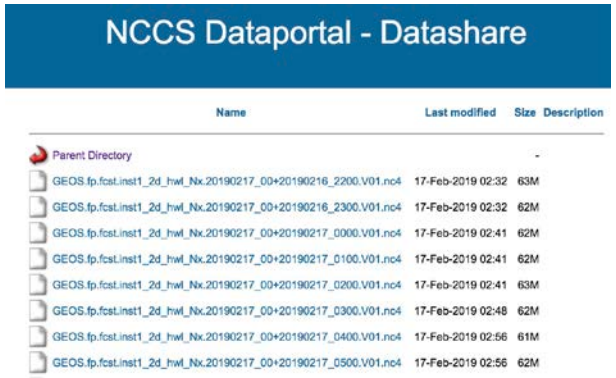






H00/ = 10-day forecast

H12/ = 5-day forecast

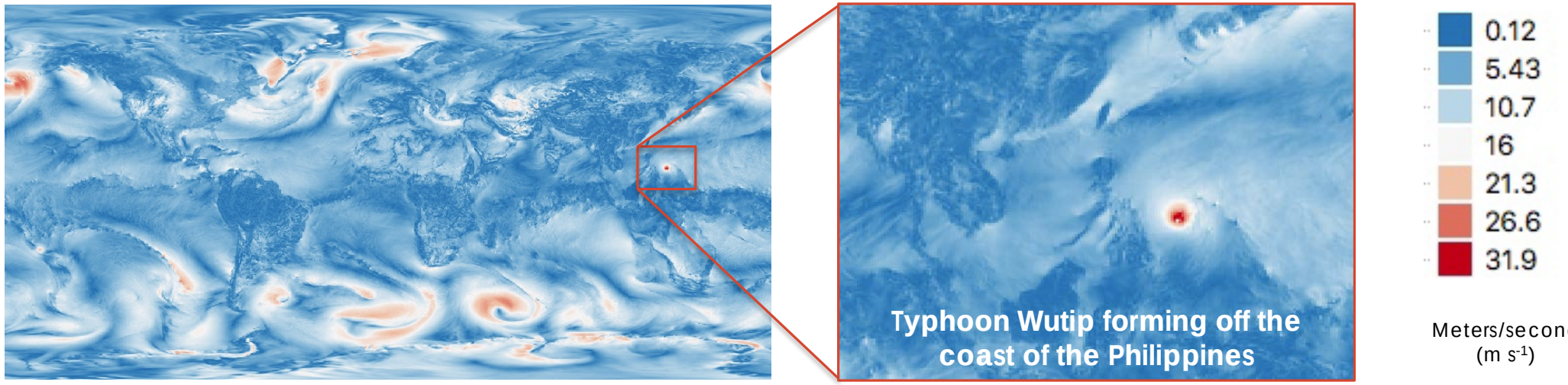


HTTP Files | Year & Month | Day | Hourly File Name*

*Refer to document below for filename convention: https://gmao.gsfc.nasa.gov/products/documents/GEOS_5_FP_File_Specification_ON4v1_1.pdf

GEOS-5 Winds

10-Day Forecast – General Circulation Model (GCM)



- 10-day forecast for **surface wind speed** displayed above. Forecast data for surface wind speed are acquired through “lfo” files via the HTTPS
  – e.g. GEOS.fp.fcst.inst1_2d_lfo_Nx.20190217_00+20190227_0000.V01.nc4
- The subfile for surface wind speed is “SPEEDLML”
- Refer to document below for filename convention: https://gmao.gsfc.nasa.gov/products/documents/GEOS_5_FP_File_Specification_ON4v1_1.pdf

Tracking Storm Surge

Monitoring Storm Surge

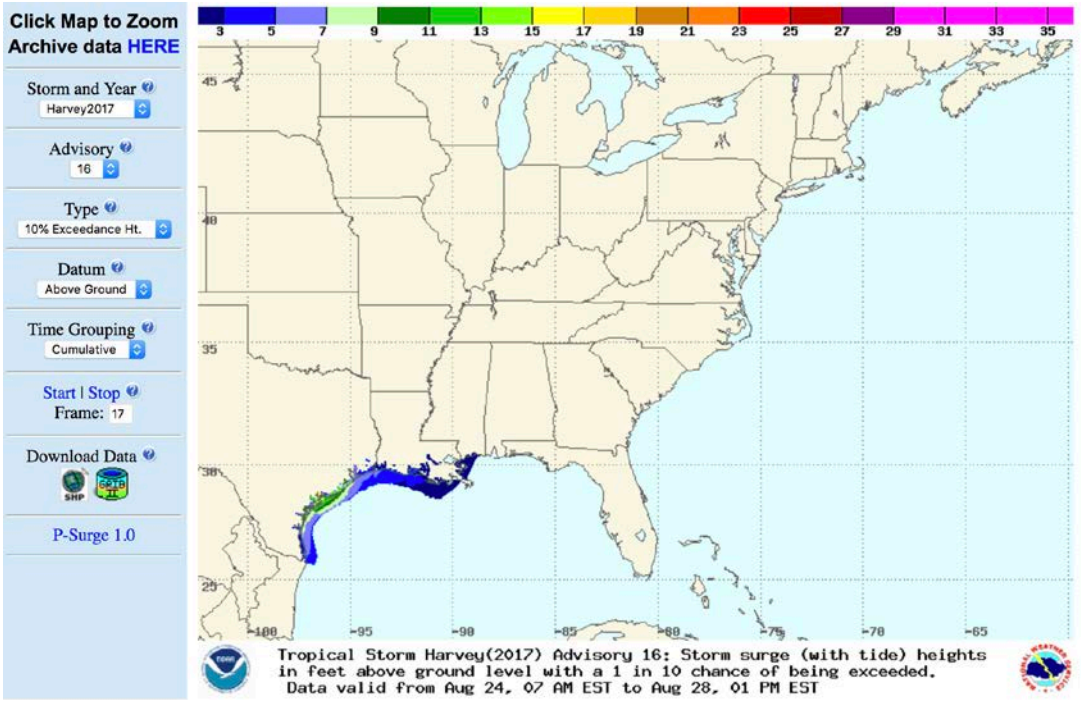
- In the U.S., storm surge is responsible for 47% of deaths directly attributed to hurricane deaths*
- The Sea Lake and Overland Surge from Hurricanes (SLOSH) model computes storm surge heights from tropical cyclones to create a model of the wind field using pressure, size, forward speed, and tracked data
  - Applies to:
    - Entire U.S. east coast, Gulf of Mexico, Hawaii, Guam, Puerto Rico, and the U.S. Virgin Islands coastal regions
  - Available at https://slosh.nws.noaa.gov/psurge2.0/
- The Coastal Emergency Risks Assessment uses a model to predict impacts and risk
  - Available at https://cera.coastalrisk.live/

*Data Source: National Hurricane Center

Example: Probabilistic Tropical Storm Surge (P-Surge)

https://slosh.nws.noaa.gov/psurge2.0/

- Graphics show **probabilities** of storm surge
- Products are provided as cumulative probability: the overall probability the event will occur at each grid cell from the start of the run until **102 hours in the future**
- Provided as **13 cumulative probability** products with 6 hour spacing: probability the event will occur from the start of the run until a specified time (e.g. 0-6 hours, …, 0-102)
- Updates to the product made 1 hr after the NHC tropical cyclone advisories issued
- Available for **download** in shapefile or GRIB file types



More Information »

Example: Probabilistic Tropical Storm Surge (P-Surge)

Storm Name & Year, most recent storm first

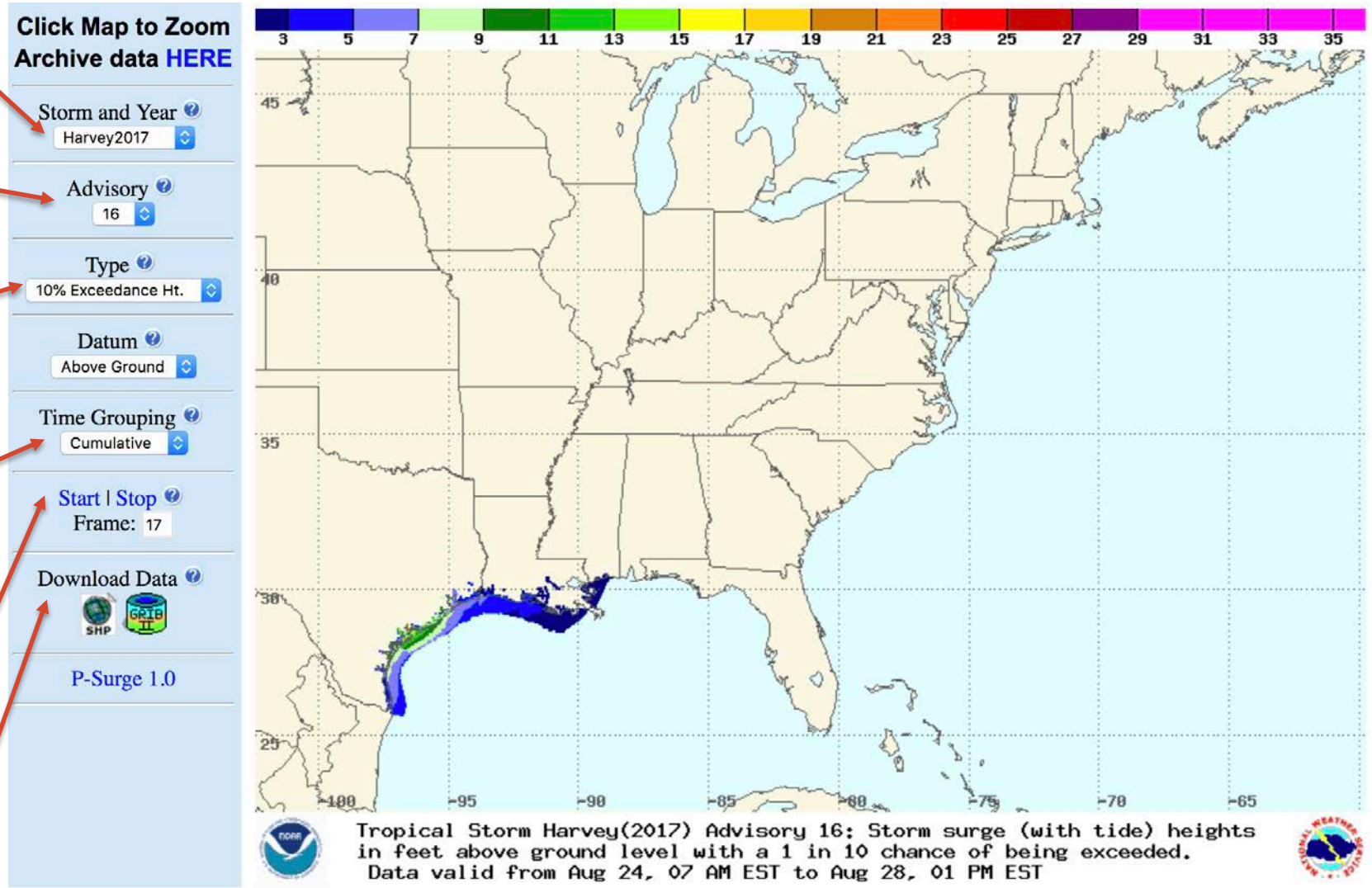
Advisories put out every 6-hrs

Exceedance and probability products

6-hr latency showing incremental water level increase (cumulative total water height)

Animation showing above-ground P-Surge results

Available for download in SHP & GRIB2 file formats



Example: Probabilistic Tropical Storm Surge (P-Surge)

Above Datum data:
are the "raw," modeled water levels, from the SLOSH model runs.
Above Ground data:
takes the above datum data and subtracts a DEM from it and then averages over each SLOSH grid cell. The result is an "average depth" over the cell.
It will always overestimate depth at local high spots and underestimate depths in local low spots.
If you have known elevations, like roads, foundations or other critical infrastructure, **you CANNOT estimate flooding** at those locations.
To calculate flooding at known locations, you need to use the Above Datum datasets.