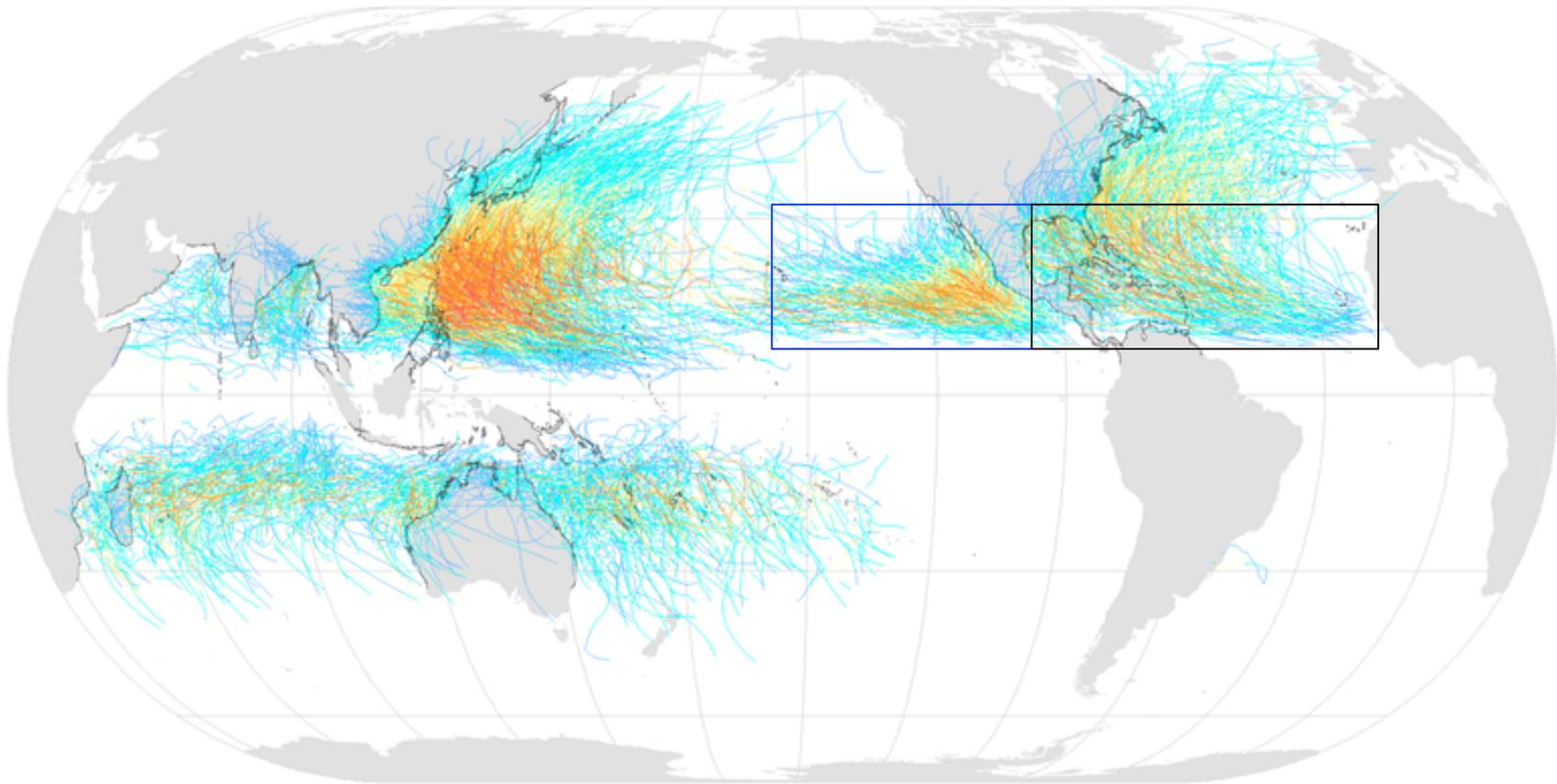
A satellite image of a hurricane over the Atlantic Ocean. The hurricane is a large, circular storm system with a distinct eye and spiral cloud bands. The surrounding ocean is dark blue, and the landmasses of North and South America are visible in the background.

# What hit me? The biological affects on marine life of hurricanes and extreme storm events

*Michelle Gierach  
Satellite Oceanographer  
Jet Propulsion Laboratory  
mgierach@jpl.nasa.gov*

# Tropical Cyclones, 1945–2006



Saffir-Simpson Hurricane Scale:

tropical  
depression

tropical  
storm

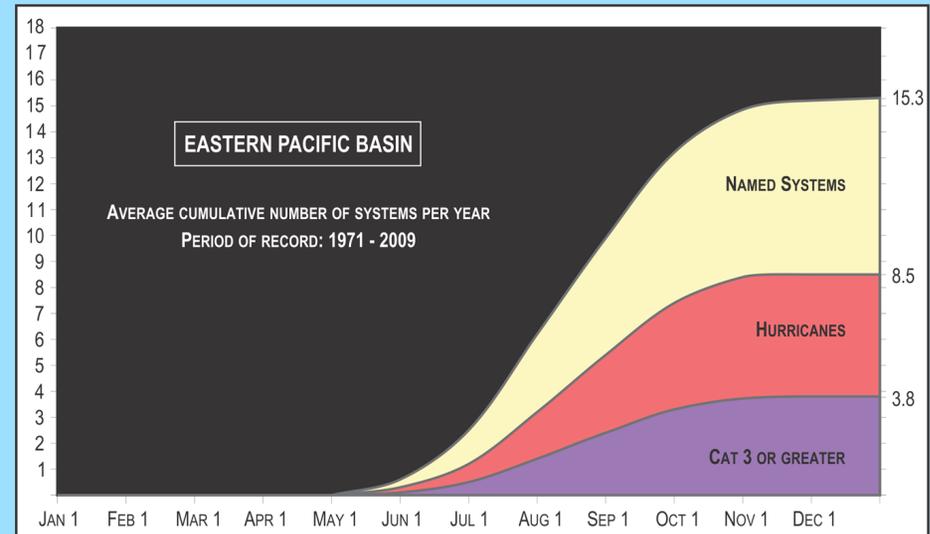
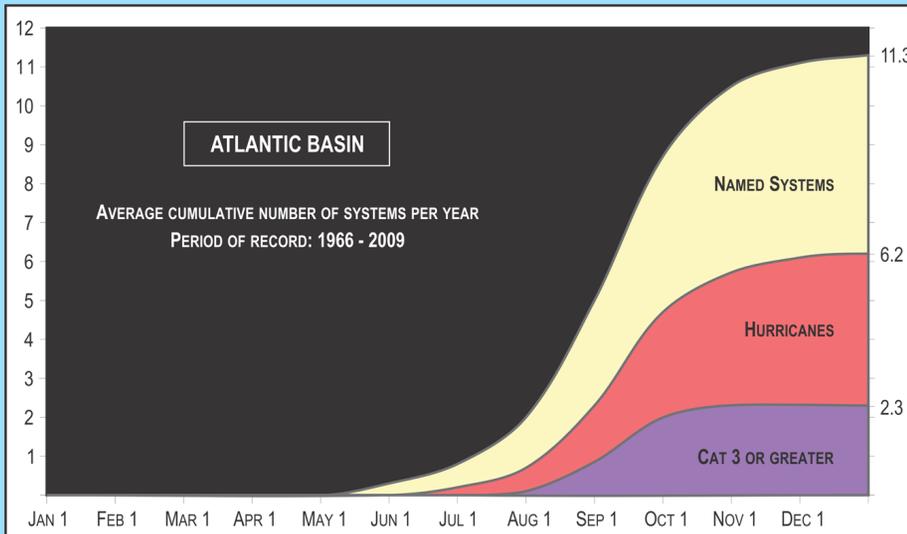
hurricane  
category 1

hurricane  
category 2

hurricane  
category 3

hurricane  
category 4

hurricane  
category 5



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

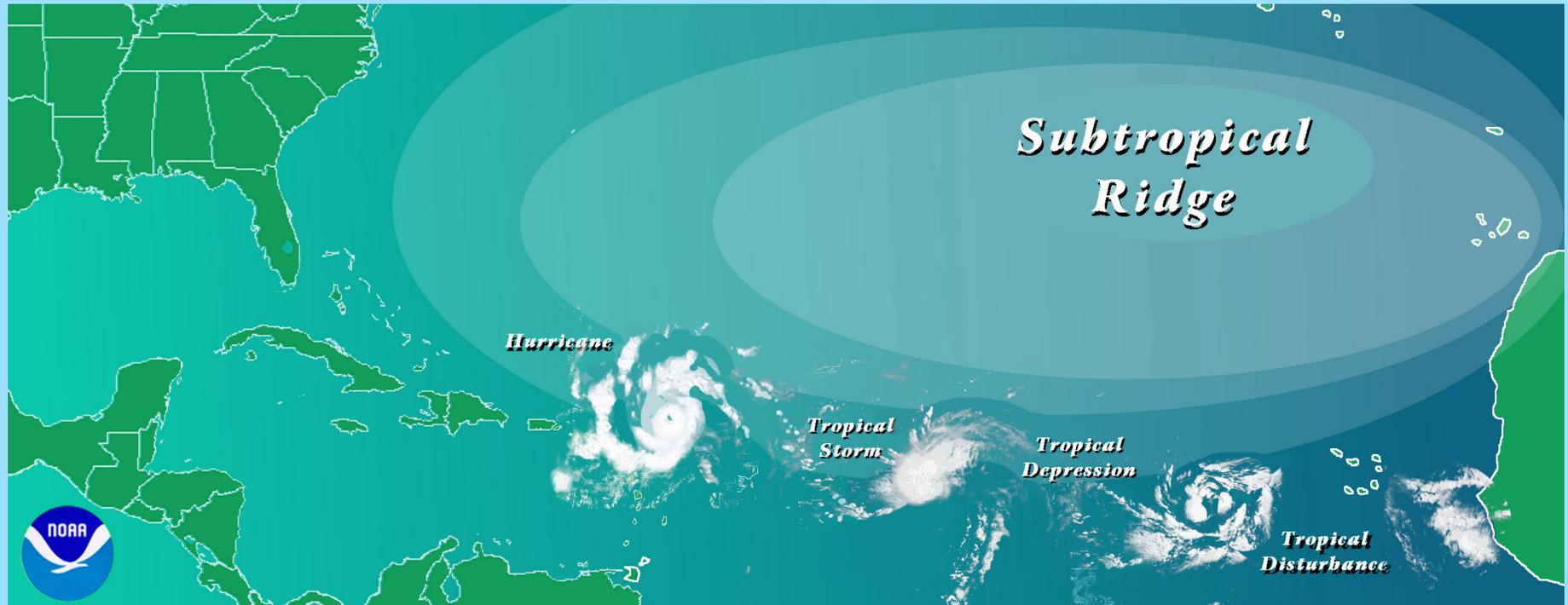
Records for the Atlantic basin (from 1944-present) and the USA coastline (1899-present):

Category	Maximum	Minimum
Named Storms	28 (2005)	4 (1983)
Hurricanes	15 (2005)	2 (1982)
Major Hurricanes	8(1950)	0 (many times, 1994 last)
USA landfalling named storms	9 (2004)	1 (many, 2010)
USA landfalling hurricanes	6+ (1916, 1985, 2004, 2005)	0 (many, 2010)
USA landfalling major hurricanes	4 (2005)	0 (many, 2010)

+ 1886 is recorded as the most active hurricane season for the continental USA with 7 landfalling hurricanes.

<http://www.aoml.noaa.gov/hrd/tcfaq/E10.html>

# Tropical Cyclone Genesis

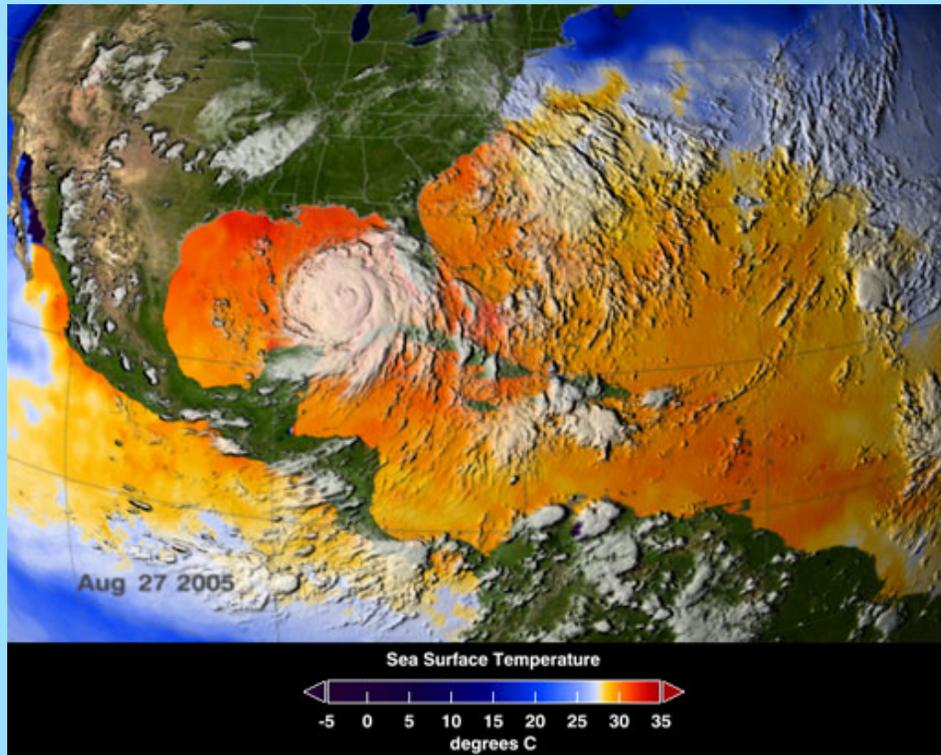
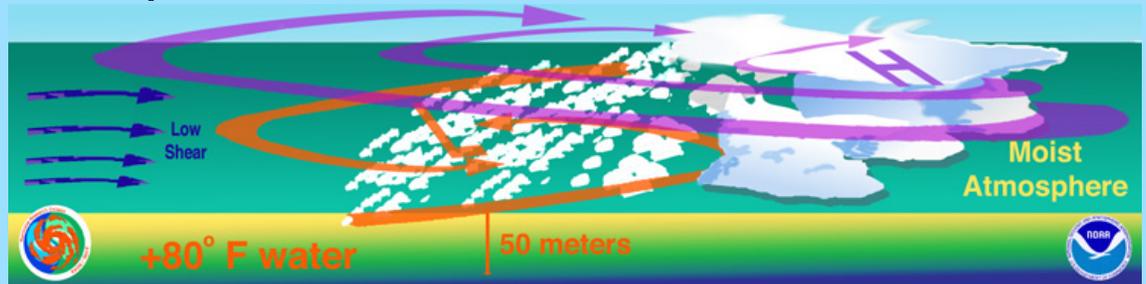


## Saffir-Simpson Scale

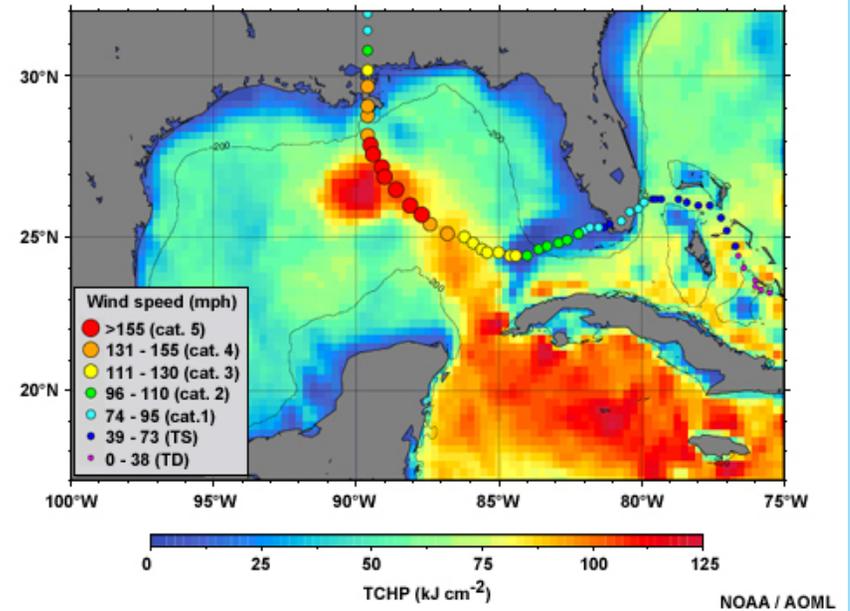
Type	Category	Pressure (mb)	Winds (knots)	Winds (mph)	Surge (ft)	Line Color
Depression	TD	-----	< 34	< 39		Green
Tropical Storm	TS	-----	34-63	39-73		Yellow
Hurricane	1	> 980	64-82	74-95	4-5	Red
Hurricane	2	965-980	83-95	96-110	6-8	Light Red
Hurricane	3	945-965	96-112	111-130	9-12	Magenta
Hurricane	4	920-945	113-135	131-155	13-18	Light Magenta
Hurricane	5	< 920	>135	>155	>18	White

# Tropical Cyclone Genesis

- **Favorable conditions:**
  - Weak wind shear
  - High humidity
  - Warm waters ( $>26.5^{\circ}\text{C}$ )



Altimeter-derived Tropical Cyclone Heat Potential (28 Aug 2005) and Hurricane Katrina Track



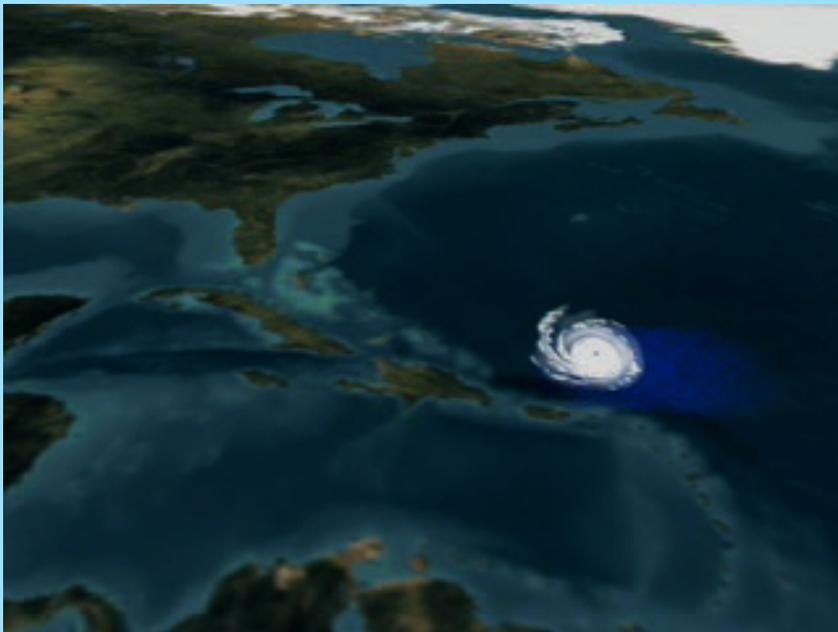
- **Unfavorable conditions:**
  - Cool water
  - Land
  - Strong wind shear



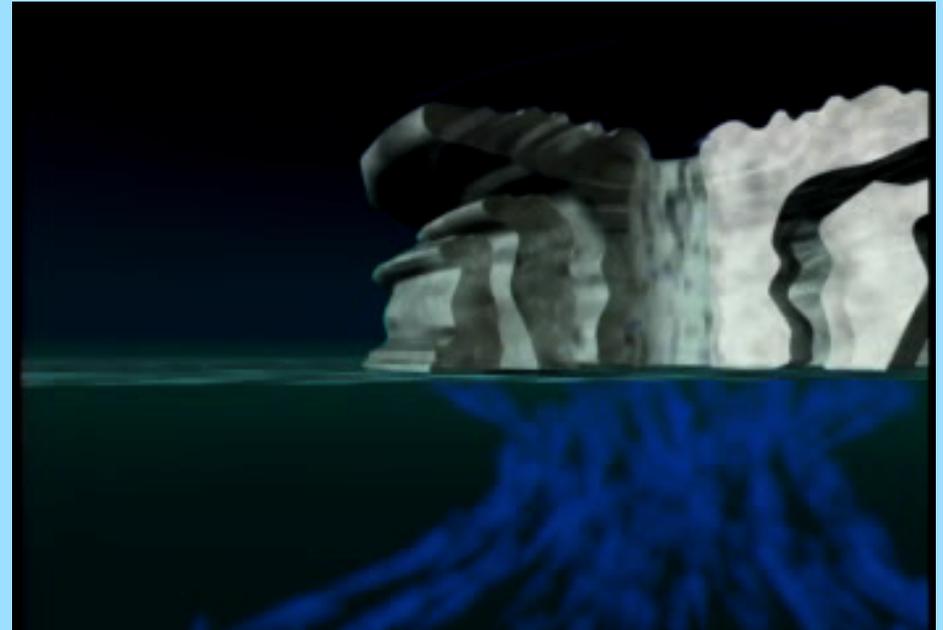
# Ocean Response to Hurricanes

- **During Hurricane Passage:**

- Strong wind stirring at the surface
- Mixed layer deepens
- Injection of subsurface nutrients and cold subsurface water into the surface layer
- Decreased salinity at the surface



[http://www.nasa.gov/mpeg/114586main\\_seabloom.mpeg](http://www.nasa.gov/mpeg/114586main_seabloom.mpeg)

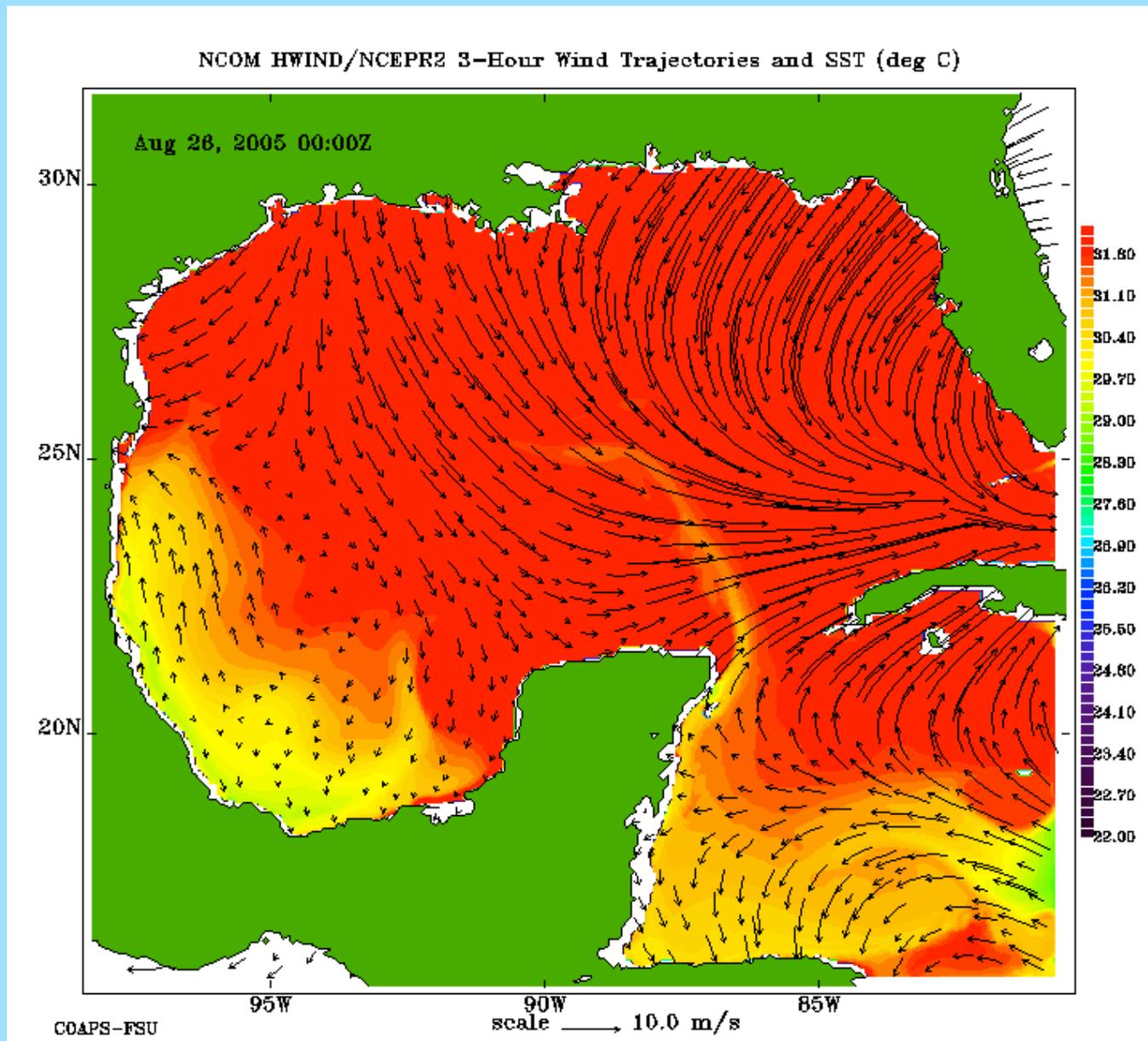


[http://www.nasa.gov/mpeg/115123main\\_ColdingEngine.mpeg](http://www.nasa.gov/mpeg/115123main_ColdingEngine.mpeg)

- **After Hurricane Passage:**

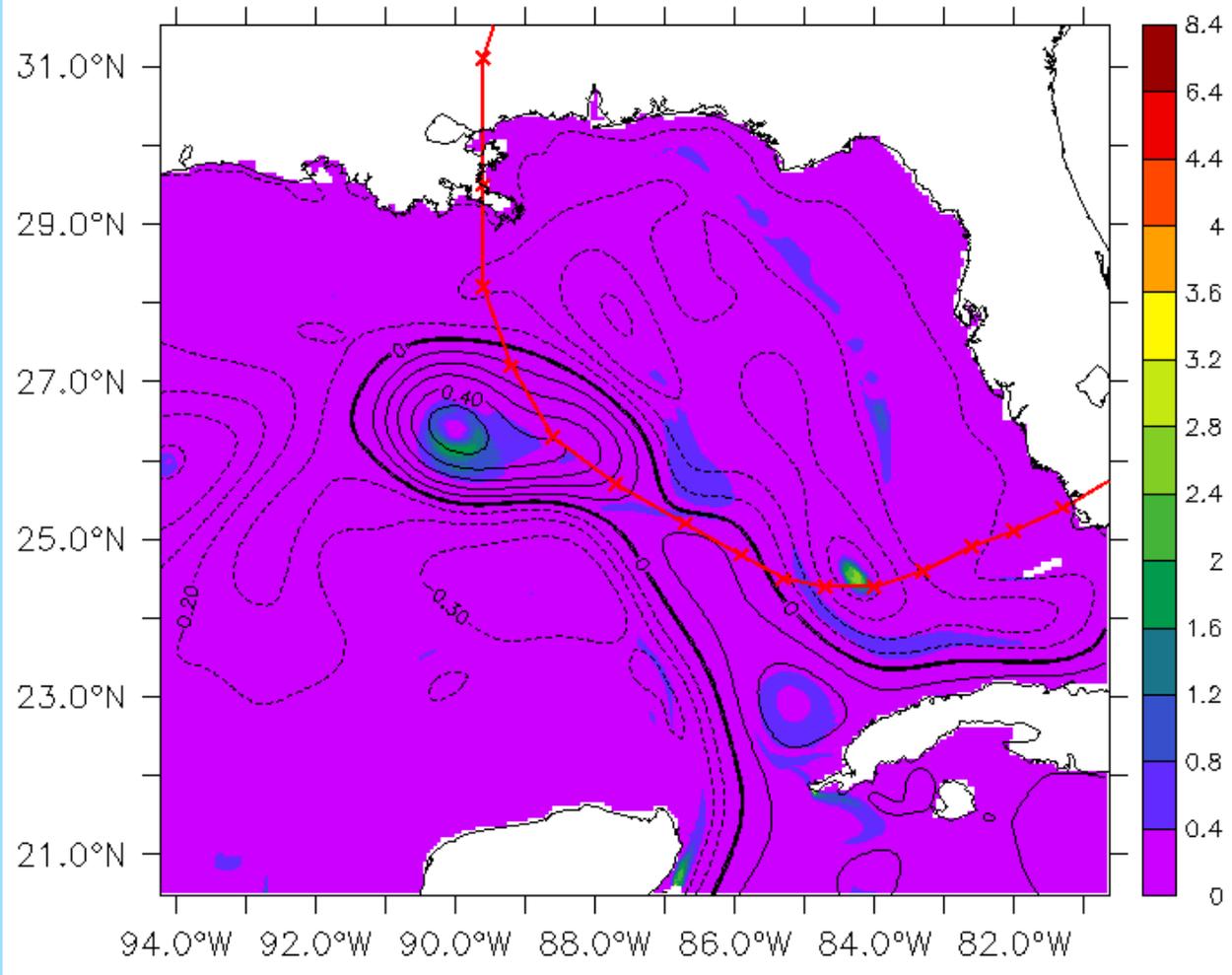
- Cold wake observed
- Phytoplankton blooms detected
- Salinity freshening

# Sea Surface Temperature (SST) Response



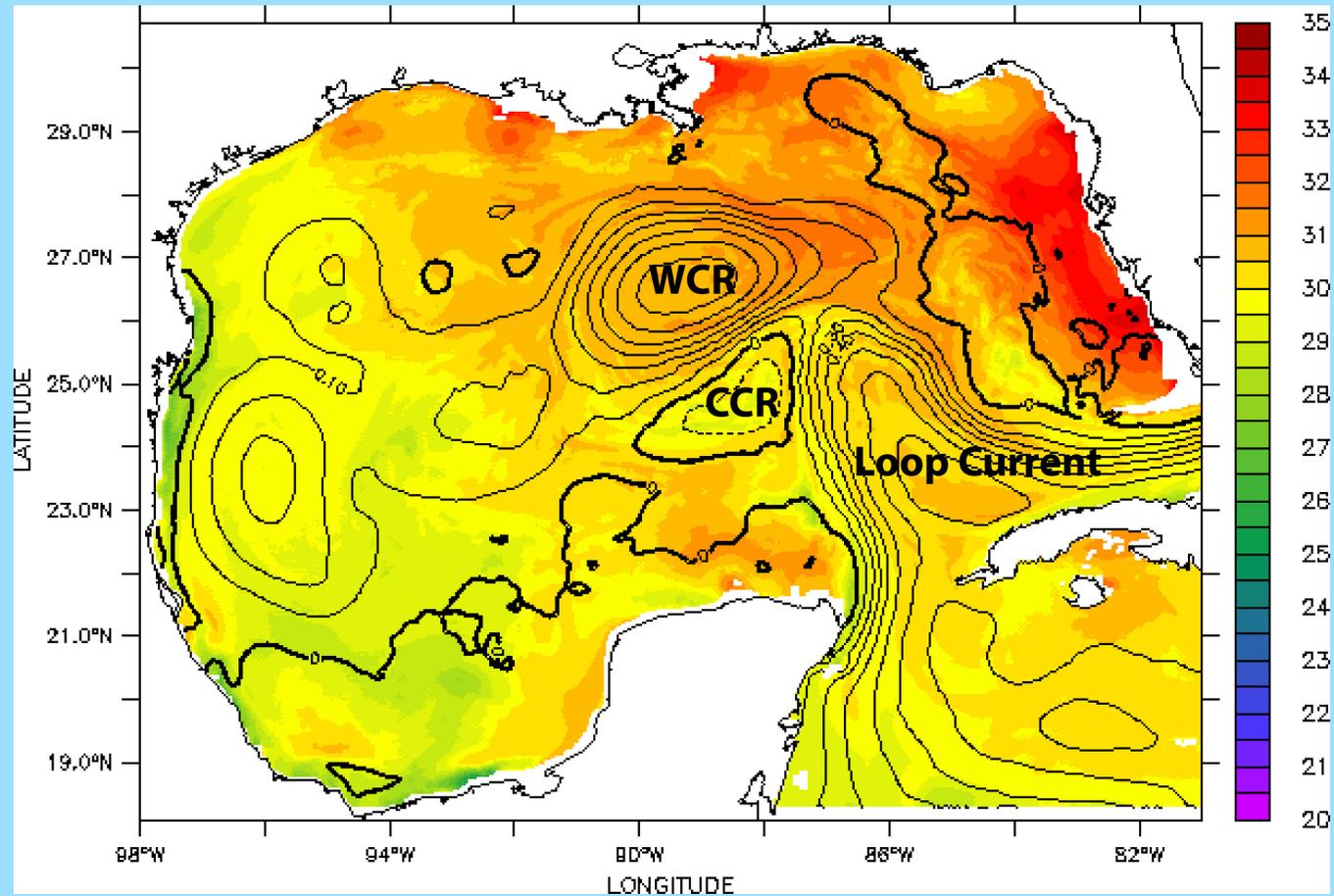
# Nutrient Response

Z (level) : 2.5  
TIME : 26-AUG-2005 00:00 DATA SET: GoM\_nit\_0001-0076x58\_kat\_new3



Nitrate (mmol N m<sup>-3</sup>)

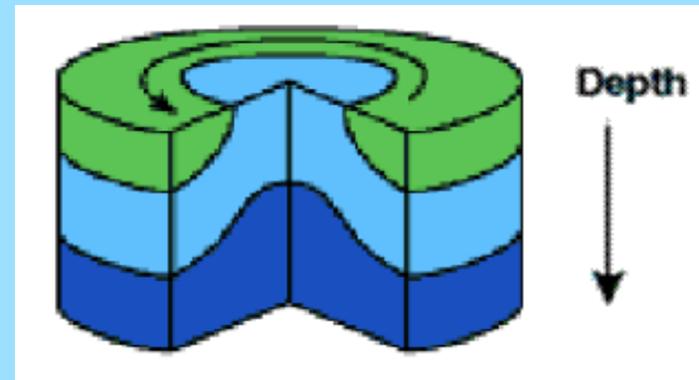
# Gulf of Mexico



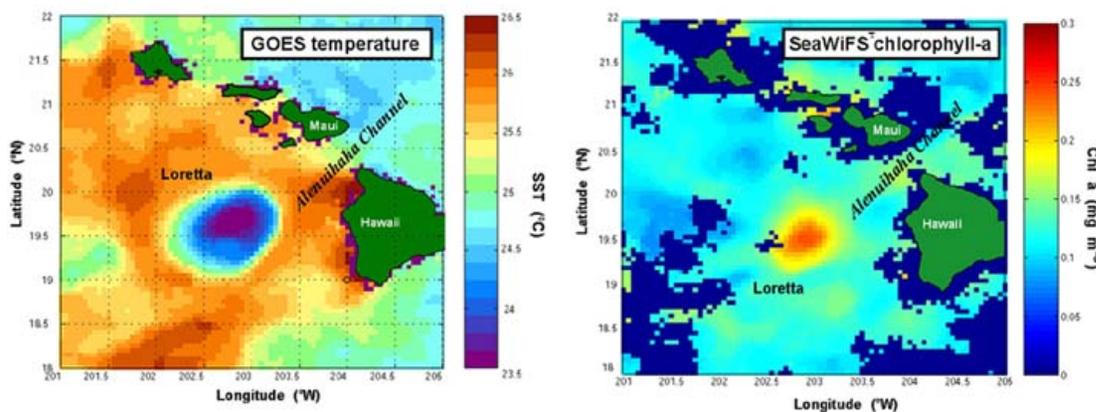
Gulf of Mexico sea surface temperatures (°C) at 0000 UTC 15 August 2005 overlaid with sea surface height contours

# Cold-Core Eddies

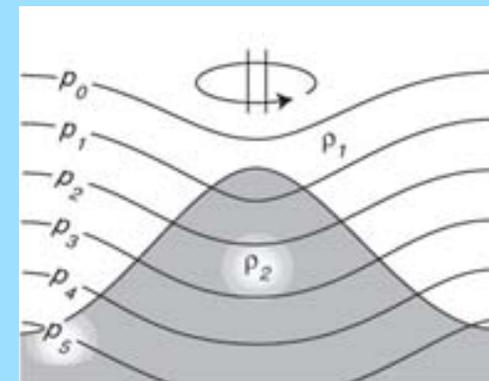
- Cyclonic eddies
- Counterclockwise spin
- Upward doming of isopycnals
- Upwelling of cold, nutrient-rich, plankton-rich subsurface water



[http://www.geol.sc.edu/cbnelson/eddy/eddy\\_files/image006.gif](http://www.geol.sc.edu/cbnelson/eddy/eddy_files/image006.gif)



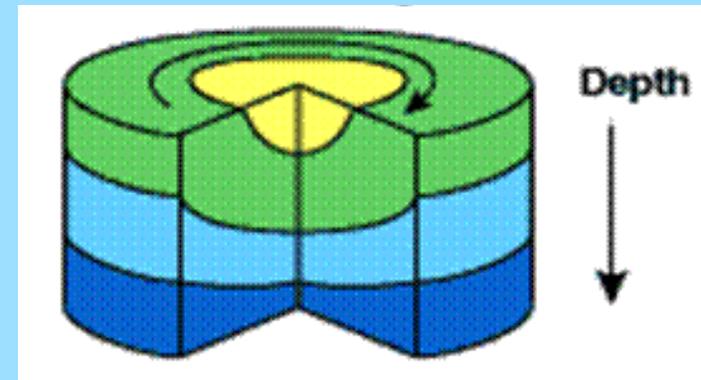
<http://www.gsfc.nasa.gov>



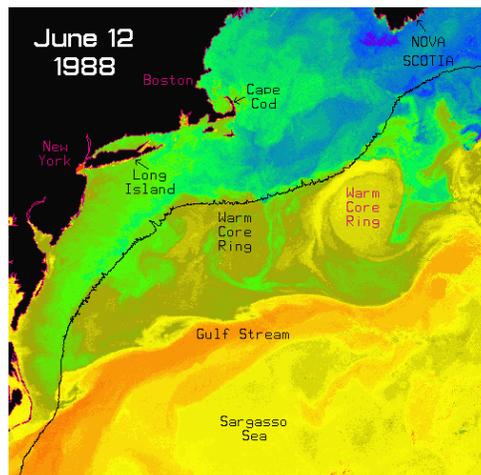
[http://oceanworld.tamu.edu/resources/ocng\\_textbook/chapter10/Images/fig10-12.jpg](http://oceanworld.tamu.edu/resources/ocng_textbook/chapter10/Images/fig10-12.jpg)

# Warm-Core Eddies

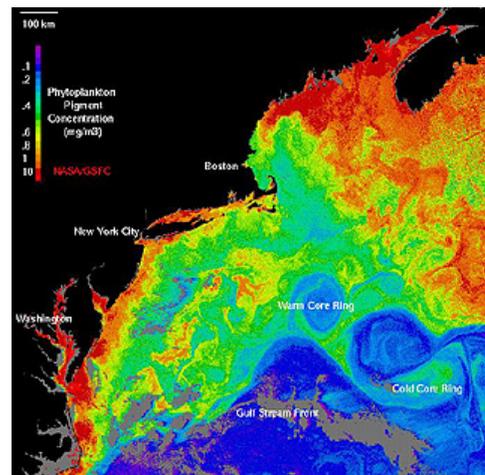
- Anticyclonic eddies
- Clockwise spin
- Downward doming of isopycnals
- Downwelling of warm, nutrient depleted surface water



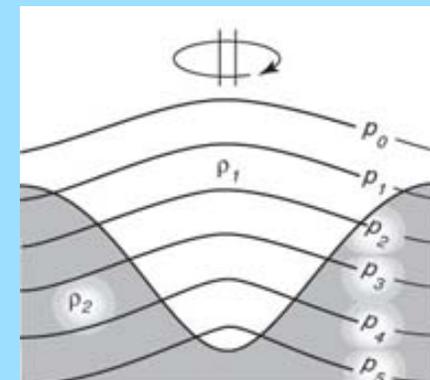
[http://www.geol.sc.edu/cbnelson/eddy/eddy\\_files/image006.gif](http://www.geol.sc.edu/cbnelson/eddy/eddy_files/image006.gif)



<http://ceos.cnes.fr:8100/cdrom-00b/ceos1/lessons/uri/feature.gif>



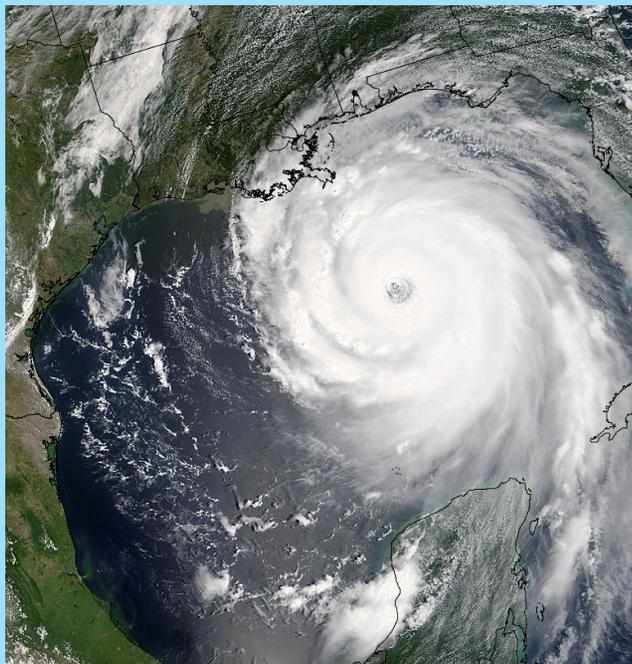
[http://www.fas.org/irp/imint/docs/rst/Sect14/originals/Fig14\\_85.jpg](http://www.fas.org/irp/imint/docs/rst/Sect14/originals/Fig14_85.jpg)



[http://oceanworld.tamu.edu/resources/ocng\\_textbook/chapter10/Images/Fig10-12.jpg](http://oceanworld.tamu.edu/resources/ocng_textbook/chapter10/Images/Fig10-12.jpg)

# Case Studies

Hurricane Katrina (August 2005)



Hurricane Rita (September 2005)



Hurricane Wilma (October 2005)



- Katrina was the costliest and one of the deadliest hurricanes on record in the United States
- Rita was the most intense storm ever in the Gulf of Mexico and had the fourth lowest central pressure (895 mb) on record in the Atlantic basin
- Wilma was one of the most intense Atlantic hurricanes, the third costliest hurricane, and had the lowest central pressure (882 mb) in NHC record

# Satellite Data

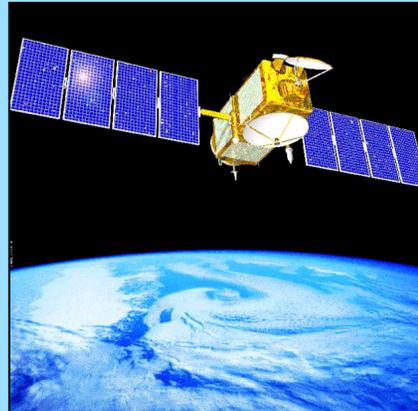
- **Sea Surface Temperature (SST):**
- *Advanced Very High Resolution Radiometer (AVHRR)*
- *Tropical Rainfall Measuring Mission Microwave Imager (TMI)*



<http://www.noaanews.noaa.gov/stories2005/images/noaa-n.jpg>



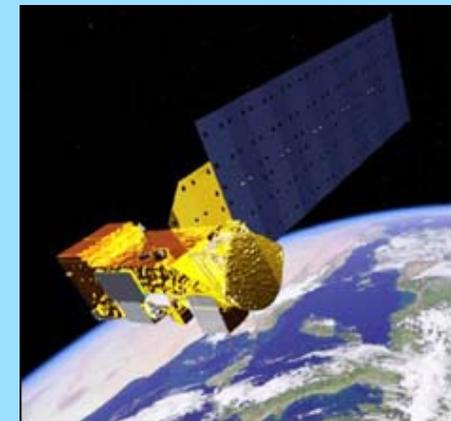
<http://www.eorc.jaxa.jp/TRMM/about/outline/image/uzutrmm.jpg>



[http://www2.jpl.nasa.gov/pub/images/browse/jason\\_browse.jpg](http://www2.jpl.nasa.gov/pub/images/browse/jason_browse.jpg)

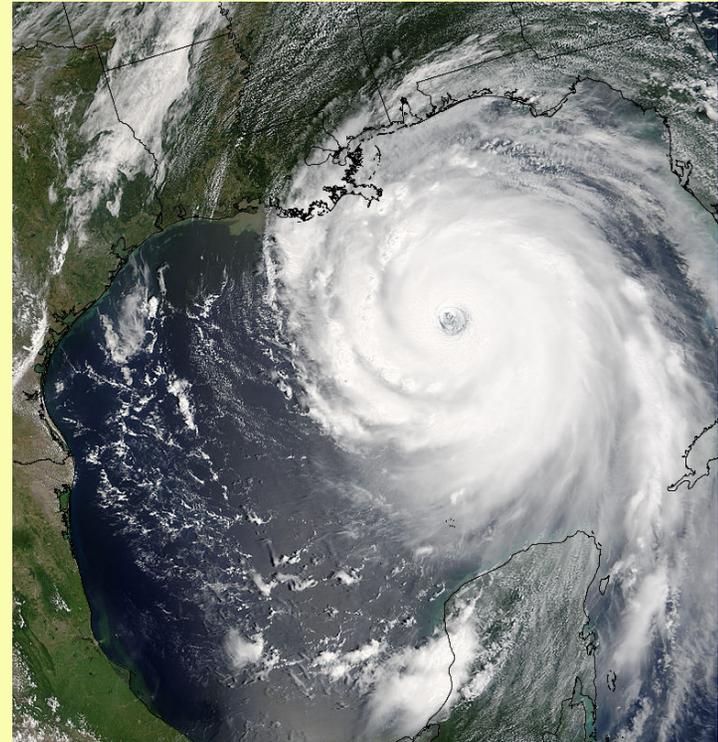
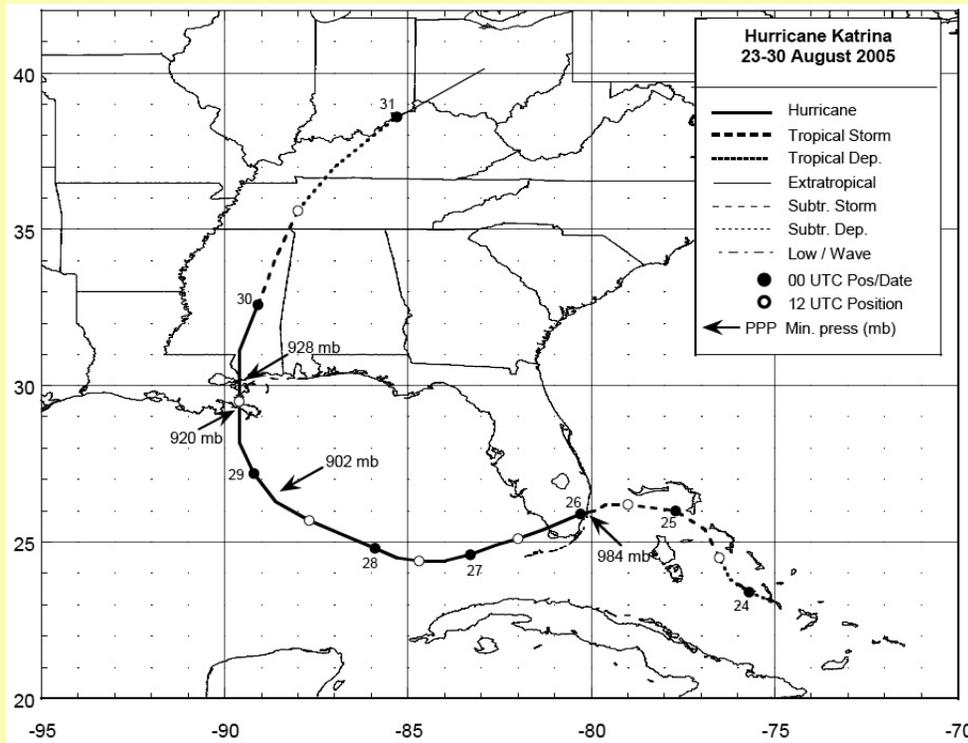
- **Sea Surface Height (SSH):**
- *Jason-1*
- *TOPEX/POSEIDON*
- *Geosat Follow-On (GFO)*
- *Envisat*

- **Chlorophyll-a Concentration:**
- *MODerate resolution Imaging Spectroradiometer (MODIS)*



[http://science.hq.nasa.gov/missions/images/aqua\\_orbit.jpg](http://science.hq.nasa.gov/missions/images/aqua_orbit.jpg)

# Hurricane Katrina (2005)

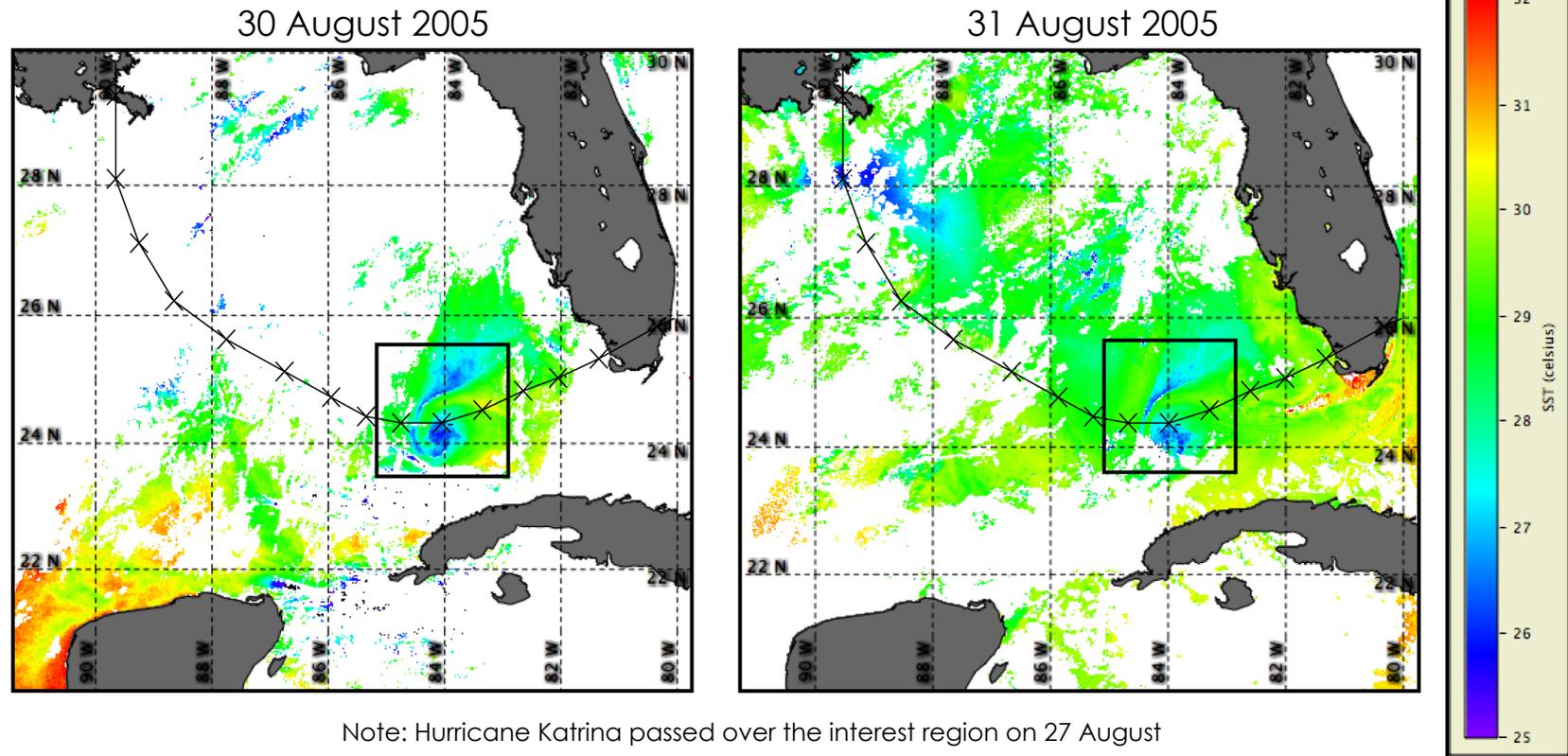


From NHC: [http://www.nhc.noaa.gov/pdf/TCR-AL122005\\_Katrina.pdf](http://www.nhc.noaa.gov/pdf/TCR-AL122005_Katrina.pdf)

- Hurricane Katrina made first landfall near the border of Miami-Dade County and Broward County at 2230 UTC 25 August as a category 1 hurricane
- Katrina made second landfall near Buras, Louisiana at 1110 UTC 29 August as a category 3 hurricane
- Katrina made its final landfall near the mouth of the Pearl River at the Louisiana-Mississippi border as a category 3 hurricane

# Hurricane Katrina (2005)

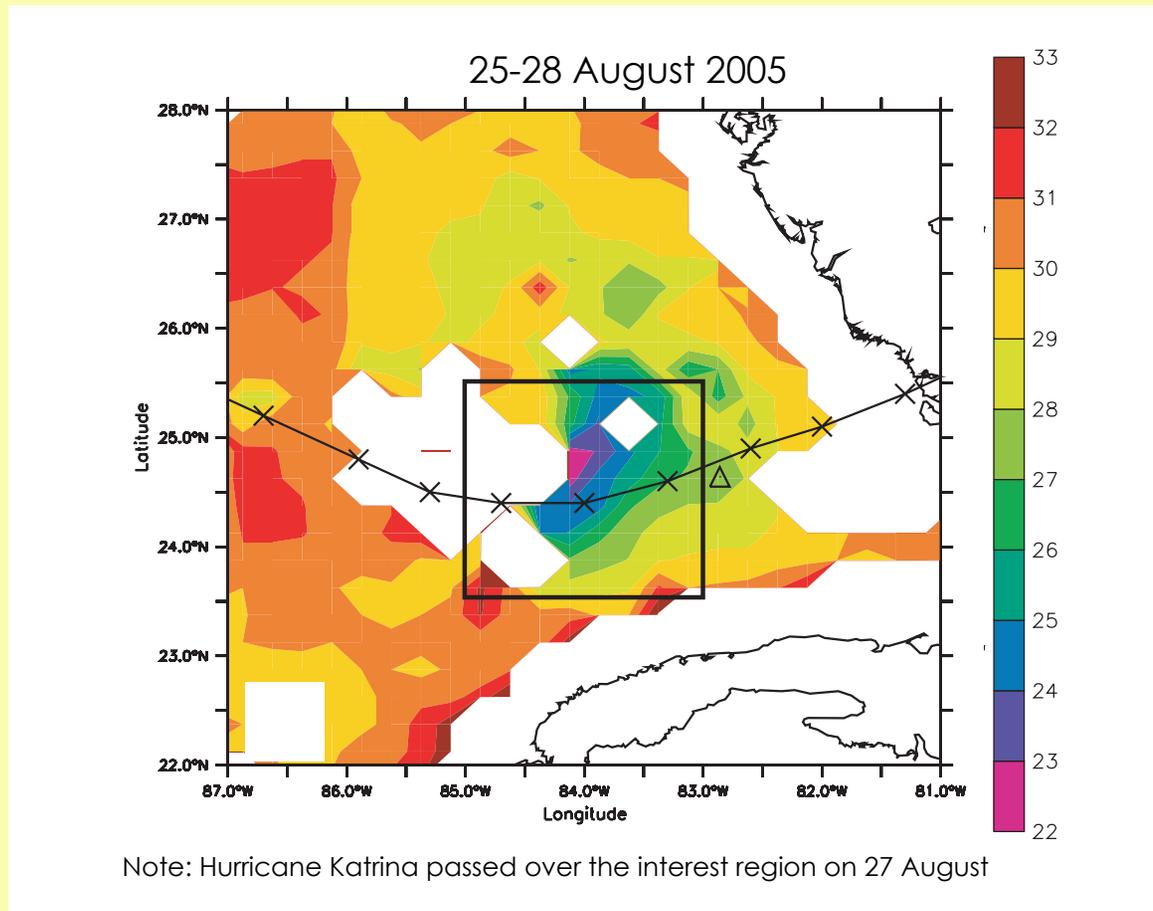
## AVHRR SST



- Initial SSTs exceeded 29°C
- SSTs cooled to approximately 26°C along the hurricane track
- Maximum SST change was 3-4°C

# Hurricane Katrina (2005)

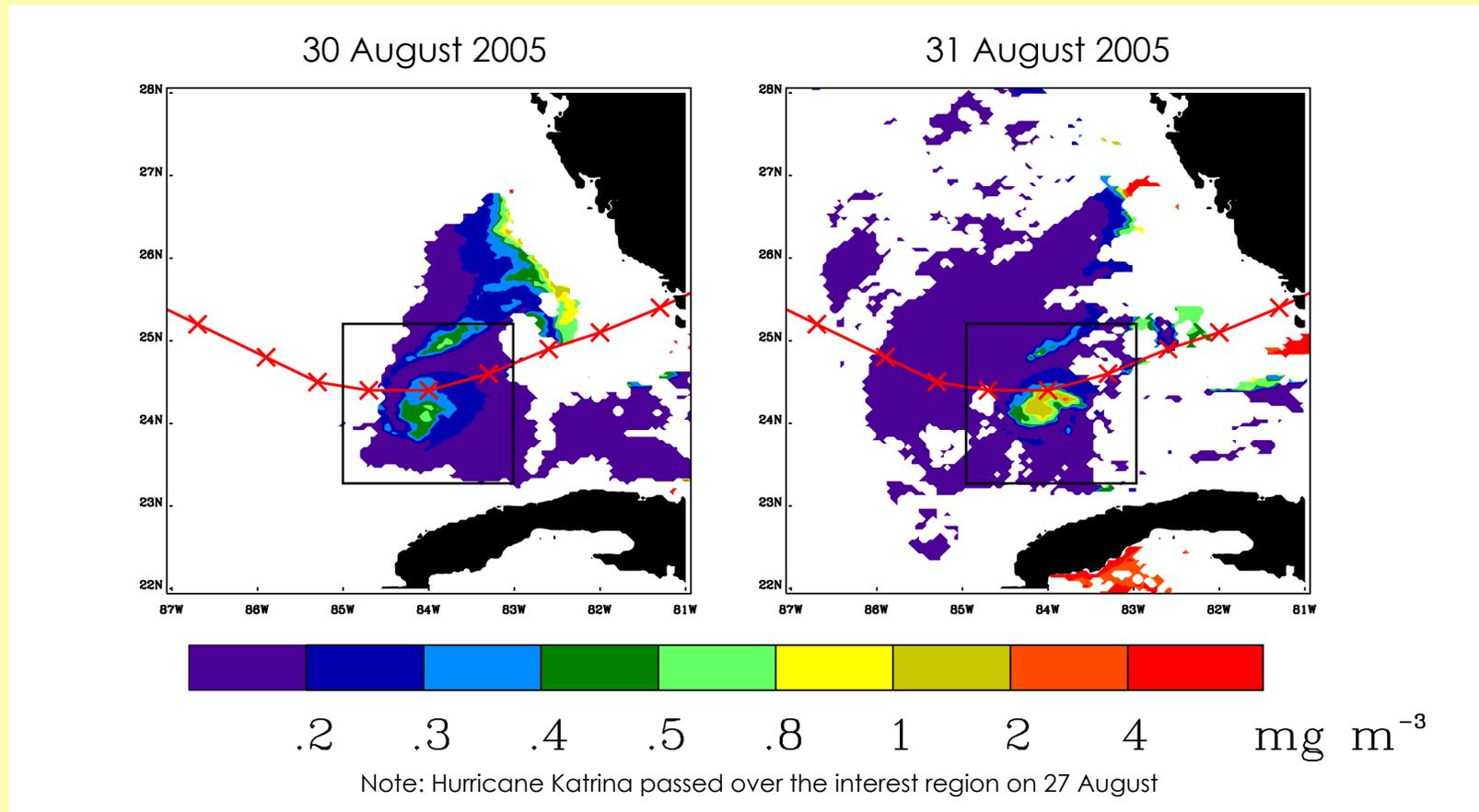
## *TMI SST*



- Initial SSTs exceeded 29°C
- SSTs cooled to approximately 22-23°C along the hurricane track
- Maximum SST change was 6-7°C

# Hurricane Katrina (2005)

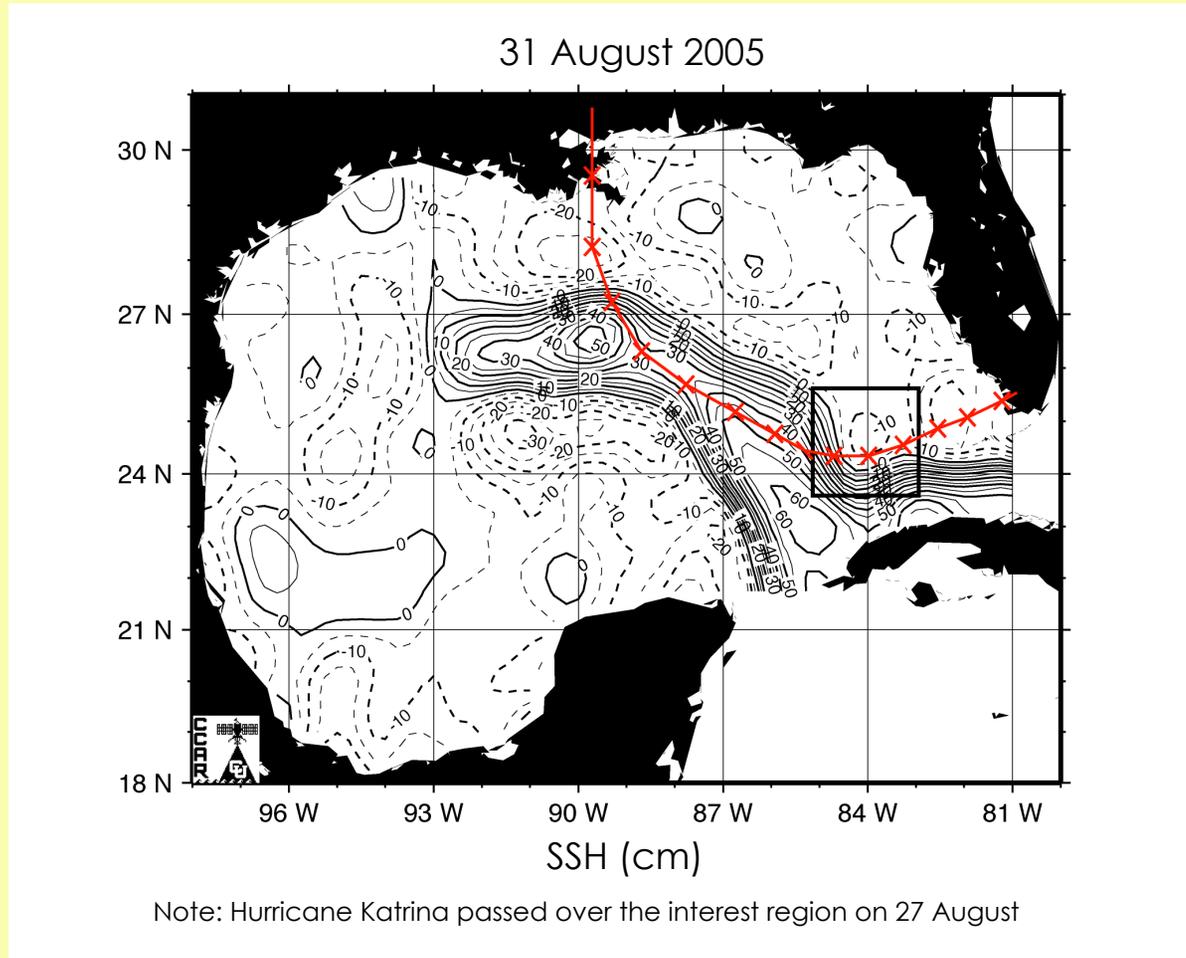
## MODIS Chlorophyll-a



- Initial chlorophyll-a values ranged between 0-0.2  $\text{mg} \cdot \text{m}^{-3}$
- Peak chlorophyll concentration was 2.69  $\text{mg} \cdot \text{m}^{-3}$  (4 days after passage)
- Chlorophyll-a values returned to initial concentrations (10-17 days after passage)

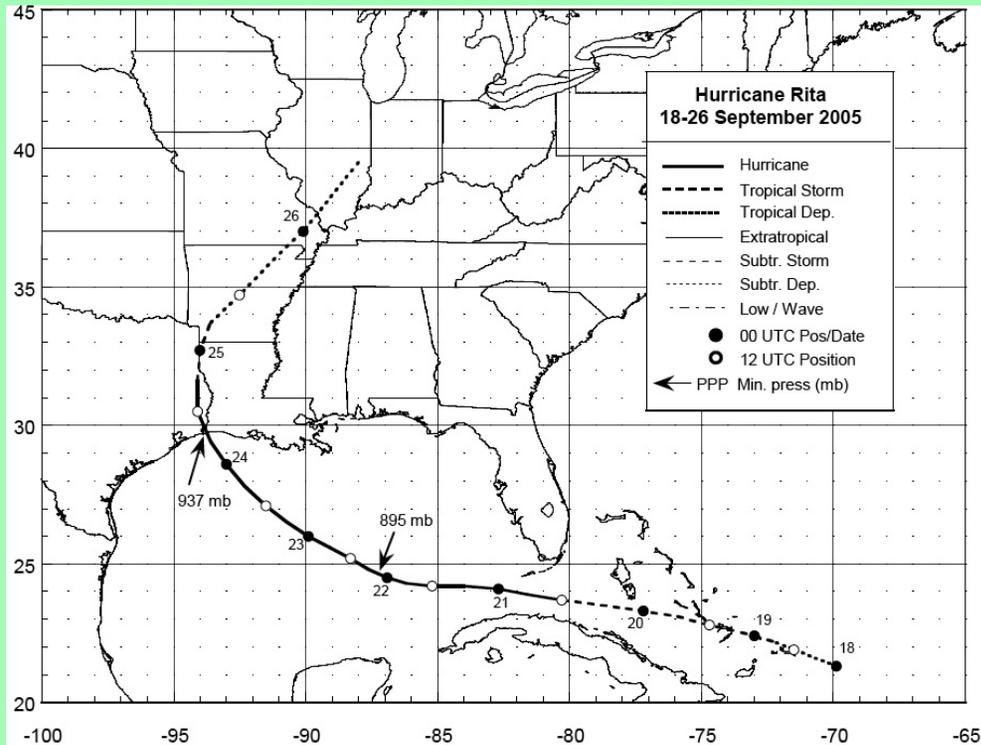
# Hurricane Katrina (2005)

## SSH

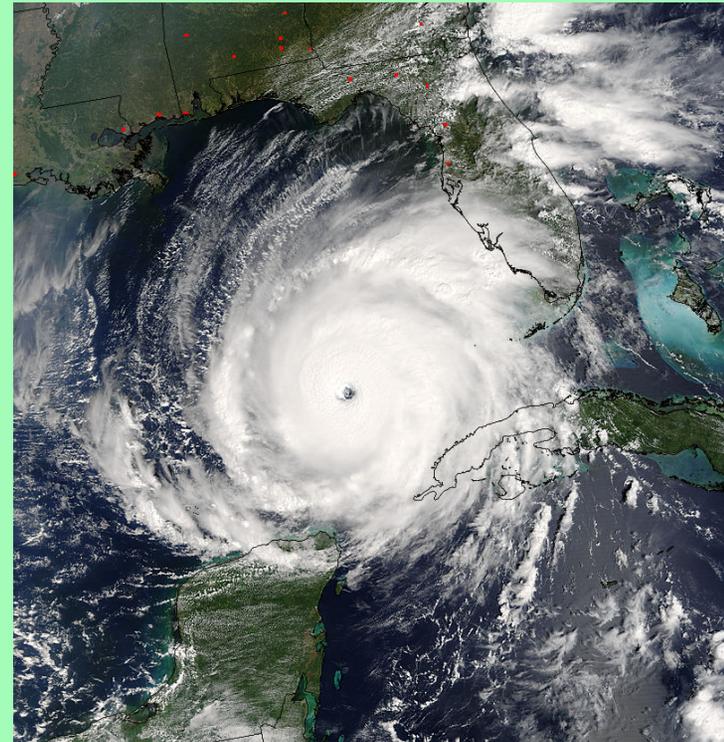


- The area of interest associated with Katrina occurred within a pre-existing cyclonic circulation

# Hurricane Rita (2005)



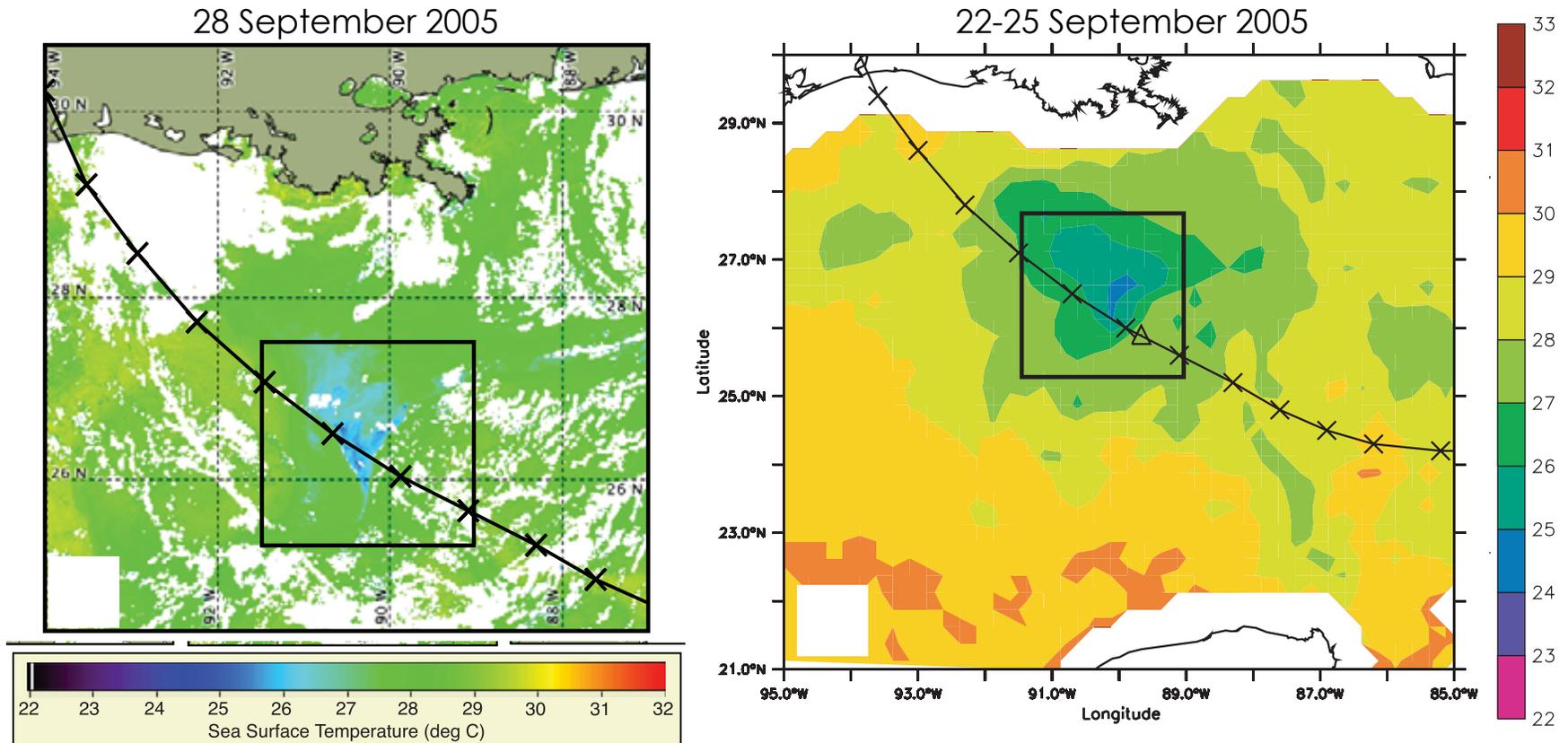
From NHC: [http://www.nhc.noaa.gov/pdf/TCR-AL182005\\_Rita.pdf](http://www.nhc.noaa.gov/pdf/TCR-AL182005_Rita.pdf)



- Hurricane Rita made landfall in southwestern Louisiana at 0740 UTC 24 September as a category 3 hurricane

# Hurricane Rita (2005)

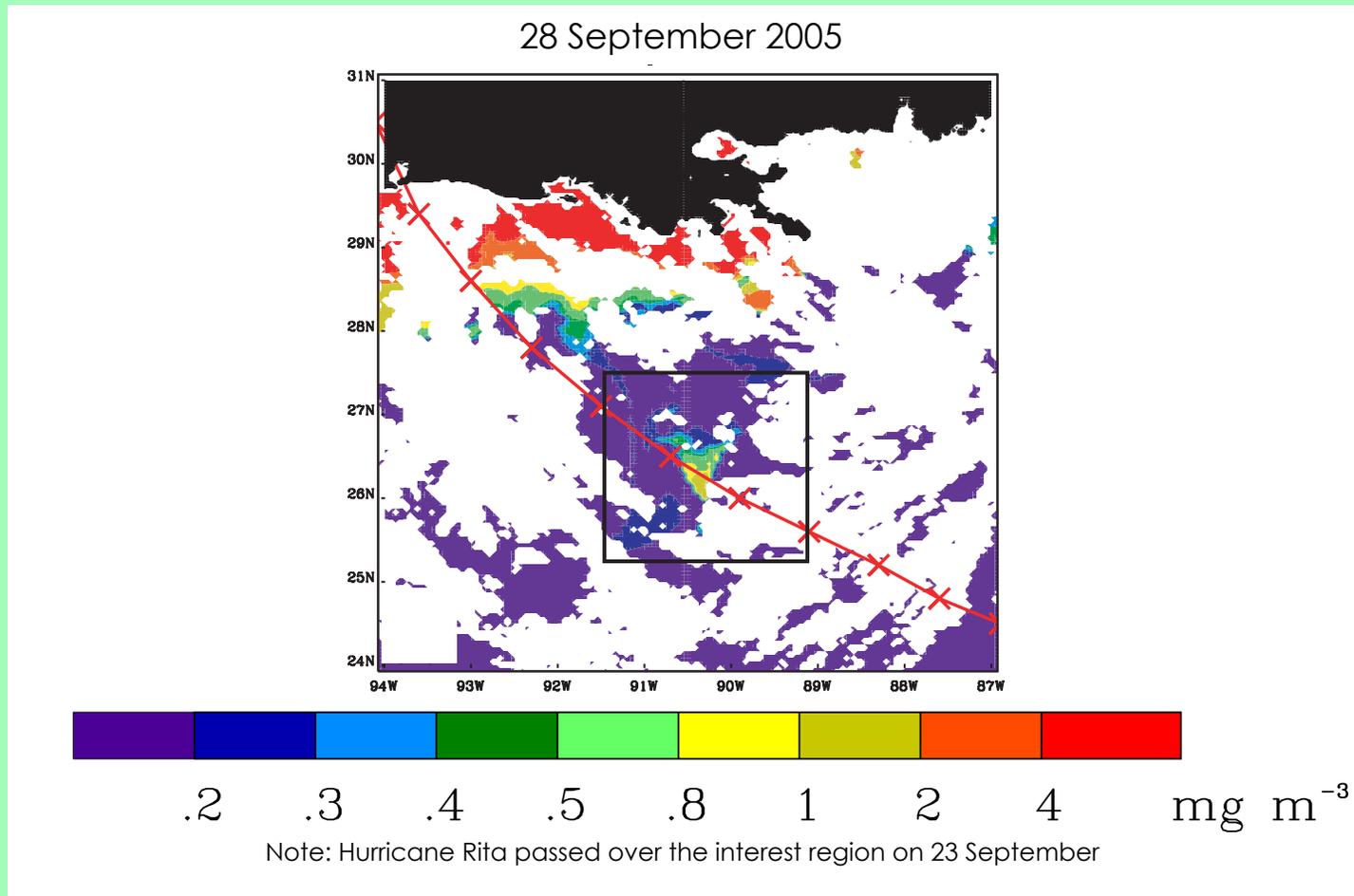
## AVHRR and TMI SST



- Hurricane Rita portrayed a similar SST response to that of Katrina
- Maximum SST change was 3-5°C

# Hurricane Rita (2005)

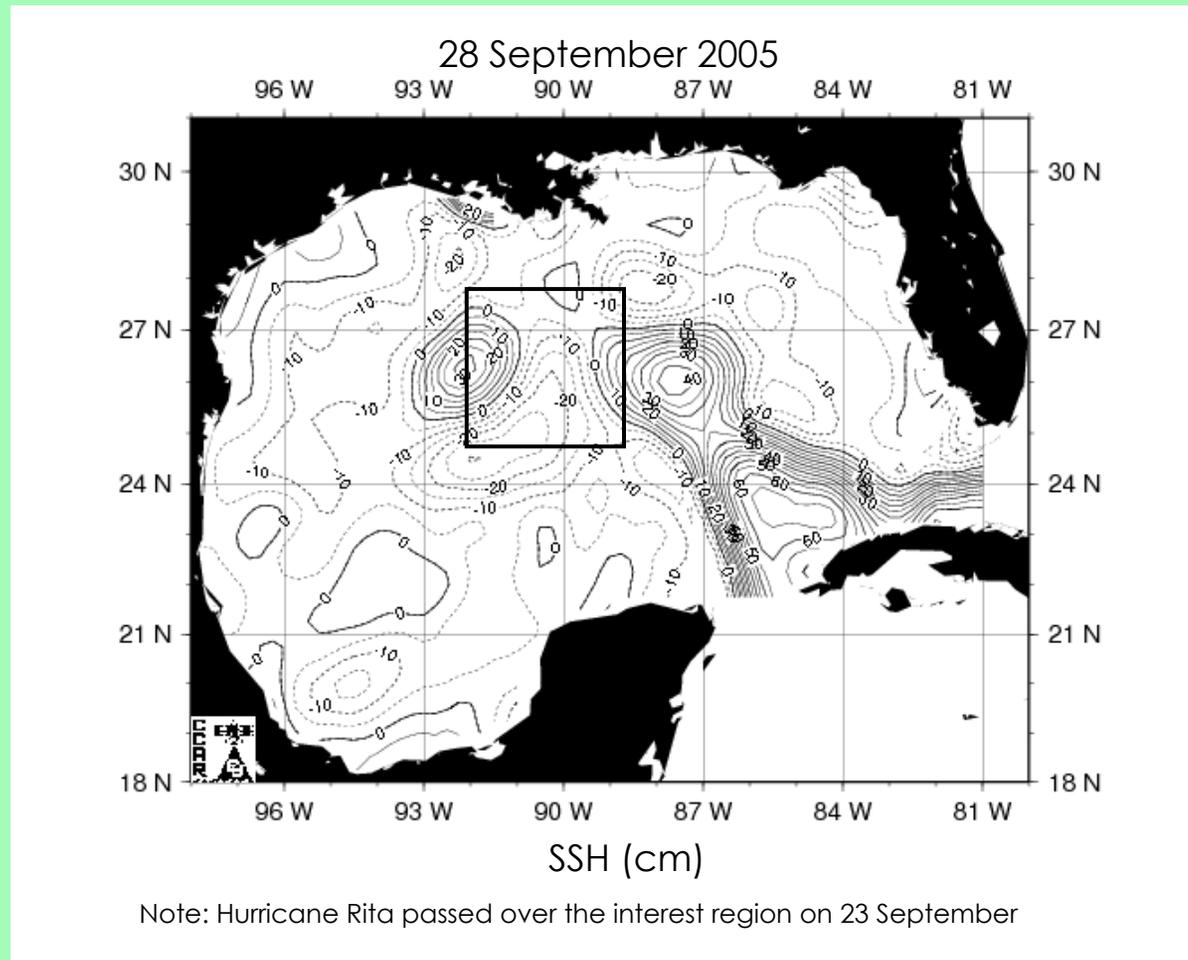
## **MODIS Chlorophyll-a**



- Initial chlorophyll-a concentrations ranged between 0-0.2 mg · m<sup>-3</sup>
- Peak chlorophyll concentration observed was 1.97 mg · m<sup>-3</sup> (5 days after passage)

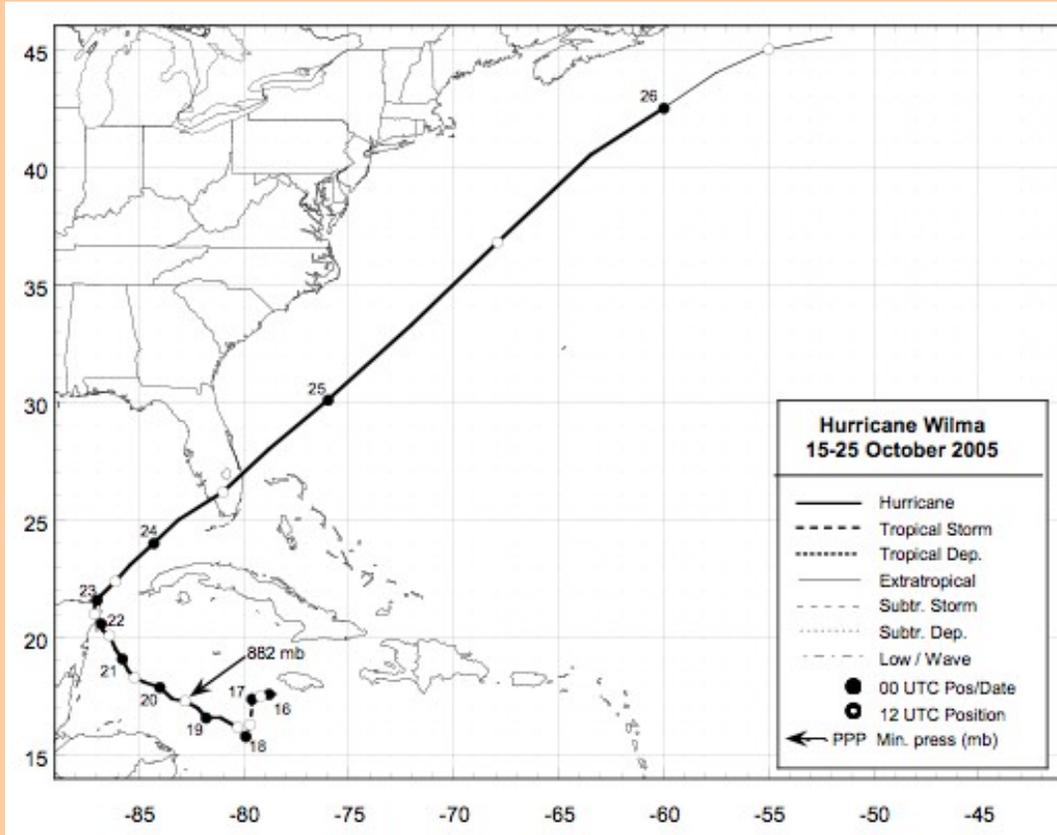
# Hurricane Rita (2005)

## SSH



- The area associated with Rita transpired in a region where a warm core eddy was shedding from the Loop Current

# Hurricane Wilma (2005)



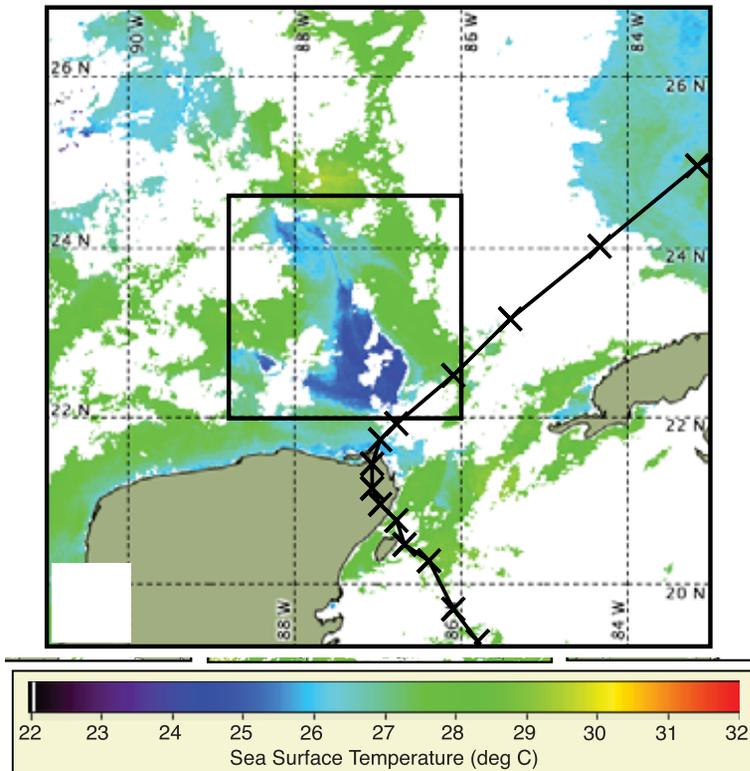
From NHC: [http://www.nhc.noaa.gov/pdf/TCR-AL252005\\_Wilma.pdf](http://www.nhc.noaa.gov/pdf/TCR-AL252005_Wilma.pdf)

- Hurricane Wilma first made landfall on the island of Cozumel at approximately 2145 UTC 21 October as a category 4 hurricane
- Wilma crossed the Yucatan peninsula 6 hours later (345 UTC 22 October)
- Wilma made final landfall in southwestern Florida near Cape Romano around 1030 UTC 24 October as a category 3 hurricane

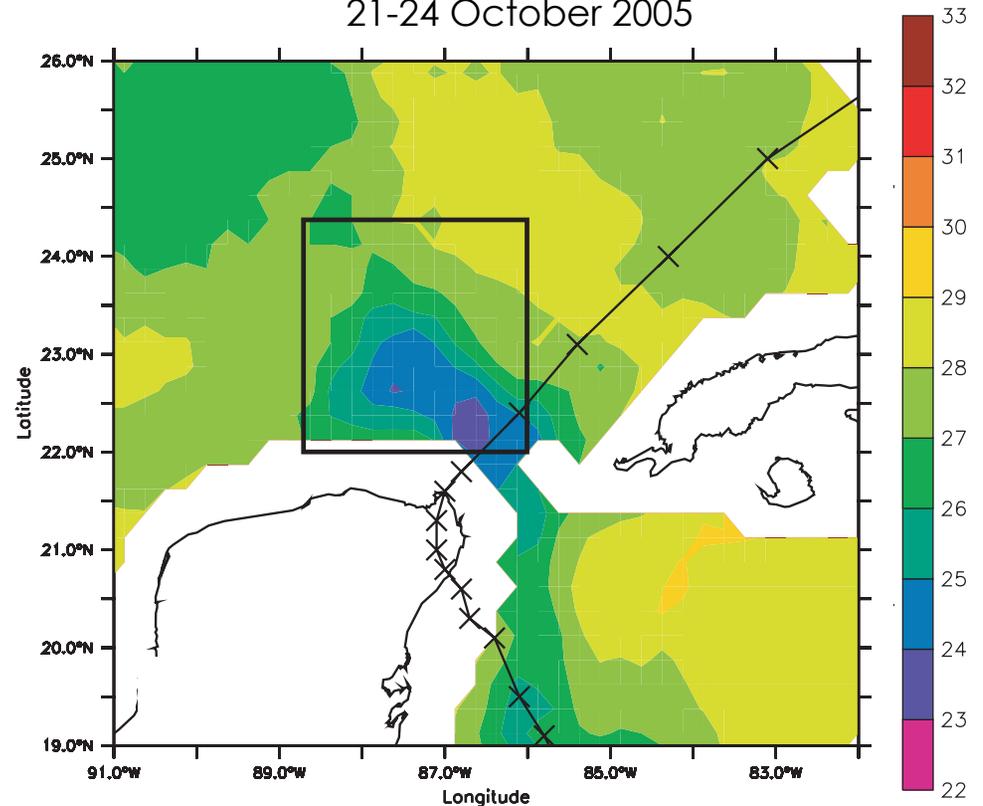
# Hurricane Wilma (2005)

## SST

27 October 2005



21-24 October 2005

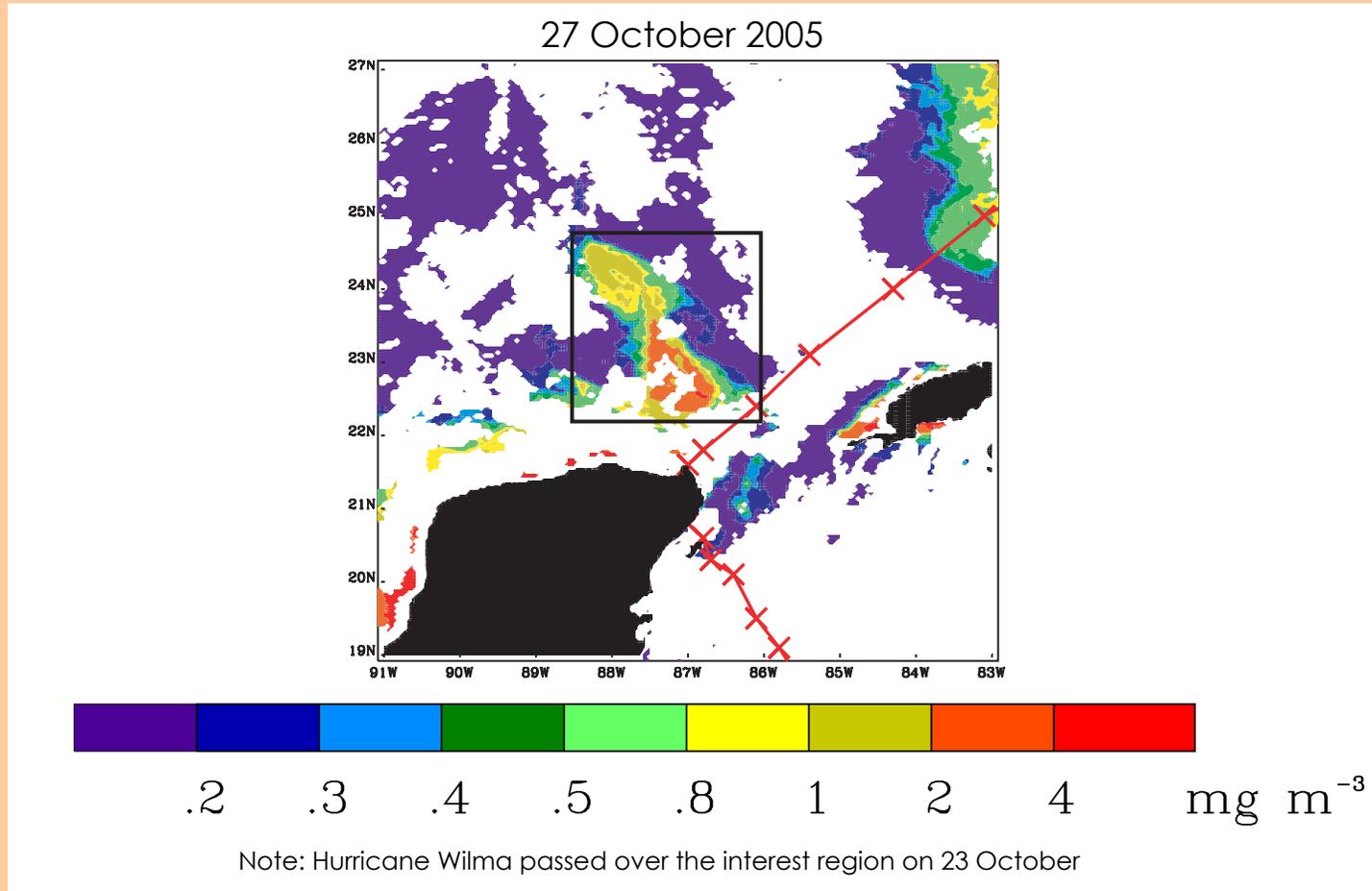


Note: Hurricane Wilma passed over the interest region on 23 October

- Initial SSTs exceeded 29°C
- Maximum SST change was approximately 3-6°C

# Hurricane Wilma (2005)

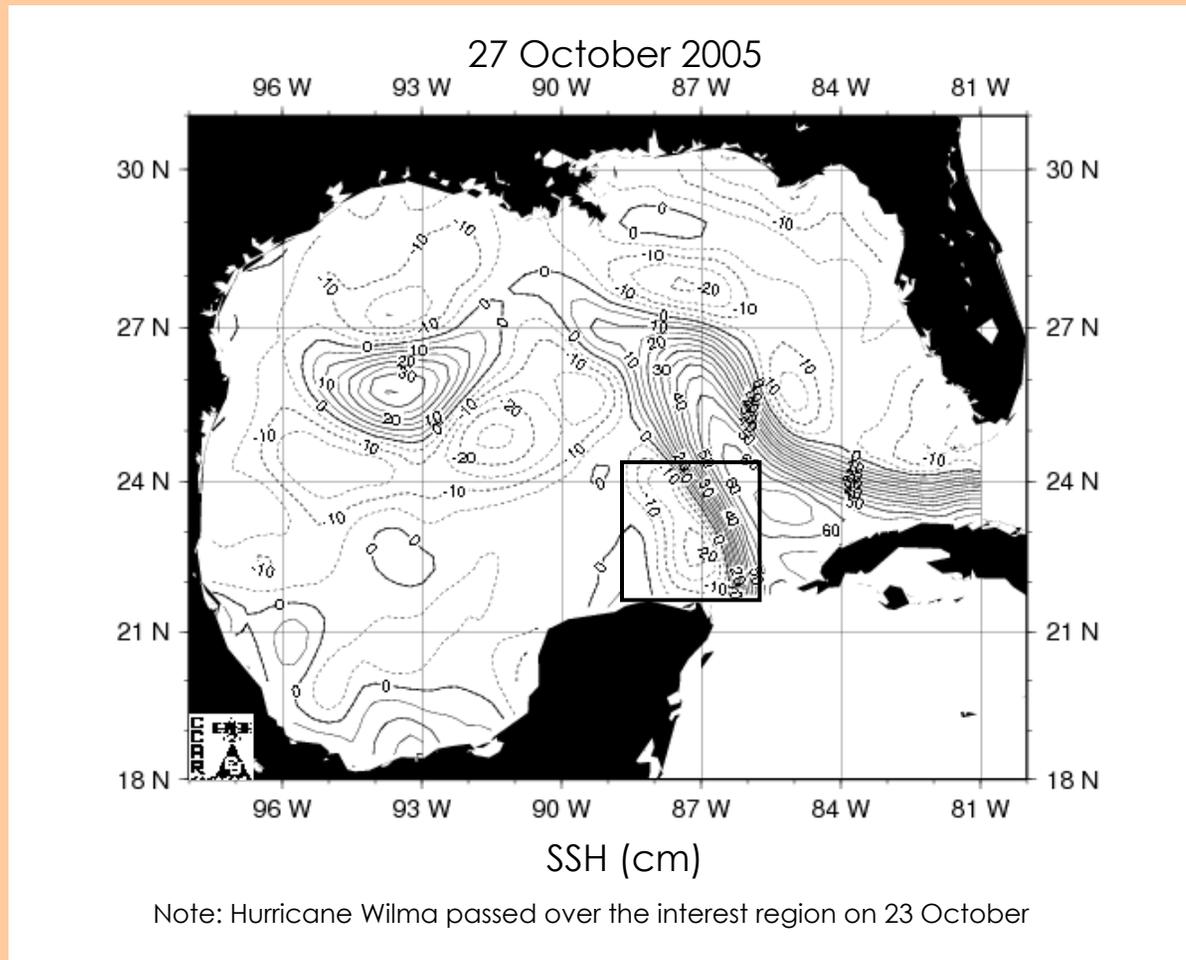
## **MODIS Chlorophyll-a**



- Initial chlorophyll-a concentrations ranged between 0-0.2 mg · m<sup>-3</sup>
- Peak chlorophyll concentration observed was 4.4 mg · m<sup>-3</sup> (4 days after passage)
- Chlorophyll-a values returned to initial concentrations (9-16 days after passage)

# Hurricane Wilma (2005)

## SSH



- The interest area associated with Wilma transpired within a cold core eddy

# Take Home Message

- Aside from devastation on land, hurricanes affect the ocean
- Expect to observe cold wakes and phytoplankton blooms after hurricane passage
- Oceanic processes can dramatically affect the biophysical responses exhibited
- Oceanic responses to hurricanes are not always what is expected
  - Leftward bias in the SST and chlorophyll-a response for Wilma

# Questions?

