

An Introduction to Remote Sensing of the Gulf of Mexico

Bob Leben

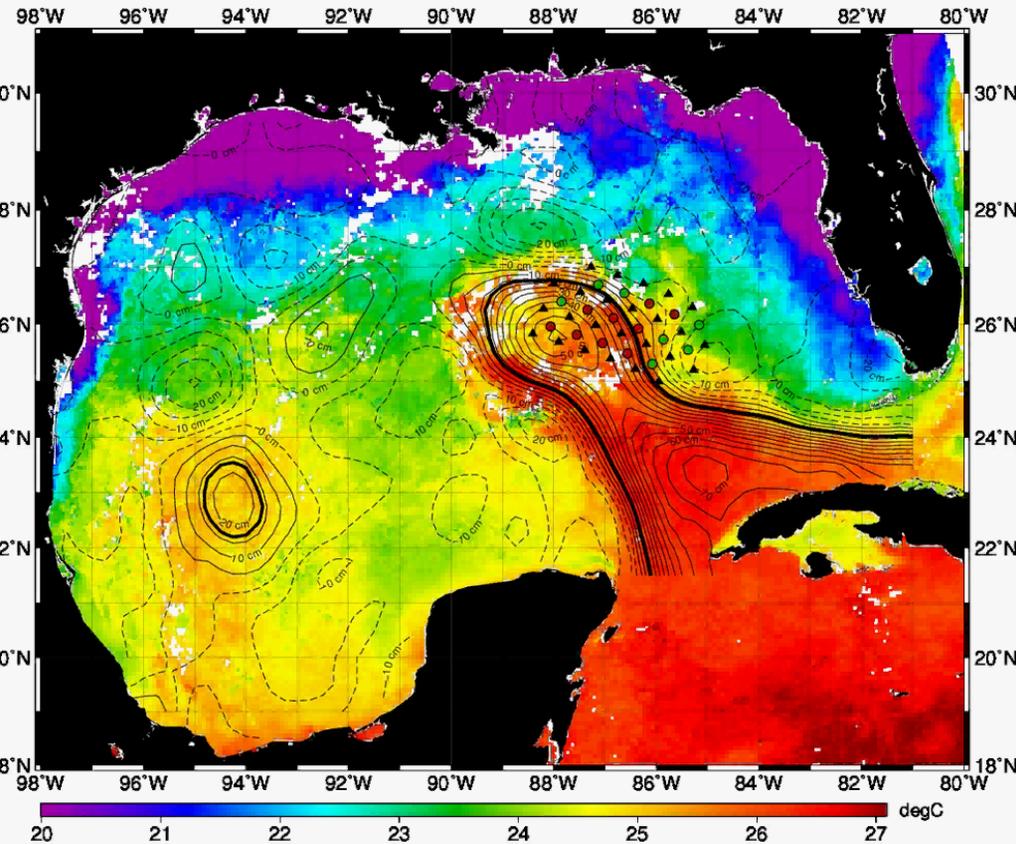
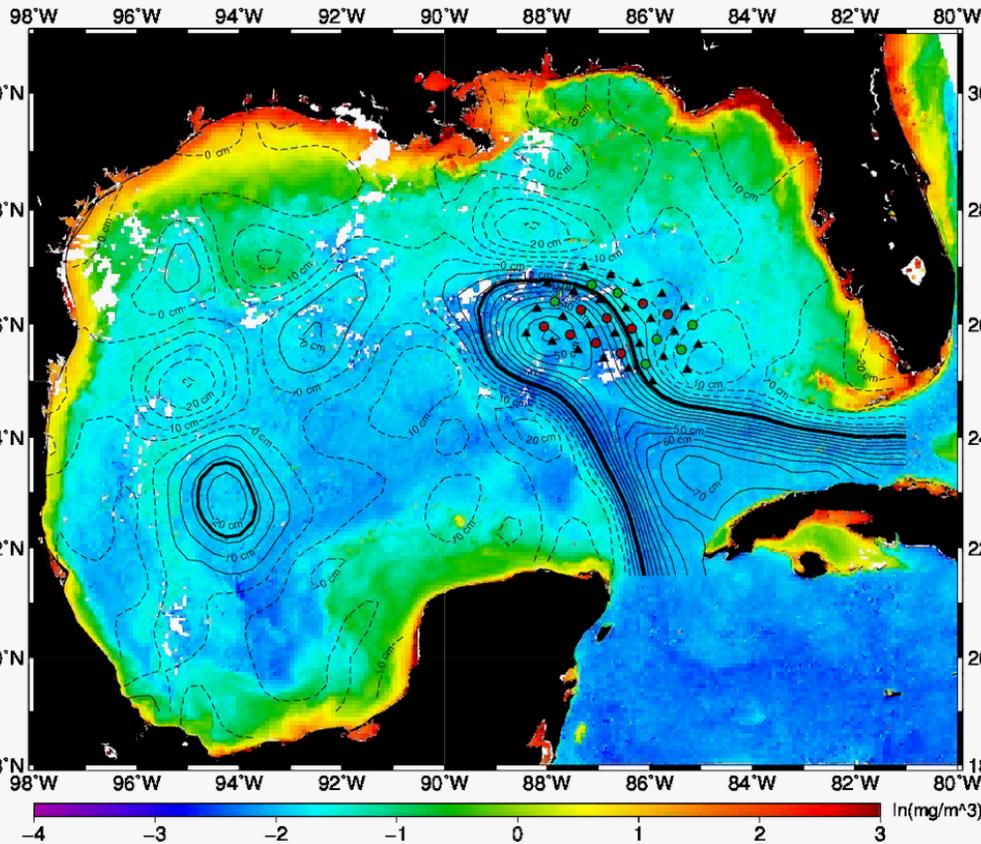
**Colorado Center for Astrodynamics Research
University of Colorado at Boulder**



SSH Overlaid on Chl and SST Imagery

L2-Aqua MODIS Chlorophyll/SSH Overlay for 01-Jan-2009

L2-Aqua SST/SSH Overlay for 01-Jan-2009



Outline

This talk is focused on Gulf of Mexico **mesoscale circulation** driven by the **Loop Current** and its associated **eddy field** that is resolved by multi-satellite sampling provided by the current generation of multiple nadir **satellite altimeters**.

4 Introduction to satellite altimetry

4 Several applications in the Gulf of Mexico

Off shore oil and gas exploration and production

Hurricane intensification

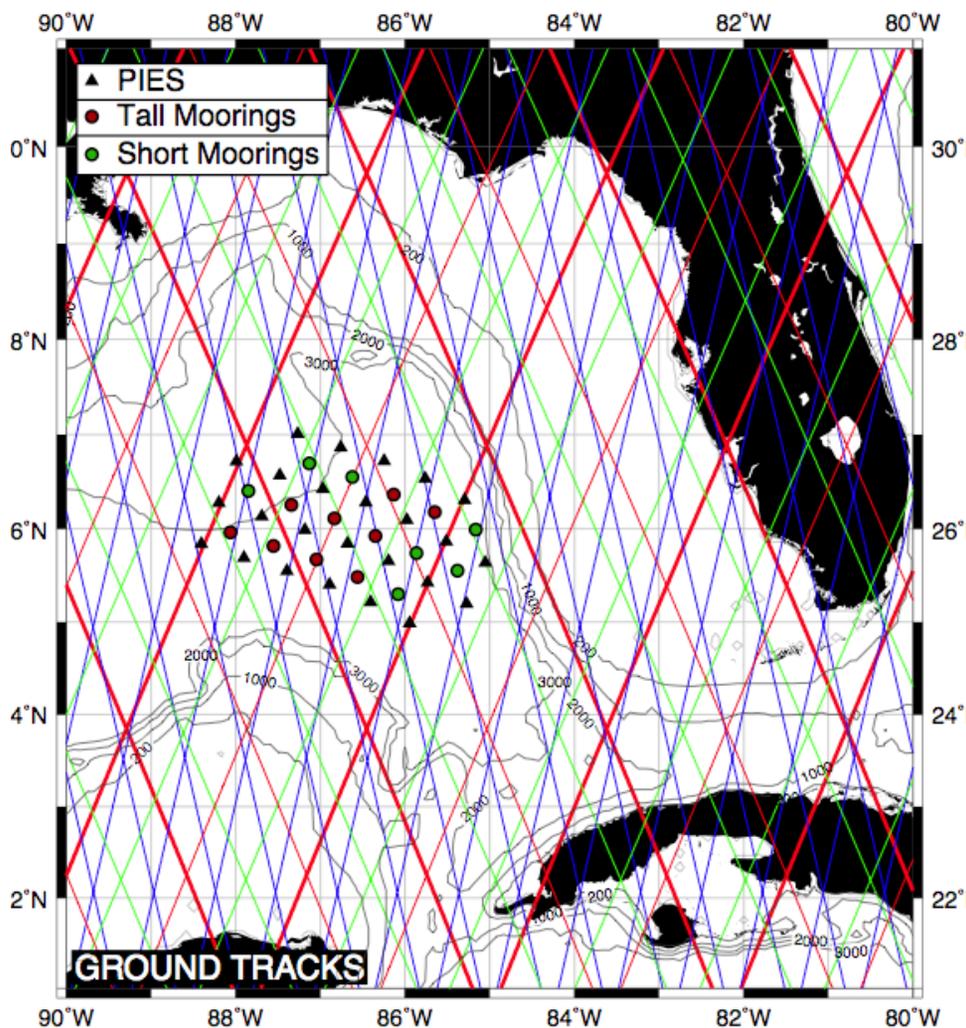


Deepwater Ocean Circulation: Satellite Altimetry



Satellite Altimeter Coverage in LC Study Area

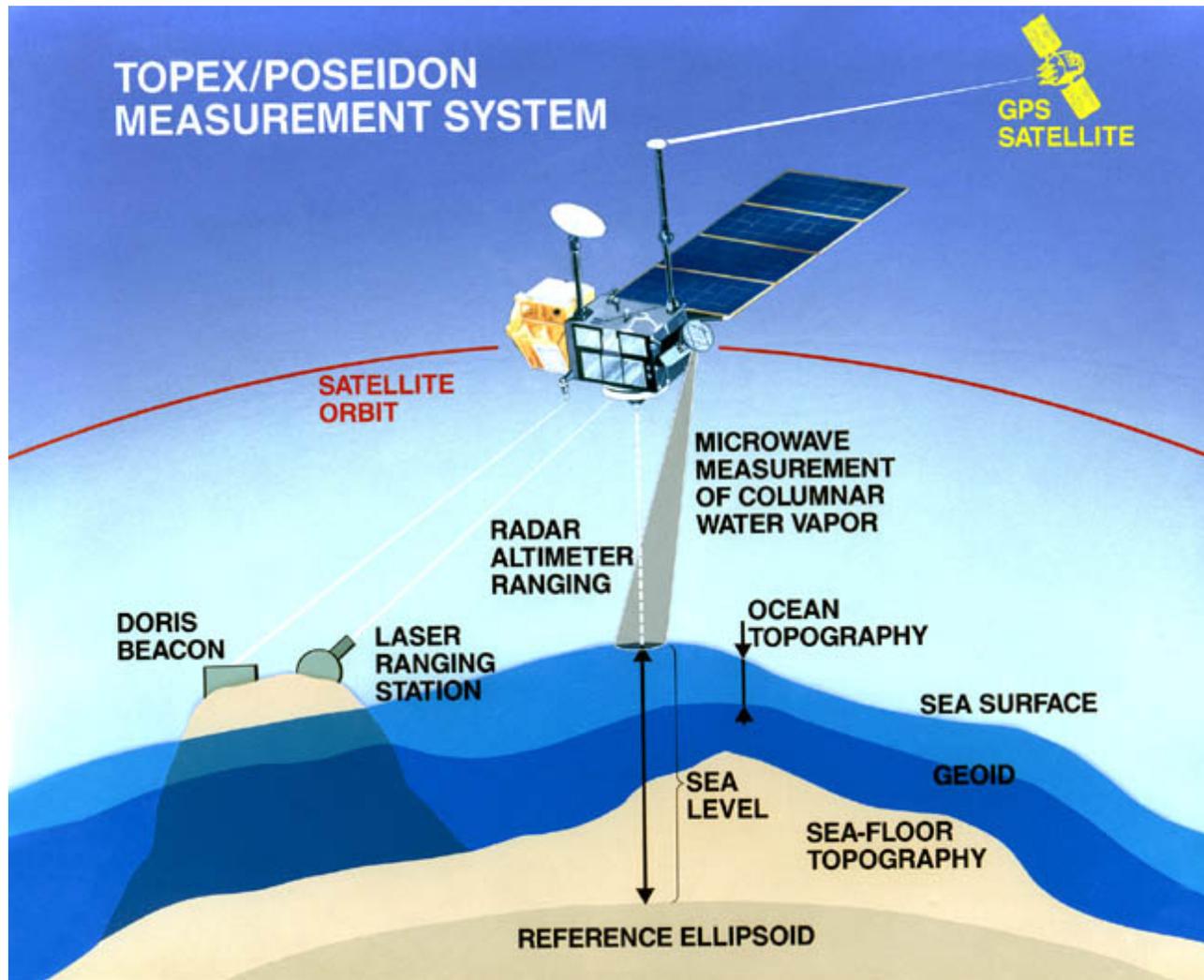
BOEM “Dynamics of the LC Study” Moorings



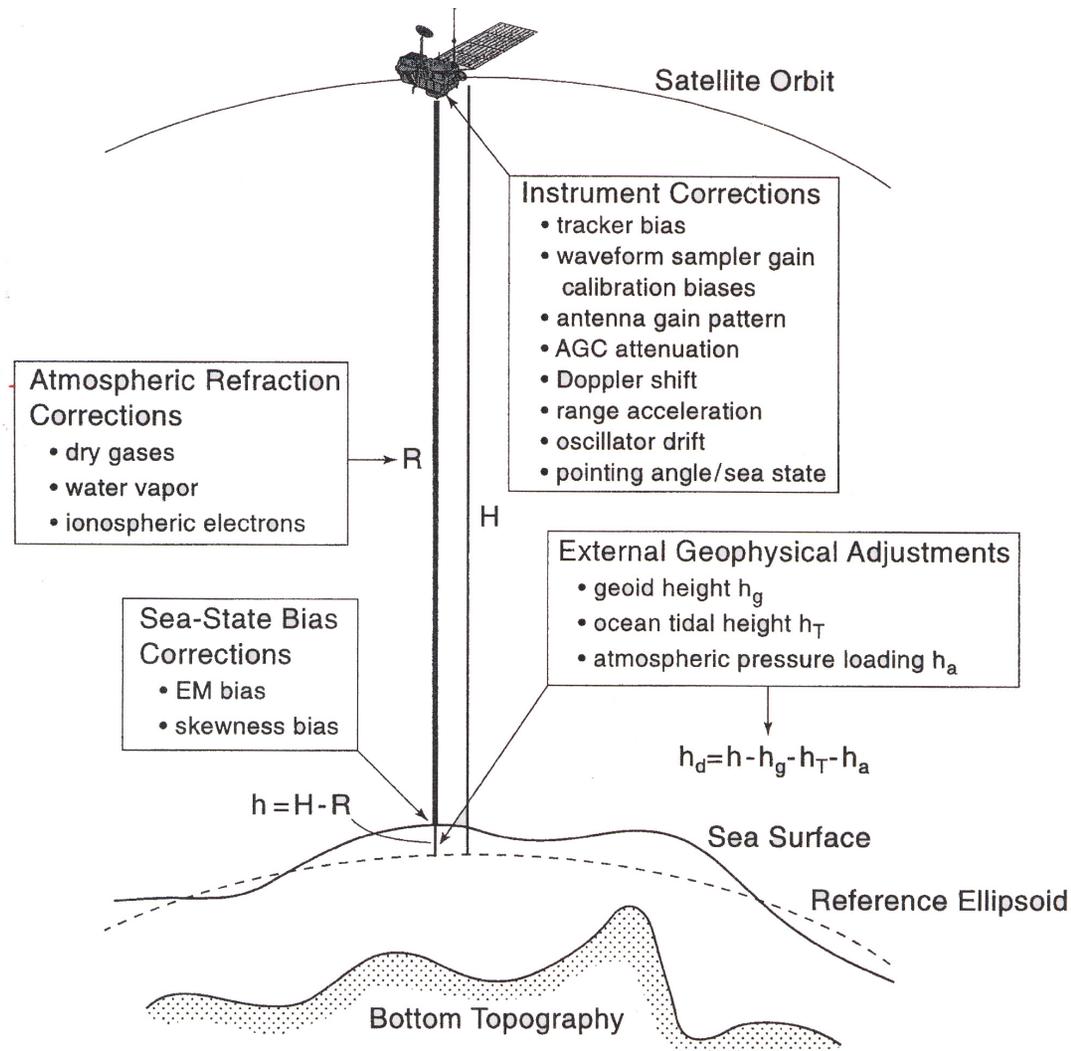
Satellite(s)	Repeat Period	Cross Track Spacing (degrees)	Cross Track Spacing (km*)
T/P, Jason, & OSTM	10 days	2.83°	285 km
GFO	17 days	1.47°	148 km
ERS-1&-2, Envisat	35 days	0.72°	73 km
OSTM/Jason Interleaved	10 days	1.42°	143 km



Schematic of Altimeter System

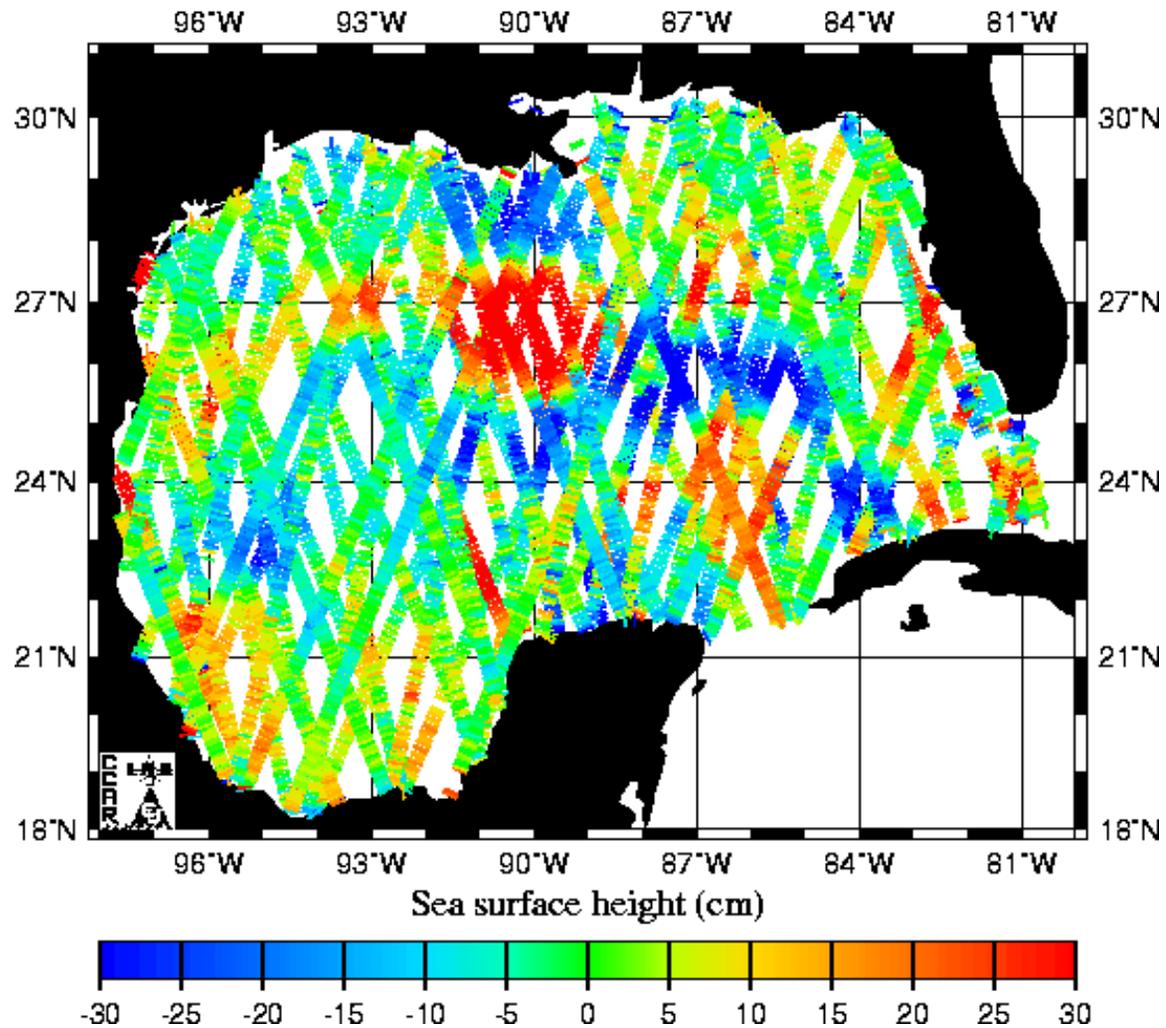


Schematic of Corrections



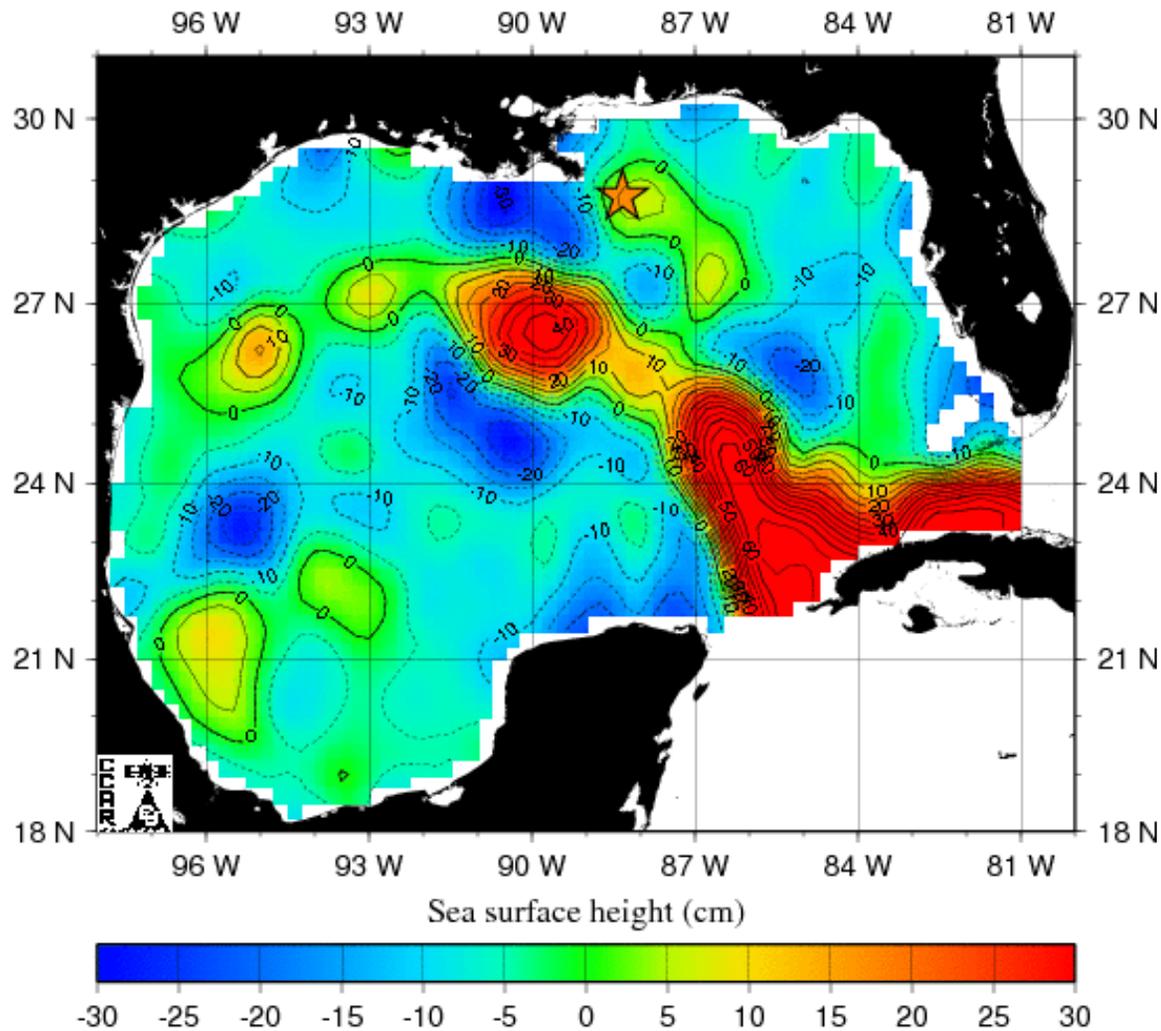
Sample along track SSH anomaly

TOPEX/ERS-2/GFO Apr 1 2001 - Apr 30 2001

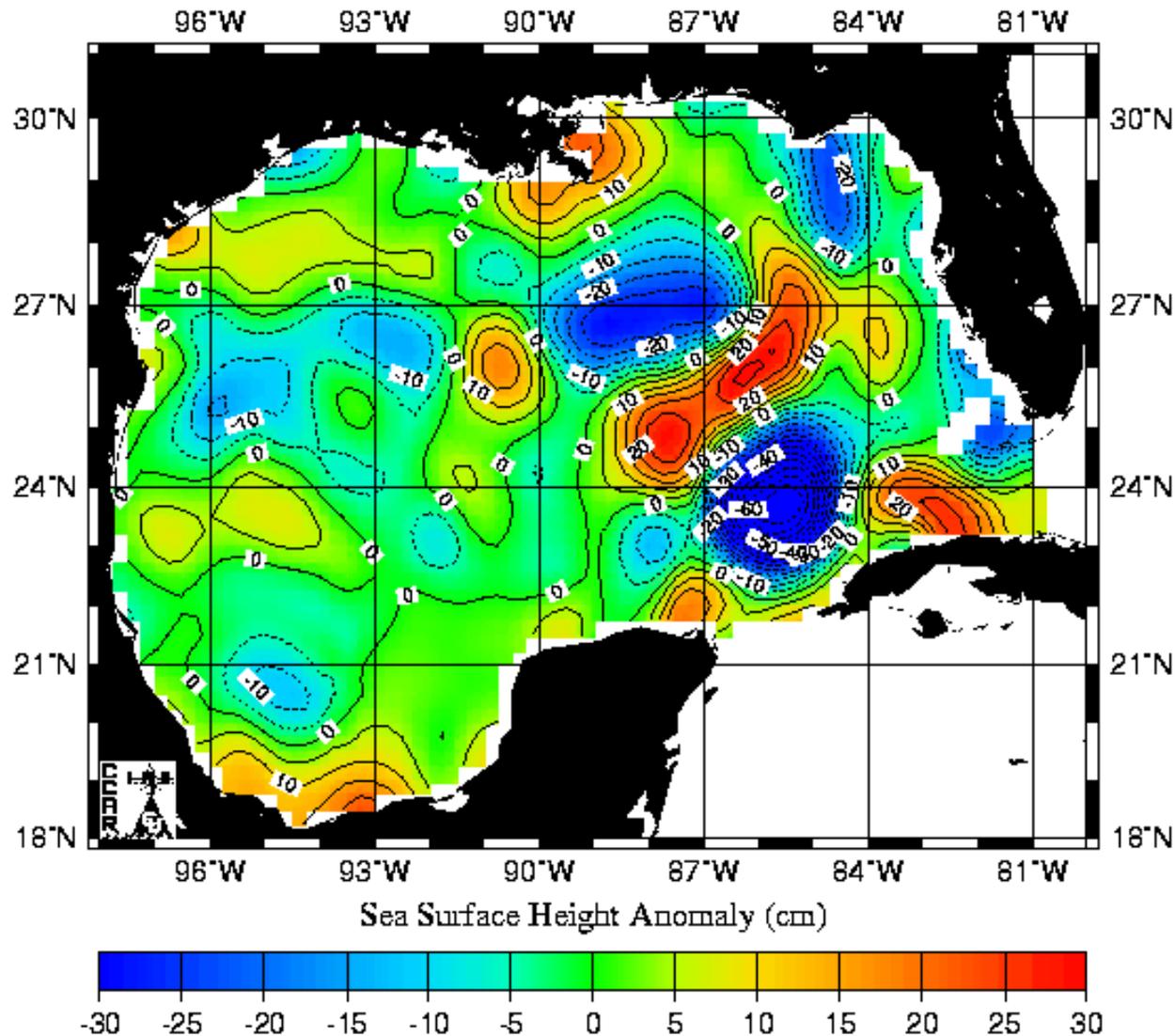


Mapped SSHA plus model mean

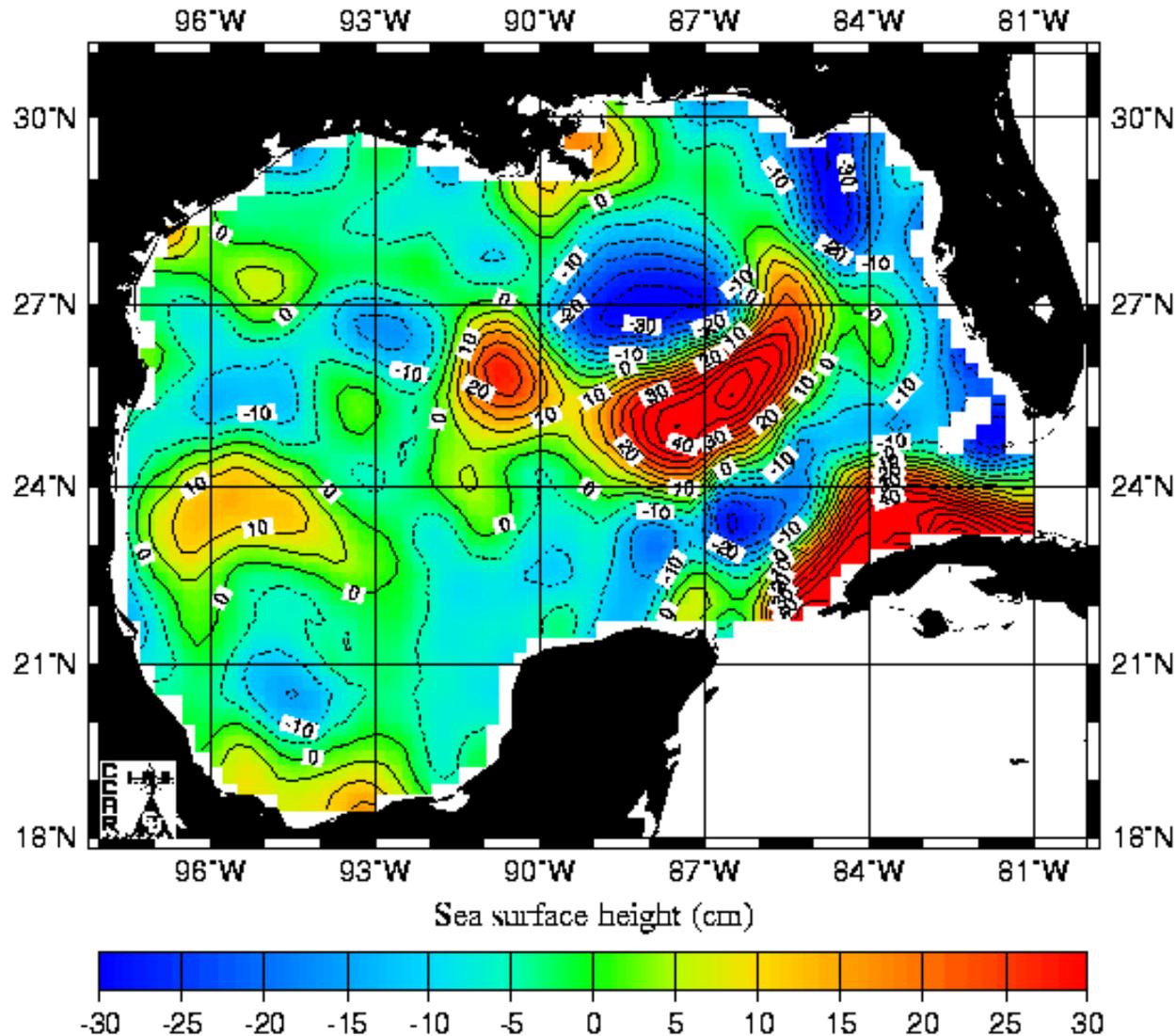
Historical Mesoscale Altimetry - Apr 15, 2001



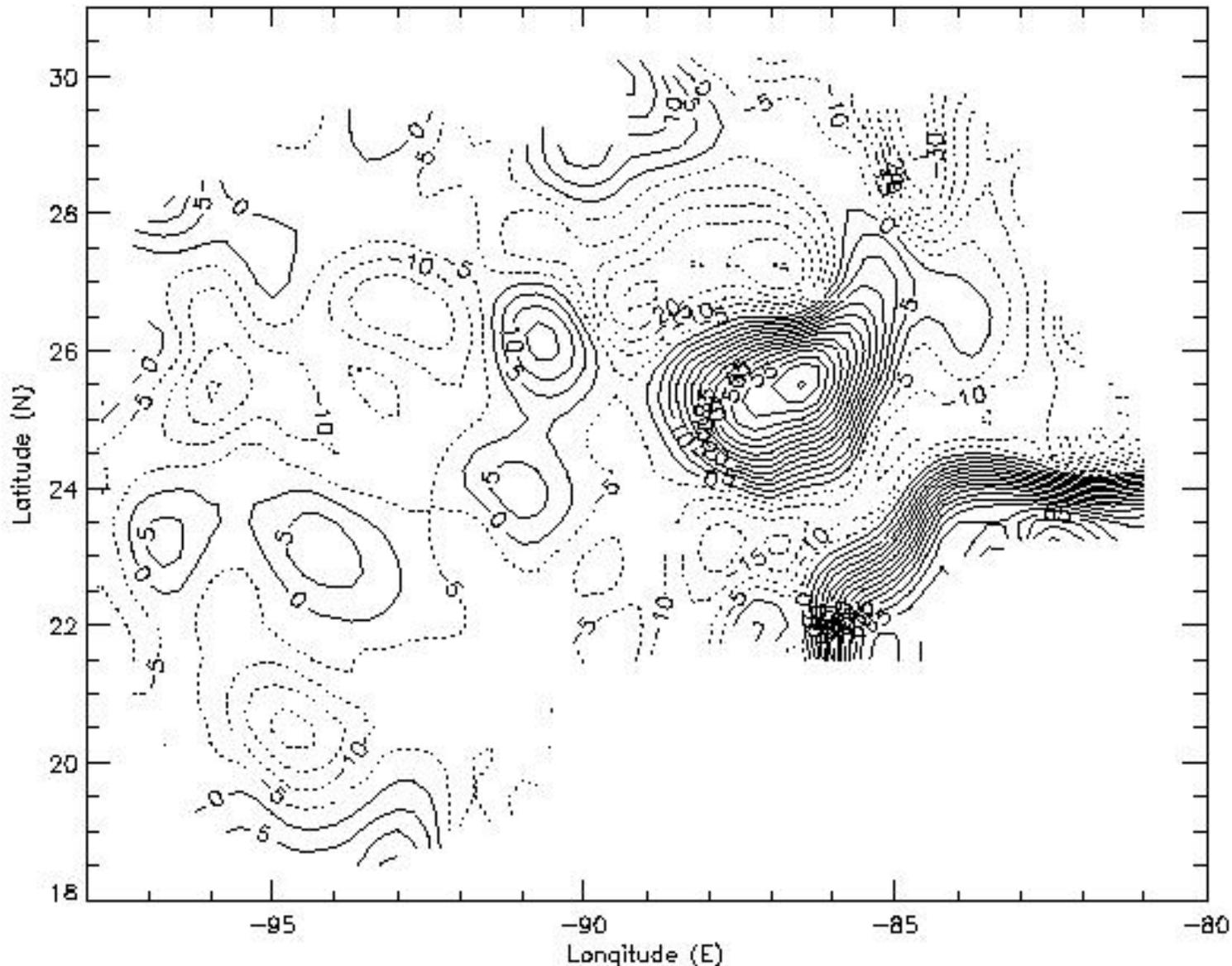
GOM SSH Anomaly 10/22/2003



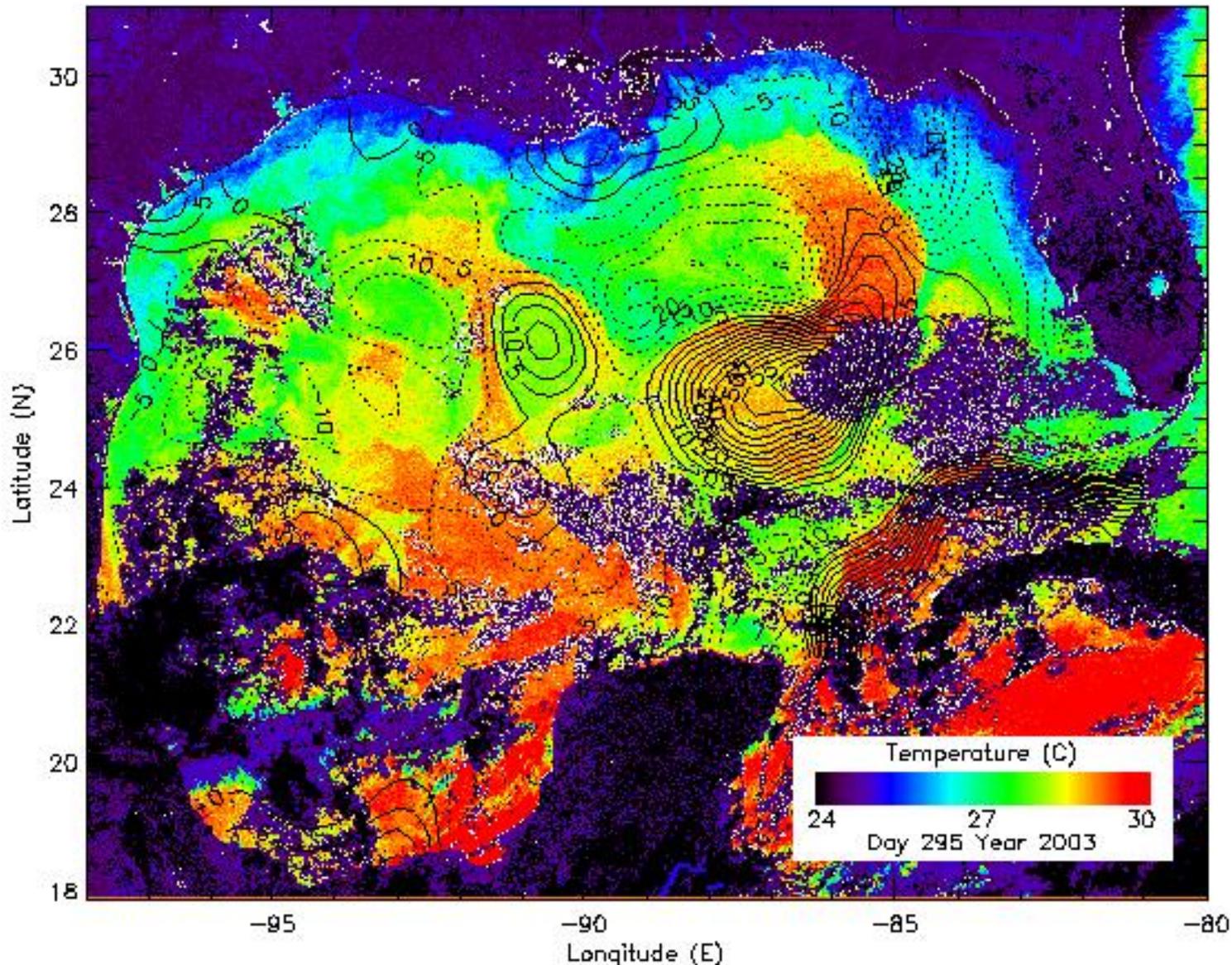
GOM SSH Map 10/22/2003



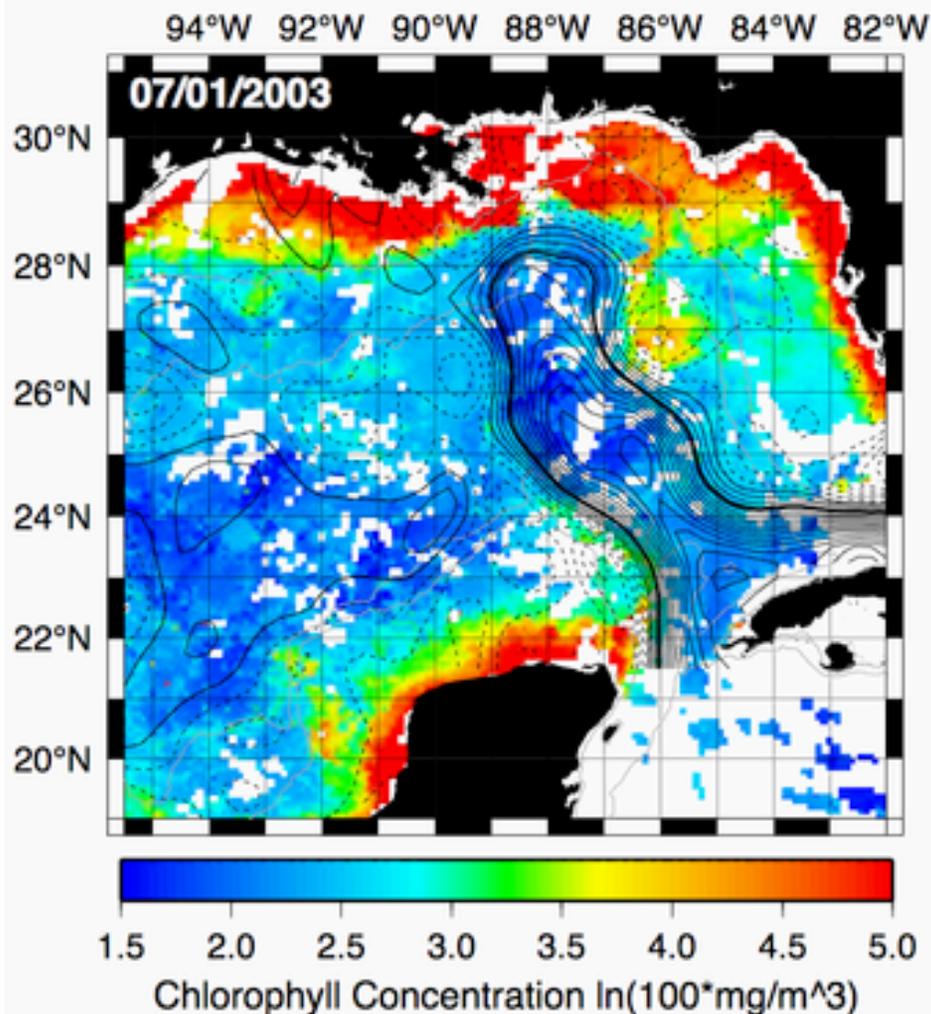
Altimetry Blended SSH



SST/SSH Overlay October 22, 2003



Altimetric Tracking of the LC and LCEs



4The 17-cm LC tracking contour is used to objectively track the LC and LCEs and identify LCE separation events.

4The day that the breaking of the LC tracking contour occurs is identified as the nominal “time” of LCE separation.

4Sometimes a detached eddy will reattach to the LC. In those cases, the time associated with the final detachment of the LCE from the LC is referred to as the LCE separation time.

4A total of **30 separation events** were observed in the altimetric record from **January 1, 1993 through December 31, 2012.**



Loop Current Metrics

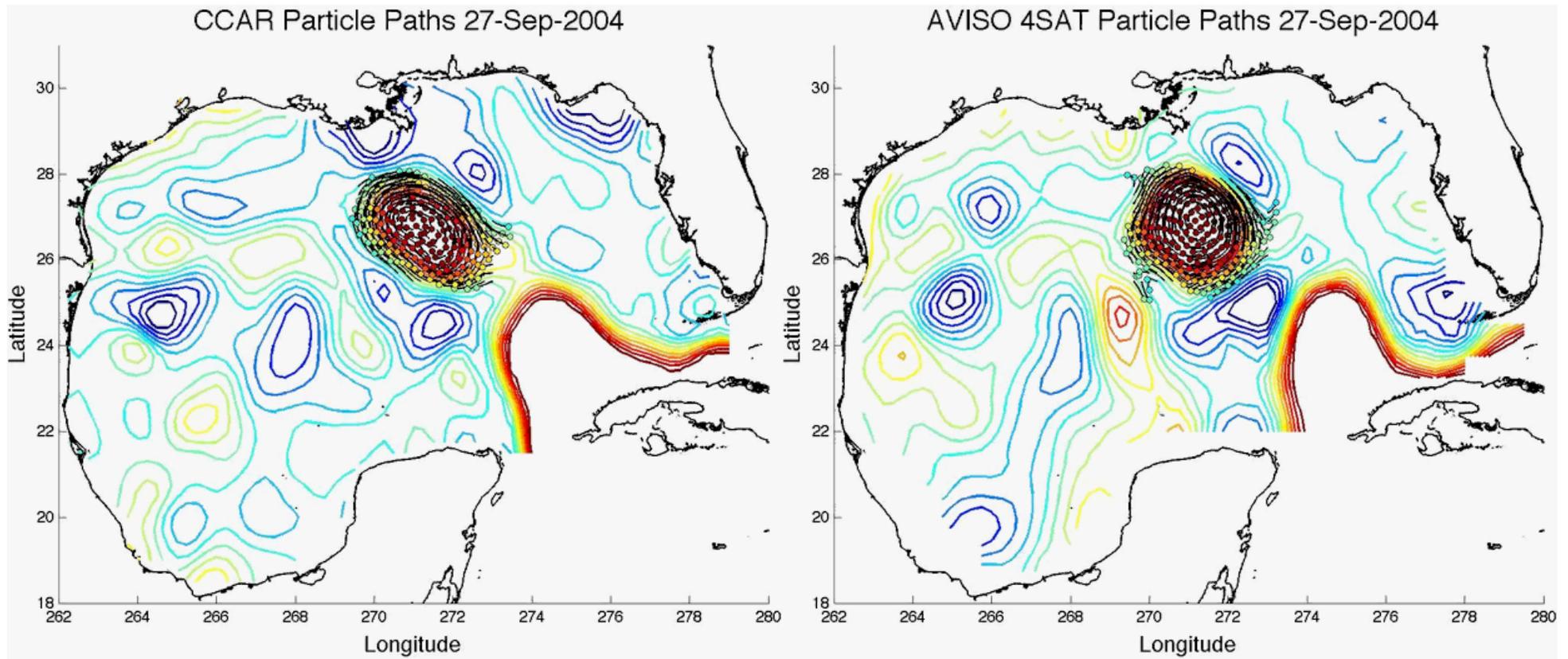
Loop Current (LC) metrics are computed using the 17-cm sea surface height contour as a proxy for the high velocity core of the LC in the eastern Gulf of Mexico.

This proxy allows objective computation of LC metrics such as:

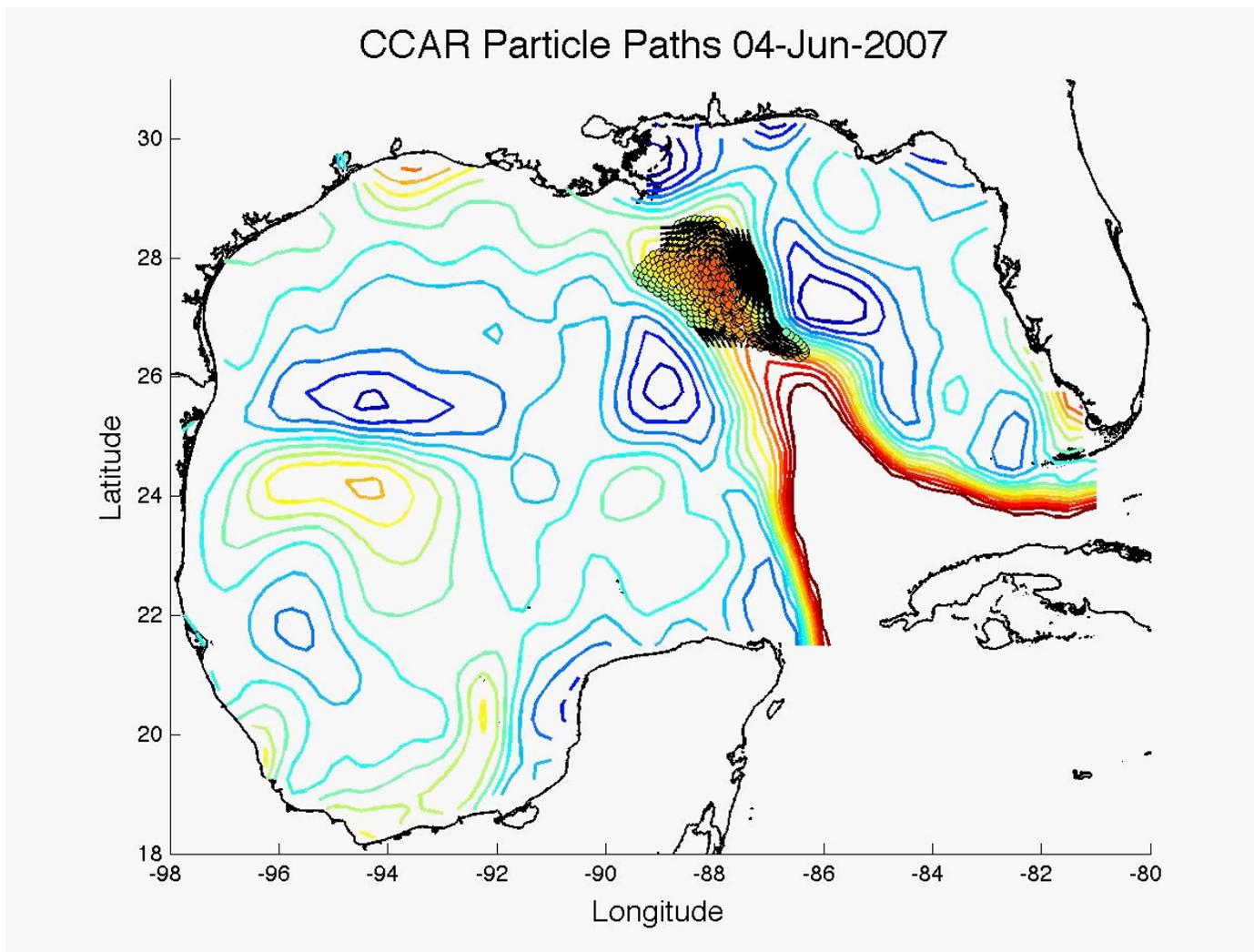
- 4 Maximum northward and westward extent of LC penetration.
- 4 Length
- 4 Area
- 4 Circulation
- 4 Volume



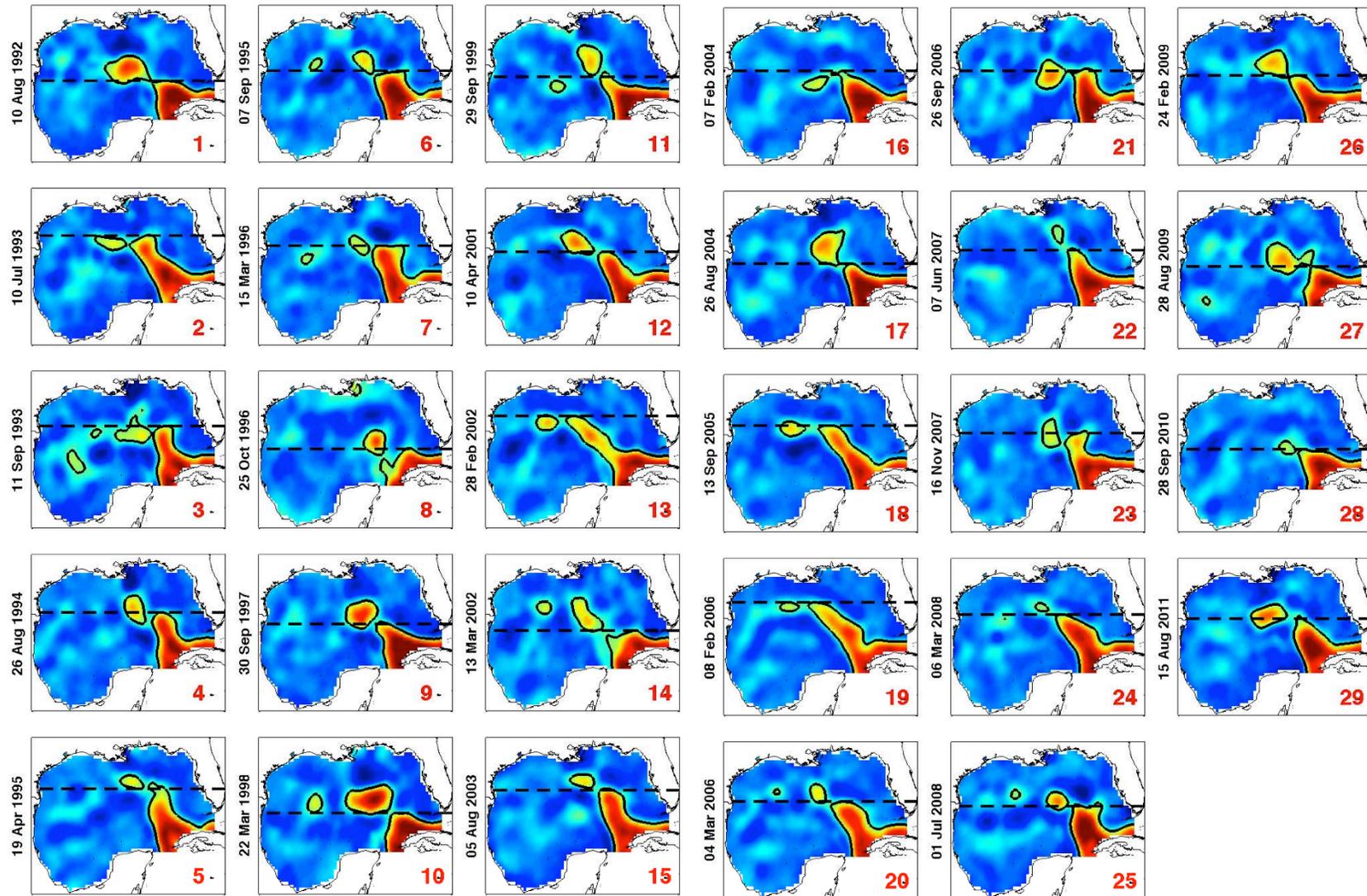
Westward Propagation of a Loop Current Eddy



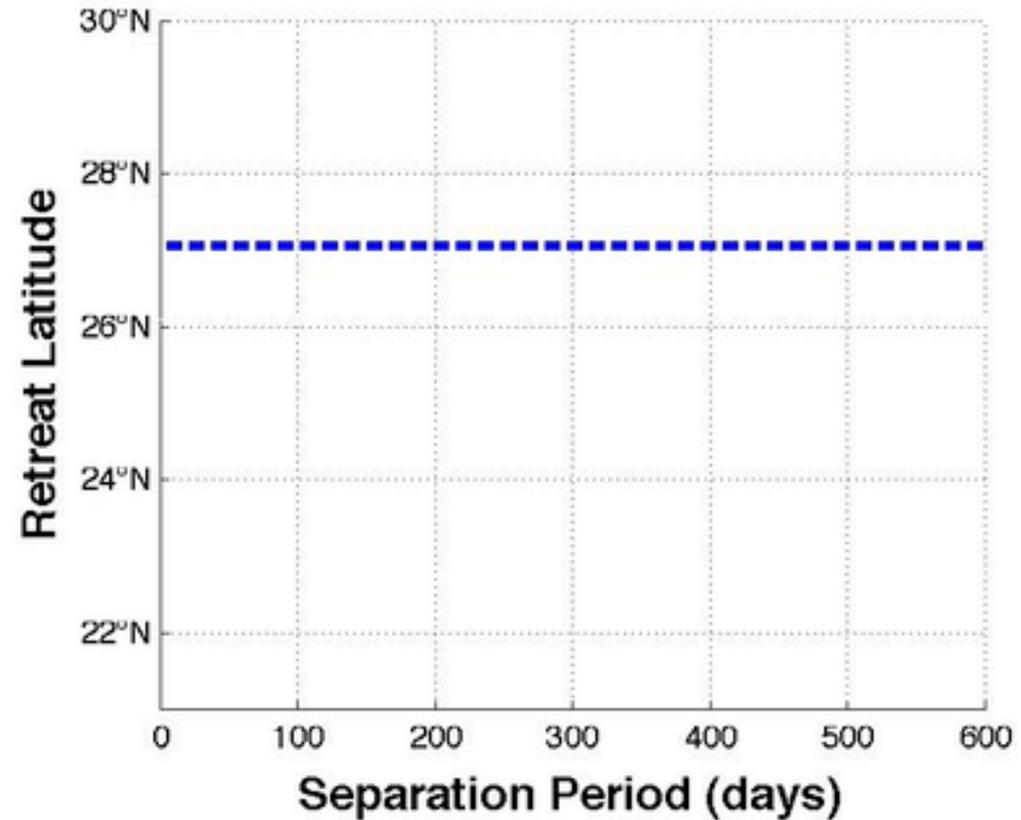
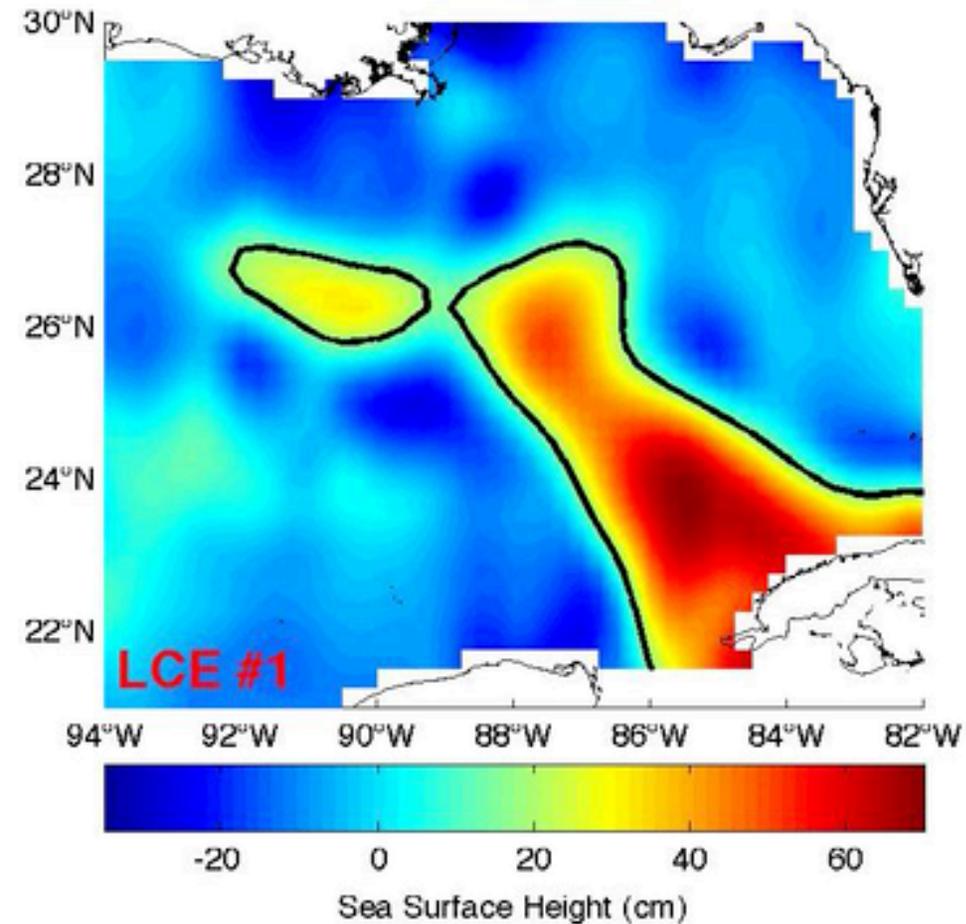
Fate of Eddy “Zorro”



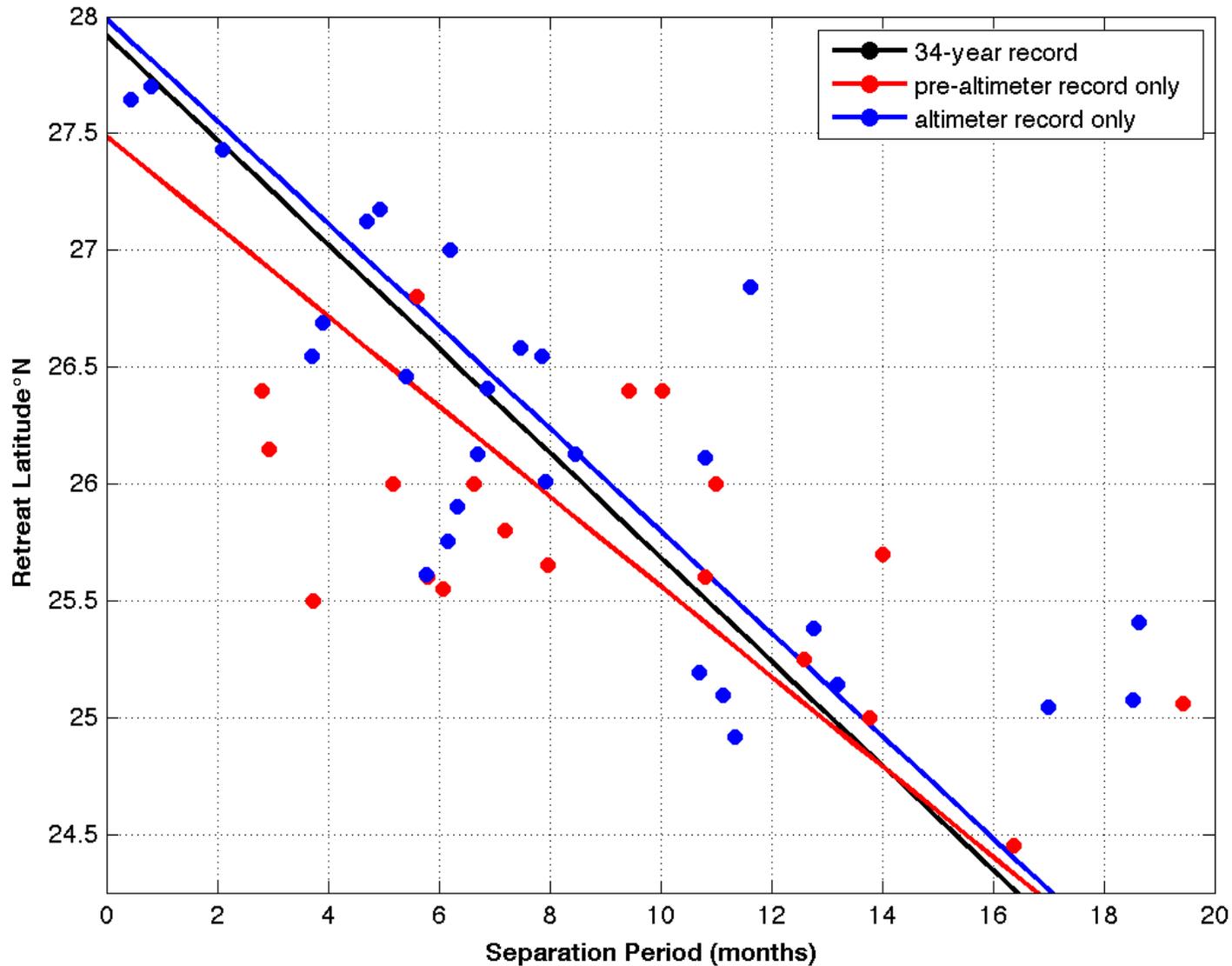
20-Year Altimetric Record of LCE Separation Events



LC Retreat Animation



Retreat Latitude Following Separation



Pre-Altimetry Record



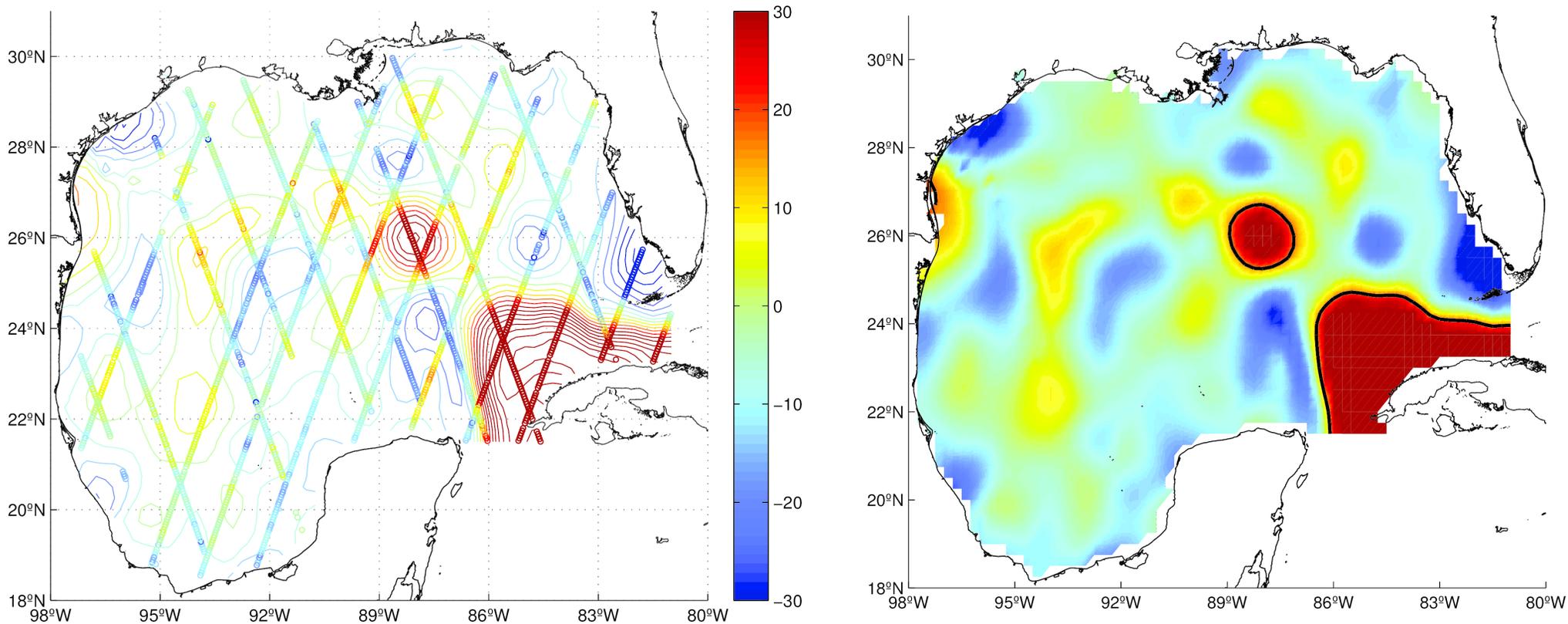
Methods and Results

The combined time series of Seasat altimetry, ocean color and SST images, and HMI/EddyWatch charts were used to manually identify LC separation events and LC retreat following separation.

- 4 Satellite coverage was sufficient to determine that there were no separation events in 1979. A separation event was identified in 1978 that was observed by an industry drifter. The retreat can now be estimated from Seasat altimetry.
- 4 **A total of 19 separation events and retreats** have been identified in the “pre-altimetry” record spanning July 1978 through 1991.

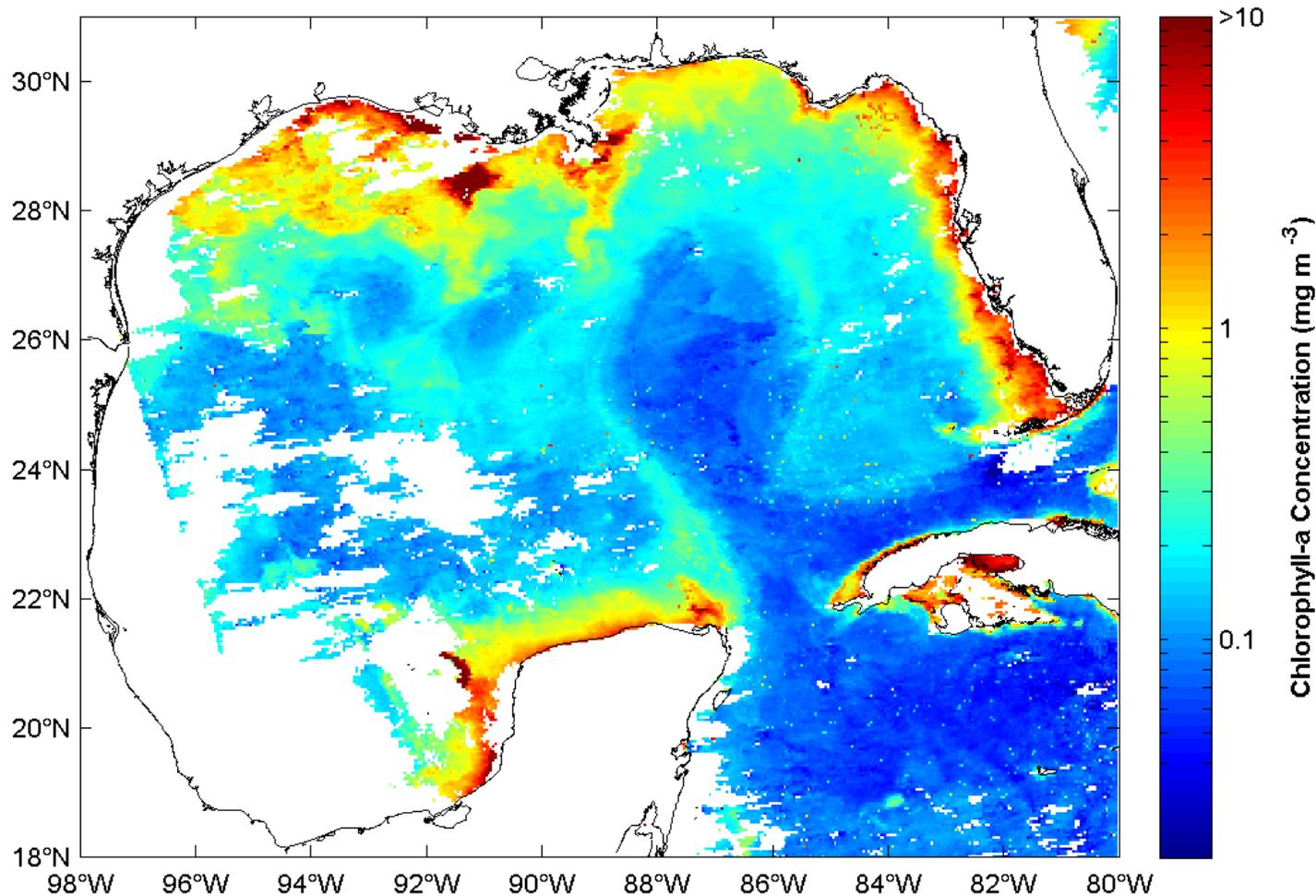


Seasat Jul-Aug 1978: Loop Current and Eddy

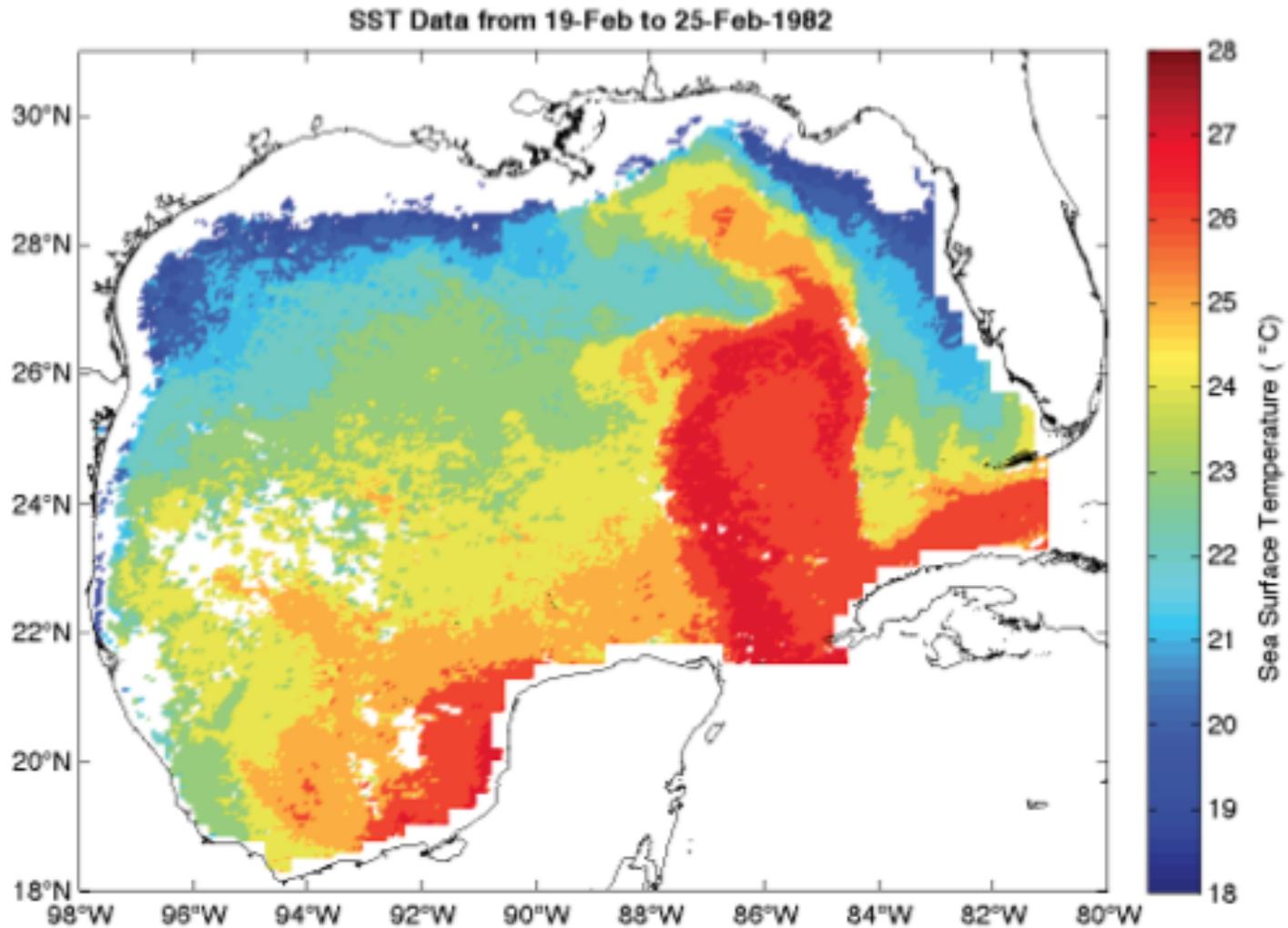


Coastal Zone Color Scanner (CZCS)

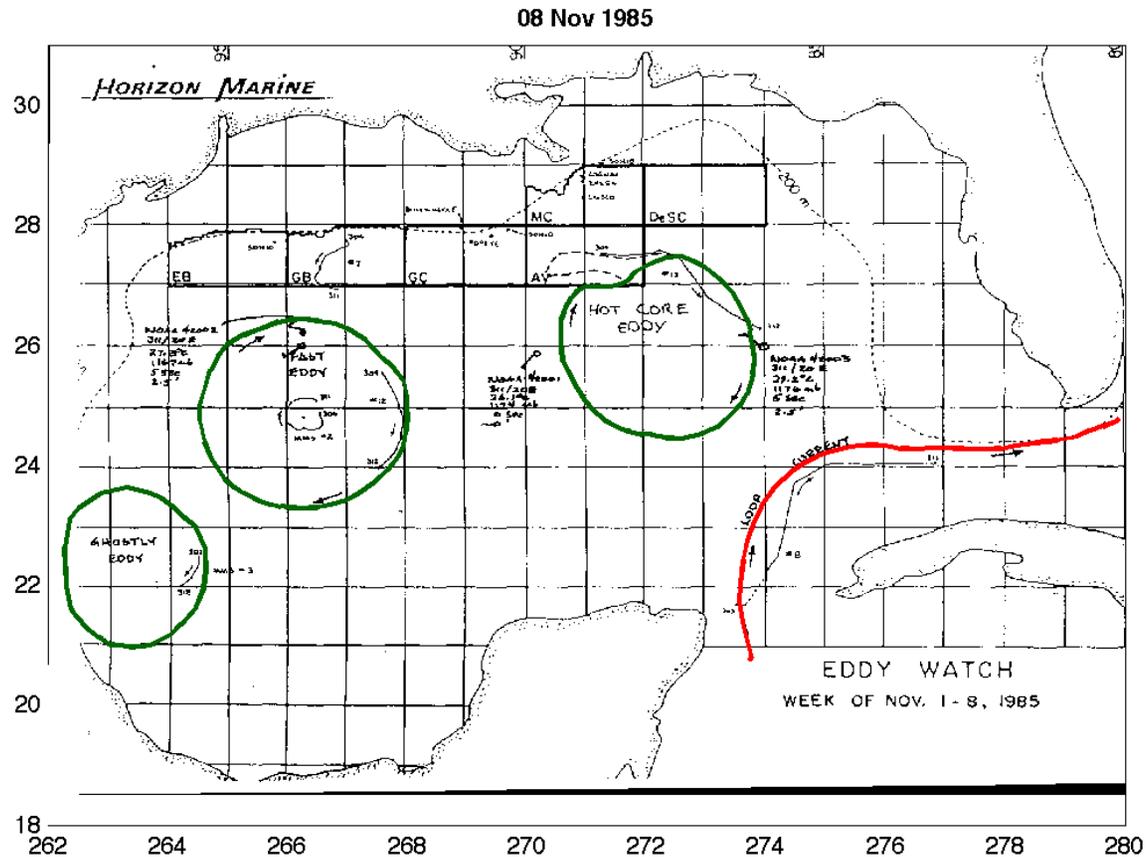
8-Day Composite Ocean Color Image 20-8-1979



Pathfinder AVHRR



Sample HMI Eddy Watch Report



LCE Separation & Retreat Latitude: 34-year Record

Pre-Altimetry

Table 1. Loop Current eddy separation period and retreat latitude from the pre-1992 observational record.

	Year-Letter	Industry Name	Source* and Separation Date	Separation Period (days)	Retreat Latitude (°N)	Confirmation Datasets
1	1978	-	D 15-Jul-78	-	24.70	Seasat/Drifter
2	1980a	-	C 18-Feb-80	583	26.15	Color
3	1980b	-	C 16-May-80	88	26.40	Color
4	1980c	-	C 08-Aug-80	84	26.00	Color
5	1981a	-	C 04-Jul-81	330	25.50	Color
6	1981b	-	C 24-Oct-81	112	26.40	SST/Color
7	1982	-	C 21-Aug-82	301	26.00	SST/Color
8	1983a	-	A 08-Mar-83	199	26.80	SST/Color
9	1983b	-	A 23-Aug-83	168	26.00	SST/Color
10	1984a	-	A 25-Jan-84	155	25.80	SST/Color
11	1984b	Arnold	H 28-Aug-84	216	25.60	HMI/Color/SST
12	1985	Fast	H 18-Jul-85	324	25.55	HMI
13	1986a	Hot-Core	H 16-Jan-86	182	25.65	HMI/SST
14	1986b	Instant	S 12-Sep-86	239	25.70	HMI/SST
15	1987	Kathleen	A 06-Nov-87	420	25.60	SST
16	1988	Murphy	H 28-Apr-88	174	24.45	HMI
17	1989	Nelson	H 01-Sep-89	491	25.25	HMI
18	1990	Quiet	H 14-Sep-90	378	25.00	HMI/SST
19	1991	Triton	H 01-Nov-91	413	26.40	HMI/SST

*Source Key: D – Drifter, C – color, A – AVHRR SST, H – HMI/EddyWatch

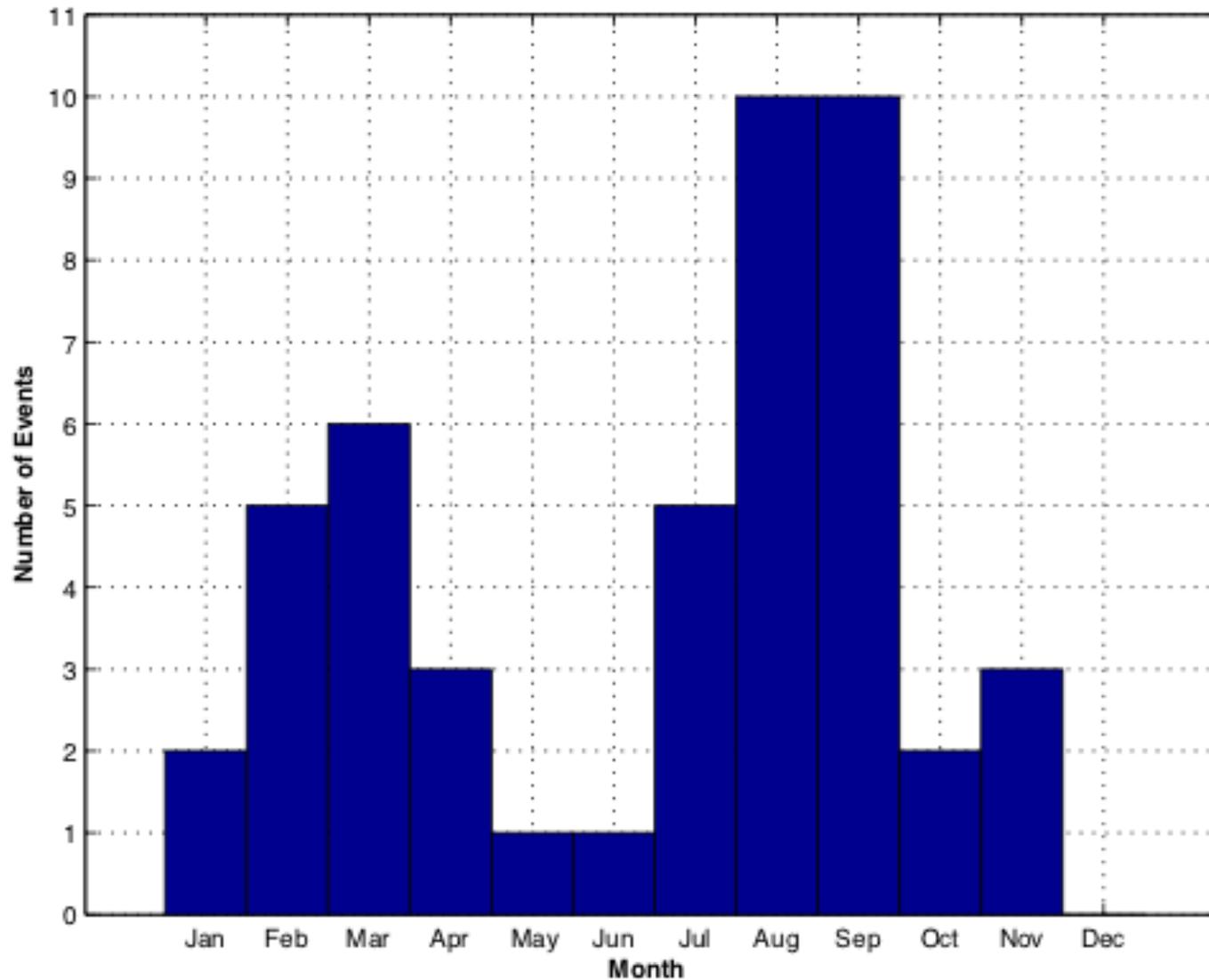
Altimetry

Table 3. Loop Current eddy separation period and retreat latitude from the altimetric record – 1992 through June 2012.

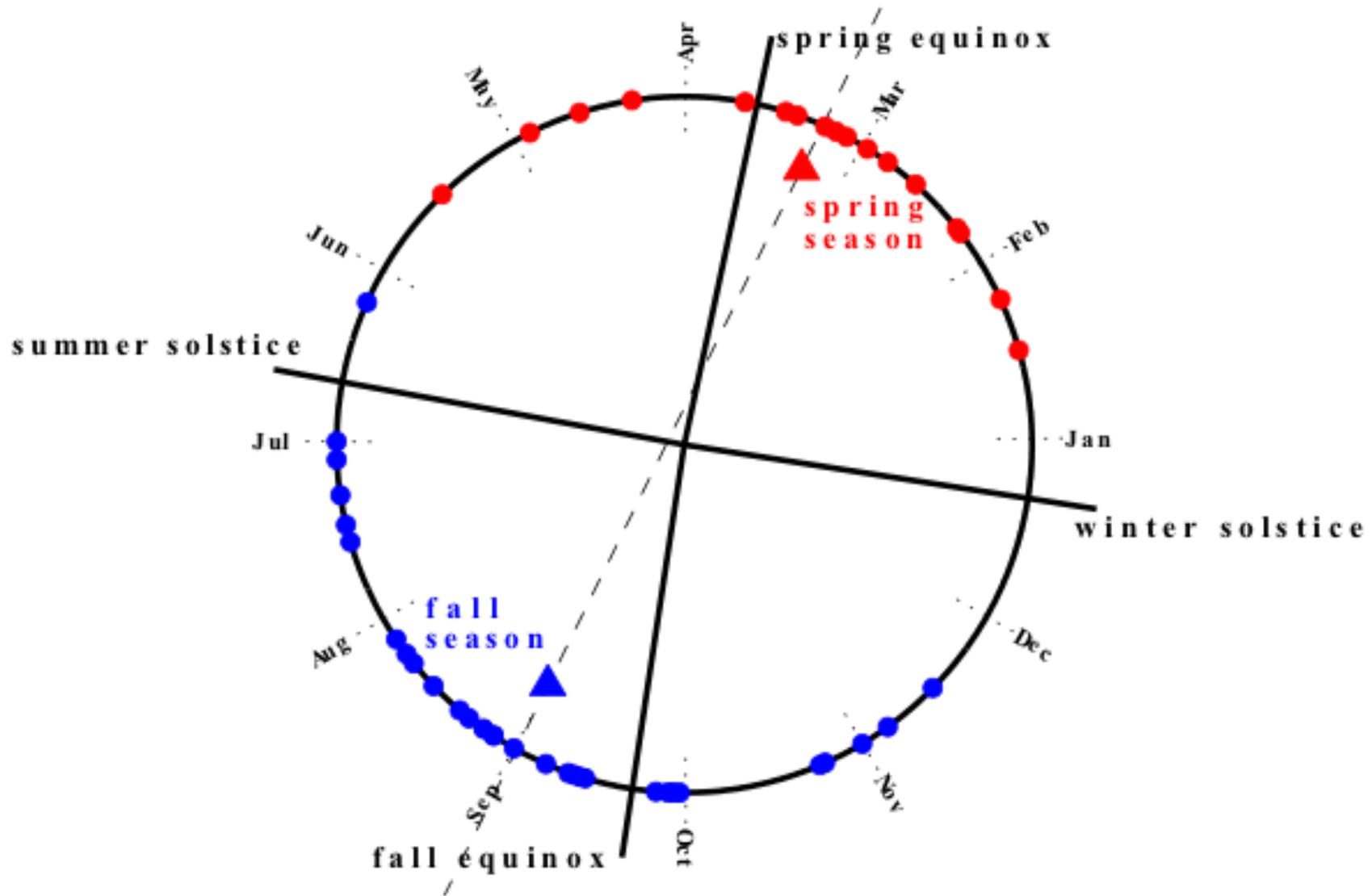
	Year-Letter	Industry Name	Separation Date	Separation Period (days)	Previous Retreat Latitude
1	1992	Unchained	10-Aug-92	283	26.400
2	1993a	Whopper	10-Jul-93	334	24.738
3	1993b	Xtra	11-Sep-93	63	27.071
4	1994	Yucatan	26-Aug-94	349	26.483
5	1995a	Zapp	19-Apr-95	236	26.190
6	1995b	Aggie	07-Sep-95	141	26.765
7	1996a	Biloxi	15-Mar-96	190	25.544
8	1996b	Creole	25-Oct-96	224	26.222
9	1997	El Dorado	30-Sep-97	340	24.557
10	1998	Fourchon	22-Mar-98	173	25.255
11	1999	Juggernaut	29-Sep-99	556	24.718
12	2001	Millennium	10-Apr-01	559	25.046
13	2002a	Pelagic	28-Feb-02	324	25.754
14	2002b	Quick	13-Mar-02	13	27.285
15	2003a	Sargassum	05-Aug-03	510	24.683
16	2003b	Titanic	07-Feb-04	186	26.643
17	2004	Ulysses	26-Aug-04	201	25.769
18	2005	Vortex	13-Sep-05	383	25.025
19	2006a	Walker	08-Feb-06	148	26.817
20	2006b	Xtreme	04-Mar-06	24	27.343
21	2006c	Yankee	26-Sep-06	206	26.050
22	2007a	Zorro	07-Jun-07	254	25.769
23	2007b	Albert	16-Nov-07	162	26.102
24	2008a	Brazos	06-Mar-08	111	26.187
25	2008b	Cameron	01-Jul-08	117	26.332
26	2009a	Darwin	24-Feb-09	238	25.651
27	2009b	Ekman	28-Aug-09	185	25.397
28	2010	Franklin	28-Sep-10	396	24.789
29	2011	Hadal	15-Aug-11	321	24.835
30	2012	Icarus	Feb-12	-	-



34-Year LCE Separation Monthly Histogram

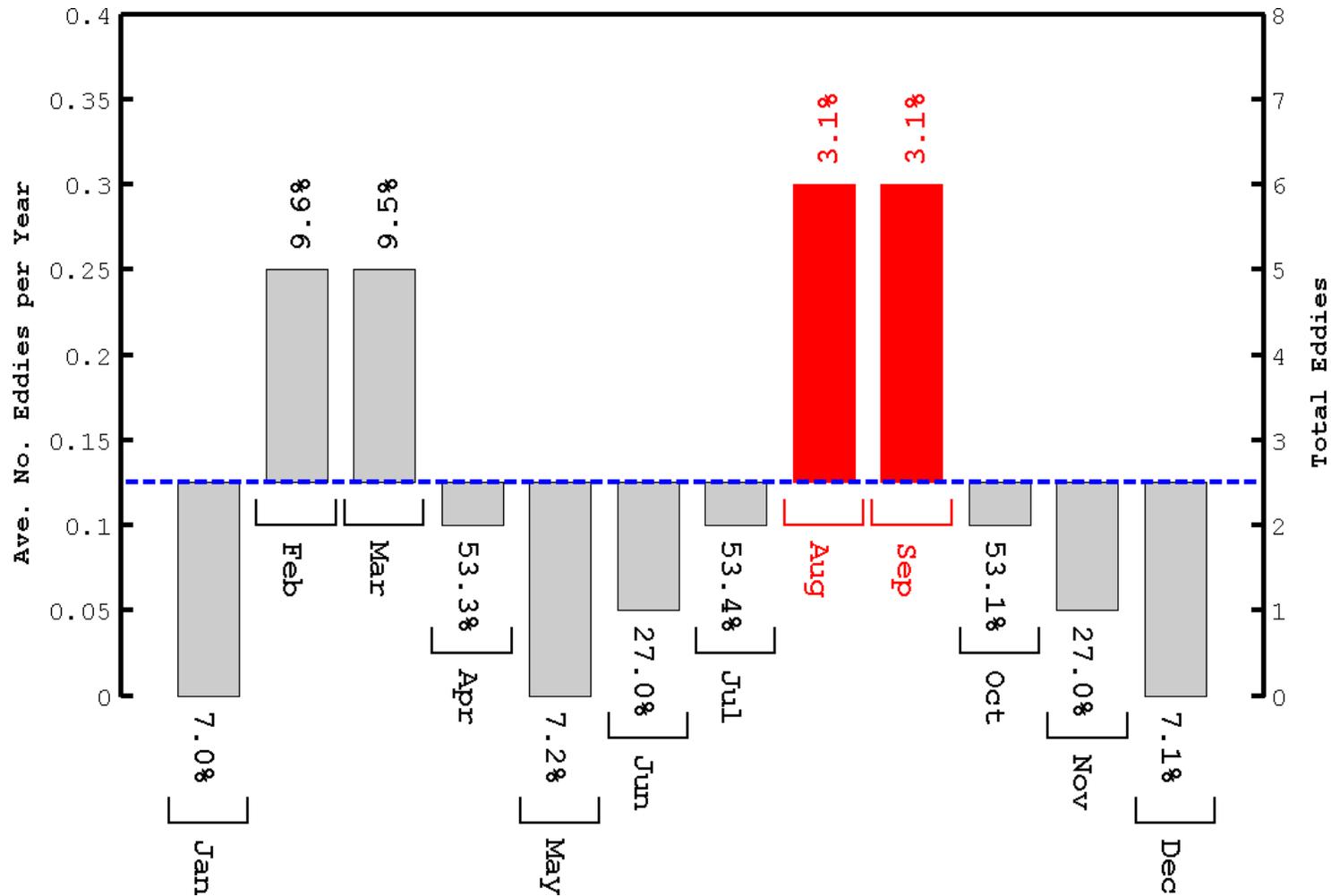


Circular Statistics 2-Mean Cluster Analysis



Randomization Significance Test

Altimeter Record: 30 Separation Events



Remote Sensing for Off Shore Oil and Gas Industry



Loop Current and Drilling Platform



Deepwater Horizon Rig

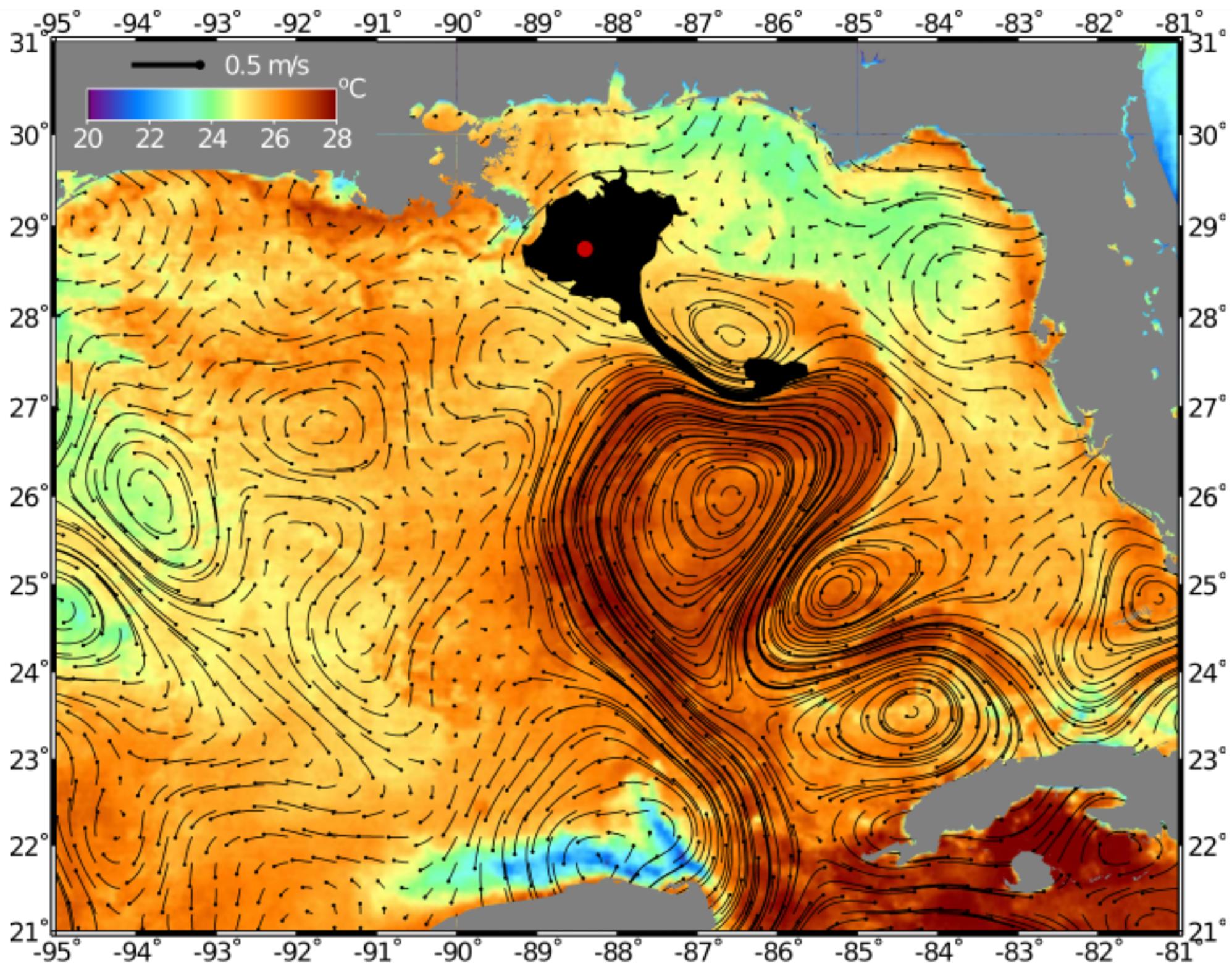


A sister rig, the Nautilus, being transported on a Heavy-Lift vessel



L and R, the Deepwater Horizon on location in better days

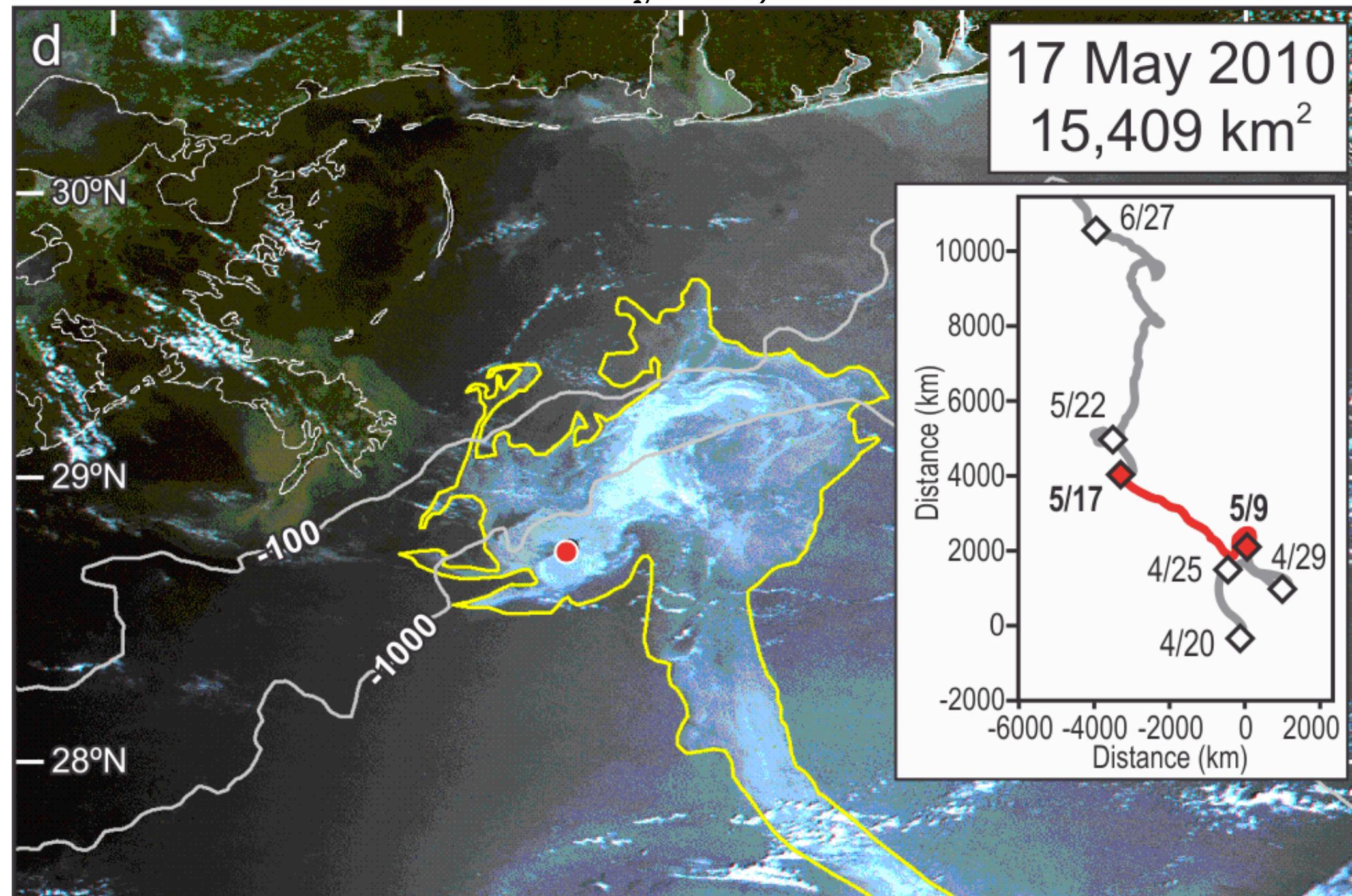




True Color MODIS Image: May 17



May 17, 2010



<http://www.nola.com/news/gulf-oil-spill/deepwater-disaster/index.ssf>

Oil Spill Gulf of Mexico 2010 - NOLA.com

http://www.nola.com/news/gulf-oil-spill/deepwater-disaster/index.ssf

DEEPWATER DISASTER
BLOW BY BLOW

MISS. ALA. FLA. LA

Gulf of Mexico

FACES OF THE SPILL

LEAVE A COMMENT

DAY 30 First signs of thick oil found in marshes near mouth of Mississippi River

May 19 July 28

Cumulative damage done

Gallons of oil leaked, high estimate	70,560,000
Gallons of oil leaked, low estimate	52,920,000
Oily animals found dead along coast	0

Labels (turn on or off)

- Satellite view
- Fishing closures
- Oyster zones
- Bays, lakes
- Islands
- Oil landfall



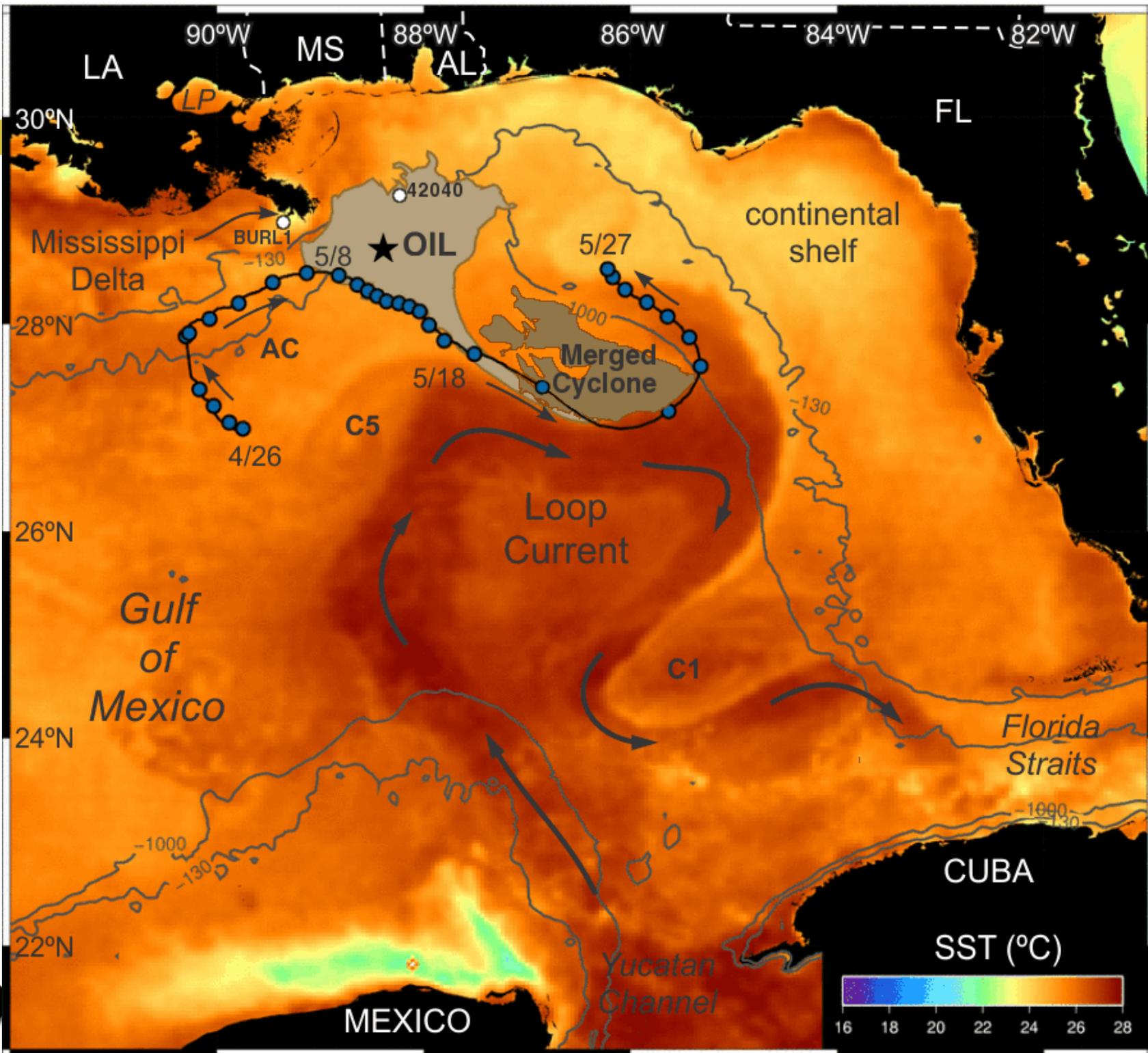
Deep Water Horizon Oil Spill

- 4 On April 20, 2010 the Macondo Prospect oil well experienced a massive blowout, causing the explosion and collapse of the Deepwater Horizon oil rig, 77 km southeast of the Mississippi River Delta, Louisiana in 1667 meters of water.
- 4 17 workers are injured and 11 workers go missing and are presumed dead.
- 4 The oil gushed into the Gulf from 22 April to 15 July, releasing approximately **800 million liters** of oil to which BP added 1.84 million gallons of dispersant.
- 4 Real-time satellite imagery using visible, infrared and radar measurements were essential for tracking the dispersed surface oil across large areas of the Gulf of Mexico (GOM) as well as the ocean currents impacting its motion.

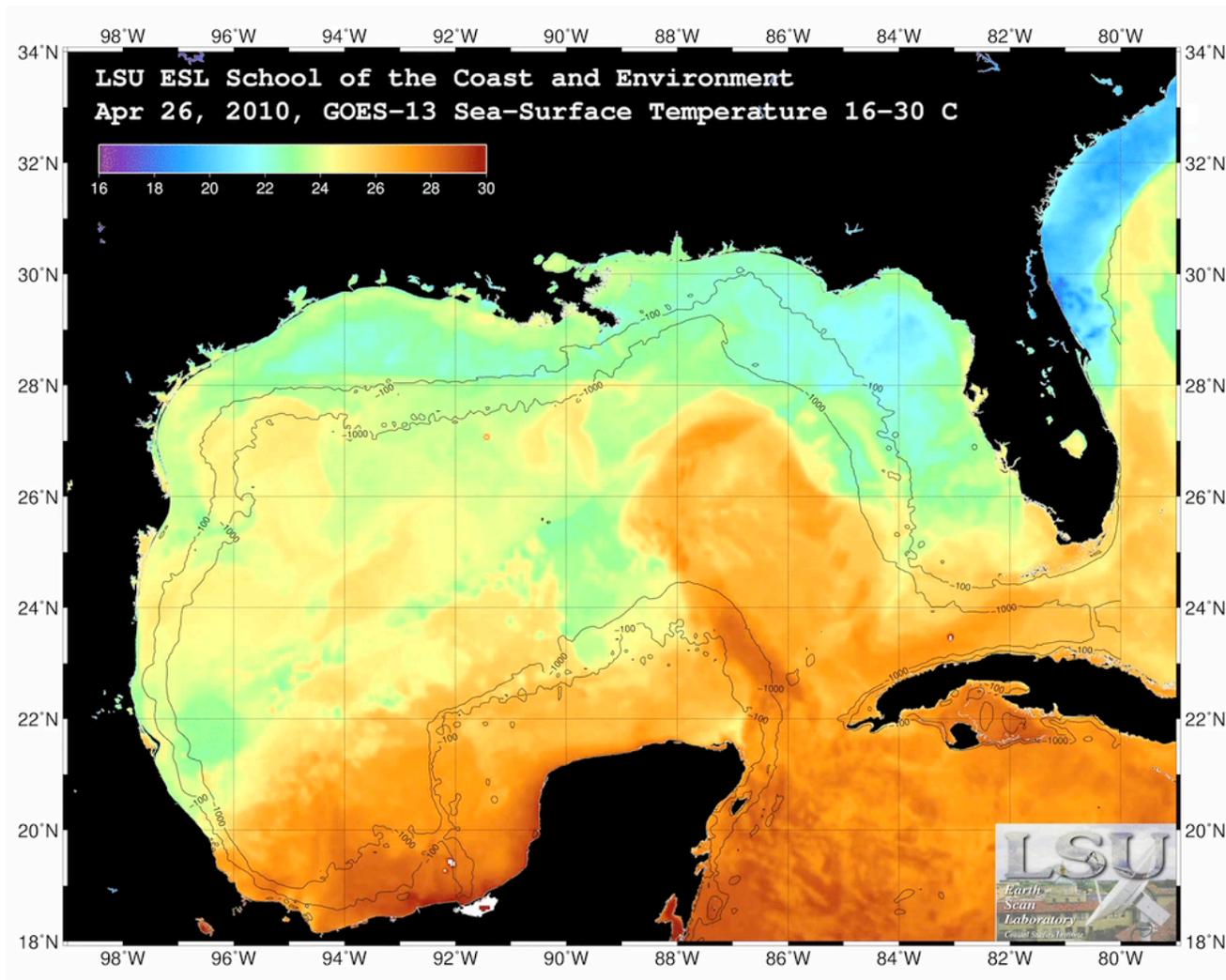




22 17:20



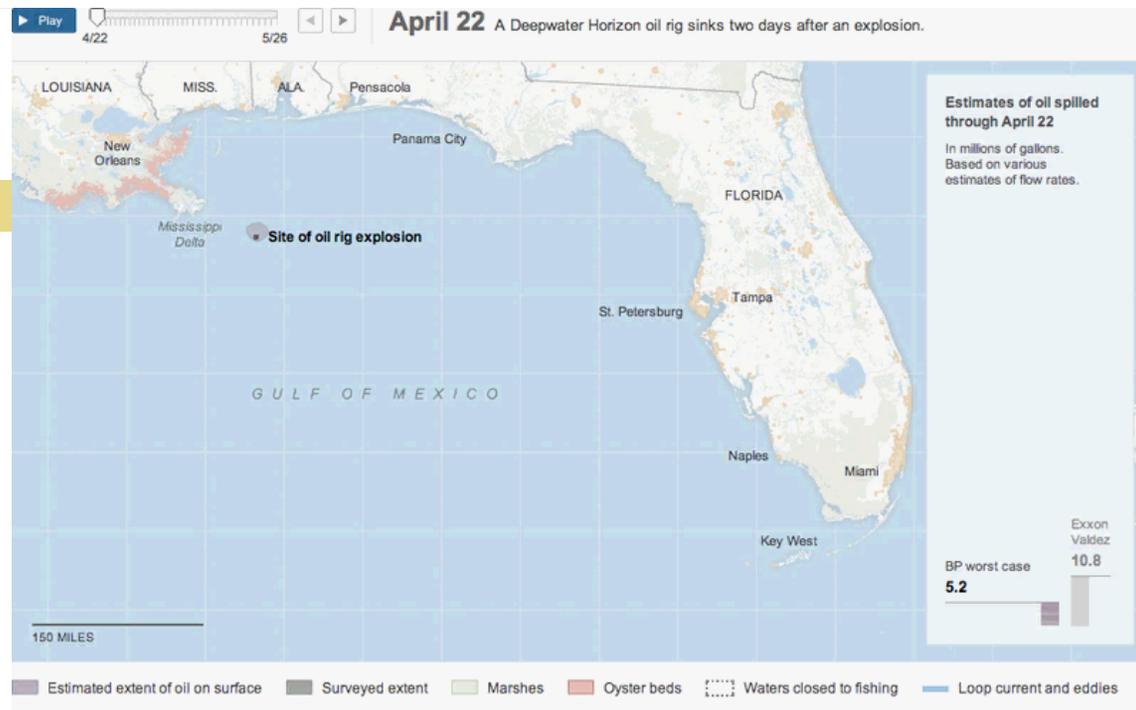
GOES Movie: April 26 through May 28



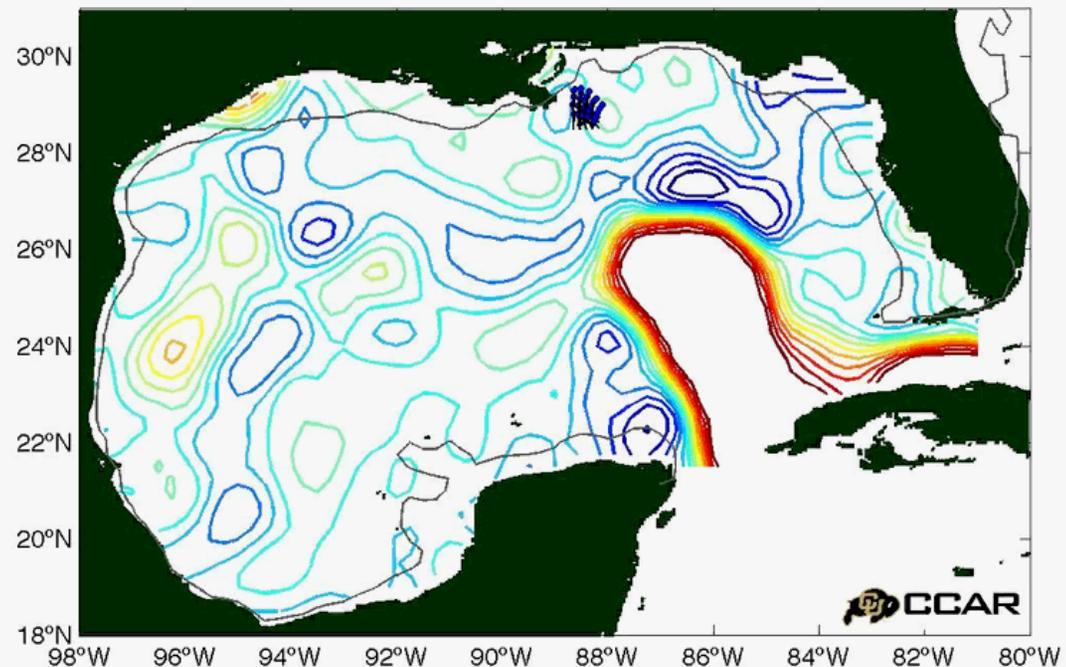
Horizon Deepwater Oil Spill

Estimated Total Spill

- 5 million barrels
- 800,000 m³... or just 1/30 sec of LC flow assuming a transport of 24 Sverdrups.
- Animation on upper right is from New York Times.
- Animation on the lower right shows particles released at the spill site and advected by surface geostrophic flow calculated from near real-time SSH maps.



Particle Paths 21-Apr-2010

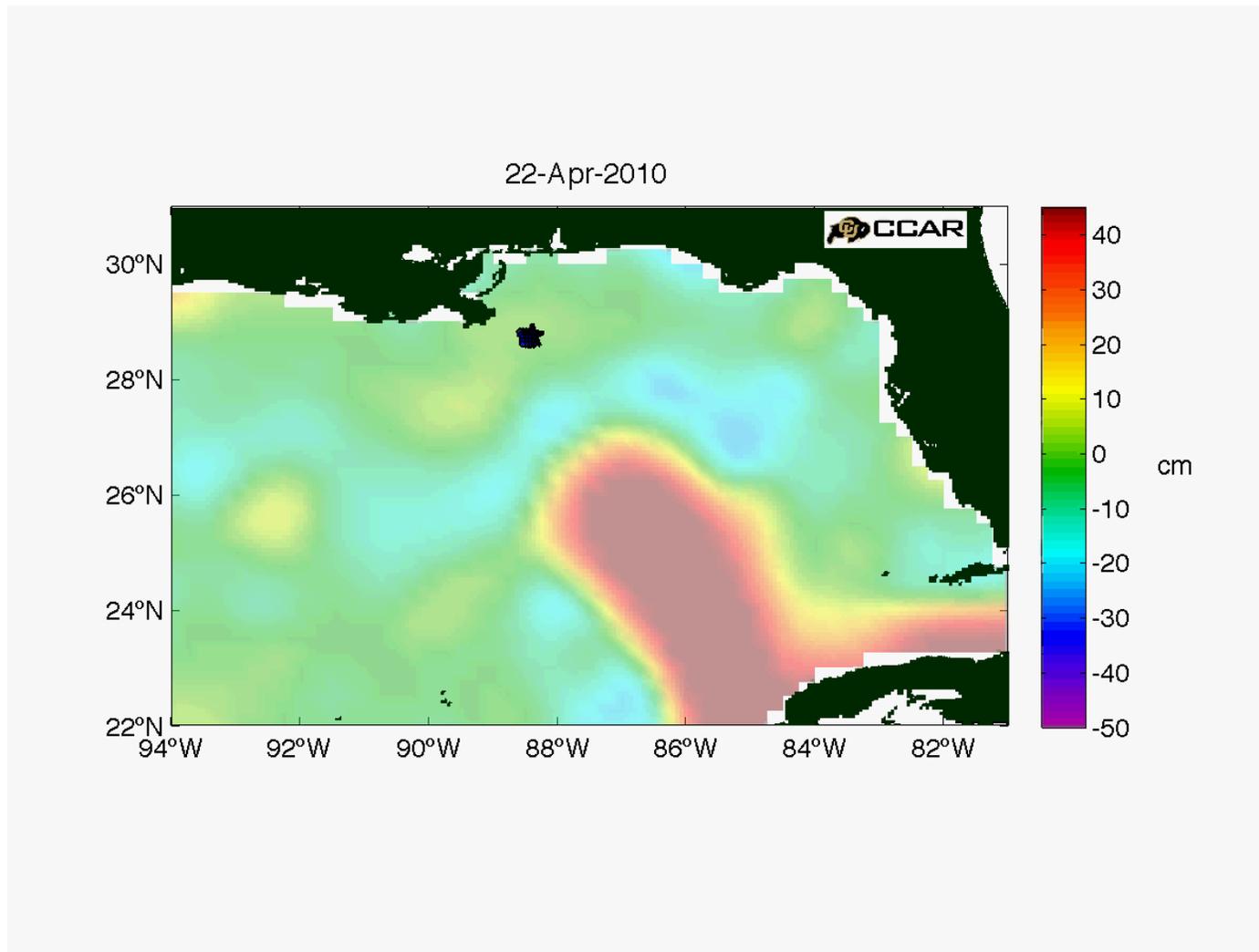


Simulated Oil Particle Tracking

- 4 Daily gridded velocity fields were obtained from hindcast gridded SSH maps using a geostrophic flow approximation on an f-plane with central finite differencing.
- 4 Velocities needed to compute the particle paths were interpolated from the gridded velocity fields using tricubic interpolation in lat, lon, and time.
- 4 The particle positions were integrated through time using a second order Runge-Kutta (RK2) method.
- 4 Twenty five particles were seeded in a patch 0.2×0.2 degrees centered on the oil leak every hour over the integration period.



Simulated Spill using Altimetry



Hurricane Intensification



Rapid Hurricane Intensification

Rapid hurricane intensification occurs in the Gulf of Mexico because of deep layers of warm current associated with the Loop Current and Loop Current eddies.

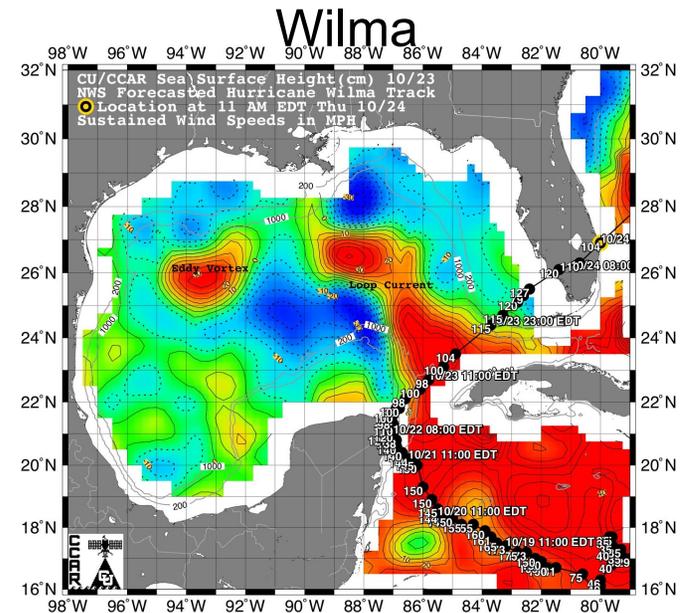
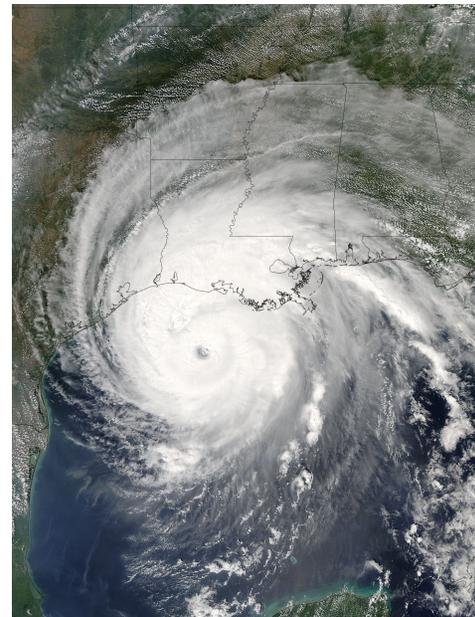
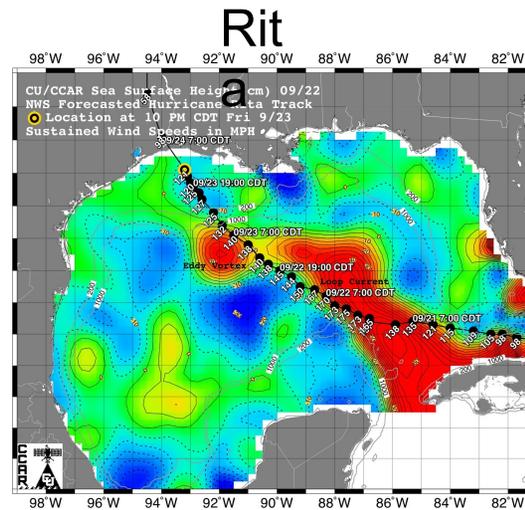
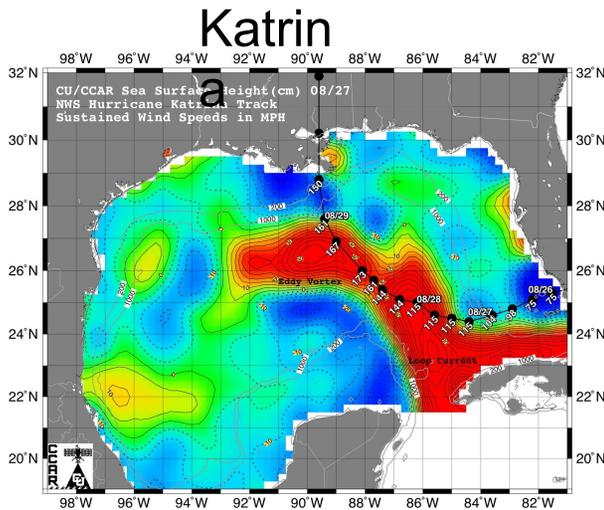
Suspected in the 1969 Hurricane Camille.

Observed and verified by modeling studies of the 1995 Hurricane Opal.

Satellite altimetry estimates of “heat potential” associated with subsurface warm layers were used operationally during Katrina, Rita and Wilma by the National Hurricane Center.



A tale of three storms ... or why is the Loop Current important?



- **Four** land-falling Gulf coast hurricanes in 2005 with damages totaling in excess of \$100 Billion.
- The only Atlantic season on record where three Cat 5 hurricanes occurred in a single season.



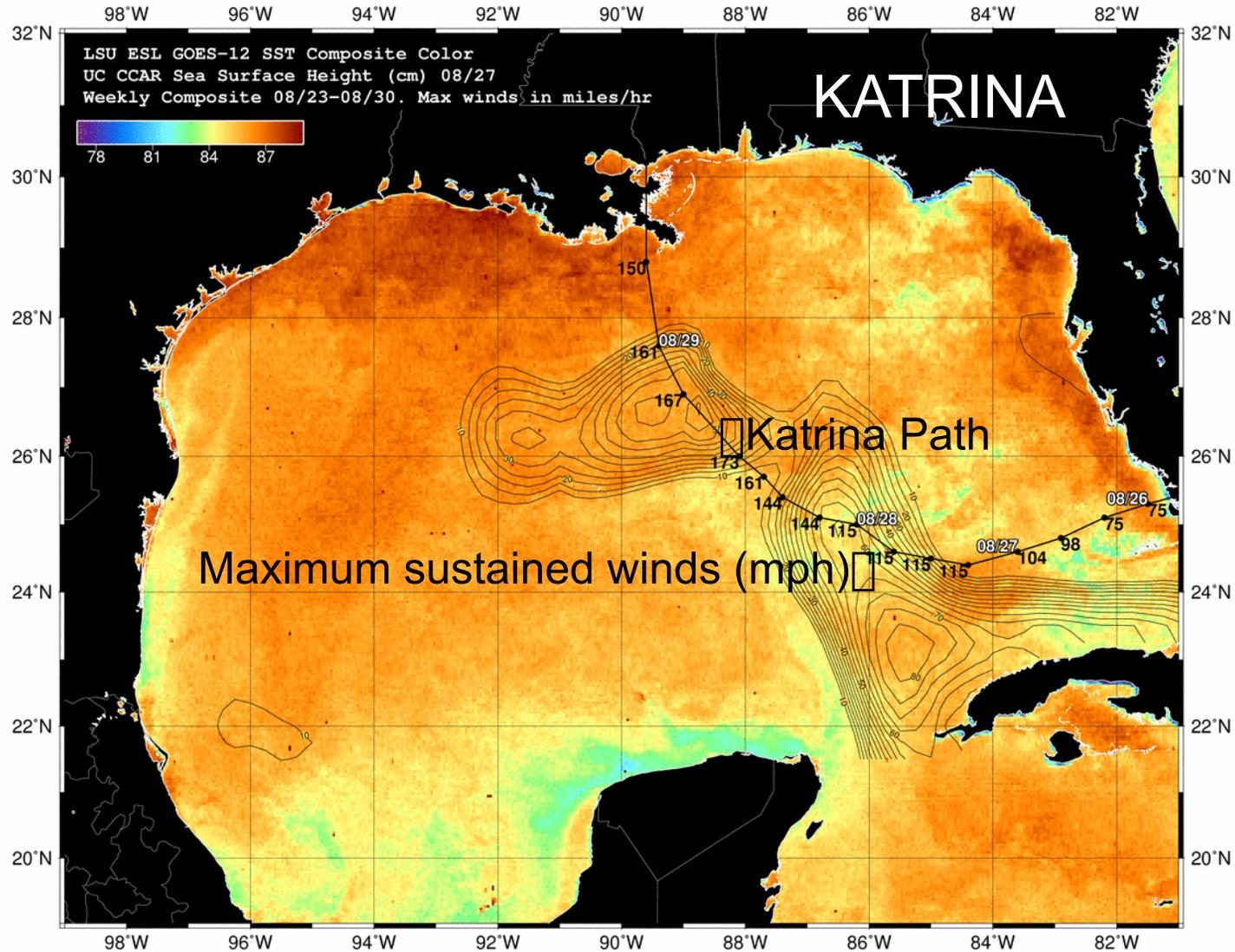
2005 Hurricane Season

The 2005 hurricane season was the most costly on record with estimated damages in the U.S. of over \$100 Billion:

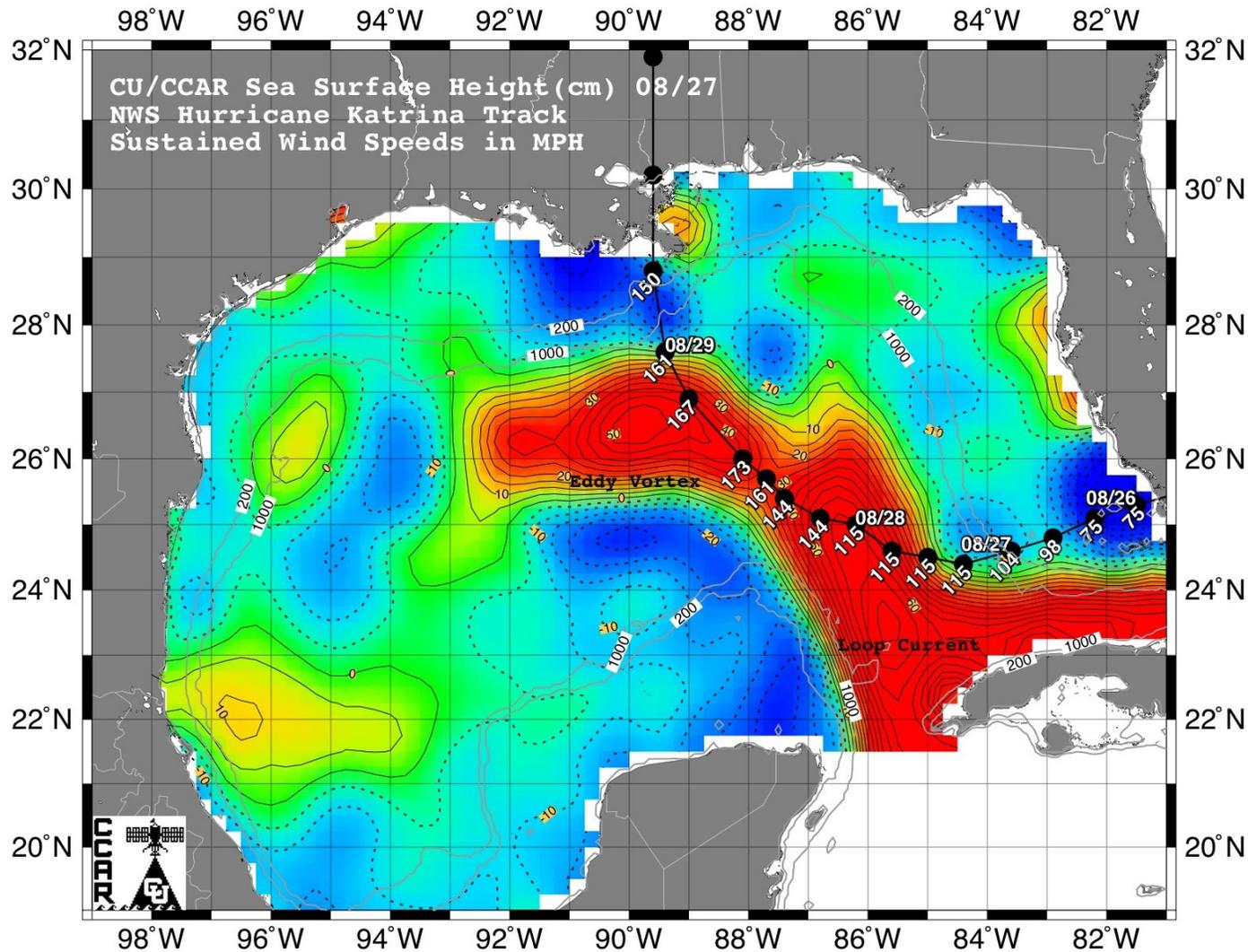
- 4 Dennis \$2.2 Billion
- 4 Katrina \$80 Billion
- 4 Rita \$9.4 Billion
- 4 Wilma \$14.4 Billion



GOES-12 SST Composite with SSH Overlaid



CCAR SSH Map Overlaid with Katrina Path/Sustained Winds



1969 Hurricane Camille

Before Katrina, Hurricane Camille was the hurricane by which all Gulf-coast hurricanes were measured:

Category 5 at landfall with 190 mph maximum sustained winds.

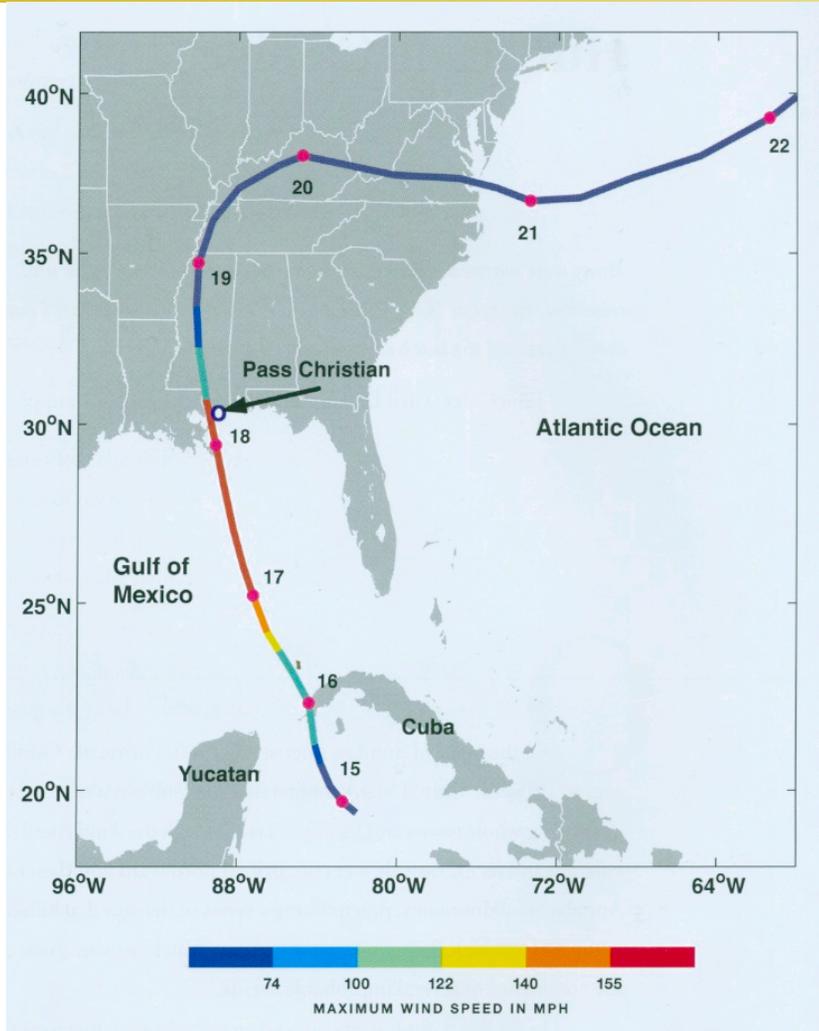
Landfall pressure was 909 mbar. Only the Labor Day Hurricane of 1935 was lower (895 mbar).

Over 20 foot storm surge from Pass Christian to Biloxi, the highest storm surge ever measured until Katrina.

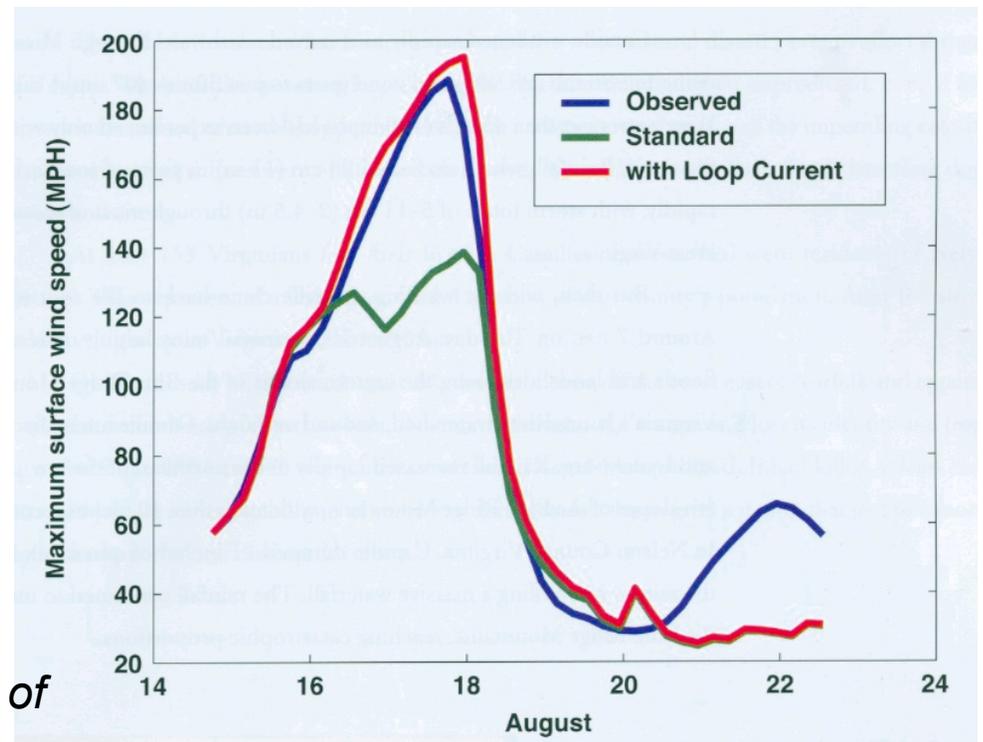
At least 150 dead in Mississippi. Another 150 killed in flooding caused by Camille in Appalachian Mountains.



1969 Hurricane Camille



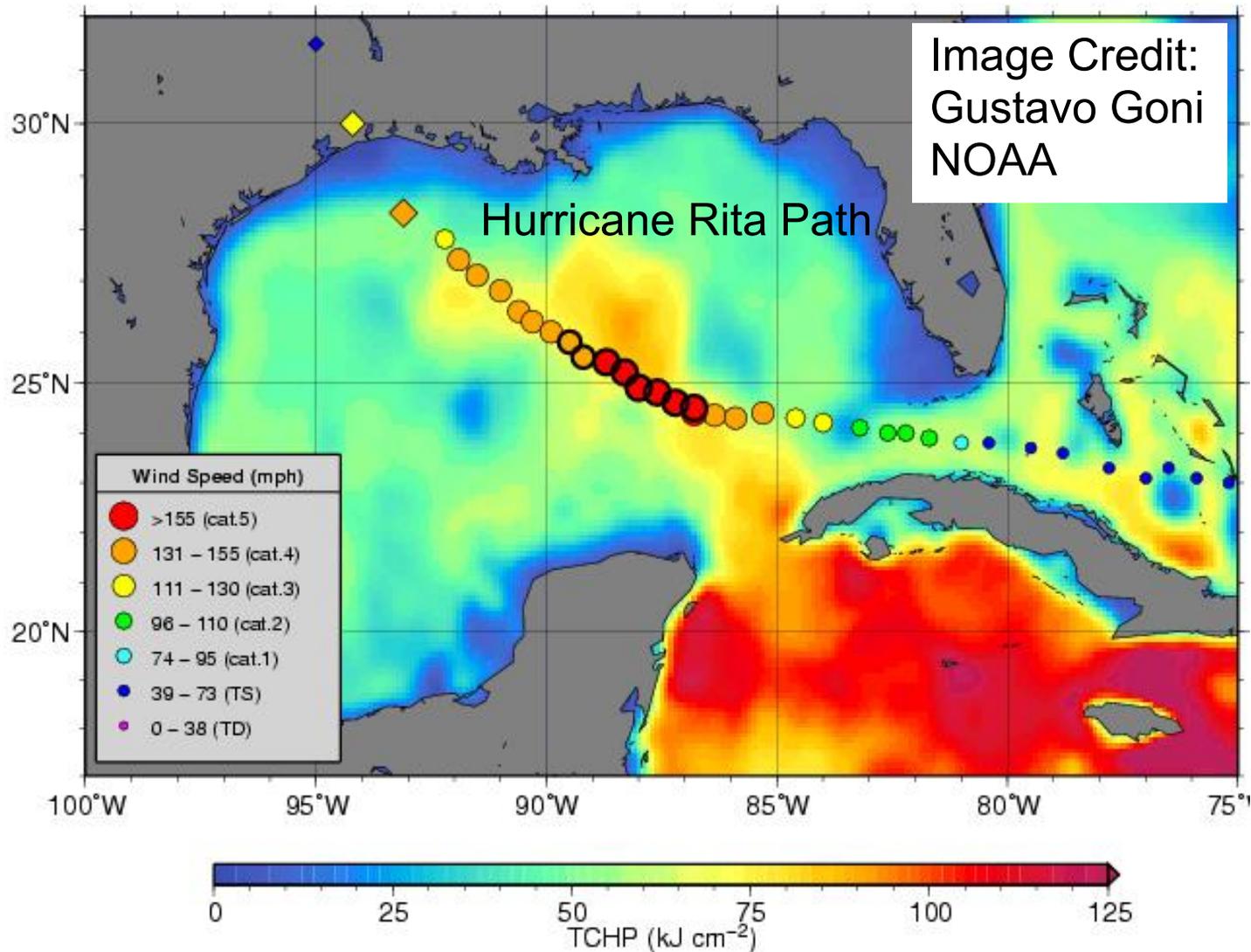
- Category 5 at landfall near Pass Christian on August 18, 1969.
- Hindcast 1-D modeling studies implicate Loop Current in the rapid intensification and severe strength.



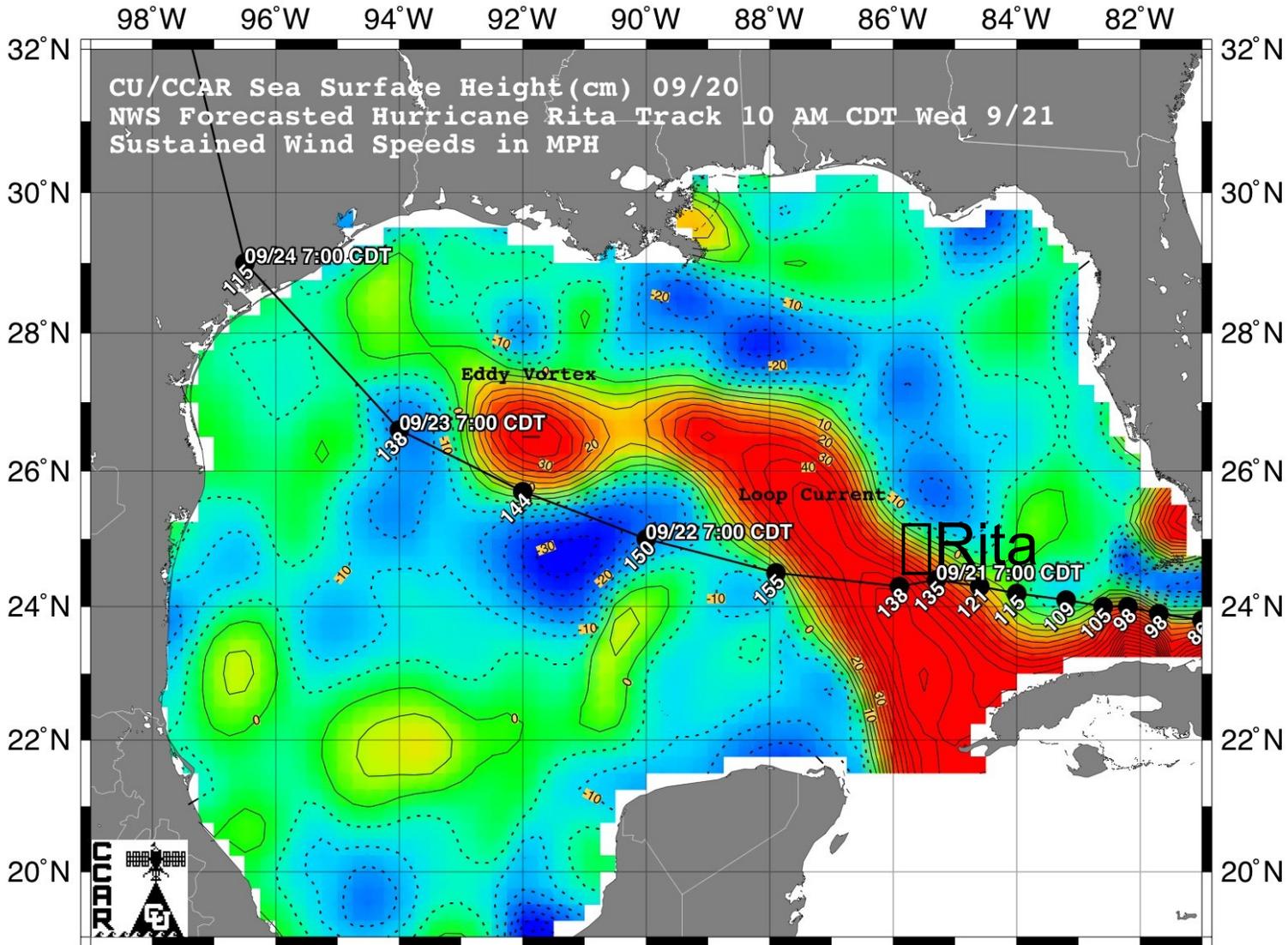
From *Divine Wind: The History and Science of Hurricanes* by Kerry Emmanuel



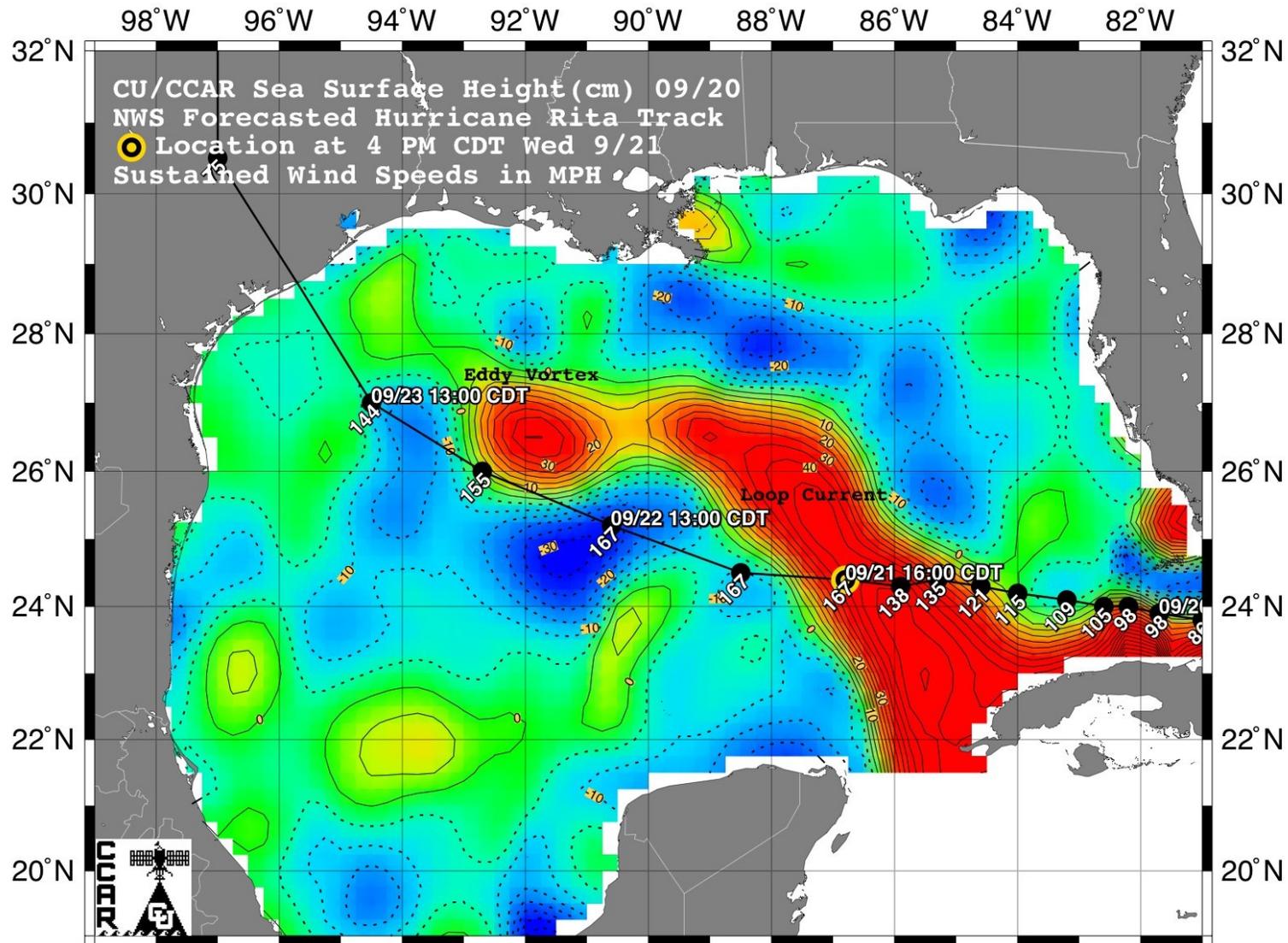
Tropical Cyclone Heat Potential: Sept 22, 2005



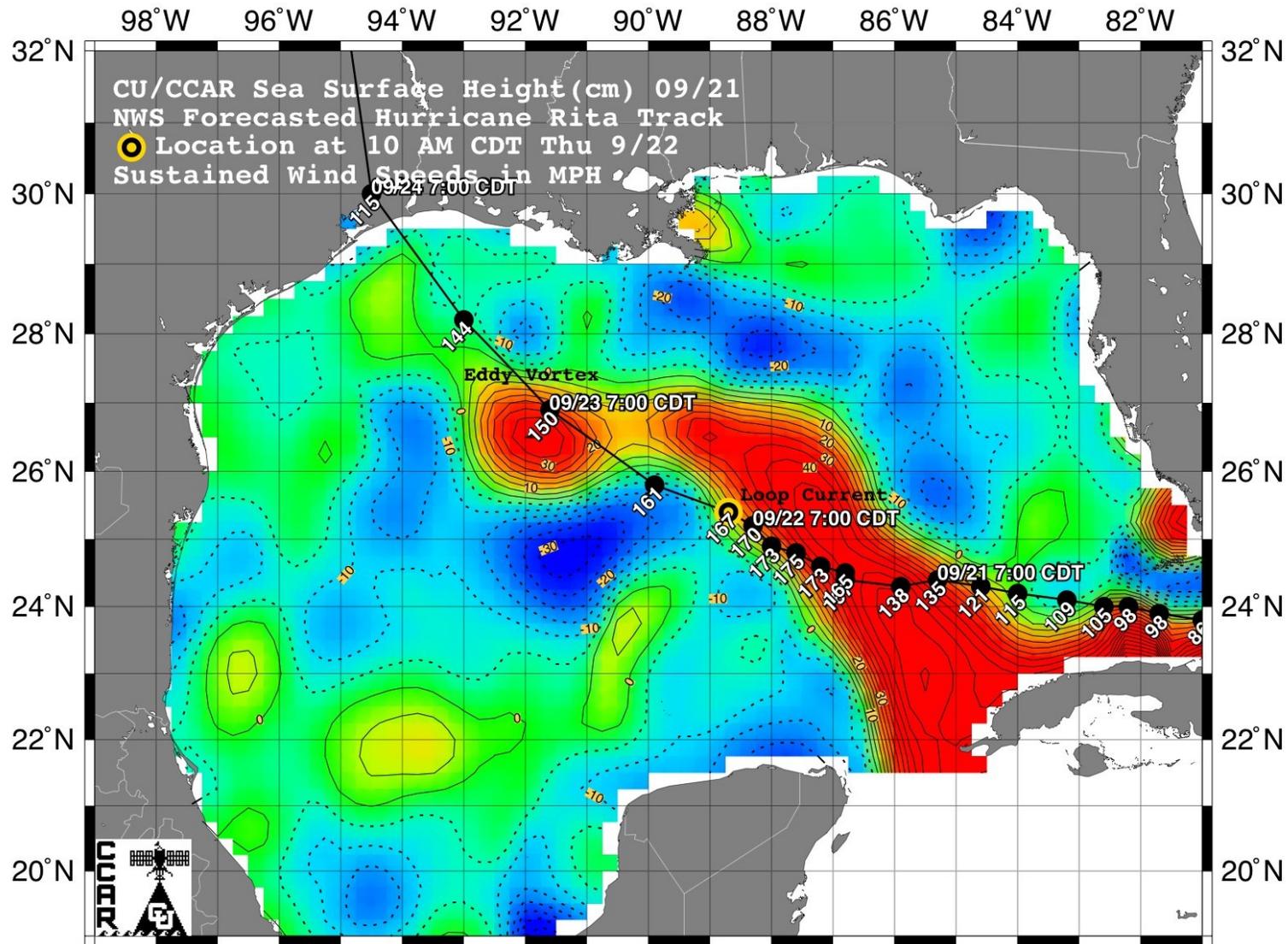
Rita Wednesday 9/21 10 AM CDT



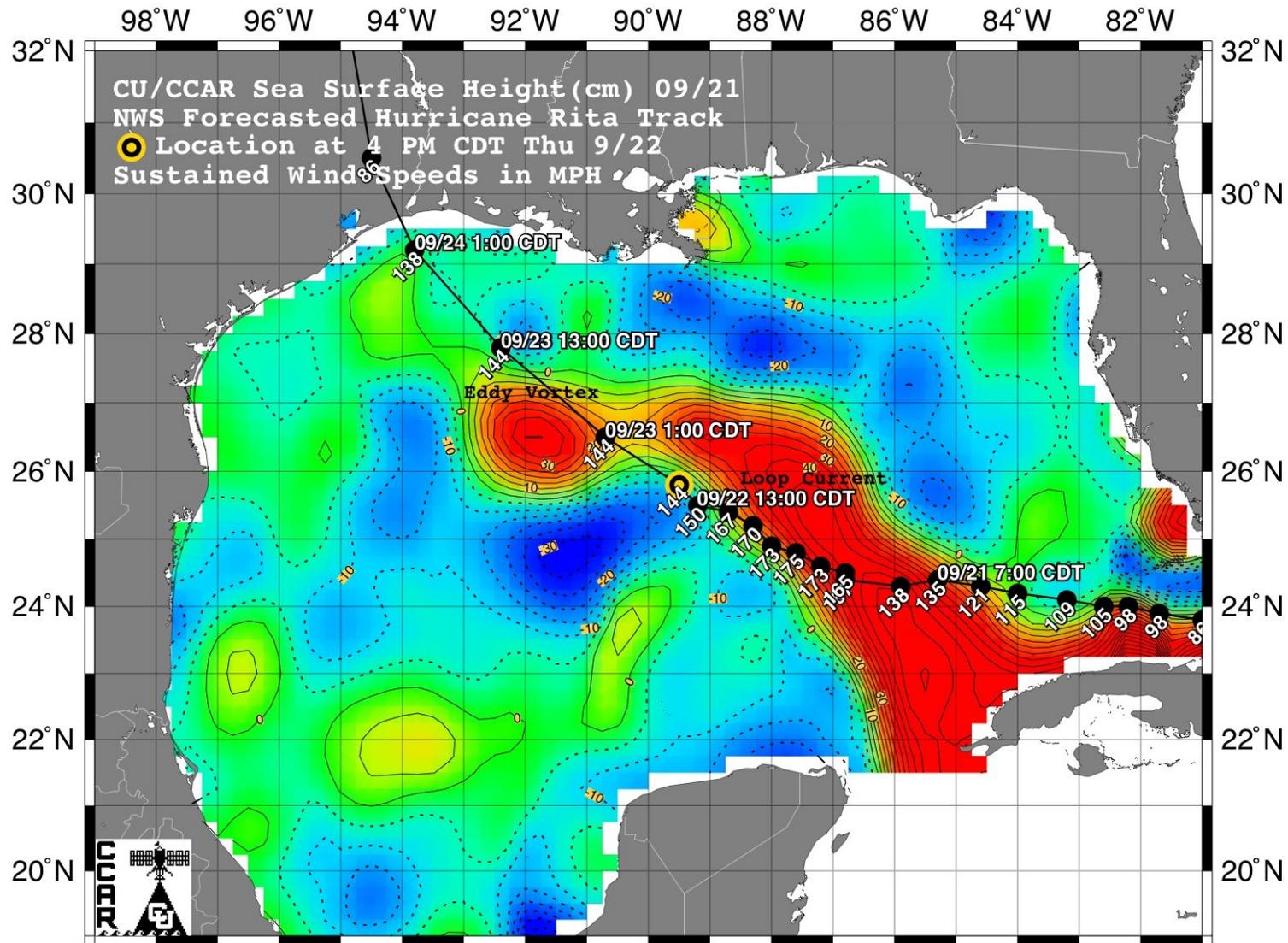
Rita Wednesday 9/21 4pm CDT



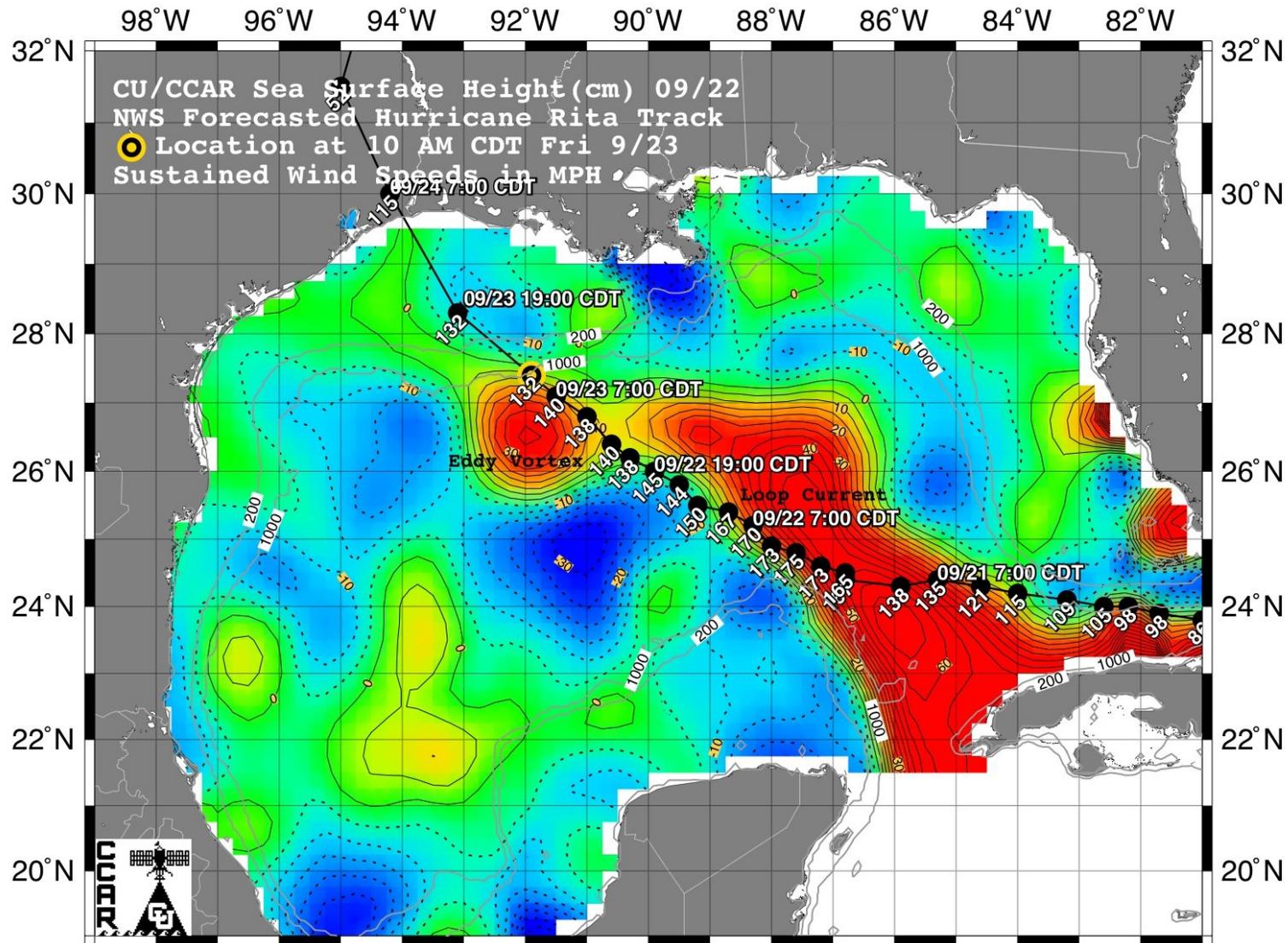
Rita Thursday 9/22 10am CDT



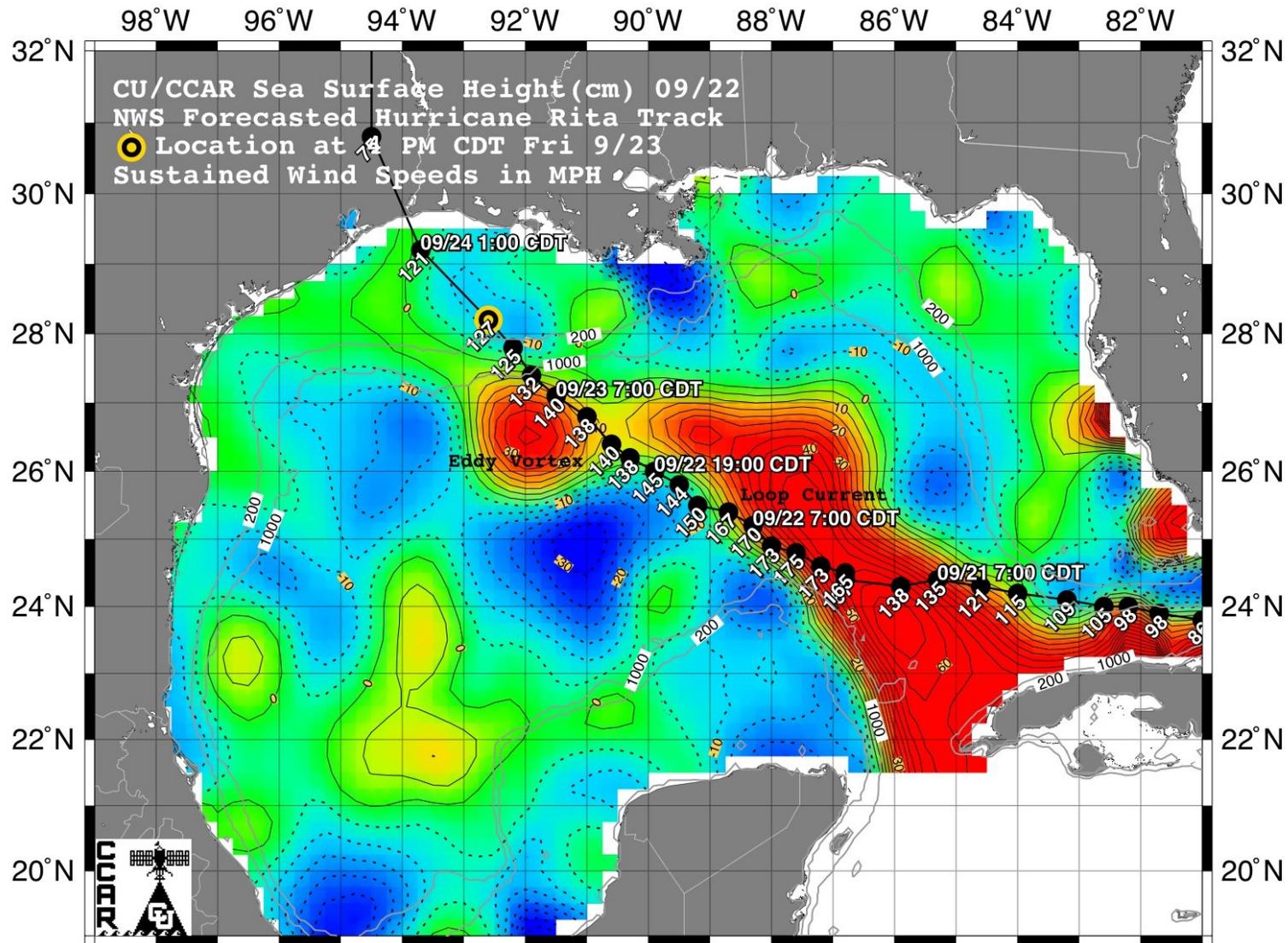
Rita Thursday 9/22 4pm CDT



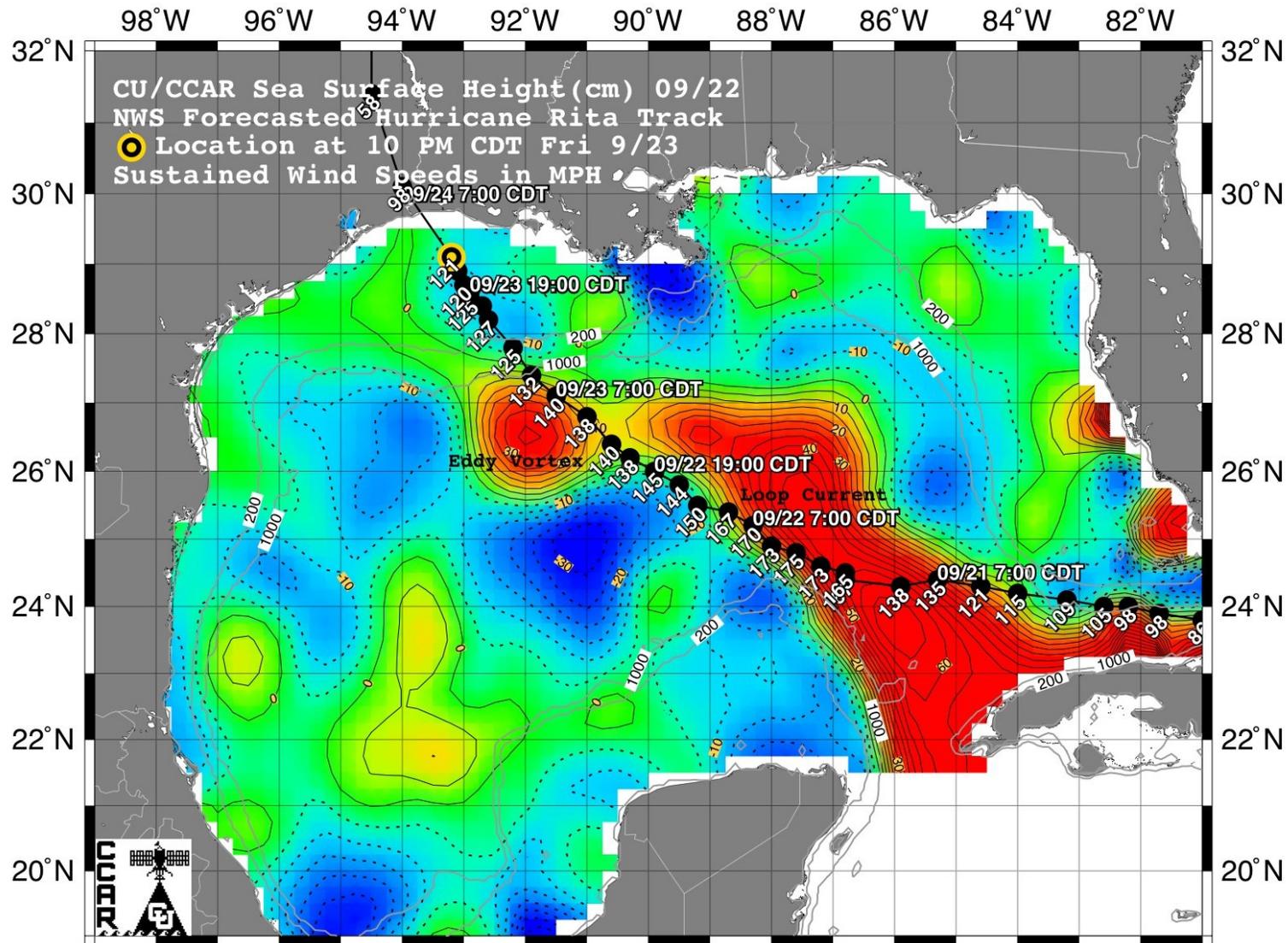
Rita Friday 9/23 10am CDT



Rita Friday 9/21 4pm CDT



Rita Friday 9/23 10pm CDT



Thanks!

