NC STATE UNIVERSITY

Physical Oceanography and Circulation in the Gulf of Mexico

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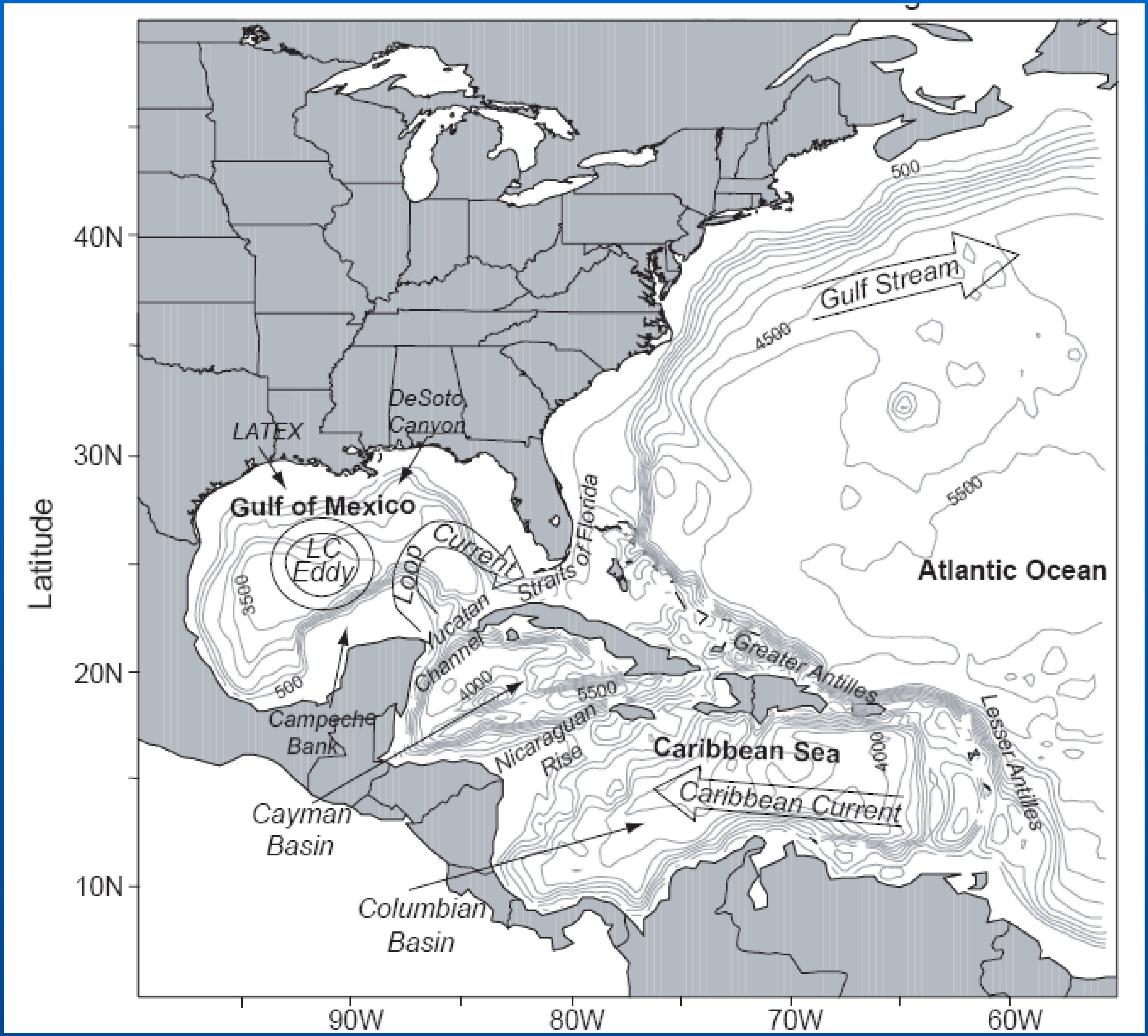
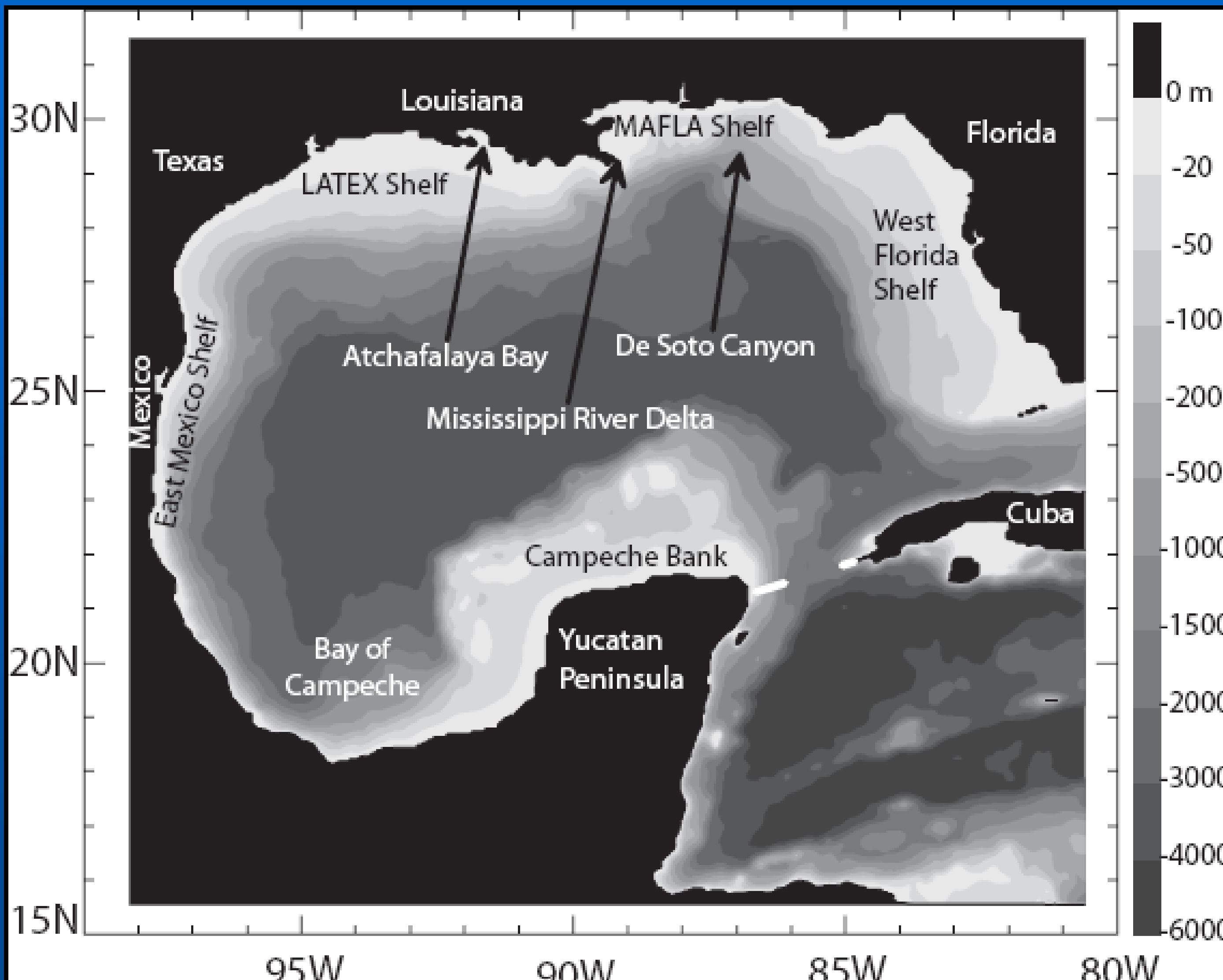
Dept. of Marine, Earth & Atmospheric Sciences

Ocean Carbon and Biogeochemistry Scoping Workshop on Terrestrial and Coastal Carbon Fluxes in the Gulf of Mexico

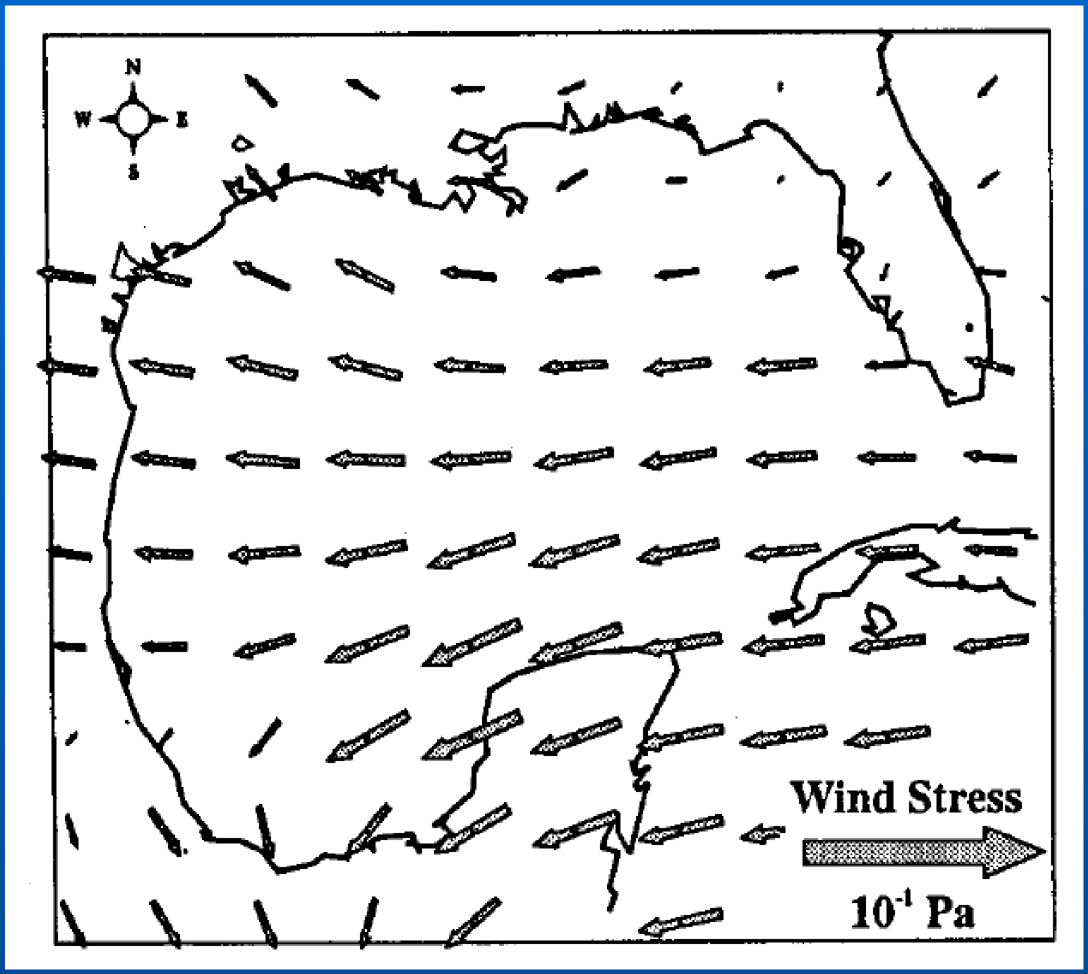
St. Petersburg, FL May 6-8, 2008



Adopted from Oey et al. (2005)



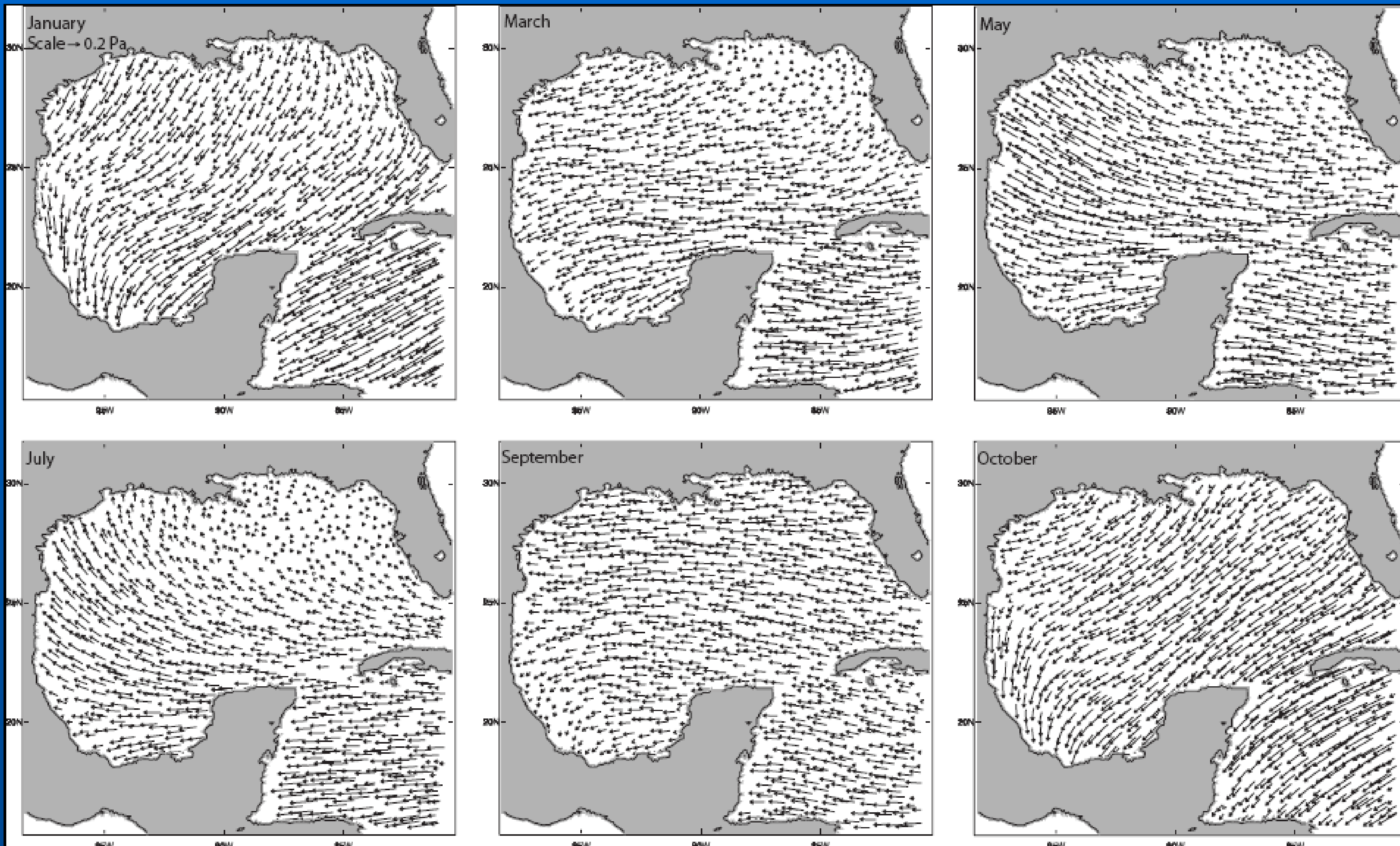
Adopted from Morey et al. (2005)



Averaged field of wind stress for the GOM.
[adapted from Gutierrez de Velasco and Winant, 1996]

Surface wind Monthly variability

Spring transition vs Fall Transition



Adopted from Morey et al. (2005)

Outline

1. General circulation in the GOM

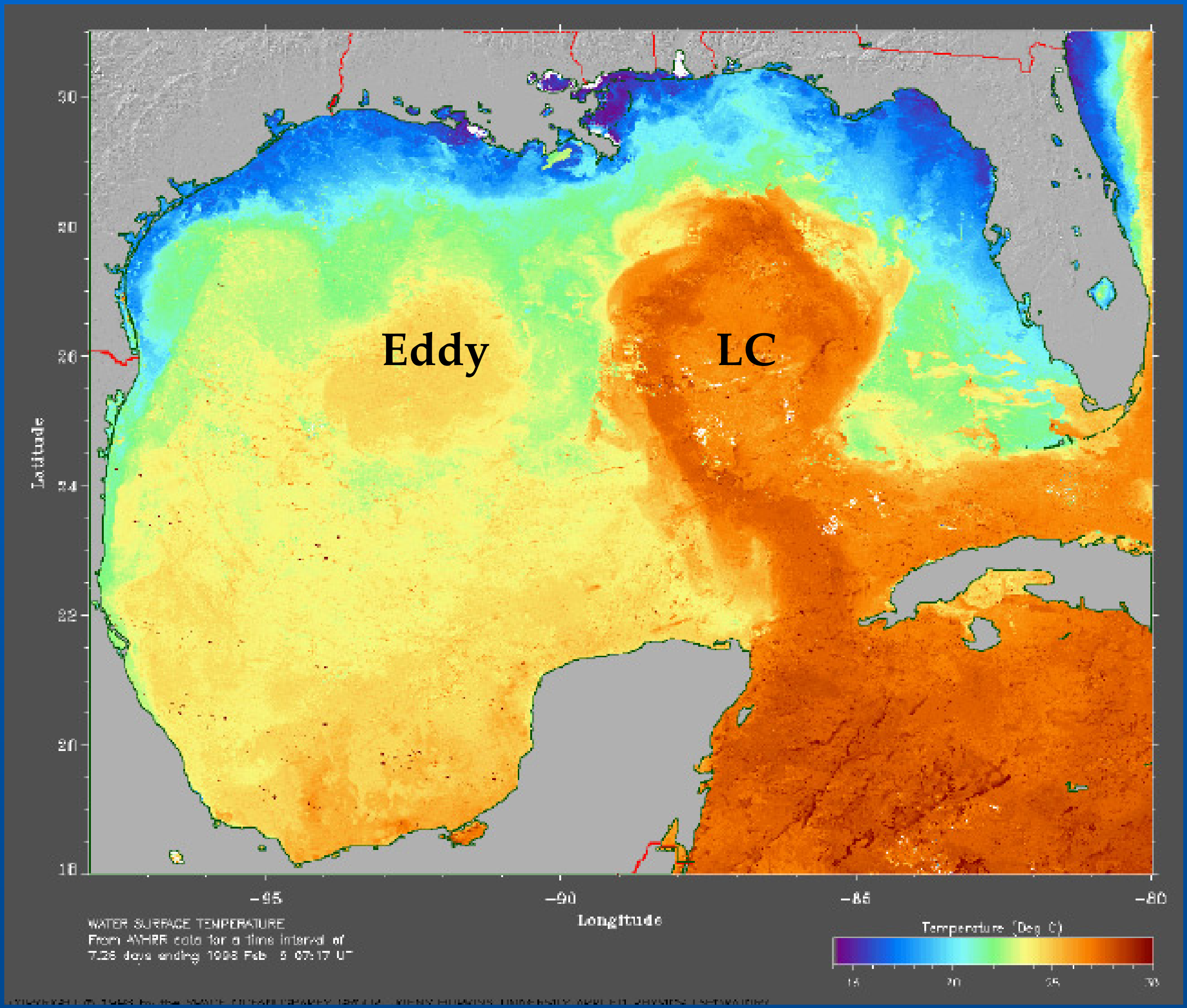
    1.1. The loop current and Eddy Shedding
    1.2. Upstream conditions
    1.3. Anticyclonic flow in the central and northwestern Gulf
    1.4. Cyclonic flow in the Bay of Campeche
    1.5. Deep circulation in the Gulf

2. Coastal circulation

    2.1. Coastal Circulation in the Eastern Gulf
    2.2. Coastal Circulation in the Northern Gulf
    2.3. Coastal Circulation in the Western Gulf

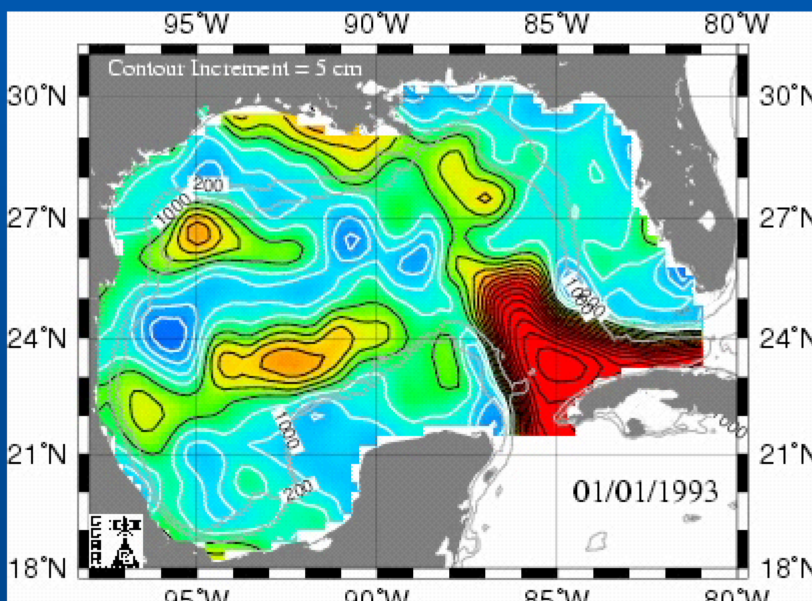
1. General Circulation in the GOM

1.1. The Loop Current (LC) and Eddy Shedding



Summary statistics for the Loop Current metrics computed from the January1, 1993 through July 1, 2004 altimetric time series

	Maximum West Longitude	Maximum North Latitude	Length	Area	Volume	Circulation
Mean	87.9°W	26.2°N	1376 km	147,240 km^2	$2.26x10^{13}$ m^3	1,396,200 m^2/sec
Std. Dev.	1.18°	0.95°	365 km	29,295 km^2	$0.37x10^{13}$ m^3	338,960 m^2/sec
Maximum	93.1°W	28.1°N	2494 km	213,540 km^2	$3.08x10^{13}$ m^3	2,311,200 m^2/sec
Minimum	85.8°W	24.1°N	614 km	55,840 km^2	$0.85x10^{13}$ m^3	611,420 m^2/sec



Leben (2005)

Date	Separation Period (months)	Date	Separation Period (months)
July 1973		May-June(?) 1989	12.5
April 1974	9	August 1990	14.5
January 1975	9	Aug- Sep 1991	12.5
July 1975	6	19 July 1992	11.5
August 1976	13	11 Jul 1993	11.5
March 1977	7	10 Sep 1993	2
June 1978	15	27 Aug 1994	11.5
April 1979	10	18 Apr 1995	7.5
January 1980	9	8 Sep 1995	4.5
March 1981	14	14 Mar 1996	6
November 1981	8	13 Oct 1996	7
May 1982	6	30 Sep 1997	11.5
March 1983	10	22 Mar 1998	5.5
February 1984	11	2 Oct 1999	18.5
August 1984	6	10 Apr 2001	18.5
July 1985	11	22 Sep 2001	5.5
January 1986	6	28 Feb 2002	5
October 1986	9	13 Mar 2002	0.5
September 1987	11	5 Aug 2003	17
May 1988	8	31 Dec 2003	5

A compilation of the 31-yr Record (July 1973 – June 2004) of LC separation event.

The separation intervals vary From a few weeks up to ~ 18 Months.

Separation intervals tend to Cluster near 4.5-7 and 11.5, And 17-18.5 months, perhaps Suggesting the possibility of ~ a 6 month duration between each cluster.

Leben (2005); Schmitz et al. (2005)
Sturges and Leben (1999)

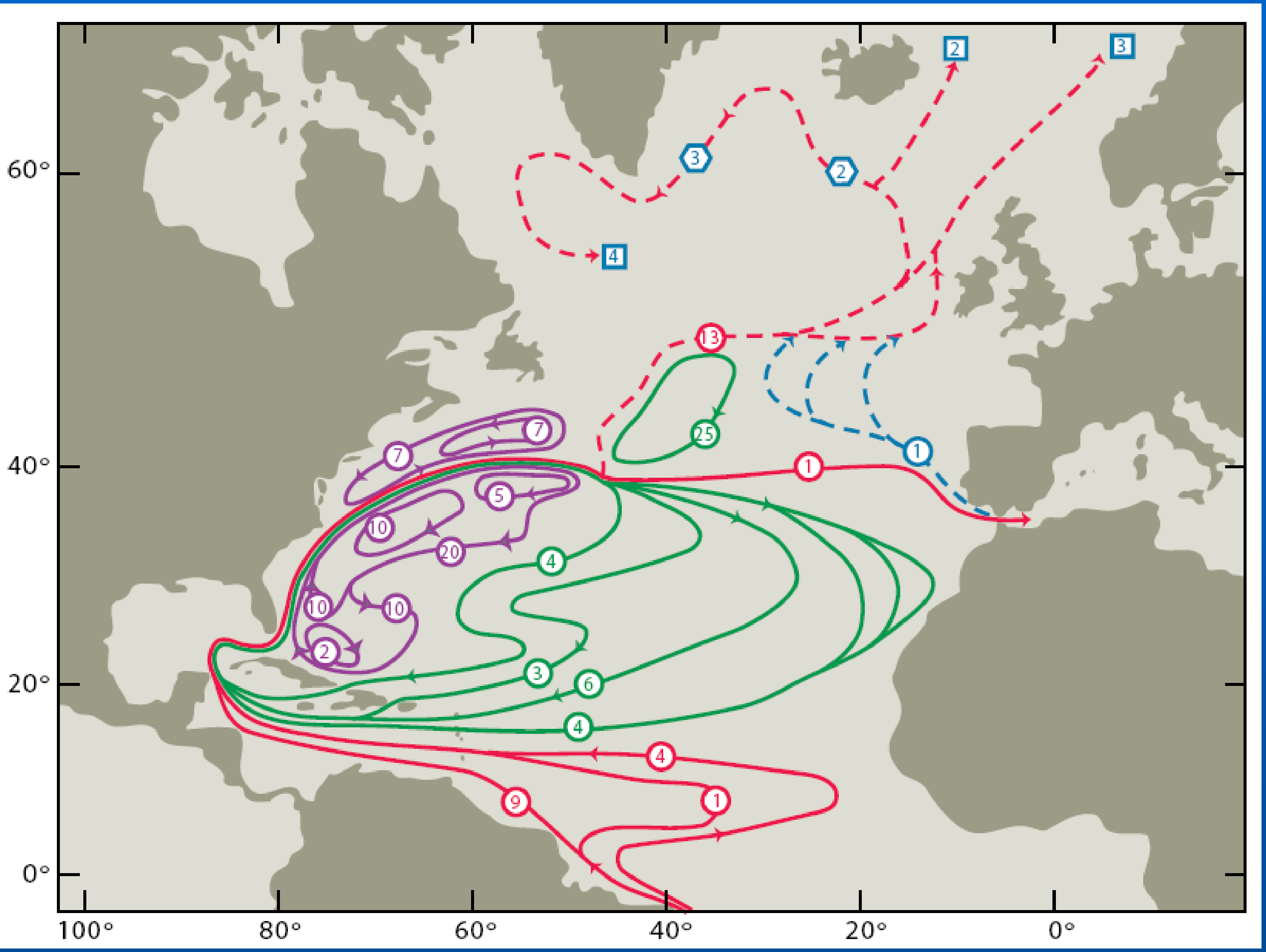
The question of why the LC and the shedding process behave in such a semi-erratic manner is a bit of a mystery

- Hurlburt and Thompson (1980) found erratic eddy shedding intervals in the lowest eddy viscosity run in a sequence of numerical experiment.
- Oey et al. (2003) proposed an upstream influence.
- Schmitz (2005) suggests blocking cyclones can impact separation intervals.
- Leben (2005) shows the relationship between separation interval and the latitude of LC at the time of the previous separation.
- Lugo-Fernandez (2007) shows LC behaves as a nonlinear driven and damped oscillator and is link with NAO, which affects the wind strength and transport across the Yucatan Channel.

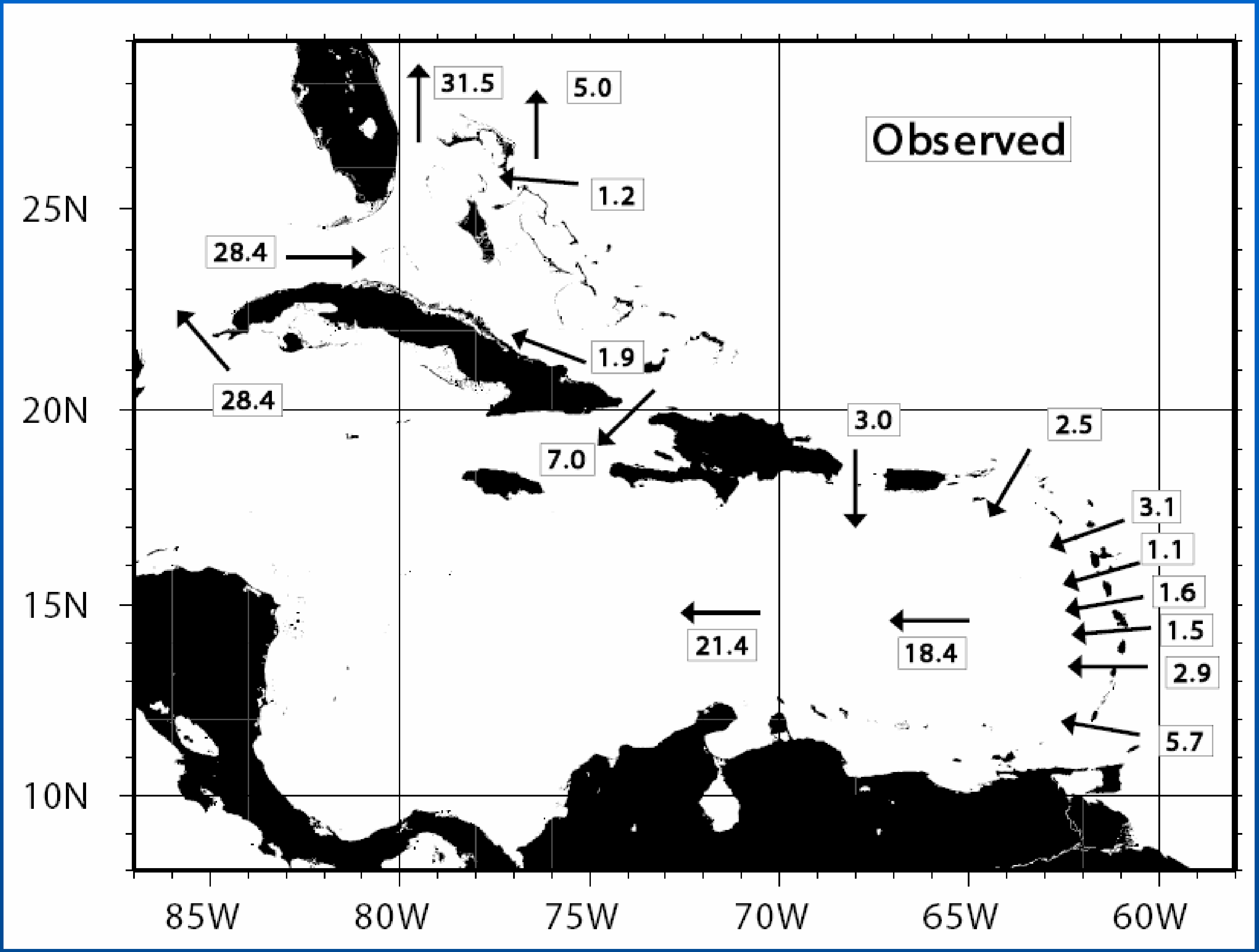
At any rate, Eddies that form from LC and along LC margin are important for GOM circulation, and biogeochemistry processes, such as nutrient supply, retention, shoreward transport (e.g., Fratantoni et al. (1998), Lee et al., (1994)).

1.2. Upstream Conditions

Adopted from Schmitz (2003)



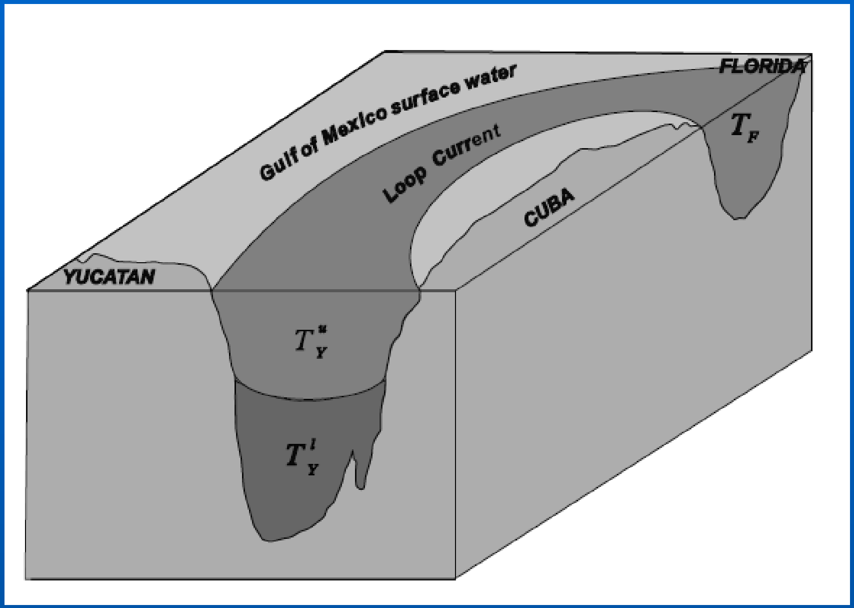
- The net inflow into the Caribbean Passages and then into the GOM is ~ 45% of South Atlantic origin (Schmitz and Richardson, 1991)
- The rest of the upper ocean water entering the Caribbean Sea and the LC and Florida Current is of North Atlantic origin



(1 Sverdrup = 10^6 m^3/s)

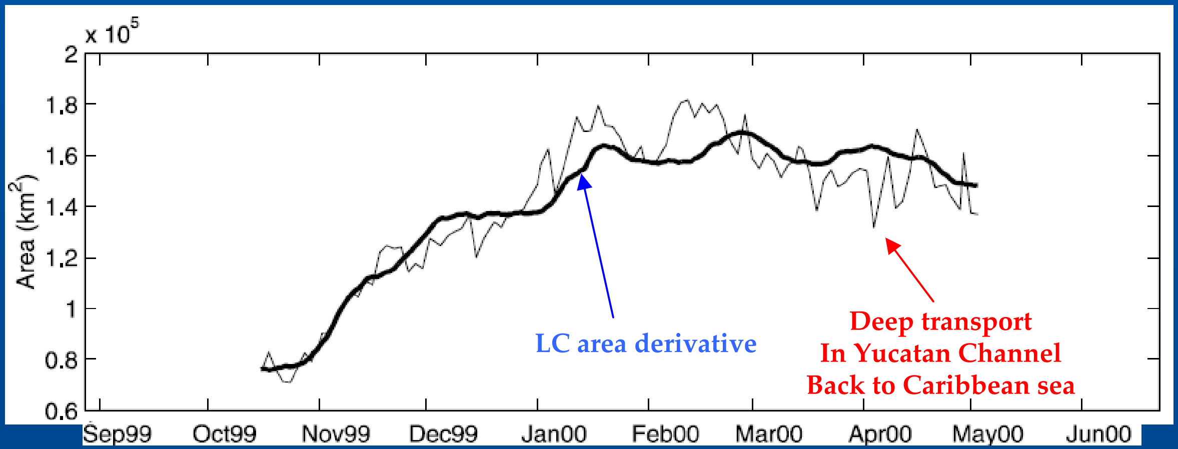
Adopted from Schmitz (2003)

Deep flows in the Yucatan Channel and their relation to changes
In the Loop Current Extension

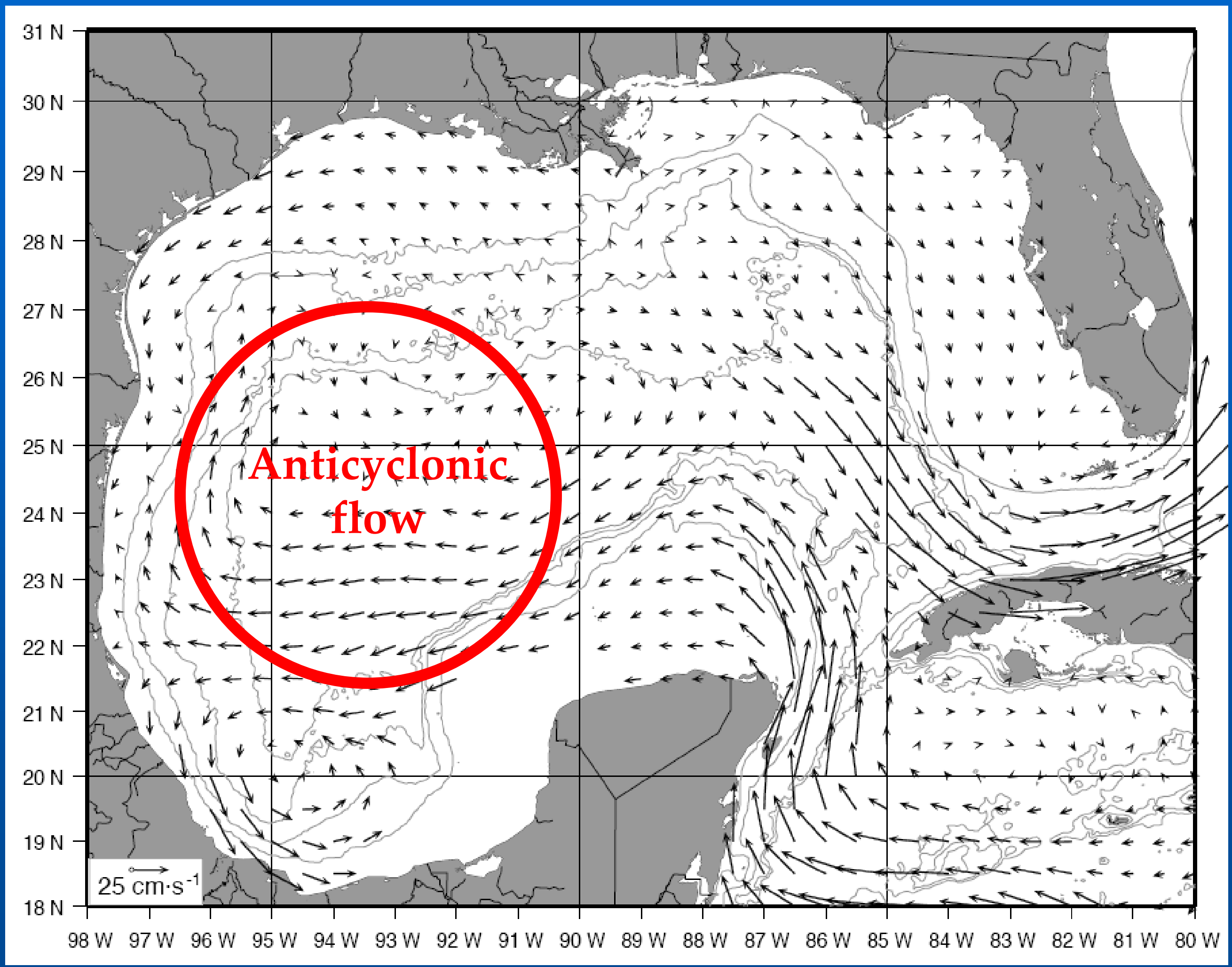


Maul (1977), Bunge et al. (2002)

The growth of the Loop Current as it expands to the north displaces an equivalent volume of Gulf water back into the Caribbean sea at depth below ~ 800 m.

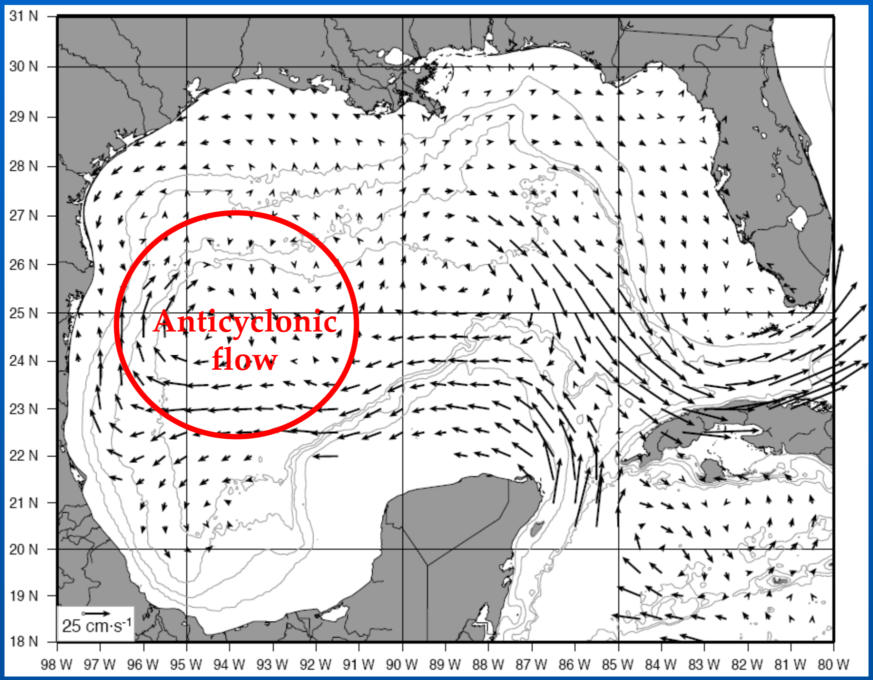


1.3. Flow in upper layers of the Central and Northwest Gulf

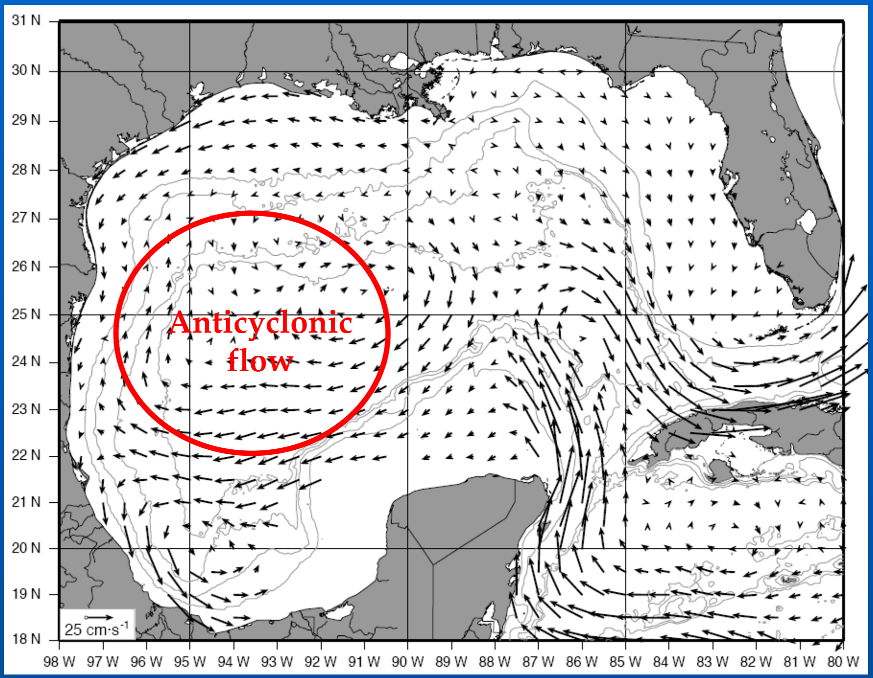


Near surface velocity estimates for each 1.5x1.5 bin based on averaging all drifter velocity Estimates in that bin for the period 1989-1999. Shown are 200, 1000, 2000, 3000-m isobaths DiMarco et al. (2005)

All summertime

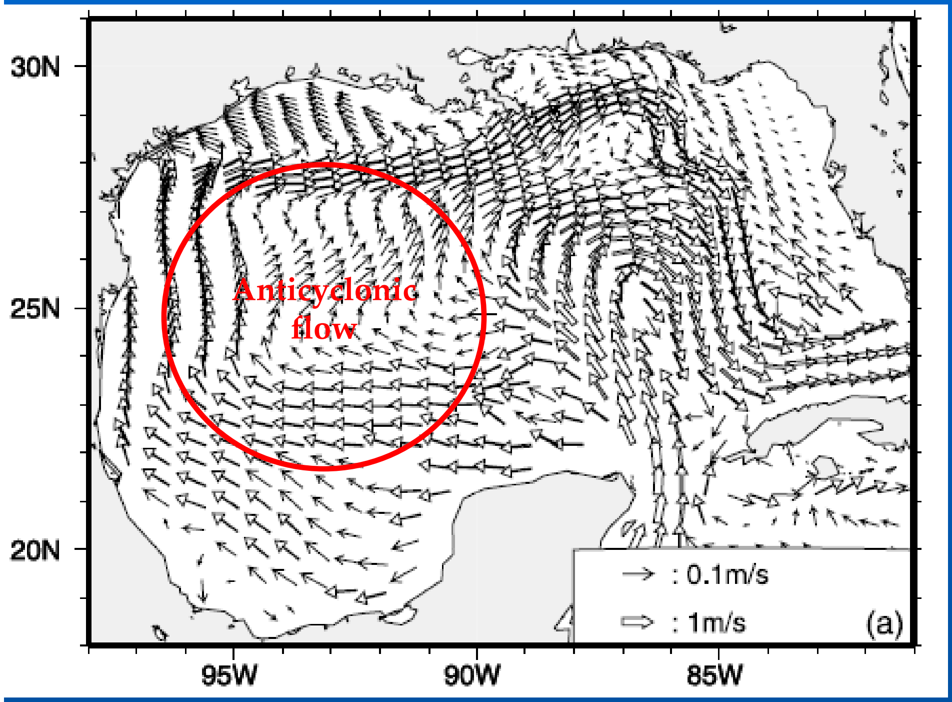


All wintertime

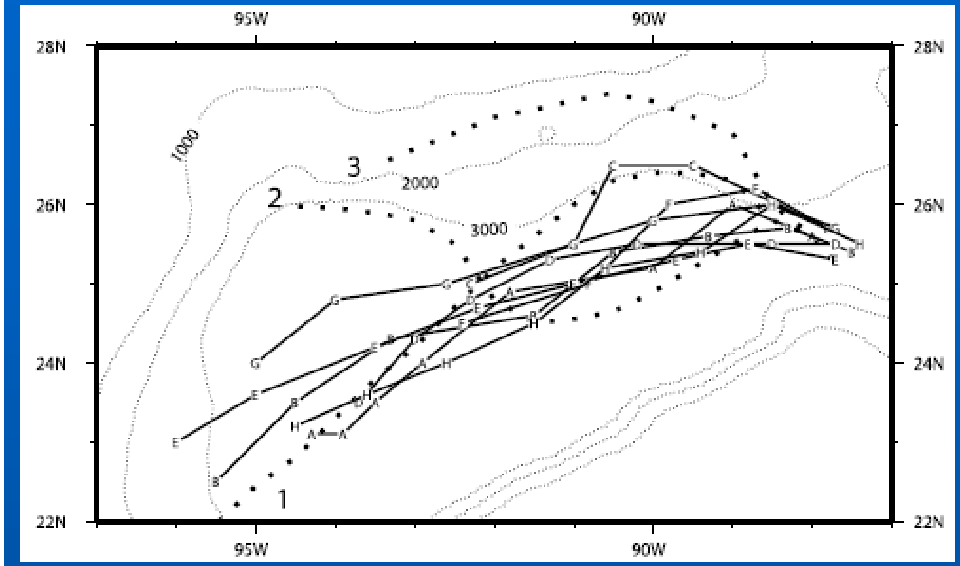


Nowlin (1972); Beringher et al (1977); Elliot (1979, 1982); Sturges (1993)

Modeled GOM Surface Circulation



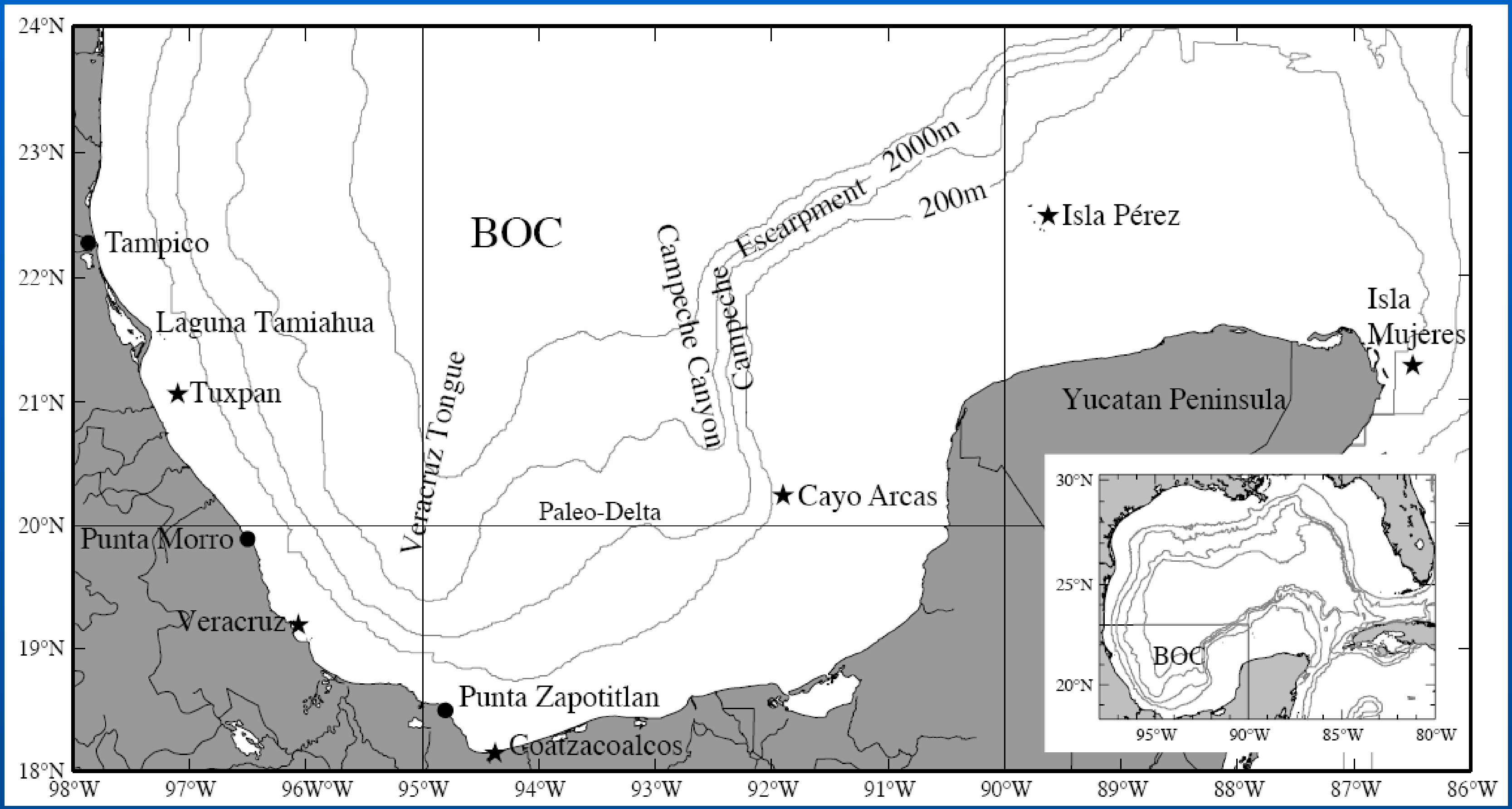
Modeled trajectories of LCR



Lee and Mellor (2003)

The anticyclonic circulation is forced by both wind stress and wind stress Curl. It is also affected by the average influence of the LCR's propagating to the west while dispersing anticyclonic vorticity.

1.4. Cyclonic Flow in the Bay of Campeche



Dynamic Heights computed from Ship Hydrographic Data

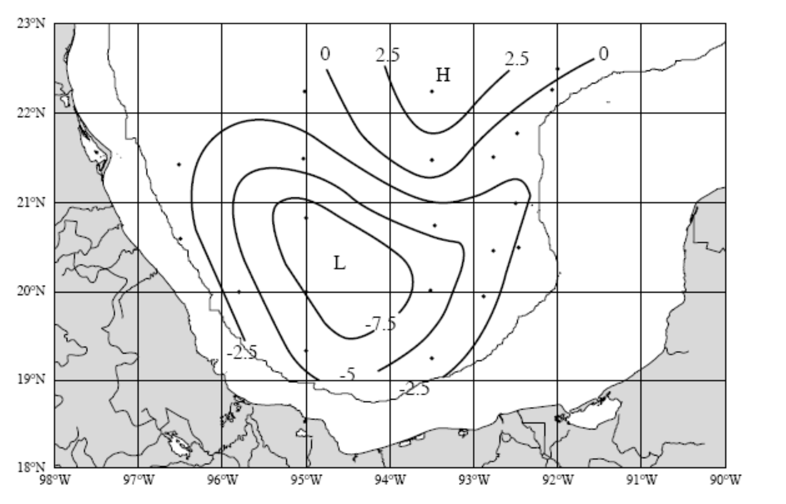


Figure 2. Contours of EOF mode 1 dynamic height (dyn cm) of the sea surface relative to 425 db for the *Geronimo* cruise 67-G-12 during 23 February–13 March 1967. See Section 2.1 for discussion of EOF mode 1 dynamic height. Dots show locations of stations. The 200-m isobath is shown.

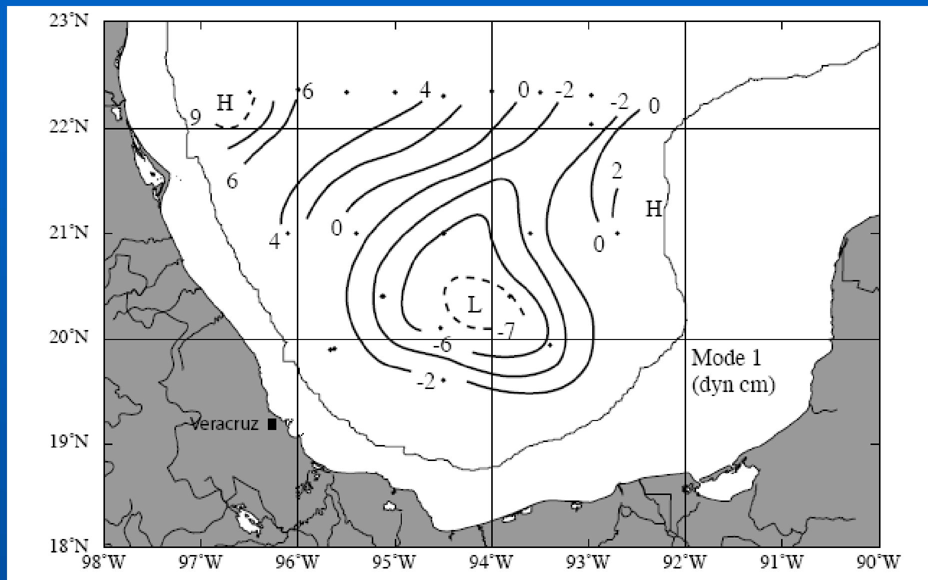
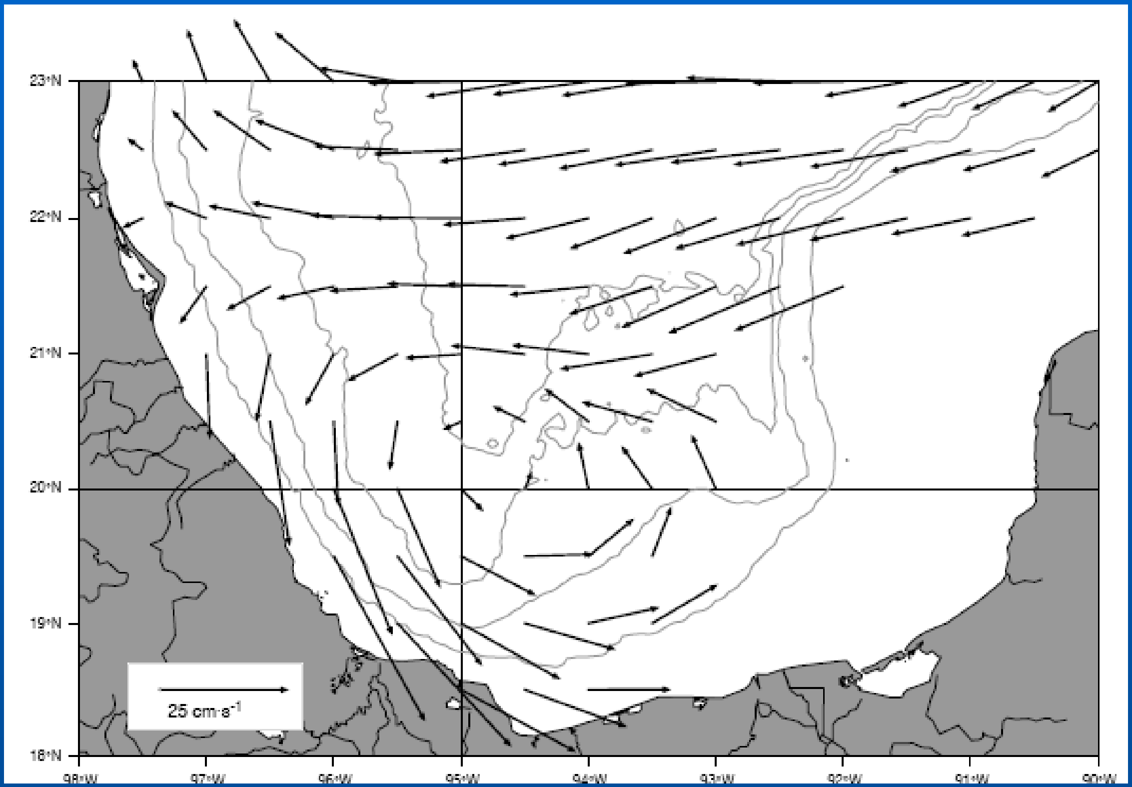


Figure 4. Contours of EOF mode 1 dynamic height (dyn cm) of the sea surface relative to 425 db for *COSMA* cruise 71-22, 27 October-10 November 1971. The 200-m depth contour is shown.

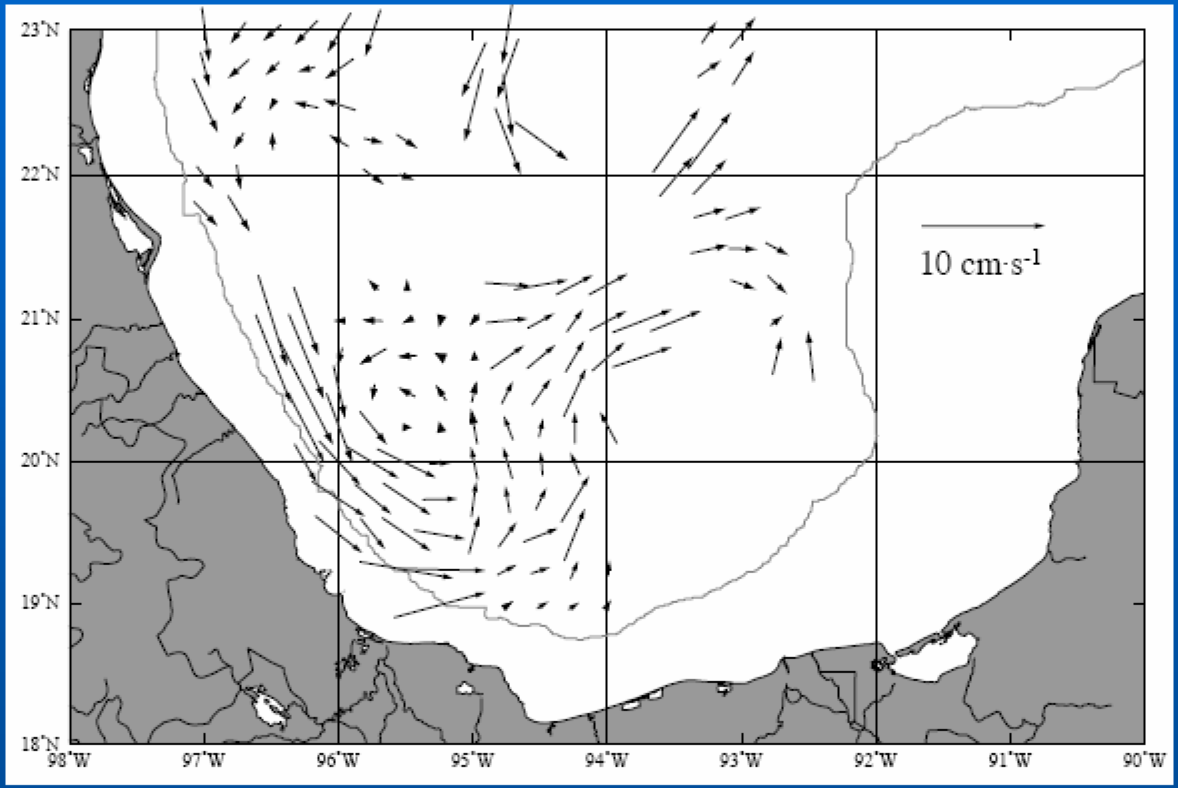
Adopted from Vazquez De La Cerda et al. (2005)

Averaged current vectors based on near surface drogued drifter data
Over 10-year period



Adopted from Vazquez De La Cerda et al. (2005)

Averaged current vectors at 900-m depth based drifter data over 4-year period



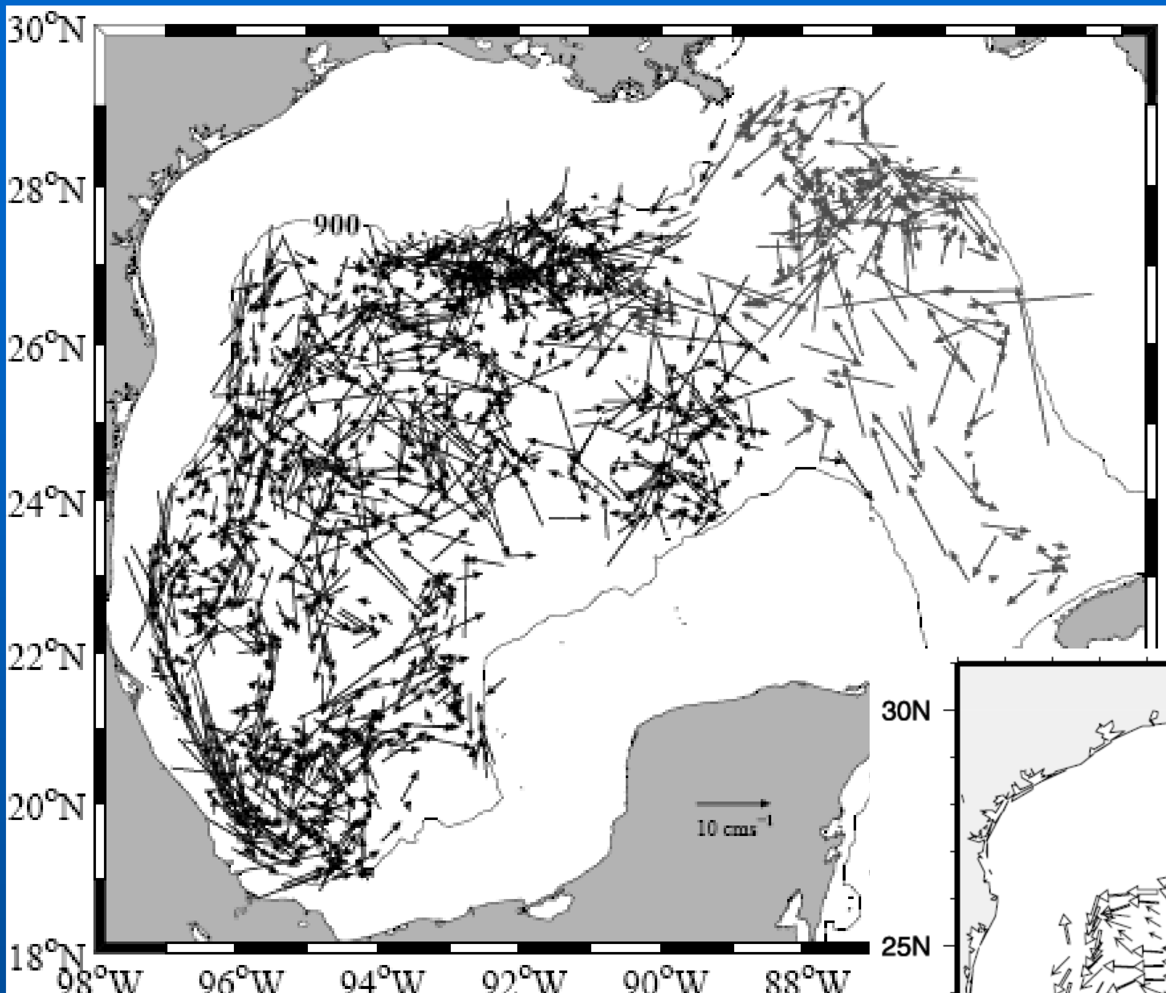
Adopted from Weatherly (2004)

Higher-than-averaged primary production due to nutrient enrichment
In the cyclone lead to elevated zooplankton and fish stock.

1.5. The Deep Circulation in the GOM

Dehaan and Sturges (2005)

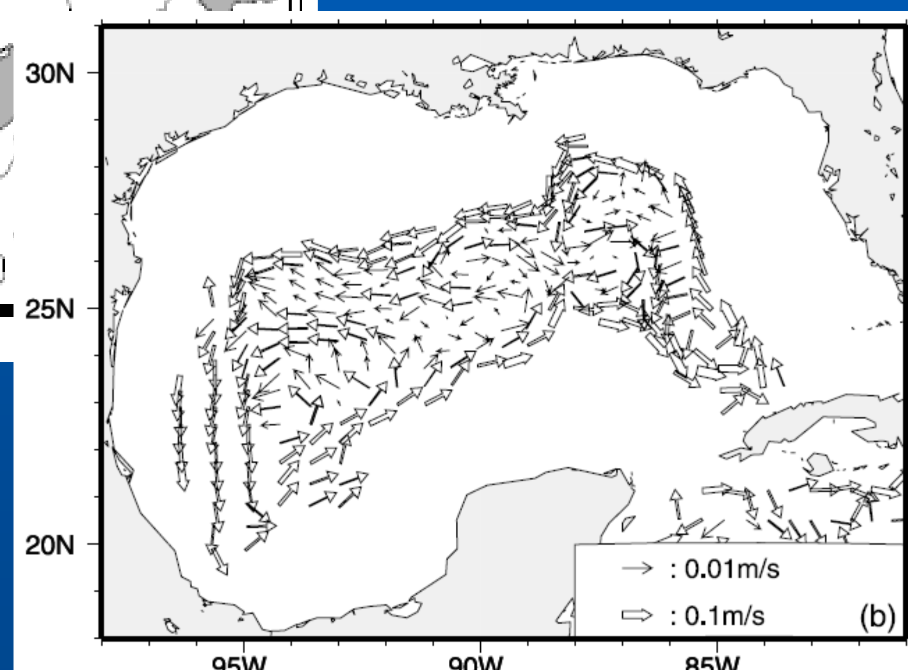
Although the upper layer mean flow in the central and northwestern gulf is anticyclonic, the mean flow near the edges of the GOM below ~1500 m is cyclonic. The supporting evidence comes from a variety of current-meter observations, from deep floats, and from the gradual decay of the cold temperature signal of the Caribbean deep water entering the GOM at Yucatan.



Weatherly et al. (2005)

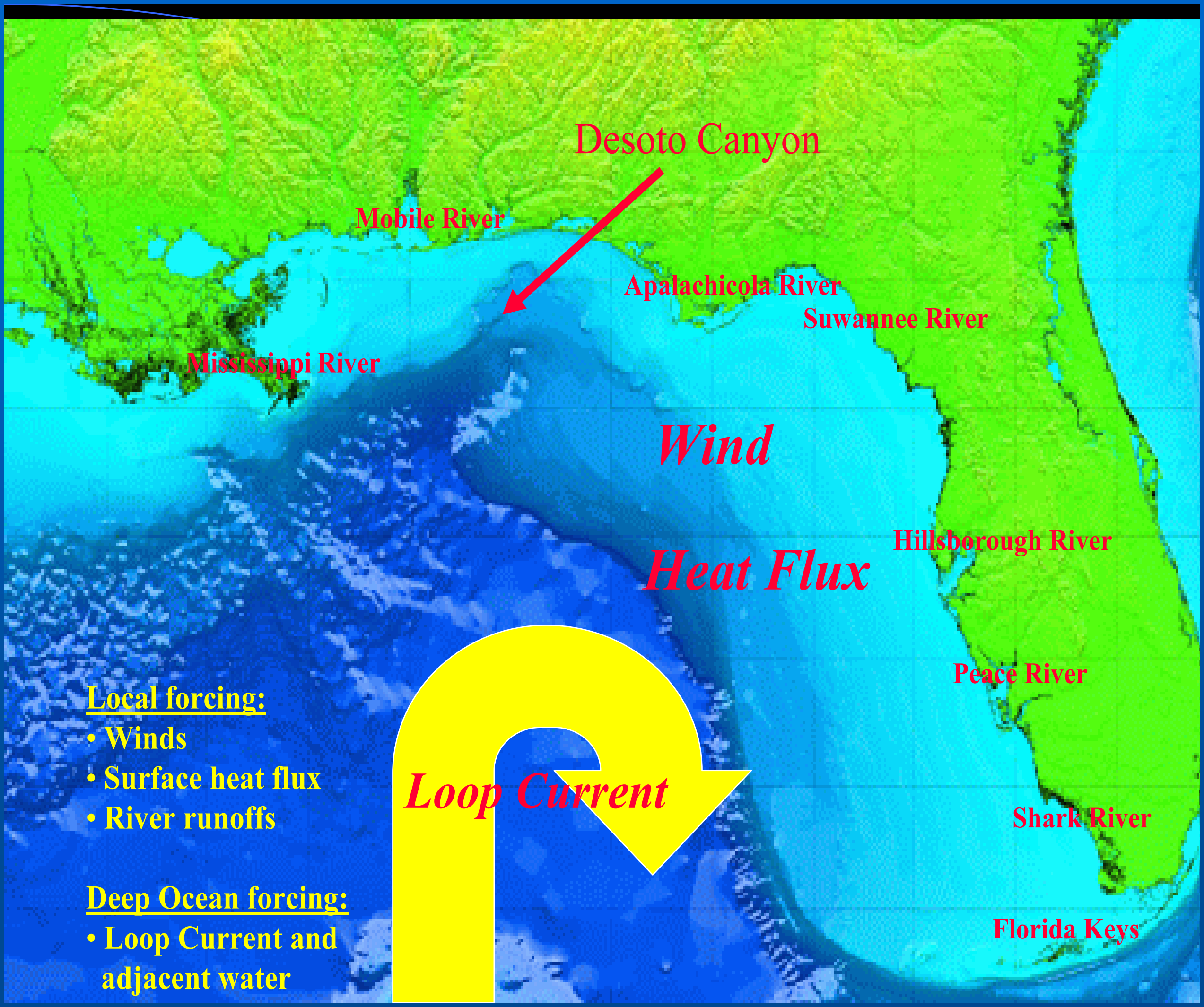
Velocity estimated from
Deep-ocean drifter
at 900 db (~ 1315 m)

Lee and Mellor. (2005)
Model simulated velocity at 1500 m

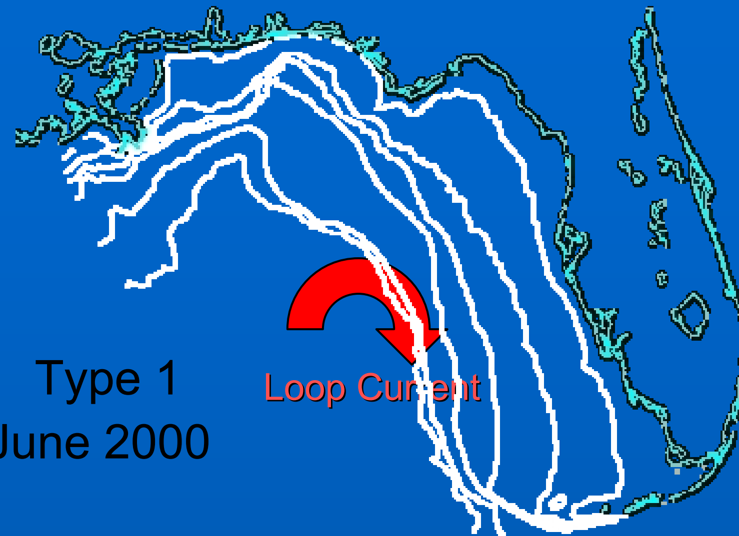


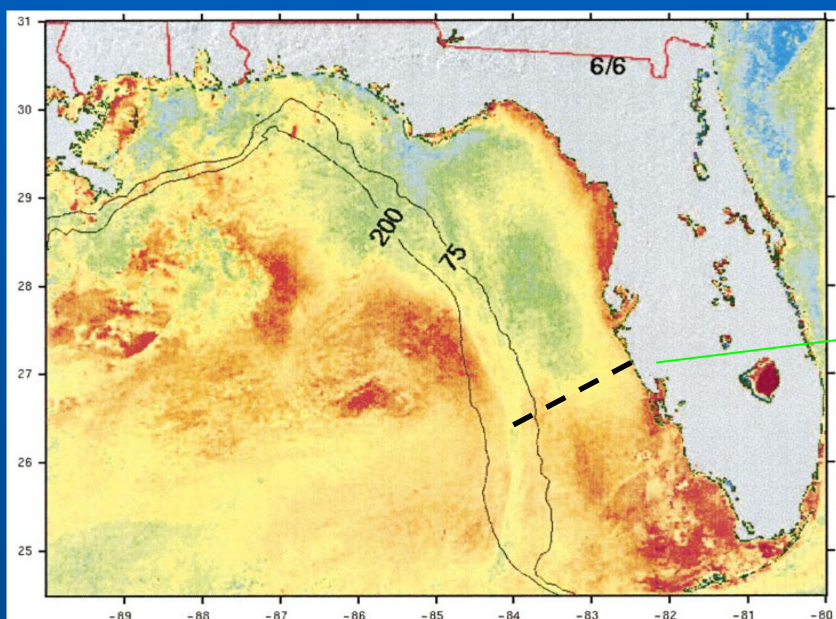
2. Coastal Circulation

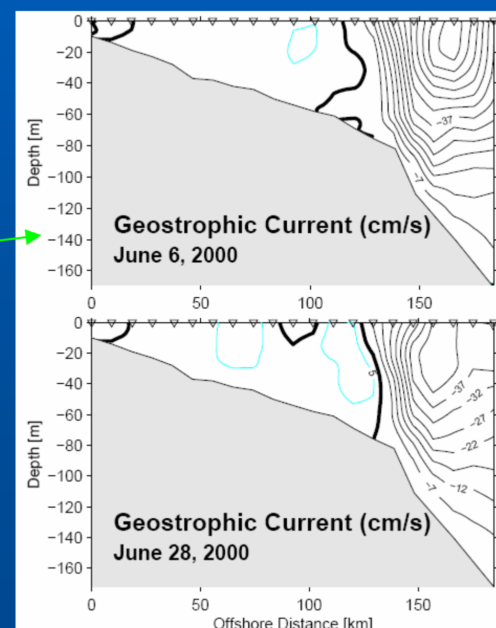
2.1. Coastal Circulations in the Eastern Gulf



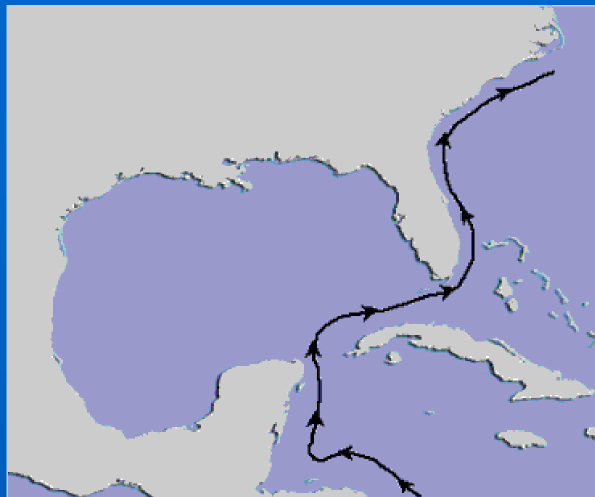
Type 1
June 2000

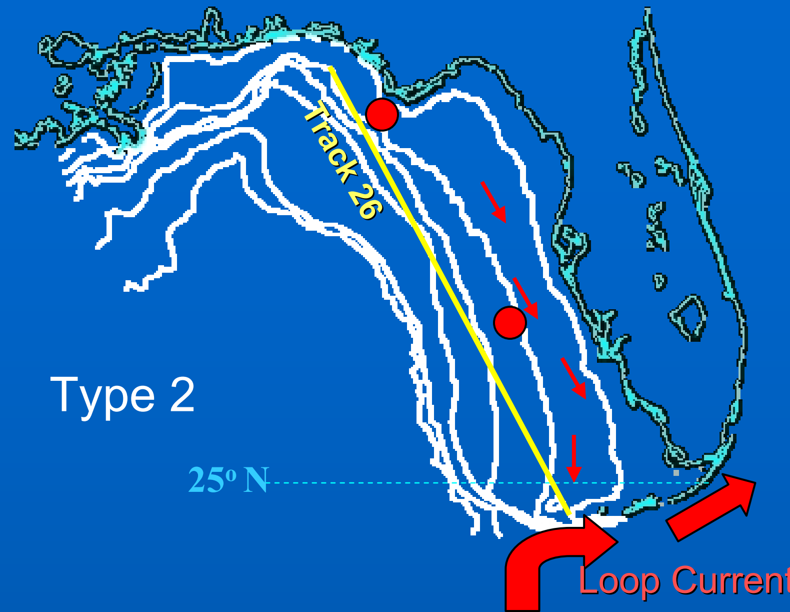


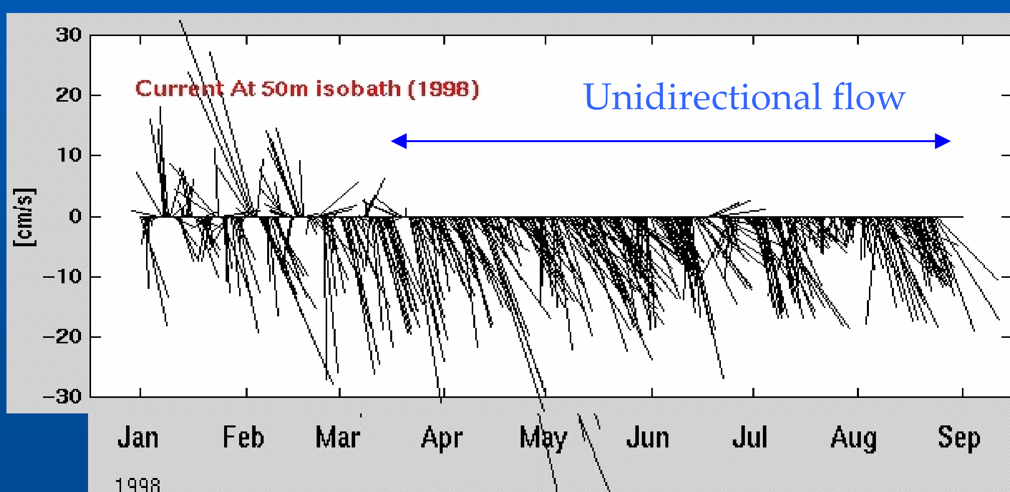


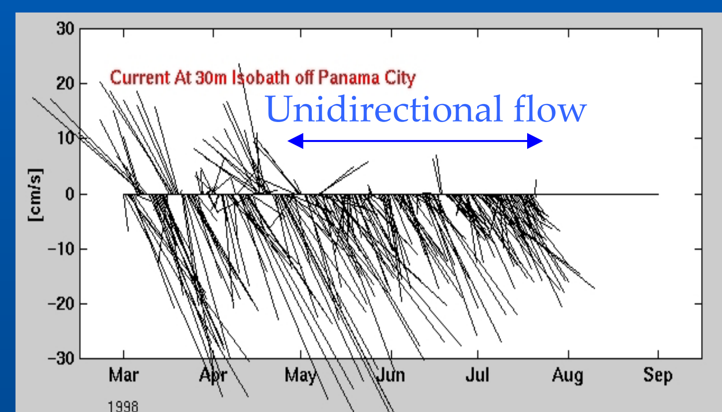


Adopted from He and Weisberg (2003)



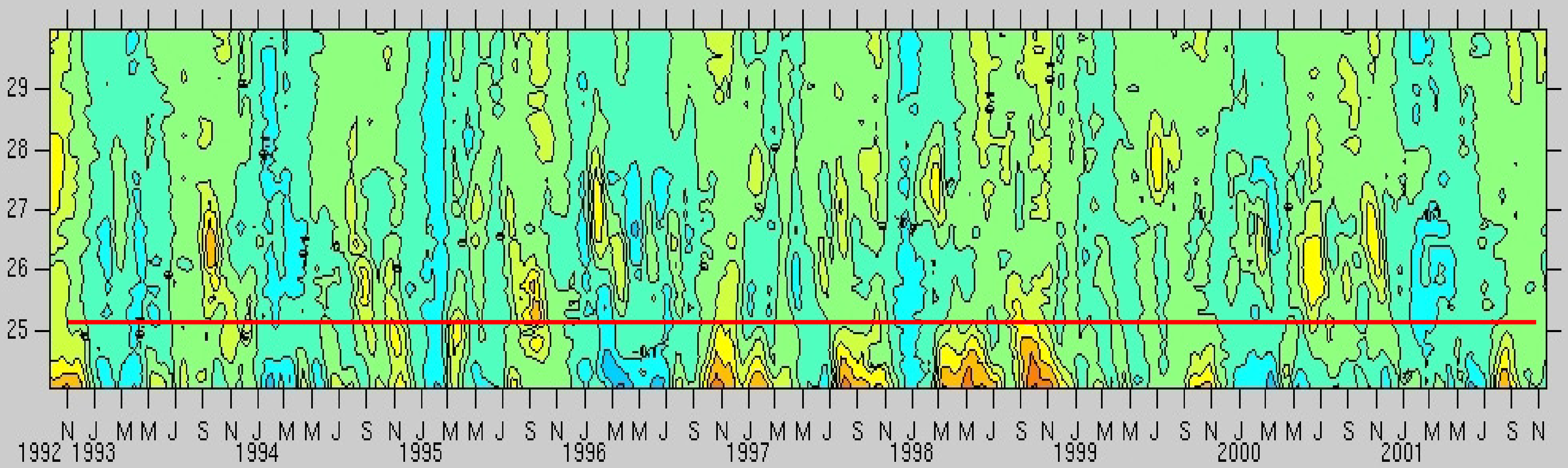


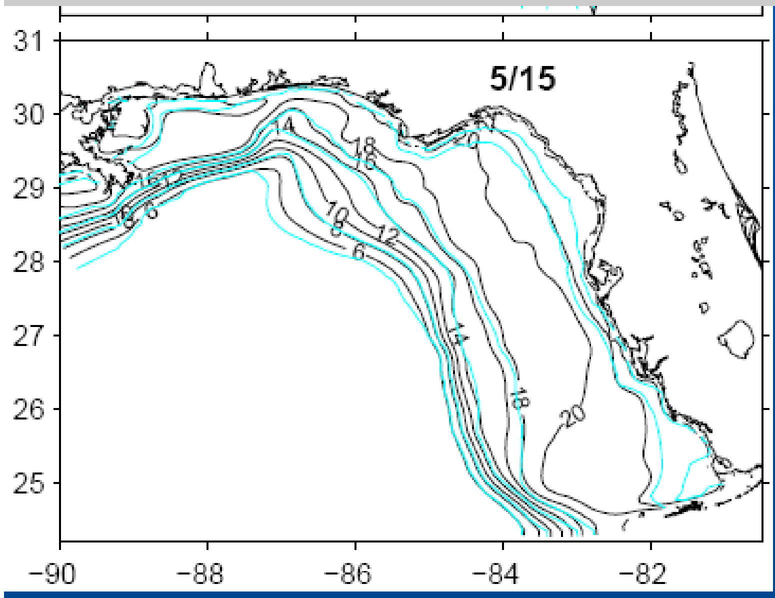




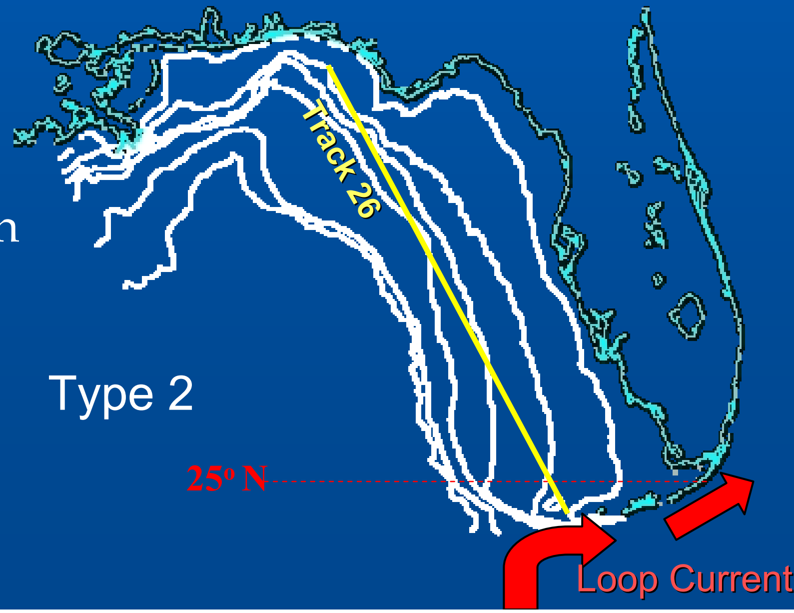
Adopted from Weisberg and He (2003)

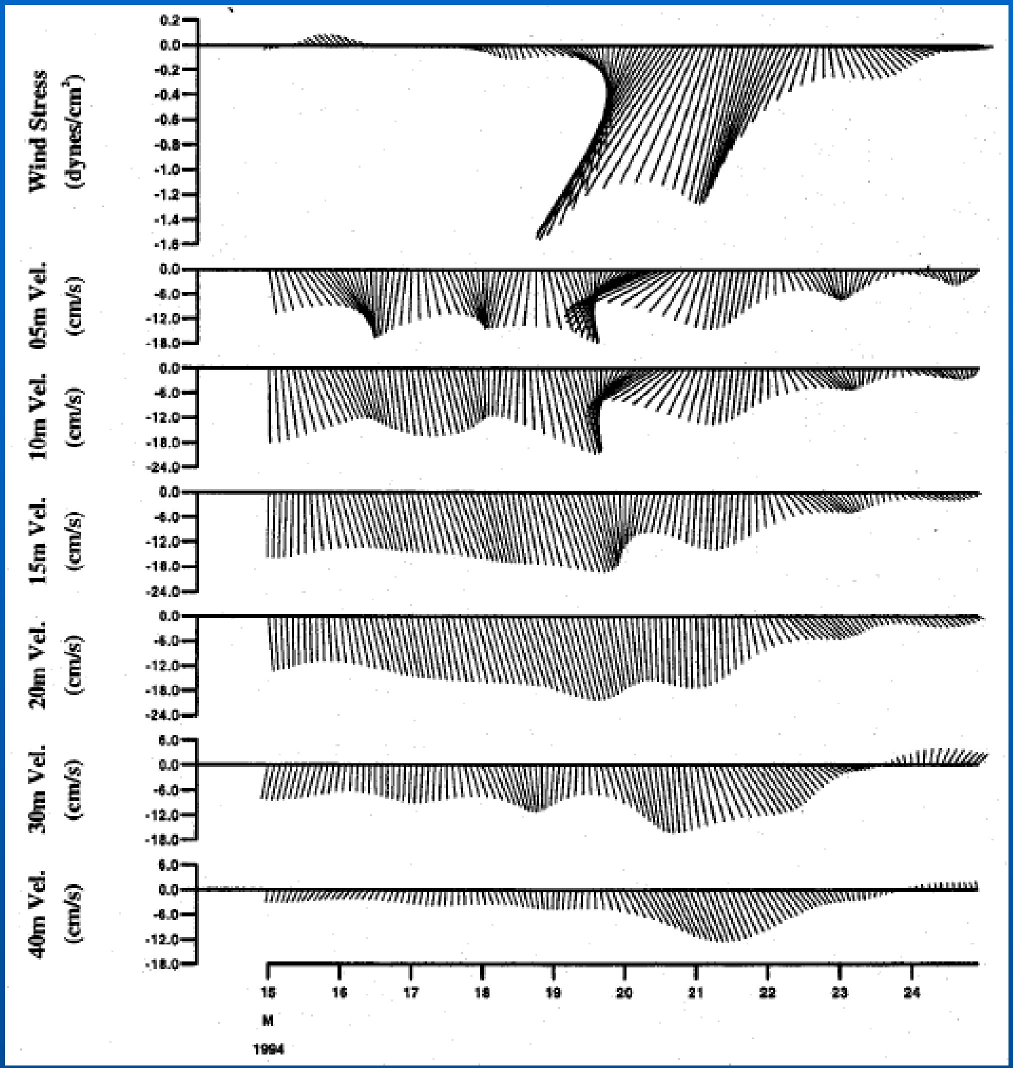
Sea Surface Height Anomaly measured by Satellite Altimeter





How often is LC southern Intrusion?





WFS inner shelf circulation is dominated by local wind Forcing, obeying Ekman and Geostrophic balances

Adopted from Weisberg et al. (2000)

Figure 5. Time series of horizontal current velocity vectors at 5 m, 10 m, 15 m, 20 m, 30 m, and 40 m depths from a mooring positioned offshore of the Florida Big Bend on the 50 m isobath, surface wind velocity from a nearby NOAA buoy 42036, ; all low pass filtered to remove fluctuations on time scales shorter than 36 hrs. The vector orientation follows the standard compass rose with north vertically up and east to the right.

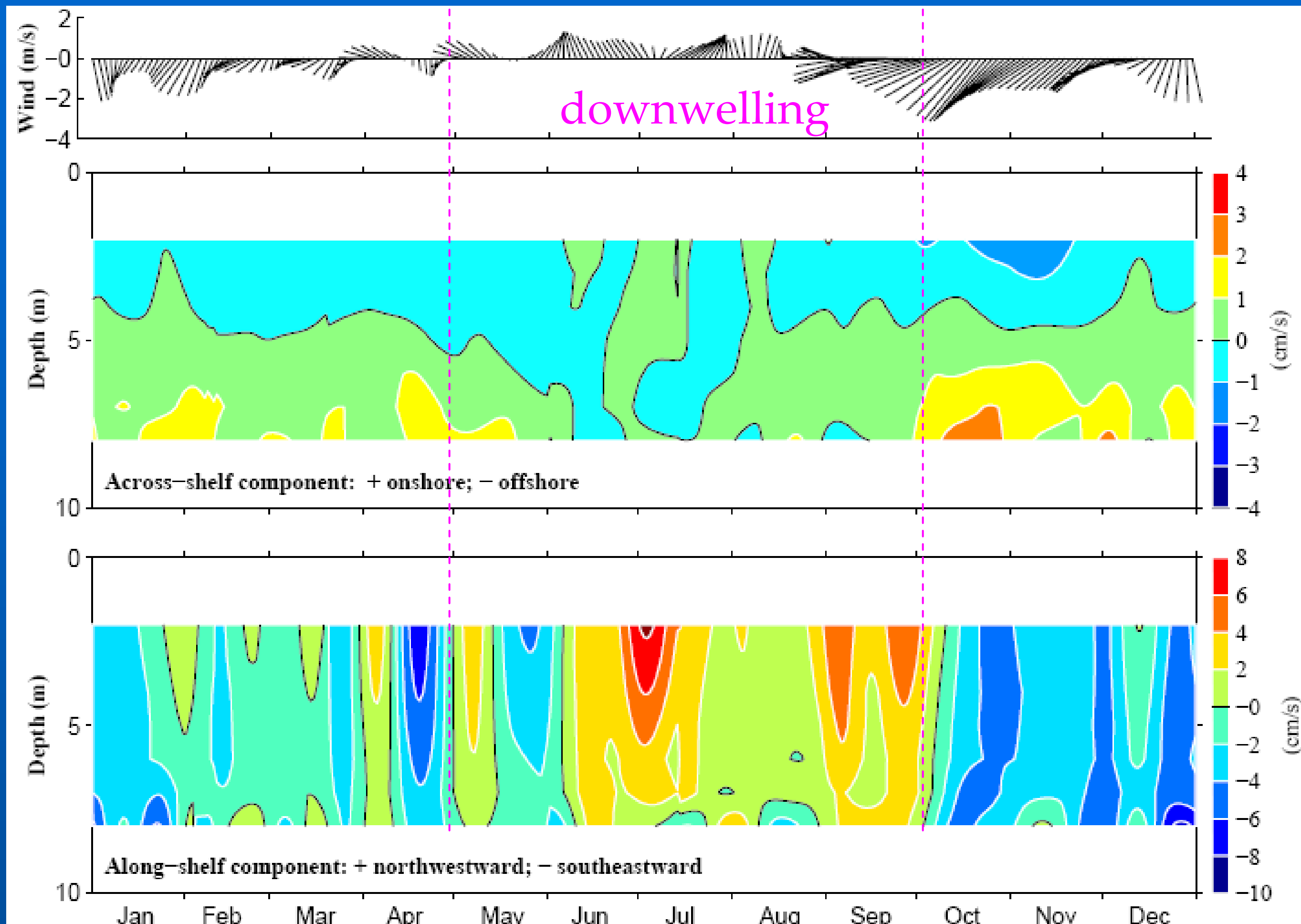


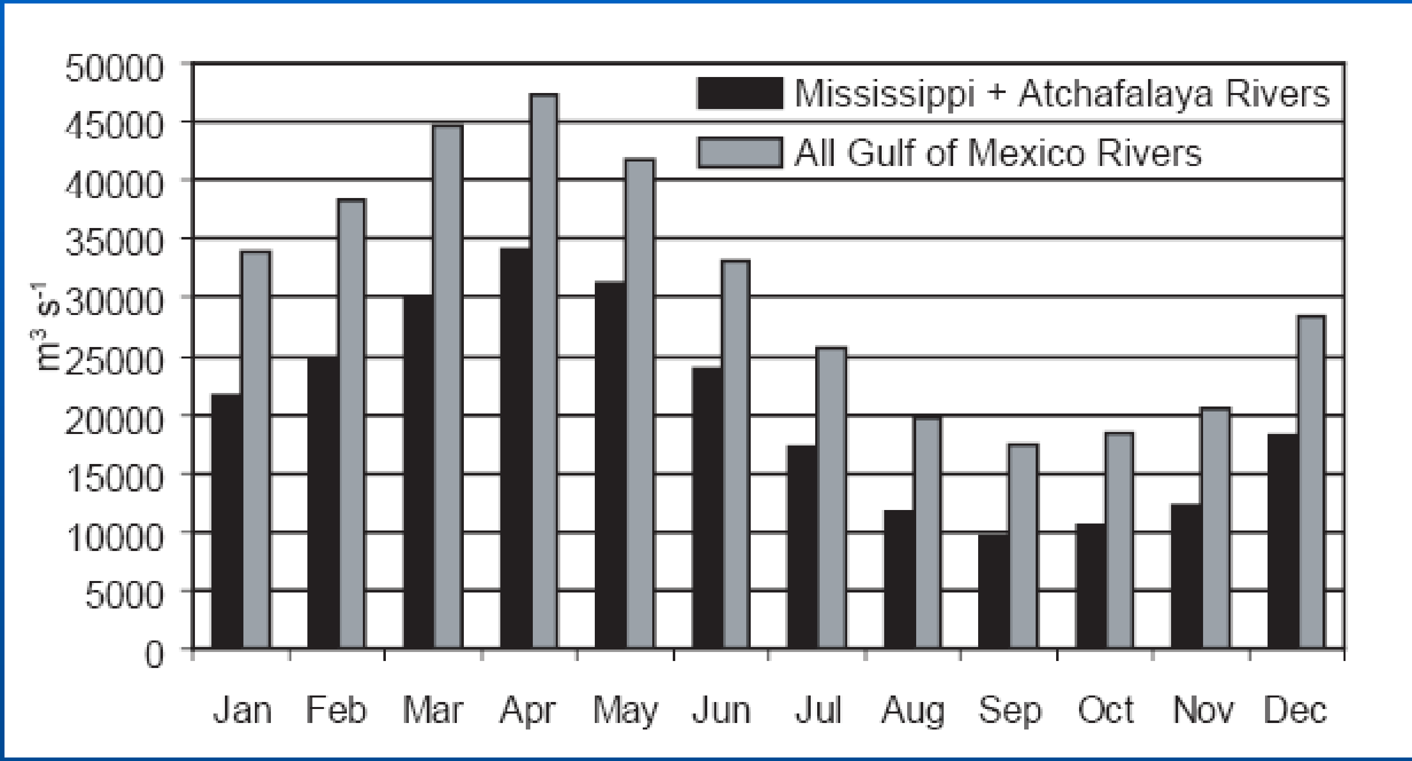
Figure 12. Climatological mean along shelf currents (bottom panel), across shelf currents (middle panel), and surface winds (upper panel). The currents are composited from observations on the 10 m isobath offshore of Sarasota from July 1998 to February 2004, and the winds are composited from the NOAA buoy #42036 from 1994 to 2003. For both the winds and currents we performed an ensemble average across years using 20-day low-pass filtered times series, each aligned with the same phase of the year.

Weisberg et al. (2005)

2.2. Coastal Circulations in the Northern Gulf

Large Riverine Influence

~70% runoff of GOM is coming from Mississippi +Atchafalaya



Adopted from Morey et al., (2005)

Isolines of sea surface height are superimposed on SeaWIFS map of 7-day composite color, centered on 8/1/2004. An illustration of the transport of high-chlorophyll water from the shelf system in the northeastern Gulf southward along the eastern side of the Loop Current.

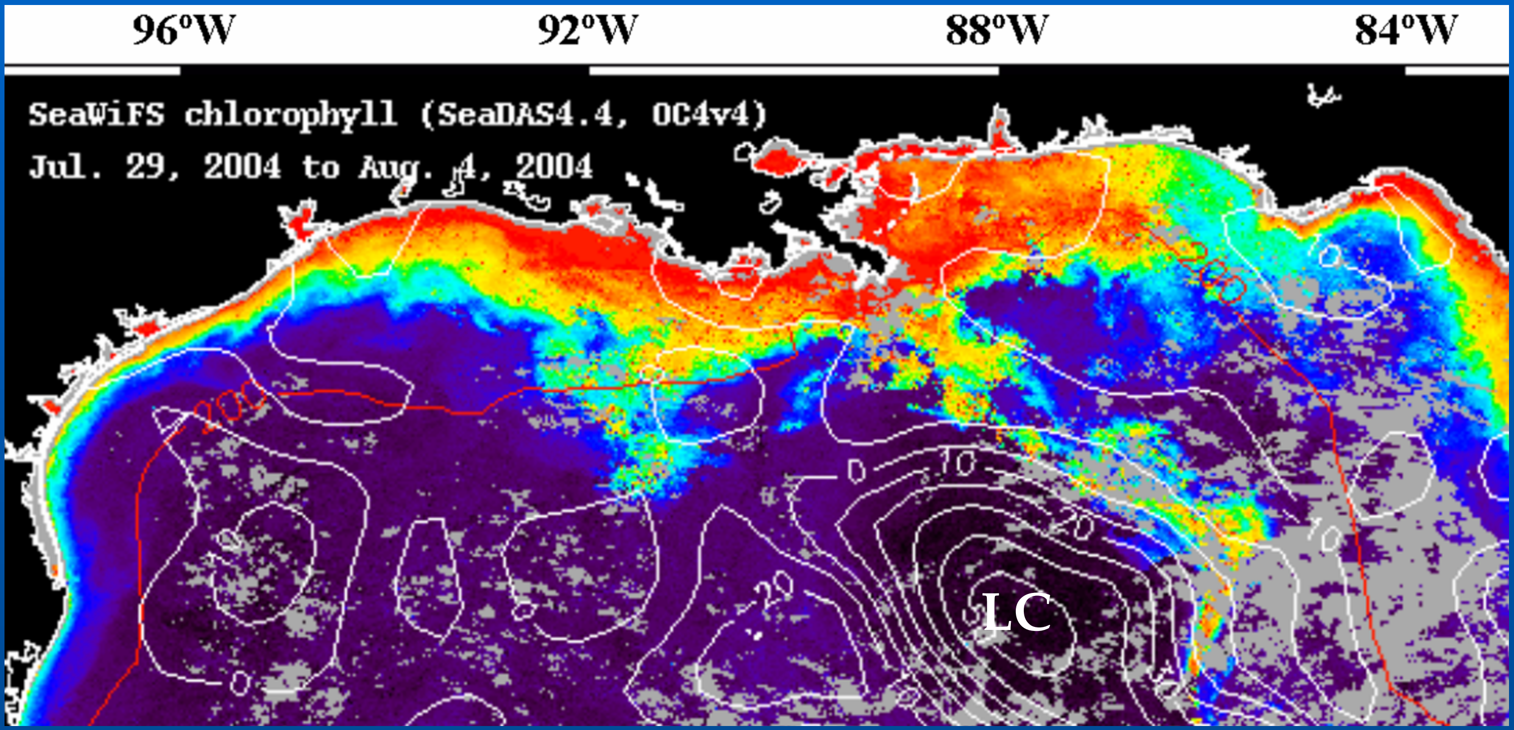


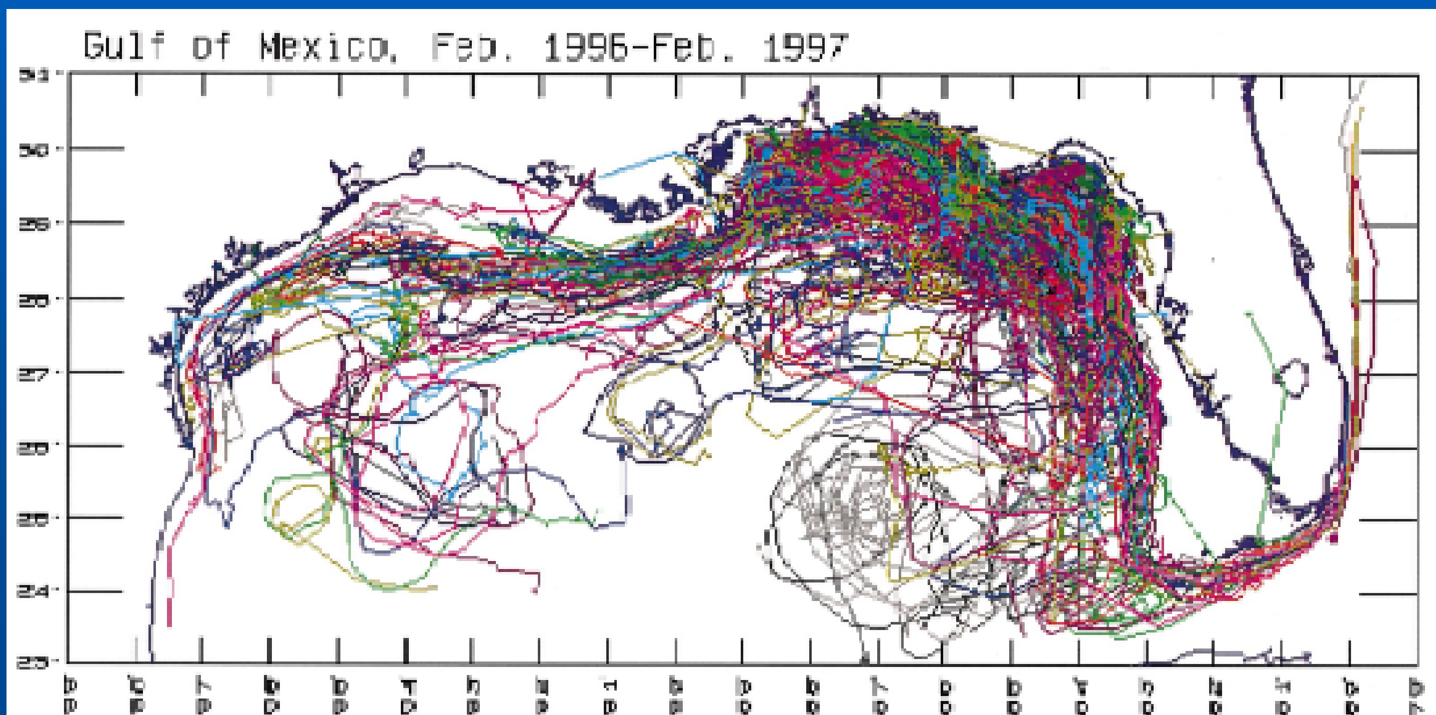
Figure courtesy of Hu et al.

Substantial amount of low salinity, high chlorophyll Mississippi River water can be entrained and transported clockwise and off margin into the deep water

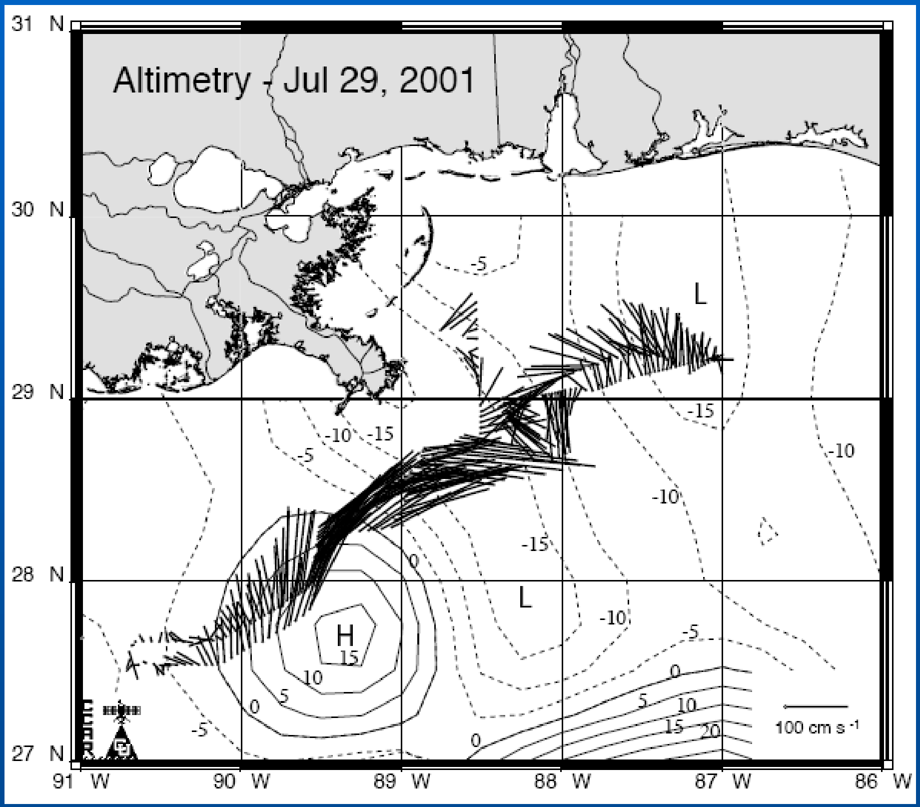
Example 1

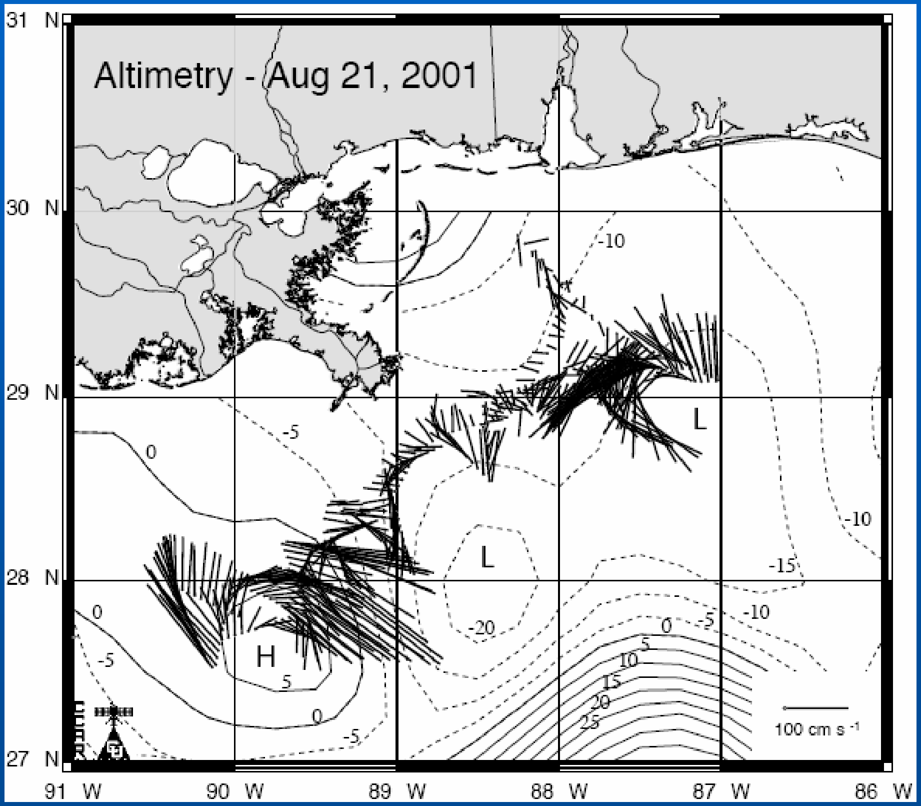
Ortner el al. (1995) provided convincing evidence of entrainment of Mississippi River water into the Gulf of Mexico LC and subsequent transport through the Florida Straits and along the U.S. east coast on the shoreward side of the GS.

Example 2



Eddy forced Variation in on- and off- margin circulation in the Northern GOM





Figures Adopted from Biggs et al., (2005)

2.3. Coastal Circulations in the western Gulf

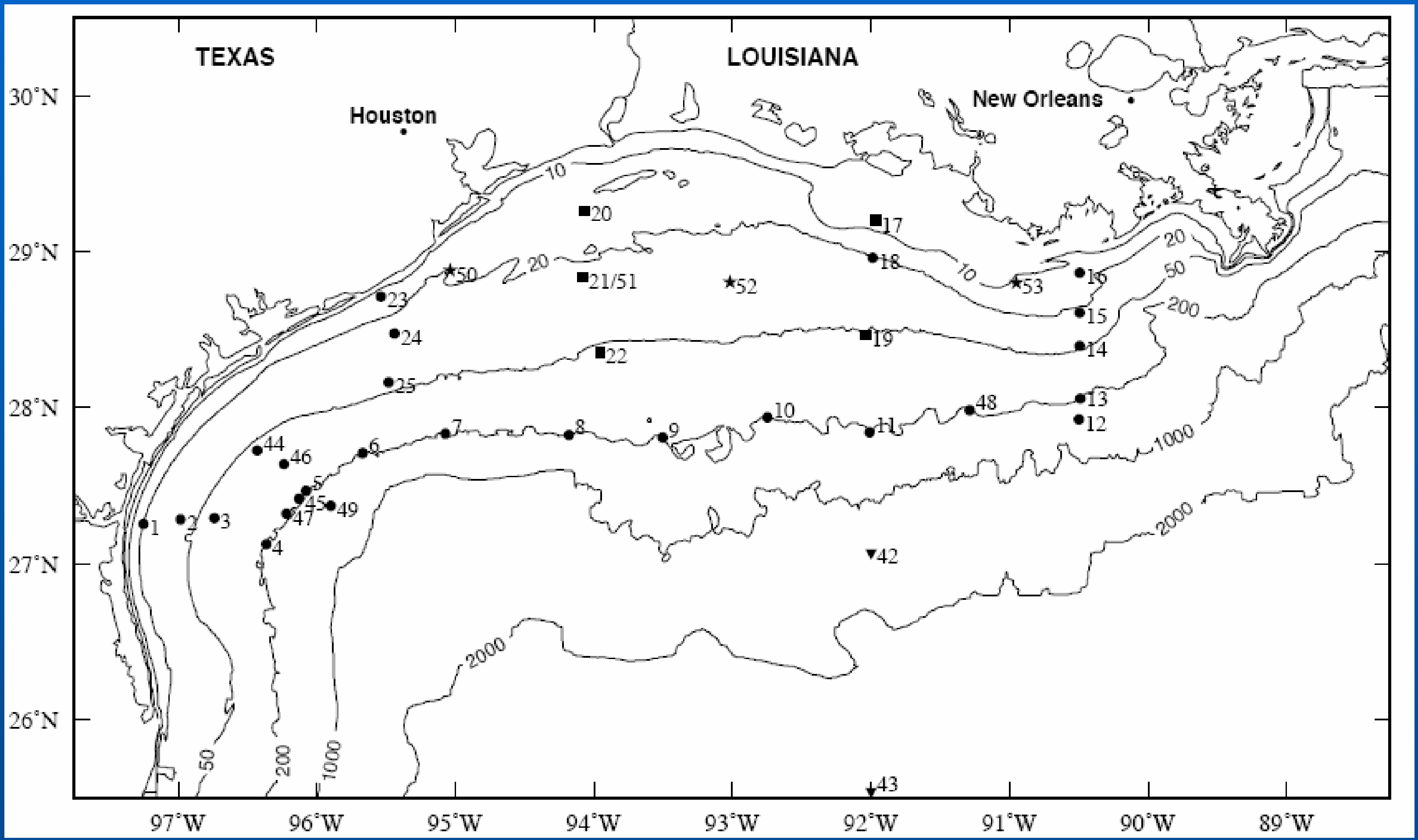


Figure adopted from Nowlin et al. (2005)

Currents over the inner shelf are upcoast (eastward) in summer and downcoast (westward) in nonsummer and are driven by an annual cycle of winds. Currents over the out shelf are variable, but predominantly upcoast throughout the year, probably a result of the integrated effects of anticyclonic eddies impinging on the shelf edge.

Non- Summer

Summer

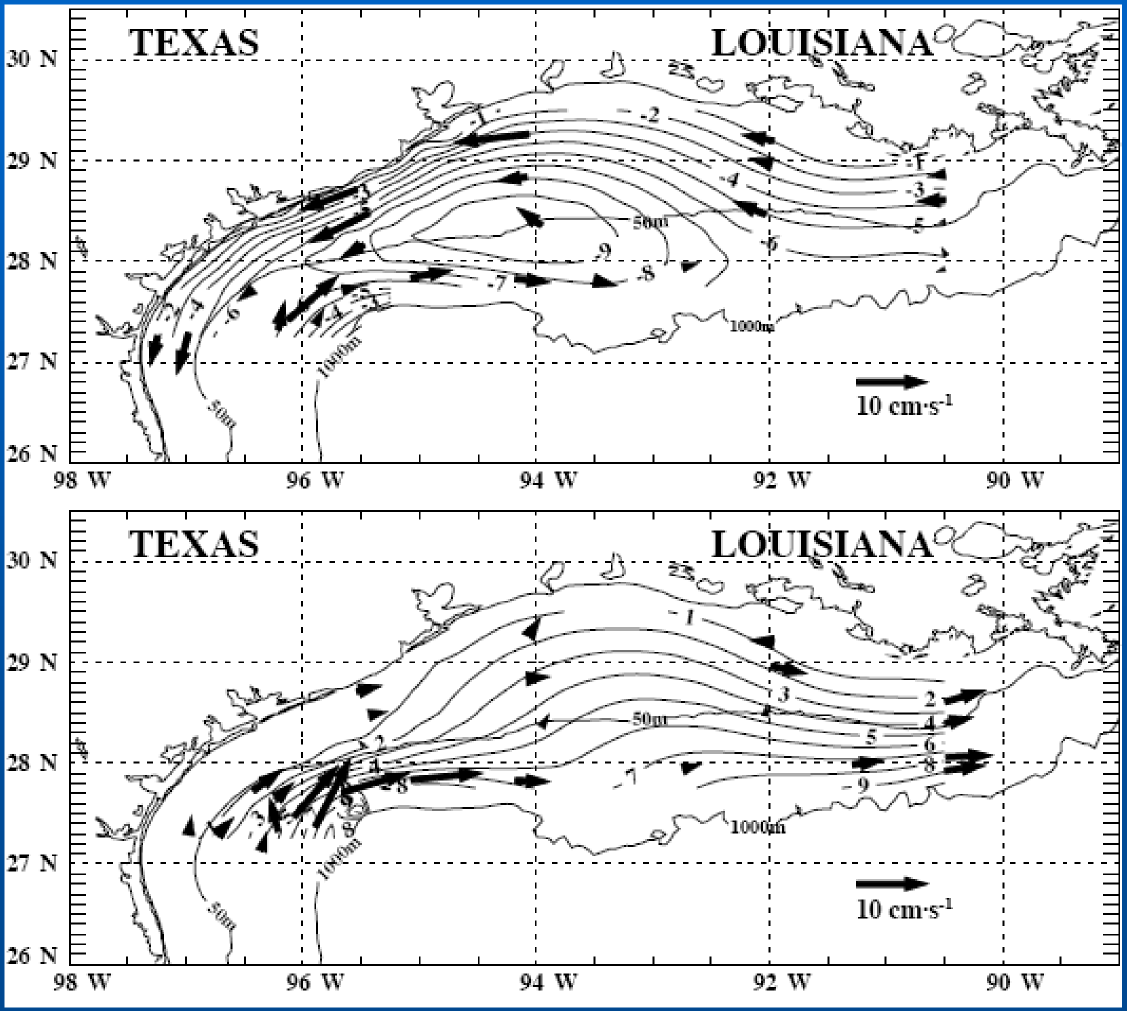


Figure adopted from Chao et al. (1998)

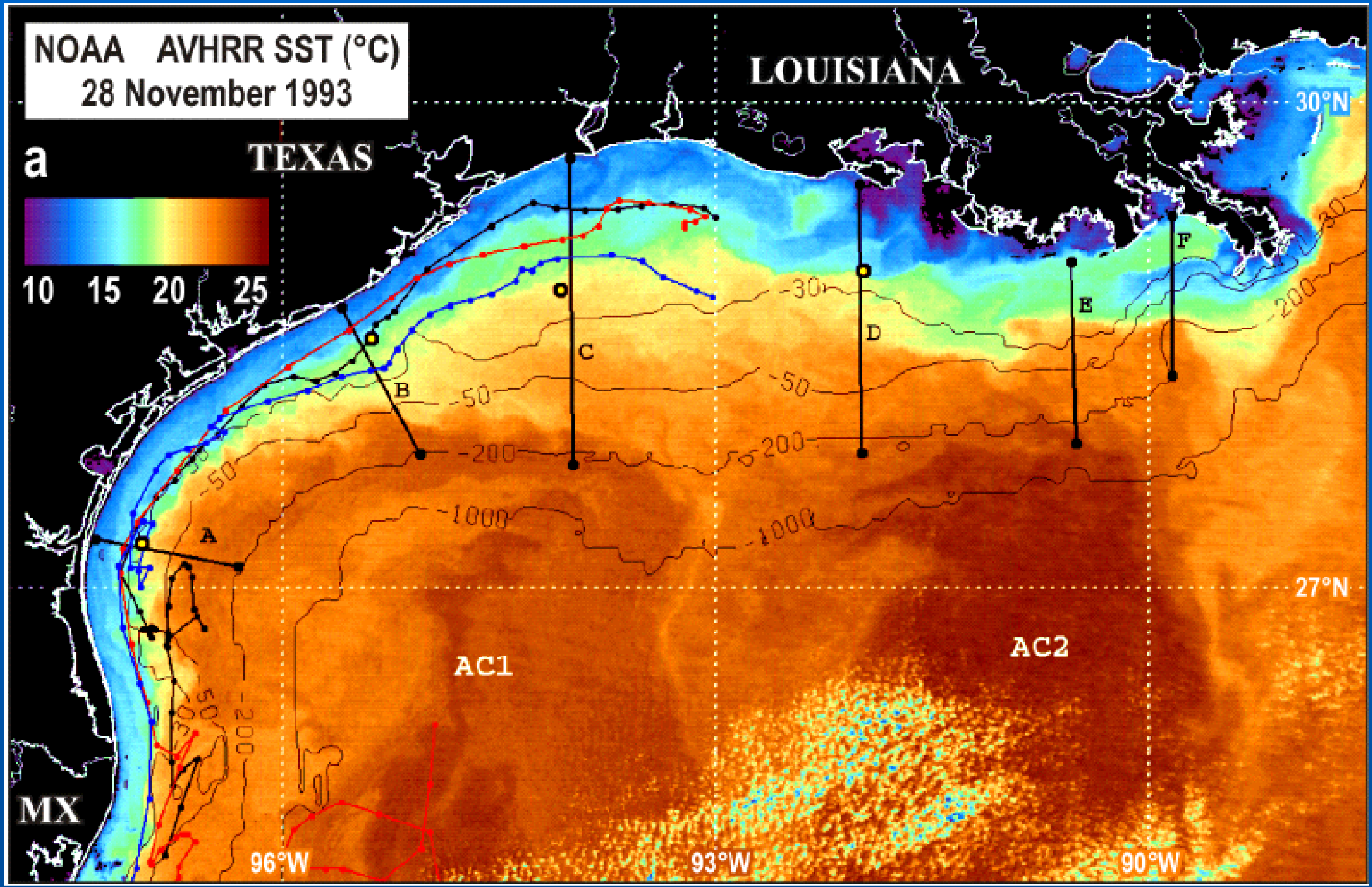


Figure 3. NOAA AVHRR SST imagery acquired on a) 28 November 1993 and b) 4 January 1994. Locations of profile lines A-F; LATEX-A current meter moorings (yellow-black dots); daily positions of three SCULP drifters in the coastal current; and AC1 and AC2 are shown.

Figure adopted from Walker (2005)

Summary

1. General circulation in the GOM

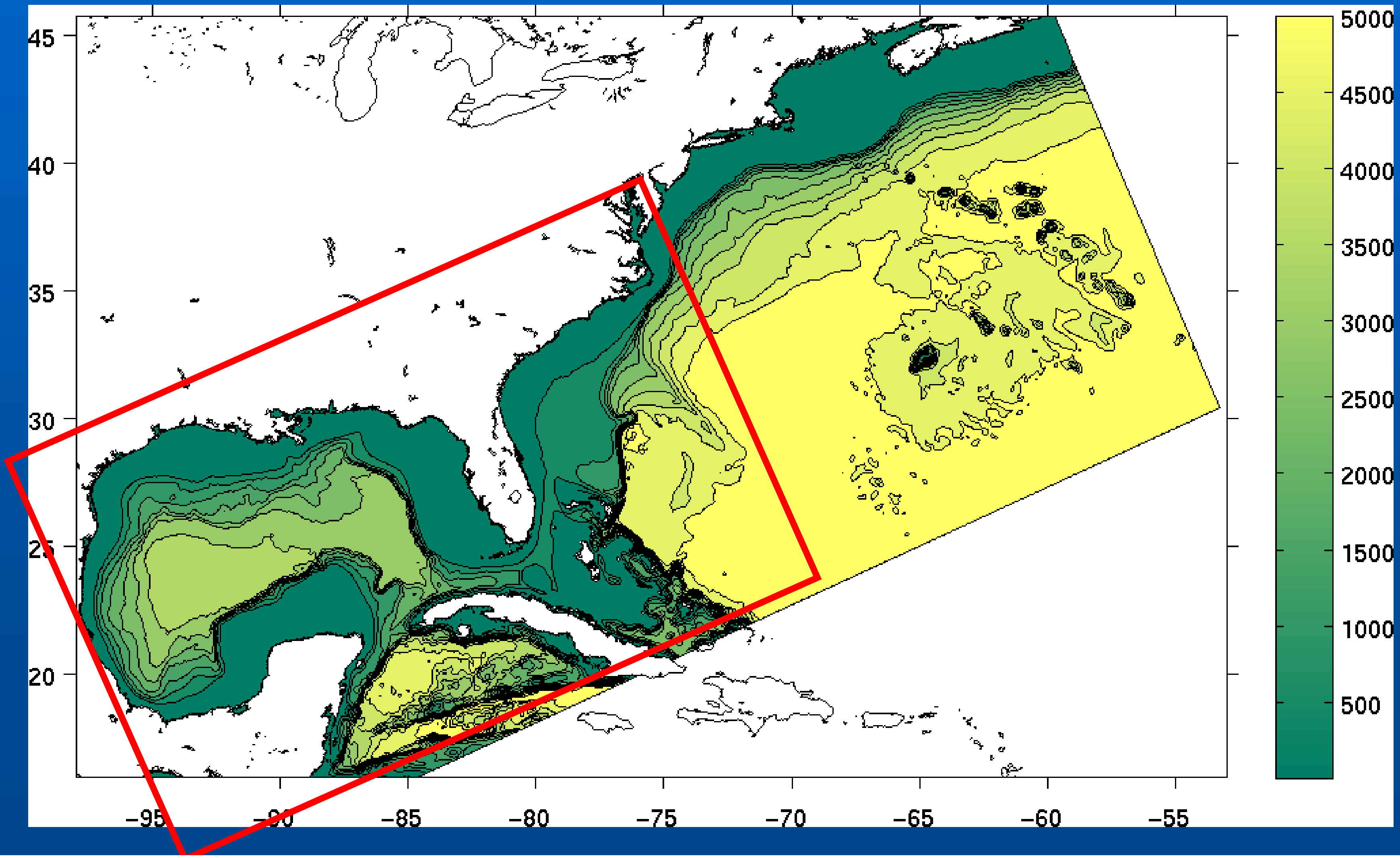
    1.1. The loop current and Eddy Shedding
    (major circulation feature of GOM, irregular shedding interval)
    1.2. Upstream conditions
    (45% of S Atlantic and 55% North Atlantic origins; LC extension and deep transport back to Caribbean Sea are highly correlated)
    1.3. Surface flow in the central and northwestern Gulf (Anticyclonic)
    1.4. flow in the Bay of Campeche (Cyclonic)
    1.5. Deep circulation in the Gulf (Cyclonic)

2. Coastal circulation

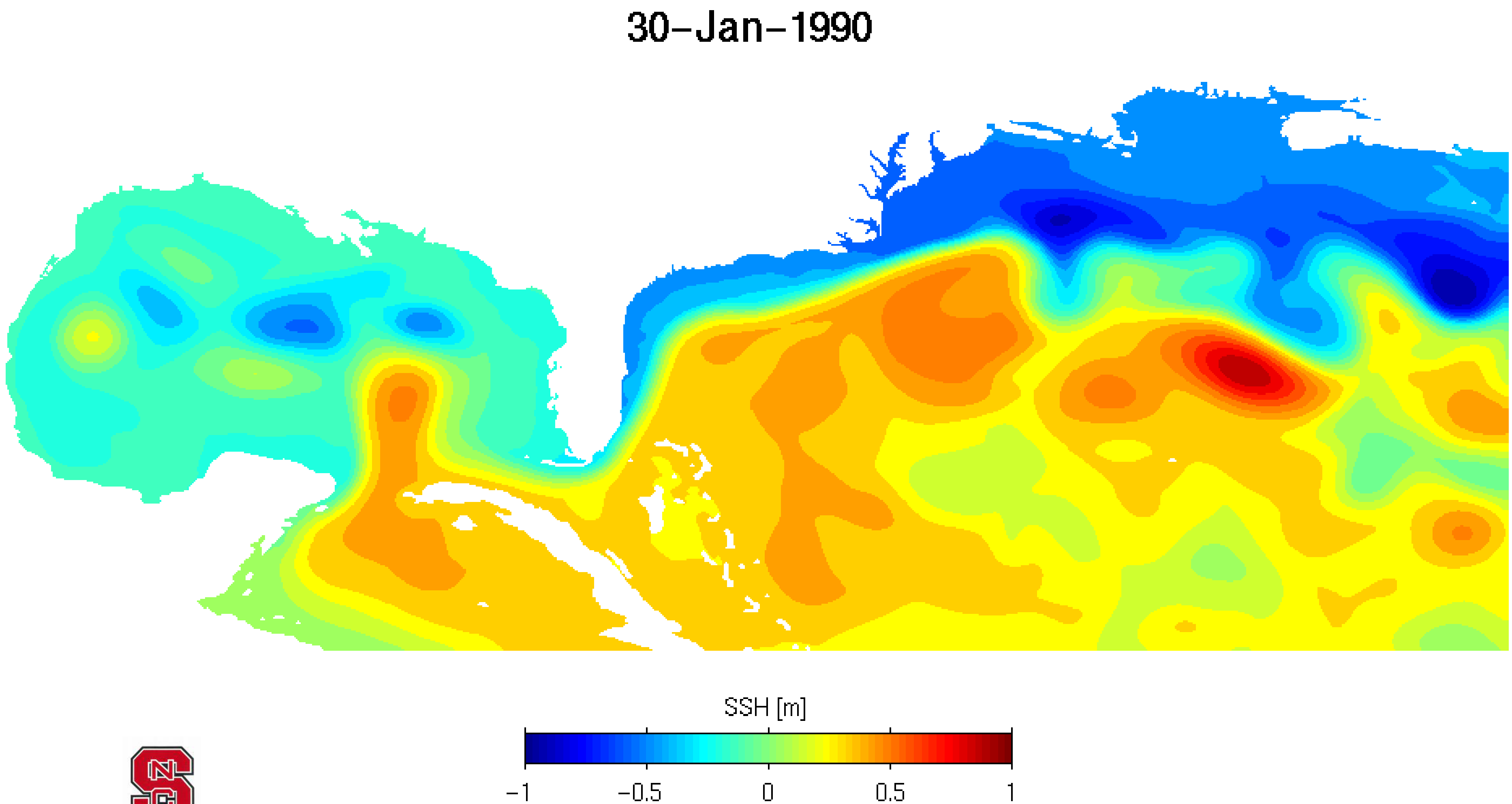
    2.1. Coastal Circulation in the Eastern Gulf
    (wide shelf, Local forcing dominates inner and mid-shelf circulation; LC influence on WFS has 2 types)
    2.2. Coastal Circulation in the Northern Gulf
    (River influx, narrow shelf, strong eddy forcing)
    2.3. Coastal Circulation in the Western Gulf
    (Currents over the inner shelf are eastward/upcoast in summer and westward/downcoast in nonsummer and are driven by an annual cycle of winds)

Research Tool: Nested Modeling Approach for studying coupled physical-biogeochemical processes

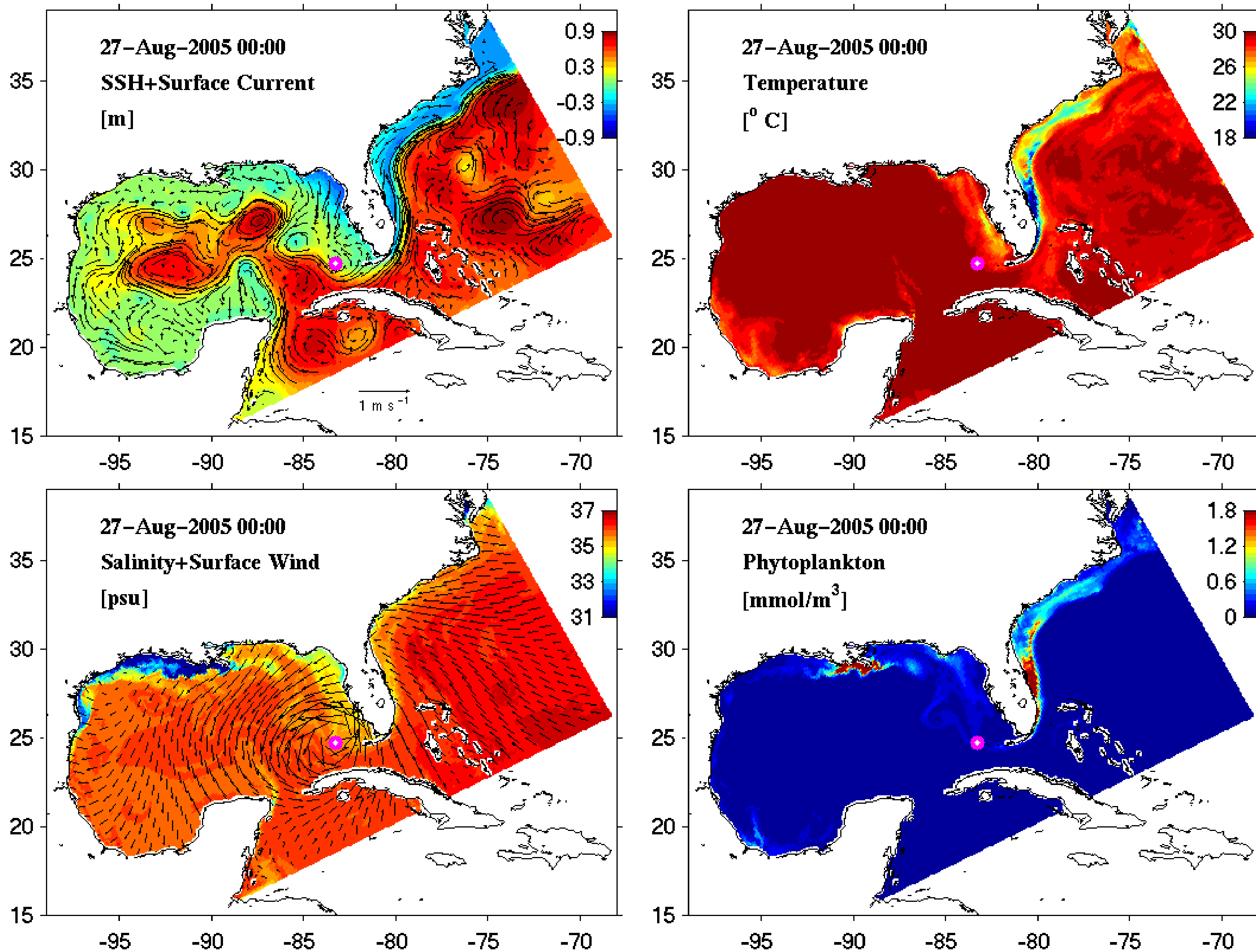
US East Coast - Gulf Mexico Domain (10 km) nested inside global circulation model
South Atlantic Bight and GOM domain (5 km) nested inside USeast/GOM model

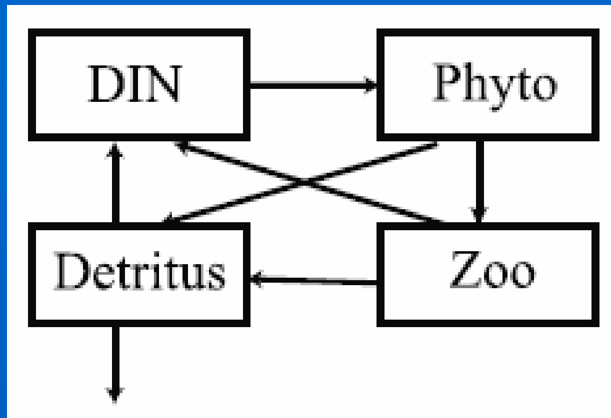


US East Coast and GOM Circulation Hindcast (1990 – 2006)

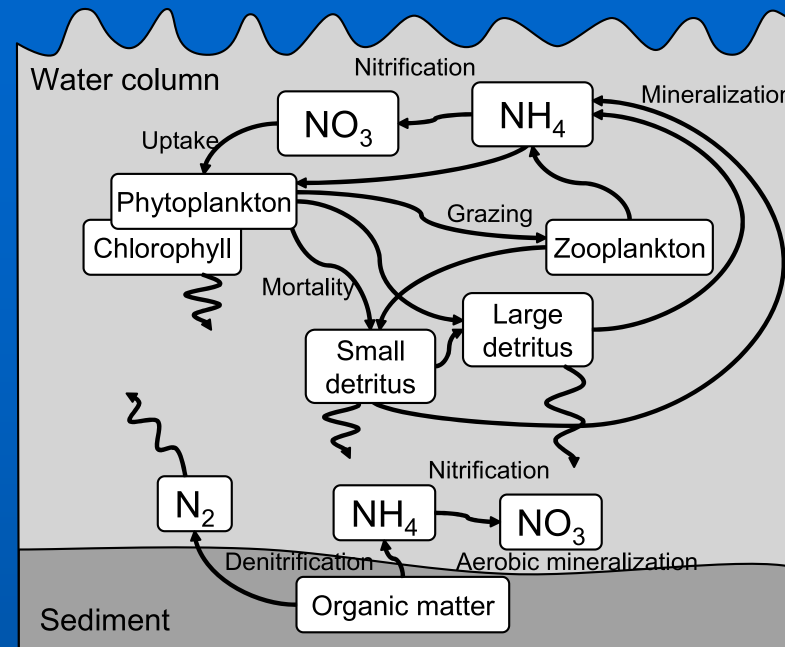


SABGOM Model Hindcast of Ocean Response to Katrina

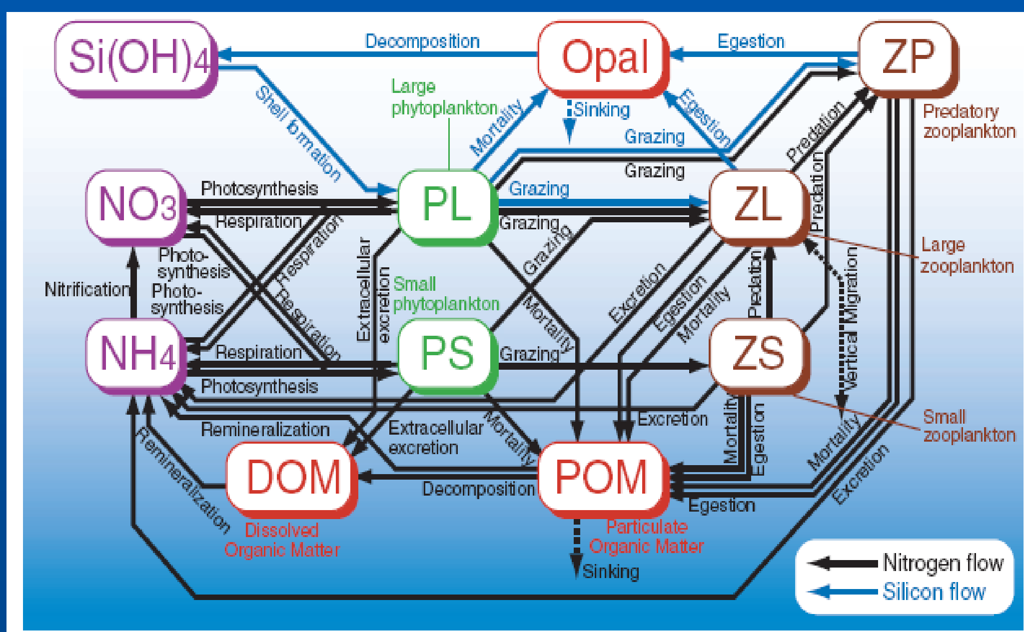




Denman and Pena (1999)



Fennel et al. (2006)



Kishi et al. (2007)