Physical Processes of the northern Gulf of Mexico and their influence on Hypoxia of the Texas-Louisiana Shelf

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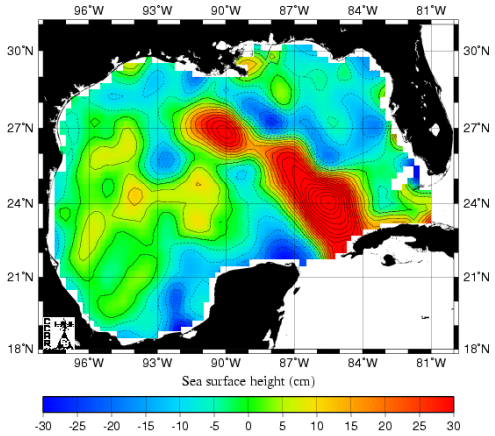
Hypoxia in the Northern Gulf of Mexico
EPA Science Advisory Board - Hypoxia Advisory Panel Meeting
7 December 2006 * Doubletree Hotel, Washington DC

Outline

- General Circulation
- Physical Forcing Processes
- Relationships to Hypoxia
  - Physical processes affecting hypoxia
  - Spring/Summer of 2004 and 2005

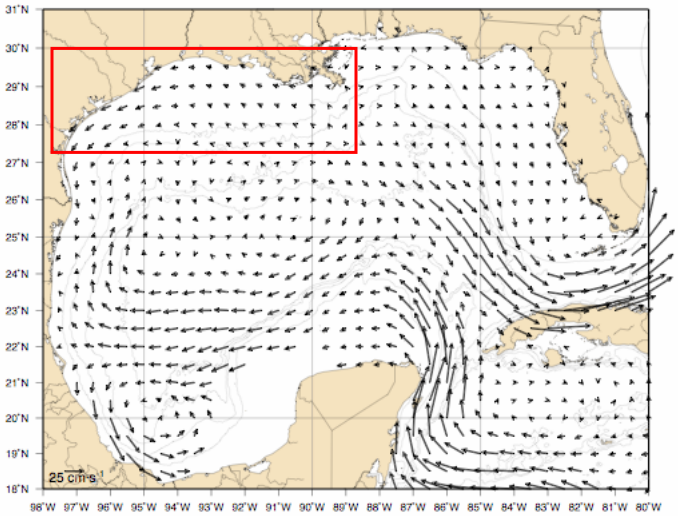
Large Scale Circulation Features of the Gulf of Mexico

Real-Time Mesoscale Altimetry - Apr 24, 2006



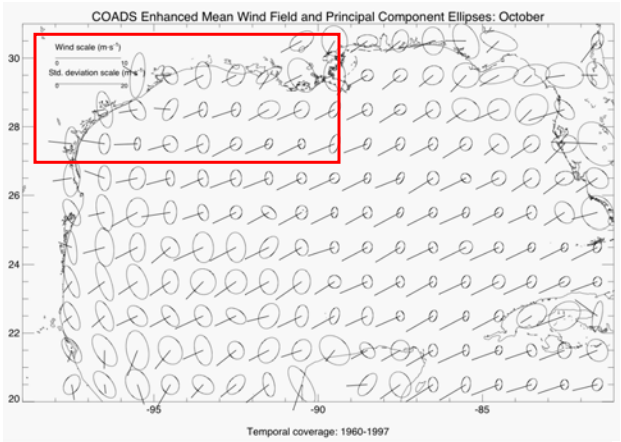
Gulf of Mexico Circulation

from surface drifters 1989-1999



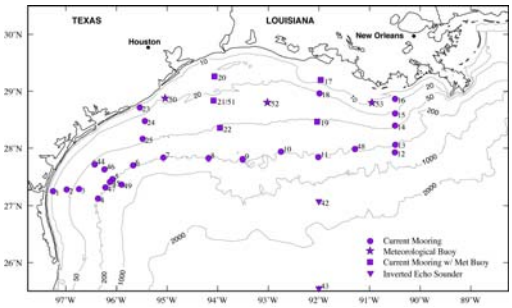
DiMarco et al. 2005

Wind Climatology (COADS Enhanced)

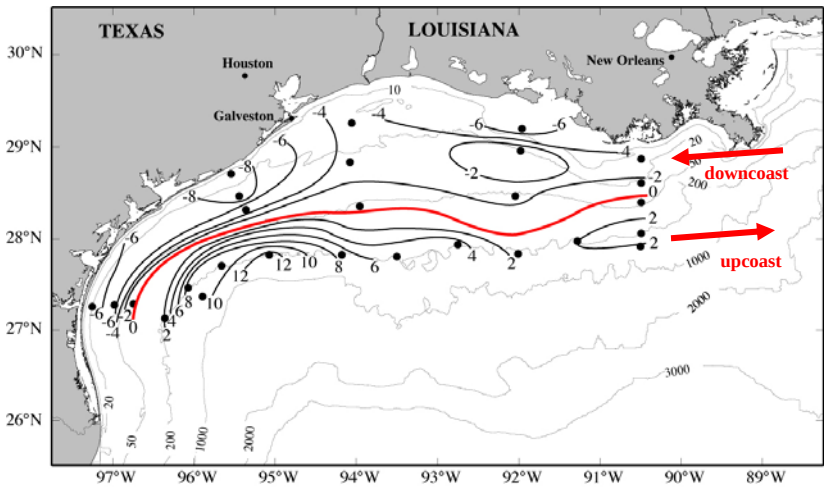


Circulation of the Texas-Louisiana Shelf

Mean Circulation from LATEX-A Observations

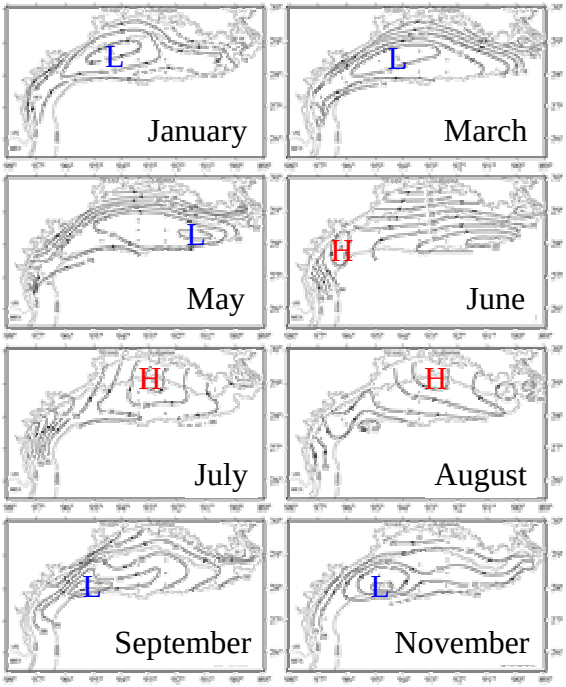


Record-length 10-m alongshelf velocity components



From Nowlin, Jochens, DiMarco, Reid, and Howard (2005)

Quasi-annual Seasonal Variability

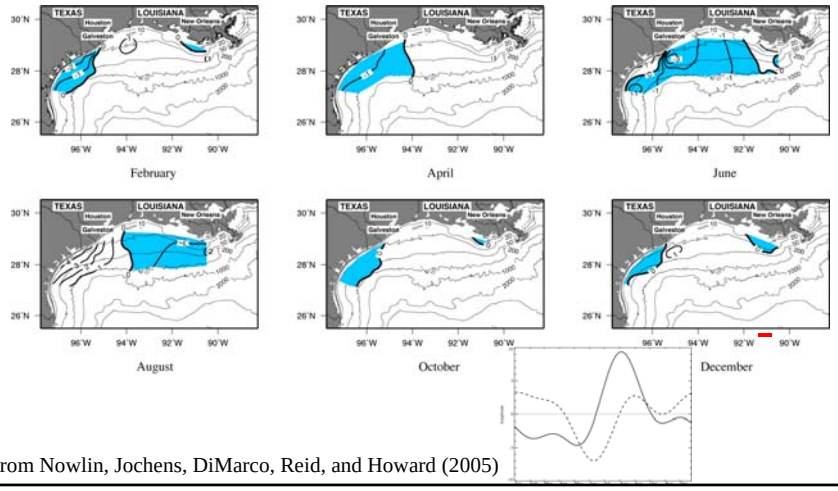


Low frequency Circulation of Texas-Louisiana Shelf

Cochrane-Kelly Scheme (JGR 1986)

- Based on hydrography
- Seasonal reversal of coastal current in June/July
- Non-summer pattern Sept thru May (downcoast)

Monthly average salinity anomaly fields: combined EOF modes 1 and 2 for the annual signal of salinity



From Nowlin, Jochens, DiMarco, Reid, and Howard (2005)

Hydrography of the Louisiana Bight

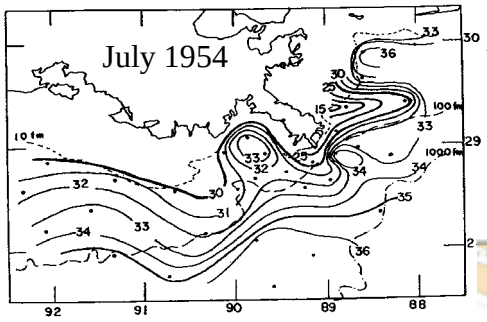
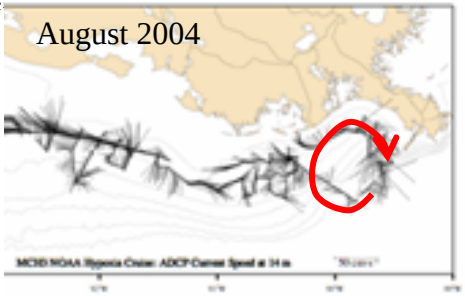


Fig. 1. Surface salinity (‰) of the Cruise 54-9 in July, 1954.

Anticyclonic Gyre (Ichiya 1962)

- Quasi-permanent
- Wind dependent
  - DW: Intensifies
  - UW: weakens/moves seaward



Shipboard ADCP
(DiMarco)

Mississippi-Atchafalaya Rivers mean annual discharge

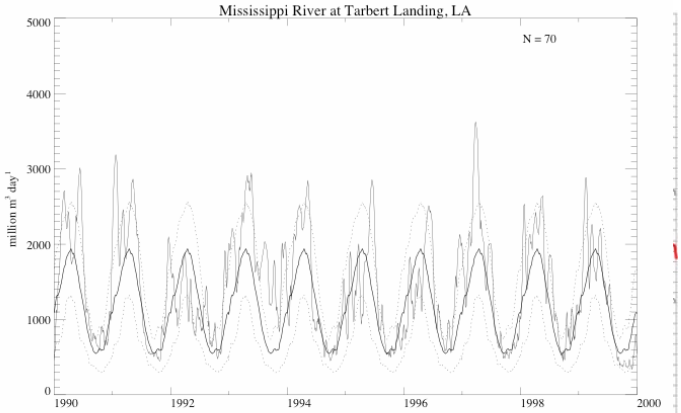


Fig. 3. Ten-year record (1990-1999) of flow in the Mississippi River at Tarbert Landing, LA. The actual flow is superimposed on the 70-year mean flow and the standard deviation about the mean.

Ratio: Atchafalaya to Atchafalaya + Mississippi River

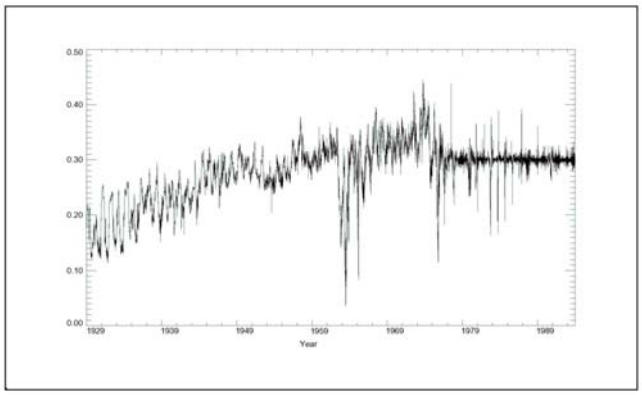


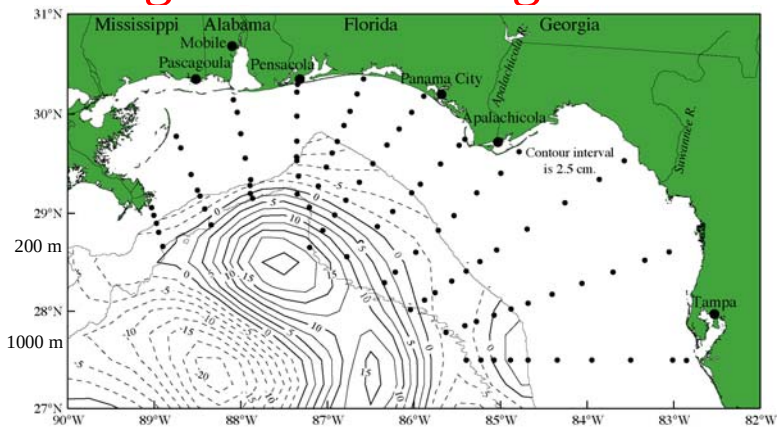
Figure 2.3-2. Long-term time series of the ratio of Atchafalaya River discharge to the combined Mississippi-Atchafalaya River discharge.

From Nowlin et al. (1998)

Freshwater Budget

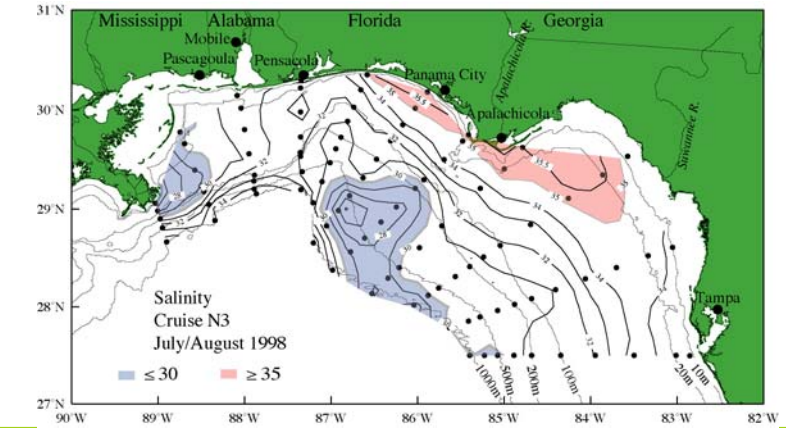
- Dinnel and Wiseman (1986)
  - 53% ± 10% of Mississippi outflow goes west
  - Remainder goes east and offshore
- Etter et al. (2004)
  - Revisited Dinnel and Wiseman estimate using LATEX data
  - 43% goes west
- The freshwater contributions to the Texas-Louisiana Shelf from the Mississippi (0.43 x 0.70 = 0.3) and Atchafalaya Rivers (0.3) are roughly equal

Sea surface height field for 5 August 1998 during cruise N3



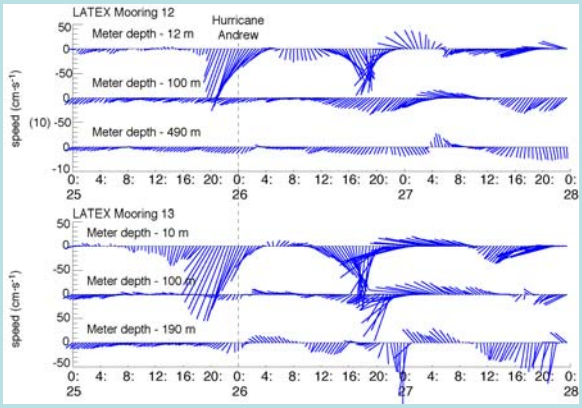
From Jochens et al. (2002)

Salinity at ~3.5 m depth in July/August 1998



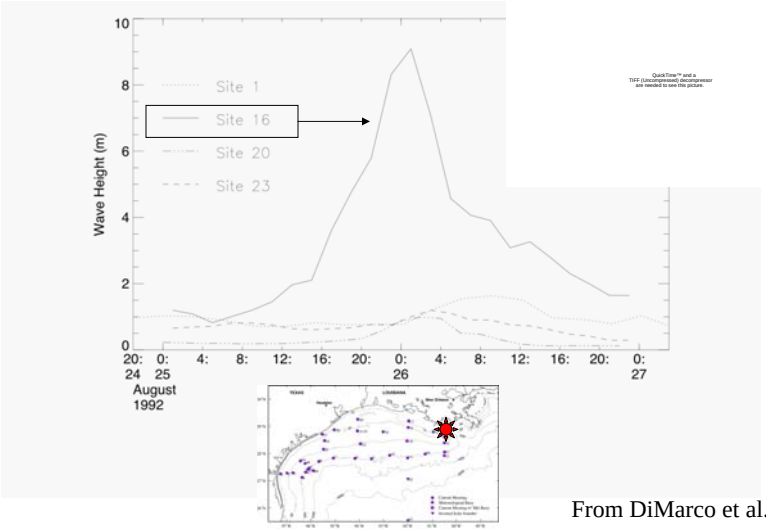
From Jochens et al. (2002)

Hurricane Andrew



Horizontal current vectors during late August 1992 from two locations off Louisiana at approximately 90.5°W on the shelf edge and upper slope. **Hurricane**

Hurricane Andrew Waves



From DiMarco et al. (1995)

Tidal Currents on the Texas-Louisiana Shelf

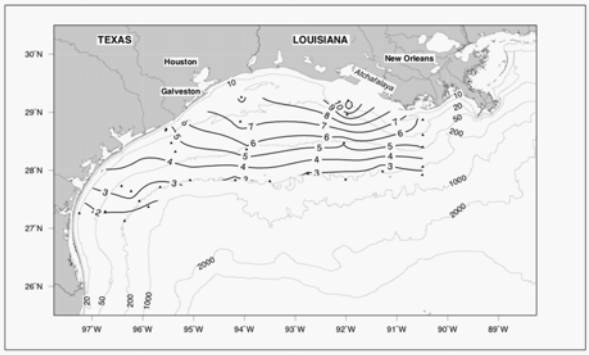


Figure 16. Contour of root mean square of maximum amplitudes of eight principal tidal current constituents for upper current meters. Triangles represent current meter locations. Contour interval is 1 cm s.$^{-1}$

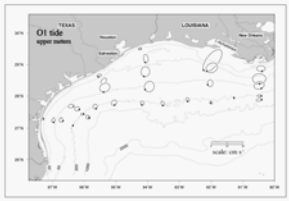


Figure 9. Mean O1 tidal current ellipses during the period April 1992 to December 1994 for upper current meters showing orientation of tidal current vectors at 0000 UTC 7 April 1992 (dot) and least squares error estimate (shaded).

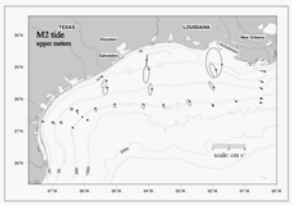
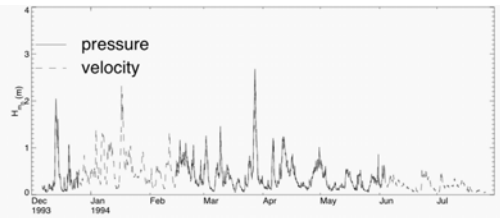
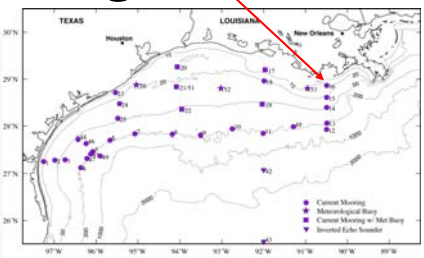


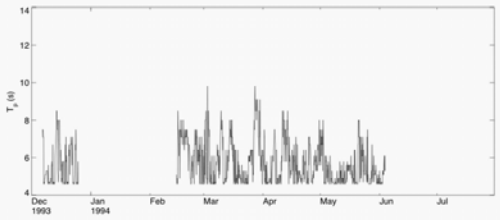
Figure 4. Mean M2 tidal current ellipses during the period April 1992 to December 1994 for upper current meters showing orientation of tidal current vectors at 0000 UTC 7 April 1992 (dot) and least squares error estimate (shaded).

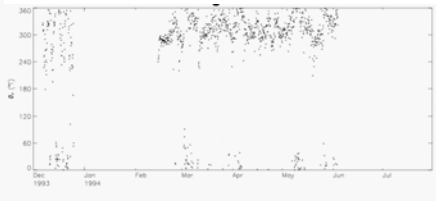
From DiMarco et al. (1998)

Wave Climatology LATEX Mooring 16



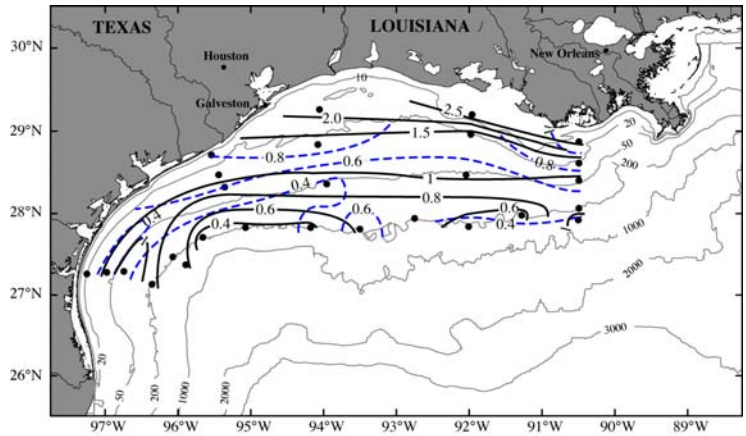






From DiMarco et al. (1996)

Ratio of weather-band to mesoscale KE from 10 m currents at locations shown. Non-summer = solid lines; summer = dashed lines.



From Nowlin, Jochens, DiMarco, Reid, and Howard (2005)

Estimates of temporal scales as function of water depth for 10-m instruments

Isobath	Alongshelf V days	Cross-shelf V days	Salinity days	Temperature days
10 m	4	3	10	22
20 m	5	6	17	44
50 m	7	5	20	27
200 m	19	9	27	28
500 m	30	21	30	24

- Scales increase from inshore to offshore
- Inshore scales in weather band (wind forcing)
- Temperature scales driven by mesoscale

From Nowlin, Jochens, DiMarco, Reid, and Howard (2005)

Spatial Scales

- Based on anomaly fields of salinity, temperature, density
- Multiple years, multiple cruises
- LATEX Spatial scales (Li et al. 1996)
  - Cross-shelf scales of eastern/central shelf
    - 20 km
  - Along-shelf scales (50 and 200 m isobath)
    - 35 km
- Mississippi-Alabama Shelf (DiMarco et al 2006)
  - Cross-shelf scale: 5-10 km

General circulation: summary

- **Along-shelf component of wind**
  - Generally downcoast in non-summer (Sept.-May)
  - Episodes of upcoast winds begin in May off Mexico
  - The transition proceeds northward and eastward
  - Generally upcoast in summer (June - August)
  - Transition to downcoast wind begins in August
  - Complete in September
- **Summertime upcoast wind components**
  - Larger over the southwestern shelf
  - Decrease upcoast
  - Minimal off Louisiana

General circulation (continued)

- **Seasonal signal of currents over inner shelf**

  Downcoast flow during non-summer (September - May)

  Upcoast flow during summer

  Correlation with wind stress is positive, highly significant

- **Seasonal signal of currents over outer shelf**

  Masked by the effects of offshore eddies

Relationships to hypoxia

- General circulation pattern is favorable to the seasonal development of hypoxia in summer
  - Wind/current reversal
  - Weak winds
  - Low waves
  - Peak solar insolation
  - Pooling of freshwater

  All are factors that are favorable for sustaining stratification

During winter…

- Frequent storms
- Downwelling favorable winds
- Minimum solar insolation

Tend to favor the breakdown of stratification

Relating total river discharge to total area of hypoxia

Wiseman et al.,
J. Mar. Sys., 1997

$r^2 \sim 0.6$!

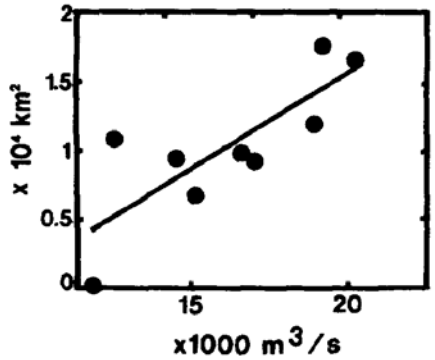
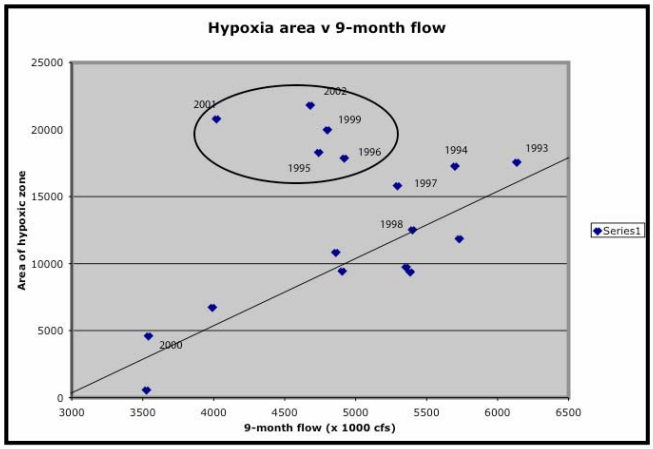
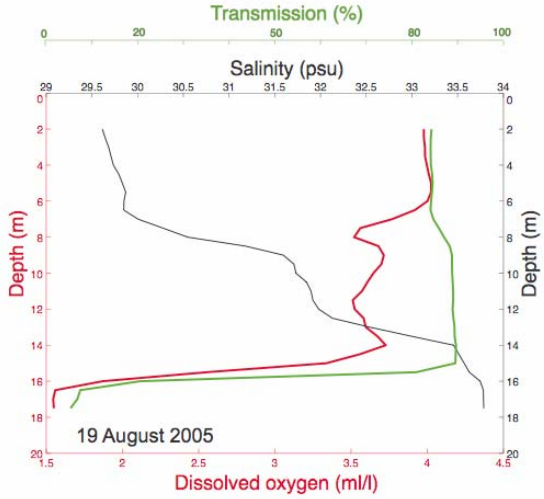


Fig. 10. Scatter plot of the observed area of mid-summer, near-bottom hypoxic waters against mean Mississippi River discharge for the preceding months of August through June. The R^2 of the least-squares fit is 0.934.

Mississippi River Discharge
Data from 1985-2002



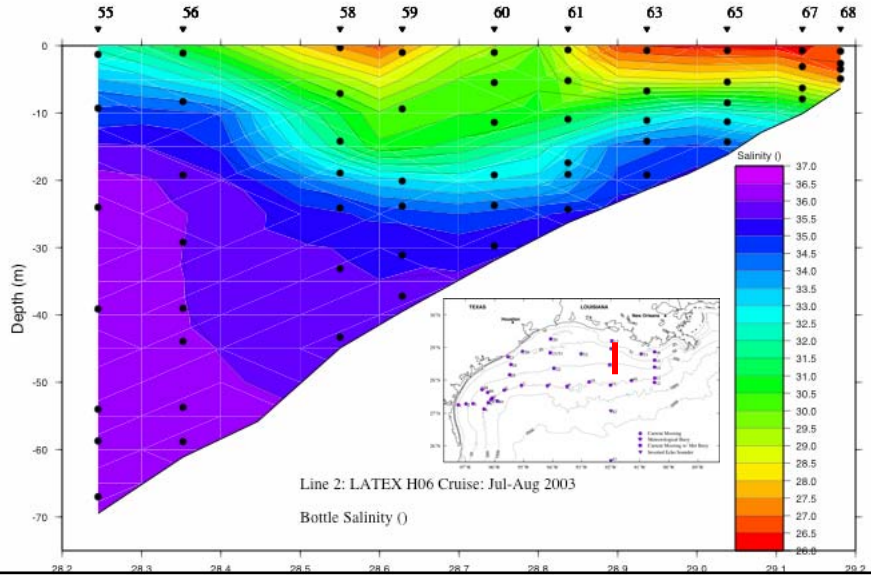
Typical Profile: South of Cameron, LA



LATEX H06: Jul 1993

Line 2 (92°W): Salinity

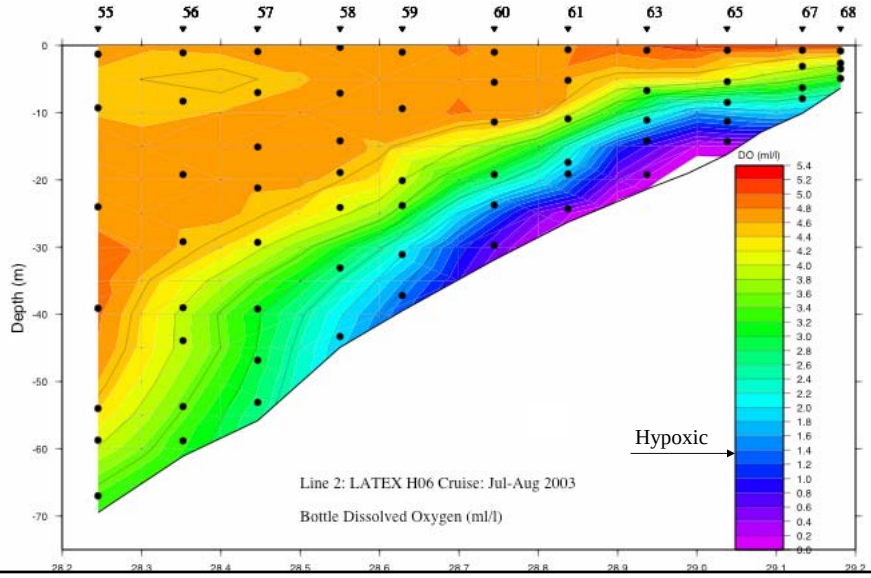
offshore inshore



LATEX H06: Jul 1993

Line 2 (92°W): Dissolved oxygen

offshore inshore



LATEX 1992-1994

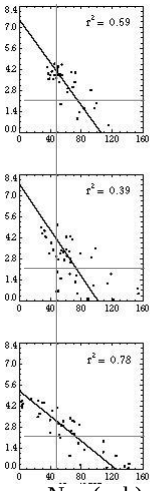
Summer

1992

1993

1994

O_b (ml/l)



Max. Brunt-Vaisala frequency versus bottom DO concentration

Measurements predominately in Zone C!

Bottom dissolved oxygen (O_b) versus the maximum Brunt Vaisala frequency (N_{max})

Belabassi, 2006

LATEX 1992-1994 N vs DOB

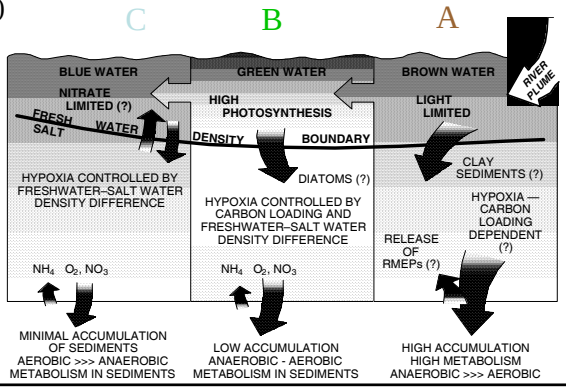
Stratification versus loading

- Fundamental issue: hypoxia requires respiration and stratification
- How to separate the two since river discharge provides freshwater that promotes stratification and nutrients that fuels production
- Not an easy question
- Starting point: hypotheses that are designed to quantify the relative affects of physical and biological processes (or at least to see how tightly *or loosely* they are coupled)

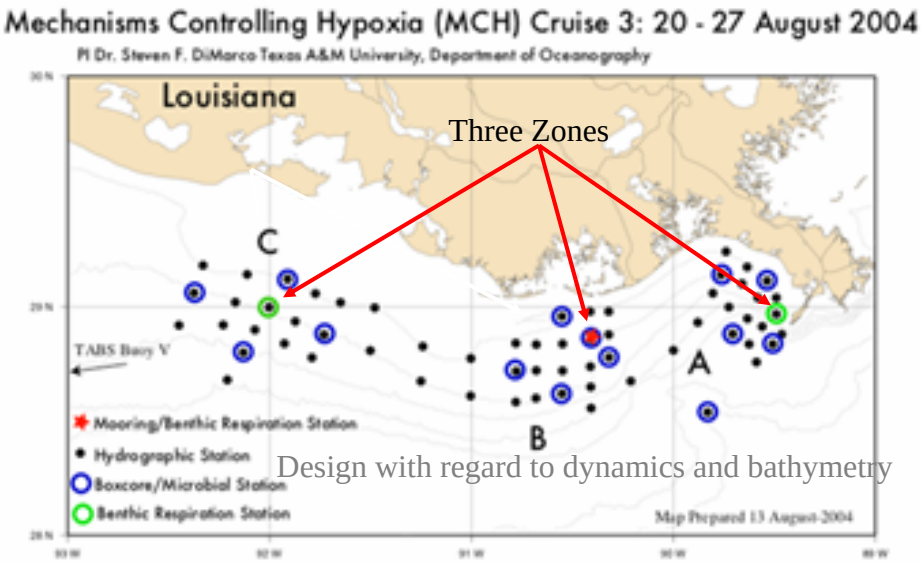
Central Hypothesis

in Rowe and Chapman 2003

- The region affected by hypoxia may be separated into zones controlled by distinct processes
  - Chemical (Zone A,Brown)
  - Biological (Zone B, Green)
  - Physical (Zone C, Blue)

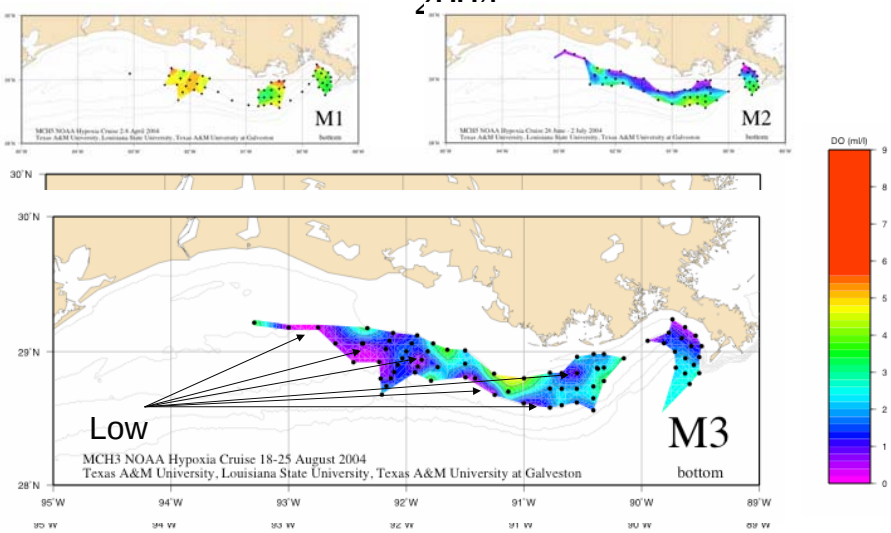


Typical Sampling Plan



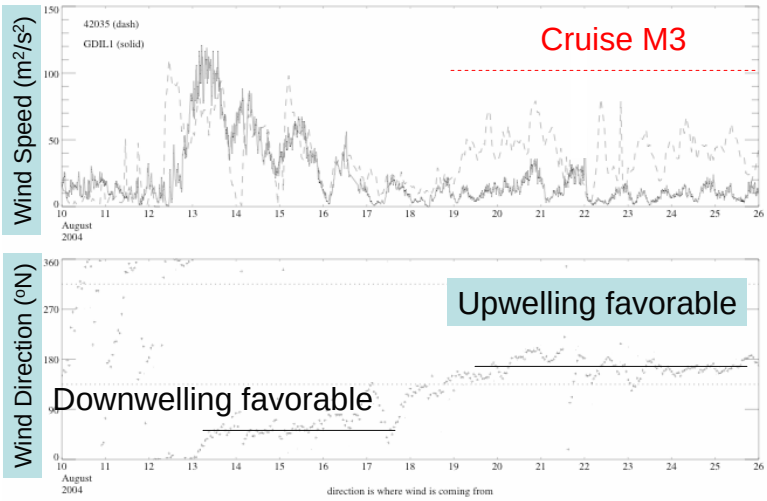
Design with regard to dynamics and bathymetry

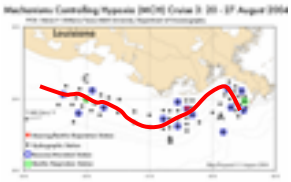
Bottom Dissolved Oxygen Concentration in 2004



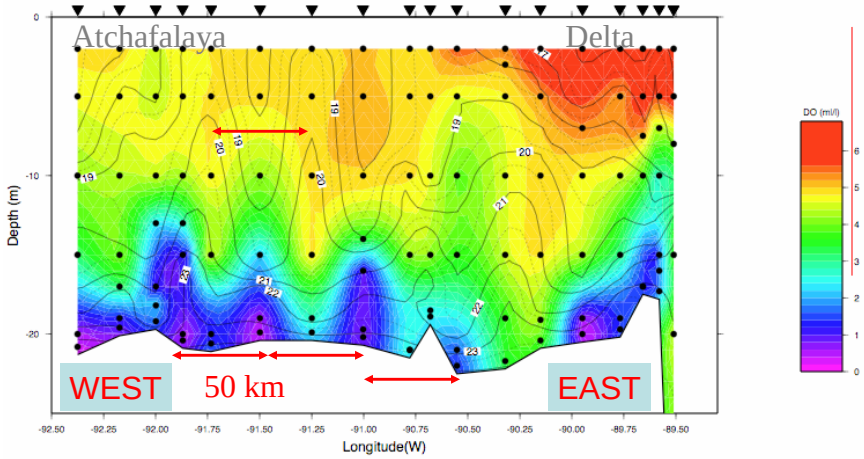
- Hypoxia moved offshore (relative to earlier cruises)
- Patchy bottom dissolved oxygen pattern

Winds at GDIL1 and 42035 August 2004



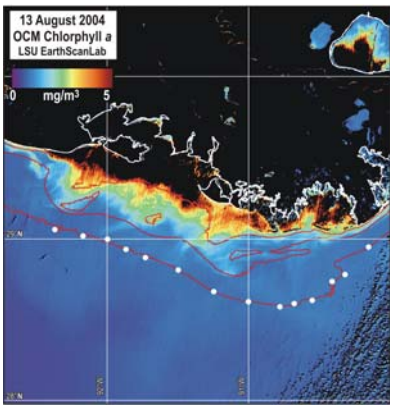


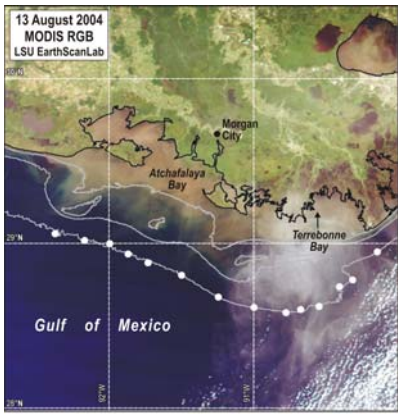
Vertical Section
20-m isobath
August 2004



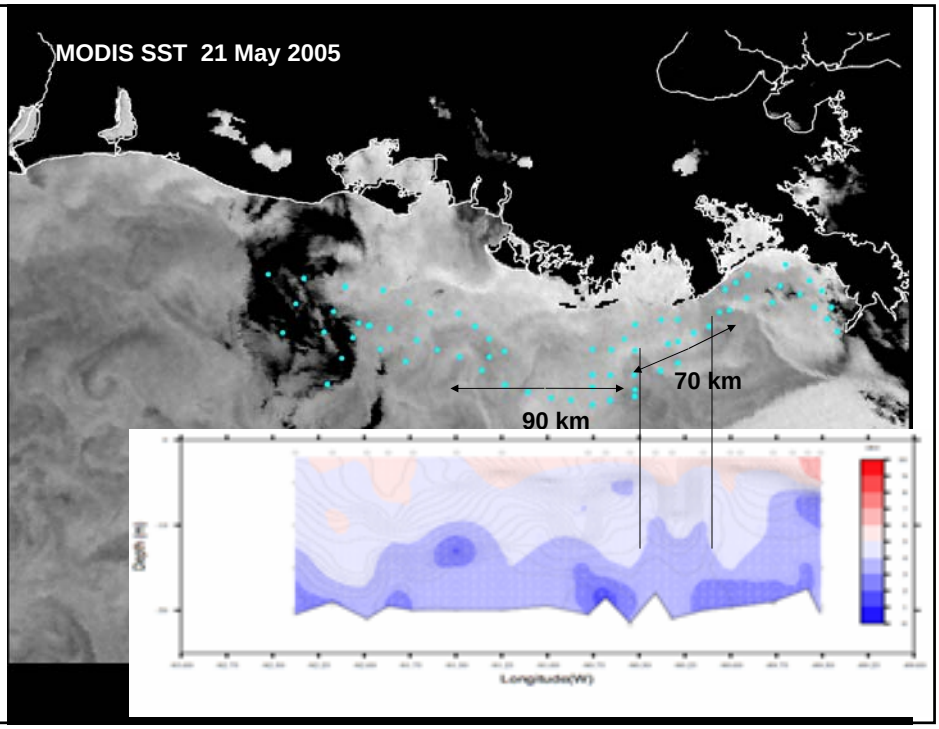
Remote sensing the Wave

13 Aug 2004



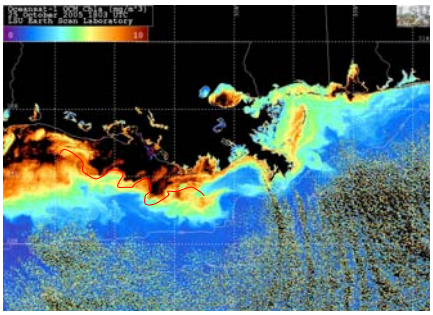


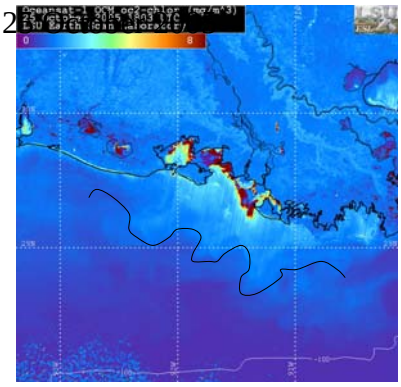
MODIS Terra-1 and OCM Chlorophyll a: N. Walker ESL-LSU



Other Waves

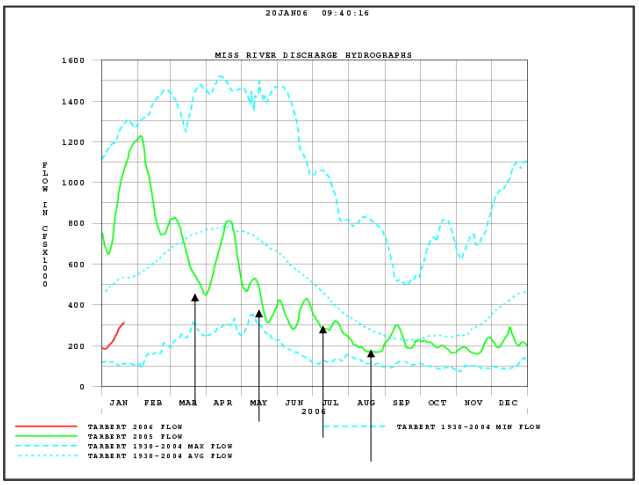
25 October 2005



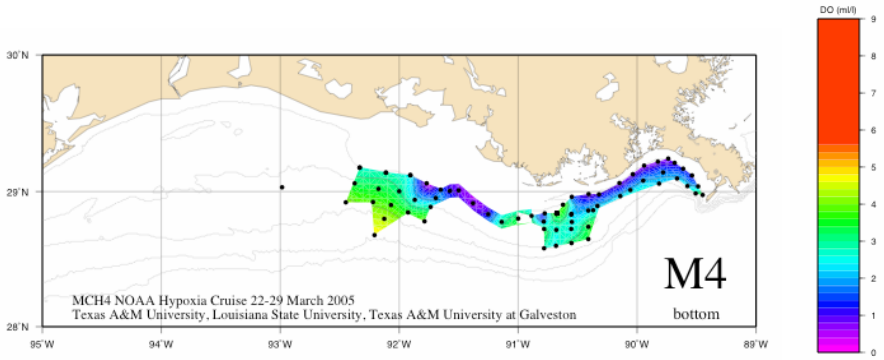


Oceansat-1 OCM Chl-a: Courtesy N. Walker LSU

2005 Field Year: Discharge

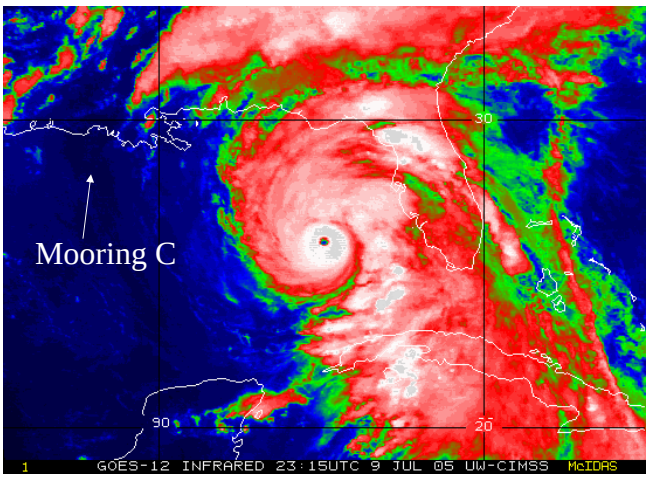


M4 Cruise (March 2005)

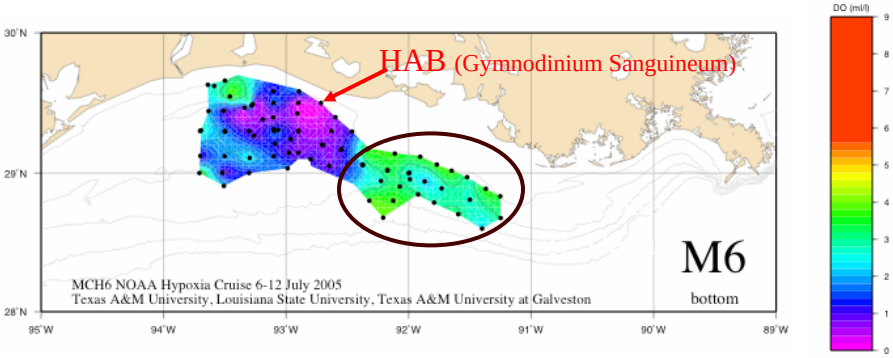


January peak river discharge
Early hypoxia formation

Hurricane Dennis: 9 July 2005



M6 Cruise (July 2005)



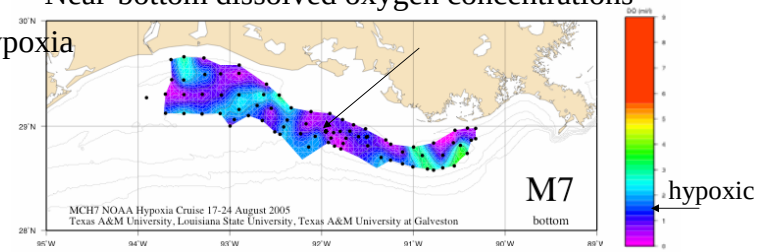
Eastern region (Zones A,B) aborted due to storms
HAB observed
2 other cruises in July by SEAMAP and Rabalais

M7 Cruise (August 2005)

Cruise ended 4 days before Katrina

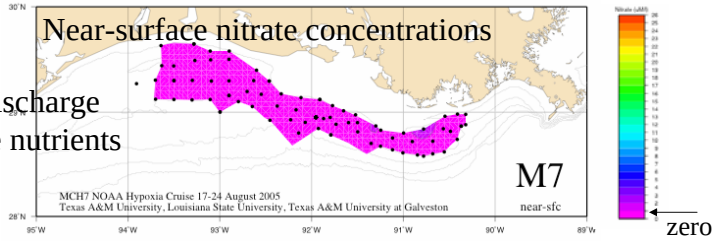
Near-bottom dissolved oxygen concentrations

Patchy Hypoxia

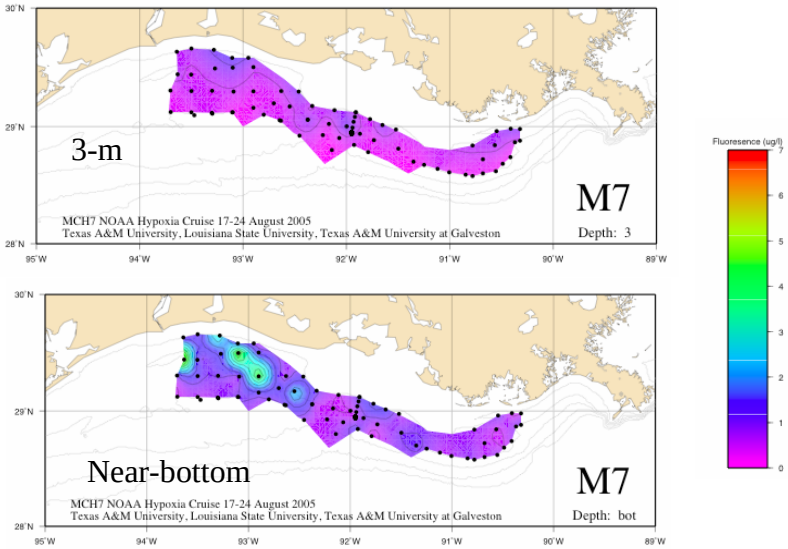


Near-surface nitrate concentrations

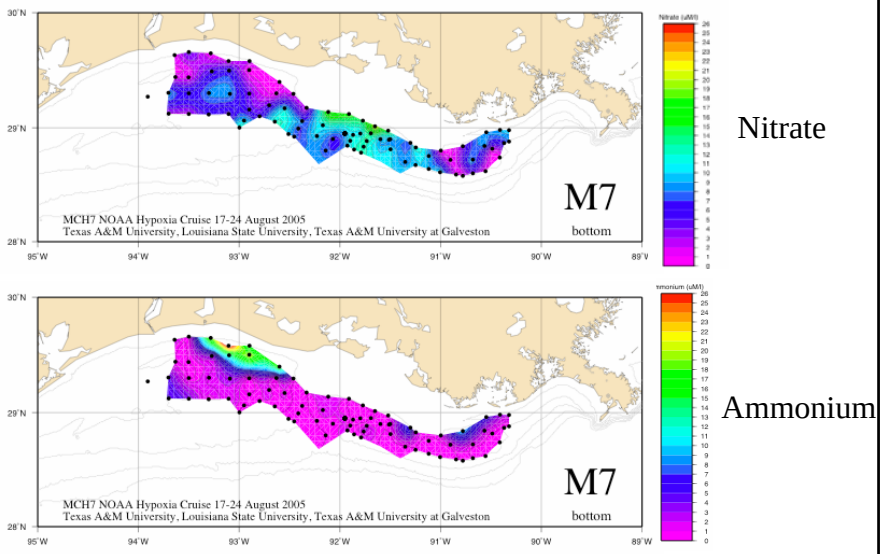
Low river discharge
Low surface nutrients



M7 Fluorometer



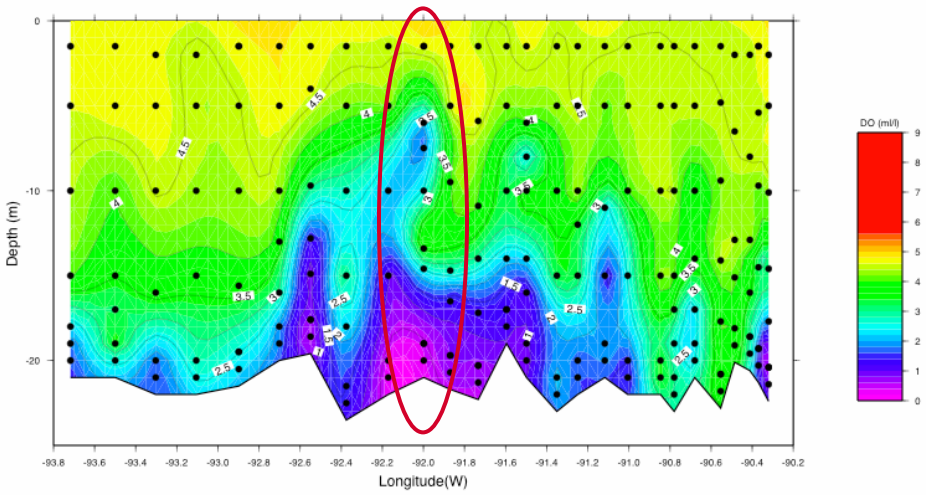
M7 Nitrate and Ammonium near-bottom



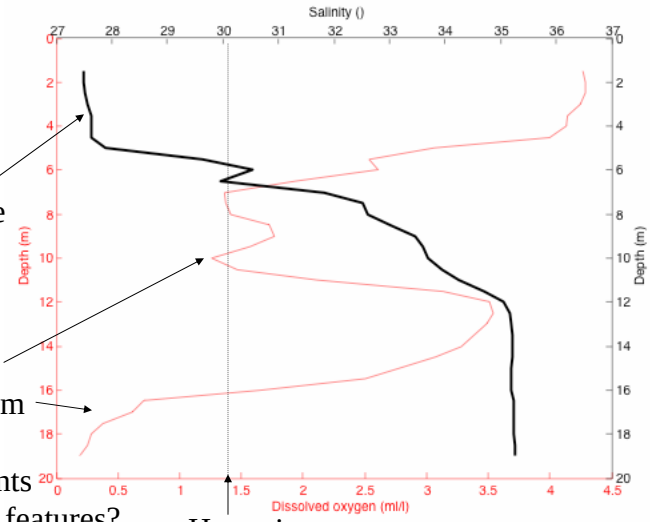
Nitrate

Ammonium

M7 20-m Isobath



CTD Cast at 29°W, 92°W(08C)



- Fresh surface layer
  - 5-m thick Plume
- Halocline 5-12 m
- Salty bottom layer

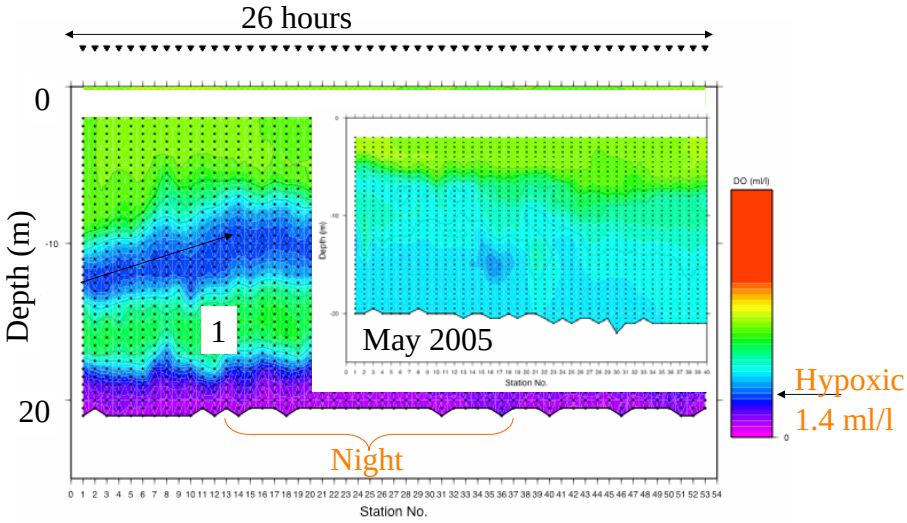
- Mid-water DO low
- Low DO near Bottom

How many instruments needed to resolve all features?

Hypoxic

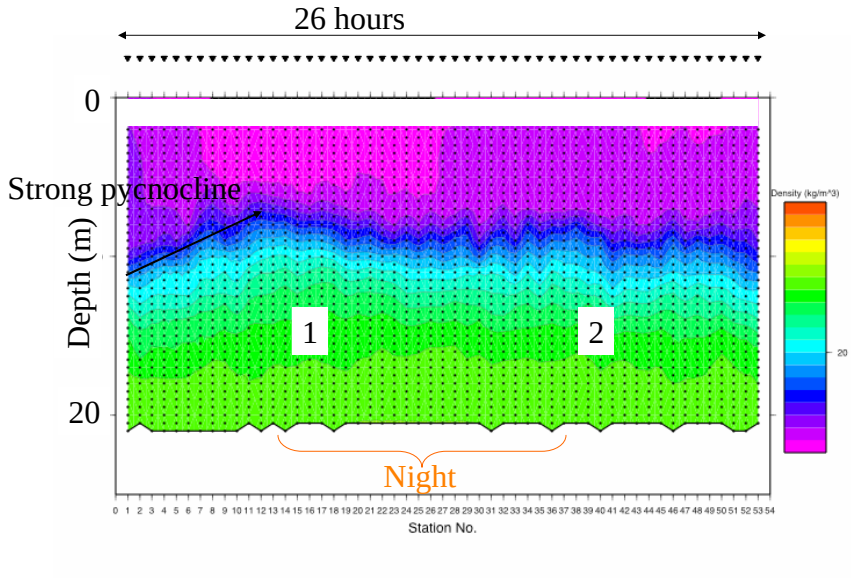
Dissolved Oxygen Concentrations

probe

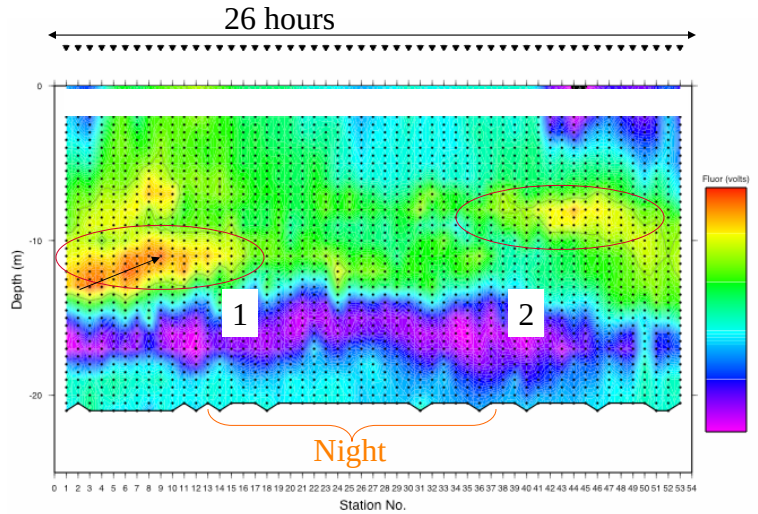


Mid-water DO low below surface mixed layer

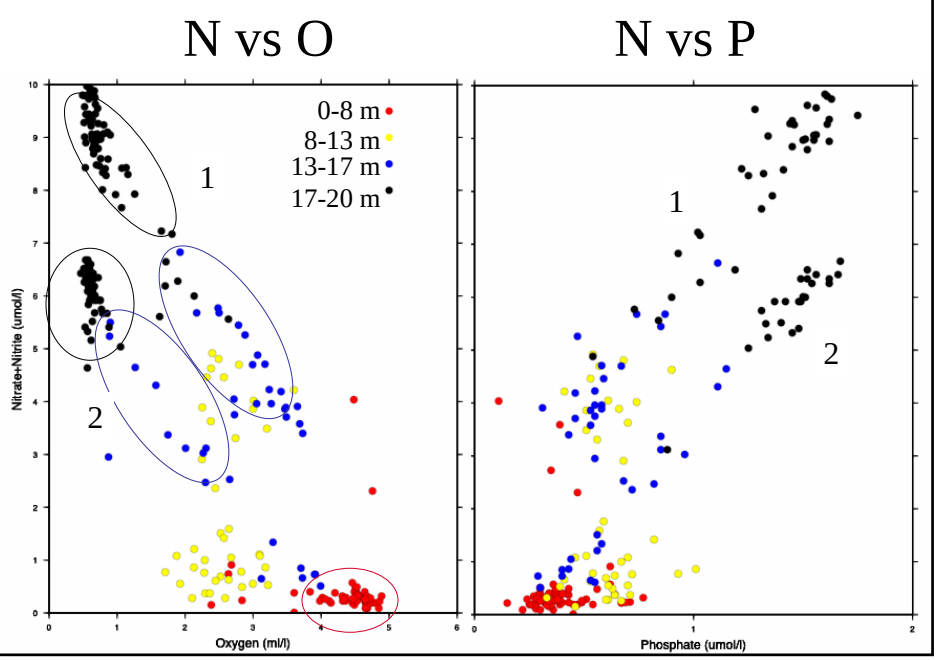
Potential Density



Fluorescence

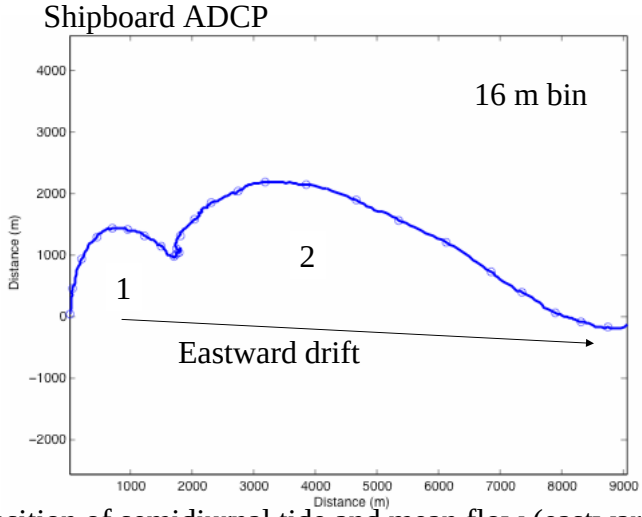


High fluorescence in mid-water low, clear near bottom layer



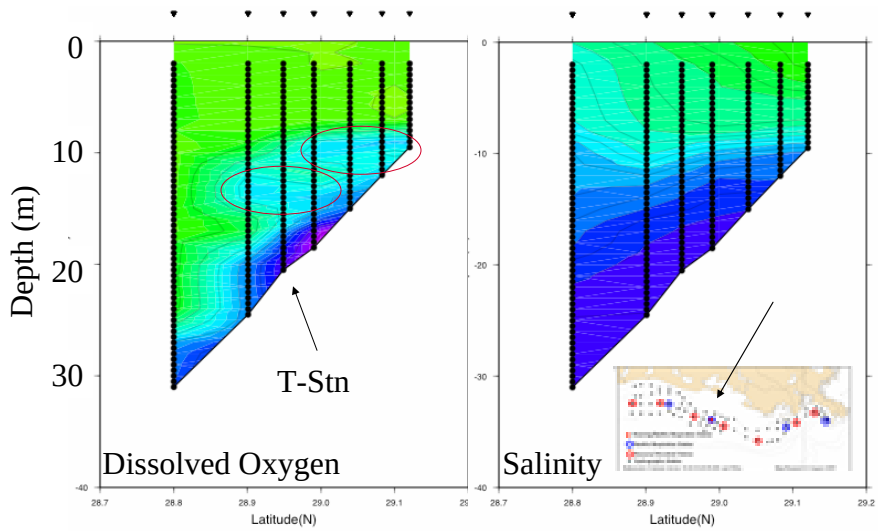
Progressive vector diagram

Shipboard ADCP

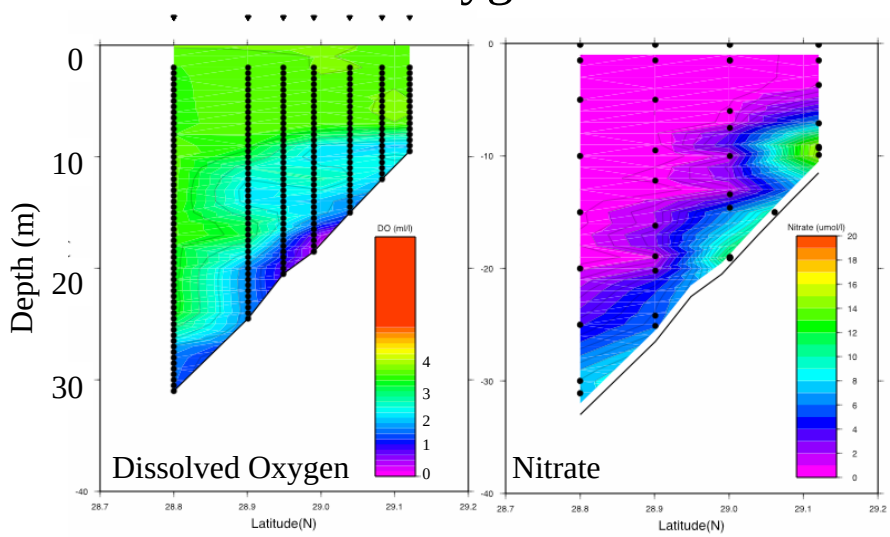


Superposition of semidiurnal tide and mean flow (eastward)

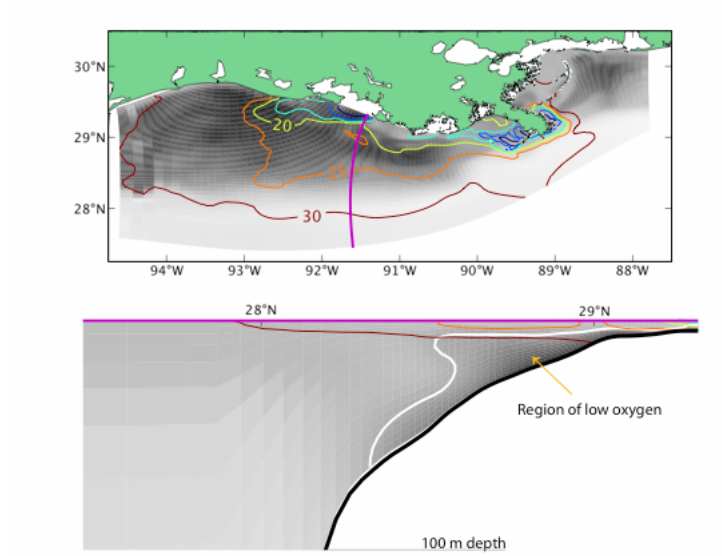
Cross-shelf Sections



Cross-shelf Oxygen and Nitrate



Coupled bio-physical Model Results



Parameterized benthic respiration *(Hetland and DiMarco submitted)*

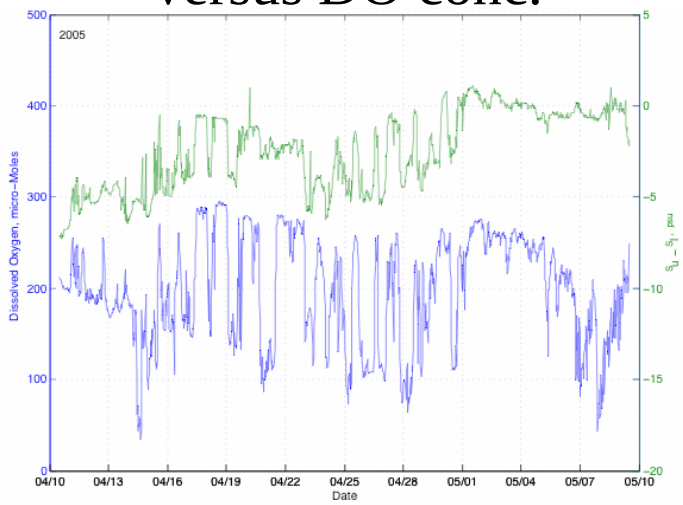
Advection Conclusions

- Mid-water cross-shelf advection
  - Low dissolved oxygen (hypoxic)
  - Enriched nutrients
  - High chlorophyll
  - Flywheel
- Short term (less than a day) variability
  - Interleaving of water masses
- Agreement with dynamical-simple biological model

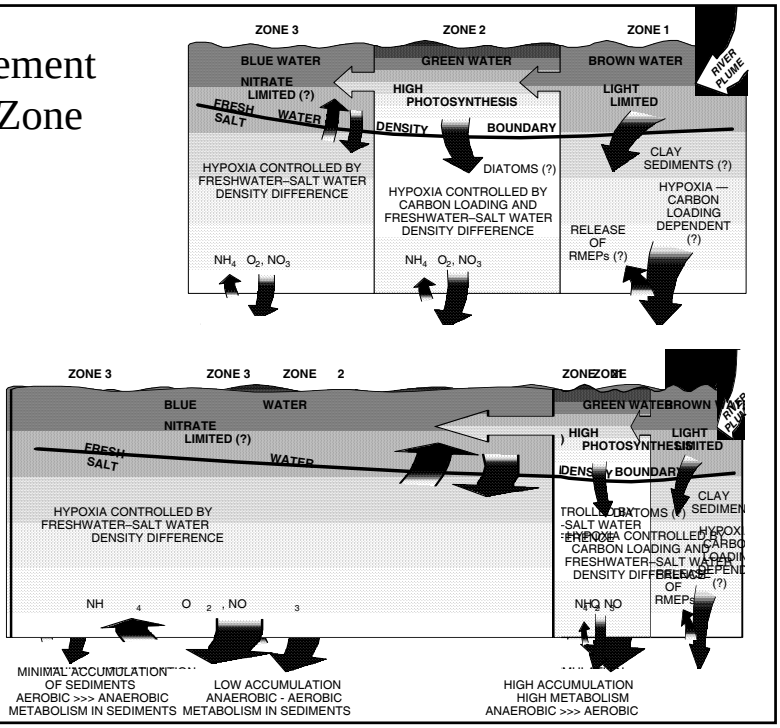
Nutrient Dynamics in West Hypoxic Region

- Are complex
  - Differences between east (direct river) and west (regeneration)
- Sensitive to physical processes
  - Affects the size of hypoxic zone
- Western region is included in total hypoxic area metric
- It is important to quantify the roll of physical processes in the west in controlling the nutrient dynamics

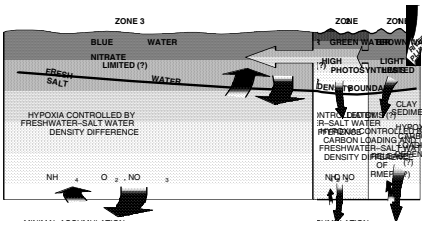
Mooring Data: Stratification versus DO conc.



Management of the Zone



Management



- Include provisions for size of different zones
- Observations/modeling must be able to distinguish between types of zones
- Establish metrics for size of Type A/B/C Hypoxia Zones
- Manage to maximize Zone C and minimize Zones A/B (because those are zones controllable by limiting nutrient fluxes)

Summary

- Many Physical Processes on the Texas-Louisiana Shelf
- Processes occur at many spatial and temporal scales
  - Seconds to years
  - Meters to basin scales
- Timing and strength of forcing events and processes can have dramatic effect on hypoxia formation and breakdown

Knowledge Gaps

The basic physical picture of the Texas-Louisiana Shelf is well documented

- Not known is relative strength and the temporal/spatial variability of each process on dissolved oxygen concentration in the water column and the sediments
- Ongoing observational (survey/mooring) and modeling are shedding insight on how the physics and biogeochemistry are related
- How do transformation and transports of the Atchafalaya differ from those of the Delta?
- How often does Hypoxia make it to Texas?
- What are the nutrient dynamics in the western part of hypoxic area?