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Hypoxia in the Northern Gulf of Mexico in 2010: was the Deepwater Horizon Oil Spill a Factor?

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Hypoxia in the Northern Gulf of Mexico in 2010: was the Deepwater Horizon Oil Spill a Factor?

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http://www.nasa.gov/topics/earth/features/oilspill/20100525_spill.html

Background on Hypoxia in NGOMEX

Defined as a $[O_2] < 2$ PPM
stress/death to benthic organisms

First observed in 1972

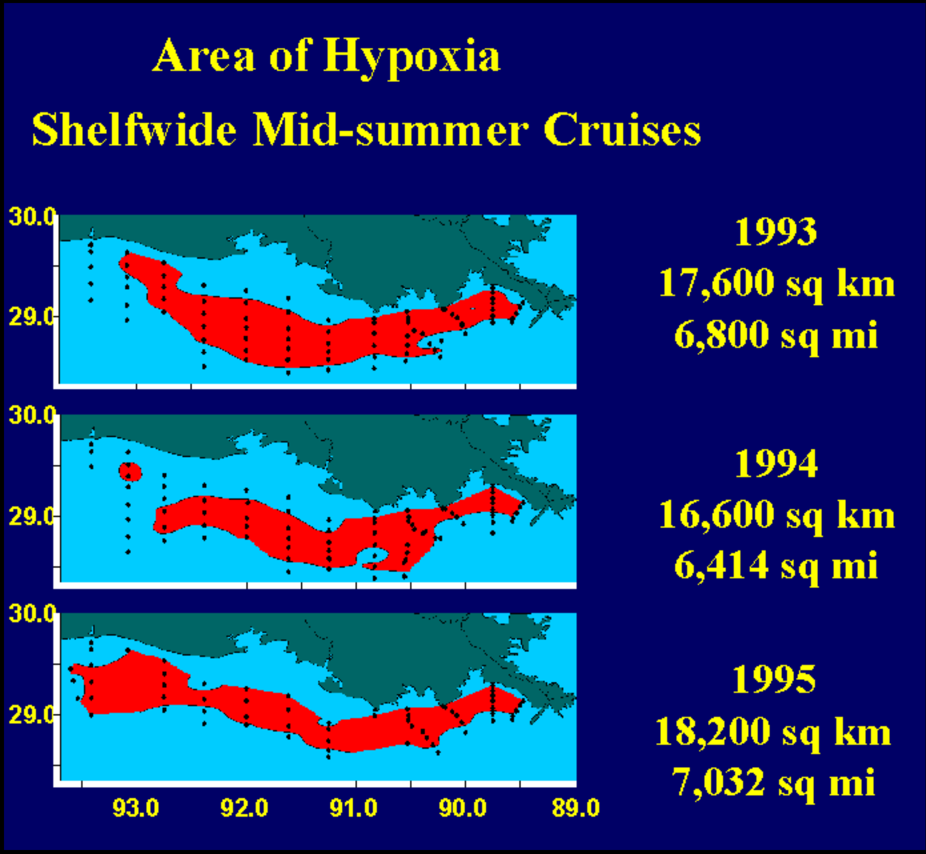
Monitored consistently since 1985

5 yr avg from 2003-2007 = 10,500 km^2

Maximum = 22,000 km^2 in 2002 =
area of NJ state

Hypoxia extends from near shore to up
to 125 km
Depths from 5-60 m

Common from June to Sept.



Rabalais et al. 2002: Ann. Rev. Ecol. Syst. 33: 235-263

Background on Hypoxia in NGOMEX

The Integrated Assessment Report in 2000 concluded that *"hypoxia in the northern Gulf of Mexico is caused primarily by the excess nitrogen delivered from the Mississippi-Atchafalaya Basin in combination with stratification of Gulf waters"* (CENR 2000)

Nitrate load increased ~ 300 % between the 1950's to the mid 1990's

Stream flow from the basin increased only 30%

www.gulfhypoxia.net

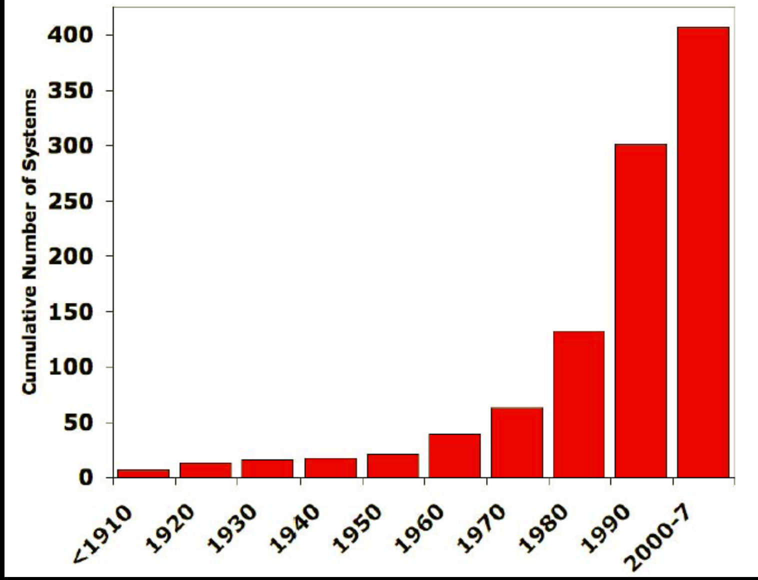
Ocean Hypoxia: “Dead Zones”

Dead zones have doubled each decade since the 1960’s

400 systems; over 245,000 km^2

Examples in U.S. include Lake Erie, Chesapeake Bay, Long Island Sound and Washington/Oregon

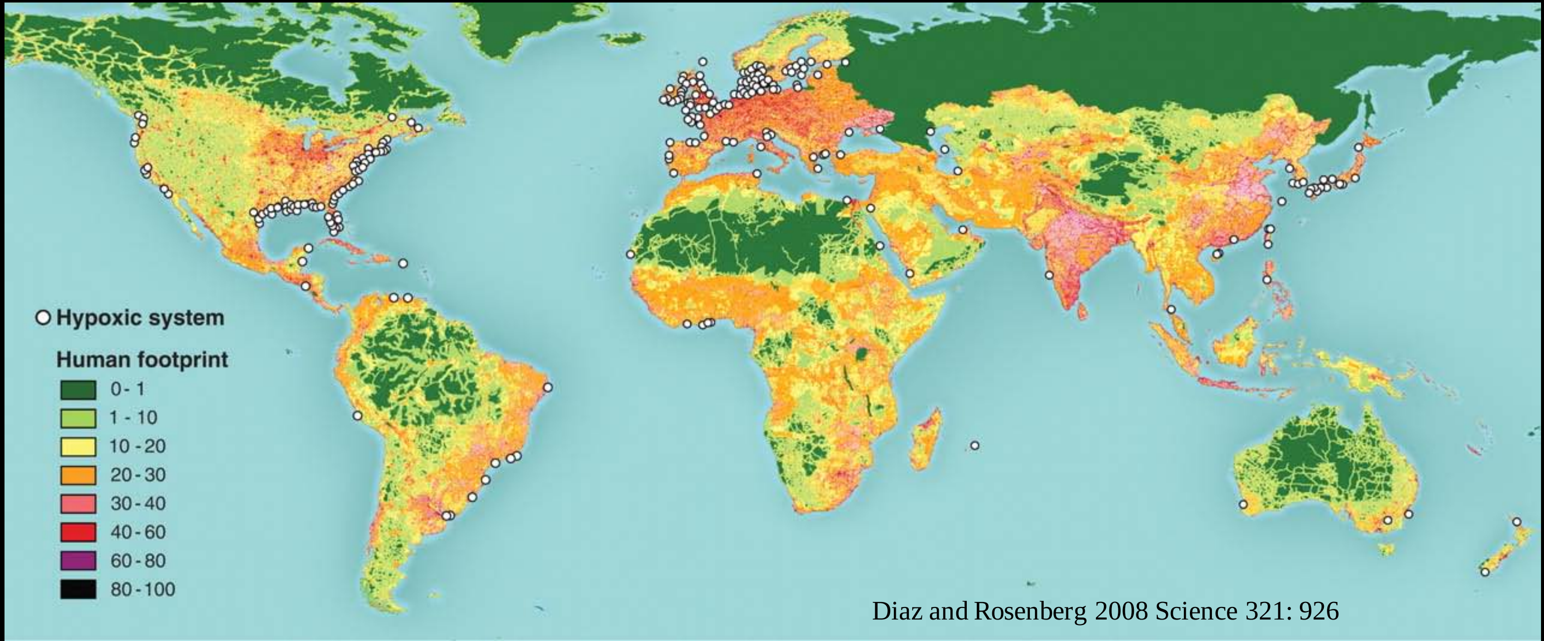
Only 4% show signs of recovery



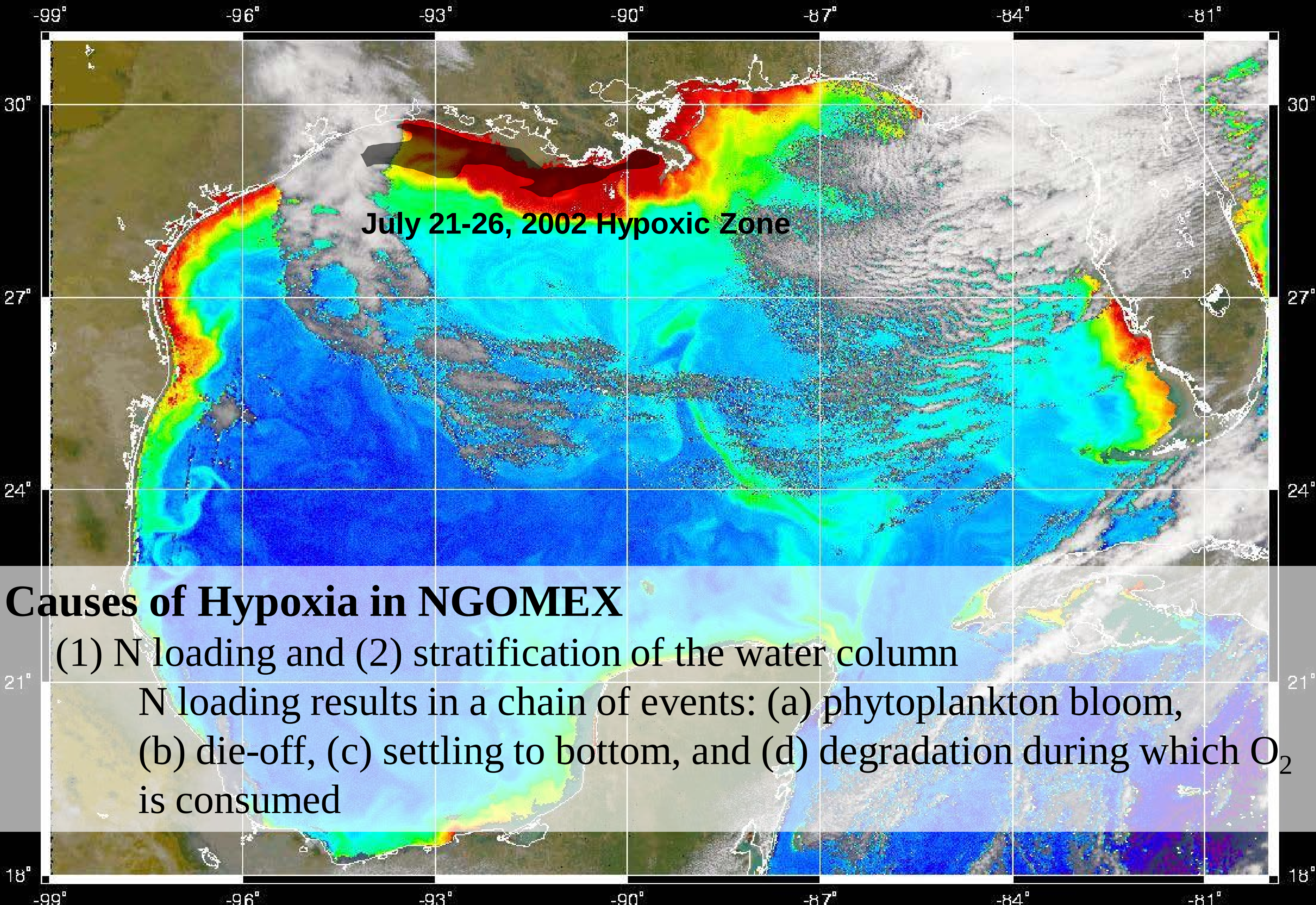
Cumulative number of hypoxic zones

Diaz and Rosenberg 2008 Science 321: 926

Locations of coastal marine hypoxic zones



Satellite Image of Chlorophyll in NGOMEX



Causes of Hypoxia in NGOMEX

(1) N loading and (2) stratification of the water column

N loading results in a chain of events: (a) phytoplankton bloom, (b) die-off, (c) settling to bottom, and (d) degradation during which O_2 is consumed

http://oceancolor.gsfc.nasa.gov/SeaWiFS/

How does "Stratification" result in Hypoxia?

Stable layers in ocean form based on differences in density = <u>Stratification</u>

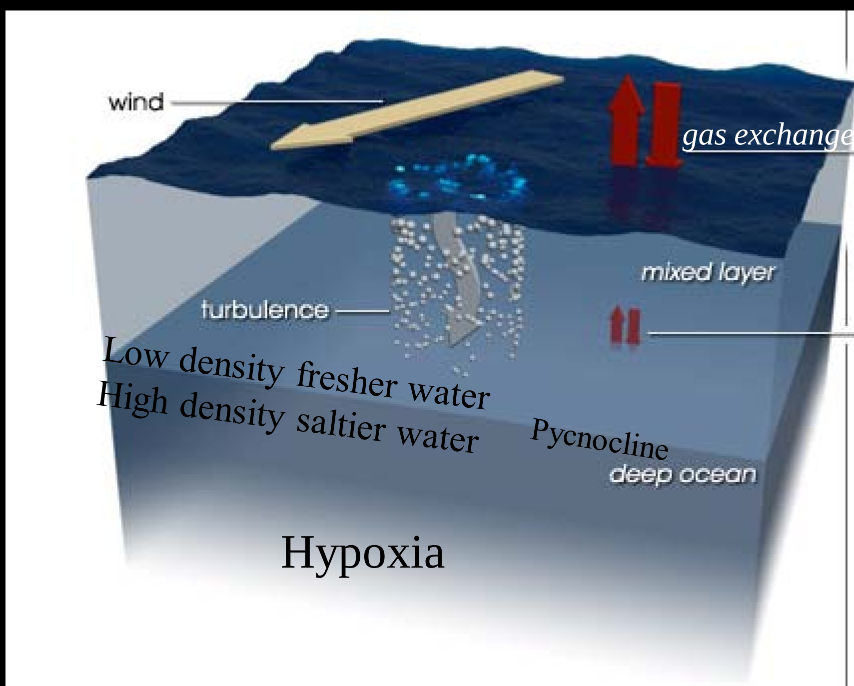
Density controlled by temperature and salinity

- warm, fresh water has a low density
- cold, salty water has a high density

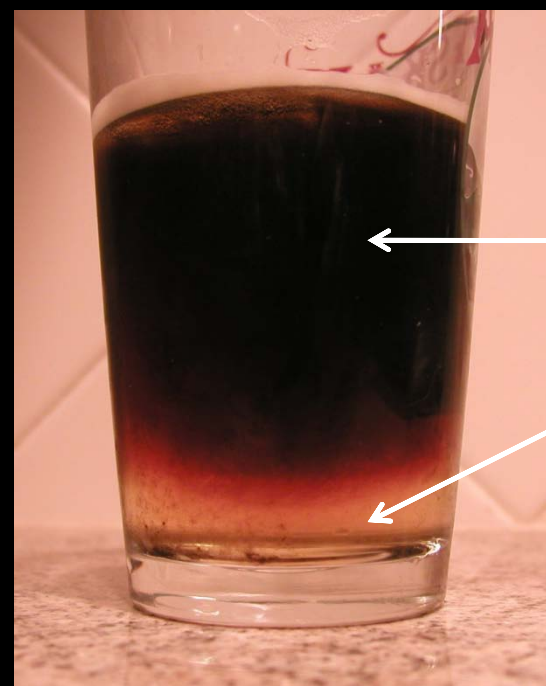
Pycnocline = the region where density changes sharply

A strong pycnocline cuts off the supply of O_2 from air

Analogy… a Black and Tan!



http://earthobservatory.nasa.gov/Features/OceanCarbon/



Guinness:
s.g. = 1.0263

St. Pauli:
s.g. = 1.0287

Difference in
s.g. = 0.24%

Stratification in NGOMEX

Stratification commonly establishes in May/June

(1) freshwater input

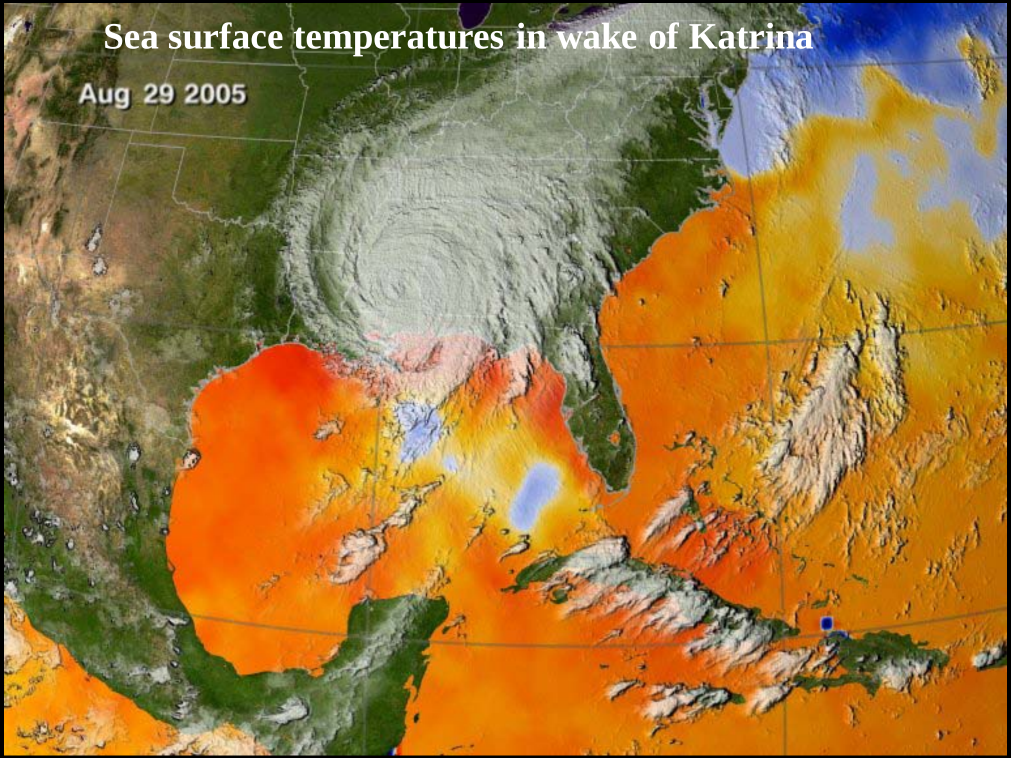
(2) warmer surface temperatures

Cold temperatures and winter storms tend to break down stratification

beneficial to O_2 levels

2005 hypoxic zone 26% smaller than predicted

Cindy, Dennis, Katrina and Rita



http://www.nasaimages.org/luna/servlet/detail/NSVS~3~3~11980~111980:Hurricane-Katrina-Sea-Surface-Tempe

Relationship between May N loading and Hypoxia

N loading in May stimulates a spring phytoplankton bloom when stratification is strengthening

Overall covariance in May N loading and size of Hypoxia Zone in June provides basis to predict size of Hypoxic Zone

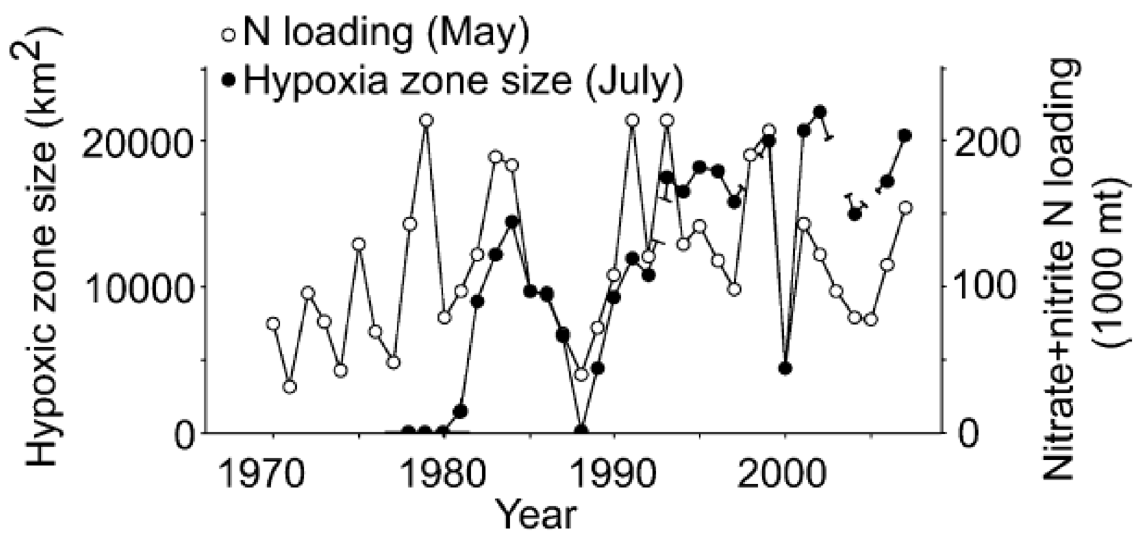


FIGURE 1. The size of the hypoxic zone in late July and the nitrate+nitrite N loading to the Gulf of Mexico for the preceding May. The broken lines for the hypoxic zone size bracket years with missing data.

Turner et al. (2008) Environ. Sci. Technol. 42: 2323

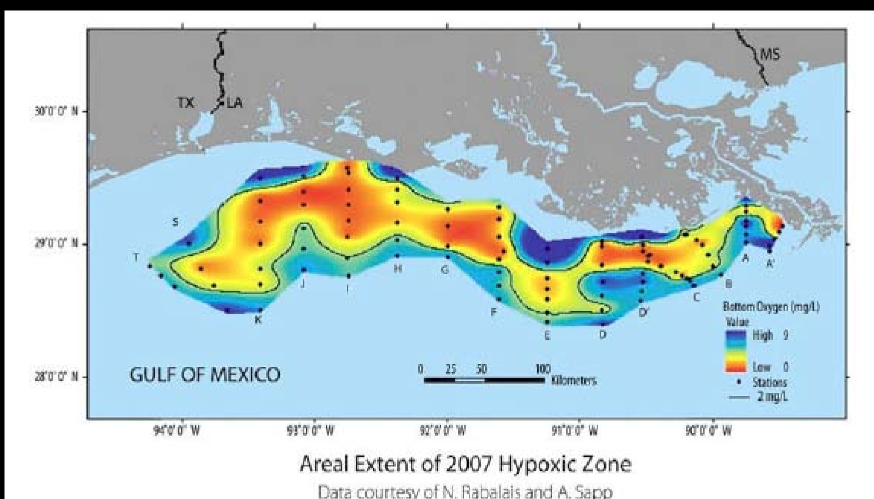
Ecosystem Restoration?

The Gulf Hypoxia Action Plan of 2008:

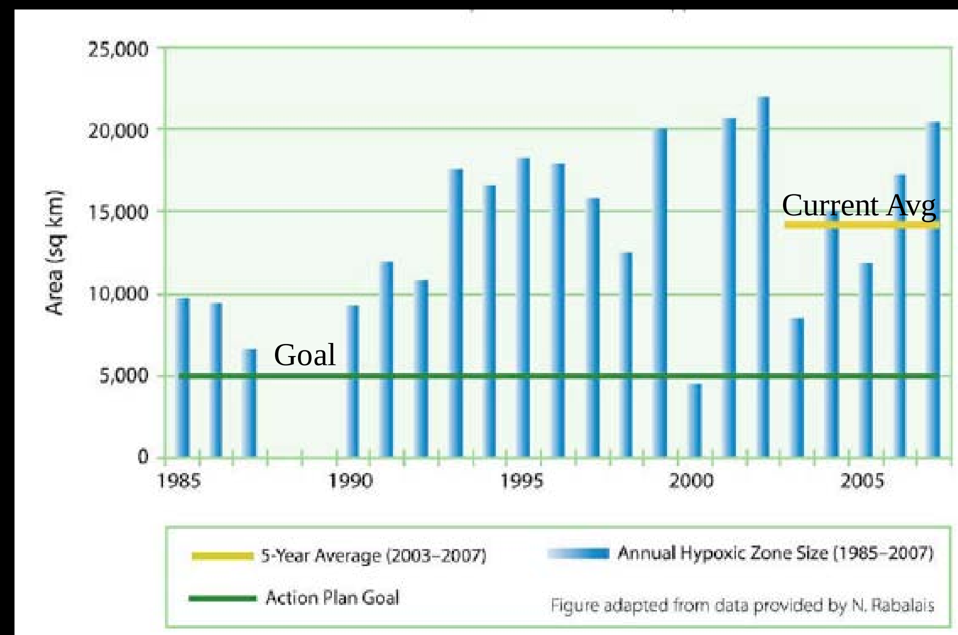
> "reduce… the five year running average areal extent of the Gulf of Mexico hypoxic zone to less than 5,000 square kilometers by 2015…"

Current Avg. ~ 15,000 km^2

Estimated to require a <u>45% reduction in N load</u>



Areal Extent of 2007 Hypoxic Zone
Data courtesy of N. Rabalais and A. Sapp



Gulf Hypoxia Action Plan 2008 (http://www.epa.gov/owow_keep/msbasin/actionplan.htm)

Relationship between May N loading and Hypoxia

However, ecosystem shifted to an "alternate state"

For the same May N load from 1981-1988 we now obtain a Hypoxic Zone 2x larger

Cause: Phytoplankton biomass from spring bloom survives over winter in sediments and increases Sediment O_2 Demand the following year

Recovery will take even further reductions in N loading than 30 years ago

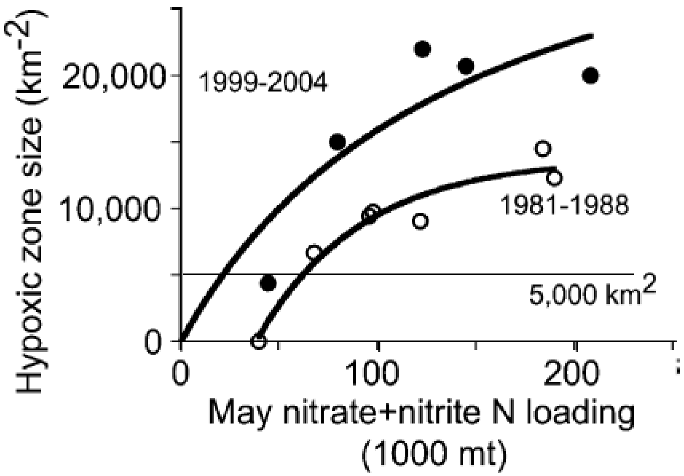


FIGURE 3. The relationship between the size of the hypoxic zone in July (km^2) and the May nitrate+nitrite N loading to the Gulf of Mexico from the Mississippi River. A nonlinear hyperbolic function was fitted to data for the 1981–1988 and the 1999–2004 intervals shown in Figure 2. The 5000 km^2 Action Plan goal is indicated.

Turner et al. (2008) Environ. Sci. Technol. 42: 2323

The Deepwater Horizon Oil Spill

- Incident occurred on April 20, 2010
- Initial capping on July 15, declared “*effectively dead*”* on Sept. 19
- Most severe marine oil disaster in U.S.
- Estimated 4.93 million barrels of oil
  - Equivalent to 0.5 to 3x annual primary production over spill area

* Retired Coast Guard Admiral Thad Allen

Oil Slick as seen from NASA’s Terra satellite on May 24, 2010
http://www.nasa.gov/topics/earth/features/oilspill/20100525_spill.html

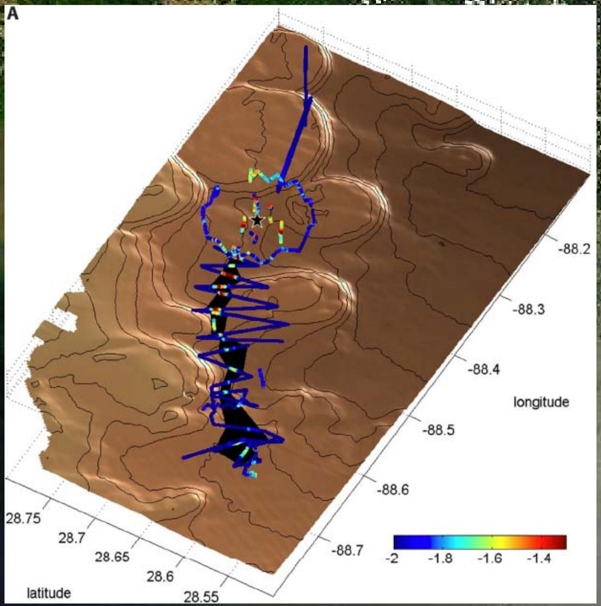
National Incident Command Joint Analysis Group

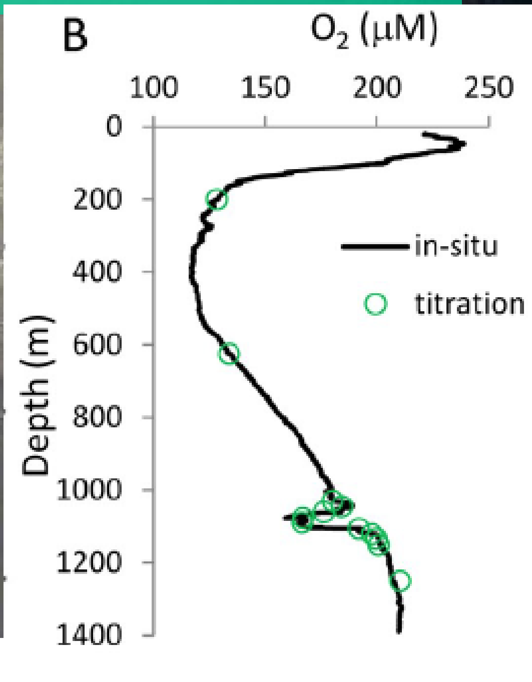
- Cited concerns regarding link between oil spill and hypoxia
- Degradation of 1 L of oil would consume O_2 from 320,000 L of water
  - Oil has survived millions of years of bacterial degradation
  - Biodegradation possible with:
    - exposure to O_2, nutrients, warm temperatures and appropriate bacterial community

National Incident Command Joint Analysis Group

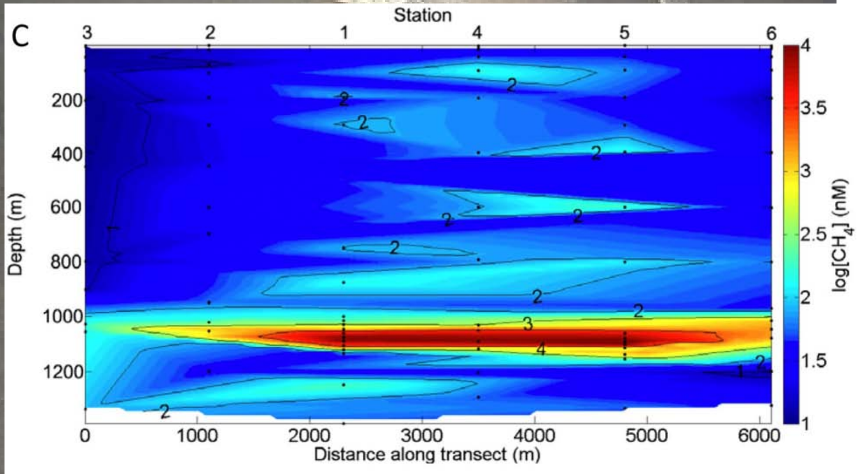
Found evidence of a depression in O_2 within a deep layer at ~ 1100 m

Concluded: "*Measurements of the DO_2 depression have not approached hypoxic levels*"





Extent of subsurface methane and hydrocarbon plume
(Camilli et al. 2010 Science Express, Aug. 19)



Concentration of methane in subsurface hydrocarbon plume
(Valentine et al. 2010 Science 303, 208-211)

Concentration of O_2 in subsurface hydrocarbon plume
(Valentine et al. 2010 Science 330, 208-211)

R/V Pelican NGOMEX Research Cruise, May 21-27, 2010:

R/V Pelican, LUMCON (Louisiana Universities Marine Consortium)
- Funded by NOAA

Deepwater Horizon oil spill: April 20, 2010

Inspired us to approach the National Science Foundation for funding via its RAPID program
- Enables rapid access to research funding for episodic events
- To date: ~ 50 research proposals funded

http://www.lumcon.edu/

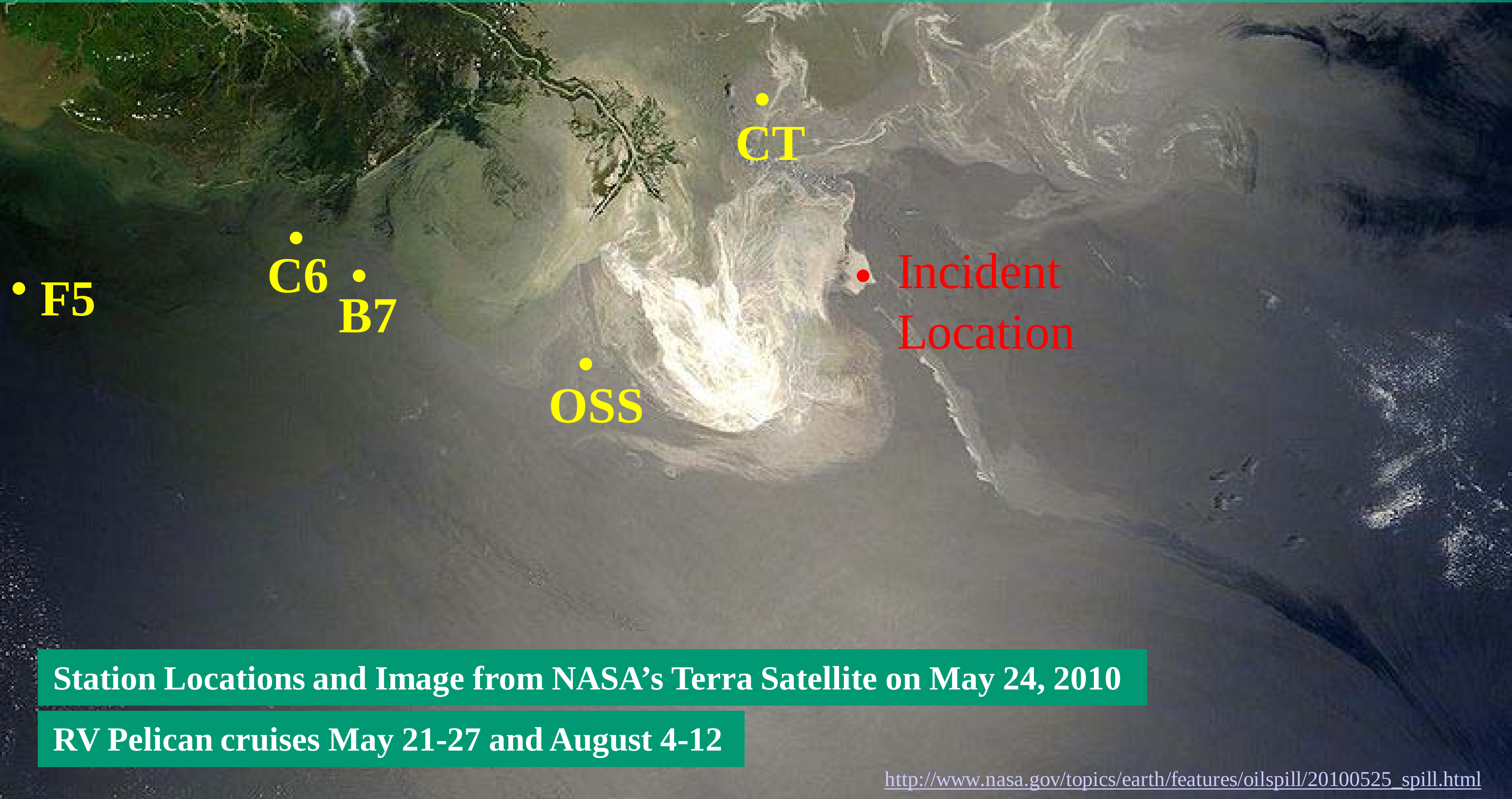
Ben Kamphuis

Impact of the Deepwater Horizon oil spill on ecosystem metabolism and gas exchange in the northern Gulf of Mexico hypoxic region

Principal Investigators:

Nathaniel E. Ostrom, Michigan State University

Zhanfei Liu, Marine Science Institute, University of Texas at Austin

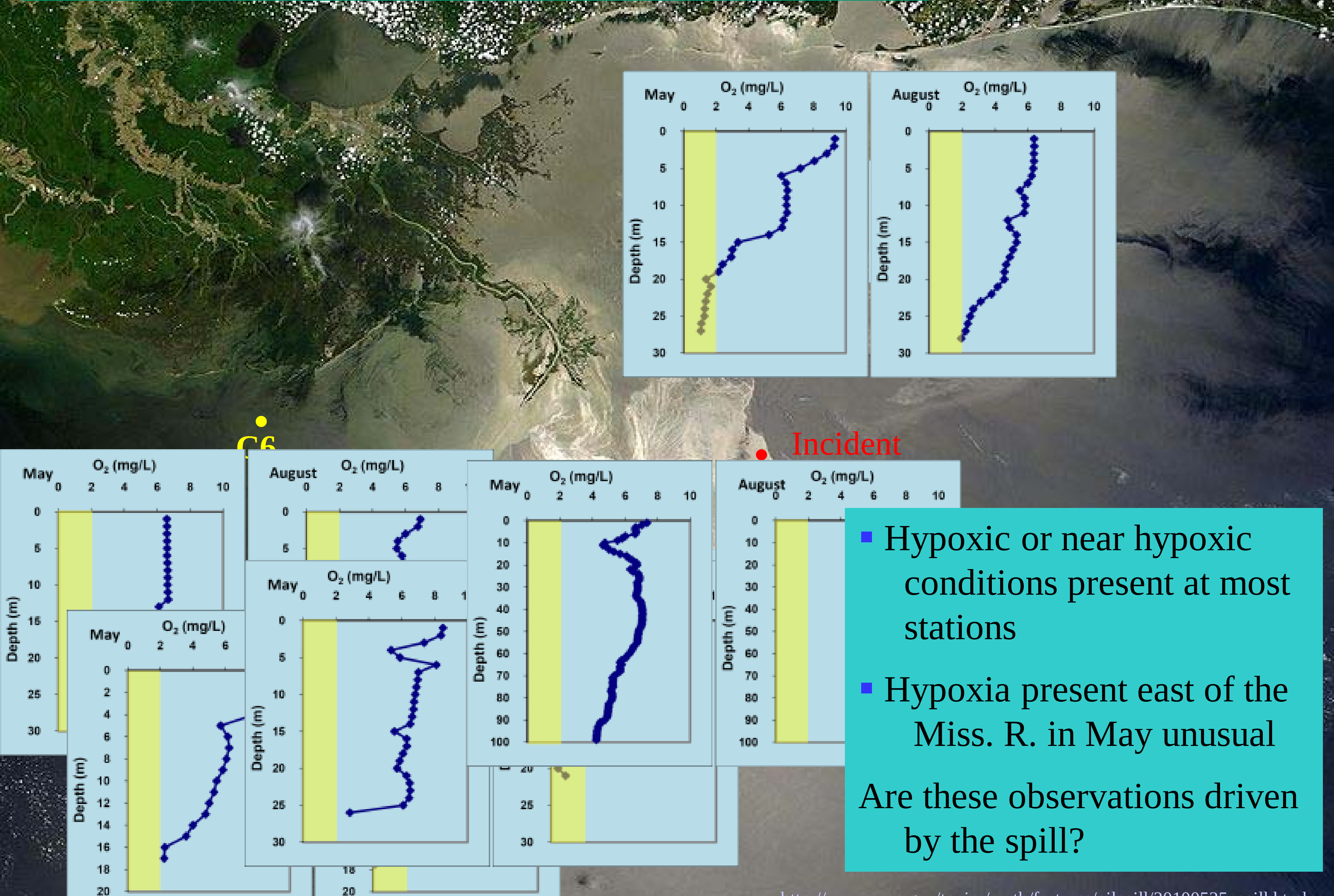


Station Locations and Image from NASA's Terra Satellite on May 24, 2010

RV Pelican cruises May 21-27 and August 4-12

http://www.nasa.gov/topics/earth/features/oilspill/20100525_spill.html

Was Hypoxia Present in May and August of 2010?



- Hypoxic or near hypoxic conditions present at most stations
- Hypoxia present east of the Miss. R. in May unusual

Are these observations driven by the spill?

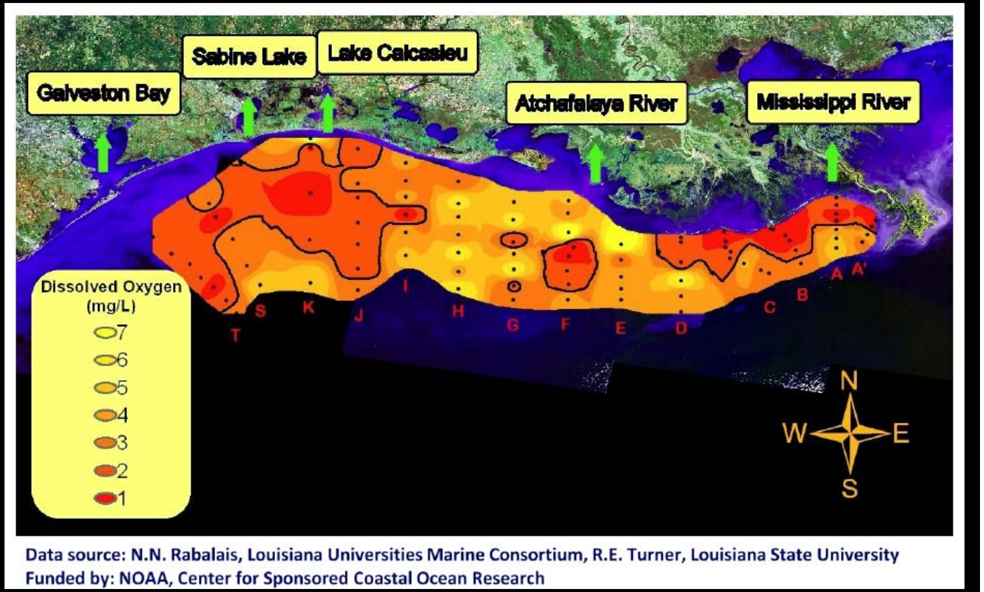
http://www.nasa.gov/topics/earth/features/oilspill/20100525_spill.html

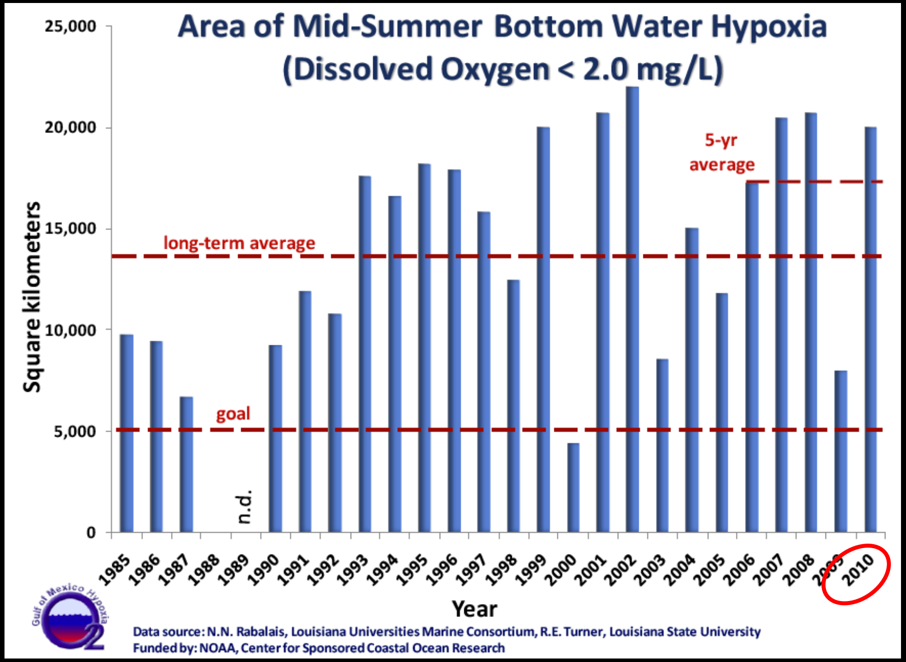
How Big Was the 2010 Hypoxic Zone?

Based on May N load LSU's Dr. Eugene Turner predicted 20,140 km^2

Survey Finding: 20,000 km^2 = state of New Jersey… likely an underestimate

- Largest hypoxic area off Texas Coast since start of surveys
- Western portion of survey not completed… likely larger
- Gulf impacted by Hurricane Alex and Tropical Depression Bonnie
- Survey does not include area east of Miss. River

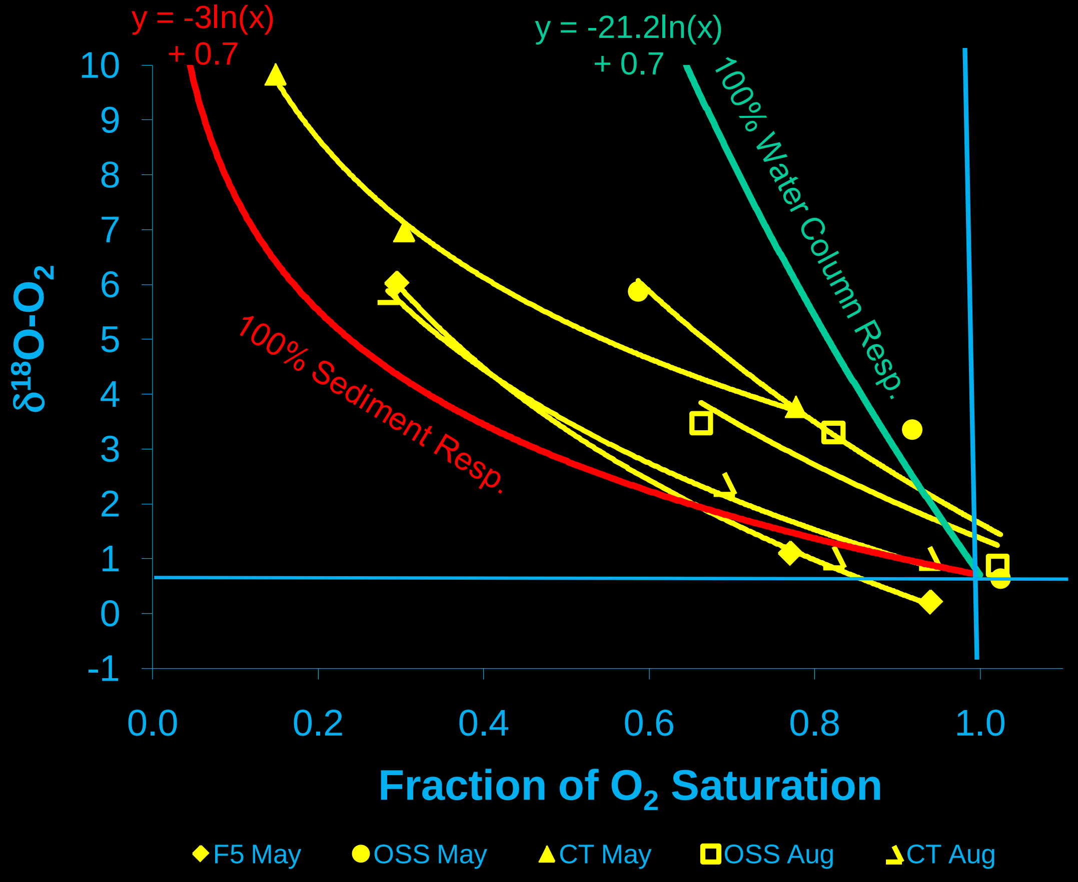




http://www.gulfhypoxia.net/research/Shelfwide%20Cruises/2010/PressRelease2010.pdf

Understanding Oxygen Demand: Oxygen Isotopes

- Respiration preferentially consumes O_2 with ^{16}O than ^{18}O
  - The degree of preferential consumption varies
    - Discrimination small in sediments but large in water
  - Can partition respiration using isotopes into sediment or water
- Hypoxia is largely driven by sediment O_2 demand



Respiration by Sediments

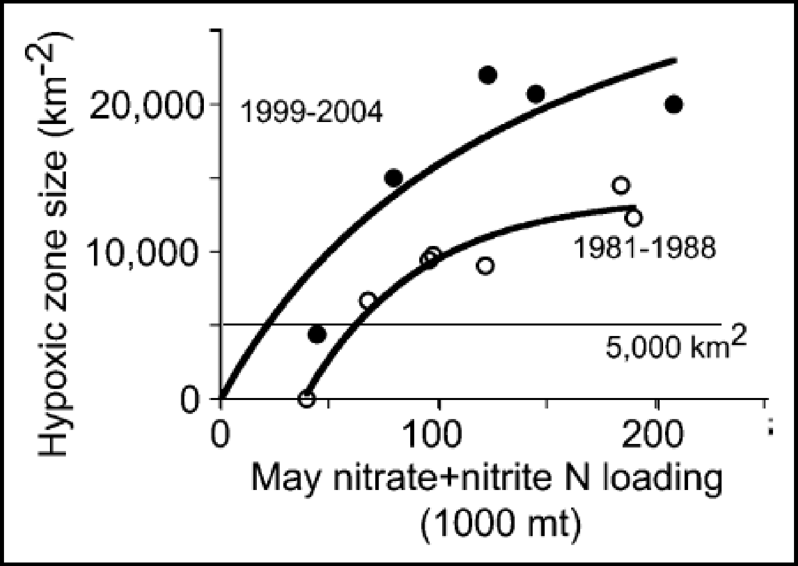
Station	Slope	%
F5 May	-5.1	88.7
C6 May	-4.3	92.8
B7 May	-7.6	64.6
OSS May	-8.3	70.9
CT May	-3.7	96.4
F5 Aug	-4.8	90.1
C6 Aug	0.2	100.0
B7 Aug	-2.3	100.0
OSS Aug	-6.0	83.5
CT2Aug	-4.2	93.4
Avg.	-4.6±2.5	89.0±10.0

Why is Sediment Oxygen Demand Important?

Remember the transition to an "alternate state"

For the same N loading we now get twice the hypoxic zone

Driven by Sediment Oxygen Demand



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Changes in Sediment Oxygen Demand?

Study	S.O.D.
Quinones-Rivera* 2001-2003	75%
This study, May 2010	85%
This study, Aug. 2010	93%

Is the increased S.O.D. driven by the oil spill?

<u>Conclusions</u>:

(1) Respiration beneath the pycnocline is strongly driven by sediments
- deposition of organics (natural or petroleum) drives hypoxia

(2) N loading in May alone predicts size of hypoxic zone but...
- areas of known hypoxia to east and west of survey not included
- hypoxia would have been greater in absence of two storms

(3) Was the oil spill a contributing factor? Maybe…
- high Sediment O_2 Demand in Aug. consistent with respiration of oil
- additional studies needed
    (a) to verify presence of oil in shelf sediments
    (b) to quantify influence of oil on respiration

(4) **Hypoxia remains an agricultural problem**
- 45% reduction in N loading the best solution
- but biodegradation of oil in sediments (if verified) may lengthen recovery time

Acknowledgements:

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RAPID program of NSF

Chemical Oceanography and Major Research Instrumentation

Collaborators at MSU and UT Marine Sciences Institute

Organizers of this session