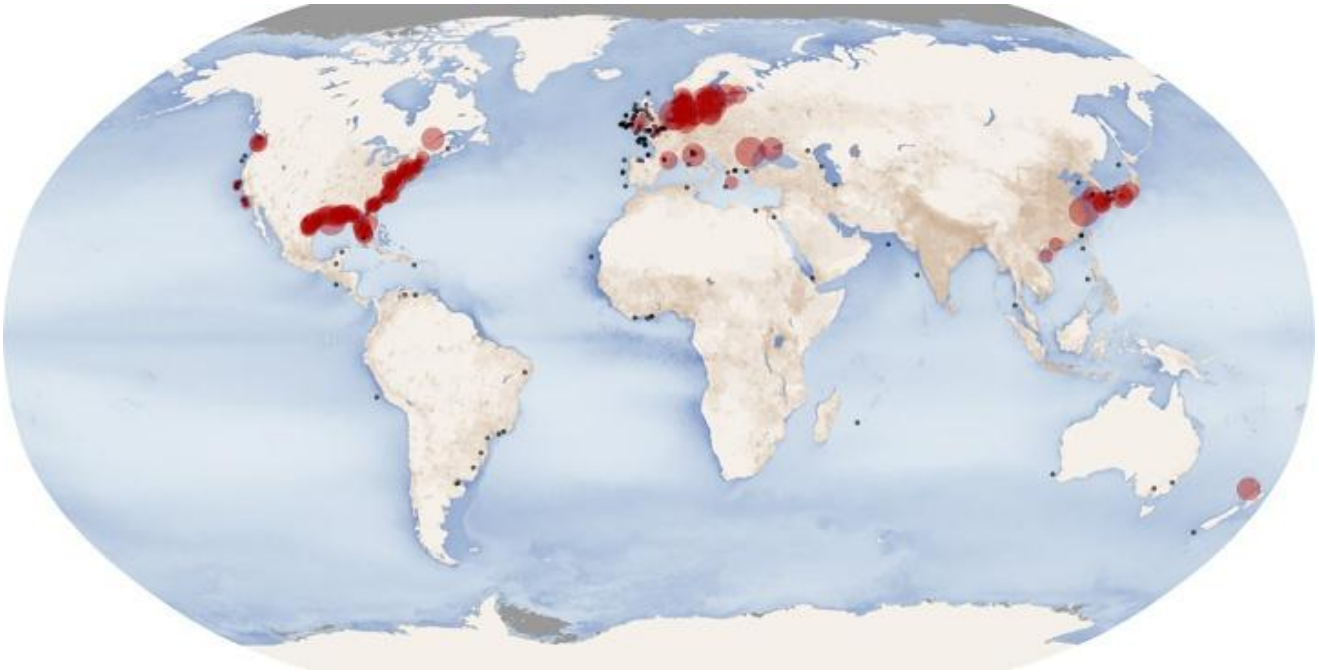
Hypoxia and Hydrology



- Generation of hypoxic conditions can be a reasonable metric for measuring ESPC success
- There are many physical causes at time scales from weeks to decades
- Observations and events are extensive
- Hypoxia resulting from eutrophication is difficult
    - Watershed nutrient load runoffs are difficult to predict
    - Biological processes are difficult to predict
    - There are modulating physical factors that are predictable

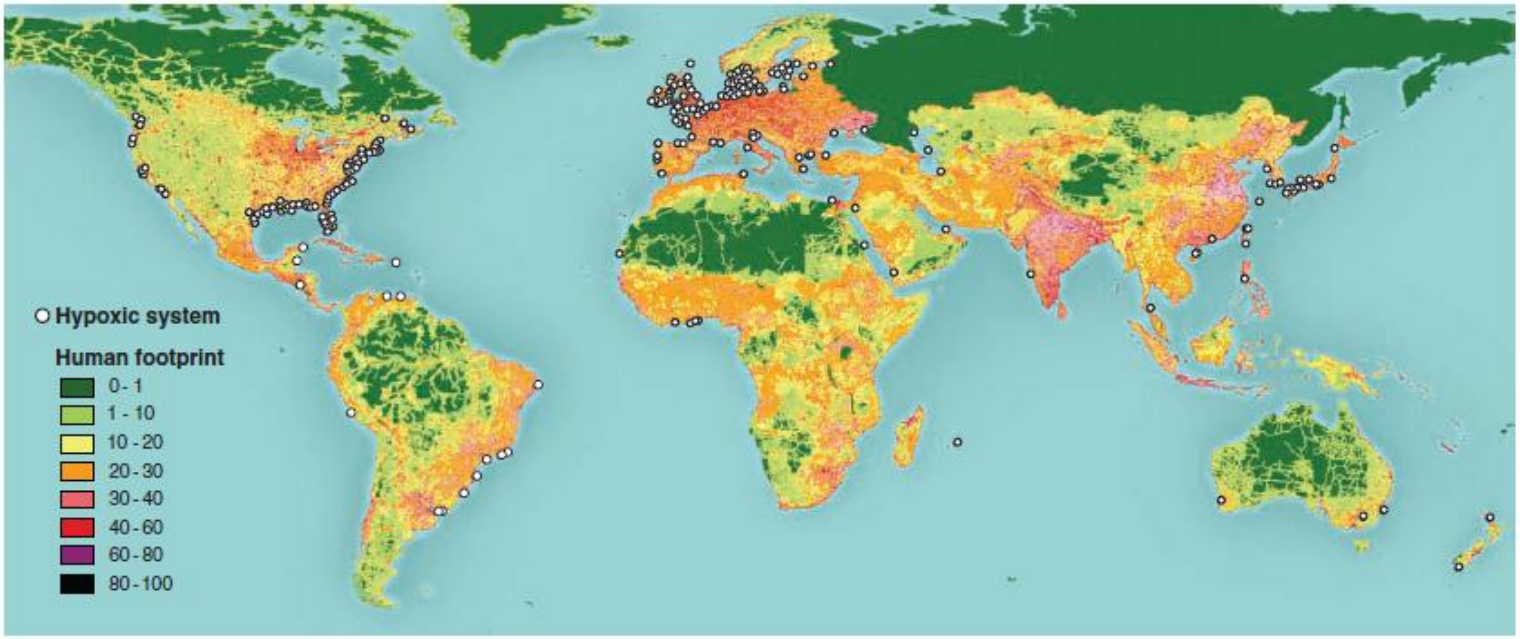
Diaz, Rosenberg, Science 2008

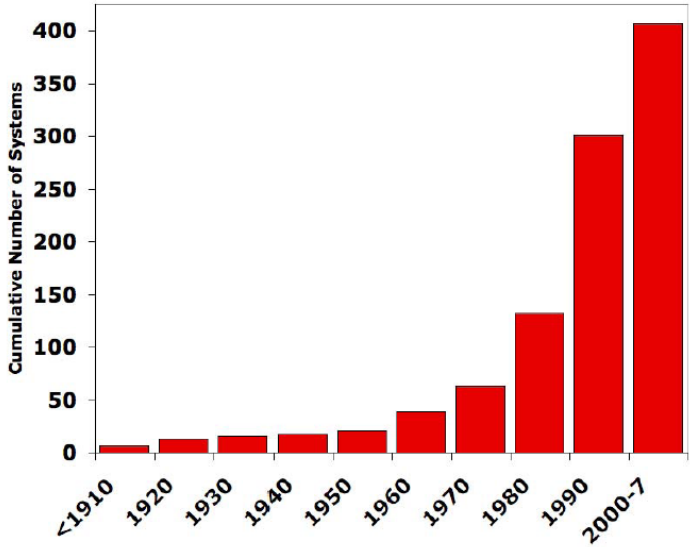
Two types of hypoxia:

- Eutrophication – driven by stimulating biological growth and subsequent decomposition by bacteria that deplete oxygen
    - Requires land chemical composition
    - Harmful Algal Blooms result, harmful in either producing toxins or by resulting in oxygen depletion
    - Prediction requires biological system and oxygen utilization models
    - Physical processes modulate the hypoxia
- Oxygen Minimum Zones (OMZ) – oxygen minima at depth (100 - 1000m) upwelled along coasts
    - Mainly physically driven upwelling generates hypoxia

Diaz, Rosenberg, Science 2008

Documented dead zones relative to population density

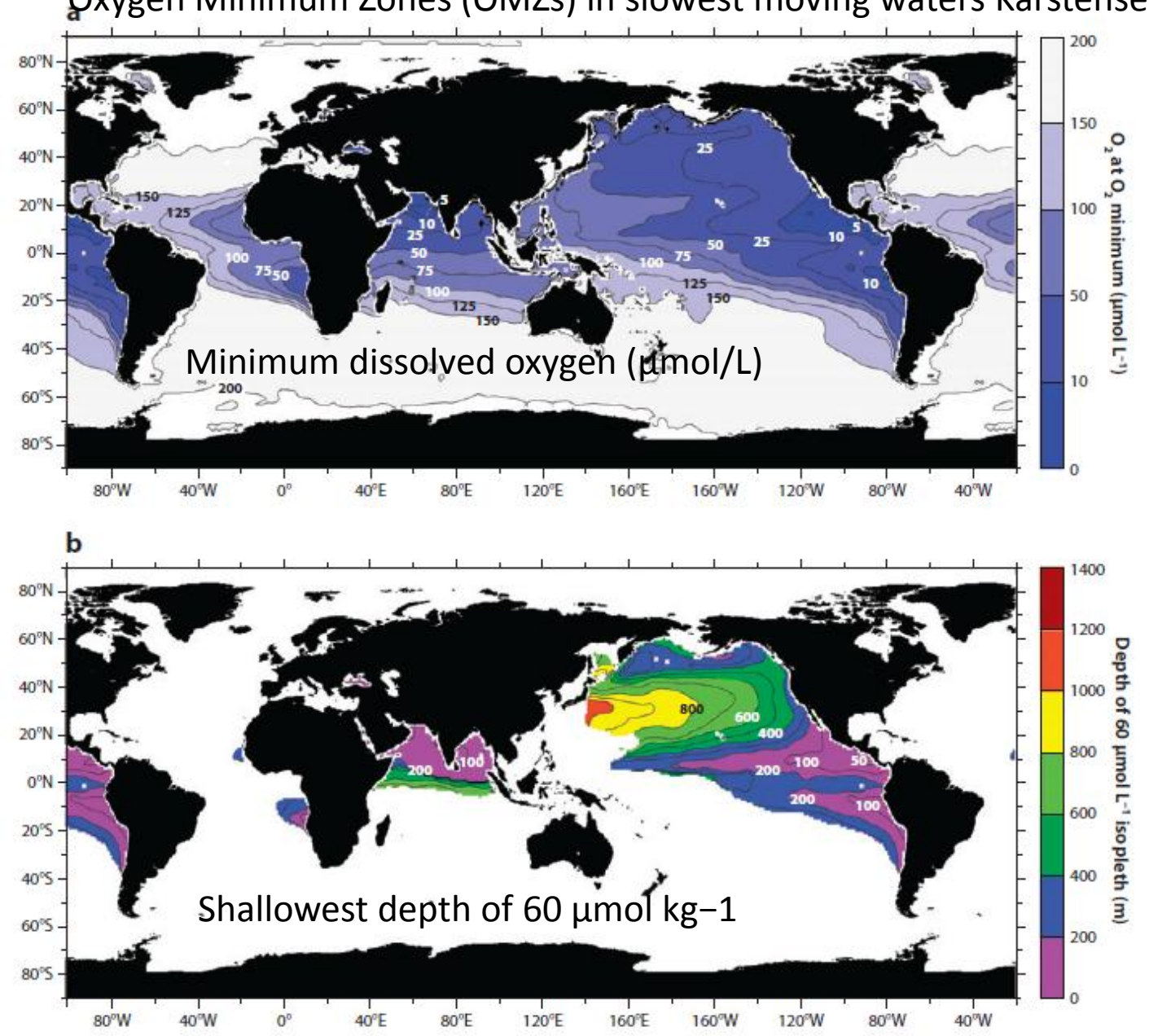




Total known dead zone systems (from episodic to seasonal to persistent)
~50% due to eutrophication

Conkright et al., World Ocean Database, NESDIS, 2002

Oxygen Minimum Zones (OMZs) in slowest moving waters Karstensen et al. 2008).



Factors controlling oxygenation:

- O_2 when parcel was last at surface
- O_2 utilization rate
- Ventilation age, time since parcel was last exposed

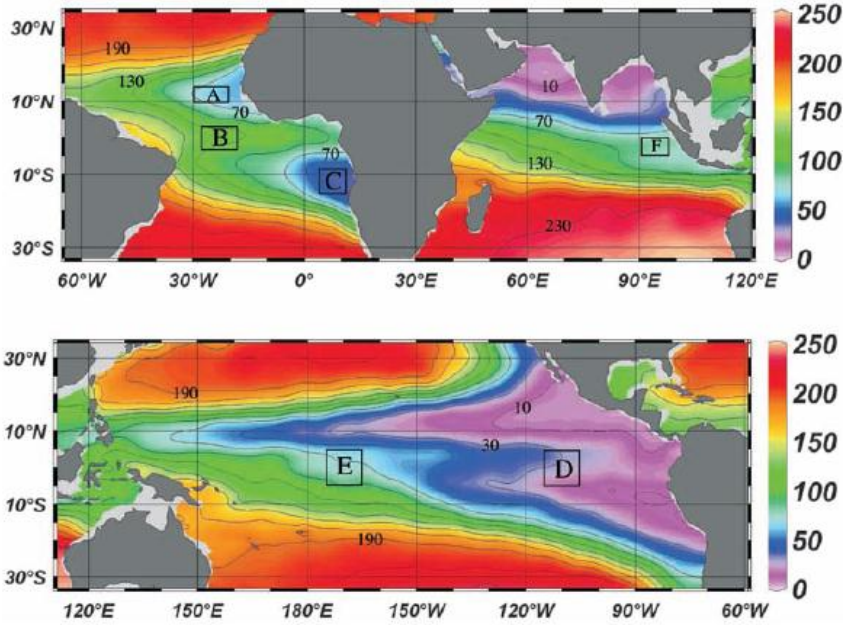
Hypoxia: < 60 µmol kg−1

Stramma, Johnson, Sprintall, Mohrholz, Science 2008

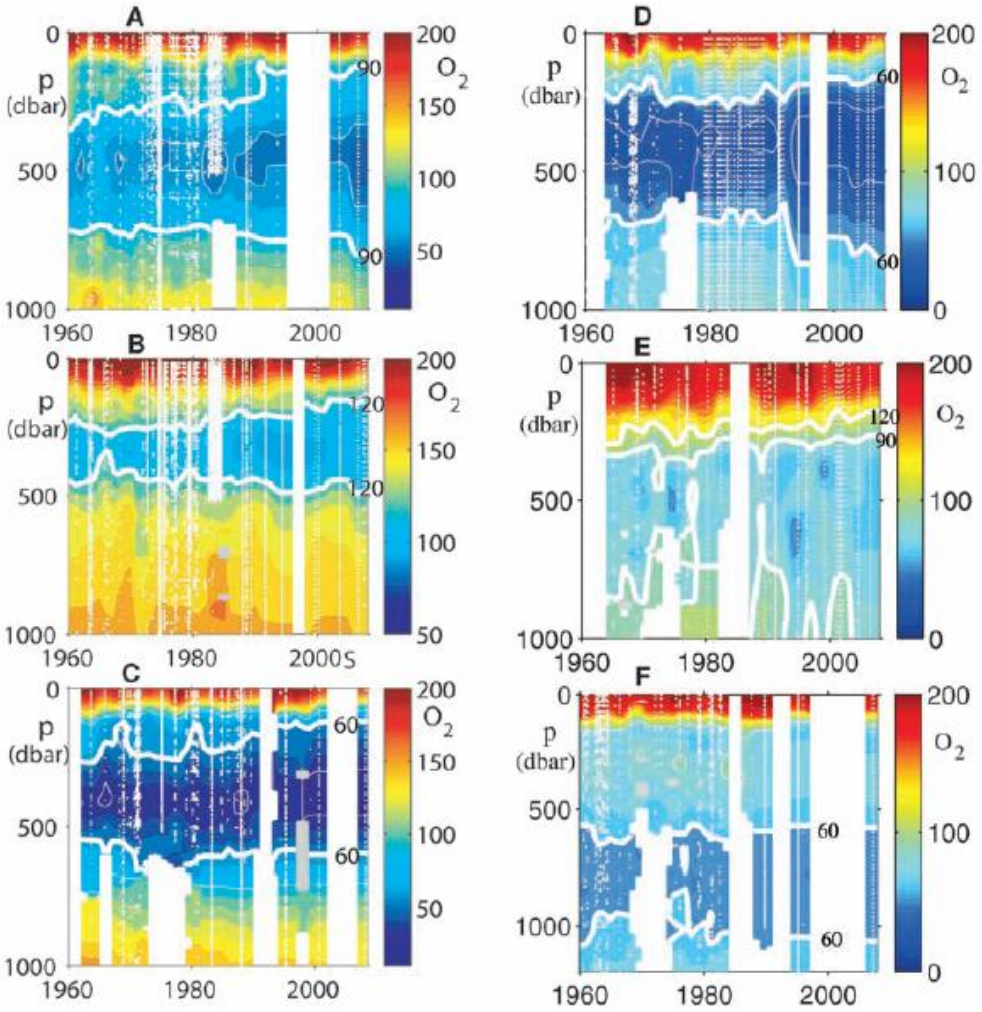
Long term trends in the dissolved oxygen and the position of the minimum in the water column

Proposed result of increased stratification reducing ventilation

In agreement with AMOC slowdown, thus Atlantic may show largest hypoxia changes in future



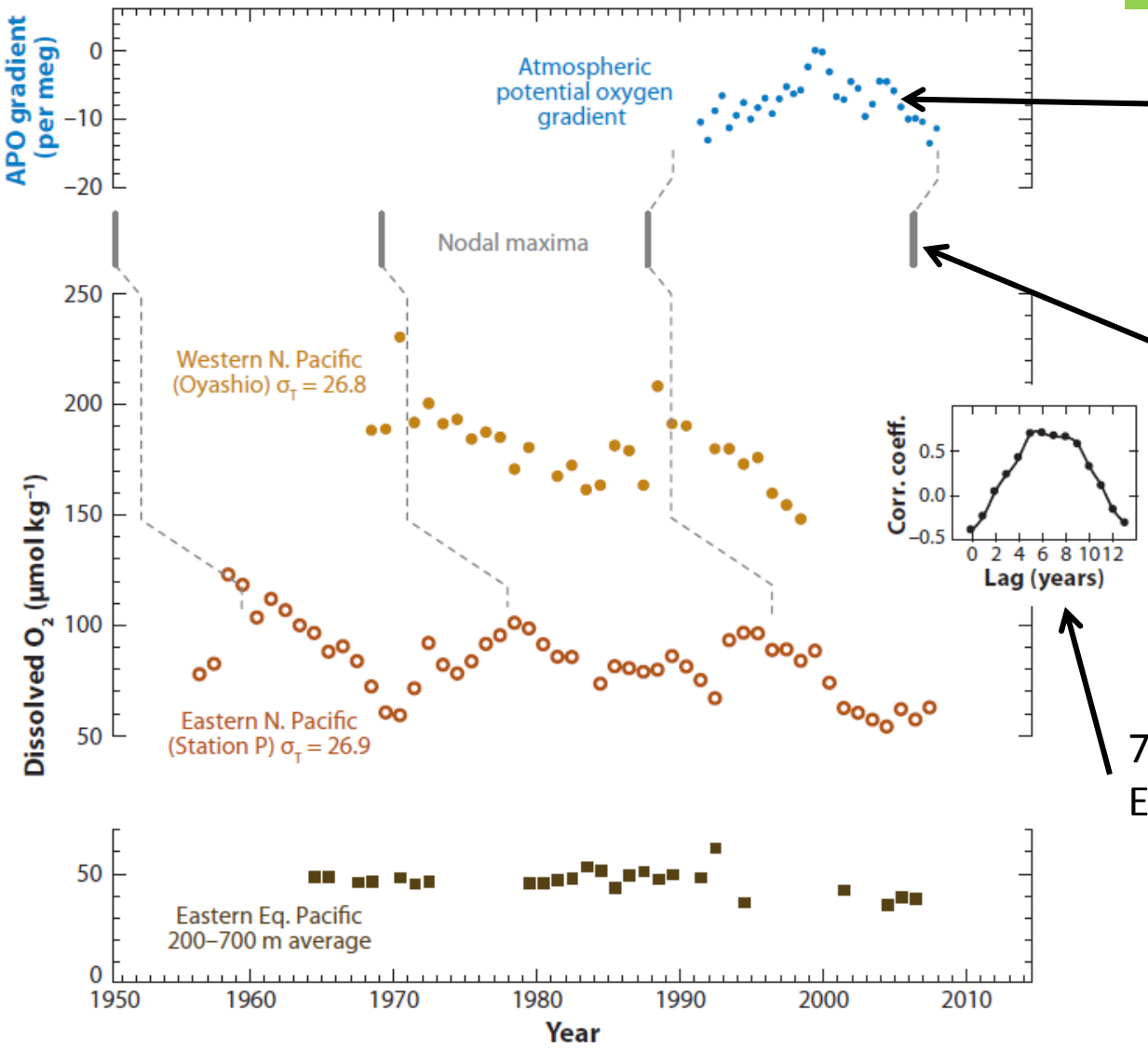
Observed trends in oxygen (µmol/L)



Keeling, Kortzinger, Gruber, Annual Reviews 2010

Long term cycles are dynamically driven
A range of mechanisms have been proposed

Long period cycles



North minus south atmospheric oxygen content

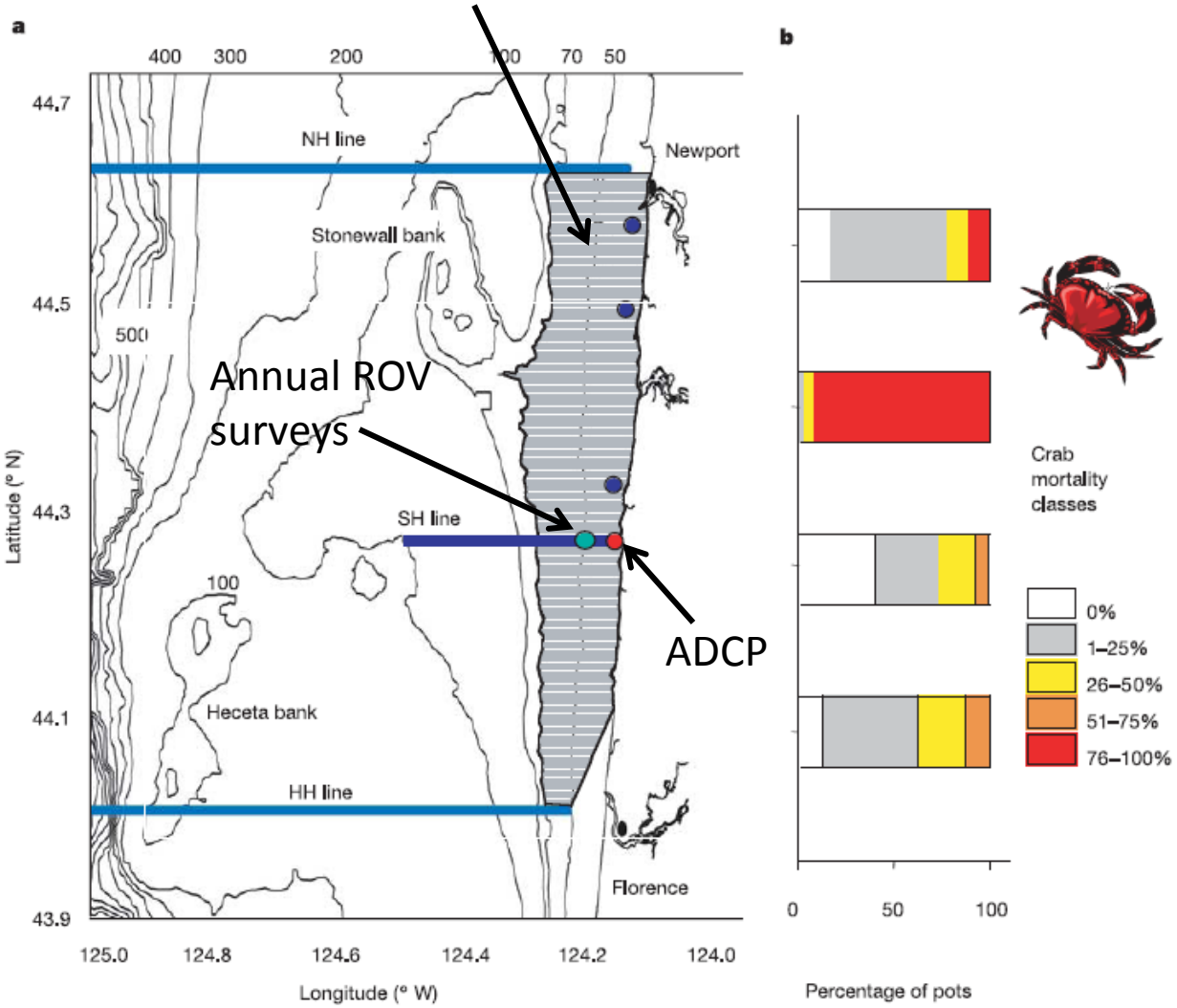
Proposed tidally-driven mechanism due to tidal mixing in straits between Sea of Okhotsk and Pacific increasing ventilation

7 year lag between West and East Pacific due to advection

Grantham, Chan, Nielsen, Fox, Barth, Huyer, Lubchenco, Menge, Nature 2004

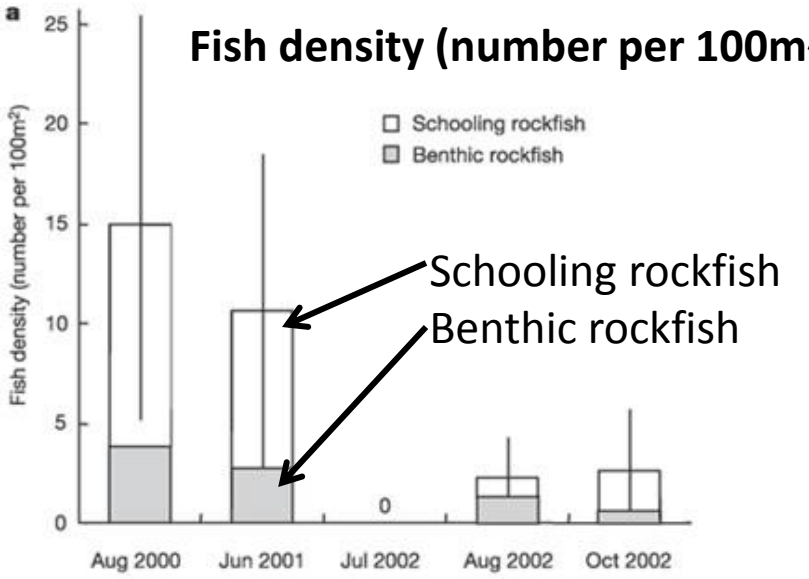
Intermittent events

Hypoxic zone observed off Oregon coast, summer 2002

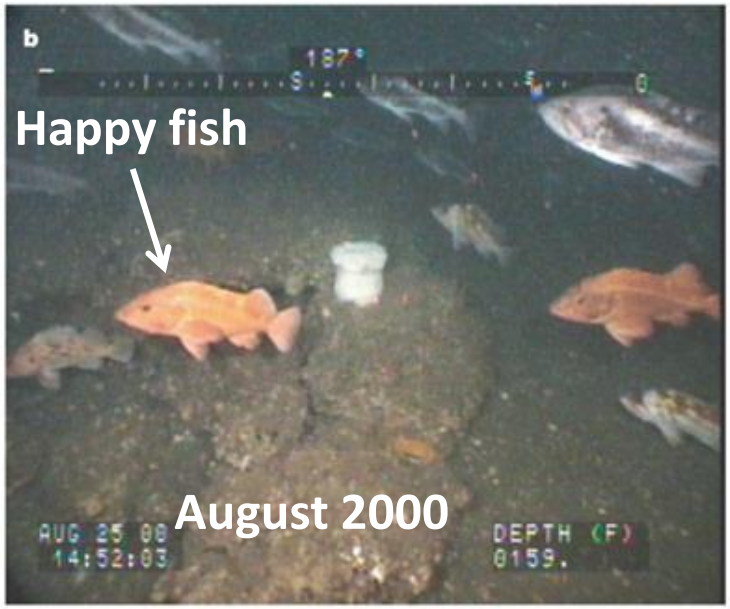


In summer 2002, the Oxygen Minimum Layer in the North Pacific intruded onto the Oregon shelf

Grantham, Chan, Nielsen, Fox, Barth, Huyer, Lubchenco, Menge, Nature 2004

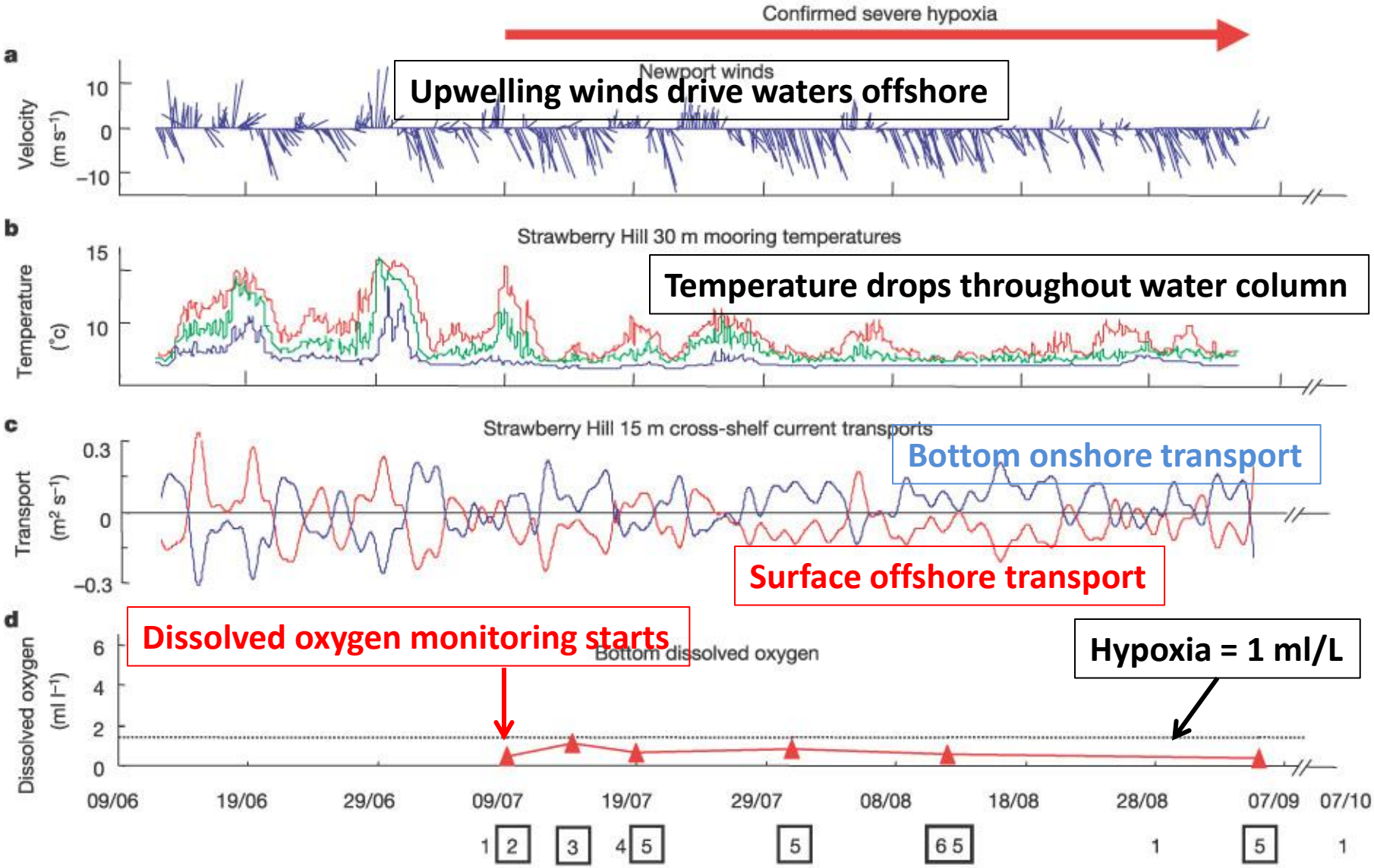


Hypoxia moved up trophic chain to affect non-benthic species



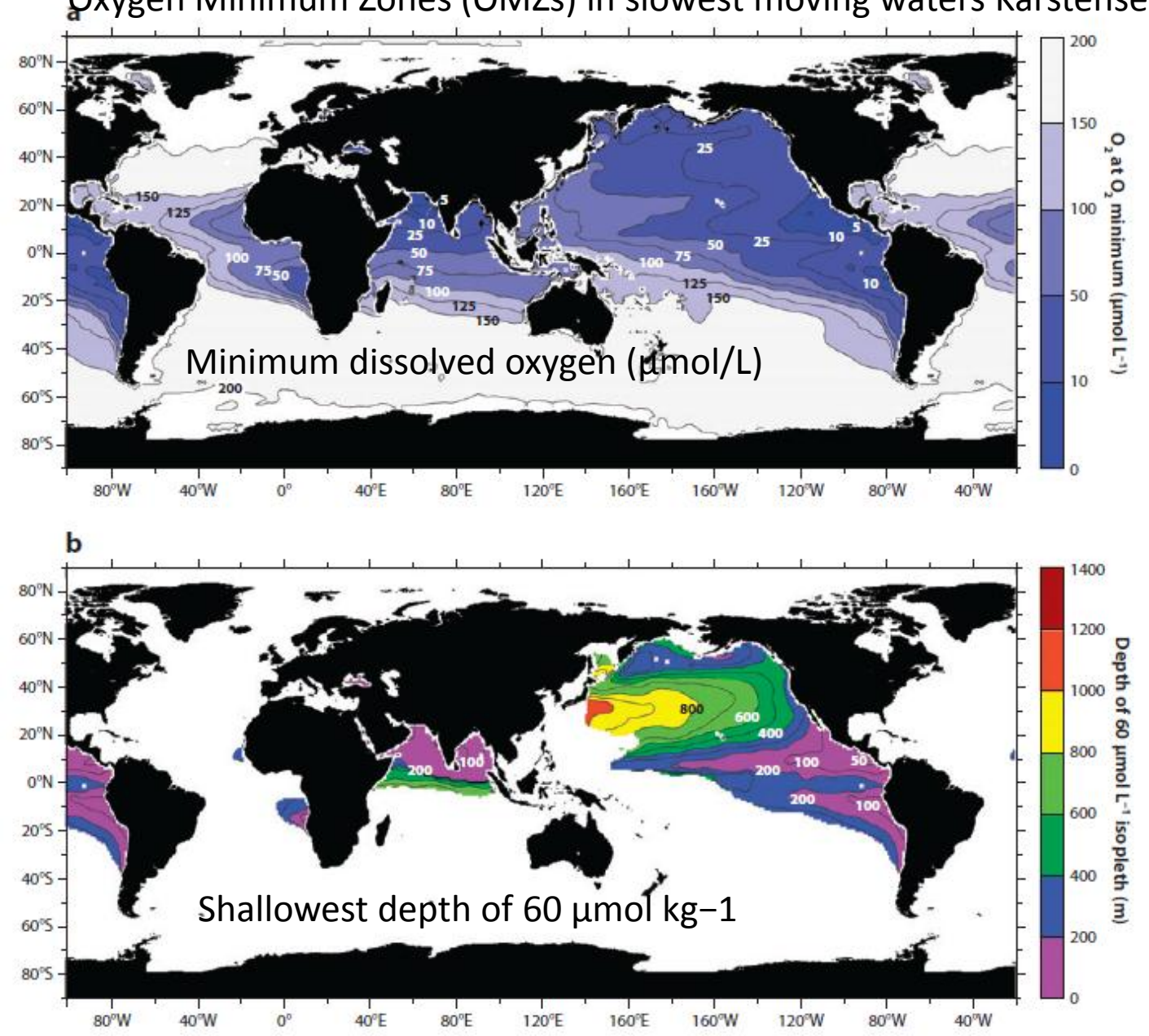
Grantham, Chan, Nielsen, Fox, Barth, Huyer, Lubchenco, Menge, Nature 2004

Wind shift results in hypoxia



Conkright et al., World Ocean Database, NESDIS, 2002

Oxygen Minimum Zones (OMZs) in slowest moving waters Karstensen et al. 2008).



Factors controlling oxygenation:

- O_2 when parcel was last at surface
- O_2 utilization rate
- Ventilation age, time since parcel was last exposed

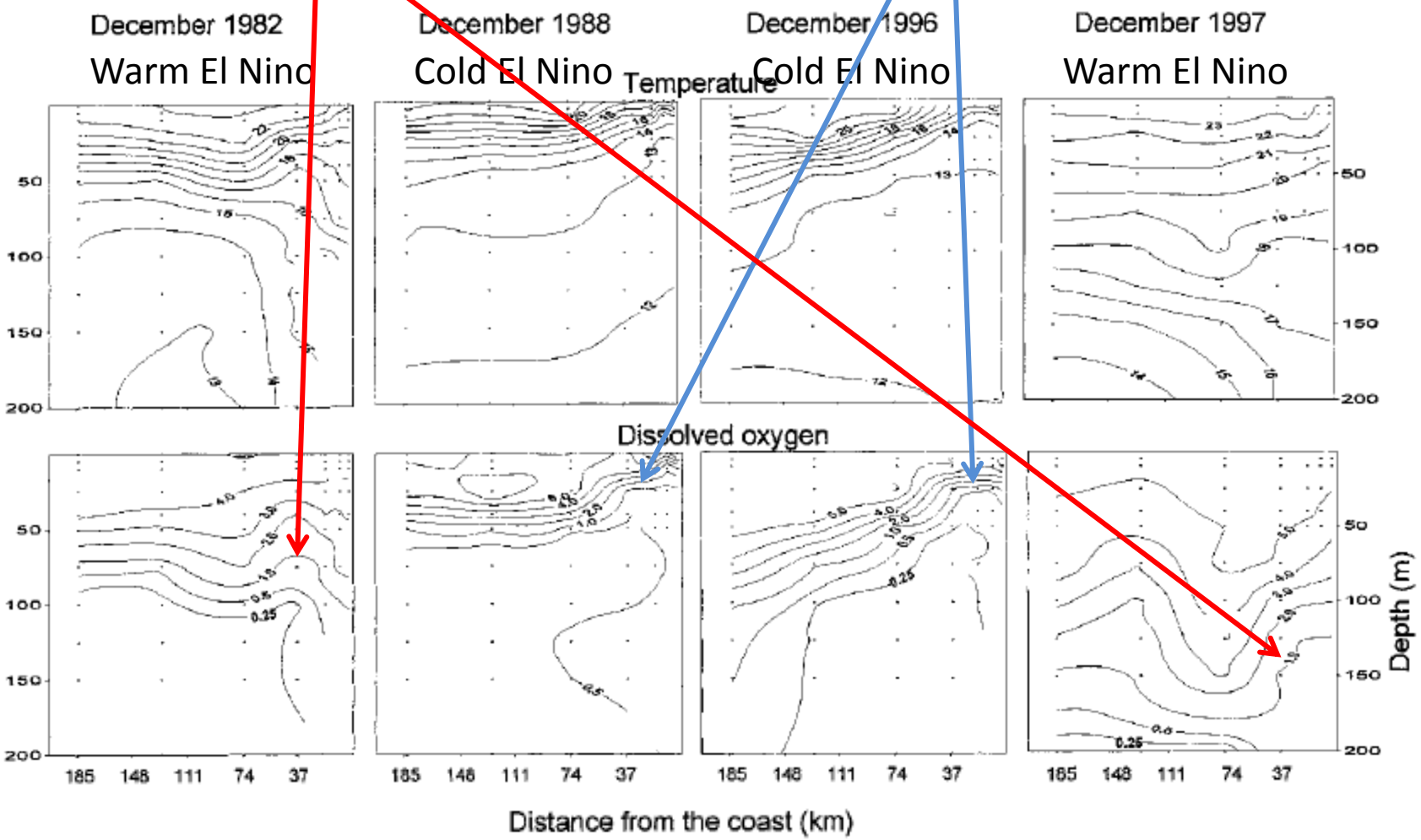
Hypoxia: < 60 µmol kg−1

Morales, Hormazabal, Blanco, J. Marine Res., 1999

Similar effects off Chile related to ENSO

Shoaling of oxycline (1 ml / liter) during cold El Nino phase relative to warm phase

Cycle-driven events



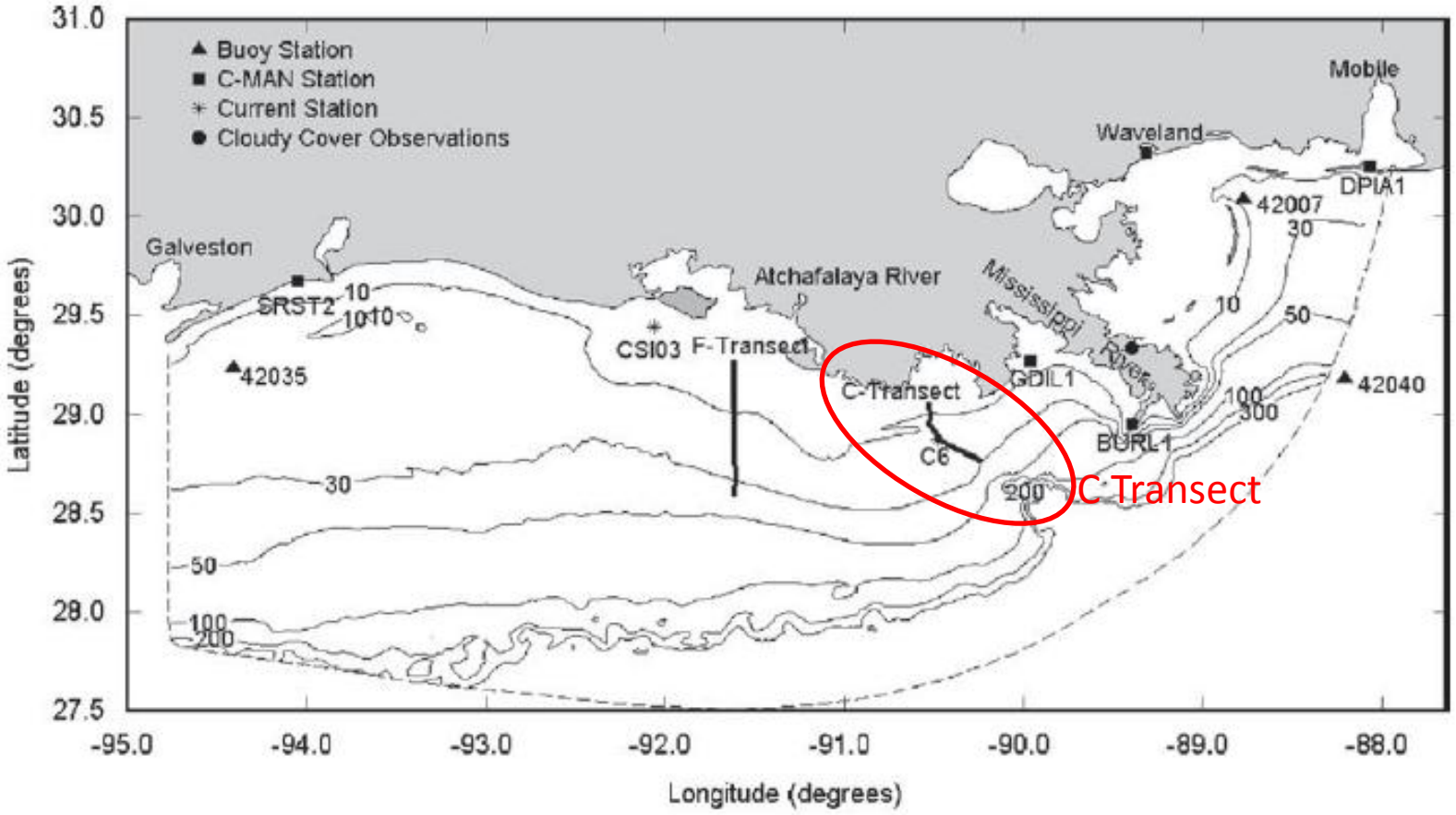
Wang, Justic, Continental Shelf Research, 2009

Louisiana hypoxic dead zone reoccurs annually

Stratification affects hypoxia by inhibiting surface and bottom water mixing

Events that affect stratification change hypoxic conditions

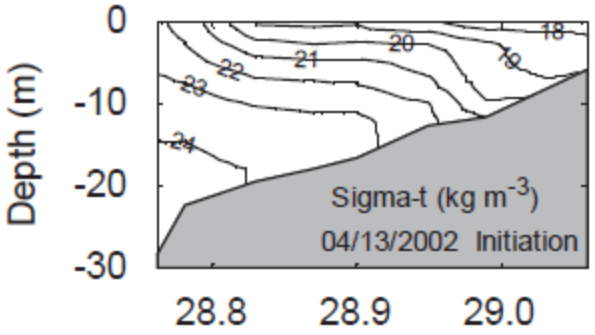
Ameliorating events

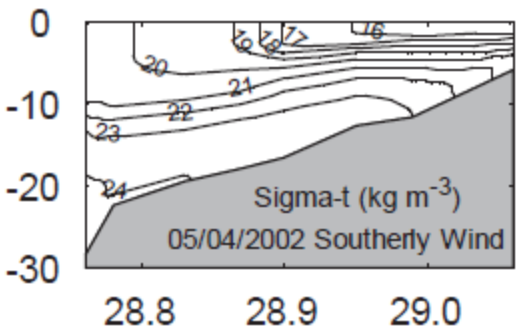


Wang, Justic, Continental Shelf Research, 2009

Sigma-t, potential density (kg/m^3) during 2002

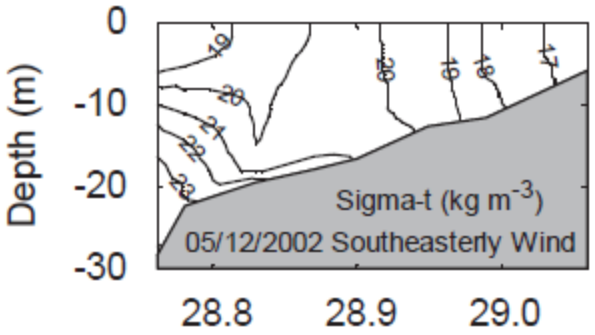
4/13
Calm winds

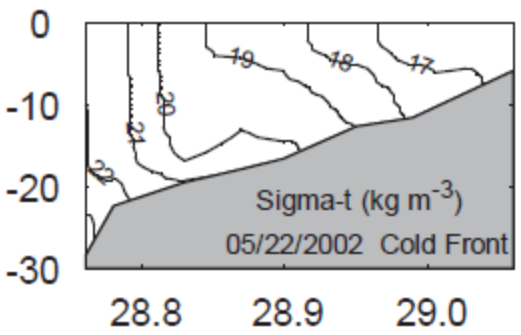




5/04
Southerly winds

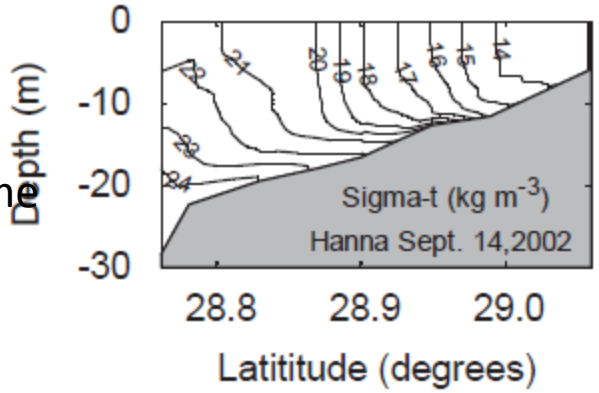
5/12
Southeasterly

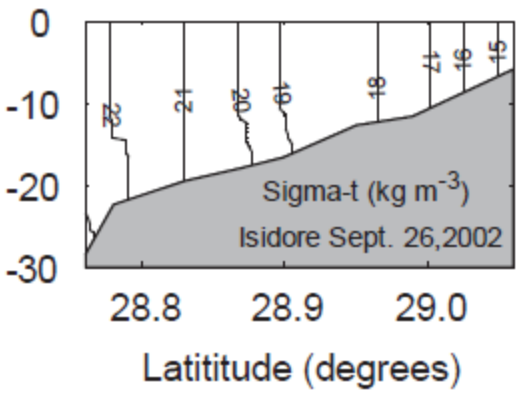




5/22
Cold front passage

7/14
Hanna
generates some
re-mixing

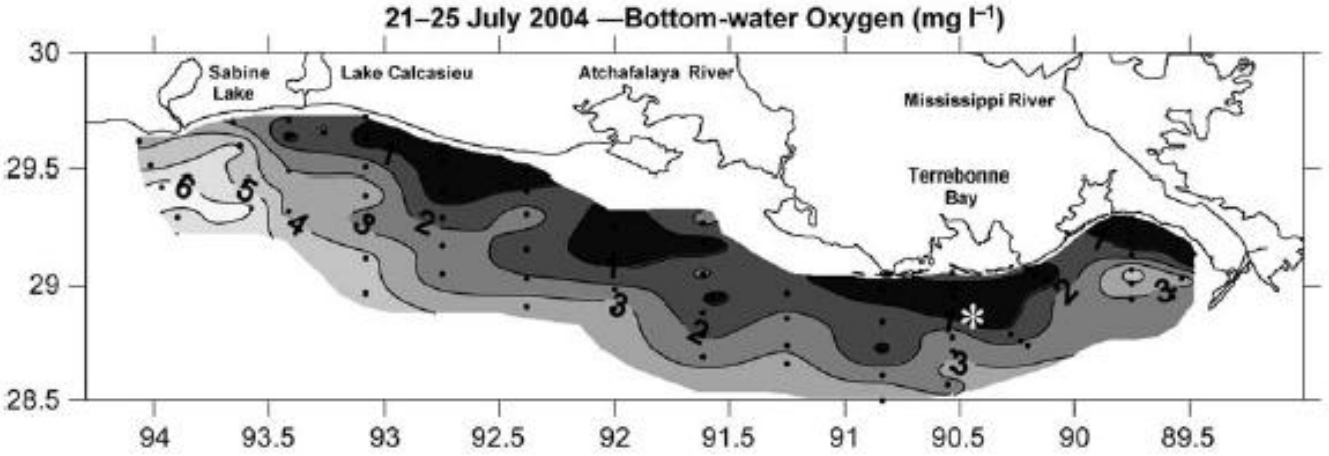




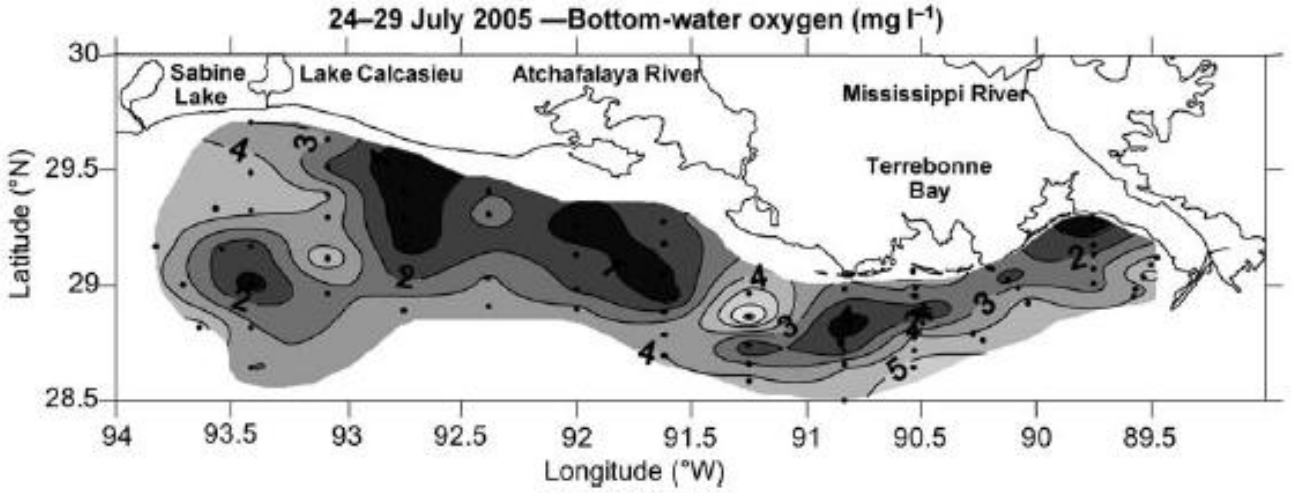
7/26
Isidore
Well mixed
water column

Rabalais, Turner, Diaz, Justic, Ices J. Marine Sciences, 2010

Hurricanes ventilate waters and induce mixing that disrupts hypoxia



2004 hypoxia coverage

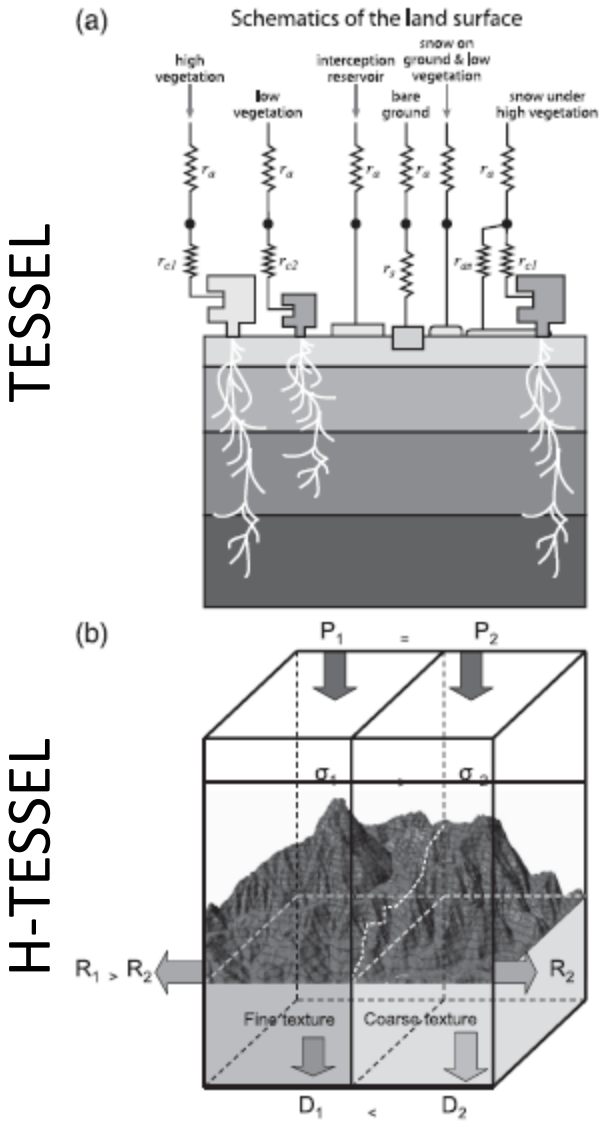


2005 after Cindy and Dennis resulted in smaller hypoxia zone than estimated from Nitrate-N load

Hypoxia was subsequently dispersed by Katrina and Rita

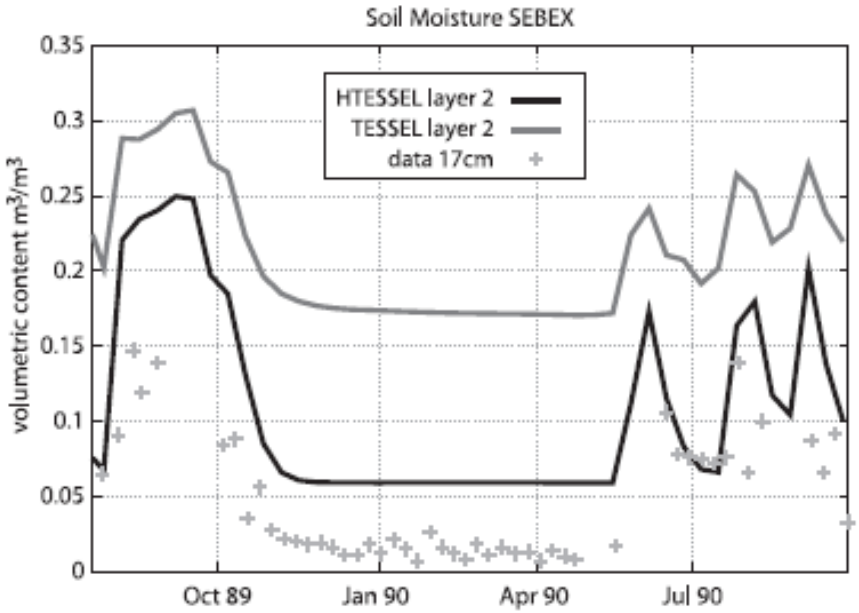
Balsamo, Viterbo, Beljaars, Van Den Hurk, Hirschi, Betts, Scipal, J. Hydrometeorology, 2009

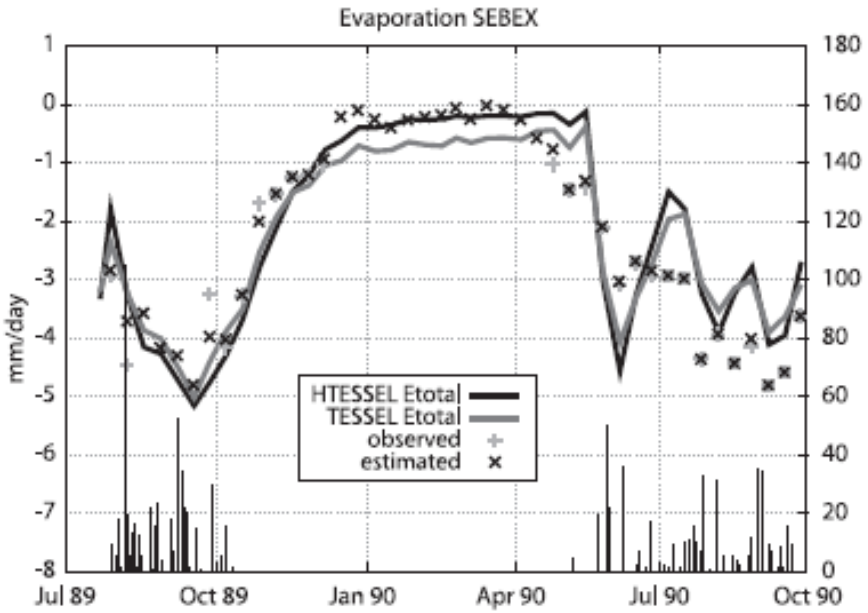
- Tiled ECMWF Scheme for Surface Exchanges over Land (TESSEL)
- Hydrology-TESSEL, H-TESSEL includes variable soil texture, soil hydraulic parameterizations, and runoff effects
- Implemented not to account for moisture and heat exchanges with atmosphere but for water movement and runoff effects
- 25km global resolution



Balsamo, Viterbo, Beljaars, Van Den Hurk, Hirschi, Betts, Scipal, J. Hydrometeorology, 2009

Sahelian Energy Balance Experiment (SEBEX; Wallace et al. 1991)



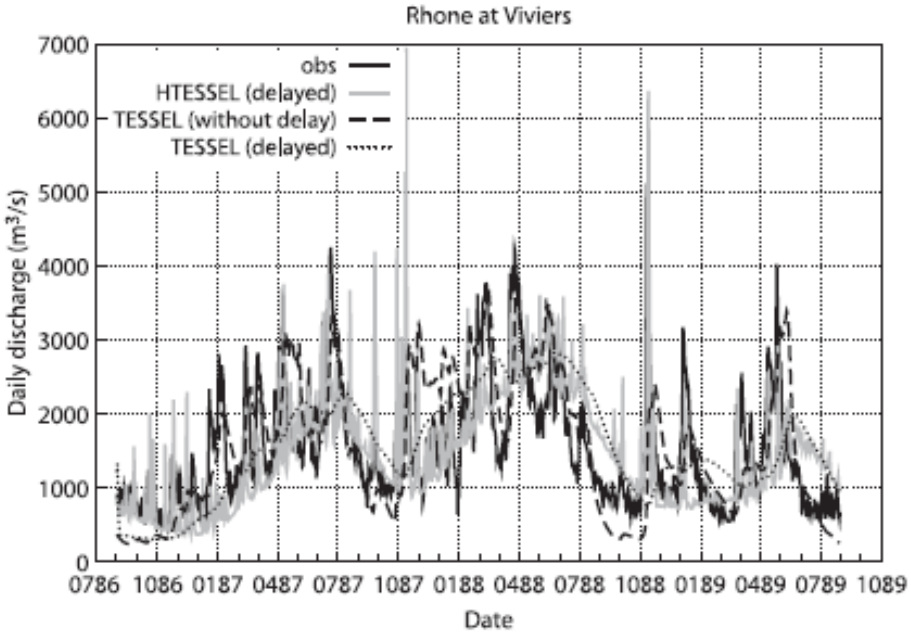


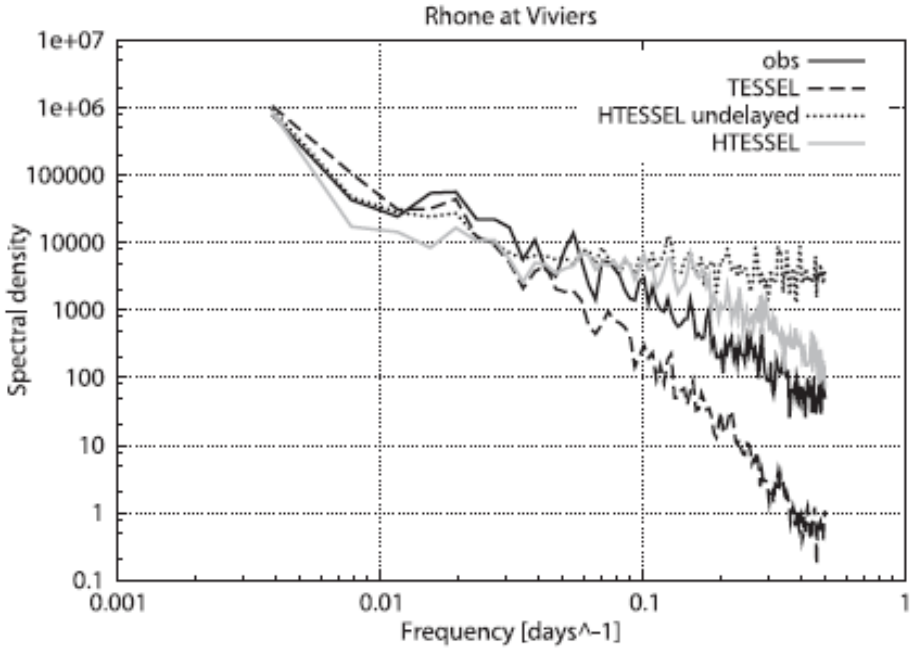
HTESSEL allows sandy soil that leads to much lower soil moisture than uniform medium texture soil of original TESSEL

Evaporation performance is very similar

Balsamo, Viterbo, Beljaars, Van Den Hurk, Hirschi, Betts, Scipal, J. Hydrometeorology, 2009

AGG experiment (Boone et al. 2004)

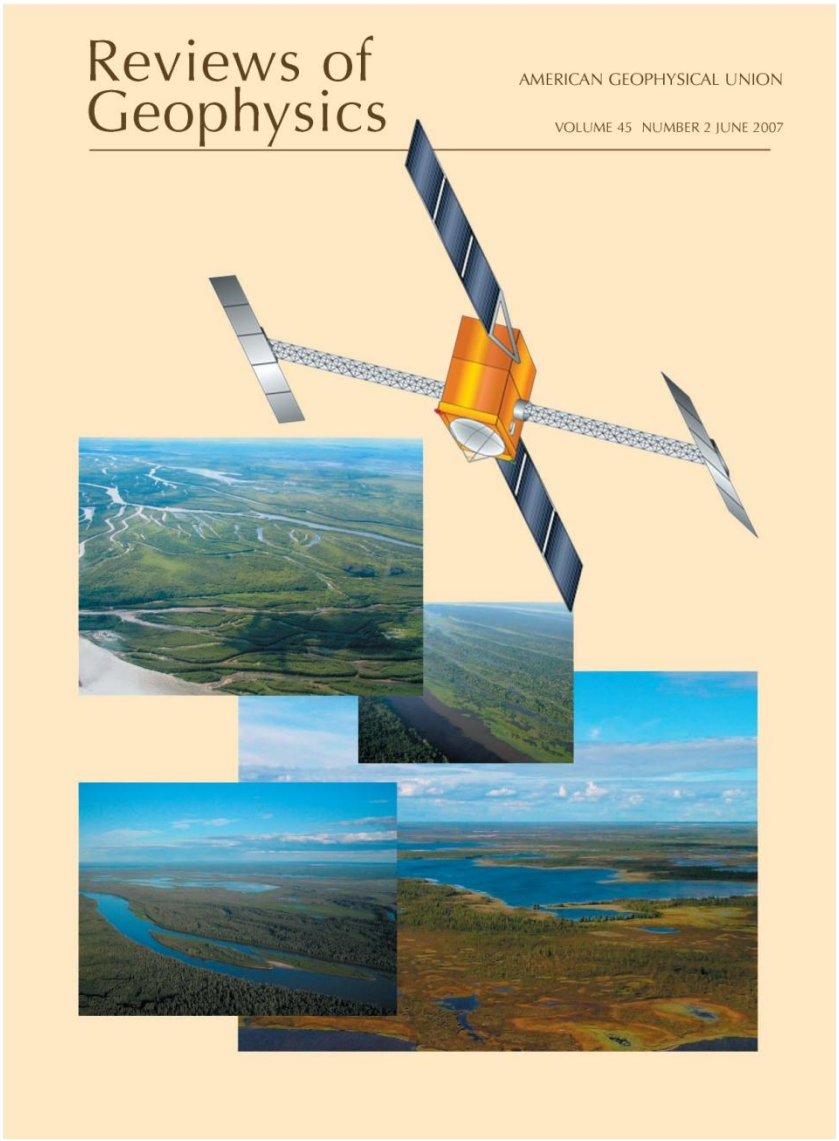


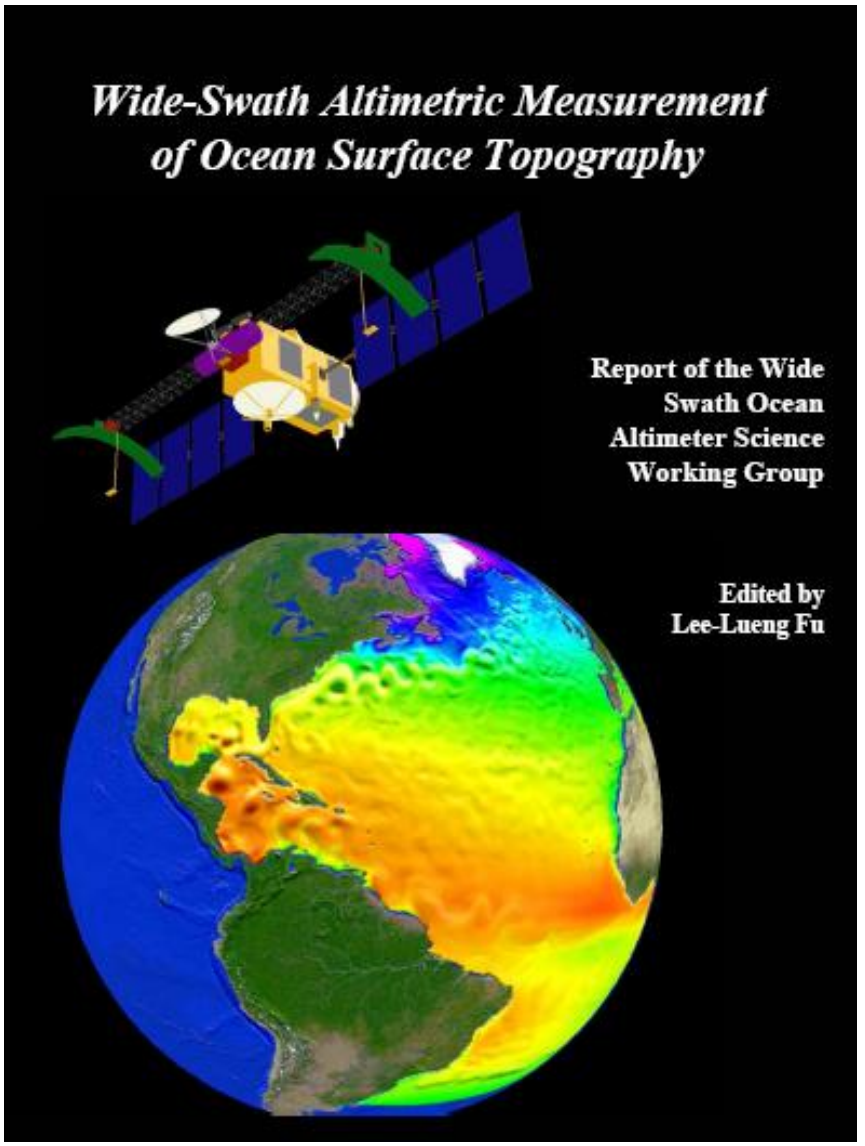


HTESSEL runoff represents high frequency variability better

A significant issue is connection from grid cell runoff to river routing

A crude routing scheme of 100km/day over the shortest path from grid cell to outflow was implemented





SWOT combines surface water hydrology with physical oceanography.

SWOT
Surface Water Ocean Topography

1. The Problem

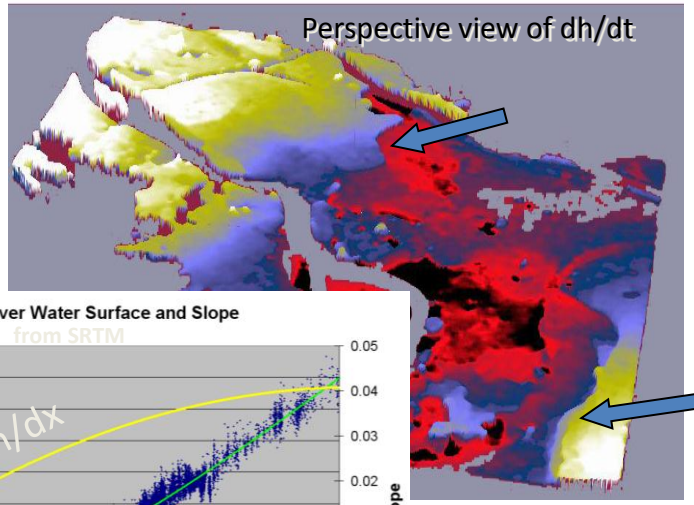
Floods are the number one hazard

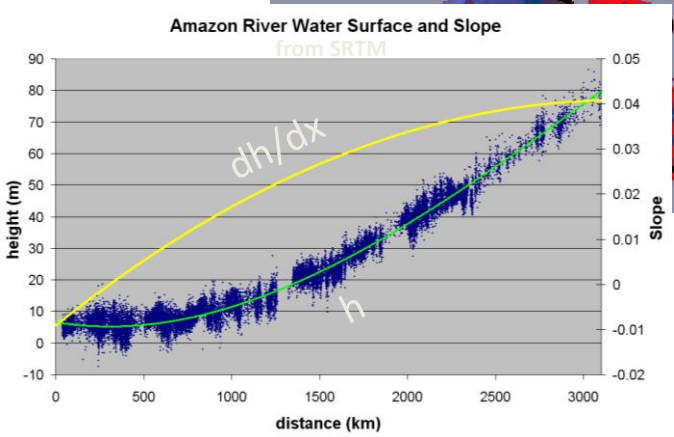
2. The Question

What is the spatial and temporal variability of freshwater stored in the world's terrestrial water bodies?

3. Measurements Required

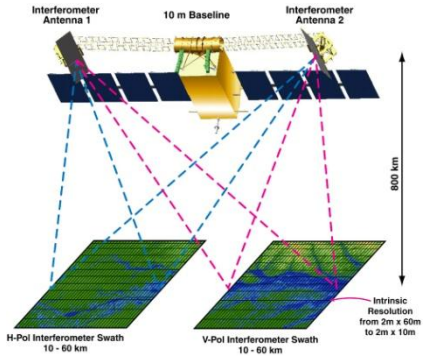
maps of h, which give maps of dh/dt and dh/dx





4. The Solution

KaRIN: Ka-band Radar Interferometer. SRTM, WSOA heritage. Maps of h globally and ~weekly.



Heisler, Glibert, Burkholder, Anderson, Cochlan, Dennison, Dortch, Gobler, Heijl, Humphries, Lewitus, Magnien, Marshall, Sellner, Stockwell, Stoecker, Suddleson, Harmful Algae, 2008

2003 EPA meeting consensus

(1) Degraded water quality from increased nutrient pollution promotes the development and persistence of many HABs and is one of the reasons for their expansion in the U.S. and other nations;

(2) The composition–not just the total quantity–of the nutrient pool impacts HABs;

(3) High-biomass blooms must have exogenous nutrients to be sustained;

(4) Both chronic and episodic nutrient delivery promote HAB development;

(5) Recently developed tools and techniques are already improving the detection of some HABs, and emerging technologies are rapidly advancing toward operational status for the prediction of HABs and their toxins;

(6) Experimental studies are critical to further the understanding about the role of nutrients in HABs expression, and will strengthen prediction and mitigation of HABs; and

(7) Management of nutrient inputs to the watershed can lead to significant reduction in HABs.

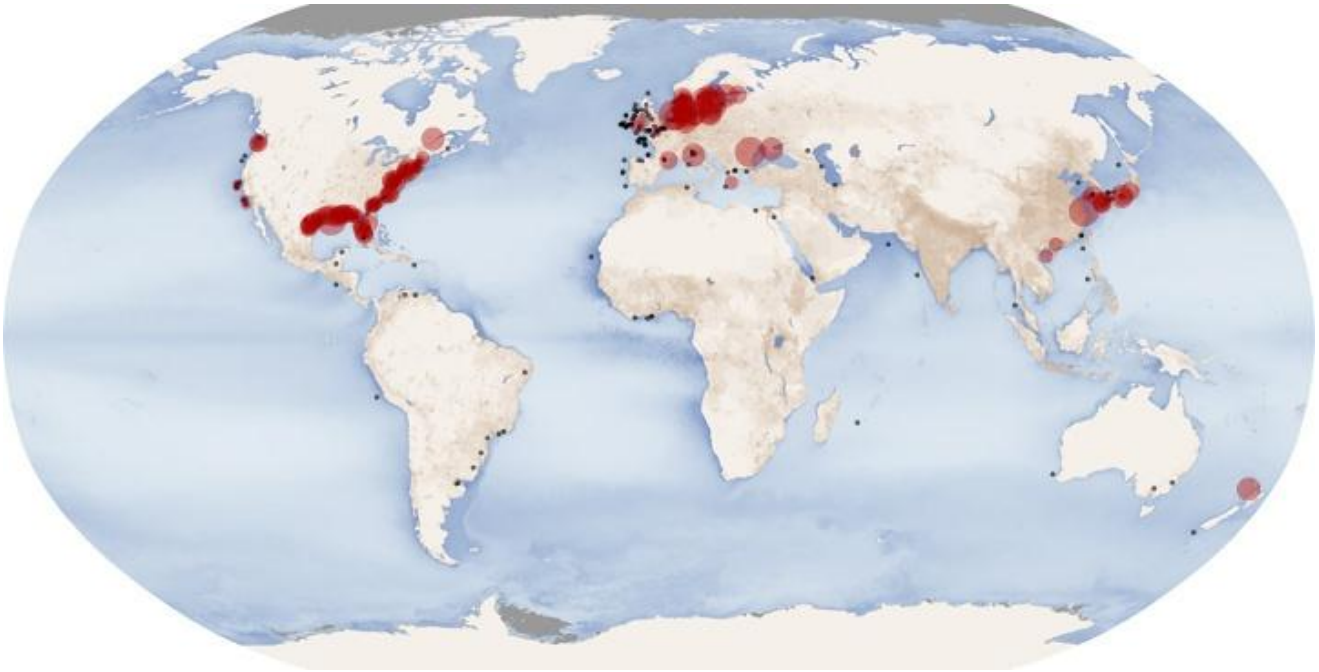
Glibert, Allen, Bouwman, Brown, Flynn, Lewitus, Madden, J. Marine Systems, 2010

Modeling of HABs and eutrophication: Status, advances, challenges

HAB prediction requires:

- Loading models of nutrients across watersheds from land and air
- Agricultural and aquacultural practices
- Precipitation
- Land geometry, physical properties
- Retentiveness of nutrients in local waters
- Rates and paths of nutrient consumption
- Plasticity of nutrient paths and food web

Hypoxia and Hydrology



- Generation of hypoxic conditions can be a reasonable metric for measuring ESPC success
- There are many physical causes at time scales from weeks to decades
- Observations and events are extensive
- Hypoxia resulting from eutrophication is difficult
    - Watershed nutrient load runoffs are difficult to predict
    - Biological processes are difficult to predict
    - There are modulating physical factors that are predictable

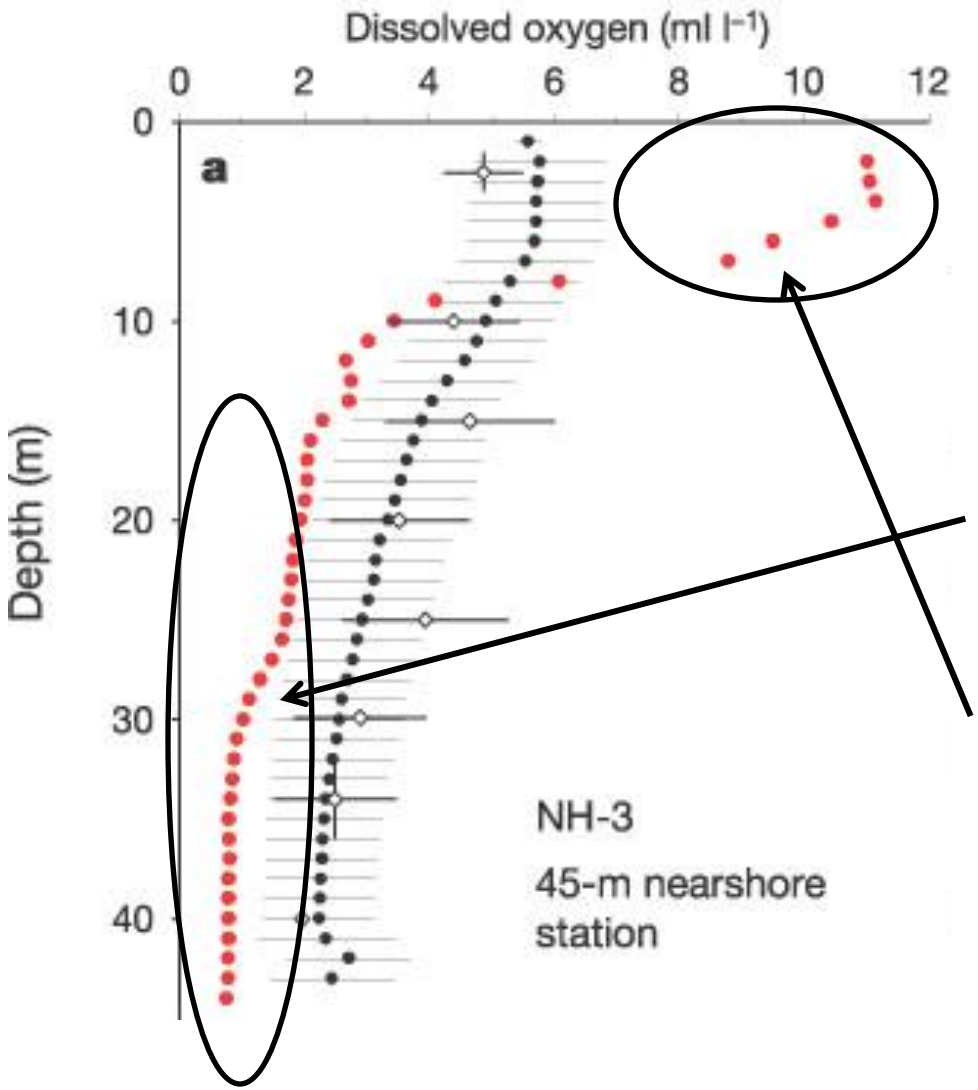
ESPC demonstration

- Oxygen Minimum Layer (OML) is a result of biology, and hypoxia induced by OML is very physically driven across a range of time scales
- Oxygen content is affected by long term cycles
- OML-driven hypoxic events are physically driven
- Physical events affect eutrophication driven hypoxia by altering stratification
- Long term cycles affecting stratification will affect eutrophication driven hypoxia
- Land models incorporating runoff, hydrology and river routing are becoming mature
- Freshwater flow from land is a strong modulator on stratification
- SWOT provides a developing science community for hydrology

- Recommend focusing ESPC demonstration on physical aspects of hypoxia

Questions

Grantham, Chan, Nielsen, Fox, Barth, Huyer, Lubchenco, Menge, Nature 2004



● July 2002 samples

● 1998-2001 samples

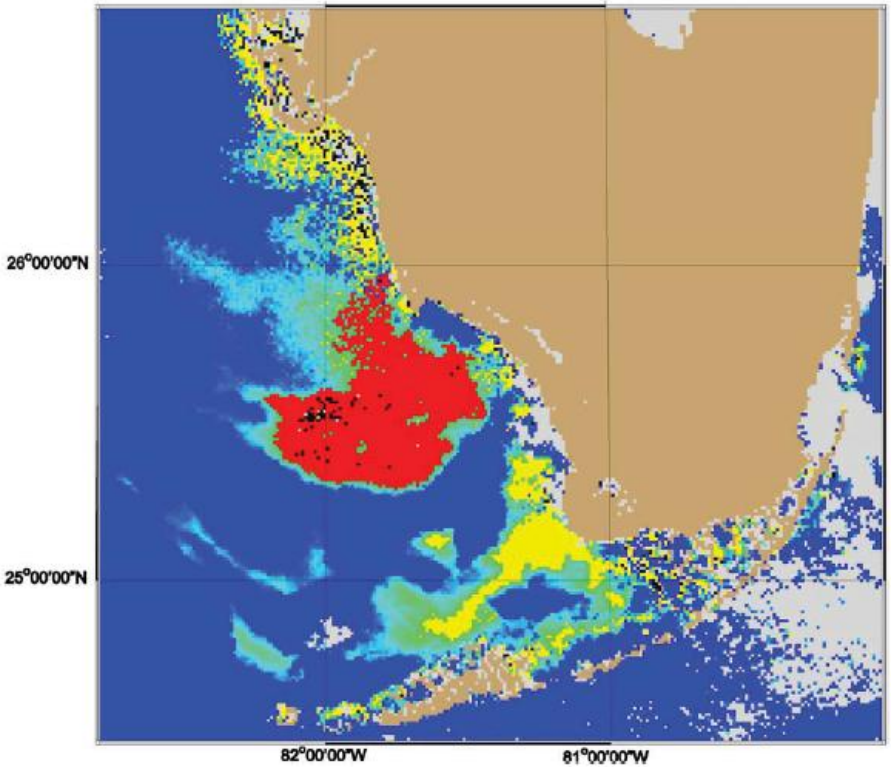
◇ July-September mean

Low oxygen waters nearshore

High winds induce wave action resulting in higher than usual oxygenated surface waters

Horizontal bars are 95% confidence intervals

Stumpf, Tomlinson, Clakins, Kirkpatrick, Fisher, Nierenberg, Currier, Wynne, J. Marine Systems, 2009



Nowcast/identification heuristic model

Chlorophyll anomaly	>1 μg L^{-1}
Season	Aug–Jan (or during persistent HAB)
Geography	Pinellas to Collier Counties (unless know bloom is tracked outside this area)
Size	>30 km^2
Shape	Patch, not coast-wide
Upwelling/ winds	>20 km onshore transport
Respiratory	Impact reported with onshore winds
Cell counts	Used for subsequent confirmation

Present state of HAB forecasting

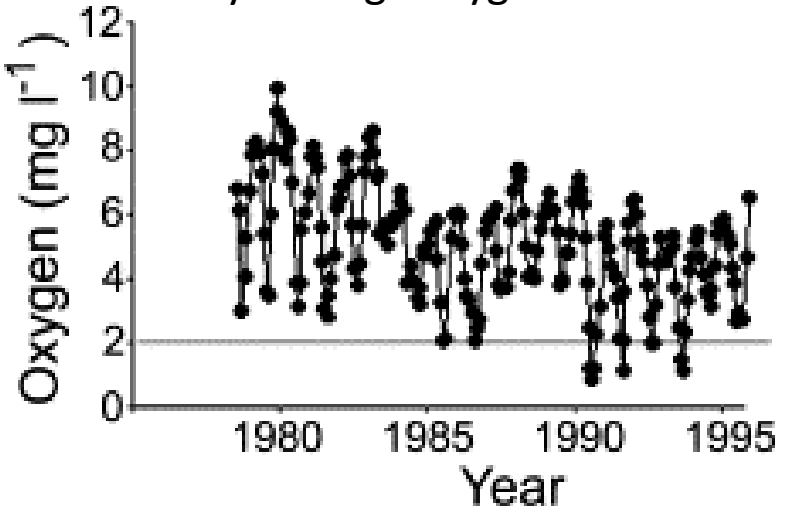
- Uses satellite chlorophyll observations
- Applies local conditions lookup table
- Heuristic transport based on forecast winds
- Site-specific due to local nutrient outflows and biological processes

Turner, Rabalais, Swenson, Kasprzak, Romaire, Marine Env. Res., 2005

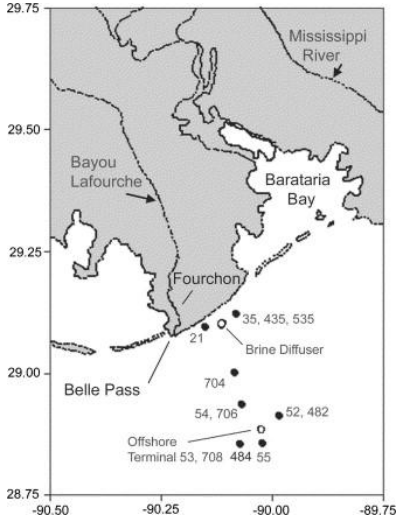
Eutrophication and harmful blooms require extensive additional information

Statistical models based on direct observations have been constructed to relate oxygen concentration to nutrient loads

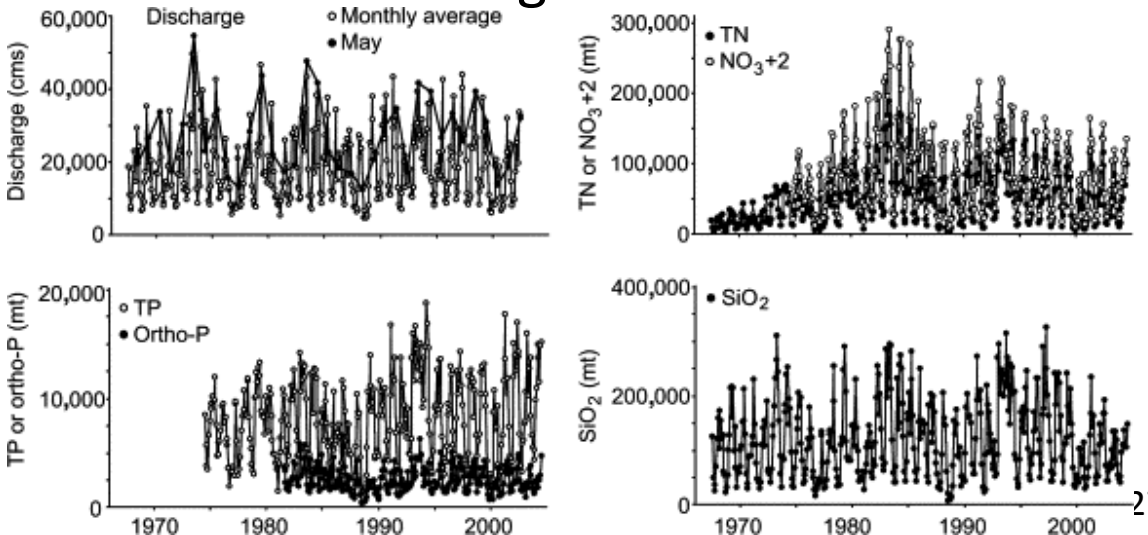
Monthly average oxygen concentration



Louisiana Offshore Oil Port (LOOP) 36m water depth



Nutrient loading at MS river mouth



Balsamo, Viterbo, Beljaars, Van Den Hurk, Hirschi, Betts, Scipal, J. Hydrometeorology, 2009

Boreal Ecosystem Research and Monitoring Sites (BERMS) site located in a Canadian boreal Old Aspen forest (central Saskatchewan) has a high soil water retention