Climate, Nutrients, and Hypoxia: Predicting Water Quality Trends in the Next 100 Years

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The Greenhouse Gases

Abnormal Levels Influenced by Man's Actions

Source: NASA/Goddard Space Flight Center
Sensitivity of the northern Gulf of Mexico to global climate change

- Dominated by discharges of one of the world largest rivers - the Mississippi River (drains 41% of the area of the contiguous 48 states);

- Coastal Louisiana’s land loss rates are the highest in the U.S. (60 - 80% of the nation’s total wetland loss);

- Supports one of the most valuable U.S. fisheries, exceeded only by the combined Pacific Coast and Alaska regions;

- Affected by tropical storms and hurricanes;

- Continental shelf of the northern Gulf of Mexico is the site of the largest and most severe coastal hypoxic (“dead”) zone in the western Atlantic Ocean (> 22,000 km²).
How can GCC affect the northern Gulf of Mexico, and the hypoxic zone in particular?

What can we do about it?
Variations of the Earth's surface temperature for...

Departures in temperature in °C (from the 1961-1990 average)

- **the past 140 years (global)**
- **the past 1000 years (Northern Hemisphere)**

- Direct temperatures
- Proxy data
Variations of the Earth’s surface temperature: year 1000 to year 2100

Departures in temperature in °C (from the 1990 value)

Observations, Northern Hemisphere, proxy data
Global instrumental observations
Projections
Several models all SRES envelope

Data show the range in year 2100 produced by several models

Scenarios
- A1B
- A1T
- A1F1
- A2
- B1
- B2
- IS92a

IPCC
INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
Global water cycle

$\left(10^3 \ \text{km}^3 \ \text{yr}^{-1}\right)$

- **Vapor transport** (40)
- **Evaporation** (425)
- **Evaporation + transpiration** (71)
- **Precipitation** (385)
- **Riverine runoff** (40)
- **Groundwater flow**
- **Percolation** (111)
Projected 2xCO₂ runoff

(adapted from Miller & Russell, 1992)
Year 2090 - 2099

Canadian

New England
Mid-Atlantic
S Atlantic – E Gulf
Mississippi River
W Gulf
Pacific NW
California

Percent Change in Runoff

(Wolock and McCabe, 1999)
FIG. E.S. 1  *Mississippi-Atchafalaya River Basin and Gulf Hypoxic Zone*

How Hypoxia develops

Hypoxia Task Force Report, 1999
Hypoxia = Dissolved $O_2 < 2$ mg/L (=2 ppm)

Data from Leming and Stuntz, 1984; SW Louis. Coast, June 1982
If you cannot breathe, nothing else matters.

(American Lung Association)
Occurrence of mid-summer hypoxia 1985-2001
(Source: N. Rabalais, LUMCON)

[Map showing the occurrence of mid-summer hypoxia in various regions]

- >75%
- >50%
- >25%
- <25%

50 km
Estimated Size of Bottom-Water Hypoxia in Mid-Summer

Area (km²)

N. Rabalais, LUMCON
Justic et al., 2002
## Trends in the Mississippi River Runoff, Nitrate Concentration, and Nitrate Flux 1954-2000

<table>
<thead>
<tr>
<th>Period</th>
<th>Q (m³ s⁻¹)</th>
<th>N-NO₃ (mg l⁻¹)</th>
<th>N-NO₃ flux (kg d⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983-00</td>
<td>x=15,874</td>
<td>x=1.37</td>
<td>x=2.01x10⁶</td>
</tr>
<tr>
<td></td>
<td>SD=7,908</td>
<td>SD=0.55</td>
<td>SD=1.36x10⁶</td>
</tr>
<tr>
<td></td>
<td>n=209</td>
<td>n=208</td>
<td>n=208</td>
</tr>
<tr>
<td></td>
<td>(p&lt;0.01)</td>
<td>(p&lt;0.001)</td>
<td>(p&lt;0.001)</td>
</tr>
<tr>
<td>1968-82</td>
<td>x=13,849</td>
<td>x=1.05</td>
<td>x=1.34x10⁶</td>
</tr>
<tr>
<td></td>
<td>SD=7,104</td>
<td>SD=0.49</td>
<td>SD=0.99x10⁶</td>
</tr>
<tr>
<td></td>
<td>n=180</td>
<td>n=153</td>
<td>n=153</td>
</tr>
<tr>
<td></td>
<td>(p&lt;0.001)</td>
<td>(p&lt;0.001)</td>
<td>(p&lt;0.001)</td>
</tr>
<tr>
<td>1954-67</td>
<td>x=11,381</td>
<td>x=0.61</td>
<td>x=0.63x10⁶</td>
</tr>
<tr>
<td></td>
<td>SD=6,359</td>
<td>SD=0.28</td>
<td>SD=0.49x10⁶</td>
</tr>
<tr>
<td></td>
<td>n=161</td>
<td>n=160</td>
<td>n=160</td>
</tr>
<tr>
<td></td>
<td>(p&lt;0.001)</td>
<td>(p&lt;0.001)</td>
<td>(p&lt;0.001)</td>
</tr>
</tbody>
</table>
Coupling between river flow and hypoxia

Mississippi River discharge

- Max
- Mean
- Min

Areal extent of hypoxia

Month

Q (m³s⁻¹)

July 1987

July 1988

July 1991

July 1993

LOUISIANA

30° 29° 30° 29° 30° 29°

93° 92° 91° 90°

Justic et al., 1996
What will happen in the next 100 years?

Prediction is very difficult, especially about the future

(Niels Bohr)
Climate Variability
Climate Change

Increased Global Temperatures
Enhanced Hydrologic Cycle

Physical Environment (Stratification)
Riverine Nutrient Fluxes

Nutrient-Enhanced Productivity

Sedimentary Carbon and Nutrient Pools
Bottom Hypoxia

Eutrophication
Justic et al., 2002
Nominal model

Justic et al., 2002
Justic et al., 2002
Model Scenarios

- 30% reduction in MR runoff (Wolock and McCabe, 1999)
- MR nitrate concentration unchanged with respect to 1954–1967
- 20% increase in MR runoff (Miller and Russell, 1992)
- 4 °C increase in NGM temperature (IPCC, 2001)
- 20% increase in MR runoff + 4 °C increase in NGM temperature (likely GCC scenario; IPCC, 2001)
- 30% reduction in MR nitrate flux (proposed management action; Rabalais et al., 2002)
MR nitrate 1954-1967

O₂ concentration (mg l⁻¹)

Surface

Bottom

Years

+20% MR runoff +4°C

O₂ concentration (mg l⁻¹)

Years

Surface

Bottom
-30% MR nitrate flux

O$_2$ concentration (mg l$^{-1}$)

Surface

Bottom

Years

## Model Results

<table>
<thead>
<tr>
<th>Scenario</th>
<th>YWMH &lt; 2 mg/l</th>
<th>YWSH &lt; 1 mg/l</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Nominal model</td>
<td>19</td>
<td>16</td>
<td>-</td>
</tr>
<tr>
<td>2. -30% MR runoff</td>
<td>8</td>
<td>4</td>
<td>-58</td>
</tr>
<tr>
<td>3. MR nitrate 1954-1967</td>
<td>0</td>
<td>0</td>
<td>∞</td>
</tr>
<tr>
<td>4. +20% MR runoff</td>
<td>26</td>
<td>20</td>
<td>+37</td>
</tr>
<tr>
<td>5. +4 °C</td>
<td>25</td>
<td>19</td>
<td>+32</td>
</tr>
<tr>
<td>6. +20% MR runoff +4 °C</td>
<td>31</td>
<td>26</td>
<td>+63</td>
</tr>
<tr>
<td>7. -30% MR nitrate flux</td>
<td>12</td>
<td>7</td>
<td>-37</td>
</tr>
</tbody>
</table>

The total number of years = 45

Justic et al., 2003
What about hurricanes?
Danny Dolly Status

- Tropical Depression
- Tropical Storm
- Hurricane 1

Status:
- 7/16/97
- 7/20/97
- 7/24/97

Dates:
- 7/16/97
- 7/20/97
- 8/19/96
- 8/25/96
- 8/19/96
Hurricane Dolly 8/19/96 - 8/25/96

(Adapted from: http://www.amerwxccnpt.com/tropical/Dolly/dolly_9608222130_4km.jpg)
Sampling design

Source: D. Justic, Coastal Ecology Institute, Louisiana State University
Comparison of Continuous Record on station C6B (19.2 m) and Wind at Grand Isle from 8/15/96 - 9/20/96

- Wind Direction (deg)
- Wind Speed (m/s)
- Temperature (°C)
- Salinity (ppt)
- DO (mg/L)

Hydrodata Measurements

Source: D. Justic, Coastal Ecology Institute, Louisiana State University
Conclusions

The ecosystem of the northern Gulf of Mexico appears to be highly sensitive to GCC.

Model simulations suggest that an increase of 20% in the annual Mississippi River discharge, accompanied by a 4 °C increase in ambient water temperatures, which are likely under a 2XCO$_2$ scenario, may cause a 60% increase in the frequency of hypoxia.

GCC could have major impacts on the abundance and diversity of benthic and epibenthic species, including those that are commercially important.
What can we do?

- Reduce MR nutrient load.
- Better management of fisheries resources to lessen negative impacts resulting from GCC.