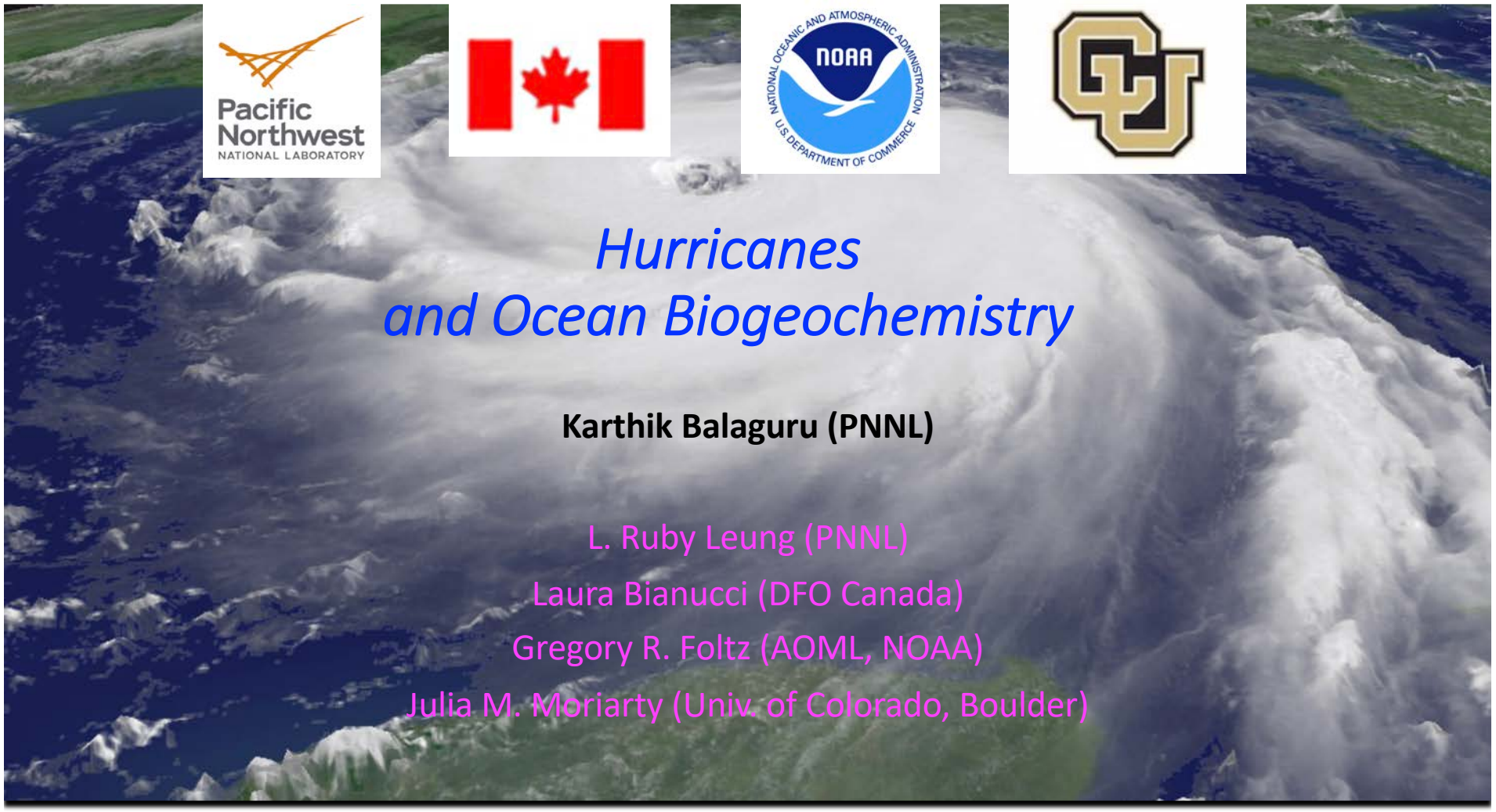


Hurricanes and Ocean Biogeochemistry

Karthik Balaguru (PNNL)

L. Ruby Leung (PNNL)

Laura Bianucci (DFO Canada)

Gregory R. Foltz (AOML, NOAA)

Julia M. Moriarty (Univ. of Colorado, Boulder)

Most destructive weather systems

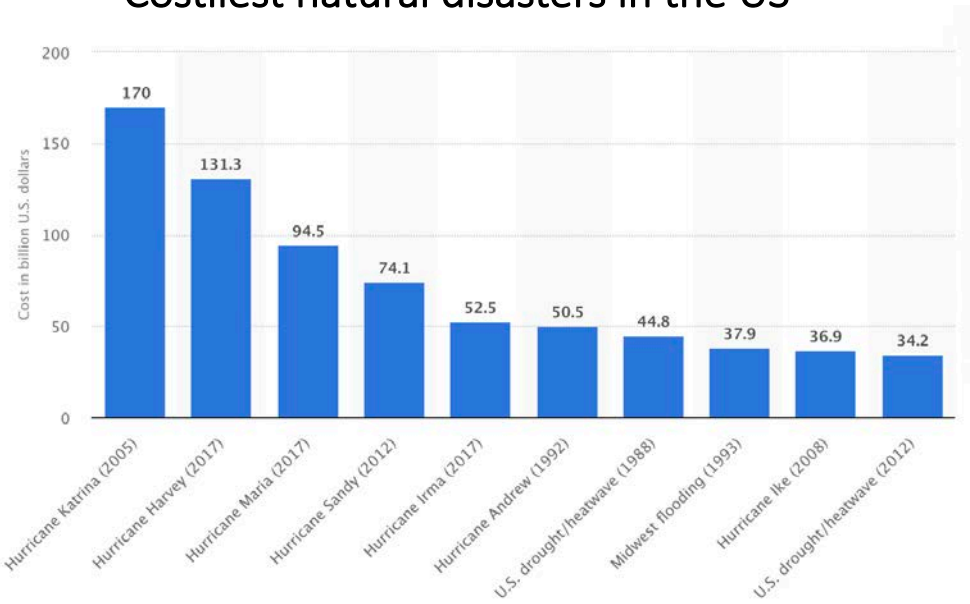
The Great Galveston Hurricane (1900)

Source: NOAA

Nearly 10,000 fatalities

Source: Library of Congress

Costliest natural disasters in the US



Source: statista

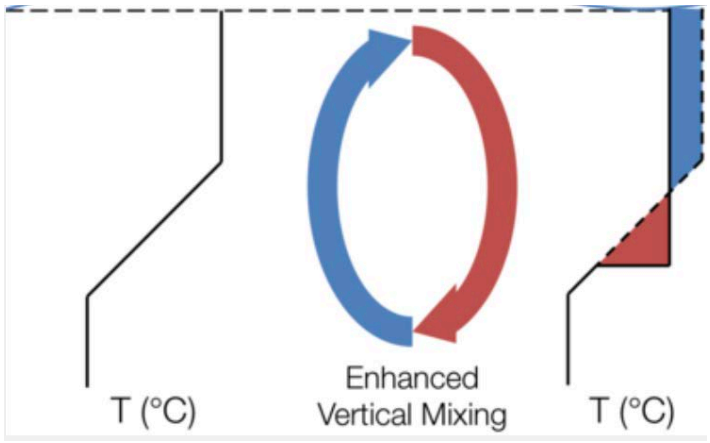
Top 5, 7 in top 10 are hurricanes

Interaction with the ocean

Hurricanes intensify by extracting heat energy from the ocean's surface

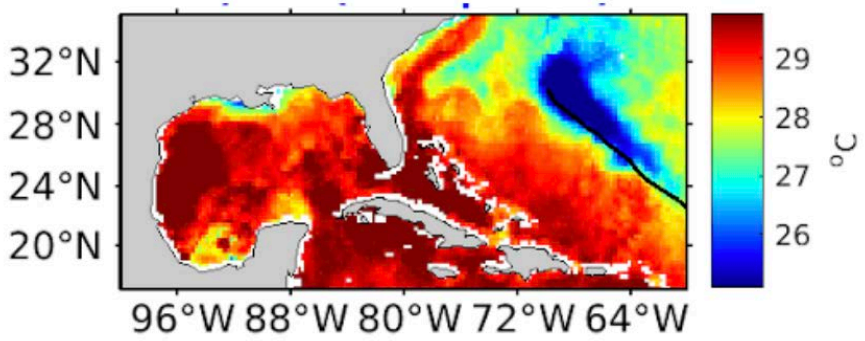
Hurricanes induce a blast of vertical mixing in the upper-ocean

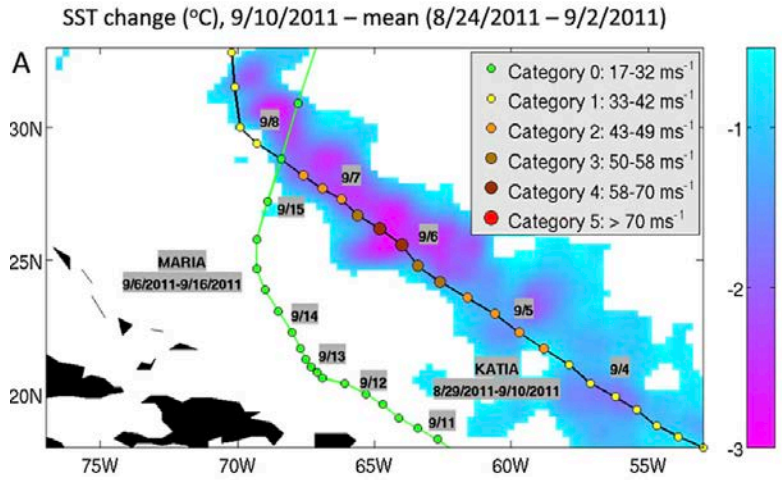
Results in cooling of the sea surface, acts as a negative feedback to the storm's intensity



Source: po.gso.uri.edu

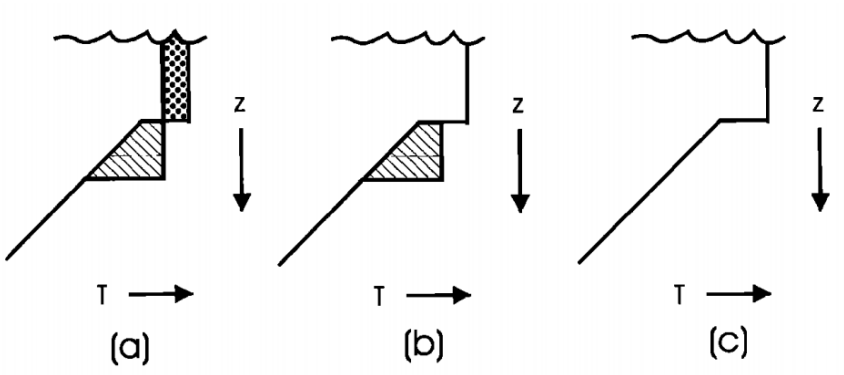
Hurricane Katia (2011)





Balaguru et al. (2014)

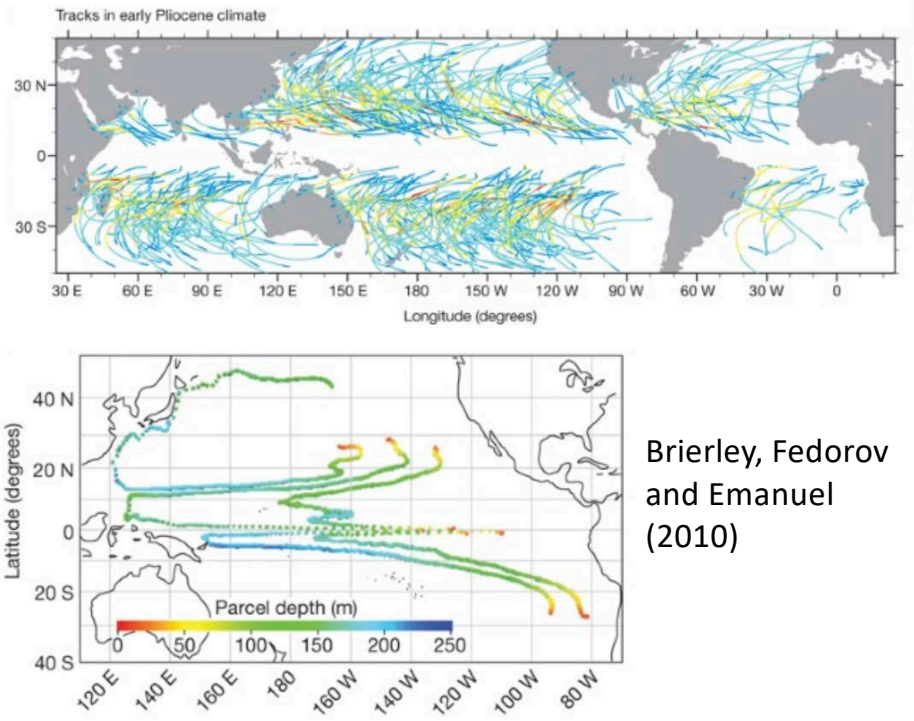
Potential to impact climate



Emanuel (2001)

Atmosphere restores the upper-ocean to pre-storm state

Build-up of heat in the sub-surface, results in poleward heat transport (~ 0.7-2 PW)



Brierley, Fedorov and Emanuel (2010)

May have played a role in the permanent El Niño like conditions during the early Pliocene

What about their role in ocean BGC ?

1) Impact on Chlorophyll Blooms in the North Atlantic

(Foltz, Balaguru and Leung (2015))

Open Ocean Study

2) Effect on Hypoxia in the Gulf of Mexico

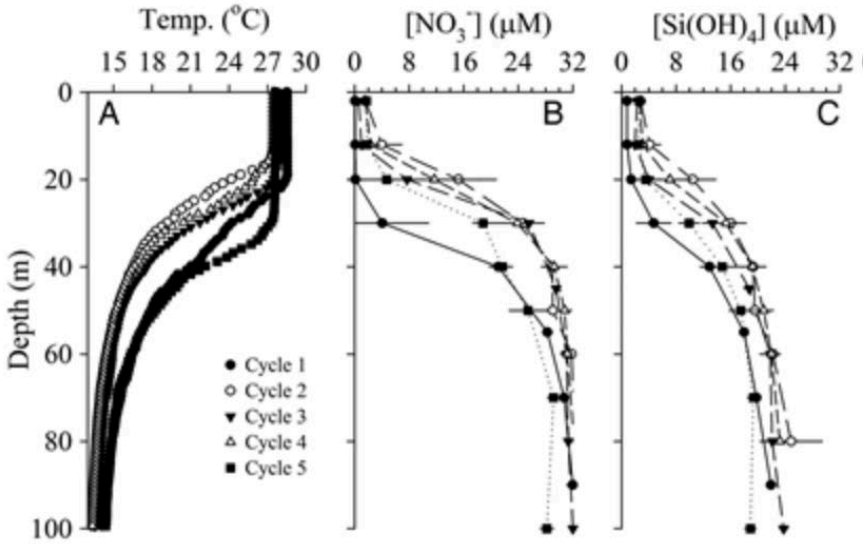
(Bianucci et al. (2018))

Coastal Ocean Study

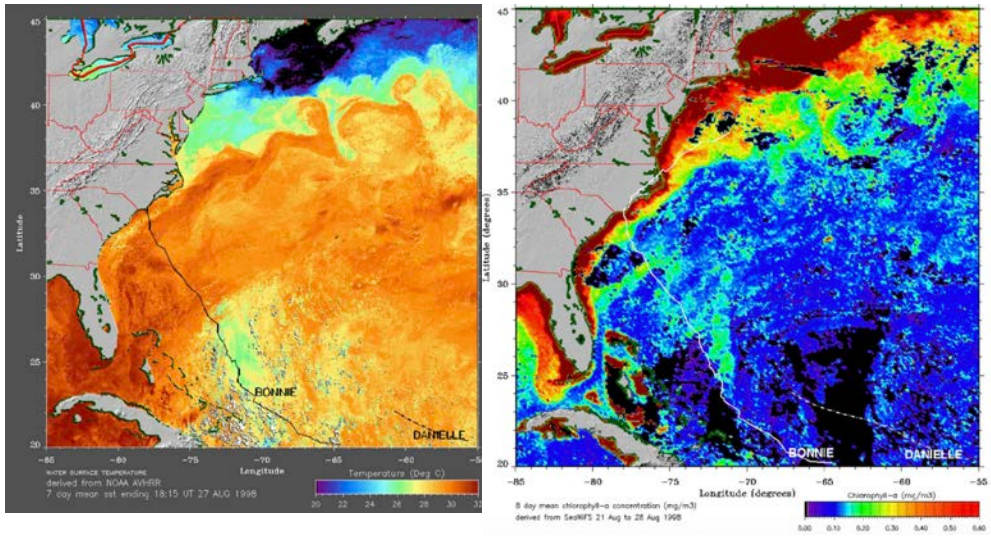
A mechanism to uplift nutrients

Tropical upper-ocean is mostly nutrient limited and stratified with very little mixing.

Hurricanes act as agents of mixing and can bring nutrients from deep below to the surface.



Krause et al. (2015)

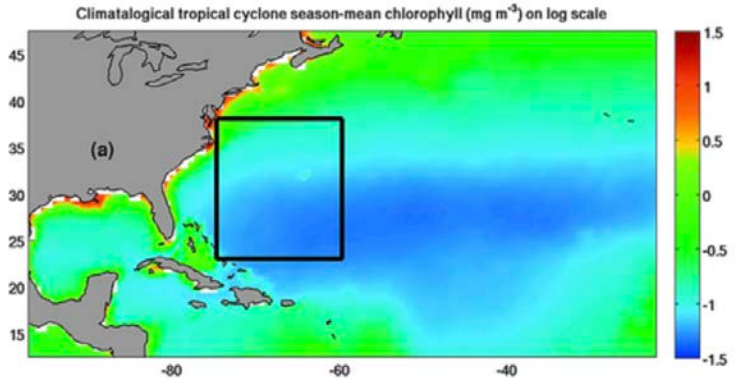


Babin et al. (2004)

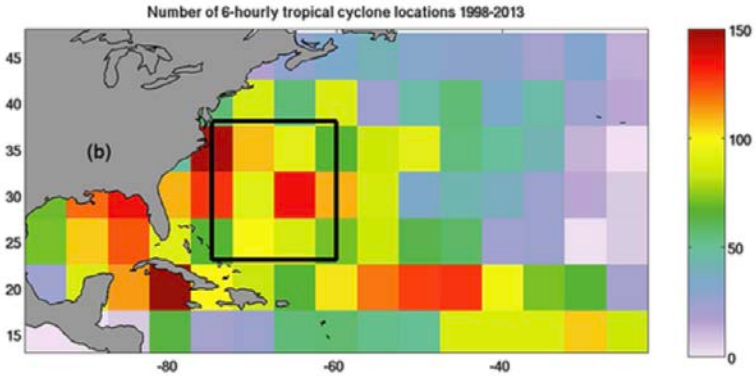
Evidence of chlorophyll blooms in the wakes of individual hurricanes

What about the cumulative effect?

Evaluation in the Sargasso Sea

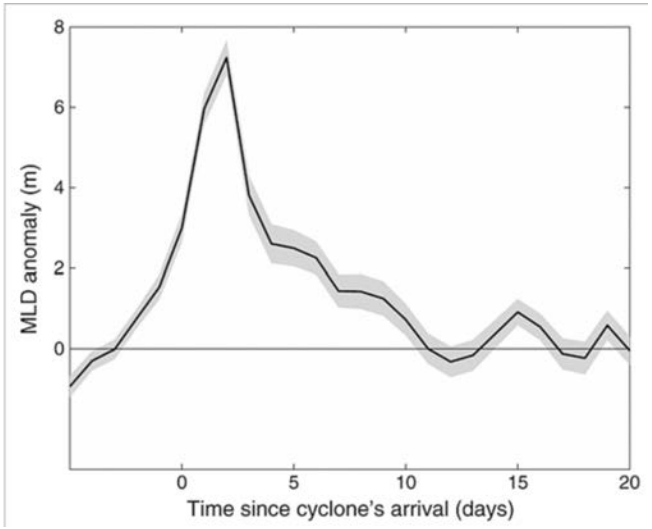


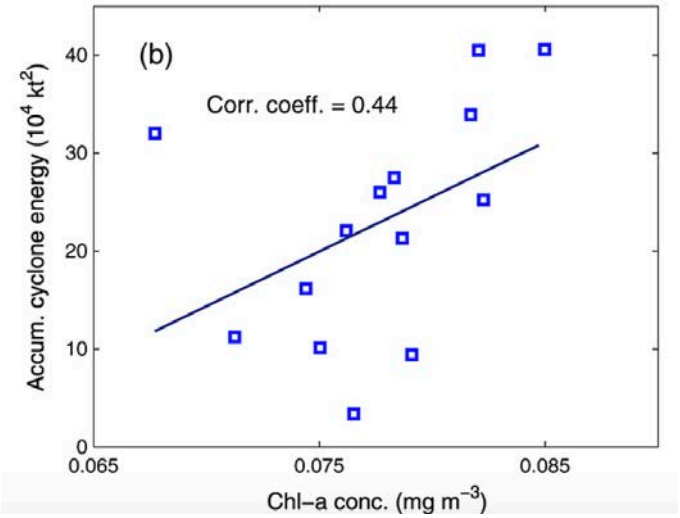
Subtropical oceans have a shallow but strong seasonal thermocline and nutricline, low chlorophyll.



This also happens to have some of the highest hurricane track densities..

Quantifying the cumulative impact on chlorophyll





Composite mean time evolution of MLD anomalies (based on HYCOM) confirms significant mixing induced by hurricanes.

Hurricane induced MLD changes account for ~12% of the total interannual variability.

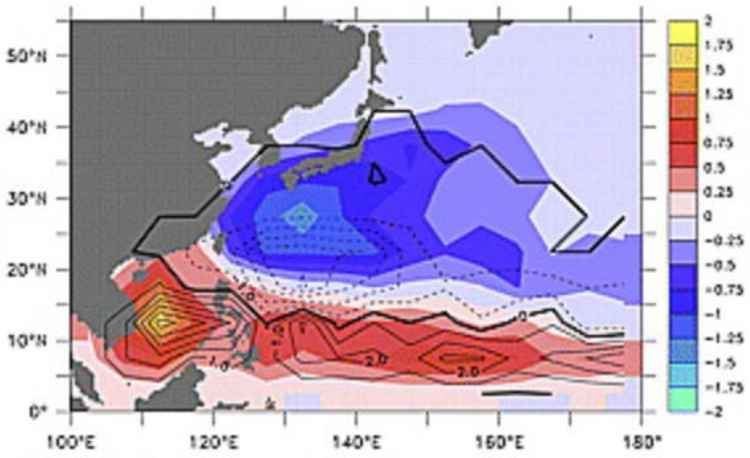
Hurricanes explain nearly 22% of the interannual variability of surface chlorophyll (based on merged product from the European Space Agency).

Represents about 70% of the effect of the NAO.

Implications

Hurricanes can play an important role in global primary productivity, comparable to major climate phenomena.

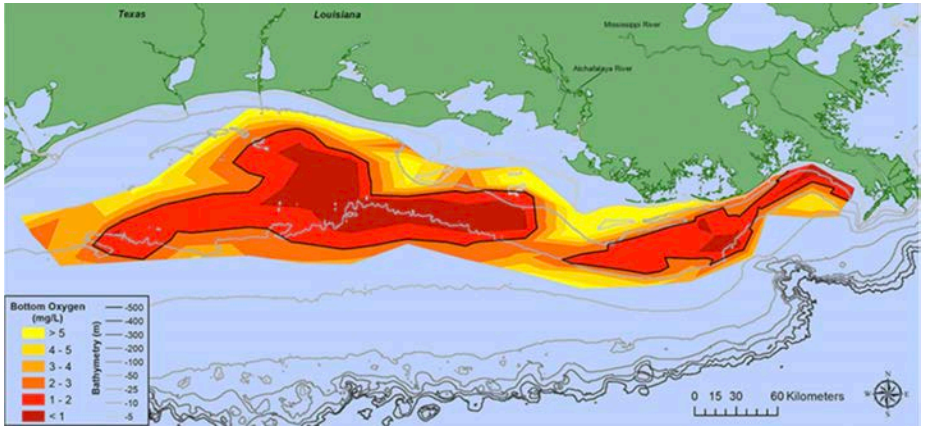
Earth system models may need to have a good representation of hurricanes in order to simulate a more accurate carbon cycle.



Gnanadesikan et al. (2010)

Some studies even suggest that there could a potential feedback mechanism operating between chlorophyll and hurricanes.

Hypoxia in the northern Gulf of Mexico



Source: EPA

Source: NASA

Low oxygen conditions at ocean bottom (DO < 1.4 ml/L)

Persistent feature that occurs every summer, huge implications for fisheries.

Hurricane mixes the water column completely over the shallow continental shelf

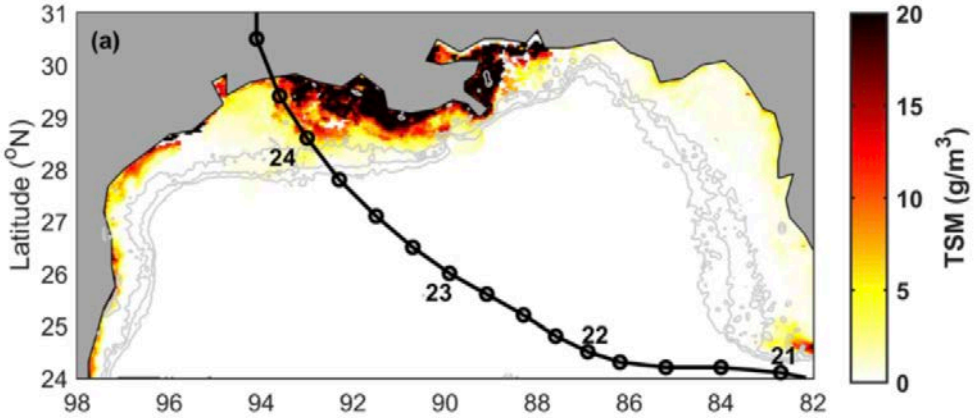
Alleviates Hypoxia temporarily

Is that all there is to the story? What about sediment resuspension?

Data and Model

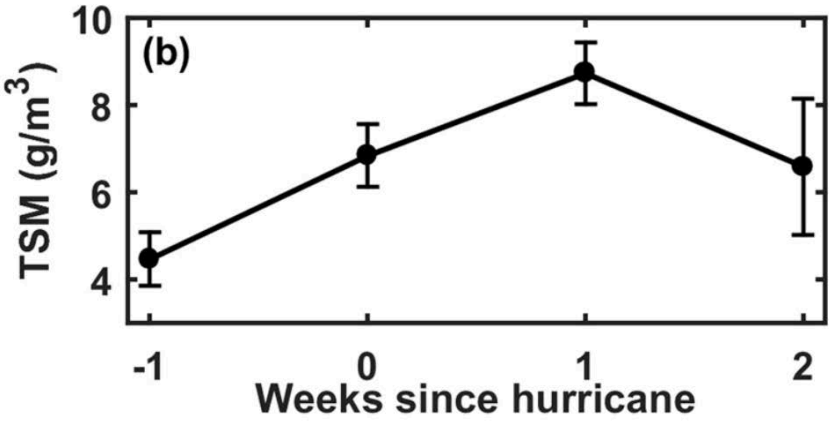
- Daily rainfall from TRMM.
- Daily vertical ocean temperature and salinity profiles from HYCOM.
- Satellite weekly Total Suspended Matter (TSM) from the European Space Agency's GlobColour project.
- Bottom Dissolved Oxygen (DO) from the World Ocean Database and cruises from the Mechanisms Controlling Hypoxia (MCH) program.
- Numerical simulations using the Regional Ocean Modeling System (ROMS).

Evidence for resuspension of sediments



Resuspension of sediments in the aftermath of Hurricane Rita (2005)

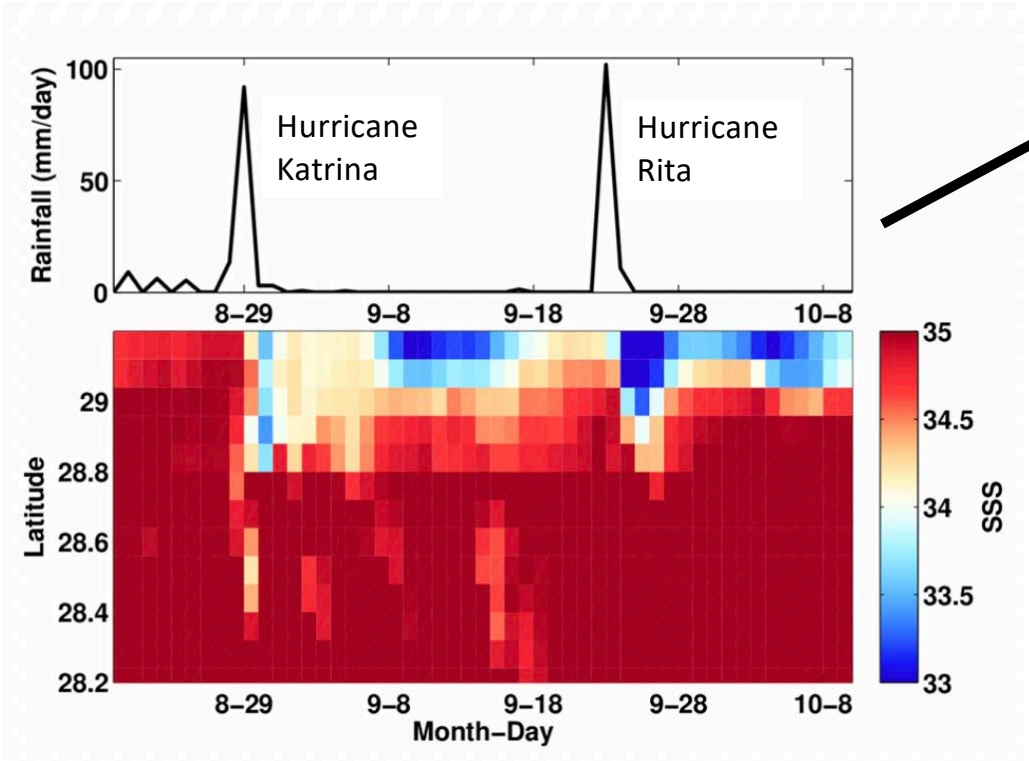
Once the hurricane reaches the shallow continental shelf, the mixing reaches the bottom and can resuspend sediments.

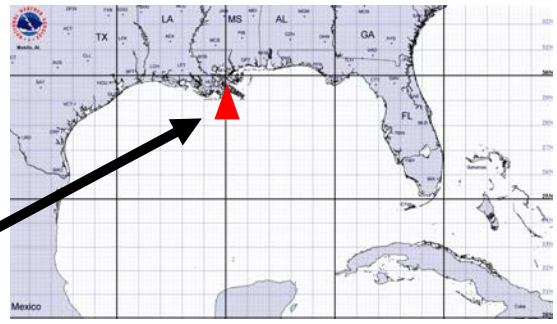


Significant increase in sediments occurs during the week of the hurricane, reaches a maximum the week after, and then starts decreasing

Is this local resuspension or is it from enhanced discharge of the Mississippi River?

Using surface salinity as a proxy



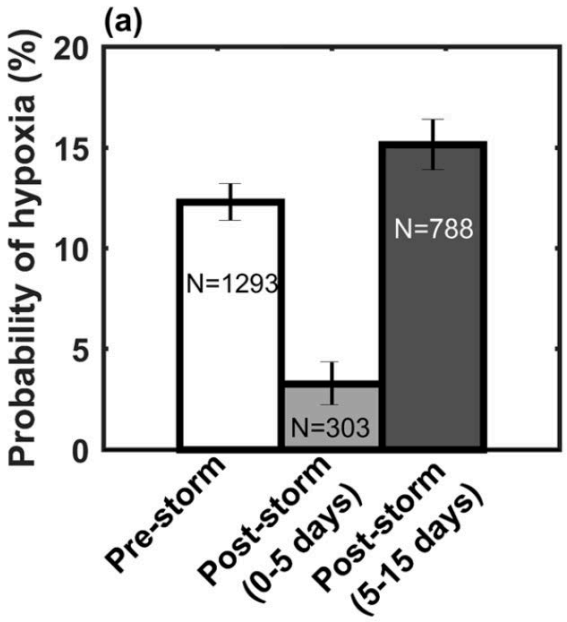


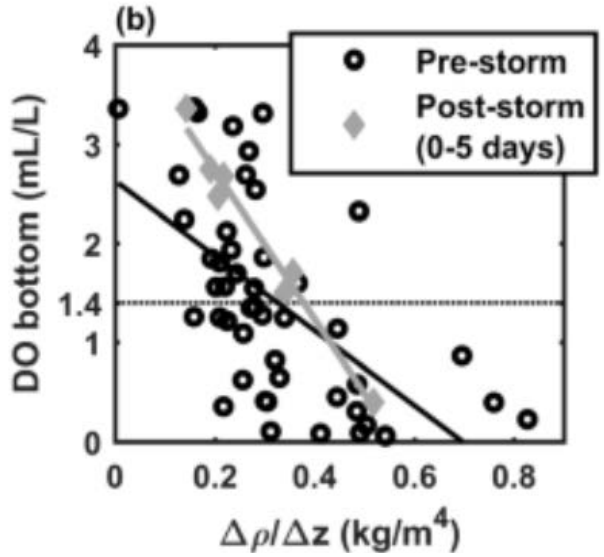
Double pulse of salinity following hurricanes near the Head of Passes or the mouth of the Mississippi River.

The arrival of river discharge is separated from the initial freshening due to storm-induced rain by 8-10 days.

Similar results are obtained from the composite mean response and examination of data from USGS hydrographs.

Hurricanes and bottom DO





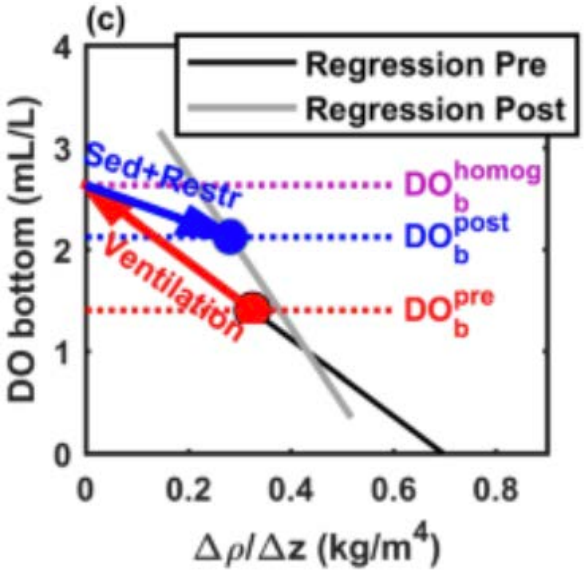
$$DO_b^{pre} = -3.77 \cdot (\Delta\rho/\Delta z)^{pre} + 2.6$$

$$DO_b^{post} = -7.49 \cdot (\Delta\rho/\Delta z)^{post} + 4.2$$

Hypoxia reduces in the immediate few days following the storm, is restored to pre-storm state afterwards.

The post-storm slope is almost double of its pre-storm value.

A two-stage process

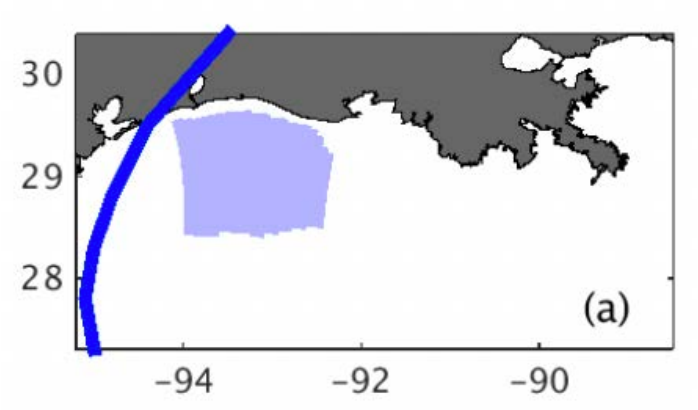


1) The process of mixing and ventilation is near-instantaneous, and hence follows the pre-storm relationship.

2) Sediment resuspension and remineralization, along with restratification, follow causing a drawdown of some of the DO.

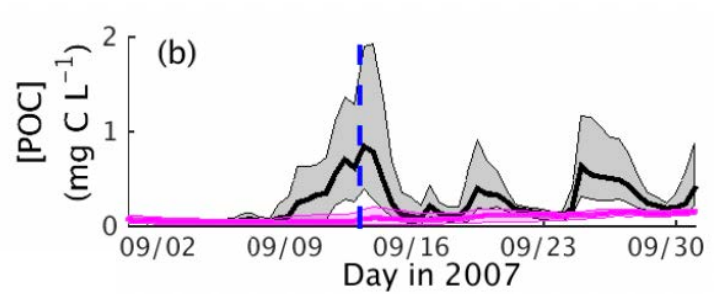
Using mean values of stratification for pre-storm and post-storm conditions in the regression equations for DO vs stratification, we estimate the effect of sediment resuspension on DO to be upto ~20% of the effect of ventilation.

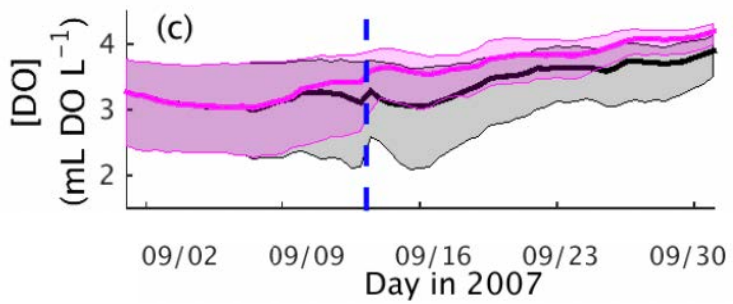
Support from numerical experiments



The case of Hurricane Humberto (2007) was simulated using ROMS.

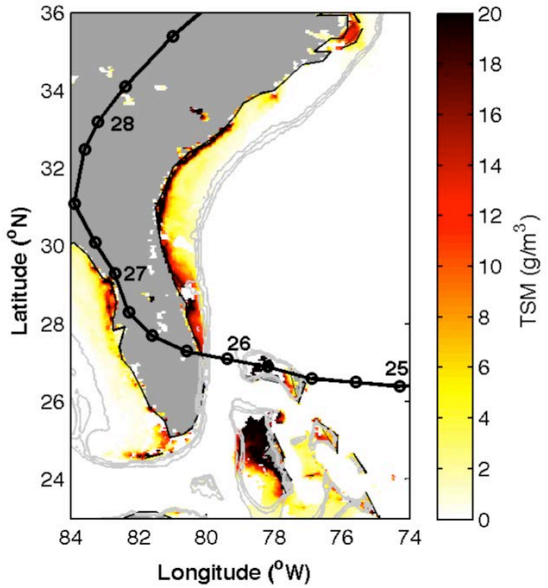
Two experiments were performed, a control or standard case with sediment resuspension and a test case with no resuspension.





Without sediment resuspension, the model simulates higher post-storm levels of DO.

Implications



Resuspension of sediments in the aftermath of Hurricane Jeanne (2004)

Resuspension of sediments occurs over every continental shelf affected by hurricanes globally, unlike coastal areas affected by major river systems (~15%) .

Sediment processes must be well-represented in earth system models.

As hurricanes become more intense due to climate change, the relative significance of sediment resuspension may also increase. However, the effect of ventilation may also change due to the effect of warmer future conditions on DO solubility.

Thanks

References

Bianucci, L., **Balaguru, K.**, Smith, R.W. *et al.* Contribution of hurricane-induced sediment resuspension to coastal oxygen dynamics. *Sci Rep* **8,** 15740 (2018). https://doi.org/10.1038/s41598-018-33640-3

Foltz, G. R., **Balaguru, K.** and Leung, L. R. (2015), A reassessment of the integrated impact of tropical cyclones on surface chlorophyll in the western subtropical North Atlantic. *Geophys. Res. Lett.*, 42: 1158– 1164. doi: 10.1002/2015GL063222.