The "new normal" of catastrophic tropical cyclone flooding in coastal North Carolina: Biogeochemical and water quality impacts

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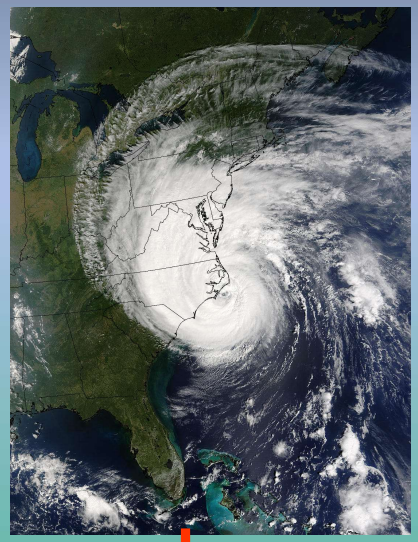
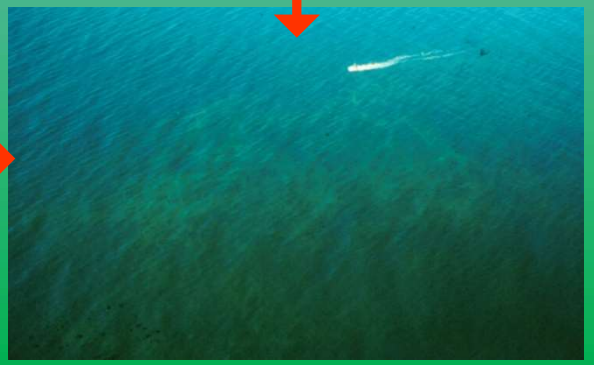
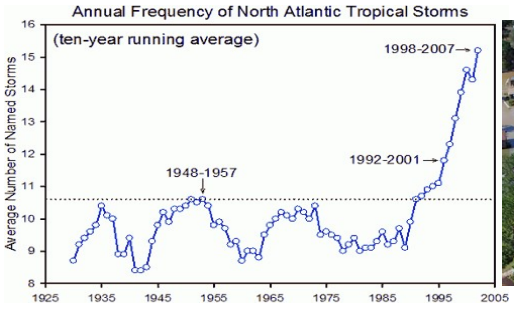




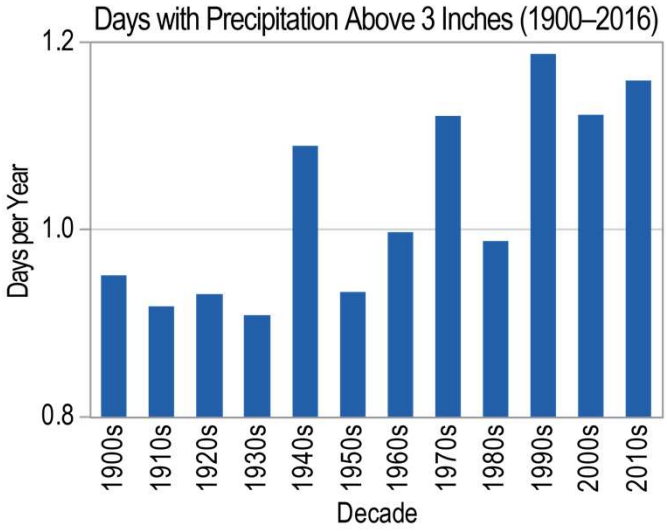
Pamlico Sound
Second largest Estuary in USA

- Most important US SE fisheries nursery
- Drains over half of NC coastal plain and Southeastern VA
- >50 years of Ag and urban expansion accompanied by enhanced N and P loading
- Lagoonal estuaries; long residence times, susceptible to eutrophication
- Increasing frequency of tropical cyclones (34 in the past 25 years), and flooding

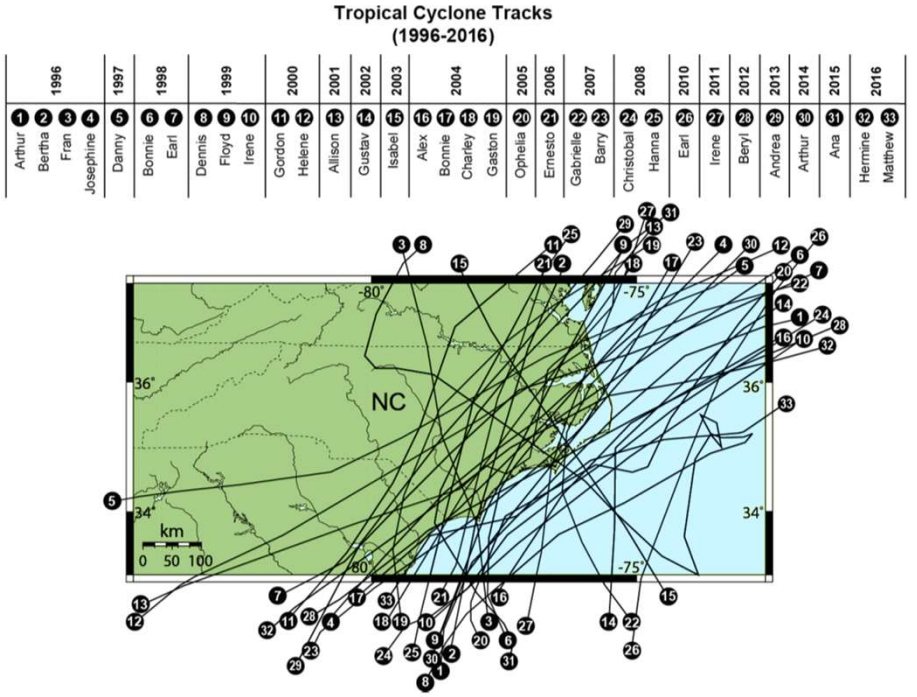


NC is a hot spot experiencing a hot moment

(McClain et al., 2003)



Change in the annual number of days with precipitation greater than 3 inches (76 mm), averaged over the Southeast by decade. Source: 4th National Climate Assessment.



Recent major cyclones and floods

Dennis & Floyd, Sept., 1999
Ernesto, Sept. 2006
Matthew, Sept.-Oct. 2015
Florence, Sept. 2018

Why the concern about tropical cyclones?

(Besides the obvious!)

Large Hydrologic perturbations

(lots of water, quickly, and persistent flooding in low-lying areas)

Increased Nutrient organic matter and contaminant inputs

Changes in sediment dynamics (transport, deposition, resuspension)

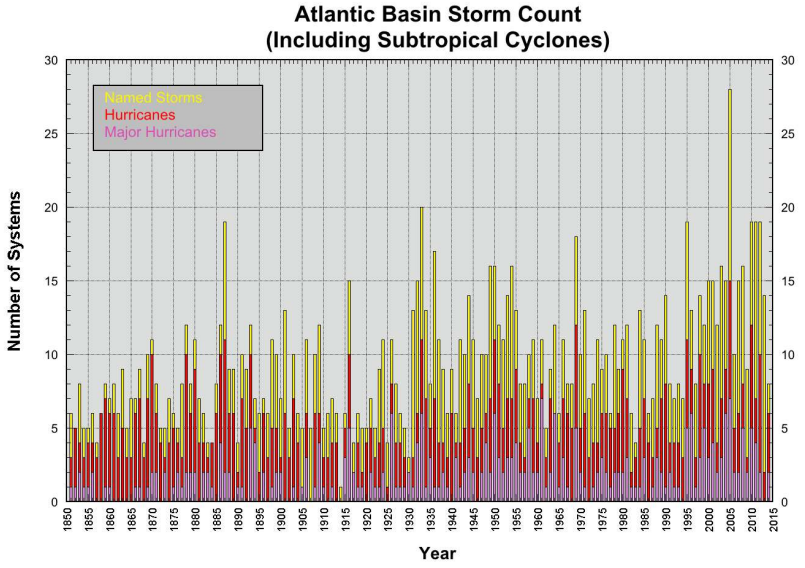
Biotic alterations (water quality, habitat, food webs)

Reason for concern……

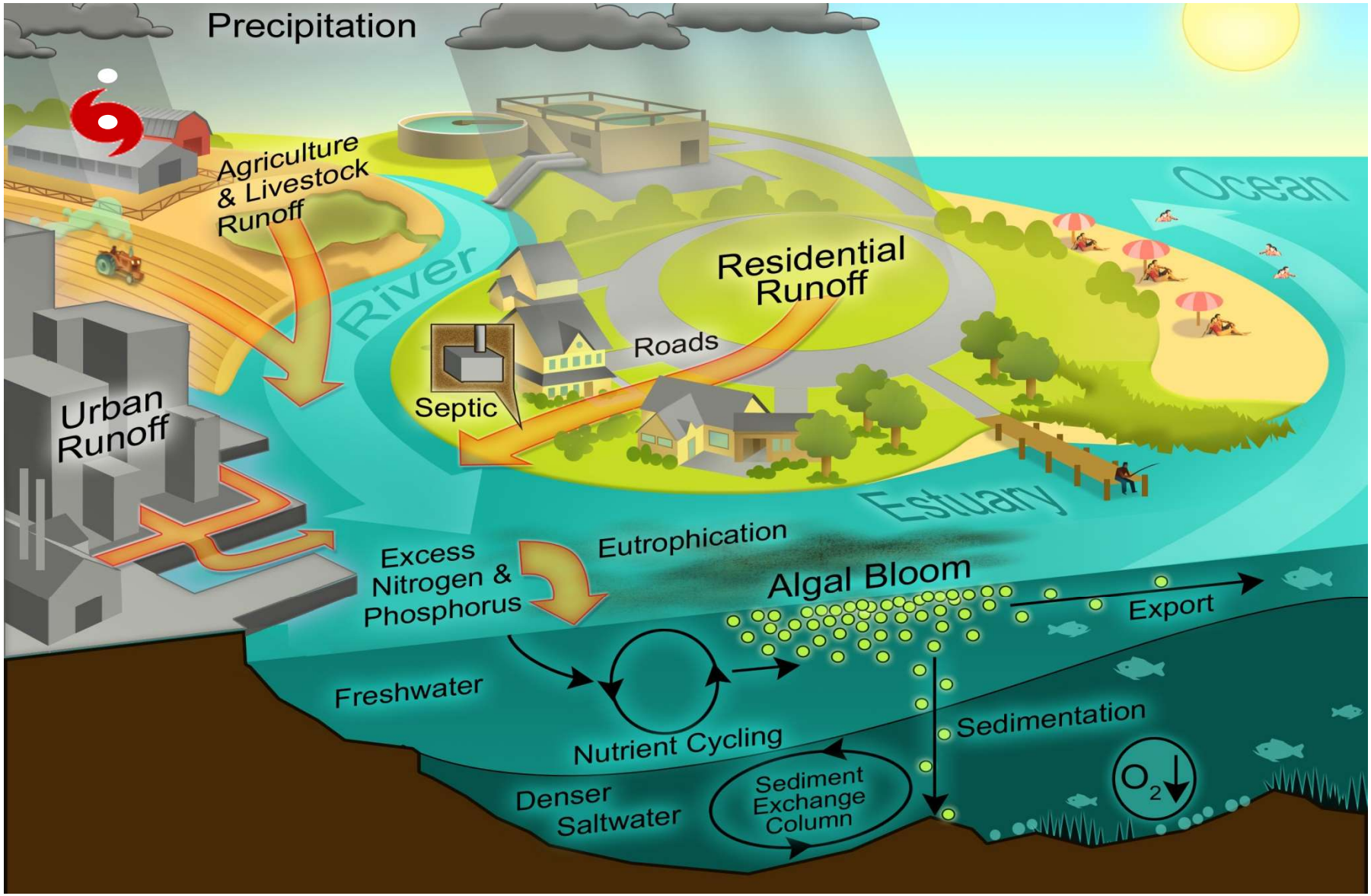
"We appear to be in a period of elevated tropical cyclone activity"

Emanuel 2005; Holland and Webster 2007; IPCC 2014; US Climate Change Report 2018

Hurricane Florence, Sept., 2018

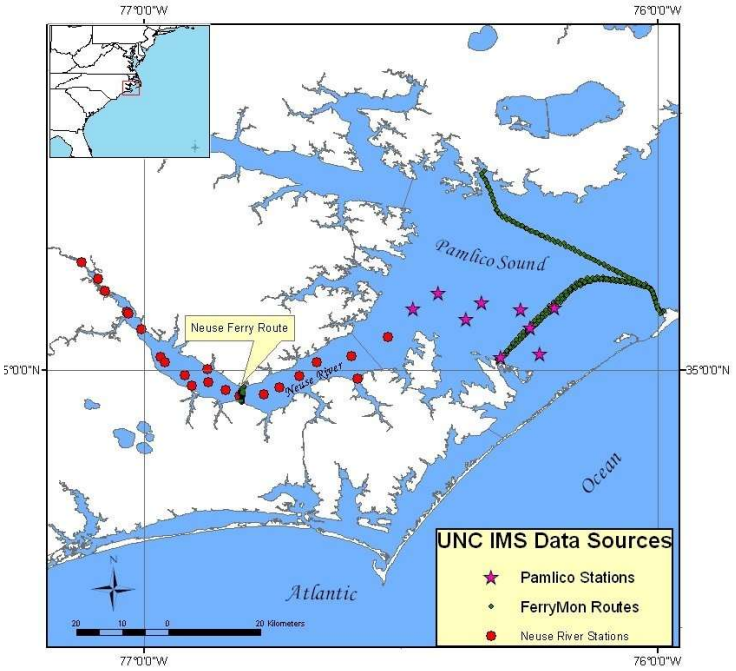


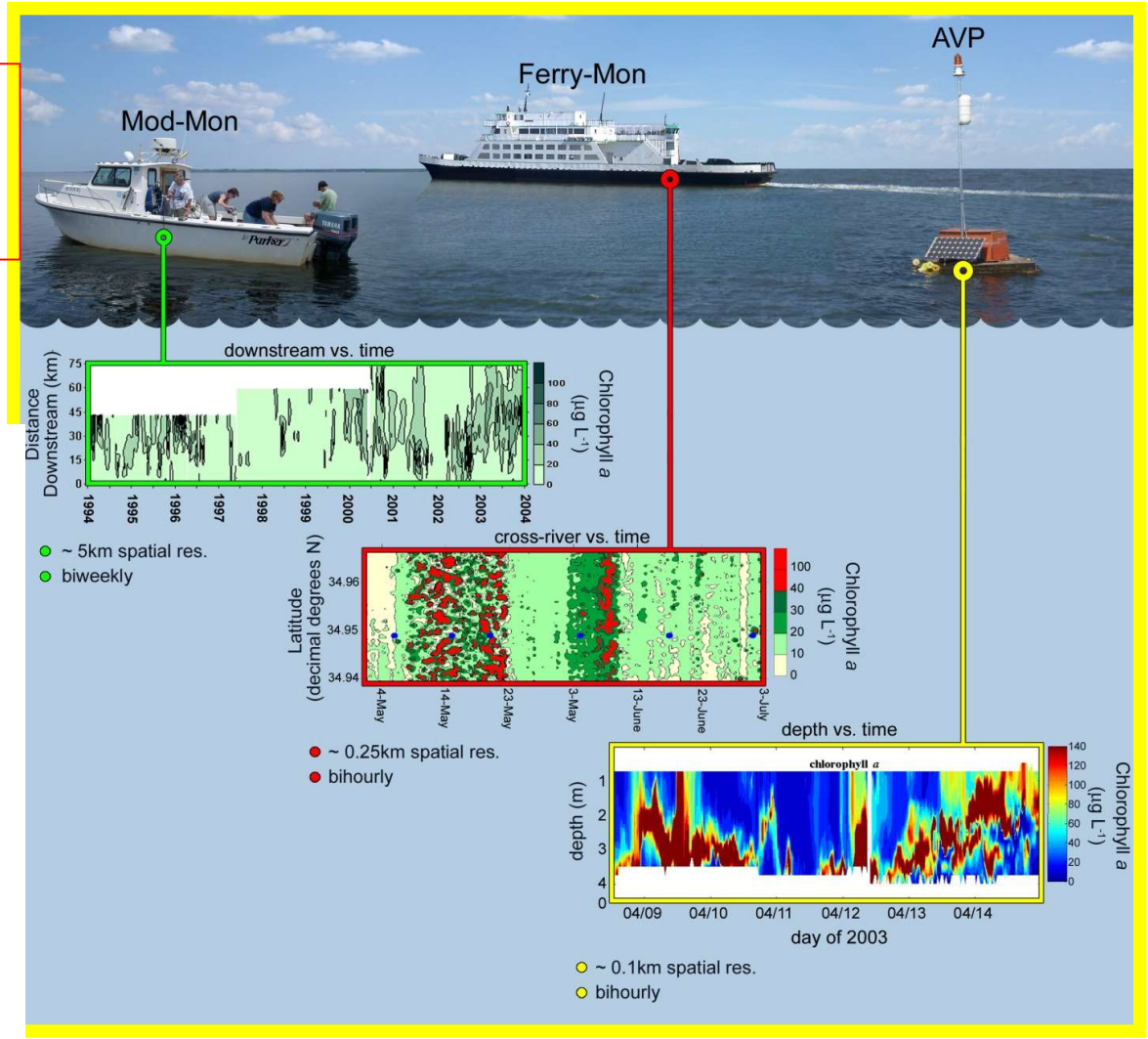
Major research/management challenge: Interacting human and climatic impacts on coastal habitat/water quality



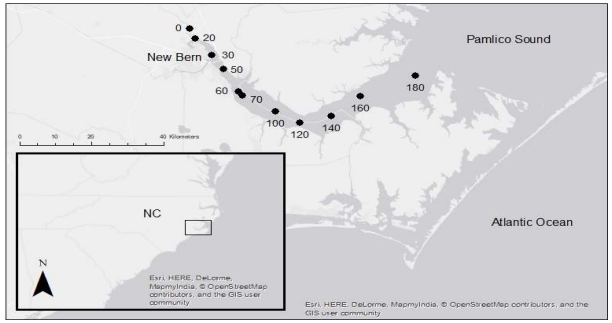
ModMon and FerryMon: space-time intensive monitoring to assess human and climatic impacts on water quality in the Albemarle-Pamlico Sound System

ModMon: Since 1994
paerllab.web.unc.edu/projects/modmon/
FerryMon: Since 2000
paerllab.web.unc.edu/projects/ferrymon/

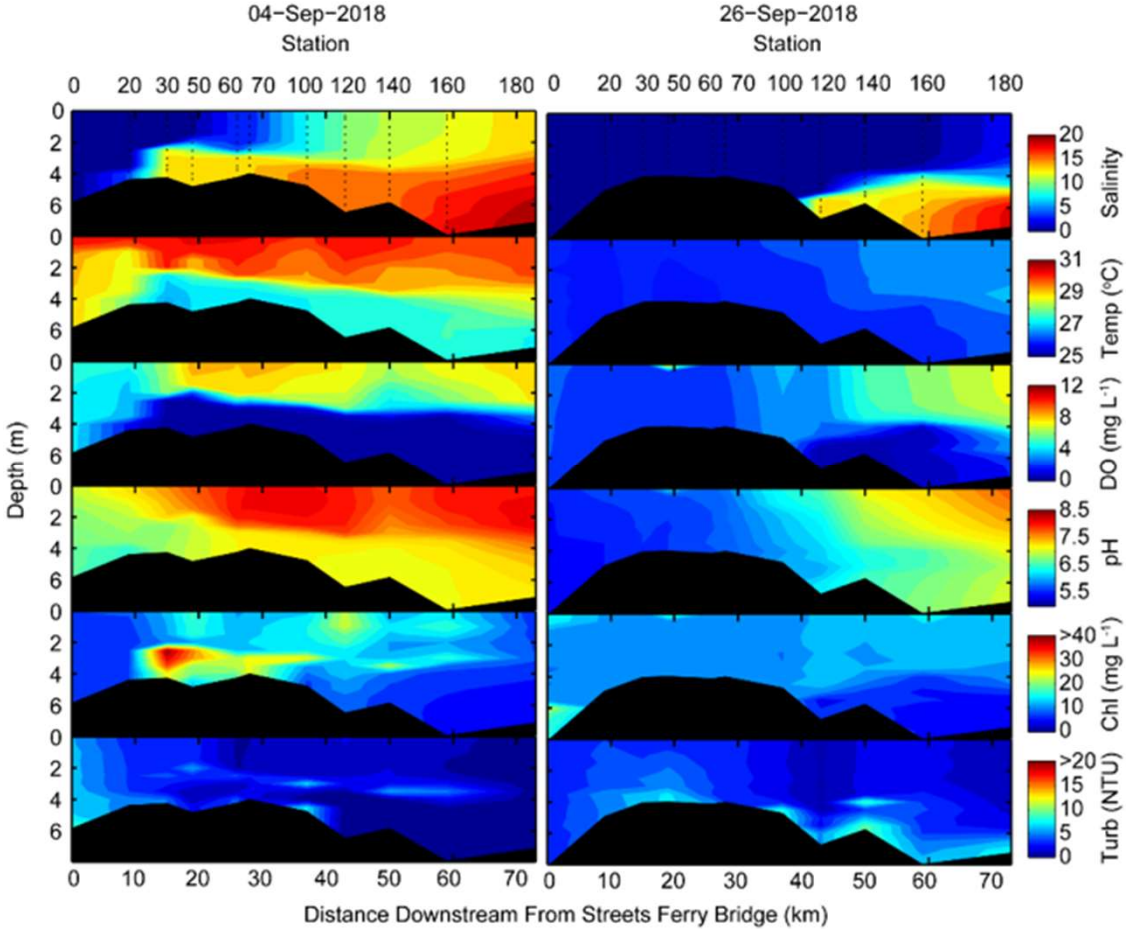




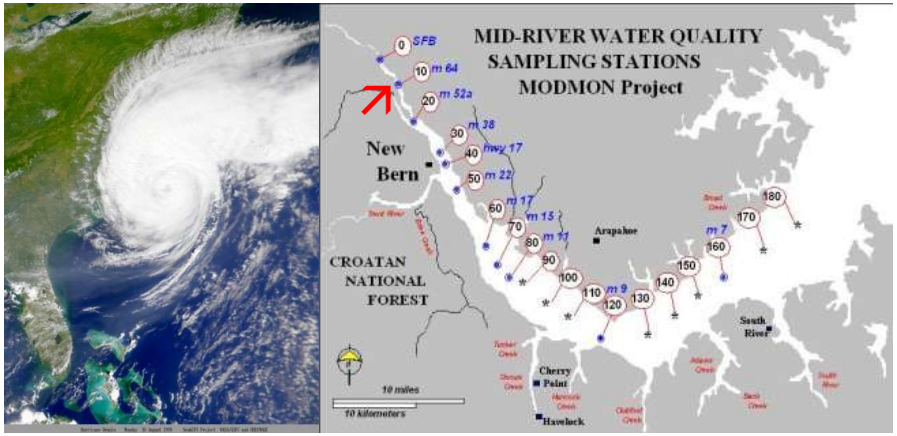
Physical-chemical impacts of hurricane Florence (Sept., 2018) on the Neuse River Estuary, NC



paerllab.web.unc.edu/projects/modmon/



First a few things about N and P loading to the Neuse R. Estuary: How important are tropical cyclones relative to "normal" hydrologic patterns ?



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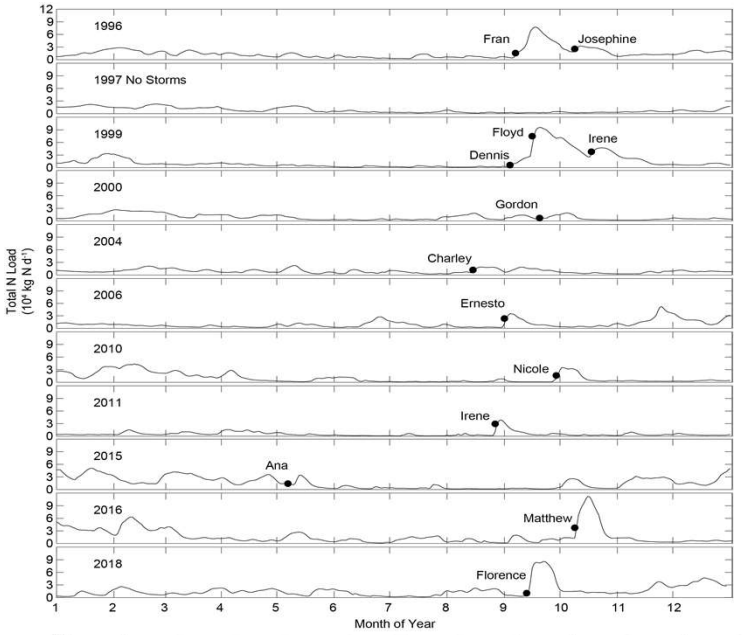
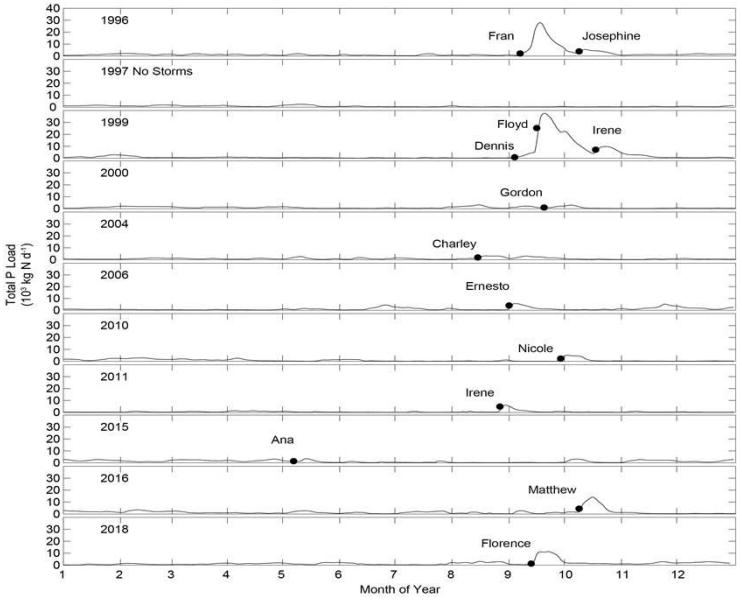
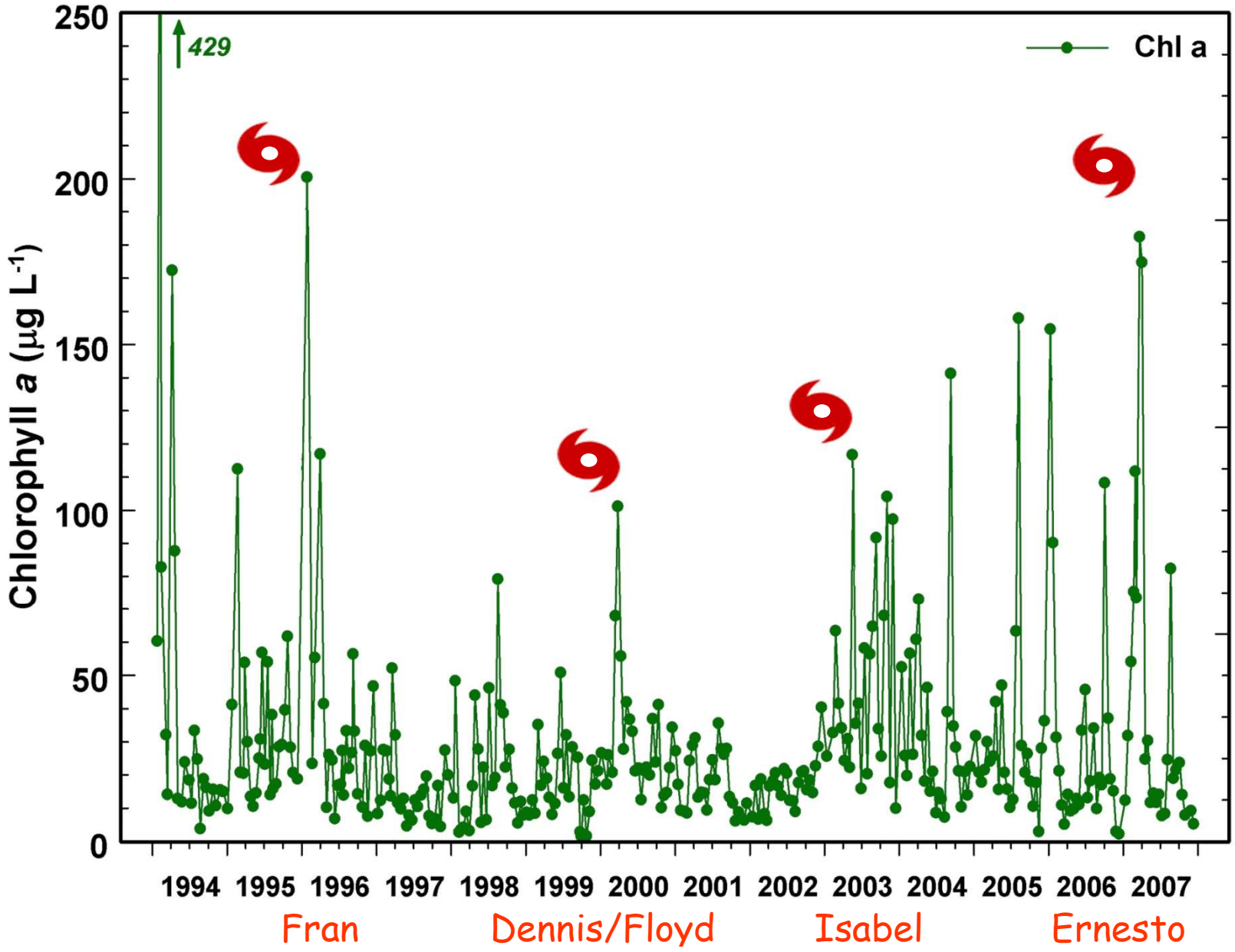


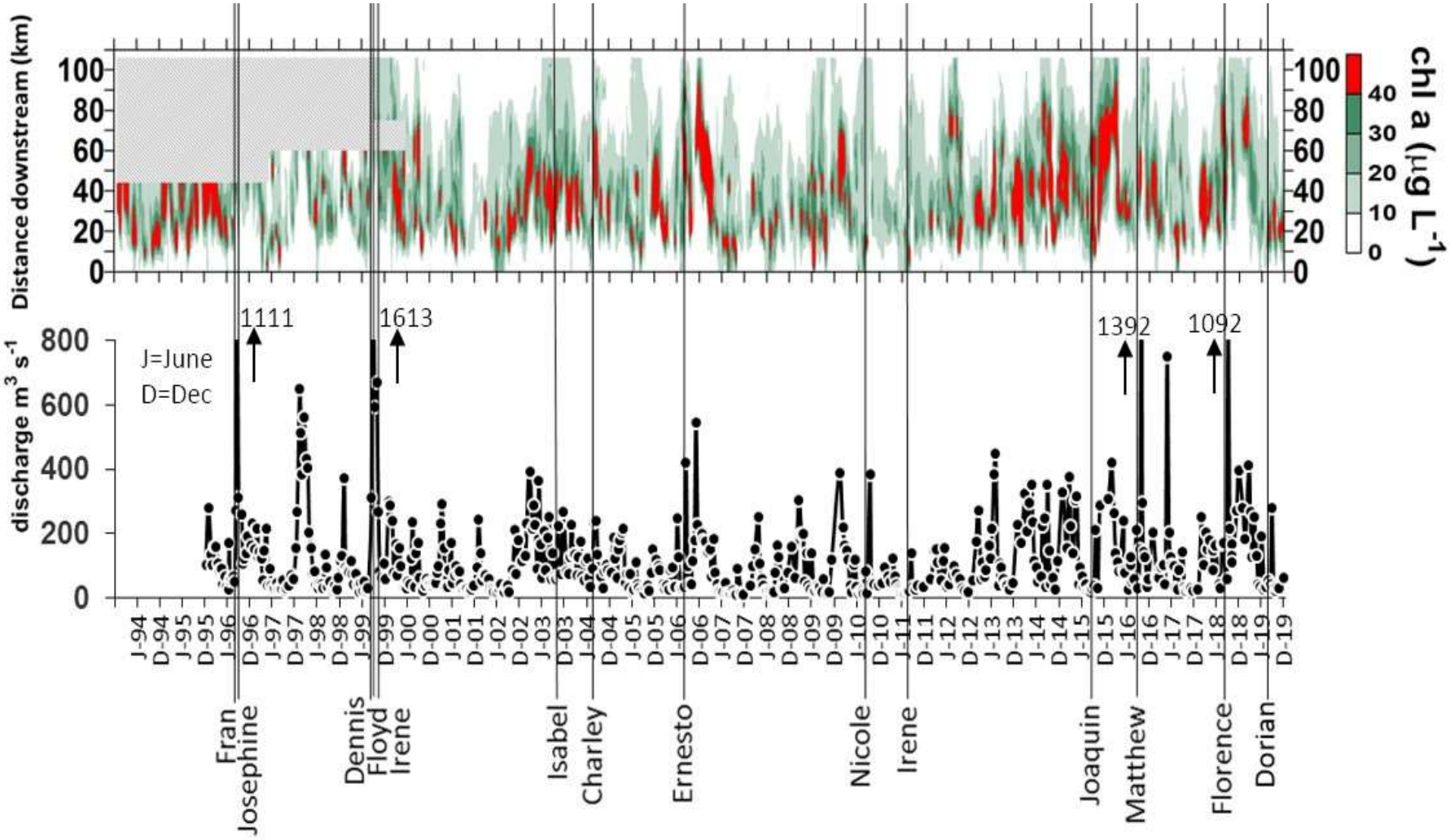


Hall et al., 2013; Peierls et al., 2012; Paerl et al., 2014, 2018, 2020

Major tropical cyclones and large rainfall events: impacts on phytoplankton biomass (Chl *a*) responses in the Neuse R. Estuary, NC

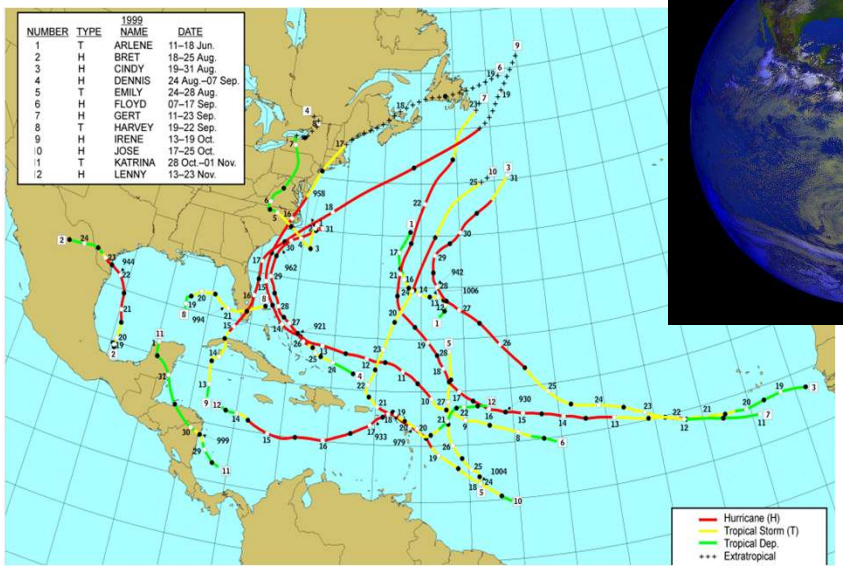


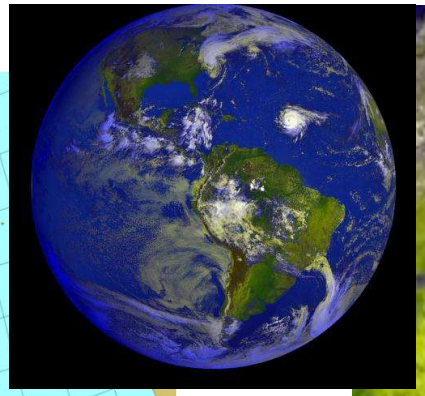
25 years of TC impacts on Chlorophyll *a* (algal biomass) in The Neuse R. Estuary

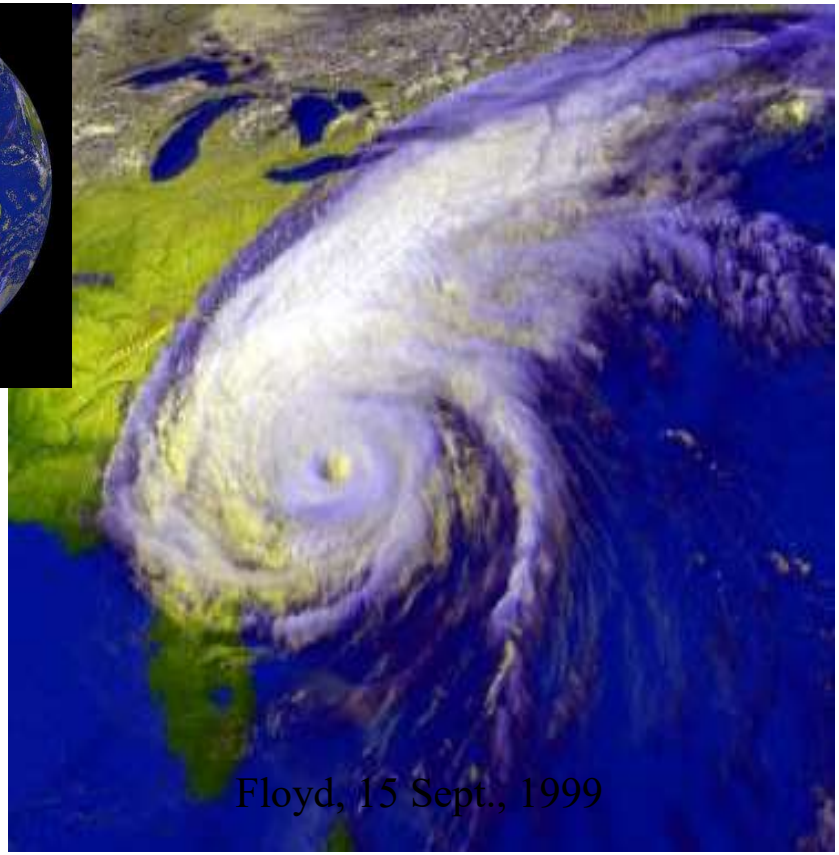


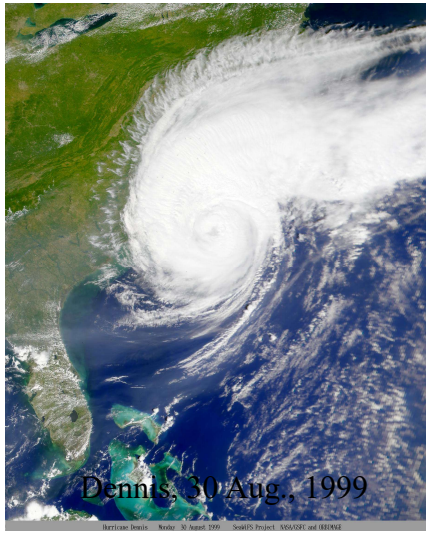
Paerl et al. 2020. Data source: ModMon: https://paerllab.web.unc.edu/projects/modmon/

The Hurricanes of 1999: What Happened?









- 3 SS-scale 3 hurricanes (Dennis, Floyd & Irene) within 6 weeks
- Record rainfalls in Pamlico Sound Basin: 12-h rainfall totals >> 100-yr.
- 50-500 year floods in PS watershed
- PS Received annual water and N loads in about 1.5 months

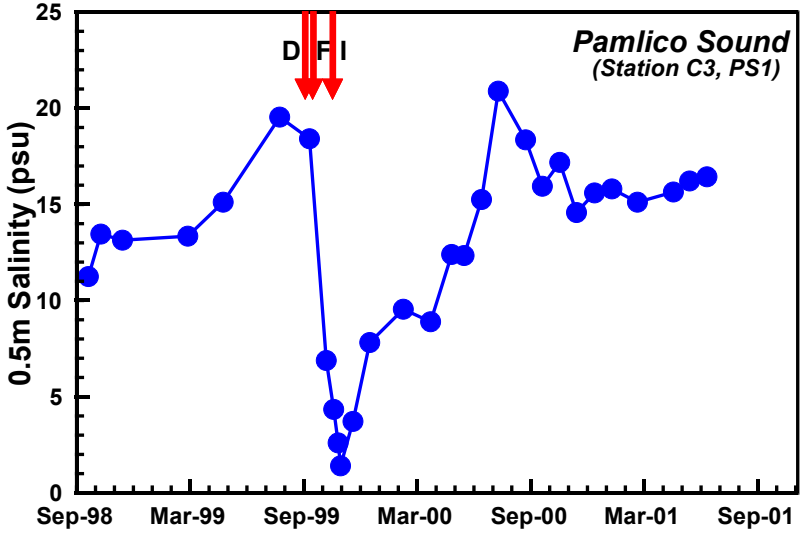
Ecosystem Impacts

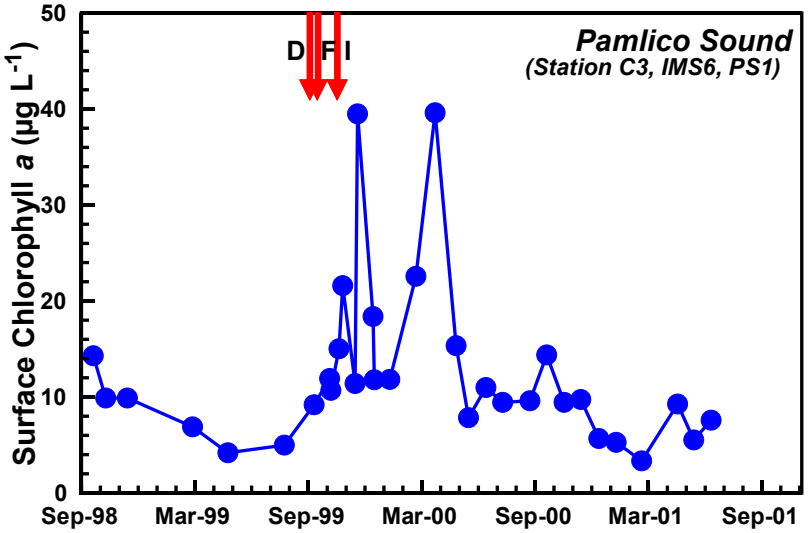
Pre-hurricane

Post-Floyd, September 23, 1999

Hurricanes Dennis, Floyd & Irene ('99)

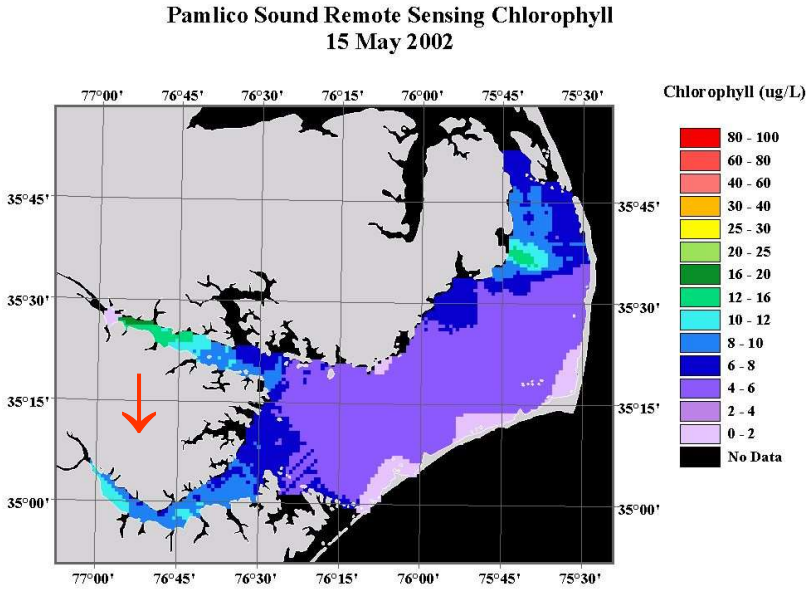
Salinity and Chlorophyll *a* responses in the Pamlico Sound

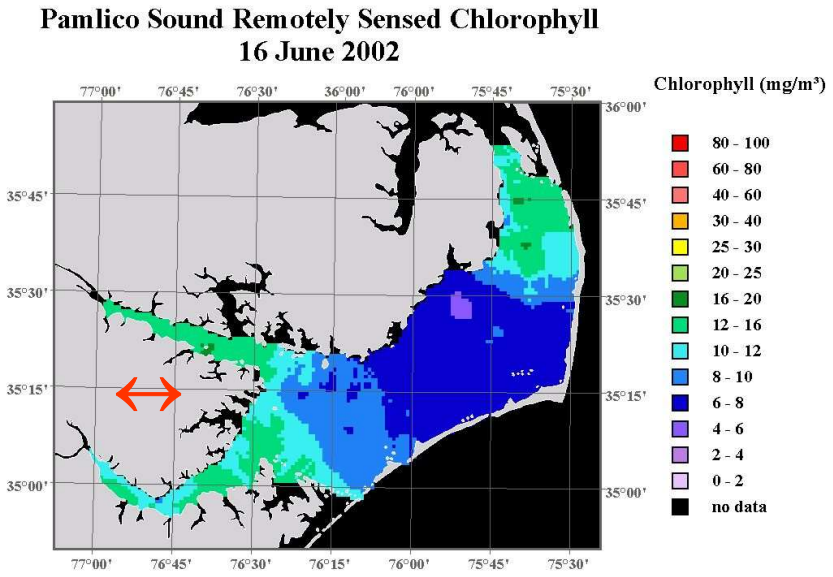


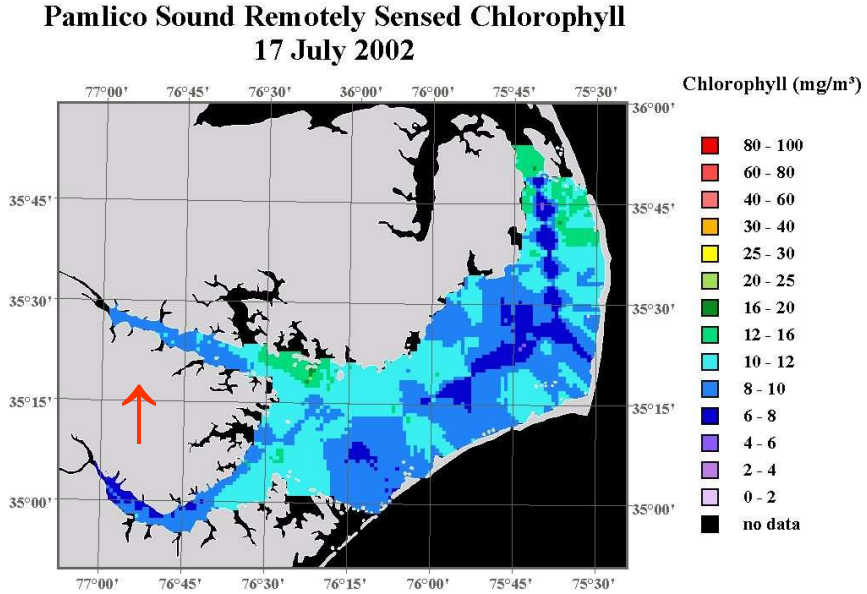


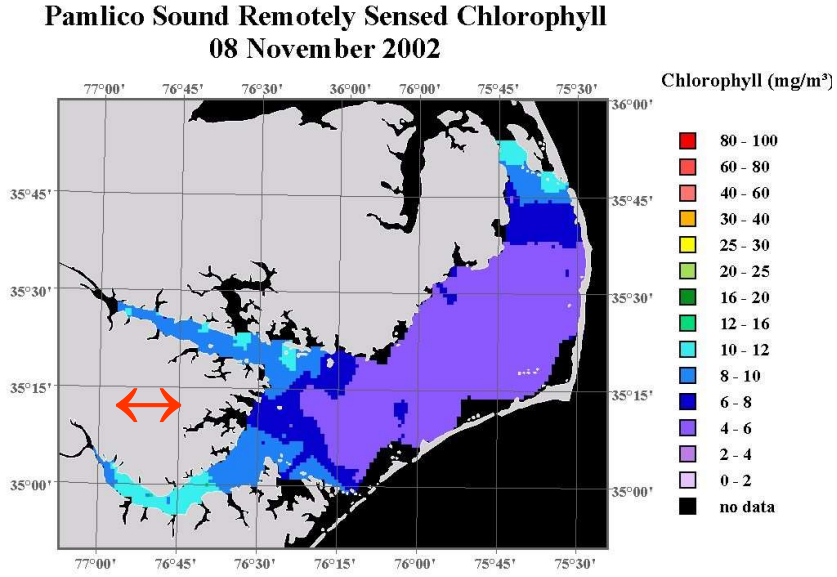
Paerl et al., 2001; Tester et al., 2003; Keith 2014

Freshwater Discharge and flushing effects on algal production (Chl *a*) in Pamlico Sound, NC



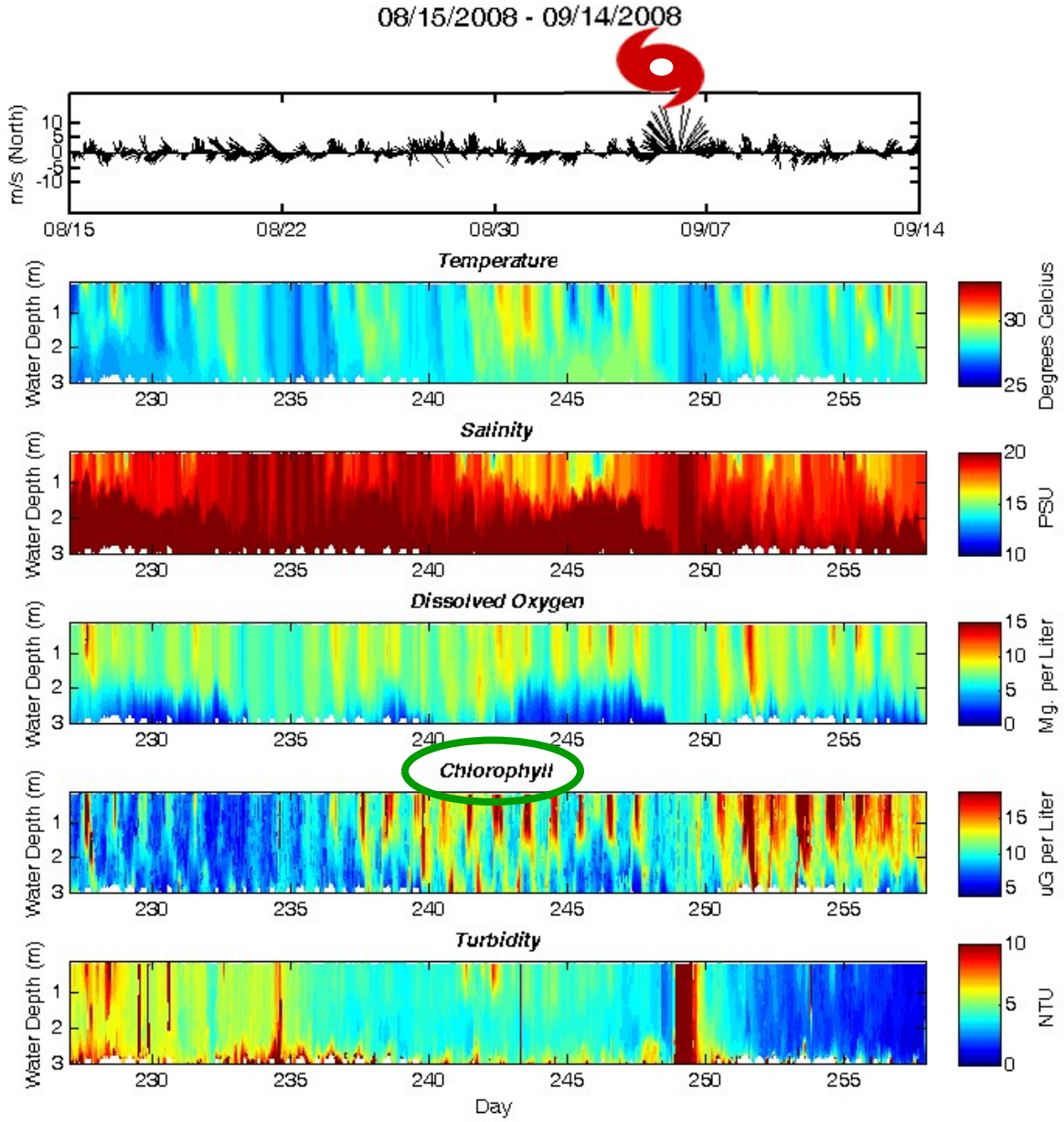






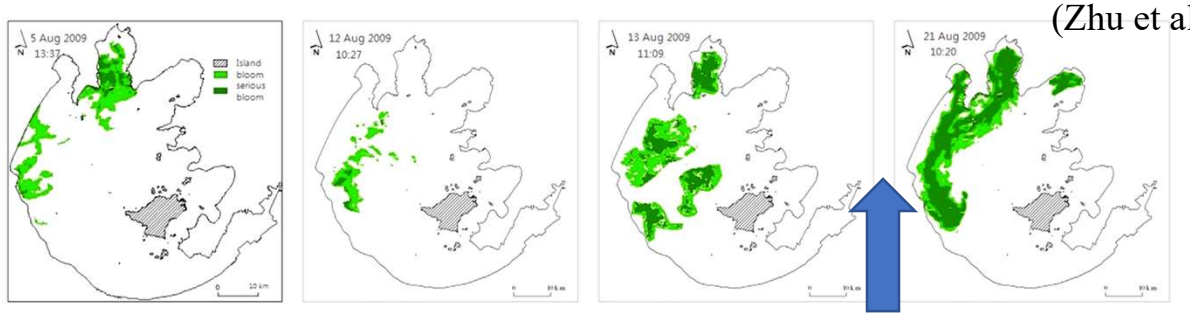
Flow: high↑, low↓, moderate↔

Impacts of Tropical Storm Hanna (8/15/08 – 9/14/08) on The New River Estuary, North Carolina, USA

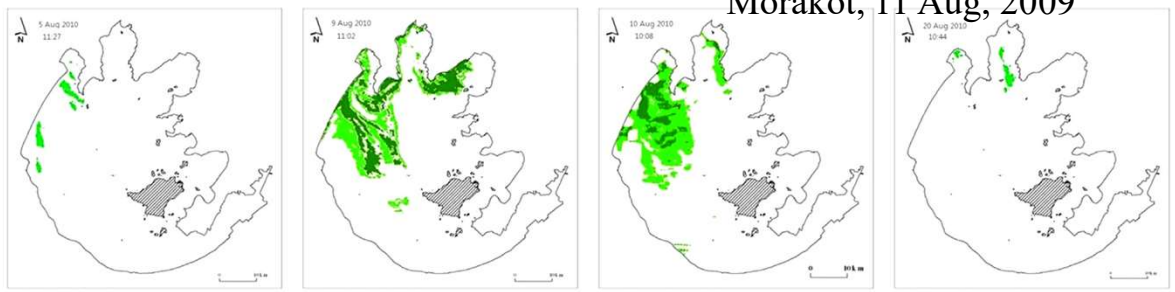


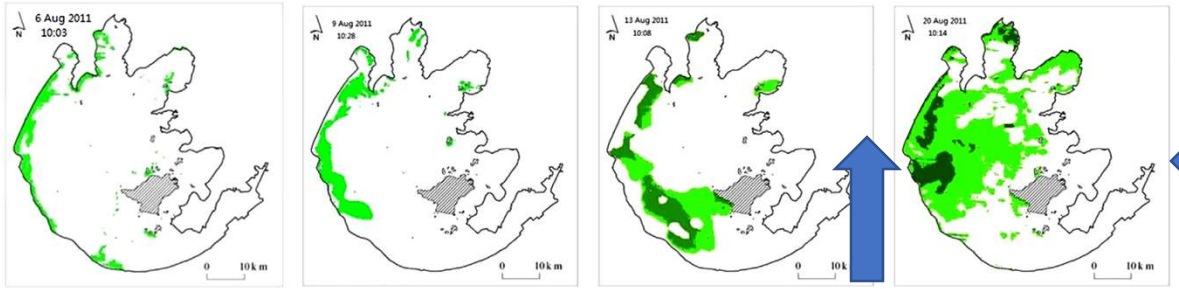
Impacts of Typhoon Passages on blue-green algae blooms in Lake Taihu, China, based on MODIS data

(Zhu et al., 2014)

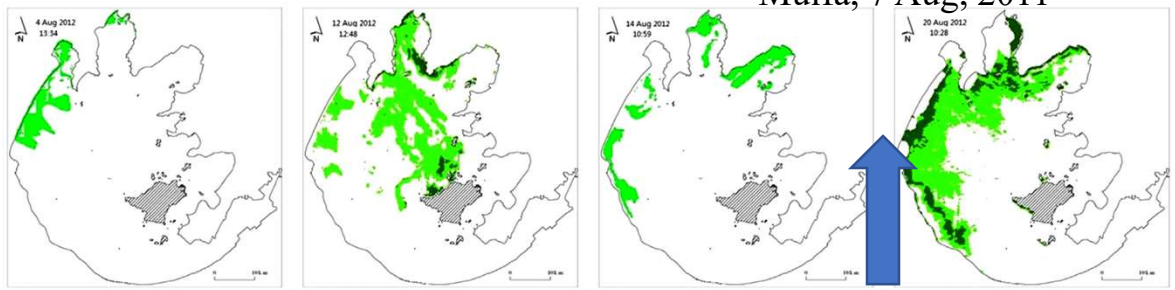


Morakot, 11 Aug, 2009



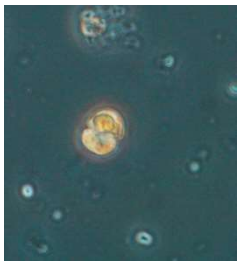


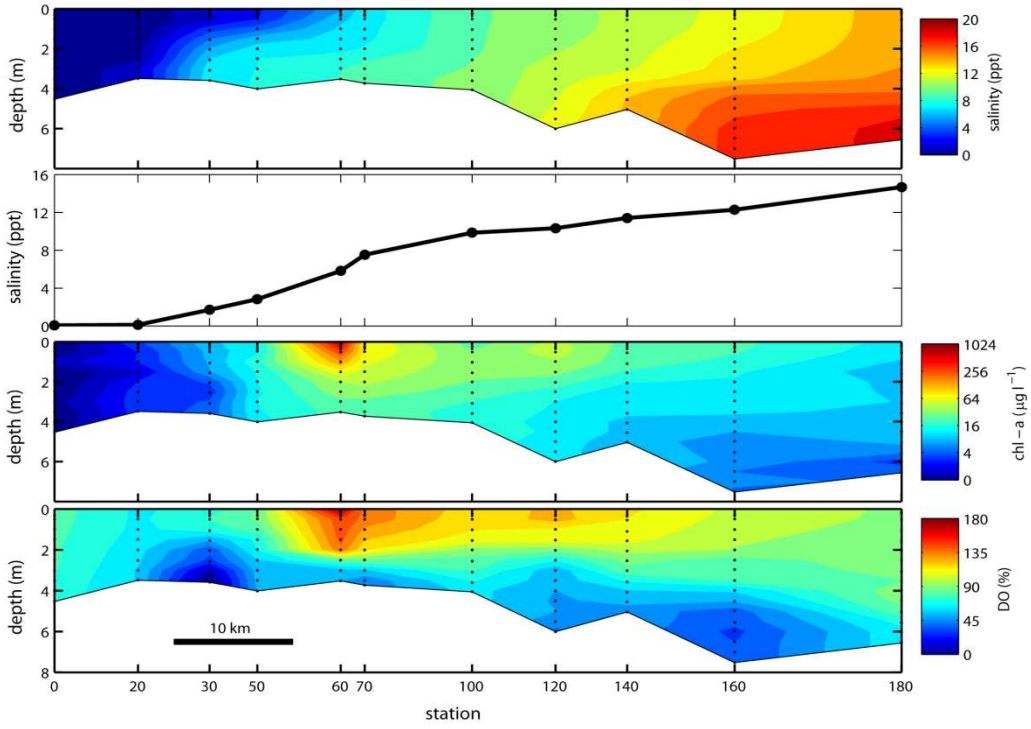
Muifa, 7 Aug, 2011

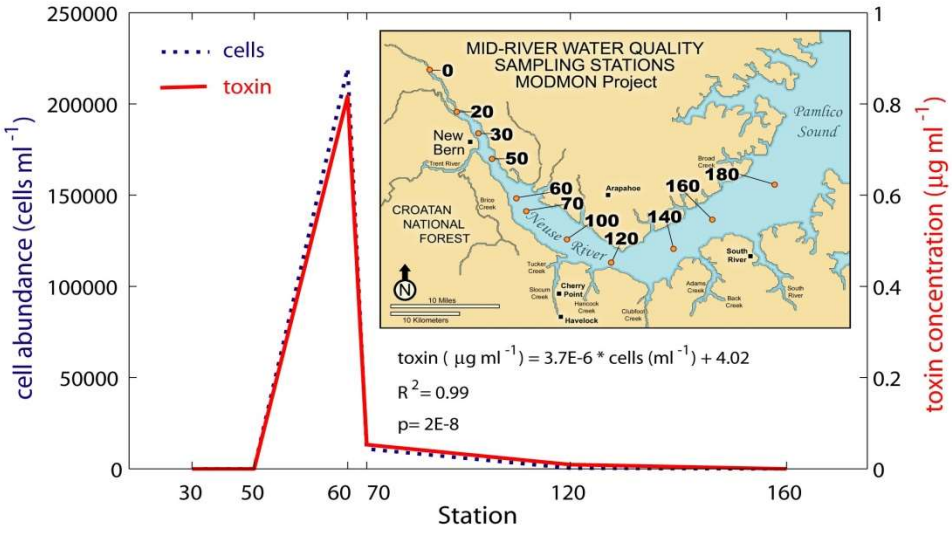


Haikiu, 8 Aug, 2012

A specific example: toxic dinoflagellate (*Karlodinium)* bloom following nutrient-enriched runoff from Tropical Storm Ernesto, Oct. 2006







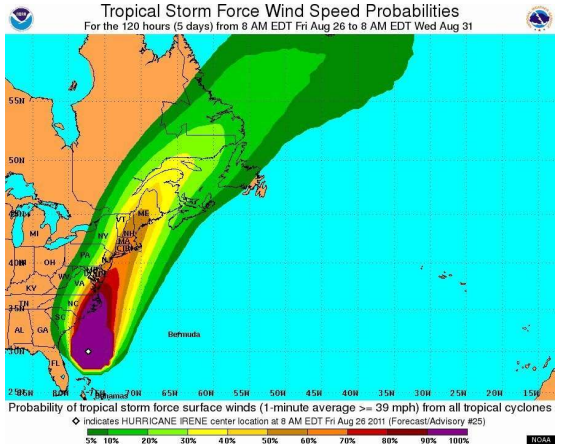
- **Runoff associated with Ernesto contained nutrient load and set up strong salinity stratification**

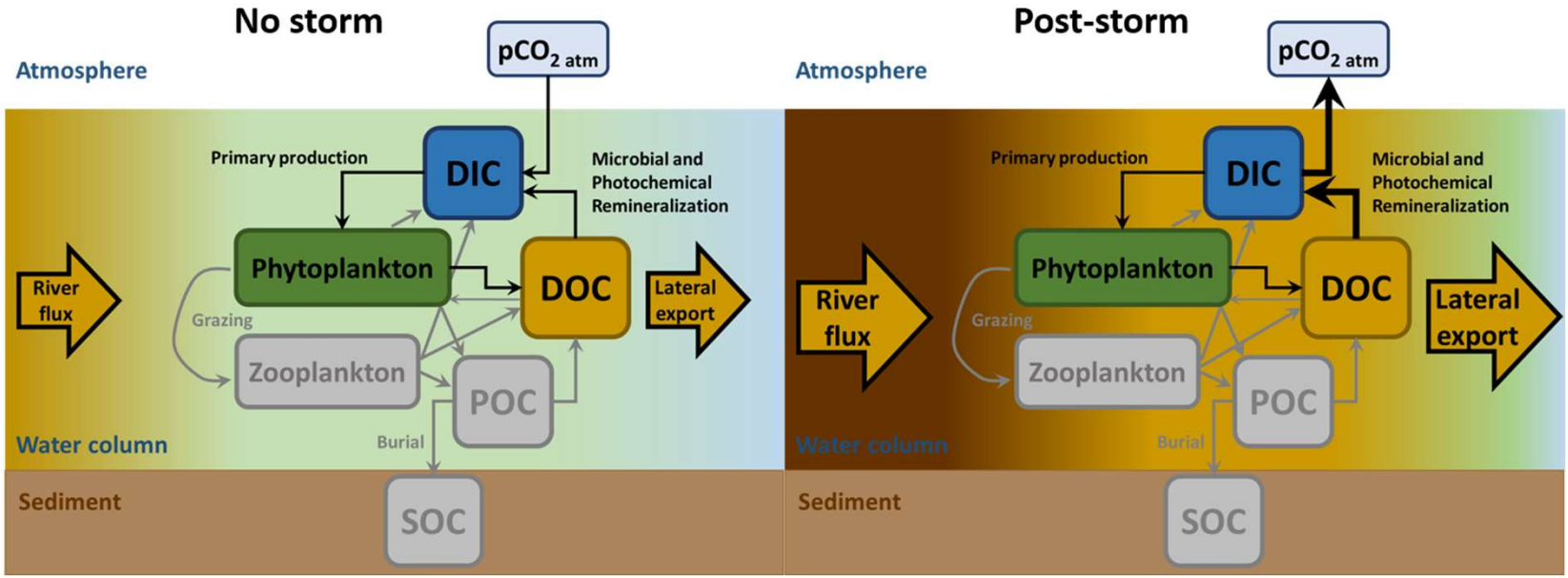
- **Favorable light and temperature created ideal conditions for an algal bloom.**

- **Near-surface stratification was favorable for motile dinoflagellates; *Karlodinium* prefers these conditions in fall.**

Hall et al. 2008

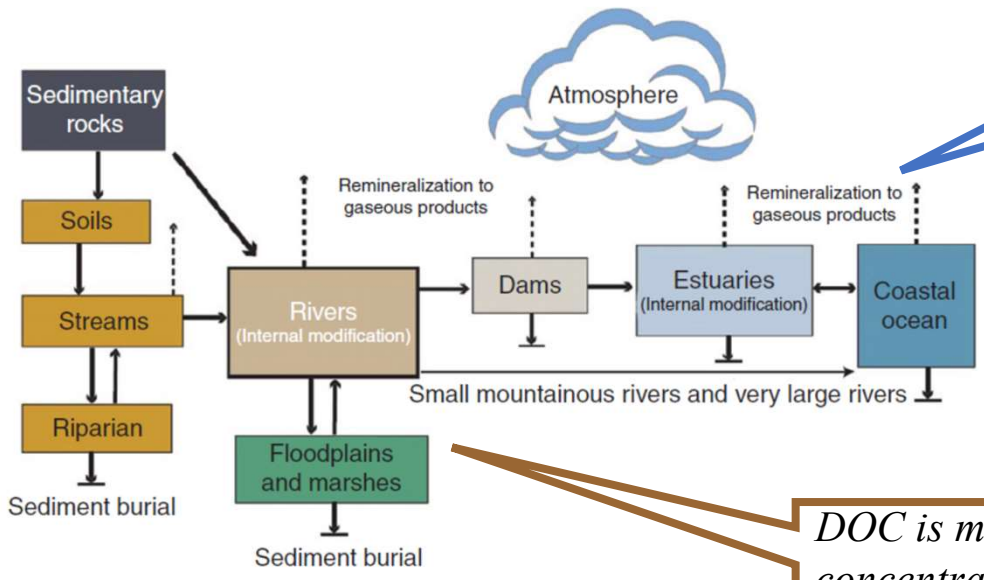
Lets look at how carbon flux is impacted…… and how storms shift coastal ecosystem states





Osburn et al. 2019 and in prep

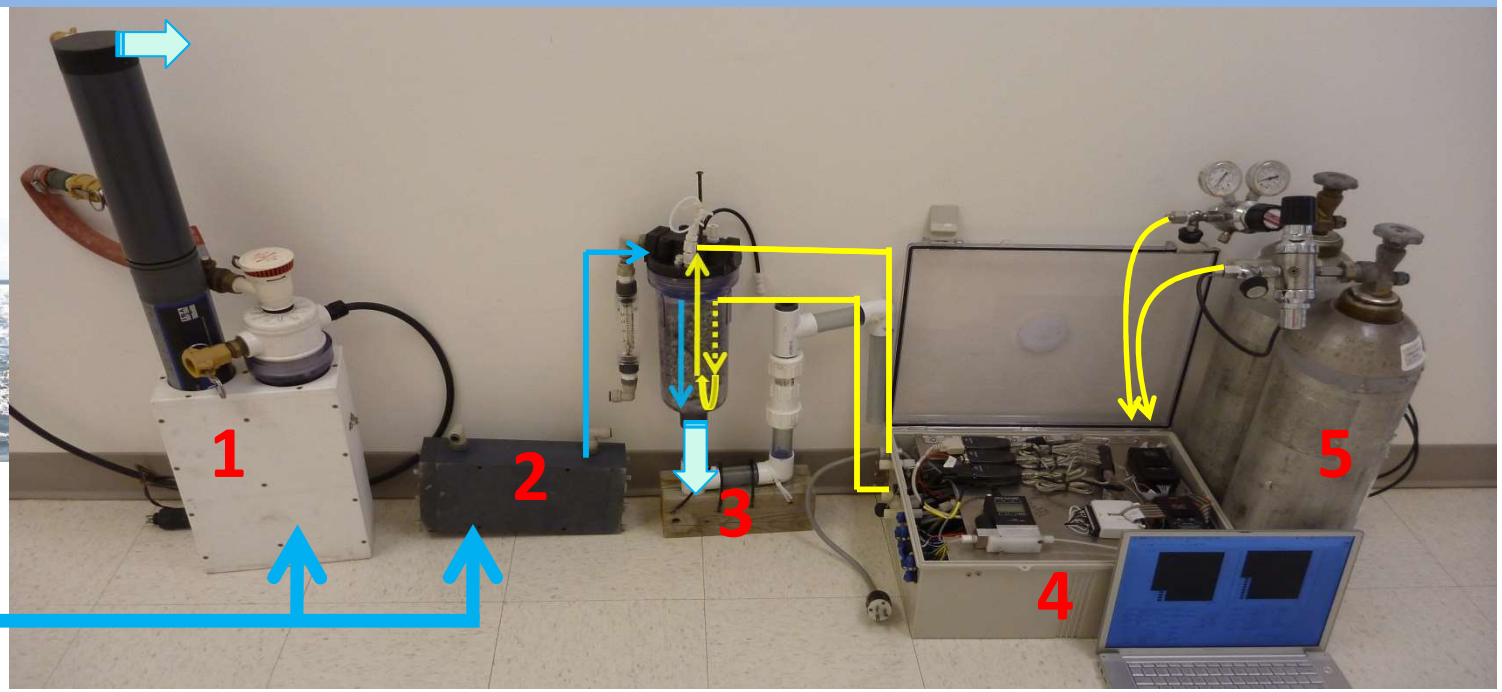
Potential sources and pathways of introduction of terrestrial DOC and POC to the coastal ocean via watersheds, rivers, and estuaries



CO_2 is the terminal product of DOC and POC degradation (largely by microbes)

DOC is more than it's concentration… ***it's quality matters.***

How's CO_2 flux affected? Flo-thru determination of pCO_2 on ModMon runs



1. Sonde (YSI)
- Chl flourescence (chl a)
- Dissolved Oxygen (DO)
- pH
- Turbidity

2. TSG (Seabird)
- Salinity (SSS)
- Temp (SST)

3. Equilibrator
- Temp
- Pressure

4. NDIR CO_2 Analyzer (Licor)
- xCO_2

5. Calibration gas standards

pCO_2

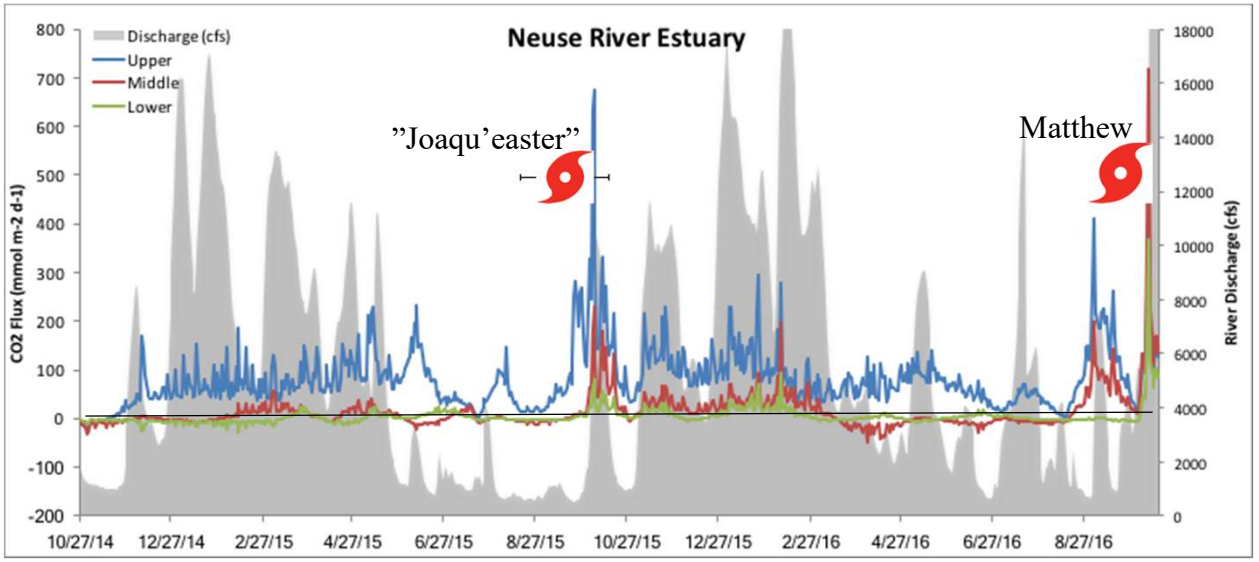
Air-water CO2 flux

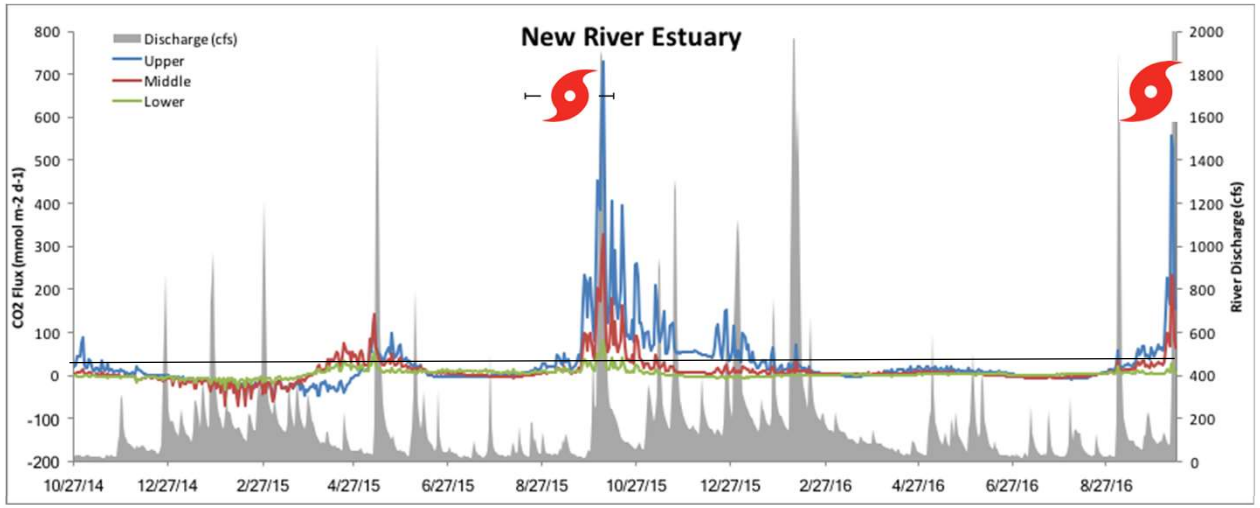
(flux equations from Jiang et al. 2008)

CO_2 Flux in the Neuse and New River Estuaries, NC in relation to recent major storms and FW discharge

”Joaqu’easter”

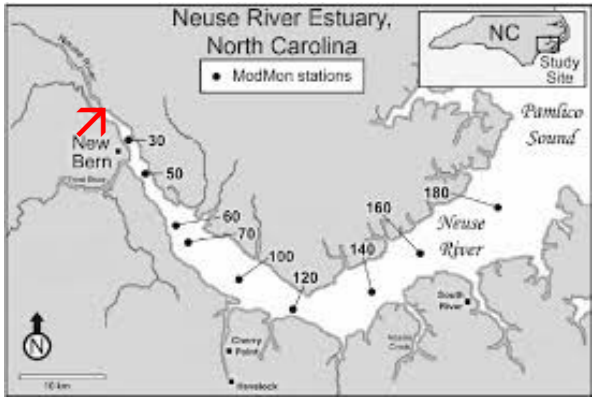
Matthew





Take home message: One tropical cyclone (e.g., Isabel) can liberate as much CO2 as fixed annually by phytoplankton. (Crosswell et al., 2014)

DOC loading to the Neuse R. Estuary: How important are tropical cyclones relative to "normal" hydrologic patterns ? Answer, VERY!



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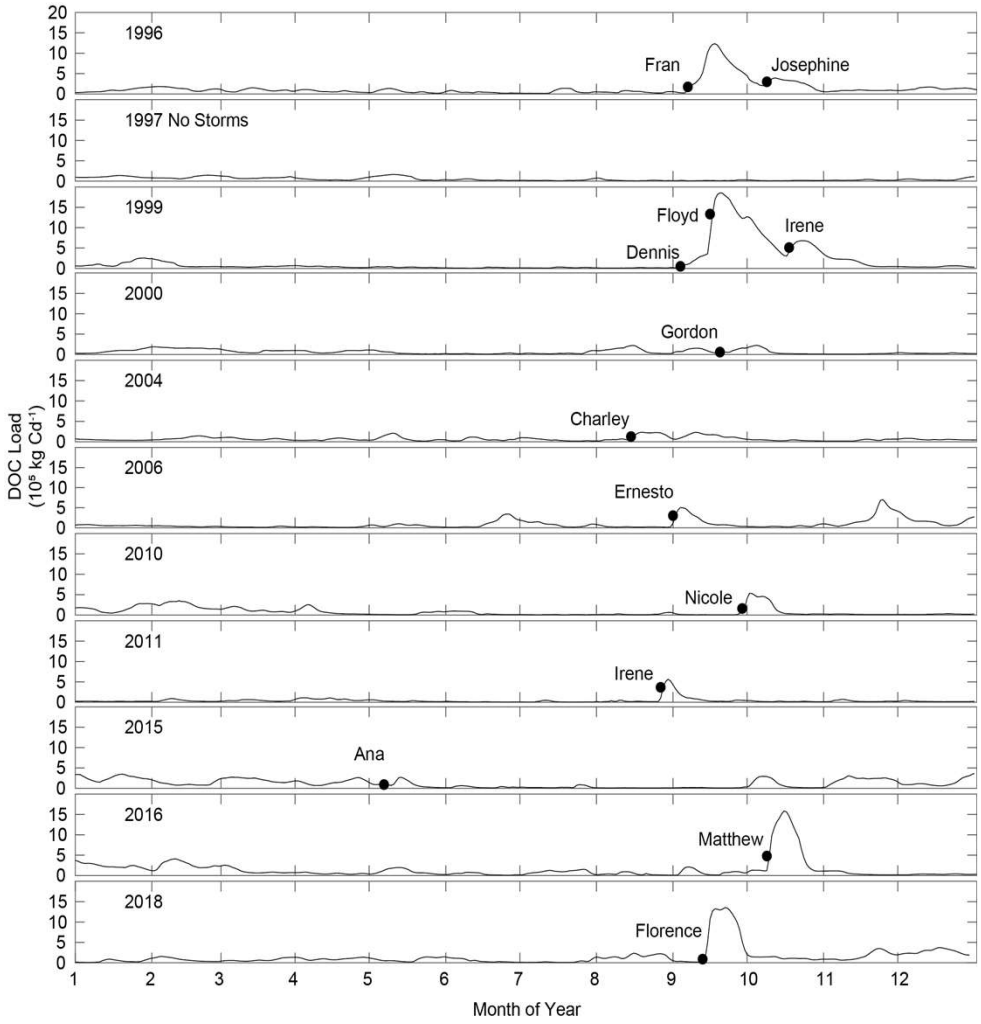


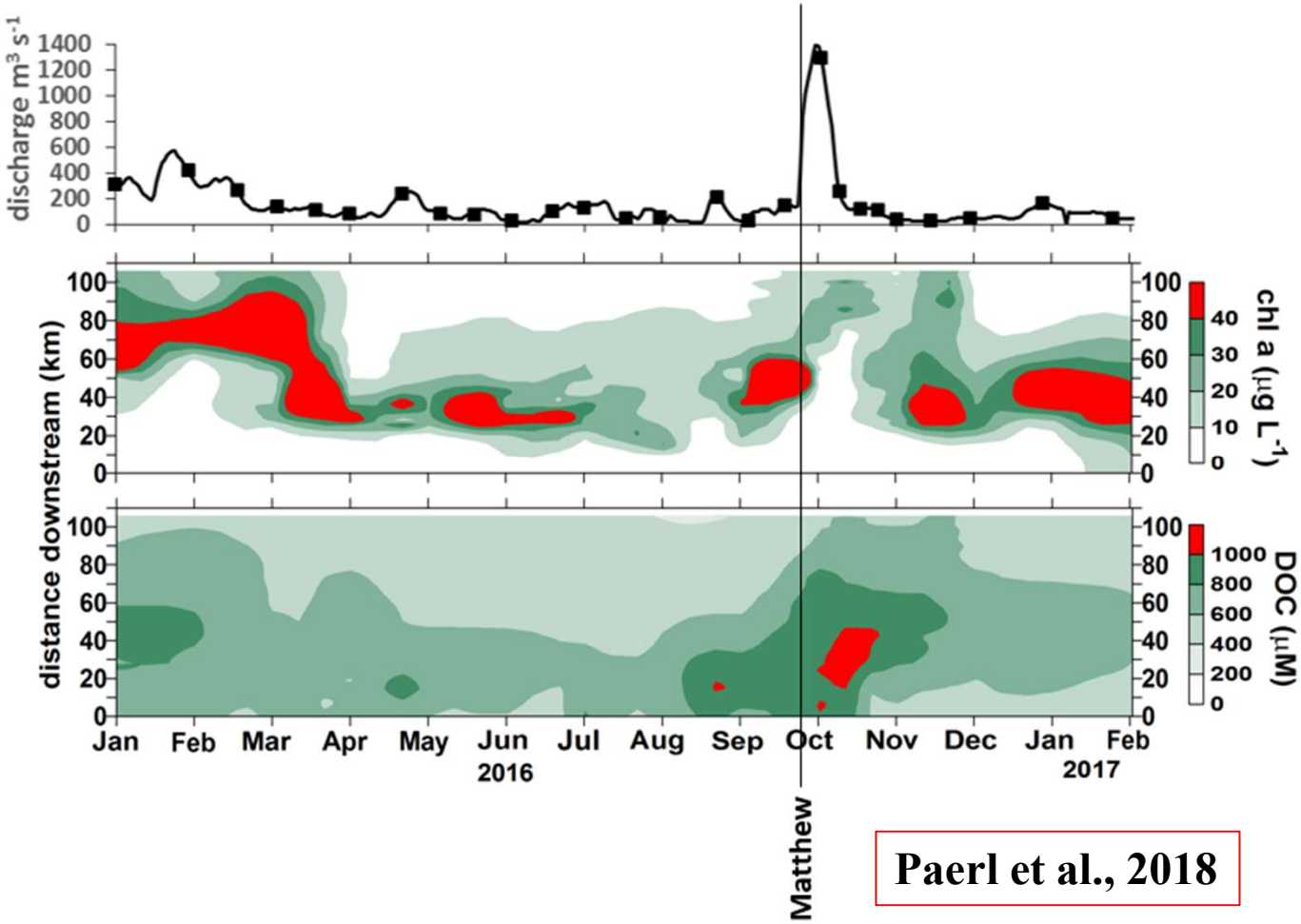
Hall et al., 2013; Peierls et al., 2012; Paerl et al., 2014, 2018

Impacts of Hurricane Matthew's (Fall 2016)
"500 year" floodwaters on the Neuse River Estuary, NC.

1. First a big flush of dissolved organic matter delivered from the watershed….
2. Then an algal bloom (as chlorophyll) response

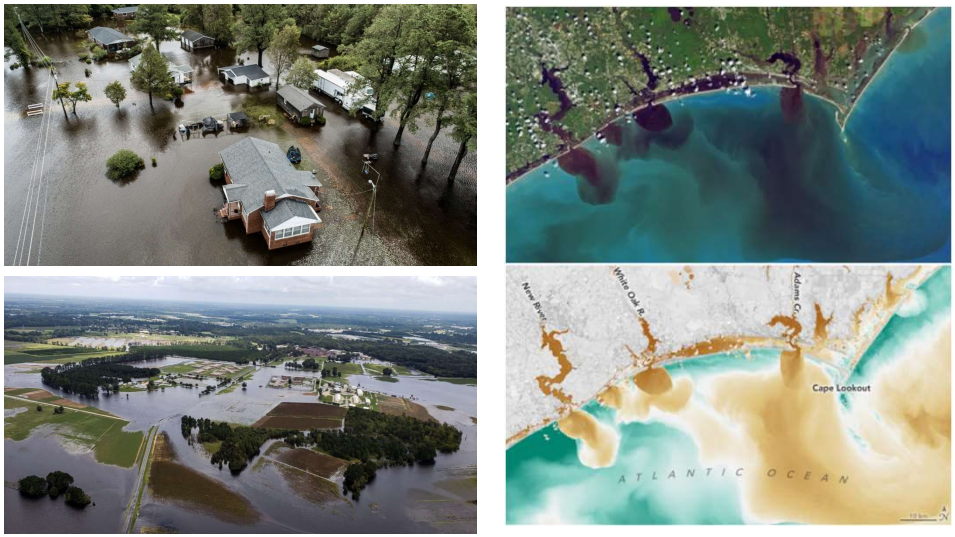
Before

After

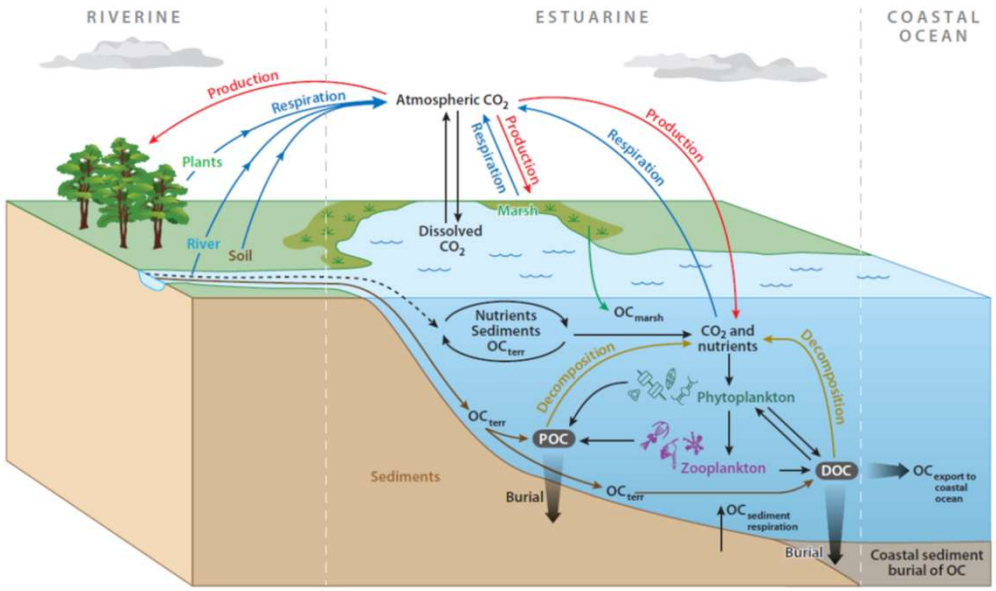


Paerl et al., 2018

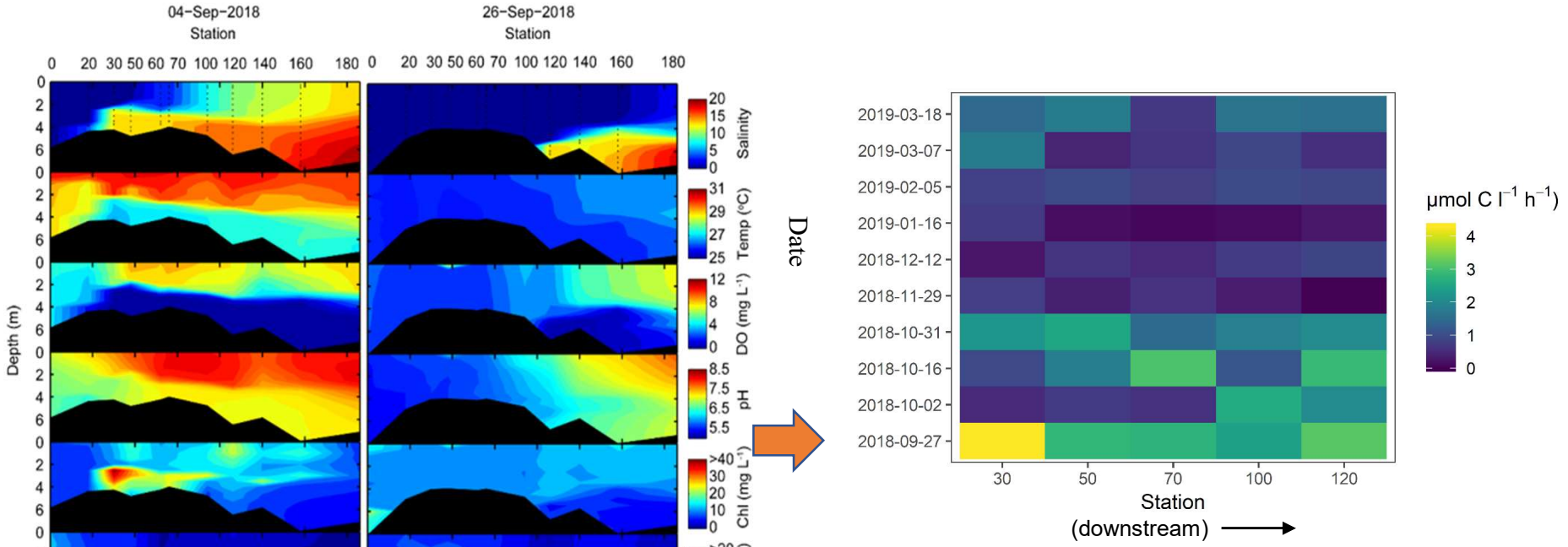
Dissolved organic C flux is strongly affected: importance?



- Organic matter as **dissolved organic carbon (DOC)** is consumed by **heterotrophs**
- **Basal resource** in food webs
  - "Microbial Loop"
- Contributes to **acidity** and **alkalinity**
- **Complexes** with metals, P, hydrophobic molecules
  - Important vector for **contaminant movement**
- **Absorbs** sunlight (CDOM)



Sustained DOC respiration in the Neuse River Estuary to Hurricane Florence's floodwaters in 2018. This is linked to hypoxia potential.

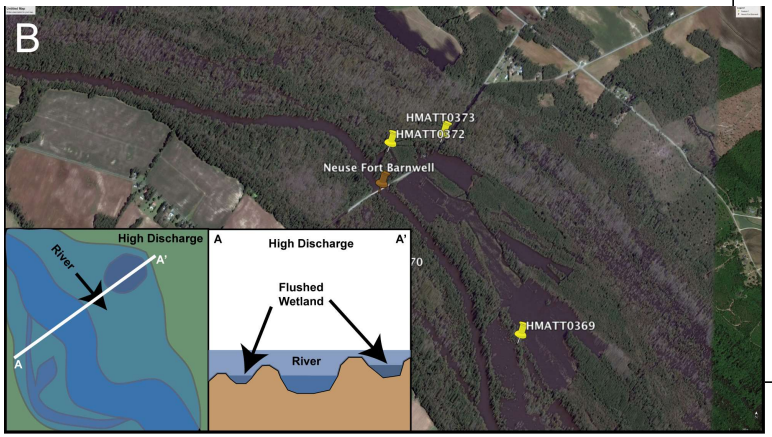


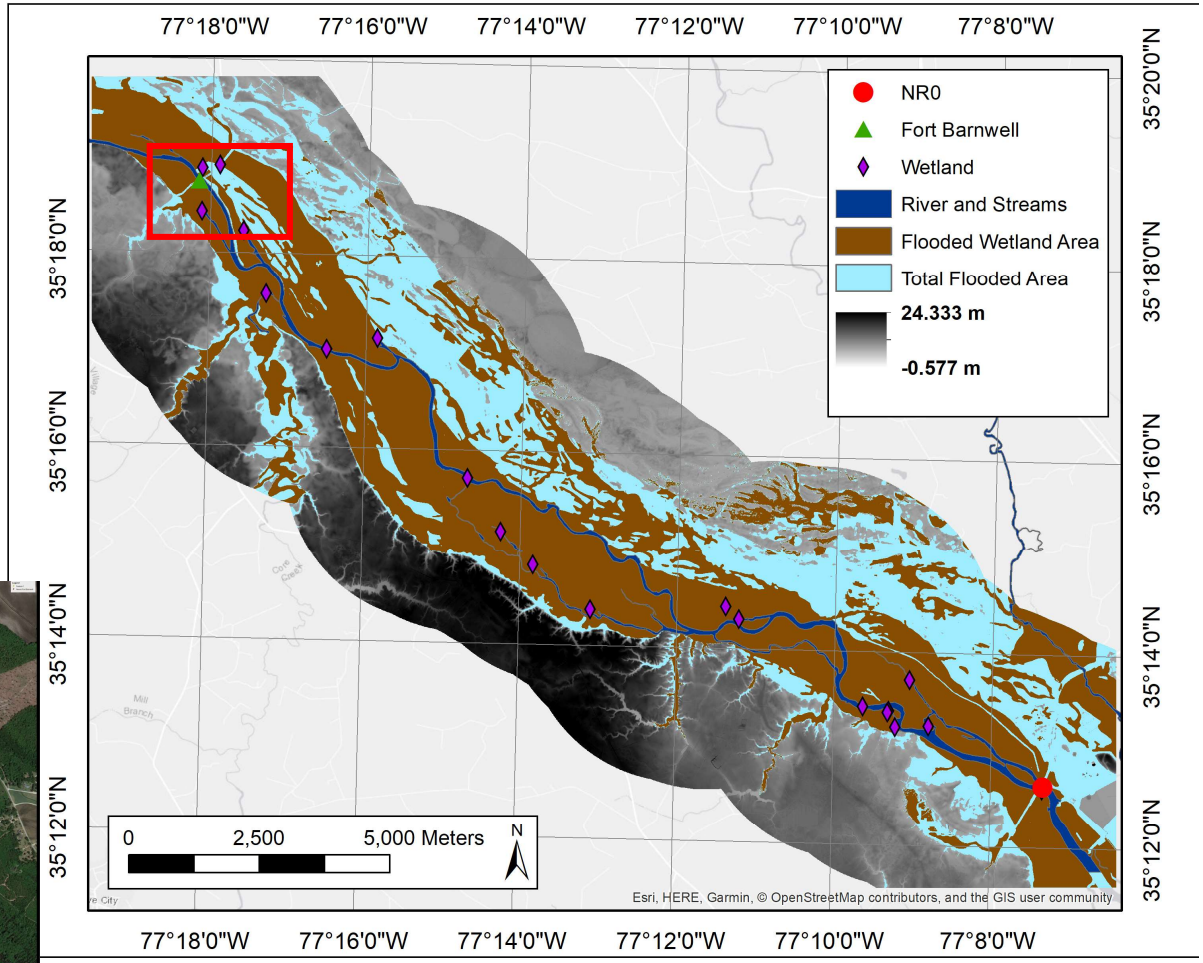
Data courtesy of R. Paerl, NCSU

Data source: ModMon, and in Paerl et al., 2020

Riparian wetlands are a major source of OM in response to storm-related flooding

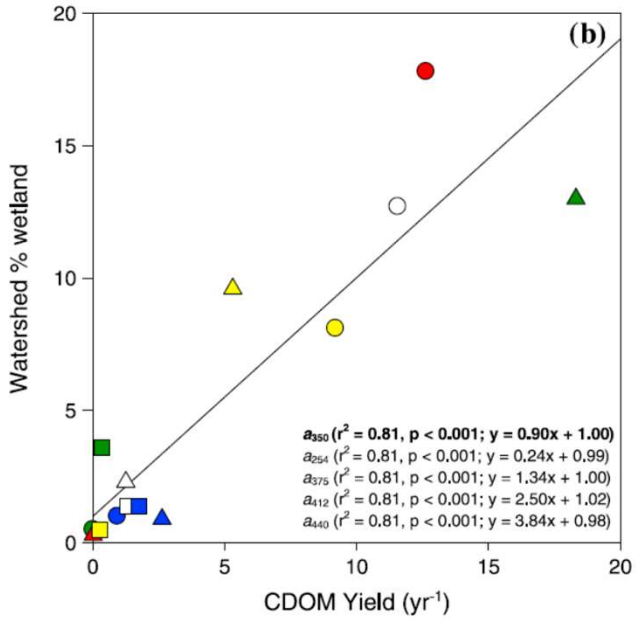
- Floodwaters cause **connectivity** between wetlands and main stem
- OM in wetlands will be flushed downstream where it can be further **processed and exported** to coastal waters





Rudolph et al., 2020, *Frontiers of Marine Science*

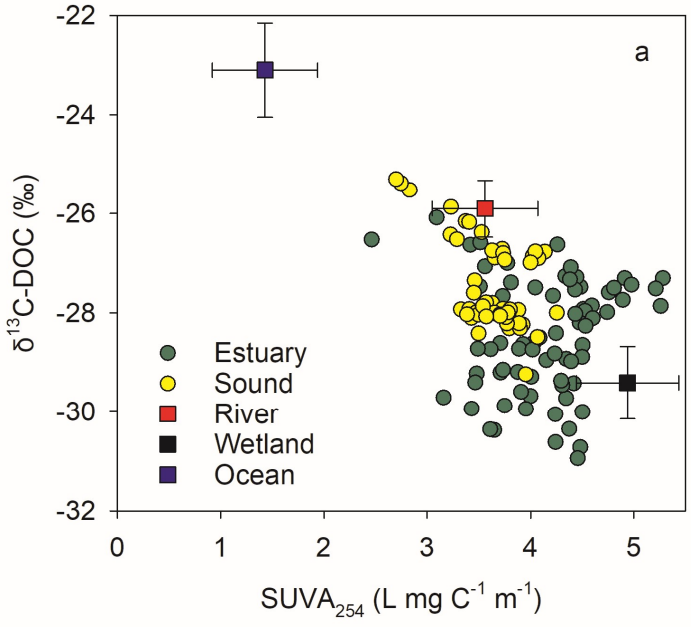
Wetlands contribute DOC to rivers



- %wetlands in catchment is a key driver in coastal watersheds
- 15 major US rivers over several terrestrial biomes
- Export of CDOM-rich water
- Small systems can yield as much as larger systems

Spencer et al. (2013) *Geophys. Res. Lett.*, *40*(8), 1575-1579

In the Neuse R. Pamlico Sound continuum, DOC exhibited wetland characteristics



Osburn et al. (2019)

- Both Estuary and Sound samples bounded by "fresh" riparian wetlands and River (uplands)
- Sound values co-occurring with River likely are a mixture of Ocean and Wetland

Characterizing watershed sources using fluorescent techniques (EEMs PARAFAC)

Environmental Science & Technology

Article

pubs.acs.org/est

ES&T 50:8473-8484

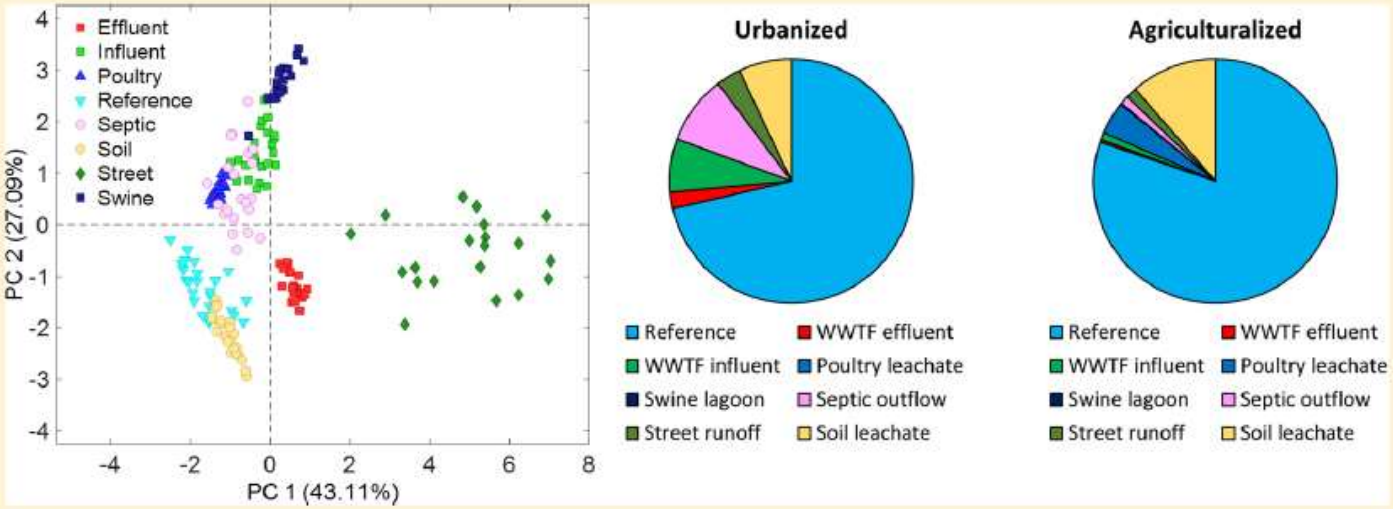
Predicting Sources of Dissolved Organic Nitrogen to an Estuary from an Agro-Urban Coastal Watershed

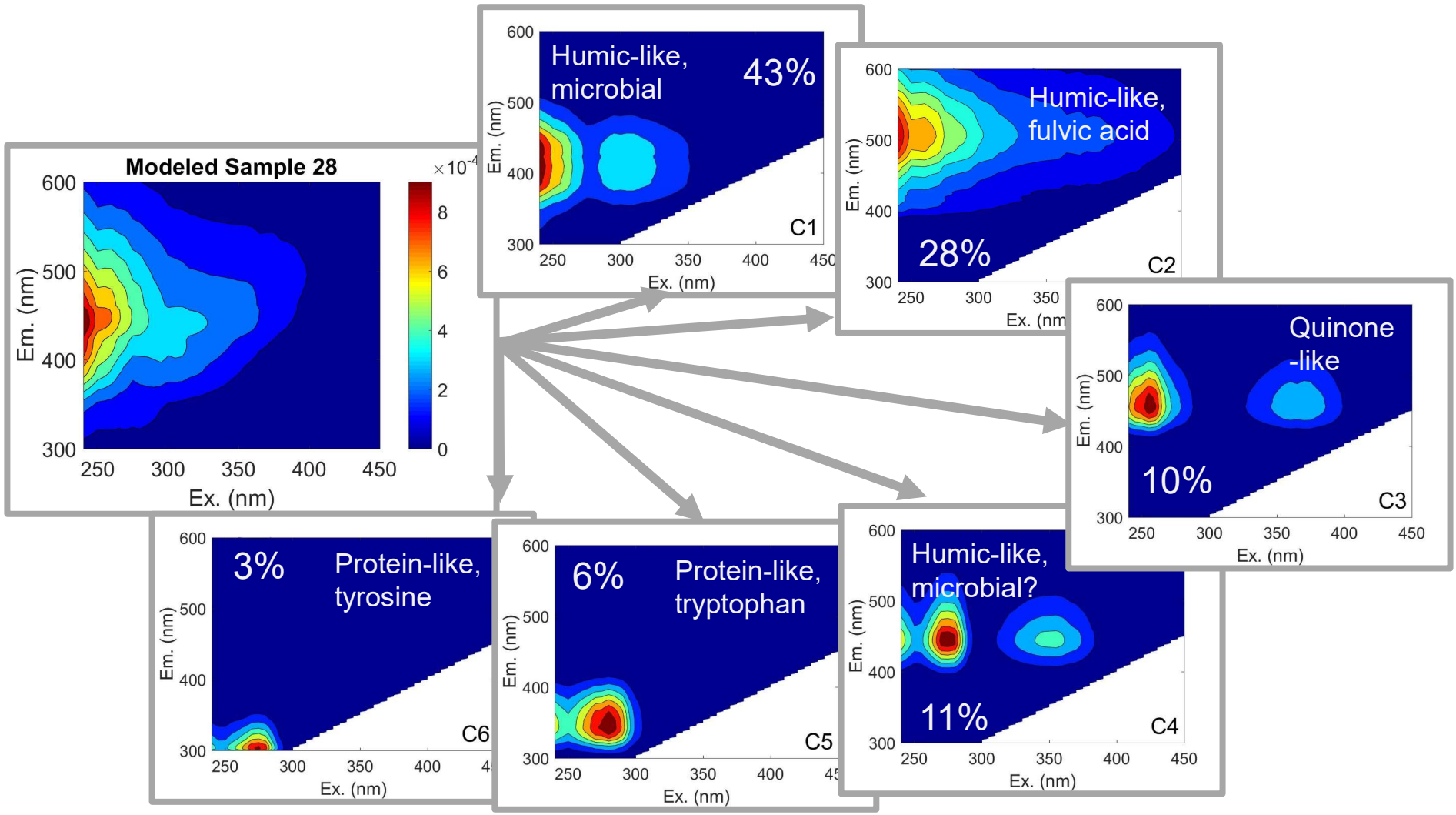
Christopher L. Osburn,*,† Lauren T. Handsel,†,§ Benjamin L. Peierls,‡ and Hans W. Paerl‡

†Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University, Raleigh, North Carolina 27695 United States

‡Institute of Marine Sciences, University of North Carolina at Chapel Hill, Morehead City, North Carolina 28557 United States

Supporting Information



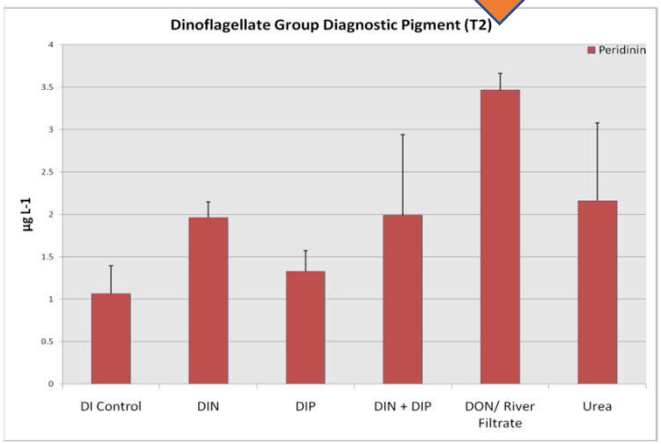


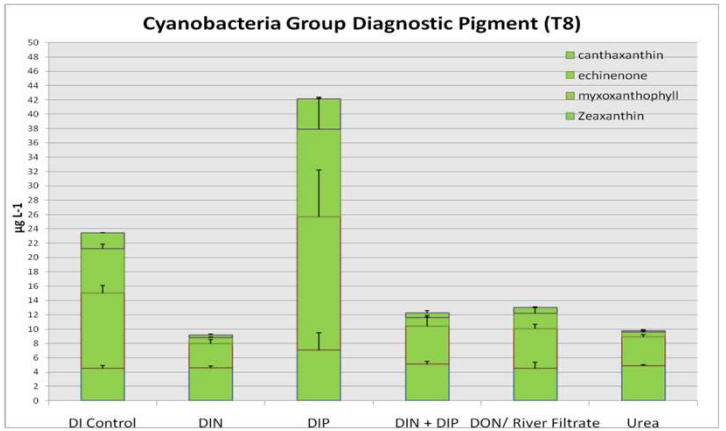
Using Fluorescence (EEM-PARAFAC) to separate different organic matter classes:

– We can track these different OM classes through the estuary to see if they are either produc
or used by microbes (algae and bacteria).

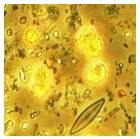
(Osburn et al., ES&T, 50:8473-8484 (2016); Hounshell et al. 2019)

Is watershed-derived DON utilized by algae?
Effects of DON relative to DIN and and P on HABs

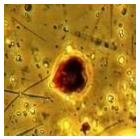




Dinoflagellate (Peredinin) biomass and Cyanobacteria (multiple pigments) on day 2 and day 8 respectively



Karlodinium sp



Scrippsiella trachoidea

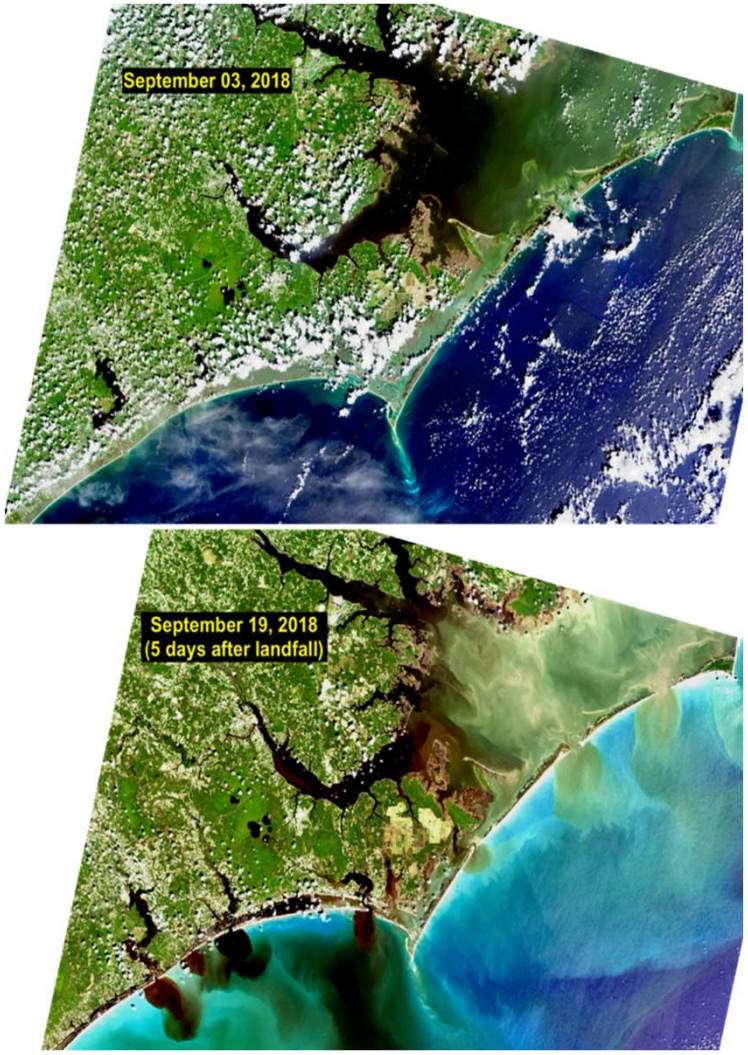
Anabaenopsis sp

Heterocysts : site of N-fixation

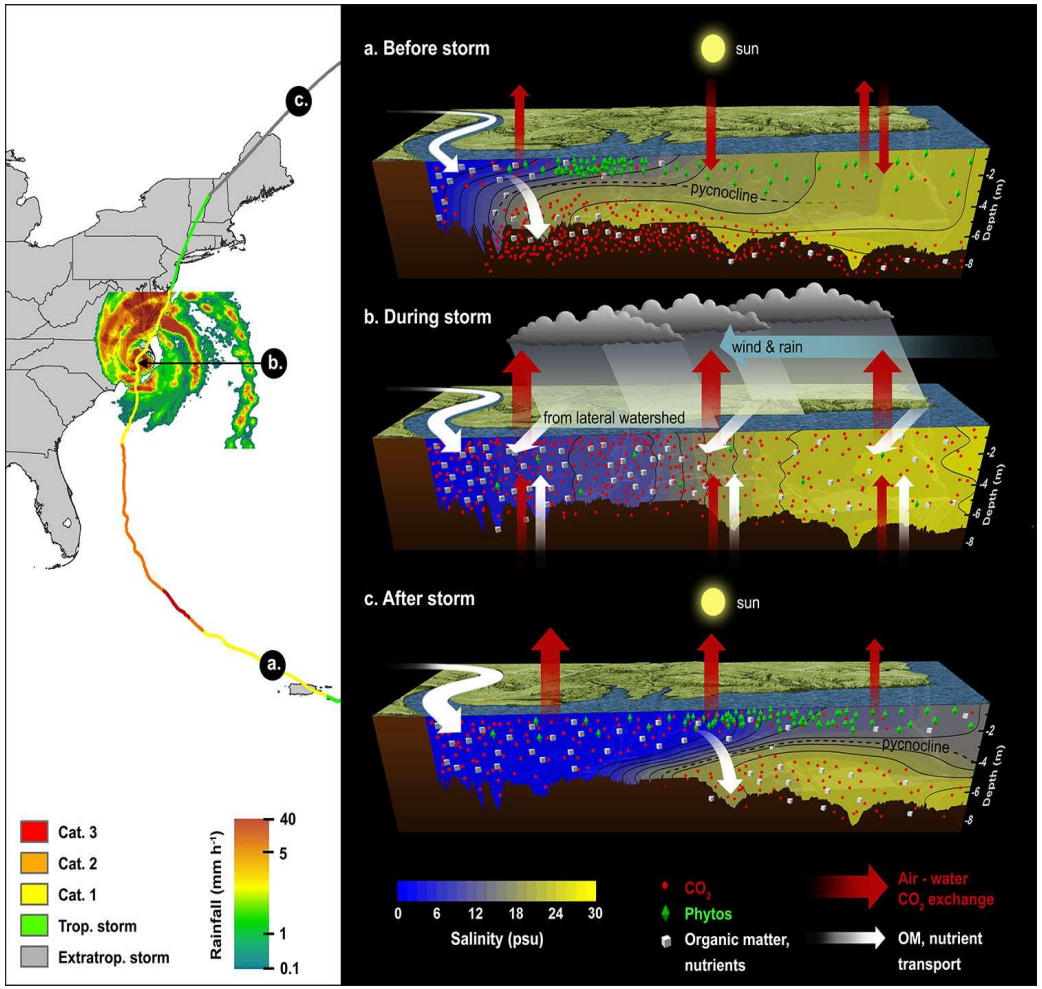
Anabaenopsis sp

Altman & Paerl 2012; Ongoing bioassay studies

Overall Effects of Hurricanes on estuarine/coastal C Dynamics

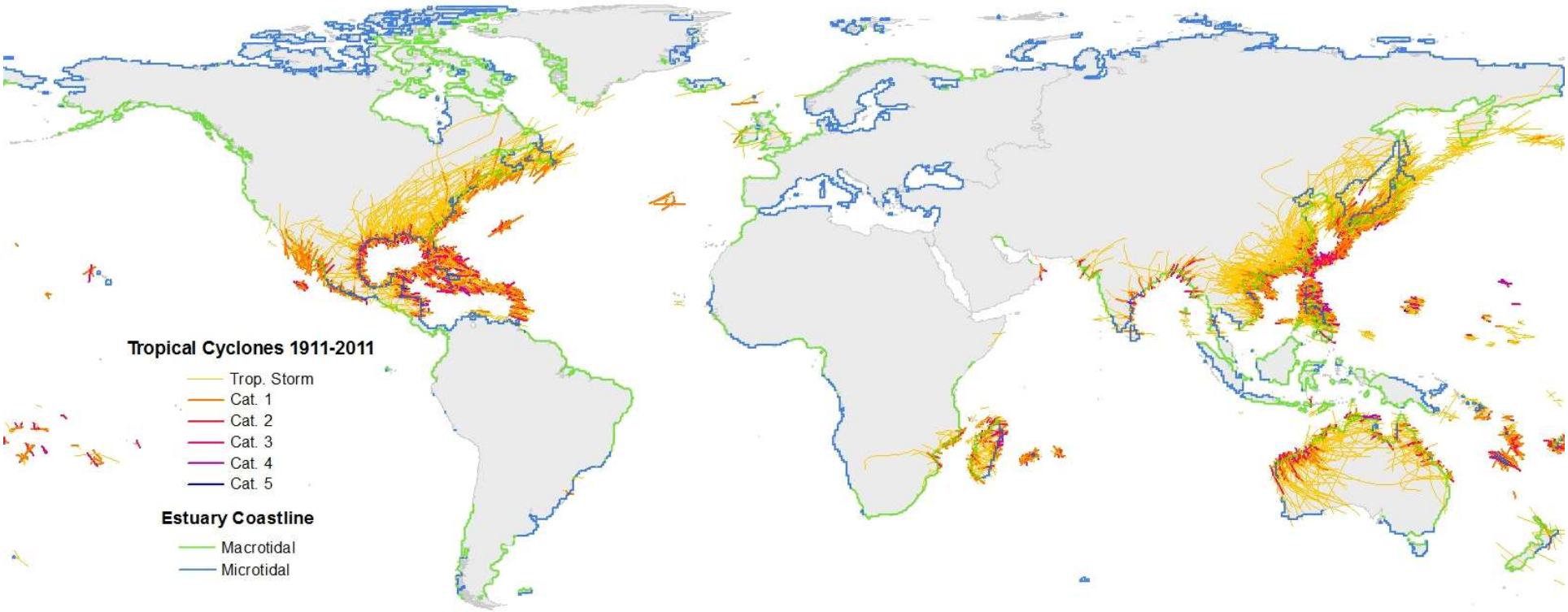


Hurricane Florence, Sept., 2018



From: Crosswell et al., 2014. L&O 59:1651

Global implications



More intense hurricanes have:

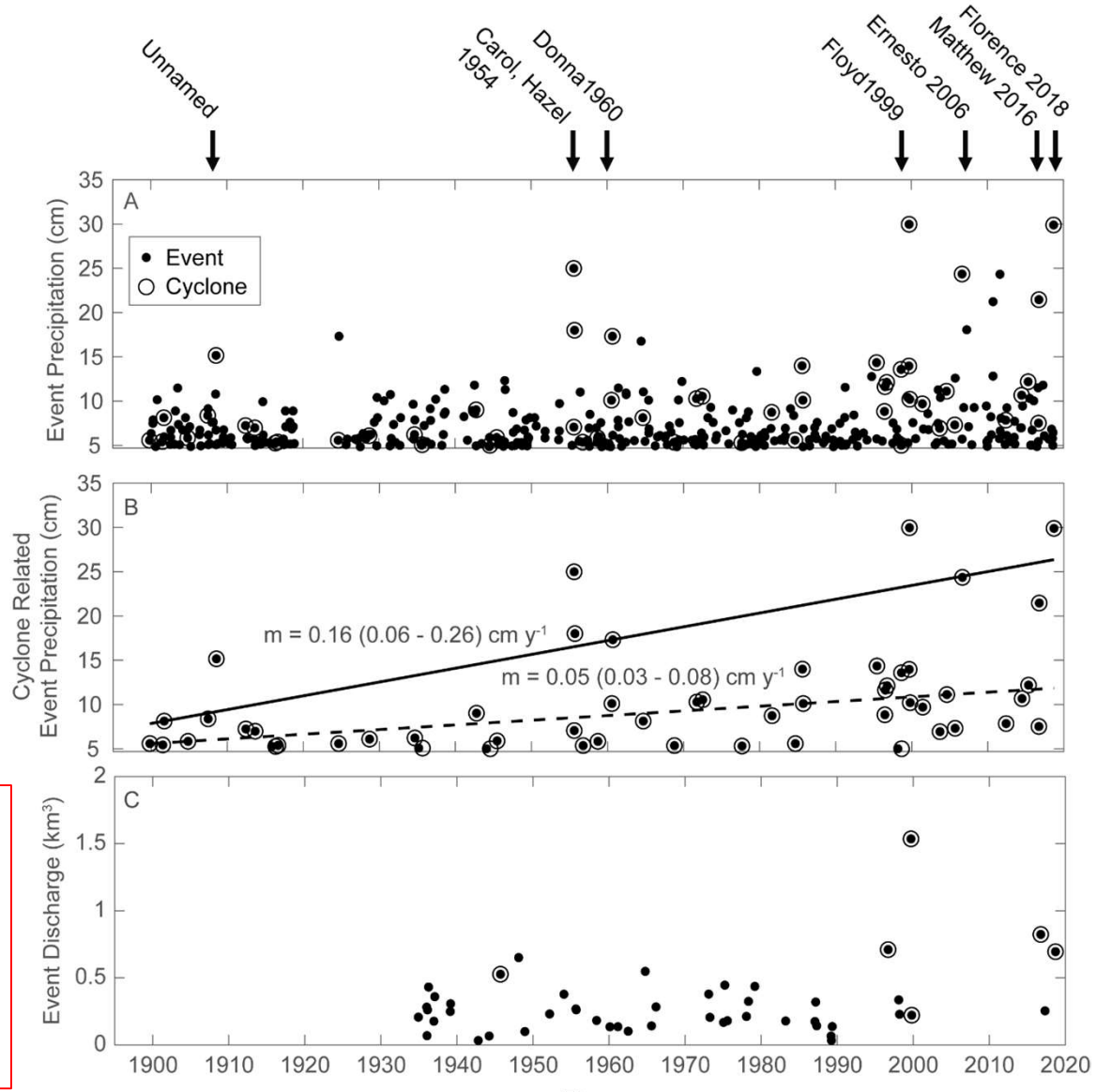
- lead to terrestrial biomass losses of 100s Tg-C
- resuspended labile coastal sediments over 1000s km^2
- mobilized C that has accumulated in wetlands over decades or even centuries

A worrysome "feedback"

More intense storms ➡ more C mobilization ➡ more CO_2 released ➡ more intense storms?

The future??

We appear to be experiencing a "new normal" with regard to tropical cyclone frequency, rainfall intensity/flooding and nutrient/C inputs to the coastal zone

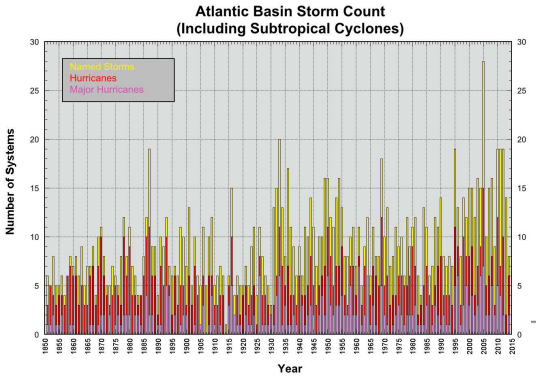


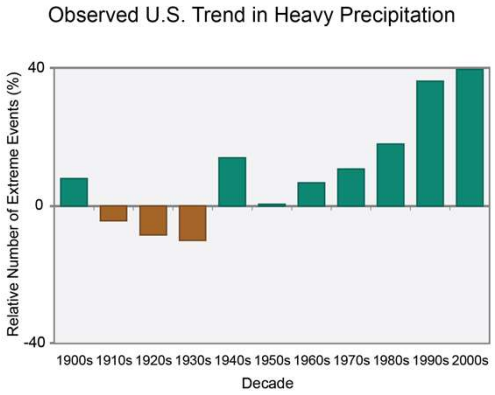
"Based on a data set going back to 1898, 6 out of 7 of the wettest tropical cyclones have occurred in the past 20 years"

Paerl et al. Nature Scientific Reports (2019)

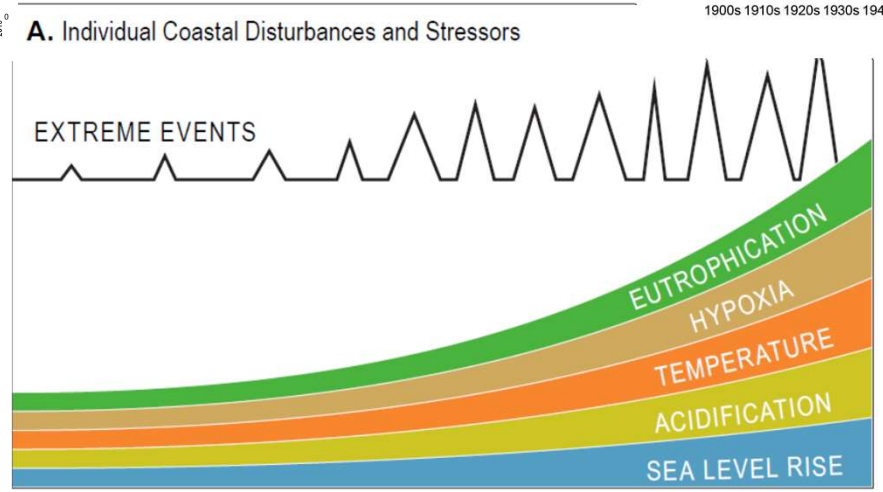
Data sources: NOAA-National Hurricane Center, USGS, NC Climate Office

This is leading to increasing “Pulse and Press” disturbances





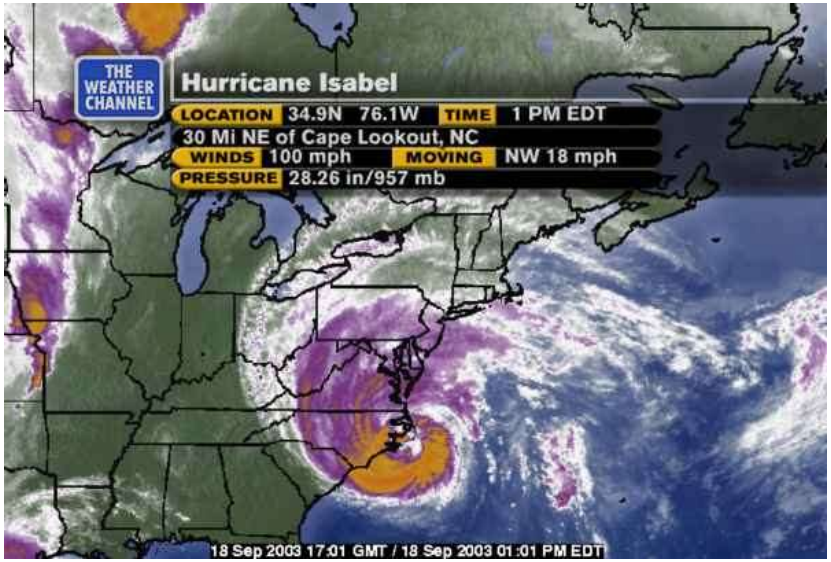
Episodic, acute pulses

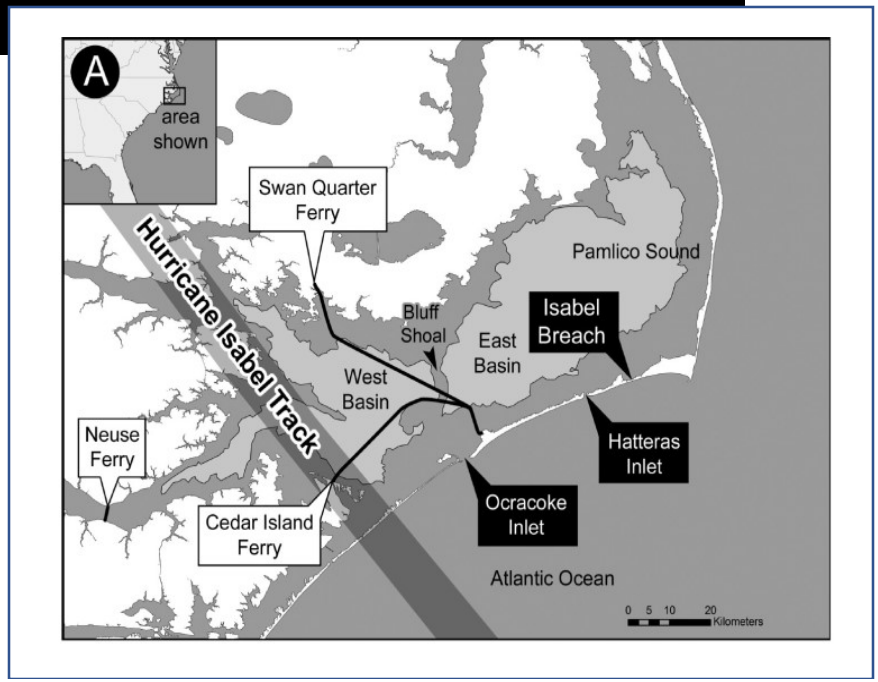


Gradual, chronic presses

Sources
NOAA National Hurricane Center
Ward et al. (2020) *Nat. Comm.* 11(1): 2458
Kunkel, 10.1175/BAMS-D-11-00262.1
WRAL-Raleigh

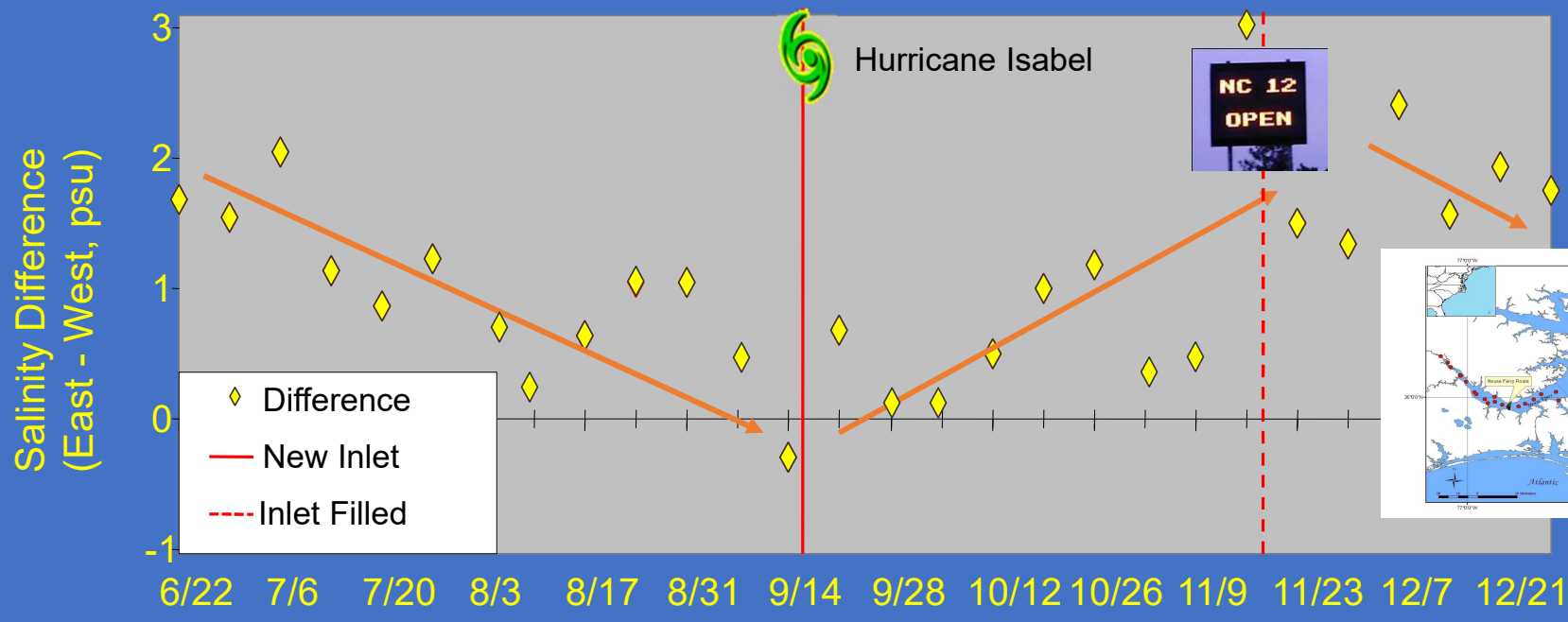
A glimpse of a more “connected” Pamlico Sound





Salinity Patterns in Pamlico Sound Determined by FerryMon Demonstrate Storm Driven Changes in Connectivity to Coastal Ocean

Difference in average weekly salinity between east and west basins



FerryMon
UNC-CH / DUKE / NCDENR / NCDOT

Paerl et al. 2009. Environ. Sci. Technol. 43:7609-7613.

The Big Picture, Long-term Concern……..
Ecosystem Resiliency and Stability in response to the "New Normal"

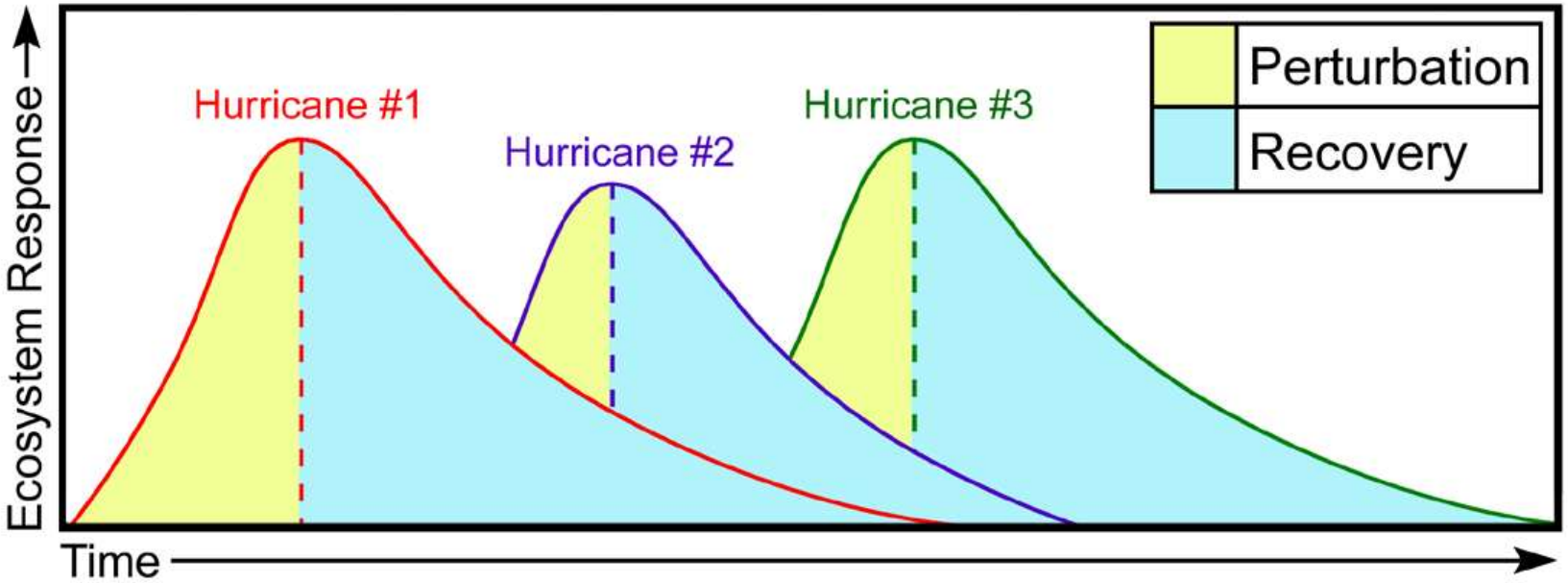
Increased frequency of Atlantic hurricanes over the next 10-40 years?

Goldenberg et al., 2001, Webster et al. 2005; Holland and Webster 2007

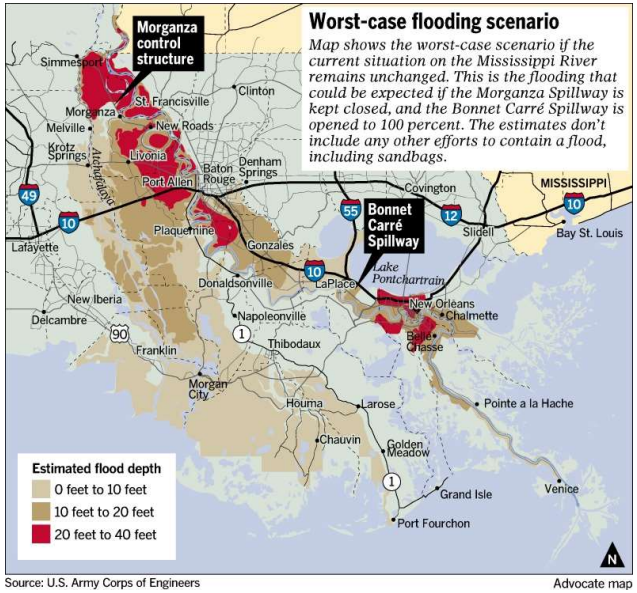
Increase in "extremeness" and scales of storm events?

Emanuel 2005; Wuebbles et al.,2014; IPCC 2014; US Climate Change Report 2018; Paerl et al. 2019, 2020

Multi-annual ecological effects and recovery?



Extreme weather pulses create feedbacks that alter coastal communities



Source: U.S. Army Corps of Engineers

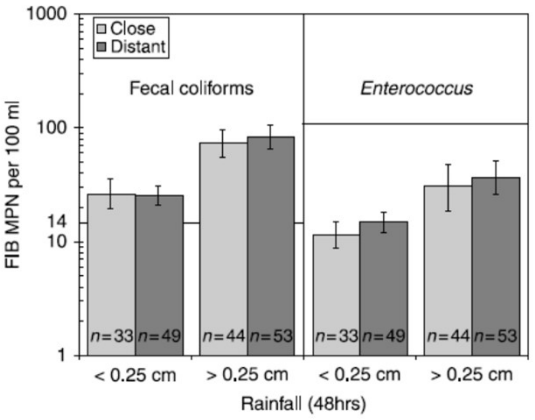
Advocate map

Flooding in New Bern, NC after Hurricane Florence, 2018

Impacts of rainfall on the water quality of the Newport River Estuary (Eastern North Carolina, USA)

Angela D. Coulliette and Rachel T. Noble

2008: doi: 10.2166/wh.2008.136



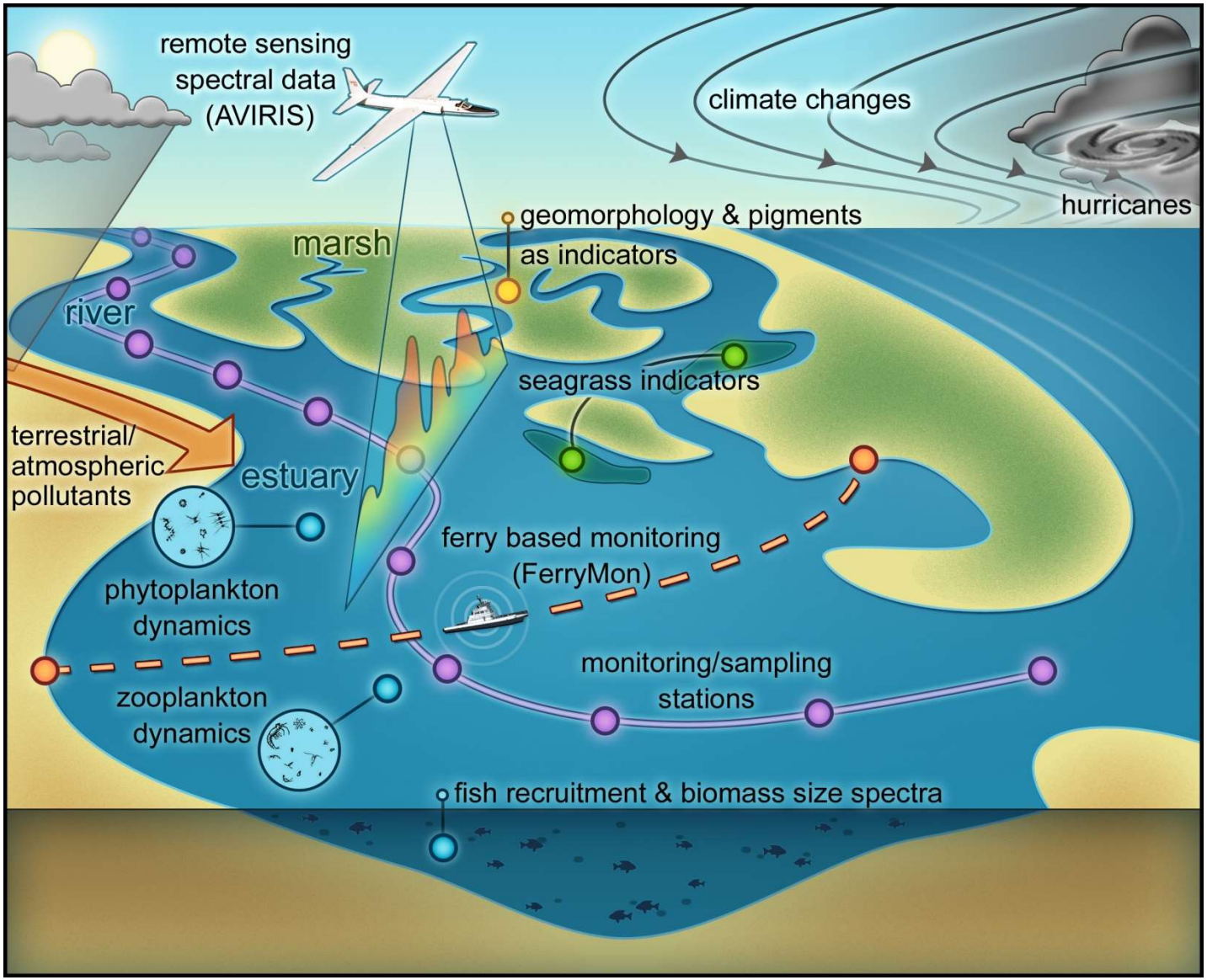
Implications and what can we do to best manage impacts

- Storm-driven N and P loading is increasing in coastal waters….promoting eutrophication and algal blooms.
- Organic matter loading has also increased, altering CO_2 flux, promoting eutrophication and hypoxia, altering planktonic and benthic habitats
- All impacted by a "new normal" in tropical cyclone frequency, rainfall intensity and flooding, driven by ocean warming and sea level rise.
- What can we do about it? Reduce emissions of greenhouse gases (CO_2 in particular), make plans for long-term, sustainable development, minimizing nutrient and organic matter loss in the watershed. Constructed buffers, wetlands and retention impoundments are critically-important.
- Immediate Needs: Tools (e.g.remote sensing, continuous water quality monitoring) to capture events/impacts over relevant scales and adaptive nutrient (N & P) and carbon management in response to climatic changes and extremes.




Thank you & questions?

This research is funded by
U.S. EPA - Science To Achieve Results (STAR) Program
Grant # 82667701



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Water Resources Research Institute

NC Sea Grant

http://paerllab.web.unc.edu