Impacts of the 'new normal' in tropical cyclone rainfall and flooding on assessing and managing estuarine/coastal water quality

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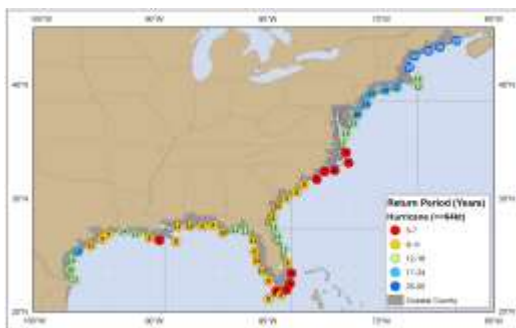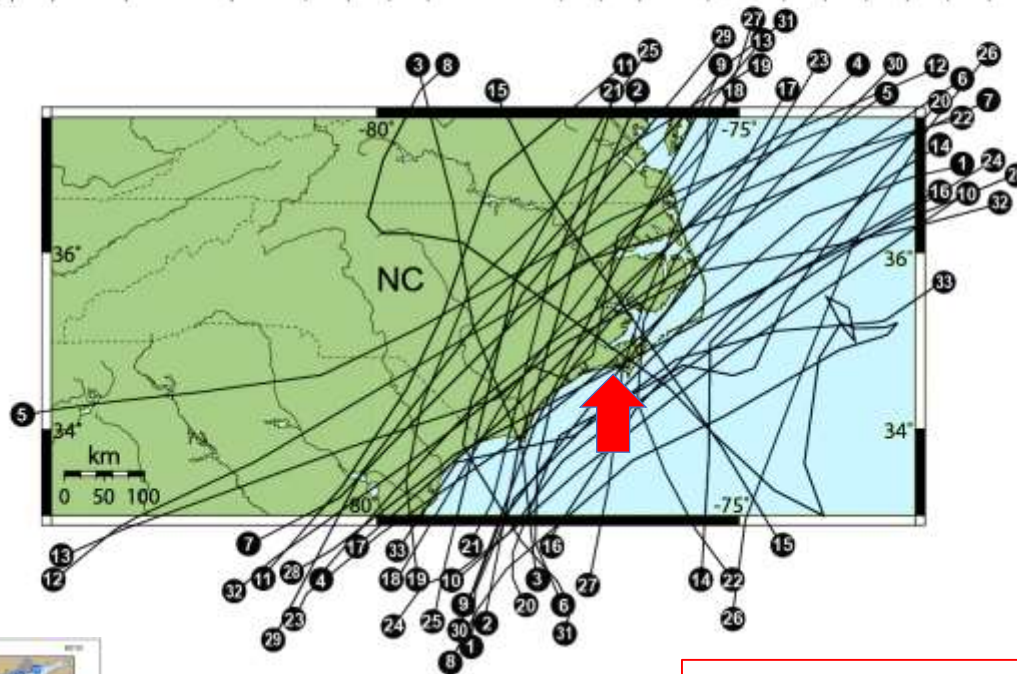www.marine.unc.edu.ims/Paerllab

Coastal North Carolina, USA: A "magnet" for tropical cyclones
(34 since 1996)

Tropical Cyclone Tracks (1996-2016)

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)
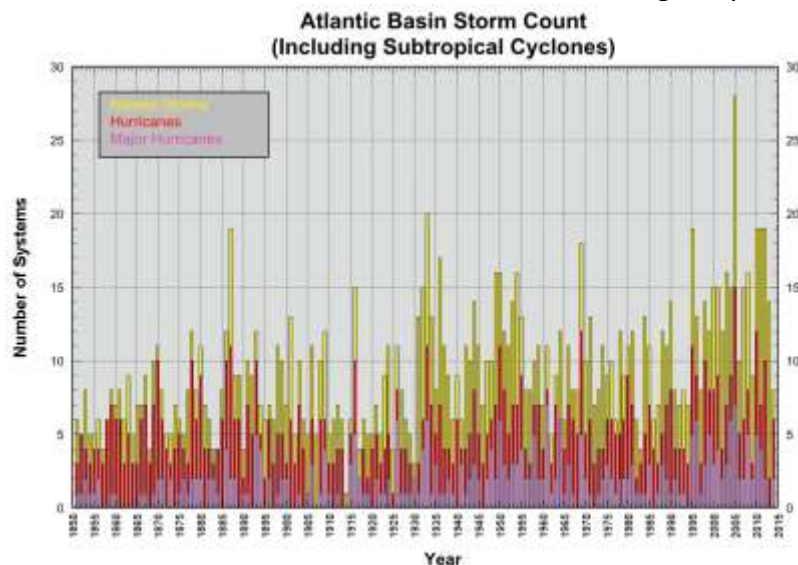
Reason for concern.........
**"We appear to be in a period of elevated tropical cyclone activity"**

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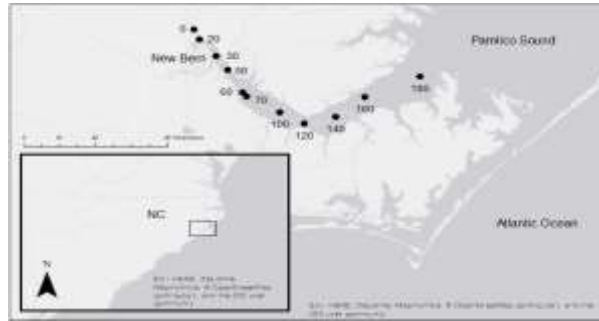

Hurricane Florence, Sept., 2018

Atlantic Basin Storm Count
(Including Subtropical Cyclones)

A major challenge: Interacting human and climatic perturbations
Their impacts on estuarine and coastal water/habitat quality
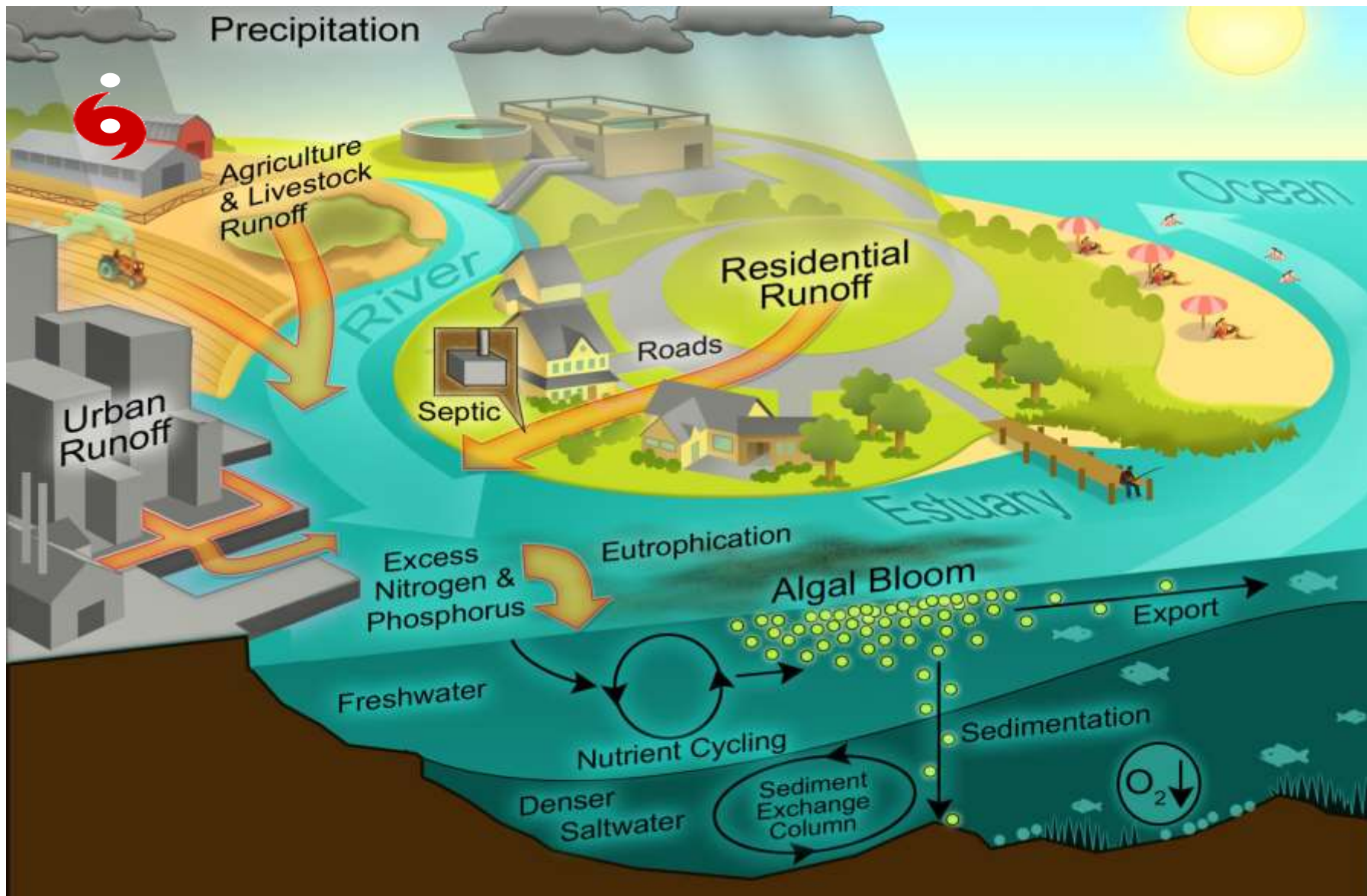
Physical-chemical impacts of hurricane Florence (Sept., 2018): The "freshening" of the Neuse River Estuary, NC
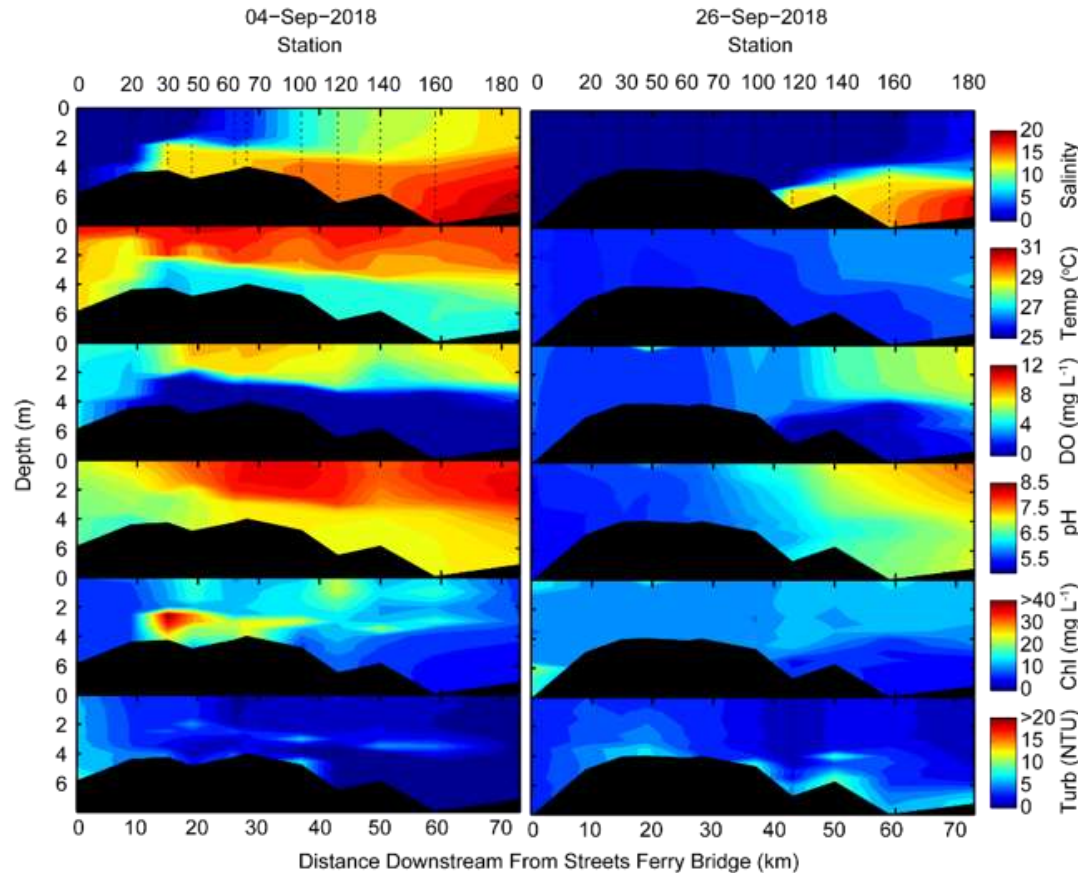
Neuse R. Estuary Modeling and Monitoring Program, ModMon
http://paerllab.web.unc.edu/projects/modmon/

Dissolved inorganic nitrogen and phosphorus loading to the Neuse R. Estuary: How Important are tropical cyclones relative to "normal" hydrologic patterns ?
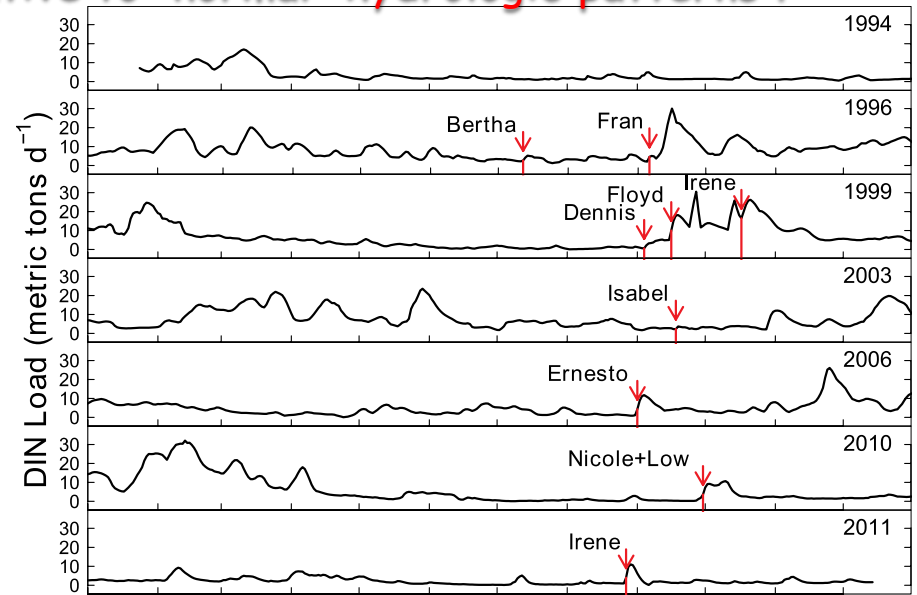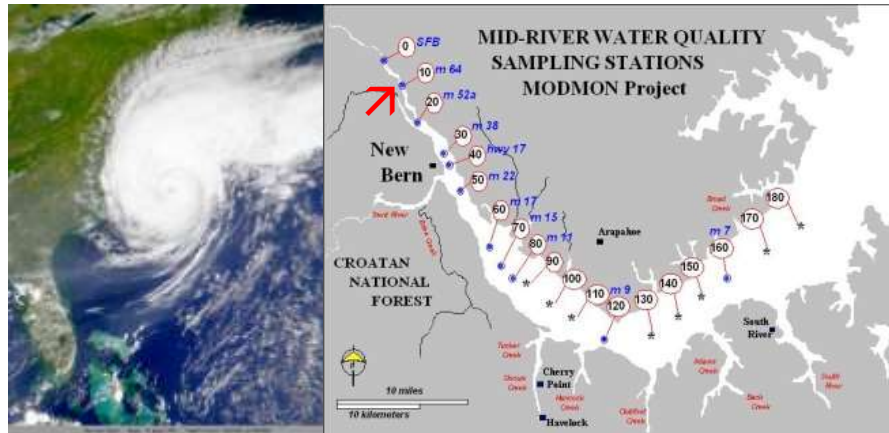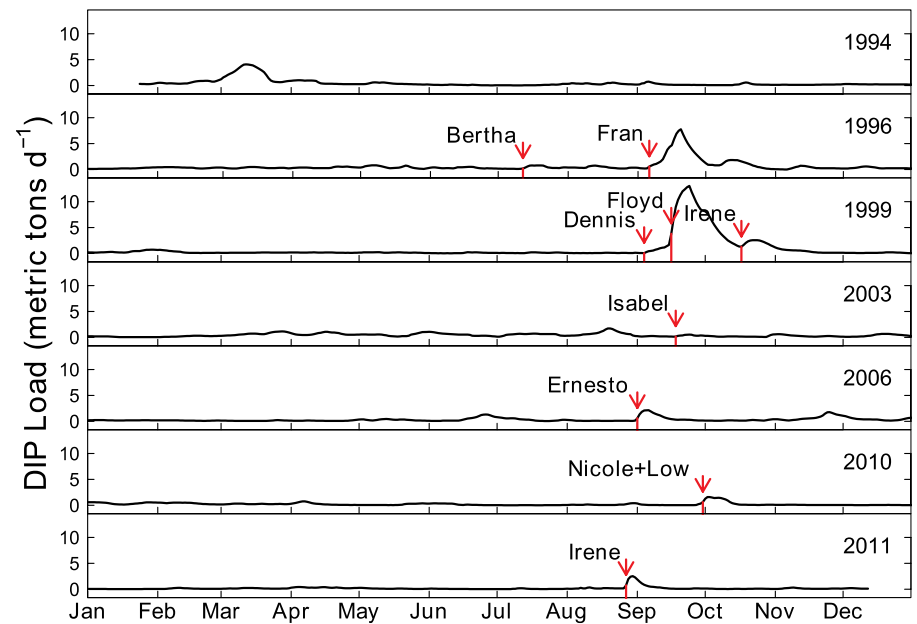

Table 4. Influence of "wet" storms on long-term (1996-2016) material loads to the Neuse River Estuary.

Parameter	Percent of Long Term Load During Storm Flows	Percent Increase Over Baseline Due to Storms
Water	13.9	15.5
TN	11.6	12.6
DIN	7.2	7.5
DON	16.0	18.3
PN	16.0	18.2
TP	21.5	25.7
SRP	26.0	32.8
DOC	21.2	25.6
POC	17.0	19.6
DIC	14.1	15.7

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

Major hurricanes/tropical storms & phytoplankton biomass (Chl a) responses in the Neuse R. Estuary, NC
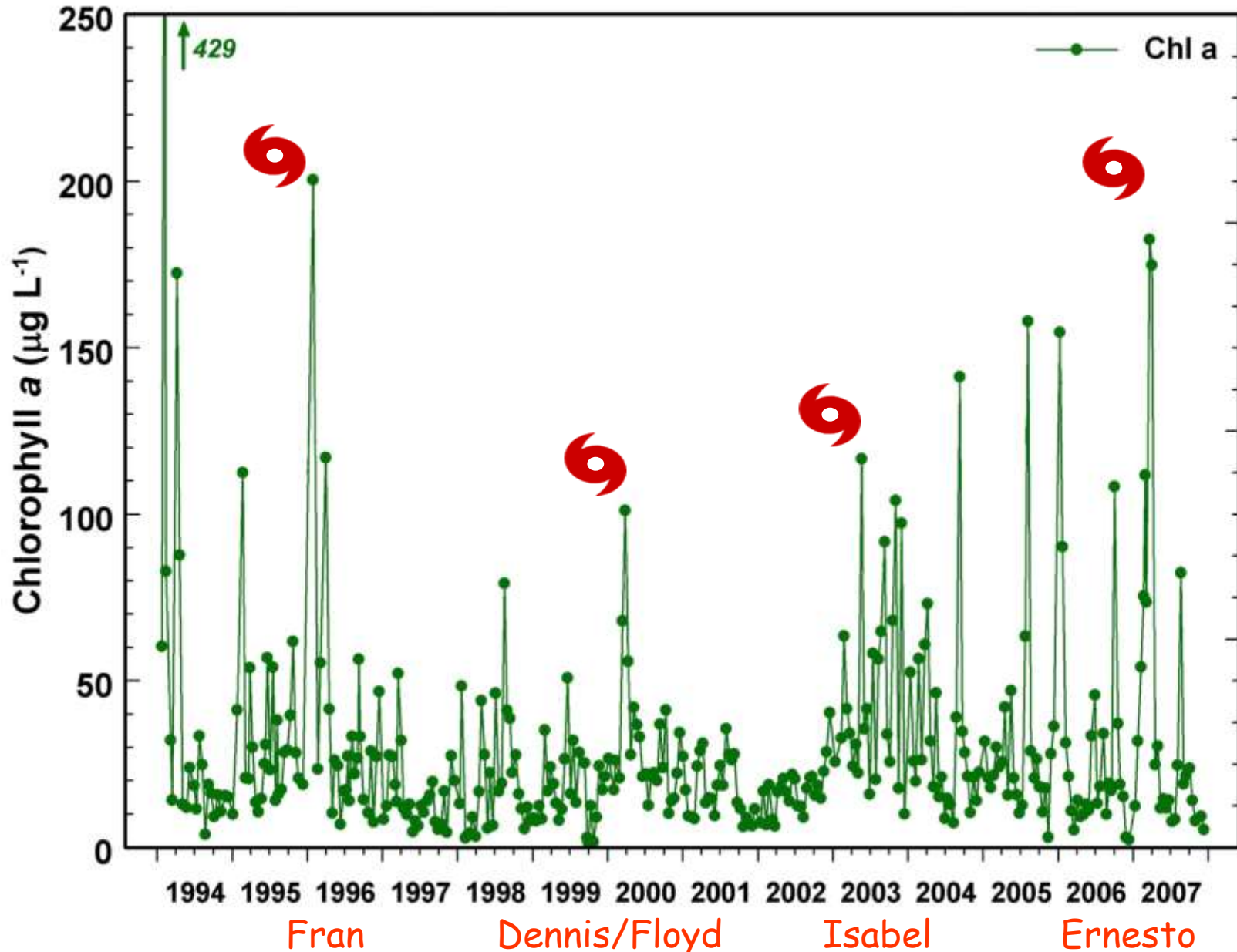
The Hurricanes of 1999: What Happened?

Floyd, 15 Sept., 1999

Dennis, 30 Aug., 1999
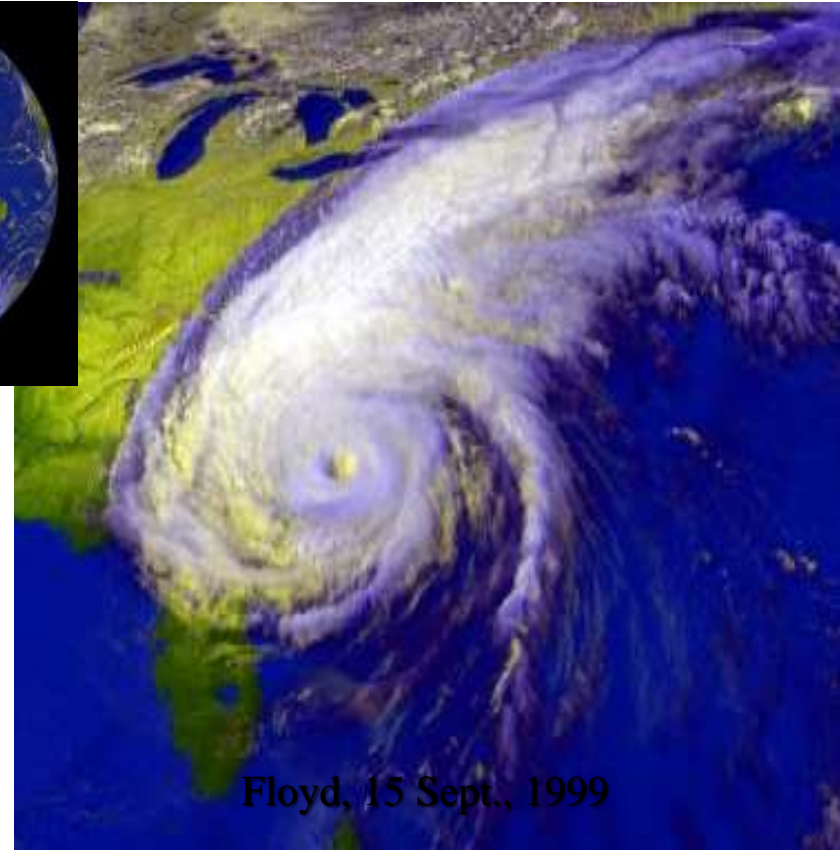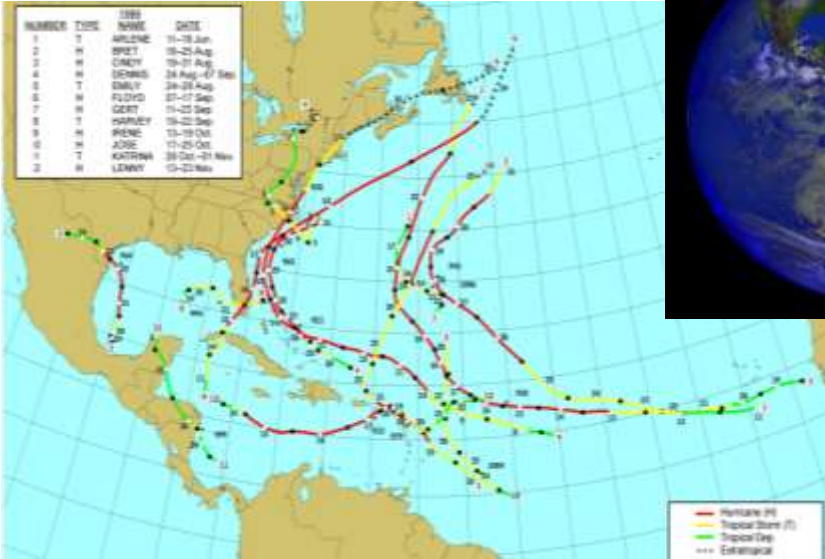
- 3 SS-scale 3 hurricanes (Dennis, Floyd & Irene) within 6 weeks
- Record rainfalls in Pamlico Sound Basin: 12-h rainfall totals >> 100-yr.
- 50-500 year floods in PS watershed
- PS Received annual water and N loads in about 1.5 months

Ecosystem Impacts

Pre-hurricane

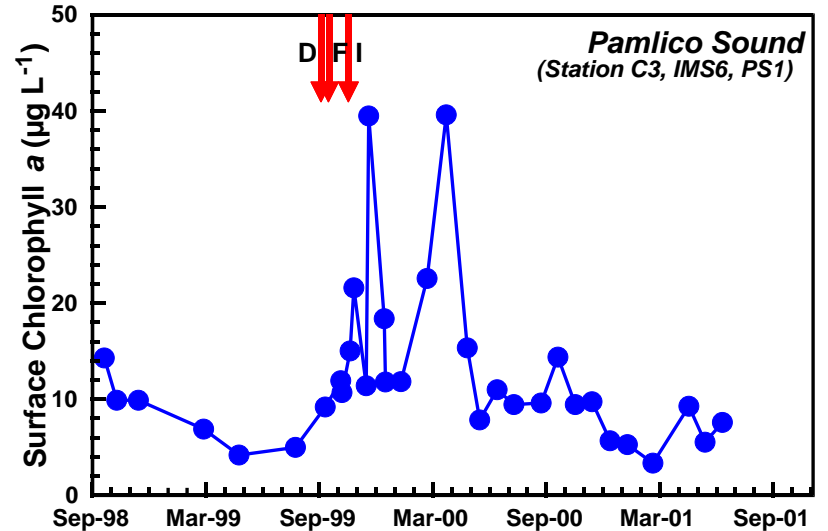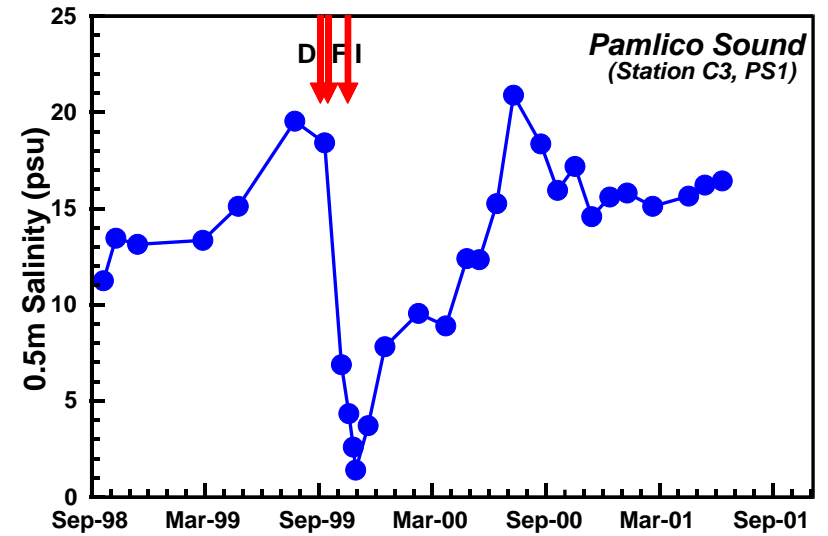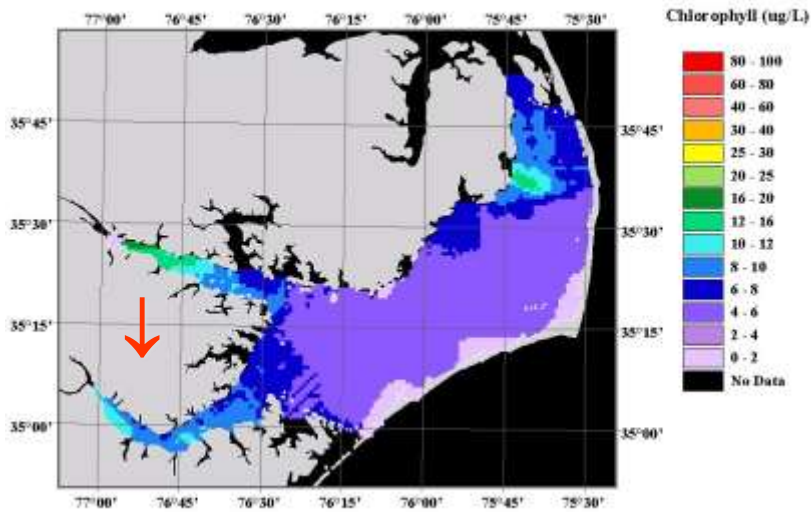**Post-Floyd, September 23, 1999**

Tar River

Neuse River

Hurricanes Dennis, Floyd & Irene ('99)
Salinity and Chlorophyll *a* responses in the Pamlico Sound

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

Pamlico Sound Remote Sensing Chlorophyll
15 May 2002

Chlorophyll (ug/L)

Pamlico Sound Remotely Sensed Chlorophyll
16 June 2002
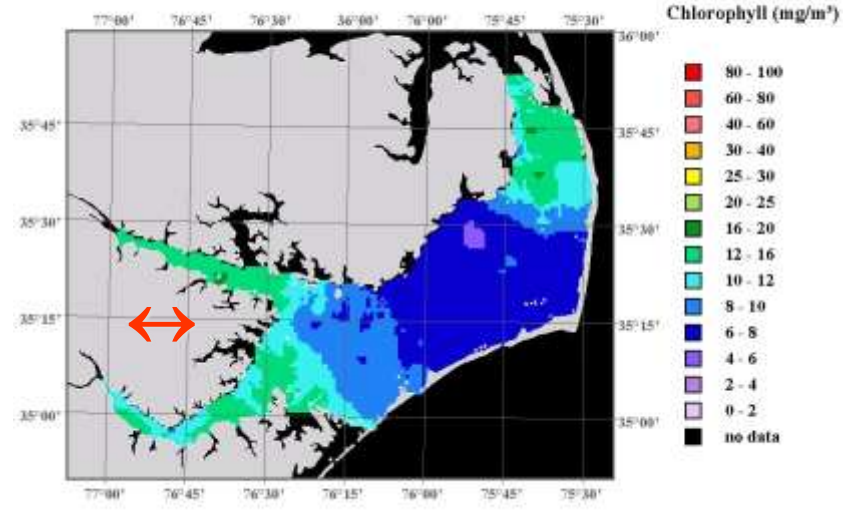
Chlorophyll (mg/m³)

Pamlico Sound Remotely Sensed Chlorophyll
17 July 2002
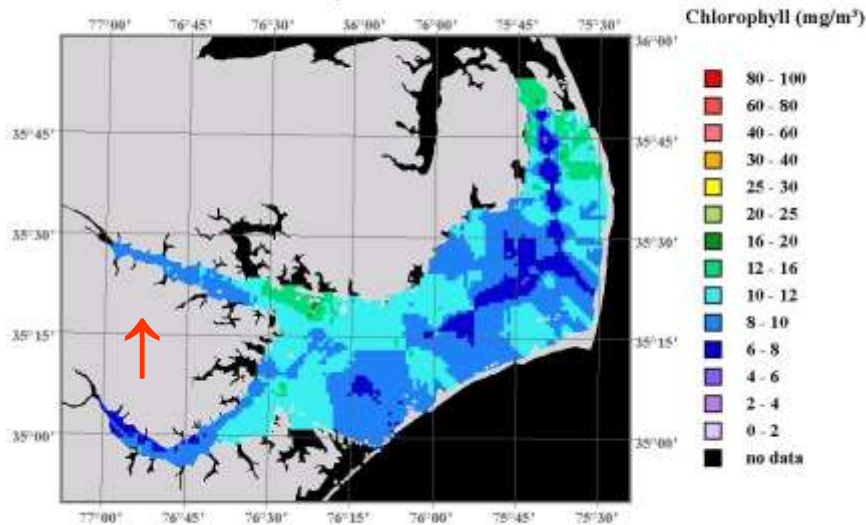
Chlorophyll (mg/m³)

Pamlico Sound Remotely Sensed Chlorophyll
08 November 2002

Chlorophyll (mg/m³)
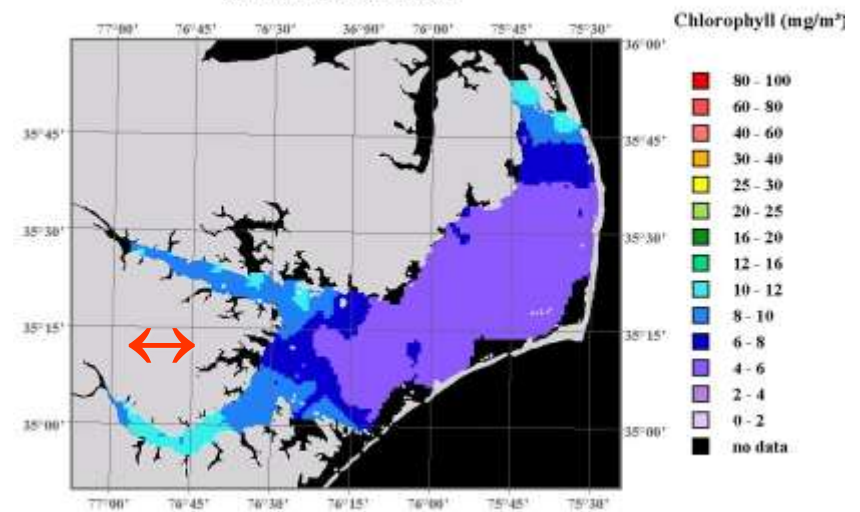
Flow: high↑, low↓, moderate↔

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

08/15/2008 - 09/14/2008
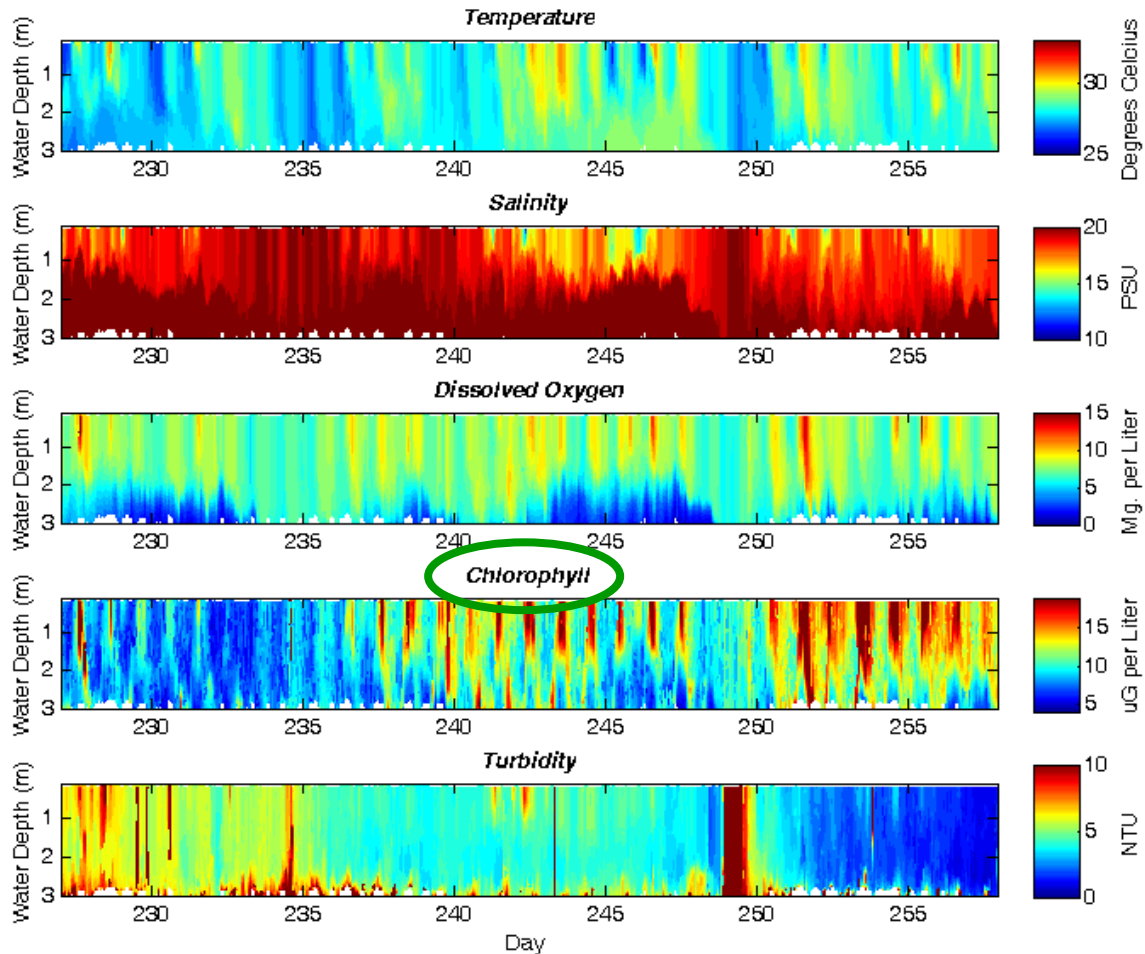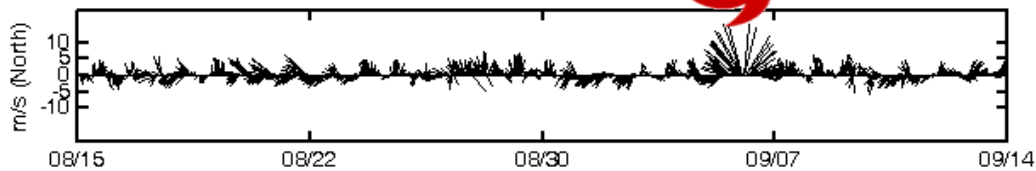
Impacts of Typhoon Passages on cyanobacterial blooms in Lake Taihu, China, based on MODIS remote sensing data

(Zhu et al., 2014)
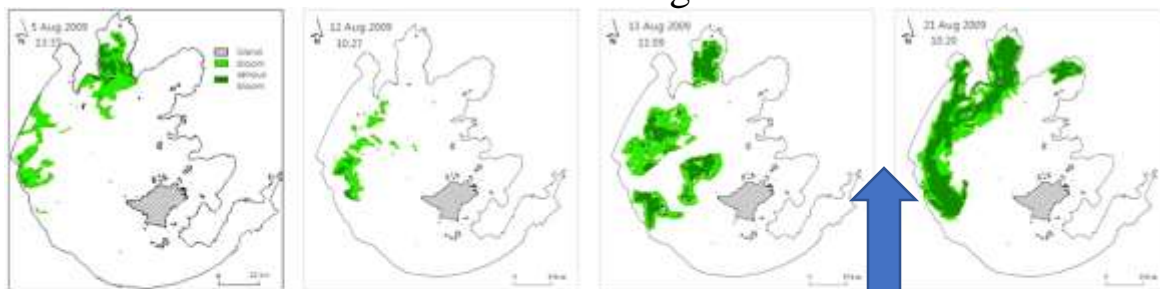
Morakot, 11 Aug, 2009
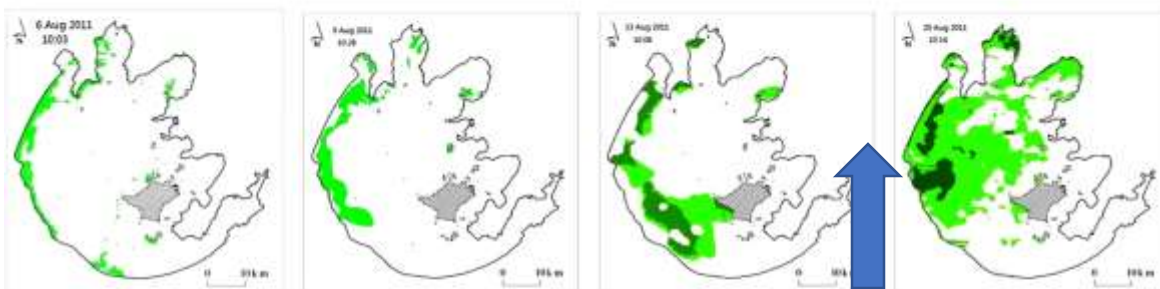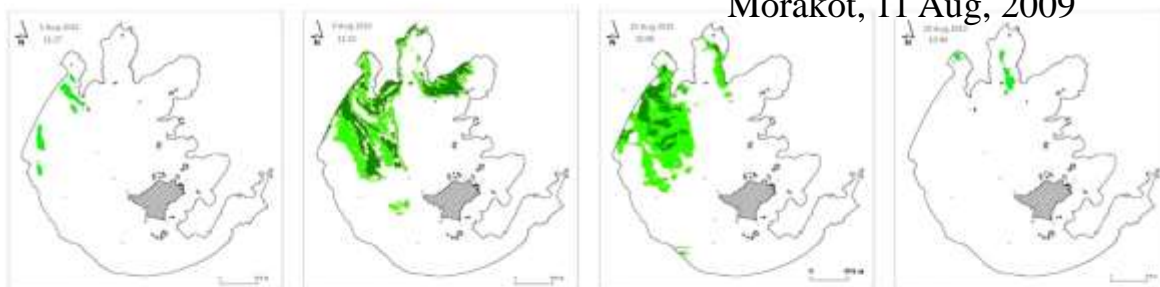
Muifa, 7 Aug, 2011
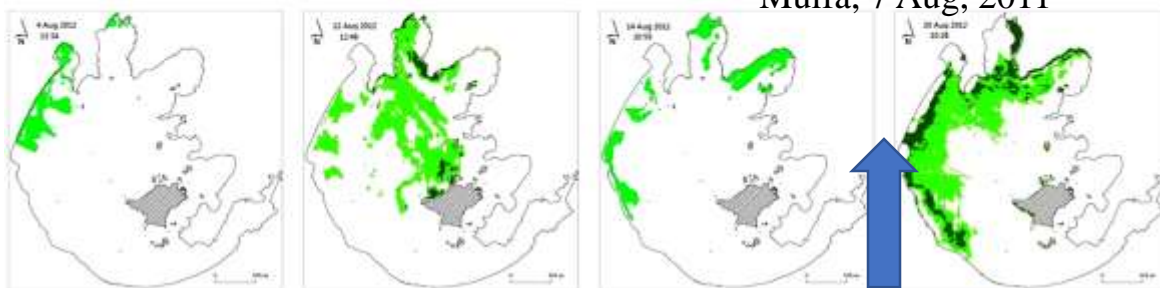
Haikiu, 8 Aug, 2012

A specific example: toxic dinoflagellate (*Karlodinium*) bloom following nutrient-enriched runoff from Tropical Storm Ernesto, Oct. 2006
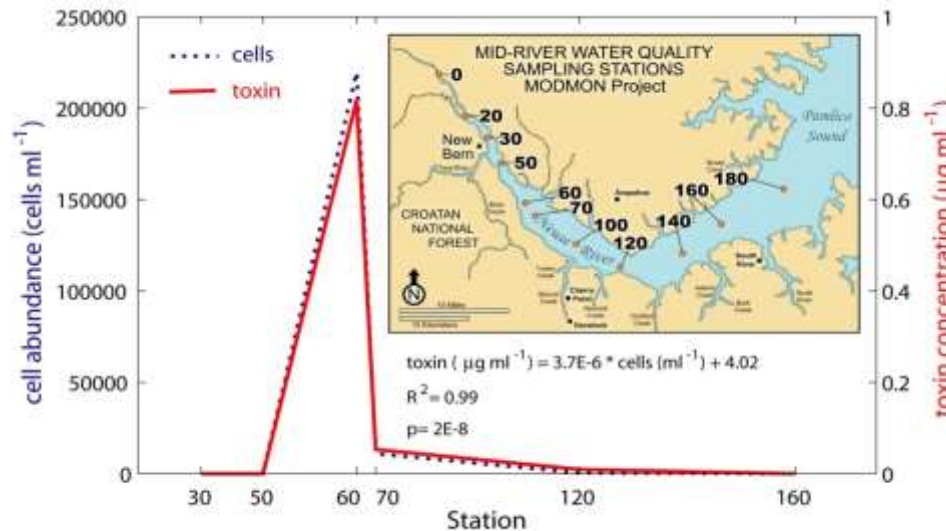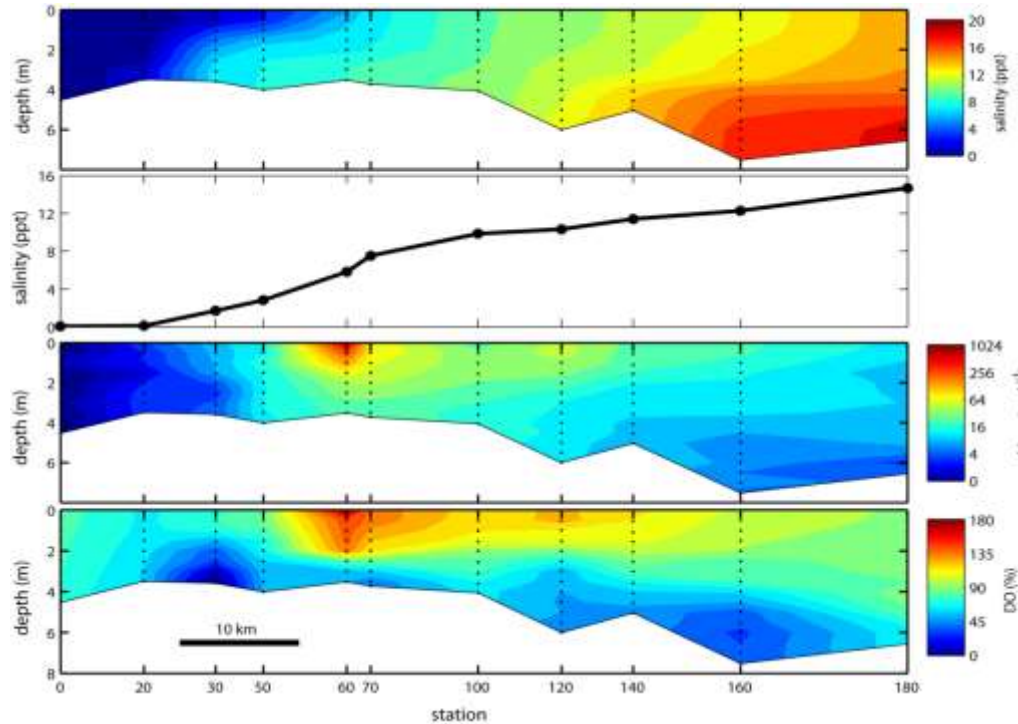
- **Runoff associated with Ernesto contained nutrient load and set up strong salinity stratification**

- 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.

$$toxin\,(\mu g\,ml^{-1}) = 3.7E\text{-}6 * cells\,(ml^{-1}) + 4.02$$
$$R^2 = 0.99$$
$$p = 2E\text{-}8$$

Hall et al. 2008

Scaling up to the ecosystem
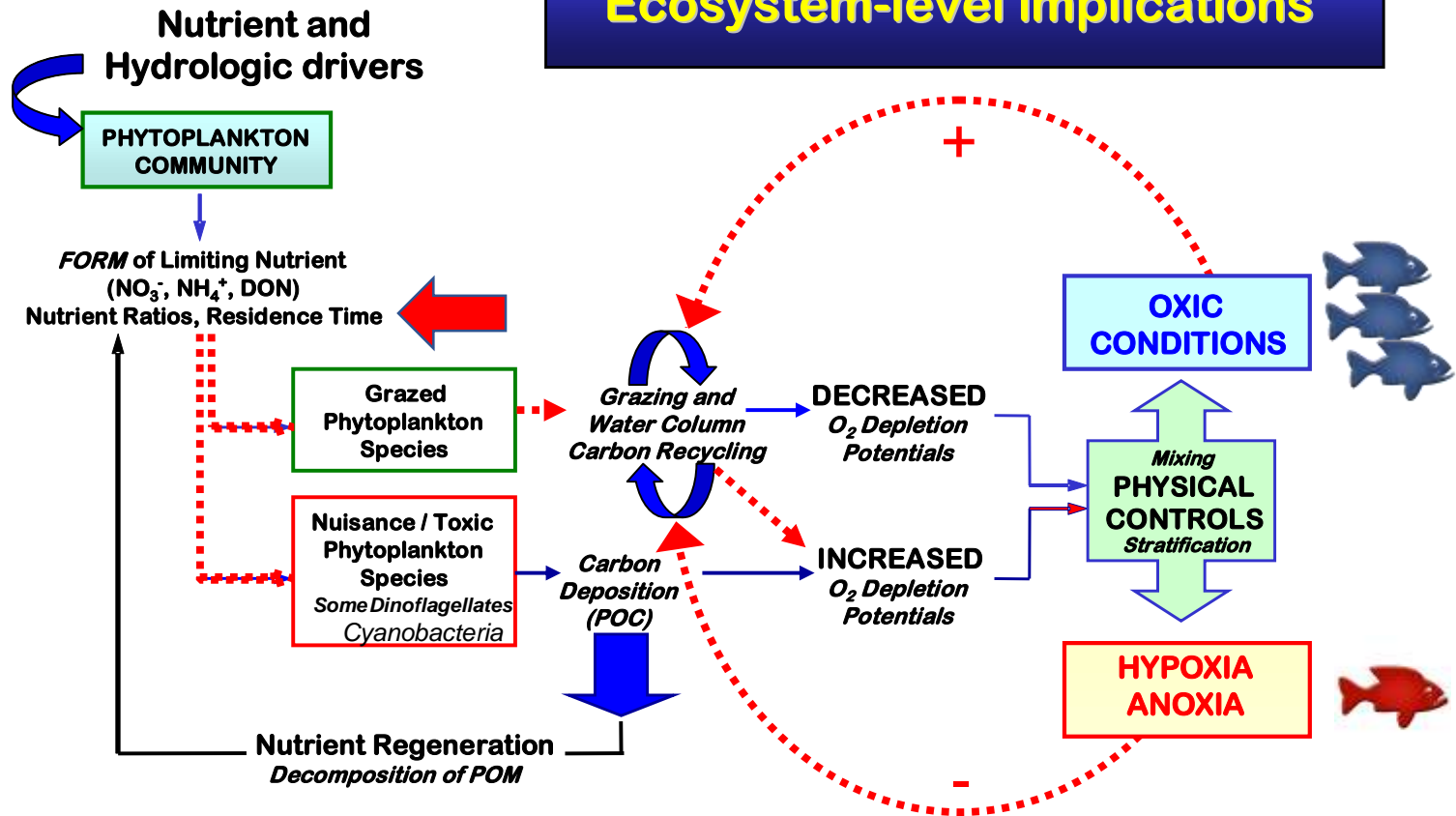
Impacts of Hurricanes on Carbon dynamics: Hurricane/TS Irene: 24-27 August, 2011

Hurricane Irene
8 AM EDT Fri Aug 26 2011
Position 30.0°N 77.3 W
Maximum Winds 110 mph
Gusts ~130 mph
Movement N at ~13 mph
Minimum Pressure 945 mb (27.90 inches)

Blue Marble bluemap imagery courtesy NASA

Satellite 1:17 PM UTC
9:17 AM EDT

wunderground.com

Tropical Storm Force Wind Speed Probabilities
For the 120 hours (5 days) from 8 AM EDT Fri Aug 26 to 8 AM EDT Wed Aug 31

Probability of tropical storm force surface winds (1-minute average >= 39 mph) from all tropical cyclones
◇ indicates HURRICANE IRENE center location at 8 AM EDT Fri Aug 26 2011 (Forecast/Advisory #25)

5% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Flo-thru system for determining pCO_2
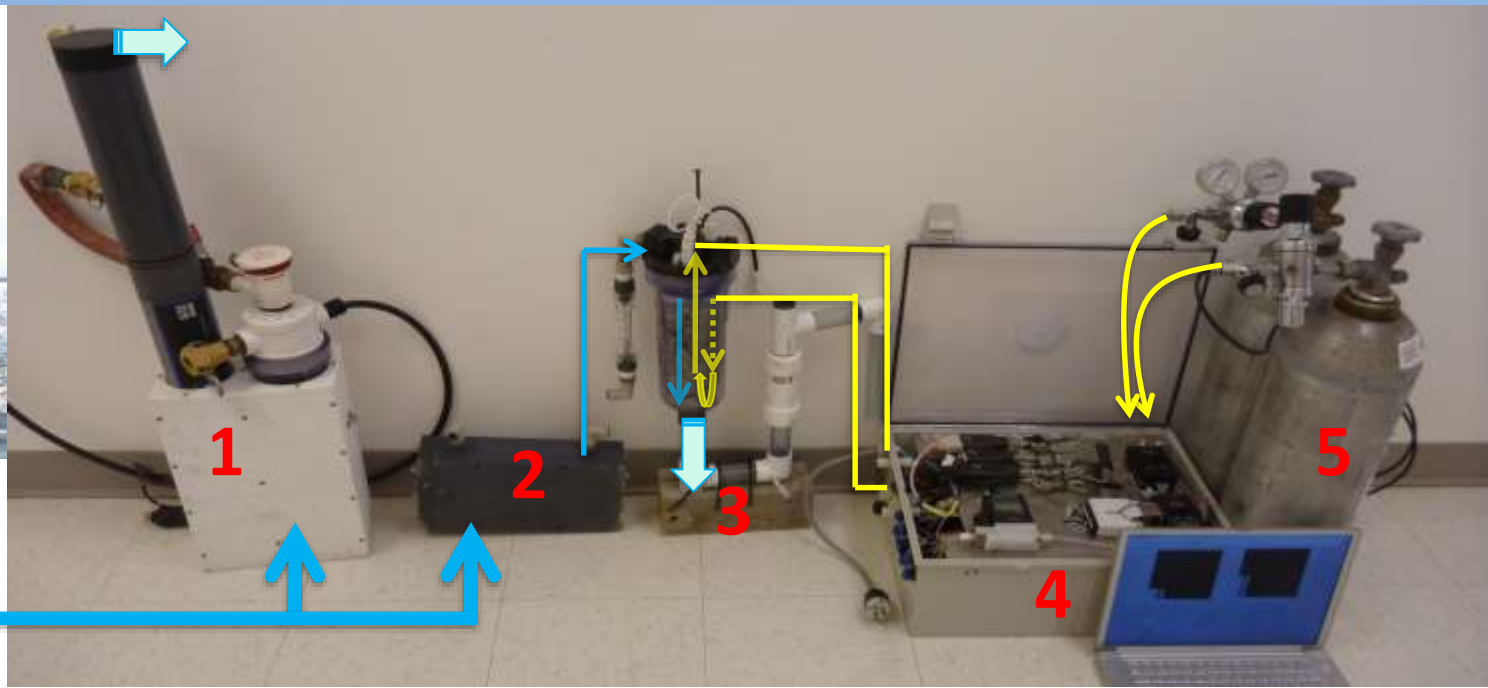
1. Sonde (YSI)
- Chl flourescence (chl a)
- Dissolved Oxygen (DO)
- pH
- Turbidity

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)

C loading and air-water CO_2 gradients (ΔpCO_2) in the Neuse R.Estuary, where positive ΔpCO_2 indicates CO_2 exchange from the water to the atmosphere. Hurricane Joaquin (2015) did not make landfall, but indirectly impacted NC as part of a large 'multiple-low' storm complex.

"Joaqu'easter"

Matthew

Crosswell et al., 2014; Van Dam et al., 2018; Paerl et al., 2018
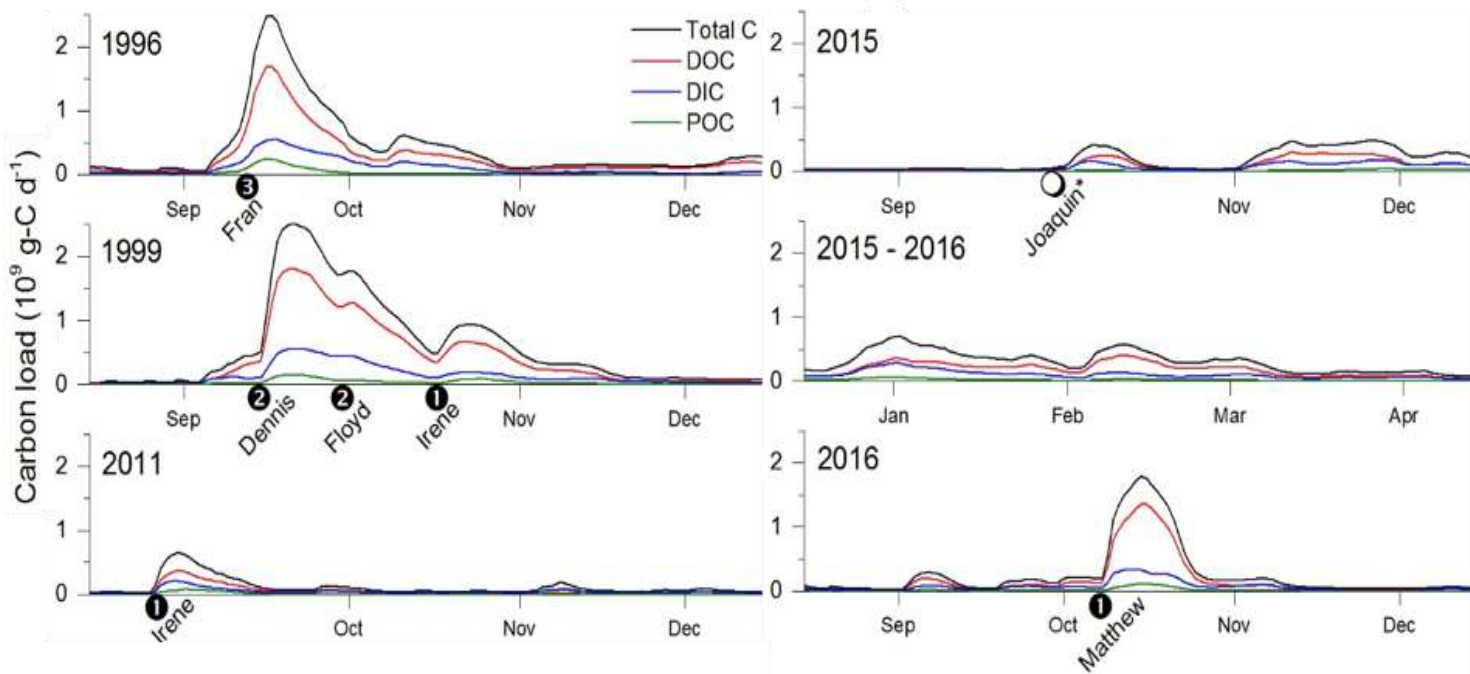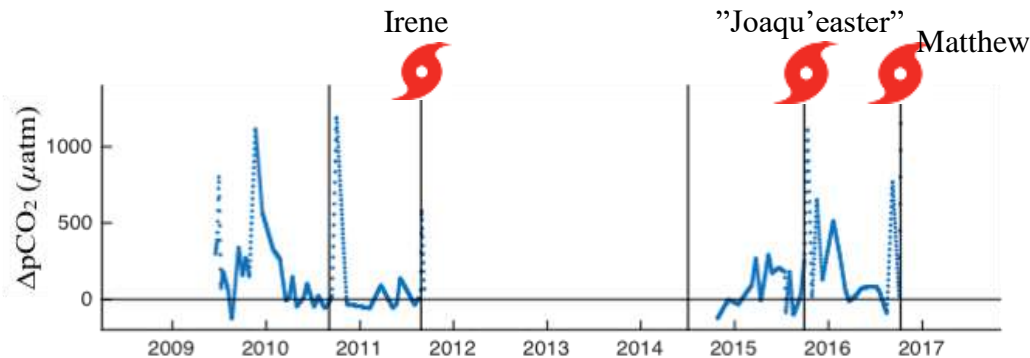
"Pulse-shunt" (Raymond et al. 2016) phenomenon after Hurricane Matthew's (Fall 2016) "500 year" floodwaters impacted the Neuse River Estuary, NC. This caused a rapid "shift", where phytoplankton production (as chlorophyll a) was flushed from the system and replaced by watershed-derived organic matter (as DOC) inputs in response to Matthew's floodwaters. However, notice Chl a response afterwards.

Before

After
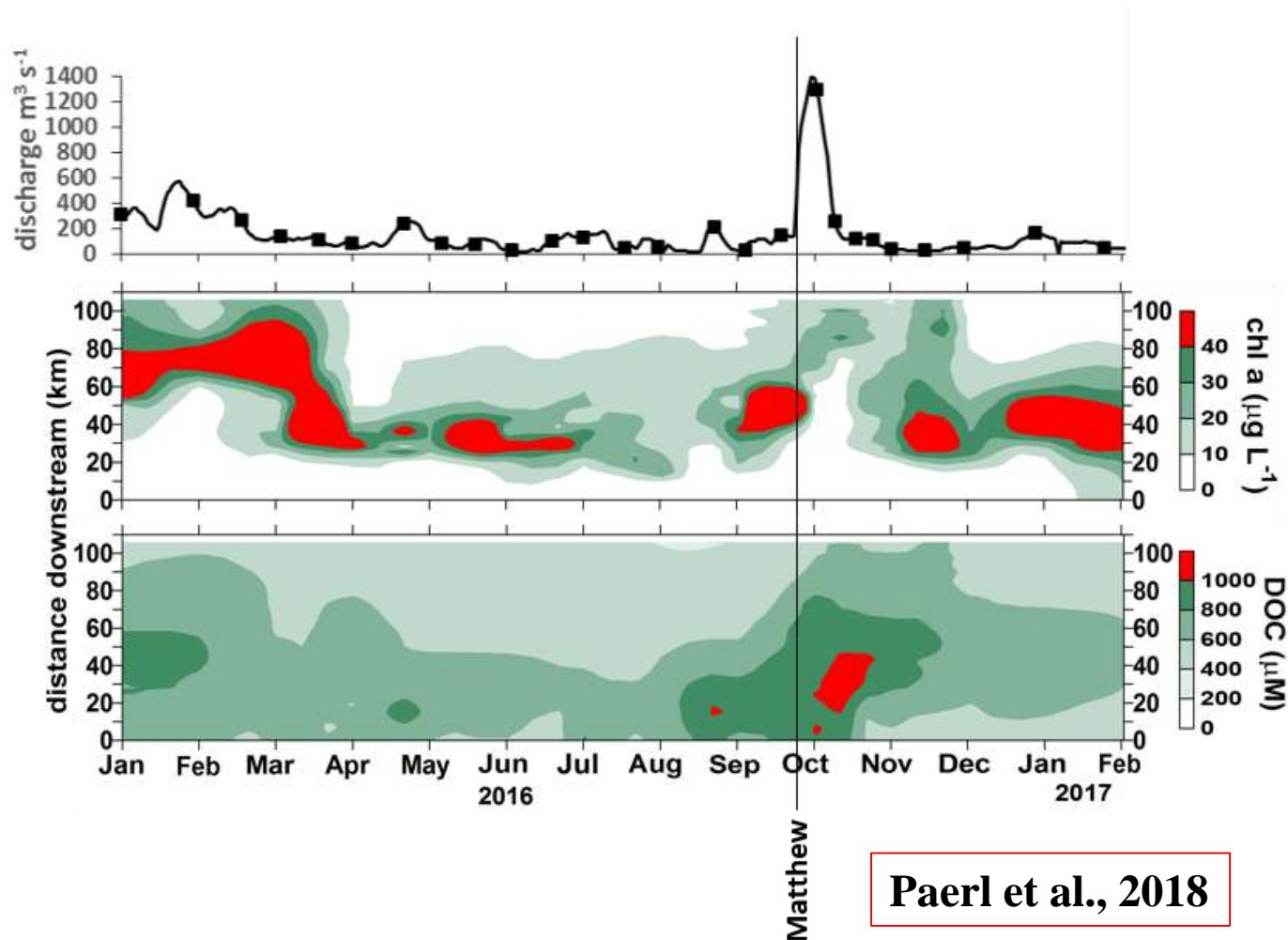
Paerl et al., 2018

Organic matter loading has gone up in response to storm events

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

S *Supporting Information*
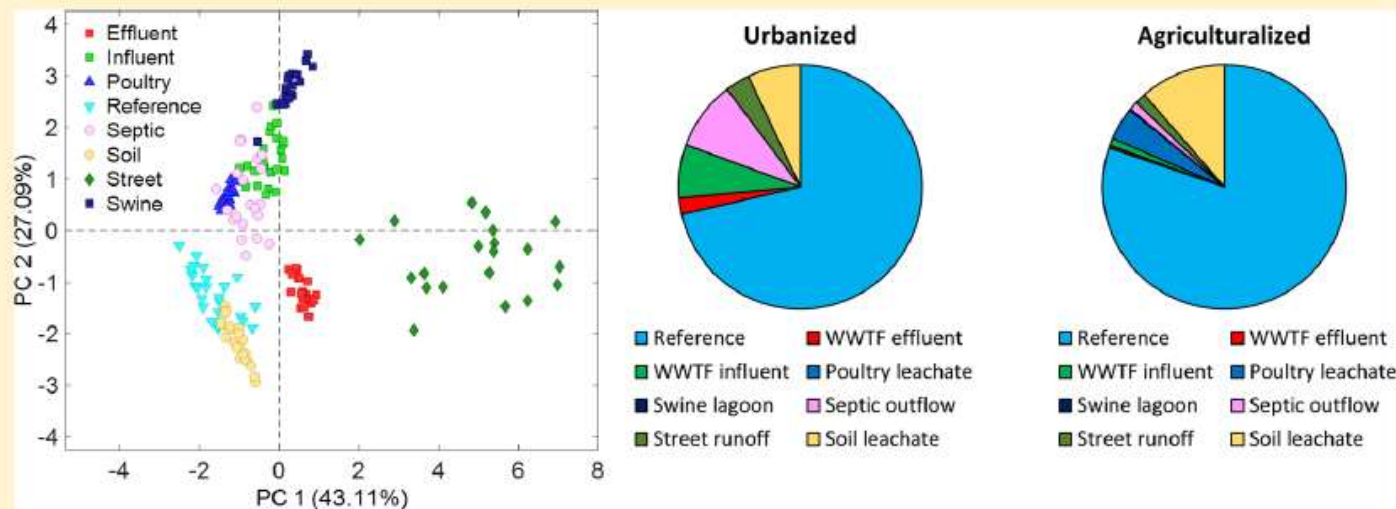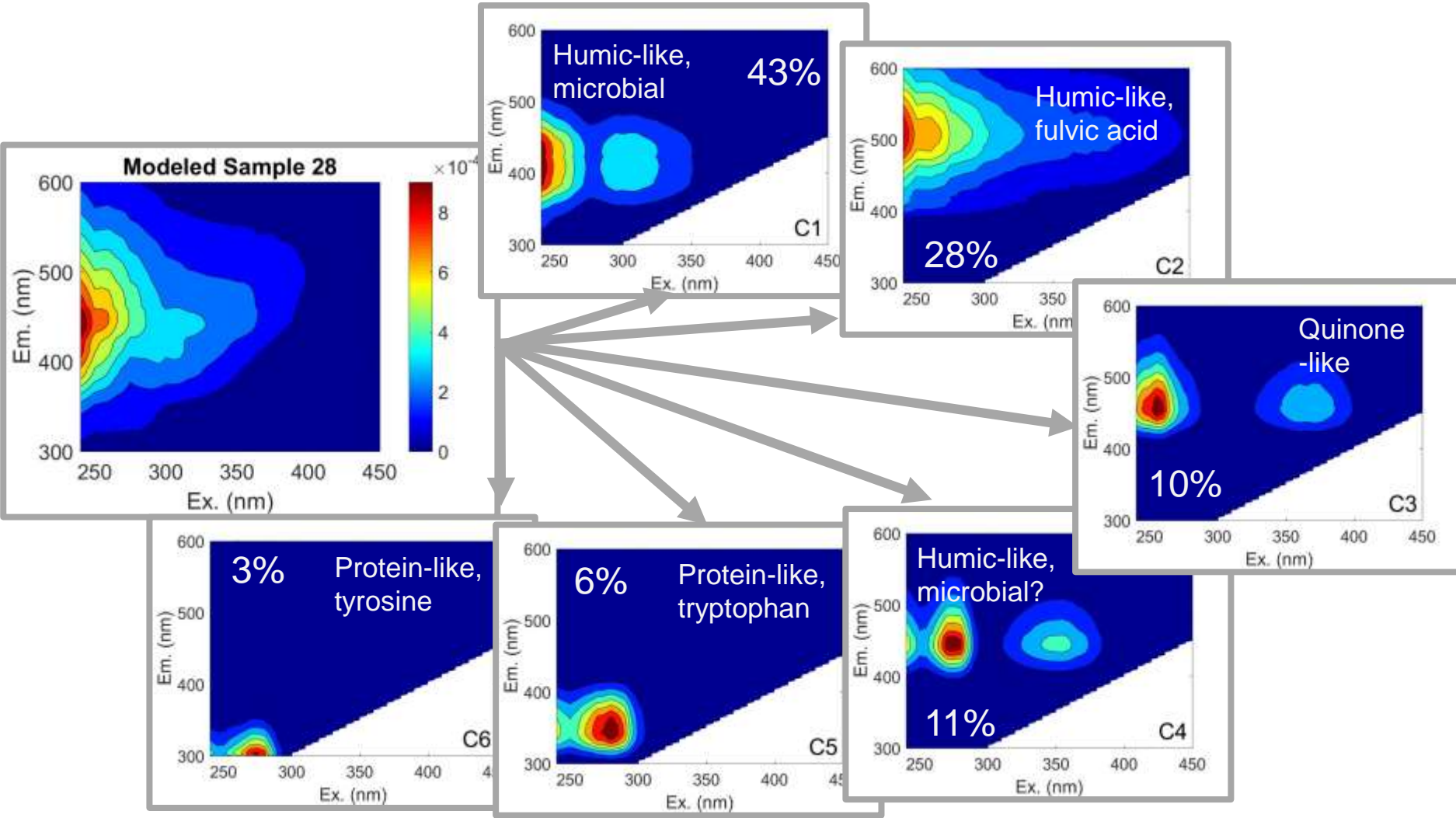
Using Fluorescence (EEM-PARAFAC) to separate different organic matter classes:
– Linking sources to fates in estuarine and coastal waters (Osburn et al., 2016)

Overview: Effects of Hurricanes on Carbon Dynamics

Hurricane Florence, Sept., 2018

The future??
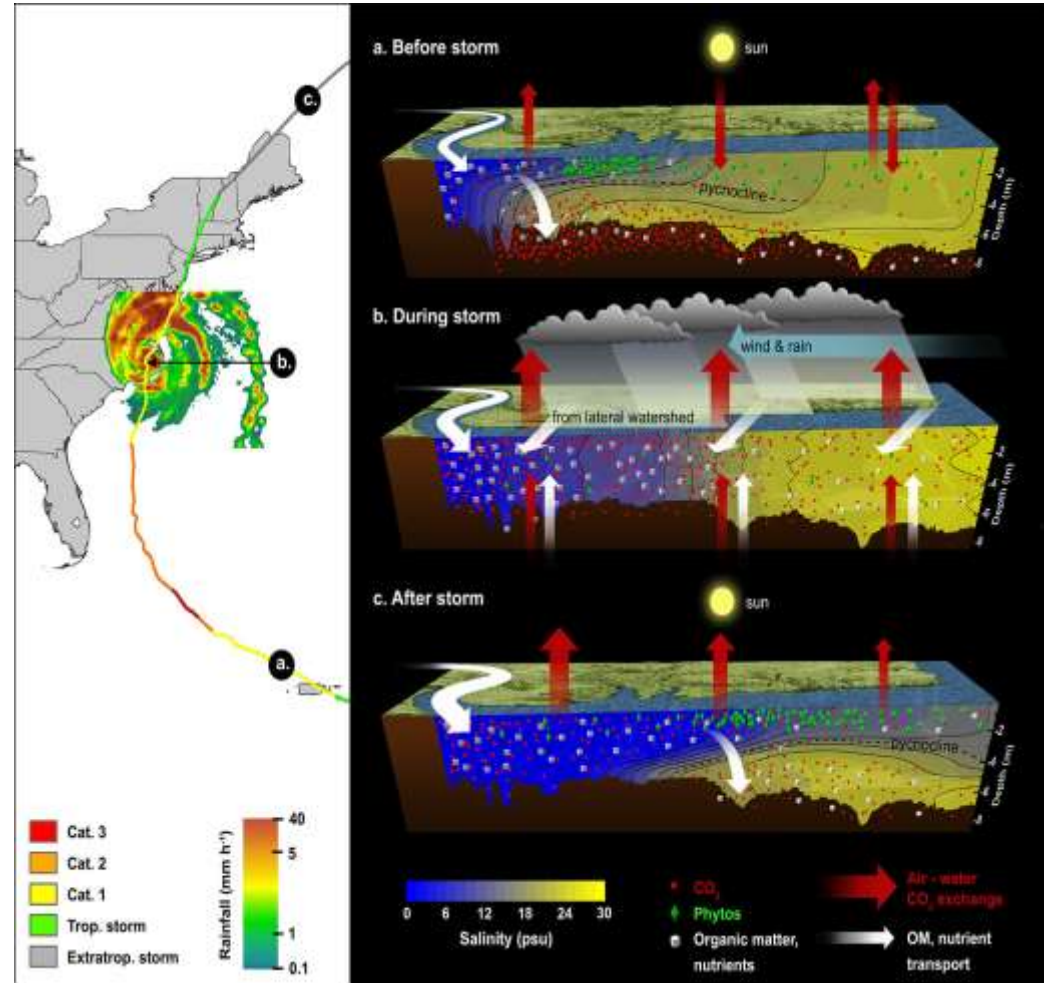## We appear to be experiencing a "new normal" with regard to tropical cyclone frequency and rainfall intensity/flooding

A) Precipitation events ascribed to tropical cyclones when a precipitation event was coincident with the passage of a tropical cyclone within 240 km (150 miles) of Kinston, NC as determined by 6 h storm advisories recorded in the National Hurricane Center's HURDAT2 database. **B)** Quantile regressions were constructed for the 90th (solid line) and 50th quantile (dashed line) of cyclone related precipitation against time. 95% confidence intervals (in parentheses) on slopes (m) were determined by 1000 rounds of bootstrapping. **C)** Total volumetric discharge for high flow events at Kinston, NC (USGS gage 02089500) from 1 May 1930 to 8 December 2018. High flow events were those during which the daily average flow was greater than 390 m^3 s^{-1}, the 99th percentile of daily average flow.
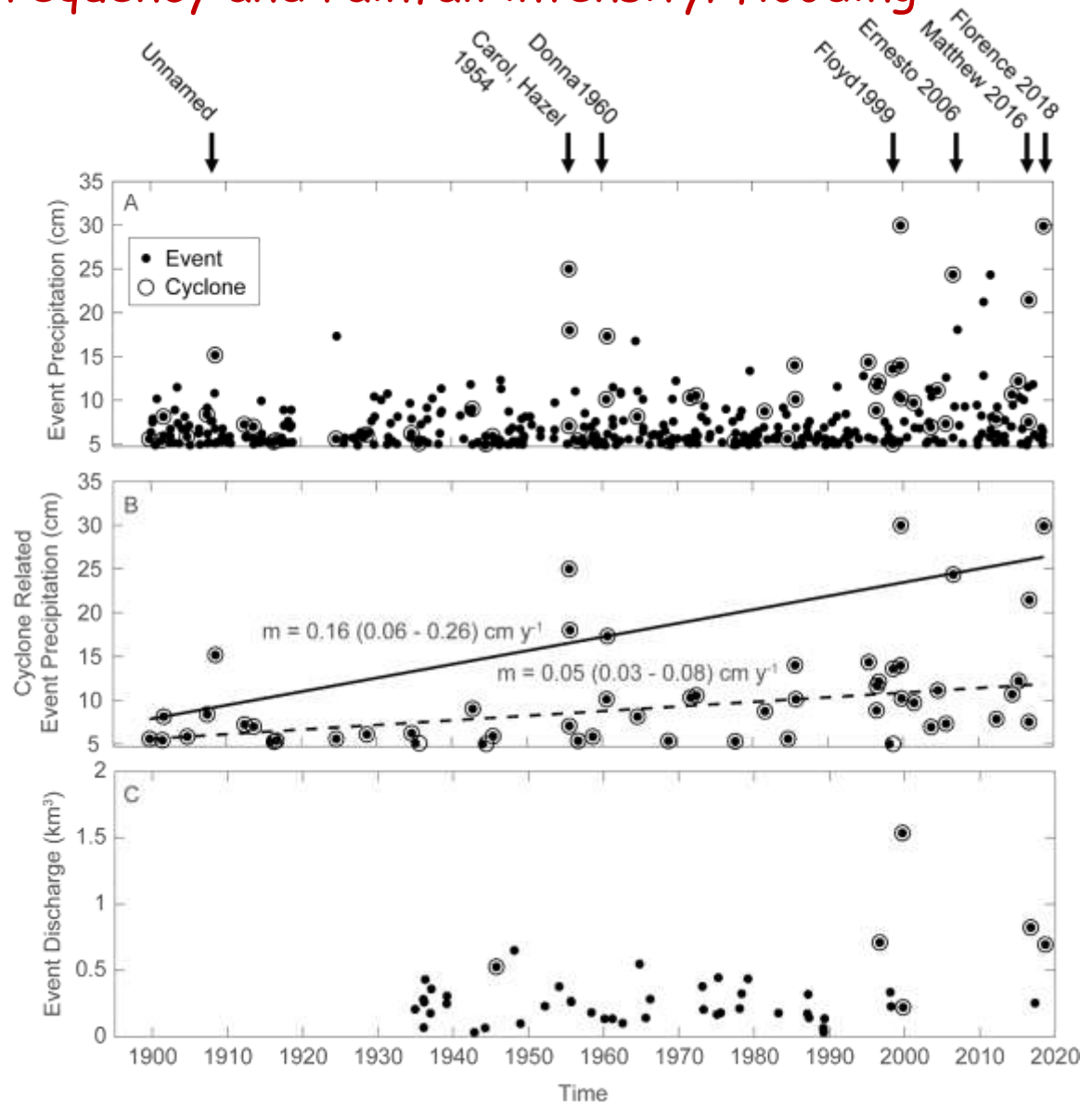
Data sources: NOAA-National Hurricane Center, USGS, NC Climate Office
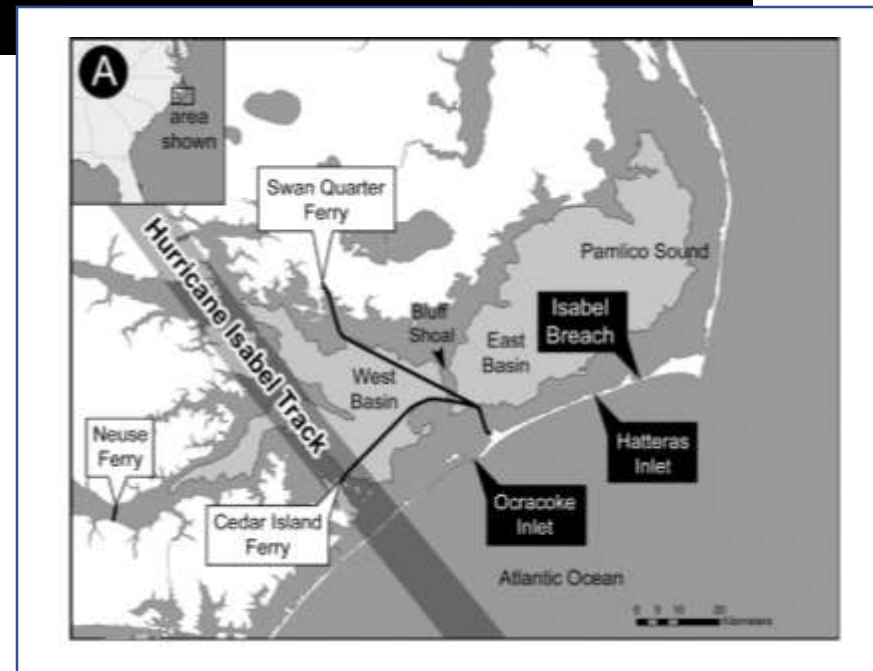
A glimpse of a more "connected" Pamlico Sound

09/08/1999, Before

Sept. 2003: Isabel "creates" a new inlet in the Outer Banks

09/21/2003, After

THE WEATHER CHANNEL **Hurricane Isabel**
LOCATION 34.9N 76.1W TIME 1 PM EDT
30 Mi NE of Cape Lookout, NC
WINDS 100 mph MOVING NW 18 mph
PRESSURE 28.26 in/957 mb

18 Sep 2003 17:01 GMT / 18 Sep 2003 01:01 PM EDT

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

Paerl et al. 2009. Environ. Sci. Technol. 43:7609-7613.
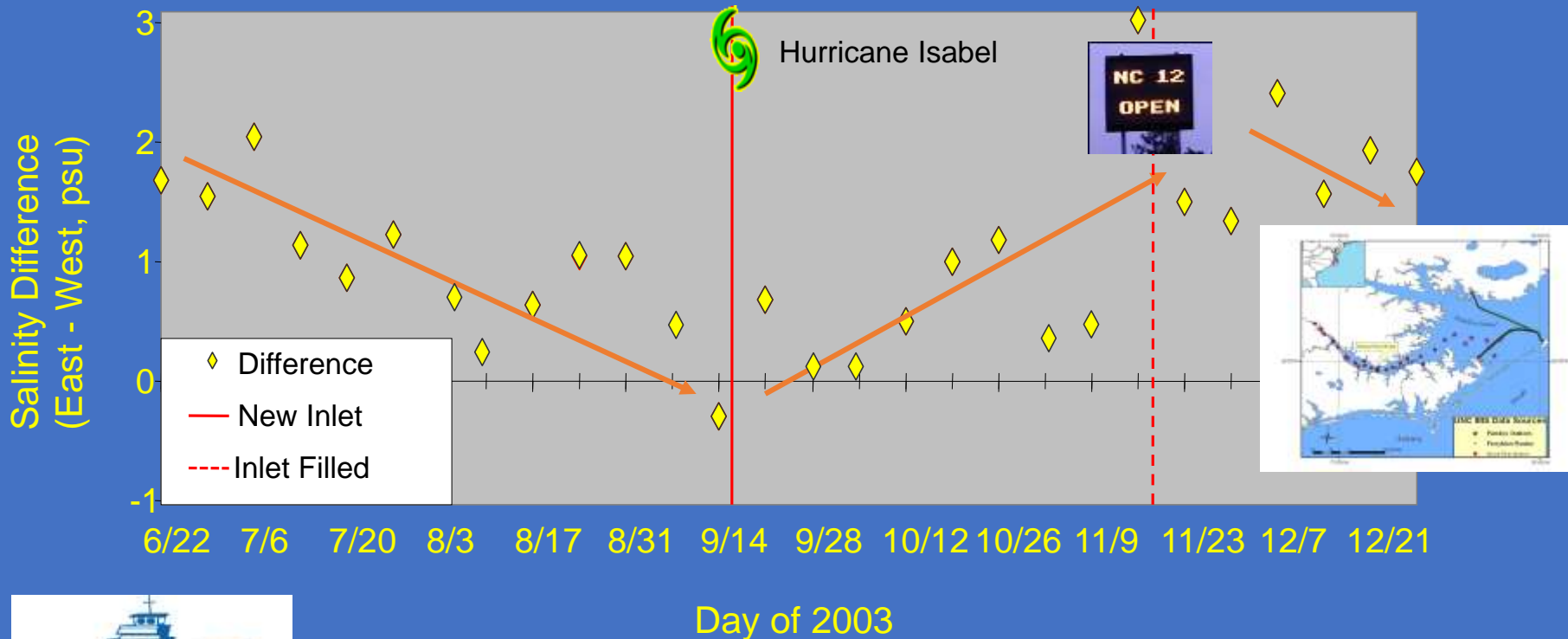
Increased frequency of Atlantic hurricanes over the next 10-40 years?
Goldenberg et al., 2001, Webster et al. 2005; Holland and Webster 2007

Increase in "extremeness" and scales of storm events?
Emanuel 2005; Wuebbles et al.,2014; IPCC 2014; US Climate Change Report 2018; Paerl et al.,in review

# Multi-annual ecological effects and recovery?
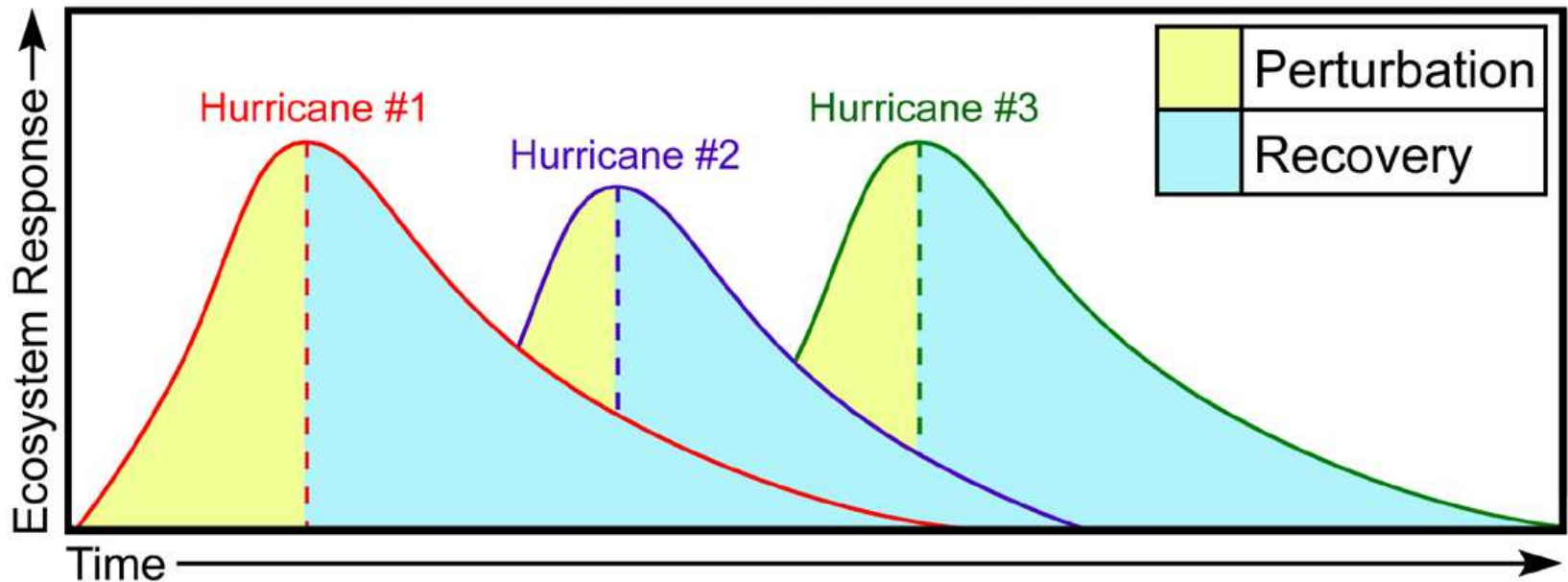
Implications, Conclusions and Recommendations

- Storm-driven N (and P) loading is increasing in coastal waters….**promoting more algal blooms**

- We're experiencing 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), and make plans for long-term, sustainable development.**

- Immediate Needs: **Tools (e.g.remote sensing, continuous water quality monitoring) to capture events/impacts over relevant scales** and **adaptive nutrient management in response to climatic changes and extremes**

Thanks for your attention!
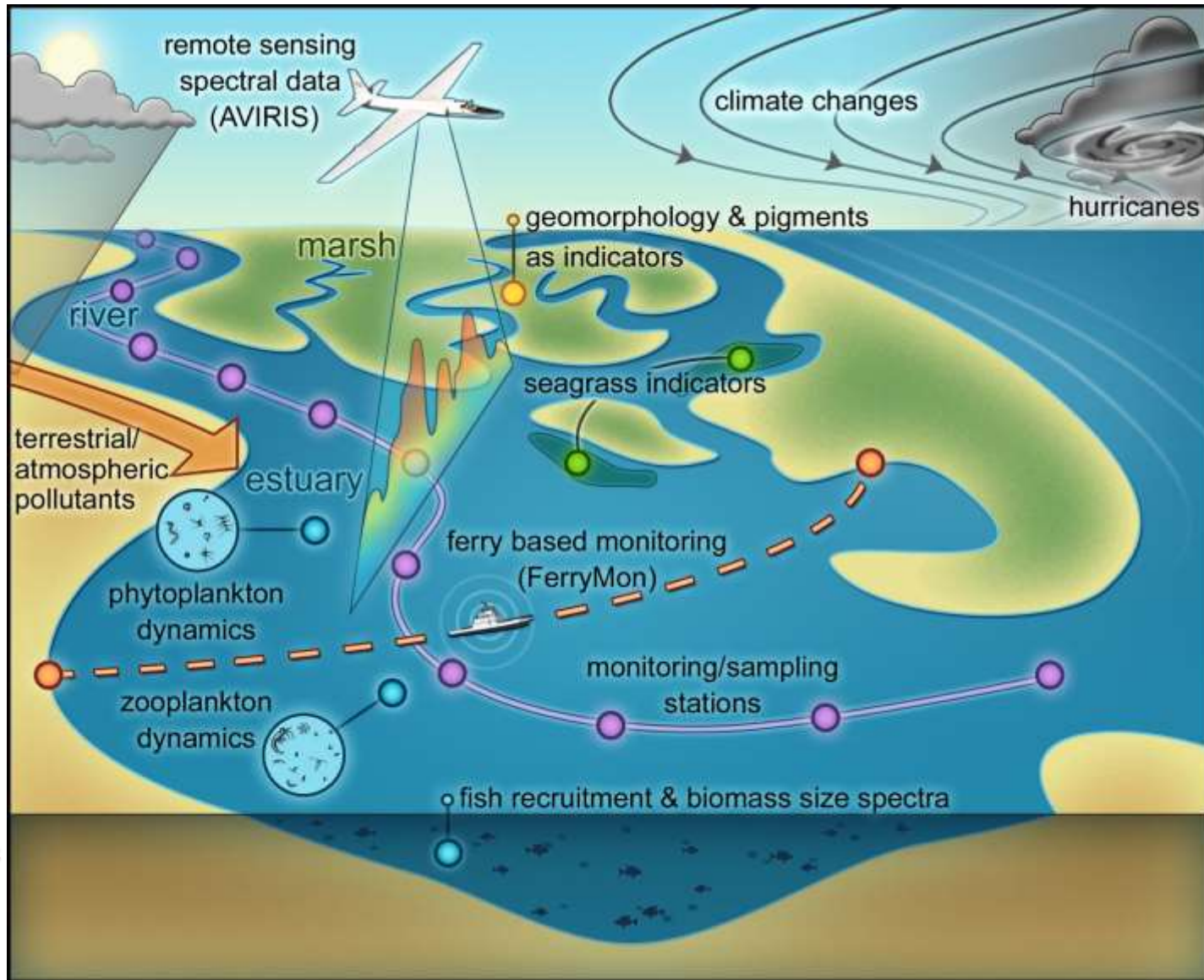
Special Thanks to:

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Water Resources Research Institute

NC Sea Grant

http://paerllab.web.unc.edu/