Extreme events and the carbon cycle in the coastal ocean from ocean color remote sensing: case studies

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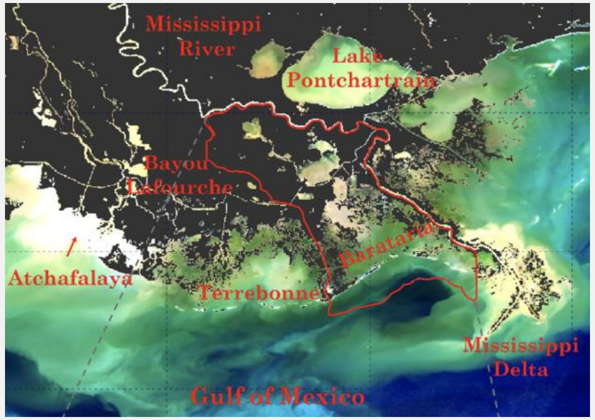
Ocean Carbon From Space 2022 Workshop

Extreme events and impacts on Carbon cycling in the coastal ocean

- Extreme events and disturbances affect aquatic carbon cycling at multiple spatiotemporal scales
- Most impactful in highly connected coastal ecosystems that include rivers, estuaries, wetlands and the shelf waters
- Many studies on phytoplankton response to TCs in the oceanic and shelf waters, but few related to carbon cycling especially in optically complex coastal and estuarine waters



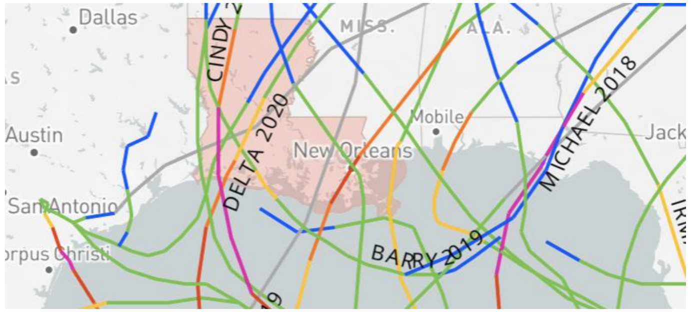
- With projected increase in intensity, frequency and precipitation associated with TCs including storm surge flooding and increasing TC activity near land (Wang and Toumi, 2021 – Science), there is a critical need to improve mechanistic understanding of their impacts on coastal carbon cycling
- We present results of DOC and POC distributions and fluxes in coastal environments (tidal wetlands, estuaries, shelf waters) in response to TC impacts

Atlantic Hurricane Season (2016 – 2021)

- Six consecutive years of above-normal Atlantic season
- Major TC Matthew – 2016 US East coast
- Harvey – 2017: >500 mm rainfall with return period >2000 years under current climate
- TC Michael – 2018: Cat 5 (250 km/hr) at landfall
- 2020 & 2021, two consecutive seasons with 21 named storms
- Zeta – Oct. 2020: Fast moving, Cat 3 (185 km/hr)
- Ida – Aug. 2021: Cat 4 (240 km/hr); second most destructive and intense TC behind Katrina in 2005.

Matthew 2016

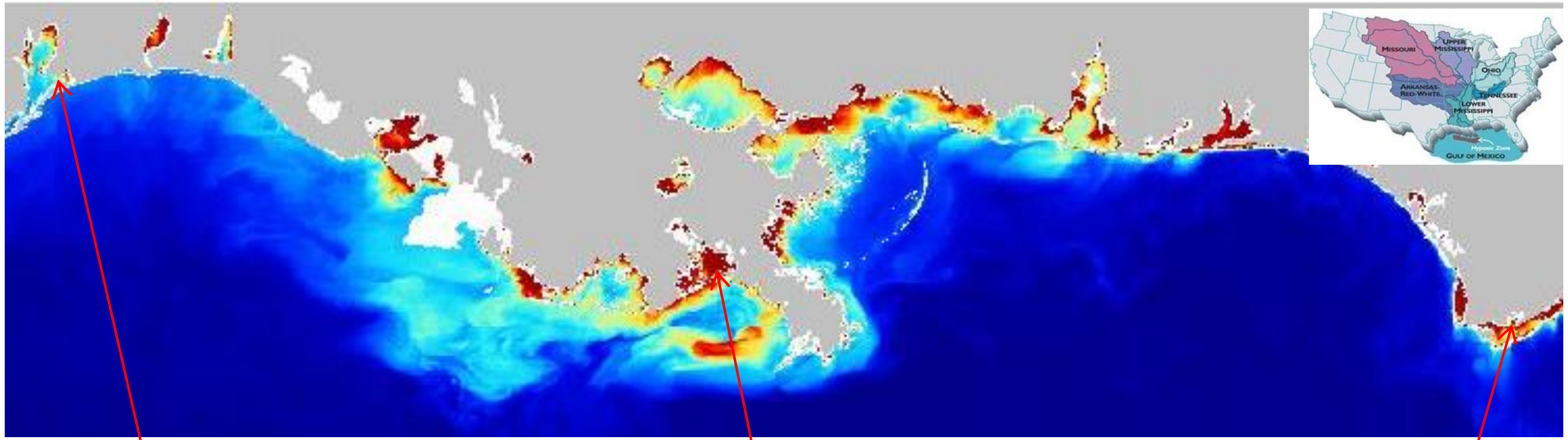
2017 - 2020

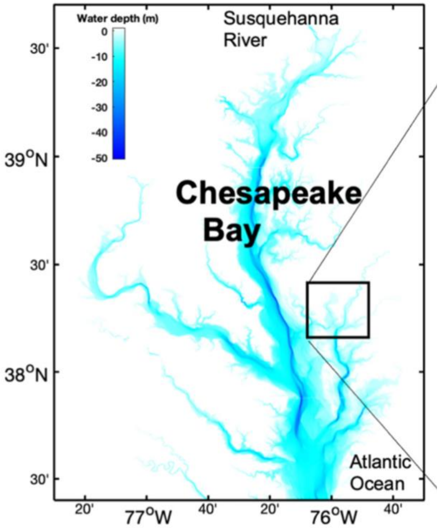


2021: named storms - 21

Study areas and motivation

- Study areas are in the Chesapeake Bay (US east Coast) and the northern Gulf of Mexico. Field work were conducted in these coastal waters as part of various NASA funded projects.
- Motivation: many of our study sites were impacted by TCs
- Rapid response field study conducted in Galveston Bay following TC Harvey in Sep & Oct 2017



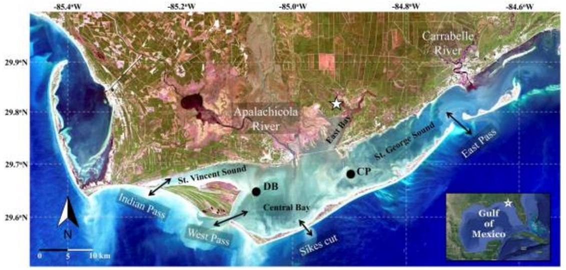


BNWR wetland-estuarine system

Galveston Bay

Barataria Bay

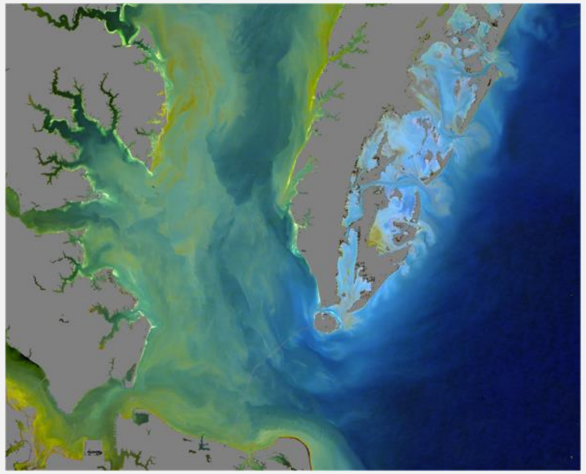
Apalachicola Bay



Field and satellite Data

- Field data
  - Remote sensing reflectance
  - Particle and CDOM absorption
  - POC & DOC concentrations
  - In situ absorption and backscattering b_{bp}

- Satellite data
  - MODIS-Aqua
  - Landsat 5, 8
  - Sentinel 3 A/B OLCI
  - Sentinel 2 MSI

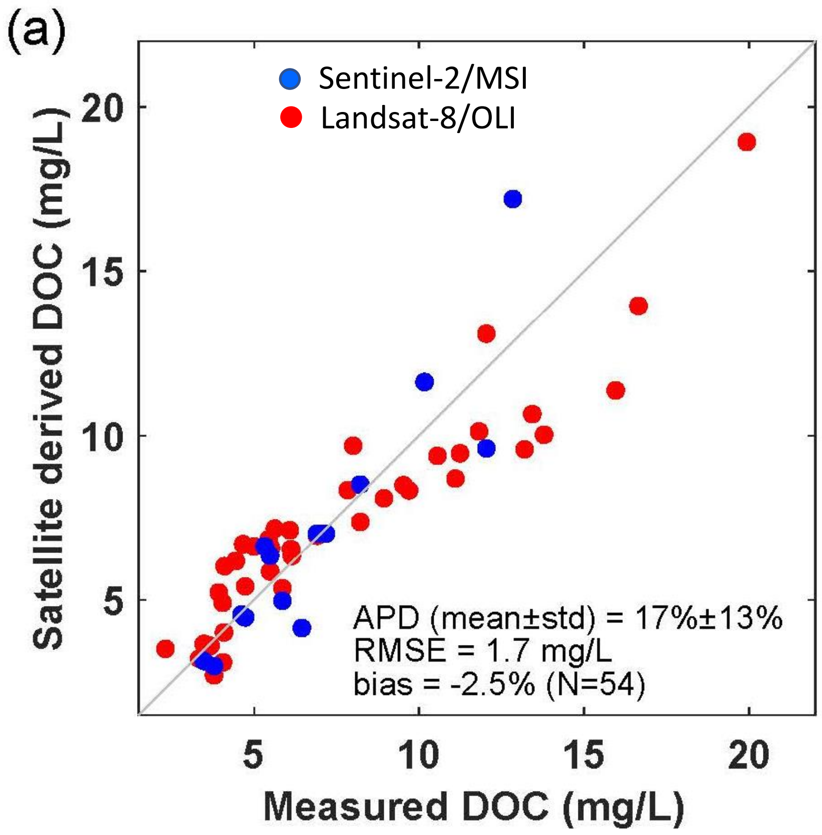


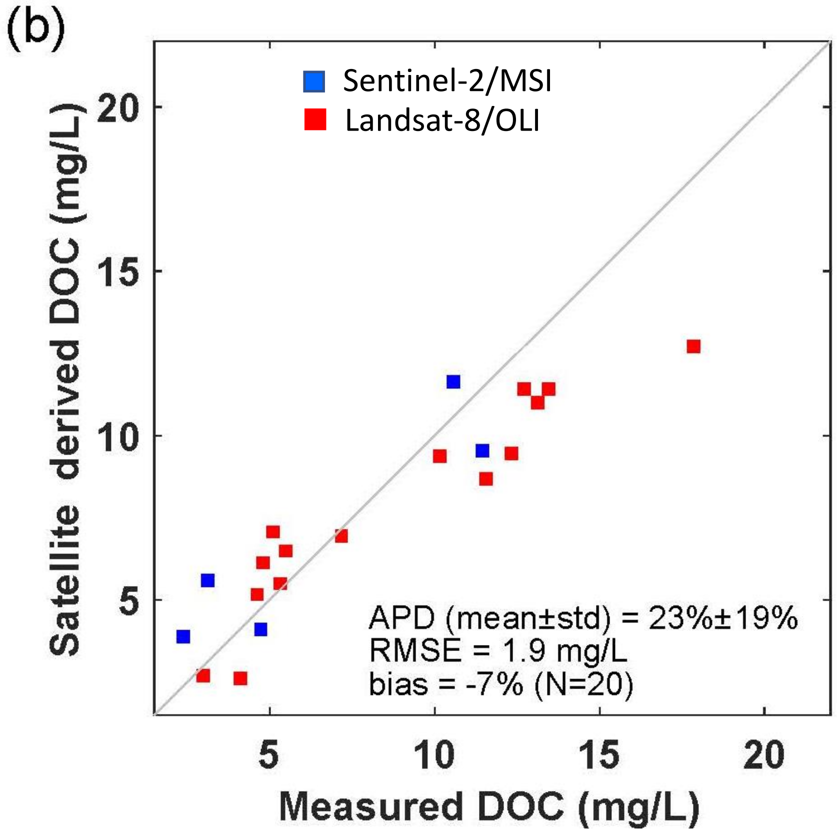
Capturing biogeochemical exchanges in tidally influenced marsh-estuarine systems

Application of Multiple-Linear-Regression (MLR) Approach DOC algorithm to high spatial resolution imagery (30 m) from Landsat/OLI and Sentinel-2/MSI

Optimal algorithm: Multiple Linear Regression linking DOC to the spectral shape in Landsat/OLI and Sentinel-2/MSI *Rrs* in 443-665 nm.

$$\mathrm{DOC} = \exp\left(0.544 \times \log\left(R_{\mathrm{rs}}(\mathrm{B1})\right) - 0.571 \times \log\left(R_{\mathrm{rs}}(\mathrm{B2})\right) - 2.181 \times \log\left(R_{\mathrm{rs}}(\mathrm{B3})\right) + 1.398 \times \log\left(R_{\mathrm{rs}}(\mathrm{B4})\right) - 1.406\right)$$





Carbon Cycling in Tidal Wetland Systems

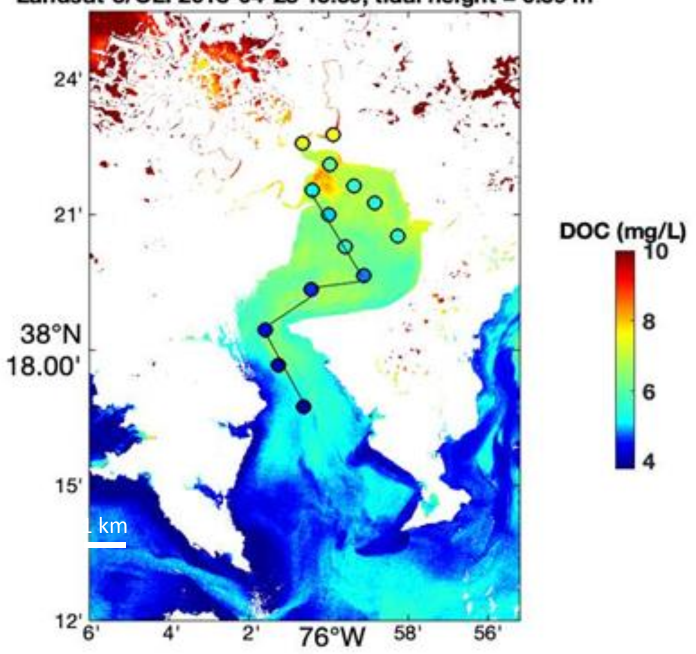
Sub-diurnal, **tidal exchanges** of DOC in wetland-estuarine systems

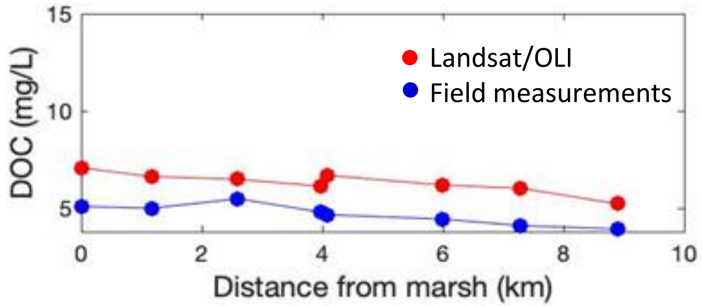
Multiple Linear Regression Model - $DOC = \exp\left(\sum_i a_i \times \log(Rrs(\lambda_i))\right)$

DOC: 2-20 mgL^{-1}*, MAPD < 23%*

High Tide

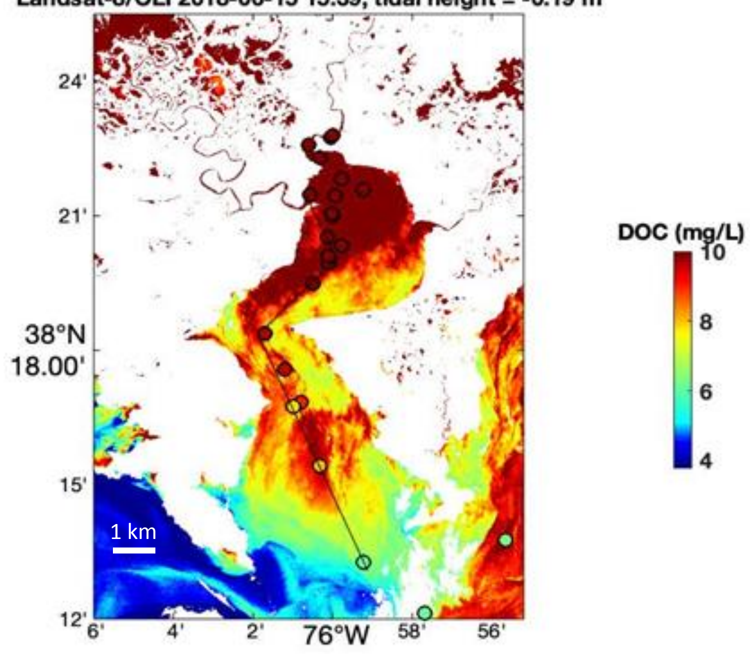
Landsat-8/OLI 2018-04-28 15:39, tidal height = 0.39 m

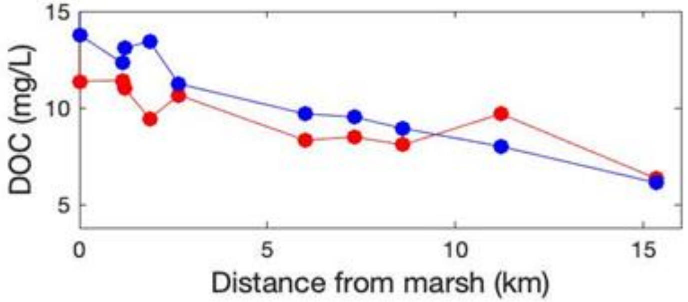




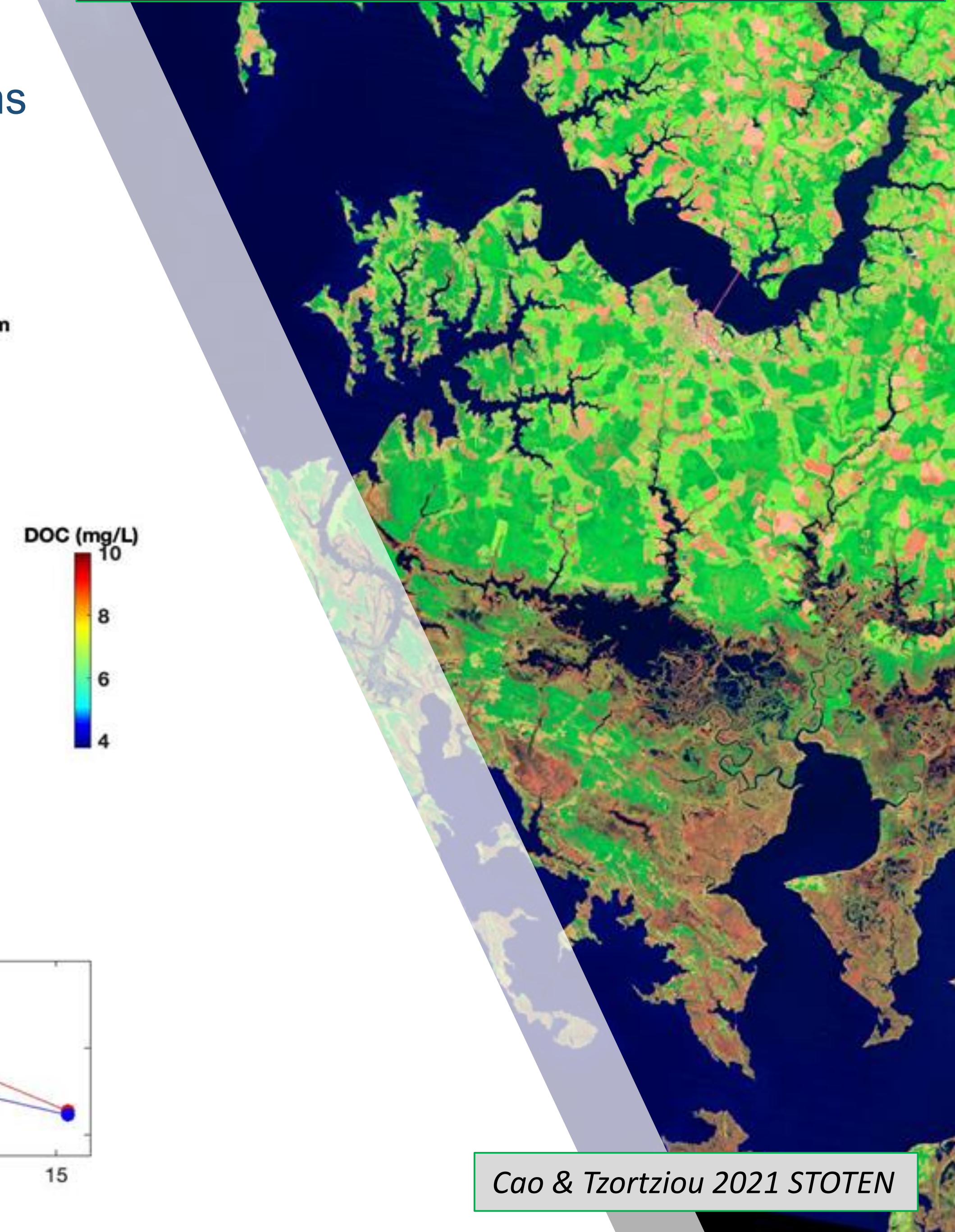
Low Tide

Landsat-8/OLI 2018-06-15 15:39, tidal height = -0.19 m





Blackwater National Wildlife Refuge (Landsat, August 31, 2011)

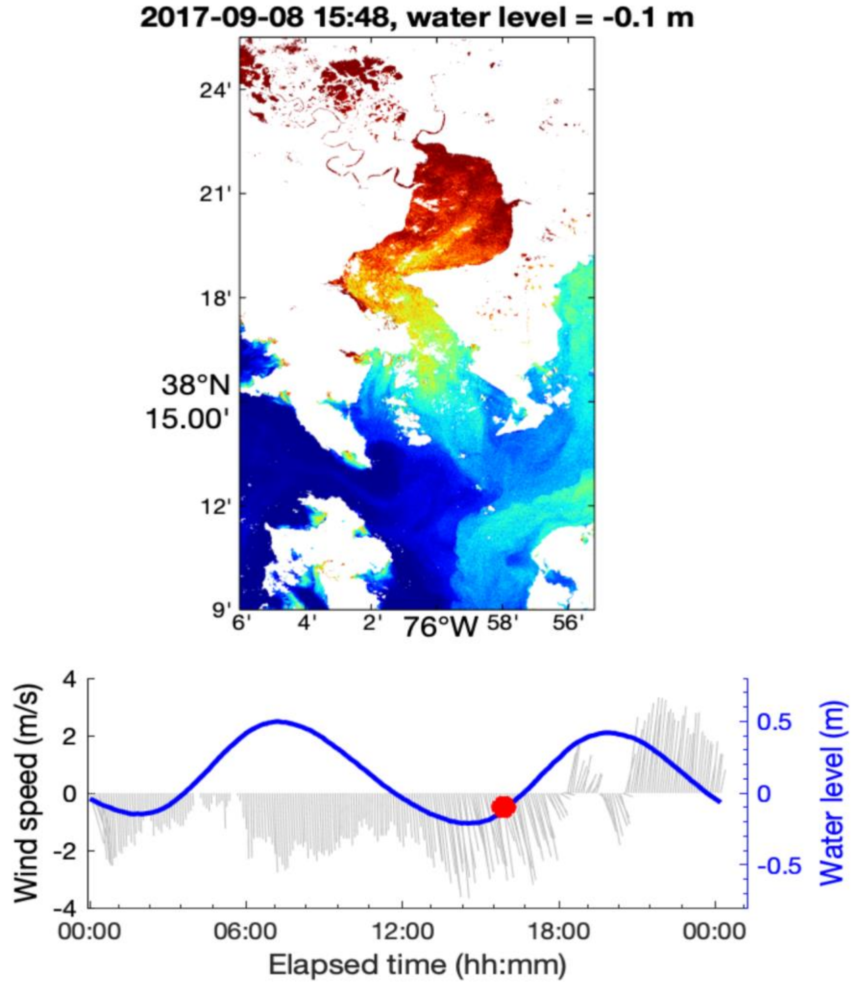


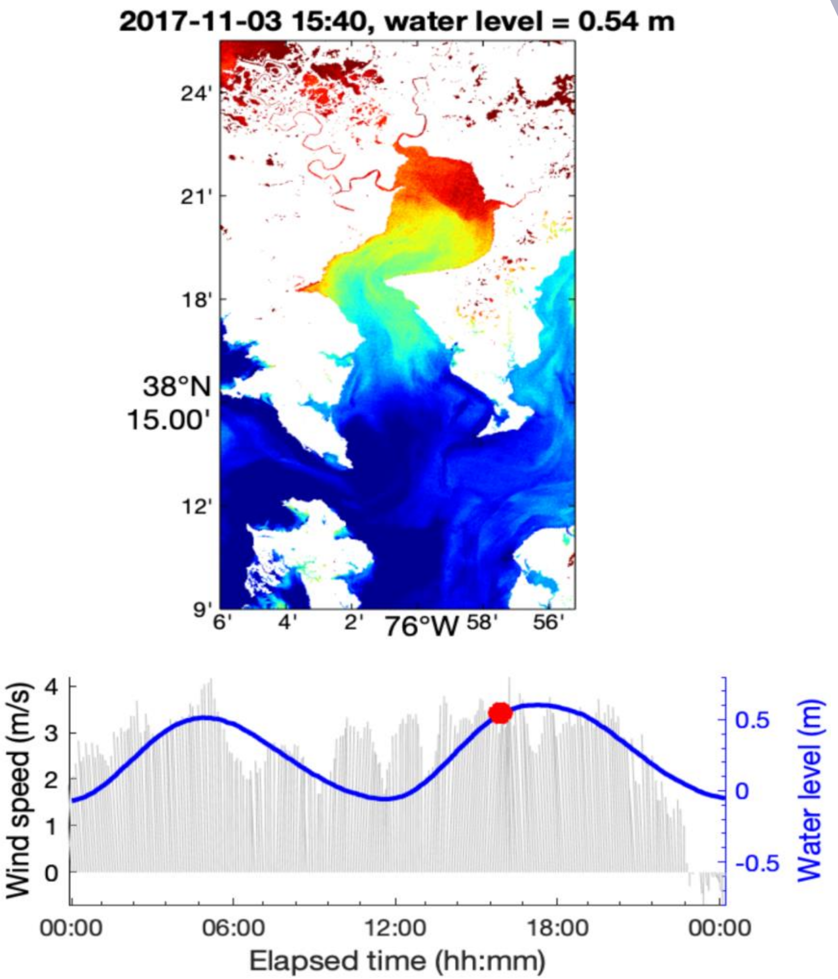
Cao & Tzortziou 2021 STOTEN

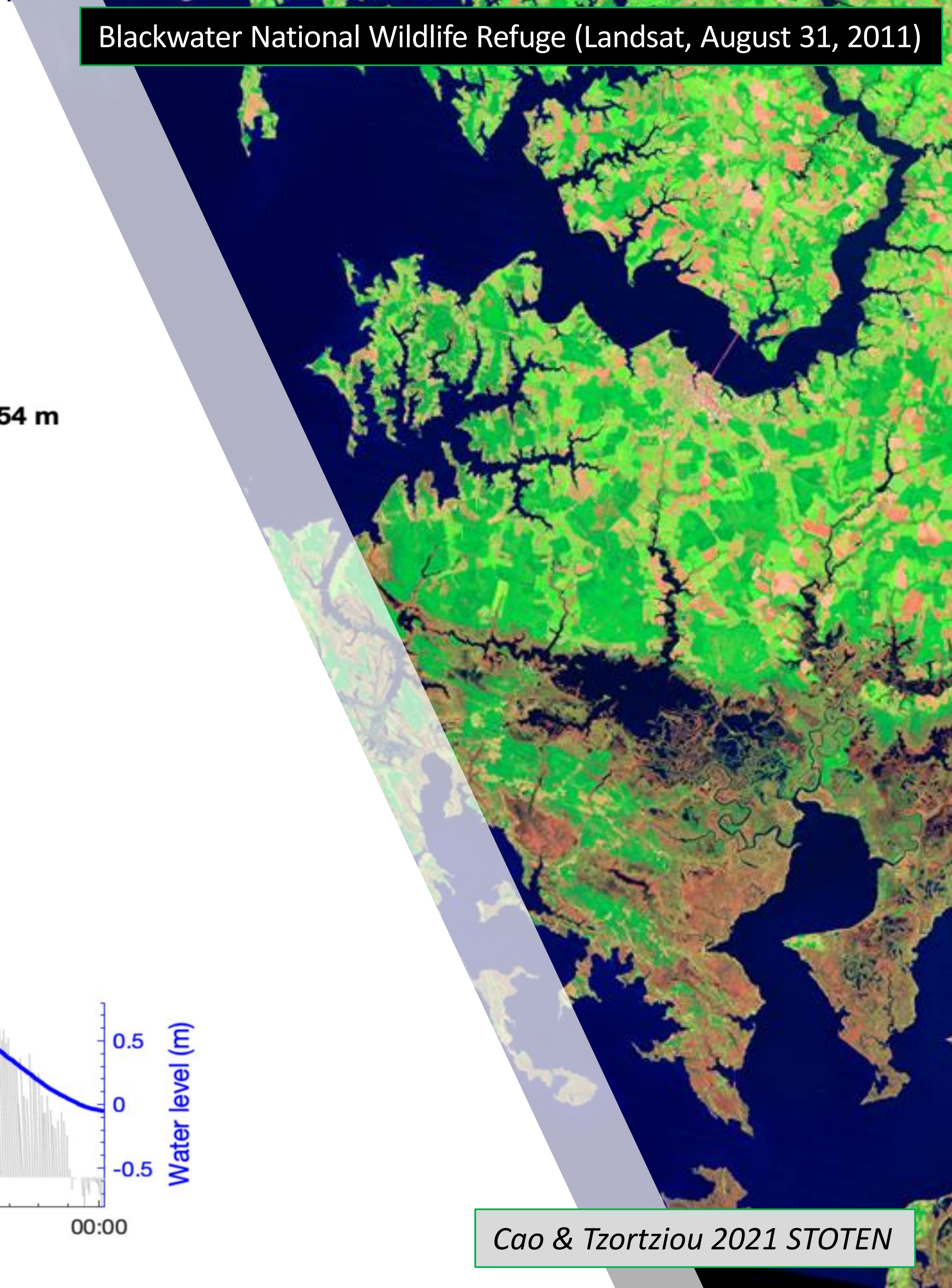
Carbon Cycling in Tidal Wetland Systems

Impact of **environmental conditions** on tidal DOC exchange

Wind conditions (changing at sub-diurnal scales), significantly affect spatial extent of marsh influence on coastal biogeochemistry





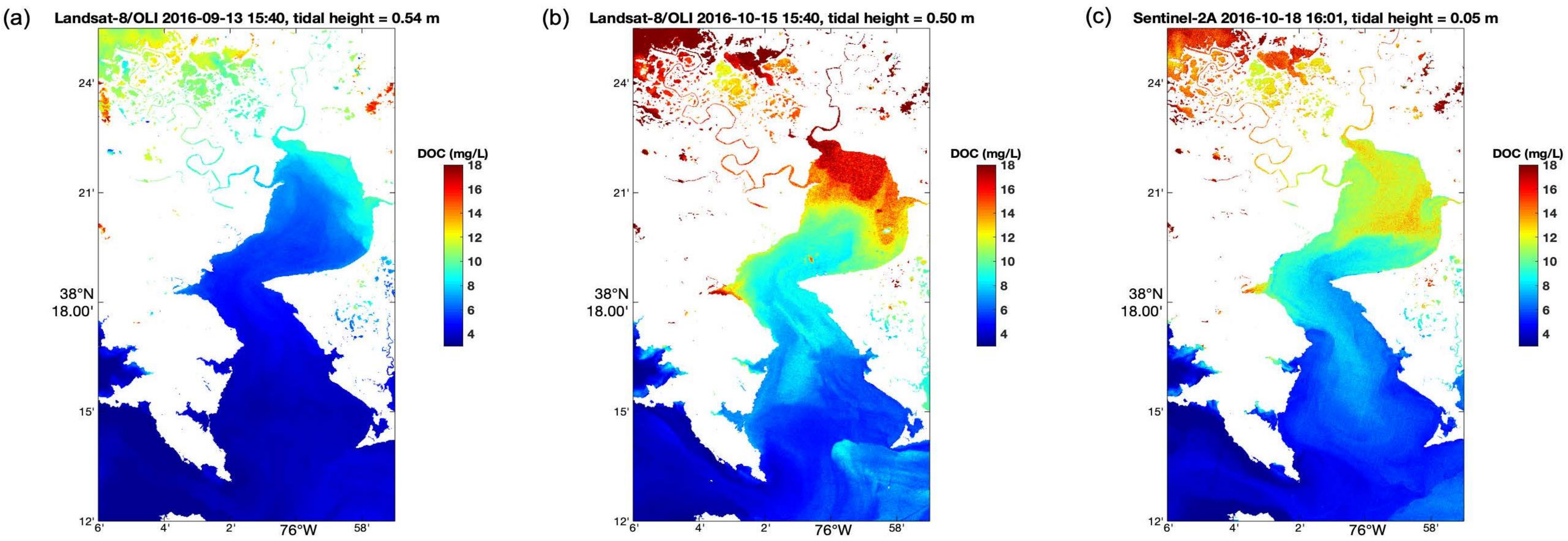


Cao & Tzortziou 2021 STOTEN

Carbon Cycling in Tidal Wetland Systems

Impact of **episodic events** on estuarine DOC dynamics

Passage of hurricane Matthew (October 5, 2016) over the Blackwater National Wildlife Refuge system

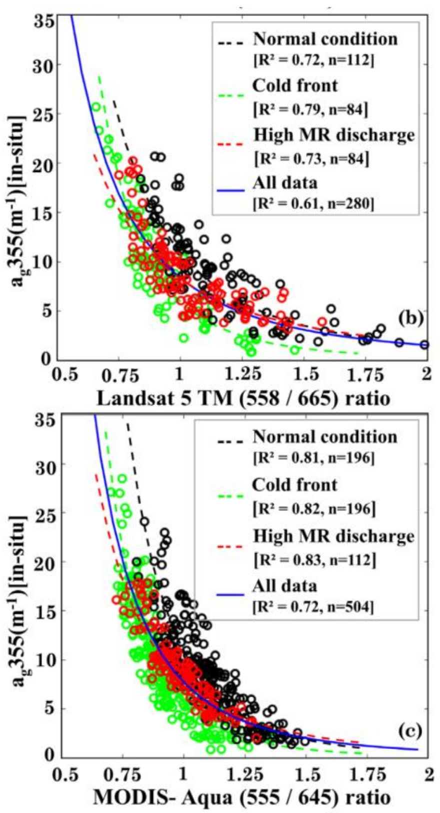


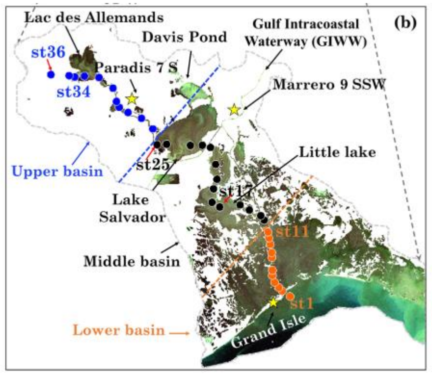
Before Hurricane Matthew | **1 week after Hurricane Matthew** | **2 weeks after Hurricane Matthew**

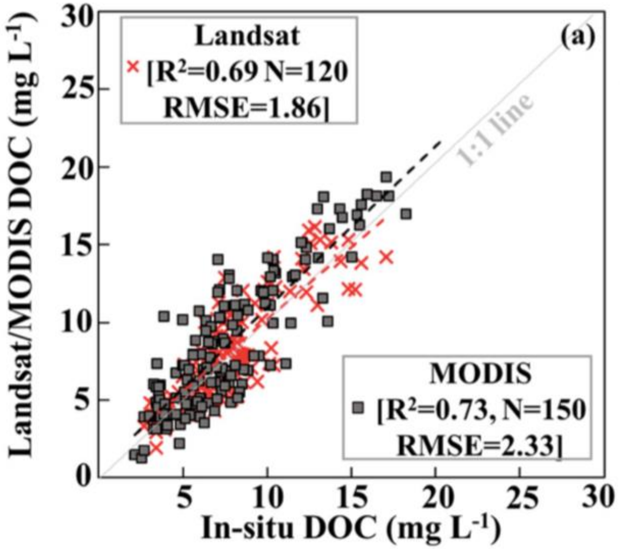
Cao & Tzortziou 2021 STOTEN

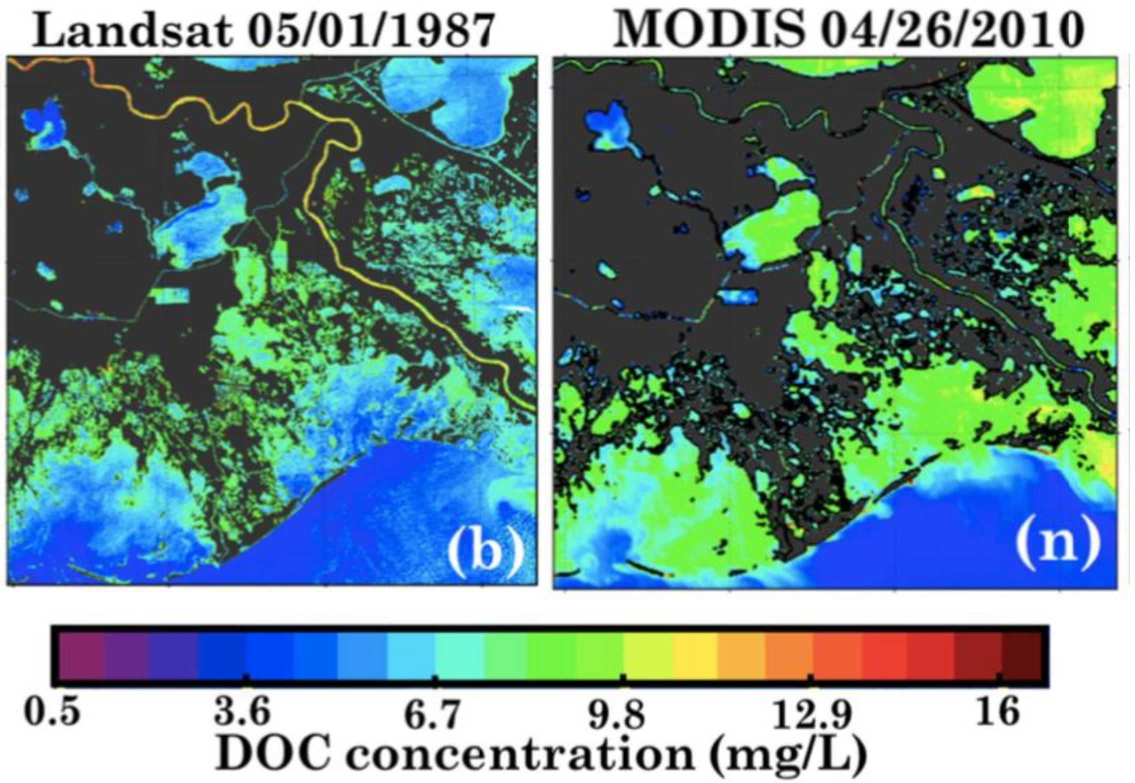
Carbon cycling in river influenced estuarine-coastal systems: short & long-term trends

Long-term DOC trends in Barataria Bay using Landsat 5 TM/MODIS (1985-2012)









Empirical BR algorithms

$$\text{DOC (mg L}^{-1}) = 0.63 \times a_g 355\ (\text{m}^{-1}) + 2.47\ [\text{All data; } R^2 = 0.80]$$

Liu, D'Sa & Joshi 2019-RSE

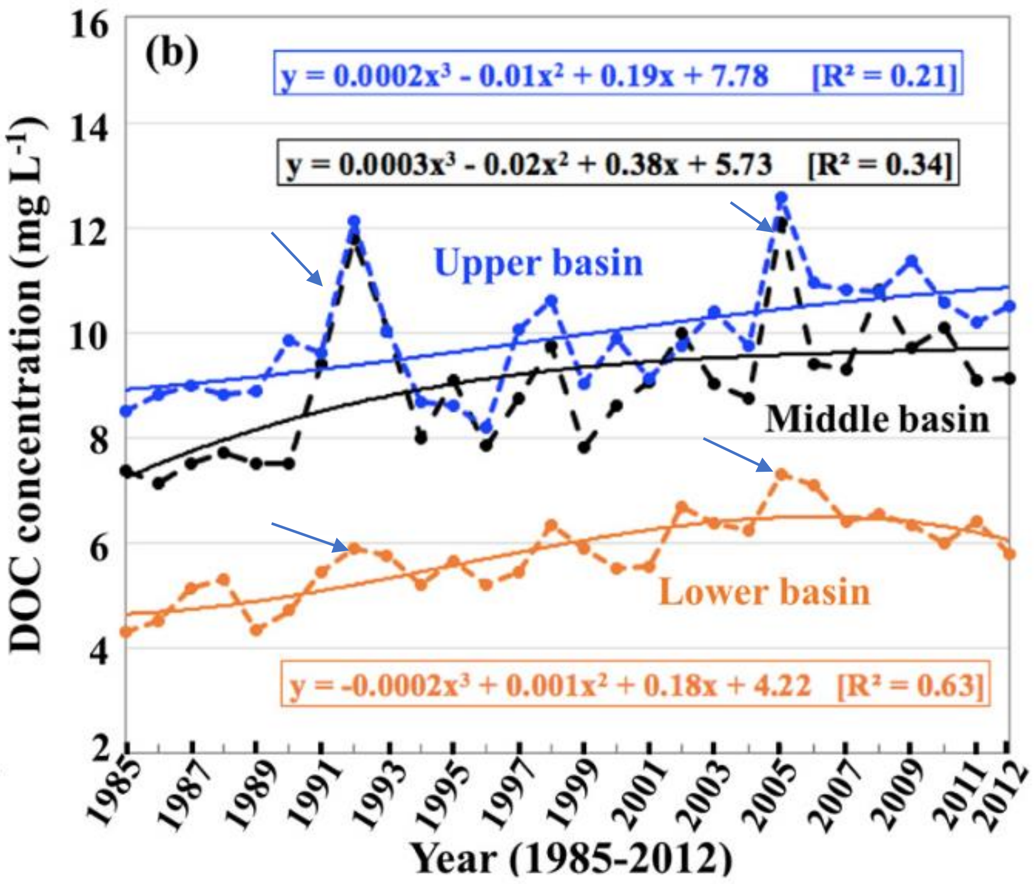
Annually averaged DOC concentrations in Barataria Bay during 1985-2012
Impacts of two major TCs

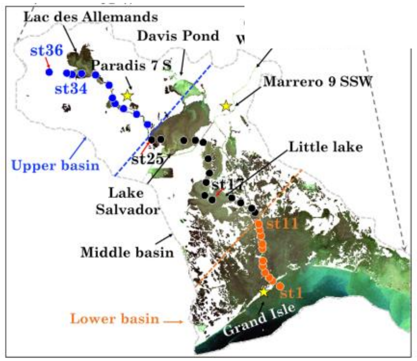
- Wetland loss in Barataria Bay is reflected in the increasing annual trend of DOC concentration in the three regions of the Basin

- Impacts of two major extreme events - Andrew in 1992 and Katrina in 2005 are considered

- Higher levels of DOC were observed due to disturbance from TCs Andrew & Katrina

- Katrina – massive deposition of inorganic sediments due to storm surge (Turner et al. 2006-Science) that likely to contributed to wetland stability and limited land loss. Also reduced carbon loss





Liu, D'Sa & Joshi 2019-Remote Sensing of Environment

DOC and POC distribution and fluxes in northern GoM
Using Adaptive Semi-analytic algorithms + Empirical relationships

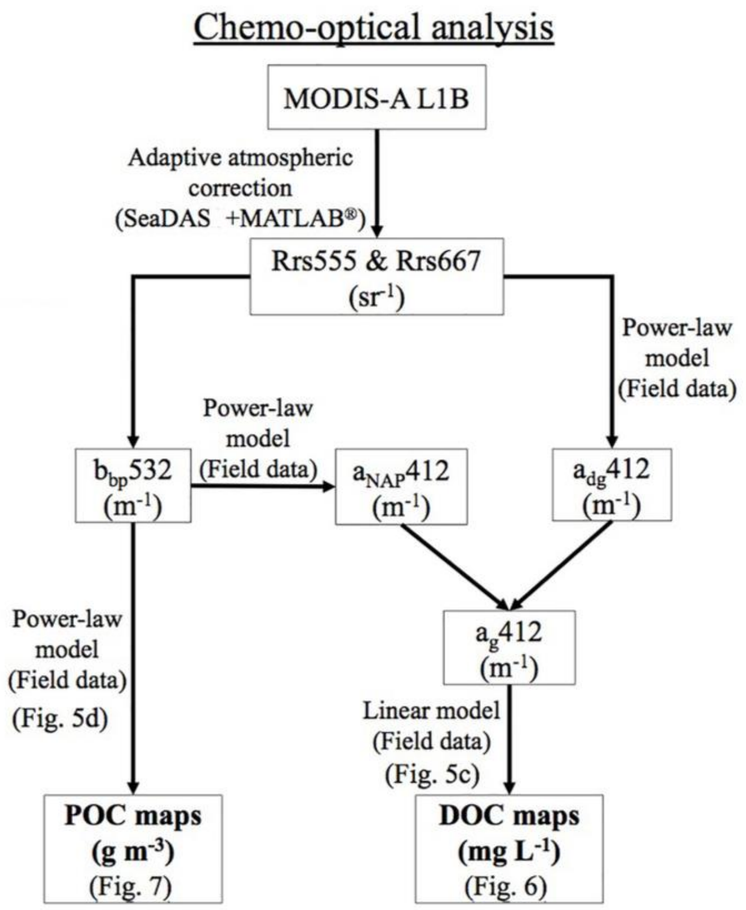
- QAA-V: Quasi-analytical (QAA; Lee et al. 2001) optimized for turbid waters (Joshi and D'Sa 2018, BGS)

- AD-QAA: Adaptive QAA (combination of QAA-V & QAA-v5) for the estuarine-ocean continuum (Joshi and D'Sa 2020; IEEE TGRS)

- From satellite R_{rs} we derive total absorption and backscattering $b_{bp}532$

- Power-law models (using satellite and field data) used to derive $a_{cdom}412$

- Relationships between $b_{bp}532$ and POC and $a_{cdom}412$ and DOC were used to generate POC and DOC maps

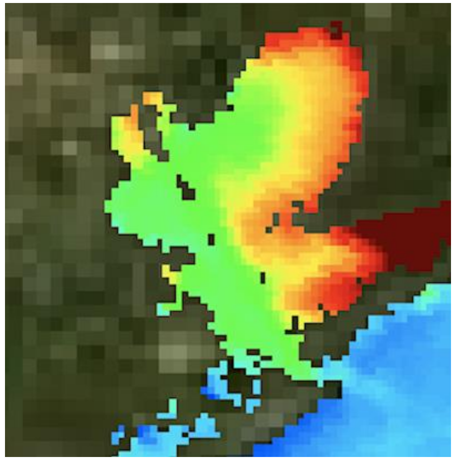


D'Sa et al. 2019-Frontiers in Marine Science

Calculating Carbon Fluxes

- River discharge and other point sources to estuaries

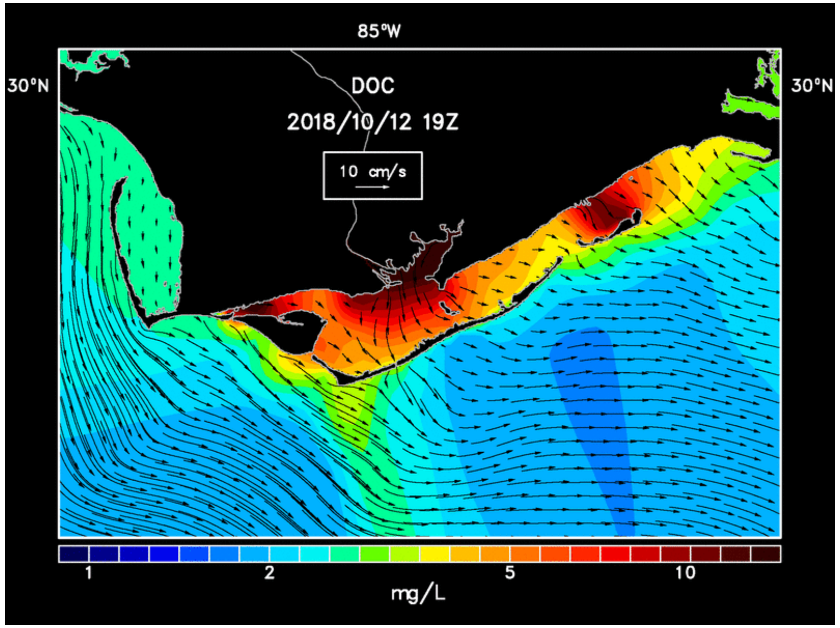
Fluxes = Water volume discharged x DOC/POC concentrations



- Currents and tidal data obtained at entrance to estuaries

Water volume transport = current (m/s) x Pass cross-sectional area (m^2)

- Hydrodynamic models: Nested high resolution (250 m) NCOM estuarine model

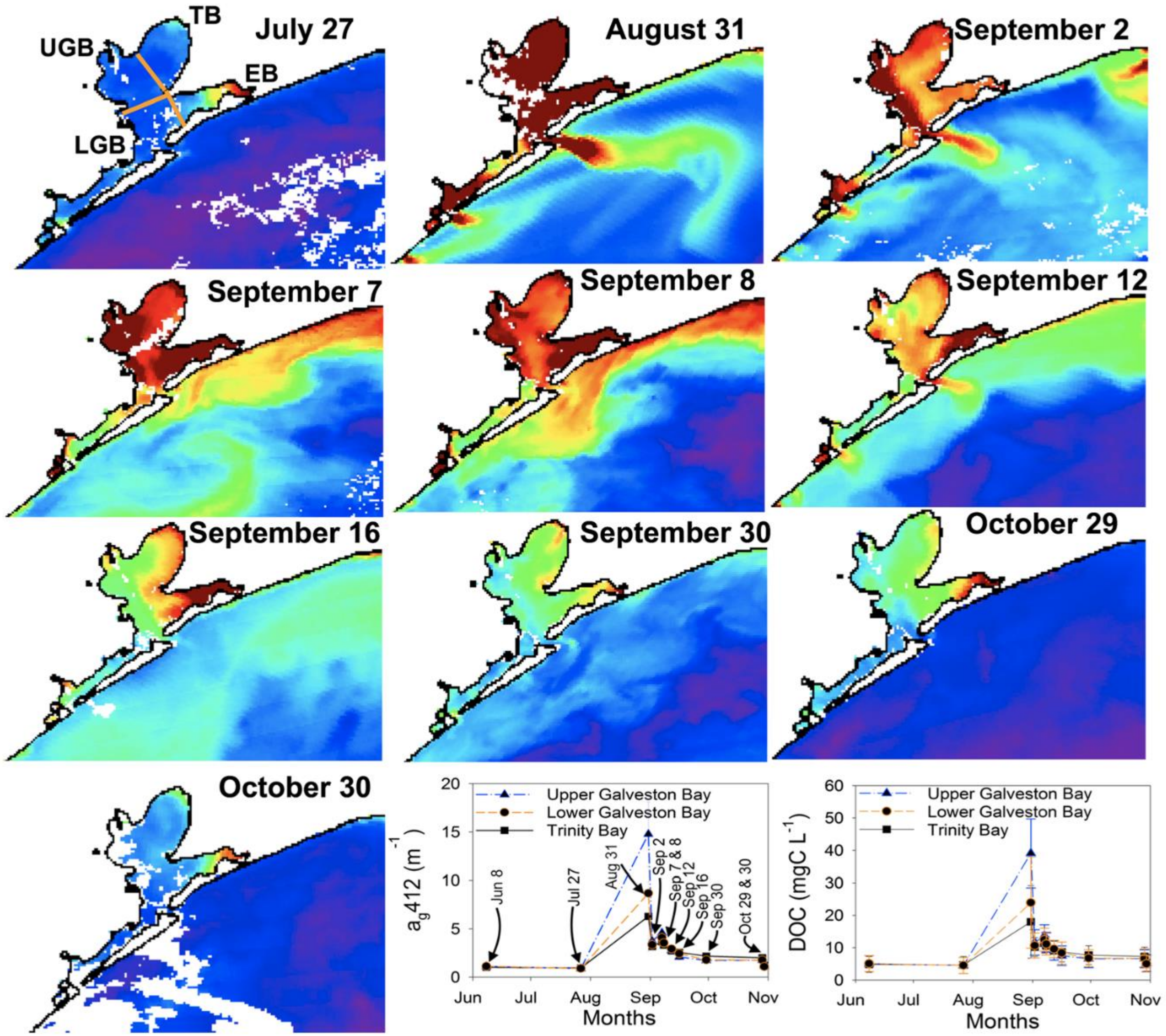


- Model driven by realistic tides, real-time river flows, winds, evaporation & rainfall
- Water volume fluxes in-or-out of the bay were obtained from model by integrating hourly flows (current, m/s x vertical xsection, m^2)
- Hourly DOC and POC flux rates over multiple tidal cycles computed : satellite derived POC/DOC x volume of water through passes

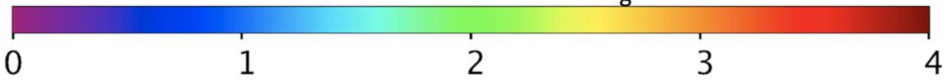
D'Sa et al. 2019-Frontiers in Marine Science

Hurricane Harvey (2017): Extreme precipitation event

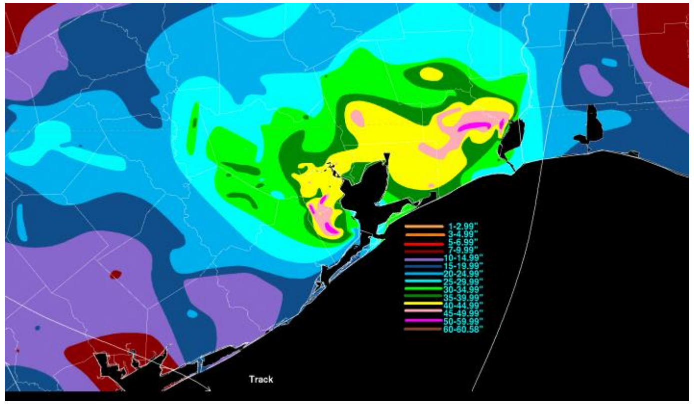
CDOM/DOC dynamics



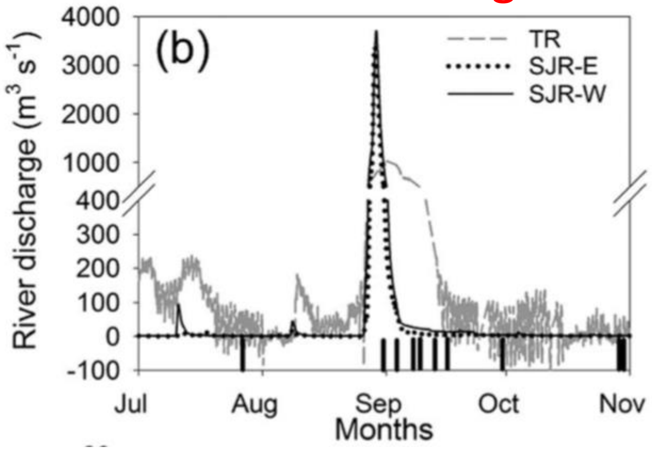
CDOM absorption at 412nm (a_g412) (m^{-1})



Rainfall total



River discharge

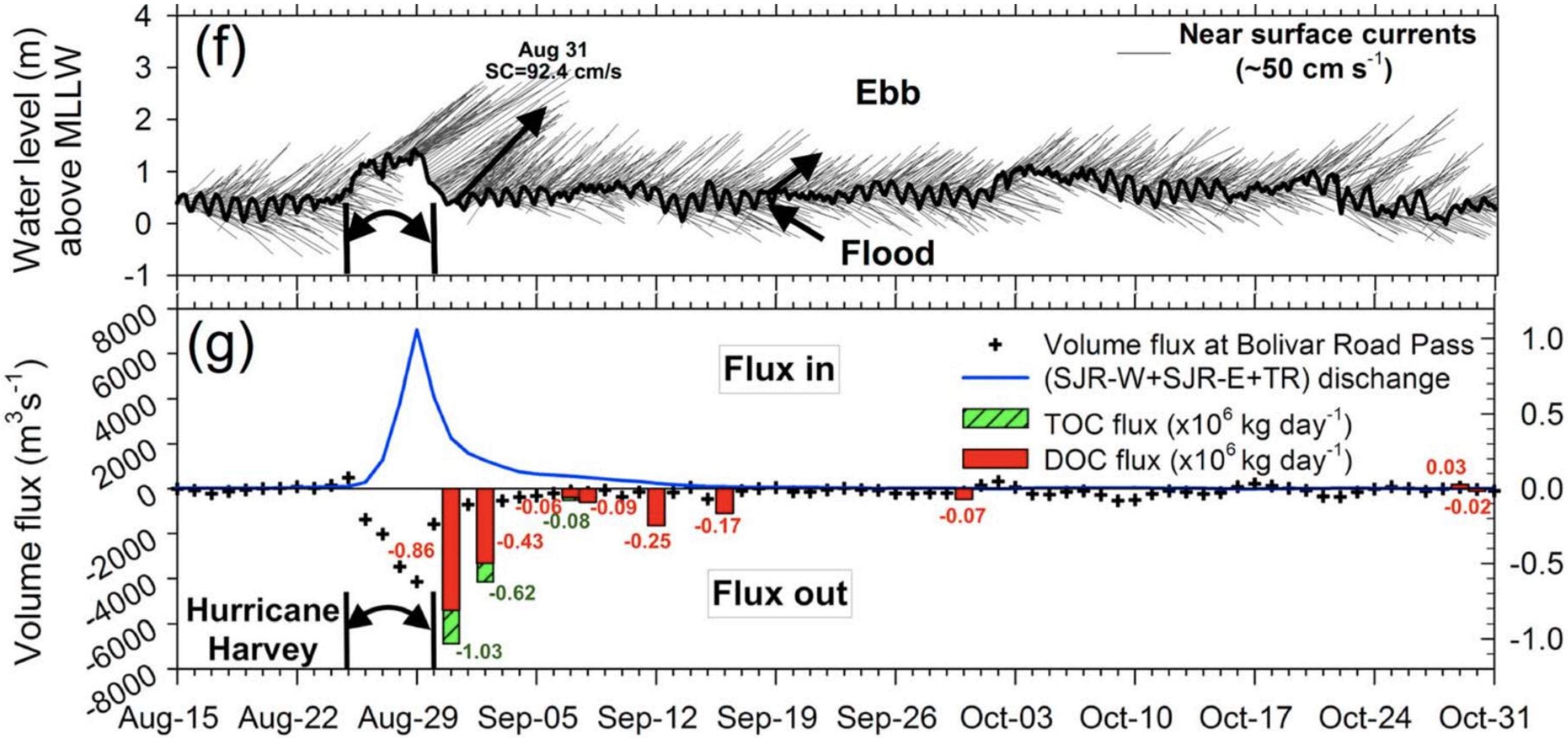


D’Sa, Liu & Joshi 2018-Geophysical Research Letters

Water volume, DOC, POC fluxes linked to Hurricane Harvey

water level and surface currents at Bay entrance

-River discharge
-volume flux at entrance
-DOC & POC fluxes

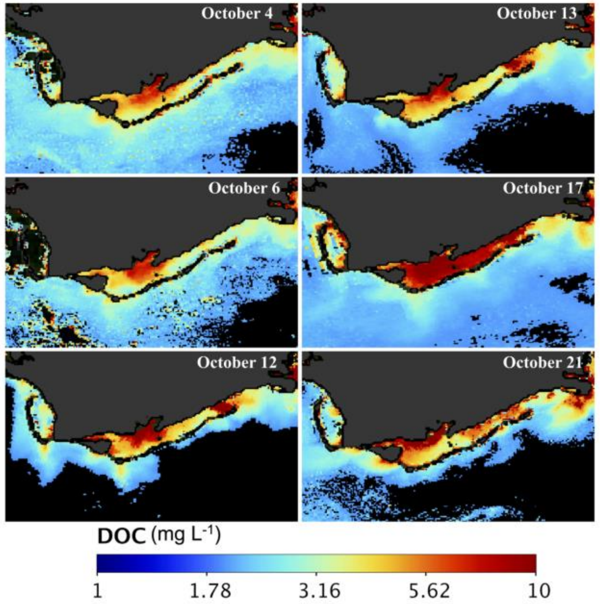


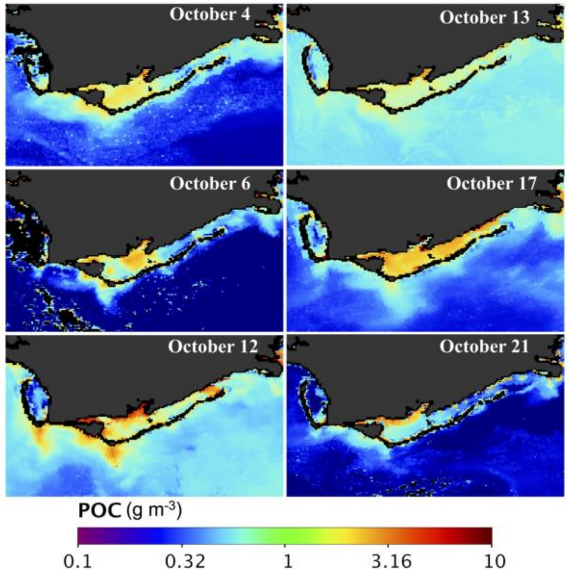
D’Sa, Joshi and Liu 2018-GRL

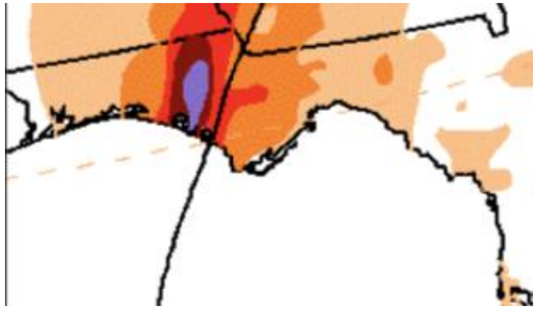
- Over 10 days during/following hurricane, ~25x10^6 kg C (TOC) were rapidly exported from Galveston Bay to shelf waters
- Represented ~0.65% of the annual Mississippi River fluxes to the Gulf of Mexico

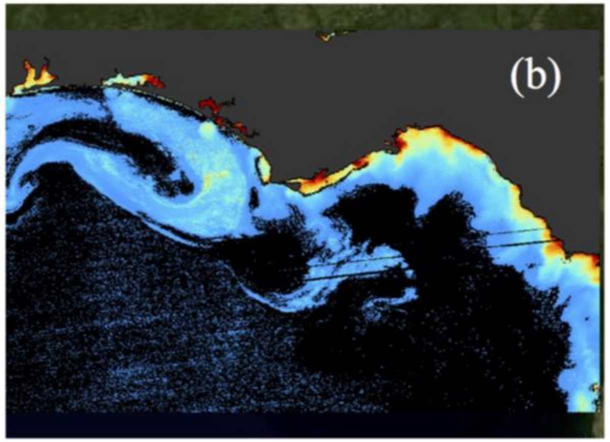
D’Sa et al. 2018-Geophysical Research Letters

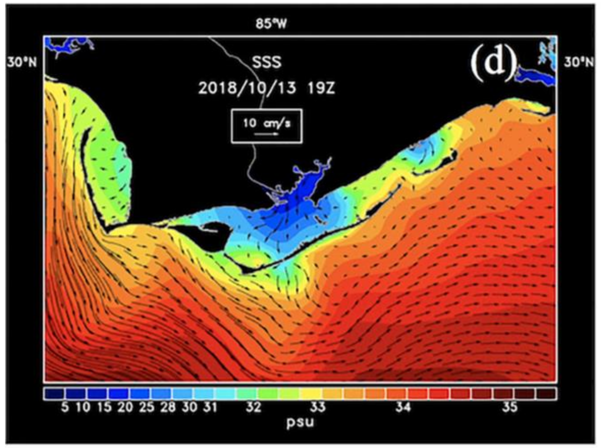
Hurricane Michael (2018): High wind impact, fast moving, strong storm surge

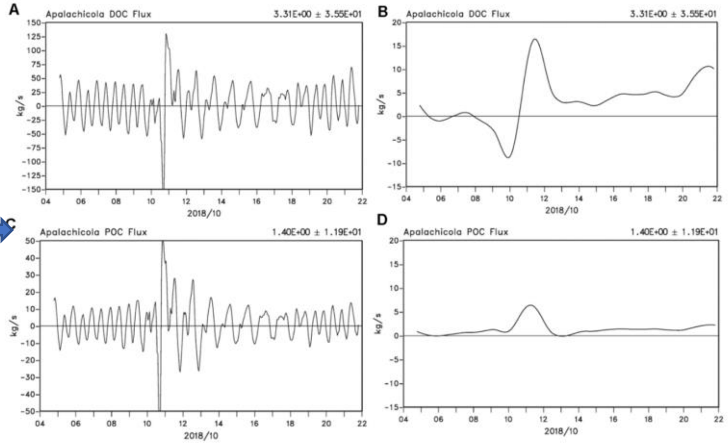












- Average flux of organic carbon exported between 5-21 Oct were much greater for DOC (0.86×10^6 kg C d^{-1}) than POC (0.21×10^6 kg C d^{-1})

NCOM hydrodynamic model

Fluxes of DOC and POC

D'Sa et al. 2019-Frontiers in Marine Science

Conclusions/Lessons learnt

- Optical/biogeochemical characterization of coastal waters critical to improved satellite carbon algorithms

- Multisource satellite data – provided improved spatiotemporal resolution

- Tidal wetland systems can have strong tidal carbon signatures superimposed on extreme events – Geostationary satellites could provide important insights

- Carbon cycling varies as a function of TCs intensity, translational speed and precipitation - each extreme event is unique

- We observed both short- and long-term impacts of extreme events; in addition, impacts were widespread and extended beyond our study sites

- Combining hydrodynamic physical models with satellite-derived chemical indicators improved understanding of carbon cycling in complex estuarine system

Challenges and Gaps

- Limited field optical-geochemical data
- Limitations of existing bio-optical instrumentation in highly turbid waters
- Long-term impacts of extreme events - can be beneficial
- Some TCs have large areal impacts and therefore greater influence on carbon cycling than most studies indicate