Intercomparison of Hypoxia Models for the Northern Gulf of Mexico and Nutrient Load Scenarios

PIs

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- Dong S. Ko* (NRL)
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Partners

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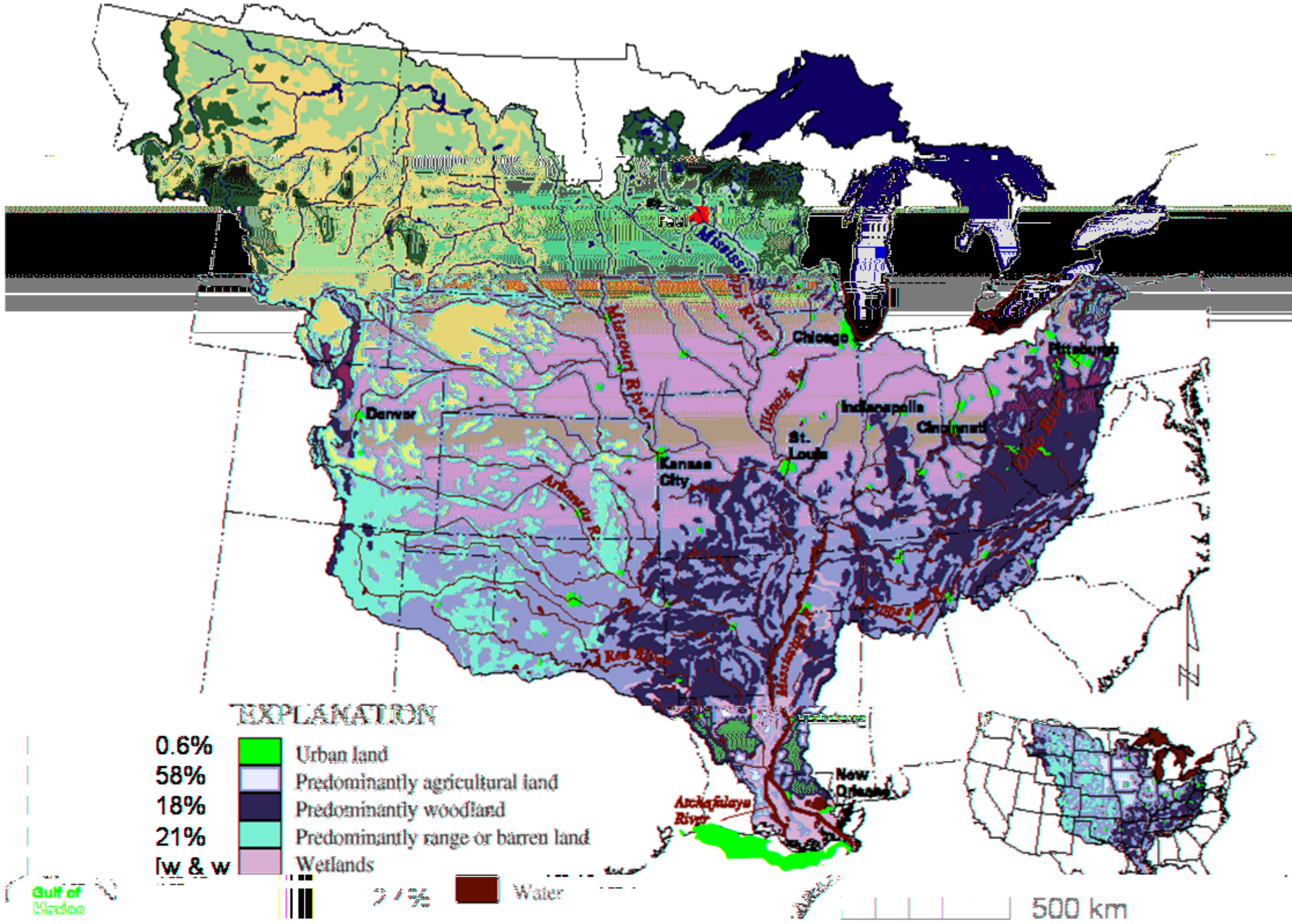


*unfunded in year 5; **funded only in year 5

Outline

- **Retrospective analysis of 2016 hypoxia season for Hypoxia Taskforce *(Fennel & Justic)***
- **Analysis of coral die-off event in FlowerGarden Marine Sanctuary in 2016 *(Hetland)***
- **Biogeochemical inter-comparison *(all)***
- **Future projection results from ROMS *(Fennel, Lehrer & Ko)***

2016 Hypoxic Zone Conditions:
Analyses With State-of-the Art Mathematical Models

Rob Magnien, NOAA
Katja Fennel, Dalhousie Univ
Dubravko Justic, LSU
Nancy Rabalais, LSU/LUMCON

HTF meeting, New Orleans
Tuesday, December 6, 2016

JOINT NEWS RELEASE
NATIONAL OCEANIC &
ATMOSPHERIC ADMINISTRATION
U.S. GEOLOGICAL SURVEY

NOAA, partners predict an average ‘dead zone’ for Gulf of Mexico

Outlook incorporates multiple hypoxia models for the second year

Scientists forecast that this year’s Gulf of Mexico hypoxic zone, also called the “dead zone,” will be approximately 5,898 square miles (15,275 square kilometers) or about the size of Connecticut - the same range as it has averaged over the last several years.

NOAA: No “Dead Zone” measurement this summer due to ship problem

NOAA, which oversees the official annual measurement of the hypoxic zone in the Gulf of Mexico, has announced that due to engine problems with *NOAA Ship Nancy Foster*, there will be no official measurement survey of the annual dead zone that forms off the coast of Louisiana and Texas.

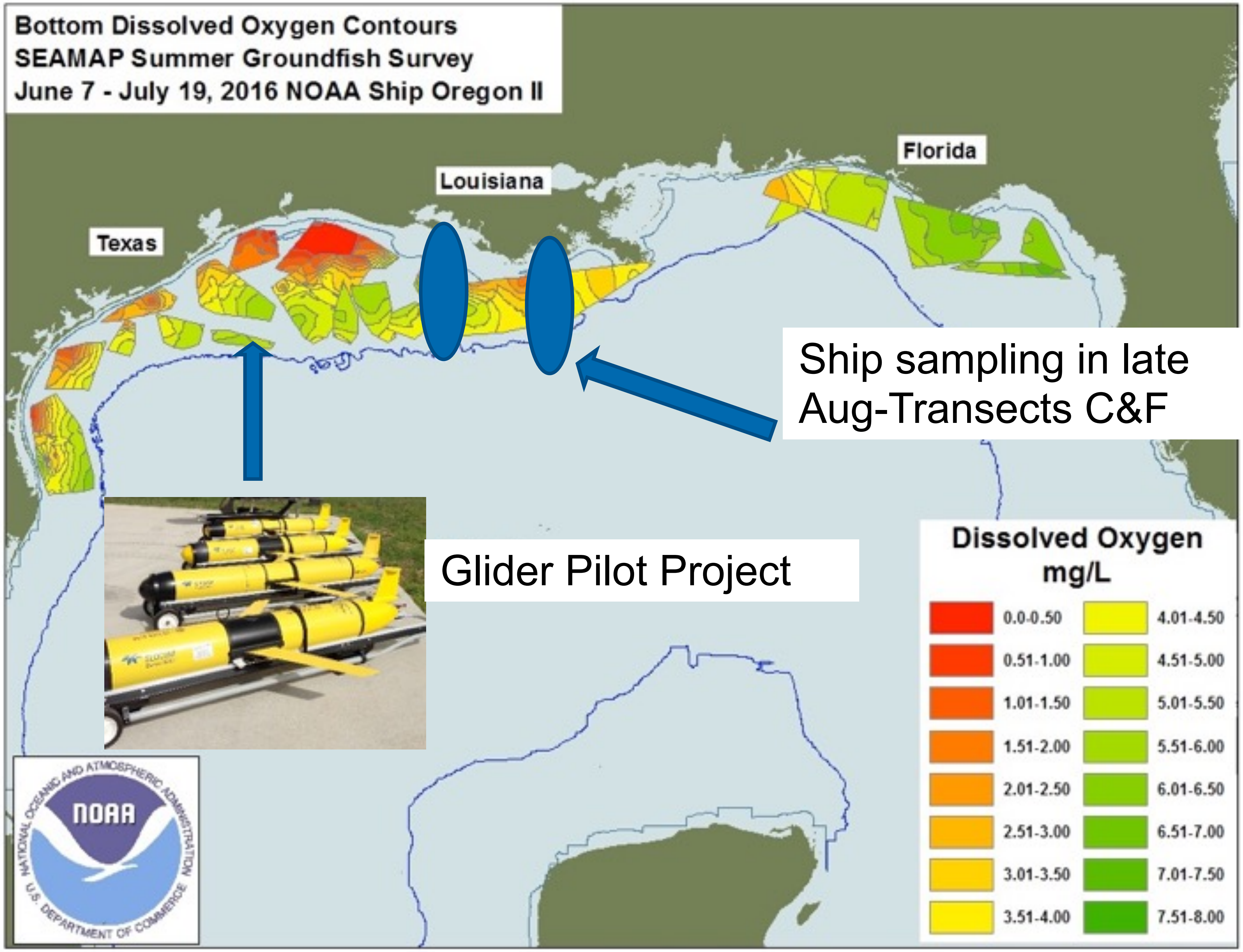
Some Monitoring Was Conducted in 2016

SEAMAP

Gliders

Late Aug transect

Continuous measurements at single location

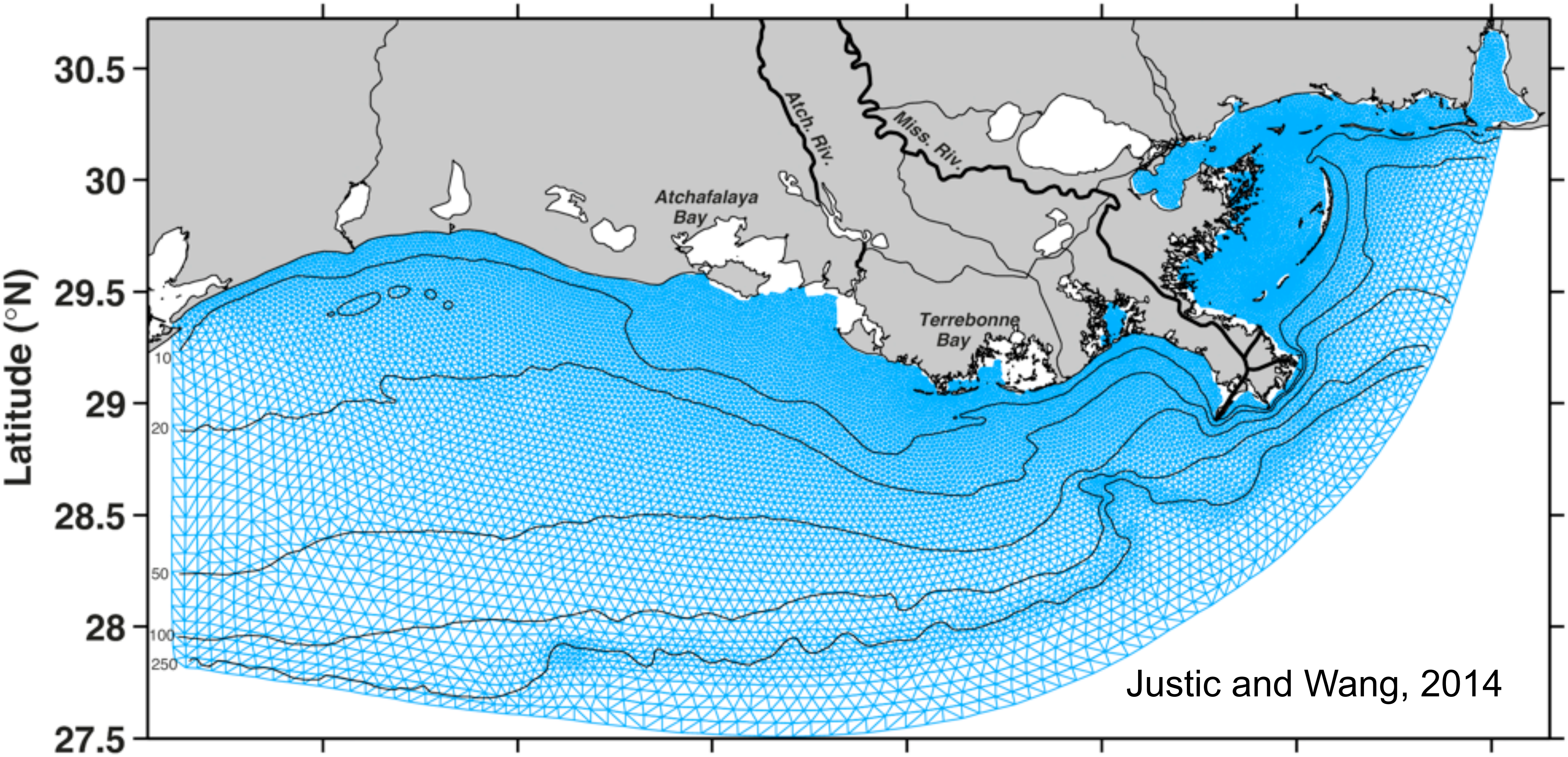


Ship sampling in late Aug-Transects C&F

Glider Pilot Project

Introduction to 3D, Time-Variable Models – We Have Two – FVCOM & ROMS!

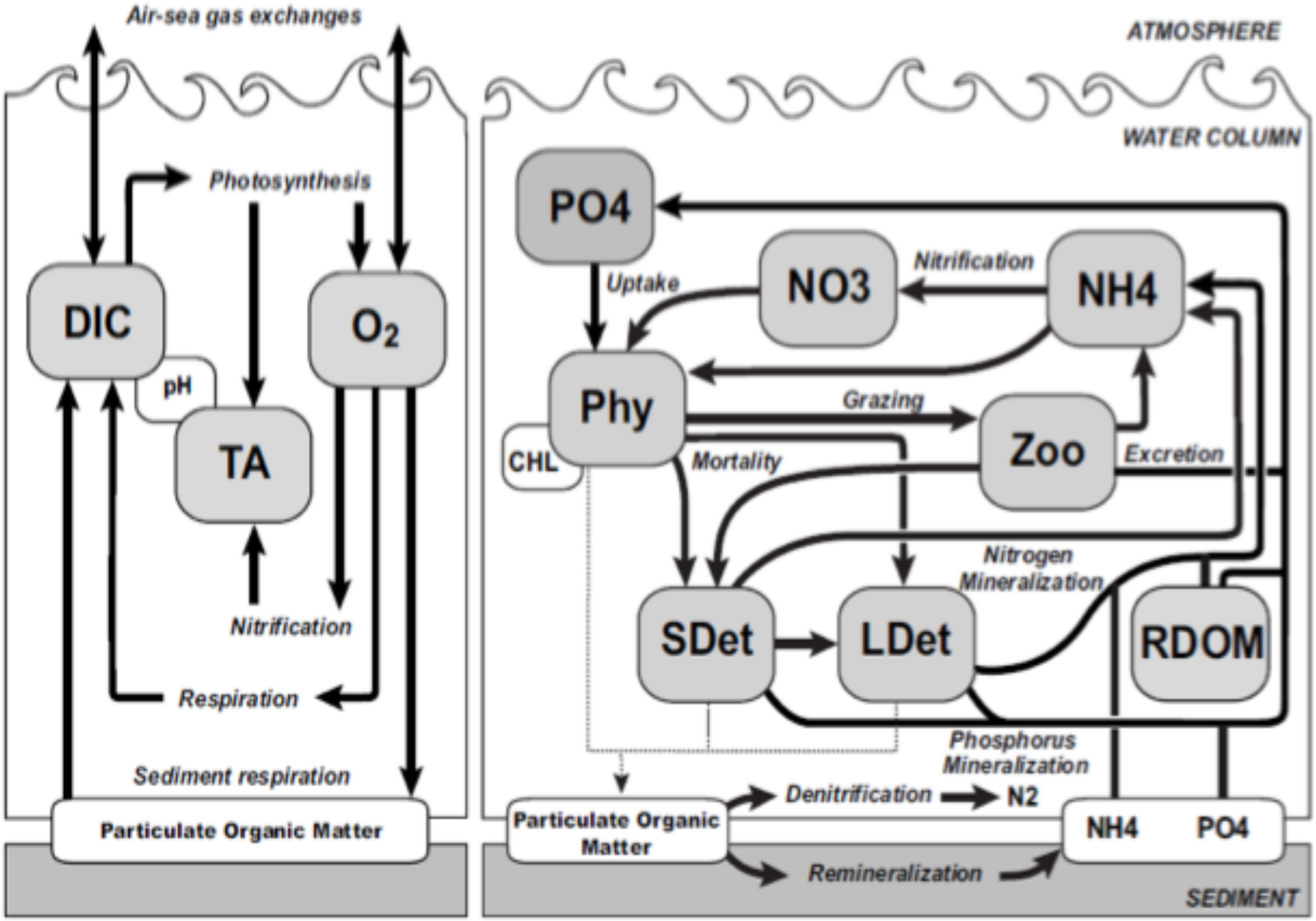
Model grid for FVCOM – additional cells in vertical dimension



Justic and Wang, 2014

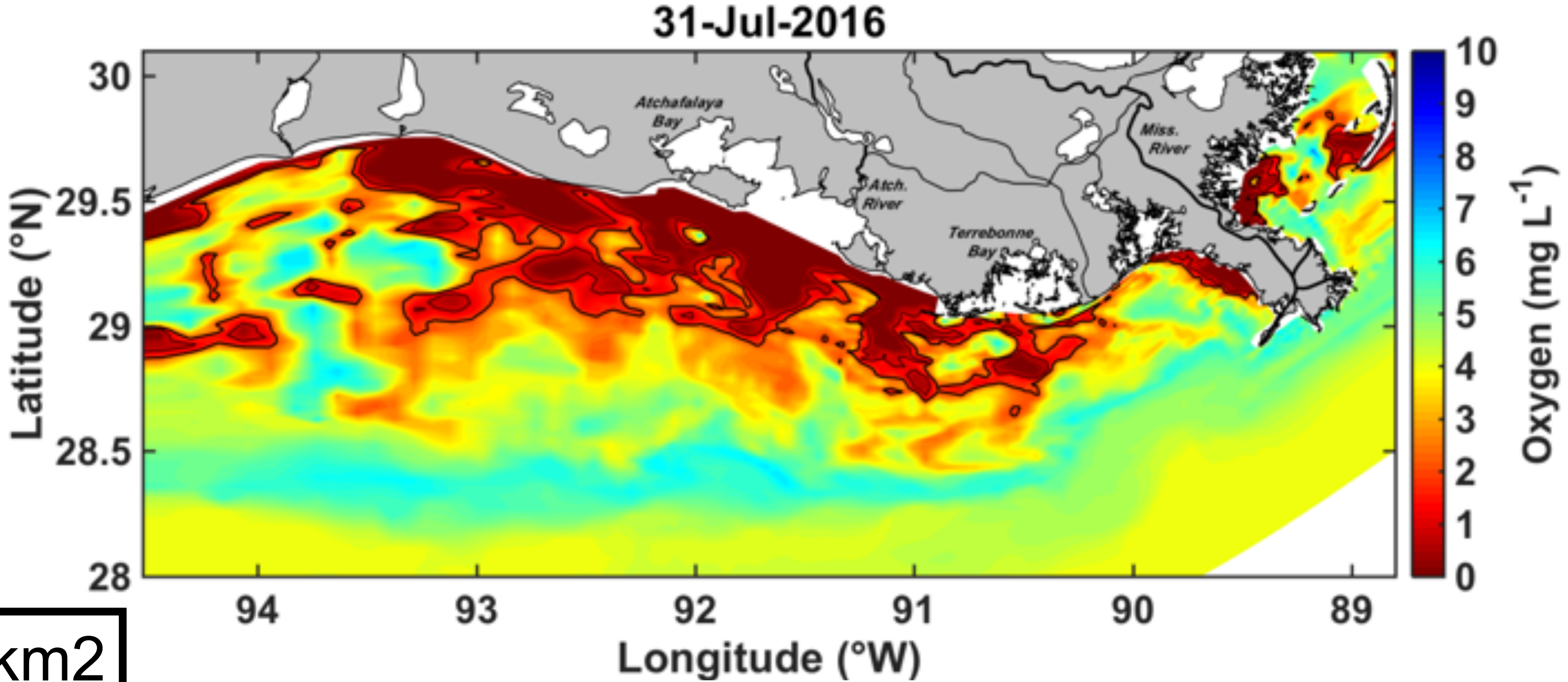
Introduction to 3D, Time-Variable Models – We Have Two - FVCOM & ROMS!

Schematic of variables and processes simulated in ROMS



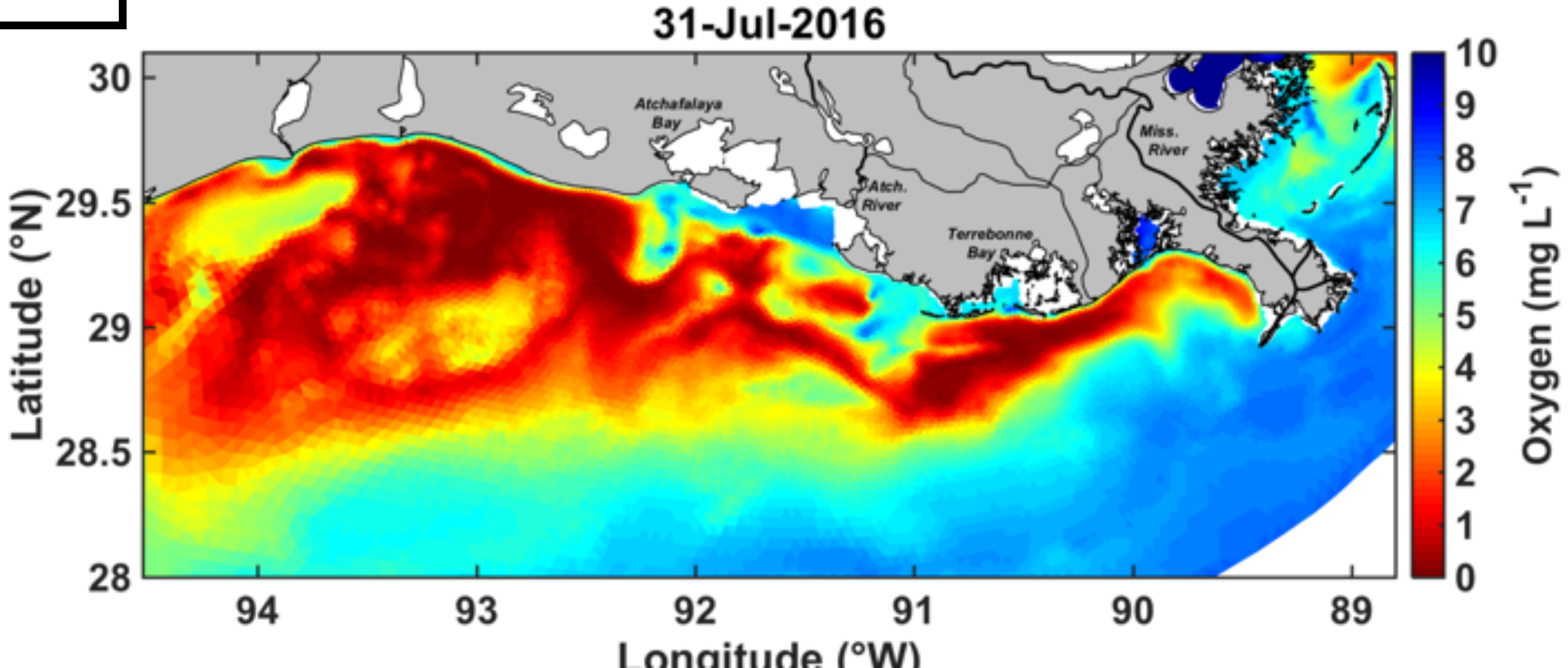
“Snapshot” simulation of Mid-Summer Hypoxia, 2016

ROMS
(hypoxic area:
13,900 km2



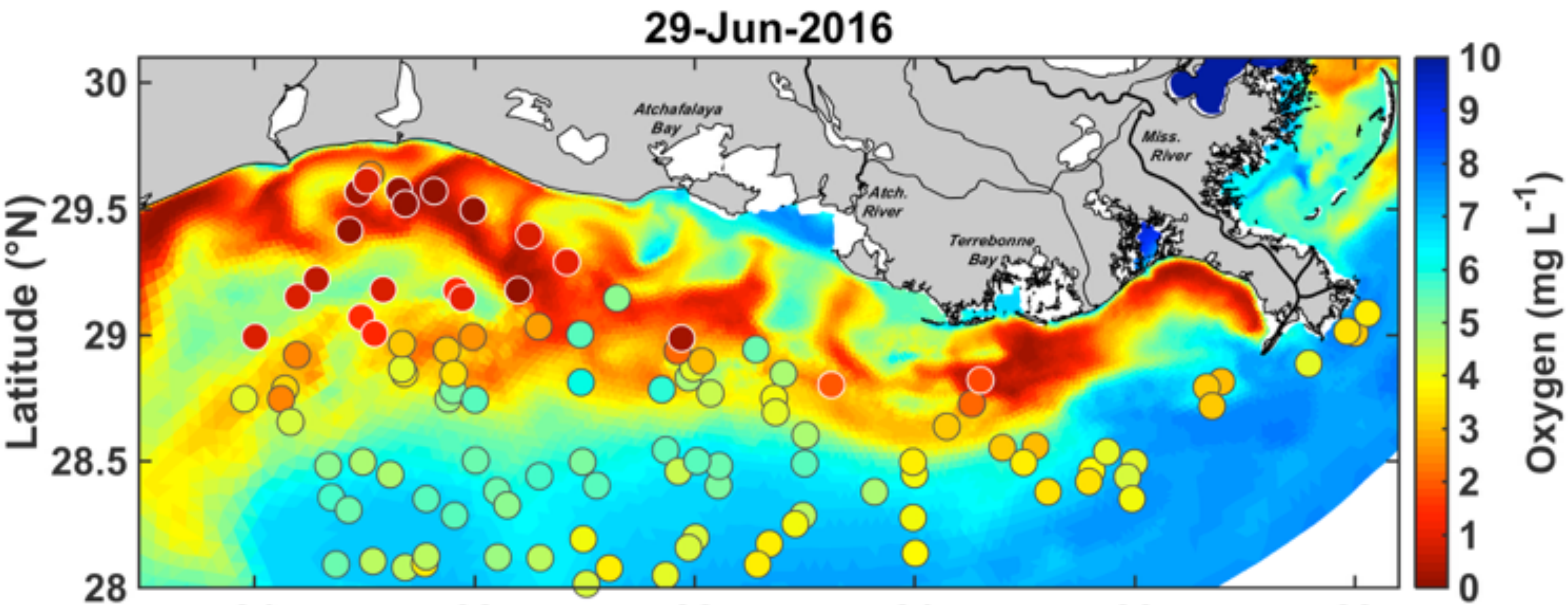
Prediction = 15,275 km2

FVCOM
(hypoxic area:
21,100 km2)

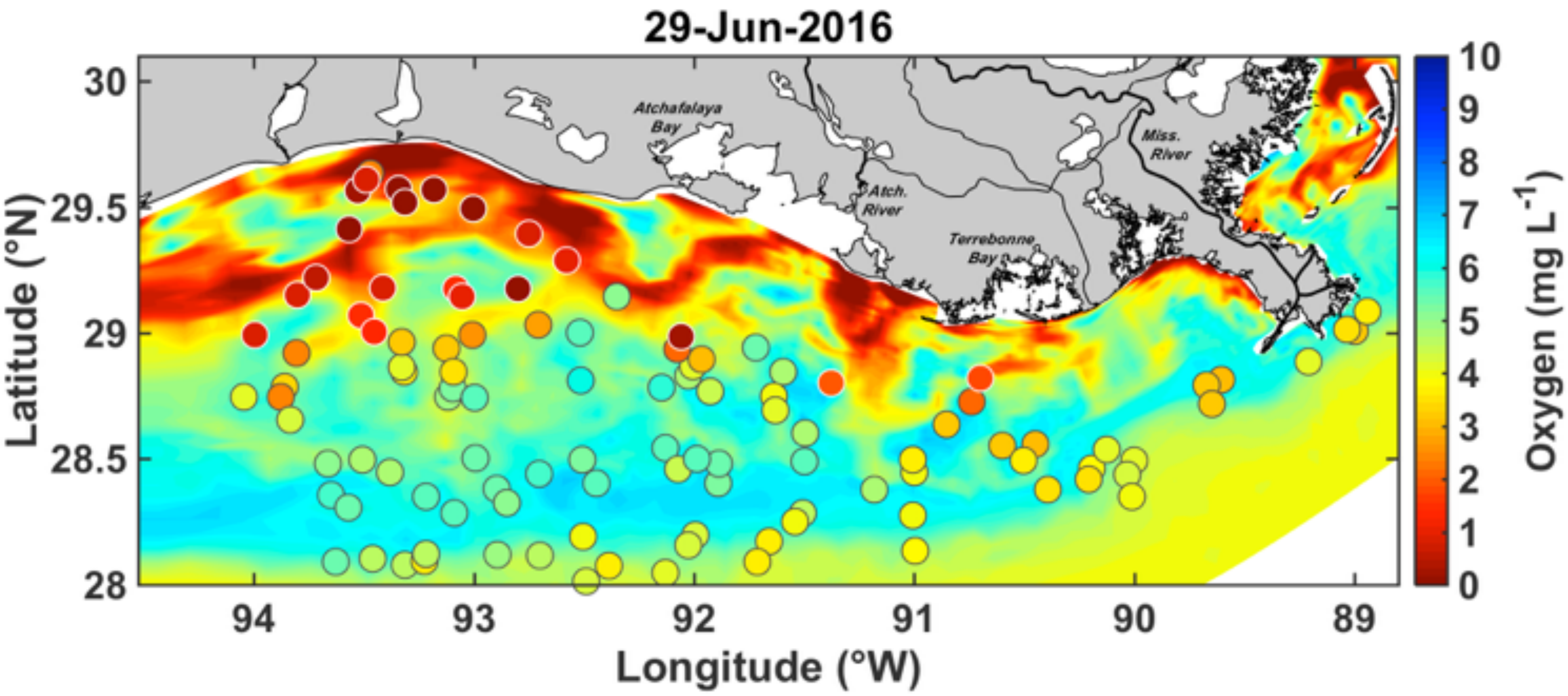


Comparison of simulated bottom DO with SEAMAP observations 2016

FVCOM

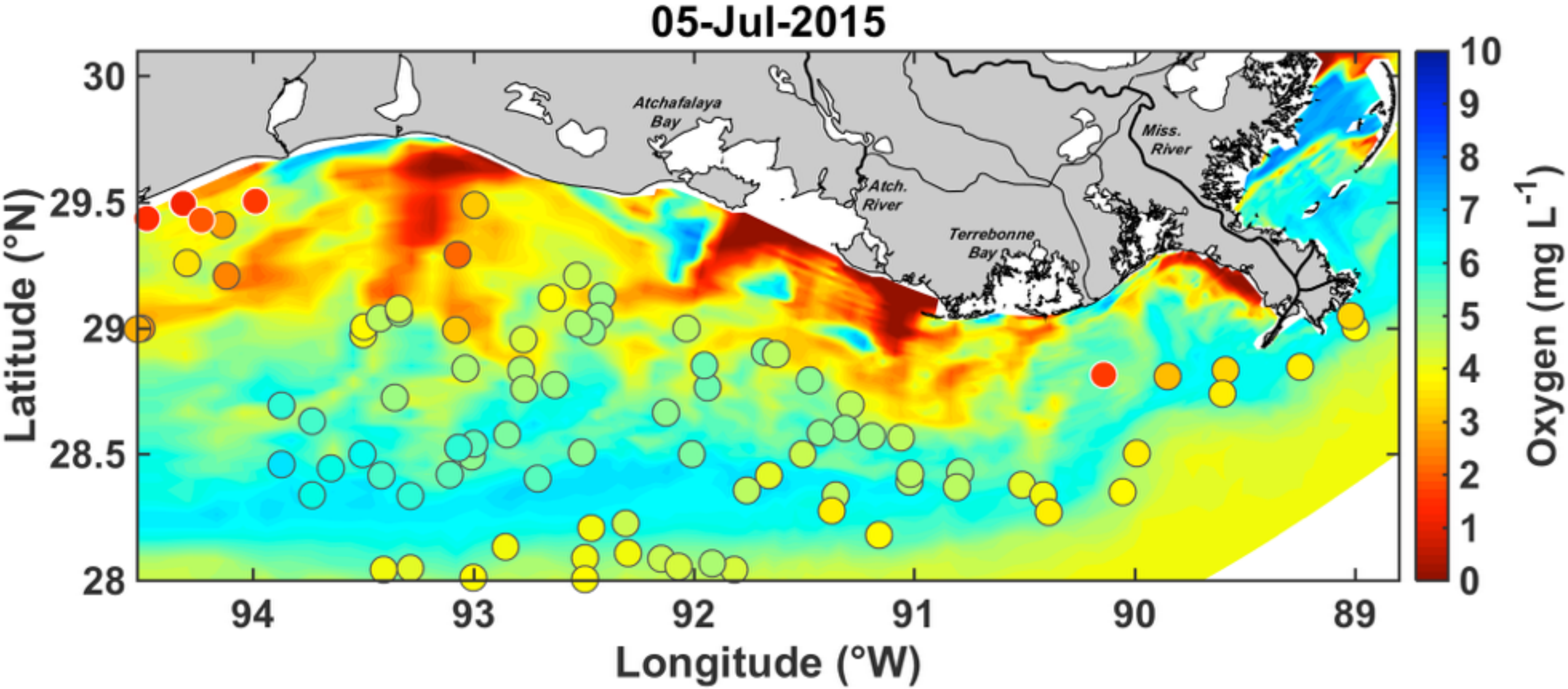


ROMS



Comparison of simulated bottom DO with SEAMAP observations 2015

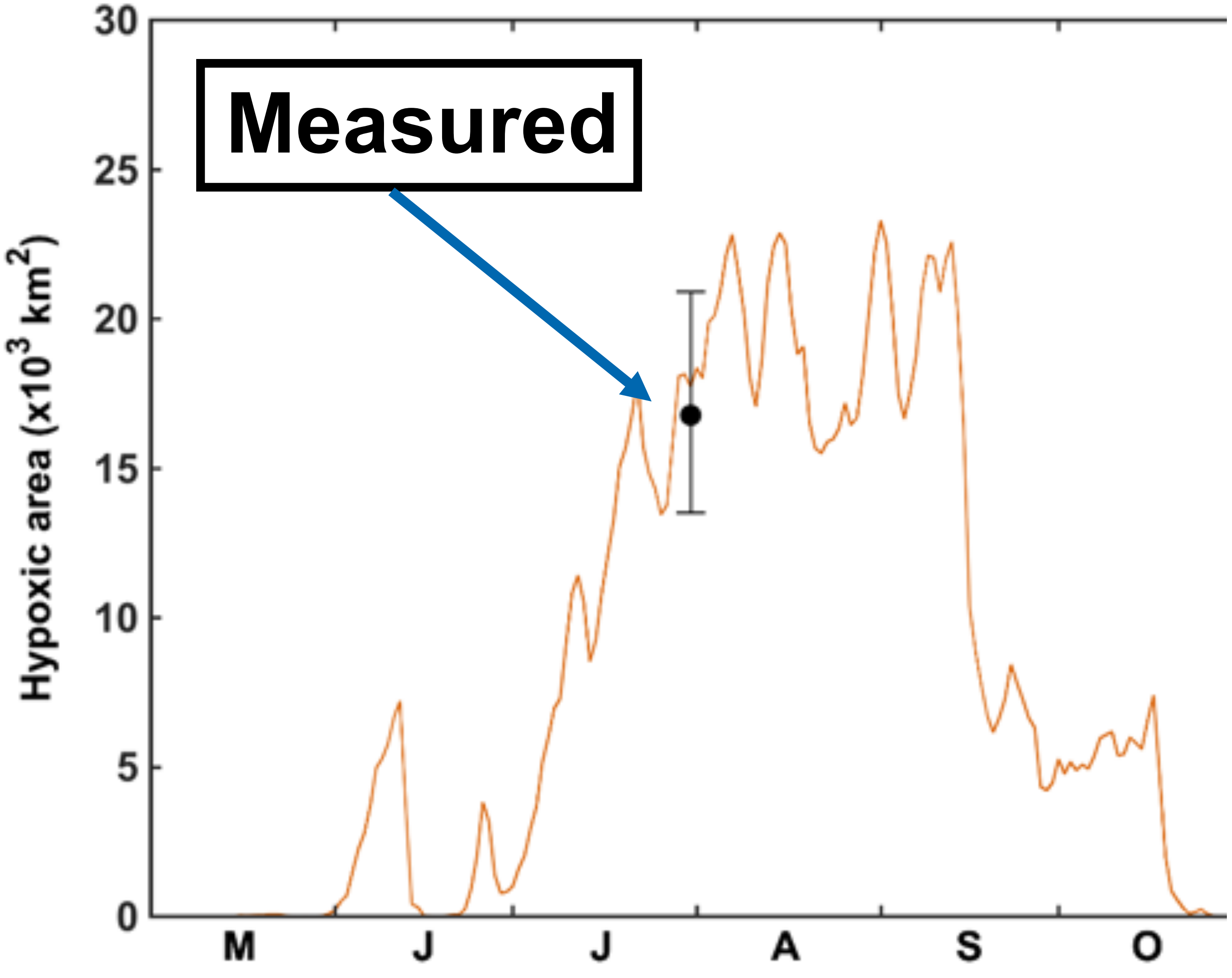
Only available from ROMS



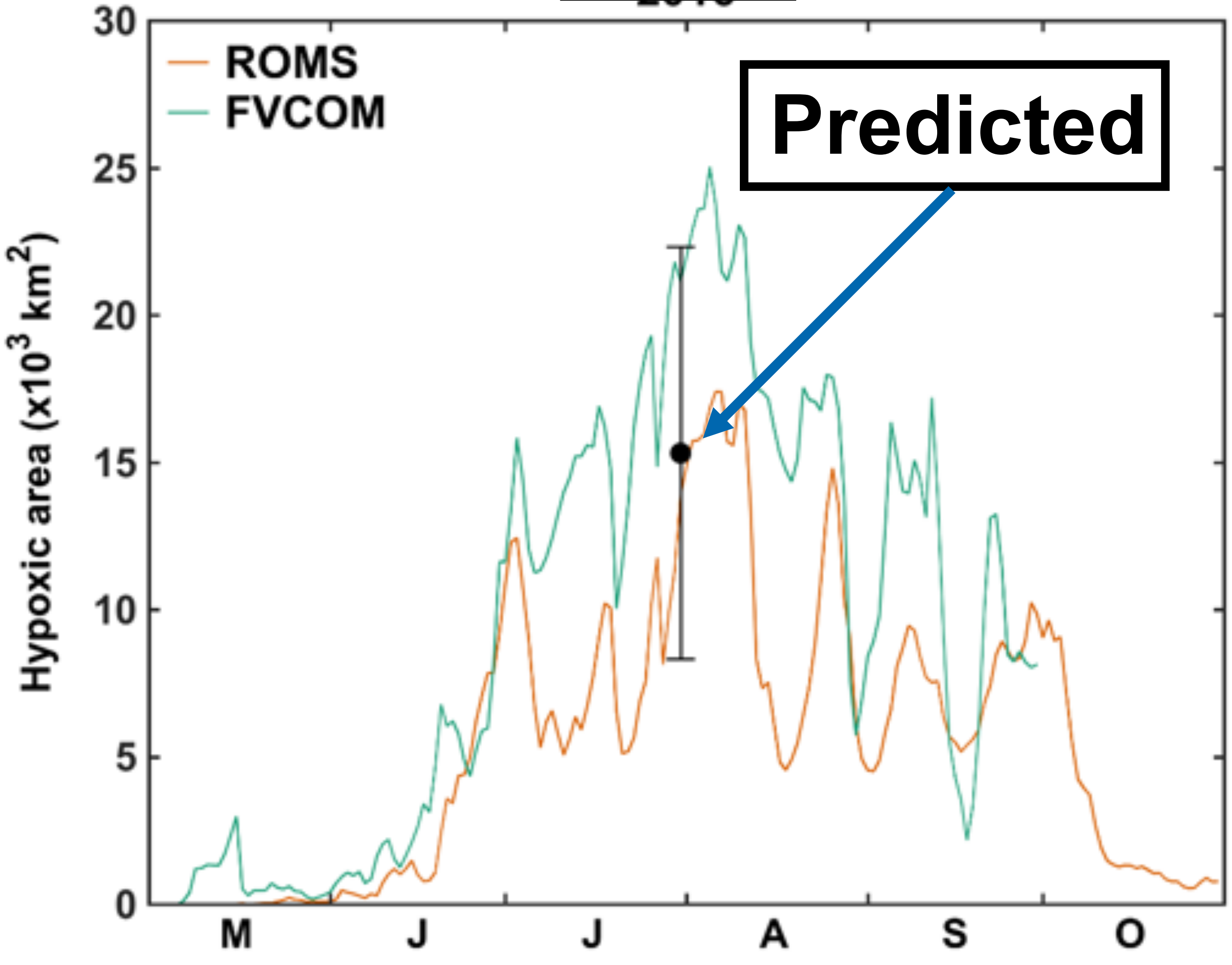
Time Series of Hypoxic Area – 2015 vs 2016

Measured (2015) and predicted (2016) areas appear to match well with model simulations.

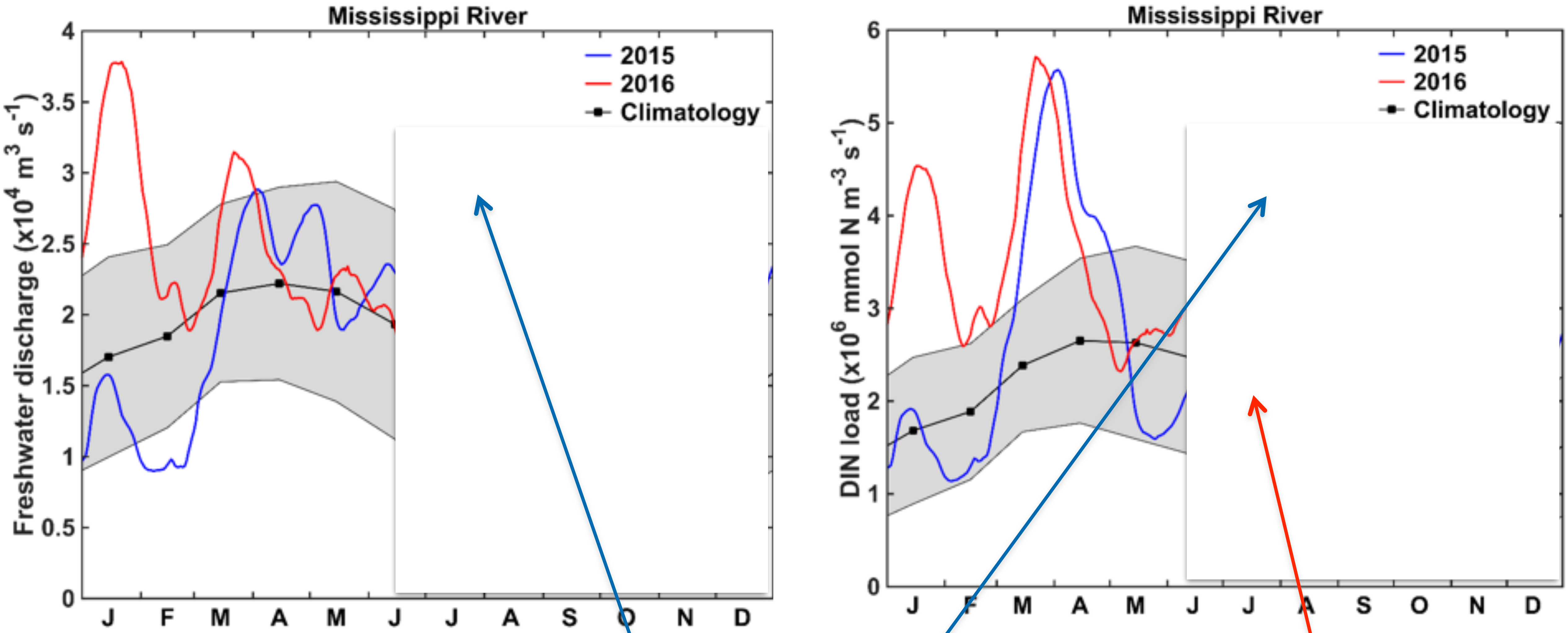
2015



2016



Freshwater and inorganic nitrogen loads for 2015 and 2016

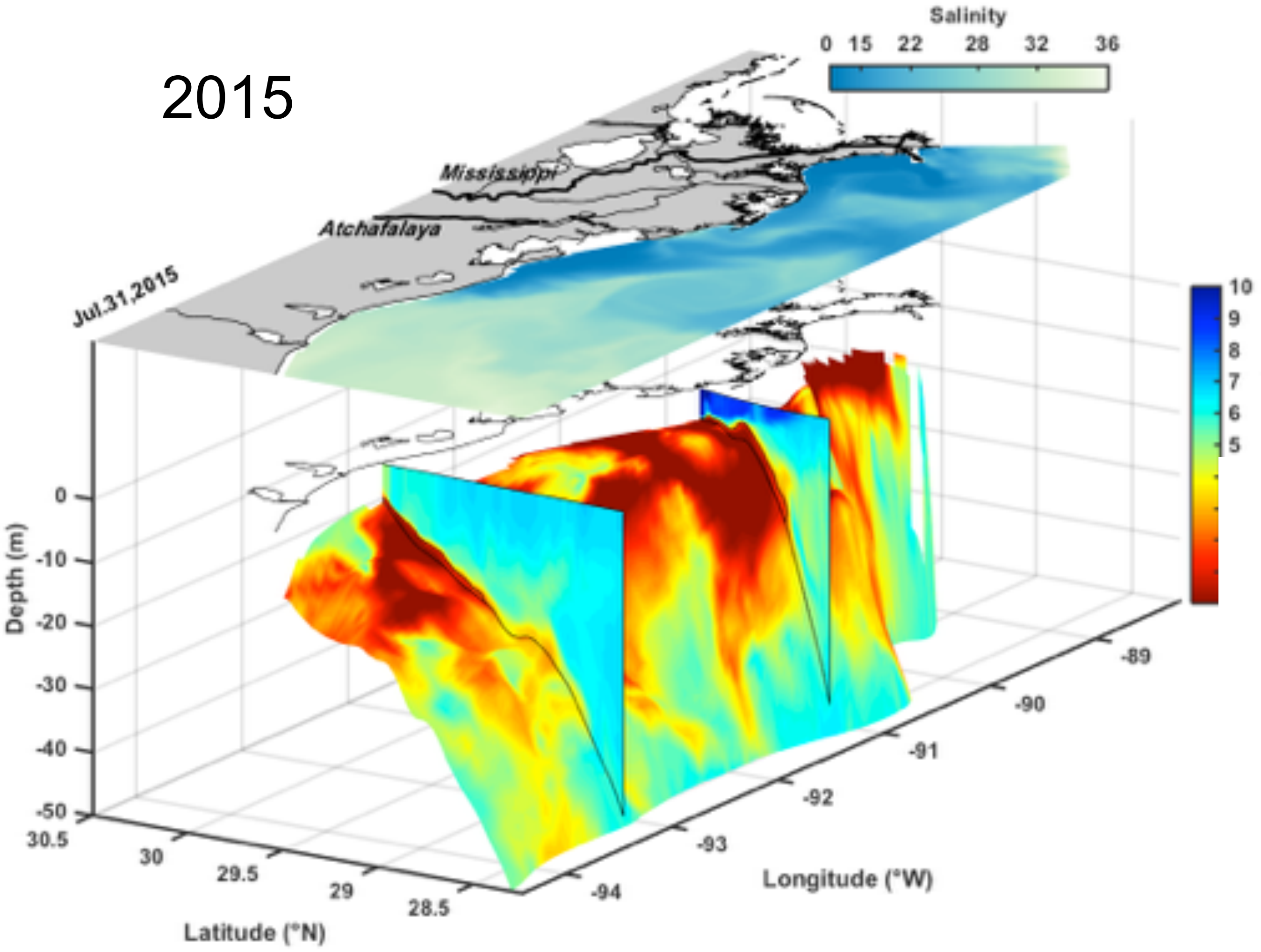


Note the large freshwater discharge and DIN load in summer 2015.

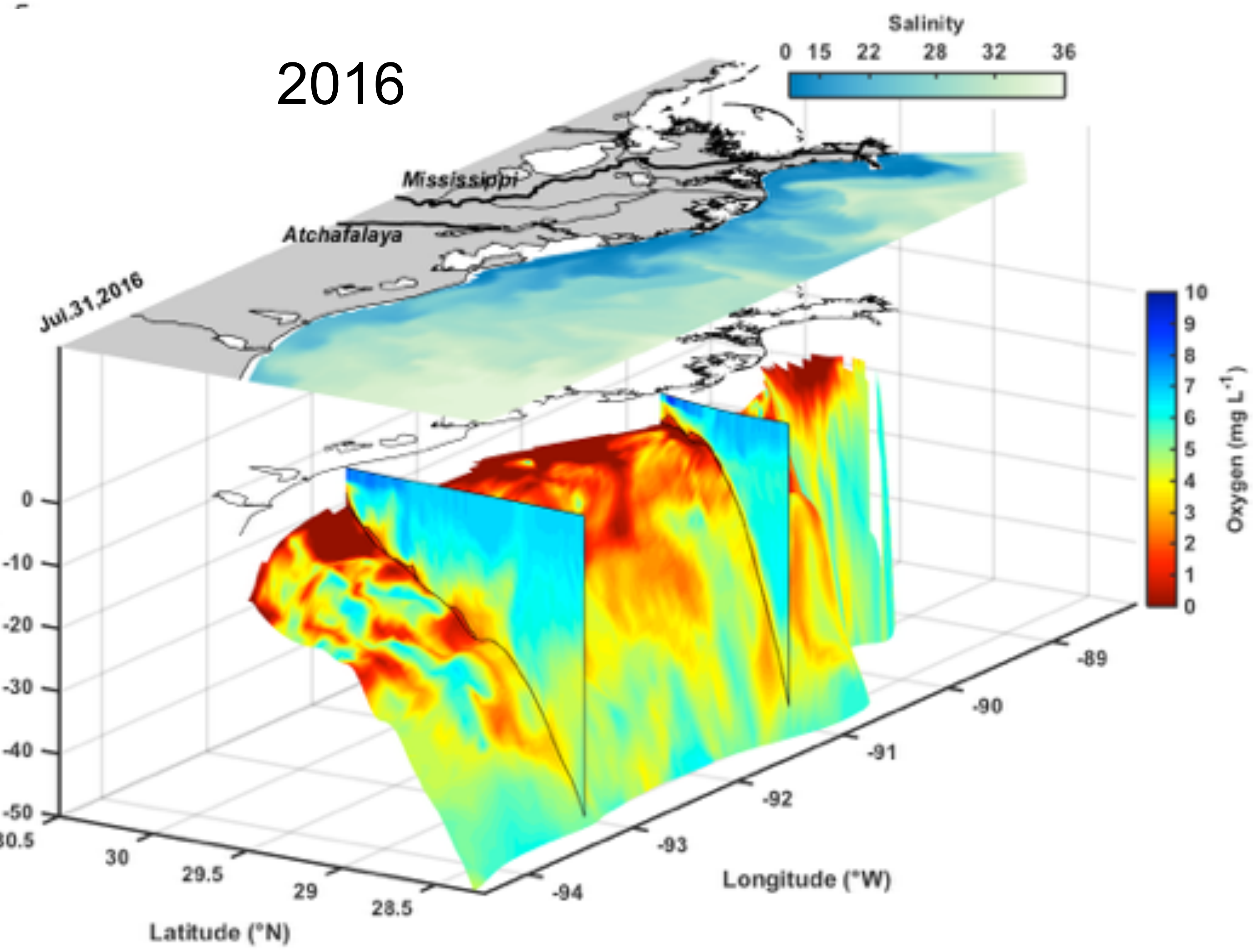
In 2016 both are closer to average in the summer.

Distribution of hypoxic area in 2015 and 2016 at the time of the hypoxia monitoring cruise (both from ROMS) – 3D view

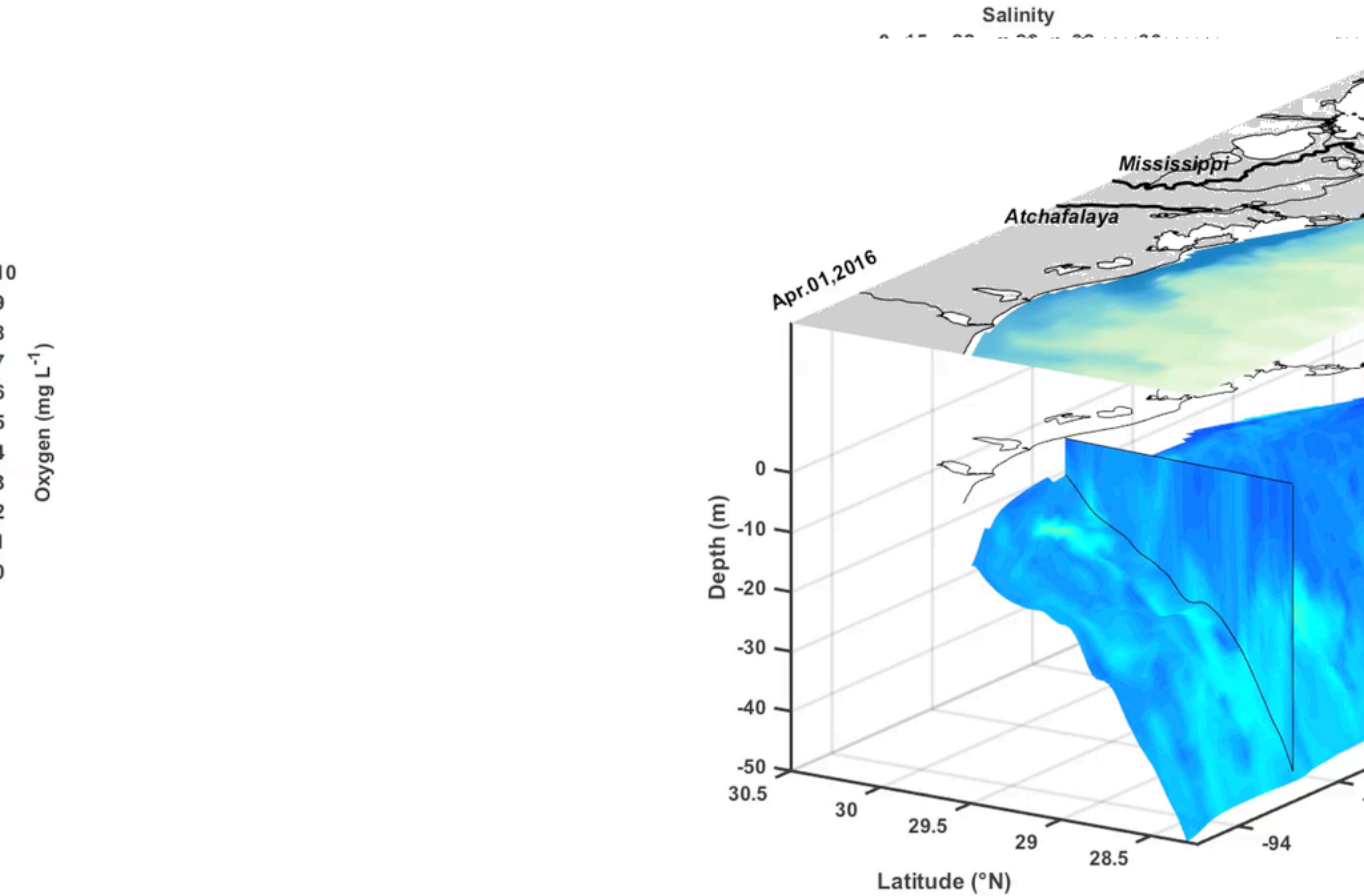
2015



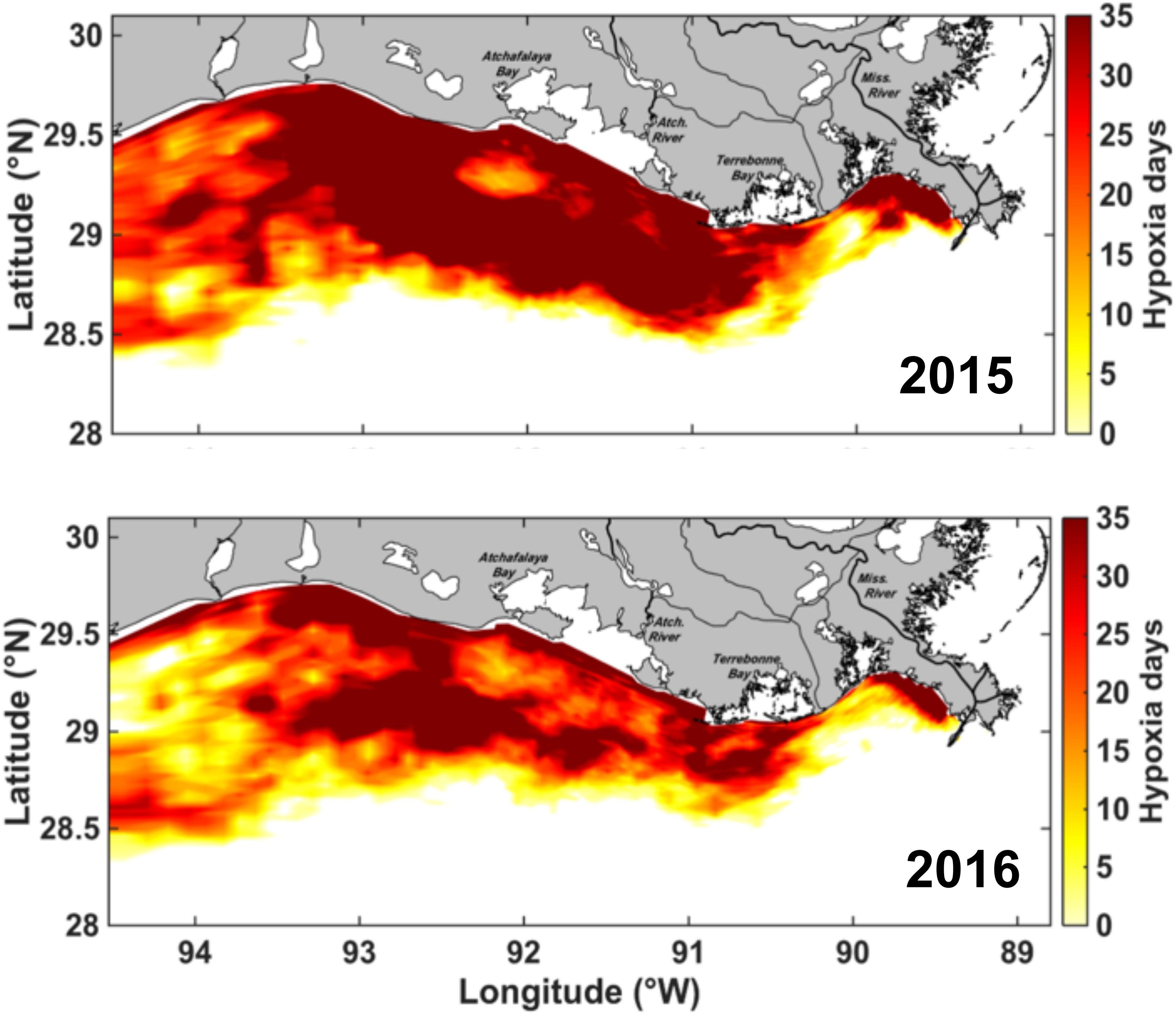
2016



Distribution of hypoxic area 2016 from ROMS – 3D animation



Cumulative exposure to hypoxia (ROMS)



Area estimate includes all locations that experienced hypoxia for at least 1 day.

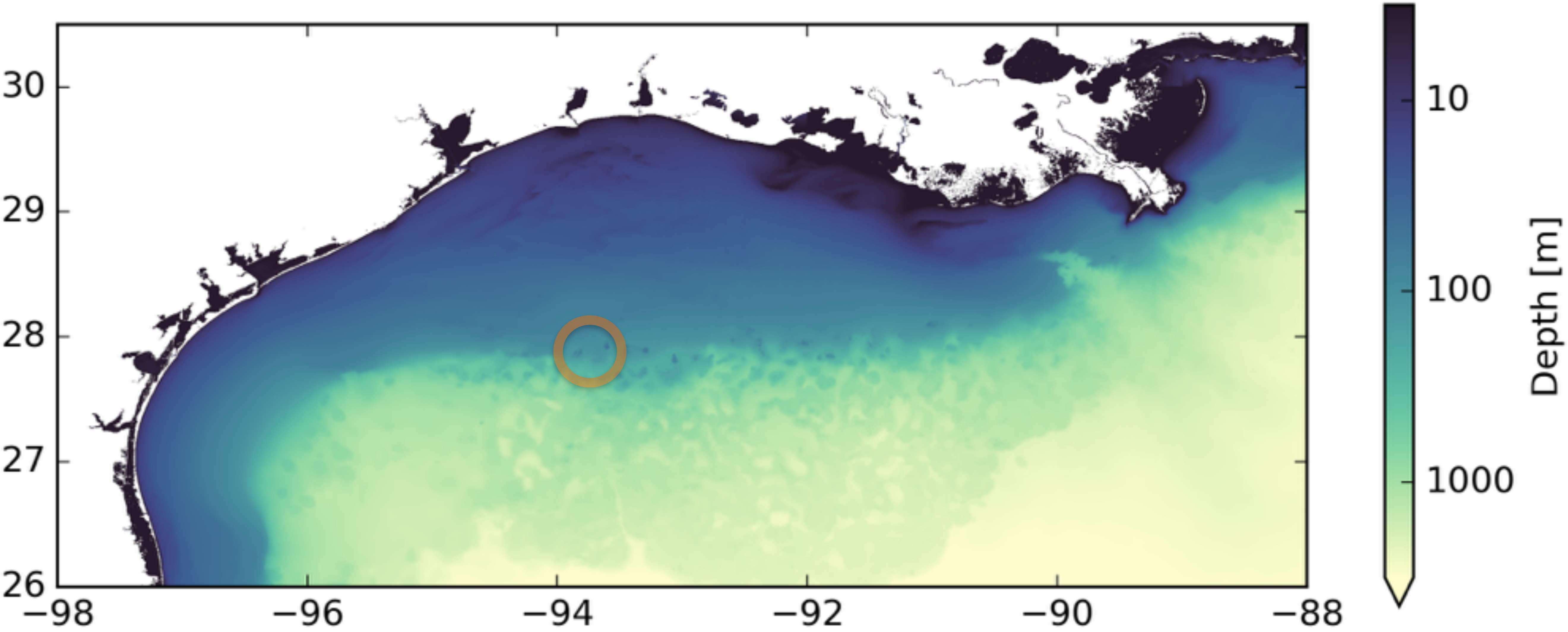
Summary

- **3D time-variable models are essential tools to support HTF science needs and provided information that could not be obtained otherwise**
- **Simulations to date for 2016 align well with limited observations and predictions based upon Spring nutrient loads**
- **Simulations allow for estimation of total bottom area exposed to hypoxia in a season which is about 3X maximum at any single point in time**
- **Climate change will challenge our efforts on hypoxia**
- **Ocean acidification will likely intensify in this region due to linkage with nutrient pollution and hypoxia – another compelling reason to reduce nutrient inputs**
- **Robust monitoring is critical to ensure validity of models and for almost all other HTF science needs**

The Flower Garden Banks National Marine Sanctuary Mysterious Mass Mortality event July 2016

Rob Hetland

The northern Gulf of Mexico



FLOWER GARDEN BANKS
NATIONAL MARINE SANCTUARY

Contact Information
1200 Briarcrest Drive
Suite 4000
Bryan, TX 77802
(979) 846-5942
flowergarden.noaa.gov

Habitats
- Coral reefs
- Algal-sponge communities
- Brine seep
- Sand flats
- Pelagic, open ocean
- Deepwater coral communities

Key Species
- Star and Brain coral
- Grouper
- Manta ray
- Hammerhead shark
- Loggerhead sea turtle
- Whale shark

Topography & Bathymetry
550 0 550
Contours in meters

Map Key
National Marine Sanctuary
Marine Sanctuary Office
Other Park
NWR National Wildlife Refuge

FLOWER GARDEN BANKS
NATIONAL MARINE SANCTUARY

Location
Roughly 110 miles south of the Texas-Louisiana border

Protected Area
56-square miles

Designation
January 1992
October 1996, Stetson Bank

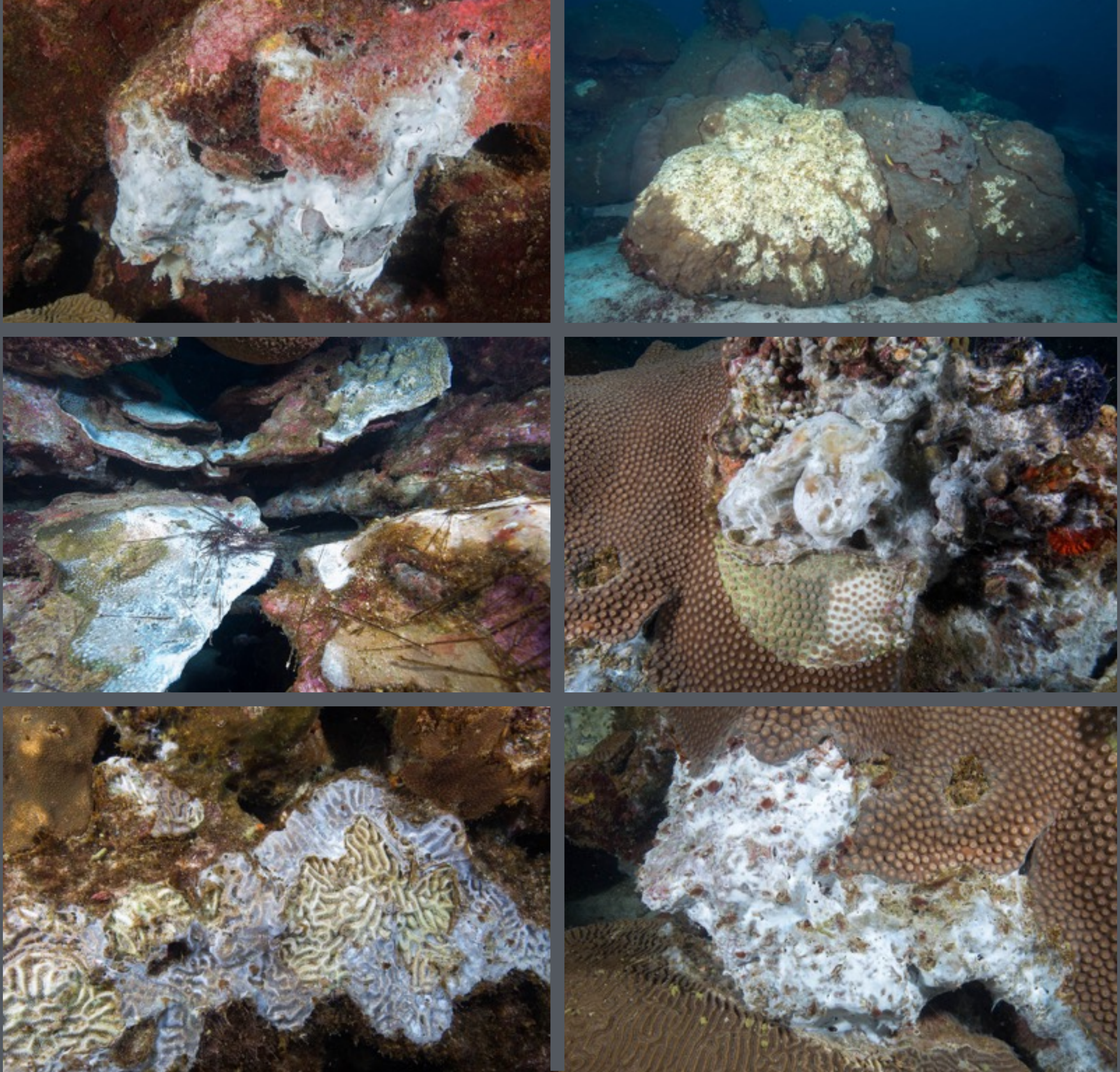
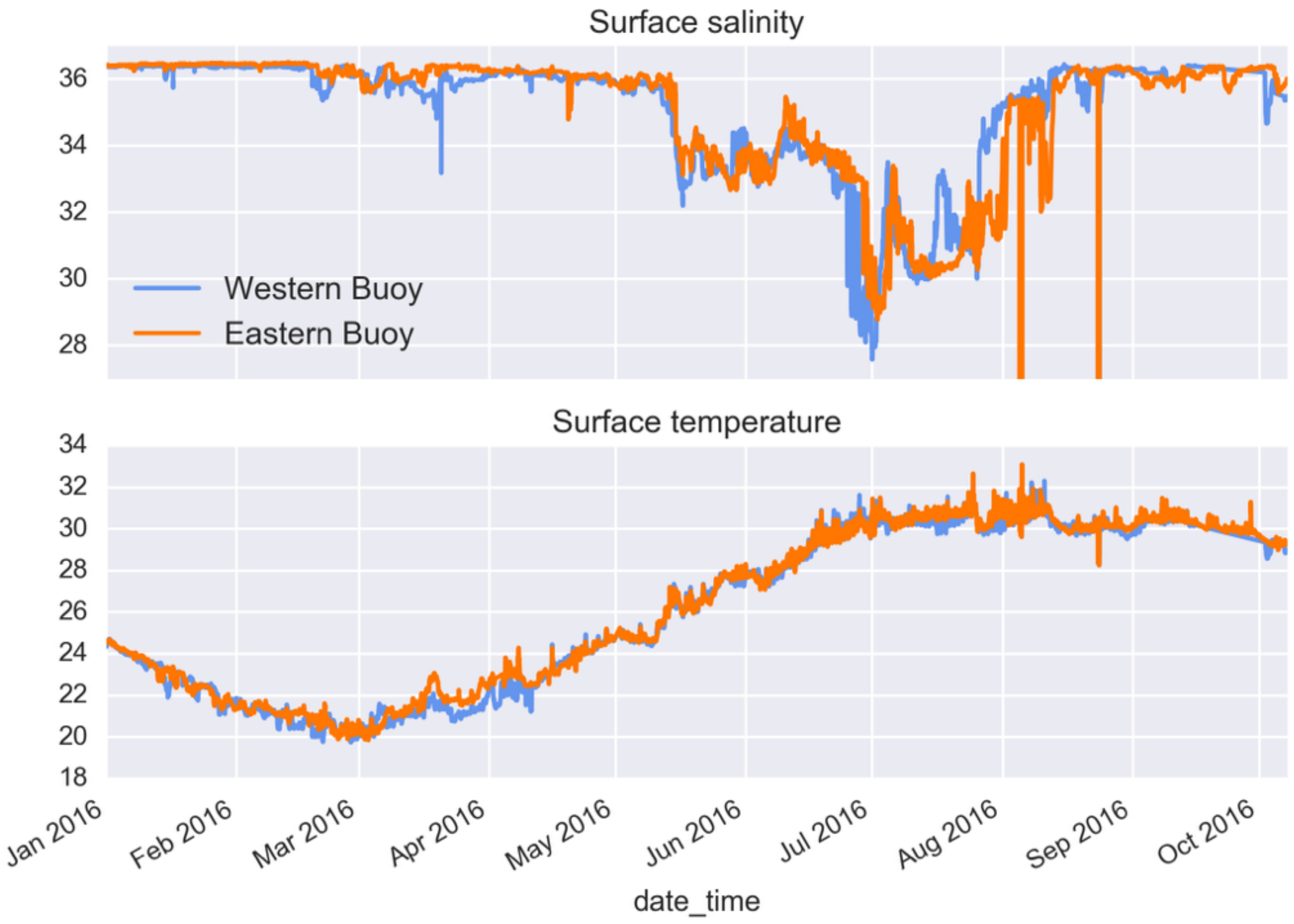


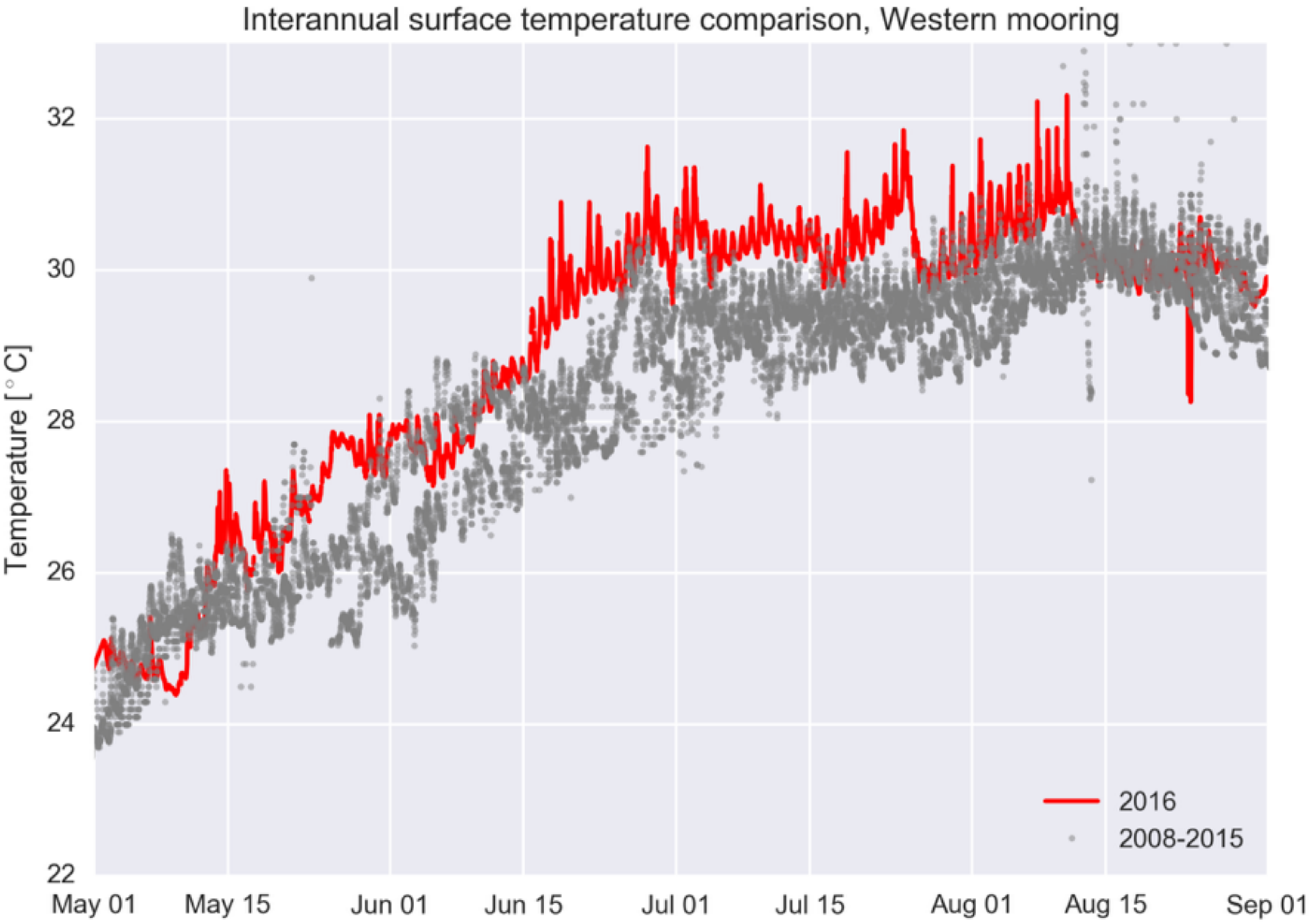
Photo credits: FGBNMS/G.P. Schmahl

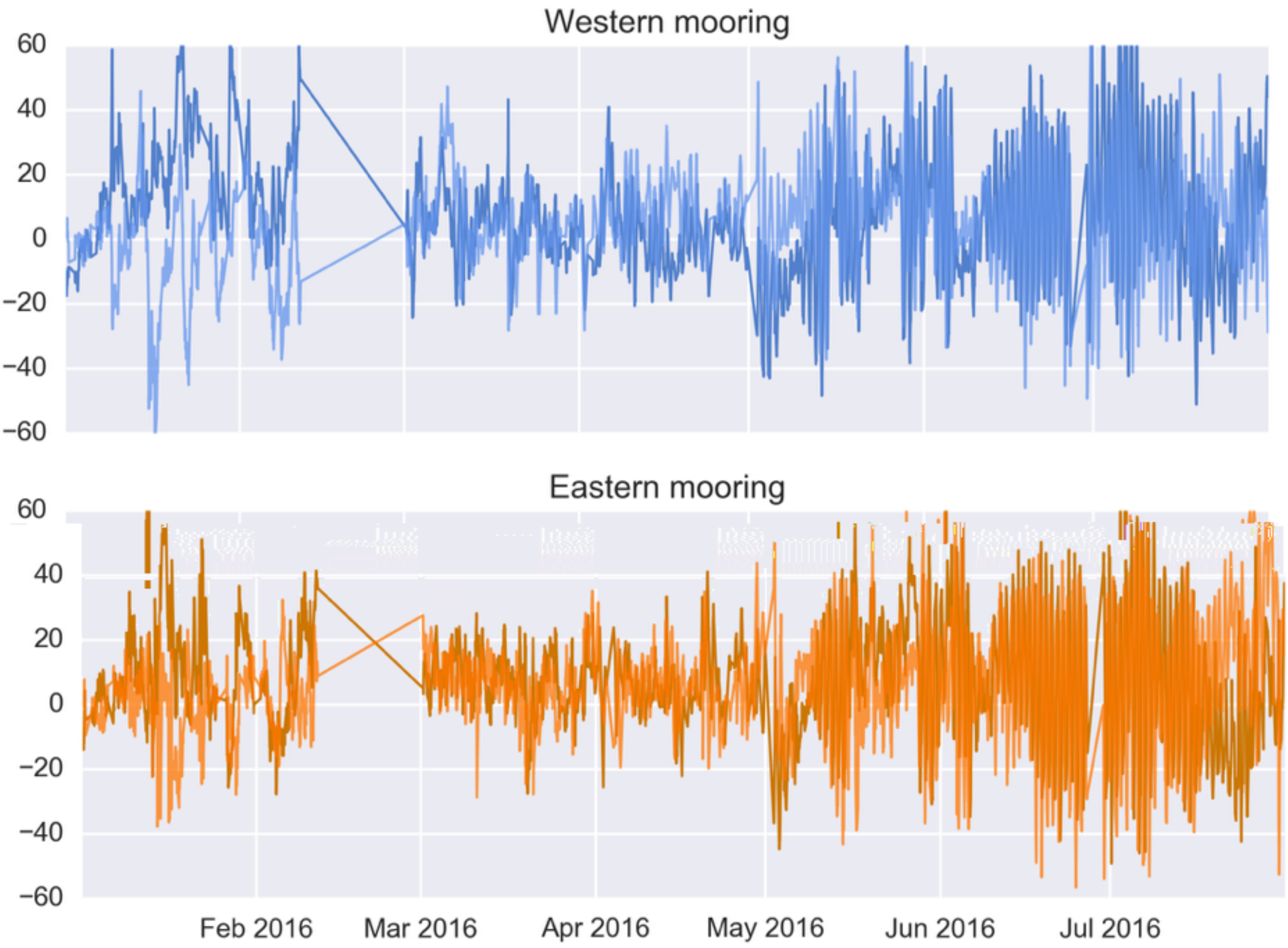
Photo credits: FGBNMS/G.P. Schmahl

Observations

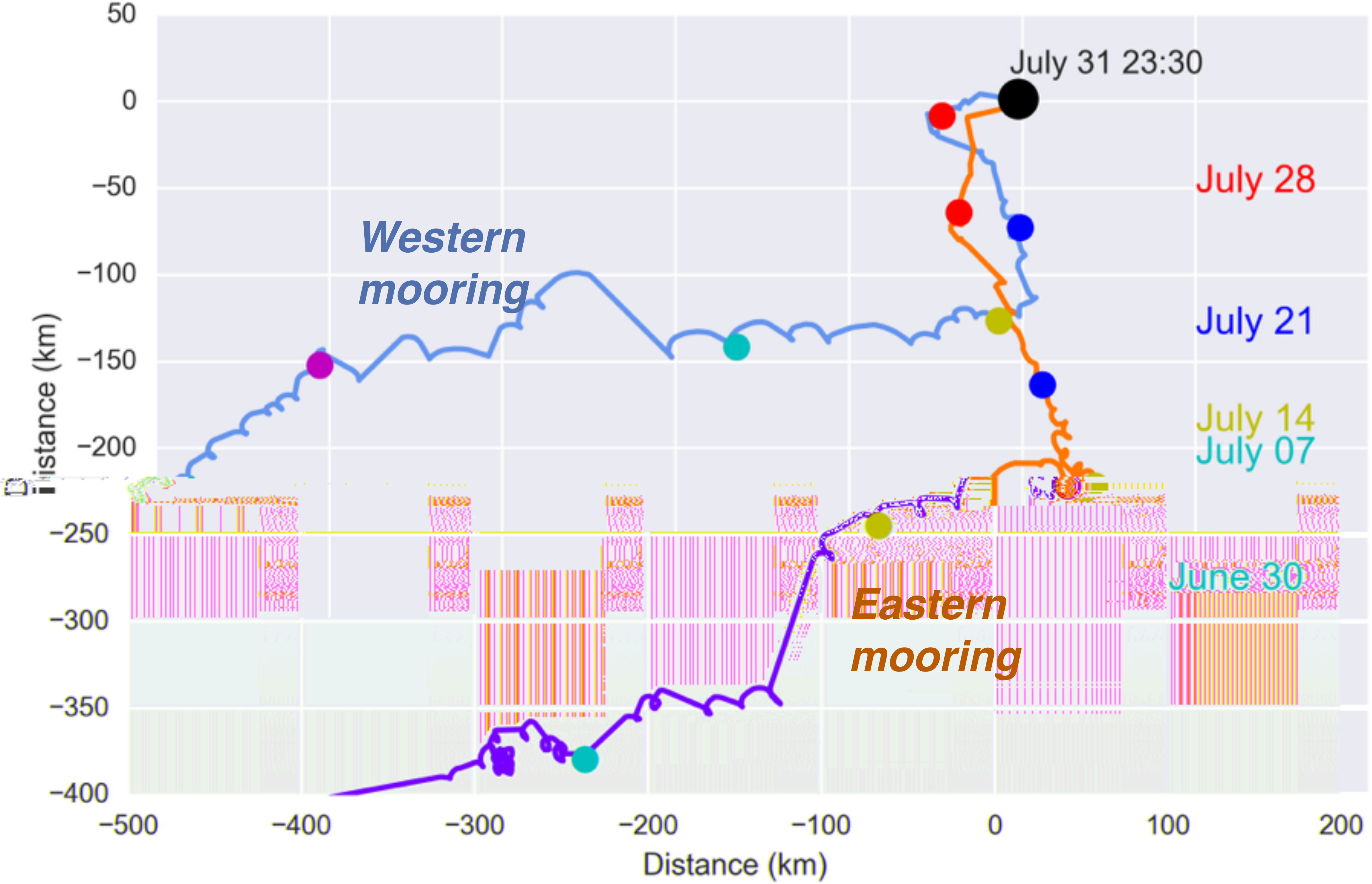
TABS Buoys ’N’ & ‘V’


Surface salinity
36
34
32
30
28
Western Buoy
Eastern Buoy
Surface temperature
34
32
30
28
26
24
22
20
18
Jan 2016
Feb 2016
Mar 2016
Apr 2016
May 2016
Jun 2016
Jul 2016
Aug 2016
Sep 2016
Oct 2016
date_time


Interannual surface temperature comparison, Western mooring
Temperature [$^\circ$C]
32
30
28
26
24
22
May 01
May 15
Jun 01
Jun 15
Jul 01
Jul 15
Aug 01
Aug 15
Sep 01
2016
2008-2015


Western mooring
60
40
20
0
−20
−40
−60
Eastern mooring
60
40
20
0
−20
−40
−60
Feb 2016
Mar 2016
Apr 2016
May 2016
Jun 2016
Jul 2016

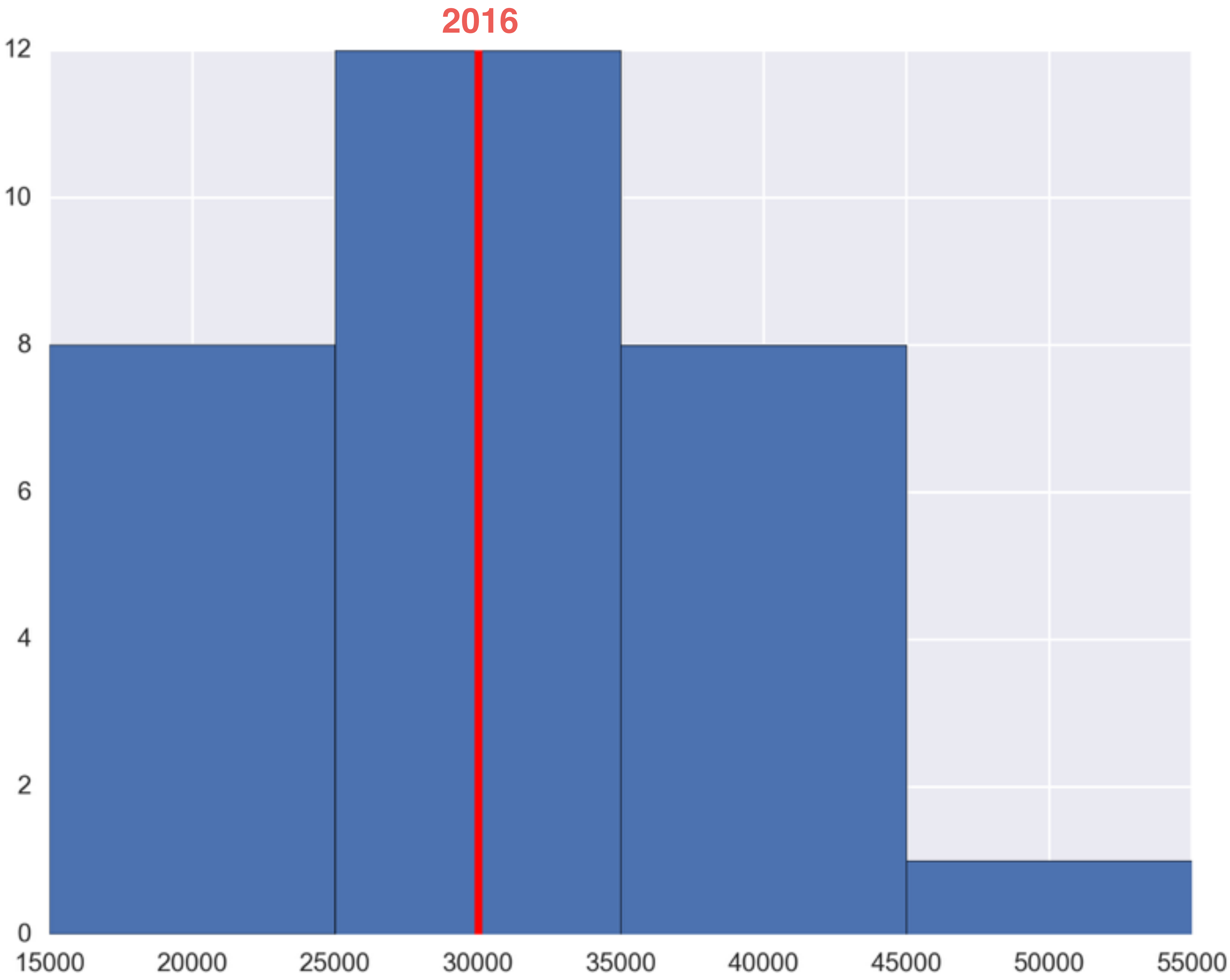
Progressive Vector Diagram



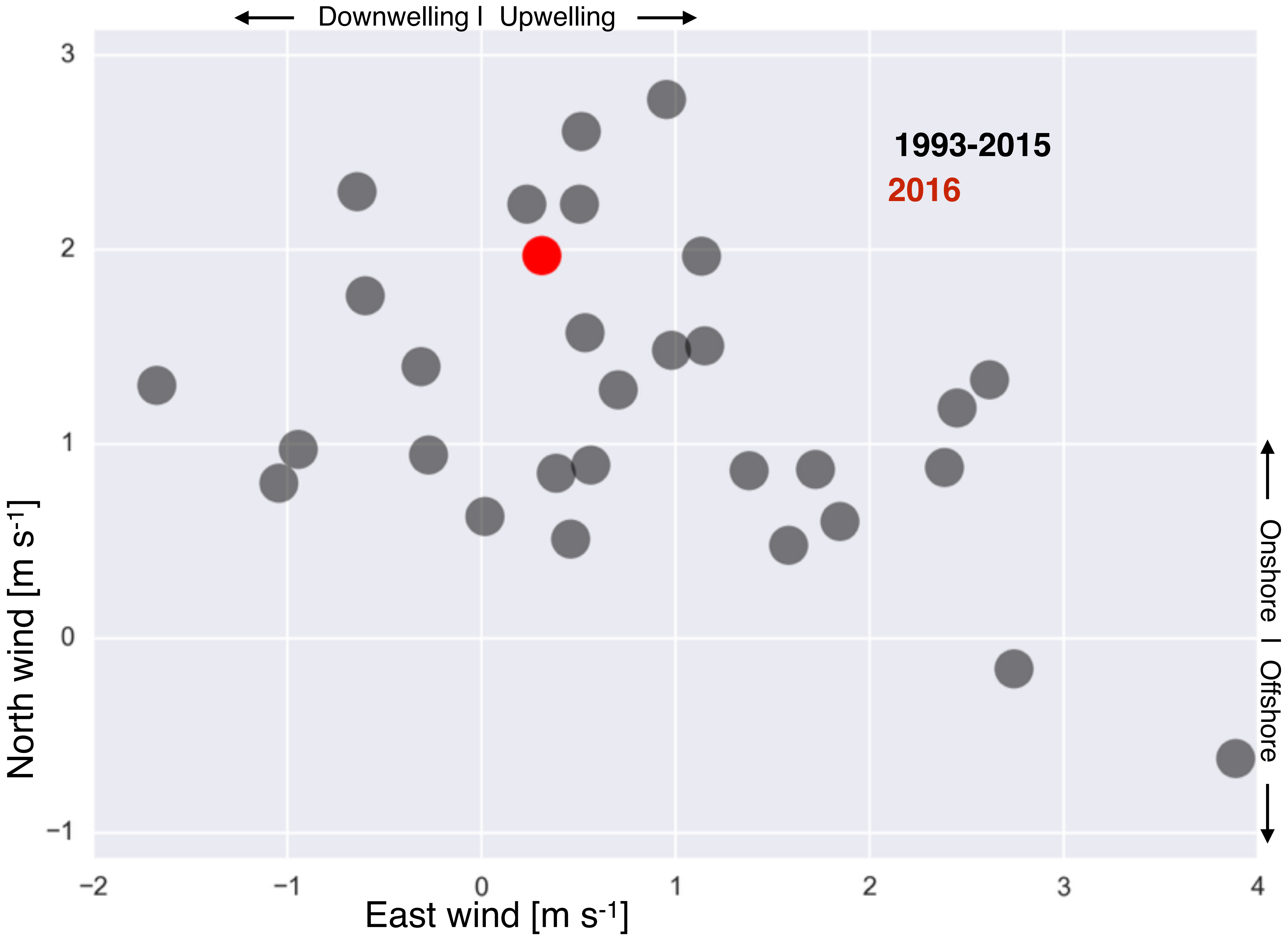
Forcing

Spring river discharge
Summer winds

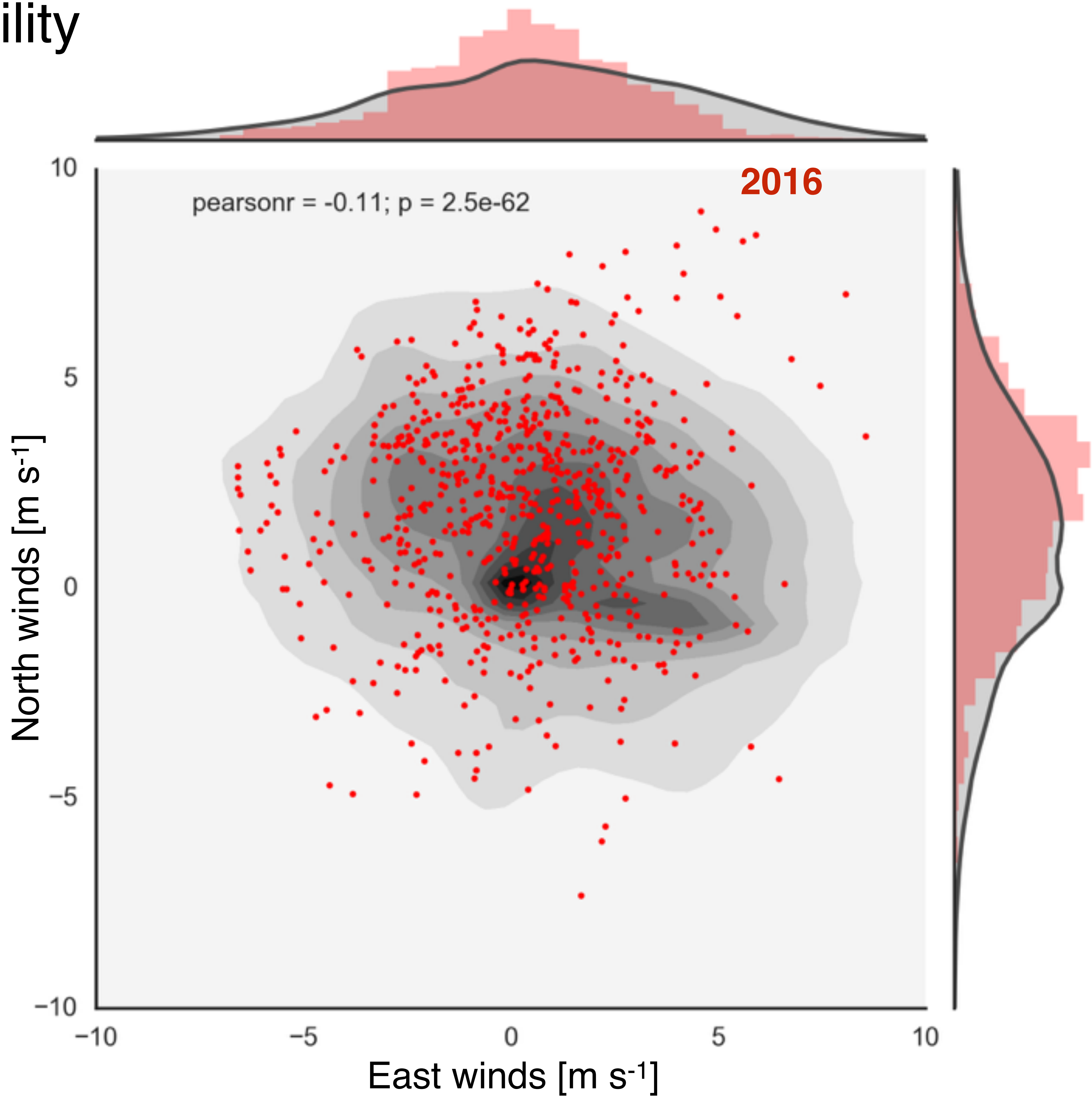
Histogram of May discharge since 1985



Mean July winds

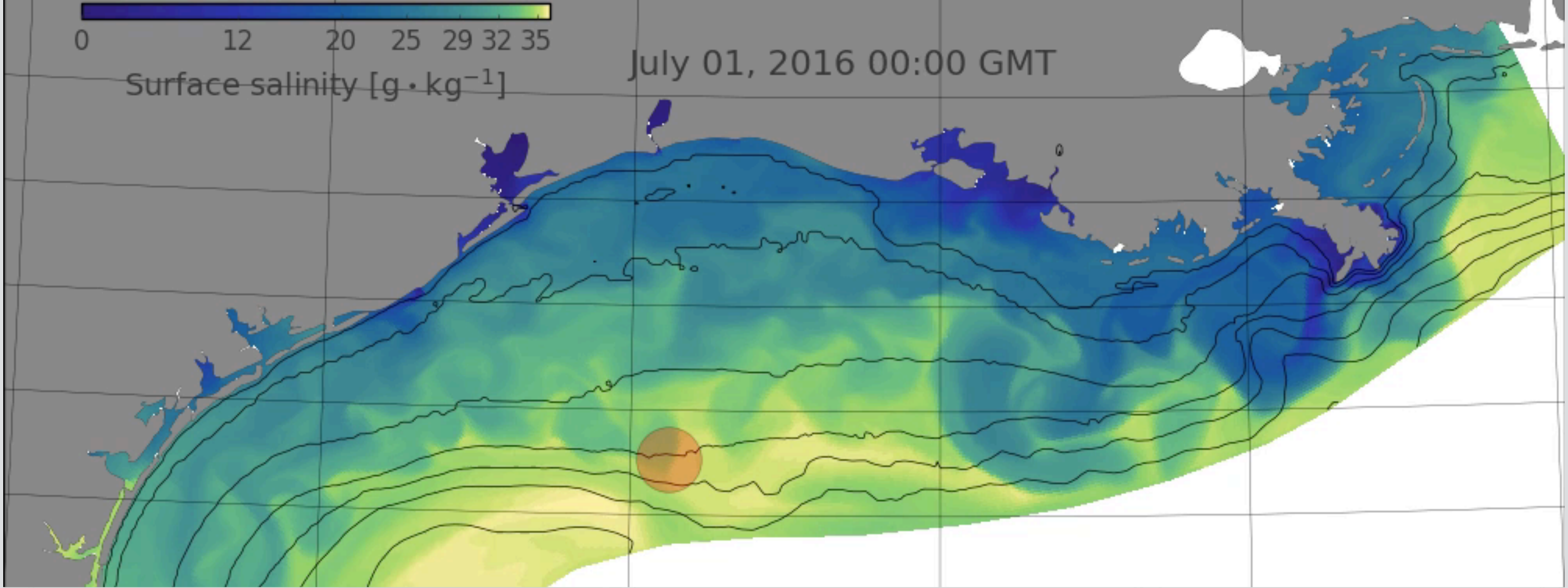


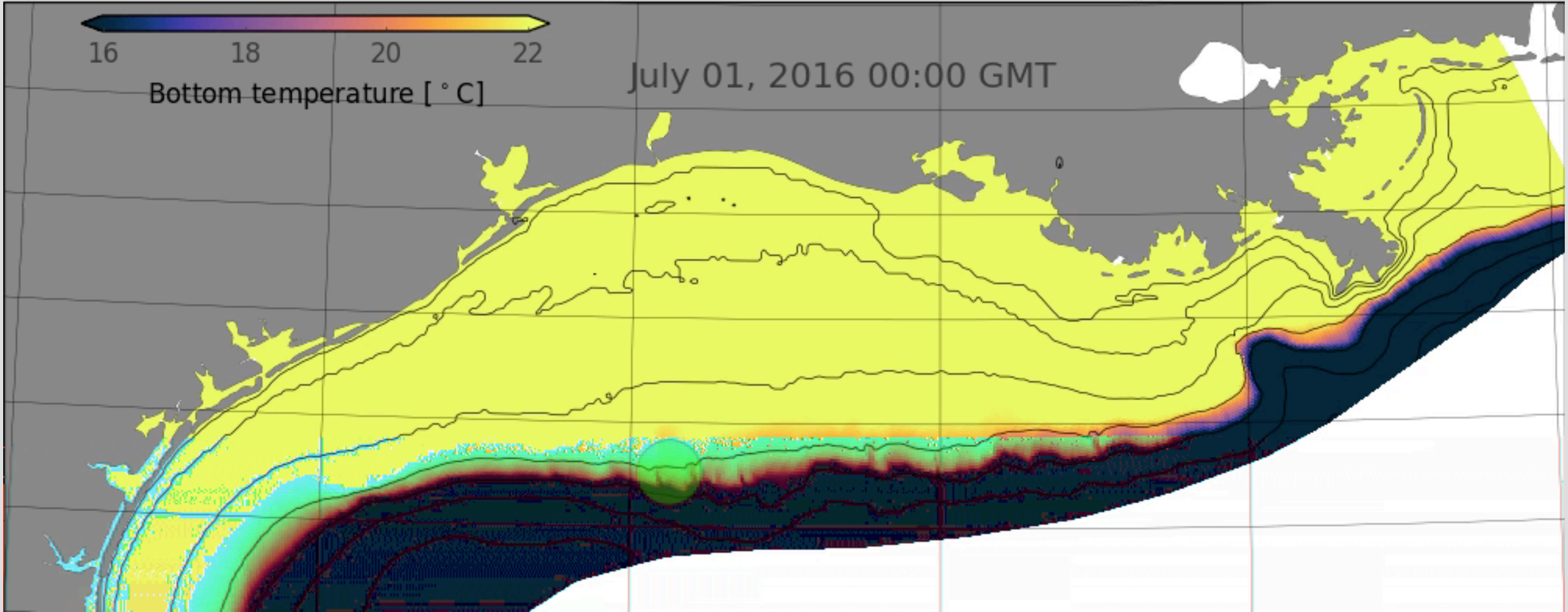
Wind variability in July

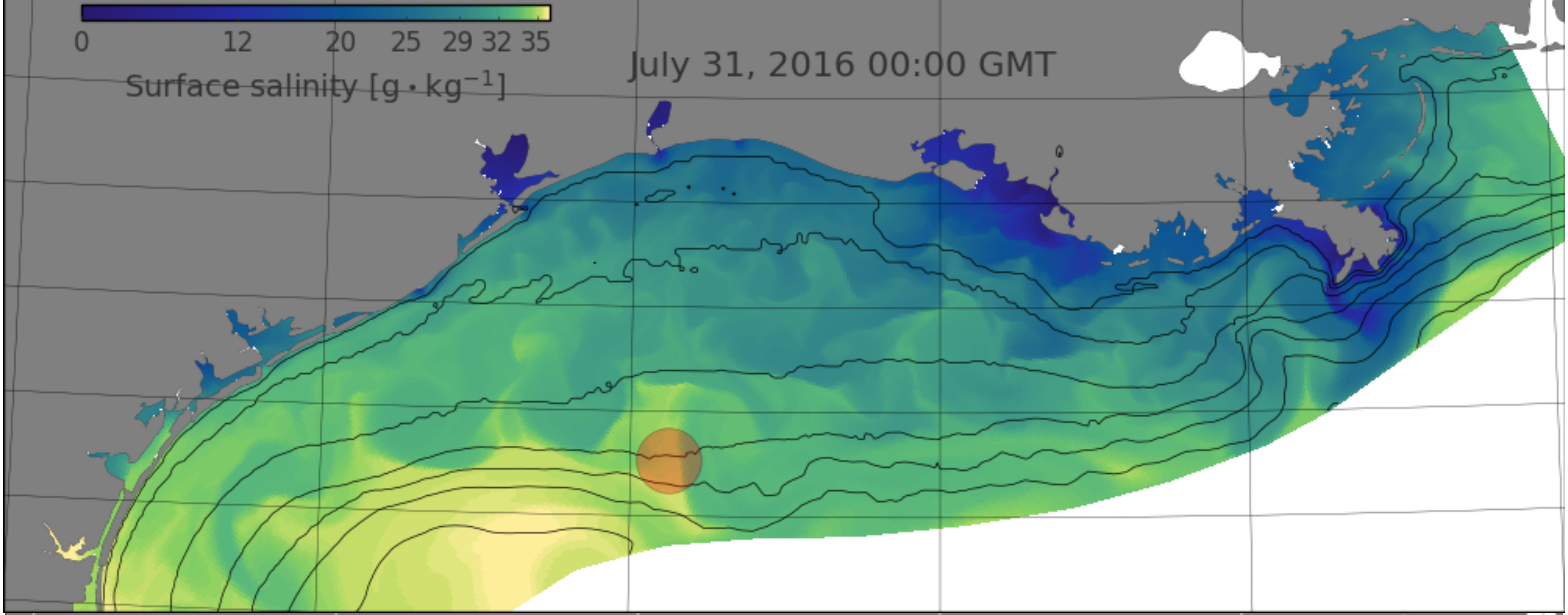


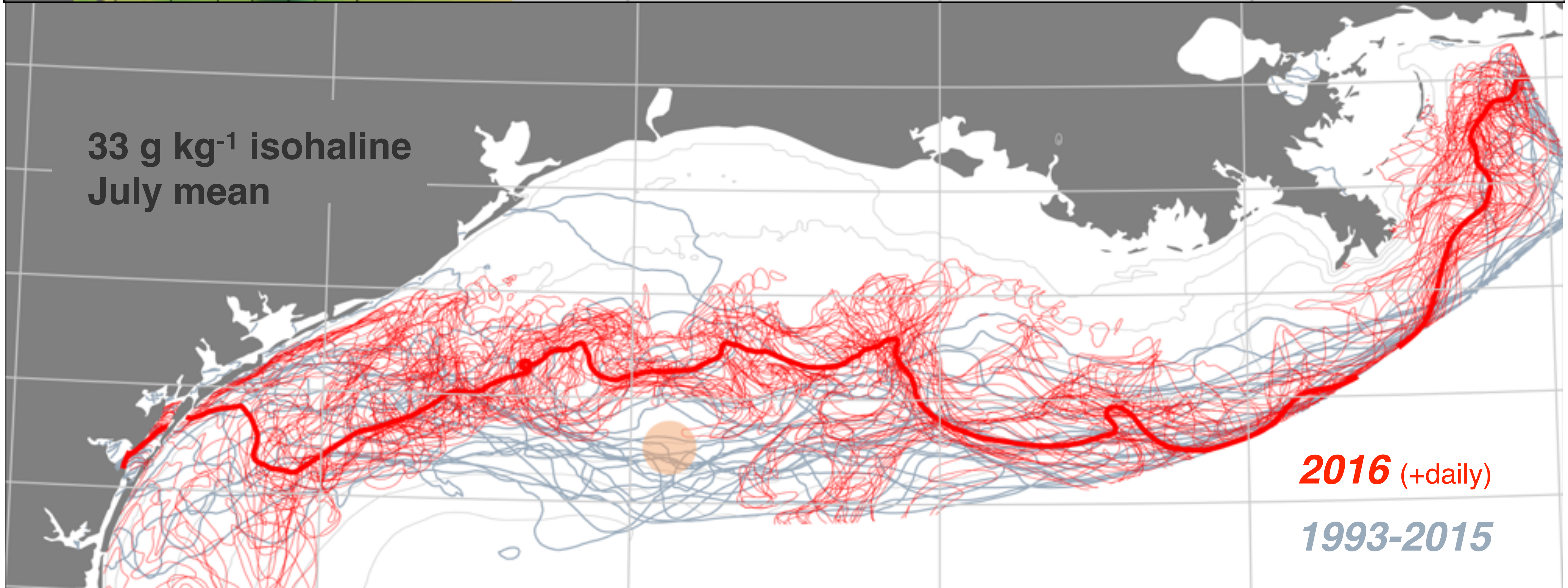
Long term trends

TXLA hydrodynamic model

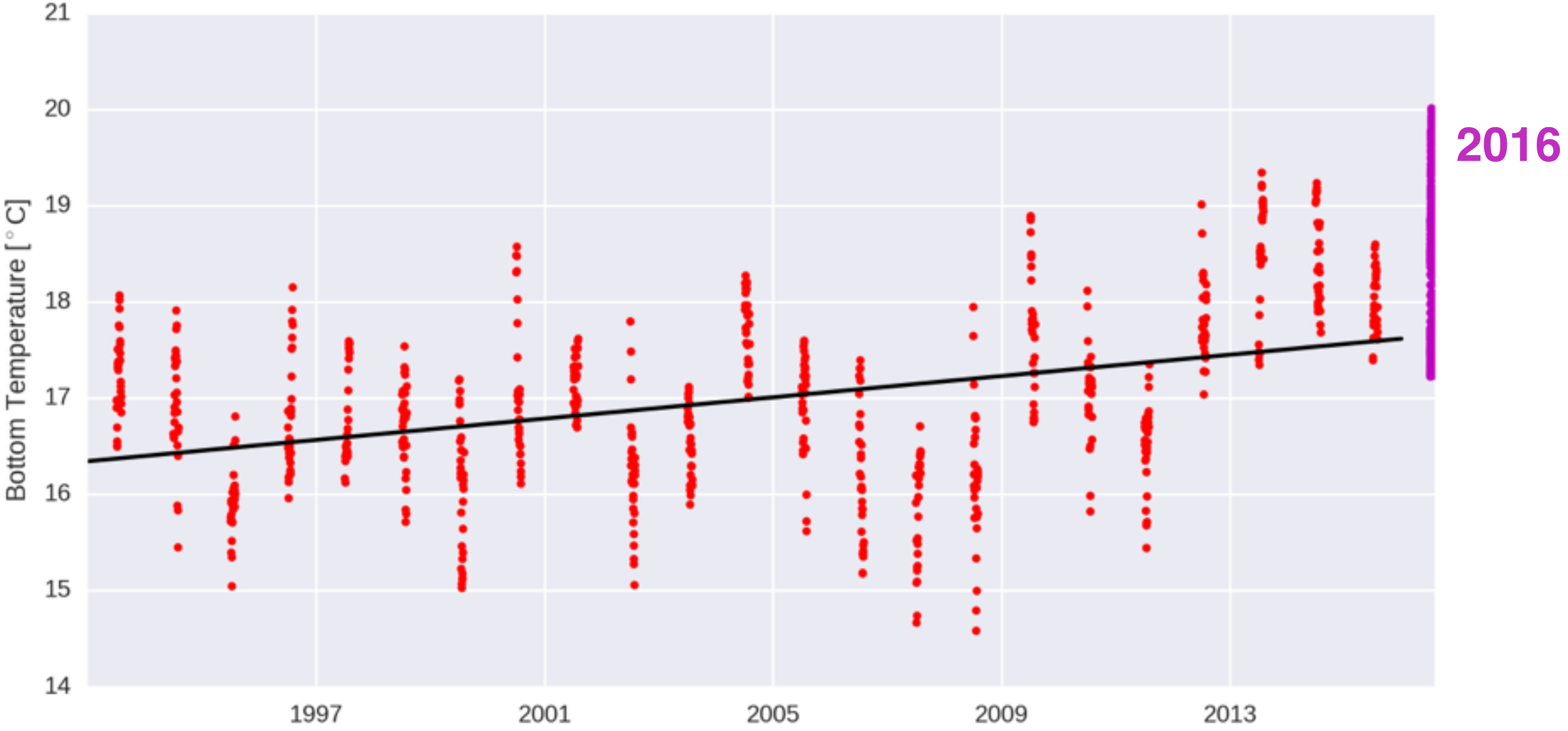

0
12
20
25
29
32
35
Surface salinity [g · kg⁻¹]
July 01, 2016 00:00 GMT


16
18
20
22
Bottom temperature [° C]
July 01, 2016 00:00 GMT


0
12
20
25
29
32
35
Surface salinity [g · kg^{-1}]
July 31, 2016 00:00 GMT


33 g kg^{-1} isohaline
July mean
2016 (+daily)
1993-2015

Bottom Temperature trends



So, what caused the mysterious mass mortality event?

Wind and river forcing were close to typical.

2016 was anomalously warm,
at the surface (*obs/model*) and bottom (*model*).

Bottom stratification (*model*) within historic variability.

Observations and model both suggest small scales.

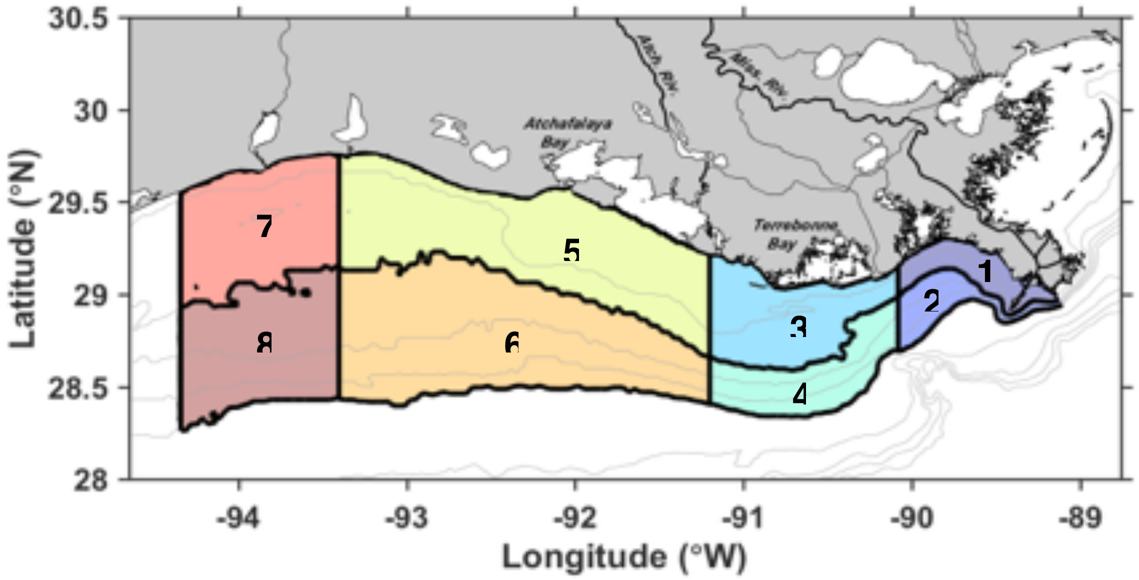
Two likely culprits:

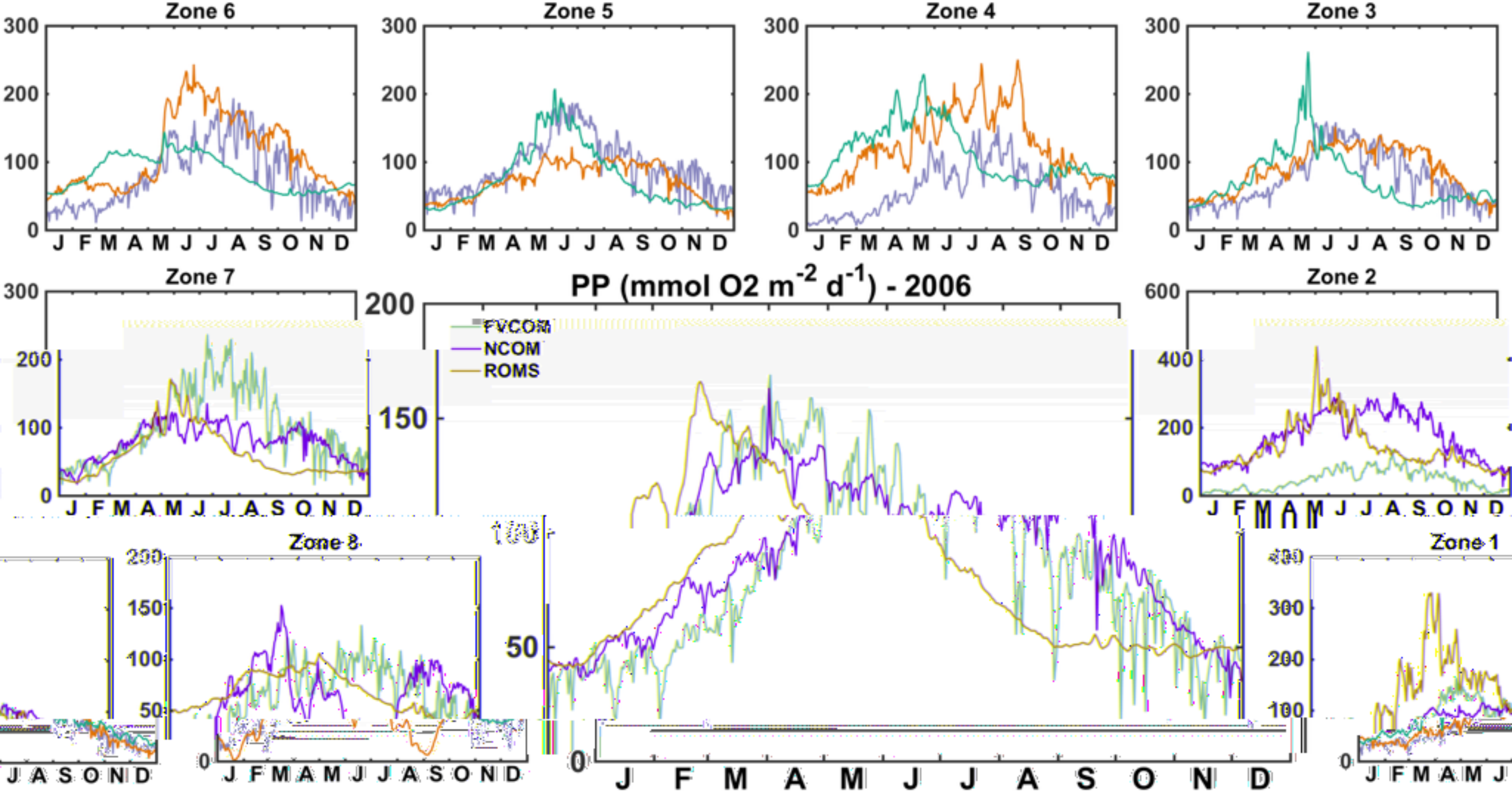
Elevated temperature (seems to be in line with trend)

A transient squirt of plume water from near-shore.

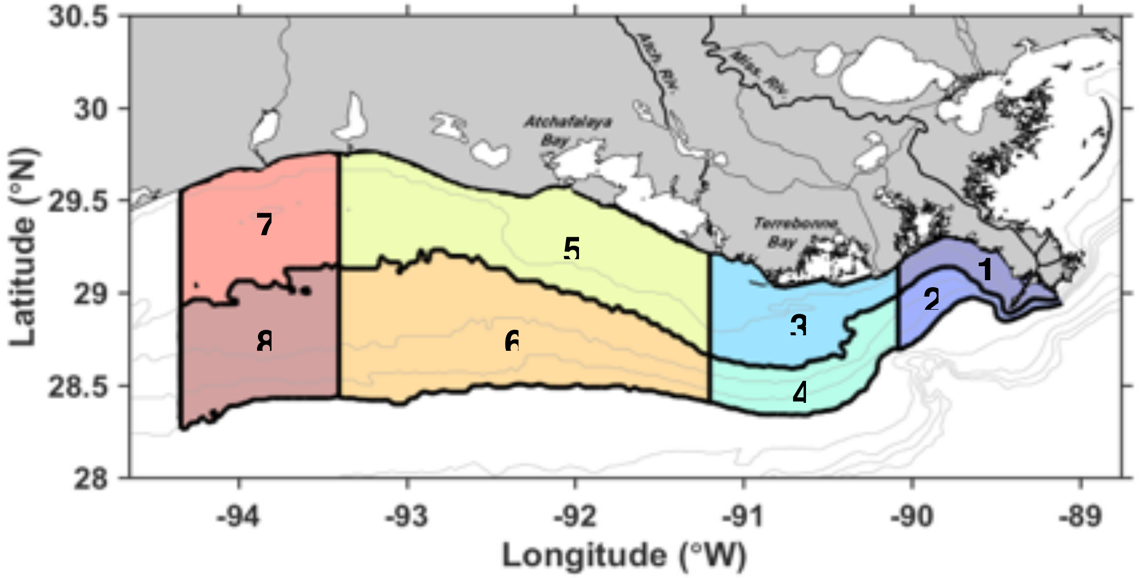
Biogeochemical model inter-comparison

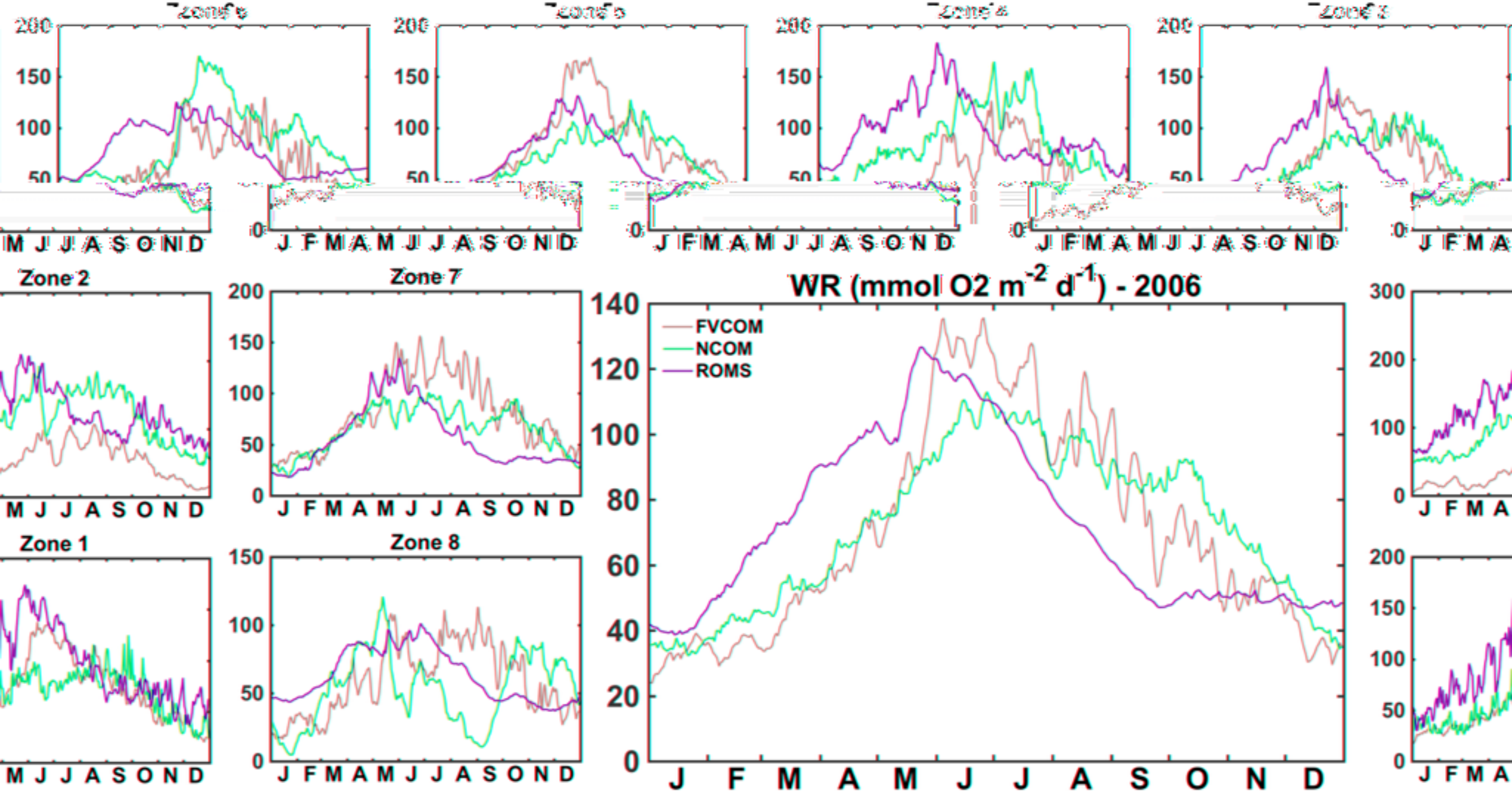
Primary Production



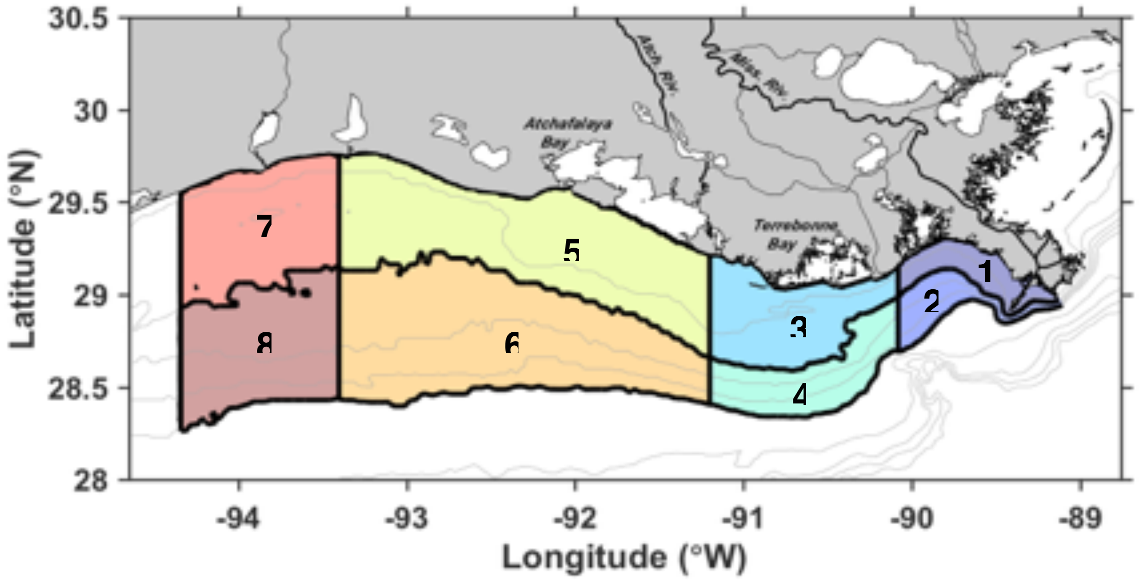


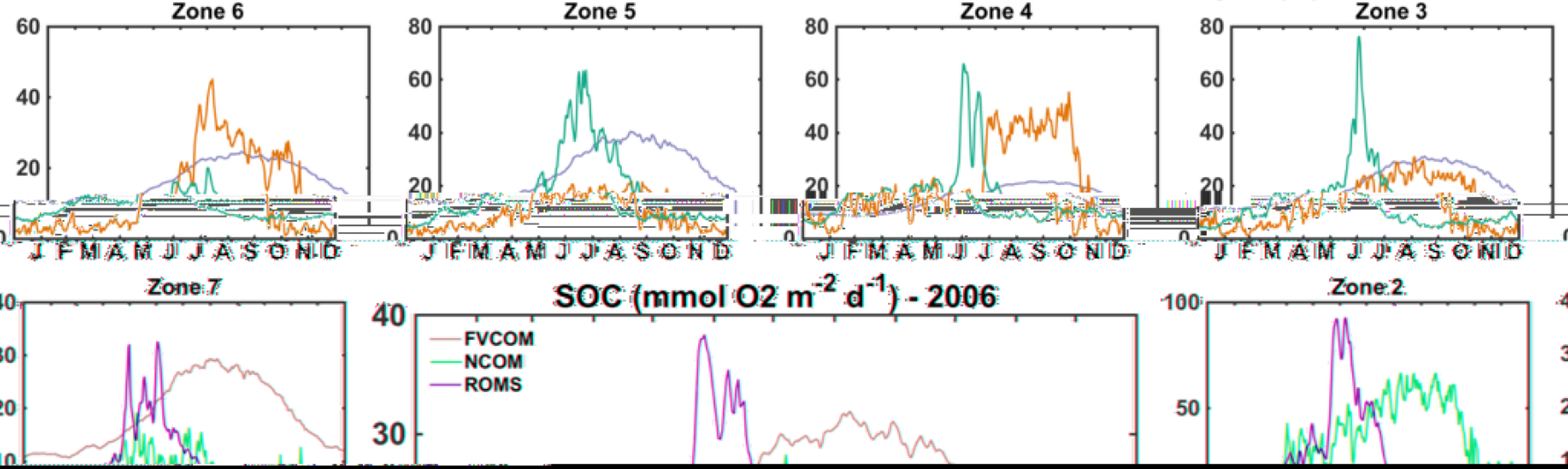
Water column respiration



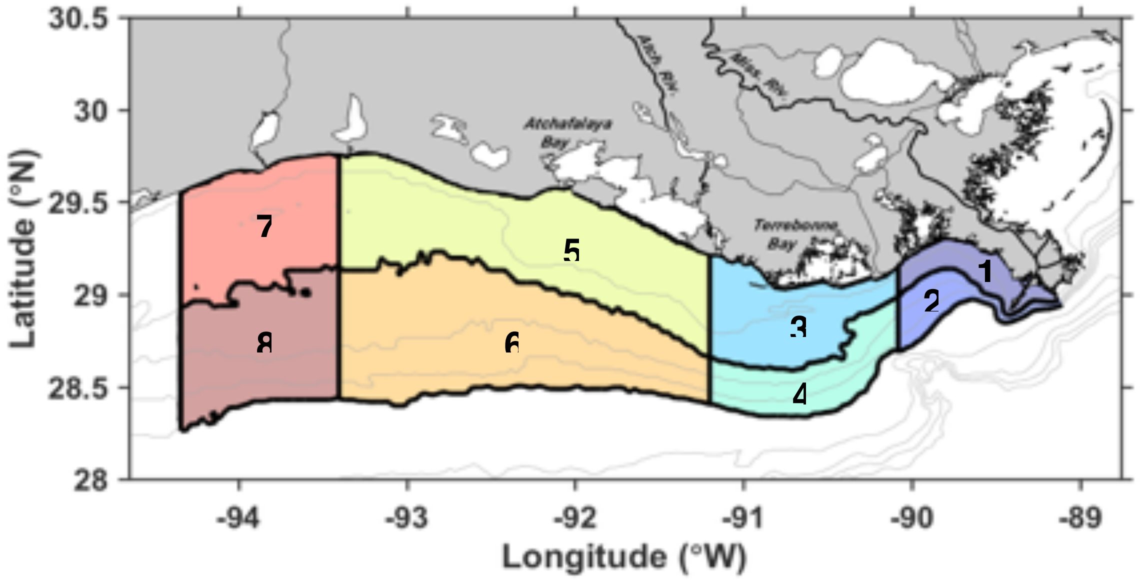


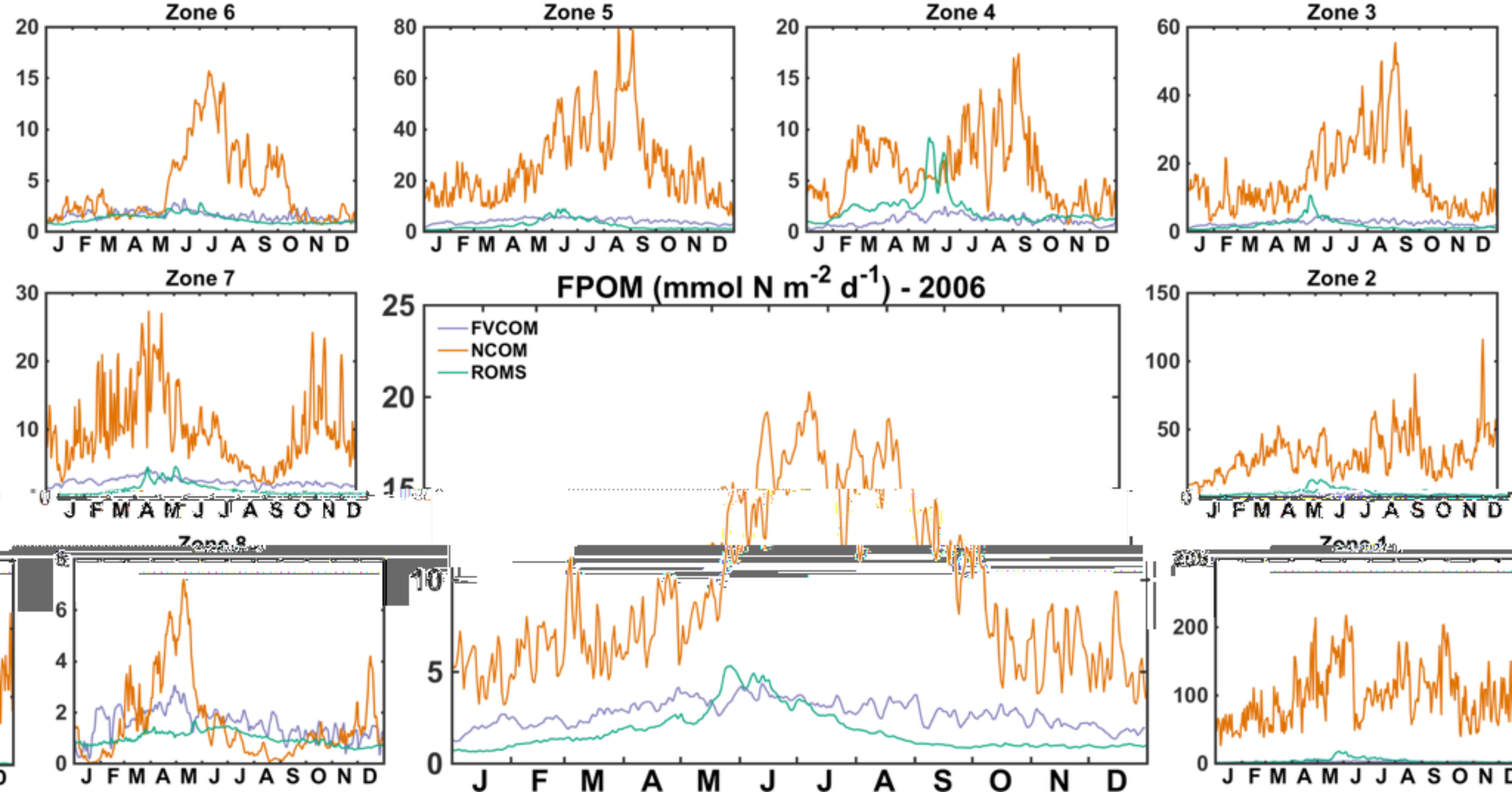
Sediment O_2 consumption



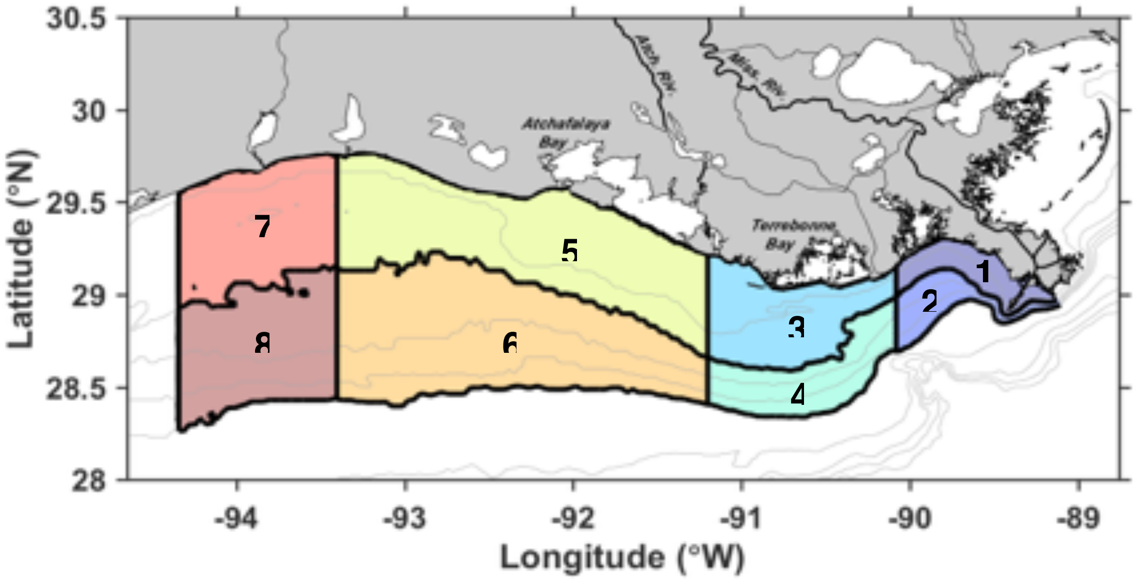


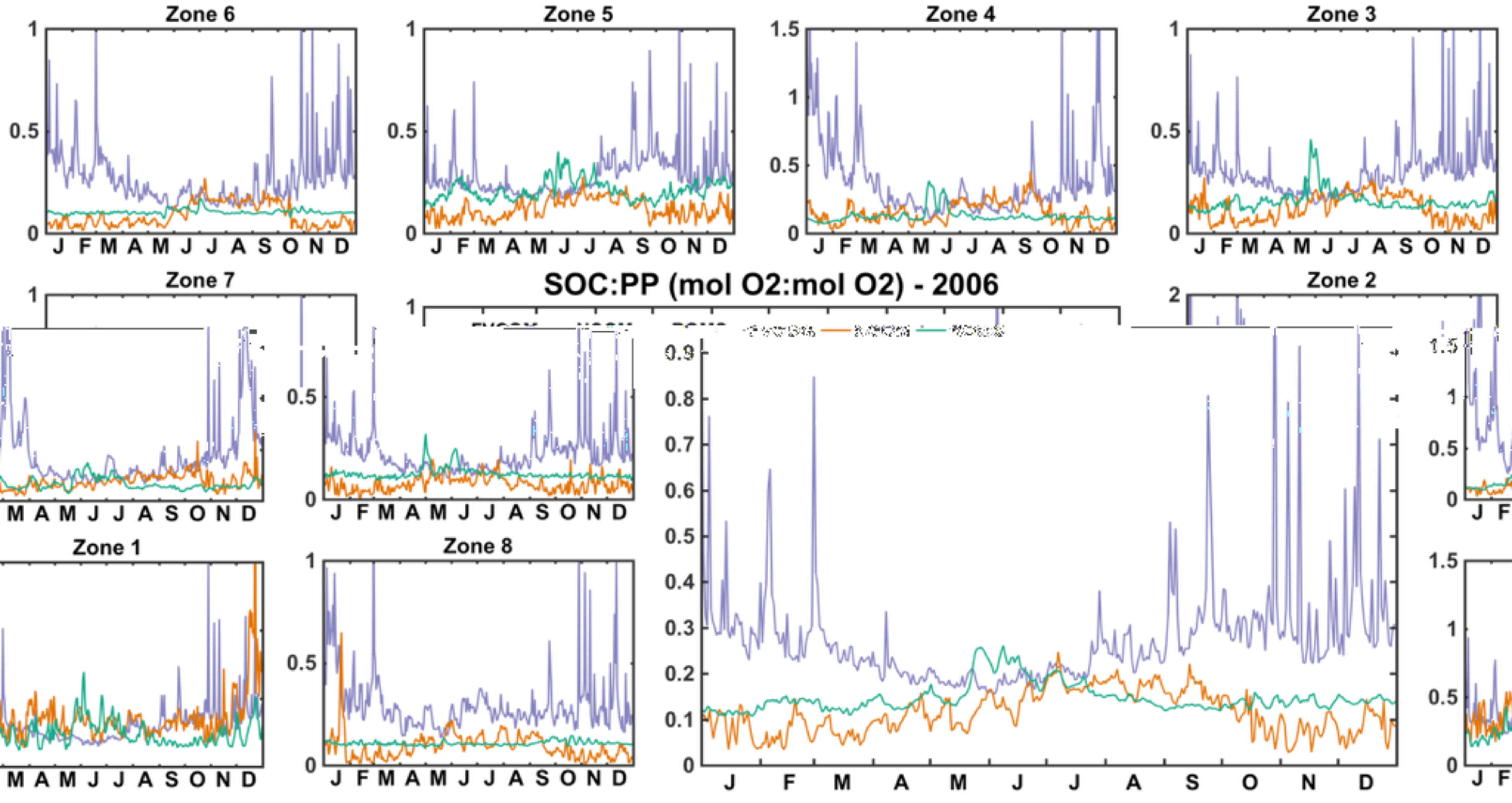
POM deposition flux





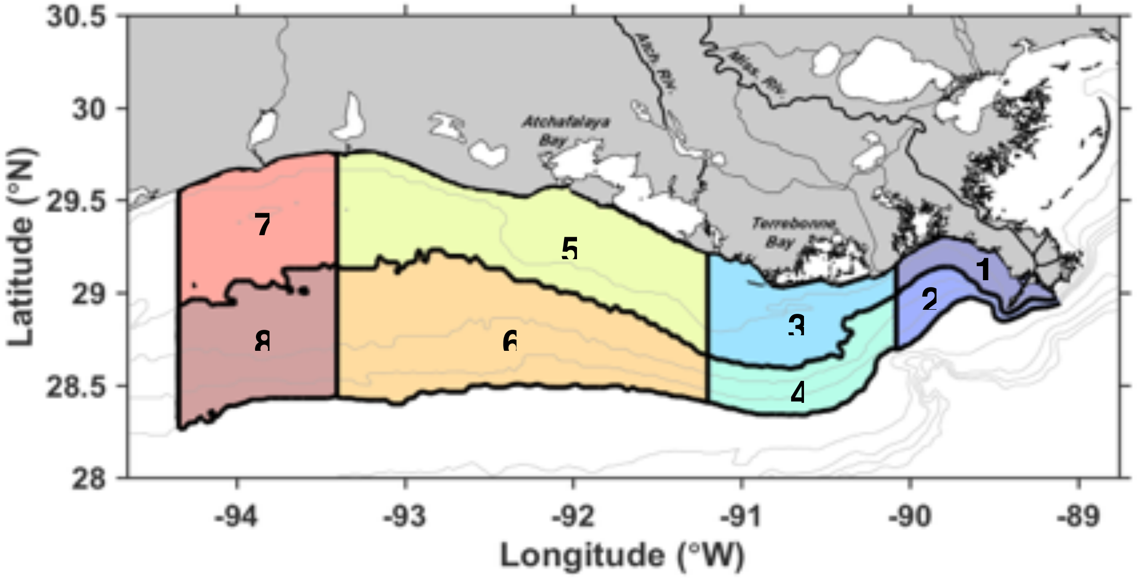
Ratio of sediment oxygen consumption to Primary Production

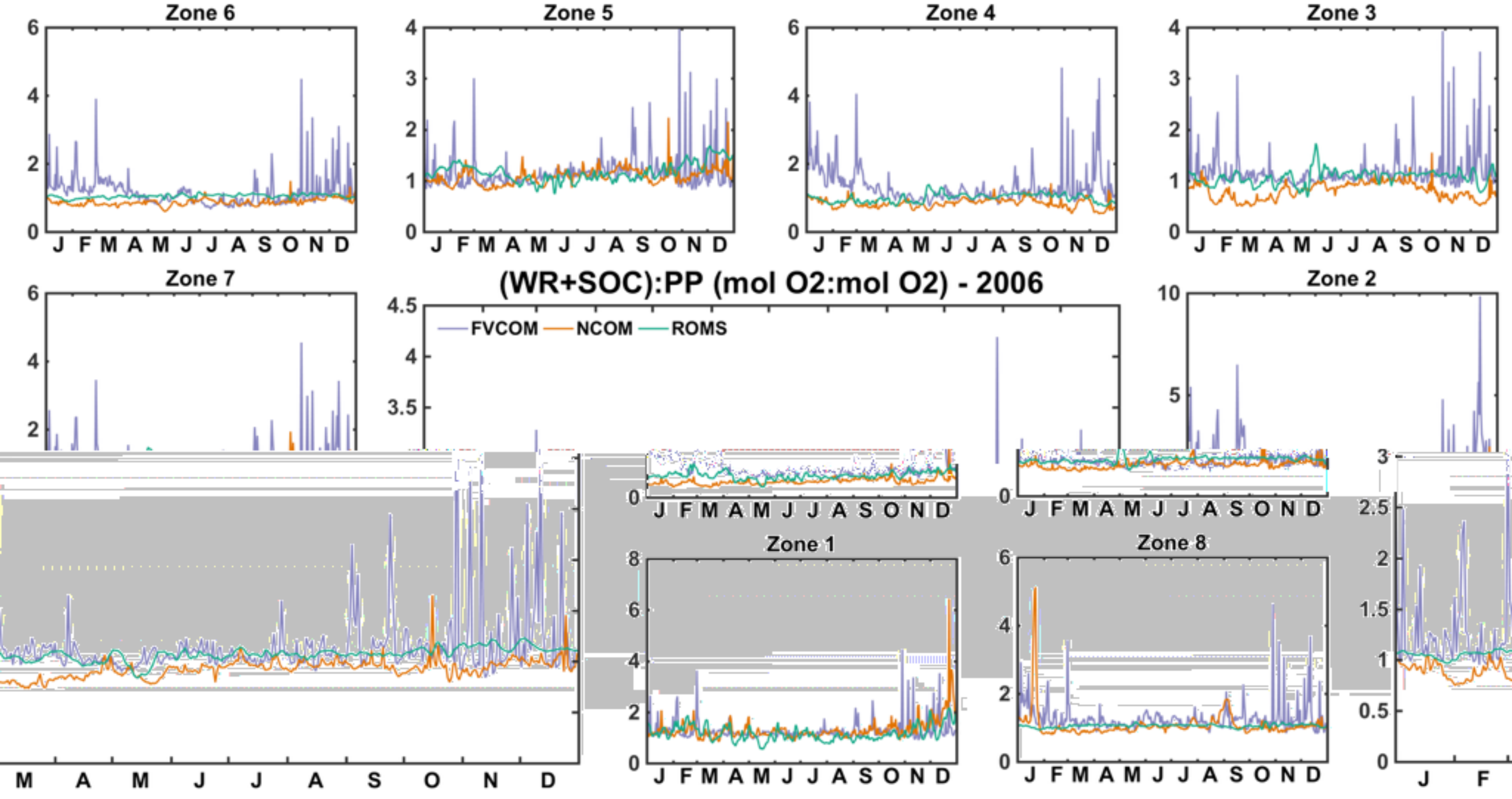




(SOC + WR) to Primary Production

This ratio should be equal to one except when significant external supply of organic matter is present (then it can be larger) or when there is buildup of biomass in the water column

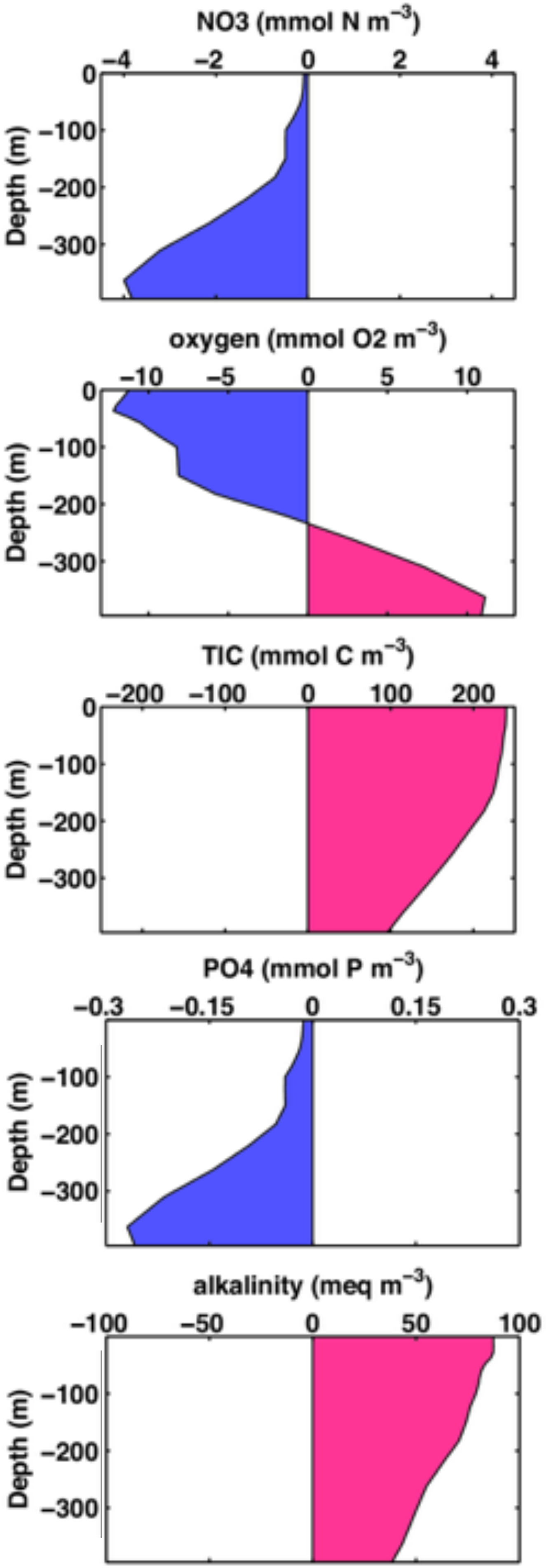




Future projection with ROMS

2100 under a “business as usual” scenario

Two simulations (**present** and **future**)



Present: 6 years with 2005-2010 river and wind forcing

Future: same as present, with the following changes:

Initial and boundary conditions

- Added (future - present) bias from MPI CMIP5 “business as usual” projection

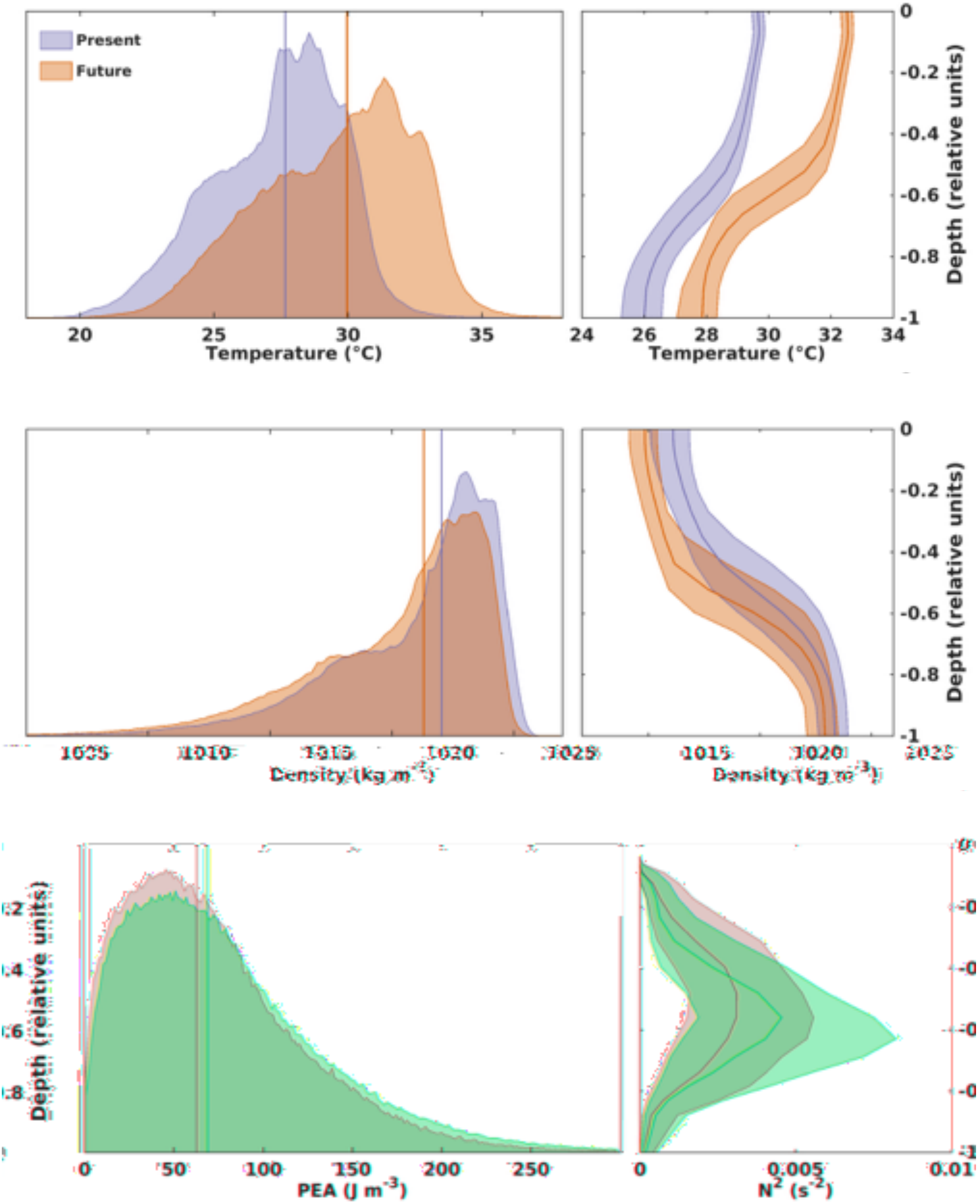
River

- +10% freshwater discharge (at constant nutrient load)

Atmosphere

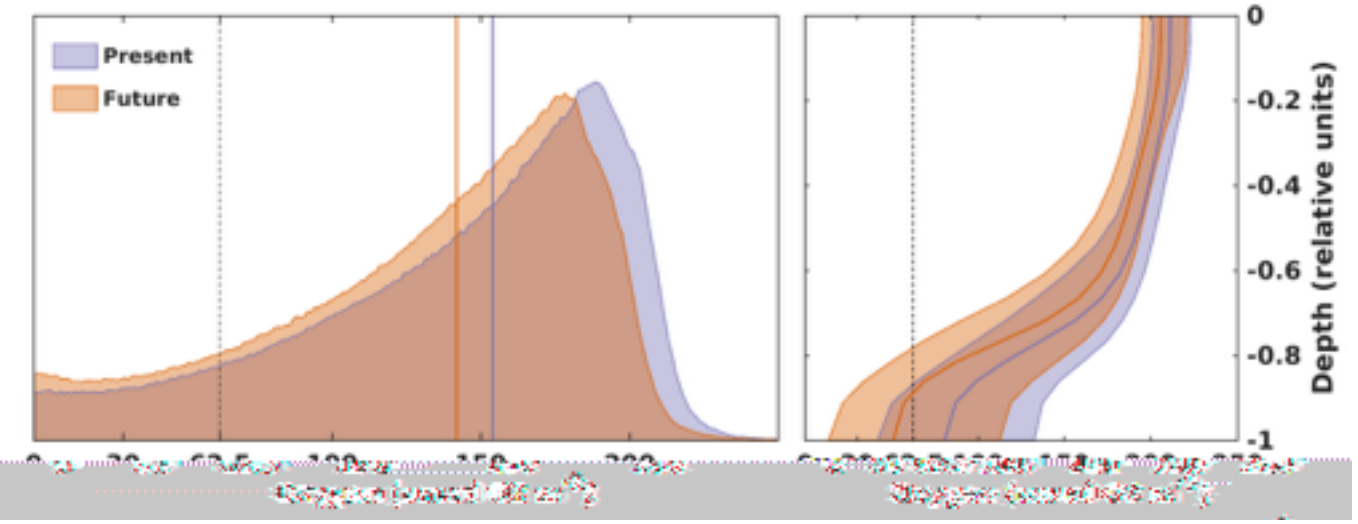
- Present temperature +3˚C
- pCO_2 = 935.85 atm

Changes in physical conditions

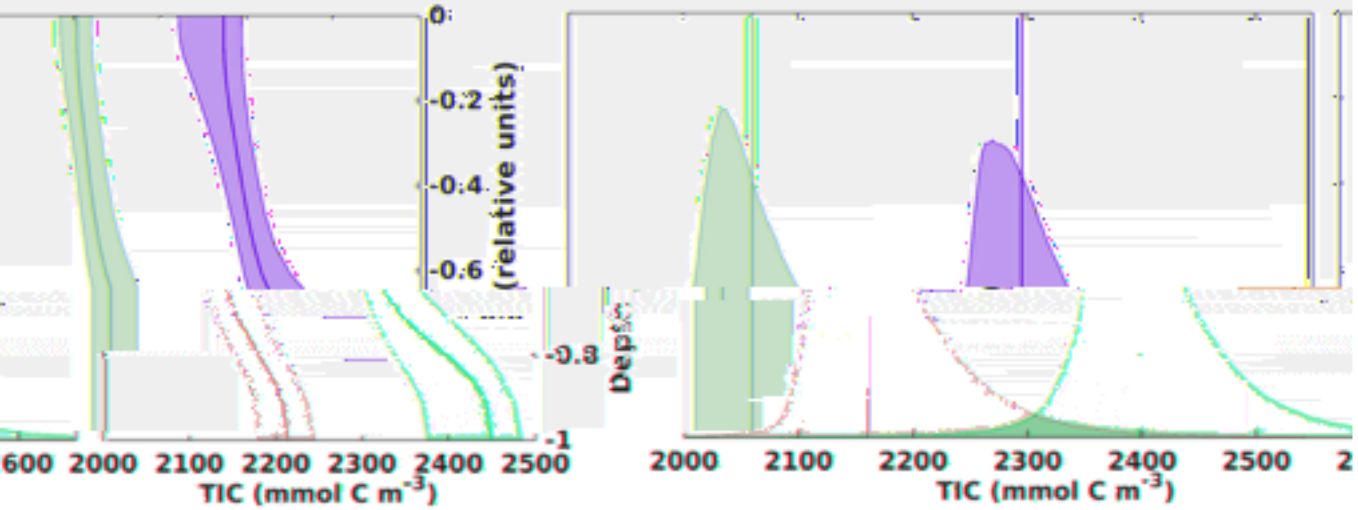


- Warmer temperature due to increased heat flux
- Lower density due to higher temperature and increased freshwater discharge.
- Thinner bottom boundary layers
- Stronger stratification in summer

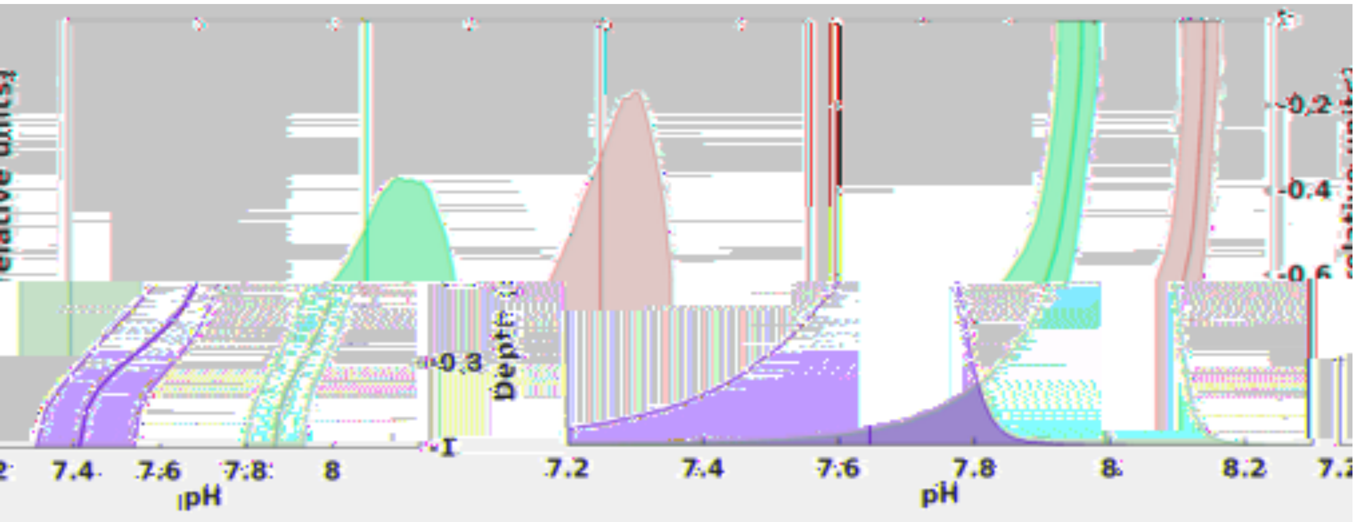
Changes in Biogeochemistry



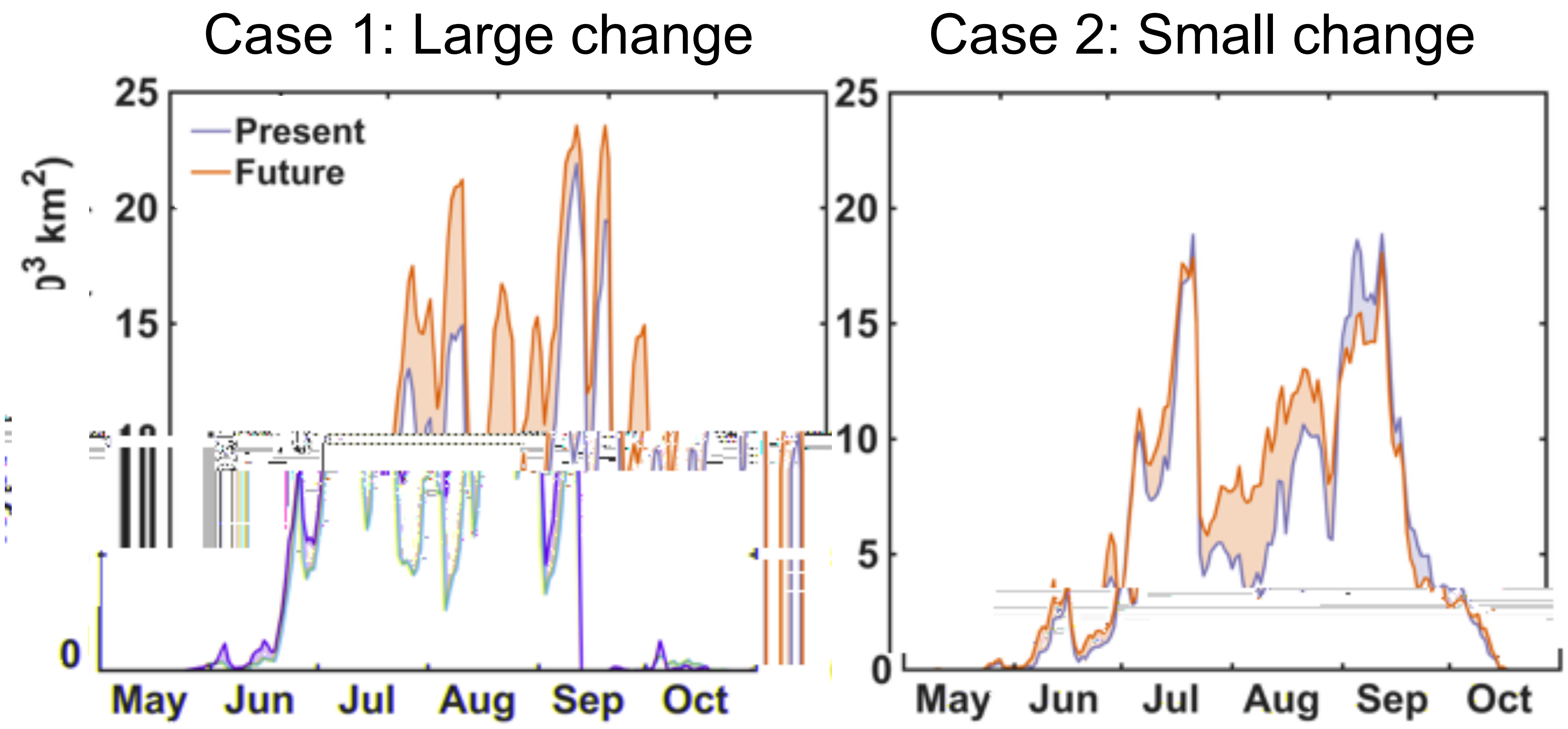
- O_2 decreases bc of lower saturation in warmer water and changes in physical conditions



- Large increase in TIC due to high atmospheric pCO_2



- Large drop in pH reflecting the change in TIC.
- Bottom waters remain mostly saturated for aragonite but approach the undersaturation limit.



<u>Year integrated hypoxic area</u> (x10² km² yr)

$\overline{H}_F = 1138$	$\overline{H}_F = 1004$
$\Delta\overline{H}_{F\text{-}P} = +355$	$\Delta\overline{H}_{F\text{-}P} = +117$

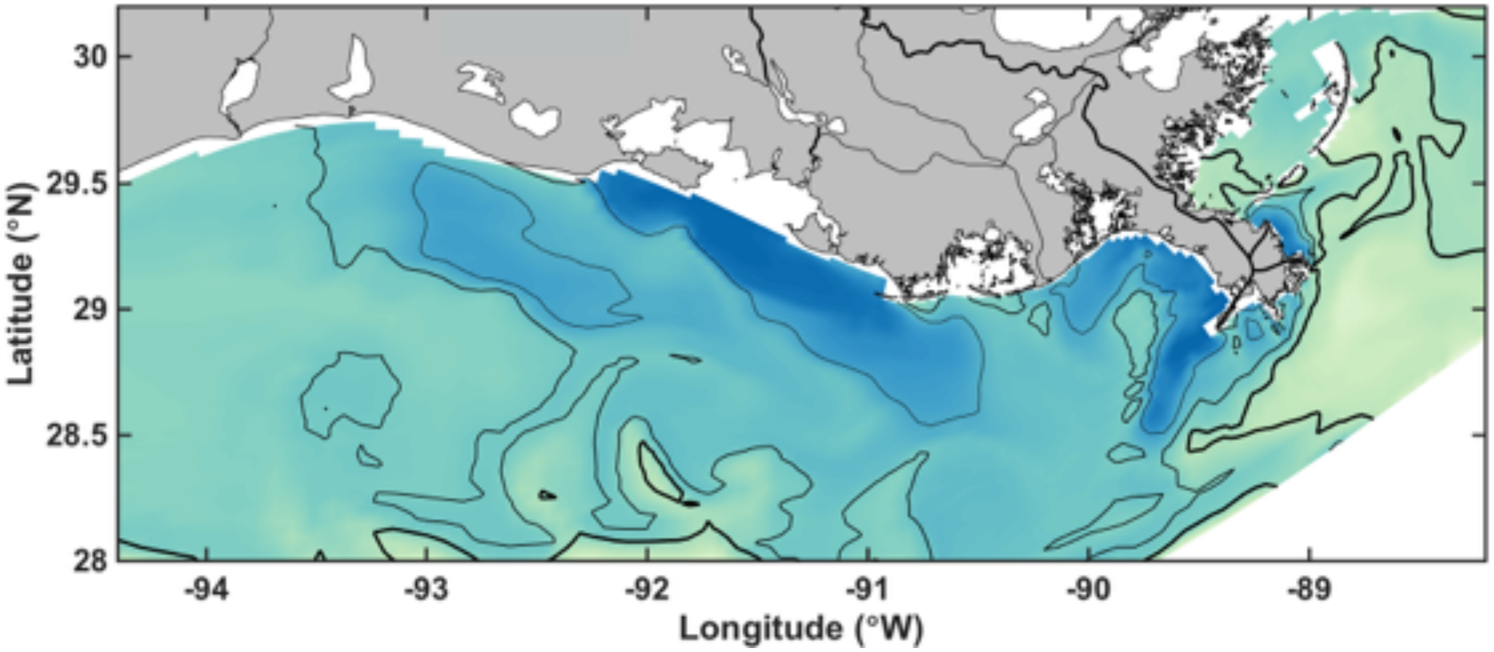
<u>Conditions</u>

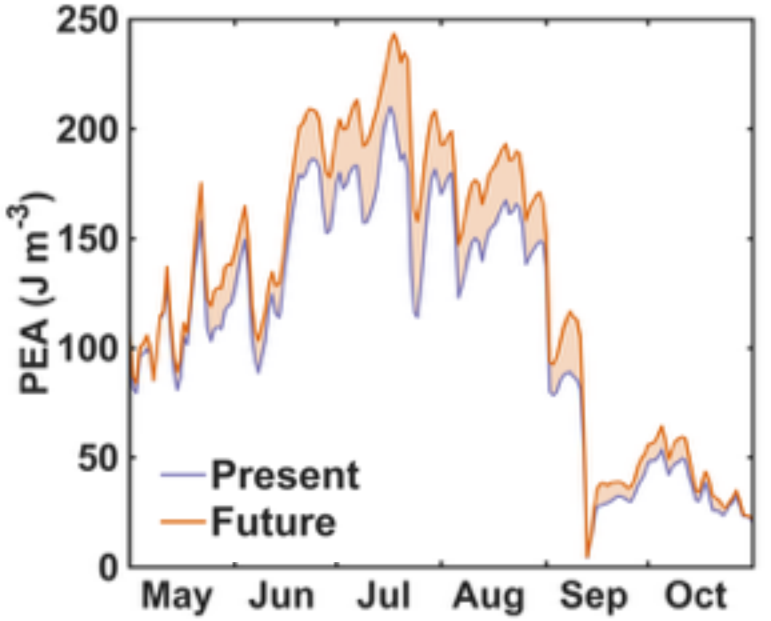
• Large discharge • Upwelling	• Low discharge • Downwelling

Case 1

- Large discharge
- Upwelling

- Large area with strong stratification
- Increased stratification in the future

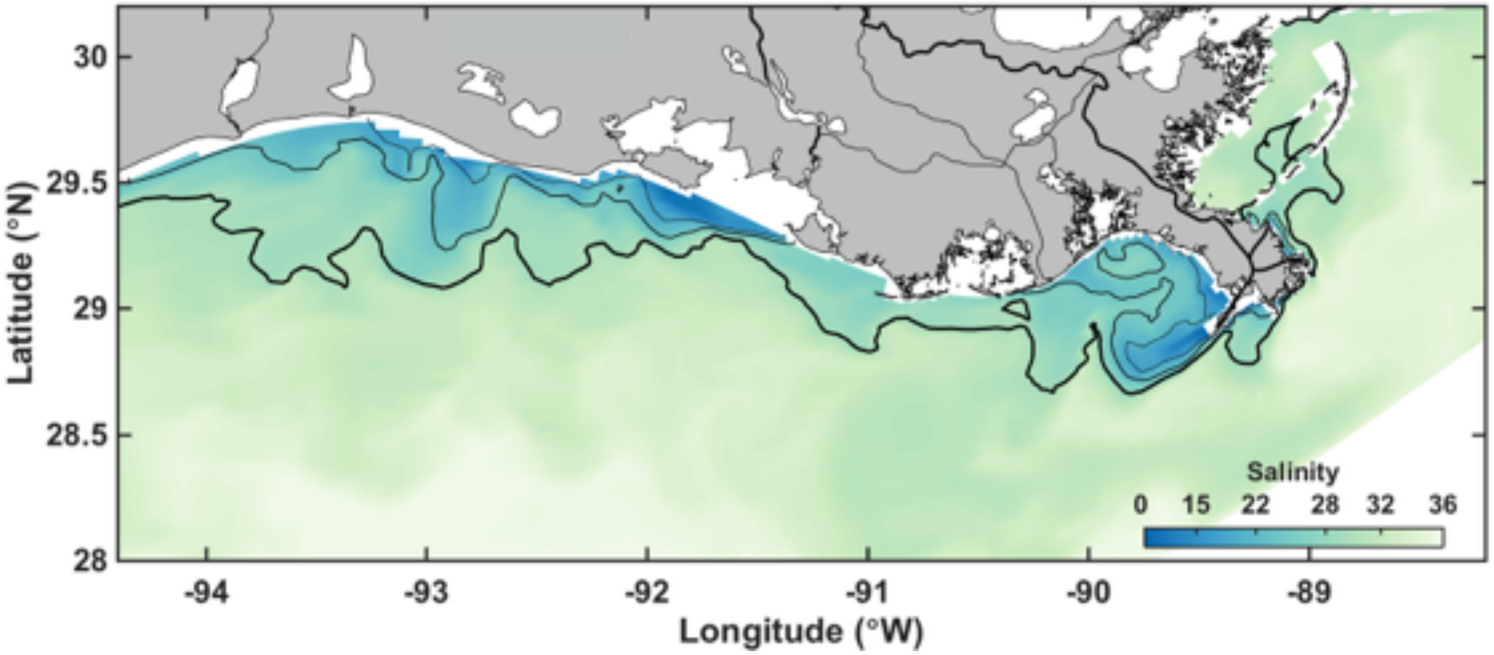

Mid-summer surface salinity (future)

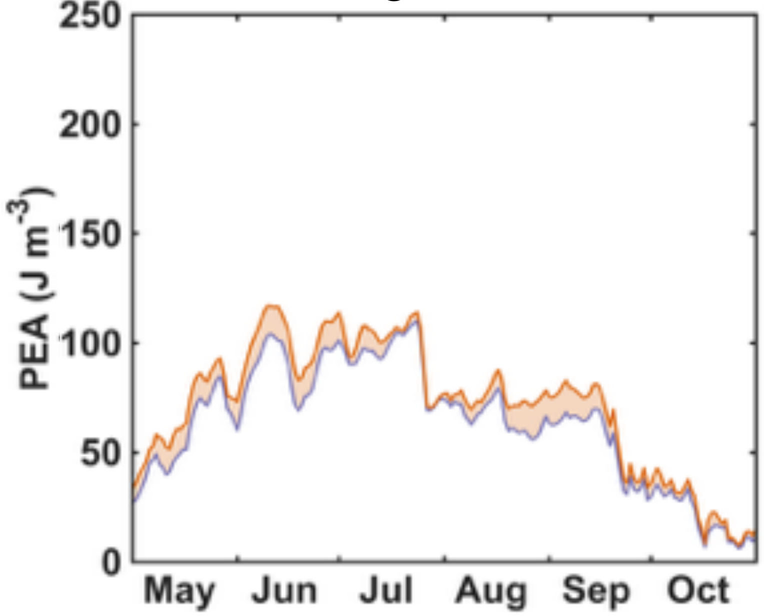

Shelf-averaged stratification

Case 2

- Low discharge
- Downwelling

- Strong stratification restricted to the coastal area
- Small increase in stratification in the future


Mid-summer surface salinity (future)


Shelf-averaged stratification

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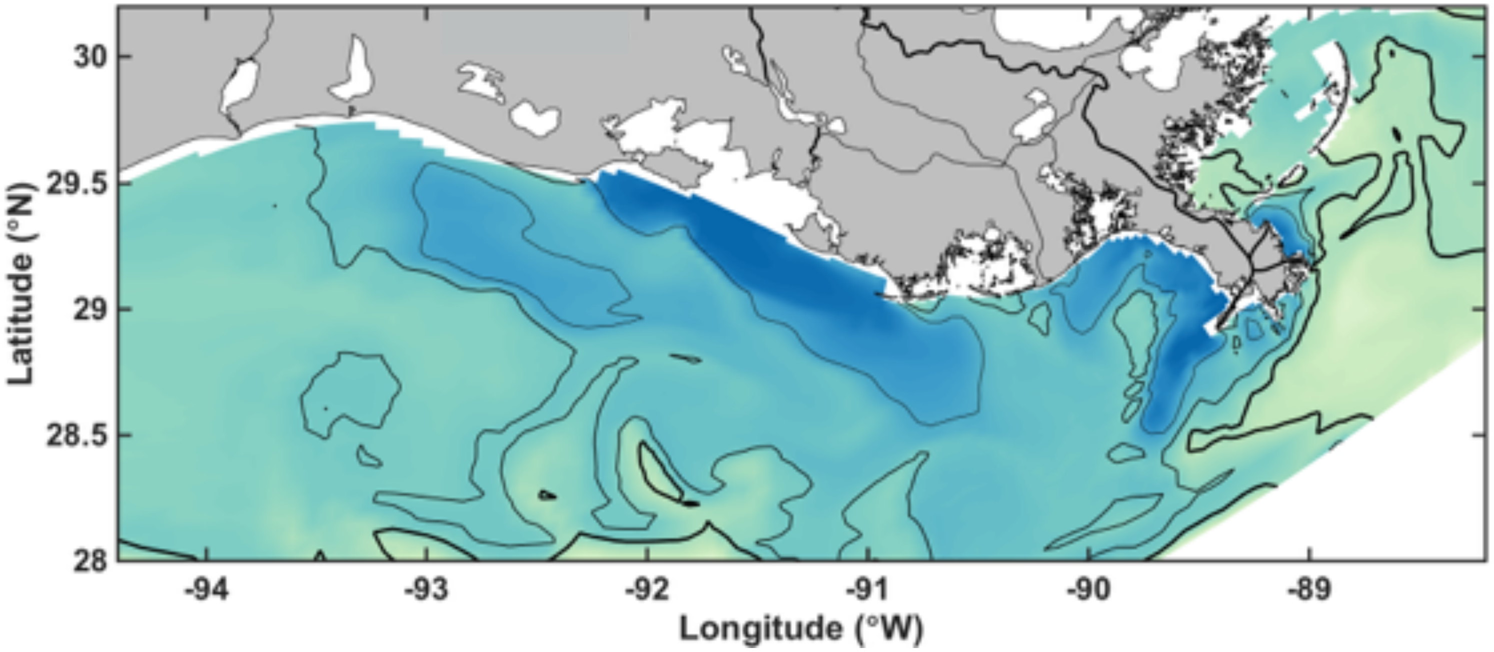
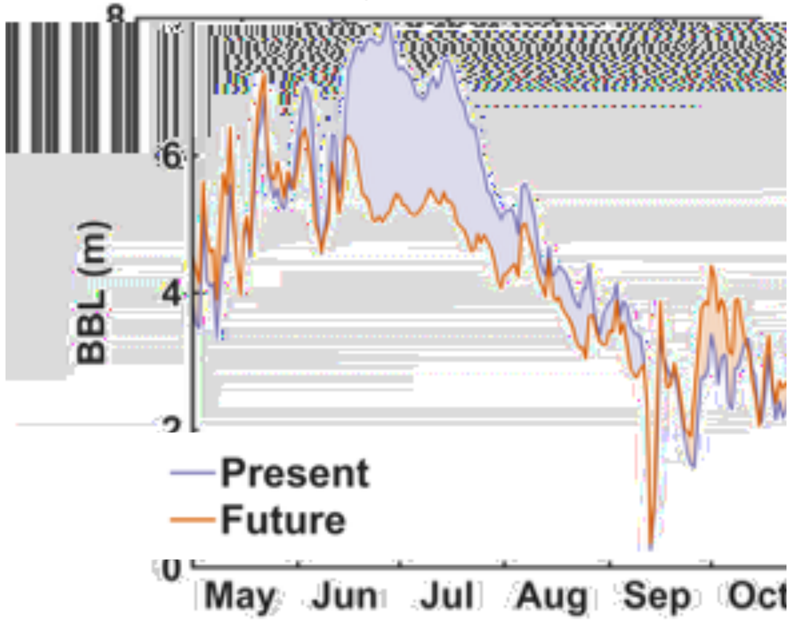
Mid-summer surface salinity (future)



Shelf-averaged BBL thickness

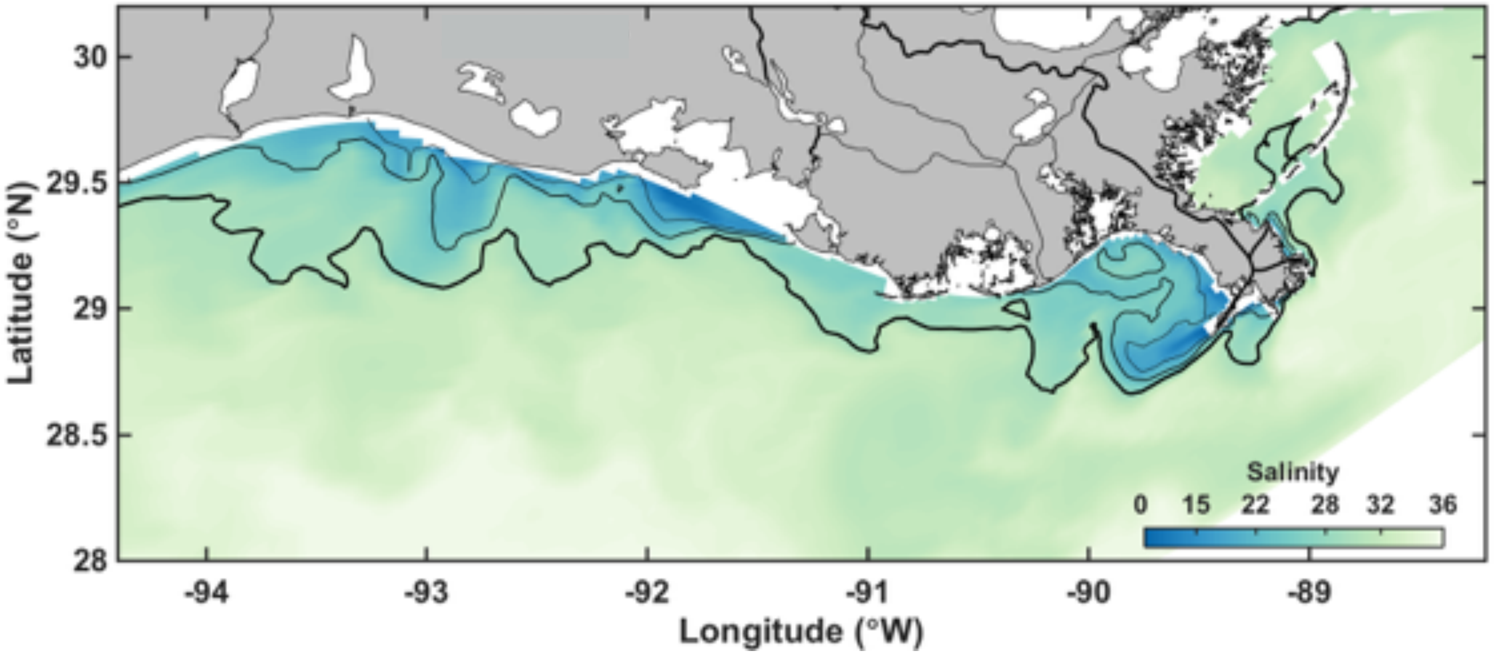


Case 2

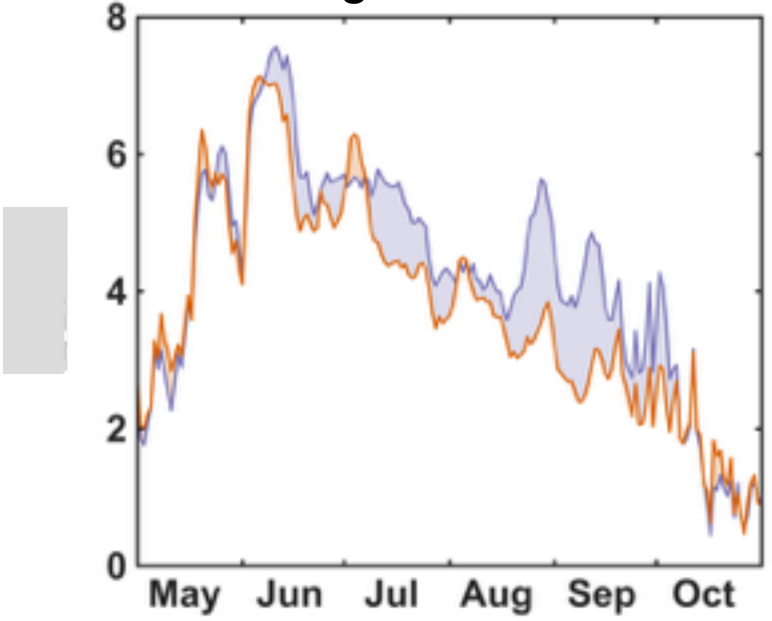
- Low discharge
- Downwelling

- Strong stratification restricted to the coastal area
- Small increase in stratification in the future

Mid-summer surface salinity (future)



Shelf-averaged BBL thickness



Summary

- Completed retrospective analysis of 2016 hypoxia season for Hypoxia Taskforce; will perform similar analysis for 2017
- Analysis of FlowerGarden Marine event in 2016 points to warming trend as most likely culprit
- Biogeochemical inter-comparison ongoing; will be main focus in final year
- Several forthcoming manuscripts for COMT Special Issue:
    - Biogeochemical model inter-comparison
    - Sensitivity to nutrient load reductions
    - Impacts of different sediment model options
    - Future projection results from ROMS