

Post-dreissenid spatial distribution of chlorophyll in a Lake Michigan biophysical model

Mark D. Rowe

University of Michigan CILER



Eric J. Anderson, Hank A. Vanderploeg,
George Leshkevich
NOAA GLERL



Foad Yousef, Michael Sayers
Michigan Tech University

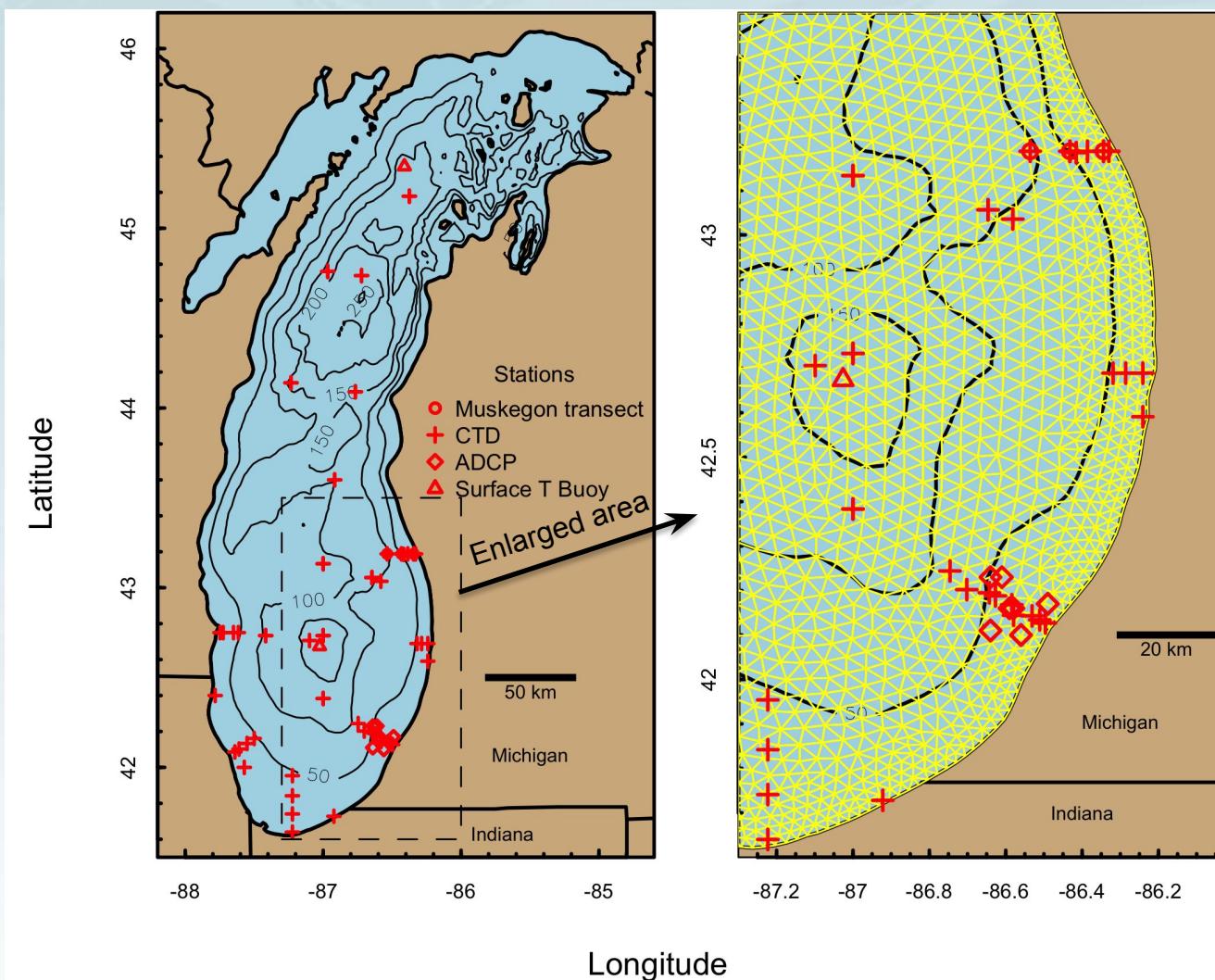
MichiganTech



Outline

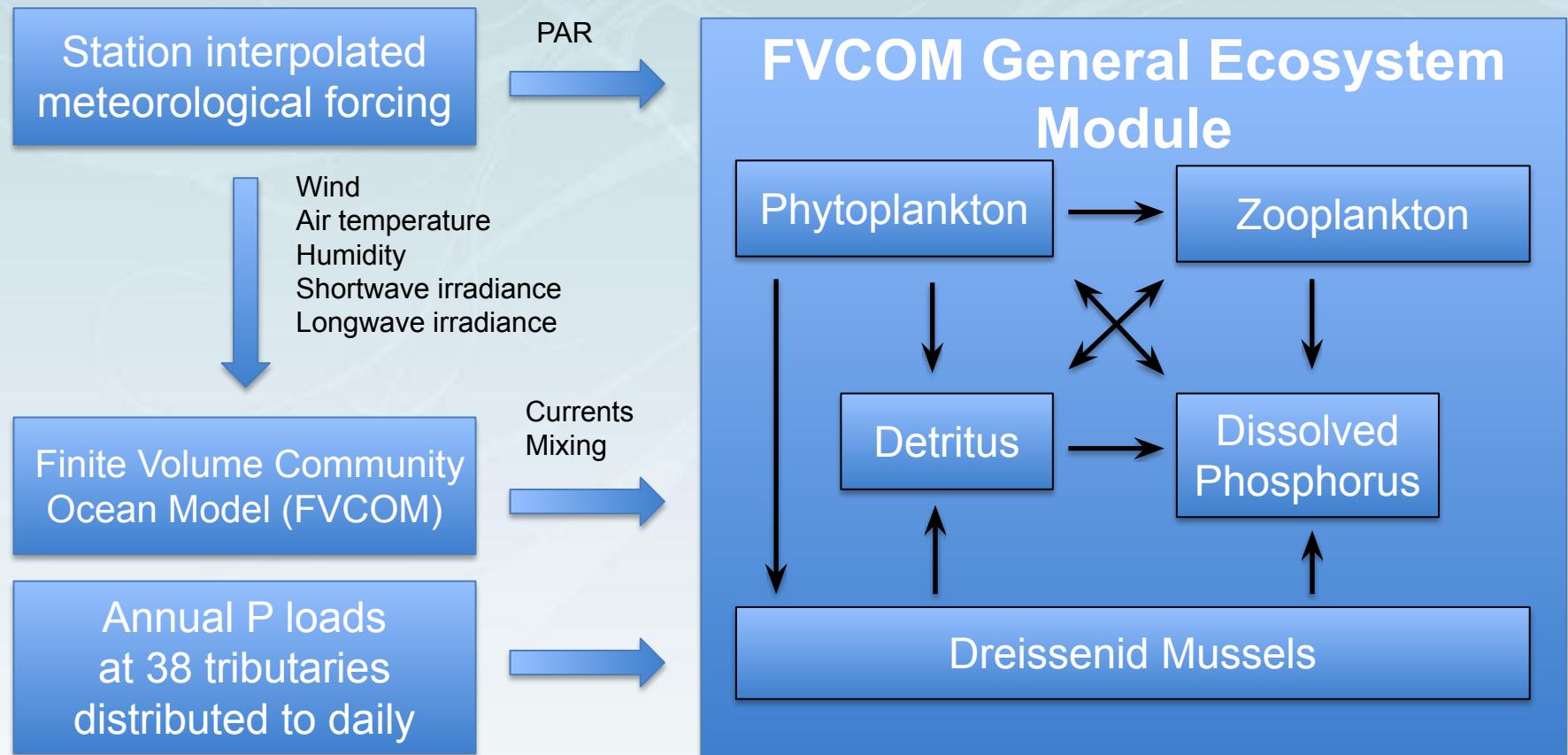
- Goal
 - Describe the influence of physical processes, dreissenid mussels, and tributary phosphorus loads on the spatial distribution of chlorophyll in Lake Michigan
- Methods
 - Biophysical model description
- Results
 - Compare simulated chlorophyll spatial distributions to satellite-derived and grab-sample chlorophyll for specific dates in 2010
 - March-April: Deep mixing, winter stratification
 - May-June: Onset of summer stratification
 - July-August: Stratification, coastal upwelling
 - September-November: Deepening mixed layer
- Conclusions

Lake Michigan Finite Volume Community Ocean model (FVCOM) hydrodynamic model grid



M.D. Rowe, E.J. Anderson, J. Wang, H.A. Vanderploeg. 2015. *J. Great Lakes Research*, 41(S3):49-65

Biophysical model of Lake Michigan



Dolan and Chapra, 2012, J. Great Lakes Res.
USGS gages

Quagga mussel bioenergetic model

$$\frac{dB}{dt} = (\varepsilon F_A P - r)B$$

B dreissenid biomass

P phytoplankton biomass

F_A filtration rate

ε assimilation efficiency

r base respiration rate

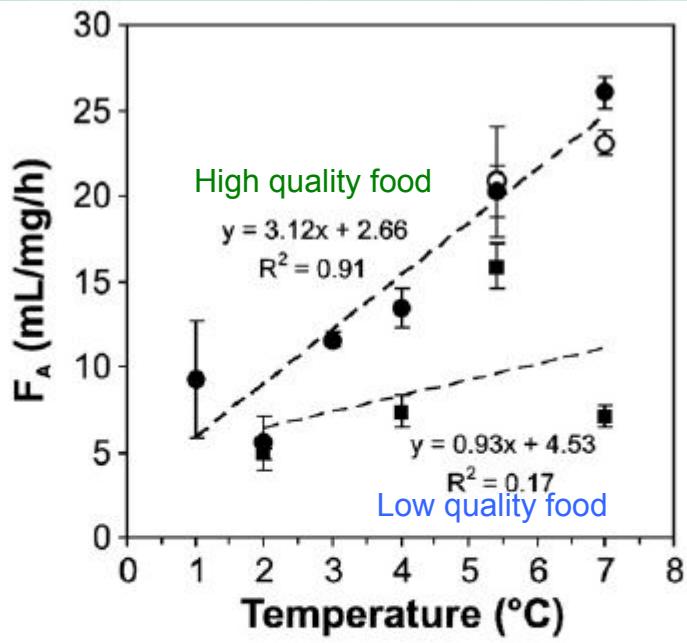
Predation/mortality was neglected

C.F. Cerco, M.R. Noel. 2010. Ecological Modeling, 1054-1064

L. Jiang et al. 2015. Ecological Modeling, 308:18-33

Quagga mussel model parameter values

Clearance rate



Vanderploeg et al. 2010, *J. Great Lakes Res.*

Additional parameters

Fate of ingested phytoplankton C and P

- 40% assimilation
- 30% specific dynamic action (excretion)
- 30% egestion (pseudofeces)

Base respiration

- 0.006 day⁻¹ at 20 °C

Maximum 24-hr ration

- 4% day⁻¹

P:C ratio

- 0.016 (T. Johengen, unpublished)

Baldwin, B.S. et al., 2002. *Can. J. Fish. Aquat. Sci.* 59: 680-694;

Bocaniov et al, 2013, *Hydrobiologia*, 1-22

Bierman et al. 2005, *J. Great Lakes Res.*

Kao et al., 2013. *J. Great Lakes Res.*



Biophysical model simulations initialized using detailed quagga mussel spatial distribution

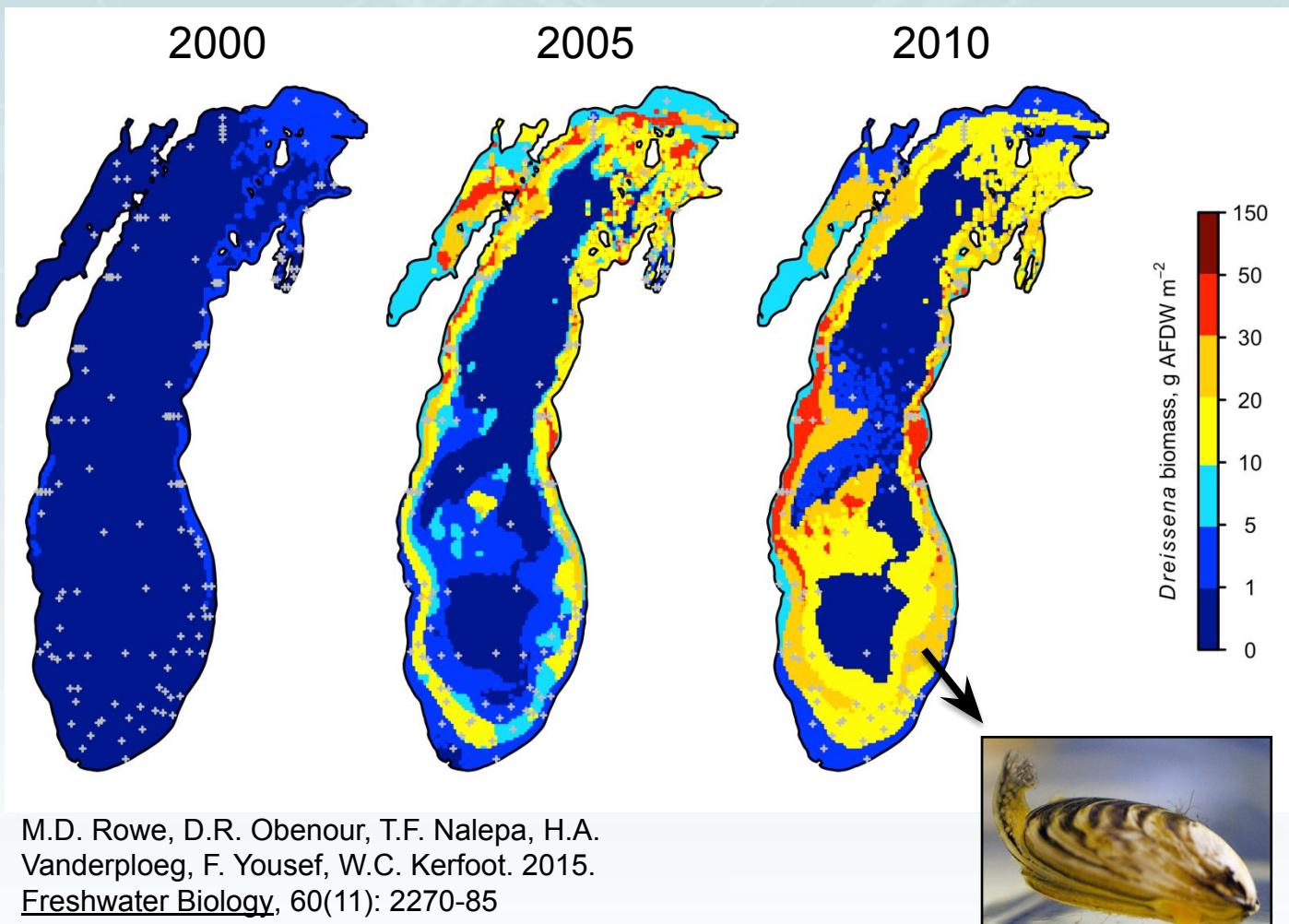
Benthic surveys



Geostatistical model



Mussel biomass
spatial distribution



Calibration of the biological model

- Calibrate for 2000 (pre-quagga mussel)
 - Key process rates within observed bounds
 - Photosynthesis-irradiance (Fahnenstiel et al. 2016 and 1989, Lohrenz et al. 2004)
 - Phytoplankton net growth rate (Fahnenstiel et al. 2000, Scavia et al., 1988)
 - Zooplankton grazing rate (Scavia et al. 1988)
 - Quagga mussel clearance rate (Vanderploeg et al. 2010)
 - State variable quantities within observed bounds
 - Chlorophyll concentration (GLERL Muskegon transect, USEPA GLNPO, SeaWiFS)
 - Dissolved and total phosphorus (GLERL Muskegon transect, USEPA GLNPO)
 - Zooplankton biomass (GLERL Muskegon transect)
- Simulate 2005 and 2010 with the same parameter set
- Initial dissolved and particulate phosphorus set based on GLNPO spring survey, uniform over the main lake

March – April Isothermal deep mixing and winter stratification

March 23, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

Satellite

| 3D Biophysical model

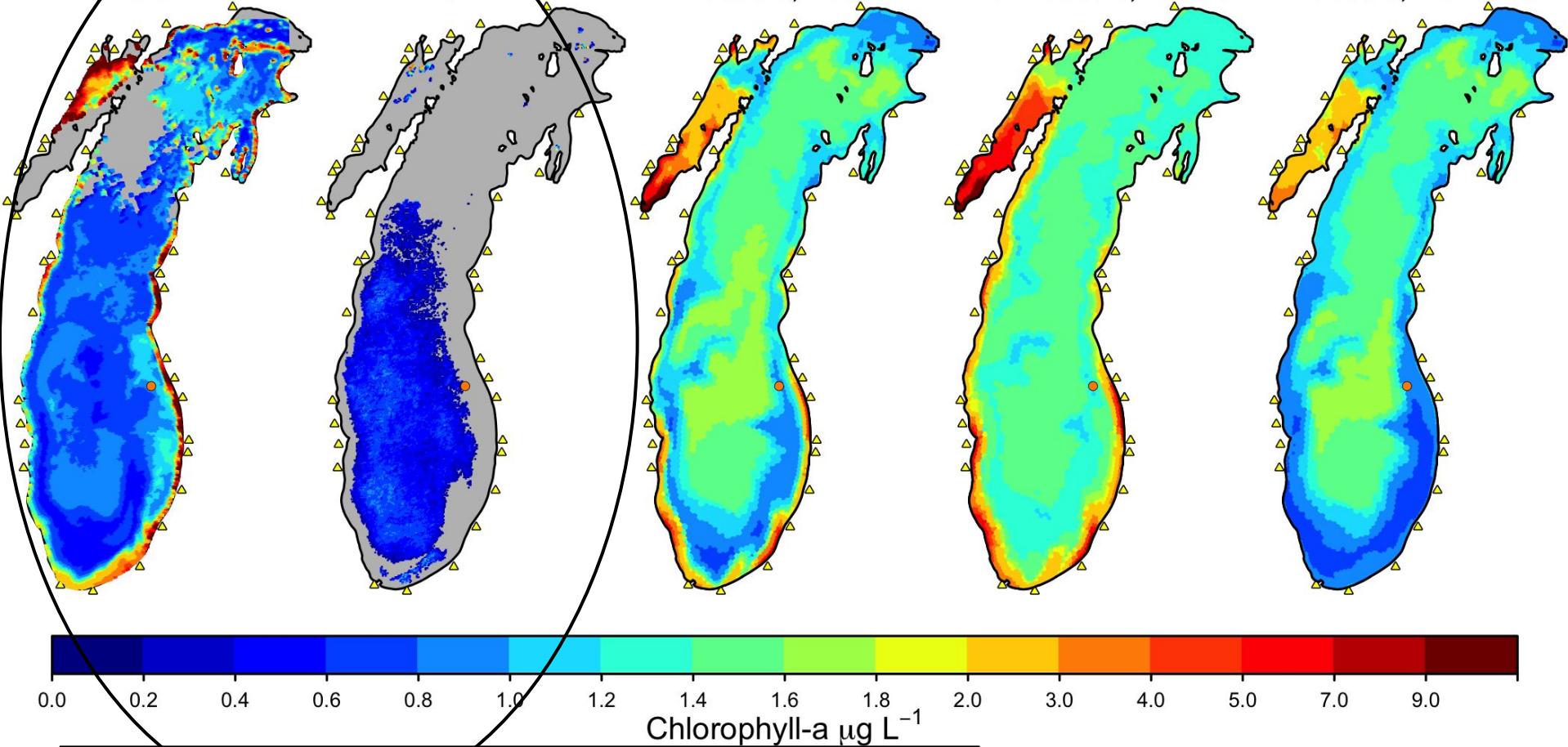
OC4

CPA

Mussels, Loads

No mussels, Loads

Mussels, No loads

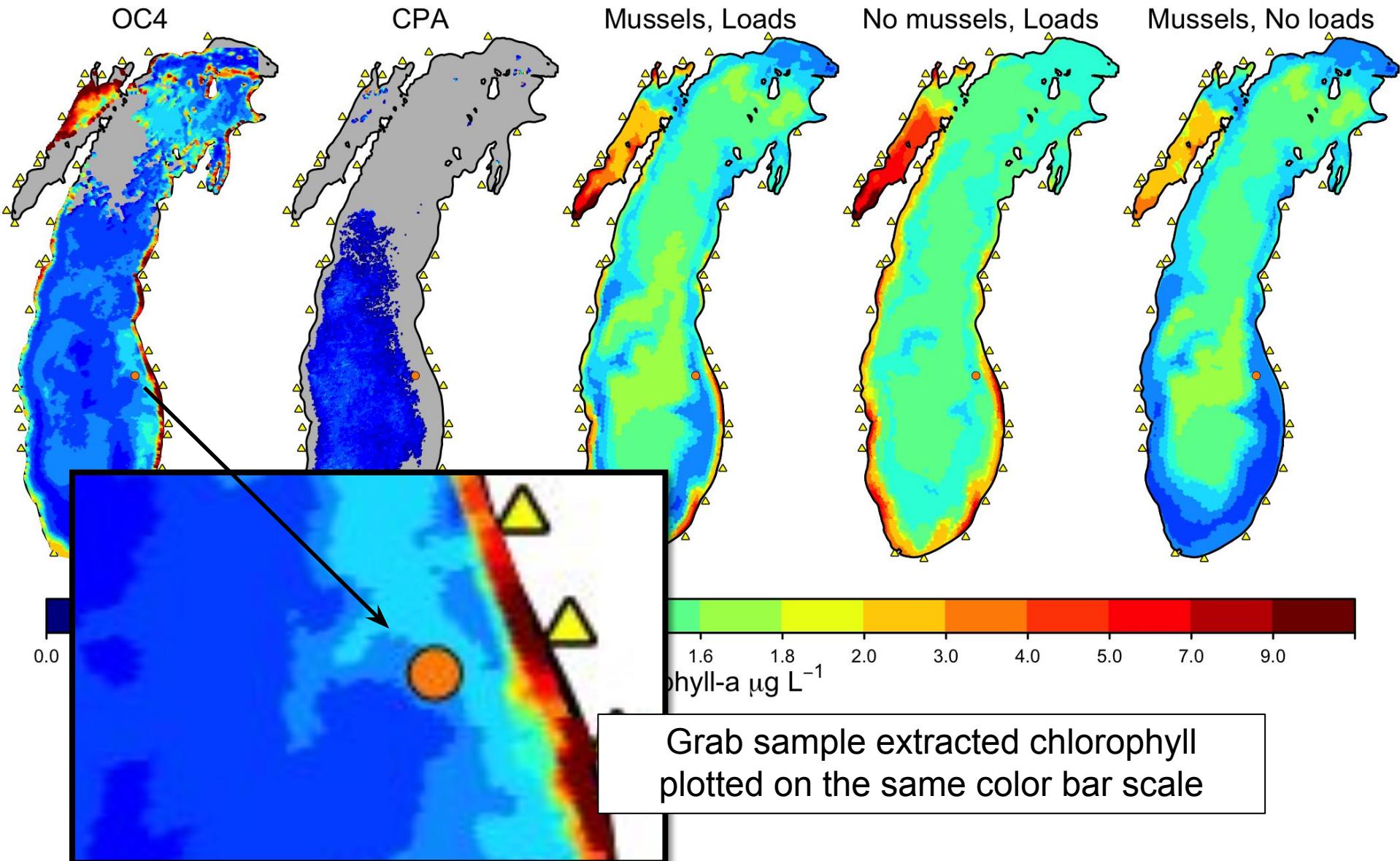


Satellite – derived chlorophyll from two sources:
SeaWiFS OC4 retrieval
MODIS Color Producing Agent (CPA) retrieval

March 23, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

Satellite

| 3D Biophysical model



March 23, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

Satellite

| 3D Biophysical model

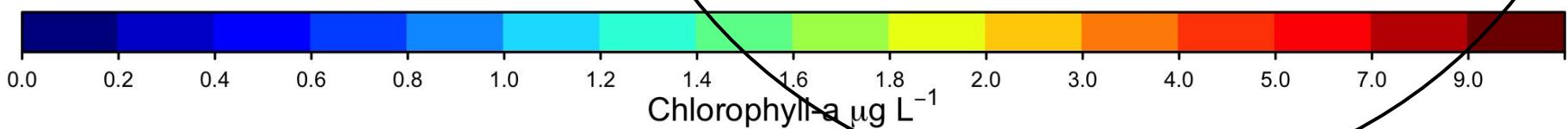
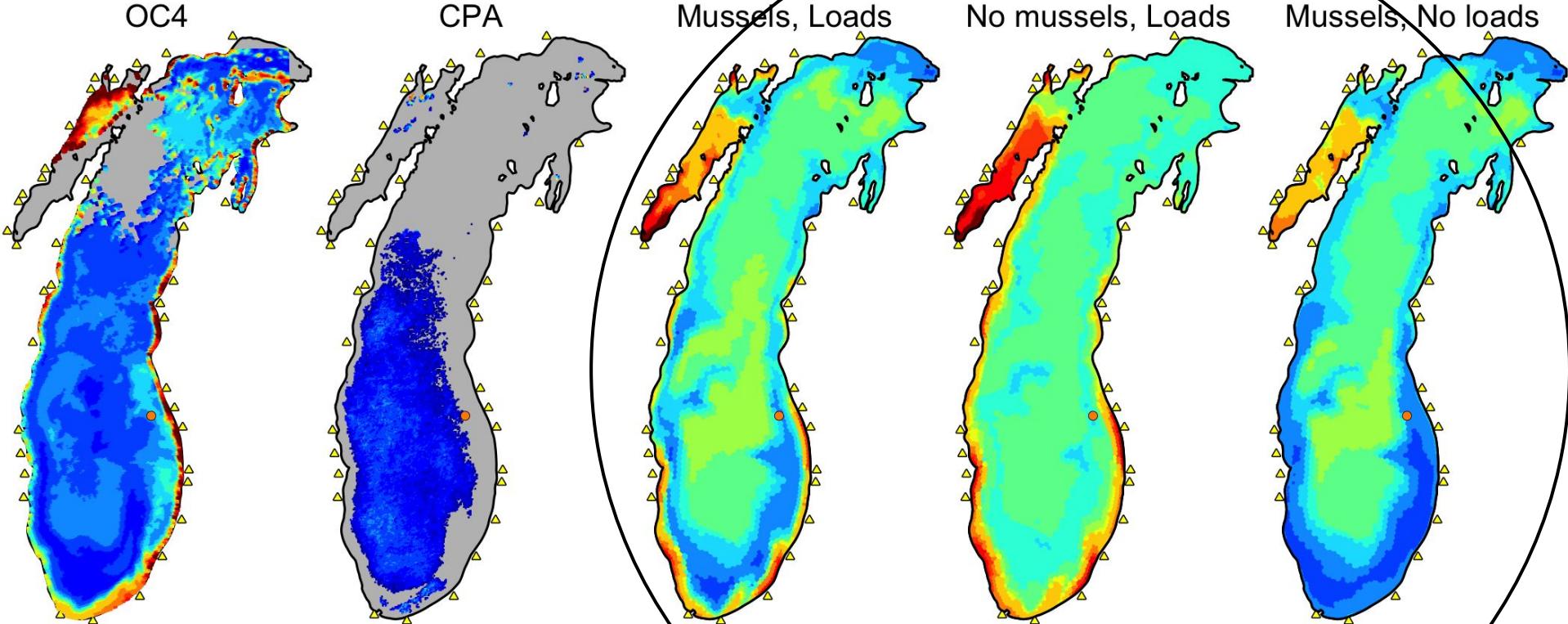
OC4

CPA

Mussels, Loads

No mussels, Loads

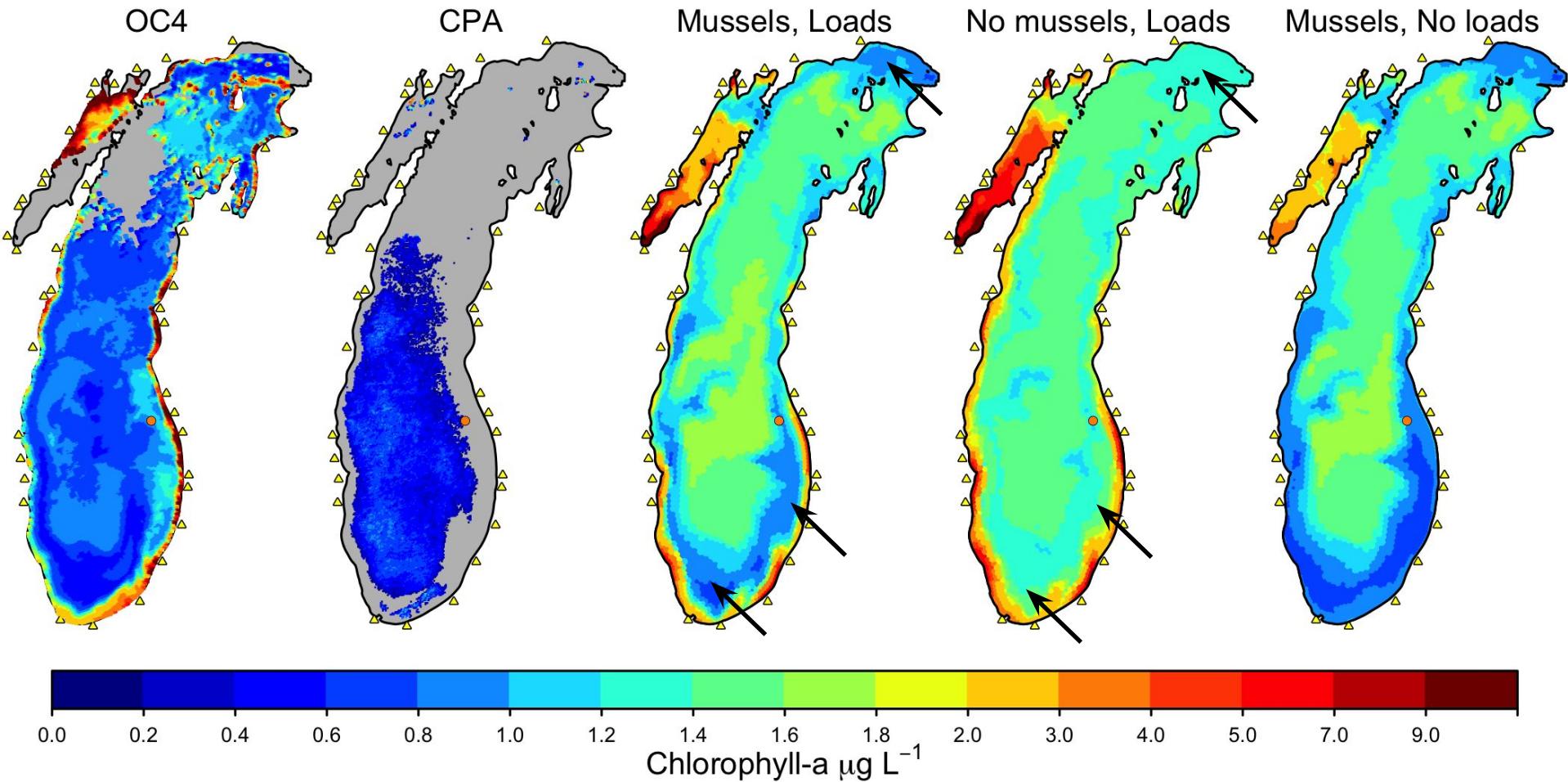
Mussels, No loads



March 23, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

Satellite

| 3D Biophysical model

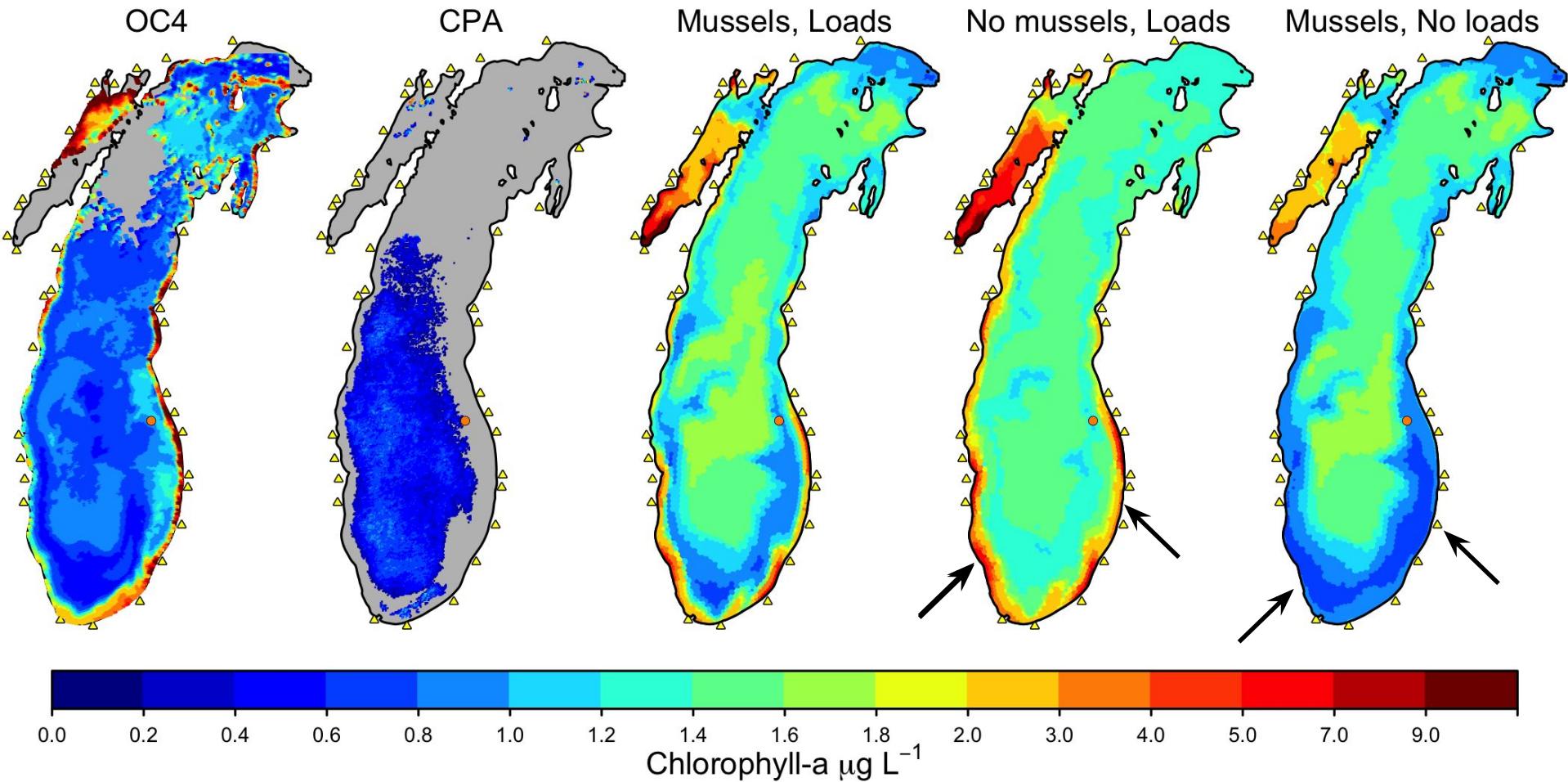


Effect of dreissenid mussels

March 23, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

Satellite

| 3D Biophysical model

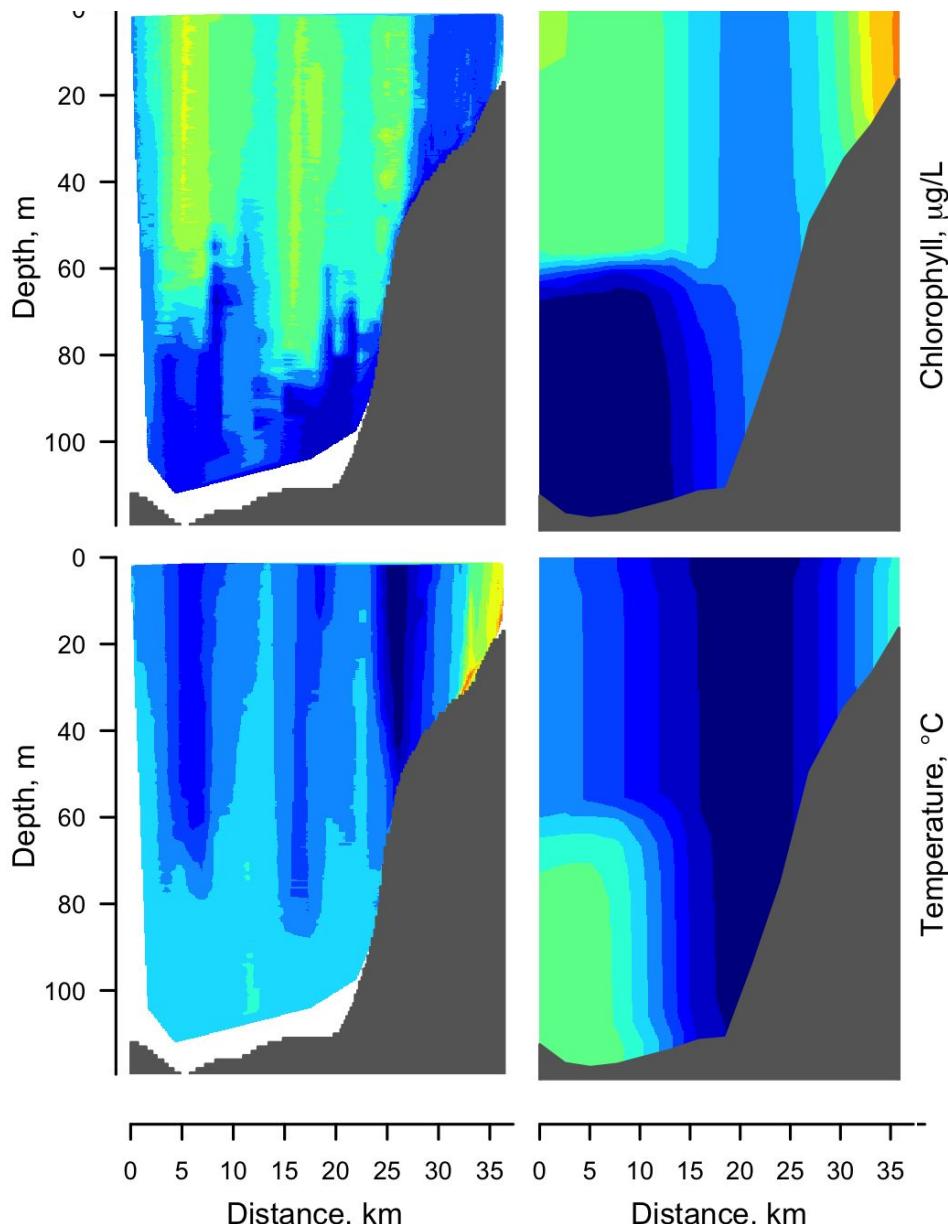


Effect of phosphorus loads

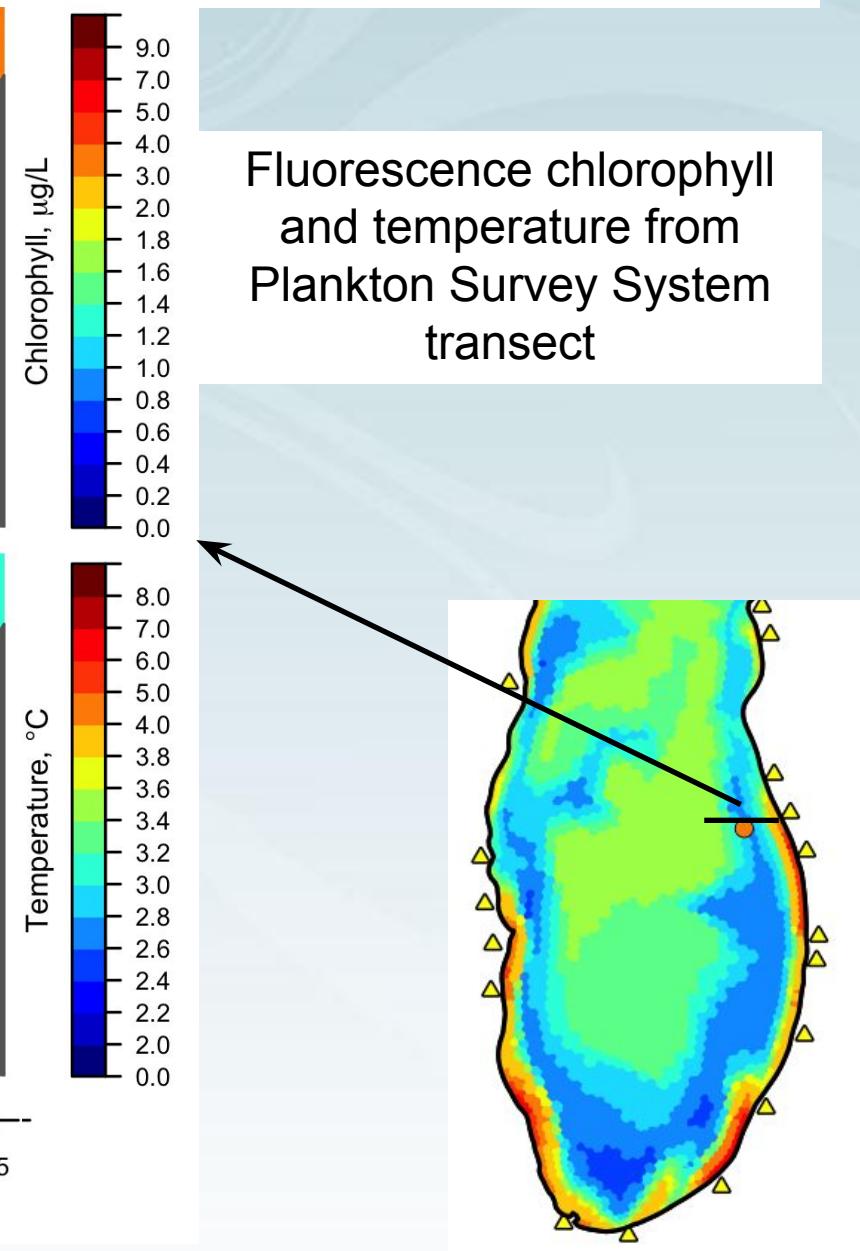
Plankton survey system

Model

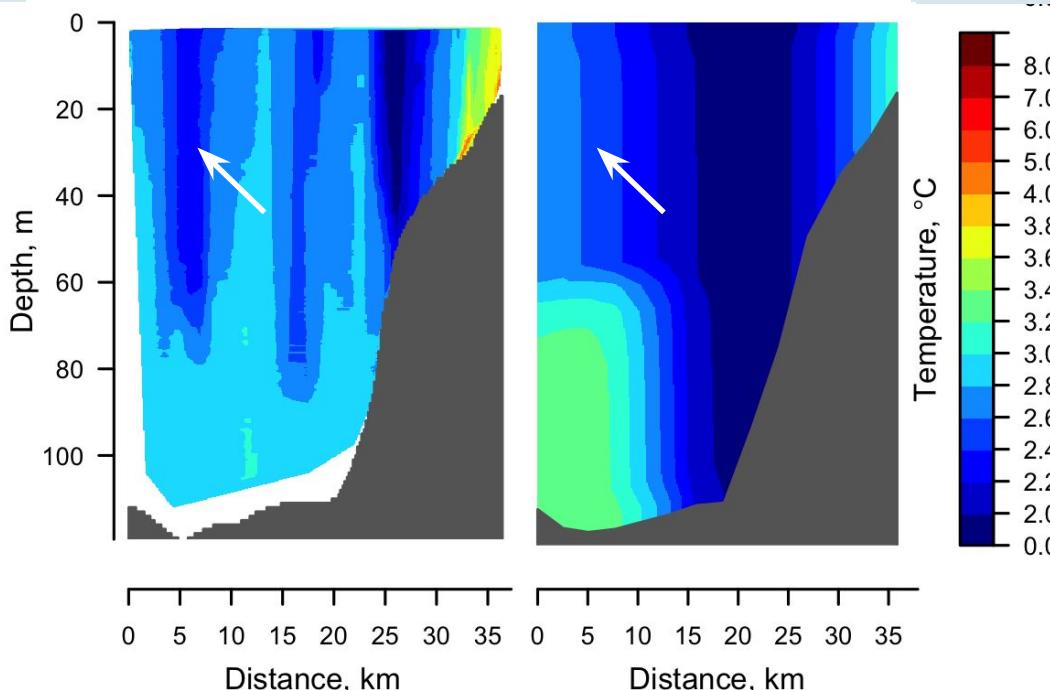
March 23, 2010



Fluorescence chlorophyll
and temperature from
Plankton Survey System
transect



Plankton survey system



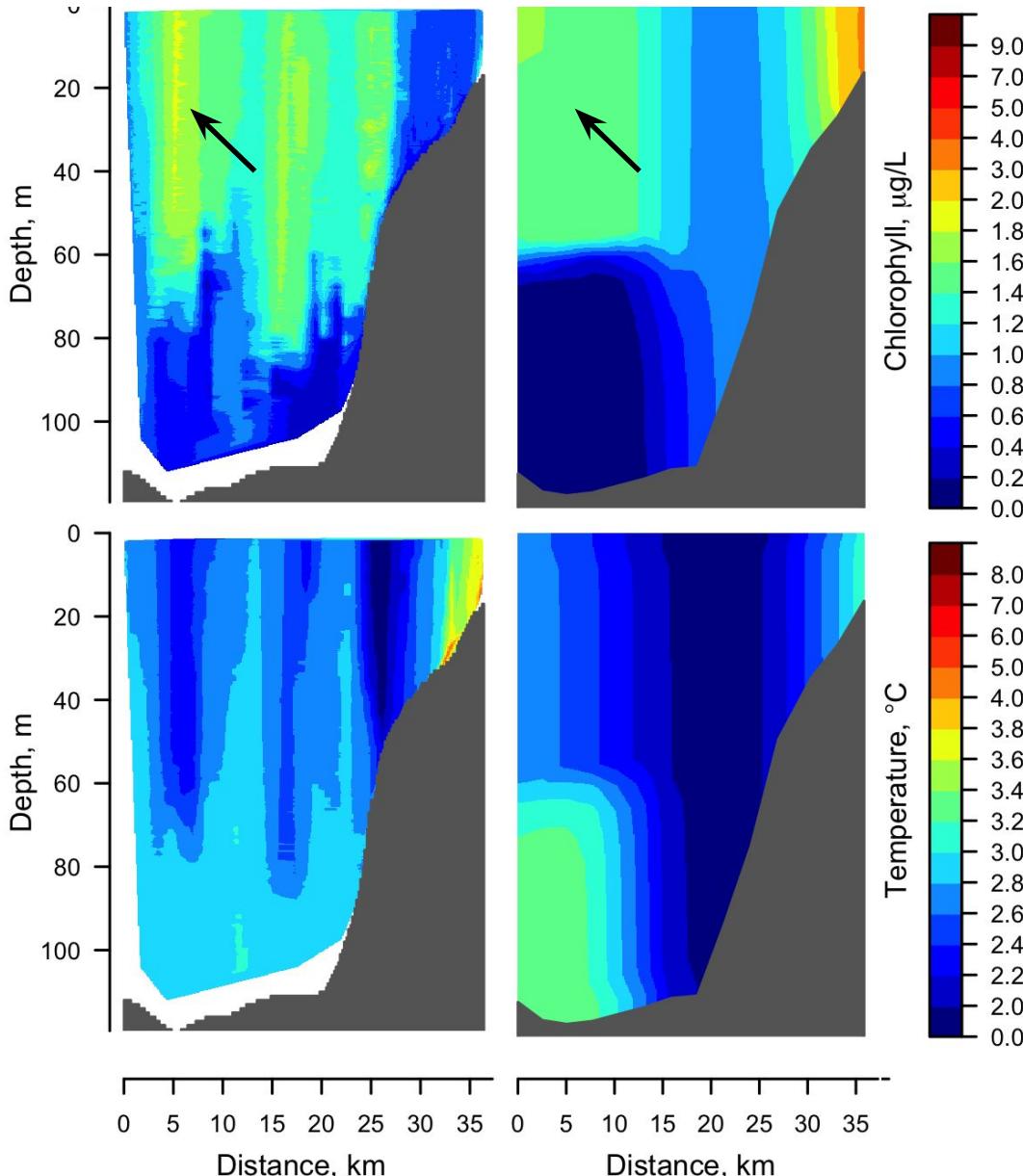
March 23, 2010

Winter stratification
offshore: surface cooled
below 4 °C

Plankton survey system

Model

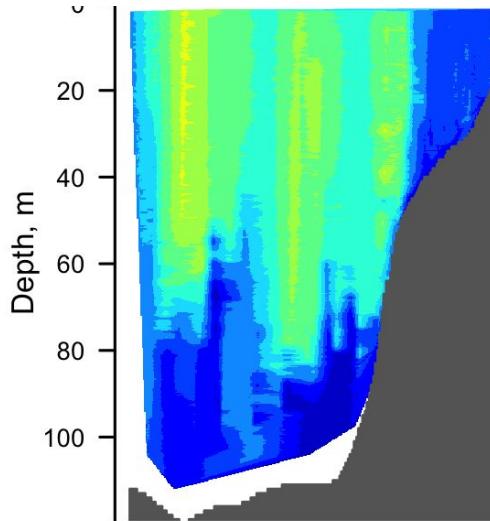
March 23, 2010



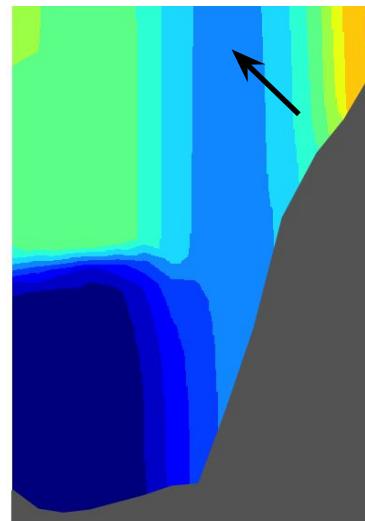
Limited mixed-layer depth
promotes phytoplankton
growth by increasing mean
light exposure

March 23, 2010

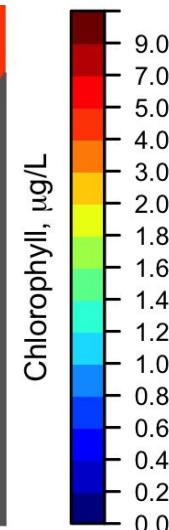
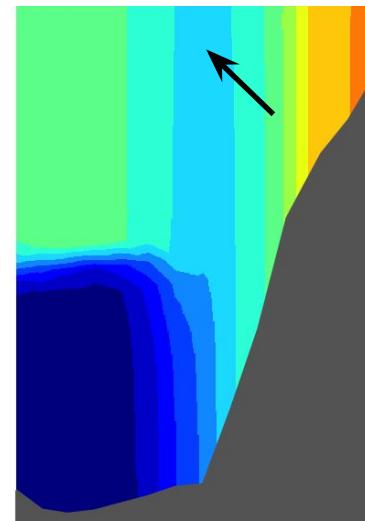
Plankton survey system



Mussels



No Mussels



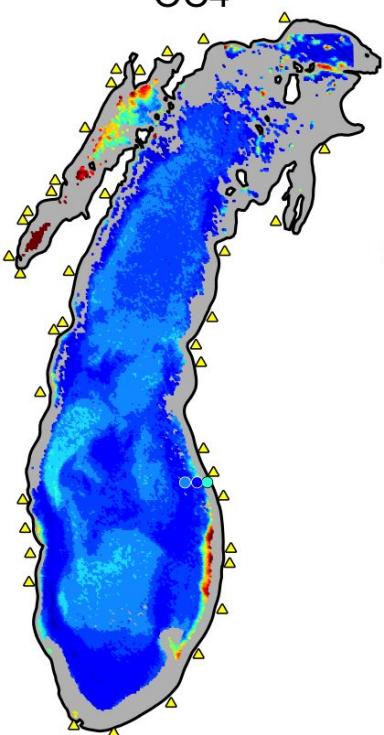
Dreissenid mussels reduced chlorophyll concentration in mid-depth region where mussel biomass is high and mixed layer contacted the bottom

April 22, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

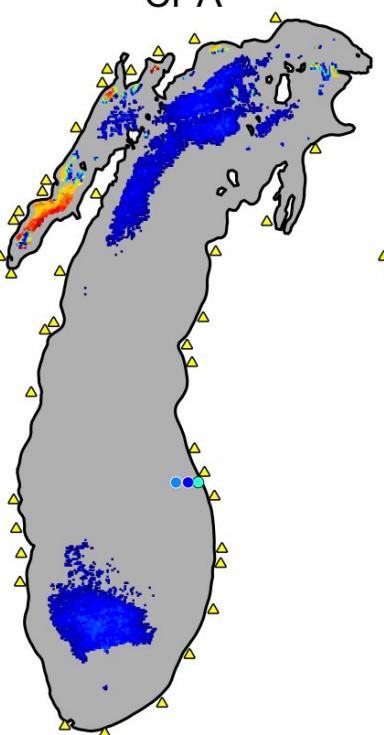
Satellite

| 3D Biophysical model

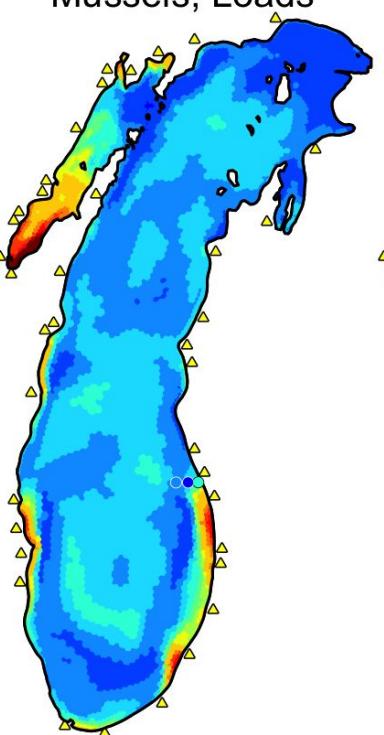
OC4



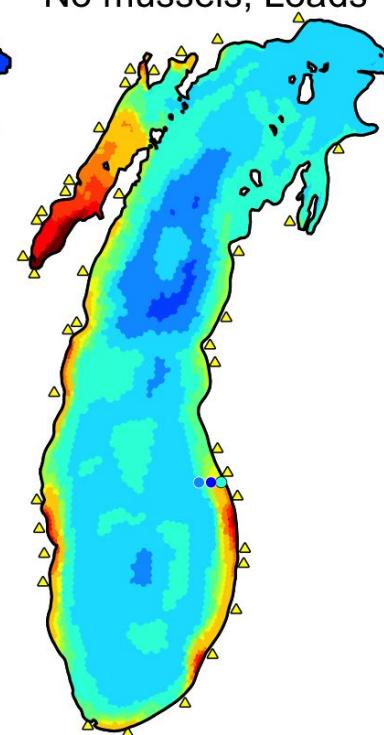
CPA



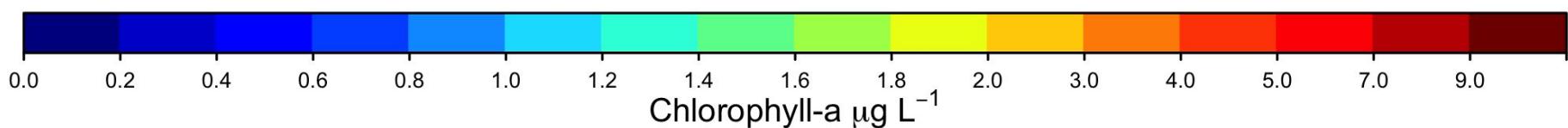
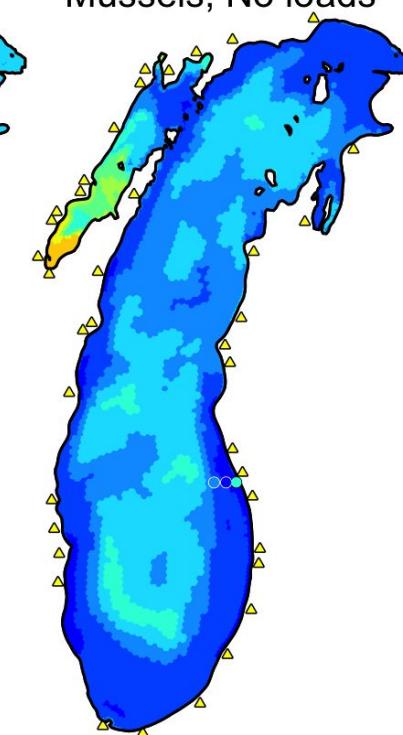
Mussels, Loads



No mussels, Loads



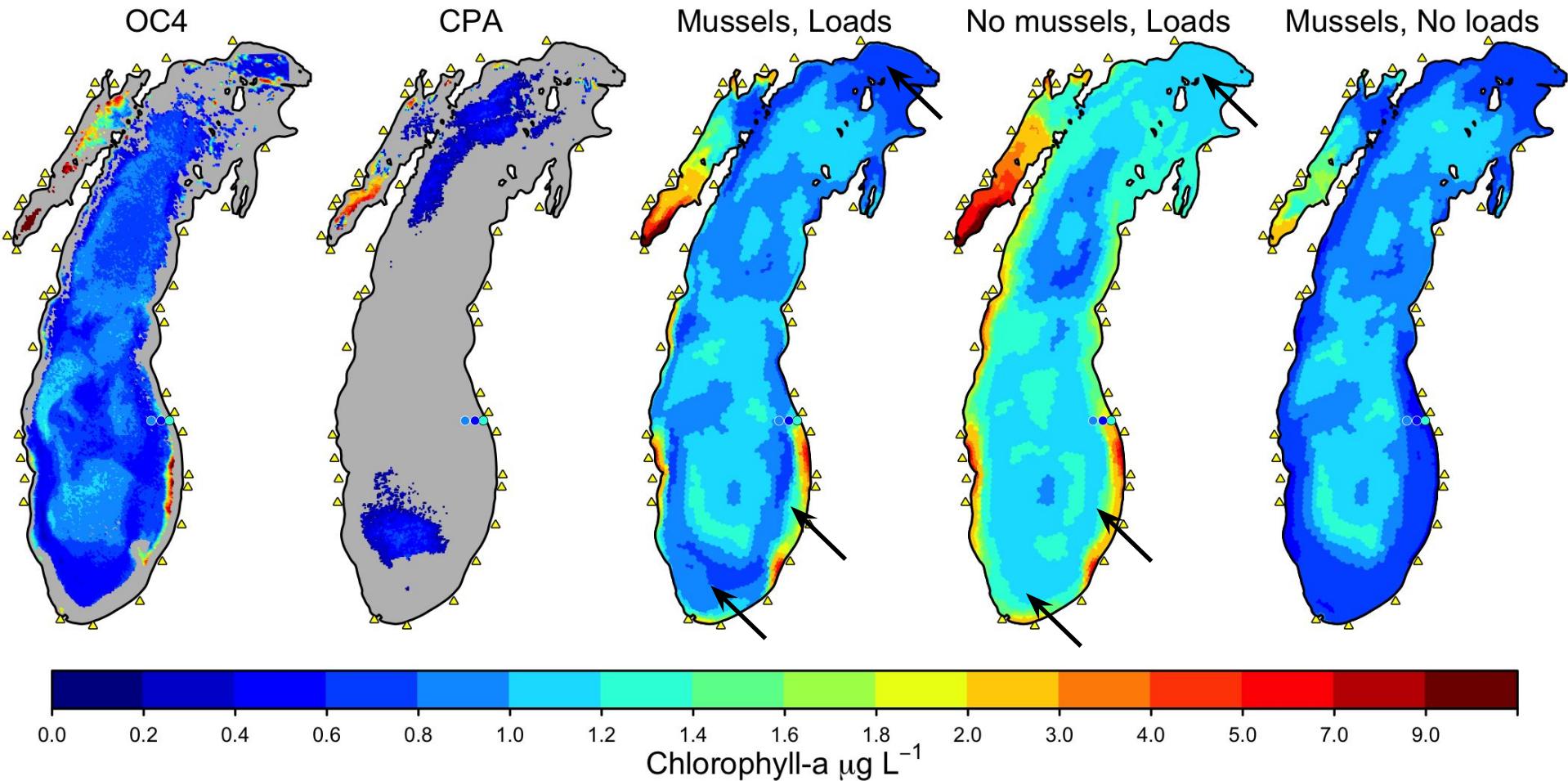
Mussels, No loads



April 22, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

Satellite

3D Biophysical model

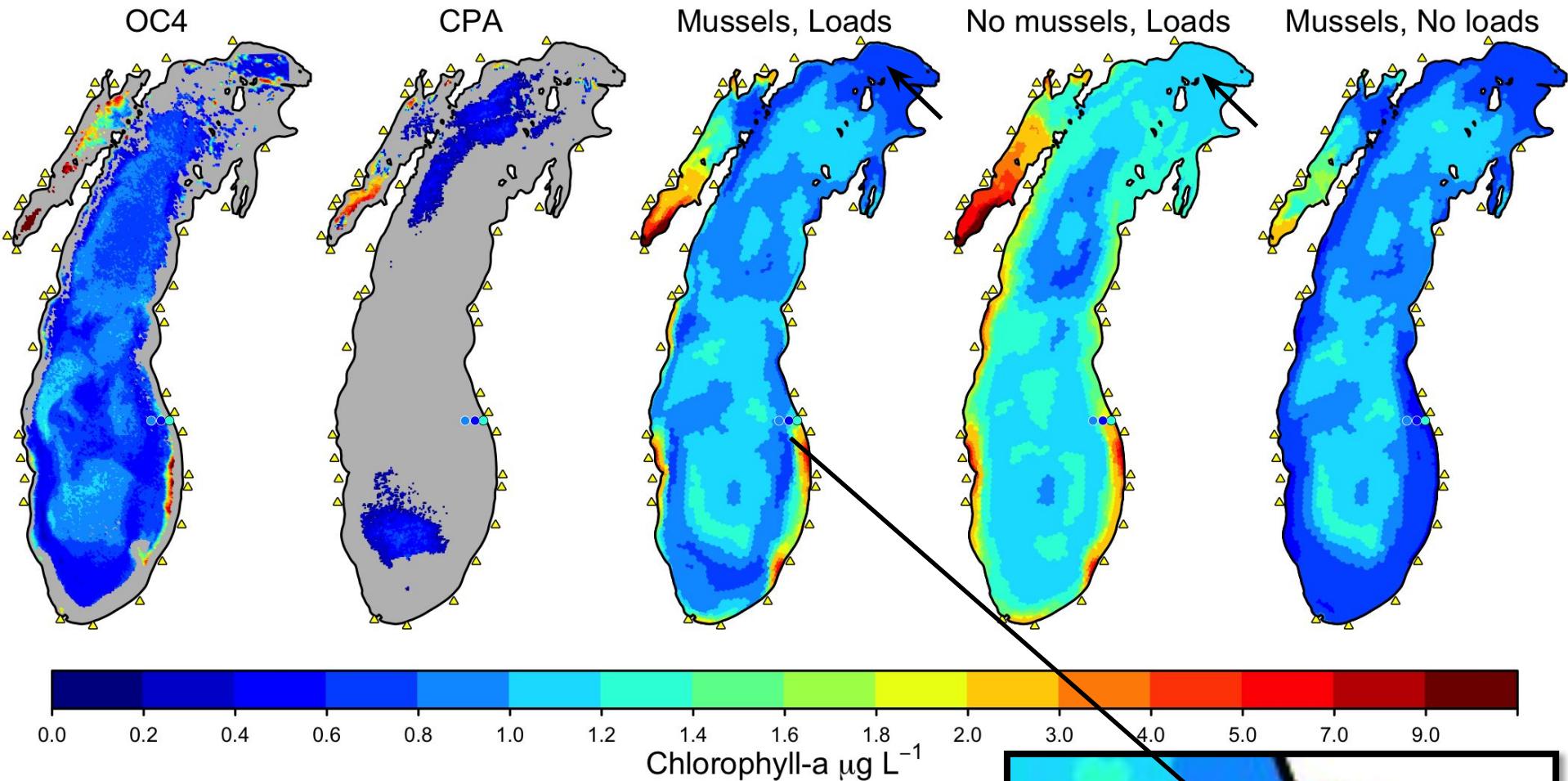


Effect of dreissenid mussels

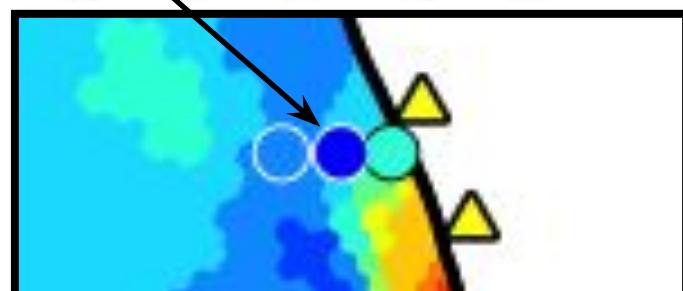
April 22, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

Satellite

3D Biophysical model



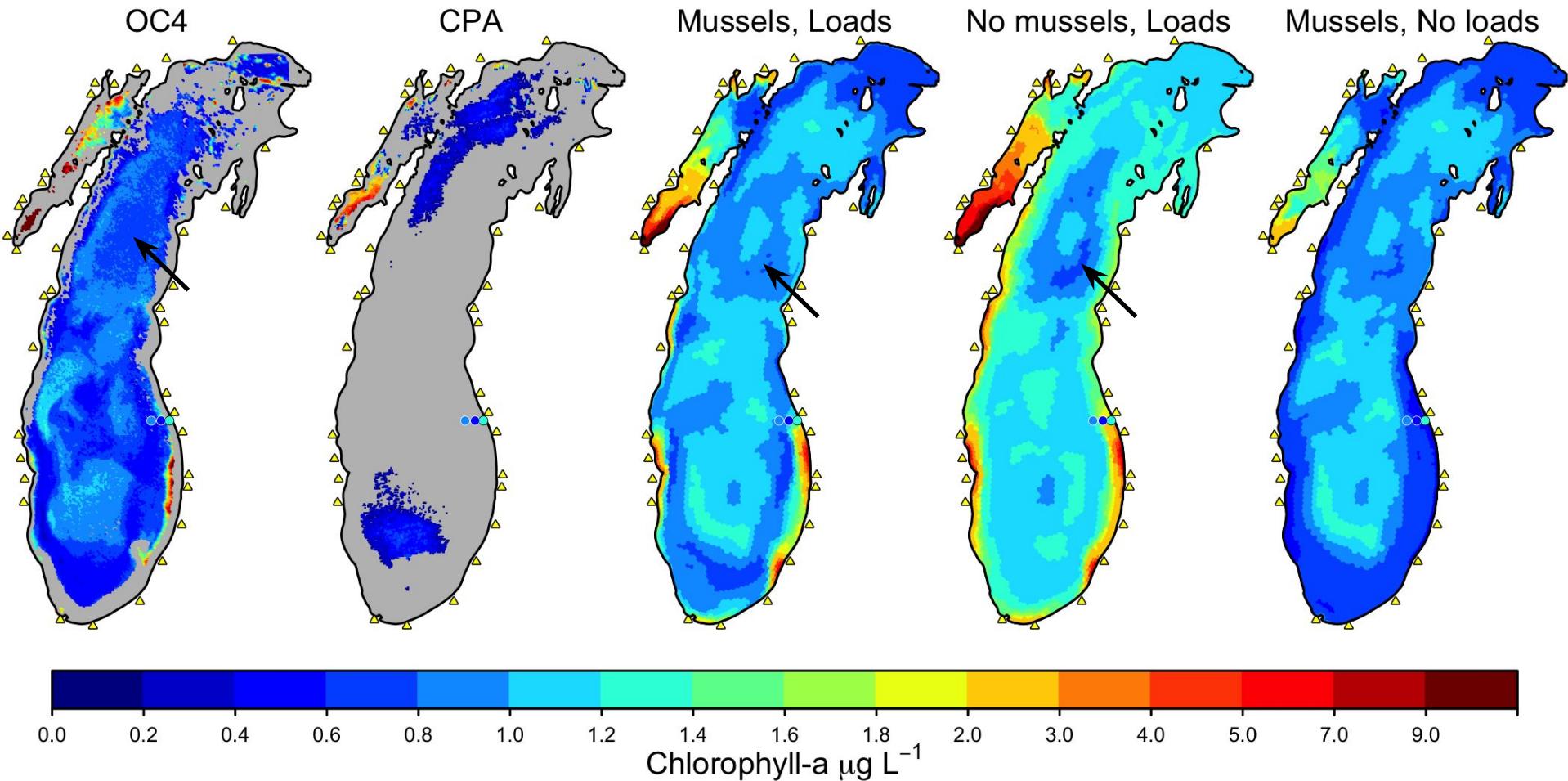
Muskegon transect observations:
Lowest chlorophyll at 45-m station



April 22, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

Satellite

| 3D Biophysical model

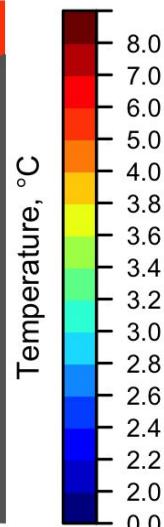
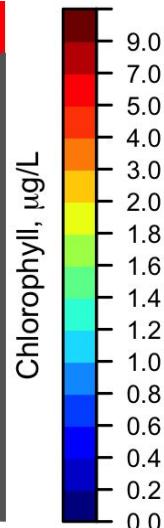
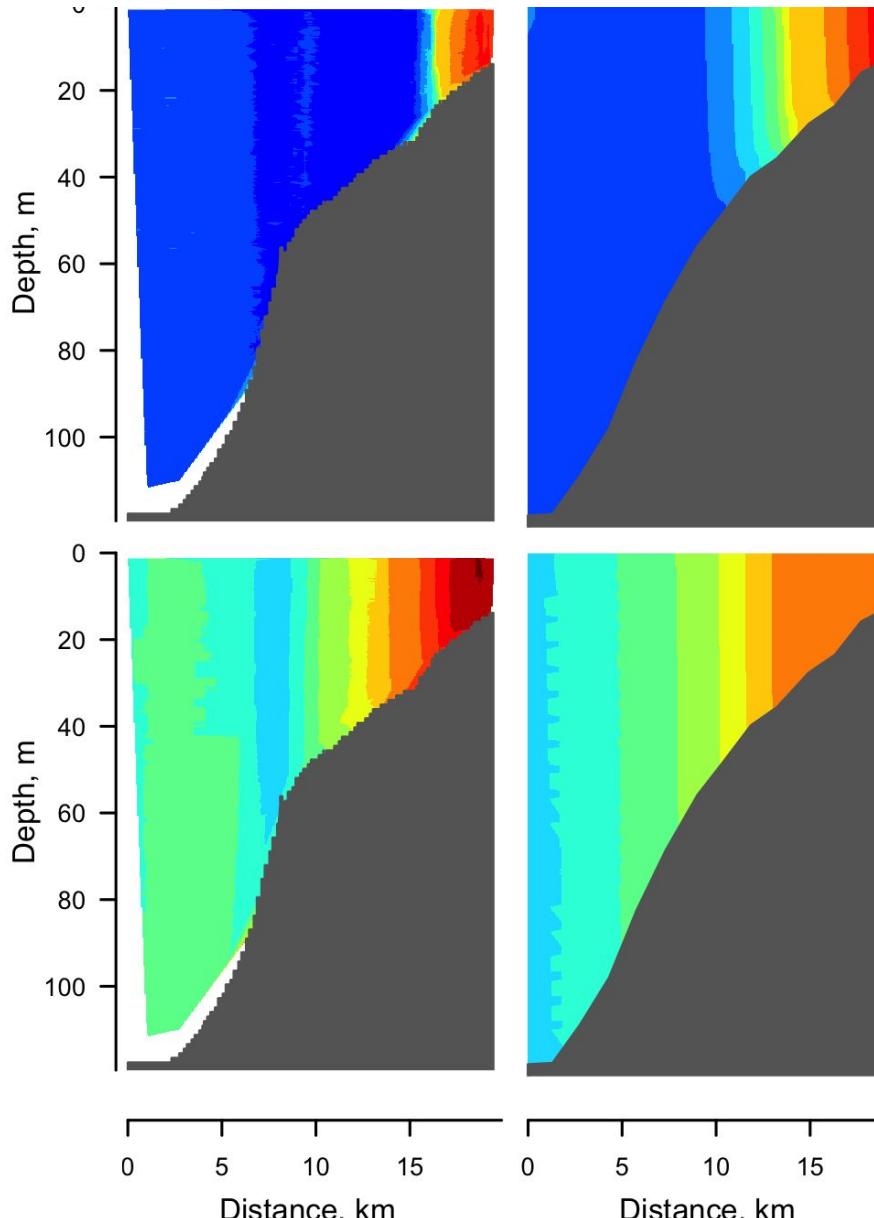


Effect of deep mixing

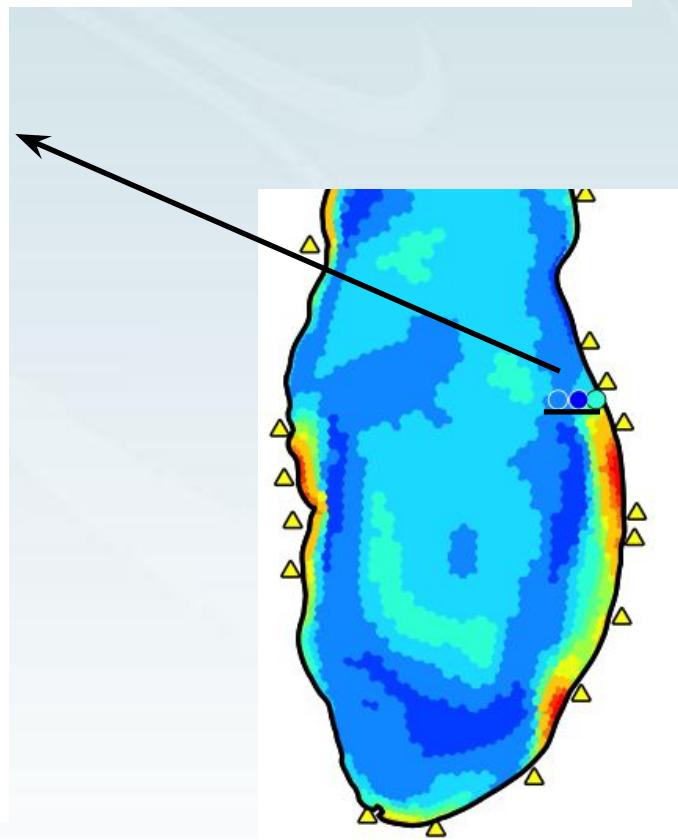
Plankton survey system

Model

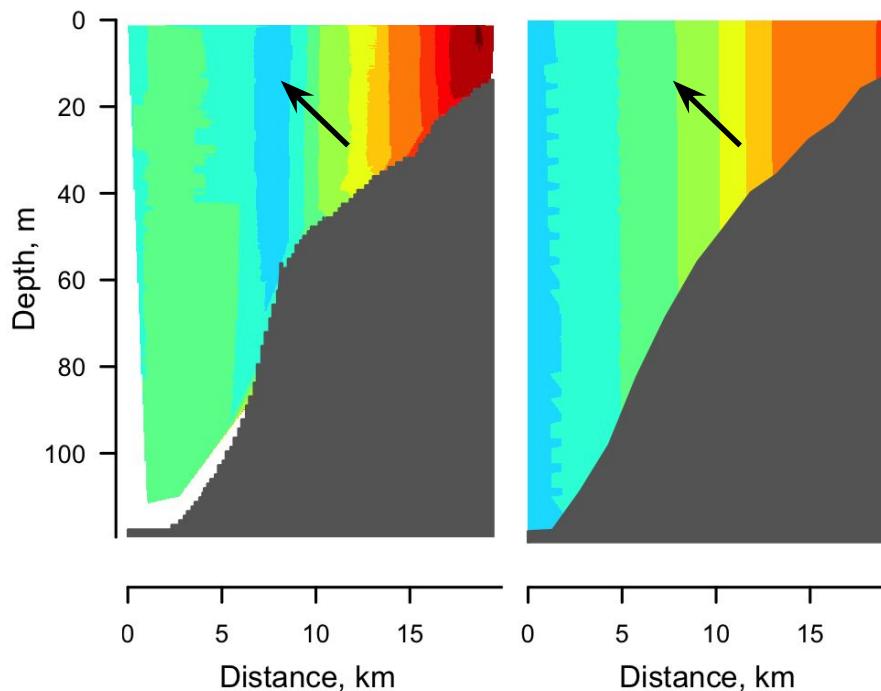
April 14, 2010



Fluorescence chlorophyll
and temperature from
Plankton Survey System
transect

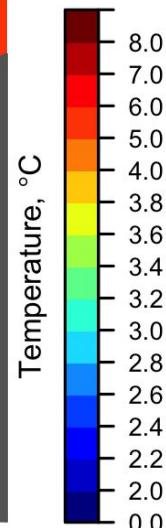


Plankton survey system



April 14, 2010

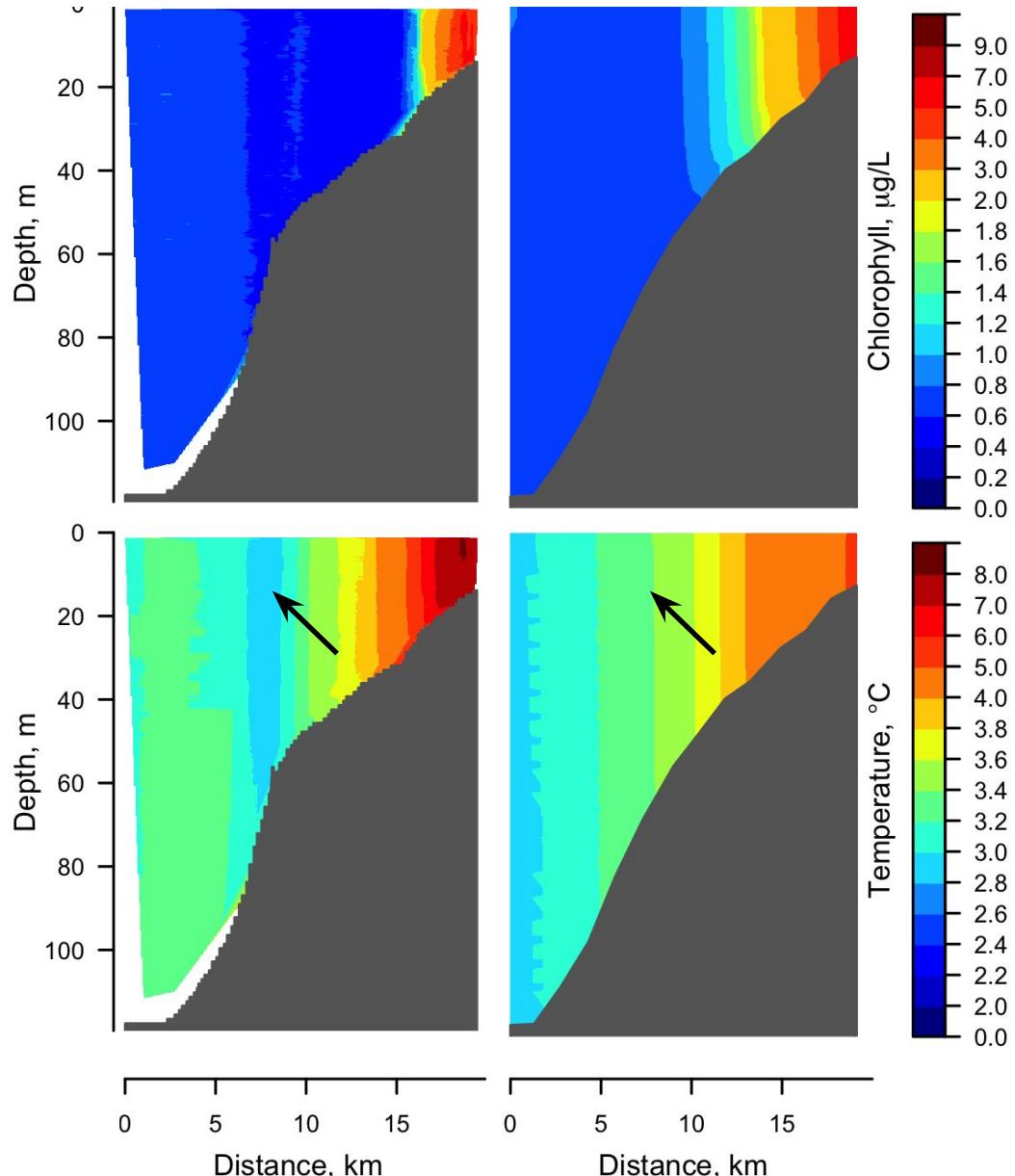
Isothermal deep mixing
mid-depth and offshore



Plankton survey system

Model

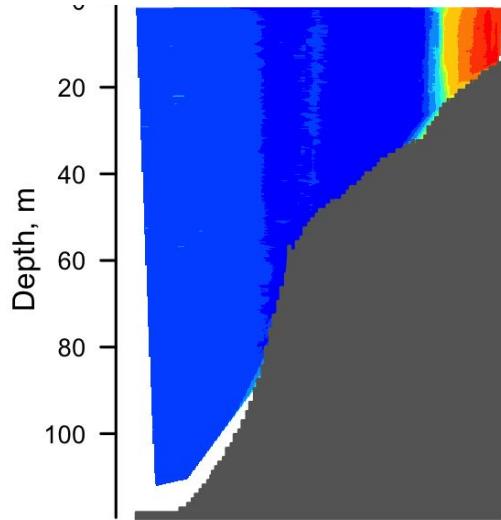
April 14, 2010



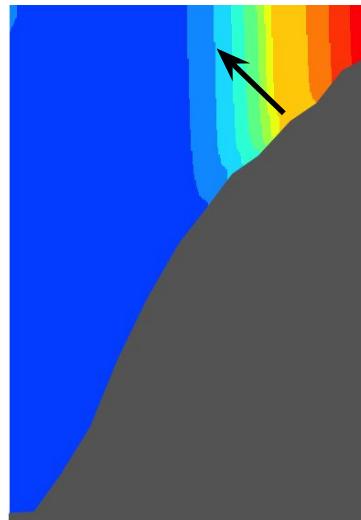
Isothermal deep mixing
mid-depth and offshore

April 14, 2010

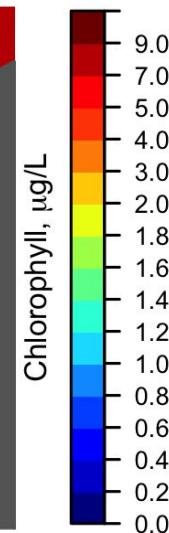
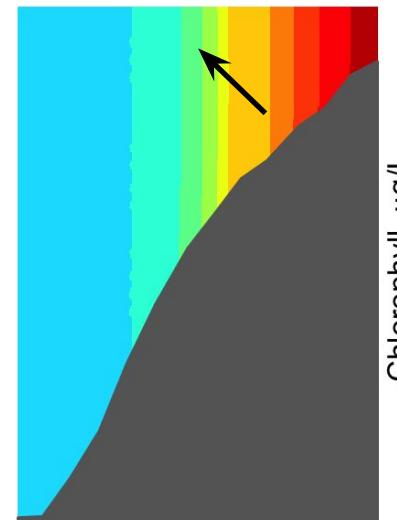
Plankton survey system



Mussels



No Mussels



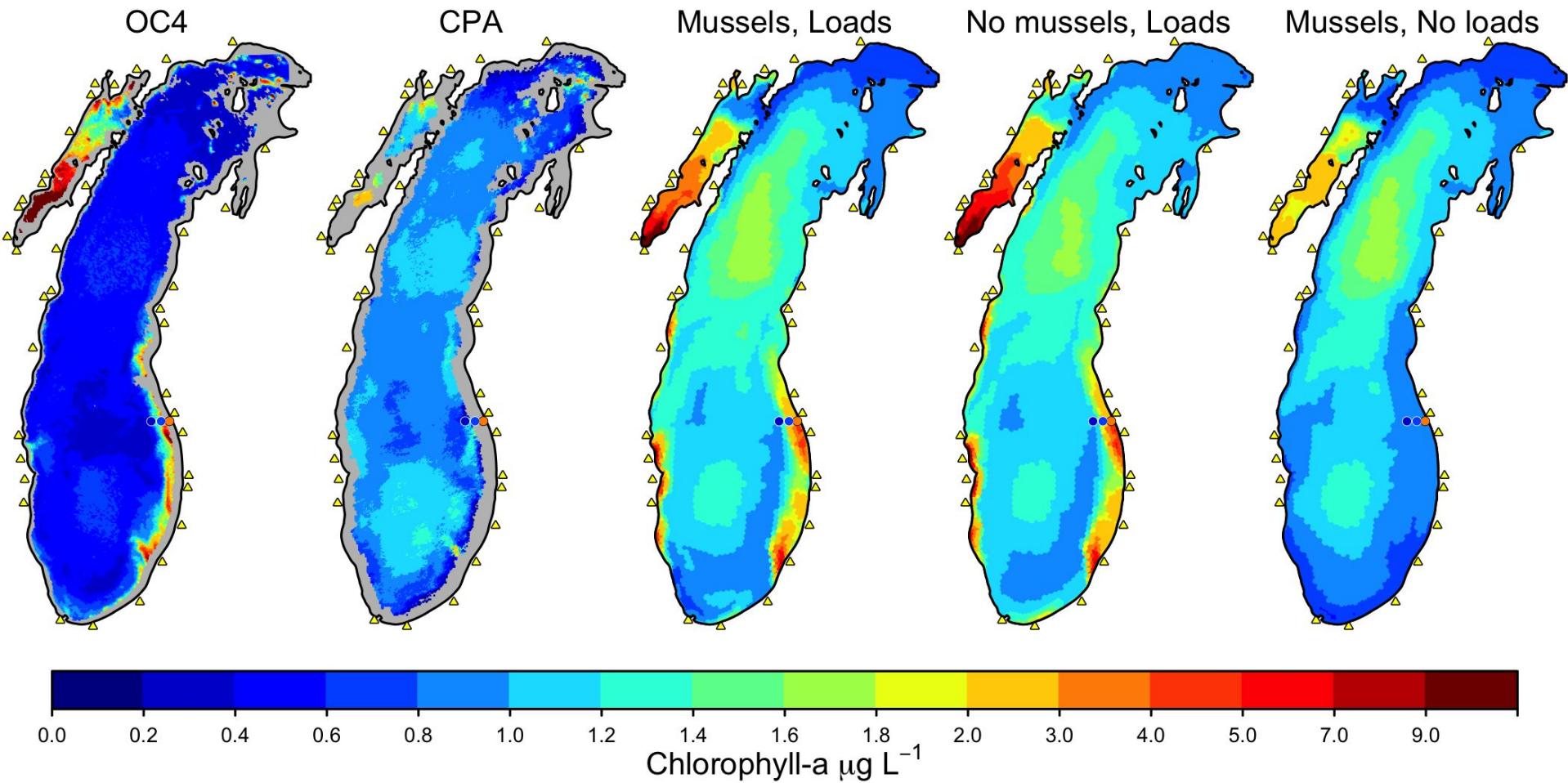
Dreissenid mussels reduced chlorophyll concentration in mid-depth and offshore regions where mussel biomass is high and mixed layer contacted the bottom

May - June Onset of summer stratification

May 19, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

Satellite

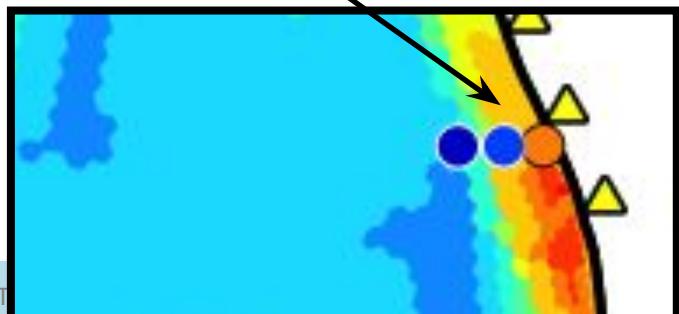
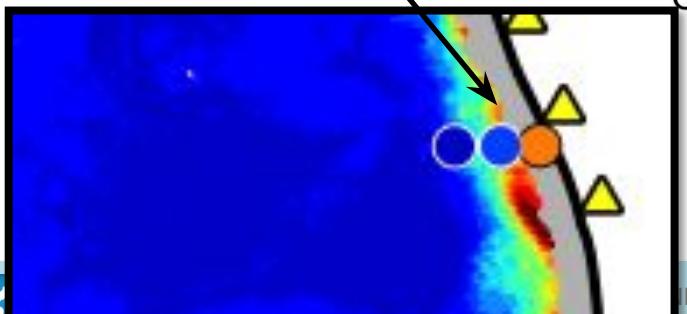
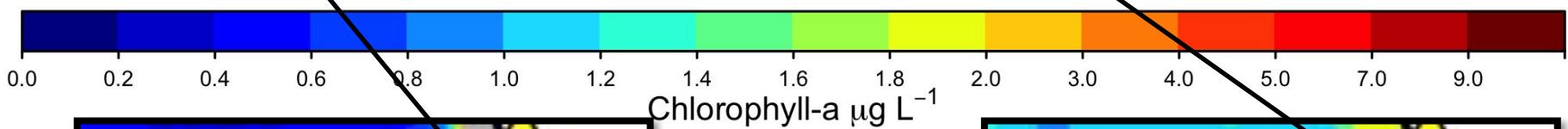
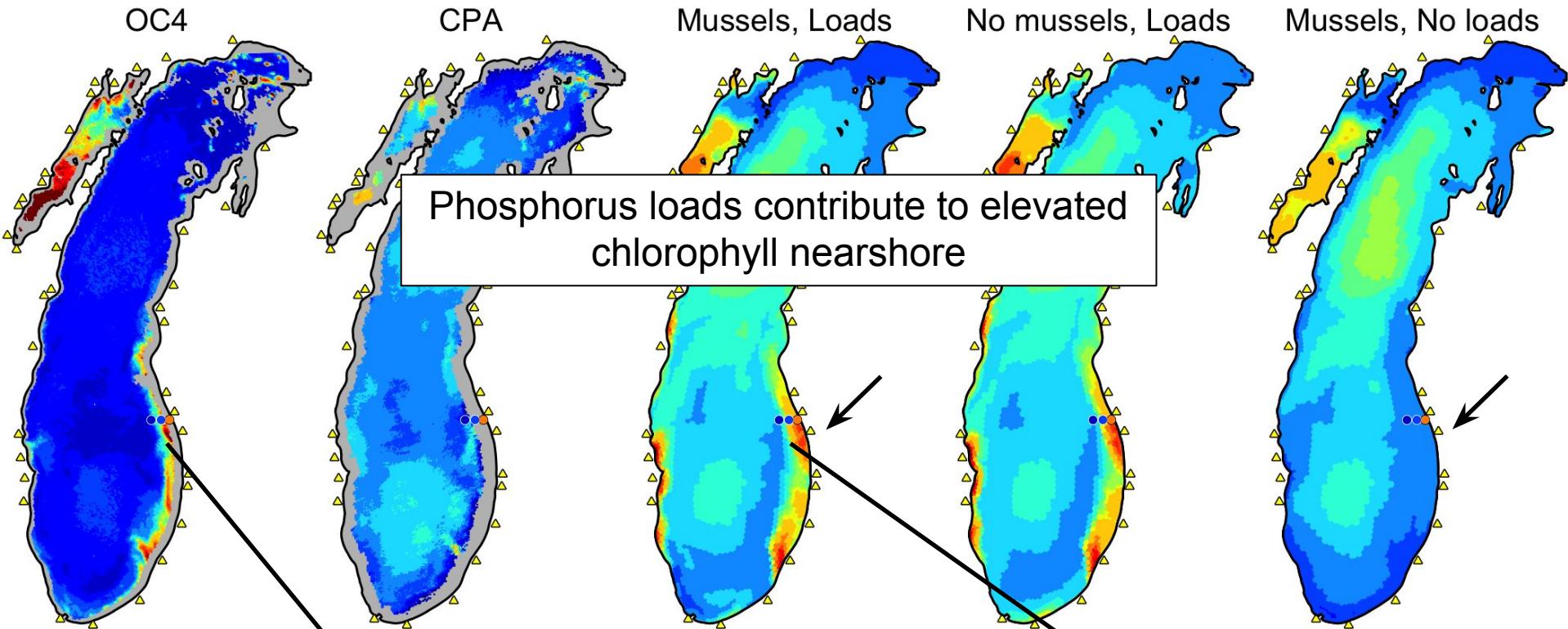
| 3D Biophysical model



May 19, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

Satellite

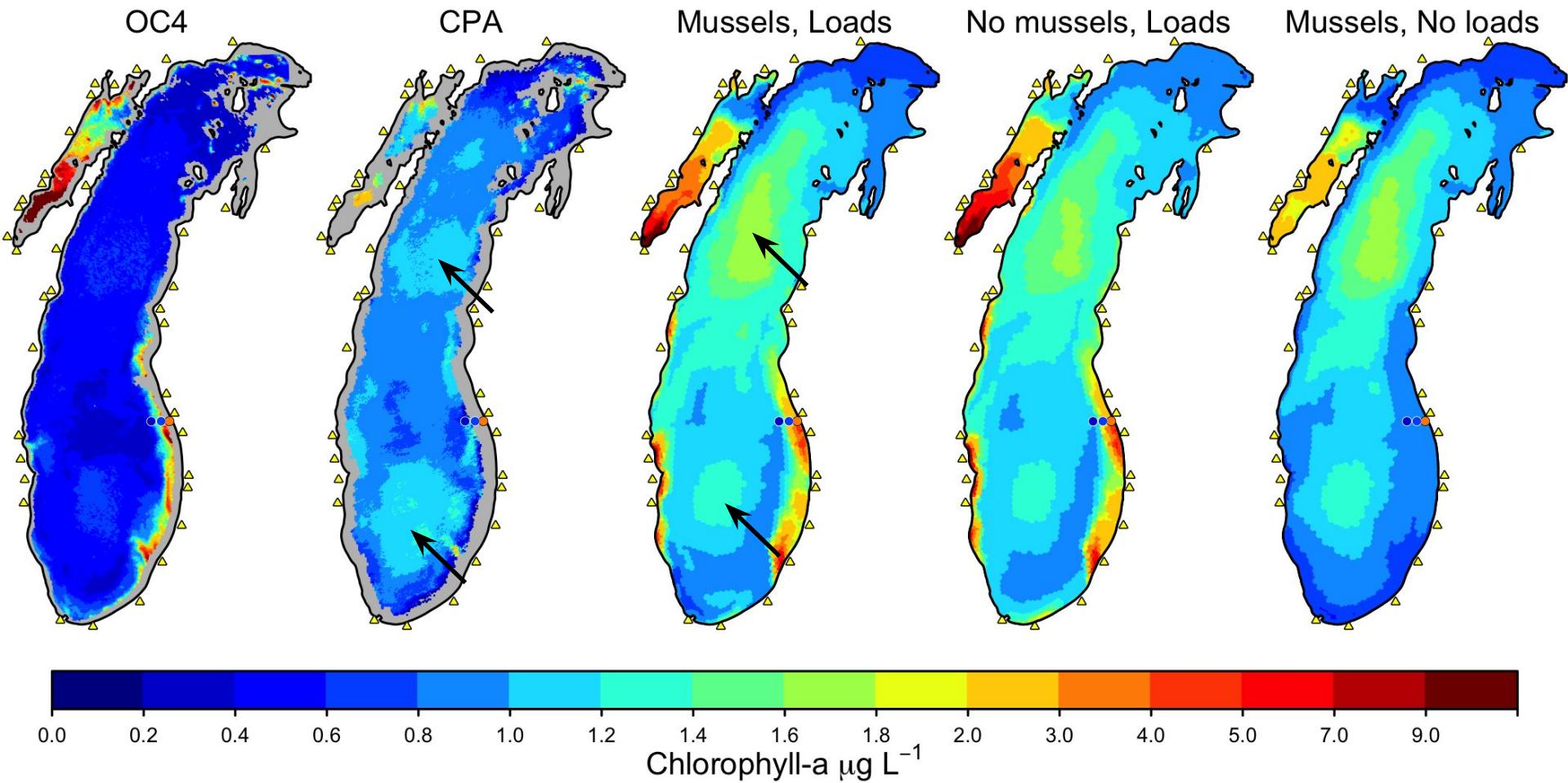
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May 19, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

Satellite

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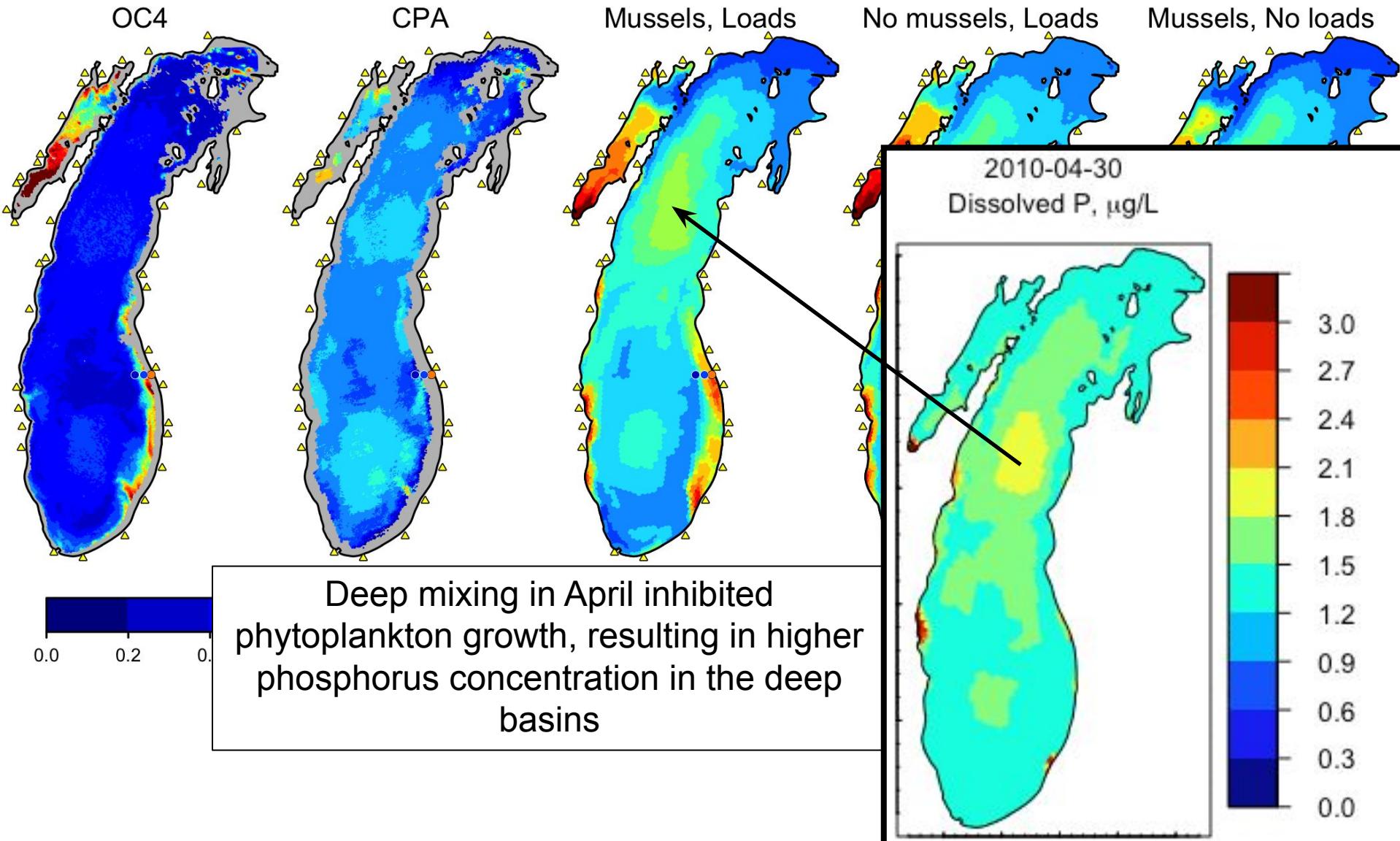


Elevated chlorophyll in the deep basins at
the onset of summer stratification

May 19, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

Satellite

| 3D Biophysical model



June 22, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

Satellite

| 3D Biophysical model

OC4

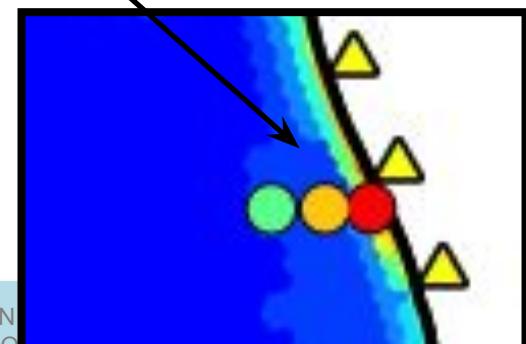
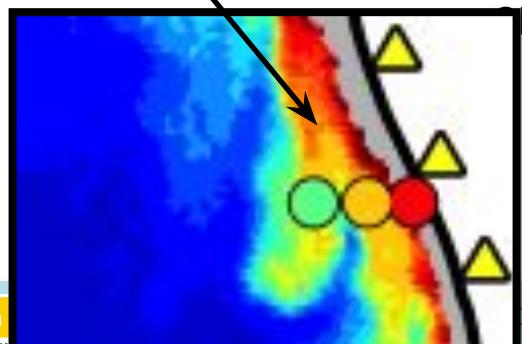
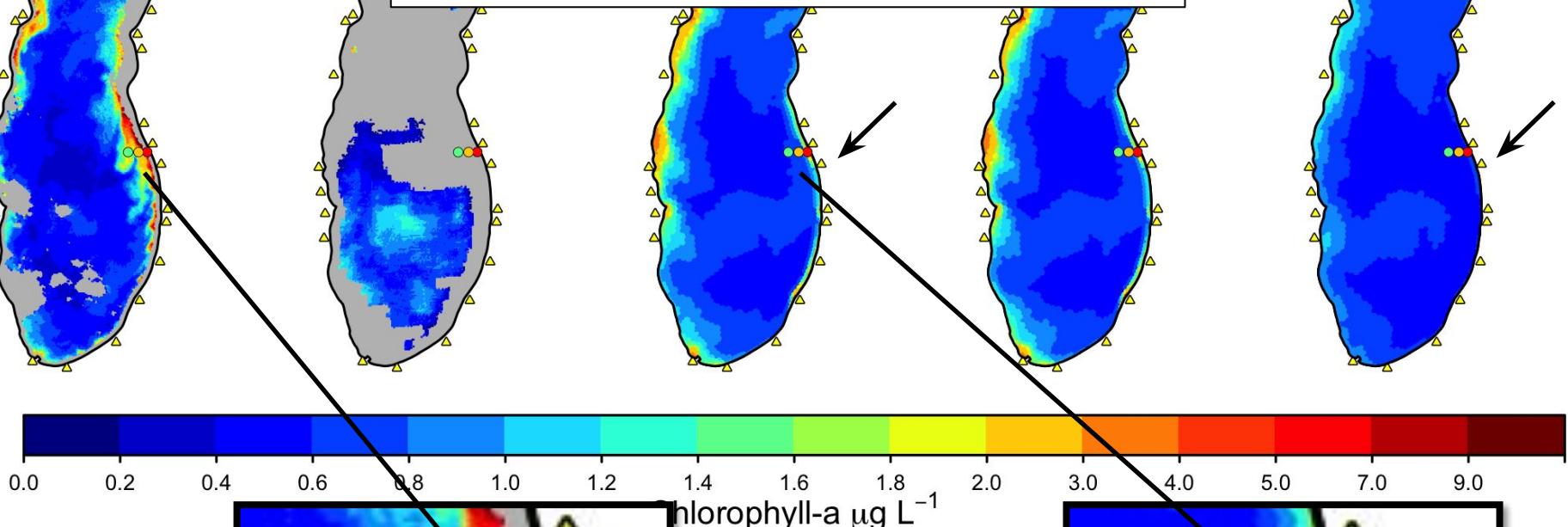
CPA

Mussels, Loads

No mussels, Loads

Mussels, No loads

Phosphorus loads contribute to elevated chlorophyll nearshore

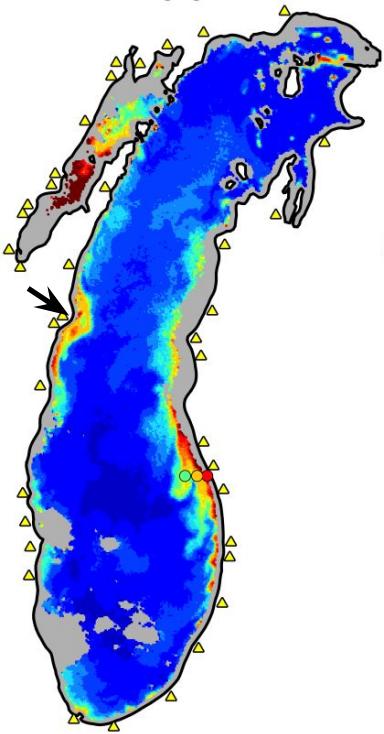


June 22, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

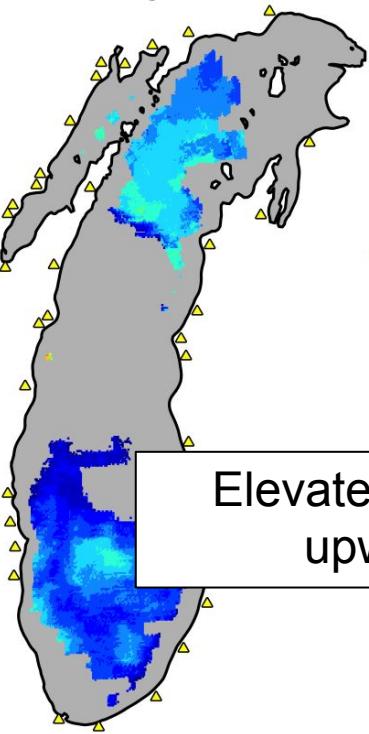
Satellite

| 3D Biophysical model

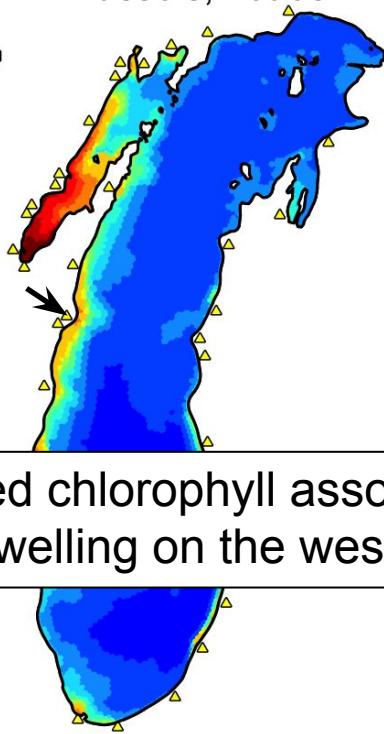
OC4



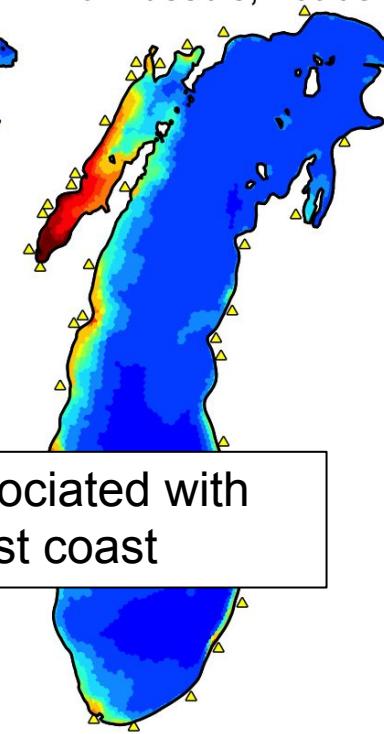
CPA



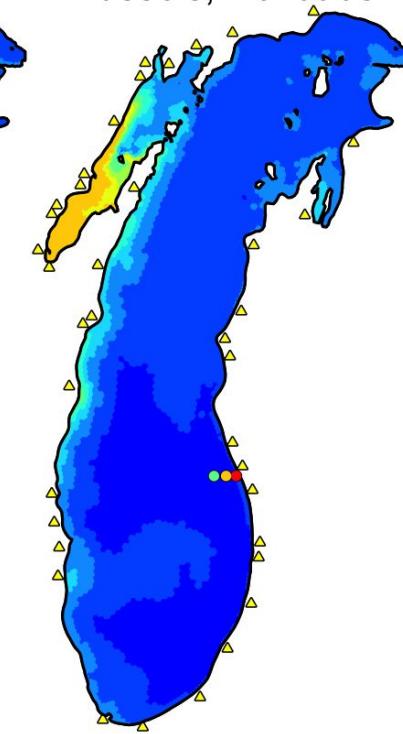
Mussels, Loads



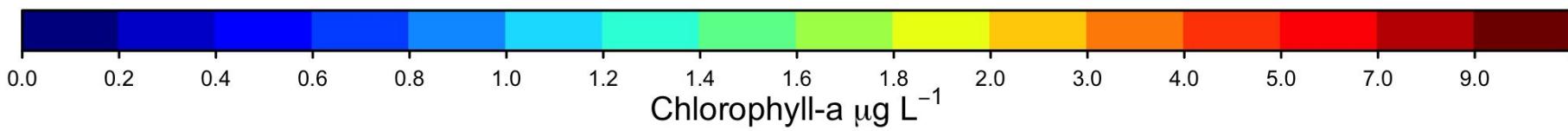
No mussels, Loads



Mussels, No loads



Elevated chlorophyll associated with
upwelling on the west coast



July – August Summer stratification Coastal upwelling

July 26, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

Satellite

| 3D Biophysical model

OC4

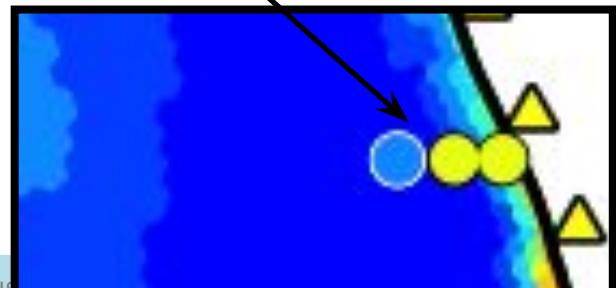
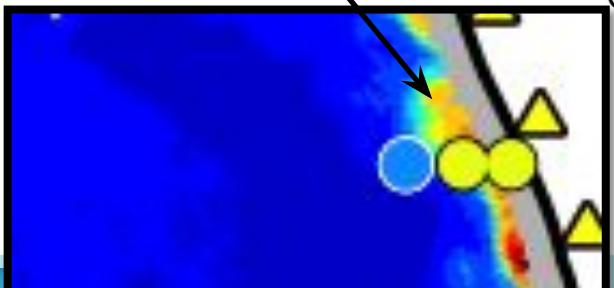
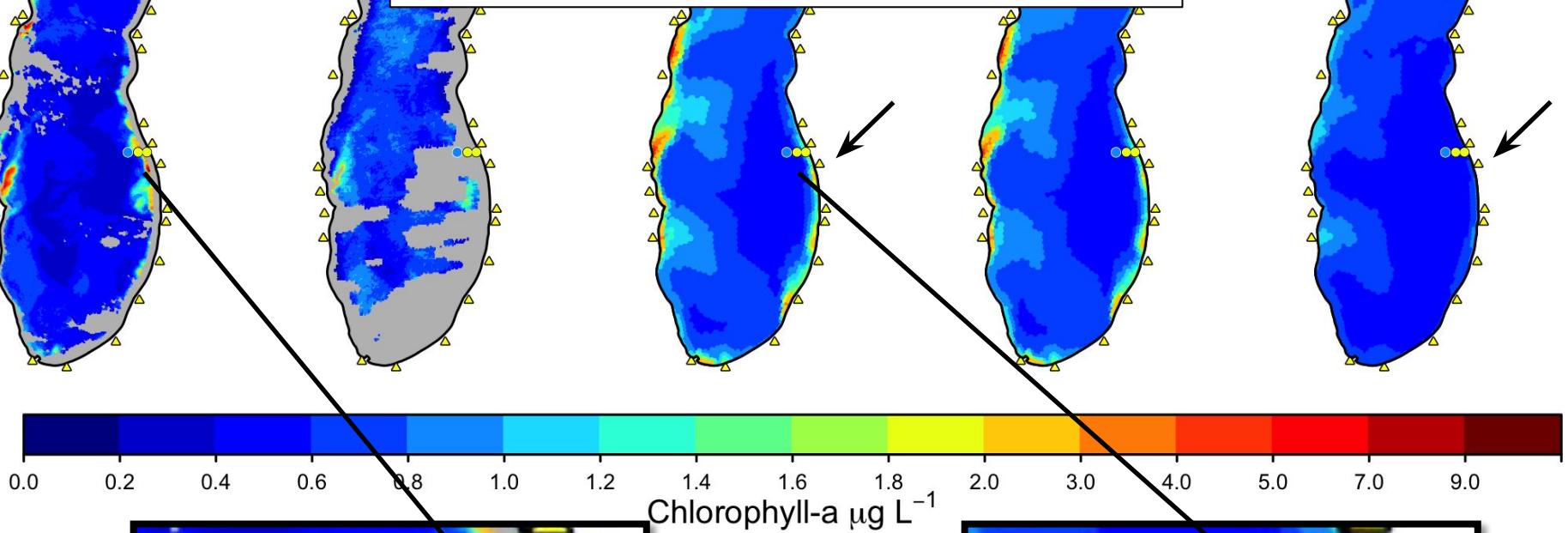
CPA

Mussels, Loads

No mussels, Loads

Mussels, No loads

Phosphorus loads contribute to elevated chlorophyll nearshore

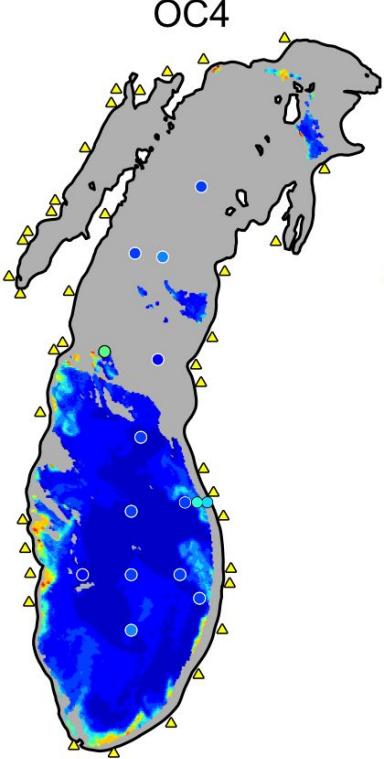


August 1, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

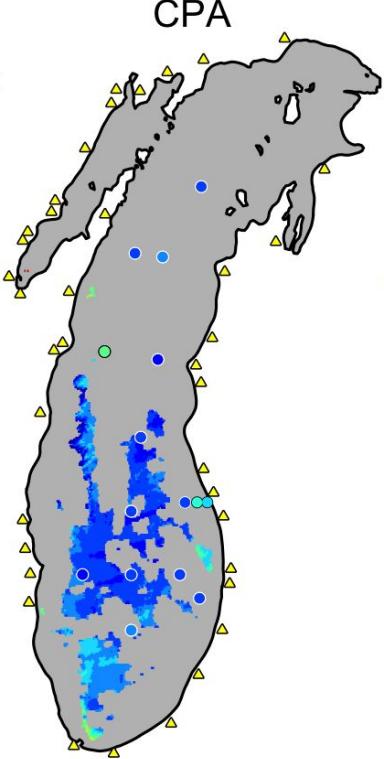
Satellite

| 3D Biophysical model

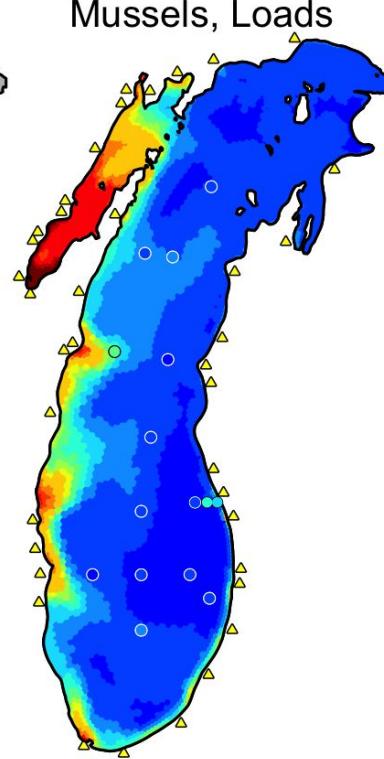
OC4



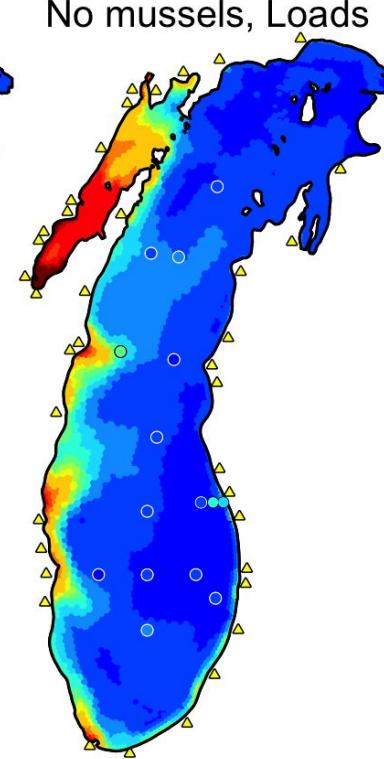
CPA



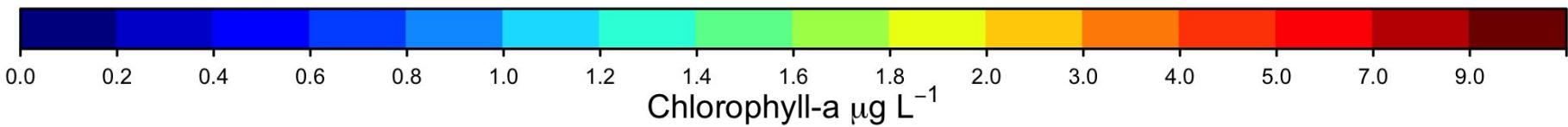
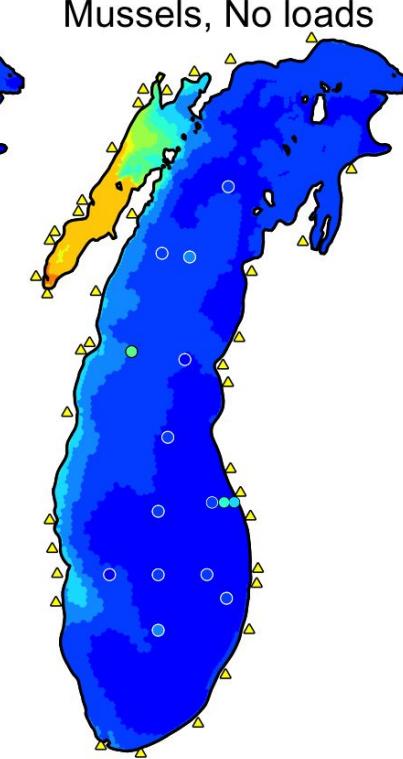
Mussels, Loads



No mussels, Loads



Mussels, No loads



West coast upwelling,
EPA GLNPO summer survey

August 1, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

Satellite

3D Biophysical model

OC4

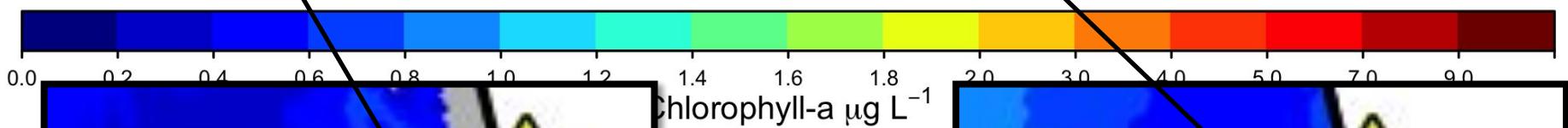
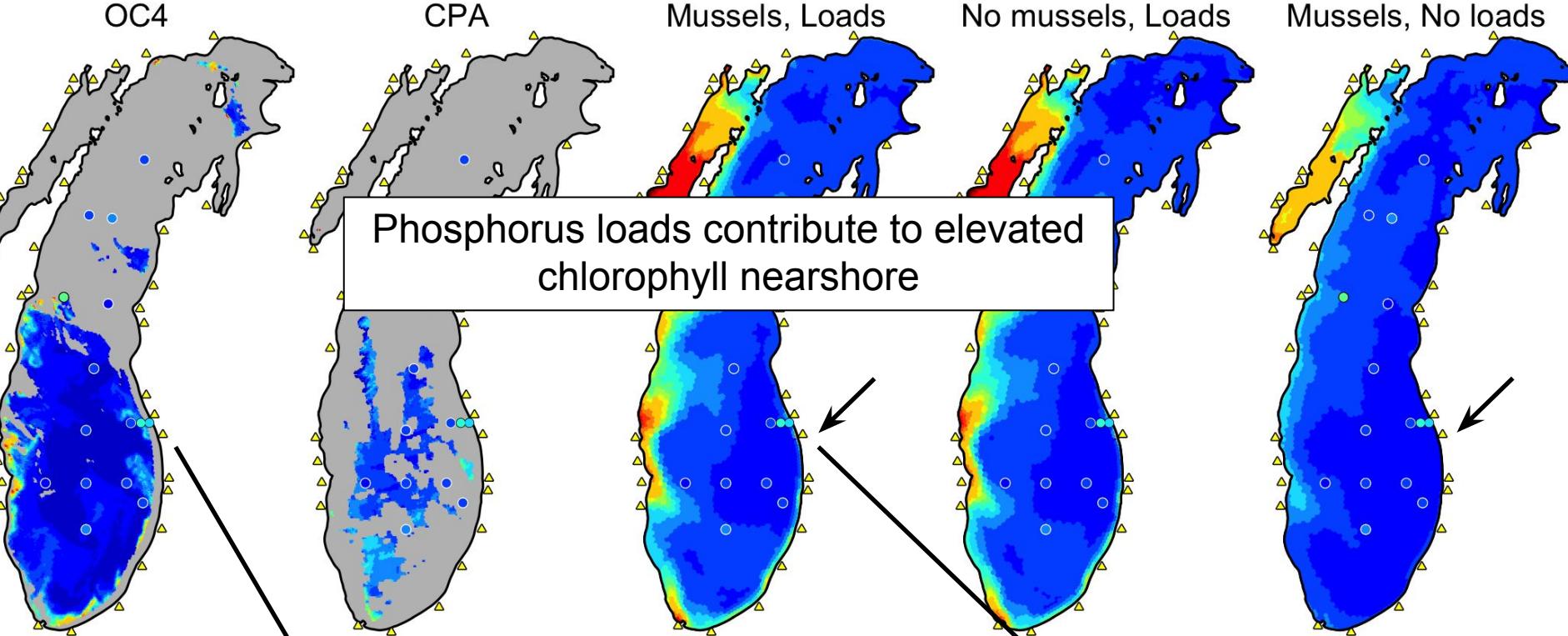
CPA

Mussels, Loads

No mussels, Loads

Mussels, No loads

Phosphorus loads contribute to elevated chlorophyll nearshore



August 1, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

Satellite

| 3D Biophysical model

OC4

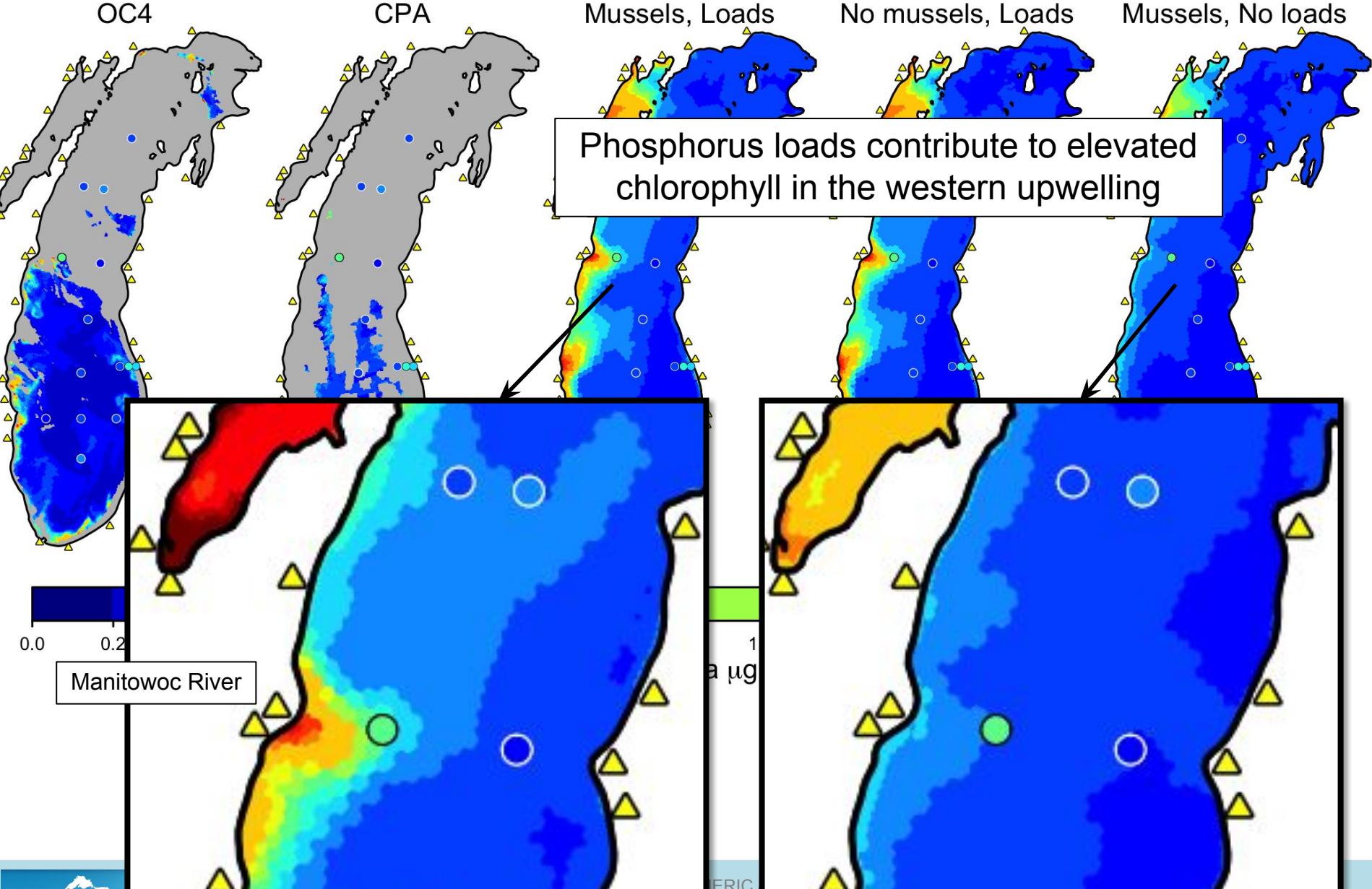
CPA

Mussels, Loads

No mussels, Loads

Mussels, No loads

Phosphorus loads contribute to elevated chlorophyll in the western upwelling



August 5, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

Satellite

| 3D Biophysical model

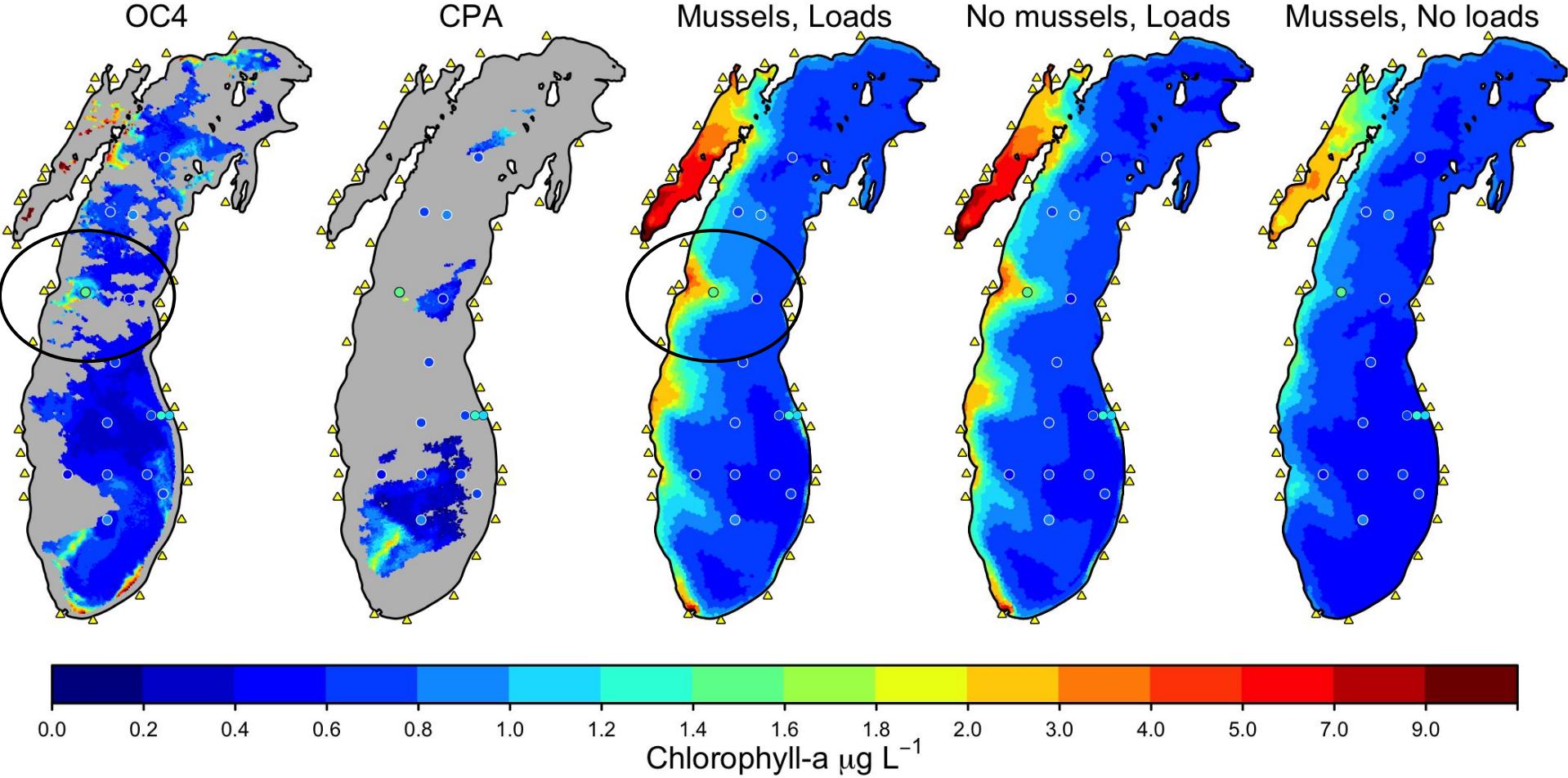
OC4

CPA

Mussels, Loads

No mussels, Loads

Mussels, No loads



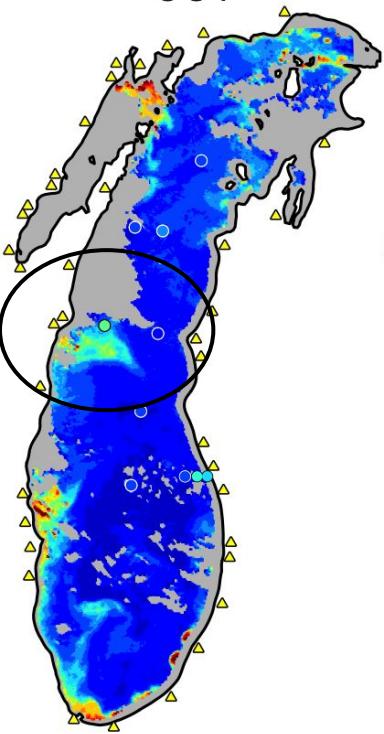
Eastward progression of the plume near
Manitowoc

August 8, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

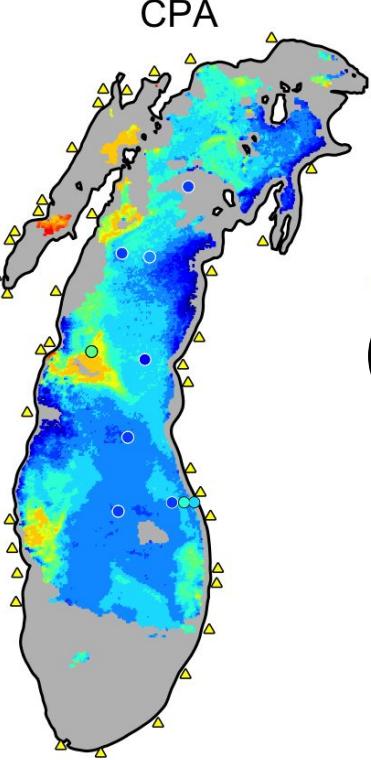
Satellite

| 3D Biophysical model

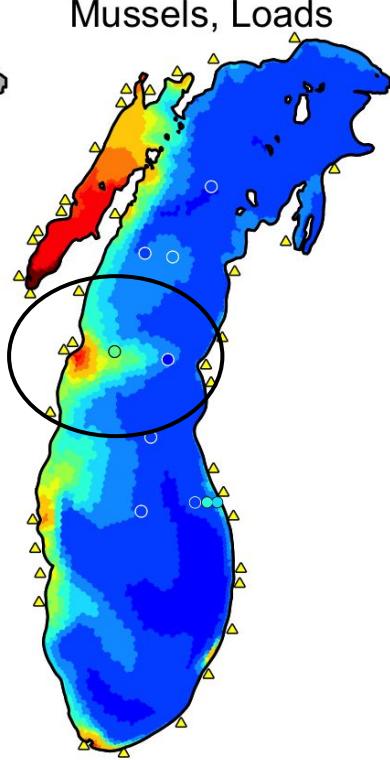
OC4



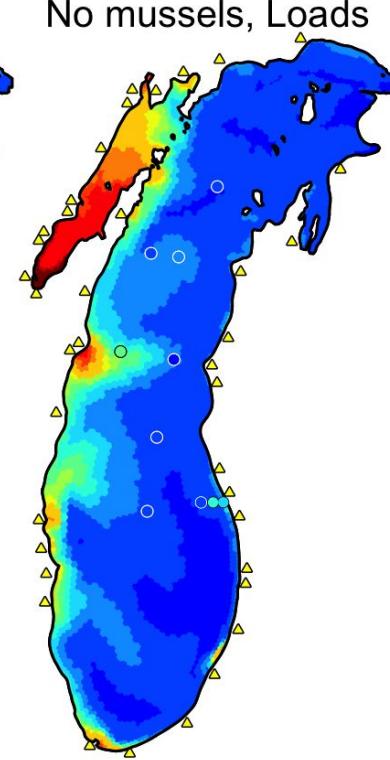
CPA



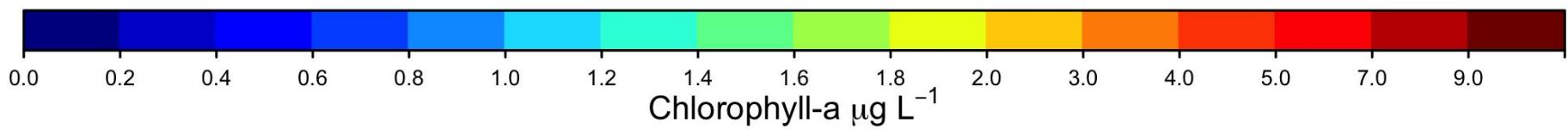
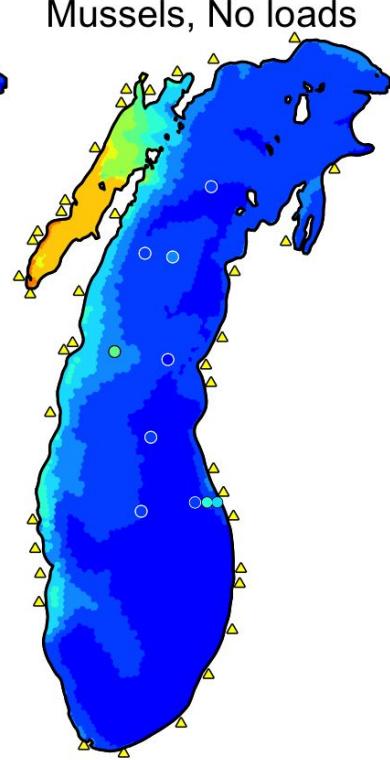
Mussels, Loads



No mussels, Loads



Mussels, No loads



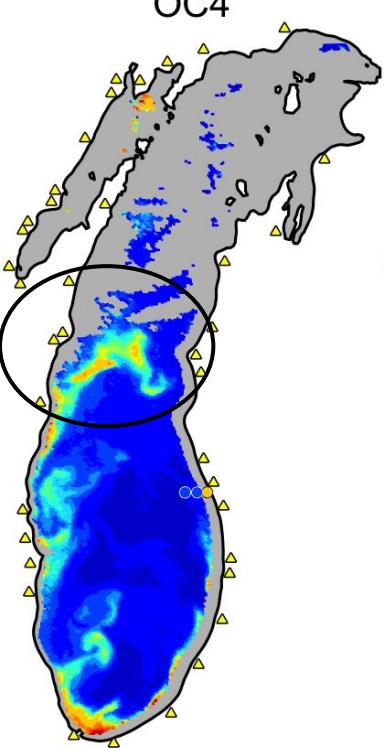
Eastward progression of the plume near
Manitowoc

August 15, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

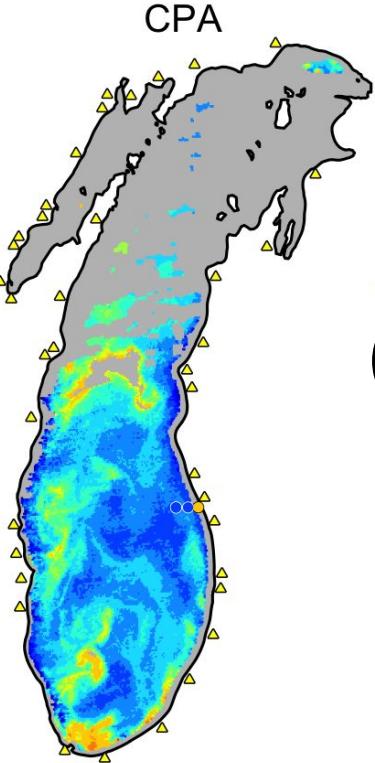
Satellite

| 3D Biophysical model

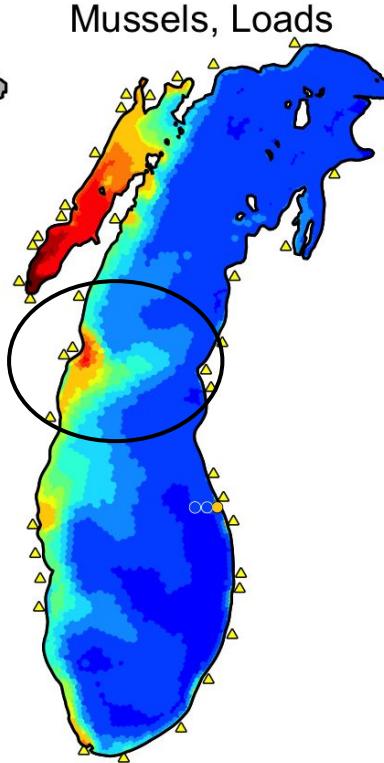
OC4



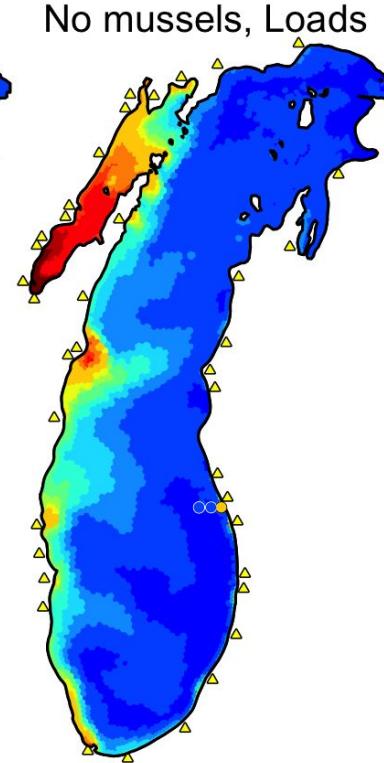
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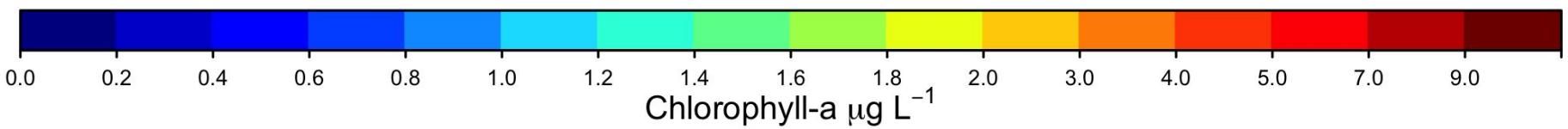
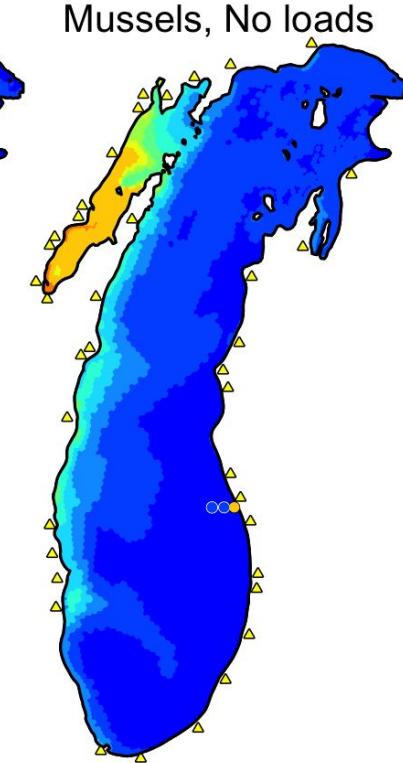
Mussels, Loads



No mussels, Loads



Mussels, No loads

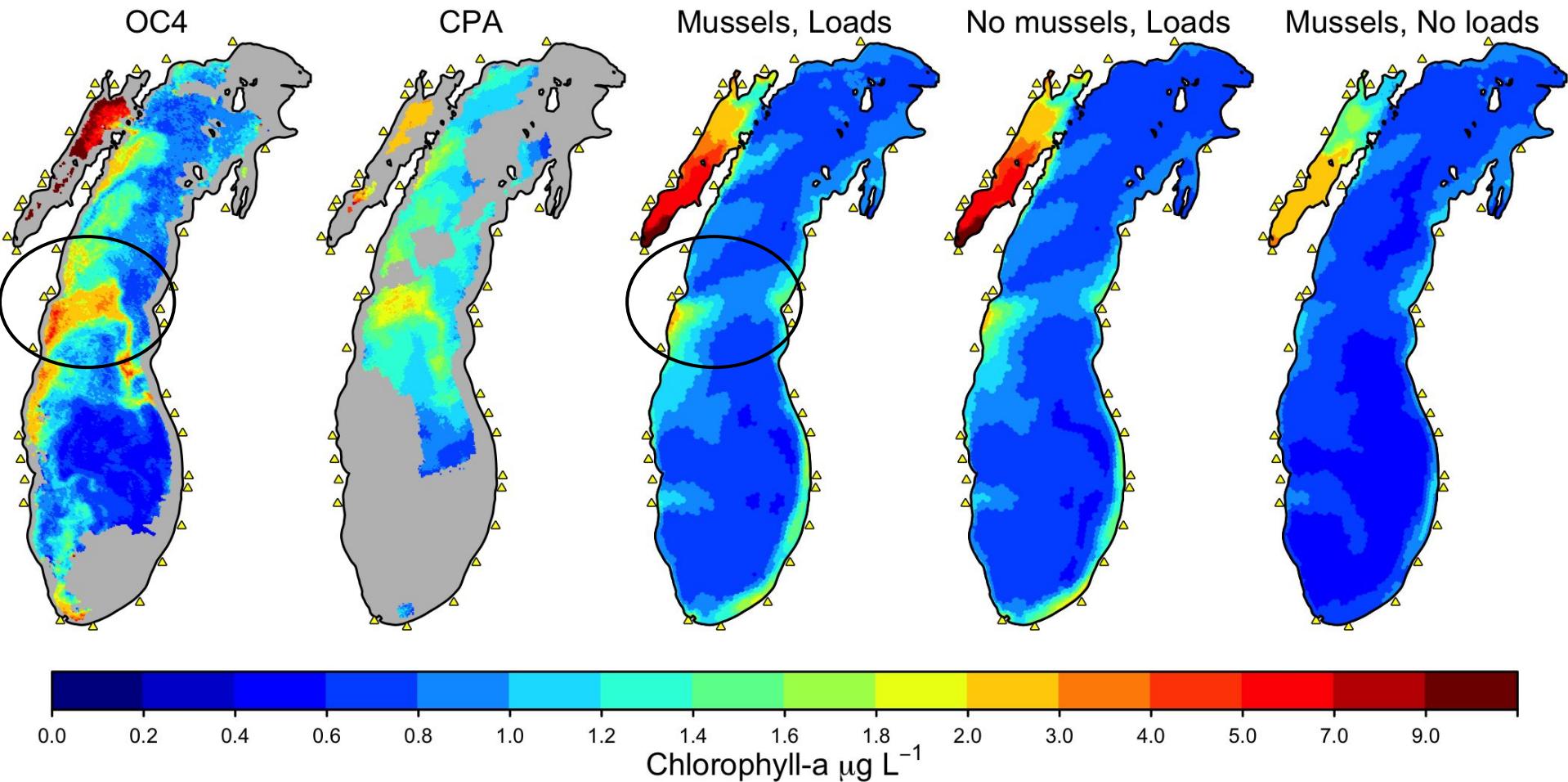


Eastward progression of the plume near
Manitowoc

August 23, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

Satellite

| 3D Biophysical model



Eastward progression of the plume near
Manitowoc

August 27, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

Satellite

| 3D Biophysical model

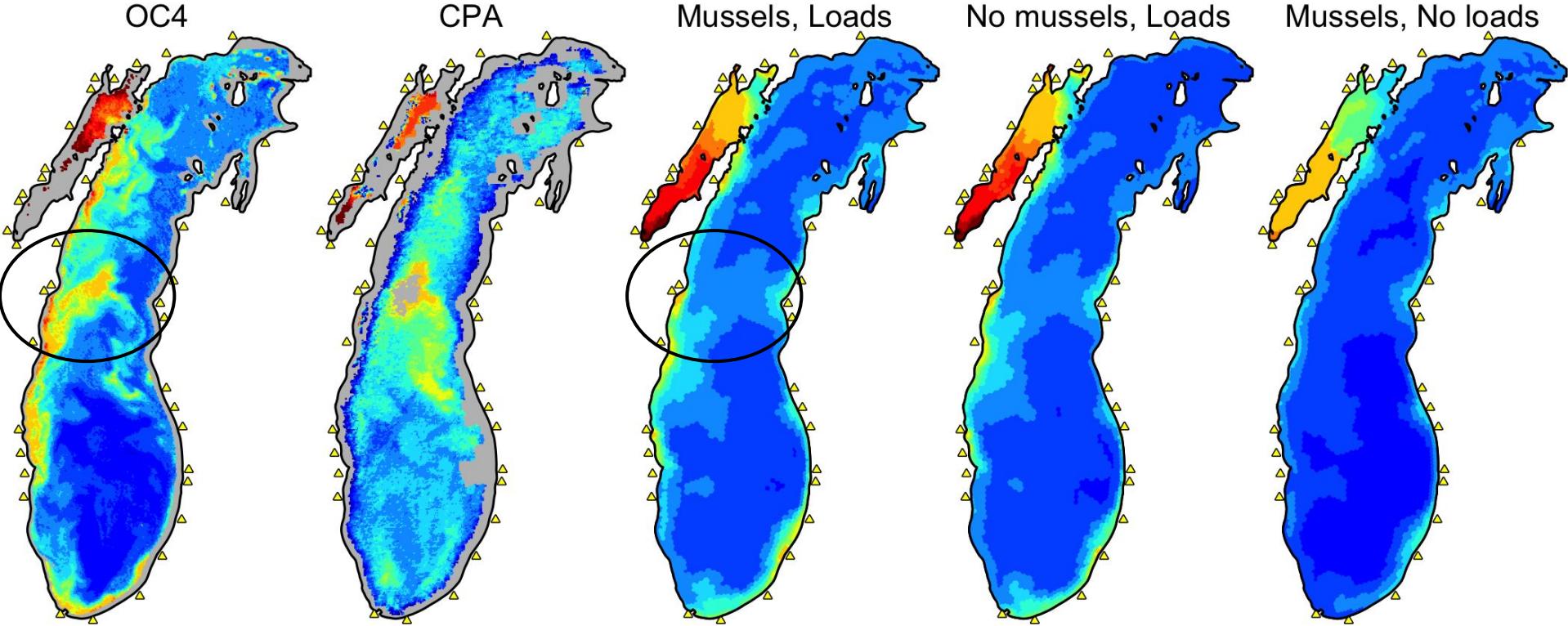
OC4

CPA

Mussels, Loads

No mussels, Loads

Mussels, No loads

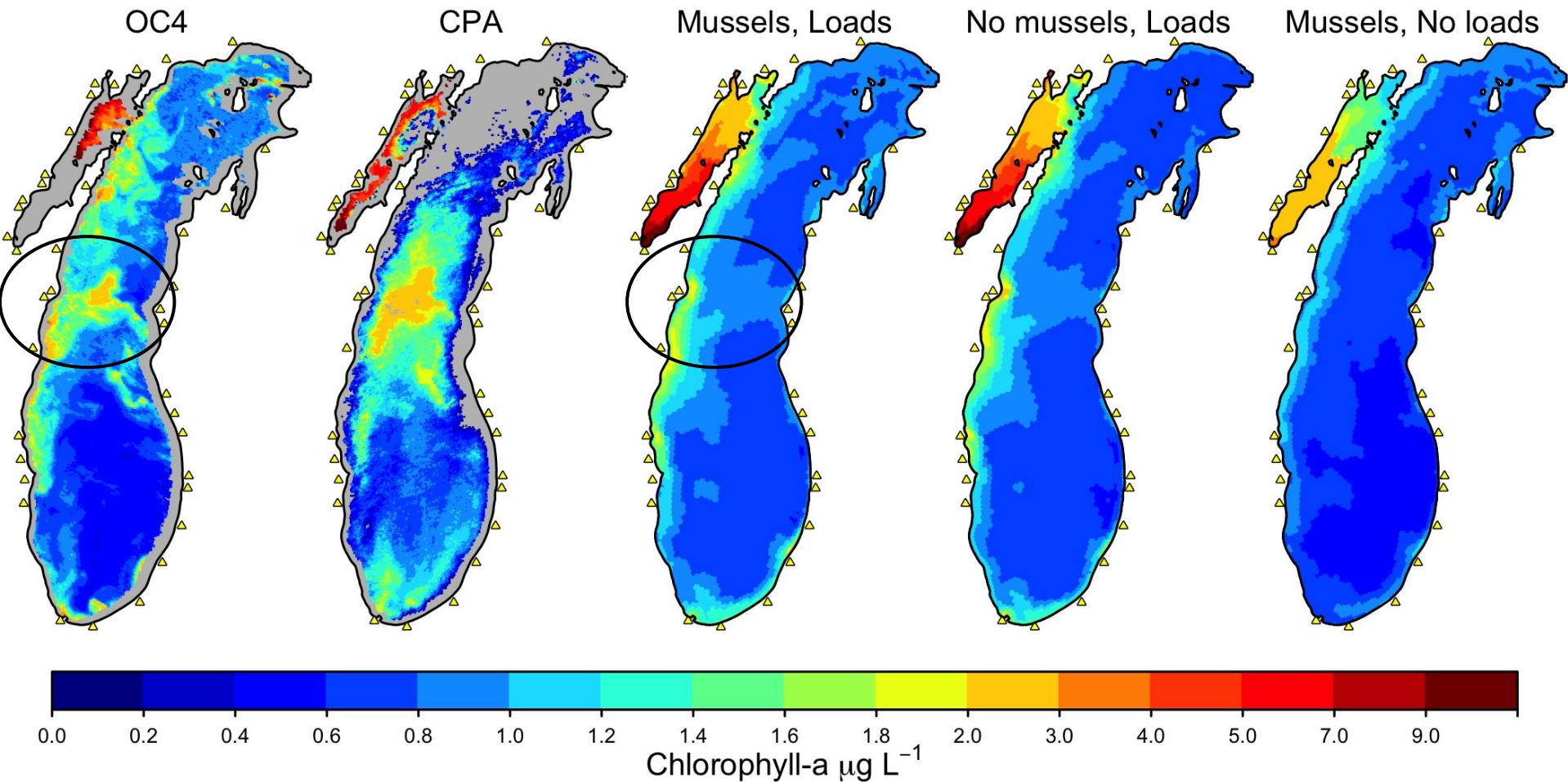


Eastward progression of the plume near
Manitowoc

August 28, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

Satellite

| 3D Biophysical model



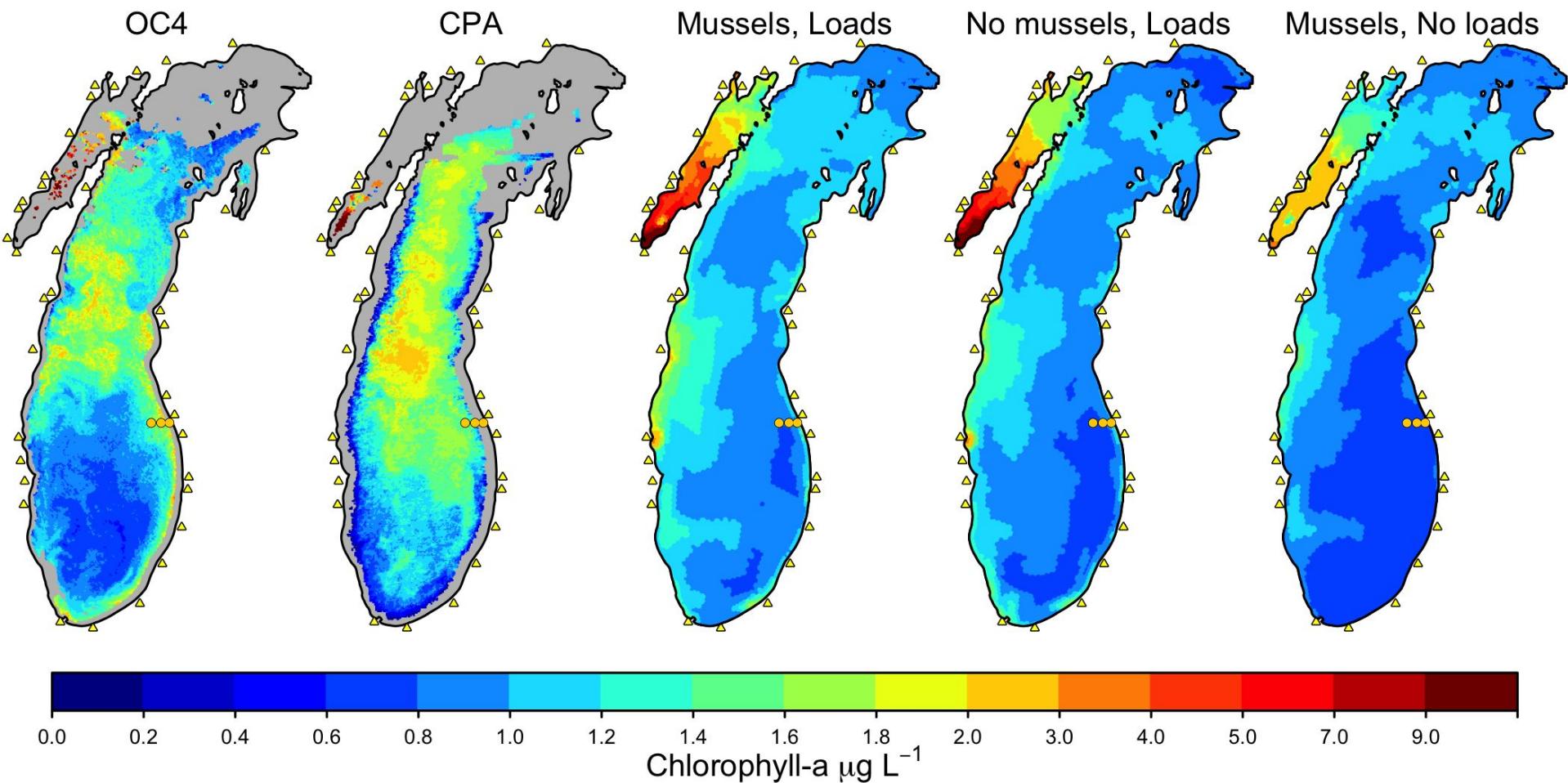
Eastward progression of the plume near
Manitowoc

September - October Deepening of the surface mixed layer

September 12, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

Satellite

3D Biophysical model

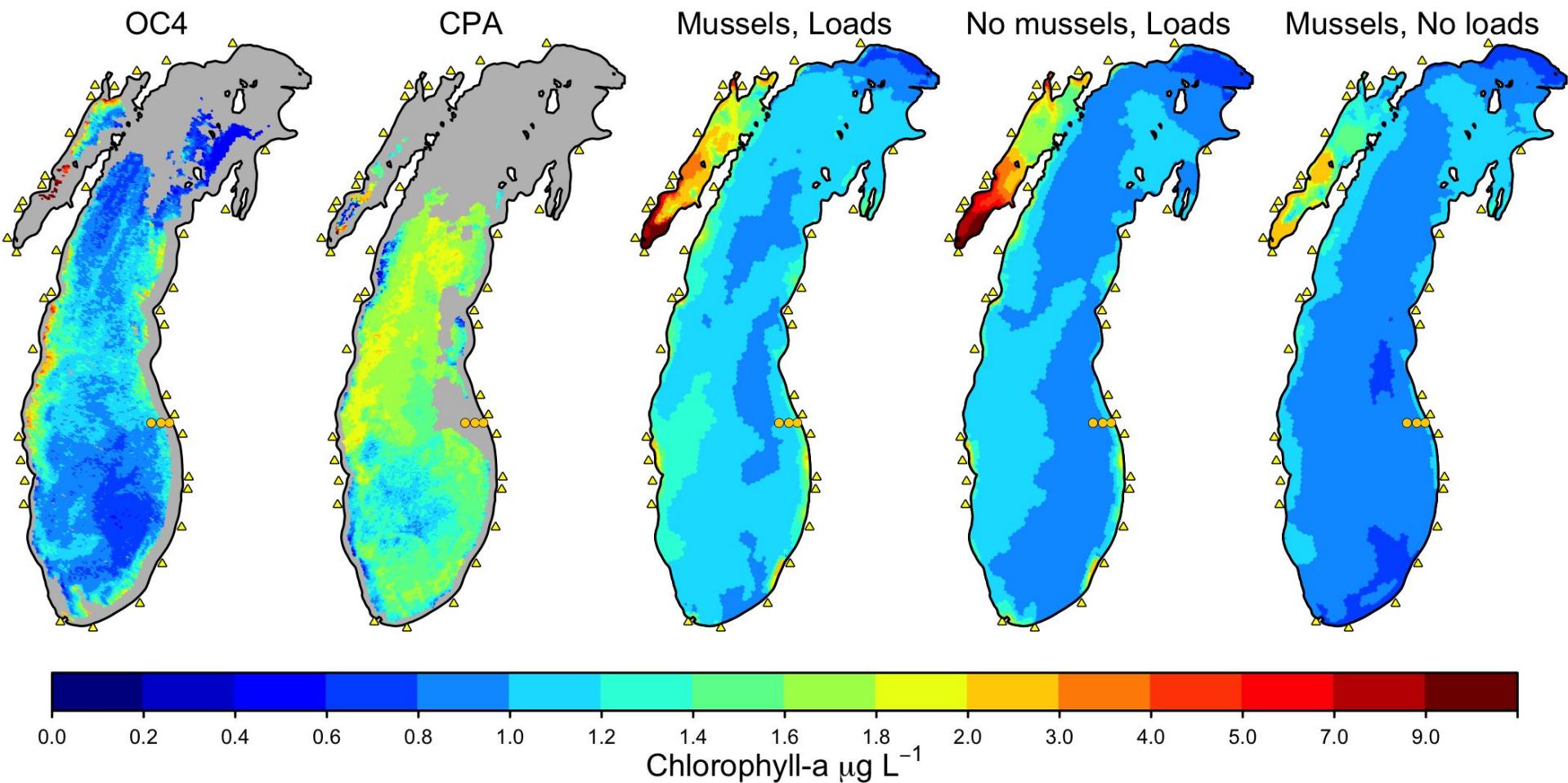


Deepening of the mixed layer brings
deep chlorophyll and nutrients to the
surface, enhancing surface chlorophyll

September 29, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

Satellite

3D Biophysical model

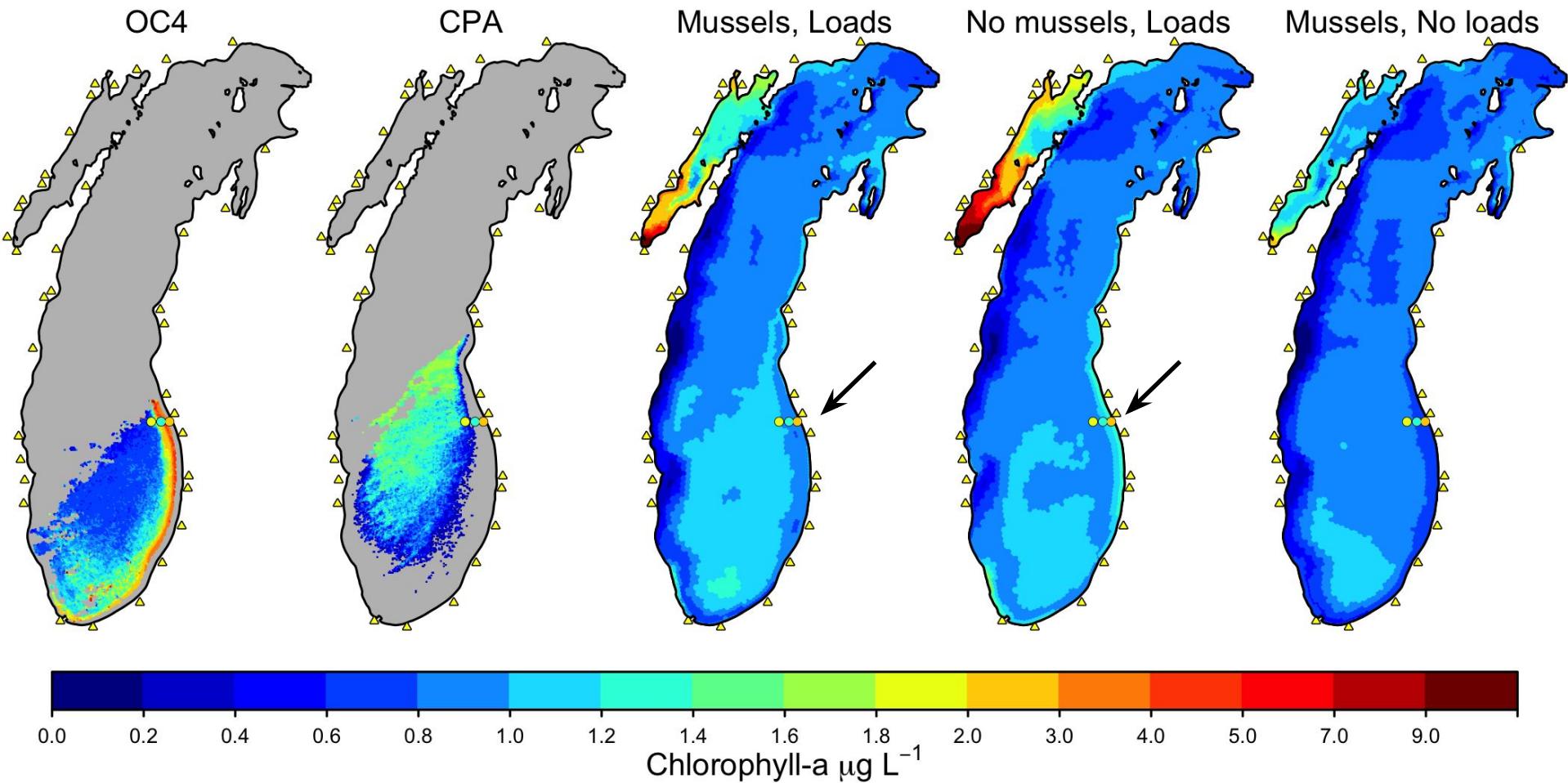


Deepening of the mixed layer brings deep chlorophyll and nutrients to the surface, enhancing surface chlorophyll

November Deepening mixed layer contacts the mussels

October 27, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

Satellite | 3D Biophysical model



Return of mussel effect:
Muskegon 45-m station has reduced
chlorophyll relative to 15 and 110-m stations

November 3, 2010 Lake Michigan Chlorophyll concentration, $\mu\text{g/L}$

Satellite

| 3D Biophysical model

OC4

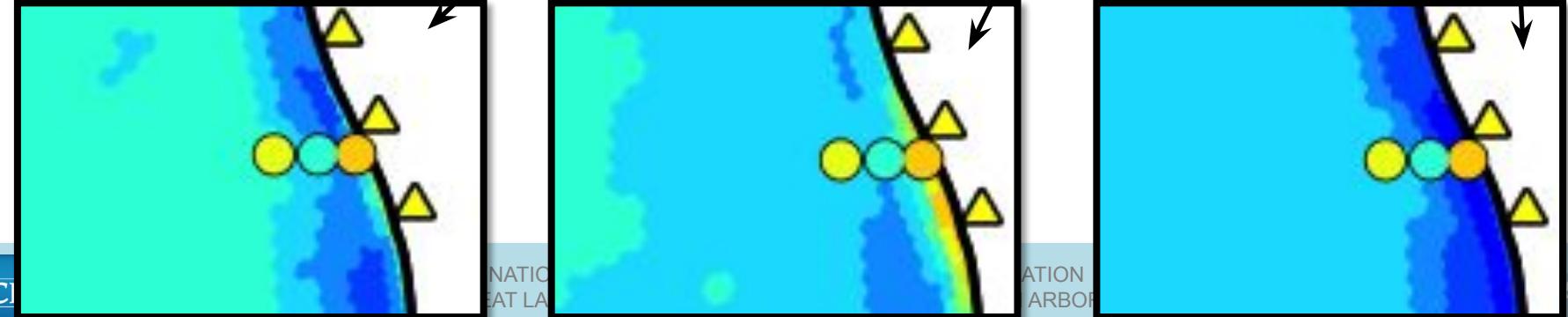
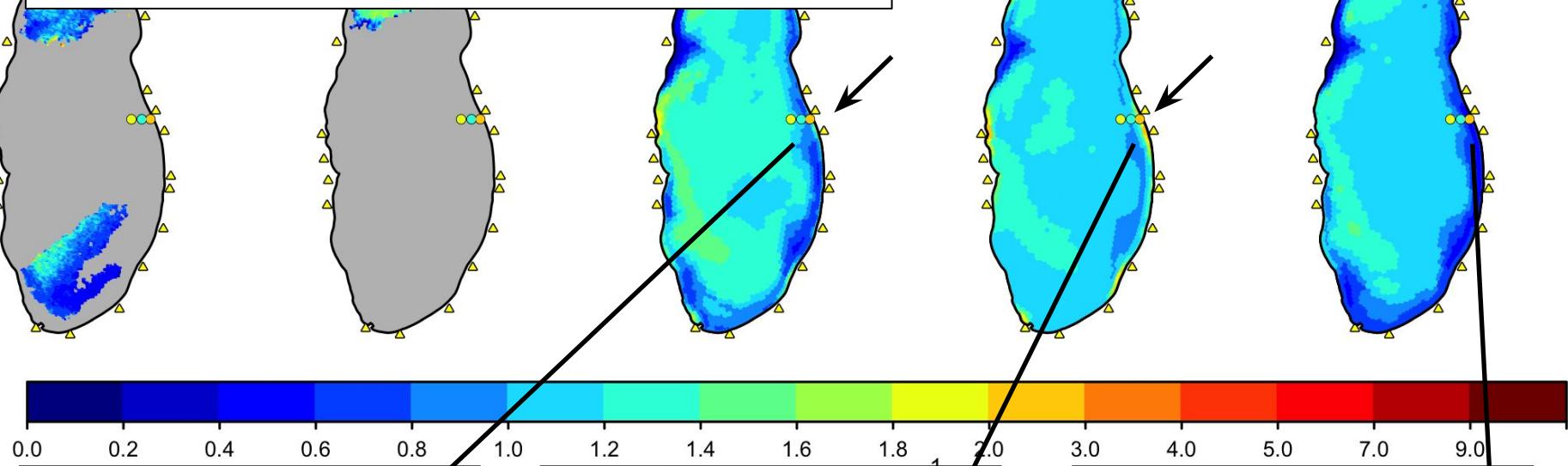
CPA

Mussels, Loads

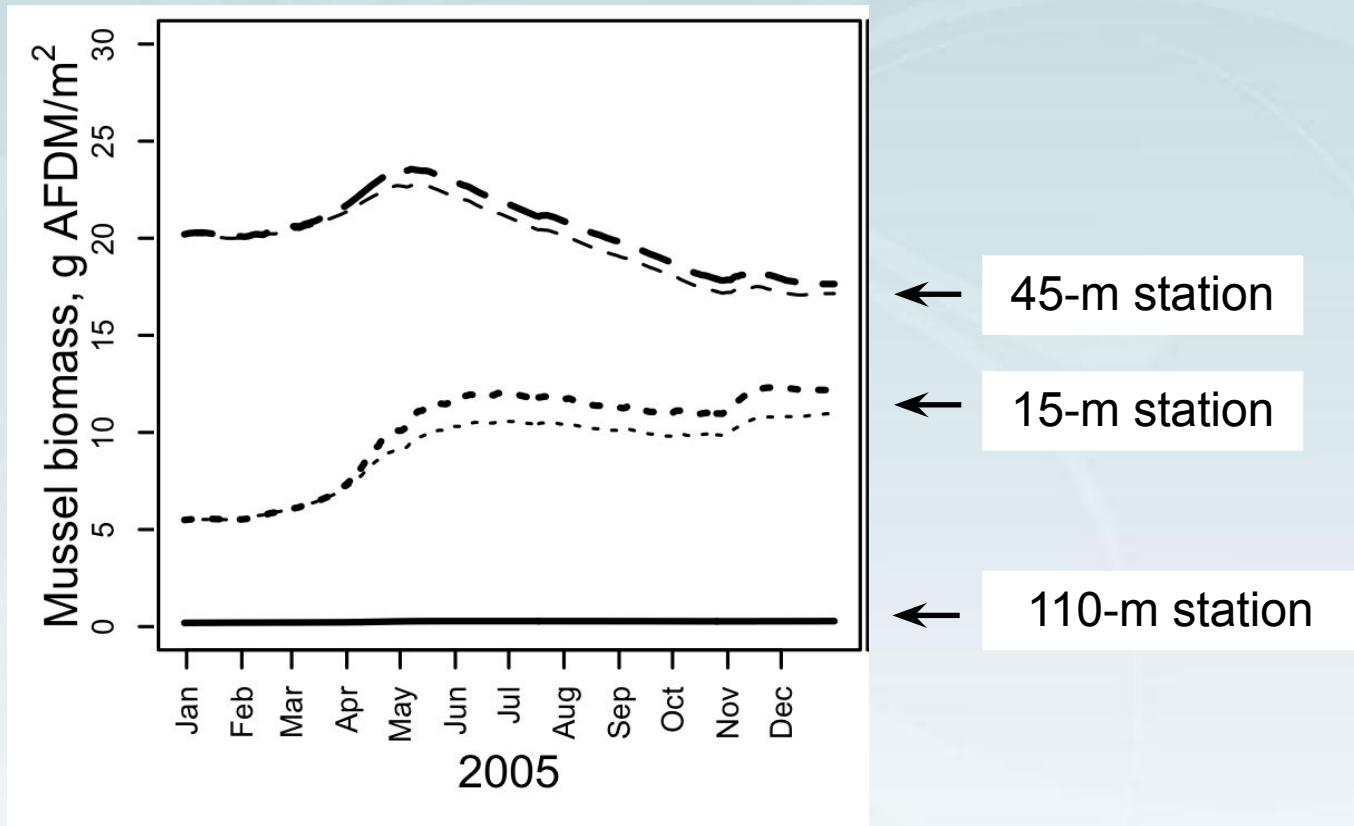
No mussels, Loads

Mussels, No loads

Both mussels and phosphorus loads contribute to the observed chlorophyll minimum at Muskegon 45-m station



Simulated mussel growth at Muskegon transect stations for 2005



- Growth rates decreased nearshore to offshore
- 2005 biomass at 45-m depth at or above carrying capacity
- Maximum growth in April and November associated with deep mixing

Conclusion

- Both quagga mussels and phosphorus loads are required to reproduce the major seasonal patterns of chlorophyll spatial distribution in post-dreissenid Lake Michigan
- Key physical processes influencing chlorophyll distribution
 - March - April
 - Light limitation: deep isothermal mixing versus winter stratification
 - May – June
 - Onset of summer stratification and influence of March – April mixing on the residual phosphorus distribution
 - July-August
 - Stratification, coastal upwelling, and tributary nutrient/chlorophyll plumes
 - September - November
 - Deepening mixed layer brings up chlorophyll and nutrients from below, and finally causes return of mussel effects