Combined modeling/remote sensing approaches for the Great Lakes

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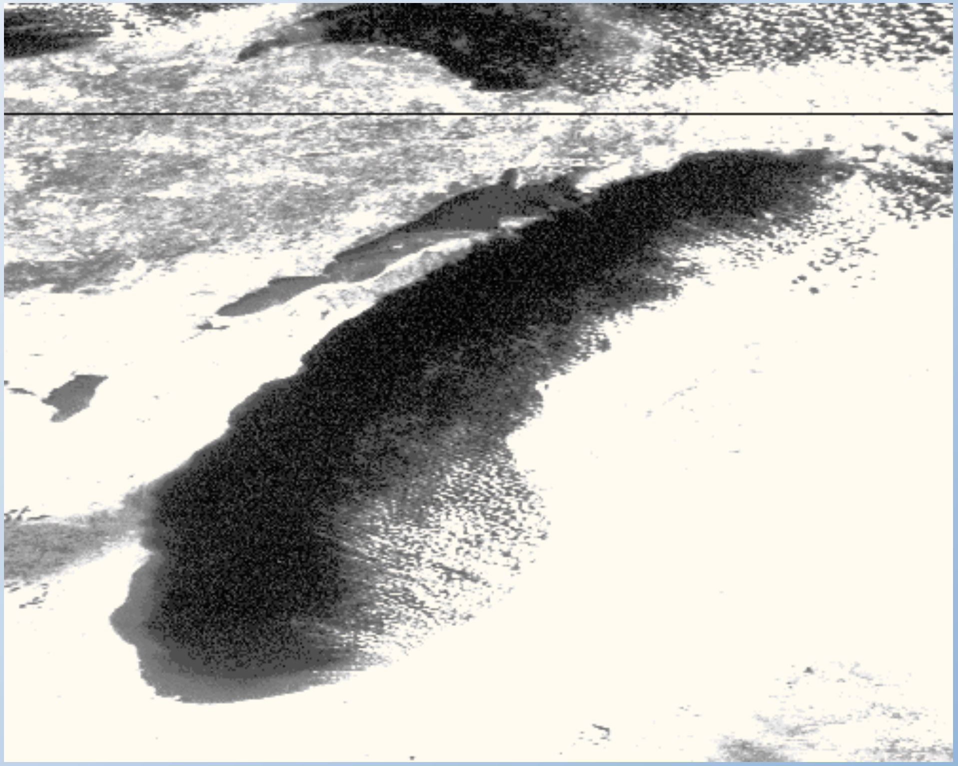
Michigan Tech Research Institute

WATER CENTER UNIVERSITY OF MICHIGAN

Example 1: Sediment plume modeling in the Episodic Events Great Lakes Experiment (EEGLE)

Goal: ***To assess the impact of major resuspension events on the transport and transformation of biogeochemically important materials and on lake ecology***

Sponsors and participants: NSF-CoOP, NOAA-COP, EPA-GLNPO, NWRI-CCIW, NOAA-GLERL, 11 Universities



GOES 8 Visible Imagery - Mar 12, 1998

SeaWiFS multichannel composite image April 22, 2000

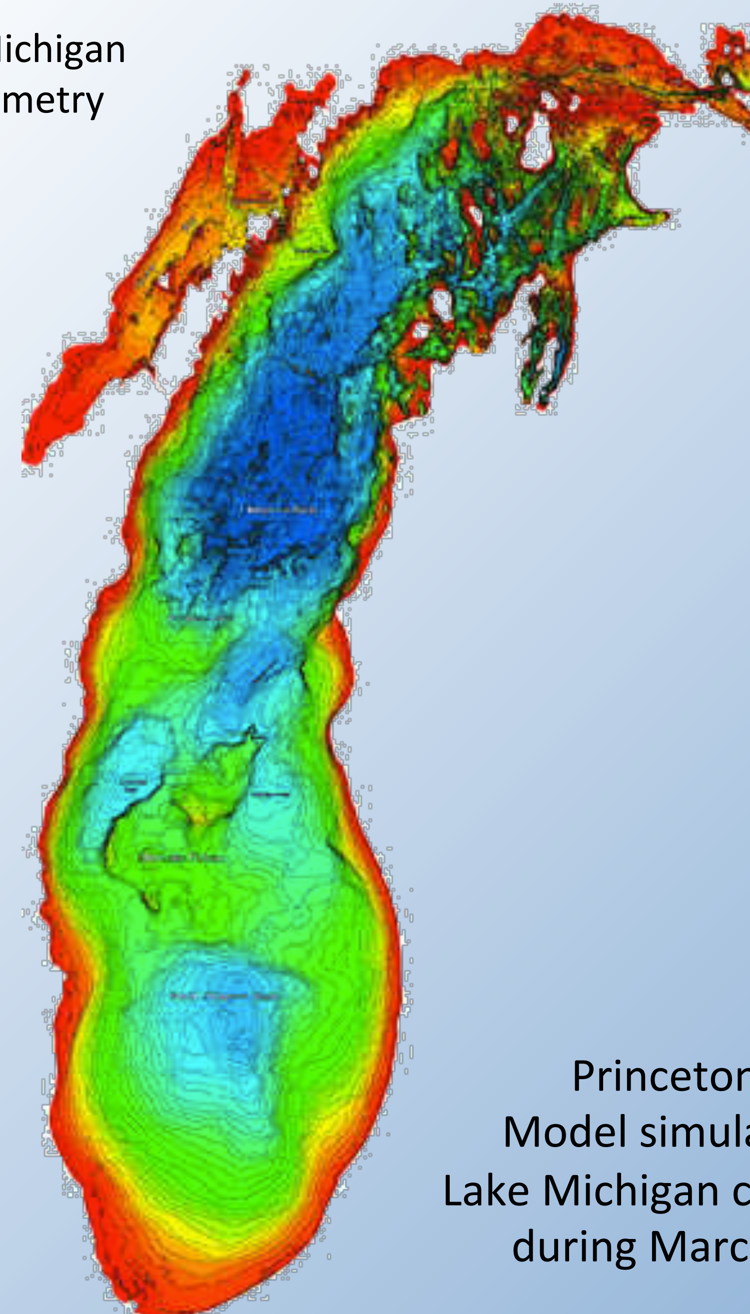
Modeling Approach:

1. Hydrodynamics - Princeton Ocean Model

2. Waves - GLERL/Donelan parametric wave model

3. Sediment dynamics model - SEDGL2
   - 2 dimensional (vertically averaged currents and sediment concentrations)
   - single characteristic grain size class
   - erosion proportional to excess shear stress
   - neglect wave-current interaction
   - deposition with single characteristic fall velocity
   - initial condition of spatially uniform bed thickness

Lake Michigan Bathymetry



Princeton Ocean Model simulation of Lake Michigan currents during March, 1998

2D Suspended Sediment Transport Model

2D advection equation:

$$\frac{\partial}{\partial t}(HC) + \frac{\partial}{\partial x}(UC) + \frac{\partial}{\partial y}(VC) = S(x,y,t)$$

Source term (Partheniades, 1965 and Krone, 1962):

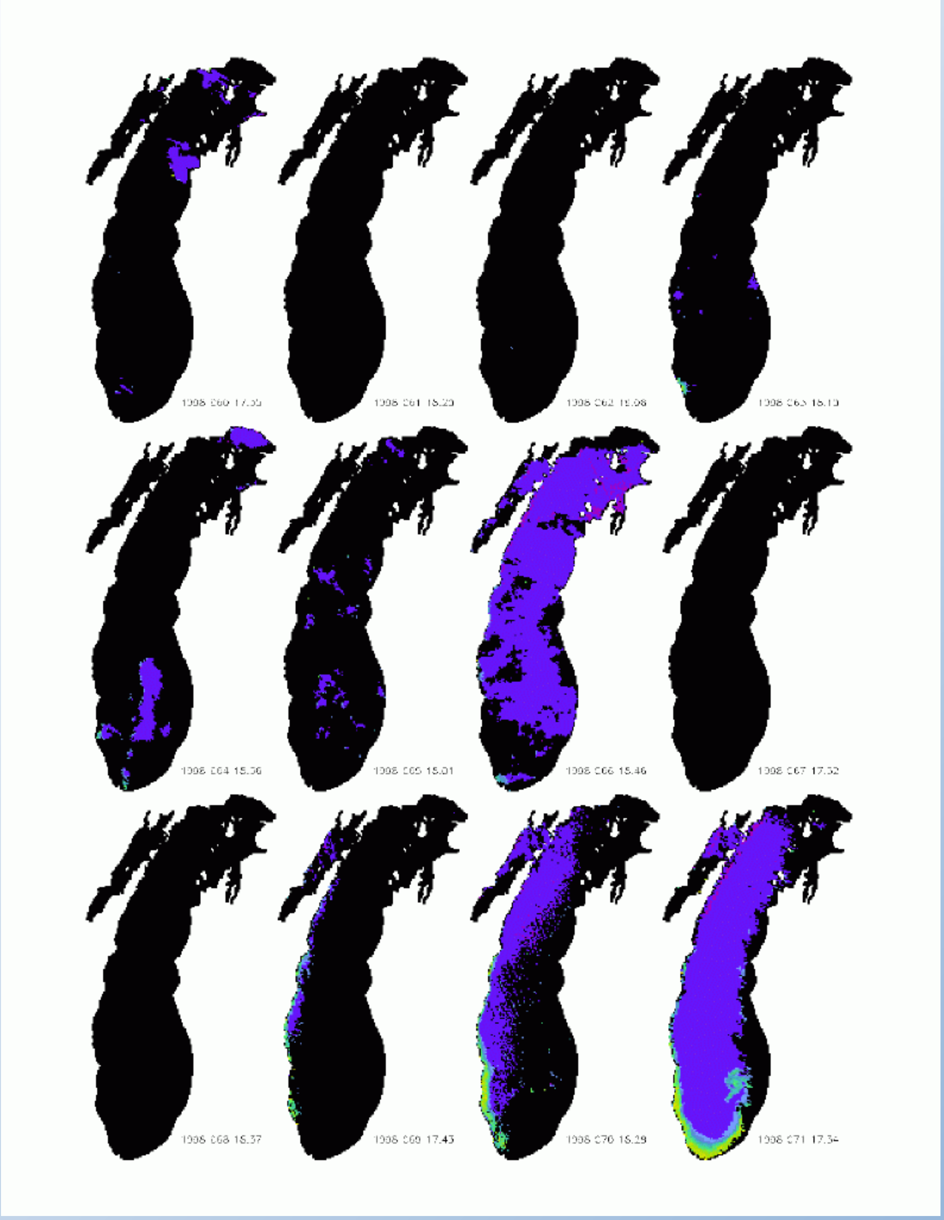
$$S(x,y,t) = \varepsilon \left(\frac{\tau}{\tau_c} - 1 \right)^n \qquad for \;\; \tau \geq \tau_c$$

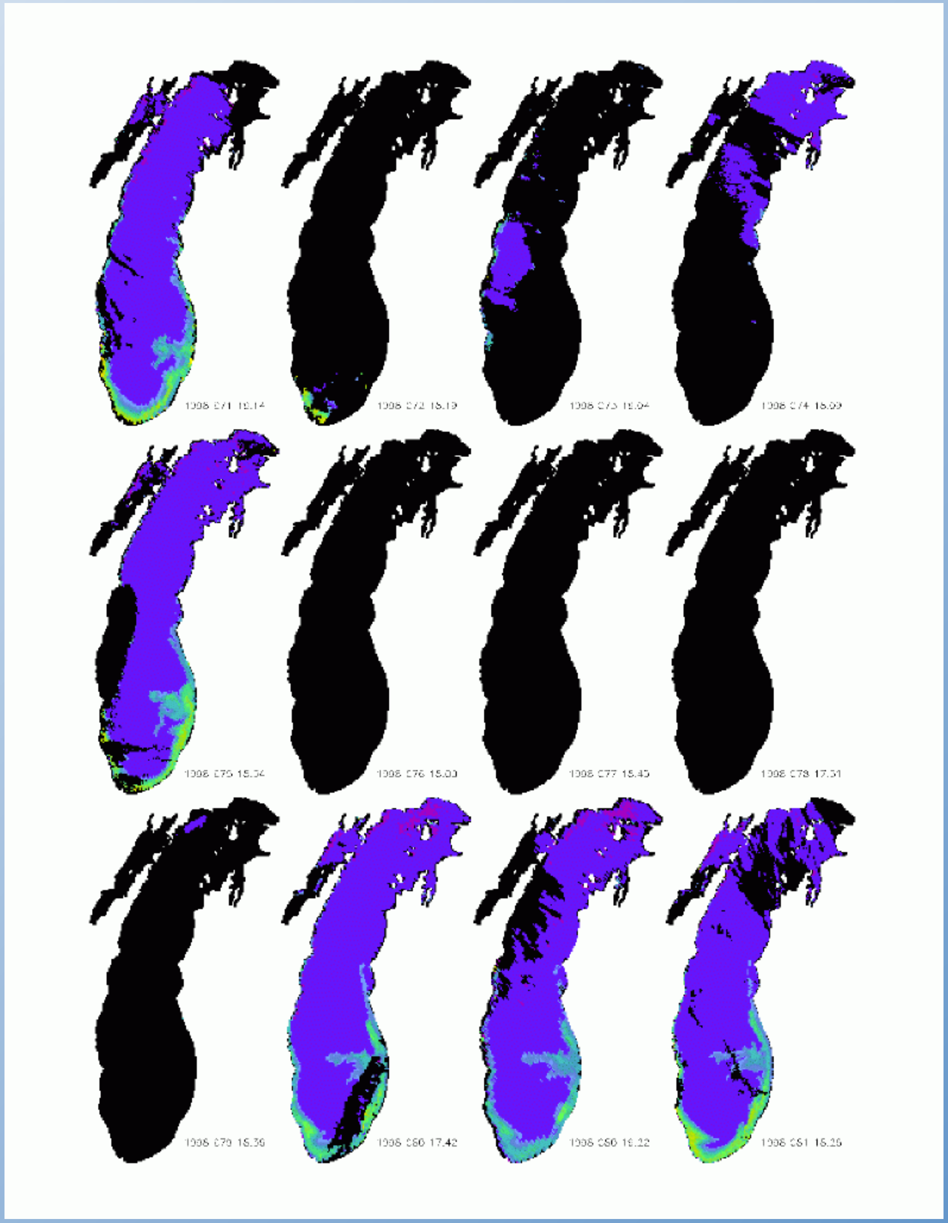
$$S(x,y,t) = -w_s C(x,y,t) \qquad for \;\; \tau < \tau_c$$

Satellite data assimilation by Newtonian nudging (Stauffer and Seaman, 1990):

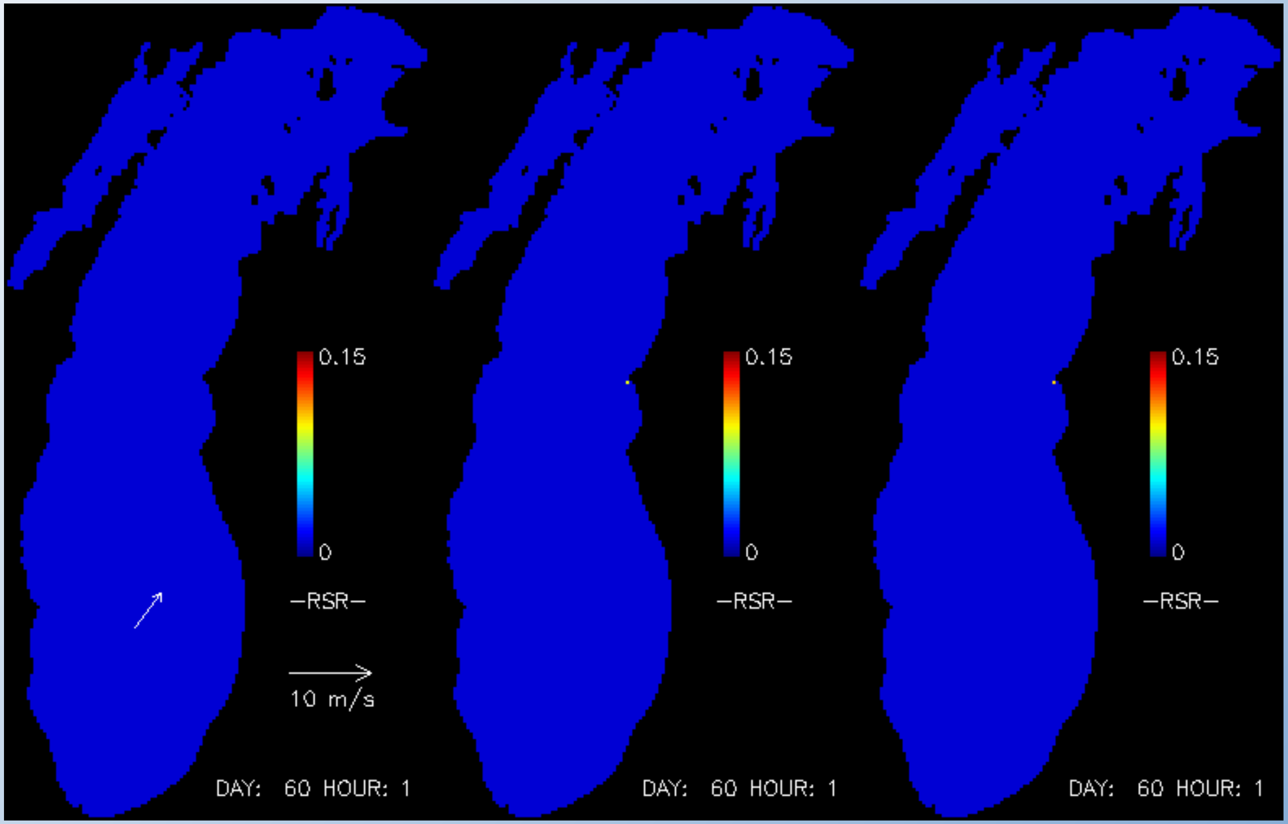
$$S'(x,y,t) = S(x,y,t) + \frac{\alpha H}{\Delta t} \sum_{i=1}^{2} a_i (C_i - C) \qquad a_i = e^{-\left(\frac{t-t_i}{t_0}\right)^2}$$

SeaWIFS 550 micron band imagery - March, 1998



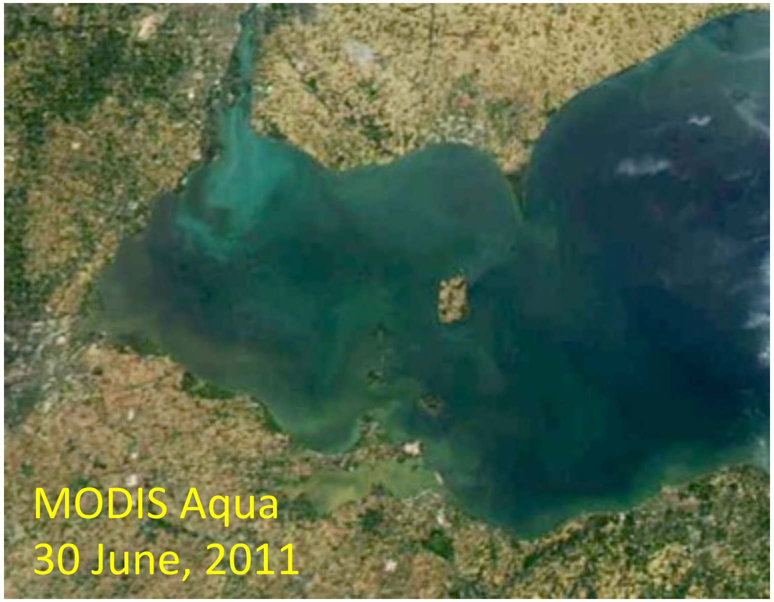


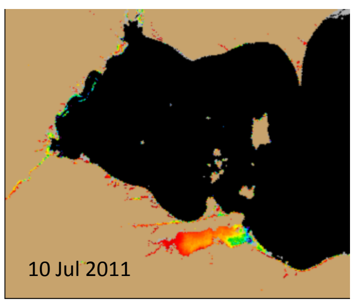
March-April, 1998 - interpolated satellite imagery, sediment model with data assimilation, sediment model without data assimilation

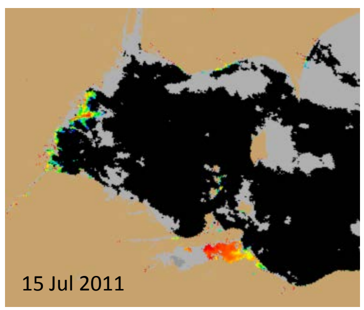


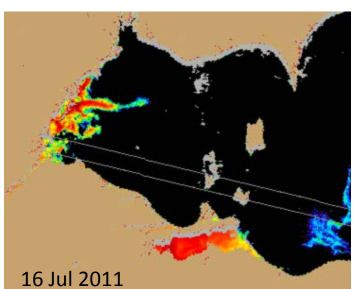
α=1, S=0 α=0.125 α=0

Example 2: The effect of Lake Circulation on the development of algal blooms in Western Lake Erie





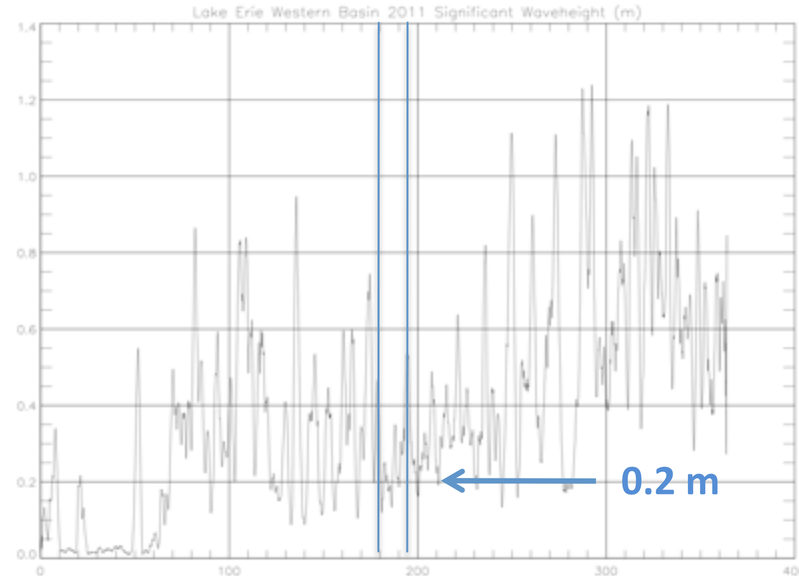




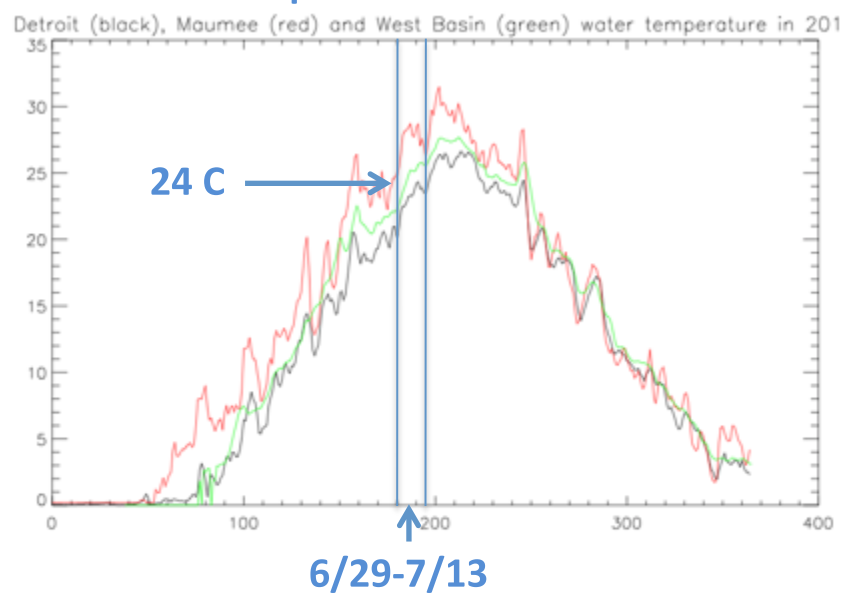
MERIS images of bloom concentration. Lake Erie. First evidence of bloom between Luna Pier and Monroe. Bloom was confirmed in late July by NOAA/GLERL (Fahnenstiel), with 1000 ug/L microcystin at Toledo Light.

Rick Stumpf NOAA National Ocean Service

Significant Waveheight in Western Basin



Water Temperature in Western Basin



Day of Year 2011

Numerical Modeling Approach

3D Hydrodynamic Models:

- Princeton Ocean Model (2 km fixed rectilinear horizontal resolution)
- FVCOM (240 m - 2.4 km variable resolution unstructured grid)
- Both models have 21 vertical levels and are driven with heat flux and wind stress at the water surface derived from hourly weather station and weather buoy observations
- Run for entire year of 2011

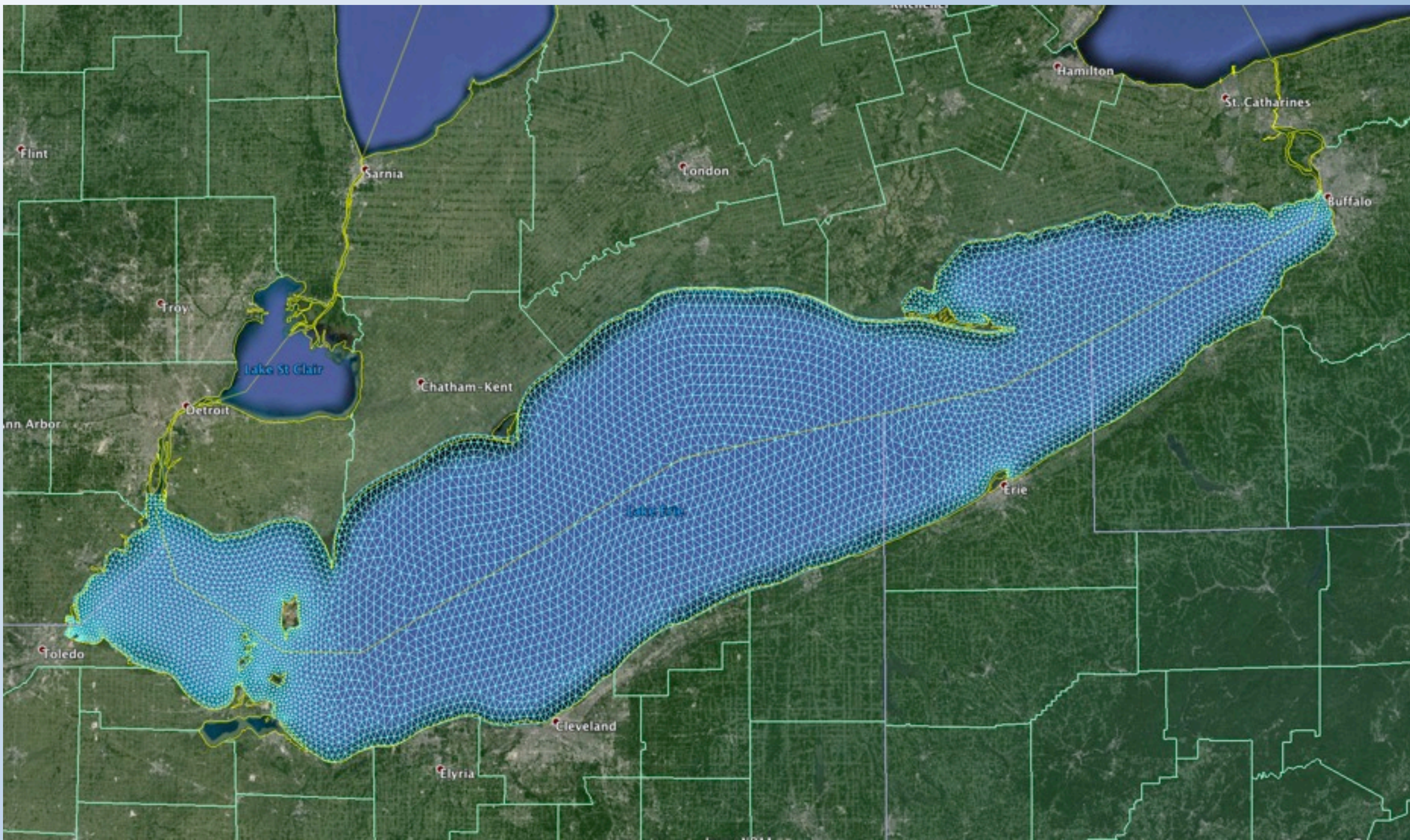
Particle trajectory model:

- 95000 tracer particles released over 3 day period starting 7/13/11
- Particles are uniformly distributed over 95 grid cells with depths less than 5 m
- Particles are initially at the surface, but move in 3d with currents
- Particles are conservative, i.e., no growth or decay
- Horizontal diffusion depends on horizontal current shear (Smagorinsky formulation with coefficient of 0.005)
- Vertical diffusion is 0.00005 m^2/s
- Particle positions recorded hourly for 60 days (7/13-9/11)

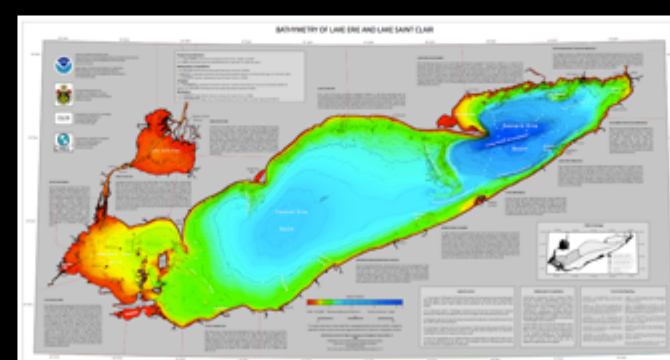
Lake Erie FVCOM mesh:

Number of Elements: 11509
Number of Nodes: 6106

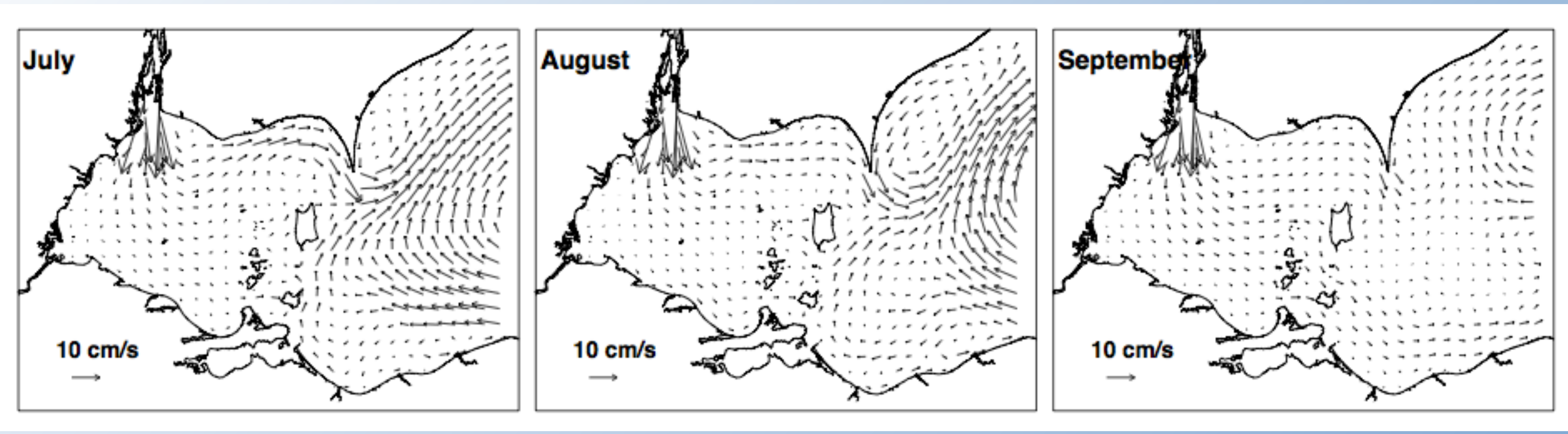
Maximum Element size: 2.4 km
Minimum Element size: 242 m
Average Element size: 1.5 km



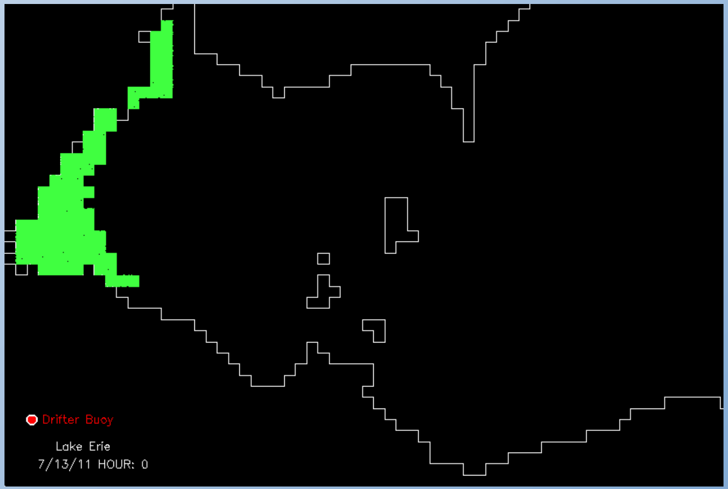
Lake Erie Circulation, January 2004



Average circulation patterns from the hydrodynamic circulation model for July, August, and September, 2011

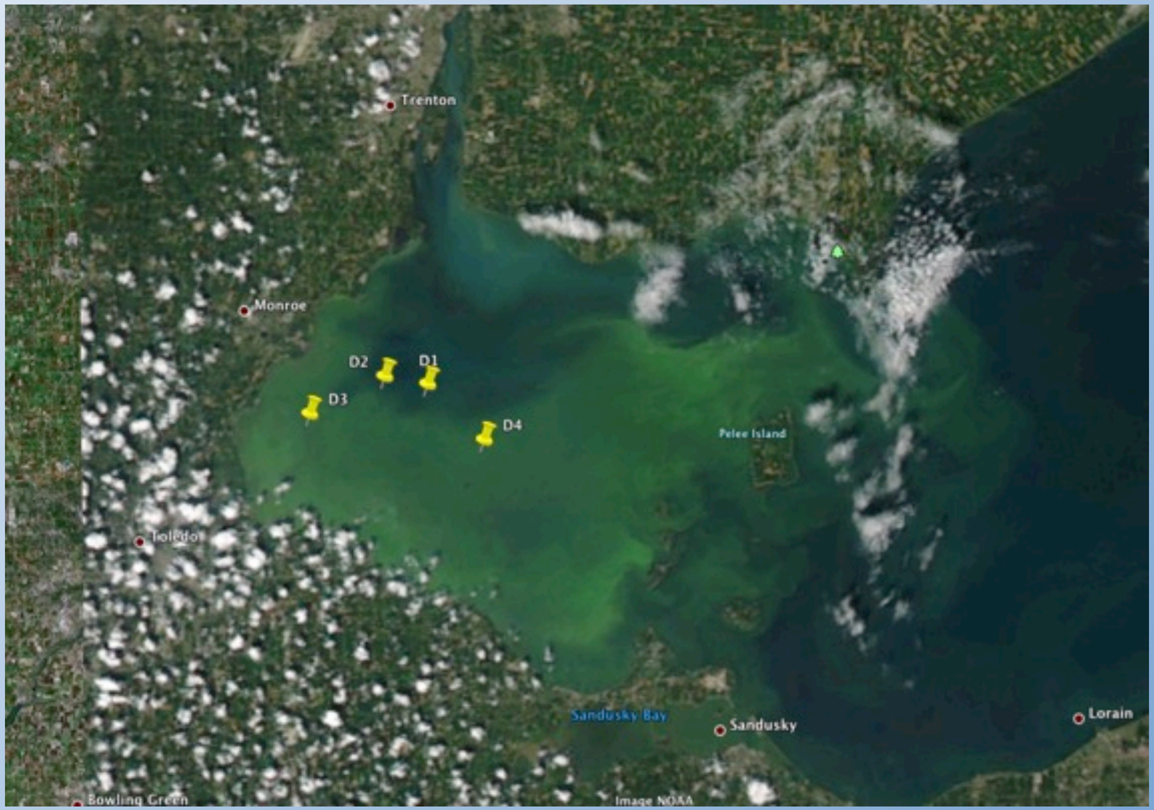


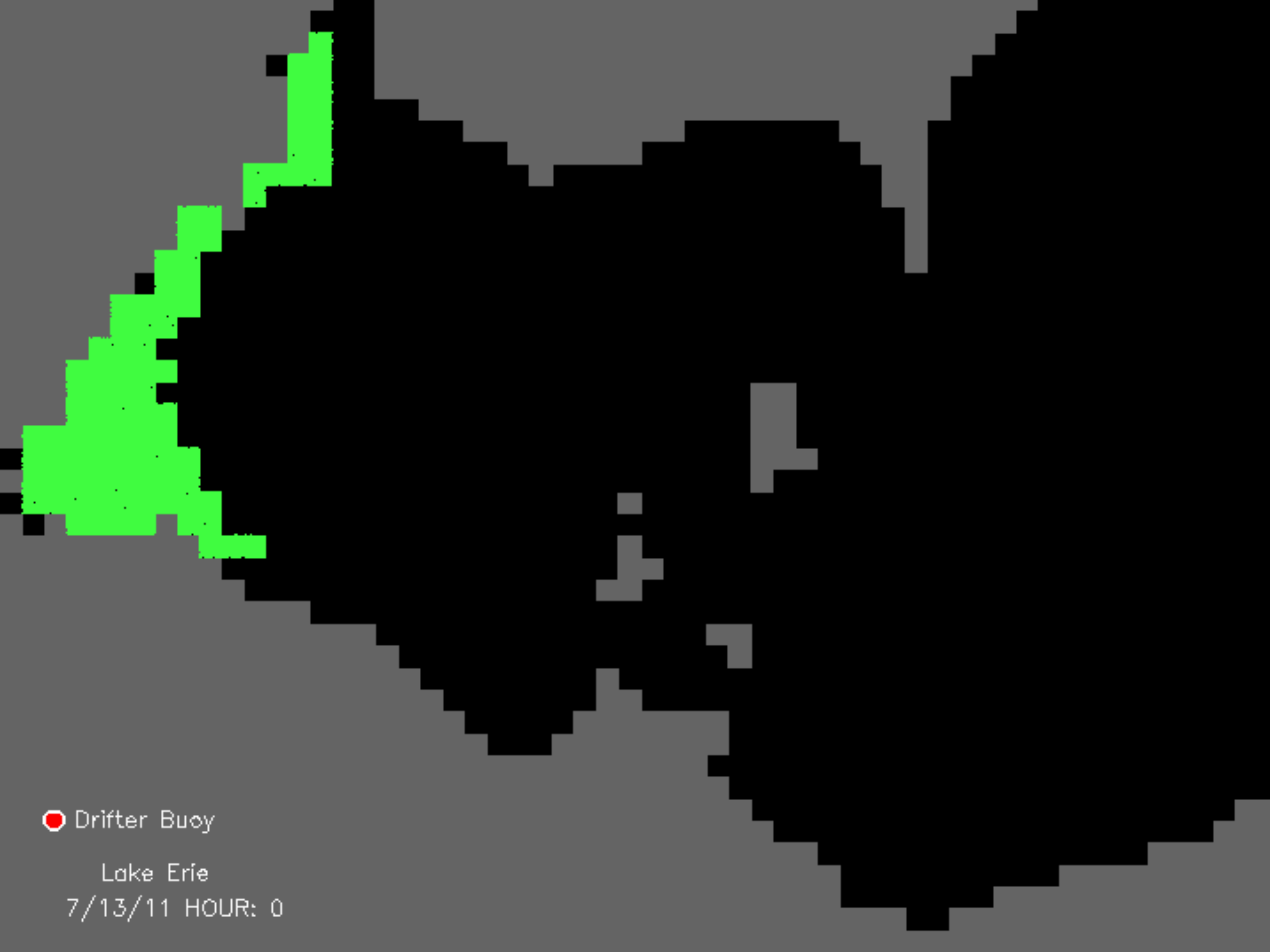
Particle release area, 13-15 July, 2011



Drifter releases in 2011

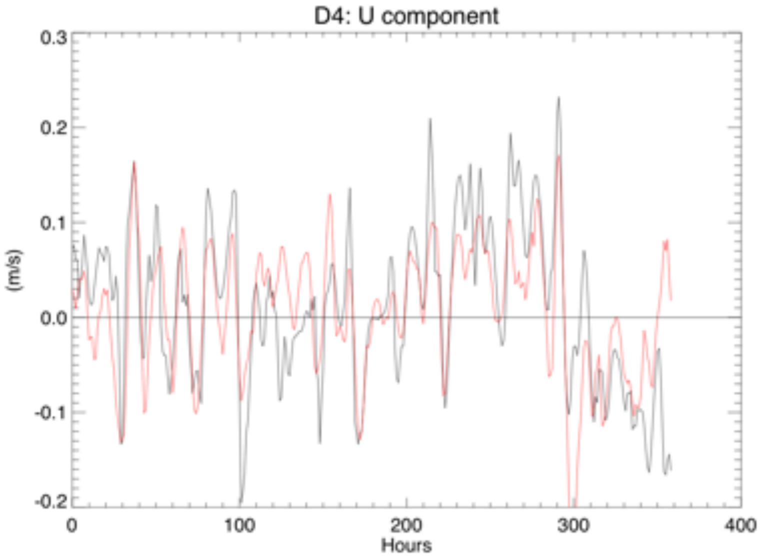
D1:	7/27/11	12 days
D2:	7/27/11	106 days
D3:	8/23/11	59 days
D4:	8/23/11	15 days

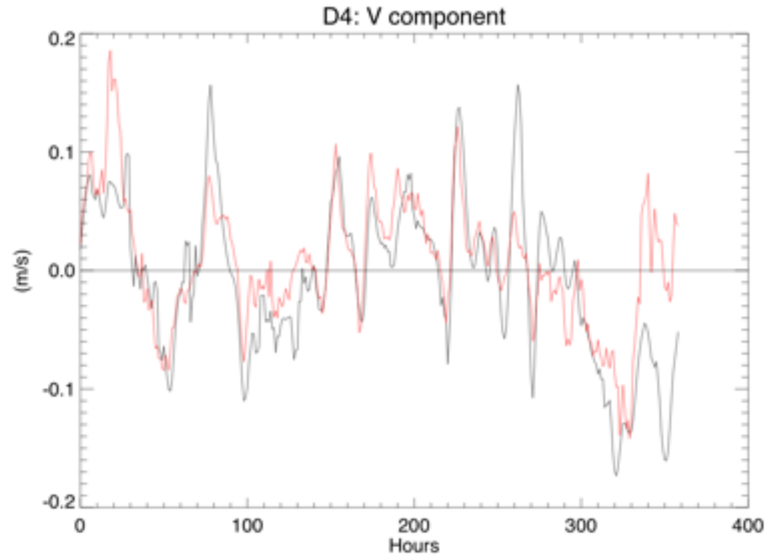


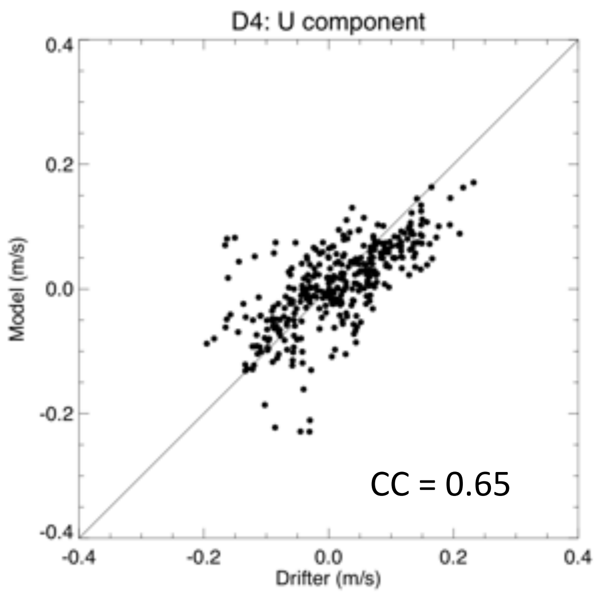


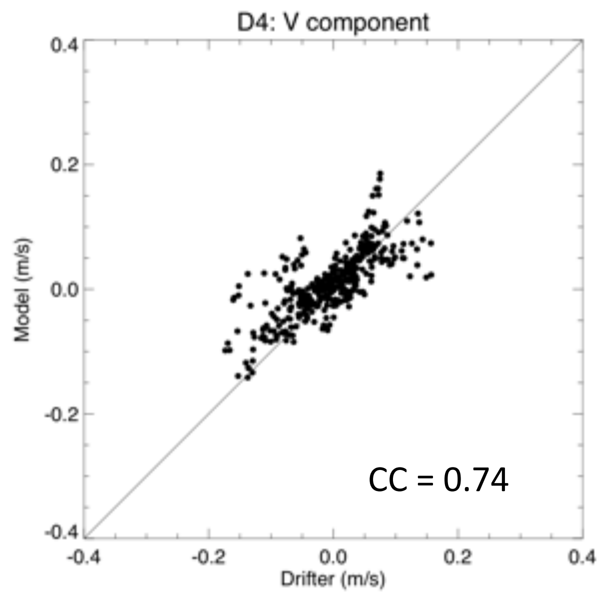
Drifter Buoy
Lake Erie
7/13/11 HOUR: 0

Difference between drifter-derived currents and modeled currents





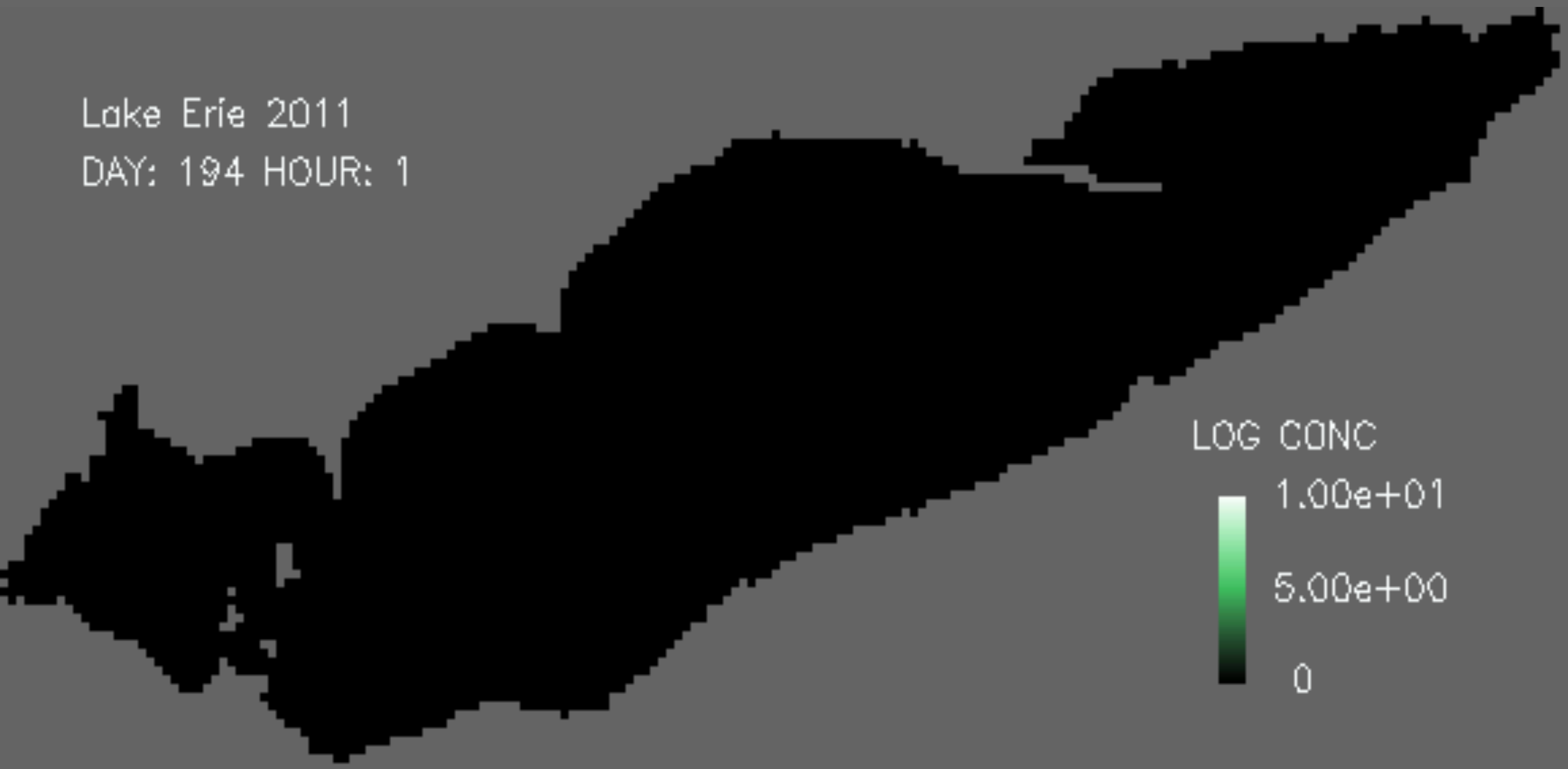


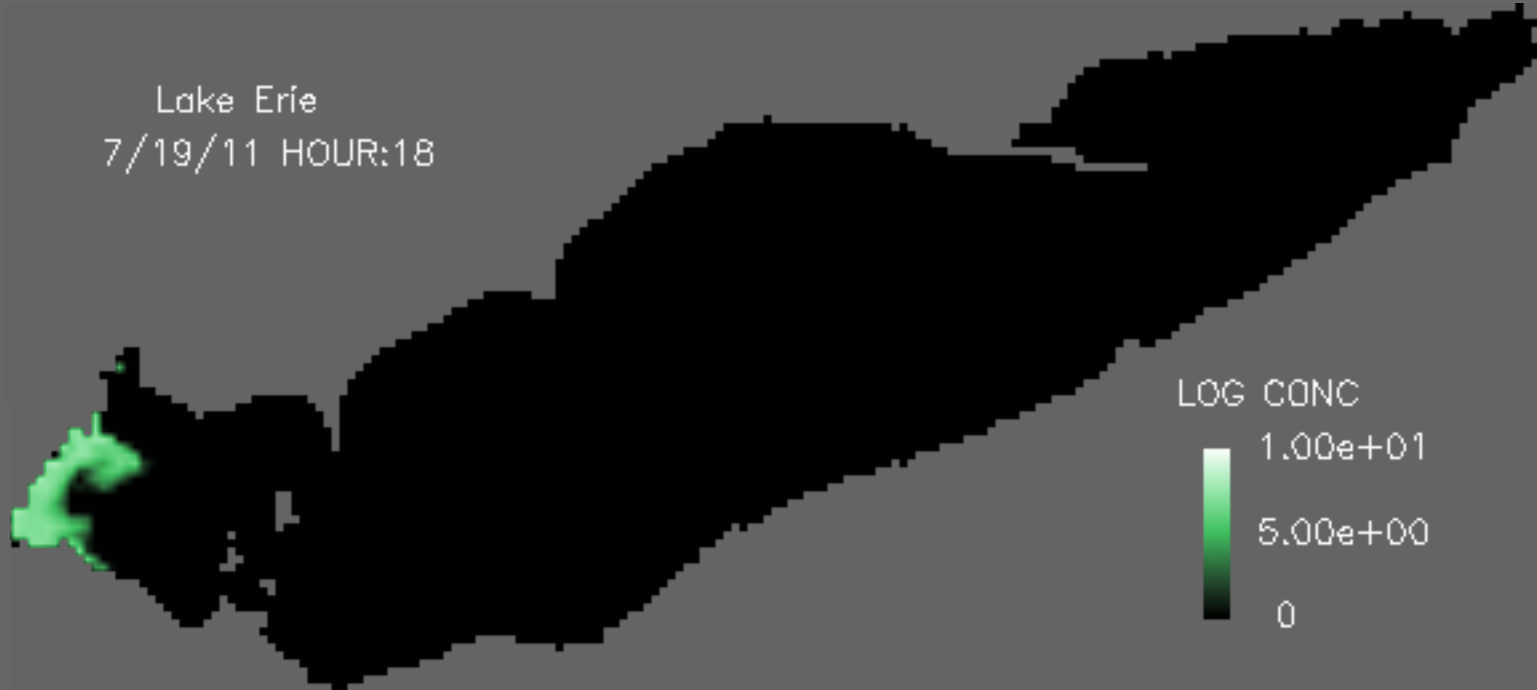


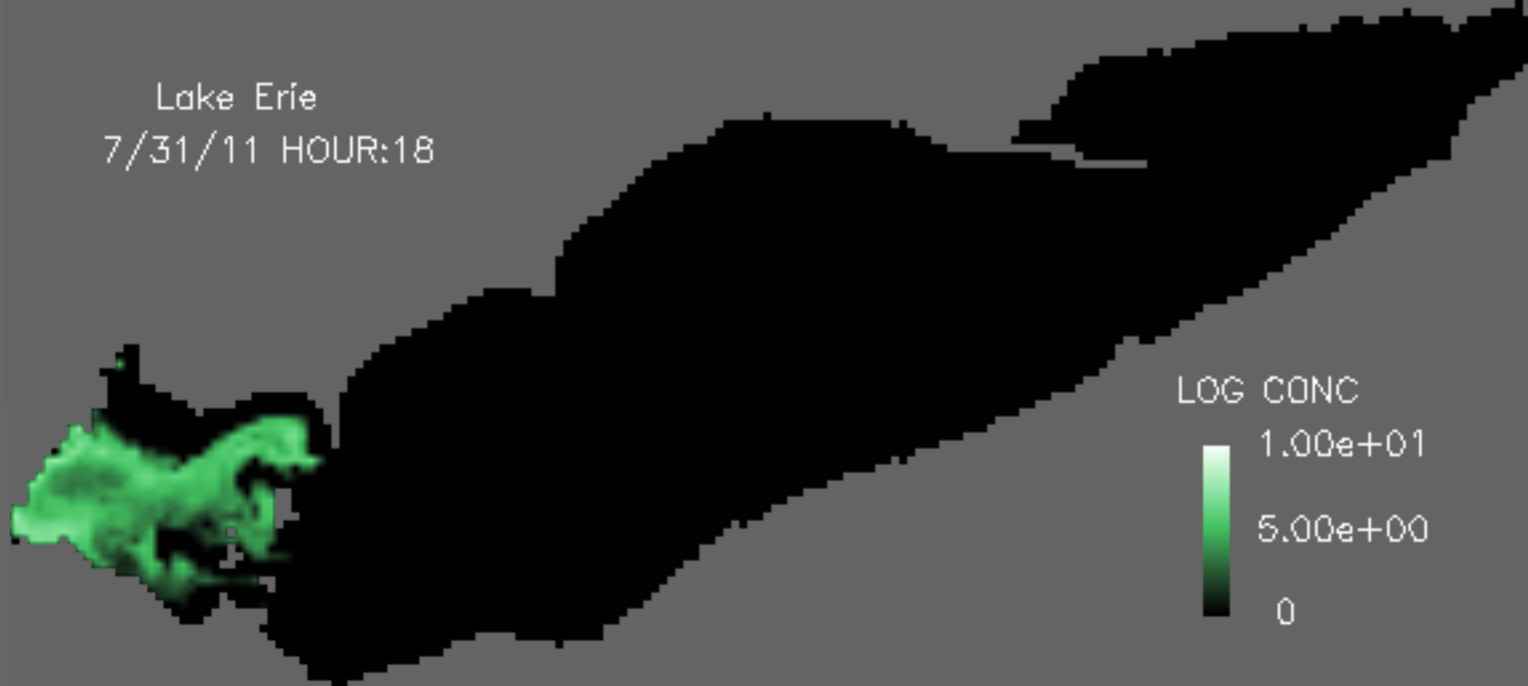
Overall Normalized RMSE
(Fourier Norm)

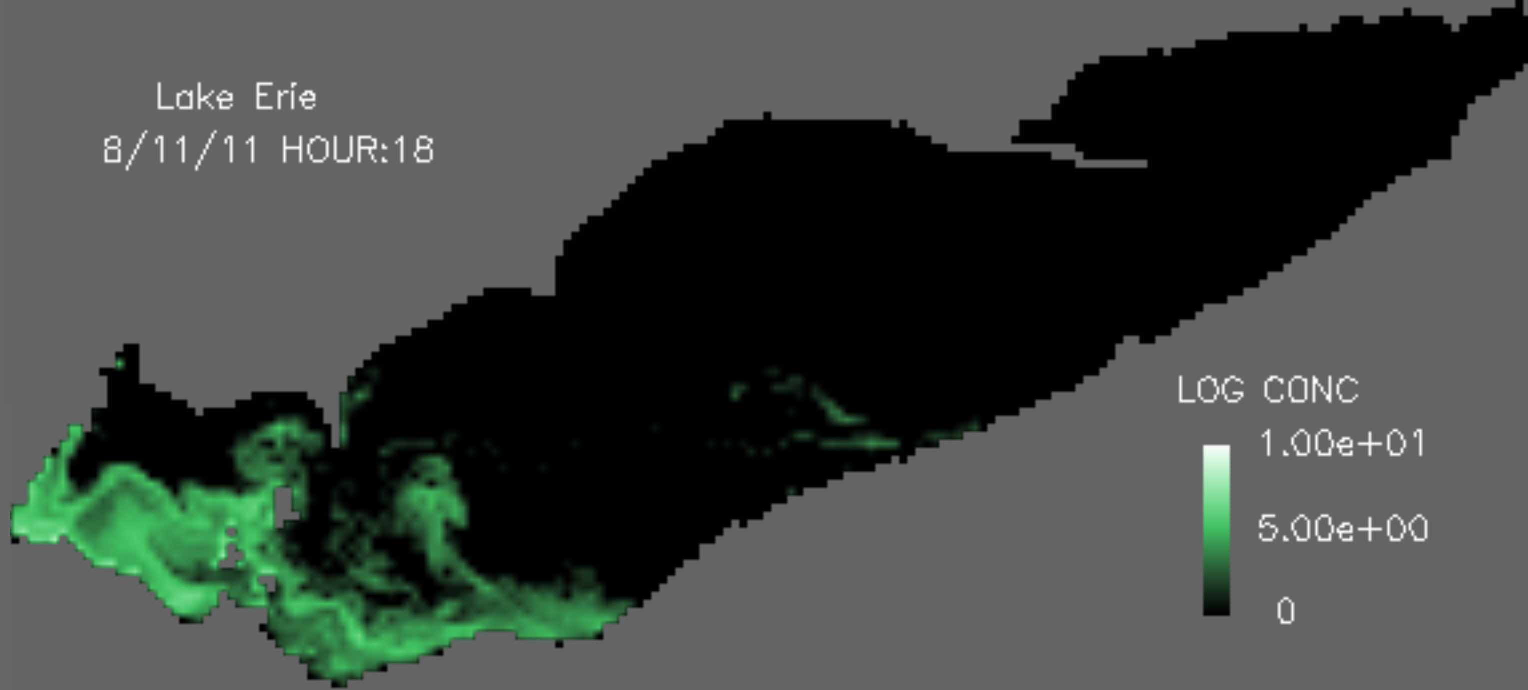
D1: 0.94
D2: 0.87
D3: 0.95
D4: 0.74

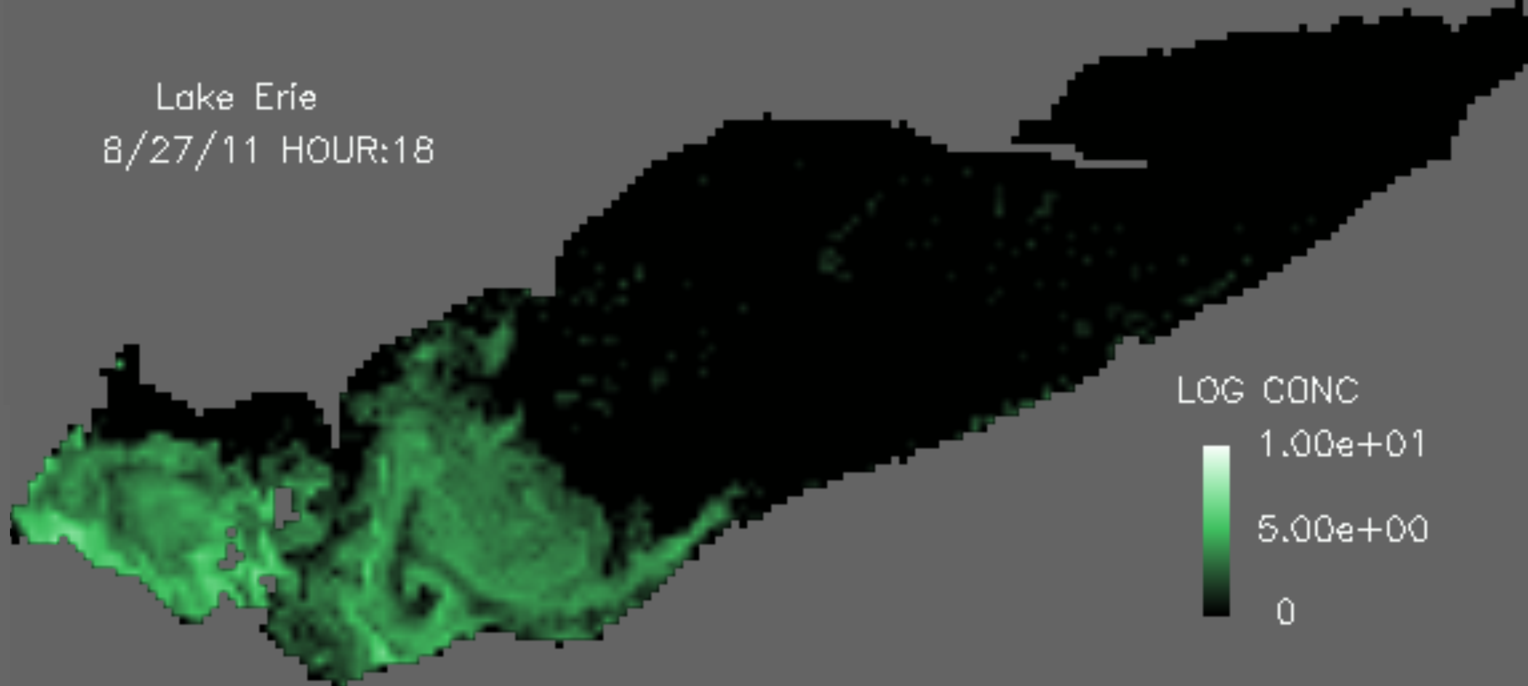
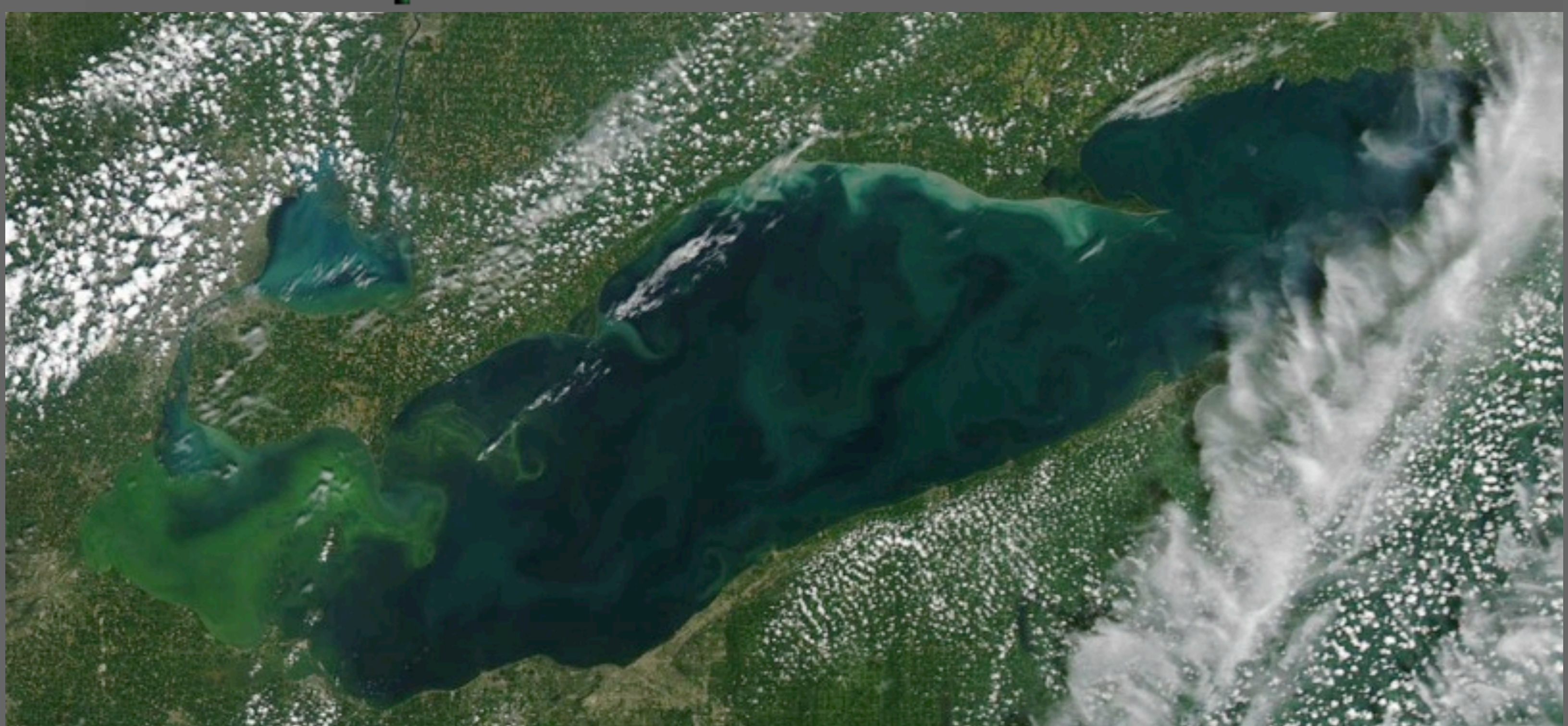
Modeled Particle Concentration

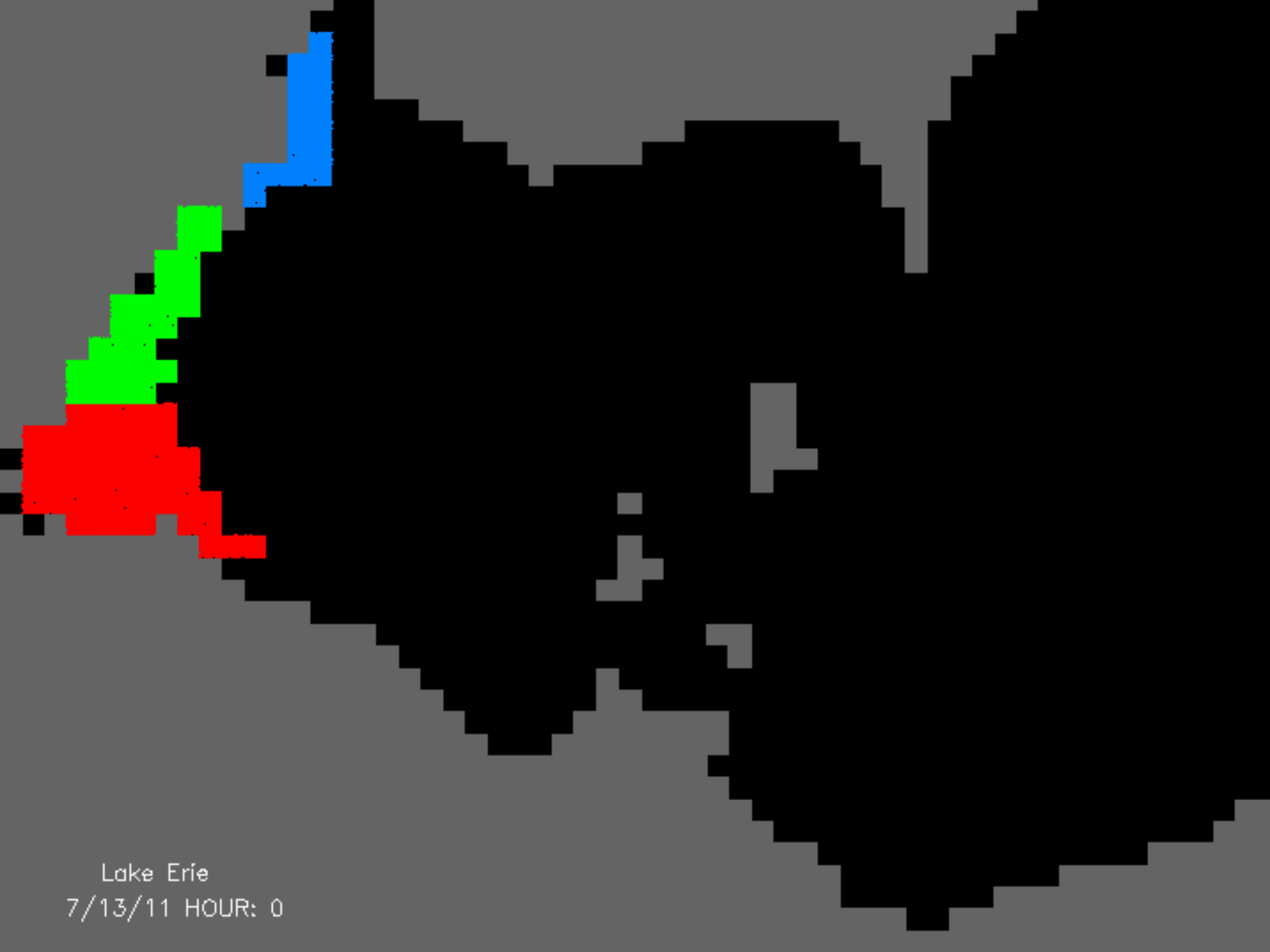



Lake Erie
7/19/11 HOUR:18
LOG CONC
1.00e+01
5.00e+00
0


Lake Erie
7/31/11 HOUR:18
LOG CONC
1.00e+01
5.00e+00
0


Lake Erie
8/11/11 HOUR:18
LOG CONC
1.00e+01
5.00e+00
0


Lake Erie
8/27/11 HOUR:18
LOG CONC
1.00e+01
5.00e+00
0



Lake Erie
7/13/11 HOUR: 0

Conclusions and future work:

•Model simulations of the SLM turbidity plume and the WLE cyanobacteria bloom demonstrate that advection by lake circulation plays a major role in the movement of materials that affect water quality in the Great Lakes.

•Short-term (up to several days) model-predicted distribution patterns of SLM turbidity and WLE cyanobacteria density are in good qualitative agreement with satellite observations.

•The combination of remote sensing and hydrodynamic modeling can be an effective tool for better undersatanding and more accurate simulation and prediction of water quality in the Great Lakes.

Questions?


Ice Concentration (%)
0 20 40 60 80 100
Image NOAA
Image Landsat
Google earth