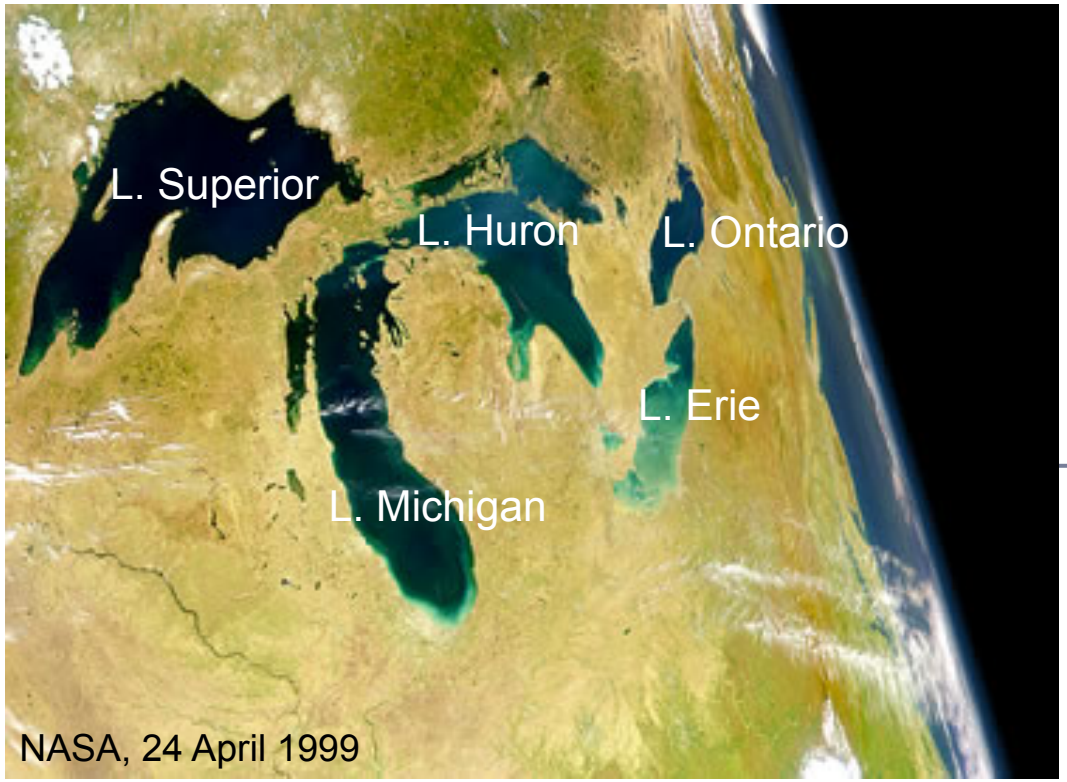

Great Lakes carbon budgets

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CCARS Meeting, WHOI

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- V. Bennington: UW-Madison-CCR
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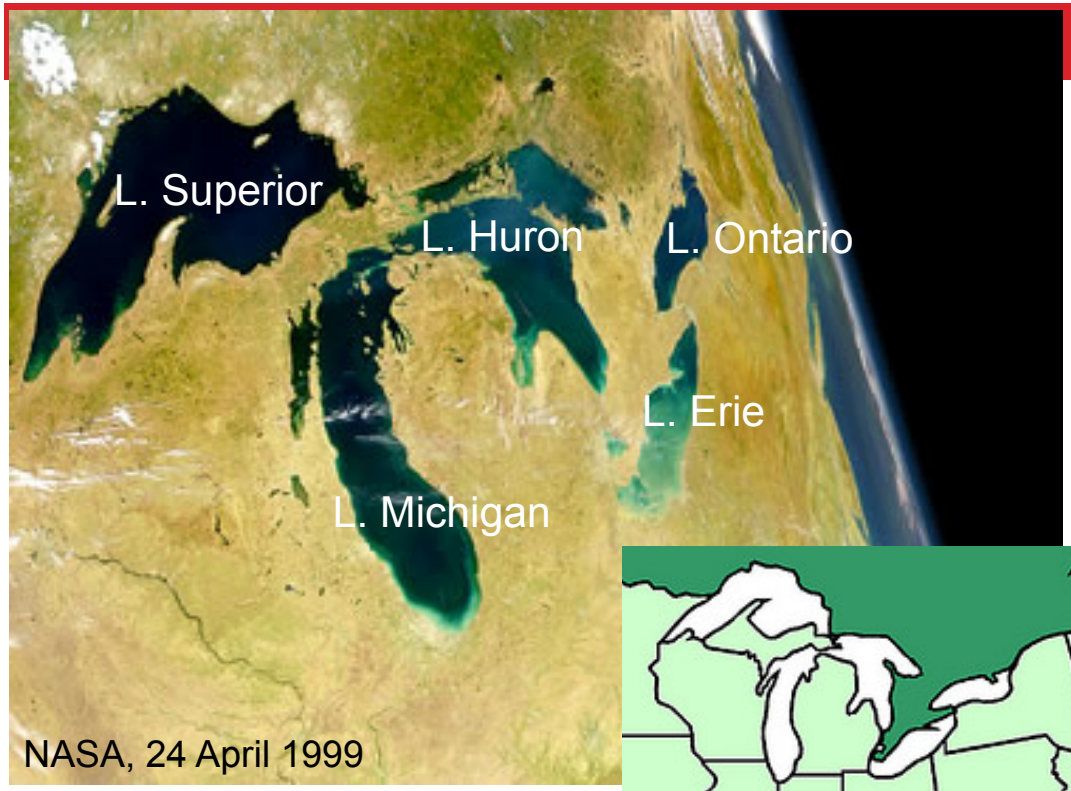
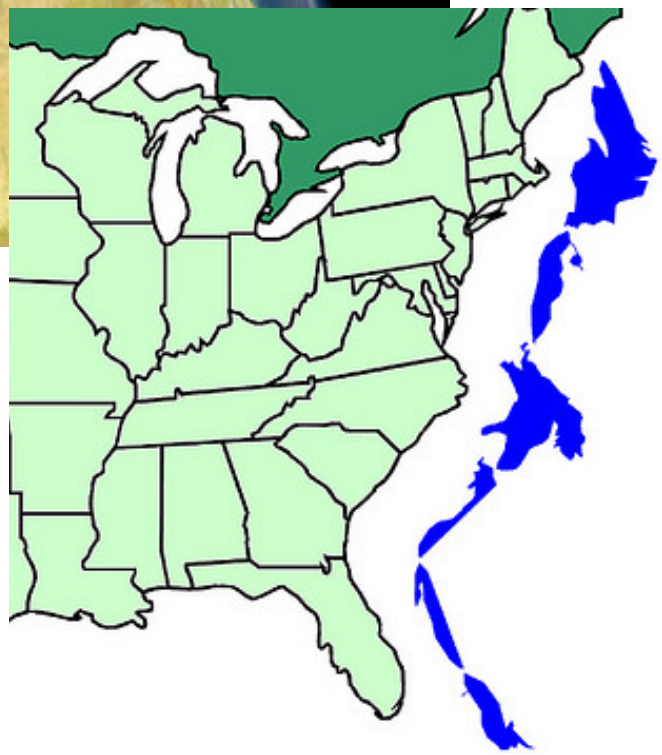
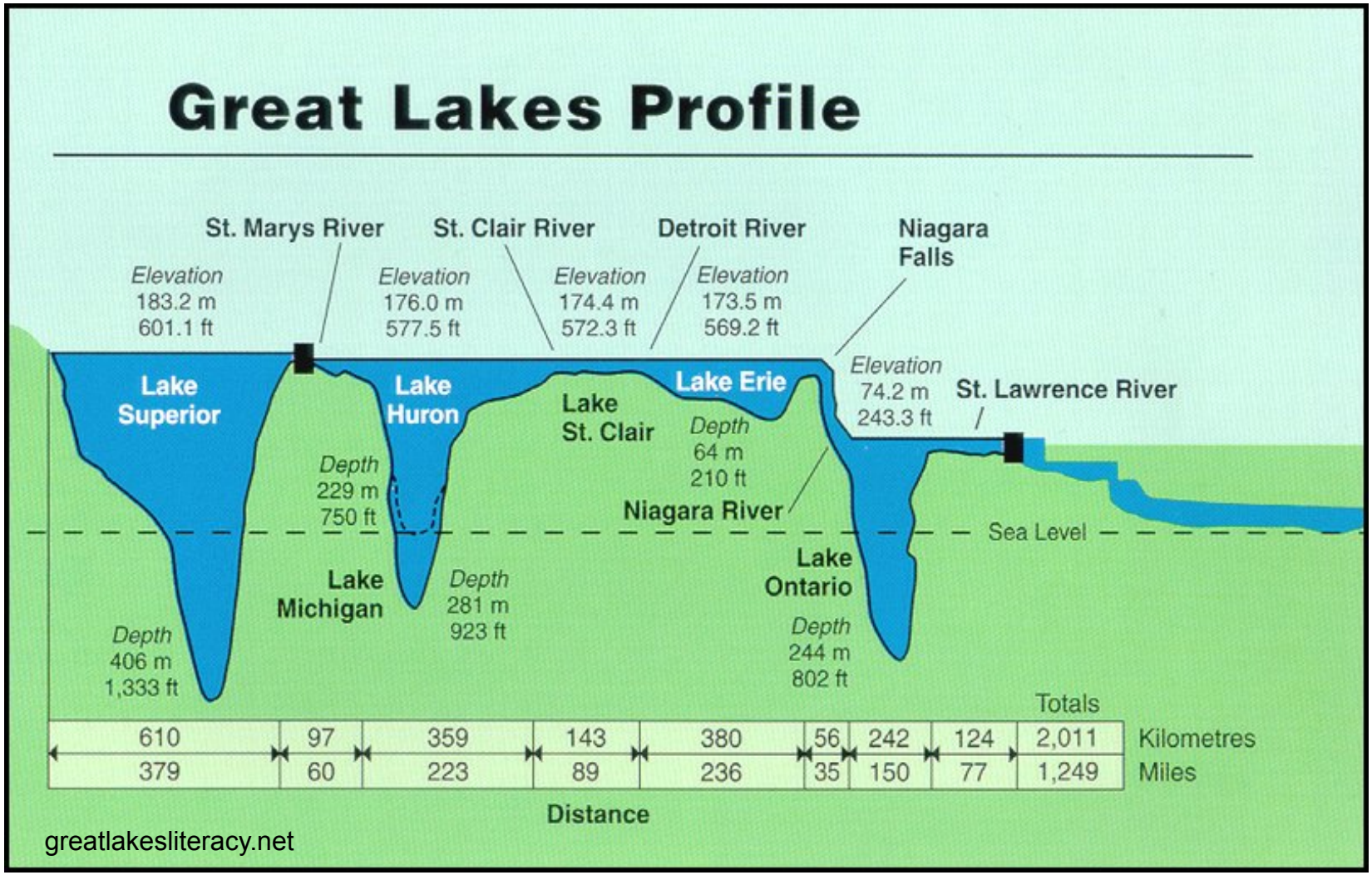
- E. Minor, R. Sterner: UMn-Duluth
- J. Lenters: LimnoTech





$5B/yr Economic Impact from Fisheries



Water Residence Times: L. Superior ~ 174 yrs vs. L. Erie ~ 3 yrs

Great Lakes carbon budgets

1. Challenges
2. Preliminary carbon budgets
3. Using a model to balance the budget for Lake Superior
4. Current work

Great Lakes carbon budgets

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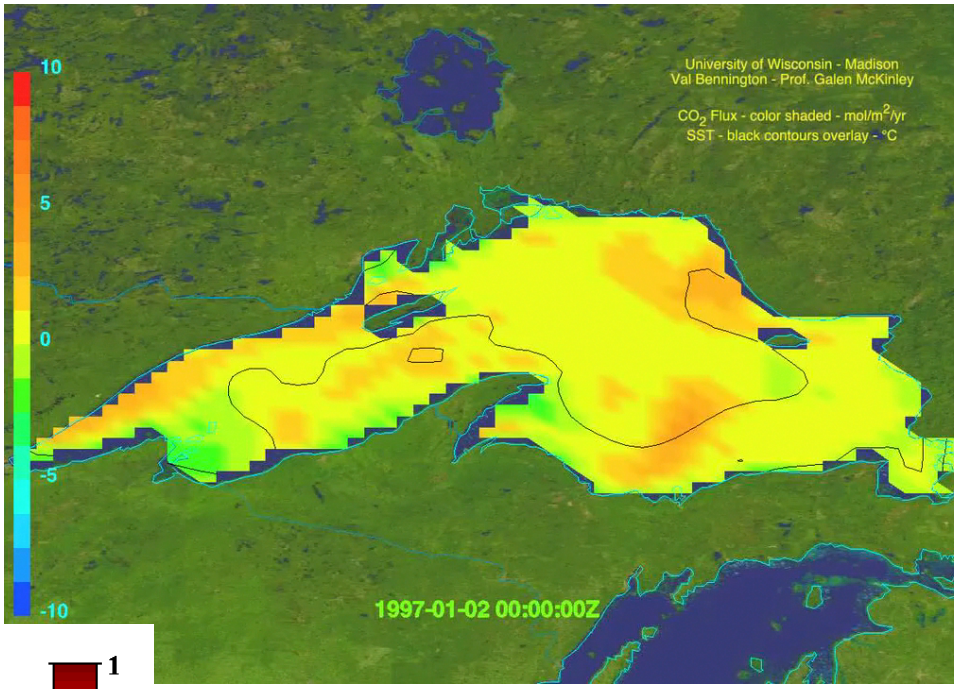
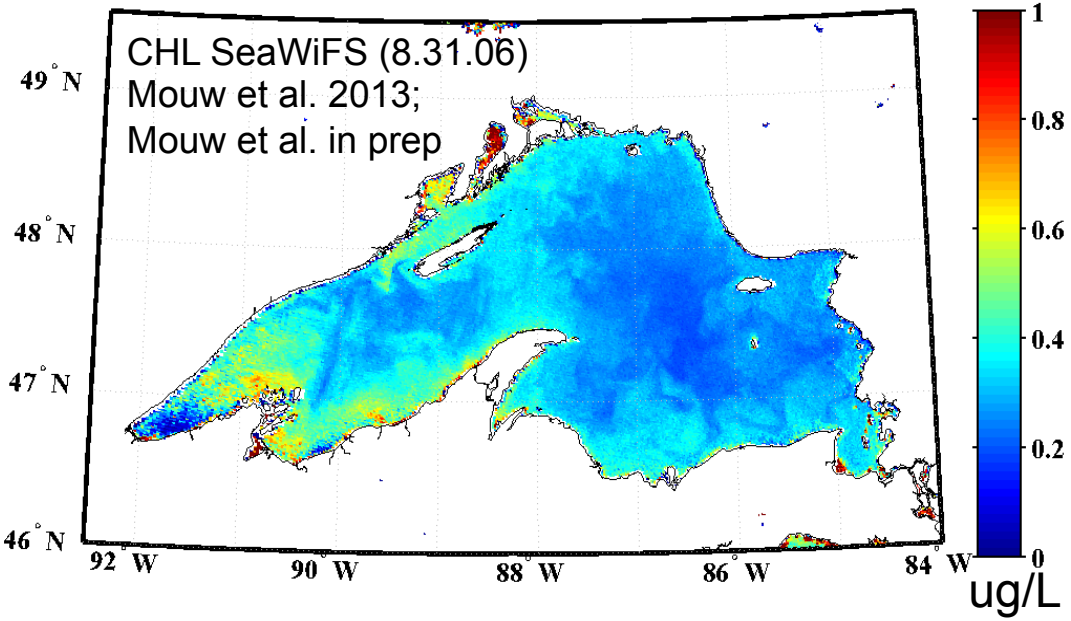
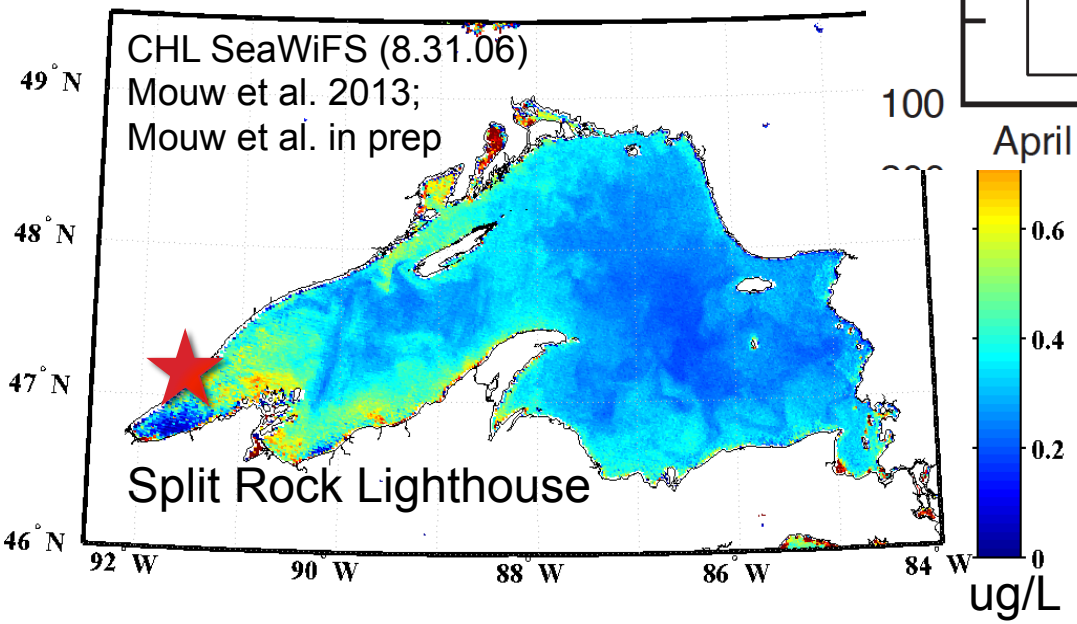
Challenge #1: Spatio-temporal variability

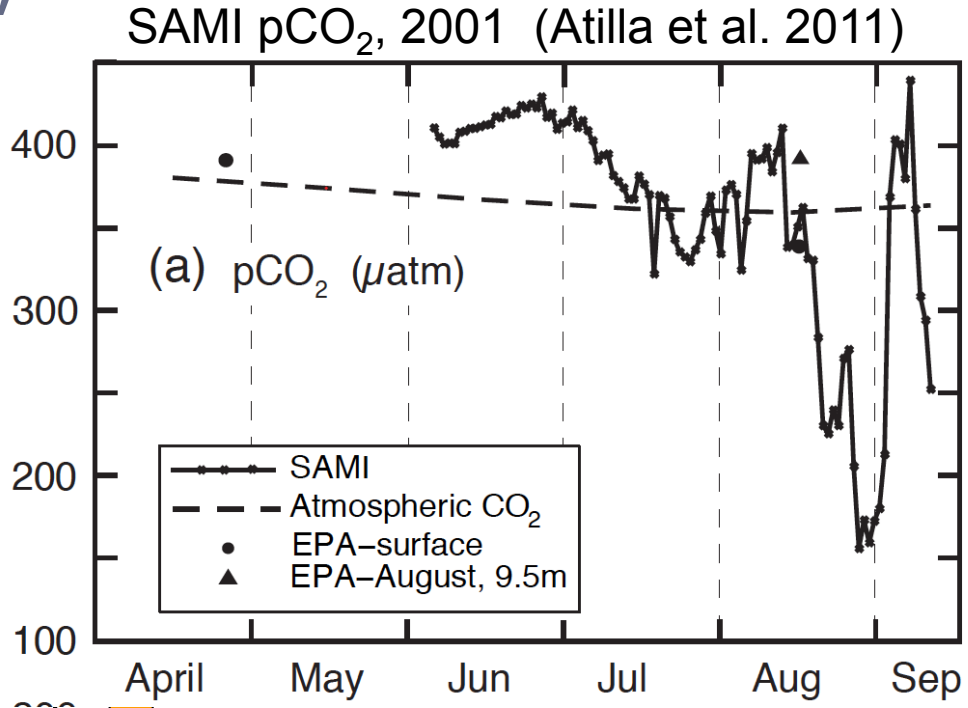
1997 Modeled CO_2 flux





Challenge #1: Spatio-temporal variability

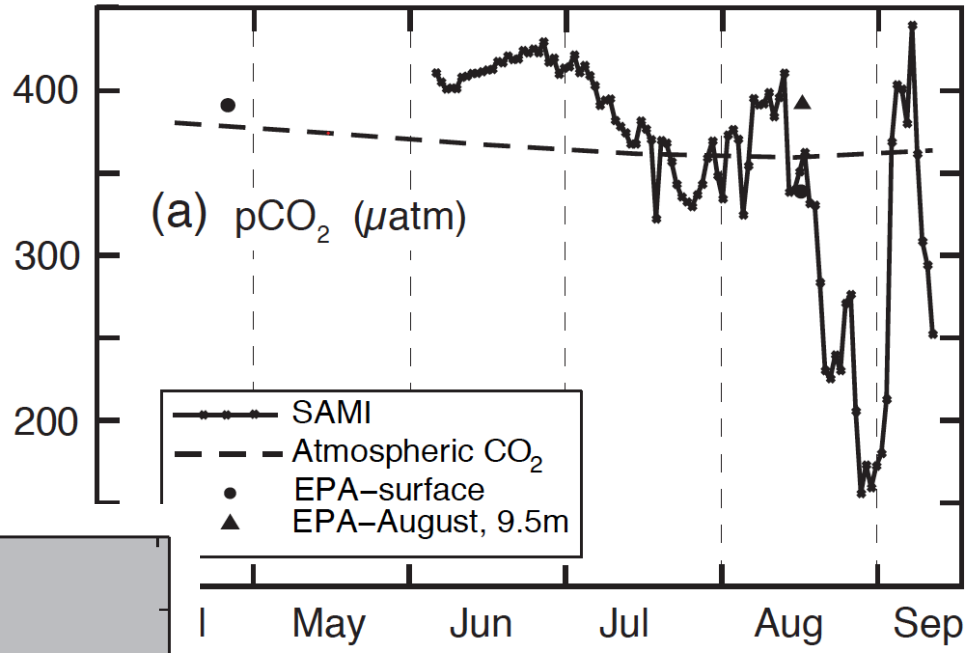


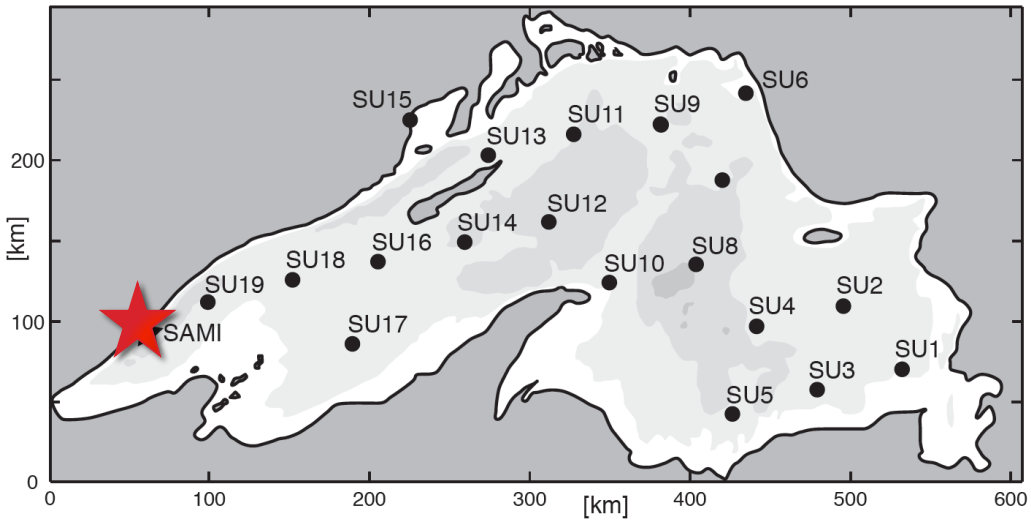


Challenge #1: Spatio-temporal variability

Need to put 2x's/year lake-wide water quality measurements into context of temporal variability

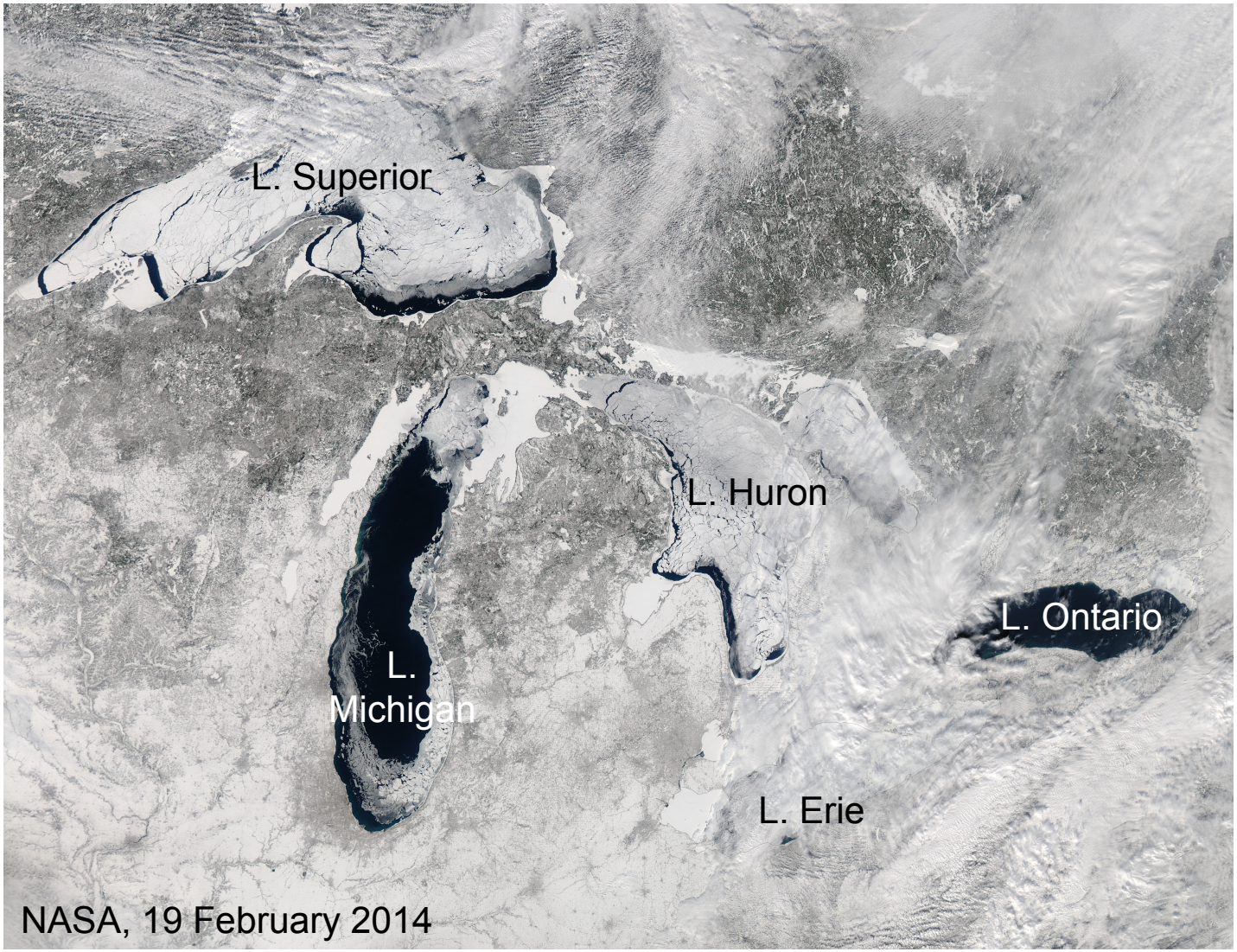
SAMI pCO_2, 2001 (Atilla et al. 2011)





EPA Bi-Annual Monitoring

Challenge #2: Ice cover means no winter data

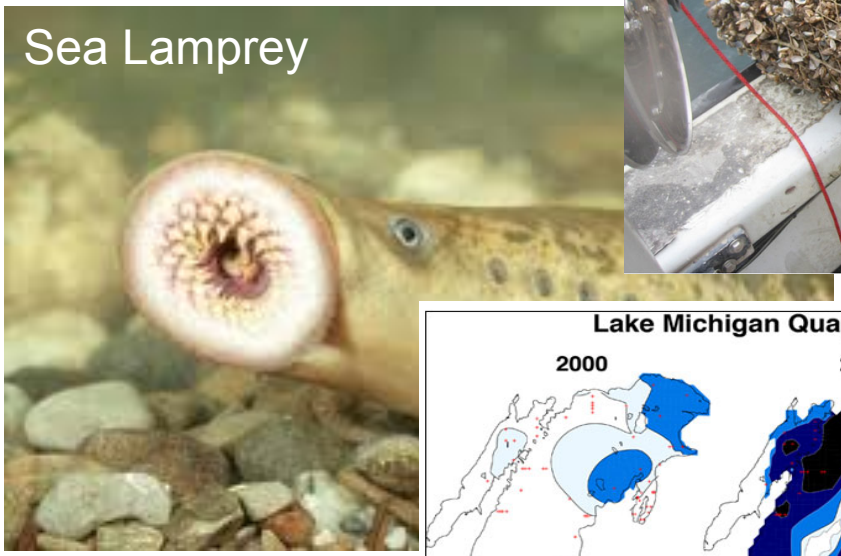


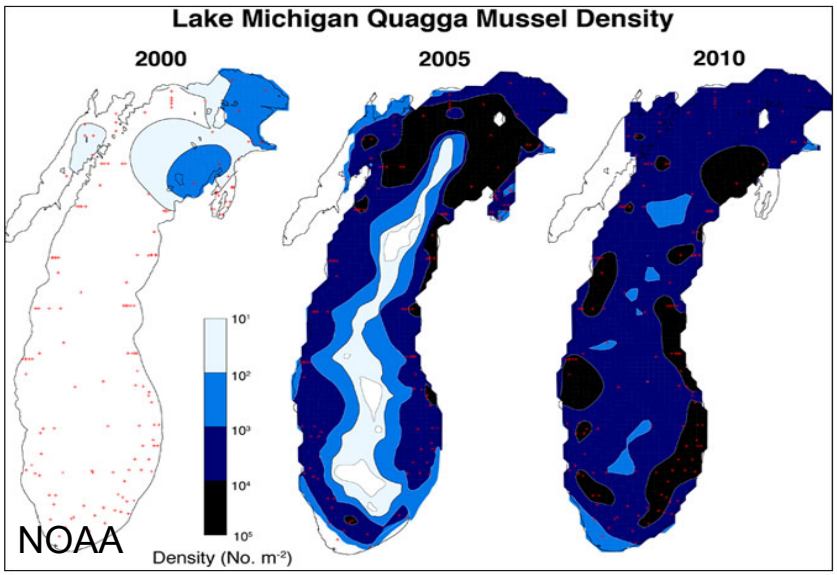
Challenge #3: Carbonate System Data

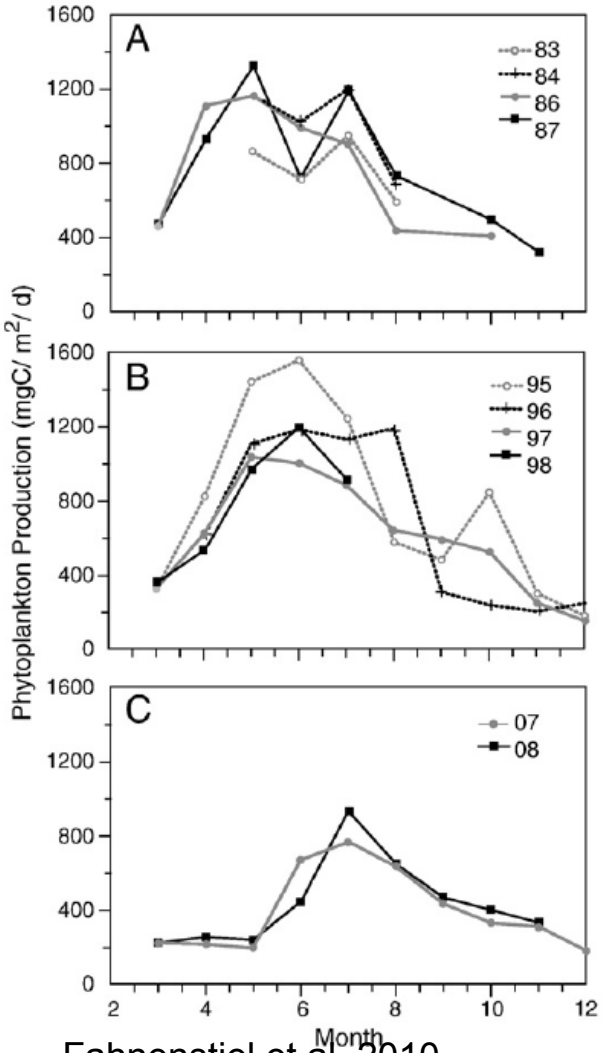
- Most pH data is electrode-based, with low precision

- Few observations of the full carbonate system

Challenge #4: Rapid Change: Invasive Species

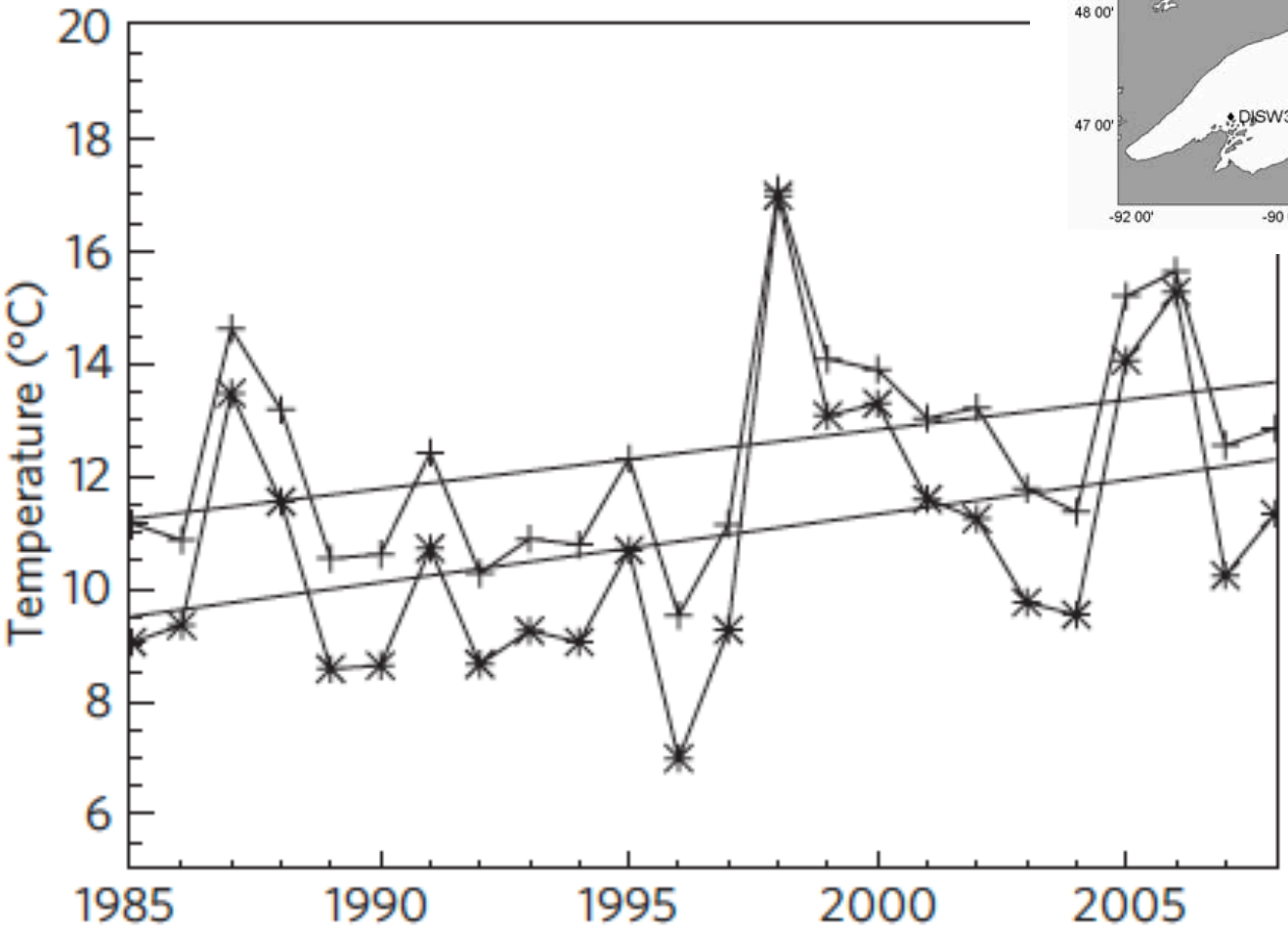


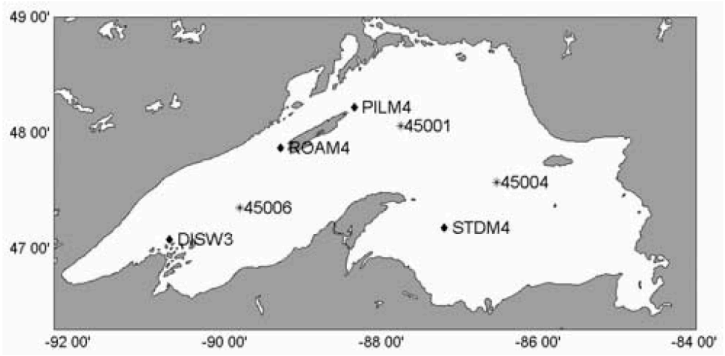




Fahnenstiel et al. 2010

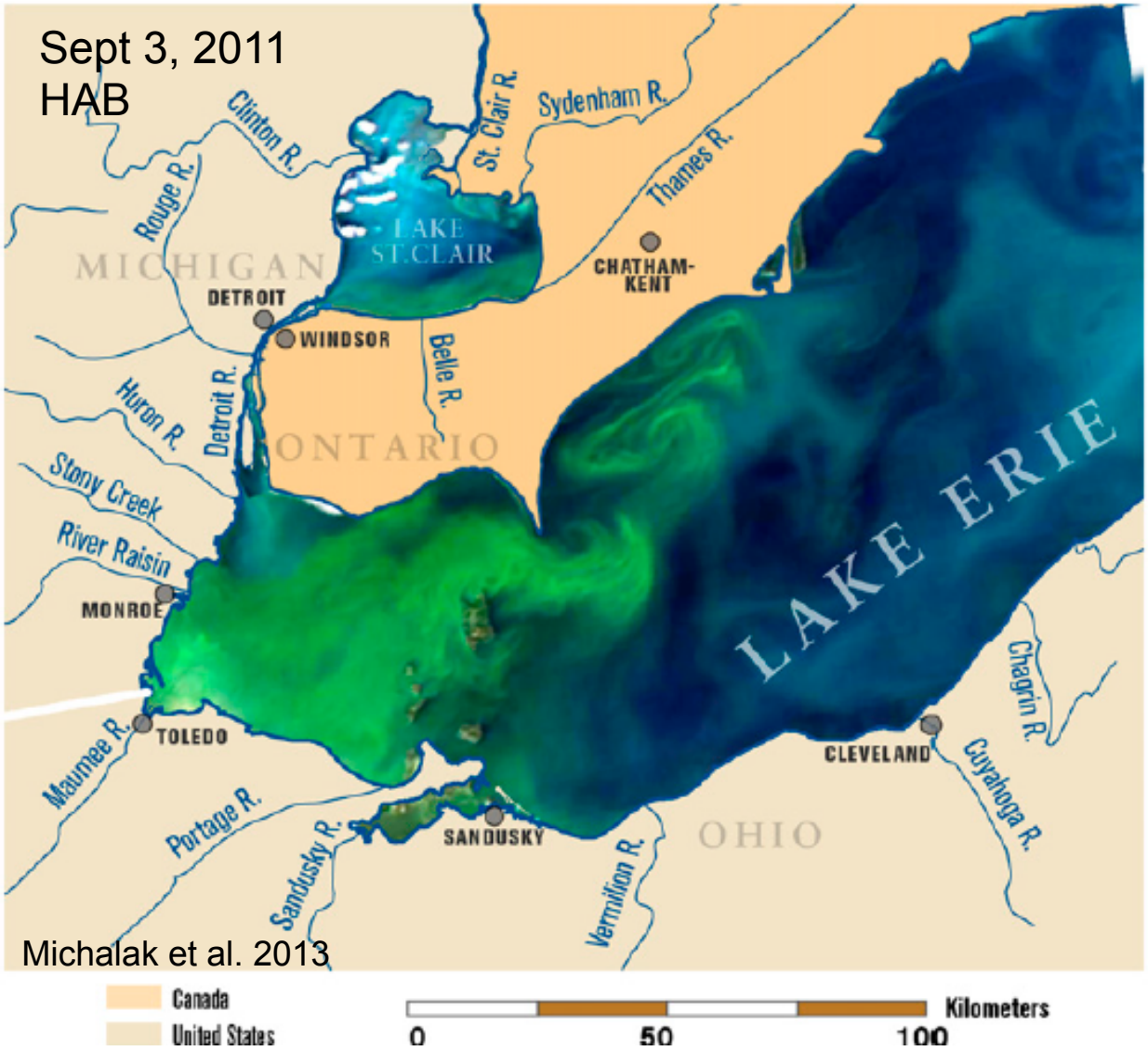
Challenge #4: Rapid Change: Climate





Desai et al. 2009, Austin and Colman 2007

Challenge #4: Rapid Change: Runoff / Climate



Great Lakes carbon budgets

1. Challenges
2. **Preliminary carbon budgets**
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4. Current work

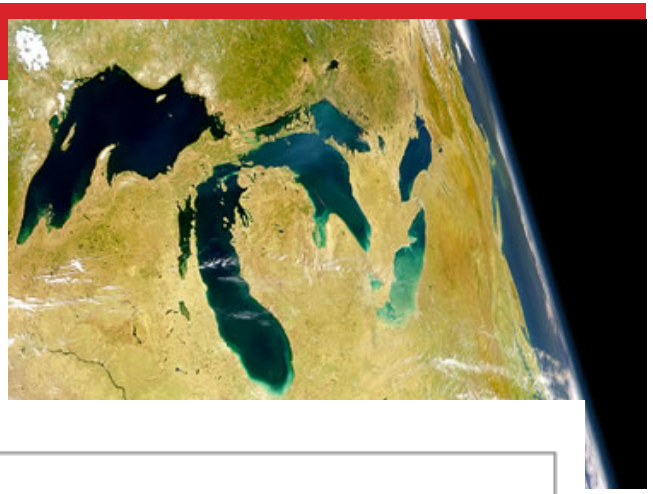
Input / Output only

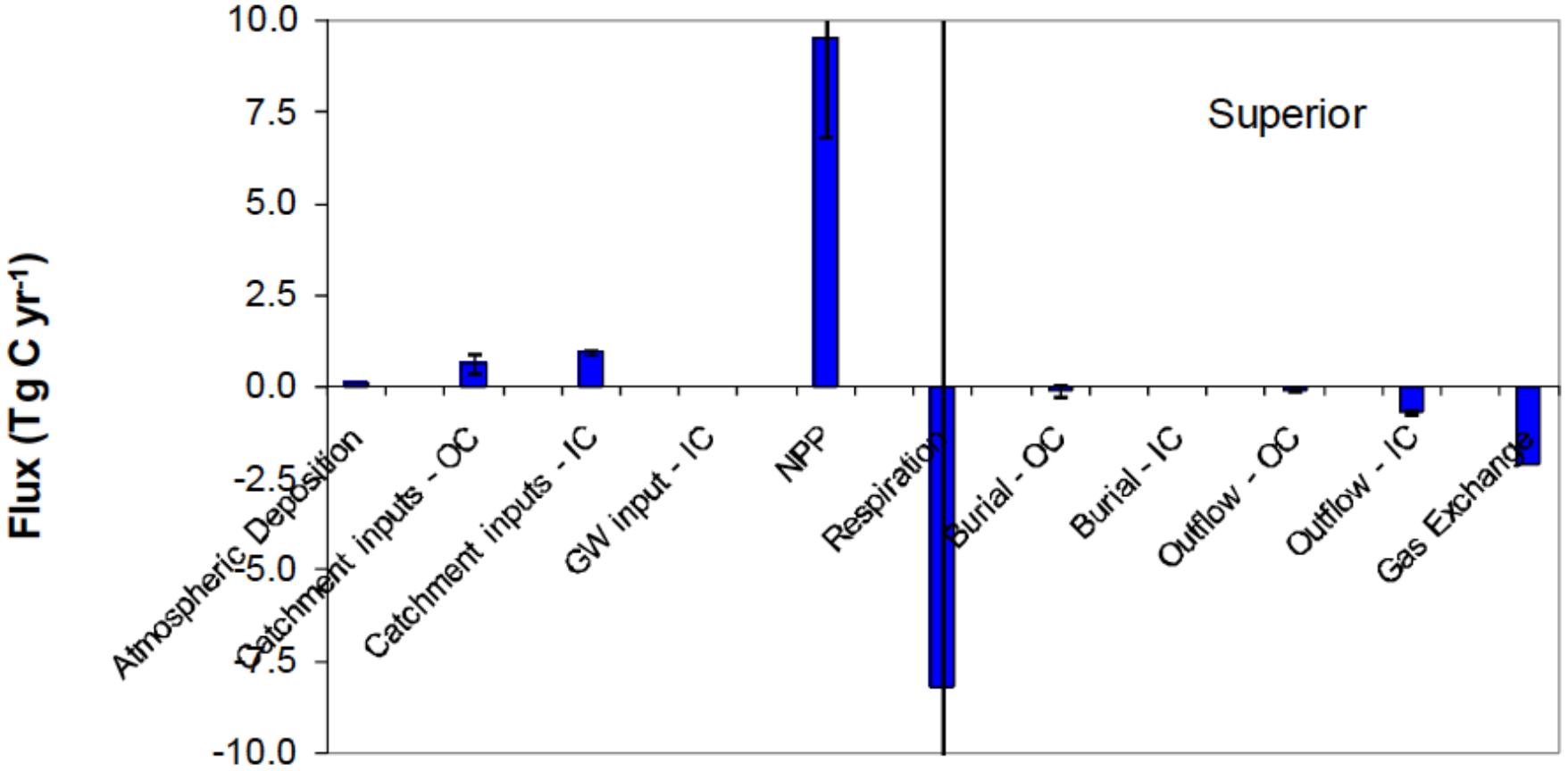
5 Lake Total Efflux
~ 0.1 TgC/yr

Lake	Respiration of Alloch. OC	Degassing of DIC inputs	Burial of Autoch. OC	Net CO2 flux
Superior	0.63	0.25	0.08 ± 0.17	+0.80
Michigan	0.53	?	0.28 ± 0.18	> +0.25
Huron	0.27	?	0.20 ± 0.09	> +0.07
Erie	0.02	?	0.49 ± 0.40	> -0.47
Ontario	0.04	?	0.57 ± 0.36	> -0.53

McKinley et al. 2011
Urban et al. in prep

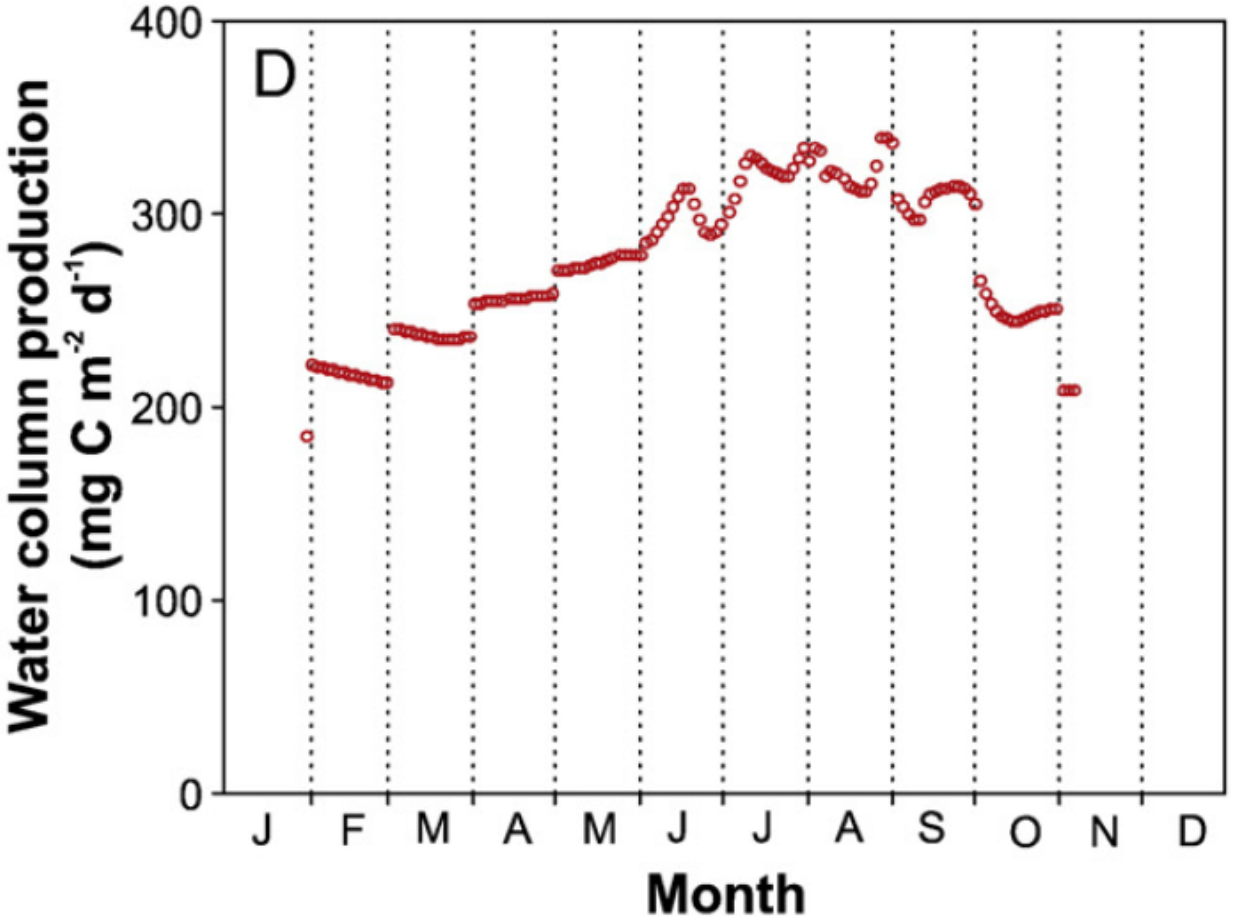
Including terms for internal cycling





McKinley et al. 2011
Urban et al. in prep

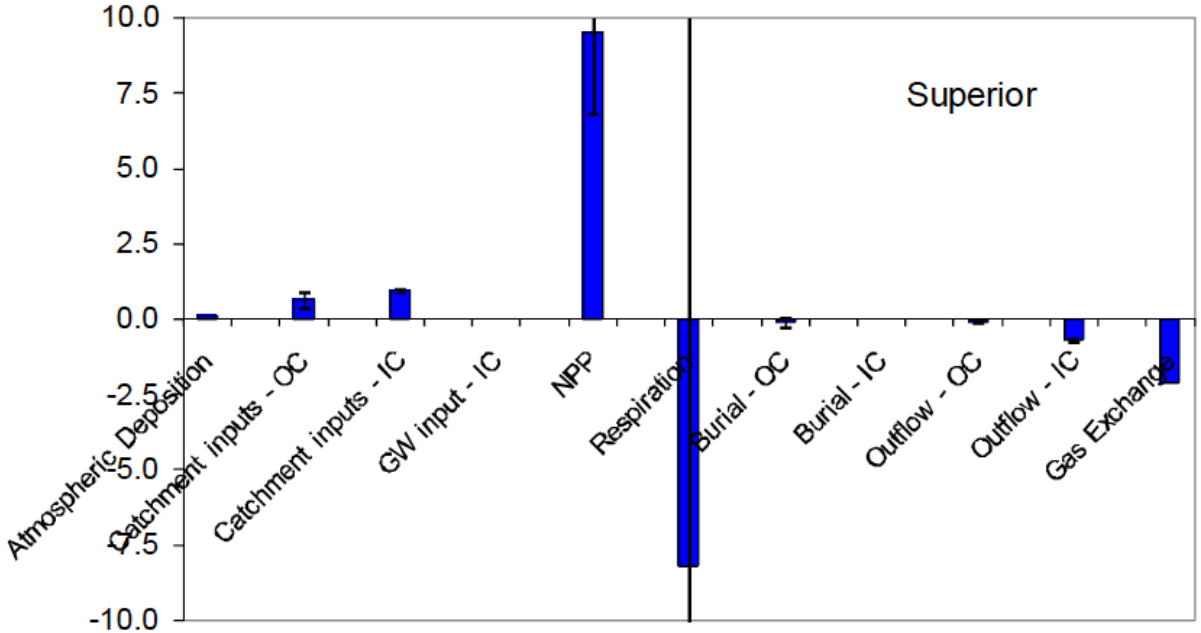
Lake Superior PP from ^{14}C incubations



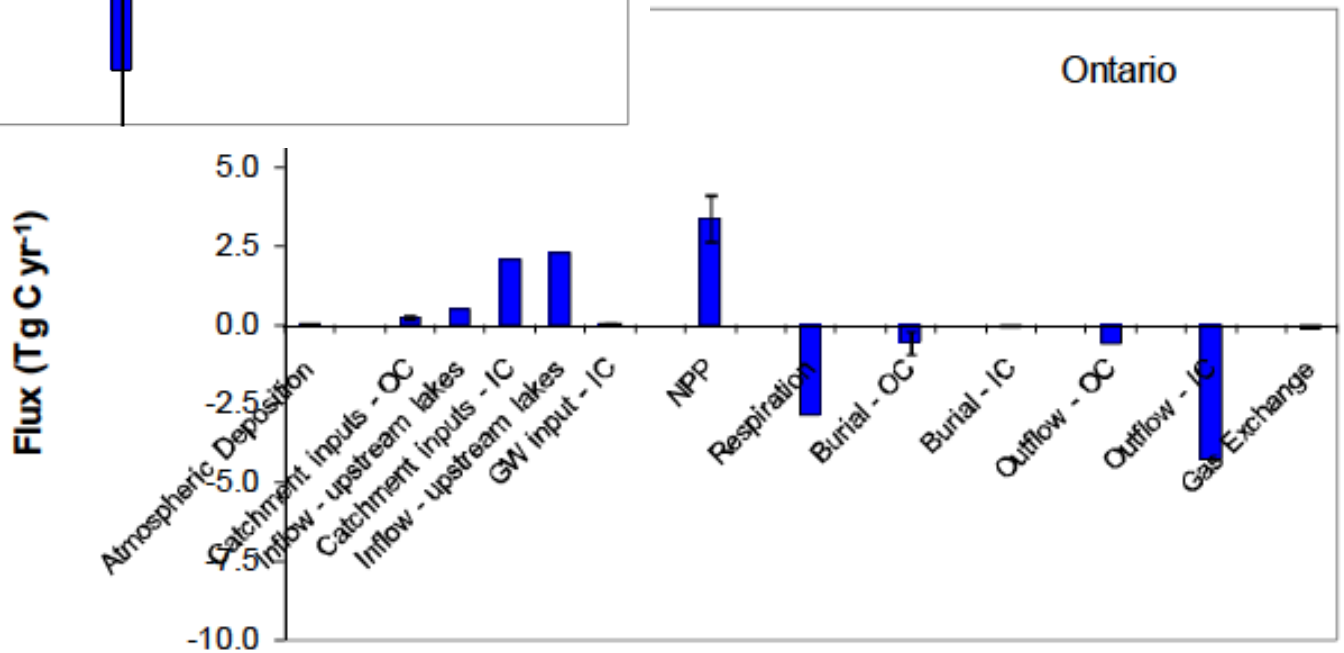
Whole lake estimate
= 9.7 TgC/yr

Sterner 2010

Including terms for internal cycling



5 Lake Total Efflux
~ 2.0 TgC/yr



McKinley et al. 2011
Urban et al. in prep

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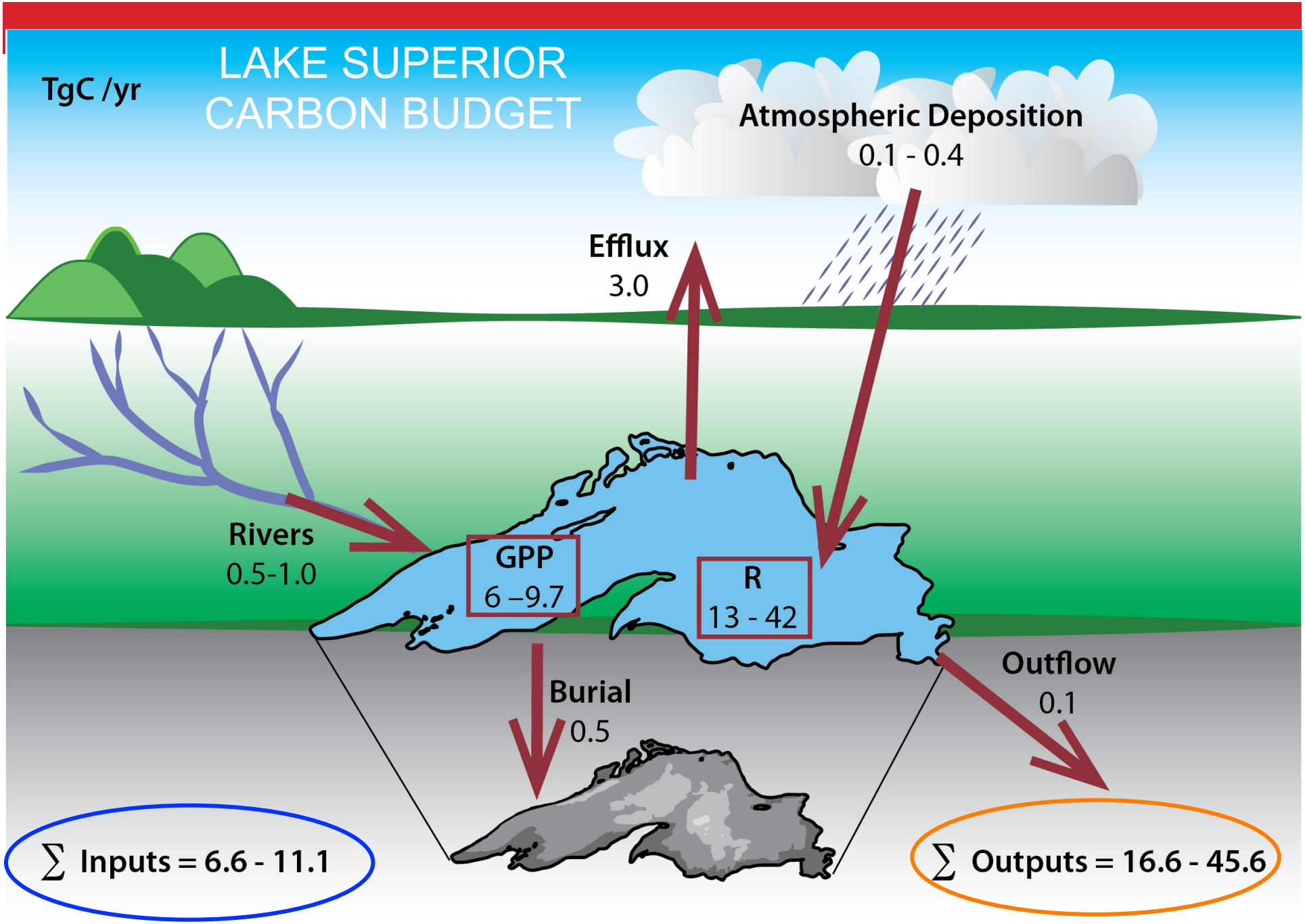
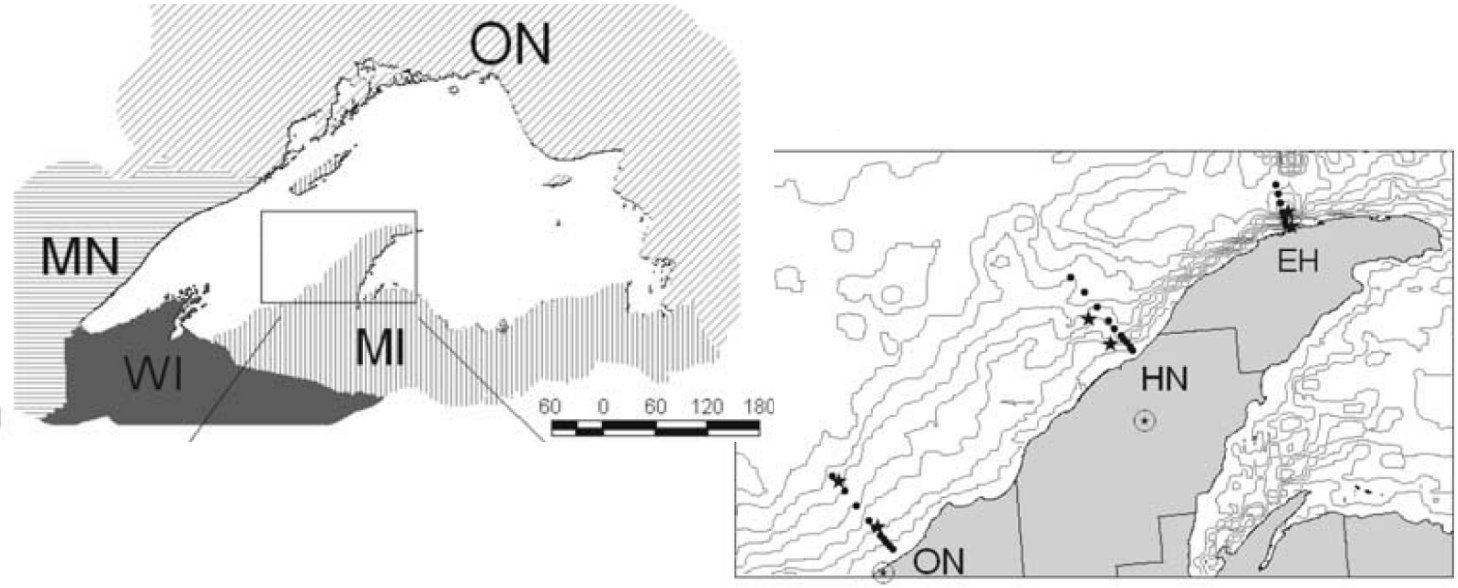
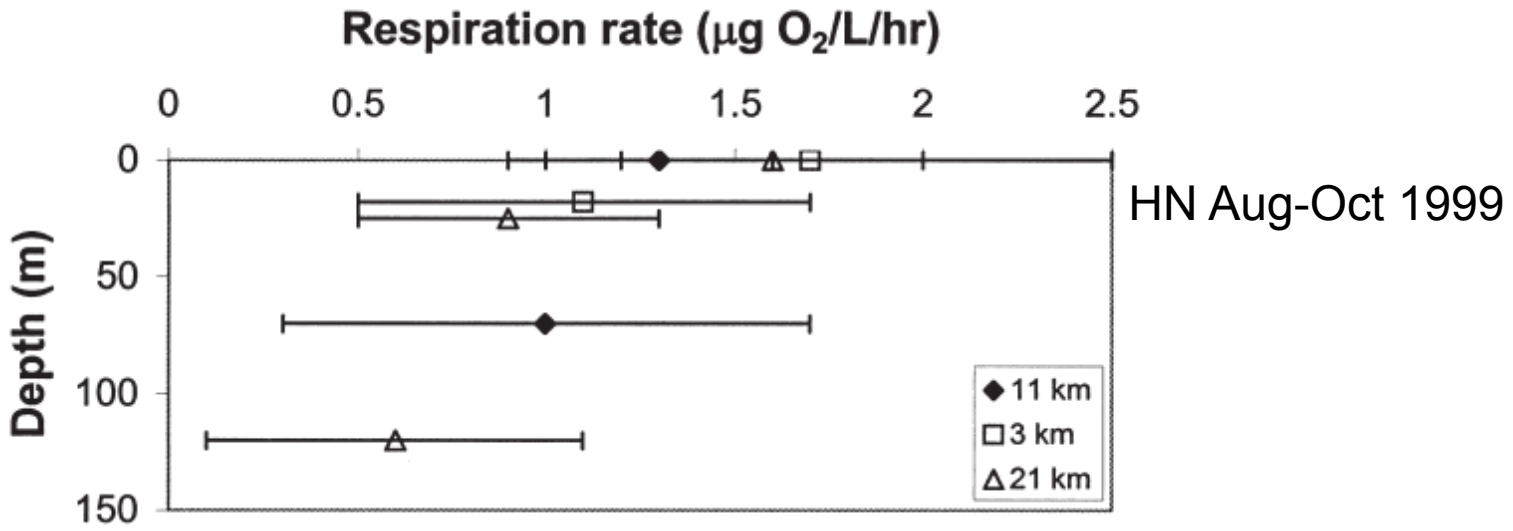


Cotner et al, 2004; Urban et al., 2005; Sterner 2010; McKinley et al. 2011; Bennington et al. 2012; Urban et al. in prep

Respiration from nearshore observations

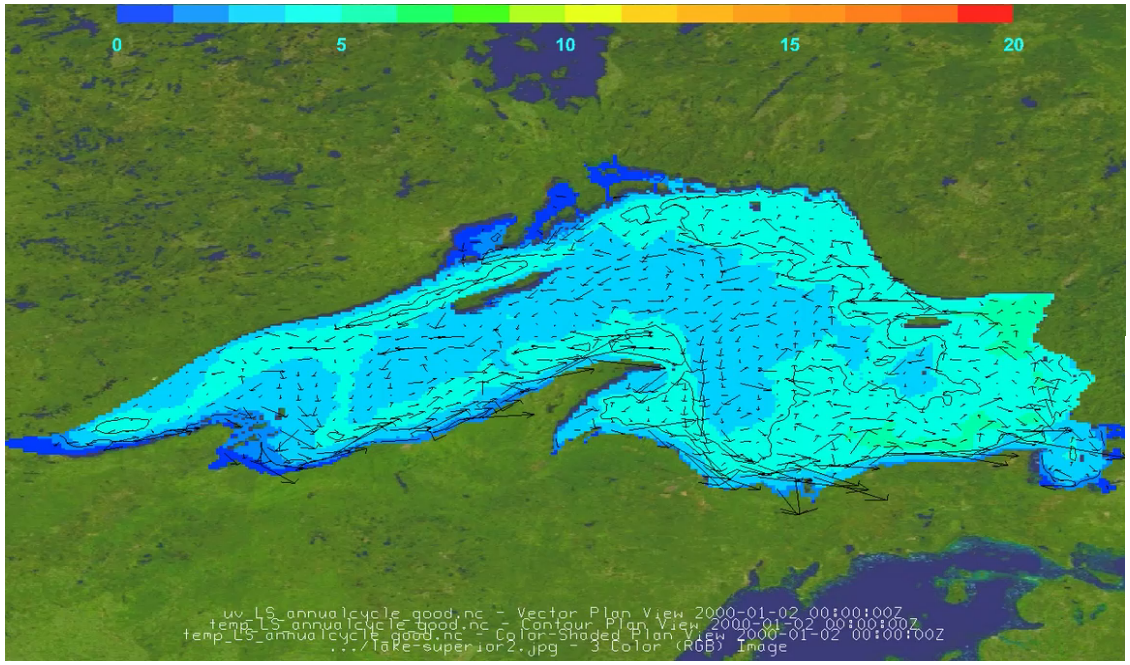




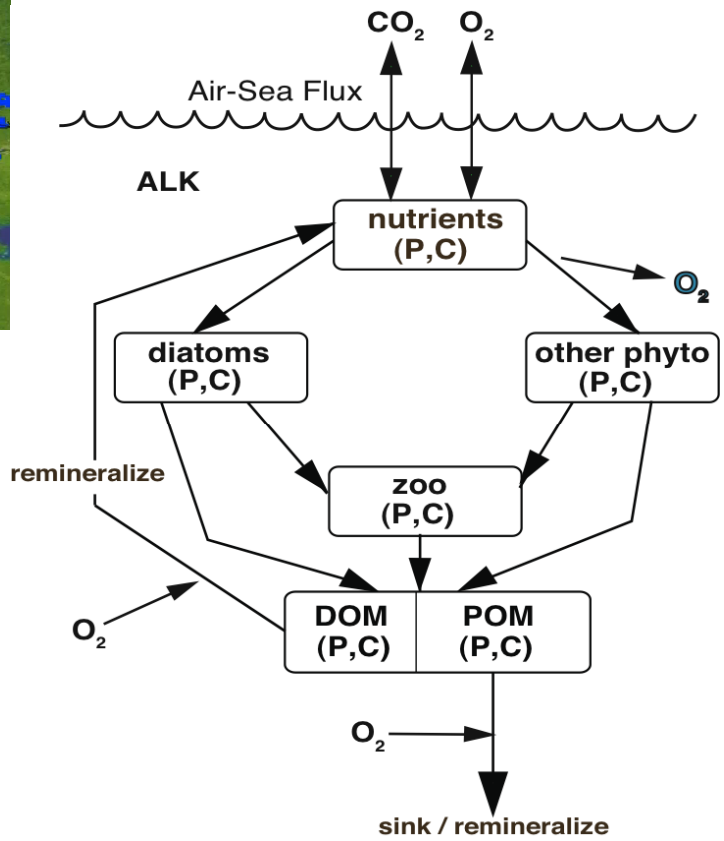
HN Aug-Oct 1999

Urban et al. 2004, 2005

Models estimate spatio-temporal variability

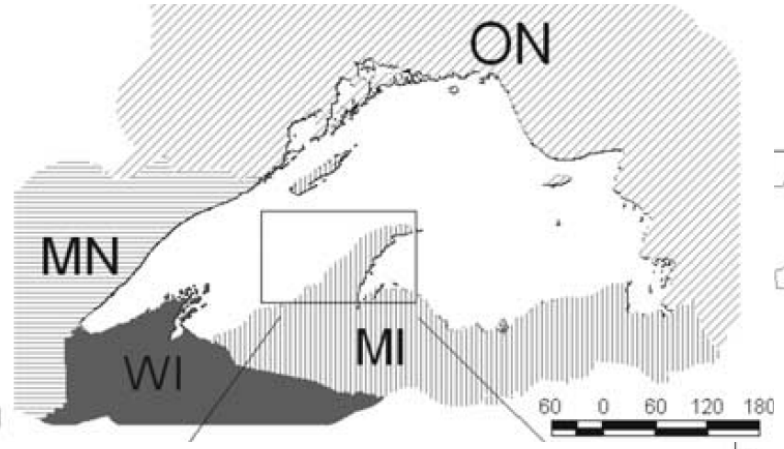


MITgcm.Superior
T (color), currents (vectors), 1 year loop

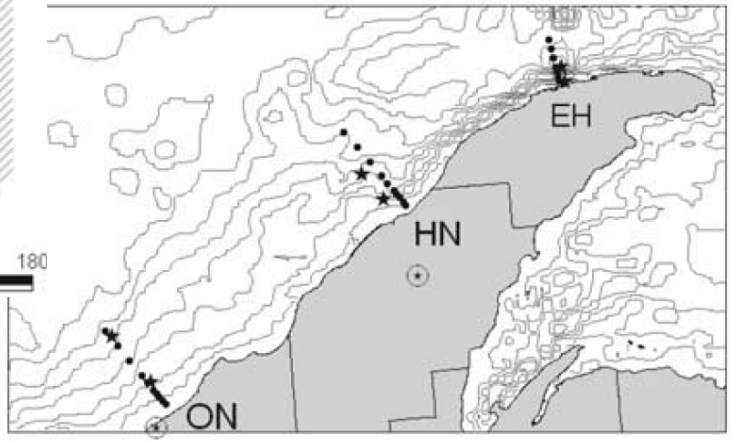


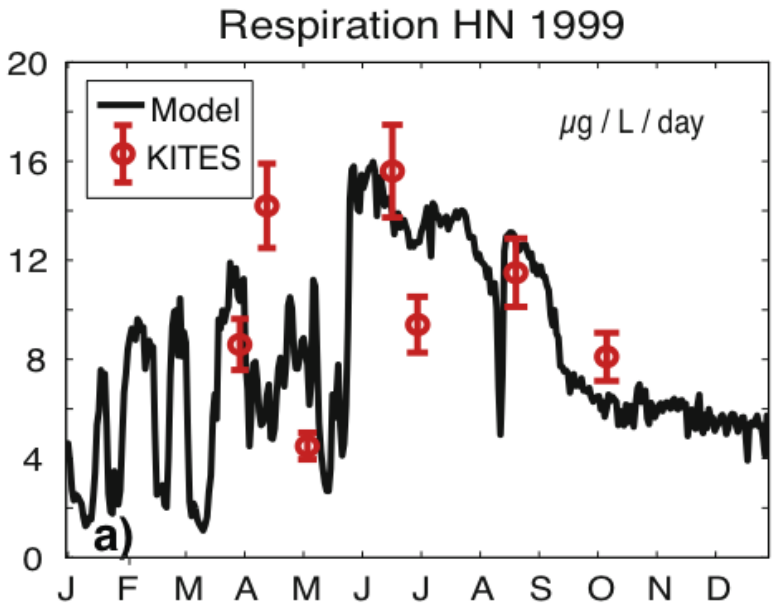
Bennington et al. 2010

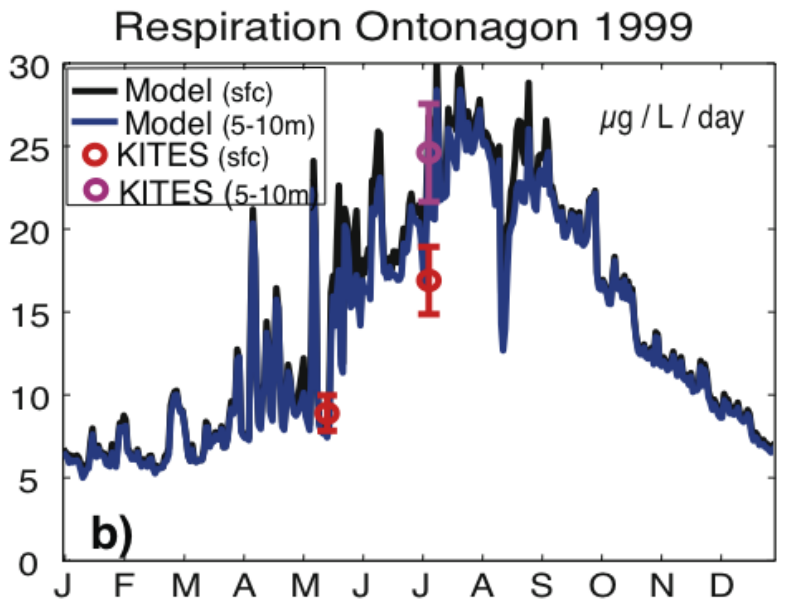
Ecosystem Validation: Nearshore Respiration



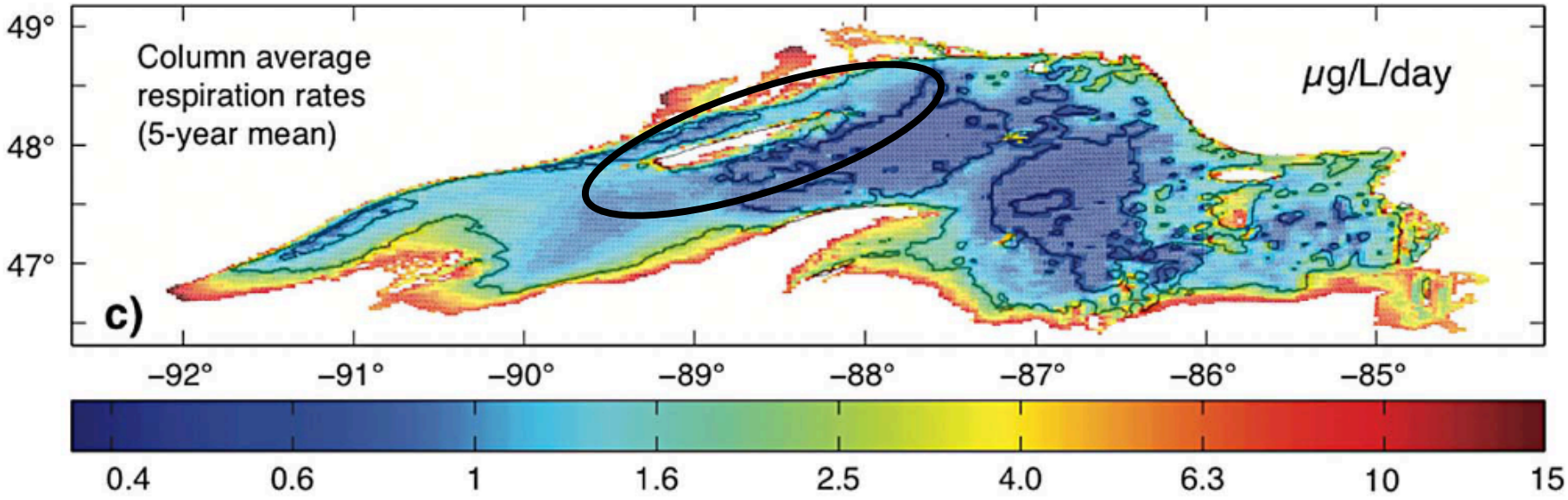
Urban et al. 2004





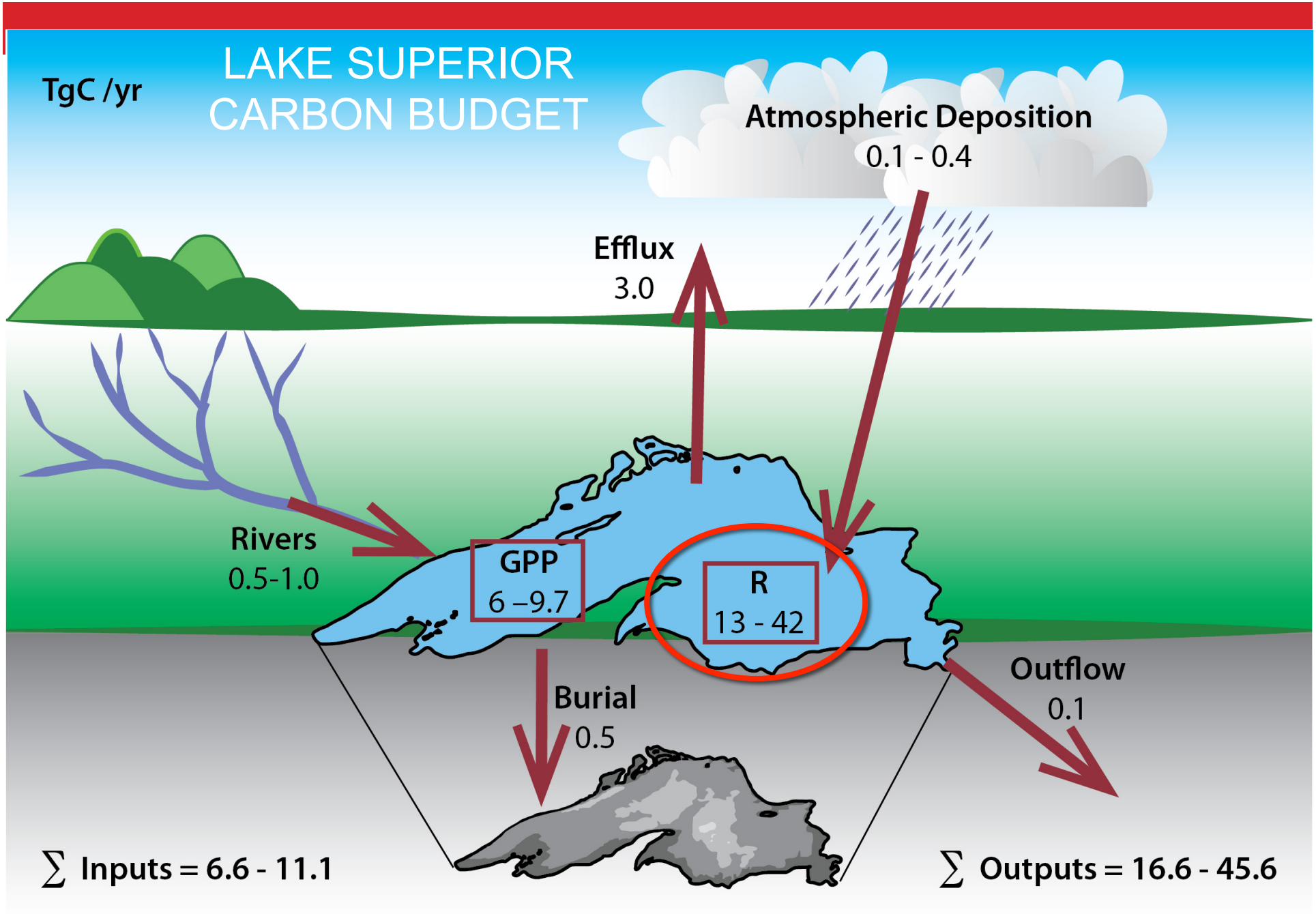


Model indicates a factor of 10 variation in respiration (volumetric)

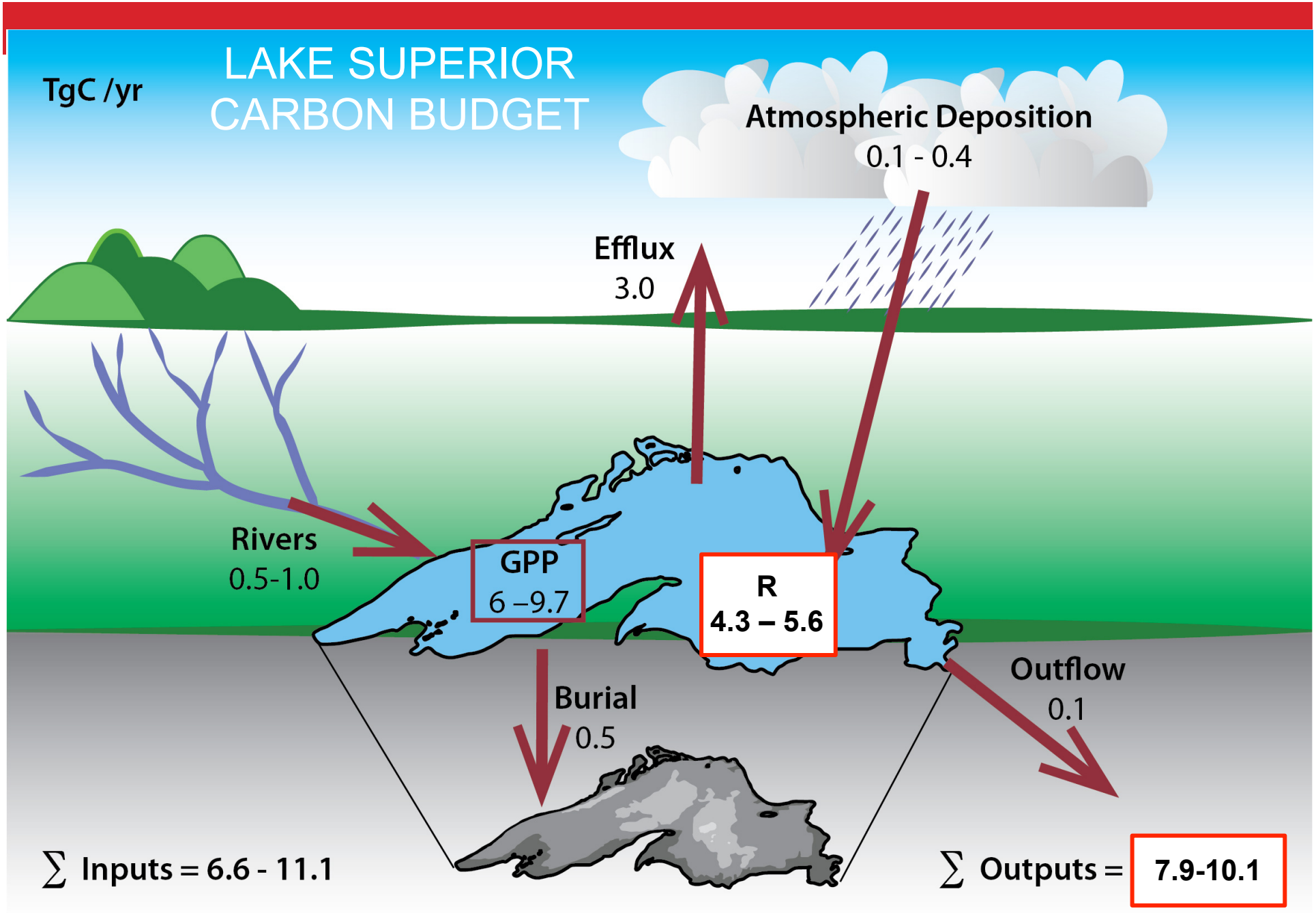


Use model pattern to scale up data ➔ 4.3 – 5.6 TgC/yr

Bennington et al. 2012



Cotner et al, 2004; Urban et al., 2005; Sterner 2010; McKinley et al. 2011; Bennington et al. 2012; Urban et al. in prep



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Great Lakes carbon budgets

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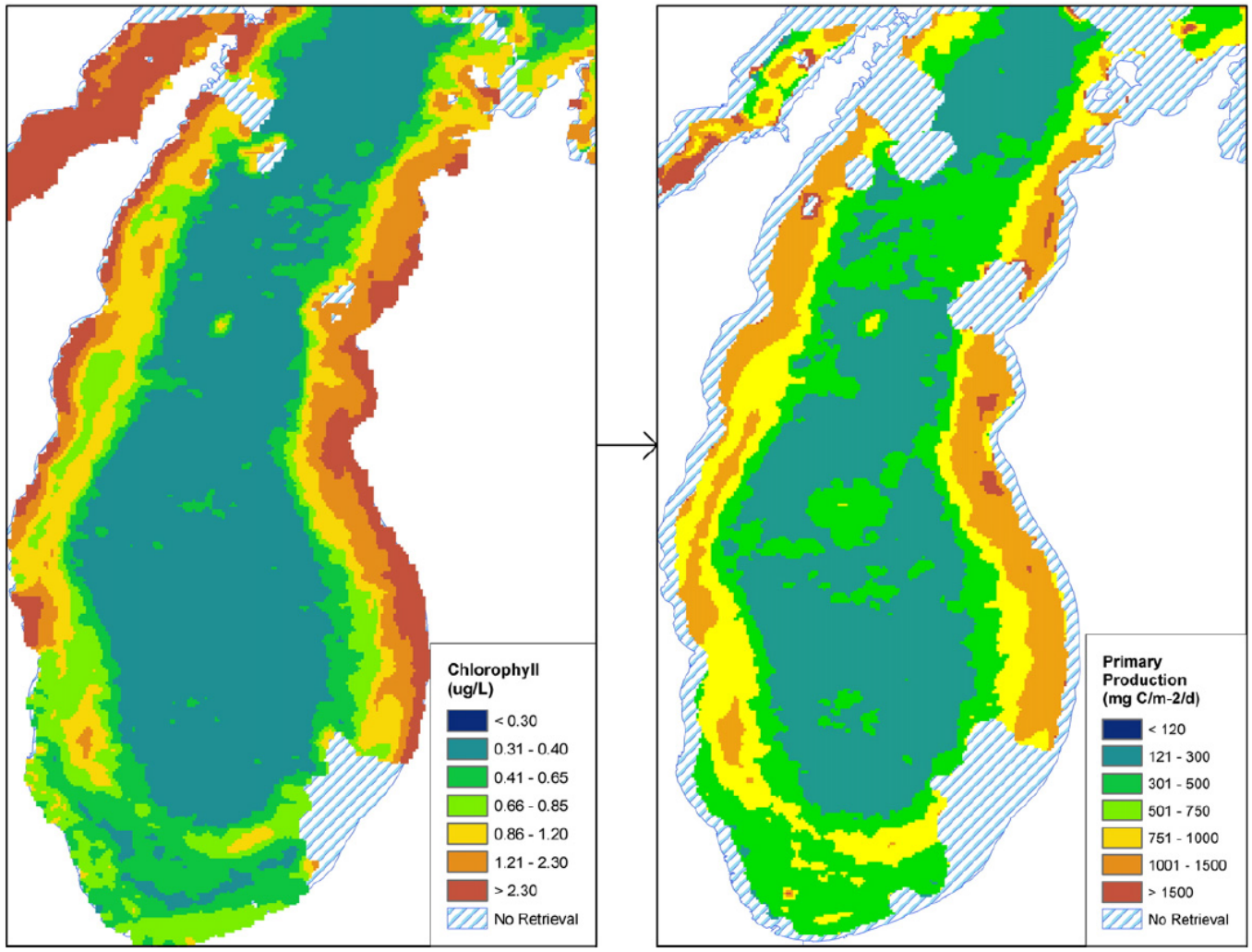
Carbon measurements currently underway

	Measurements	PI
L. Superior	Underway pH on R/V Blue Heron	Sterner (UMn-Duluth)
	^{14}C Primary Productivity	Sterner (UMn-Duluth)
	DIC, spectrophoto. pH (12 stn.)	Minor (UMn-Duluth)
	Eddy flux covariance (2 sites)	Blanken, Lenters, Spence, Froelich (UCB, LimnoTech, EC, NMU)
L. Michigan	Lake Express underway pCO_2	Bootsma (UW-Milwaukee)
L. Huron		
L. Erie	Eddy flux covariance (1 site)	Chen (U. Toledo / MSU)
	CH_4, CO_2 fluxes (ship-based)	Townsend-Small (U. Cincinnati)
	Large multidisciplinary C-cycle study	Xenopoulos (Trent Univ.)
L. Ontario		

Also, Eddy flux covariance for physical properties at 7 sites, at least 1 per lake (Great Lakes Evaporation Network)

Satellite biogeochemistry for carbon cycling



CHL and PP
12 May 2008

Shuchman et al. 2013; see also Mouw et al. 2013

Conclusions

- Laurentian Great Lakes Efflux ~ 0.1-2.0 TgC/yr
  - Lakes Superior, Michigan, Huron likely sources
  - Lakes Erie and Ontario likely sinks

- Constraints needed, all lakes
  - Lake-Air CO_2 Flux
  - Primary Production and Respiration
  - Inputs and Burial

- New datasets, satellite algorithms, and modeling offer promising opportunities to improve understanding

References

1. Atilla, N. G.A. McKinley, V. Bennington, M. Baehr, N. Urban *et al.* Observed variability of Lake Superior pCO2. *Limnol Oceanogr* **56,** 775–786 (2011).
2. Bennington, V., Mckinley, G. A., Urban, N. R. & McDonald, C. P. Can spatial heterogeneity explain the perceived imbalance in Lake Superior's carbon budget? A model study. *J. Geophys. Res* **117**, G03020 (2012).
3. Bennington, V., McKinley, G., Kimura, N. & Chin, W. General circulation of Lake Superior: Mean, variability, and trends from 1979 to 2006. *J. Geophys. Res* **115**, C1201 (2010).
4. Cotner, J. B., Biddanda, B. A., Makino, W. & Stets, E. Organic carbon biogeochemistry of Lake Superior. *Aquatic Ecosystem Hlth. & Man.* **7**, 451–464 (2004).
5. Fahnenstiel, G. *et al.* Recent changes in primary production and phytoplankton in the offshore region of southeastern Lake Michigan. *J Great Lakes Res* **36,** 20–29 (2010).
6. French, C. R. *et al.* Spectrophotometric pH measurements of freshwater. *Analytica Chimica Acta* **453,** 13–20 (2002).
7. McKinley, G. A., Urban, N., Bennington, V., Pilcher, D. & McDonald, C. Preliminary Carbon Budgets for the Laurentian Great Lakes. *OCB News* **4**, (2011).
8. Mouw, C. B., H. Chen, G.A. McKinley, St. Effler, D. O'Donnell *et al.* Evaluation and optimization of bio-optical inversion algorithms for remote sensing of Lake Superior's optical properties. *J Geophys Res-Oceans* (2013). doi:10.1002/jgrc.20139
9. Shuchman, R. A., G. Leshkevich, M. J. Sayers, T.H. Johengen, C.N. Brooks & D. Pozdnyakov. An algorithm to retrieve chlorophyll, dissolved organic carbon, and suspended minerals from Great Lakes satellite data. *J Great Lakes Res* **39,** 14–33 (2013).
10. Sterner, R. W. In situ-measured primary production in Lake Superior. *JGLR* **36,** 139–149 (2010).
11. Urban, N., M.T. Auer, S.A. Green, X. Lu, D.S. Apul *et al.* Carbon cycling in Lake Superior. *J. Geophys. Res* **110**, C06S90 (2005).