# Advancing approaches for multi-year high-frequency monitoring of temporal and spatial variability in carbon cycle fluxes and drivers in freshwater lakes

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Photo Credit: Ted Bier

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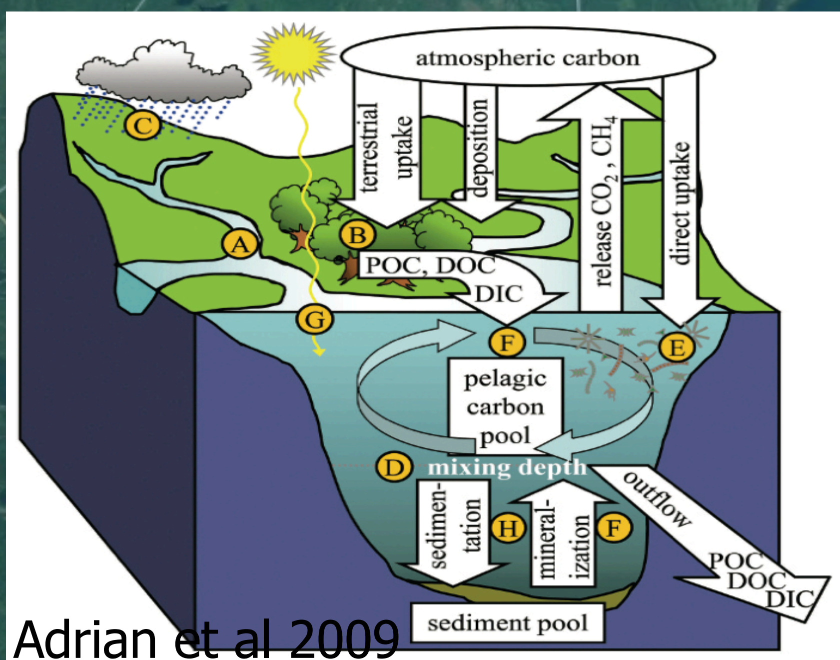
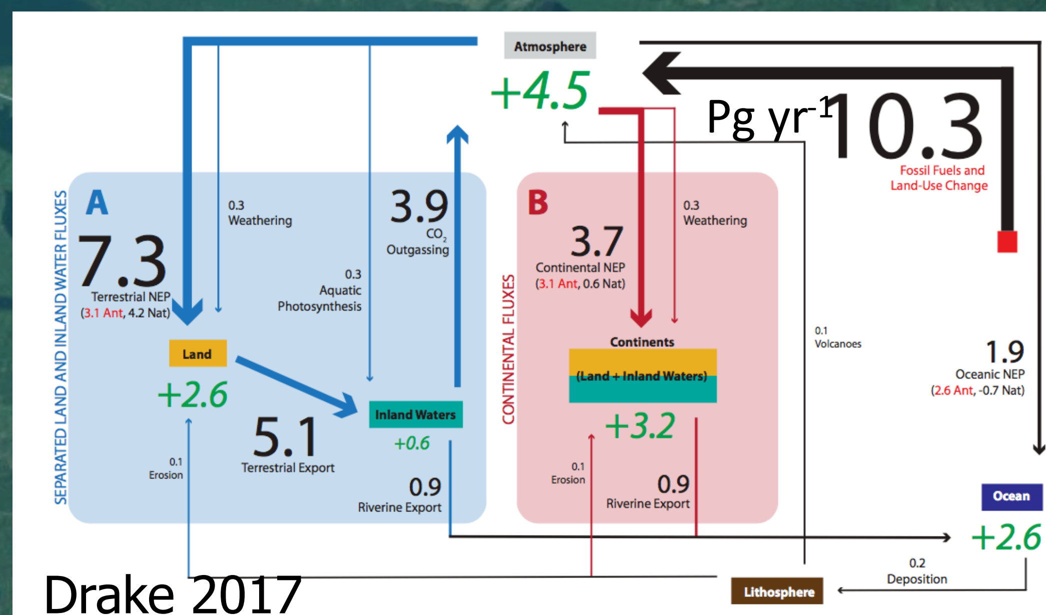
- Elisabeth Cartwright, Verona Area High School

# Why study lakes?

- Inland waterbodies comprise significant component of many landscapes
- They disproportionally influence regional carbon cycles, and possibly global carbon cycle




Adrian et al 2009

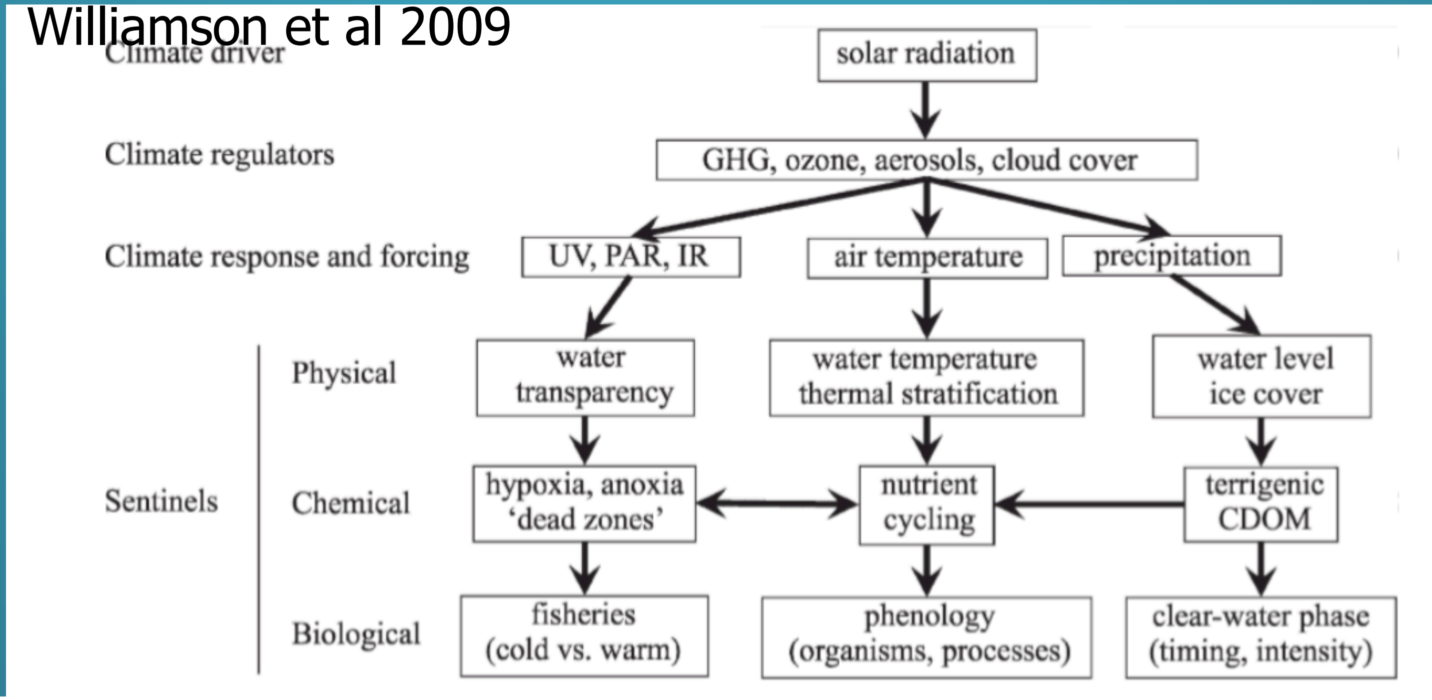



Drake 2017

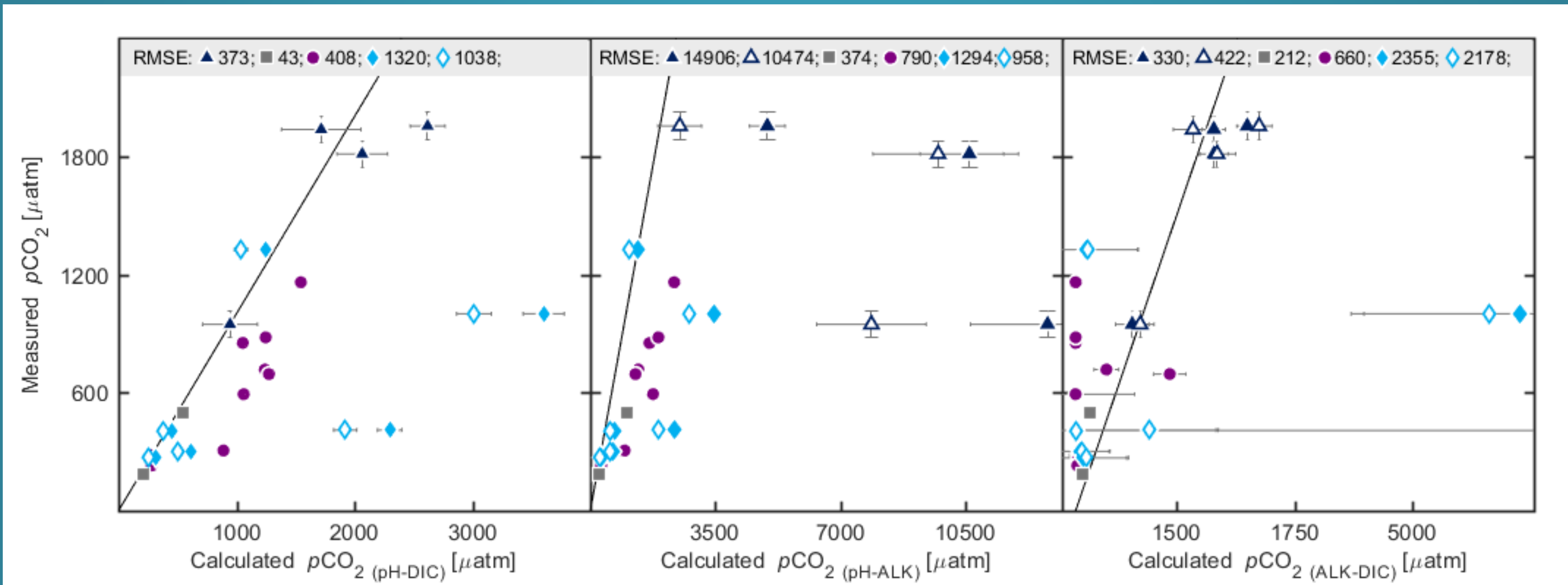
# The Problem

- Carbon cycling in lakes involves interaction of multiple physical and biological drivers
- Measurements of carbon efflux and drivers is often limited to 1-2/year and labor intensive

Williamson et al 2009



# Further, traditional approaches to estimating pCO2 by carbonate chemistry is fraught with uncertainty!




*p*$CO_2$ from pH-DIC *p*$CO_2$ from pH-Alk *p*$CO_2$ from Alk-DIC

**Golub**, M.G., Desai, A.R., McKinley, G.A., Remucal, C.K., and Stanley, E.H., 2017. Large uncertainty in estimating pCO2 from carbonate equilibria in lakes. *J. Geophys. Res.-G.*, 122. doi:10.1002/2017JG003794

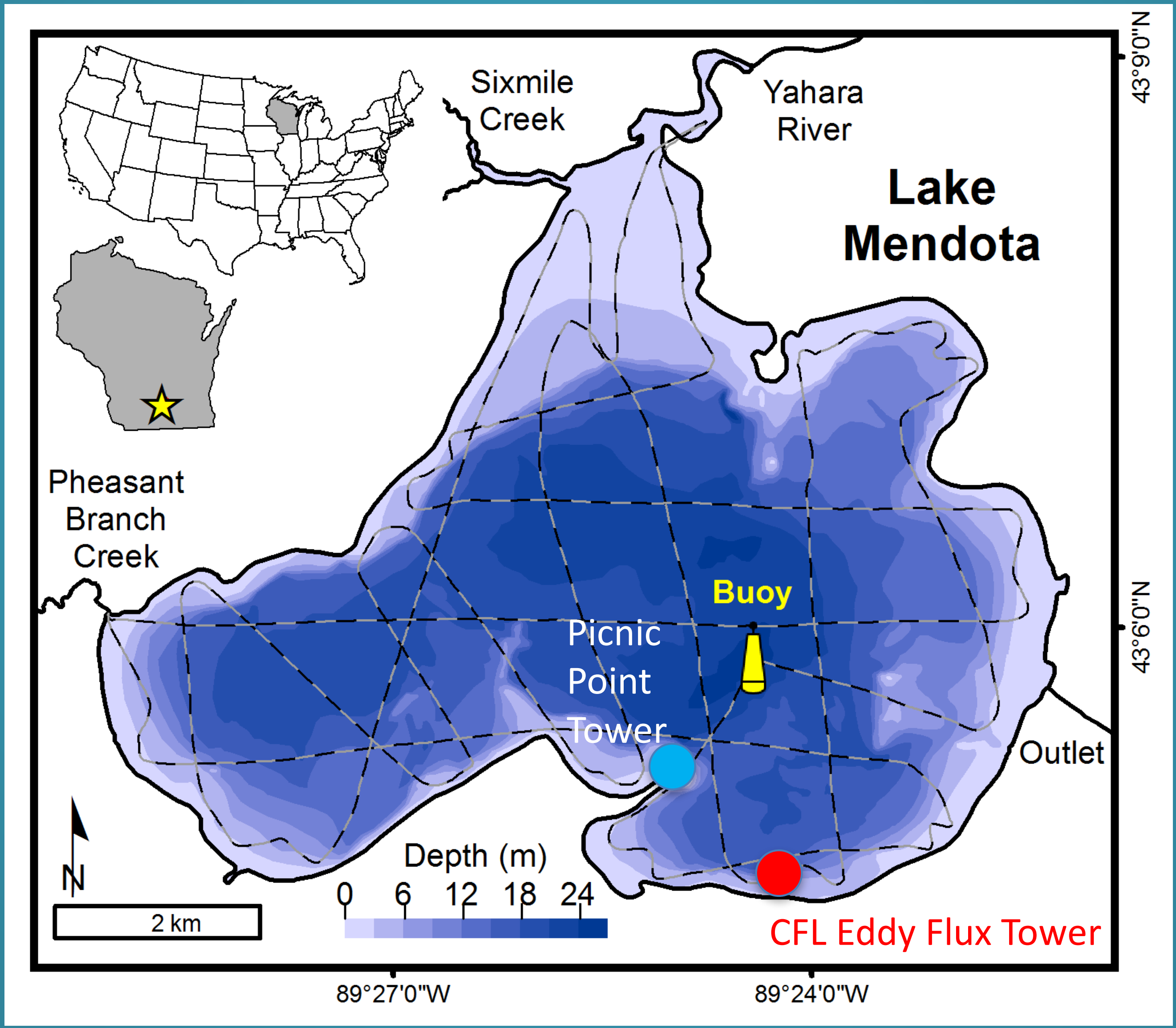
# Therefore,

Can we combine recent advances in

*high-frequency*
eddy covariance over lakes,
boat-mounted or buoy-mounted gas analyzers,
and direct chamber fluxes

to better investigate role of biology and physics
on lake C efflux?

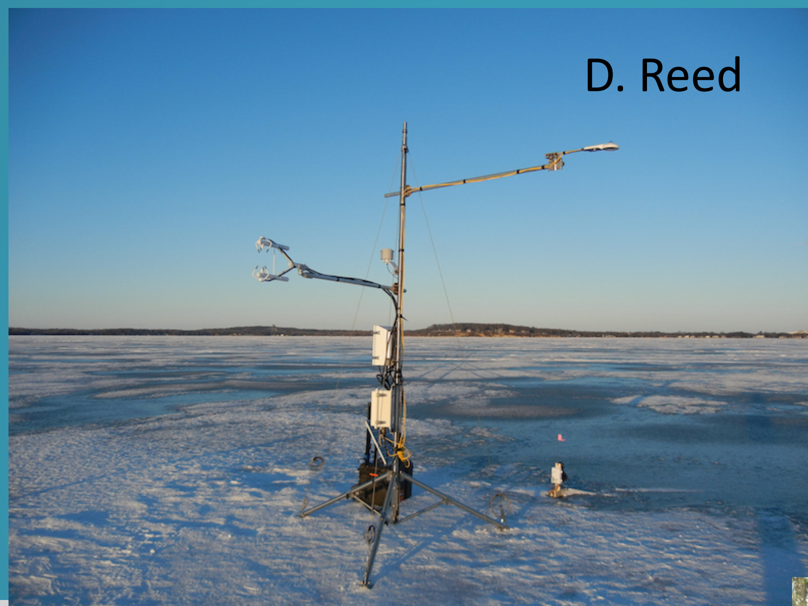
# Study site and tools



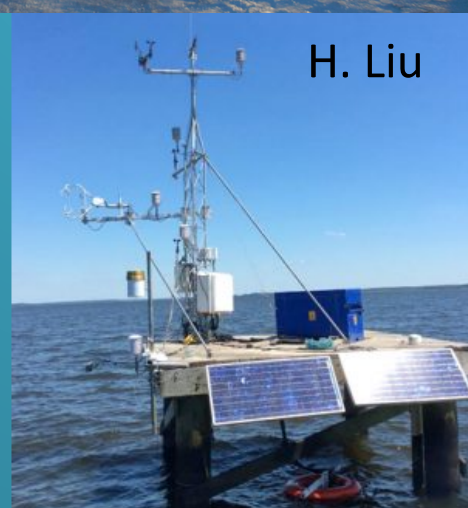

**Loken** et al., in prep

# Eddy Covariance

$$Flux = \overline{\rho w' c'}$$




# Buoys

$$Flux = k_{600} \cdot Kh \cdot (pCO_{2_{water}} - pCO_{2_{air}})$$

NTL-LTER Blog


A. Kruger

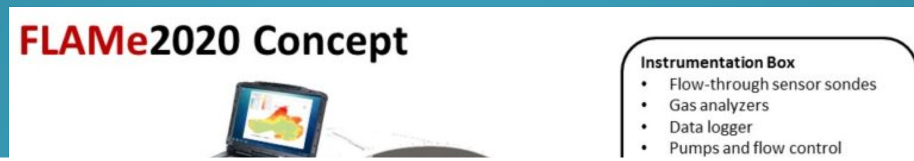
Turner

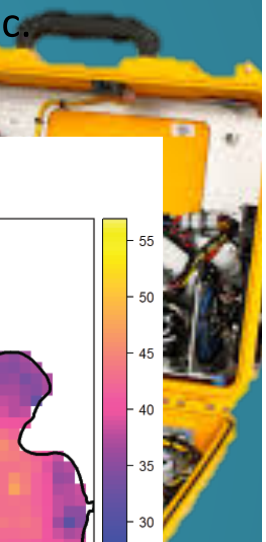
# Fast Limnological Automated MEasurements (FLAME)

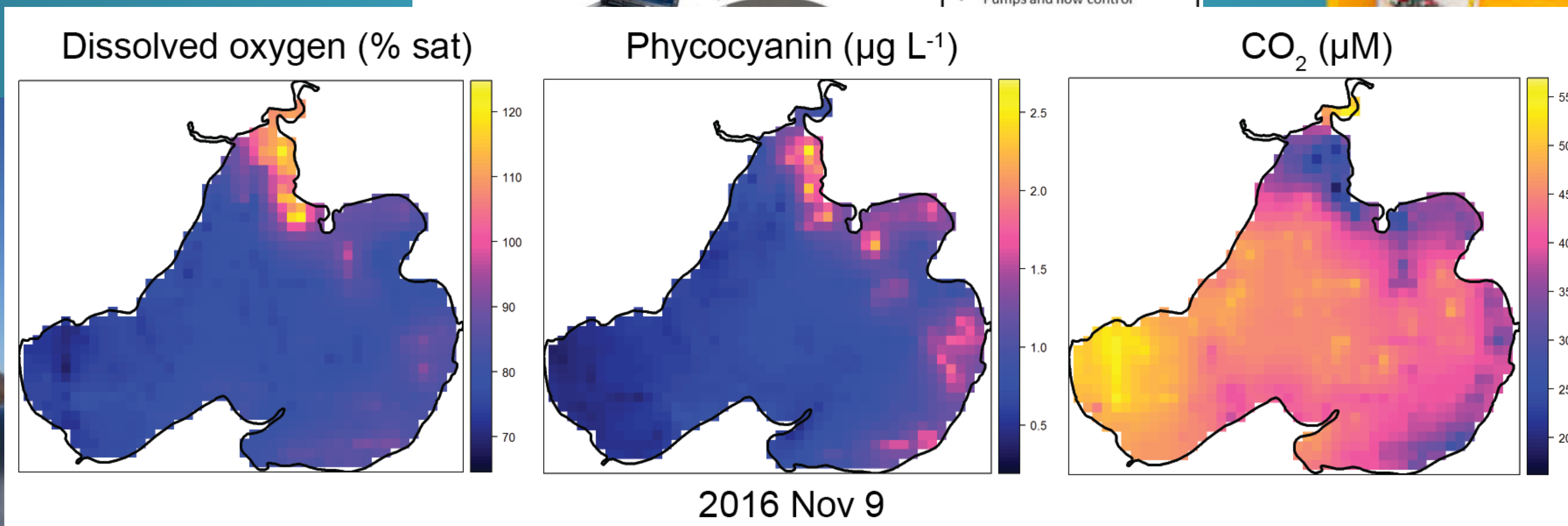
http://flame.wisc.edu

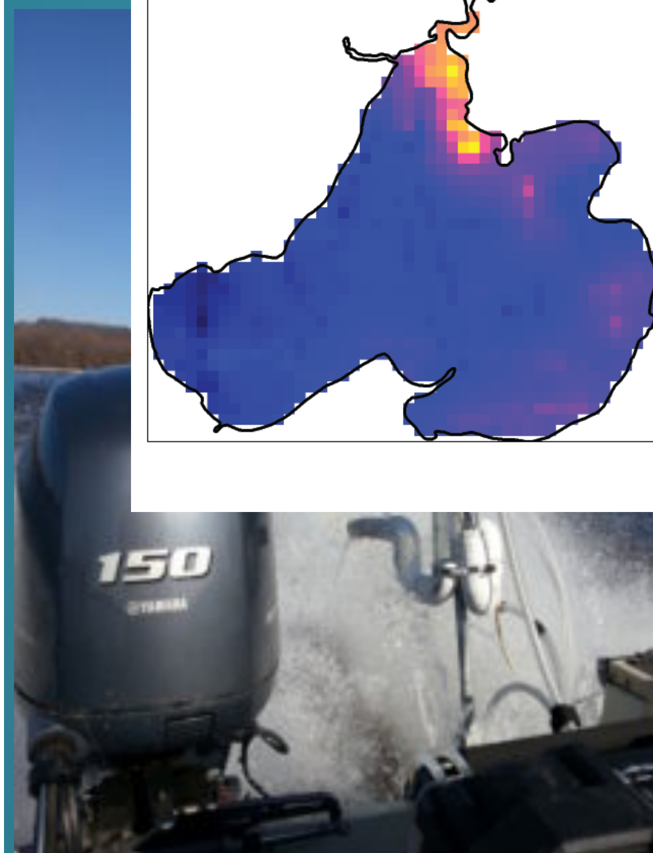
**Crawford** et al., 2015

$$Flux = k_{600} \cdot Kh \cdot (pCO_{2_{water}} - pCO_{2_{air}})$$




**Crawford** JT, Loken LC, Casson NJ, Smith C, Stone AG, and Winslow LA (2015) High-speed limnology: Using advanced sensors to investigate spatial variability in biogeochemistry and hydrology. *Environmental Science and Technology* 49:442-450, doi:10.1021/es504773x

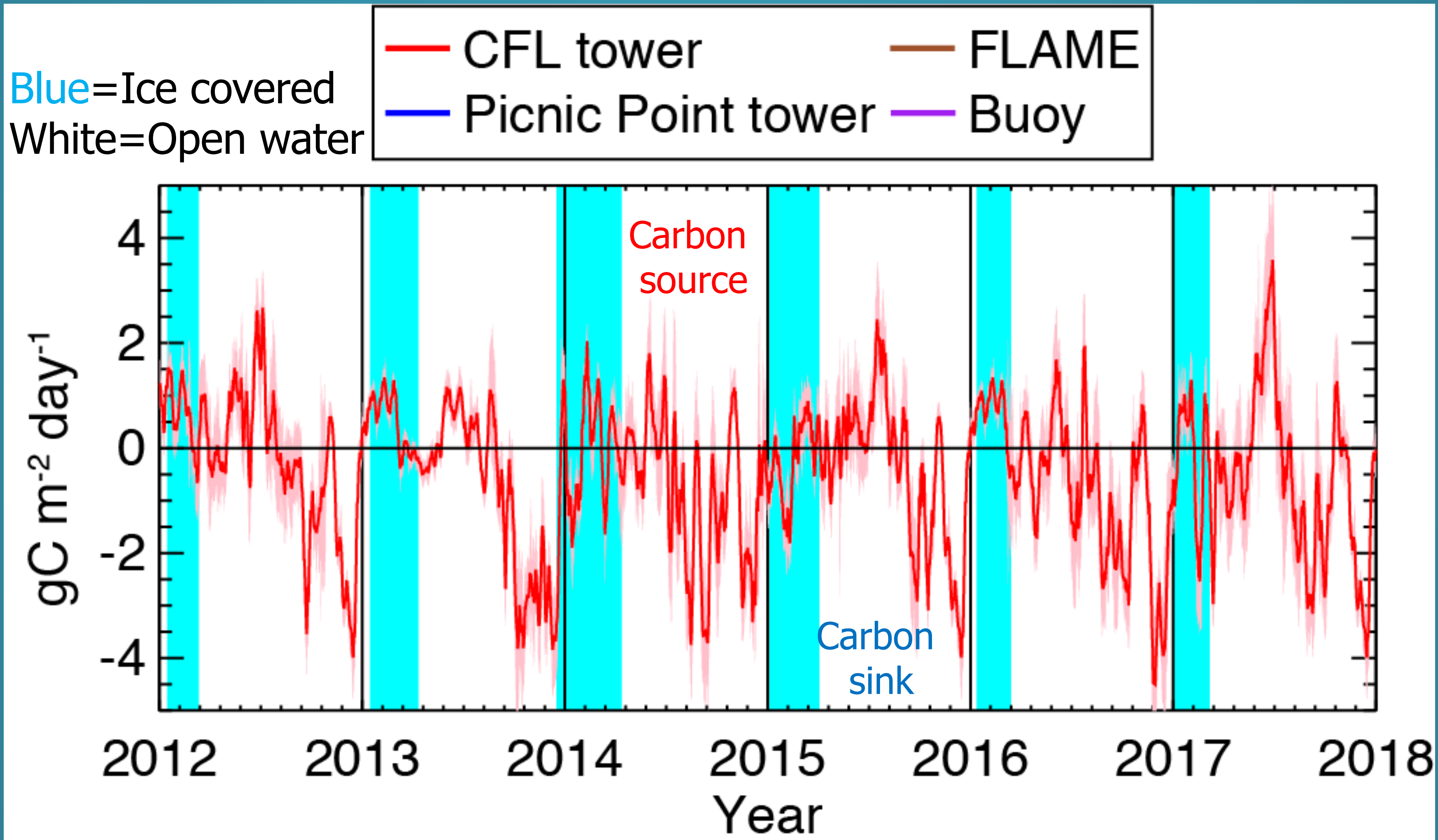
# Chambers

$$Flux = \rho \frac{Vol}{Area}\left(\frac{dCO_2}{dt}\right)$$

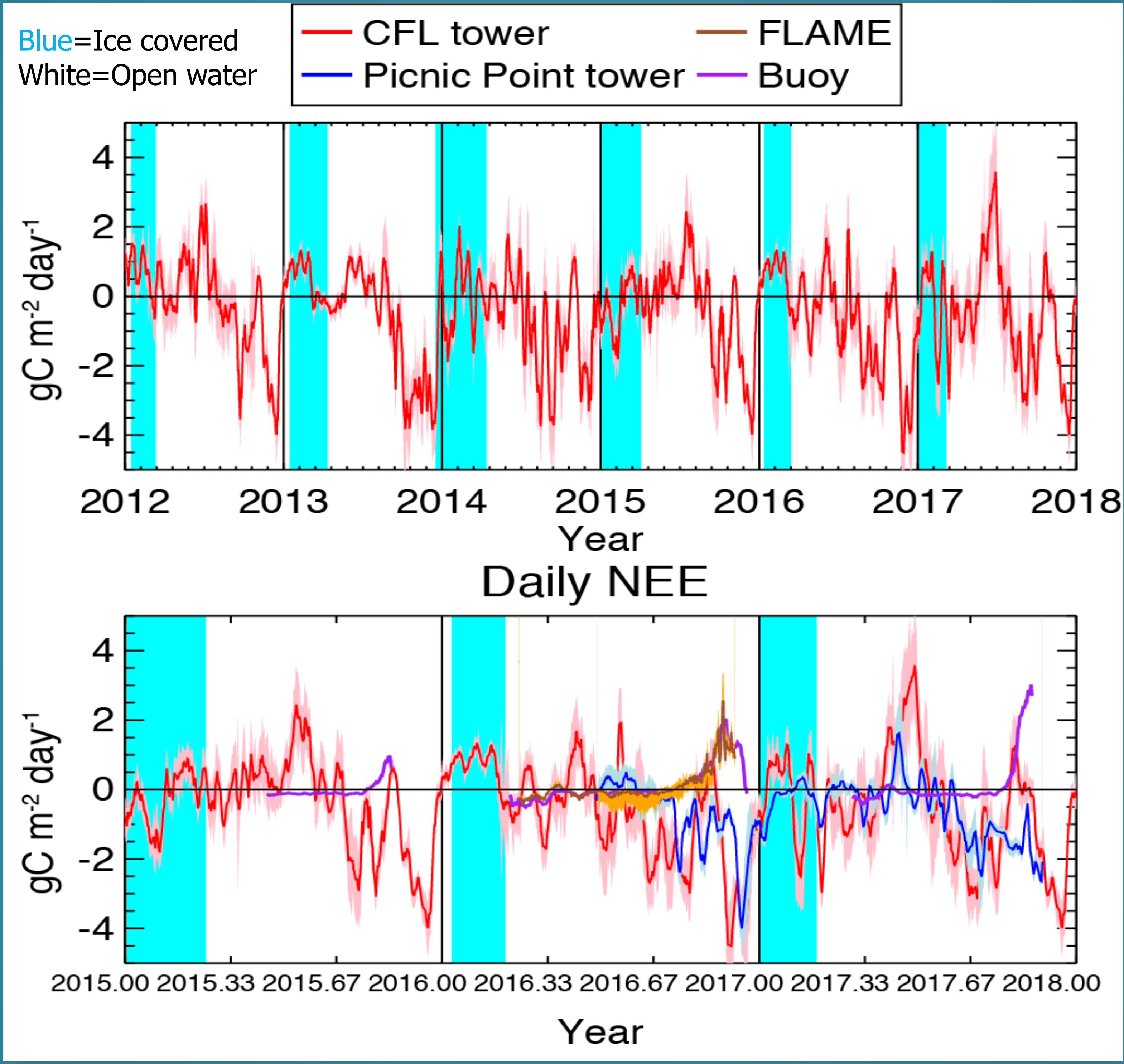

Elvira **de Eyto**

So what do they say?

# Six years of a shoreline flux tower!

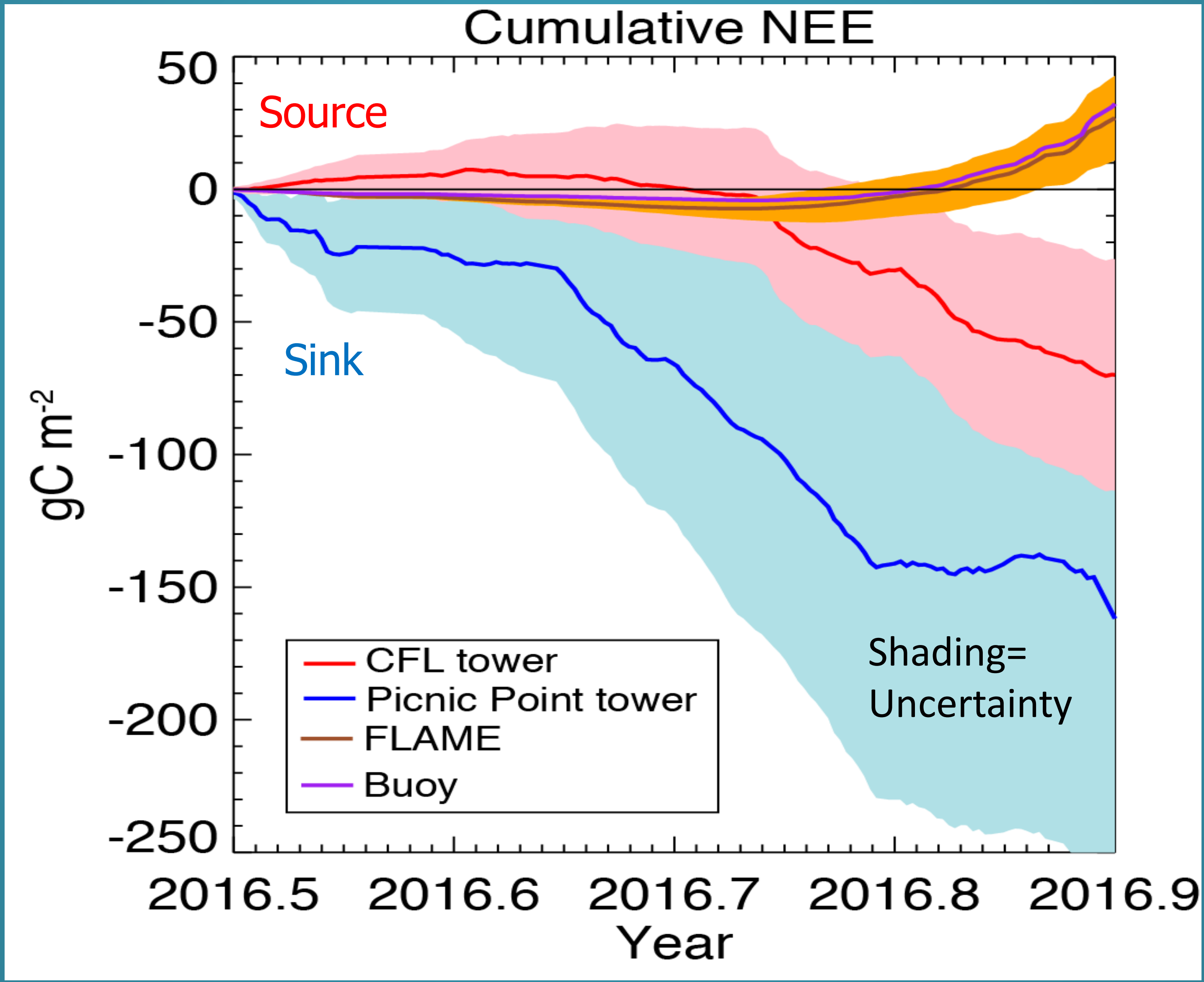


Daily NEE

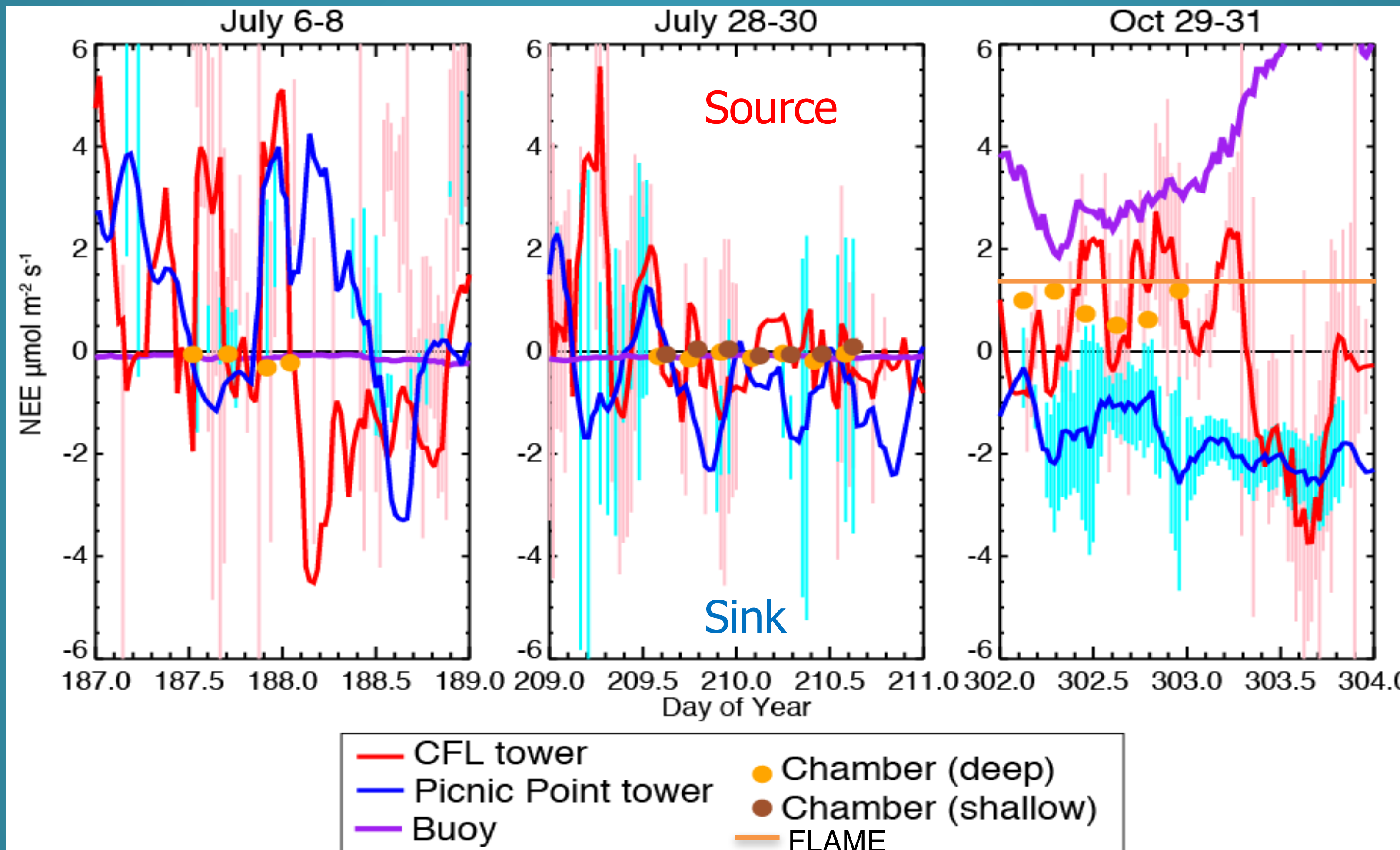


Blue=Ice covered
White=Open water
CFL tower
Picnic Point tower
FLAME
Buoy
gC m-2 day-1
2012
2013
2014
2015
2016
2017
2018
Year
Daily NEE
2015.00 2015.33 2015.67 2016.00 2016.33 2016.67 2017.00 2017.33 2017.67 2018.00

# Source or sink? Depends who you ask



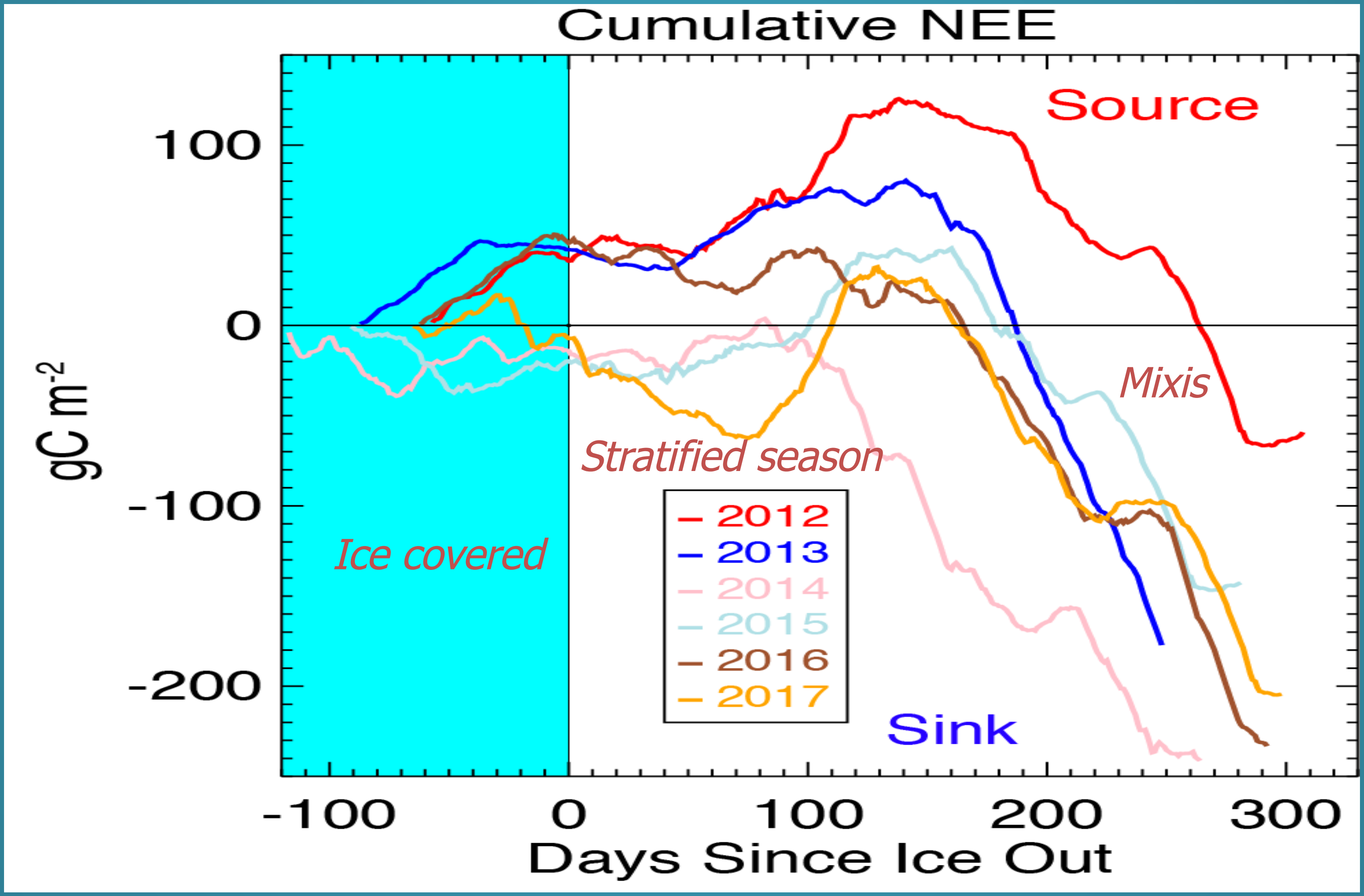
# Lots of noise, but some encouraging signs when looking at details



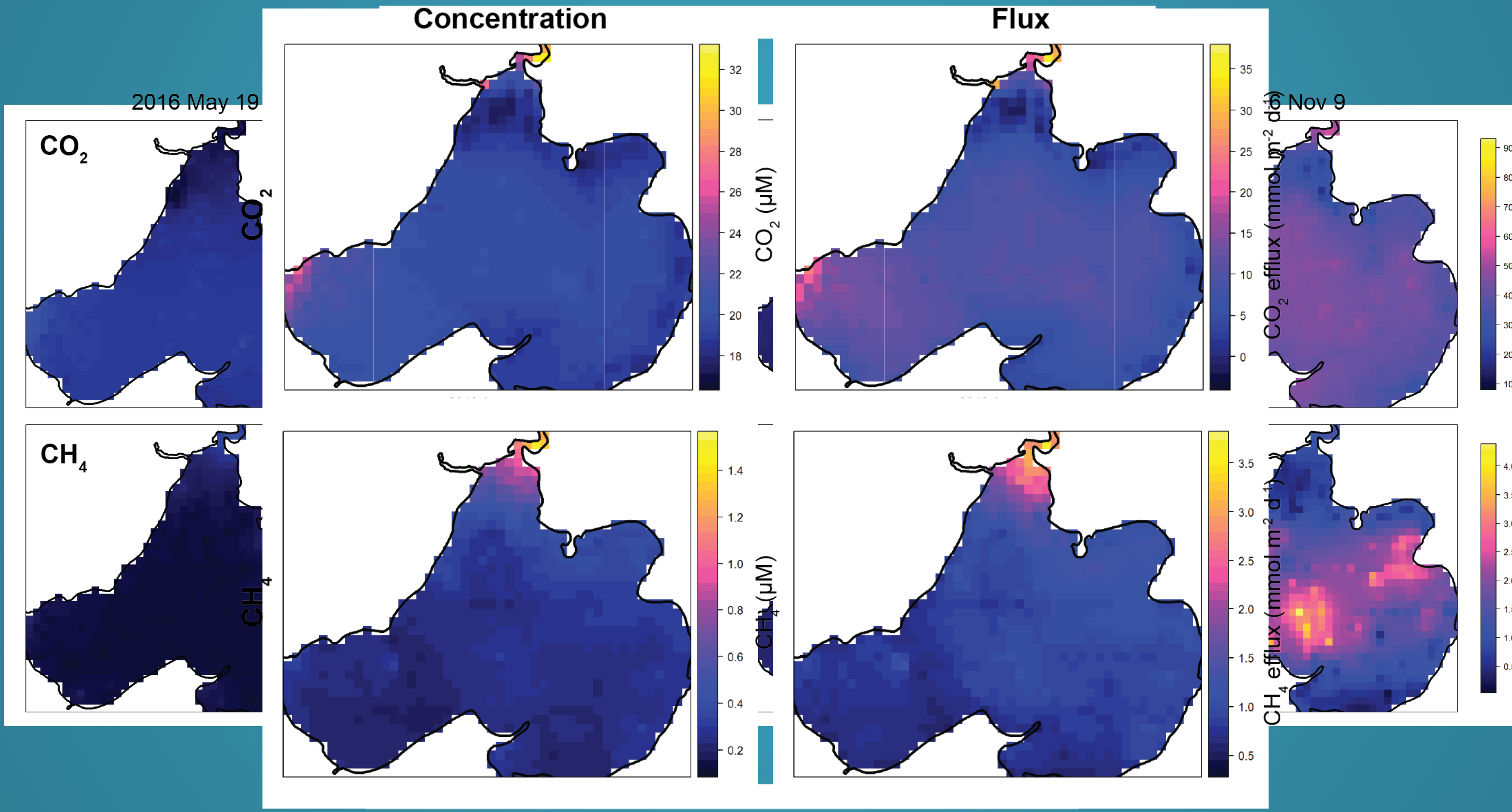

Angela **Baldocchi**

**B51I-1941**: A Spatial-Temporal Comparison of Lake Mendota $CO_2$ Fluxes and Collection Methods, **FRI, 08:00 - 12:20,** *Poster Hall D-F*

# Still, can we learn something about lake carbon efflux?



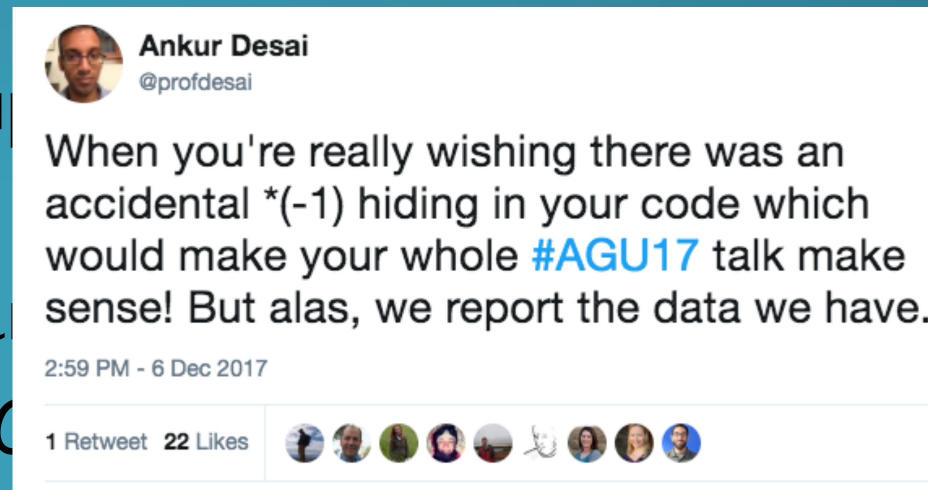
# Spatial variations are persistent




**Loken**, L.C., Crawford, J.T., Schramm, P.J., Stadler, P., and Stanley, E., Spatiotemporal variability of carbon dioxide and methane in a eutrophic lake, in prep.

# Issues with eddy covariance over lakes

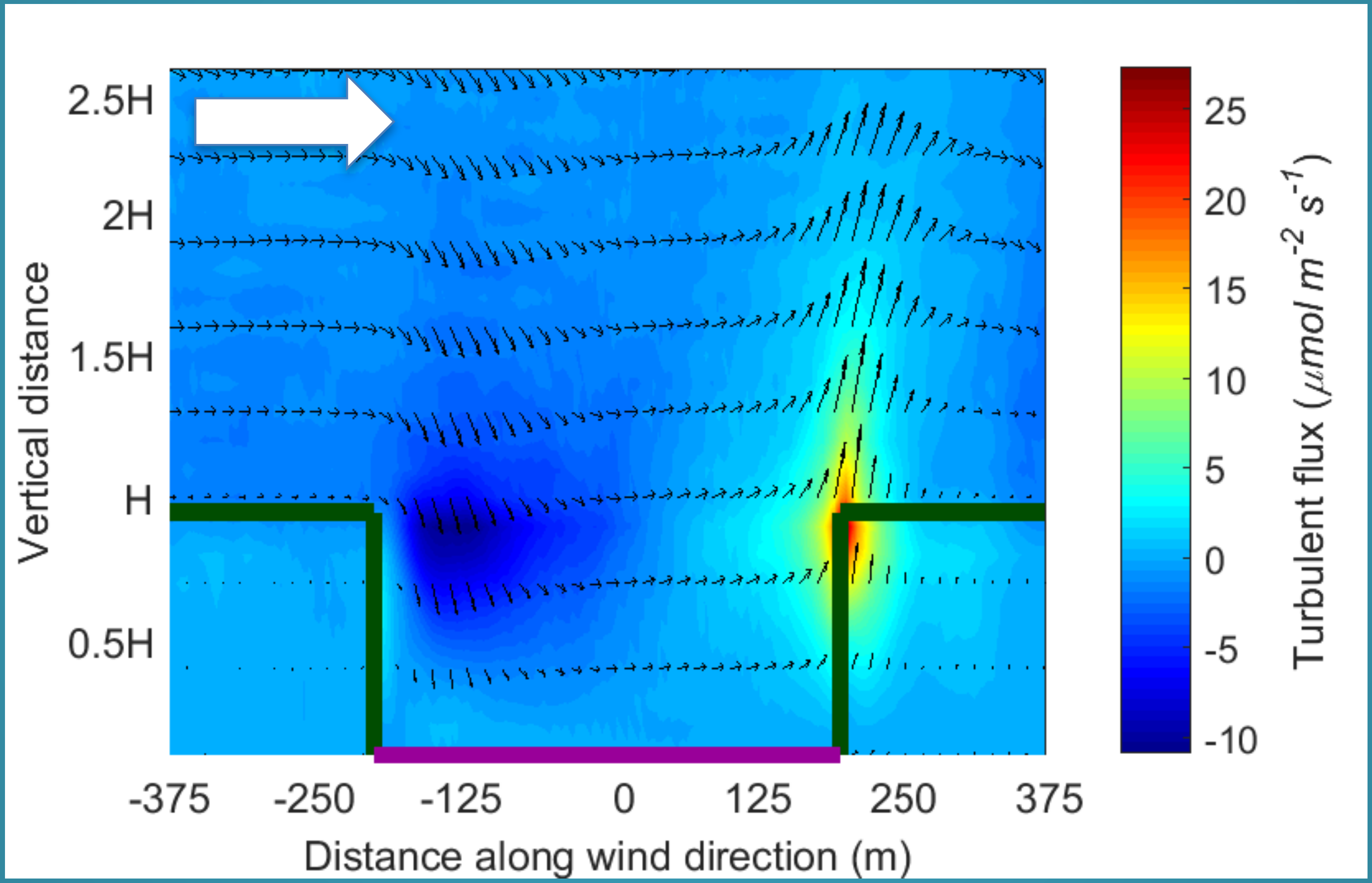
- Fluxes look like they are u
  theory
- Are periods of over ice ca
- Large fall uptake when *pC*
  convective, so could happen
- High noise floor
- Flux footprint screening
- Shoreline/building flow concerns





**Vesala**, T., Eugster, W., Ojala, A., 2011. Eddy Covariance Measrements Over Lakes, in Aubinet, M. et al., Eddy Covariance: A practical guide to measurement and data analysis. *Springer*.

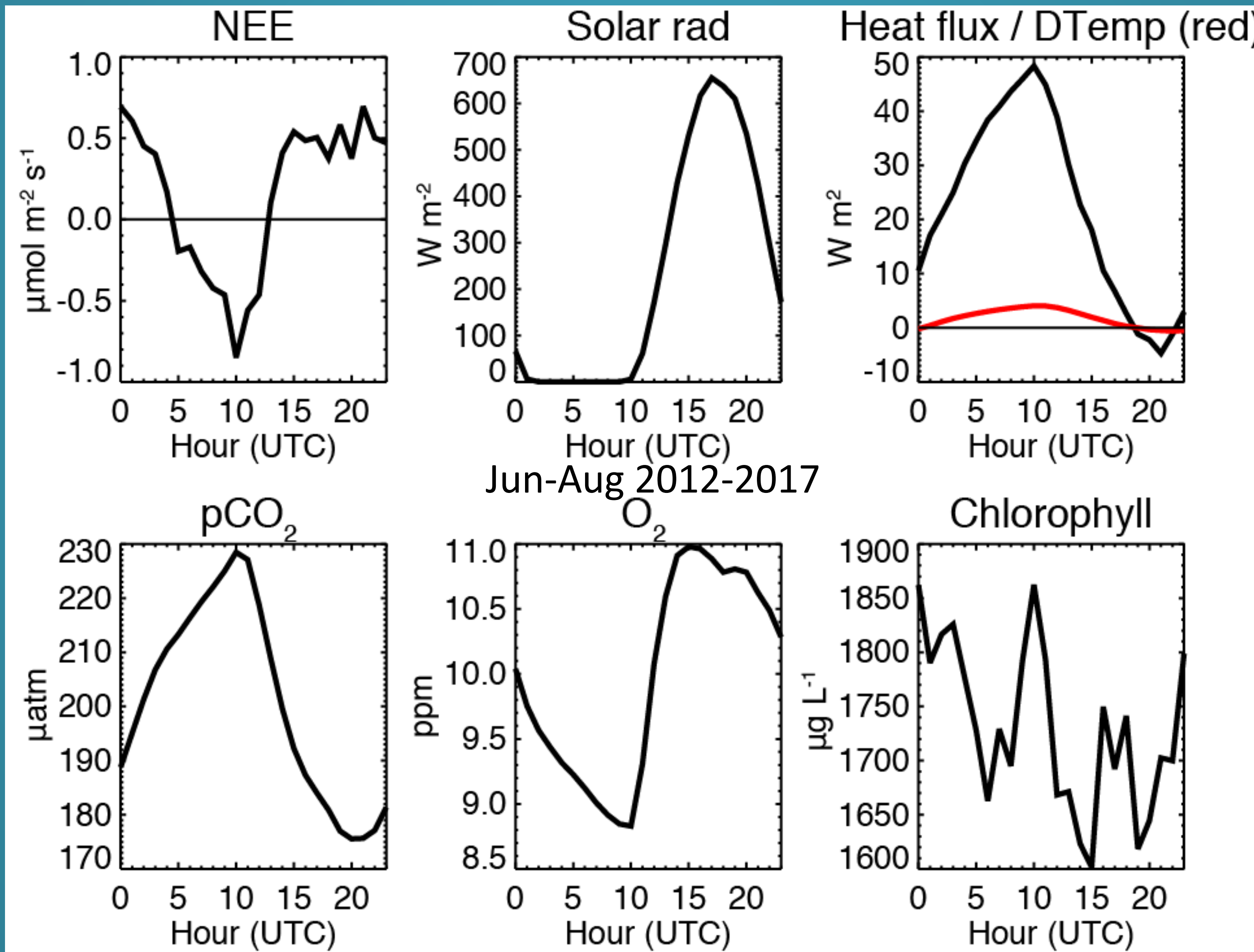
# Lakes are much harder to make good flux measurements than other surfaces



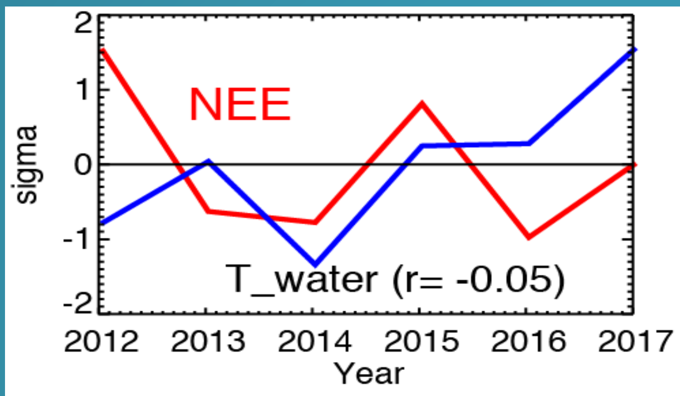


**Kenny**, W.T., Bohrer, G., Morin, T.H., Vogel, C.S., Matheny, A.M., and Desai, A.R., 2017. A Numerical Case Study of the Implications of Secondary Circulations to the Interpretation of Eddy-Covariance Measurements Over Small Lakes. *Boundary-Layer Meteorol.*, 165, 311–332, 10.1007/s10546-017-0268-8.

# Averaging helps. Diurnal cycles have some interesting patterns



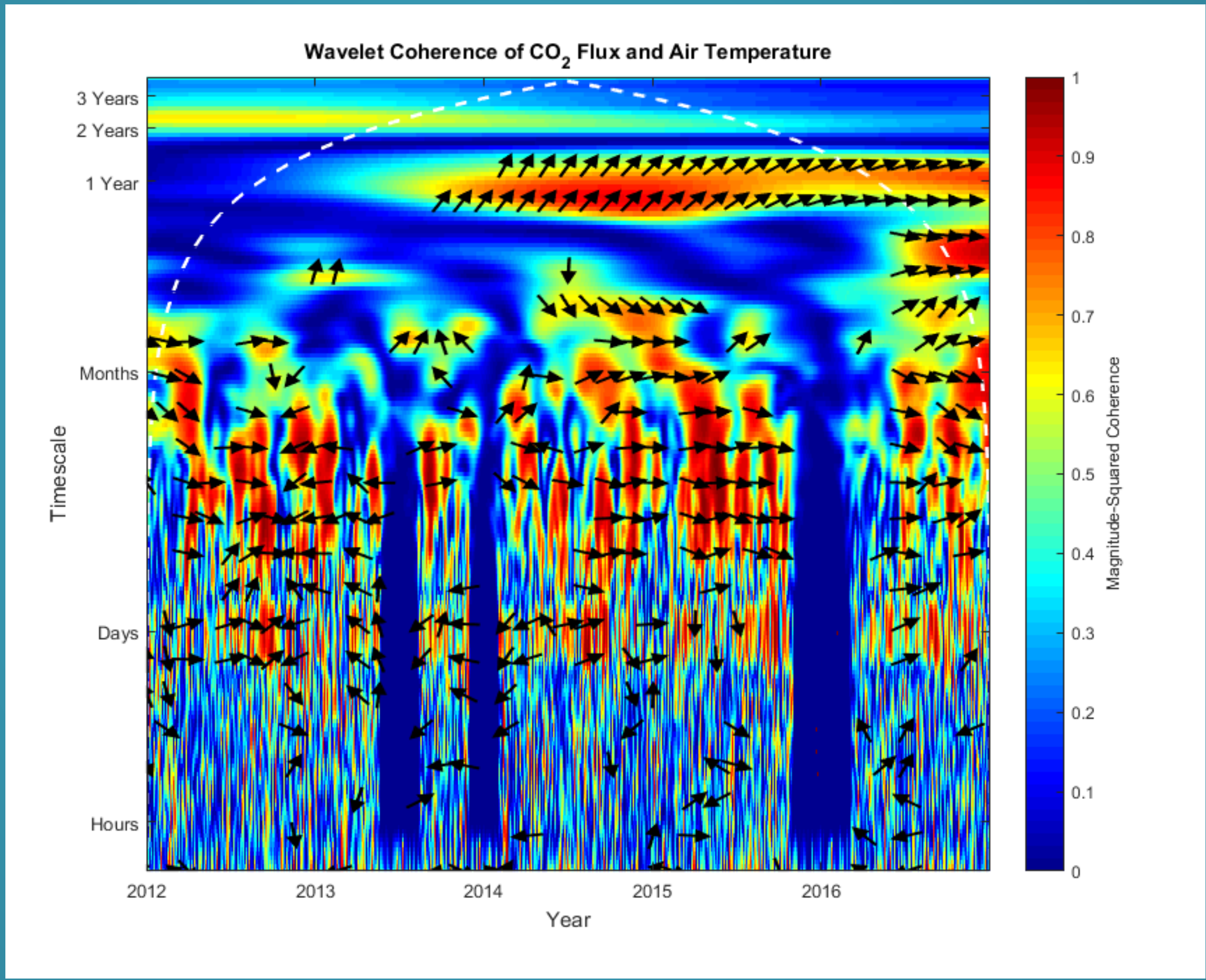
# Can we explain interannual variability?



# Multi-timescale modes of variability require more sophisticated approaches

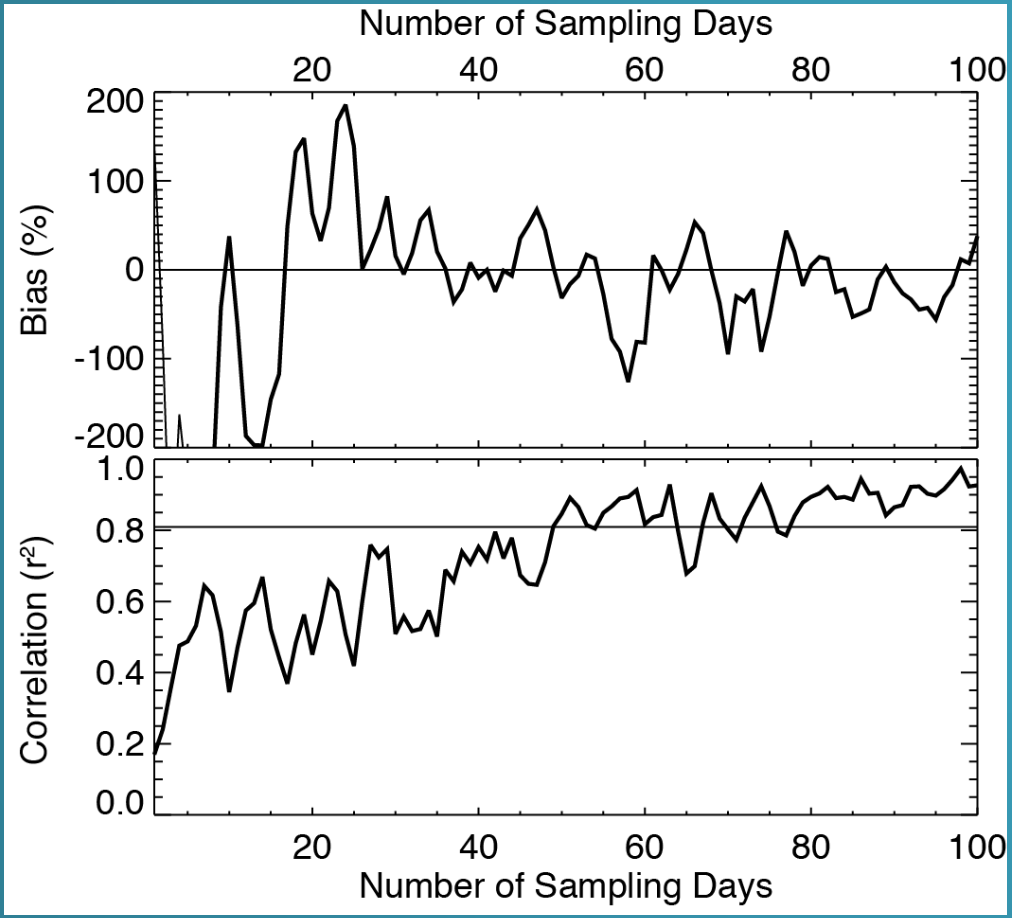
Wavelet Coherence Spectra

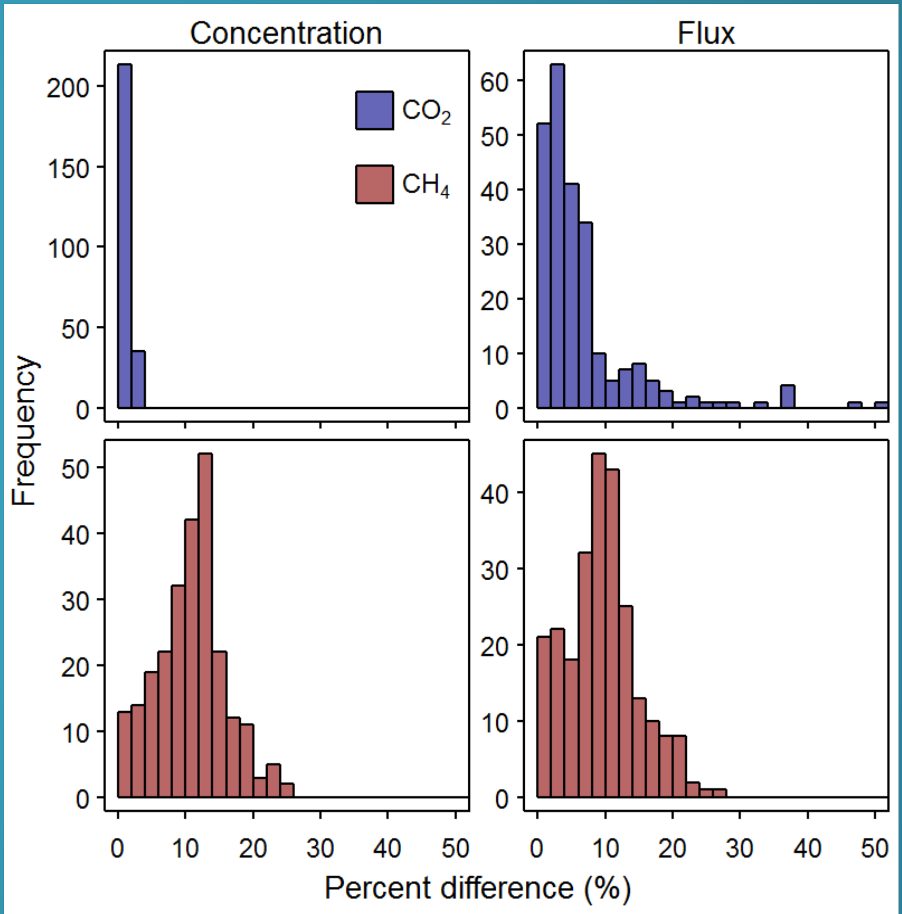
NEE Vs. Air Temperature




**Reed**, D.R., Dugan, H., Flannery, A., and Desai, A.R., 2017. The carbon sink and source see-saw of a eutrophic deep lake. *Limnology and Oceanography Letters*, in revision.

# Advancing lake carbon cycle research: The impact of temporal and spatial sampling



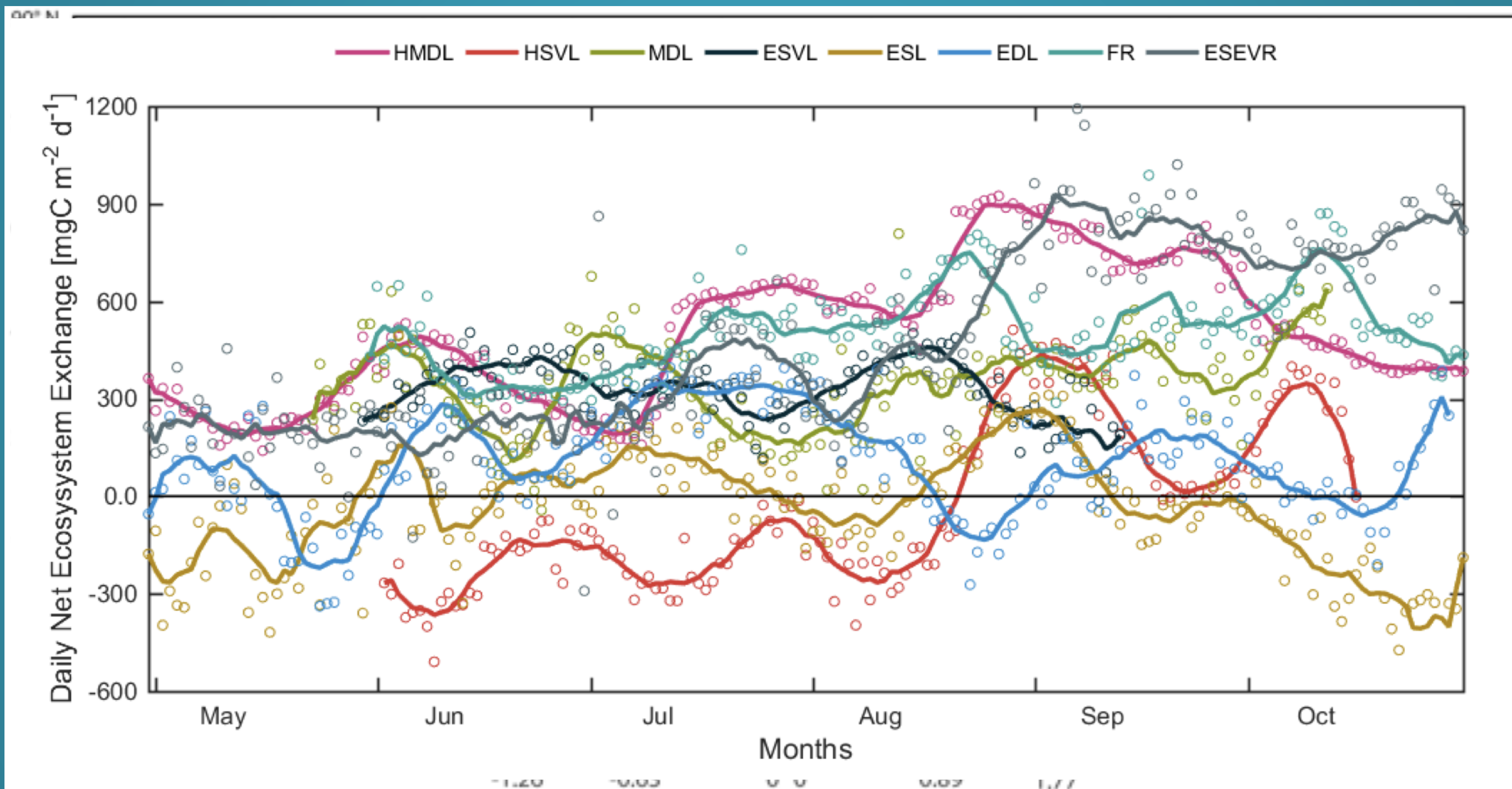




Temporal Sampling

Spatial Sampling

**Loken** et al., in prep

# Advancing lake carbon cycle research: Moving towards a global synthesis




**Golub, M.,** Desai, A.R., *et al.,* 2018. Globally coherent patterns in CO2 exchange by lakes and reservoirs derived from high-frequency temporal sampling *Nature Geoscience*, to be submitted.

# Thank you!



- Funding:
  - NSF DEB-1440297 (North Temperate Lake LTER)
  - NSF DBI-1457897
  - Dept. of Energy Ameriflux Network Management Program (ChEAS Core Site)
  - University of Wisconsin WARF UW2020 Discovery Initiative


- Websites:
  - https://flame.wisc.edu/
  - https://lter.limnology.wisc.edu/
  - http://flux.aos.wisc.edu/
- Publications:


  - Malgorzata Golub *et al.*, 2017, J Geophys Res.-G (*p*$CO_2$ uncertainty),
  - David Reed *et al.*, in review L&O (CFL Eddy flux Tower)
  - John Crawford *et al.*, 2015 *Env. Sci. and Tech.* (FLAME Tech)
  - Luke Loken *et al.*, in prep (FLAME Mendota)
  - Angela Baldocchi *et al.*, in prep (FLAME-Tower)
  - Malgorzata Golub *et al.*, near submission, Nature Geo. (Tower synthesis)



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