Little lakes and large lakes: The first global inland water eddy covariance flux synthesis

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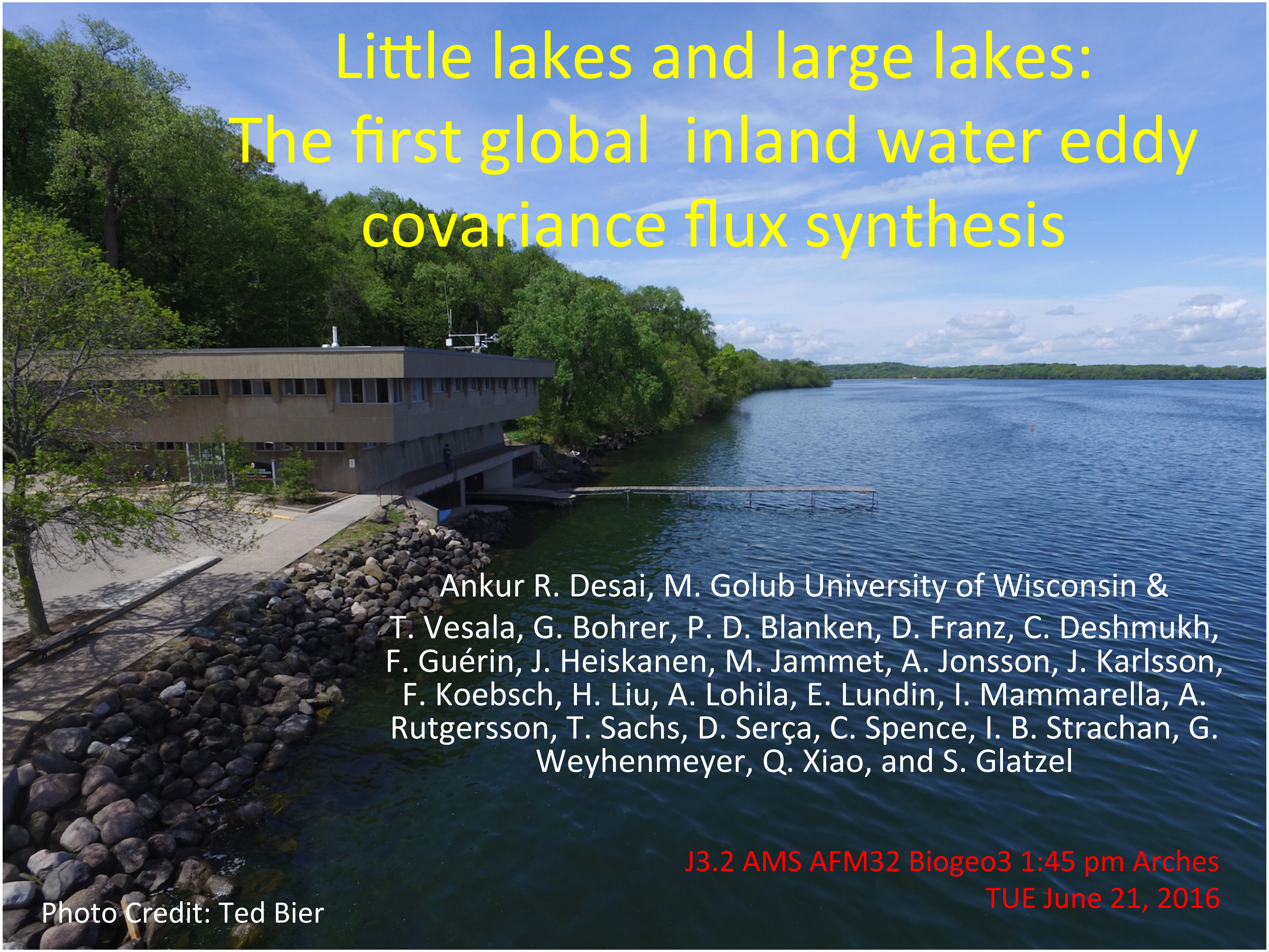
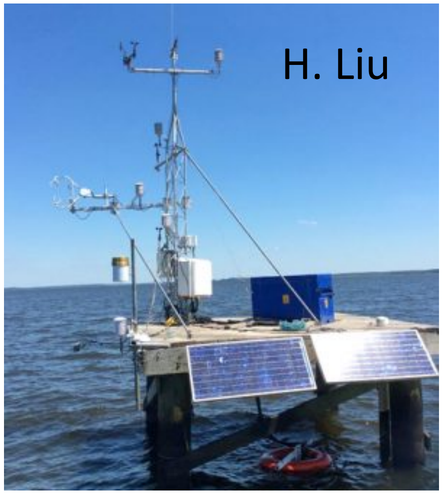


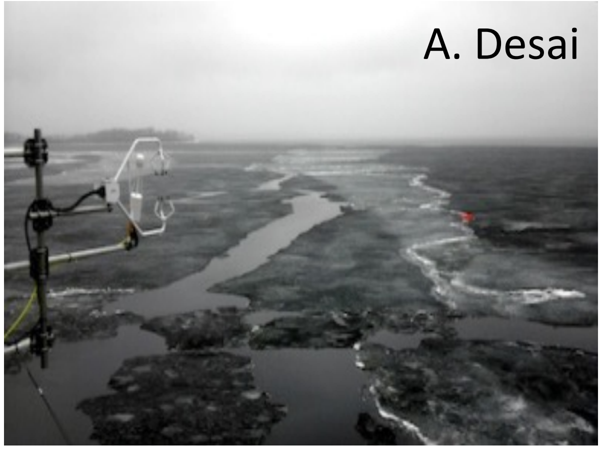
Photo Credit: Ted Bier

J3.2 AMS AFM32 Biogeo3 1:45 pm Arches
TUE June 21, 2016

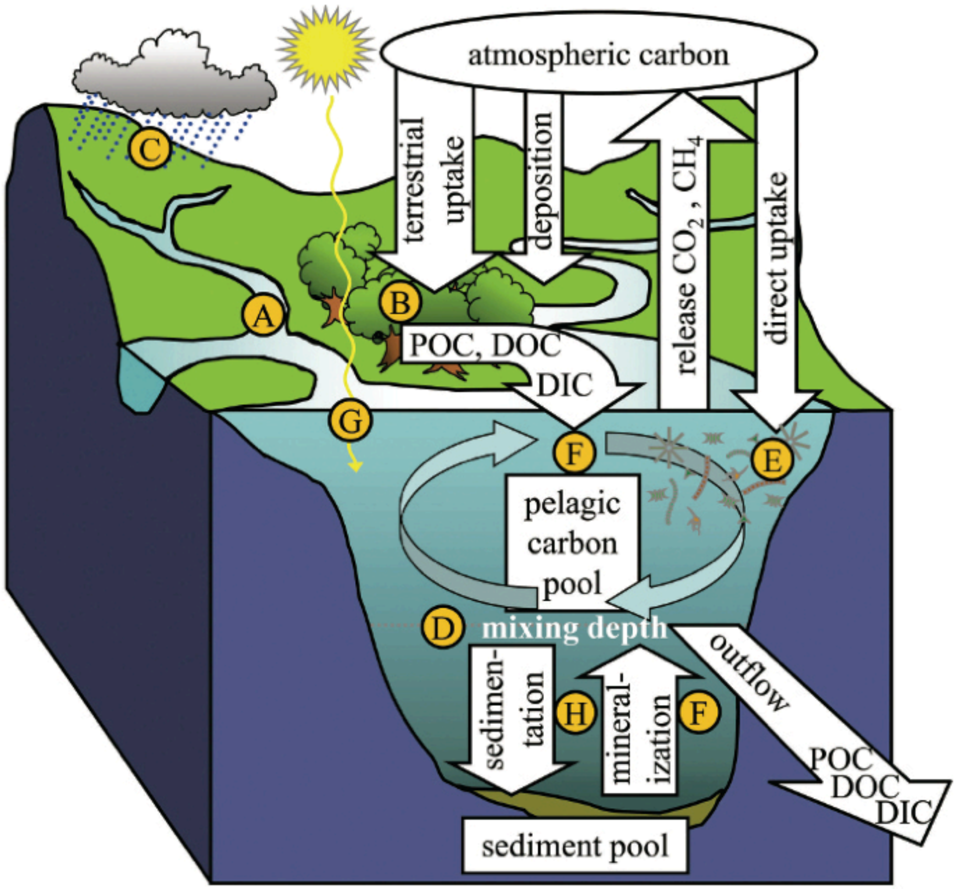
Why Lakes?

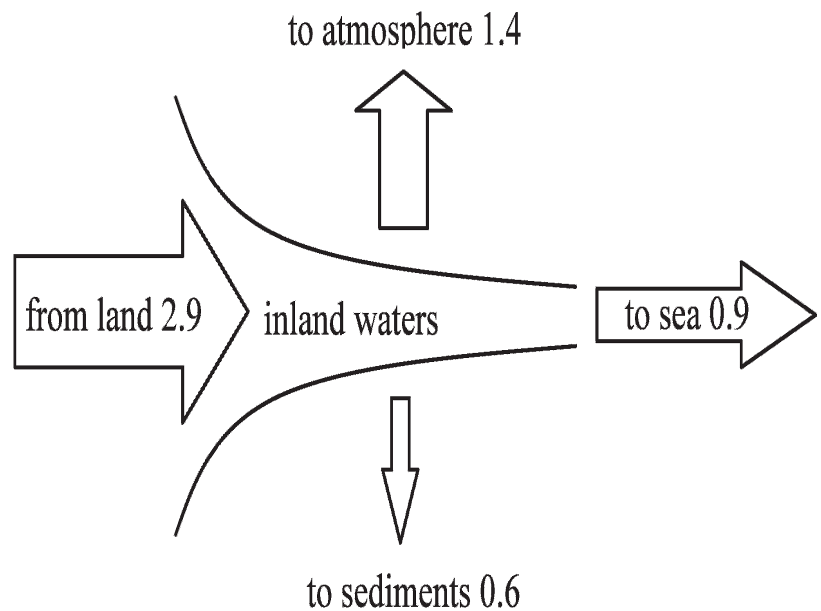
- Inland waterbodies comprise significant components of many landscapes
- Rarely included in estimates of energy and CO_2 fluxes
- When they are, based on measurements at low frequencies (1-2x/yr up to weekly at 1-2 points) and high uncertainty (>100%!) which prevents from studying drivers at shorter timescales
- Several dozens of fluxes towers located over inland water bodies allowing for study of short time variation of fluxes and mechanisms controlling them





Lakes and riverine systems process a lot of carbon, maybe.

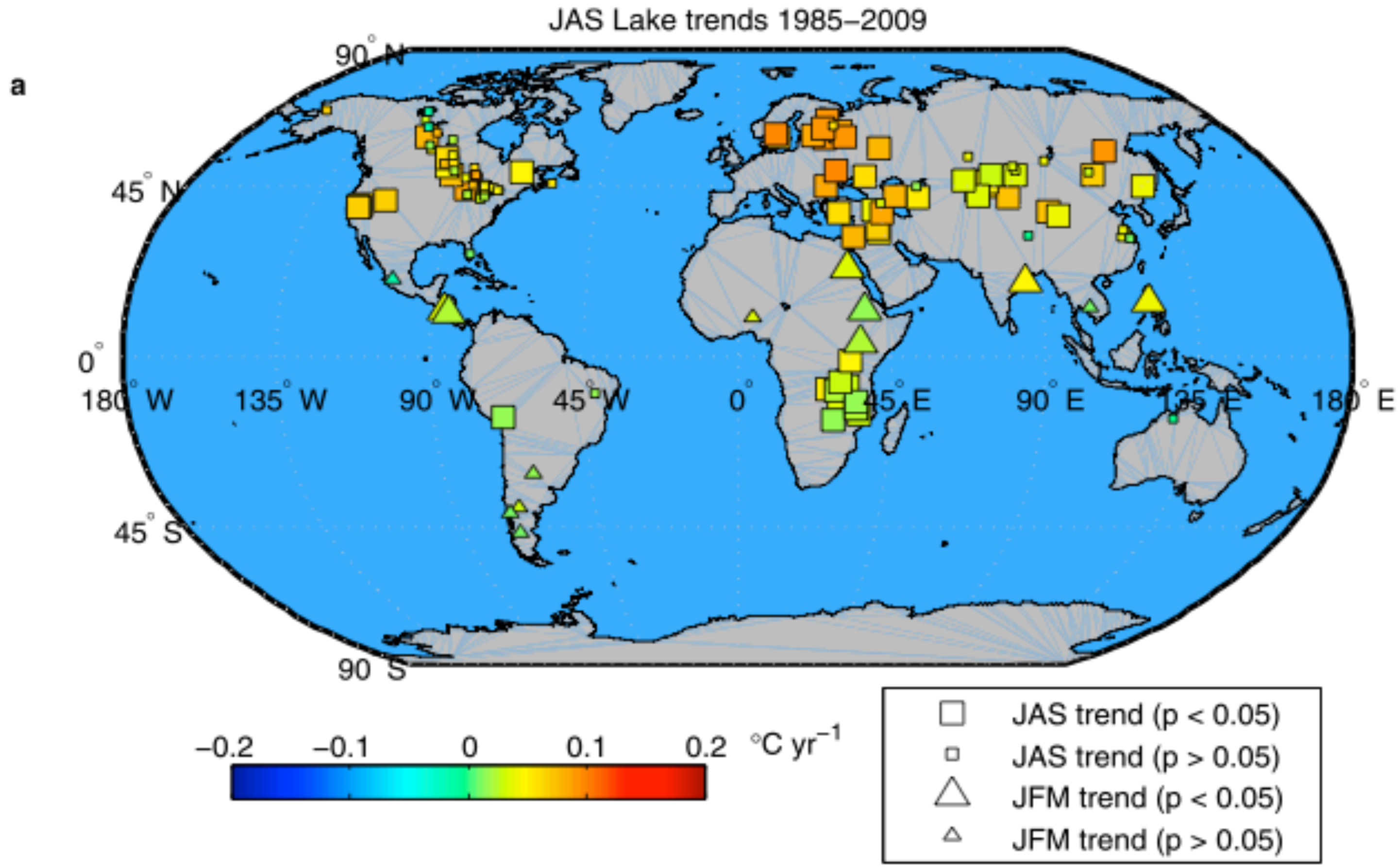




Tranvik 2009

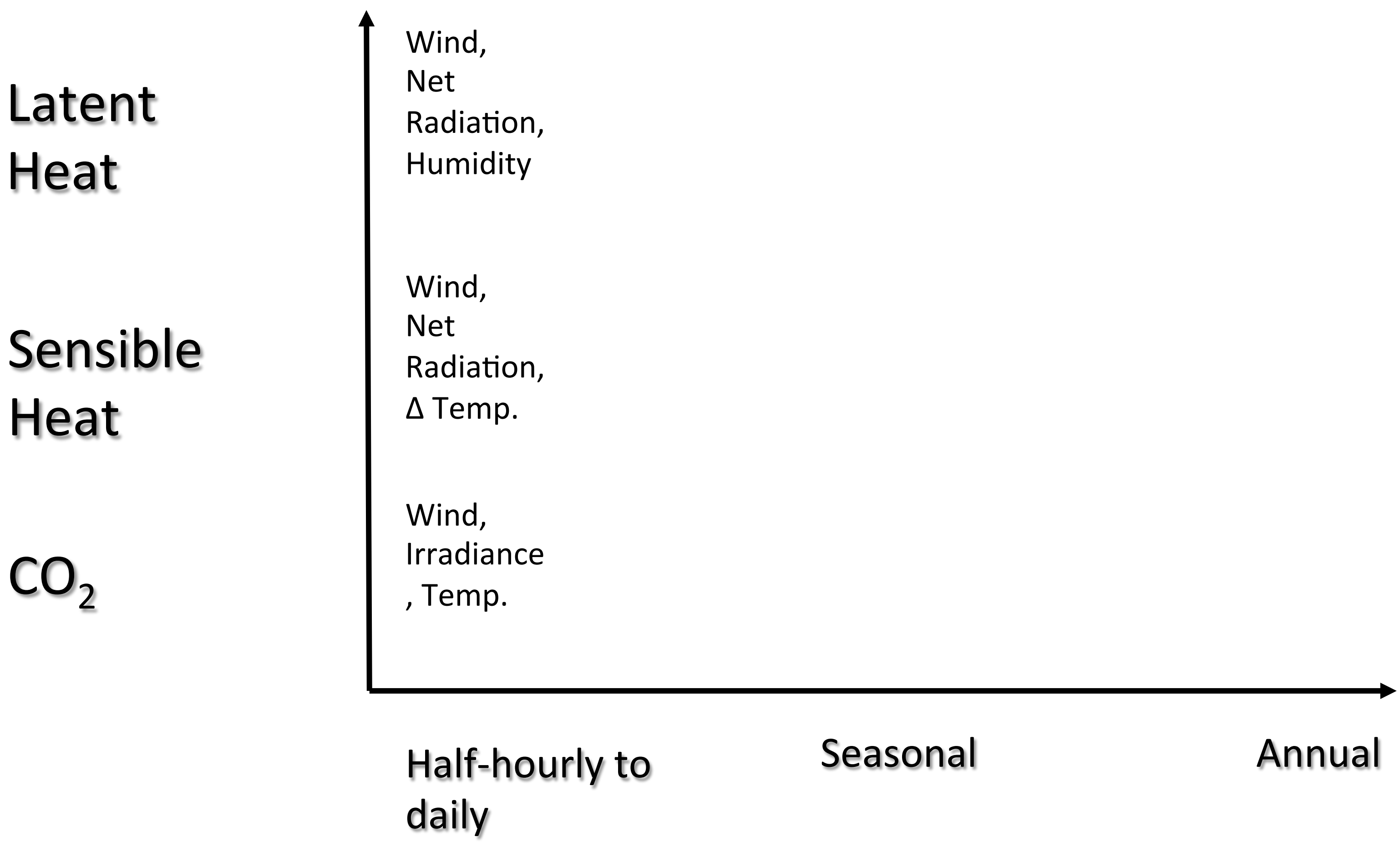
Adrian et al 2009

Globally, lakes are warming faster than the atmosphere

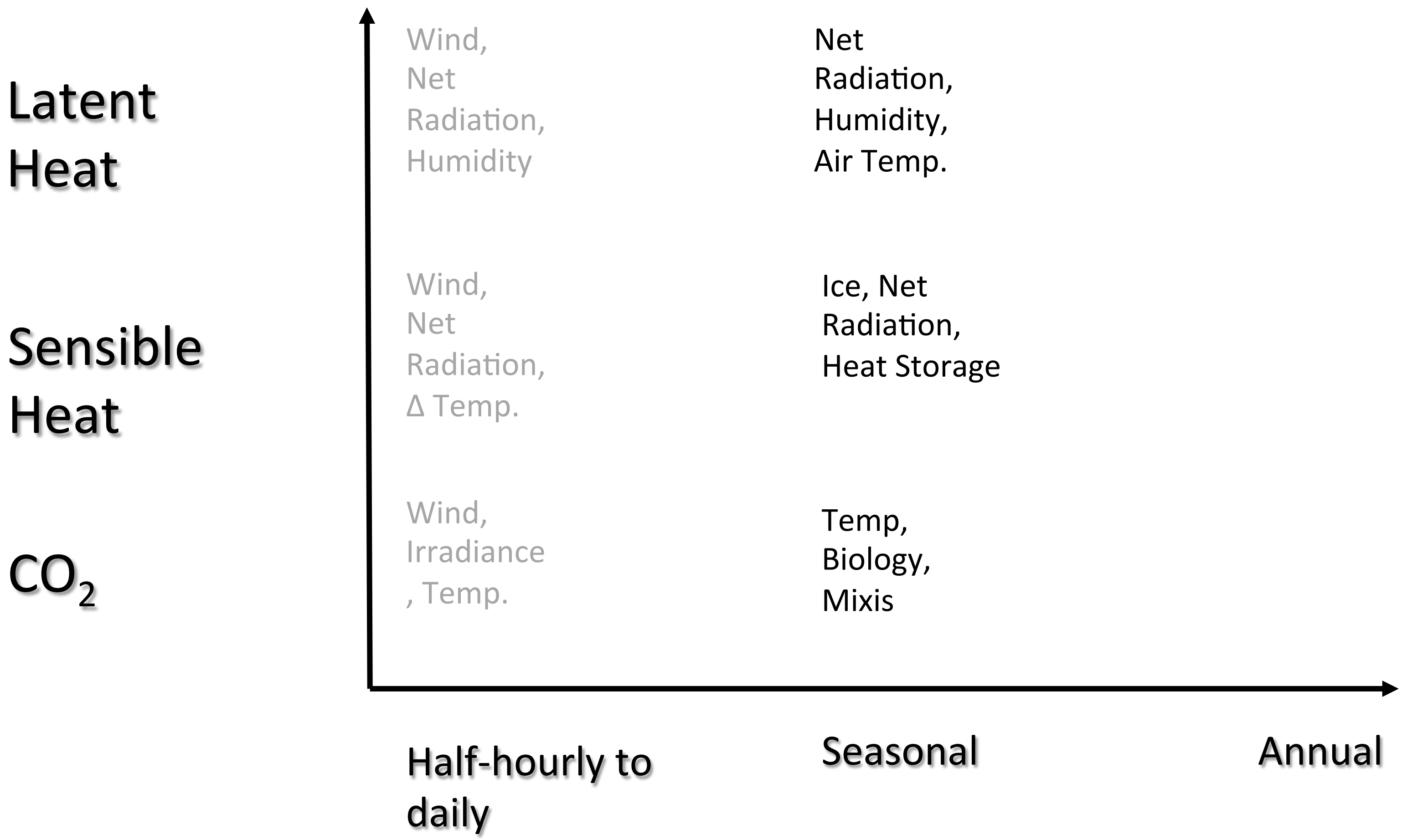


Schneider and Hook, 2010 GRL

- Inland water energy and carbon fluxes are highly dynamic in space and time



- Inland water energy and carbon fluxes are highly dynamic in space and time

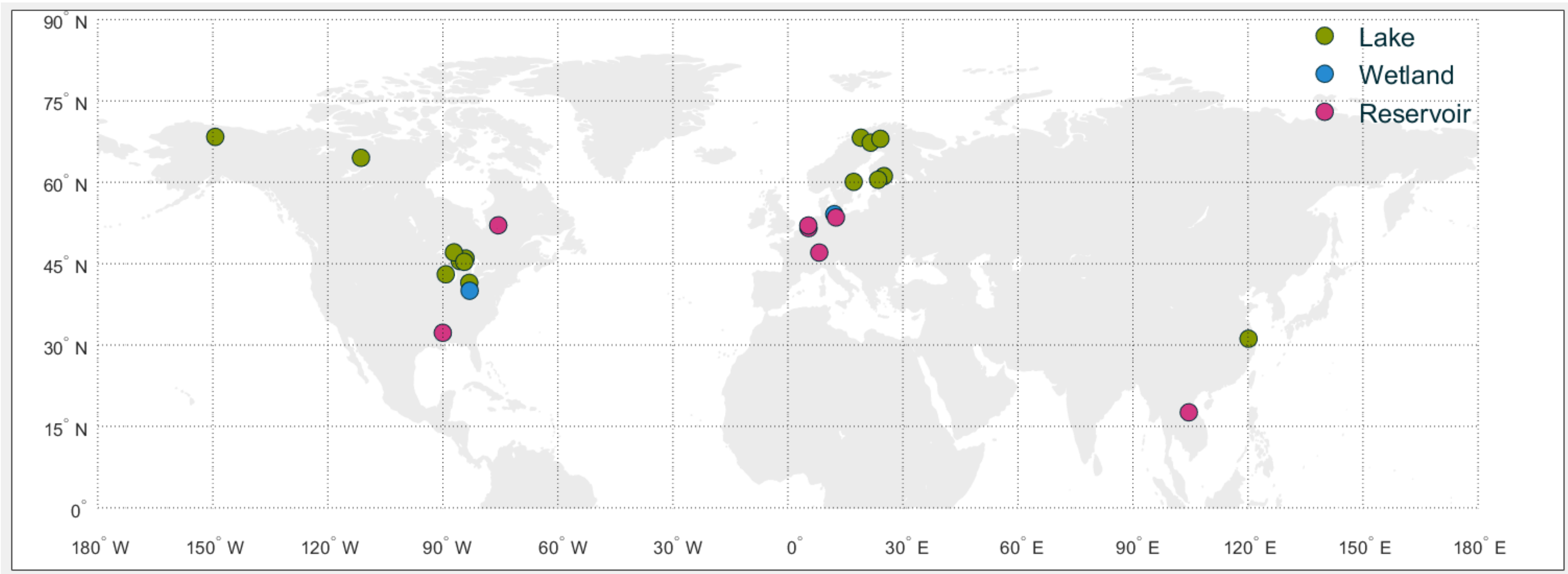


- Inland water energy and carbon fluxes are highly dynamic in space and time

	Half-hourly to daily	Seasonal	Annual
Latent Heat	Wind, Net Radiation, Humidity	Net Radiation, Humidity, Air Temp.	Net Radiation, Ice, Air Temp.
Sensible Heat	Wind, Net Radiation, Δ Temp.	Ice, Net Radiation, Heat Storage	Net Radiation, Ice,
CO_2	Wind, Irradiance, Temp.	Temp, Biology, Mixis	DOC load, Biology, Temp,

Our goal

- THEREFORE: We conduct the world's first synthesis of eddy fluxes across lakes that vary in size, type, location



Lakes
(n = 16)

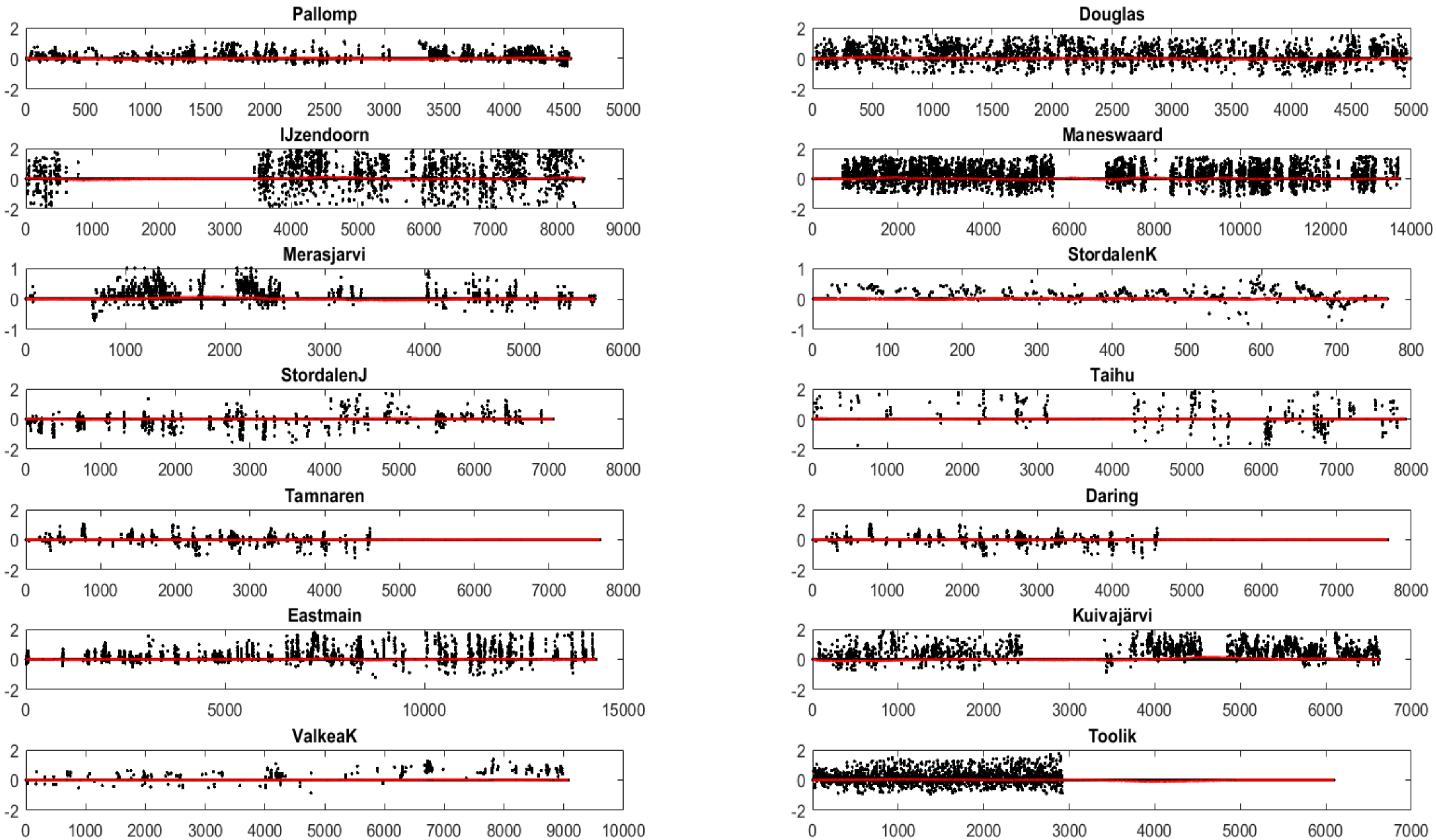
Reservoirs
(n = 7)

Wetlands
(n = 2)

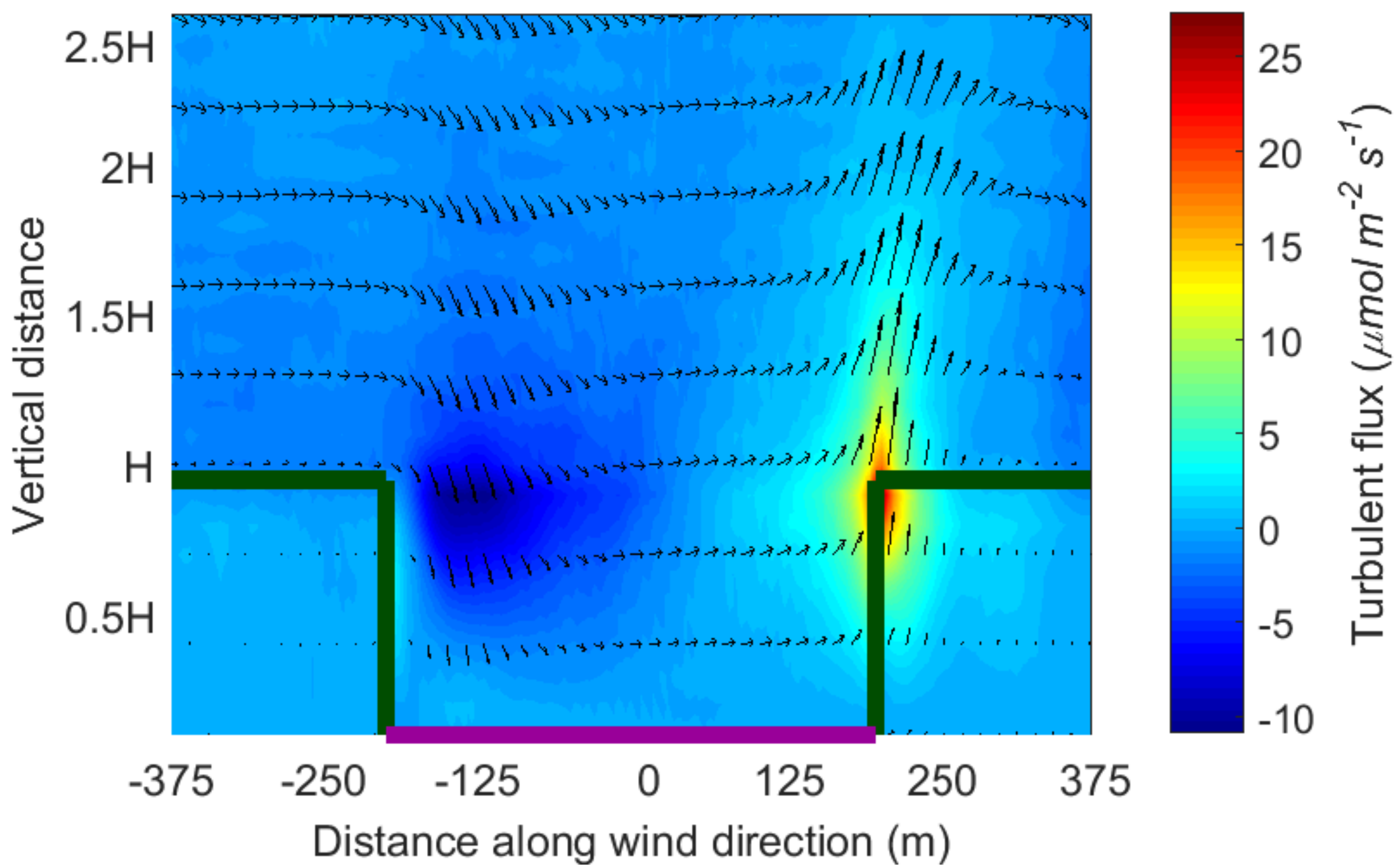
Latent Heat Flux: n = 112 476

Sensible Heat Flux: n = 119 190

CO_2 Flux: n = 32 746

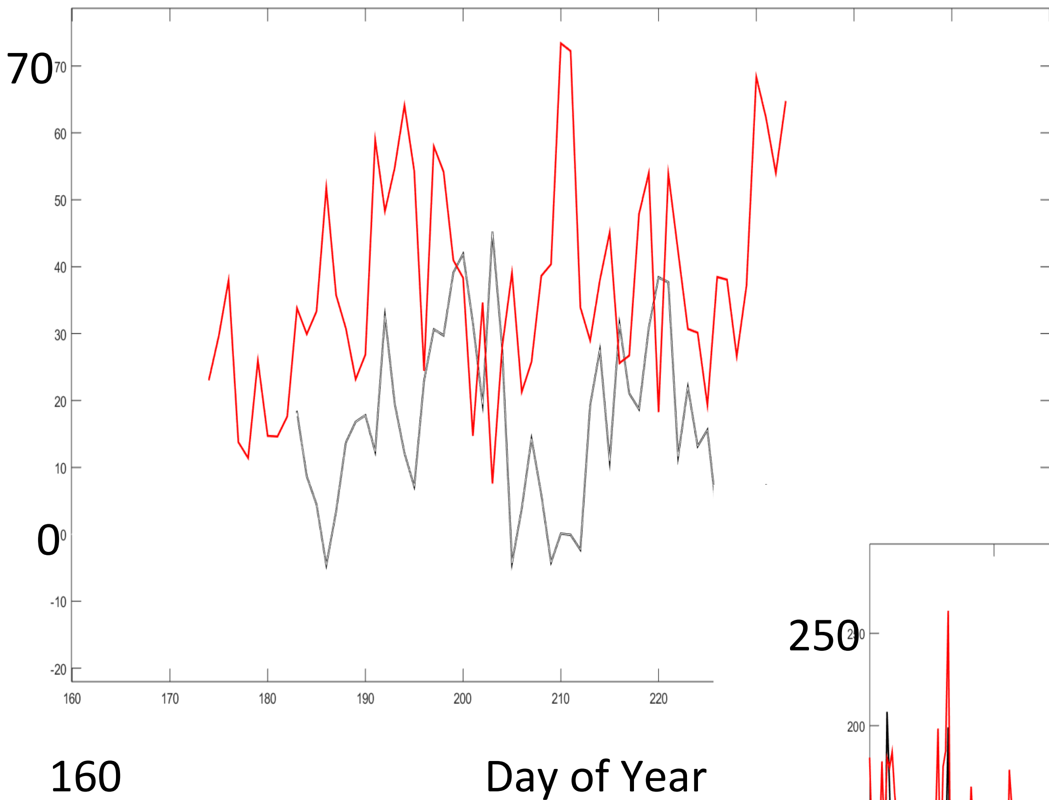

Pallomp
2
0
-2
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000
Douglas
2
0
-2
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000
IJzendoorn
2
0
-2
0 1000 2000 3000 4000 5000 6000 7000 8000 9000
Maneswaard
2
0
-2
0 2000 4000 6000 8000 10000 12000 14000
Merasjarvi
1
0
-1
0 1000 2000 3000 4000 5000 6000
StordalenK
1
0
-1
0 100 200 300 400 500 600 700 800
StordalenJ
2
0
-2
0 1000 2000 3000 4000 5000 6000 7000 8000
Taihu
2
0
-2
0 1000 2000 3000 4000 5000 6000 7000 8000
Tamnaren
2
0
-2
0 1000 2000 3000 4000 5000 6000 7000 8000
Daring
2
0
-2
0 1000 2000 3000 4000 5000 6000 7000 8000
Eastmain
2
0
-2
0 5000 10000 15000
Kuivajärvi
2
0
-2
0 1000 2000 3000 4000 5000 6000 7000
ValkeaK
2
0
-2
0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000
Toolik
2
0
-2
0 1000 2000 3000 4000 5000 6000 7000

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



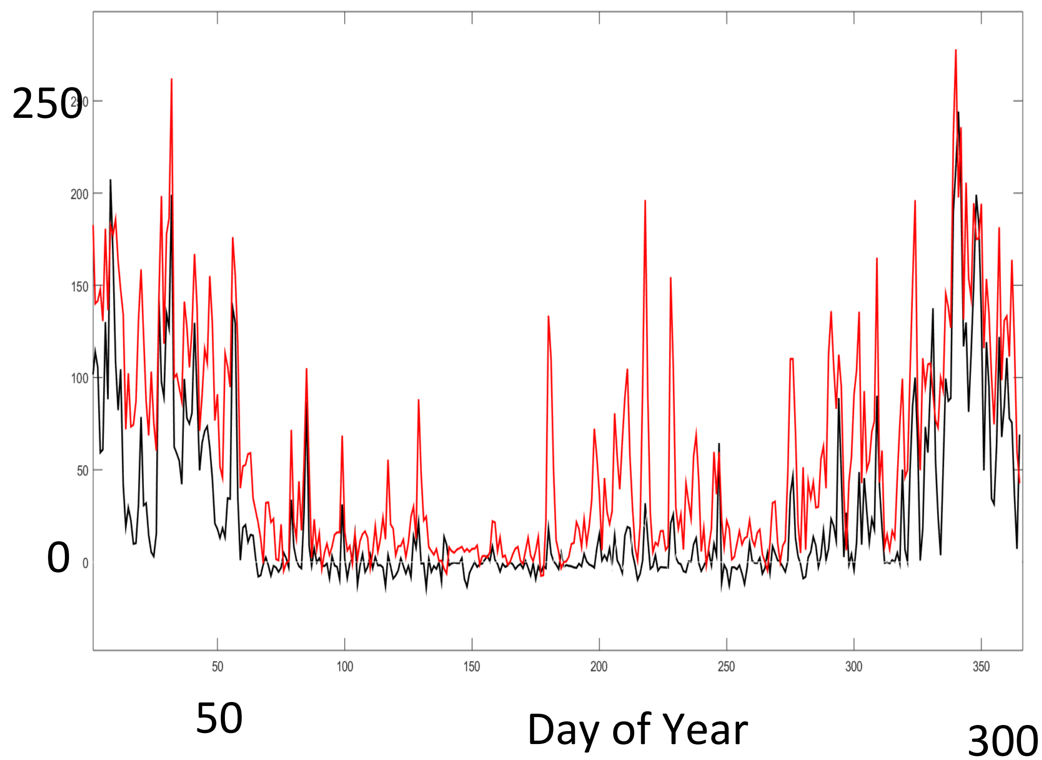
Morin, Bohrer, et al., in prep

Sub-arctic lake



Sensible Heat (black)
Latent Heat (red)

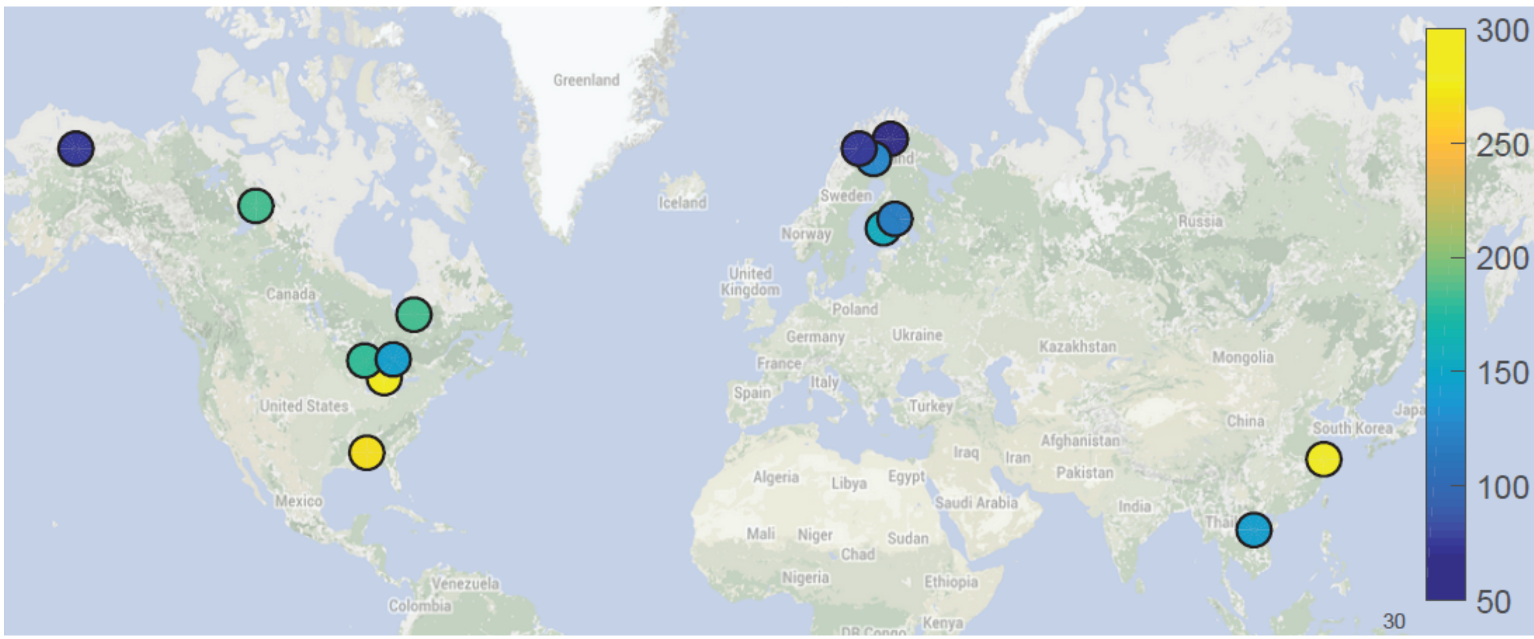
Temperate lake



Open-Water Daytime Net Radiation

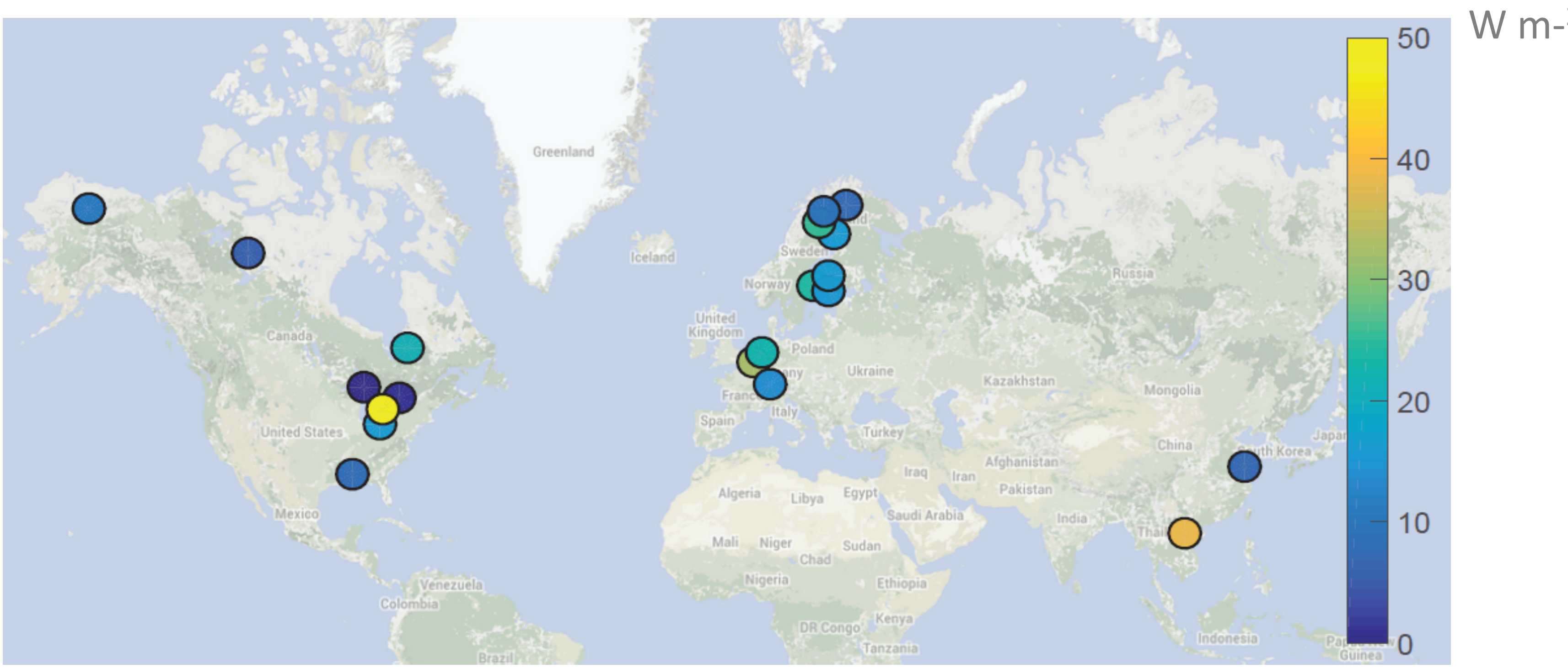
(Median)

W m^{-2}

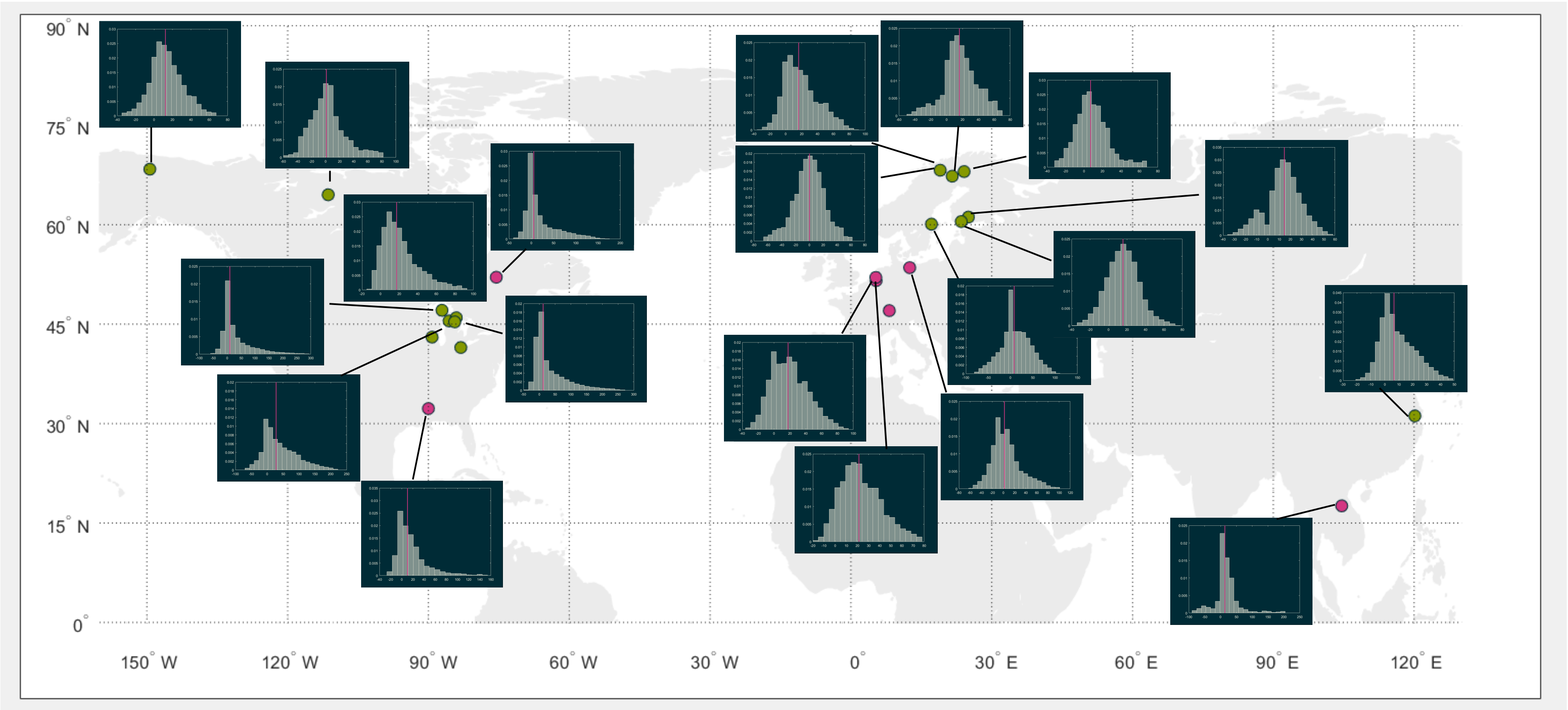


Open-Water Daytime Sensible Heat Flux

(Median)



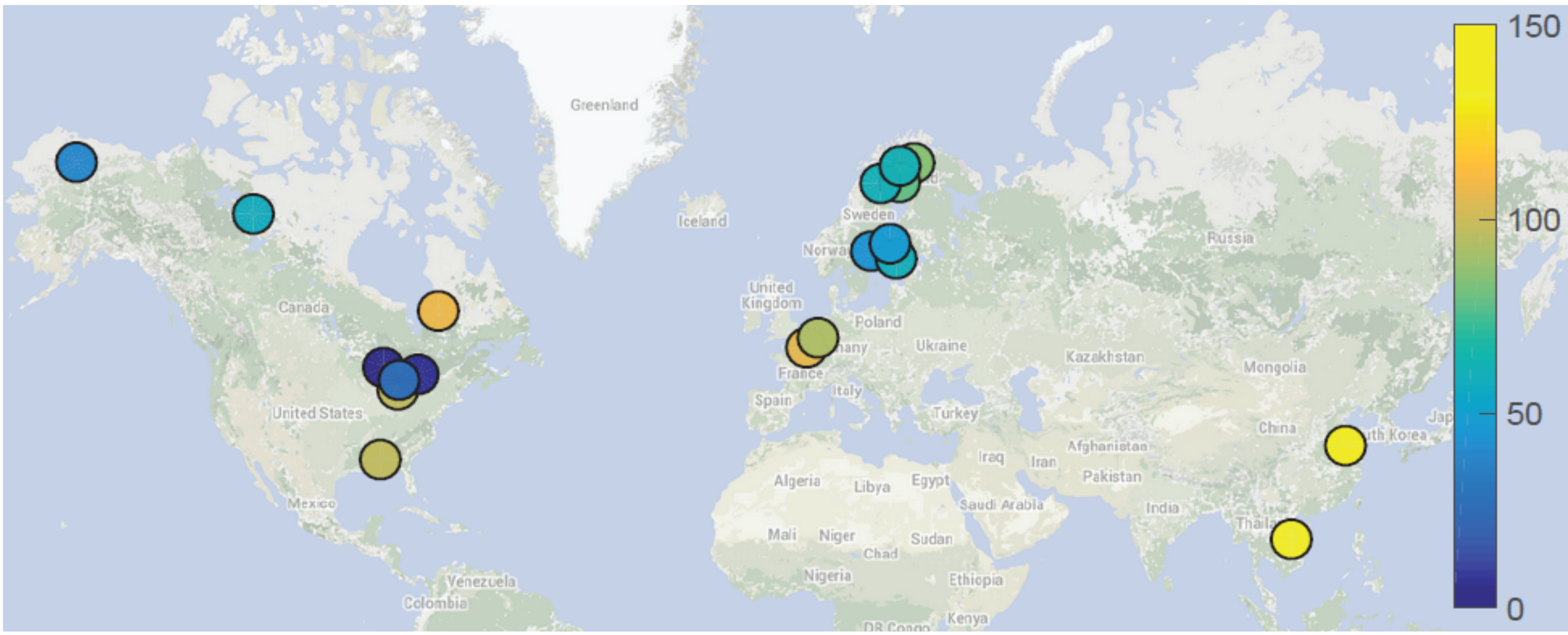
Median Daily H Flux



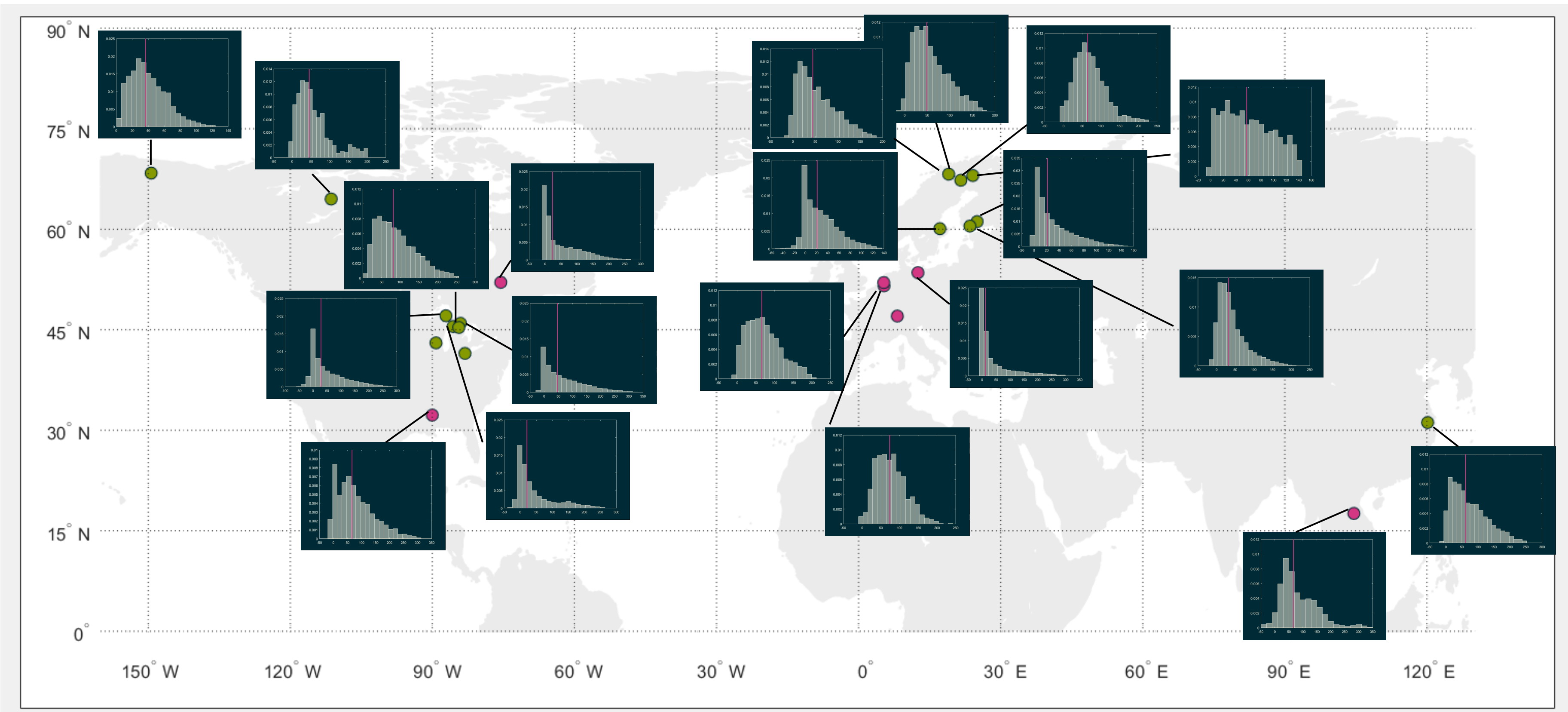
Open-Water Daytime Latent Heat Flux

(Median)

W m-2



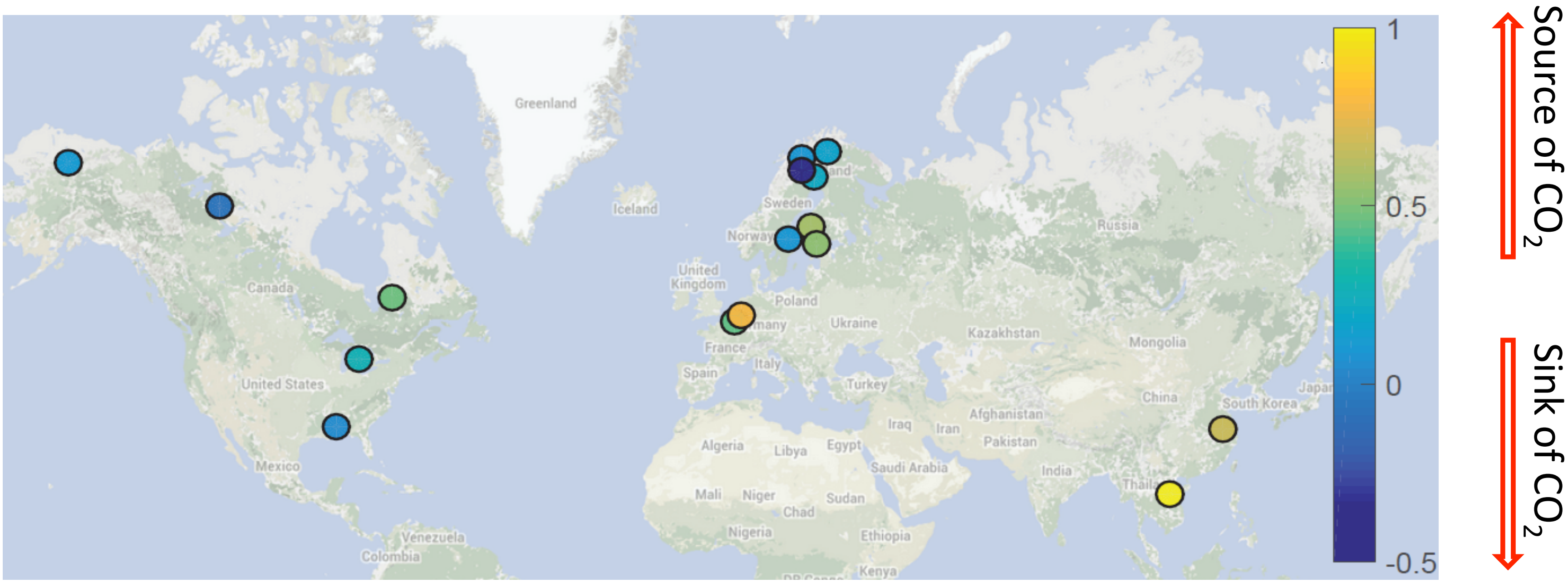
Median Daily LE Flux



Open-Water Daytime Carbon Dioxide Flux

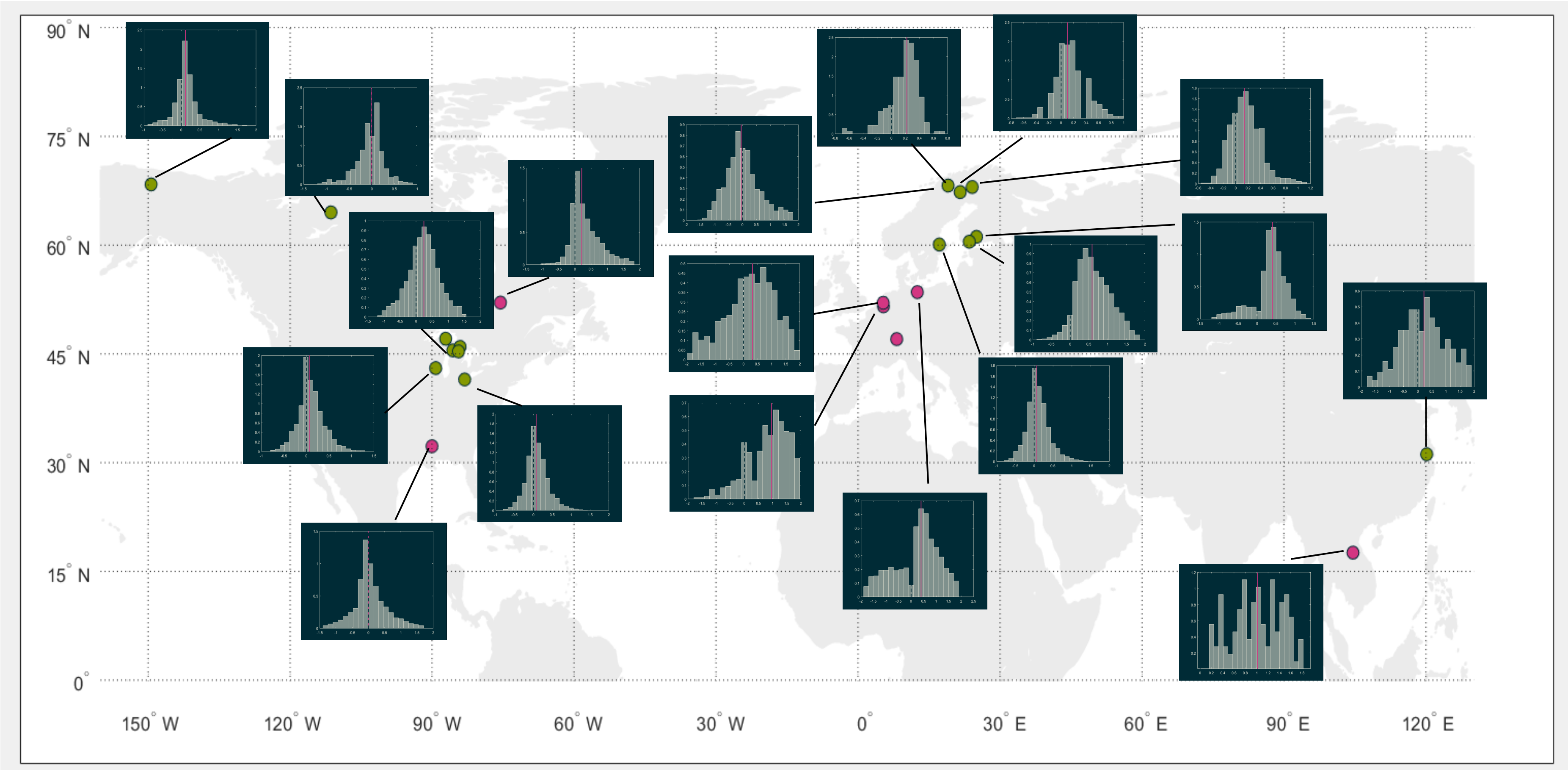
(Median)

umol m-[2]

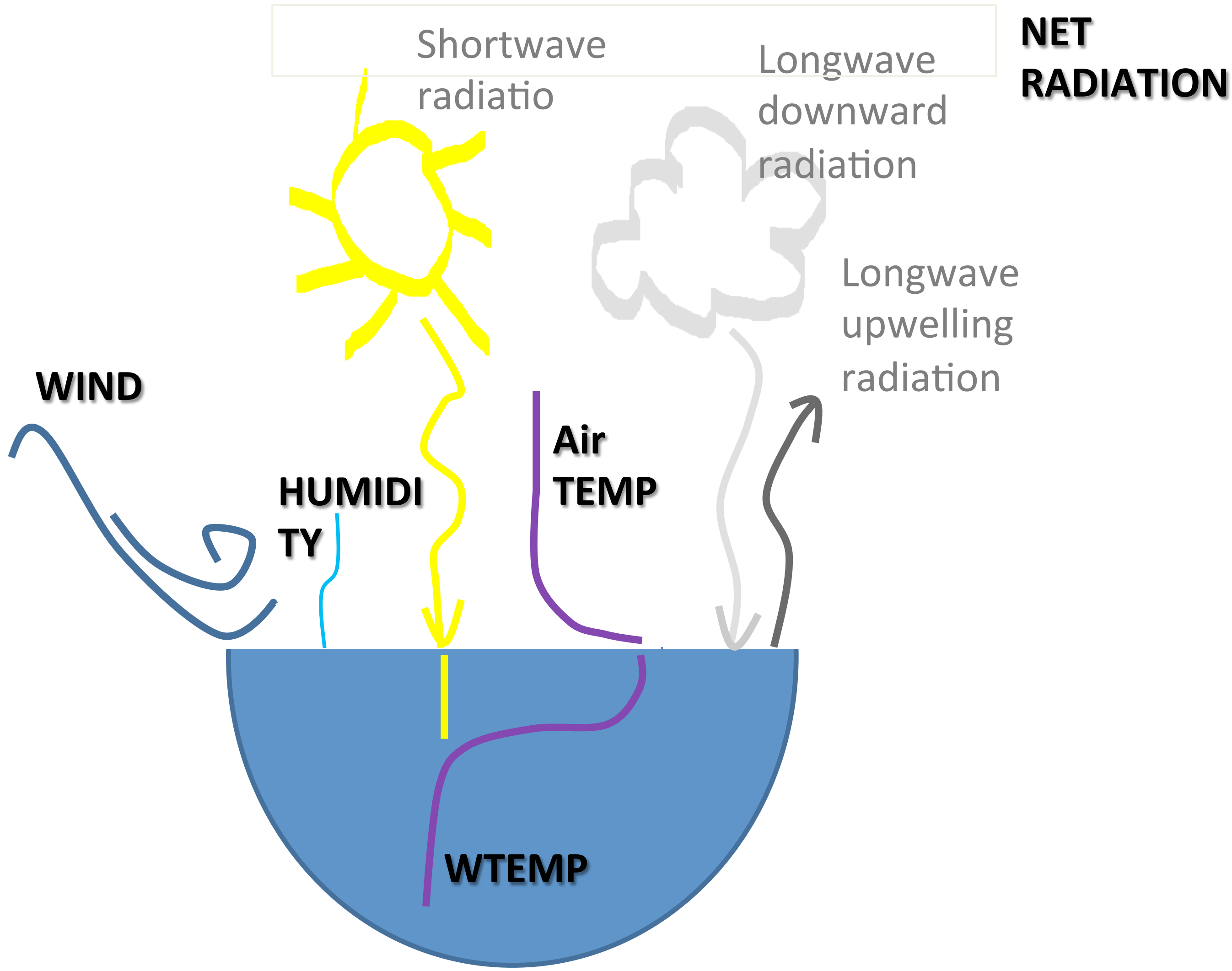


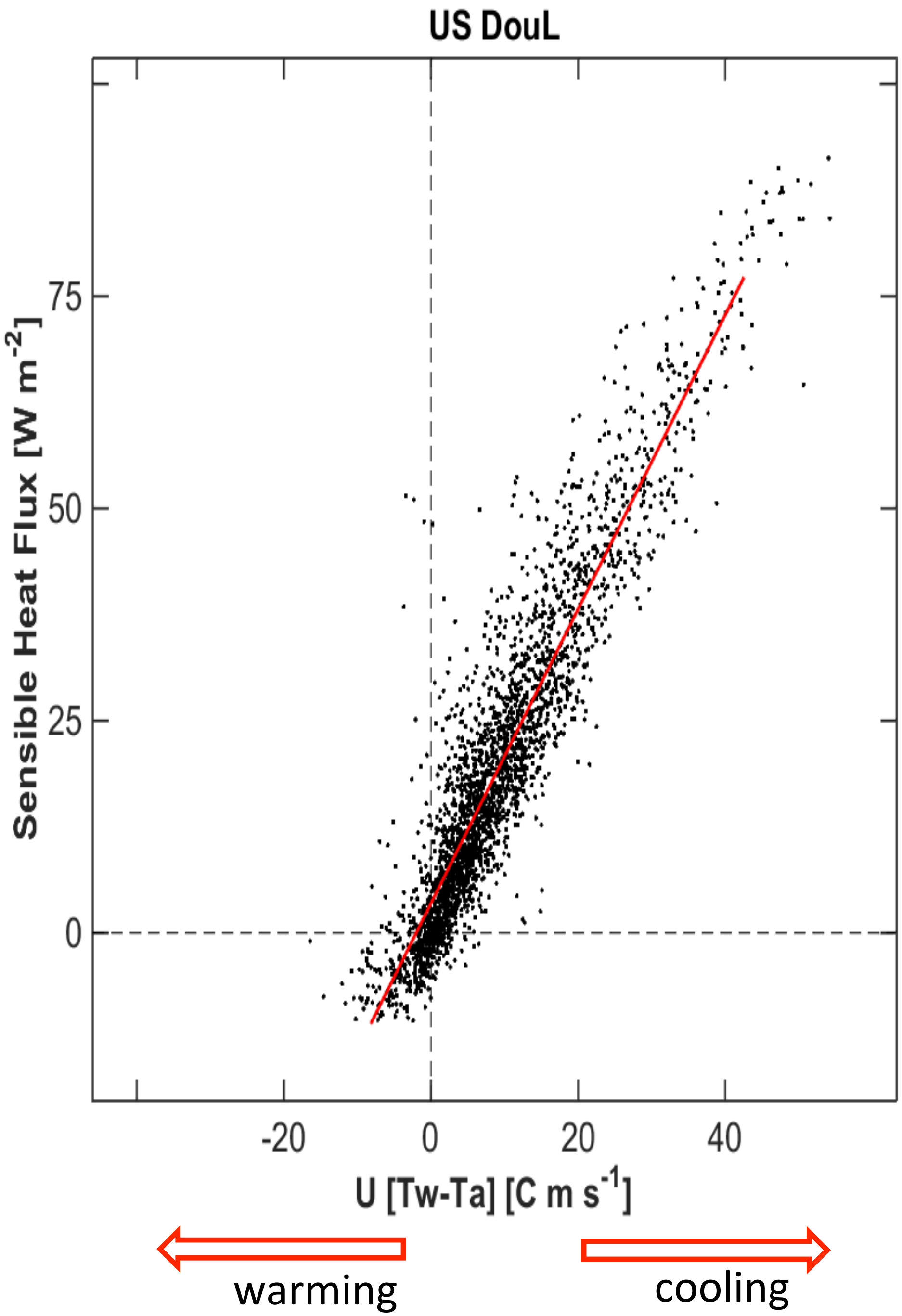
- Majority of water bodies are source of CO_2 to atmosphere
- Large emissions from reservoirs
- No clear latitudinal pattern (i.e. site-specific characteristics play more important role)

Median Daily CO_2 Flux



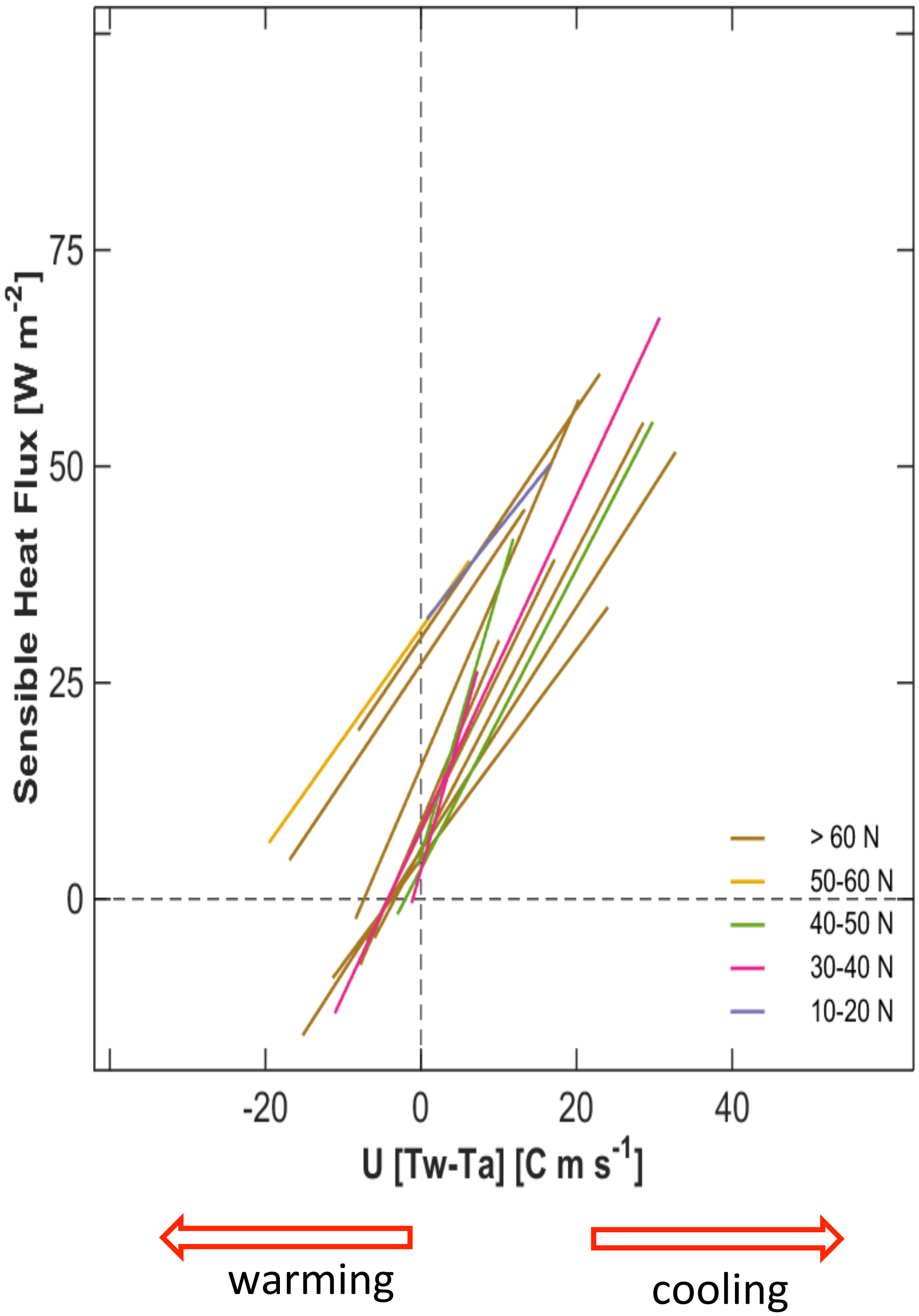
Short-term controls of heat fluxes

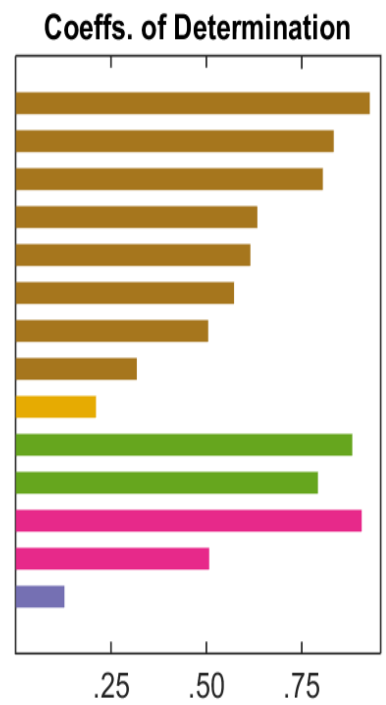




Wind speed and temperature gradient at air-water interface control sensible heat flux

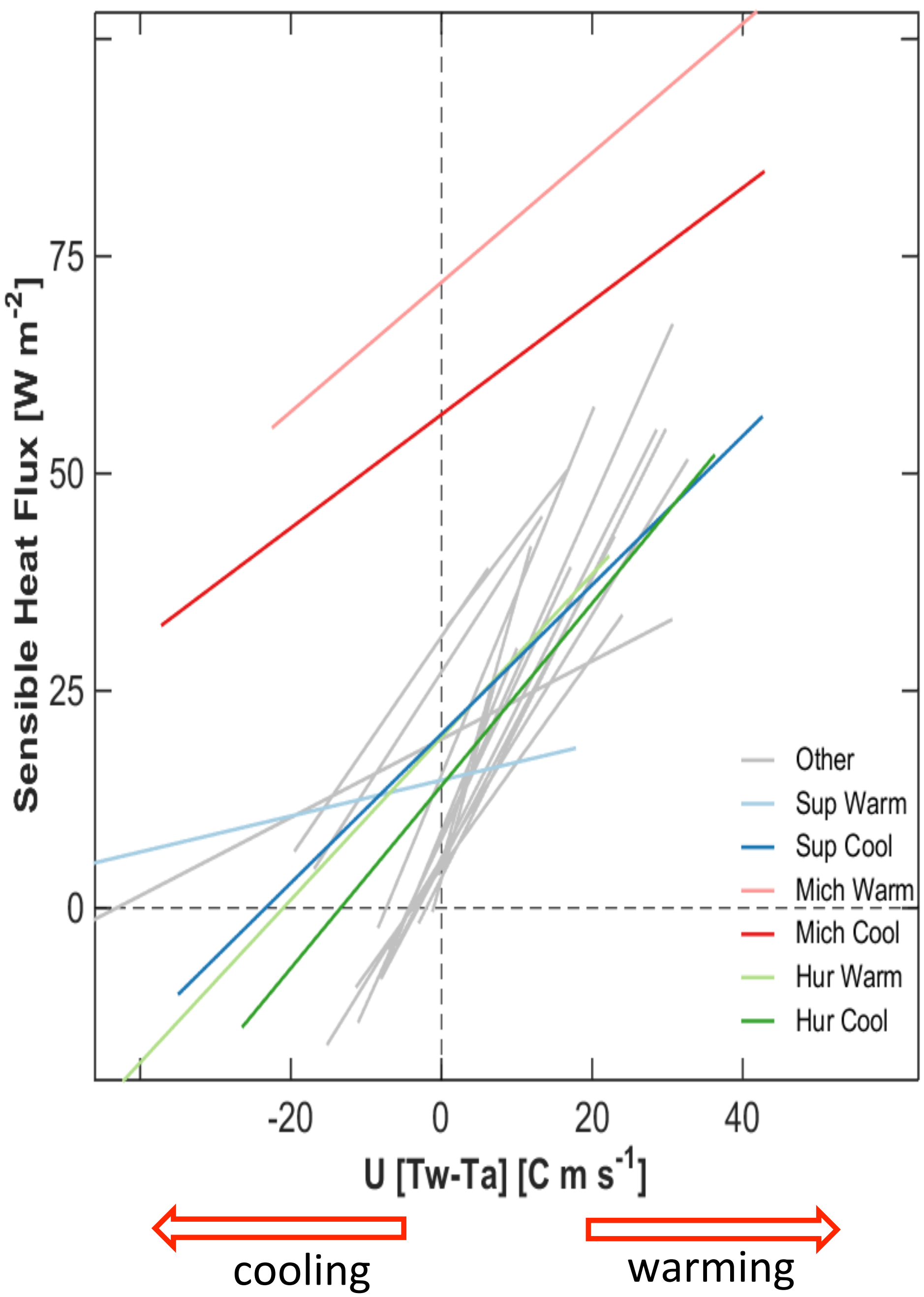
Wind speed and temperature gradient explains >50% of variation in H flux in majority of lakes

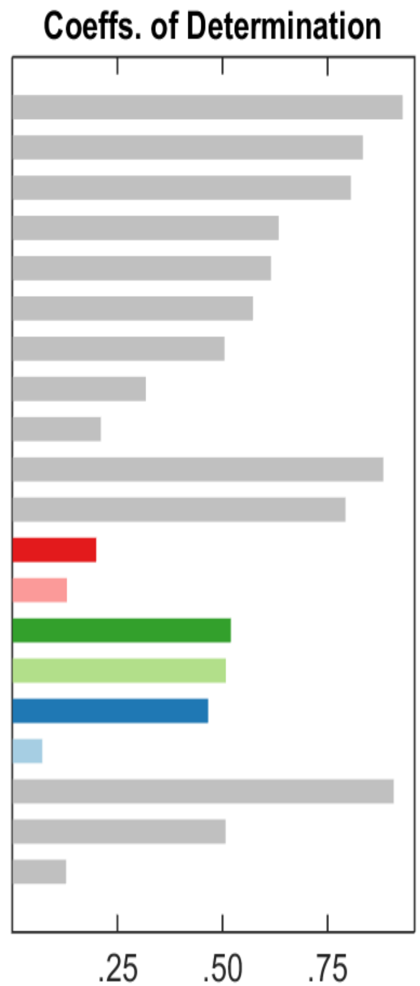




- Fairly universal control
- Steeper slopes in mid-latitudes
- No clear latitudinal gradient

Variable H response to wind speed and temperature gradient in Great Lakes

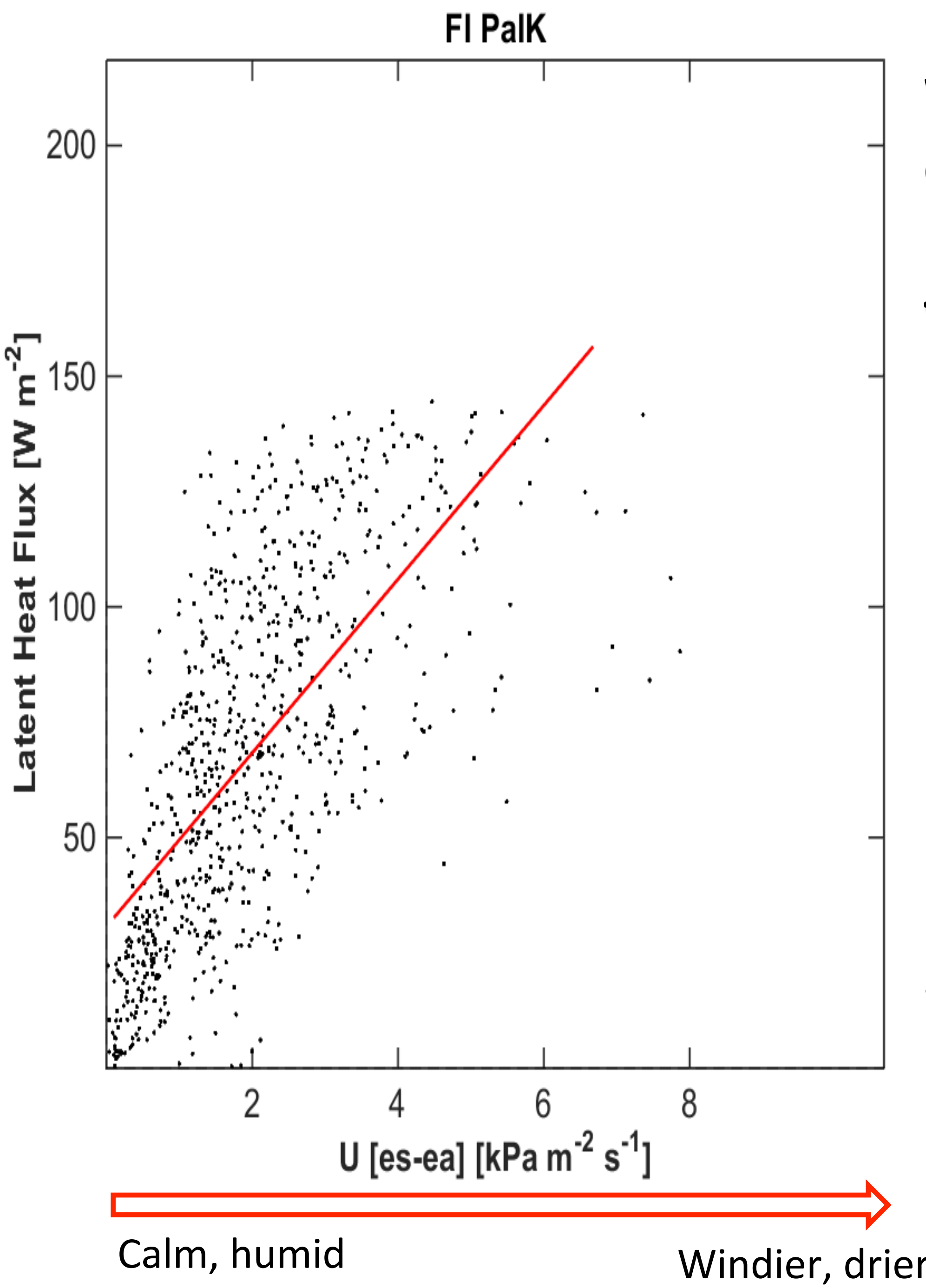




- Poor controls during cooling season

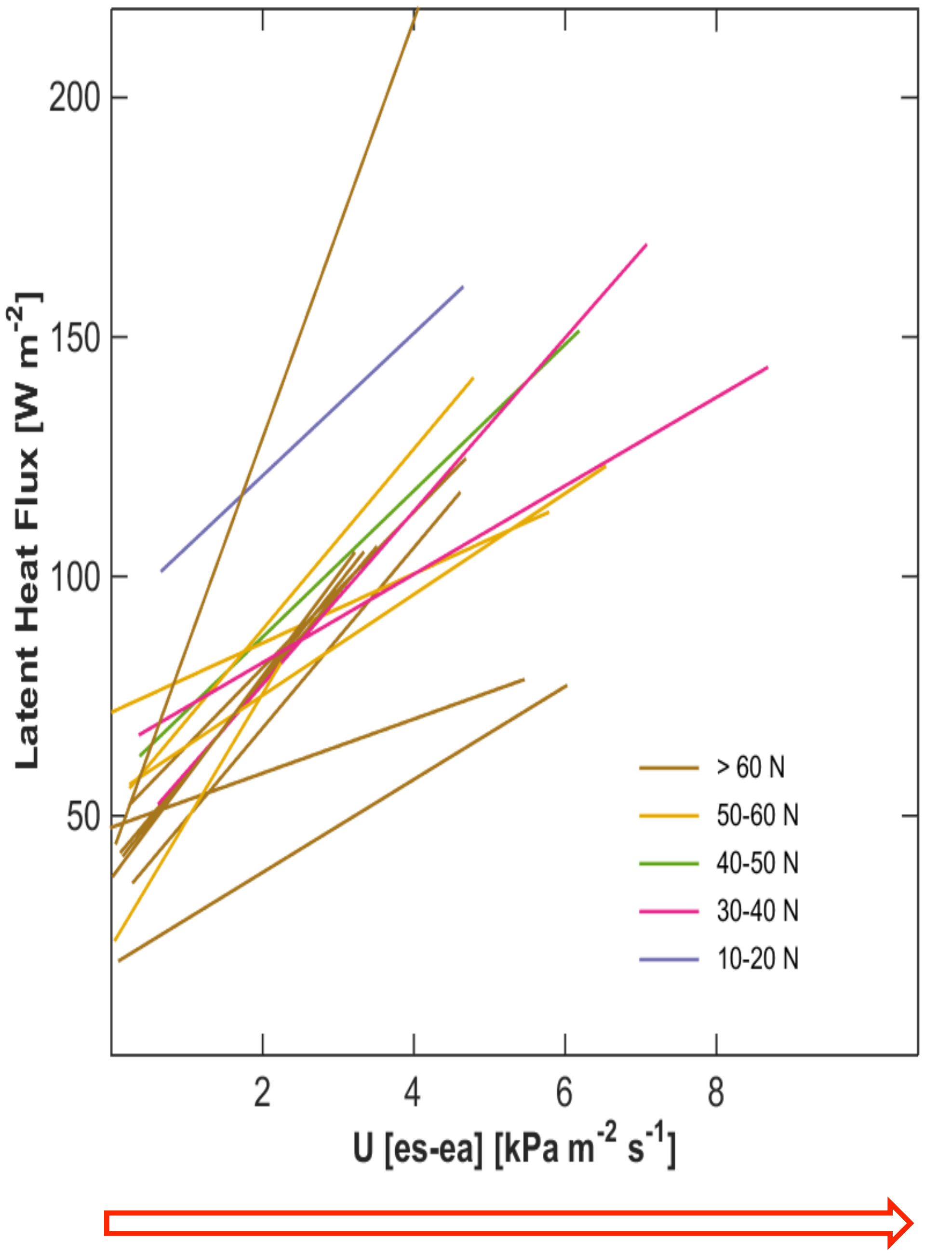
	Sensible Heat Flux
Sub-arctic lake (Toolik)	WSpeed *ΔT (r^2=.78) ΔT (r^2=. 0.71) Air Temp (r^2=.47)
Boreal lake (Kuivajarvi)	WSpeed *ΔT (r^2=.84) ΔT (r^2=. 0.57) Ustar (r^2=.37)
Temperate lake (Huron)	WSpeed * ΔT (r^2=.46) Sat. Vap. Press (r^2=.37) ShotWave Rad. (r^2=.34)
Subtropical lake (Jackson)	WSpeed * ΔT (r^2=.67) ΔT (r^2=.43) WTemp (r^2=.35)

Half-hourly TIMESCALE



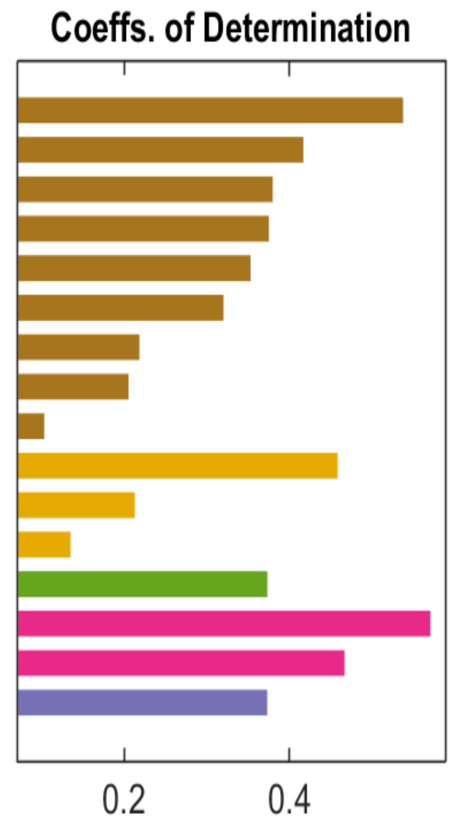
Wind speed and humidity differences at air-water interface control latent heat flux

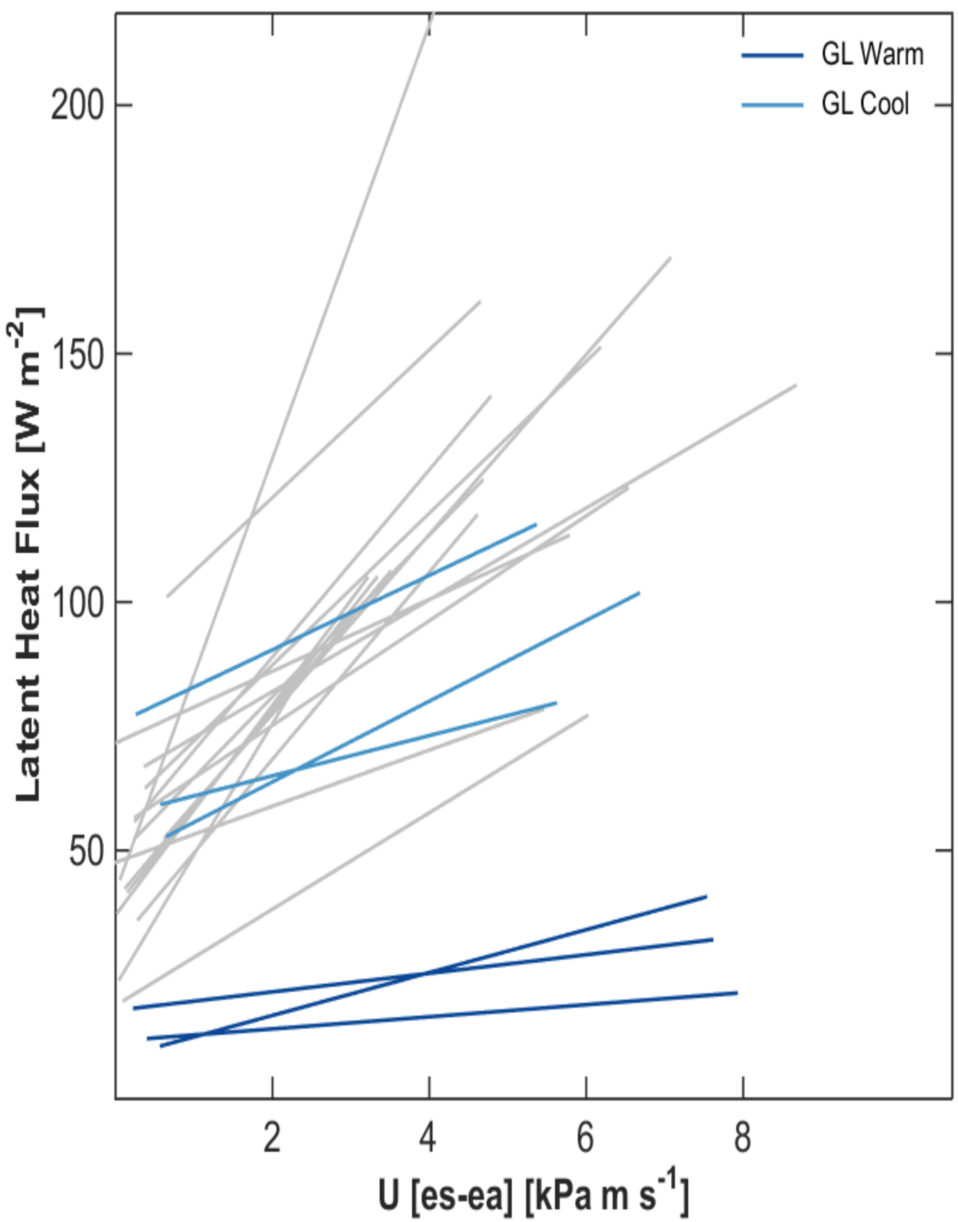
- Higher variation in windier and drier conditions



Calm, humid
Windier, drier

Wind speed and humidity gradient explain >30% of latent heat variation in majority of lakes

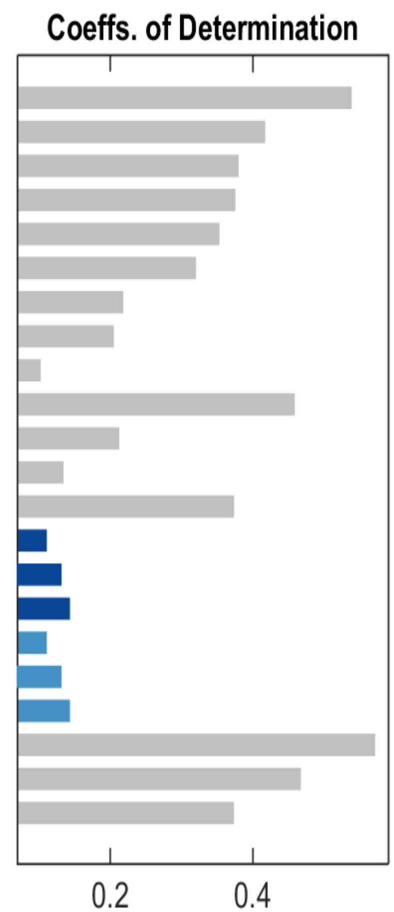




Calm, humid

Windier, drier

Poor relationships of LE with wind speed and humidity differences in both seasons for Great Lakes

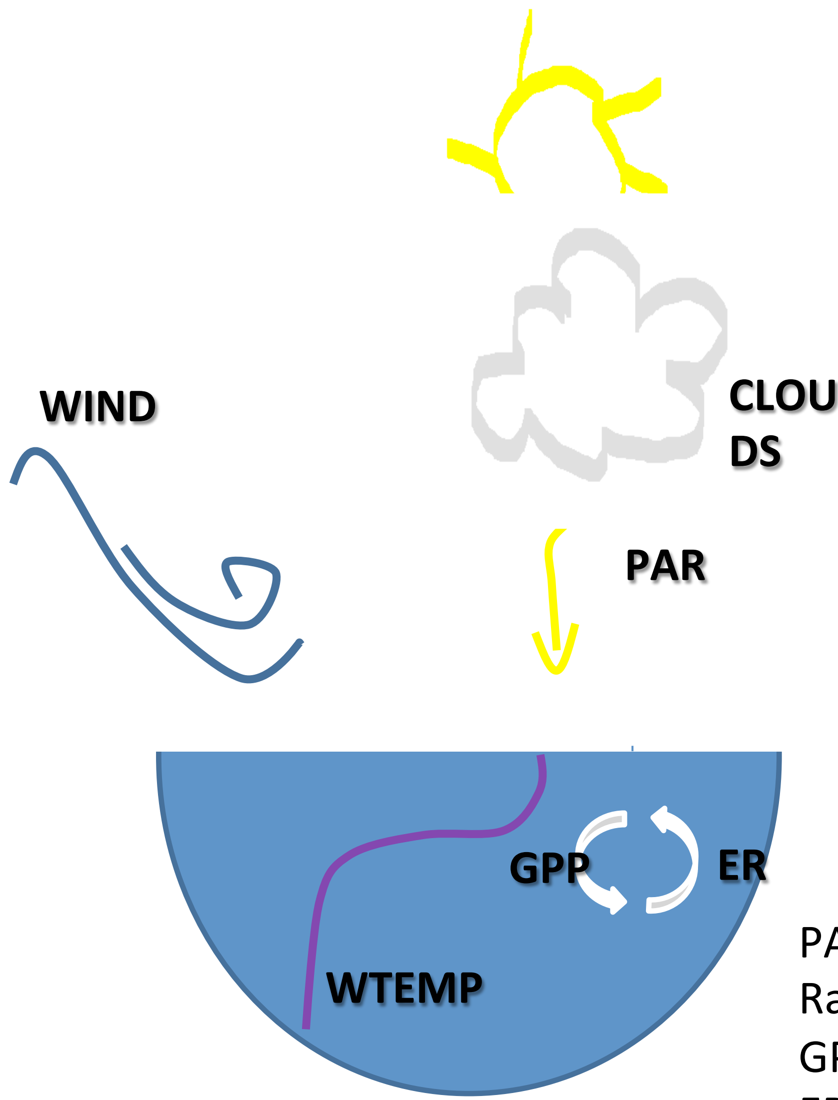


- Too short timescales to detect drivers

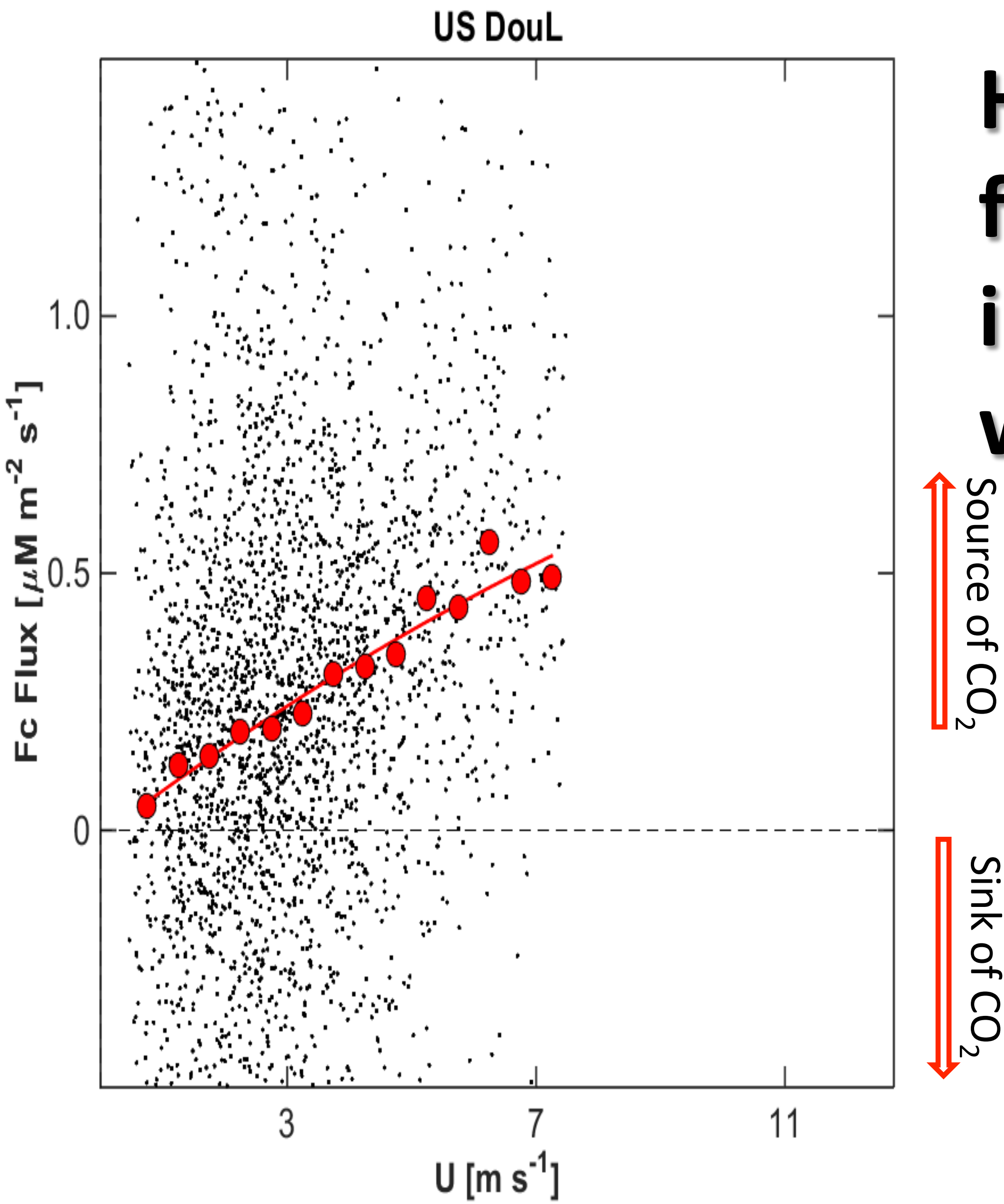
	Sensible Heat Flux	Latent Heat Flux
Sub-arctic lake (Toolik)	WSpeed *ΔT (r^2=.78) ΔT (r^2=. 0.71) Air Temp (r^2=.47)	WSpeed *Δ Vap. Press. (r^2=.36) Relat. Humidity (r^2=.33)
Boreal lake (Kuivajarvi)	WSpeed *ΔT (r^2=.84) ΔT (r^2=. 0.57) Ustar (r^2=.37)	WSpeed *Δ Vap. Press. (r^2=.46) Sat. Vap. Press (r^2=.37) ShotWave Rad. (r^2=.34)
Temperate lake (Huron)	WSpeed * ΔT (r^2=.46) Sat. Vap. Press (r^2=.37) ShotWave Rad. (r^2=.34)	WSpeed *Δ Vap. Press. (r^2=.30)
Subtropical lake (Jackson)	WSpeed * ΔT (r^2=.67) ΔT (r^2=.43) WTemp (r^2=.35)	WSpeed *Δ Vap. Press. (r^2=.35)

Half-hourly TIMESCALE

Short-term controls of CO_2 flux

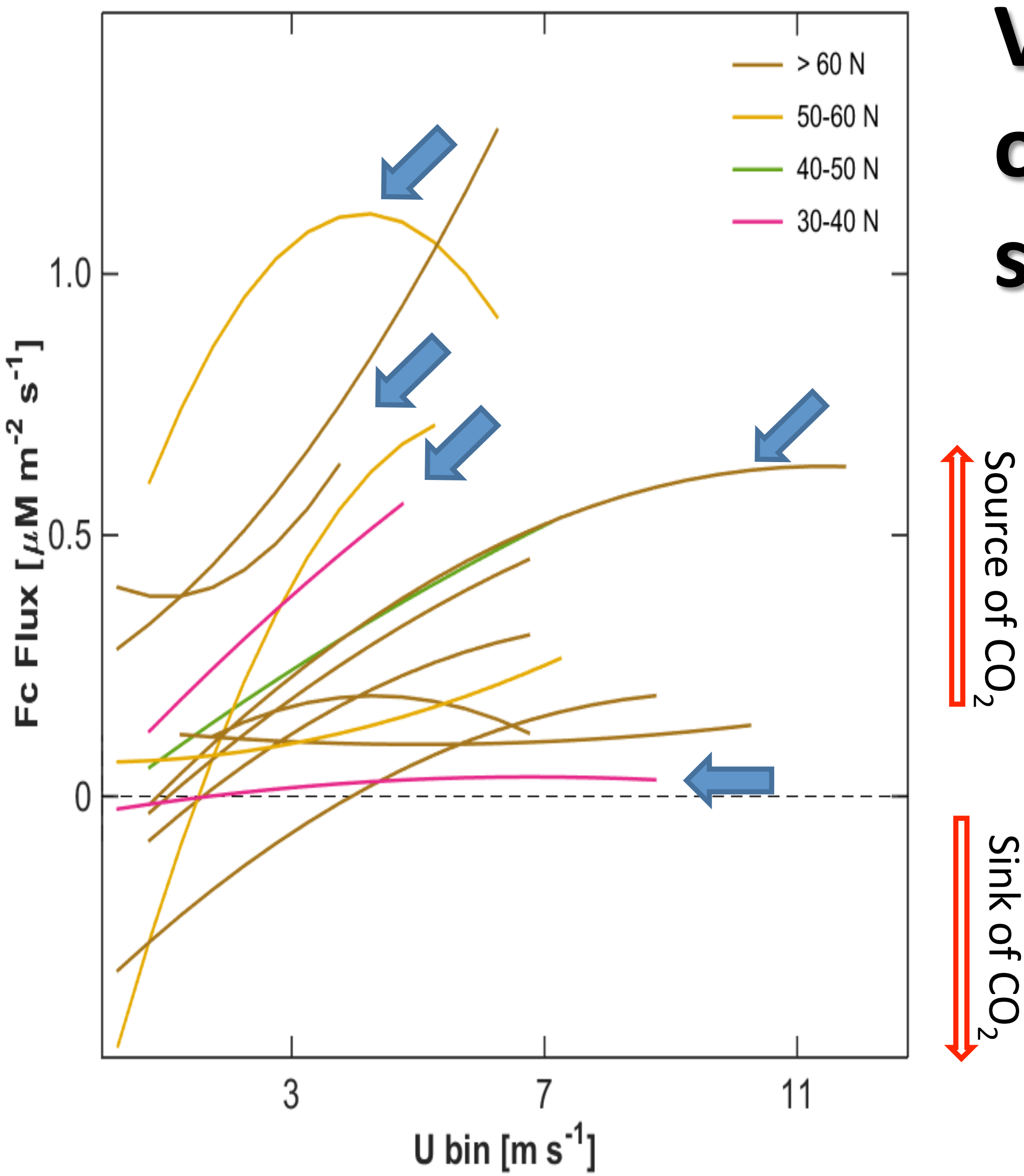


PAR – Photosynthetically Active Radiation
GPP – Gross Primary Production
ER - Ecosystem Respiration



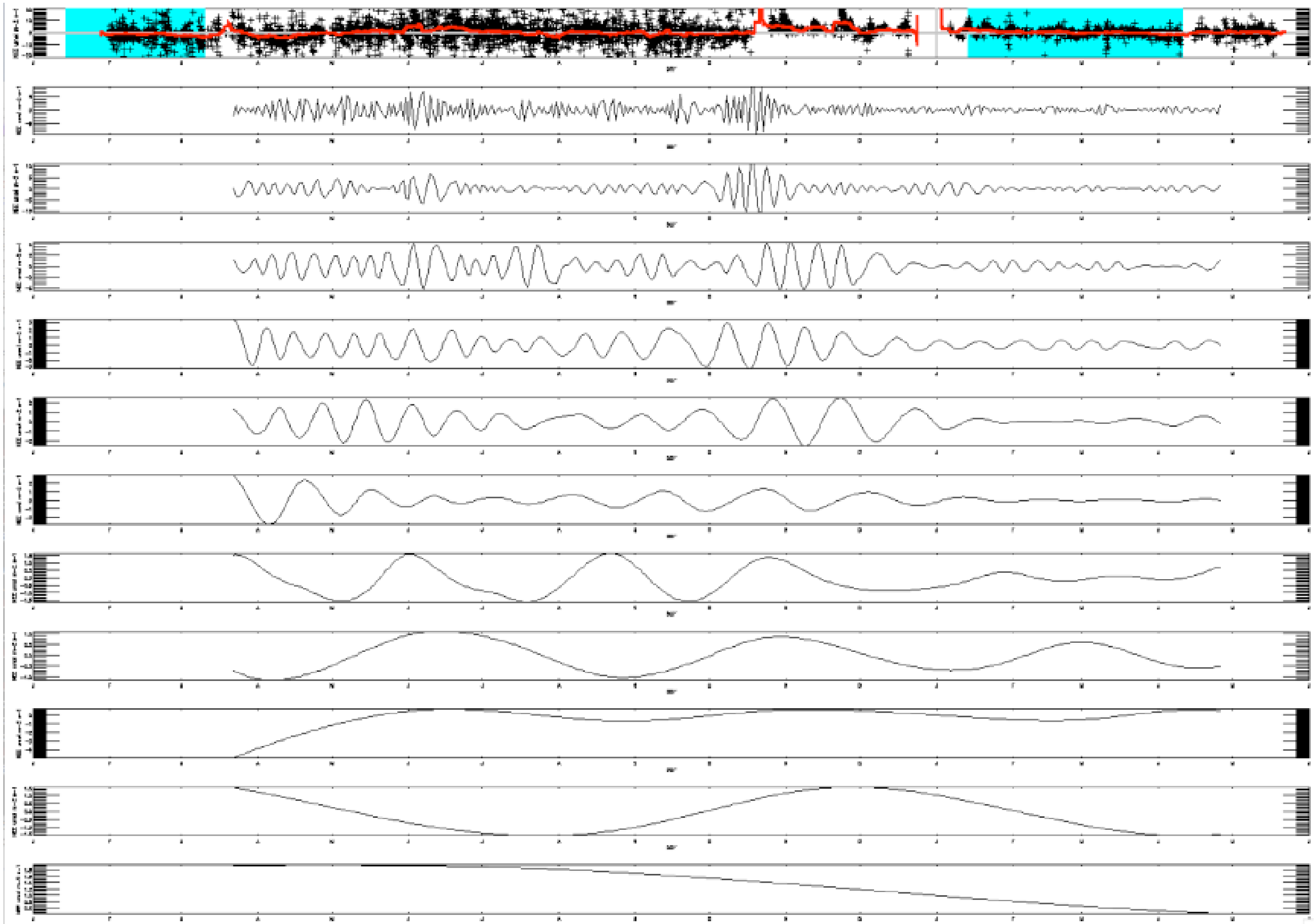
Highly variable CO_2 flux but generally increases with wind speed

- Observations were binned into 0.5 m s^{-1} bins
- Scatter implies influences of other factors



Variable responses of CO_2 flux to wind speed

Wavelet Analysis



Summary

- Water temperature and meteorological characteristics of over-water air masses (e.g. wind speed, air temp, humidity) control short term-variation of sensible and latent heat fluxes

- Responses of LE and H in Great Lakes vary by warming/cooling seasons
  - Time-lags
  - Poor predictors → too short timescales presented here

- Higher wind speed promotes greater CO_2 exchange, but large variability suggests other physical and biological driving factors

- Carbon fluxes probably can not be reliably extrapolated from single point measurements given high temporal variability

Challenges

- Eddy covariance quality is highly variable and sensitive to screening, footprints, type of lake, stable boundary layers over cold surfaces
- Lack of in-water data on pCO_2 or temperature profiles in many systems limit interpretation and derivation of gas transfer coefficients
- Ice-covered lakes rarely have winter data
- Data sharing is never simple

Thank you

- Analysis plans: Gap-filling, wavelet coherence analysis, derivation of gas transfer velocity
- Manuscript in preparation (fall submission), open dataset to be placed in repository afterwards
- Contact Gosia Golub mgolub@wisc.edu if you want to participate or analyze data
- Funding: NSF DEB-1440297, NTL LTER, NSF DEB-0845166 + PI support for each site

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