Mangrove Ecosystem Function and Response to Climate Change

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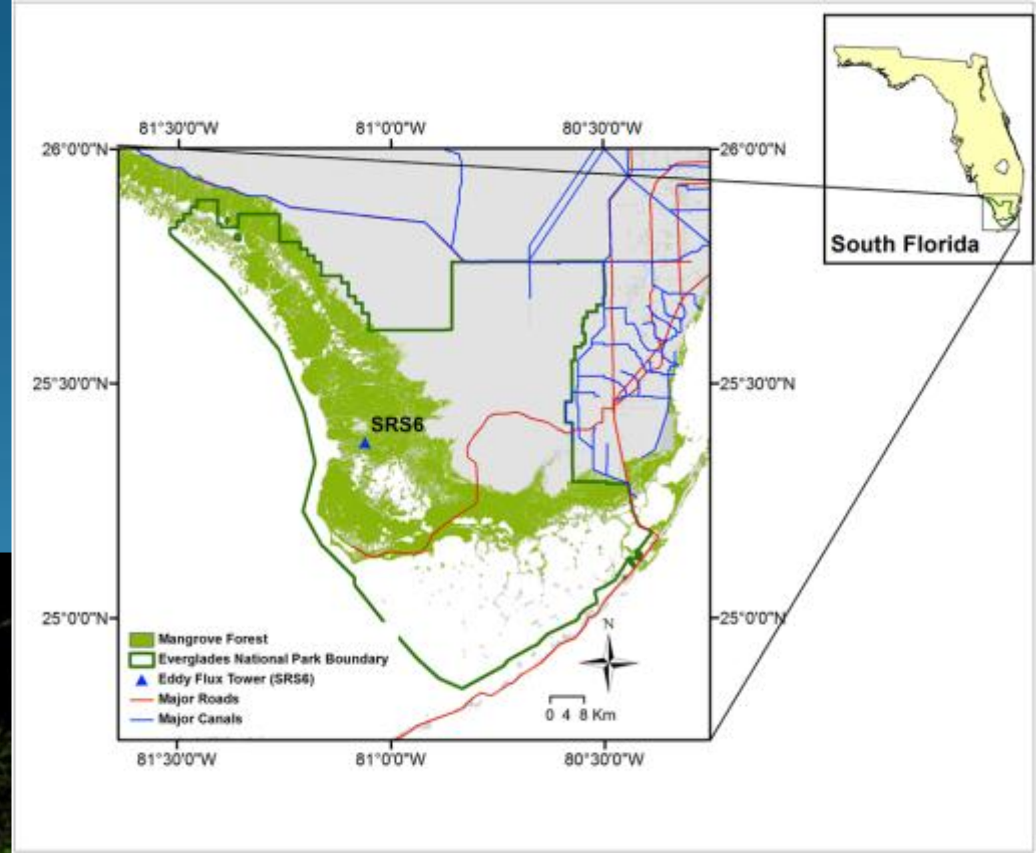
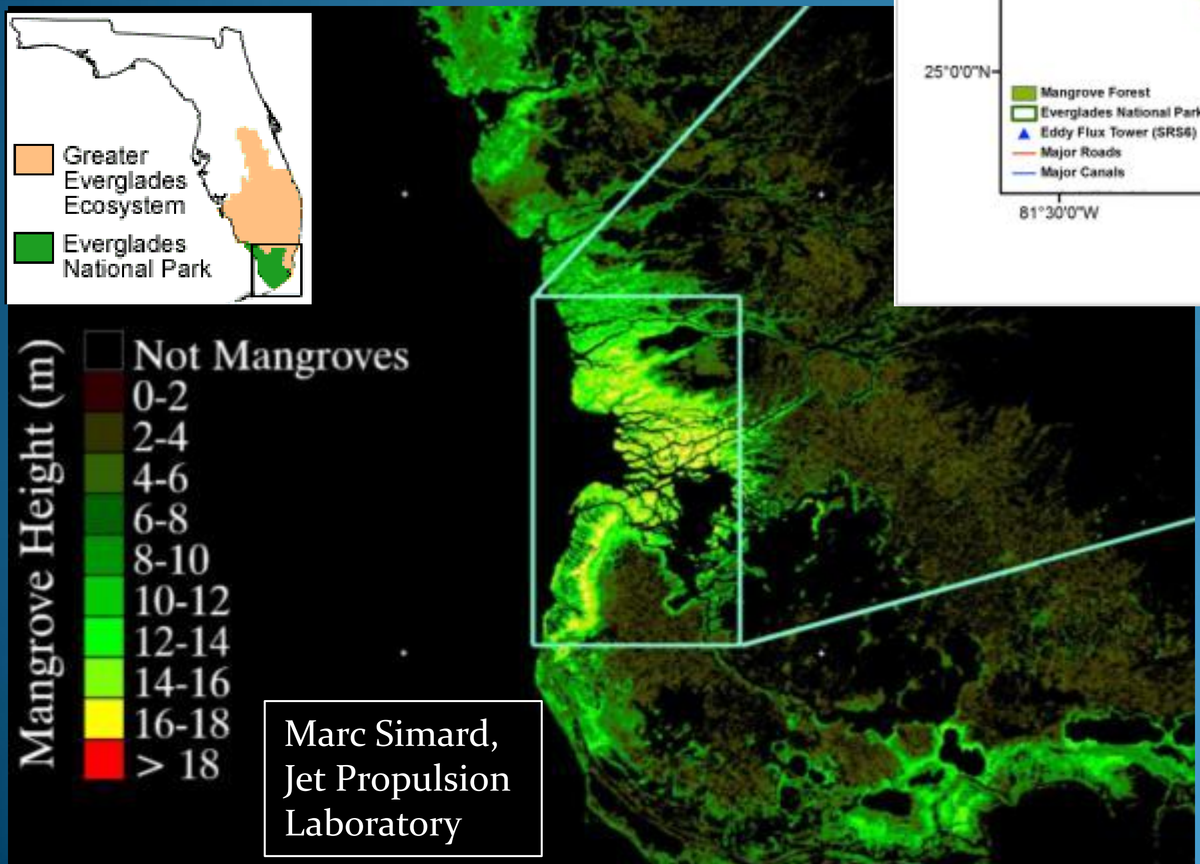
Mangrove Ecosystem Function and Response to Climate Change

- Mangrove eddy covariance (EC) flux tower site and ecosystem characteristics
- Carbon budgets of coastal ecosystems: What is the role of EC in constraining mangrove C budgets?
- Partitioning net ecosystem exchange (NEE) of CO_2 into ecosystem respiration (R_E) and gross primary production (GPP).
  - $GPP = -NEE + R_E$
- Modeling light-use efficiency (LUE) and GPP:
  - Understand controls on ecosystem function
  - Implications for spatiotemporal scaling
- Climate change & disturbances
- Conclusions

Everglades National Park

- ❑ Riverine mangrove forest dominated by *R. mangle, A. germinans, L. racemosa*
- ❑ Mangrove forest structure varies across the salinity mixing zone
- ❑ Growth and total biomass reflect [P] gradients and peat depths (up to 6 m)





- ❑ **Peat depth > 5 m**
- ❑ **Semi-diurnal tides**
- ❑ **Distinct wet and dry seasons**
- ❑ **Avg. precipitation: 160 cm yr^{-1}**
- ❑ **Avg. ann. air temperature: 24 C**

Everglades National Park
Study site

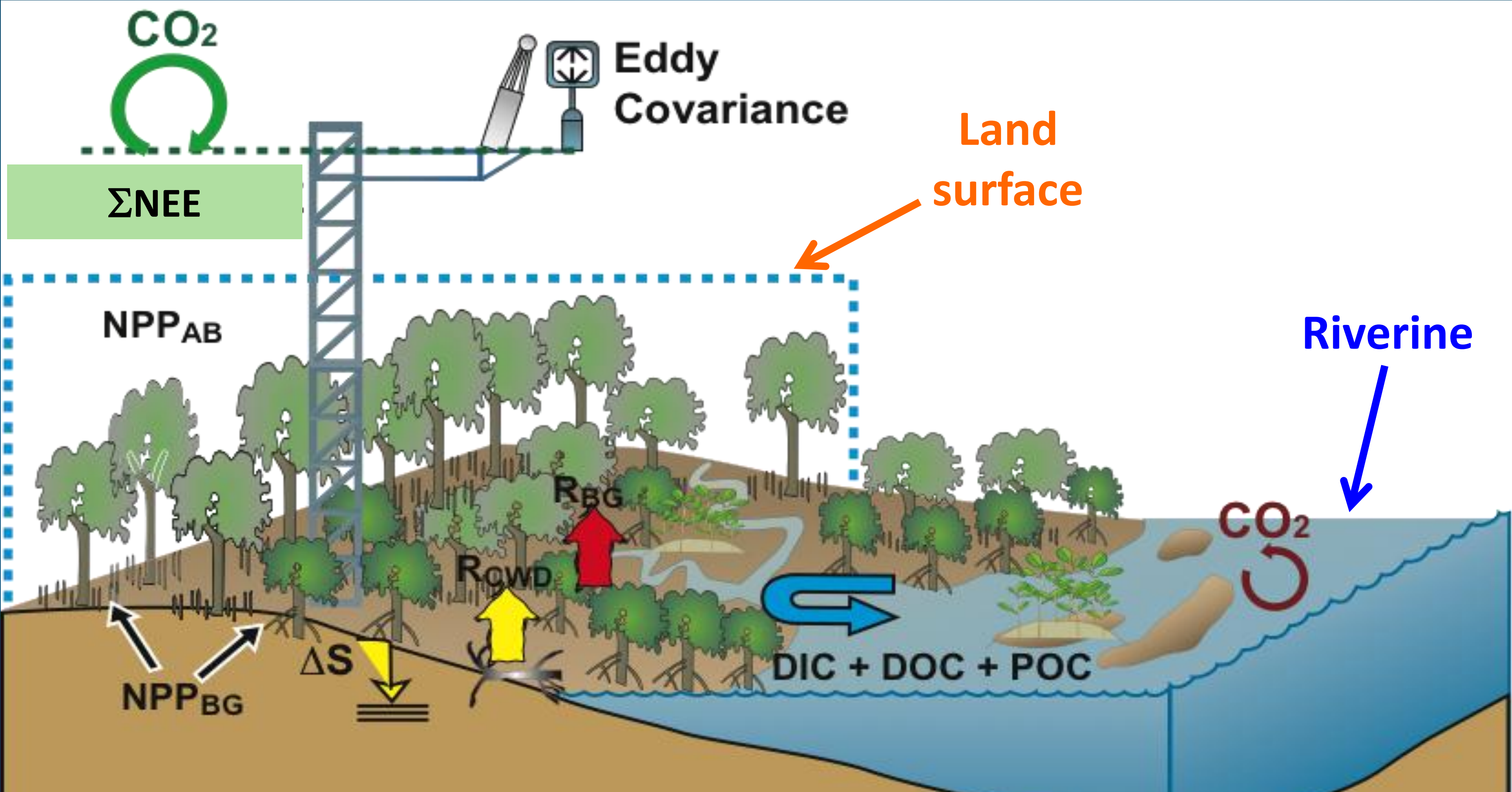
- Height (m)[b] 19.0 ± 0.2
- Basal area ($m^2\ ha^{-1}$)[a] 39.7
- Tree density (ind. ha^{-1})[b] 7450
- Flood frequency (floods yr^{-1})[b] ~500
- Flood duration (h yr^{-1})[b] 4622 (52% of time)

Total:

- N (%)[a] 1.2 ± 0.1
- P (%)[a] 0.12 ± 0.01
- C (%)[a] 22.2 ± 1.2
- Bulk density (g cm^{-3})[b] 0.212

[a] Chen and Twilley, 1999
[b] Krauss et al. 2006

Two components to the mangrove ecotone carbon budget



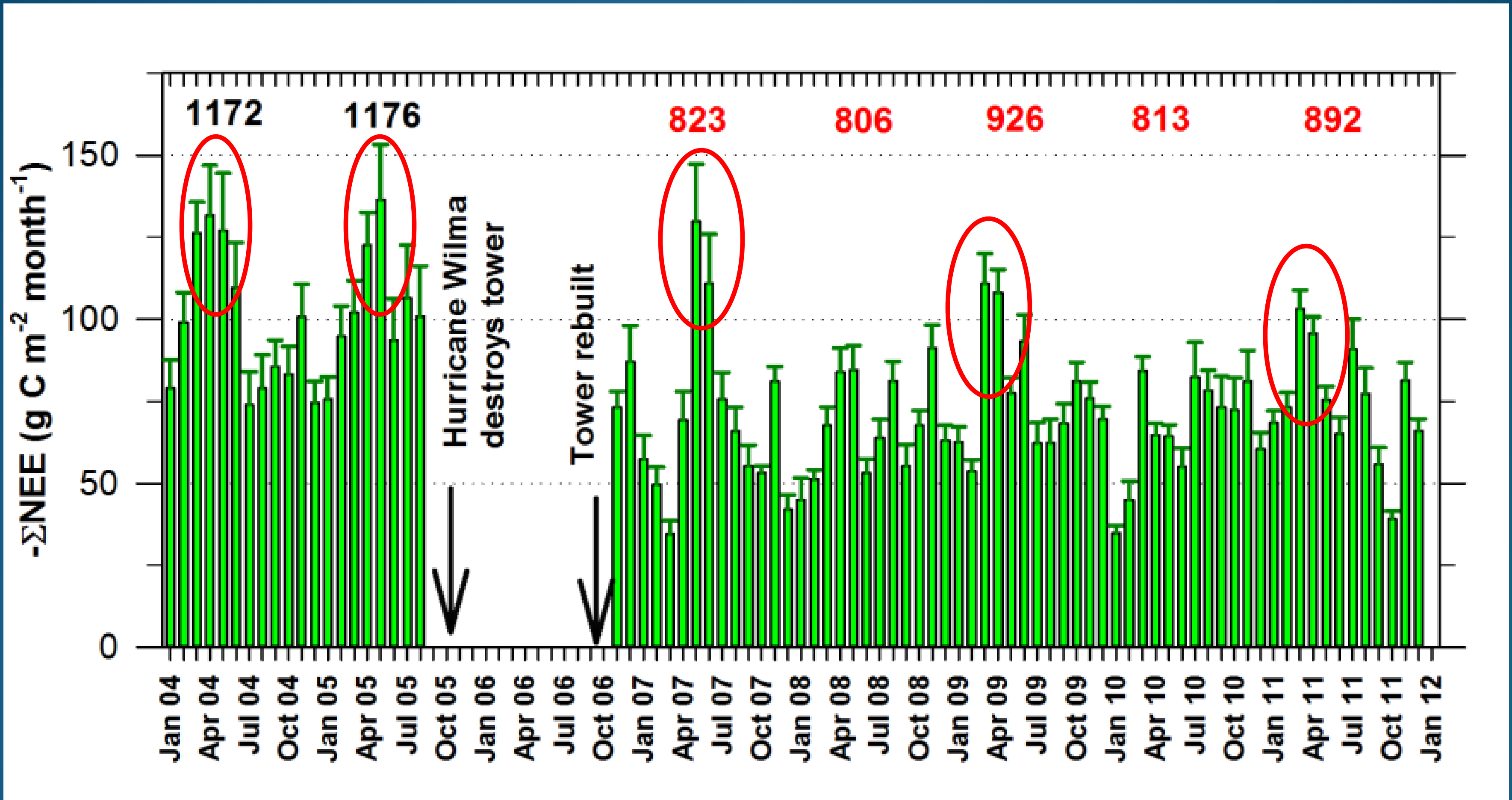
Governing equation for Land surface C budget

$NECB = -\Sigma NEE + F_{DIC,DOC,POC}$ (Chapin et al. 2006)

NEE == Net ecosystem exchange of CO_2

NECB == Net ecosystem carbon balance

Net ecosystem exchange of CO_2 (-ΣNEE)



- Annual –ΣNEE rates are some of the highest of any known ecosystems.
- ~30% reduction in annual –ΣNEE 1 year following hurricane Wilma disturbance.

Carbon budget fluxes (g C m^{-2} yr^{-1}) and estimates of $F_{DOC,DIC,POC}$

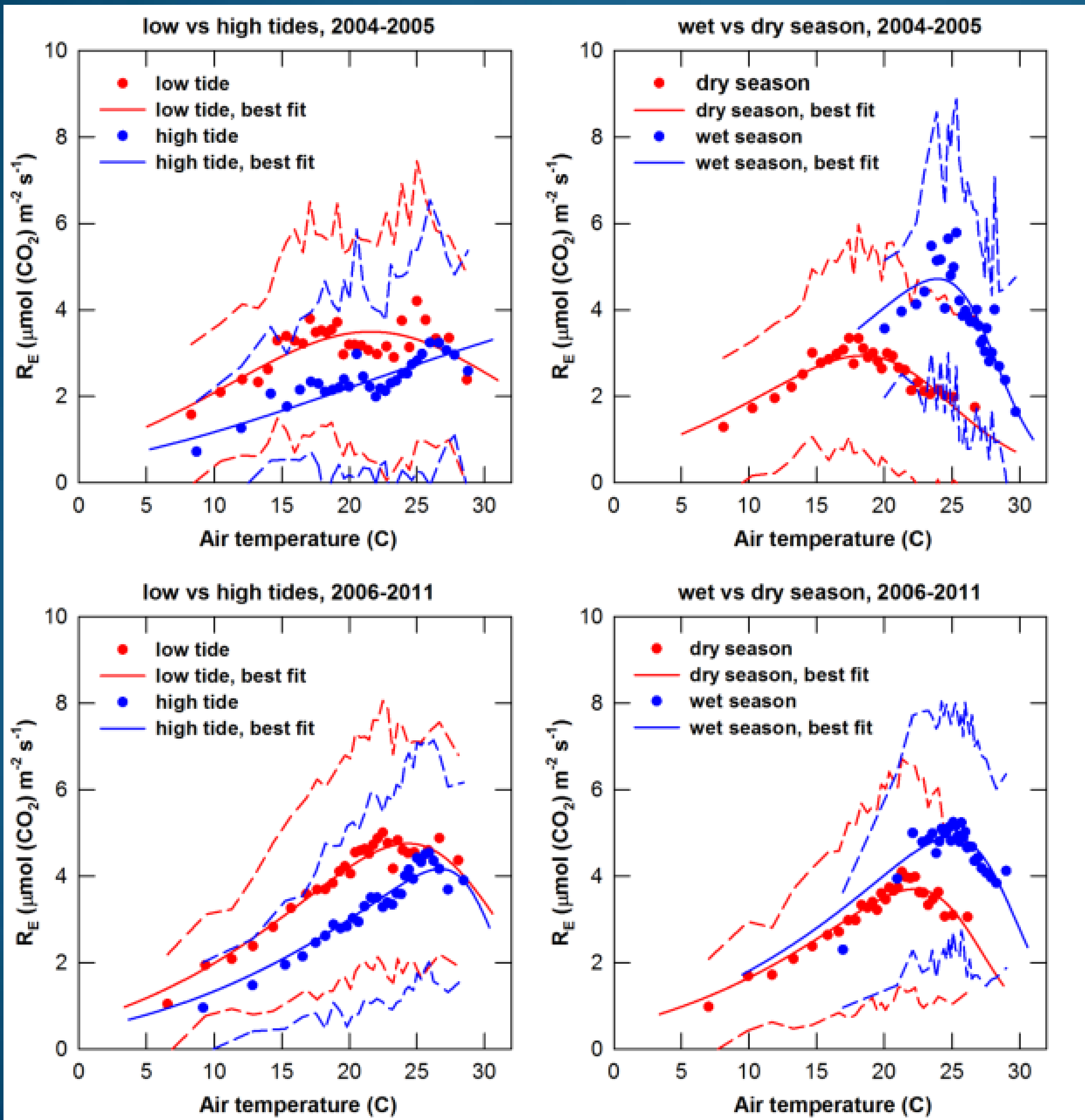
Year		-ΣNEE (J.Barr et al.)	NPP (Castañeda 2010; Castañeda et al. 2011; Rivera-Monroy et al. unpublished)				$F_{DOC, DIC, POC}$	Soil C accumulation (J. Smoak)
			Litter	Wood	Roots	Total		
Pre-Wilma	Pre-2004			227 ± 17 (2002)	206 ± 49 (2002-04)	870 (2001-04)		123 (1924-2000)
	2004	1172 ±64	553 ± 19	198 ± 46	206 ± 49 (2002-04)		-213± 182	201 (2002-04)*
	2005	1176 ±66						
Post-Wilma	2006		140 ± 20	142 ± 11				169 (2006-09)*
	2007	823 ± 84	306 ± 4.0					
	2008	806 ± 66	405 ± 20	102 ± 8	N/R	579	-227 ±103**	
	2009	926 ± 70	443 ± 31	156 ± 11	N/R	671	-226 ±103**	
	2010	813 ± 55	502 ± 6	129 ± 10***	45 ± 7		-200 ± 92	
	2011	892 ± 62	473 ± 19***	129 ± 10***	99 ± 21		-225 ± 113	

* Wilma deposits likely influenced the estimated organic C accumulation rates for these intervals.

** Calculated using 2010 value for root productivity

***Litter and wood production for 2010 and 2011 estimated as average of 2008, 2009 values

Ecosystem respiration

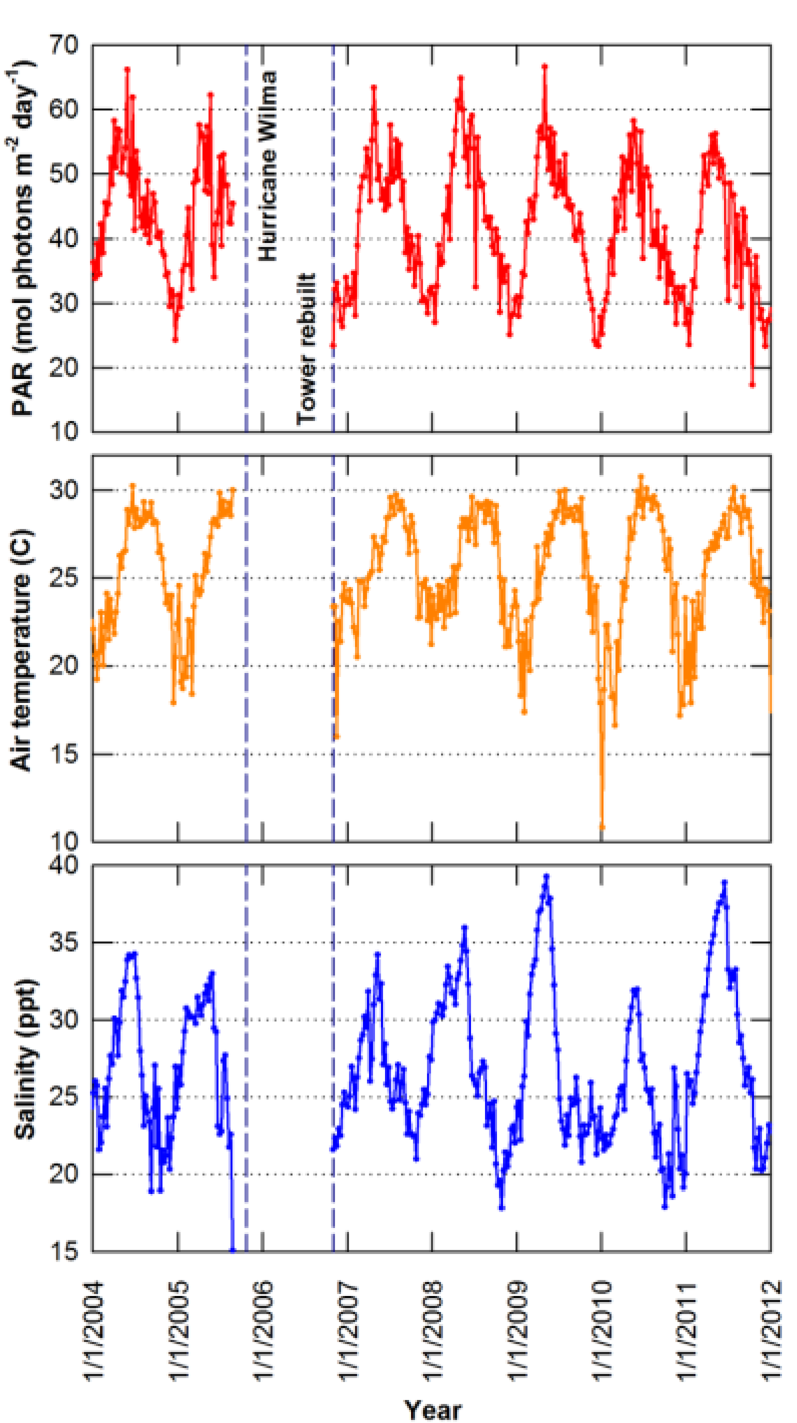


$$R_E = \frac{Activation}{Deactivation}$$

$$R_E = \frac{R_{E20}\exp\left(E_0\left(1/\left(T_{REF}-T_0\right)-1/\left(T_A-T_0\right)\right)\right)}{1+\exp\left(E_D\left(T_A-T_D\right)\right)}$$

- R_E response function changes with time.
- R_E response to temperature mirrors that of leaf-level carboxylation and ecosystem gross primary productivity (GPP).
- Daytime RE required to estimate GPP as:

$$GPP = R_E - NEE$$



Modeling light use efficiency (LUE)

$$LUE = \sum GPP \,/\, \sum PAR = \varepsilon_g \times FAPAR$$

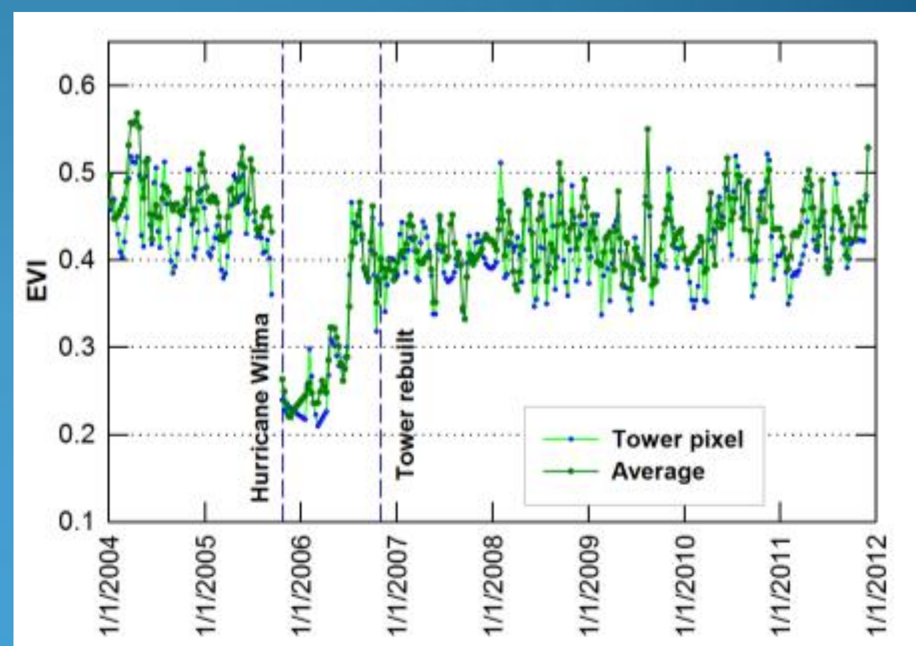
$$\varepsilon_g = \varepsilon_{gmax} \times f_{TA} \times f_{Salinity}$$

$$f_{TA} = \frac{(T_A - T_{min})(T_A - T_{max})}{(T_A - T_{min})(T_A - T_{max}) - \left(T_A - T_{opt}\right)^2}$$

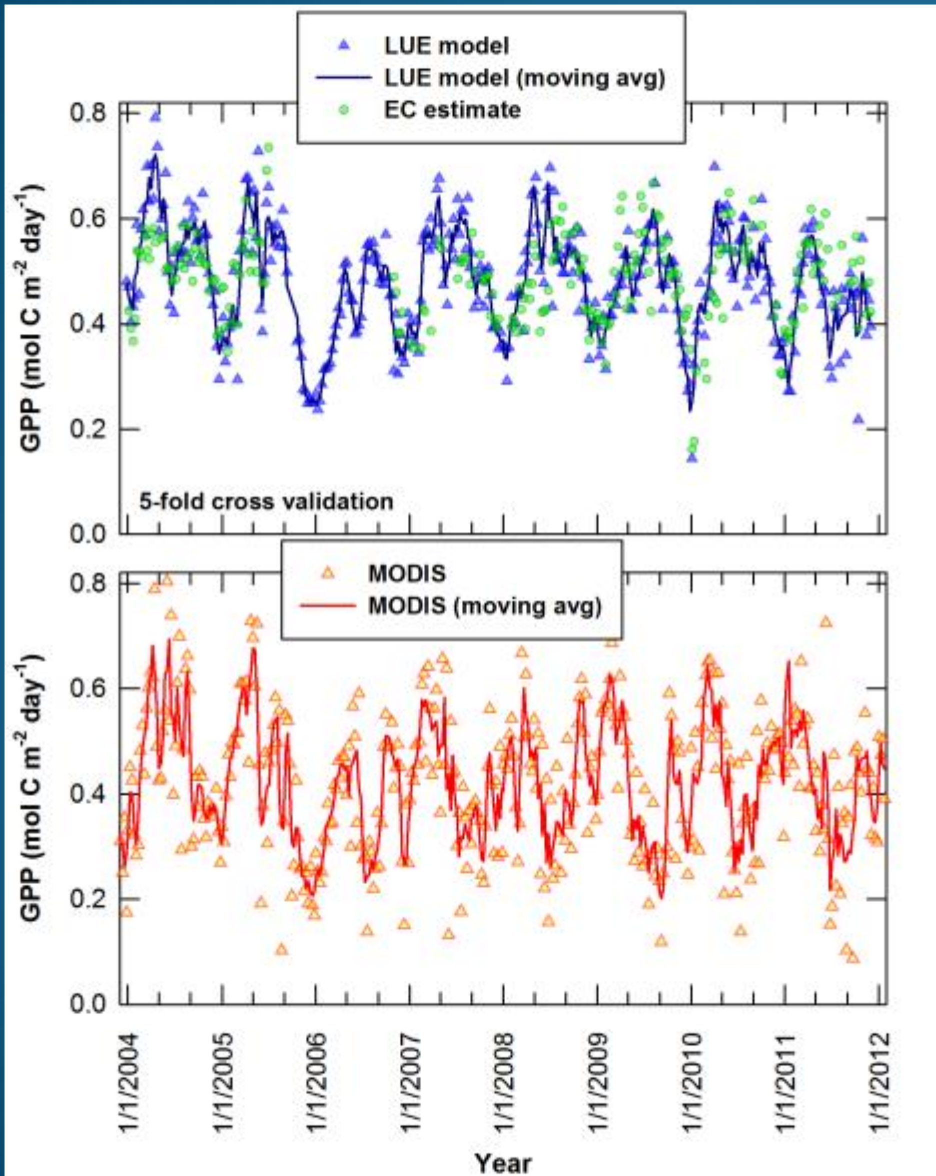
$$f_{Salinity} = 1 - m_{Sal}\, Salinity$$

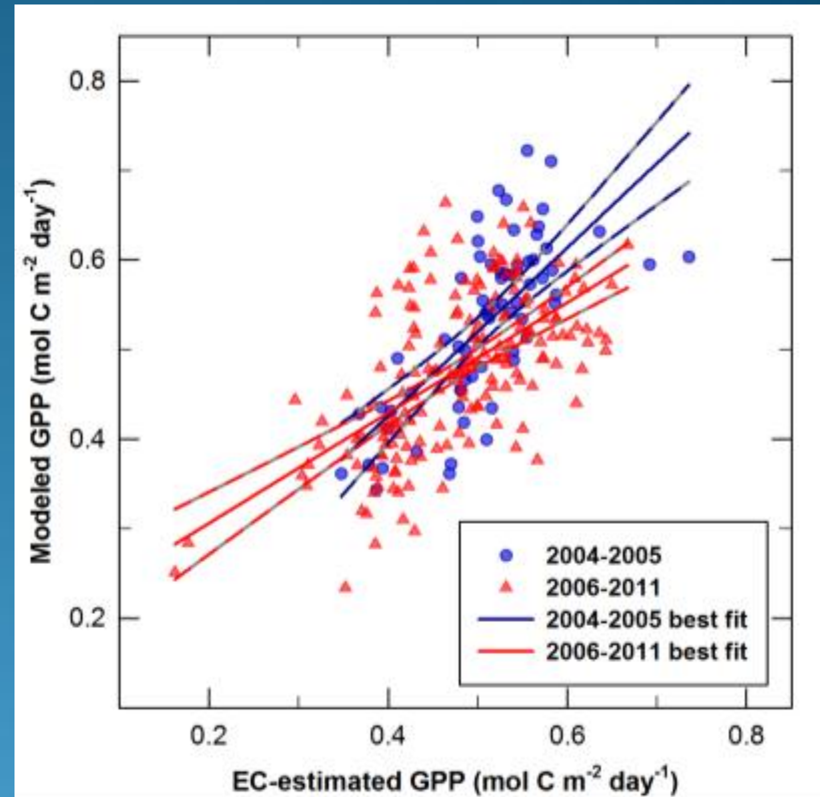
$$FAPAR = 1 - e^{-m_{EVI} \times EVI}$$

From MODIS



LUE model performance

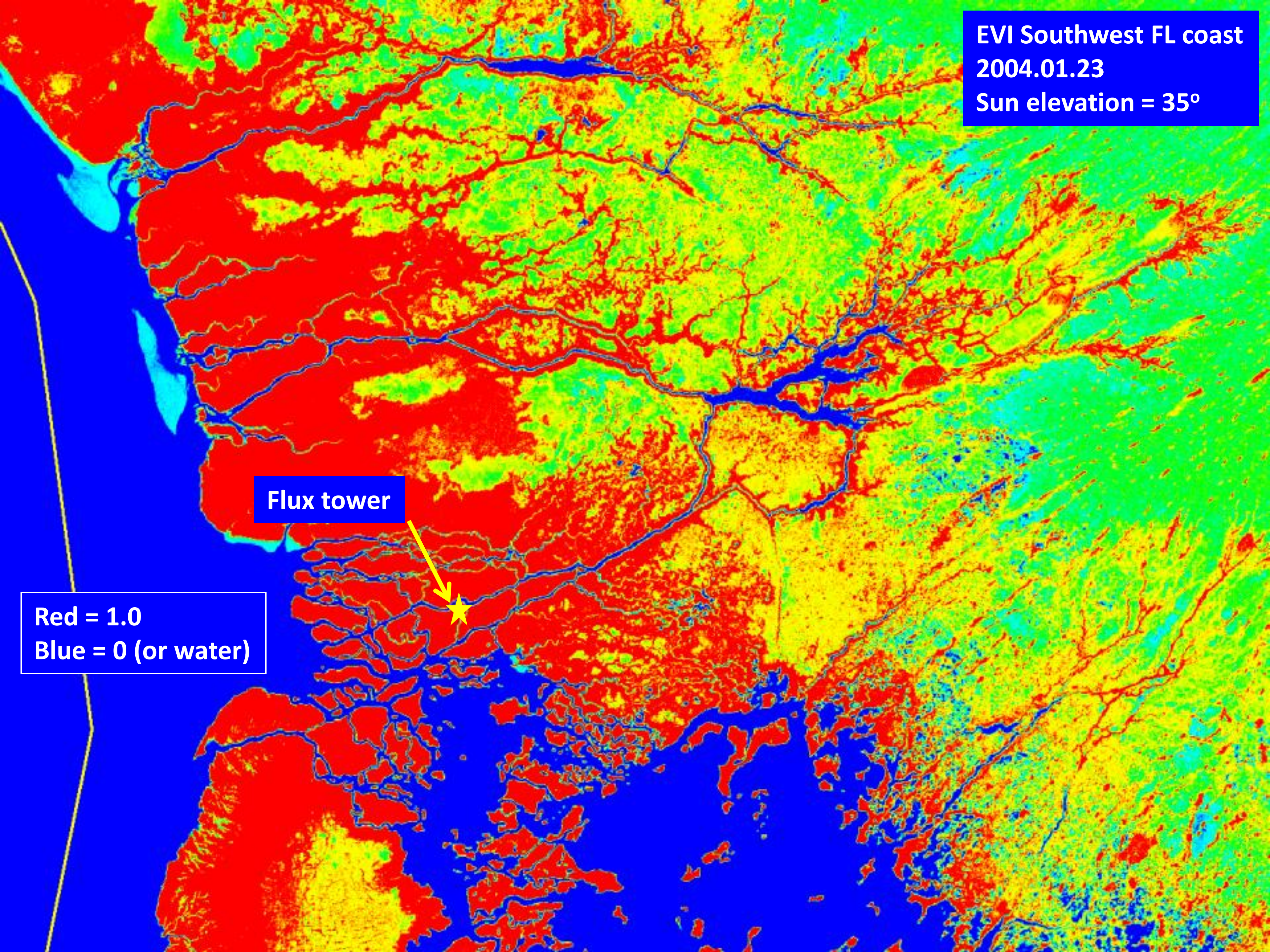




2004-2005:
slope = 0.94, intercept = 0.05, R = 0.71
2006-2011:
slope = 0.62, intercept = 0.18, R = 0.61

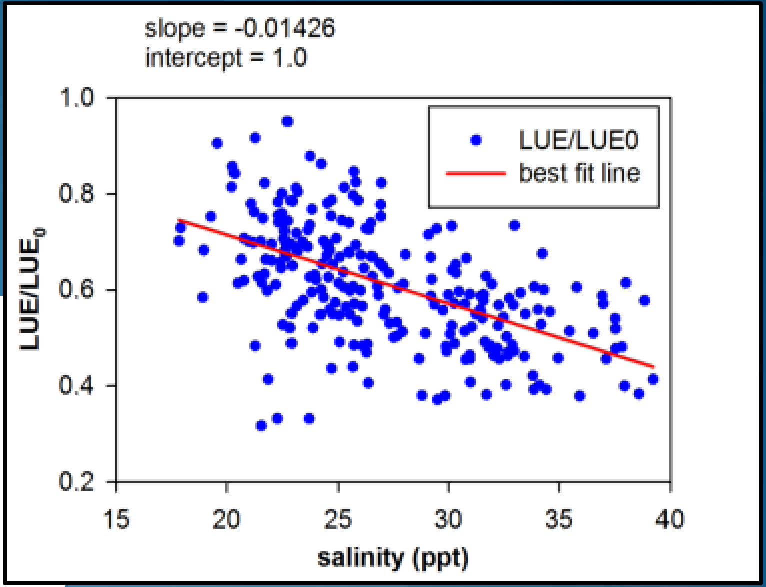
LUE model - conclusions

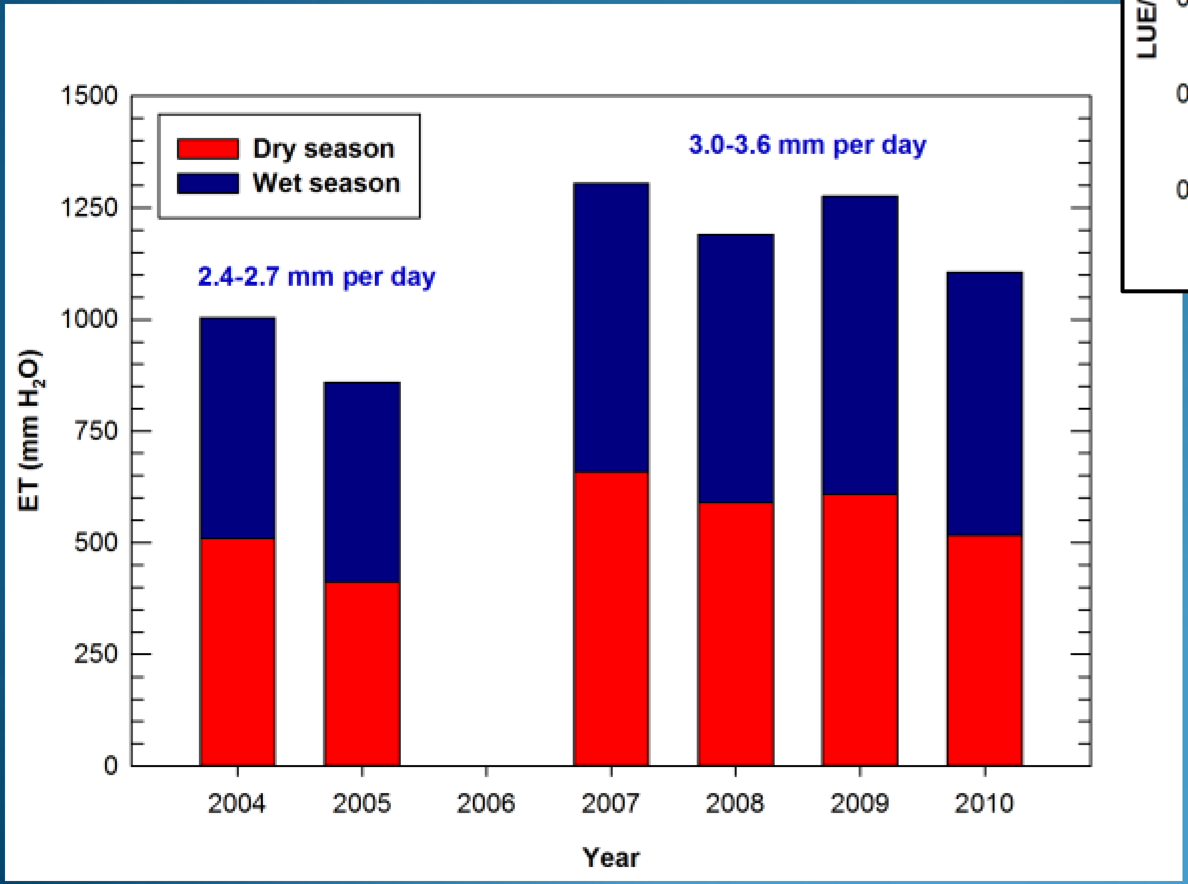
- Mangroves exhibit a maximum light-use efficiency (quantum yield) of **3.0±0.8%**.
- Carboxylation rates are maximum for air temperatures of **~26 C** and decline sharply as temperatures approach **~33 C**.
- Mangroves become physiologically inactive as temperatures approach **5 C**.
- Mangrove LUE (and therefore GPP) declines **1.5% per 1 ppt** increase in surface water salinity.
  - Applying this linear trend, mangrove primary production ceases at a salinity of 67 ppt. This is consistent with salinity tolerance limits reported for red, white, and black mangroves.


EVI Southwest FL coast
2004.01.23
Sun elevation = 35°
Flux tower
Red = 1.0
Blue = 0 (or water)

Future disturbances and climate change

- With SLR: Increasing salinity upstream results in declining LUE and productivity.
- Disturbance results in higher surface evaporation rates and less fresh water available to fine roots.





- <u>25-33% increase</u> in ET in years 2-5 following hurricane Wilma disturbance.

Conclusions

- Mangroves in the Everglades are one of the most effective ecosystems known for sequestering CO_2 from the atmosphere.
- Conservatively, 25% of annual $-\Sigma$NEE is transported laterally into the estuary as dissolved inorganic (DIC), organic (DOC), and particulate (POC) carbon. The true amount is likely to be much higher (~50%).
- Salinity represents an important control on NEE and GPP, determined from both observations and modeling results.
- Spatiotemporal changes in salinity resulting from SLR, disturbances, and changes in fresh water flow will influence productivity and the delicate balance of NECB. In turn, positive rates of NECB are a prerequisite for surface elevations keeping pace with SLR.

Acknowledgements

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Extra slides…

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Eddy covariance derived estimates of net ecosystem exchange (NEE) of carbon dioxide and vertical energy fluxes have been determined in a riverine mangrove forest in southwestern Everglades National Park since 2004. These fluxes have been used to 1) understand near real time environmental and hydrological controls on forest-atmosphere exchange, 2) quantify the carbon sequestration potential of mangrove forests, and 3) guide the development of light-use efficiency (LUE) models of productivity in response to environmental controls and management practices. Though this tall (15-20 m) forest is located within the subtropics, -NEE is seasonally variable with highest values of 100 to 130 g C m^{-2} per month during March to May when solar irradiance levels are maximal and before ecosystem respiration rates (R_E) have reached summertime peak values (120 to 160 g C m^{-2} per month) during July to September. Monthly -NEE is lowest (35 to 80 g C m^{-2} per month) during December to January resulting from seasonal minimum values of air temperature and solar irradiance. By combining gross primary productivity (GPP) estimates from –NEE data with satellite-based indices of ecosystem function and greenness, we have quantified the response of mangrove productivity to individual drivers of air temperature, salinity, and fraction irradiance absorbed by green vegetation. These LUE-based models are now being implemented to quantify productivity across the entire mangrove ecotone in southwest Florida. Advantages of this modeling framework include the ability to track both seasonal and inter-annual changes in ecosystem function using spatially explicit satellite-derived metrics of physiology (e.g., greenness, normalized difference vegetation index (NDVI), and enhanced vegetation index (EVI)), and to determine changes in productivity attributed to salinity levels. Given projected changes in salinity with sea level rise at the coast and/or changes in fresh water flow through Shark River Slough, LUE-models may be used to quantify the resulting changes in productivity. In addition, repositories of satellite multispectral reflectance data exist for the last decade and three decades in the case of MODIS and LANDSAT, respectively. Data analyses using these products will prove essential for understanding changes in mangrove functioning already in progress.

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Disturbance from Hurricane Wilma, Oct. 2005

T.J. Smith III, USGS

before ***after***

Bayesian LUE model parameter distributions