Exploring Methane and Carbon Dioxide Exchange from Agricultural and Wetland Land Use Classes in the Sacramento-San Joaquin Peatland Delta in California

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Royal Society Seminar, Chicheley Hall, UK, December, 2013

The Delta is a Vulnerable Peatland Ecosystem via Drainage and Severe Land Subsidence

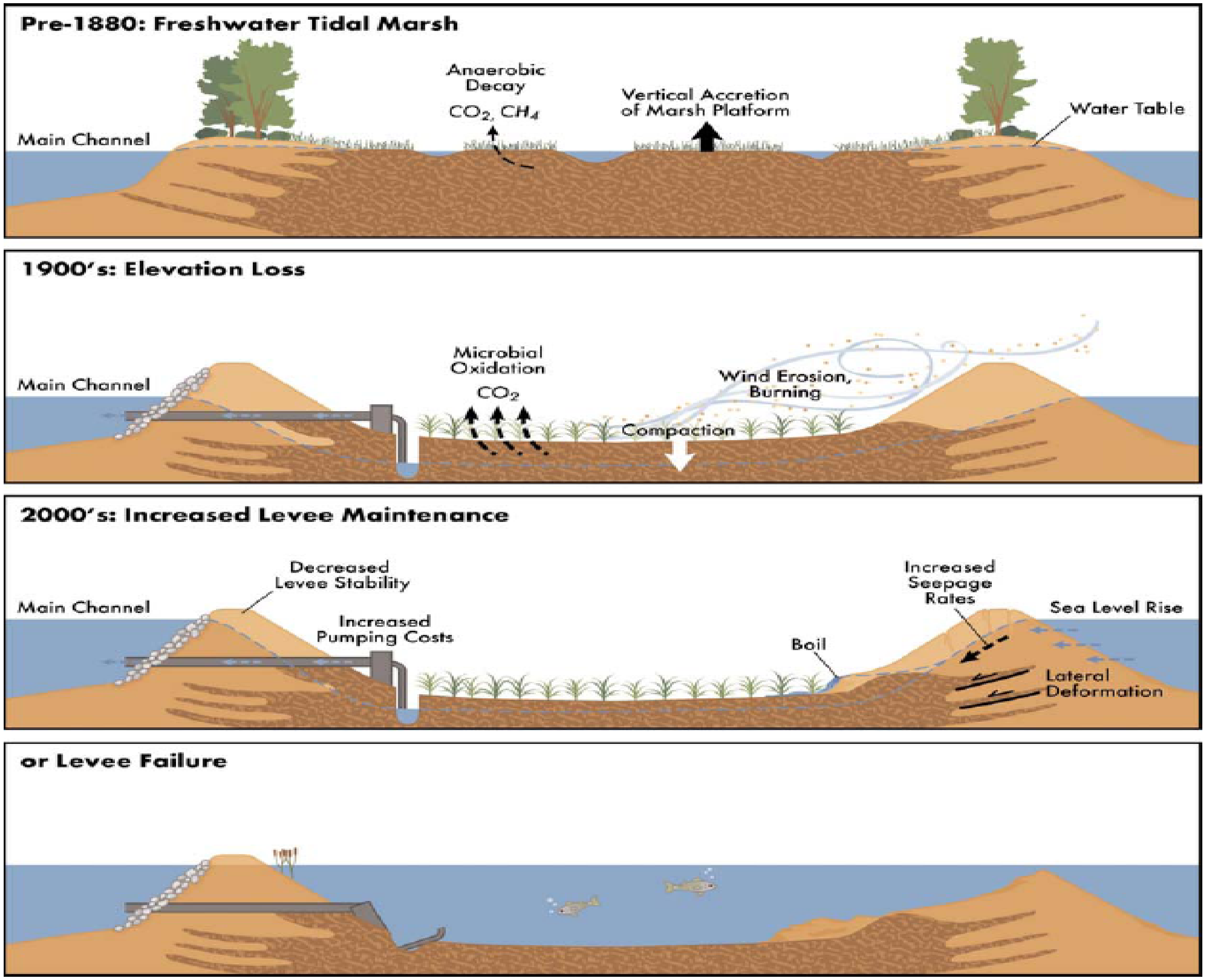


Figure 2. Conceptual diagram illustrating evolution of Delta islands due to levee construction and island subsidence. Modified from Ingebritsen et al. (2000).

Delta Peatland is Subsiding!
Landscape is Vulnerable to Flooding by Levee Failure; Its Collapse would Shut-Down California's Water Conveyance System

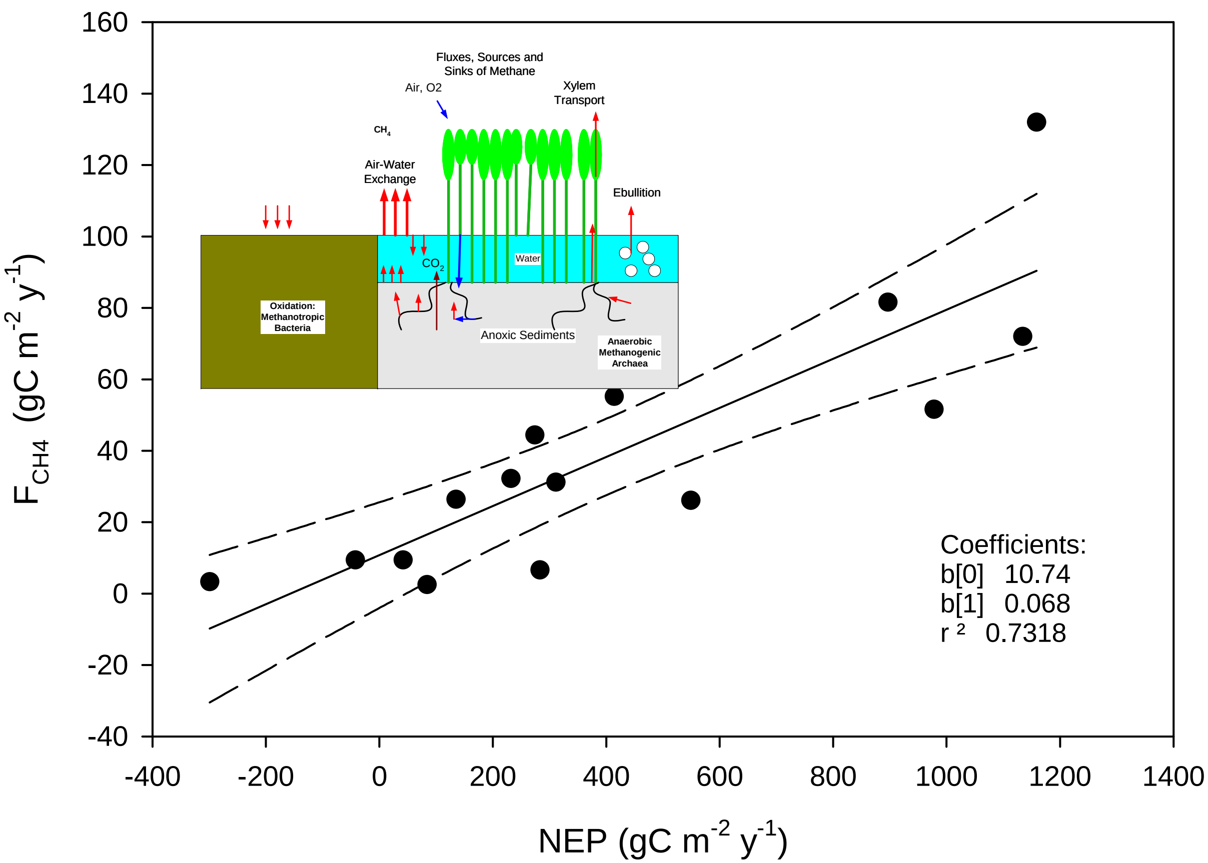
New Plans to Abate or Reverse Subsidence with Carbon Farming: Restored Tule Wetlands and Rice on Twitchell and Sherman Islands

What are the: Cost/Benefits?; Unintended Consequences?

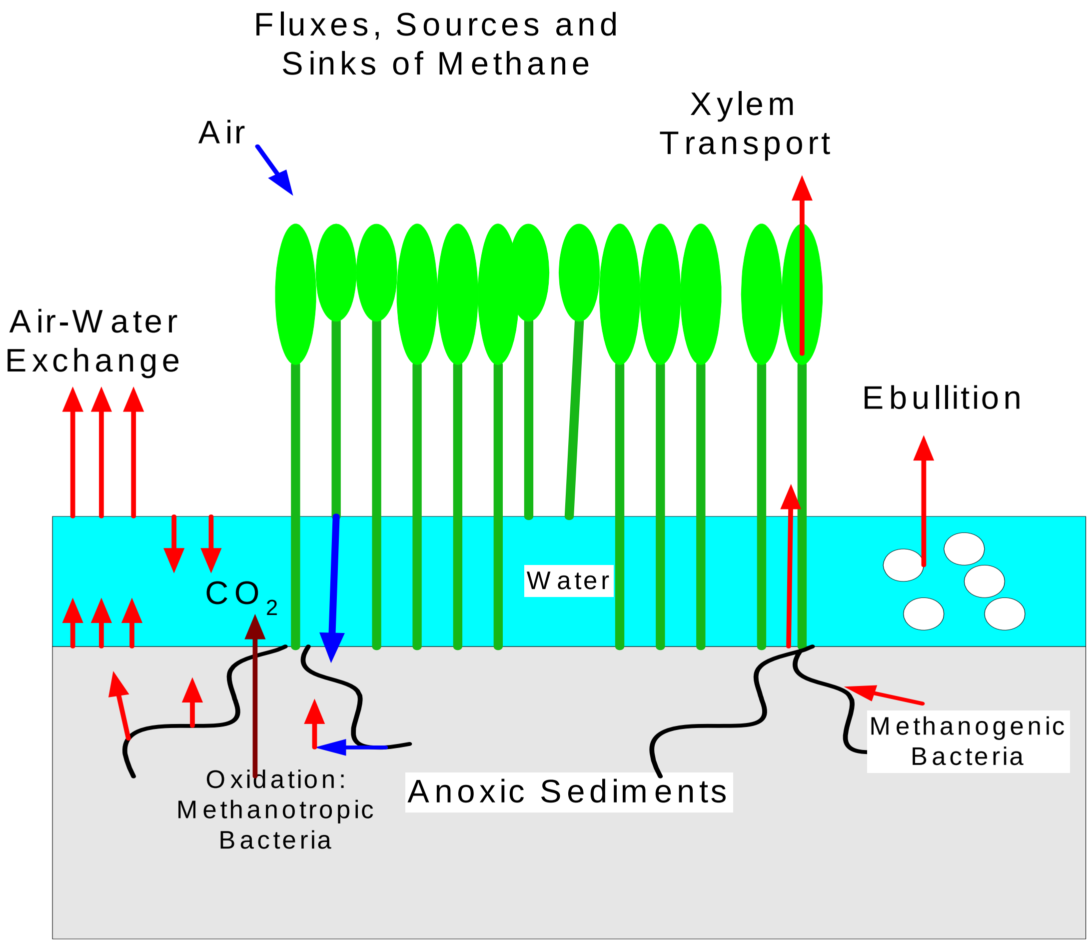
What Are the Trade-Offs?

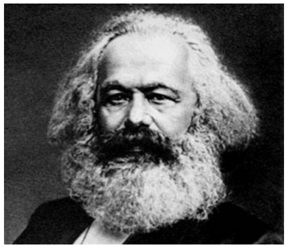
Annual Methane Emission Scales with Net Primary Productivity of Wetlands, Natural and Managed

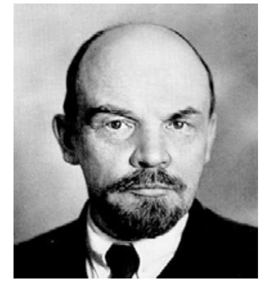
- **In Wetlands, Large Carbon Uptake is Associated with Large Methane Losses**



Methane Fluxes Travel by Multiple Routes:
Need Eddy Covariance Measurements to Assess Fluxes Across a Spectrum of Time and Space Scales, without Sampling Artifacts







There Has Been A Revolution
in Stable, Precise, Accurate and Low Power
Fast Response Methane Sensors

Eddy Covariance Flux Method

$$F = -\overline{w'c'}$$

New Generation of Open-Path, Low Power, Laser Spectrometers allow us to Measure Methane Fluxes Continuously and where Methane is Being Produced, in Remote Wetlands

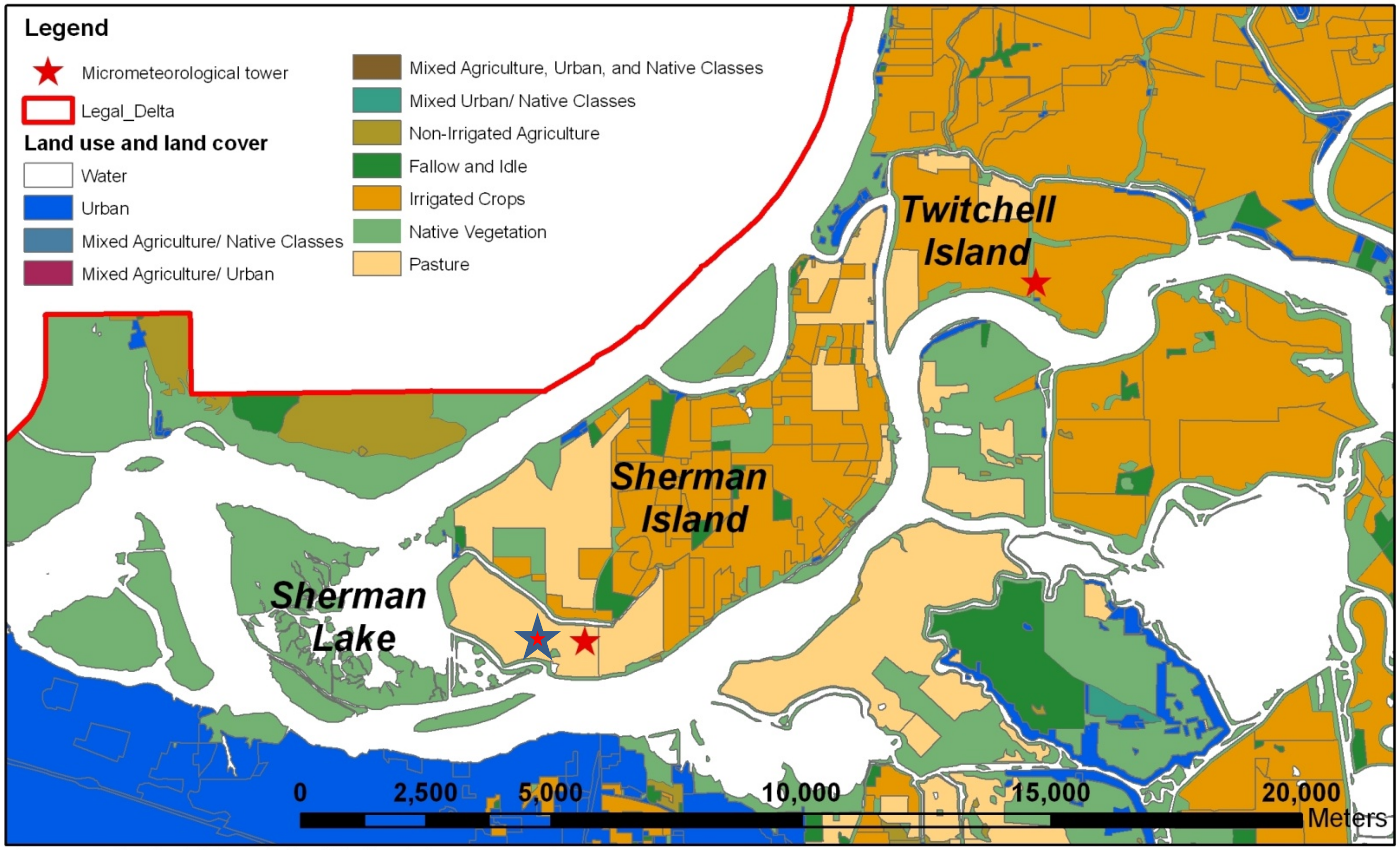
Big Ideas/Concepts to Explore

- What are the Seasonal and Annual Sums of Methane Emission?
  - How do they Vary with Weather/Climate, Plant Traits and Depth/Temperature/Chemistry of the Water?
- What are the Links between Photosynthesis and Methane Emissions, on short and long time scales?
- How Do Methane Fluxes Change with Time since Disturbance?
  - How to Minimize Methane Fluxes with Ecological Restoration of Wetlands?
  - How to Manage Rice to Minimize Methane Emissions?

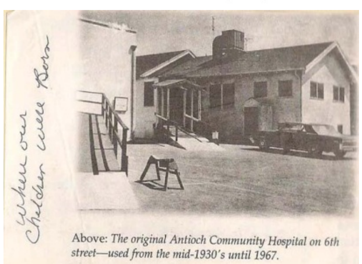
Outline

- Experiences with Open and Closed Path Methane Sensor performance
- Experiences with Eddy Covariance Flux Measurements of Methane and CO_2 under Natural (tidal wetland), Disturbed (pasture, rice and corn), and Reclaimed (restored wetlands) conditions
- Demonstrate the Use of Multiple Flux Towers, Flux Footprint Modeling and Remote Sensing to Quantify Spatial Variation in Fluxes in a Wetland Mosaic

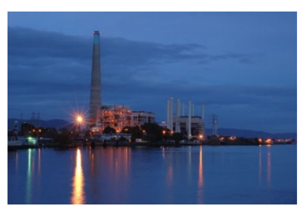
Delta Field Sites



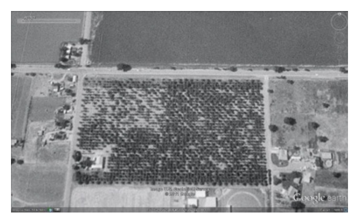
Source: Delta Vision (http://deltavision.ca.gov/)



DDB Birth Place



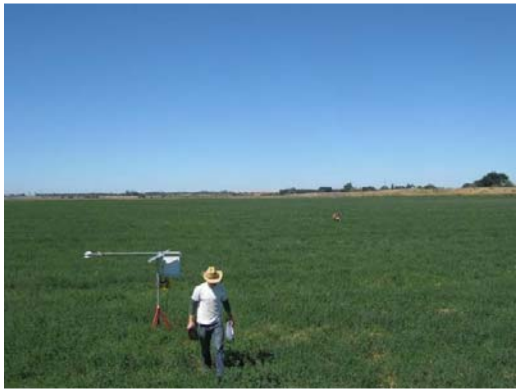
Father's Birth Place



DDB Childhood Home

Six Contrasting Study Sites

Drained Peatland Pasture, BAU

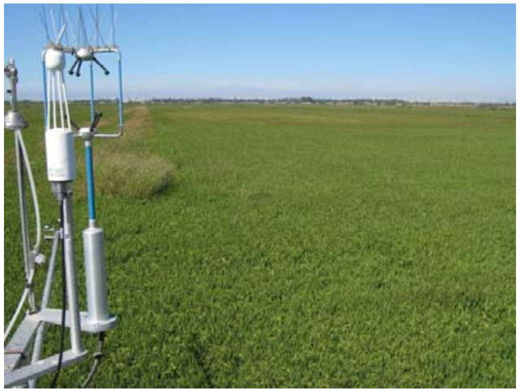


Alfalfa, BAU

Corn, BAU

Newly Restored, Wetland

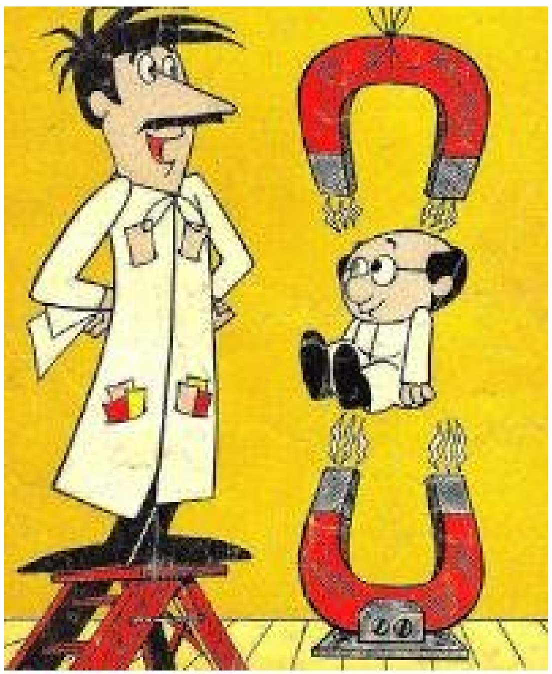
15+ Year Old, Restored Wetland



Seasonally-Flooded, Rice, Agricultural Option

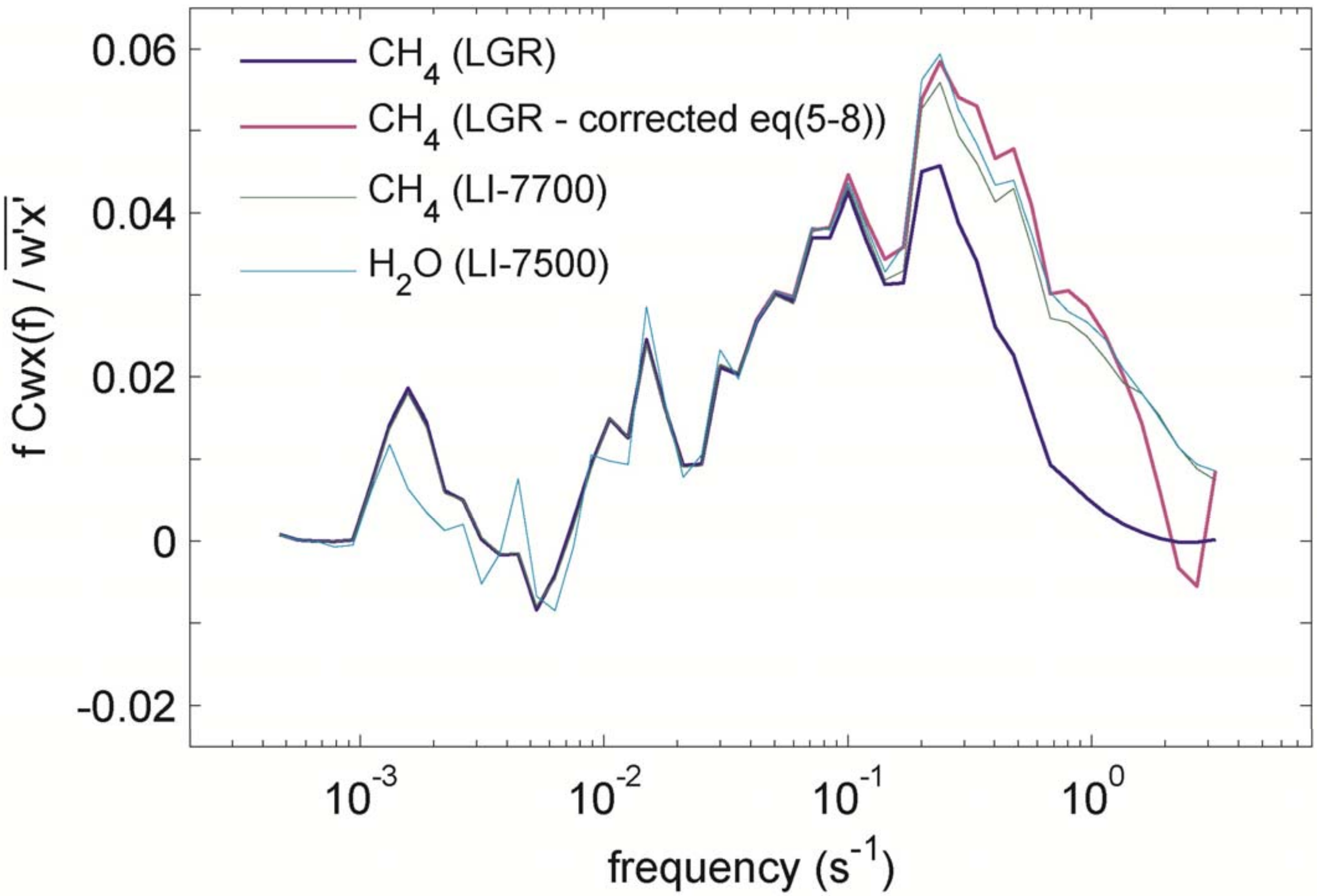
Pilot Study:
C Flux Measurements on Natural Tidal Wetland

SCIENCE, RESULTS and DISCUSSION



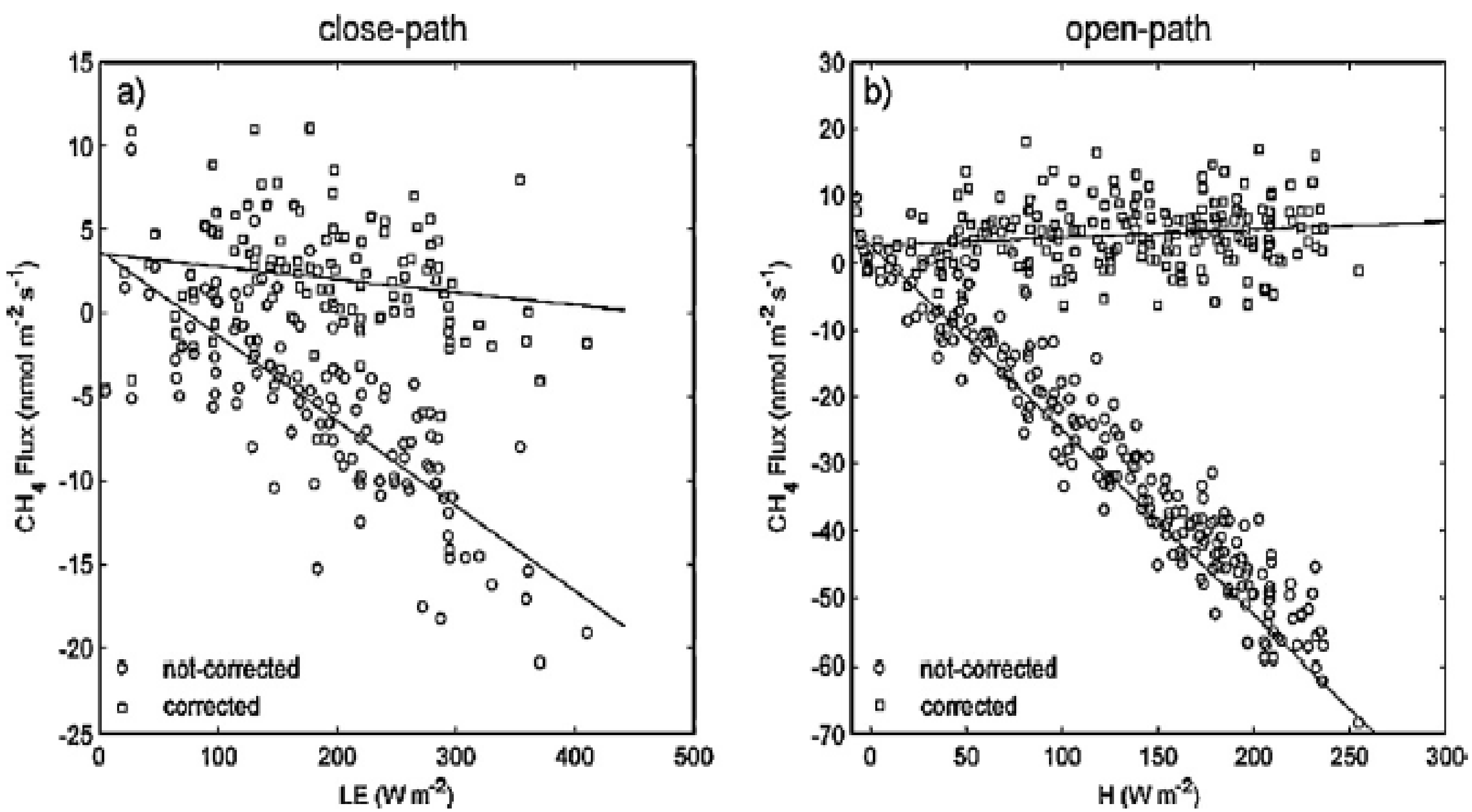
Bagdasarian

CoSpectra Open Vs Closed Path Methane Sensors



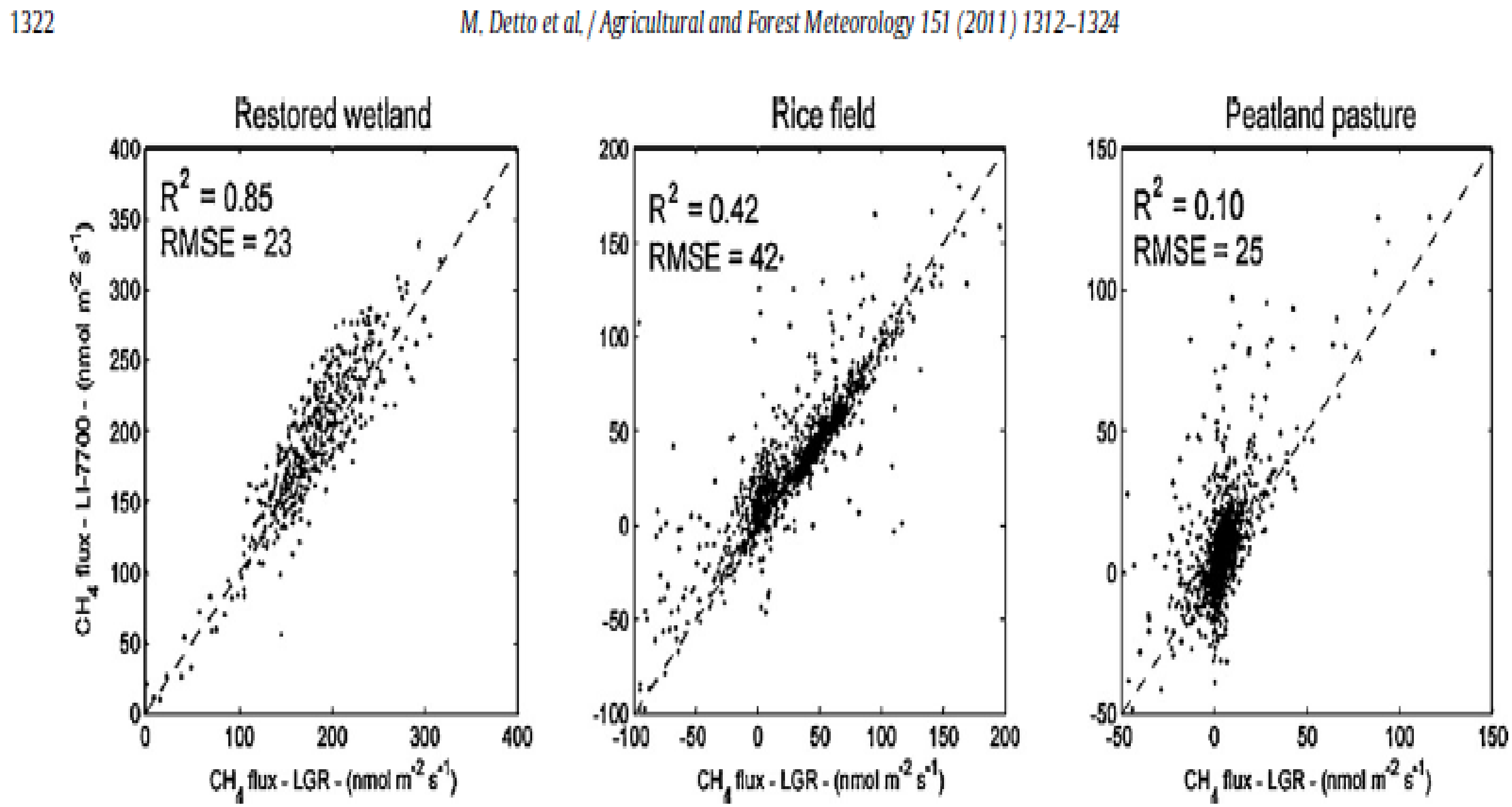
Detto et al. 2011 AgForMet

Density Corrections Open Vs Closed Path Methane Sensors



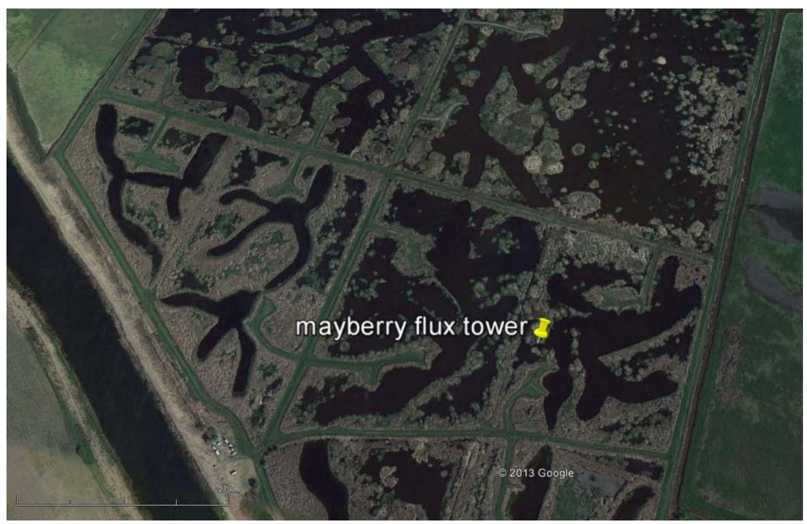
Detto et al. 2011 AgFormet

Open vs Closed Path Methane Sensor Flux Measurements



Detto et al. 2011 AgForMet

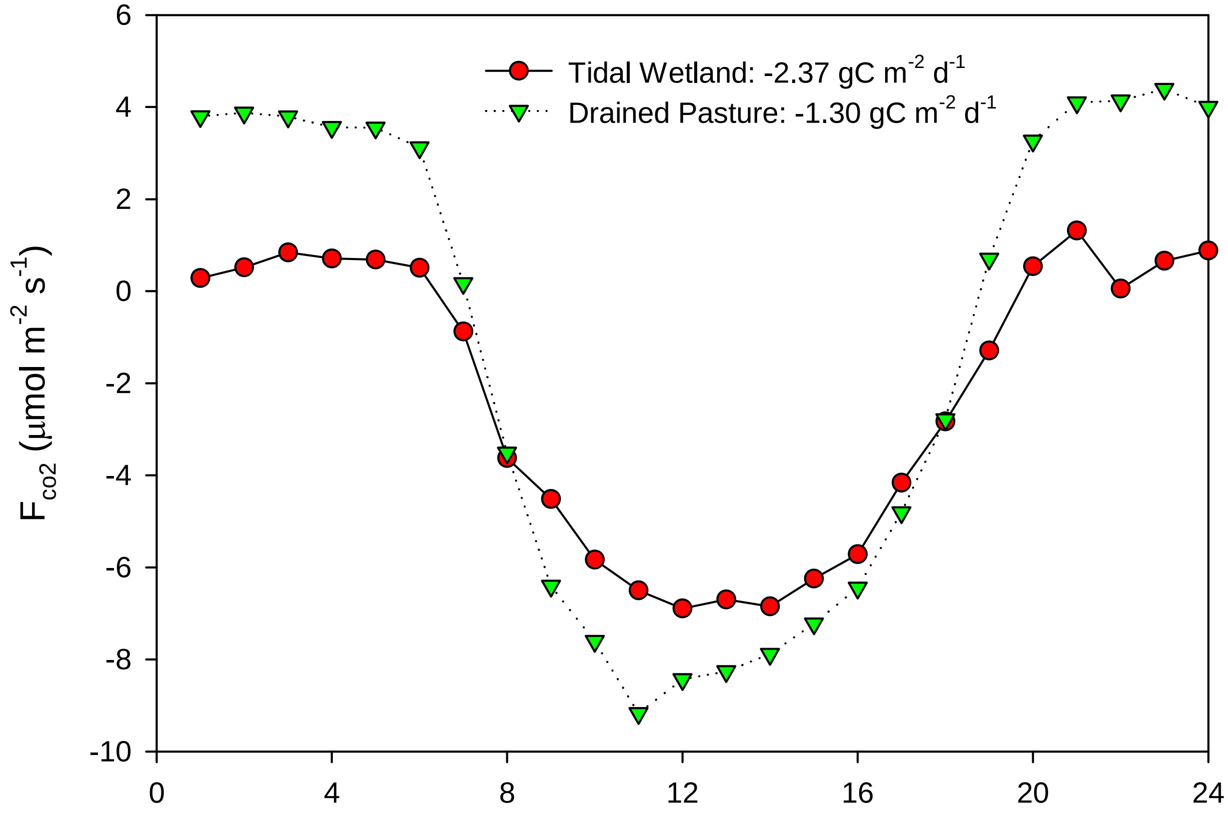
Natural Tidal Wetland



Newly Restored Wetland

Wetland Vs Drained Peatland Pasture

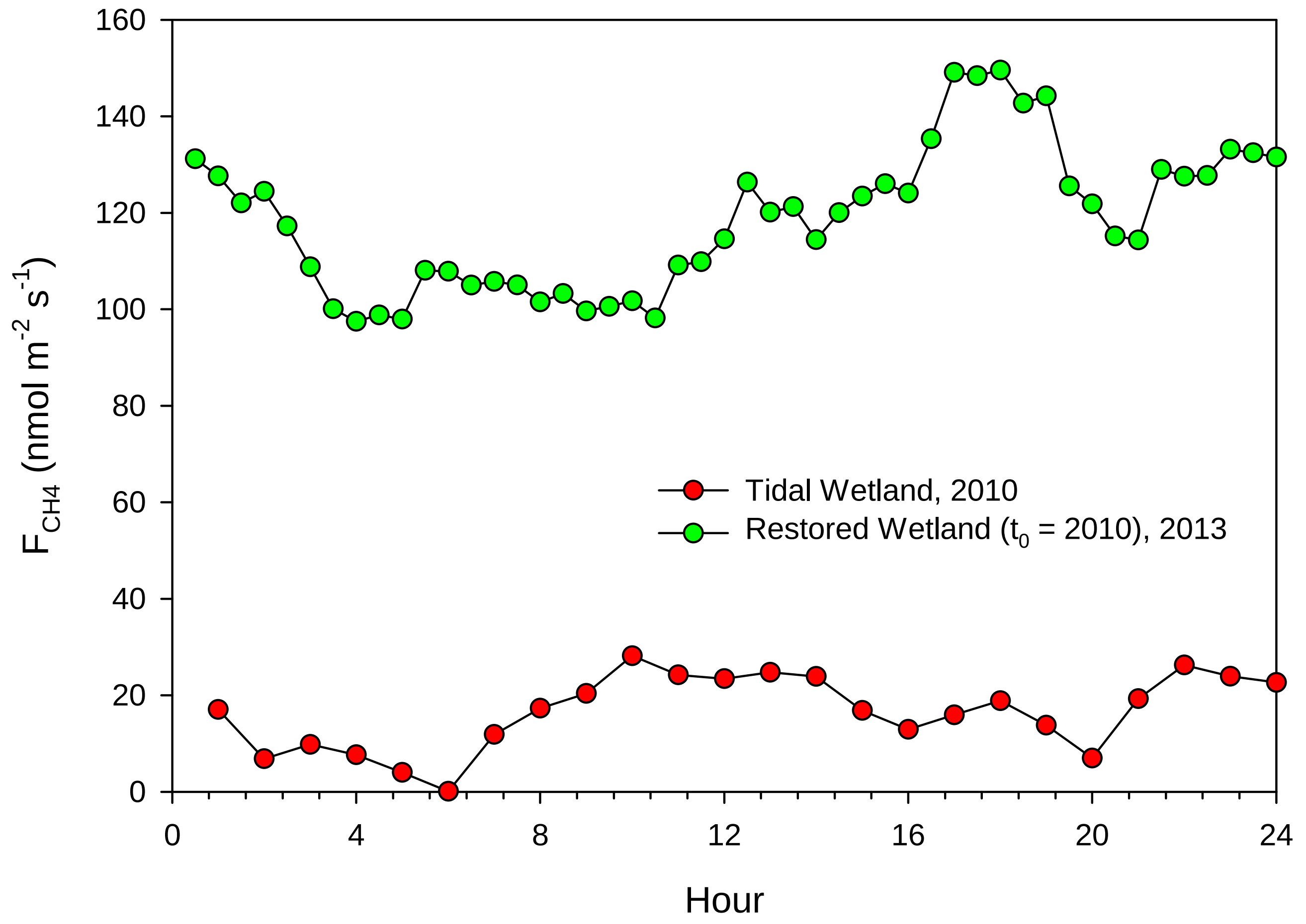
Sherman Island, D 98-168, 2010



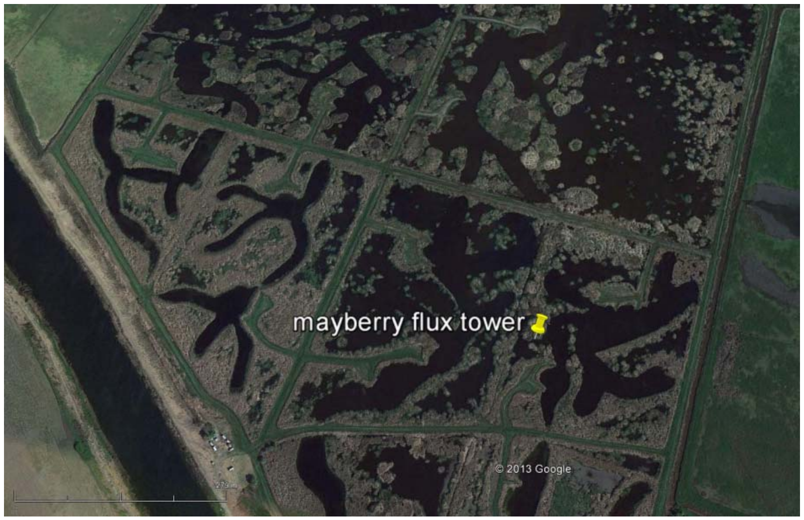
Flooding Inhibits Nocturnal Respiration and Daytime Photosynthesis, Compared to the Drained Peatland.

Methane from a Tidal vs Non-Tidal and Restored Wetland

Day 98-124



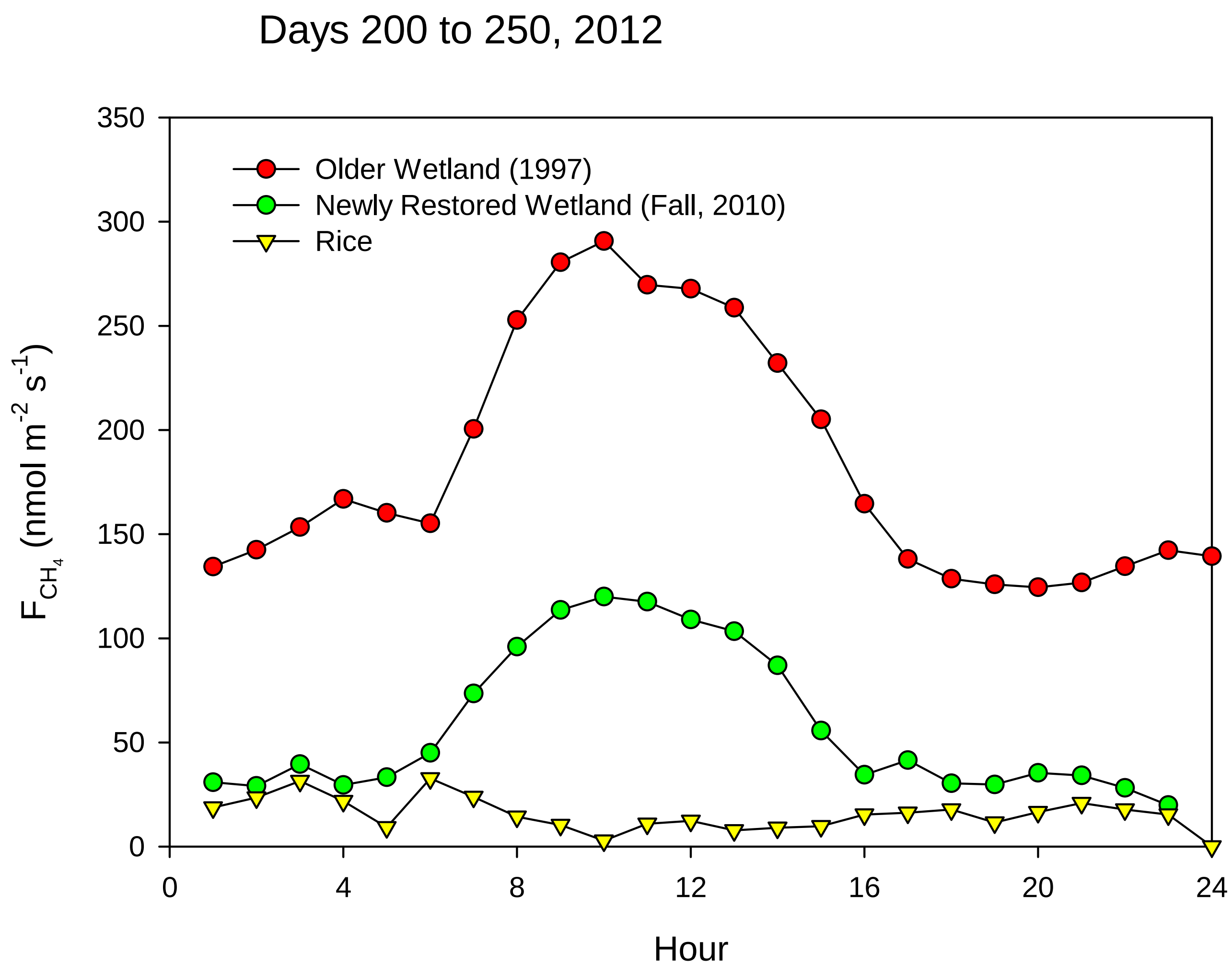
Old Wetland, Pilot Project, USGS



Newly Restored Wetland

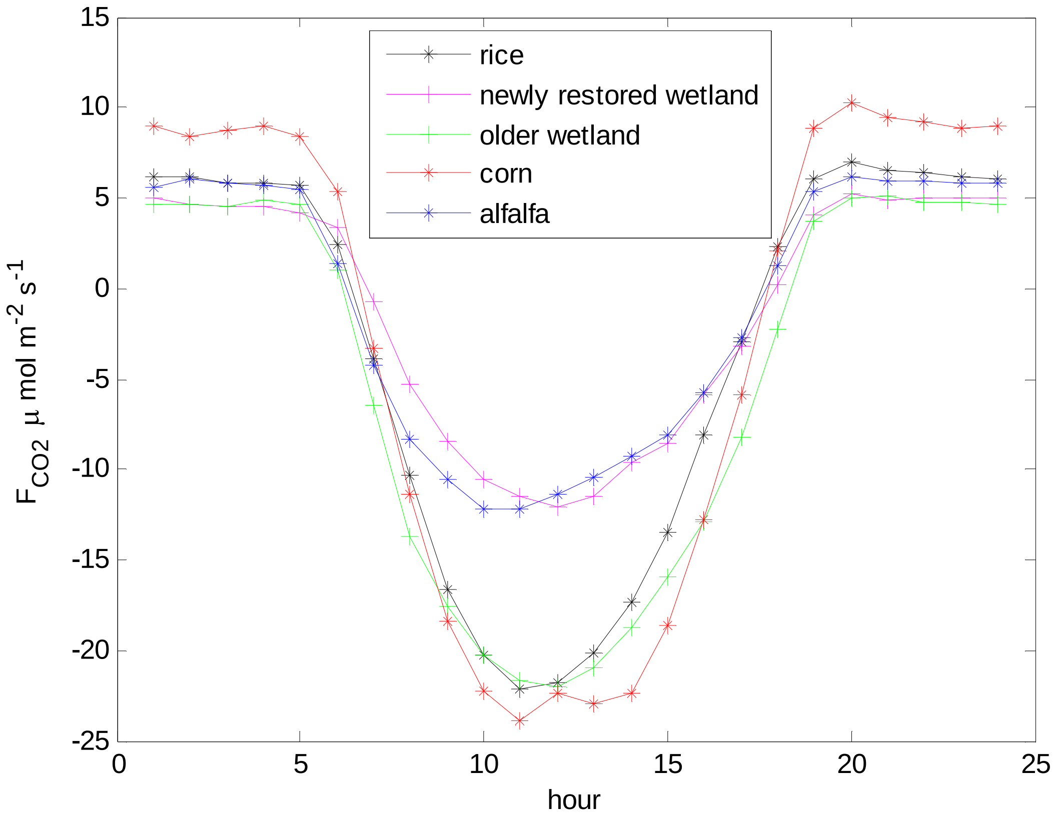
Rice

Mean Diurnal Pattern of CH_4 Exchange, Summer 2012



- Old Wetland is a Huge Methane Source
- Convection at Night in the Water Layer Promotes Methane Transport
- Methane Emissions Increase with Age and Density of the Wetland

Mean Diurnal Pattern of CO_2 Exchange, Summer 2012



- Corn photosynthesis enhances respiration

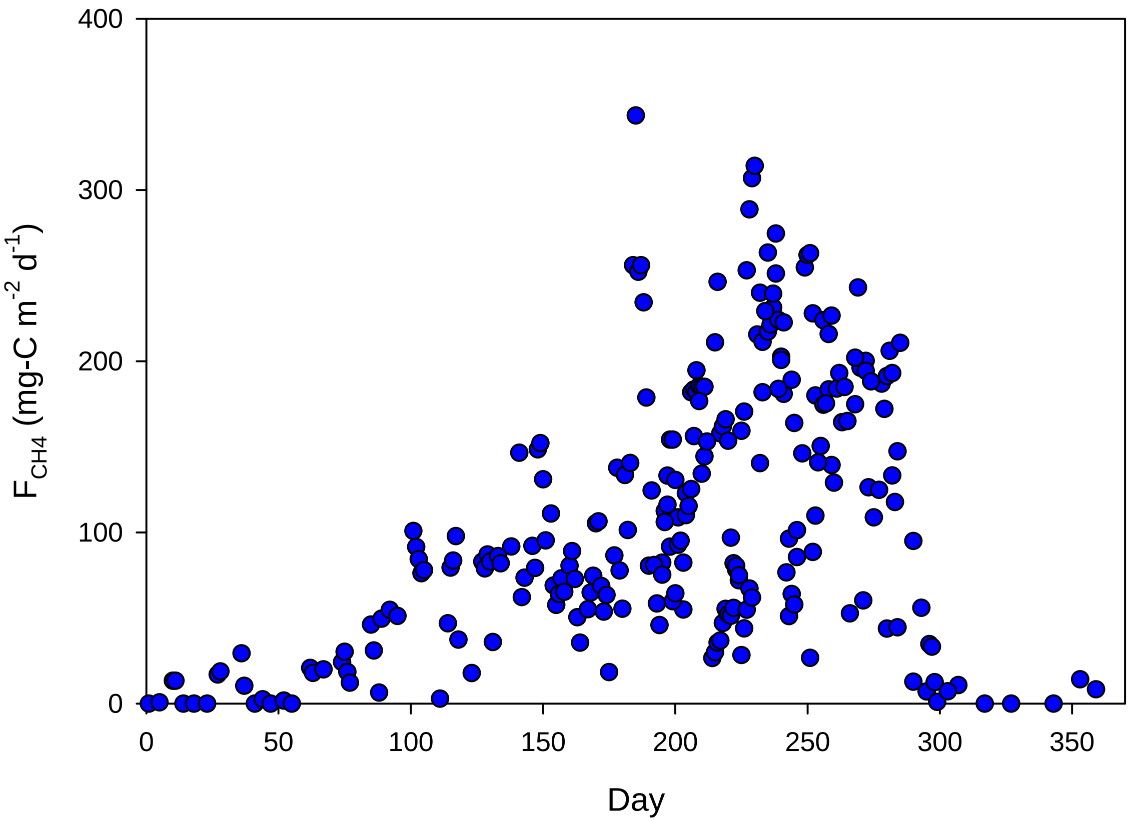
- Drainage (corn) & Disturbance by Restoration
- Promote Dark Respiration

- Flooding of Rice and the Older
- Wetland Suppresses Dark Respiration

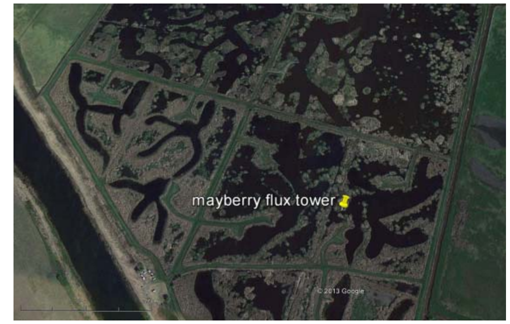
- Photosynthesis of C_4 Corn out paces C_3 Photosynthesis of Rice and Wetlands

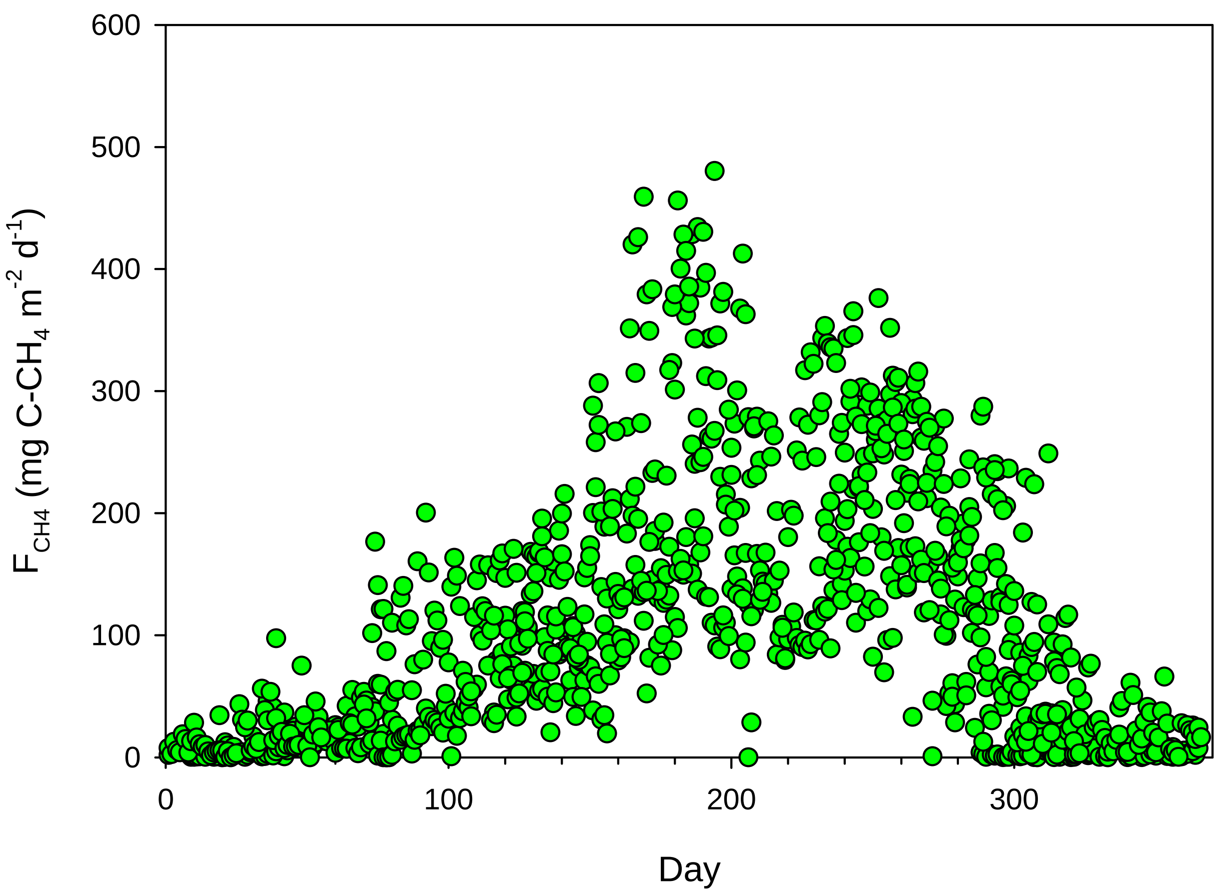
- Ranking of Carbon Sequestration Potential, peak summertime: Wetland > Rice > Corn

Old Wetland, Favorable Windds



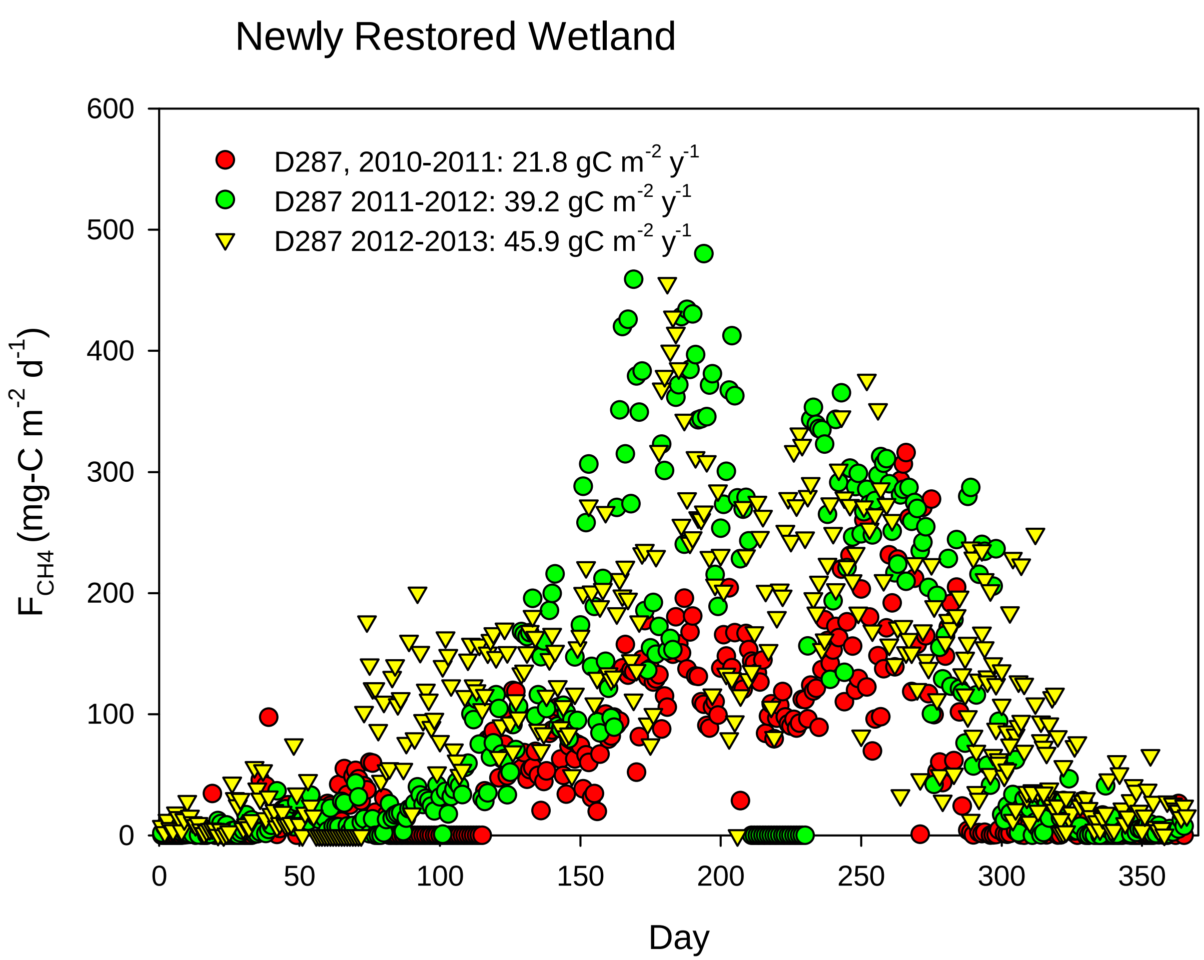
Newly Restored Wetland



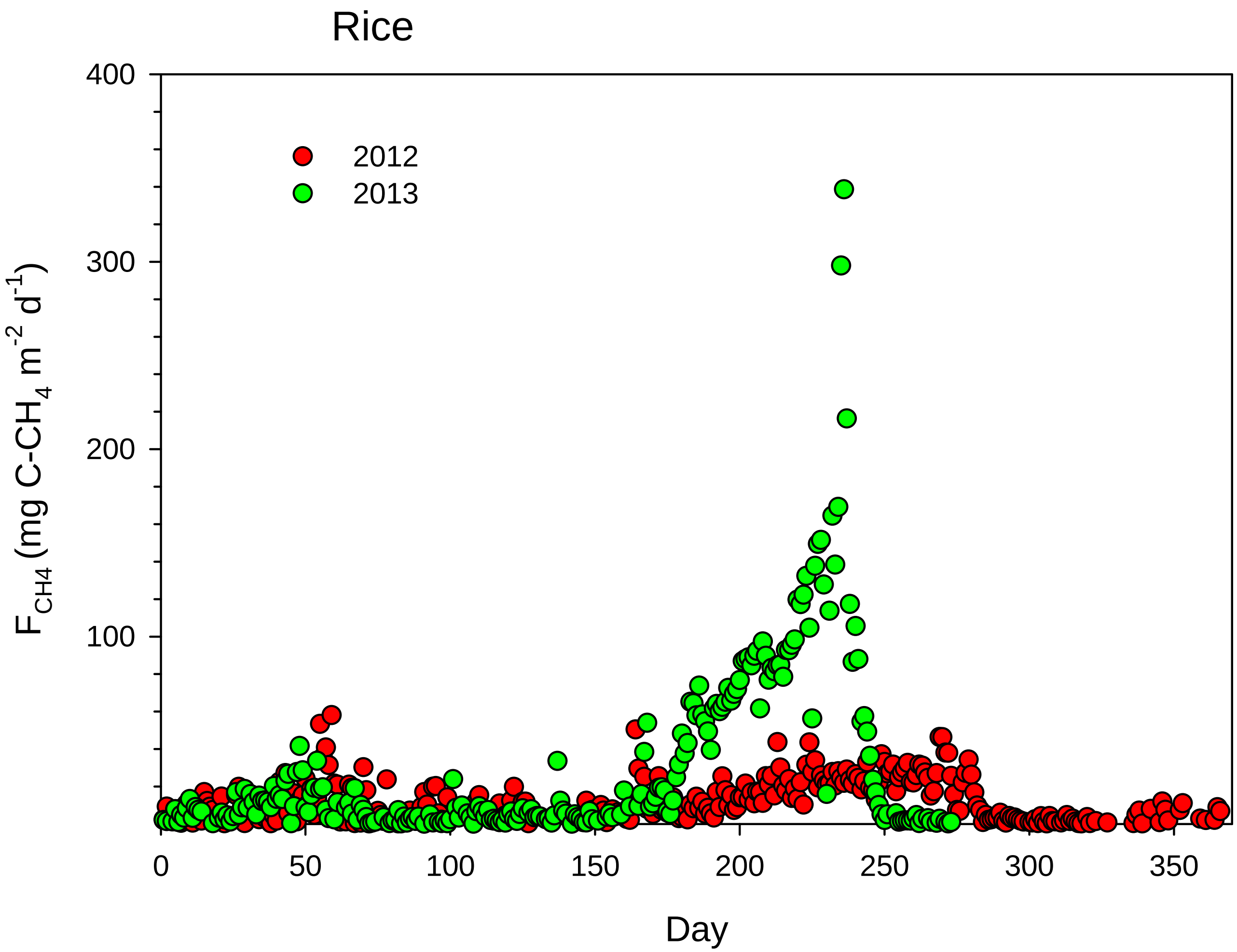


Carbon Sink Strength of Wetland Increases with Time since Restoration

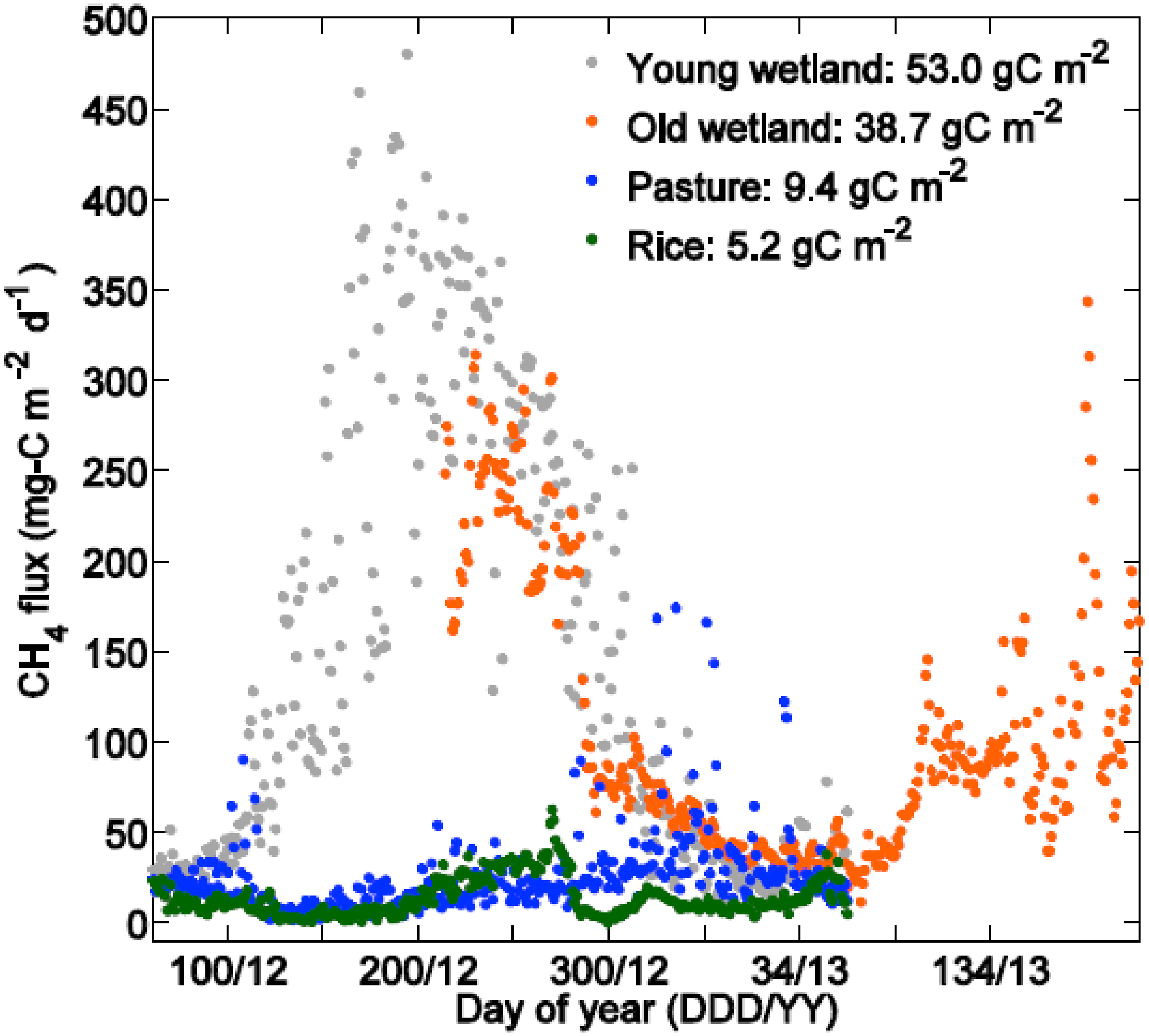
C Fluxes Depend on Percent of Open Water in Fetch



Much Year to Year Variability in Methane Lost by Rice



One Year of Methane Flux Measurements



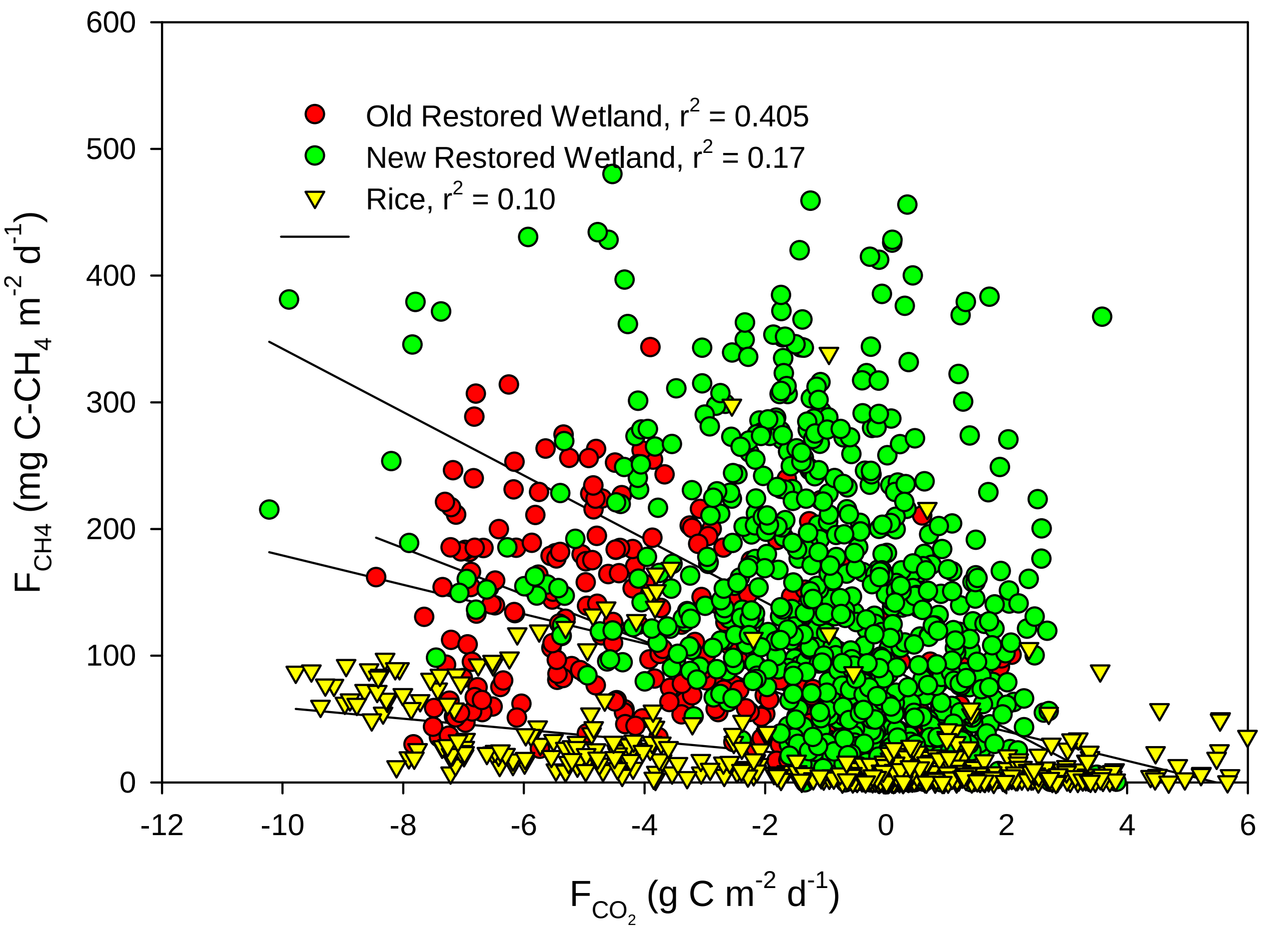
Knox, Sturtevant, Koteen, Verfaillie, Hatala, Baldocchi, unpublished

Carbon Budget

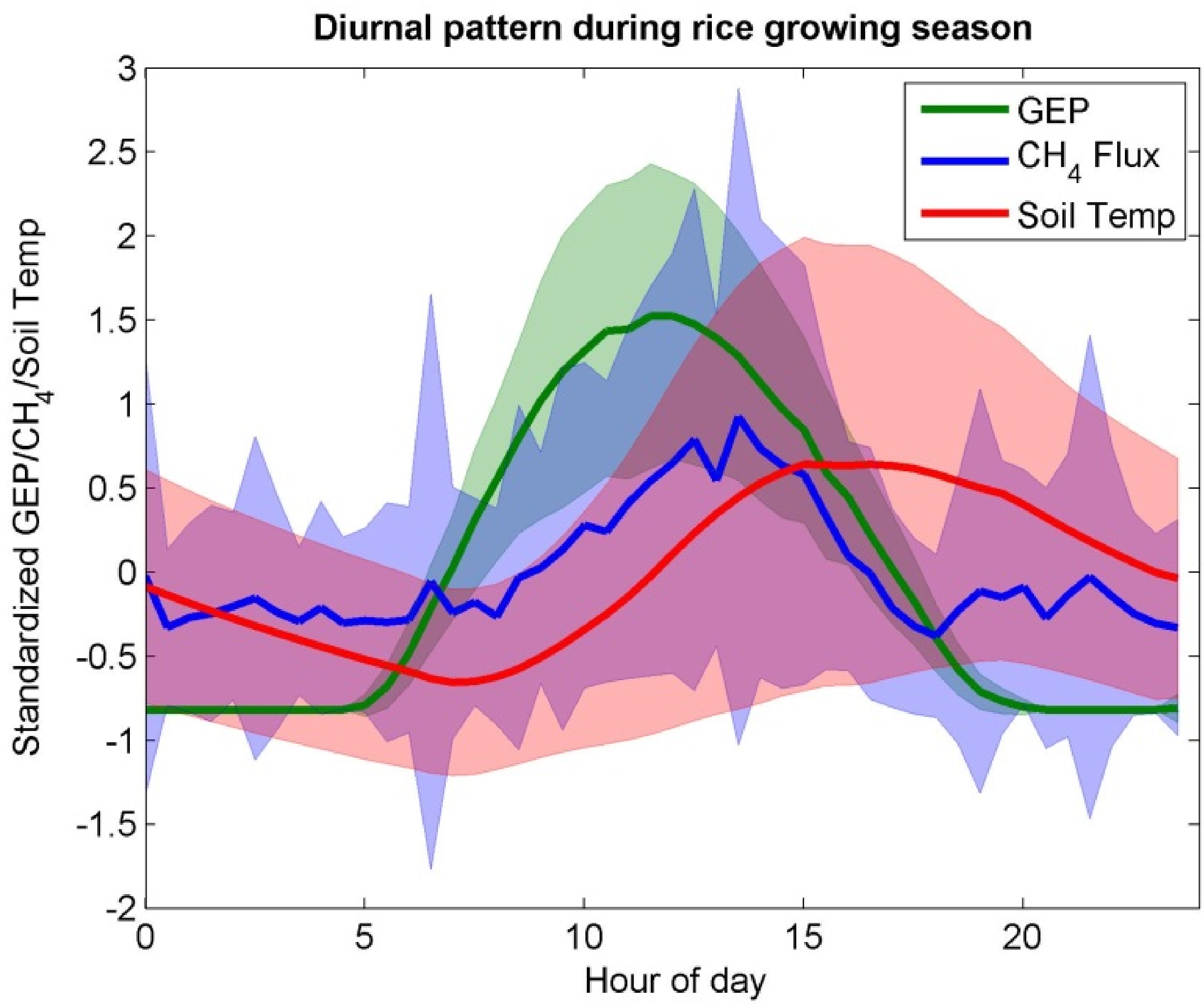
Site	ET $(mm\ y^{-1})$	NEE $(g\text{-}C\ m^{-2}\ y^{-1})$	GPP $(g\text{-}C\ m^{-2}\ y^{-1})$	ER $(g\text{-}C\ m^{-2}\ y^{-1})$	CH_4 $(g\text{-}C\ m^{-2}\ y^{-1})$
DC (May 9 2012- May 9 2013)	719 (704-737)	291 (270-310)	-1327	1600	N/A
WP (Aug 1 2012- Aug 1 2013)	993 (970-1008)	-397 -(418-371)	-2067	1312	38.7 (37.8-39.6)
MB (Mar 1 2012- Mar 1 2013)	1600 (1575-1614)	-368 -(424-331)	-3815	3447	53.0 (52.4-54.1)
SI (Mar 1 2012- Mar 1 2013)	676 (662-682)	341 (283-408)	-2360	2798	9.40 (8.81-11.7)
TI (Mar 1 2012- Mar 1 2013)	1036 (1020-1047)	-20.9 (-40.2-3.66)	-2350	2132	6.51 (6.11-7.69)

Knox, Sturtevant, Koteen, Verfaillie, Hatala, Baldocchi, unpublished

How Well Does Carbon Uptake Modulate Methane Emissions, in General?

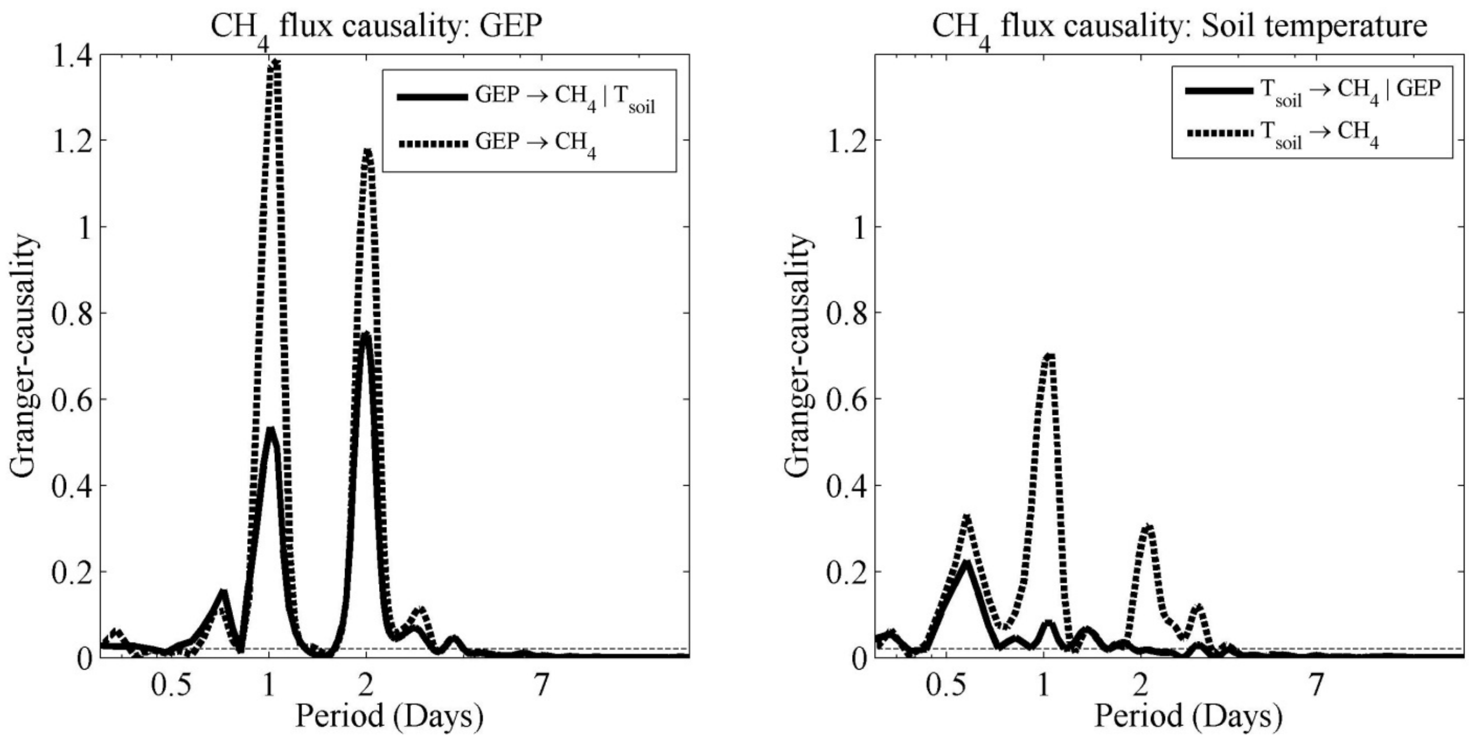


Does Photosynthesis Prime Methane Production in Rice?



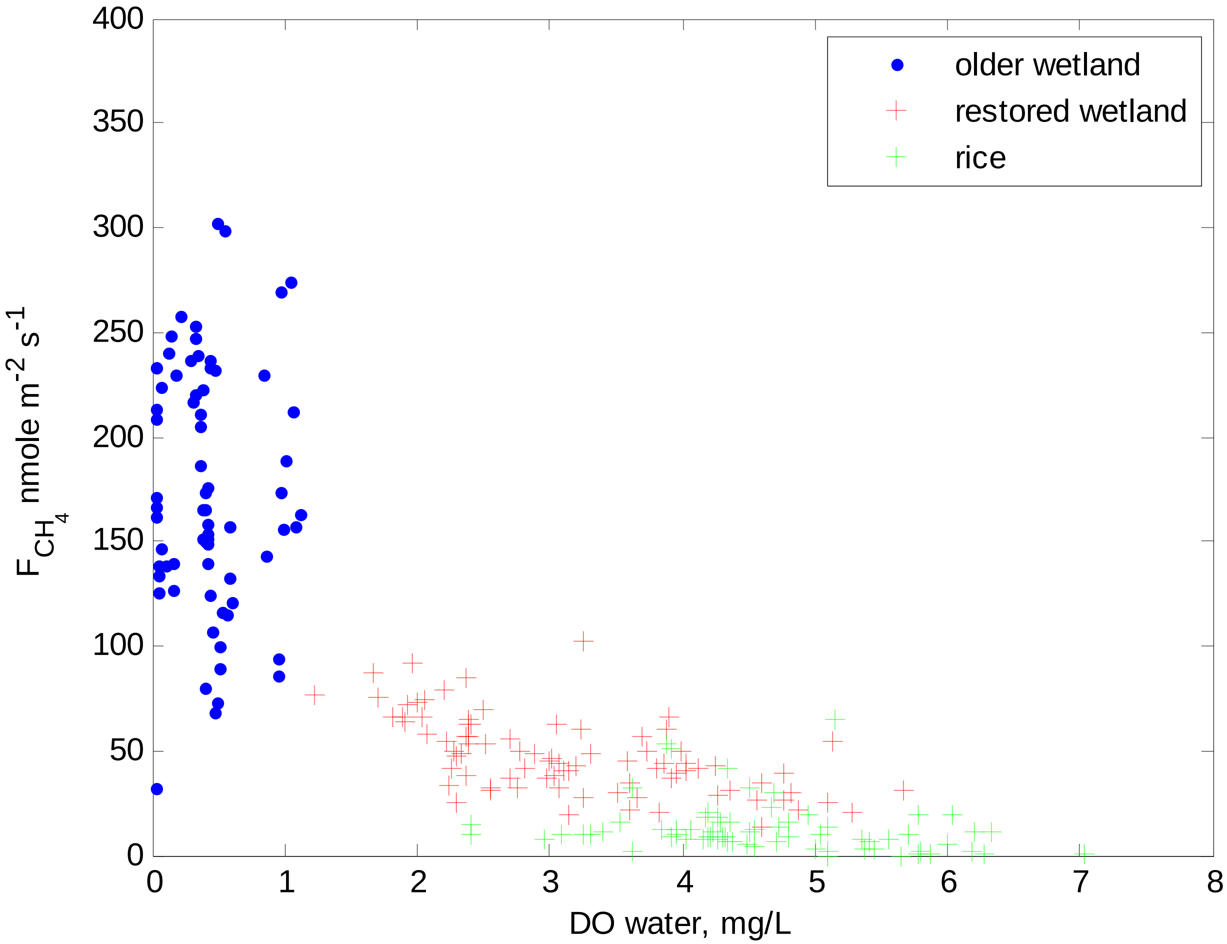
Hatala et al. GRL 2012

Methane scales with Photosynthesis



Hatala et al. GRL 2012

Low O_2 in Water Promotes High Methane Fluxes

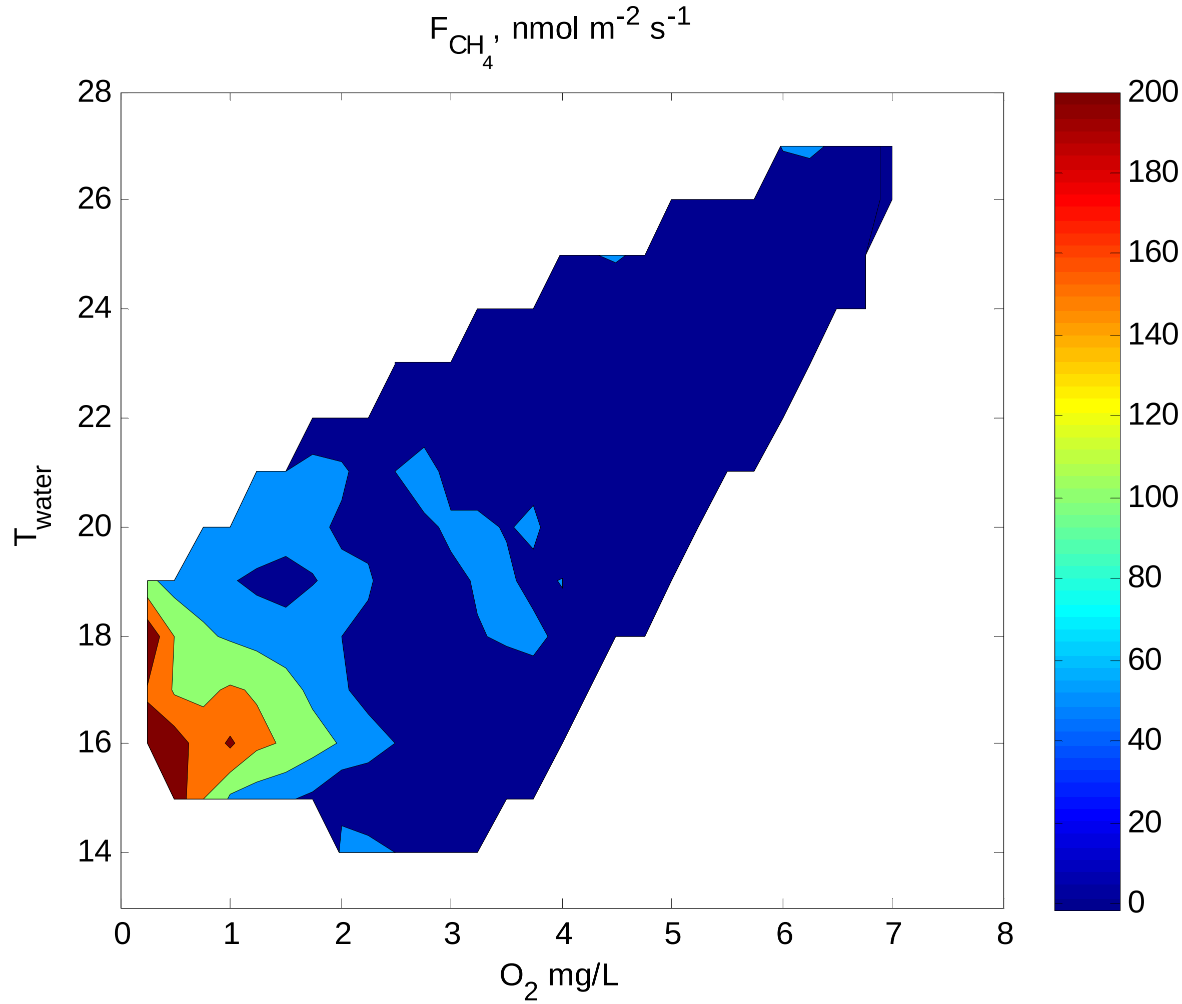


Daily Averages

Windy Region, Open Water is Well Oxygenated

White Caps on New Wetland, July, 2011

Newly Restored + Older Wetland + Rice



Shallow Water (< 10 cm) under Rice is Warmer, More Convective and more Oxygenated, Inhibiting Methane Loss compared to non-Tidal, Older Wetland with Deeper and Colder Water (~ 35 cm)

Spatial Upscaling in Complex Mosaics

Wetland Restoration Project, Mayberry Slough

Partition Methane Fluxes According to Water and Vegetation Fractions

$$F_{CH_4} = F_{water}\ f_{water} + F_{veg}\ f_{veg}$$

One Equation and Two Unknowns

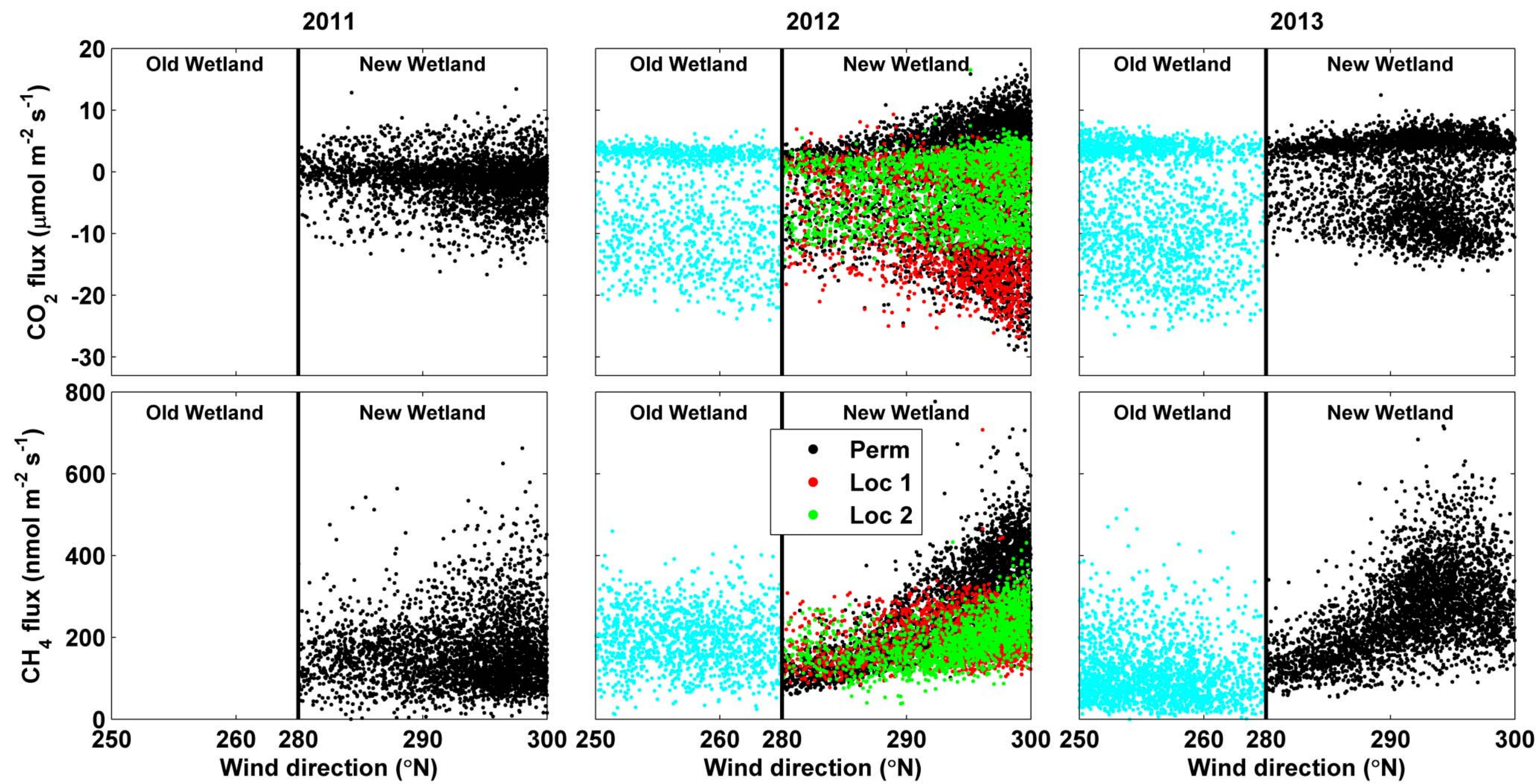
Deploy a Second Flux Tower over Different Water/Vegetation Fraction
And Assess Fraction of Water and Vegetation in Flux Footprint with
Remote Sensing and Solve for
F_{water} and F_{veg}

Anchor and Roving Flux Towers

Soccer/Flux Mobile

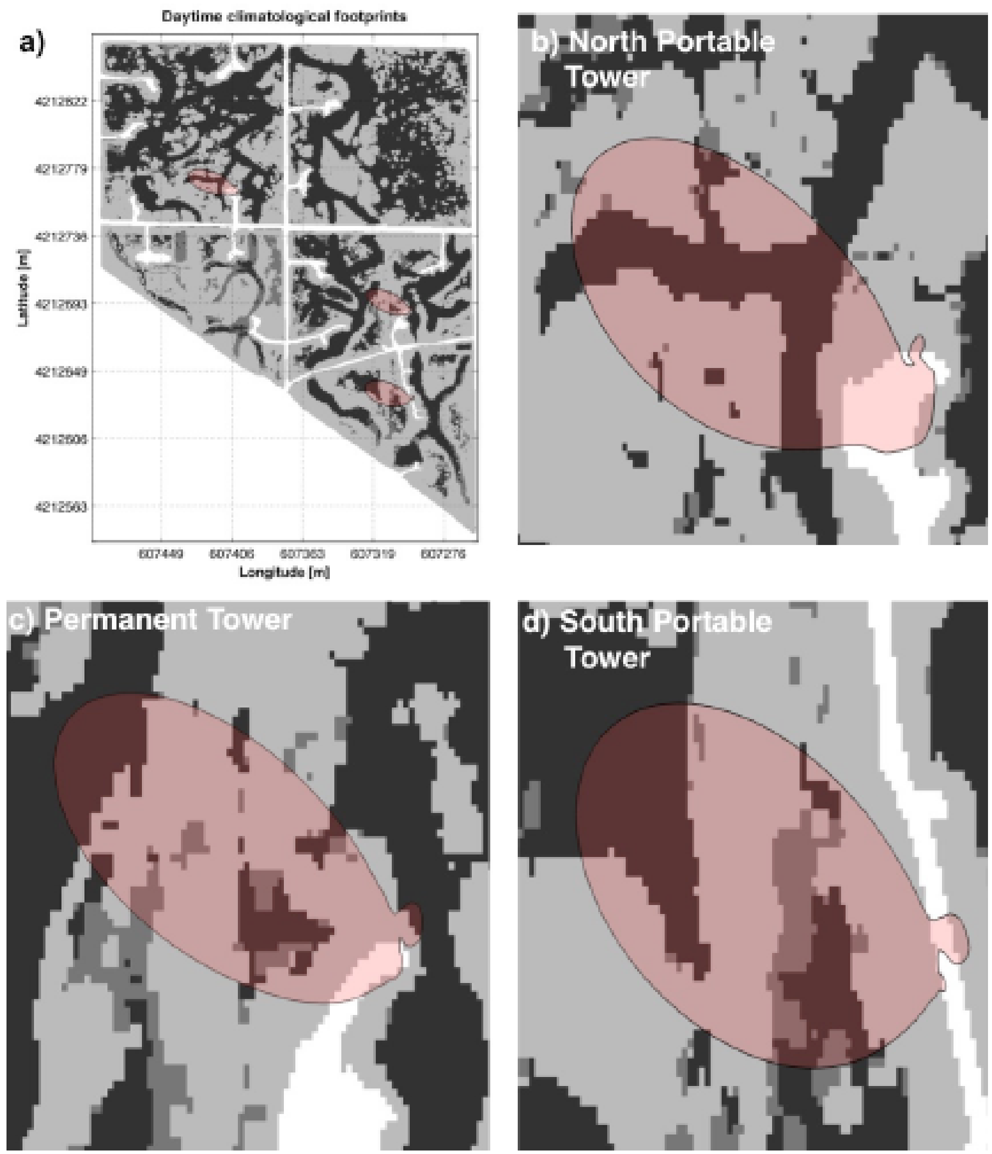
Restored Wetland, Mayberry Ranch on Sherman Island

Fluxes Vary by Wind Direction and Tower Location



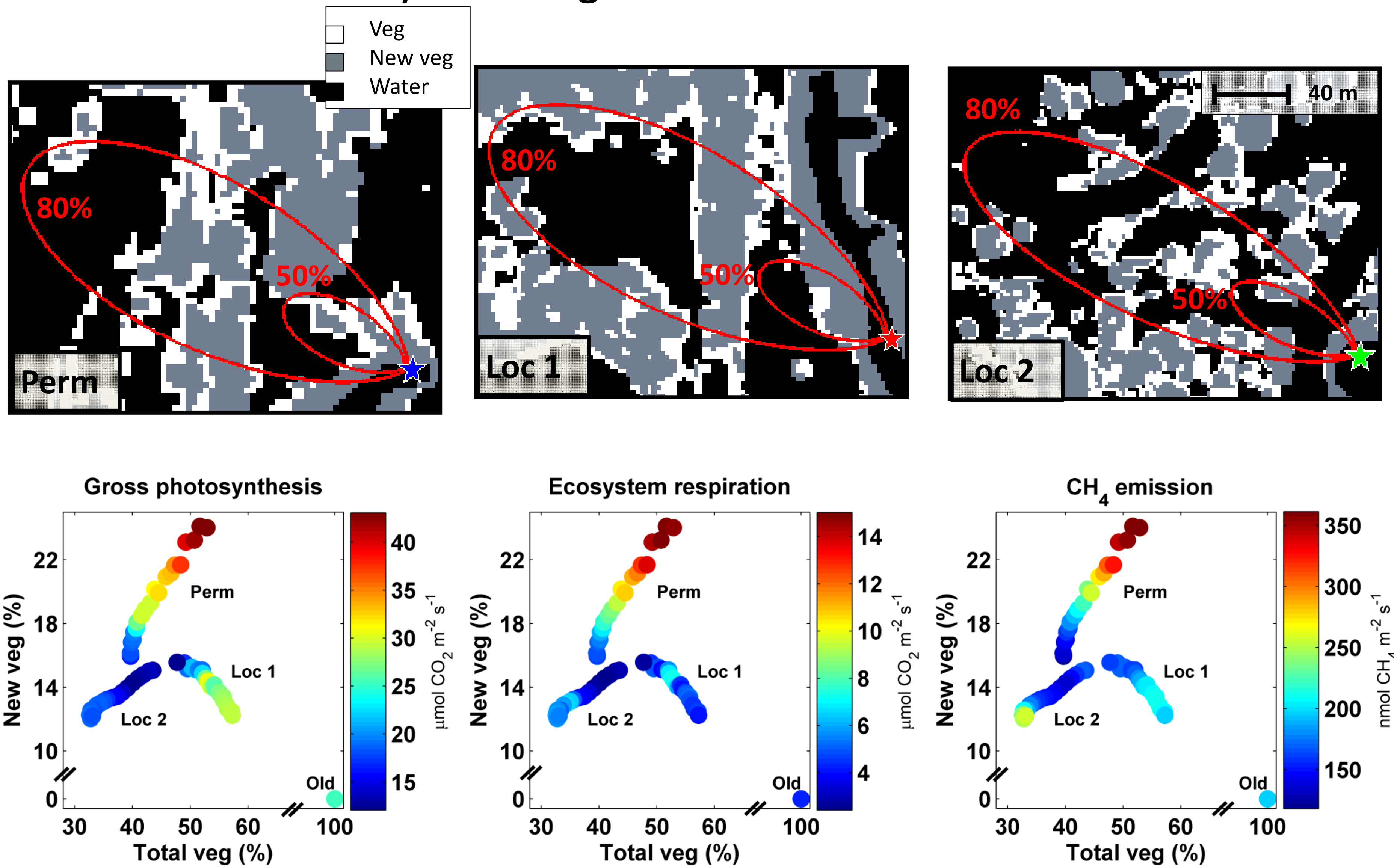
Sturtevant, Hatala, Knox, Koteen, Verfaillie, Baldocchi, unpublished

Different Vegetation/Water Footprints Across Landscape



Hatala, 2013, PhD

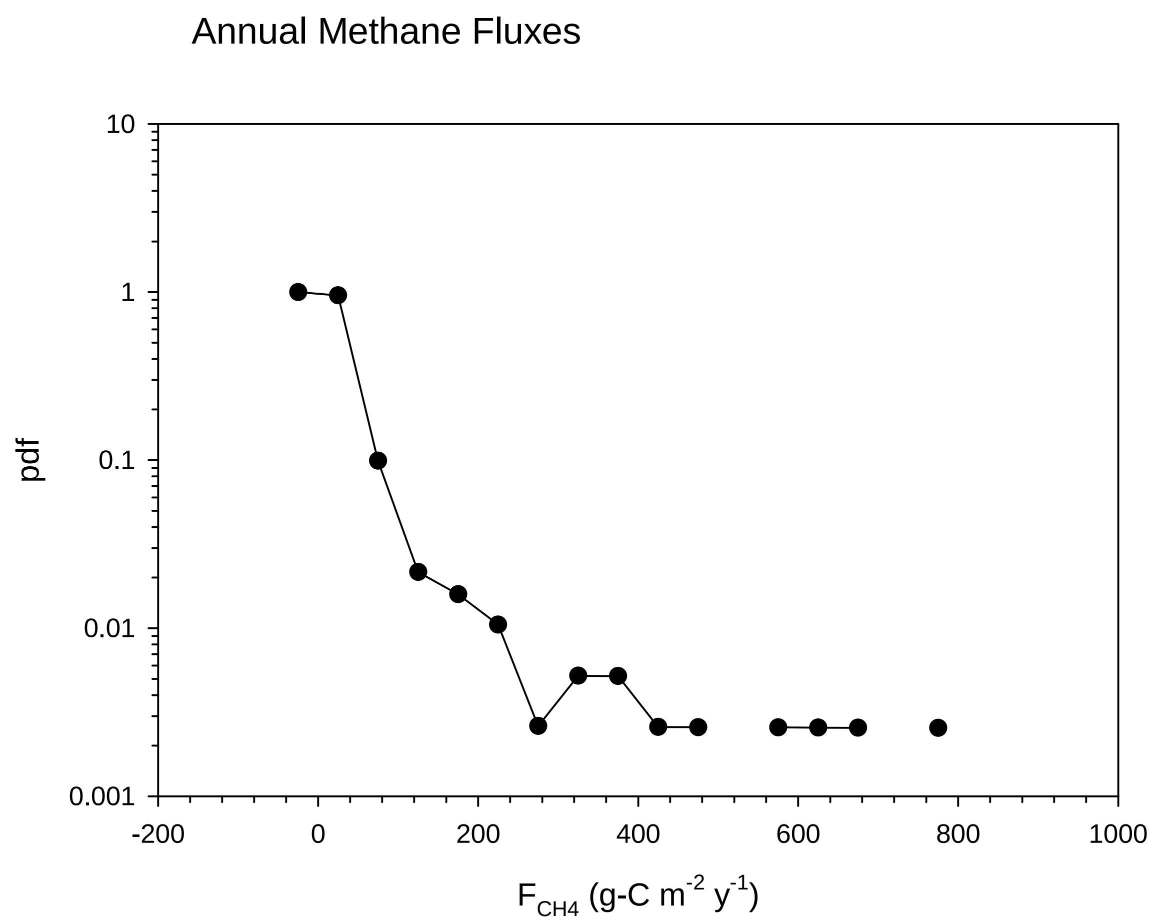
Perimeter of Vegetation Patches and Veg Fraction Affects Variability and Magnitude in Methane Fluxes

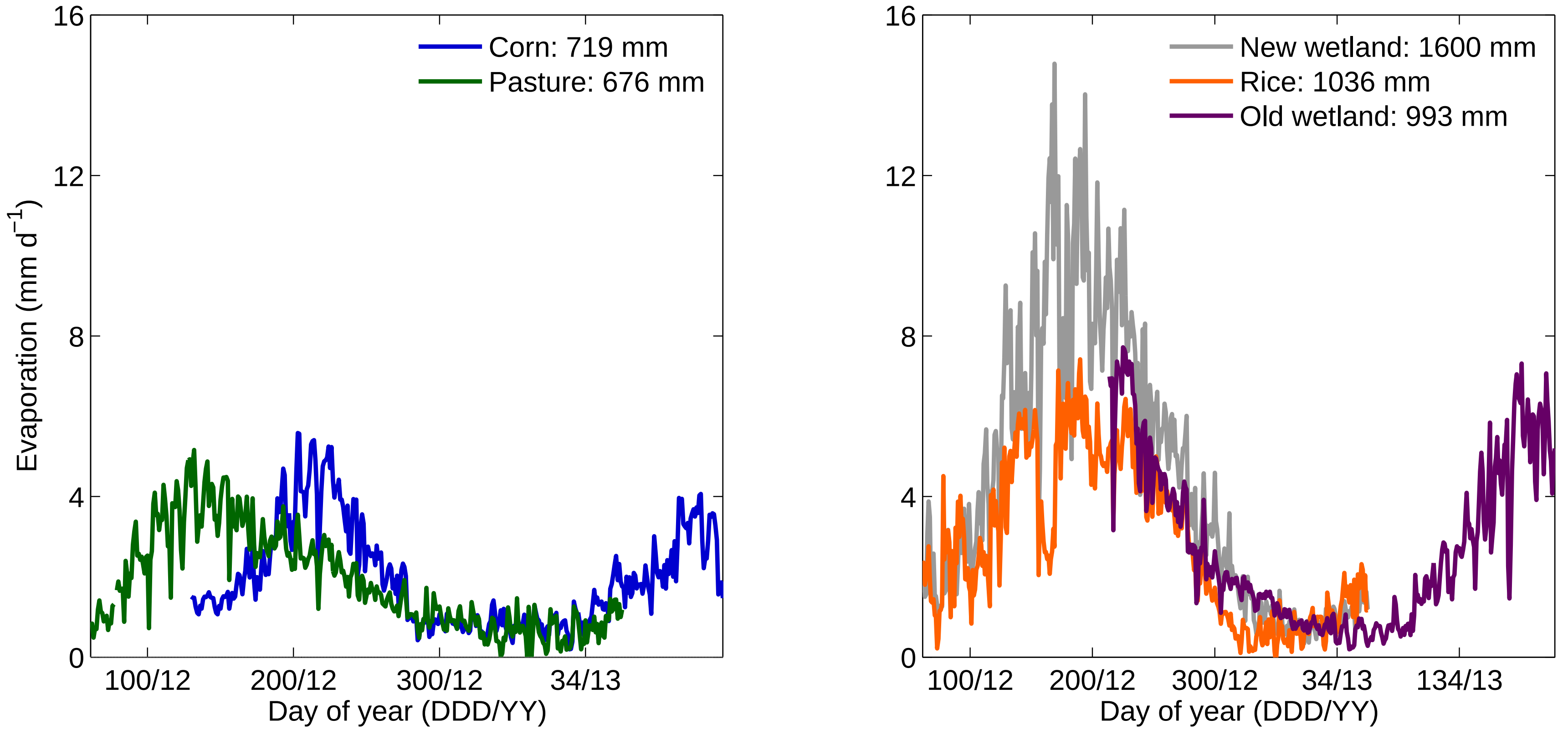


Sturtevant, Hatala, Knox, Koteen, Verfaillie, Baldocchi, unpublished

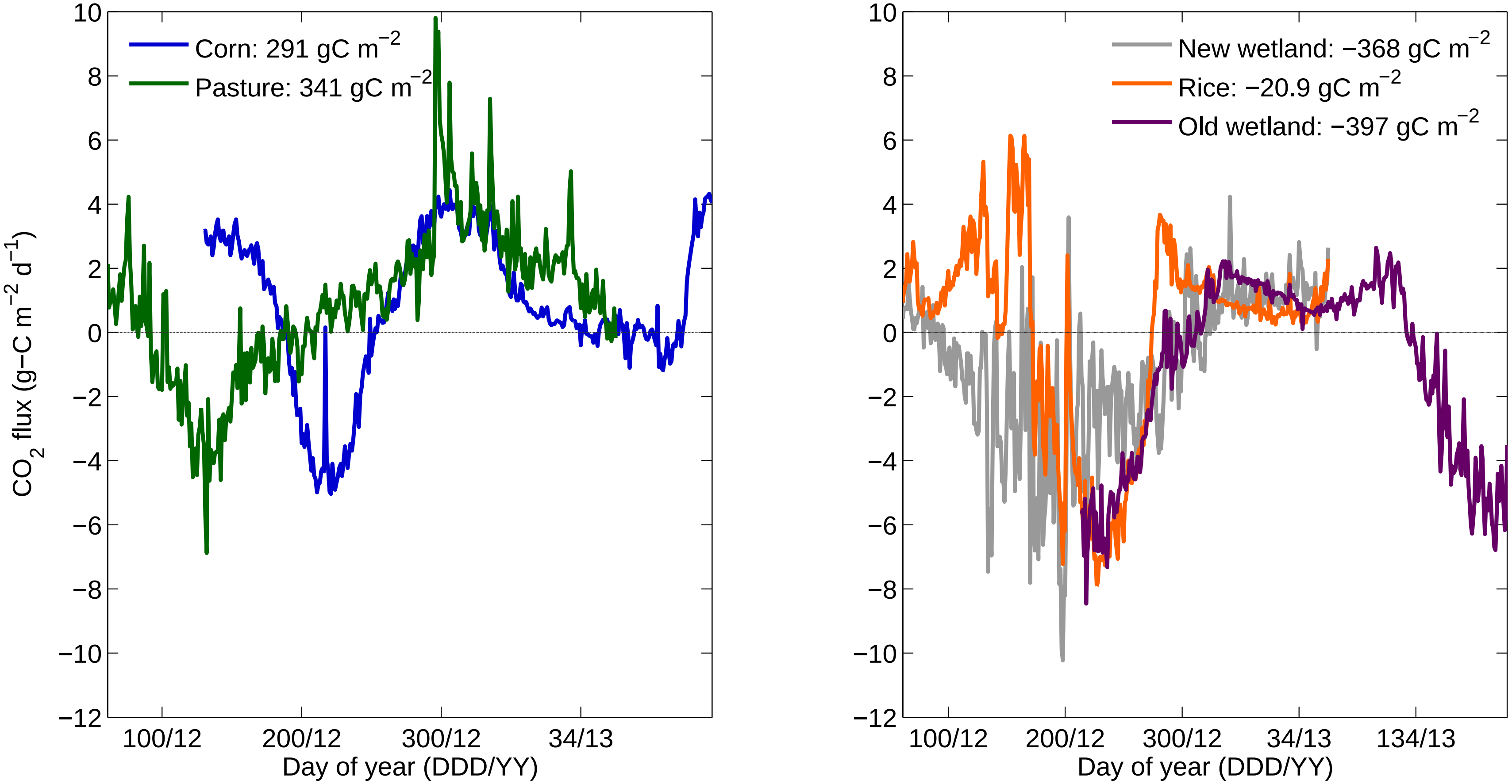
Concluding Remarks

- Methane Emissions at Highly Productive, Restored Wetlands, in California, are Extremely High
- Methane Emissions from Restored Wetlands Increase with Time
- Spatial Scaling Depends on Vegetation Fraction and Size of Patches
  - Accurate Flux Footprint Models are Key towards Interpreting Methane Fluxes

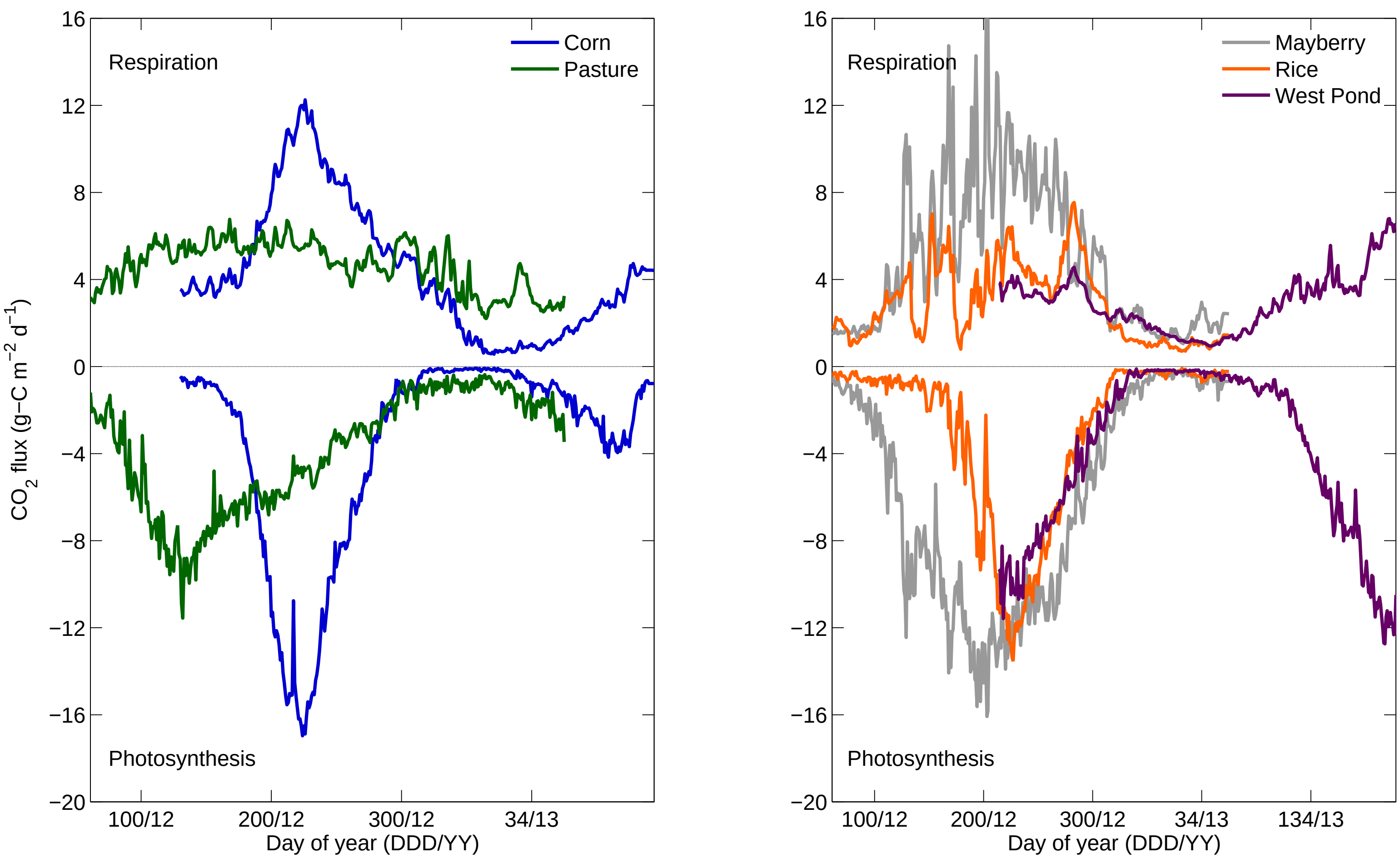

Annual Methane Fluxes
10
1
0.1
0.01
0.001
pdf
-200
0
200
400
600
800
1000
F_{CH4} (g-C m^{-2} y^{-1})



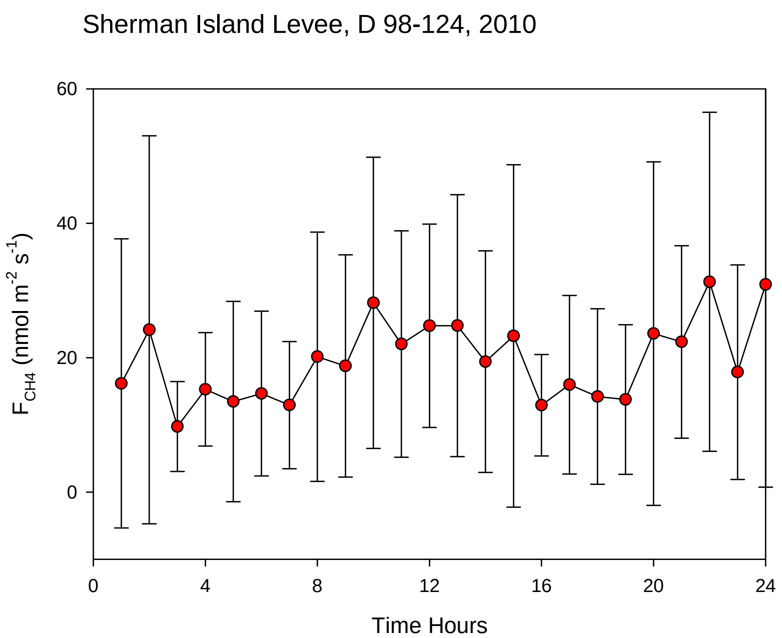
16
12
8
4
0
Evaporation (mm d^{-1})
100/12
200/12
300/12
34/13
Day of year (DDD/YY)
Corn: 719 mm
Pasture: 676 mm
16
12
8
4
0
100/12
200/12
300/12
34/13
134/13
Day of year (DDD/YY)
New wetland: 1600 mm
Rice: 1036 mm
Old wetland: 993 mm

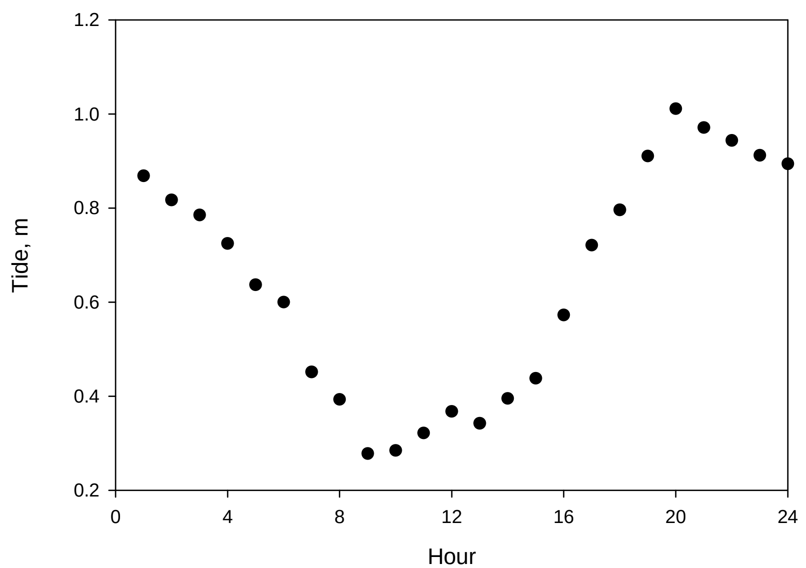


10
8
6
4
2
0
−2
−4
−6
−8
−10
−12
Corn: 291 gC m−2
Pasture: 341 gC m−2
CO2 flux (g−C m−2 d−1)
100/12
200/12
300/12
34/13
Day of year (DDD/YY)
New wetland: −368 gC m−2
Rice: −20.9 gC m−2
Old wetland: −397 gC m−2
134/13



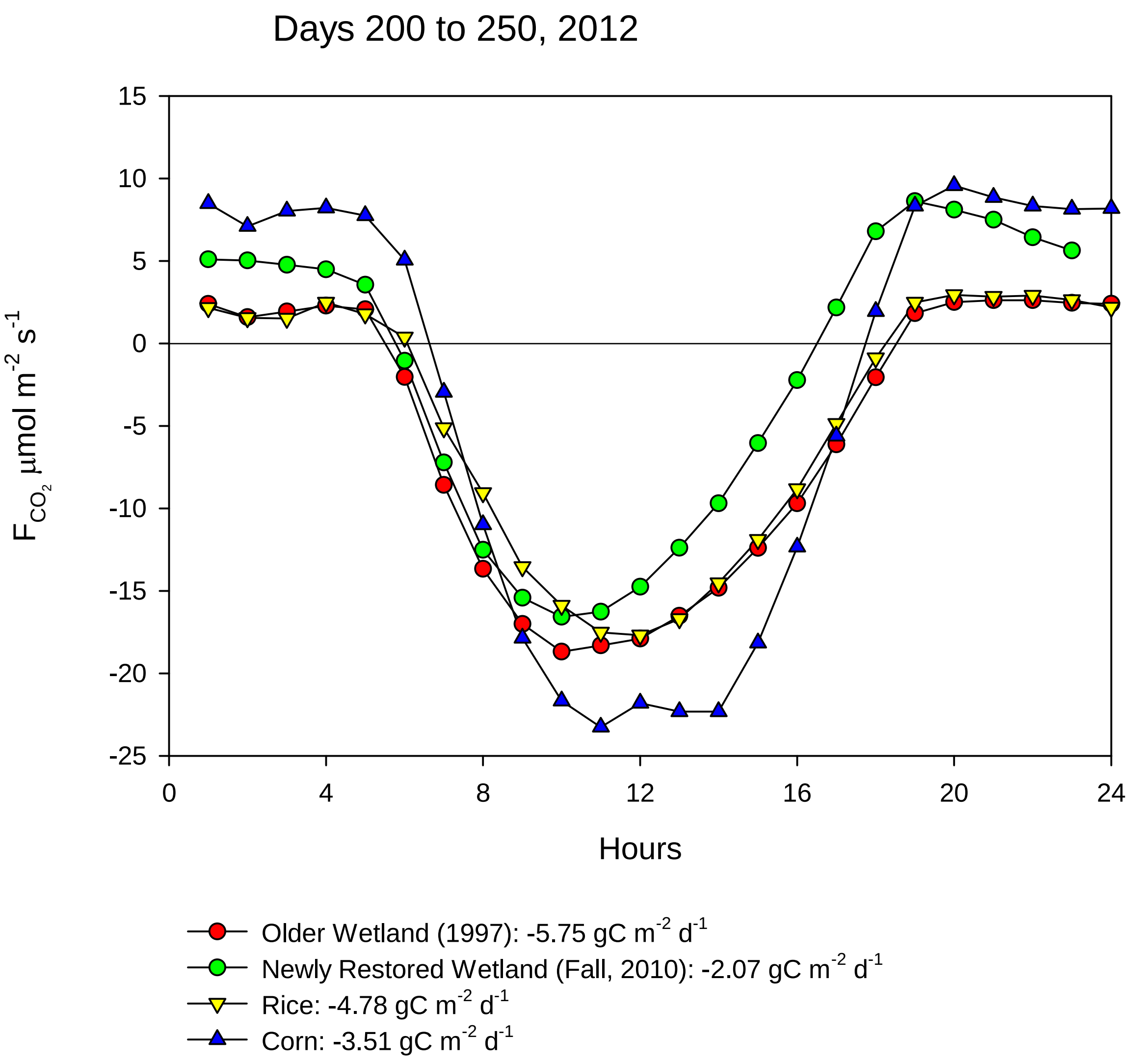
Respiration
Photosynthesis
Corn
Pasture
Mayberry
Rice
West Pond
CO_2 flux (g−C m^{-2} d^{-1})
Day of year (DDD/YY)
100/12
200/12
300/12
34/13
134/13
16
12
8
4
0
−4
−8
−12
−16
−20





Did Not See a Tidal Signal

Study was Short, in Spring



Days 200 to 250, 2012
15
10
5
0
-5
-10
-15
-20
-25
0
4
8
12
16
20
24
Hours
F_{CO_2} µmol m^{-2} s^{-1}
Older Wetland (1997): -5.75 gC m^{-2} d^{-1}
Newly Restored Wetland (Fall, 2010): -2.07 gC m^{-2} d^{-1}
Rice: -4.78 gC m^{-2} d^{-1}
Corn: -3.51 gC m^{-2} d^{-1}