Using hydrogeophysical methods to constrain carbon distribution and fluxes in peat soils of the Everglades

Xavier Comas, William Wright, and Gerhard Heij

Department of Geosciences,
Florida Atlantic University, Davie, FL

FAU
FLORIDA ATLANTIC UNIVERSITY

Outline:

- 1. Introduction:
- 2. Methodology:
  - 2.1. Hydrogeophysical methods:
    - 2.1.1. Ground Penetrating Radar
    - 2.1.2. Capacitance moisture Probes
  - 2.3. Other methods
    - 2.3.1. Time-lapse cameras; gas traps
- 3. Results
  - 3.1. Characterization of peat thickness
  - 3.2. Biogenic gas dynamics
- 4) Conclusions
- 5) Future directions

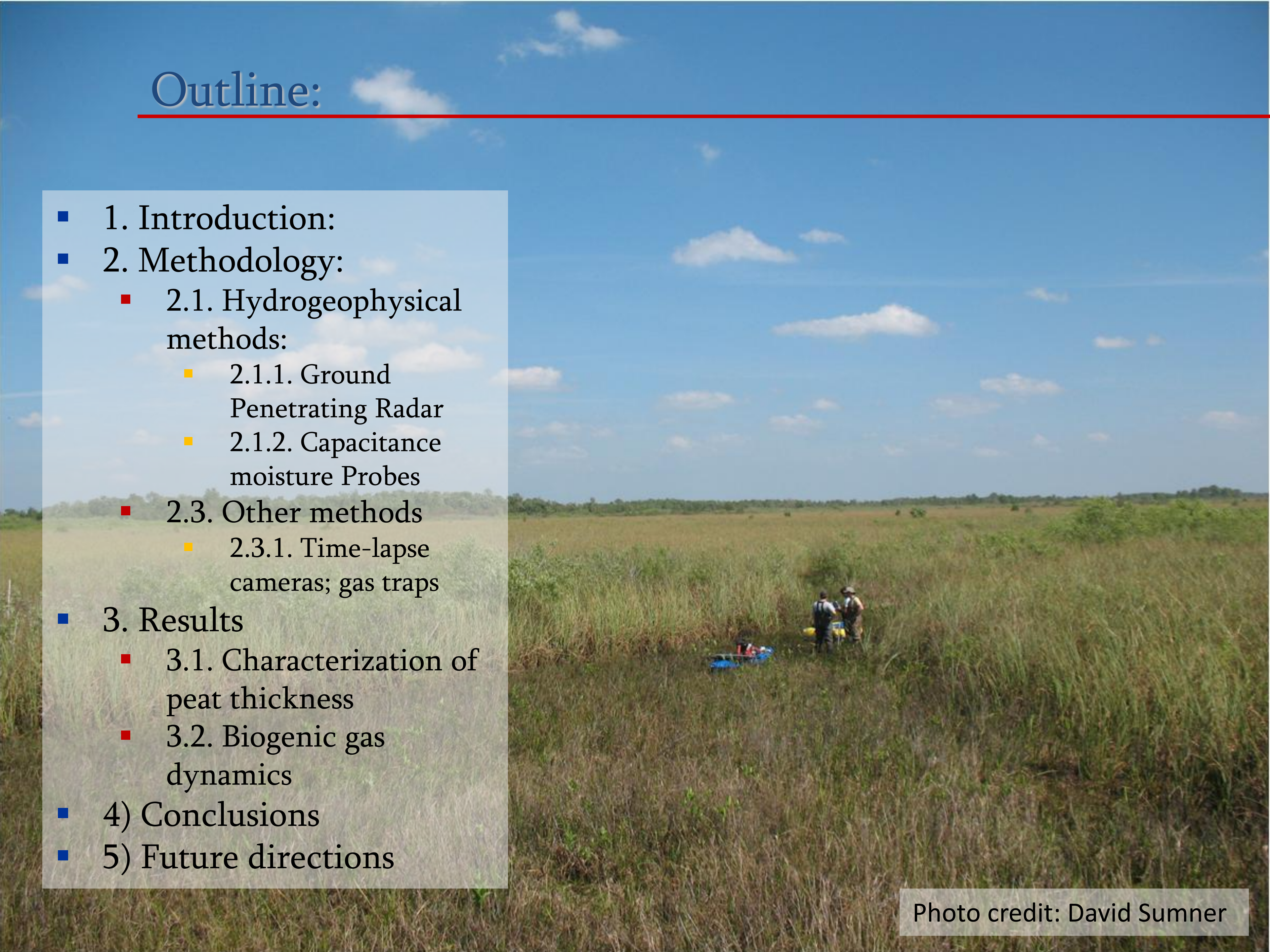
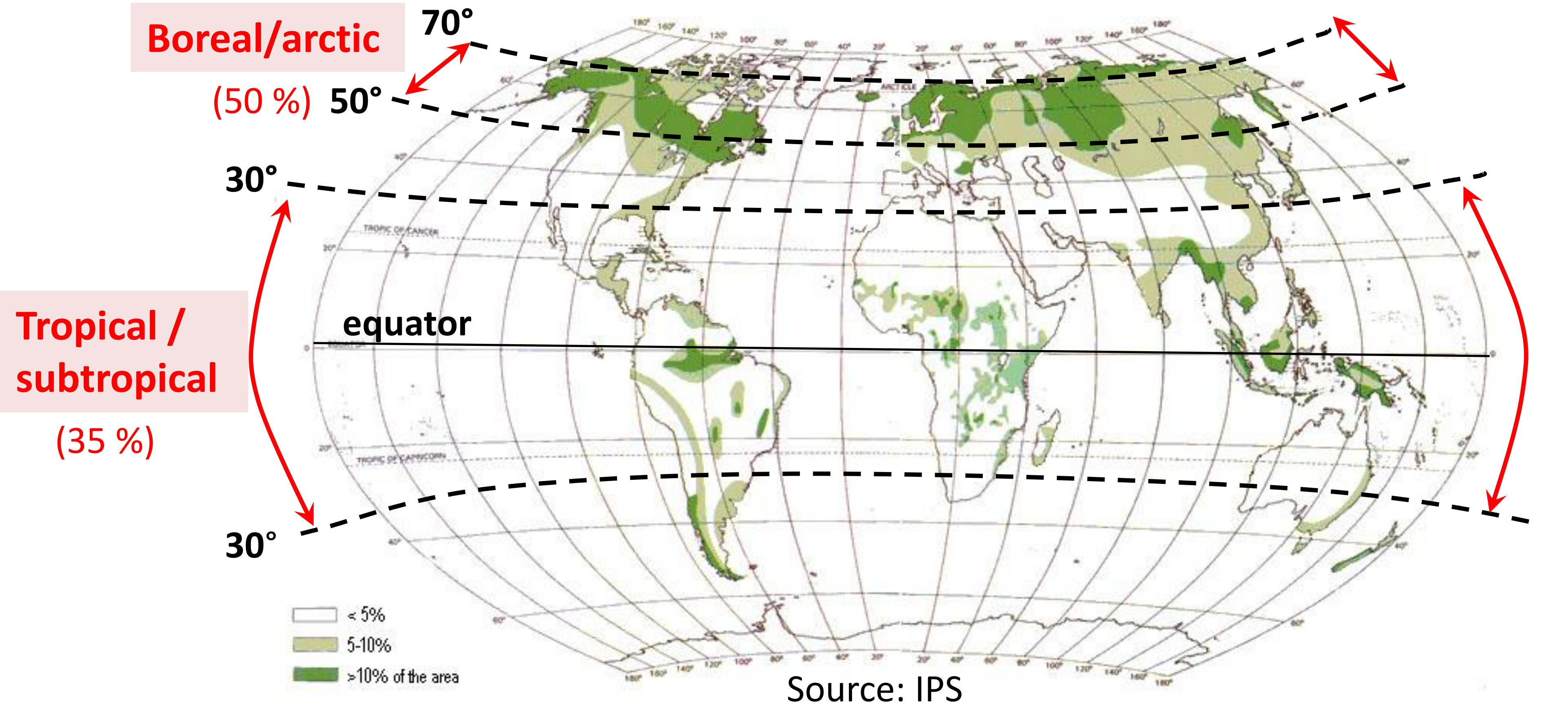


Photo credit: David Sumner

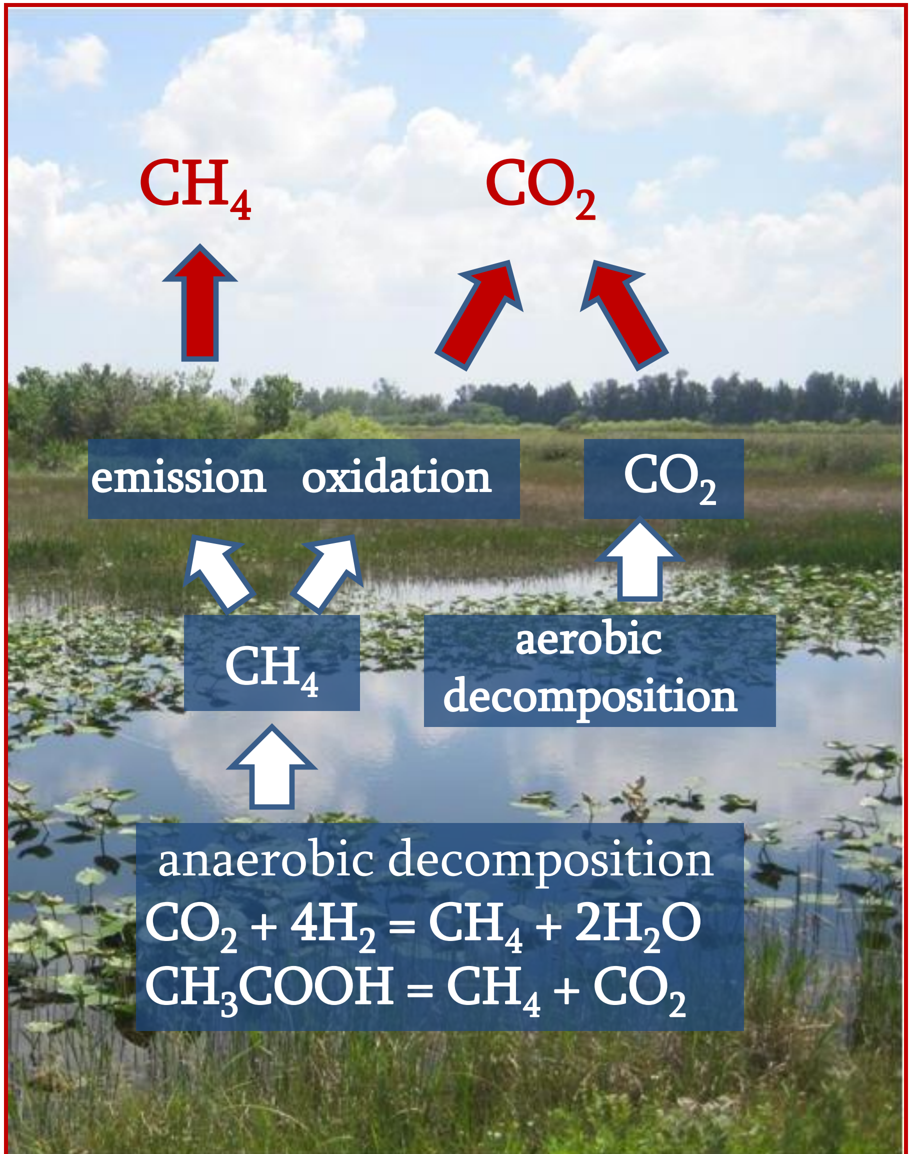
1. Introduction

Peatland distribution in the World



- Total area ≈ 6-8% of land surface
- Distribution roughly bimodal

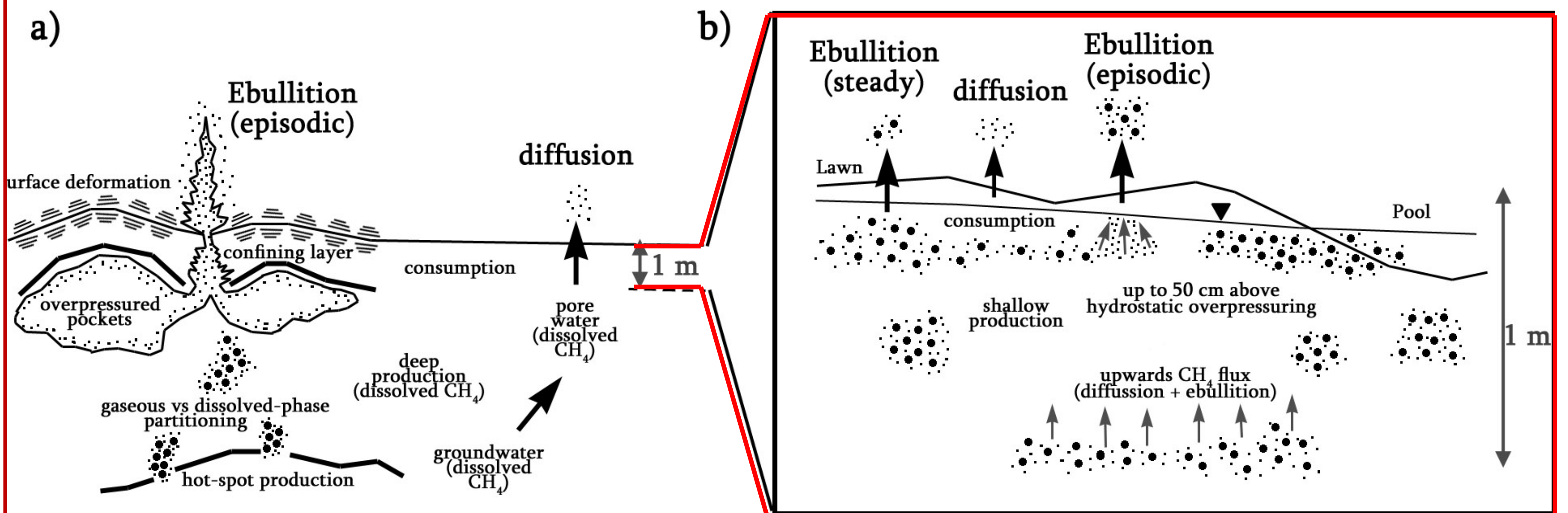
Motivation: Carbon cycling in peat soils



- <u>**Peat soils**</u> play a critical role in the global carbon (C) cycling. Act as:
- **C storage** (global) = 694-528 Pg C or 95-72% of total 730 Pg C held in atmosphere
- **C sources** of **greenhouse gases** to the atmosphere (mainly methane [CH_4] and carbon dioxide [CO_2])
- Many <u>**uncertainties**</u> in terms of:
  - <u>**Spatial distribution**</u>
  - <u>**Temporal distribution**</u>

Spatial distribution: current models for gas accumulation in peatlands

- Deep vs. shallow accumulations: based on ***boreal systems***



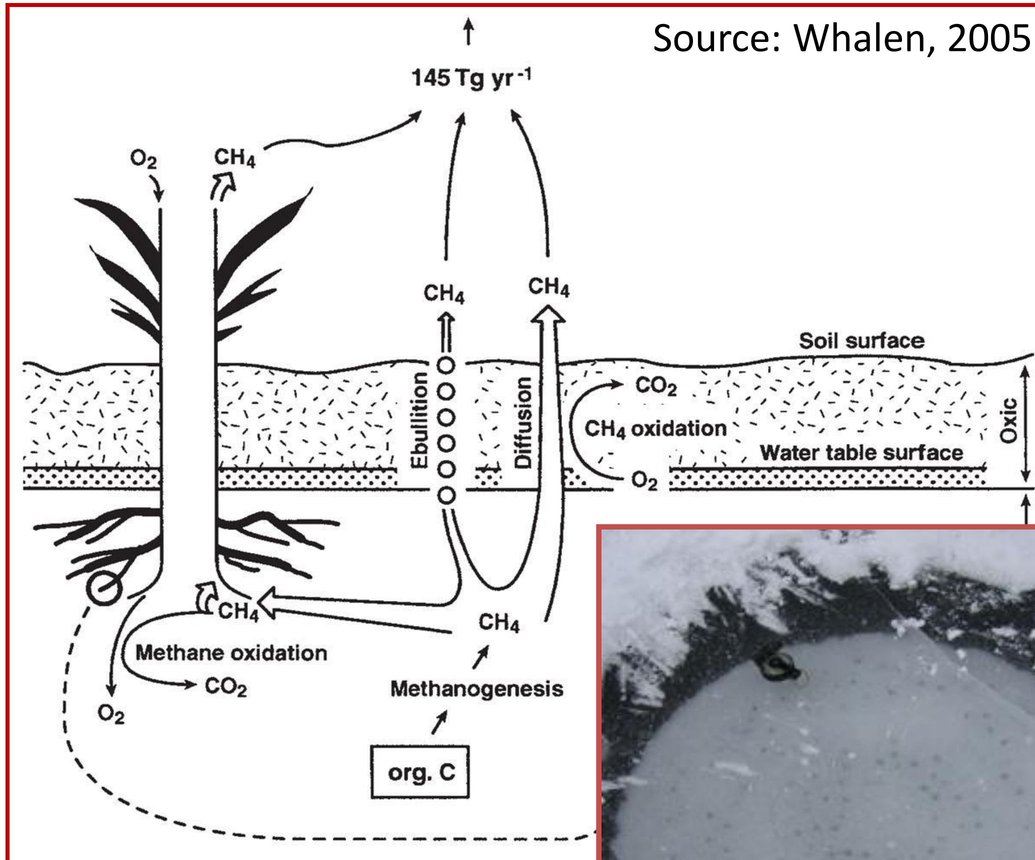
"deep peat model"
(modified from *Glaser et al, 2004*)

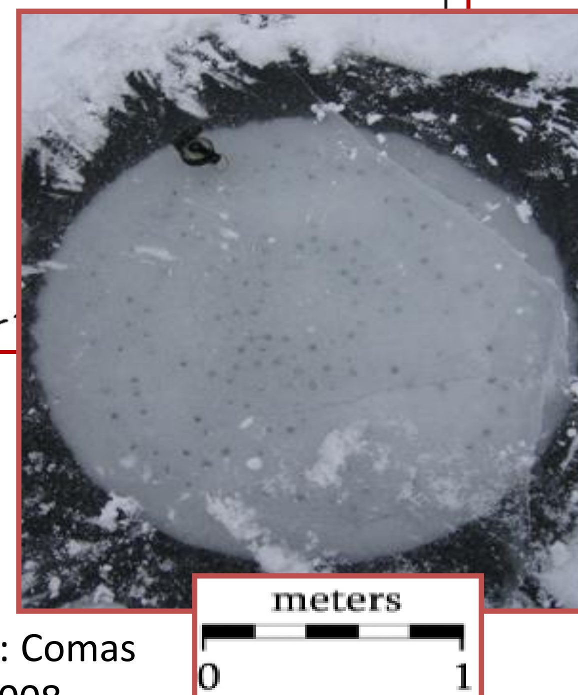
"shallow peat model"
(modified from *Coulthard et al, 2009*)

*Very uncertain for **tropical/subtropical systems***

Temporal distribution: biogenic gas release from peatlands

<u>Mechanisms</u>:
- Diffusion
- Transport through vascular plants
- **Ebullition**:
  - **Episodic vs. steady**





Source: Comas et al, 2008

<u>Controls</u>:
- Soil T
- Chemical composition (organic matter quality)
- Plant community structure
- Water table elevation (redox boundary)
- <u>Atmospheric Pressure</u>

Gas fluxes from peatlands

- Boreal systems:

Mechanism	mg CH_4 m^{-2} d^{-1}	Study type	Location	Method	Reference
Episodic ebullition	**2,780-2,070**	Field based	ME	GPR	Comas et al, 2011
	2,450	Field based	MN	Hydraulic head	Rosenberry et al, 2003
	1,999-389	Field based	ME	GPR	Comas et al, 2008
	1,666 – 10	Field based	Canada	Chamber	Strack et al, 2004
	1,200	Lab based	ME	Chamber	Comas and Slater, 2007
	356	Field based	MN	Surface deformation	Glaser et al, 2004
	83 – 2.2	Lab scale	UK	TDR	Baird et al, 2004
Diffusive fluxes	**480-1**	Field based	MN	Chamber	Crill et al,1998
	35	Field based	MN	Chamber	Chasar, 2002

- Wide array of methods with different spatial and temporal resolutions

- Tropical/subtropical systems:

Mechanism	mg CH_4 m^{-2} d^{-1}	Study type	Location	Method	Reference
Ebullition	**912-146**	Field based	Louisiana	Chamber	Alford et al, 1997
	263	Field based	FL	Chamber	Whiting and Chanton, 2001
	243	Field based	FL	Chamber	Hapell et al, 1993
	230-192	Field based	Amazon	Chamber	Barlett et al, 1988
Diffusive fluxes	**53-44**	Field based	Amazon	Gas filter correlation	Barlett et al, 1990
	52	Field based	FL	Chamber	Happell and Chanton, 1993

- Methods mainly based in chambers with more limited temporal and spatial resolution

- **C stocks and spatial and temporal distribution of C gases** have been better studied in boreal peatlands, while remaining much more uncertain for *subtropical systems (such as the Everglades)*
- **Therefore, uncertain response to global warming and/or restoration efforts** (i.e. change in water table elevation, water chemistry, etc)

2. Methodology

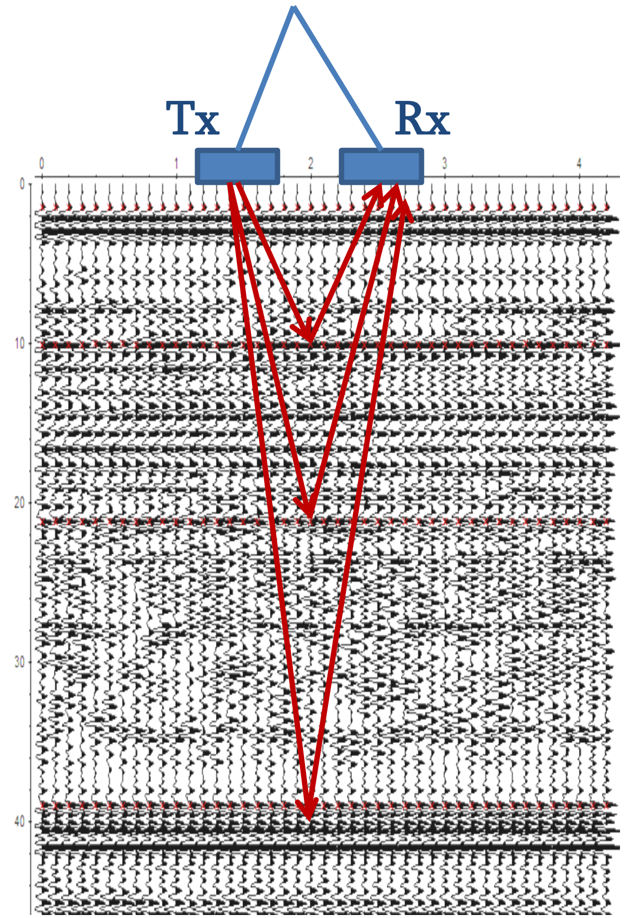
2.1. Hydrogeophysical methods

2.1.1. Ground Penetrating Radar (GPR)

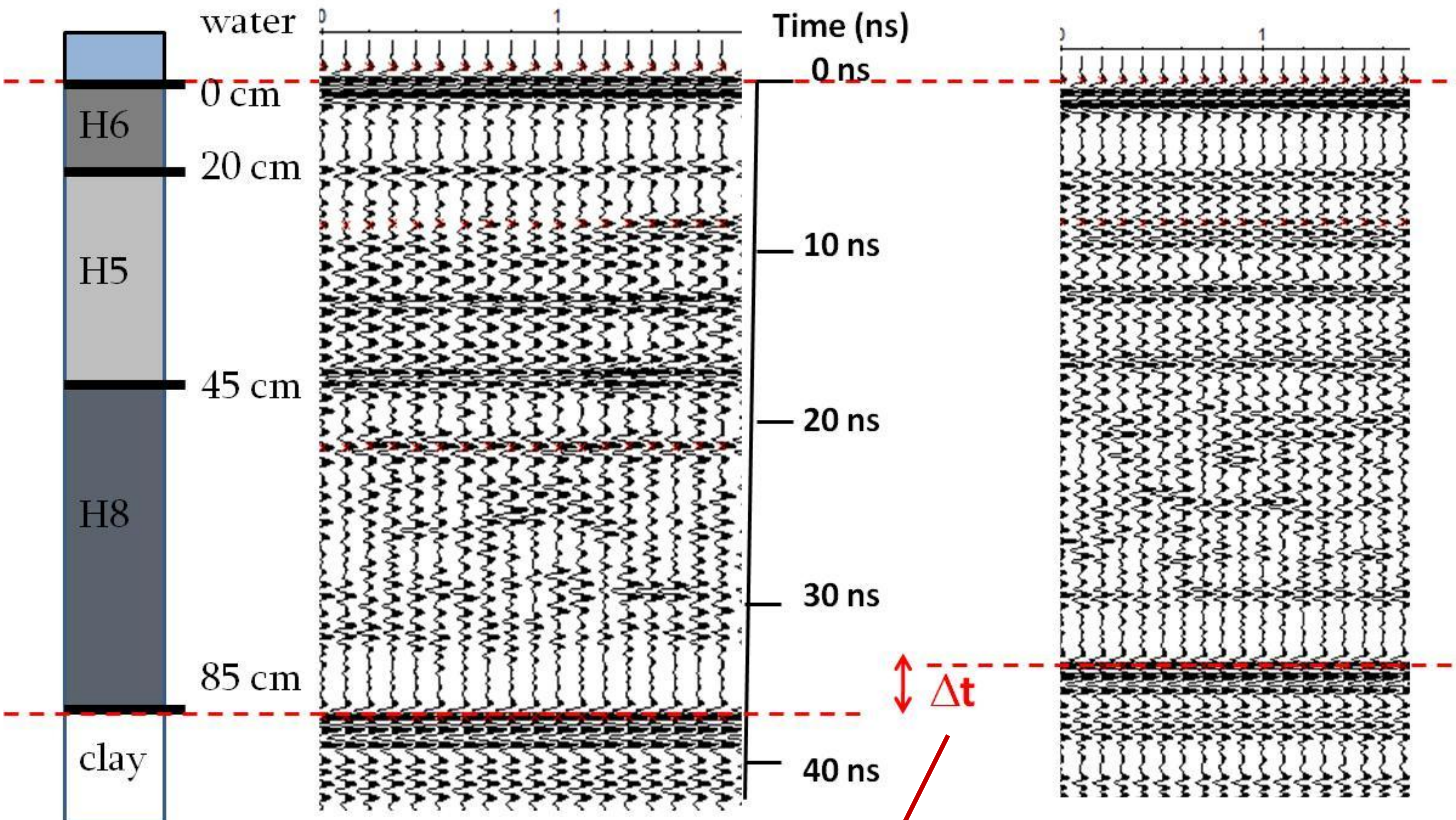
- Principle: a pulse of electromagnetic (EM) waves travels from a transmitter (**Tx**) to a receiver (**Rx**) antenna **non-invasively**

- Physical property measured: *relative dielectric permittivity* (ε_r)

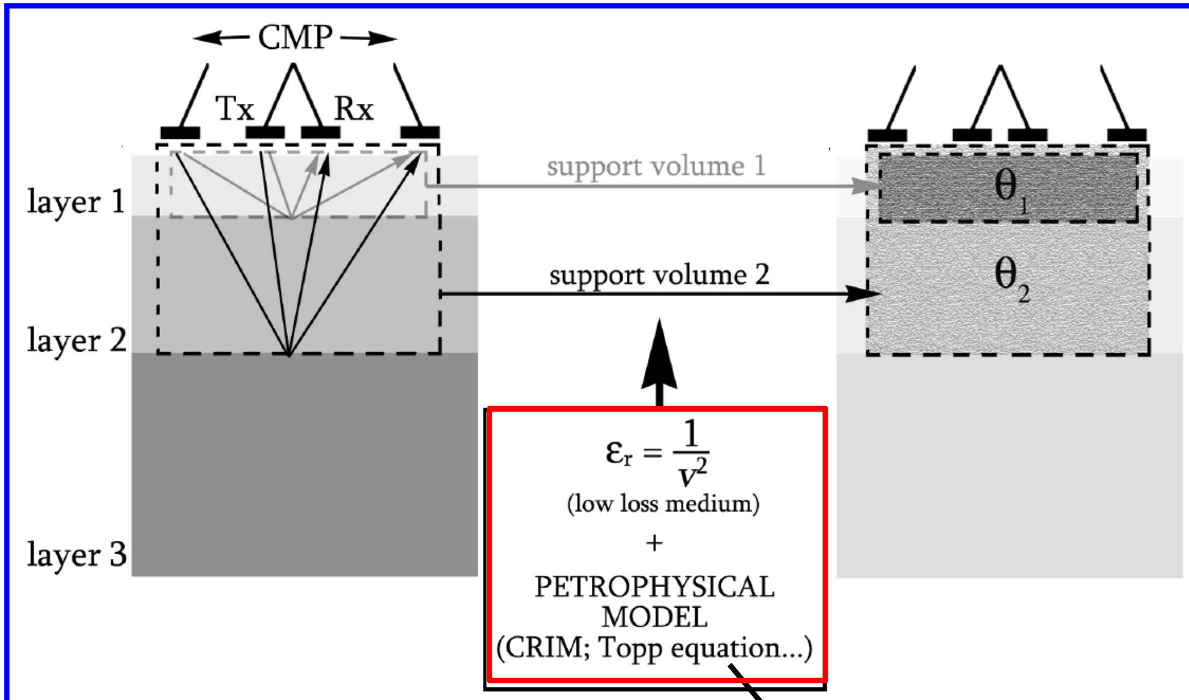
- any contrast in ε_r (e.g. changes in water content) will return a reflection on the GPR record



- *Very sensitive to changes in water content* ***and thus gas content***



Since depth to the mineral soil is constant, changes in time (Δt) are related to changes in water content (and thus air content) within the peat column



Slater and Comas , 2009

- Change in time over known depth is converted to velocity
- CRIM model is applied to express velocity in terms of **gas content**

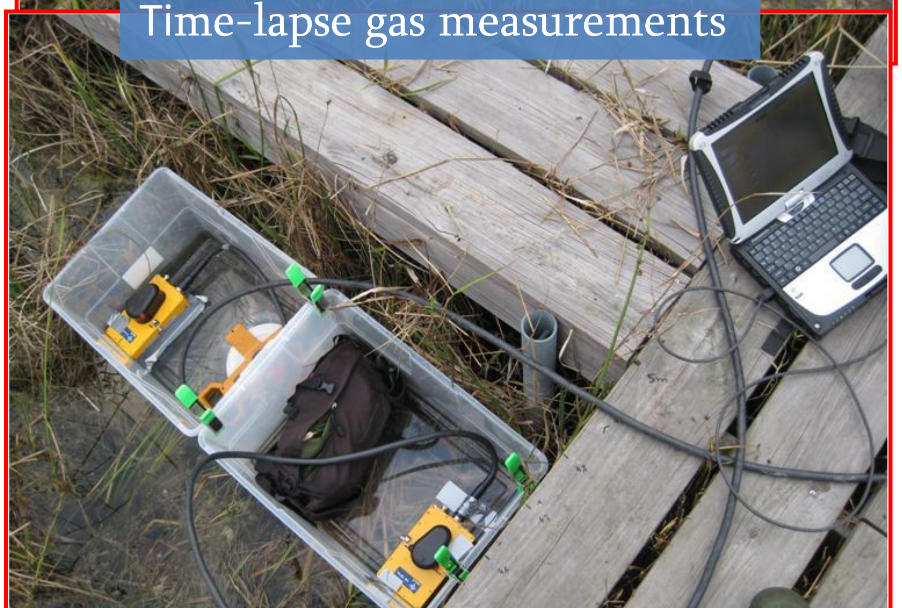
Gas content

Complex Refractive Index model (CRIM):

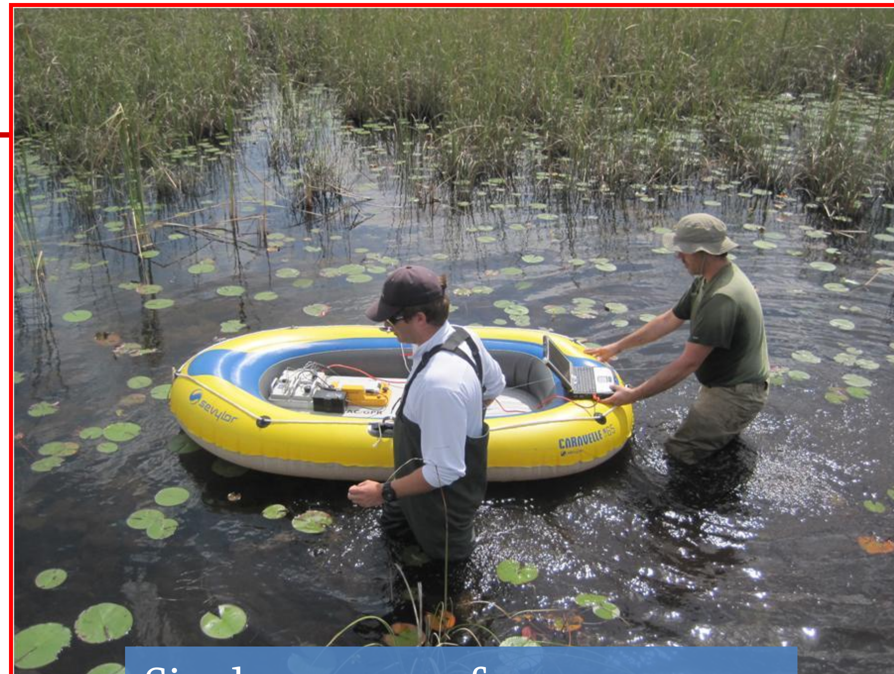
$$\varepsilon_{r(b)}^{\alpha} = \theta\varepsilon_{r(w)}^{\alpha} + (1-n)\varepsilon_{r(s)}^{\alpha} + \boxed{(n-\theta)}\varepsilon_{r(a)}^{\alpha}$$

$\varepsilon_{r(w)}$; $\varepsilon_{r(a)}$; $\varepsilon_{r(s)}$: relative dielectric permittivity of water (81), biogenic gas (1), and peat matrix; n : porosity, θ: volumetric soil water content and α : factor accounting for orientation of the electrical field

GPR experimental setup: Field scale

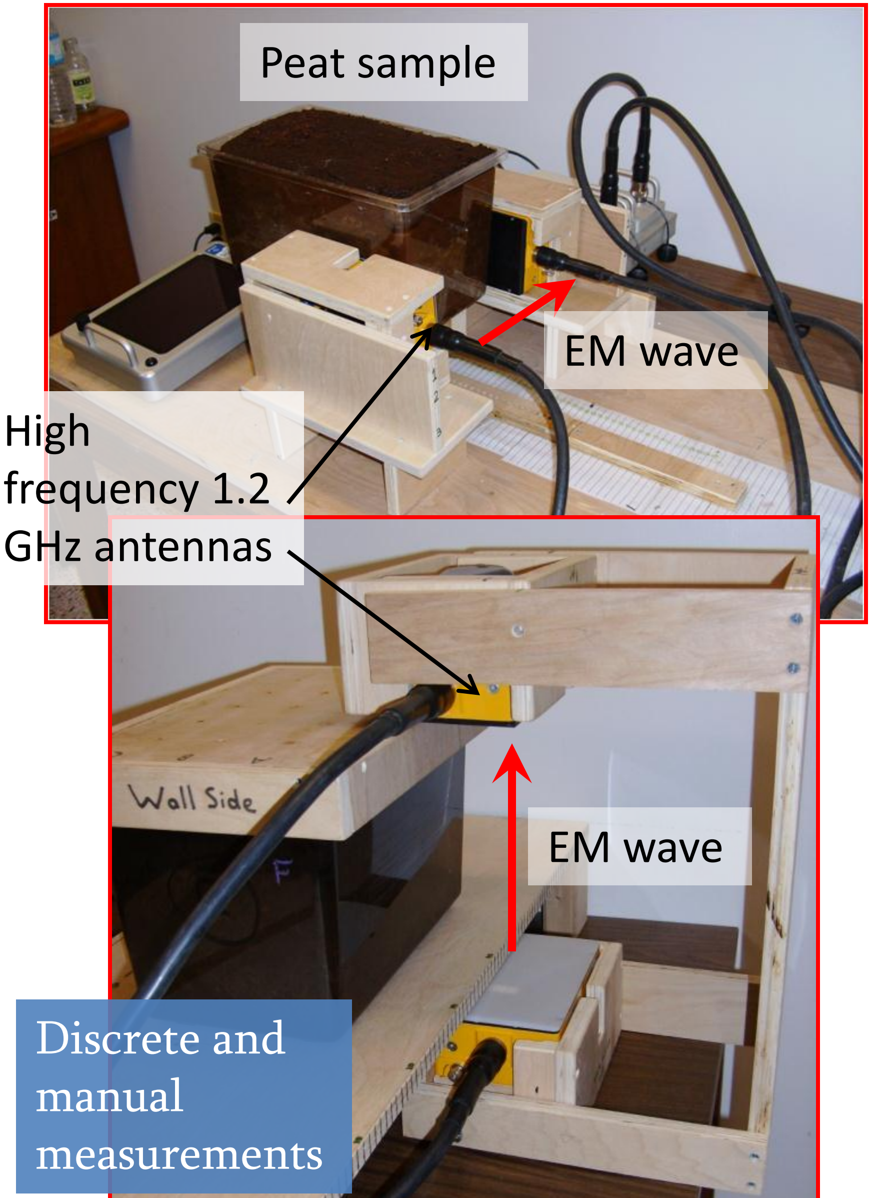


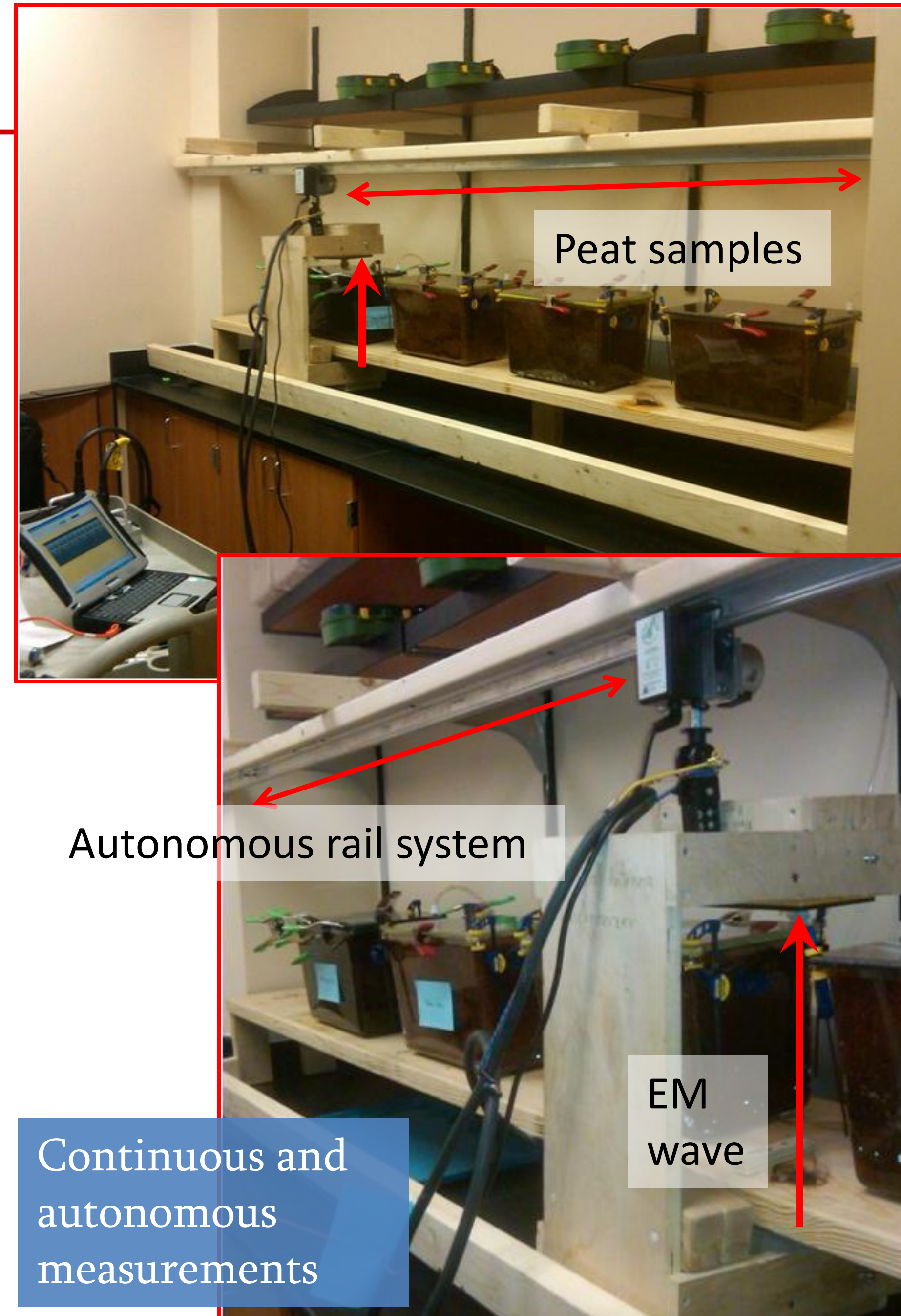
Time-lapse gas measurements



Single transects for stratigraphic characterization

GPR experimental setup: Laboratory scale

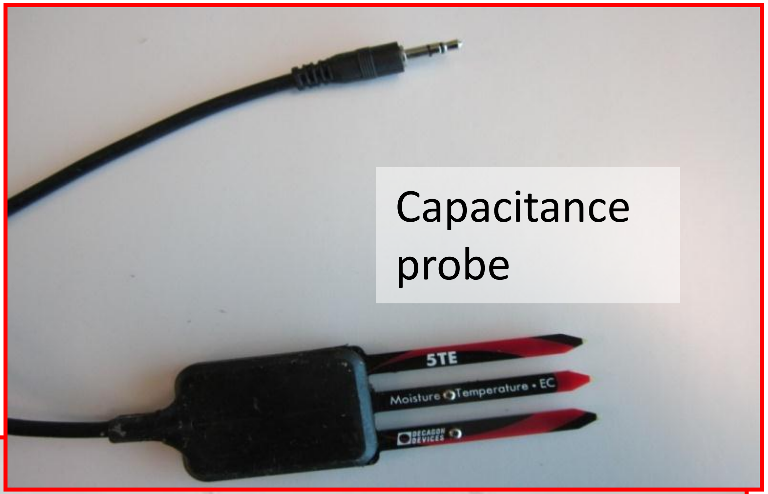


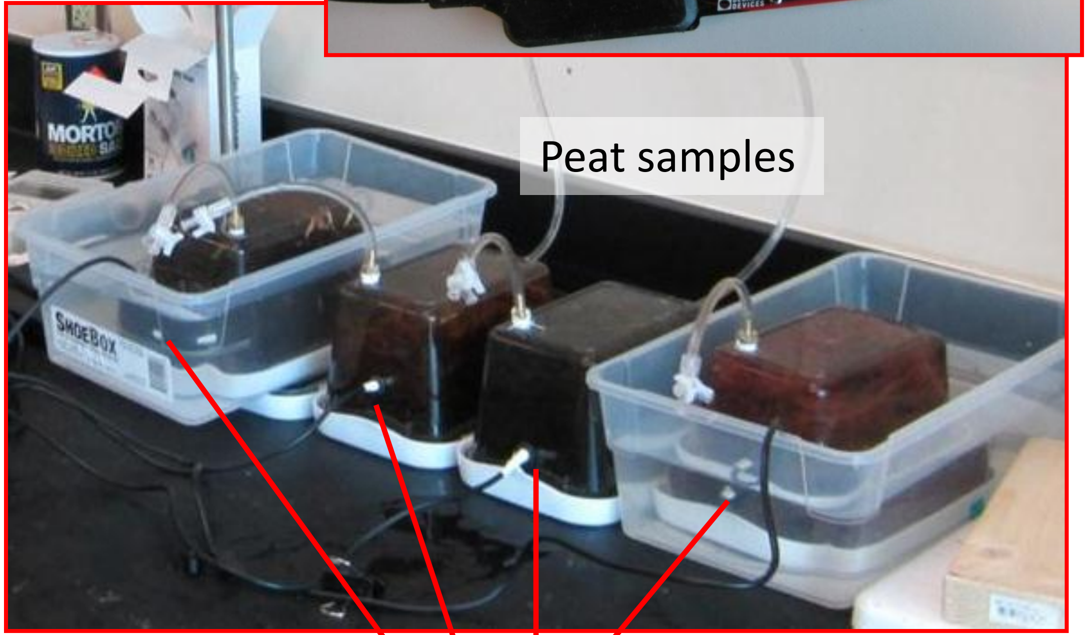


2.1.2. Moisture probes

- <u>Principle</u>: uses *capacitance* (or ability to store an electrical charge) to measure dielectric permittivity
- Changes in capacitance due to changes in dielectric permittivity can be directly correlated with <u>changes in water content **and thus gas content**</u>

- <u>Experimental setup</u>: invasive; data logger allows for autonomous and continuous measurements

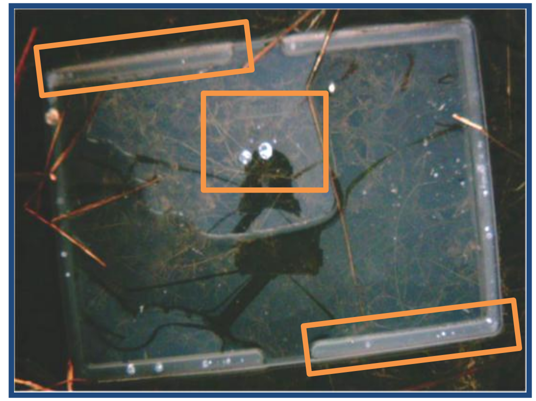




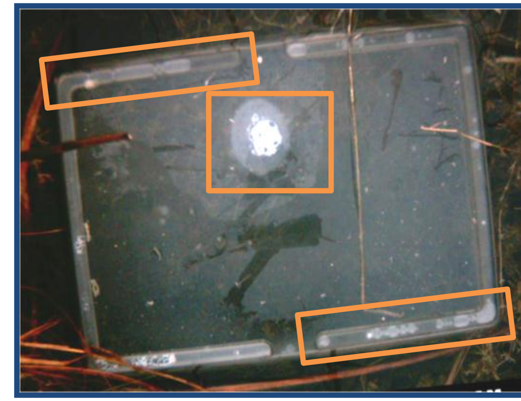
Moisture probes inserted into soil

2.1.3. Other methods: time lapse gas cameras and traps

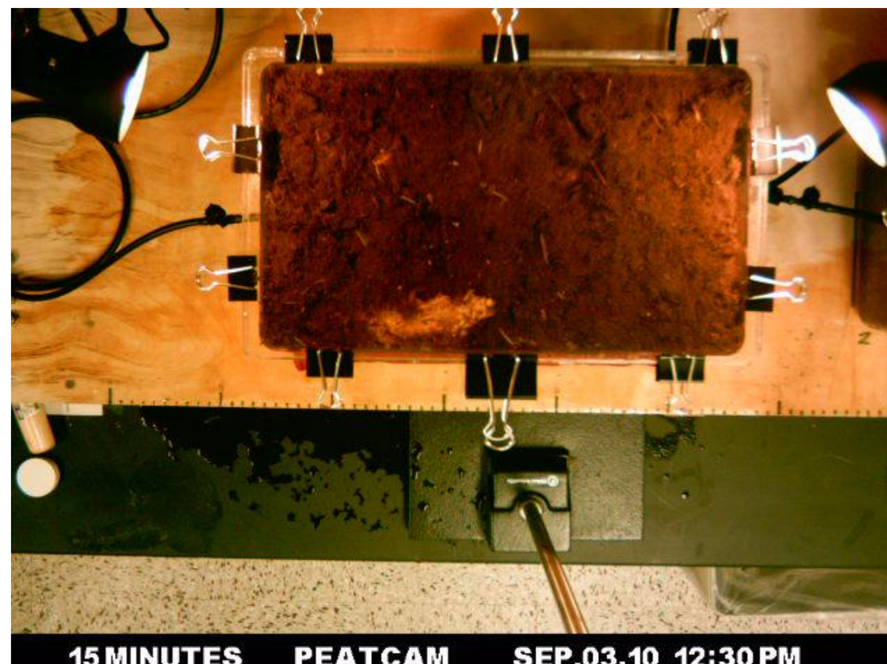
- Volume of bubble release directly measured over time



Feb 14, 2011 6:08AM

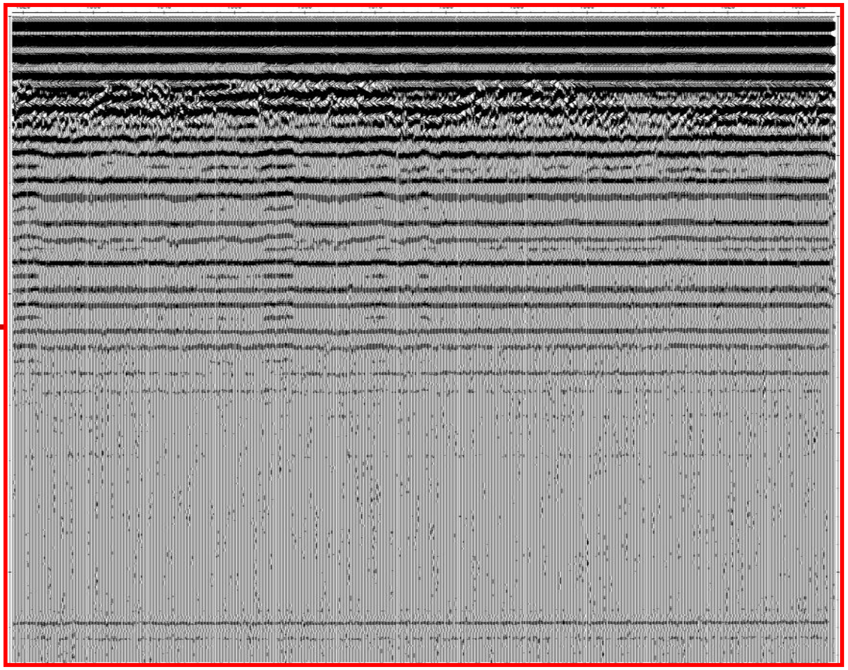


Feb 21, 2011 6:50AM

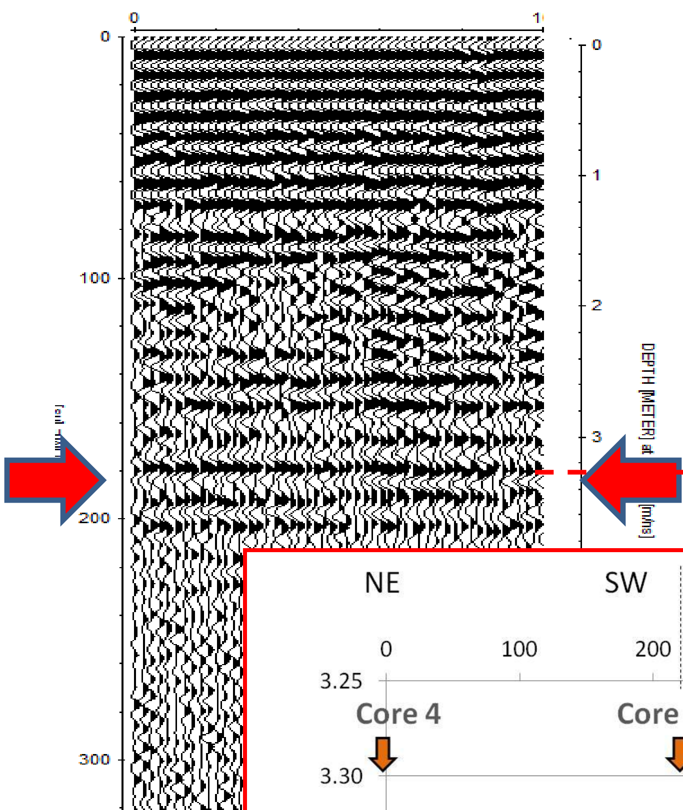


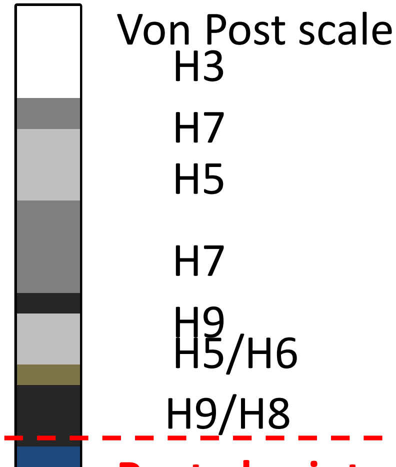
Comas, X. and Wright, W. 2012. Heterogeneity of biogenic gas ebullition in subtropical peat soils is revealed using time-lapse cameras, Water Resources Research, 48, W04601, doi:10.1029/2011WR011654

3. Results

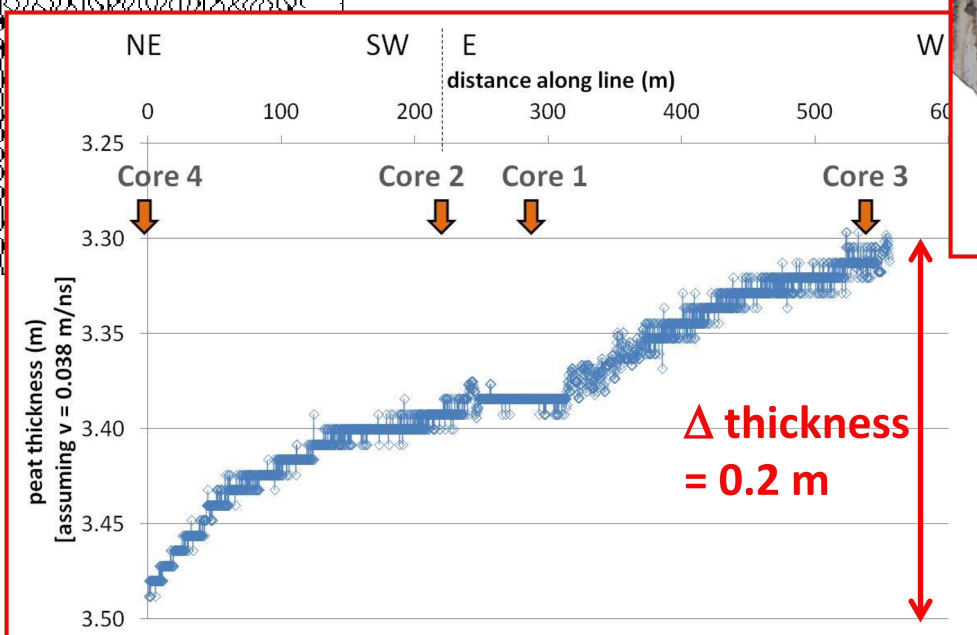


3. 1. Characterization of peat thickness





Peat-clay interface



3. 2. Biogenic gas dynamics

- a) Internal gas dynamics: CH_4/CO_2 production vs. release

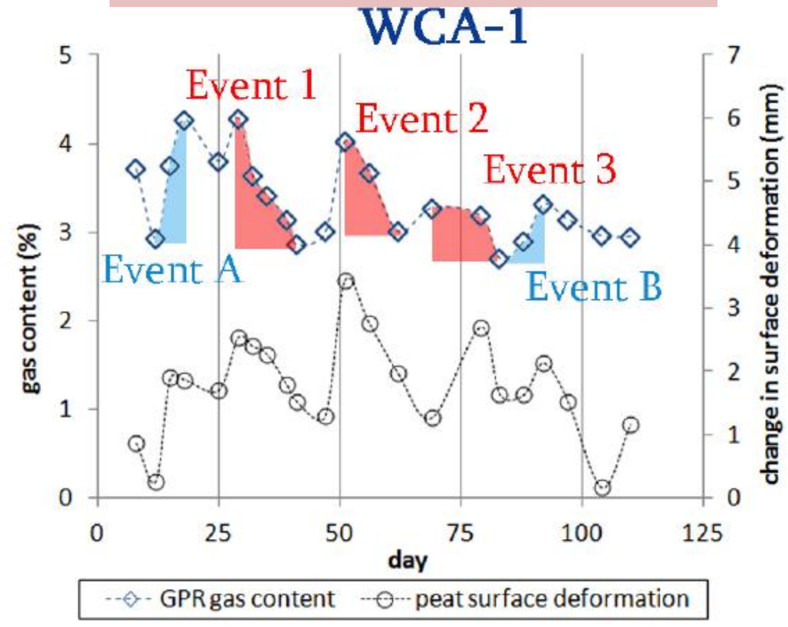
Release

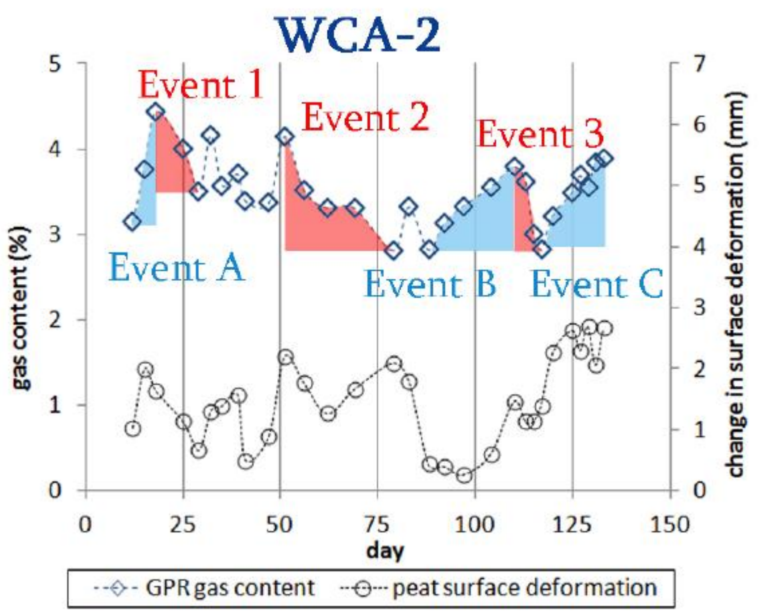
Sample	event	gas lost (%)	gas lost (% day^{-1})	flux rate * (mg CH_4 m^{-2} day^{-1})	flux rate * (mg CO_2 m^{-2} day^{-1})	surface deformation (cm)
WCA-1	1	1.42	0.12	**119.56**	**54.80**	-1.23
	2	1.00	0.09	**91.88**	**42.11**	-1.46
	3	0.60	0.04	**43.46**	**19.92**	-1.10
WCA-2	1	0.94	0.09	**86.34**	**39.57**	-0.96
	2	1.32	0.05	**47.65**	**21.84**	-0.94
	3	1.00	0.14	**144.38**	**66.18**	-0.34
				* assuming 60 % CH_4 and 10 % CO_2		

Production

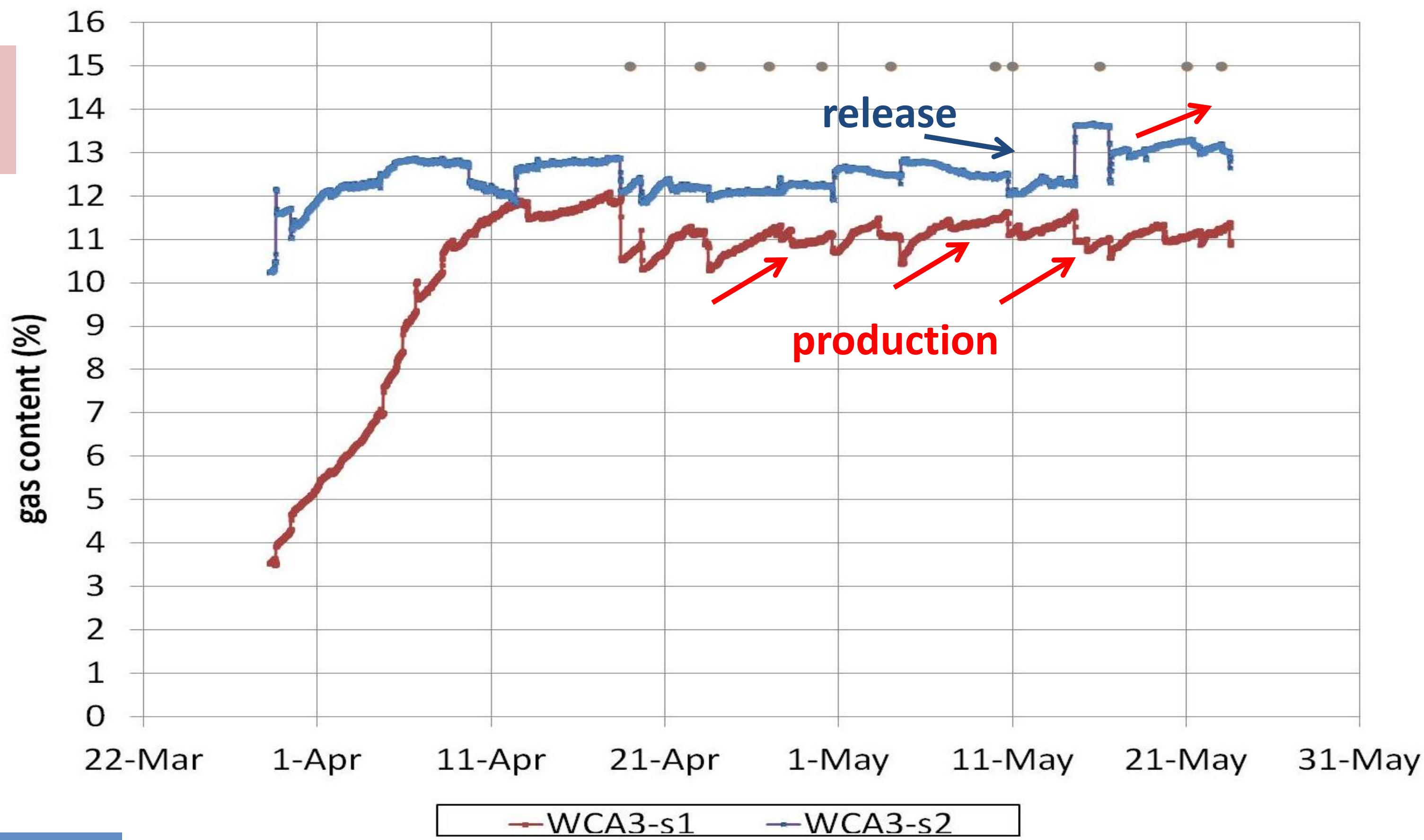
Sample	event	gas lost (%)	gas lost (% day^{-1})	production rate * (mg CH_4 m^{-2} day^{-1})	production rate * (mg CO_2 m^{-2} day^{-1})	surface deformation (cm)
WCA-1	A	1.35	0.23	**227.33**	**104.20**	1.60
	B	0.61	0.07	**68.50**	**31.40**	0.50
WCA-2	A	1.28	0.21	**215.55**	**98.79**	0.60
	B	1.00	0.05	**45.94**	**21.06**	1.03
	C	0.80	0.04	**44.92**	**20.59**	1.57
				* assuming 60 % CH_4 and 10 % CO_2		

GPR + surface deformation





Capacitance probes



Production

WCA3-s1:

148.5 mg $CH_4 m^2 day^{-1}$

68.0 mg $CO_2 m^2 day^{-1}$

WCA3-s2:

48.3 mg $CH_4 m^2 day^{-1}$

22.0 mg $CO_2 m^2 day^{-1}$

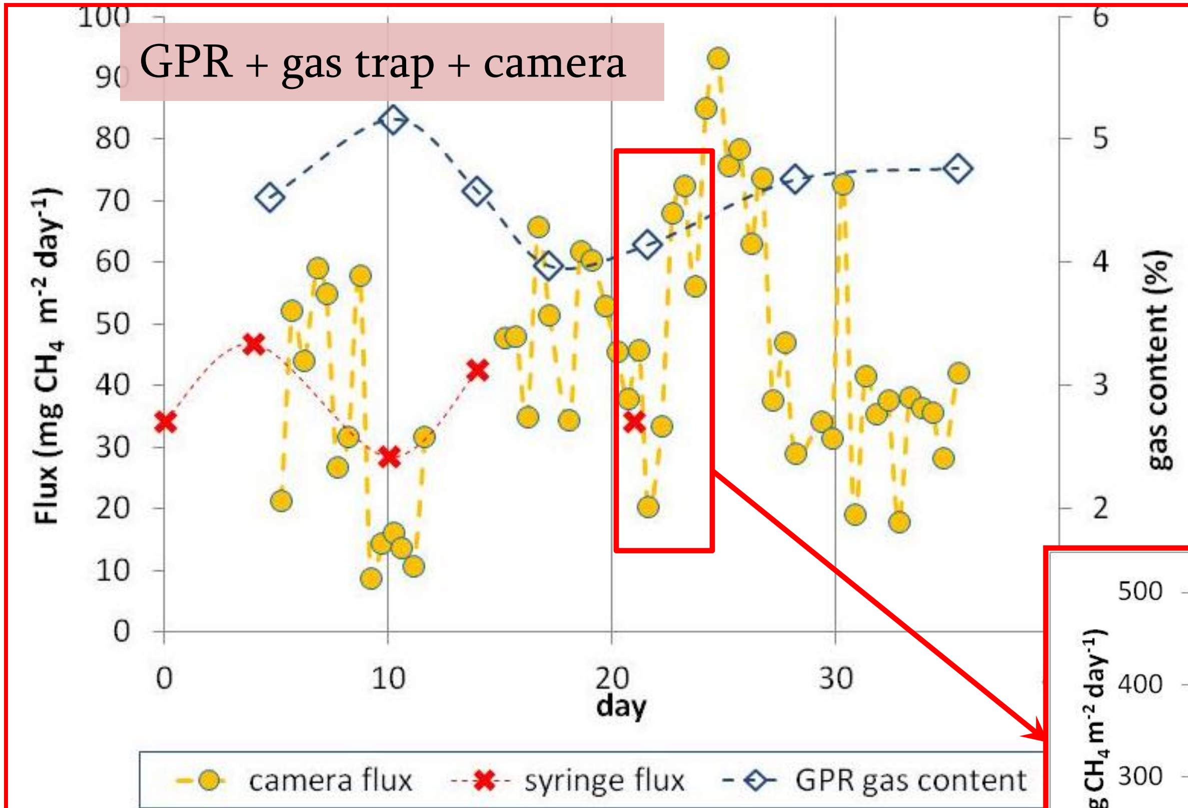
Release

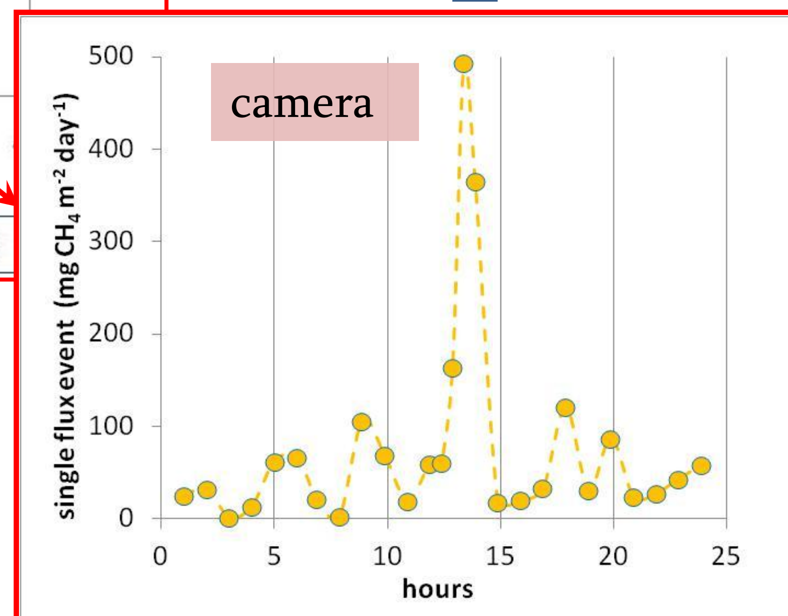
WCA3-s2:

43.3 mg $CH_4 m^2 day^{-1}$

19.8 mg $CO_2 m^2 day^{-1}$

b) Gas dynamics: **steady vs. episodic ebullition**





Episodic

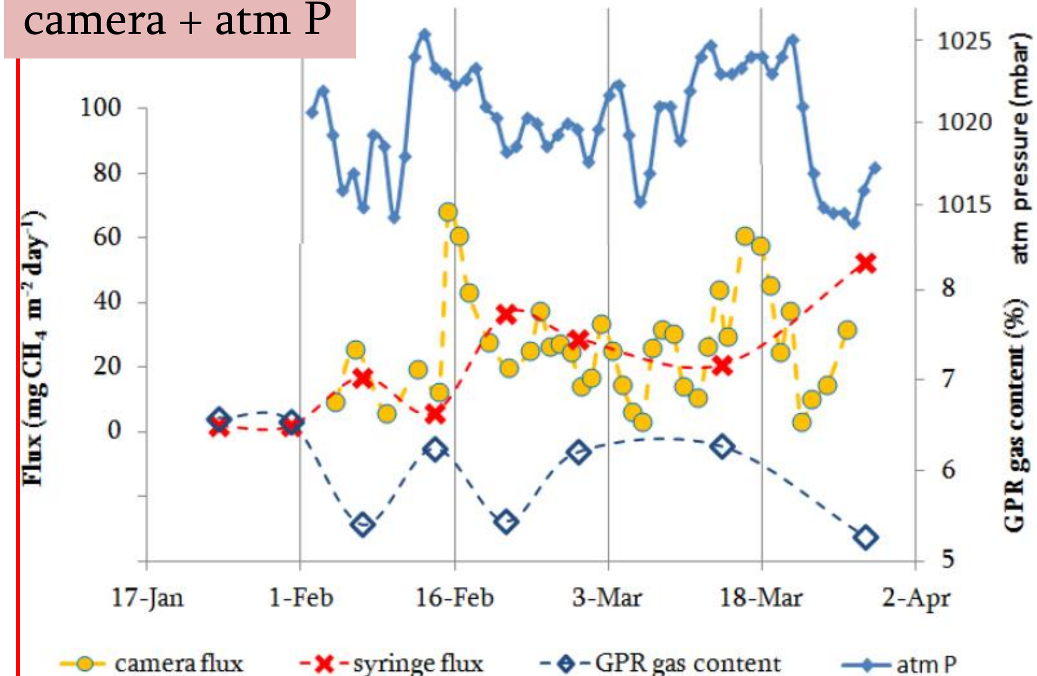
Fluxes between 493-164 mg CH_4 m^{-2} day^{-1} during 1.5 hours

Fluxes averaging 44 mg CH_4 m^{-2} day^{-1} during 30 days

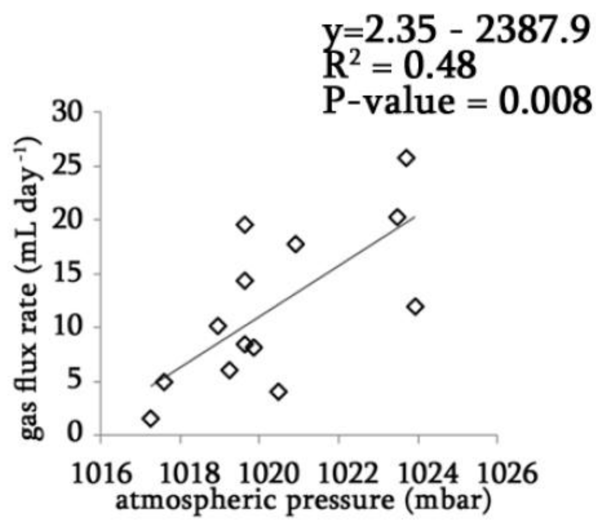
Steady

c) Gas dynamics: **ebullition and atmospheric pressure**

GPR + flux + camera + atm P



LILA-WCA1



tree island site
0.85 m peat column (H6-H8)
average porosity = 90%

Positive linear relationship between changes in gas content and changes in atm P
(i. e. ebullition events during high atm P events = volume decrease during high P = increased mobility)

4. Conclusions:

- Hydrogeophysical methods, mainly GPR and capacitance probes combined with gas traps and time-lapse cameras provide consistent information in peat soils of the Everglades as related to:
  - Peat thickness
  - Biogenic gas production and release
  - Ebullition events (differentiation of steady vs. episodic ebullition)
  - Correspondence of gas fluxes and changes in atmospheric pressure

- They allow for non-invasive (i.e. GPR and gas traps/time-lapse cameras) investigation of gas dynamics in peat soils

- They show promise for continuous and autonomous data acquisition beyond discrete measurements

5. Future directions

- Autonomous GPR measurements in the field
- Expanded discrete measurements for biogenic gas dynamics in the field
- Peat thickness characterization in the field at larger scales


Caribou Bog, Maine


WCA3, Everglades


LILA, WCA1, Everglades

Thanks to:

- Funding:
  - USGS (Greater Everglades Priority Ecosystem Science)
  - South Florida Management District
- Individuals:
  - Eric Cline, David Sumner; Marc Royer; Greg Mount; Tyler McNaab; Anastasia Cabolova; Diego Quiros; Tyler Beck; Bryan Botson; Dale Gawlik; Len Berry; Ronnie Best