Cornell University
College of Agriculture and Life Sciences

Constrained Estimate of Methane Emissions

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Outline

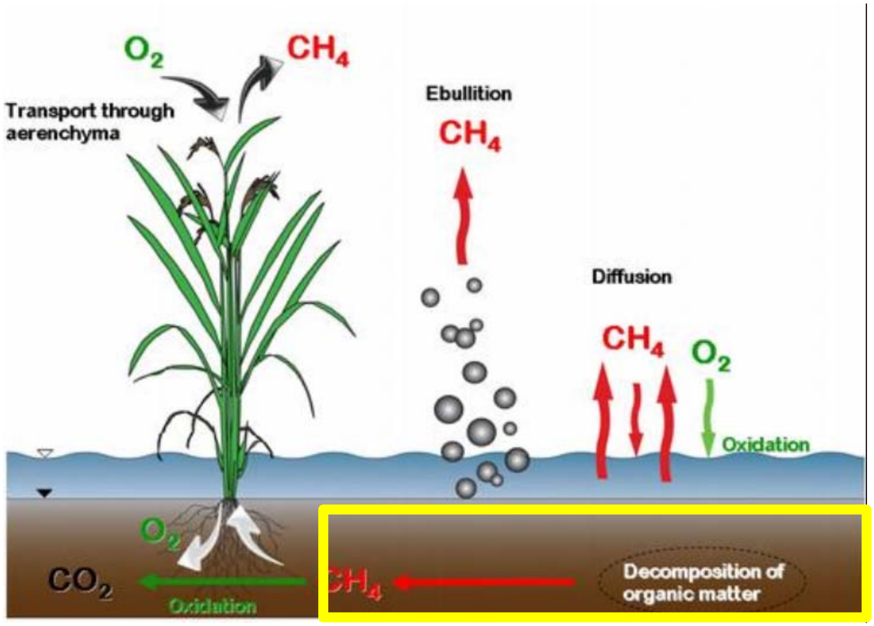
- Modifications to the model
- Site level comparison to observations
- Global level comparison to observations
- Sensitivity analysis
- Conclusions

CH_4 Production

- Modeled methane production depends on CLM-CN predicted soil respiration.

$$P = R_H * f_{CH4} * Q_{10}' * S * \boldsymbol{f_{pH}} * \boldsymbol{f_{pE}}$$

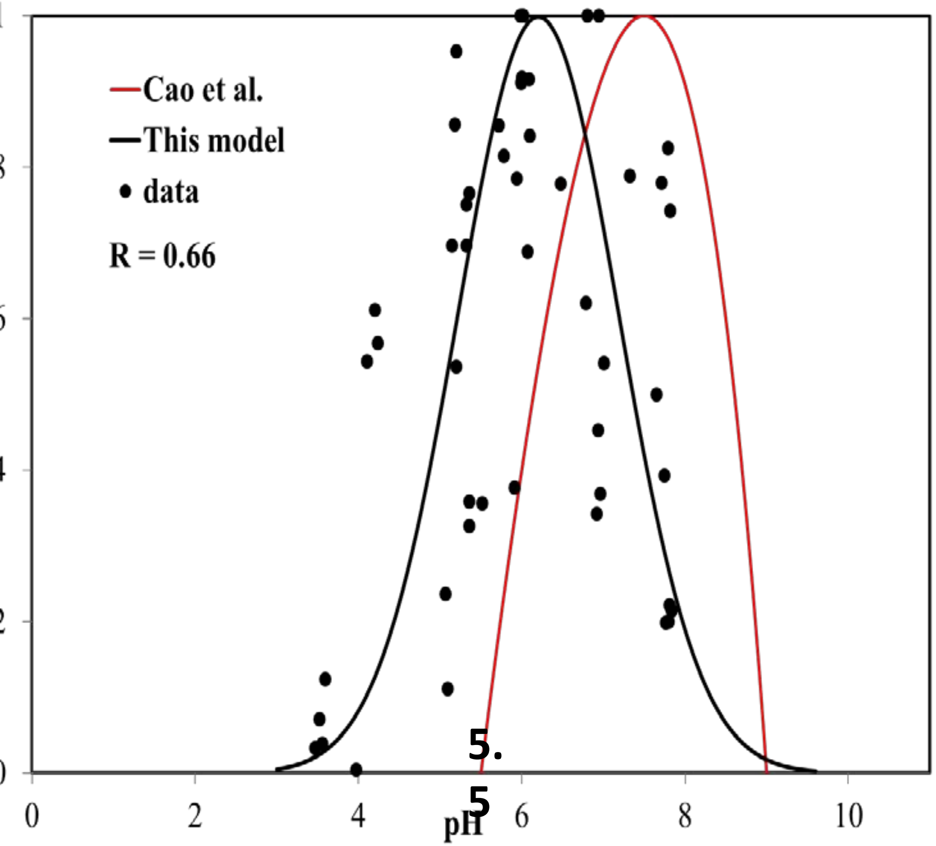
R_H is heterotrophic respiration
f_{CH4} is CH4/CO2 ratio
Q_{10}' is soil temperature function
S is seasonal inundation factor
f_{pH} is pH factor
f_{pE} is redox potential factor



(Riley et al. submitted, Meng et al. to be submitted)

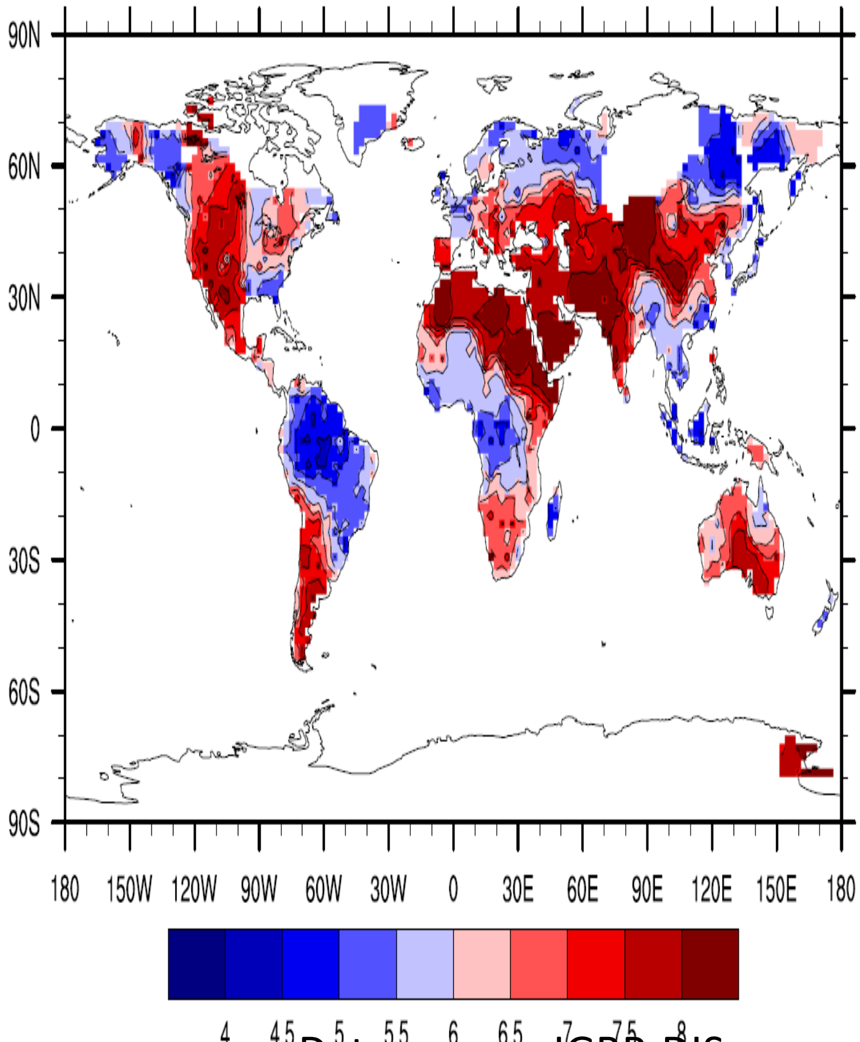
https://www1.ethz.ch/ibp/research/environmentalmicrobiology/research/Wetlands

Impact of soil pH on methane production



Data source: Dunfield et al. 1993

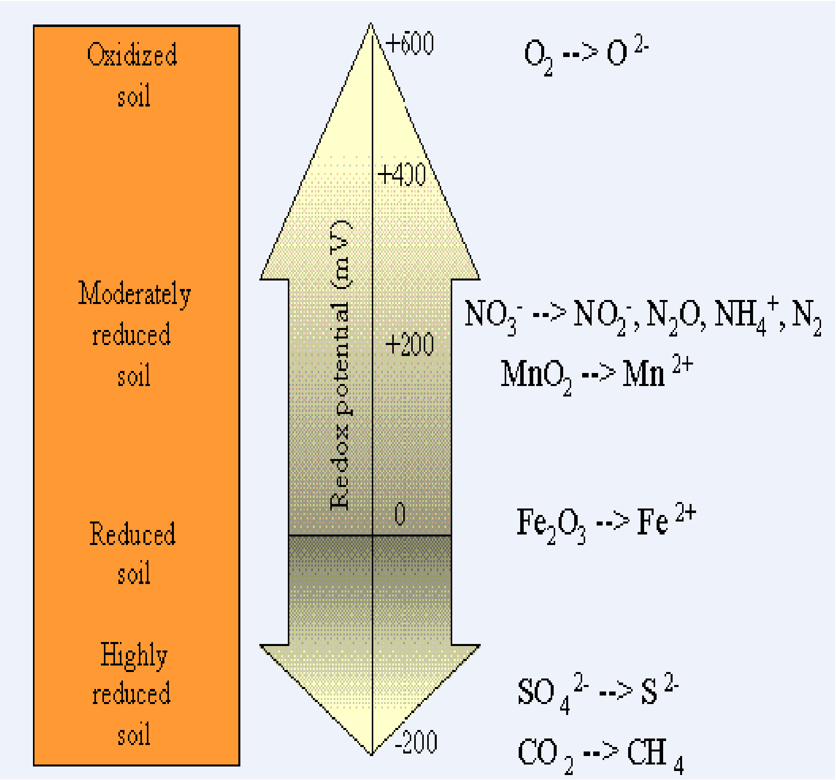
Global distribution of soil pH



Data source: IGBP-DIS

Impact of redox potential (f_{pE})on methane production

- Redox potential is an indicator of the abundance of alternative electron acceptors (such as O_2, NO_3^-, Mn^{+3},Fe^{+3}, SO_4^{-2}).
- Methane production only occurs when redox potential is below ~-200mV.
- We assumed alternative electron receptors are consumed with an e-folding time of 30 days following inundation



CH_4 Oxidation: $CH_4 + O_2 \longrightarrow CO_2 + H_2O$

- Oxygen transport

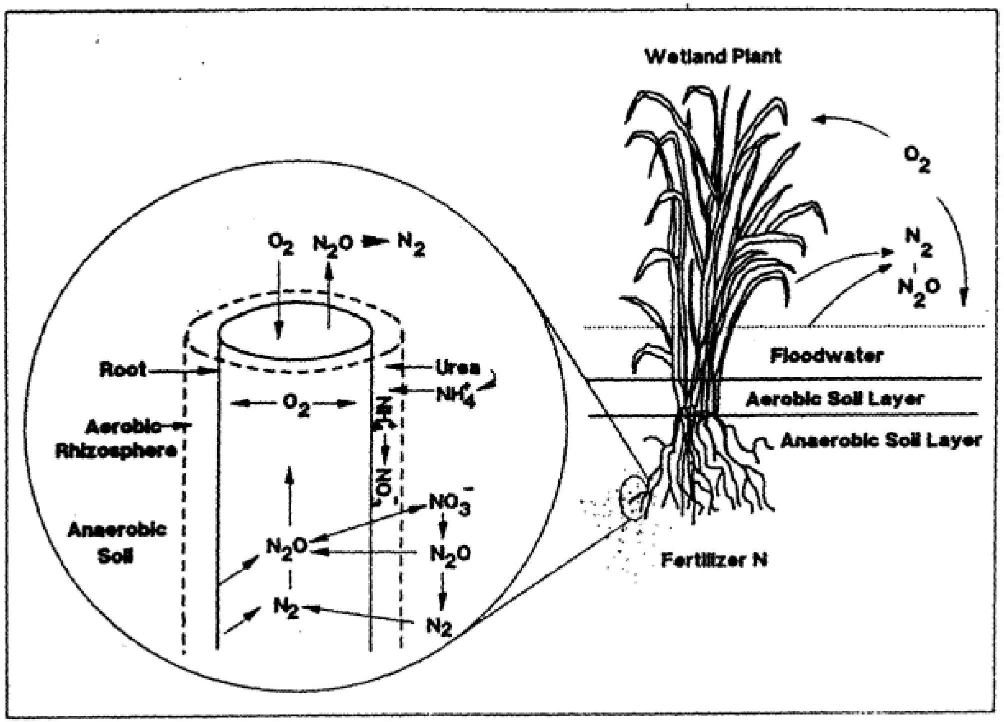
through Aerenchyma

The diffusive transport through aerenchyma (A, mol m^{-2} s^{-1}) from each soil layer is represented in the model as:

$$A = f(C(z) - C_a) * Area * f_{npp}$$

$$f_{npp} = \max(0, \frac{npp(t)}{npp_{ann\max}})$$

where $C(z)$ (mol m^{-3}) is the gaseous concentration at depth z (m); *npp is net primary production, A is the specific aerenchyma area (m^2 m^{-2})*



- f_{npp} is used here to introduce the seasonal variation in root O_2demand

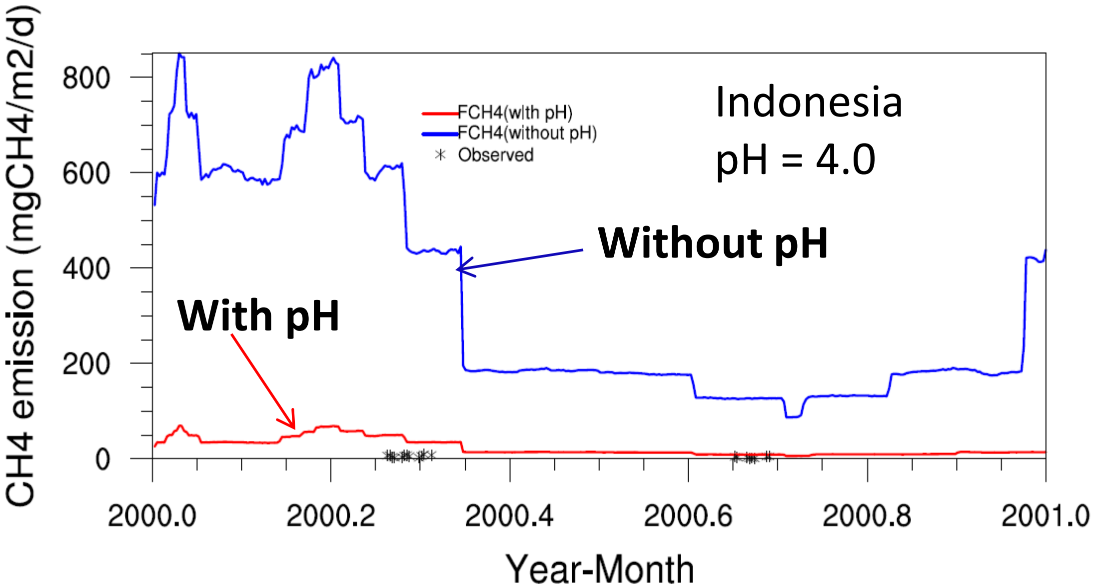
(Meng et al. to be submitted)

Site Level Comparisons

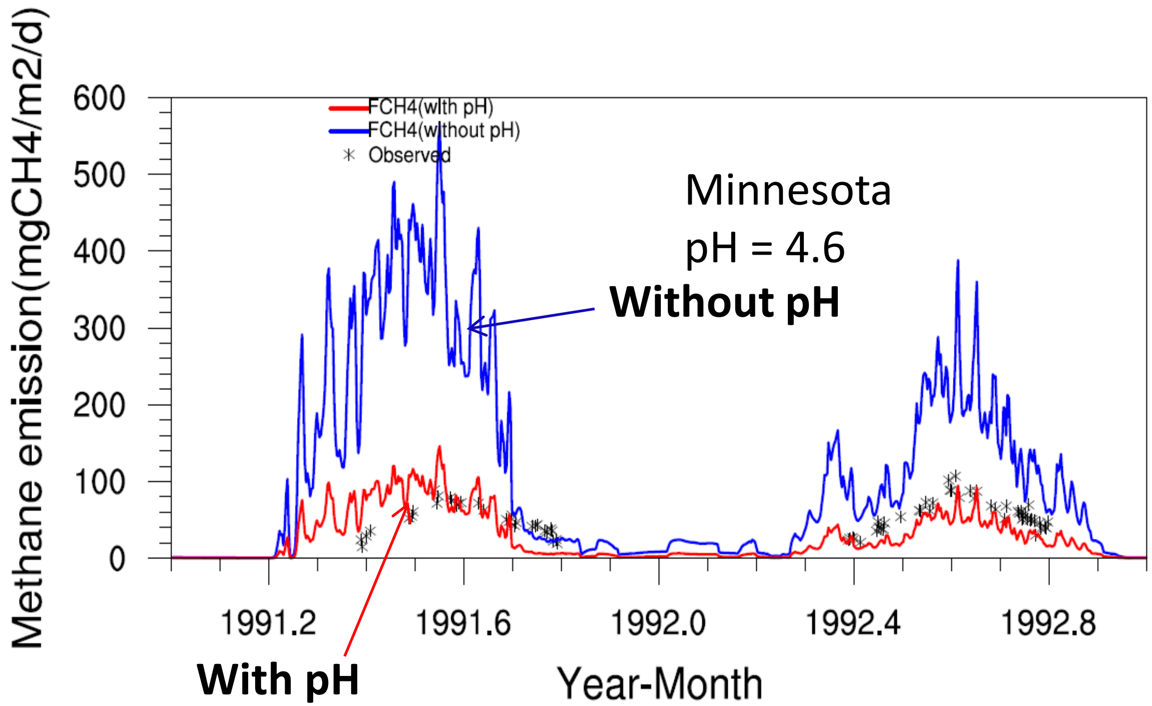
- CLM spun-up on at a number of individual sites
- Explicitly forced with site specific water table height
- NCEP reanalysis data

Site Name	Location	Wetland type	Dominant vegetation	Mean Precipitation and temperature	Soil and climate characteristics	Measurement technique	forcing data	References
Central Kalimantan, Indonesia	2.33S, 113.92 E	ombrotrophic bog	Tree seedlings	Mean precipitation is 2331 mm and mean T is 26.3 between 2002 and 2005	wet season lasts from October to May and dry season lasts from June to September, soil pH is 4.0	Closed chamber method	NCEP atmospheric forcing, except measured water table positions	Jauhiainen et al. 2005
Panama	9N, 80W	swamp	Palm	Mean precipitation is 1600 mm in Panama city and mean temperature is 27	Four-month dry season between Febrary and May. Soil pH is 6.2	Static chamber method	NCEP atmospheric forcing, except modeled water table positions from Walter and Heimann (2000)	Keller (1990); Walter and Heimann (2000)
Salmisuo, Eastern Finland	62.75N, 30.93E	Minerogenic, oligotrophic pine fen	Sphagnum papillosum	Mean temperature is about 10 C	wet season from July to September	dark static chamber	NCEP atmospheric forcing, except measured water table positions	Saarnio et al. 1997
Michigan peatland	42.45N, 84W	ombrotrophic peatlands	Sphagnum	Mean precipitation for 1948-80 is 761 mm	soil pH 4.2	Static chamber method	NCEP atmospheric forcing, except measured water table positions	Shannon and White, 1994
Minnesota	47.53N, 266.53	oligotrophic	Sphagnum, Carex, Sheushzeria palustris	Average precipitation is 553 mm and mean temperature is about 13.6 °C for the May-October period	soil pH is 4.6	Eddy correlation technique	NCEP atmospheric forcing, except measured water table positions	Shurpali and Verma, 1998
Alberta, Canada	54.6N, 246.6E	Fen	Carex aquatilis and cares rostrata	N/A	The freeze-thawn cycle spans from May to October, pH =7	Cylindrical plexiglas chambers	NCEP atmospheric forcing, fully saturated areas	Popp et al. 2000

Importance of pH in methane emissions



pH is important in constraining methane emissions and should be included in process-based methane models



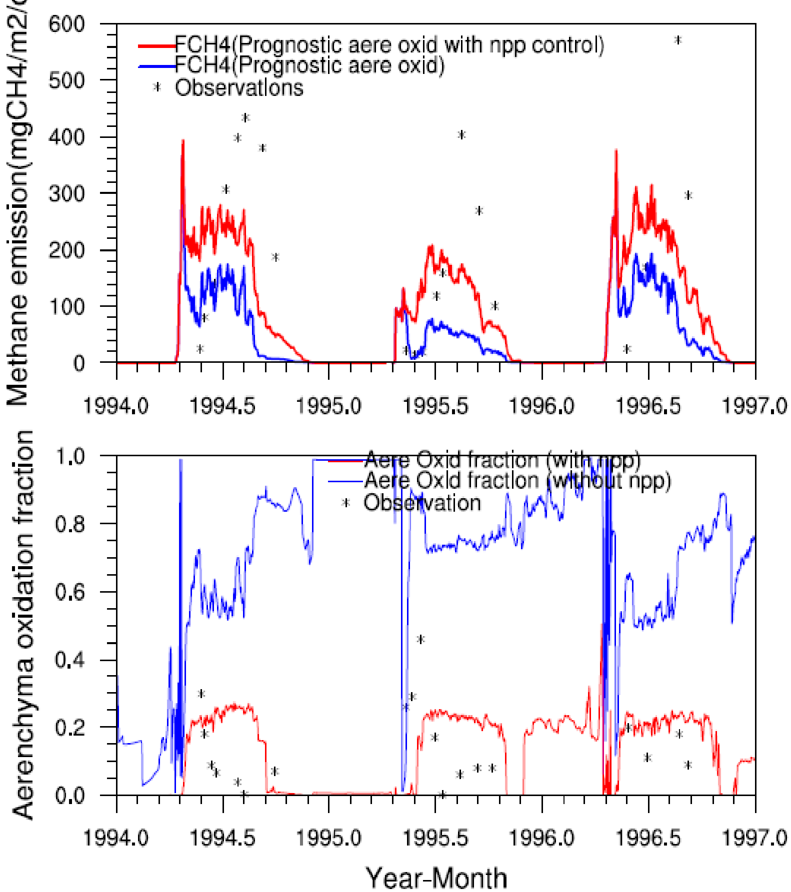
Jauhiainen et al. 2005, Shurpali and Verma, 1998

NPP-factor

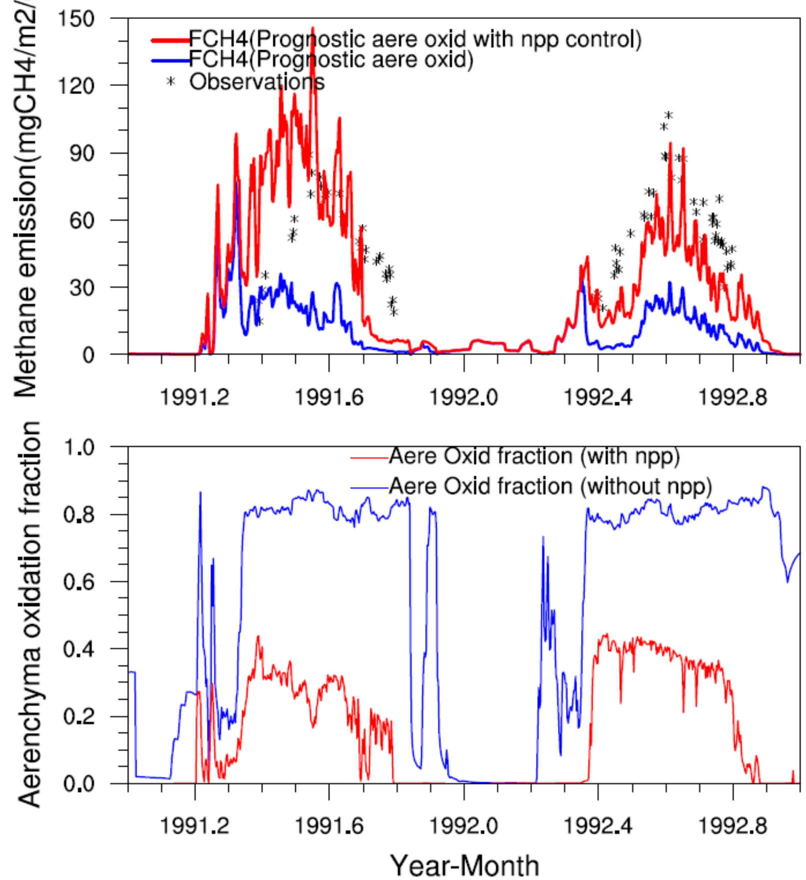
$$A = f(C(z) - C_a) * Area * f_{npp}$$

$$f_{npp} = \max(0, \frac{npp(t)}{npp_{ann\max}})$$

Alberta, Canada



Minnesota



With the npp factor, both the magnitude and seasonal variation of methane emissions and aerenchyma oxidation fraction are better simulated

Popp et al. 2000, Shurpali and Verma, 1998

Redox Potential

- Inclusion of Redox potential reduces CH_4 emissions
- No site level measurements found where redox has a large impact

Site Simulations: Rice paddy simulations

Table 1 Site descriptions for rice paddy fields

Site Name	Year	Location	pH	Date of field flooded	Date of final drainage	Nitrogen added	Rice type (cultivar)	Measurement techniques	Soil type	References
Texas	1994	29.95N, 265.5E	N/A	17-May	11-Aug	Yes	Lemont	Chamber	Bernard-Morey	Sigren et al. [1997]
Italy	1991	45.3N, 8.42E	6	7-May	30-Aug	Yes	Roma/Lido	Static (Closed) Chamber	Sandy loam	Butterbach-Baul et al. [1997]
Chengdu (China)	2003	31.27N,105.45E	8.1	9-May	7-Sep	Yes	hybrid II-You 162	Chamber	Purplish	Jiang et al. [2006]
Nanjing (China)	1999	32.8N, 118.75E	N/A	18-Jun	13-Oct	Yes	# 9561	Chamber	Hydromorphic	Huang et al. [2001]
California	1982	40.2N,237.98E	N/A	11-May	2-Oct	Yes	M101	Static chamber	Capay silty clay	Cicerone et al. [1992],Cicerone et al. [1983
	1983			21-May	1-Oct	Yes				
Japan	1991	36.02N, 140.22E	6.6-6.9	7-May	12-Aug	Yes	Koshihikar	Automated chamber	Gley soil (Sandy clay loam)	Yagi et al.[1996]
	1993		6.6-6.9	7-May	2-Sep	Yes	Koshihikar			
New Delhi, India	1995	20.08N, 77.12E	8.2	1-Jul	1-Nov	Yes	IR72	Closed chamber, manual	Ustochrept (sandy loam)	Jain et al. [2000]
	1996									
Cuttack, India	1996	20.42N, 85.92E	6.19	19-Jul	30-Oct	Yes	CR 749-20-2	Automatic chamber	Haplaquept (Alluvial)	Adhya et al. [2000]
Beijing, China	1995	40.55 N, 116.78E	7.99	4-Jun	17-Oct	Yes	Zhongguo	Automatic chamber	silty clay loam	Wang et al. 2000
Central Java, Indonesia	2001-2002	6.63S, 110E	5.1	1-Nov	28-Feb	Yes	Memberamo, Cisadane, IR64, Way Apoburu	Automatic closed chamber	Aeric Tropaquept (Silty loam)	Setyanto et al. 2004 (Indonesia Journal of Agricultural Science)
Lampung, Indonesia	1993	4.52S, 105.3E	5	21-Nov	4-Mar	yes	Oryza Sativa var. IR-64	Chamber	Typic Paleudult (Sandy clay)	Nugroho, et al. 1994 (SSPN

- CH_4/CO_2 emission ratio= 0.5[1]

-Constant aerenchyma oxidation of 50%

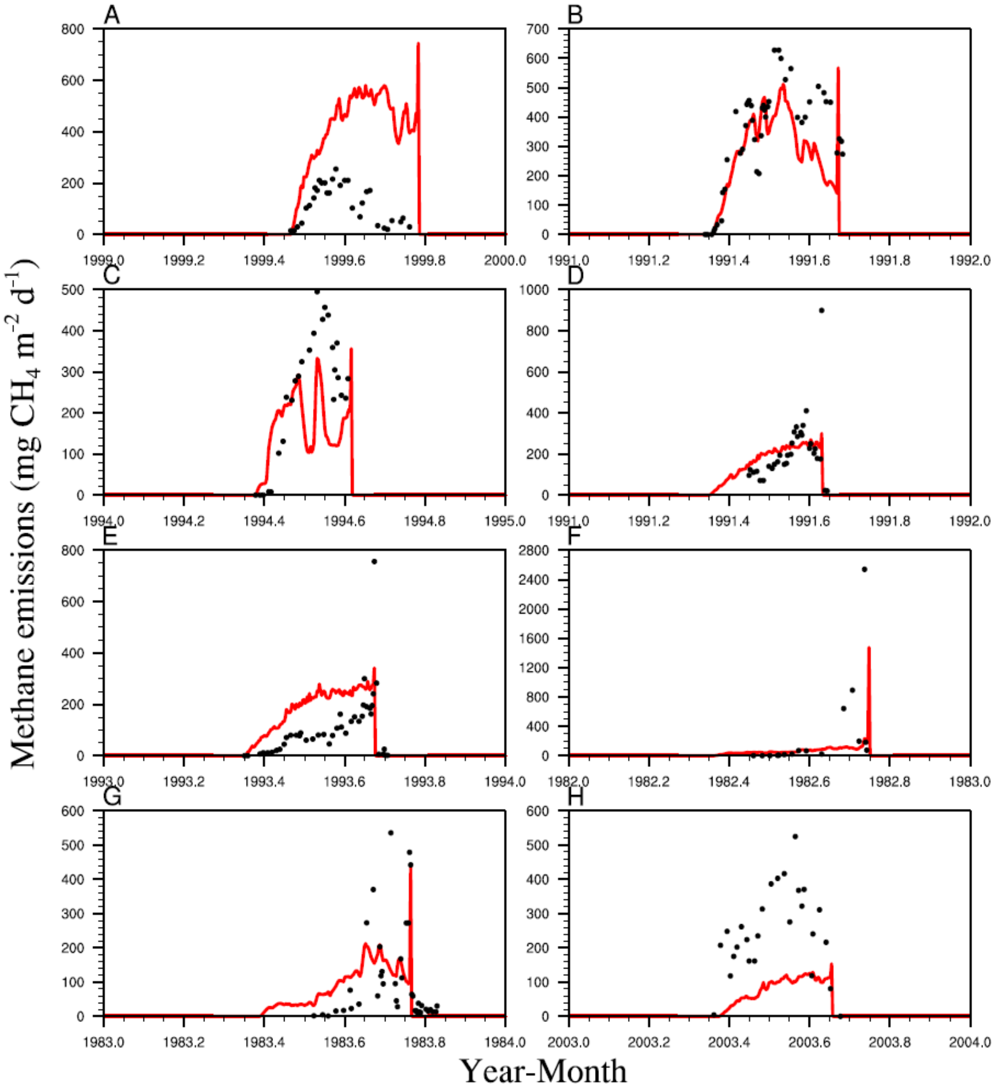
-50% is the mean value of large range 0%-94%

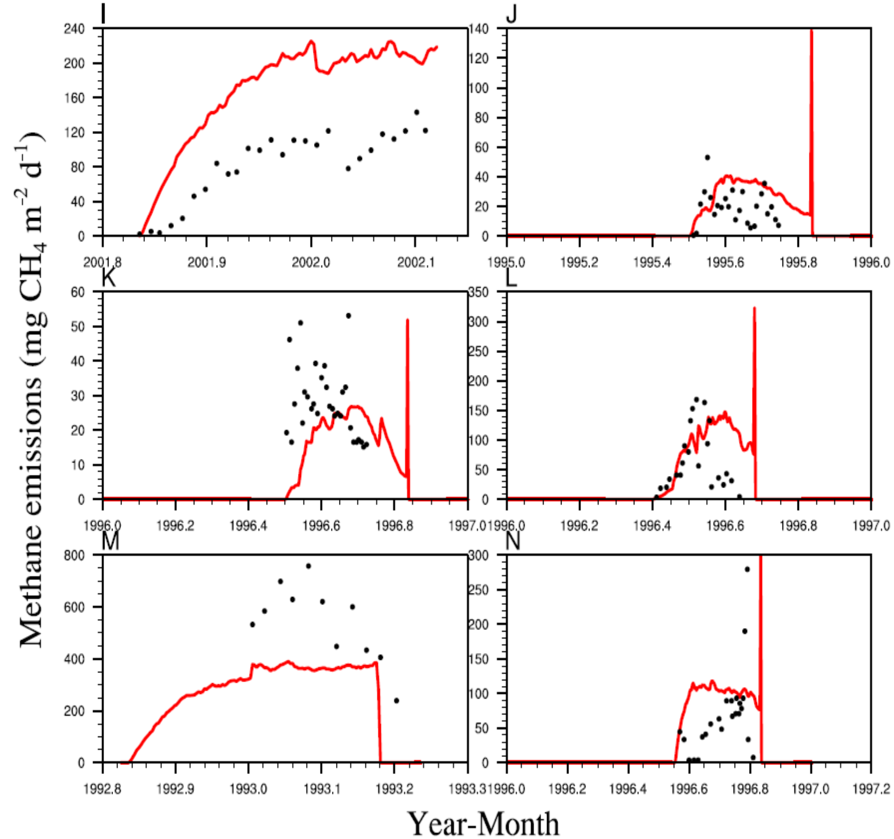
- Rice paddies are always inundated

[1]Conrad and Klose, 1999;Conrad, 2002

[2] Groot et al. 2003

Rice paddy simulations

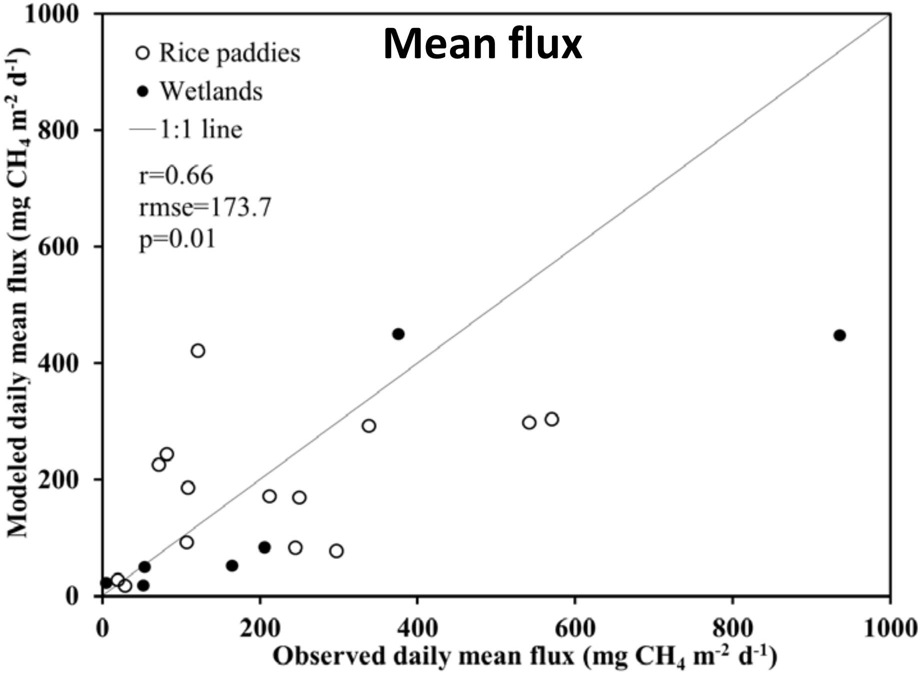


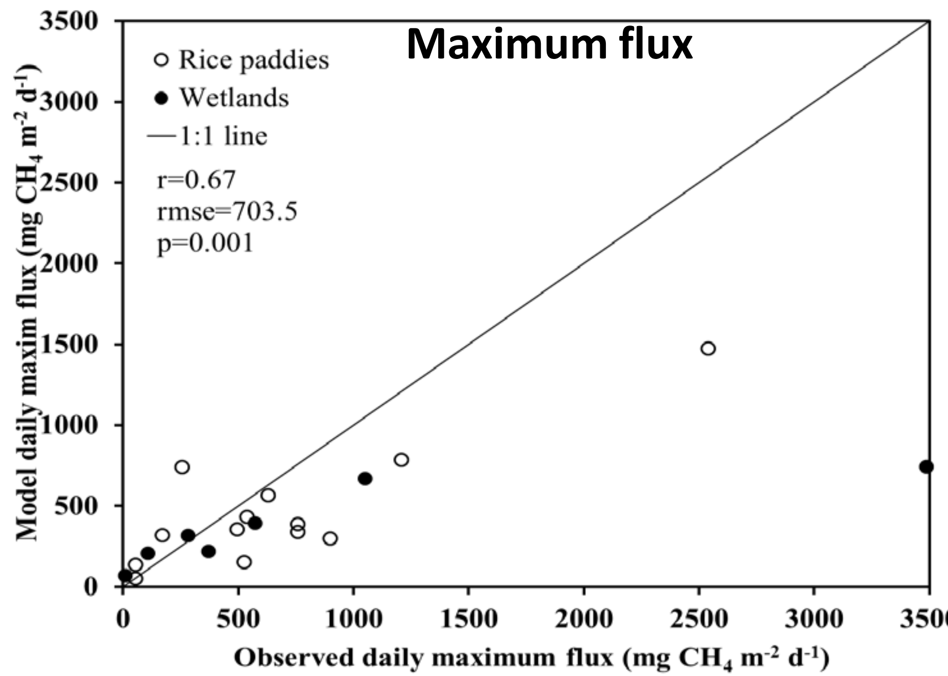


A: Nanjing, China; B: Italy; C:Texas, USA; D: Japan,1991; E:Japan,1993; F:California, USA, 1982; G: California, USA, 1983; H:Chengdu, China;). I: Central Java, Indonesia; J: New Delhi, India, 1995; K: New Delhi, India, 1996; L: Beijing, China; M: Lampung, Indonesia; N: Cuttack, Indonesia.

Sigren et al. [1997], Butterbach-Baul et al. [1997], Jiang et al. [2006], Huang et al. [2001], Cicerone et al. [1992],Cierone et al. [1983], Yagi et al.[1996], Jain et al. [2000], Adhya et al. [2000], Wang et al. 2000, Setyanto et al. 2004 , Nugroho, et al. 1994

Model vs. Observations





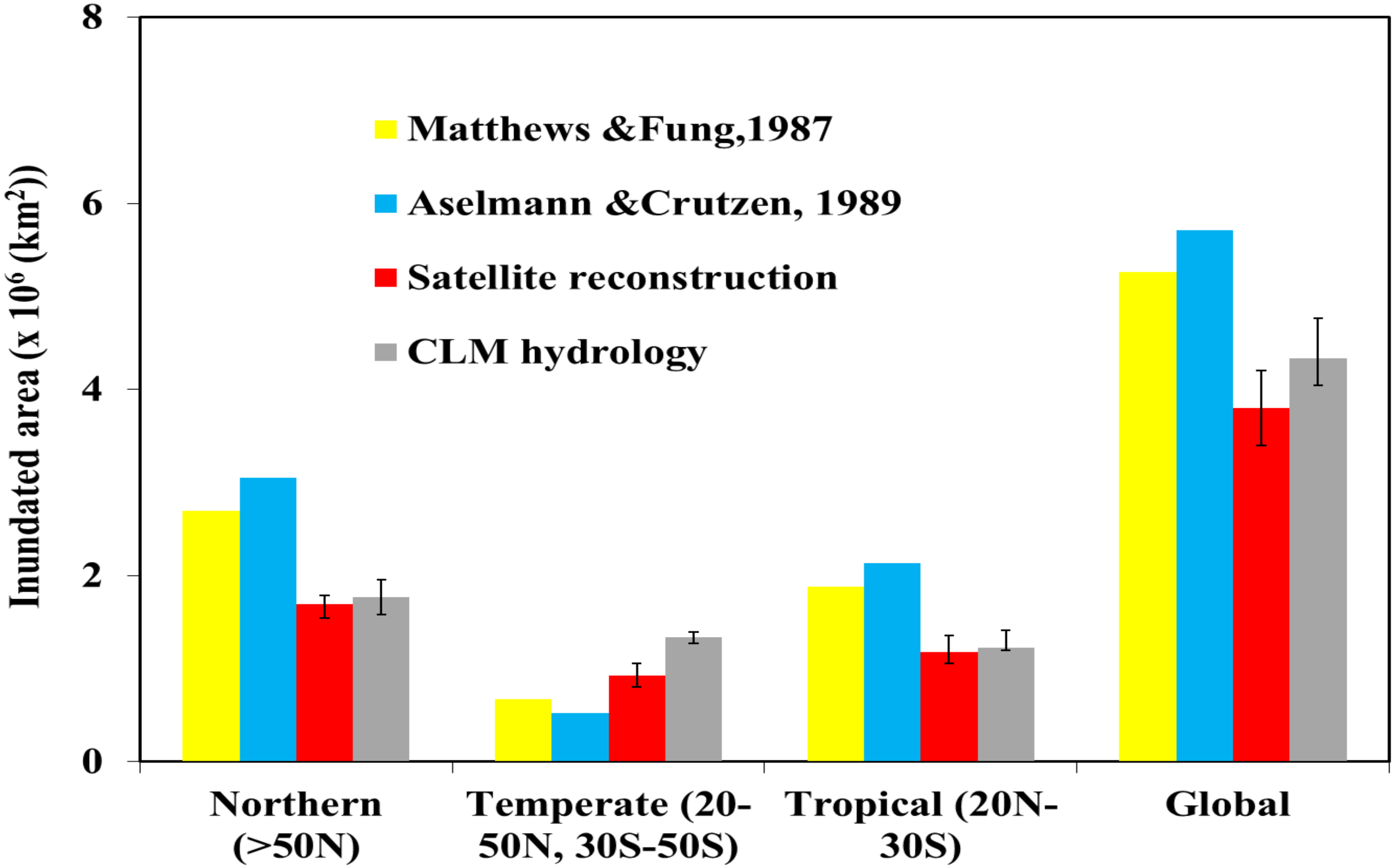
Gridpoint Level Comparisons

NCEP reanalysis data (precipitation, temperature, and solar radiation, etc.)

At global scale, model is forced with satellite inundated fraction

- **Multi-satellite reconstruction (Prigent et al., 2007, Papa et al. 2010)**
  - Cover the period of 1993-2004
- **Strength and weakness of satellite dataset**
  - Seasonality of wetland extents
  - Remove the potential errors associated with CLM hydrology
  - Satellites may underestimate wetland extents, particularly in high latitudes

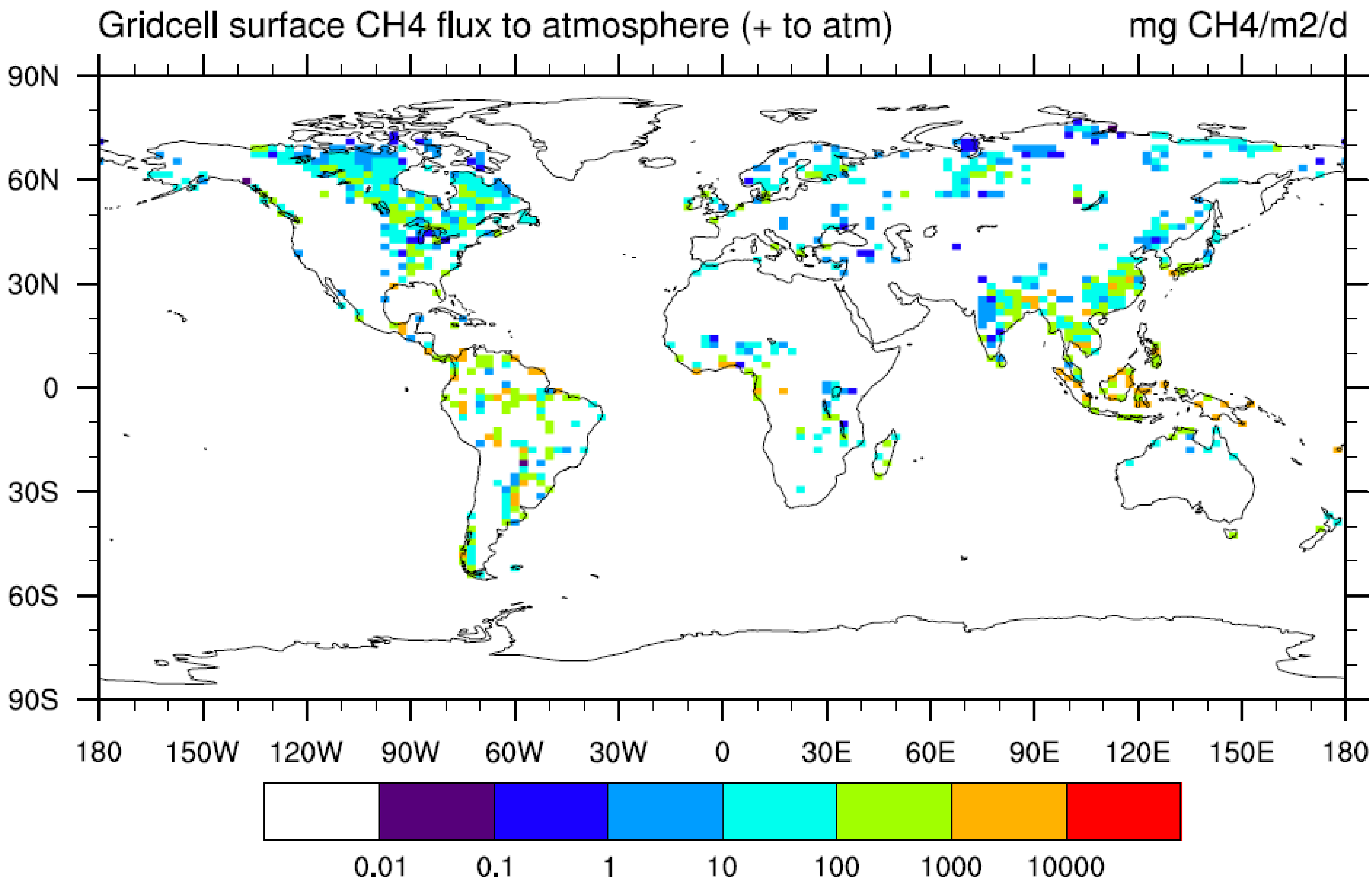
Comparison of wetland areas

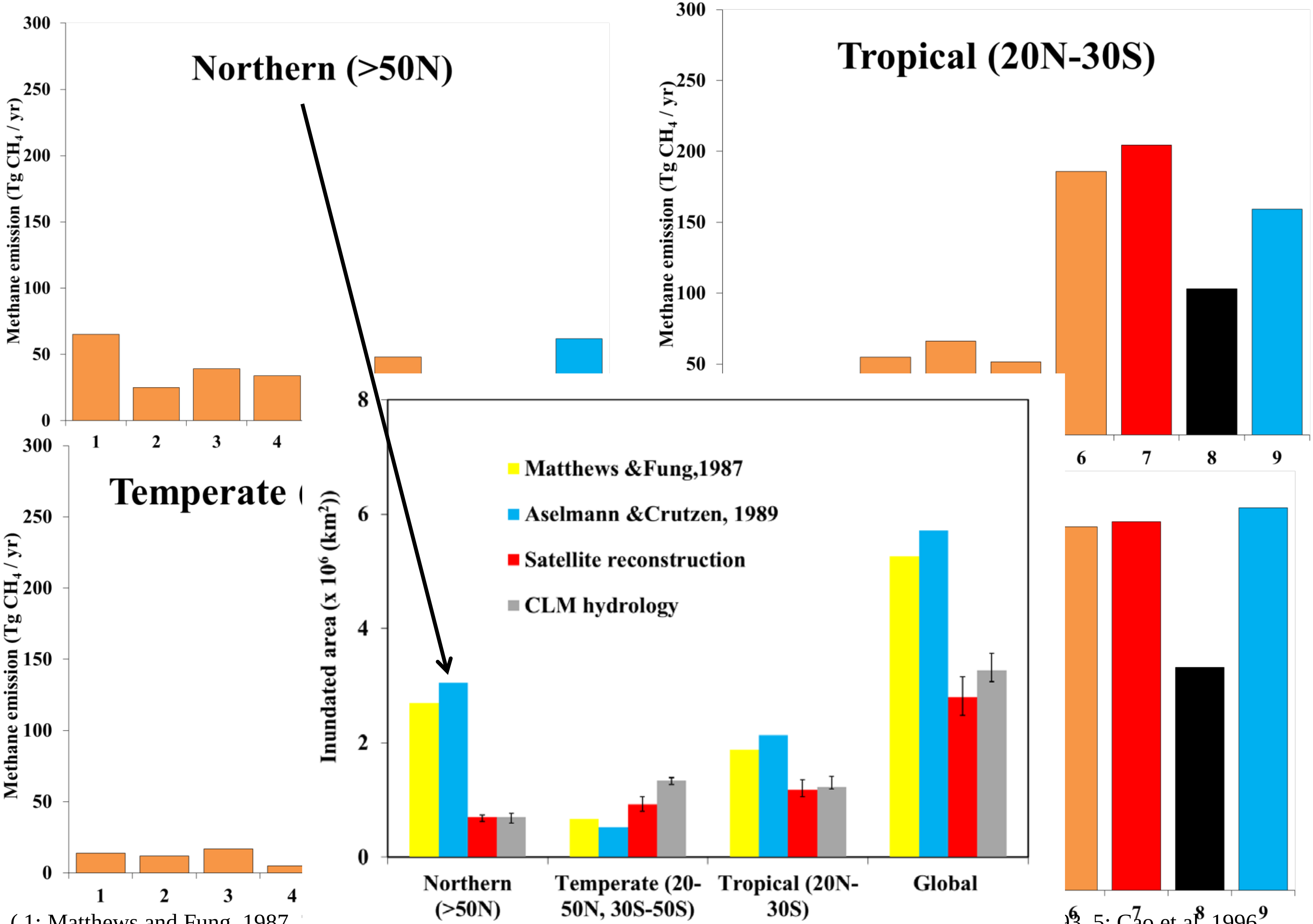


Note: For northern regions, inundated areas in June, July, August, and September are used to calculate the mean inundated area

(Meng et al. to be submitted)

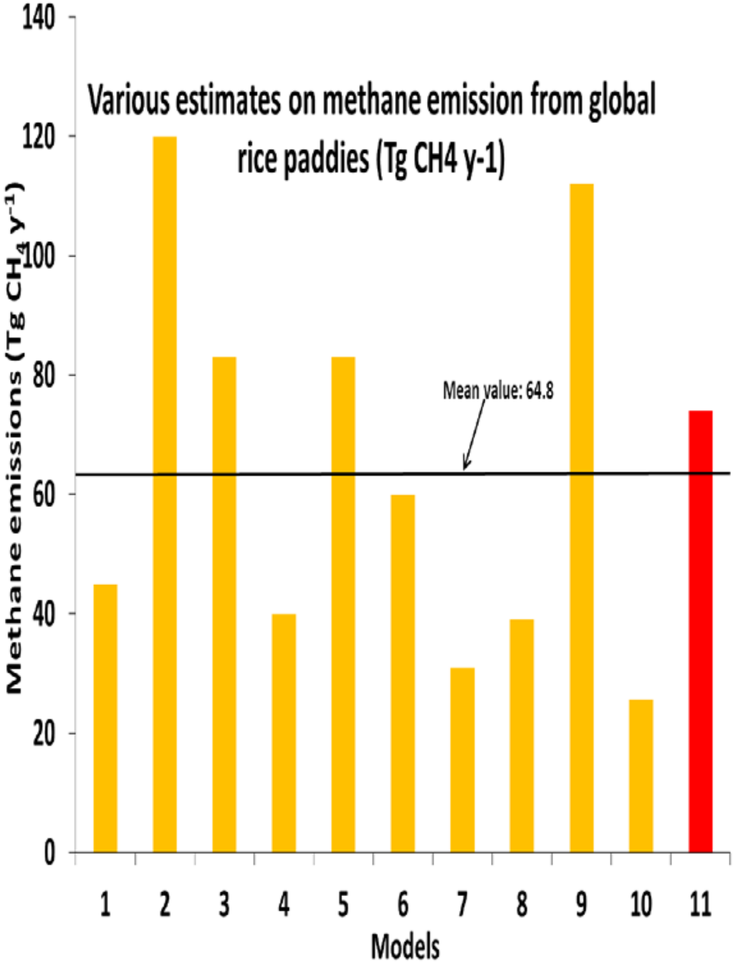
Spatial distribution of methane emissions

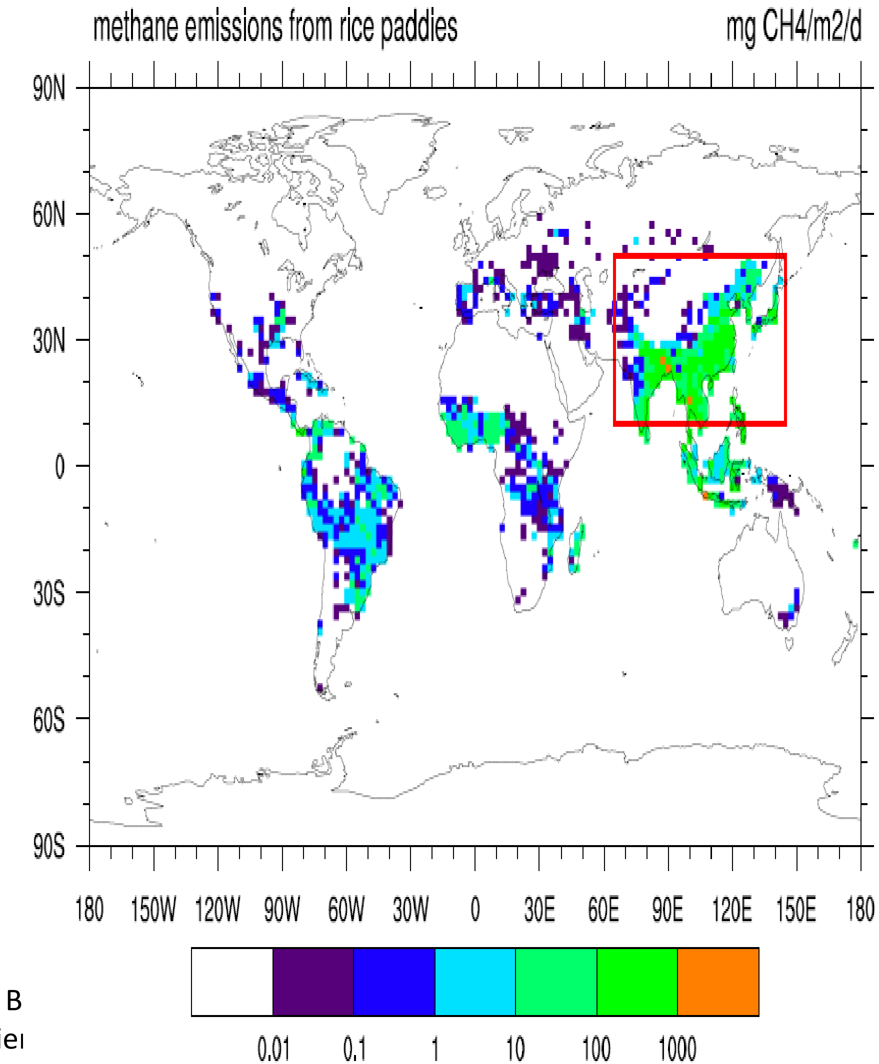




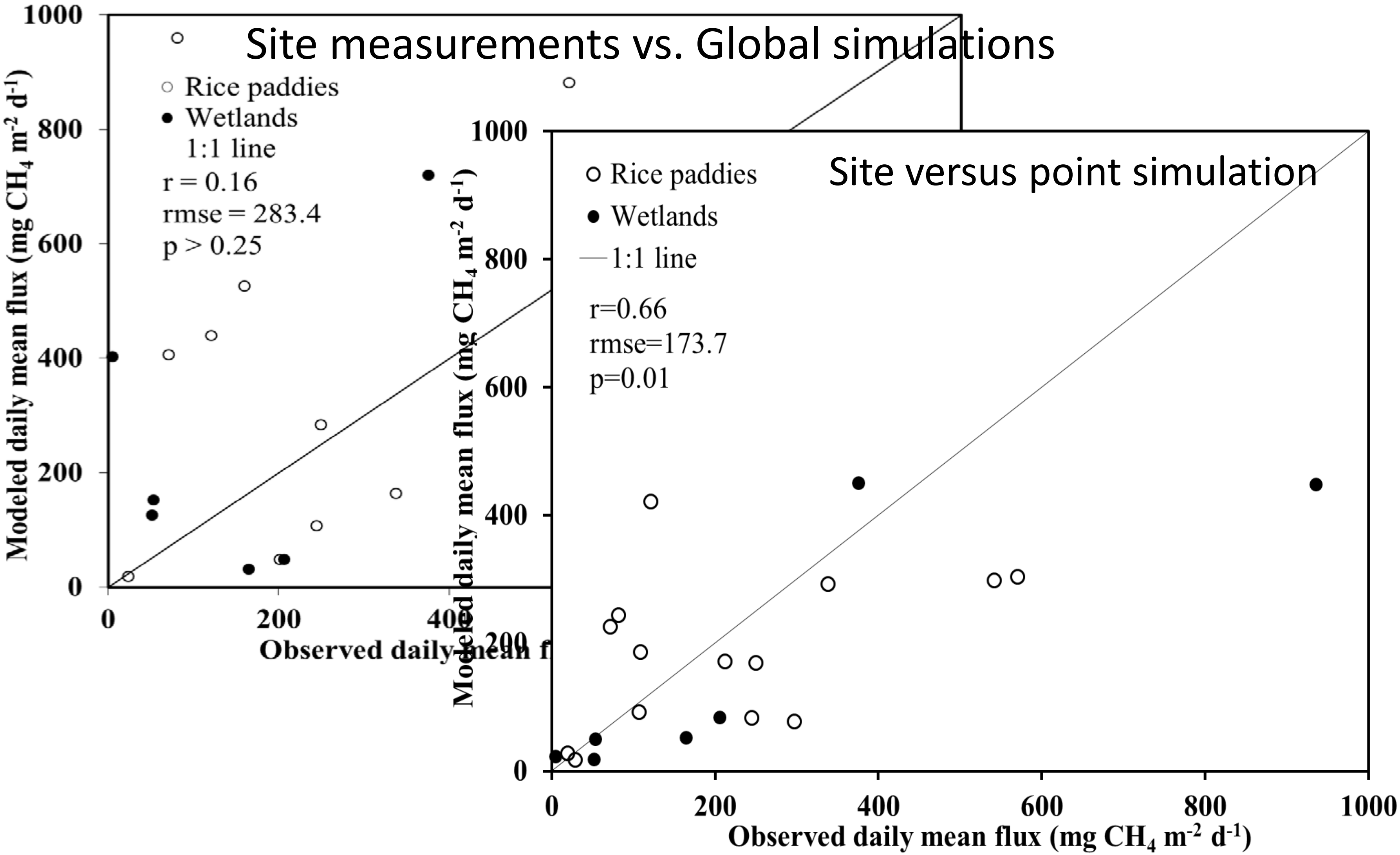
.(1: Matthews and Fung, 1987, 2: Aselmann and Crutzen, 1989, 3: Bartlett et al., 1990, 4: Bartlett and Harriss, 1993, 5: Cao et al. 1996, 6: Walter et al., 2001, 7: This model, 8: Bousquet et al. 2006; 9: Riley et al. simulation. Red indicates our model. Black indicates top-down model.)

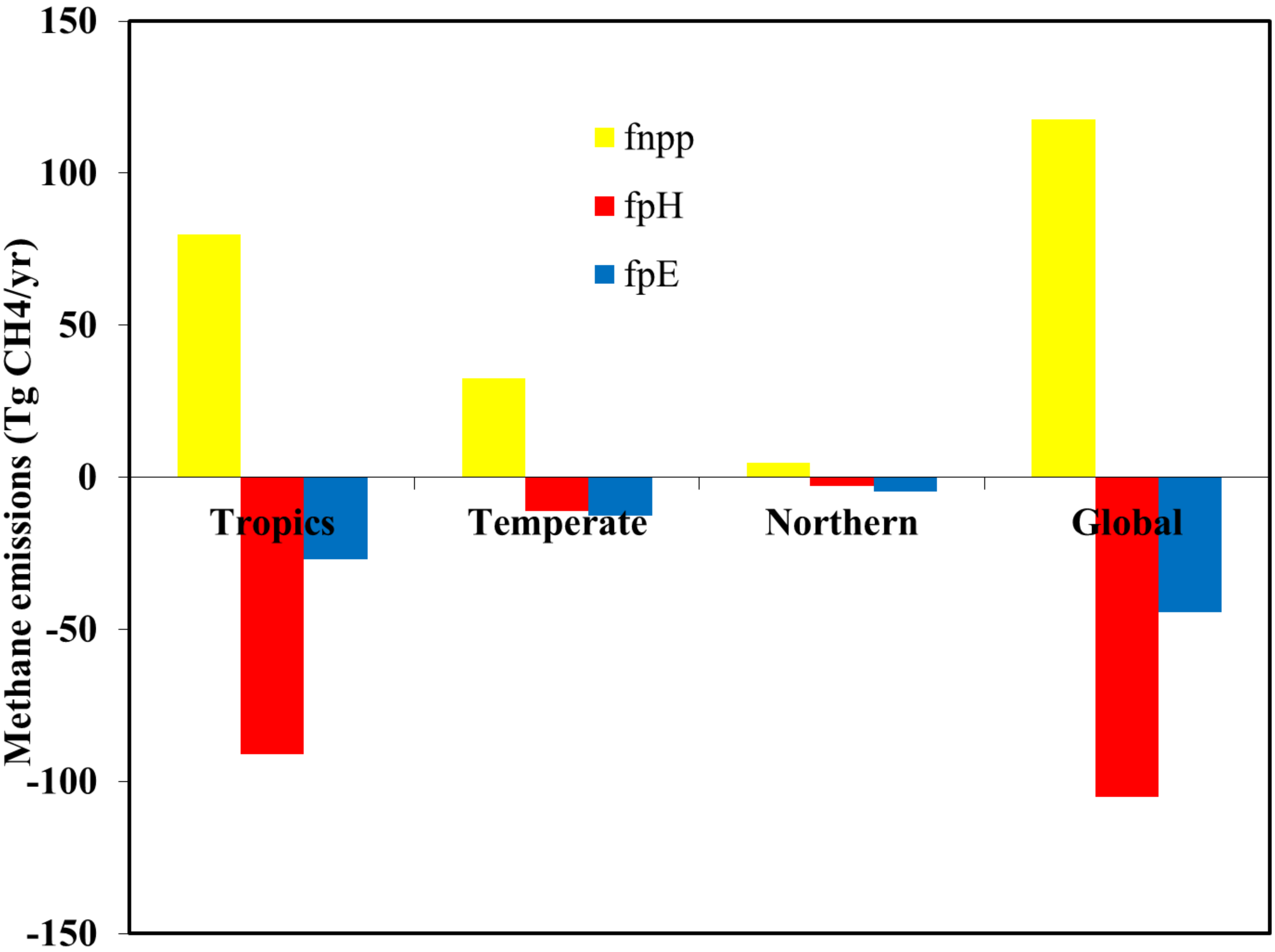
Rice paddy





1: Seiler et al. 1984; 2: Holzapfel-Pschorn and Seiler, 1986; 3: B
6:Wuebbles and Hayhoe, 2000;7:Scheehle et al. 2002; 8:Olivier

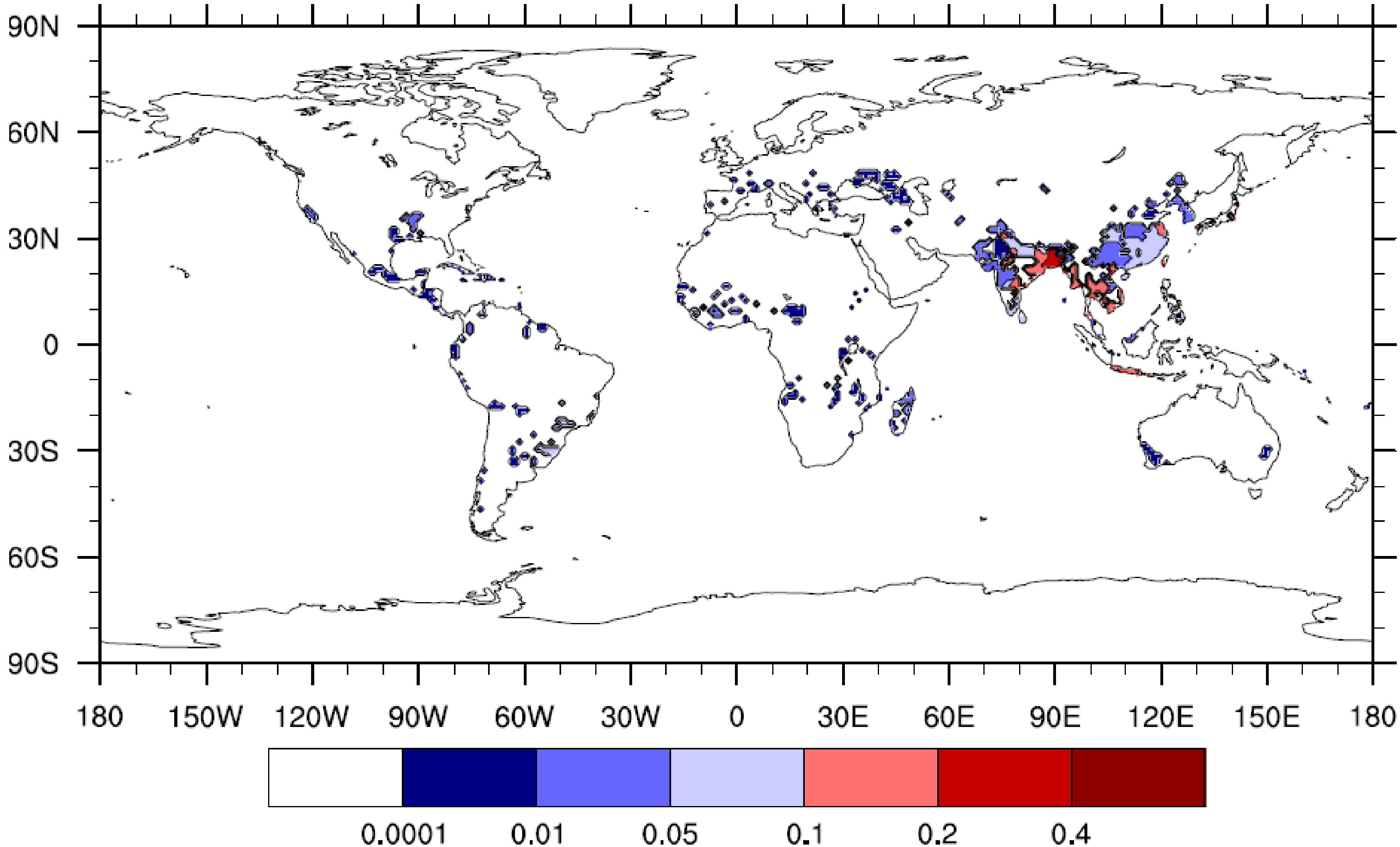

Site measurements vs. Global simulations
Rice paddies
Wetlands
1:1 line
r = 0.16
rmse = 283.4
p > 0.25
Modeled daily mean flux (mg CH4 m-2 d-1)
1000
800
600
400
200
0
0
200
400
Site versus point simulation
Rice paddies
Wetlands
1:1 line
r=0.66
rmse=173.7
p=0.01
Modeled daily mean flux (mg CH4 m-2 d-1)
1000
800
600
400
200
0
0
200
400
600
800
1000
Observed daily mean flux (mg CH4 m-2 d-1)

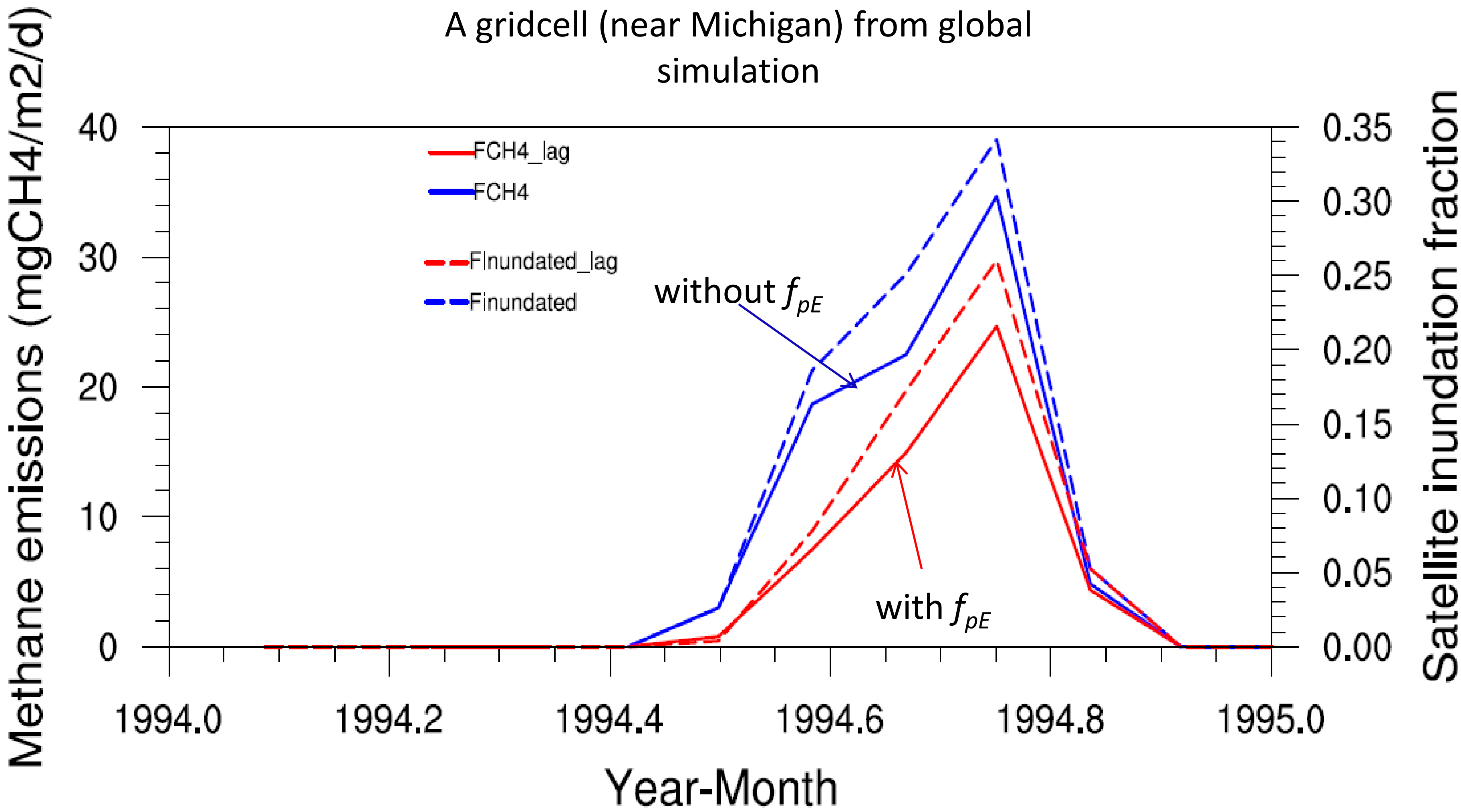

150
100
50
0
-50
-100
-150
Methane emissions (Tg CH4/yr)
fnpp
fpH
fpE
Tropics
Temperate
Northern
Global

Conclusions

- soil pH, redox potential, and NPP controlled oxygen diffusion are potentially important in constraining methane emissions and should be included in process-based models.
- Model estimates of methane budget are at the higher end of current estimates, but vary from region to region.
- On average, 40% of methane is oxidized when transported through aerenchyma.

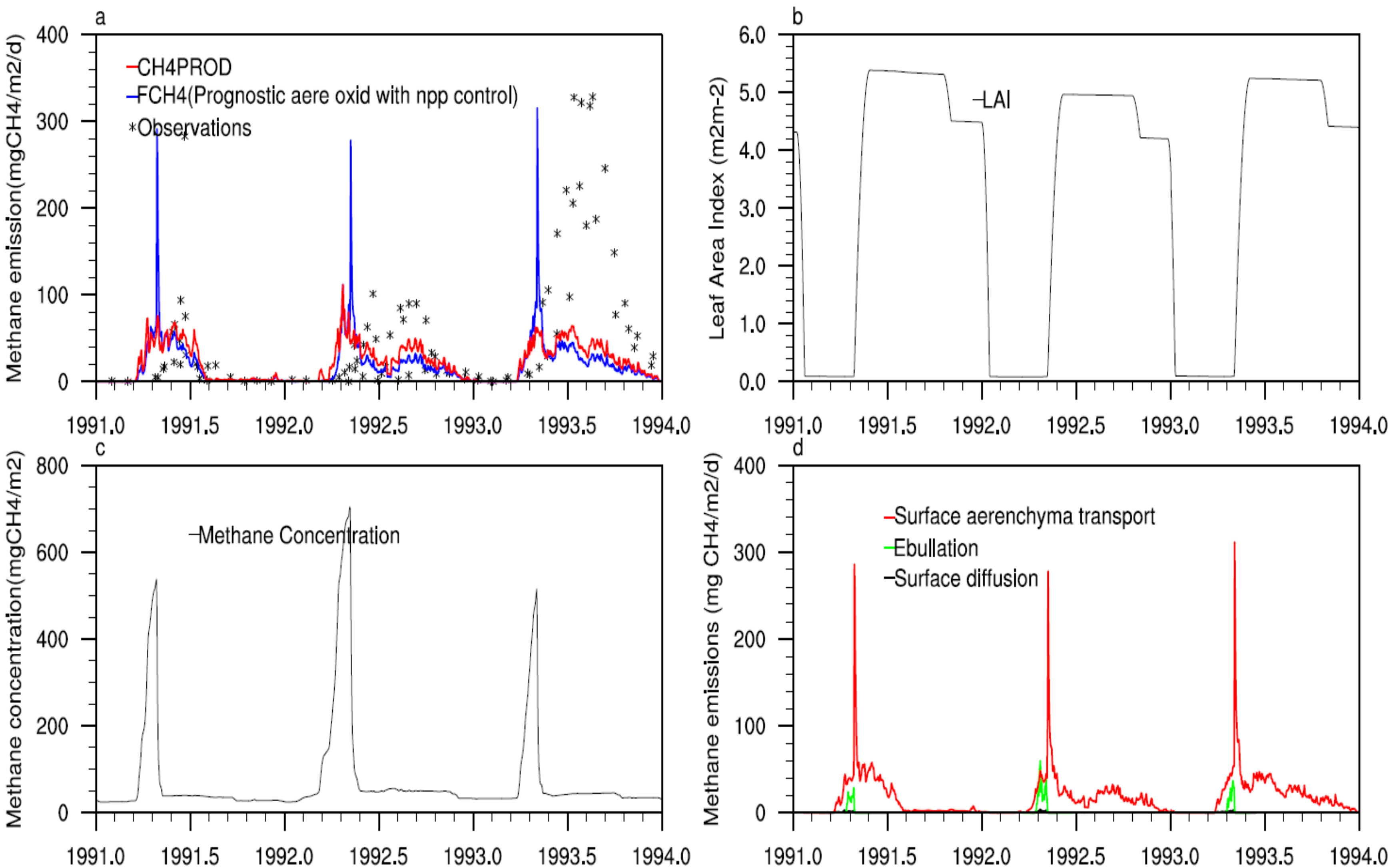
Rice paddy distribution





Redox potential is more important when there is a large variation in WTL or fractional inundation

Spikes in methane emission at Michigan site



Parameters used in this model

Mechanism	*Parameter*	*Baseline Value*	*Range for Sensitivity Analysis*	*Units*	*Description*
Production	Q_{10}	2	1.5 – 4	-	CH_4 production Q_{10}
	f_{pH}	1	On, off	-	Impact of pH on CH_4 production
	f_{pE}	1	On, off	-	Impact of redox potential on CH_4 production
	S	Varies	NA	-	Seasonal inundation factor
	β	0.2	NA	-	Effect of anoxia on decomposition rate (used to calculate *S* only)
	f_{CH_4}	0.2	NA	-	Ratio between CH_4 and CO_2 production below the water table
Ebullition	$C_{e,max}$	0.15	NA	mol m^{-3}	CH_4 concentration to start ebullition
	$C_{e,min}$	0.15	NA	-	CH_4 concentration to end ebullition
Diffusion	f_{D_0}	1	1, 10	$m^2\ s^{-1}$	Diffusion coefficient multiplier (Table 2)
Aerenchyma	p	0.3	NA	-	Grass aerenchyma porosity
	R	2.9×10^{-3} m	NA	m	Aerenchyma radius
	r_L	3	NA	-	Root length to depth ratio
	F_a	1	0.5 – 1.5	-	Aerenchyma conductance multiplier
Oxidation	K_{CH_4}	5×10^{-3}	5×10^{-4} - 5×10^{-2}	mol m^{-3}	CH_4 half-saturation oxidation coefficient (wetlands)
	K_{O_2}	2×10^{-2}	2×10^{-3} - 2×10^{-1}	mol m^{-3}	O_2 half-saturation oxidation coefficient
	$R_{o,\max}$	1.25×10^{-5}	1.25×10^{-6} - 1.25×10^{-4}	mol m^{-3} s^{-1}	Maximum oxidation rate (wetlands)

Sensitivity analysis will be focused on the impact of **soil pH, redox potential, and NPP controlled oxygen diffusion** on **global methane fluxes**.

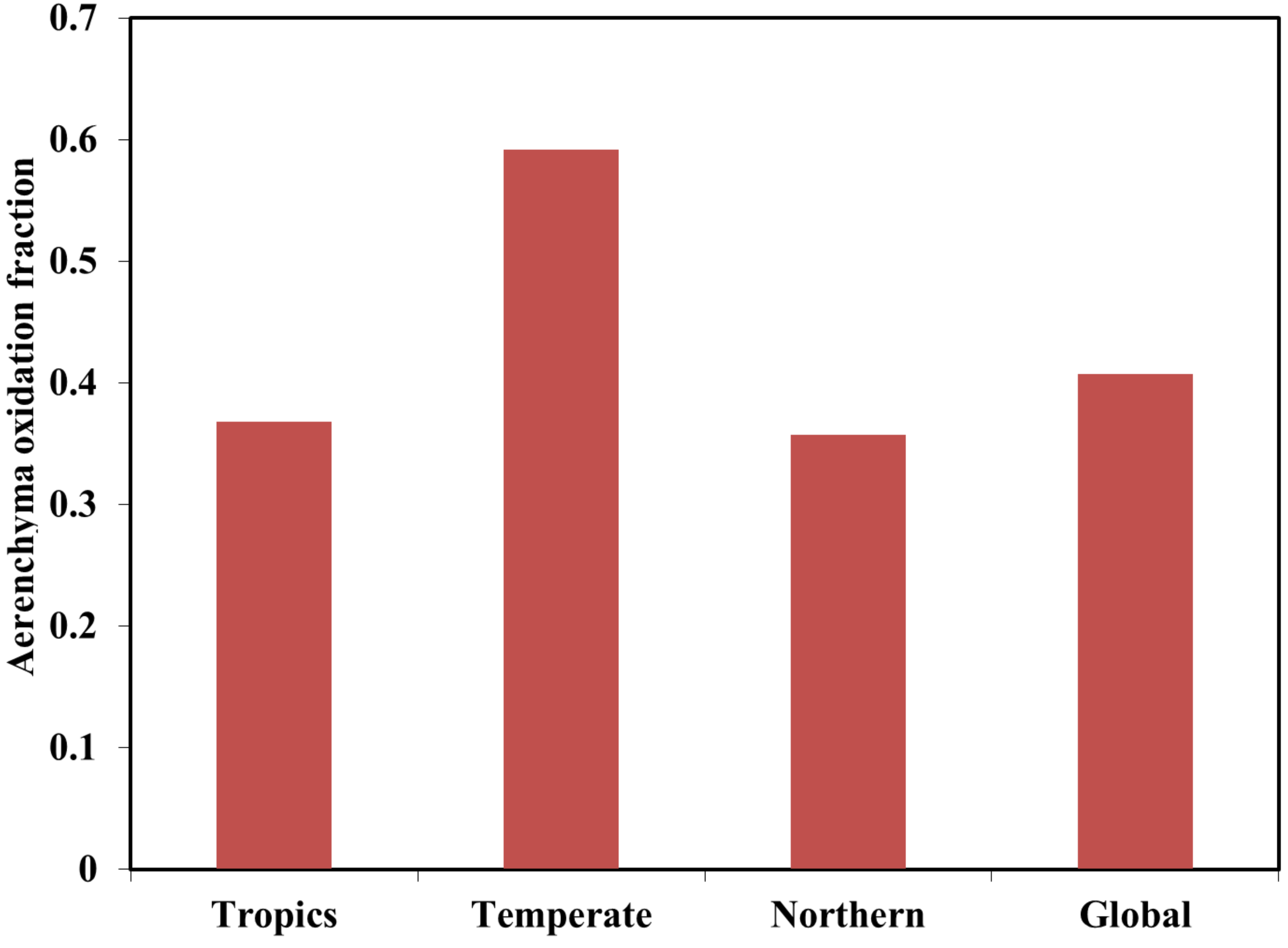
(Bill et al. Submitted, Meng et al. to be submitted)

Sensitivity analysis on global scales

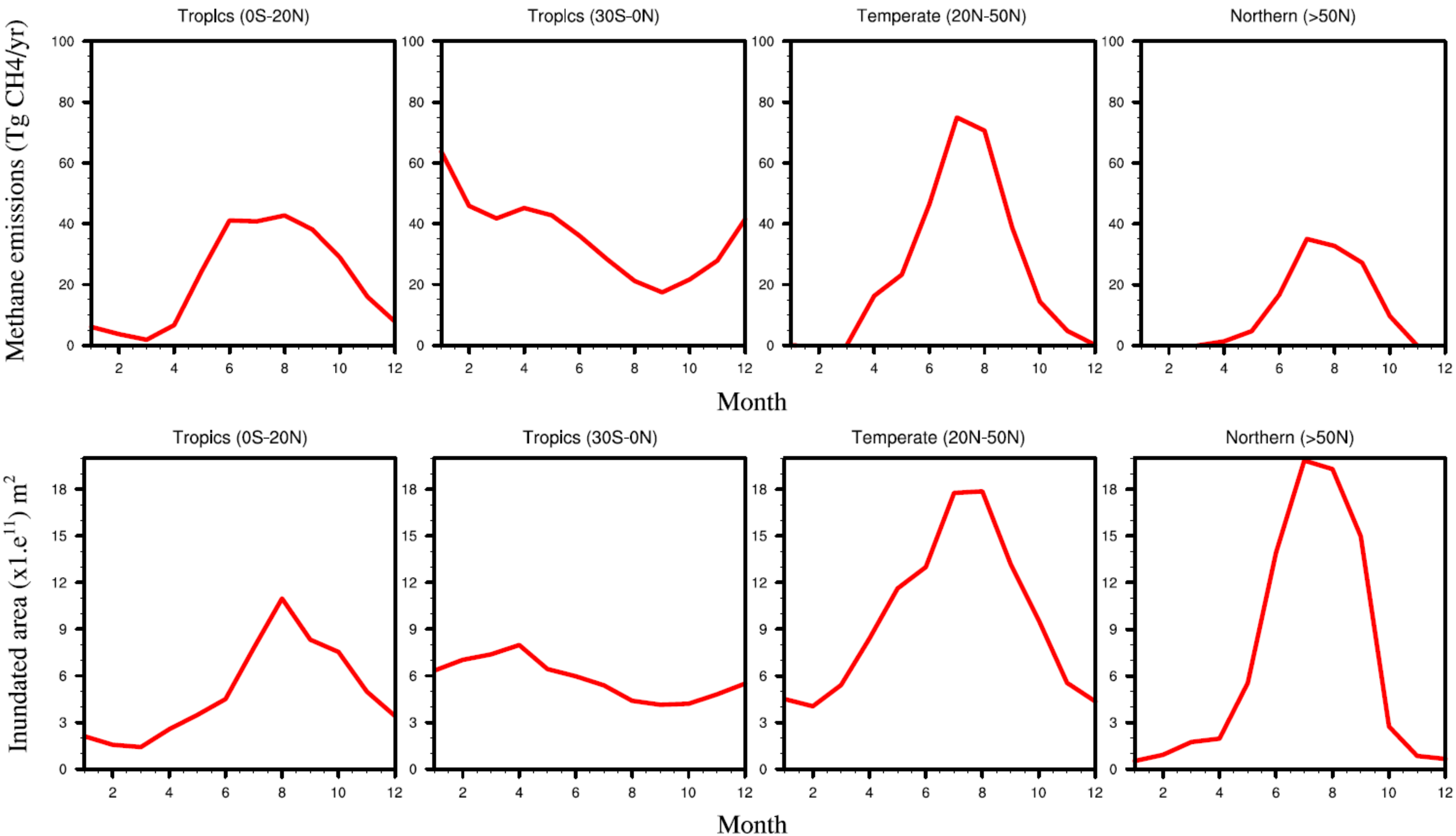
simulation	global budget	percentage change	Description
Base	267.5	0%	All features are included
NoRedox	313.1	17%	Same as Base, except f_{pE} = 1.0
NopH	373.7	40%	Same as Base, except f_{pH} = 1.0
NoNPP	151.1	-44%	Same as Base, except f_{npp} =1.0

Sensitivity analysis shows large range of methane emissions from natural wetlands.

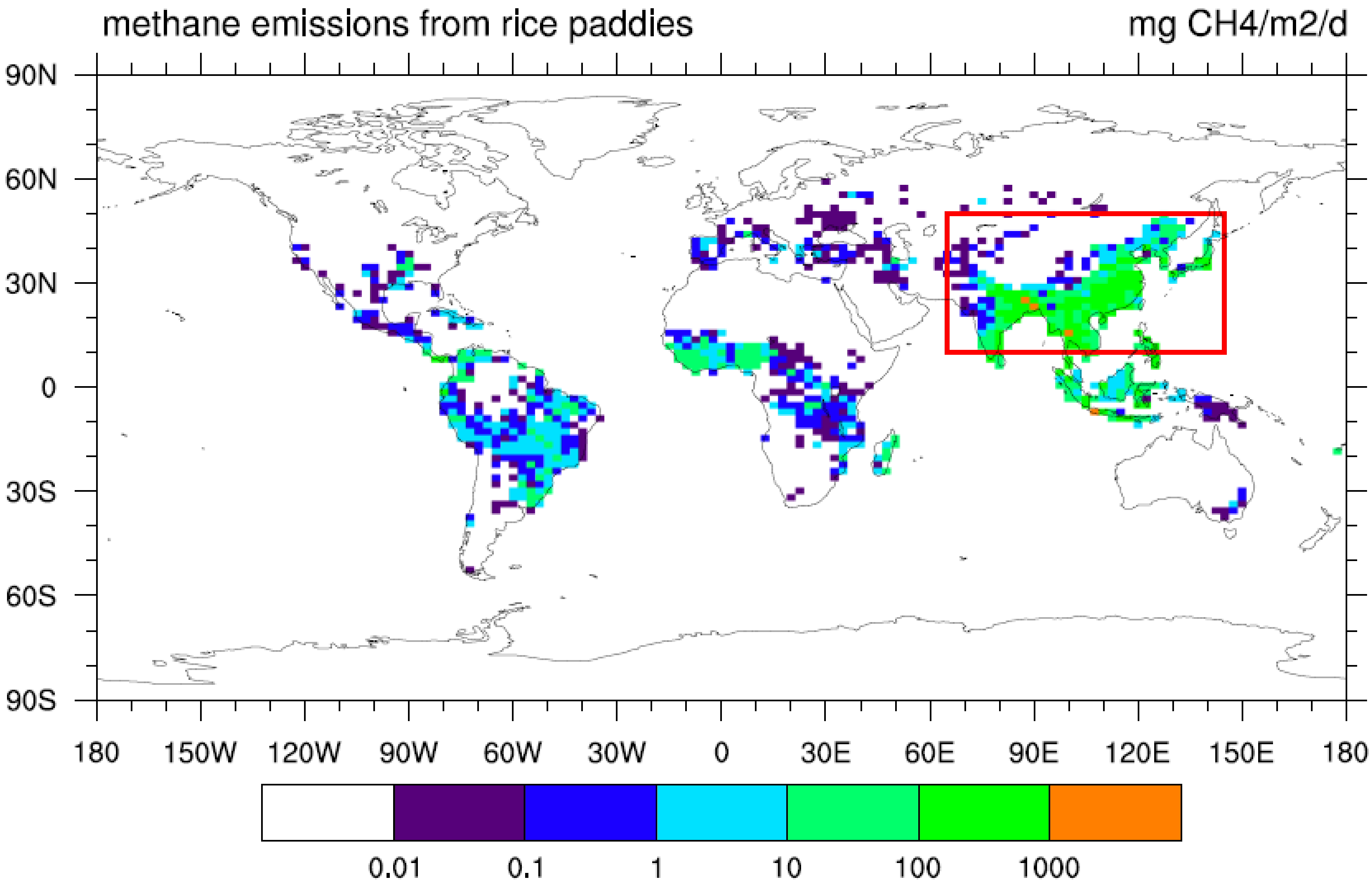
Aerenchyma oxidation fraction



Seasonal variation of methane emissions



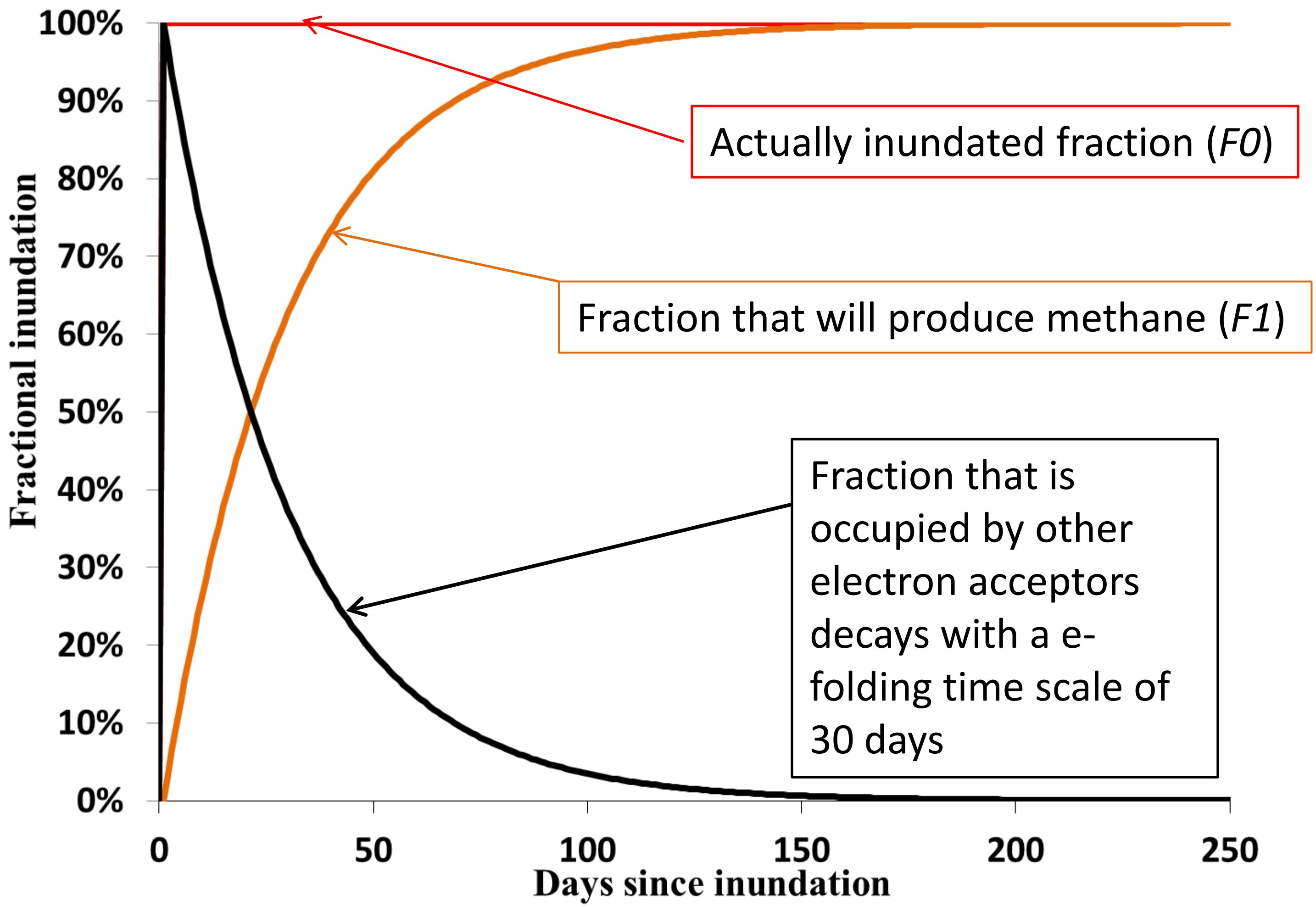
Rice paddy emissions



Thanks!
Comments and suggestions?

Example of redox potential (f_{pE})on methane production

$$P = R_H * f_{CH4} * Q'_{10} * S * f_{pH} * \boldsymbol{f_{pE}}$$



$$f_{pE} = \frac{F1}{F0}$$

(Meng et al. to be sutmitted)