Effects of sulfur deposition on the wetland methane source

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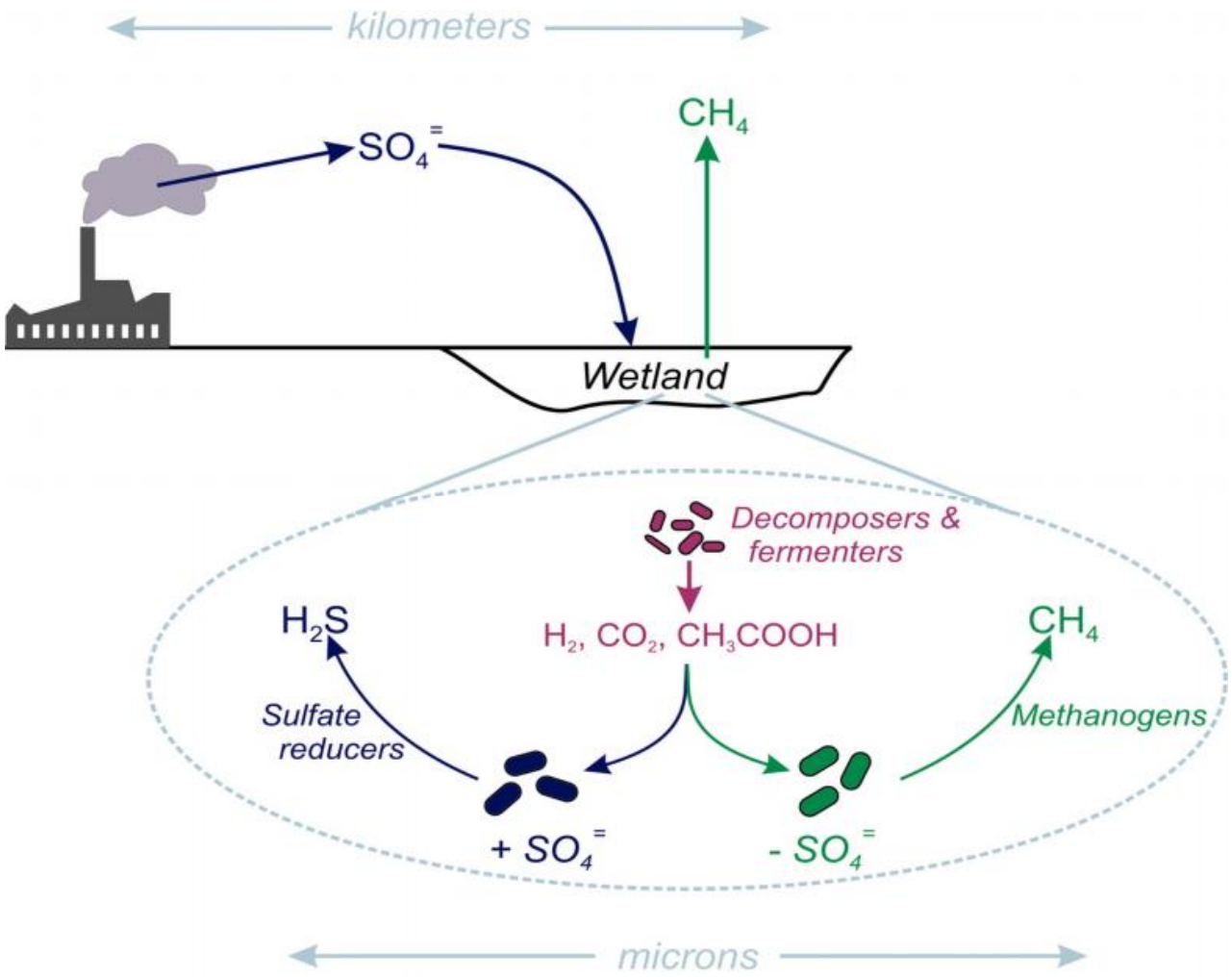
The Open University CEPSAR Centre for Earth, Planetary, Space & Astronomical Research METHANENET

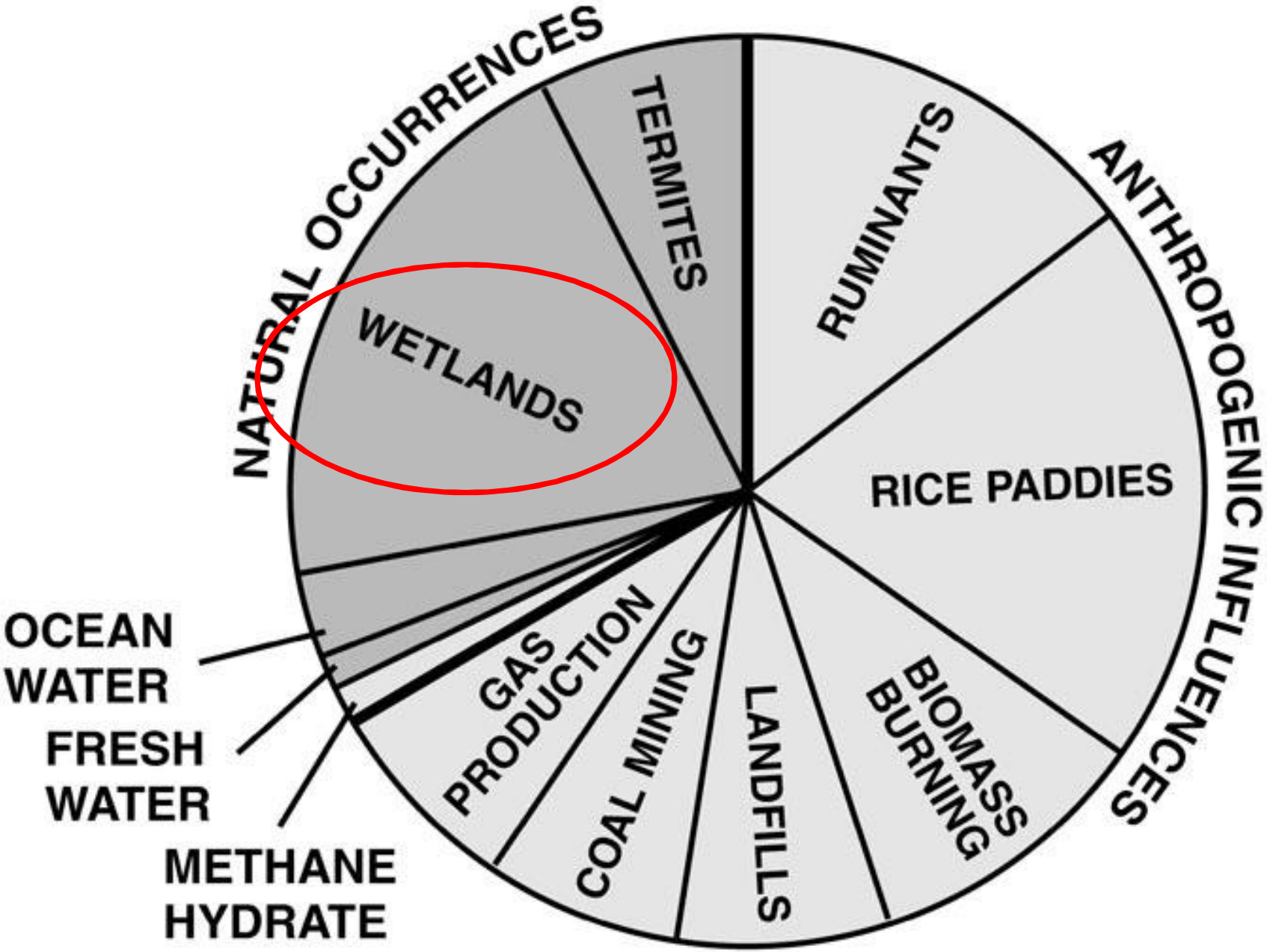
INTERFACE/ClimMani talk, Iceland

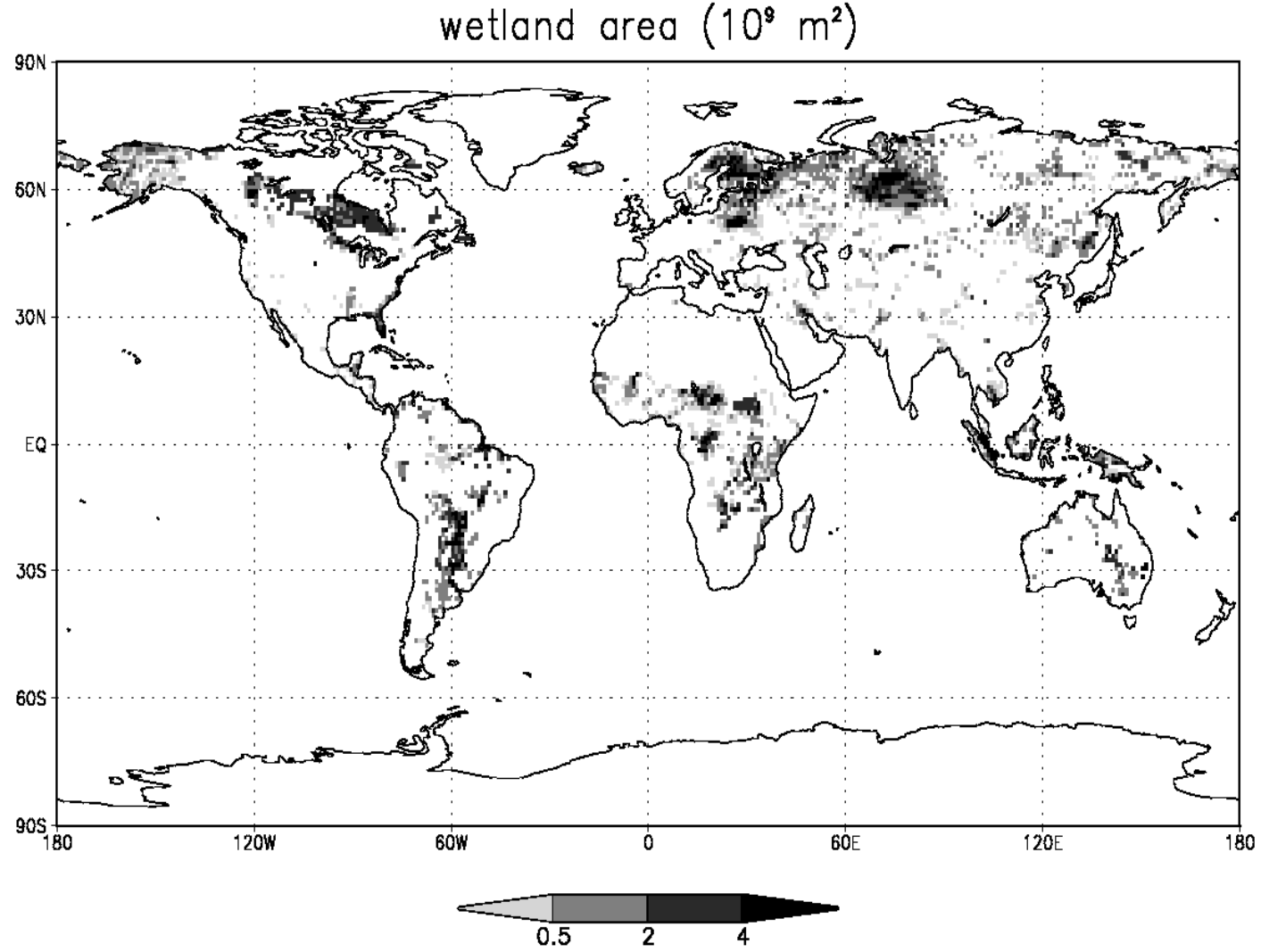
16th June2011

Interactions between methane production and industrial emissions of S gases



Schimel, Joshua (2004) Proc. Natl. Acad. Sci. USA 101, 12400-12401


NATURAL OCCURRENCES
TERMITES
WETLANDS
ANTHROPOGENIC INFLUENCES
RUMINANTS
RICE PADDIES
BIOMASS BURNING
LANDFILLS
COAL MINING
GAS PRODUCTION
OCEAN WATER
FRESH WATER
METHANE HYDRATE

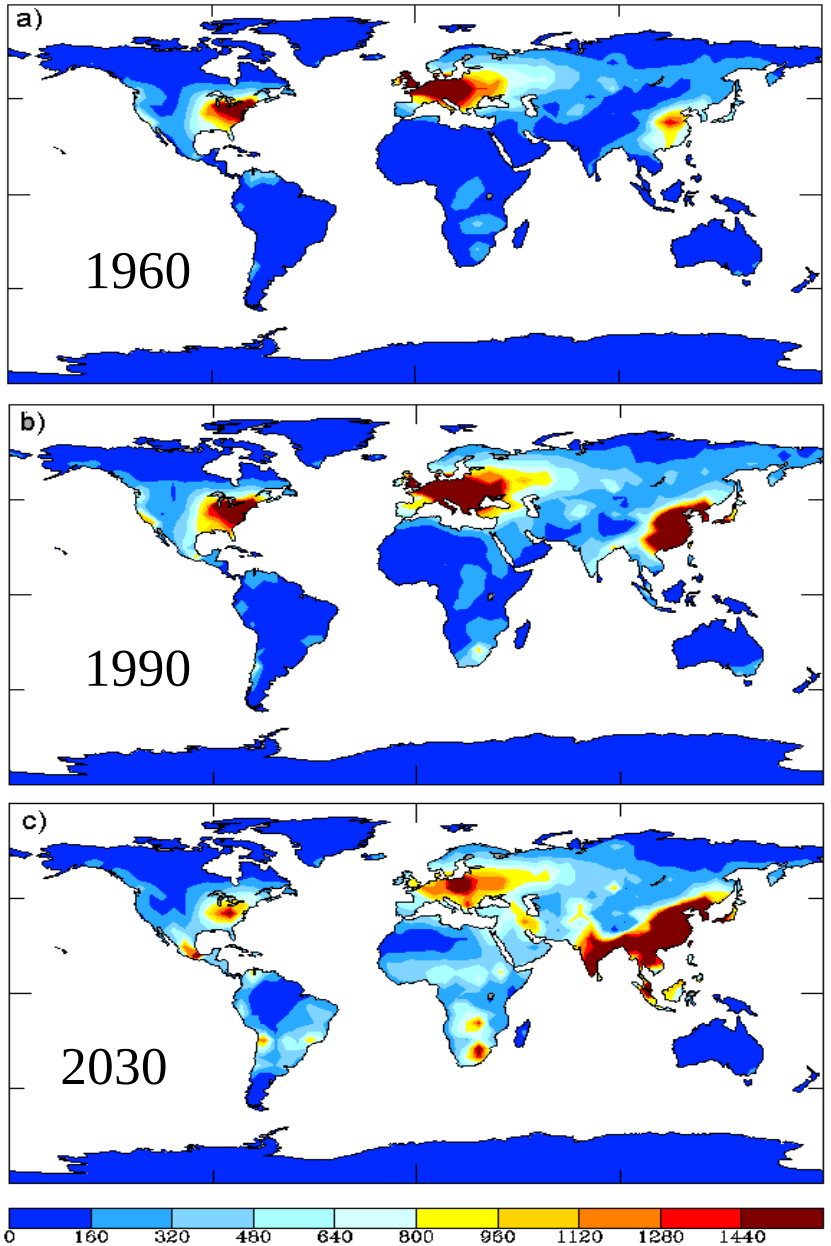


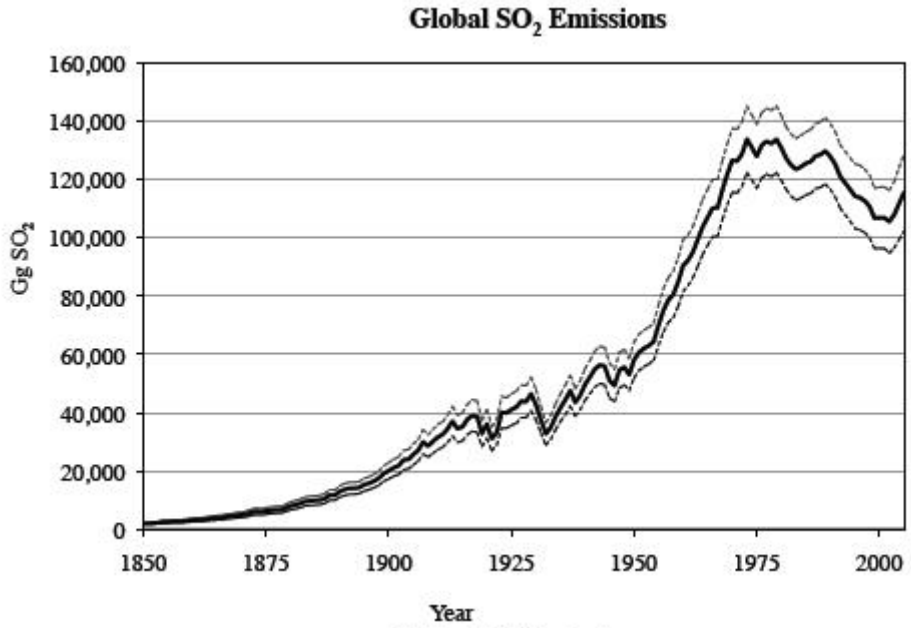
Global distribution of wetland area (10^9 m^2/ 1^ox1^o grid cell). (Matthews and Fung, 1987).

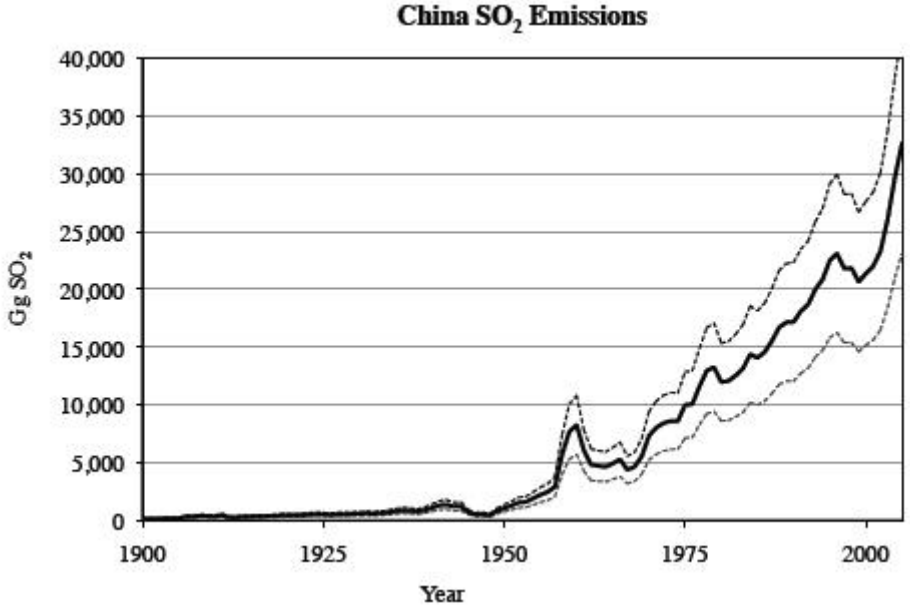
Modelled total S-dep

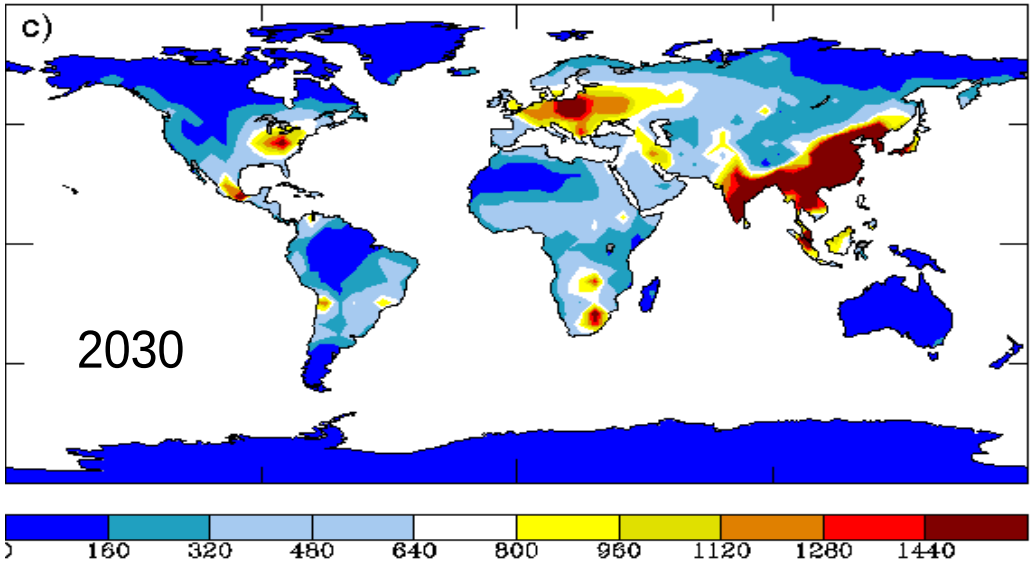
1960-2030

Global interpolated distribution of total (wet + dry) S-deposition (mg/m^2/year) for the years 1960 (a), 1990 (b) and 2030 (C)





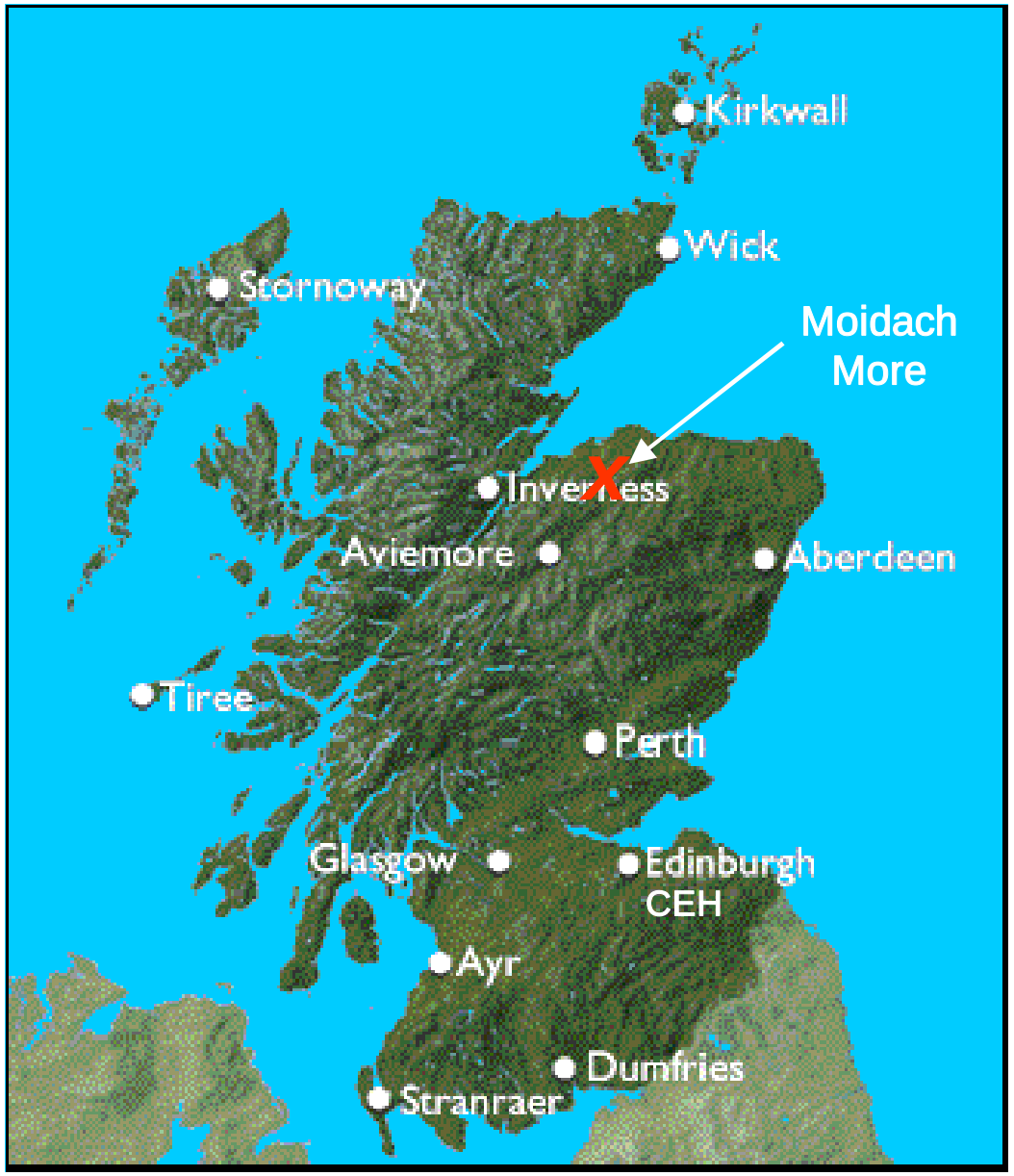




Global interpolated distribution of total (wet + dry) S-deposition ($mg/m^2/year$) for 2030

S. J. Smith et al.: Anthropogenic sulfur dioxide emissions: 1850–2005
Atmos. Chem. Phys., 11, 1101–1116, 2011

Location of Moidach More experimental field site

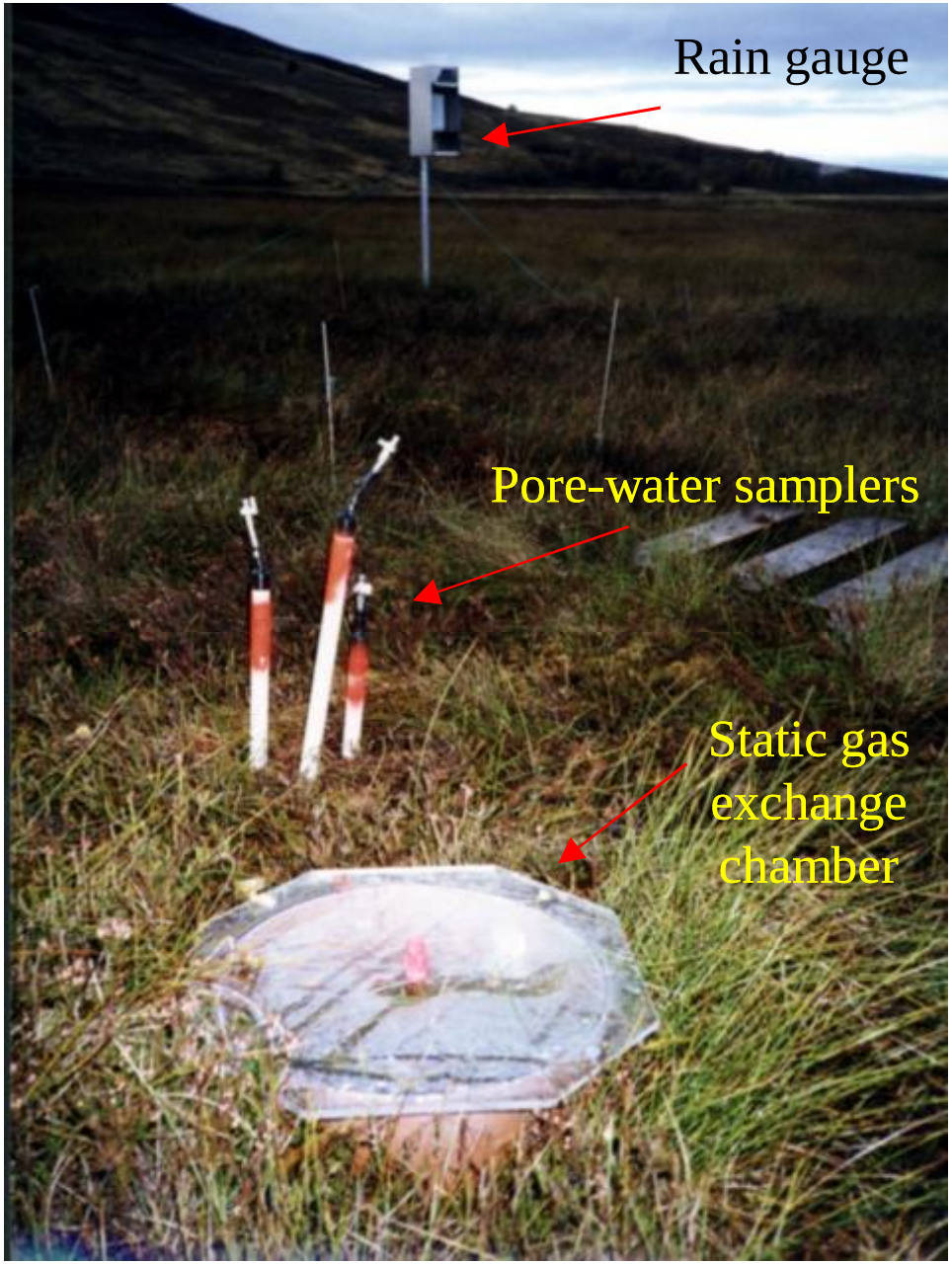


Na_2SO_4 additions at Moidach:

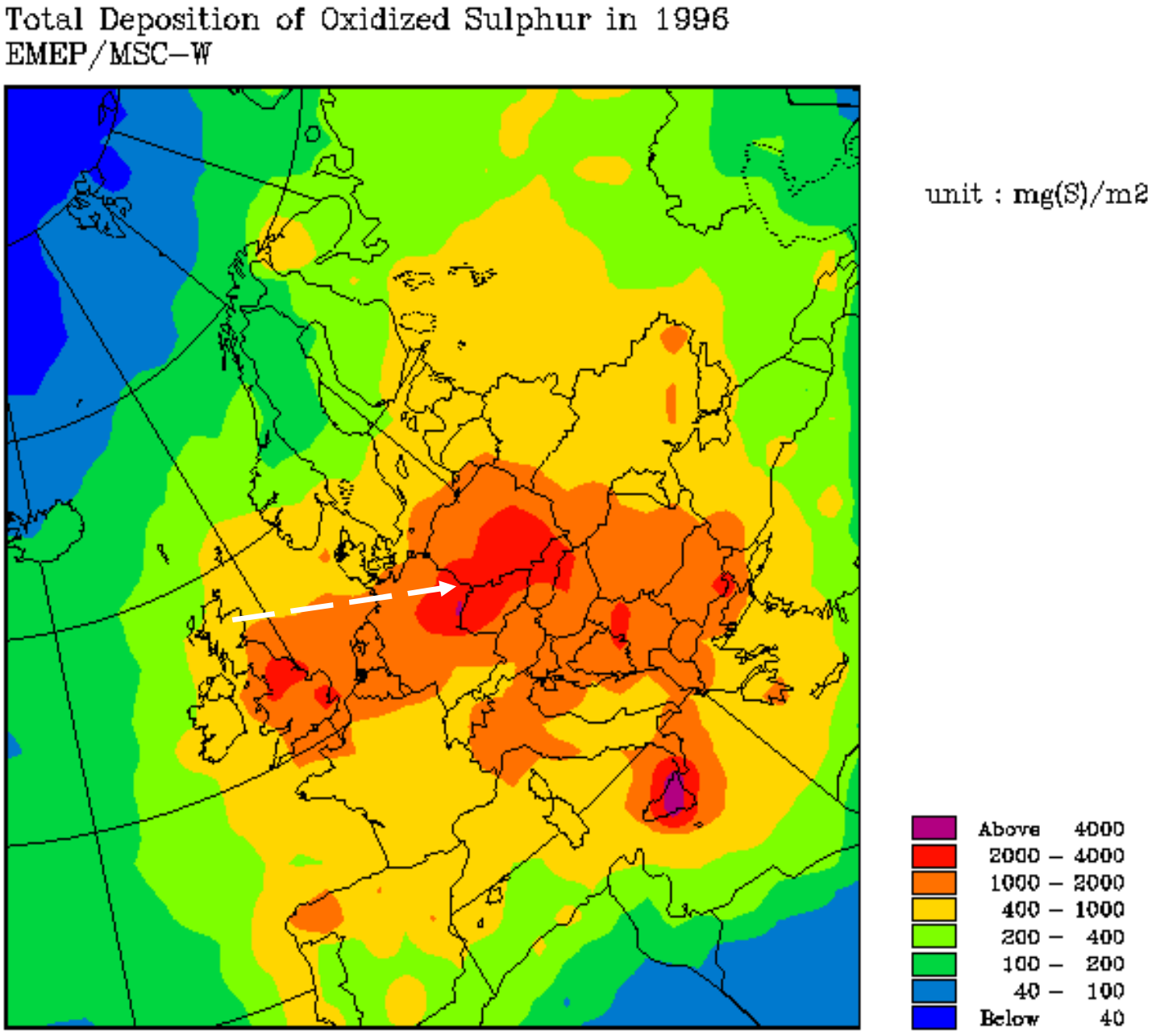
25 kg S ha^{-1} y^{-1}

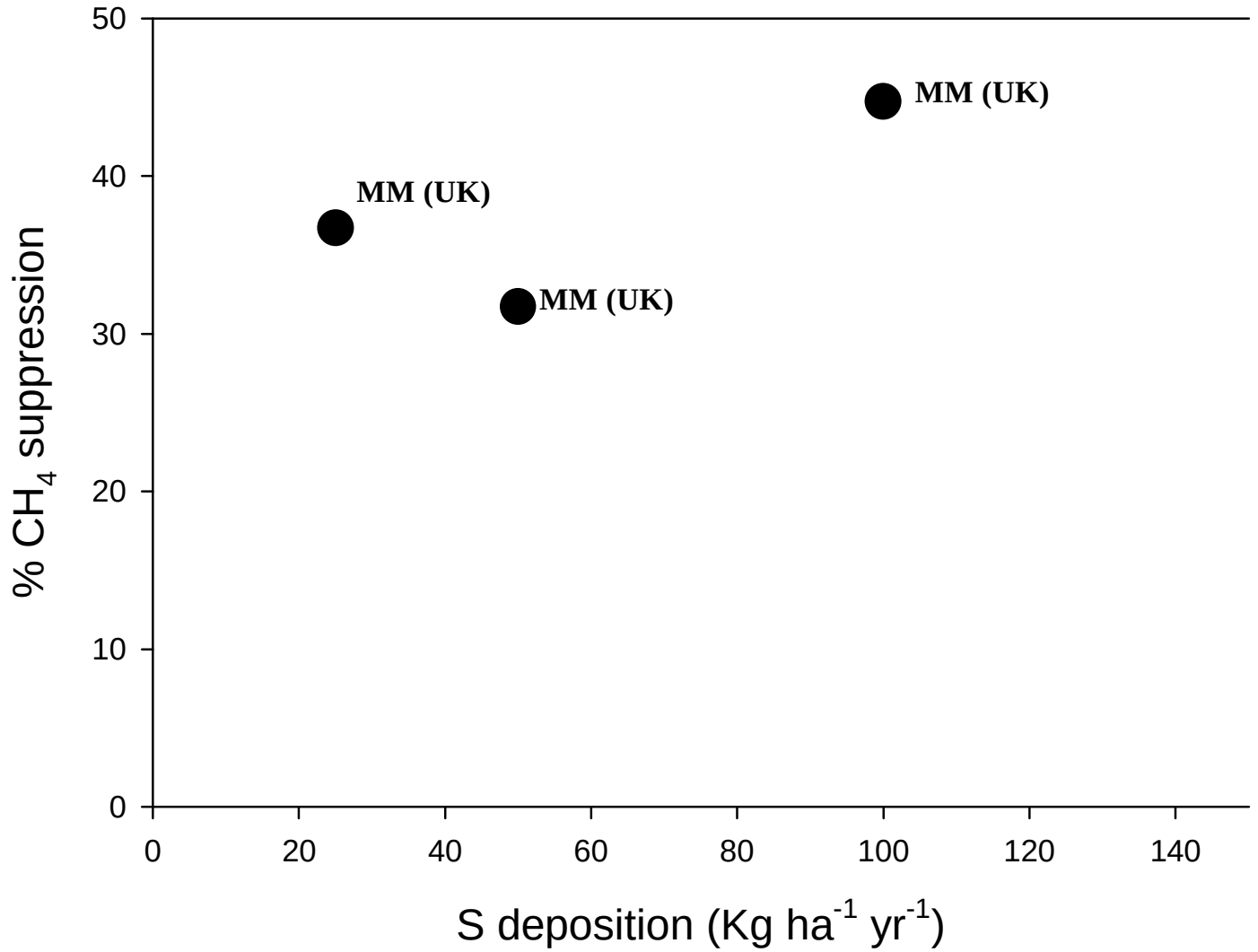
50 kg S ha^{-1} y^{-1}

100 kg S ha^{-1} y^{-1}



Deposition of SO_4^{2-}-S across Europe

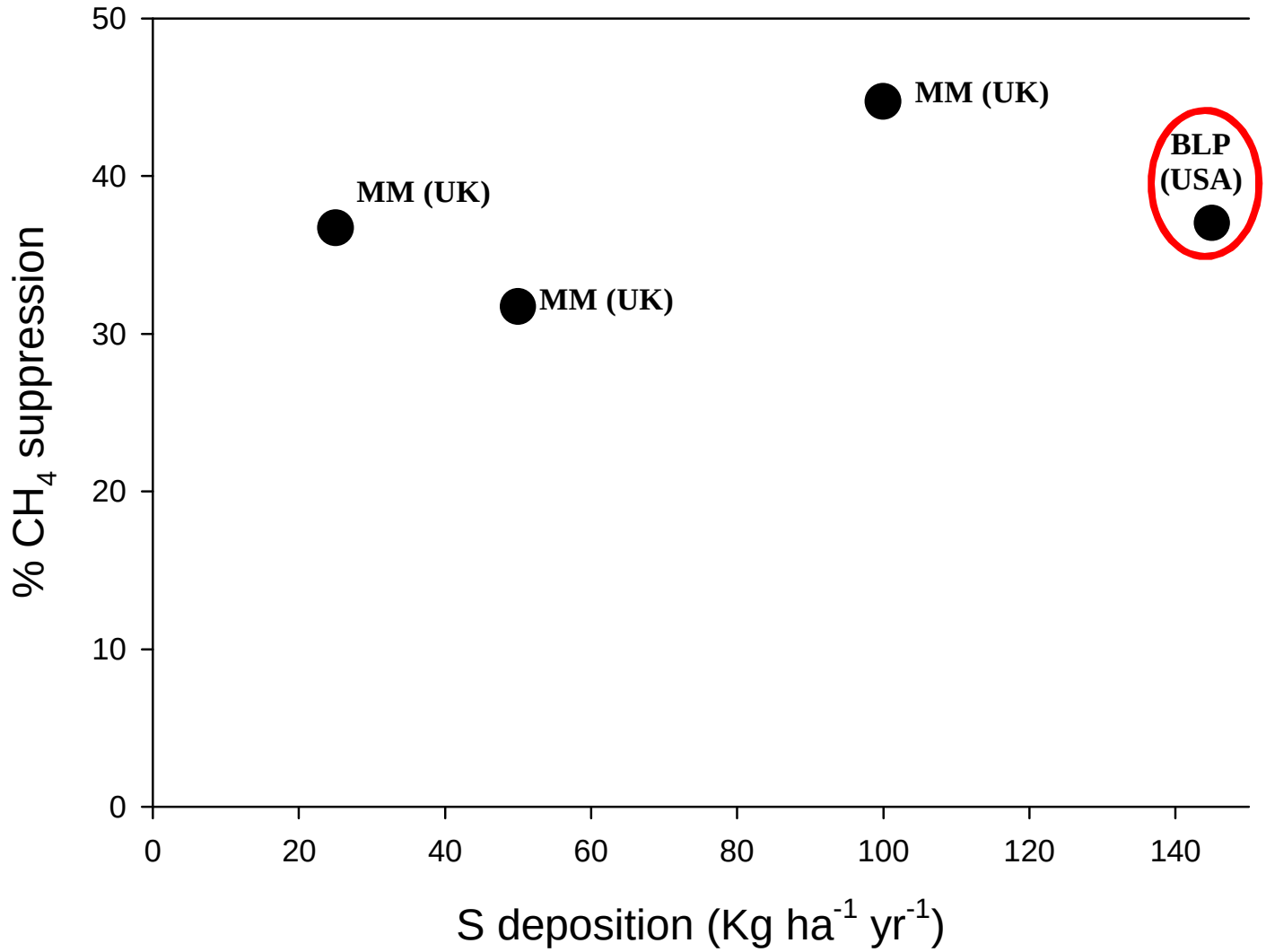




Gauci *et al* 2002

Other Experimental Evidence

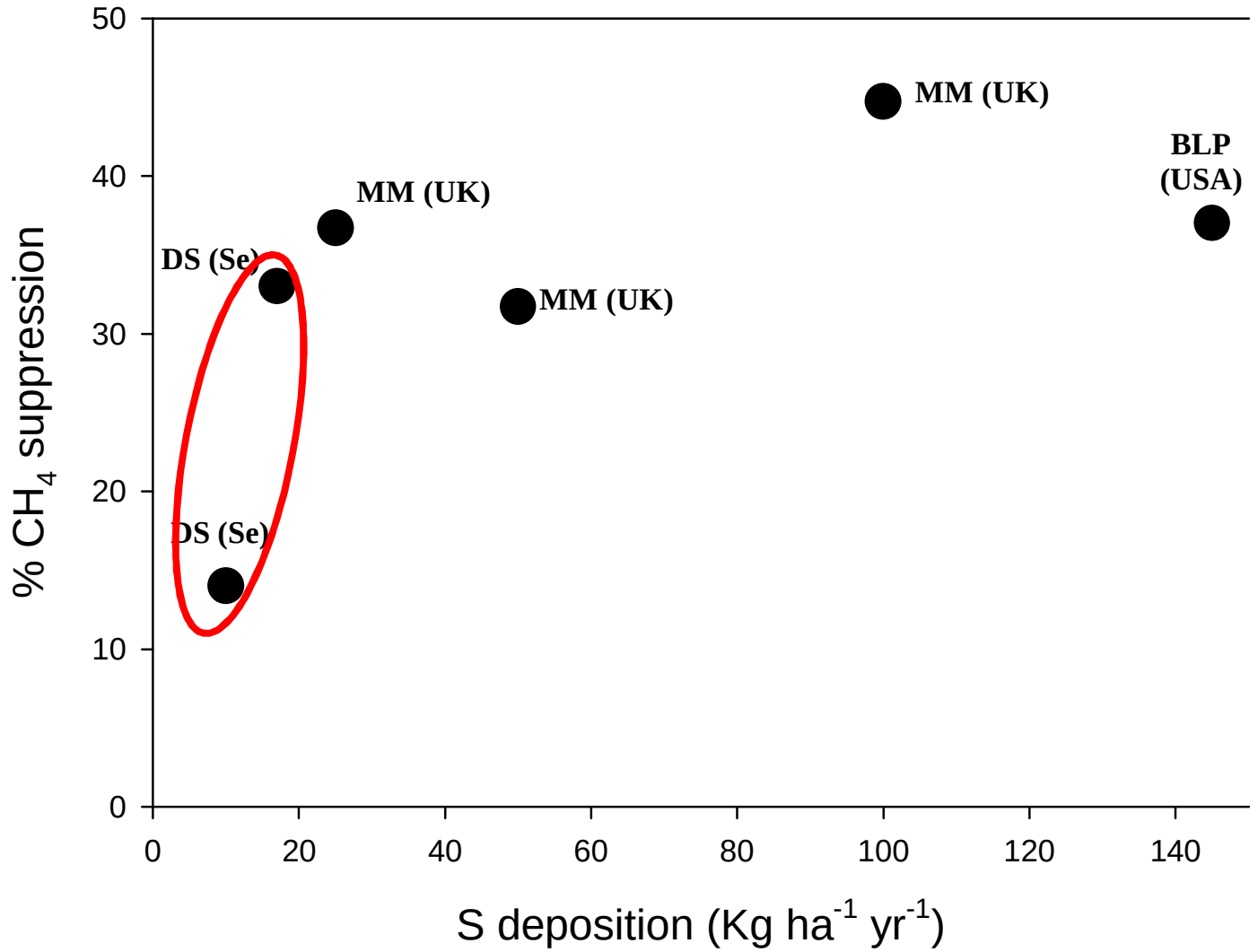
- **A short-term experiment in Minnesota USA (Dise and Verry 2001)**


50
40
30
20
10
0
% CH_4 suppression
0
20
40
60
80
100
120
140
S deposition (Kg ha^{-1} yr^{-1})
MM (UK)
MM (UK)
MM (UK)
BLP
(USA)

Other Experimental Evidence

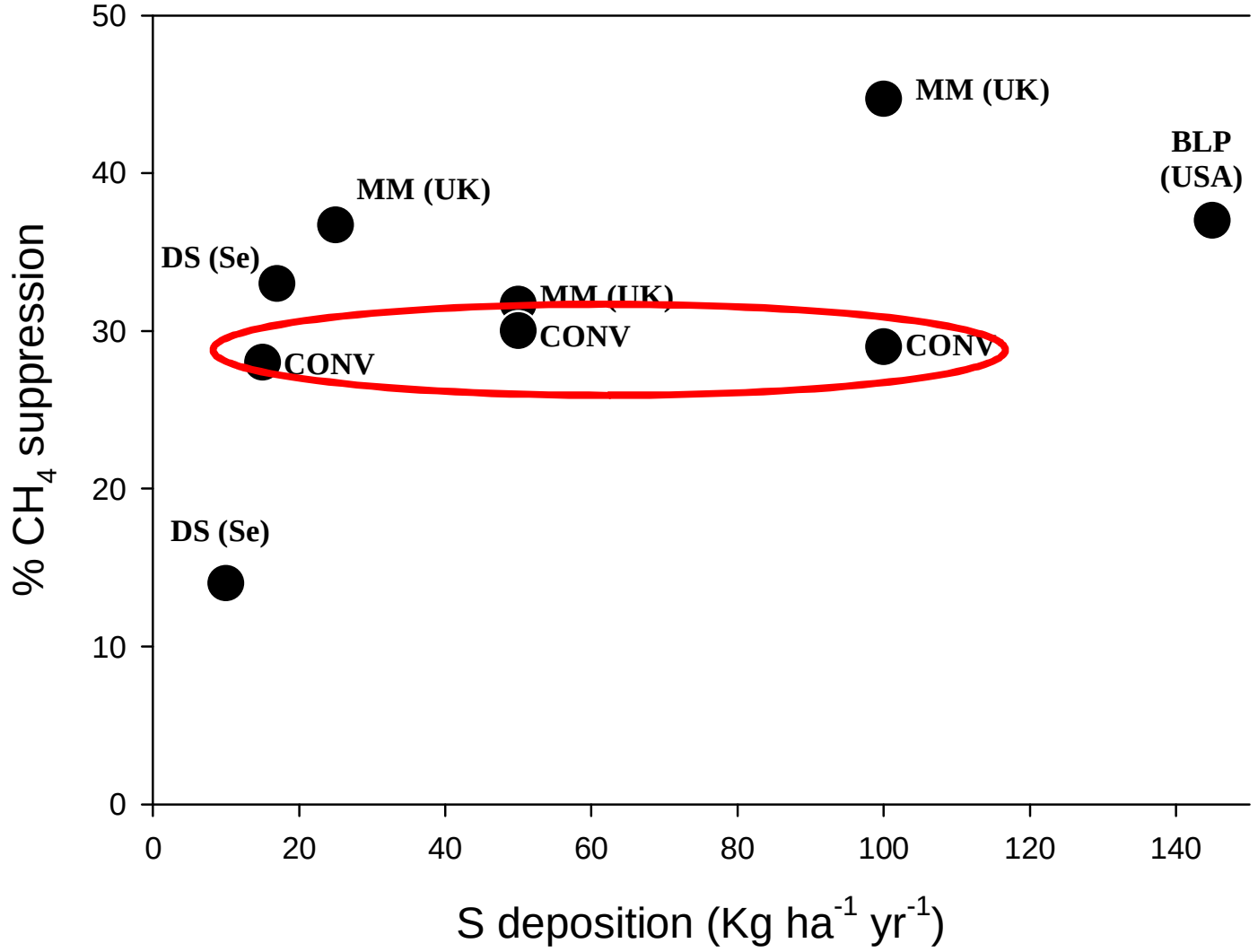
- **A short-term experiment in Minnesota, USA (Dise and Verry 2001)**

- **A long-term manipulation experiment in Sweden (Granberg et al 2001)**


50
40
30
20
10
0
0
20
40
60
80
100
120
140
% CH_4 suppression
S deposition (Kg ha^{-1} yr^{-1})
MM (UK)
BLP (USA)
MM (UK)
DS (Se)
MM (UK)
DS (Se)

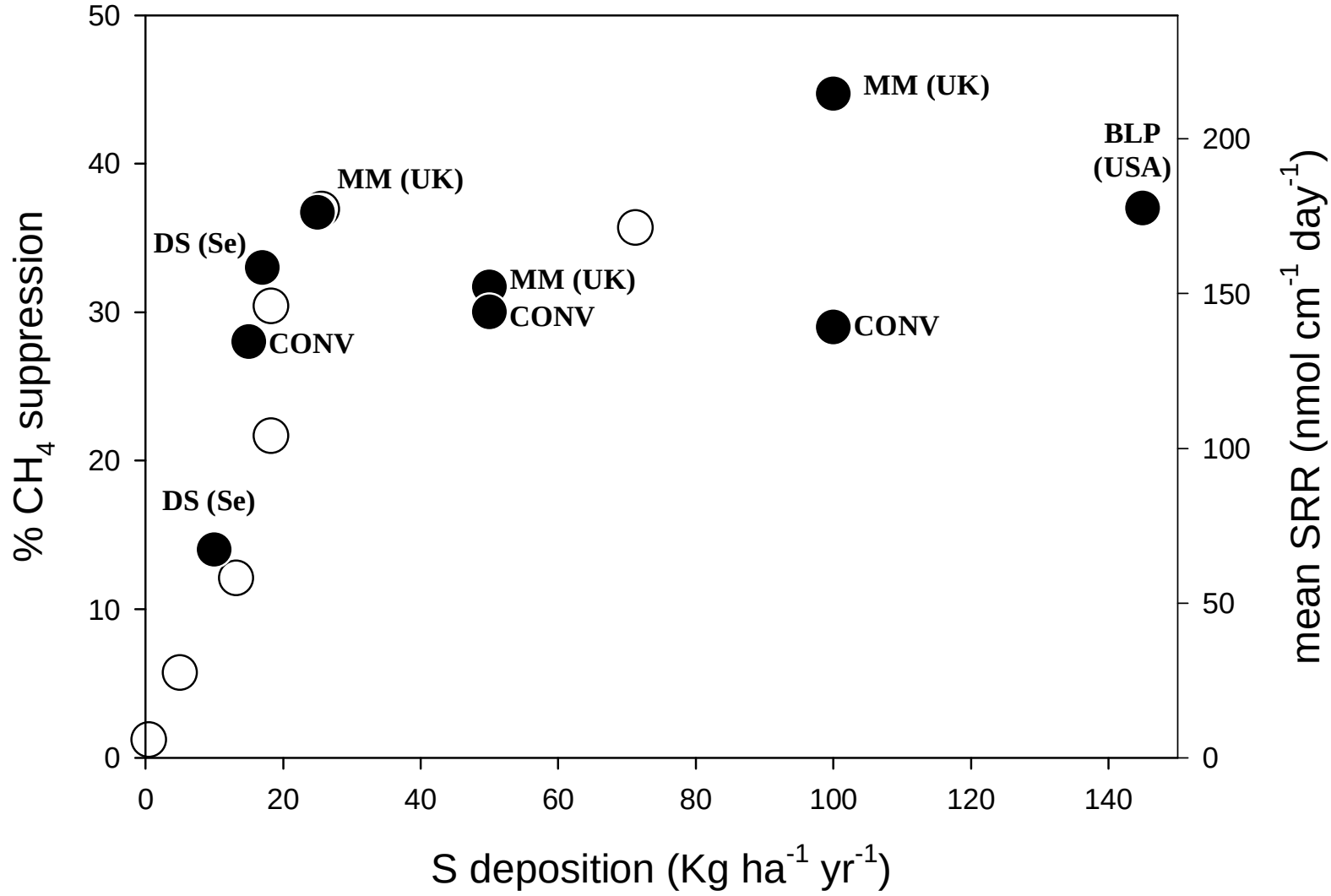
Other Experimental Evidence

- **A short-term experiment in Minnesota, USA (Dise and Verry 2001)**
- **A long-term manipulation experiment in Sweden (Granberg et al 2001)**
- **Short-term controlled environment experiment (Gauci et al 2004b)**


50
40
30
20
10
0
0
20
40
60
80
100
120
140
% CH_4 suppression
S deposition (Kg ha^{-1} yr^{-1})
MM (UK)
BLP (USA)
MM (UK)
DS (Se)
MM (UK)
CONV
CONV
CONV
DS (Se)

Other Experimental Evidence

- **A short-term experiment in Minnesota, USA (Dise and Verry 2001)**
- **A long-term manipulation experiment in Sweden (Granberg et al 2001)**
- **Short-term controlled environment experiment (Gauci et al 2004b)**
- **A study of sulfate reduction in peatlands along a global S deposition gradient (Vile et al 2003)**


50
40
30
20
10
0
0
20
40
60
80
100
120
140
200
150
100
50
0
% CH_4 suppression
mean SRR (nmol cm^{-1} day^{-1})
S deposition (Kg ha^{-1} yr^{-1})
MM (UK)
BLP (USA)
DS (Se)
MM (UK)
CONV
MM (UK)
CONV
CONV
DS (Se)

SO_4^{2-} reduction potential (nmol SO_4^{2-} g^{-1} hr^{-1}, 10cm depth)

November 1997

control	9.1 (3.0)	
50 kg SO_4^{2-} S/ha/yr	8.7 (2.8)	NS

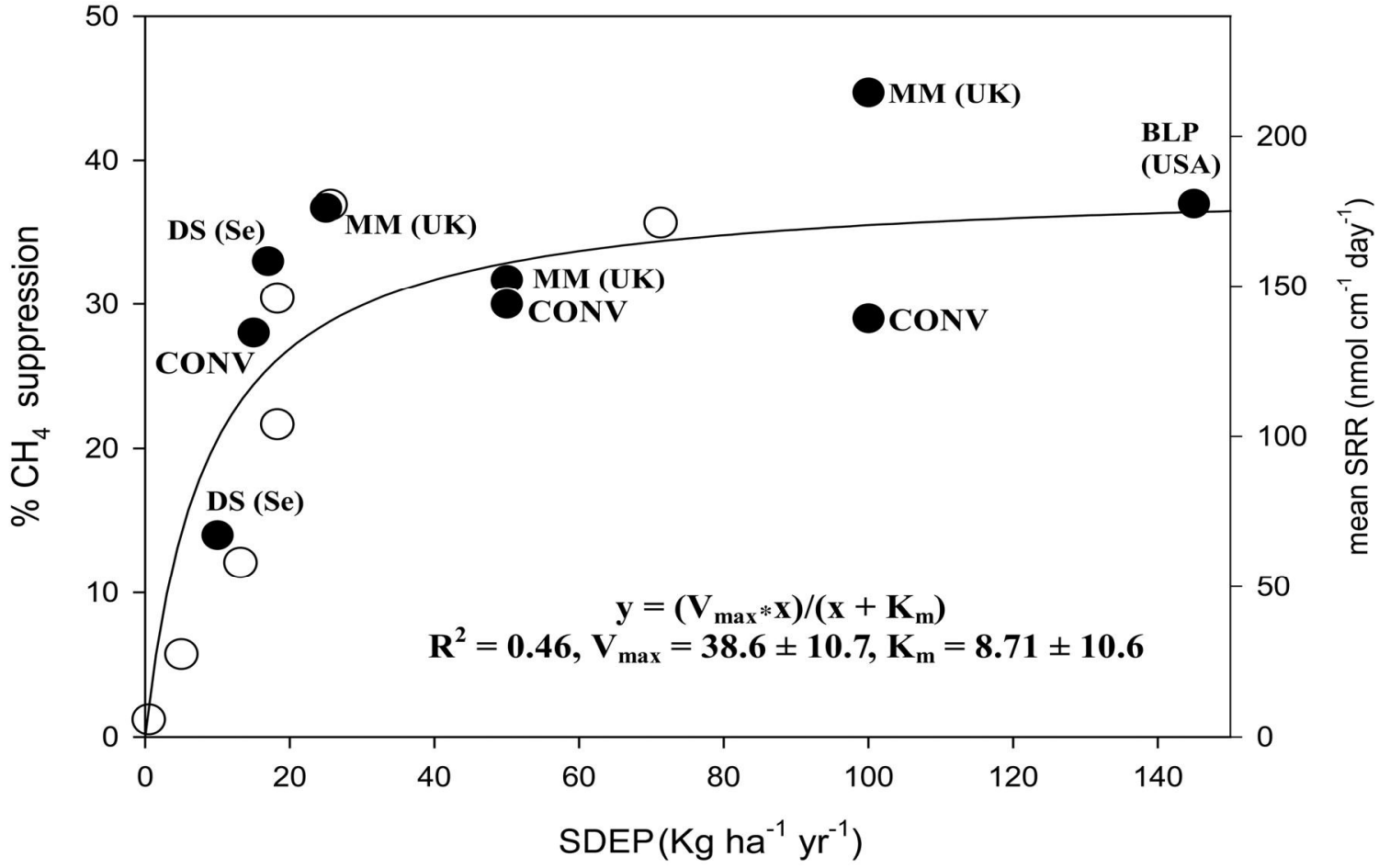
November 1998

control	4.8 (0.8)
50 kg SO_4^{2-} S/ha/yr	40.0 (4.5)*

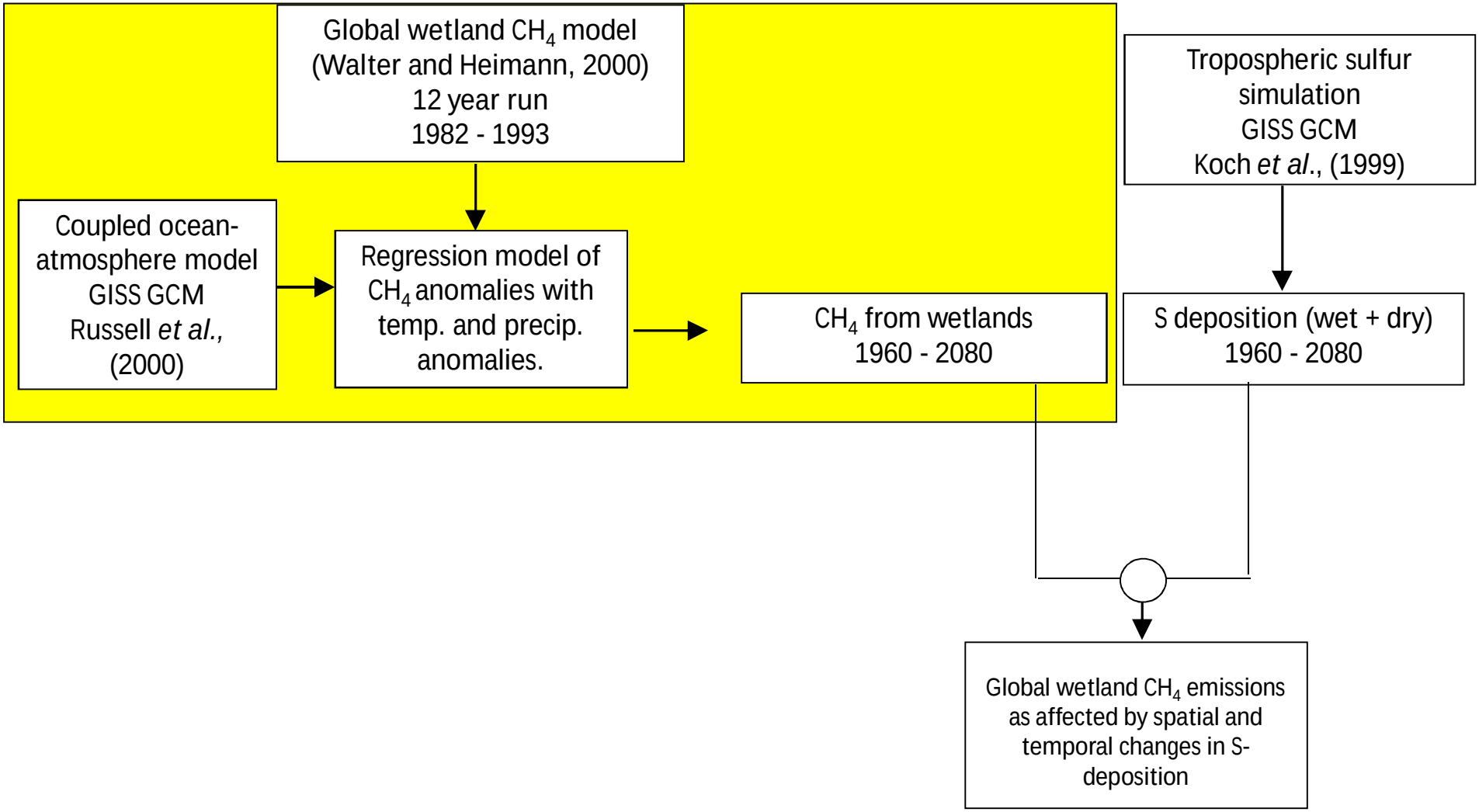
MACAULAY LAND USE RESEARCH INSTITUTE

Gauci and Chapman (2006)

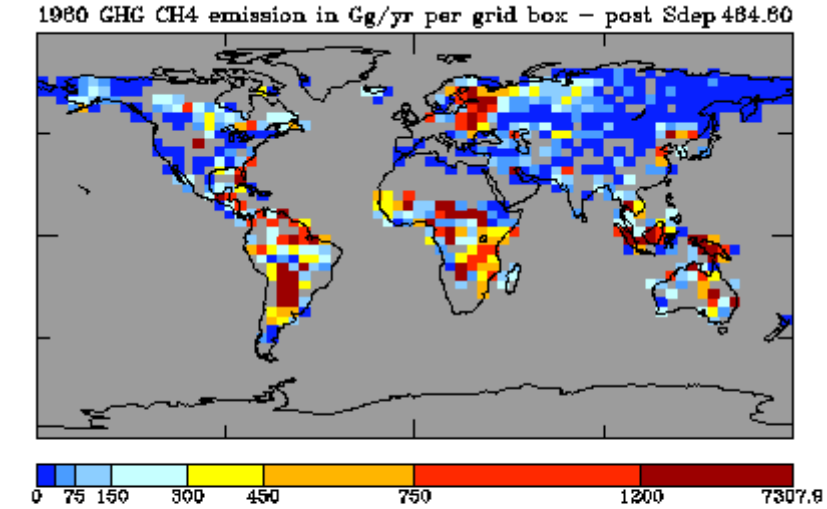
Percentage change in suppression of CH4 flux and change in sulfate-reduction rates with SDEP

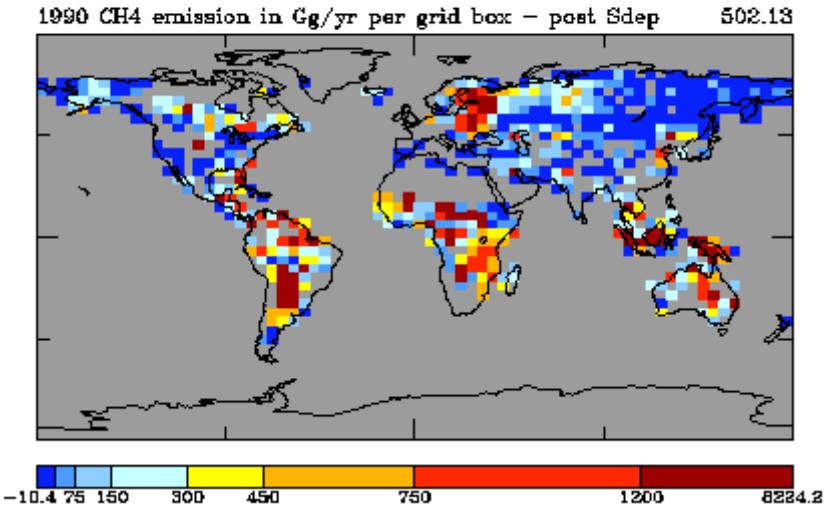


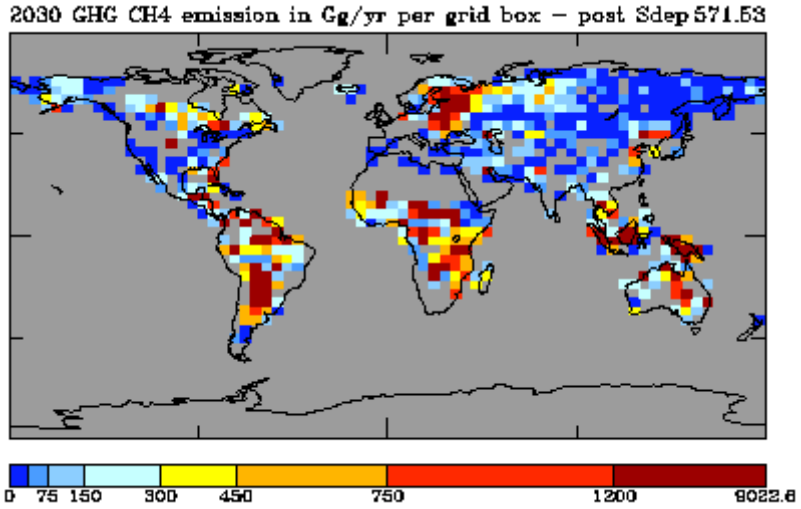
Gauci, Vincent et al. (2004) Proc. Natl. Acad. Sci. USA 101, 12583-12587



Schematic representation of models utilised for estimation of the effects of spatial and temporal changes in sulfur deposition on the global wetland CH_4 source.



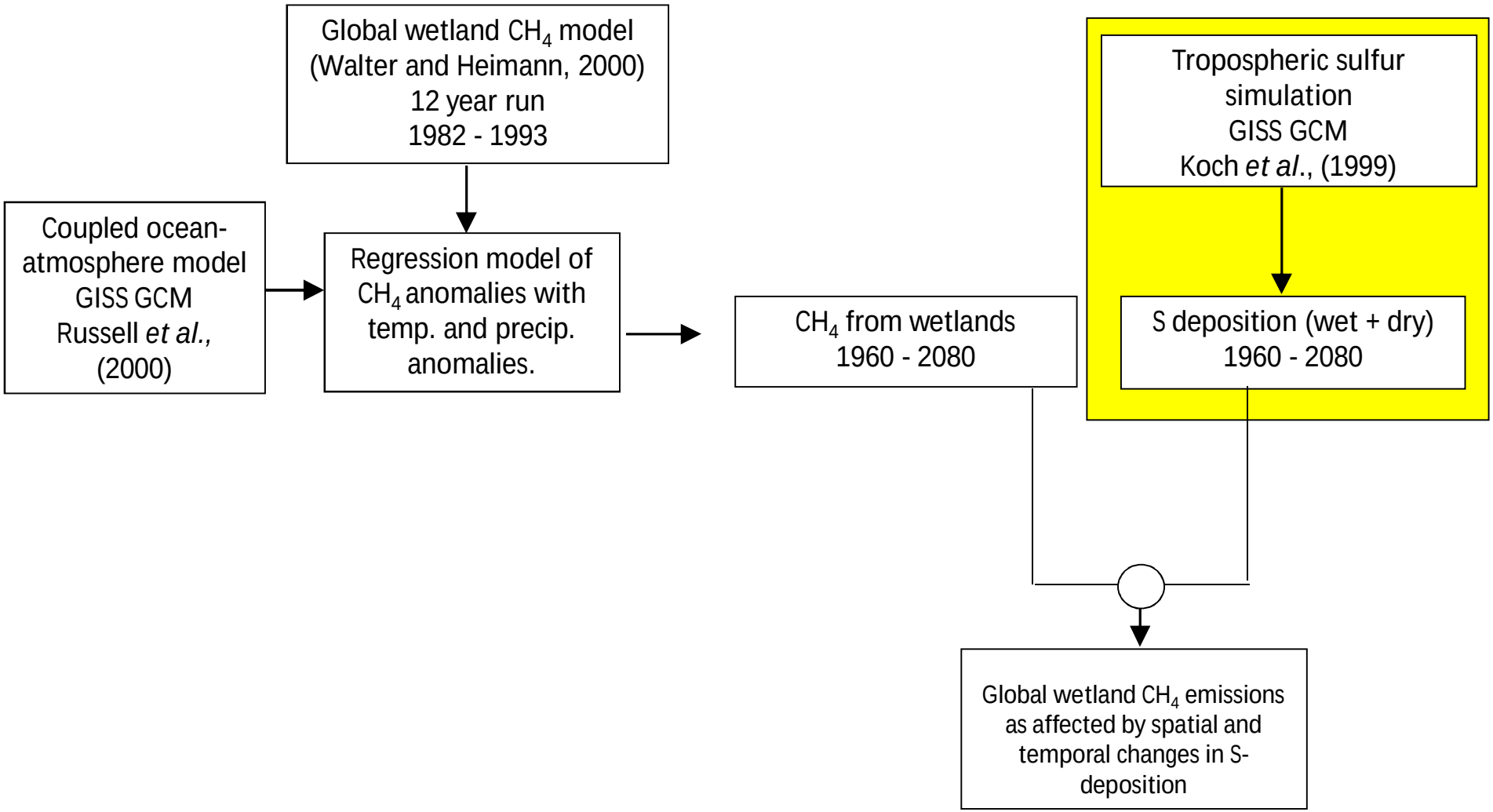




Natural wetlands

CH_4 emissions

1960-2080



Schematic representation of models utilised for estimation of the effects of spatial and temporal changes in sulfur deposition on the global wetland CH_4 source.

Global wetland CH_4 model
(Walter and Heimann, 2000)
12 year run
1982 - 1993

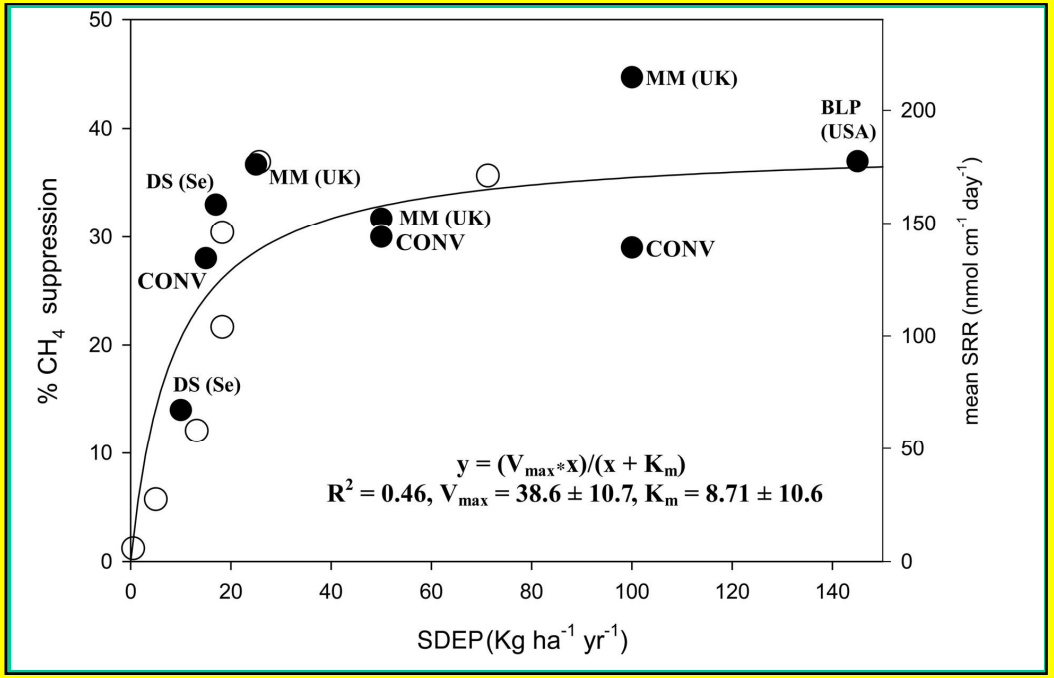
Tropospheric sulfur
simulation
GISS GCM
Koch *et al.*, (1999)

Coupled ocean-
atmosphere model
GISS GCM
Russell *et al.*,
(2000)

Regression model of
CH_4 anomalies with
temp. and precip.
anomalies.

CH_4 from wetlands
1960 - 2080

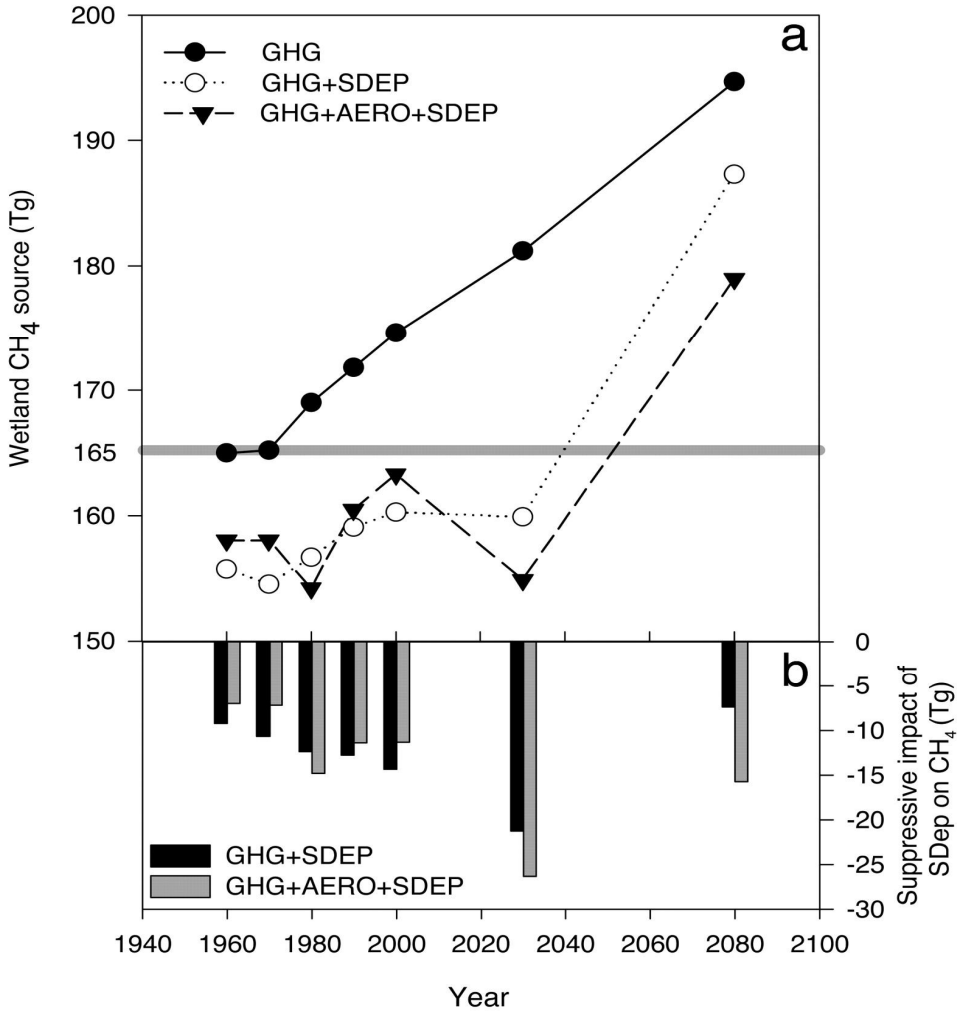
S deposition (wet + dry)
1960 - 2080



Global wetland CH_4
emissions as affected by
spatial and temporal
changes in S- deposition

Schematic representation of models utilised for estimation of the effects of spatial and temporal changes in sulfur deposition on the global wetland CH_4 source.

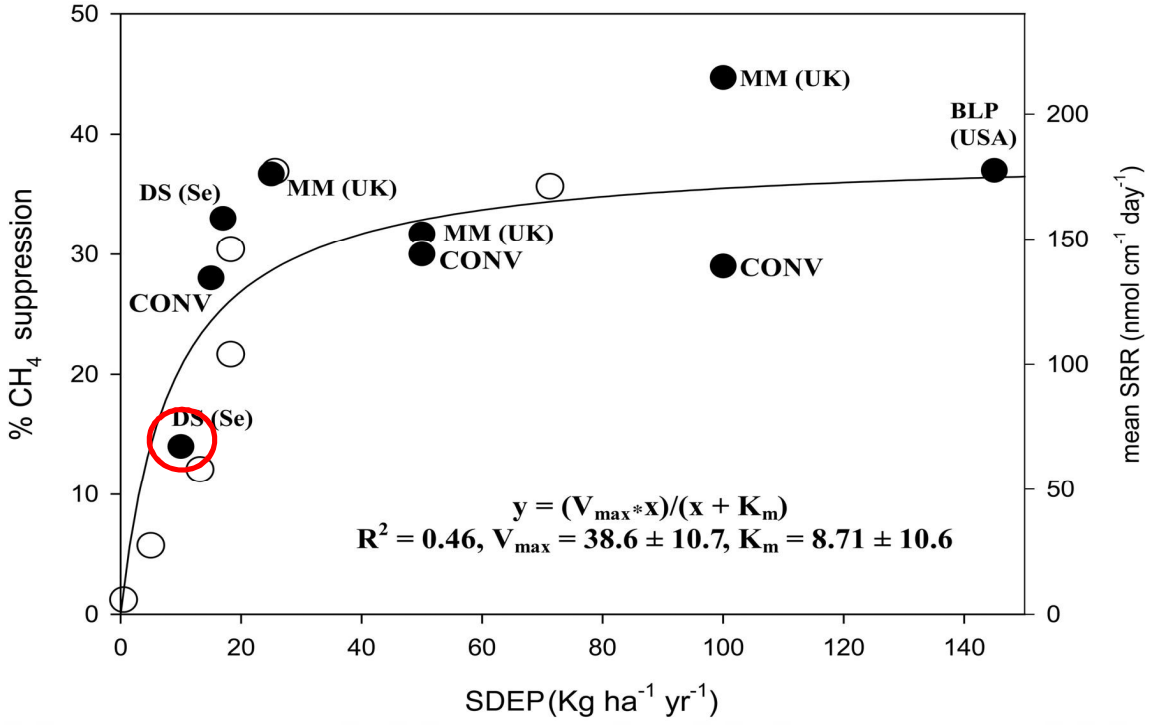
Effect of SDEP on the global wetland CH4 source with time



Gauci, Vincent et al. (2004) Proc. Natl. Acad. Sci. USA 101, 12583-12587

Problems?

- How representative are short-term manipulation studies of the ‘real world’ situation?
- Results from N manipulation experiments are unclear – long-term experiments required.
- Low S-dep manipulation is difficult (background deposition is increasing)



Percentage change in suppression of CH4 flux and change in sulfate-reduction rates with SDEP

Gauci, Vincent et al. (2004) Proc. Natl. Acad. Sci. USA 101, 12583-12587

The RICH$_4$ES approach

Regional Integration of CH_4 Emission Studies

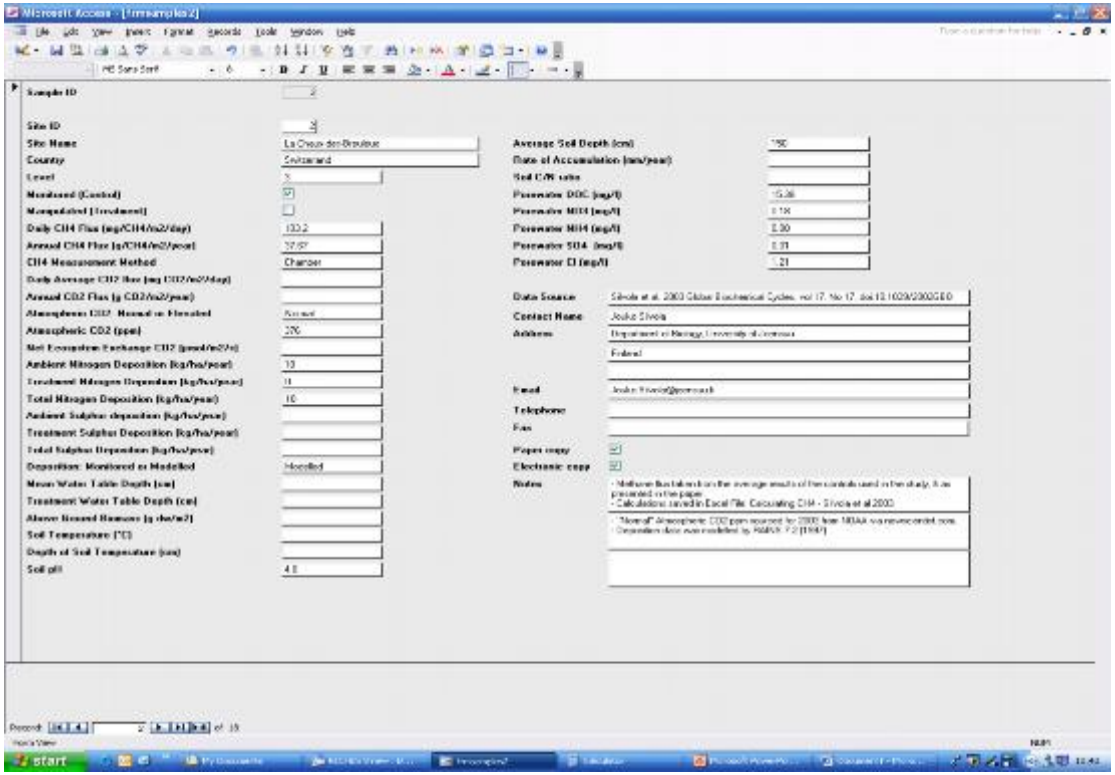
>100 sites with CH_4 emission

But…

All sites don't have all data.

Inconsistent approaches

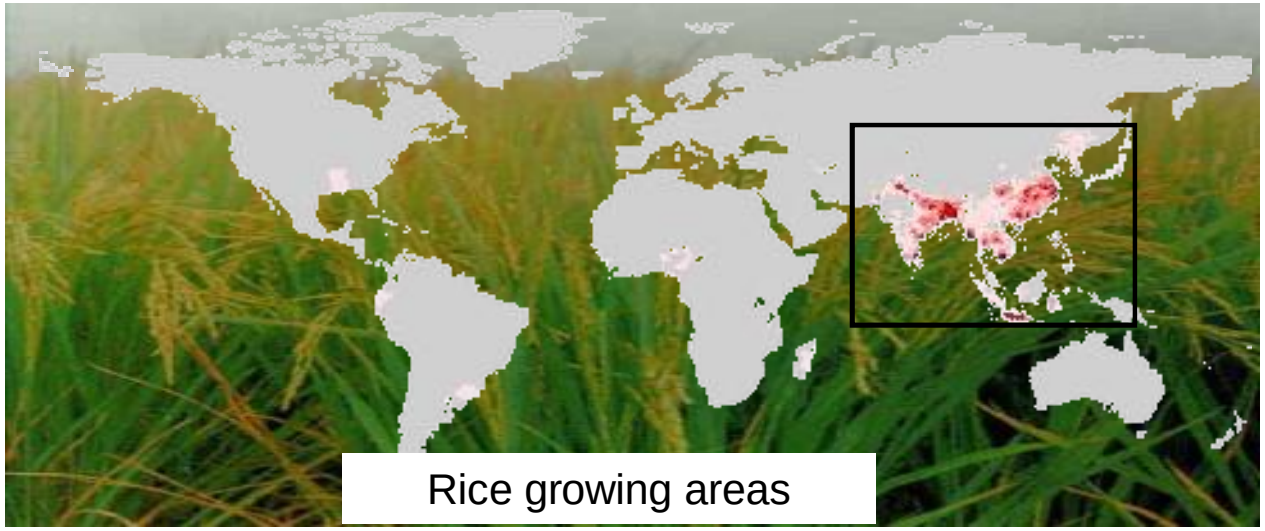
Etc…



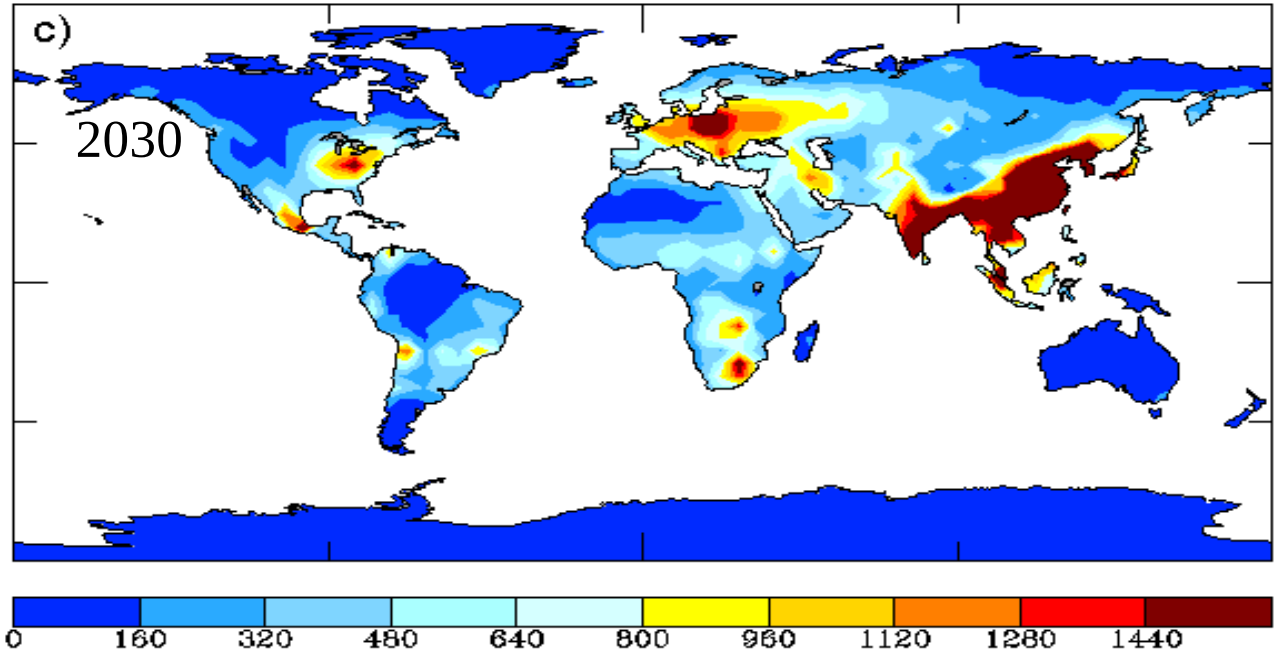
NATURAL ENVIRONMENT RESEARCH COUNCIL

What about rice agriculture?

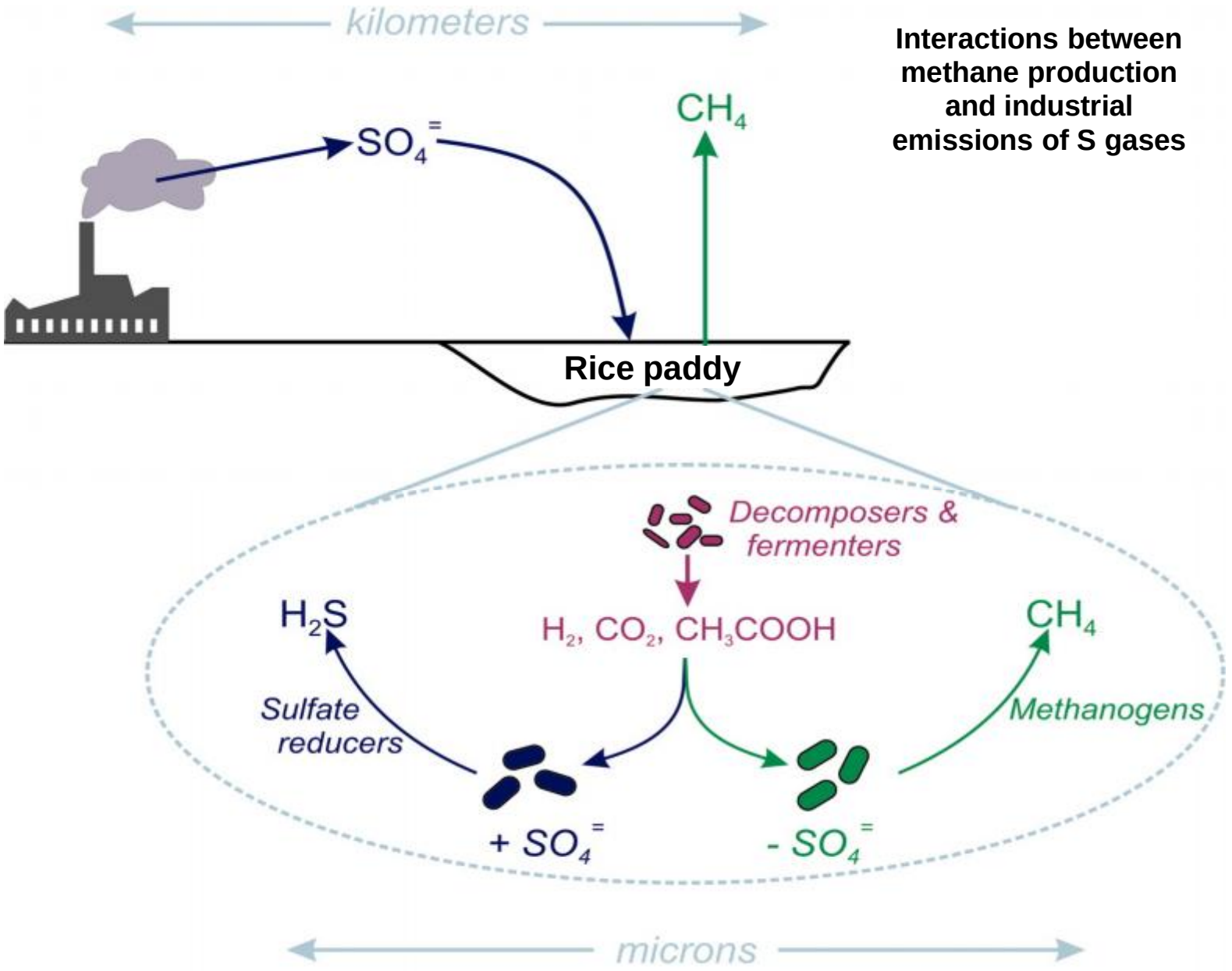
NATURAL ENVIRONMENT RESEARCH COUNCIL



Rice growing regions are predicted to become more polluted in the future.

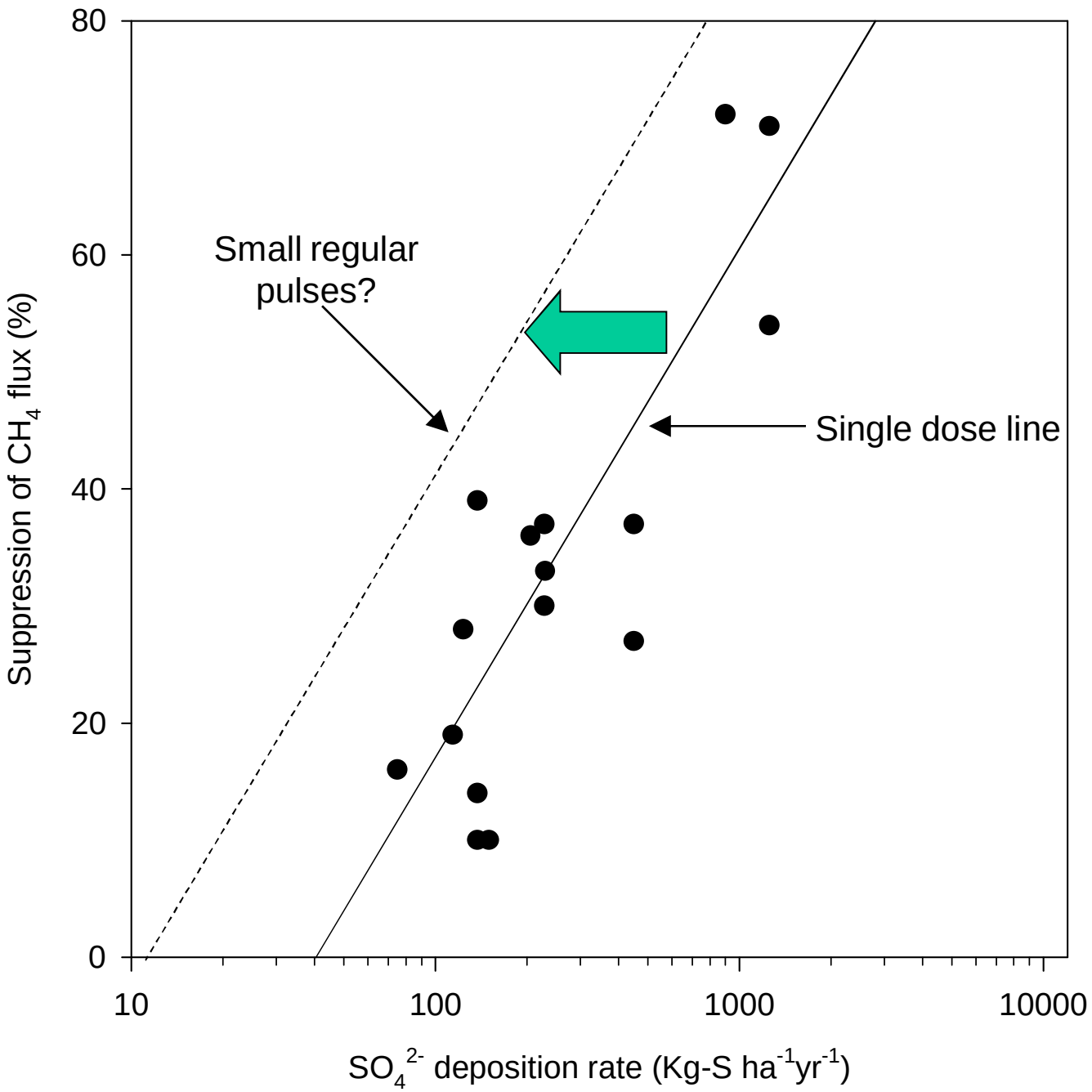


S deposition mg m^{-2} yr^{-1}



Interactions between methane production and industrial emissions of S gases

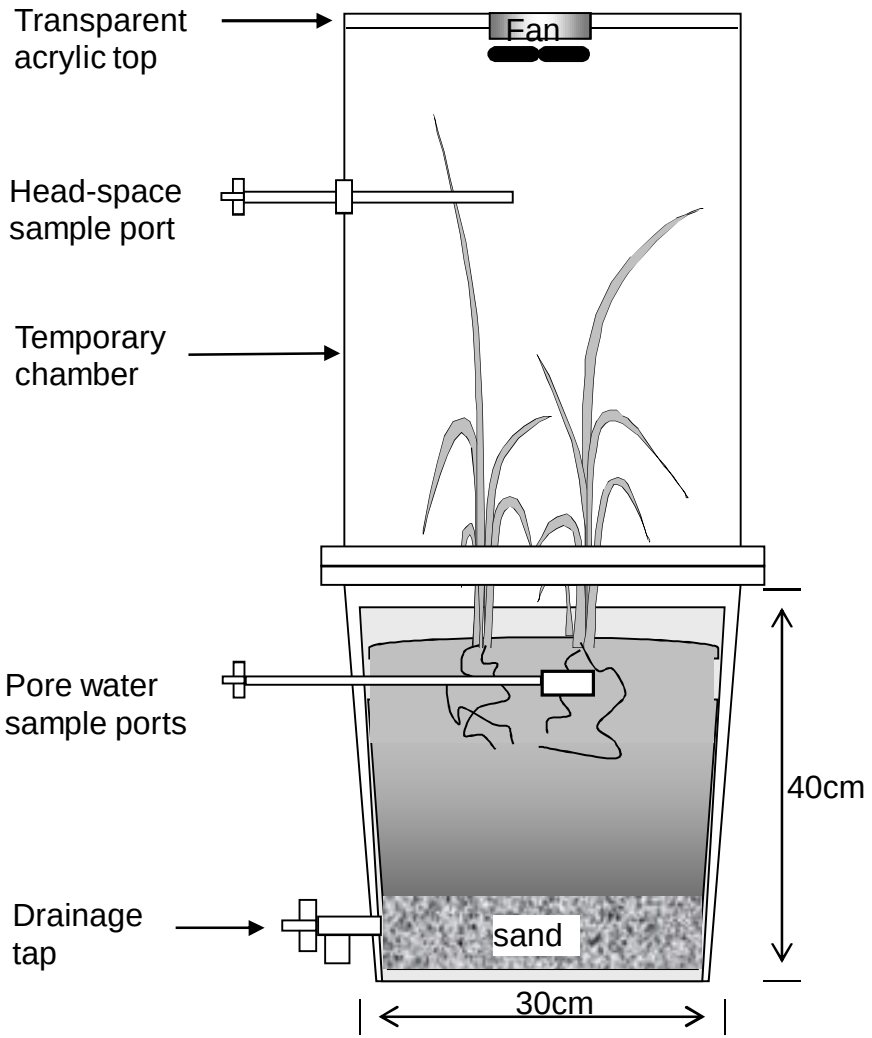
Modified from Schimel, Joshua (2004) Proc. Natl. Acad. Sci. USA 101, 12400-12401



Single ‘dose’ sulfate application data from van der Gon *et al* (2001)

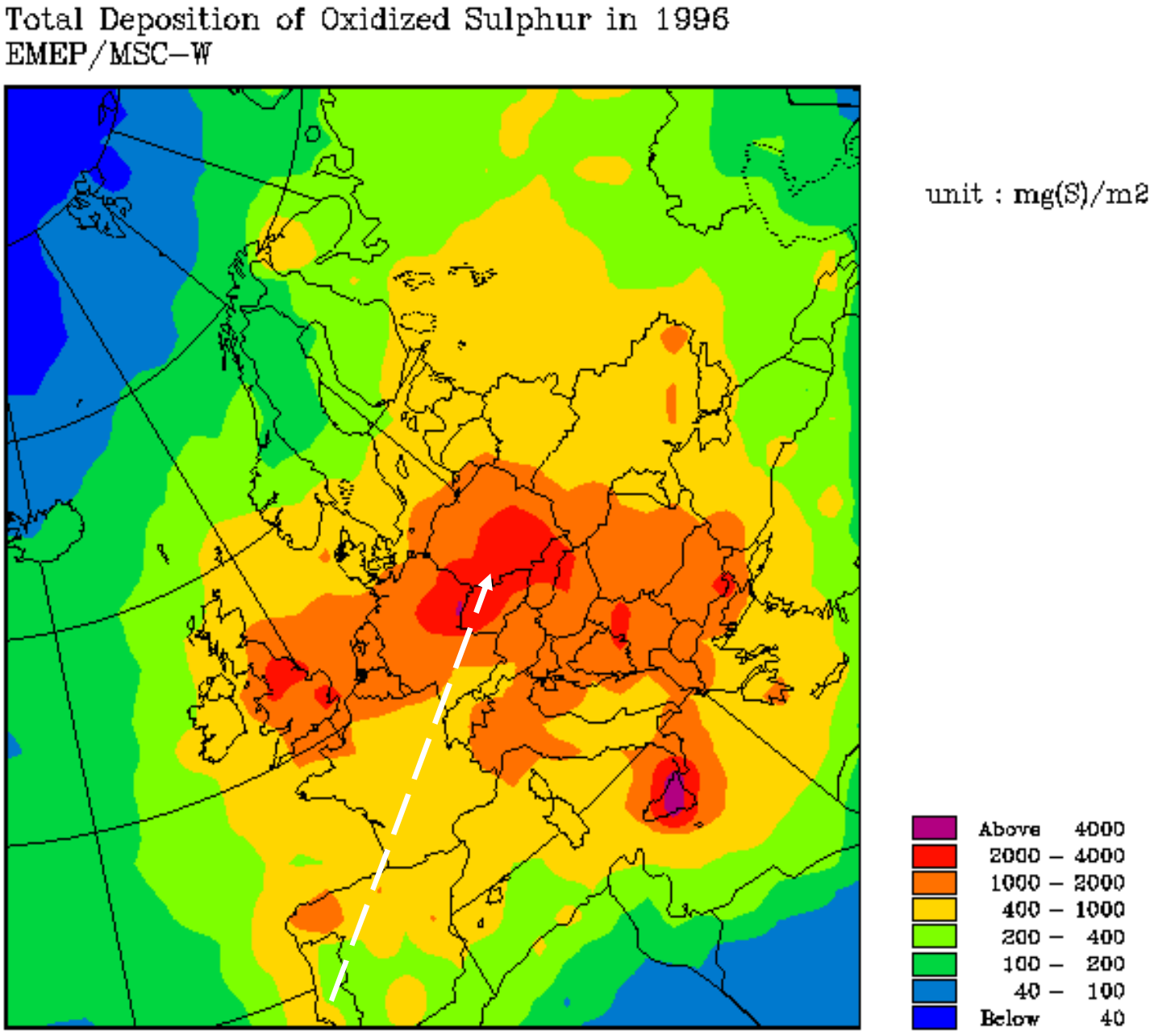

U.K
Milton Keynes
EUROPE
PORTUGAL
Coimbra
COSTA de PRATA
Nazare
Airport
Cascais
Lisbon
Estoril
Elvas
Estremoz
Evora
SPAIN
Soil collection site location
Monte dos Alhos
Beja
ALGARVE
Sagres
Lagos
Portimao
Albufeira
Faro Airport
(S deposition ~5kg ha-1yr-1)
ATLANTIC OCEAN

Na_2SO_4 additions at
100 kg S ha^{-1} y^{-1} or
100 kg S ha^{-1}(single pulse)



Rice mesocosm and gas exchange chamber schematic.

Deposition of SO_4^{2-}-S across Europe



Results

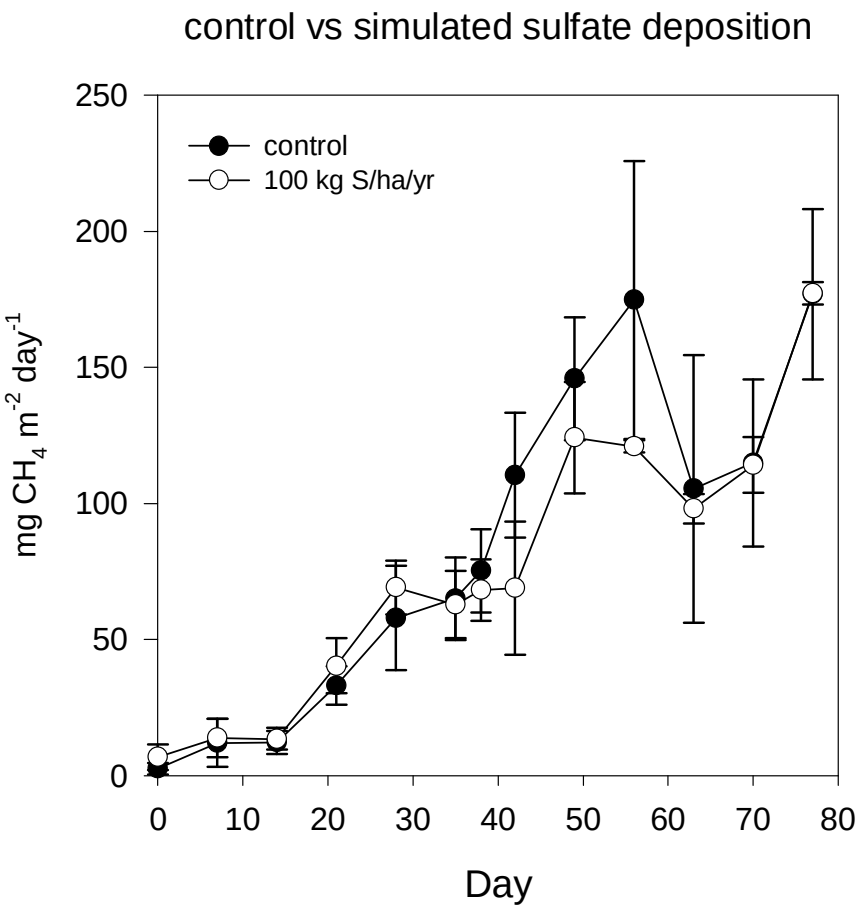
Day 1
(after transplanting)

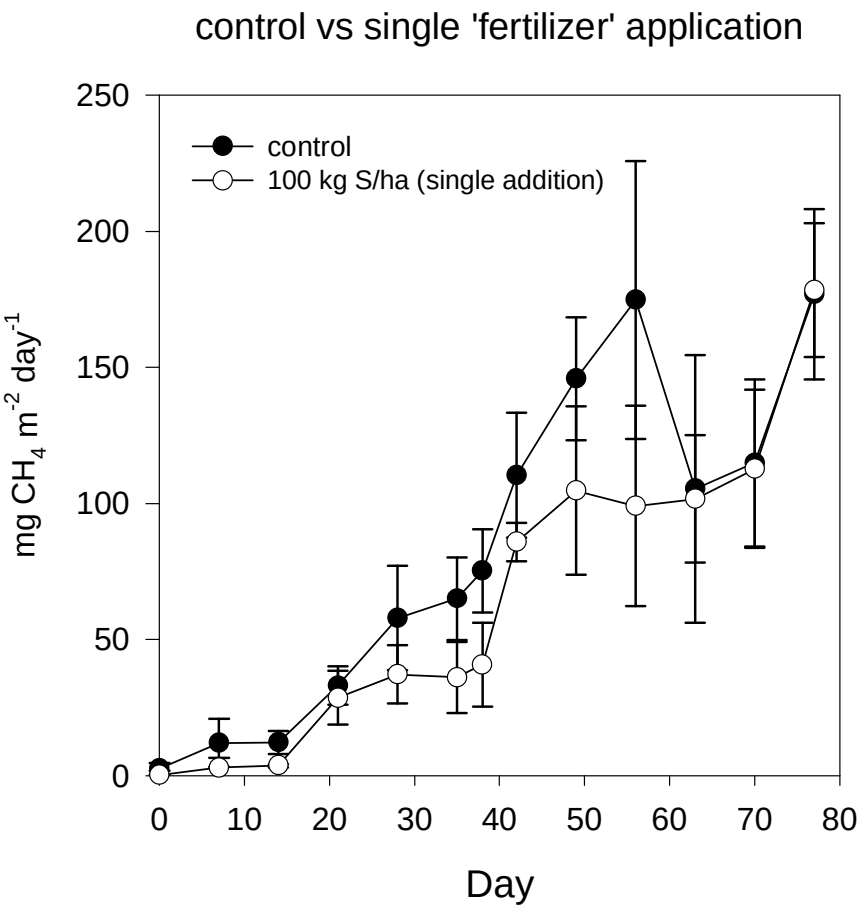
Day 11

Day 42

Day 67

Time series of treatments vs. controls (n =4)





Error bars = +/- SE

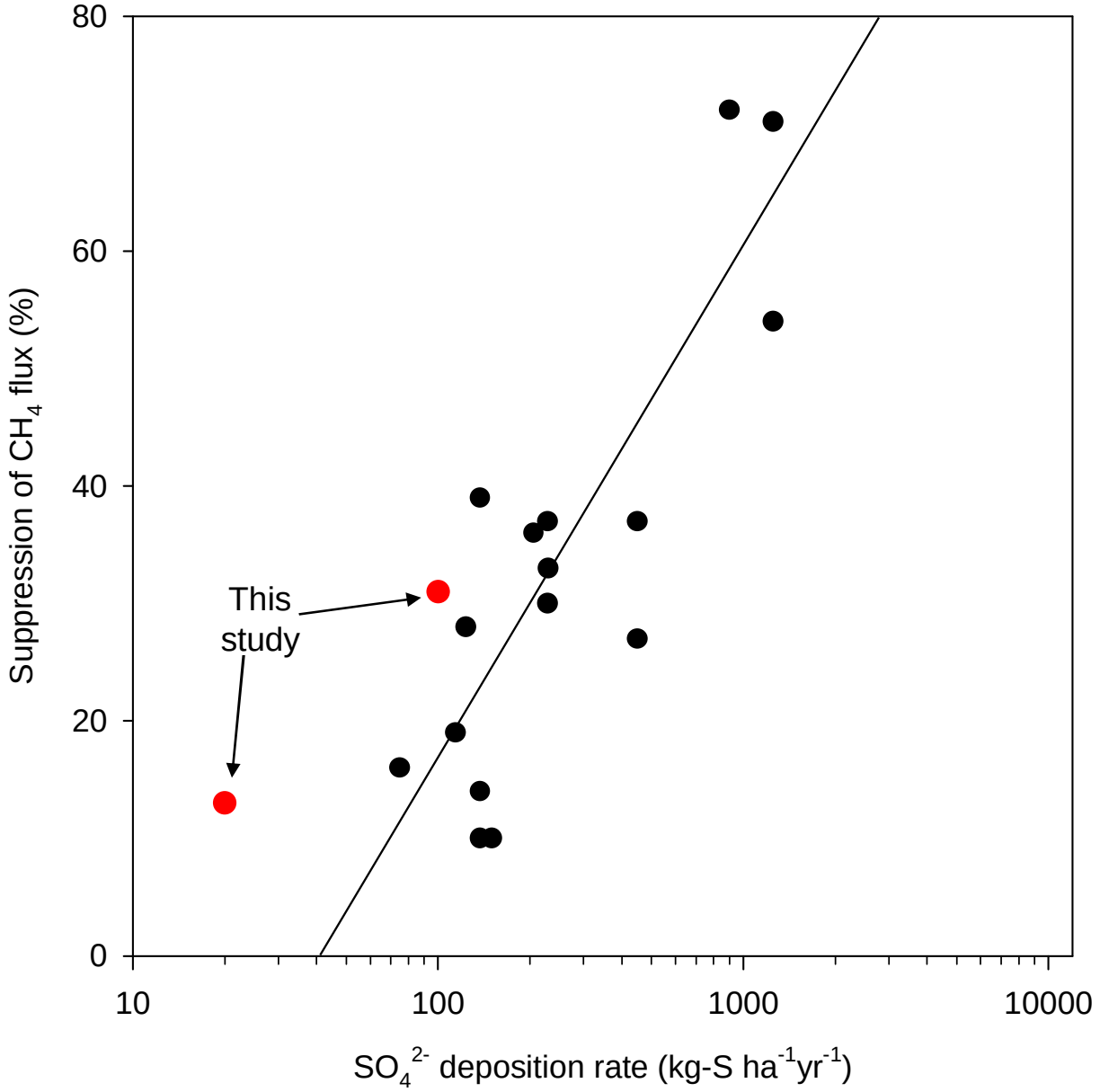
Gauci et al (JGR 2008a)

Treatment	Mean CH_4 flux (±SE) ($mg\ CH_4\ m^{-2}d^{-1}$)	Total CH_4 Emission ($g\ CH_4\ m^{-2}$)	% suppression (treatment vs. control)	*P* –value (MANOVA)
Duration of experiment (day 1-77) *n=60*				
Control	82.9 (8.8)	6.61		
100 kg S $ha^{-1}y^{1}$	75.3 (6.8)	5.74	13	n.s.
100 kg S ha^{-1}	64.0 (8.8)	4.86	31	<0.01
Grain filling/ ripening stage (day 38 – 63) *n=20*				
Control	134 (14.8)	3.65		
100 kg S $ha^{-1}y^{1}$	103 (8.8)	2.77	24	<0.05
100 kg S ha^{-1}	86 (10.5)	2.45	43	<0.05

Table 1. Summary table of CH_4 emission response to experimental SO_4^{2-} addition. p values denote the significance level of any difference between individual treatments and the control.

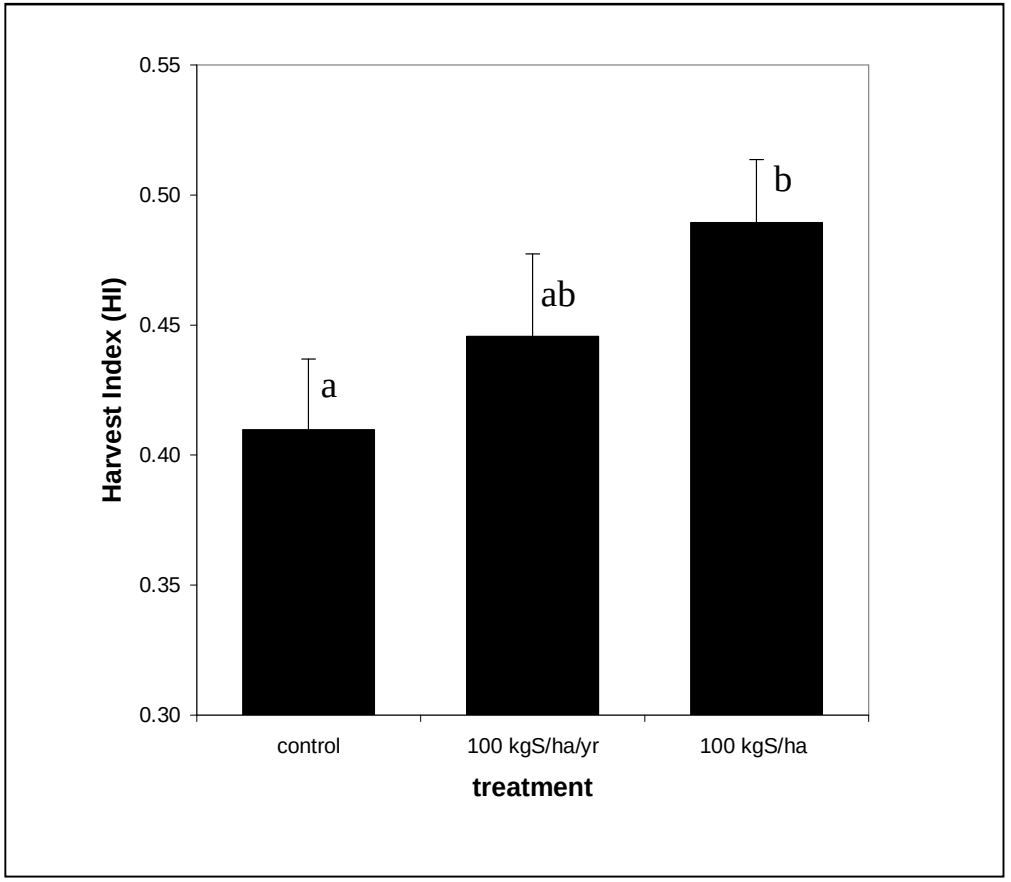
Gauci *et al* JGR (2008a)

New data vs van der Gon data set for comparison



Single ‘dose’ sulfate application data from van der Gon *et al* (2001) + acid rain simulation data – this study.

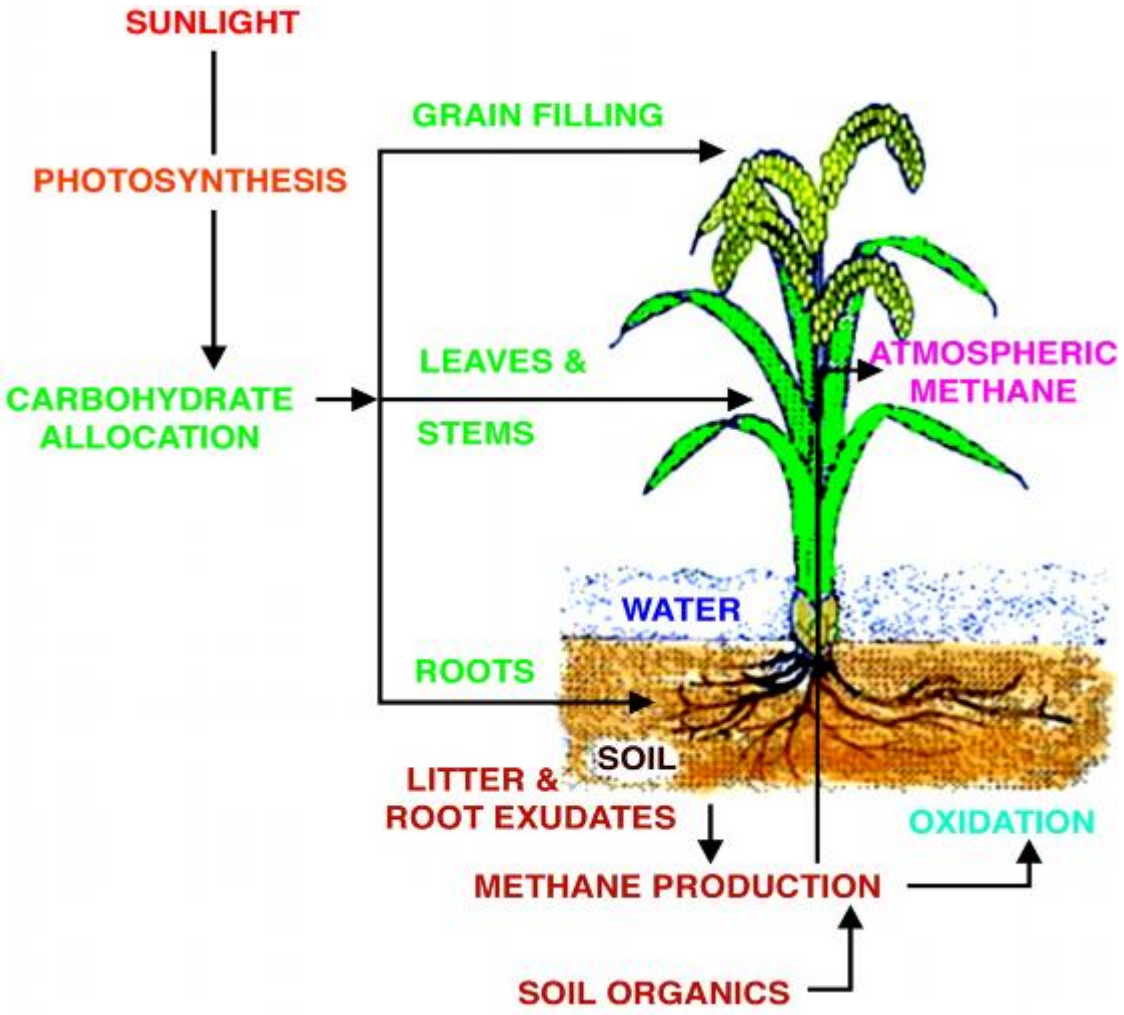
Applied S and Harvest Index



Different letters indicate significant difference $p < 0.05$ (ANOVA)

Gauci *et al* JGR (2008a)

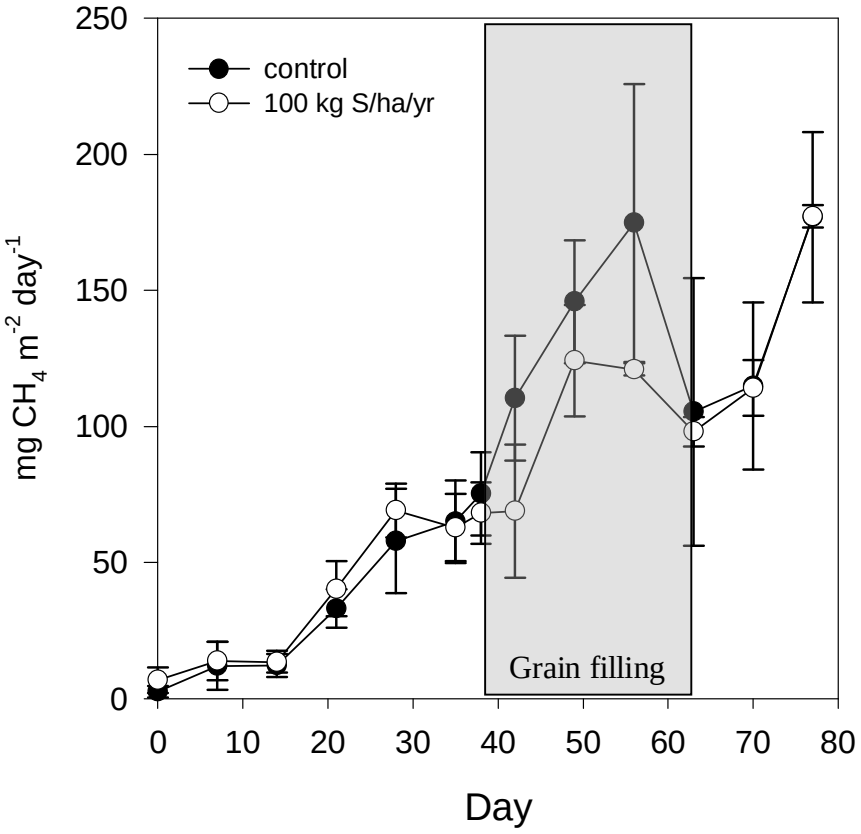
Yield is linked to substrate supply and methane production



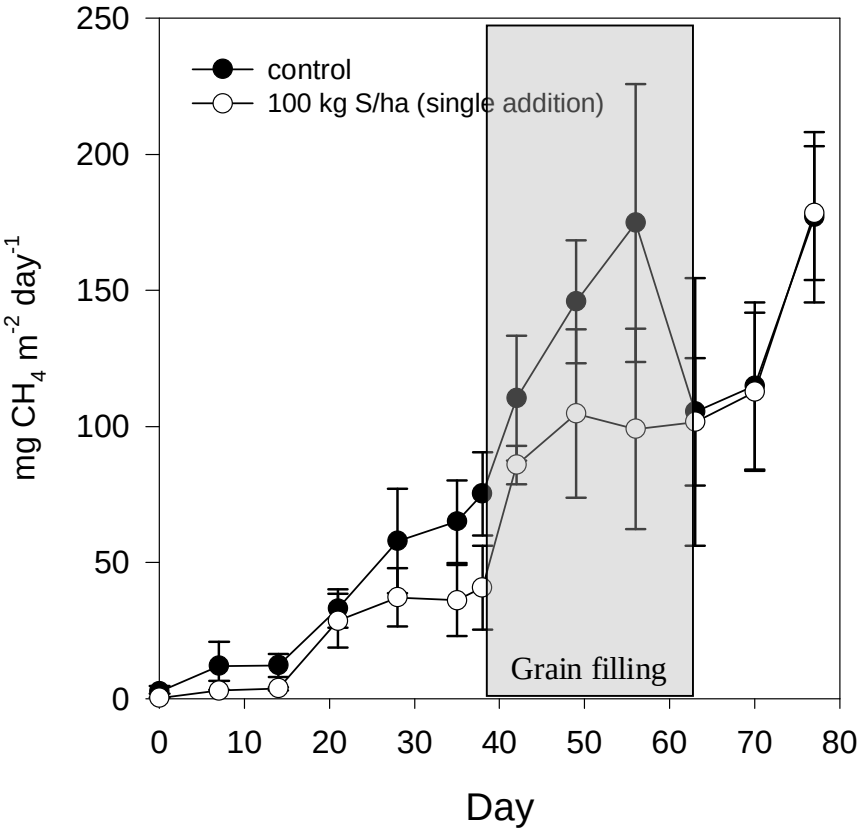
Sass, Ronald L. and Cicerone, Ralph J. (2002) Proc. Natl. Acad. Sci. USA 99, 11993-11995

Temporal variation in suppressive effect of sulfate.

control vs simulated sulfate deposition

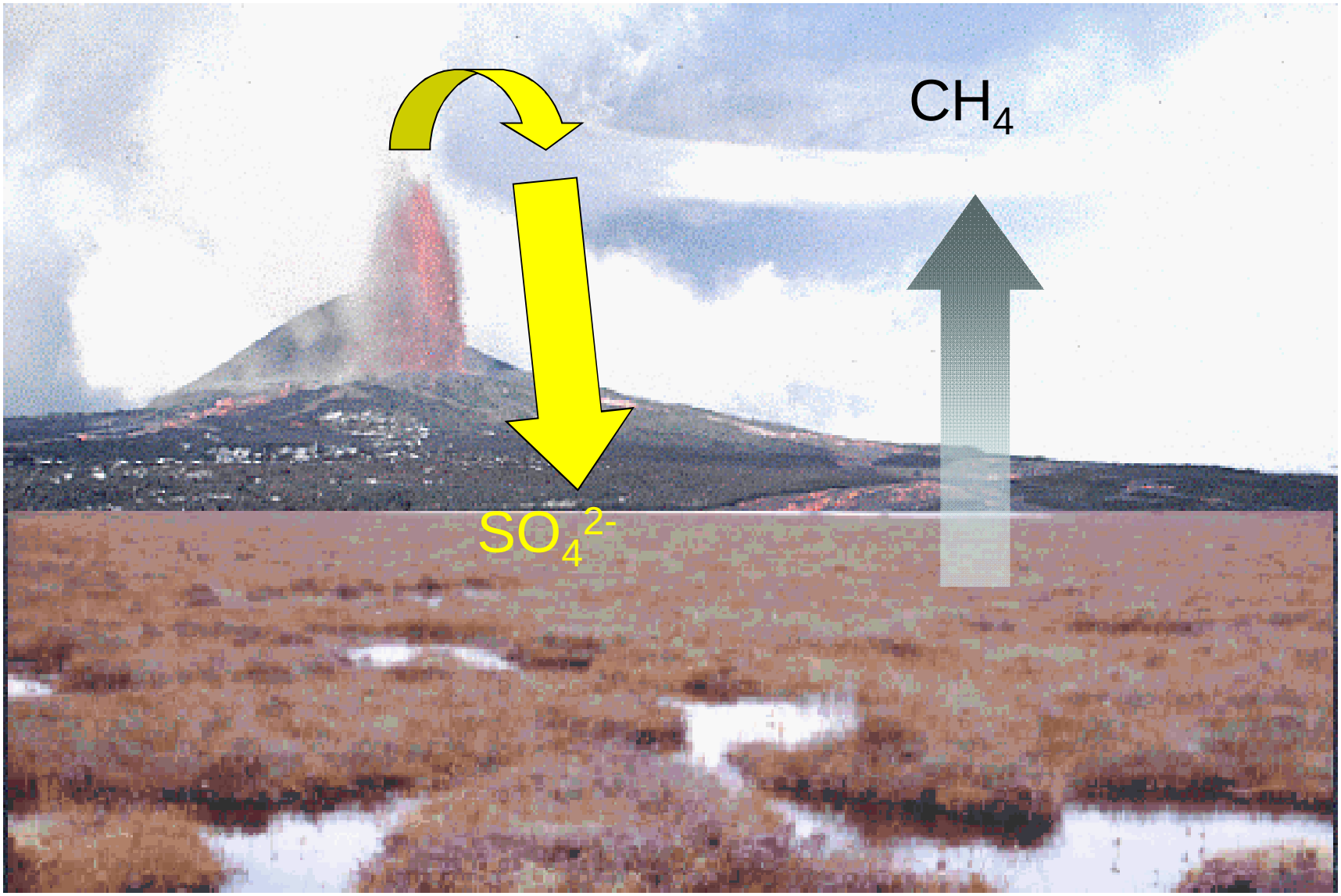


control vs single 'fertilizer' application



Error bars = +/- SE

How long does the sulfur effect last?



Return to Moidach:
CH_4 recovery from pollution events?

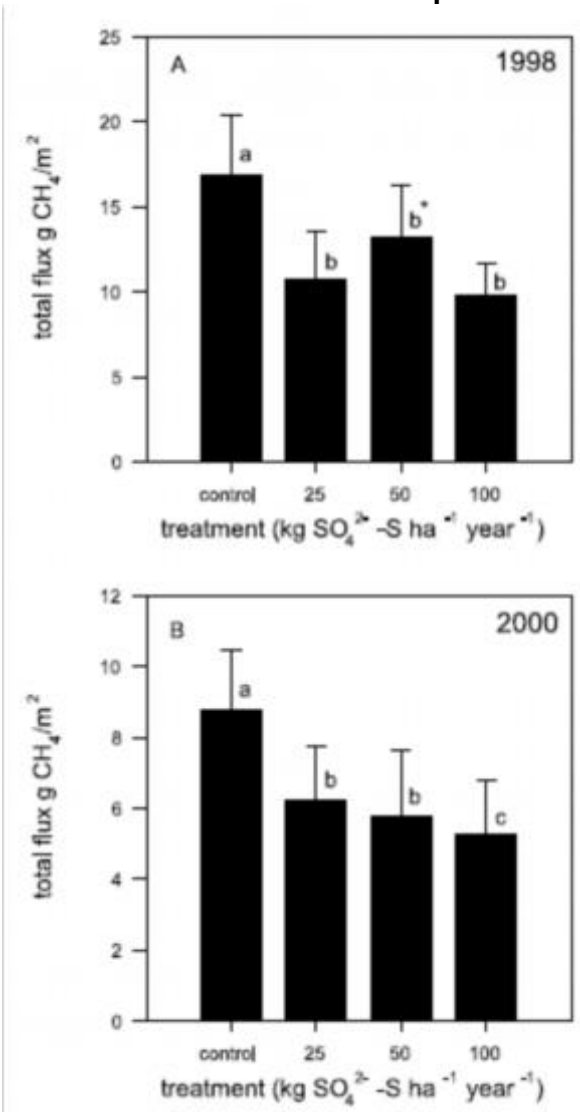


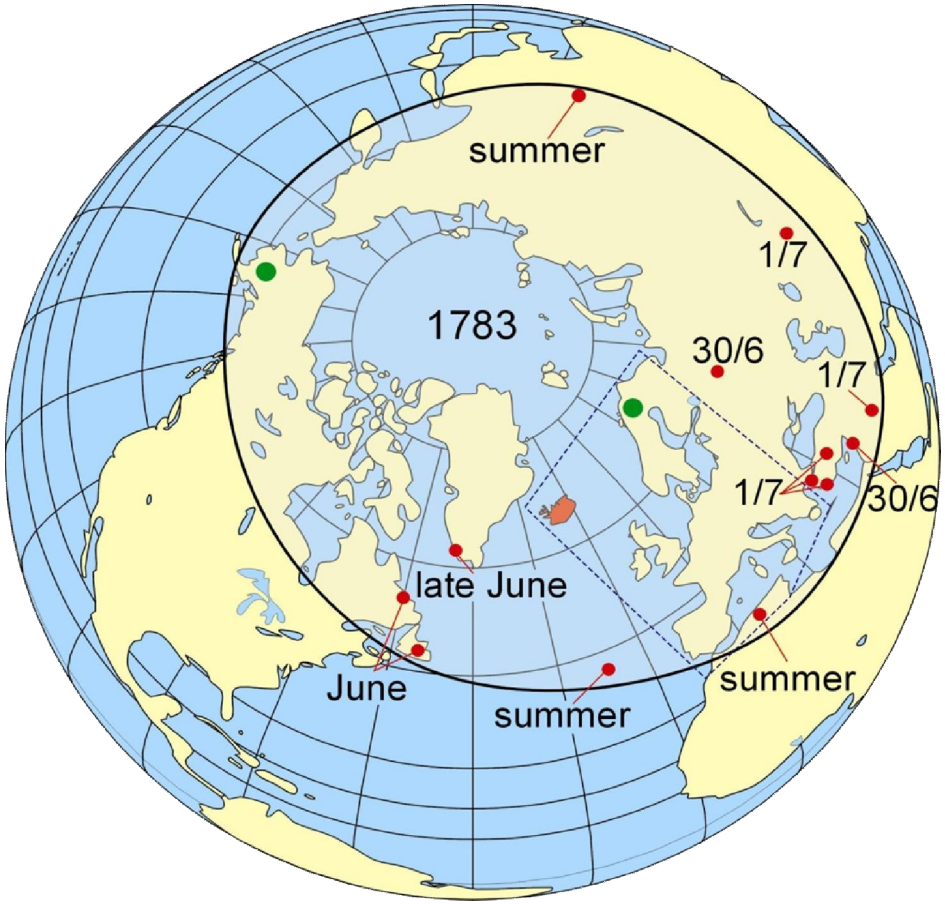
Table 1. Molar Ratios of Suppressed CH_4 to Applied SO_4^{2-} for Three Time Periods: 1997, 1997+1998, and 1997 to 2000[a]

Period	Treatment, kg SO_4^{2-} S/ha/yr	Applied SO_4^{2-} moles/m^2	Suppression of CH_4 moles/m^2	CH_4: SO_4^{2-} (±)
1997	25	0.08	0.38	4.9
	50	0.16	0.23	1.4
	100	0.31	0.44	1.4
1997+1998	25	0.12	0.44	3.8
	50	0.23	0.34	1.5
	100	0.47	0.49	1.1
1997 to 2000	25	0.12	0.88 (0.14)	7.3 (1.2)
	50	0.23	0.74 (0.23)	3.2 (1.0)
	100	0.47	1.05 (0.14)	2.2 (0.3)

[a]Parentheses indicate a ± envelope around the mean based on low and high CH_4 emission scenarios for 1999 where the conservative estimate was equivalent to emissions in 2000 and the high estimate was equivalent to 1998 emissions.

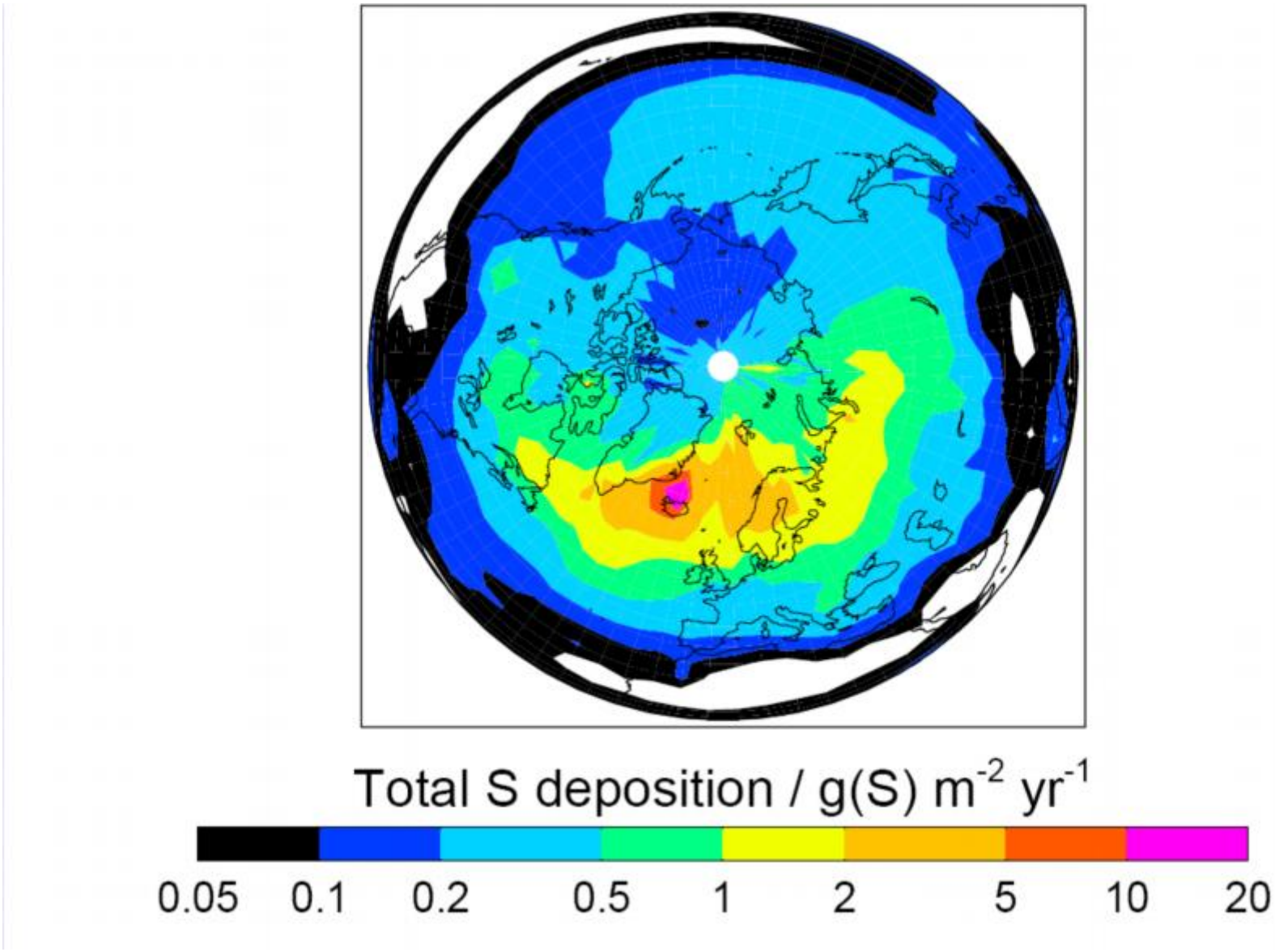
Gauci *et al* (2005) GRL

1783-84 Laki Eruption in Iceland
(8 June 1783 – 7 February 1784)



Extent and date of first appearance of Laki haze at surface.

Thordarson and Self (2003)



Laki S-deposition 1783-84 (Stevenson *et al* 2003)

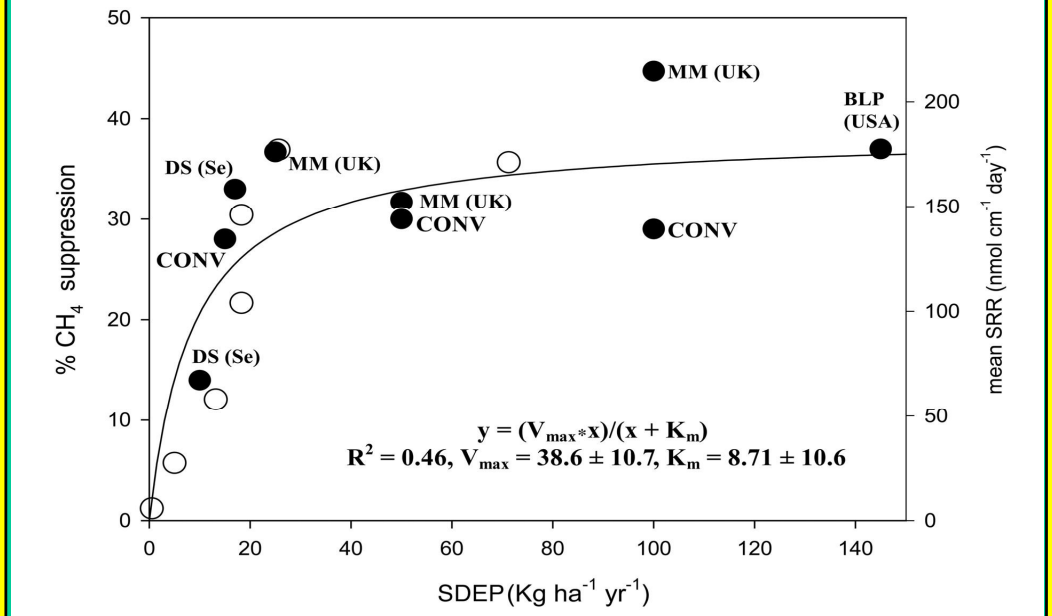
Atmospheric Laki sulfur simulation MetOffice GCM (Stevenson et al *et al*., 2003)

1782-85 climate as influenced by Laki aerosol (Highwood and Stevenson 2003)

Regression model of CH_4 anomalies with temp. and precip. anomalies.

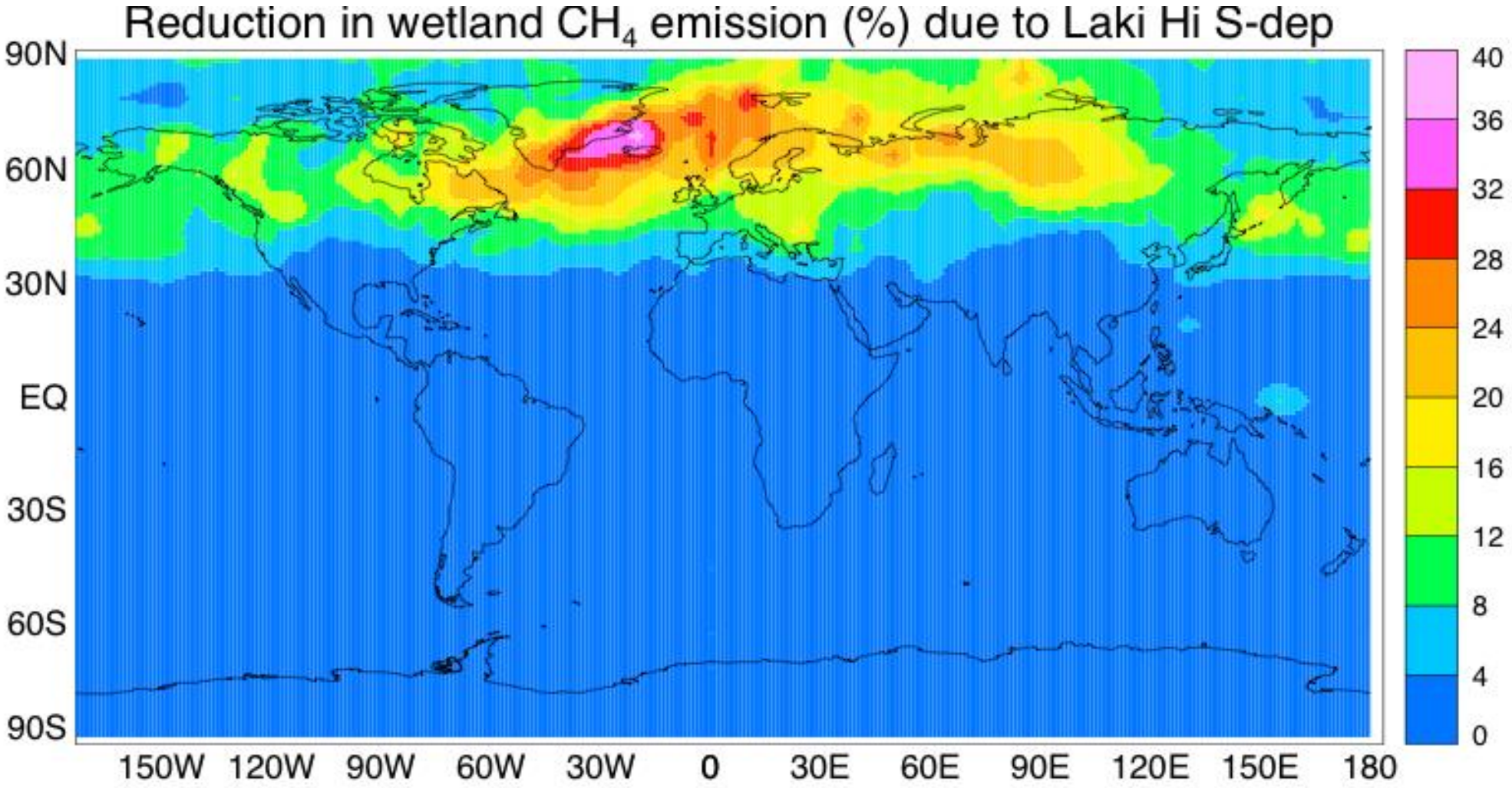
CH_4 from wetlands 1782 - 85

S deposition (wet + dry) 1783-84

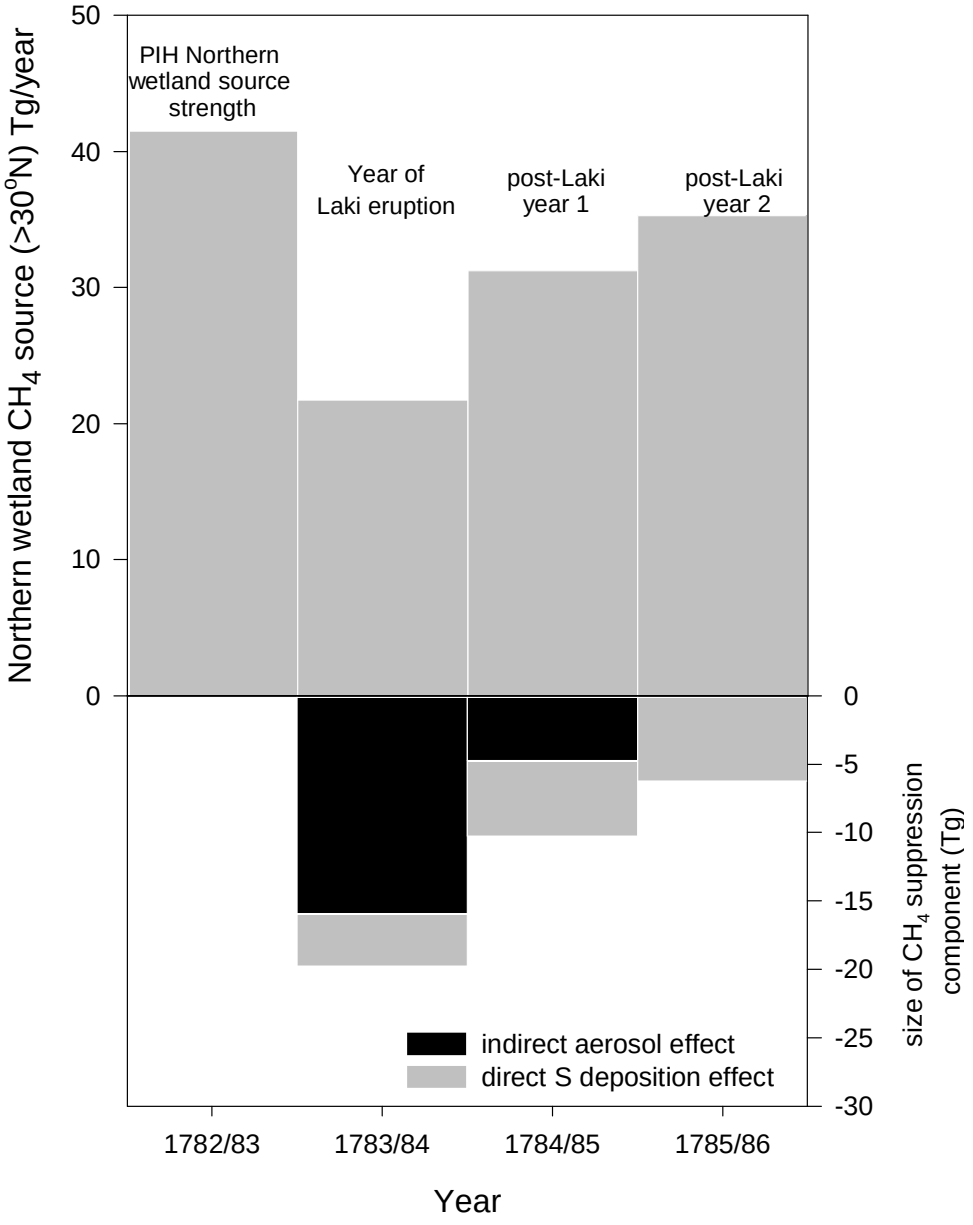


Global wetland CH_4 emissions as affected by spatial and temporal changes in S- deposition

Schematic representation of models utilised for estimation of the effects of spatial and temporal changes in sulfur deposition on the global wetland CH_4 source.



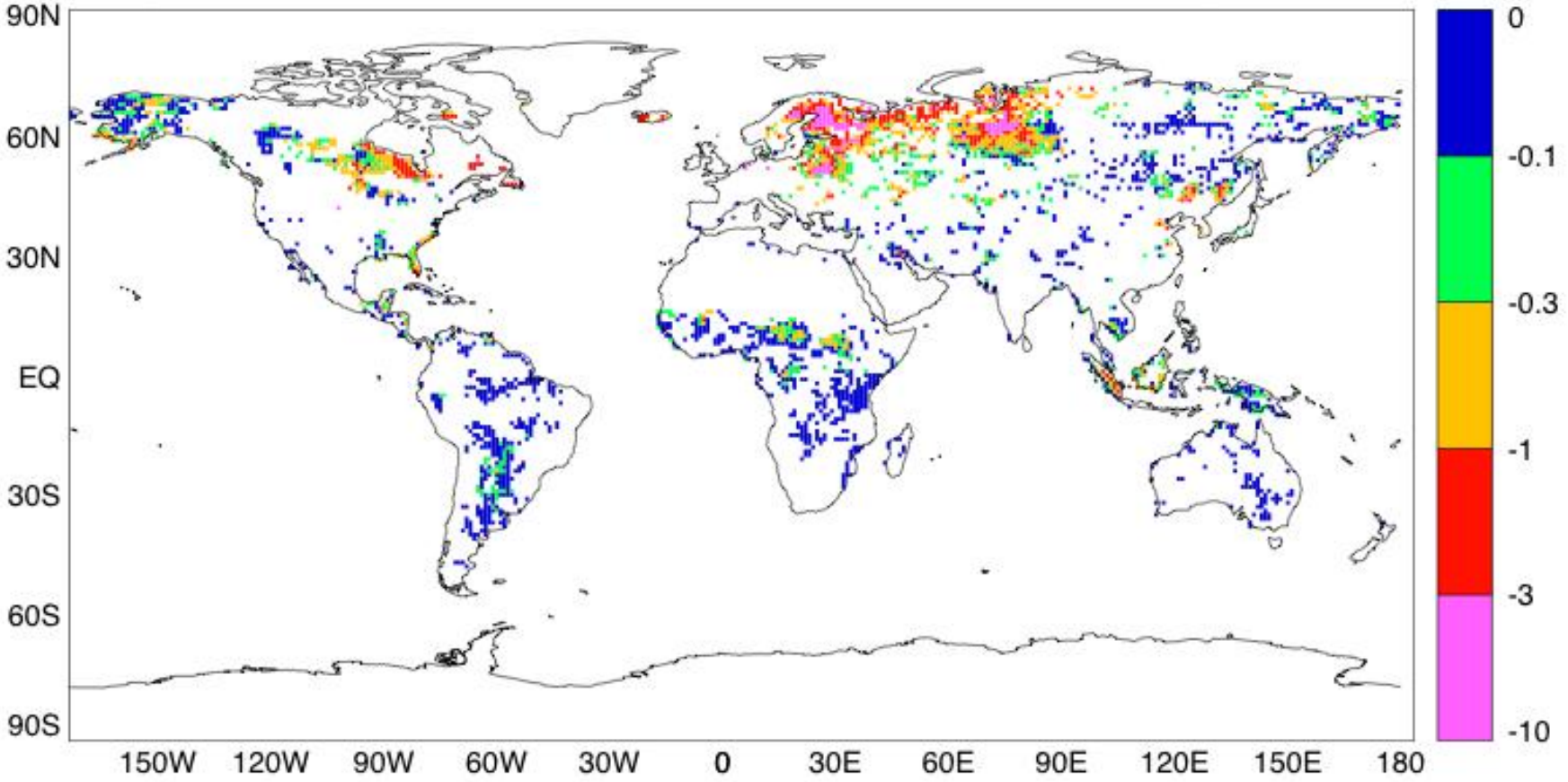
Gauci *et al* (2008b) JGR



Modelled effect of Laki on the northern wetland CH_4 source

Gauci *et al* (2008b) JGR

Change in Wetland CH_4 emission due to Laki Hi S dep (g $CH_4/m^2/yr$)



Gauci *et al* (2008b) JGR

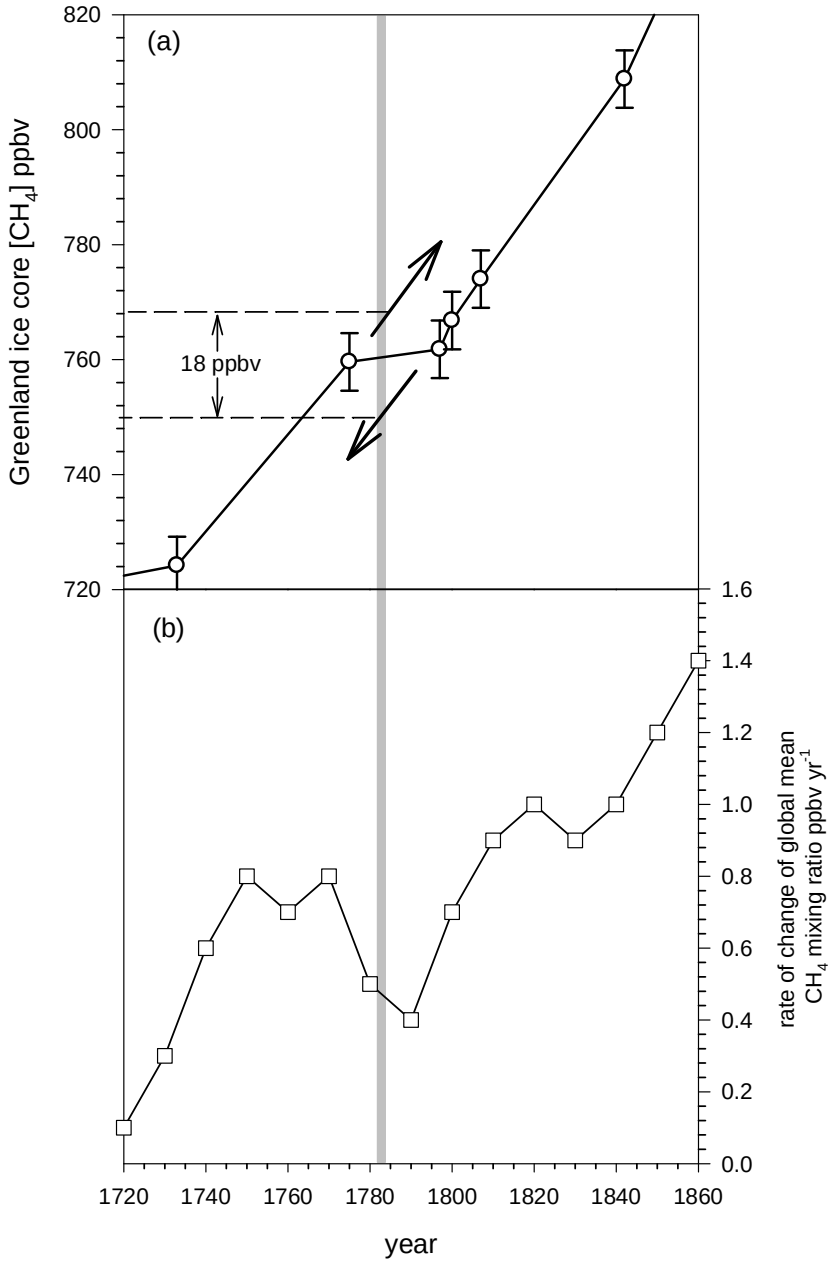
Modelling the impact on atmospheric methane concentrations over time

The effect of a change in emission rate on the atmospheric load was modelled using the equation describing the methane budget [*Etheridge et al,* [1998] equation 1]:

$$\frac{dB}{dt} = S - \frac{B}{T}$$

where *B* is the methane burden in atmosphere (Tg), *t* is time (year), ***S* is the methane source emission rate (Tg year^{-1})**, and *T* is the lifetime of methane in the atmosphere (year). The mixing ratio [CH4] in ppbv is related to the burden, *B*, by [CH4] = *B*/*c* where the constant *c* = 2.767 Tg ppbv-1 [*Fung et al.,* 1991].

Gauci *et al* (2008b) JGR



Comparison with ice core CH_4 records

Gauci et al (submitted to JGR)

Summary

- Methane emissions from wetlands are suppressed by sulfate deposition.
- The effect is significant at the global scale and is offsetting growth in the wetland source that would be taking place due to warming.
- CH_4 emissions may rebound if S suppression is reduced.
- Recovery may only take place over decadal time scales.
- The effect may also be reducing rice CH_4 emissions.
- Work is required to synthesise CH_4 emissions from wetlands spanning deposition gradients and to examine the effect in the tropics.
- Volcanic eruptions can have a similar effect and the Laki eruption provides a historical ‘experiment in time’.

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