Peatlands: Methane vs. CO_2

By Frolking, Roulet, Fuglestvedt

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Math Climate Seminar

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How northern peatlands influence the Earth's radiative budget: Sustained methane emission versus sustained carbon sequestration

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What is a Peatland?

What is a Peatland?

Red Lake Peatland with water track, Minn., EG

What is a Peatland?

Bog "islands" in sedge fen, Upper Red Lake Peatland, perfect "teardrops",1961

What is a Peatland?

Raised Bog with Spruce

What is a Peatland?

Hudson Bay Lowlands

Contents

Carbon Accumulation

Simplest view of the carbon accumulation in peatlands:

(1) new carbon is added to the surface through photosynthetic processes at a rate proportional to the surface area, independent of the volume of material already accumulated.

(2) existing carbon is lost through decomposition at a rate that is proportional to the volume already accumulated.

Carbon Accumulation

Simplest view of the carbon accumulation in peatlands:

(1) new carbon is added to the surface through photosynthetic processes at a rate proportional to the surface area, independent of the volume of material already accumulated.

(2) existing carbon is lost through decomposition at a rate that is proportional to the volume already accumulated.

Then the dynamics are

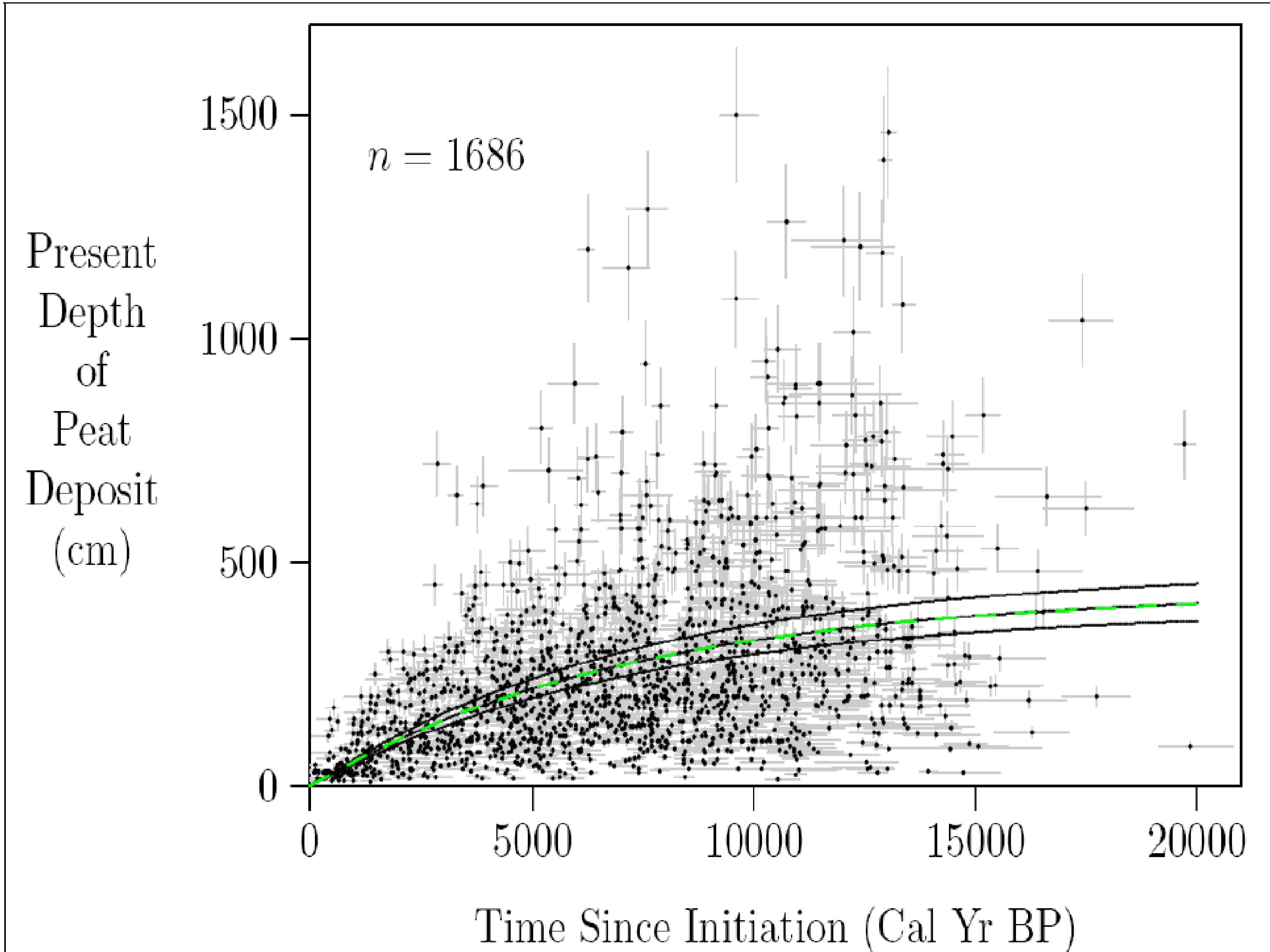
$$\frac{dH}{dt} = a - bH$$

$$\frac{dH}{dt} = r_0 \left(1 - \frac{H}{H_0}\right)$$

$$H(t) = H_0 \left(1 - e^{-r_0 t/H_0}\right)$$

r_0 is the rate of increase in depth when the peatland is young (just initiated).

H_0 is the maximum depth, where decomposition exactly balances production.



AgeDepth2.png

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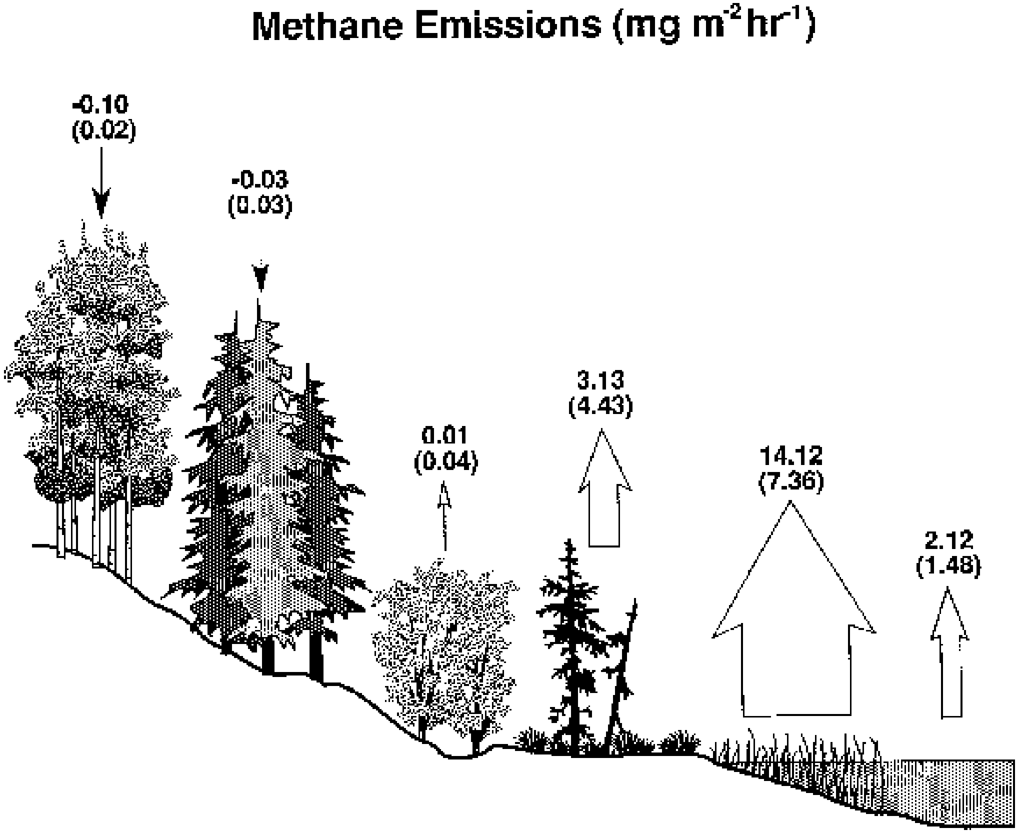
- Why do we care about Methane?
- Global Warming Potential (GWP)
- Modeling net radiative forcing.
- Results: Dynamics of Peatland's radiative forcings.

How do Peatlands create Methane?

In anaerobic conditions, microbial decomposition released Methane.



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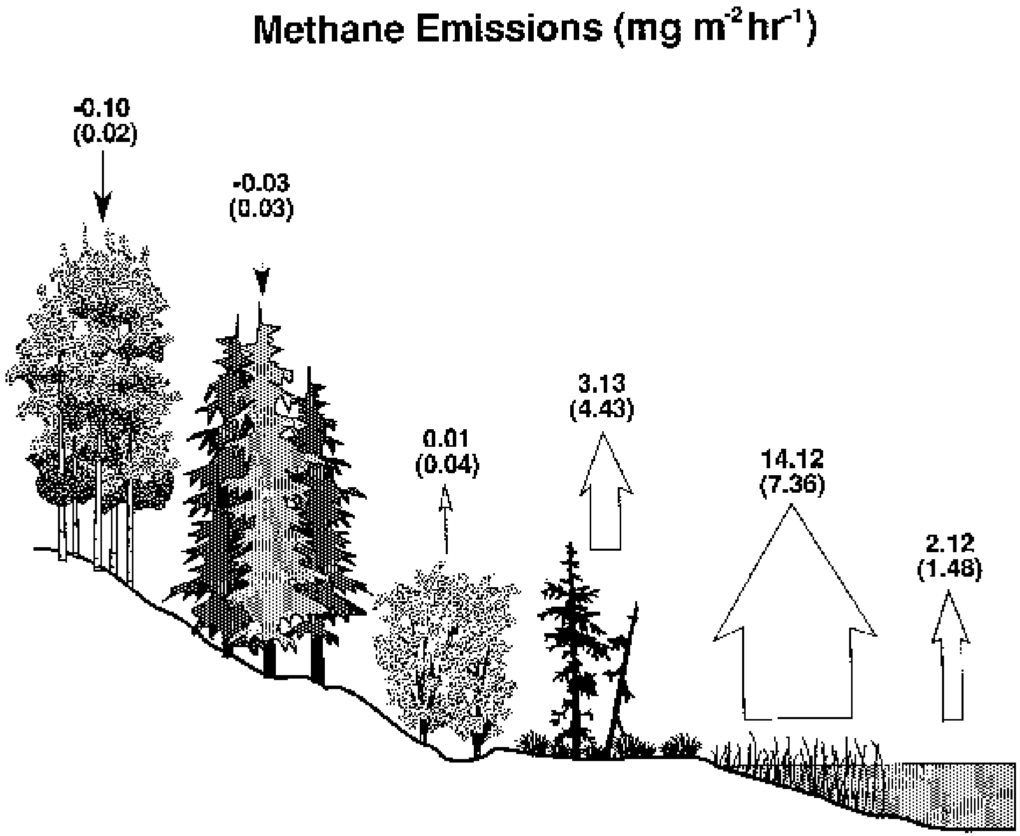

Northern Peatlands contribute 3-5% of the total global methane emissions.

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Why do we care about Methane?

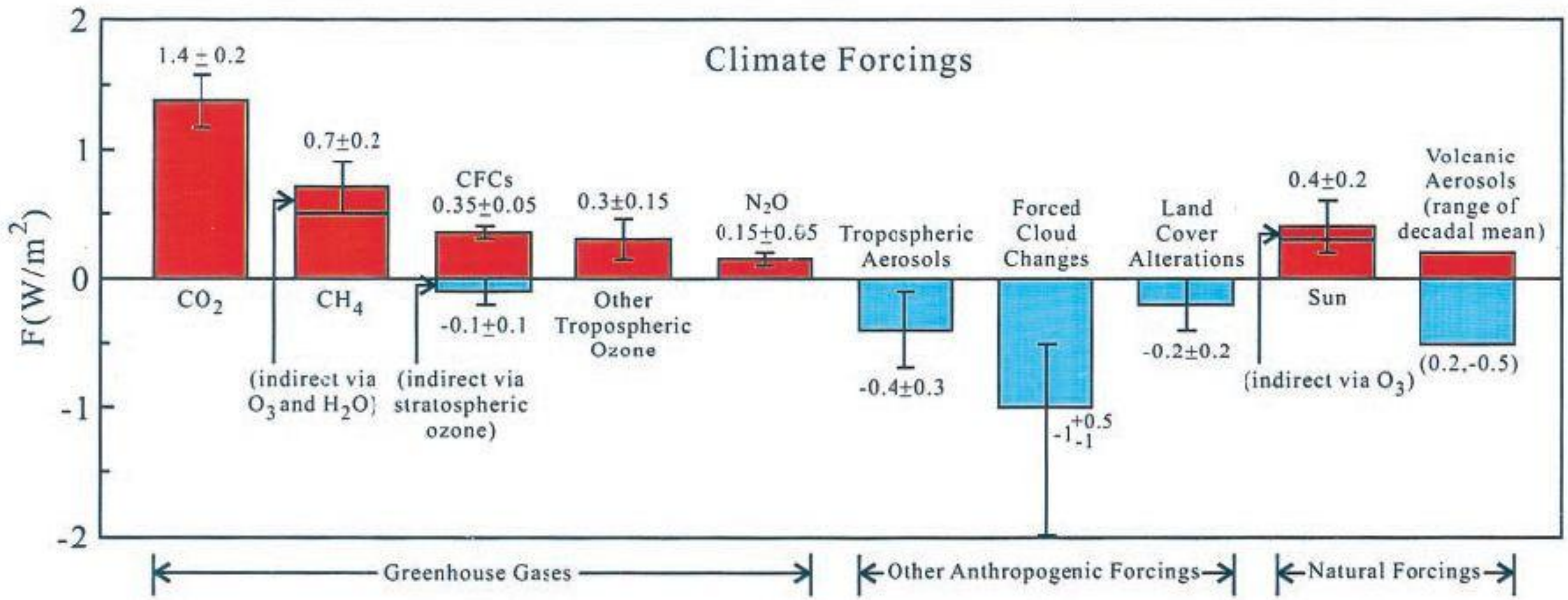
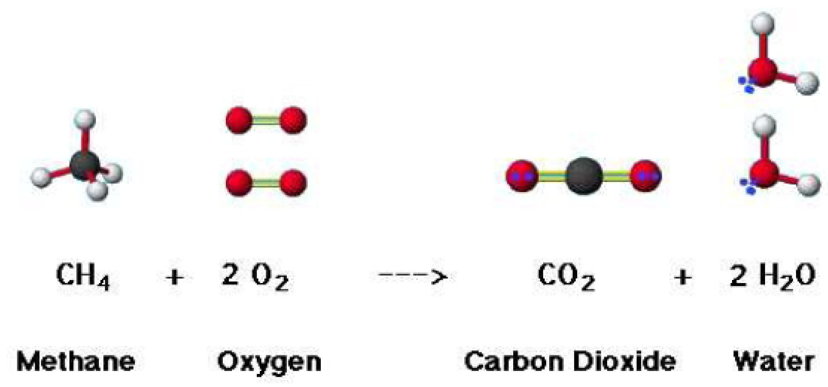


Fig. 1. Estimated climate forcings between 1850 and 2000.

Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland, 2007: Changes in Atmospheric Constituents and in Radiative Forcing. *In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Why do we care about Methane?

Methane causes 40% more temperature change than CO_2 because it becomes CO_2 after a short time of being hyper effective as CH_4 in the atmosphere.



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Global Warming Potential

$$GWP_i \equiv \frac{\int_0^{TH} RF_i(t)\,dt}{\int_0^{TH} RF_r(t)\,dt} = \frac{\int_0^{TH} a_i \cdot [C_i(t)]\,dt}{\int_0^{TH} a_r \cdot [C_r(t)]\,dt}$$

TH= time horizon

RF_i = global mean radiative forcing (RF) of component I

a_i = the RF per unit mass increase in atmospheric abundance of component I
= radiative efficiency

$[C_i(t)]$ = is the time-dependent abundance of i.

Subscript r = reference gas which is CO_2 in our case.

Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland, 2007: Changes in Atmospheric Constituents and in Radiative Forcing. *In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Global Warming Potential

	Global Warming Potential		
	20 years	100 years	500 years
Methane	72	25	7.6

- These are based on a 1-kg pulse emission
- GWP methodology does NOT include oxidation-generated CO_2 as a component of the direct or indirect radiative forcing impact of CH_4 emissions.

Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland, 2007: Changes in Atmospheric Constituents and in Radiative Forcing. *In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Global Warming Potential

- Classifying a Peatland as a *source* or a *sink* is based on GWP.
- "For any given ratio of emissions, there is a particular compensation GWP value that results in the CO_2–equivalent emission of the methane flux exactly offsetting the CO_2 uptake."

Global Warming Potential

- Classifying a Peatland as a *source* or a *sink* is based on GWP.
- "For any given ratio of emissions, there is a particular compensation GWP value that results in the CO_2–equivalent emission of the methane flux exactly offsetting the CO_2 uptake."
- A peatland is a *net greenhouse source* if, for a given time horizon, the ratio of CH_4 to CO_2 was higher than the compensation value.
- Else it is a *net greenhouse sink*.

Global Warming Potential

- Classifying a Peatland as a *source* or a *sink* is based on GWP.
- Example Peatland
  - releases 1 kg of Methane in a given year.
  - sequesters 50 kg of CO_2 in a given year.
- Is this a source or sink over the three timescales?

	Global Warming Potential		
	20 years	100 years	500 years
Methane	72	25	7.6
Source or Sink?			

Global Warming Potential

- Classifying a Peatland as a *source* or a *sink* is based on GWP.
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	Global Warming Potential		
	20 years	100 years	500 years
Methane	72	25	7.6
Source or Sink?	Source		

- Over 20 years, 1kg of Methane is worth 72kg of CO_2.
- $72 > 50$

Global Warming Potential

- Classifying a Peatland as a *source* or a *sink* is based on GWP.
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	Global Warming Potential		
	20 years	100 years	500 years
Methane	72	25	7.6
Source or Sink?	Source	Sink	

- Over 100 years, 1kg of Methane is worth 25kg of CO_2.
- $25 < 50$

Global Warming Potential

- Classifying a Peatland as a *source* or a *sink* is based on GWP.
- Example Peatland
  - releases 1 kg of Methane in a given year.
  - sequesters 50 kg of CO_2 in a given year.
- Is this a source or sink over the three timescales?

	Global Warming Potential		
	20 years	100 years	500 years
Methane	72	25	7.6
Source or Sink?	Source	Sink	Sink

- Over 500 years, 1kg of Methane is worth 7.6kg of CO_2.
- $7.6 < 50$

Global Warming Potential

- Classifying a Peatland as a *source* or a *sink* is based on GWP.
- Example Peatland
  - releases 1 kg of Methane in a given year.
  - sequesters 50 kg of CO_2 in a given year.
- Is this a source or sink over the three timescales?

	Global Warming Potential		
	20 years	100 years	500 years
Methane	72	25	7.6
Source or Sink?	Source	Sink	Sink

- Questions about this piece?

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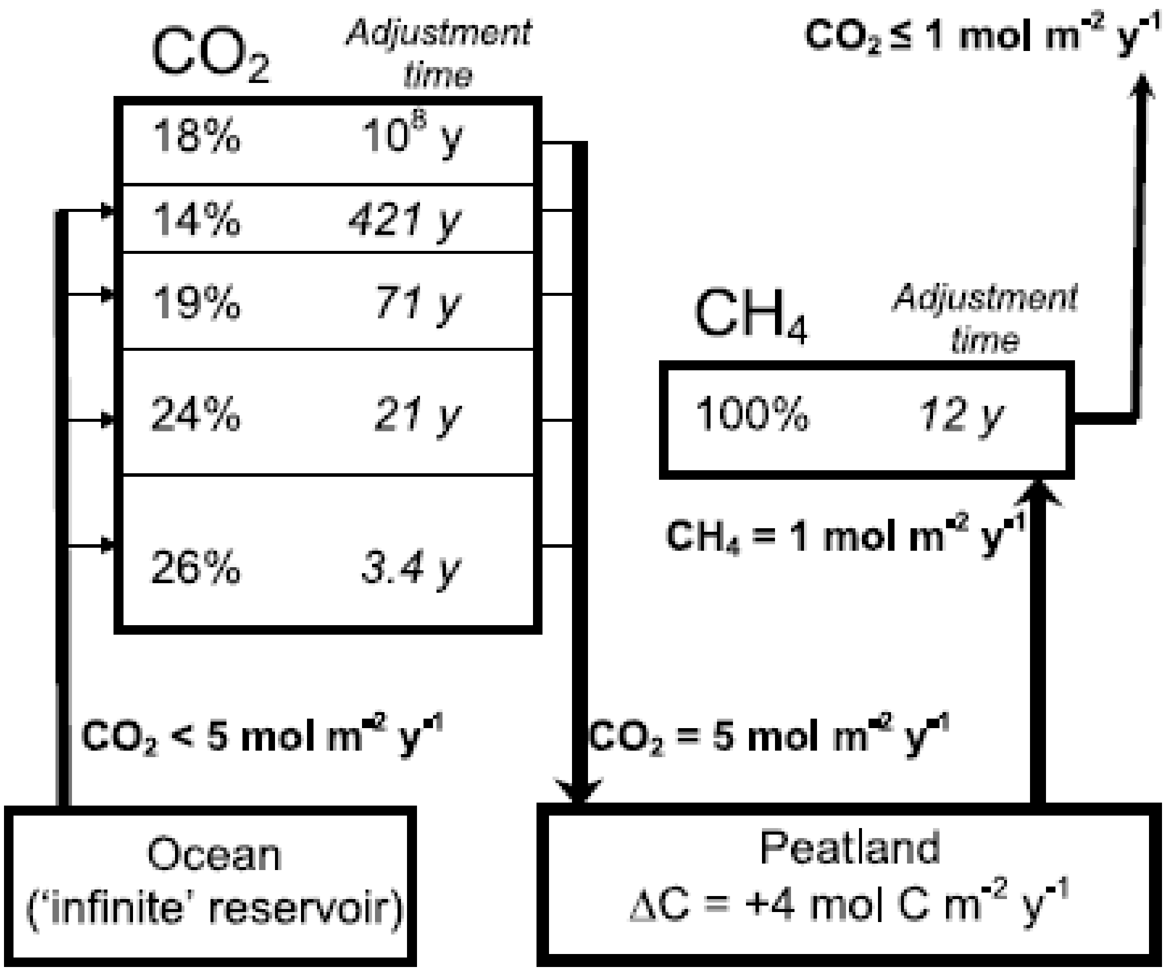
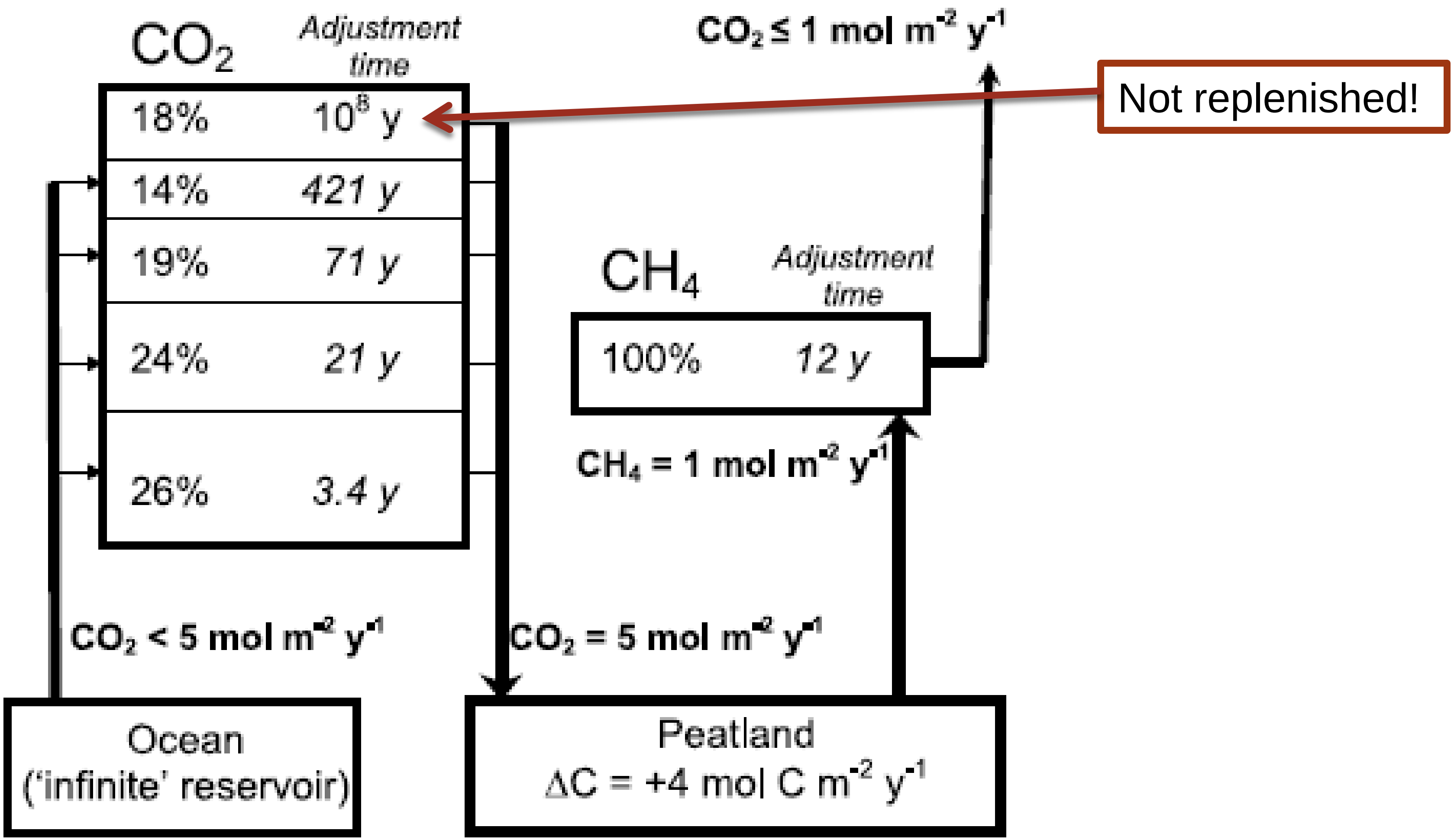
Modeling net radiative forcing.



Our Model

Modeling net radiative forcing.



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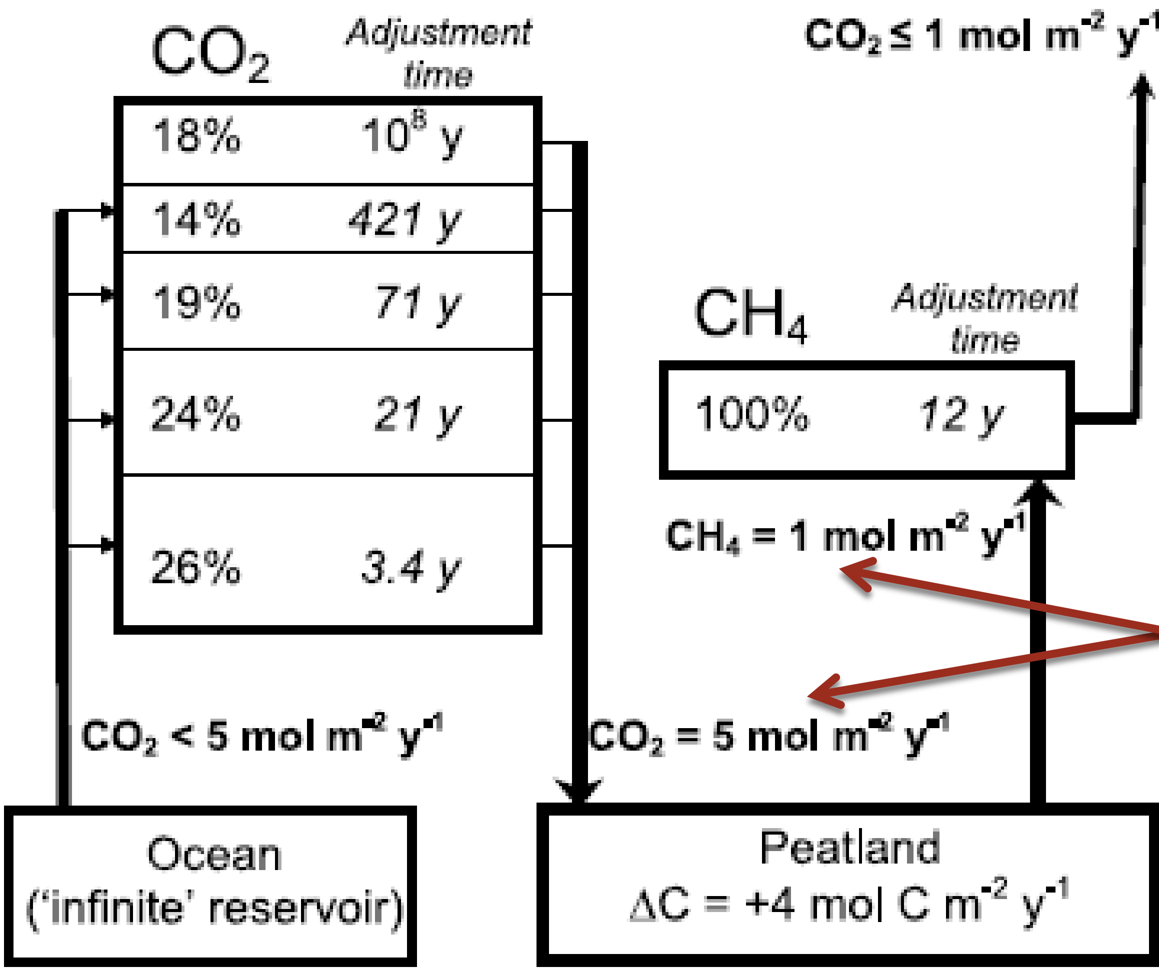


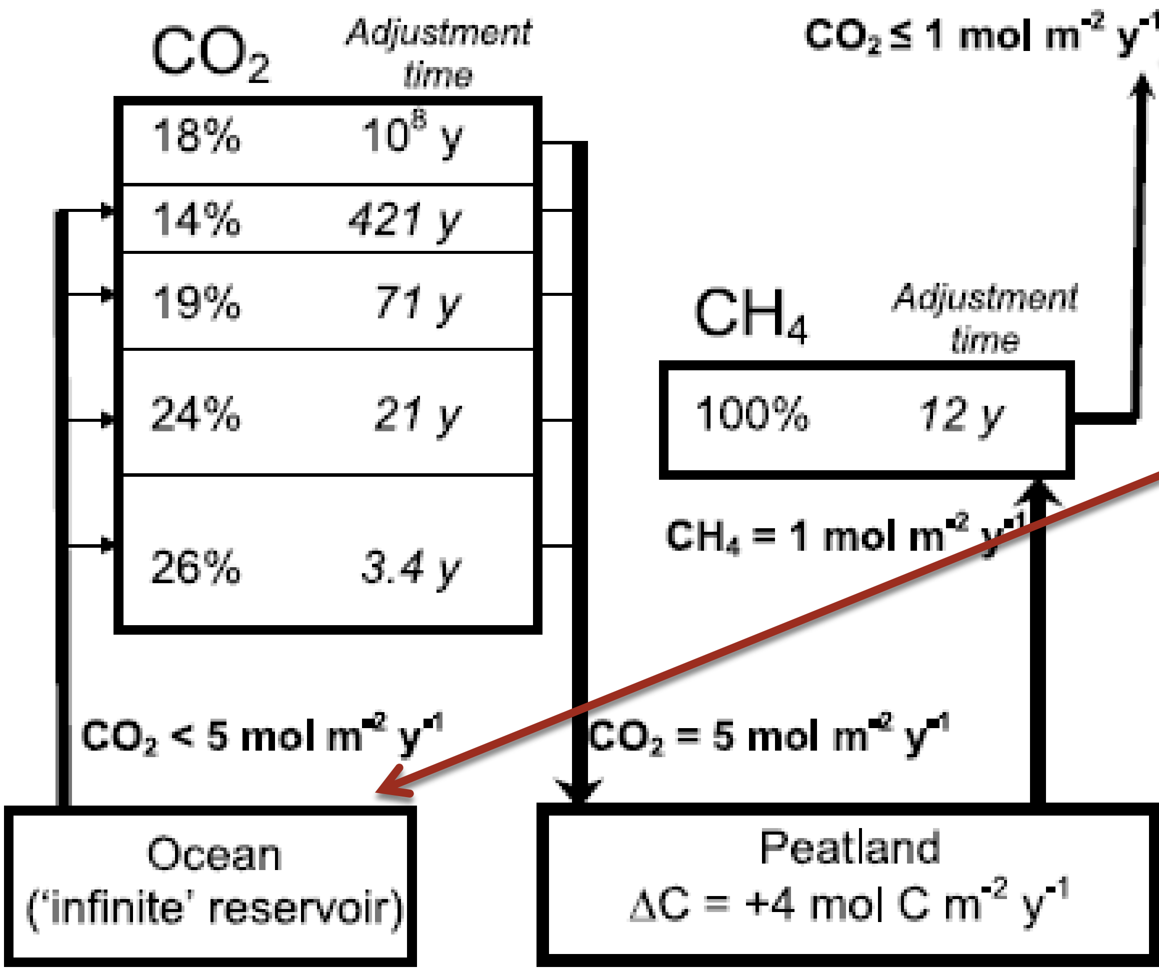
Total northern peatlands fluxes from observation

CH_4 flux:
20 Tg CH_4/ yr ≈
.02 Pg CH_4/ yr

C flux:
0.07 Pg C/yr

Thus,
CH_4 :CO_2 flux should be
0.02/0.07 ≈ .28 ≈ .25

Modeling net radiative forcing.

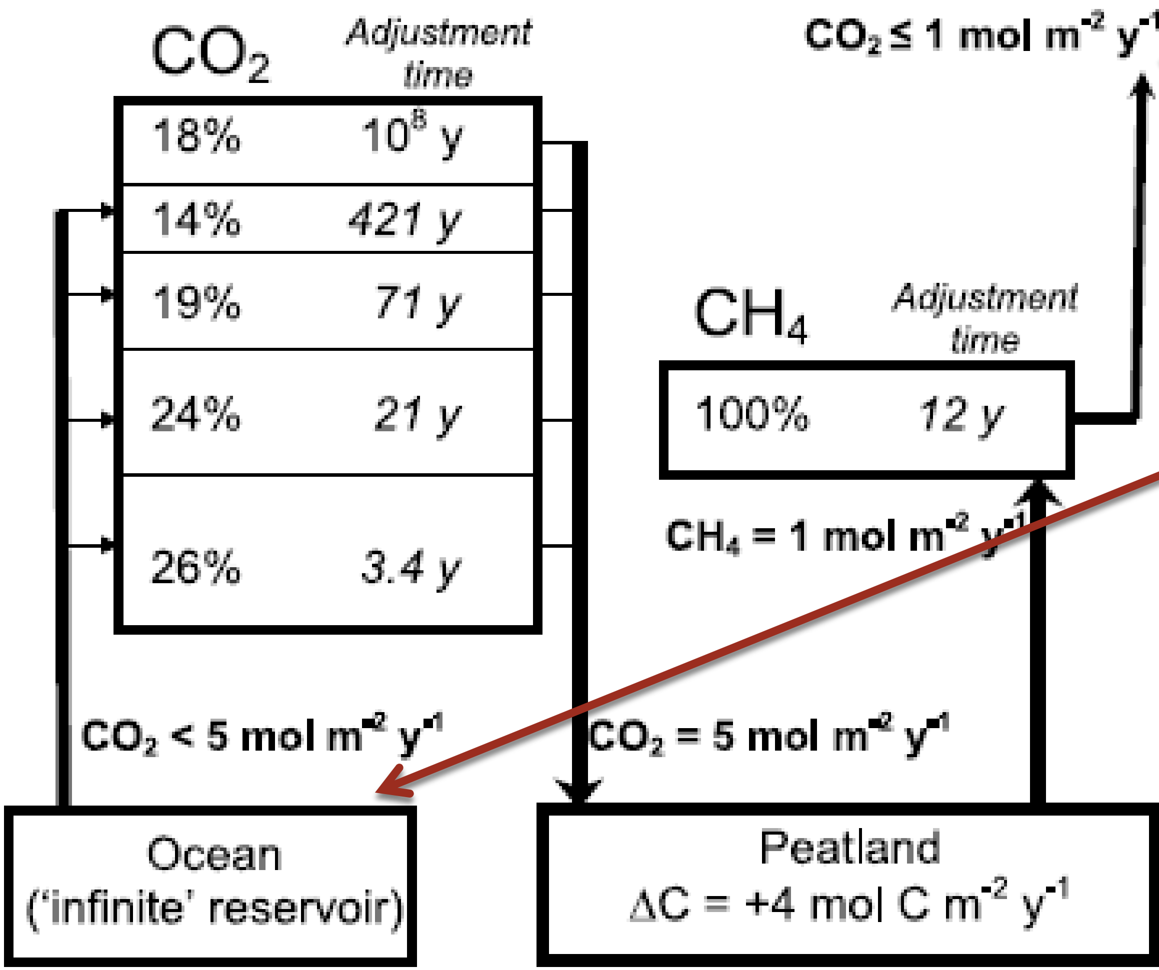


<u>Where does it go?</u>

Because the CO_2 pools are replenished from an infinite reservoir, we ignore this bit of CO_2.

Thus, CH_4 does NOT turn into CO_2 in a feedback producing way.

Modeling net radiative forcing.



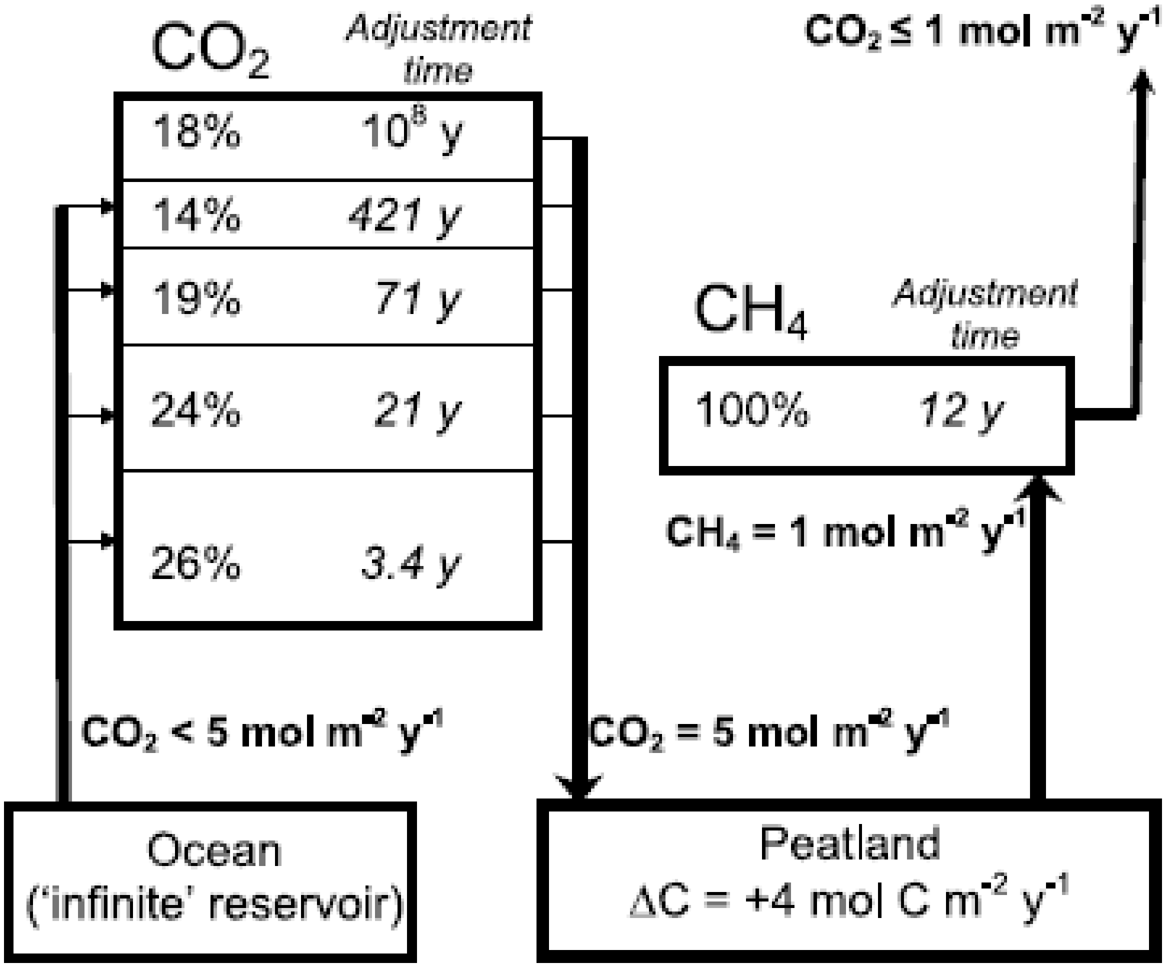
<u>Where does it go?</u>

Because the CO_2 pools are replenished from an infinite reservoir, we ignore this bit of CO_2.

Thus, CH_4 does NOT turn into CO_2 in a feedback producing way.

Darn!

Modeling net radiative forcing.



This model's behavior is equivalent to GWP for pulse emissions.

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Results

- Consider the simple GWP comparison:
- Representative Peatland:
  - releases 1 Mol of Methane in a given year.
  - sequesters 5 Mol of CO_2 in a given year.
- Is this a source or sink over the three timescales?

	Global Warming Potential		
	20 years	100 years	500 years
Methane	72	25	7.6
Source or Sink?	Source	Source	Source

- The only reason we see a net sink is because there is a finite reservoir of carbon which is not replenished, so we are actually lowering atmospheric carbon.

Results

Initially, CH_4 dominates the impact and the net effect is a positive radiative forcing (warming), which peaks in about year 50 (Figure 4b). After this, as the methane impact has stabilized and the negative radiative forcing impact of CO_2 continues to increase, the net impact declines toward zero.

Results

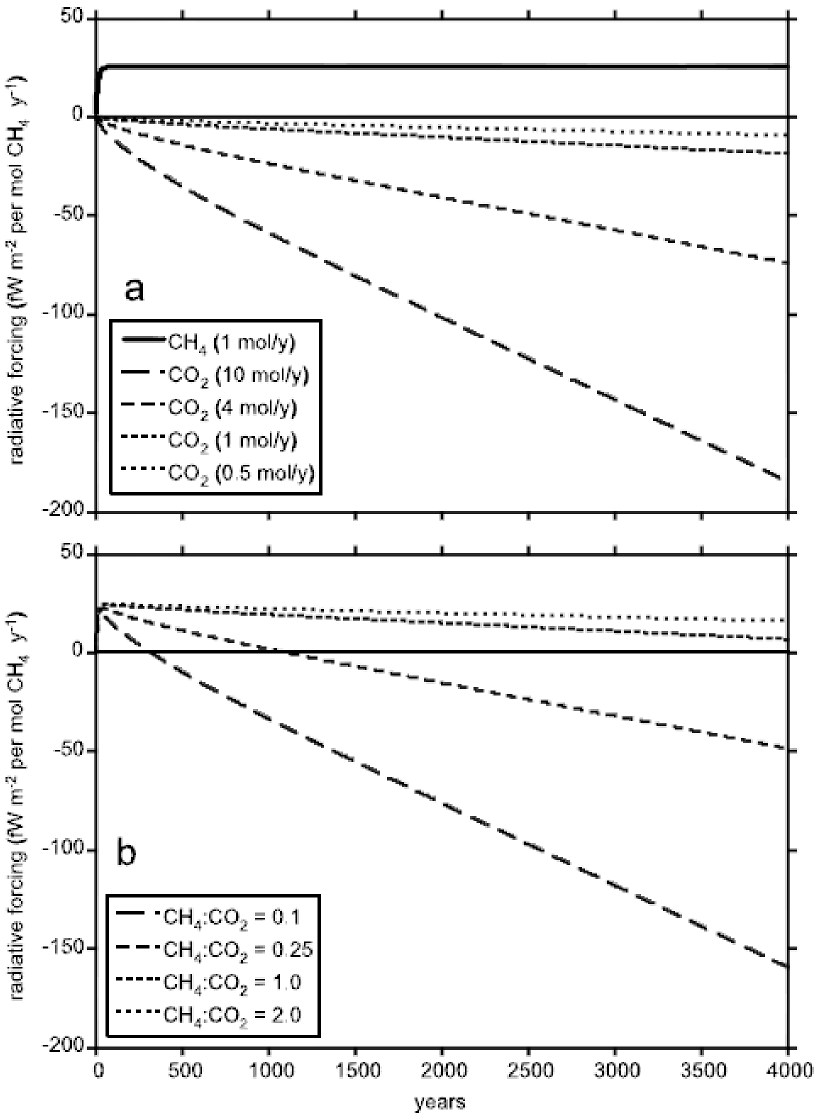

Figure 4. Instantaneous radiative forcing (a) by CH_4 (solid line) and CO_2 (dashed lines) and (b) total forcing due to perturbations in atmospheric burdens of CO_2 and CH_4 resulting from constant emission of 1 mol CH_4 yr^{-1} and removal of CO_2, at 10, 4, 1, and 0.5 mol yr^{-1}, and both beginning in year 0. The CH_4 and CO_2 radiative forcings are equal to the size of the perturbed CH_4 and total CO_2 atmospheric pools times each gas's radiative efficiency; 1 fW = 10^{-15} Watts.

Results

1. Thus a model which doesn't include the fact that Methane turns into CO_2 suggests that peatlands are a net sink over long scales.

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2. Most of current peatlands would be categorized as sources by a 20-year or 100-year GWP analysis are actually sinks by this model.

Results

1. Thus a model which doesn't include the fact that Methane turns into CO_2 suggests that peatlands are a net sink over long scales.
2. Most of current peatlands would be categorized as sources by a 20-year or 100-year GWP analysis are actually sinks by this model.
3. "The overall current climate impact of northern peatlands is likely to be a net cooling."

Any Questions?

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The End!