EGU2015-7073: Model Estimates of Climate Controls on Pan-Arctic Wetland Methane Emissions

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EGU General Assembly, Vienna, Austria, April 14, 2015

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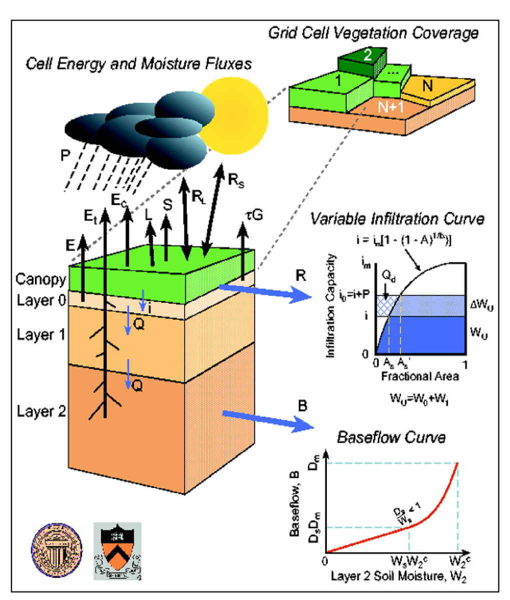
Abstract

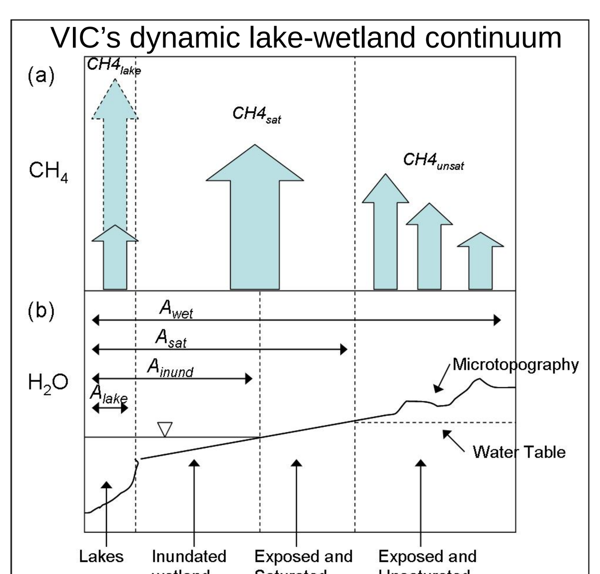
Climate factors including soil temperature and moisture, incident solar radiation, and atmospheric carbon dioxide concentration are important environmental controls on methane (CH_4) emissions from northern wetlands. We investigated the spatio-temporal distributions of the influence of these factors on northern high latitude wetland CH_4 emissions using an enhanced version of the Variable Infiltration Capacity (VIC) land surface model. We simulated CH_4 emissions from wetlands across the Pan-Arctic domain over the period 1948-2006, yielding annual average emissions of 35.1$\pm$6.7 $TgCH_4\ y^{-1}$ for the period 1997-2006. We characterized historical sensitivities to air temperature, precipitation, incident long- and short-wave radiation, and atmospheric [CO_2] as a function of average summer air temperature and precipitation. Emissions from relatively warm and dry wetlands in the southern (permafrost-free) portion of the domain were positively correlated with precipitation and negatively correlated with air temperature, while emissions from wetter and colder wetlands further north (permafrost) were positively correlated with air temperature. Over the entire period 1948-2006, our reconstructed CH_4 emissions increased by 20%, a change of which over 90% can be attributed to climate change. An increasing trend in summer air temperature explained the majority of the climate-related variance. We estimated future emissions in response to 21st century warming as predicted by CMIP5 model projections to result in end of century CH_4 emissions 42% higher than our reconstructed 1997-2006 emissions, accompanied by the northward migration of warmer- and drier-than optimal conditions for CH_4 emissions, implying a reduced role for temperature in driving future increases in emissions.

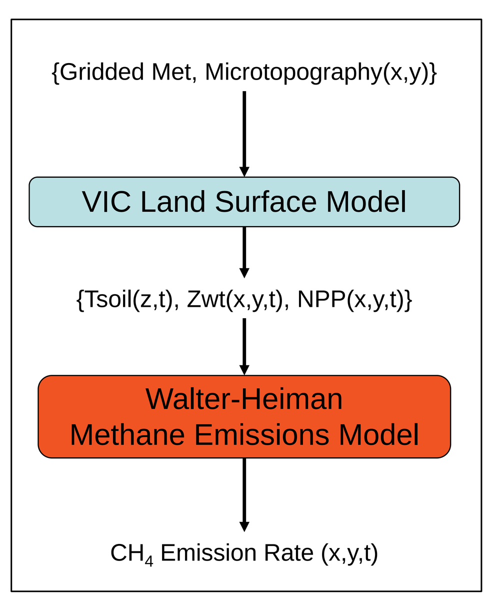
1. Motivation and background

- Wetlands are the world's largest natural source of CH_4, a powerful greenhouse gas
- Nearly 50% of the world's wetlands are located in the northern high latitudes (north of 45º N)
- The high latitudes have experienced pronounced climate change over the last half-century, and are projected to continue doing so through the next centuries
- There is concern that future changes in wetland CH_4 emissions could produce a substantial feedback to climate change. Related science questions include ***What is the magnitude of the possible response?*** and ***How much of the historical increase of atmospheric [CH_4] was caused by climate change in the past half century?***

2. Modeling Framework

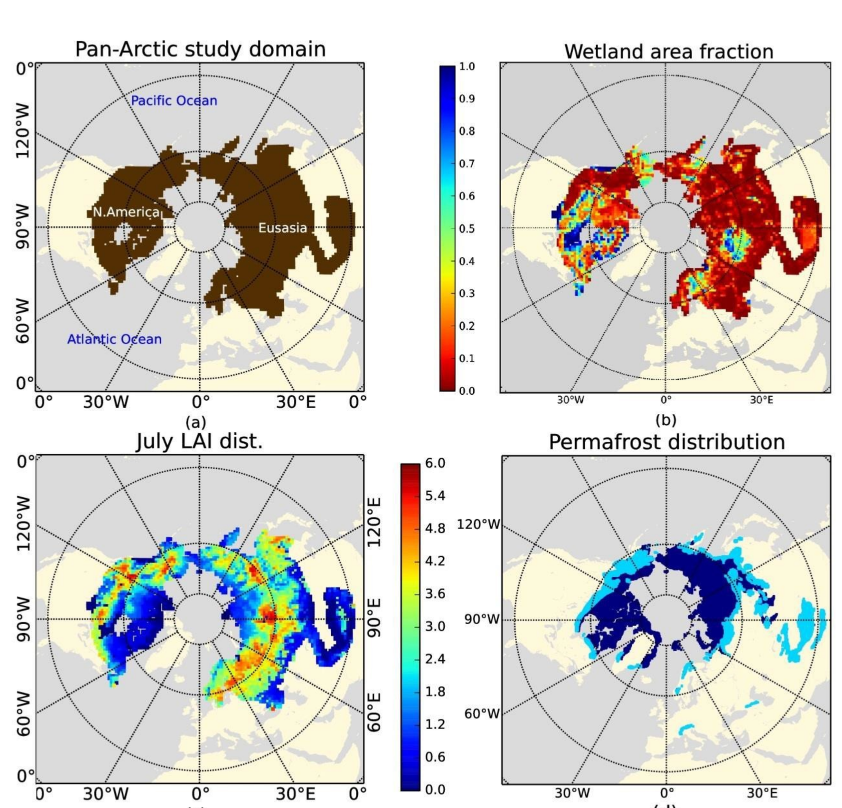






Our procedure was as follows: 1) Simulate land surface hydrology and carbon cycle using Variable Infiltration Capacity (VIC) model; 2) Use VIC's dynamic lake-wetland model which allows lakes to expand and flood wetlands; within exposed wetlands, the water table is distributed according to microtopography; 3) Distributed water table is input to Walter-Heimann (2001) wetland methane emissions model

3. Experiment Design



1 Historical simulation:

R01: Historical simulation

5 control runs:

R02: Air temperature and longwave radiation (TLW) control (approach 1)

R03: atmosphere [CO_2] control (approach 2)

R04: TLW + precipitation (P) control (approach 1)

R05: Precipitation (P) control (approach 1)

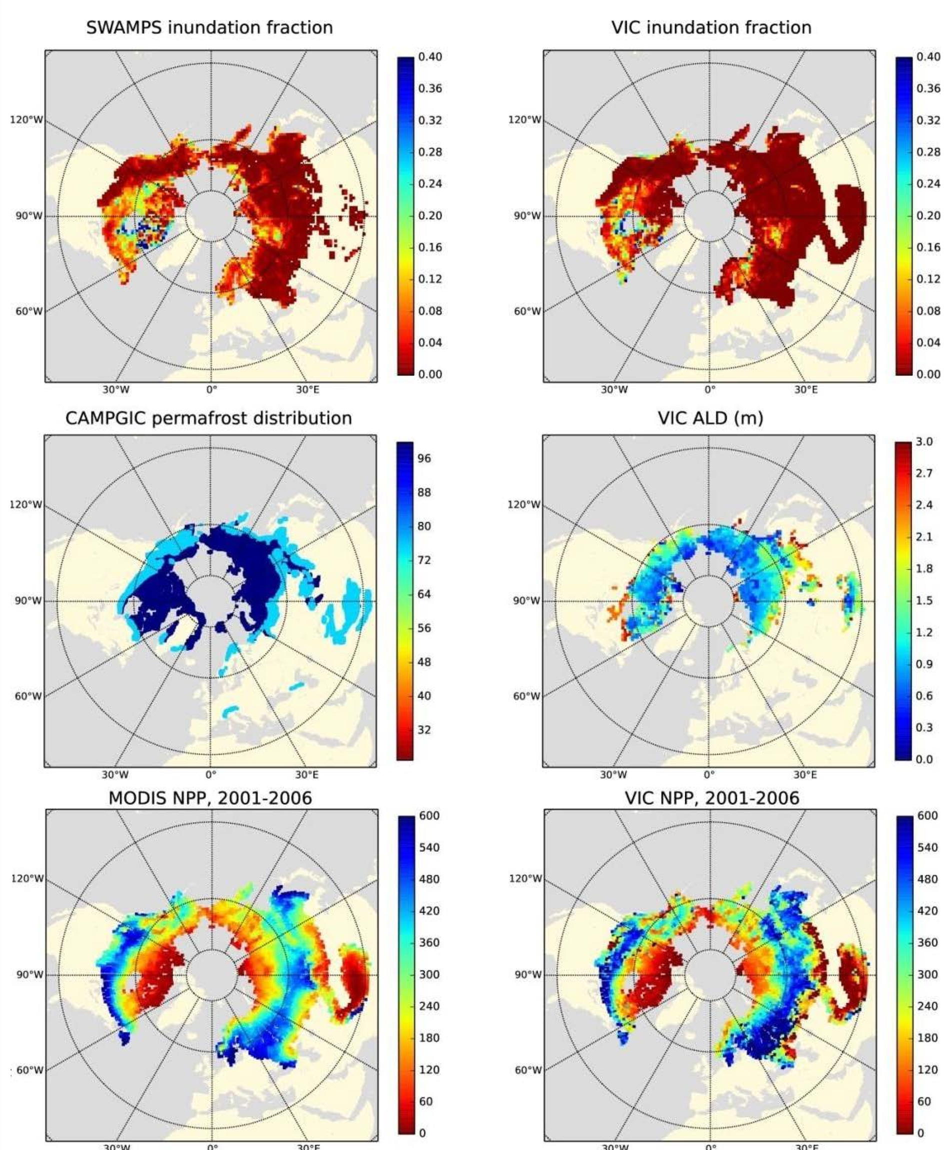
R06: Atmospheric Shortwave radiation (SW) control (approach 1)

Approach 1: remove linear trend during 1960-2006

Approach 2: use1960-level forcing during 1960-2006

(a) Study domain;
(b) Wetland identified in GLWD, MODIS land type, Northern Circum-Polar Soil Carbon Database (Tarnocai et al., 2009)
(c) MODIS LAI in July, 2001-2006
(d) Permafrost dist. (Brown et al., 2014)

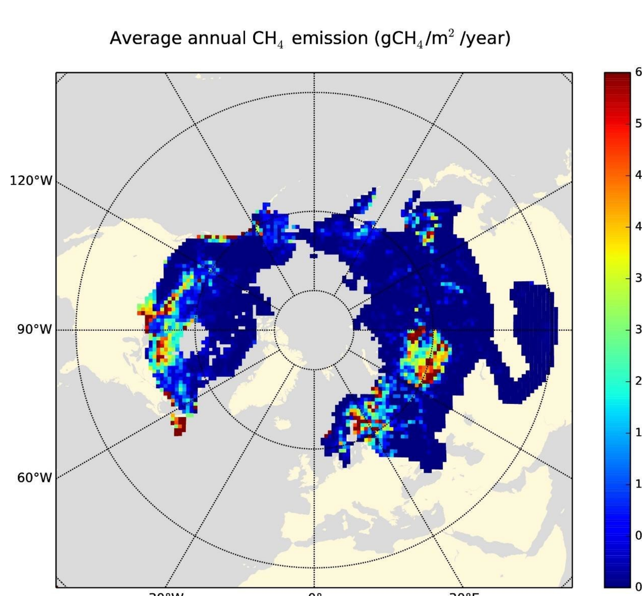
4. Simulation of Historical Emissions



Comparison of model output against observation/satellite measurement suggests that model is able to handle:

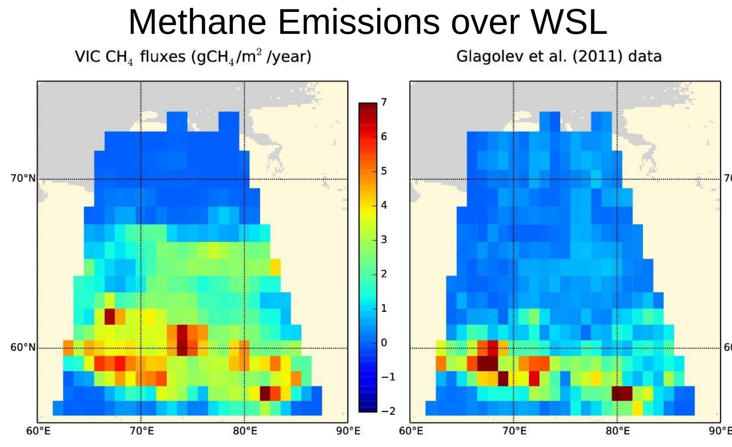
(1)wetland hydrological processes (inundation fraction);
(2)permafrost thawing/freezing processes (Active Layer Depth, ALD);
(3)carbon source into the ecosystem (Net Primary Productivity, NPP).

- Surface WAter Microwave Product Series (SWAMPS) is from *Schroeder et al. (2010)*
- Circular-Arctic Map of Permafrost and Ground-Ice Condition (CAMPGIC) is from *Brown et al. (2014)*

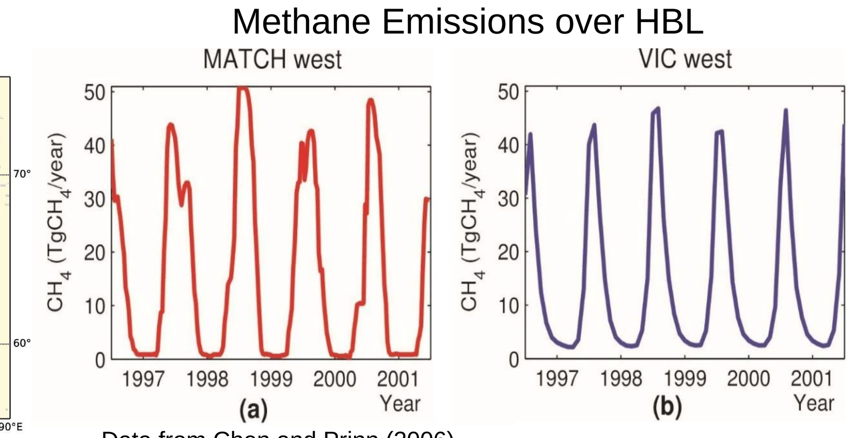


Our estimate of current wetland methane emissions is 35.0$\pm$6.7 $TgCH_4$/year, which is within the range of various studies (20 ~ 60 $TgCH_4$/year) ;
Methane emissions are concentrated in the West Siberia Lowland (WSL), Hudson Bay Lowland (HBL) and Scandinavia.

Methane Emissions over WSL

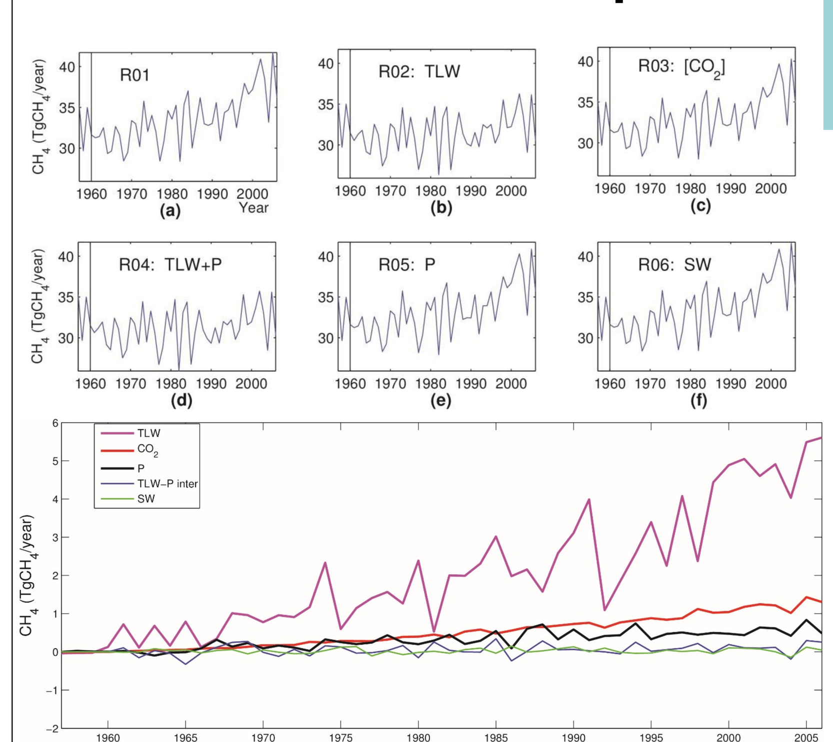


Methane Emissions over HBL



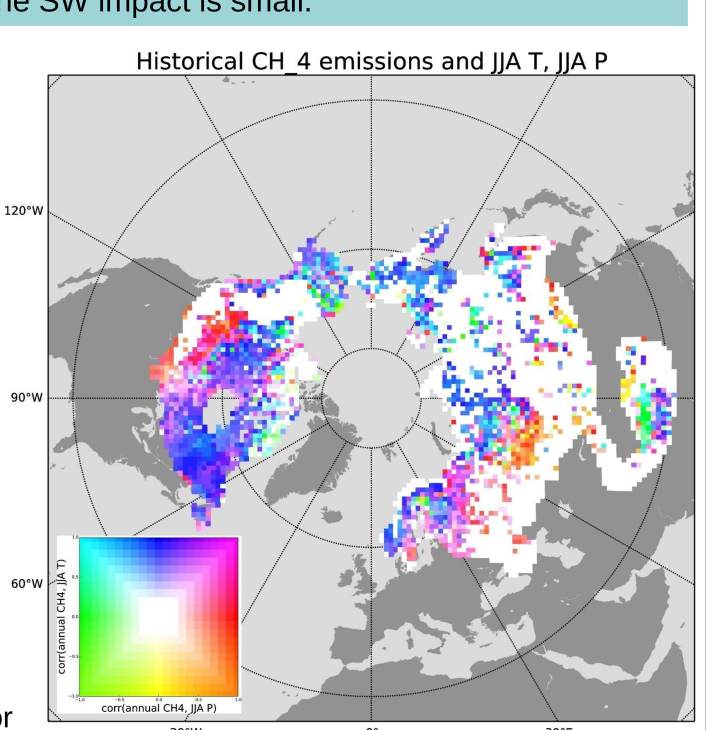
Data from Chen and Prinn (2006)

5. Historical Climate Impact



(a)-(f) Total annual methane emission in the domain
(g) Historical annual methane emissions due to each climate factor

1. Air temperature and longwave radiation (TLW) and [CO_2] have the biggest impact, followed by precipitation (P).
2. The interaction between TLW and P is small, also the SW impact is small.



Climate Sensitivities

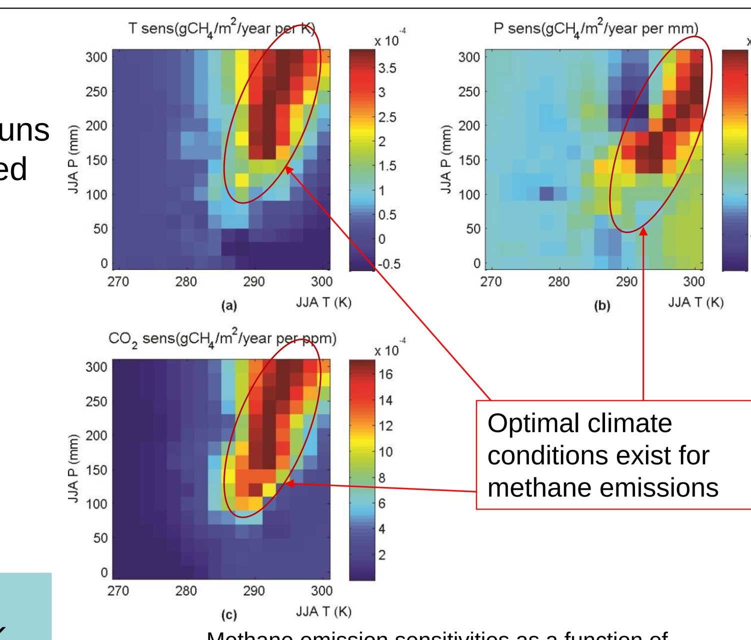
1. Calculated between historical simulation and climate control runs
2. Defined as the differences between methane emissions divided by the differences in climate forcings. More specifically,

$$\alpha_p = \frac{dCH_4}{dP}\ (gCH_4 \cdot m^{-2} \cdot year^{-1} \cdot mm^{-1})$$

$$\alpha_{TLW} = \frac{dCH_4}{dT_{air}}\ (gCH_4 \cdot m^{-2} \cdot year^{-1} \cdot K^{-1})$$

$$\alpha_{CO2} = \frac{dCH_4}{d[CO_2]}\ (gCH_4 \cdot m^{-2} \cdot year^{-1} \cdot ppm^{-1})$$

Methane emission has an optimal T-P condition, within which summer P increases by 15mm when summer T increases by 1K



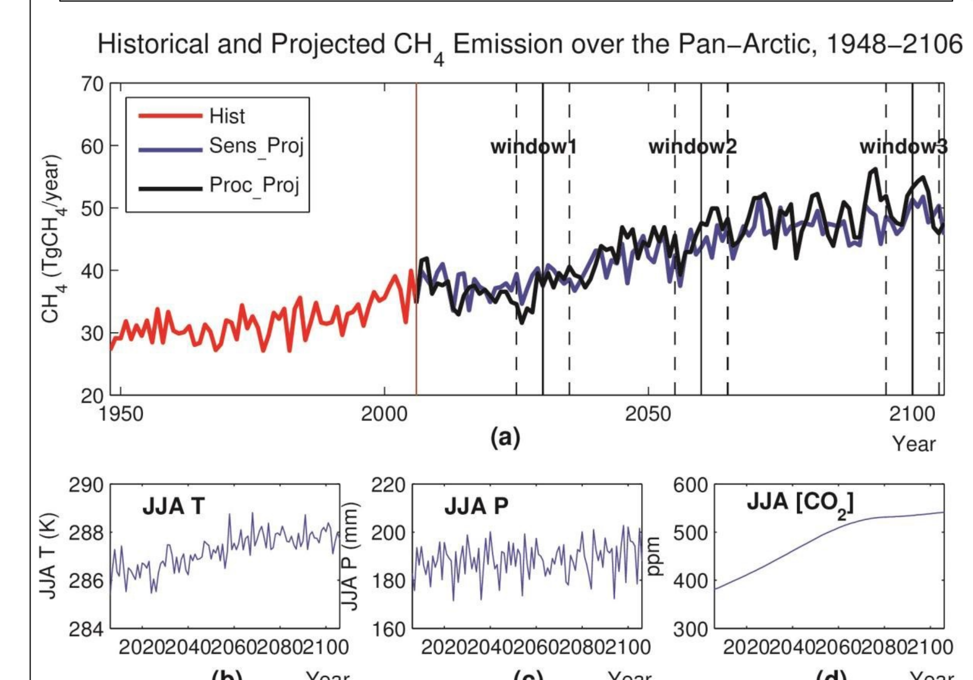
Methane emission sensitivities as a function of local summer T and summer P.

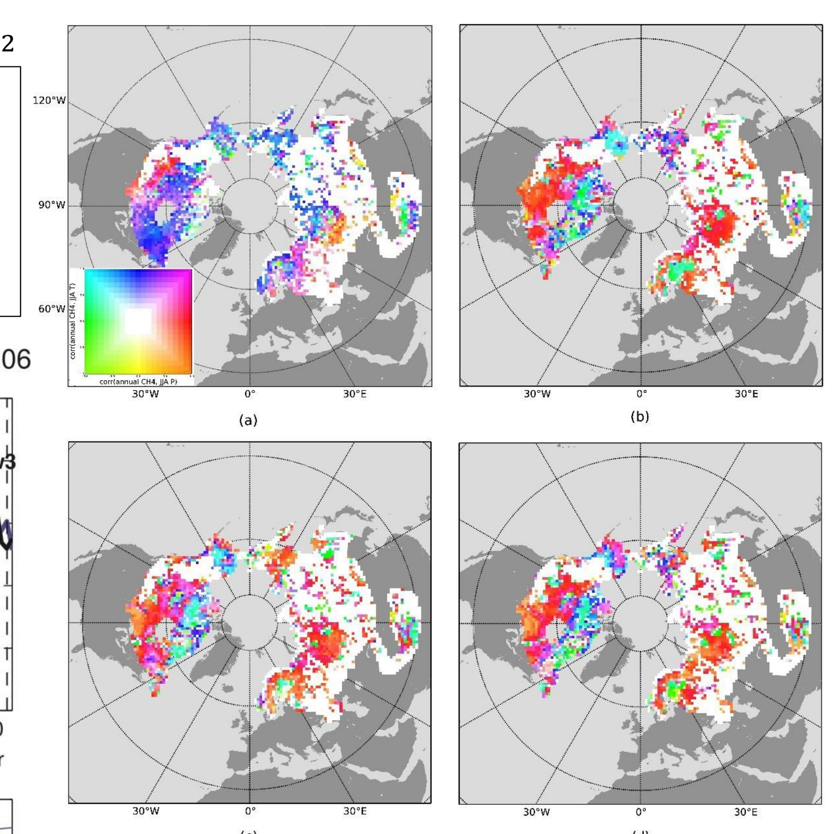
6. Sensitivity-based Future Projection

Future projection is done using sensitivities and validated using process-based models (VIC+Walter methane model)

$$CH_4' = CH_4 + \alpha_P \times dP + \alpha_{TLW} \times dT_{air} + \alpha_{CO2} \times dCO_2$$

How we did our sensitivity-based projection
1. Known or calculated emission rate CH_4 at year i;
2. Find out the decadal summer P and T (e.g. 2020-2029 averaged P and T for years between 2020 and 2029);
3. Find out the P, T and CO_2 sensitivities from above plot;
4. Calculate the year i+1 emission CH_4' using this eqn.





Correlations between annual methane emissions with summer climate conditions in:
(a)1960-2006; (b) 2026-2035;
(c) 2056-2065; (d) 2096-2105.

1. Sensitivity-based approach produces comparable results when compared with process-based projection.
2. By the 2100s, methane emissions will increase to 135-142% of 2000s level and the emissions will be more limited by water due to an increase in air temperature.

7. Conclusions

(1) The annual CH_4 emissions from Pan-Arctic wetlands averaged over the period 1997-2006 to be 35.0$\pm$6.7 $TgCH_4\ y^{-1}$. This is slightly higher than (but within the range of) previous estimates.

(2) Climate change over the last ~half century has led to a substantial (20%) increase in total emitted CH_4, with increases in air temperature (and associated downward longwave radiation) being the dominant driver. Increases in temperature and [CO_2] were responsible for over 84% of the inferred increase in emissions. Most of the remainder is attributable to changes in shortwave radiation (decreasing) and precipitation (increasing).

(3) The dominance of air temperature as a driving factor is corroborated by the predominance of temperature-limited wetlands throughout most of the domain, with water-limited wetlands primarily only in the southernmost portion of the domain (south of 60° N latitude).

(4) Both process-based and sensitivity-based projections agreed that wetland CH_4 emissions from Pan-Arctic wetlands will increase to 135-142% of present-day levels by the end of this century. Because this study did not account for potential acclimatization or the wetland-climate-CH_4 feedback resulting from CO_2 fertilization, this projected increase may be biased upward.

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