# Methane emissions from high latitude peatlands: Constraining models with observations

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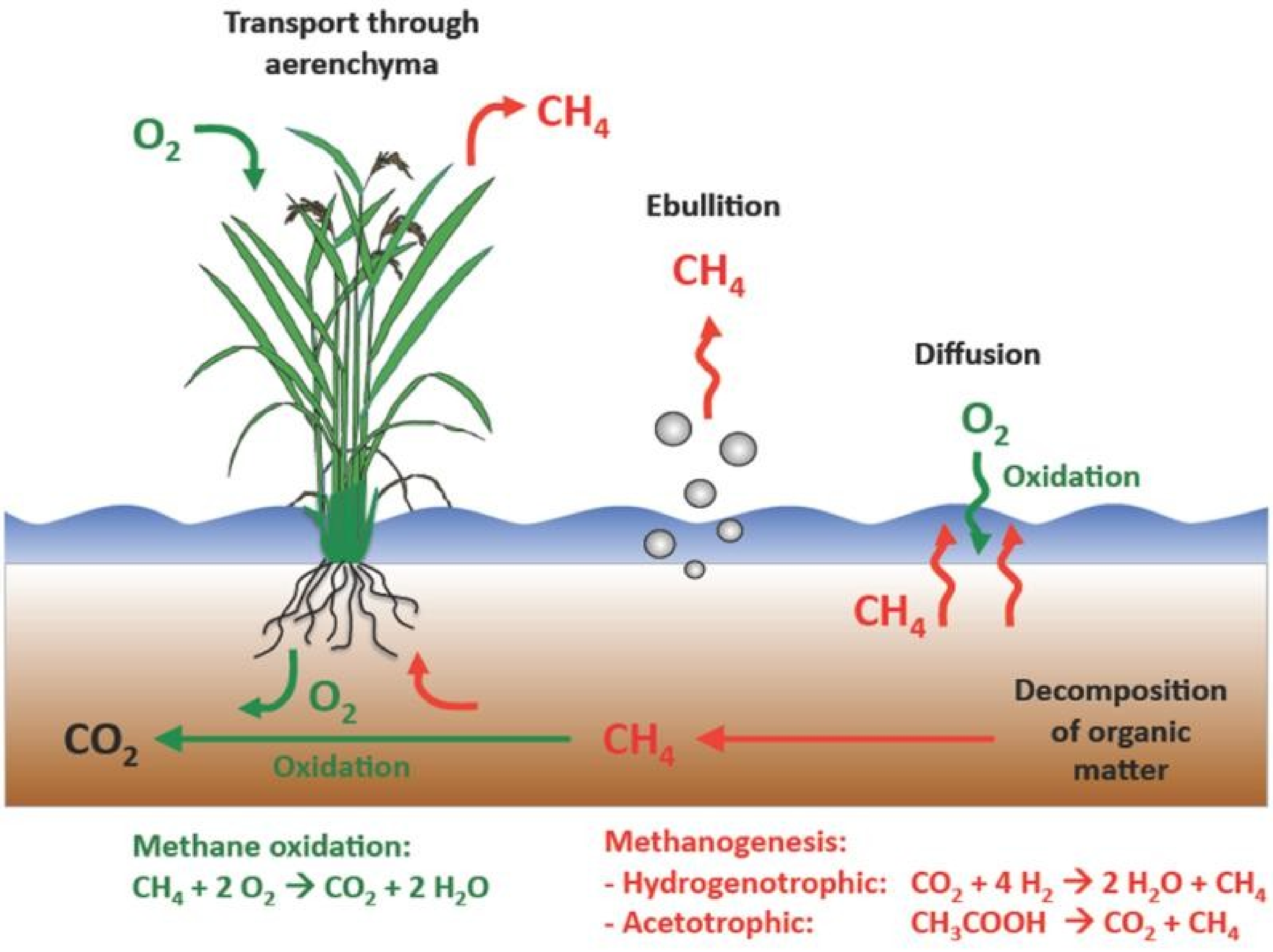
Helsinki 26.4.18

# Motivation

- Representing wetland $CH_4$ emissions in Earth system model.
- CLIFFTOP: Allowed anthropogenic emissions to reach 1.5/2°C targets reduced by 9-17% when wetland $CH_4$ feedback included (Comyn-Platt et al., in review).
- Need to properly constrain and quantify uncertainties.

# Modelling CH4

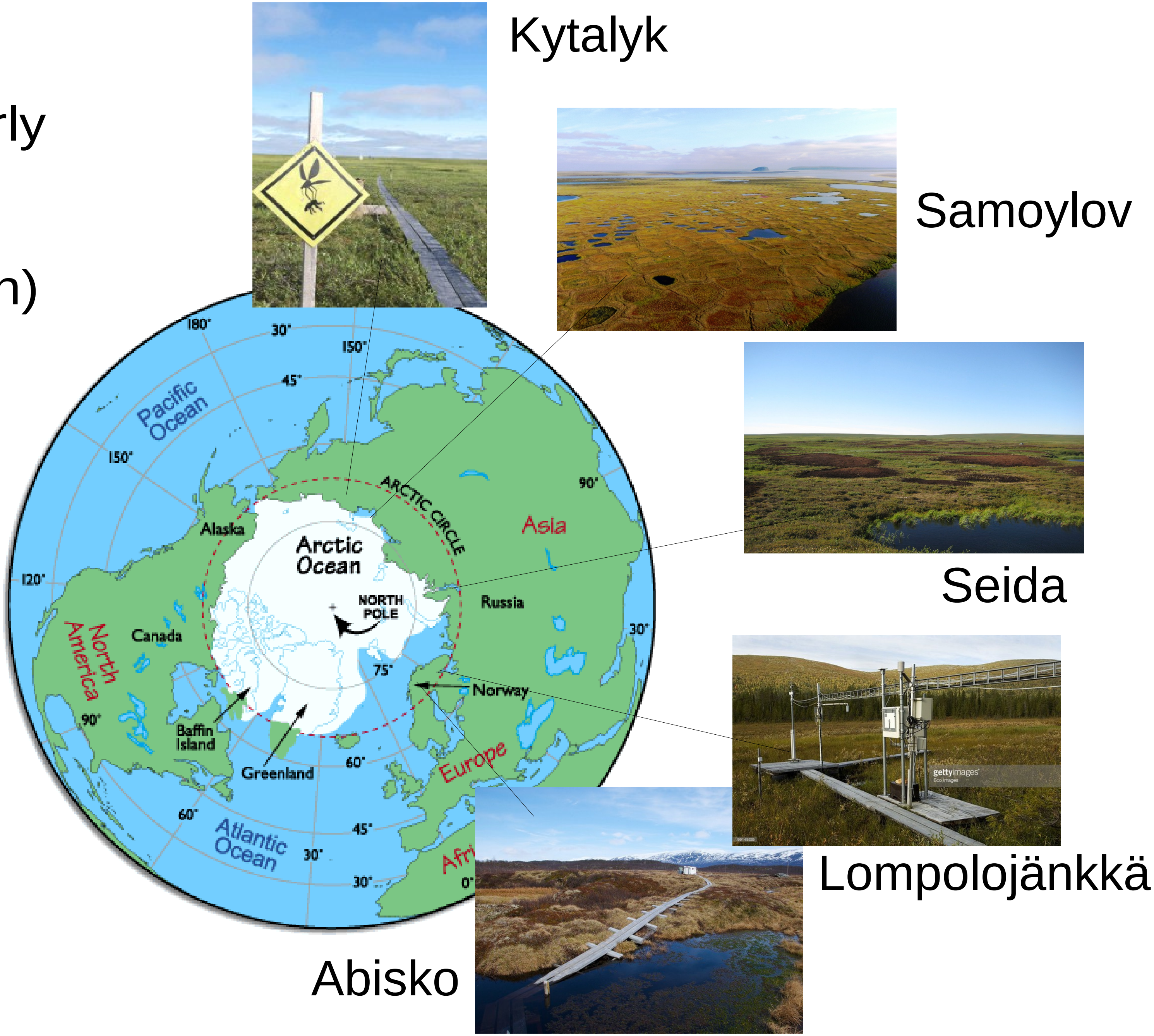
My approach: simplest possible model that captures *annual mean* CH4 emissions *for the right reasons* (i.e. process based).



# Observational data

CH4 flux half-hourly from eddy covariance (factor by wetland fraction)

+ Observed soil C profile and Tsoil



Research question:

## Do the observational data provide enough information to constrain the model parameters?

- **Aim**: Use robust statistical process (Monte Carlo simulation) to calculate a probability distribution in model parameters.

  → Quantify need for more data?

  → Translates to a probability distribution for the future.

- Follow work of Susiluoto et al., 2018!
- Need a plausible model first.

# A plausible model?

- **JULES formulation:** depends on temperature (Tsoil), substrate (C) and wetland fraction (fwet):

$$FCH_4 = \int_{-\infty}^{0} A\, f_{wet}\, C(z)\, Q_{10}^{\frac{T_{soil}(z)}{10}} \exp(-\tau z)\, dz$$

- Sum $CH_4$ production over the soil column with an exponential decay with depth (τ).
- Assume all $CH_4$ oxidised unless water table is close to surface.*

*e.g. Turetsky et al., *Global Change Biology* **20** 2183-2197 (2014)

# A plausible model?

- **JULES formulation:** depends on temperature (Tsoil), substrate (C) and wetland fraction (fwet):

$$FCH_4 = \int_{-\infty}^{0} A f_{wet} C(z) Q_{10}^{10T_{soil}(z)} \exp(-\tau z) dz$$

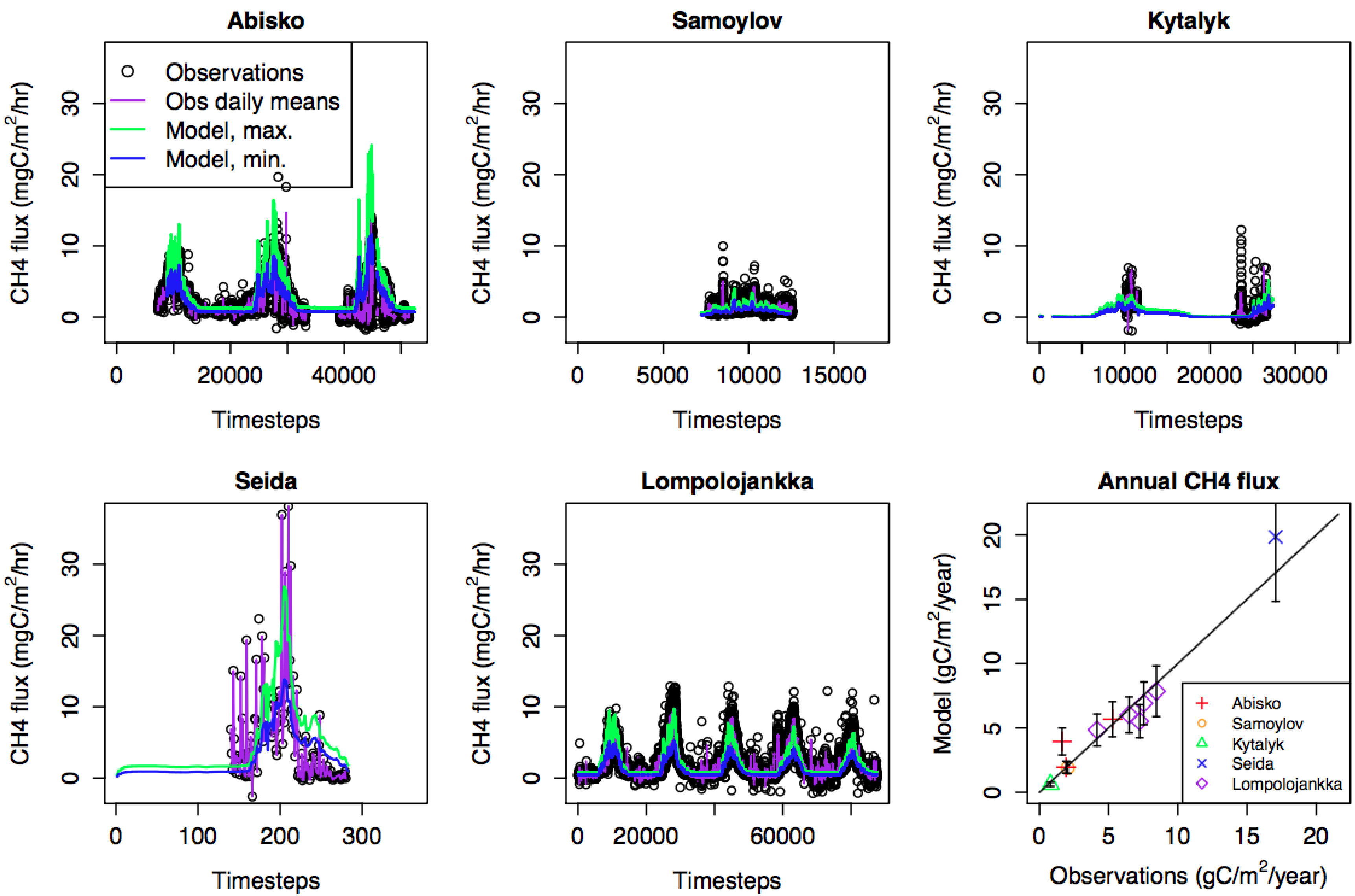
- Questionable:

→ Soil C (or NPP!) as a proxy for substrate.

→ Depth dependence of emissions approximated by τ.

# Tsoil model

- Q10, τ and scale factor fitted to Abisko and Samoylov data. Same parameters applied across all sites.

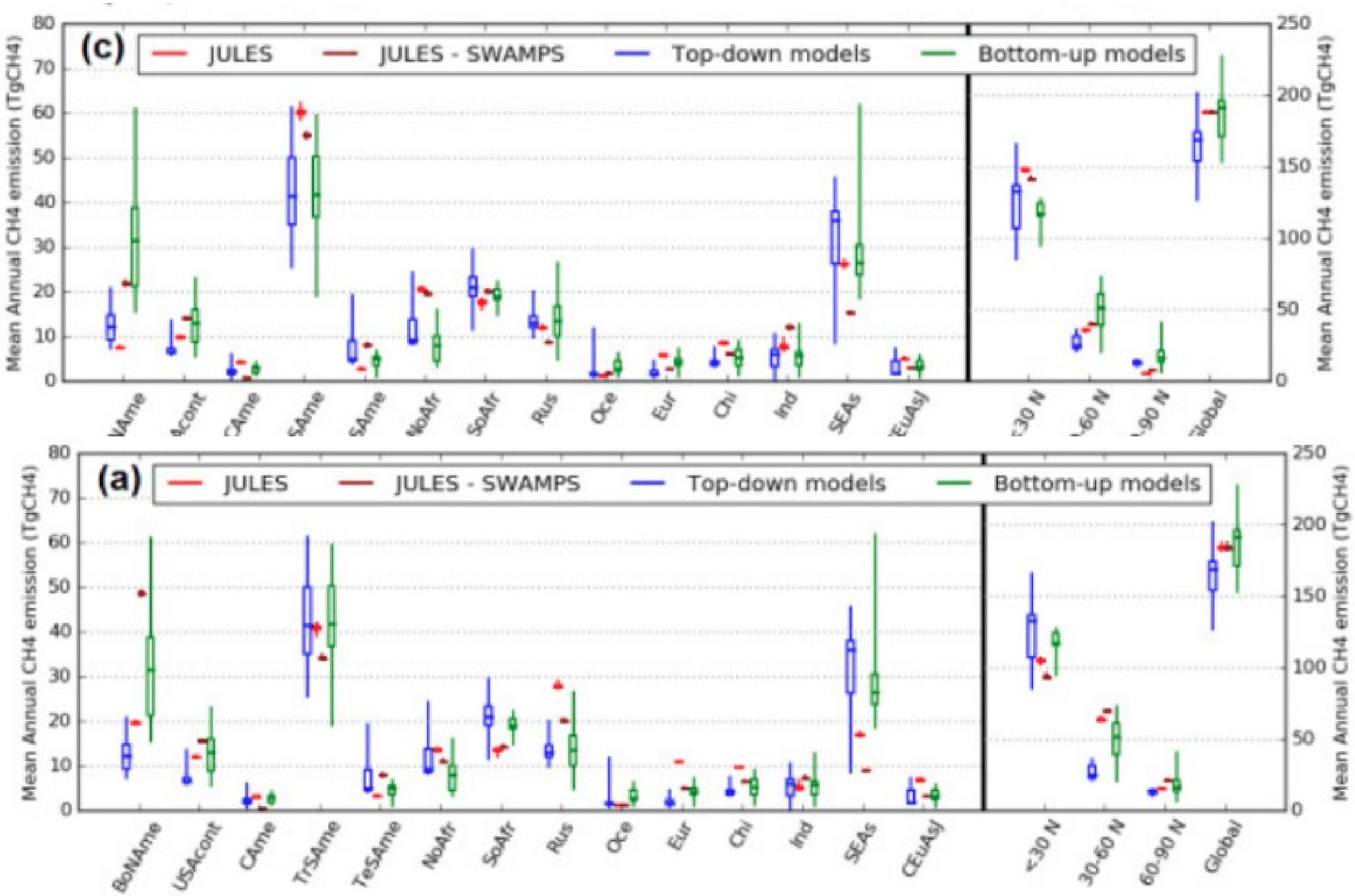


# Tsoil model

- Captures variability between sites quite well
- However:

  Statistical measure of plausibility (modified $\chi^2$) is weak.

  Q10 is too high for global simulation (~6).

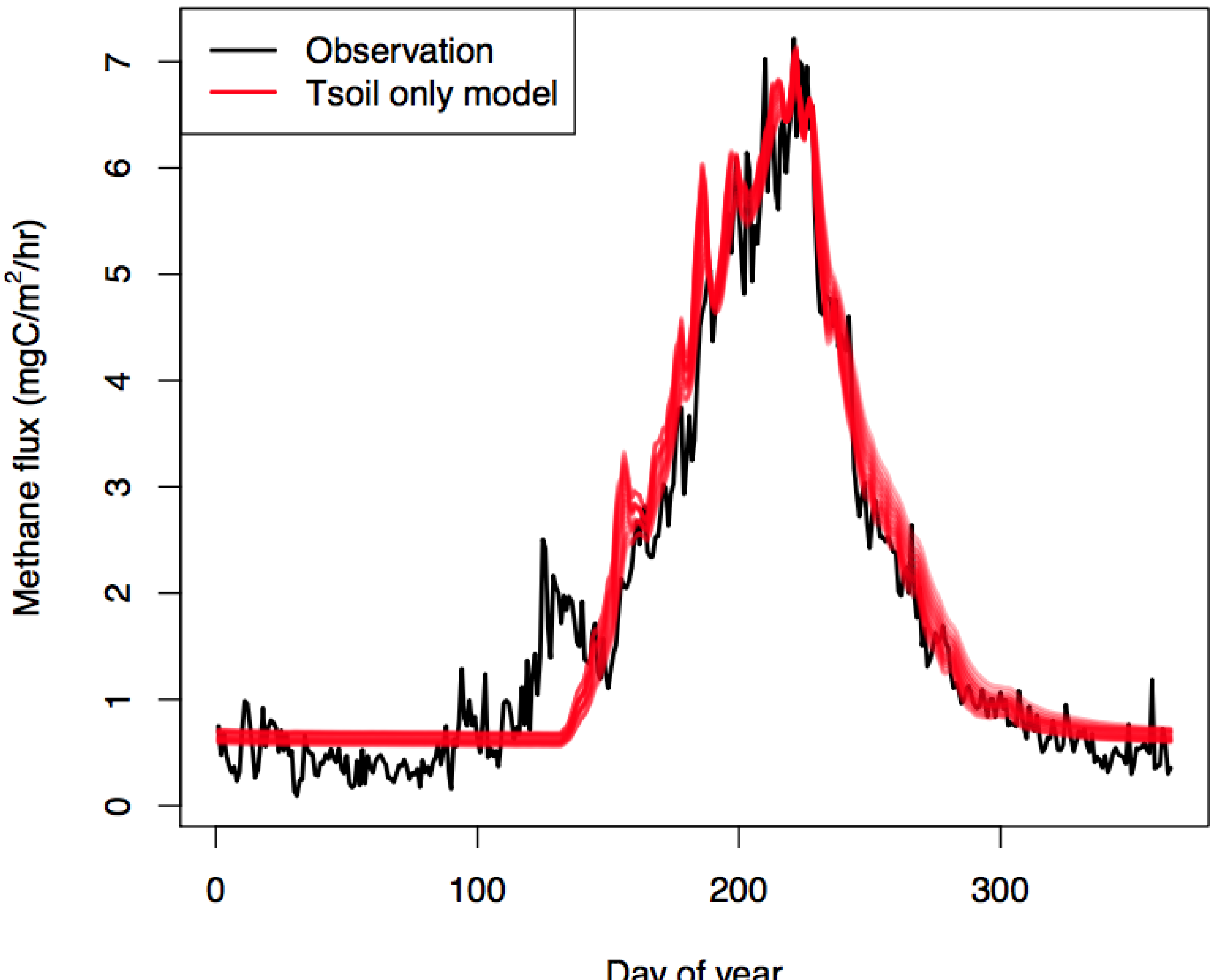



High Q10

Low Q10

# What is missing from the model?

Best fit of Tsoil model with Lompolojänkkä observations:



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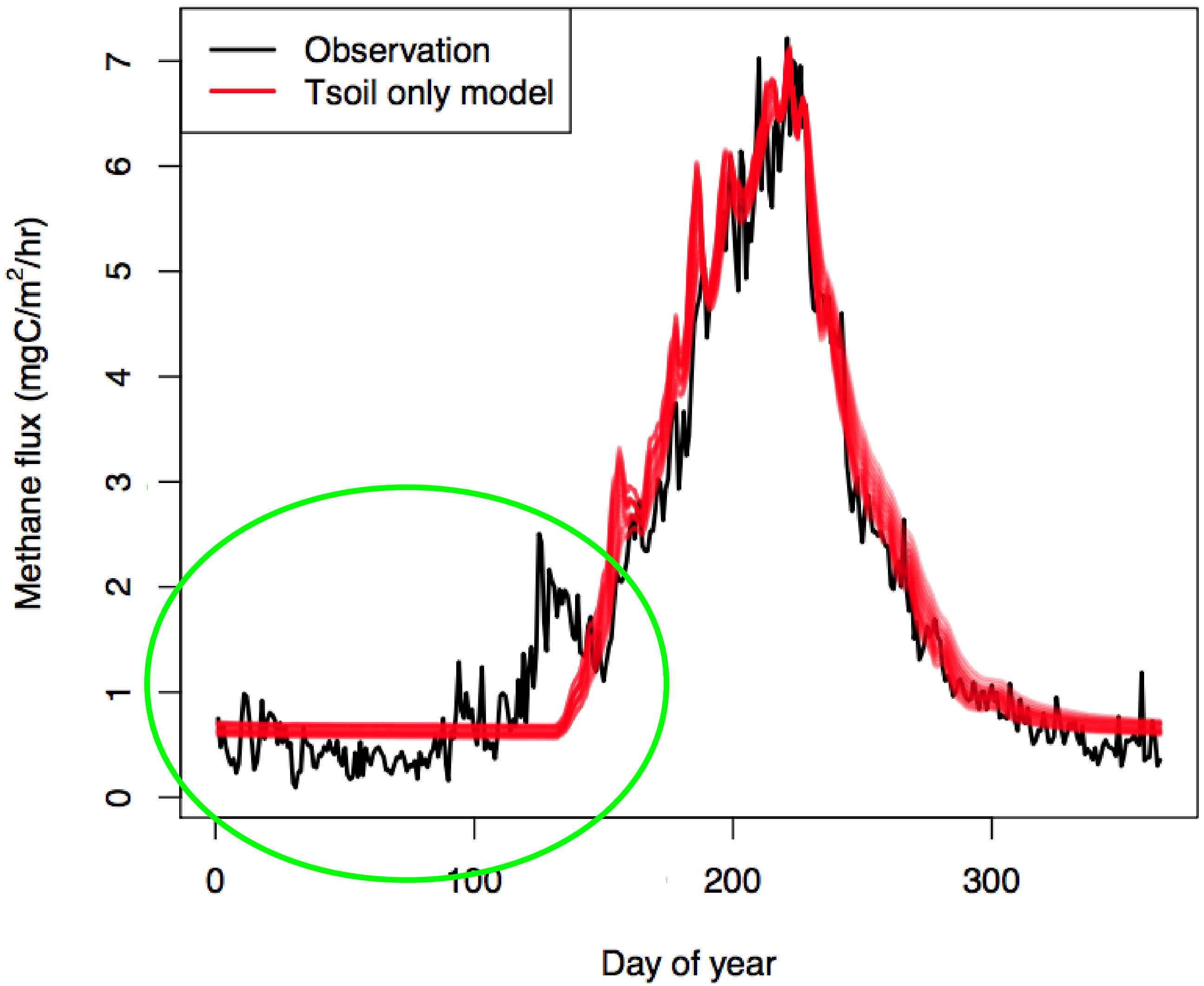
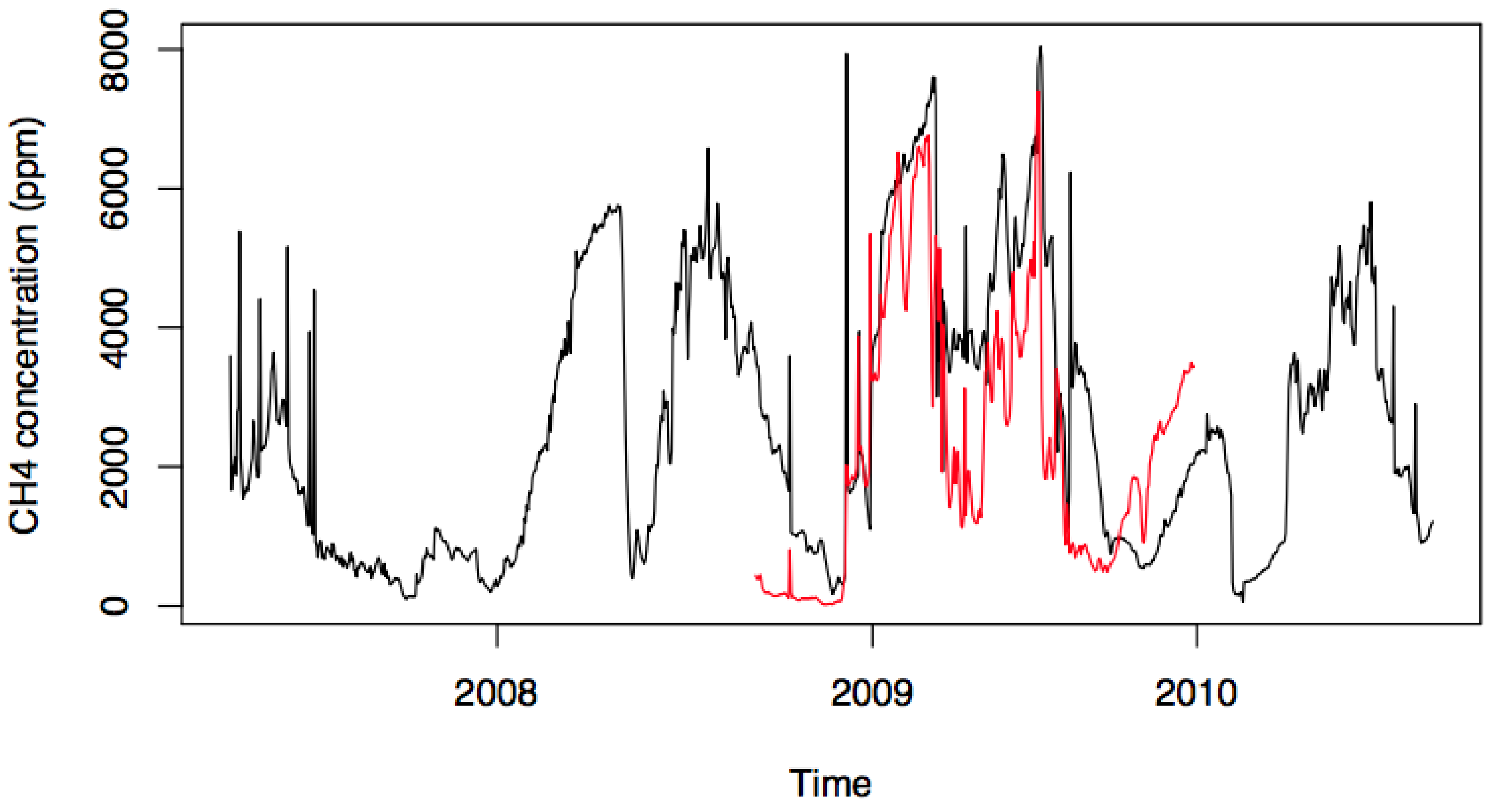


# Equilibrium assumption

Production – Emission – Oxidation = 0

- Assumes that concentration is not changing.
- Definitely not true on sub-annual timescale



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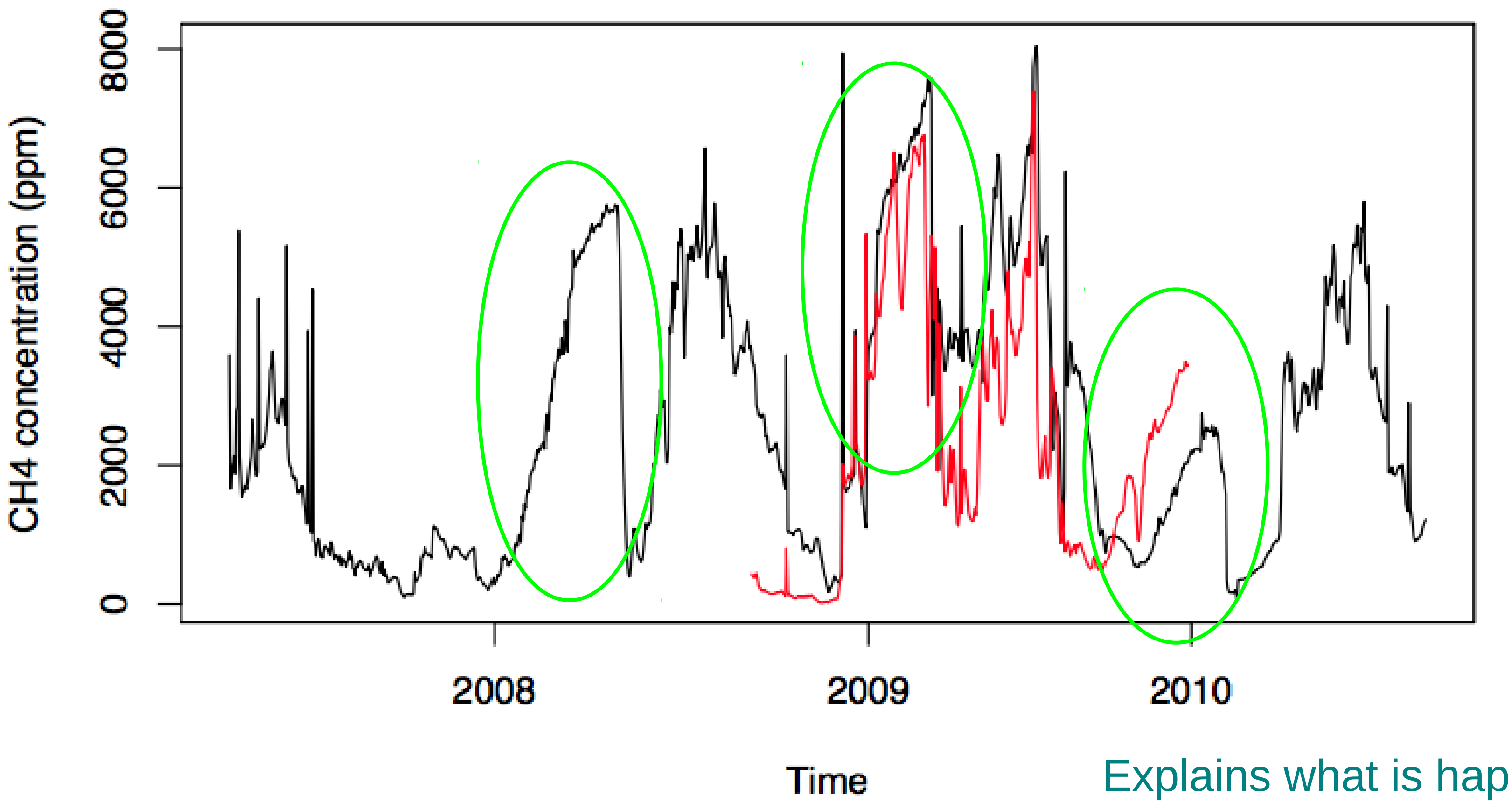
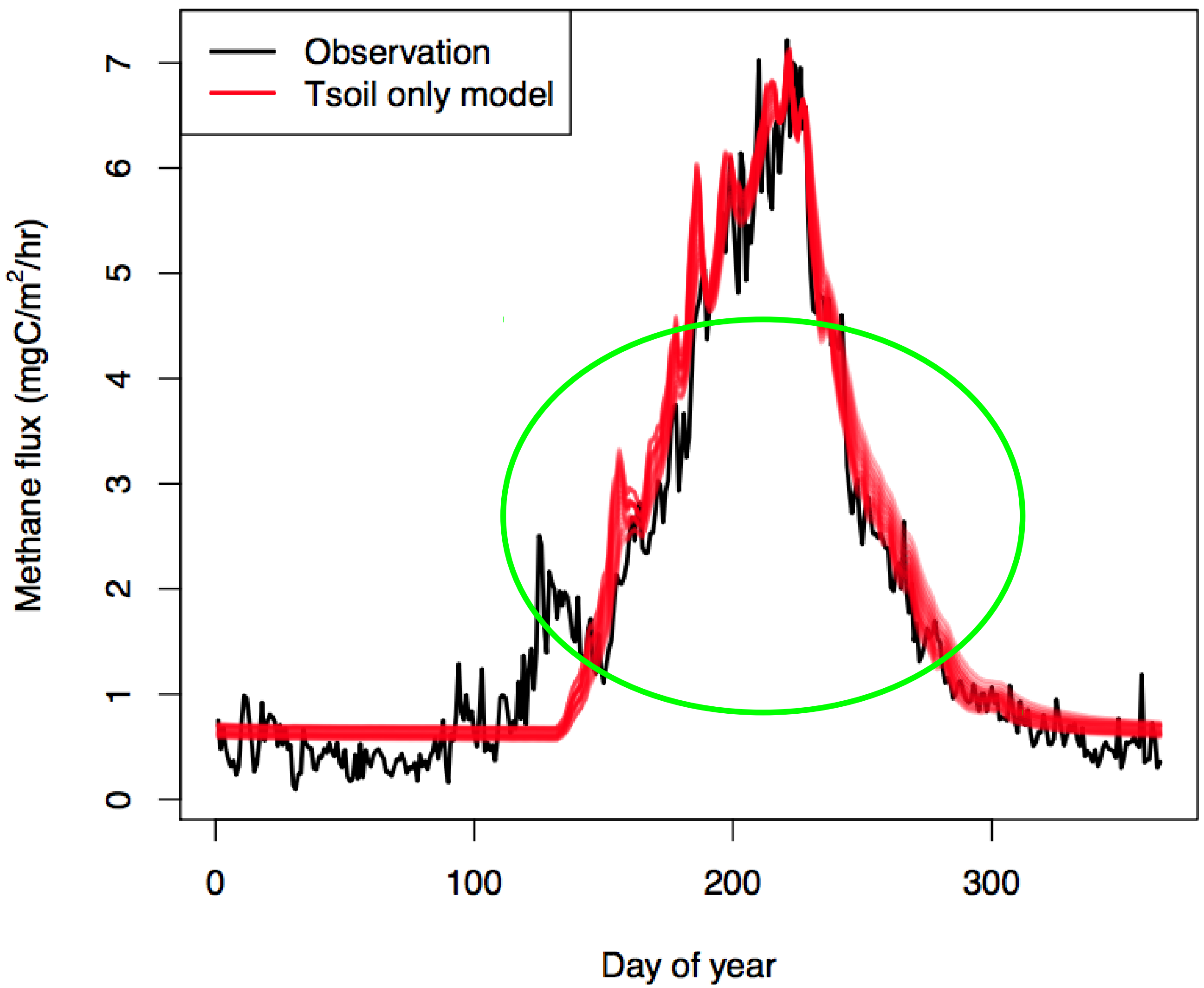



Explains what is happening in winter/early spring.

# What is missing from the model?

- Model annual cycle is not ‘pointy’ enough. Q10 is too high for global simulation. These could both be linked...



# Key missing process: substrate availability?

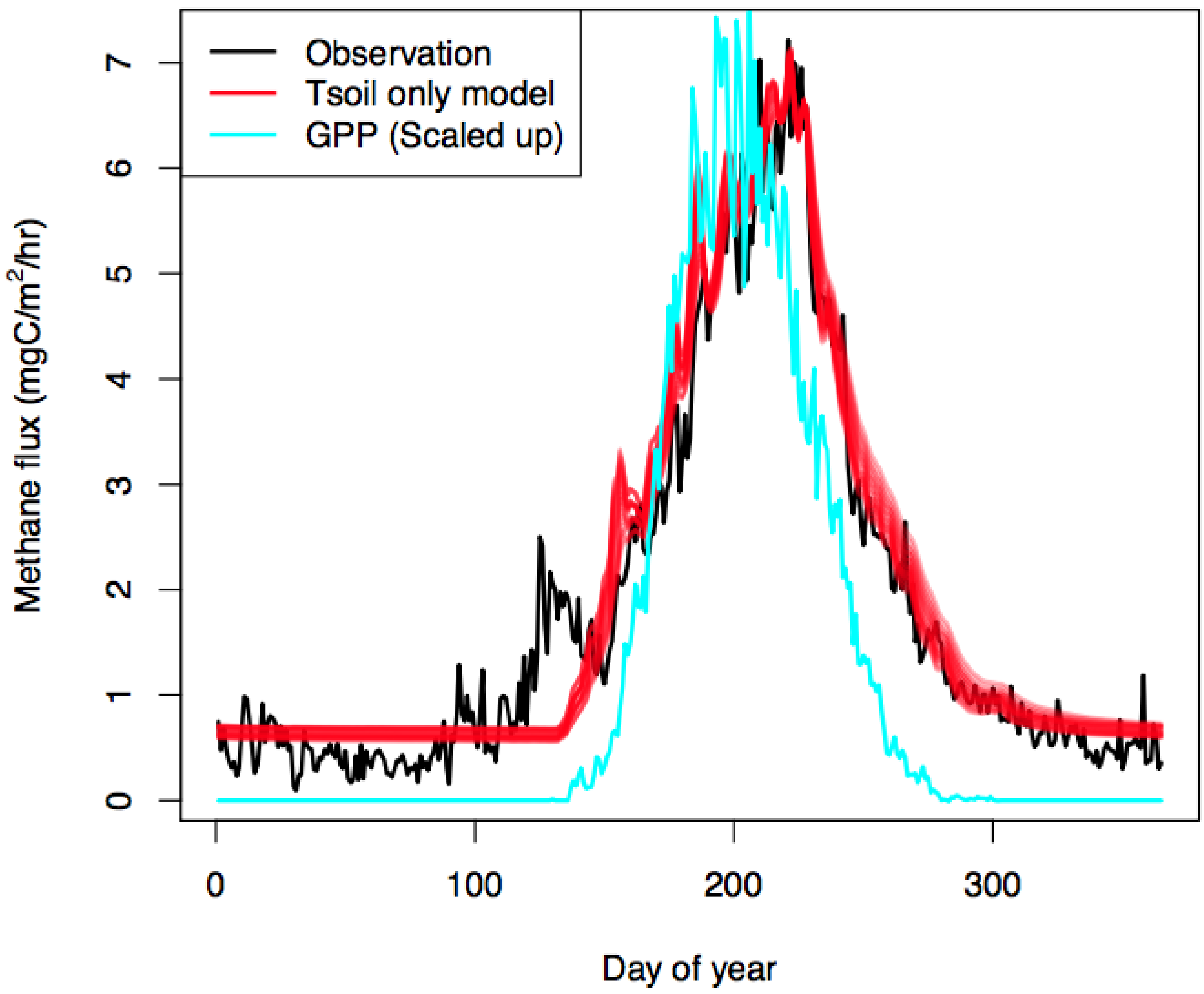
- Seasonal cycle of substrate availability could provide

  → Correction to modelled annual cycle

  → Explanation of why we are fitting a high Q10

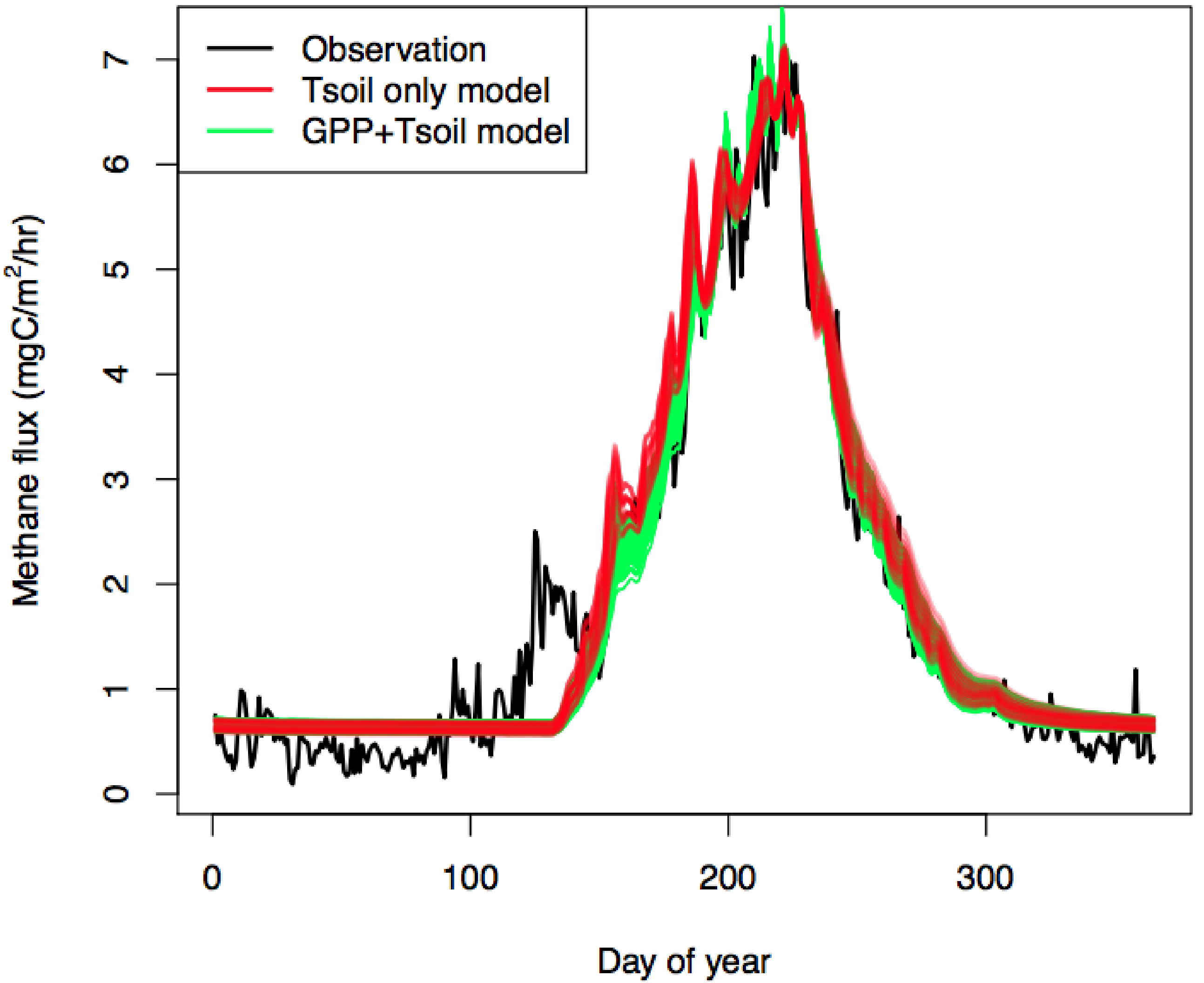
# Seasonal cycle of substrate

- No direct measurement available? What proxies could be used?
- Model needs to be ‘pointier’ - resembles GPP!



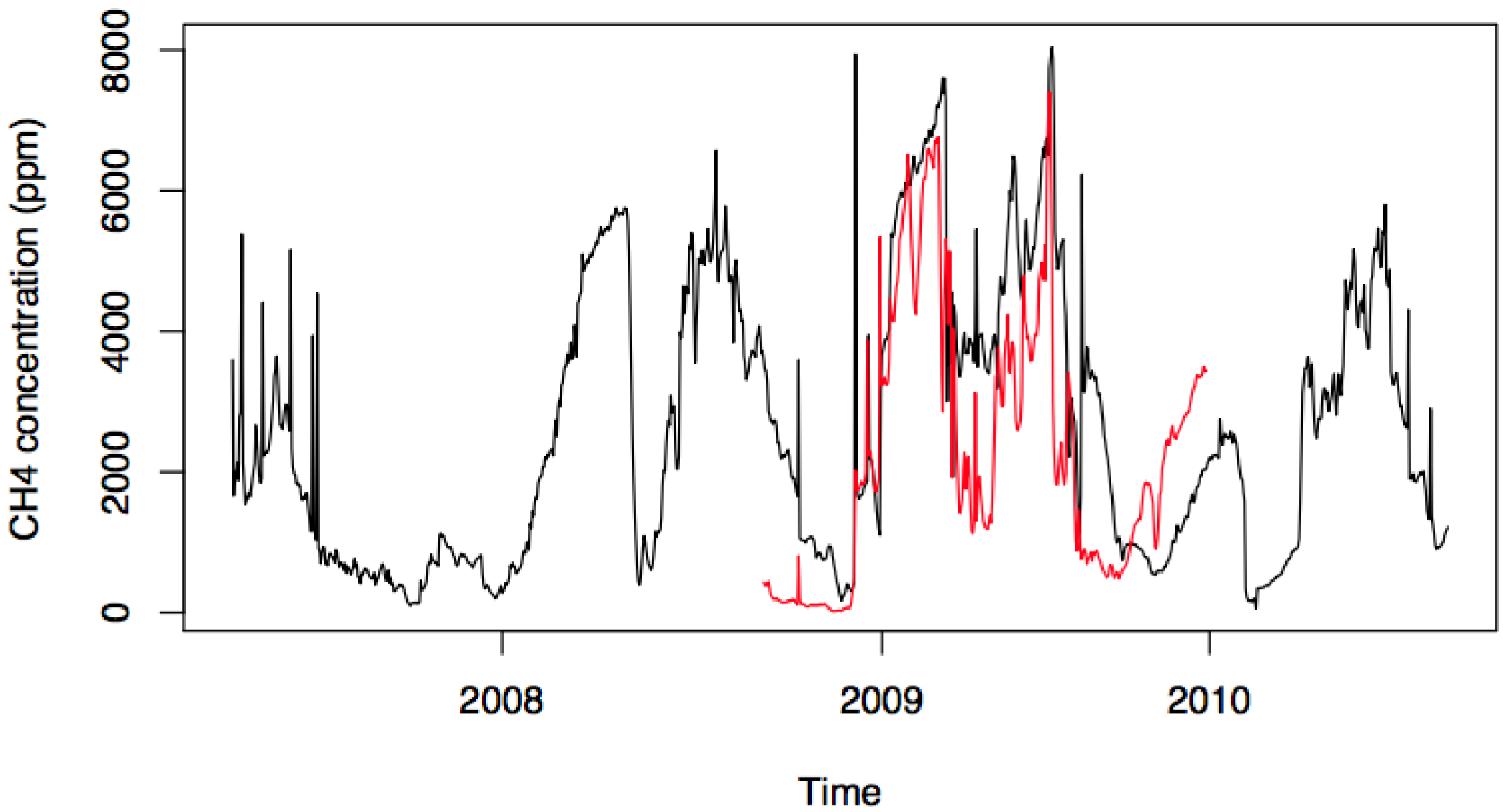
# Seasonal cycle of substrate

- GPP + Tsoil model: Multiply by (1+k*GPP) and re-fit other parameters.
- Better fit, but *only* if GPP is shifted so the peak is later.



# Next thoughts...

- How realistic is ‘lagged’ GPP as a proxy for substrate?
- Are there any better proxies?
- *Does change in concentration explain the lag?*



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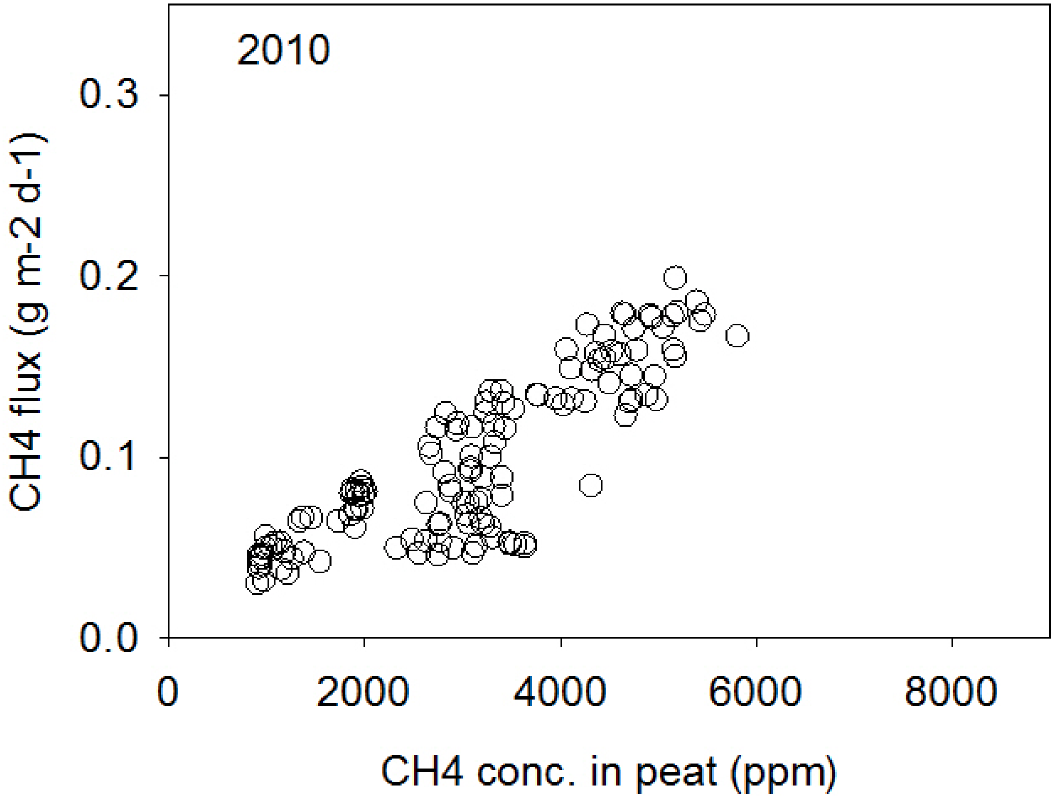


Plot and data from Annalea Lohila

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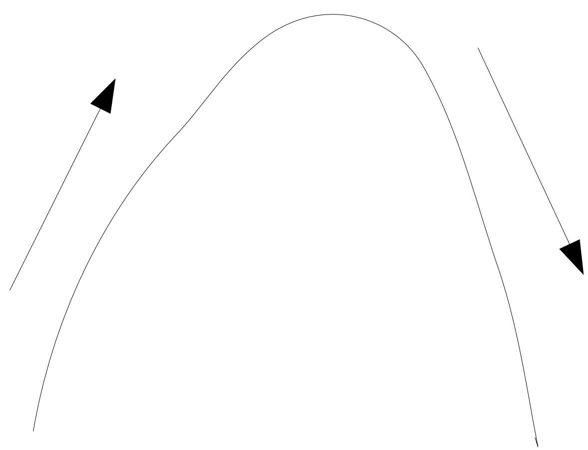



→ Annual cycle is shifted.

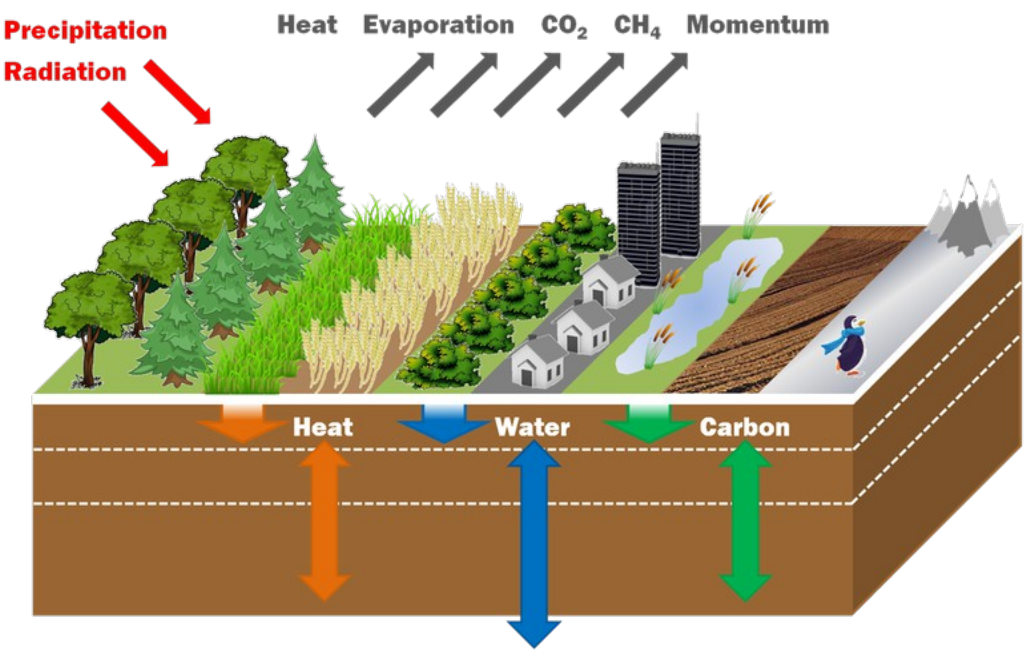
# How does this compare to the land surface models?

Have simulated measurement sites using JULES and CLM

Interlude… What is JULES?

# JULES land surface model in a nutshell

- *Vegetation:* DGVM (9 PFT's plus crops).
- *Physics:* Surface energy balance, dynamic snowpack, soil hydrology, freeze-thaw, organic soil characteristics...
- *Soil biogeochemistry:* Vertically discretised (recently added N), based on RothC.
- *Wetland scheme:* Dynamic, topography-based.
- *Peatland dynamics:* no.
- *DOC:* new development.



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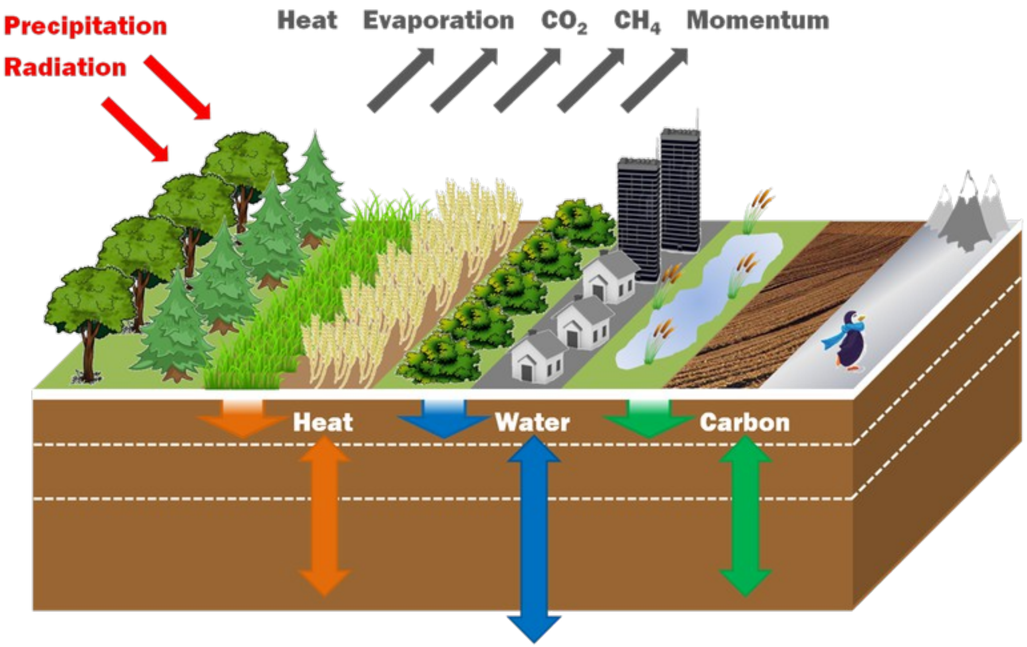
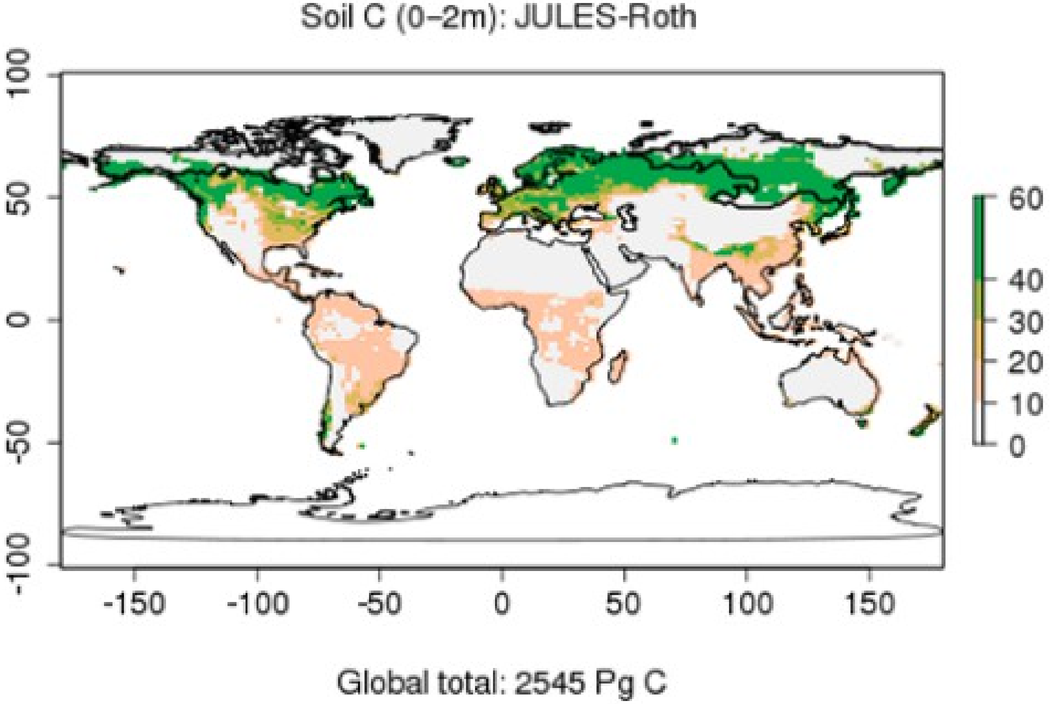


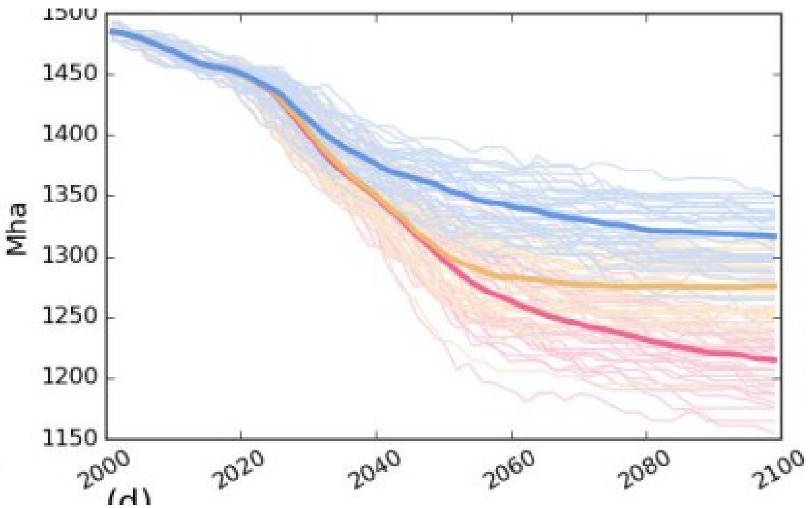
# JULES land surface model

- Application to large-scale C cycle, e.g. permafrost



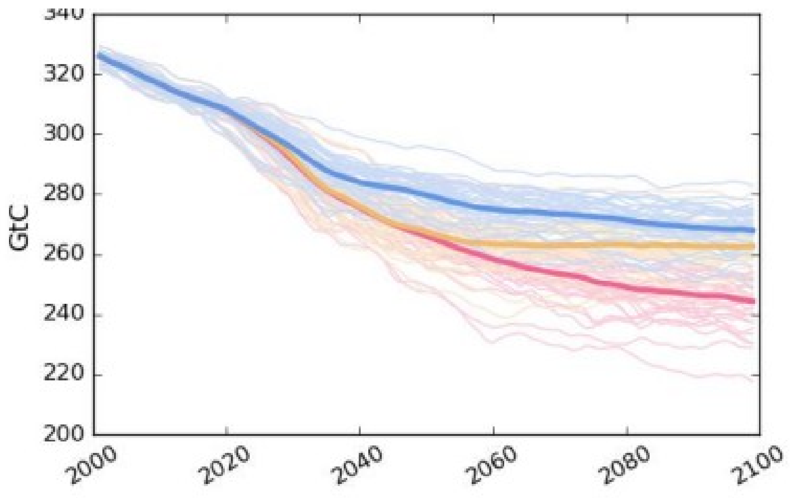

Soil C simulation in JULES

Burke, et al. *Geosci. Model. Dev.* 2017



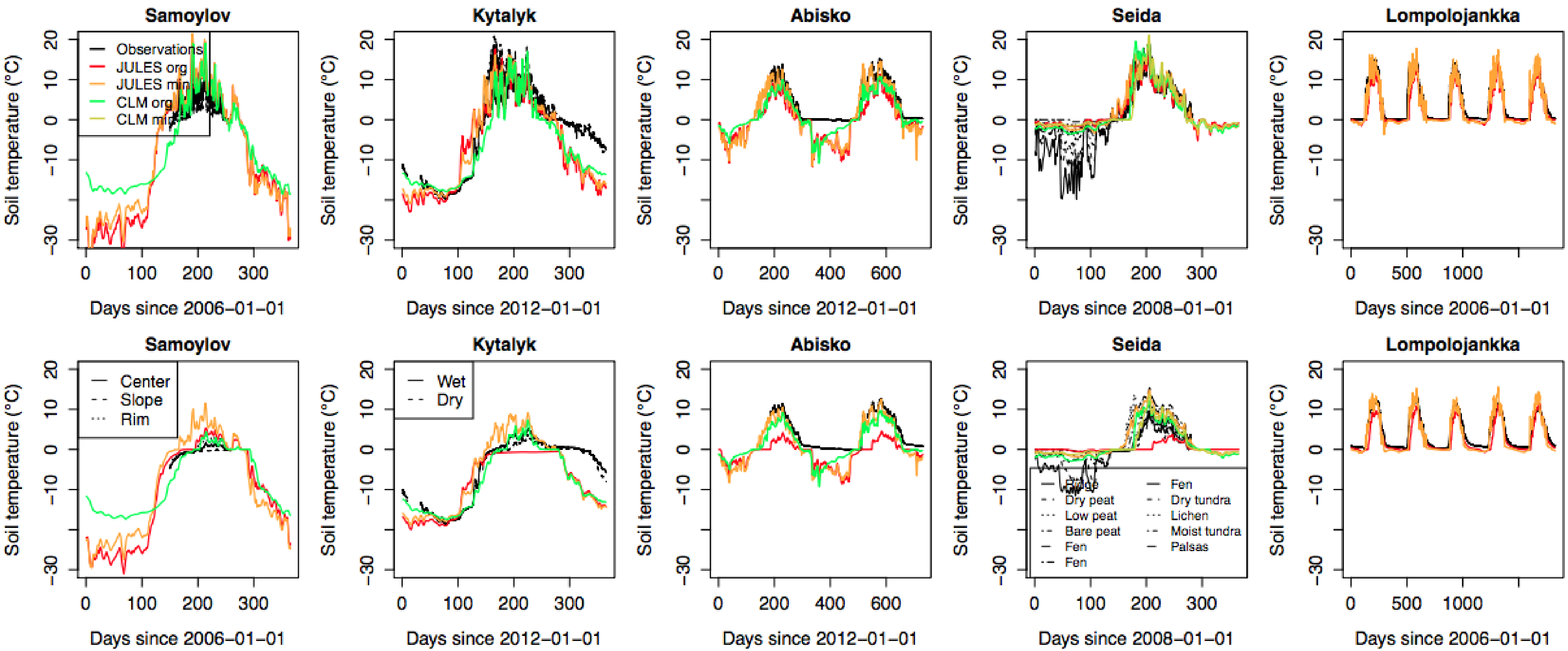

Area with permafrost in top 3m

Previously frozen C that is now unfrozen...



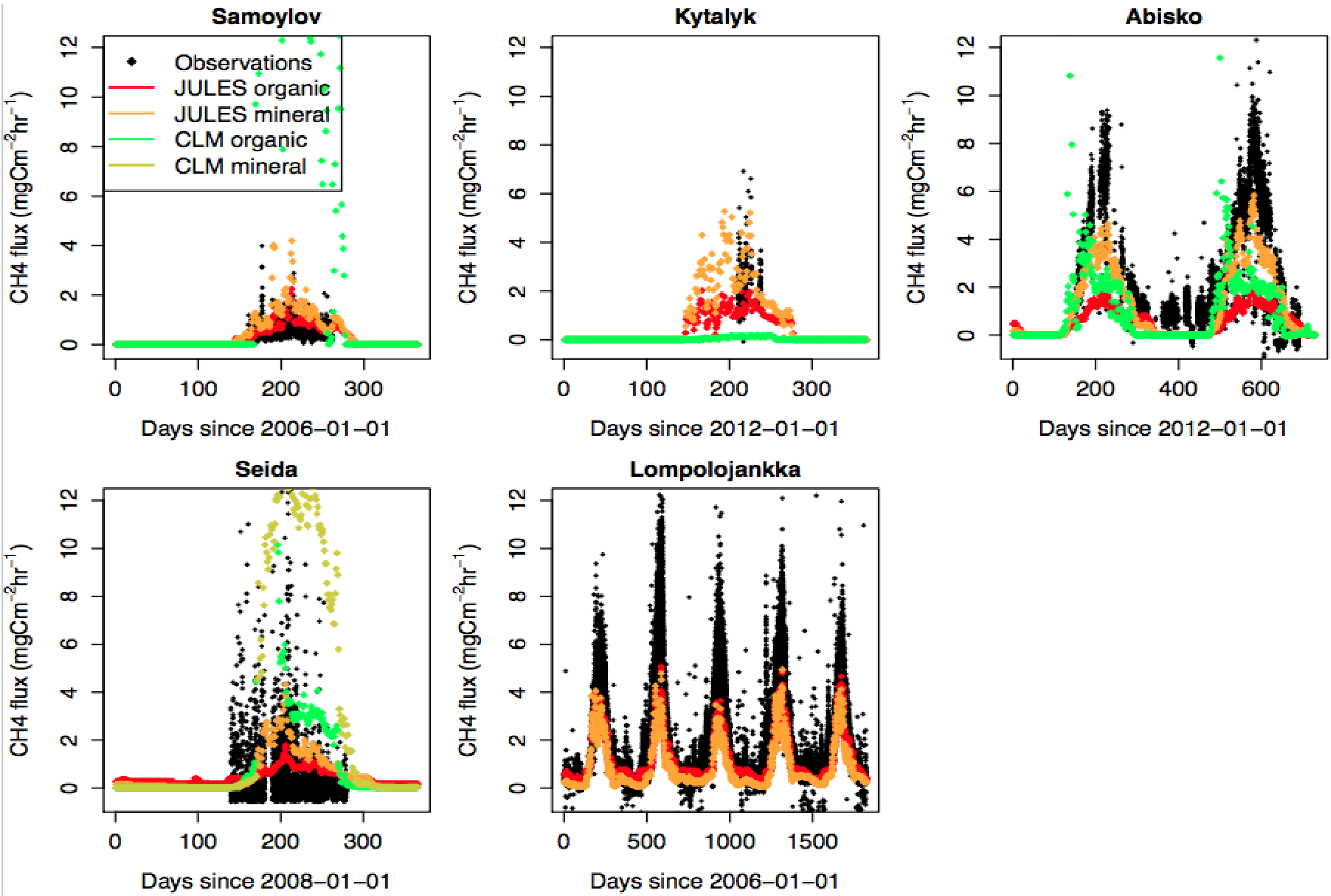
# Site simulations with land surface models

- Results from JULES and CLM: Tsoil simulation



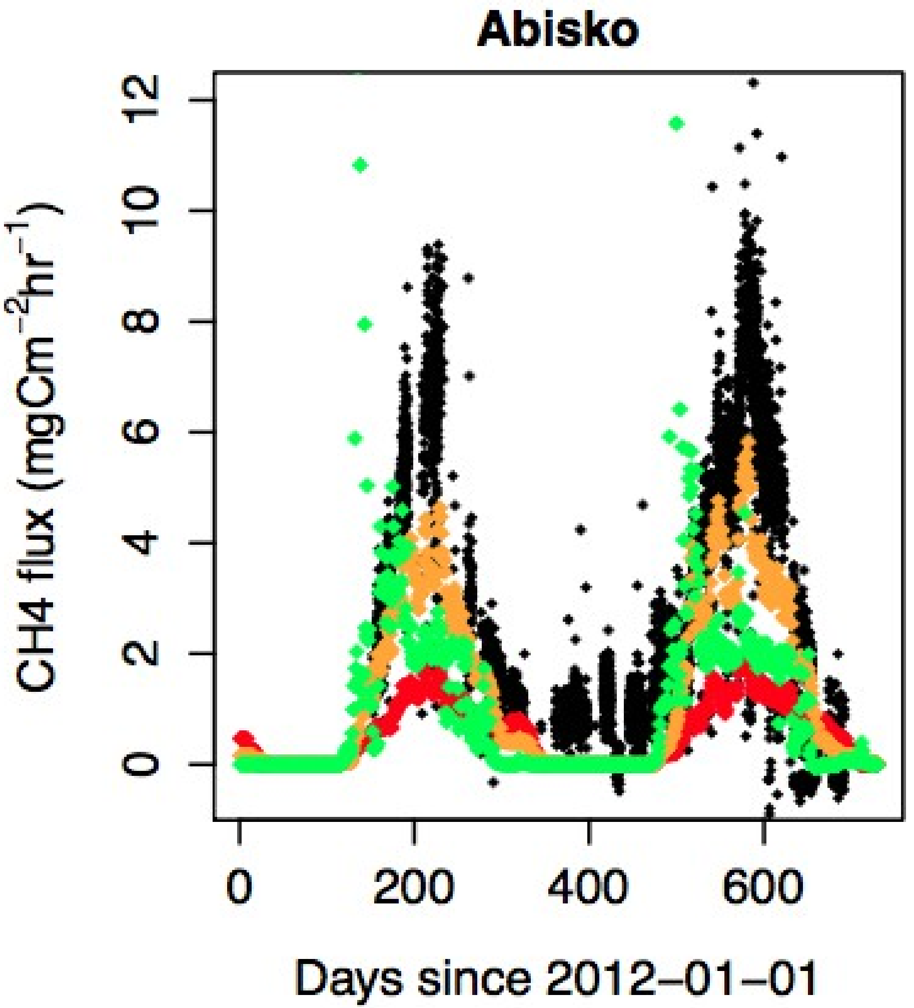
# Site simulations with land surface models

- Results from JULES and CLM: CH4 per m² of wetlands



# CLM: process-based methane scheme

- CLM can simulate bust of emissions in spring.
- However, doesn't include annual cycle of substrate.




$$P = R_{\mathrm{H}} f_{\mathrm{CH_4}} f_T f_{\mathrm{pH}} f_{\mathrm{pE}} S.$$

Riley et al. Biogeosciences, 8, 1925-1953, 2011

# Summary & outlook

- To constrain model parameters with observations: need a plausible model.
- Distinctive spring ‘burst’ related to snow/frozen ground.
- For annual mean methane emissions, the key missing process in models is *substrate availability*?

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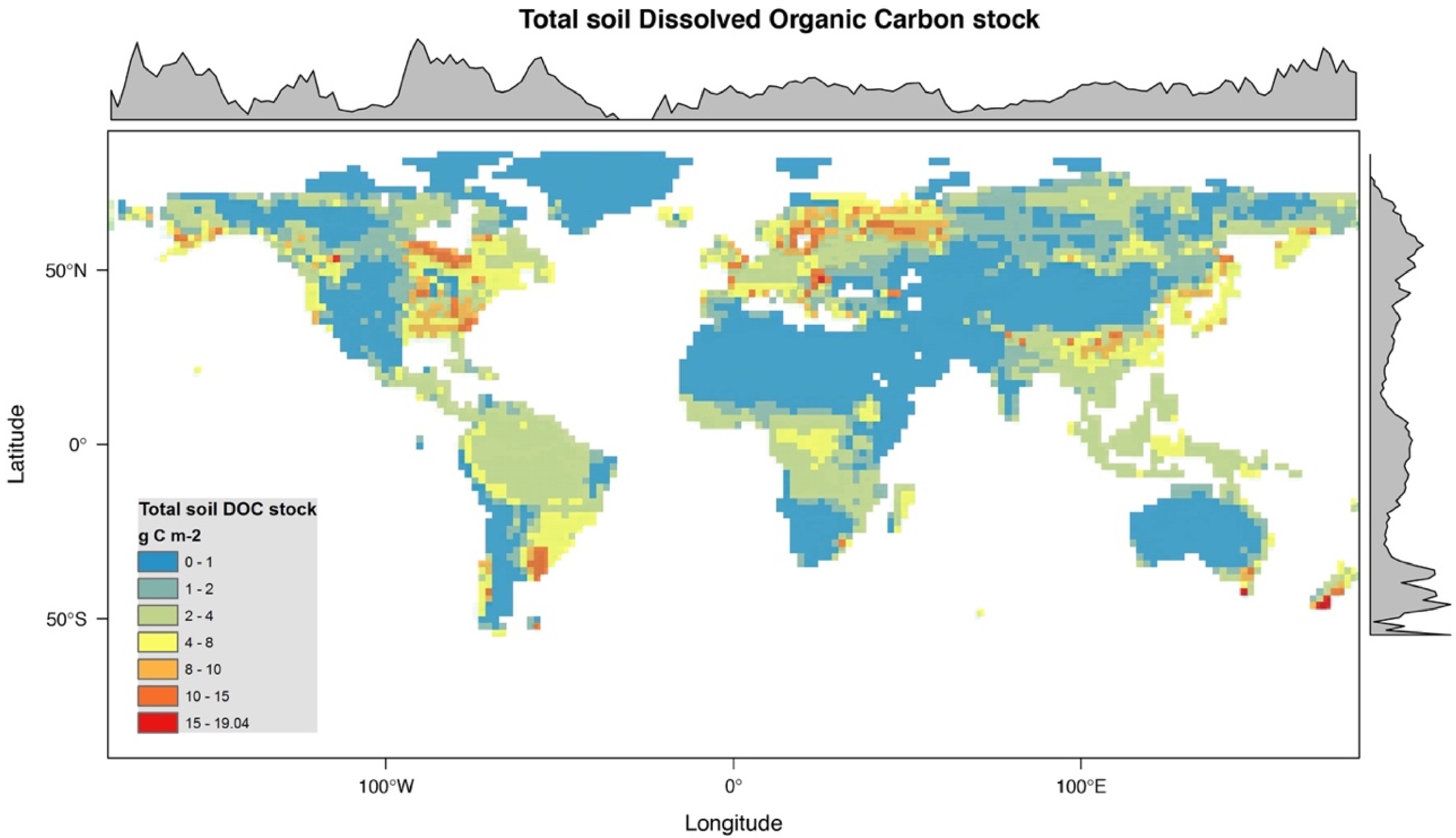
- Latest JULES developments include root exudates and DOC…
- Next 5 years, fellowship project includes :
  * Development of soil tiling resolving wetlands, peatland dynamics in JULES
  * Much more integration of model and observations.

# DOC in JULES

Nakhavali et al., submitted to GMD.



# How to link the observations to the models?

Proposed model:

$$FCH_4 = \int_{-\infty}^{0} A\, f_{wet}\, DOC(z)\, Q_{10}^{10 T_{soil}(z)} \exp(-\tau z)\, dz$$

- JULES: Parameters (Q10, tau) can be translated straight back to model.
- Depends on simulation of DOC and root exudates: recent additions to JULES.