# P**ermafrost and wetland CH4 emissions in ORCHIDEE**

Shushi Peng, Philippe Ciais, Gerhard Krinner,
Isabelle Gouttevin, Bruno Ringevel, Charles D. Koven

LSCE and LGGE

**Abstract**: The permafrost degradation under the context of climate warming is one of the most interesting questions in climate change science, because (1) permafrost contains the largest organic carbon reservoir in the terrestrial system, which may contribute a powerful greenhouse gas such as $CO_2$ and $CH_4$ positive feedbacks on climate; and (2) permafrost stability have important impacts on social-economics of permafrost domain. Here, the progress of permafrost and wetland CH4 emissions modules incorporated into 11-layer soil diffusion scheme was introduced. Then, we show a part of results of high-latitude version of ORCHIDEE for the current international projects RCN and PAGE21. Finally, the future plan of ORCHIDEE development including thermokarst module was also discussed in this presentation.

# Permafrost and wetland CH4 emissions in ORCHIDEE

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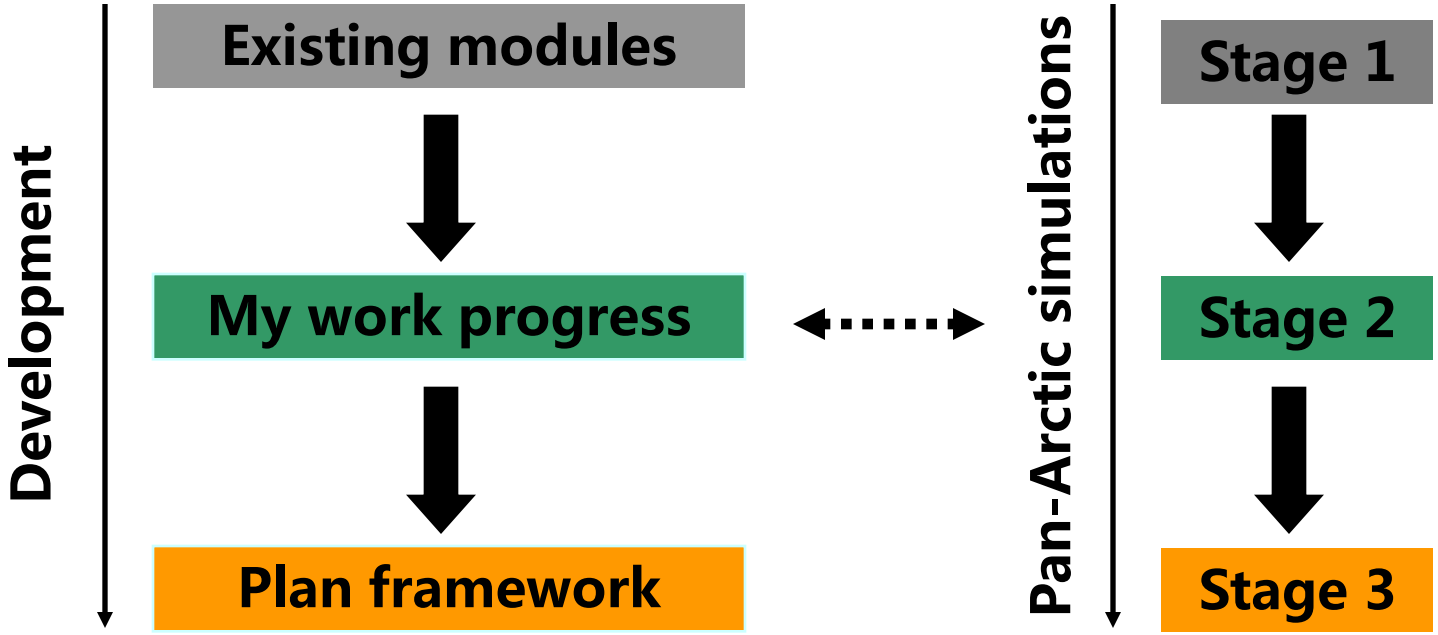
18.7 million km$^2$

~1672 Pg C in permafrost soil

**Possible strong feedbacks of CO2 and CH4 on climate**

# ORCHIDEE on high latitude



# ORCHIDEE on high latitude

## Permafrost

- ✓ Vertical SOC distribution
- ✓ Organic insulation
- ✓ Cryoturbation
- ✓ Deep C deposit

## Methane

- ✓ TOPMODEL
- ✓ CH4 emission (Q10)

## Freeze-Thaw

- ✓Ice-liquid water content
- ✓Soil thermal parameters

## Snow

- ✓ Multi-layer

# Permafrost OC

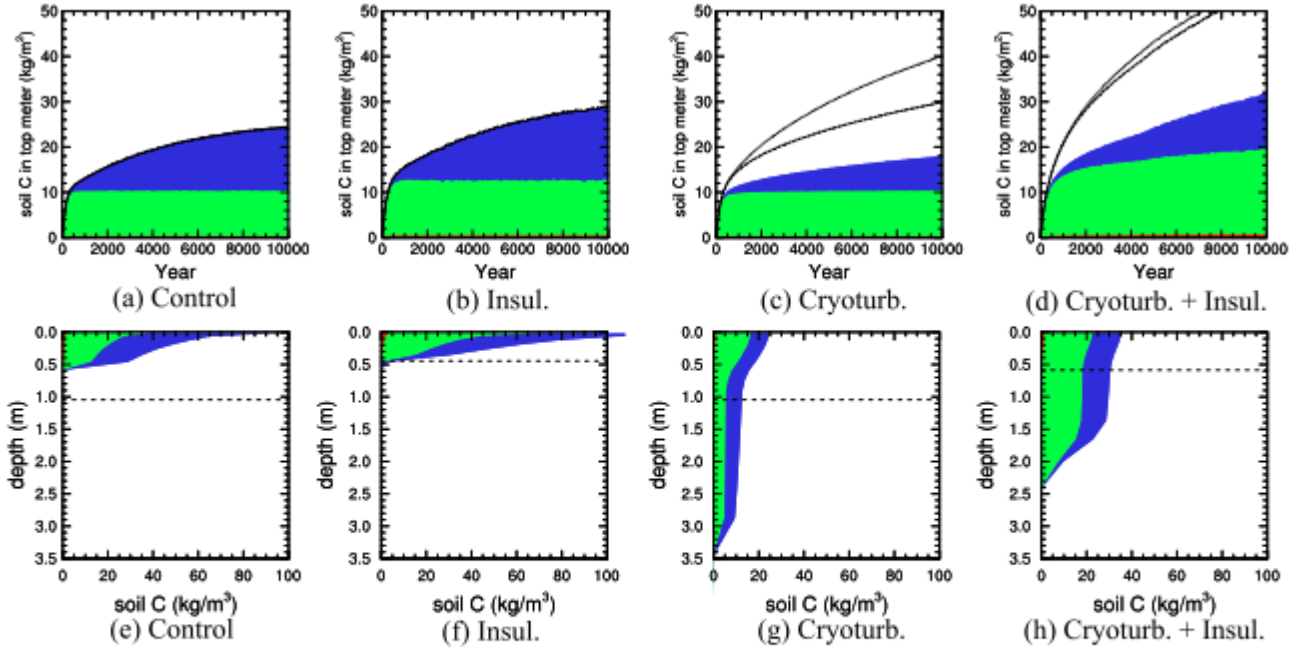
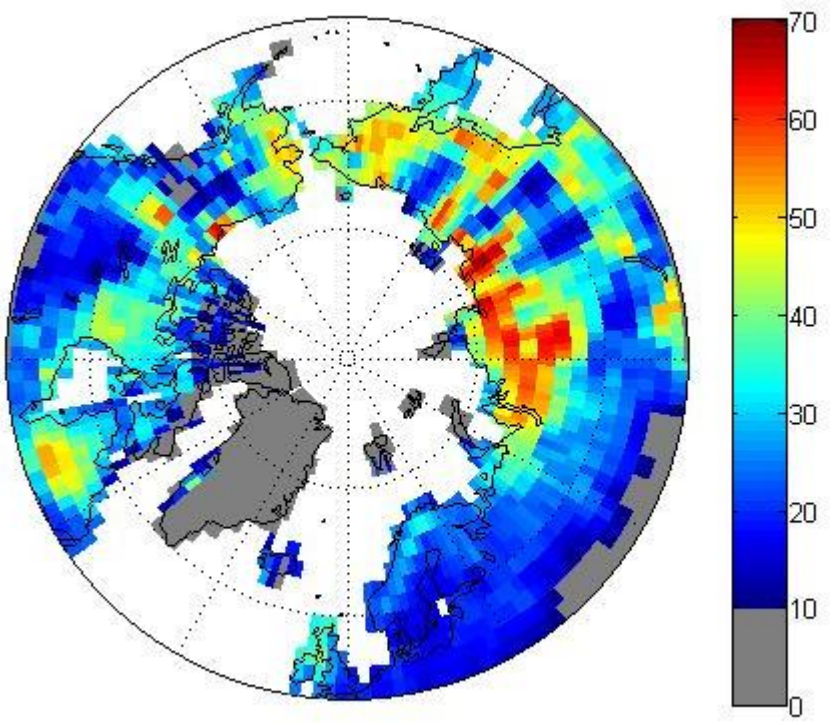
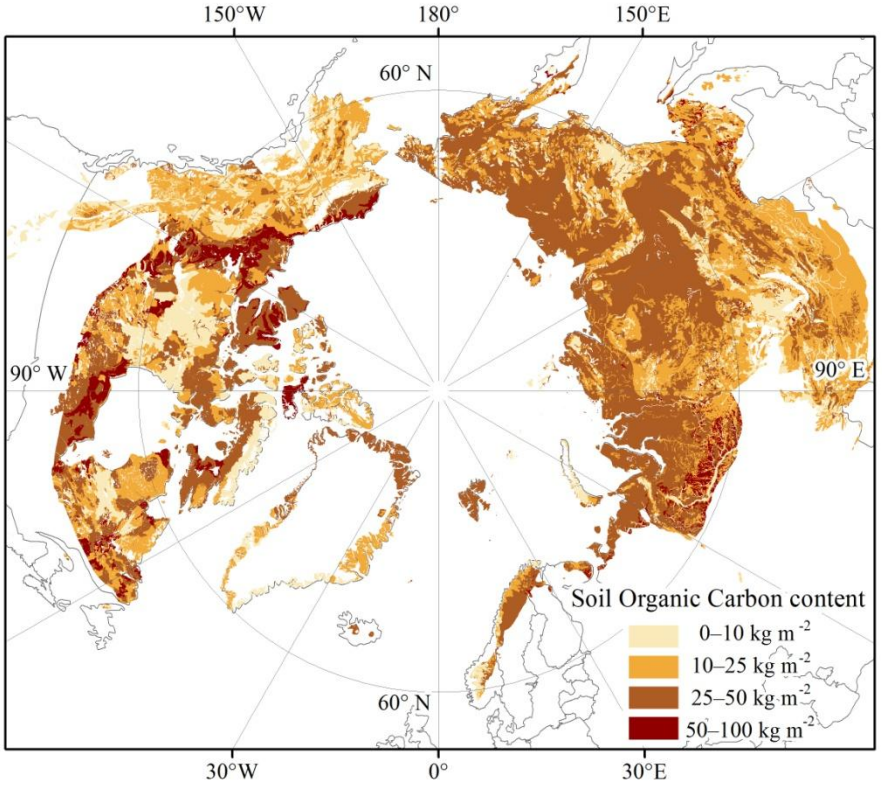



**Figure 1.** Time series of carbon accumulation in the upper meter of soil at Cherskii: (a) no insulation by organic or cryoturbation, (b) insulation by organic, (c) cryoturbation, (d) both insulation by organic and cryoturbation. Shaded area corresponds to: active pool(red), slow pool(green), passive pool(blue). Dashed line in Figures 1a–1d corresponds to total carbon in top 2 meters of soil, dotted line corresponds to total carbon in top 3 meters. (e–h) Same as Figures 1a–1d but for vertical profile of carbon at end of run. Dashed line corresponds to mean modelled active layer depth for each experiment.

Koven et al., 2009, GRL

# Permafrost OC



# Permafrost OC

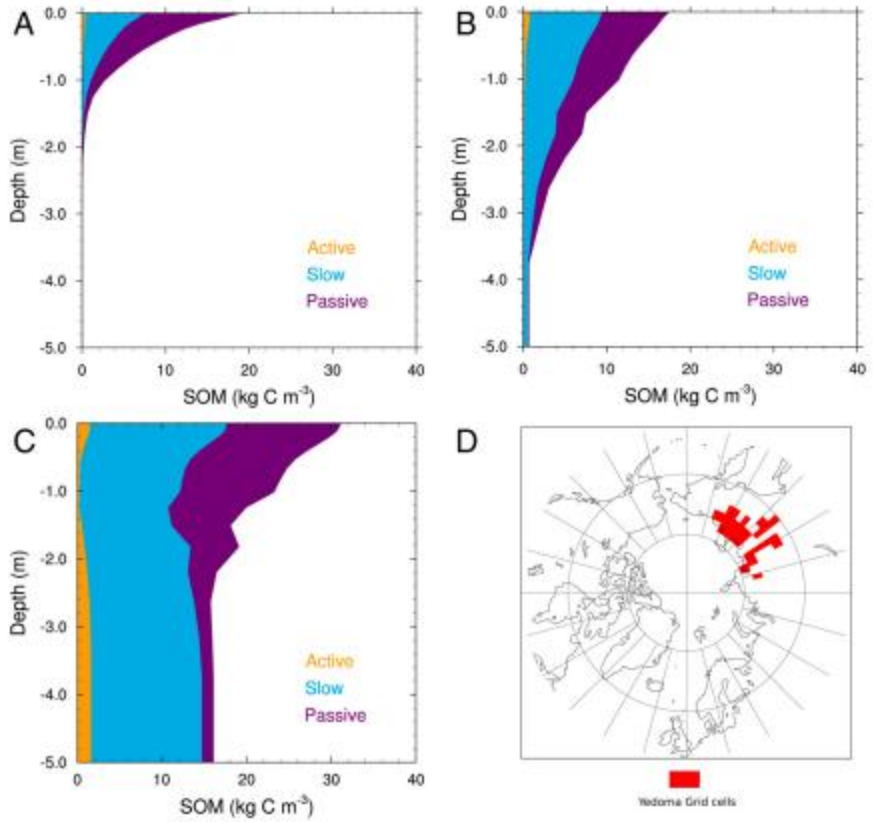



**Fig. S3.** Modeled soil C vertical profiles. (*A*) Mean over all permafrost grid cells in freeze case. (*B*) Mean over permafrost grid cells in permafrost case. (*C*) Mean over all yedoma grid cells in permafrost case. (*D*) Map of grid cells where yedoma is initialized to be present.

Koven et al., 2011, PNAS

# Freeze-thaw

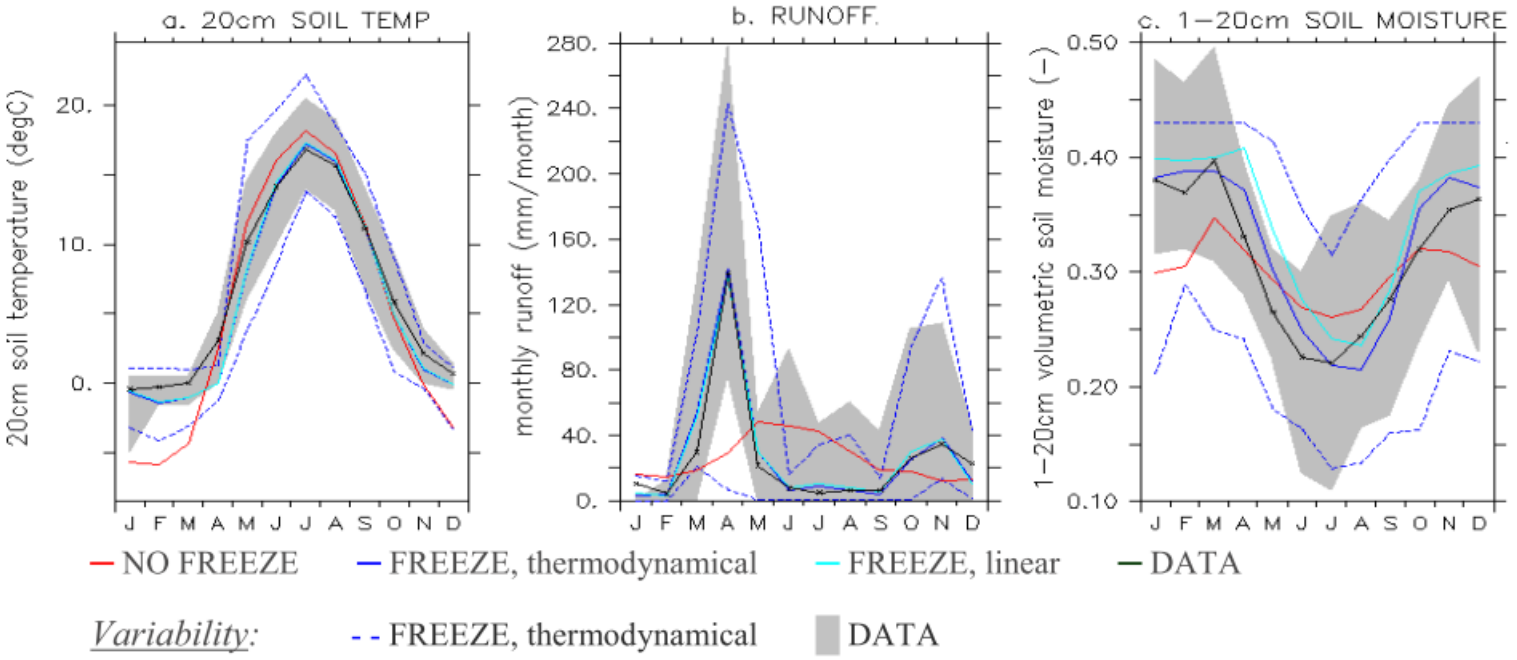
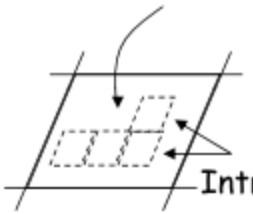



**Fig. 6.** Annual cycles of monthly mean 20 cm soil temperature **(a)**, monthly mean runoff **(b)** and monthly mean 1–20 cm volumetric soil moisture **(c)** simulated by ORCHIDEE with (FREEZE) and without (NOFREEZE) the freezing scheme, and compared to available data (DATA) over 1966–1983. The grey and the dashed blue envelopes respectively represent the annual variability in the data and in the FREEZE, thermodynamical simulation.

Gouttevin et al., 2012, TC

# Methane emission from wetlands

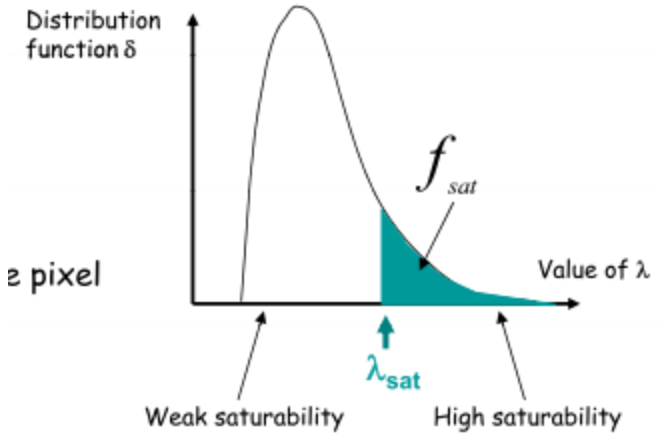
TOPMODEL: sub-grid

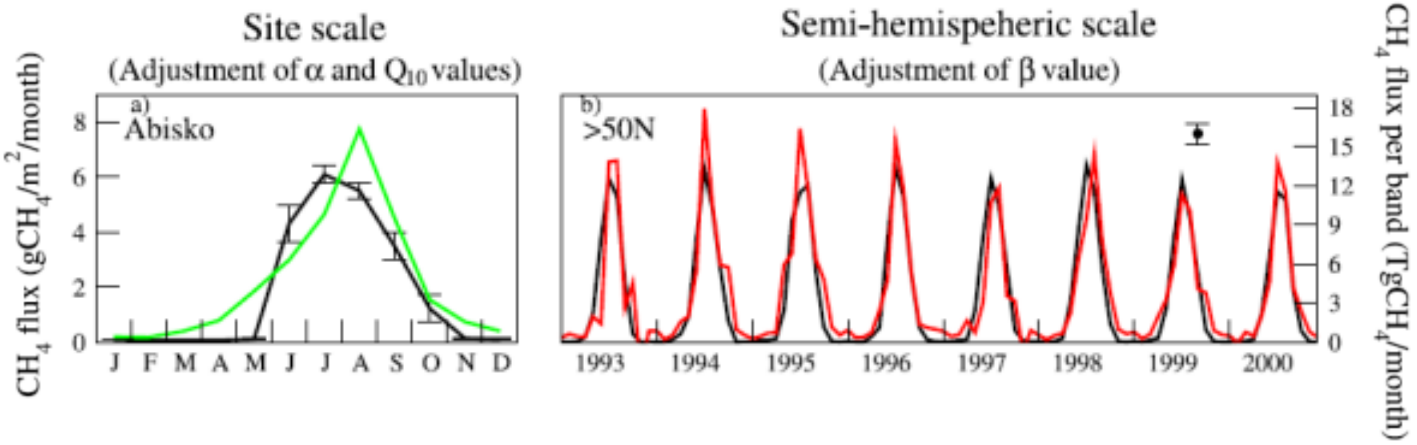


Introduction of a sub-grid scale:

divide g into many **pixels**

$(d_{1,t}, \lambda_1),(d_{2,t}, \lambda_2),\ldots, (d_{i,t}, \lambda_i)$



# Pan-Arctic simulation Stage 1

## Permafrost

- ✓ **Vertical SOC distribution**
- ✓ Organic insulation
- ✓ Cryoturbation
- ✓ Deep C deposit

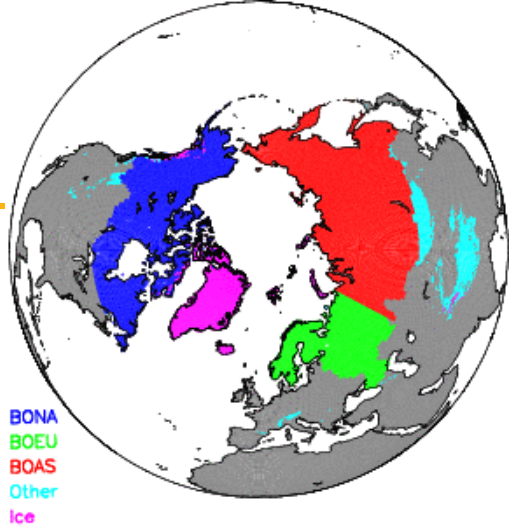
## Methane

- ✓ TOPMODEL
- ✓ CH4 emission (Q10)

## Freeze-Thaw

- ✓**Ice-liquid water content**
- ✓**Soil thermal parameters**

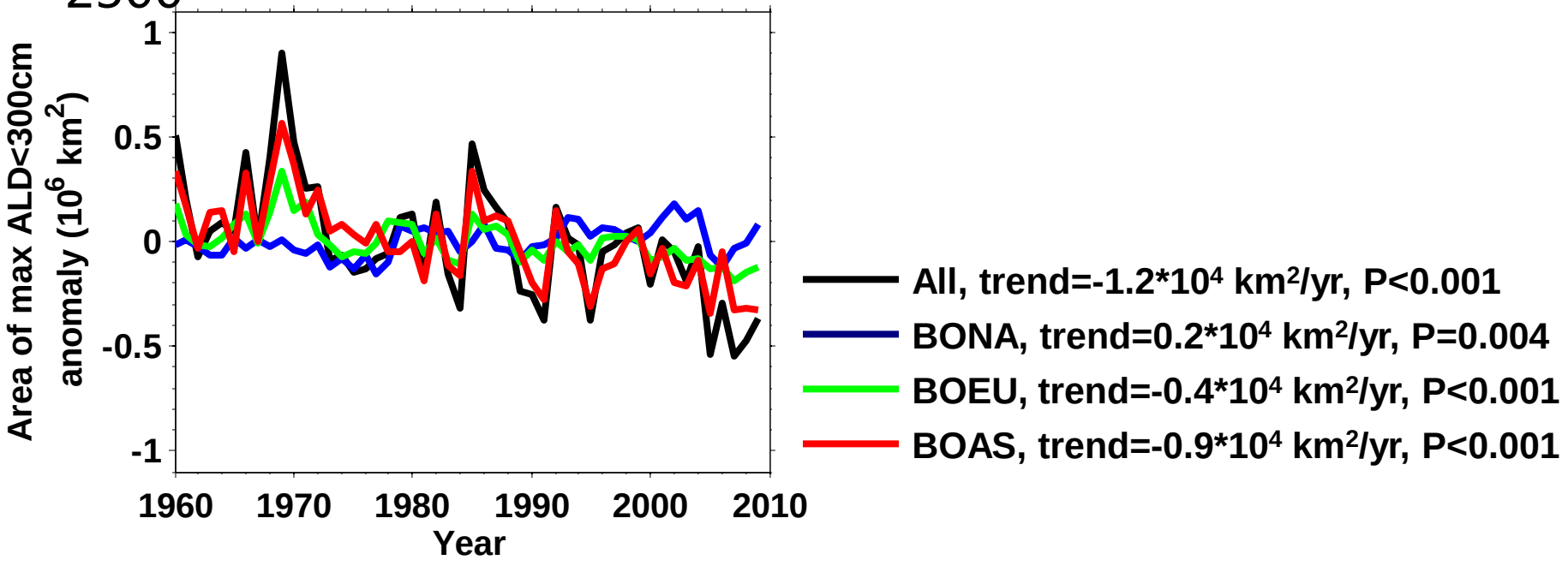
# Pan-Arctic simulation Stage 1




RCN and PAGE21

8 historical simulations from 1960-2009

4 simulations*2 scenarios future simulations from 2010-2300



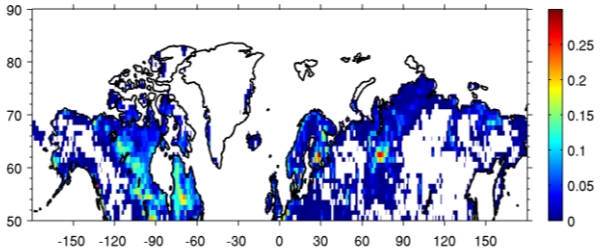
# Work progress

For parallel run:

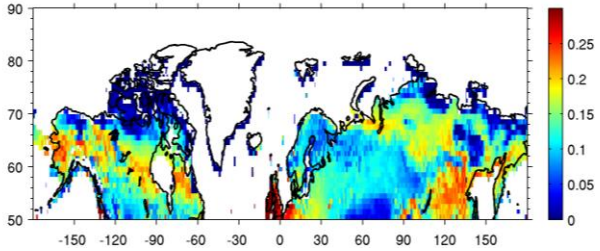
1. Add deep yedoma map into SOC
2. Debug for cryoturbation and other flags for permafrost
3. Debug for TOPMODEL

# 11-layer soil moisture + TOPMODEL needs calibrations

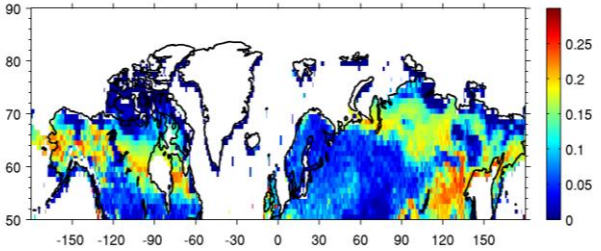
Prigent Mean annual



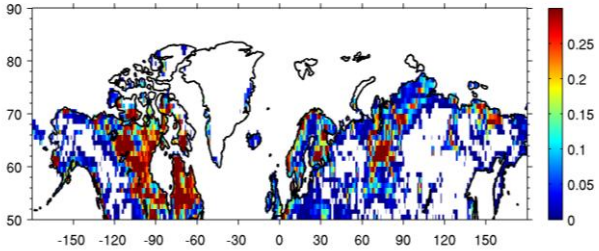

ORCHIDEE Fsat mean annual



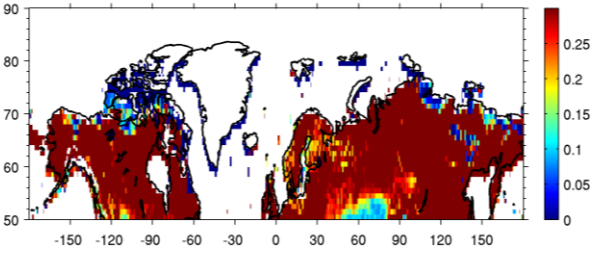

ORCHIDEE Fwet mean annual



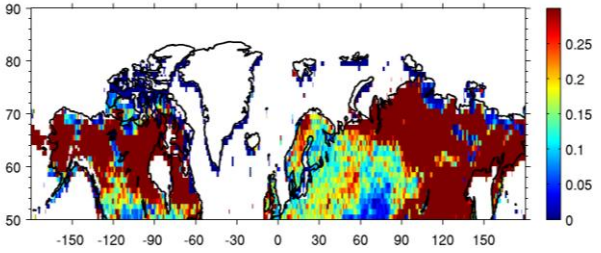

Prigent Maximum fraction




ORCHIDEE Fsat maximum




ORCHIDEE Fwet maximum




**Global simulations for large rivers runoff comparison is running…**

# Pan-Arctic simulation Stage 2

## Permafrost

- ✓ Vertical SOC distribution
- ✓ Organic insulation
- ✓ Cryoturbation
- ✓ Deep C deposit

## Methane

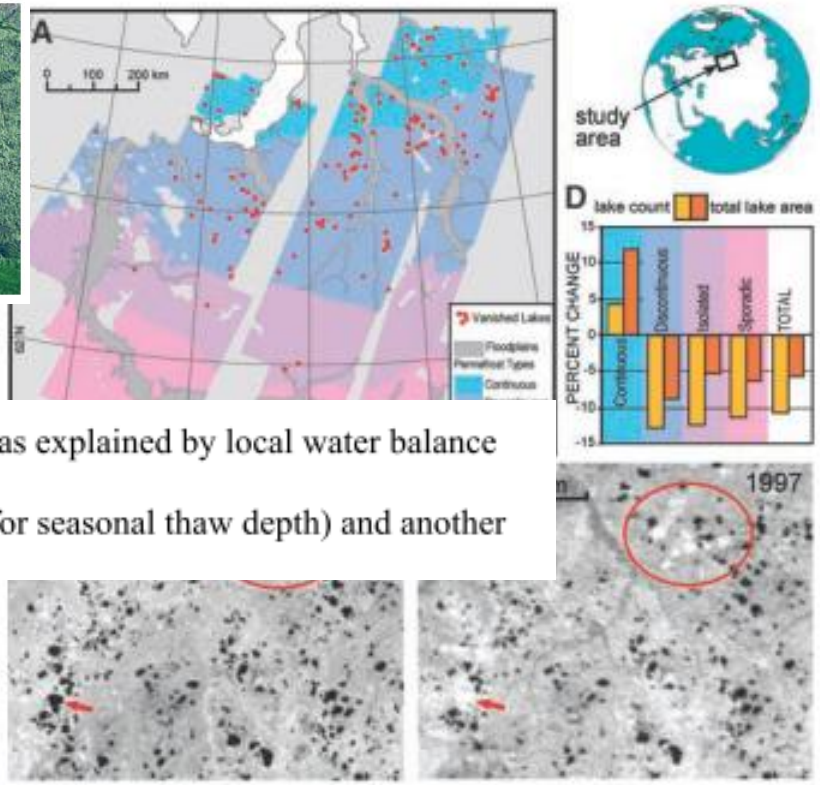
- ✓ TOPMODEL
- ✓ CH4 emission (Q10)

## Freeze-Thaw

- ✓Ice-liquid water content
- ✓Soil thermal parameters

On going test and need calibration for the saturation fraction and methane emission rate…

# Thermokarst module plan



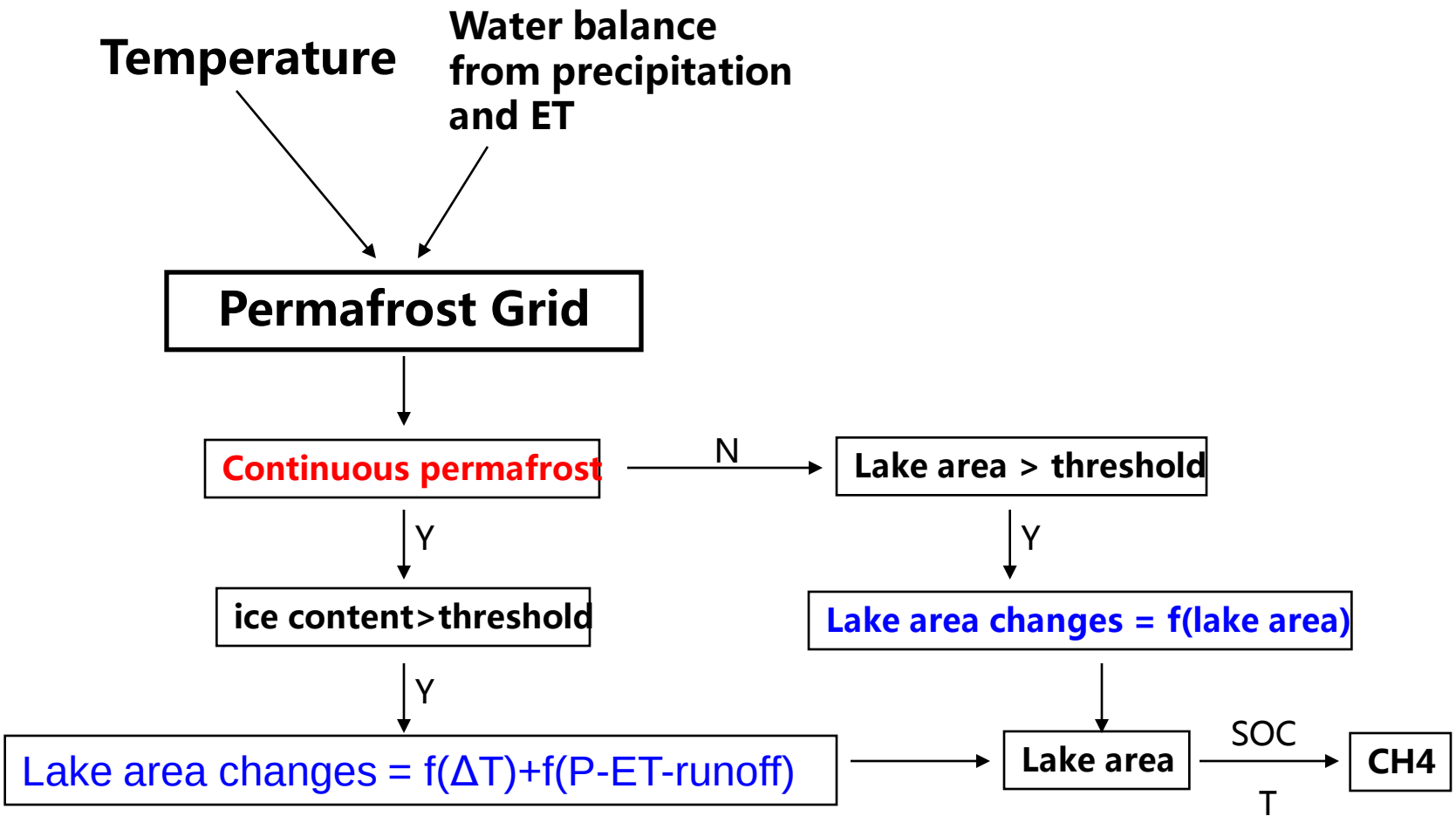

area. We found that 80.7% of variation in lake areas of 17 dates was explained by local water balance and mean air temperature since snowmelt (interpreted as a proxy for seasonal thaw depth) and another

Chen et al., 2012

**Fig. 1.** (A) Locations of Siberian lake inventories, permafrost distribution, and vanished lakes. Total lake abundance and inundation area have declined since 1973 (B), including (C) permanent drainage and revegetation of former lakebeds (the arrow and oval show representative areas). (D) Net increases in lake abundance and area have occurred in continuous permafrost, suggesting an initial but transitory increase in surface ponding.

Smith et al., 2005, Science

# Thermokarst algorithm v1



# Thermokarst lakes maps

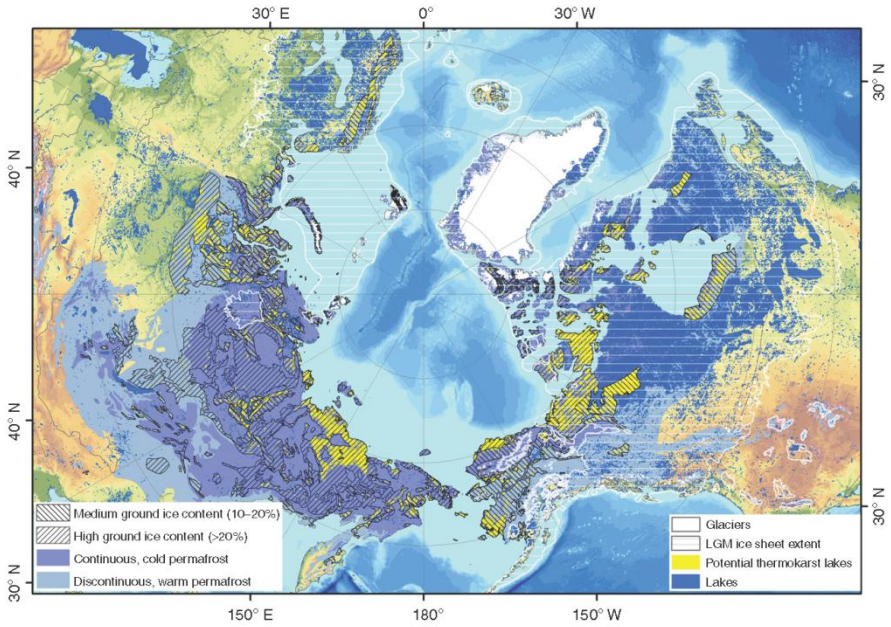



**Figure 4** Pan-Arctic map showing probable thermokarst lake regions. Lake cover (Lehner and Döll, 2004) in the high northern latitudes is strongly aligned with permafrost (Brown et al., 1997) distribution and glaciation history (Ehlers and Gibbard, 2003).

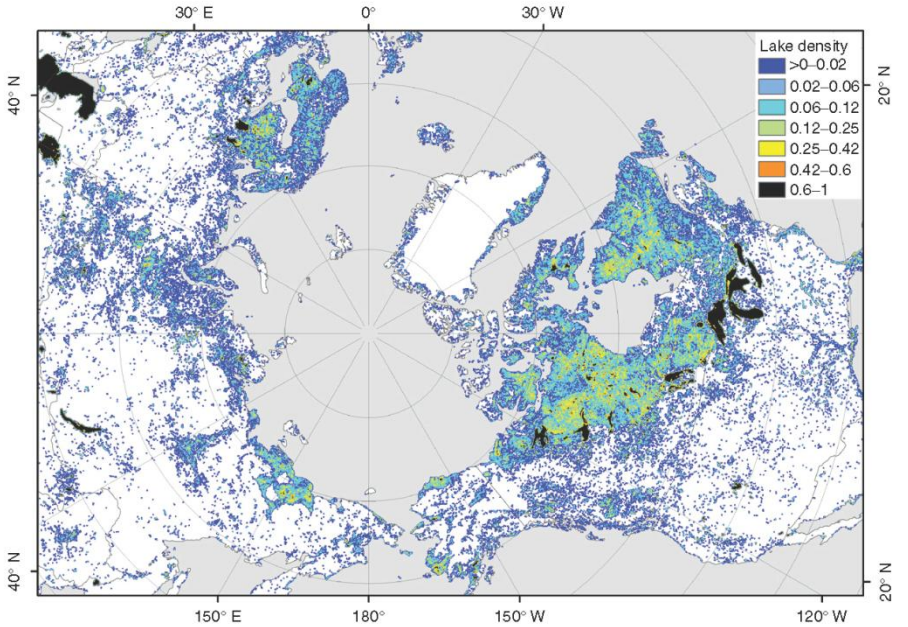



**Figure 5** Lake area fraction in northern high latitudes based on 5 km grid cells and the Global Lake and Wetland Database (Lehner and Döll, 2004).

# Pan-Arctic simulation Stage 3

## Permafrost

- ✓ Vertical SOC distribution
- ✓ Organic insulation
- ✓ Cryoturbation
- ✓ Deep C deposit

## Methane

- ✓ TOPMODEL
- ✓ CH4 emission (Q10)

## Thermokarst

## Freeze-Thaw

- ✓Ice-liquid water content
- ✓Soil thermal parameters

# High latitude ORCHIDEE framework

Fire

Snow

Permafrost

CO2

Wetland+
Thermokarst

CH4