Title: Last Glacial Maximum Permafrost Carbon Pools and Fluxes by Dan Zhu

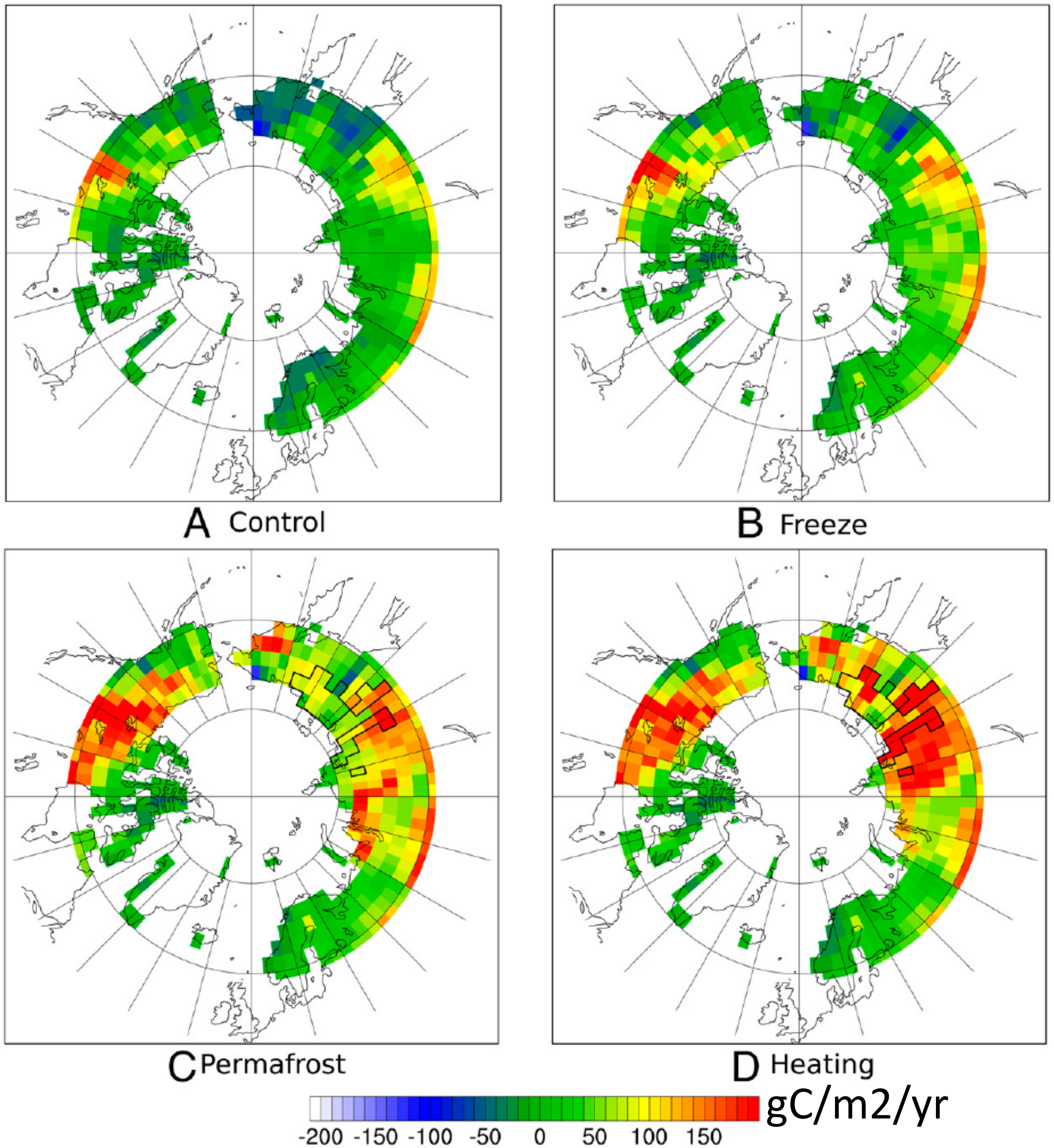
Abstract:

Atmospheric $CO_2$ concentration rose by nearly 100 ppm during late Pleistocene glacial–interglacial transitions. To make clear the sources of this carbon requires better knowledge of carbon reservoirs during glacial periods. It was estimated that the terrestrial biosphere contained 330 PgC less carbon in the Last Glacial Maximum compared with pre-industrial time, yet with a large area of low-productivity but carbon-rich biomes. During LGM, an inert carbon pool of more than 2000 Pg C has been inferred, which exceeds carbon stored in permafrost today by more than 700 Pg C. This large terrestrial inert pool partly disappeared during the climate warming to the Holocene, and may have contributed to the deglacial rise in atmospheric $CO_2$. During the three-year PhD study, I will use and further develop the process-based ecosystem model ORCHIDEE, by improving DGVM, introducing soil accumulation rates and introducing interactions with steppe-tundra mammals, in order to simulate the extent and distribution of LGM permafrost carbon pools and dynamics. The model results will be evaluated using new paleo-environmental reconstructions.

# Last Glacial Maximum Permafrost Carbon Pools and Fluxes

Dan Zhu, Philippe Ciais, Masa Kageyama, Gerhard Krinner, Shushi Peng

# Vulnerability of permafrost carbon to future warming




A climate-induced loss of carbon by terrestrial ecosystems north of 60N when forced by (SRES) A2 scenario: 25±3 ~ 85±16 PgC

C. Koven et al, 2011

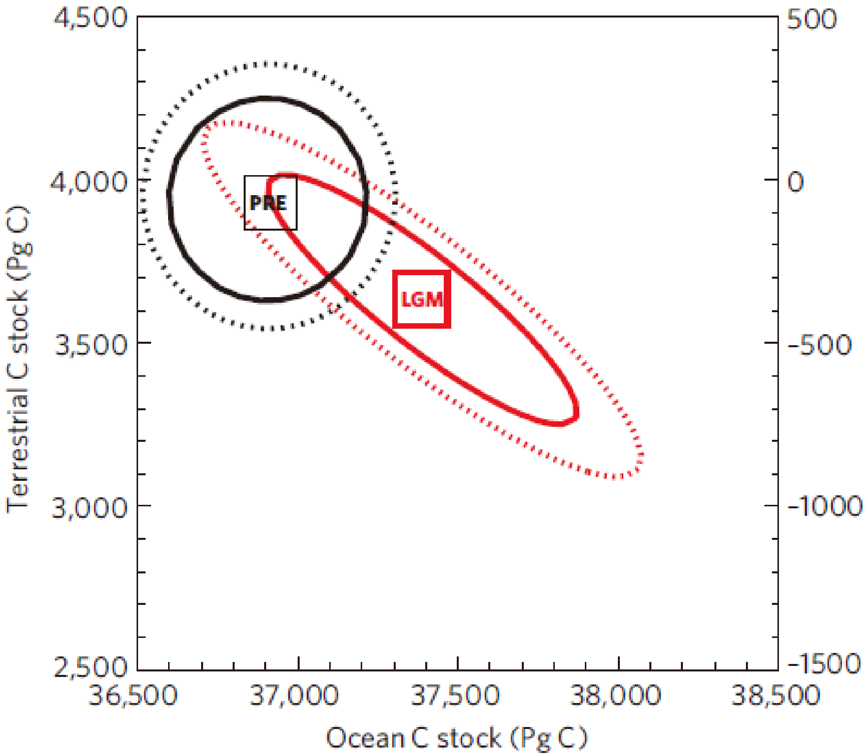
Fig. net $CO_2$ fluxes due to climate change at end of 21st century

Introduction

# redistributions among carbon reservoirs during glacial-interglacial transitions

**Table 1 | Terrestrial and ocean carbon stocks, and global photosynthesis estimates for the LGM and PRE.**

| Time period | Carbon stocks (Pg C) | | | | | | | Photosynthesis (Pg C $yr^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|
| | Land | | | | | Ocean | Atmosphere | Land | Ocean |
| | Sum of: | Land active | + | Land inert | | | | | |
| PRE | 3,970±325 | 2,370±125 | + | 1,600±300 | | 36,830±170 | 593±2 | 80±30 | 110±30 |
| LGM | 3,640±400 | 1,340±500 | + | 2,300±300 | | 37,350±400 | 399±2 | 40±10 | 110±30 |
| LGM minus PRE | −330 | −1,030 | + | 700 | | 520 | −194 | −40 | 0 |




P. Ciais et al, 2012

- During late Pleistocene glacial–interglacial transitions, atmospheric CO2 rose by almost 100 ppm

Introduction

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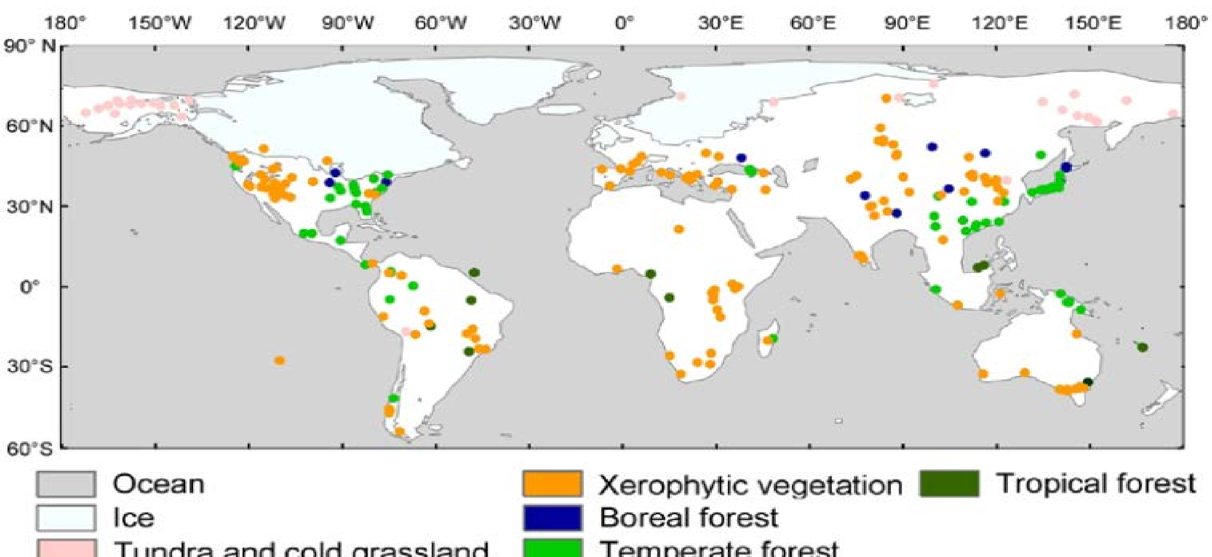



Fig. reconstruction of LGM vegetation from pollen data and plant macrofossil data from the BIOME-6000 database.

- Carbon-rich and low-productivity biomes during LGM
- A stock of 2,300±300 PgC of 'inert' terrestrial carbon pool

## Yedoma: frozen deposits of Pleistocene carbon up to 50 meters thick

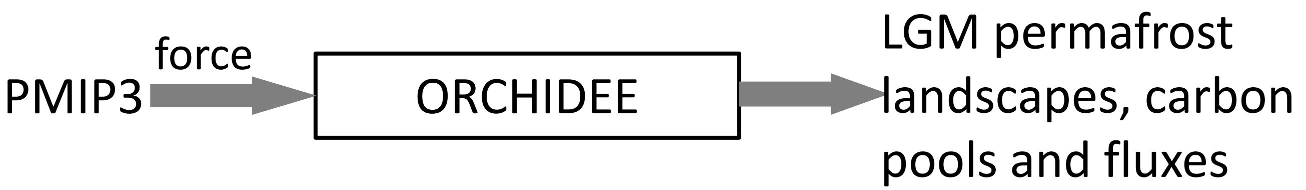
Ancient soils. (**Left**) Exposed carbon-rich soils from the mammoth steppe-tundra along the Kolyma River in Siberia. The soils are 53 m thick; massive ice wedges are visible. (**Right**) Soil close-up showing 30,000-year-old grass roots preserved in the permafrost.

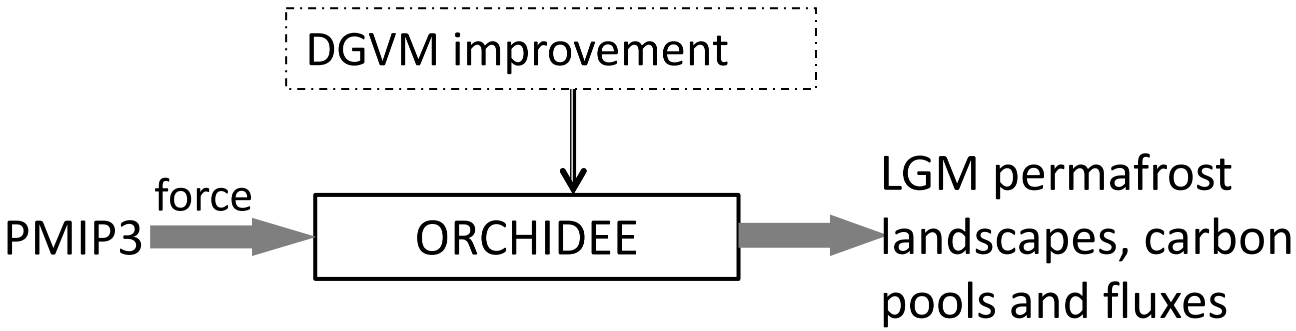
SA. Zimov et al, 2008

- Late Pleistocene age (accumulation over several 10,000 yrs)
- Fossils from the Mammoth Steppe (plants + mega fauna)
- Coverage: estimated 1 million $km^2$
- Average depth of ~25m, average carbon contents from 2% to 5%
- Permafrost soils of Mammoth Steppes could have stored ~1,000 PgC more carbon during the LGM than today

# Goals of the project

- Model Pleistocene permafrost distribution from climate model simulations (PMIP3)
- Model LGM permafrost carbon stocks
- Model permafrost carbon dynamics in response to climate change


PMIP3
force
ORCHIDEE
LGM permafrost landscapes, carbon pools and fluxes


DGVM improvement
force
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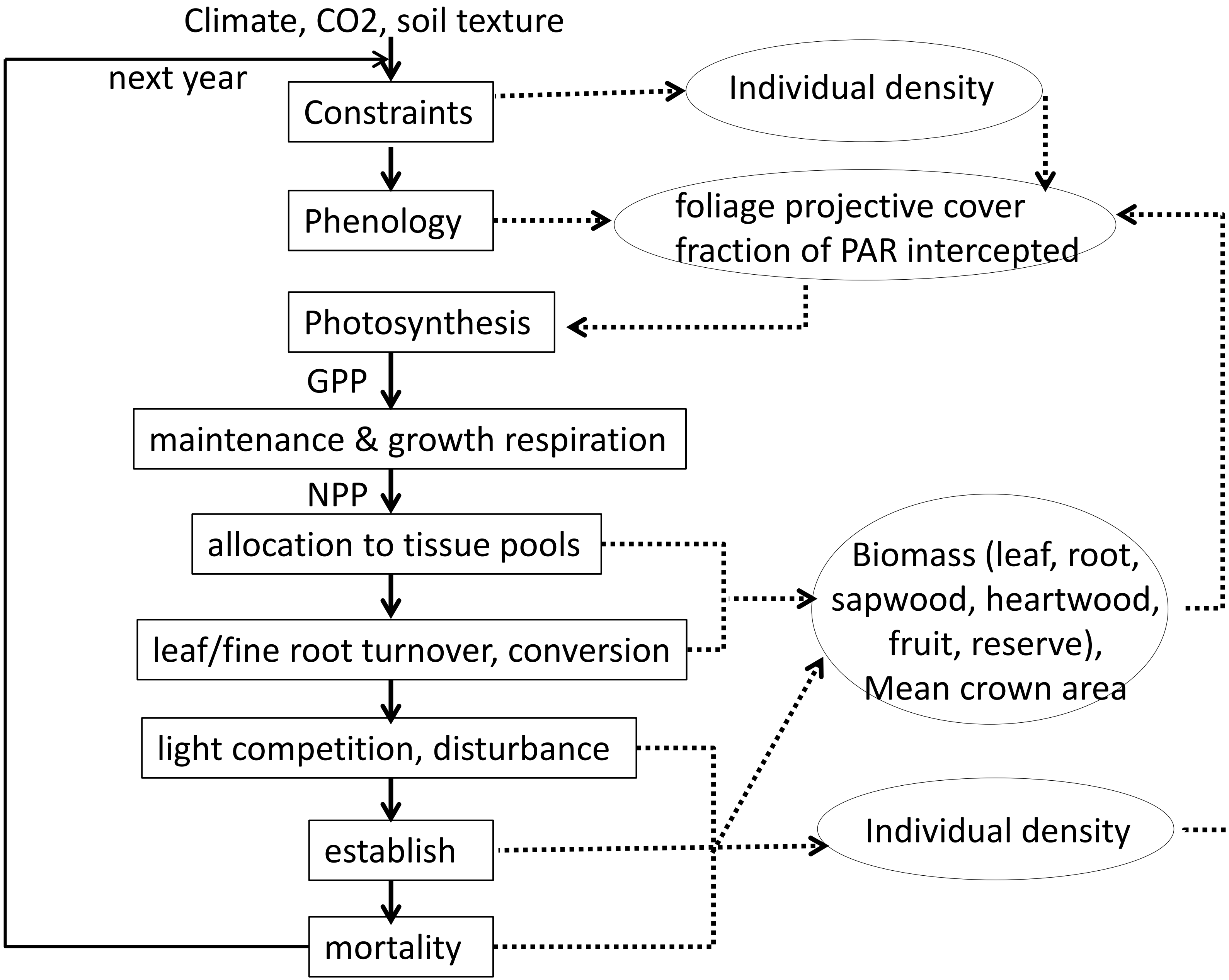
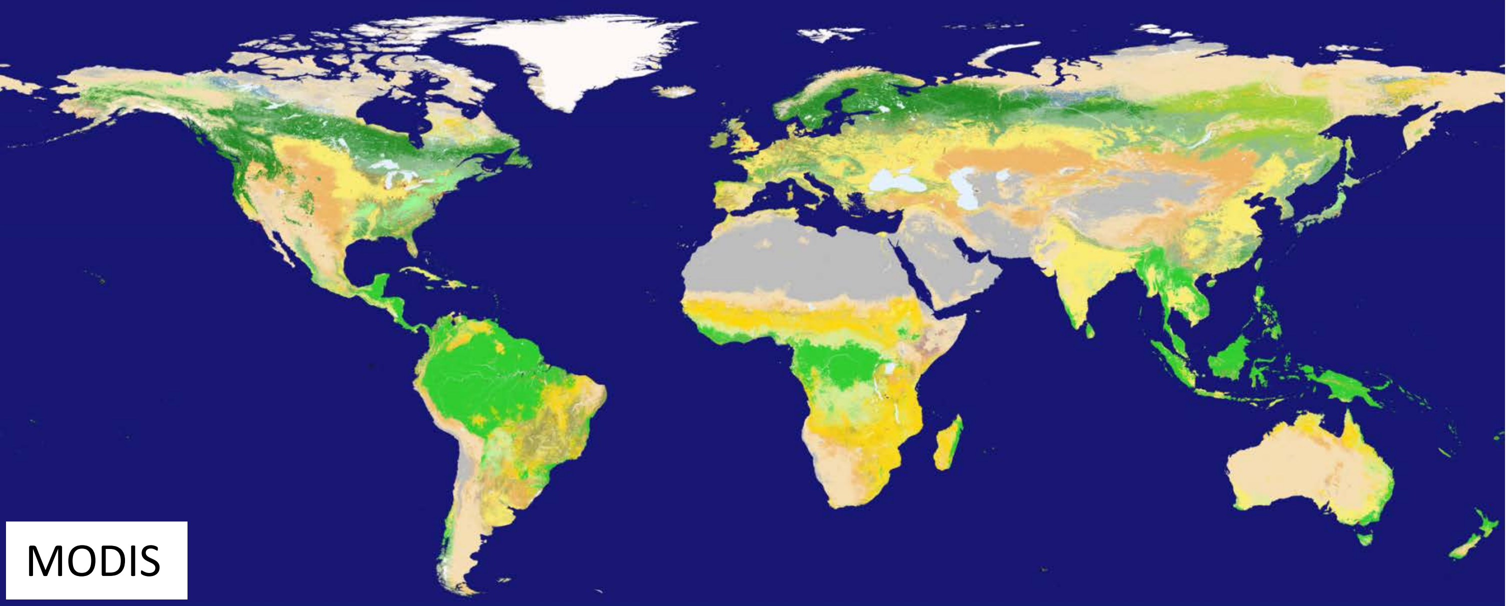
# DGVM in ORCHIDEE



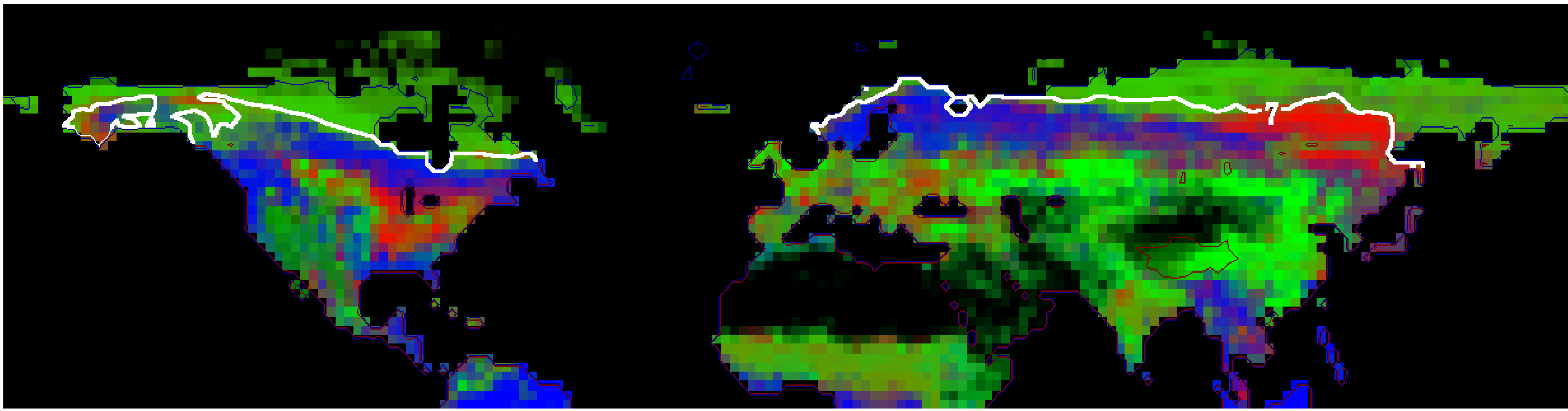
# Problem: Overestimation of DN in high latitudes

# Temperature constraint for trees

In older ORCHIDEE versions, warm season temperature (Tws) must exceed 7 ◦C for trees to be adapted to the given climate.

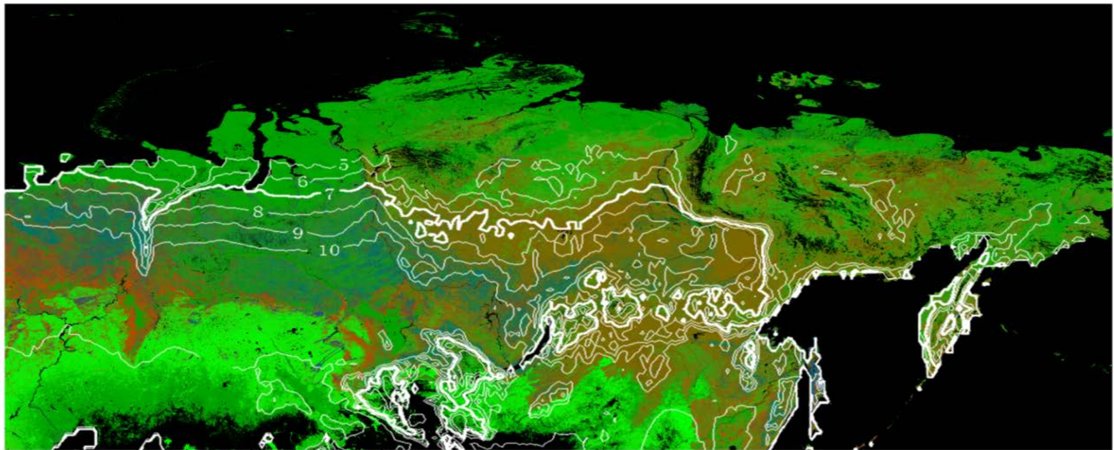
Calculated using relaxation method: Tws <— $\frac{(60-1)*Tws+T\_daily}{60}$




Tws 7 ◦C isotherm on composite-color map of ORCHIDEE standard PFTmap.

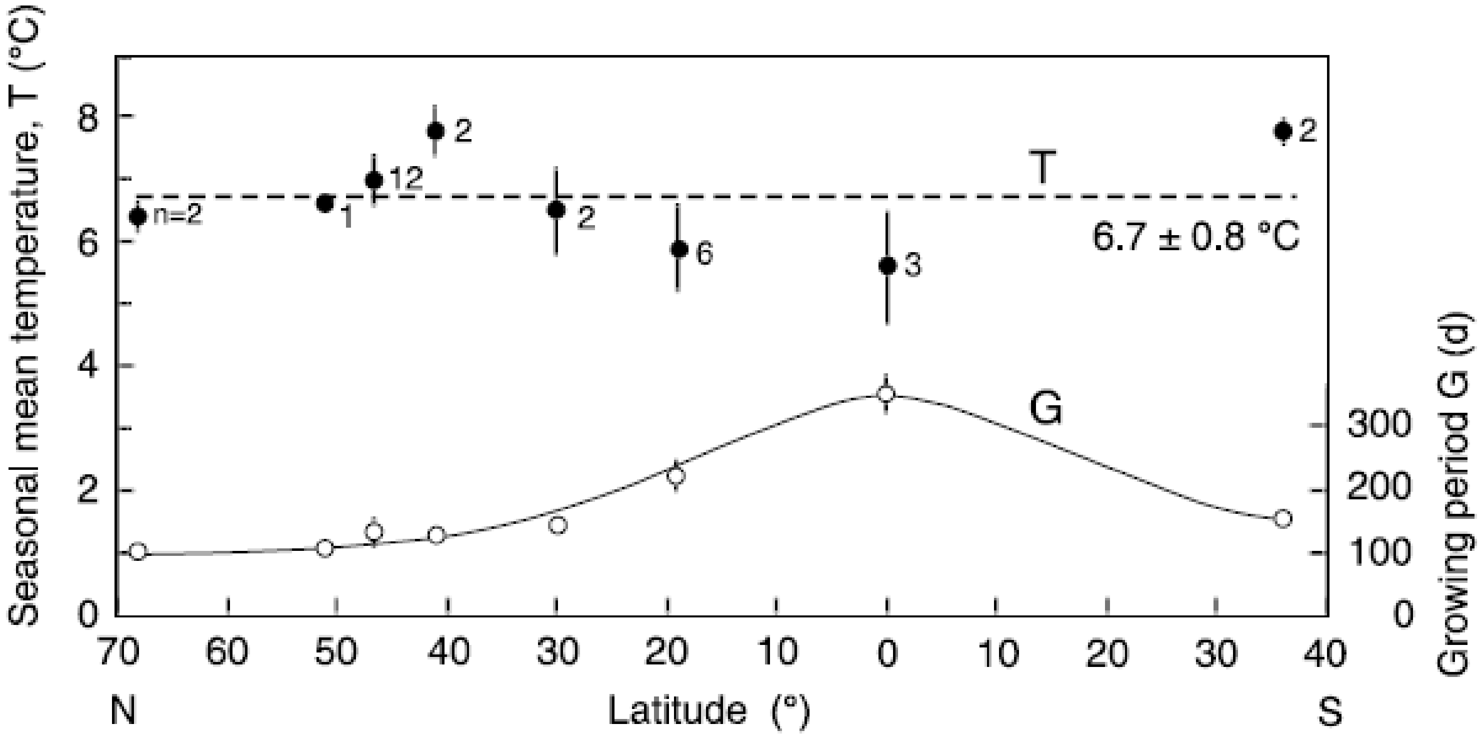
evergreen deciduous herbaceous

Tws constrained treeline:
very strict, not precise



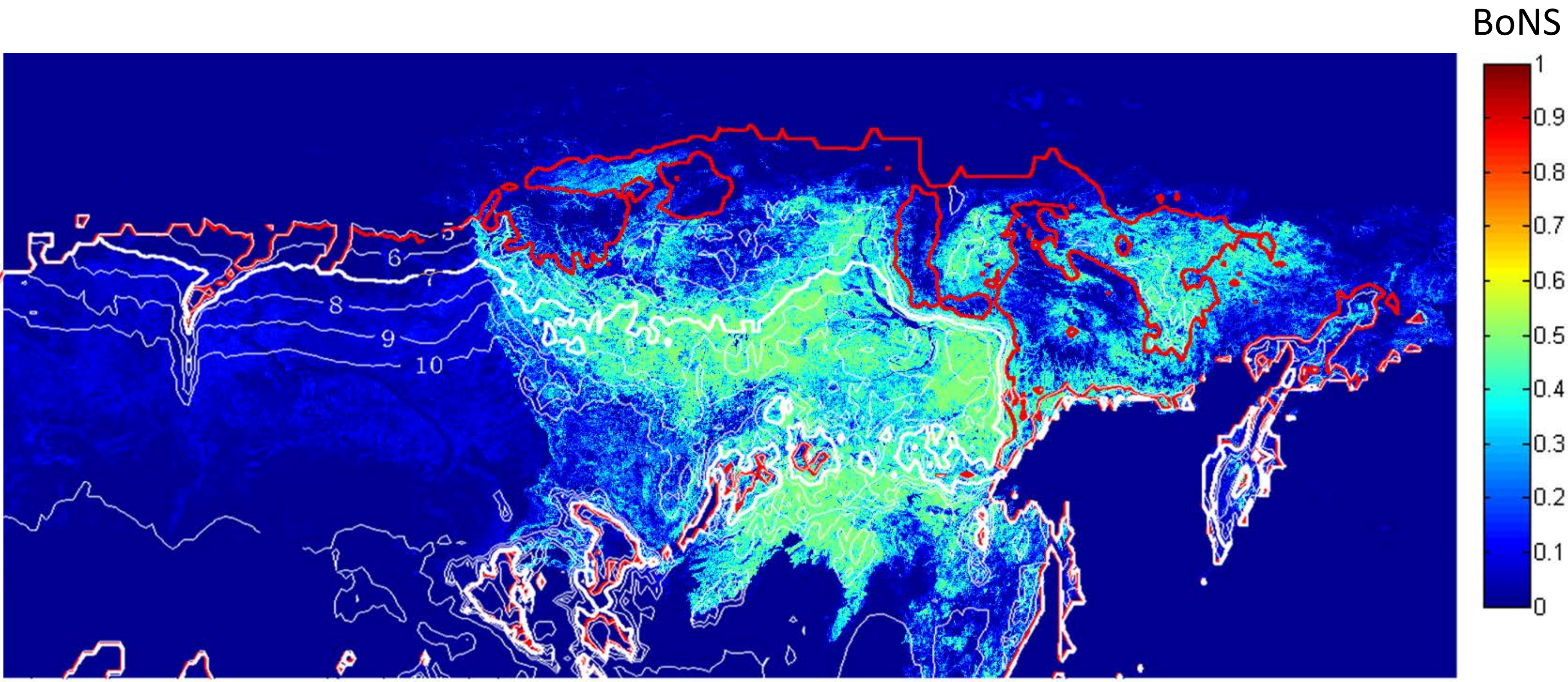
# High altitude treeline temperature character

Seasonal mean root zone (10cm depth) temperature at treeline across latitudes

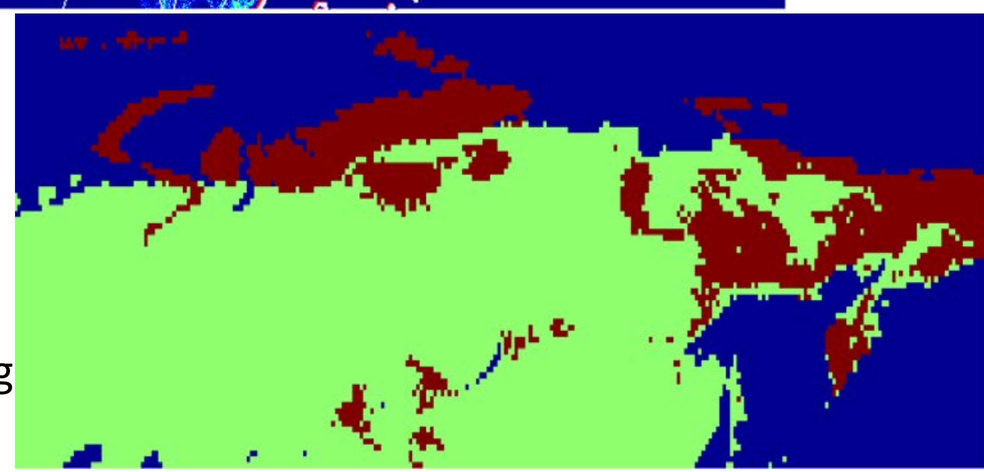



Korner et al., 2004

# A better criterion to constrain boreal treeline



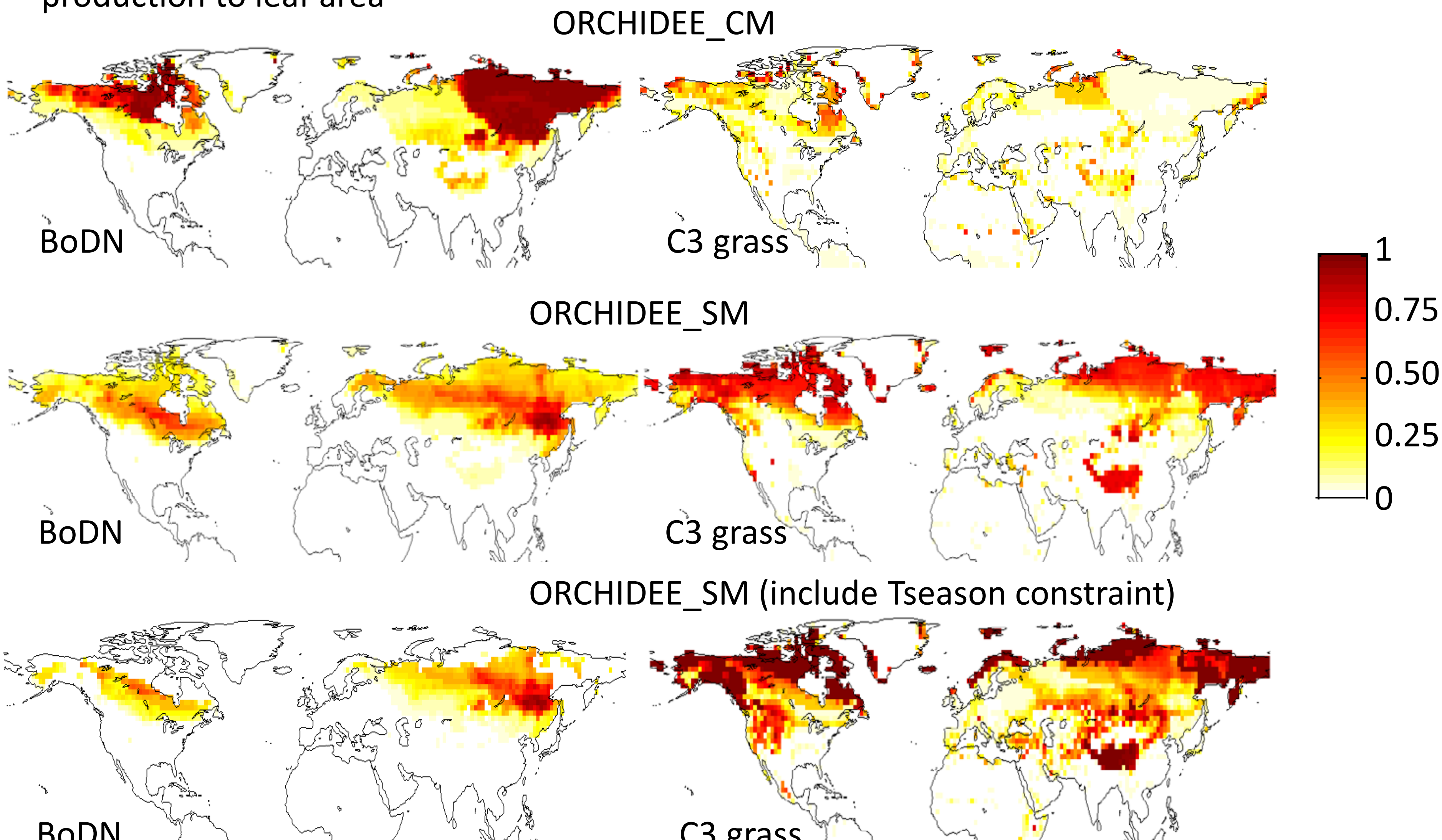

White line: Tws constrained treeline
Red line: Tseason constrained treeline

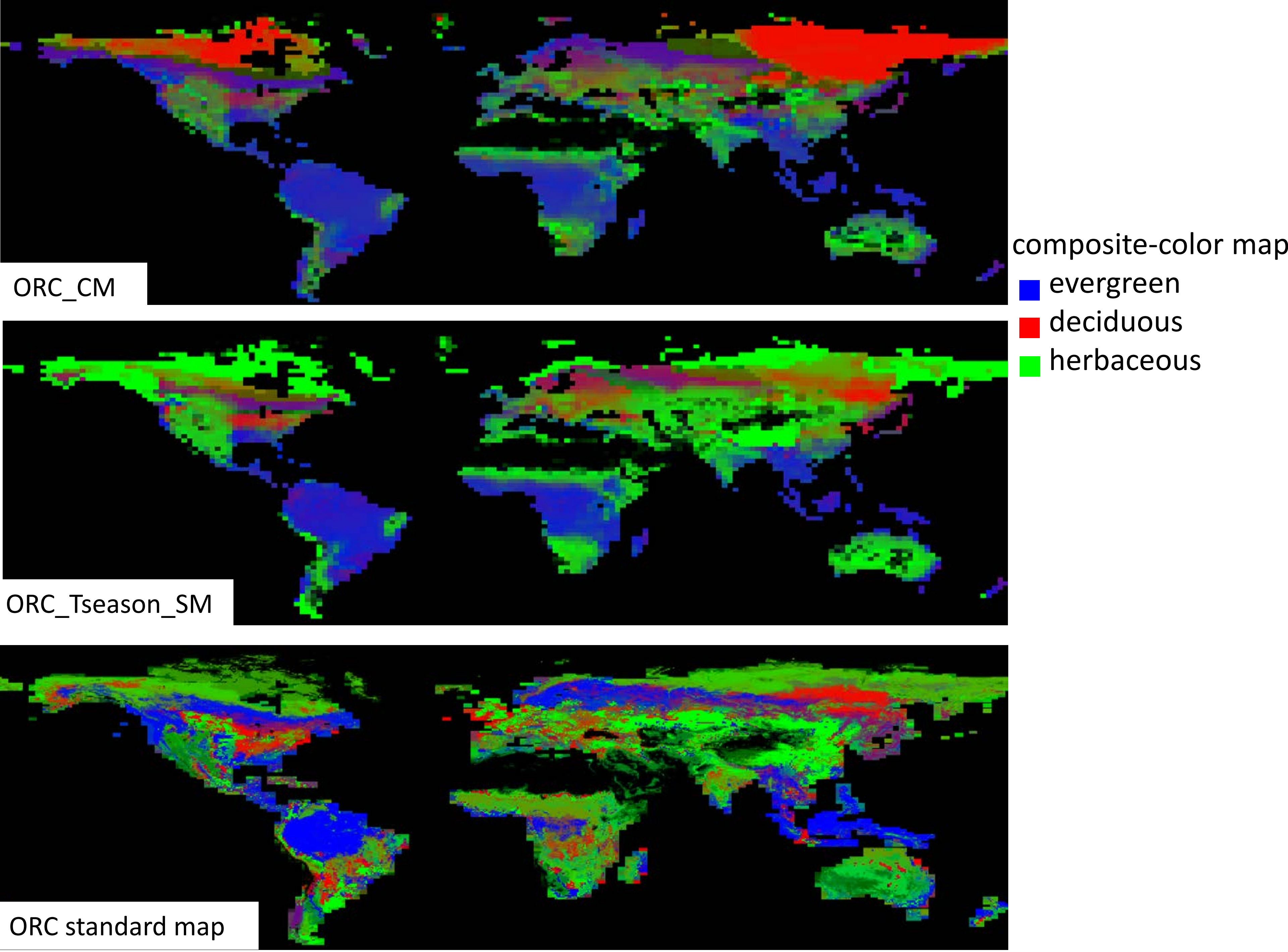


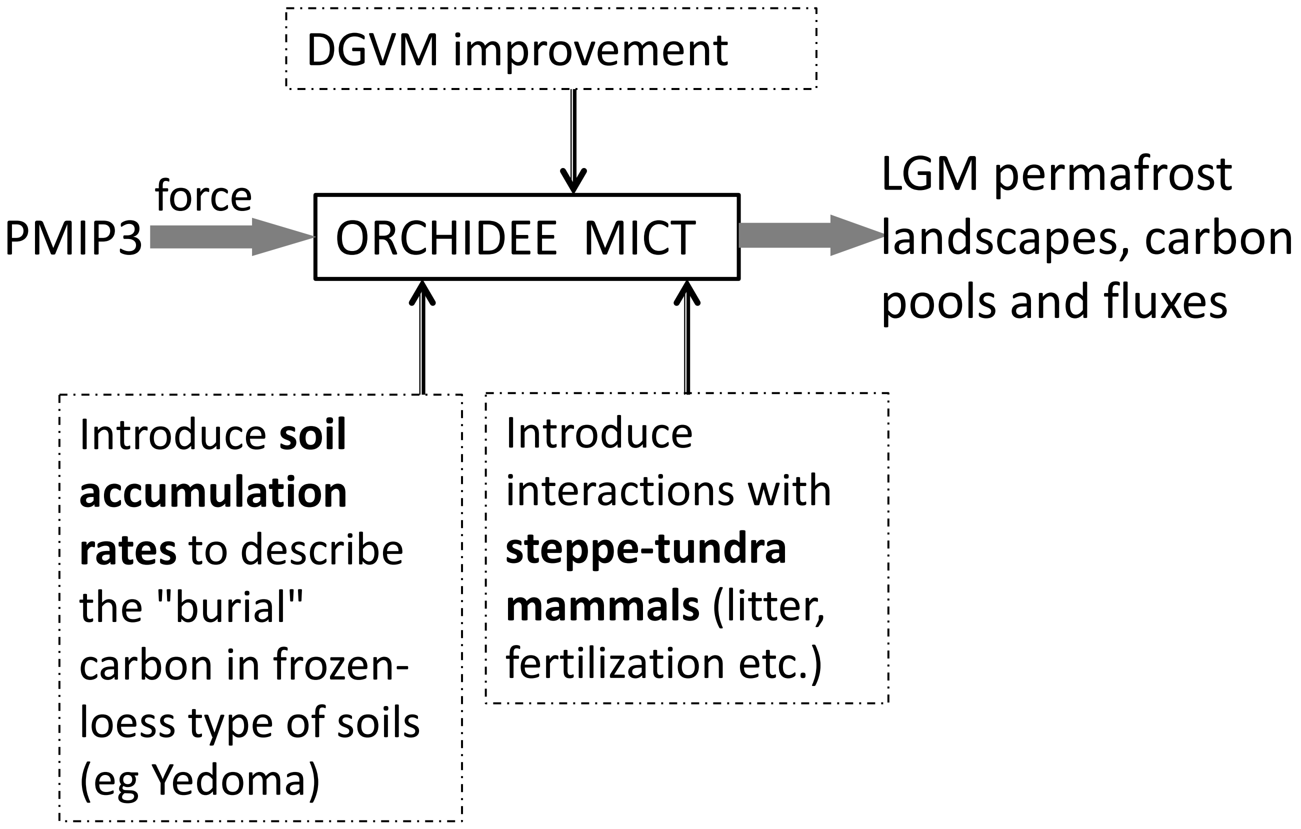
No trees can grow according to Tseason criterion

# Different mortality calculations

1. Constant mortality (CM): inverse of PFT longevity
2. Stress mortality (SM): inversely related to vigour, defined as the ratio of net annual production to leaf area




ORC_CM
ORC_Tseason_SM
ORC standard map
composite-color map
evergreen
deciduous
herbaceous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LGM permafrost landscapes, carbon pools and fluxes
Introduce **soil accumulation rates** to describe the "burial" carbon in frozen-loess type of soils (eg Yedoma)
Introduce interactions with **steppe-tundra mammals** (litter, fertilization etc.)

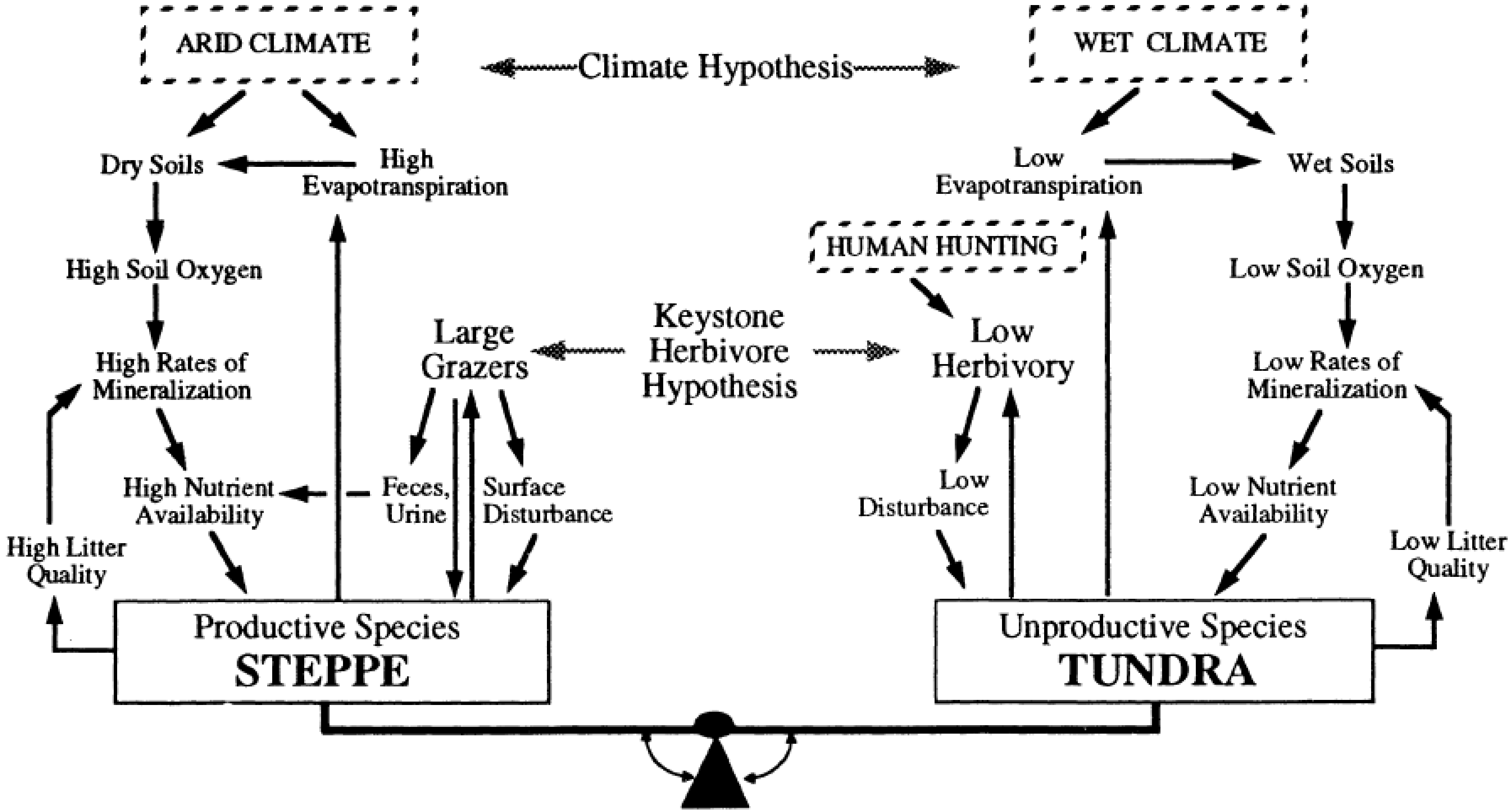
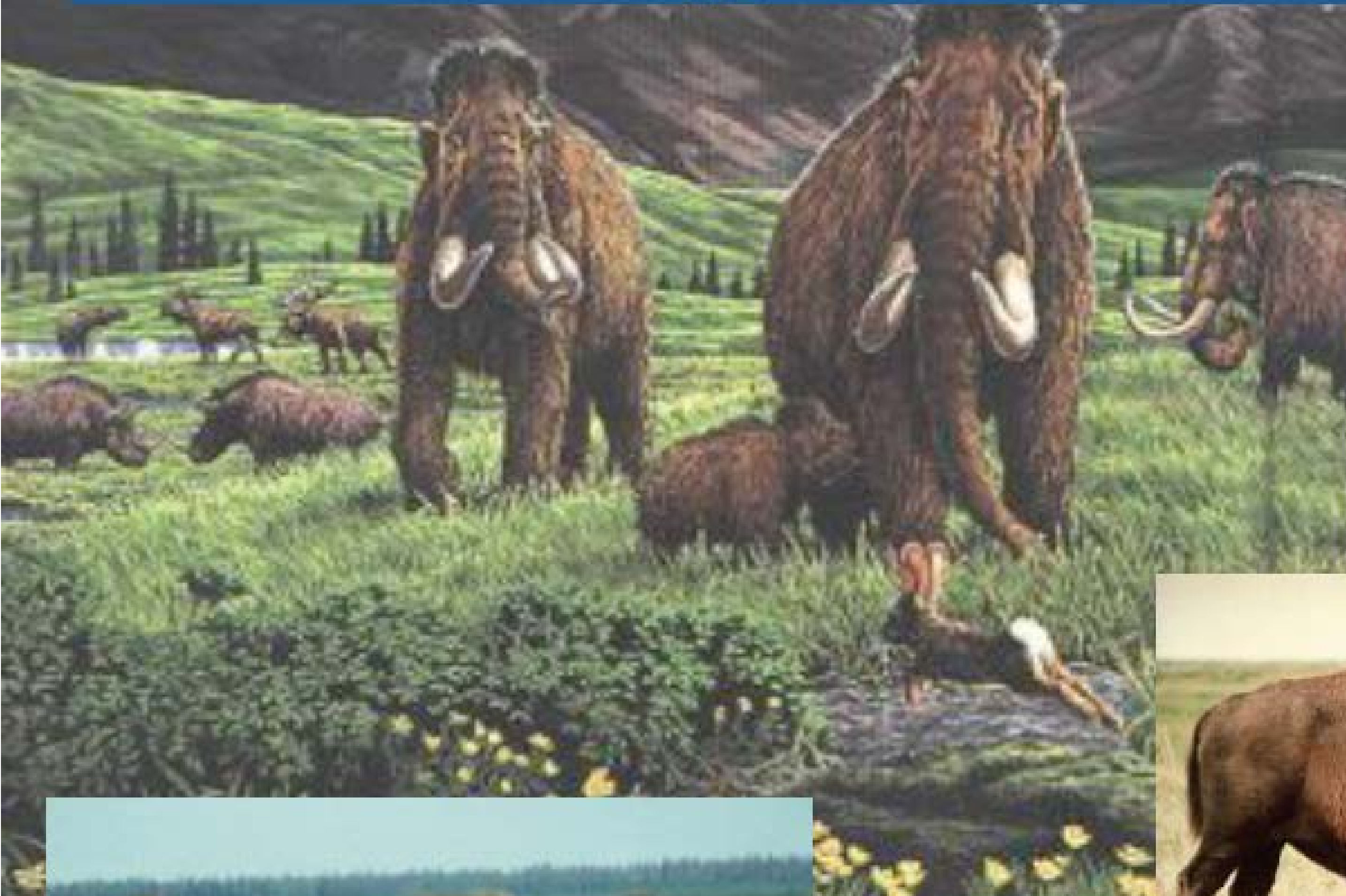



FIG. 1.—Interactions among climatic, vegetation, and soil processes leading to either tundra or steppe. The balance between tundra and steppe can be shifted by changes in either of two independent variables (shown in dashed boxes): climate (climatic hypothesis) or human hunting, which alters the abundance of large grazers (keystone-herbivore hypothesis).

SA. Zimov et al, 1995

# The Mammoth-Steppe was like the African Savanna



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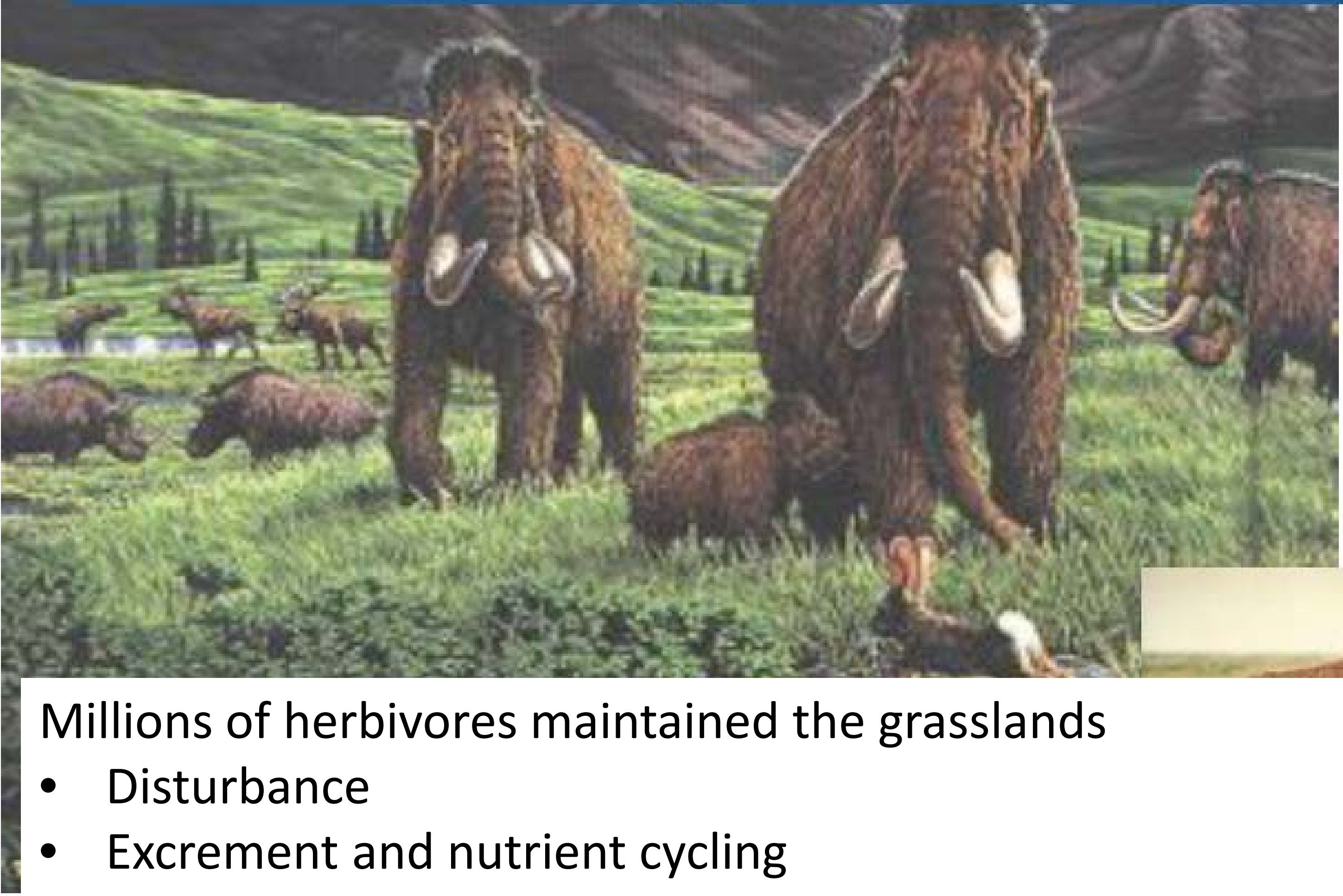
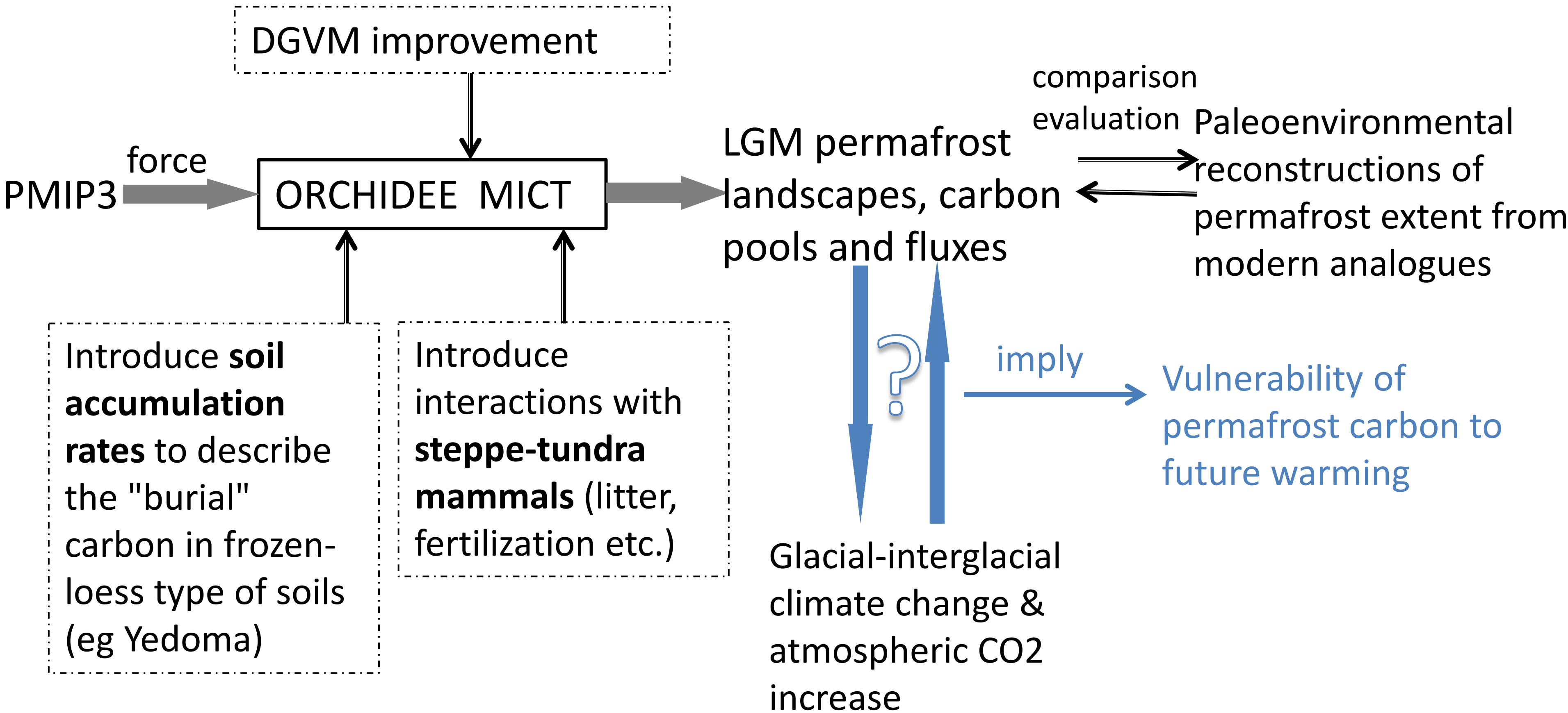


Millions of herbivores maintained the grasslands

- Disturbance
- Excrement and nutrient cycling

Grasslands are unstable without herbivores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?
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Vulnerability of permafrost carbon to future warming
Glacial-interglacial climate change & atmospheric CO2 increase

# Thanks!