Land-Use and Land-Cover Changes and Their Effects on Carbon and Water Cycling in Northern Eurasia and the Arctic

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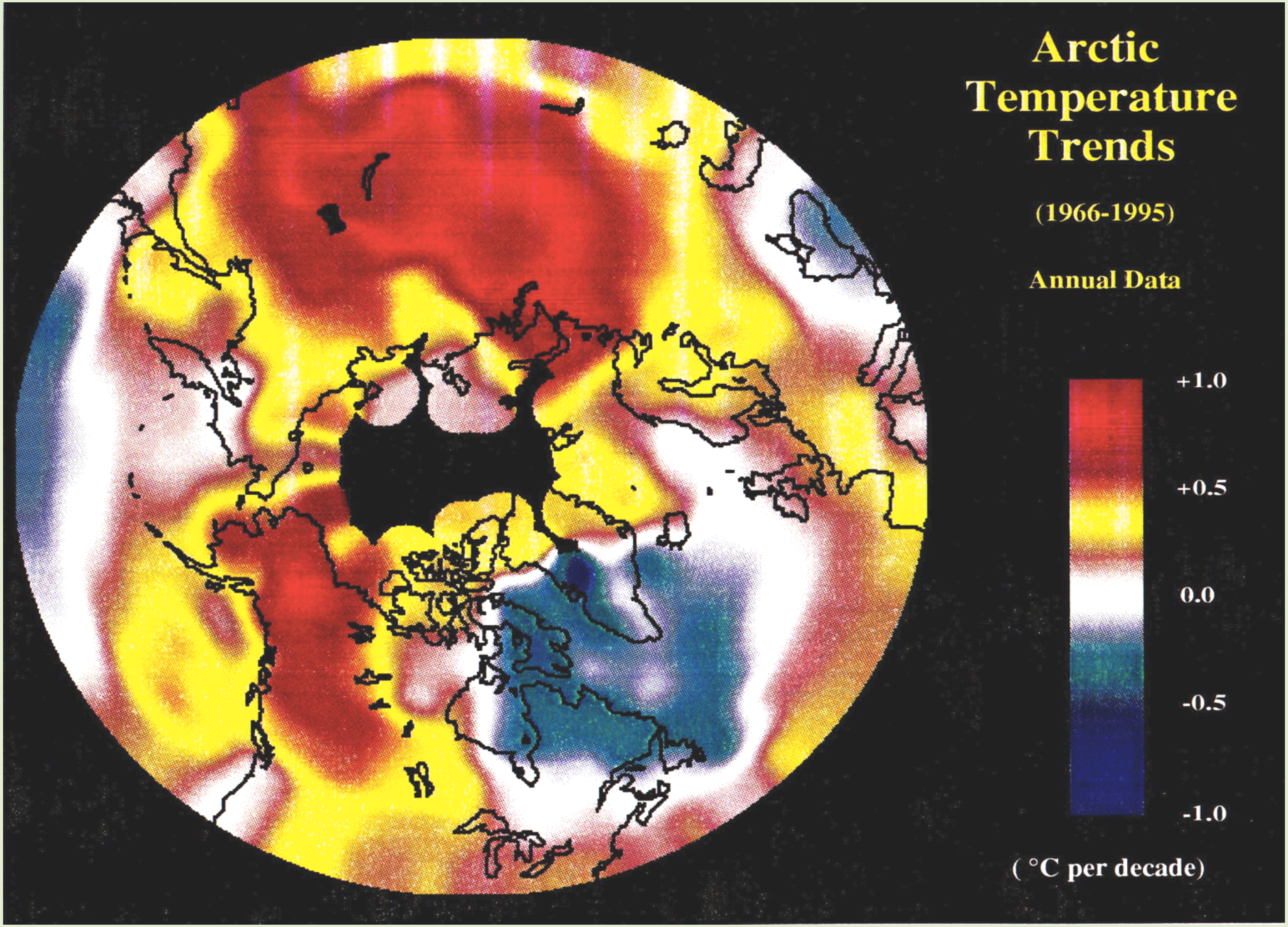
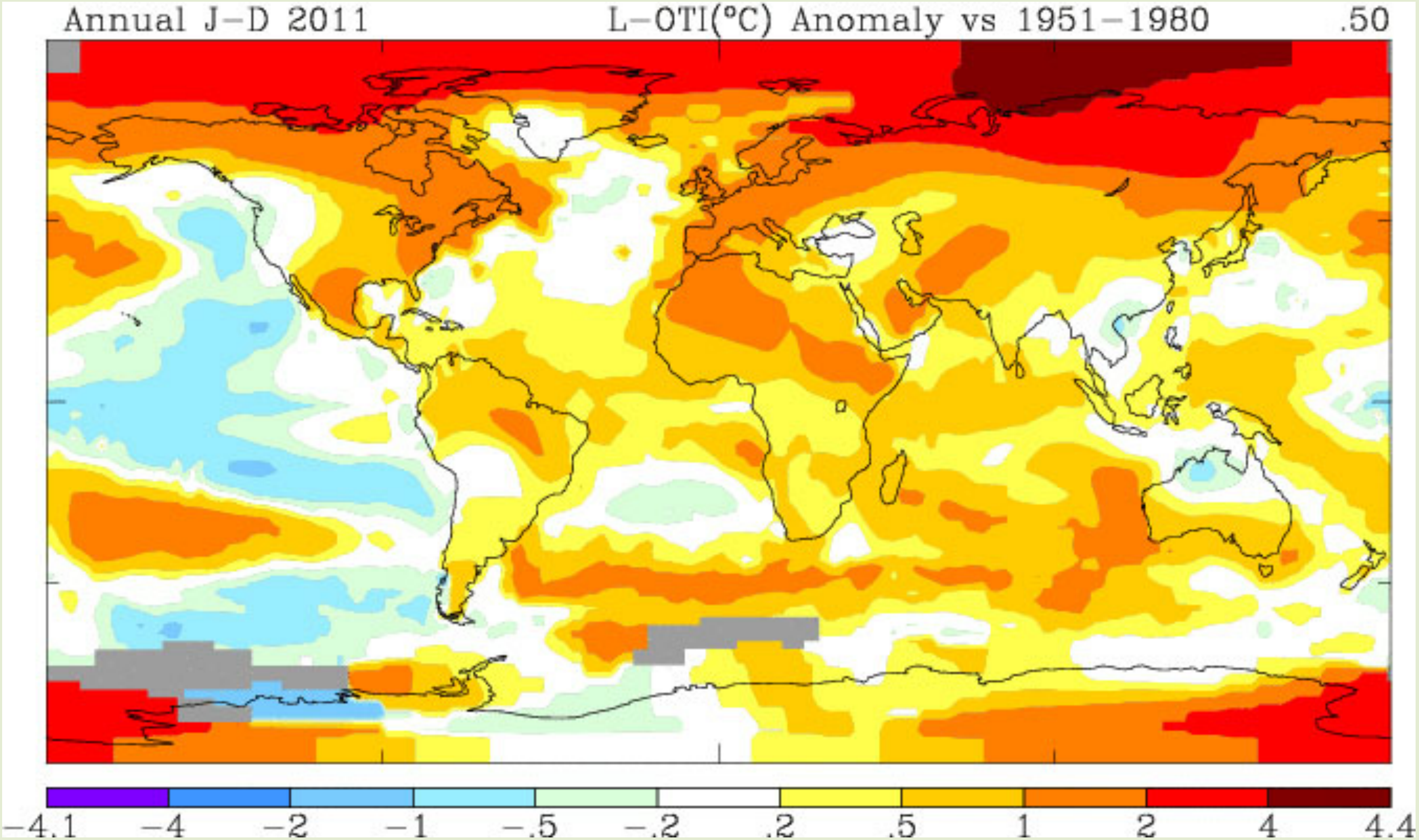


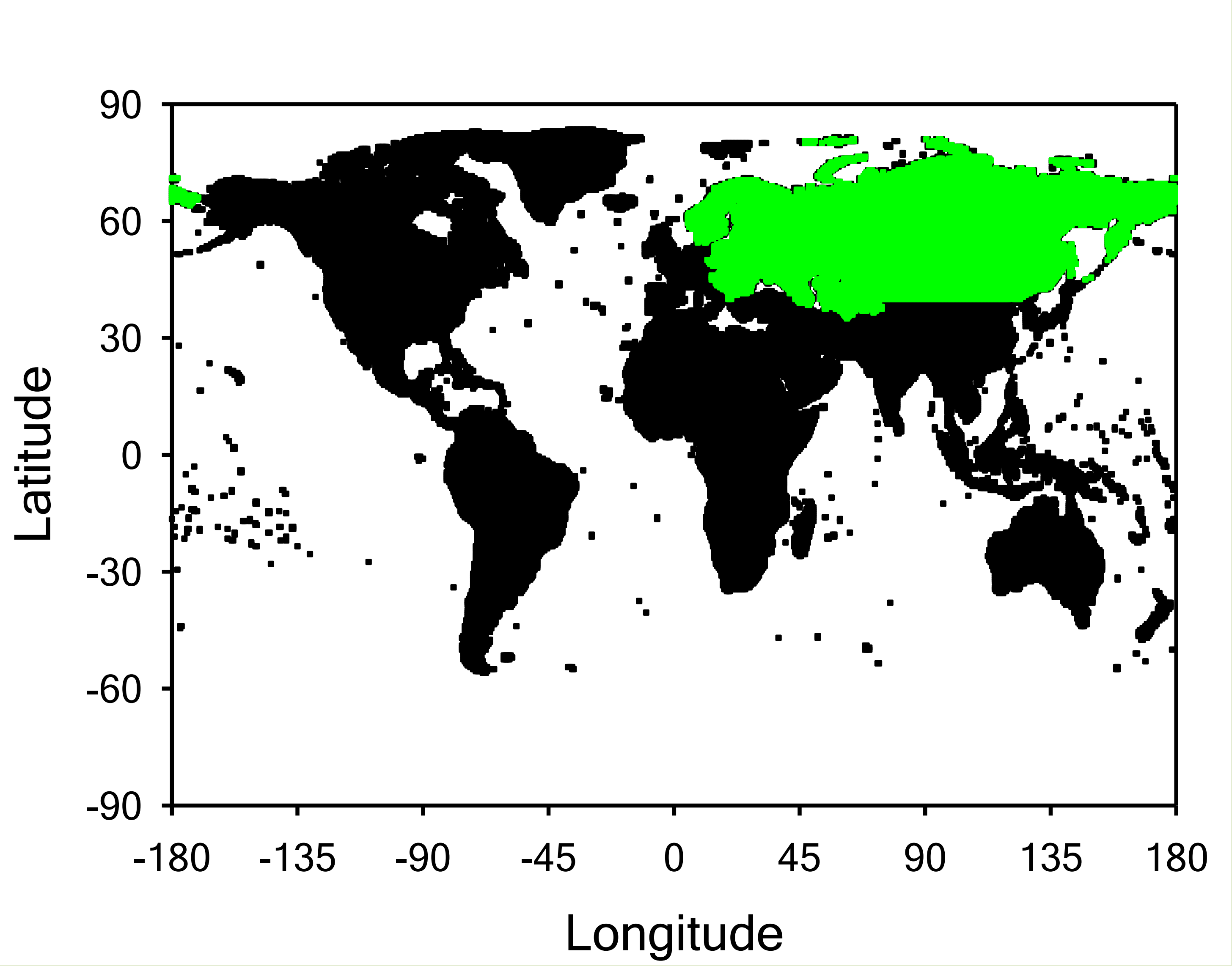
(Serreze et al., 2000, Climatic Change)

Annual global surface temperature anomalies, 2011



The largest and most extensive warming (indicated in shades of red) was concentrated in the Arctic. Source: NASA Goddard Institute for Space Studies.

Northern Eurasia

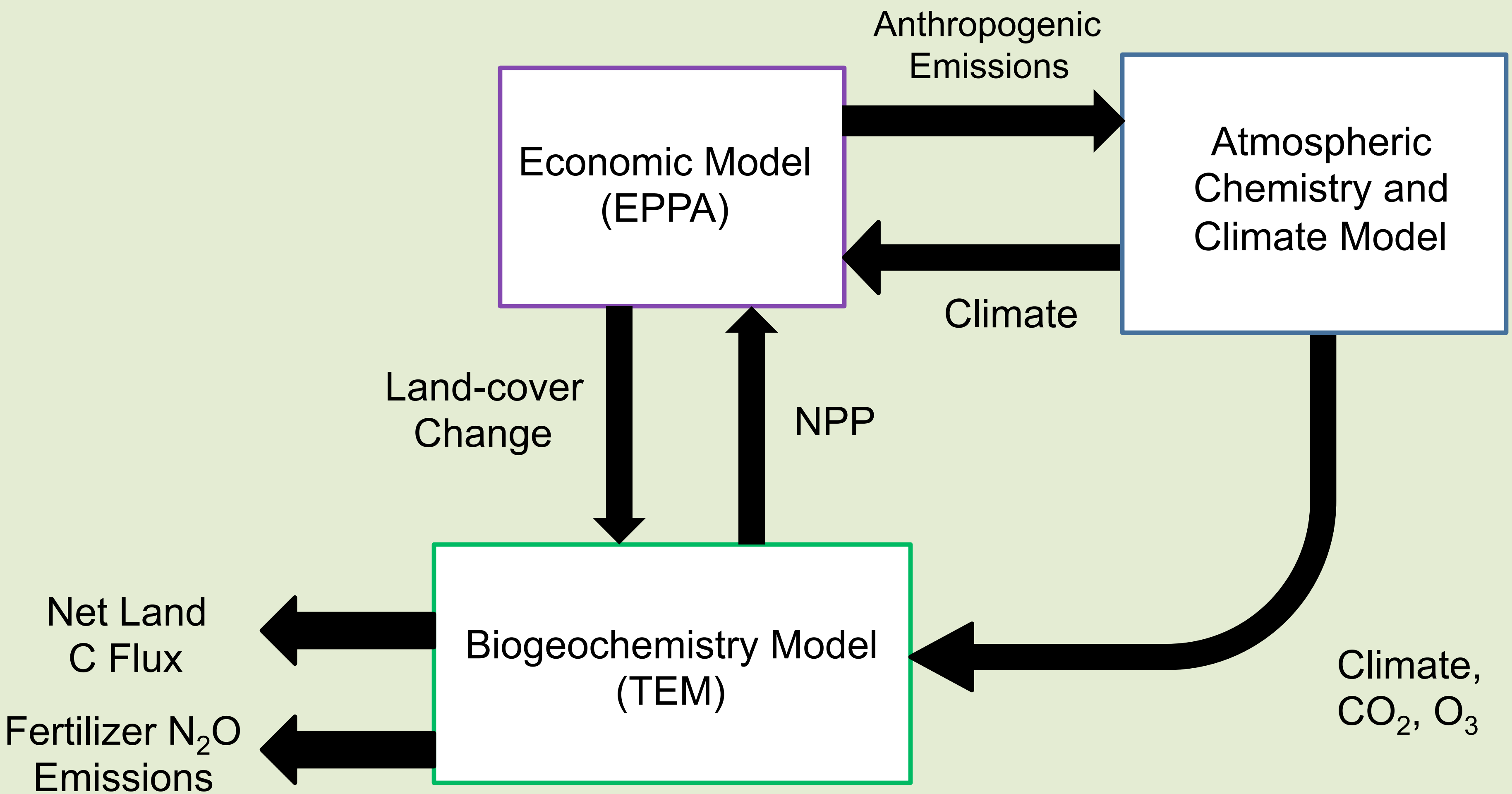


Research Questions

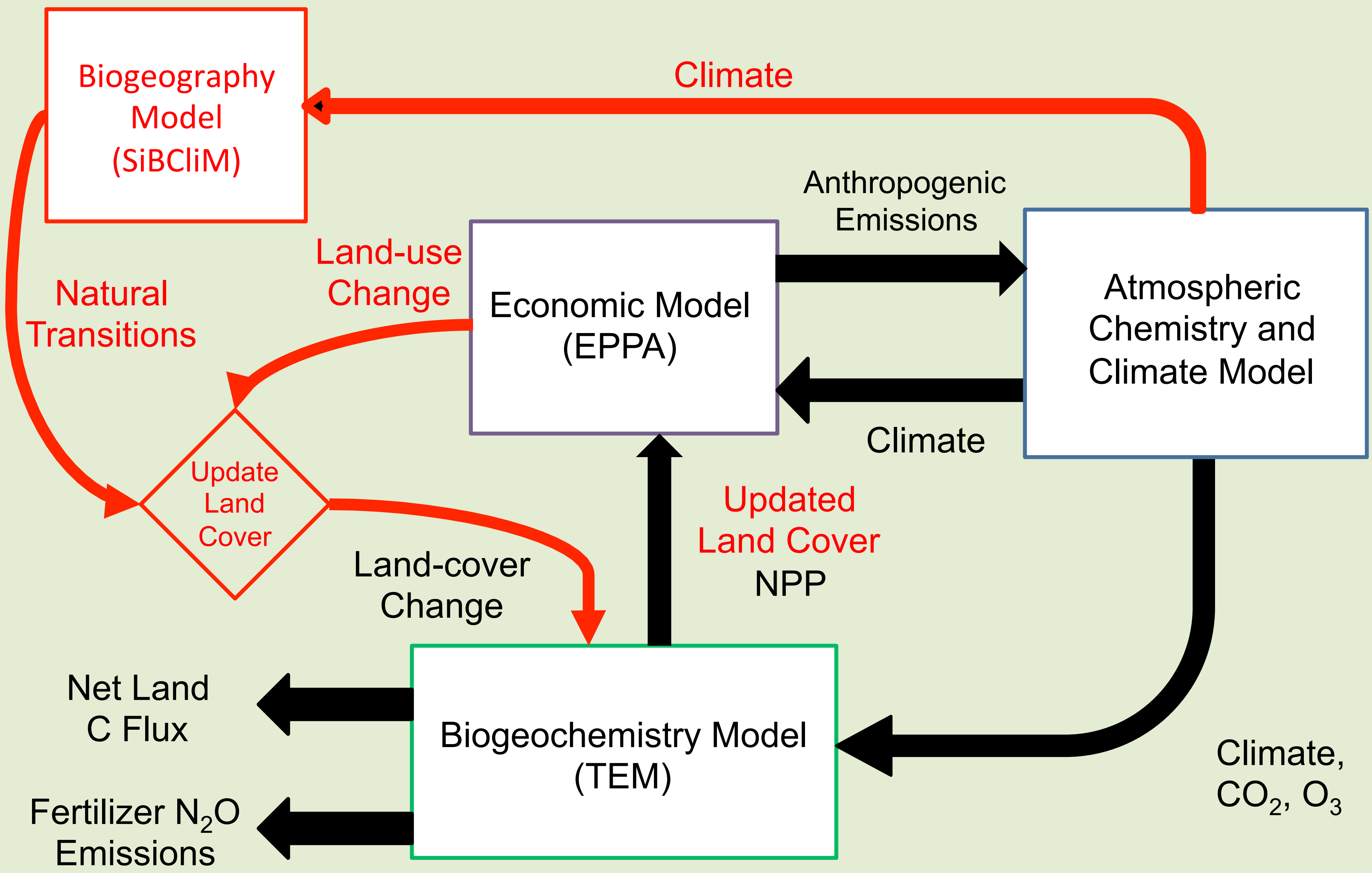
- How the land use and land cover in Northern Eurasia and the Pan-Arctic will be affected by the global natural and anthropogenic changes in this century?

- How the biogeochemical cycles of carbon and water will change in these regions during this century?

General Approach



(*Melillo et al. 2009*)


Biogeography Model (SiBCliM)
Climate
Anthropogenic Emissions
Land-use Change
Natural Transitions
Economic Model (EPPA)
Atmospheric Chemistry and Climate Model
Climate
Update Land Cover
Updated Land Cover
NPP
Land-cover Change
Net Land C Flux
Biogeochemistry Model (TEM)
Climate, CO_2, O_3
Fertilizer N_2O Emissions

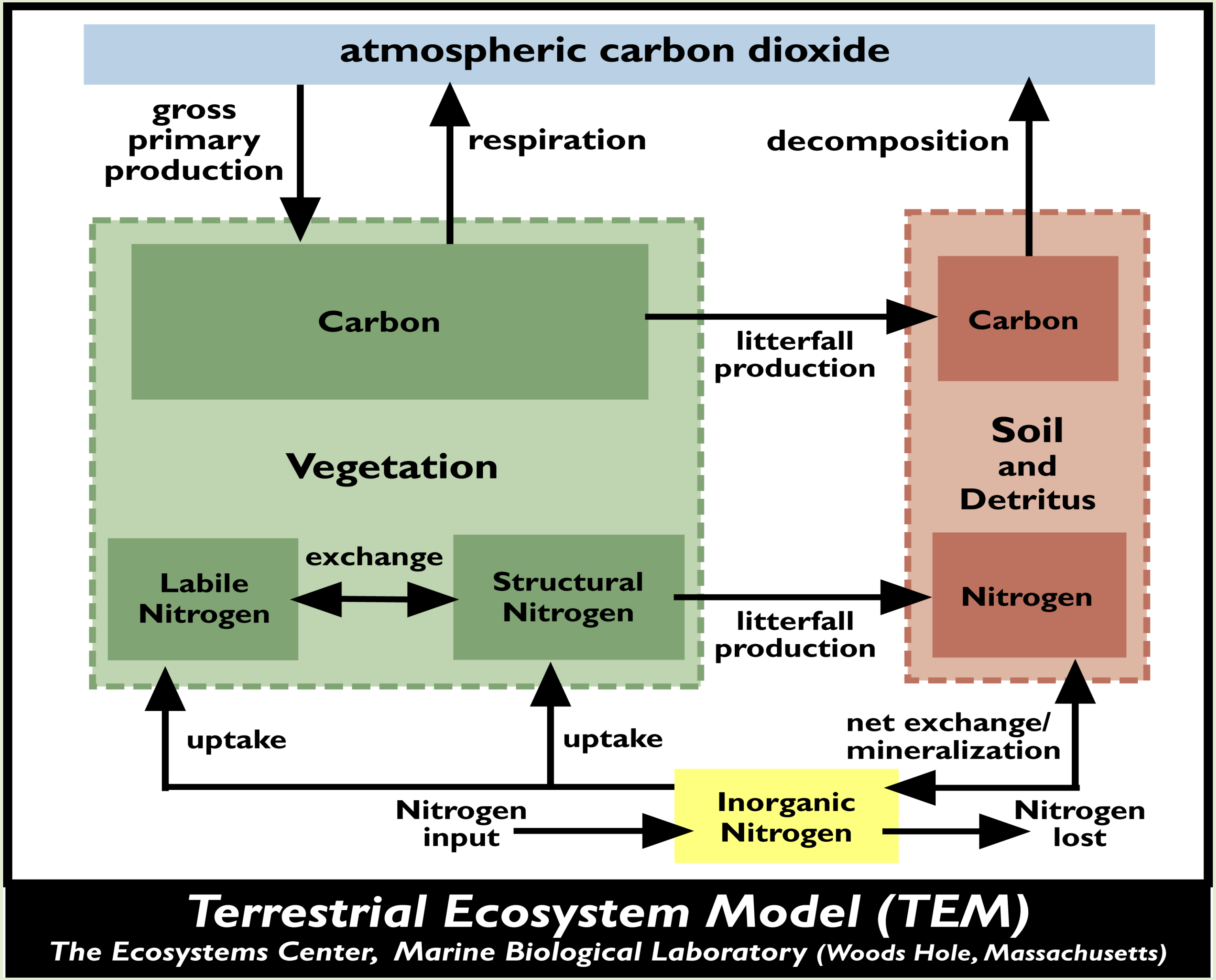
Major Features of EPPA and TEM

EPPA

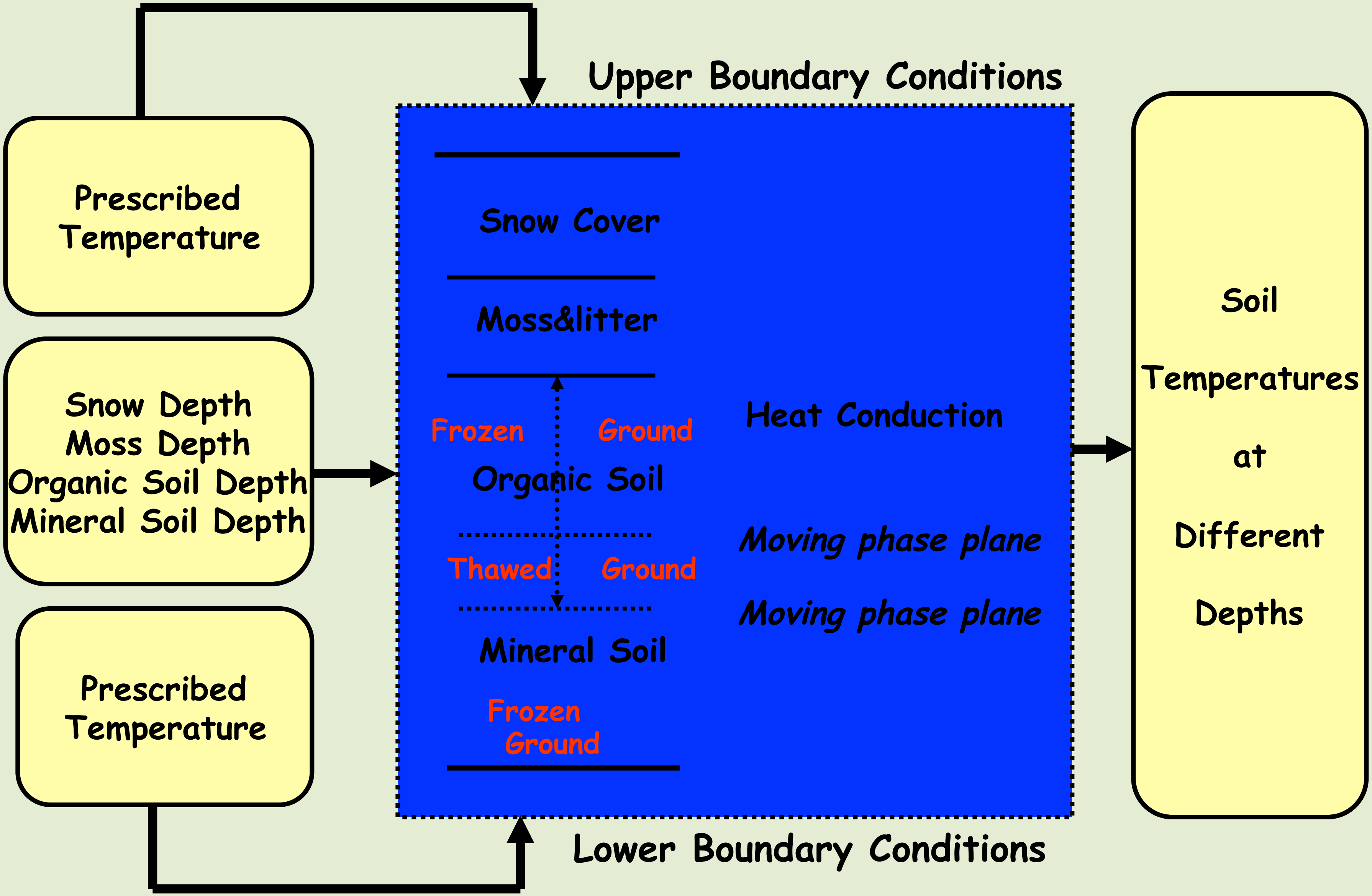
- Multiple regions - Globe divided into 16 economic regions
- Multiple fuels - Fossil, Nuclear, Wind, Solar, Biomass, Biofuels
- Multiple sectors – Industry, Transportation, Households, Agriculture, Forestry

TEM

- Cycling of carbon, nitrogen, and water
- Spatial information on soils, vegetation, climate, elevation, atmospheric chemistry (carbon dioxide, tropospheric ozone)
- Coupled with permafrost and fire dynamics


atmospheric carbon dioxide
gross primary production
respiration
decomposition
Carbon
litterfall production
Carbon
Soil and Detritus
Vegetation
Labile Nitrogen
exchange
Structural Nitrogen
litterfall production
Nitrogen
uptake
uptake
net exchange/ mineralization
Nitrogen input
Inorganic Nitrogen
Nitrogen lost
Terrestrial Ecosystem Model (TEM)
The Ecosystems Center, Marine Biological Laboratory (Woods Hole, Massachusetts)

Soil Thermal Model



(Zhuang et al., 2001)

Major Features of SiBCliM

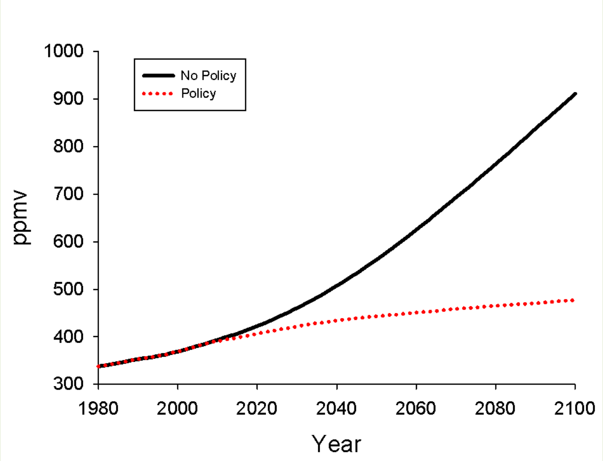
- A static envelope-type large-scale bioclimatic model based on the vegetation classification of Shumilova (1962)
- SiBCliM uses three bioclimatic indices: (1) growing degree-days above 5^0C; (2) negative degree-days below 0^0C; and (3) an annual moisture index (ratio of growing degree days above 5^oC to annual precipitation)
- SiBCliM has been updated to include permafrost (the active layer depth)

Fire & Vegetation Shifts

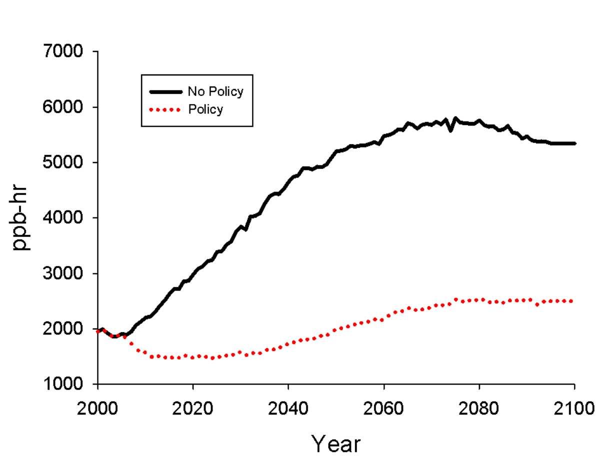
New Vegetation Type	Old Vegetation Type										
	Tundra	Needle-leaf Evergreen Forest-Tundra	Needle-leaf Deciduous Forest-Tundra	Needle-leaf Evergreen Taiga	Needle-leaf Deciduous Taiga	Boreal Birch Subtaiga/ Temperate Broadleaf	Temperate Mixed Forest	Forest-Steppe Boreal	Forest-Steppe Temperate	Steppe Boreal, Temperate	Semi-Desert/ Desert
Tundra	No Change	Fire	Fire	Fire	Fire	Fire	Fire	Fire	Fire	Fire	Succession
Needle-leaf Evergreen Forest-Tundra	Succession	No Change	Succession	Fire	Fire	Fire	Fire	Succession	Succession	Succession	Succession
Needle-leaf Deciduous Forest-Tundra	Succession	Fire	No Change	Fire	Fire	Fire	Fire	Succession	Succession	Succession	Succession
Needle-leaf Evergreen Taiga	Succession	Succession	Succession	No Change	Succession	Succession	Succession	Succession	Succession	Succession	Succession
Needle-leaf Deciduous Taiga	Succession	Fire	Succession	Fire	No Change	Fire	Fire	Succession	Succession	Succession	Succession
Boreal Birch Subtaiga/ Temperate Broadleaf	Succession	Fire	Fire	Fire	Fire	No Change	Fire	Succession	Succession	Succession	Succession
Temperate Mixed Forest	Succession	Succession	Succession	Fire	Fire	Succession	No Change	Succession	Succession	Succession	Succession
Forest-Steppe Boreal	Fire	Fire	Fire	Fire	Fire	Fire	Fire	No Change	Succession	Succession	Succession
Forest-Steppe Temperate	Fire	Fire	Fire	Fire	Fire	Fire	Fire	Succession	No Change	Succession	Succession
Steppe Boreal, Temperate	Fire	Fire	Fire	Fire	Fire	Fire	Fire	Fire	Fire	No Change	Succession
Semi-Desert/ Desert	Fire	Fire	Fire	Fire	Fire	Fire	Fire	Fire	Fire	Fire	No Change

Fire assumed to be associated with 62 vegetation transitions!

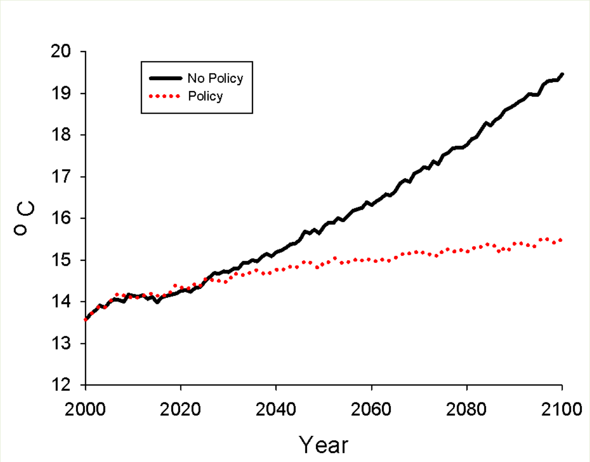
a) Atmospheric CO_2 concentrations



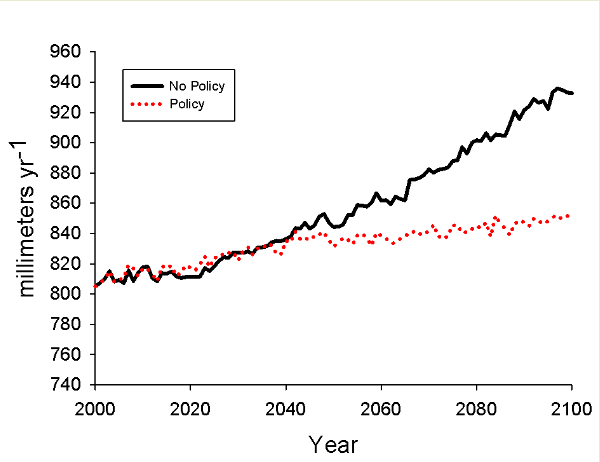
b) AOT40 ozone index



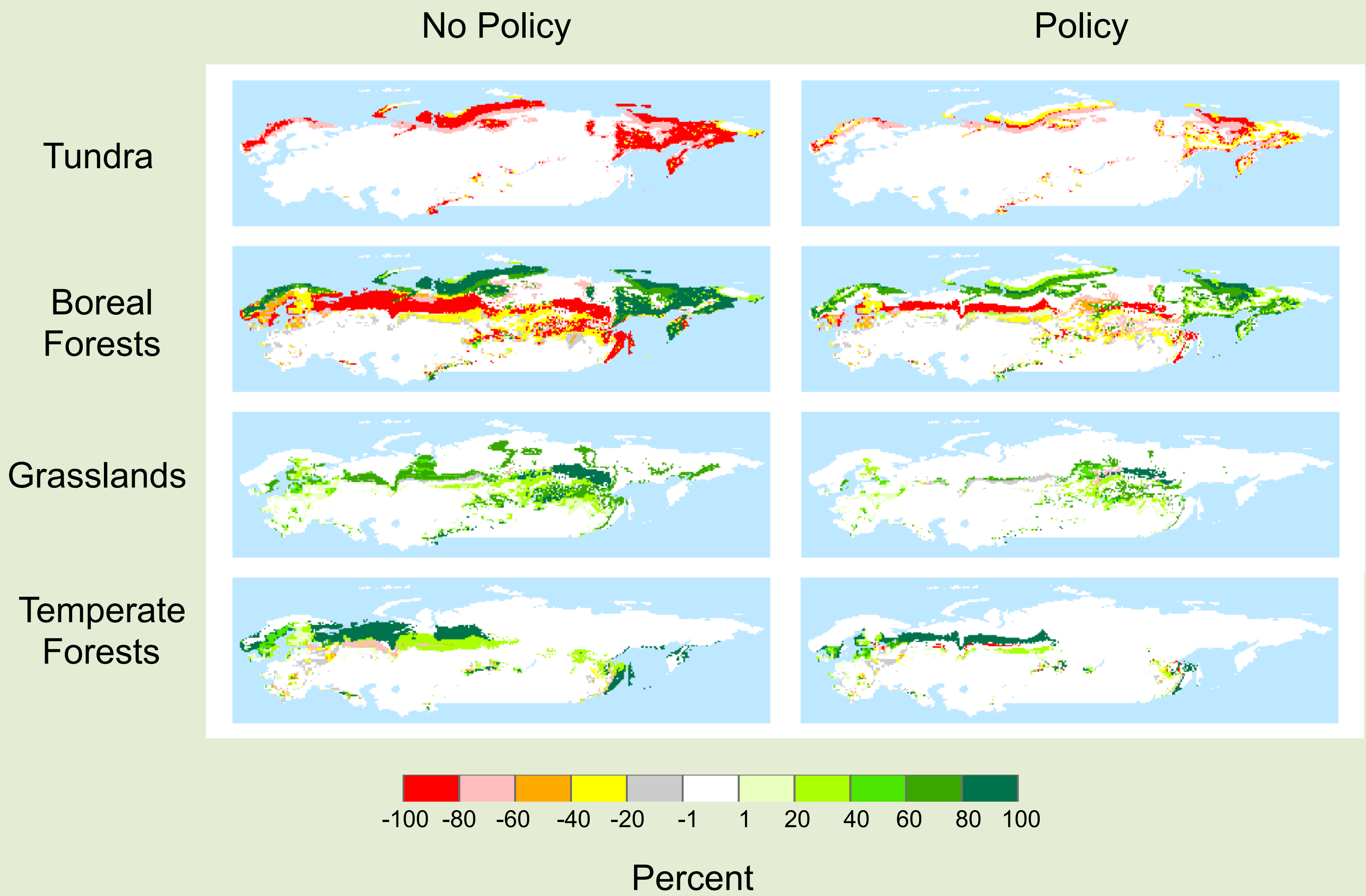
c) Global mean air temperature



d) Global mean precipitation



Shifts of Natural Vegetation in Northern Eurasia (2000-2100)



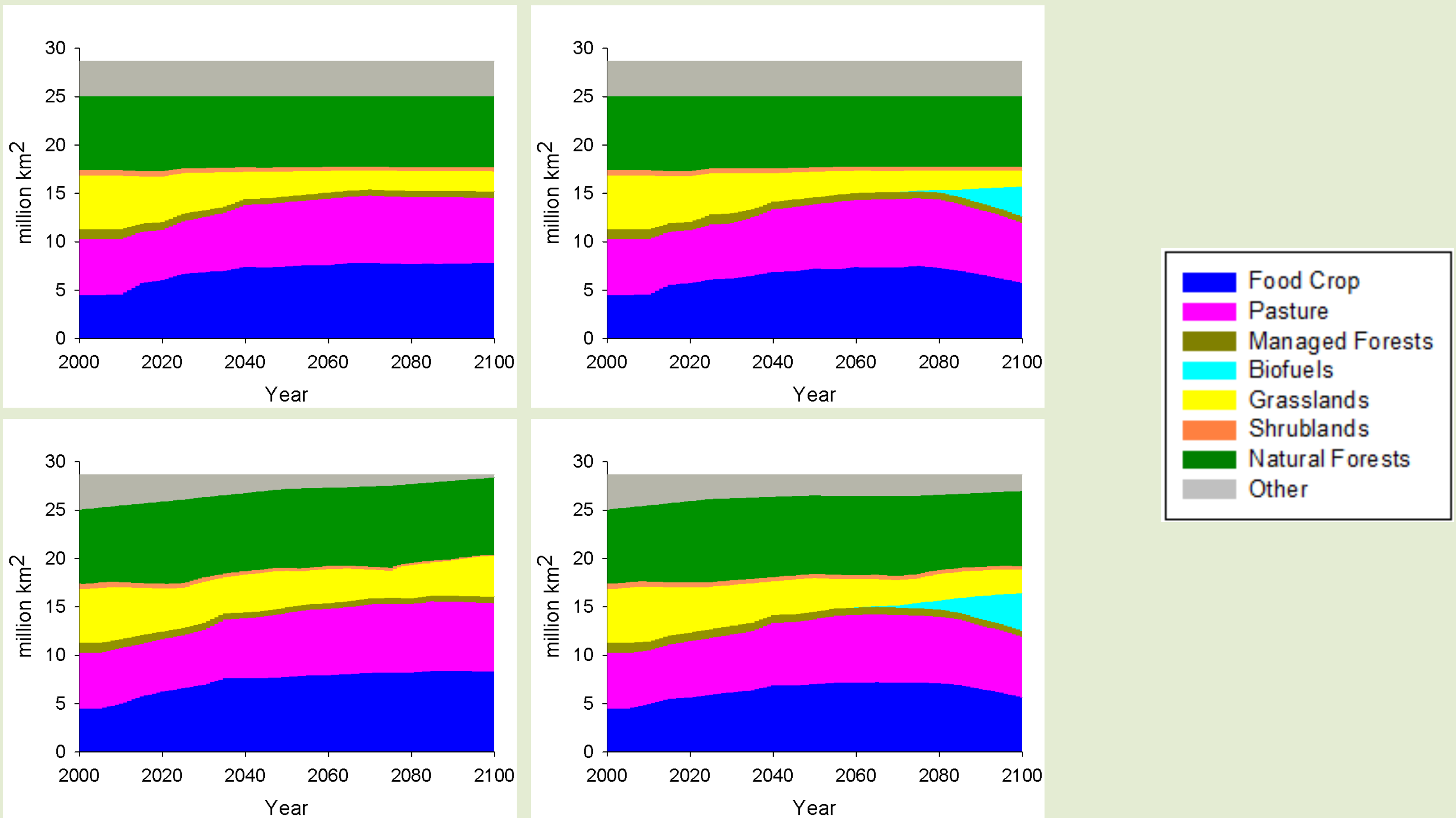
Land-cover and Land-use Change in Northern Eurasia 2000-2100

No Policy

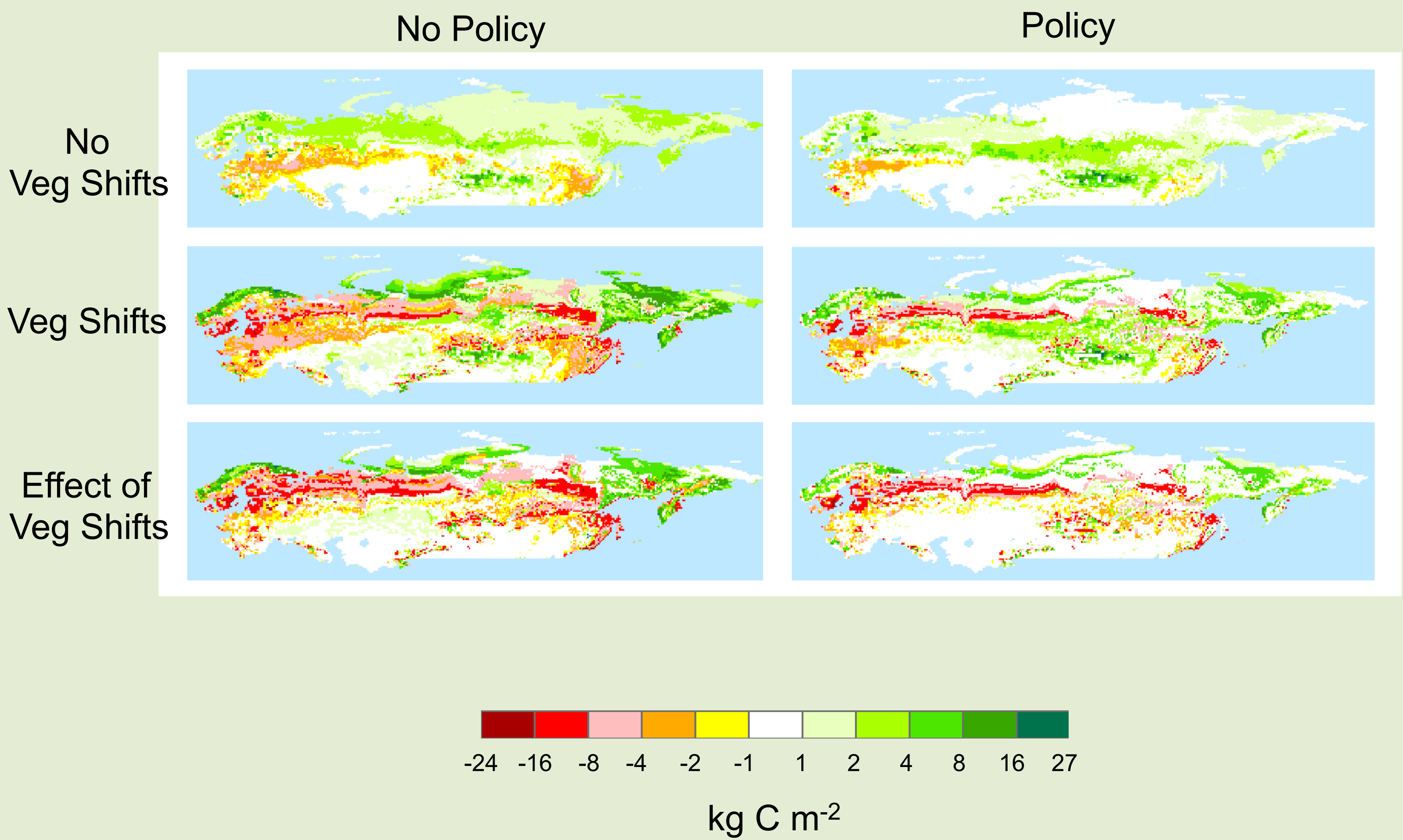
Policy

No Veg Shifts

Veg Shifts



Distribution of Land Carbon Gain/Loss in Northern Eurasia
2000-2100

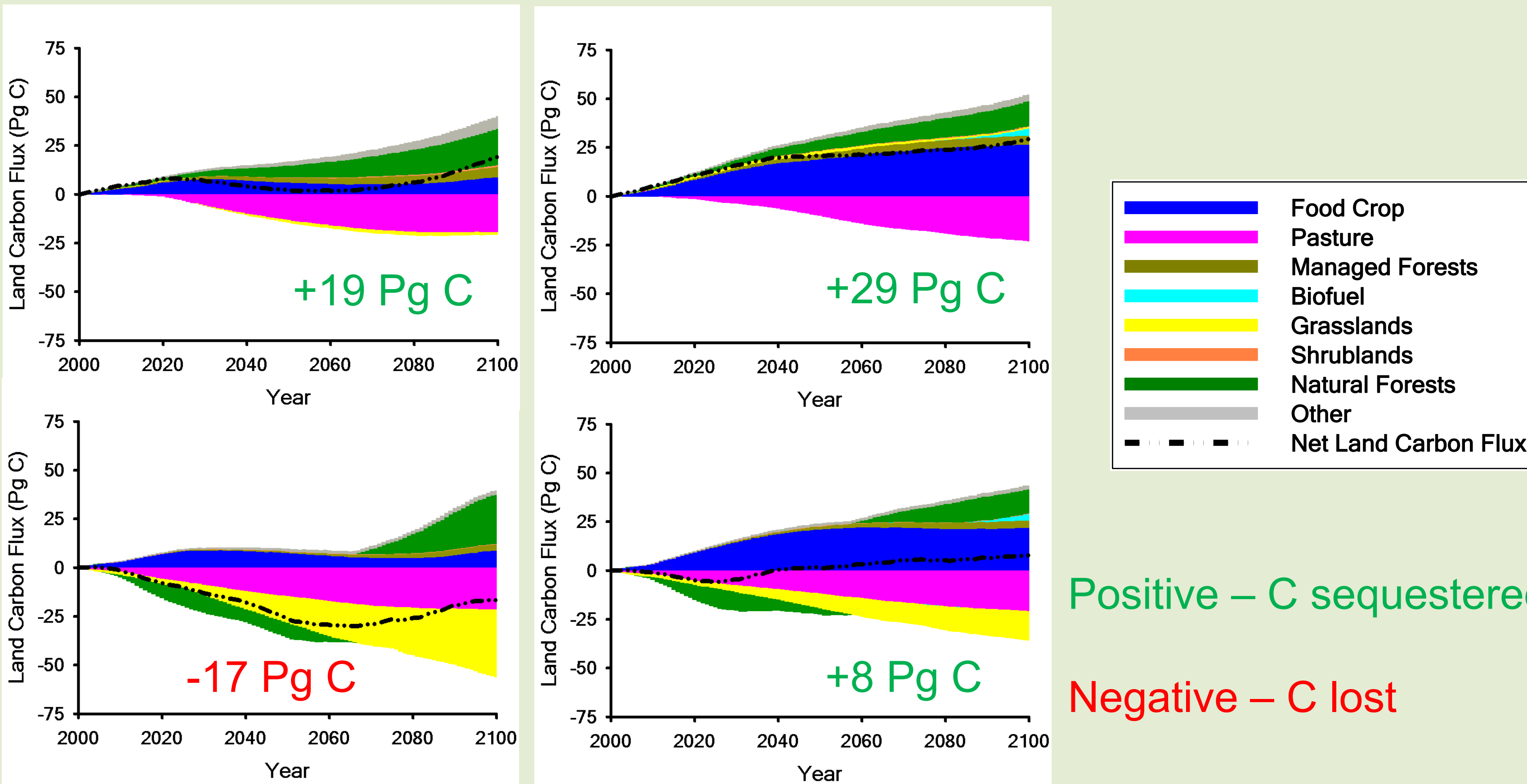


Net Land Carbon Fluxes in Northern Eurasia

No Policy | Policy

No Veg Shifts

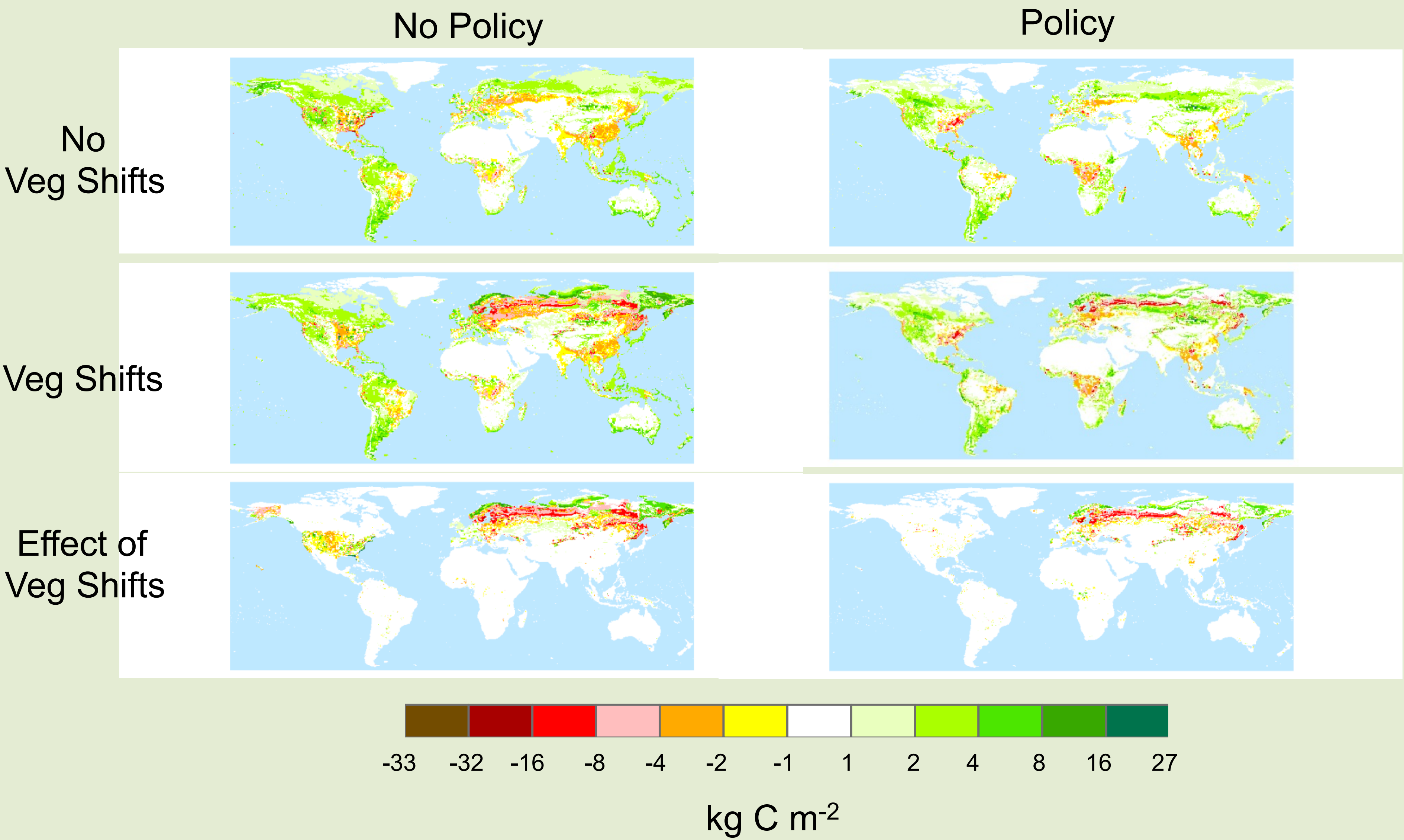
Veg Shifts



Positive – C sequestered

Negative – C lost

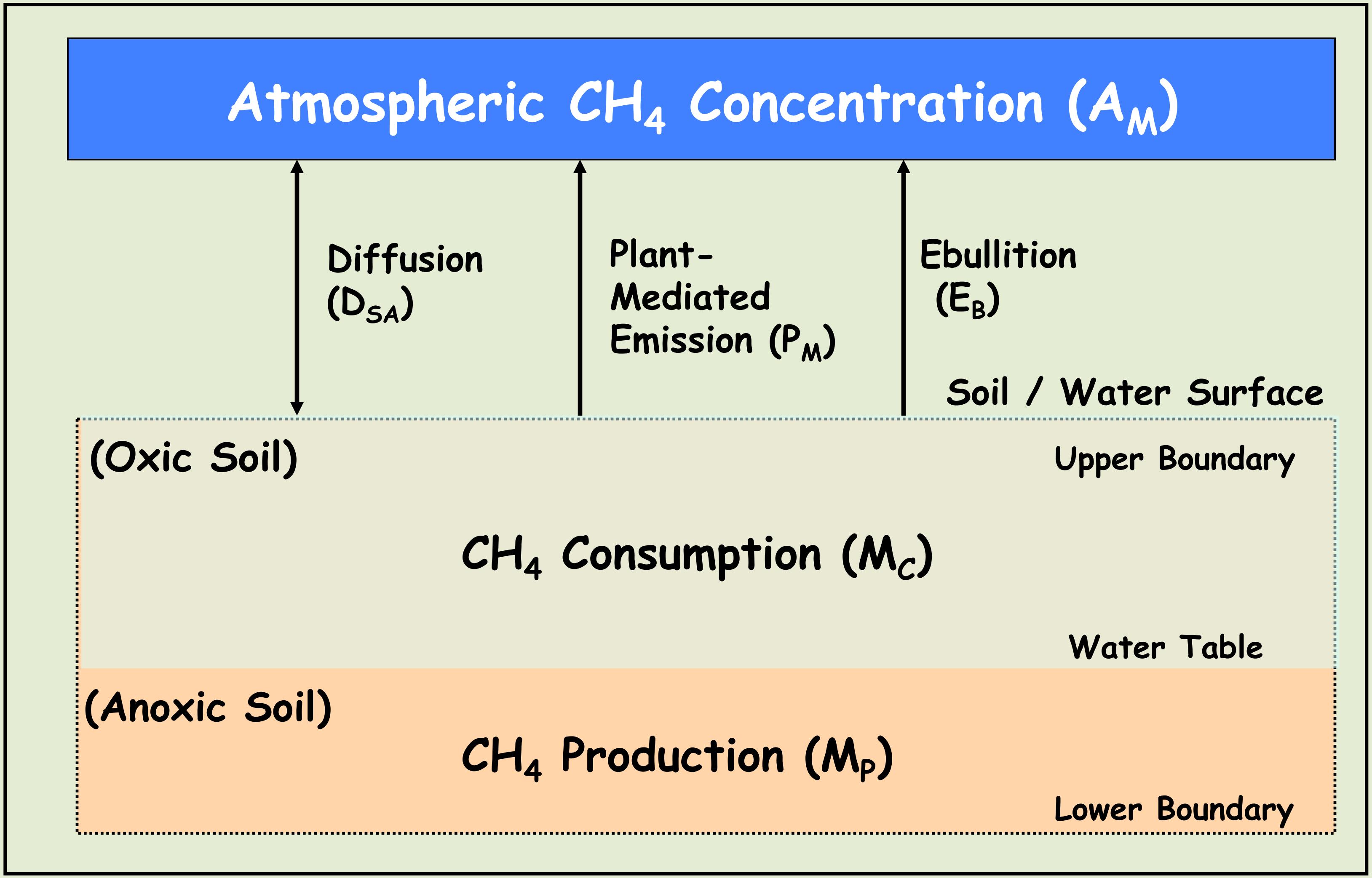
Distribution of Land Carbon Gain/Loss across Globe
2000-2100



Summary 1

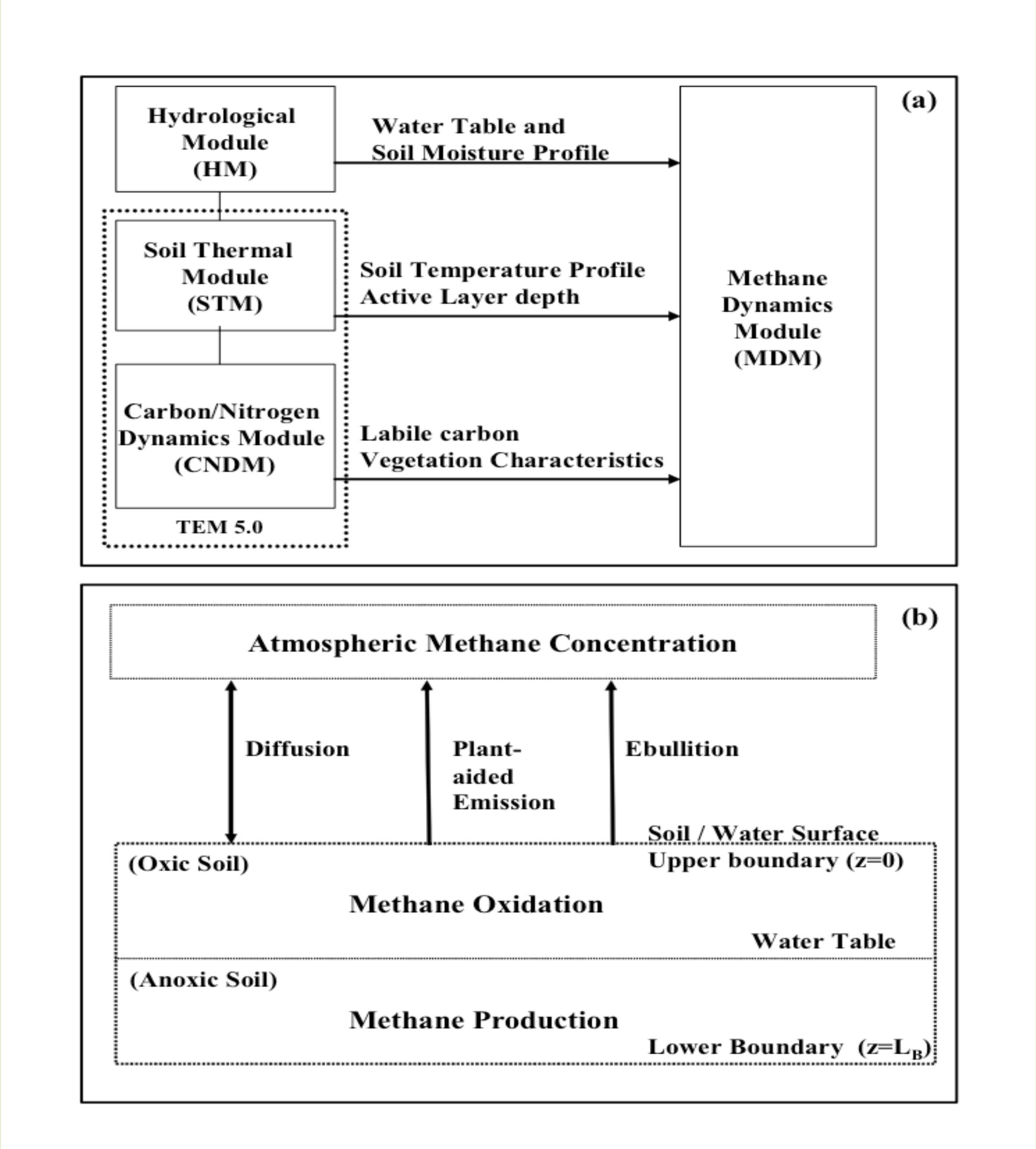
- **Climate-induced vegetation shifts in Northern Eurasia**
  - **Decreases area of tundra and boreal forests**
  - **Increases area of temperate forests and grasslands**
- **Impacts of vegetation shifts on global managed lands**
  - **Allows ~6% expansion of food crops and pastures with No Policy**
  - **Allows ~25% expansion of biofuels with Policy**
- **Impacts of vegetation shifts on global terrestrial carbon fluxes**
  - **Enhances carbon emissions from some areas and enhances carbon sequestration in other areas**
  - **Overall, decreases the terrestrial carbon sink by 72% or creates a carbon source in Northern Eurasia over the 21st century**
  - **Overall, decreases the global terrestrial carbon sink by 27-41%**
  - **Effect of wildfires on carbon budgets from vegetation shifts in Northern Eurasia has a large uncertainty**

Methane Consumption and Emission Model



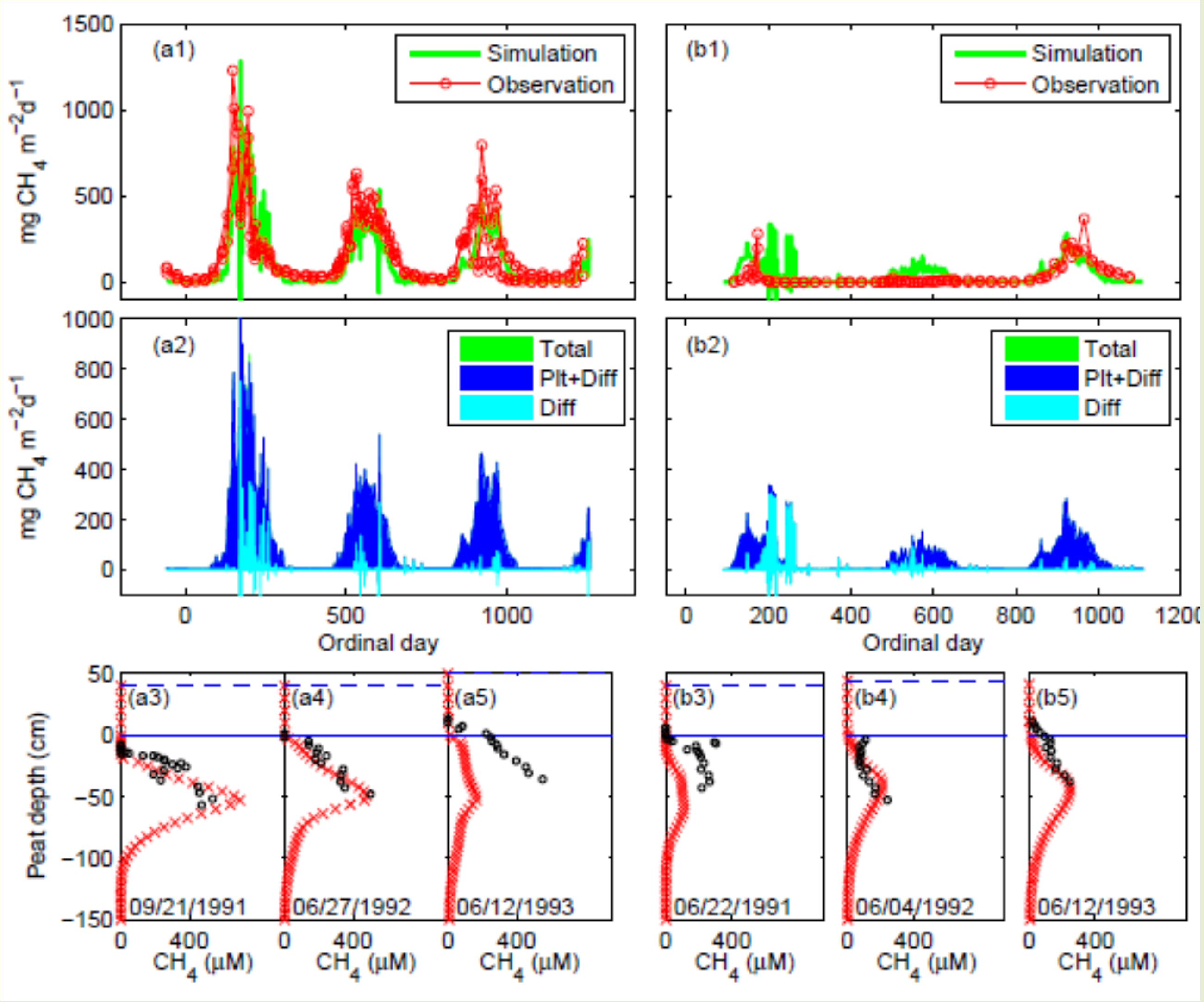
(Zhuang et al., 2004 GBC)

An Integrated Biogeochemistry Model



(Zhuang et al., 2006)

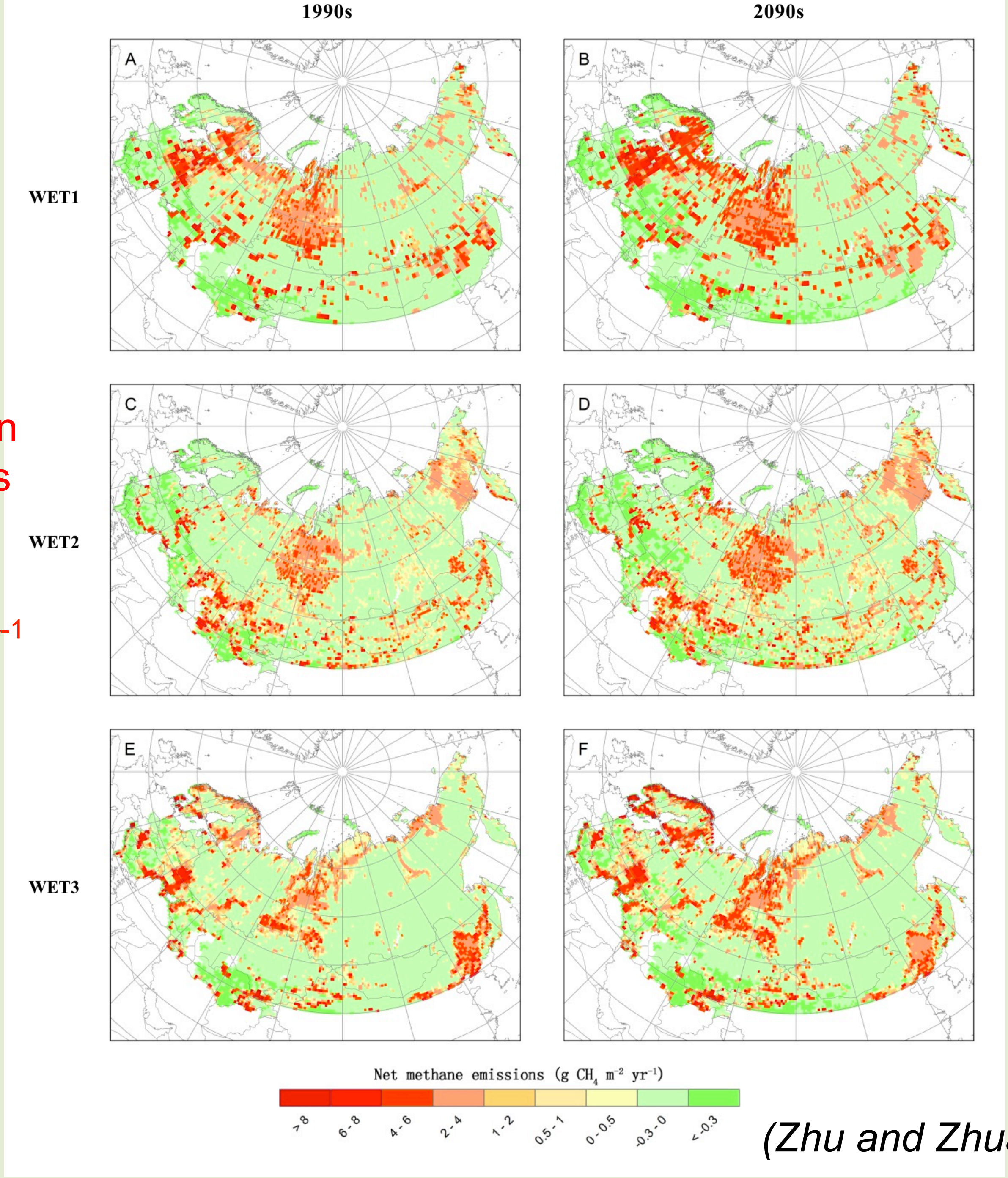
Comparison between Simulations and Observation



(*Tang and Zhuang et al., 2010*)

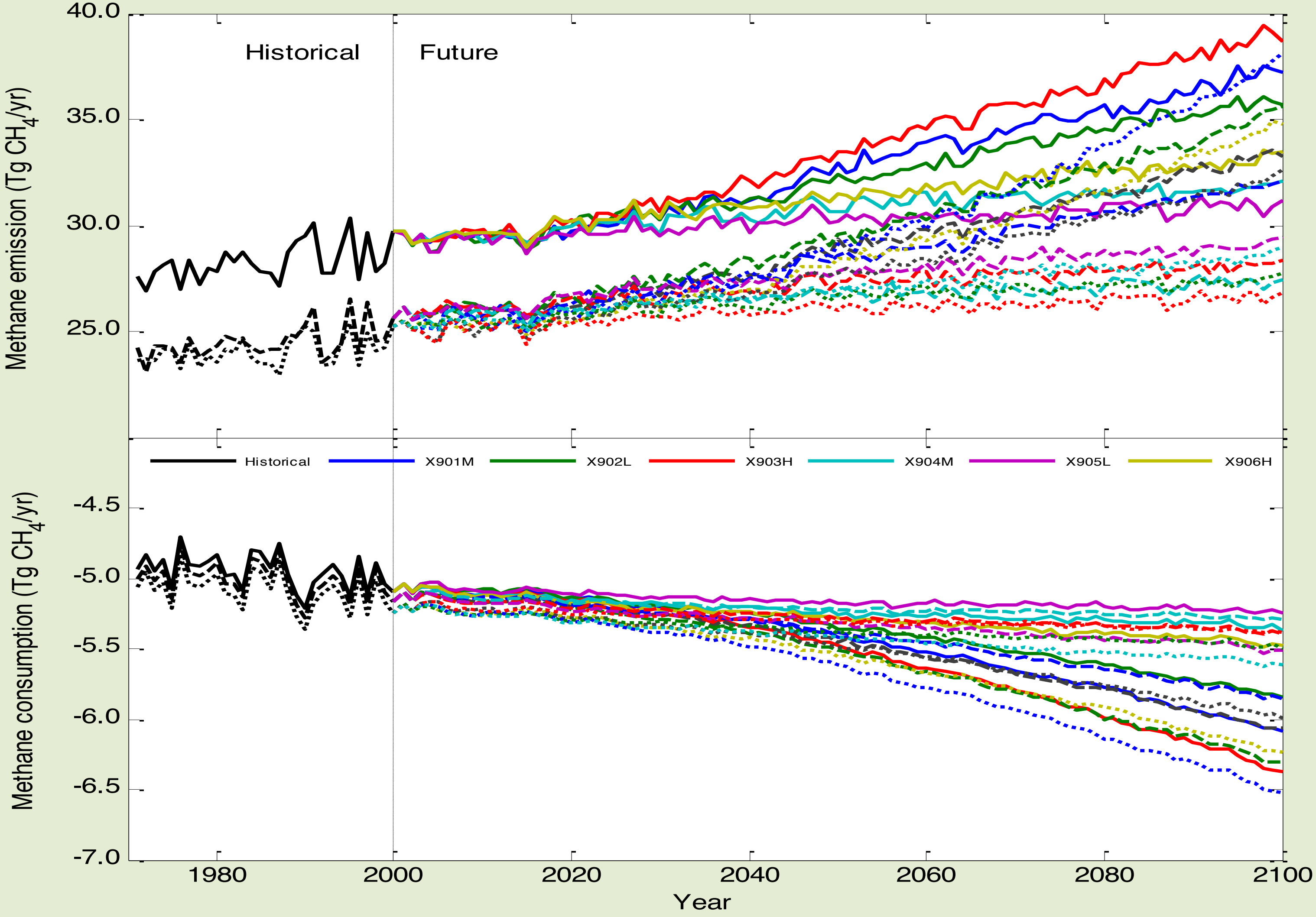
CH$_4$ Emission and consumption during the 1990s

20-24 Tg CH$_4$ yr^{-1}

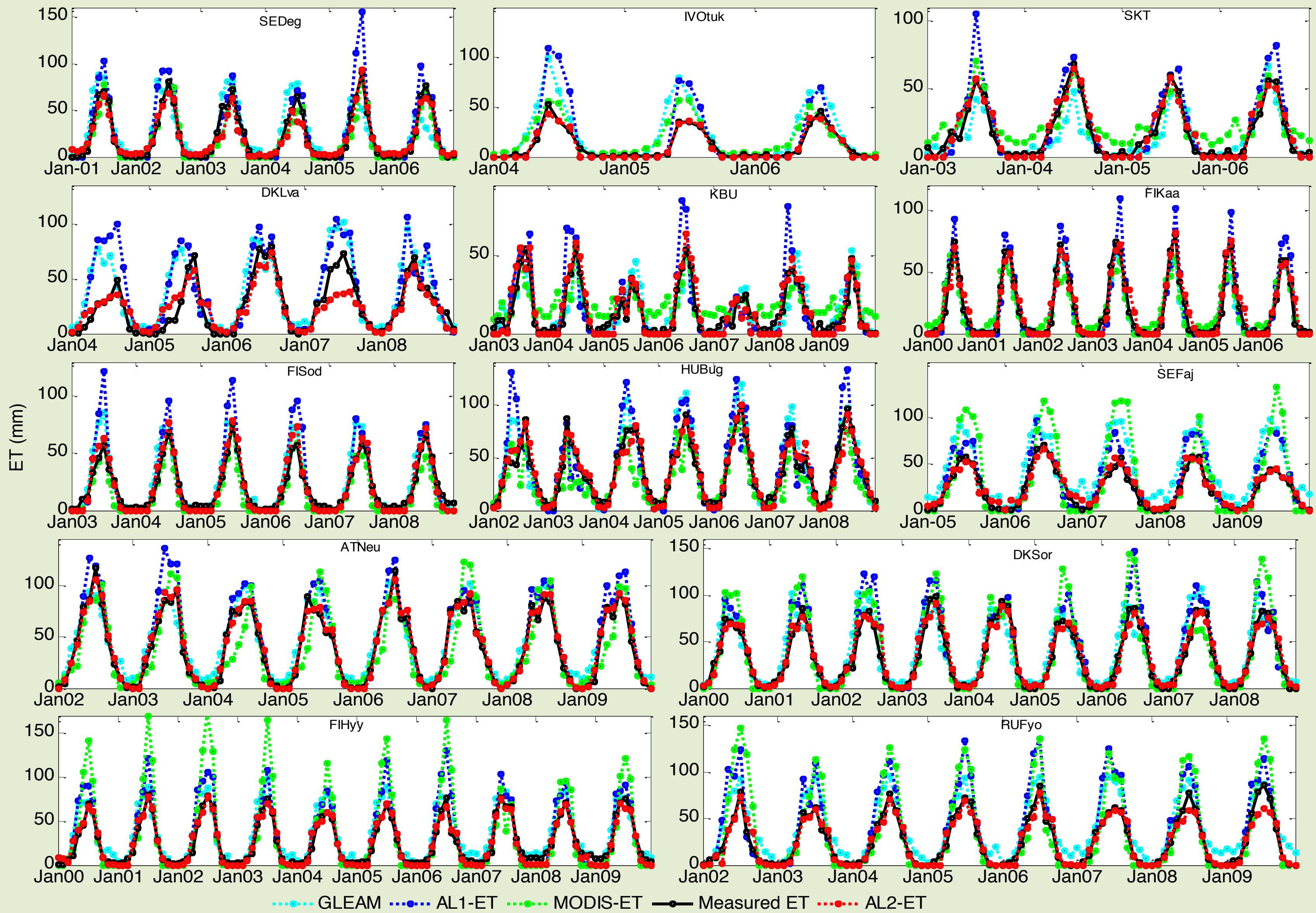


(*Zhu and Zhuang et al., 2011*)

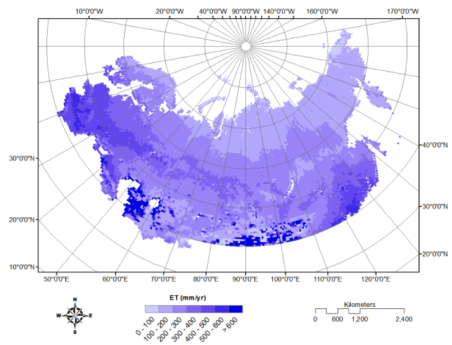
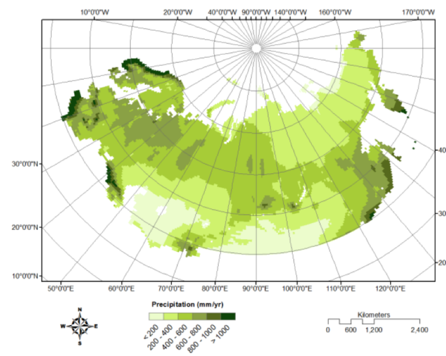
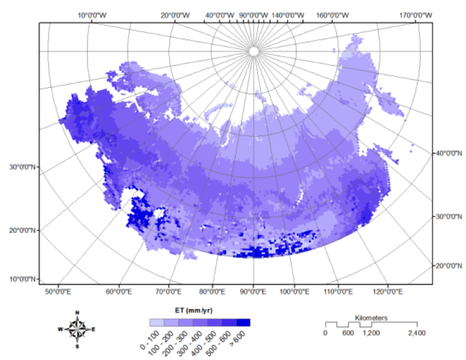
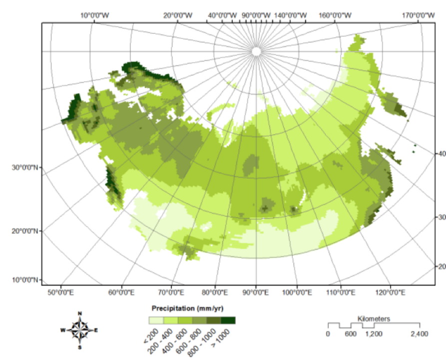
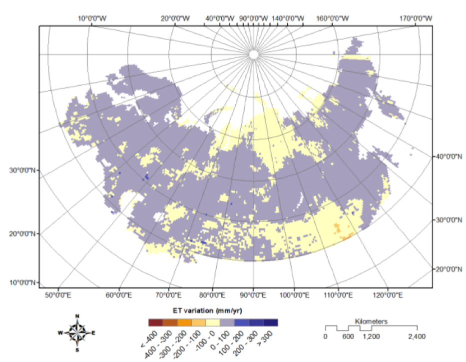
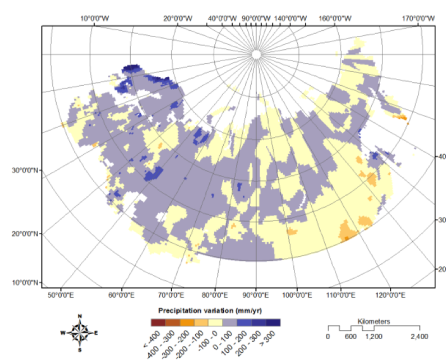
Annual methane emission and consumption over Northern Eurasia during the 21st century



Comparison between Observed, Modeled and Satellite Evapotranspiration in Northern Eurasia



(*Liu et al., 2013*)

	ET	Precipitation
1950s		
2000s		
1950s-2000s		

Simulated Evapotranspiration from the 1950s to 2000s in Northern Eurasia

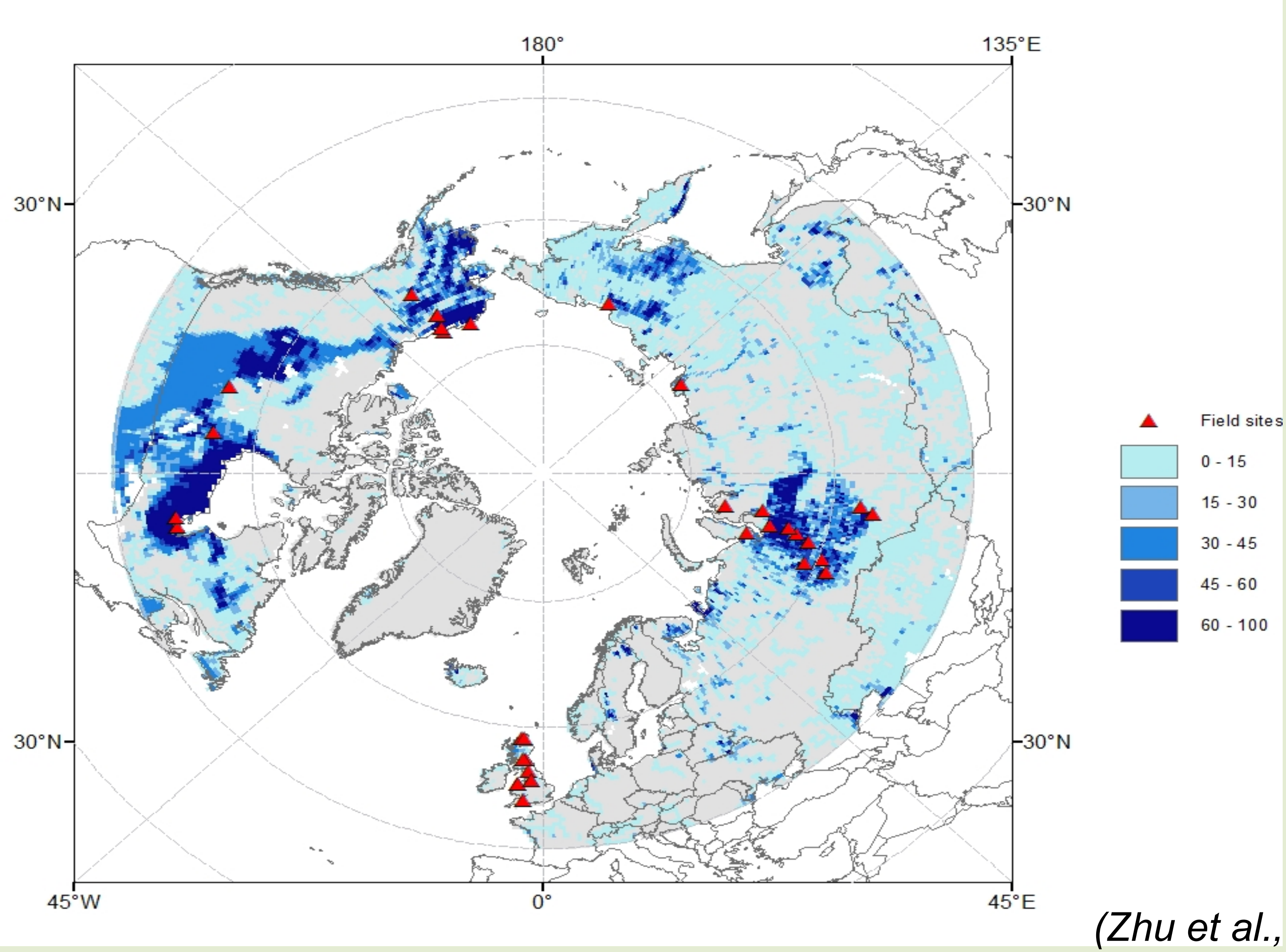
Summary 2

- Current net methane emissions are 20-24 Tg per year

- Emissions are projected to increase by 6–51% under various wetland extent datasets and climate scenarios by the end of the 21st century, relative to present conditions

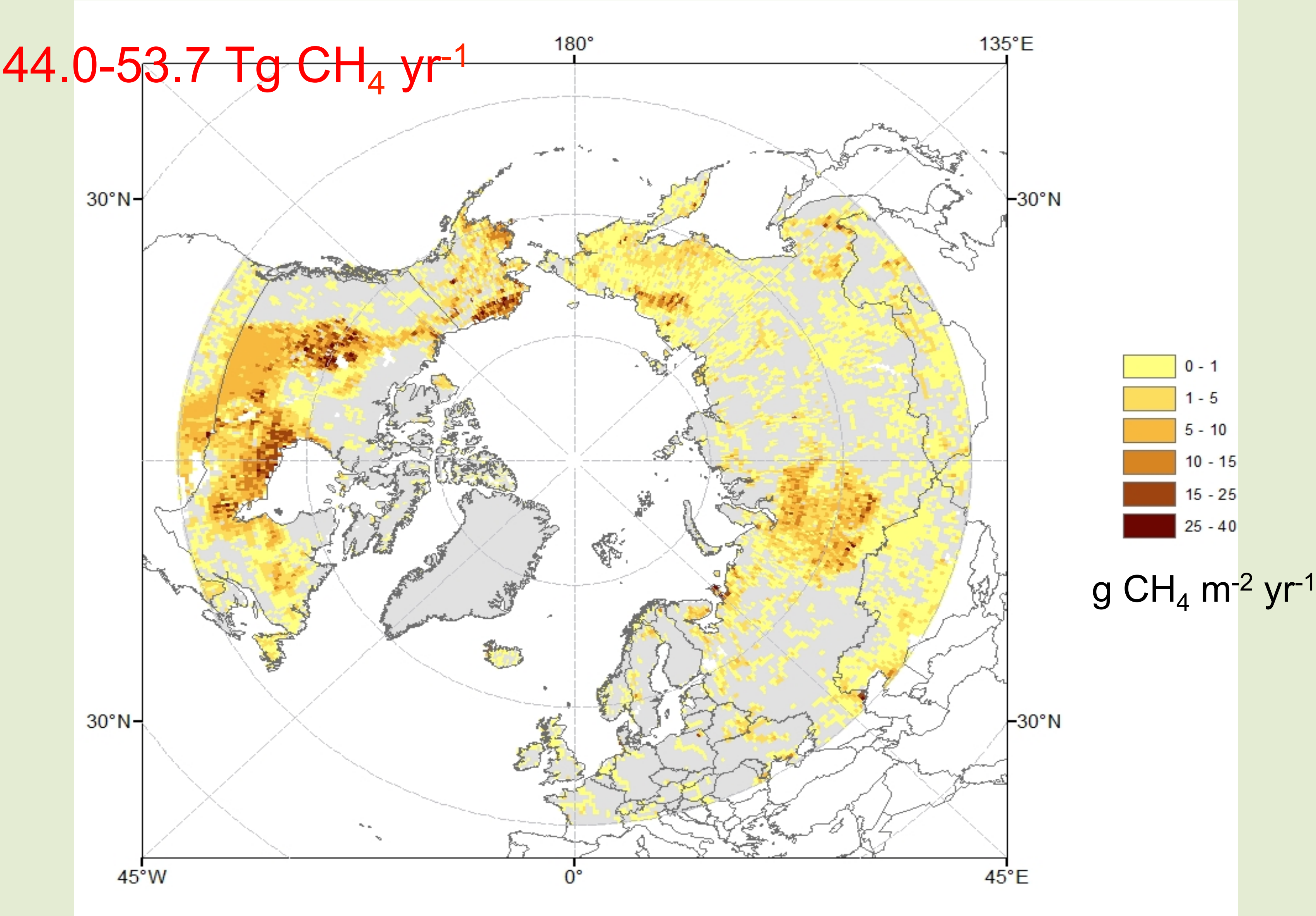
- Terrestrial ecosystems ET has decreased from the 1950s to 2000s in Northern Eurasian

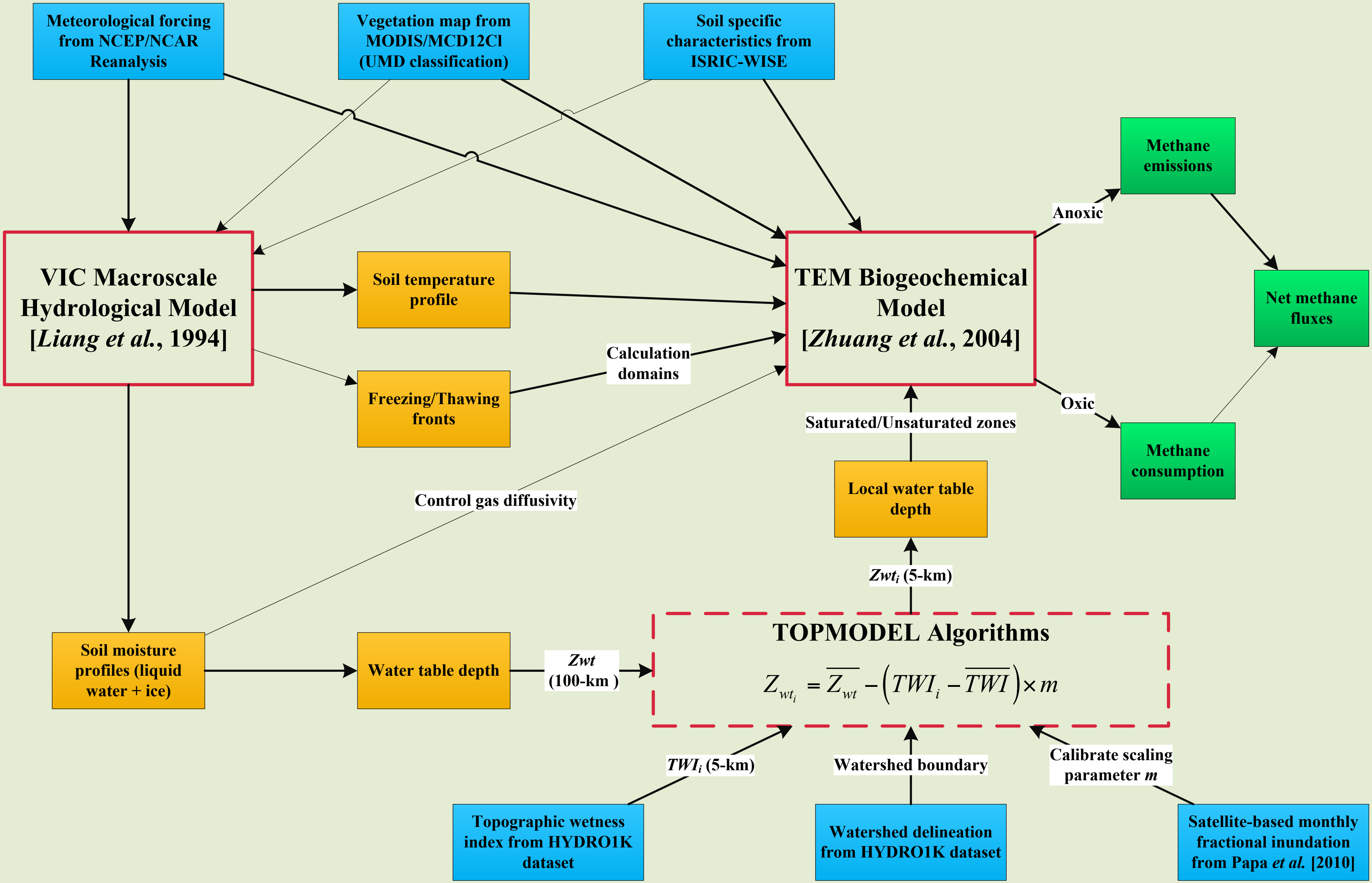
Observational Sites of Methane Fluxes and Environmental Variables Used in Methane Modeling



(Zhu et al., 2013)

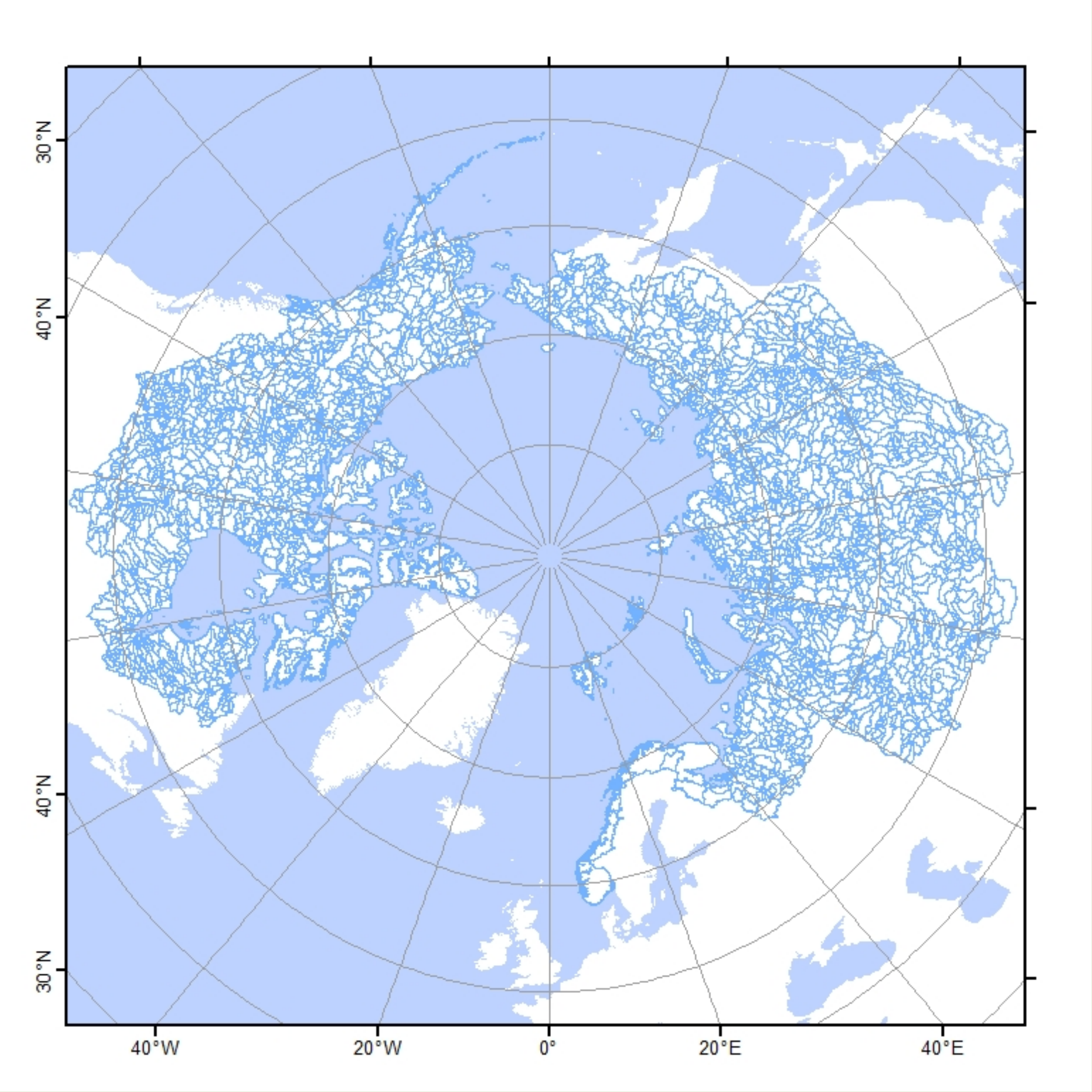
Annual wetland CH_4 emissions during 1990-2009 Based on an Neural Network Approach

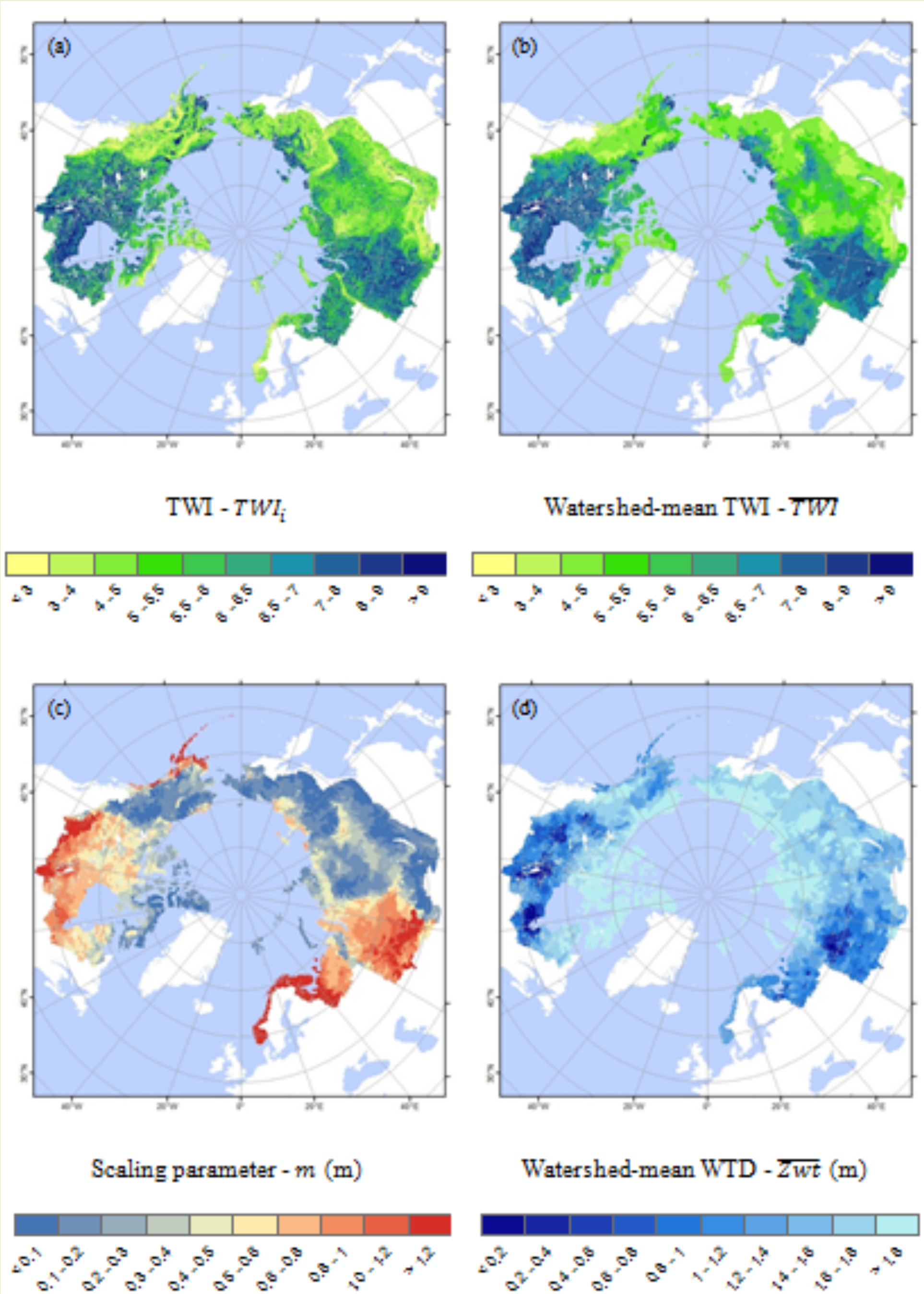




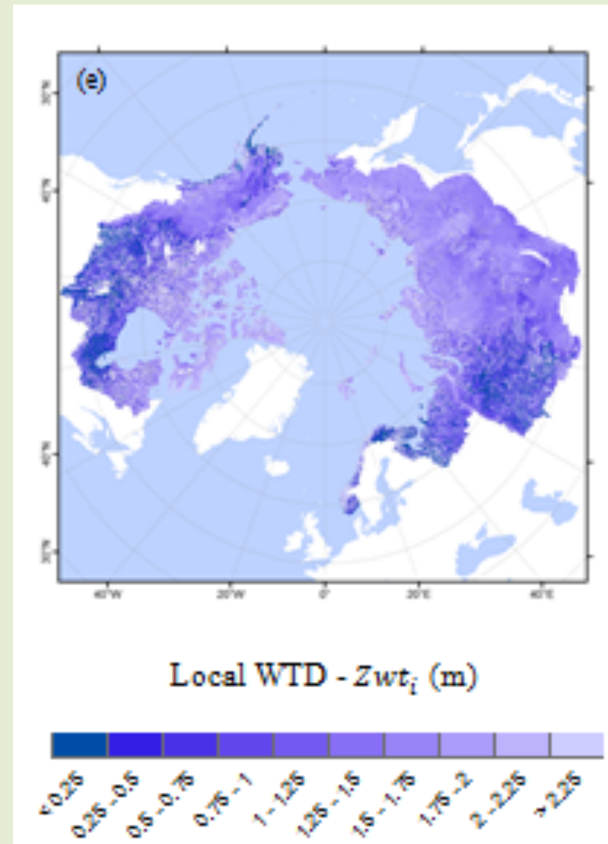
Meteorological forcing from NCEP/NCAR Reanalysis
Vegetation map from MODIS/MCD12Cl (UMD classification)
Soil specific characteristics from ISRIC-WISE
VIC Macroscale Hydrological Model [*Liang et al.*, 1994]
Soil temperature profile
Freezing/Thawing fronts
Calculation domains
TEM Biogeochemical Model [*Zhuang et al.*, 2004]
Anoxic
Methane emissions
Net methane fluxes
Oxic
Methane consumption
Saturated/Unsaturated zones
Local water table depth
Control gas diffusivity
Zwt_i (5-km)
Soil moisture profiles (liquid water + ice)
Water table depth
Zwt (100-km)
TOPMODEL Algorithms
$Z_{wt_i} = \overline{Z_{wt}} - \left(TWI_i - \overline{TWI}\right) \times m$
TWI_i (5-km)
Watershed boundary
Calibrate scaling parameter *m*
Topographic wetness index from HYDRO1K dataset
Watershed delineation from HYDRO1K dataset
Satellite-based monthly fractional inundation from Papa *et al.* [2010]

The delineation of the watersheds across the Pan-Arctic land region, derived from HYDRO1K dataset

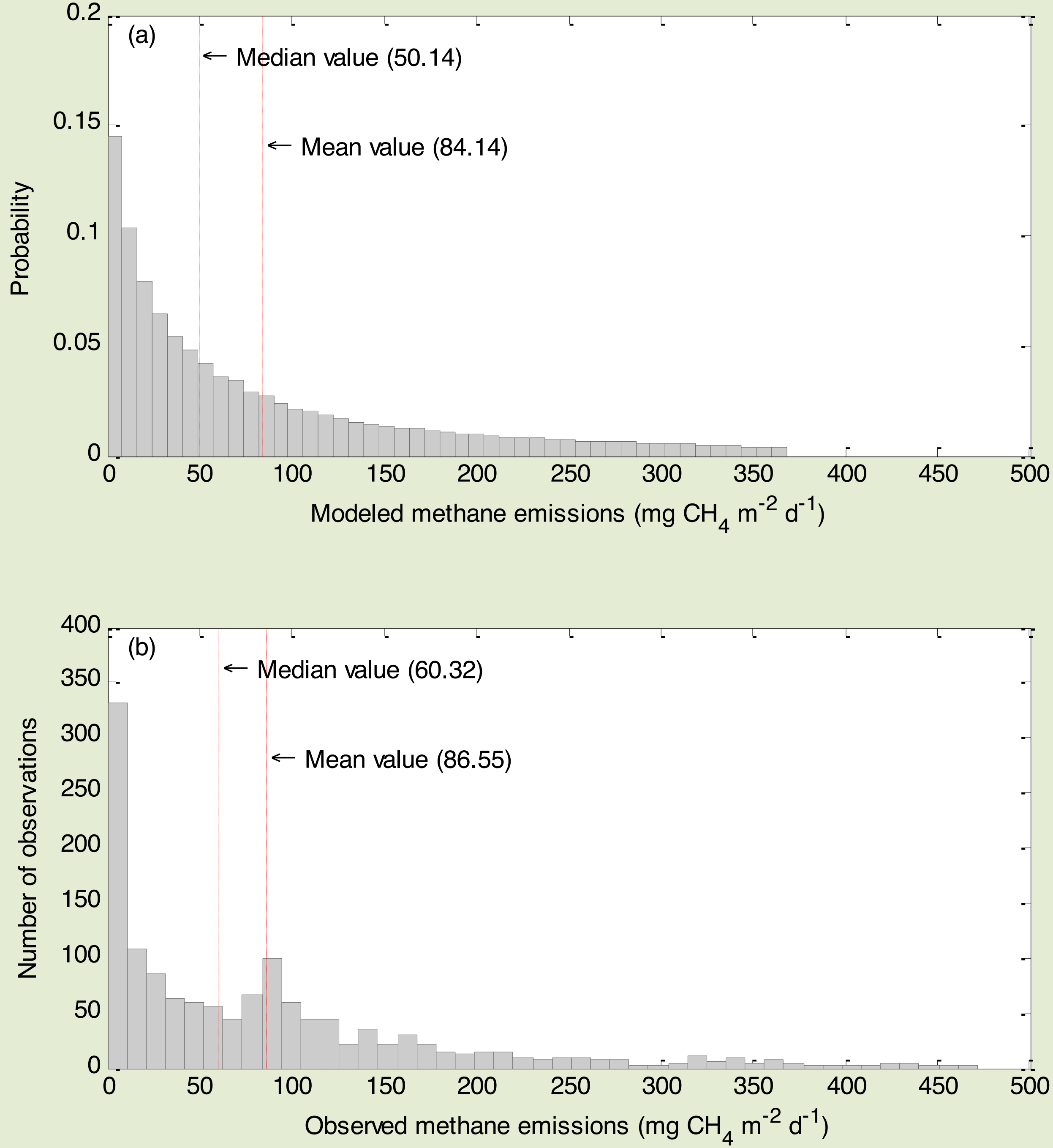




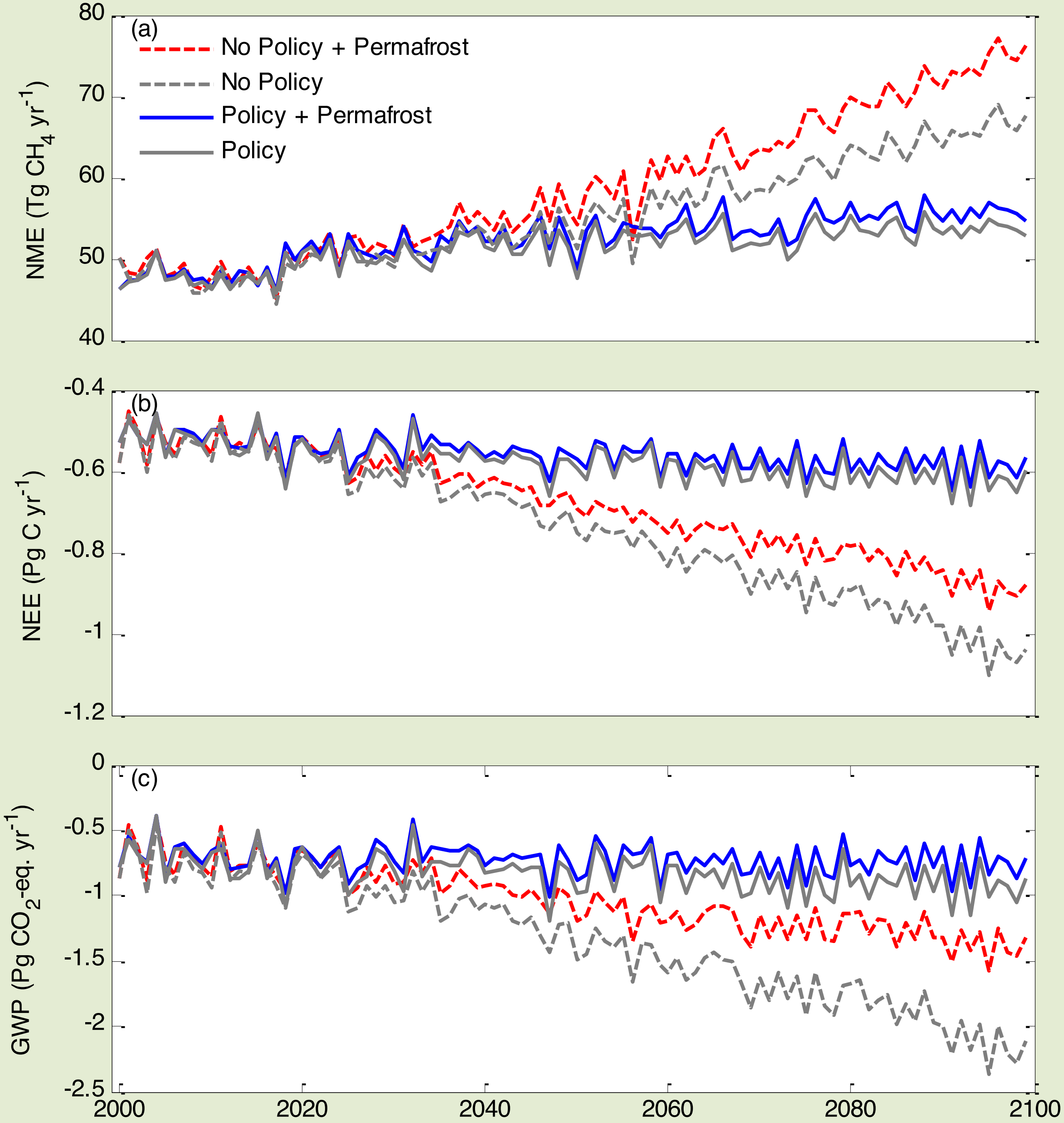
$Zwt\downarrow i = Zwt - (TWI\downarrow i - TWI)$



Probability distribution of modeled (at a 5-km spatial resolution) (a) and observed (b) mean methane emissions during the growing season (May - Sep.) across West Siberian Lowlands



Annual net methane exchange (NME) (a), net ecosystem exchange (NEE) (b), and global warming potential (GWP) (c) over the pan-Arctic for the 21st century, under the no-policy (dashed lines) and policy (solid lines) scenarios. Grey lines indicate the simulations without considering the permafrost-thawing effect



Summary 3

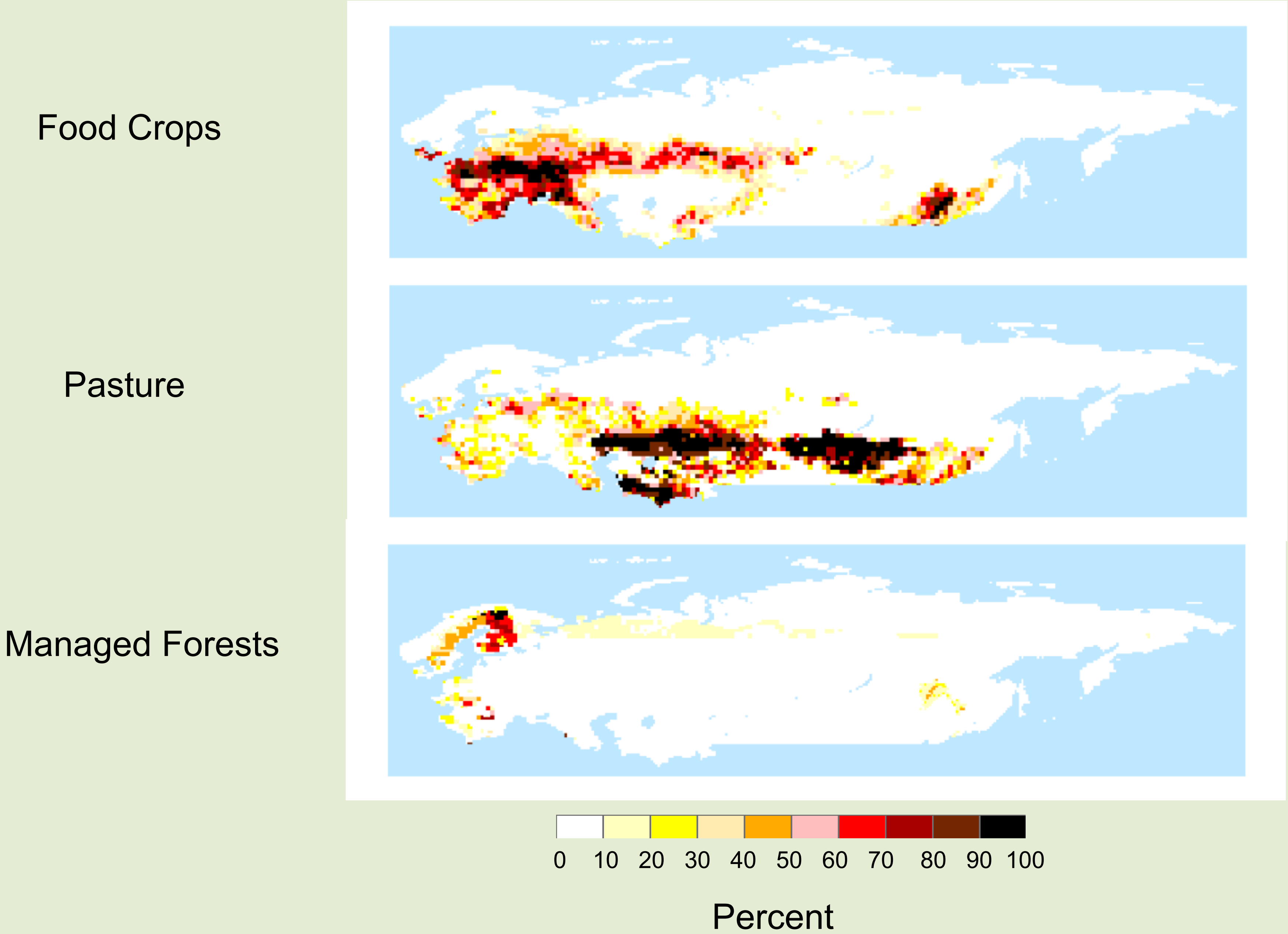
- Large uncertainty in methane emission quantification is due to 1) uncertain wetland /peatland area information and 2) uncertain complex hydrological dynamics upon permafrost thawing

- Net methane emissions over the region significantly affect the total radiative forcing

Acknowledgement

- NASA LCLUC Program
- NSF Biocomplexity Program – carbon and water
- DOE Abrupt Climate Change and SciDAC Programs

Distribution of Land use in Northern Eurasia during year 2000



Difference in Land Use due to Veg Shifts in Northern Eurasia
2000-2100