Quantifying the Role of Northern Eurasia in the Global Carbon and Water Dynamics during the 21st Century

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Northern Eurasia

The coldest land mass at continental scales.
Home of about 20 indigenous nations

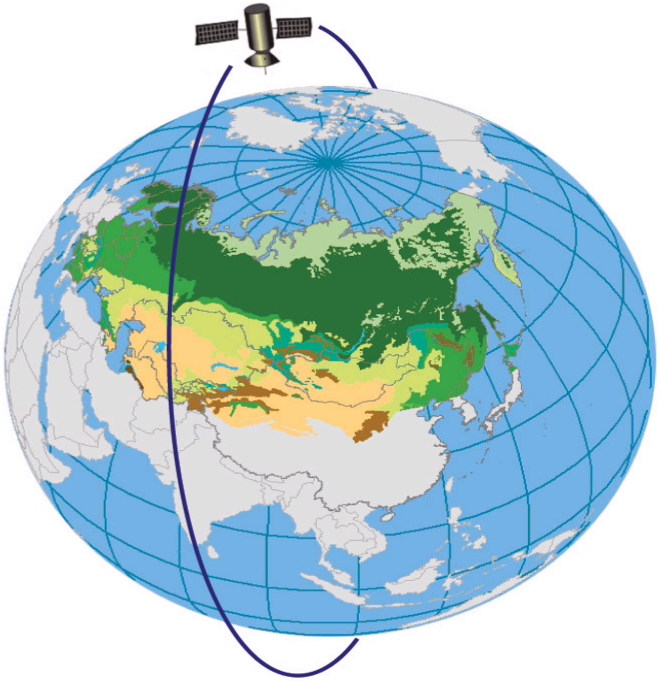
22% of global forests; Accounts for more than 50% of industrial coniferous wood

2/3 of the area is underlain by permafrost which contains from 500-900 Pg C

Dramatic climate changes occurred in the last few decades

Unregulated and devastating anthropogenic activities

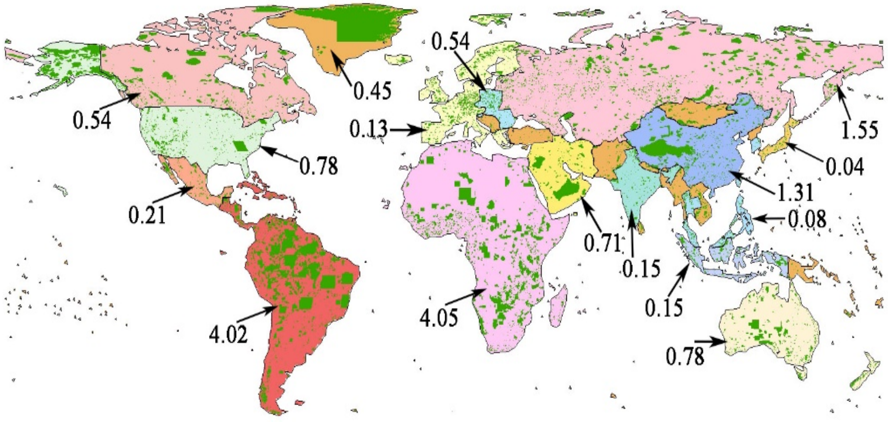
One of the most vulnerable regions of the globe



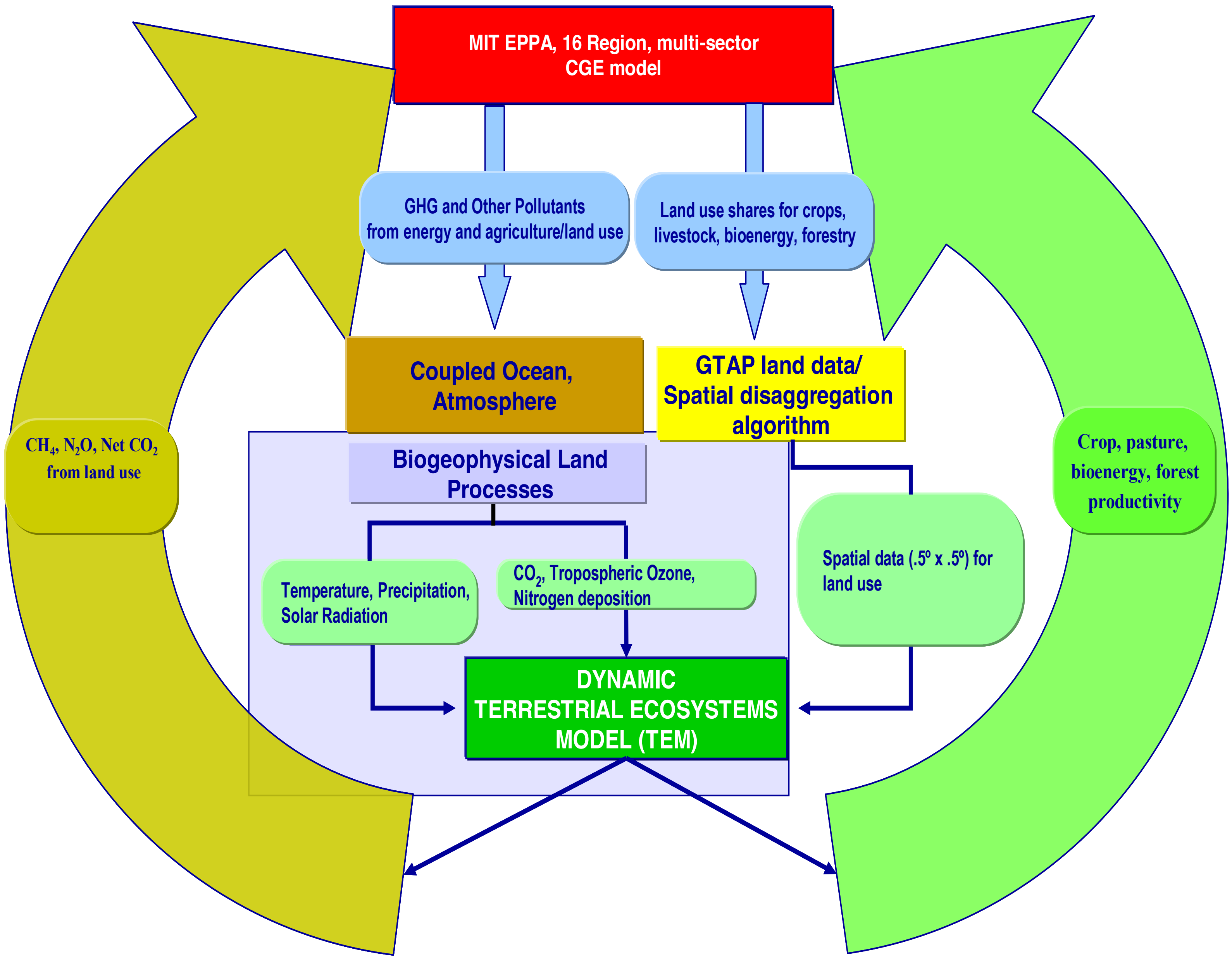
Research Questions

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

- How carbon and water cycles will be affected by the changes of land use and land cover and climate at the regional and global scales? – Implications to the global climate system and socioeconomic system



Coupled Natural and Human Systems



Major Features of EPPA and TEM

Socioeconomic Model EPPA

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

  - Based on GTAP (Global trading database developed at Purdue)

Land Ecosystem and Biogeochemistry Model 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

Major Features of SiBCliM

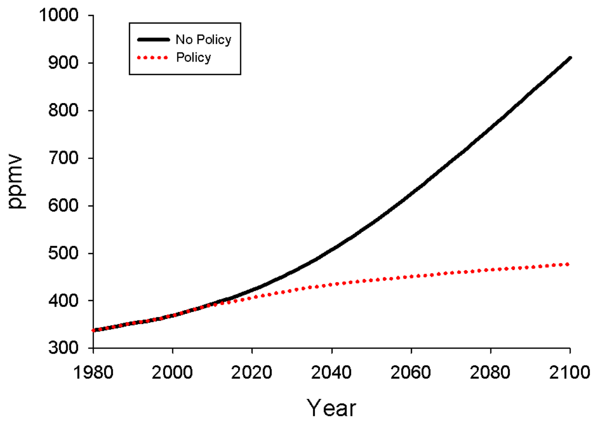
- A static envelope-type large-scale bioclimatic model based on the vegetation classification of Shumilova (1962)

- 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)

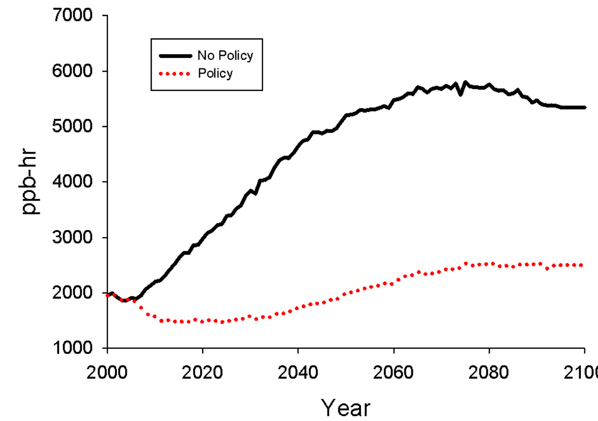
- SiBCliM has been updated to include permafrost (the active layer depth)

Global Climate and Atmospheric Conditions

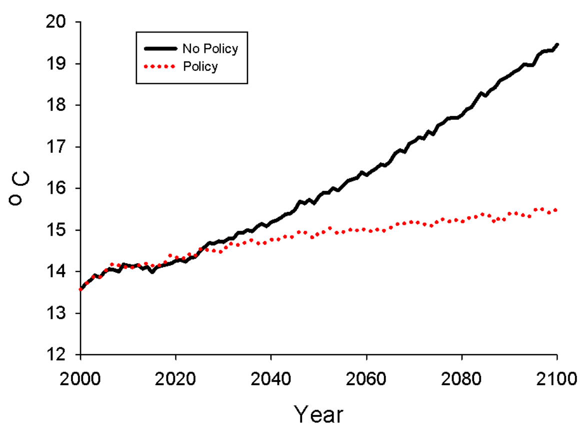
a) Atmospheric CO_2 concentrations



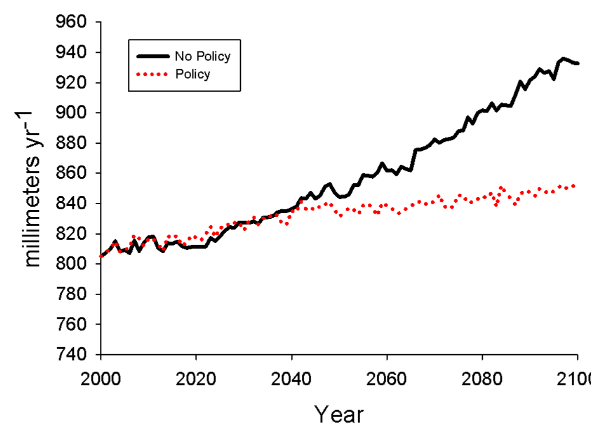
b) AOT40 ozone index



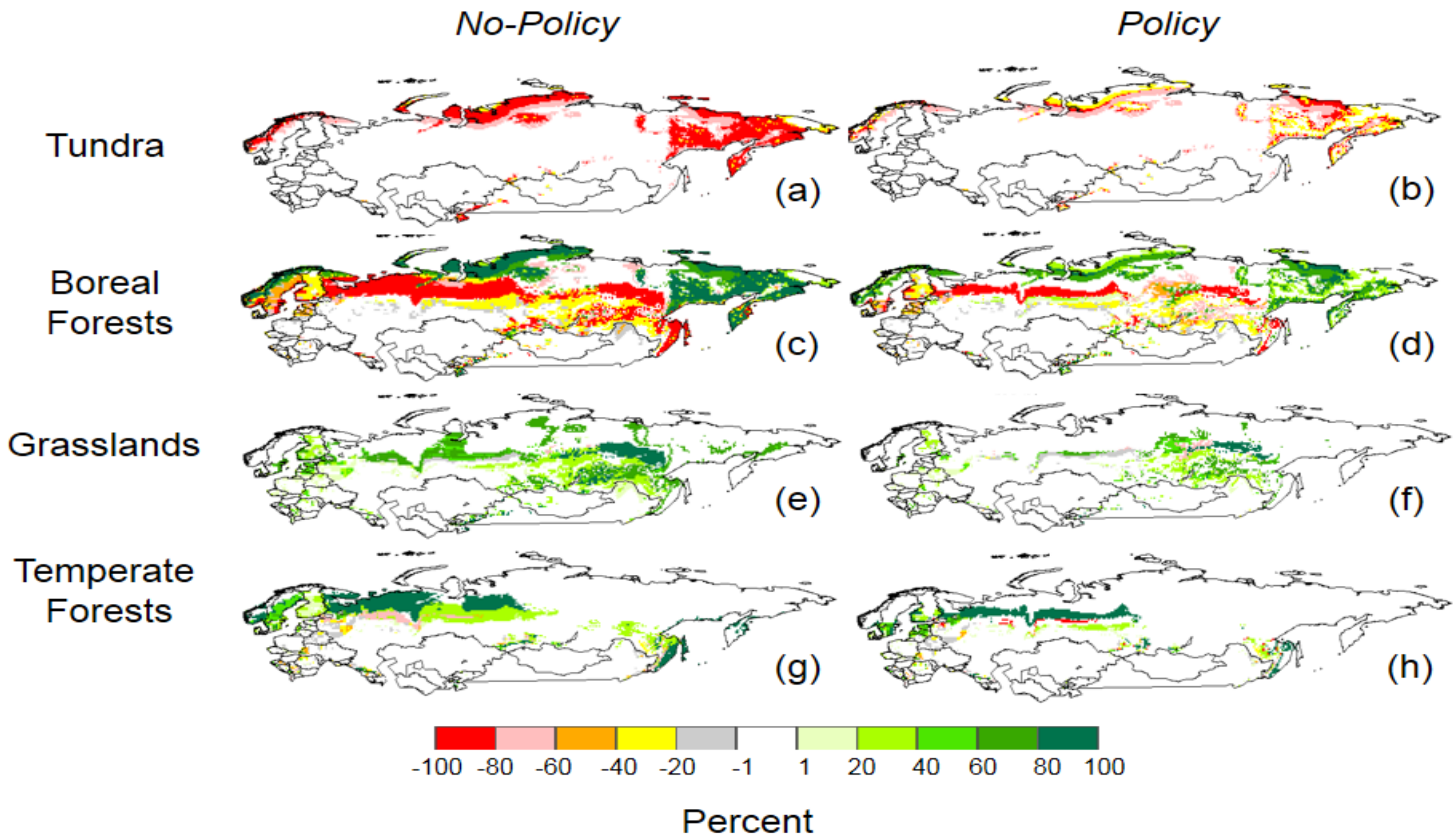
c) Global mean air temperature



d) Global mean precipitation



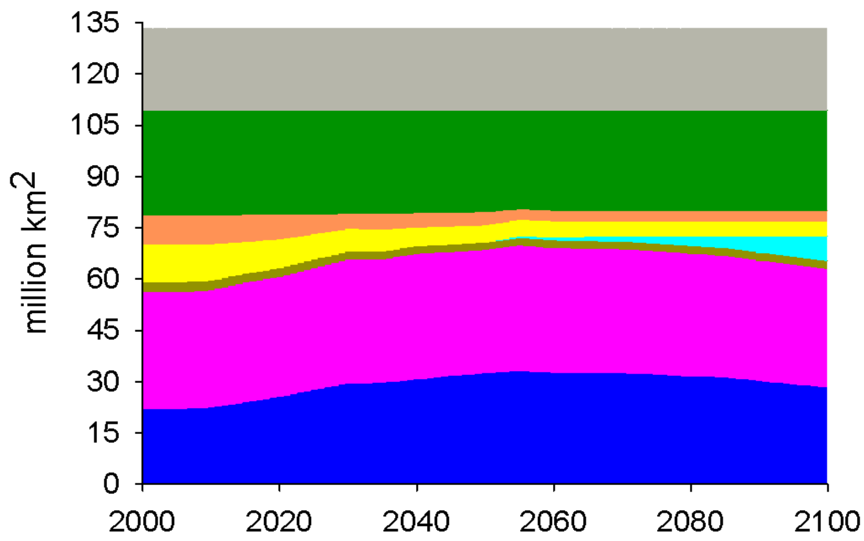
Shifts in tundra, boreal forests, grasslands, and temperate forests over the 21st century. Values represent the changes in vegetation coverage from year 2000

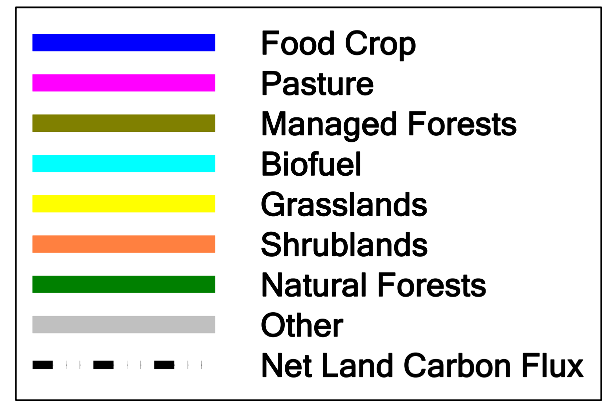


Kicklighter et al. 2014, *Environmental Research Letters* **9**, 035004

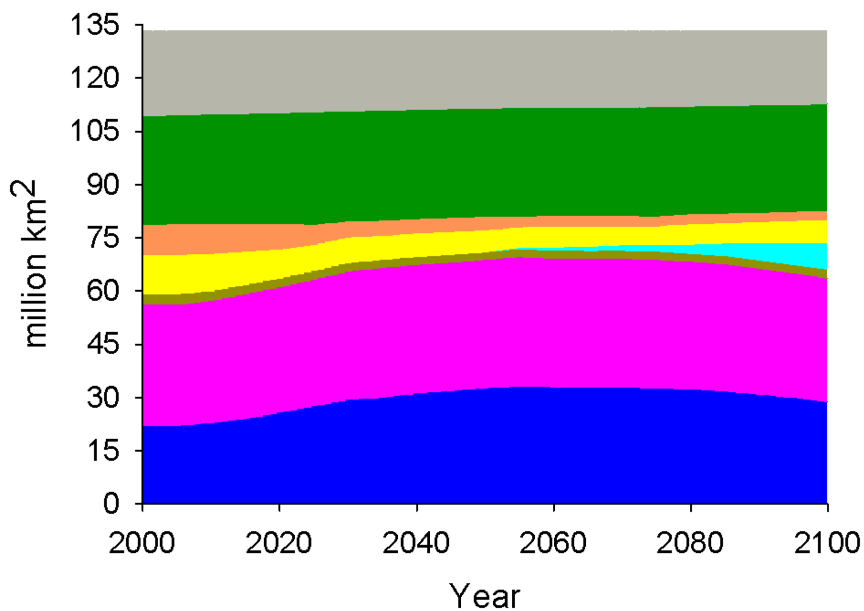
Global Land-Use Change under the No-Policy Scenario

No Vegetation Shift





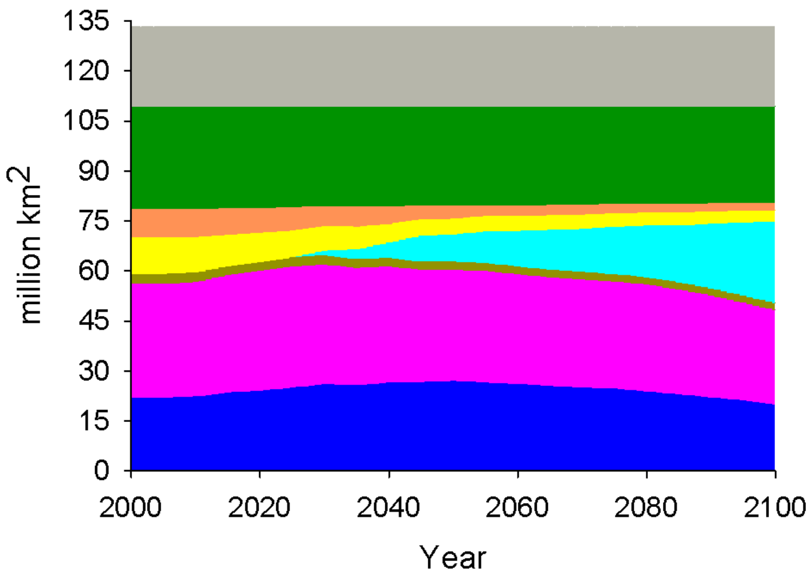
Vegetation Shift

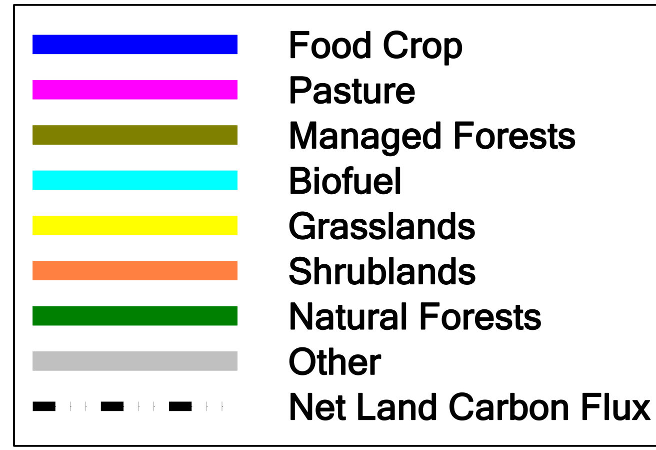


💥NE vegetation shift has a small impact on global LCLUC

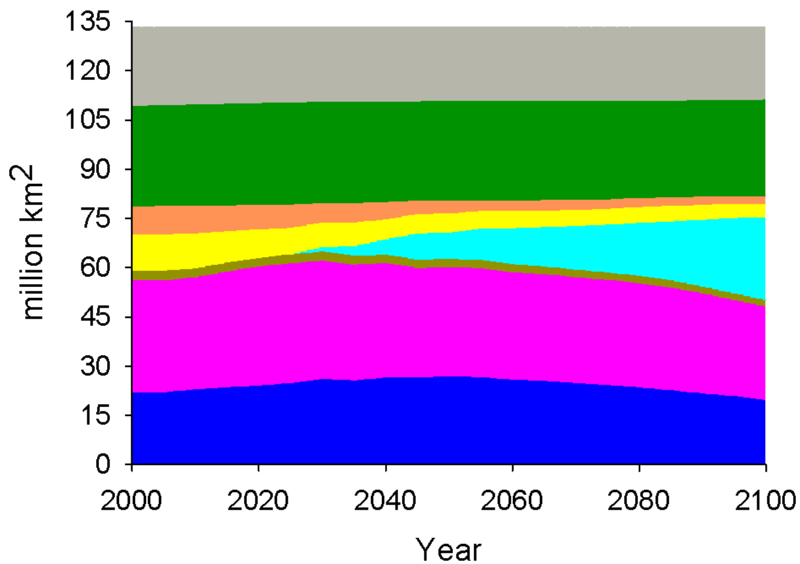
Global Land-Use Change under the Policy Scenario

No Vegetation Shift





Vegetation Shift



Policy allows more lands to biofuel crops.

Changes in global land cover (million km^2) over the 21st century for land use change and NE vegetation shift

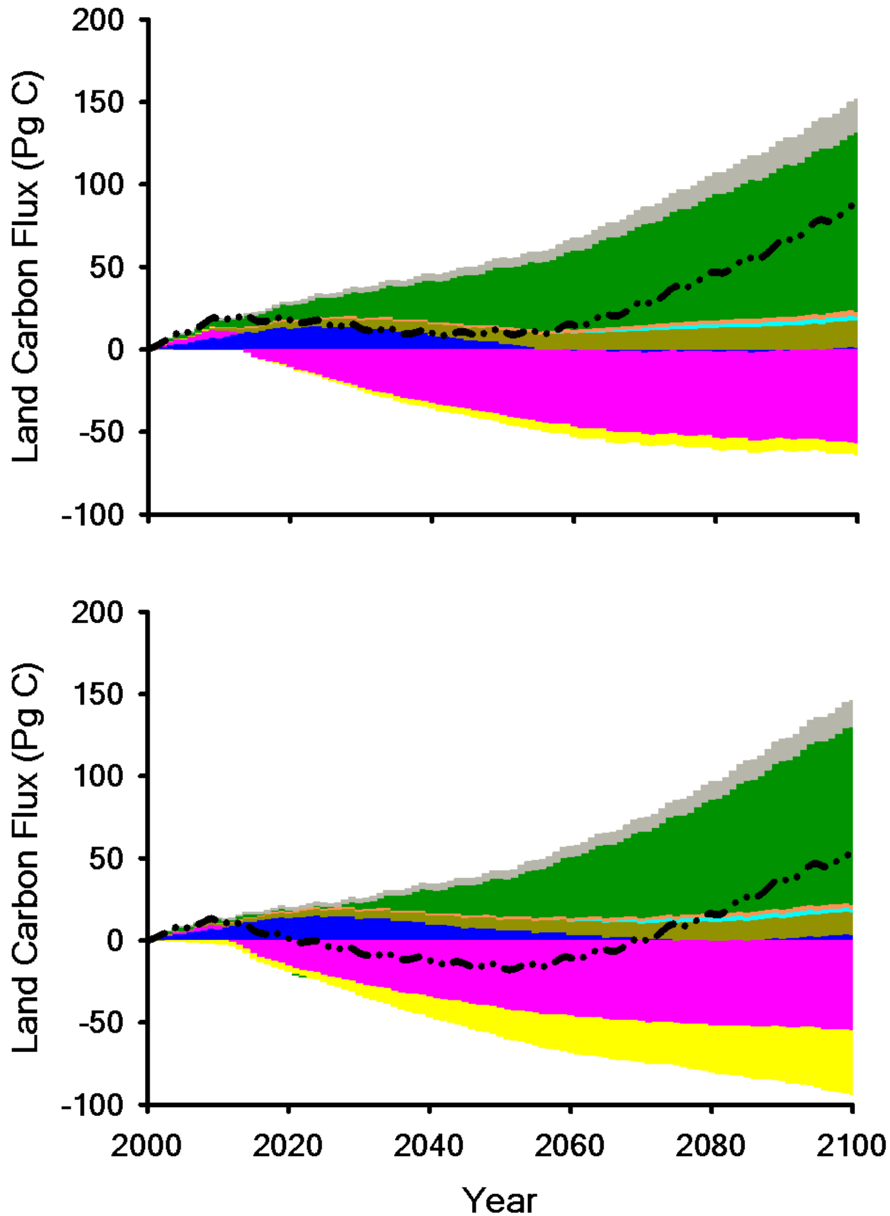
Land Cover	Current (2000)	No Policy (2100)			Policy (2100)	
			Median Climate Sensitivity			Median Climate Sensitivity
Food Crops	22.12		28.84			19.87
Biofuel Crops	0.00		7.53			25.11
Pasture	34.12		34.78			28.39
Managed Forests	3.00		2.43			1.98
Natural Forests	30.60		30.17			29.49
Shrublands	8.67		2.48			2.29
Grasslands	10.94		6.53			4.25
Other	23.85		20.54			21.92
Total	133.30		133.30			133.30

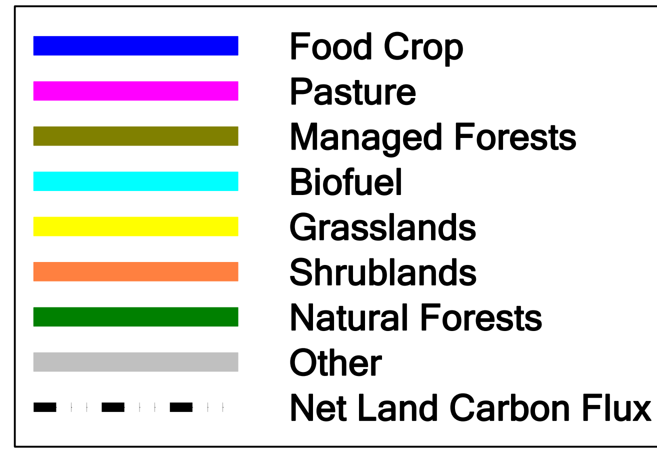
Various land cover types changed due to land use change & NE vegetation shift

Global Net Carbon Exchange under the No-Policy Scenario

No Vegetation Shift

Vegetation Shift

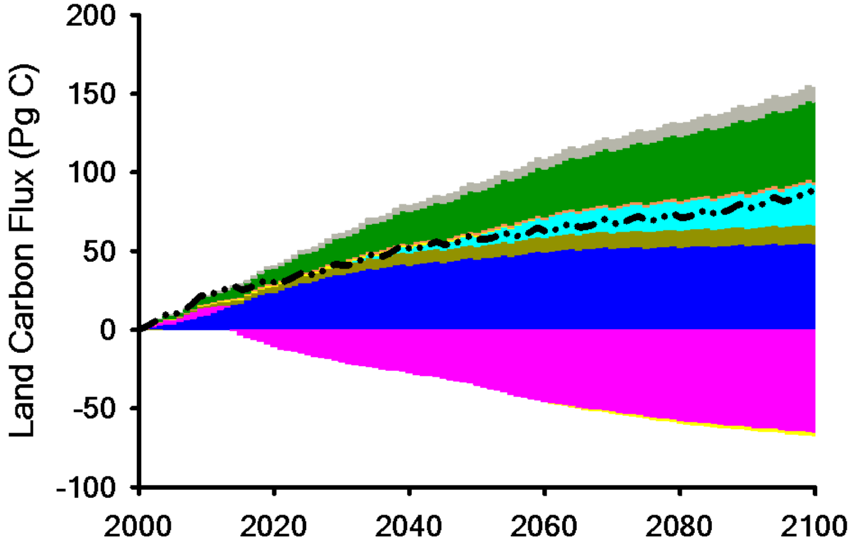


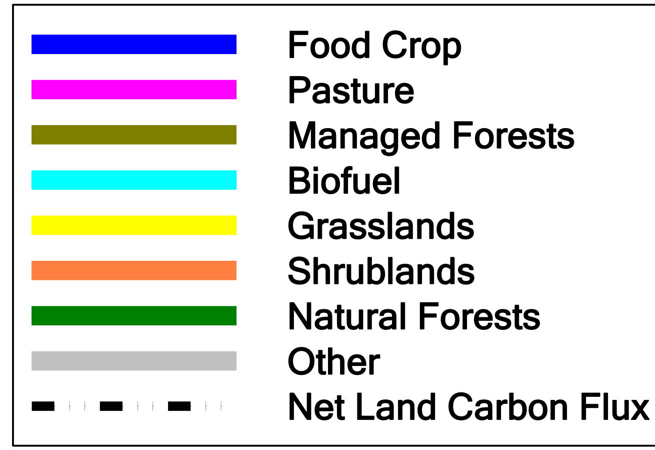


- Vegetation shift reduces the global C sink
- Grassland expansion due to conversion – losing carbon

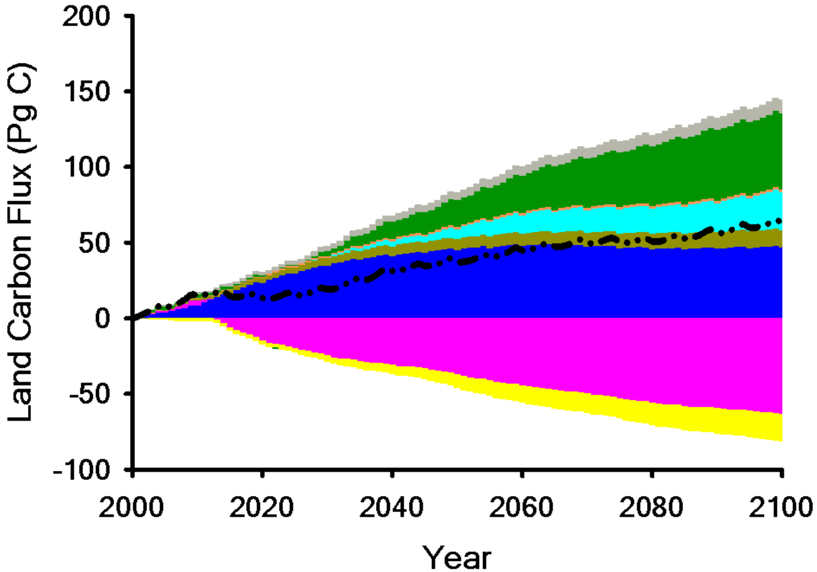
Global Net Carbon Exchange under the Policy Scenario

No Vegetation Shift





Vegetation Shift



💥Vegetation shift reduces the global sink

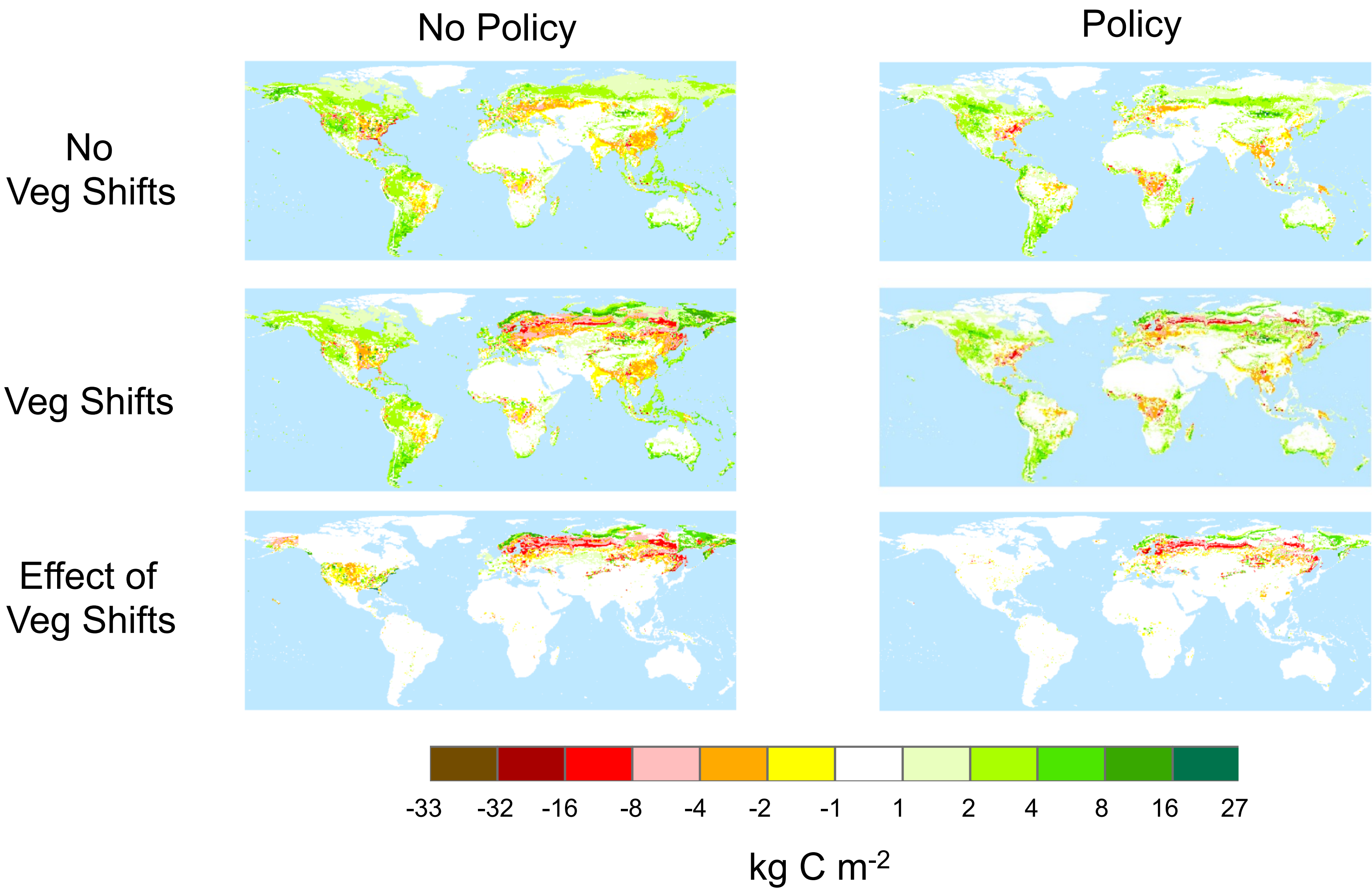
💥Grassland expansion due to conversion – losing carbon not the magnitude as no-policy scenario

Net land carbon flux (Pg C) from global terrestrial ecosystems during the 21st century for land-use change and NE vegetation shift

Land Cover	No Policy (2001 to 2100)			Policy (2001 to 2100)		
		Median Climate Sensitivity			Median Climate Sensitivity	
Food Crops		+8.94			+21.92	
Biofuel Crops		0.00			+3.38	
Pasture		-21.44			-20.84	
Managed Forests		+3.09			+3.75	
Natural Forests		+25.19			+12.42	
Shrublands		+0.33			+0.23	
Grasslands		-34.84			-15.02	
Other		+1.99			+1.84	
Total		-16.74			+7.68	

Global C sink is determined by climate and land-use change as well as NE vegetation shift

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

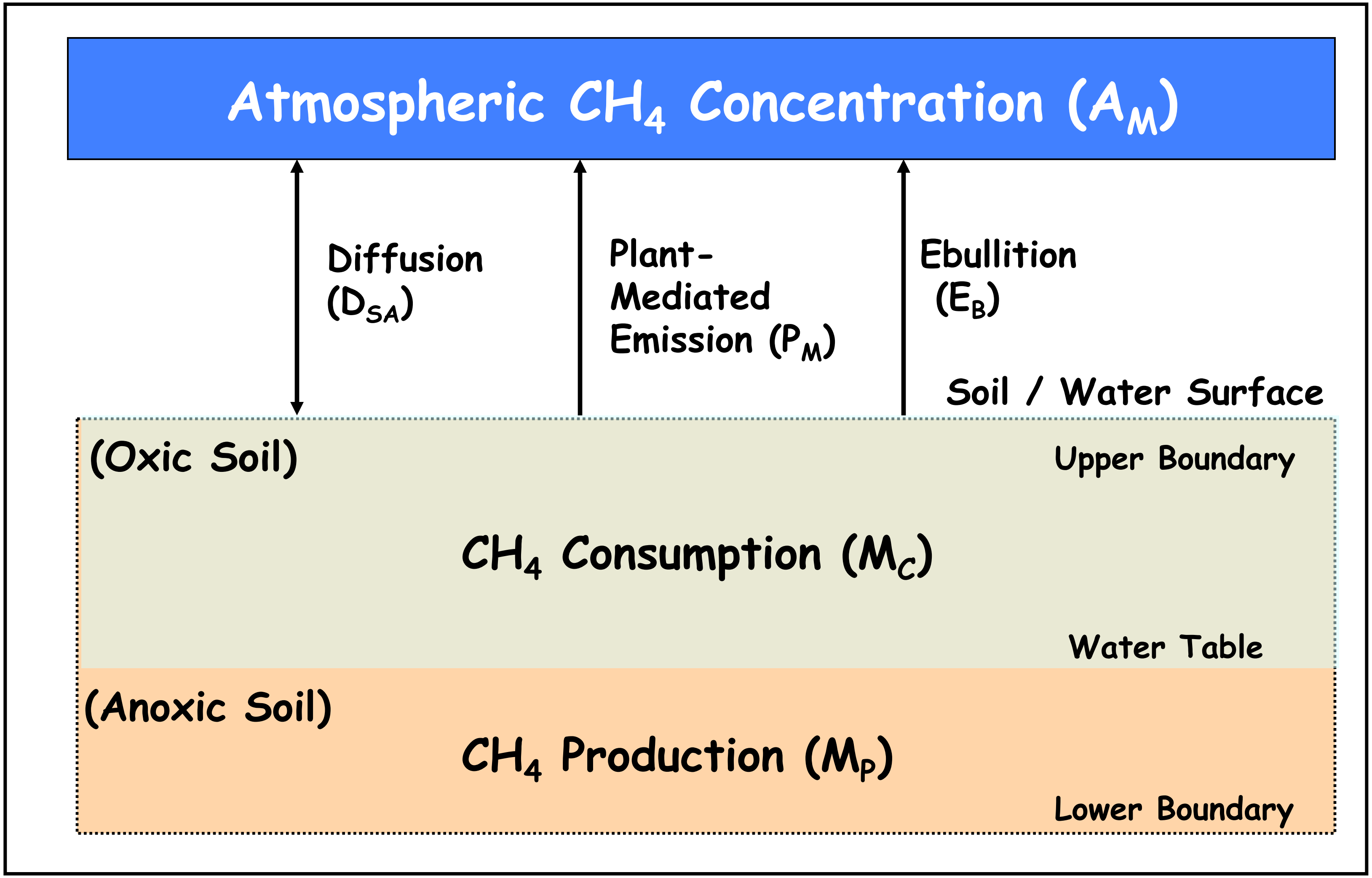


Summary-1

- Impacts of NE vegetation shifts on global managed lands:
  - Allow ~1% expansion of food crops and pastures with No Policy
  - Allow ~4% expansion of biofuels with Policy
  - Allow ~2% expansion of managed forests with no policy

- Impacts of NE 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 74% or creates a carbon source (~17 Pg C) over the 21st century

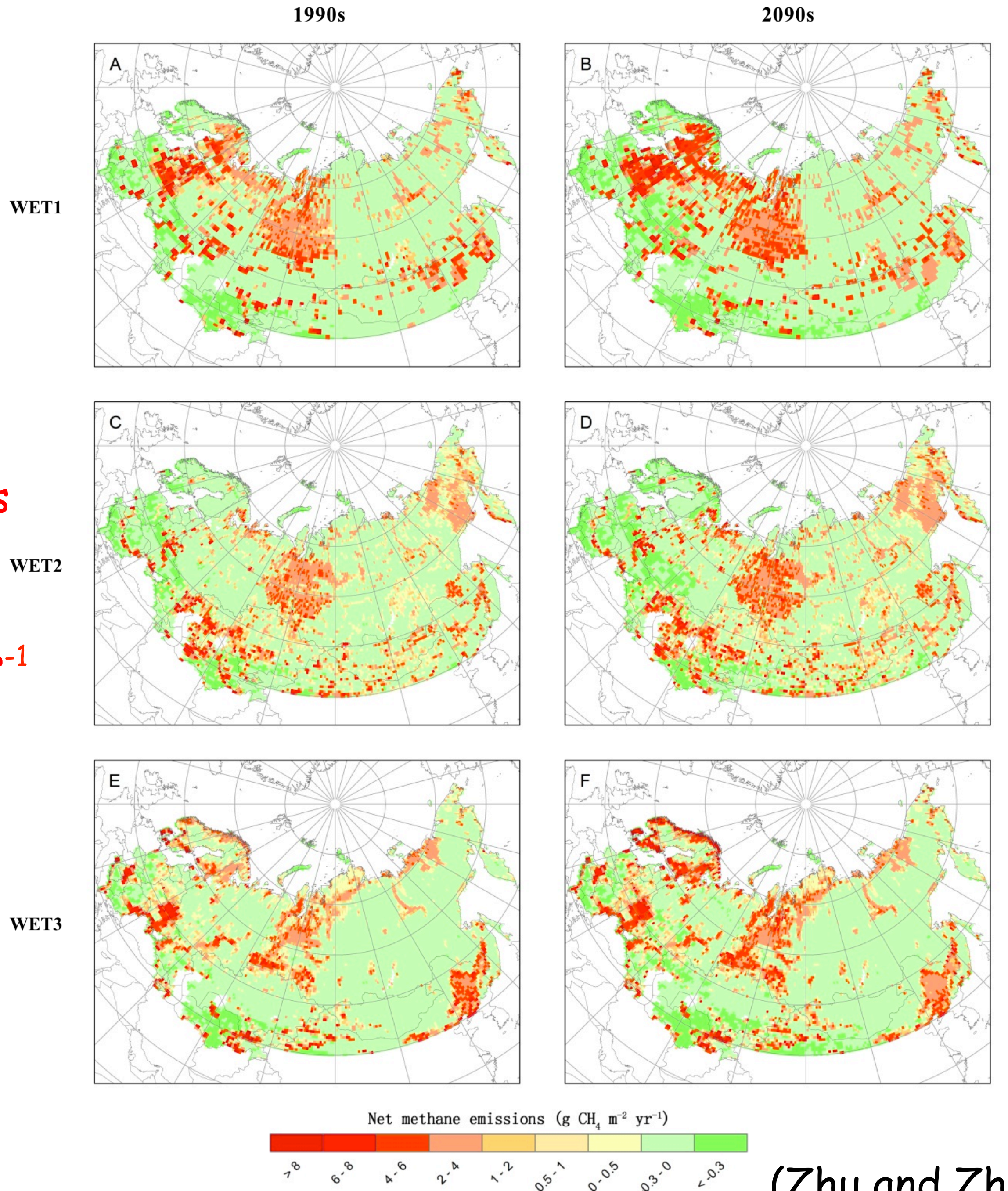
Methane Consumption and Emission Model



(Zhuang et al., 2004 GBC)

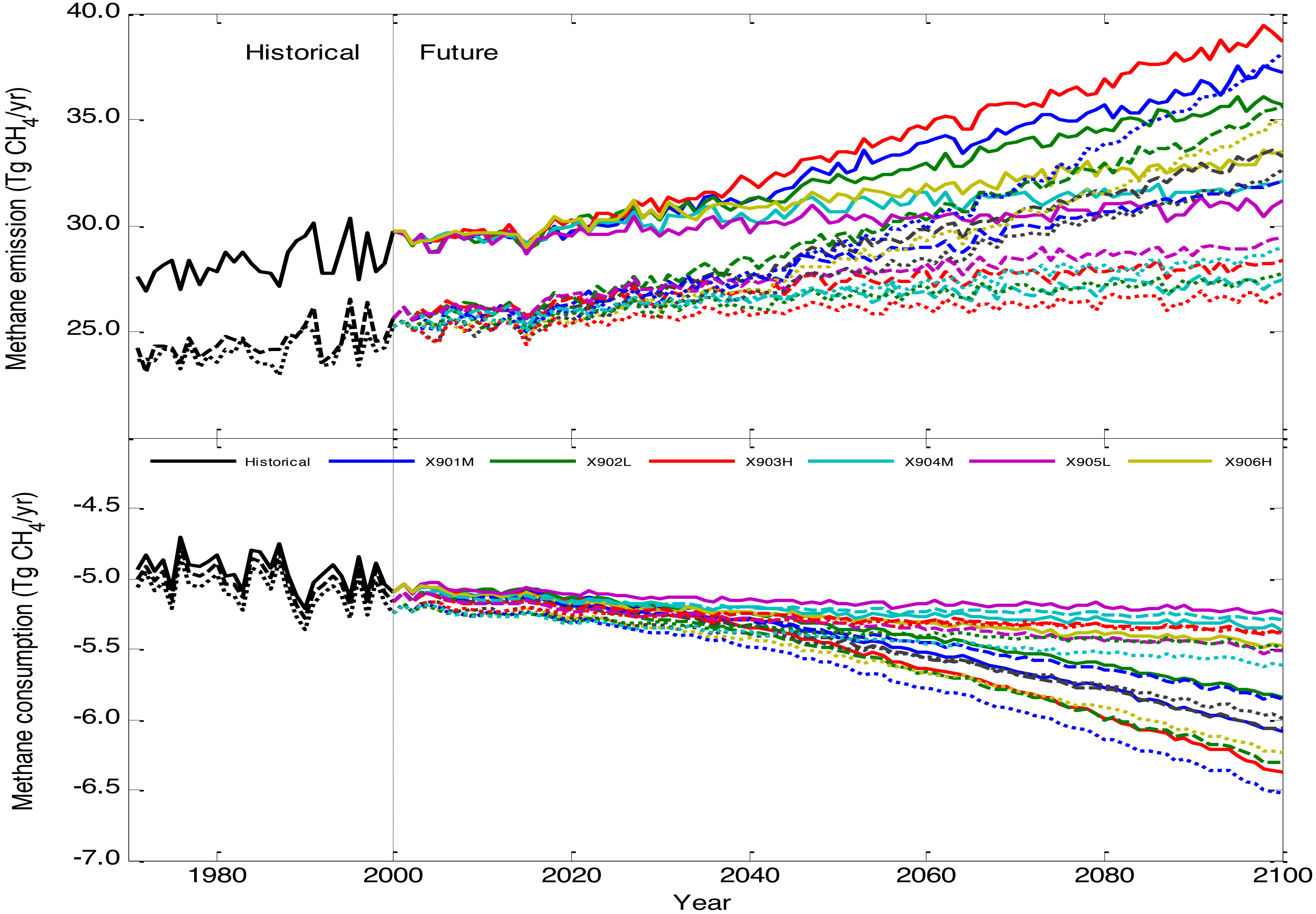
CH_4 Emission and consumption during the 1990s

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



Summary-2

- Large uncertainty in methane emission quantification is due to uncertain wetland /peatland area information for both historical and future periods
- Large uncertainty in methane emissions is due to uncertain complex hydrological dynamics upon permafrost thaw
- Net methane emissions over the region affect the total radiative forcing greatly

Forcing datasets

1)CRU TS3.1

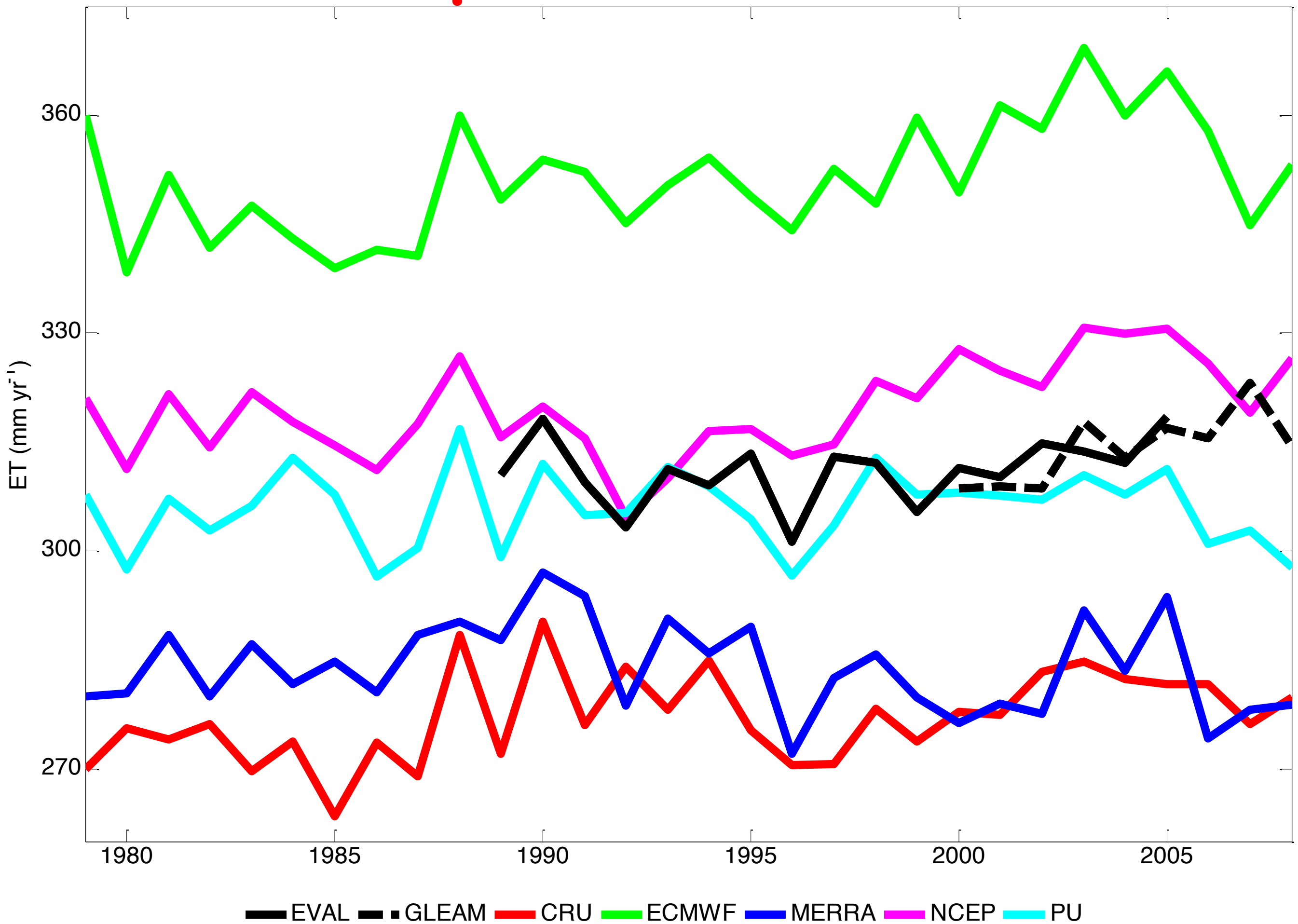
2) ECMWF Interim Re-Analysis (ERA-Interim)

3) NASA MERRA

4) NCEP/NCAR reanalysis

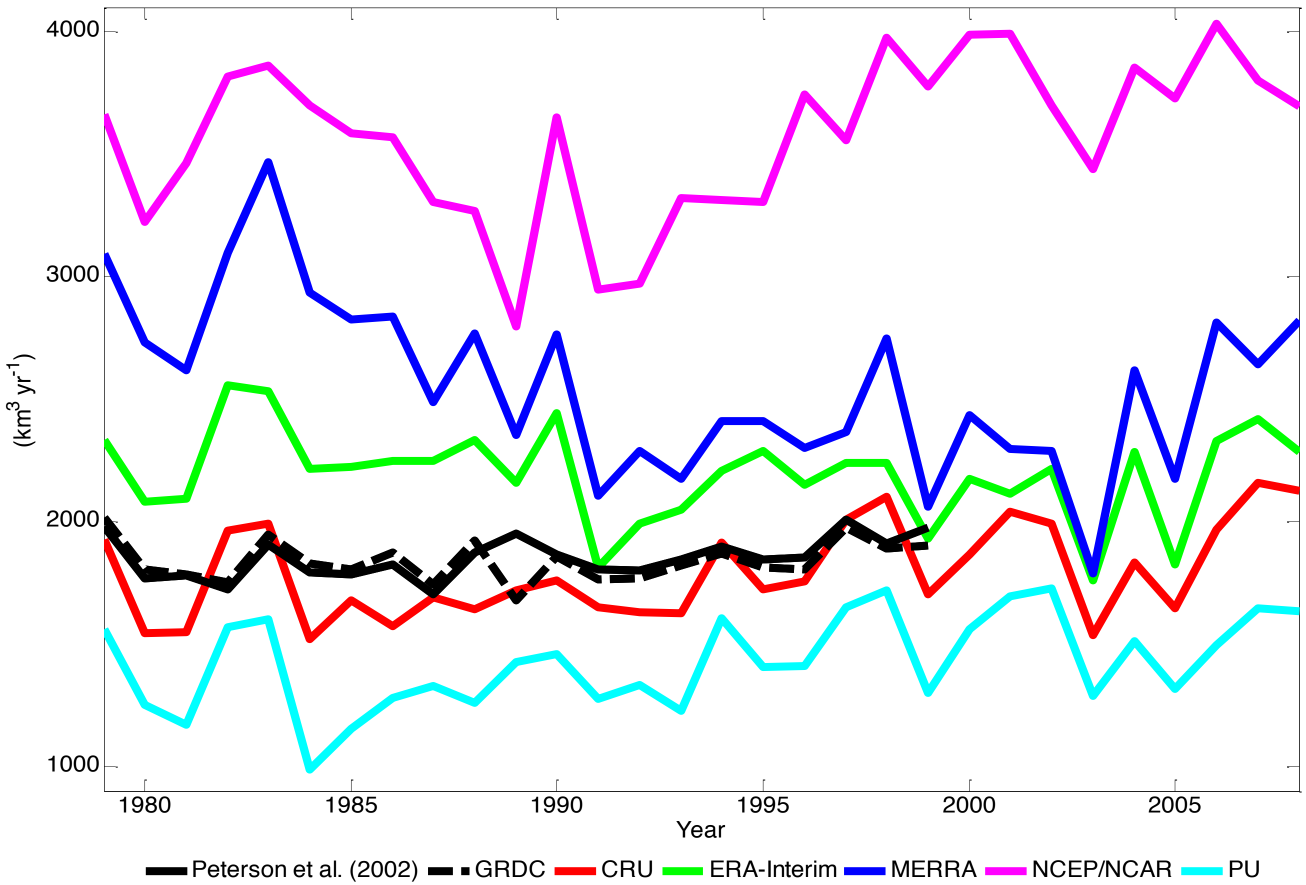
5) Global Meteorological Forcing Dataset for land surface modeling by Princeton University (PU).

Temporal ET variation



- Large ET spread (31% of mean ET, 90.1 mm yr^{-1}). ET_{PU} is closer to GLEAM, EVAL.
- mean temporal σ of ET ensemble >3 times the temporal σ of each product
- ET_{ERA} is the highest, with highest T, VPD and u.
- ET_{CRU} are the lowest, agreeing with the lowest T, R and P.

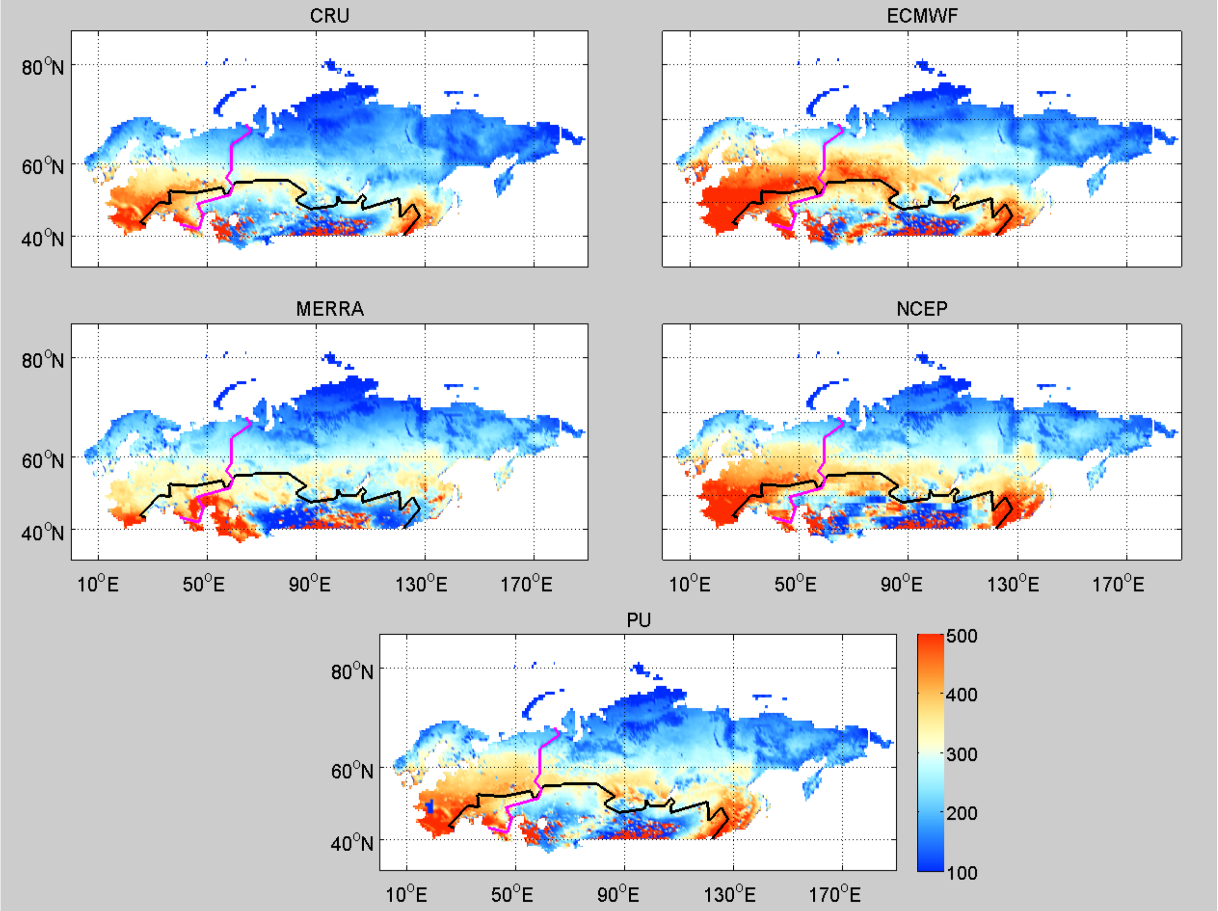
P-ET for 6 biggest watersheds



- $(P\text{-}ET)_{CRU}$ and $(P\text{-}ET)_{ERA}$ are closest to measurements, $(P\text{-}ET)_{NCEP}$ deviate most.

(Liu and Zhuang et al., 2014)

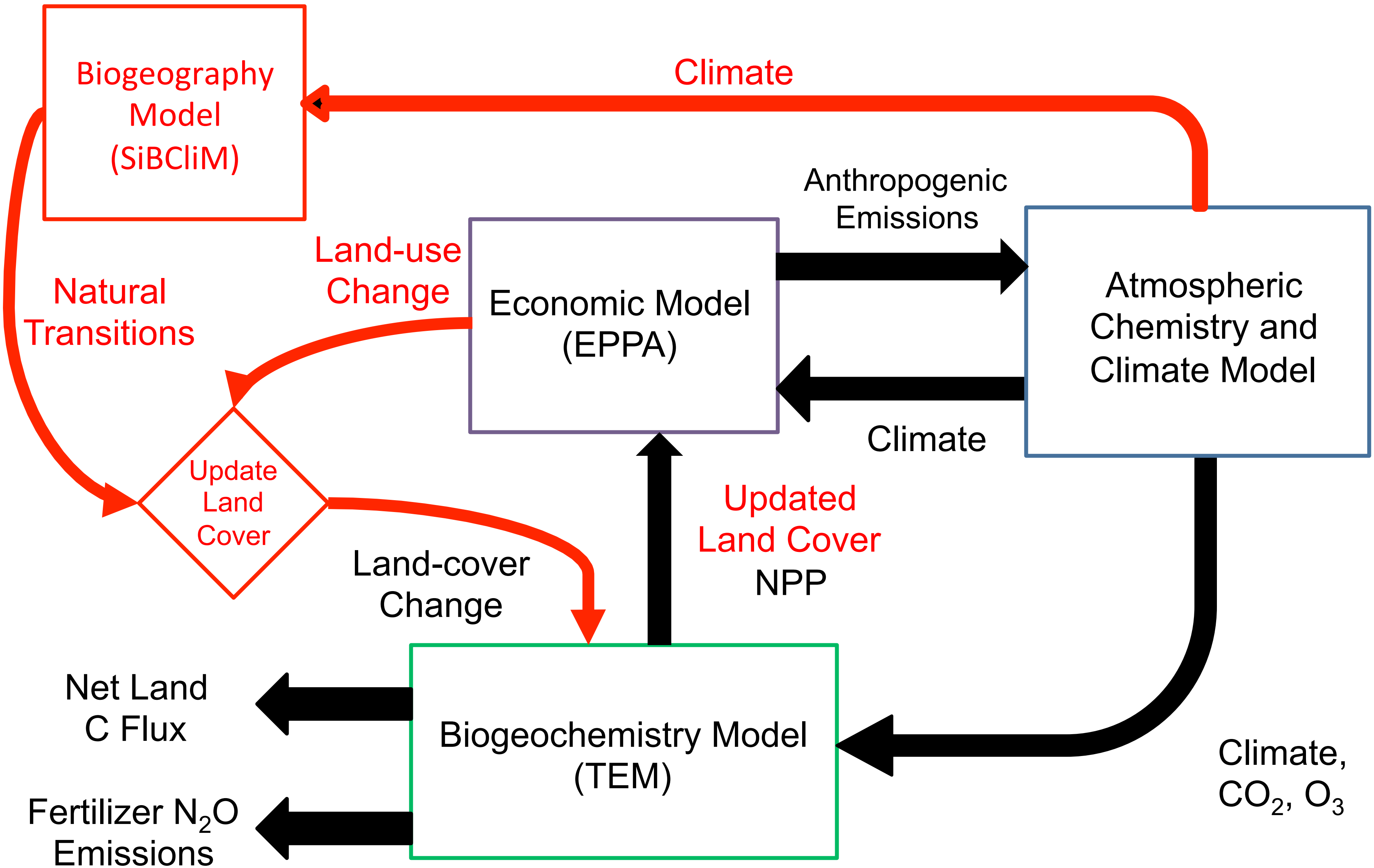
Spatial variation of ET



- Spatial patter are overall consistent.
- ET_{ERA} is higher in the west, due to higher P, T and VPD
- ET_{CRU} is overall lower, due to substantially lower R and T
- inter-product spatial σ > the mean spatial σ of each product

Summary-3

- Uncertain forcing data lead to a large spread of ET (90 mm yr^{-1}).
- While CRU dataset appears as a better choice, the quality of forcing data remains a major challenge for accurate quantification of the regional water balance.
- Dominant drivers of ET do not change with change of forcing data, namely T is dominant in the North and P in the South in growing season.

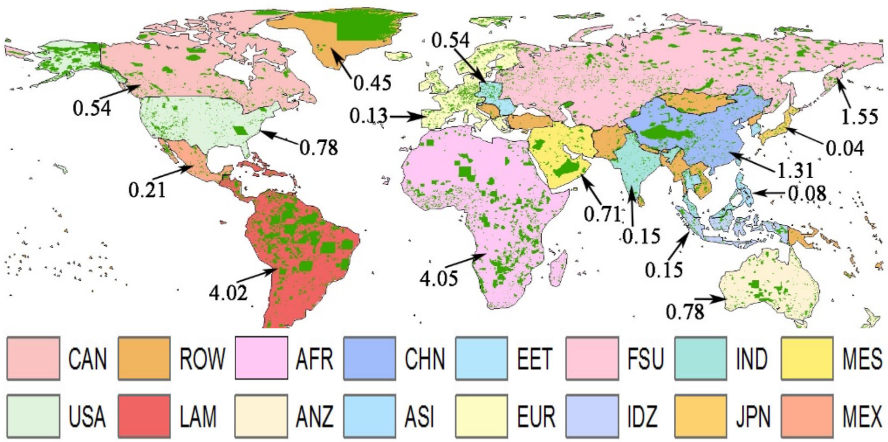


Biogeography Model (SiBCliM)
Climate
Anthropogenic Emissions
Land-use Change
Natural Transitions
Economic Model (EPPA)
Atmospheric Chemistry and Climate Model
Climate
Update Land Cover
Updated Land Cover
NPP
Land-cover Change
Net Land C Flux
Biogeochemistry Model (TEM)
Climate, CO_2, O_3
Fertilizer N_2O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

Protected Areas' Role in Climate-change Mitigation in Northern Eurasia

D. W. Kicklighter[1], X. Lu[1], E. Monier[2], A. P. Sokolov[2], J.M. Melillo[1], J. M. Reilly[2], and Q. Zhuang[3]
[1]MBL, Woods Hole, MA, USA; [2]MIT, Cambridge, MA, USA; [3] Purdue University, West Lafayette, IN, USA

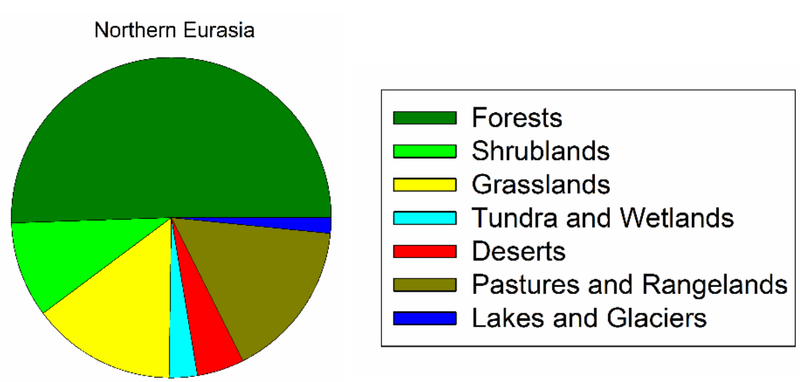
Distribution of Global Protected Areas



(Fig. 2 in Melillo et al., 2016, *Ambio* **45**, 133-145)

In Northern Eurasia, about **2.1 million km²** of land are currently identified as protected areas, which provide society with many ecosystem services including climate-change mitigation. These areas represent about 14% of the protected areas identified across the globe.

Distribution of Land Cover in Protected Areas

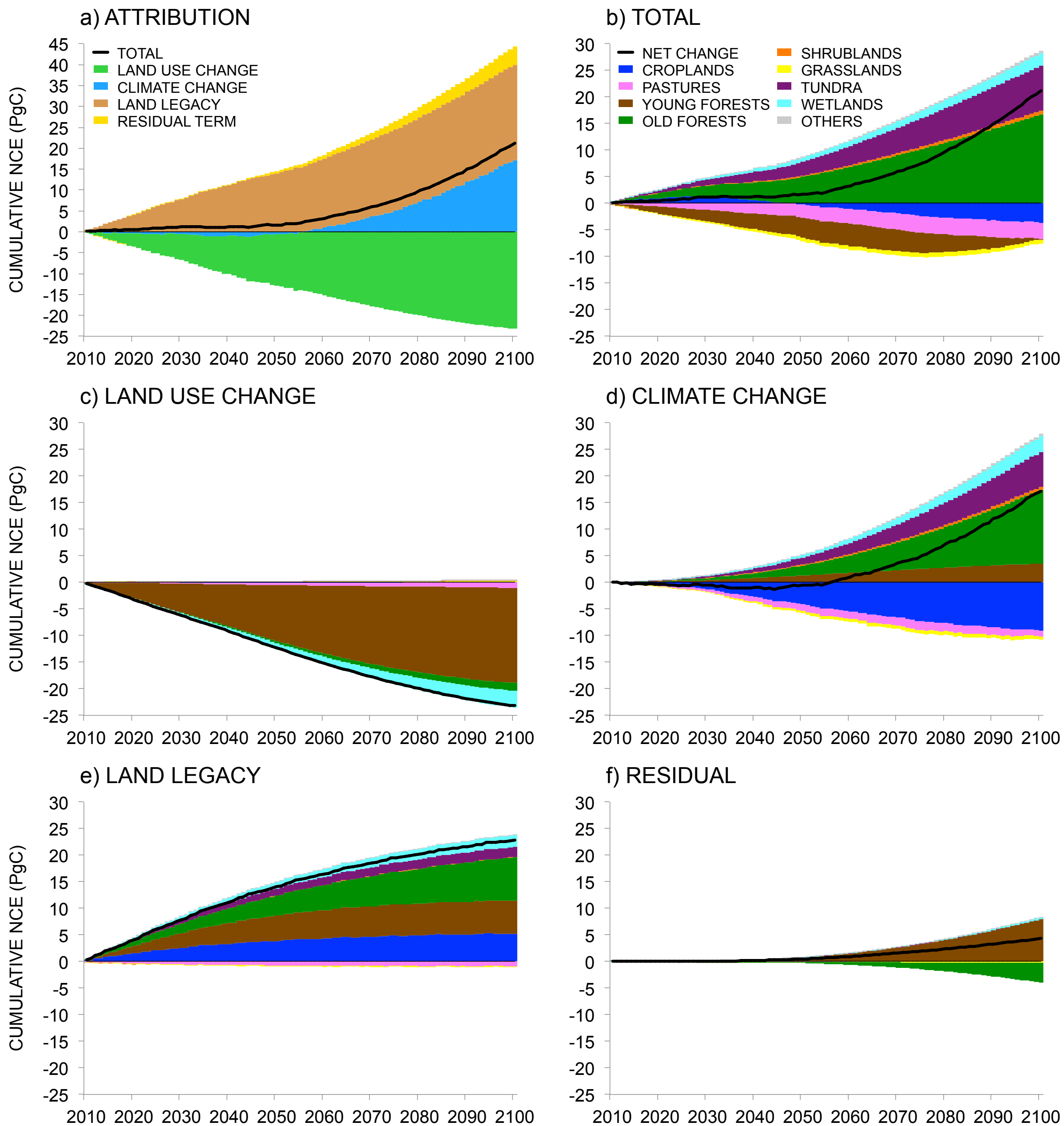


Combining a global database of protected areas, a reconstruction of global land-use history, and a terrestrial biogeochemistry model, we estimate that protected areas in Northern Eurasia currently sequester **0.05 Pg C annually**, which is about one tenth of the carbon sequestered by all land ecosystems annually in this region (0.5 Pg C yr^{-1}) and also about one tenth of the carbon sequestered in all protected areas across the globe.

Importance of land legacy on future carbon dynamics over Northern Eurasia

Erwan Monier, David Kicklighter, Jerry Melillo, Andrei Sokolov, John Reilly, and Qianlai Zhuang

Cumulative net carbon exchange (PgC) over Northern Eurasia from 2005 to 2100 for each component (land legacy, land-use change, climate change, total effects and residual) and decomposed by vegetation types for the RCP8.5 under the median climate sensitivity and averaged over the 5-ensemble members with different representations of natural variability



Next Steps

- **Incorporate local fine-scale socioeconomic dynamics into the global-scale analysis (e.g., land decision making for agriculture, mining, livestock)**

  - Implications to the climate system, ecosystem goods and services, adaptation and mitigation

- **Incorporate geographically-dependent natural processes and controls of climate and terrestrial biosphere into the global-scale analysis (e.g., fire, permafrost, drought)**