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VEGETATION COUPLING
The boreal and Arctic zone

Frode Stordal
Tang Hui, Johanne H Rydsaa
University of Oslo, Norway

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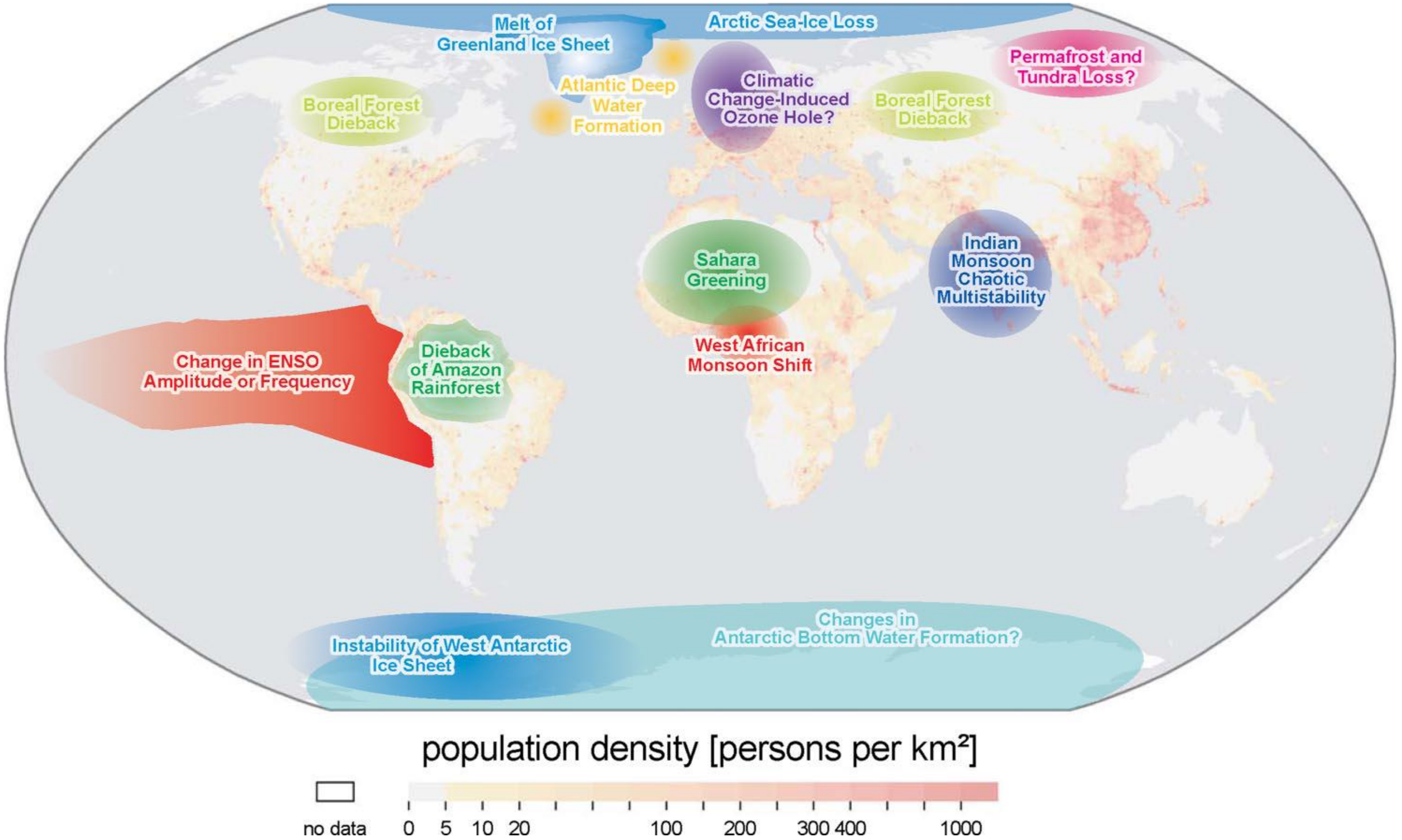
Outline

- Motivation and background
- WRF regional modelling vegetation impacts
  - Northward migration of vegetation in the Boreal and Arctic zones
- NorESM global climate modelling
  - Dynamic global vegetation modelling: CLM4.5 – BGCDV
  - Feedbacks and stability
- Summary and future research

Motivation Arctic vegetation as a tipping element



Lenton et al. 2008

Motivation Arctic vegetation as a tipping element

increased water stress, increased peak summer heat stress

↓

increased mortality, vulnerability to disease and subsequent fire, as well as decreased reproduction rates

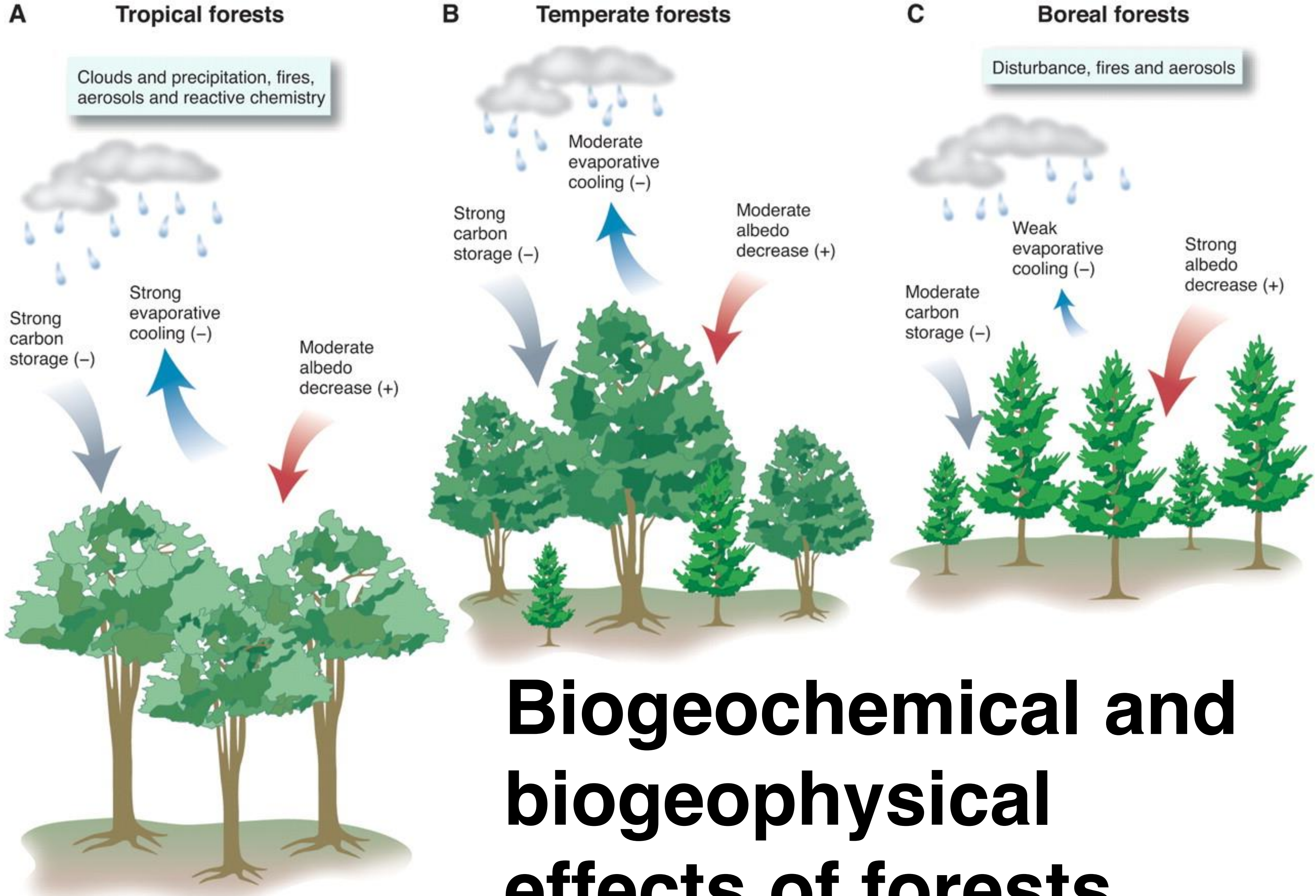
↓

Continental steppe grasslands will expand at the expense of boreal forest

Lenton et al. 2008

Tipping element	Boreal forest	Amazon rainforest
Feature (direction) of change	Tree fraction (-)	Tree fraction (-)
Control parameter	Local ΔT_{air}	Precipitation, dry season length
Critical value	+~7°C	1,100 mm/yr
Global warming	+~3-5°C	+~3-4°C
Transition timescale	~50 yr (gradual)	~50 yr (gradual)
Key impacts	Biome switch	Biodiversity loss, decrased rainfall

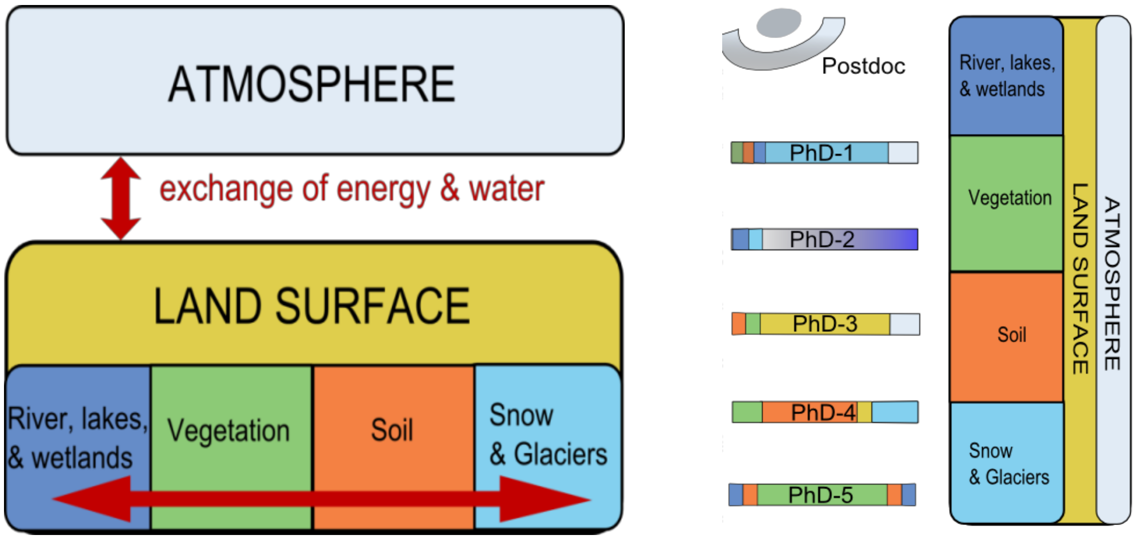
Lenton et al., PNAS, 2008



Biogeochemical and biogeophysical effects of forests

Bonan, Science , 2008

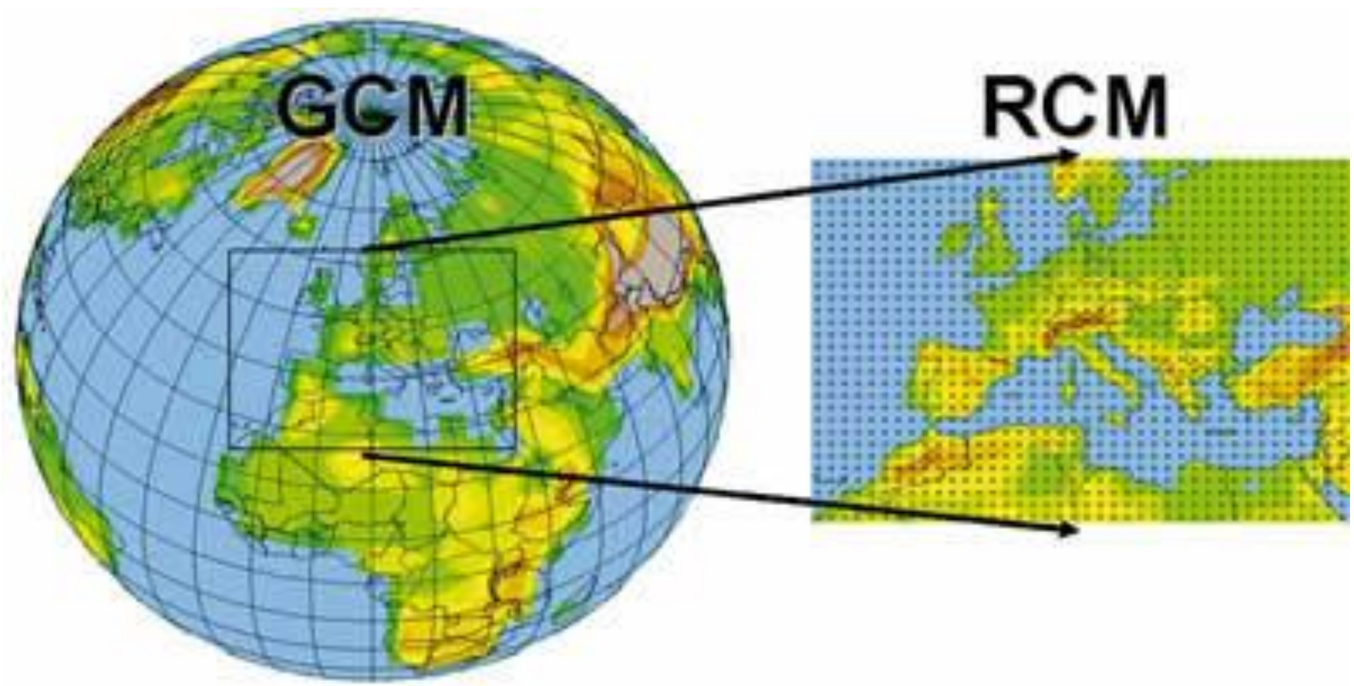
LATICE:
Land ATmosphere Interactions in Cold Environments



- Land-Atmosphere feedbacks and regional climate
- Cold environments (snow, ice, permafrost, vegetation)
- Interdisciplinary group at UiO (met, hyd, cryo, ecology)
- Observation and modelling based approach
- Process understanding yielding improved ESM

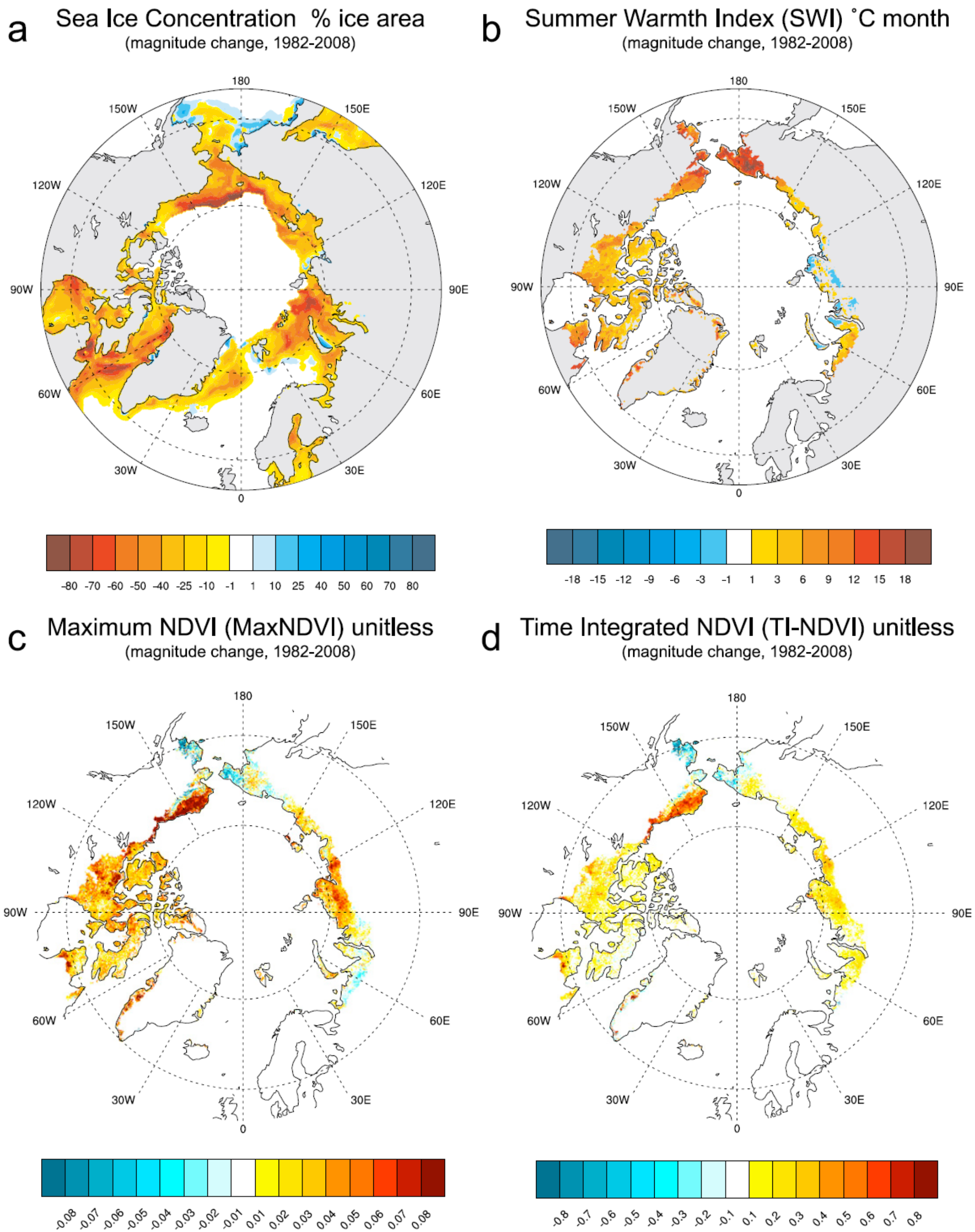
Climate modelling

Global: NorESM - CLM	Regional: WRF NOAH->CLM



Giorgi et al., WMO Bulletin

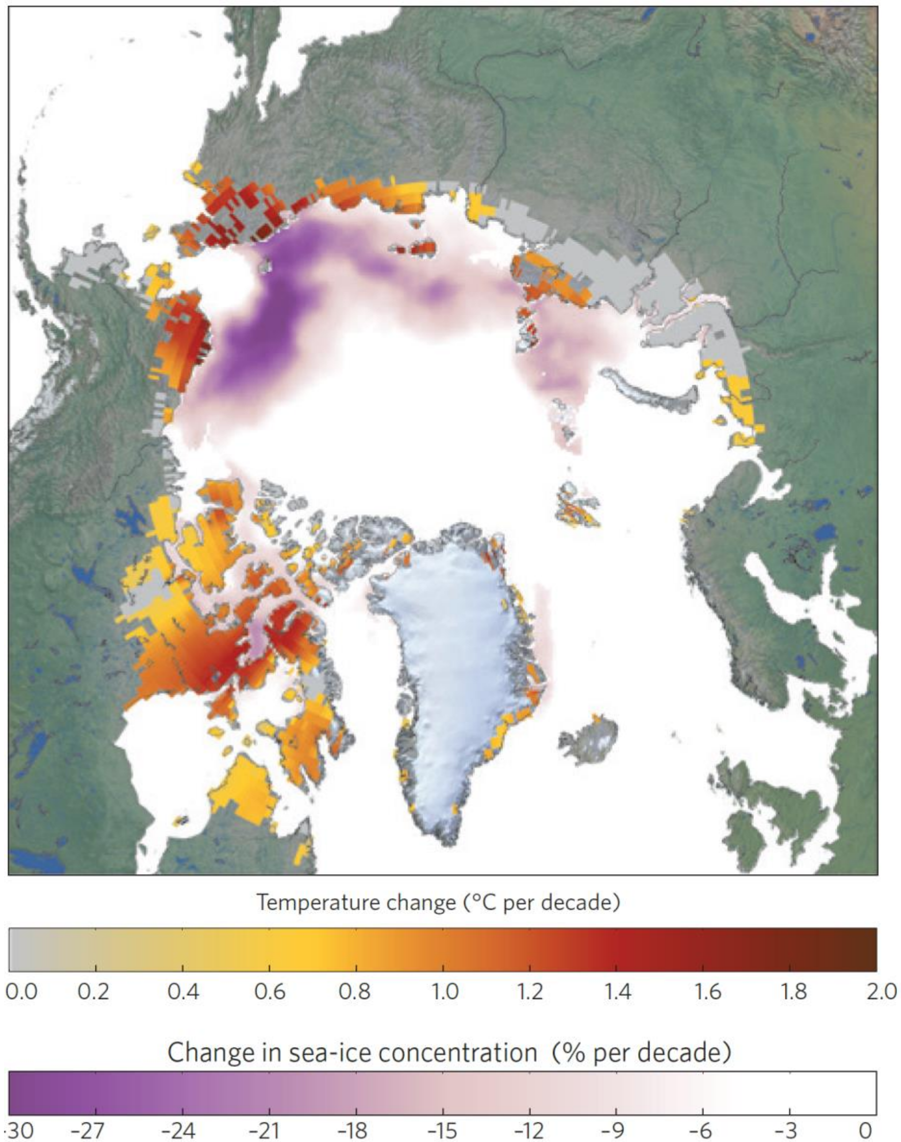
NDVI vs climate trends 1982-2008



Magnitude of Arctic trend from 1982 to 2008 (i.e., total trend magnitude over 27 yr) of (a) sea ice concentration at the 50% climatological value, (b) SWI, (c) MaxNDVI, and (d) TI-NDVI. SWI and NDVI trends are shown only for tundra regions (southernmost plot latitude is 558N and color scales are not linear).

Bhatt et al., Earth Interactions, 2010

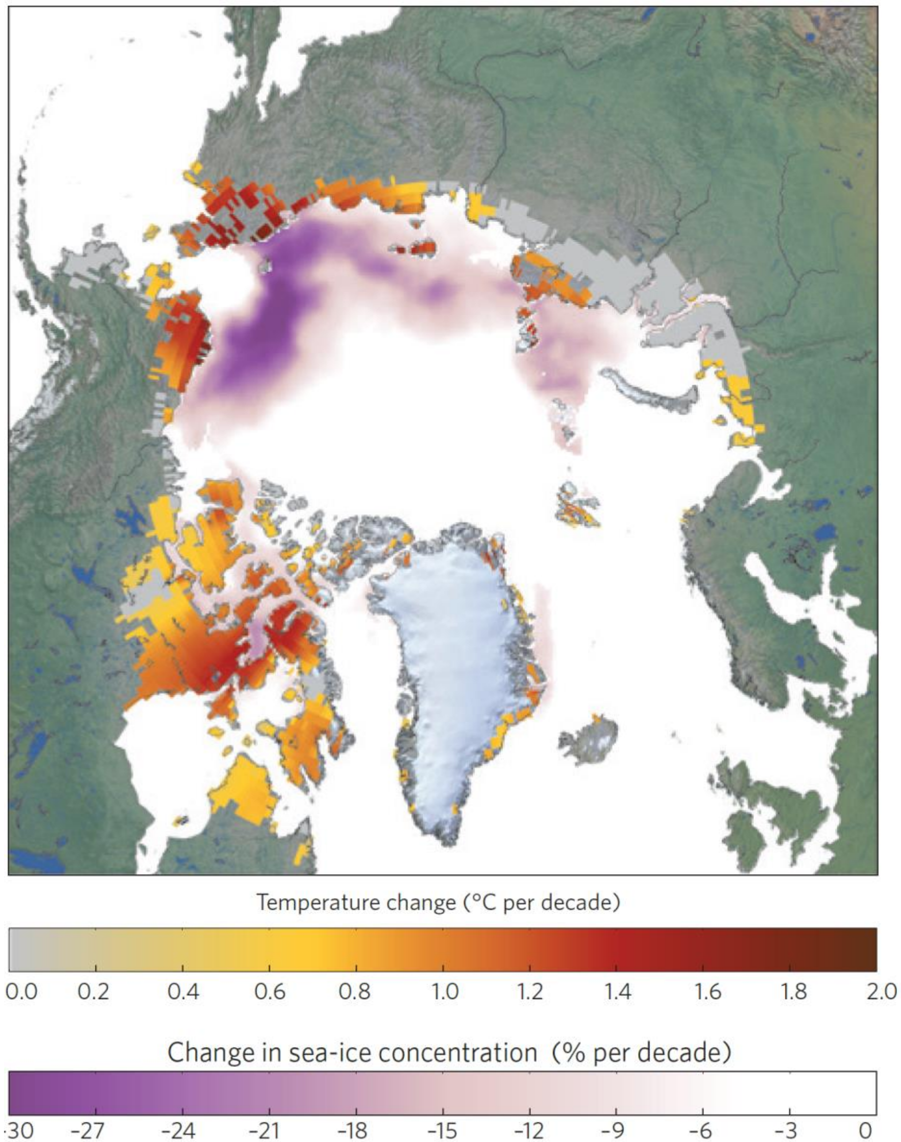
Arctic vegetation vs sea ice

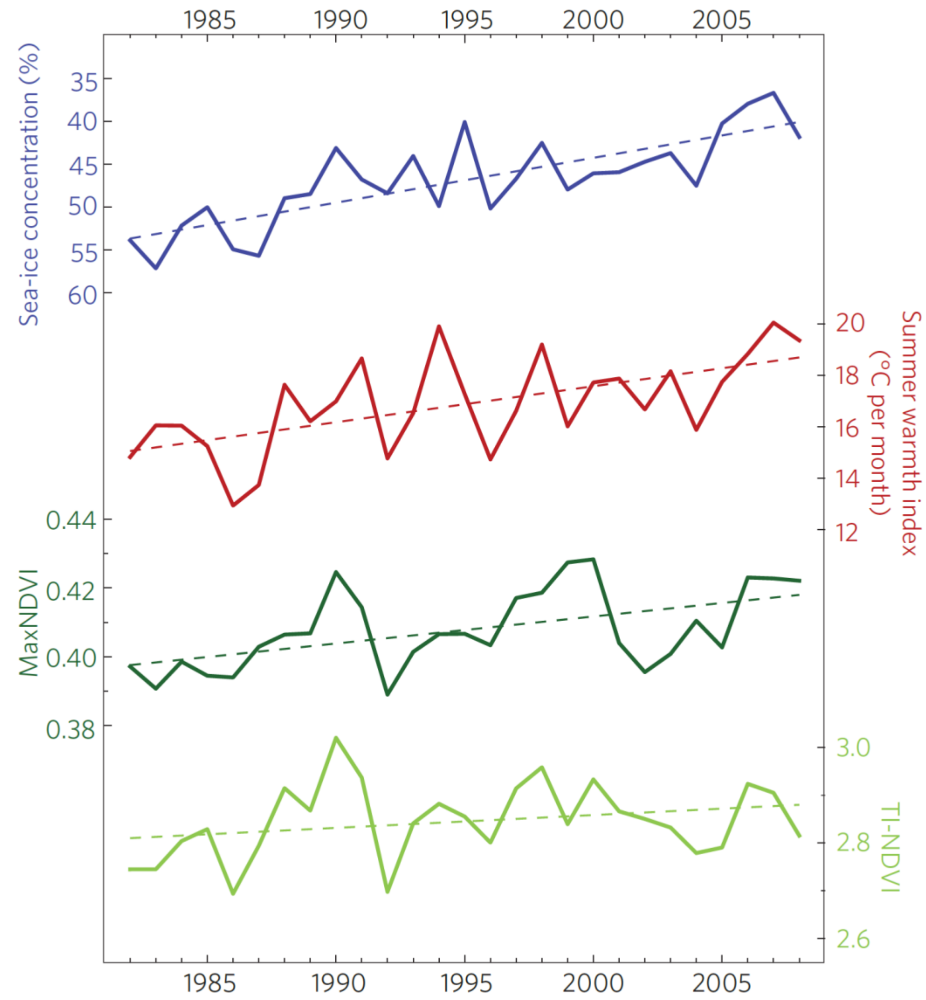


Autumn sea-ice and temperature trends in the Arctic. Linear trends in tundra mean air-temperature and sea-ice concentration (September and October, 1979 to 2011). Where temperature or sea-ice trends were insignificant ($p<0.05$), the value was set to zero (white for the ocean, grey for the tundra).

Parmentier et al. 2013, Nature Geosc

Arctic vegetation vs sea ice



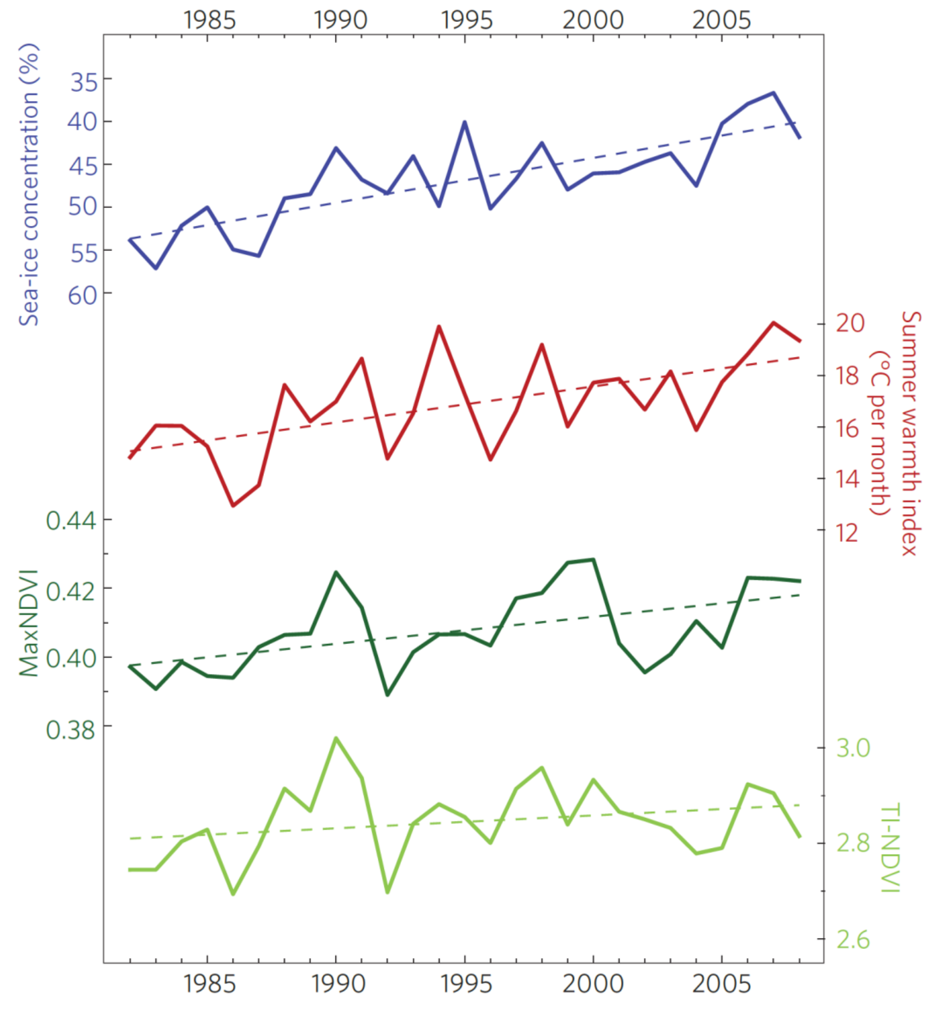


Parmentier et al. 2013, Nature Geosc

Arctic vegetation vs sea ice

Detrended time series of sea-ice concentration, SWI and TI-NDVI correlate with each other at a 95% level

Suggest a connection — through higher temperatures — between sea ice and plant productivity



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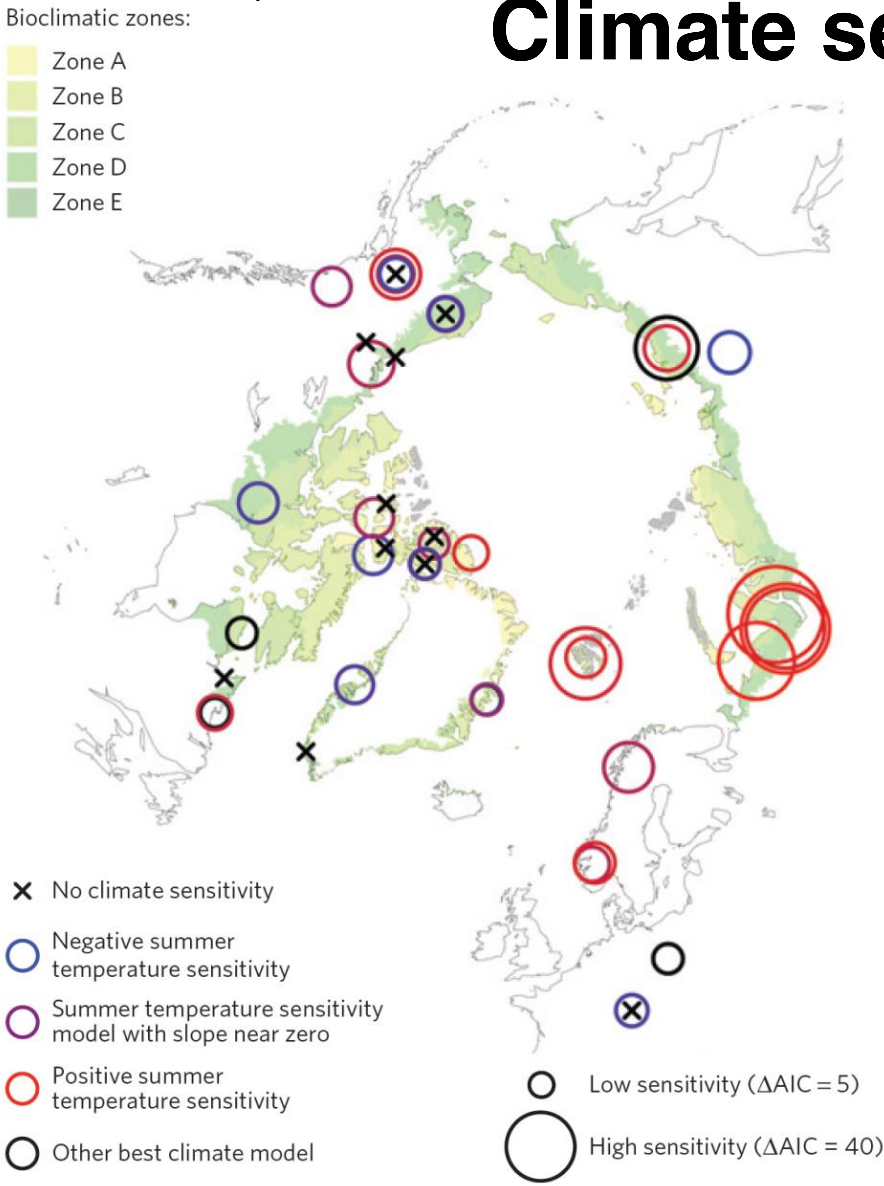
Climate sensitivity: Δgrowth/ ΔT



Dendroecological data (treerings), 37 sites, 25 species, 1950-2010

Dendroecological data (treerings)

- 37 sites
- 25 species
- 1950-2010

Climate sensitivity across the tundra biome. The size of the circle shows the strength of the summer temperature sensitivity as indicated by the ΔAIC. The colour of the circles indicates the direction of the relationship with summer temperature variables. Locations with multiple circles indicate study sites where multiple species were sampled.

Myers-Smith et al., Nature Climate Change, 2015

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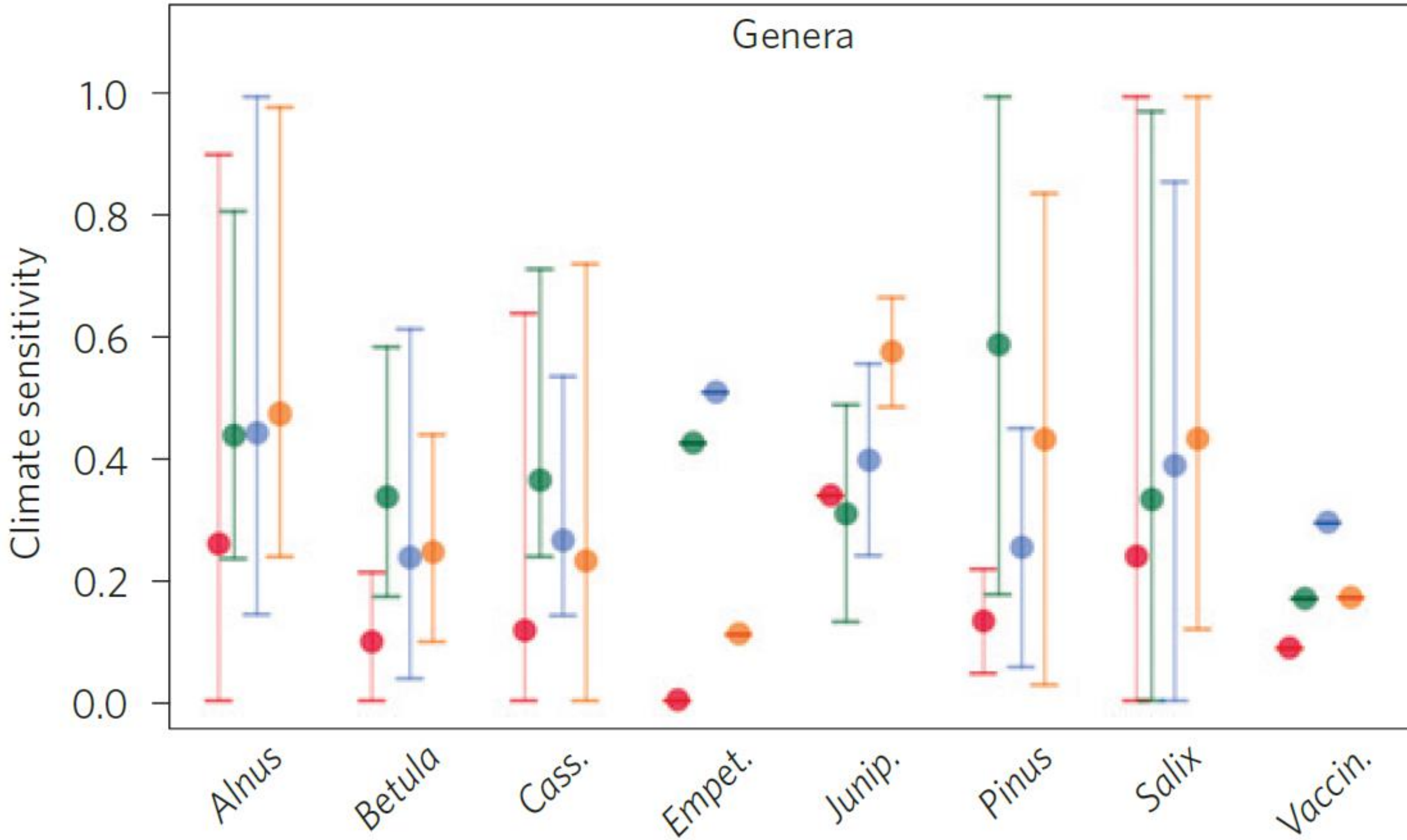
Climate sensitivity: Δgrowth/ΔT



Dendroecological data (treerings), 37 sites,
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Myers-Smith et al., Nature Climate Change, 2015

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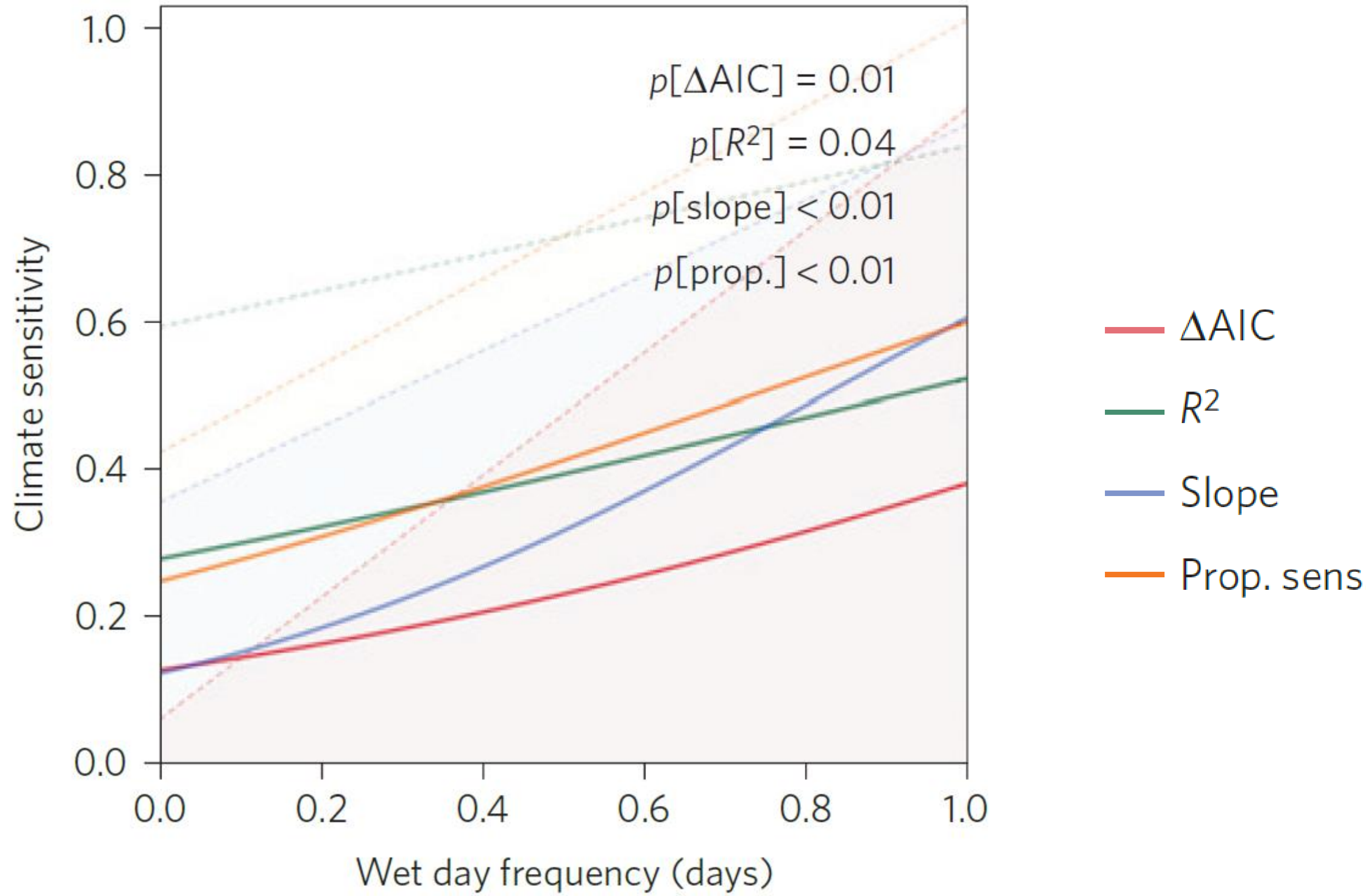

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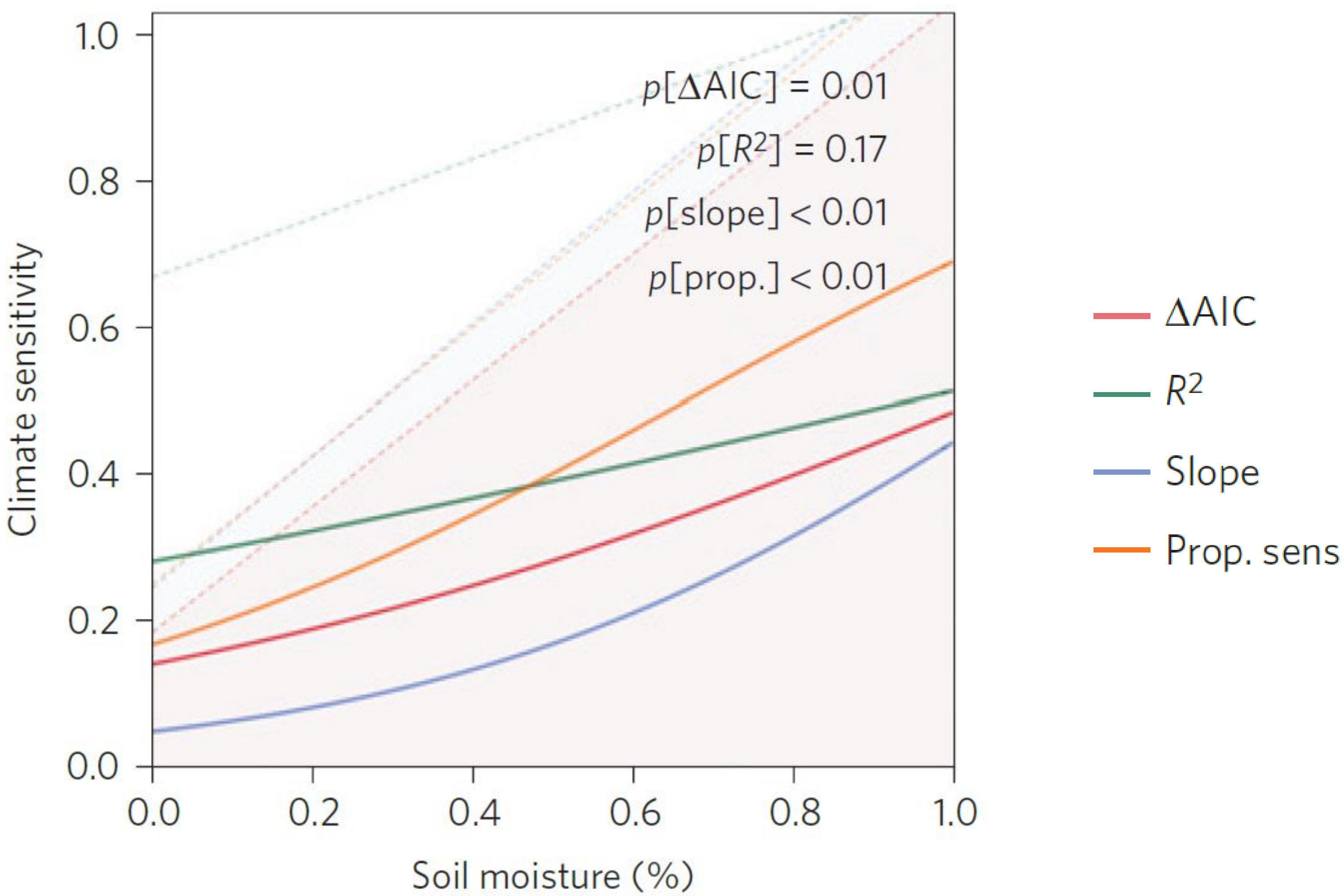

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Biogeosciences, 12, 3071–3087, 2015
www.biogeosciences.net/12/3071/2015/
doi:10.5194/bg-12-3071-2015

Biogeosciences Open Access

Sensitivity of the regional European boreal climate to changes in surface properties resulting from structural vegetation perturbations

J. H. Rydsaa, F. Stordal, and L. M. Tallaksen

Department of Geosciences, University of Oslo, Oslo, Norway

Correspondence to: J. H. Rydsaa (j.h.rydsaa@geo.uio.no)

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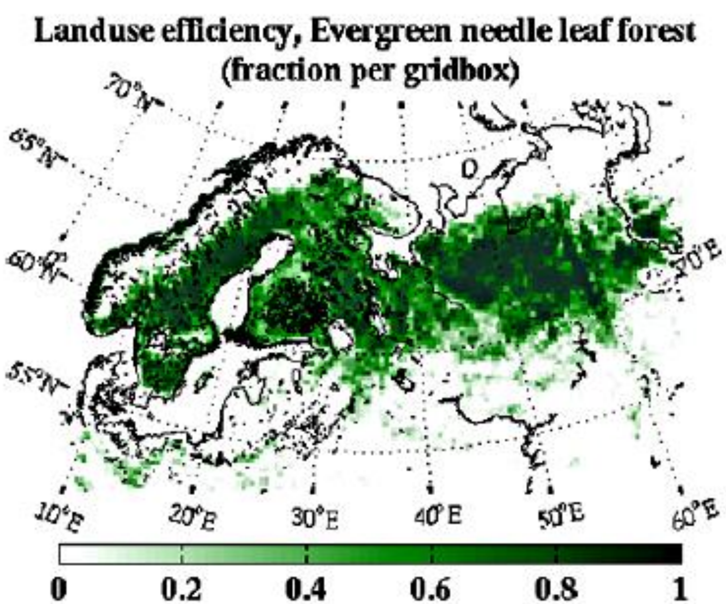


Investigates atmospheric response to specific, observed and anticipated vegetation changes in the boreal region

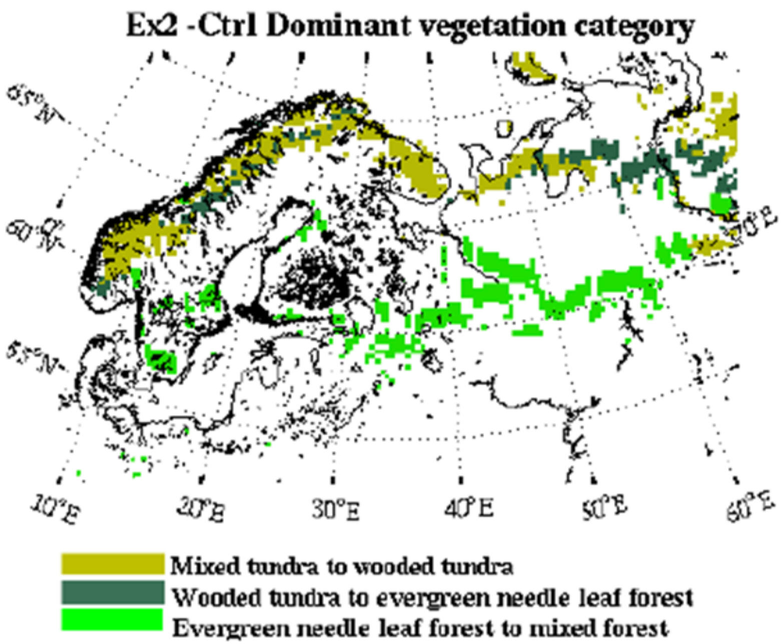
Manually imposed land cover perturbations

- **Weather Research and Forecasting Model V3.5.1 (WRF)**
- NOAH LSM
- 27 km x 27 km resolution
- 10 year simulation

Vegetation cover perturbations:

To the north:
Migration of evergreen needleleaf boreal forest and shrub cover increase

From the south:
Mixing broad leaf forest into needle leaf



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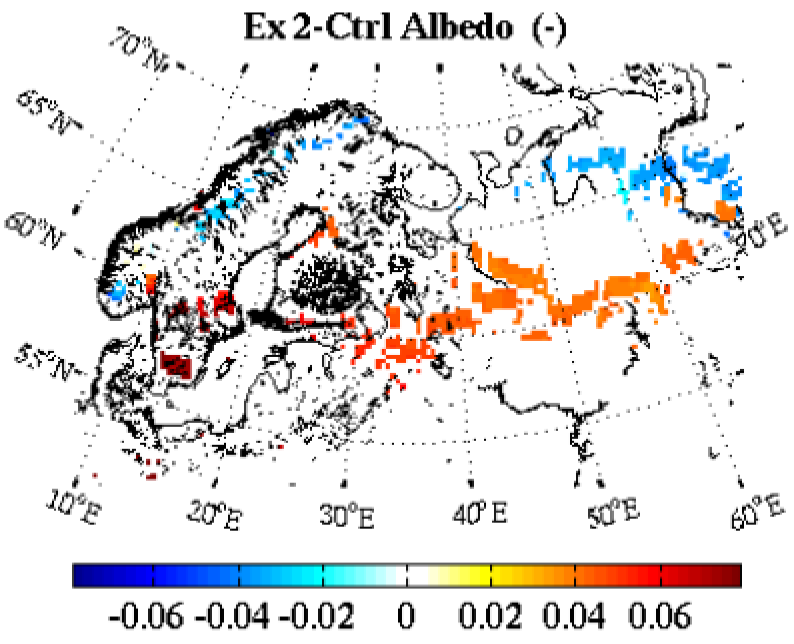
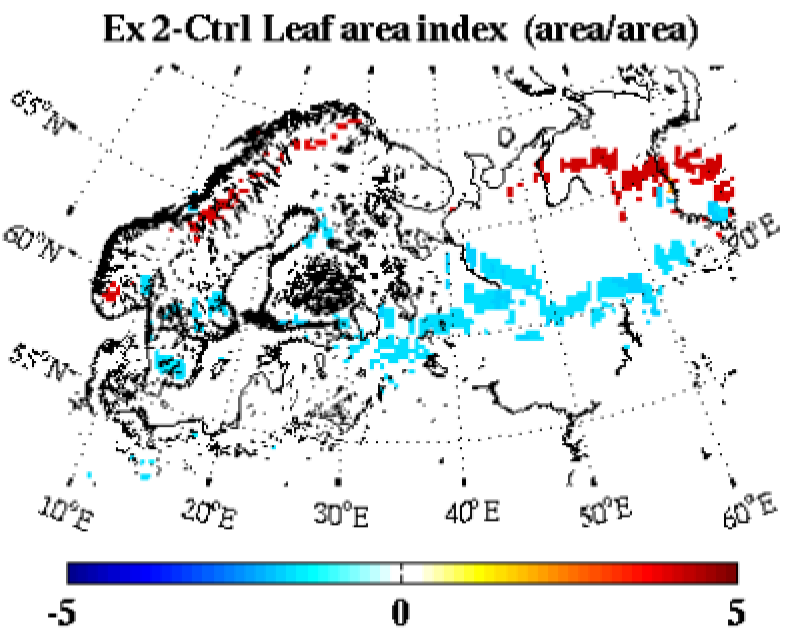
- 10 year simulation

Biophysical changes in surface properties

- Evergreen needleleaf forest taking over for tundra (northern border):
  - Albedo decrease, LAI increase
- Mixed forest taking over for needleleaf forest (southern border):
  - Albedo increase, LAI decrease





10 year annual means. From Rydsaa et al. (2015)

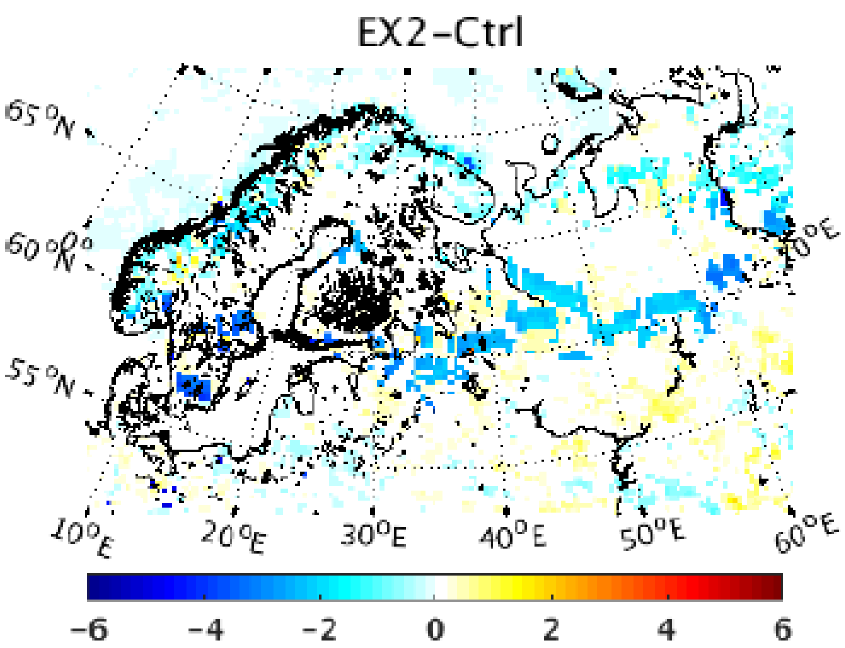
Effect on surface fluxes

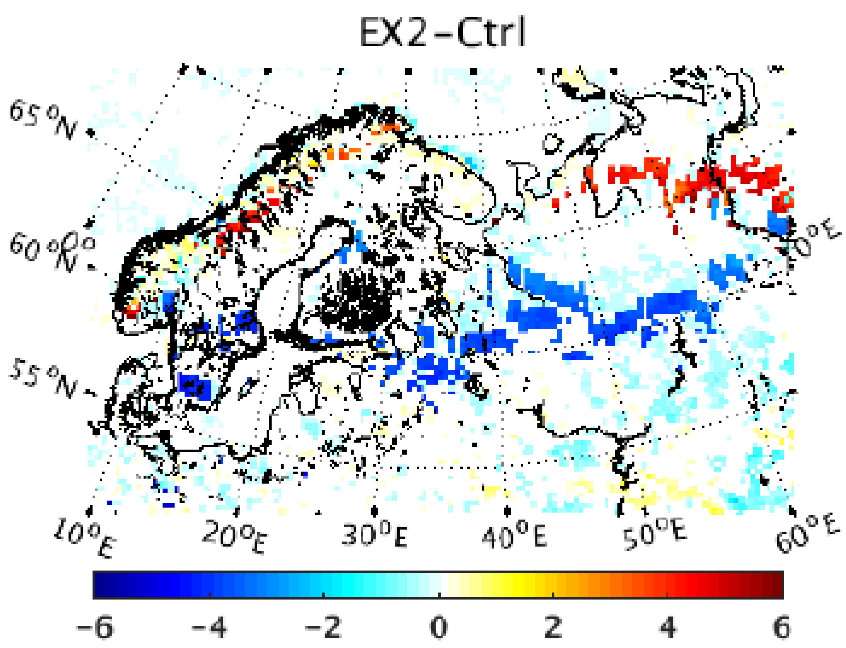
Sensible heat flux

- Weak decrease along northern border due to increased LH/cloud cover and weaker windspeeds
- Strong decrease along southern border due to increased albedo

Latent heat flux

- Strong increase along northern border due to increased LAI and deeper roots
- Strong decrease along southern border due to decreased LAI and icreased albedo





10 year annual means. (Only showing significant results at the 95% confidence level). From Rydsaa et al. (2015)

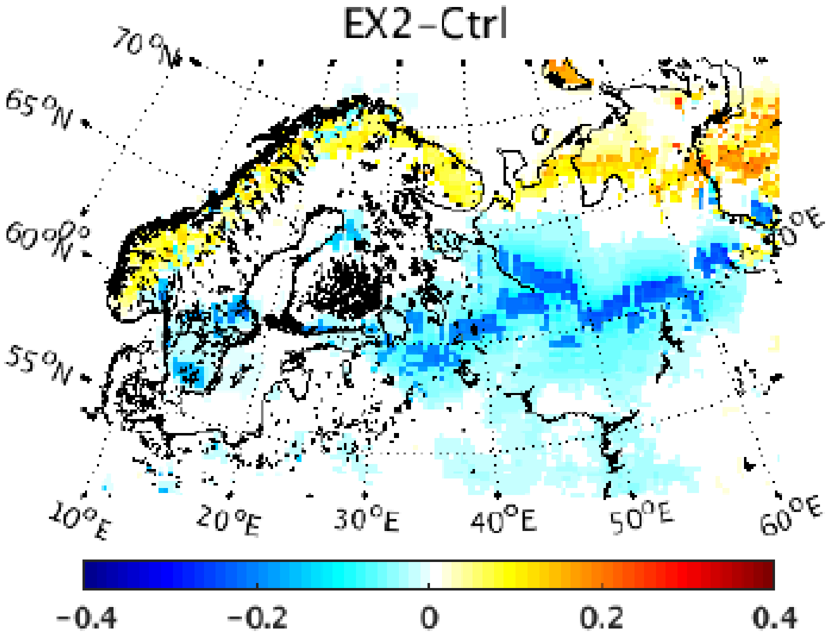
Effect on near surface temperature and humidity

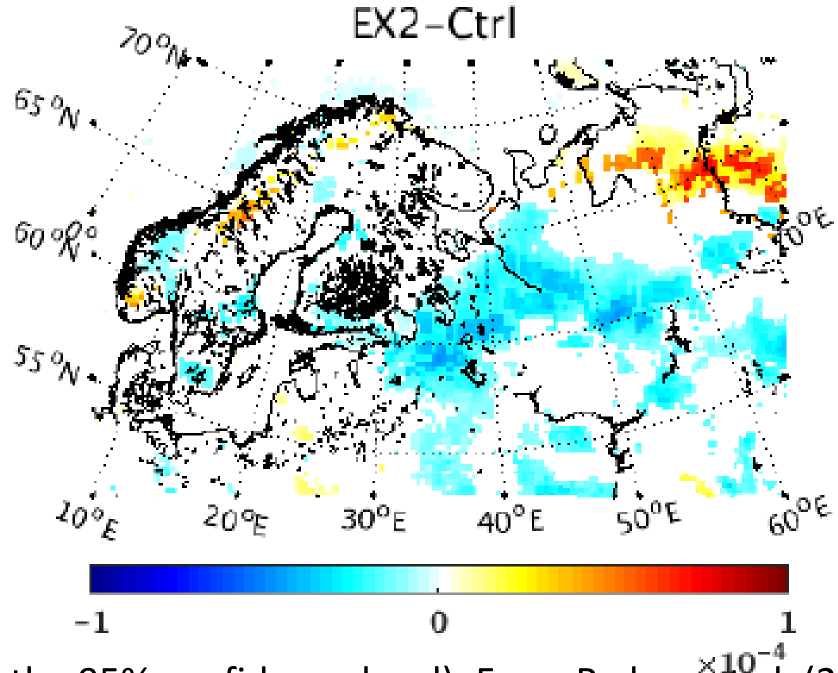
Near surface temperature (2m)

- Increased near surface temperature (2m) along northern border and shrub increase areas
- Decreased along southern border and surroundings

Absolute humidity (2m)

- Increase in areas with increase in evergreen needleleaved forest
- Decrease along southern border due to decreased LH





10 year annual means. (Only showing significant results at the 95% confidence level). From Rydsaa et al. (2015)

Shrub expansion: zooming in

MOTIVATION

Investigate the land-atmosphere interactions and **feedback mechanisms** induced by increased shrub cover

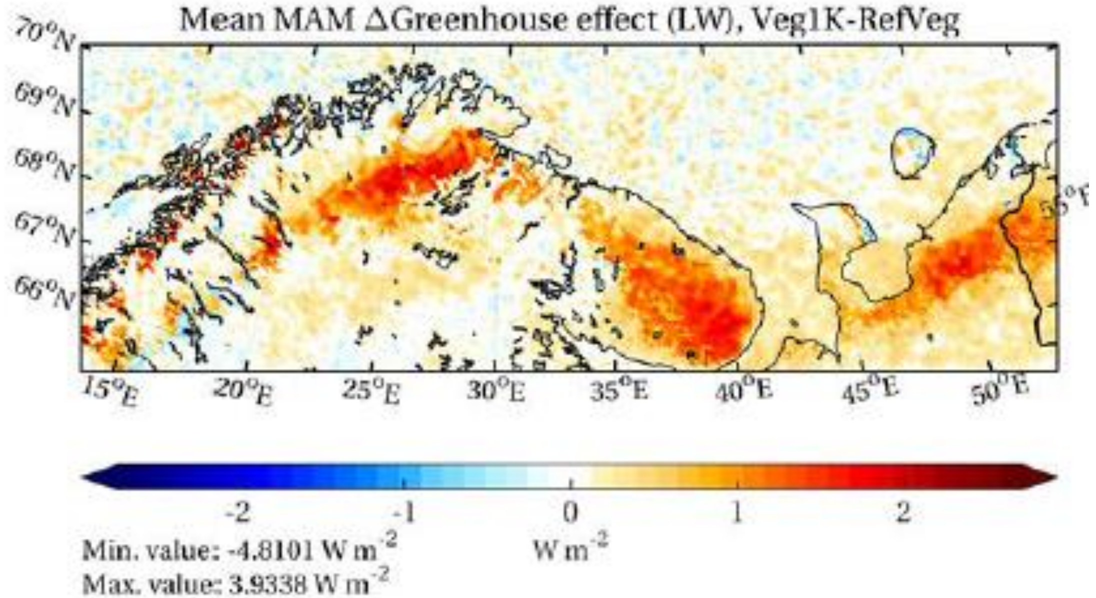
Determine effect of **varying shrub cover height** and sensitivity to **snow cover** and **temperature** on atmospheric response.

METHODOLOGY

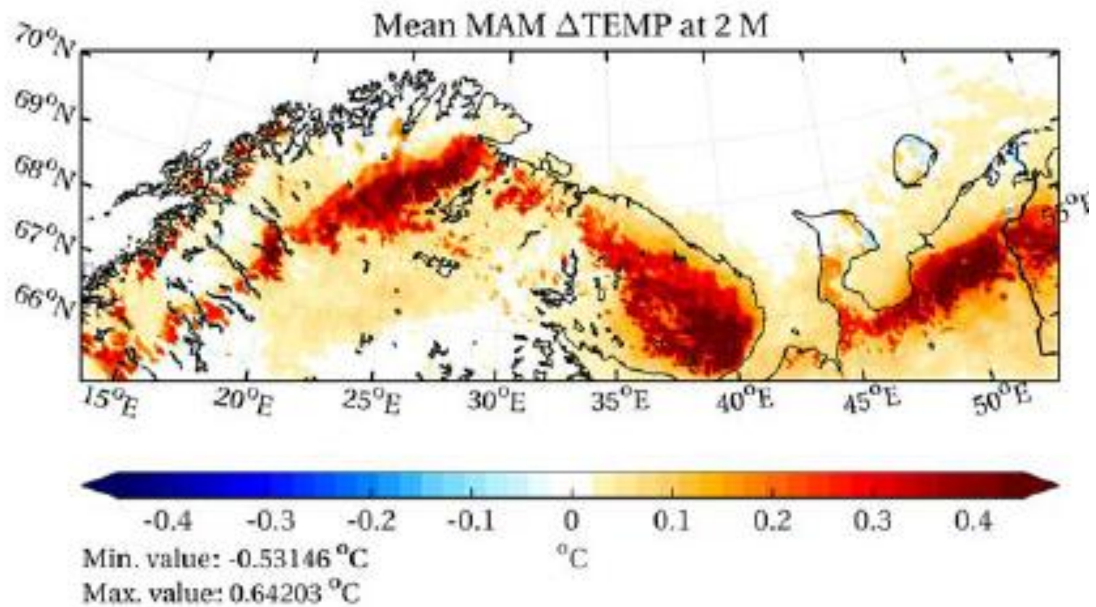
- WRF with NOAH-UA land model with high resolution (5.4 km)
- 2 summer seasons: warm, cold
- 2 spring seasons: snow rich, snow poor

- Vegetation zones derived by summer temperatures
- 3 shrub categories with different height
  - Sub alpine >5 m
  - Low alpine (2-5 m)
  - Mid alpine (0.5-2 m)

Change in greenhouse effect ($LW_{surface} - LW_{TOA}$)

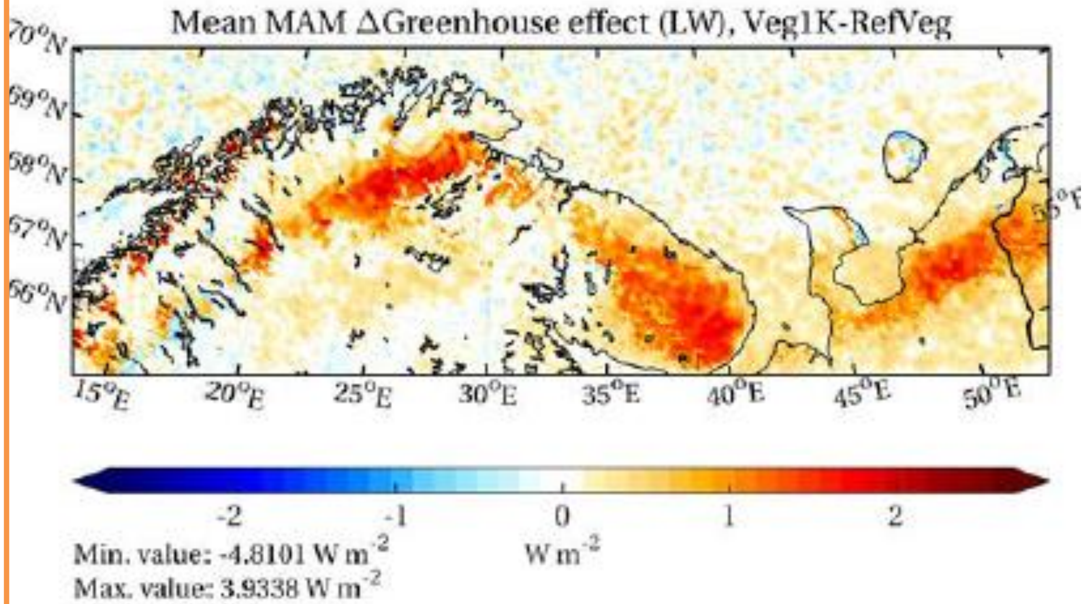


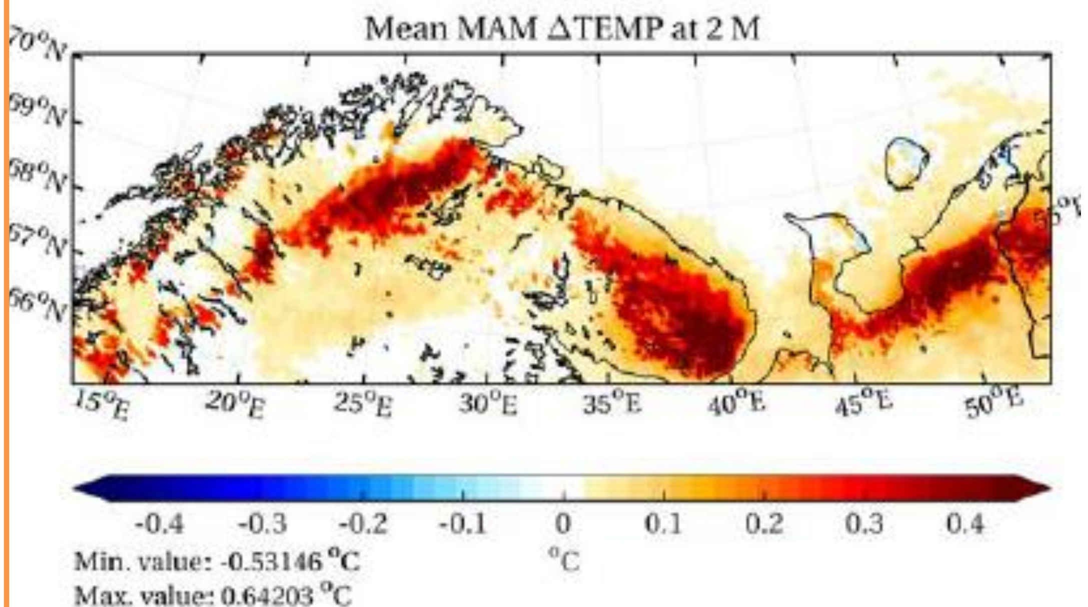
Change in temperature



Increased shrub cover leads to

- Increased near surface temperatures
- Earlier onset of melting season
- Increased latent heat flux
- More atmospheric water, clouds and precipitation
- Increased greenhouse effect
- Strongest effect in areas with taller shrubs

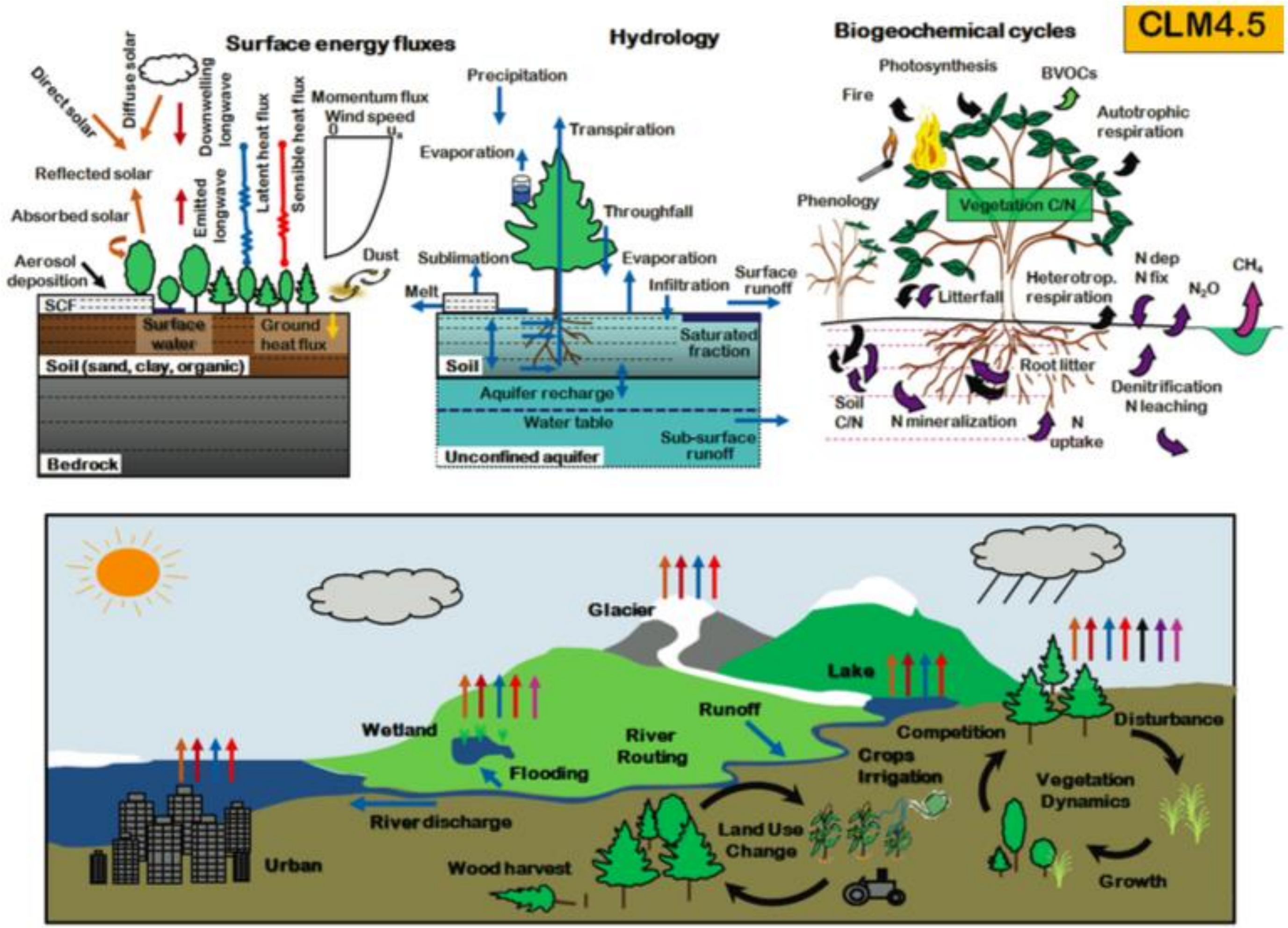




Dynamic global vegetation model (DGVM) in NorESM

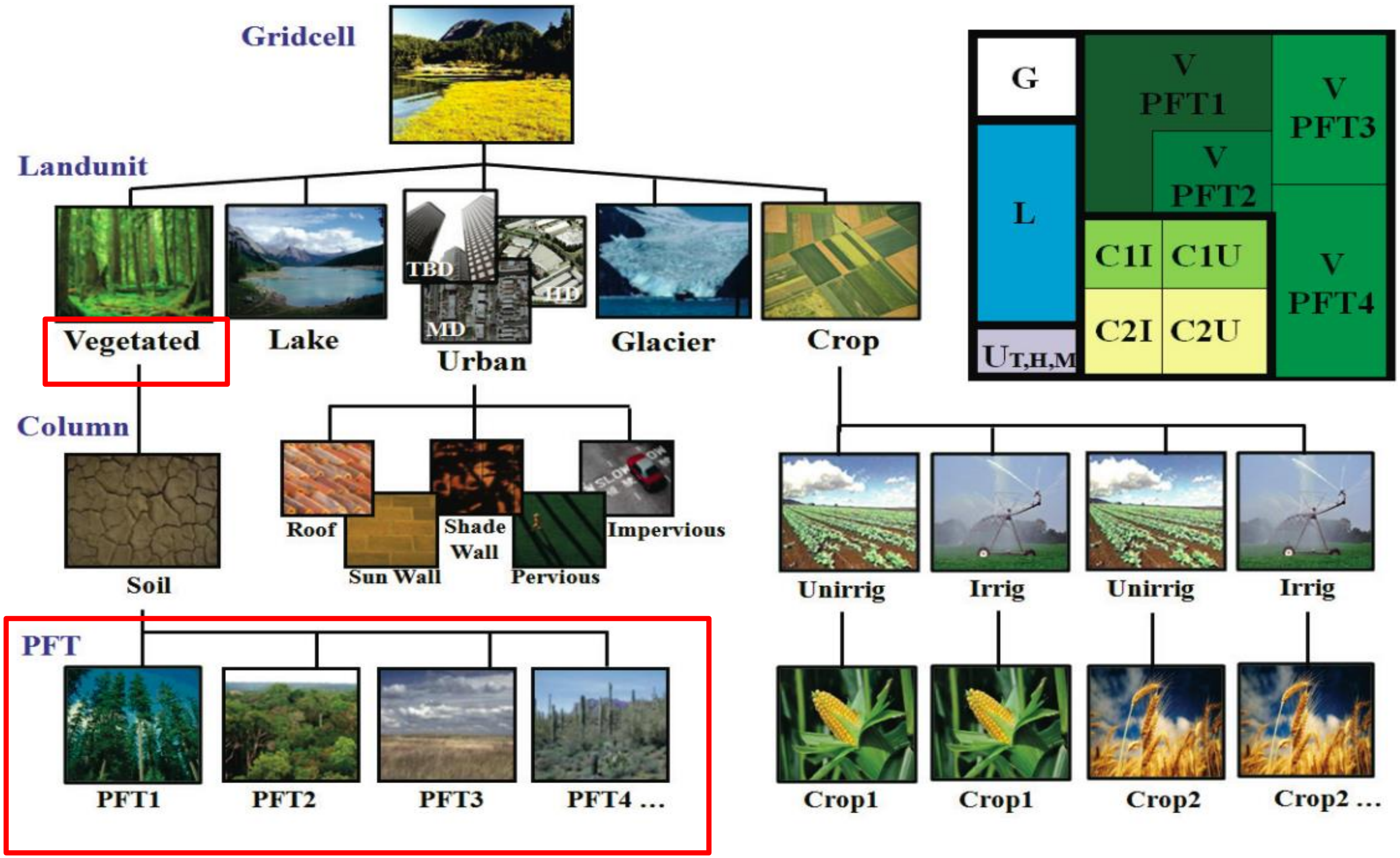
CLM4.5-BGCDV

- CN cycle
- vegetation dynamics
- vertical-layer soil biogeochemistry based on CENTURY model



Oleson et al. 2013

CLM4.5-BGCDV: Sub-Grid Structure



Oleson et al. 2013

CLM4.5-BGCDV: Plant functional types (PFTs)

PFT and PFT number corresponding to the list of PFTs in Table 2.1		Survival $T_{c,min}$ (°C)	Establishment $T_{c,max}$ (°C)	GDD_{min}
Tropical broadleaf evergreen tree (BET)	(4)	15.5	No limit	0
Tropical broadleaf deciduous tree (BDT)	(6)	15.5	No limit	0
Temperate needleleaf evergreen tree (NET)	(1)	-2.0	22.0	900
Temperate broadleaf evergreen tree (BET)	(5)	3.0	18.8	1200
Temperate broadleaf deciduous tree (BDT)	(7)	-17.0	15.5	1200
Boreal needleleaf evergreen tree (NET)	(2)	-32.5	-2.0	600
Boreal deciduous tree	(8)	No limit	-2.0	350
Temperate broadleaf deciduous shrub (BDS)	(10)	-17.0	No limit	1200
Boreal broadleaf deciduous shrub (BDS)	(11)	No limit	-2.0	350
C_4	(14)	15.5	No limit	0
C_3	(13)	-17.0	15.5	0
C_3 arctic	(12)	No limit	-17.0	0

Oleson et al. 2013

Present-day runs

Atm run

CAM5+CLM4.5SP: 10 yr
Prescribed veg. & phenology

Veg run: spin-up

CLM4.5-BGCDV: 400 yr
Prescribed atmosphere (Qian et al. 2006)

→

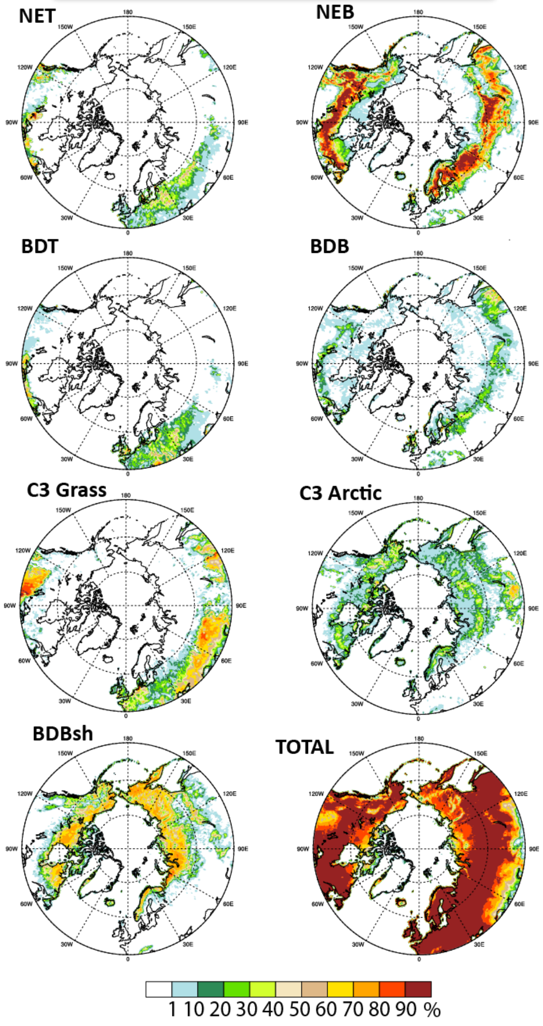
AtmVeg run

CAM5+CLM4.5-BGCDV: 30 yr
↓
CLM4.5-BGCDV: 100 yr
↓
CAM5+CLM4.5-BGCDV: 30 yr

Resolution:
CAM5: 1.9x2.5, 30 level
CLM4.5: 1.9x2.5 15 soil levels
Prescribed SST in all experiments

Plant cover fraction (%)

Observation



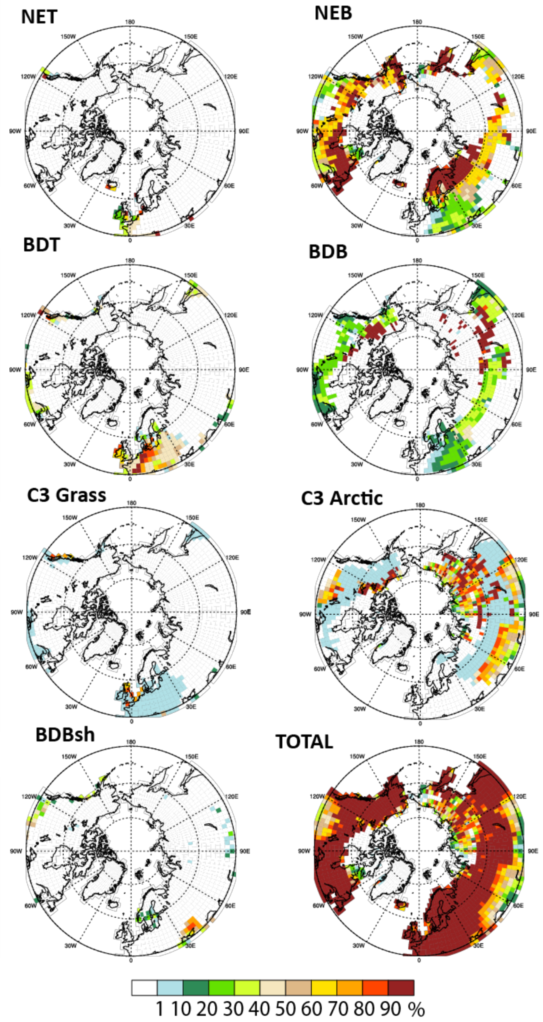
NET: Needleleaf evergreen temperate tree
NEB: Needleleaf evergreen boreal tree

BDT: Broadleaf deciduous temperate tree
BDB: Broadleaf deciduous boreal tree

C3 grass
C3 Arctic Grass

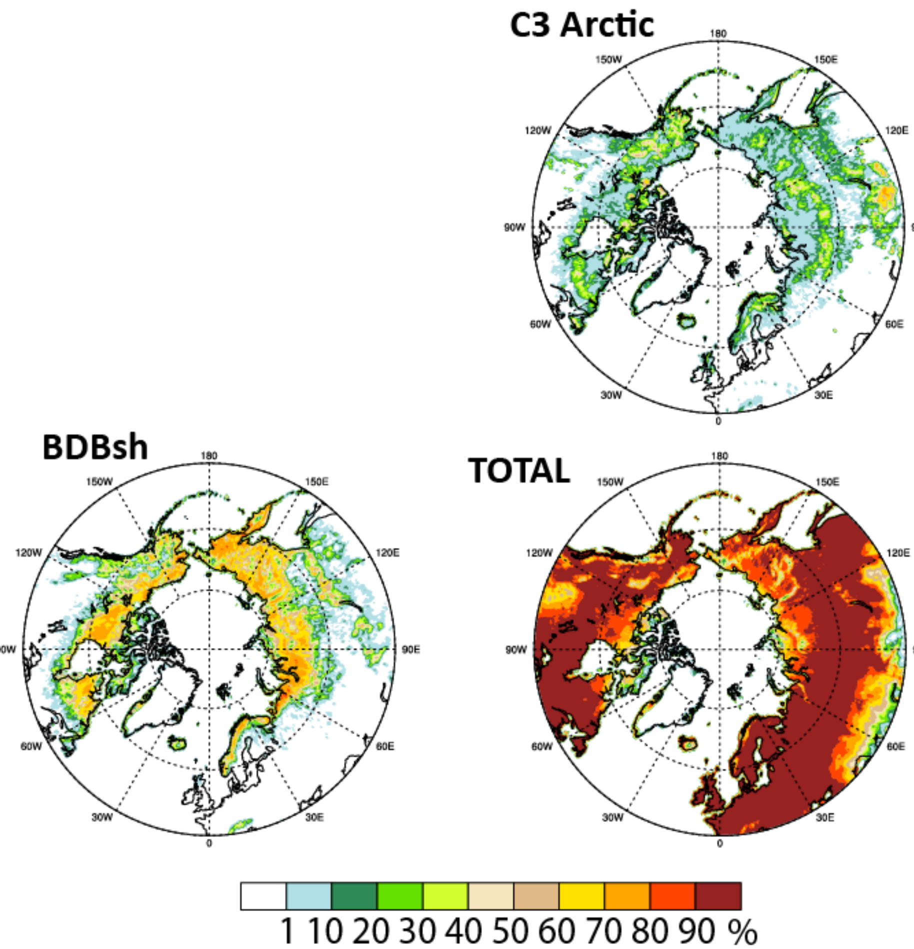
BDBsh: Broadleaf deciduous boreal shrub
Total: Total plant cover

Veg run

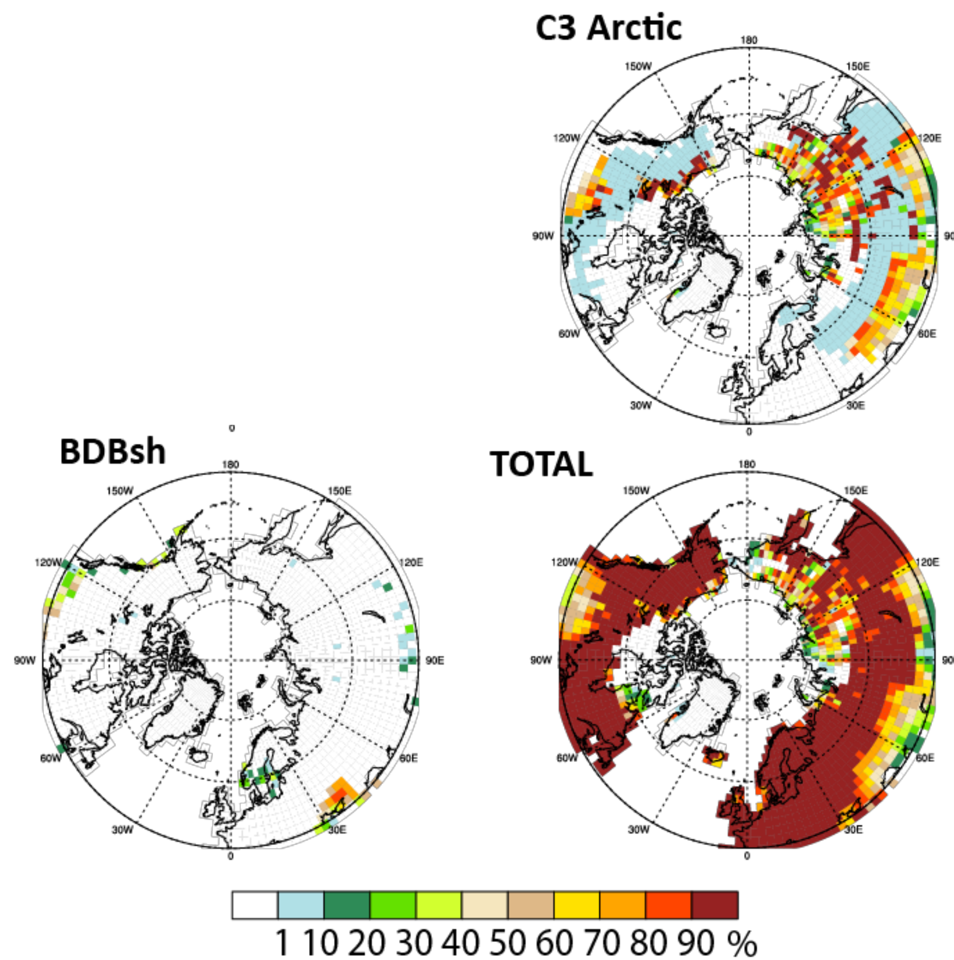


Plant cover fraction (%)

Observation

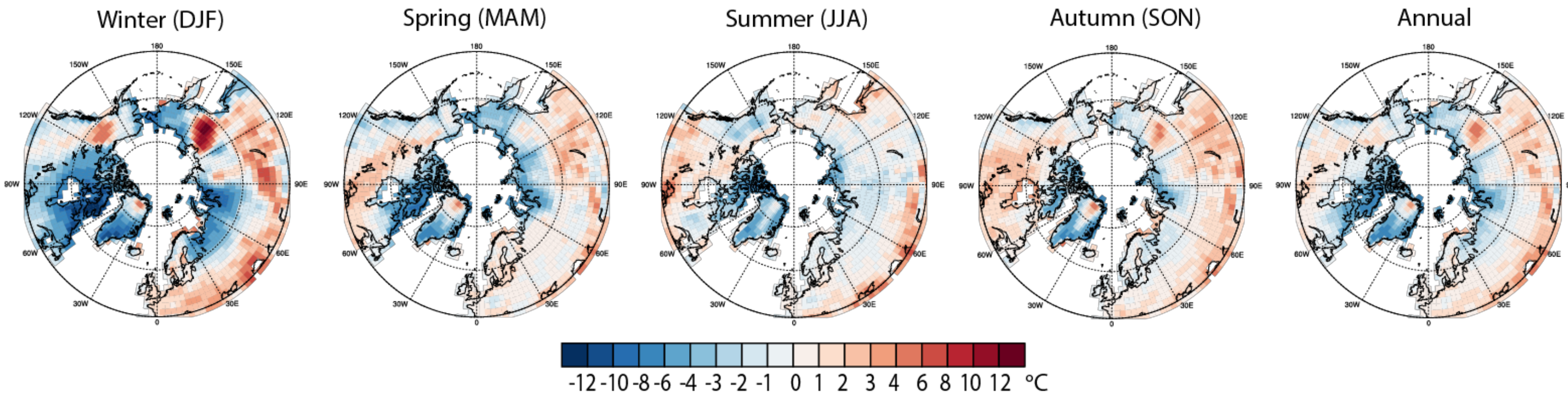


Veg run

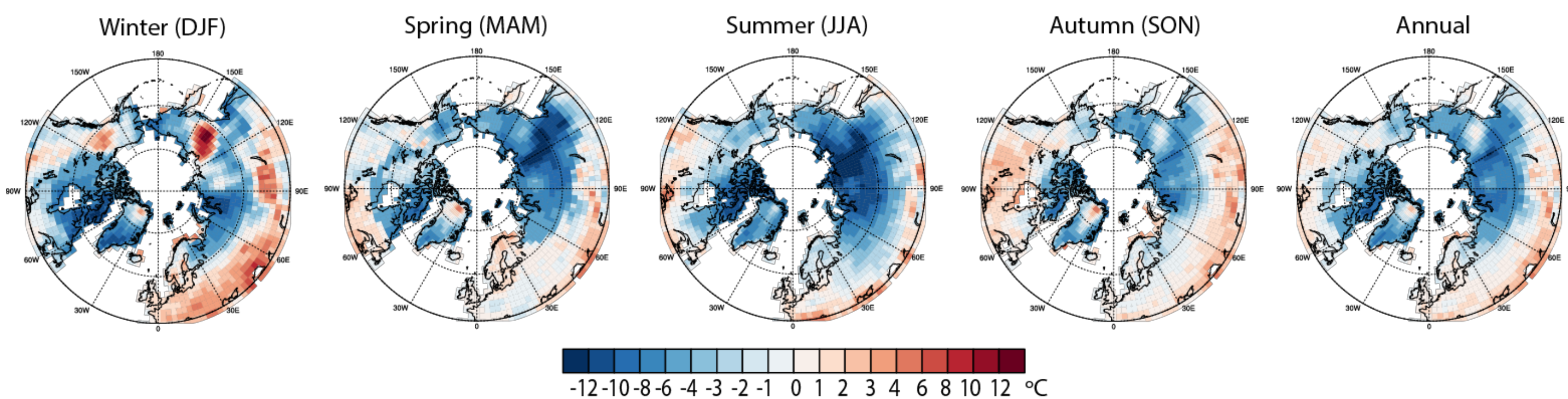


Temperature: Strong cold biases in AtmVeg run

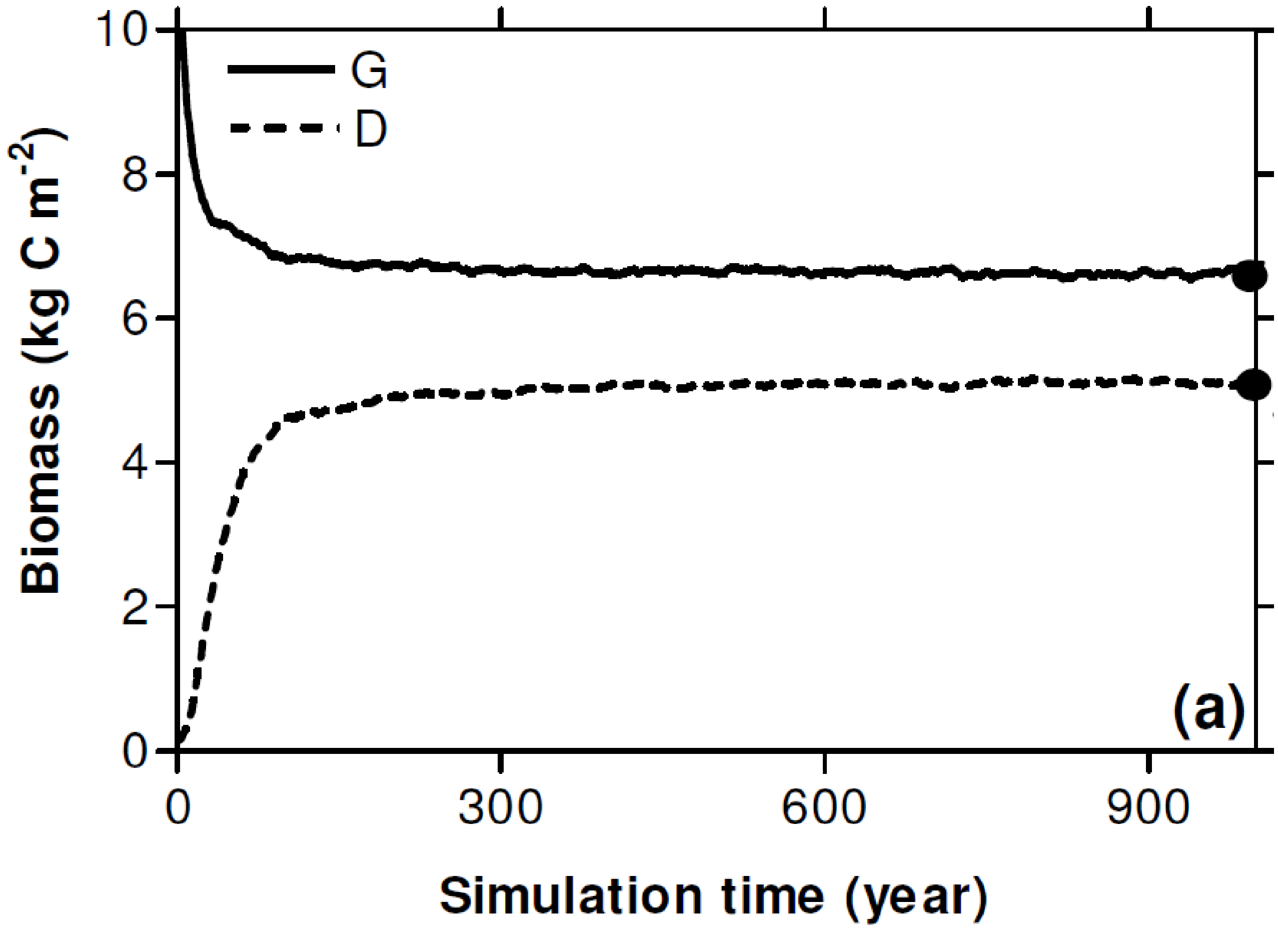
Atm run *minus* Observation



AtmVeg run *minus* Observation

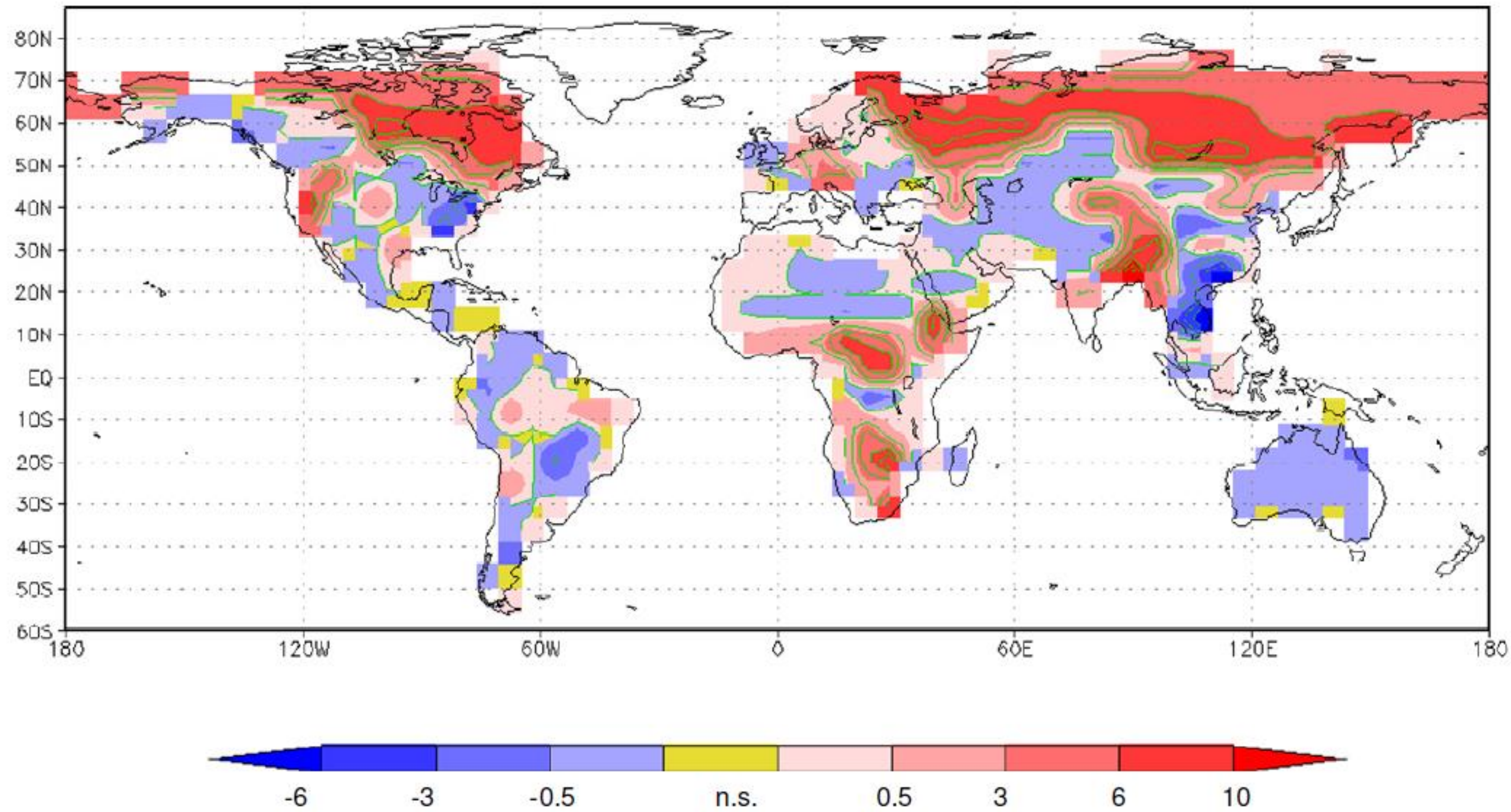


Strong positive feedback between T and vegetation
Multiple states of vegetation?



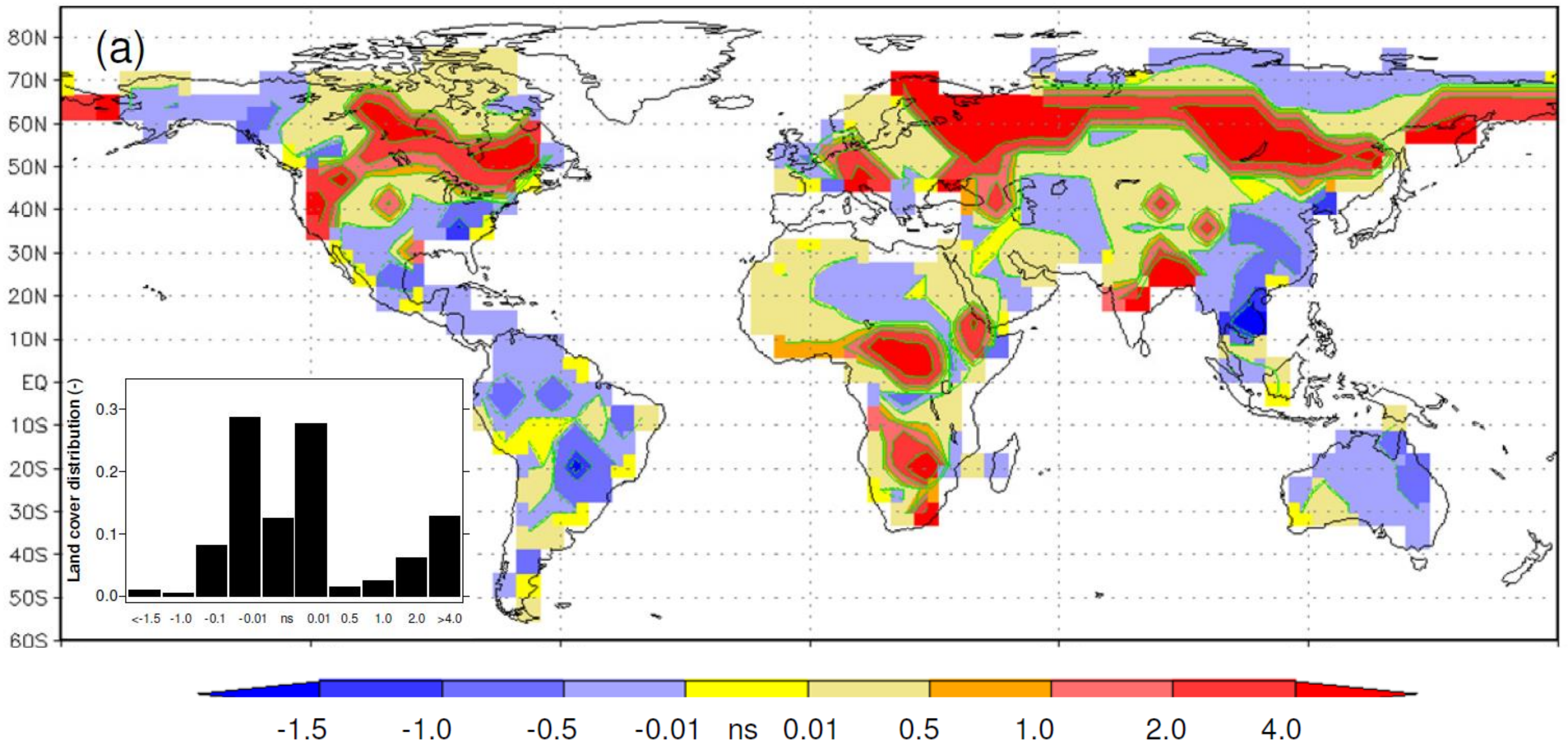
Model of Intermediate Complexity (EMIC)
Planet Simulator (PlasSim)

Dekker et al., 2010



Biomass anomalies between the two states (G-D)

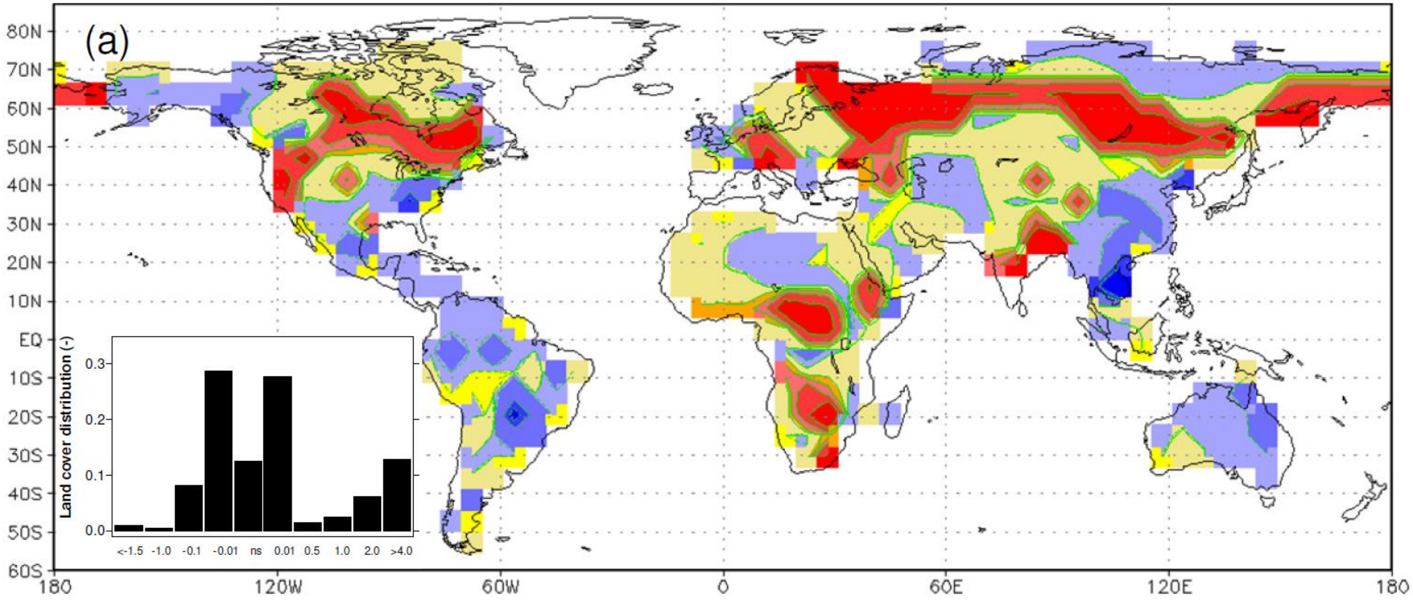
Dekker et al., 2010



Susceptibility factor: $$S_i = \frac{B_i - Bo_i}{P}$$

Si >1: The resilience of the system is so low that a change in biomass induced by the perturbation is amplified indicating a net positive vegetation-climate feedback

Dekker et al., 2010



HOWEVER

- The positive feedback between vegetation and temperature may be too strong in coupled models
  - The limitation of nutrients on the growth of plants are often not well represented in models
  - When taken into account may dampen the strong positive feedback

Single cell test runs with modified parameters
Shrub location (63.5 ºN, 132.5 ºE)

- Light competition
fpc_shrub_max increase
fpc_grass_max decrease
- N limitation: removed
- Photosynthetic capacity
V_{cmax25} *increase*
- Water stress resistance increase

- Light competition
fpc_shrub_max increase
fpc_grass_max decrease
- N limitation: removed
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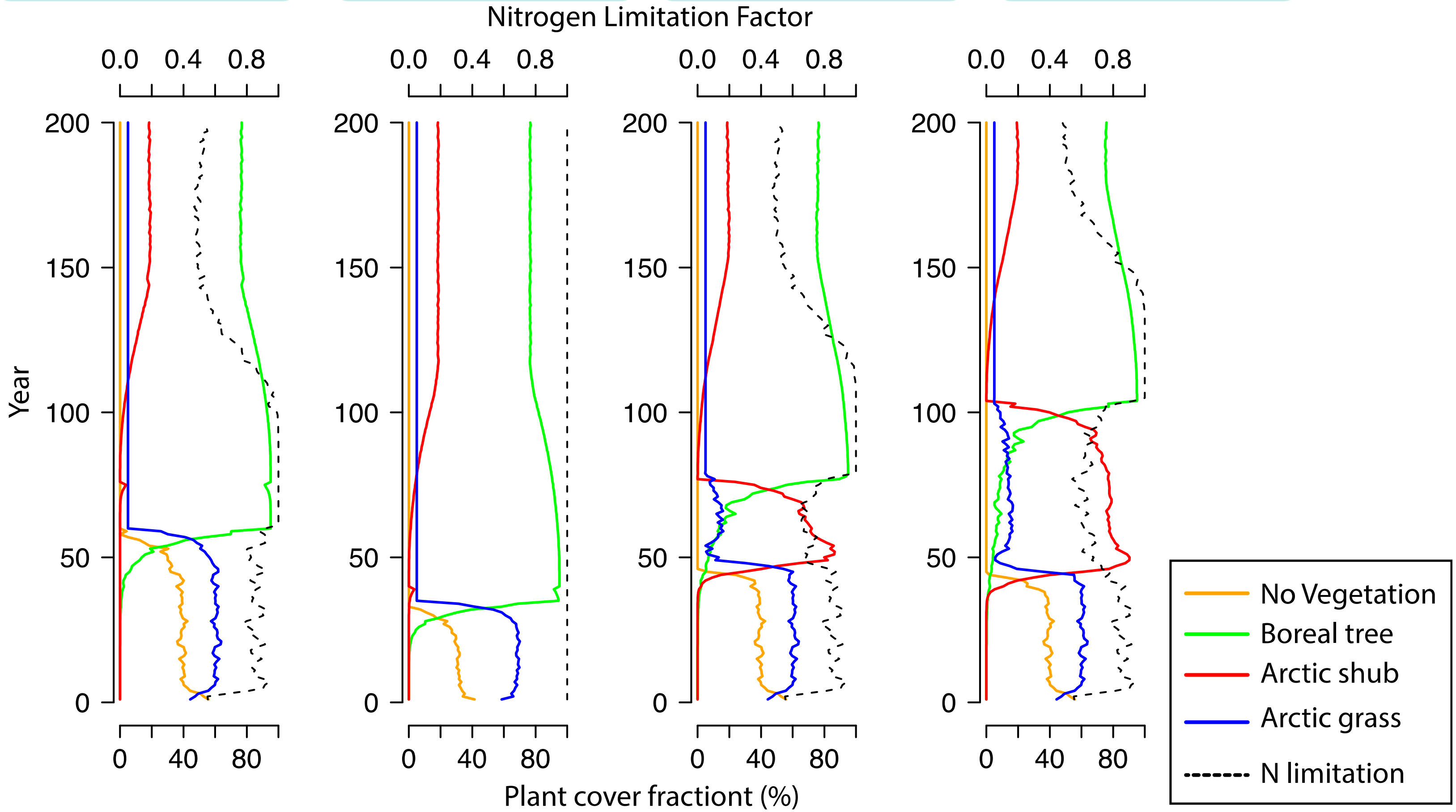


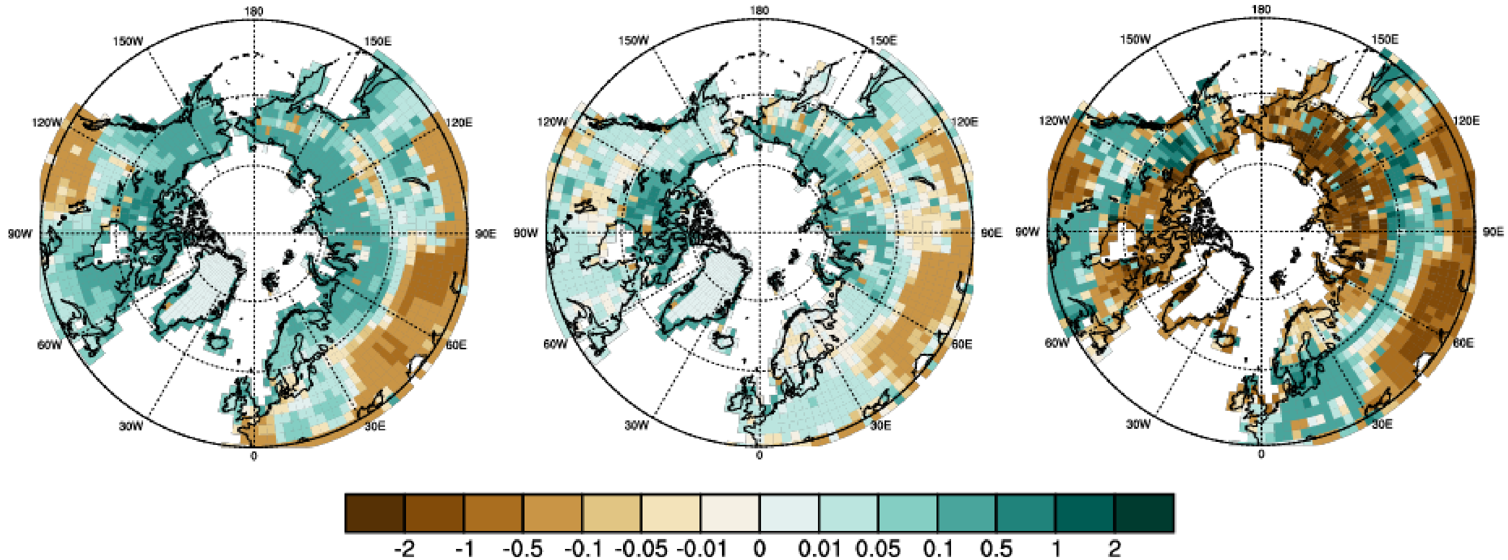
Strong climate-vegetation feedbacks can further enhance cooling

Veg run, JJA

Temp. – Photosyn. rate

Temp. – LAI

LAI – Albedo



Regression coefficiency (standardized)

Albedo is more influenced by SAI in forest:

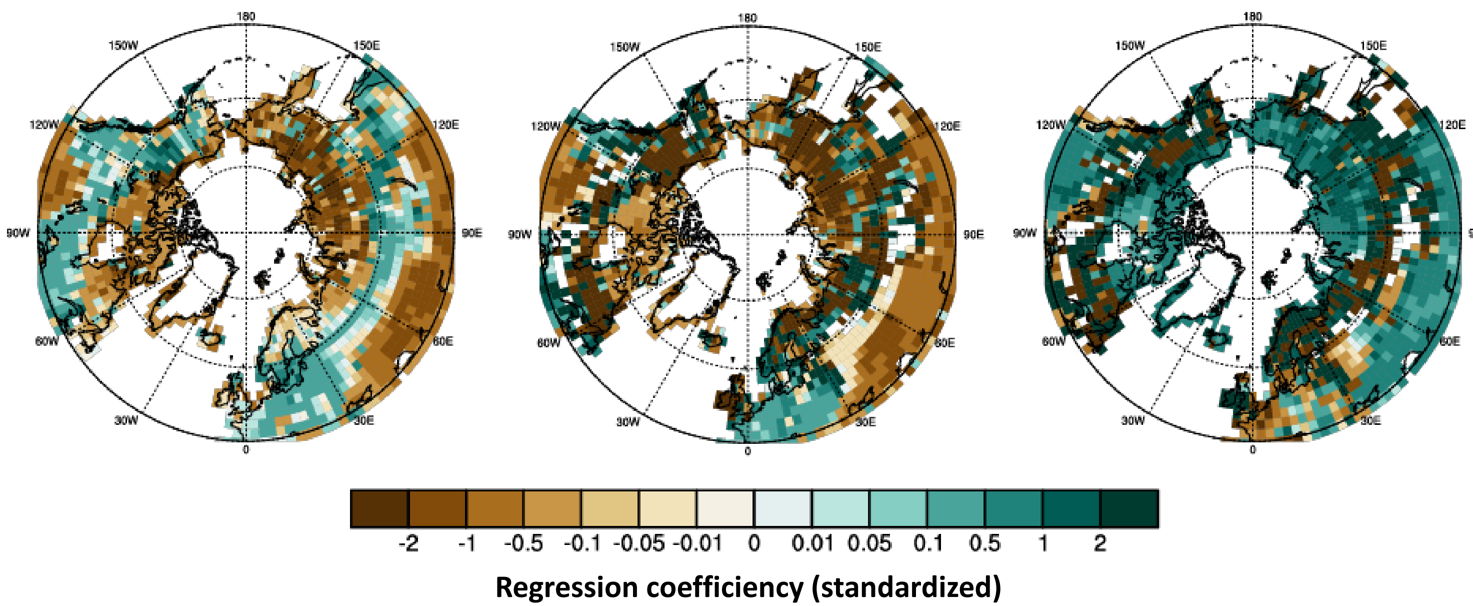
High SAI -> Low Albedo

High LAI correspond to low SAI in forest zone

Therefore: High LAI -> Low SAI -> High Albedo

Veg run, JJA

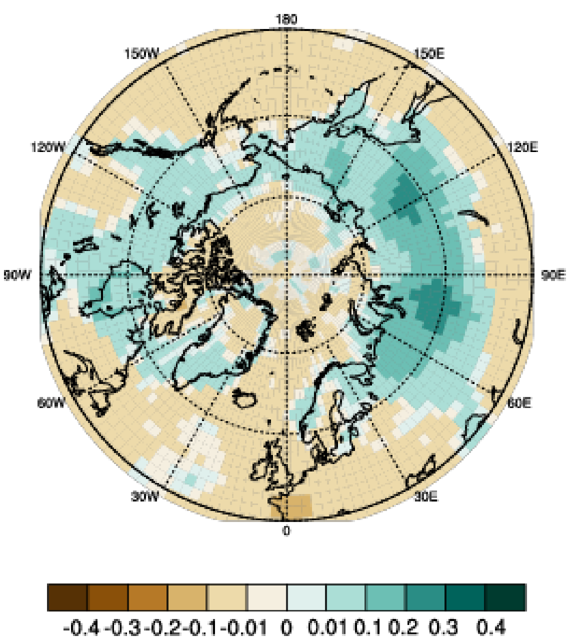
LAI – Albedo | SAI - Albedo | SAI - LAI



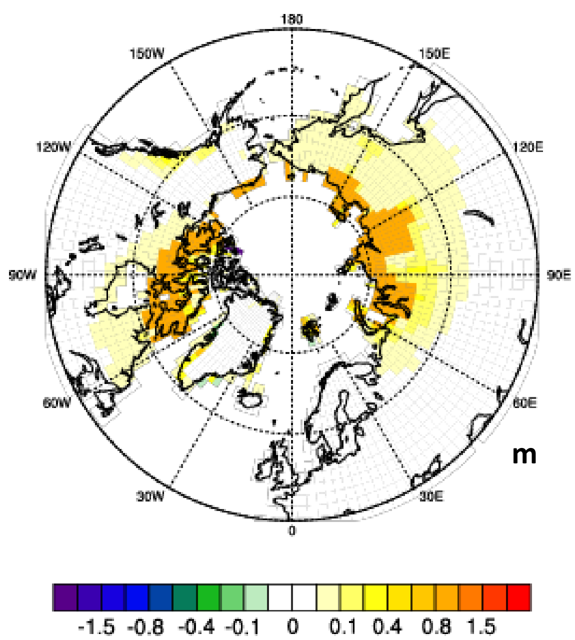
Strong snow and cloud feedbacks may also play a role

AtmVeg Run *minus* Atm Run, JJA

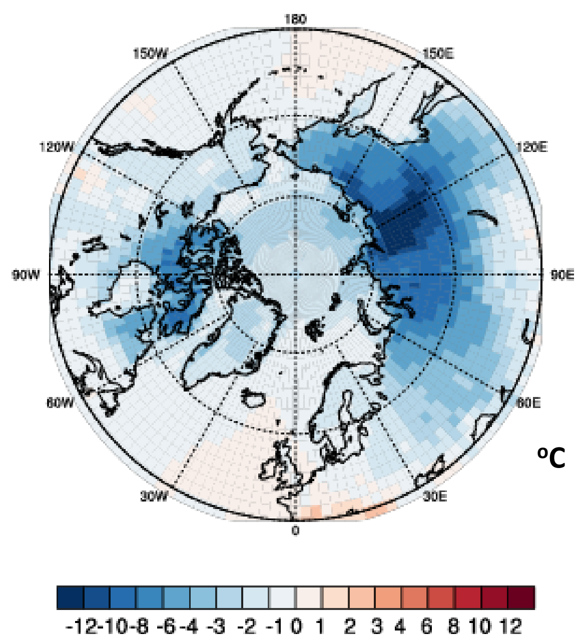
Cloud cover fraction



Snow water equivalent



Temperature



Summary

- WRF uncoupled runs: Increased shrub cover leads to
  - Increased near surface temperatures
  - Earlier onset of melting season
  - Increased latent heat flux
  - More atmospheric water, clouds and precipitation
  - Increased greenhouse effect
- CLM4.5-BGCDV (**Veg run**) underestimates Arctic shrubs, while overestimates Arctic grass
- The coupled dynamic vegetation-atmosphere run (**AtmVeg run**) underestimates total Arctic plant cover, leading to strong cold biases in the Arctic
- The positive feedback between vegetation and temperature is particularly strong in Arctic, making the coupled vegetation-atmosphere model highly unstable in this region

Future work

- Decide how to handle cold bias
- Global CC experiments
- Couple WRF with CLM through coupler
  - Use ecosystem data from Norway (NHM/LATICE) to improve CLM parameters and parametrizations
    - Current and additional (e.g. mosses and lichens) PFTs
  - Regional CC and LUC (forest management)
- Chemistry impacts
  - Ozone impacts on vegetation (crops)
  - BVOC impacts on ozone and clouds


Thanks for attenting my talk/walk in the Arctic shrublands