The Baltic Sea in Transition, 11 June 2018

Regional and Global Earth System Modelling Activities in MERGE

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(With thanks to Ben Smith and many MERGE colleagues)

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LUND UNIVERSITY

LUCCI
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EC-EARTH3

CRESCENDO

MERGE

Outline

- What is MERGE?
- Terrestrial ecosystems in the climate system
- LPJ-GUESS – a state-of-the-art DGVM
- Modelling vegetation feedbacks to climate with RCA-GUESS
- The EC-Earth ESM and plans for CMIP6
- Outlook

MERGE

Modelling the Regional and Global Earth System

MERGE

- **Strategic research area (SRA) =**
  - **Result of a Swedish government-initiated call for proposals in 2008.**
  - **Universities invited to compete for a share of 1.8 billion SEK to establish SRAs on 24 topics for a 5-year trial period (2010-14)**
  - **increase in central university funding in exchange for a commitment by the university to pursue and develop research in a particular area of strategic (applied) importance for Sweden**
  - **network of researchers at one or a number of universities, research institutes, faculties, departments and research groups linked by collaboration or common focus on one or a number of related topics or themes**
- **Modelling the Regional and Global Earth System (MERGE) was one of two successful proposals on the topic "Climate models"**
- **The SRAs will be evaluated in 2019/20 with a view to being made permanent from 2020**

MERGE Aims

www.merge.lu.se

- To advance the state-of-the-art for representing biosphere-atmosphere forcing and feedbacks in global and regional Earth system (climate) models
- To contribute to national and international efforts to describe and attribute climate change, underpinning policy responses
- To educate a new generation of young ESM model experts
- To support the ClimBEco graduate school - www.climbeco.lu.se
- To improve the societal relevance of climate models and their results

MERGE

Addressing the Research Challenges
The Four Linked Research Themes

LPJ-GUESS DGVM
RCA-GUESS RCM
EC-Earth ESM
WRF RCM

Theme 1 – ESM development

climate-biosphere interactions

Theme 2 – learning from the past

palaeoclimate & land cover

LPJ-GUESS
Vegetation and land-use reconstruction using REVEALS
Solar activity reconstructions
COSMO-wiso

Theme 3 – particles

aerosol-cloud parameterisations for ESMs

LPJ-GUESS
Laboratory and field studies
EC-Earth (BVOC & SOA, TM5)
EMEP
ADCHEM

Theme 4 – statistics

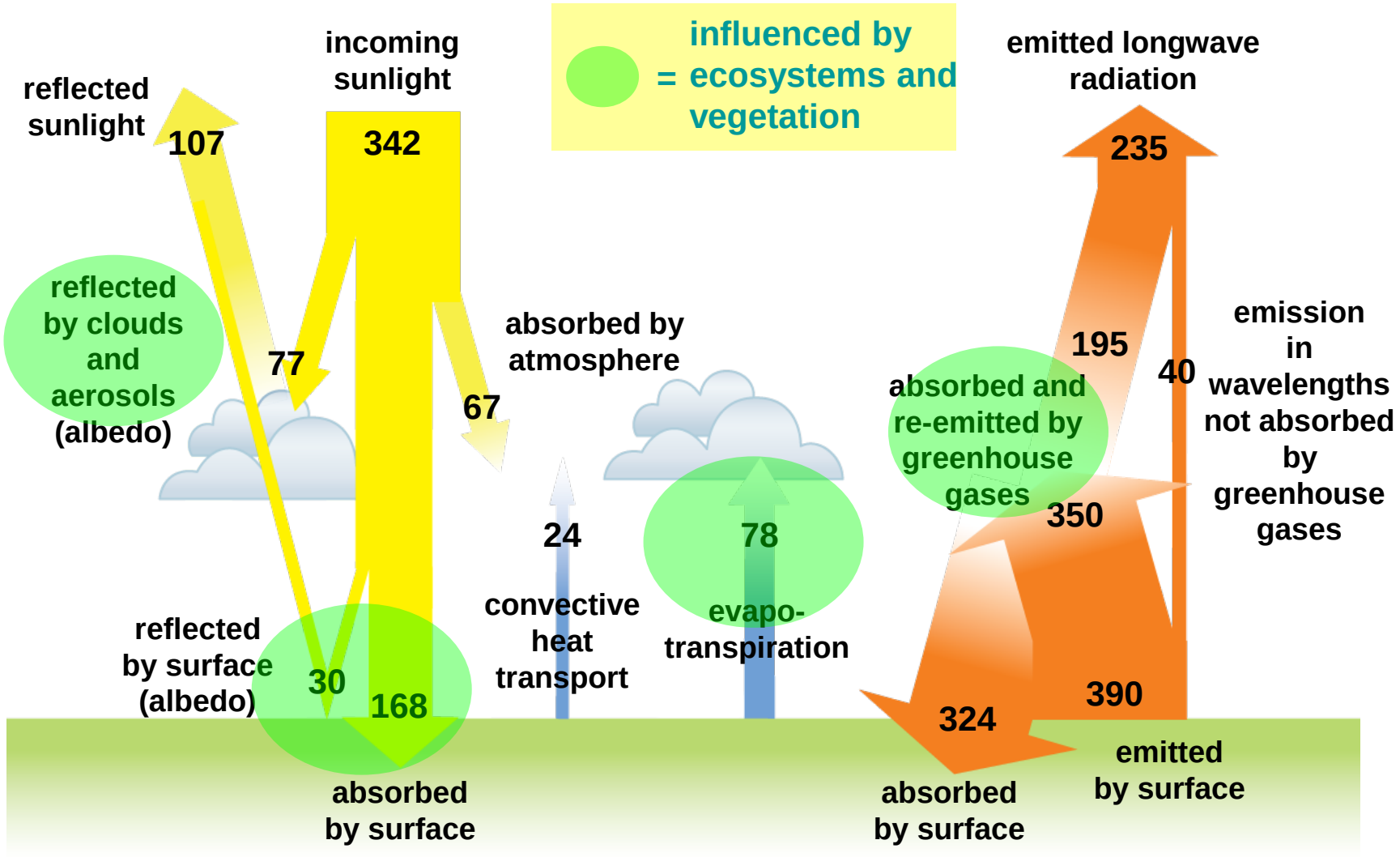
new methods for ESM analysis and simulation

Landscape reconstruction using Gaussian Markov Random Fields

Inverse modelling of CO_2

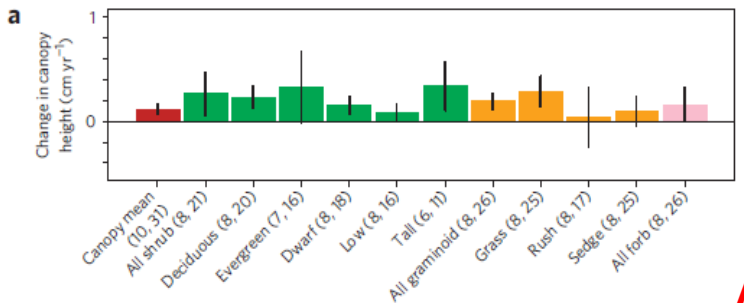
Energy budget of the Earth

Global average point fluxes (Wm^{-2})

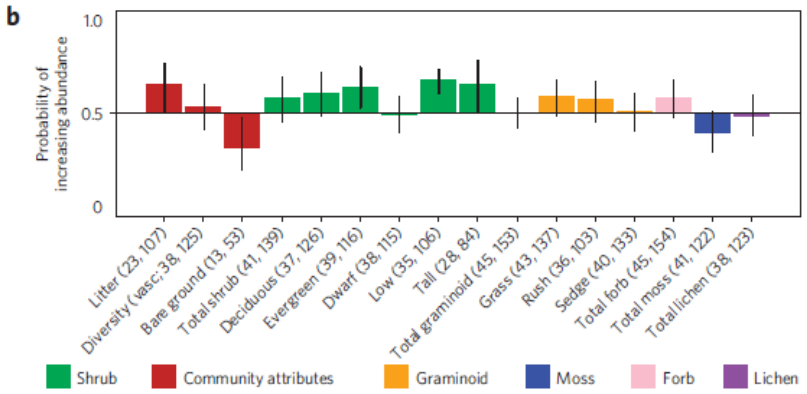


Slide: Ben Smith (Lund Univ.)

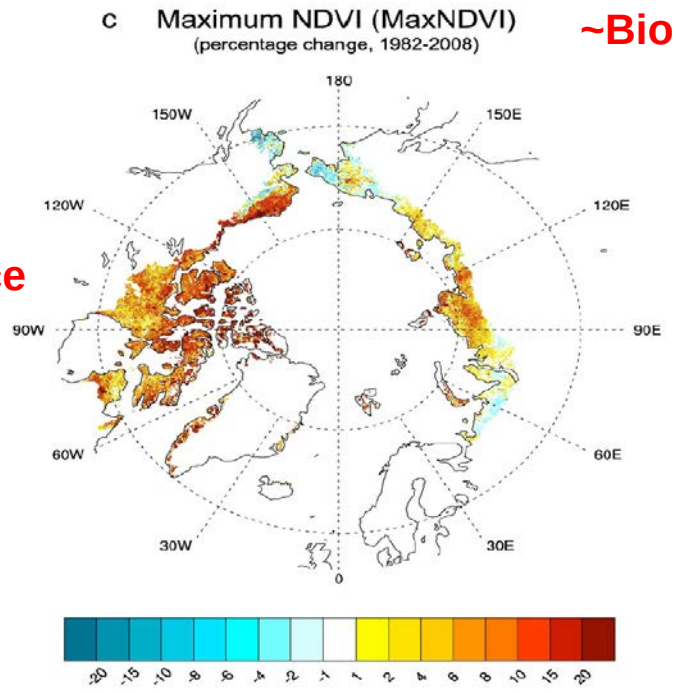
Tundra ecosystems are changing



Canopy Height



Abundance



~Biomass

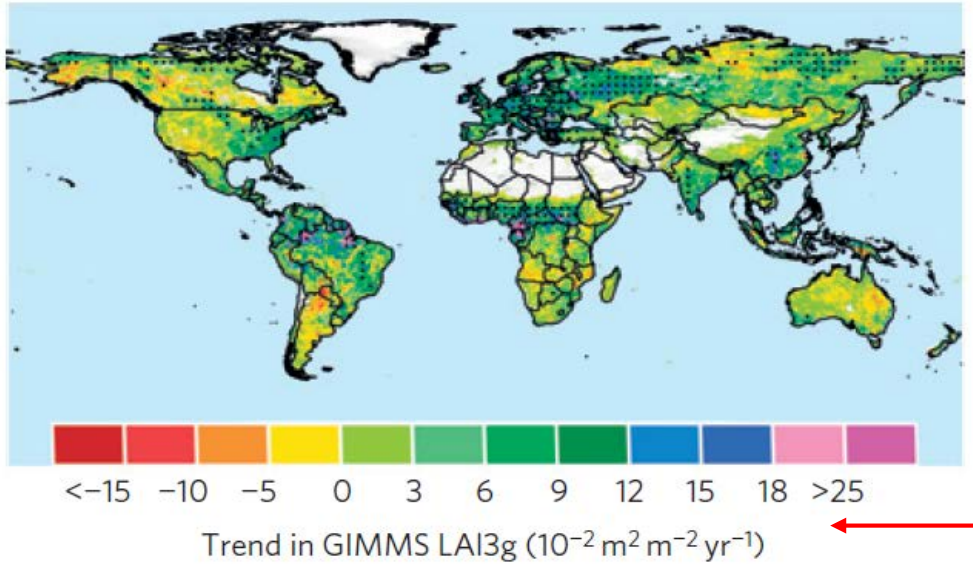
Bhatt et al., 2010

Plot-scale analysis by Elmendorf et al., NCC, 2012

Shrub Expansion

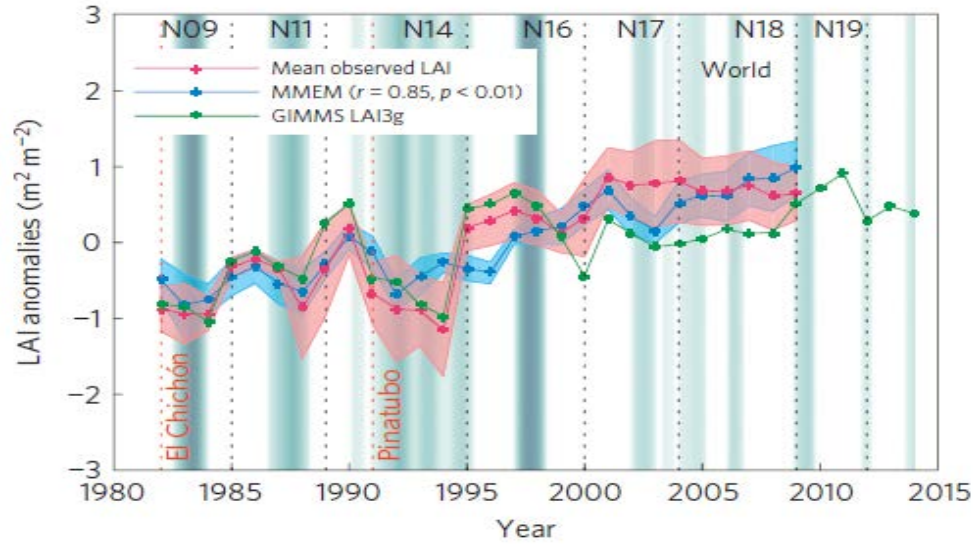
Sturm et al., 2005

Vegetation cover and productivity have increased in concert with recent decades' climate warming and CO_2 increases



Trend attribution from models:
- CO_2 fertilization (increased NPP)
- Climate change
- Nitrogen deposition
- Land cover change

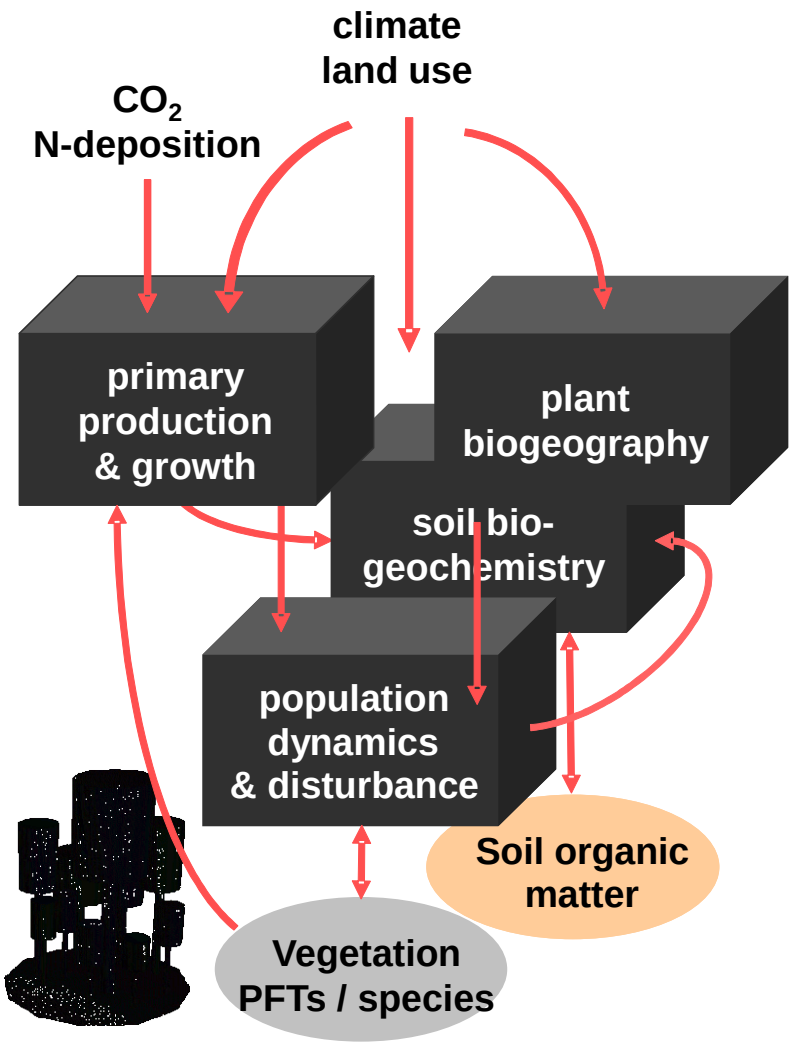
Change in land surface greenness 1982-2009

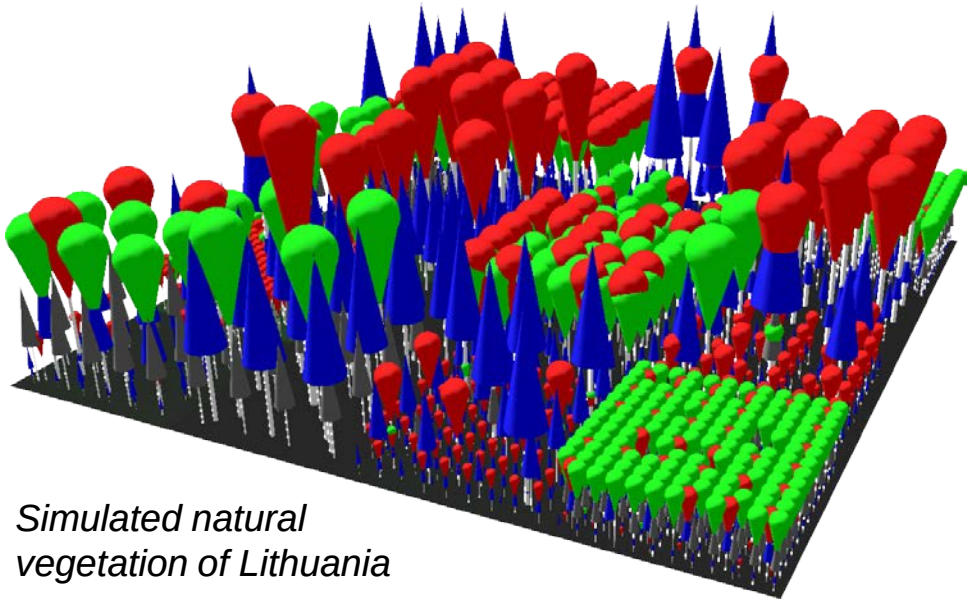


Recent greening trends have mitigated background climate warming, mainly due to increased evapotransipration

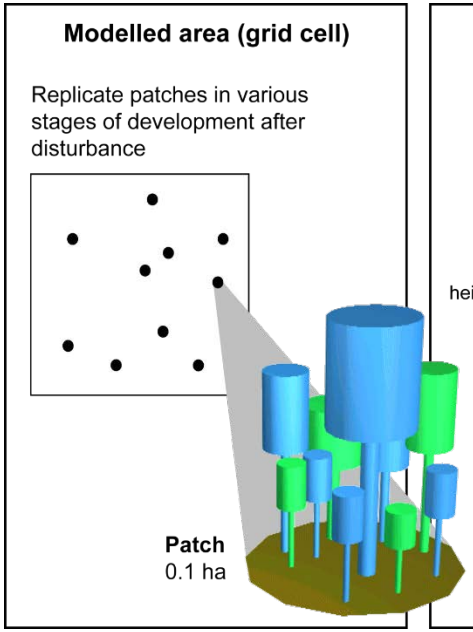
Zhu *et al.* (2016), *Nature Climate Change*

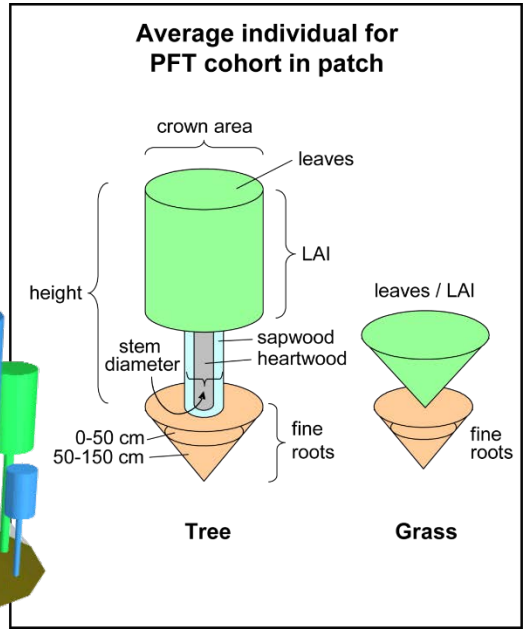
LPJ-GUESS – global DGVM & ecosystem model*





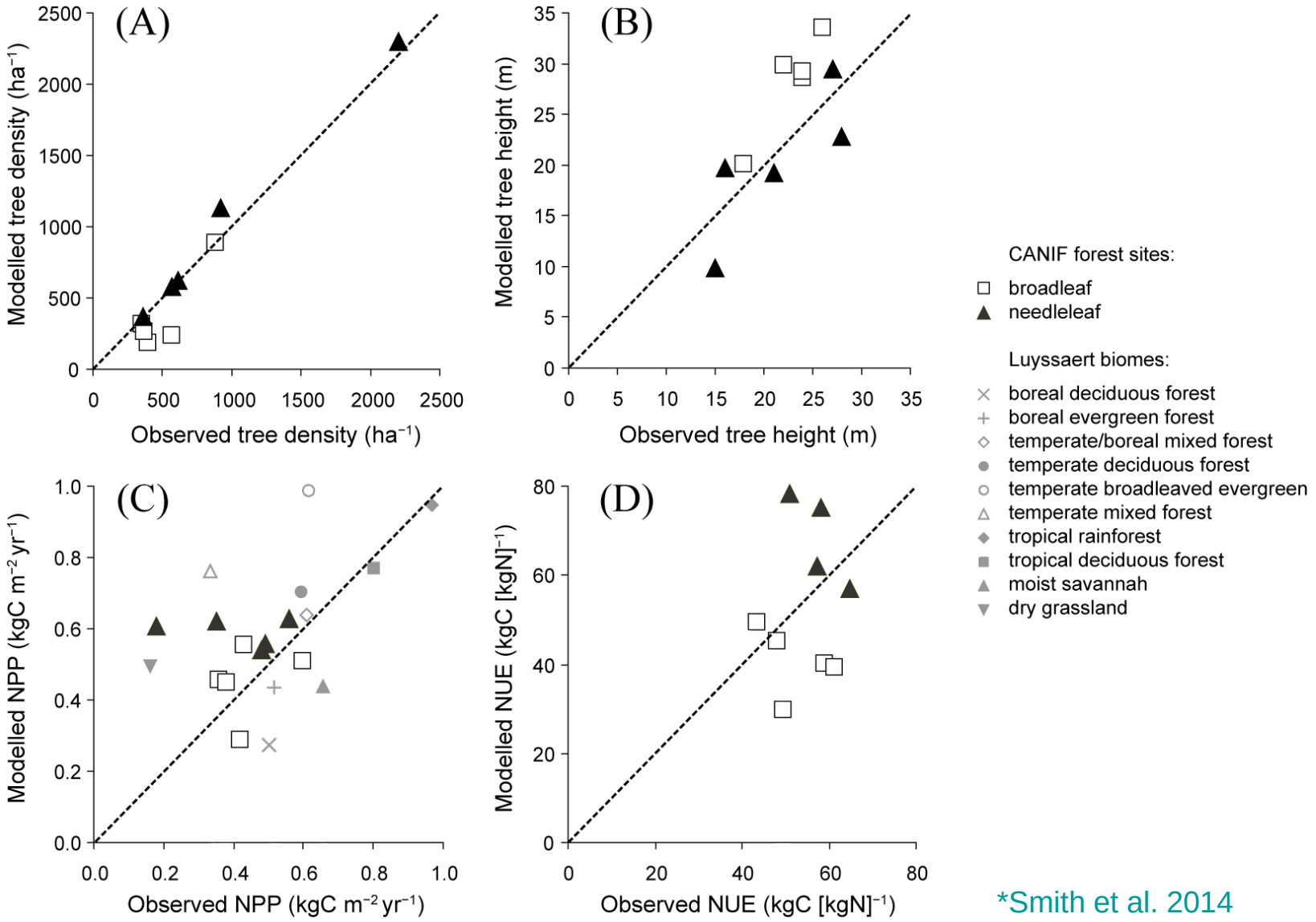
Simulated natural vegetation of Lithuania





*Smith et al. 2001, 2014

Forest stand structure, productivity, N cycling*



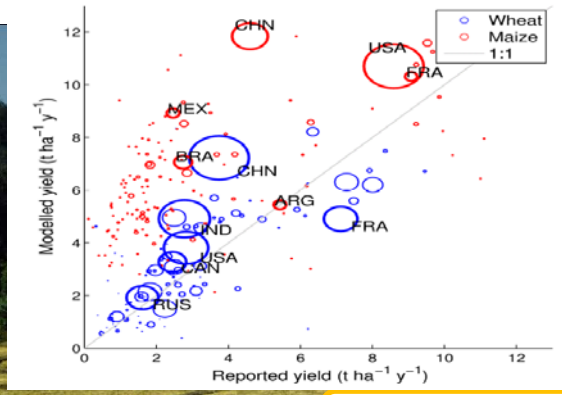
*Smith et al. 2014
Biogeosciences 11: 2027-2054

Managed land version accounts for land use*

Daily grazing

Yearly cutting

PASTURE



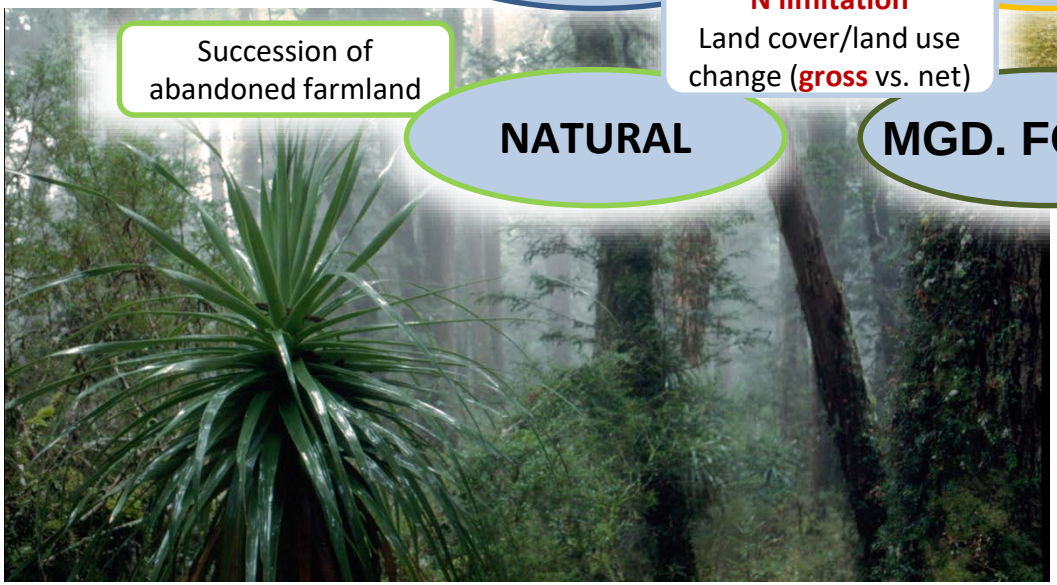
Crop rotations

Cover crop

CROPLAND

Irrigation

N limitation
Land cover/land use change (**gross** vs. net)



Succession of abandoned farmland

NATURAL

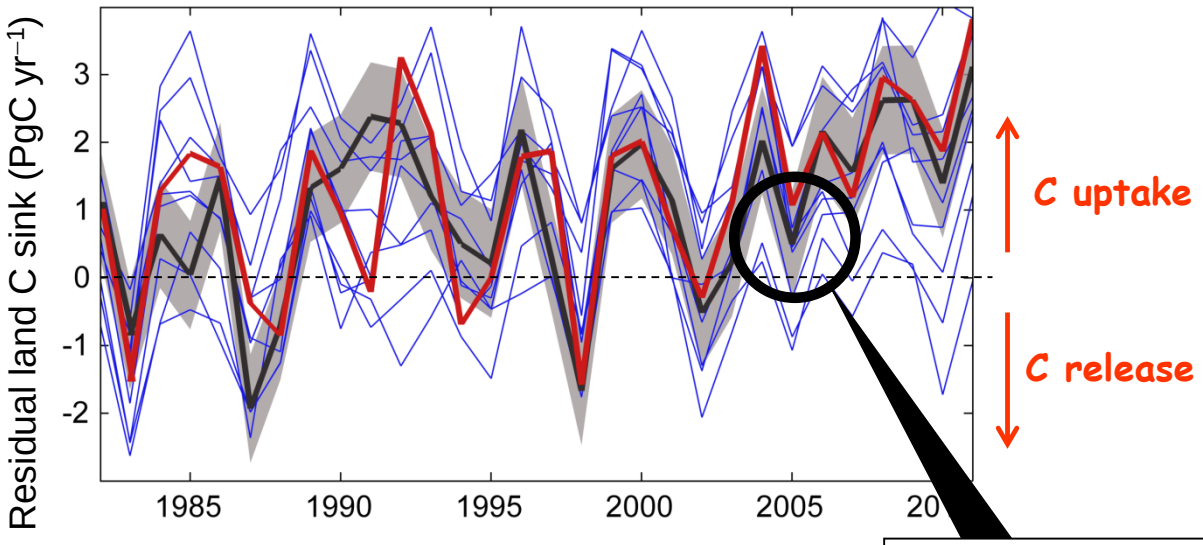
MGD. FOREST

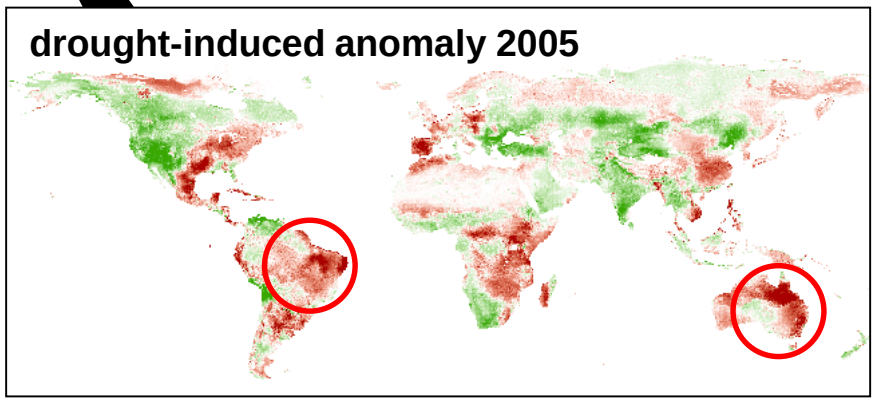
Continuous forestry

Detailed forest management

*Lindeskog et al. 2013. *Earth System Dynamics* 4: 385-407
Olin et al. 2015. *Biogeosciences* 12: 2489-2515

Terrestrial carbon cycling*





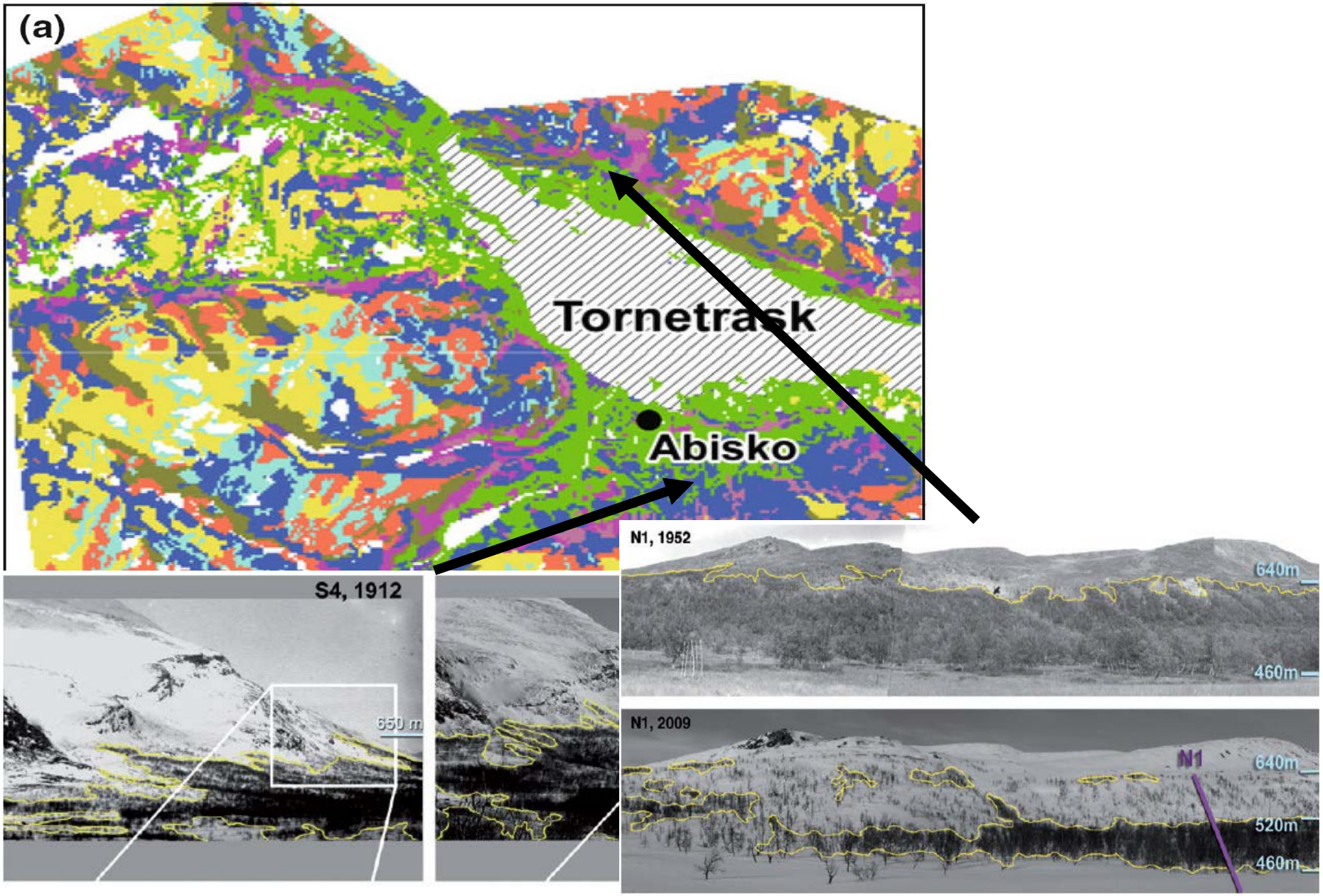
GCP residual land C flux ± 0.8 PgC

LPJ-GUESS

other DGVMs

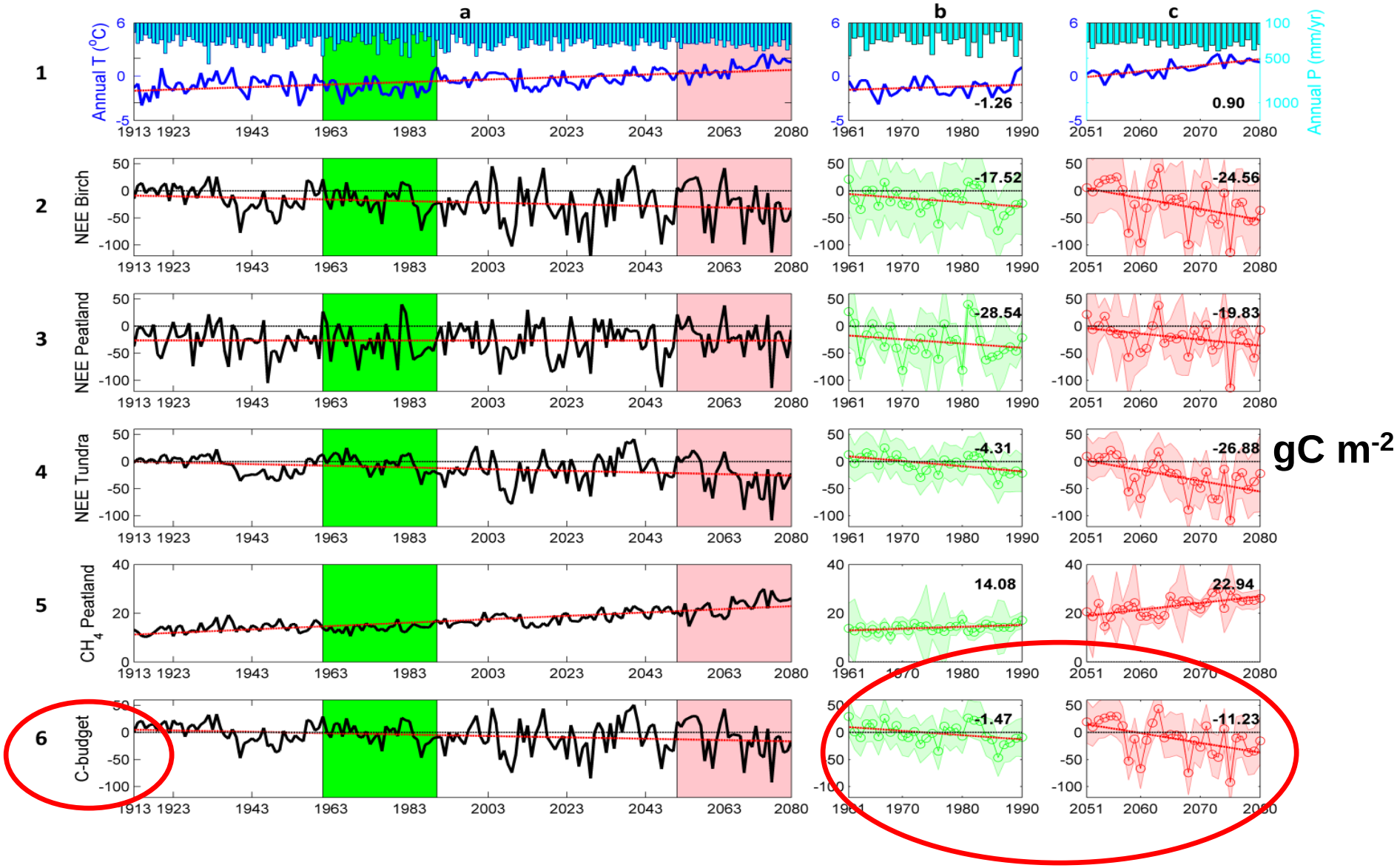
*TRENDY2 ensemble
unpublished

Landscape studies with LPJ-GUESS



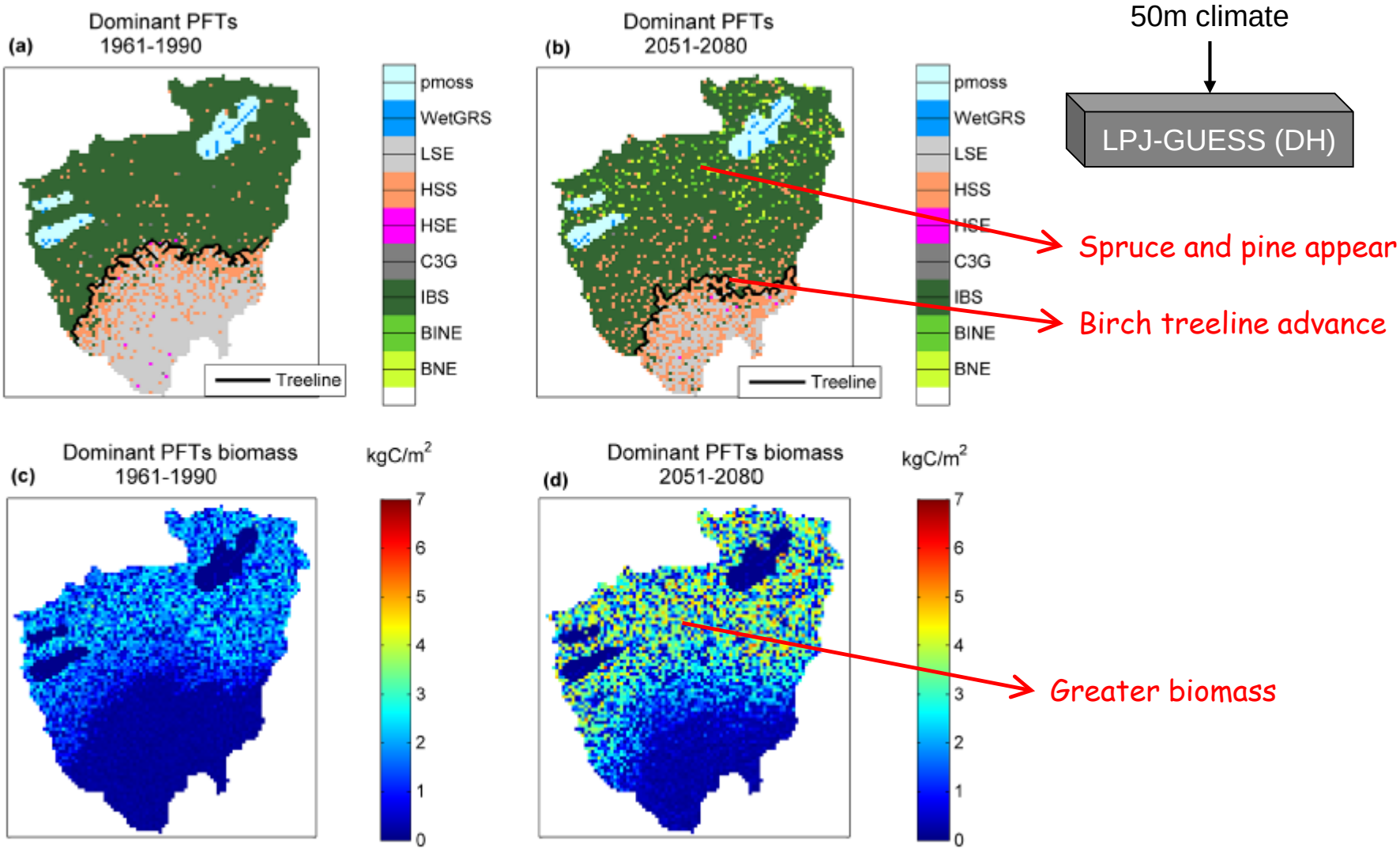
Sources: Yang et al. (2012), Christensen et al. (2007), Heliasz et al. (2011), Van Bogaert et al. (2011)

Comprehensive Stordalen Catchment C Budget, 1913-2100



Source: Tang, Miller *et al*.,Biogeosciences (2015)

Vegetation dynamics resulting from climate change



Source: Tang, Miller *et al*. Biogeosciences (2015)

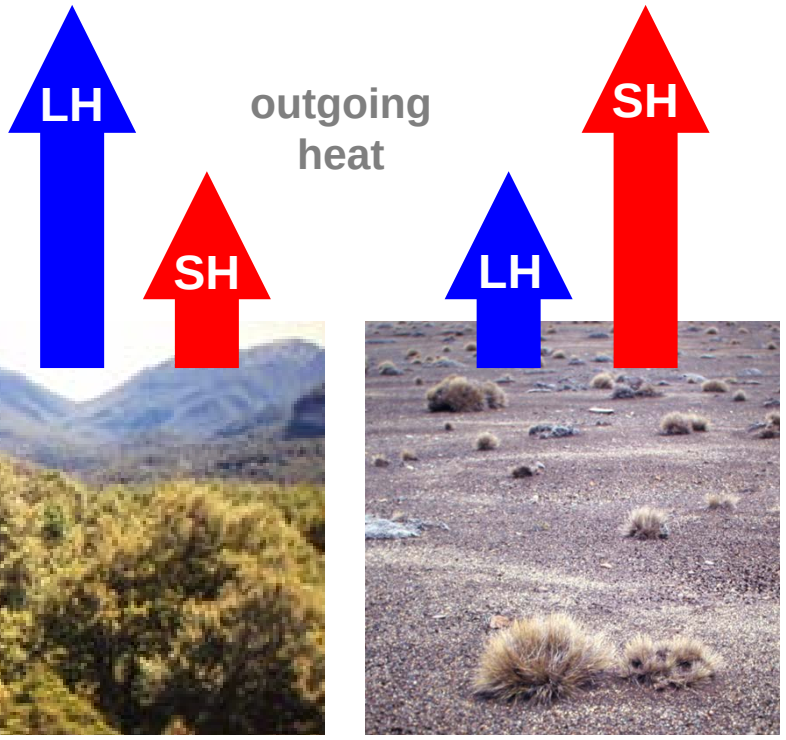
But! Offline studies miss feedbacks to climate via changed land-atmosphere energy balance

Albedo (reflected sunlight) **differs between forest and open land**, especially during period of **snow lie**

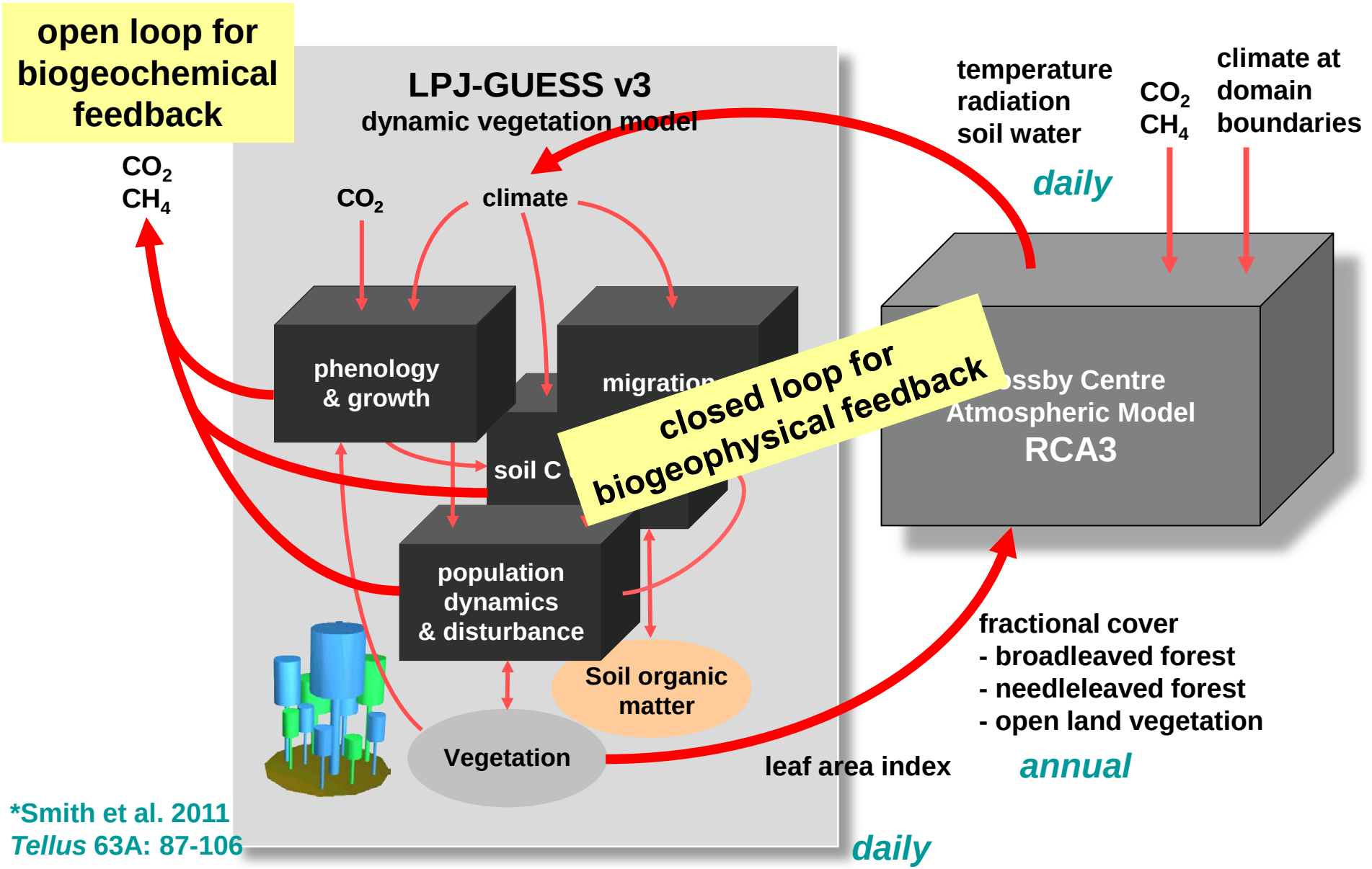
incoming shortwave radiation

Greater evaporative surface area of **tall, dense vegetation enhances latent heat flux**, reducing surface warming

outgoing heat



RCA-GUESS: a regional Earth system model*

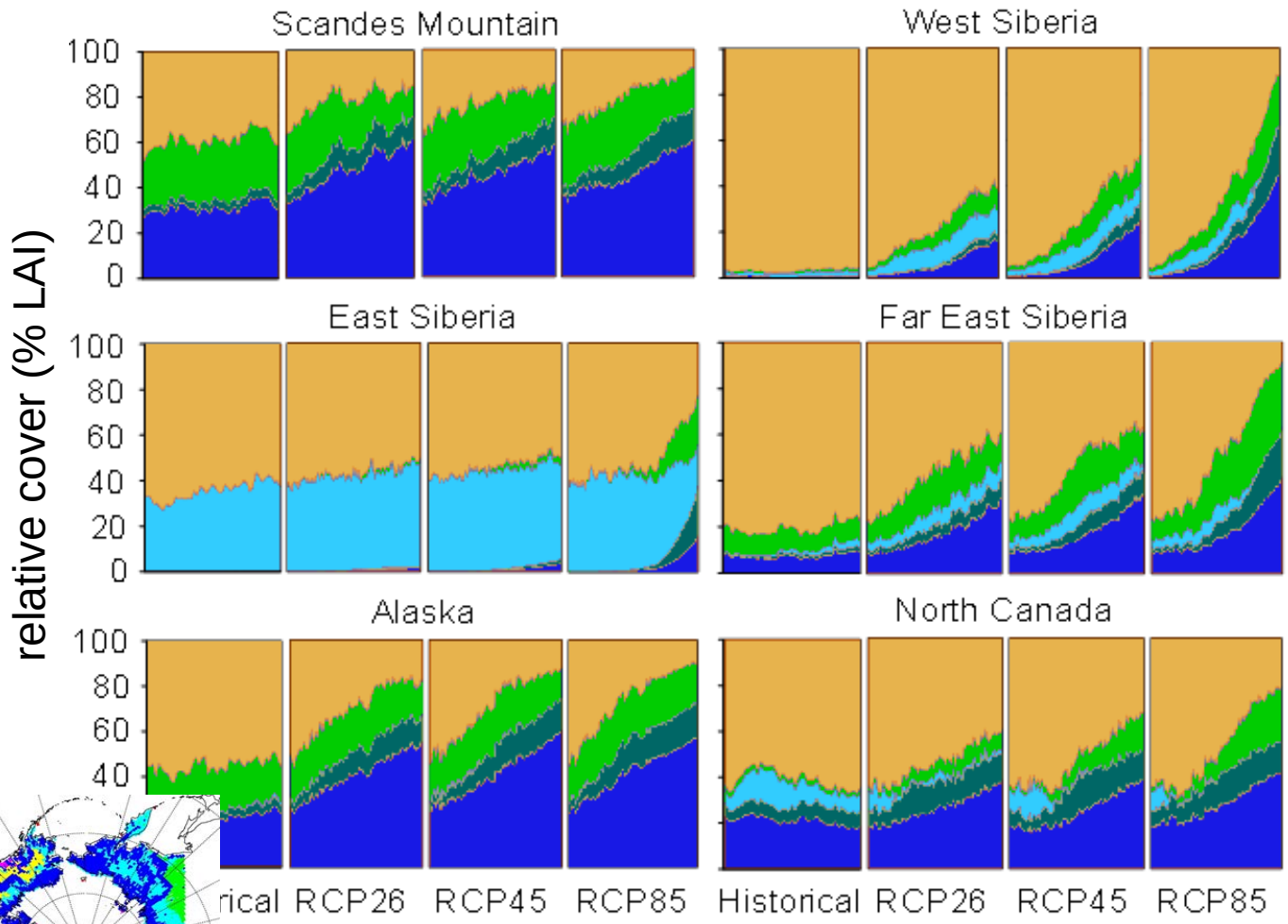


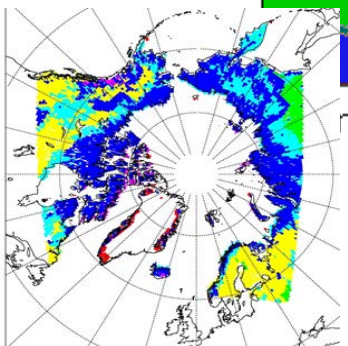
*Smith et al. 2011
Tellus 63A: 87-106

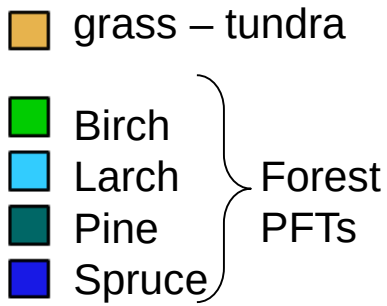
+ Multiple published studies for CORDEX Europe, Africa, Arctic, S. America

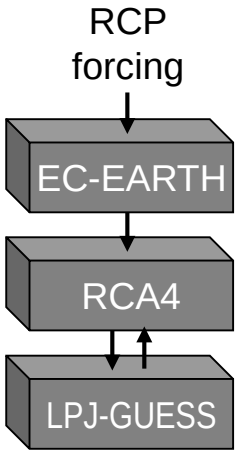
CORDEX-Arctic domain vegetation present and future*

coupled simulation (veg biophysical feedbacks included)





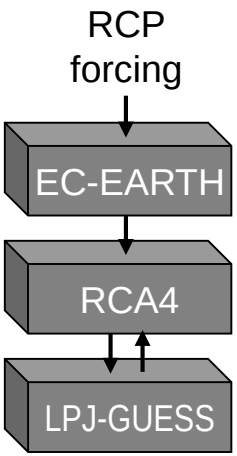


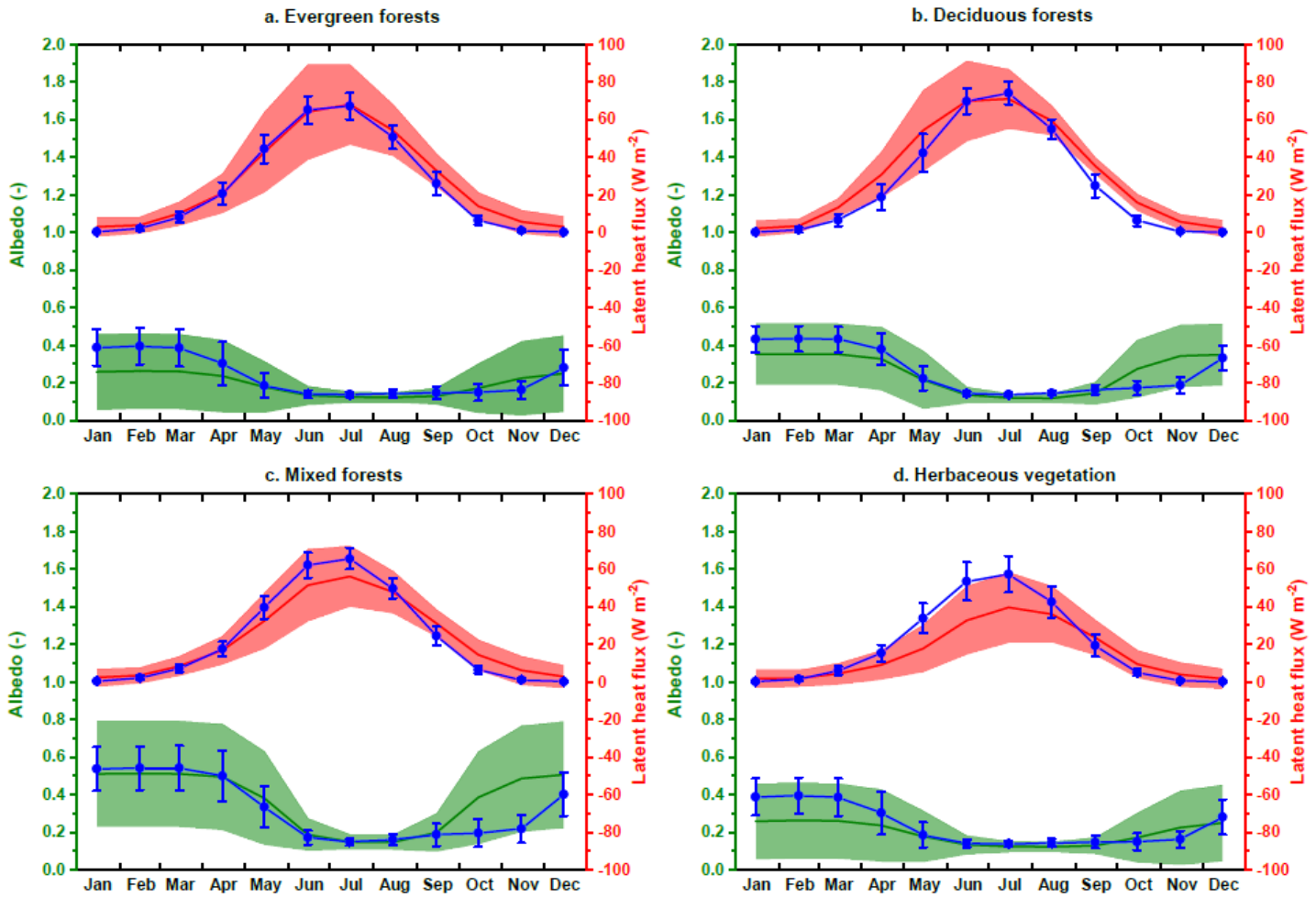


*W. Zhang et al. in revision.

RCA-GUESS evaluation*

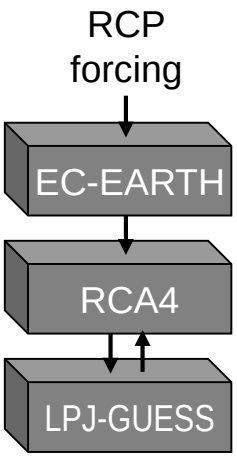
Evaluation of Albedo (Globalbedo) and Latent Heat Flux (upscaled FLUXNET) by Vegetation Type



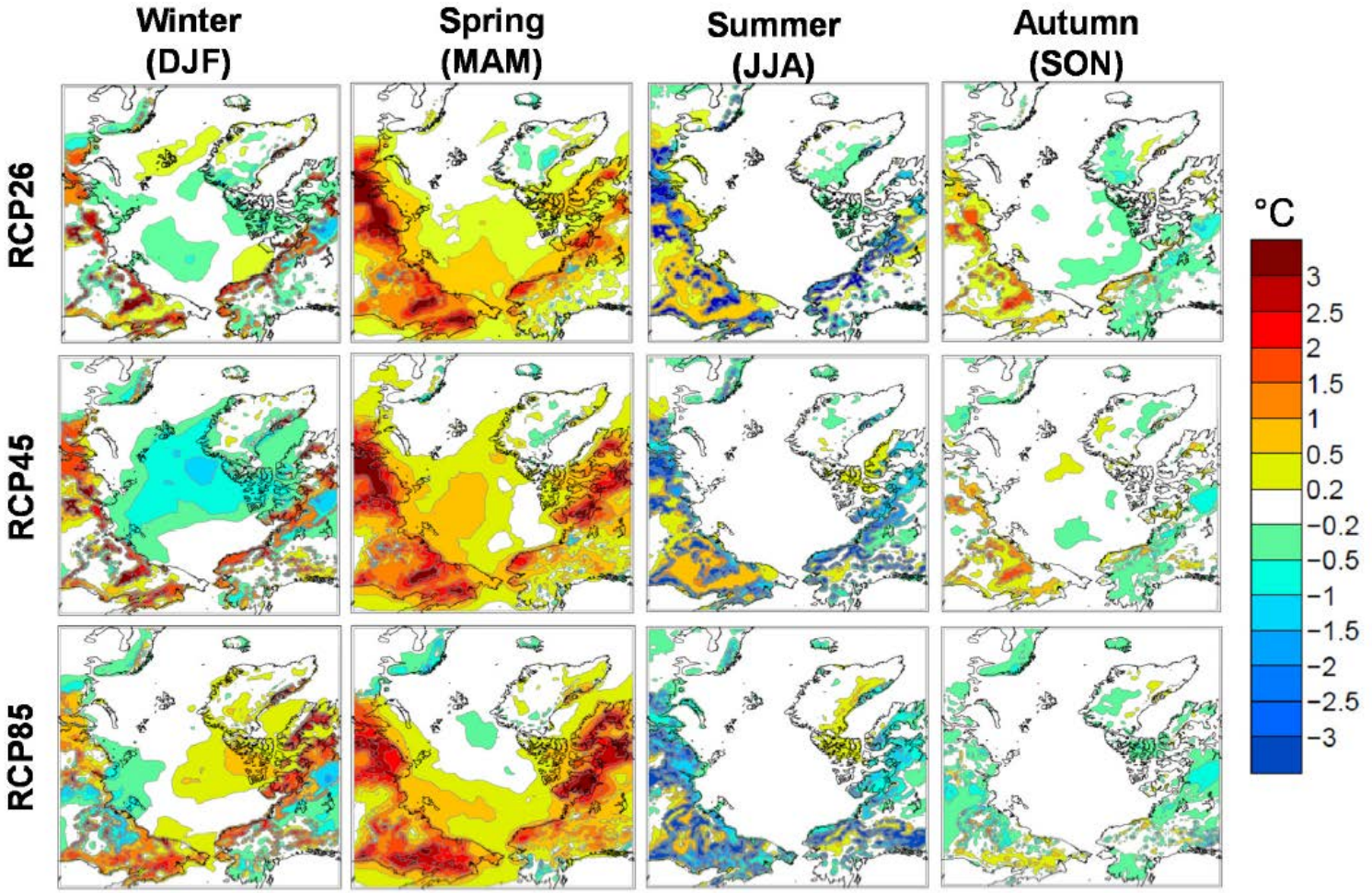


*W. Zhang et al. in revison

Feedbacks to surface air temperature*

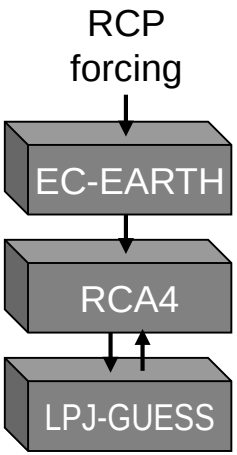


Additional temperature change due to vegetation feedback
(2071-2100)–(1961-1990)

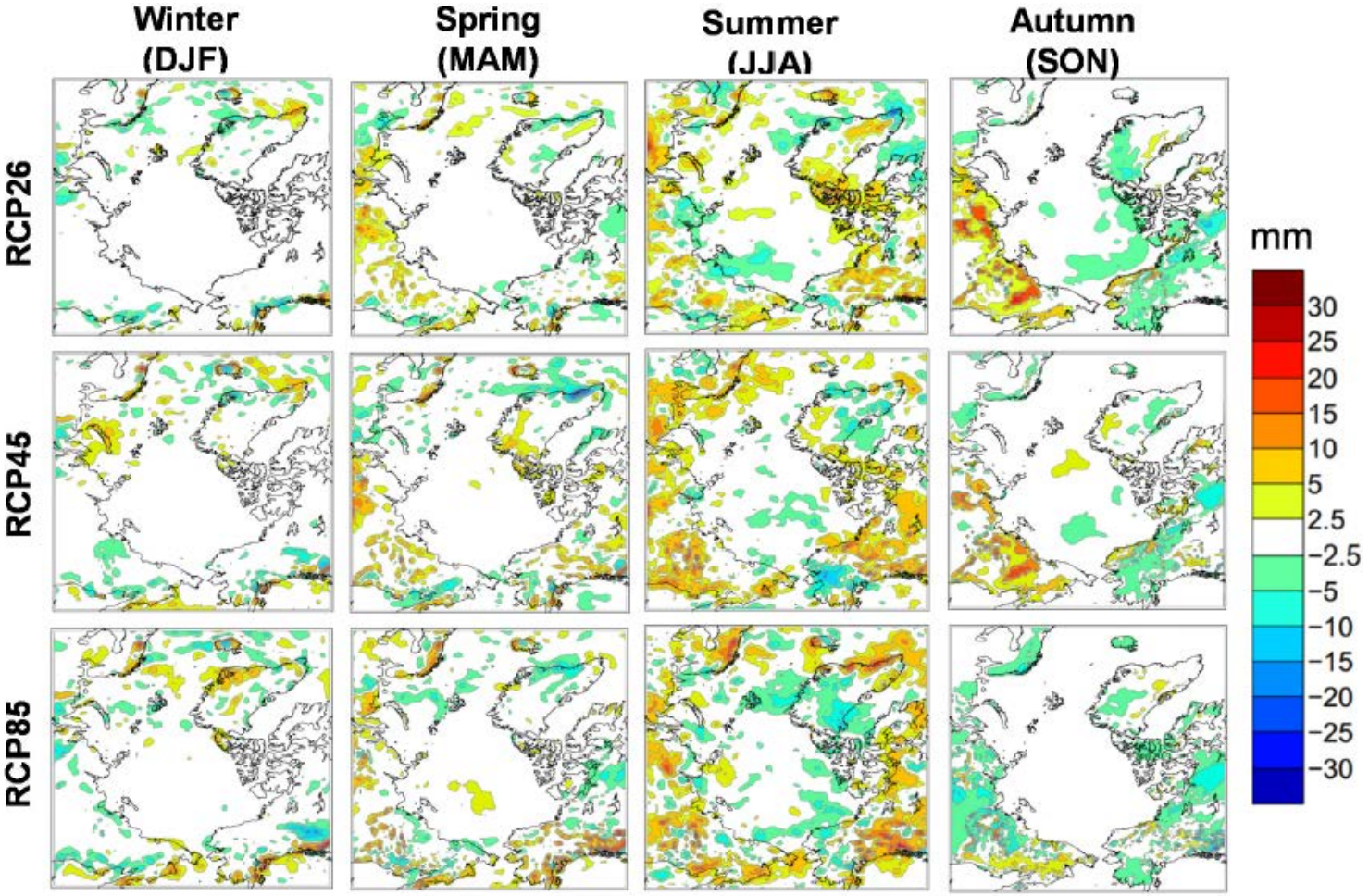


*W. Zhang et al.
In revision.

Feedbacks to precipitation*

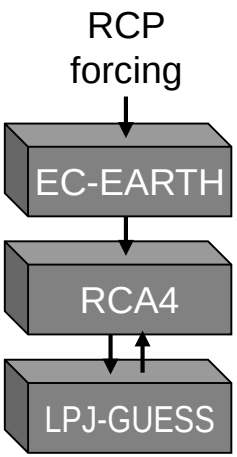


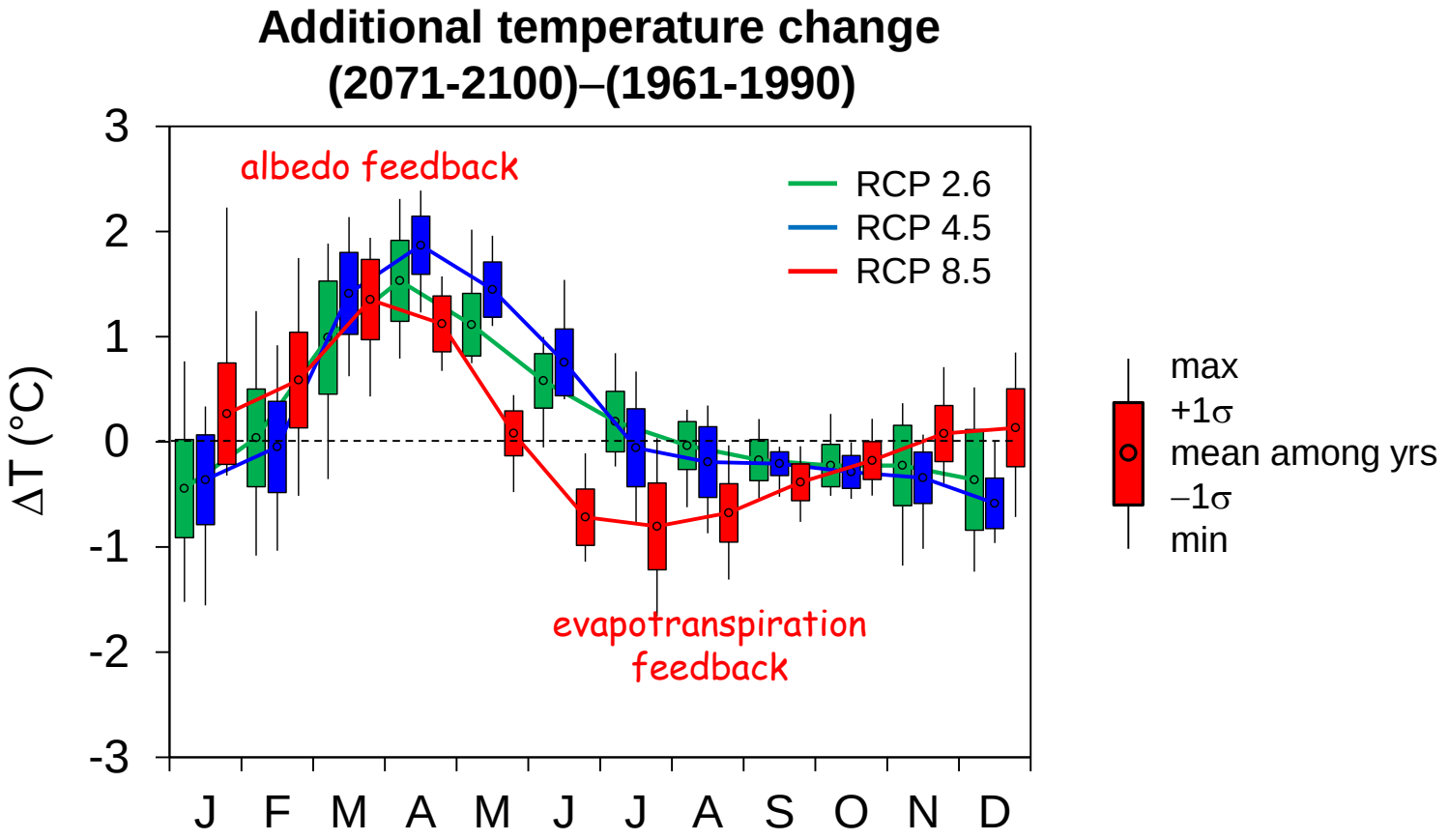
Additional precipitation change due to vegetation feedback
(2071-2100)–(1961-1990)



*W. Zhang et al.
in revision

Arctic vegetation feedbacks show the potential for dynamic vegetation change to alter regional climate





- Seasonality shift – longer growing season, earlier temperature peak
- Evaporative cooling evens out growing season temperature profile
  - → favours further shrub encroachment and treeline advance
  - → Enhances the terrestrial C sink (Zhang et al. 2014)

*W. Zhang et al. in revision.

CMIP6 – Scientific Context and Research Questions

WCRP Grand Challenges

- Clouds, Circulation and Climate Sensitivity
- Changes in Cryosphere
- Climate Extremes
- Regional Climate Information
- Regional Sea-level Rise
- Water Availability

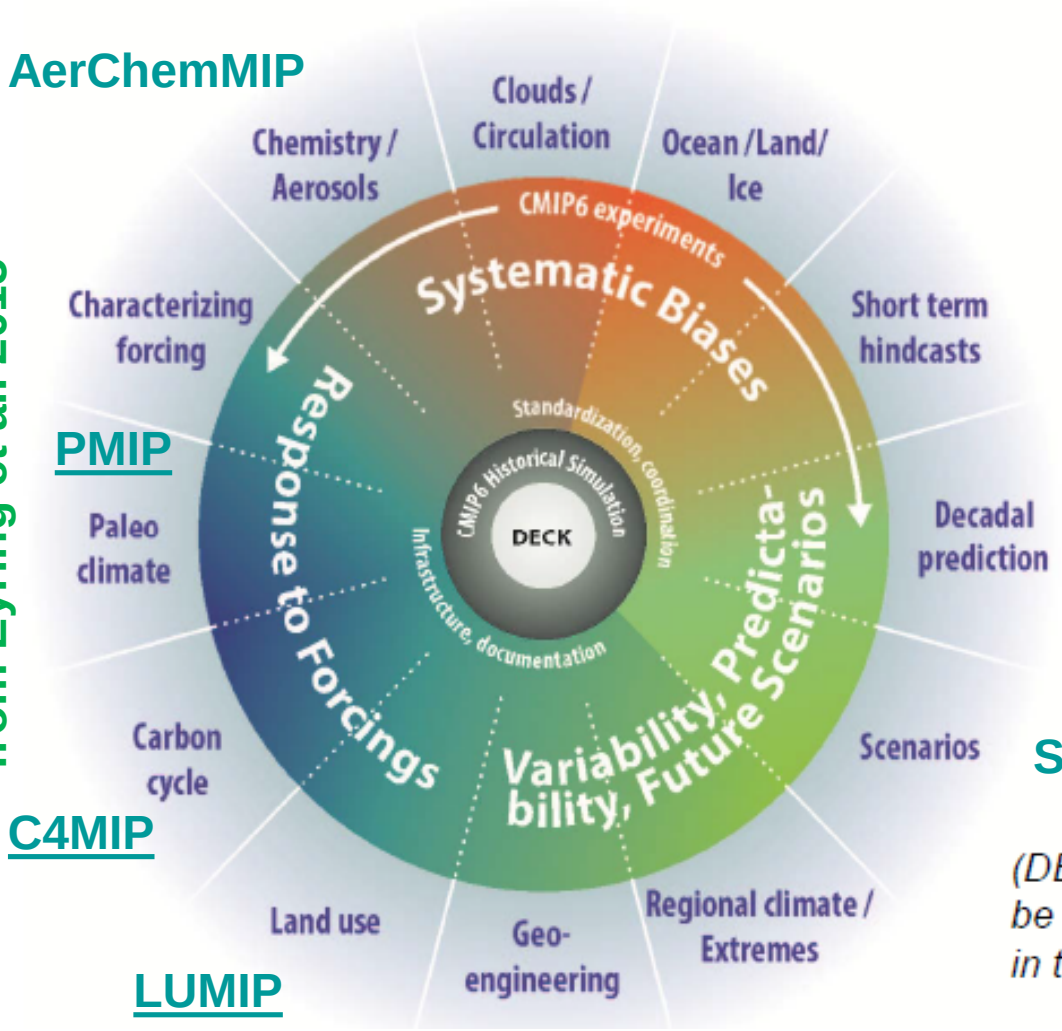
and

- Biogeochemical forcings and feedbacks

<u>CMIP6 experimental design</u> will address:

1. How does the Earth System respond to forcing?
2. What are the origins and consequences of systematic model biases?
3. How can we assess future climate changes given climate variability, predictability and uncertainties in scenarios?

CMIP6 DECK & Model IntercomParisons (MIPs)



from Eyring et al. 2015

DECK (entry card for CMIP)

i. AMIP simulation (~1979-2014)
ii. Pre-industrial control simulation
iii. 1%/yr CO_2 increase
iv. Abrupt 4xCO_2 run

CMIP6 Historical Simulation (entry card for CMIP6)

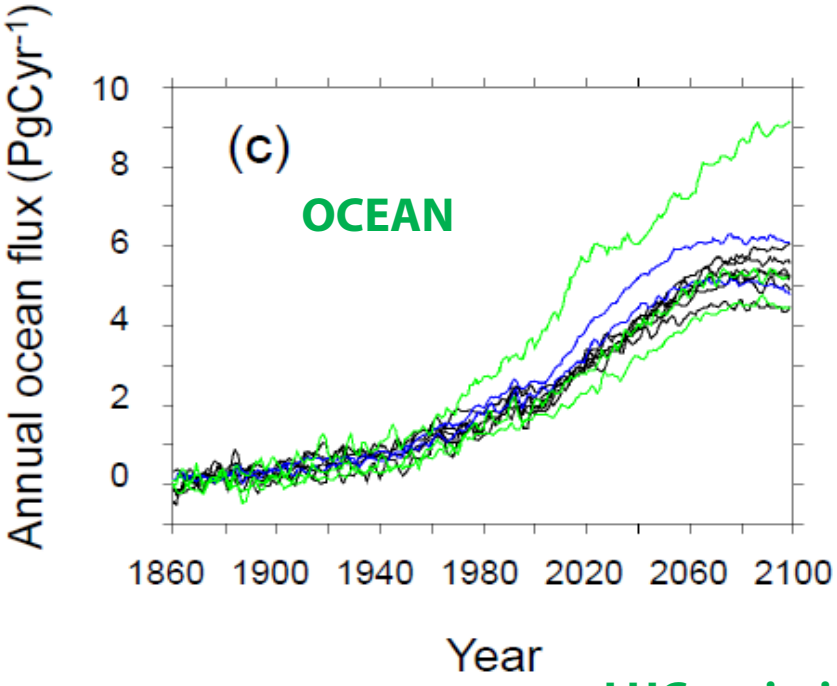
v. Historical simulation using CMIP6 forcings (1850-2014)

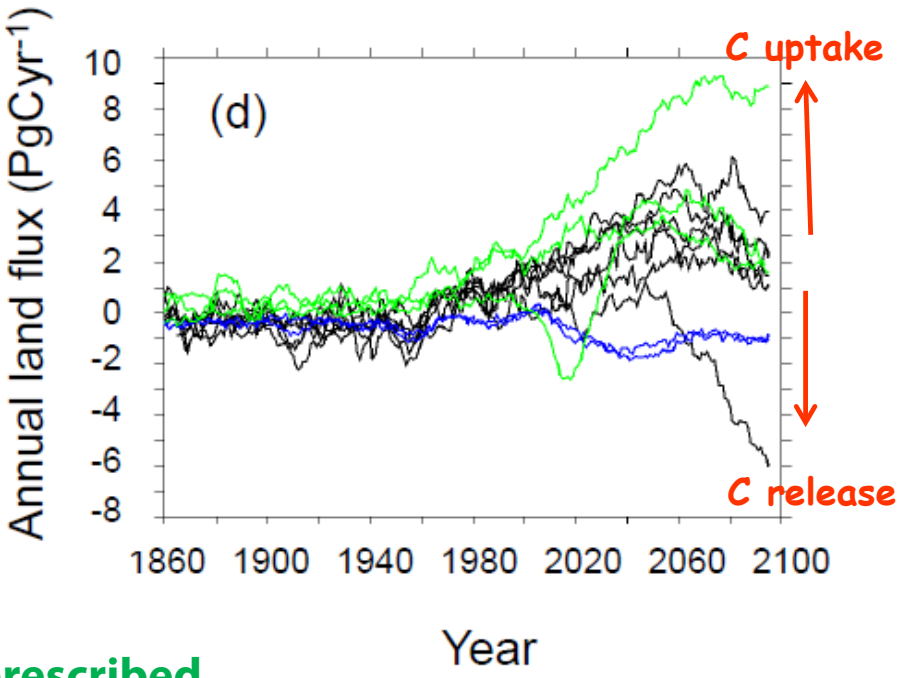
ScenarioMIP

(DECK & CMIP6 Historical Simulation to be run for each model configuration used in the subsequent CMIP6-Endorsed MIPs)

CMIP6 Historical Simulation will serve as a benchmark for CMIP6-endorsed MIPs

Terrestrial carbon cycle fluxes differ widely in 11 carbon-climate CMIP5 ESMs (RCP 8.5 CO_2 emissions)



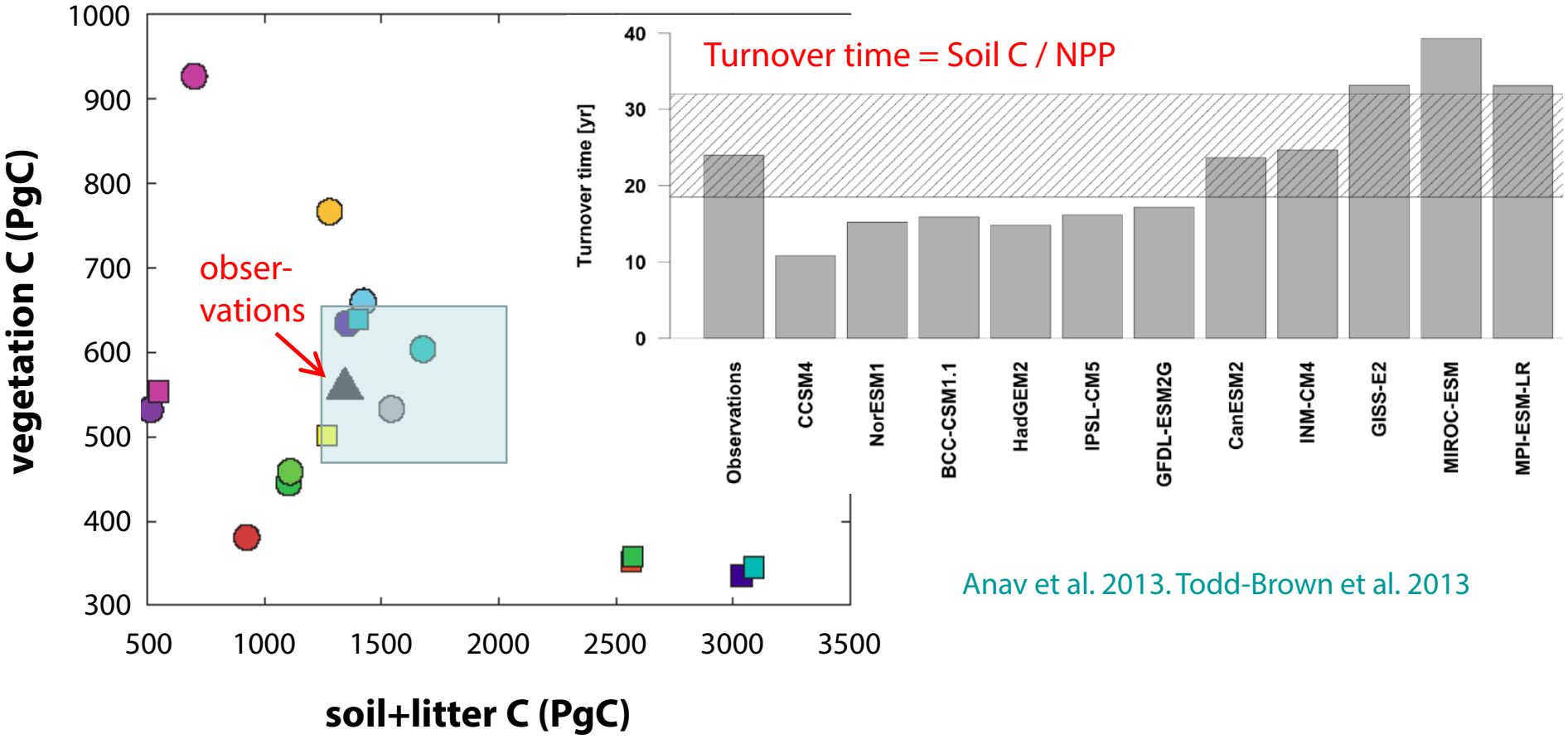


LUC emissions prescribed
LUC emissions calculated
Interactive C-N dynamics

Friedlingstein et al. 2014
J. Climate

- Land Use Change (**LUC**) emissions were treated differently in the models
- Some AR5 models had dynamic vegetation
- Some AR5 models had nutrient (N) limitations on plant growth
- No AR5 model included dynamic vegetation AND C-N interactions

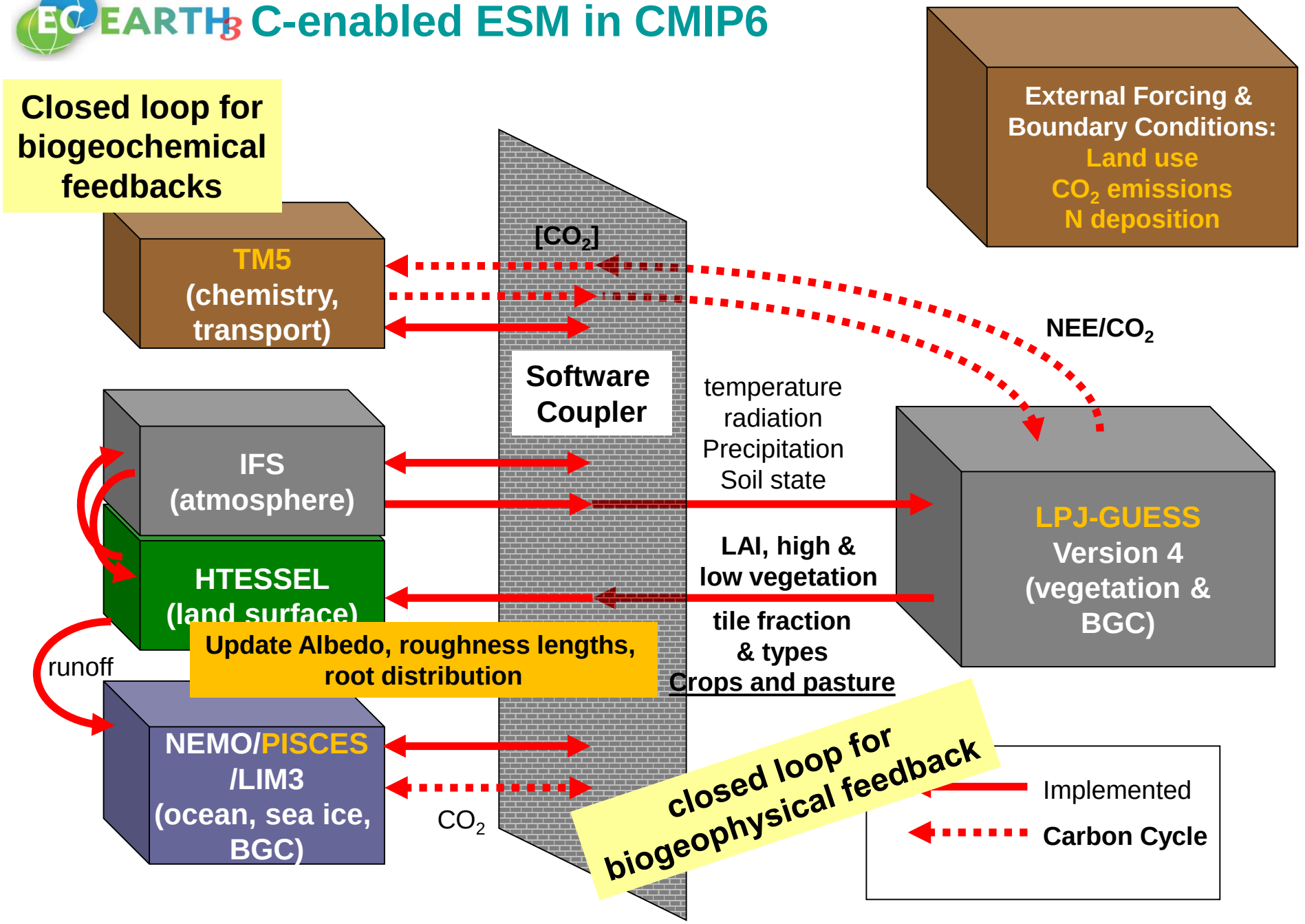
There is a large spread in the modelled terrestrial ecosystem C pools in IPCC-AR5 carbon-climate ESMs



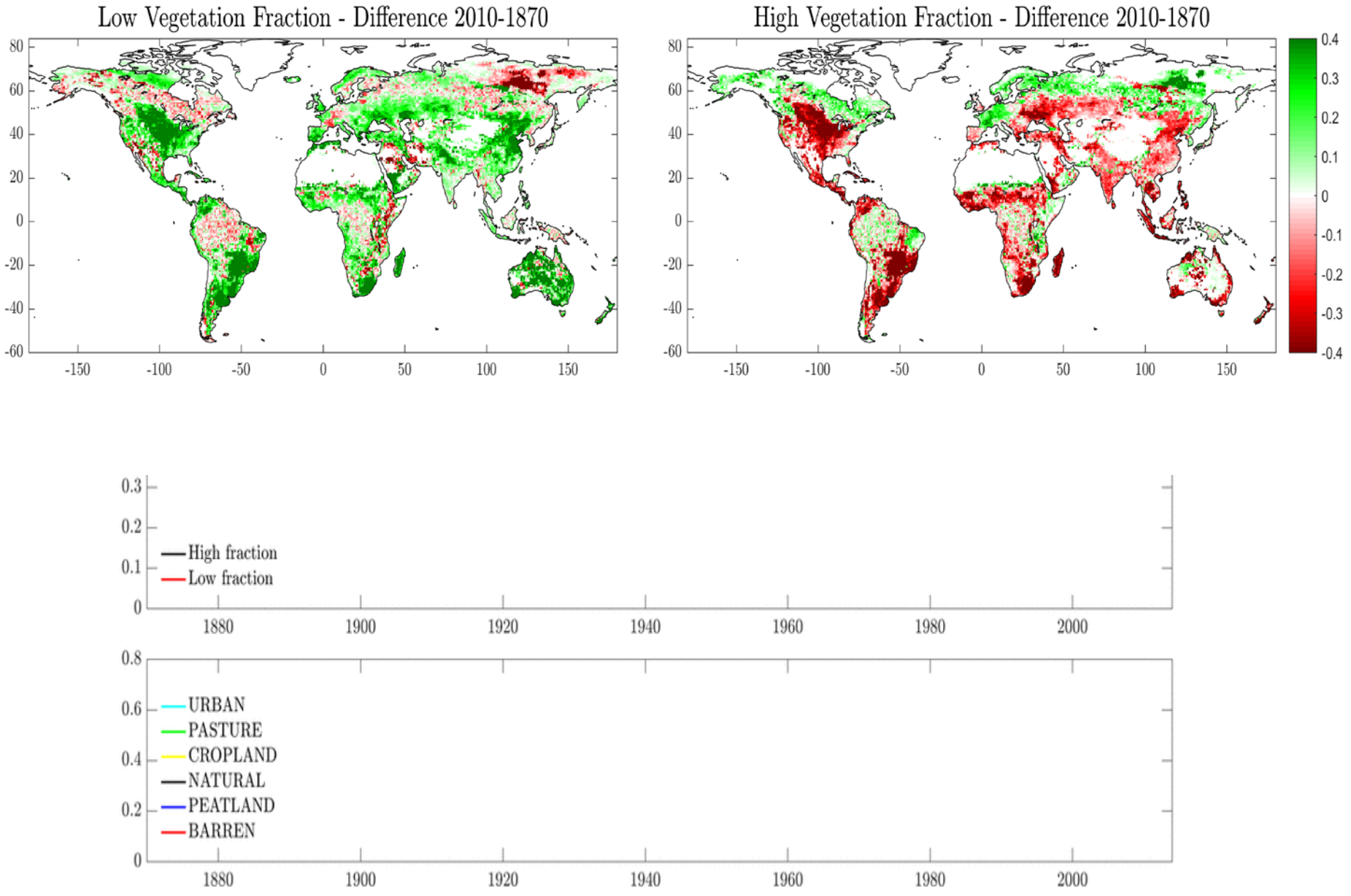
Anav et al. 2013. Todd-Brown et al. 2013

- The large spread in ESM soil C is due to differences in NPP and parameterisation of heterotrophic respiration response to soil water and temperature
- CMIP5 ESMs generlally overestimate CO2 fertilization

EC-EARTH3 C-enabled ESM in CMIP6



Dynamic Vegetation in EC-Earth, 1870-2010

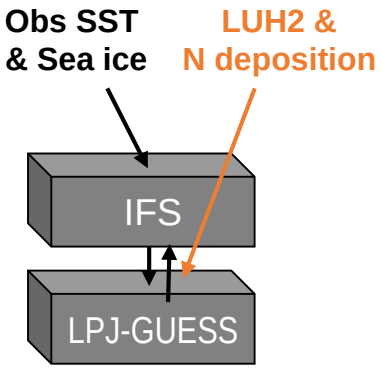


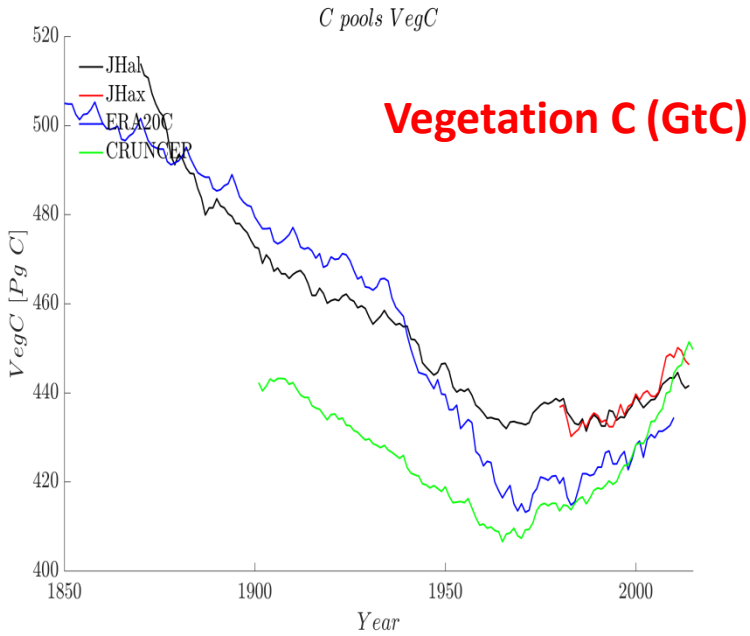
D. Wårlind & L. Nieradzik (Lund Univ.)

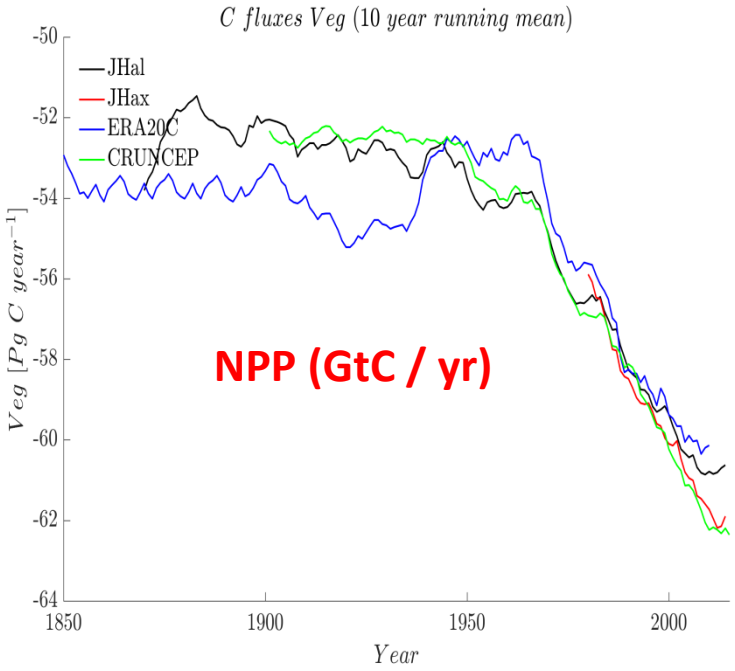
Evaluation – terrestrial C pools and fluxes

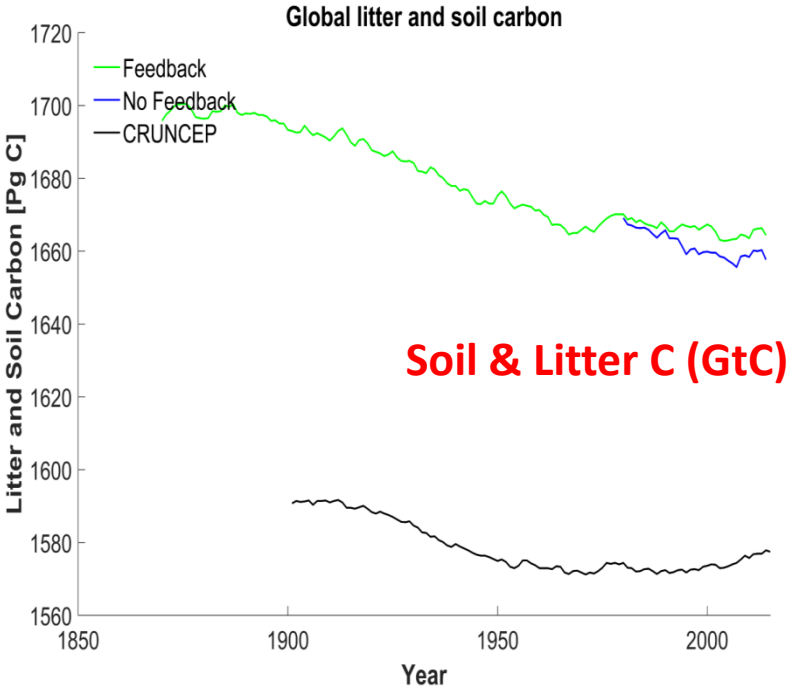
LPJ-GUESS – IFS
Fully coupled simulation 1870-2015

D. Wårlind & L. Nieradzik
(Lund Univ.)



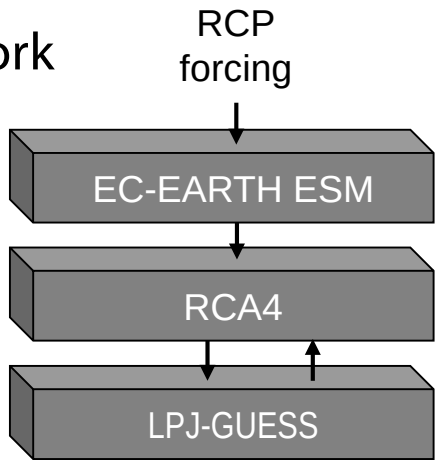






CMIP6 and EC-Earth

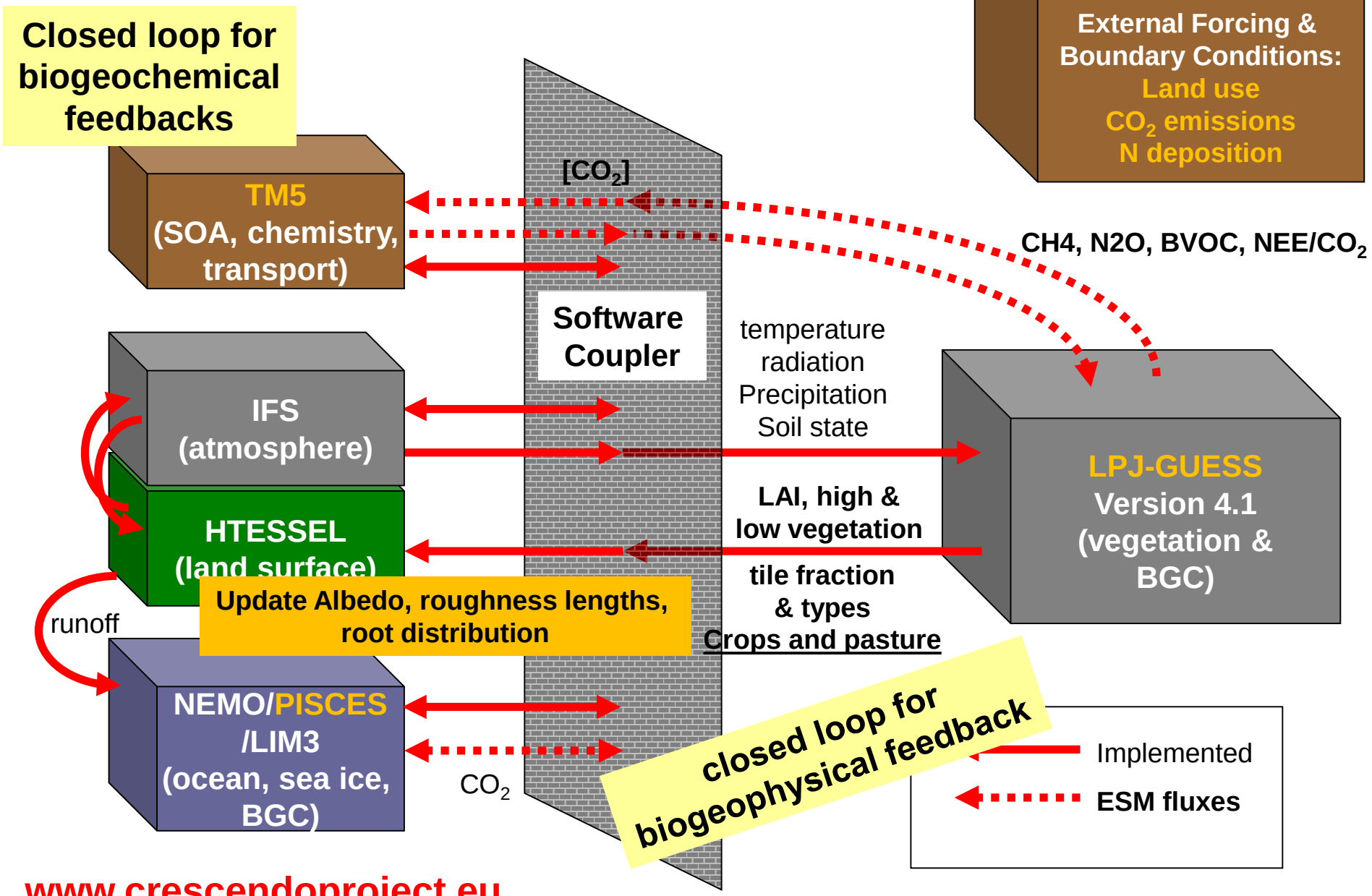
- Final tuning ongoing
- DECK experiments due to begin this month
- Systematic and comprehensive ESM evaluation. E.g. using ESMValTool with CMIP6 models
- Even EC-Earth runs without LPJ-GUESS coupled will use LPJ-GUESS vegetation fields, ensuring consistency across GCM and ESM experiments
- Multiple model configurations and MIP commitments make this a huge technical and scientific challenge!
- Dynamical downscaling will use a consistent ESM framework



Outlook and further model improvements

- Field studies, observations and modelling highlight the importance of including detailed biosphere-atmosphere interactions in coupled modelling frameworks
- But a modeller's work is never done! We need to include
- Permafrost-C interactions and wetland CH_4 emissions
- Phosphorous limitation in addition to N important in the tropics
- Improved wildfire parameterizations with BLAZE
- New ecosystem disturbances such as insect attacks
- Plant functional types (PFTs) must be added that can better quantify the potential for bioenergy carbon capture and storage (BECCS) to mitigate climate change
- Etc.
- LPJ-GUESS developments will be available to RCA-GUESS and EC-Earth, providing better projections and for the Baltic Sea region

ESM in H2020



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Thank you!