Carbon cycle in land surface models

CHESS Land Modelling Course
Friday 6.10.17
Sarah Chadburn – Exeter, UK

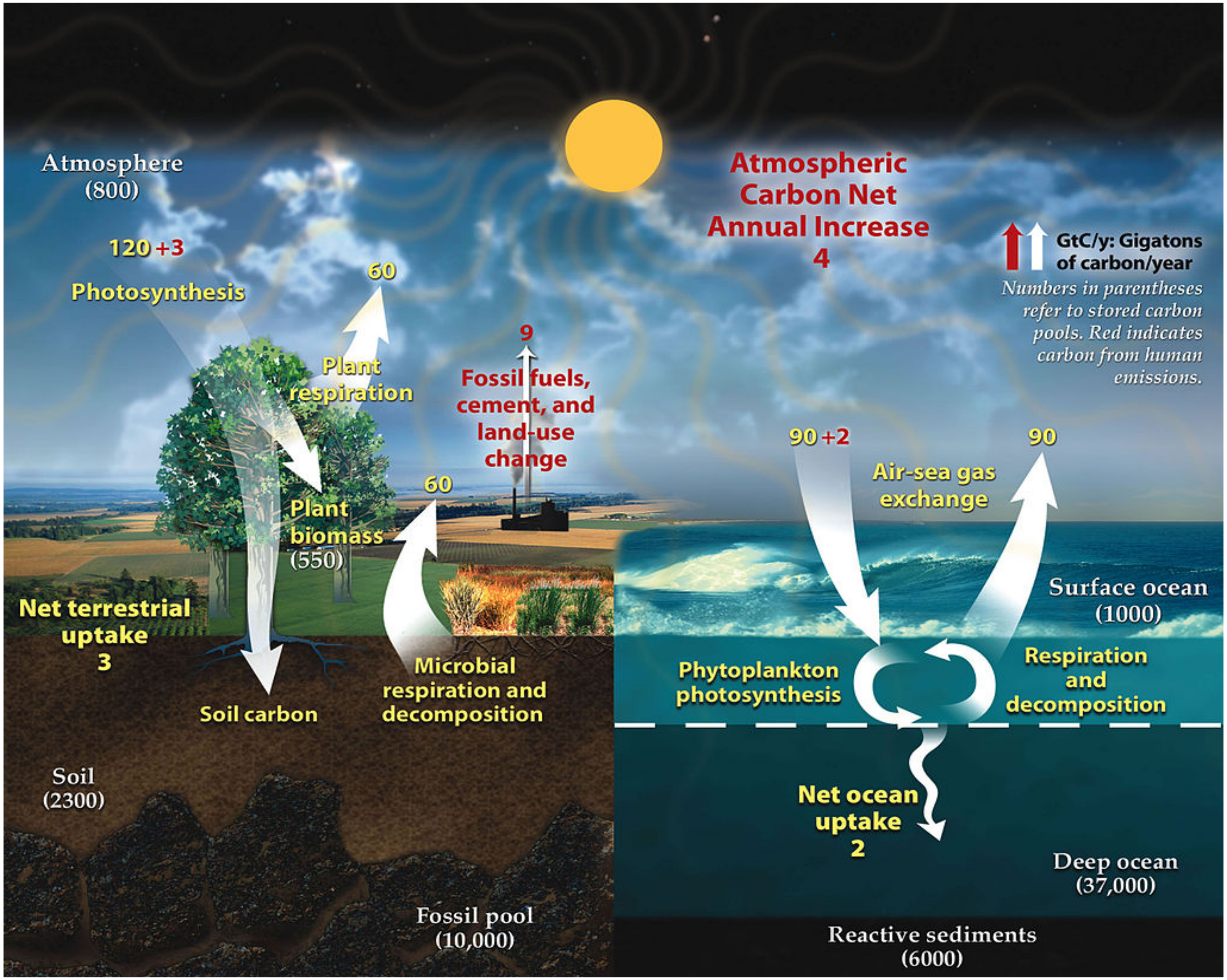
Overview

- What is the carbon cycle?
- Model processes:
  - Coupling a DGVM to a climate model
  - Land use change and fire
  - Soil carbon modelling
- Case study: Site simulations

Overview of me

- I work on ‘JULES’
- I work mainly with soil, and mainly it’s cold
- My background is theoretical physics

The carbon cycle



Carbon quantities

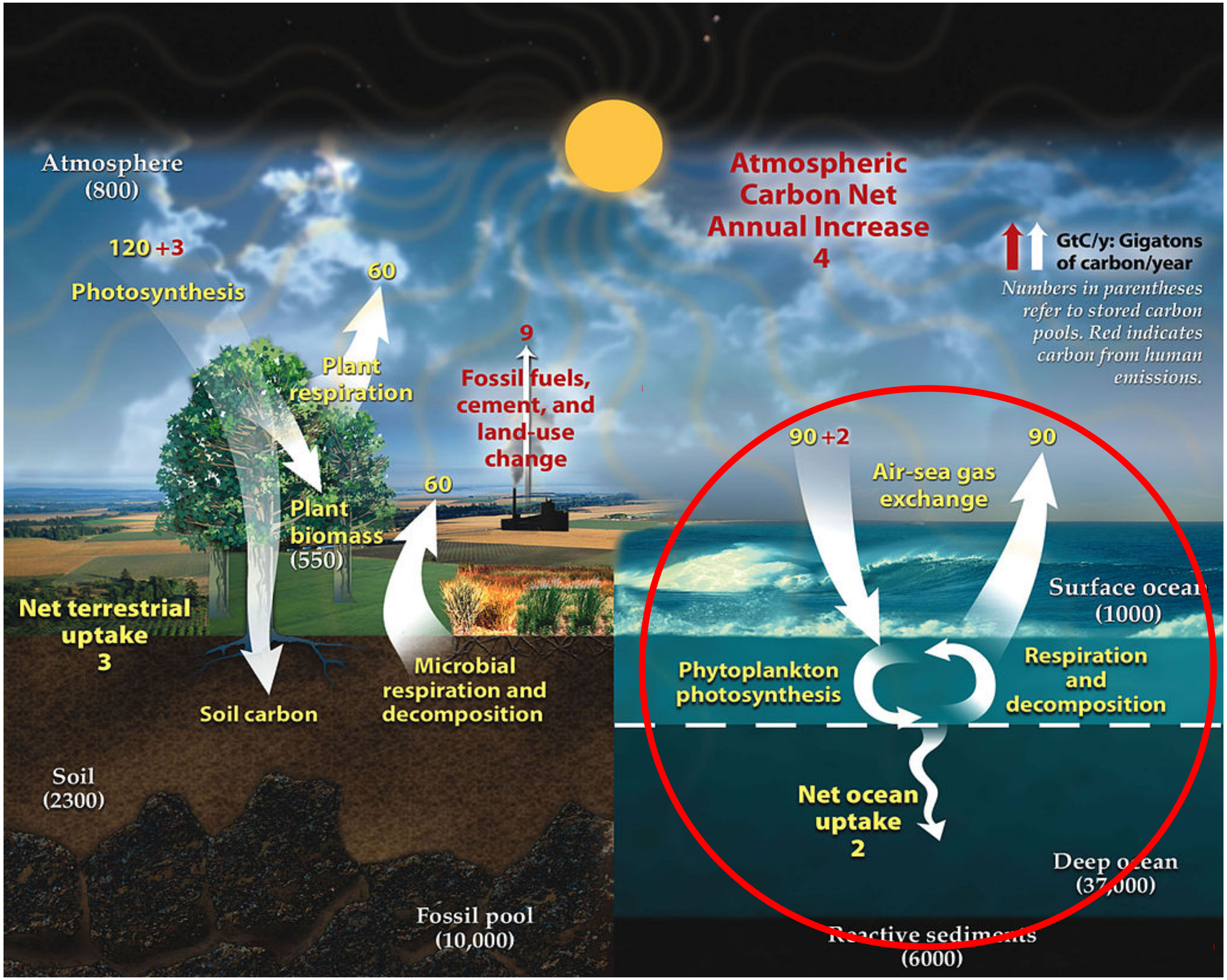
Peta grams (Pg) = Giga tonnes (Gt).

10^{15} grams = 10^{9} tonnes.

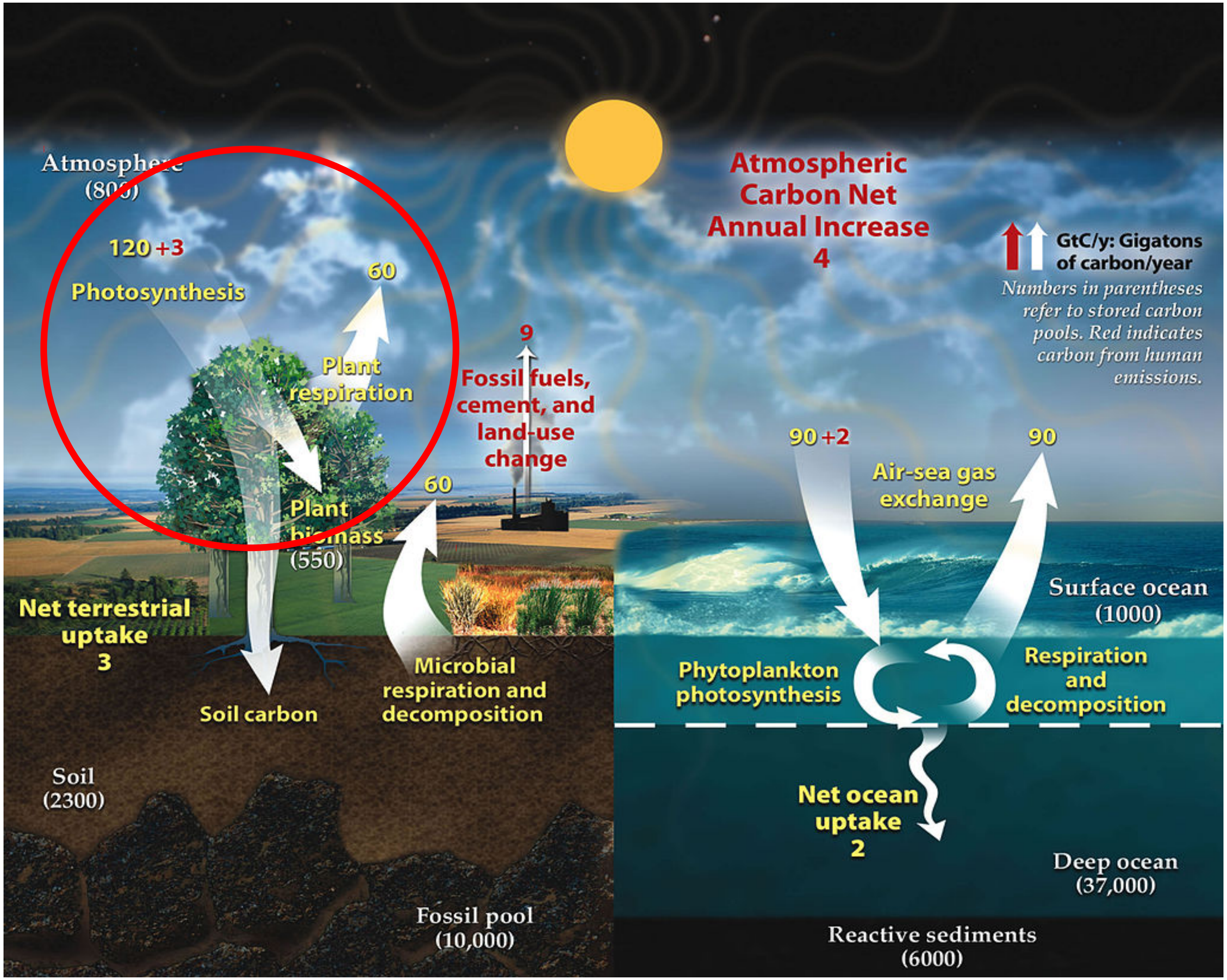
For reference: Emission since pre-industrial ~ 550 Gt.
Allowed emissions to stay below 2ºC, another 450 Gt.

Estimates of total soil carbon ~ **2300 Gt**
Atmosphere ~ 700 Gt
Vegetation ~ 500-600 Gt
Ocean ~ 37,000 Gt

The carbon cycle



The carbon cycle



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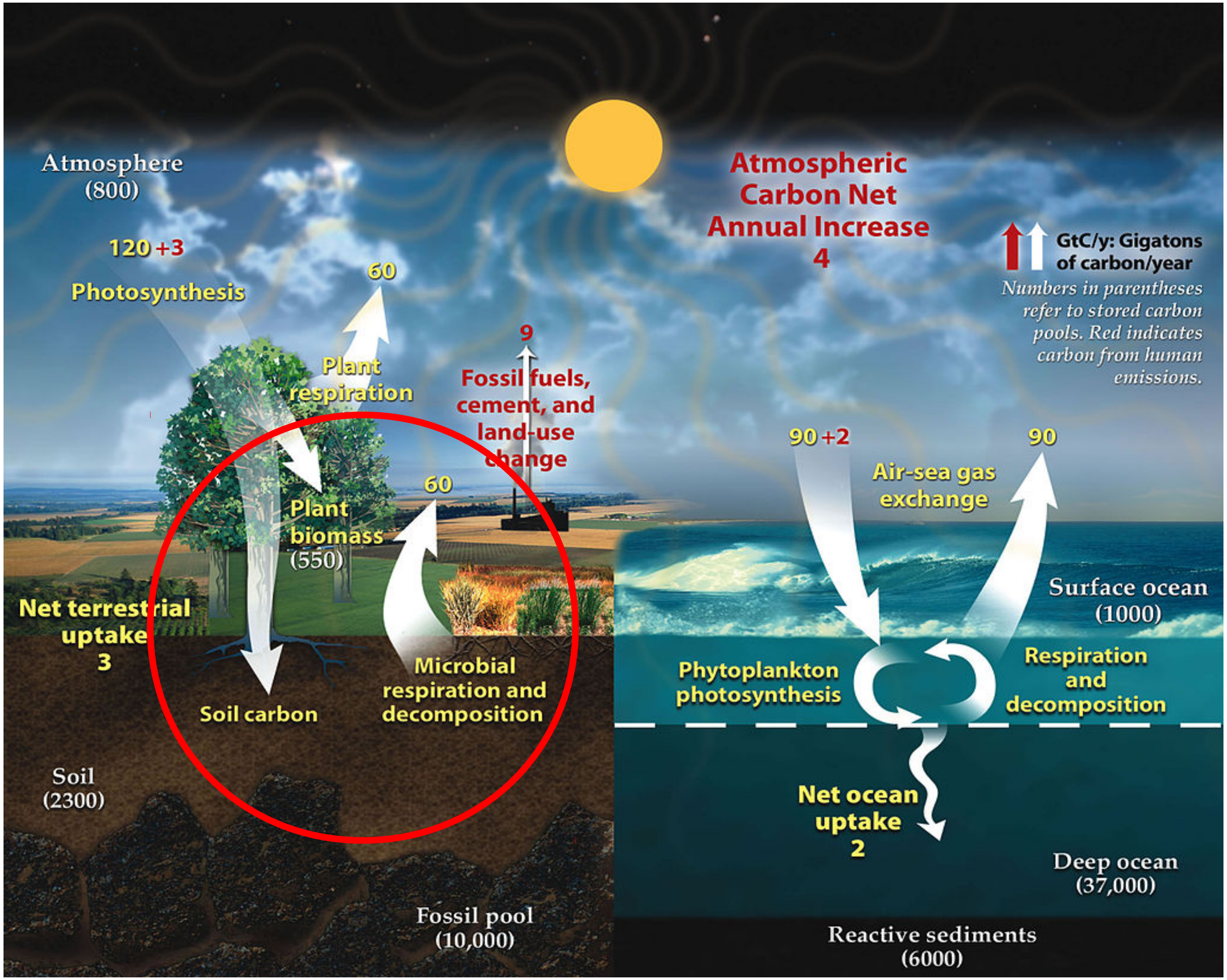
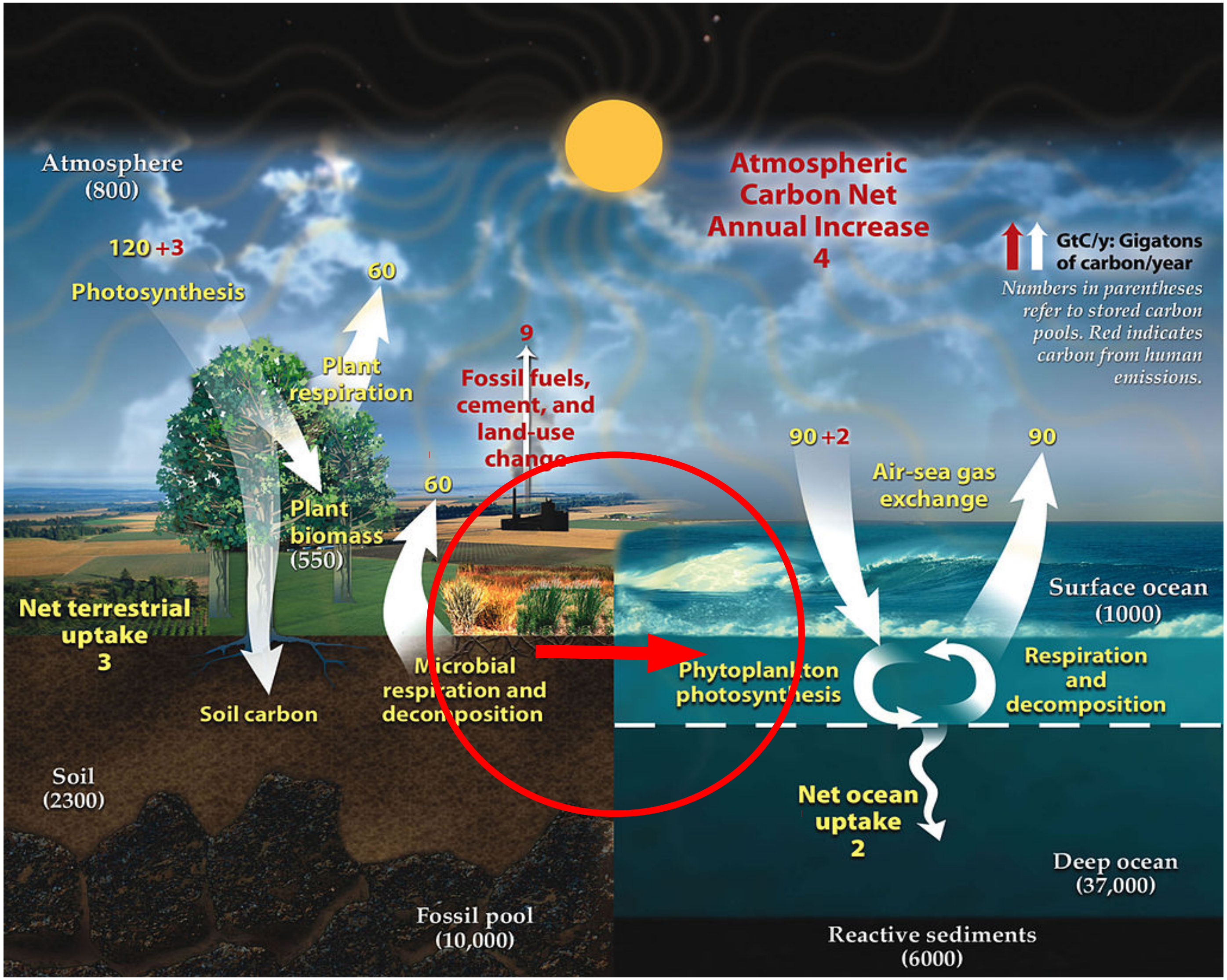
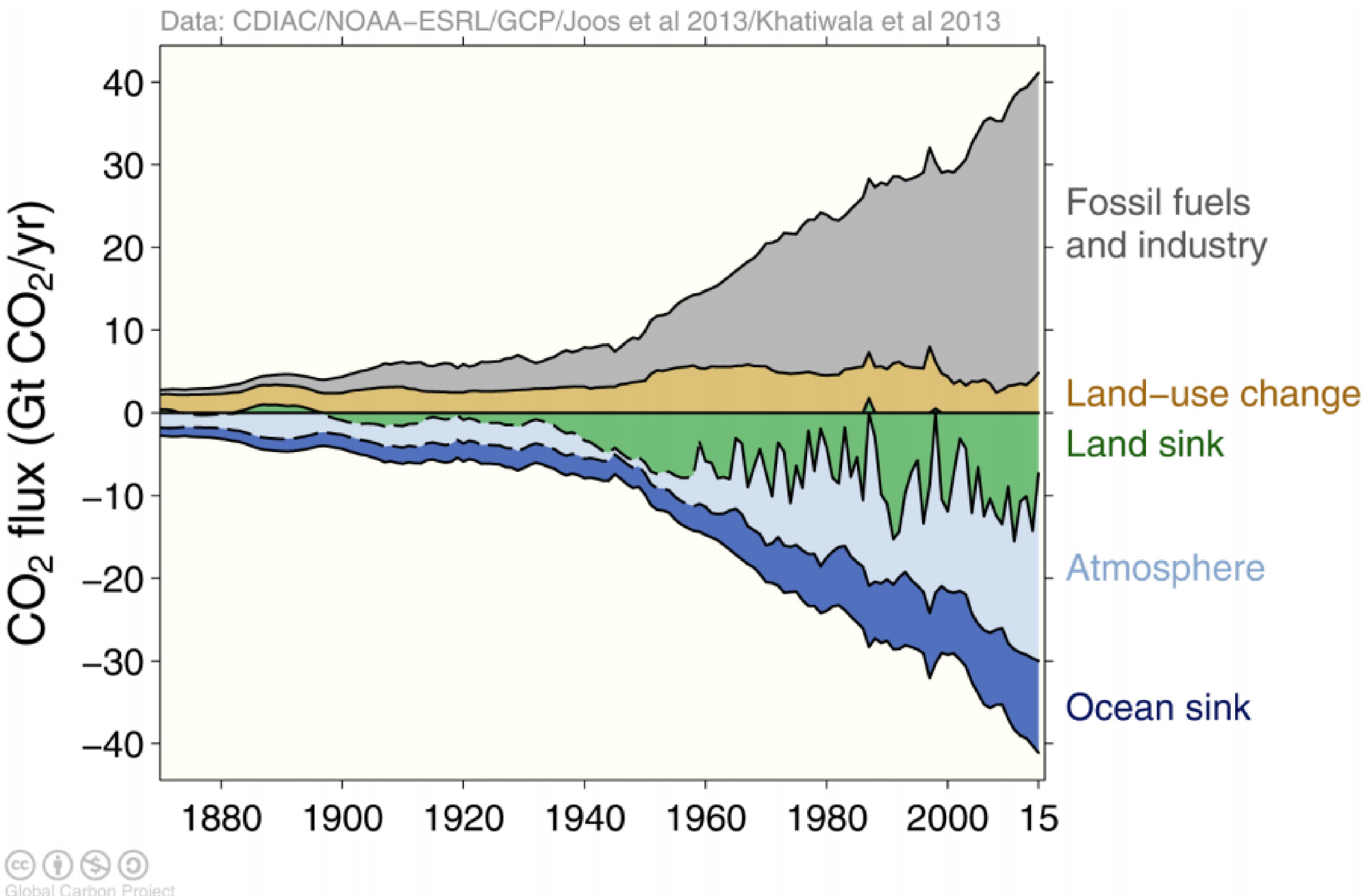


The carbon cycle



Transport of dissolved carbon
to ocean via rivers.

Global carbon cycle



Model processes

Net Ecosystem C Uptake

=

Primary production – Respiration(plant) – Respiration(microbe) – DOC etc – Fire emissions – Land use change

Model processes

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Increases with CO_2

Model processes

Net Ecosystem C Uptake

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Primary production – Respiration(plant) – Respiration(microbe) – DOC etc – Fire emissions – Land use change

Increases with temperature

Model processes

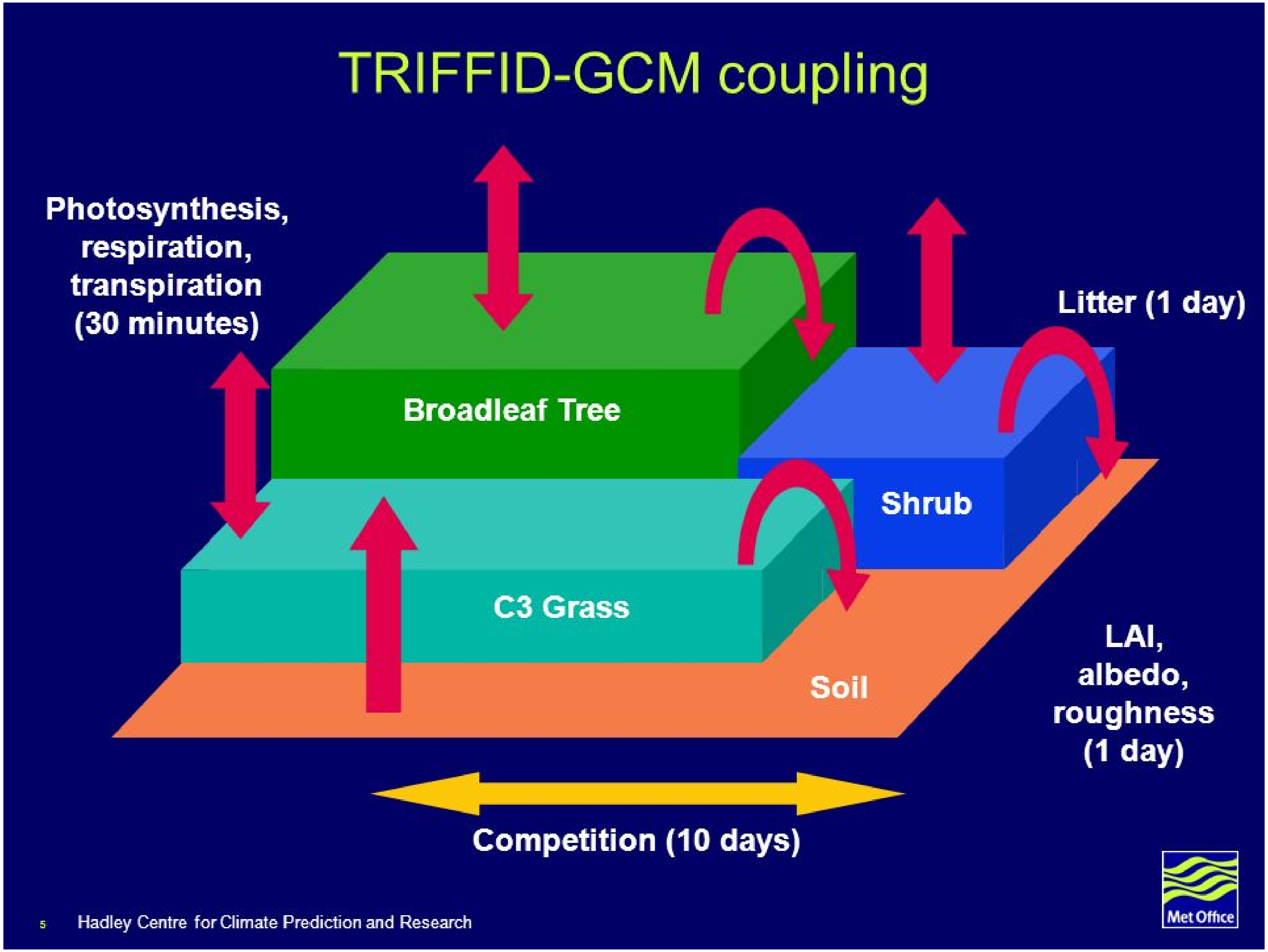
Net Ecosystem C Uptake

=

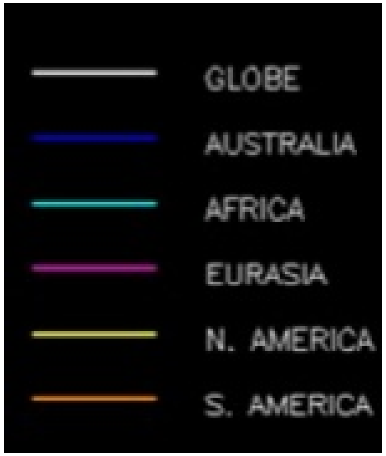
Primary production – Respiration(plant) – Respiration(microbe) – DOC etc – Fire emissions – Land use change

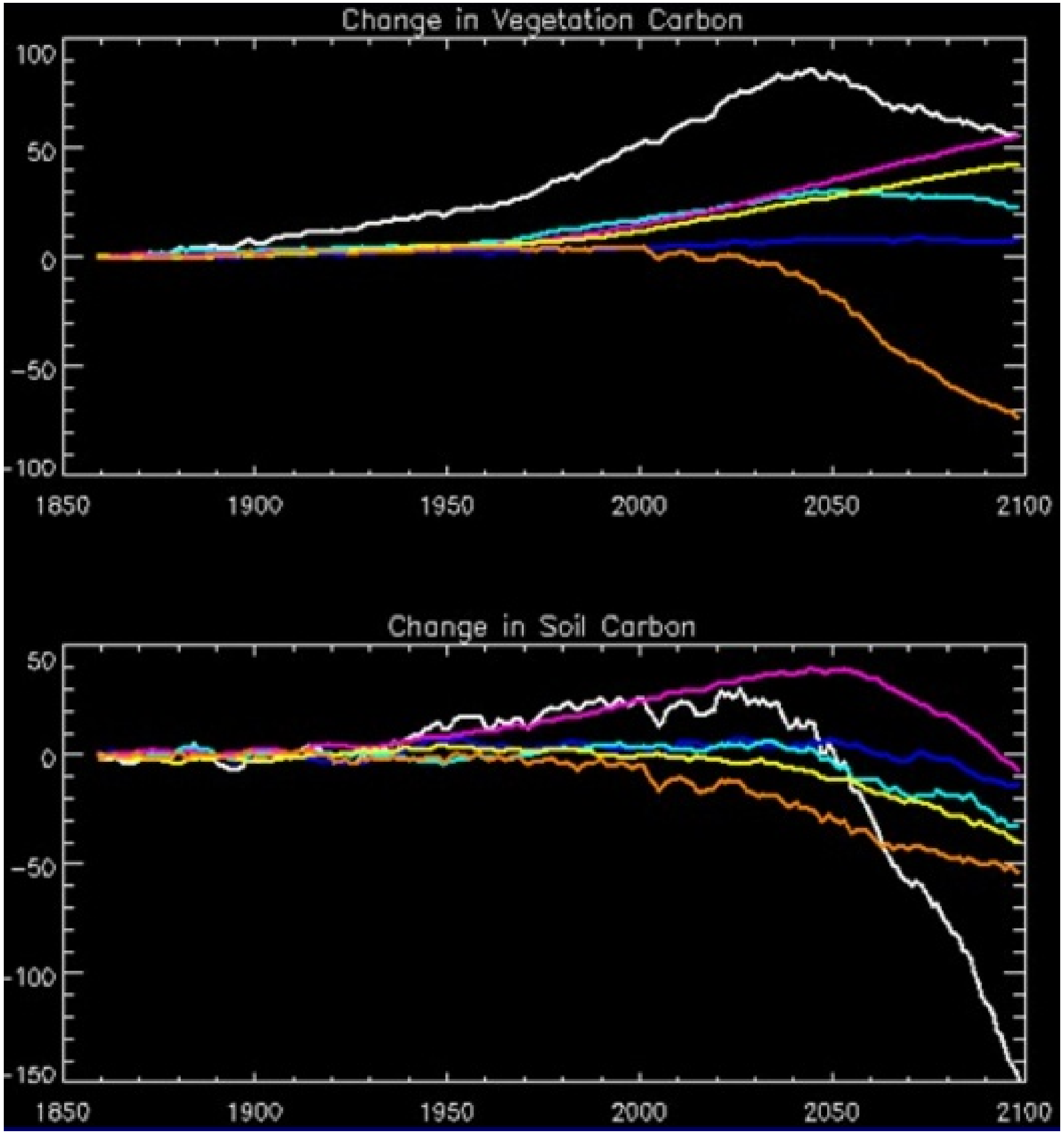
Soil moisture effects?

Dynamic vegetation model

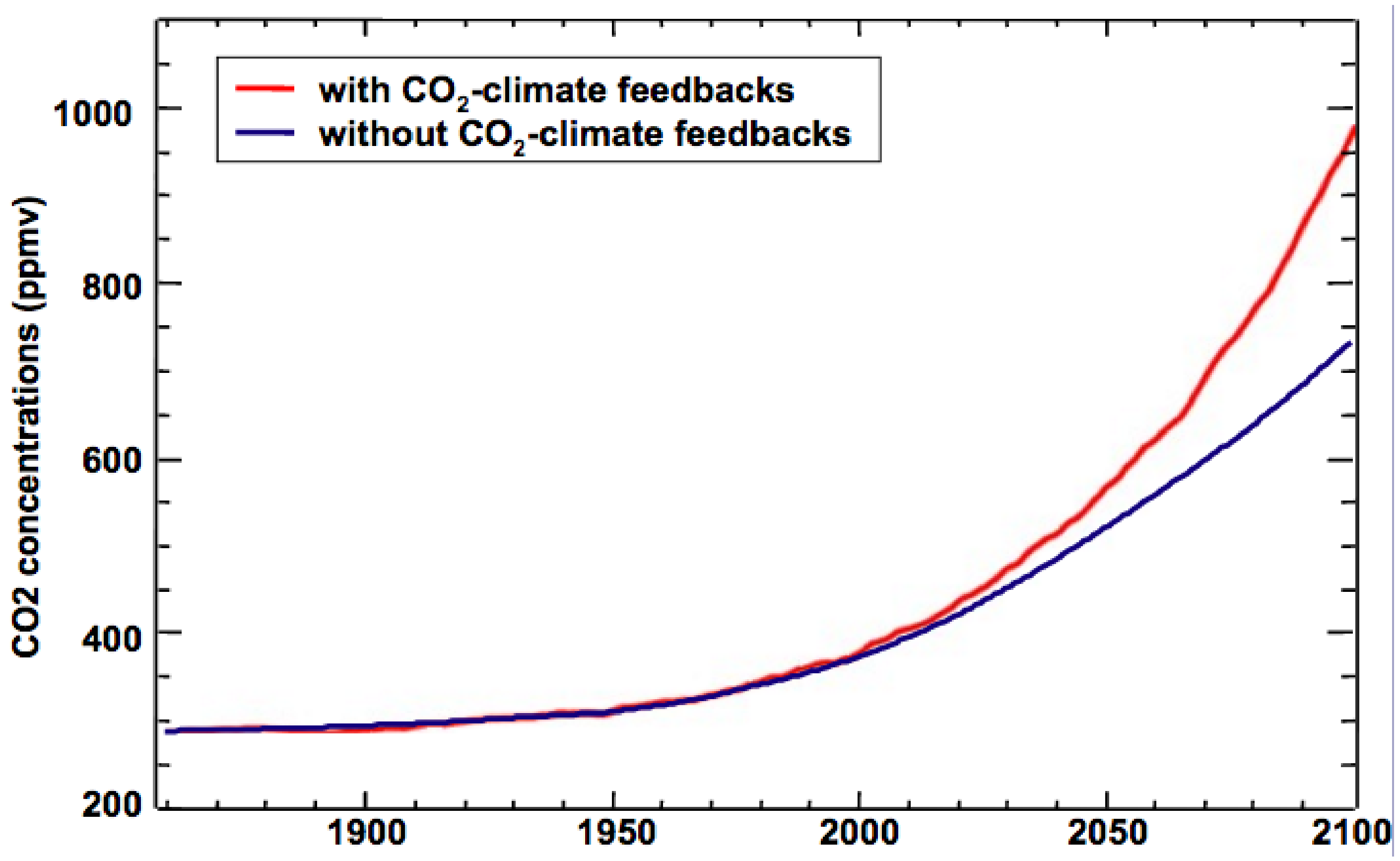


Earliest global carbon cycle model...





Coupling to the atmosphere



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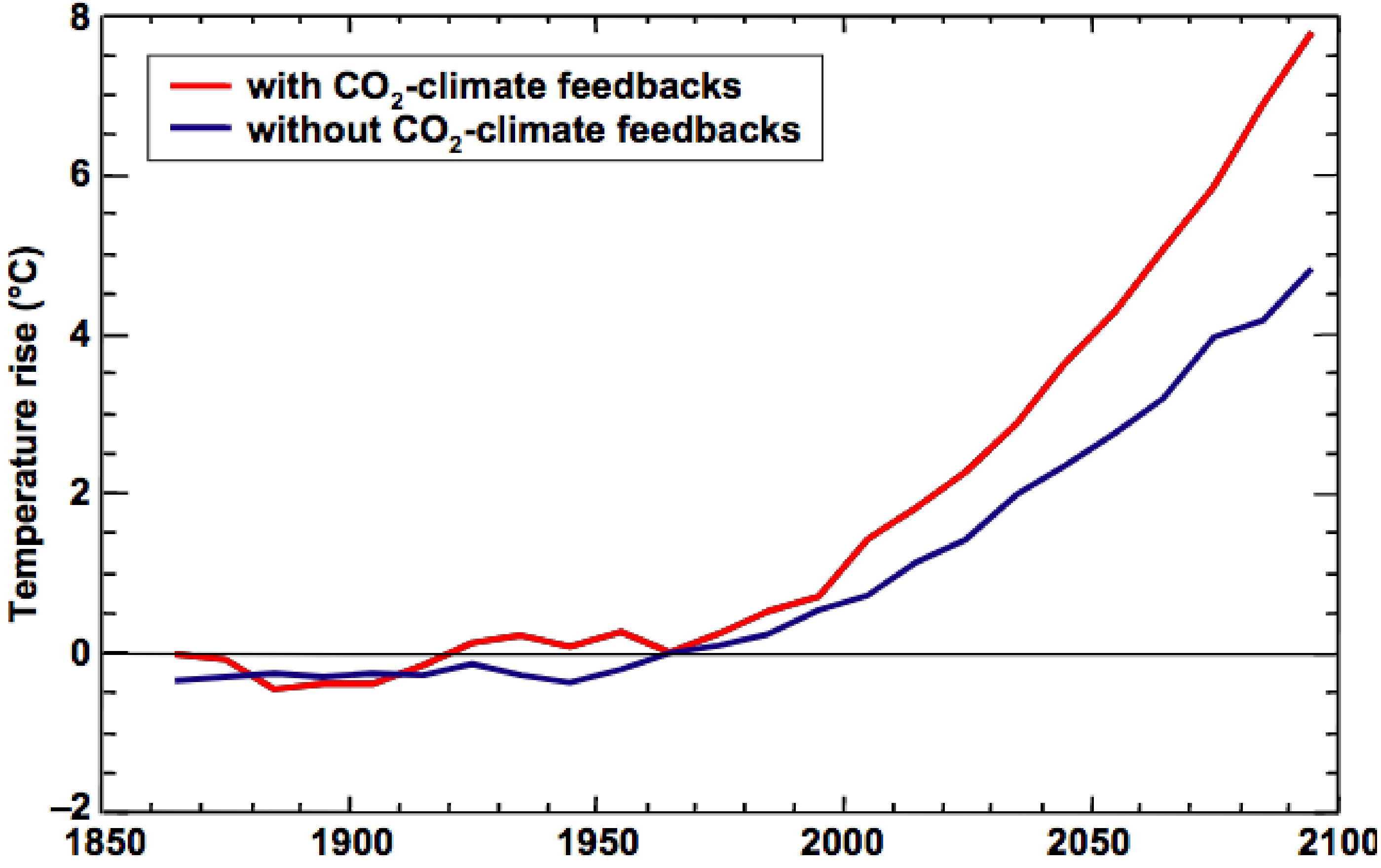


Carbon-cycle modelling has come a long way since these early days

But there is still a long way to go...

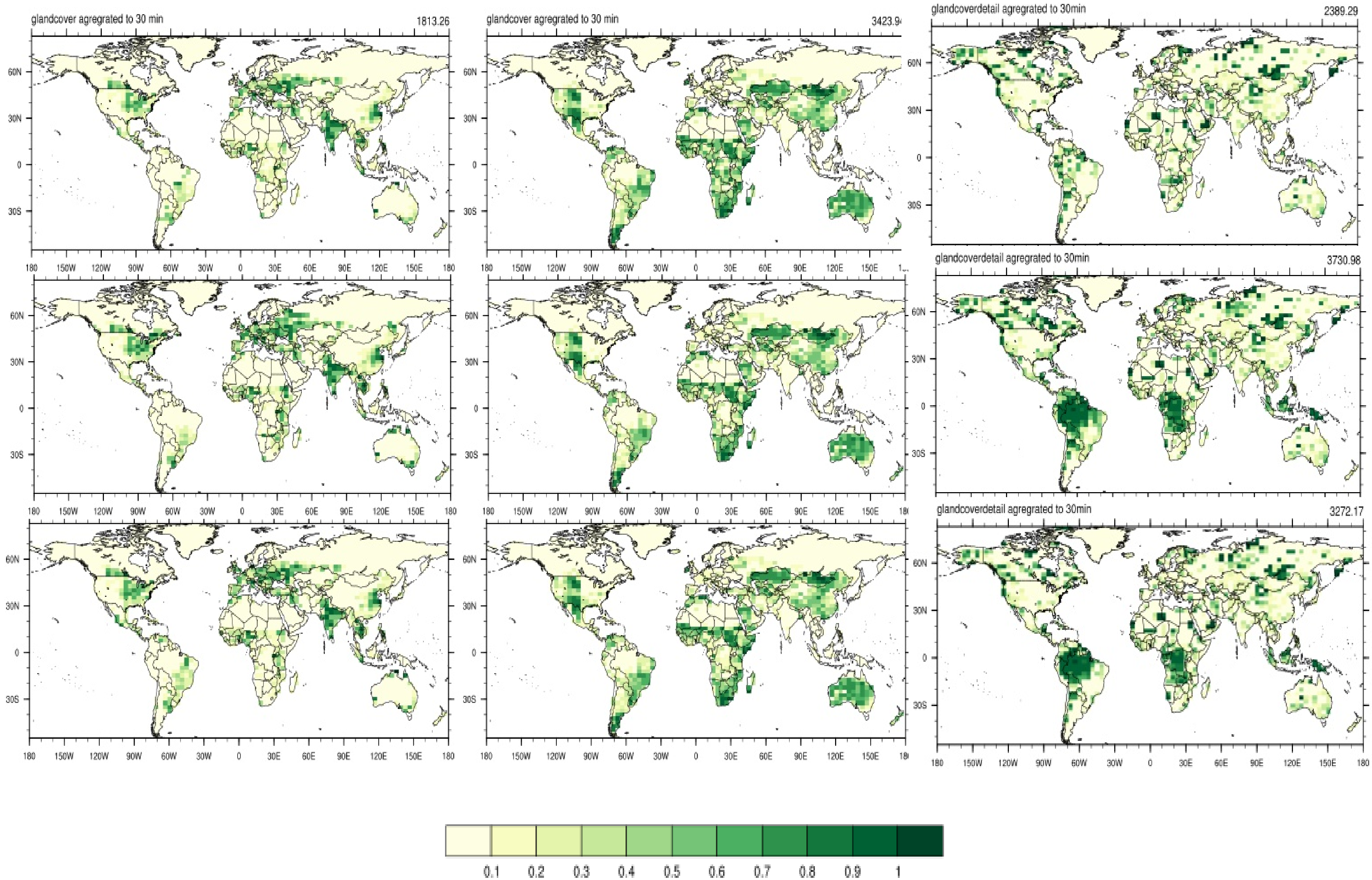
Impacts of land use change

- Link land use change to mitigation strategies.
- Can we still feed everyone?

Land-use scenarios

Crops | Pasture | Protected Areas

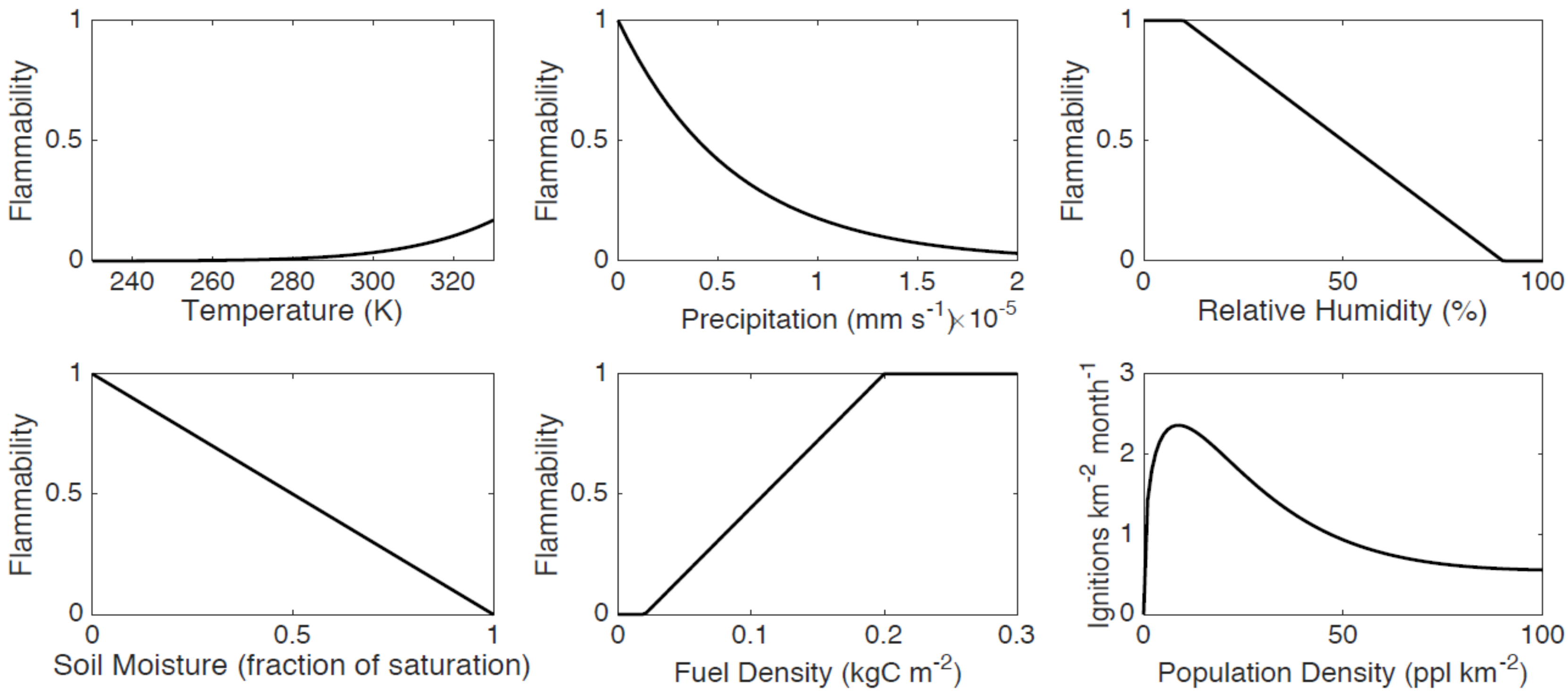
SSP2 Baseline | SSP2 RCP1.9 | SSP2 RCP2.6



Fraction of grid cell

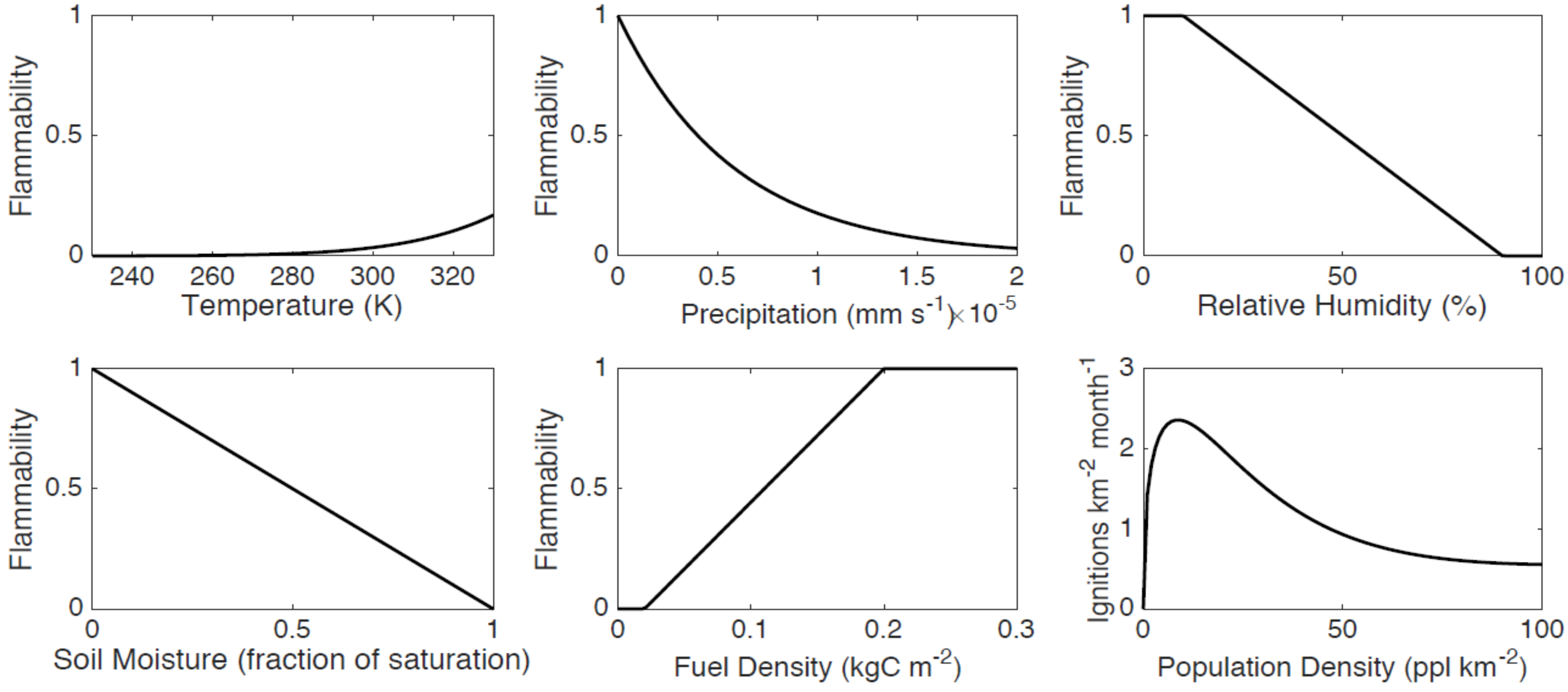
Fire modelling: INFERNO

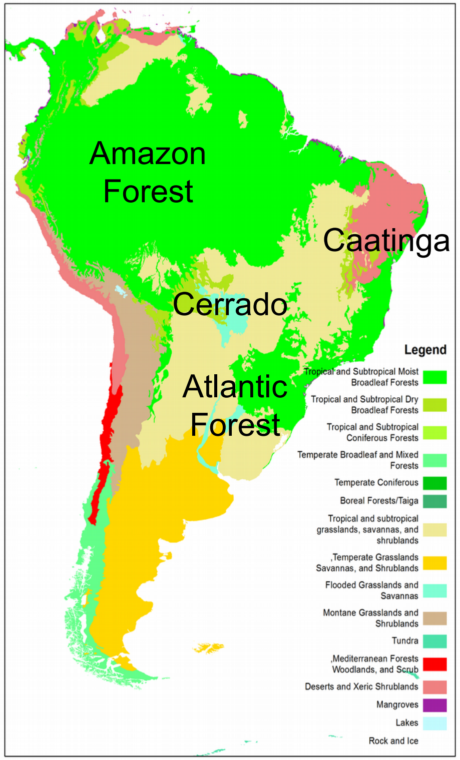
- Combine factors → Burnt area



Fire modelling: INFERNO

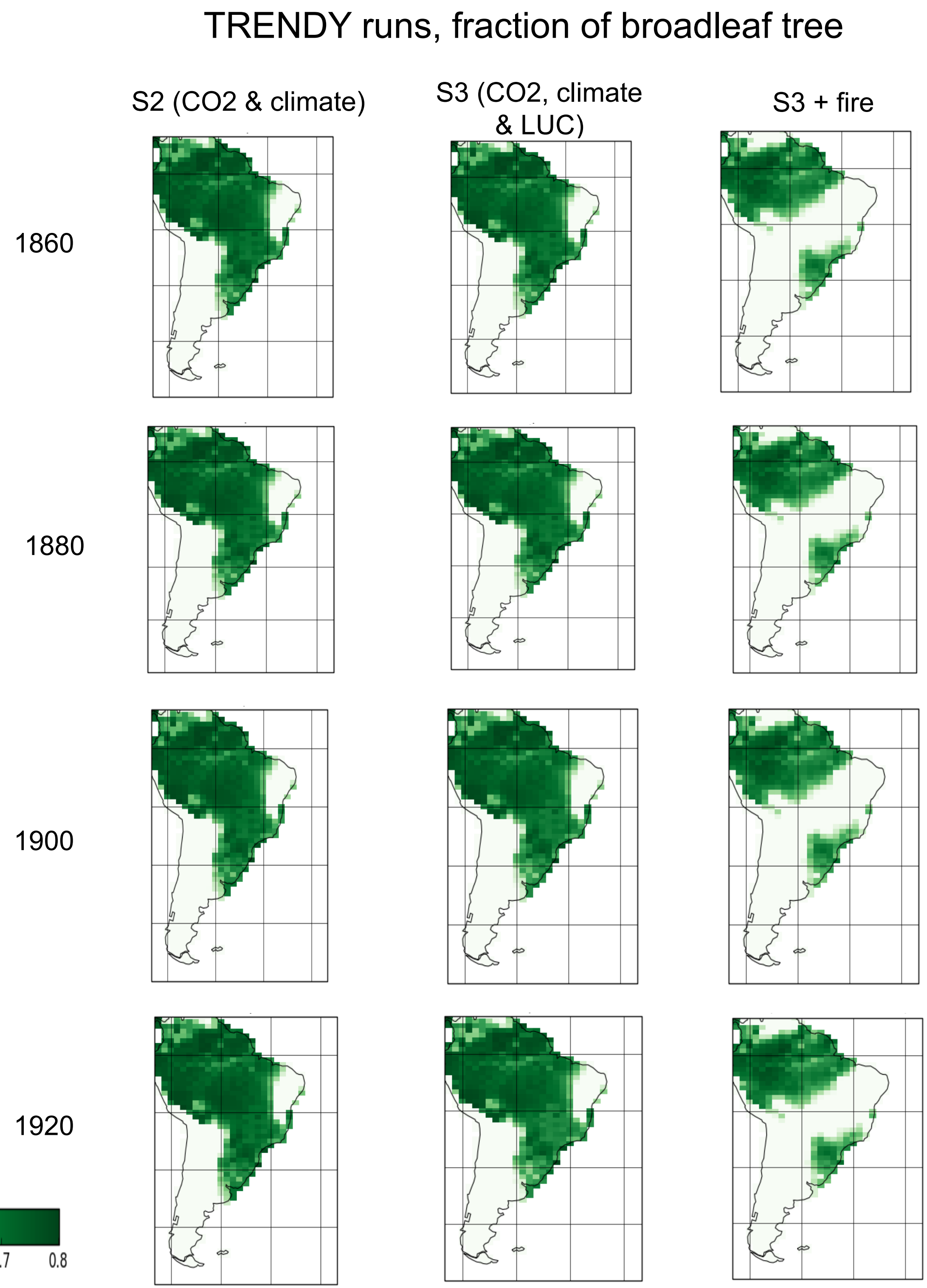
- Combine factors → Burnt area → Carbon emissions (depending how much vegetation was in that area)

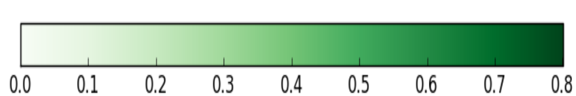




WWF Biome and ecoregions

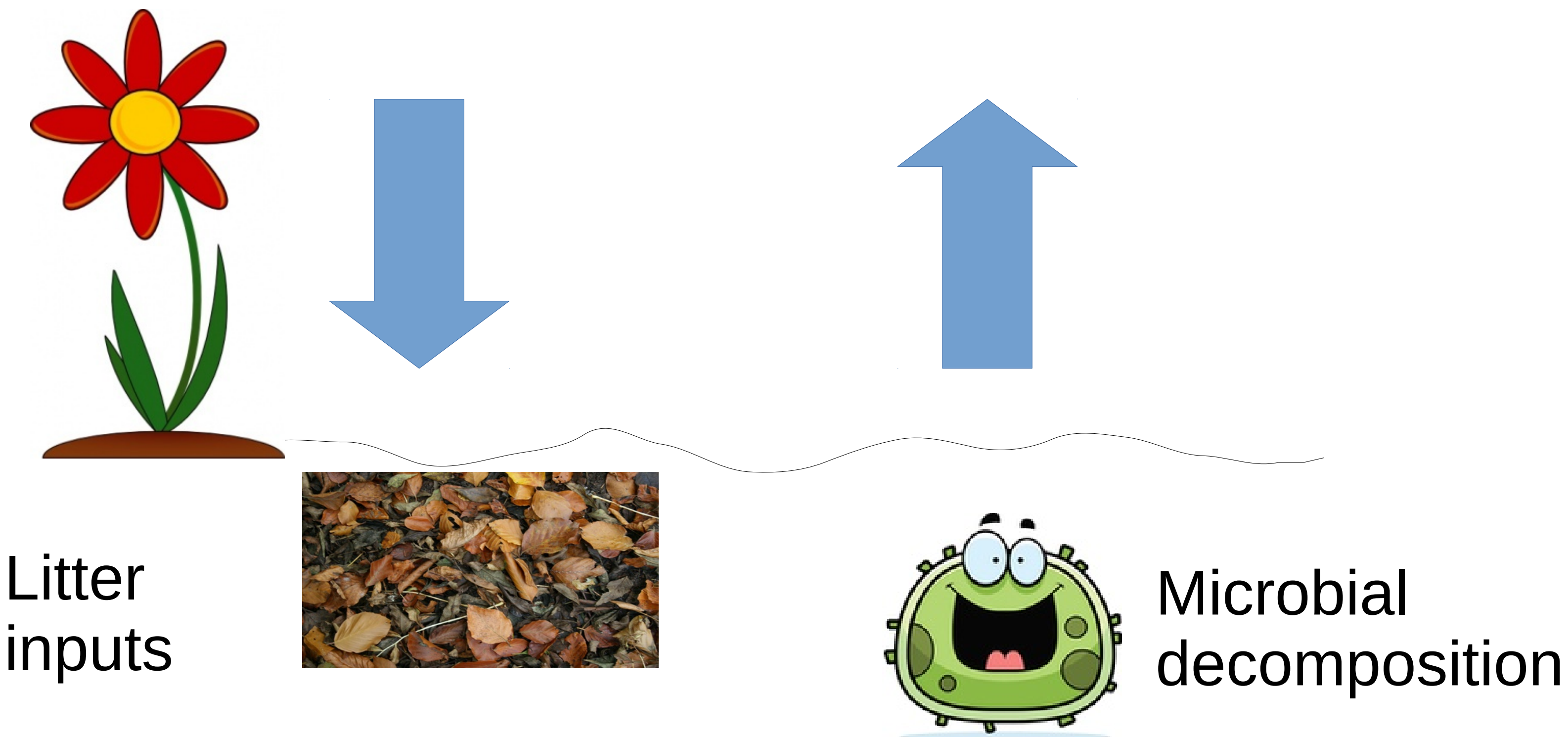
Impact of fire in the DGVM





Soil carbon modelling

- Basic equation: ΔC = inputs – outputs



Soil carbon modelling

- Basic equation: ΔC = inputs – outputs
- The first soil carbon models:

$$\frac{dC}{dt} = L_{input} - k(t)C$$

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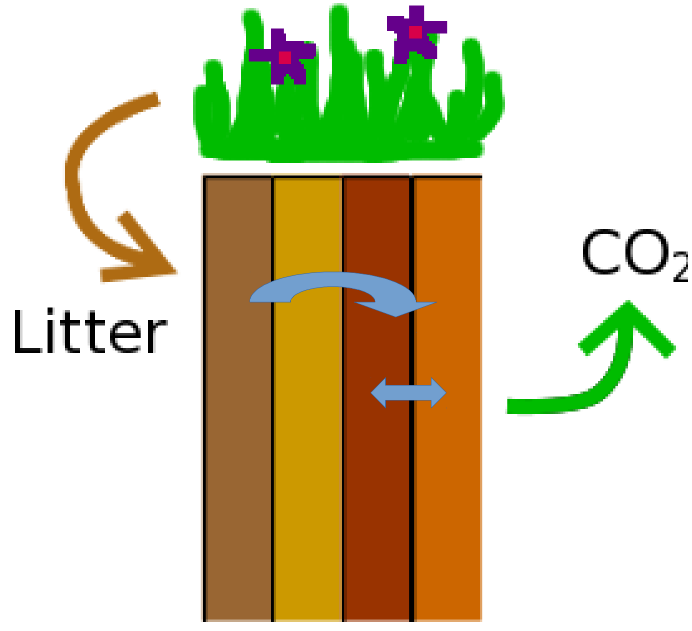
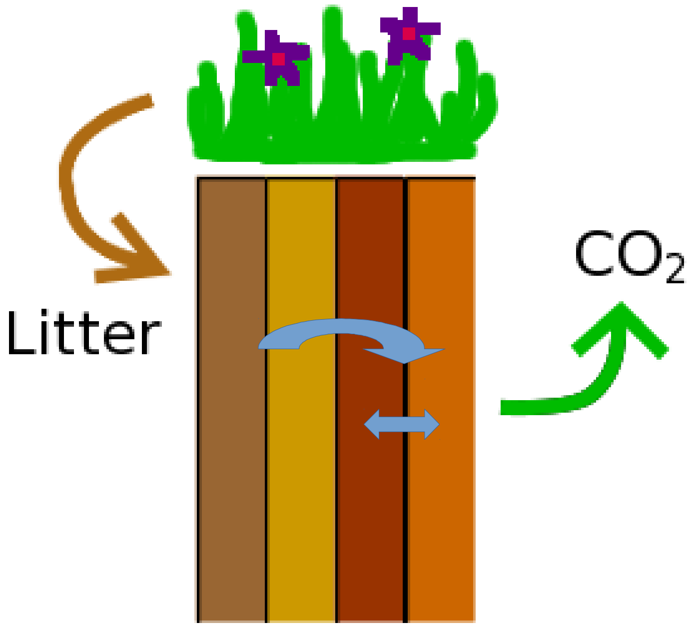


Including soil carbon below the surface

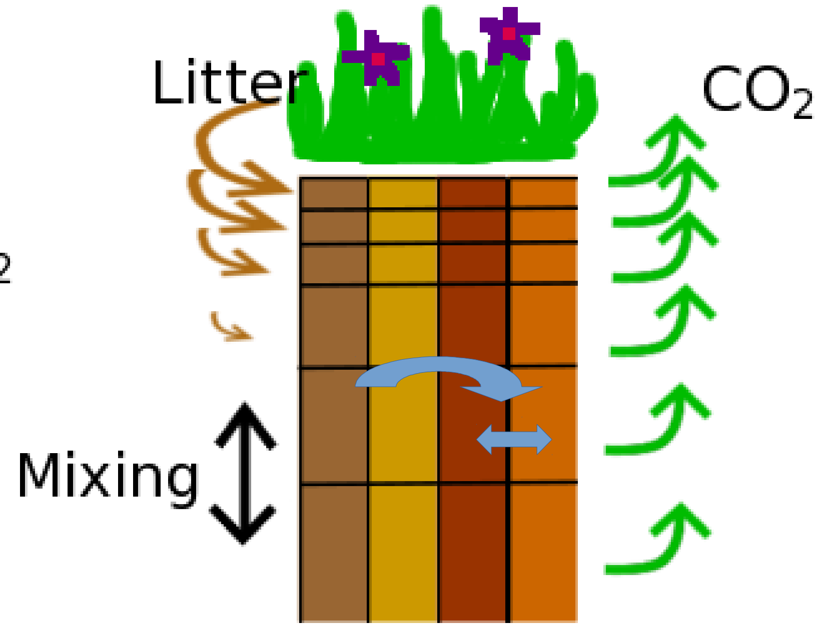


Original scheme

4 soil carbon pools

Decomposable plant material
Resistant plant material
Biomass
Humus

No structure with depth



New scheme

4 soil carbon pools - layered

Decomposable plant material
Resistant plant material
Biomass
Humus

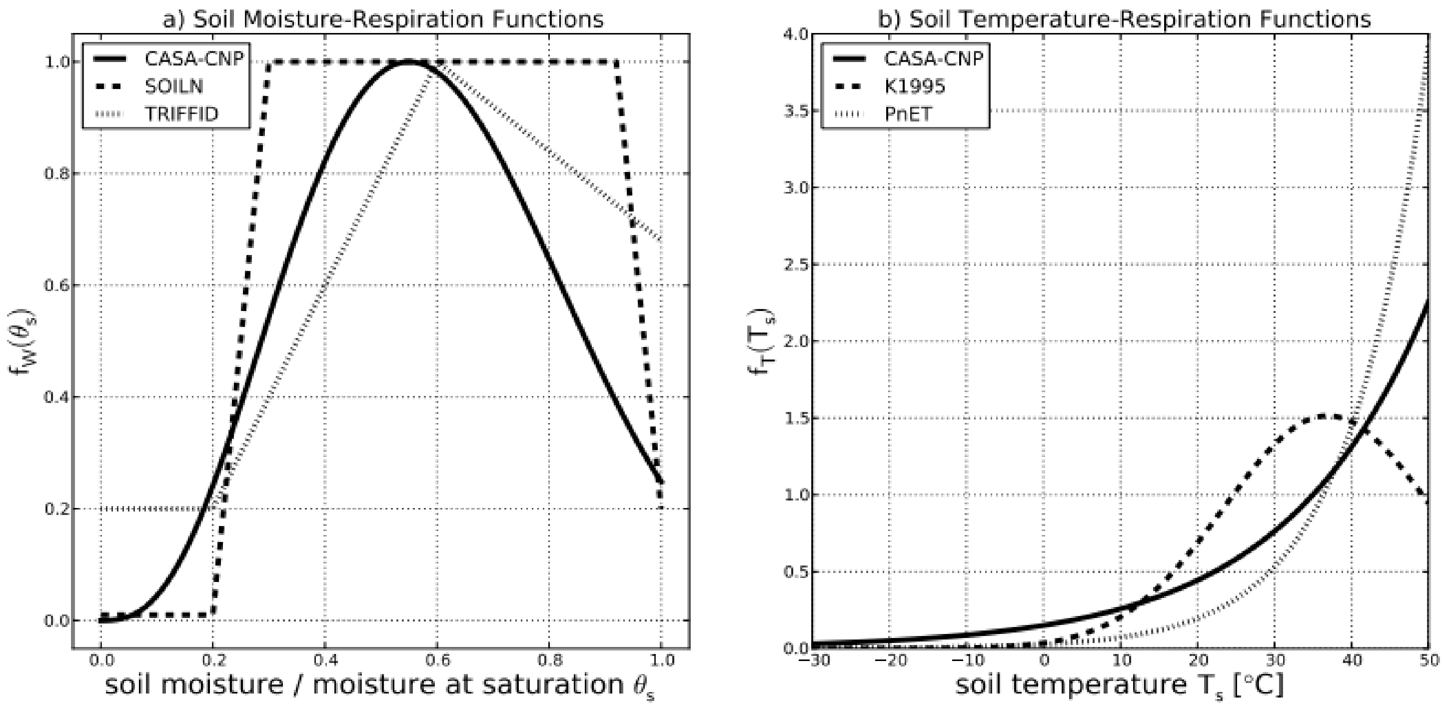
Soil carbon modelling

- Can also add a *dissolved organic carbon* (DOC) model which has its own decomposition, leaching, and transfer between pools.

Modelling soil carbon

- Basic equation: $$\frac{dC}{dt}=L_{input}-k\left(t\right)C$$

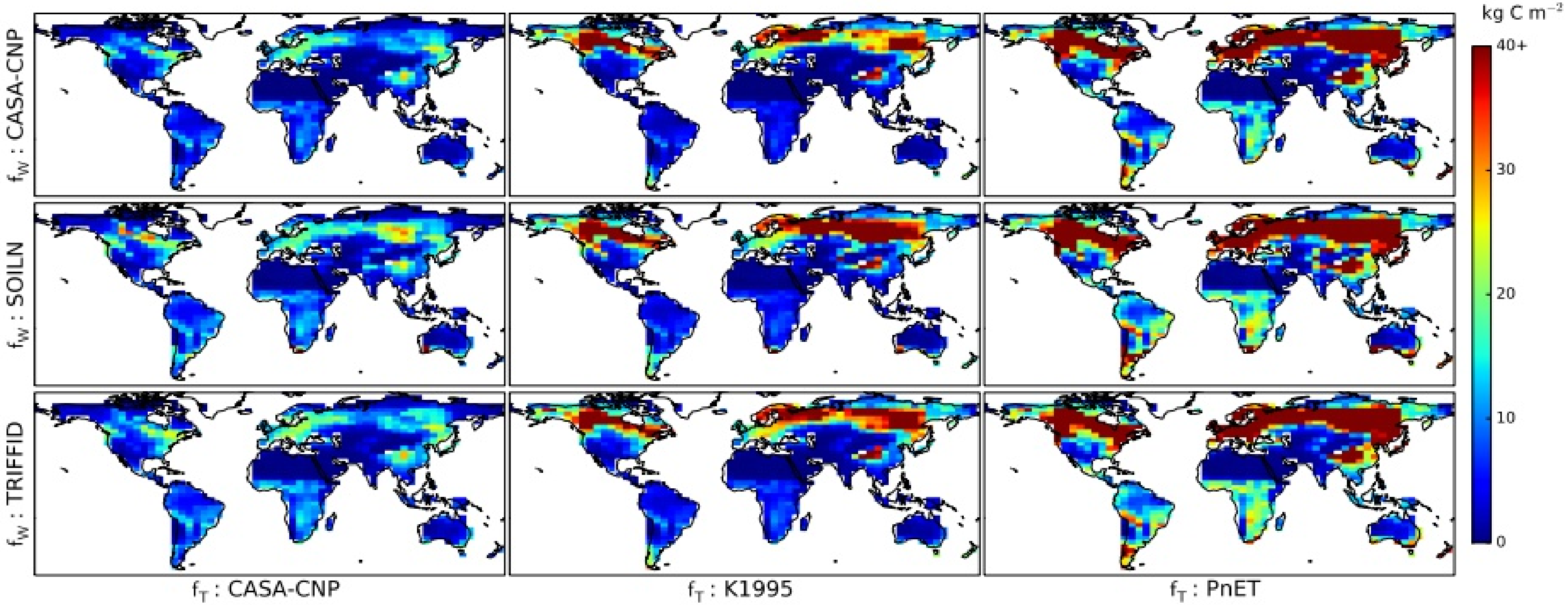
- k(t) = modification of respiration due to temperature, moisture, etc. Different functions used in different models!



Exbrayat, J.-F. (2013) *Biogeosciences*, **10**, 7095-7108.

Modelling soil carbon

- Impact of different temperature and moisture functions on global soil carbon:



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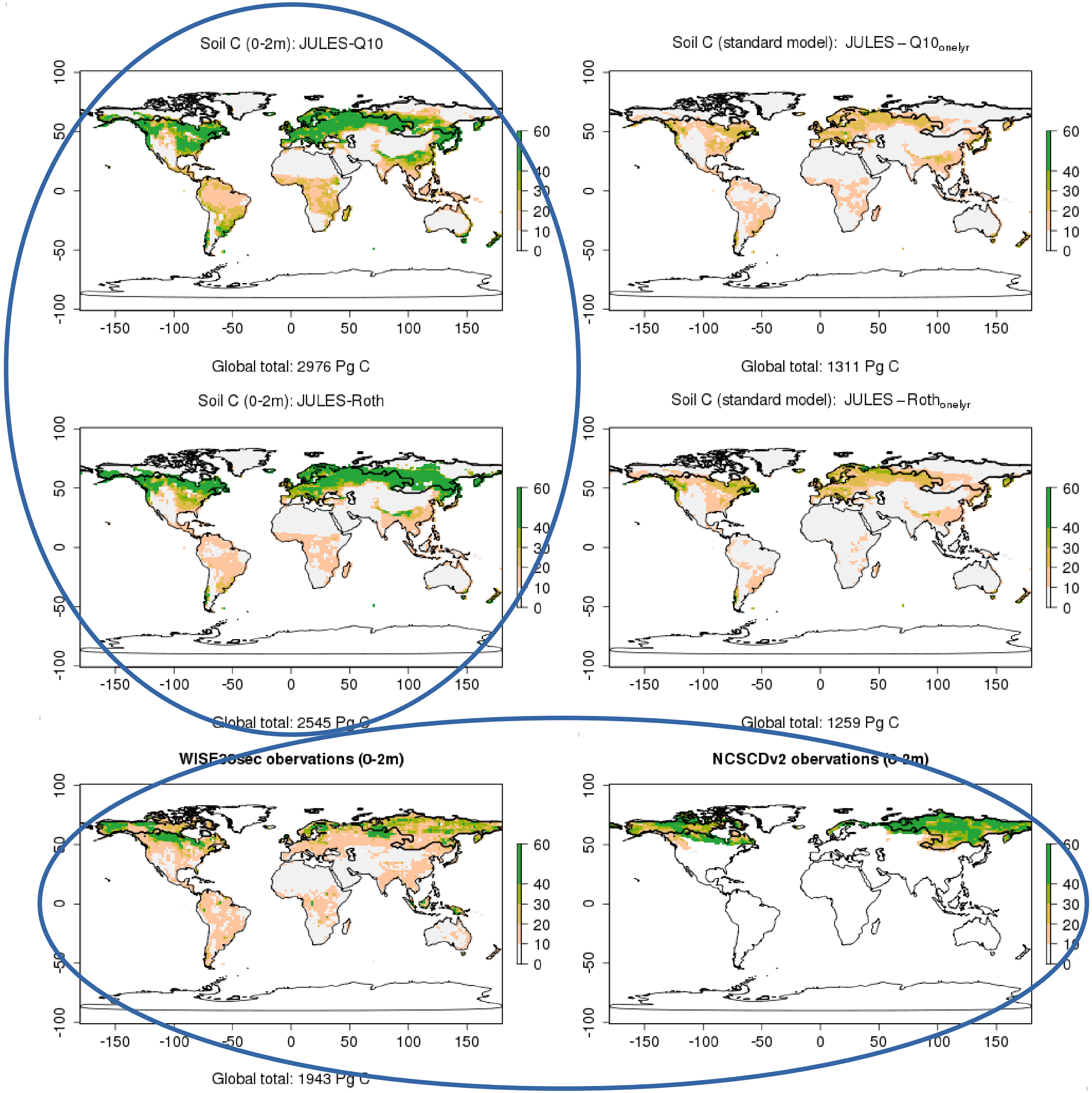
Evaluating the model

- Are we getting the right answers for the right reasons?
- Have to evaluate the right things!

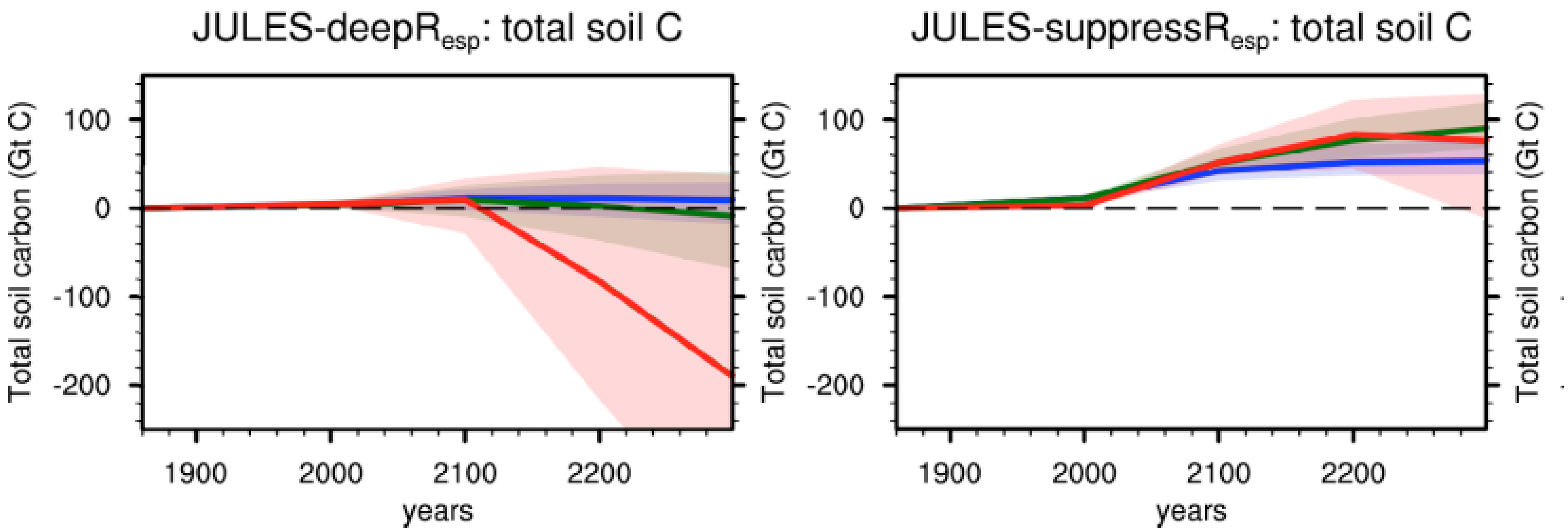
Evaluating the model

- Are we getting the right answers for the right reasons?
- Have to evaluate the right things!
- But this means you need to measure the right things.

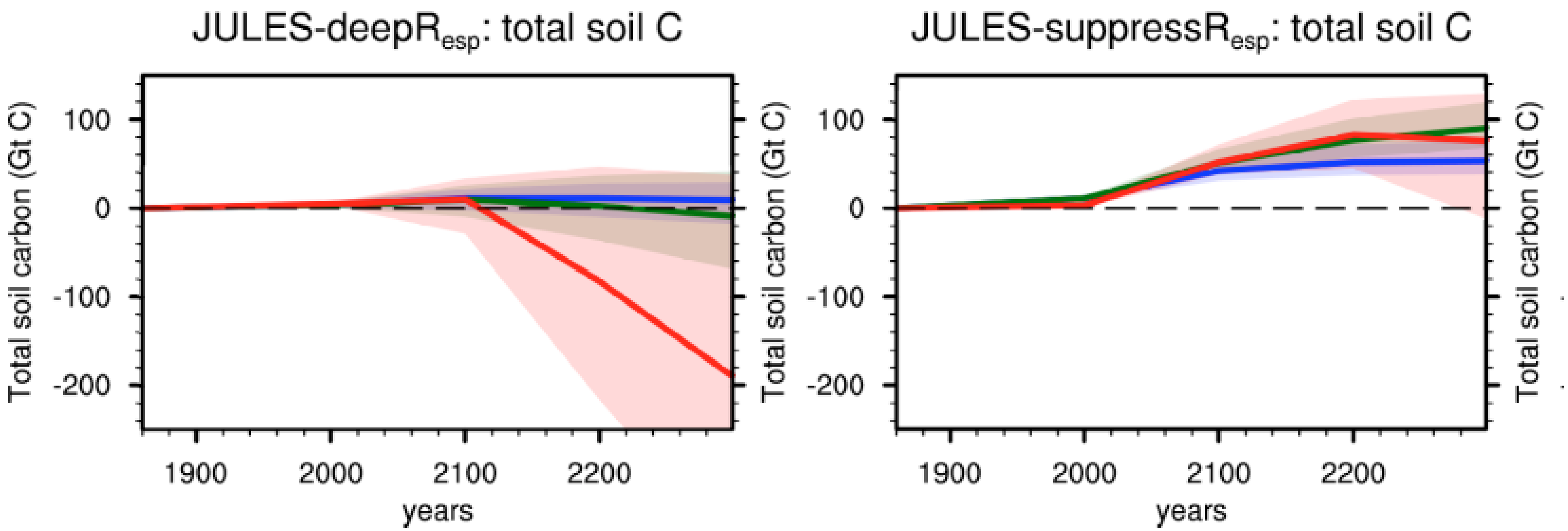
Historical soil carbon distribution



Future response...

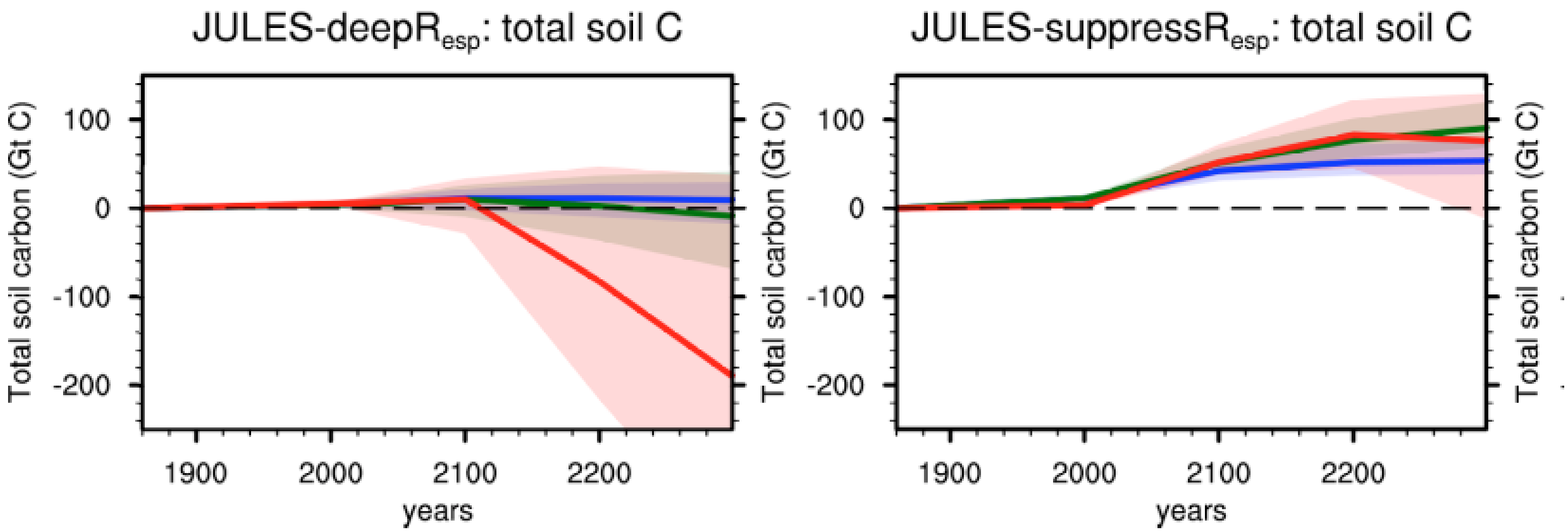


Future response...



How can we constrain this?

Future response...



How can we constrain this?

We need to measure processes

Case study: *Site simulations* to understand model processes

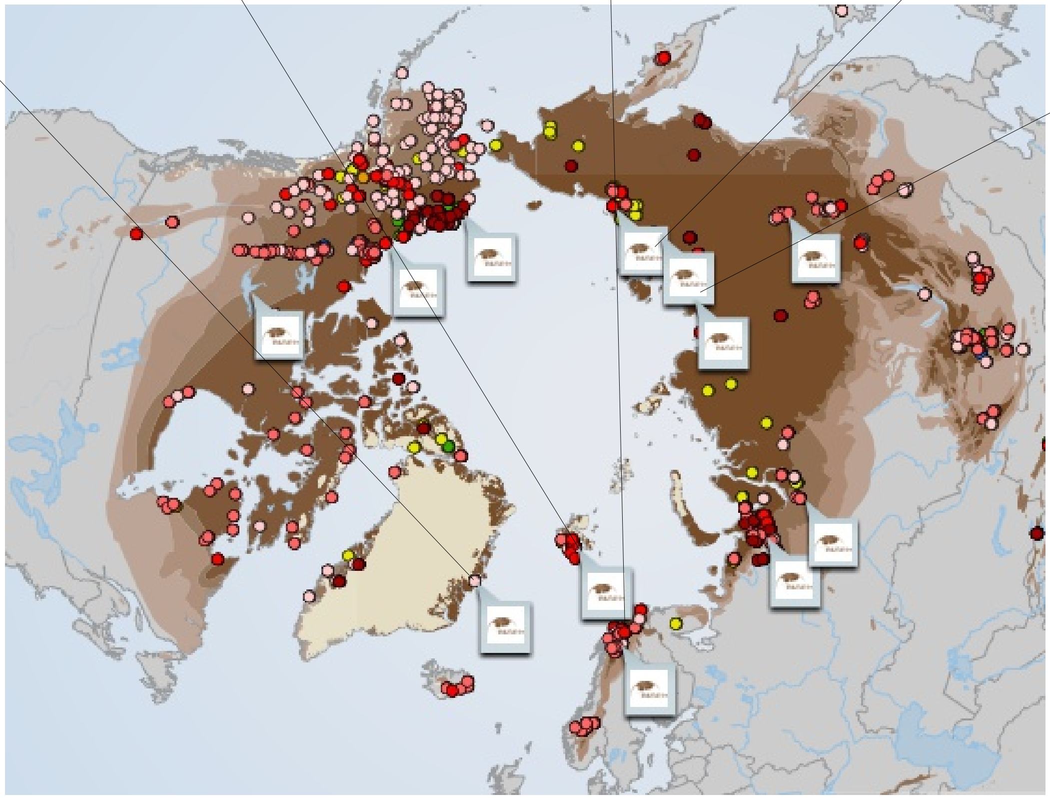

Zackenberg


Bayelva


Abisko


Kytalyk


Samoylov



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How to set it up?

- Every half hour, the model needs to know:

Air temperature. Humidity. Wind speed. Downwards shortwave radiation. Downwards longwave radiation. Precipitation. Air pressure.

- All of these need to be *realistic for the site*.
- E.g. Air pressure is easy. Snowfall is very difficult.

How to set it up?

- **Type of soil?** Preferably, a *profile* of soil thermal and hydraulic properties (including… thermal conductivity, heat capacity, hydraulic conductivity, ‘b’ exponent, porosity, saturated soil water suction)

Note - you can also estimate these from a combination of texture (sand/silt/clay) and organic matter.

- **Type of vegetation?** (required for CLM) = “plant functional type”

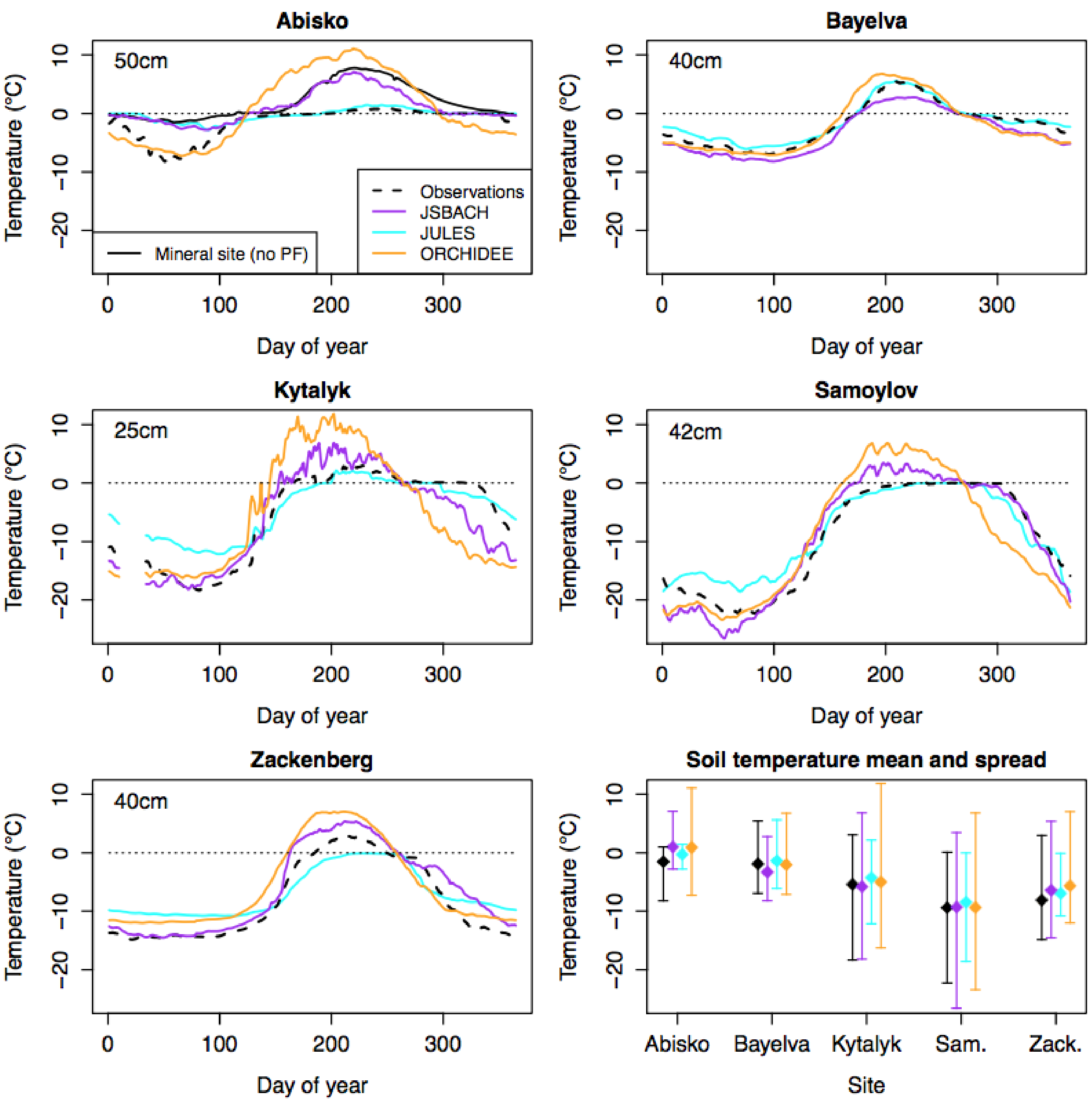
Note - do not calibrate, only evaluate.

How to run it?

- **‘Spin up’ to equilibrium**
- **Start in this state and run to present day...**

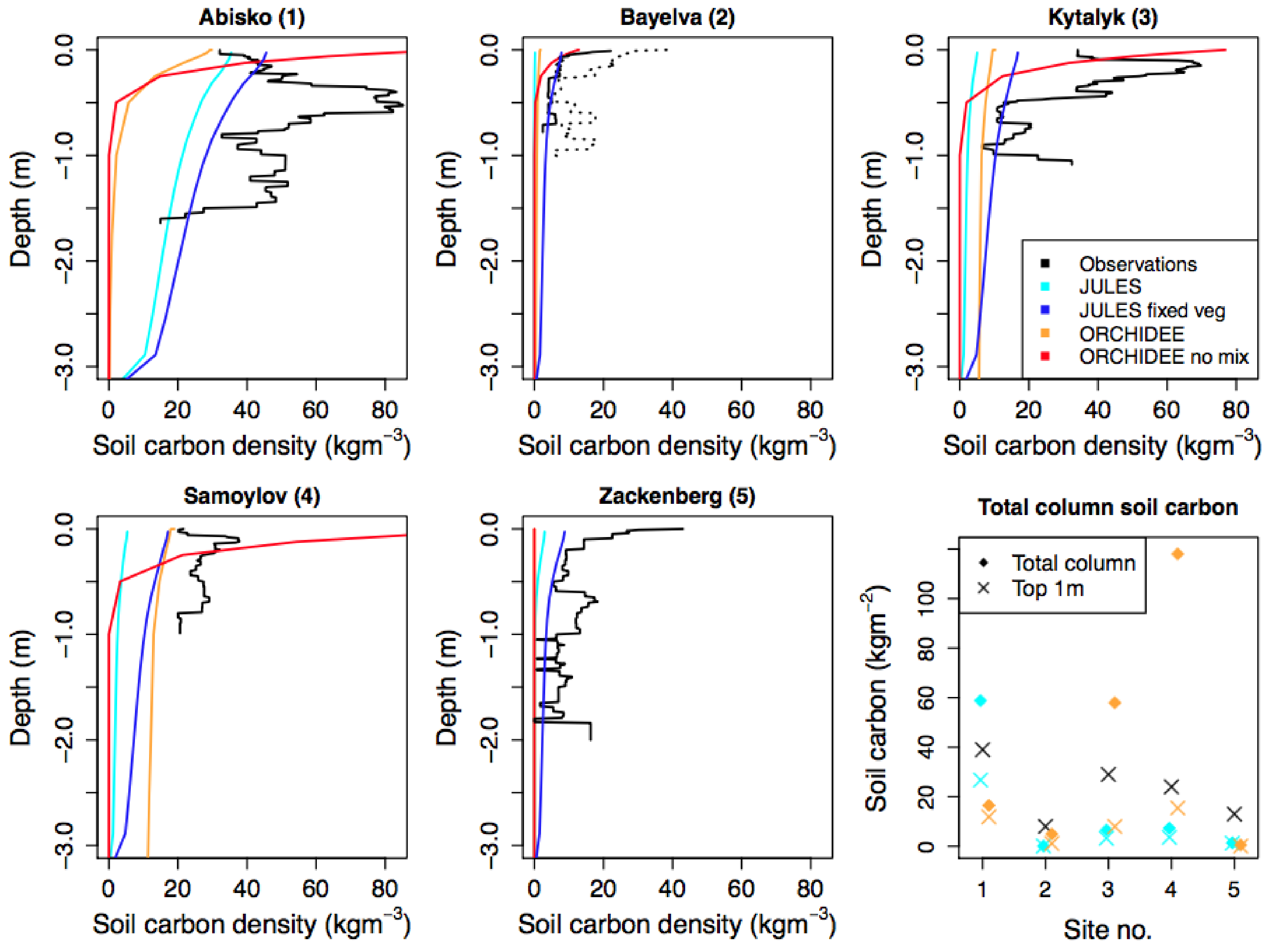
Evaluating

- **1. Continuous temperature and moisture**



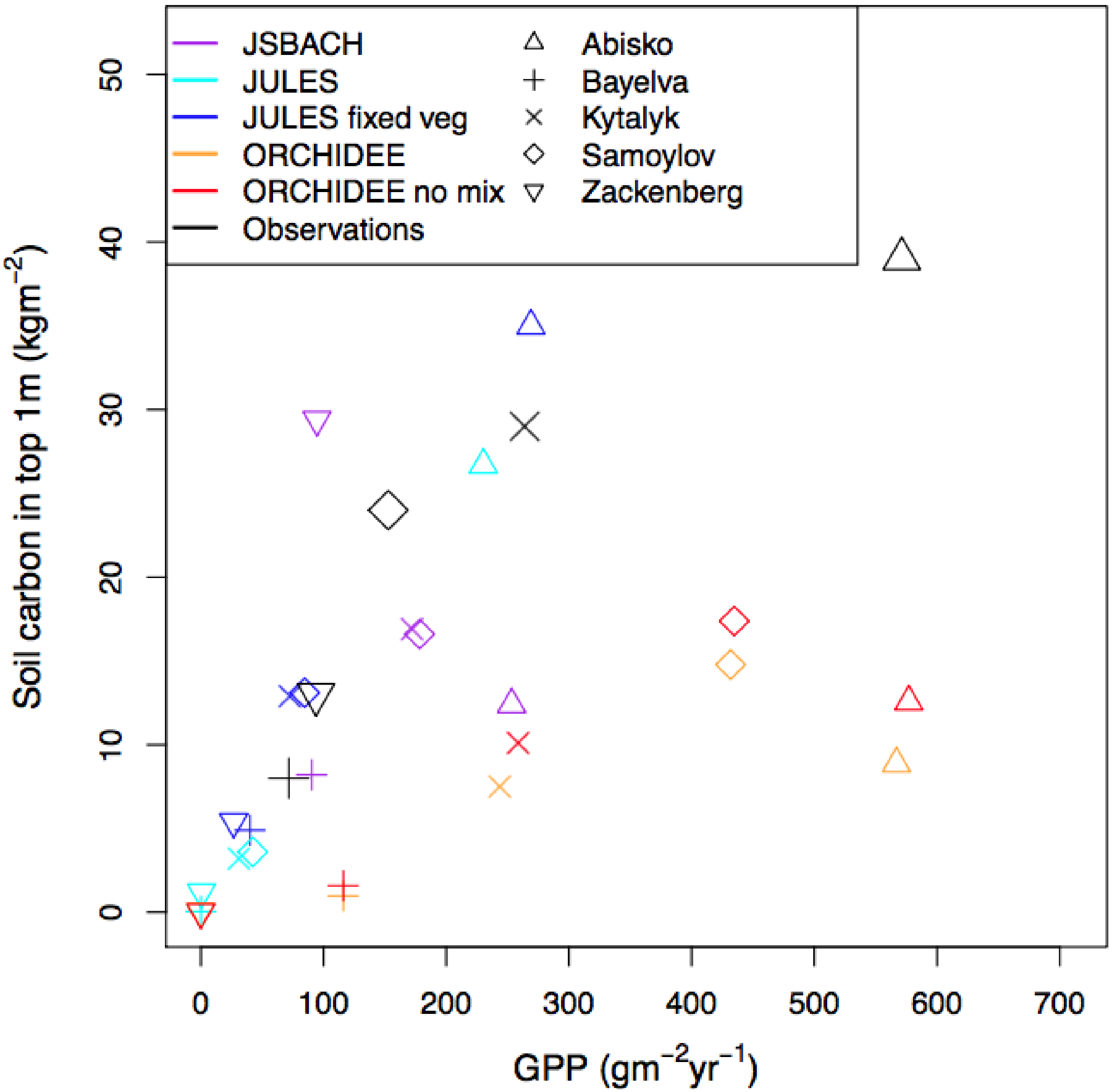
Evaluating

- **2. Detailed soil carbon profiles**



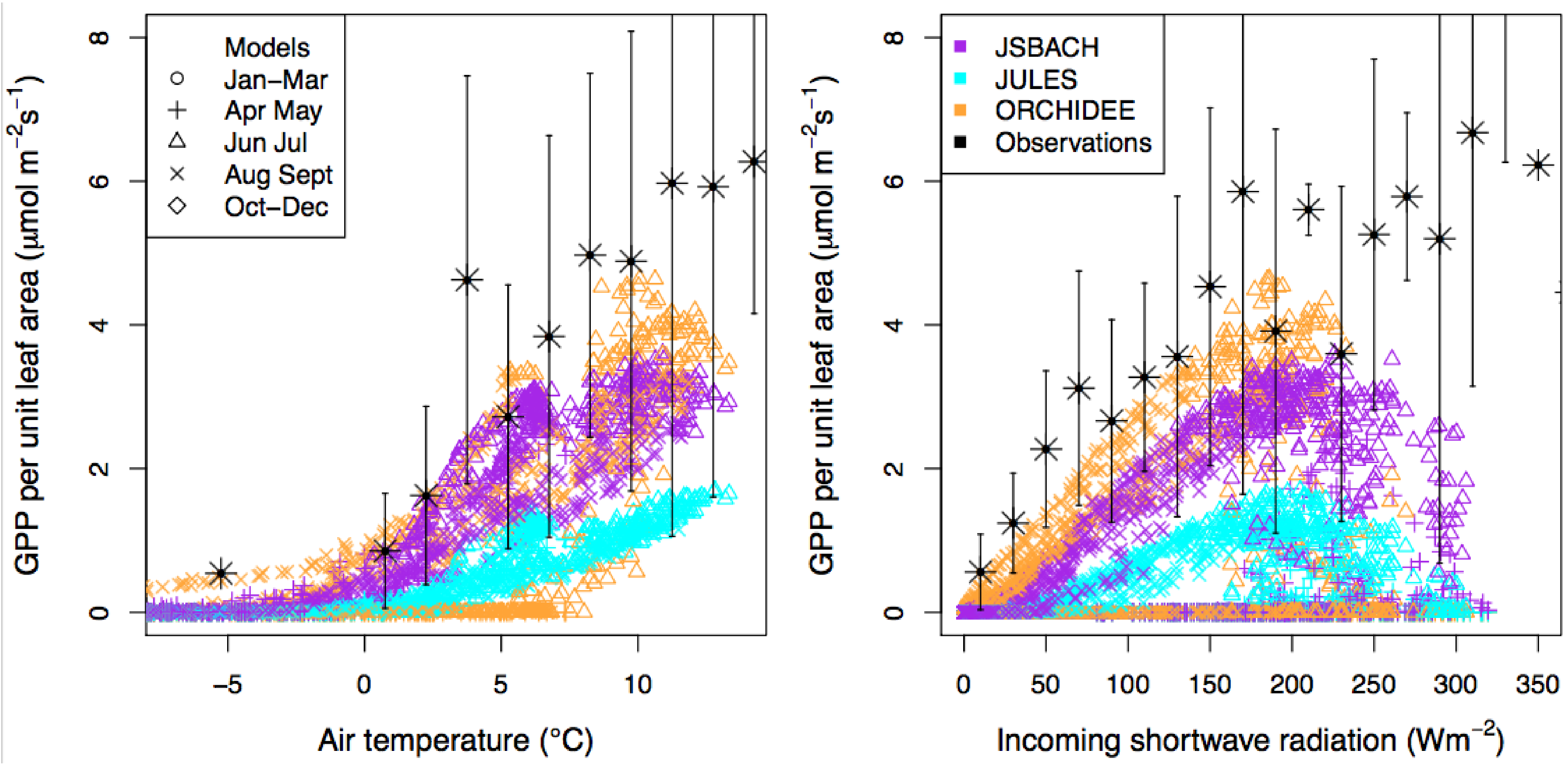
Evaluating

- **3. Eddy covariance data partitioned to give GPP**



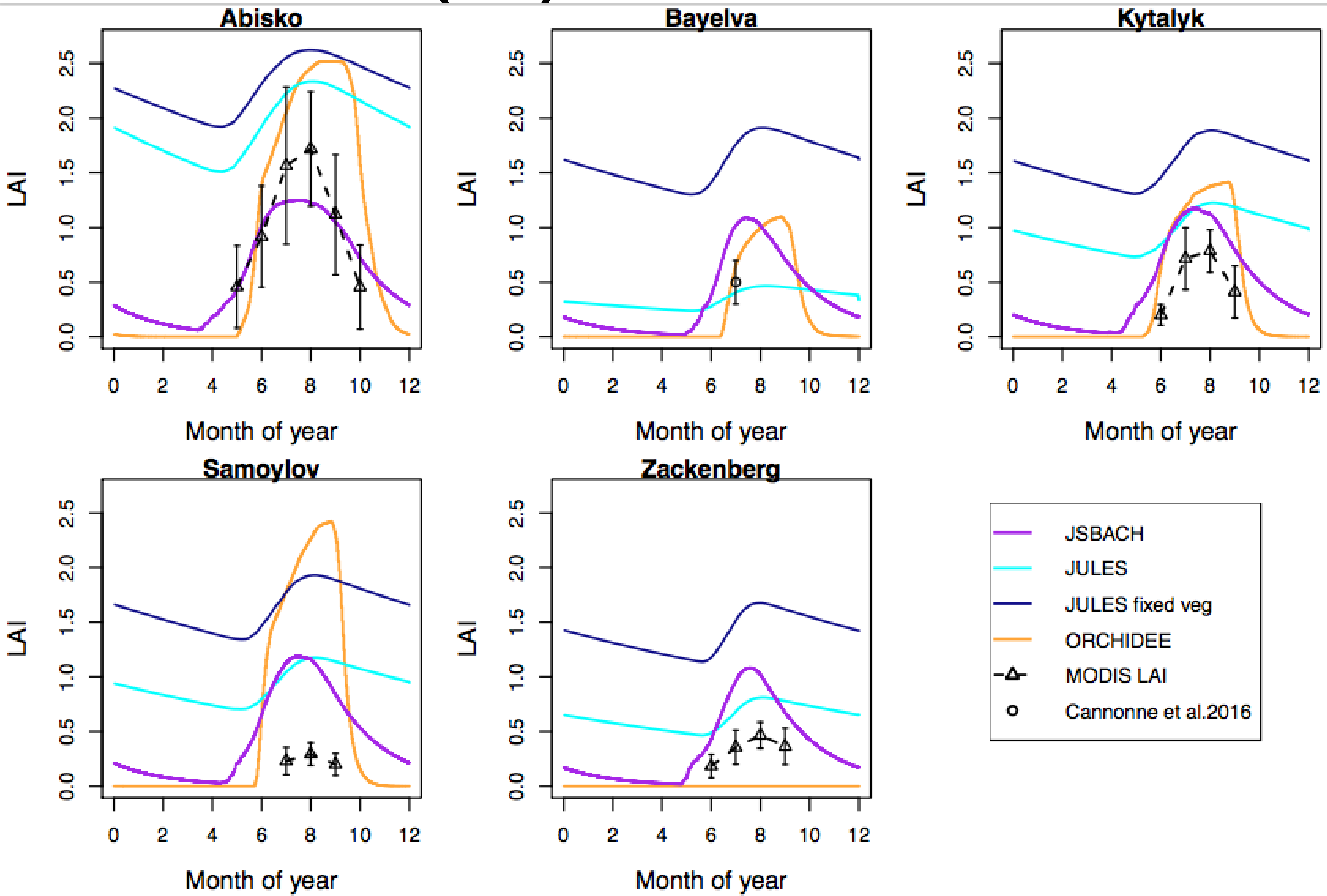
Evaluating

- **GPP per unit leaf area...**



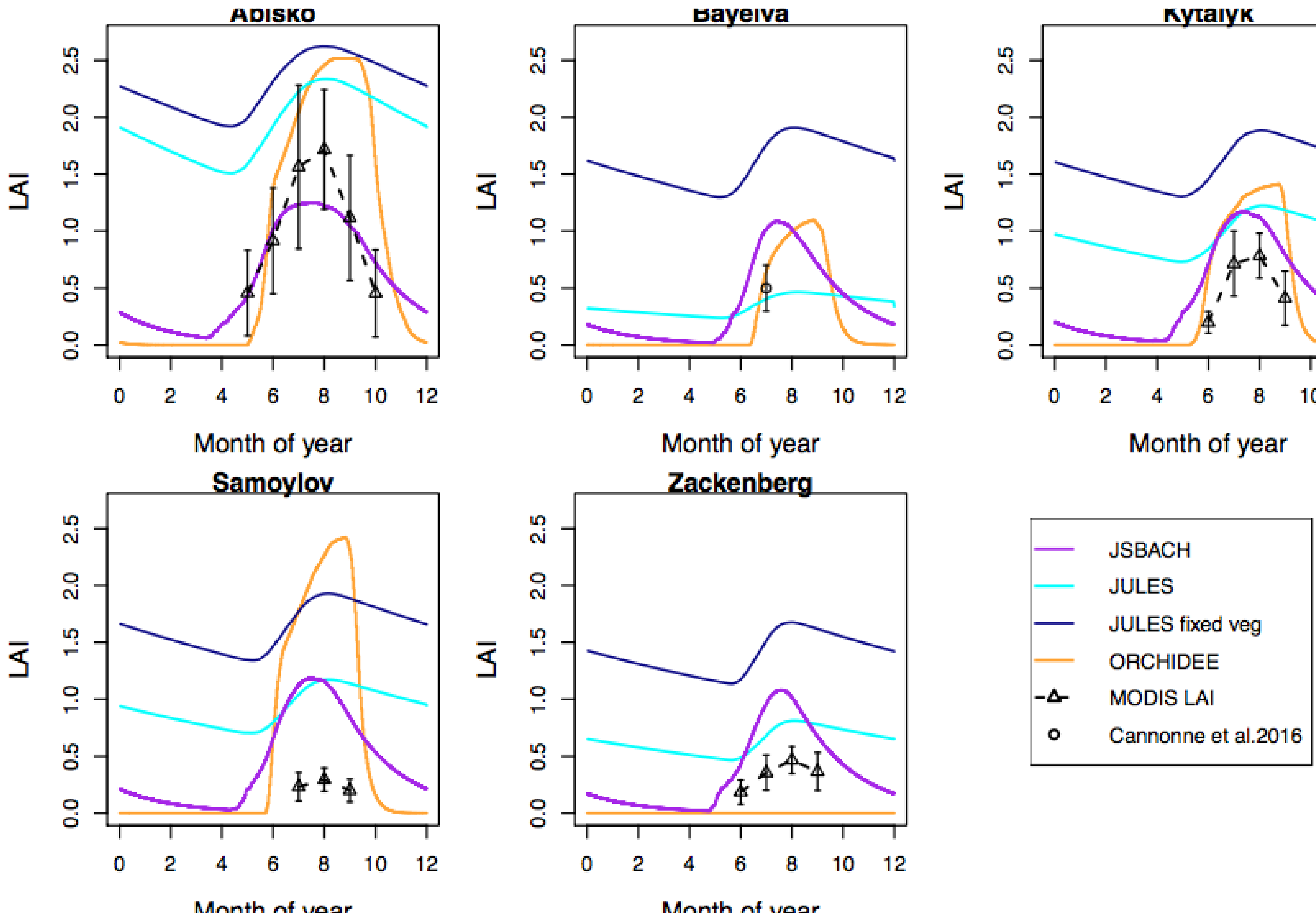
Evaluating

- **Leaf Area Index (LAI)**



Developing

- Next steps to improve LAI?



Take home messages

- Models represent important components of the carbon cycle but the uncertainties are still very large.
- Site simulations can help to understand the processes.
- Need to measure lots and lots of variables.