Interactions between Carbon and Water cycles

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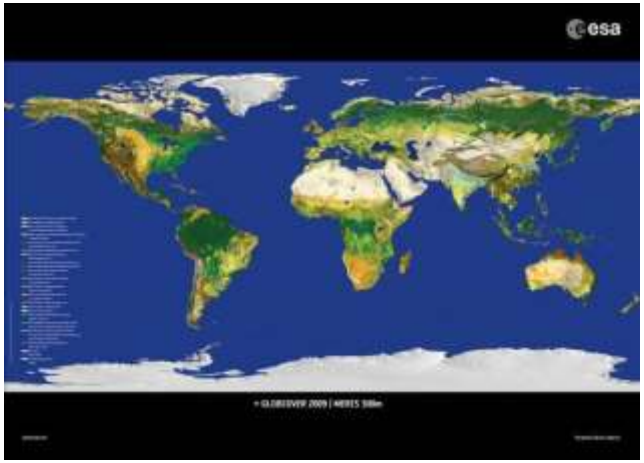
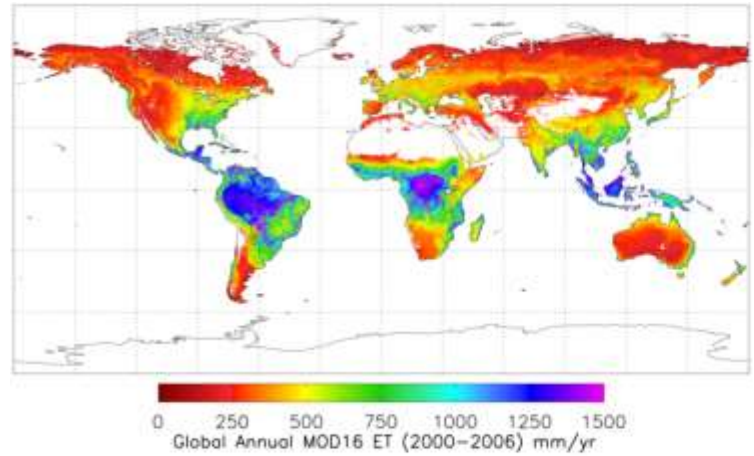
The terrestrial world: plants, water, energy, carbon, food

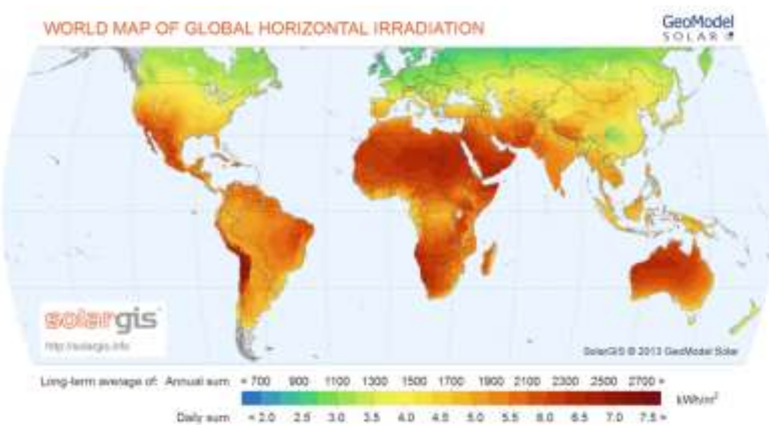
Vegetation Map



Evaporation Map

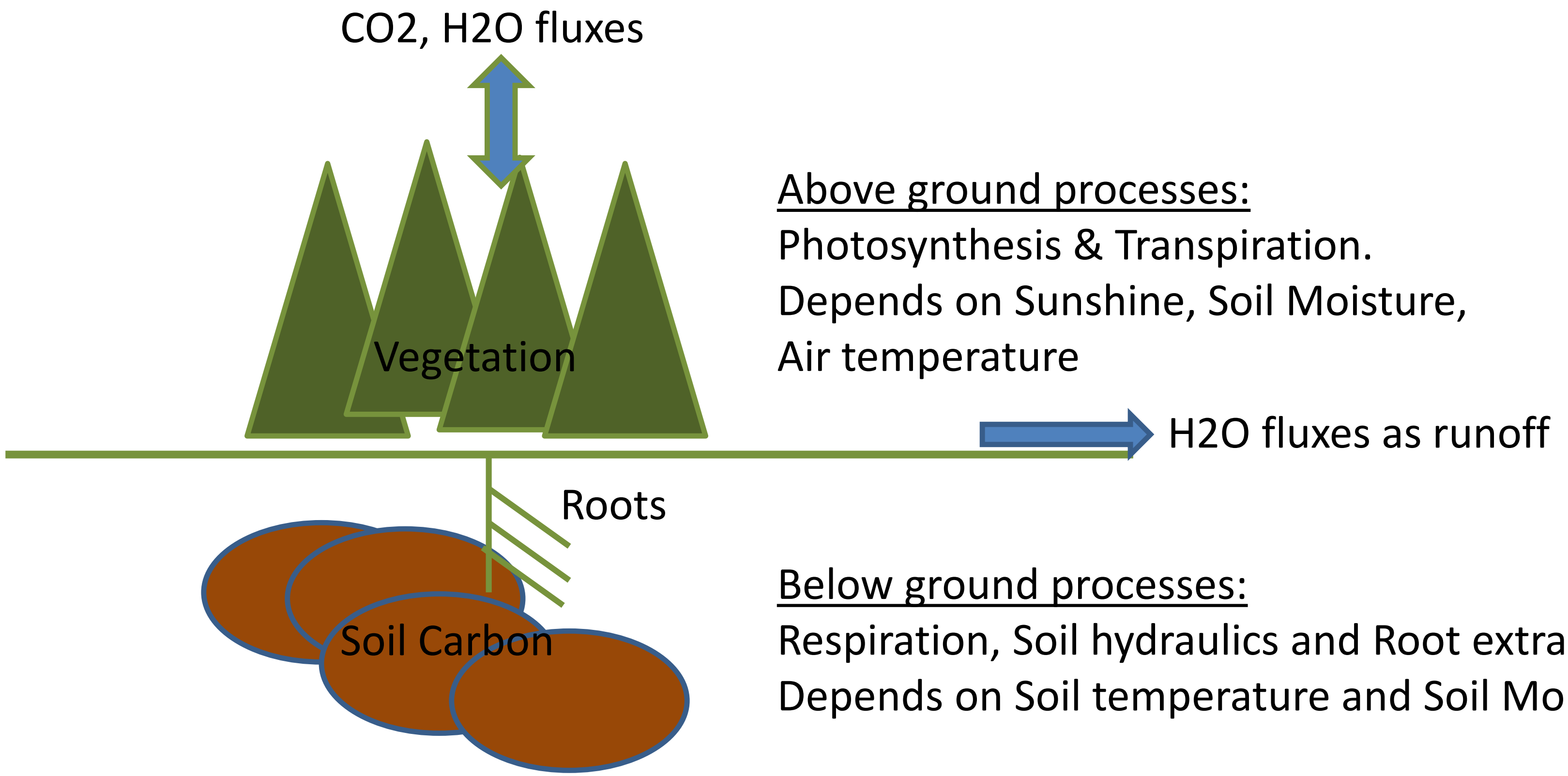


Sunshine Map



Terrestrial Carbon Map

Above and Below ground processes

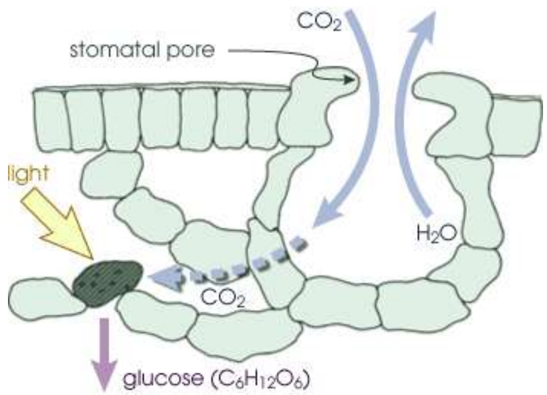


<u>Above ground processes:</u>
Photosynthesis & Transpiration.
Depends on Sunshine, Soil Moisture,
Air temperature

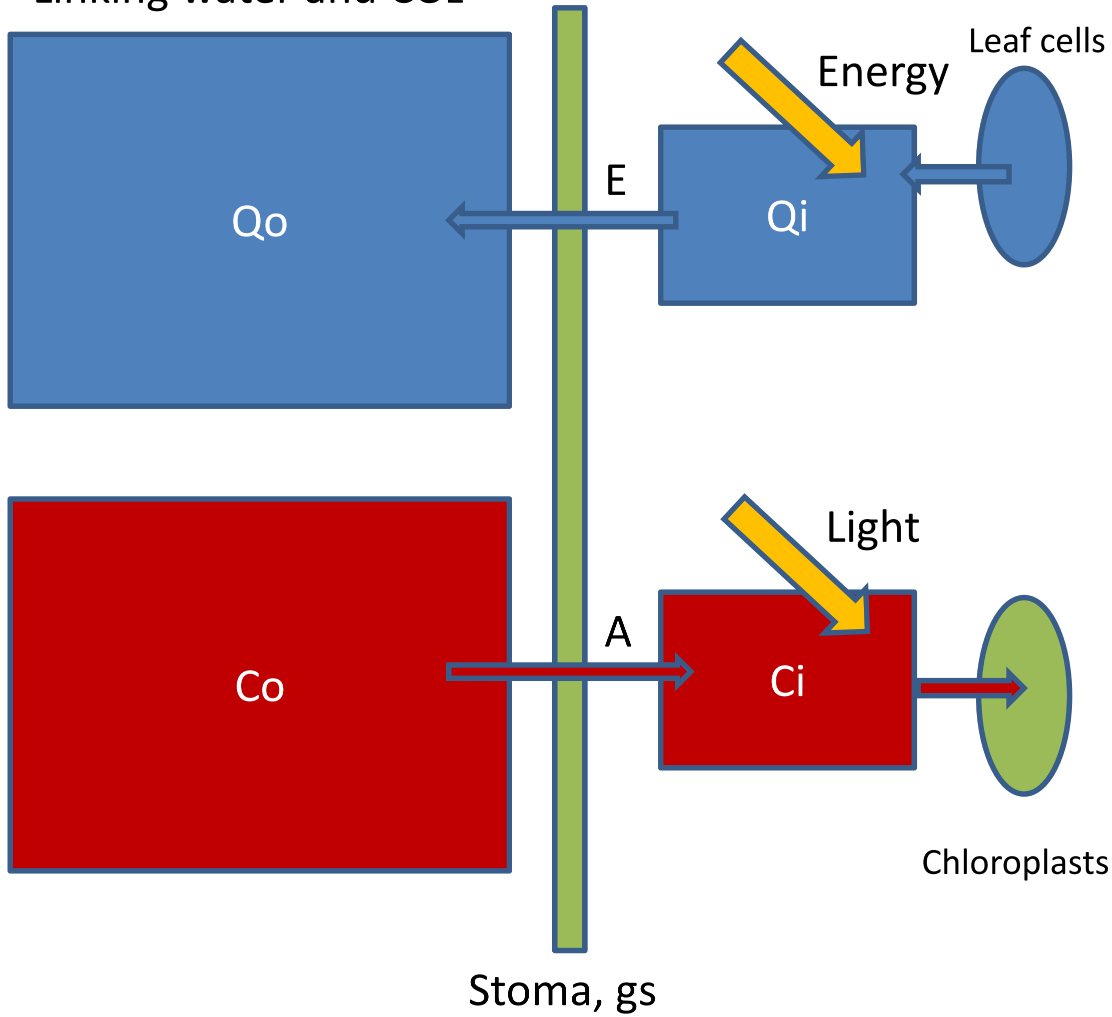
<u>Below ground processes:</u>
Respiration, Soil hydraulics and Root extraction.
Depends on Soil temperature and Soil Moisture

Photosynthesis and the role of the stomata

Schematic of a stoma



Linking water and CO_2



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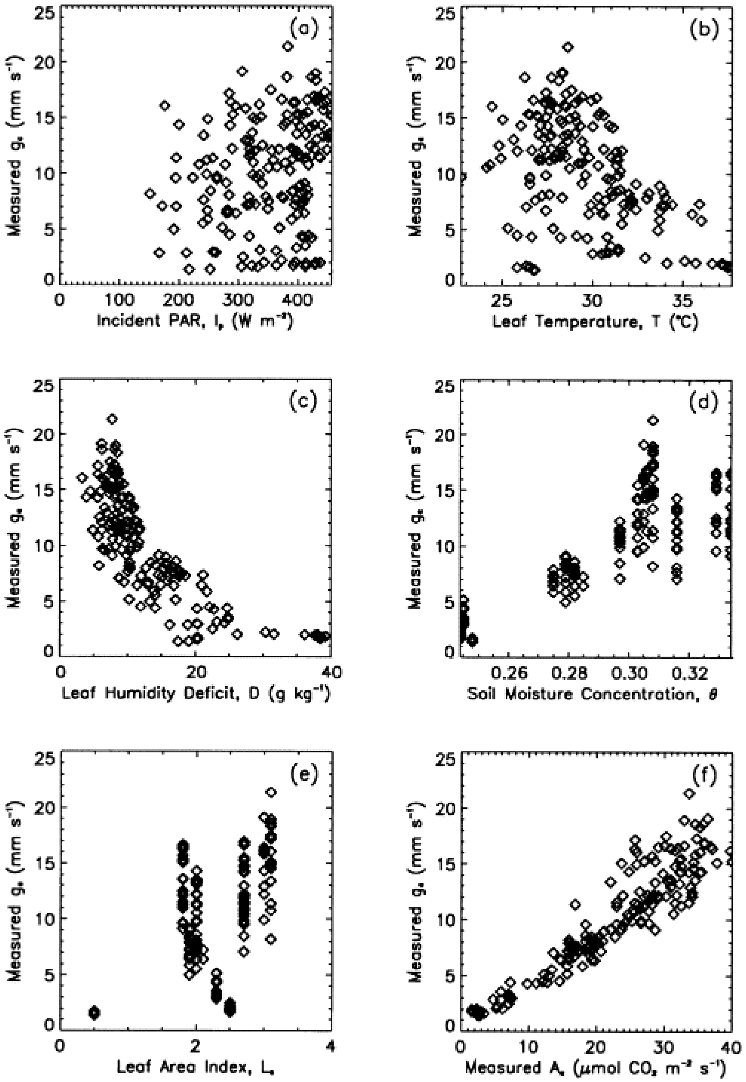
Model of Photosynthesis



Three limits to Photosynthesis, A:

- Temperature Limit
- Light Limit
- CO2 limit

A=(Co-Ci)*gs

A calculated, then gs inferred, altered by soil moisture limit then passed on to E

E=(Qi-Qo)*gs

Qi is subject to energy balance (function of Ta, Rn, D, gs)

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Flux Data from FIFE

Cox et al, J Hydrol, 1996

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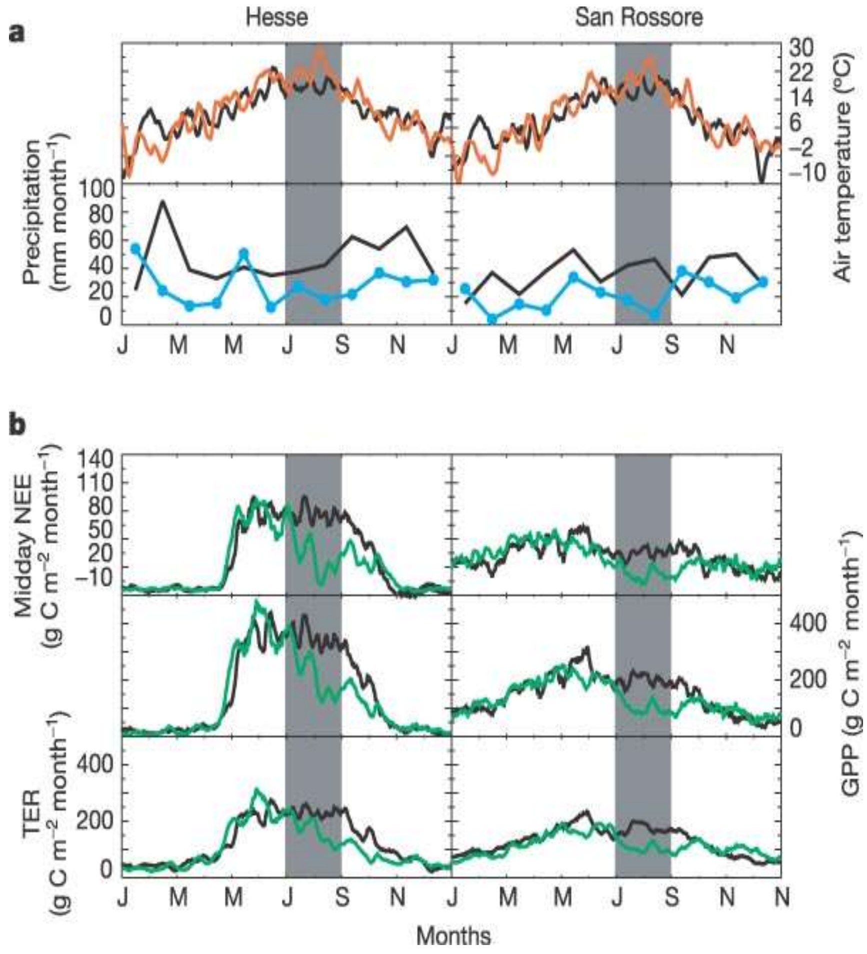
Impact of the link on Carbon systems

Limit to Carbon Dioxide uptake during drought?

Deciduous beech forest, France (Hesse)
Evergreen pine forest, Italy (San Rossore)

A five-day running average (precip is monthly)

Data for 2002 are in black and for 2003 in colour



Ciais et al, Nature, 2005: 'Europe-wide reduction in primary productivity caused by the heat and drought in 2003'

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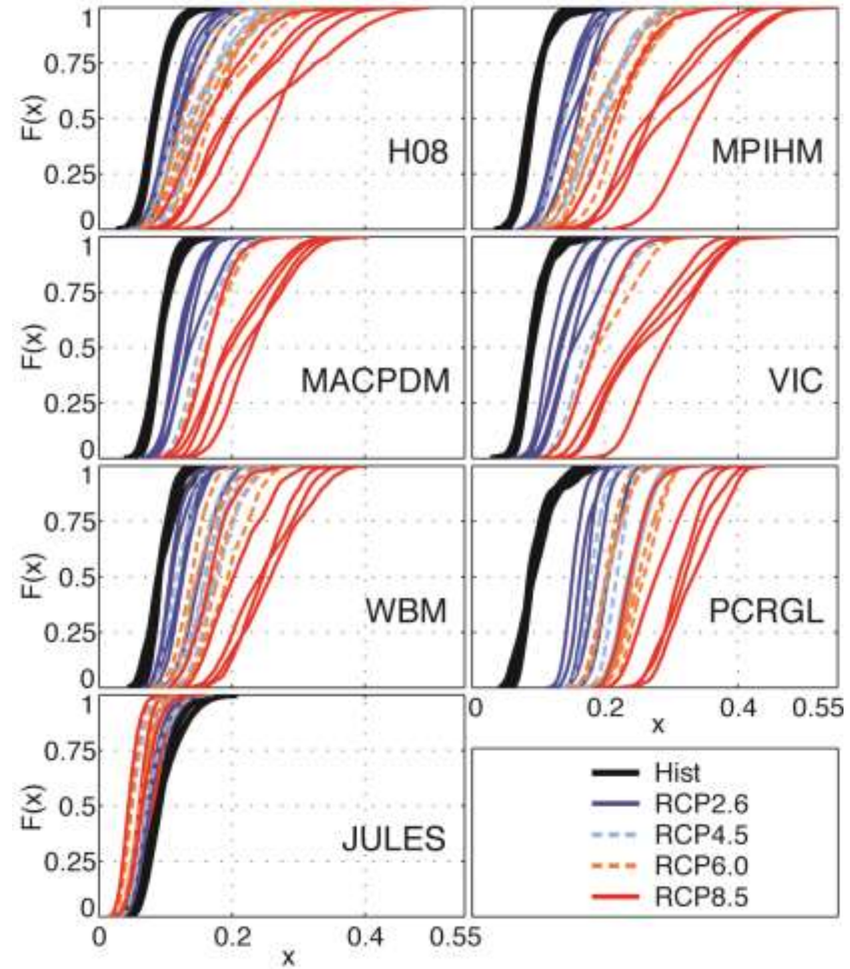
Impact of the link on hydrological systems

Impact of CO2 fertilisation:
x: proportion of land under ‘drought’ at the same time
F(x): cumulated time this happened.

I.e. For JULES the maximum land over under drought is 20% (0.2) and is reached under historical climate; for H08 maximum drought extent is ~ 55%

When JULES is run without dynamic CO_2, the maximum land area under drought is 40%.



Prudhomme, C., et al. (2013) Hydrological droughts in the 21st century, hotspots and uncertainties from a global multimodel ensemble experiment. PNAS

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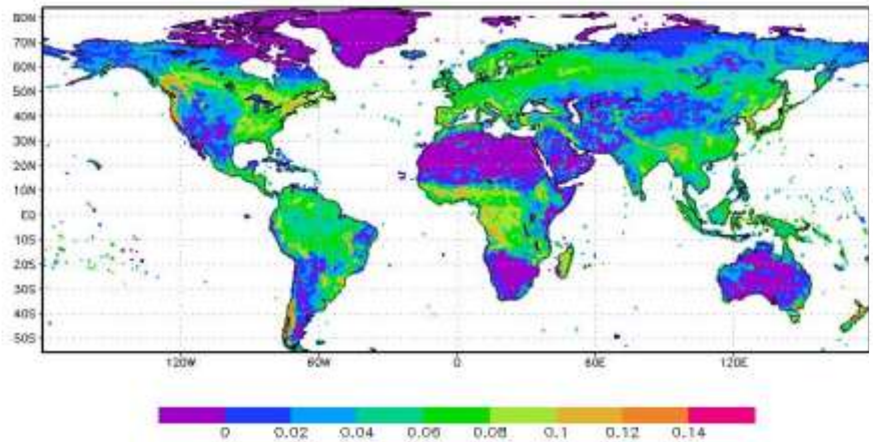
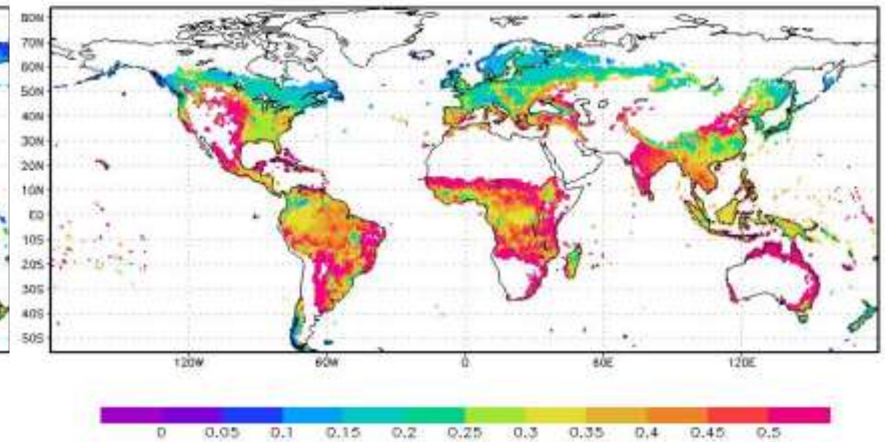
ΔE and ΔA with different ambient CO2

Fractional change in Quantity over one year with a double of CO2

Transpiration reduced by about 10%:
shows similar response in Europe and Amazon



Photosynthesis increased by 10 to 40%:
shows smaller response in Europe than Amazon



Keenan et al, Nature, 2013. *Increase in forest water use efficiency as atmospheric carbon dioxide concentrations rise.*
Analysis of Flux-tower data at 21 sites suggests a substantial increase in water use efficiency in temperature and boreal forests of the Northern Hemisphere over the past 20 years.

Frank et al, Nature Climate Change, 2015. *Water Use efficiency and transpiration across European forests during the Anthropocene.*
Data (δ13 C tree ring) over 20C suggests increase of WUE of 14 (broadleaf) and 22 (conifer)%
Models that include increased plant cover due to increased A (not included here) demonstrate that there will be a counteraction to the decrease in evaporation from the CO2 fertilisation.

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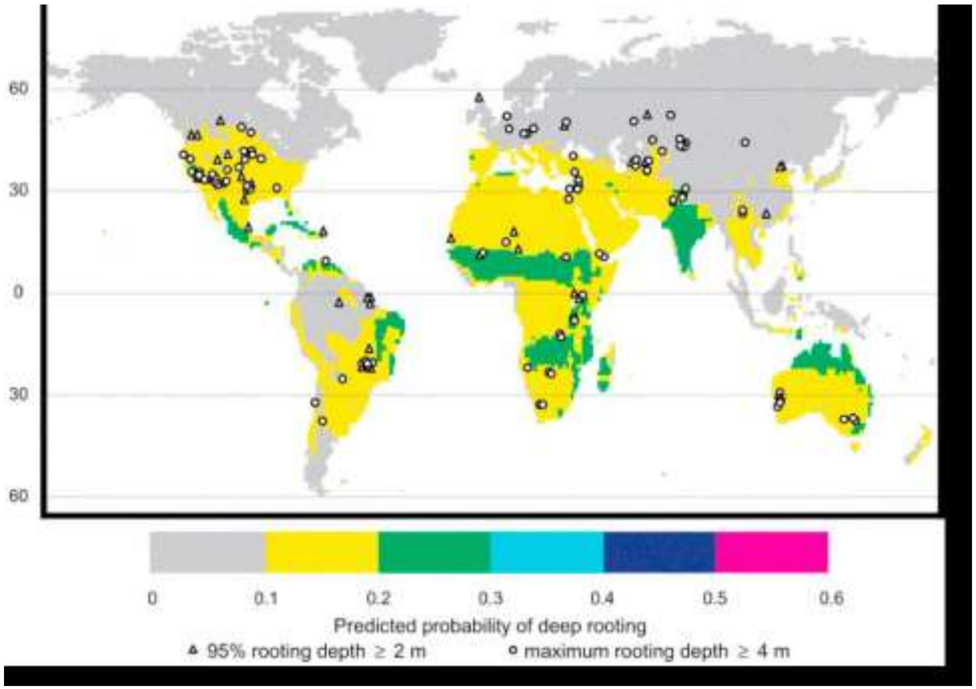
In real life, plants adapt to their environment

Root Depth in models is fixed.
Plants' root depths are dynamic.



Data suggests that in dry
Regions plants have roots
Greater than 2 m.

Models tend to have much
Shallower roots than this.

Wang and Dickinson, 2012. A review of global terrestrial evapotranspiration: observation, modeling, climatology, and climatic variability. Reviews of Geophysics

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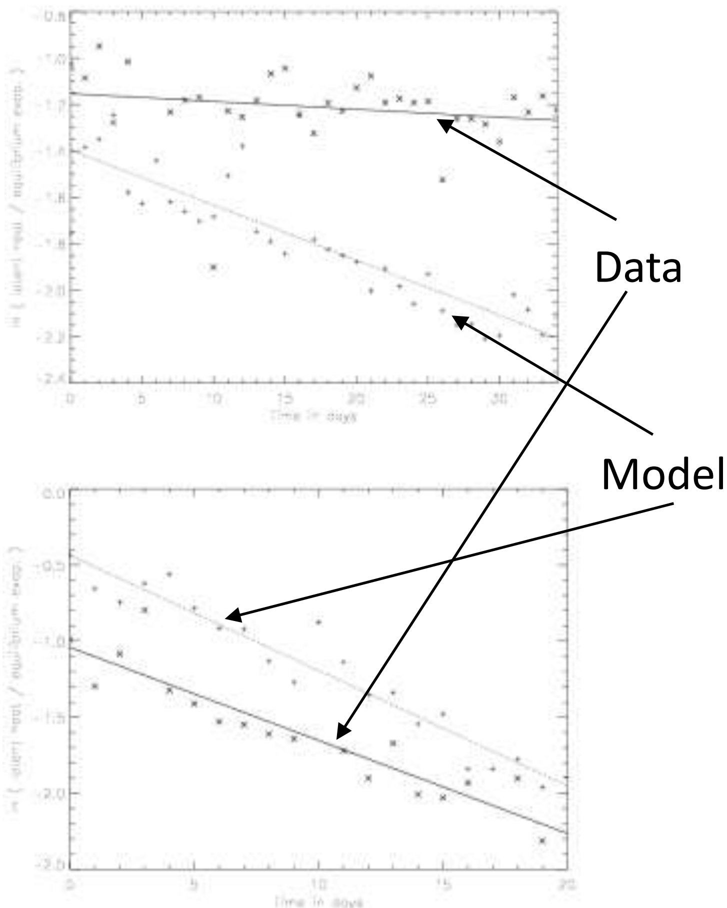
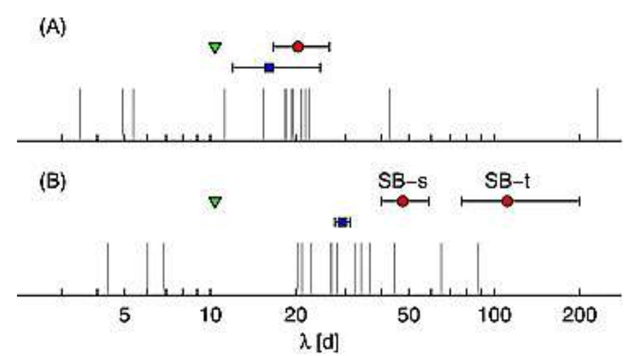
Data suggests models dry-down too quickly

$$E = E_0 \exp\left(\frac{-t}{\tau}\right)$$



Blyth, et al 2010, Evaluating JULES land surface model energy fluxes using FLUXNET data. JHM, 11



λ for the GSWP-2 LSMs (vertical lines) at (a) Rheindahlen (b) SEBEX. Obs (circle) and GSWP-2 ensemble (square). Triangle indicates the *Dardanelli et al.* [2004] model.

Teuling et al, 2009, Observed timescales of evapotranspiration response to soil moisture, GRL, 33

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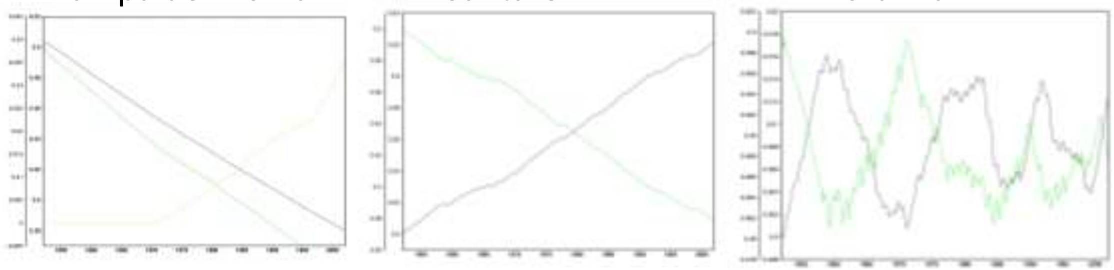
New model of dry-deciduous trees

New model where leaves are shed at low soil moisture: similar to model for temperature deciduous

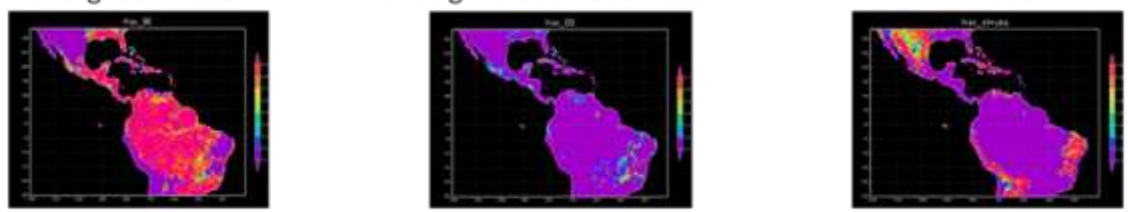
black: Evergreen, green: Deciduous

Pampa de Aroma　Santarem　Roraima

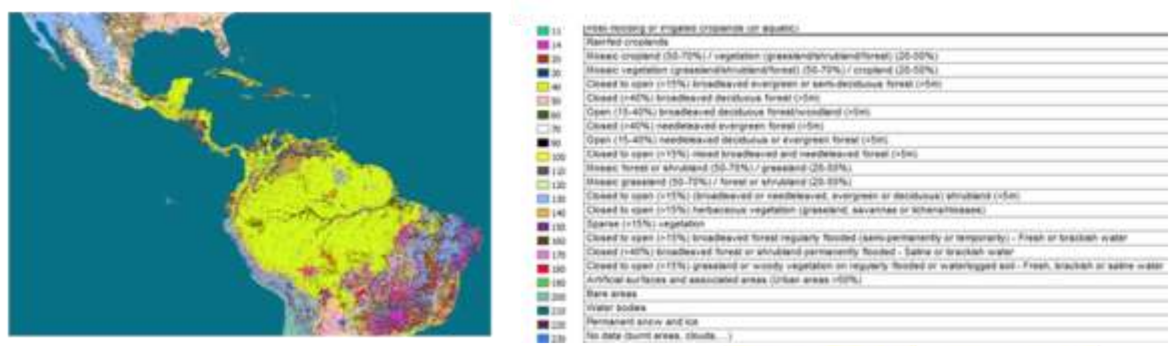


Model output (JULES)

Evergreen Trees　Drought Deciduous Trees　Shrubs



Observation-based land cover map (Globcover 2009)



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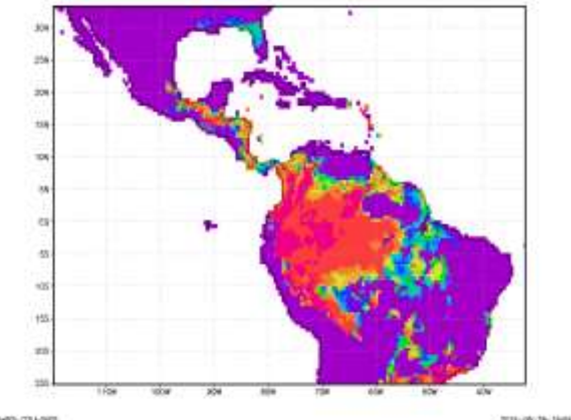
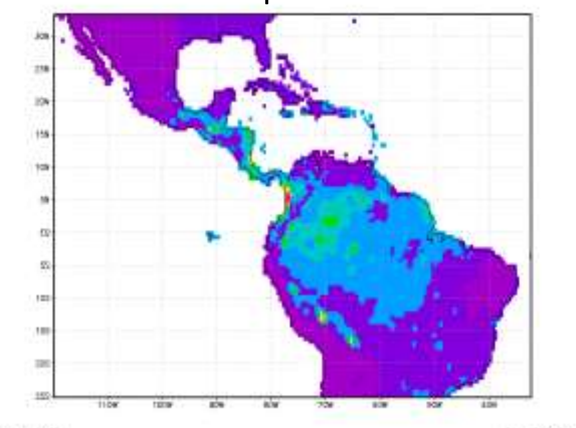
Results of the modelling for future climate

Current Climate

Leaf Area Index of Trees

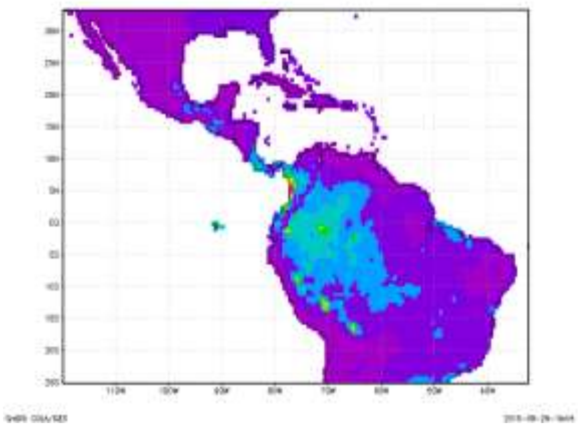


Precipitation

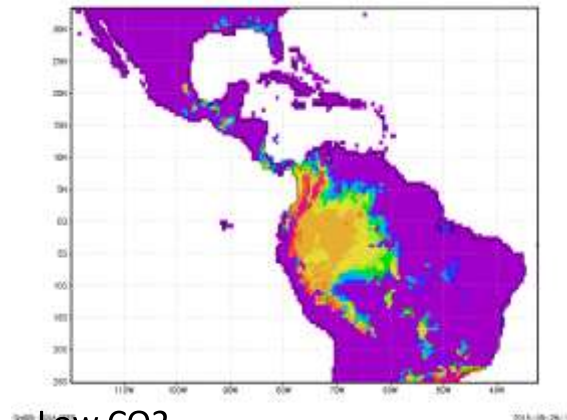


Future Climate – 2085 to 2095

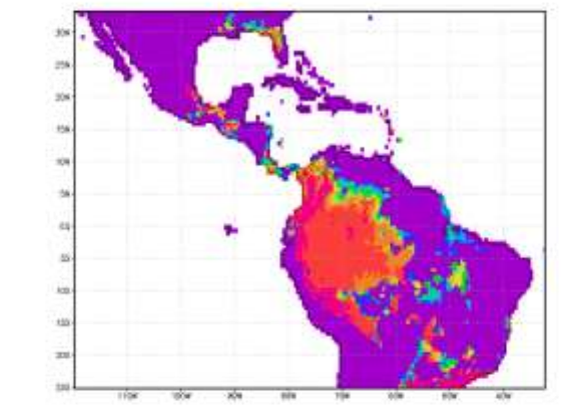
Precipitation



Leaf Area Index of Trees



Low CO2



High CO2

Need for more research into how these limits to photosynthesis affect the water cycle

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Below ground processes

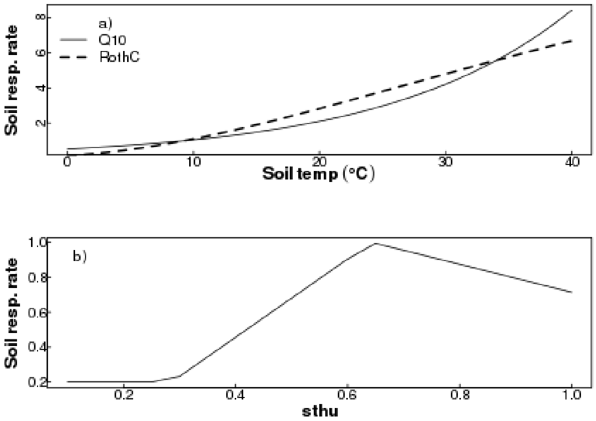
Impact of Carbon on Water

- Through the Soil Hydraulic Properties – peat soils
- Through Vegetation Type (forests and grass)
- Through roots affecting the soil hydraulic properties

Impact of Water on Carbon

- Through soil moisture impact on respiration
- Through impact of saturation on vegetation growth

$$R = \kappa C F_T F_\theta F_v$$



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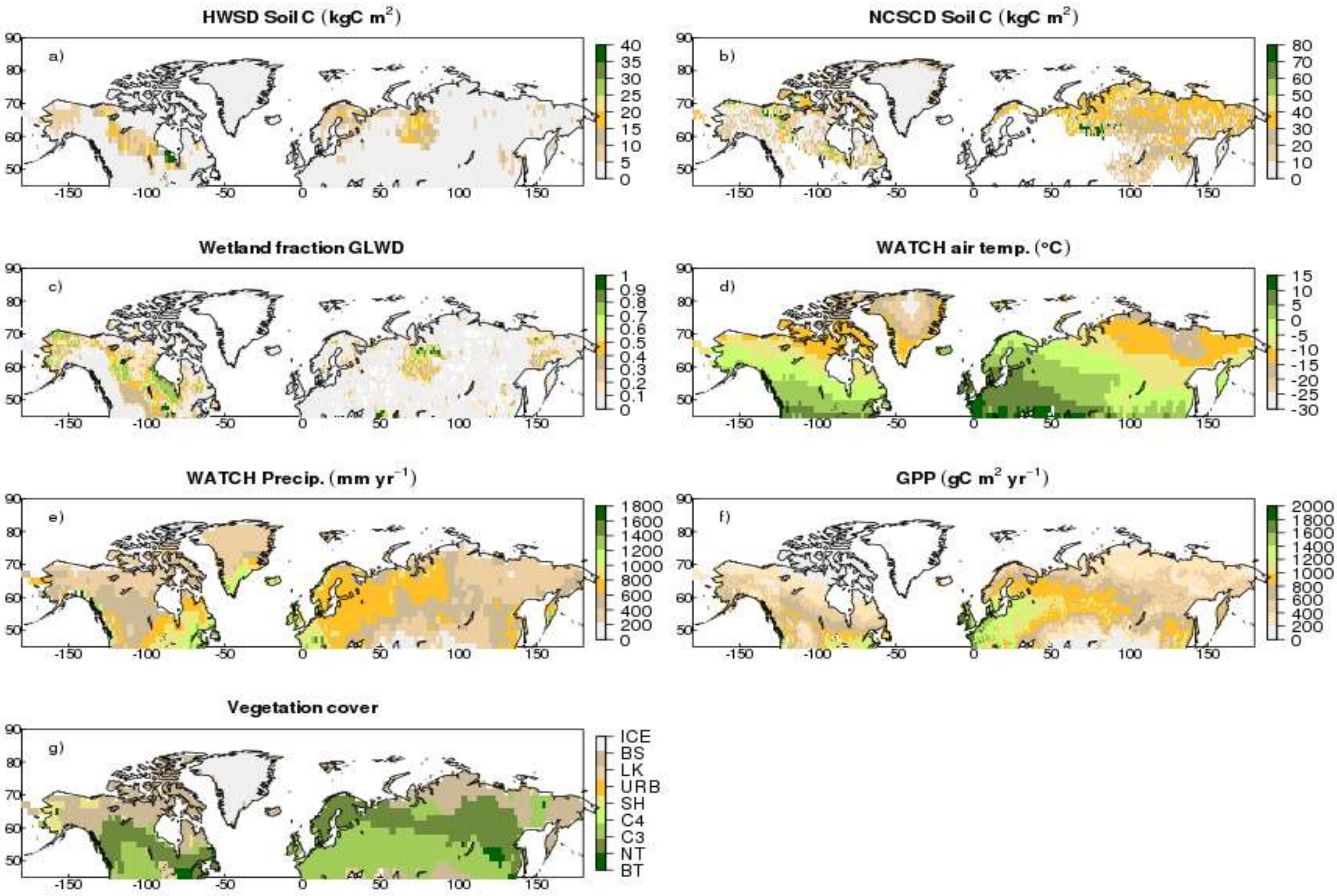
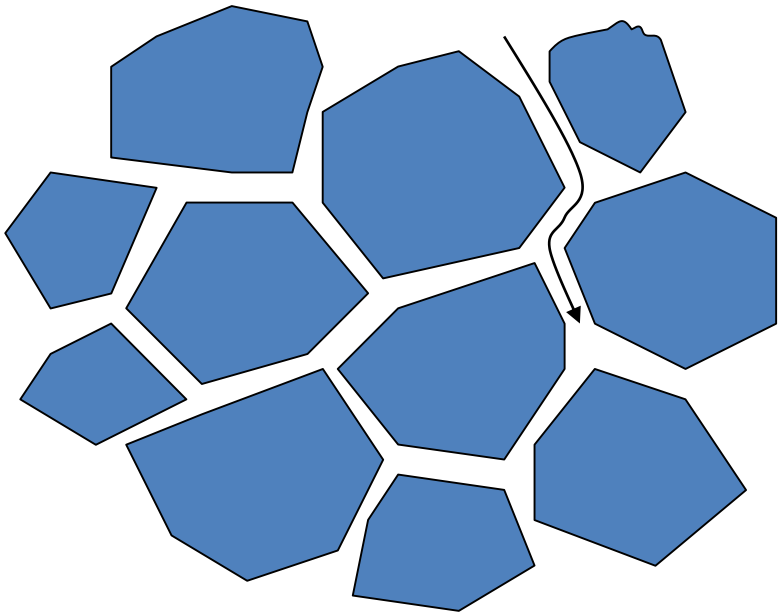
Global maps of below ground conditions



Schematic of soil hydraulic processes



- Gravity
- Surface tension
- Drainage
- Upward flow
- Groundwater
- Evaporation
- Soil Freezing
- Organic soils

- Vapour Flow
- Soil swelling/cracking
- Macropores
- Chalk Soils

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JULES *Hydrology*

1. Incoming moisture is split into runoff and water absorbed. Runoff is diverted in rivers.

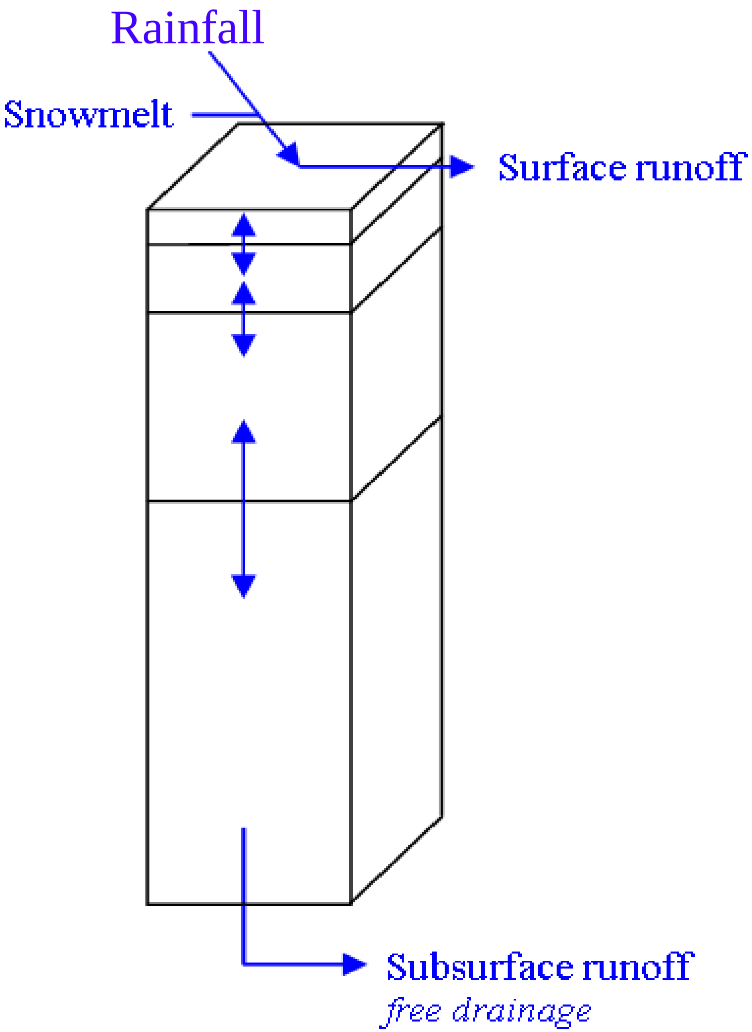
2. There is a constant redistribution of water within the soil column as it tries to reach a state of equilibrium. This is determined using the Darcy's law :

$$q = K\left(\frac{\partial \Psi}{\partial z} + 1\right)$$

3. At the bottom of the soil layers (3m), water is taken out at a rate assuming only gravitational effects – free drainage.

$$q = K$$

This drainage joins the surface runoff in rivers.



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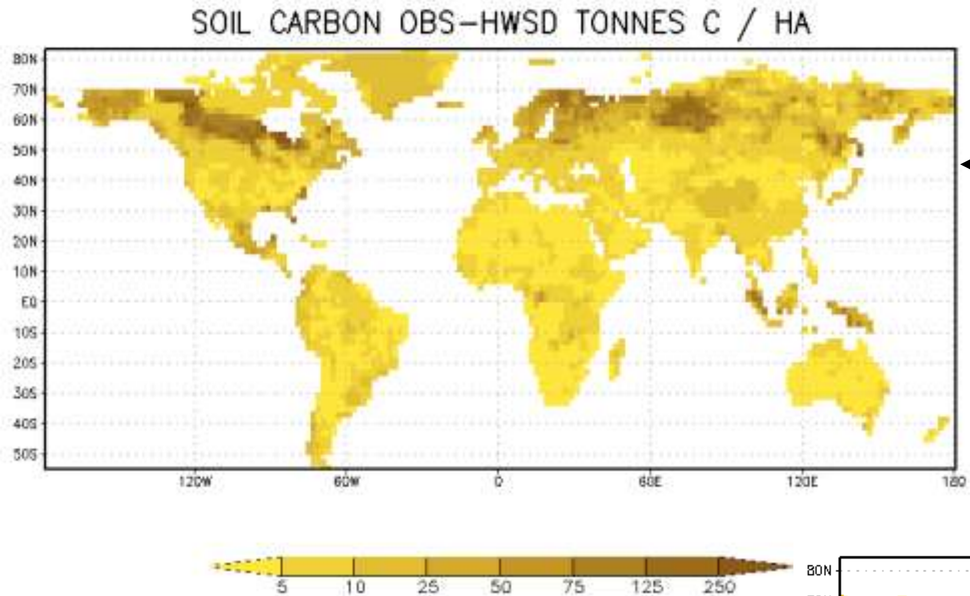
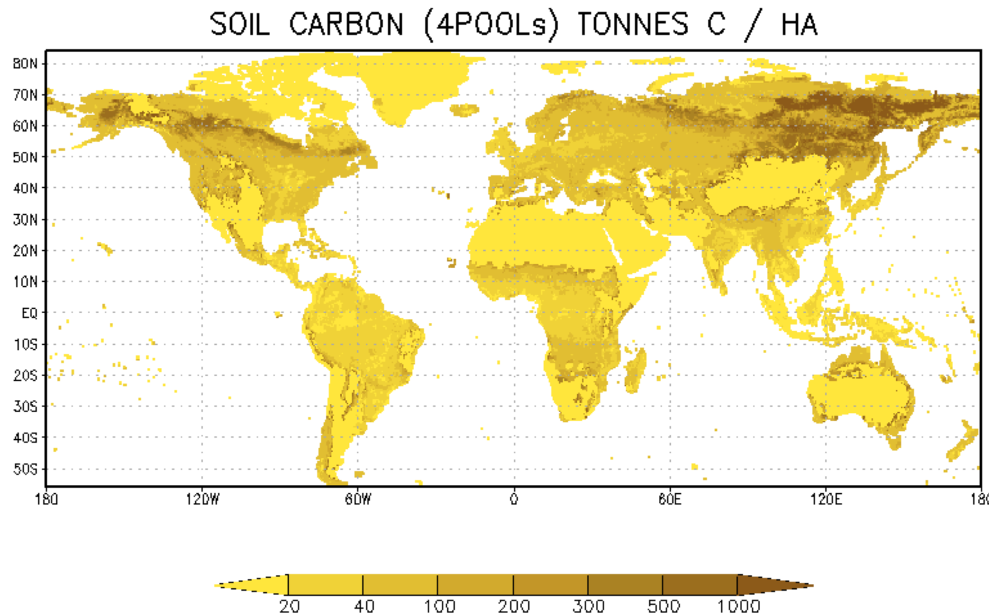
Carbon Store in the Soil



Observed patterns verses
Modelled patterns



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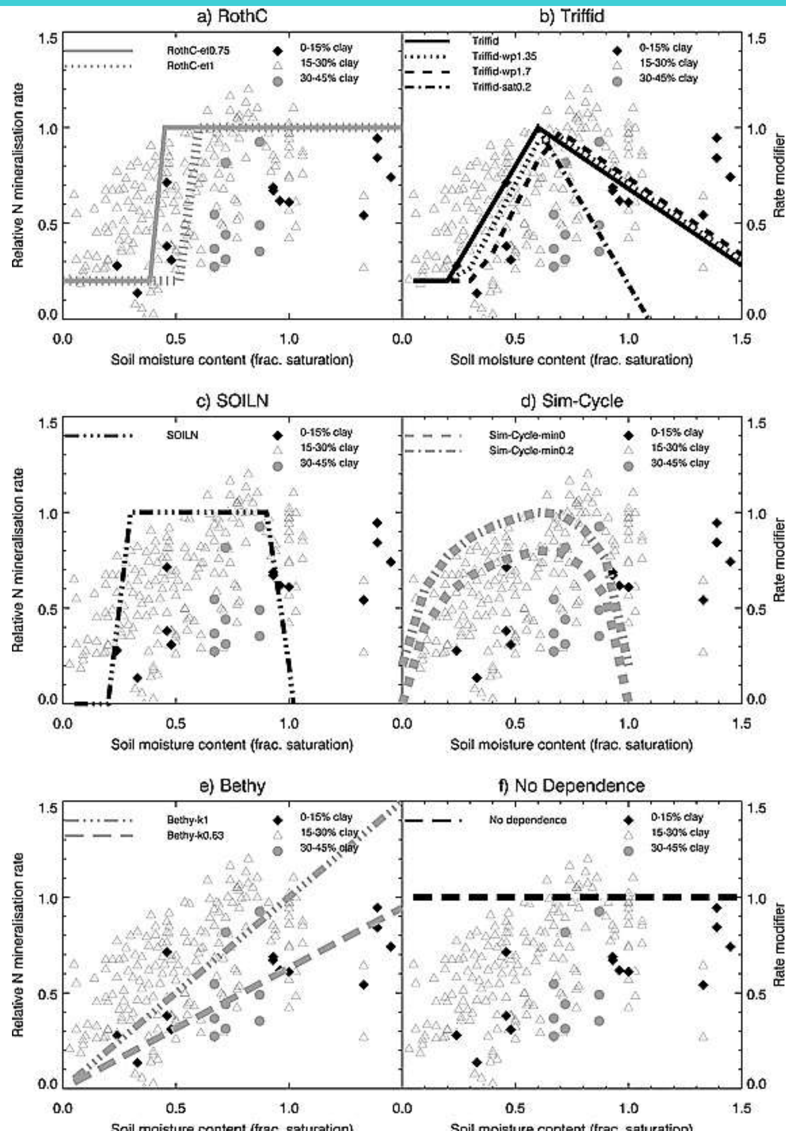
Uncertainty in the soil moisture function



There is little comprehensive soil respiration data available across soil types and soil moisture values. However, the strong linear relationship between nitrogen mineralization rates and carbon respiration rates suggests that the observed nitrogen mineralization rates found at different soil moisture values for 41 soil types (covering a range of soil textures) by ***Paul* [2001]** and ***Paul et al.* [2003]** provide a suitable surrogate for soil respiration

Direct soil moisture controls of future global soil carbon changes: An important source of uncertainty. Falloon et al.
Global Biogeochemical Cycles
Volume 25, Issue 3, GB3010, 22 JUL 2011

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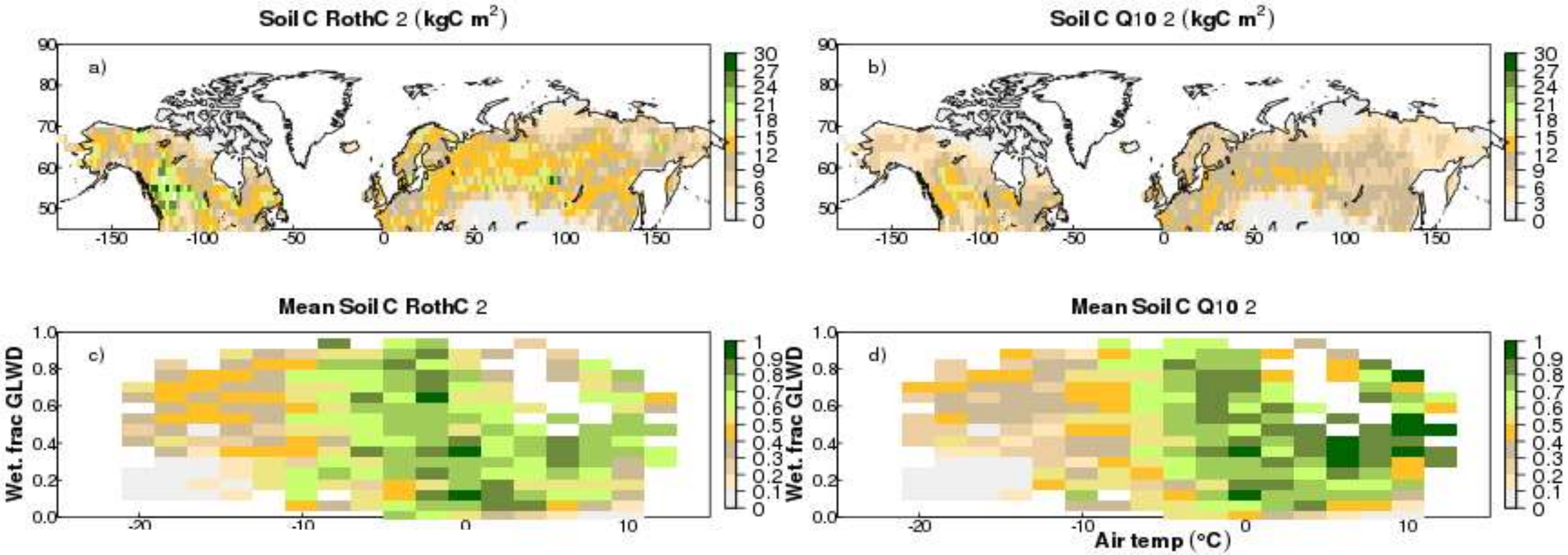
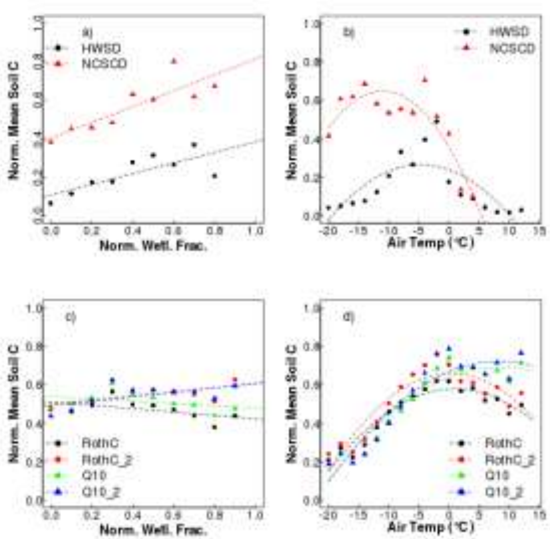
E. Carbon Store in the soil





Reduce respiration with wetland fraction:
Rnew=Rold*(1-wetland_fraction)

Need for more research into soil moisture control of soil respiration and hydrology of wetlands

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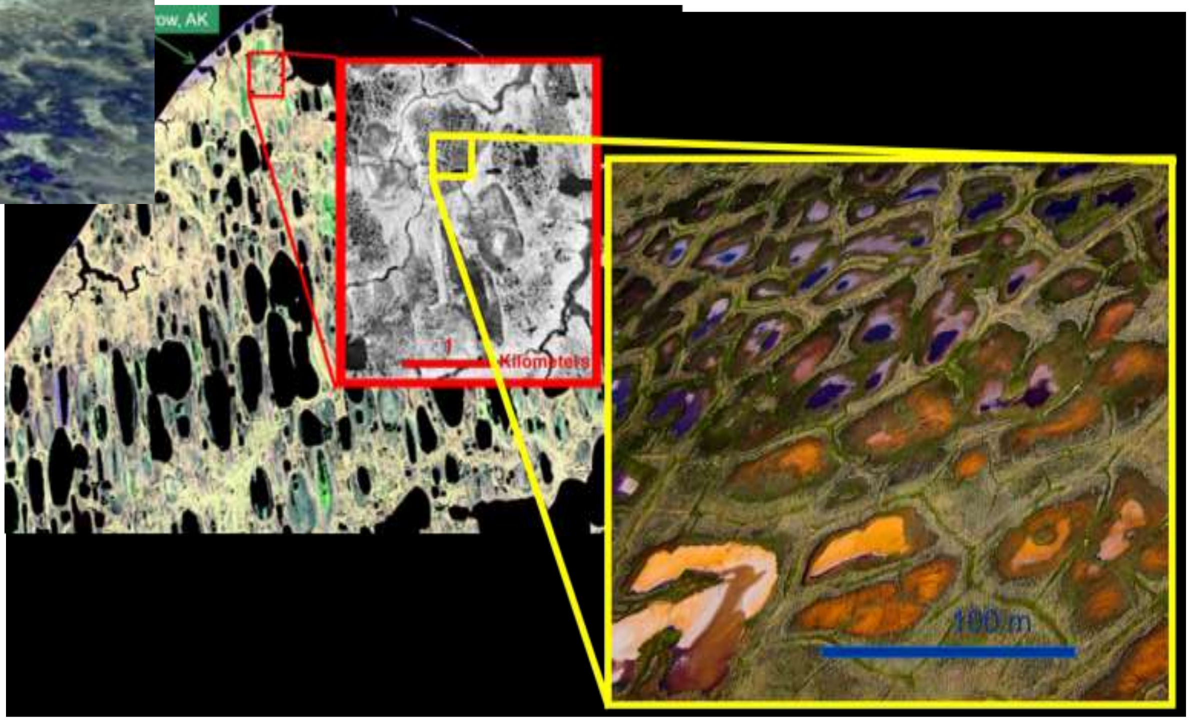
Vegetation sensitive to saturated conditions

Arial photo: Finland
Satellite image: Alaska



Models do not include soil saturation to inhibit non-wetland type Vegetation growth (only light competition)

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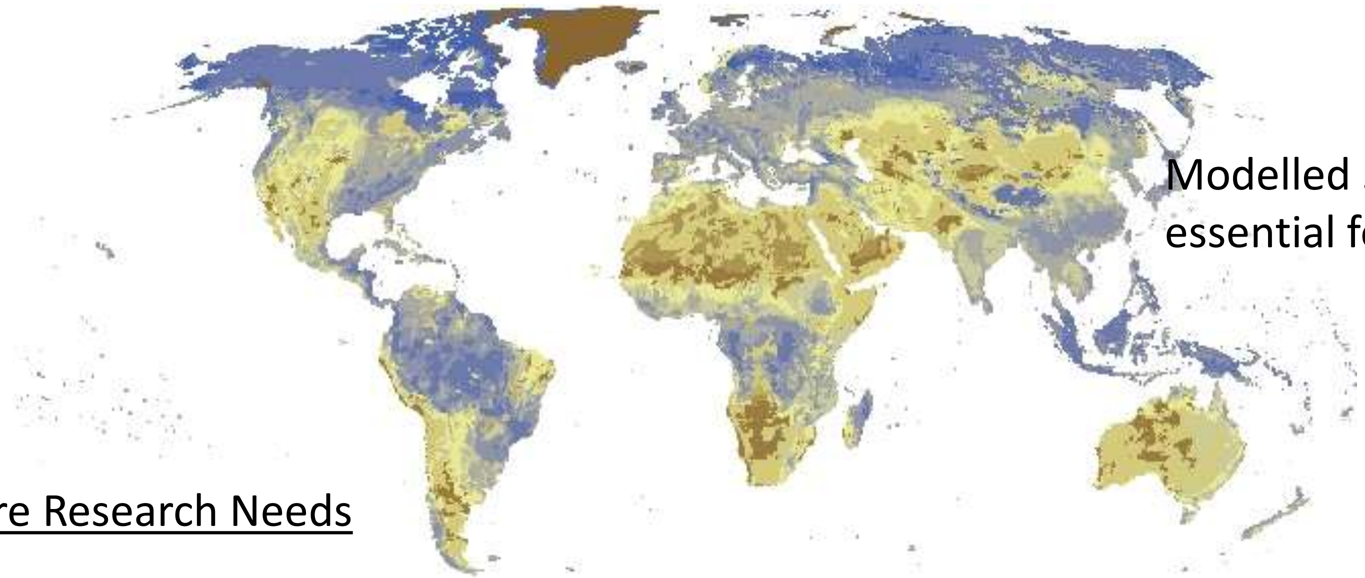
Conclusions



Modelled soil moisture – essential for all the others....

Future Research Needs

1. CO_2 fertilisation
2. Wetlands Hydrology and soil carbon
3. Dynamic vegetation models to look down as well as up

'Easy to get simple models to work

Future climate conditions requires us to venture into the unknown adding untestable complexity'

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Thank you!

Any Questions?

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