Modelling the global carbon cycle

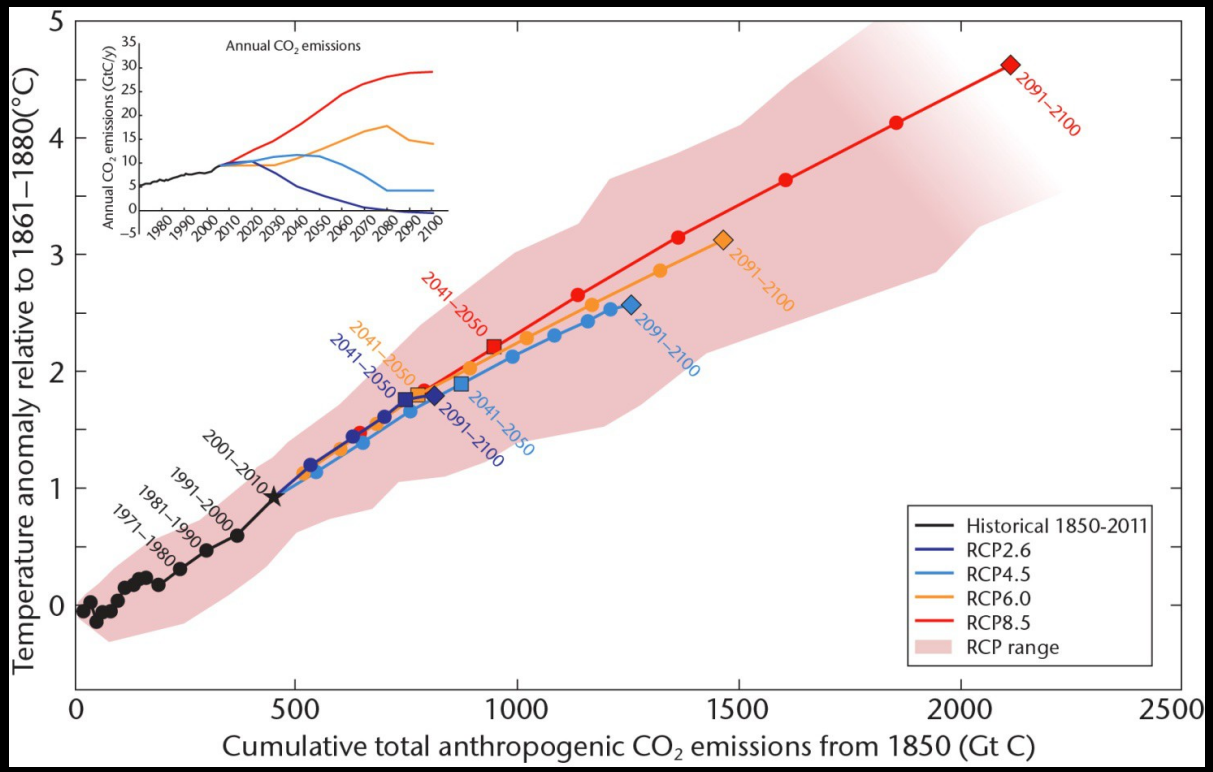
Chris Jones , Eleanor Burke, Angela Gallego-Sala (U. Exeter)

UNFCCC, Bonn, 24 October 2013

Introduction

- Why model the global carbon cycle?
  - Motivation from climate perspective
- CMIP5 / IPCC AR5 WG1 results
  - “compatible fossil fuel emissions” to achieve a scenario/target
  - Land/ocean model uncertainty
- What's in / not in the models?
  - Processes
  - Ecosystems
  - Model evaluation

Total CO_2 emissions are strongly linked to total warming



- Total CO2 emissions to 2011 are in range 460-630 GtC.
- If warming due to human emissions alone is to be limited to 2˚C, total emissions need to be limited to 800-1000 Gt C. More than half of this was already emitted by 2011.

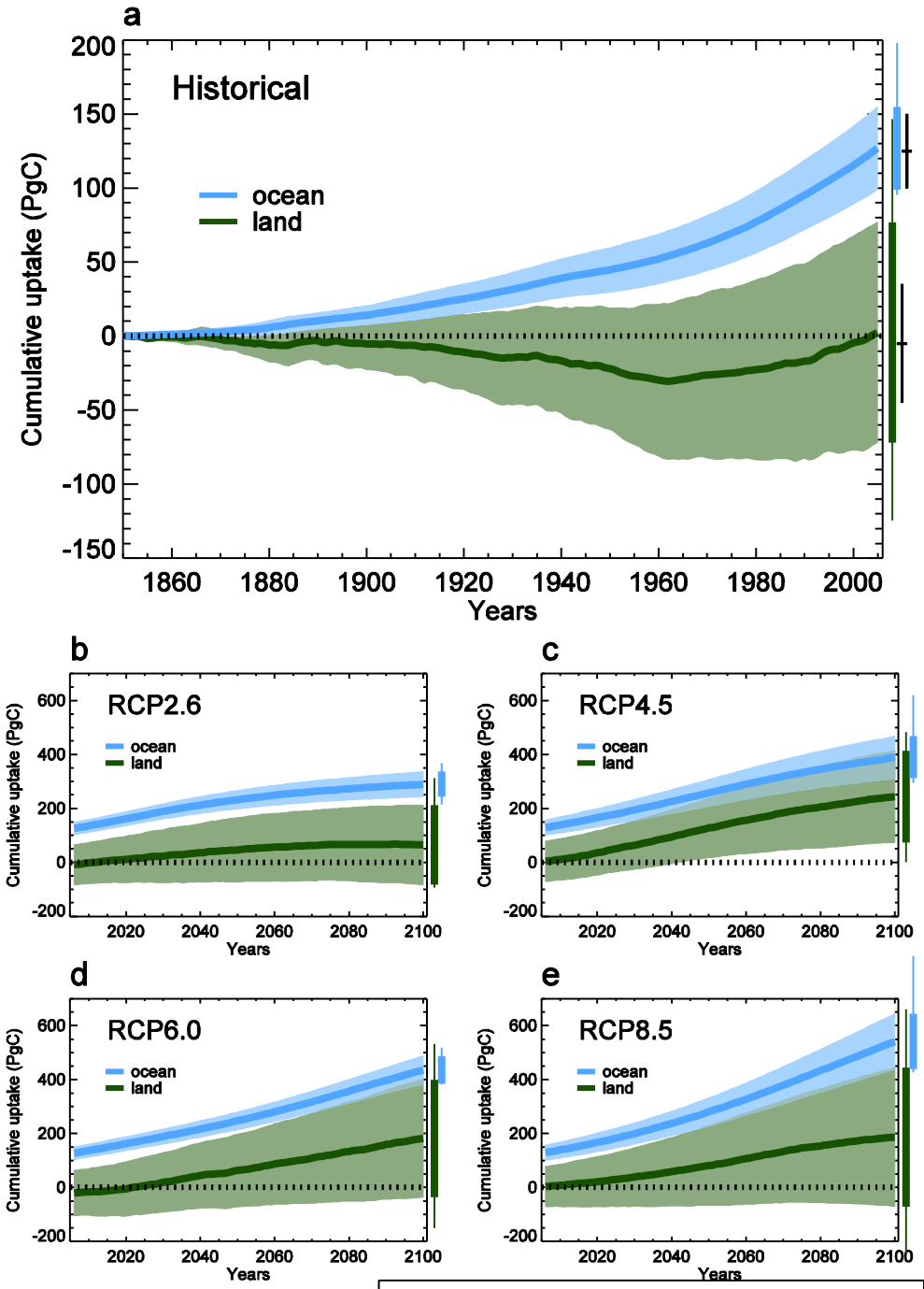
IPCC 2013, WG1 AR5, SPM

21st Century global carbon uptake: CMIP5 results

Ocean models agree much better – ocean will continue to take up carbon. For all scenarios. *High confidence.*

Land models have much greater spread. And also lack some key processes. Therefore *low confidence*.

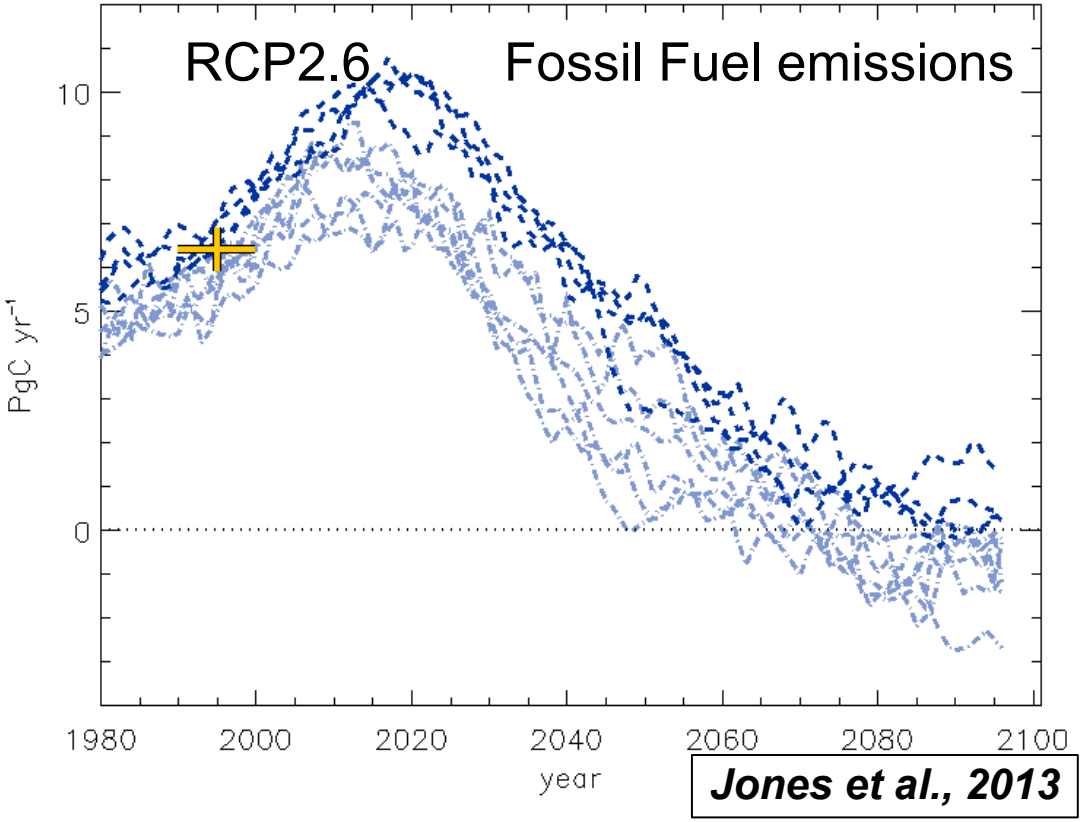
- But still generally show continued uptake. Minority of models have negative carbon balance, primarily due to land use change.



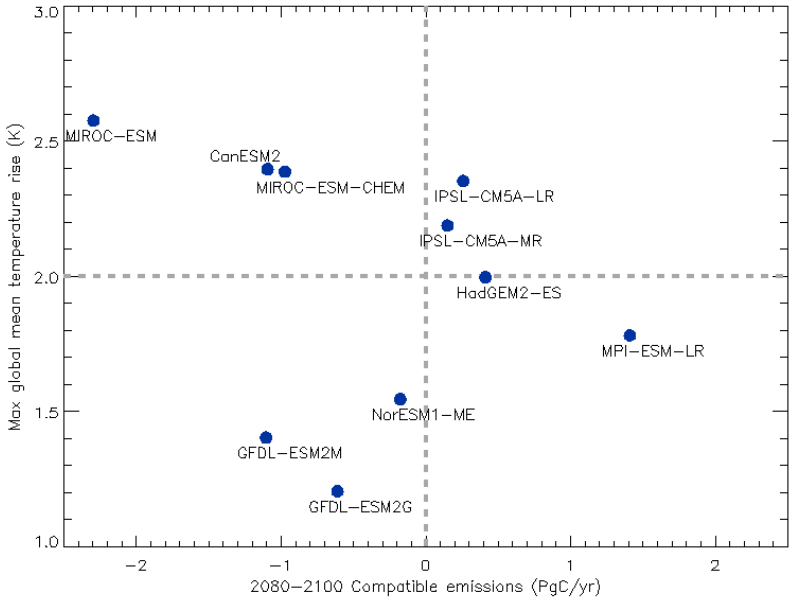
IPCC 2013, WG1 AR5, Ch.6

Simulating the land and ocean carbon uptake allows us to infer CO_2 emissions required to follow scenarios

About ***as likely as not*** that we'll need –ve emissions to achieve RCP2.6



Jones et al., 2013

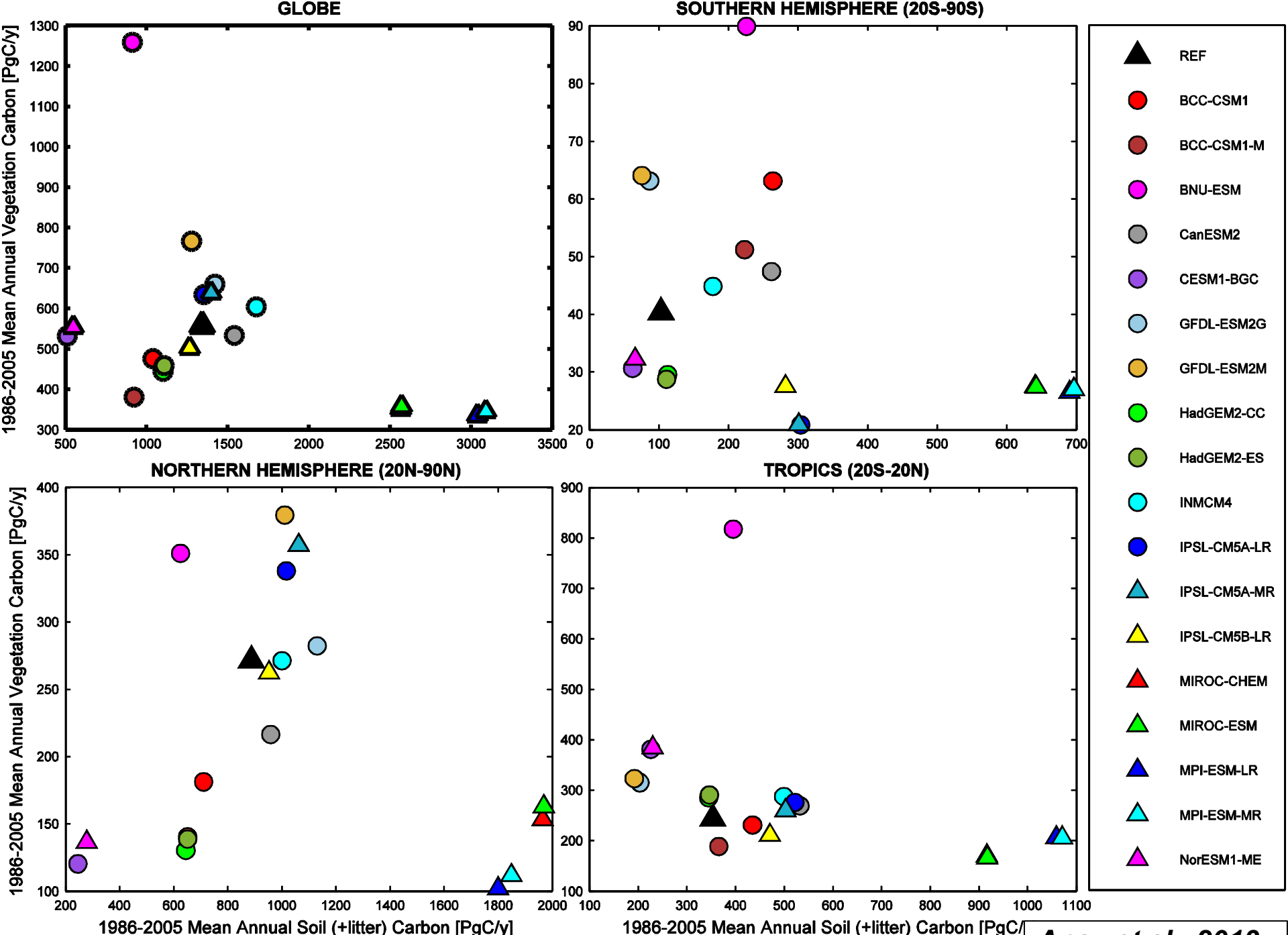


In some models, but not all, this will succeed in avoiding 2 degrees warming

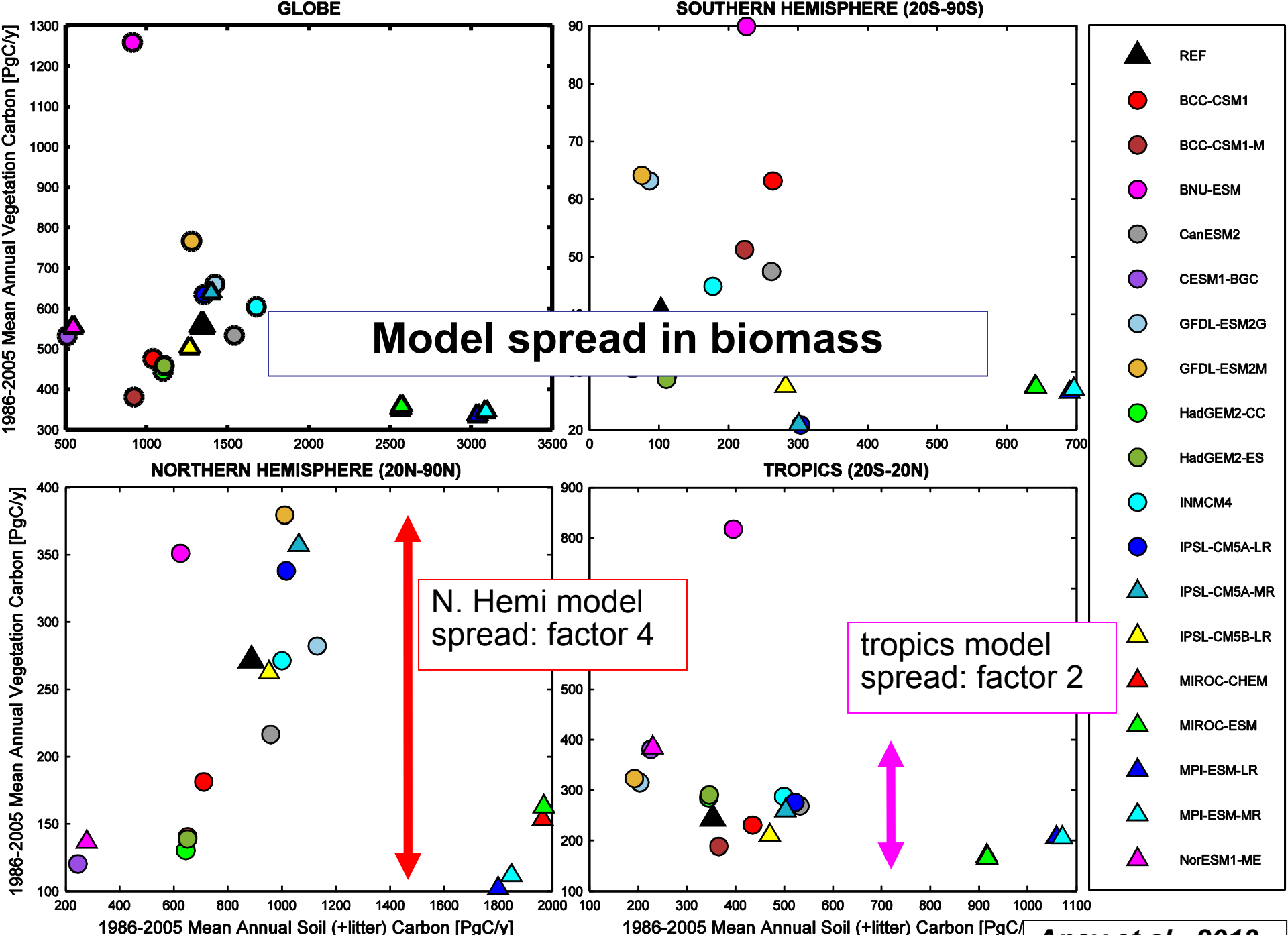
BUT: Any additional carbon source increases the requirement for negative emissions

What's in these models?

- Vegetation functional types
  - Typically 5-10
  - Broadleaf/needleleaf, deciduous/evergreen tree
  - C3/C4 grass
- Soil carbon – SOC in mineral soils (top 1m)
- Need for better model evaluation
  - Big spread in land models
  - Including in initial conditions (global soil and biomass carbon stores)



Anav et al., 2013



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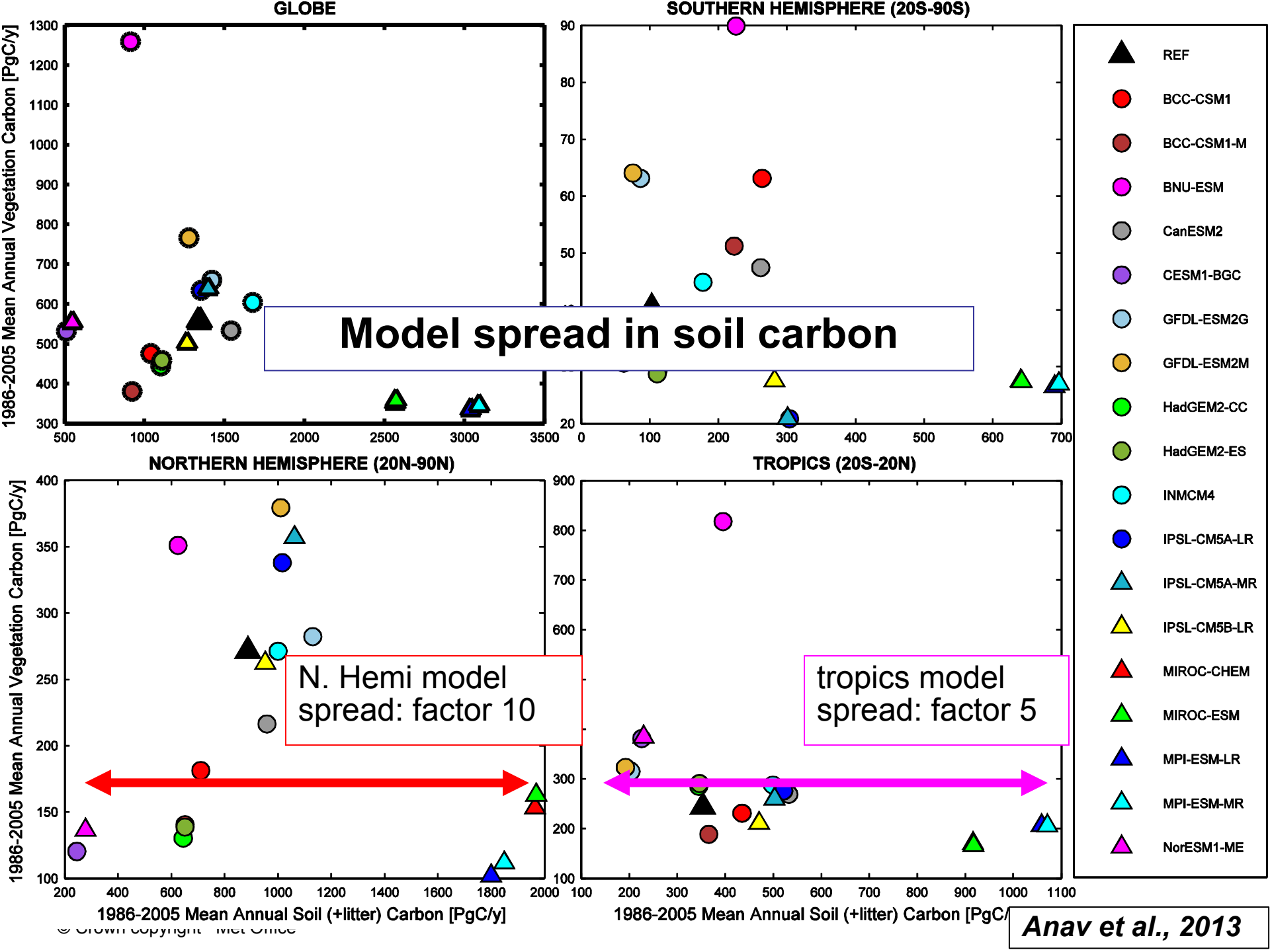


Anav et al., 2013

What's missing?

- Missing processes
  - nutrient cycles – nitrogen, phosphorous
- Non-represented ecosystems
  - Permafrost
    - Physics (soil freezing)
    - but not C storage
  - Peatlands/wetlands
    - Vegetation cover – mosses, sedges
    - Deep organic soils
  - Mangroves, seagrass, marshes
  - [not covered further here – but not in global models at all]

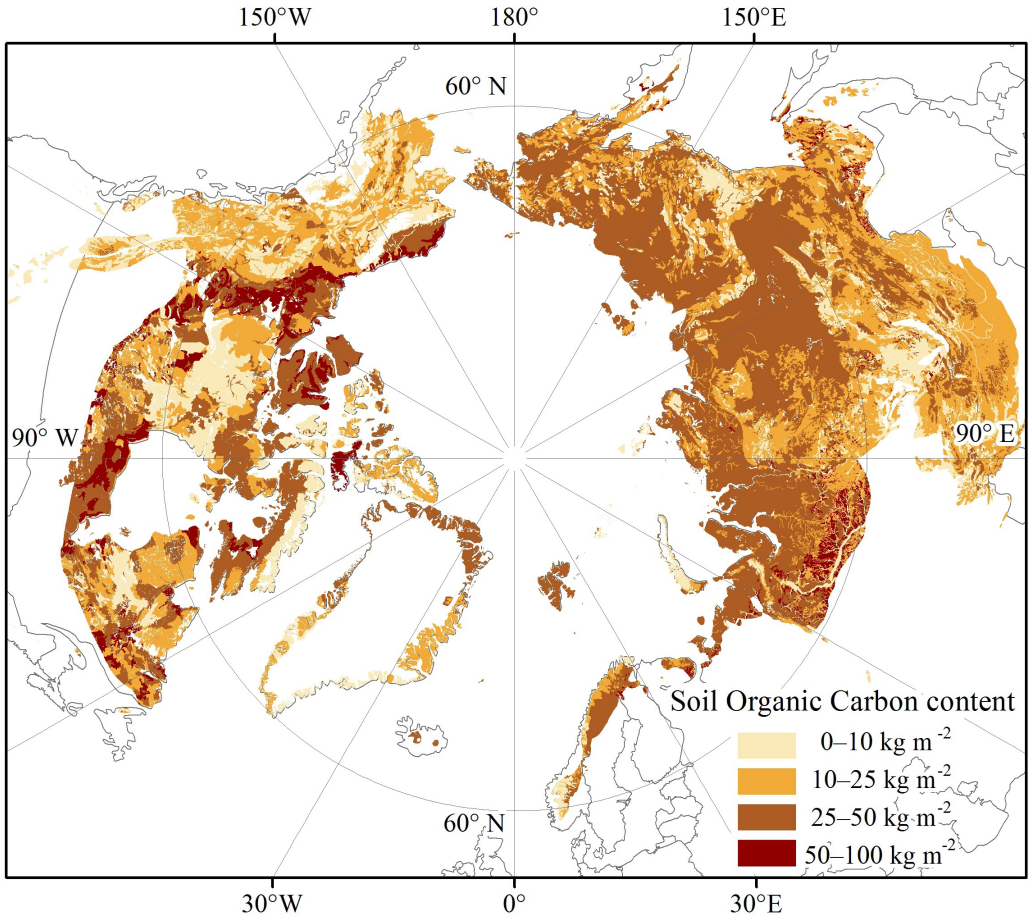
Potential further sources/sinks of greenhouse gases

Observed northern hemisphere permafrost distribution

Permafrost impacts ~ 25 % of the land surface.

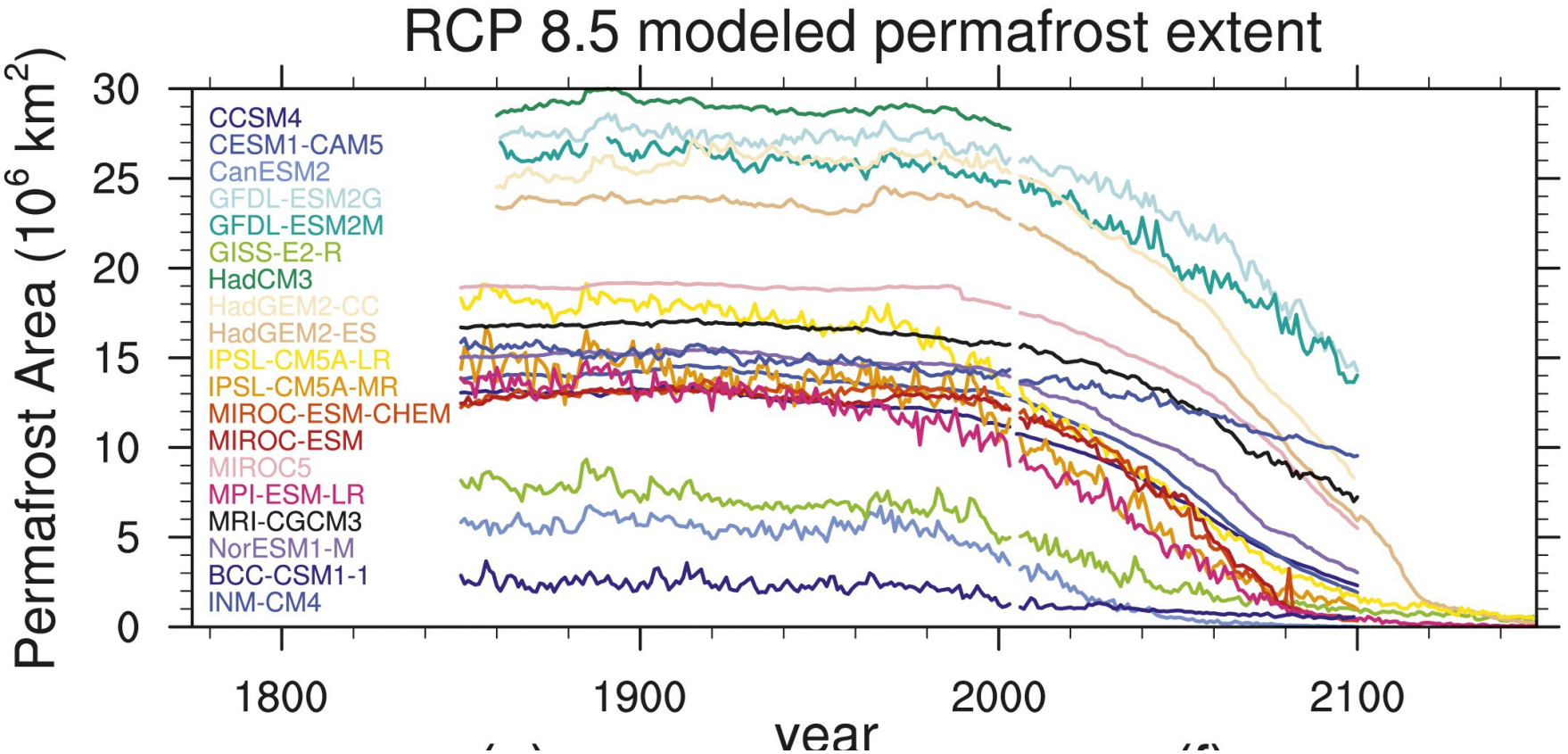
Sub-sea permafrost also exists

Frozen soil carbon stores



- Permafrost soils contain around 1,672 Pg carbon (highly uncertain)
- More than twice as much as is currently in the atmosphere.

Representation of loss of permafrost extent in CMIP5 models



From Koven et al., 2013

"It is ***virtually certain*** that near-surface permafrost extent at high northern latitudes will be reduced as global mean surface temperature increases." IPCC 2013 [37-81% loss by 2100]

Soil carbon decomposition

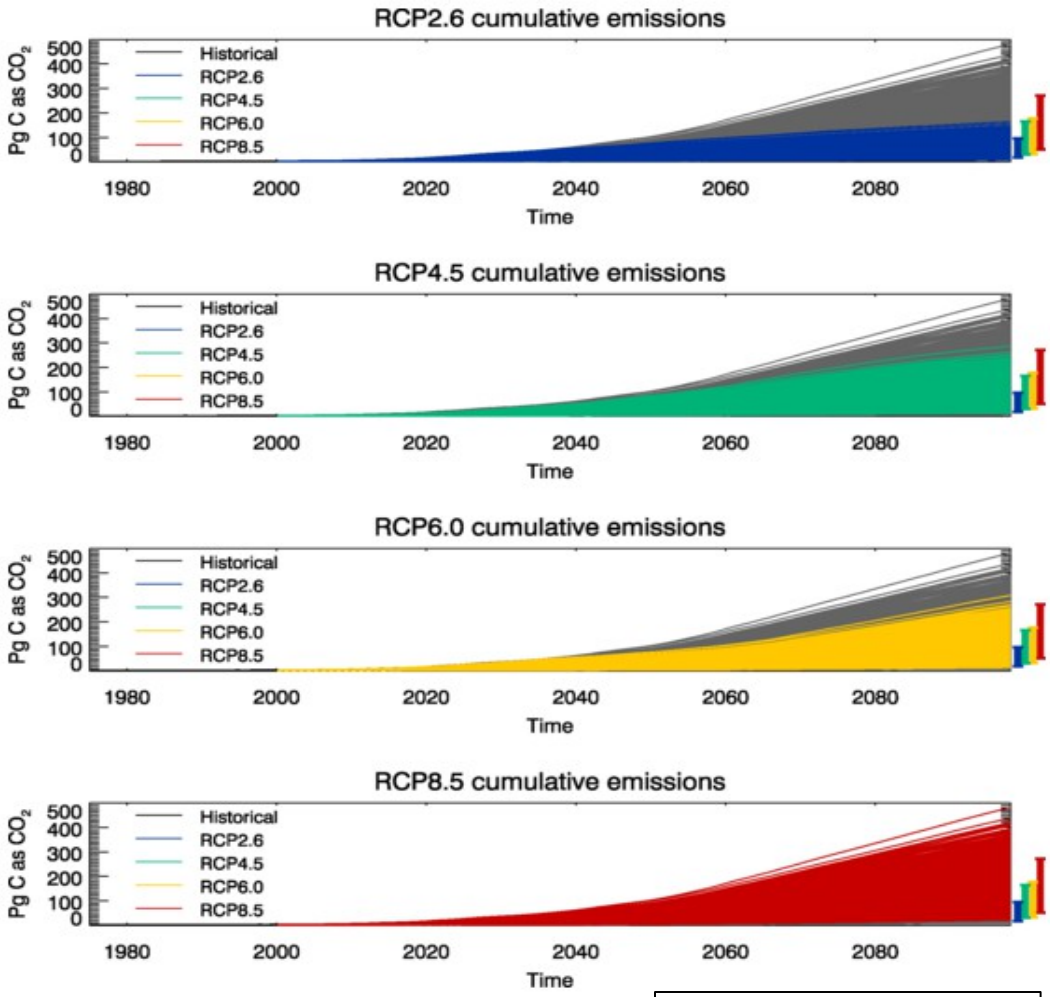
AR5 WG1 assessed a range of 50-250 PgC release, by 2100, for RCP8.5

Uncertainty assessment of future carbon release from permafrost

- degree of warming (scenario)

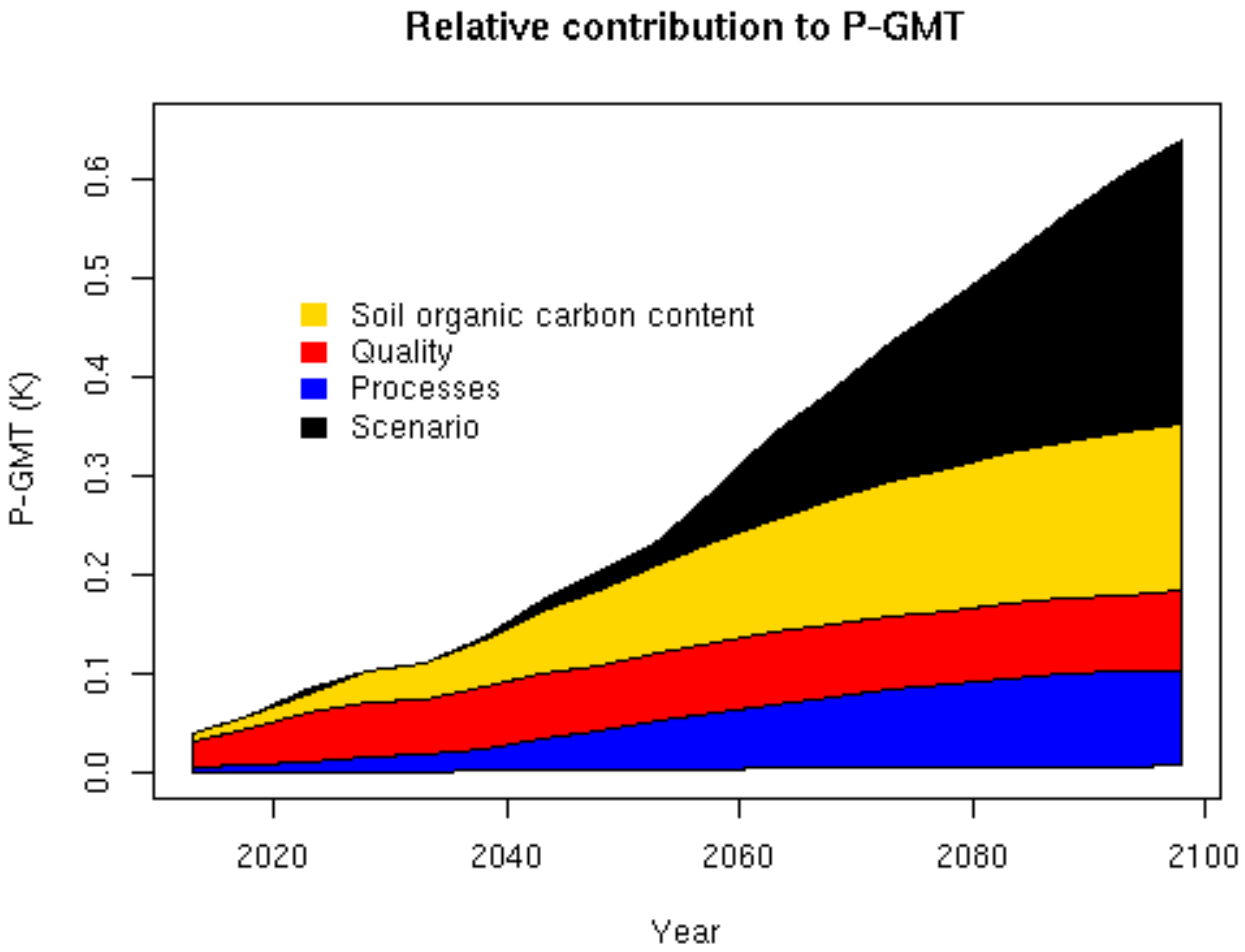
- amount/distribution of carbon

- process uncertainty



Burke et al., 2013

Relative roles of uncertainty



- PF carbon content and distribution (yellow) one of the biggest sources of uncertainty
- “quality” / lability (red) also important
- Both reducable by better observations

Burke et al., 2013

Peatlands and wetland ecosystems

- The carbon pool in peatlands is big: >600 PgC globally
  - determining controls on future dynamics is an important part of carbon cycle feedbacks to climate change
- Peat accumulation is slow
  - May be dominated by NPP changes rather than decay; spatial and temporal patterns of accumulation over the past millennium (and whole Holocene) suggest a negative feedback – but small.
- Peatland extent may be important and a positive feedback
- Methane emissions clearly important too

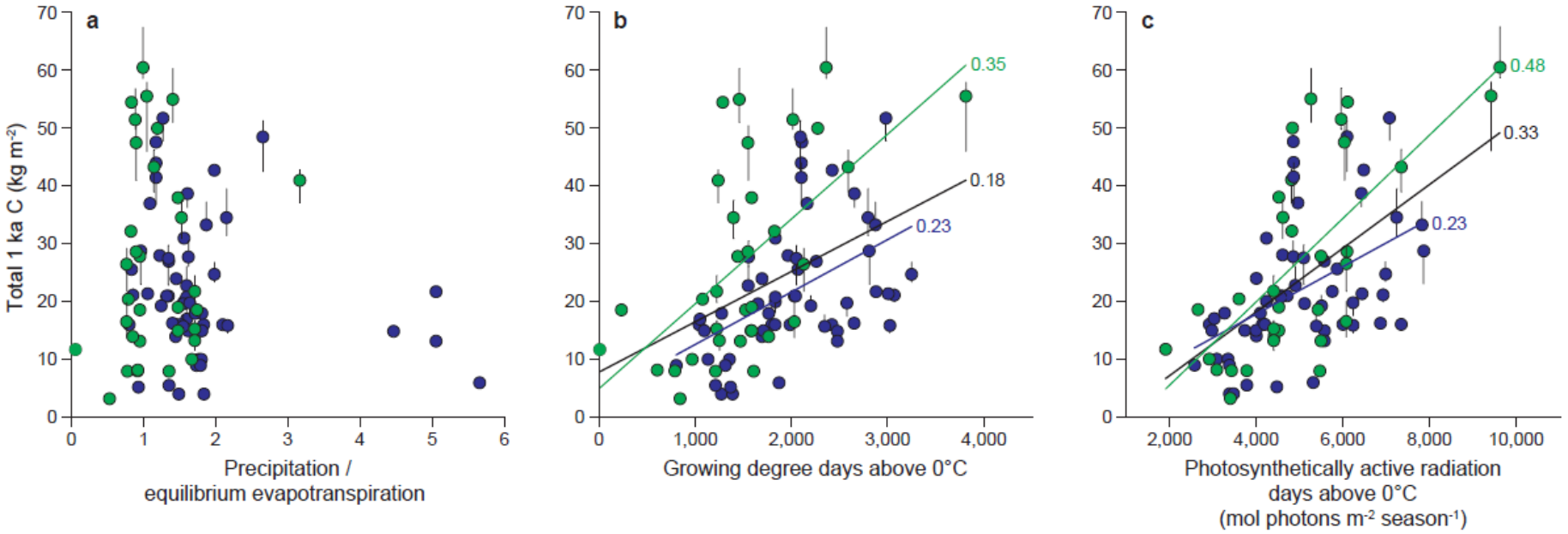
courtesy Angela Gallego-Sala, U. Exeter

Spatial variability in total 1kyr peat C

Moisture index

Growing season temperature

Growing season radiation



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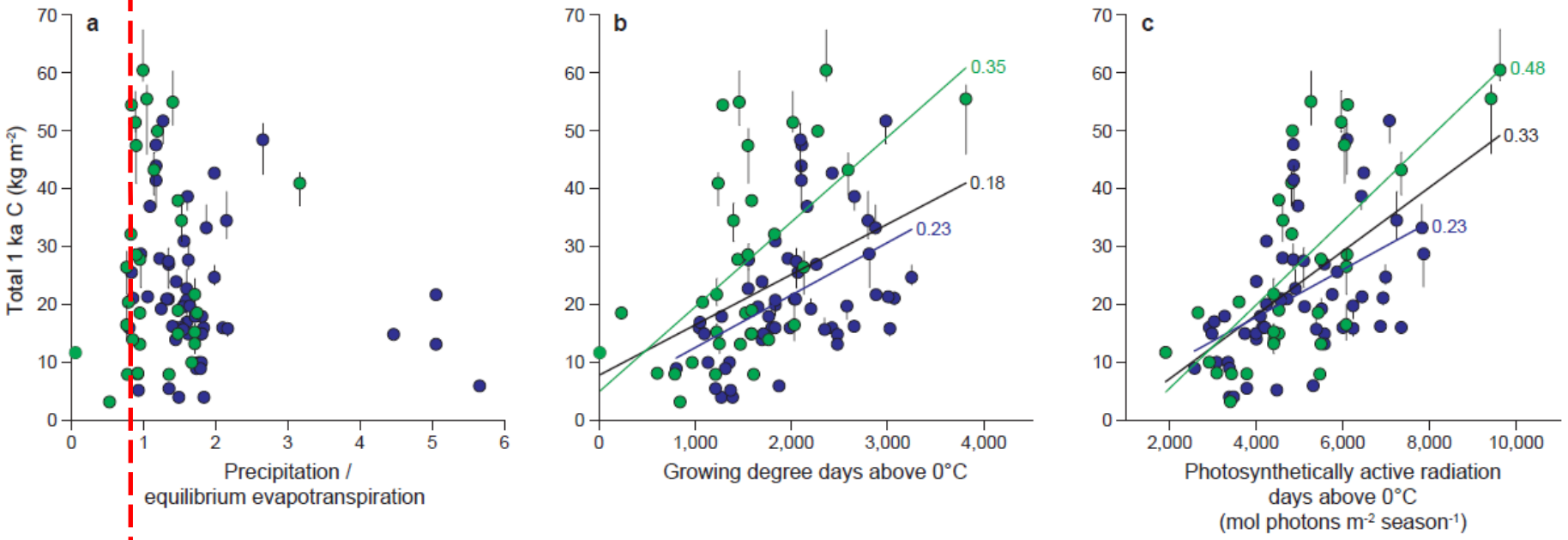


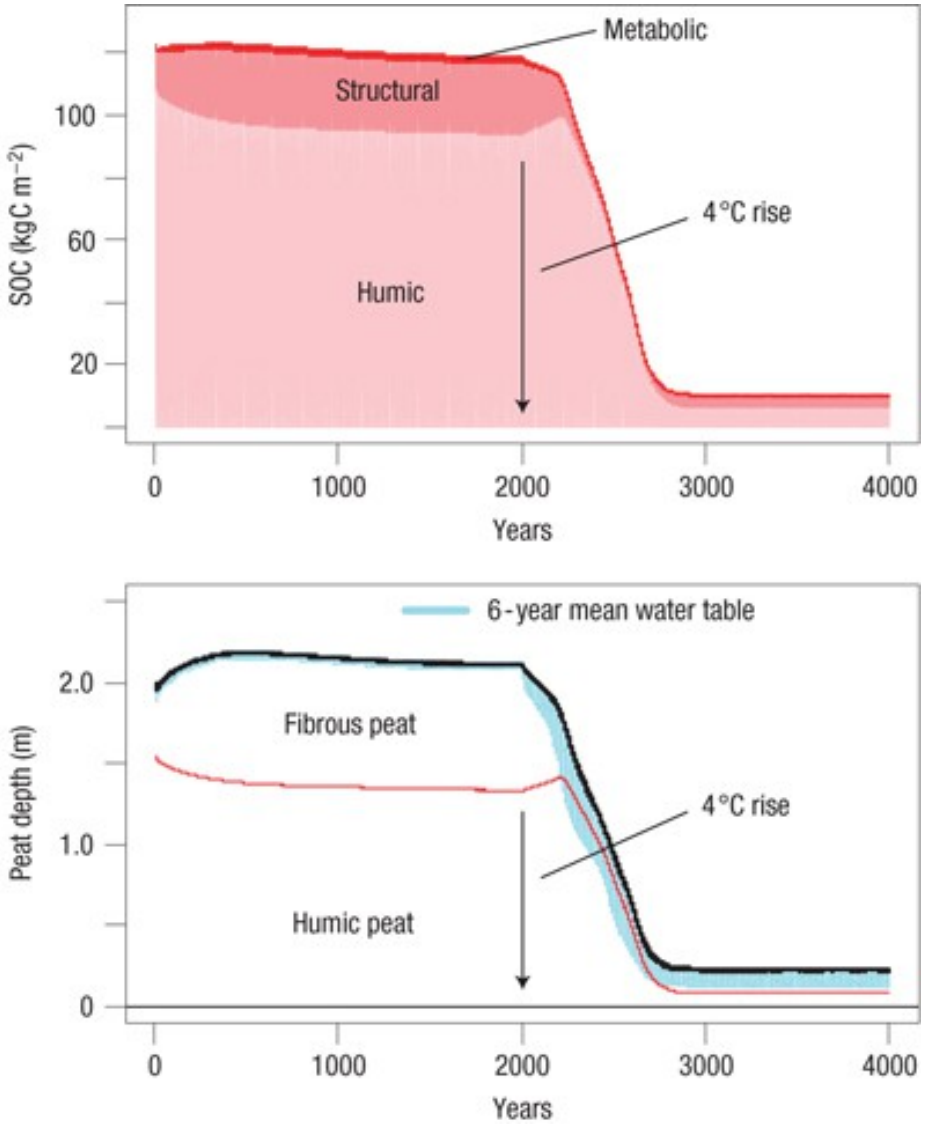
Possible threshold – climate change could drive loss of peatland areas

courtesy Angela Gallego-Sala, U. Exeter

Positive feedbacks on soil texture may accelerate any peat loss

- Feedback between the water table and peat depth increases the sensitivity of peat decomposition to temperature
  - intensifies the loss of soil organic carbon in a changing climate.

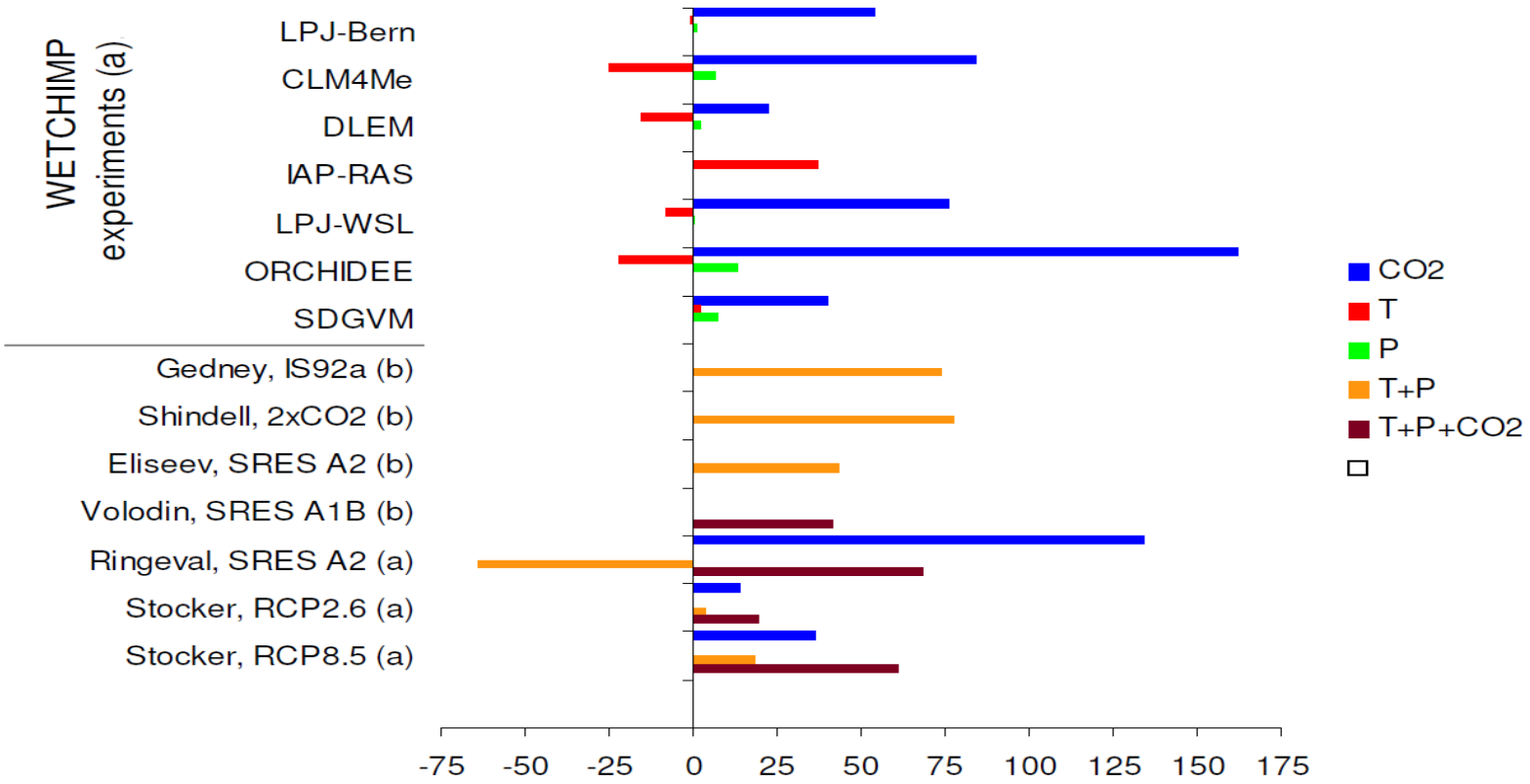
- Peatlands may quickly respond to warming this century by losing labile SOC during dry periods.



Ise et al., Nature GeoSci., 2008

Methane emissions

- Permafrost thaw may also release methane
  - May be more important driver of climate change on short (decade) timescales than CO2 release
- Wetland methane emissions also ***likely*** to increase
  - Driven by CO2 fertilisation as well as a changing climate



IPCC 2013, WG1 AR5, Ch.6

Summary

- Global carbon cycle responds to climate change
  - Essential link between human activity and climate change

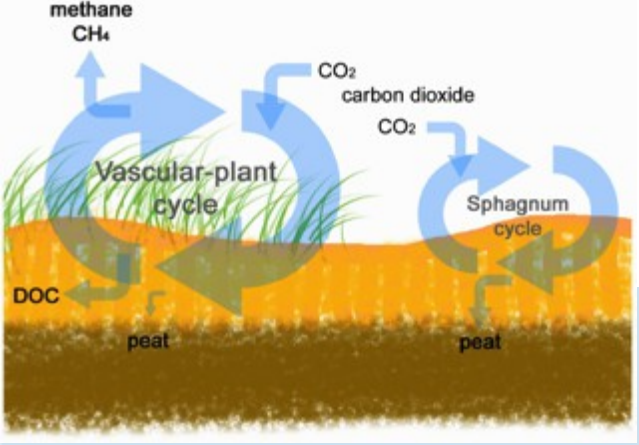
- Low mitigation CO_2 pathways, such as RCP2.6 as likely as not require global negative emissions
  - But large model uncertainty (especially on land)
  - Missing process/ecosystems play big role in achievability of targets

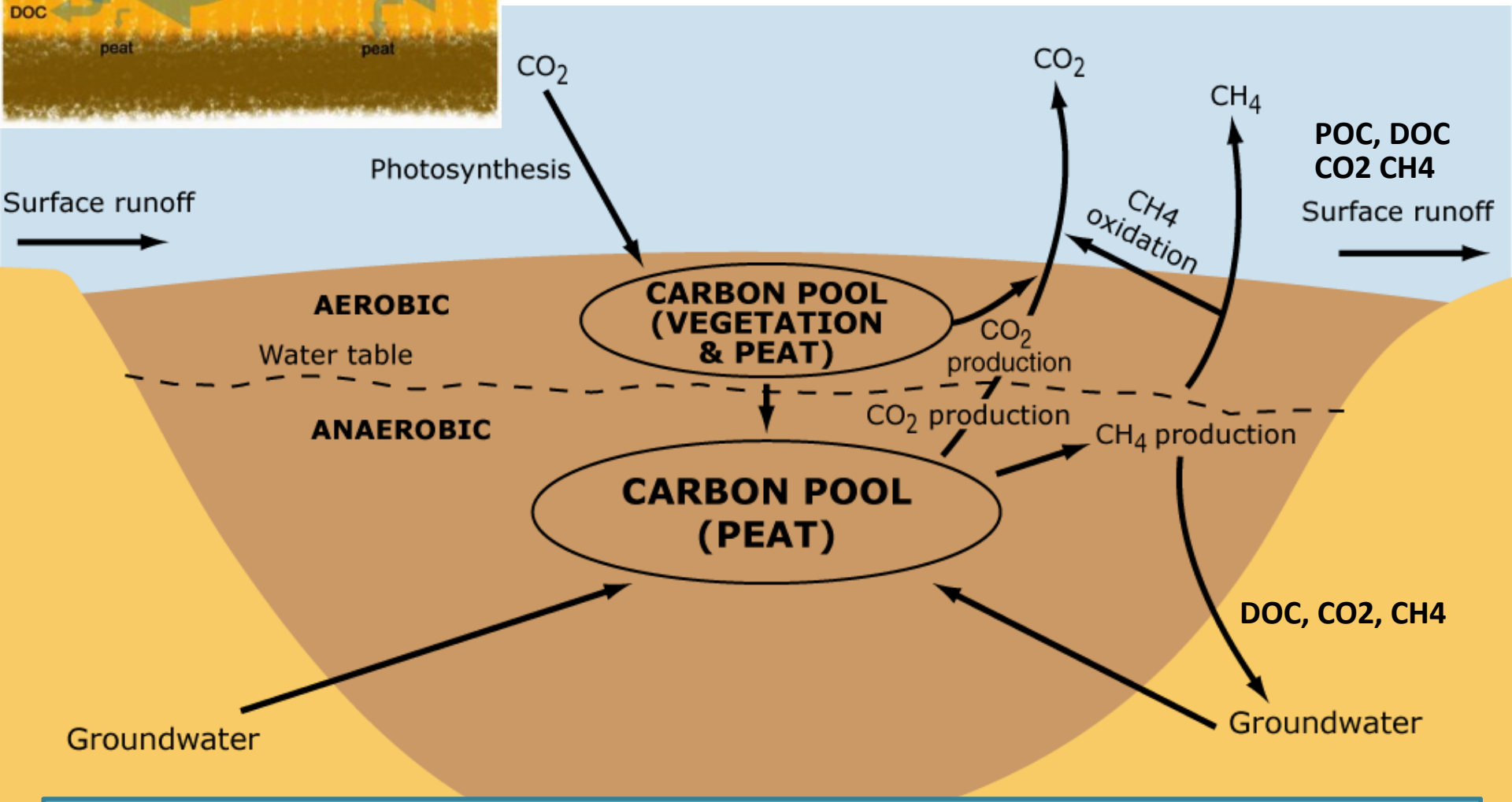
- Need better / more complete inventories:
  - Model evaluation / initial conditions
  - Ecosystems
    - Permafrost
      - Likely to release additional carbon this century
    - Peatlands/wetlands
      - May release additional carbon (CO_2) this century
      - Likely to emit more methane this century
    - Both provide additional positive feedback onto climate change

References

- Anav et al., 2013, J. Climate *(C4MIP Special Collection)*
- Burke et al., 2013, The Cryosphere
- Ise et al., 2008, Nature Geoscience
- Jones et al., 2013, J. Climate *(C4MIP Special Collection)*
- Koven et al., 2013, J. Climate *(C4MIP Special Collection)*

Peatland carbon cycling





Higher water table: increased CH4 production, reduced respiration

courtesy Angela Gallego-Sala, U. Exeter

Charman (2002)