Conflicting drivers of land carbon uptake variability reconciled by land-atmosphere coupling

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One-slide summary

- Using CMIP5 Earth system models, we find that **90% of the inter-annual variability of land carbon uptake depends on soil moisture** anomalies

- While the effects of **temperature** and **vapour pressure deficit** appear to be important, they are in fact almost entirely controlled by soil moisture as a result of land-atmosphere coupling

For each Earth system model, two runs are compared

Control run (CTL)

With dynamic soil moisture

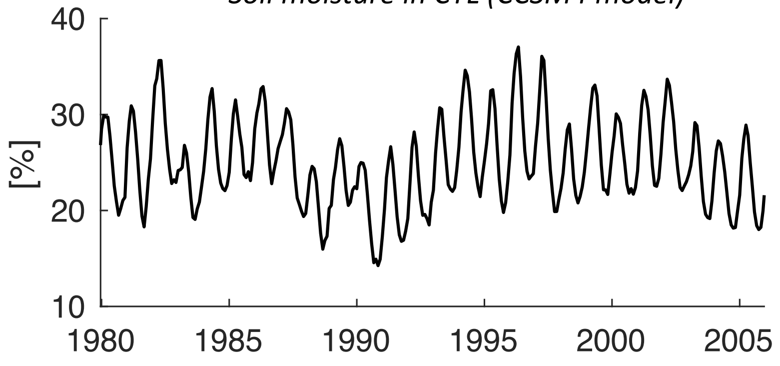
VS

Experiment run (ExpA)

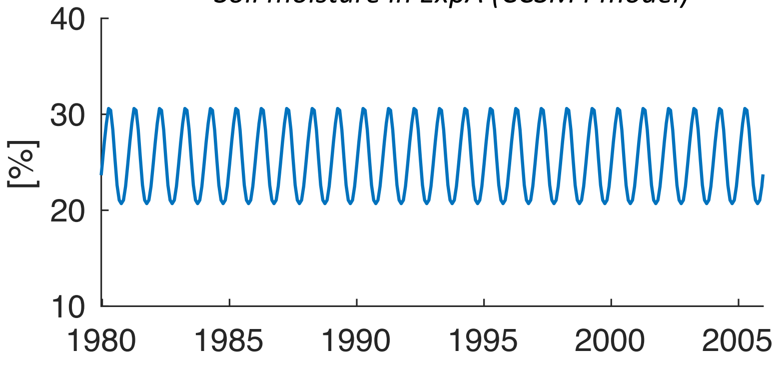
Soil moisture is only seasonal

(seas. cycle injected from the CTL run)

Soil moisture in CTL (CCSM4 model)



Soil moisture in ExpA (CCSM4 model)

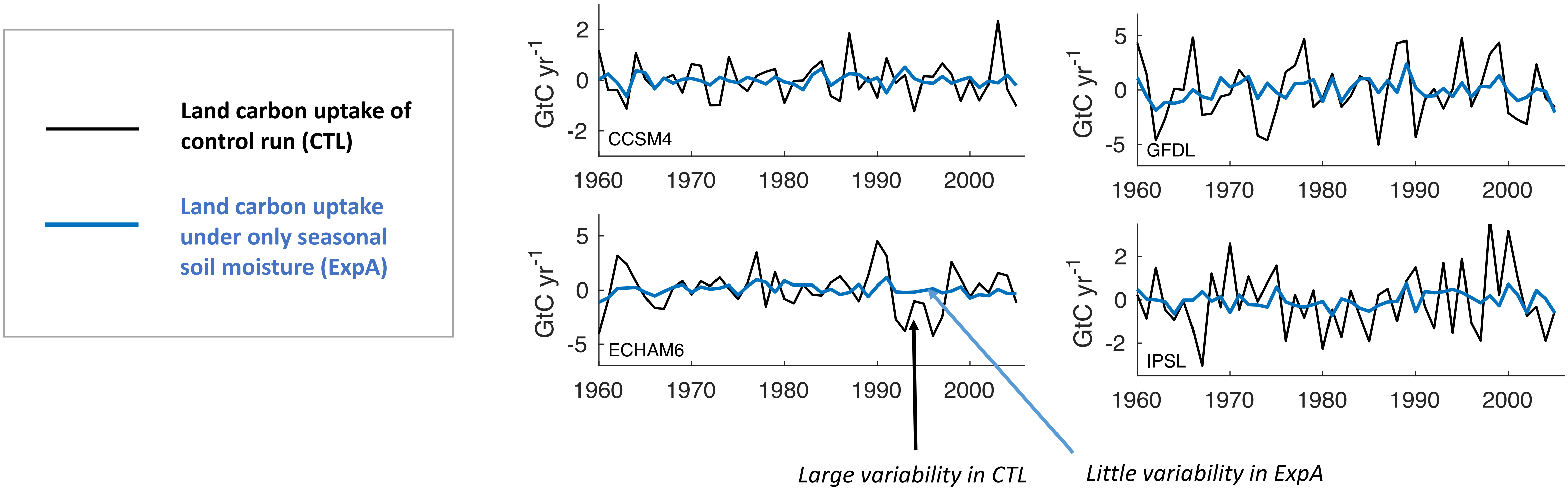


Both runs are otherwise identical (same sea surface temperatures, same historical CO_2 concentration, etc.)

(from 4 CMIP5 models which participated in the GLACE-CMIP5 experiment, Seneviratne et al. 2013, GRL)

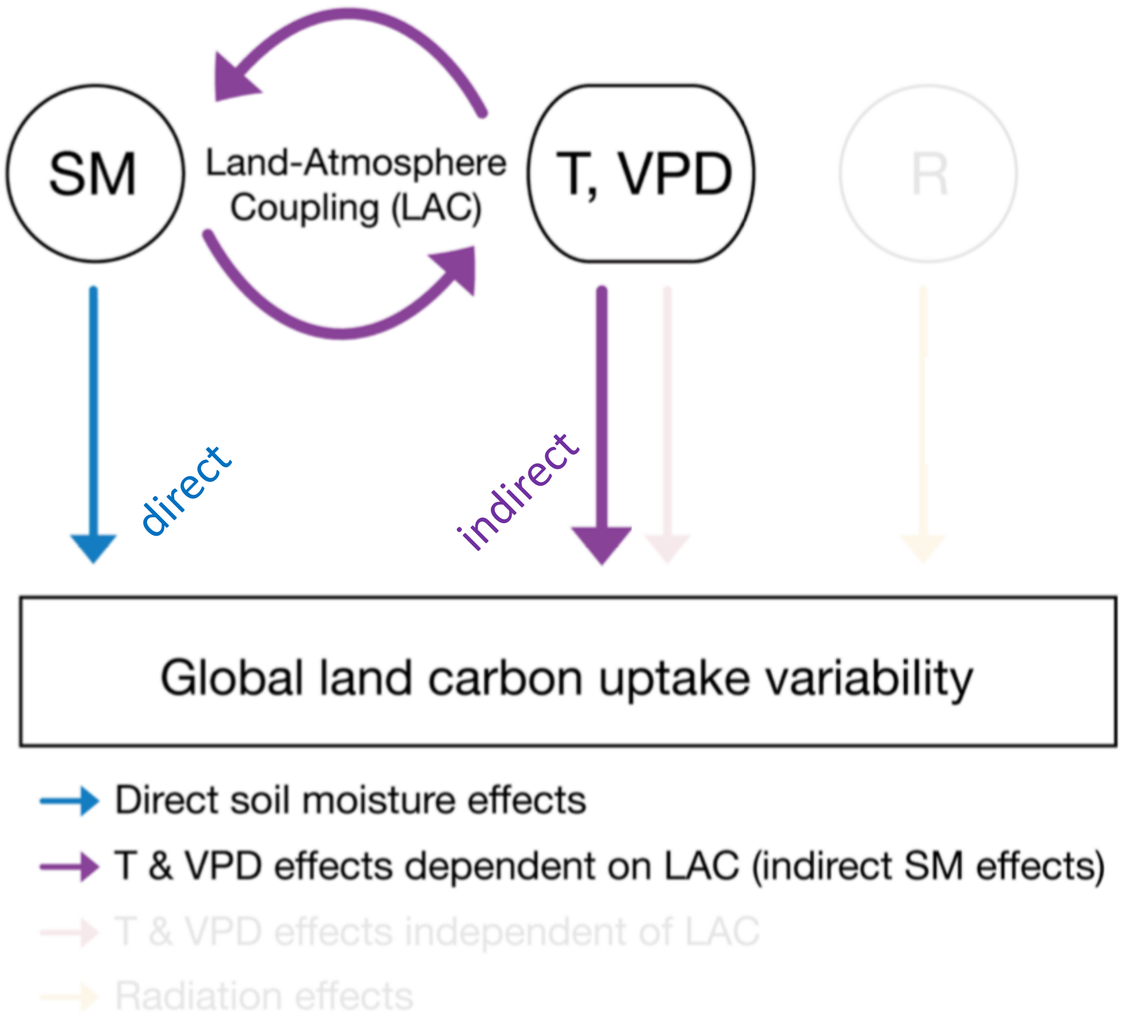
Global land carbon uptake variability is reduced by **90%** in the run with seasonal soil moisture

Global Net Biome Production (4 different models)

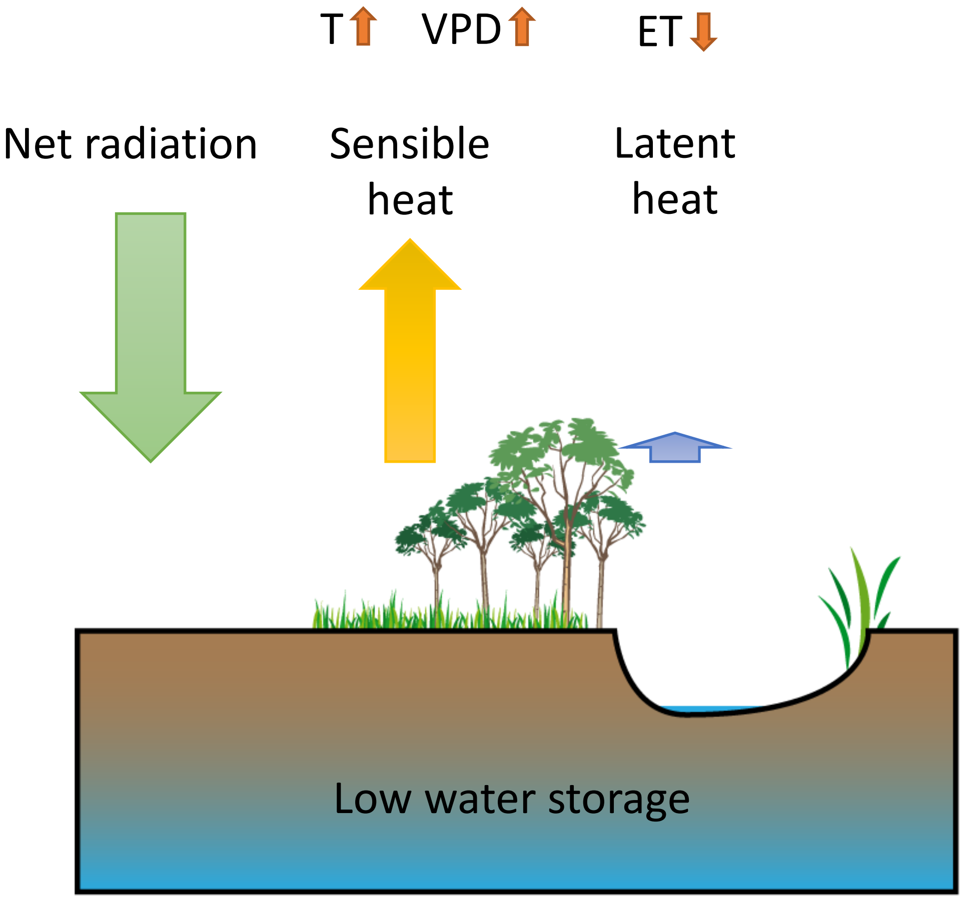


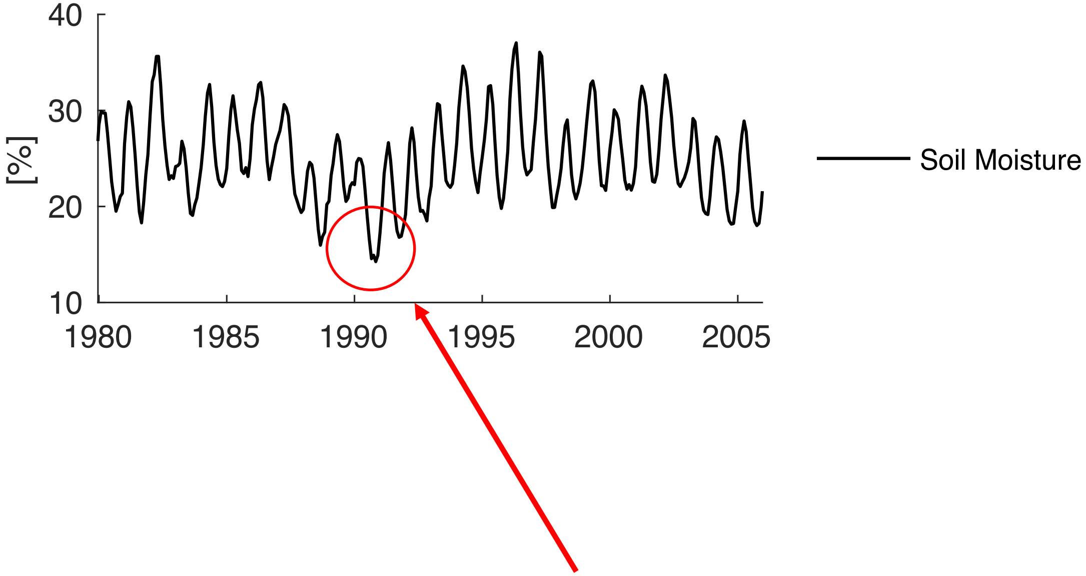
This occurs because of both direct and indirect soil moisture effects

- **A direct effect** is an ecosystem response to soil moisture content
- **An indirect effect** is an ecosystem response to an atmospheric variable (i.e. temperature or vapour pressure deficit) that is influenced by soil moisture
- Because we use coupled land-atmosphere models, any change to soil moisture feeds back to the atmosphere and potentially affects T and VPD…



Indirect effects are present in the control run (CTL)

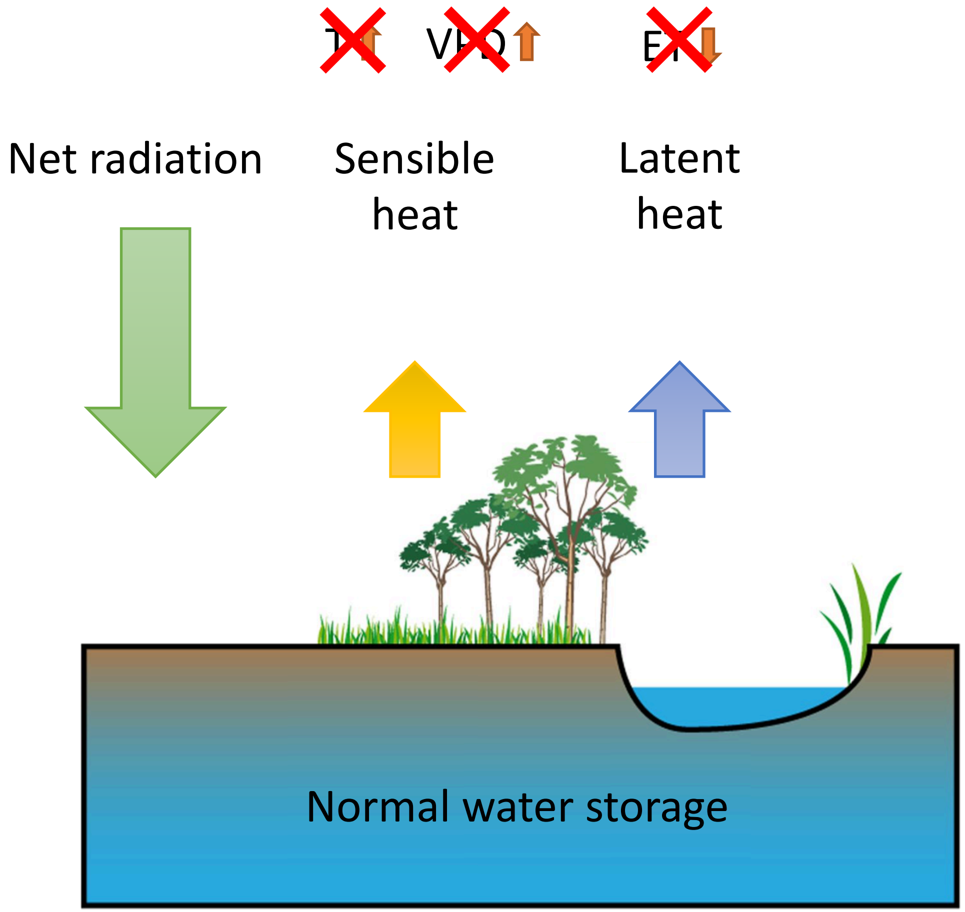


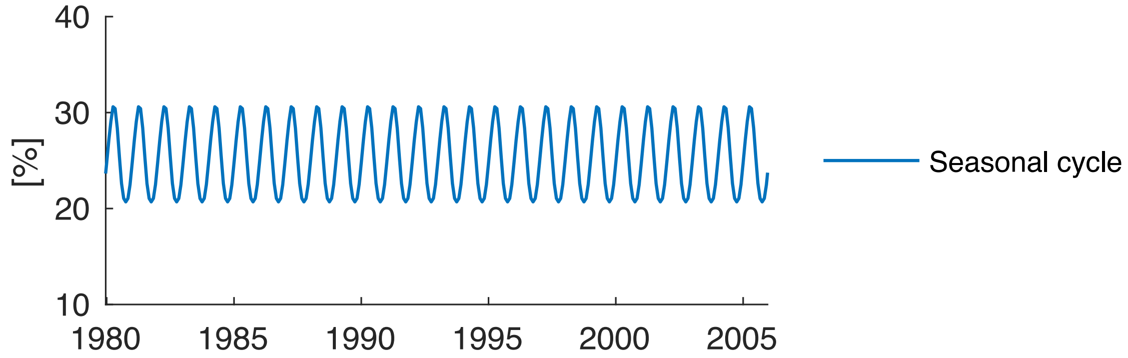


During exceptionally dry years, evaporative cooling is reduced, leading to extreme temperatures and VPD.

These are indirect effects of soil moisture variability.

Indirect effects are reduced in the experiment (ExpA)



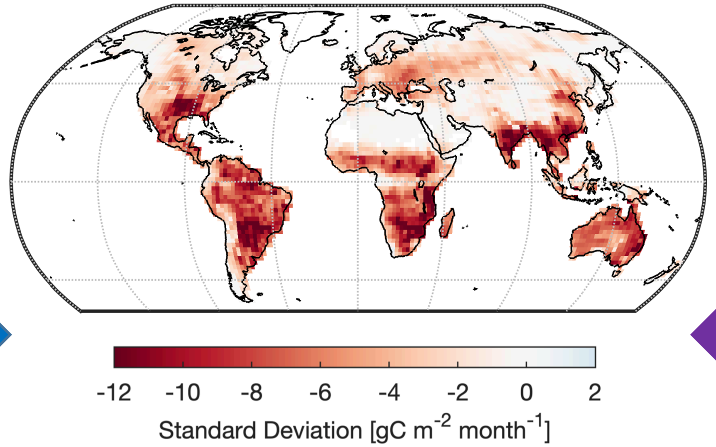


In the experiment with seasonal soil moisture, exceptionally dry (and wet) years never happen

Thus, there are much less temperature and VPD extremes in ExpA

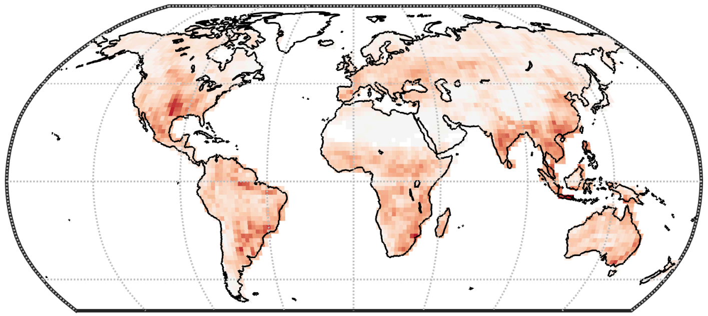
Comparison of direct and indirect effects

Overall 90% reduction in NBP variability when using seasonal soil moisture (ExpA minus CTL)



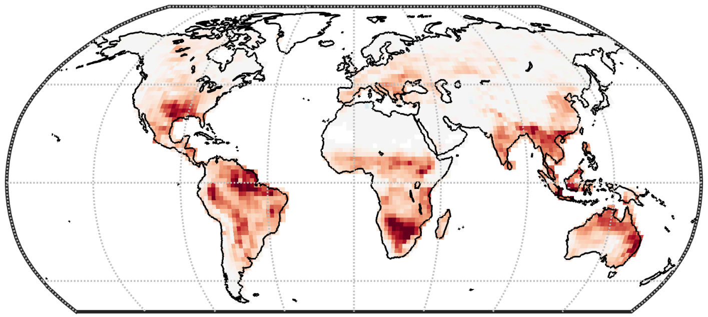
Due to direct effects

Δ SD(NBP^{SM})



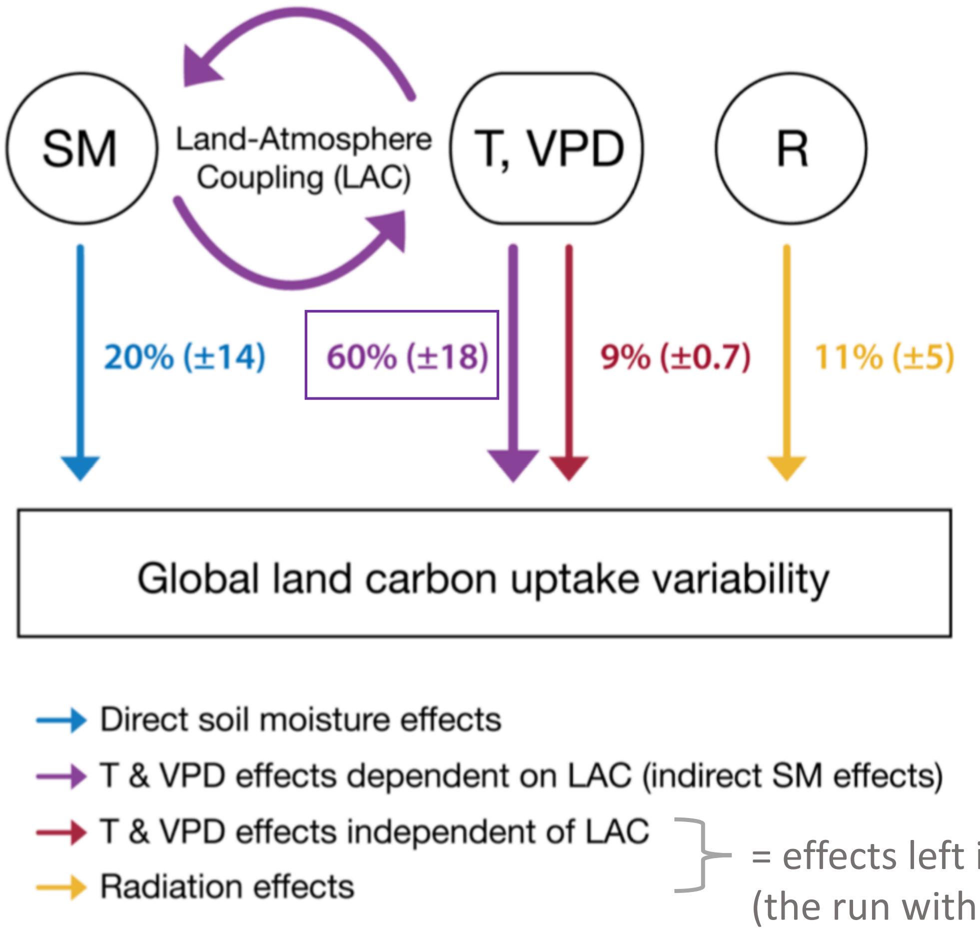
Due to indirect effects

Δ SD(NBP^{T,VPD})



In most semi-arid regions, inter-annual variability in **soil moisture affects land carbon uptake variability mainly via indirect effects**

At global scale, indirect effects account for 60% of all the NBP variability



All the effects present in CTL

= effects left in ExpA
(the run with only seasonal soil moisture)

This helps reconcile seemingly contradicting results

- **Take-home: a large part of NBP variability is due to temperature and VPD extremes that depend on soil moisture**
- Understanding that most temperature and VPD effects are actually indirect soil moisture effects helps reconcile some recent findings:

1. Semi-arid regions, which are water-limited, contribute most of the inter-annual variability and trend in model-based NBP (Poulter et al. 2014, Nature; Ahlström et al. 2015, Science)

2. Land surface models and machine learning approaches indicate that temperature effects constitute the dominant driver of globally averaged NBP (Jung et al. 2017, Nature)

3. Anomalies of the CO_2 growth rate are well correlated to global terrestrial water storage (Humphrey et al. 2018, Nature)

Back-up slide

Method for attributing NBP anomalies to drivers

- Regression of NBP anomalies against anomalies in meteorological drivers
  - Gridcell-dependent relationships
  - Month-dependent relationships
  - Applied to CTL and ExpA separately

$$\boldsymbol{NBP^{*}_{s,m} = \beta^{SM}_{s,m} \cdot SM_{s,m} + \beta^{T}_{s,m} \cdot T_{s,m} + \beta^{VPD}_{s,m} \cdot VPD_{s,m} + \beta^{R}_{s,m} \cdot R_{s,m}}$$

s: spatial index (grid point)
m: month index (1 to 12)
β : regression coefficients
NBP: net biome production (anomaly)
SM: total soil moisture (anomaly)
T: 2m air temperature (anomaly)
VPD: vapour pressure deficit (anomaly)
R: net shortwave radiation (anomaly)

Approach identical to Jung et al. 2017