School of Earth and Environment
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Interactive Diffuse Radiation in UKESM: Impact on Global and Regional Productivity

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Diffuse Fertilisation Effect

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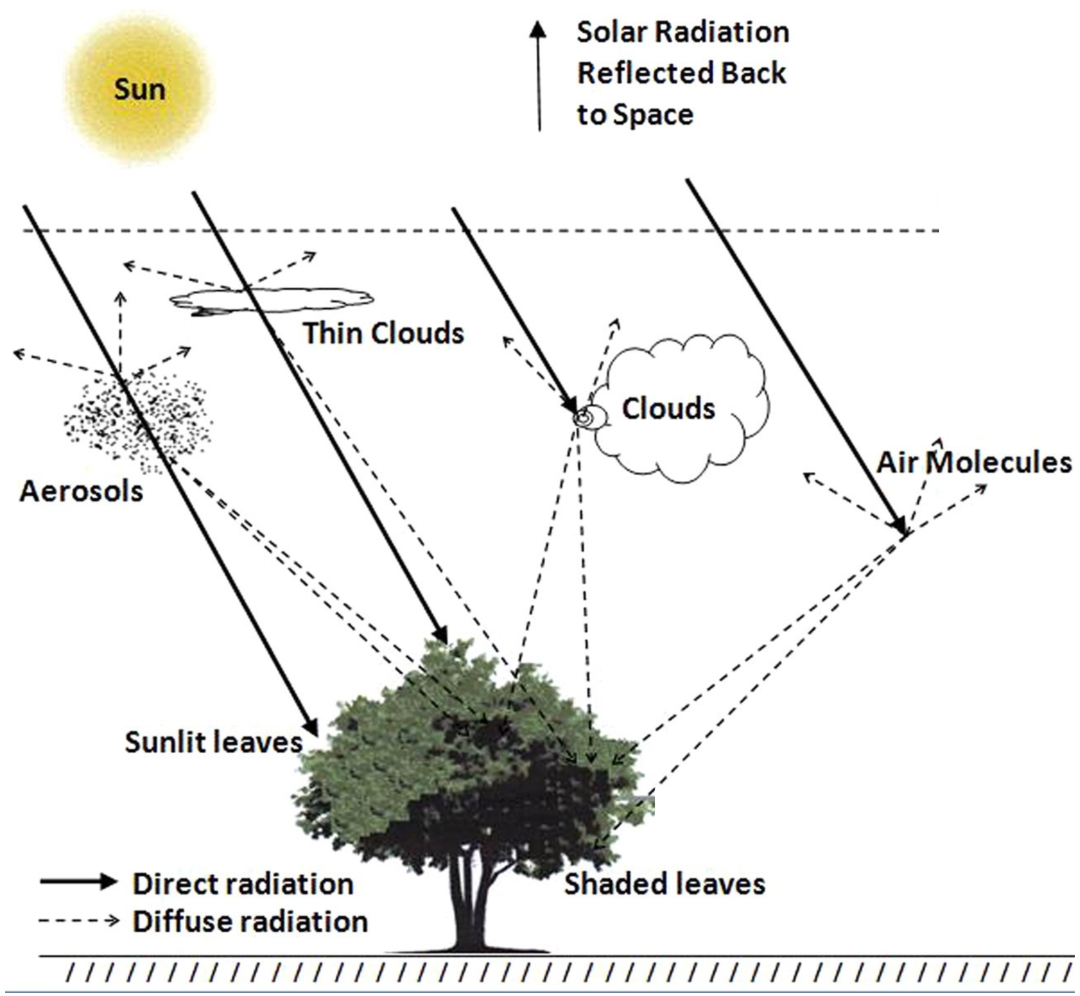
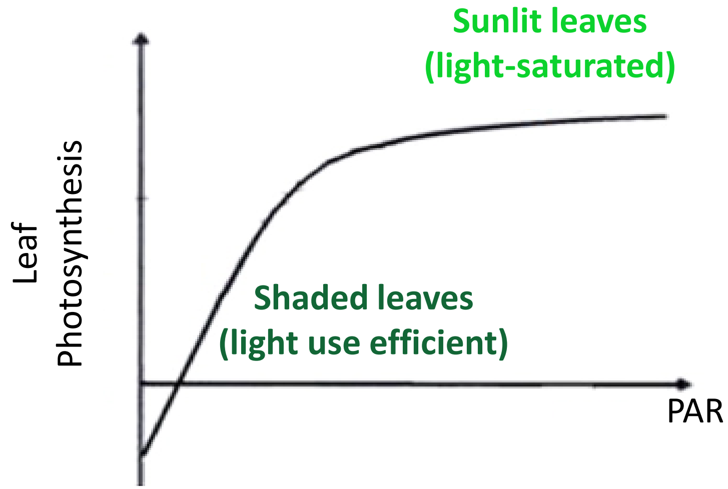


Adapted from Kanniah et al. 2012

Leaf photosynthesis rates increase non-linearly with PAR:



Under diffuse conditions canopies are illuminated more evenly so fewer leaves are light saturated, and photosynthesis tends to increase.

Net effect depends on a balance between the increase in the diffuse fraction and the reduction in total radiation .

Studies using JULES offline

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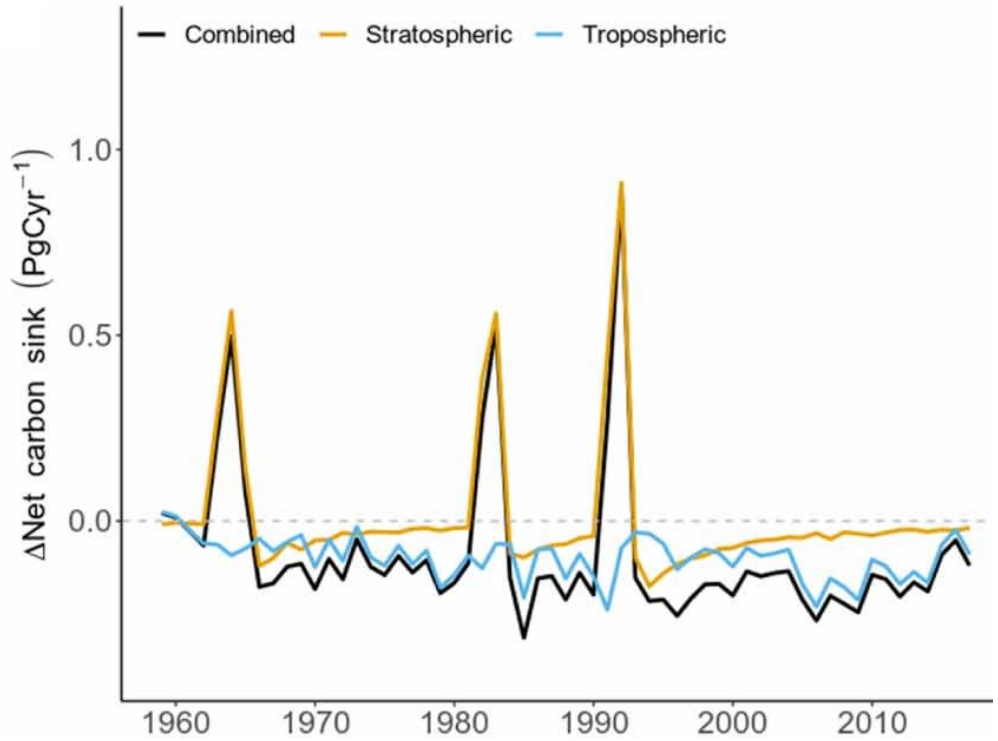

Adapted from O'Sullivan et al. (2021)

Studies using **JULES offline** have shown that variability in aerosols and the land carbon sink are closely linked.

- Increases in diffuse light have enhanced the global land carbon sink by 24% (1960-1999) *(Mercado et al., 2009).*
- Volcanic aerosols drive a large carbon response (up to 0.9 Pg C yr^{-1}), and including these effects can cut the carbon budget imbalance term by 55% in years after volcanic eruptions *(O'Sullivan et al., 2021).*

An online coupled framework is needed to account for potential climate feedback effects.

Climate feedbacks

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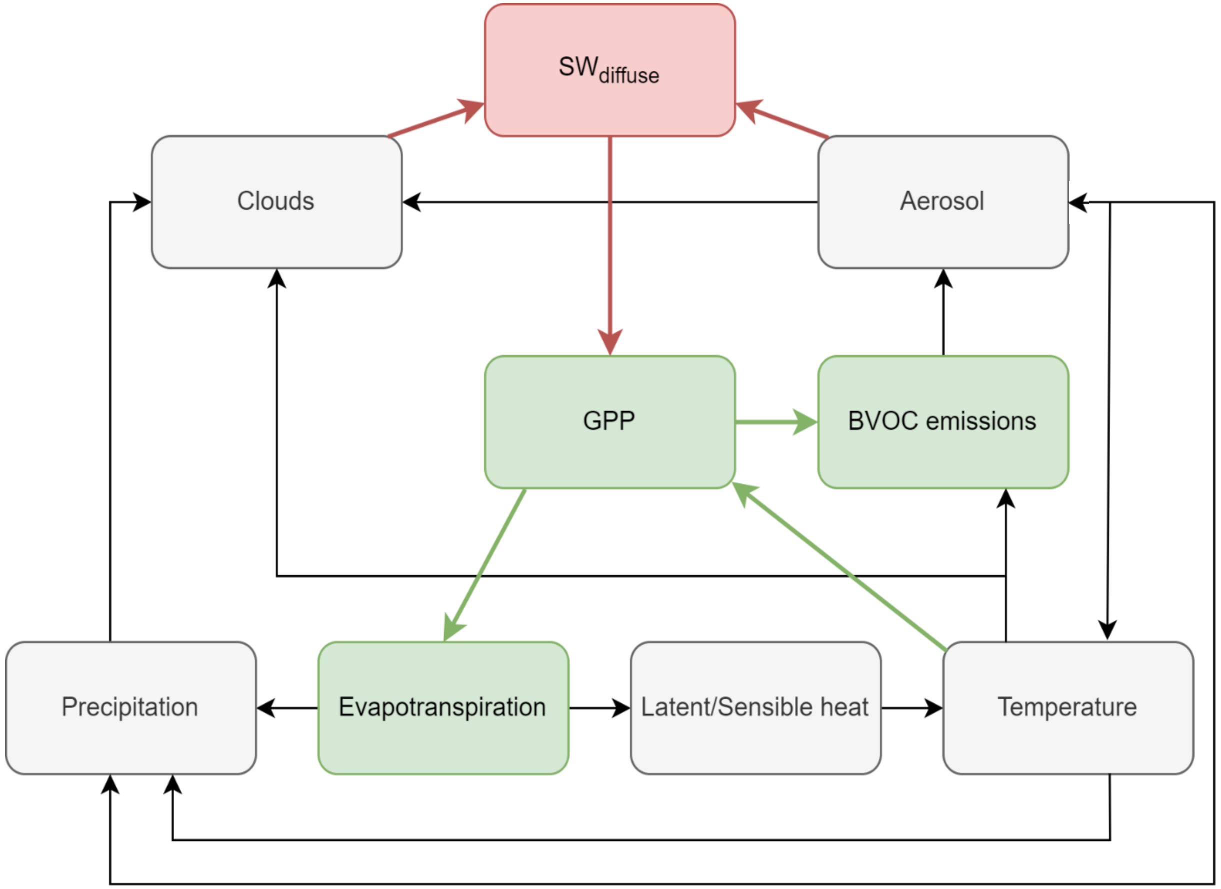
The initial GPP response to diffuse radiation can trigger a cascade of climate feedbacks between the land surface and atmosphere.

These can modulate the overall productivity response and affect the diffuse fraction.

Previous studies using coupled Earth system models to incorporate these climate feedbacks:

- Focused only on one aerosol type or specific regions.
- Disagree on the magnitude and sign of the productivity impacts.



Interactive Diffuse Radiation Coupling Scheme

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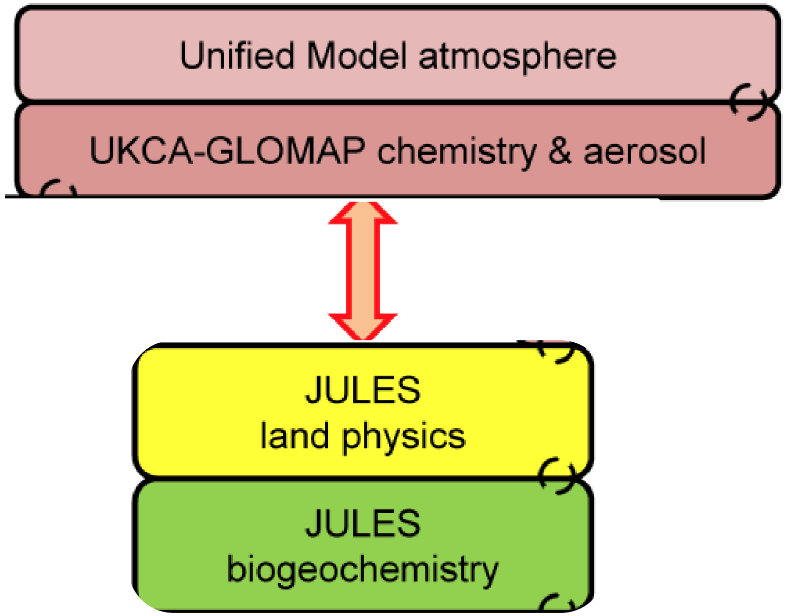
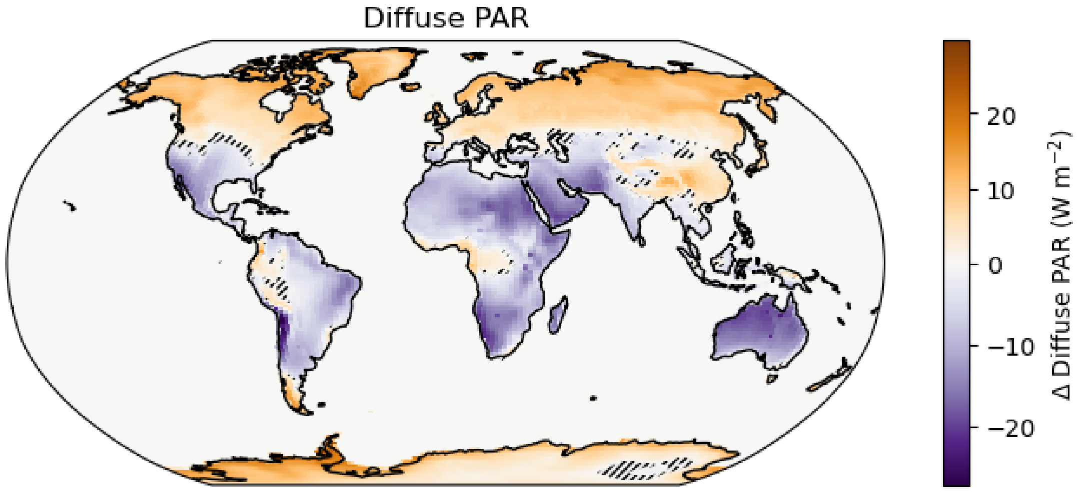
The default UKESM coupling passes a time and spatially constant **fixed diffuse fraction (0.4)** to JULES.



To better represent the effects of diffuse radiation we have implemented a new **interactive diffuse radiation coupling scheme**
(coupling code written by Spencer Liddicoat)

Aim: To quantify the impact of interactive diffuse radiation on simulated 1984-2008 global and regional terrestrial ecosystem productivity.

Diffuse PAR (int_diffuse – cntrl)



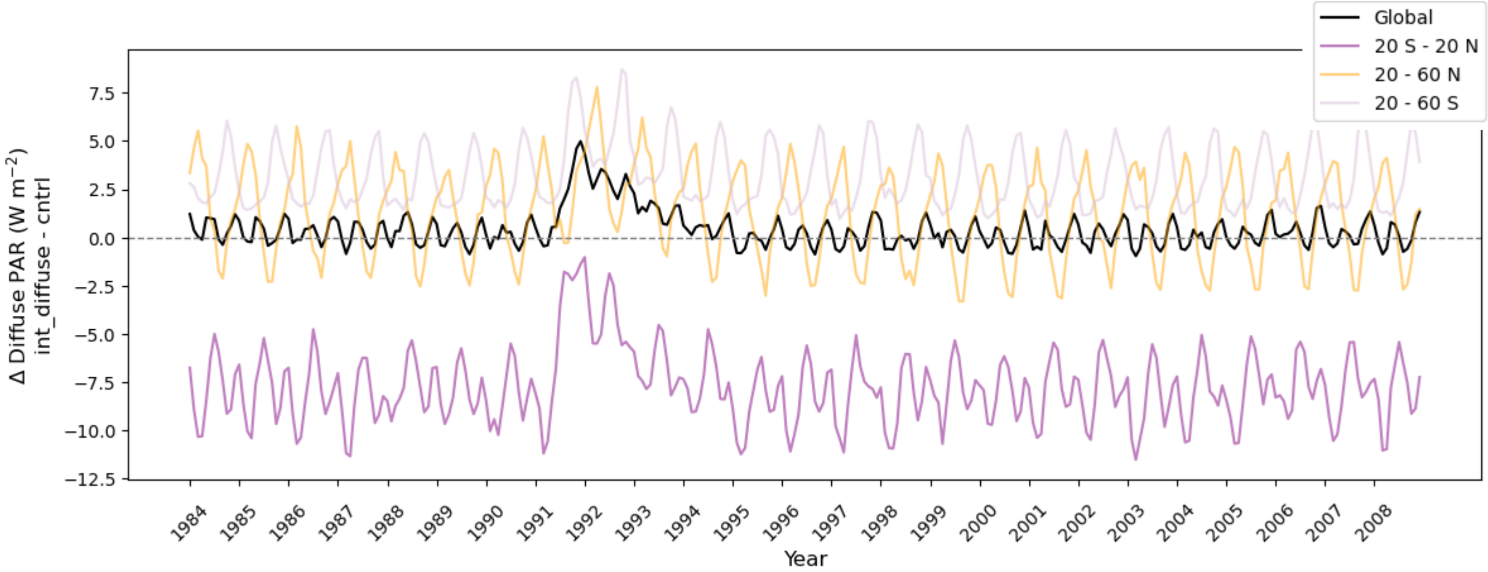
The control includes some diffuse effects (fixed fraction of 0.4) but there are clear latitudinal effects leading to an:

- Underestimation in the Northern Hemisphere.
- Overestimation in the tropics.

Regions with high cloud cover and/or AOD exhibit weaker or opposing changes to interactive diffuse radiation (i.e. Indonesia, central Africa, China).

Timeseries:

- Strong seasonal cycle and some interannual variability.
- Sharp increase following the Pinatubo eruption in 1991.



Impact on Gross Primary Productivity

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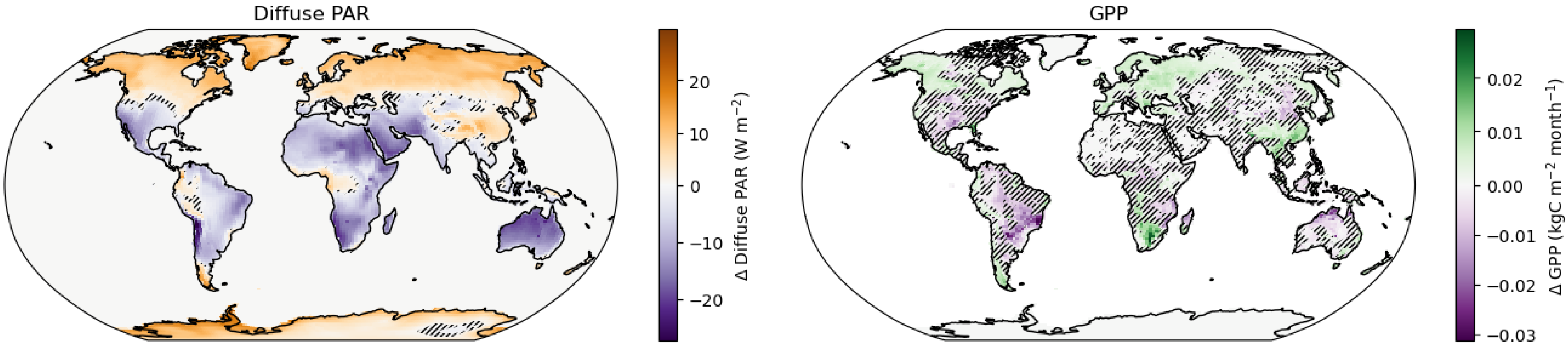

The sign of the GPP and diffuse PAR change agree in most regions where response is statistically significant:

- Increase in productivity over most of the northern hemisphere (boreal regions, **Europe** and China).
- Dipole response over North America.
- Reduction over most of the tropics (i.e. **South America**, Indonesia, Northern Australia).

An exception to this is **South Africa** where:

- GPP increases despite a reduction in diffuse PAR.
- Suggesting that climate feedbacks are a dominant driver of the overall productivity response.

Regional effects – South America

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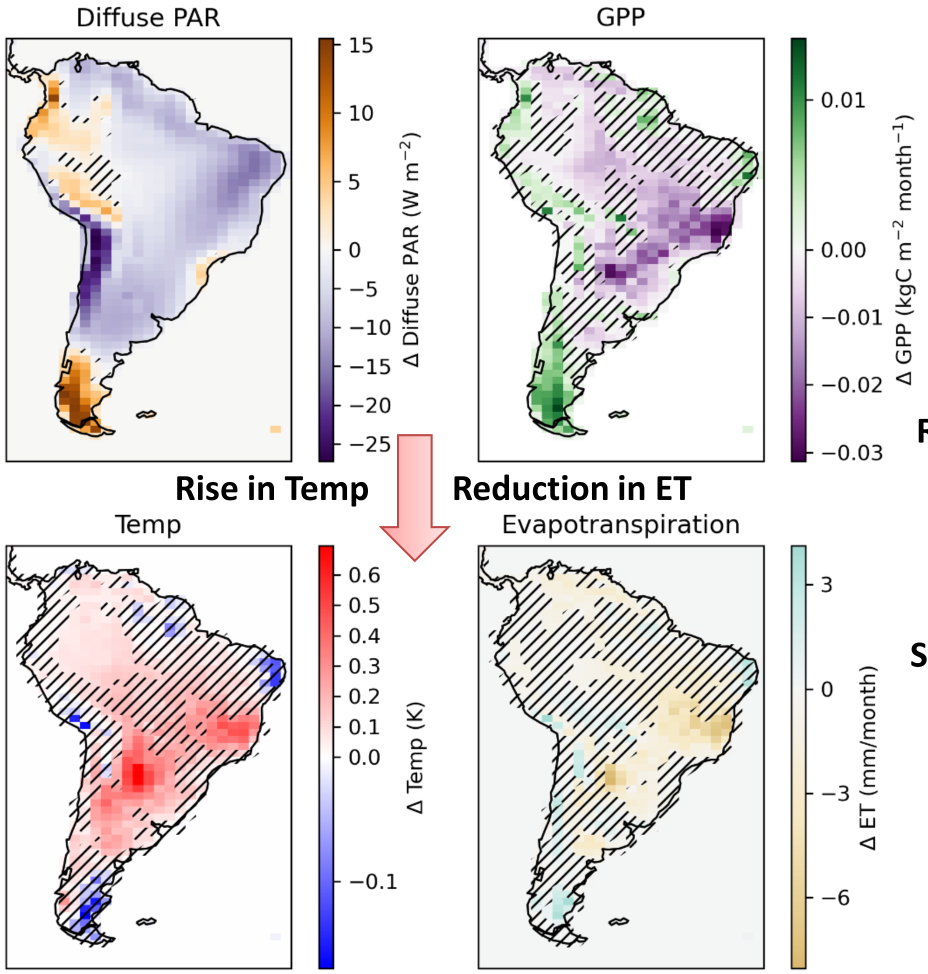
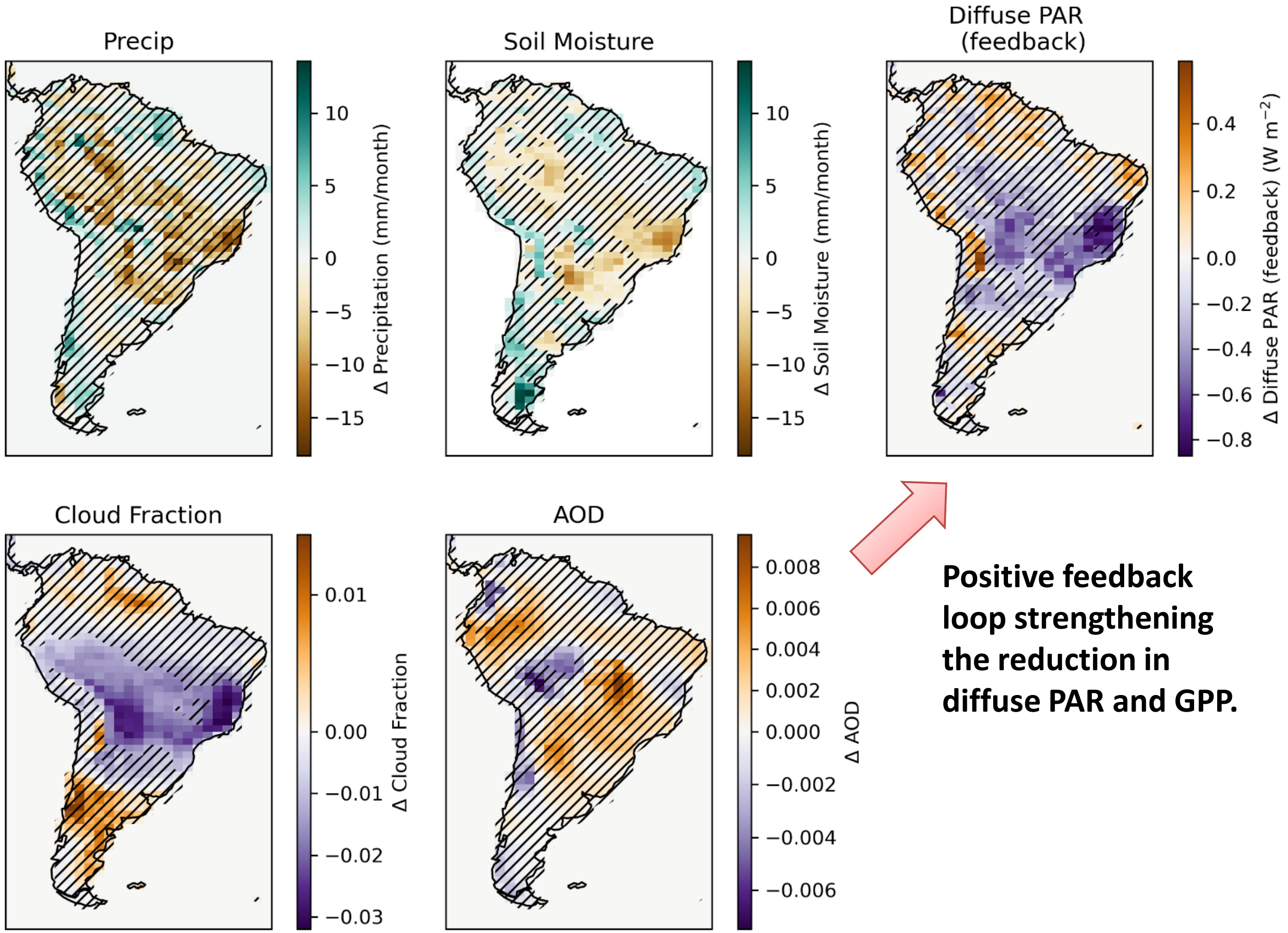


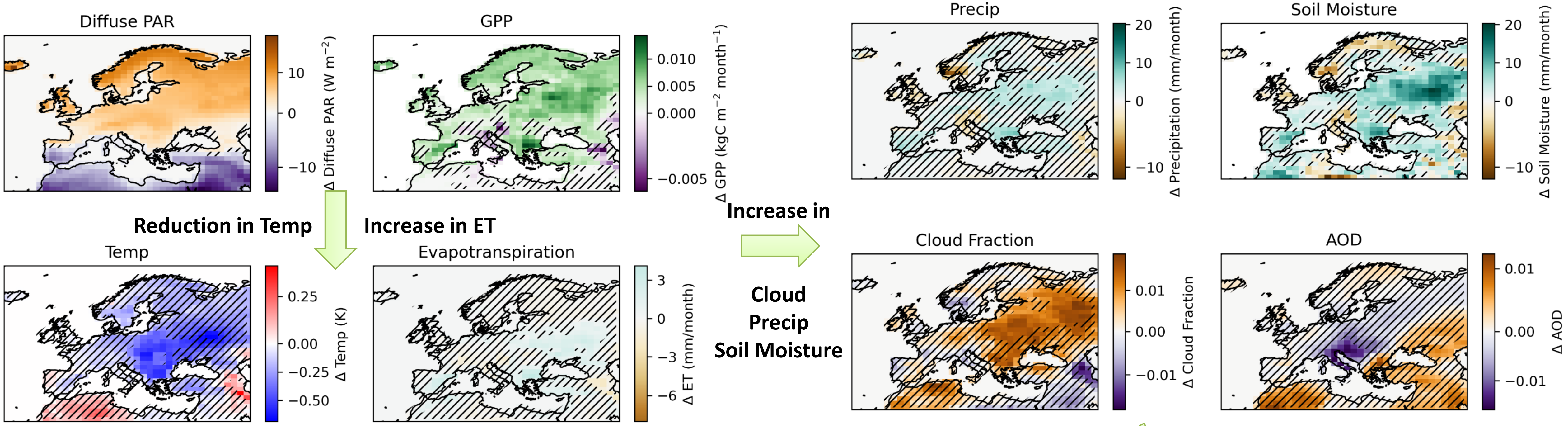
Reduction in

Cloud
Precip
Soil Moisture



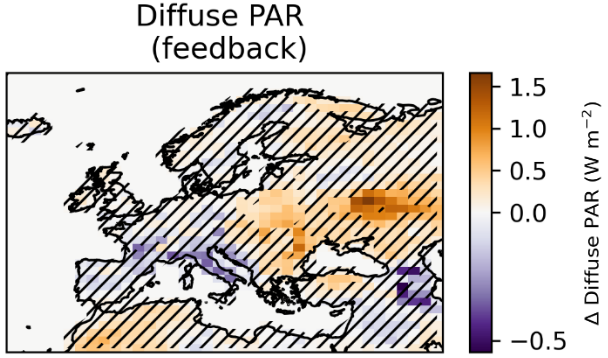
Positive feedback loop strengthening the reduction in diffuse PAR and GPP.

Regional effects – Europe



Boreal regions:

- Diffuse PAR increase correlates with a rise in GPP.



Central and Eastern Europe:

- Climate feedbacks result in a general cooling and wetting effect which enhances the GPP response.
- Cloud fraction increase also leads to a positive diffuse PAR feedback effect.

Regional effects – South Africa

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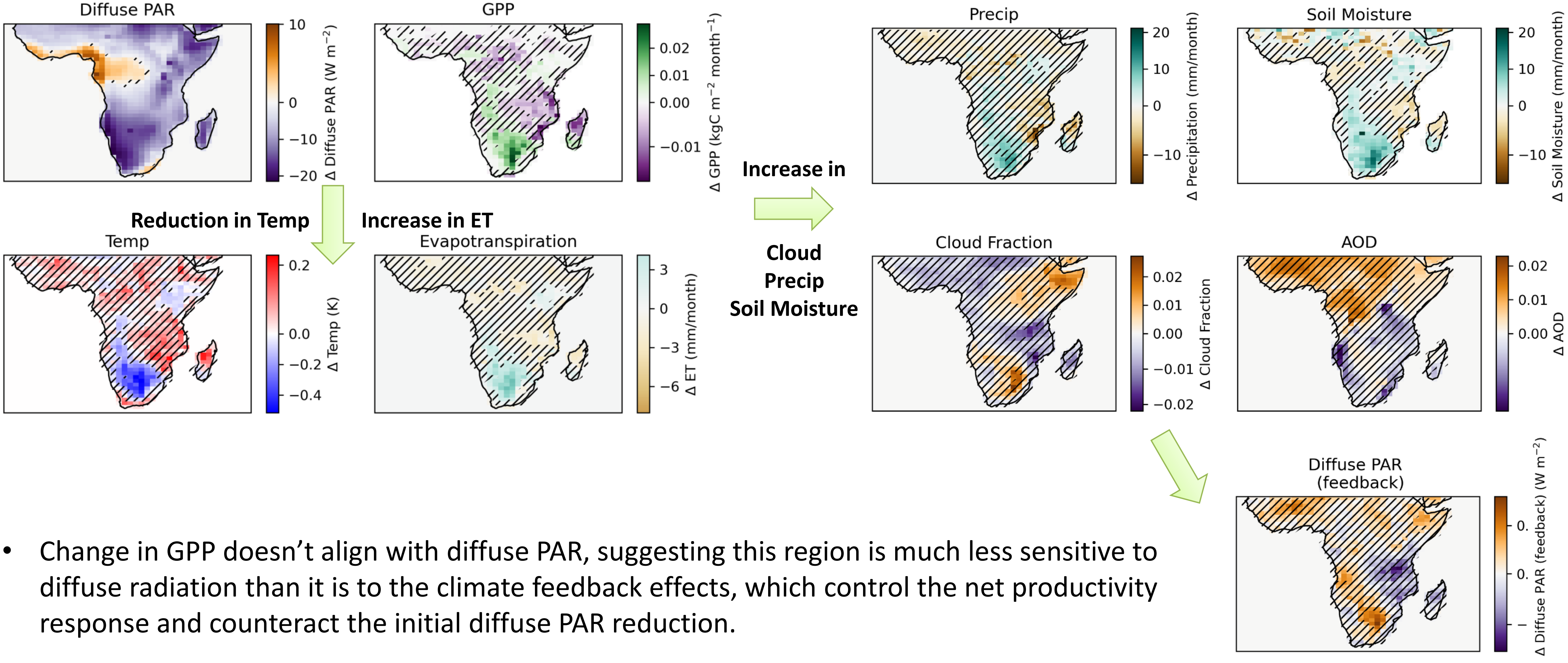

- Change in GPP doesn't align with diffuse PAR, suggesting this region is much less sensitive to diffuse radiation than it is to the climate feedback effects, which control the net productivity response and counteract the initial diffuse PAR reduction.

Global impacts

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Regional effects combine to give a global productivity response (1984-2008):

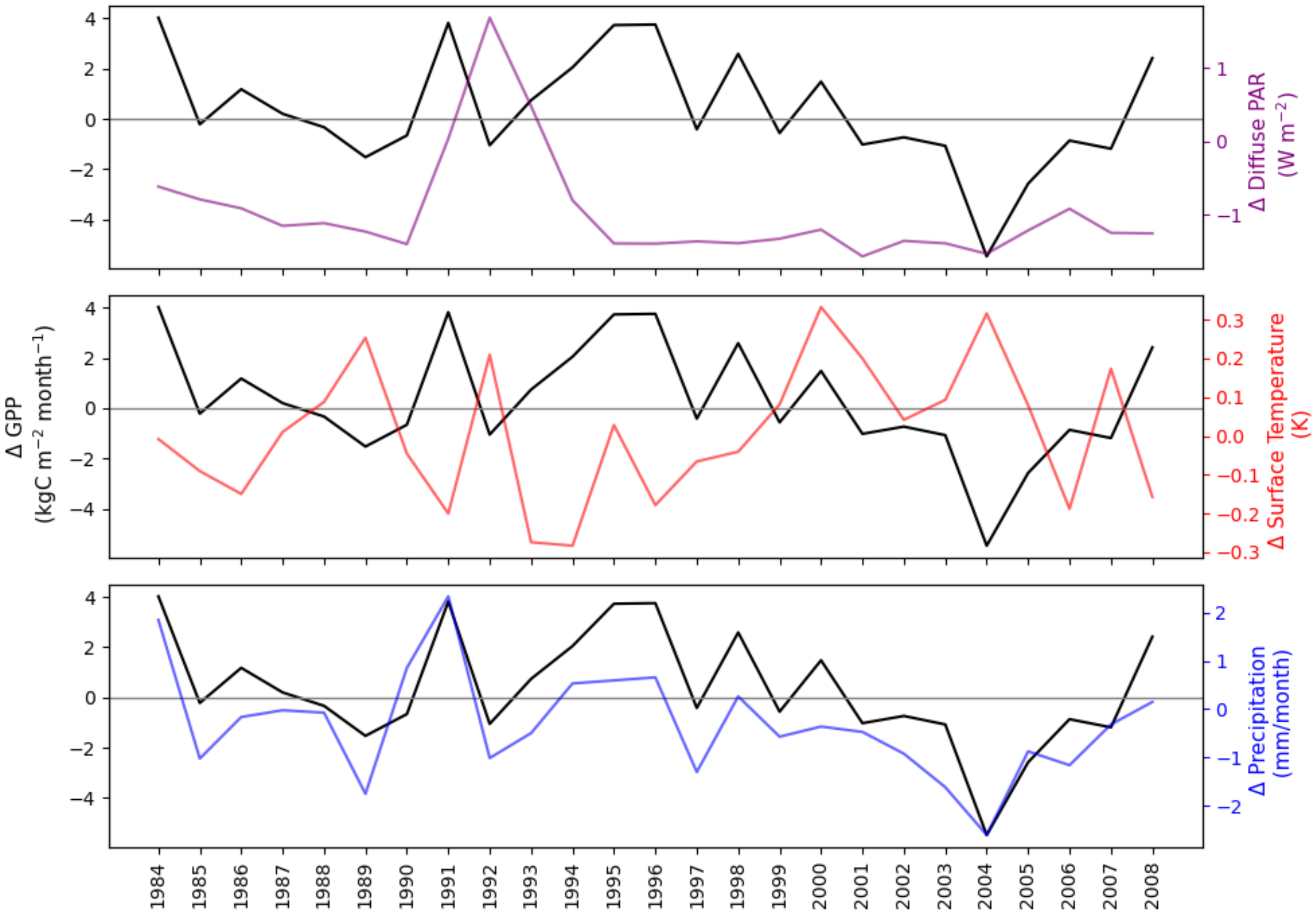
- GPP = + 8.3 PgC
- NPP = + 7.2 PgC

(~ 4% of fossil fuel emissions during this period)

Global mean land changes show:

- Stronger correlation of GPP with precipitation (r = 0.83) and temperature (r = -0.55).
- Weak correlation with diffuse PAR (r = 0.13).

Climate feedbacks (initiated by the initial GPP change from diffuse radiation) are shown to be dominant drivers of the global productivity response.



Future Work

- Explain varying regional sensitivities to diffuse radiation (e.g. PFT, climate zones and if photosynthesis tends to be limited by light, water, or temperature).
- Assess temporal trends in the productivity response (using fixed volcanic aerosol simulations), and how well changes align with the imbalance in the global carbon budget.
- Validate changes in variables affected by climate feedbacks (i.e. temperature and precipitation) against observations.
- Run offline JULES to isolate the coupled feedback response on productivity.
- Explore the impact of perturbing parameters in the JULES canopy radiative transfer scheme based on measurements taken at AmazonFACE.

Ecoregion sensitivity to diffuse PAR

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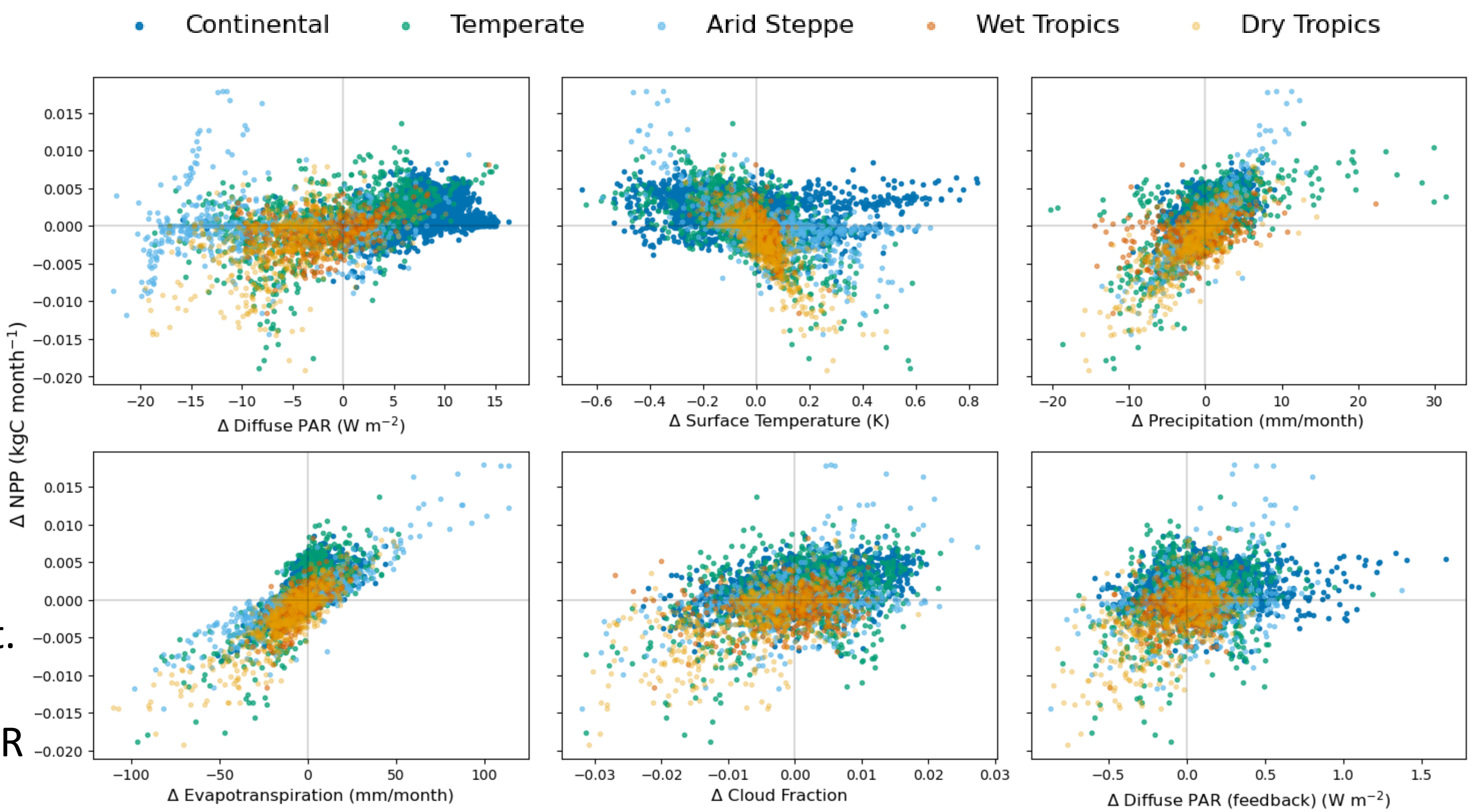
Monthly mean NPP change in each land grid cell, grouped into different Köppen-Geiger climate zones (kgcpy package):

- Diffuse PAR correlation is fairly weak.
- Temperature is a strong driver in the tropics.
- Precipitation dominates the regional (temperate and dry tropics) and global response.
- Low correlation with cloud fraction but this tends to drive the diffuse PAR feedback effect.

Currently looking at how sensitivity to diffuse PAR varies between PFT types and across regions where photosynthesis is typically light, temperature, or water limited.



Summary

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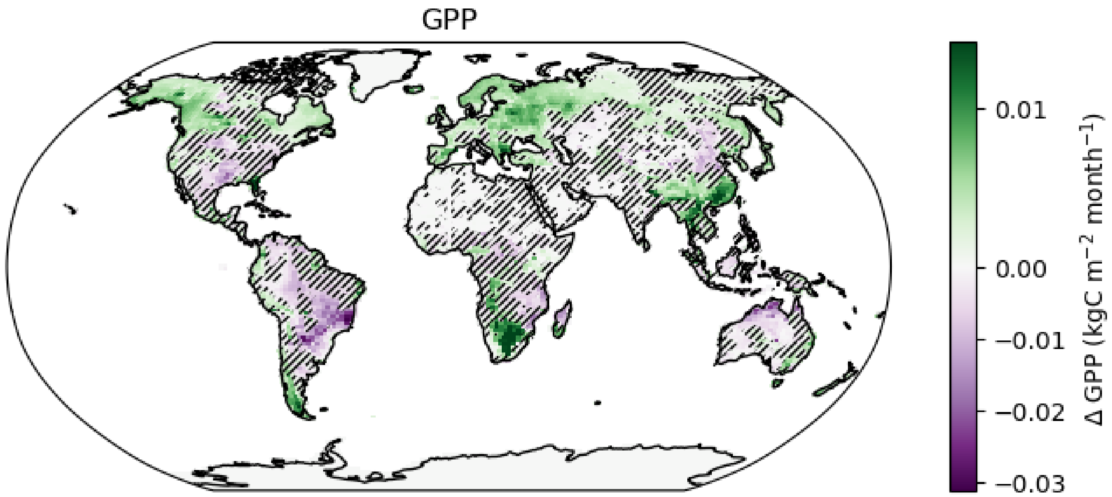
- In the standard UKESM configuration (fixed diffuse fraction of 0.4) diffuse PAR is underestimated in most of the northern hemisphere and overestimated in the tropics.

- In most regions the productivity response mirrors the sign of change in diffuse PAR, and climate feedbacks seem to enhance the change in GPP and diffuse radiation.



- Whereas in South Africa, diffuse PAR and GPP show opposing changes showing that this region is more sensitive to the climate feedback effects than to the initial diffuse radiation change.

- Globally there is an enhancement of GPP (+ 8.3 PgC) and NPP (+7.2 PgC) between 1984-2008, and this is also strongly influenced by precipitation and temperature effects.

References

Kanniah, K.D. et al. 2012. Control of atmospheric particles on diffue radiation and terrestrial plant productivity: A review. *Prog. Phys. Geogr.* **36** 209-37

Mercado, L.M. et al. 2009. Impact of changes in diffuse radiation on the global land carbon sink. *Nature*. **458** 1014-1017.

O’Sullivan, M. et al. 2021. Aerosol-light interactions reduce the carbon budget imbalance. *Env. Res. Lett.* **16** 124072

Global Carbon Budget Imbalance / Pinatubo

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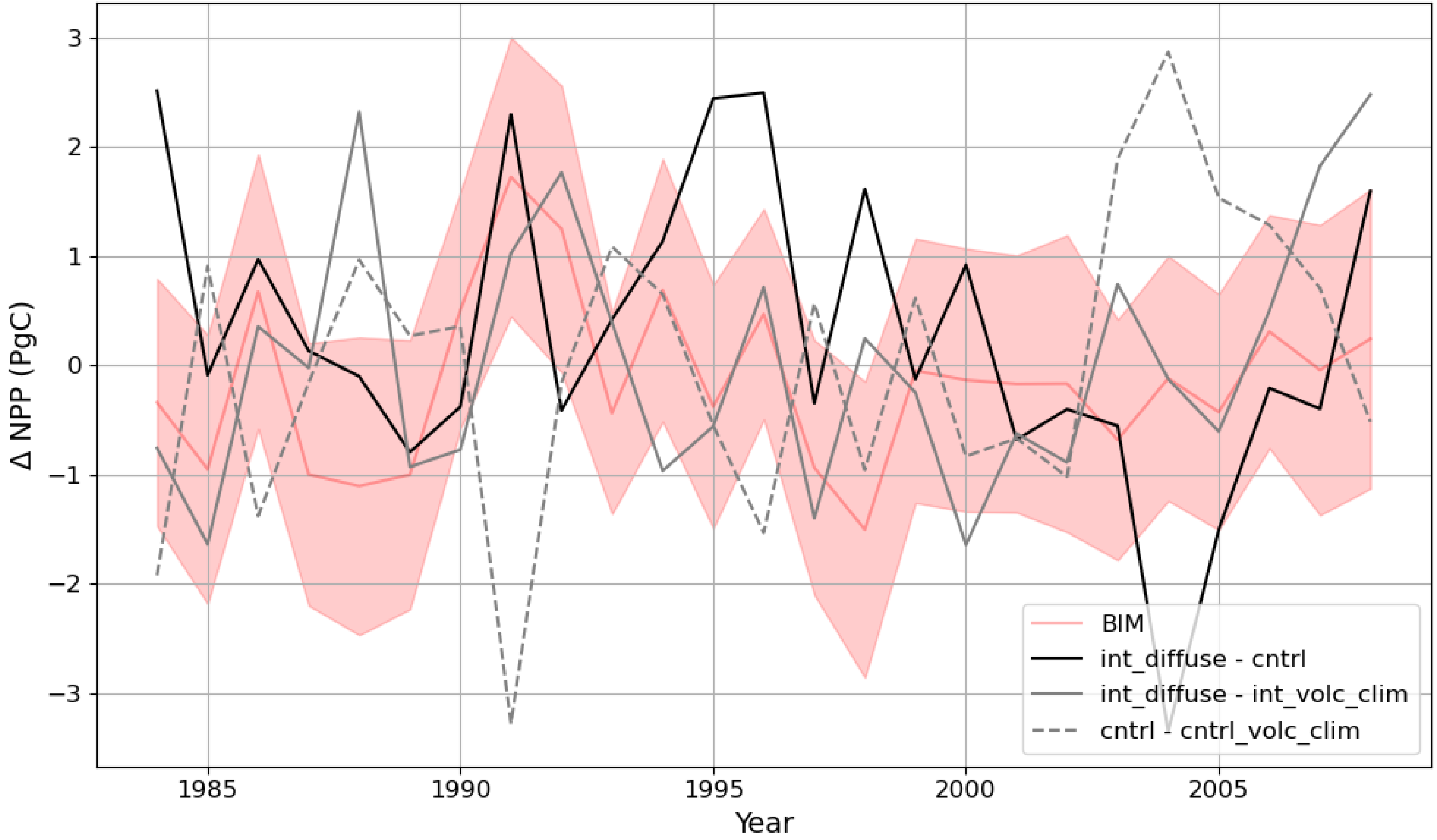
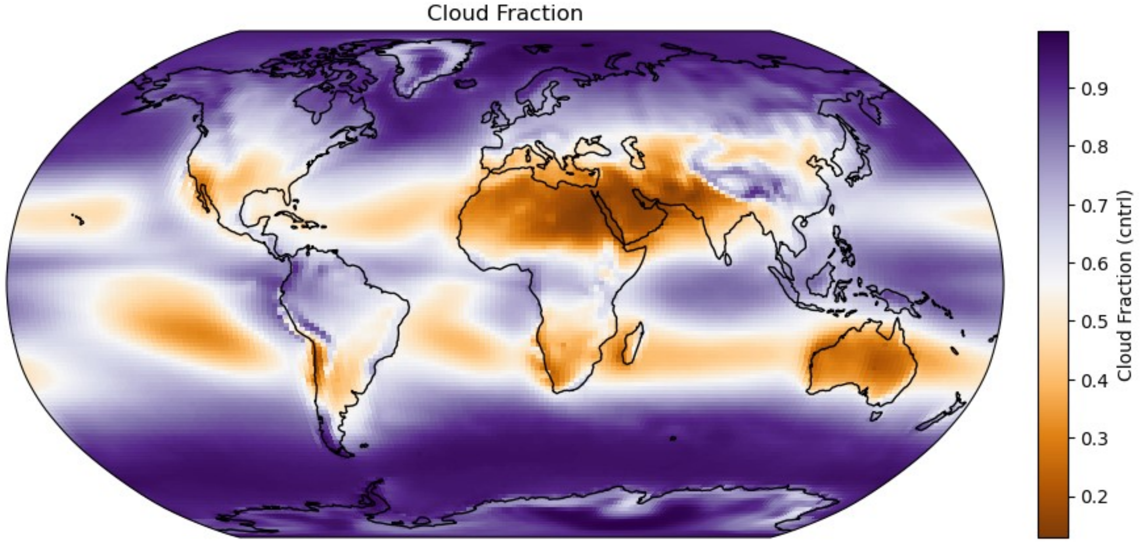
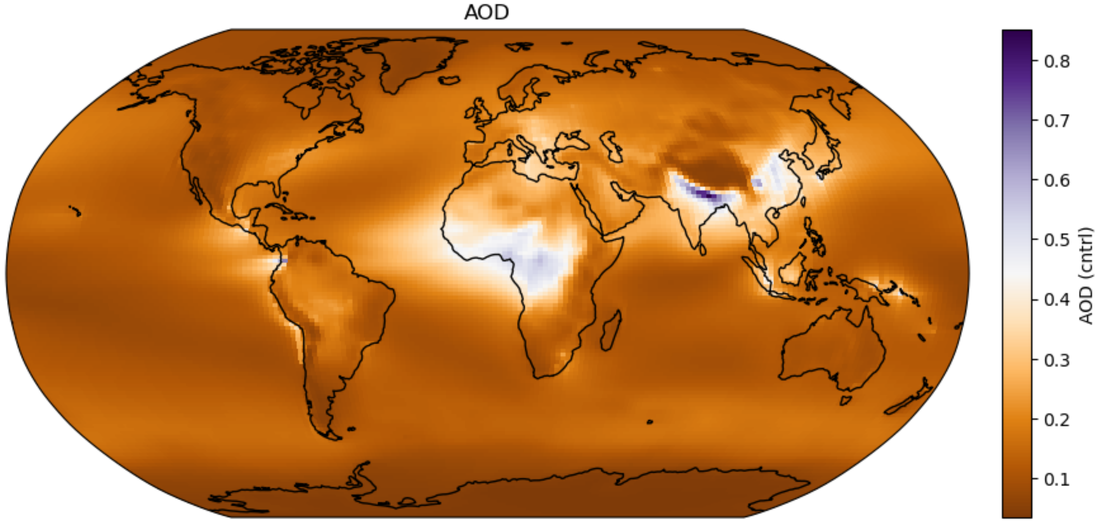


Supplementary – Cloud fraction and AOD (cntrl)





Supplementary: Correlation matrix

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