Journal Club
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machine learning in climate science

Markus Deppner

Compensatory climate effects link trends in global runoff to rising atmospheric CO_2 concentration

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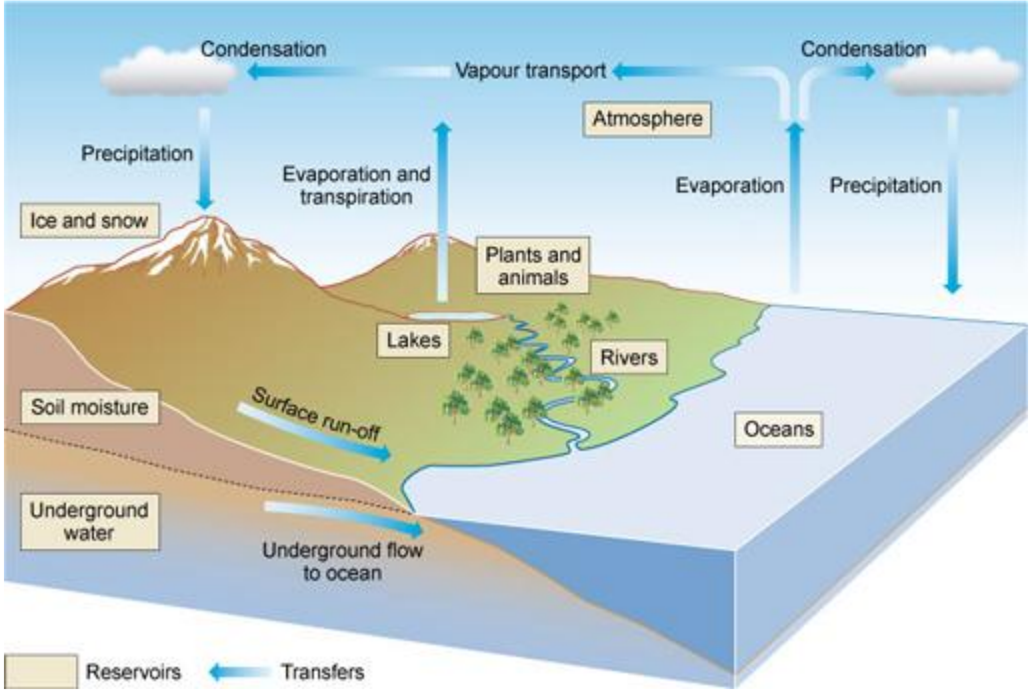
The hydrological cycle



https://www.open.edu/openlearncreate/mod/oucontent/view.php?id=79936&section=3

Data

- Discharge measurements from farthest downstream stations for 42 large scale basins from
  - Global River Discharge Center
  - China Statistical Yearbook
  - River Discharge Archive

  on a (1.25° lat x 1.875 lon resolution)
- Historic land surface conditions (1901 - 1999) from observational-based meteorological forcing dataset CRU-NCEP v4
- Annual atmospheric CO_2 concentration data from Keeling and Whorf
- LUC data from HYDE dataset
- Nitrogen composition from ACCMIP

JULES-C and JULES-CN model

Table 1. Initial factorial simulations with JULES-C and JULES-CN. Driving factors include rising CO_2, climate change, land use/land cover change, carbon–nitrogen interaction and nitrogen deposition. Factors changing over the transient period have the '√' symbol and factors that are fixed at the pre-industrial levels have no symbol.

Model	Simulation	CO_2	CLIM	LUC	CN&NDE
JULES-C	C_{ctrl}				
	C_{CO2}	√			
	$C_{CO2+CLIM}$	√	√		
	$C_{CO2+CLIM+LUC}$	√	√	√	
JULES-CN	$CN_{ctrl+CN\&NDE}$				√
	$CN_{CO2+CN\&NDE}$	√			√
	$CN_{CO2+CLIM+CN\&NDE}$	√	√		√
	$CN_{CO2+CLIM+LUC+CN\&NDE}$	√	√	√	√

Table 2. Second factorial simulations, including atmospheric aerosols and tropospheric O_3 concentration effects. The symbol '√' means factors are changing over the transient period, while factors that are fixed at the pre-industrial levels and conditions have no symbol. Simulation $CN_{CO2+CLIM+LUC+CN\&NDE}$ is identical between the tables 1 and 2.

Simulation	CO2	CLIM	LUC	CN&NDE	AER	O3
$CN_{CO2+CLIM+LUC+CN\&NDE}$						
$CN_{CO2+CLIM+LUC+CN\&NDE+AER}$			√		√	
$CN_{CO2+CLIM+LUC+CN\&NDE+O3}$						√

The driving factors

CLIM	CO_2
• Precipitation (amount and intensity) • Temperature • Wind speed • Radiation Factors of direct and indirect influence on runoff. • Indirect through evapotranspiration. • Impact of climate change on vegetation growth, plant respiration, phenology	Increase in CO_2 affects runoff in two compensatory ways: • Enhanced vegetation growth - Increase in leaf area index (LAI) - Extended growing season - Increases evapotranspiration - Decline in runoff • Reduction in stomatal conductance - Increase in water use efficiency - Reducing evapotranspiration - Increase in runoff

The driving factors

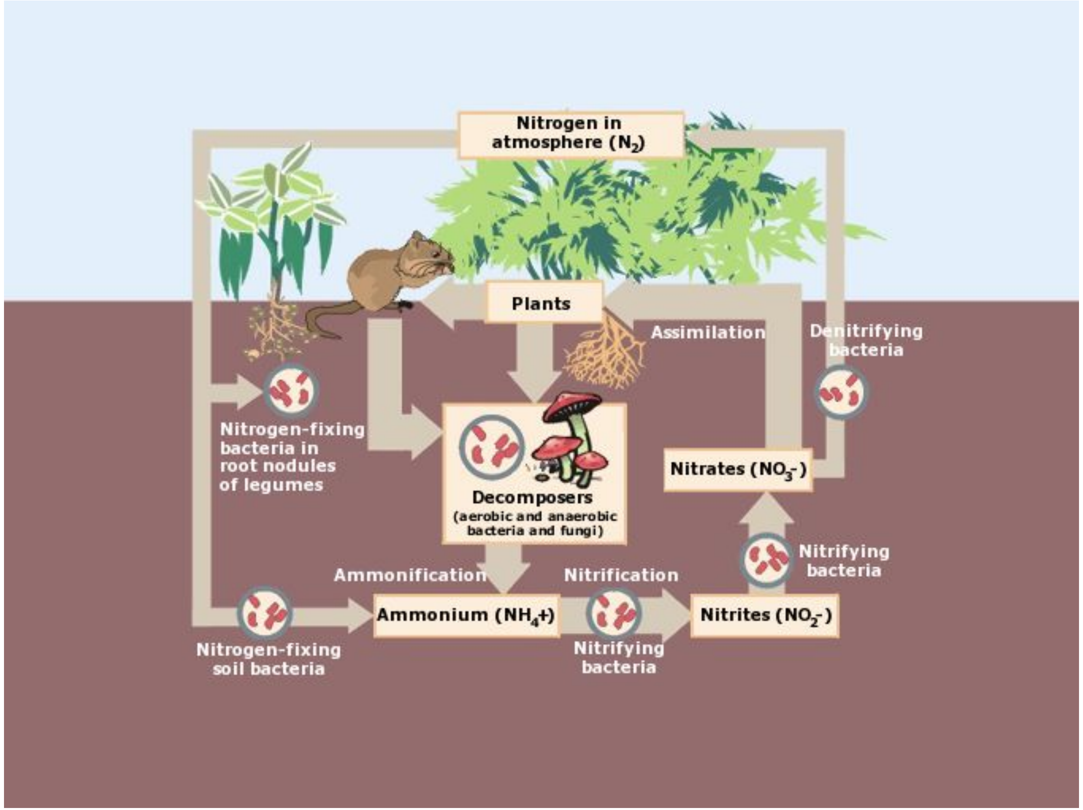
<table>
<tr><th>CN & NDE</th><th>LUC</th></tr>
<tr><td>Carbon Nitrogen interactions & Nitrogen Deposition

• Limitation in CO_2 - fertilization due to terrestrial nitrogen availability.
• Atmospheric nitrogen could enhance plant growth in nitrogen-limited systems
• Enhances evapotranspiration
• Decreases runoff</td><td>Land Use Change

• Alters in canopy interception
• Soil infiltration
• Evapotranspiration
• Land surface albedo (reflection)

Can influence runoff in either way</td></tr>
</table>

The nitrogen cycle

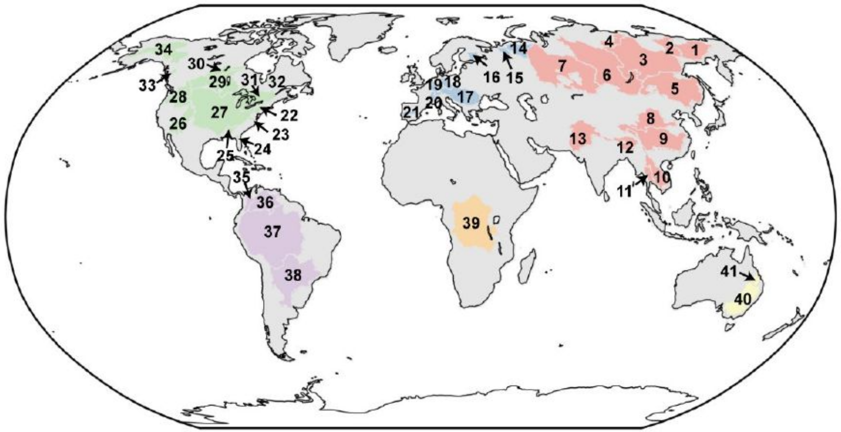


https://earthhow.com/nitrogen-cycle/

The driving factors

AER	O_3
Atmospheric Aerosols • Can enhance photosynthesis via increased diffuse radiation conditions - Alternating water balance of ecosystems and therefore evapotranspiration - Might results in change of runoff	Tropospheric Ozone • Affects plant stomata • Reduces photosynthesis rates • Reduction in transpiration rates • Enhancing runoff

Large scale basins



Asia (13)

1 Kolyma
2 Indigirka
3 Lena
4 Olenek
5 Amur
6 Yenisey
7 Ob
8 Yellow
9 Yangtze
10 Mekong
11 Chao Phraya
12 Brahmaputra
13 Indus

Europe (8)

14 Pechora
15 Mezen
16 Vuoki
17 Danube
18 Elbe
19 Rhine
20 Rhone
21 Tejo

North America (13)

22 Susquehanna
23 James
24 Suwannee
25 Alabama
26 Colorado
27 Mississippi
28 Columbia
29 Nelson
30 Churchill
31 St Lawrence
32 Eastmain
33 Nass
34 Yukon

South America (4)

35 Magdalena
36 Orinoco
37 Amazon
38 Parana

Africa (1)

39 Congo

Australia (2)

41 Fitzroy
42 Murray

Performance of the Jules-CN model

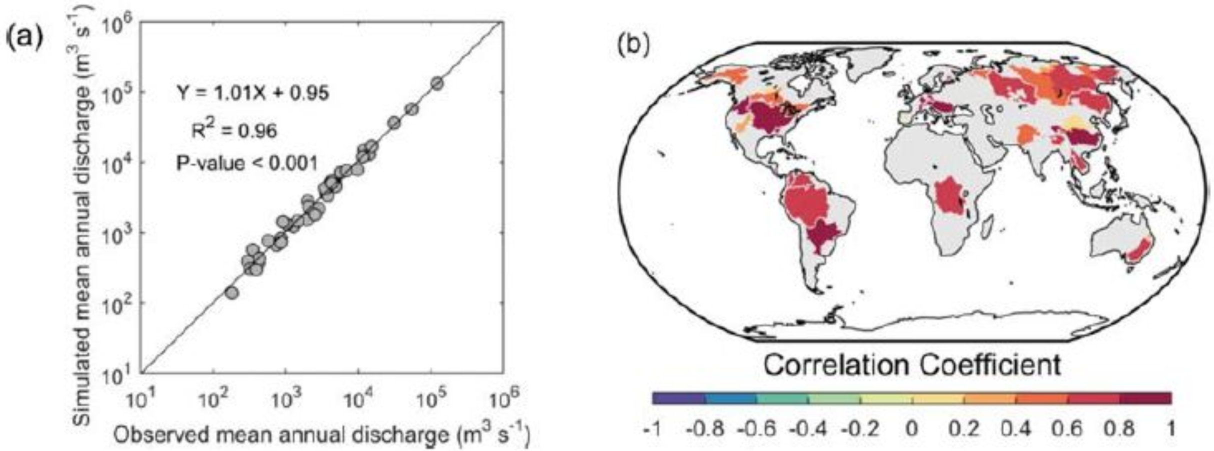
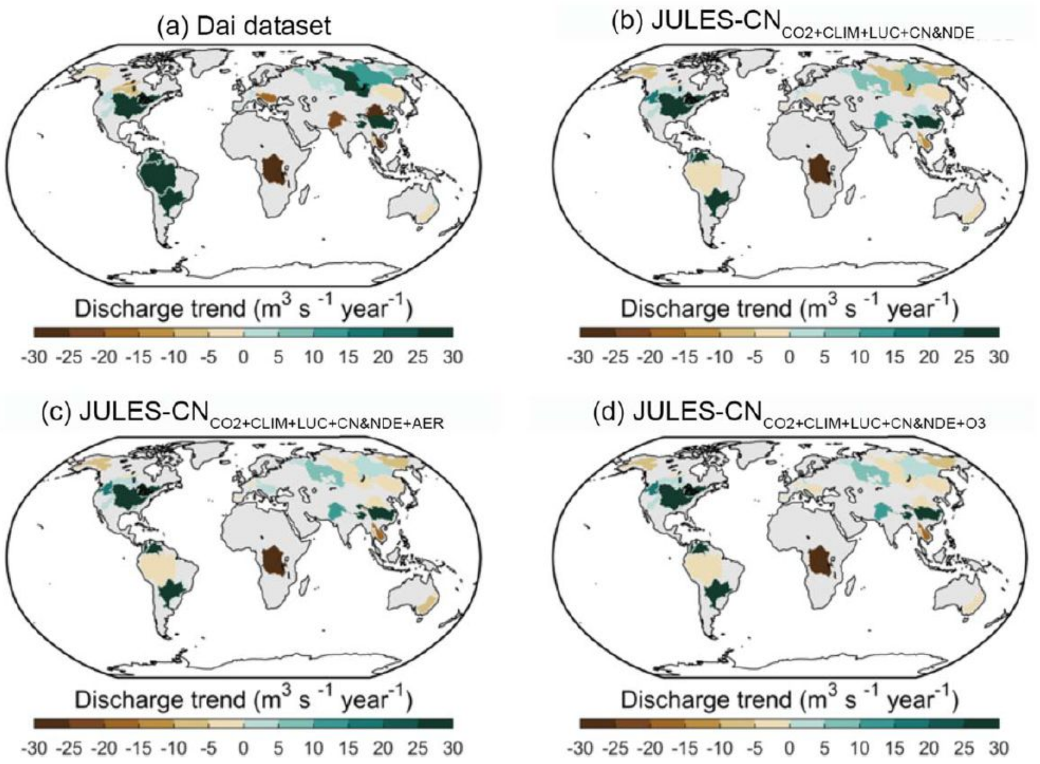


Figure 1. Assessment of model performance. (a) Comparison of mean annual river discharge measured at gauging stations versus that simulated by the JULES-CN model with all forcings ($CN_{CO2+CLIM+LUC+CN\&NDE+AER}$ simulation + O3 effects). (b) A map of Pearson correlation coefficients of modelled annual river discharge (again, from $CN_{CO2+CLIM+LUC+CN\&NDE+AER}$ simulation + O3 effects) with the measured river discharge time series.

Factor contribution to global runoff trends

- Good performance on most basins like Congo, Mississippi and Yangtze
- Improvable model performance in Eurasian Arctic rivers, Amazon and Pakistan
- AER and O3 as relatively small drivers of global runoff



Factor contribution to global runoff trends

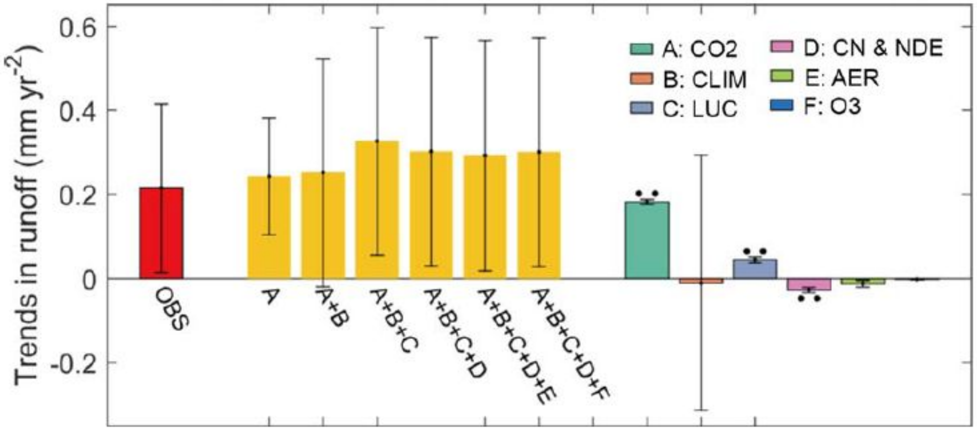


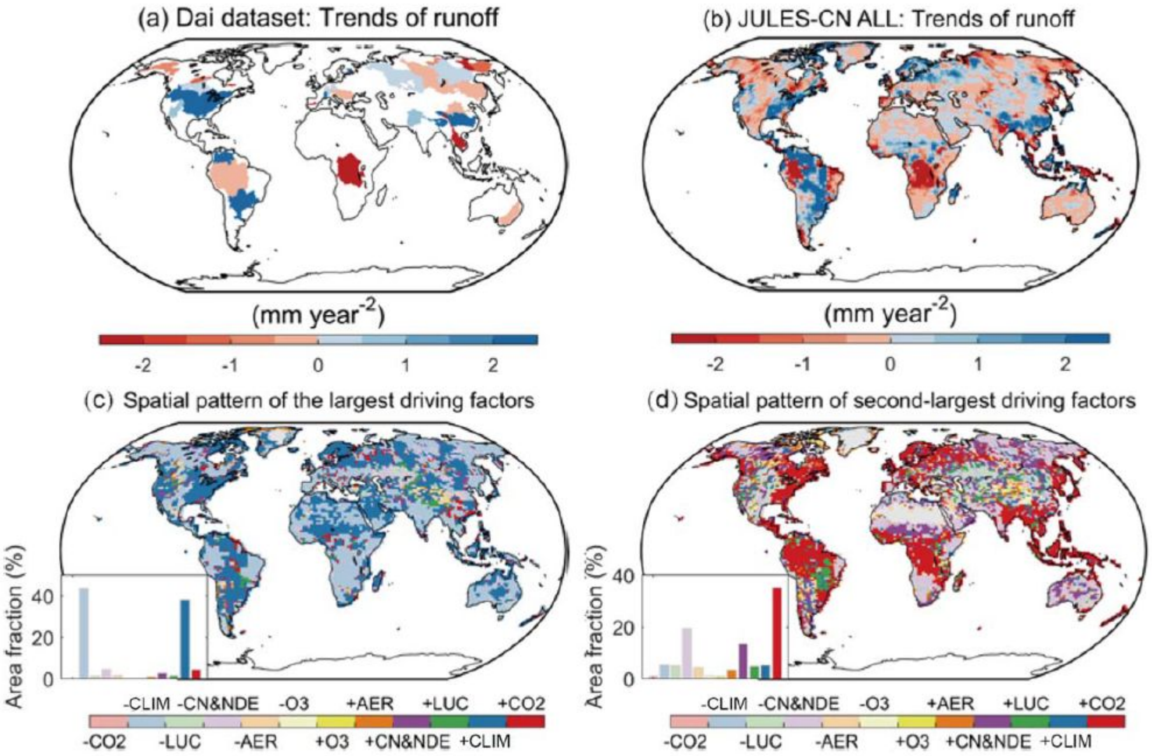
Figure 3. Global averages of observed (red) and modelled runoff linear trends (yellow, represents the factorial simulations) for the period of 1960–1999. Global averages are calculated from the river basins used in the study only. Modelled runoff changes due to the single effects of elevated CO_2 concentration (A: CO_2), climate change (B: CLIM), land use change (C: LUC), carbon–nitrogen interactions and nitrogen deposition (D: CN&NDE), aerosol radiative effects (E: AER) and tropospheric ozone changes (F: O3). Error bars show one standard error of the regression coefficients. Two dots indicate that the trend is statistically significant ($P < 0.10$).

Drivers of global river runoff trends

- For over 82% of land cover CLIM is the largest driving factor
  - 38% positive impact
  - 44% negative impact

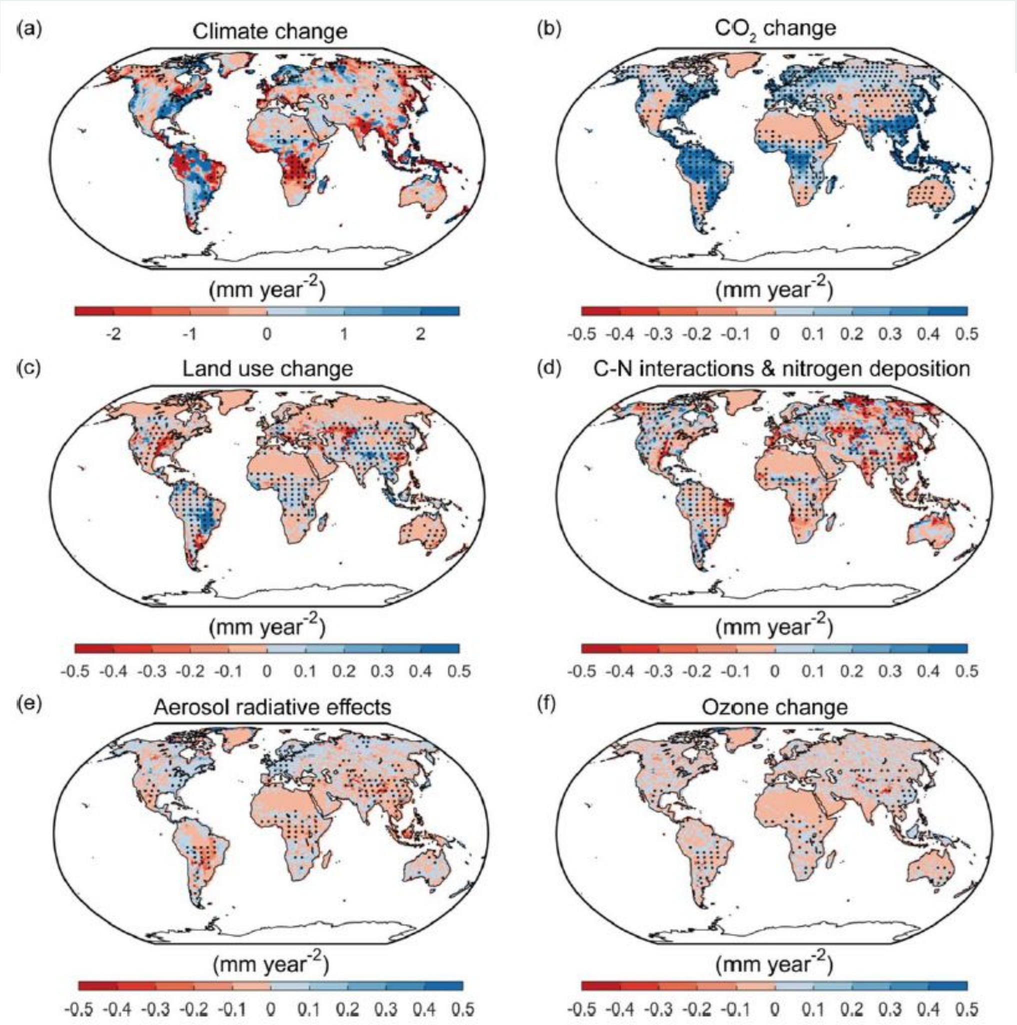
- CO_2 as the second-largest driving factor, followed by LUC

- CN&NDE as second largest driver in nitrogen limited regions: Australia and boreal regions in high latitudes.



Contribution of factors of global runoff trends

- CO_2 as the most important driver of global runoff trend
- LUC and CN&NDE as the second most important drivers for runoff trends.



Increased CO2 and its effect

CO_2 fertilization effect	Direct physiological effect

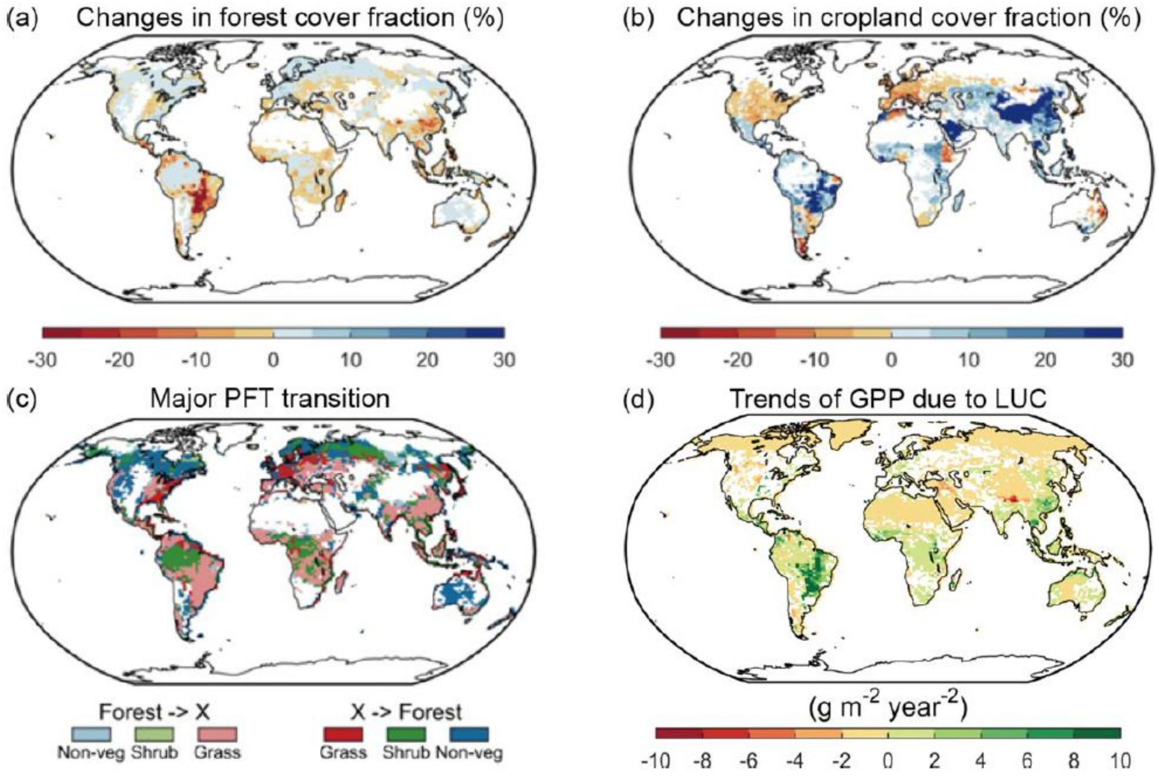
• Changes in vegetation structure
• Stimulates photosynthesis
• Rise of biomass
    ○ Increase of transpiration by increased stomata and LAI
    ○ Increase in canopy interception loss
    ○ Soil evaporation decreases.
• Reduction of local runoff
	• Stomatal closure
	• Transpiration decrease
	• Increase in local runoff

Runoff in drylands has decreased, but in wet regions it has increased.

Changes in forest and cropland cover fractions

- In the Amazonian region:
  JULES-CN model suggest that when forest is replaced by cropland ET decreases.
    - results in runoff increases

- Replacement of croplands in Southeast China leads to an increase in ET
    - results in decrease of runoff



The hydrological cycle

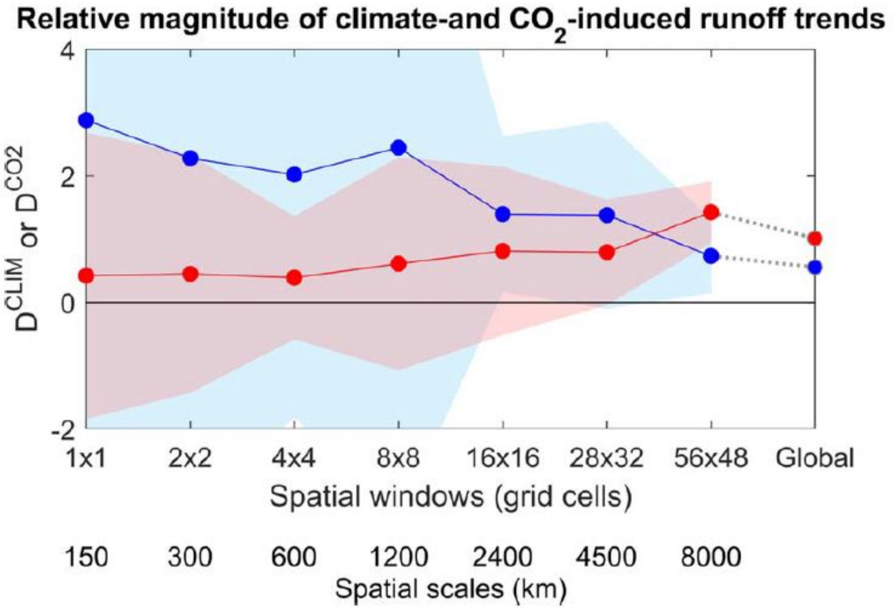


Figure 7. The relative magnitude of climate-induced and CO_2-induced runoff trends (i.e. D^{CLIM} and D^{CO2}) over different spatial scales of interest. This relative magnitude is calculated for spatial windows of $1 \times 1, 2 \times 2, 4 \times 4, 8 \times 8, 16 \times 16, 28 \times 32, 56 \times 48$ grid cells, and for all the grid cells over the globe. The longitudinal distance at 45°N is also marked along the x-axis for quantifying the magnitude of the spatial scales. Uncertainty bounds (given as shaded areas) refer to ± 1 standard deviations.

Comparison of JULES-C and JULES-CN model

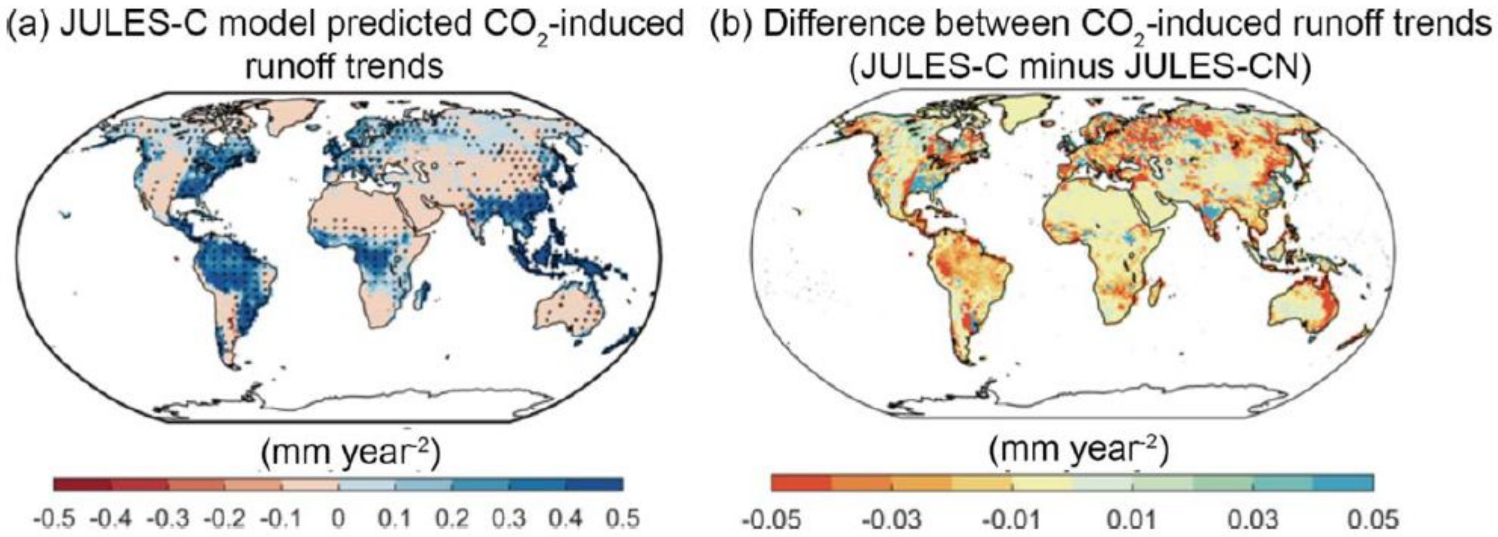


Figure 8. The influence of elevated CO_2 concentration on runoff and N-cycle interactions from the JULES model. (a) Global patterns of modelled runoff trends due to elevated atmospheric CO_2 concentration derived from JULES-C model. Black dots denote where the trends are statistically significant at the 10% level. (b) Global patterns of differences in CO_2-induced runoff trends between JULES-C model (without carbon–nitrogen interactions; figure 8(a)) and JULES-CN model (with carbon–nitrogen interactions; figure 5(b)).

Take home message

- Including the nitrogen cycle in models of runoff trend prediction leads to better results
- CO_2 as the most important driving factor on a large (global) scale
- Climate as the most important driving factor on a local scale
  (climate mostly impacts in precipitation)
- Modelling the terrestrial nitrogen cycle in general suppresses runoff decreases induced by the CO_2 fertilization effect