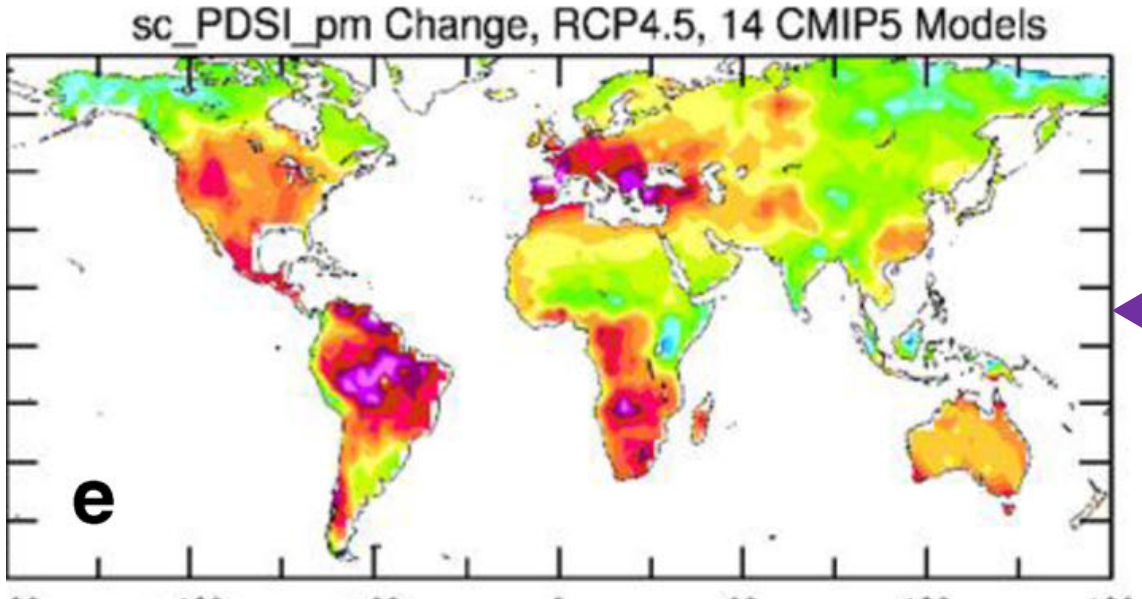
Under what conditions do the global warming responses of dryness indices and land-surface models agree?



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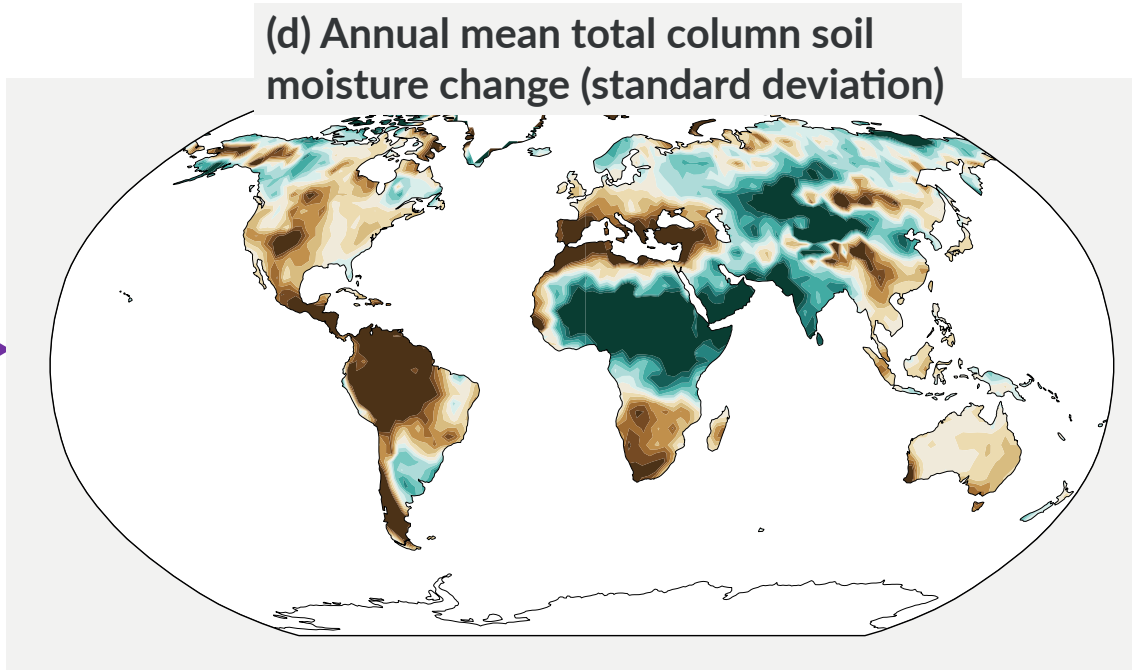
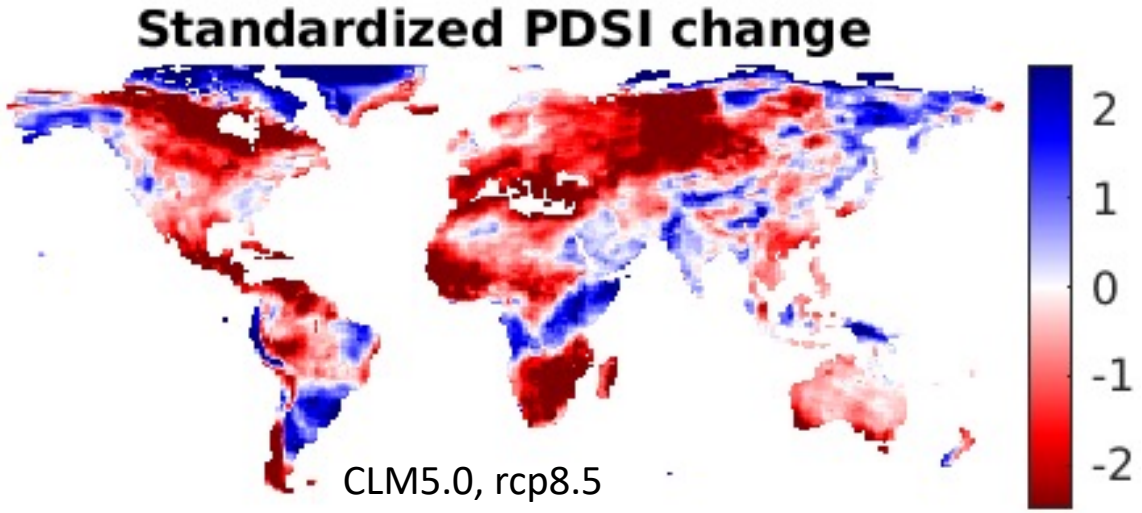


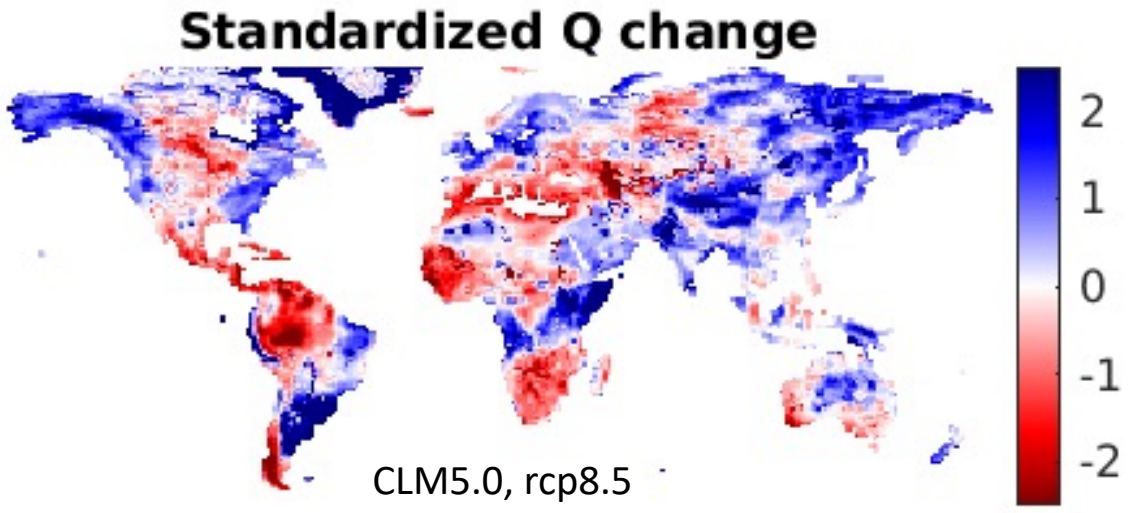
Jack Scheff (UNC Charlotte), Sloan Coats (U of Hawaii), Marysa Laguë (U of Saskatchewan)

In prep, *Earth's Future*

Background

- Global warming strongly increases temperature
- But only weakly changes precipitation (at least over mid- to low latitude land)
- Thus, climatic dryness indices (PDSI, SPEI, P/E_0) obtain **widespread, temperature-driven drying** when applied to RCP projections
- Yet, land-surface models simulate much more **mixed** responses in Q, deep-layer SM, etc when driven by those same projections!

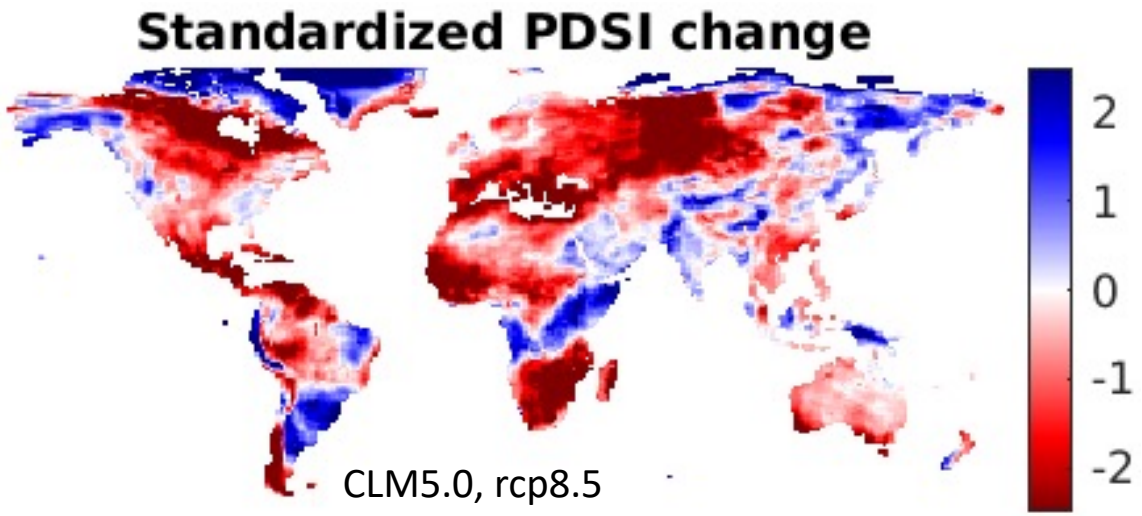


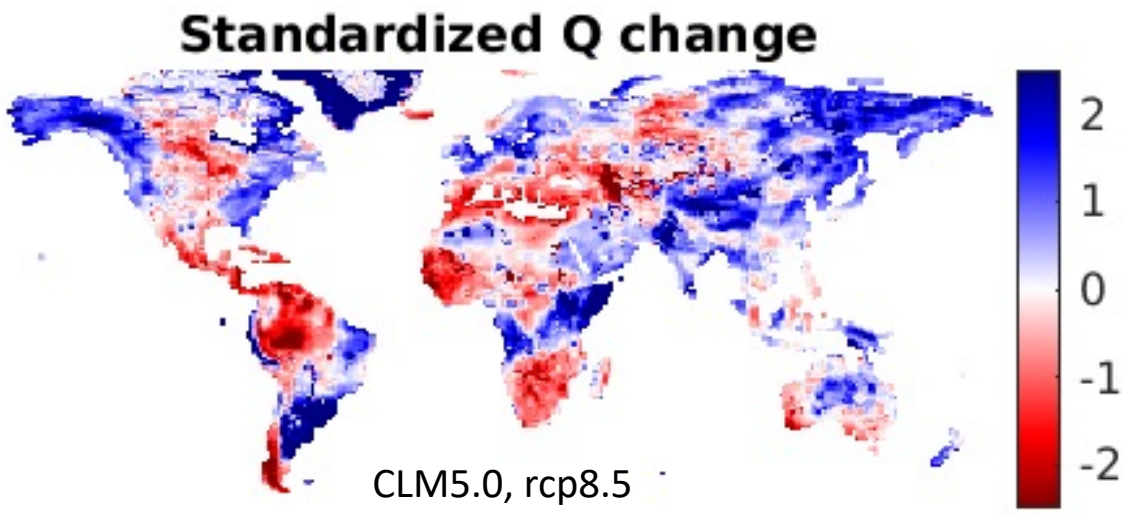


Background

- **Which picture are we to believe in practice??**

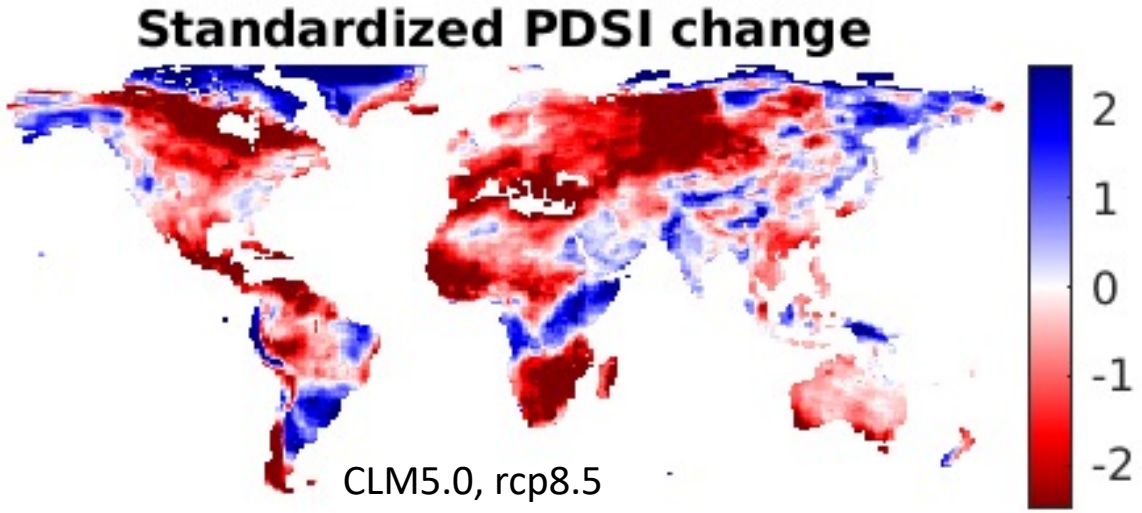
- Do we trust the simple dryness indices, or do we trust the land-surface models' complex runoff schemes (or neither?)

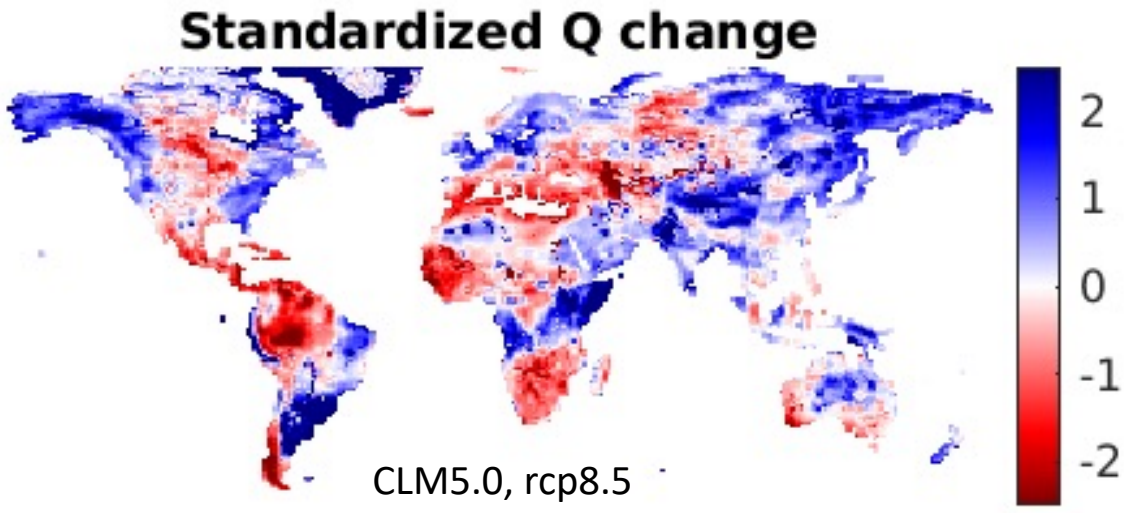




Background

- It would be helpful to know **why** they differ!
- Roderick et al (2015), Milly and Dunne (2016), Swann et al (2016), etc. assumed it's due to CO_2 closing leaf stomates in the models
- But Scheff et al (2021, *ERL*) showed most of the gaps **persist** in CMIP simulations in which CO_2-plant effects are switched off
- CO_2 effects can't be the main reason for the gaps





This study

- Here we test four alternative explanations for the dryness index-impact gaps in NCAR's Community Land Model v5.0 (CLM5.0).

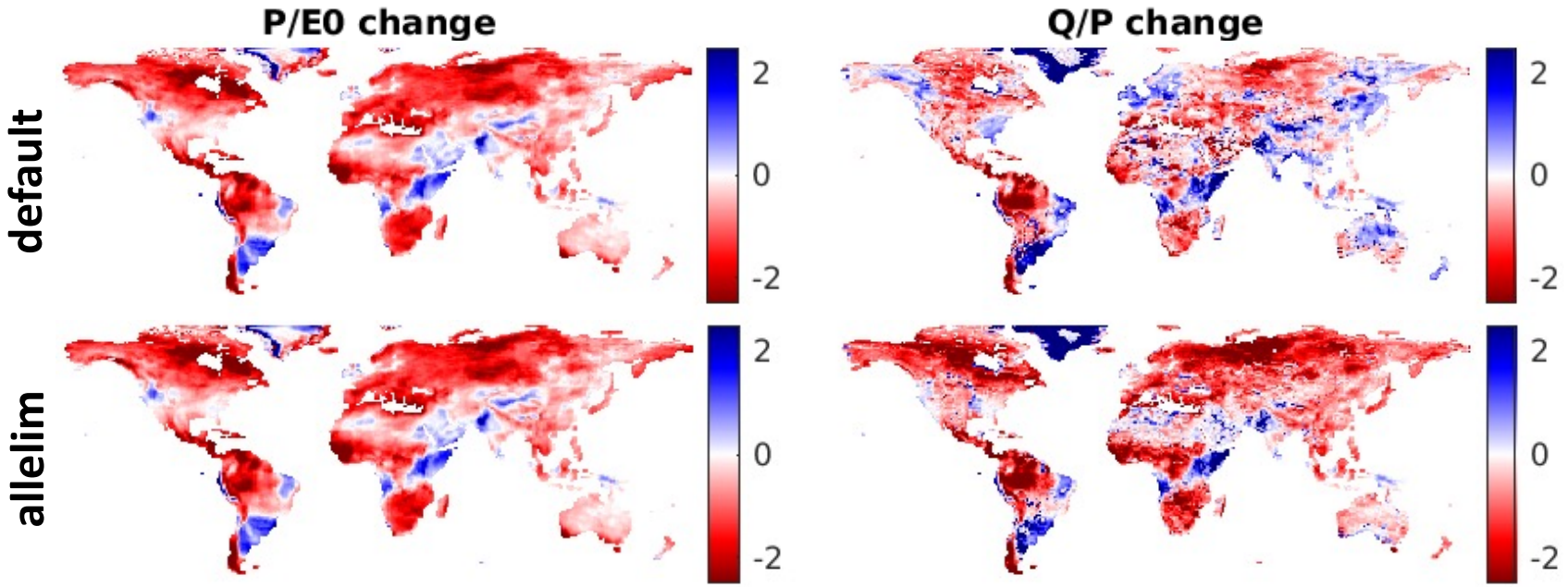
- Closure of leaf stomates by high CO_2
- Closure of leaf stomates by high VPD (Novick et al. 2016, etc)
- Concentration of precip into "flashier" events (Pendergrass and Hartmann 2014, Dai et al 2018, Mankin et al 2018, etc)
- Movement of precip into the existing wet season (Allen and Anderson 2018, Chou et al 2013, etc)
- All would increase annual Q and/or SM but not PDSI, SPEI or P/E_0

Model runs

- 6 pairs of offline CLM5.0 simulations driven by saved historical (1985-2014) and rcp8.5 (2071-2100) coupler output from CESM2
- ‘default’: all the usual settings
- ‘fixedCO2’: CO_2 held to 370 ppmv
- ‘medlynconst’: VPD seen by the stomatal code held to 1.5 kPa
- ‘noflash’: rcp8.5 coupler output replaced by “pseudo-rcp8.5” = historical coupler output scaled to match rcp8.5’s seasonal climate
- ‘noflashnoseas’: like noflash, but precip scaled to match rcp8.5’s *annual* climate only (so precip seasonality stays historical)
- ‘allelim’: fixedCO2, medlynconst, and noflashnoseas *simultaneously*

Results

- First: gap between P/E_0 (aridity index) and Q/P (runoff ratio)
- Most concerning of the gaps, since Budyko says P/E_0 drives Q/P
- Largely gone in allelim!



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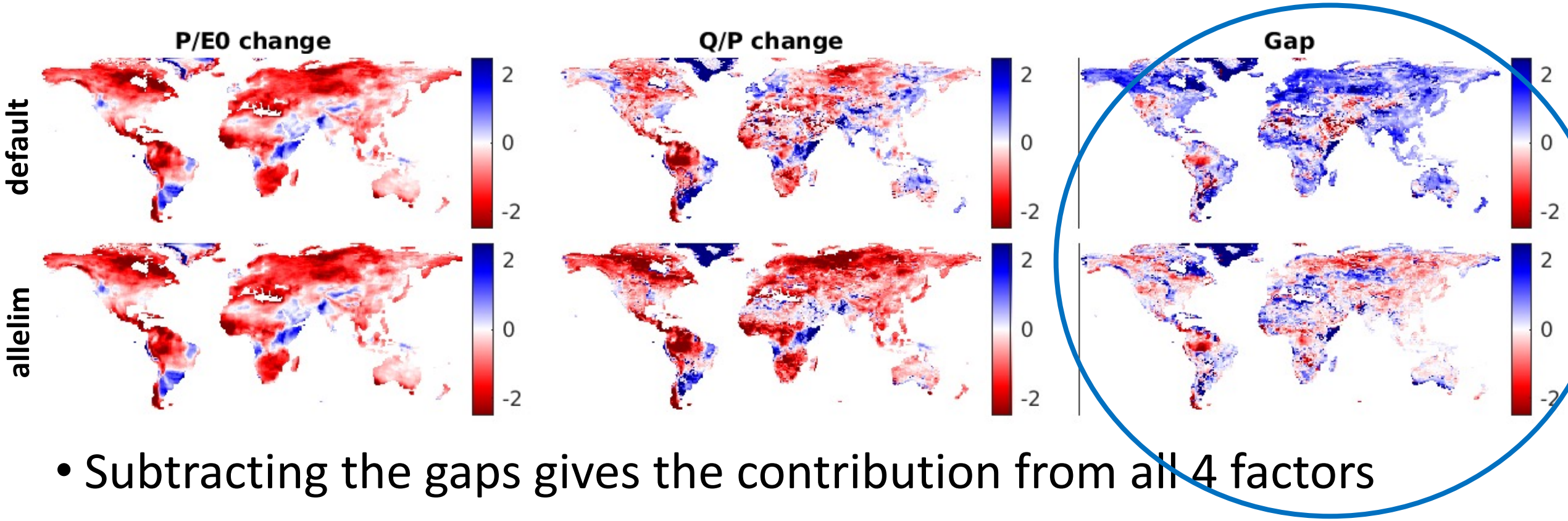
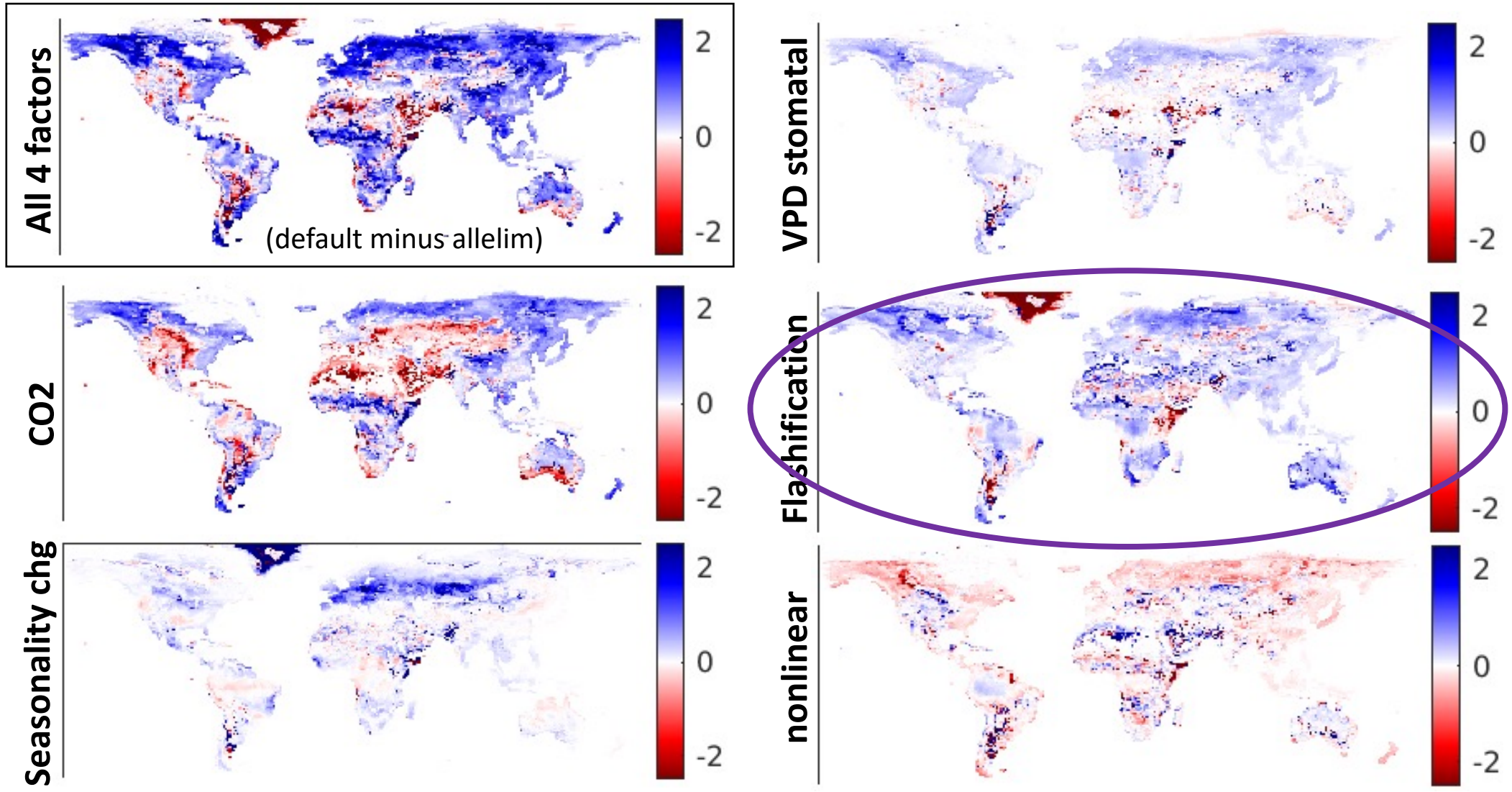


- Subtracting the gaps gives the contribution from all 4 factors

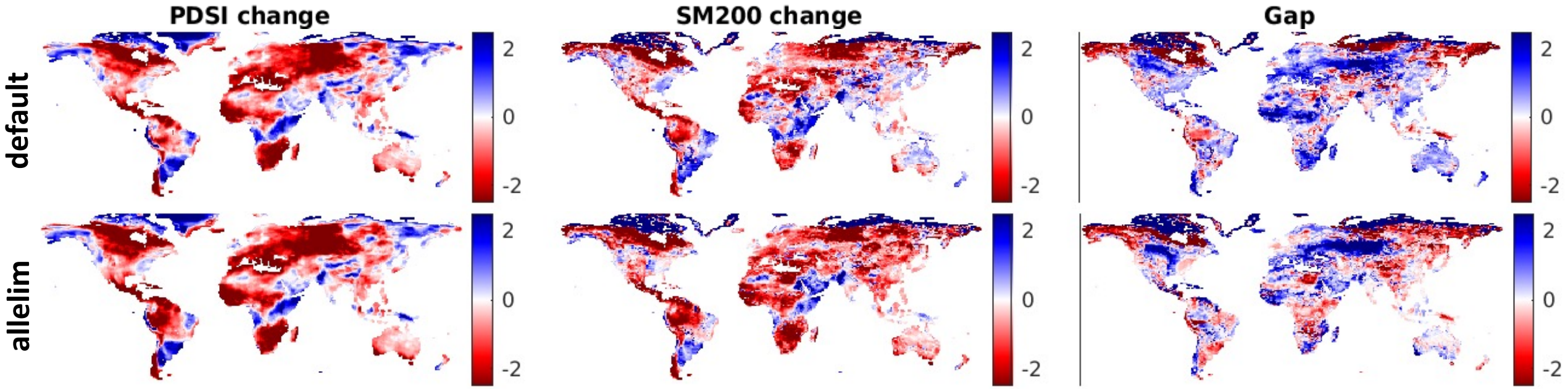
Results

- Contributions to the Q/P - P/E_0 gap from:



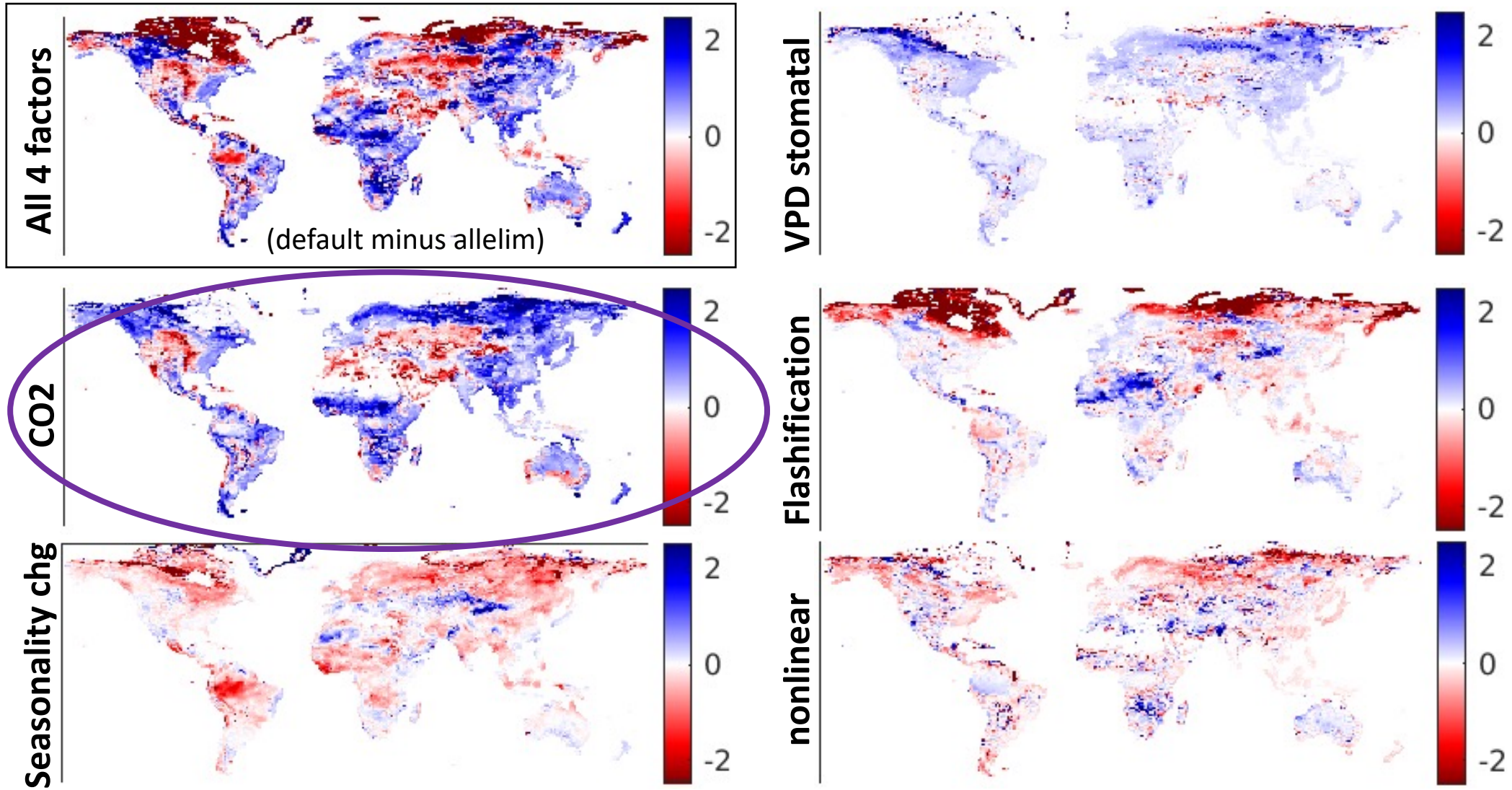
Results

- SM200 - PDSI gap: both signs, but generally SM200 increasing more
- In allelim, though, relative increases and decreases are more equal
- SM200 qualitatively resembles PDSI more in allelim



Results

- Contributions to the SM200 - PDSI gap from:



Summary

- *When physiological, "flashification", and seasonality effects are cut,* P/E_0 change does look like Q/P change under global warming
- And PDSI change does look like SM200 change (roughly)
- Indices work as designed! Not "useless" for understanding
- Gaps are mainly due to flashification (for P/E_0) and CO_2 (for PDSI)

- However **runoff itself (Q)** still increases much more strongly than any of the above quantities. [Q = (Q/P) * P]
- These indices are not directly relevant for runoff, despite working well for their intended purposes.