

Supplementary material for:

Environmental flow envelopes: quantifying global, ecosystem-threatening streamflow alterations

Vili Virkki^{*#}, Elina Alanärä[#], Miina Porkka, Lauri Ahopelto, Tom Gleeson, Chinchu Mohan, Lan Wang-Erlandsson, Martina Flörke, Dieter Gerten, Simon N Gosling, Naota Hanasaki, Hannes Müller Schmied, Matti Kummu^{*}

equal contribution to the article

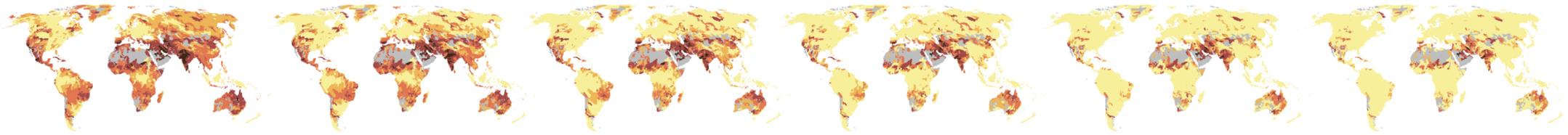
** Correspondence to:* Vili Virkki (vili.virkki@aalto.fi), Matti Kummu (matti.kummu@aalto.fi)

Contents:

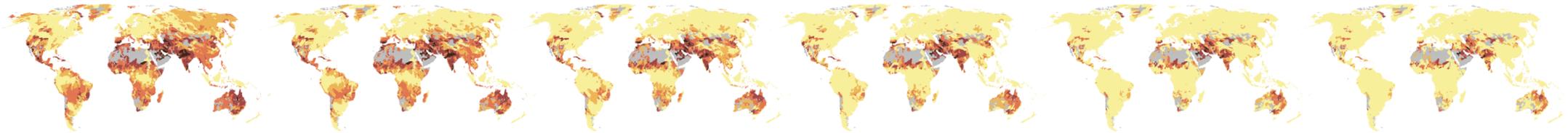
Supplementary figures S1-S3. Frequency and categorisation of EFE violations with variable-length minimum violation streak.

Supplementary figures S4-S11. Frequency, categorisation, and trends of EFE violations using individual global hydrological models (GHMs)

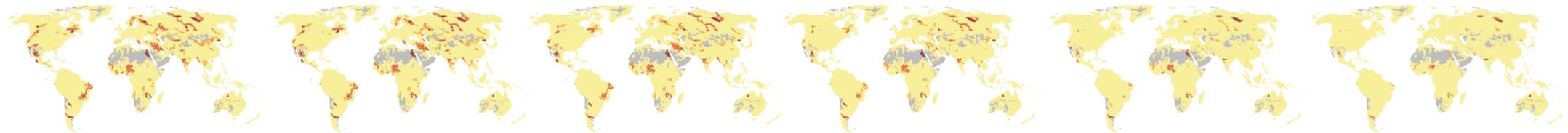
(a) EFE lower or upper bound violation



(b) EFE lower bound violation



(c) EFE upper bound violation



Considering... all violated months

...violation streaks of ≥ 2 months

...violation streaks of ≥ 3 months

...violation streaks of ≥ 4 months

...violation streaks of ≥ 5 months

...violation streaks of ≥ 6 months

Percentage of months violating EFE across all GHMs

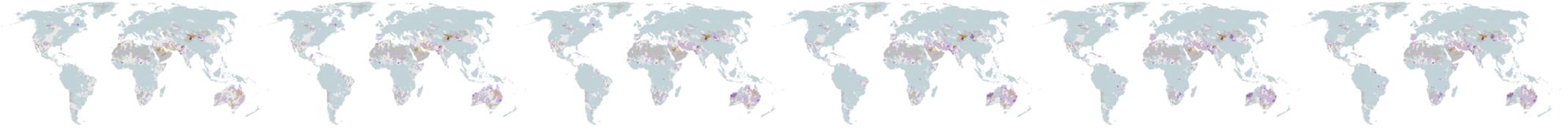
< 5% 5–10% 10–20% 20–40% > 40%

MAF < $10 \text{ m}^3 \text{ s}^{-1}$

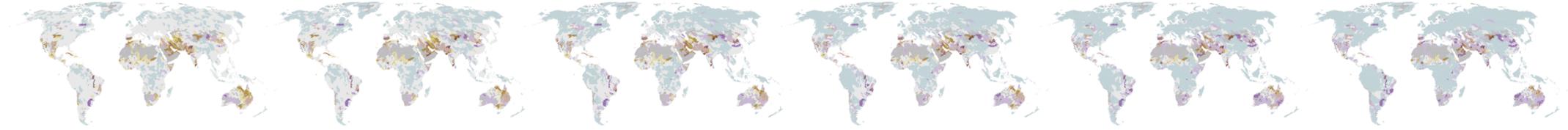
Figure S1. Frequency of EFE violations of both upper and lower bounds (a), lower bound only (b), and upper bound only (c) with respect to the minimum number of consecutive violated months, computed for the GHM ensemble.

EFE lower bound violations

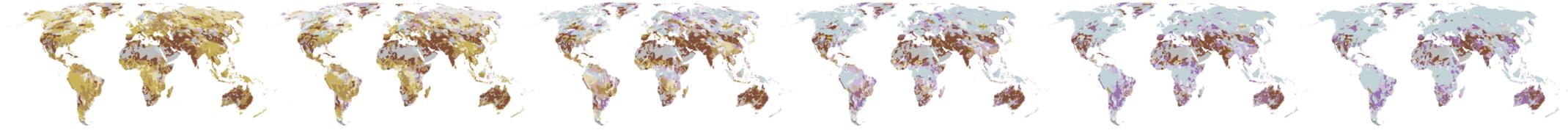
(a) High flow months ($Q > \text{MAF}$)



(b) Intermediate flow months ($0.4\text{MAF} \leq Q \leq \text{MAF}$)



(c) Low flow months ($Q < 0.4\text{MAF}$)



Considering... all violated months ...violation streaks of ≥ 2 months ...violation streaks of ≥ 3 months ...violation streaks of ≥ 4 months ...violation streaks of ≥ 5 months ...violation streaks of ≥ 6 months

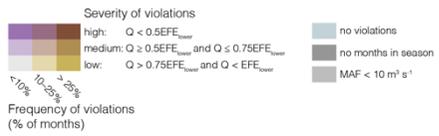


Figure S2. Seasonal frequency and severity of EFE violations of the lower bound for high flow season (a), intermediate flow season (b), and low flow season (c) with respect to the minimum number of consecutive violated months, computed for the GHM ensemble.

EFE upper bound violations

(a) High flow months ($Q > \text{MAF}$)



(b) Intermediate flow months ($0.4\text{MAF} \leq Q \leq \text{MAF}$)



(c) Low flow months ($Q < 0.4\text{MAF}$)

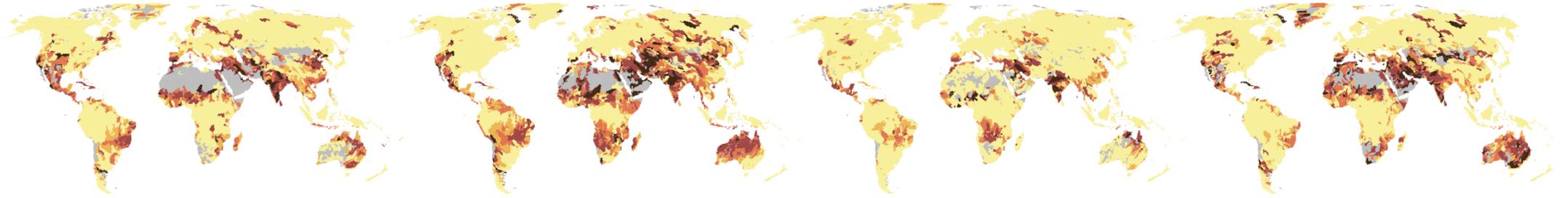


Considering... all violated months ...violation streaks of ≥ 2 months ...violation streaks of ≥ 3 months ...violation streaks of ≥ 4 months ...violation streaks of ≥ 5 months ...violation streaks of ≥ 6 months

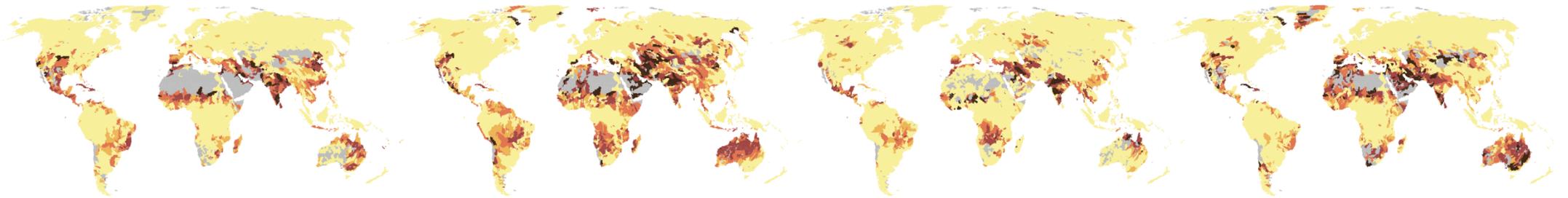


Figure S3. Seasonal frequency and severity of EFE violations of the upper bound for high flow season (a), intermediate flow season (b), and low flow season (c) with respect to the minimum number of consecutive violated months, computed for the GHM ensemble.

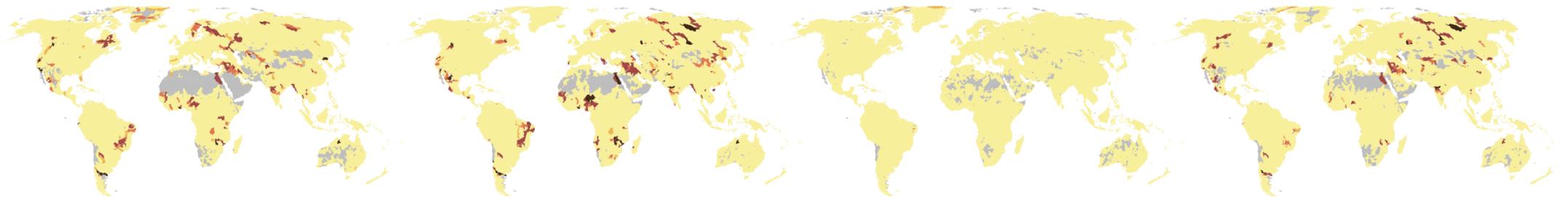
(a) EFE lower or upper bound violation



(b) EFE lower bound violation



(c) EFE upper bound violation



H08

LPJmL

PCR-GLOBWB

WaterGAP2

Percentage of months violating EFE across all GHMs



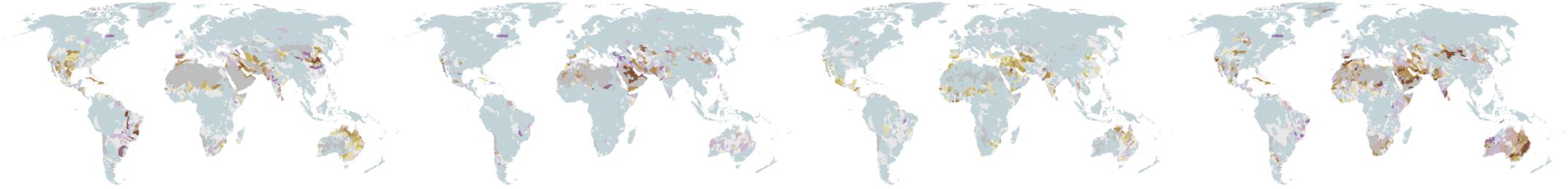
Figure S4. Frequency of EFE violations of both upper and lower bounds (a), lower bound only (b), and upper bound only (c), computed separately for each GHM.

EFE lower bound violations

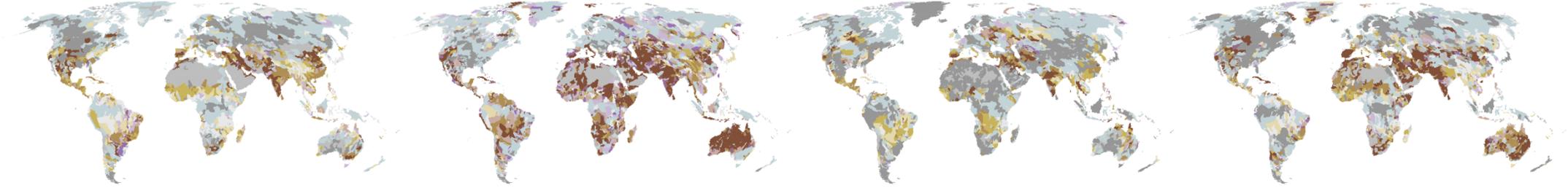
(a) High flow months ($Q > \text{MAF}$)



(b) Intermediate flow months ($0.4\text{MAF} \leq Q \leq \text{MAF}$)



(c) Low flow months ($Q < 0.4\text{MAF}$)



H08

LPJmL

PCR-GLOBWB

WaterGAP2

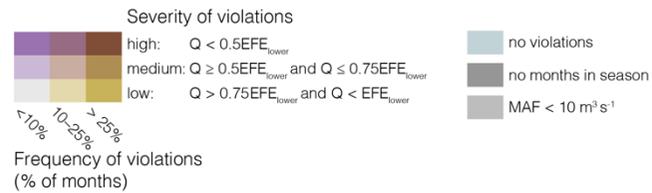


Figure S5. Seasonal frequency and severity of EFE violations of the lower bound for high flow season (a), intermediate flow season (b), and low flow season (c), computed separately for each GHM.

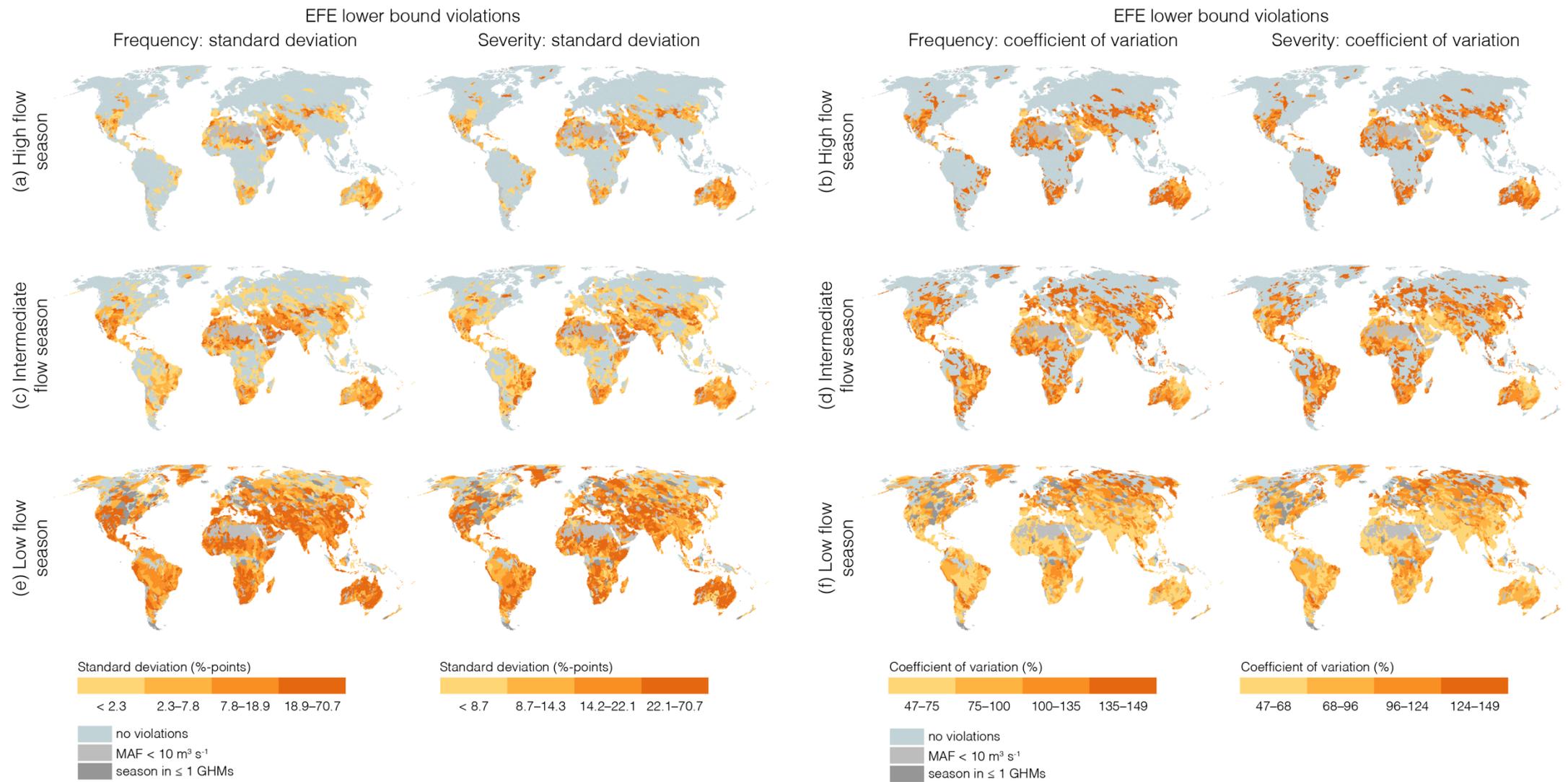


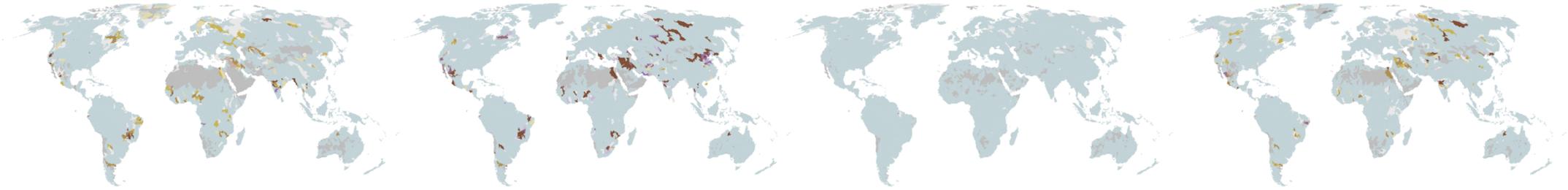
Figure S6. The standard deviation (a, c, e) and coefficient of variation (b, d, f) of EFE lower bound violation frequency and severity between GHMs, computed for high flow season (a-b), intermediate flow season (c-d), and low flow season (e-f).

EFE upper bound violations

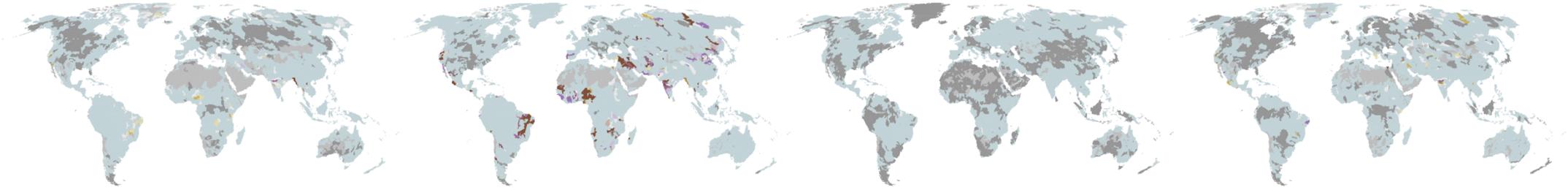
(a) High flow months ($Q > \text{MAF}$)



(b) Intermediate flow months ($0.4\text{MAF} \leq Q \leq \text{MAF}$)



(c) Low flow months ($Q < 0.4\text{MAF}$)



H08

LPJmL

PCR-GLOBWB

WaterGAP2

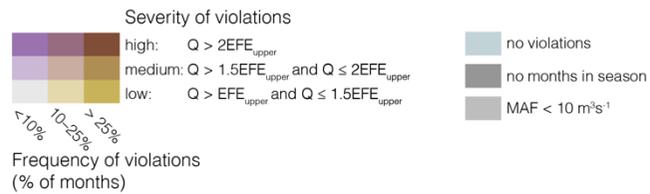


Figure S7. Seasonal frequency and severity of EFE violations of the upper bound for high flow season (a), intermediate flow season (b), and low flow season (c), computed separately for each GHM.

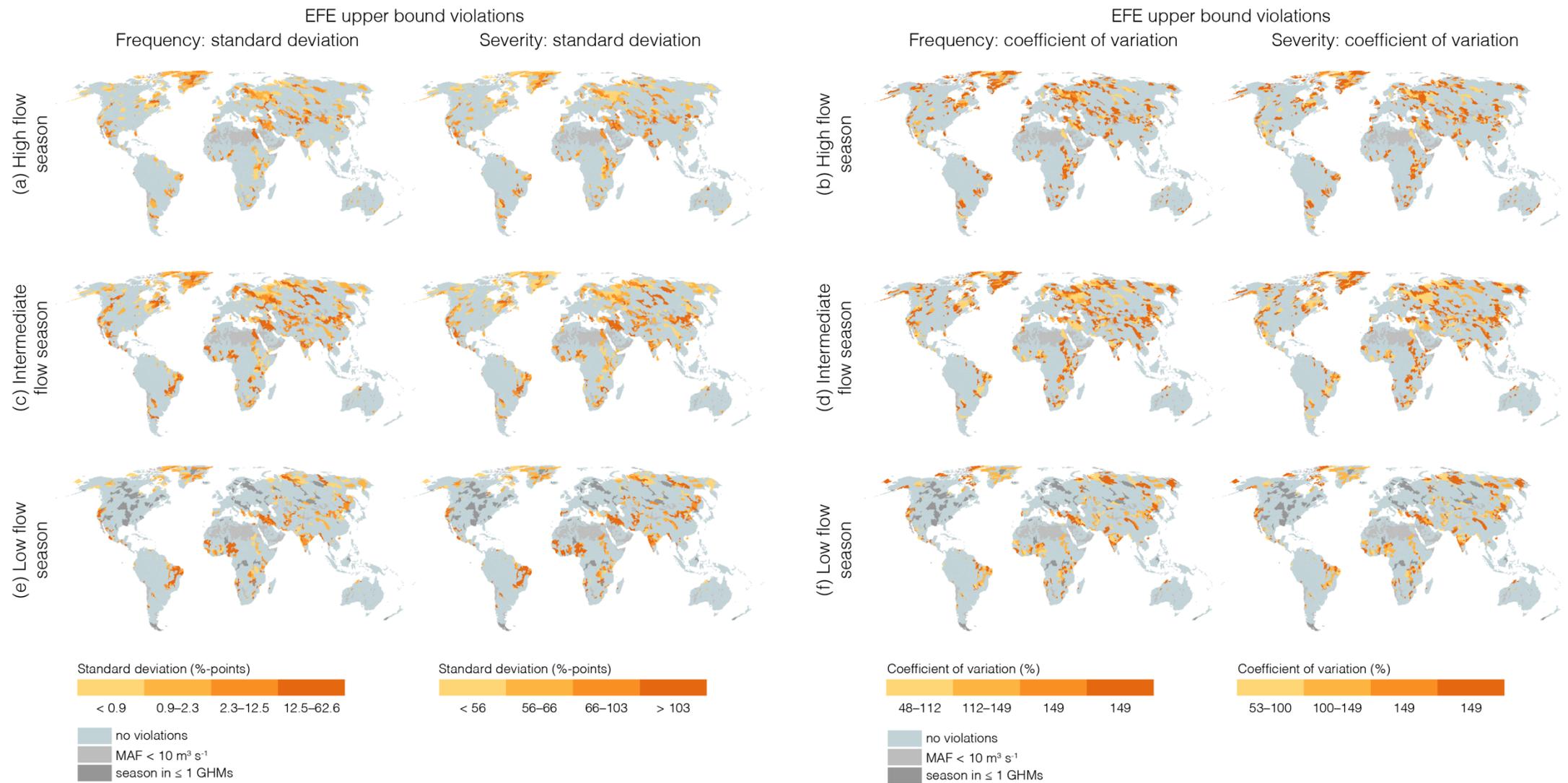
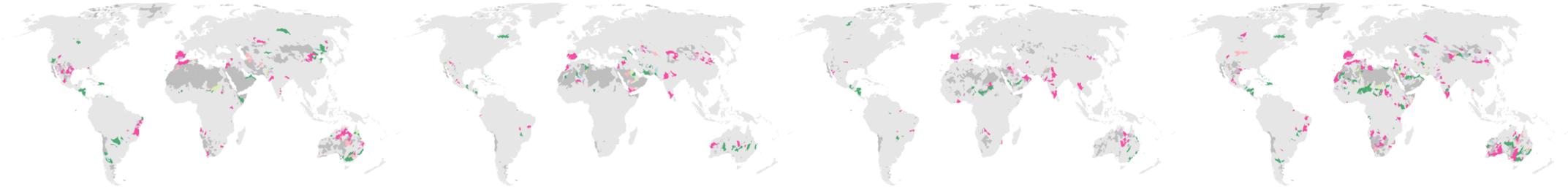


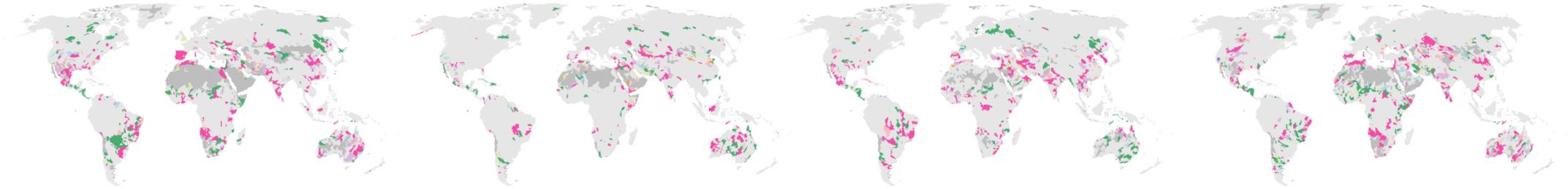
Figure S8. The standard deviation (a, c, e) and coefficient of variation (b, d, f) of EFE upper bound violation frequency and severity between GHMs, computed for high flow season (a-b), intermediate flow season (c-d), and low flow season (e-f).

EFE lower bound violations

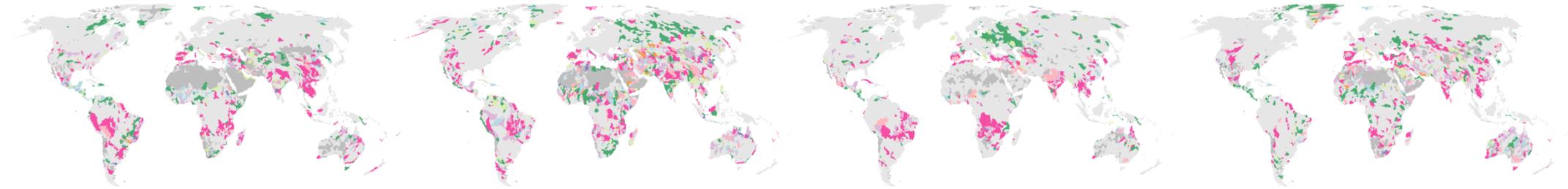
(a) High flow months ($Q > \text{MAF}$)



(b) Intermediate flow months ($0.4\text{MAF} \leq Q \leq \text{MAF}$)



(c) Low flow months ($Q < 0.4\text{MAF}$)



H08

LPJmL

PCR-GLOBWB

WaterGAP2

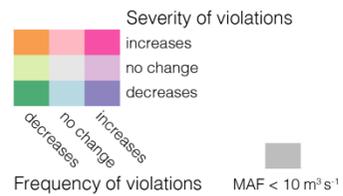


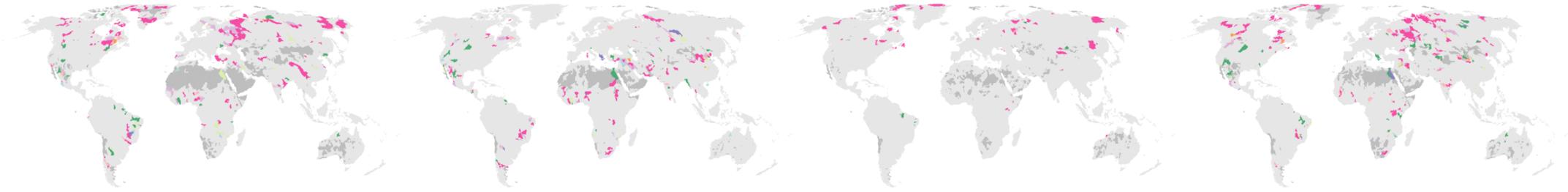
Figure S9. Trends of frequency and severity of EFE violations of the lower bound for high flow season (a), intermediate flow season (b), and low flow season (c), computed separately for each GHM.

EFE upper bound violations

(a) High flow months ($Q > \text{MAF}$)



(b) Intermediate flow months ($0.4\text{MAF} \leq Q \leq \text{MAF}$)



(c) Low flow months ($Q < 0.4\text{MAF}$)



H08

LPJmL

PCR-GLOBWB

WaterGAP2

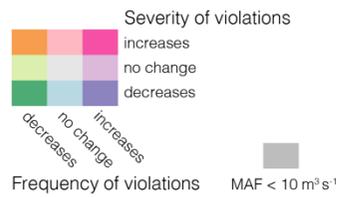


Figure S10. Trends of frequency and severity of EFE violations of the upper bound for high flow season (a), intermediate flow season (b), and low flow season (c), computed separately for each GHM.

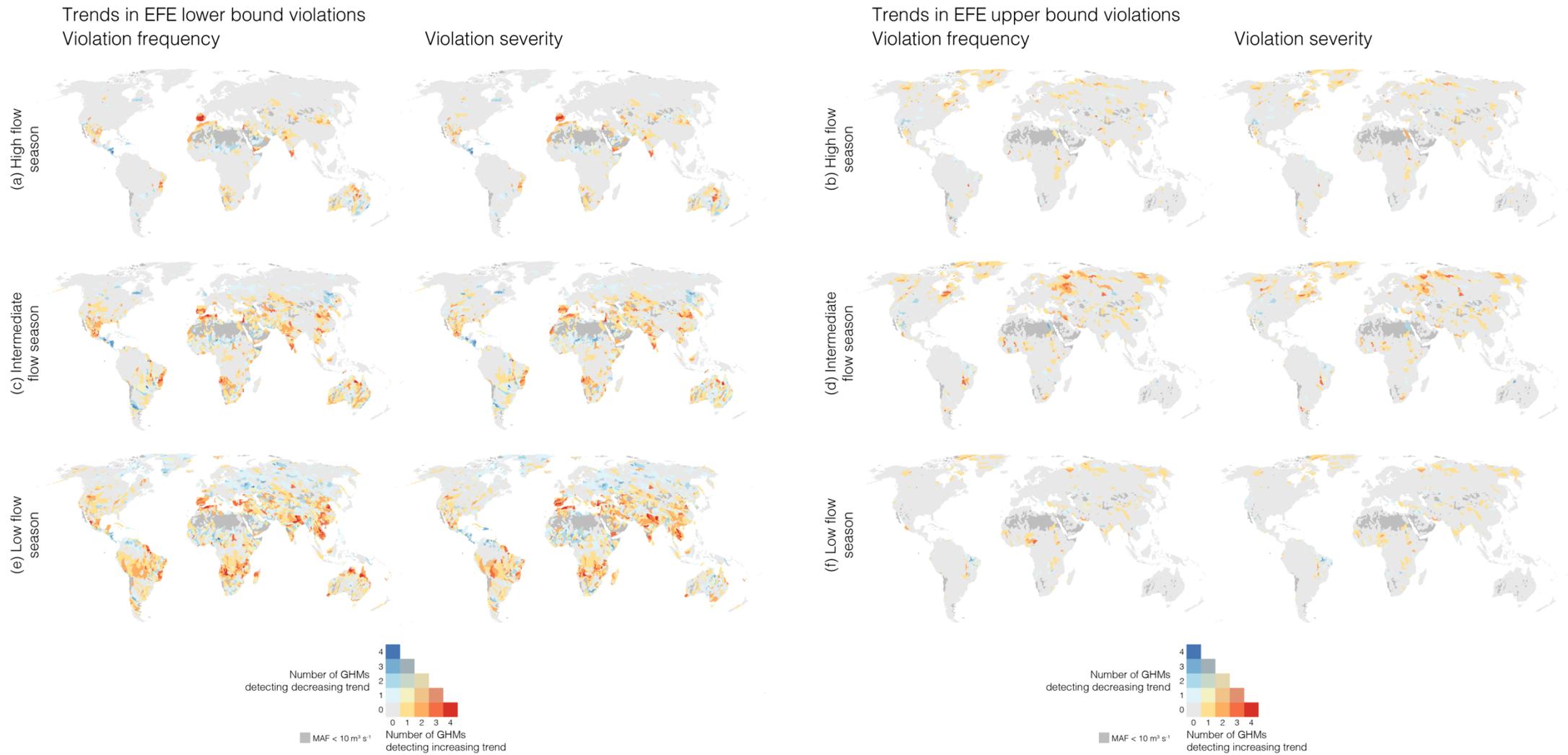


Figure S11. The agreement of EFE violation trends between GHMs for EFE lower bound violations (a, c, e) and EFE upper bound violations (b, d, f), computed for high flow season (a-b), intermediate flow season (c-d), and low flow season (e-f).