

Supplementary material for:

Widespread and increasing violations of environmental flow envelopes

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equal contribution to the article

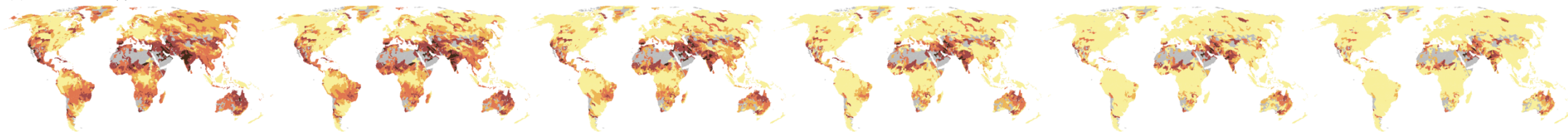
** Correspondence to:* Vili Virkki (vili.virkki@aalto.fi), Matti Kummu (matti.kummu@aalto.fi)

Contents:

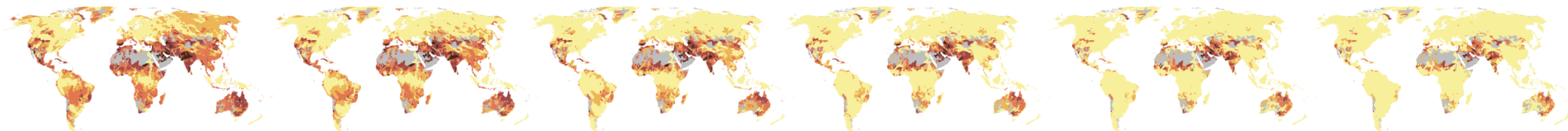
Supplementary figures S1-S3. Frequency and categorisation of EFE violations with variable-length minimum violation streak.

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

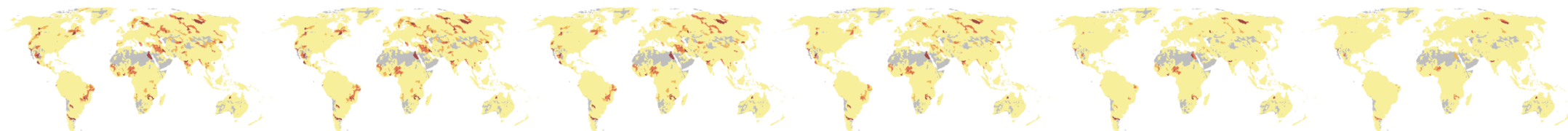
(a) EFE lower or upper bound violation



(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



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.

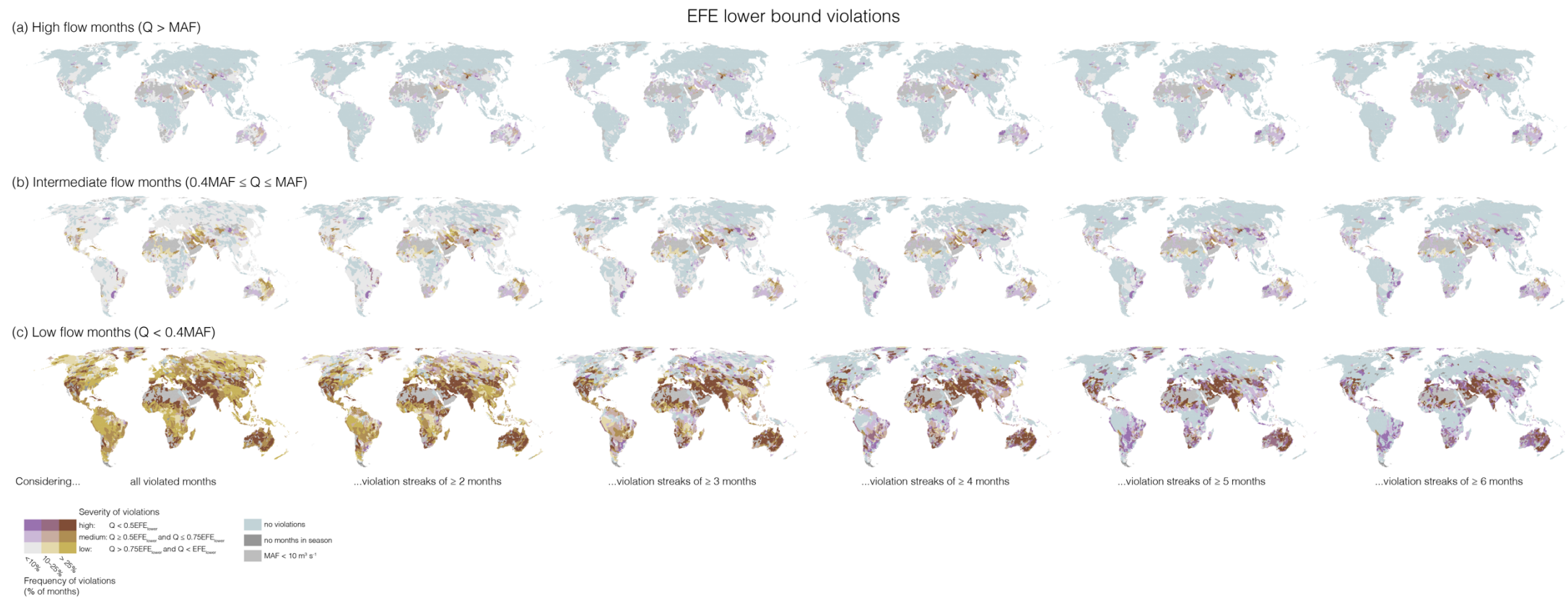


Figure S2. Seasonal frequency and severity of EFE violations of the lower bound for high flow season (a), intermediate flow season (b), and low flow season (c) with respect to the minimum number of consecutive violated months, computed for the GHM ensemble.

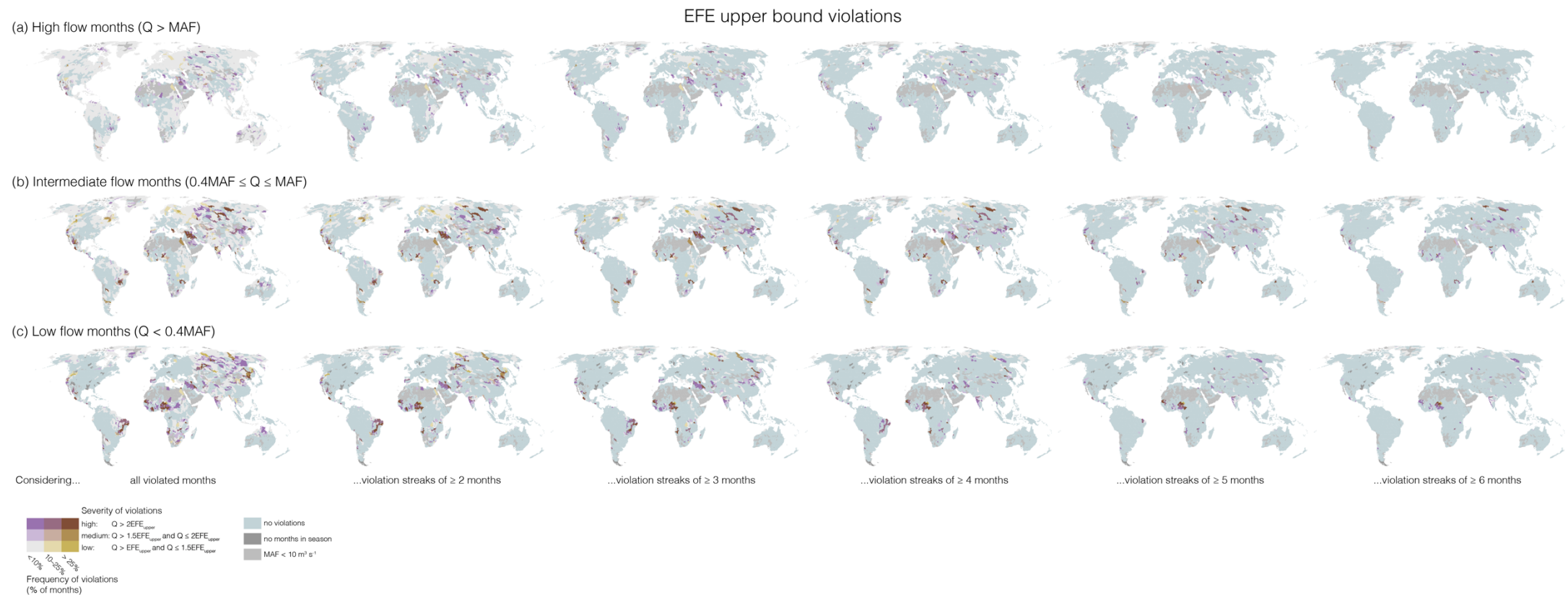
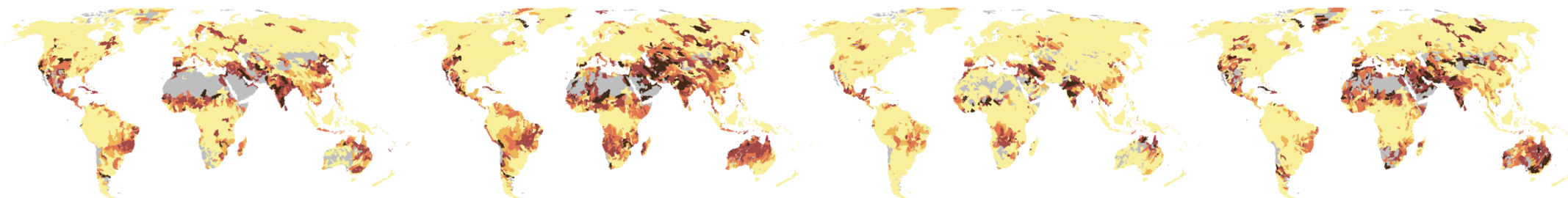
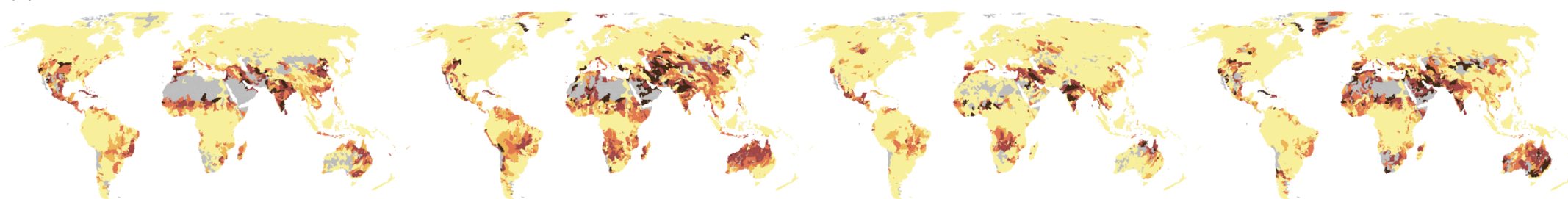


Figure S3. Seasonal frequency and severity of EFE violations of the upper bound for high flow season (a), intermediate flow season (b), and low flow season (c) with respect to the minimum number of consecutive violated months, computed for the GHM ensemble.

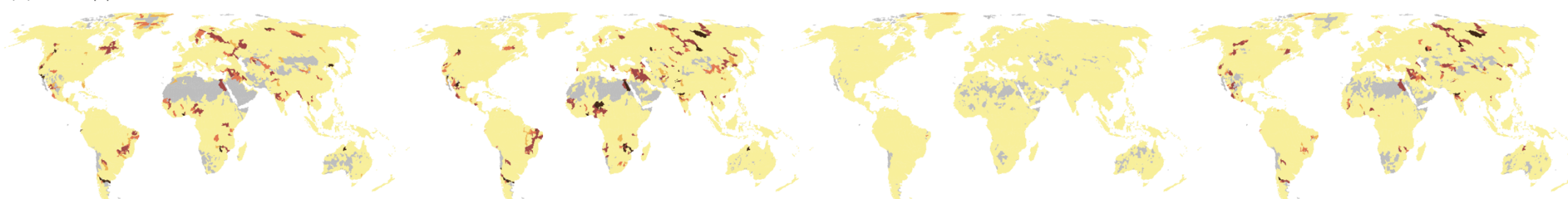
(a) EFE lower or upper bound violation



(b) EFE lower bound violation



(c) EFE upper bound violation



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Percentage of months violating EFE across all GHMs

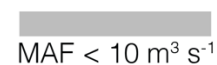
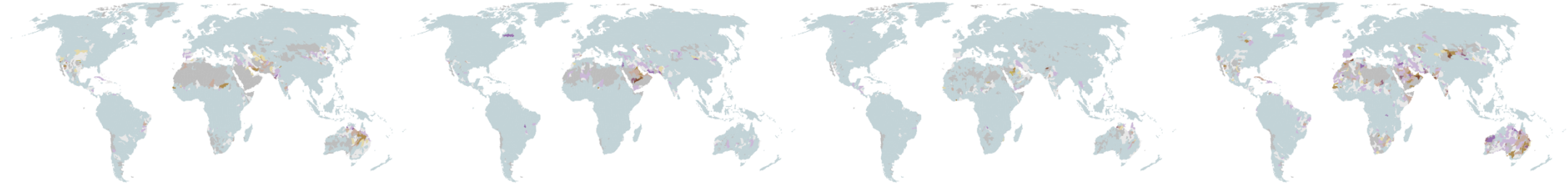


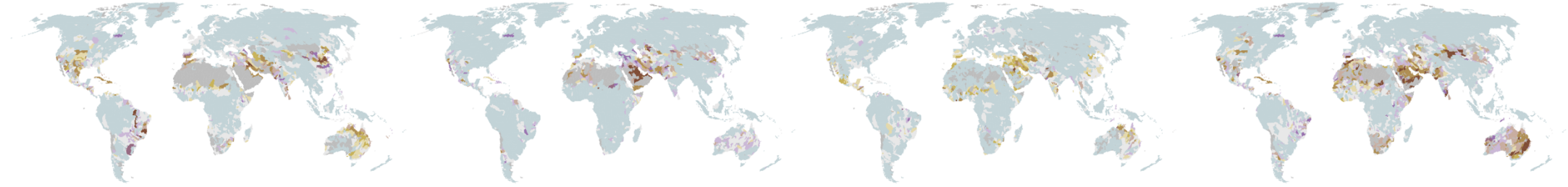
Figure S4. Frequency of EFE violations of both upper and lower bounds (a), lower bound only (b), and upper bound only (c), computed separately for each GHM.

EFE lower bound violations

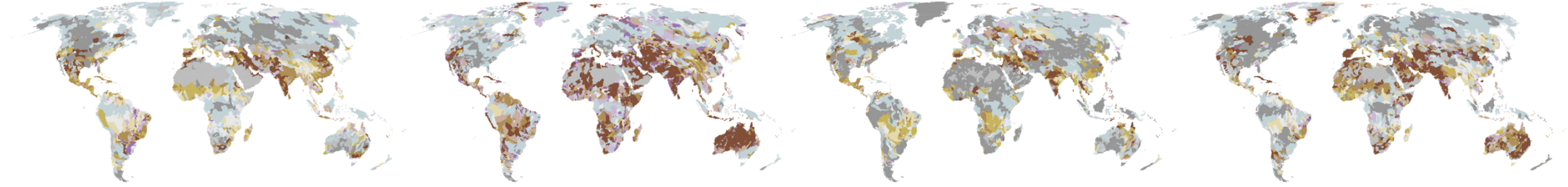
(a) High flow months ($Q > \text{MAF}$)



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



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



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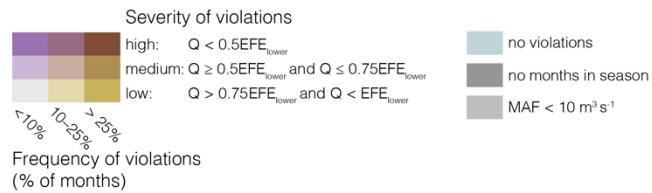


Figure S5. Seasonal frequency and severity of EFE violations of the lower bound for high flow season (a), intermediate flow season (b), and low flow season (c), computed separately for each GHM.

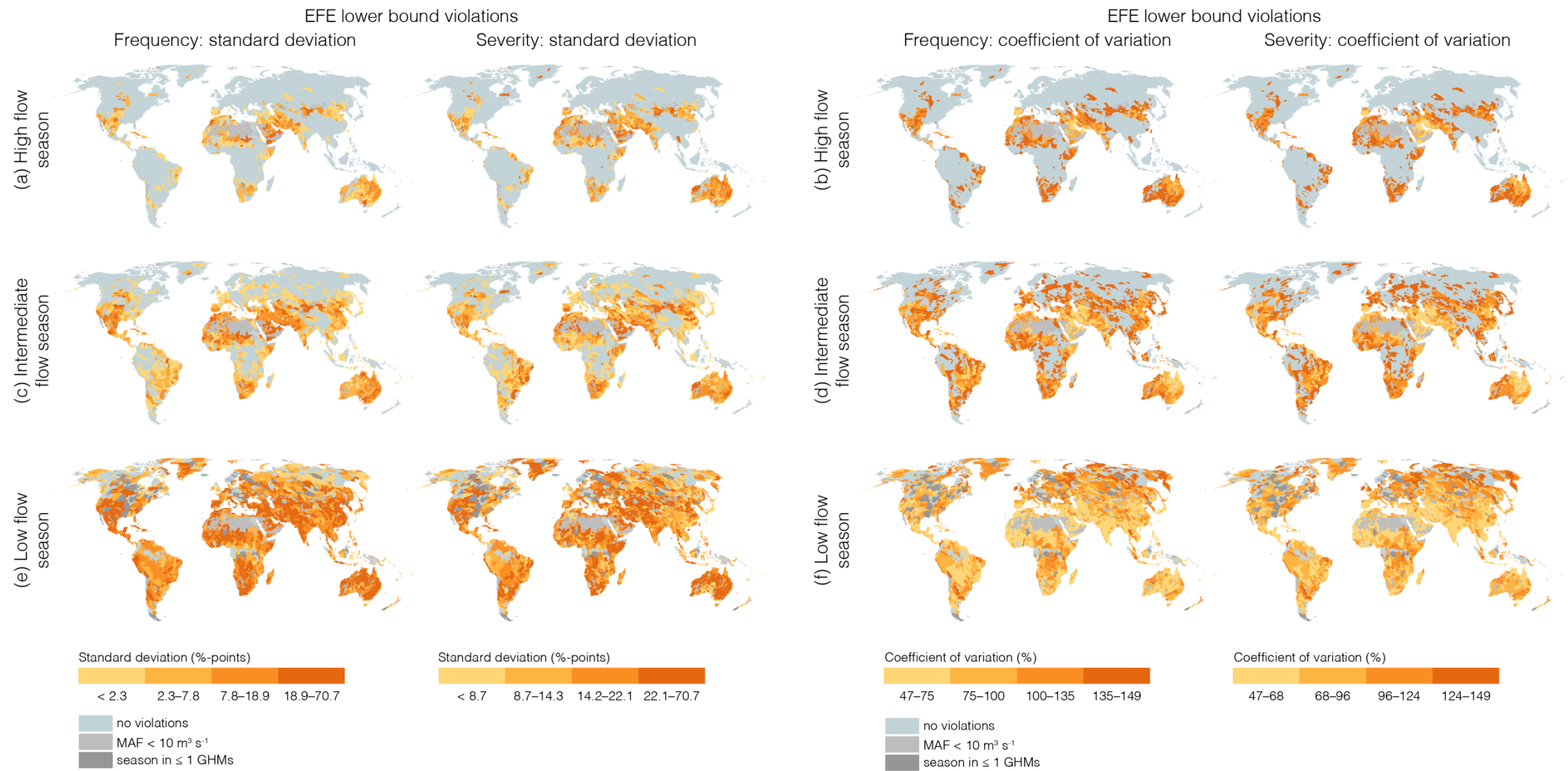
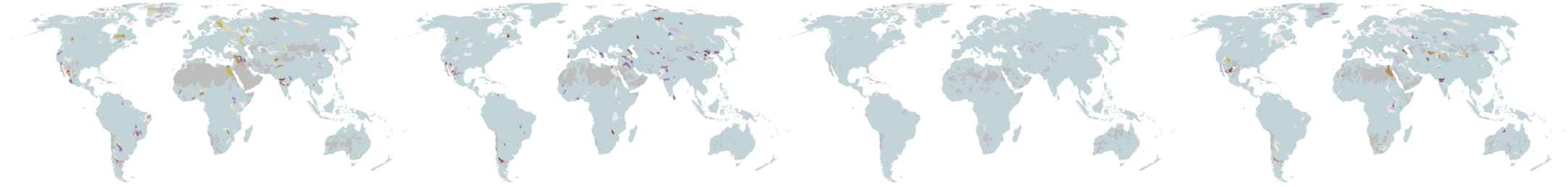


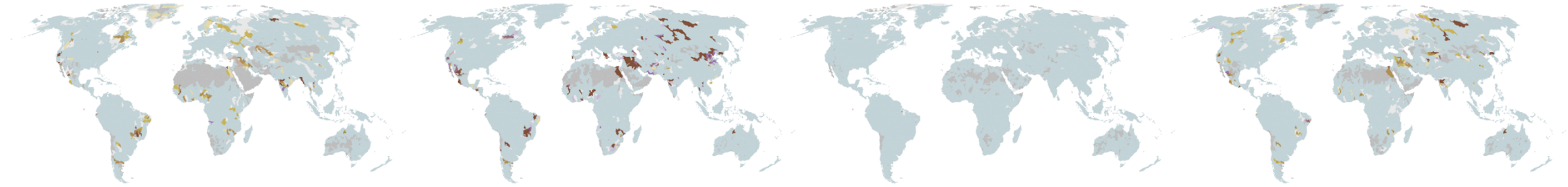
Figure S6. The standard deviation (a, c, e) and coefficient of variation (b, d, f) of EFE lower bound violation frequency and severity between GHMs, computed for high flow season (a-b), intermediate flow season (c-d), and low flow season (e-f).

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 ($Q < 0.4\text{MAF}$)



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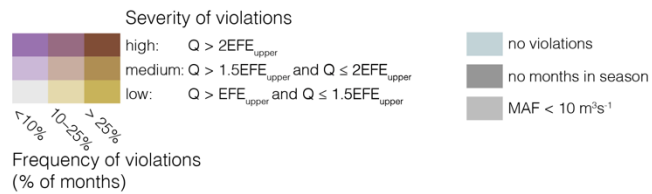
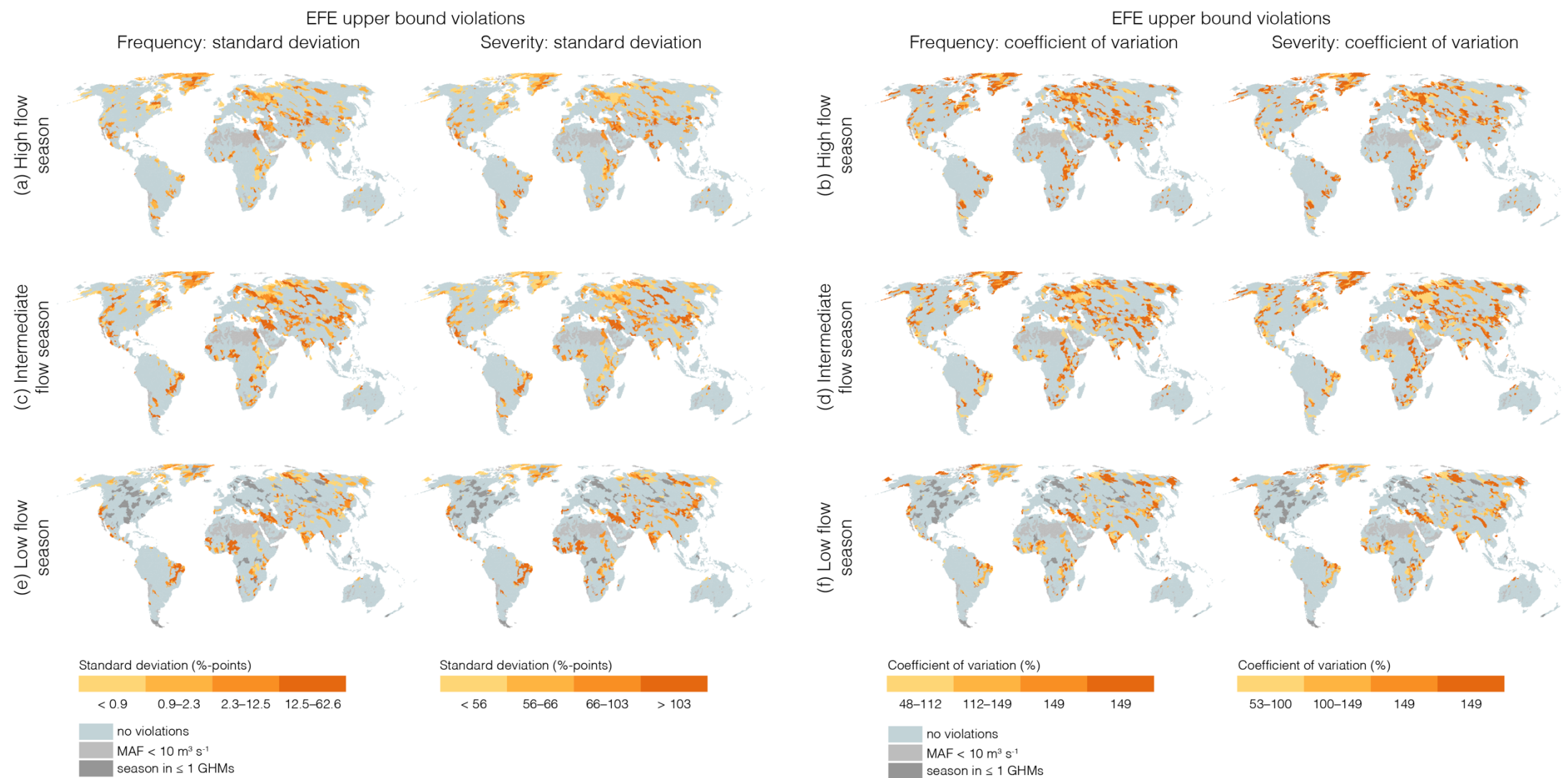
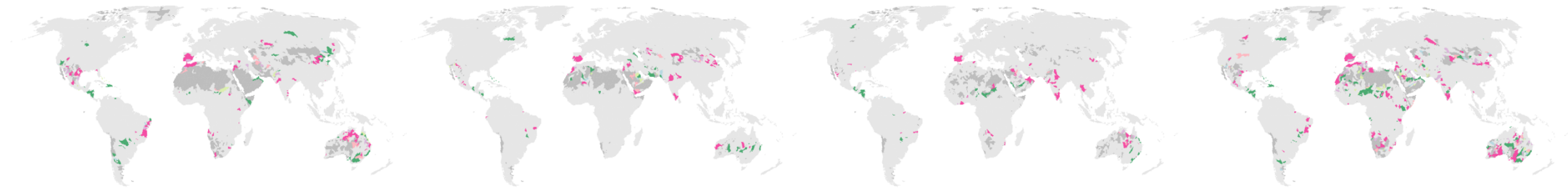


Figure S7. Seasonal frequency and severity of EFE violations of the upper bound for high flow season (a), intermediate flow season (b), and low flow season (c), computed separately for each GHM.

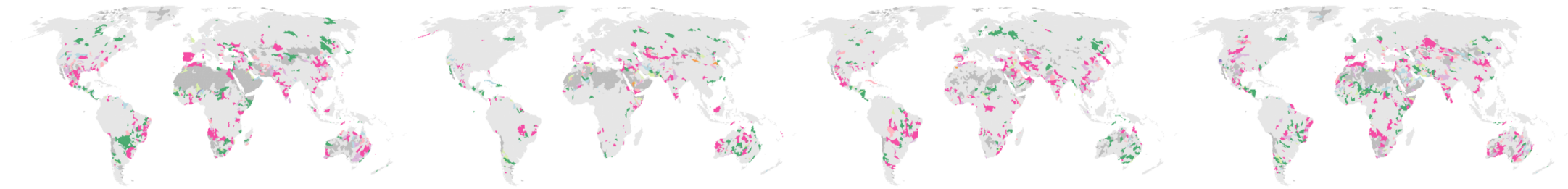


EFE lower bound violations

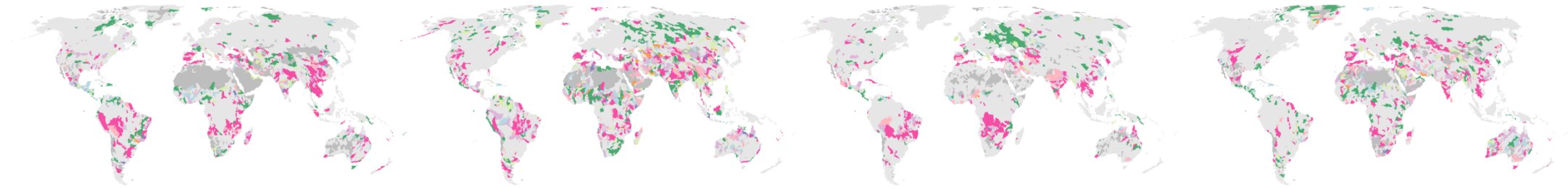
(a) High flow months ($Q > \text{MAF}$)



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



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



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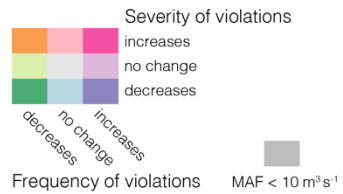
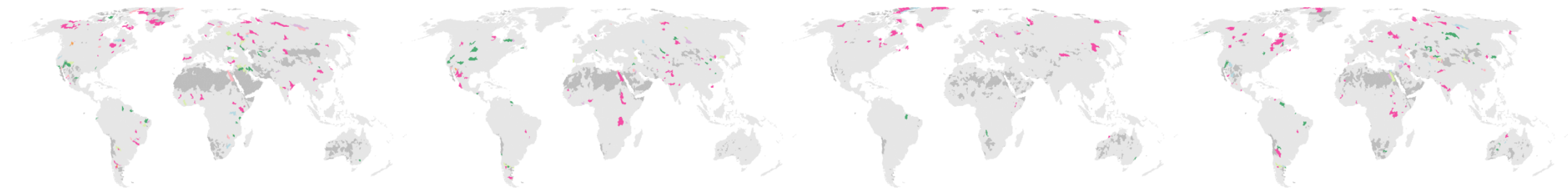


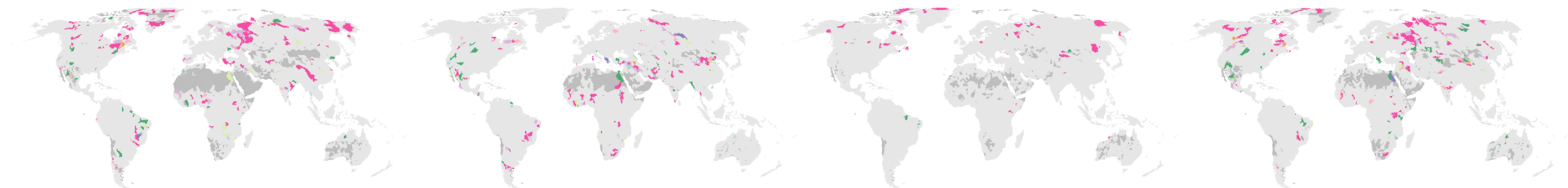
Figure S9. Trends of frequency and severity of EFE violations of the lower bound for high flow season (a), intermediate flow season (b), and low flow season (c), computed separately for each GHM.

EFE upper bound violations

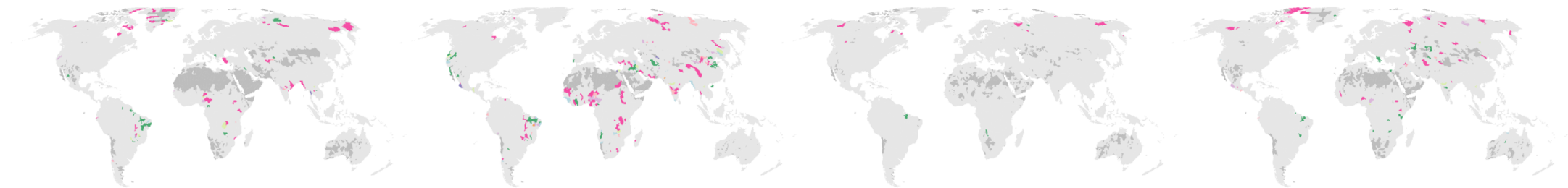
(a) High flow months ($Q > \text{MAF}$)



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



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



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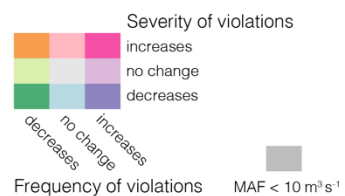


Figure S10. Trends of frequency and severity of EFE violations of the upper bound for high flow season (a), intermediate flow season (b), and low flow season (c), computed separately for each GHM.

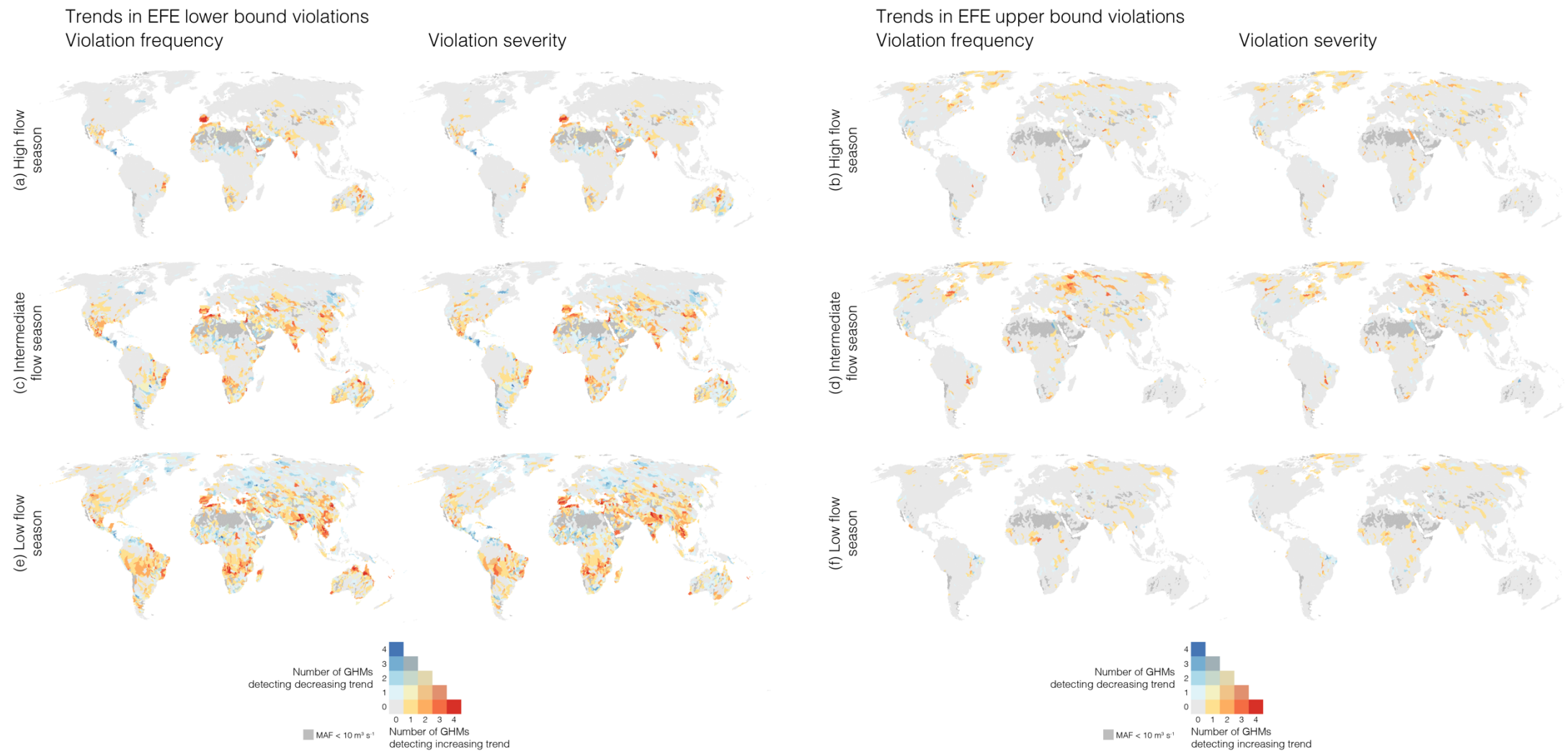


Figure S11. The agreement of EFE violation trends between GHMs for EFE lower bound violations (a, c, e) and EFE upper bound violations (b, d, f), computed for high flow season (a-b), intermediate flow season (c-d), and low flow season (e-f).