

Supplementary Information - Compounding future
escalation of emissions- and irrigation-induced increases in
humid-heat stress

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1 Supplementary Tables

1.1 Supplementary Tables

Table S1: **Three groups of IPCC reference regions.** 13 IPCC regions are categorised into three groups for analysis.

Group	Regions
1	West North America, Central North America, East Asia
2	Mediterranean, West Central Asia, Arabian-Peninsula, South Asia, Southeast Asia
3	Southwest South America, Sahara, West Africa, West South Africa, East South Africa

Table S2: **Correlation between different socio-economic or hydro-climatic variables and current national irrigation techniques share** Spearman's coefficient between present-day irrigation techniques fraction from the present-day irrigation techniques fraction¹ and socio-economic (GDP: gross domestic product, GOV: governance, URB: urbanisation, and GII: gender inequality index) or hydro-climatic (P: precipitation, PPET: precipitation divided by potential evapotranspiration, and TWS: terrestrial water storage) variables (* indicates p value < 0.1 , ** indicates p value < 0.5 , *** indicates p value < 0.01)

	Flood fraction	Sprinkler Fraction	Drip Fraction
GDP	-0.5252***	0.4803***	0.4155***
GOV	-0.5302***	0.4625***	0.4676***
URB	-0.4428***	0.3796***	0.3723***
GII	0.4542***	-0.4104***	-0.3063***
P	0.2709***	-0.2110**	-0.2483***
PPET	-0.0203	0.0761*	-0.1773**
TWS	0.2082**	-0.1353	-0.3112***

Table S3: **Reference irrigation techniques change from USA and Iran.** Fraction of different irrigation techniques in the USA and Iran at the national level during the historical period. The trend is calculated with the lineal regression.

USA	1985	1990	1995	2000	2005	2010	2015
flood (%)	61.18	60.31	54.91	47.51	43.53	42.03	36.77
sprinkler (%)	38.82	39.69	42.23	45.74	49.84	50.58	54.58
drip (%)	0	0	2.86	6.75	6.63	7.39	8.65
Trend in flood irrigation: -0.87% / year							
Iran	2003	2009	2013	2015	2019		
flood (%)	94.41	91.61	85.16	83.71	76.15		
sprinkler (%)	3.60	5.29	8.55	9.36	11.85		
drip (%)	1.99	3.10	6.29	6.93	12.00		
Trend of flood irrigation: -1.21% / year							

Table S4: **Suitable irrigation techniques for different crop functional types.**

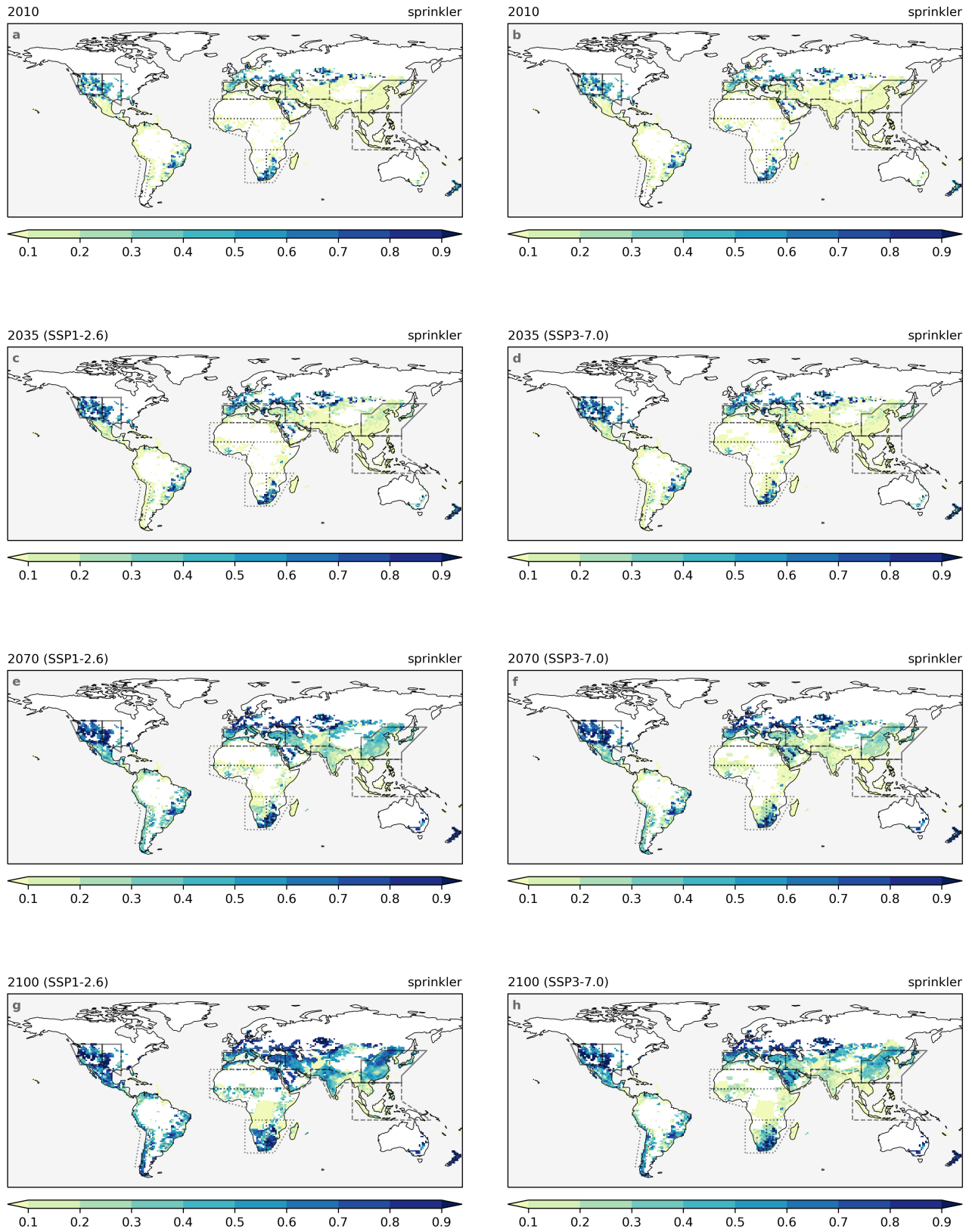
Crop type	drip	sprinkler	flood
Spring wheat	No	Yes	Yes
Winter wheat	No	Yes	Yes
Barley	No	Yes	Yes
Winter barley	No	Yes	Yes
Rye	No	Yes	Yes
Winter rye	No	Yes	Yes
Rice	No	No	Yes
Temperate maize	No	Yes	Yes
Tropical maize	No	Yes	Yes
Millet	No	Yes	Yes
Sorghum	No	Yes	Yes
Pulses	Yes	Yes	Yes
Cassava	No	No	No
Sunflower	Yes	Yes	Yes
Temperate soybean	Yes	Yes	Yes
Tropical soybean	Yes	Yes	Yes
Groundnuts	No	Yes	Yes
Rapeseed	No	Yes	Yes
Sugarcane	No	Yes	Yes
Citrus	Yes	Yes	Yes
Cocoa	Yes	Yes	Yes
Coffee	Yes	Yes	Yes
Cotton	Yes	Yes	Yes
Date palm	Yes	Yes	Yes
Grapes	Yes	Yes	Yes
Oil palm	Yes	Yes	Yes
Potatoes	Yes	Yes	Yes
Fodder grass	No	Yes	Yes
Miscanthus	No	Yes	Yes

Table S5: **Adjusting factors based on socio-economic capacity and hydro-climatic complexity.** Based on the correlation between the variables and present-day irrigation techniques fraction (Table S2), these factors are assumed to project future irrigation techniques share.

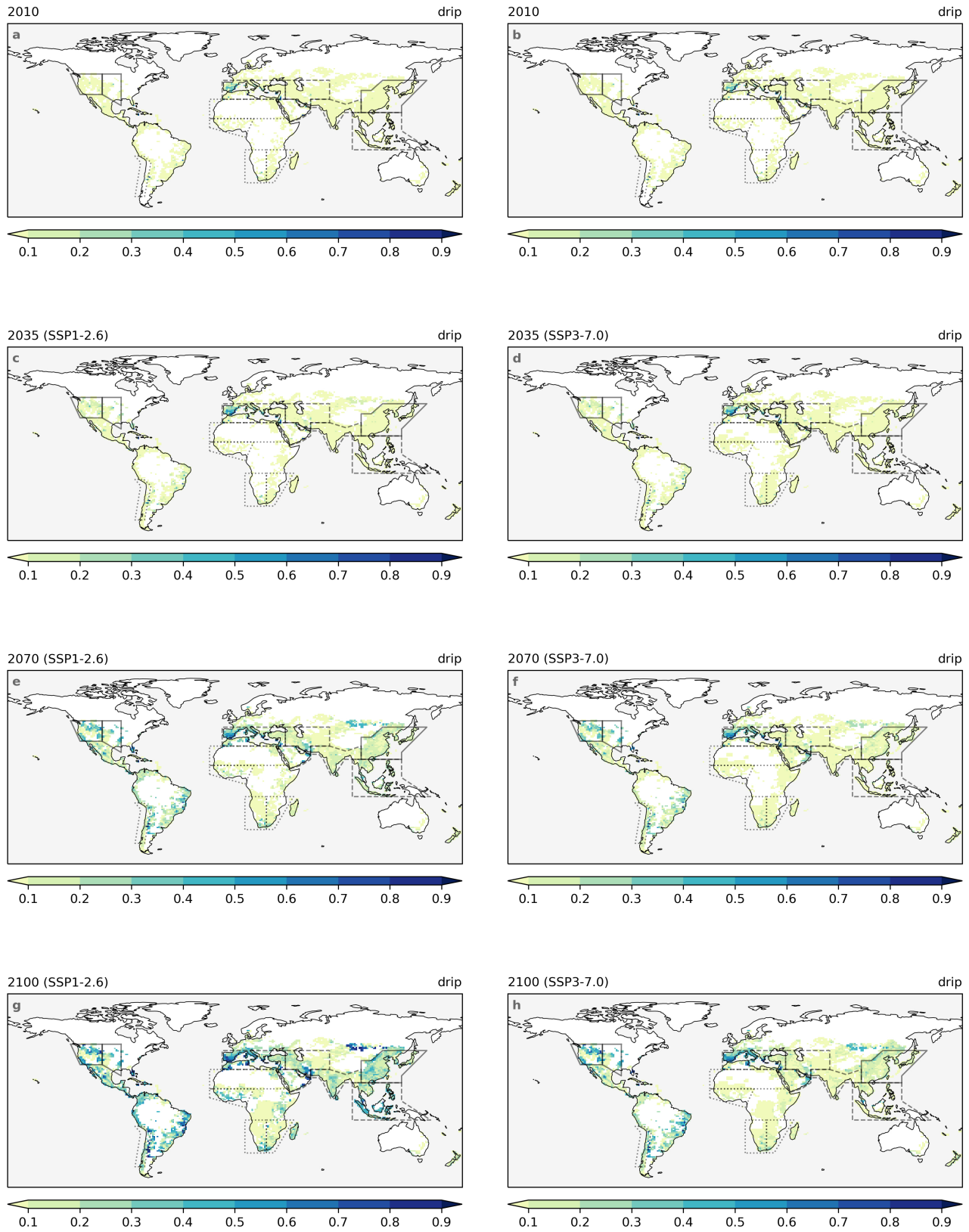
Socio-economic capacity	<0.5	0.5-0.75	0.75-1	1-1.25	>1.25
	-0.8	-0.4	0	+0.4	+0.8
Hydro-climatic complexity	<0.25	0.25-0.5	0.5-0.75	0.75-1	>1
	-0.2	-0.1	0	+0.1	+0.2

2 Supplementary Figures

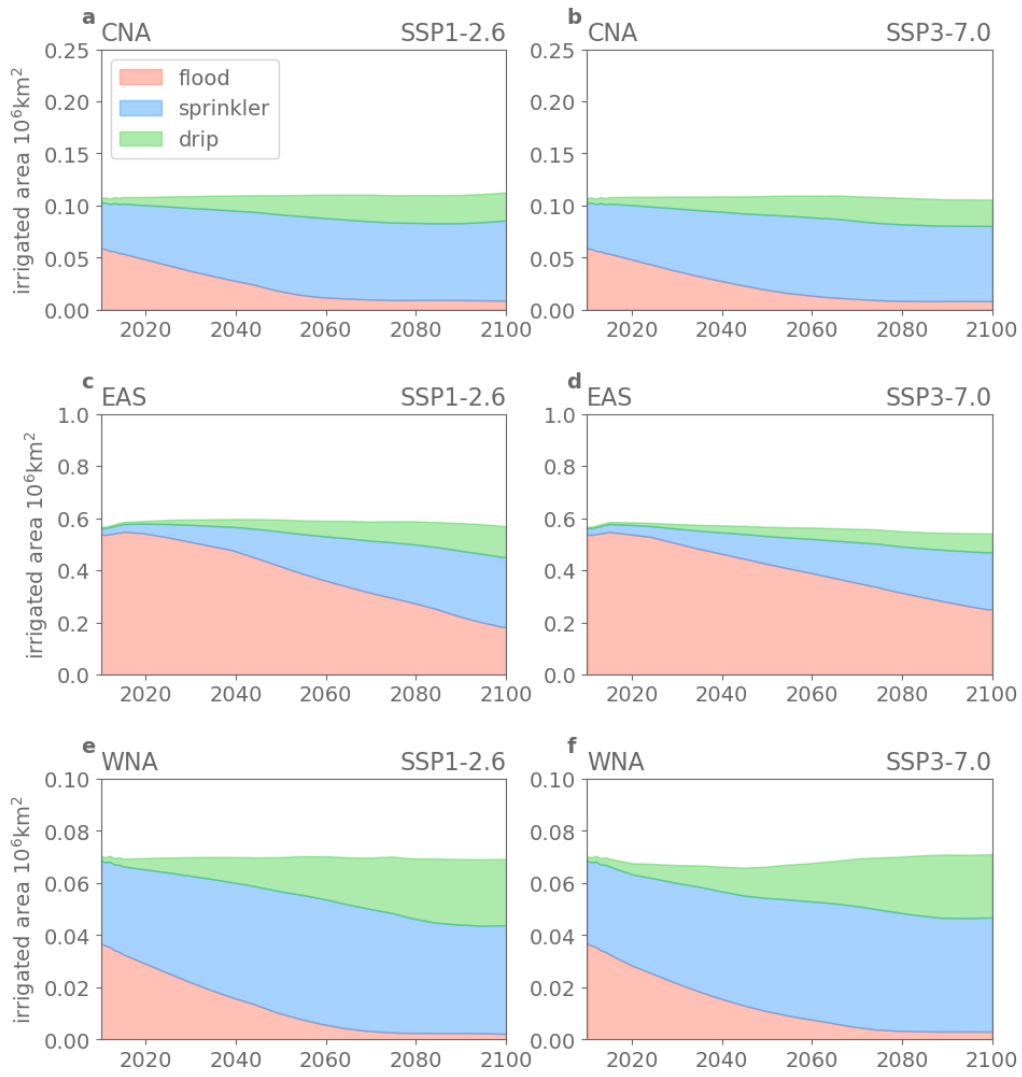
2.1 Supplementary Figures 1: Appendix Figures



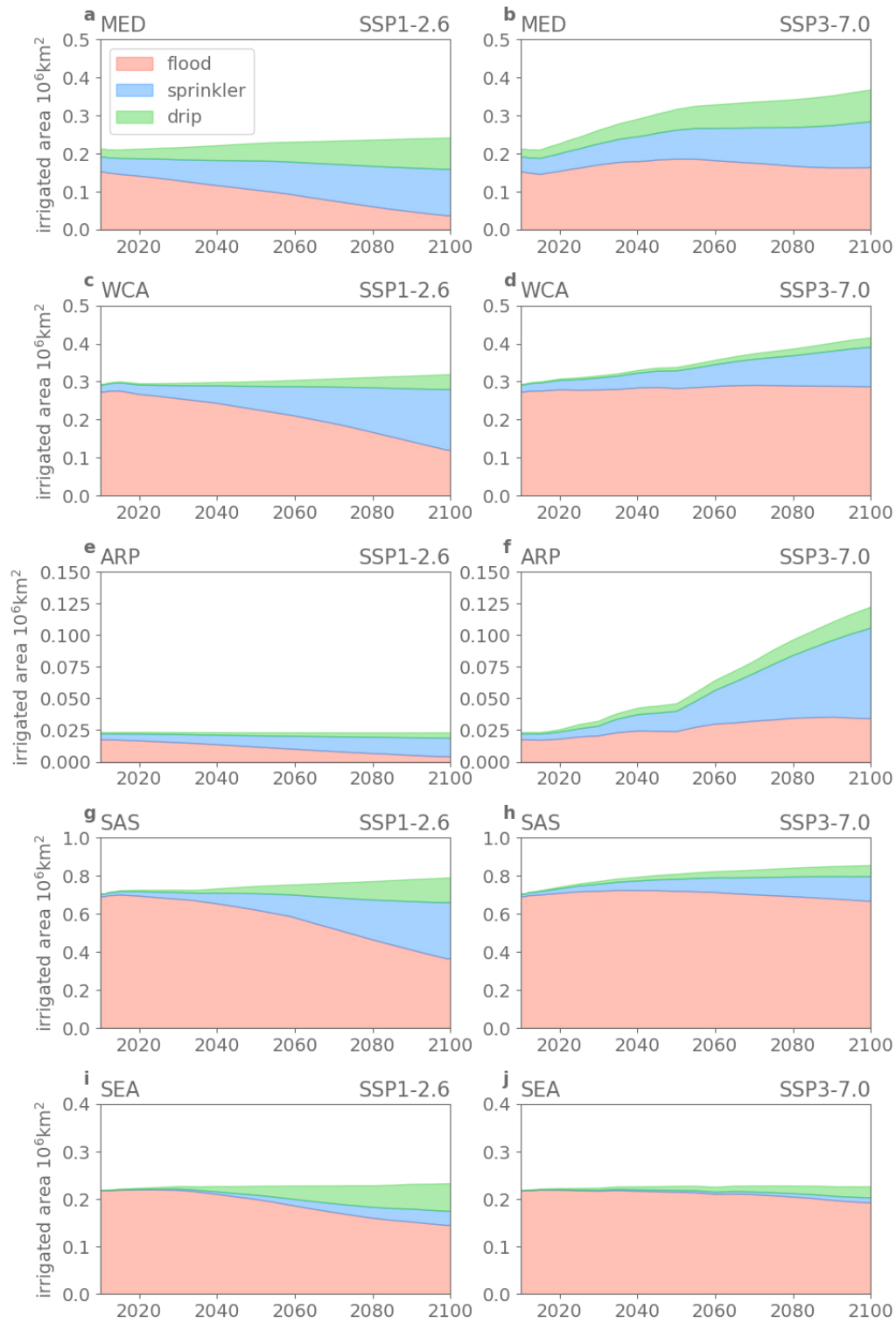
Supplementary Figure S1 | Fraction of sprinkler irrigation in the year 2010 (a-b), 2035 (c-d), 2070 (e-f), and 2100 (g-h), under SSP1-2.6 and SSP3-7.0. The spatial coverage of the IPCC reference regions² used in this study is indicated by solid lines, dashed lines, and dash-dotted lines.



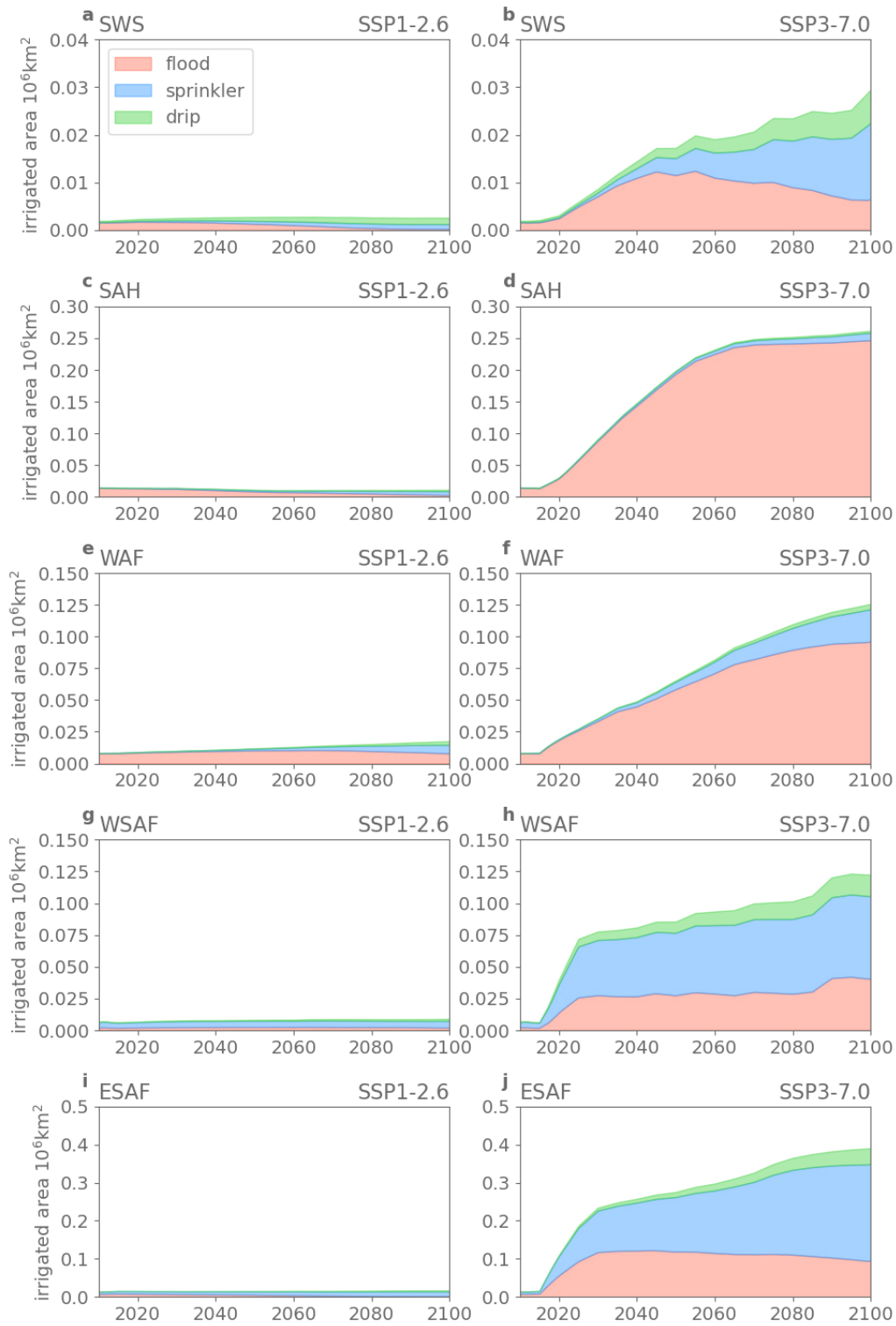
Supplementary Figure S2 | Fraction of drip irrigation in the year 2010 (a-b), 2035 (c-d), 2070 (e-f), and 2100 (g-h), under SSP1-2.6 and SSP3-7.0. The spatial coverage of the IPCC reference regions² used in this study is indicated by solid lines, dashed lines, and dash-dotted lines.



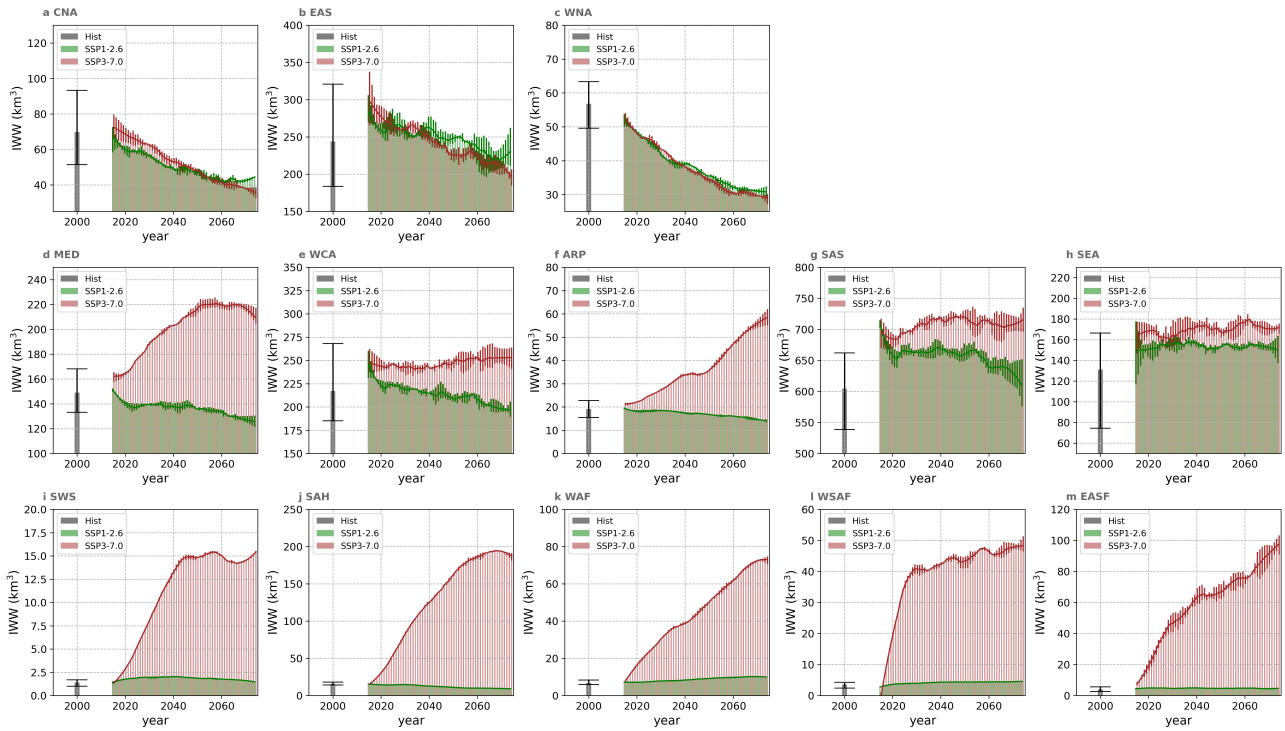
Supplementary Figure S3 | Group 1's regional areas equipped for irrigation (AEI) equipped with different irrigation techniques under SSP1-2.6 (**left column**) and SSP3-7.0 (**right column**). Regions include Central North America (**a,b**), East Asia (**c,d**), and West North America (**e,f**).



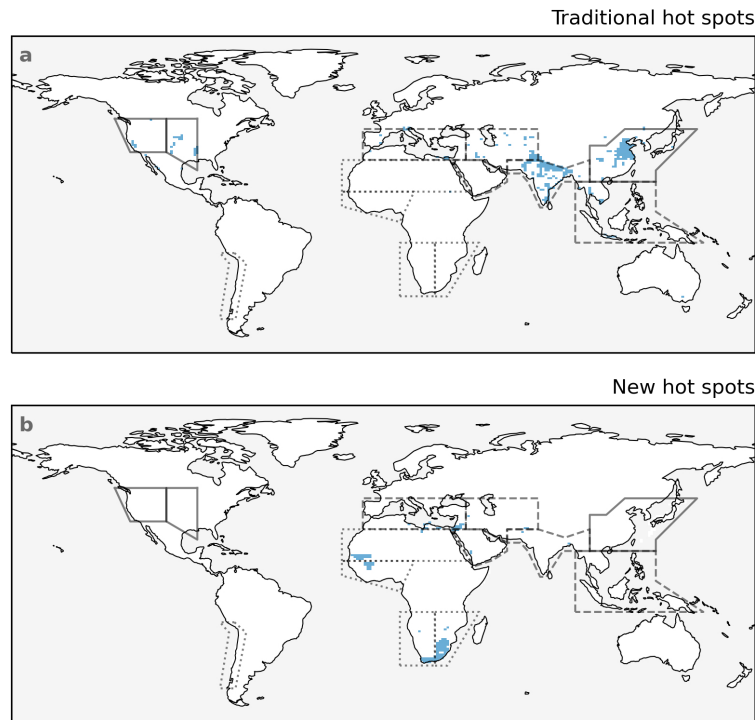
Supplementary Figure S4 | Group 2's regional areas equipped for irrigation (AEI) equipped with different irrigation techniques under SSP1-2.6 (**left column**) and SSP3-7.0 (**right column**). Regions include Mediterranean (**a,b**), West Central Asia (**c,d**), Arabian Peninsula (**e,f**), South Asia (**g,h**), and Southeast Asia (**i,j**).



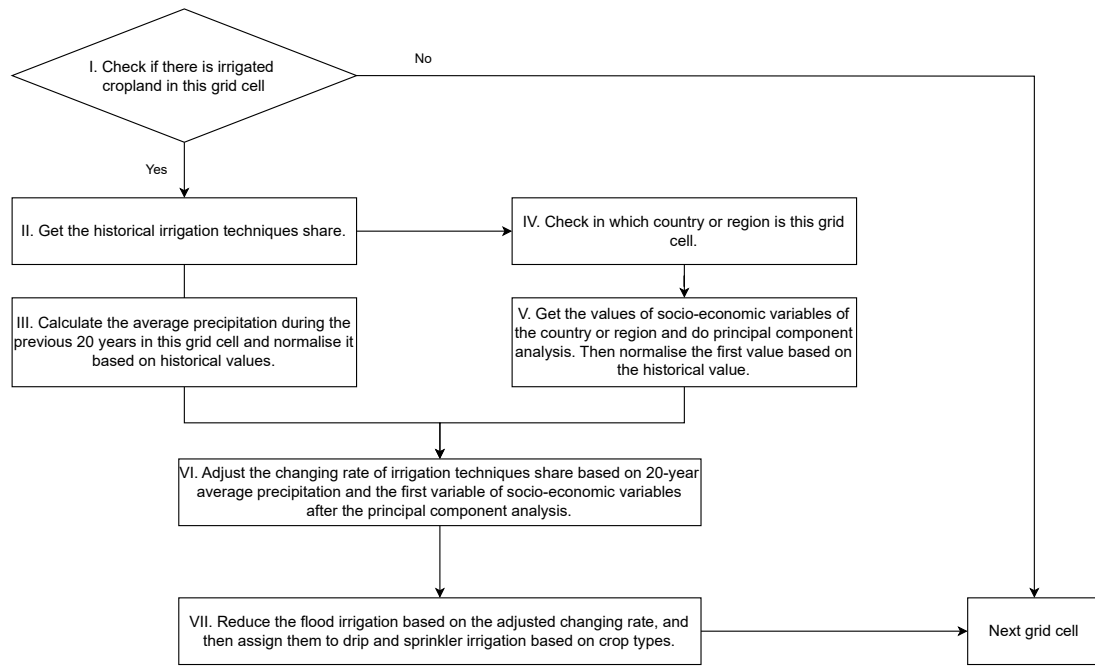
Supplementary Figure S5 | Group 3's regional areas equipped for irrigation (AEI) equipped with different irrigation techniques under SSP1-2.6 (**left column**) and SSP3-7.0 (**right column**). Regions include Southwest South America (**a,b**), Sahara (**c,d**), West Africa (**e,f**), West South Africa (**g,h**), and East South Africa (**i,j**).



Supplementary Figure S6 | Regional summed irrigation water withdrawal of individual regions.

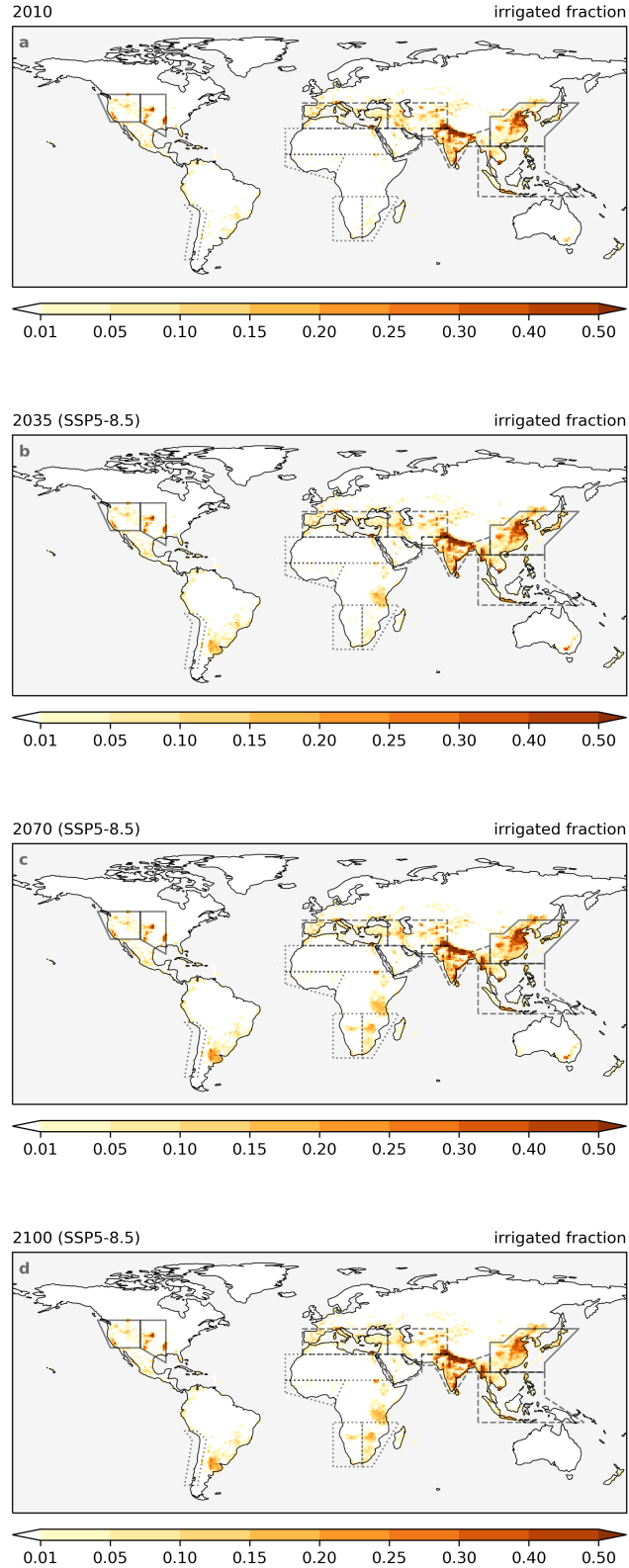


Supplementary Figure S7 | Traditional and new irrigation hot spot grid cells. a Grid cells with more than 20% of irrigated area in the year 2010. **b** Grid cells with less than 20% of irrigated area in the year 2010 but more than 20% in the year 2070 under SSP3-7.0. The spatial coverage of the IPCC reference regions² used in this study is indicated by solid lines, dashed lines, and dash-dotted lines.

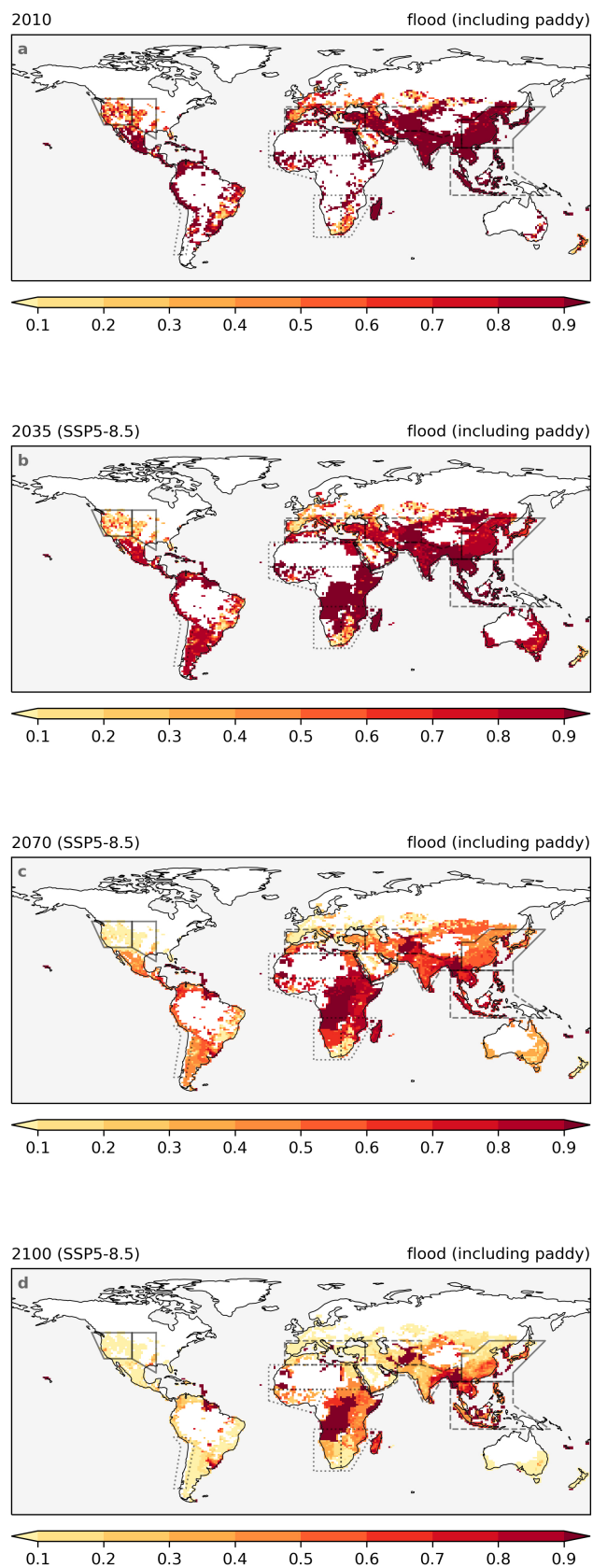


Supplementary Figure S8 | Illustrative flowchart for irrigation techniques share change.

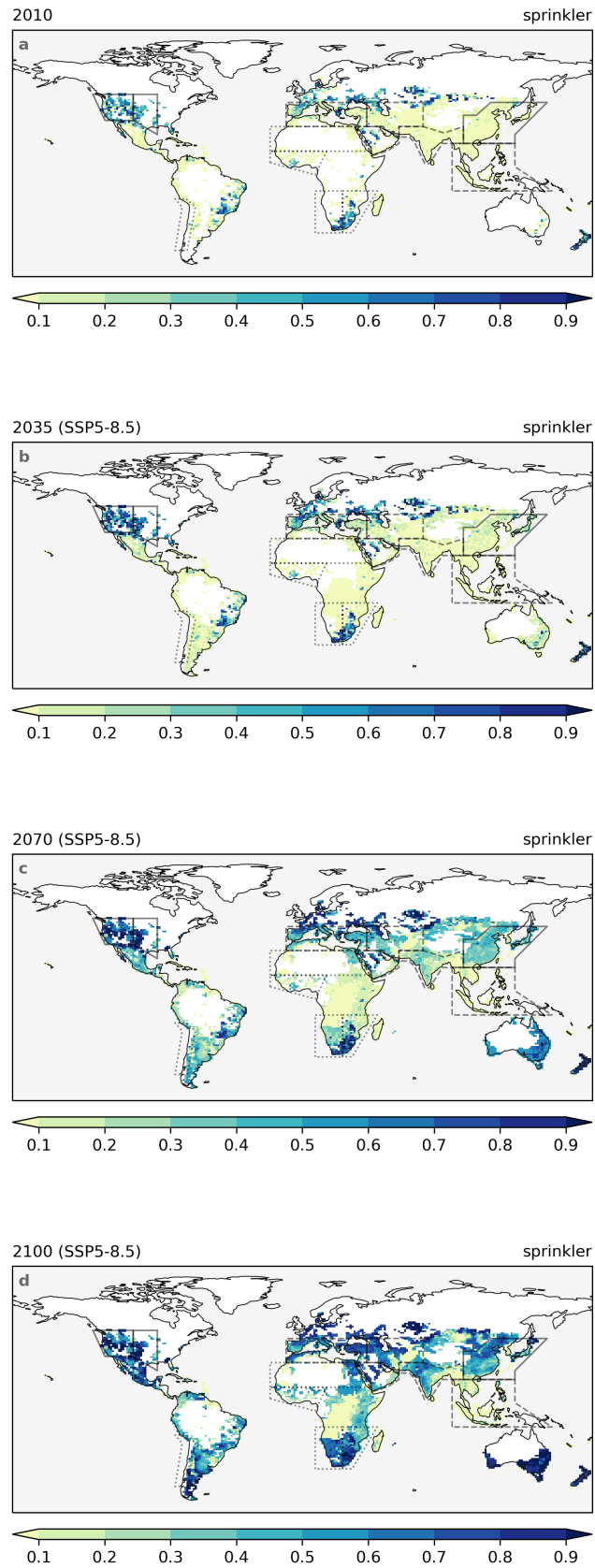
2.2 Supplementary Figures 2: Dataset generated for SSP5-8.5



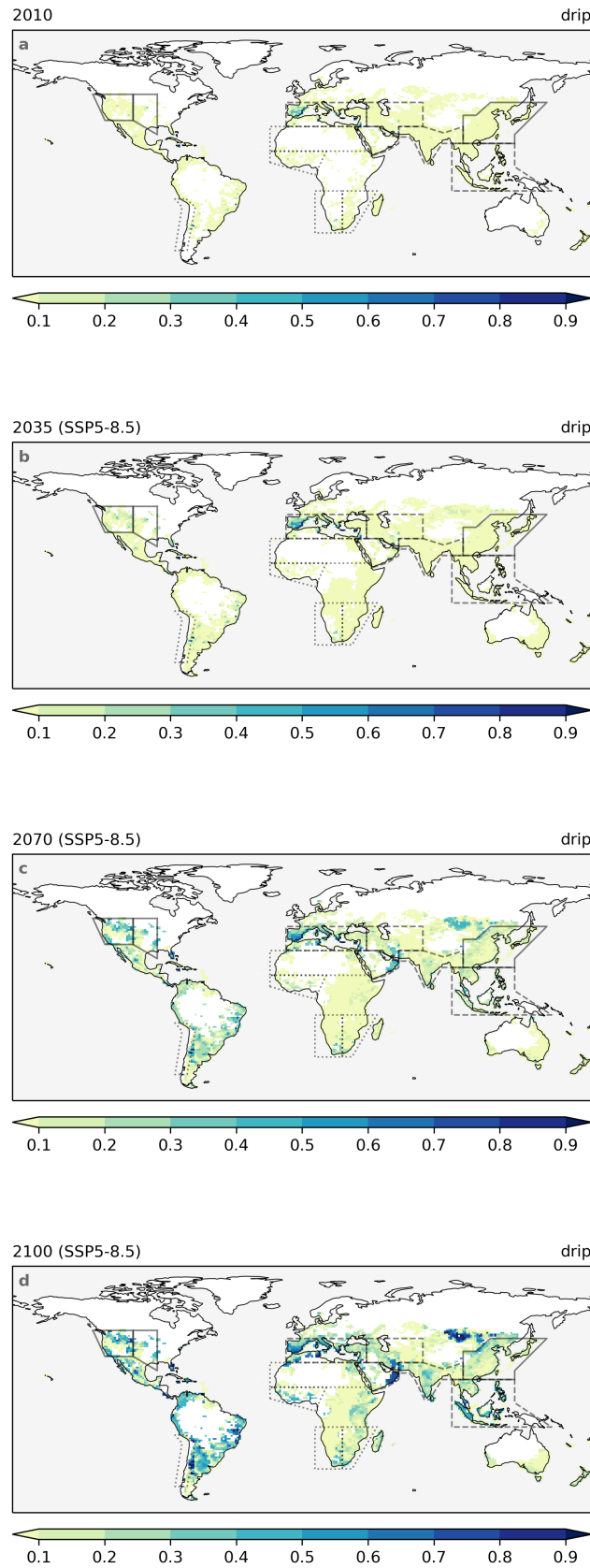
Supplementary Figure S9 | Irrigated fraction in the year 2010 (a), 2035 (b), 2070 (c), and 2100 (d), under SSP5-8.5. The spatial coverage of the IPCC reference regions² used in this study is indicated by solid lines, dashed lines, and dash-dotted lines.



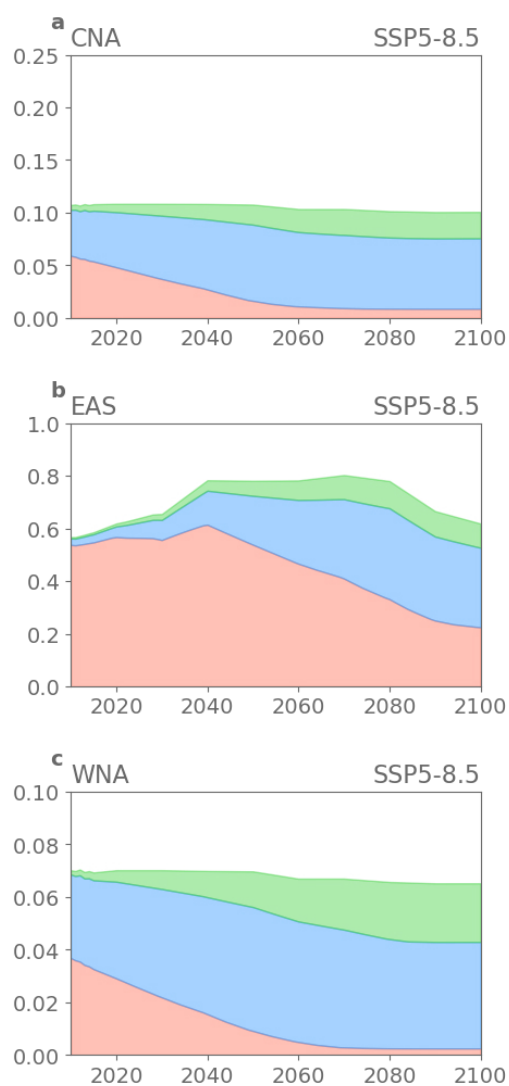
Supplementary Figure S10 | Fraction of flood irrigation in the year 2010 (a), 2035 (b), 2070 (c), and 2100 (d), under SSP5-8.5. The spatial coverage of the IPCC reference regions² used in this study is indicated by solid lines, dashed lines, and dash-dotted lines.



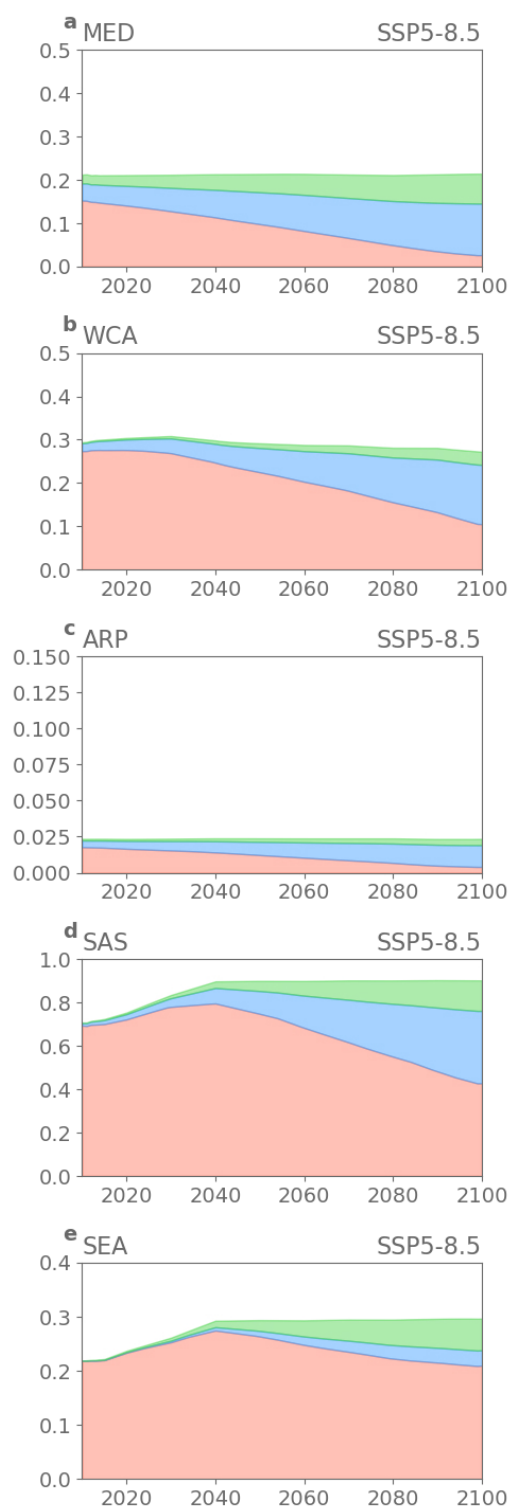
Supplementary Figure S11 | Fraction of sprinkler irrigation in the year 2010 (a), 2035 (b), 2070 (c), and 2100 (d), under SSP5-8.5. The spatial coverage of the IPCC reference regions² used in this study is indicated by solid lines, dashed lines, and dash-dotted lines.



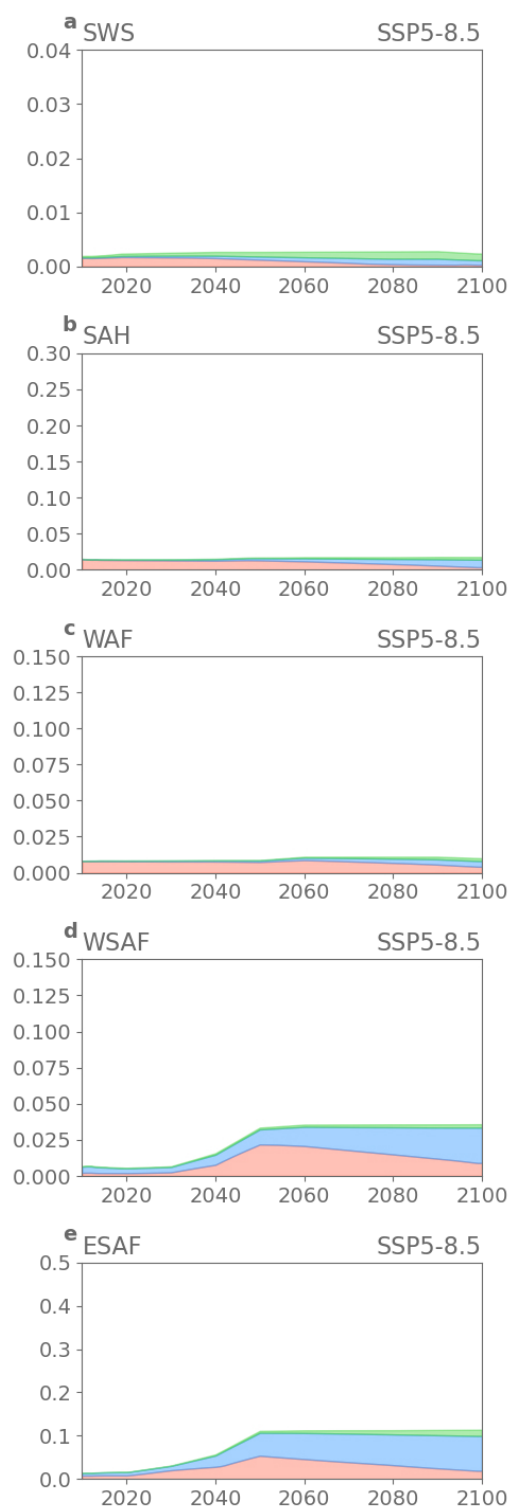
Supplementary Figure S12 | Fraction of drip irrigation in the year 2010 (a), 2035 (b), 2070 (c), and 2100 (d), under SSP5-8.5. The spatial coverage of the IPCC reference regions² used in this study is indicated by solid lines, dashed lines, and dash-dotted lines.



Supplementary Figure S13 | Group 1's regional areas equipped for irrigation (AEI) equipped with different irrigation techniques under SSP5-8.5. Regions include Central North America (**a**), East Asia (**b**), and West North America (**c**).



Supplementary Figure S14 | Group 2's regional areas equipped for irrigation (AEI) equipped with different irrigation techniques under SSP5-8.5. Regions include Mediterranean (**a**), West Central Asia (**b**), Arabian Peninsula (**c**), South Asia (**d**), and Southeast Asia (**e**).



Supplementary Figure S15 | Group 3's regional areas equipped for irrigation (AEI) equipped with different irrigation techniques under SSP5-8.5. Regions include Southwest South America (a), Sahara (b), West Africa (c), West South Africa (d), and East South Africa (e).

Supplementary References

- [1] Jägermeyr, J., Gerten, D., Heinke, J., Schaphoff, S., Kummu, M. & Lucht, W. Water savings potentials of irrigation systems: global simulation of processes and linkages. *Hydrology And Earth System Sciences*. **19**, 3073-3091 (2015)
- [2] Iturbide, M., Gutiérrez, J., Alves, L., Bedia, J., Cerezo-Mota, R., Gimadevilla, E., Cofiño, A., Di Luca, A., Faria, S., Gorodetskaya, I. & Others An update of IPCC climate reference regions for subcontinental analysis of climate model data: definition and aggregated datasets. *Earth System Science Data*. **12**, 2959-2970 (2020)