

Seasonal shifts in temperate grassland productivity under future climate scenarios

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Permanent grasslands and climate change

Importance of
grasslands

66% of Belgium's permanent grasslands are in Wallonia

They represent 41.8% of the utilized agricultural area

Climate change
pressure

Rising temperatures and changing precipitation patterns

Seasonal productivity shifts and increased risks of drought stress

Modeling
approach

Process-based modeling framework for grassland systems

Used to investigate potential future responses of grassland
systems

Climate and soil data

Temperature	Model	Period	CO ₂ (ppm)
+2	CMCC	2024 - 2053	429
	MPI	2036 - 2065	545
	MIR	2045 - 2074	592
+3	CMCC	2048 - 2077	605
	MPI	2066 - 2095	722
	MIR	2071 - 2100	757
+4	CMCC	2060 - 2079	741
	MPI	2081 - 2100	1005
	MIR	2081 - 2100	1005

ERA5 reanalysis (1981-2010)

Global warming levels: +2°C, +3°C, +4°C

Three CMIP6 models (2024 - 2100)

CMCC : drier / moderately warm

MPI : intermediate

MIROC6 (MIR) : wetter

Time Windows

30 years: +2°C and +3°C

20 years: +4°C.

Weather data resolution: 5 km × 5 km

Walloon soil database (0.25 km × 0.25 km)

Grassland Management

Residual cutting height: 5 cm

Cutting triggered by biomass threshold and suitable weather conditions

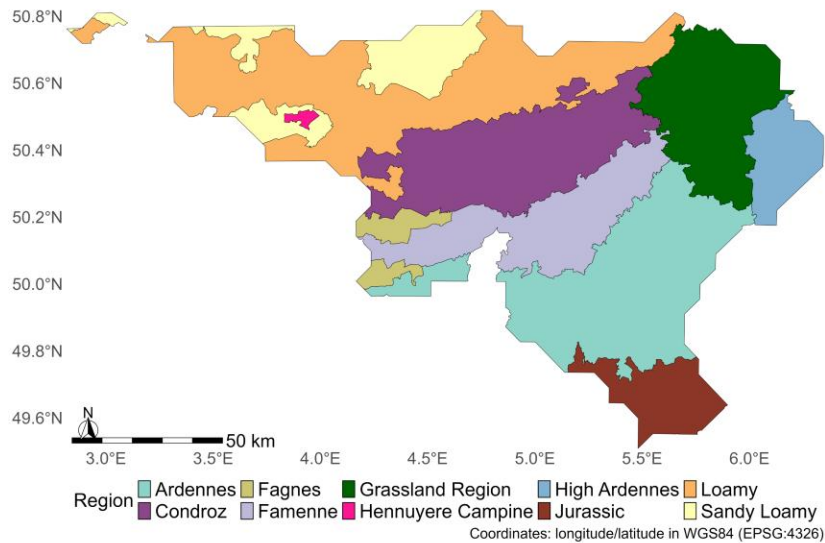
Maximum 3 fertilization events per year

Simulations focused on two species: *Dactylis glomerata* and *Lolium perenne*.

Gras-Sim: process-based model of grassland dynamics

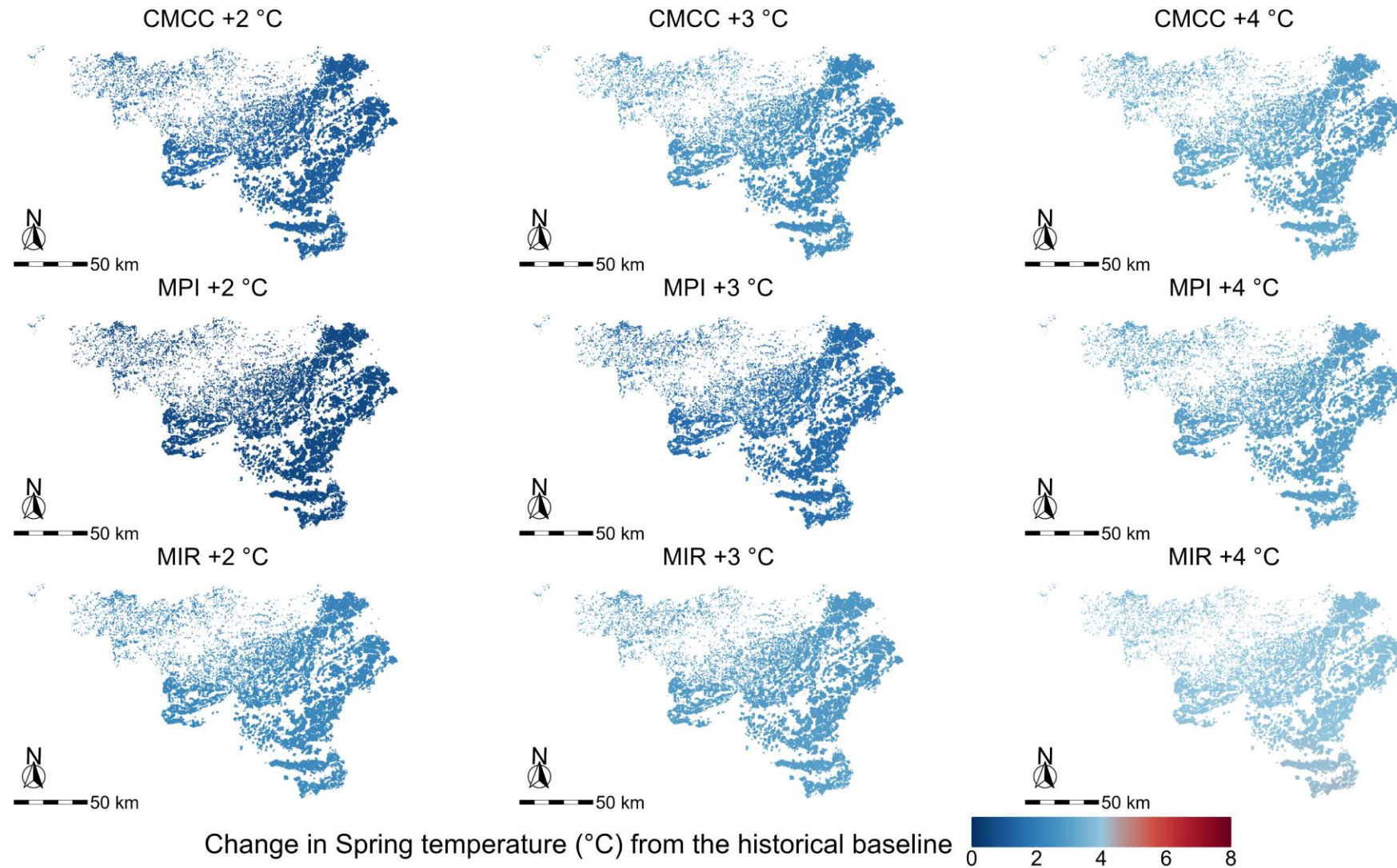
Season	Biomass threshold (t DM ha ⁻¹)	Rainfall condition for the cut	Fertilization (kg N ha ⁻¹)
Spring	> 3.0	3 days < 2 mm day ⁻¹	60 (before cut 1)
Summer	> 2.0	2 days < 2 mm day ⁻¹	50 (5 days after cut 1)
Autumn	> 1.5	2 days < 2 mm day ⁻¹	40 (5 days after cut 2)

Agricultural regions of Wallonia

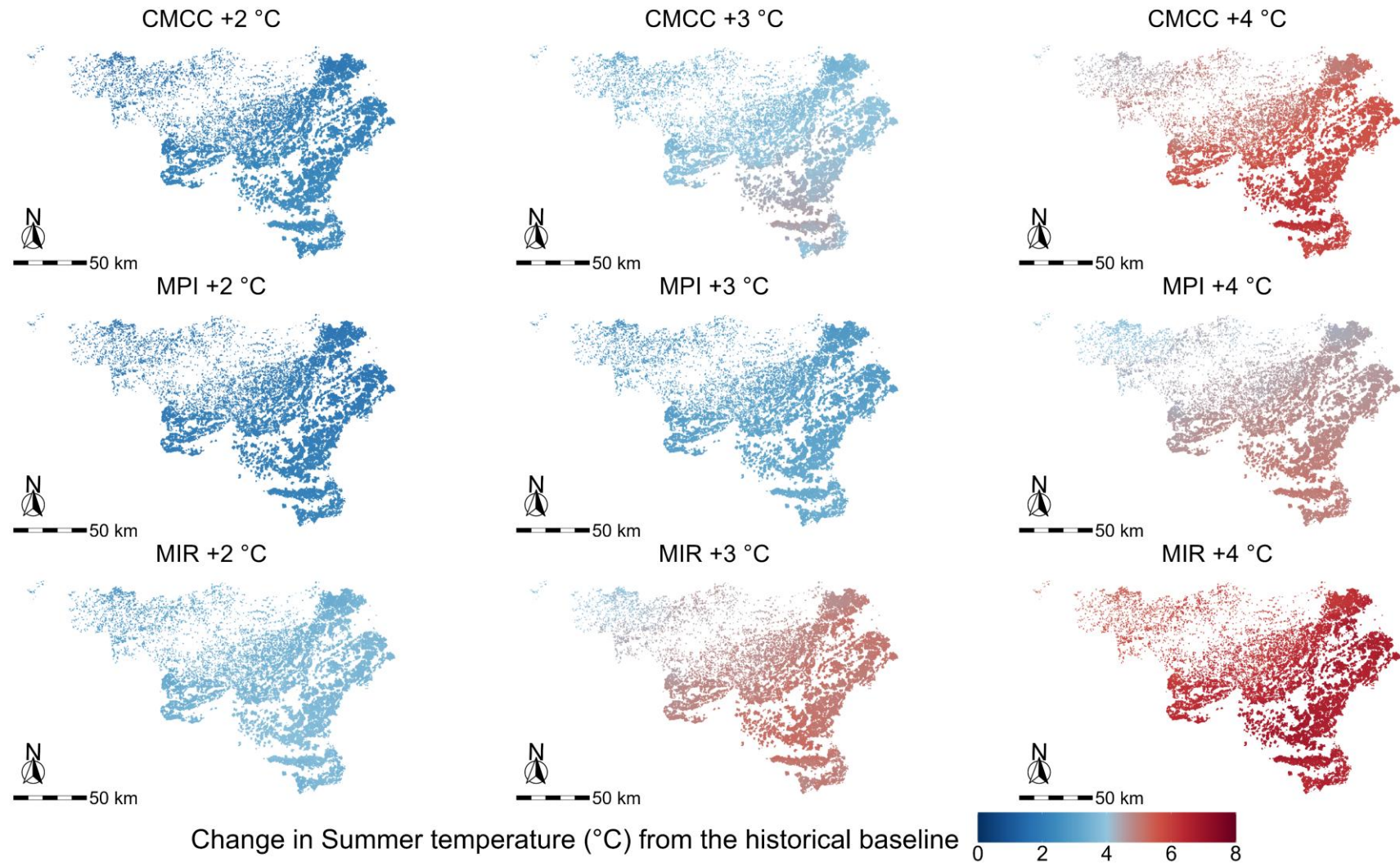


Region	Dominant soils & landform	Typical historical yield (t DM ha ⁻¹ year ⁻¹)
Loamy	Deep, fertile	7-11
Condroz	Hilly, calcareous-clayey	6.5-11
Famenne	Shallow, cherty, calcareous	5-8
Ardennes	High altitude, shallow, acidic,	6-10
High Ardennes	Coldest and wettest region	5.5-9
Grassland Region	Rugged, heavy soils, bocage	6.5-11
Fagnes	Variable soils, frequent waterlogging	4.5-7
Jurassic	Clay-limestone and marly	6.5-11
Sandy-Loamy	Sandy-loamy	7-11
Hennuyere Campine	Poor, sandy soils	6.5-11

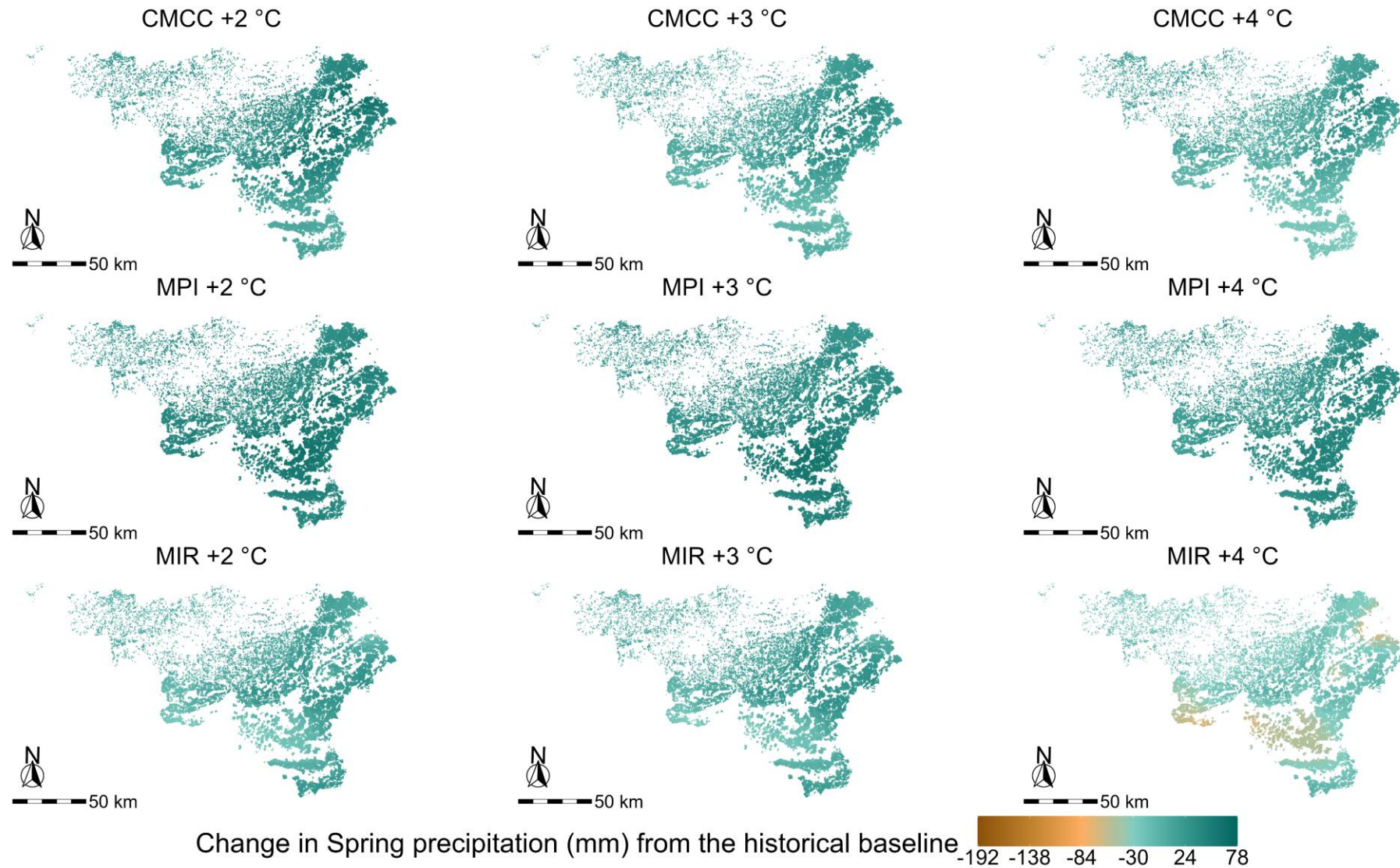
Spring temperature change vs. historical baseline



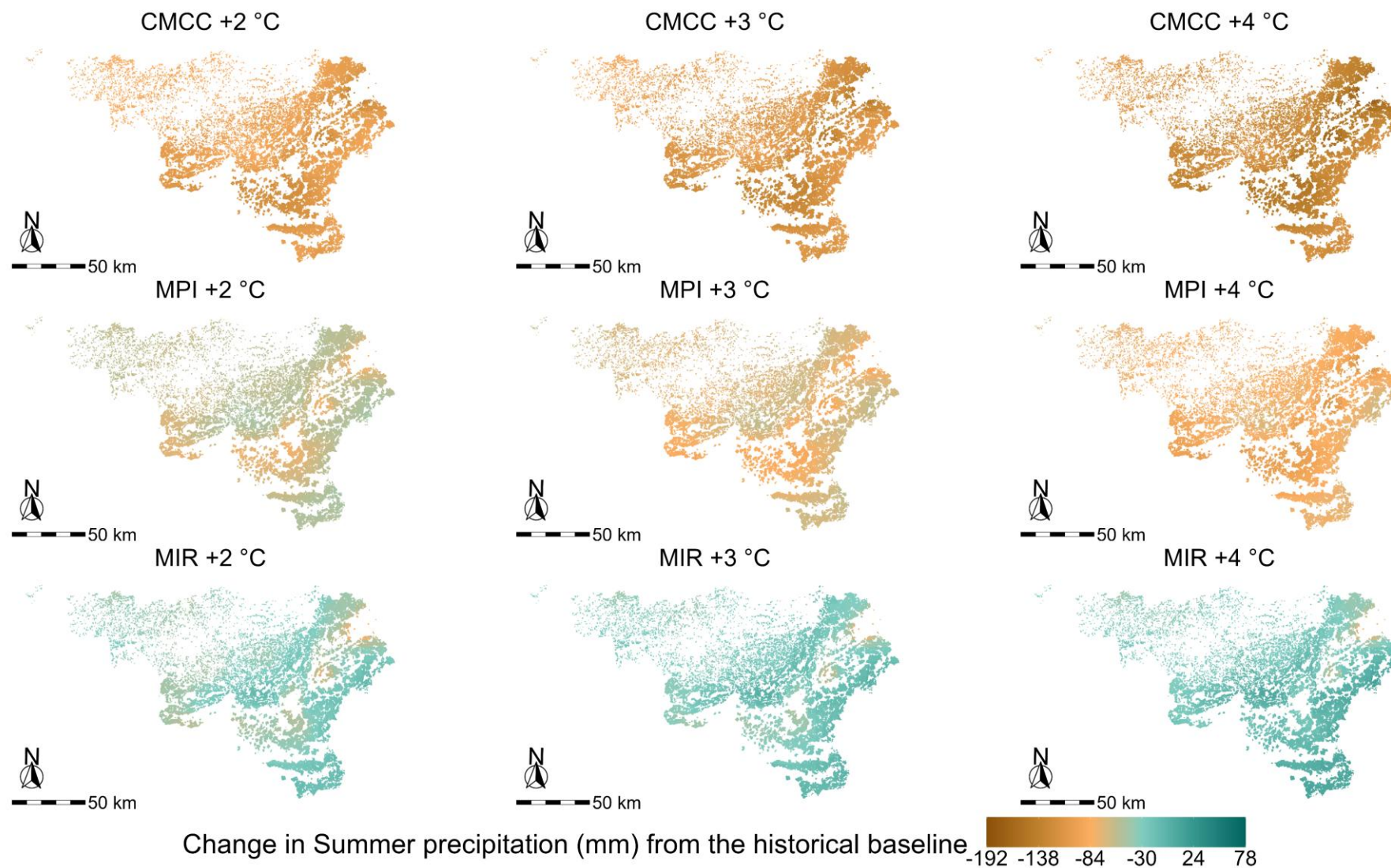
Summer temperature change vs. historical baseline



Spring precipitation change vs. historical baseline



Summer precipitation change vs. historical baseline



Seasonal yield changes across models and regions

Category	Type	Group	Spring		Summer		Autumn	
			Δ Yield (t DM ha ⁻¹)	Rank	Δ Yield (t DM ha ⁻¹)	Rank	Δ Yield (t DM ha ⁻¹)	Rank
Model ranking	Climate model	MIR	3.54 ± 1.05	1	-1.75 ± 0.97	—	0.04 ± 1.10	—
		MPI	2.06 ± 1.45	2	-0.78 ± 0.96	—	-0.47 ± 1.24	—
		CMCC	2.00 ± 1.46	3	-1.24 ± 1.10	—	-0.56 ± 1.21	—
Region ranking	Region	High Ardennes	2.60 ± 1.51	1	-0.93 ± 0.99	1	0.14 ± 1.16	1
		Ardennes	2.56 ± 1.52	3	-0.94 ± 1.05	2	-0.14 ± 1.2	2
		Fagnes	2.55 ± 1.55	6	-1.11 ± 1.09	3	-0.15 ± 1.17	3
		Grassland Region	2.48 ± 1.49	10	-1.31 ± 1.04	6	-0.36 ± 1.2	5
		Condroz	2.53 ± 1.53	8	-1.33 ± 1.07	7	-0.2 ± 1.25	4
		Famenne	2.51 ± 1.51	9	-1.28 ± 1.09	4	-0.48 ± 1.13	7
		Sandy Loamy	2.55 ± 1.55	5	-1.43 ± 1.15	8	-0.5 ± 1.18	8
		Loamy	2.56 ± 1.54	4	-1.45 ± 1.13	9	-0.38 ± 1.17	6
		Hennuyere Campine	2.57 ± 1.56	2	-1.46 ± 1.15	10	-0.54 ± 1.12	9
		Jurassic	2.54 ± 1.49	7	-1.28 ± 1.06	5	-0.97 ± 1.26	10

Seasonal yield changes under warming scenarios

Model	Season	Warming level +2 °C		Warming level +3 °C		Warming level +4 °C	
		$\Delta \pm \text{SD (t DM ha}^{-1}\text{)}$	P value	$\Delta \pm \text{SD (t DM ha}^{-1}\text{)}$	P value	$\Delta \pm \text{SD (t DM ha}^{-1}\text{)}$	P value
CMCC	Spring	-0.06 ± 0.07	< 0.001	3.02 ± 0.09	< 0.001	3.03 ± 0.09	< 0.001
CMCC	Summer	-0.07 ± 0.21	< 0.001	-1.80 ± 0.90	< 0.001	-1.84 ± 0.86	< 0.001
CMCC	Autumn	0.24 ± 1.37	< 0.001	-0.88 ± 0.93	< 0.001	-1.04 ± 0.85	< 0.001
MIR	Spring	3.06 ± 0.08	< 0.001	3.10 ± 0.09	< 0.001	4.48 ± 1.42	< 0.001
MIR	Summer	-1.64 ± 0.98	< 0.001	-1.52 ± 1.04	< 0.001	-2.43 ± 0.22	< 0.001
MIR	Autumn	-0.50 ± 1.02	< 0.001	-0.25 ± 0.96	< 0.001	0.86 ± 0.84	< 0.001
MPI	Spring	0.00 ± 0.10	< 0.001	3.09 ± 0.10	< 0.001	3.08 ± 0.08	< 0.001
MPI	Summer	0.14 ± 0.17	< 0.001	-1.69 ± 0.97	< 0.001	-0.80 ± 0.39	< 0.001
MPI	Autumn	0.47 ± 1.21	< 0.001	-0.59 ± 1.07	< 0.001	-1.29 ± 0.67	< 0.001

Seasonal redistribution of grassland productivity

Main findings

- Climate change induces a redistribution of grassland growth across seasons.
- Spring productivity increases, reflecting earlier phenological development under warmer conditions.
- Summer yields decline consistently across models, driven by increasing drought stress.
- Autumn responses remain uncertain, depending on precipitation and soil water availability.

Implications

- Earlier spring growth may advance cutting or grazing dates.
- Summer forage deficits may increase, requiring reductions in stocking rates or supplementary feeding.

Thank you!

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Grassland vulnerability to climate change varies by region and season through productivity-stability trade-offs

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ABSTRACT

Understanding the vulnerability of permanent grasslands to climate change is essential for sustaining forage production and other ecosystem services. Potential adaptation levers include adjustments in management strategies and the selection of plant functional types (PFTs). This study quantifies changes in biomass yield and interannual stability of temperate permanent grasslands under future climate scenarios, using Gras-Sim, a process-based model integrating climate, soil management, and PFT composition. Simulations were performed for contrasting agricultural regions at +2 °C, +3 °C, and +4 °C warming levels, using downscaled CMIP6 projections (CMCC, MIR, MPI) with corresponding CO₂ trajectories. Significant interactions between region, climate model, and PFT ($P < 0.001$) revealed context-dependent responses. In high-altitude regions such as the High Ardennes, annual yields increased by up to 2.52 t DM ha⁻¹ compared to the historical baseline (1981–2010). Across all scenarios, PFT B (e.g. *Dactylis glomerata*) exhibited significantly higher yields, while PFT A (e.g. *Lolium perenne*) showed significantly higher interannual stability, confirming a productivity-stability trade-off. Seasonal shifts were more pronounced under MIR +4 °C, with spring yields increasing by 4.5 t DM ha⁻¹ and summer yields decreasing by 2.4 t DM ha⁻¹ relative to historical baselines ($P < 0.001$). The frequency of pixel-years without a summer cut increased up to 14% under MIR at +4 °C, highlighting an emergent signal of production collapse during peak drought. These results support the need for adaptation strategies that combine functional complementarity, flexible management, and spatially explicit simulation tools to sustain grassland productivity and stability under climate change.