Impact of groundwater – soil moisture interaction on evolution of evapotranspiration and air temperature under climate change

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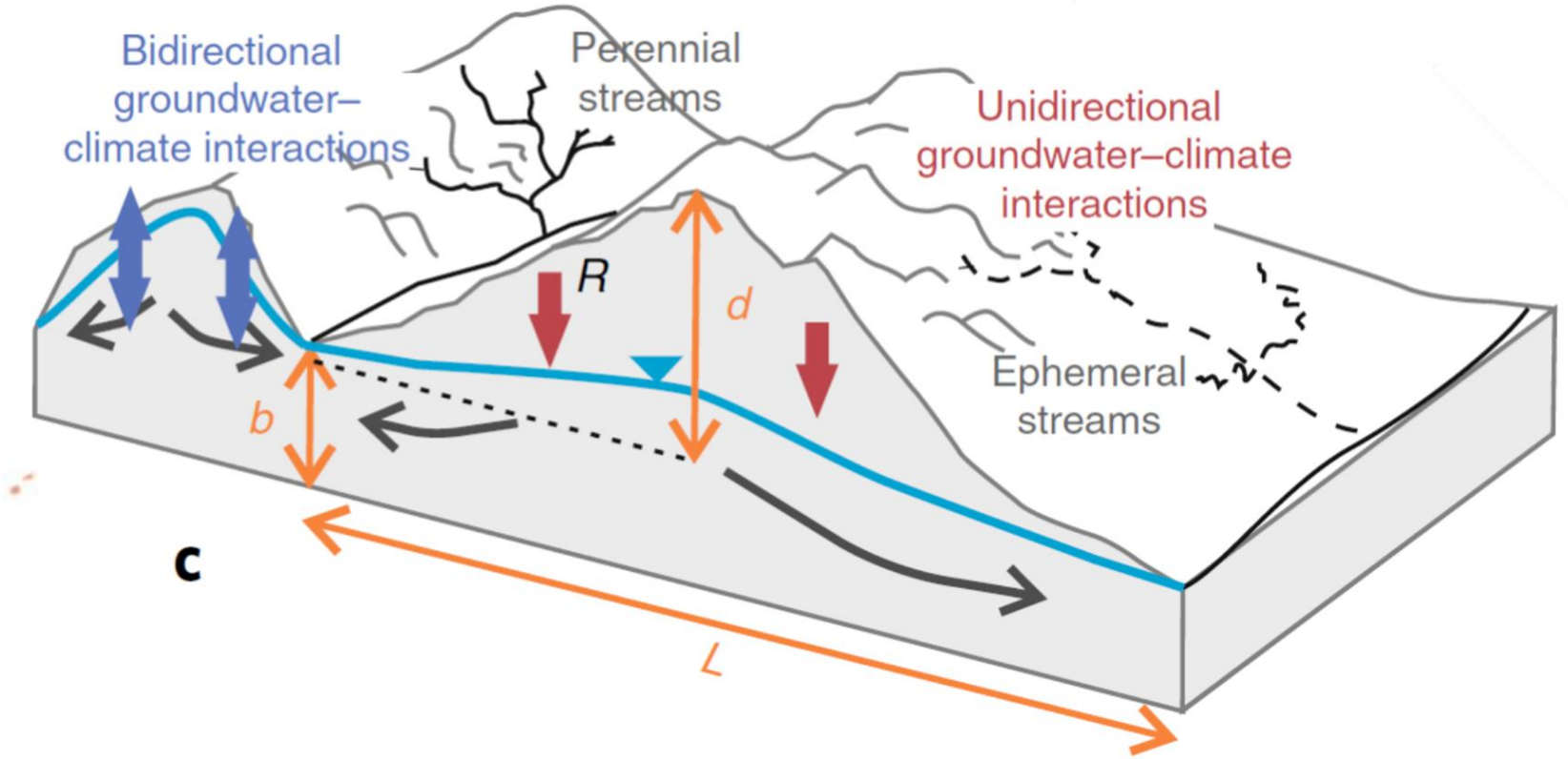
1. Introduction
2. ORCHIDEE-Hillslope
3. Experiment setup and input data
4. Effect of hillslope flow in current climate
5. Modulation of climate change projection
6. Regional analysis of the modulation
7. Conclusions

1. Introduction

- Groundwater (GW) may sustain soil moisture (SM) through hillslope flows.
- If it is shallow enough, GW can support bidirectional interactions with the atmosphere.
- It implies complex land-atmosphere feedbacks in climate models. And may impact climate change projections.

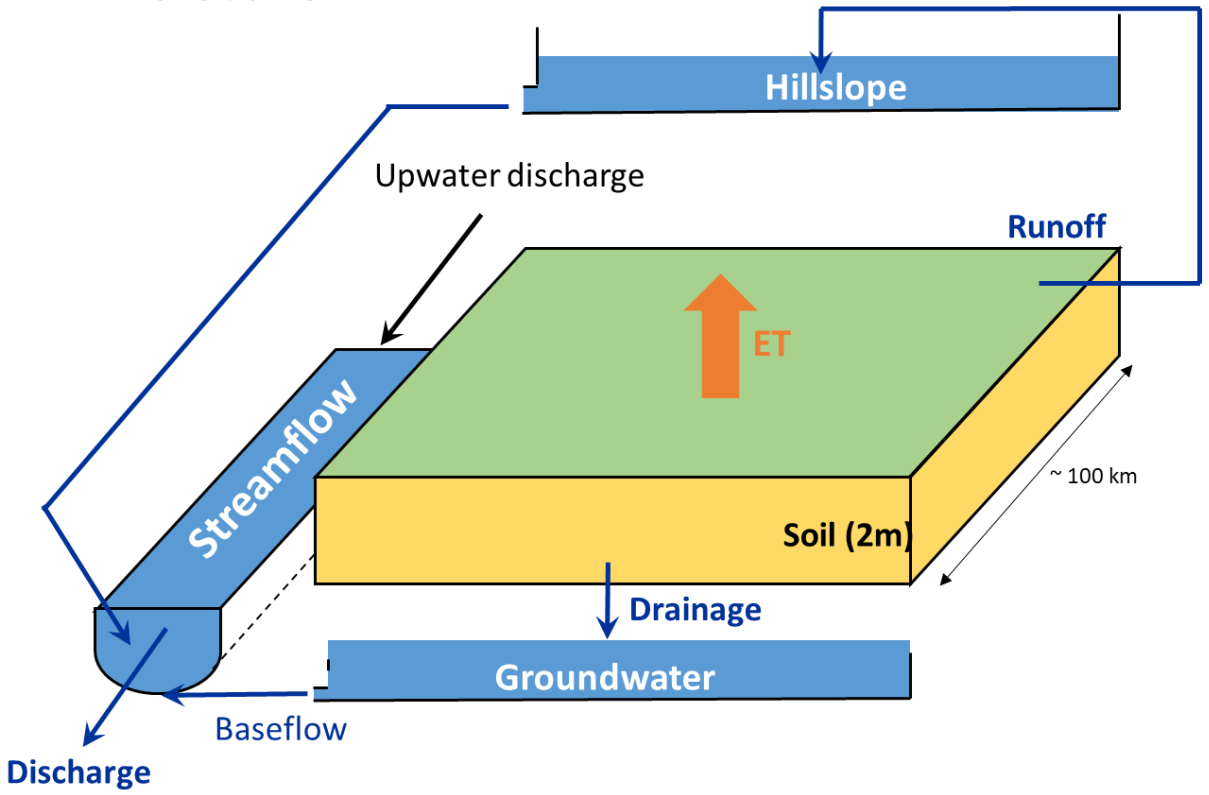


Taken from Cuthbert et al., 2019

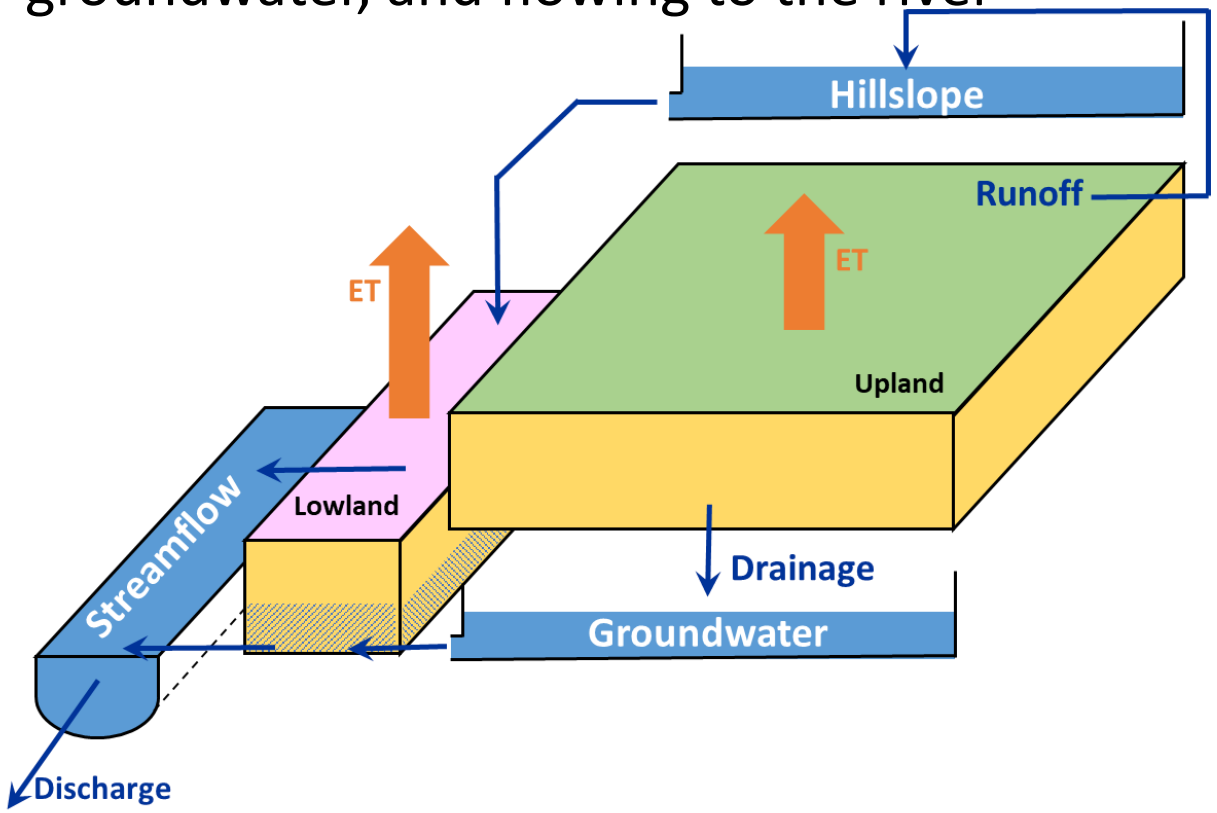
Goal: to asses the impact of hillslope flows on evapotranspiration and temperature in present climate and on its evolution during the XXI century, using LMDZ-ORCHIDEE coupled simulations

2. ORCHIDEE-Hillslope

Default version of ORCHIDEE does not represent GW interaction with soil moisture



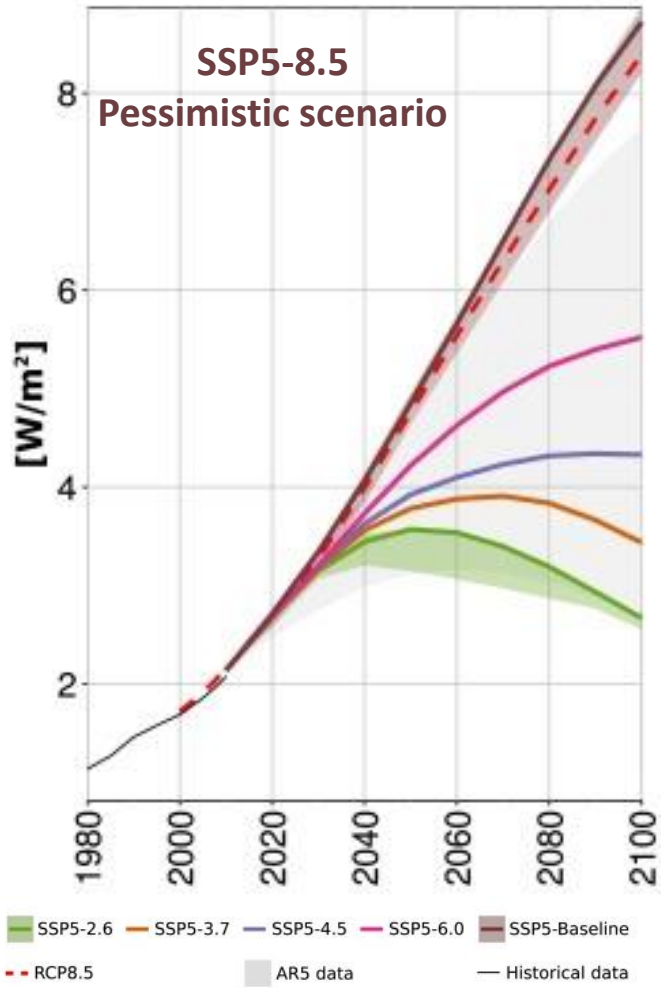
New version, **ORCHIDEE-Hillslope**, adds a lowland fraction, fed by small channels and groundwater, and flowing to the river



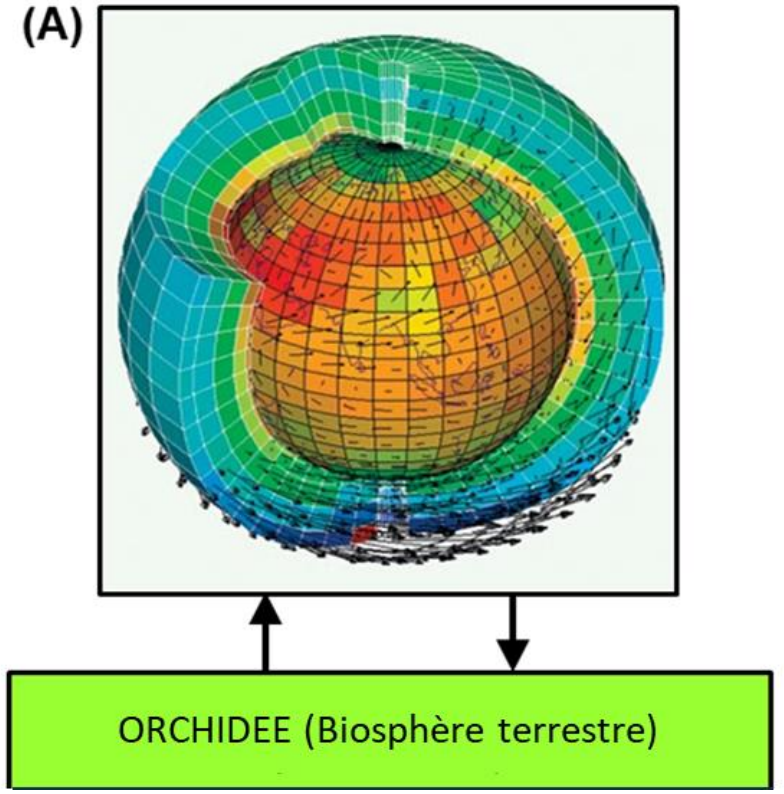
It introduces a **potentially wetter fraction** in the grid cell (the lowland fraction, equivalent to a riparian wetland) due to topography

3. Experiment setup and input data

Radiative forcing scenario



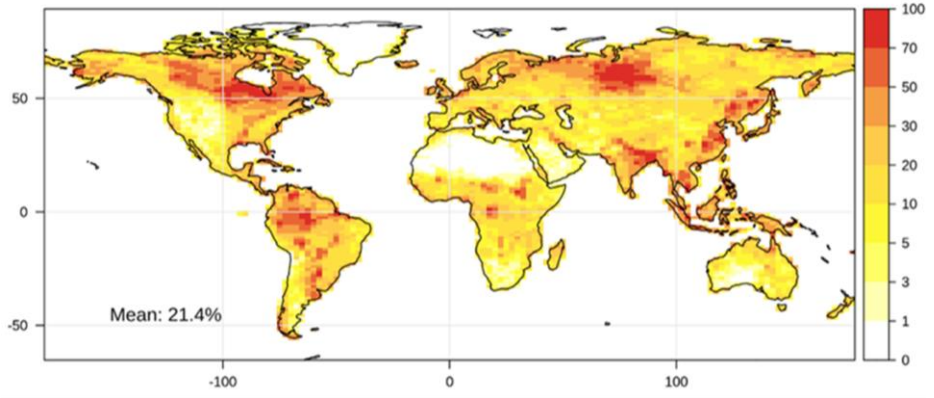
Climate model
IPSL-CM6-LR



Land + Atmosphere (LMDZORC) simulations with prescribed ocean

Two climate change simulation:
REF (Default) vs **GWF (With ORC-Hillslope)**

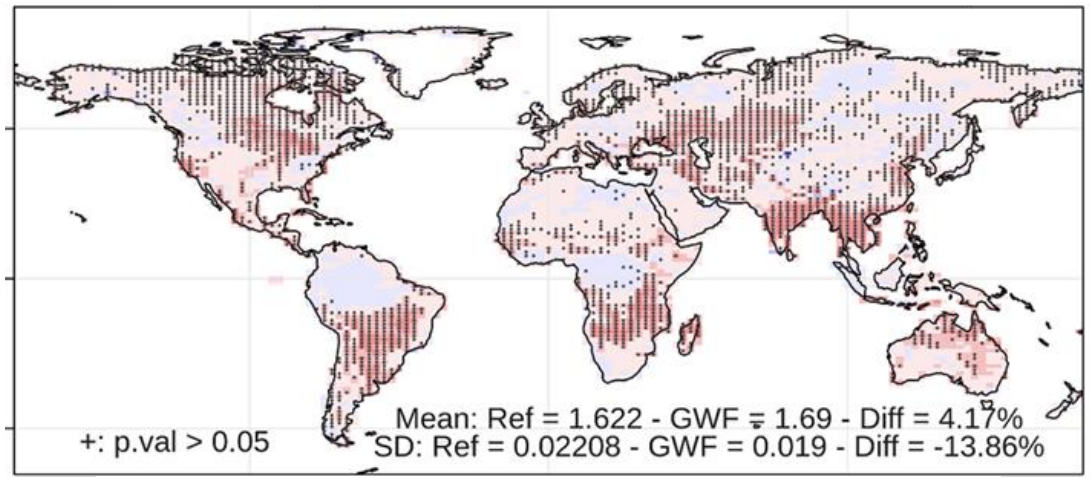
Lowland fraction is prescribed from a global wetland map for **GWF** simulation



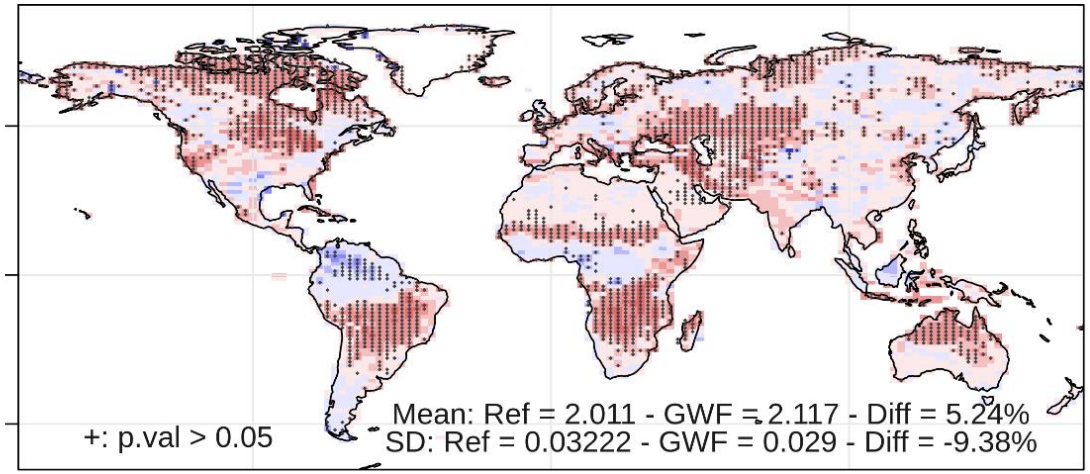
4. Effect of hillslope flow in current climate

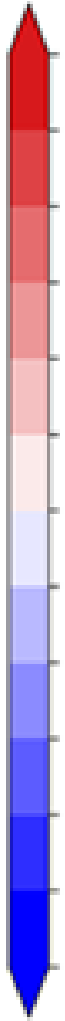
GWF – REF diff. 1980 – 2009

ET - yearly (mm/day)

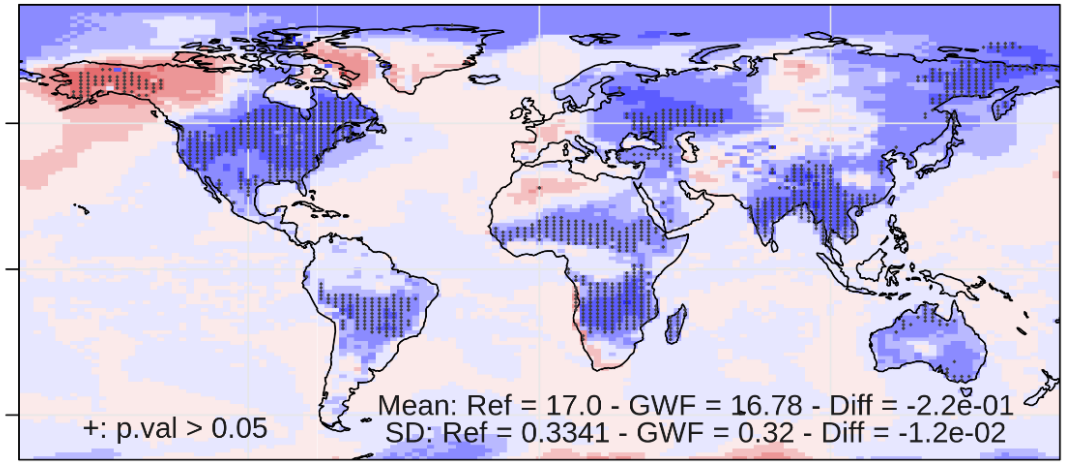


ET - JJA (mm/day)

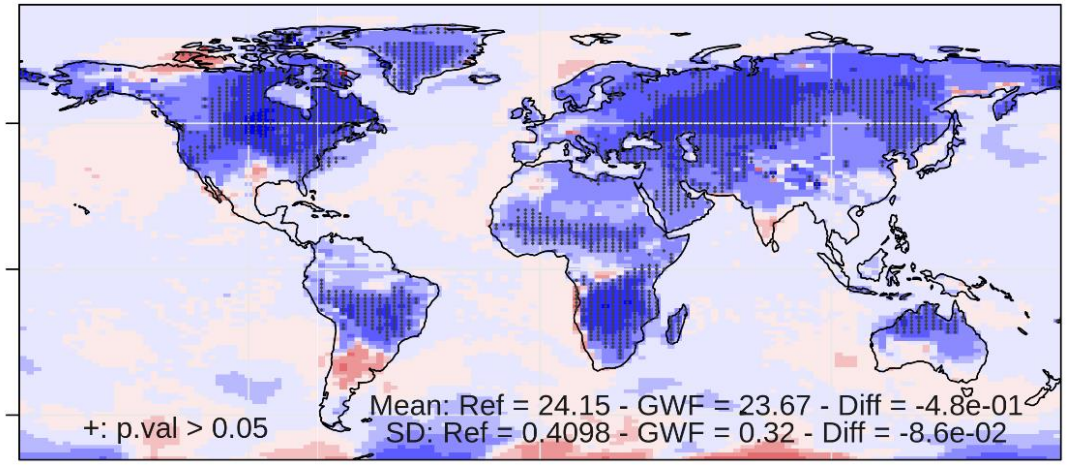


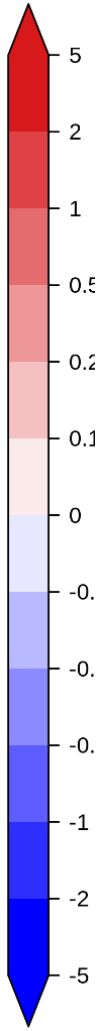


Max. air temperature - yearly (°C)



Max. air temperature - JJA (°C)



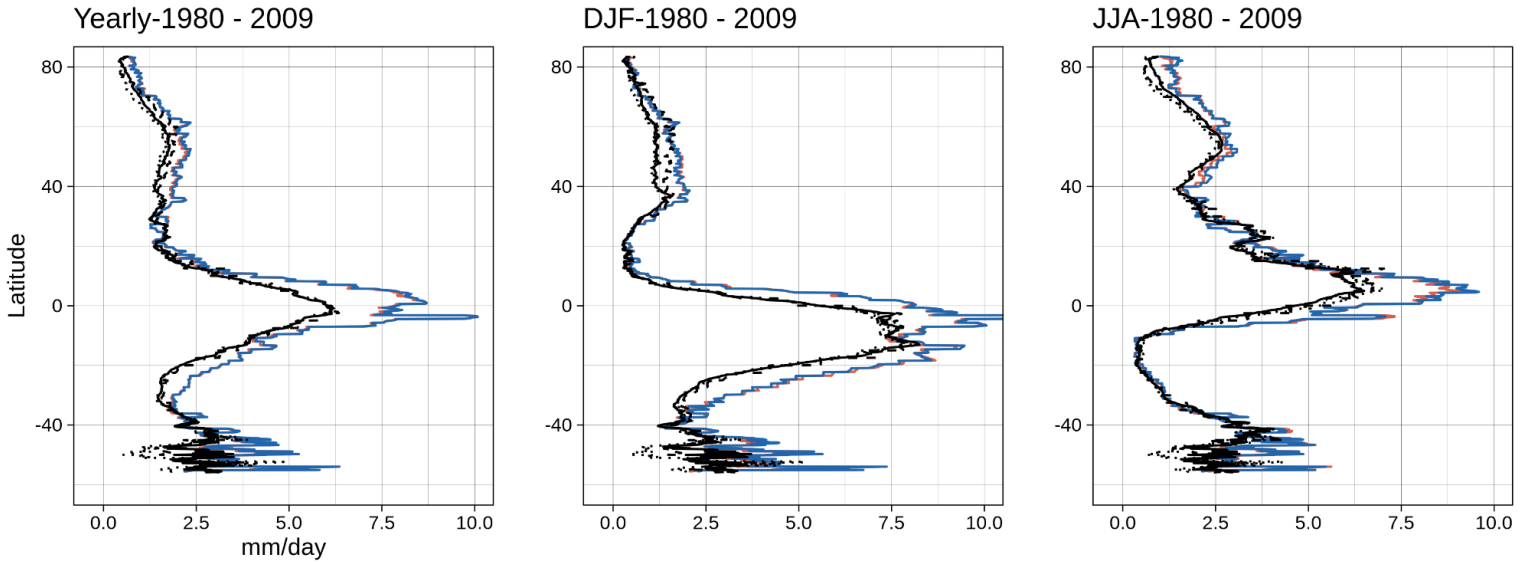


Soil moisture increases (**+ 10%) in GWF**, it enhances evapotranspiration **(ET, +4%)** and **cools down** the air (mean daily max. temperatures, Tasmax, **-0.2°C**)

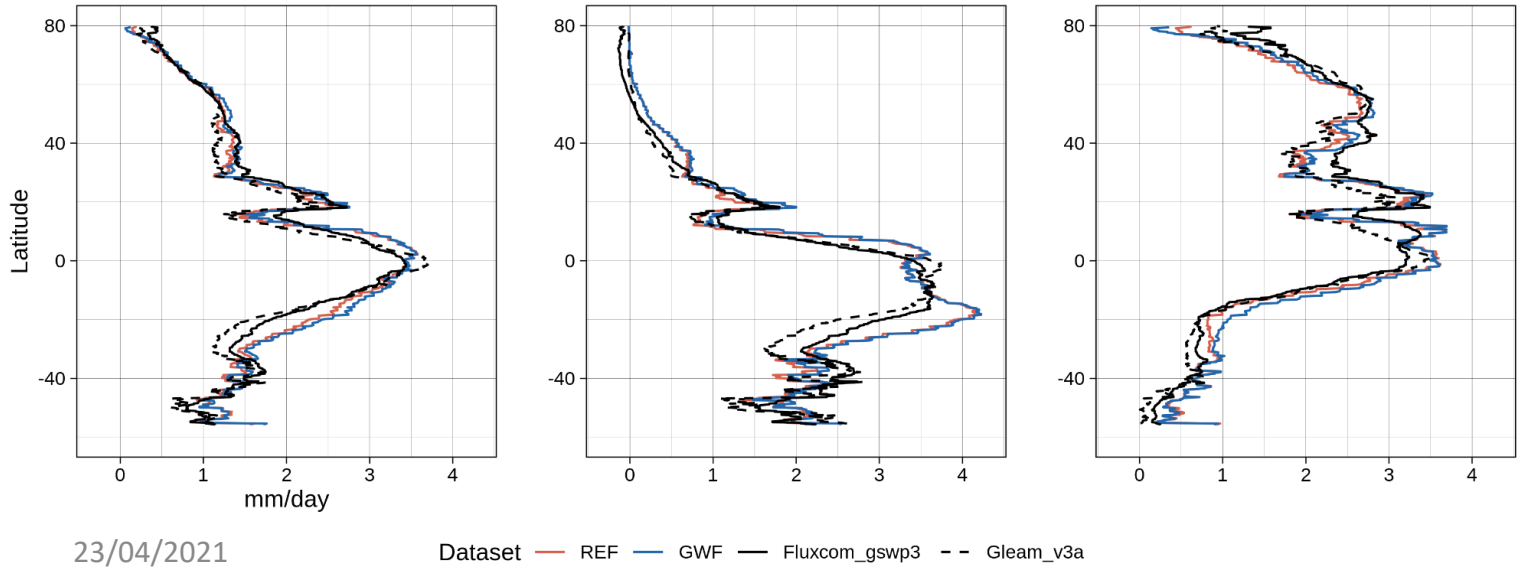
4. Effect of hillslope flow in current climate

Zonal average over land

Precipitation



Evapotranspiration



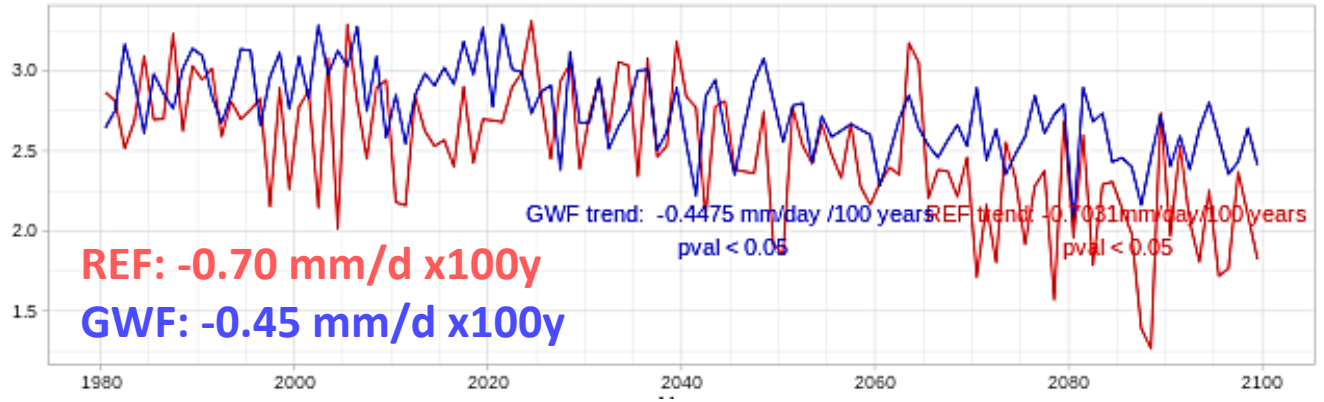
Positive bias on precipitation (P) from LMDZ impacts ET rates

ORCHIDEE-Hillslope increases P and ET rates in a smaller proportion.

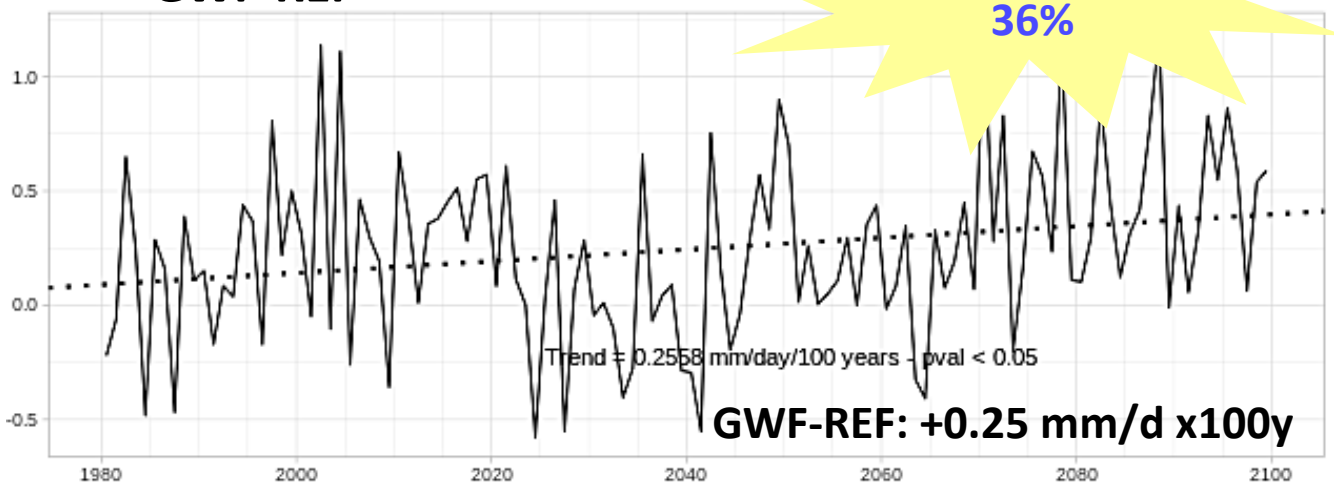
Despite this positive bias, LMDZORC allows to assess the coupled trajectory of surface and climate.

5. Modulation of climate change projection

Paris, ET (mm/d) JJA

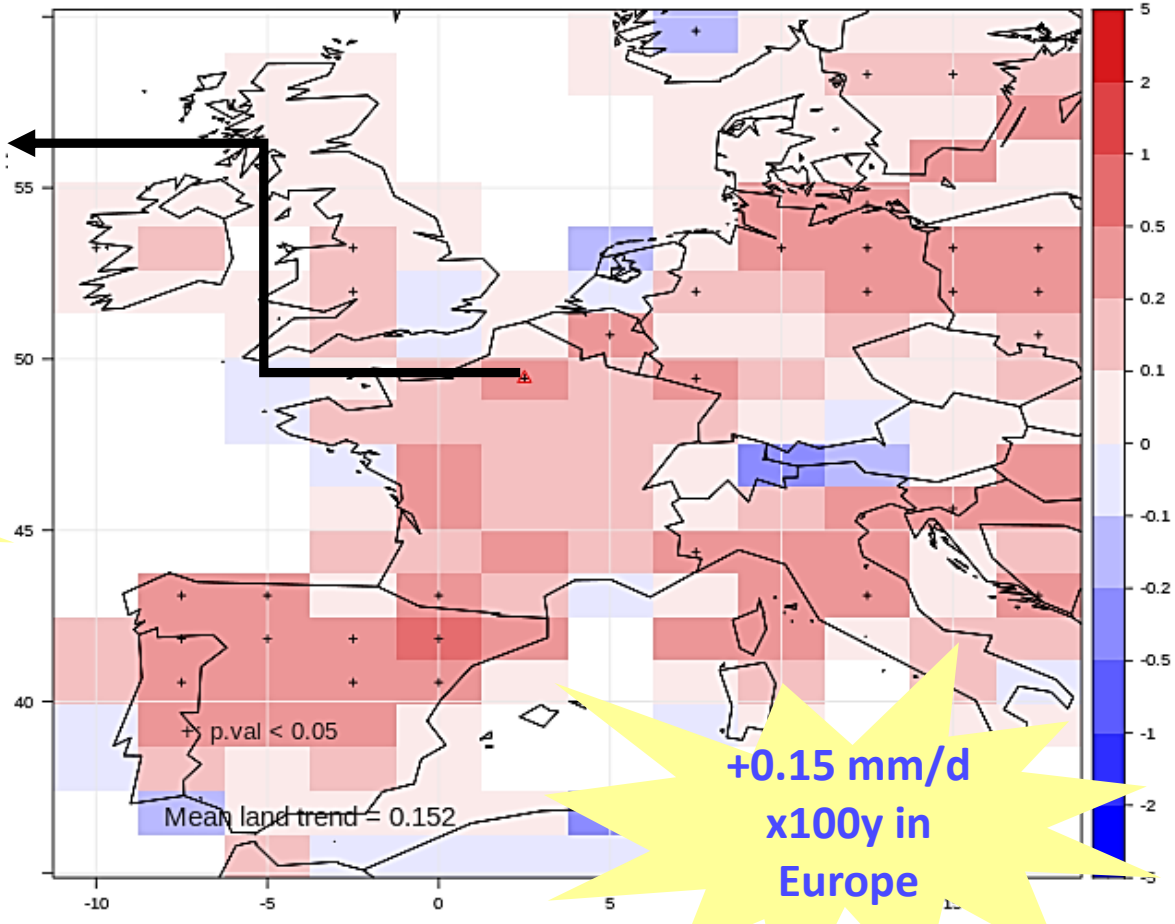


GWF-REF



Attenuation 36%

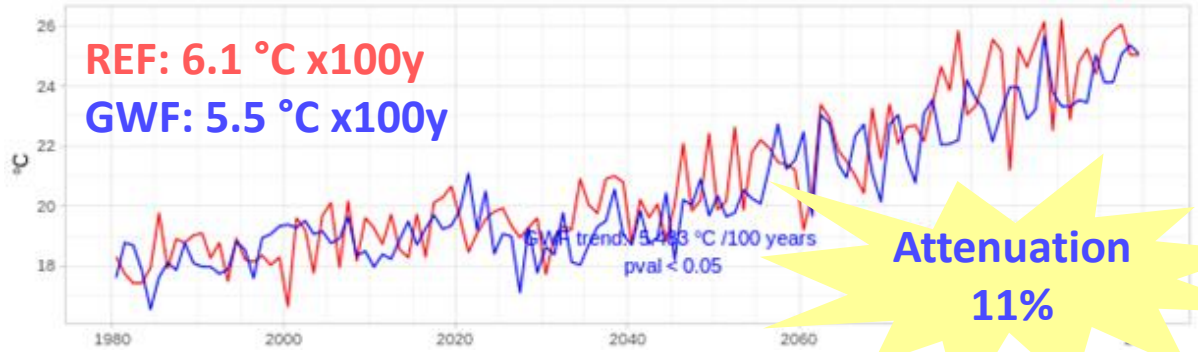
Trend of GWF-REF
ET (mm/d x100y) JJA



+0.15 mm/d x100y in Europe

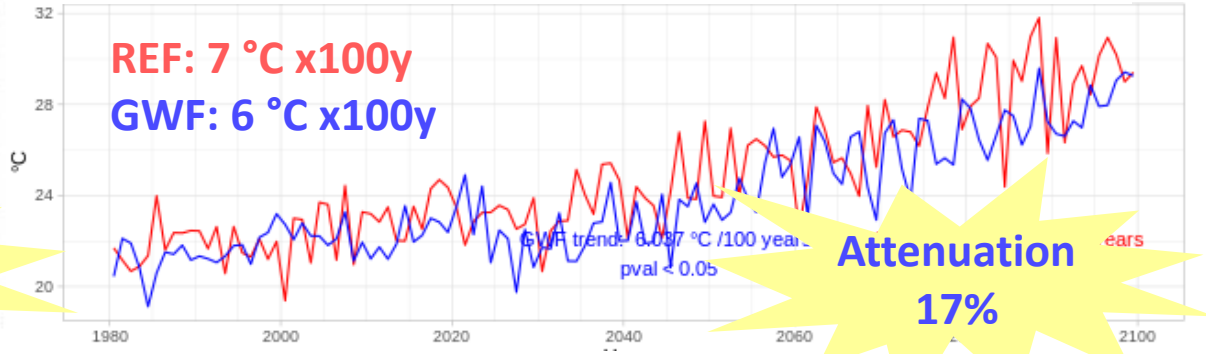
5. Modulation of climate change projection

Paris, mean air temperature (°C) JJA



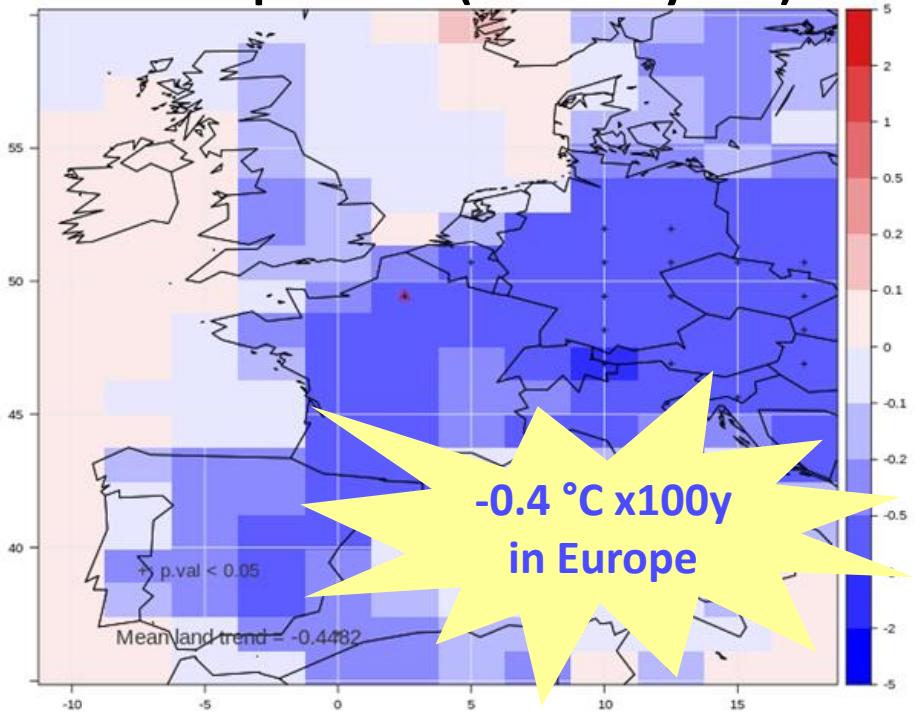
Attenuation 11%

Paris, max. air temperature (°C) JJA



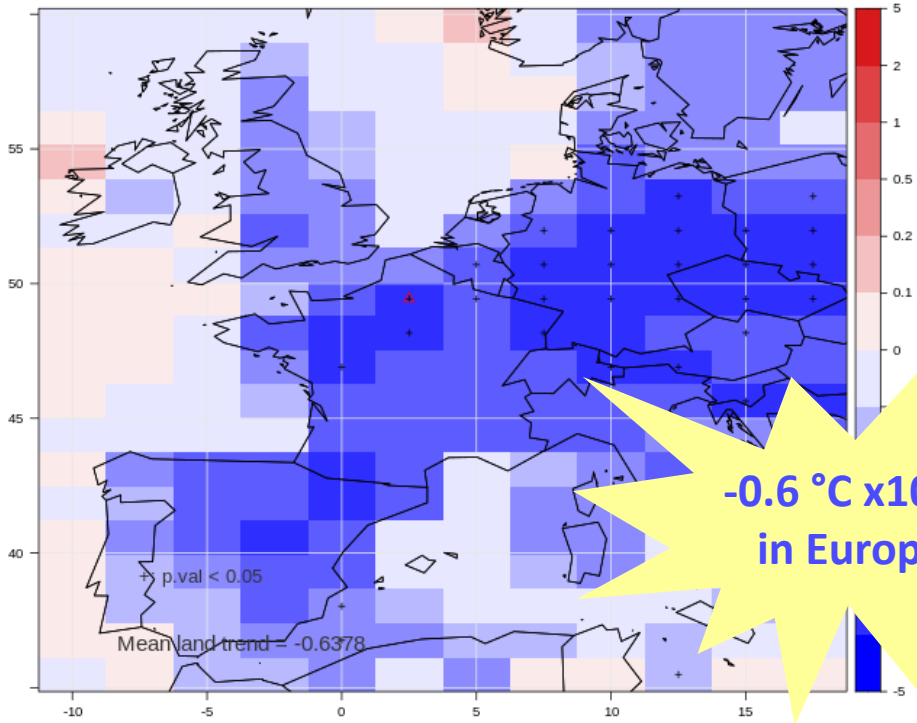
Attenuation 17%

Trend of GWF-REF
Mean air temperature (°C x 100 years) JJA



-0.4 °C x100y in Europe

Trend of GWF-REF
Max. air temperature (°C x 100 years) JJA

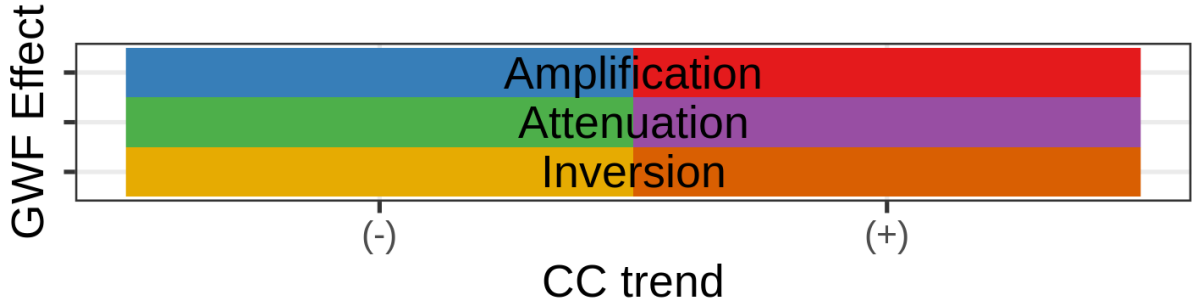


-0.6 °C x100y in Europe

5. Modulation of climate change projection

Land average (excluding Groenland and Antartica)

Season	Variables	ET mm/day x100y	Tasmax °C x100y	Tas °C x100y
Yearly	Climate change trend	**0.02**	**6.2**	**6.4**
	Modulation	**50.5%**	**-1.3%**	-1.2%
DJF	Climate change trend	**0.05**	**5.9**	**6.6**
	Modulation	-2.0%	-1.6%	-1.7%
MAM	Climate change trend	**0.05**	**5.4**	**5.7**
	Modulation	**41.1%**	**-3.9%**	**-3.6%**
JJA	Climate change trend	**-0.03**	**6.6**	**6.6**
	Modulation	-39.2%	-0.9%	-0.8%
SON	Climate change trend	**0.02**	**6.6**	**6.8**
	Modulation	**91.5%**	-0.02%	0.2%

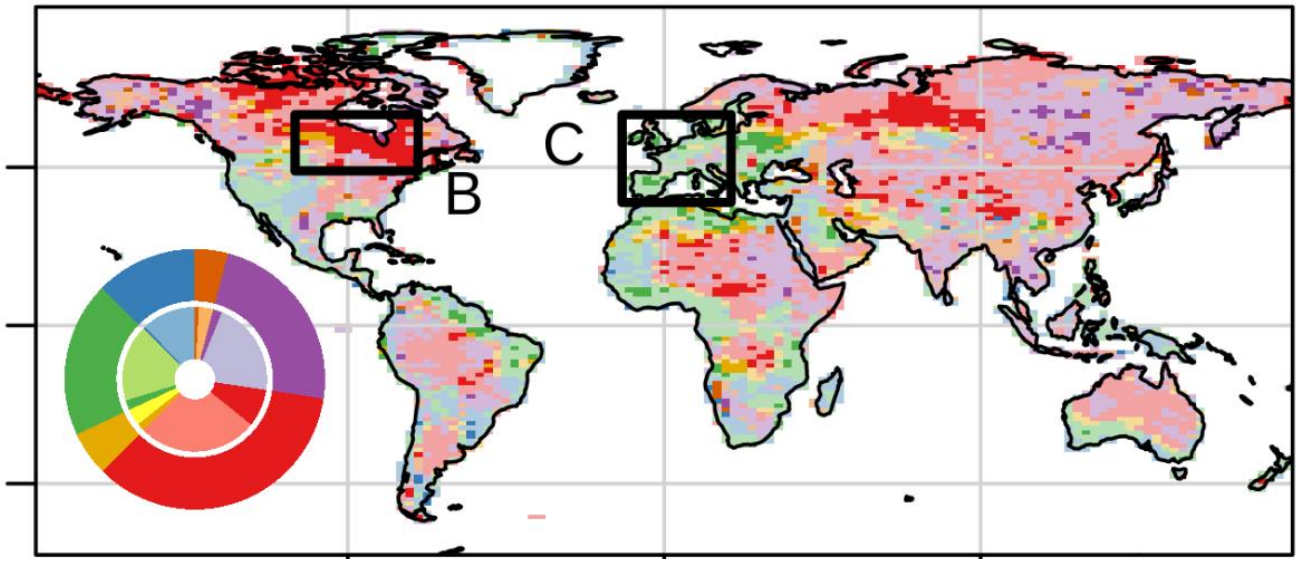


Significant at 95% with Mann Kendall test in bold

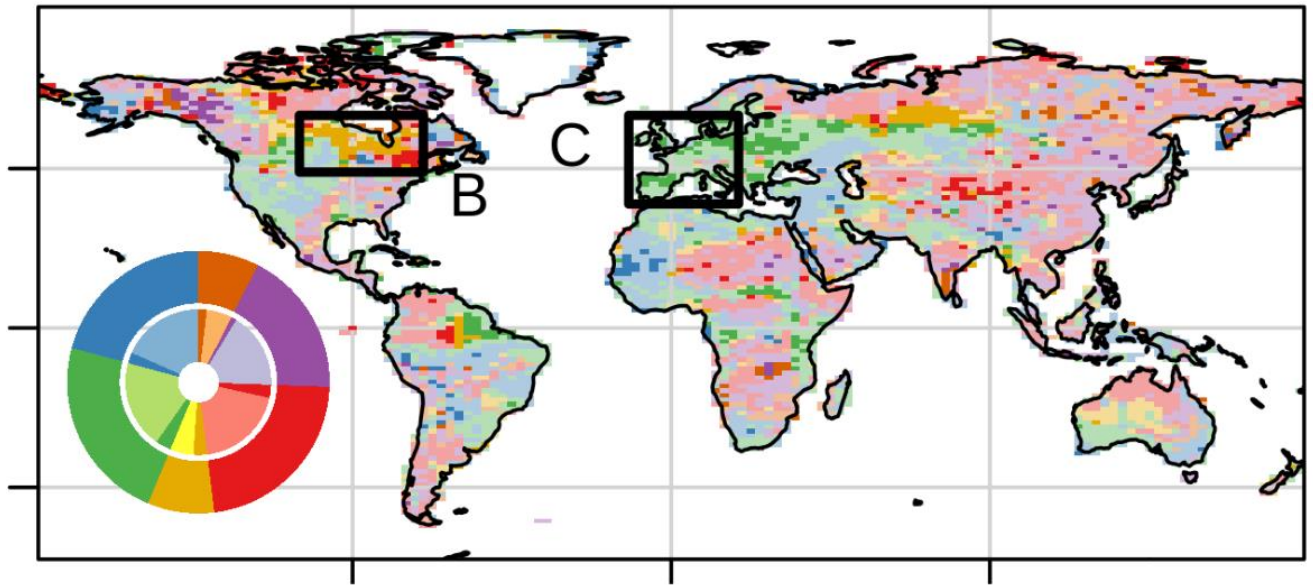
Tasmax: mean of max. Air temp.
Tas: mean air temp.

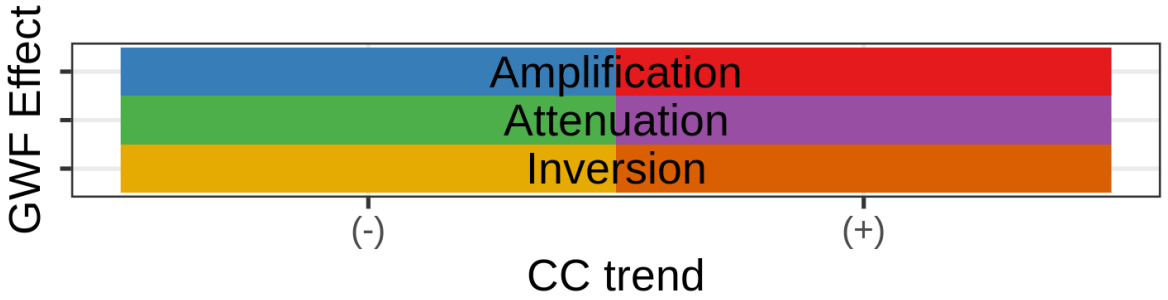
5. Modulation of climate change projection

Evapotranspiration - Yearly



JJA





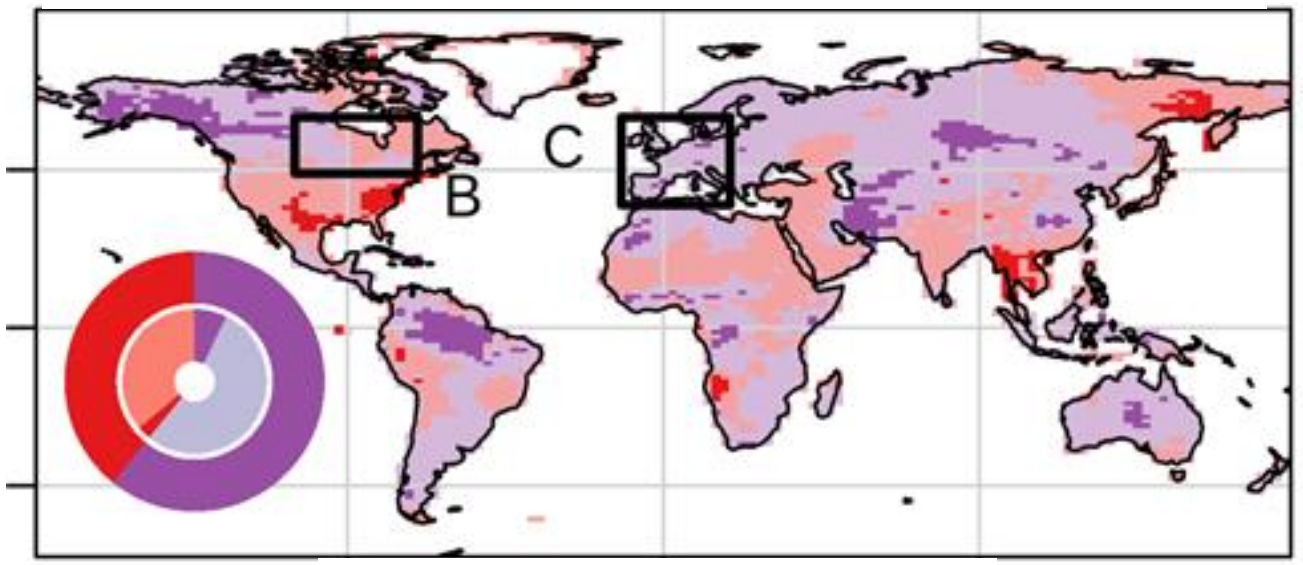
Hillslope flow amplifies ET positive trends, and attenuates ET reductions.

It sustain higher ET rates during boreal summer, like in Europe.

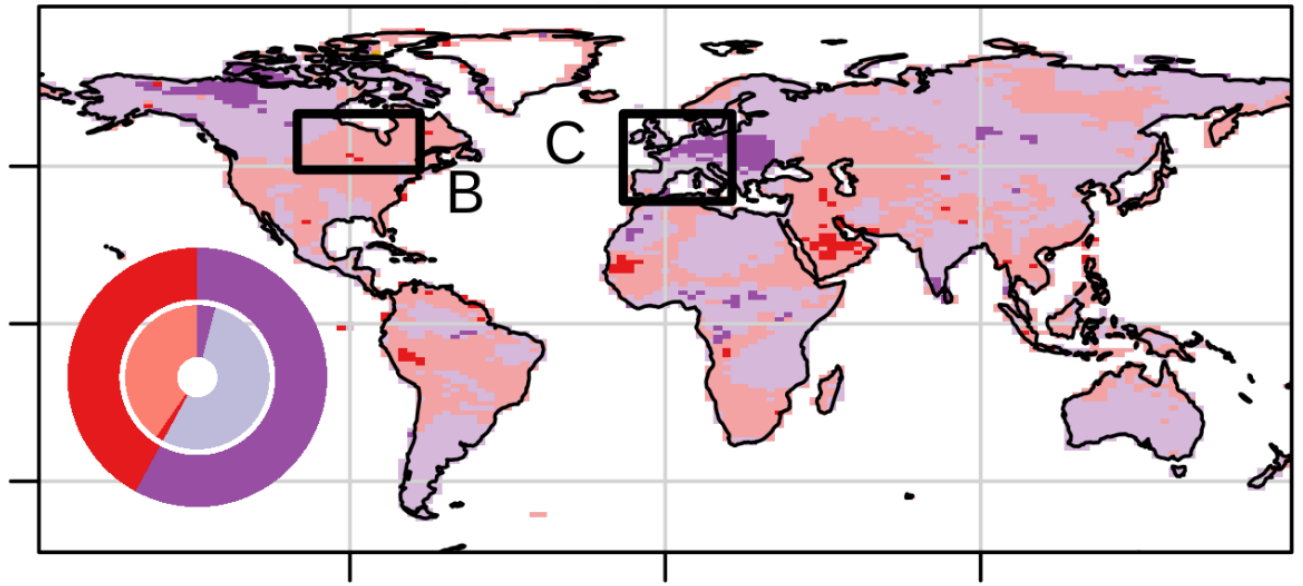
In Canada, climate change diminution is counteracted during boreal summer.

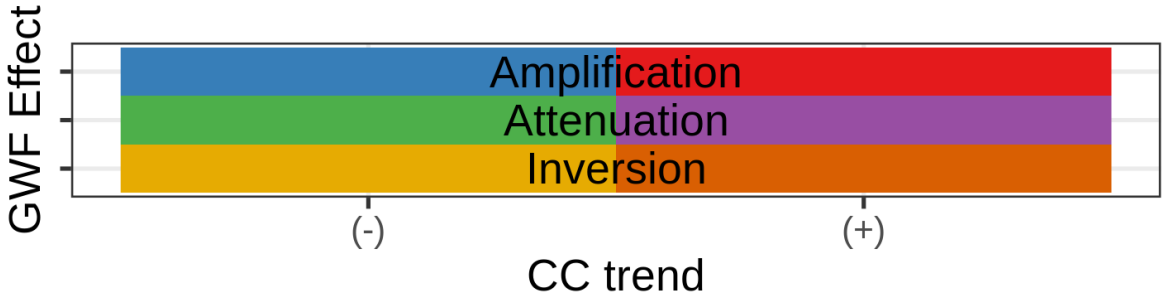
5. Modulation of climate change projection

Tasmax - Yearly



JJA



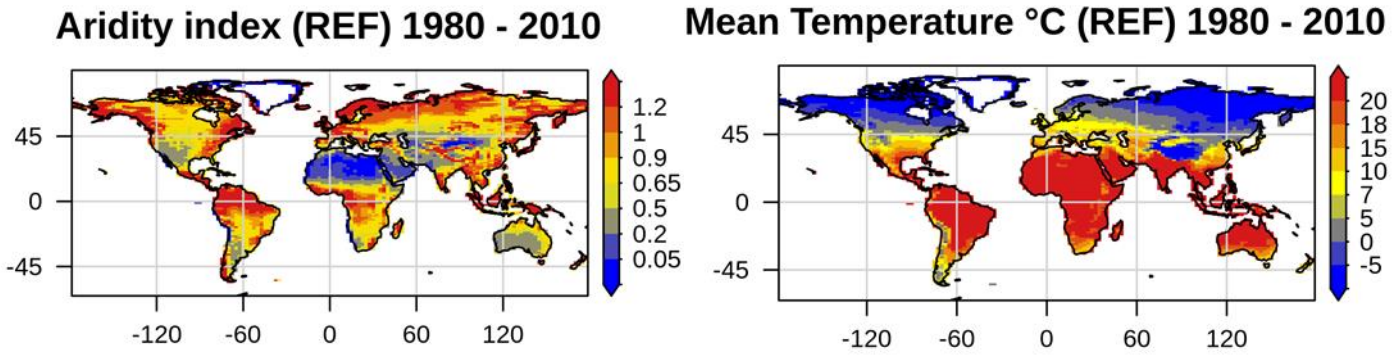


Hillslope flows attenuates warming in temperate and tropical areas.

During the boreal summer, warming grows slower in Europe. It is not the case in Canada.

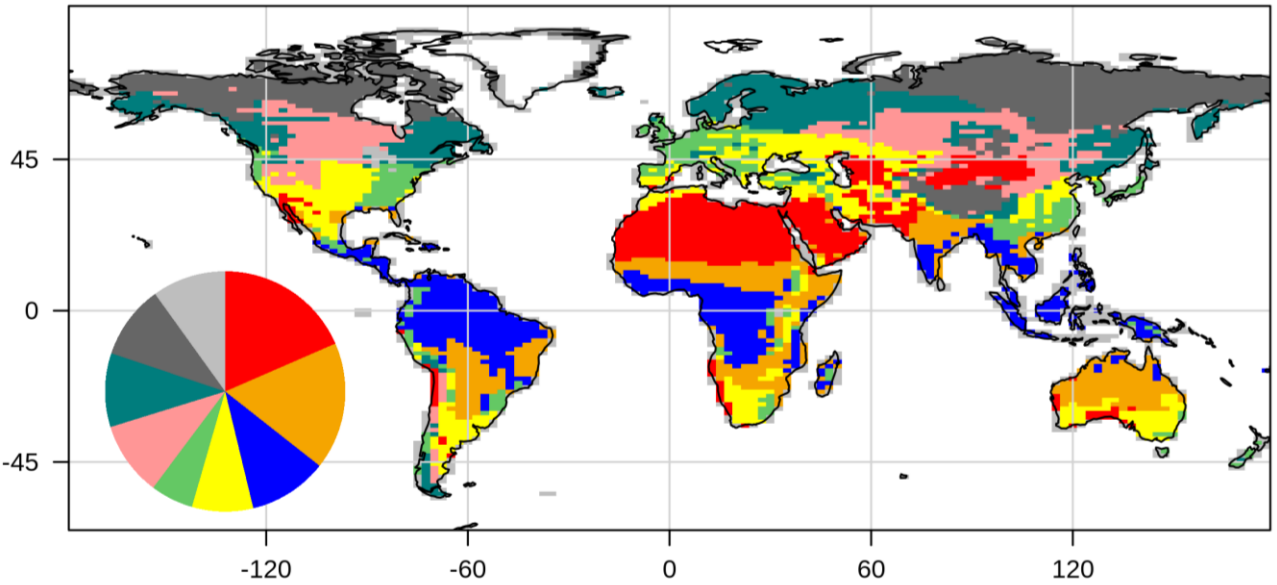
Some areas depict an amplification of warming, because hillslope flows plays a reduced role there.

6. Regional analysis of the modulation



A **simple climate classification** based on **aridity index** (P/PET) and **mean air temperature**

Climate classification map



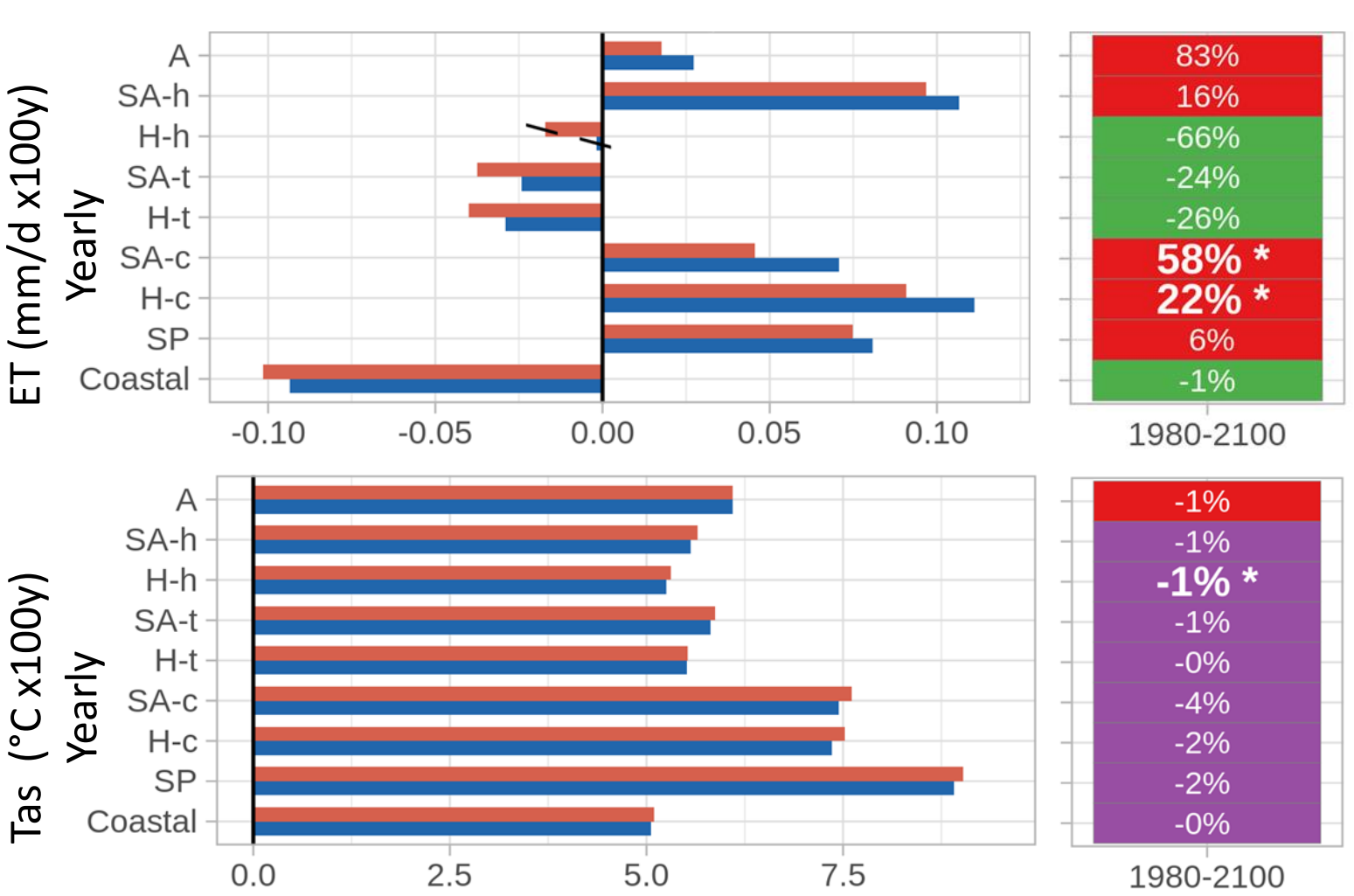
Based on Köppen-Geiger and Thornthwaite climate classification

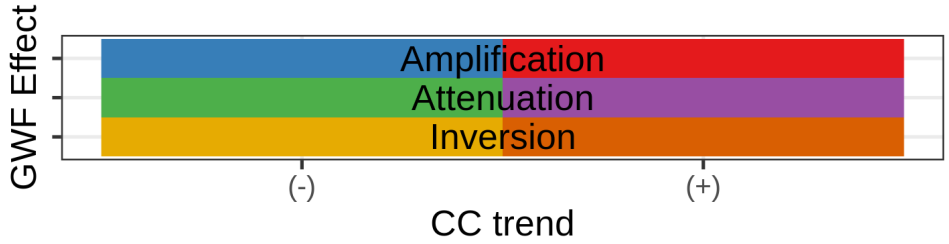
Climate classification groups and colors

Subpolar (SP) Tas < -5°C	**cold (-c)** -5 < Tas < 7 °C	**Temperate (-t)** 7 < Tas < 20 °C	**Hot (-h)** Tas > 20 °C
	Arid regions (A) AI < 0.35		
	Semiarid (SA) 0.35 < AI < 1.125		
	SA-c	SA-t	SA-h
	Humid (H) AI > 1.125		
	H-c	H-t	H-h
	Coastal (Land Surface < 50% of grid cell)		

6. Regional analysis of the modulation

Mean trend per climate group and modulation





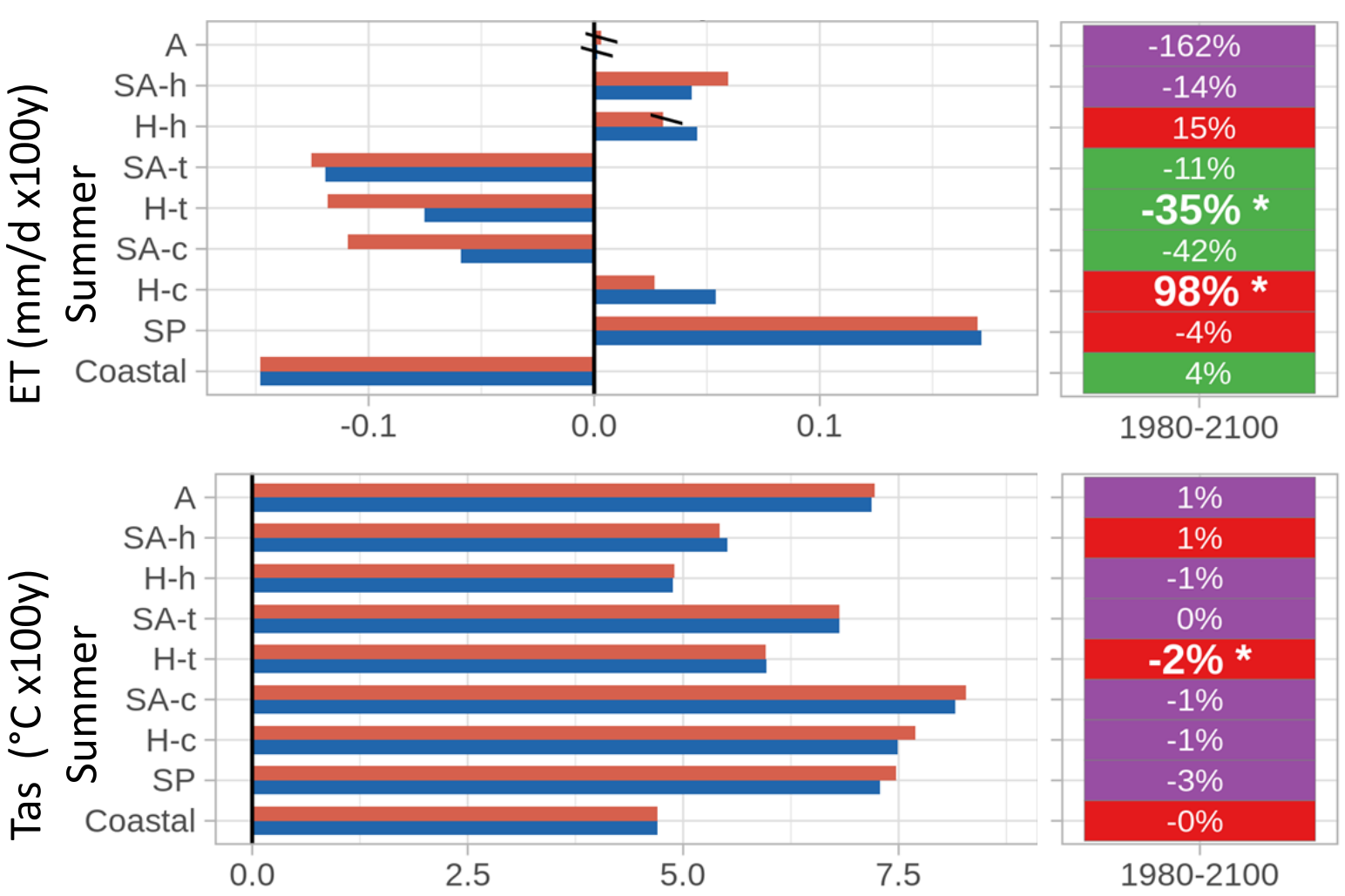
ET reduction is attenuated in **temperate areas** (and hot-humid zones), but ET growth is amplified in **cold regions** (and arid/semiarid).

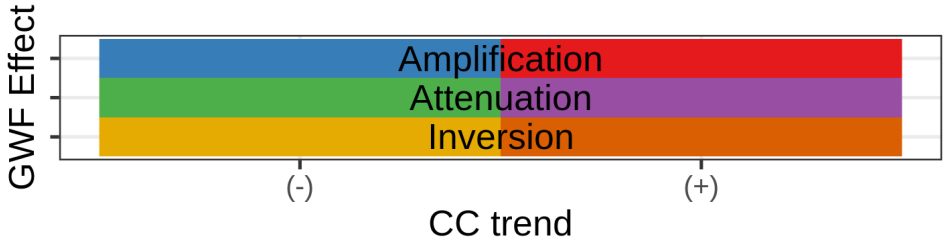
Warming is **attenuated** everywhere, except in **arid areas,** where it is **amplified**.

Significant at 5% with Mann Kendall in bold and *

6. Regional analysis of the modulation

Mean trend per climate group and modulation





During summer, ET reduction is **attenuated** in **temperate semiarid zones**, growth is **amplified** in **humid areas**, and **attenuated** in **dry zones.**

For temperature, seasonality **amplifies** warming in **SA-h and H-t areas**, whereas **attenuation** is **kept in other regions**

Summer is defined as JJA season if the cell is located in the northern hemisphere, and DDJ if located in the southern hemisphere

Significant at 5% with Mann Kendall in bold and *

7. Conclusions

1. The interaction of groundwater and soil moisture impacts the mean values of ET (+4%) and cools down the air (-0.2°C) under current climate.
2. This interaction modulates the climate change projection at regional and global scale. For ET it amplifies (+50%) climate change increase, and attenuates the global warming (-1%).
3. Two mechanisms for ET modulation: the hillslope flow increases the ET rates faster (in cold regions), or counteracts climate change, attenuating the reduction (in temperate regions). Seasonality may reinforce one of these mechanisms except in dry and hot areas, where the ET increase is attenuated.
4. For temperatures, there is an attenuation on warming almost everywhere, but in some areas warming grows faster (in arid regions). Seasonality may induce faster warming in semiarid and humid-temperate regions.

Thanks for your attention

Dans le marais de Saint Gond

Bassin du petit Morin

References

Cuthbert, M. O., Gleeson, T., Moosdorf, N., Befus, K. M., Schneider, A., Hartmann, J., & Lehner, B. (2019). Global patterns and dynamics of climate–groundwater interactions. Nature Climate Change, 9(2), 137–141. https://doi.org/10.1038/s41558-018-0386-4

Tootchi, A., Jost, A., & Ducharne, A. (2019). Multi-source global wetland maps combining surface water imagery and groundwater constraints. Earth System Science Data, 11(1), 189–220. https://doi.org/10.5194/essd-11-189-2019