

Future Earth Taipei - Webinar Series on Global Sustainability
September 28, 2022

Feedback of terrestrial hydrology on climate change

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@ Institut Pierre Simon Laplace (IPSL), Paris, France



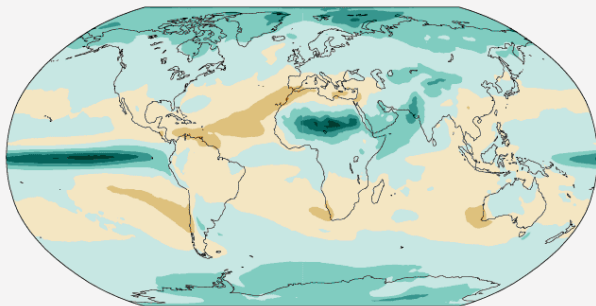
Climate change intensifies the global water cycle

- We expect increased global precipitation
- But decreased annual precipitation in many land areas
- And increased frequency /duration / intensity of droughts (and floods)
- Large uncertainties in projections of the water cycle

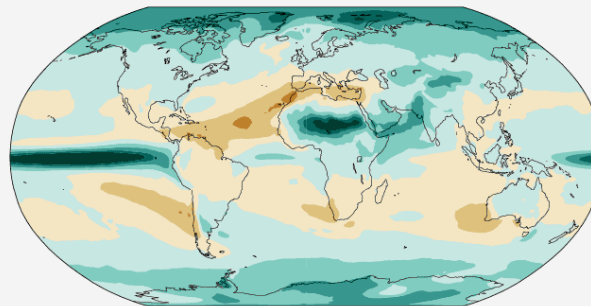
(c) Annual mean precipitation change (%) relative to 1850–1900

Precipitation is projected to increase over high latitudes, the equatorial Pacific and parts of the monsoon regions, but decrease over parts of the subtropics and in limited areas of the tropics.

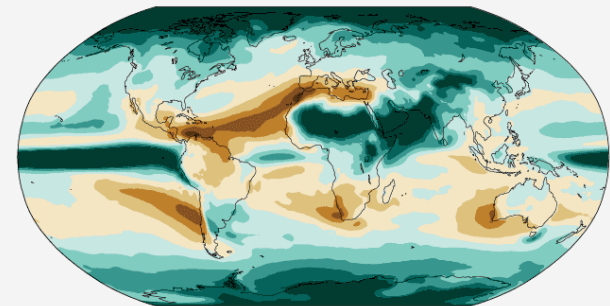
Simulated change at 1.5°C global warming



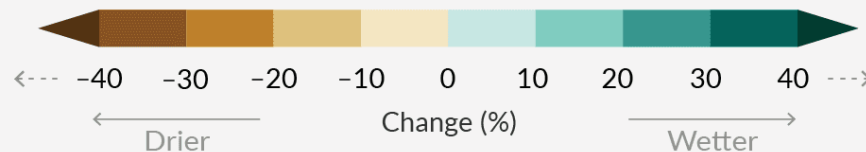
Simulated change at 2°C global warming



Simulated change at 4°C global warming



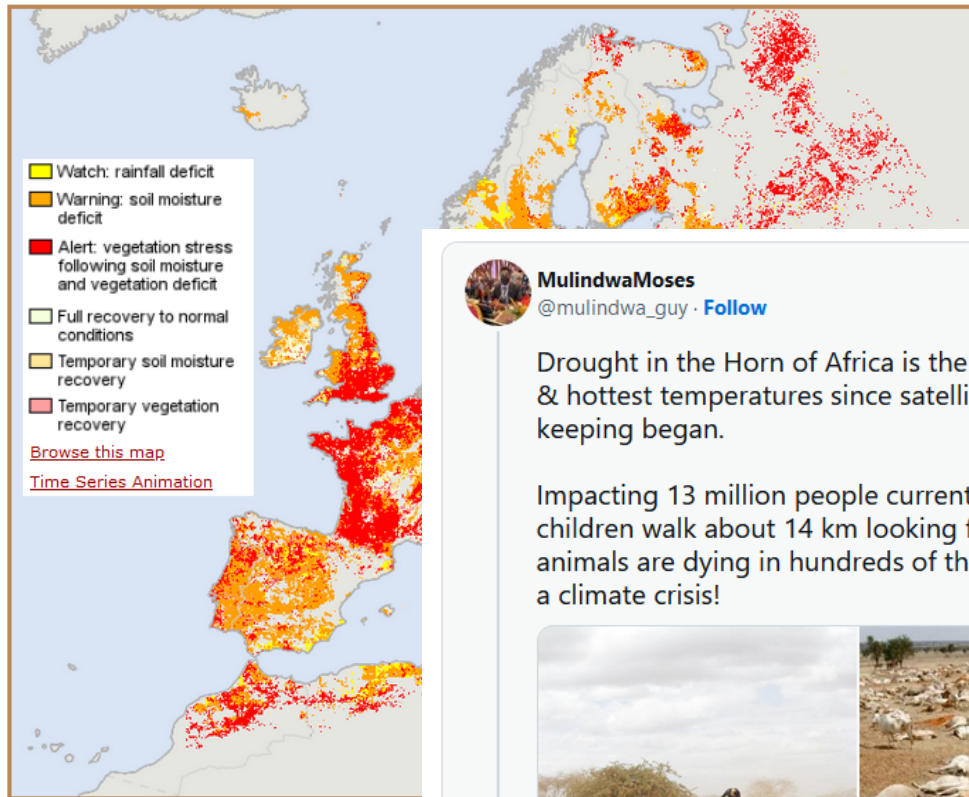
Relatively small absolute changes may appear as large % changes in regions with dry baseline conditions



Climate change is ongoing

→ Situation of Combined Drought Indicator in Europe - 1st ten-day period of September 2022

According to the latest map of the **Combined Drought Indicator** 33% of the EU territory is in **Warning** conditions and 26% is in **Alert** conditions



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China's extreme weather challenges scientists trying to study it

...rts of China exacerbated a drought and fuelled wildfires.



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Drought in the Horn of Africa is the driest conditions & hottest temperatures since satellite record-keeping began.

Impacting 13 million people currently, women & children walk about 14 km looking for water & animals are dying in hundreds of thousands. This is a climate crisis!



3:54 PM · Aug 21, 2022



Extreme drought caused water levels in China's largest freshwater lake, Poyang Lake, to drop by almost 10 metres between June and August. Credit: Shen Junfeng/VCG via Getty

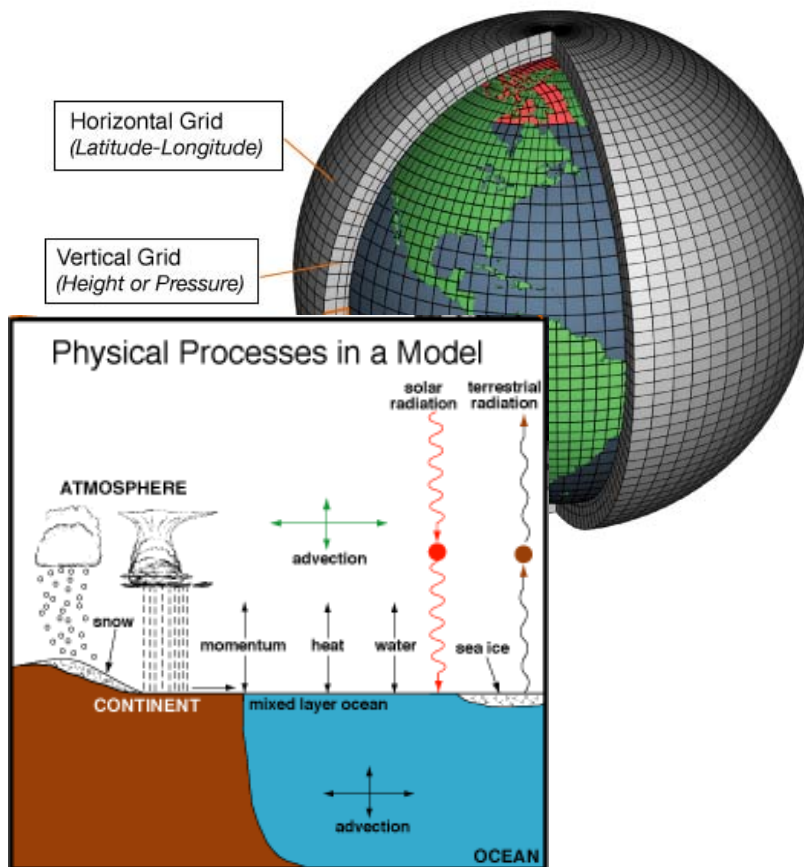
Climate modelling overview

Earth system model = 3D numeric model of planetary climate

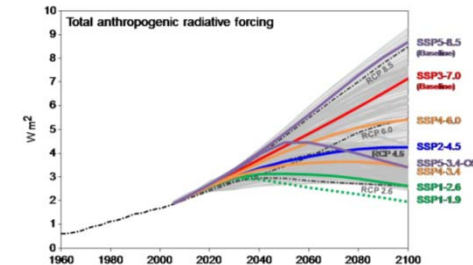
Ocean – Atmosphere – Land

Interactions with Biosphere, Cryosphere, Biogeochemical Cycles

Horizontal resolution $\approx 1^\circ \approx 100$ km



Future scenarios of CO₂ and GHGs, aerosols, and solar radiation,



CLIMATE CHANGE PROJECTIONS

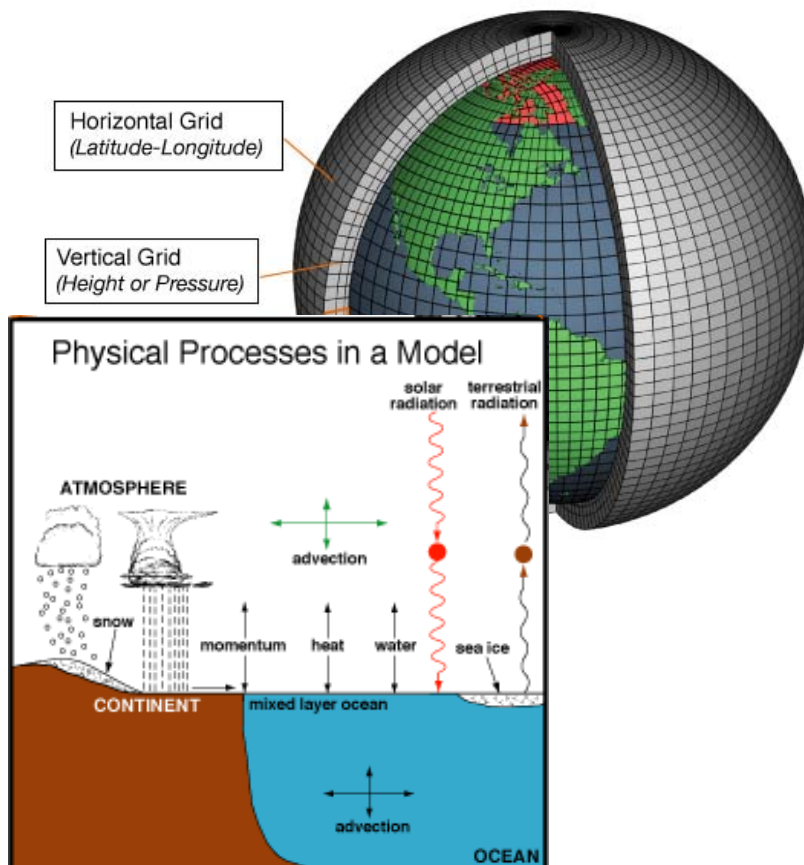
Climate modelling overview

Earth system model = 3D numeric model of planetary climate

Ocean – Atmosphere – Land

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Horizontal resolution $\approx 1^\circ \approx 100$ km



WATER CYCLE UNCERTAINTIES

Atmosphere

Large uncertainties due to convection and clouds + atmospheric circulations

Soil moisture, evaporation, precipitation

Continents

Simplified description of soils, groundwater, and human activities

Outline

Introduction

Feedback of two features of land hydrology on climate change

- 1** Impact of soil moisture redistribution along landscapes
- 2** Impact of irrigation

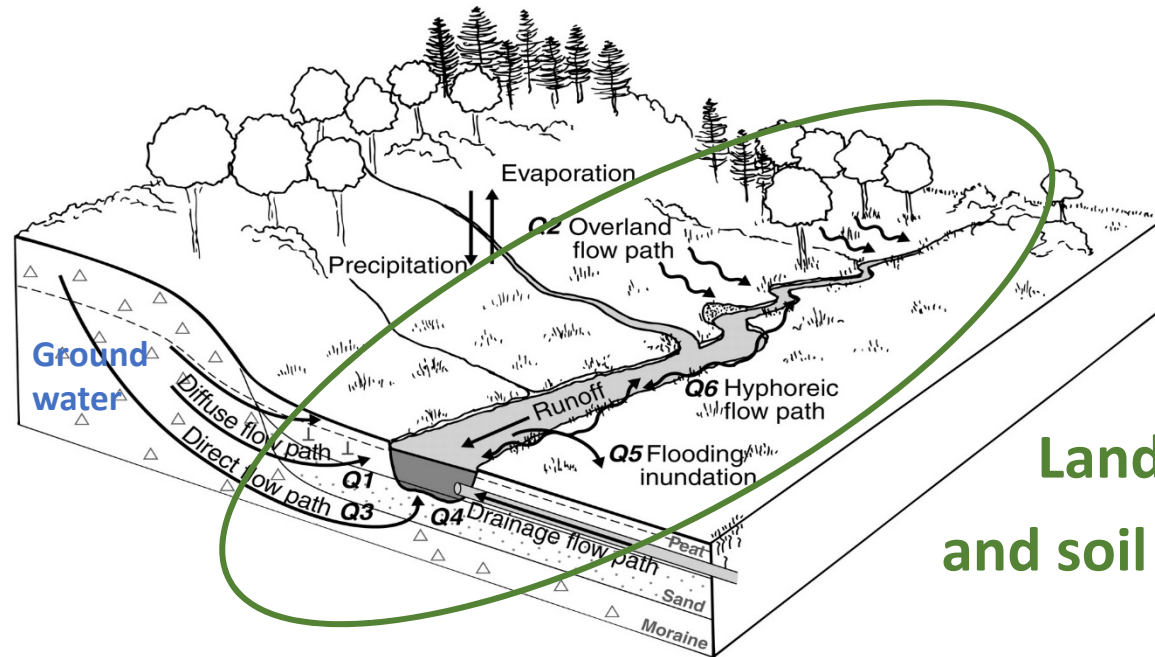
Combined impacts along the Anthropocene: the BLUEGEM project

Franco-Taiwanese Scientific Grand Prize 2021



1

Soil moisture redistribution along landscapes



Landscapes are not flat
and soil moisture accumulates
in lowlands

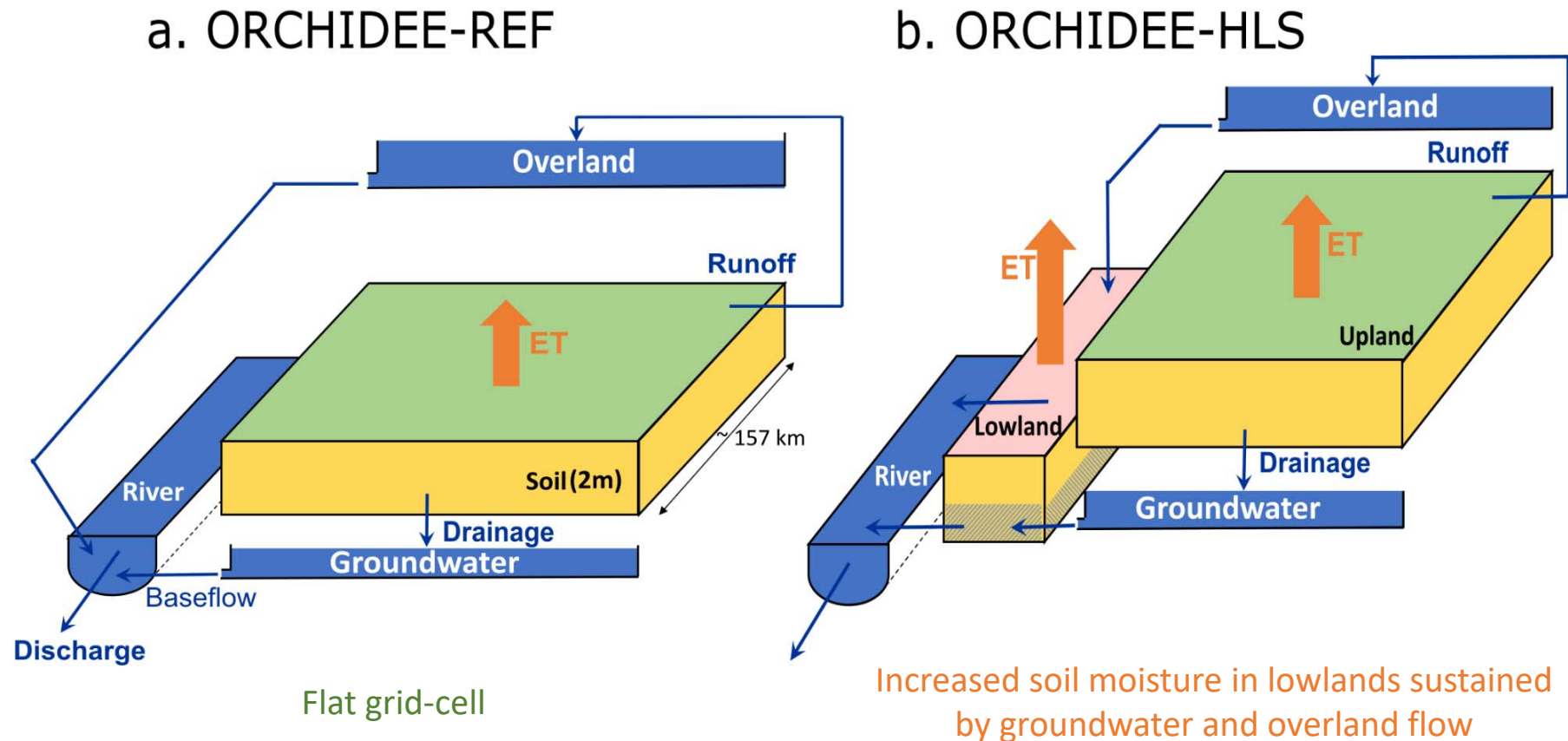


Photographs from Fan et al. 2019, WRR

1

Soil moisture redistribution along landscapes

We addressed this influence by introducing a lowland fraction in the IPSL climate model

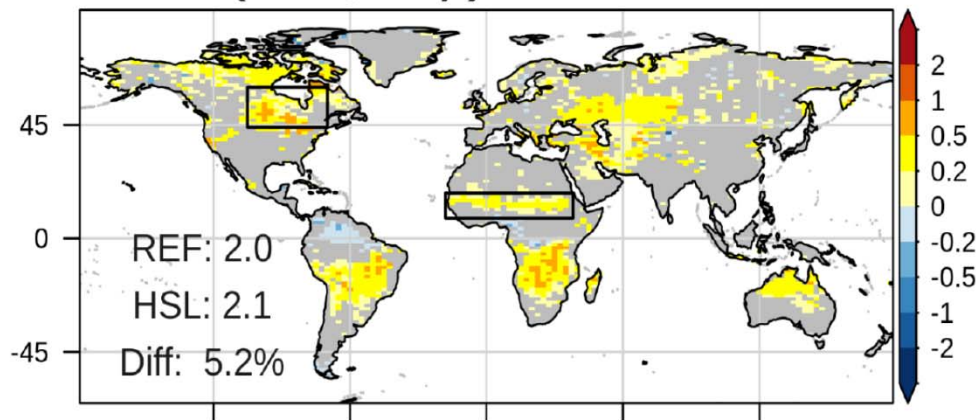


1

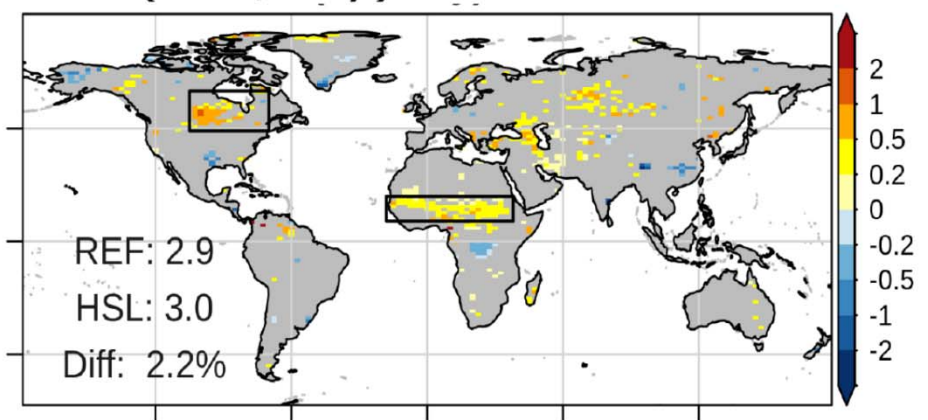
Soil moisture redistribution along landscapes

Impact on simulated historical climate (1980-2010, boreal summer)

a. ET (mm/day) - JJA

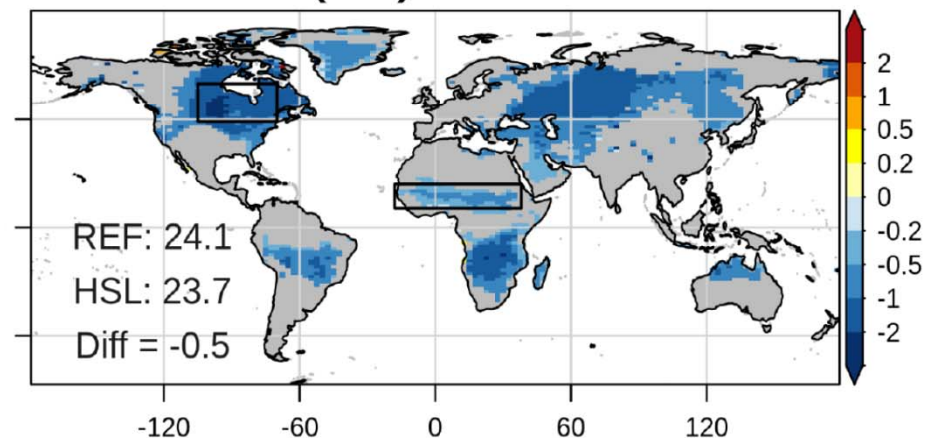


b. P (mm/day) - JJA



- Evaporation increases owing to increased soil moisture in lowlands
- Main impacts in areas with large lowland fractions with dry seasons
- Decrease of temperature in the same areas
- Limited effect on precipitation

d. Tasmax (°C) - JJA

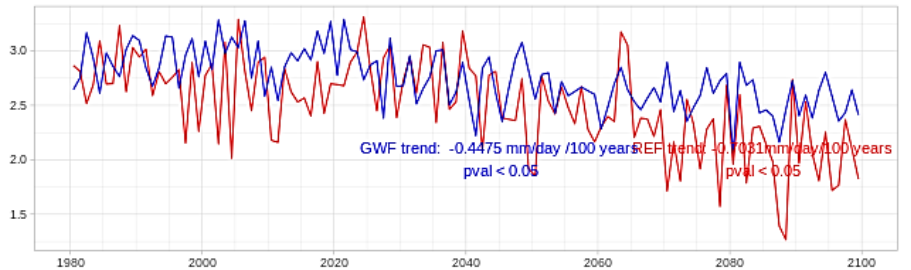


1

Soil moisture redistribution along landscapes

Impact on simulated climate change (until 2100, SSP5.8.5)

Paris, evapotranspiration ET (mm/d) JJA



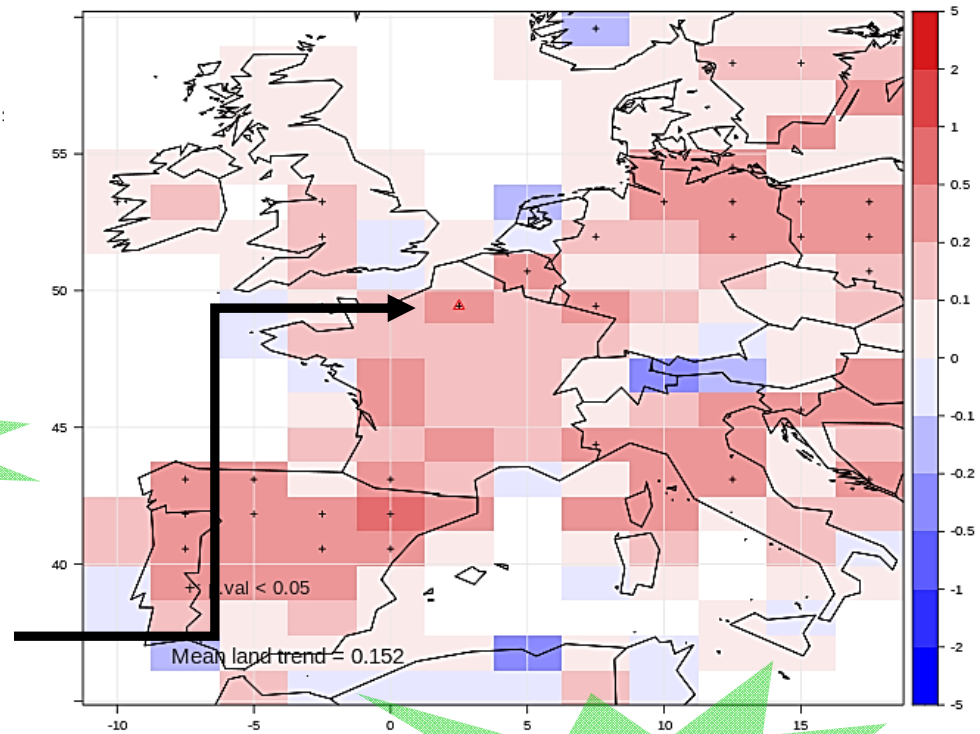
With redistribution: -0.45 mm/d en 100 years
REF: -0.70 mm/d in 100 years

Difference HLS -REF



Attenuation of 36%

Trend of ET difference HLS – REF (mm/d over 100 years) JJA

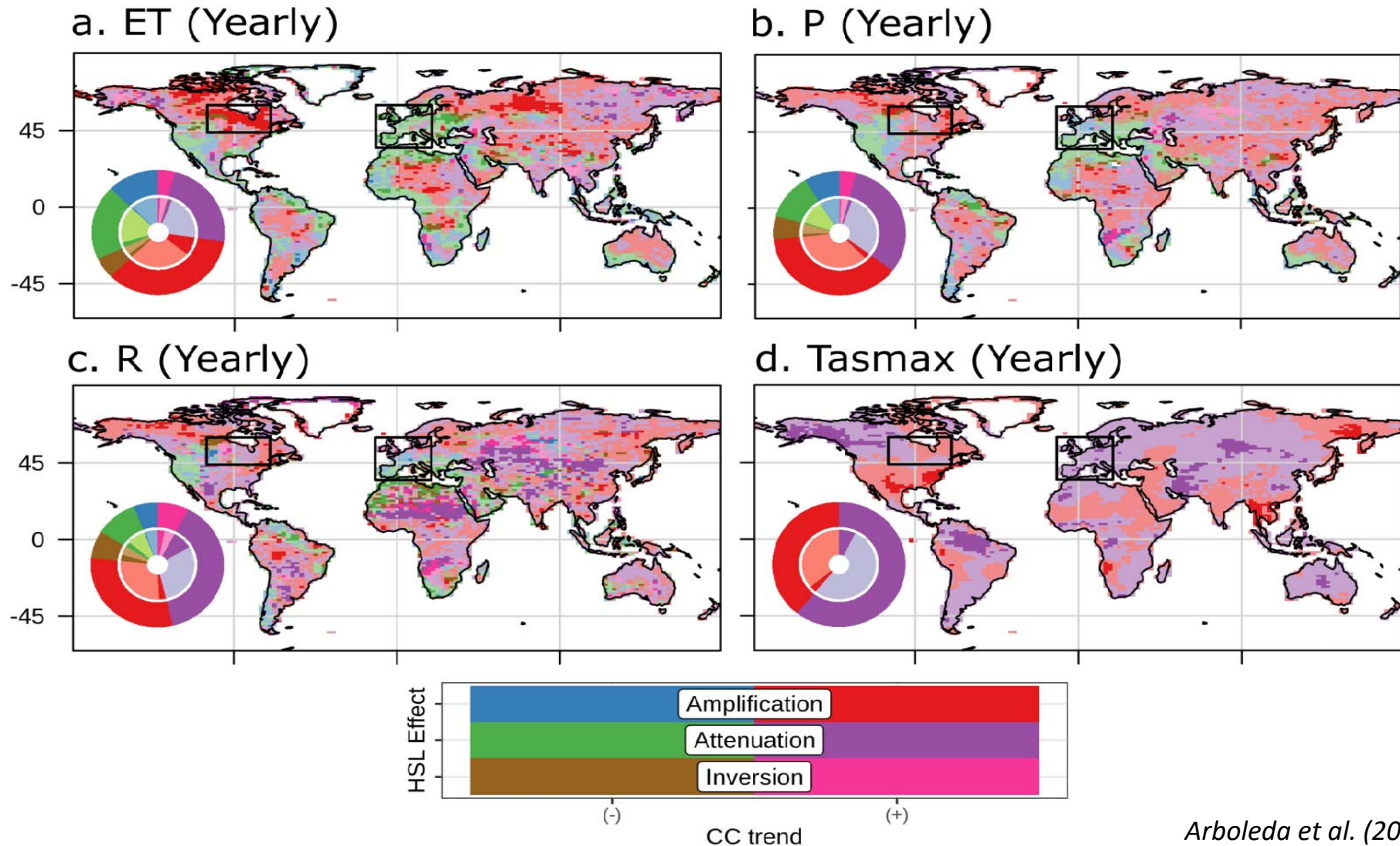


+ 0.15 mm/d in 100 years across Western Europe

1

Soil moisture redistribution along landscapes

Impact on simulated climate change (until 2100, SSP5.8.5)

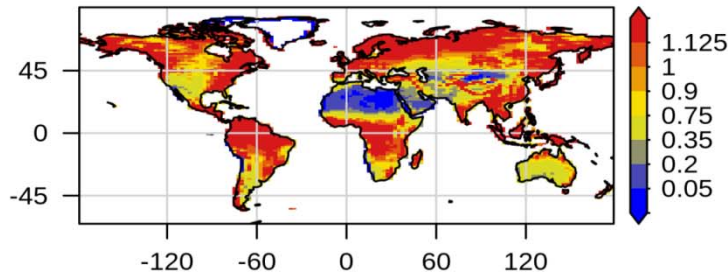


1

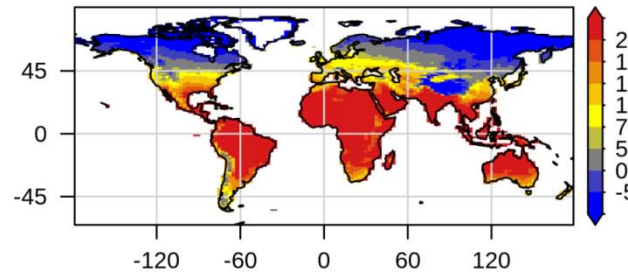
Soil moisture redistribution along landscapes

How to explain the patterns of climate change modulation?

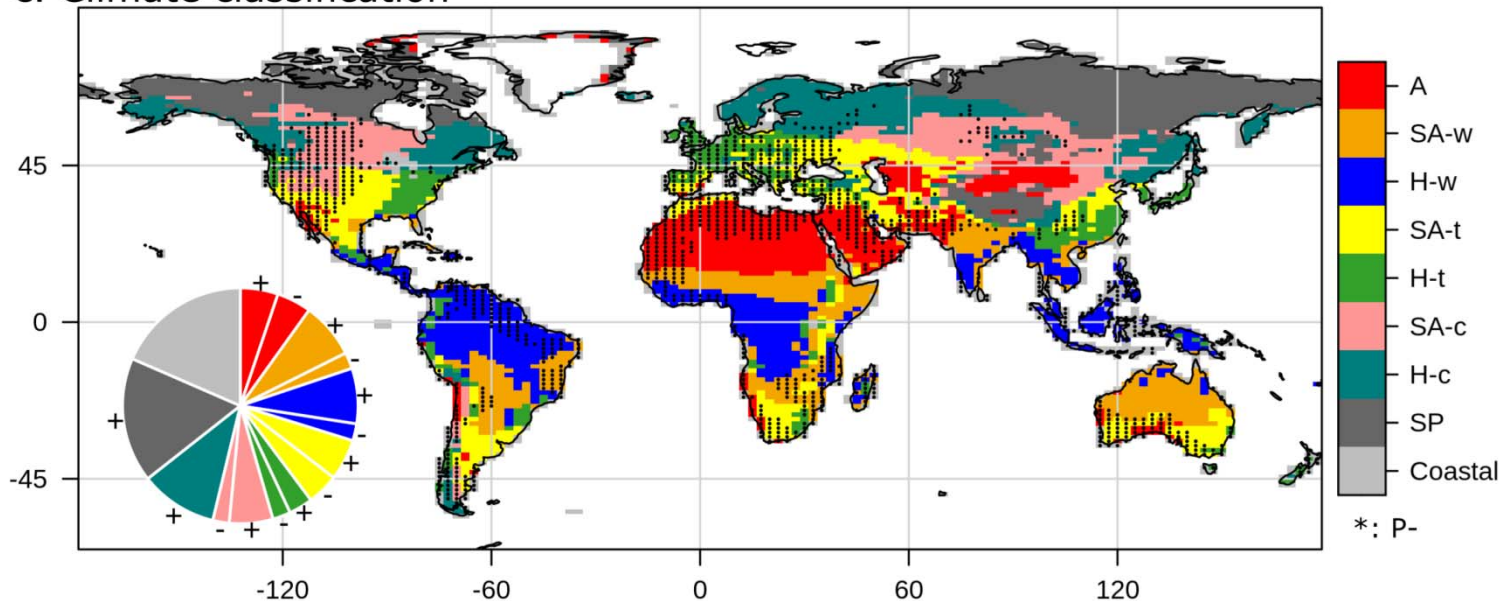
a. Aridity index (REF) 1980 - 2010



b. Temperature °C (REF) 1980 - 2010



c. Climate classification

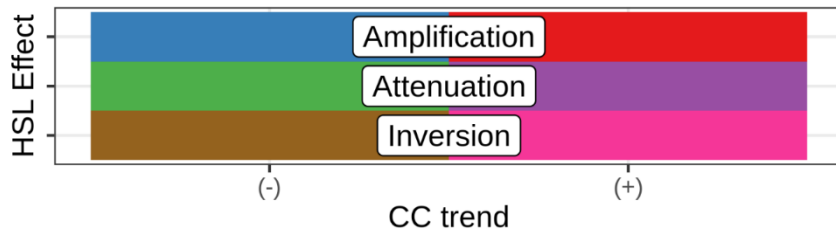


A = Arid
SA = Semi-arid
H = Humid
SP = Sub-Polar

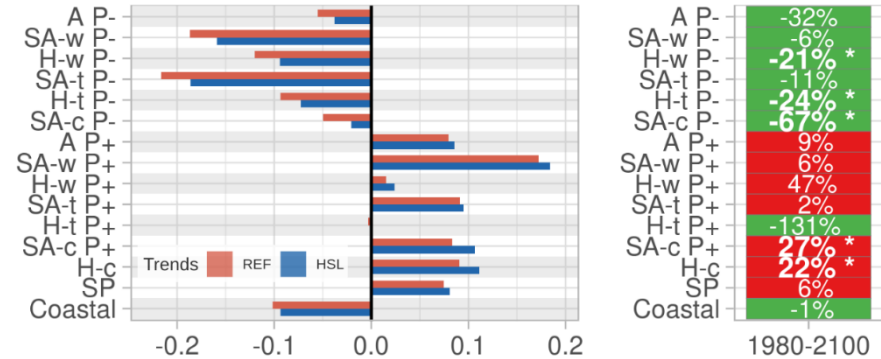
w = warm
t = temperate
c = cold

1

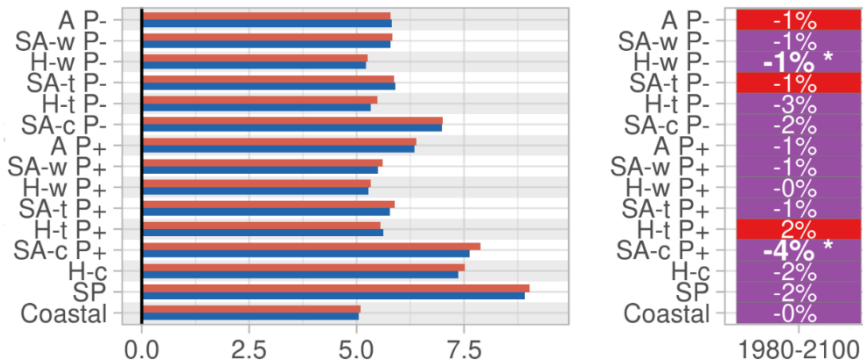
Soil moisture redistribution along landscapes



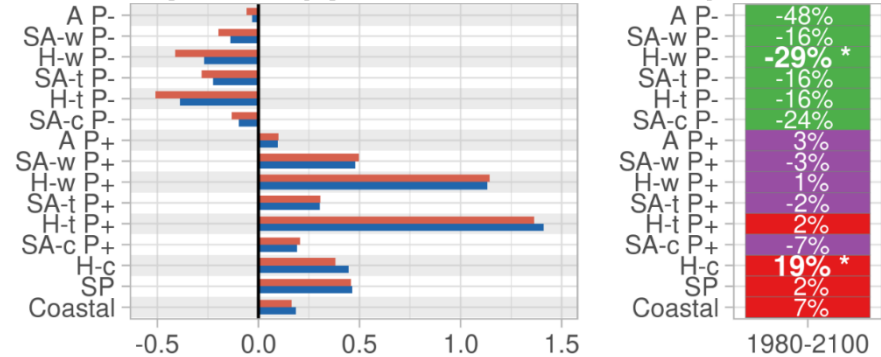
a. ET (Yearly) mm/d/Century



g. Tas (Yearly) °C/Century



c. P (Yearly) mm/d/Century



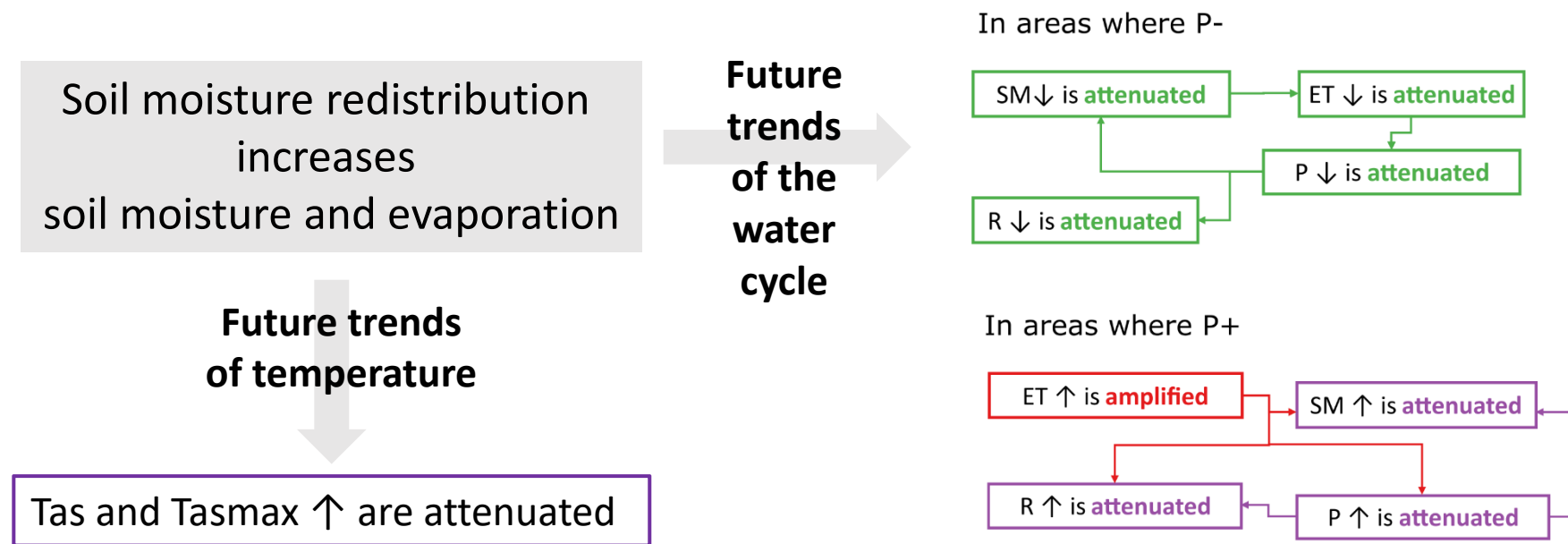
Major role of P change with global warming

1

Soil moisture redistribution along landscapes

Conclusions

based on simulations with the IPSL climate model



Arboleda Obando PF, Ducharne A, Cheruy F, Jost A, Ghattas J, Colin J (2022)
Influence of hillslope flow on hydroclimatic evolution under climate change
Earth Future, accepted.

2

Irrigation

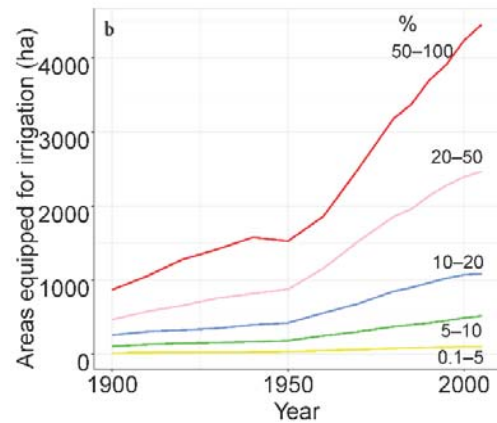
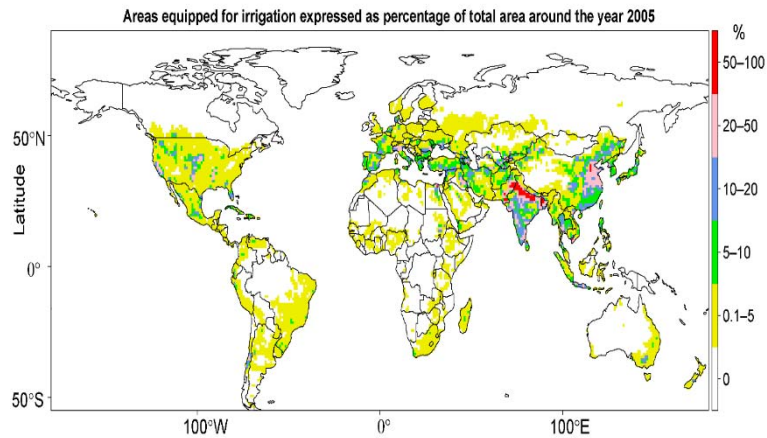
Irrigation is used to increase crop yields, secure them against droughts, or for weed control (paddy rice)



2

Irrigation

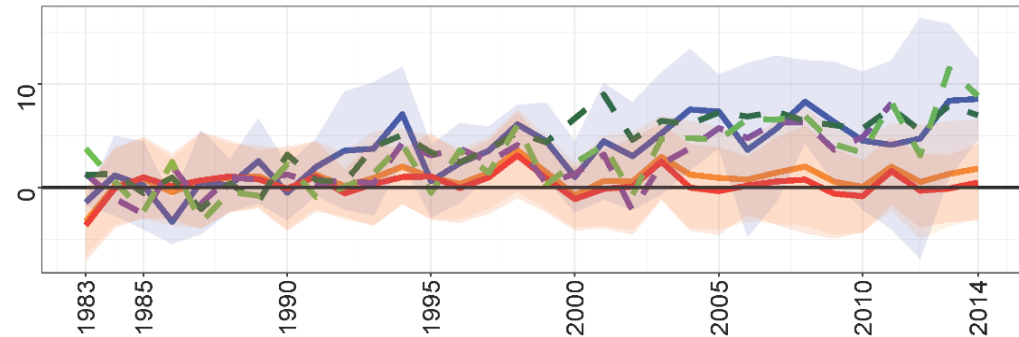
Impact on simulated climate over the 20th century (CMIP6 models)



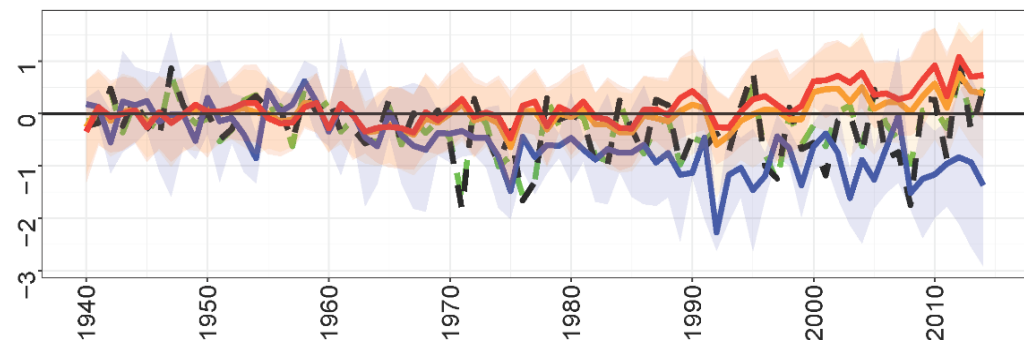
Most irrigated areas

Only 3 models over 18 with irrigation
But not limited by water availability

Evaporation (W/m^2)



Temperature (K)

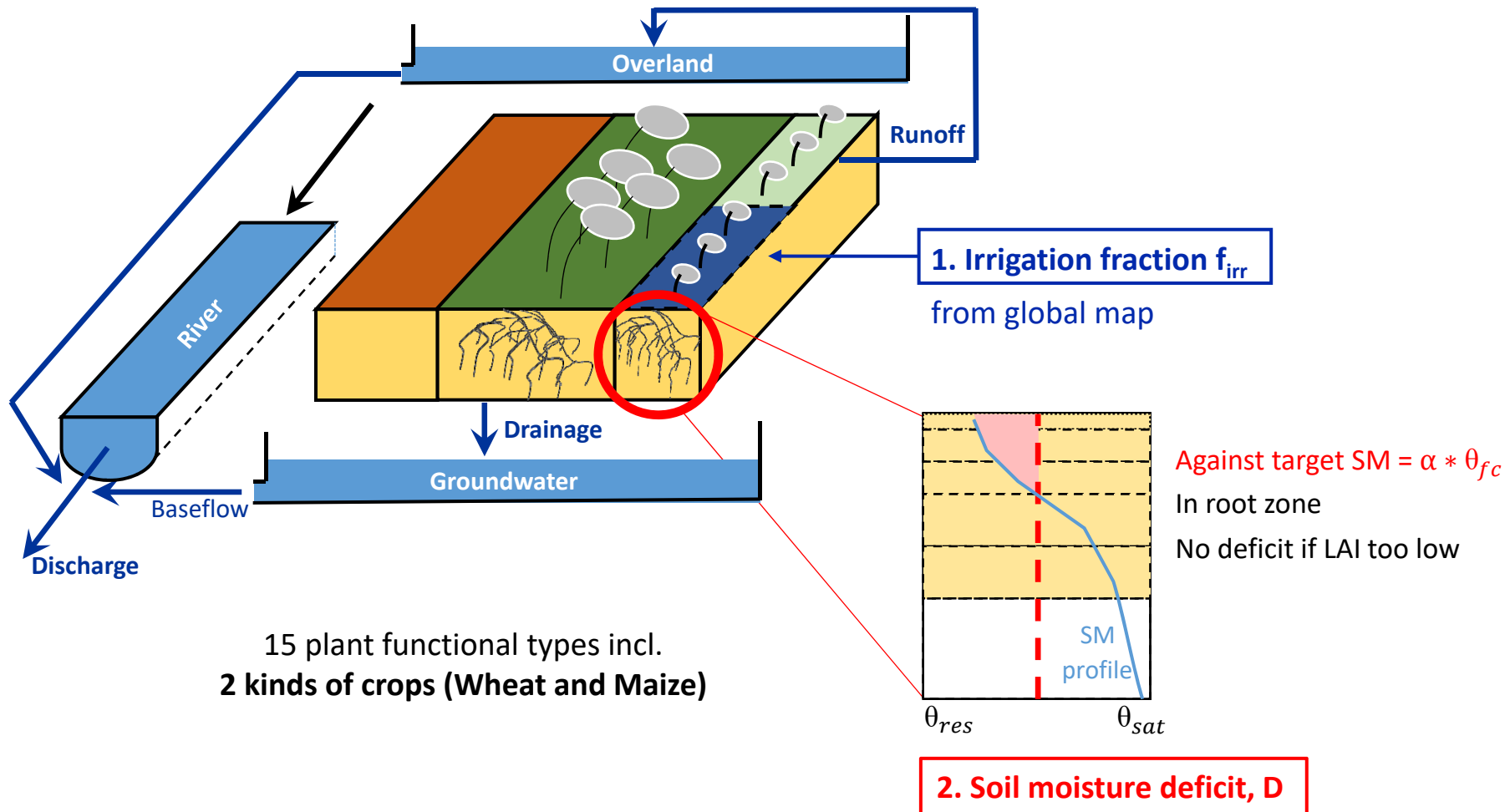


— CMIP6.all
— CMIP6.irr
— CMIP6.noirr
- - OBS

2

Irrigation

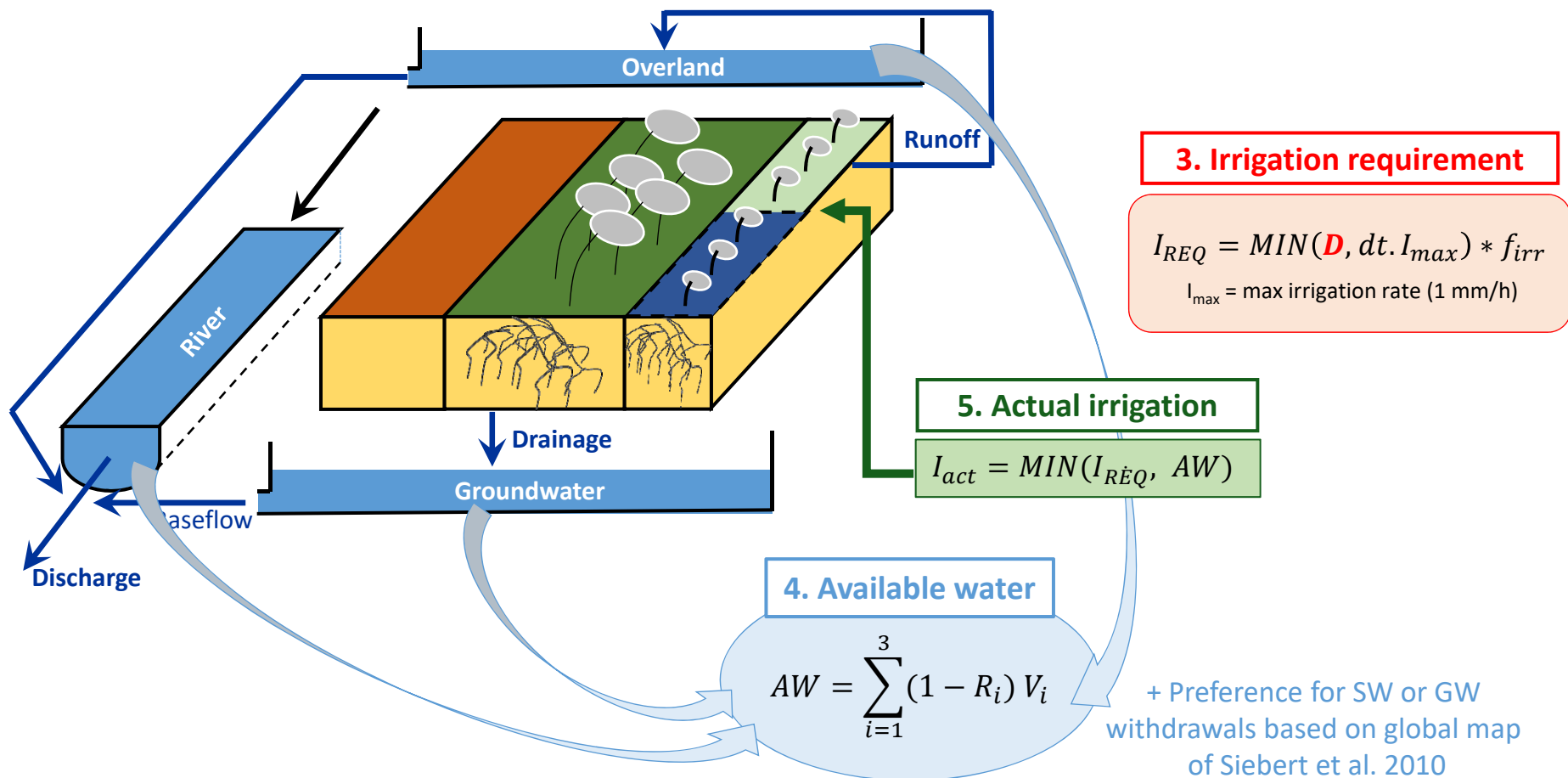
New description in the IPSL climate model



2

Irrigation

New description in the IPSL climate model



V_i = volume within each reservoir

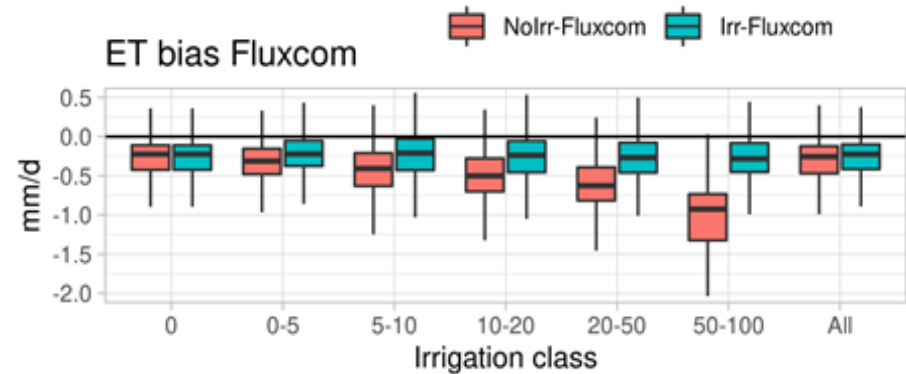
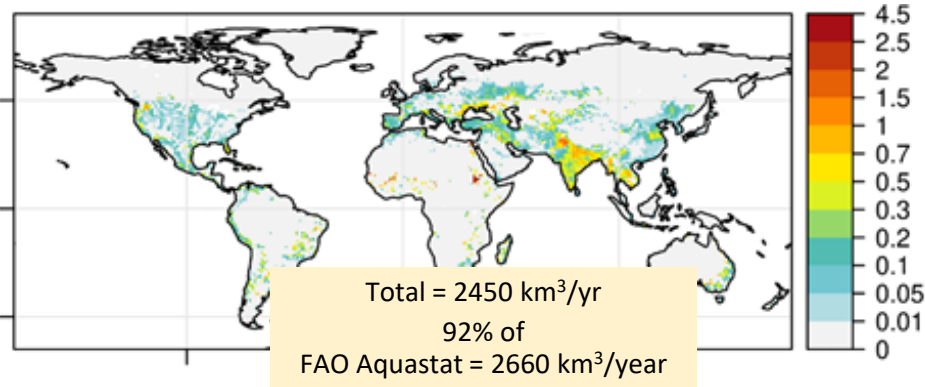
R_i = reserved flow for ecosystems

2

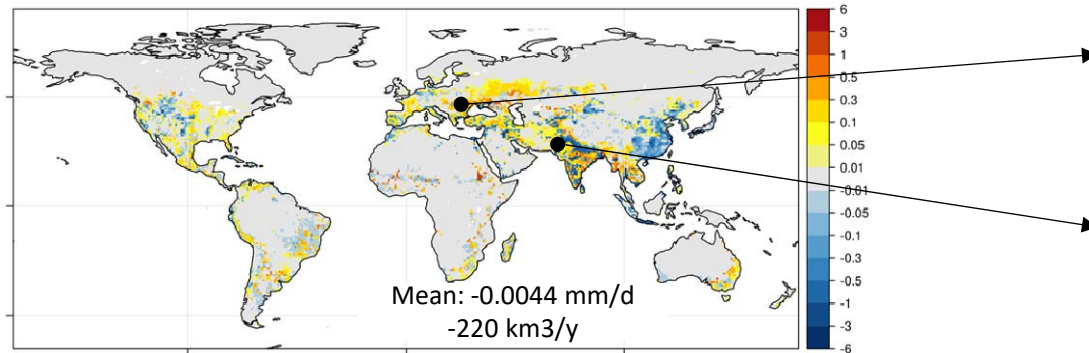
Irrigation

Evaluation of this irrigation scheme around 2000 (offline)

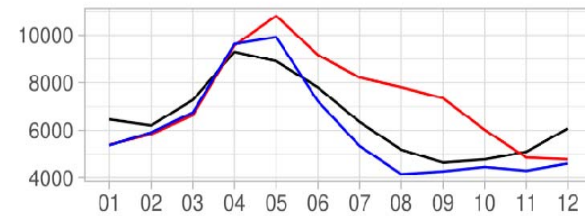
Simulated irrigation (mm/d, yearly)



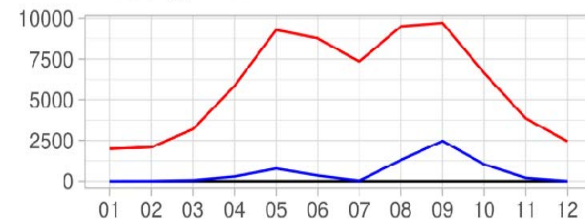
Irrigation bias vs Sacks et al. 2009 (mm/d, yearly)



Danube @ Ceatal Izmail



Indus @ Kotri



OBS
NOIRR
IRR

No climate model simulation with / without irrigation so far



The BLUEGEM project

Biosphere and Land Use Exchanges with
Groundwater and soils in Earth system Models



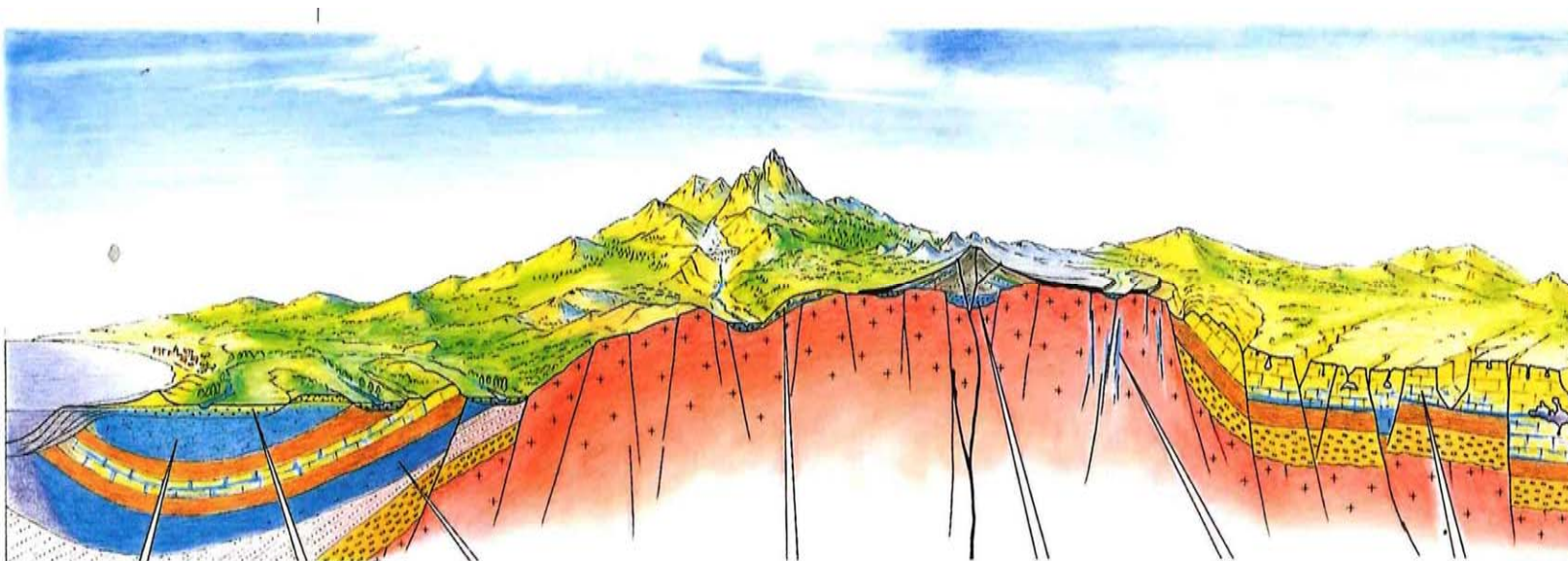


The BLUEGEM project

Overarching goal

Explore the joint evolutions of climate, soils, groundwater, and irrigation, throughout the Anthropocene (1900-2100)

To better understand their coupling, and to foresee their potential changes, including possible social consequences.





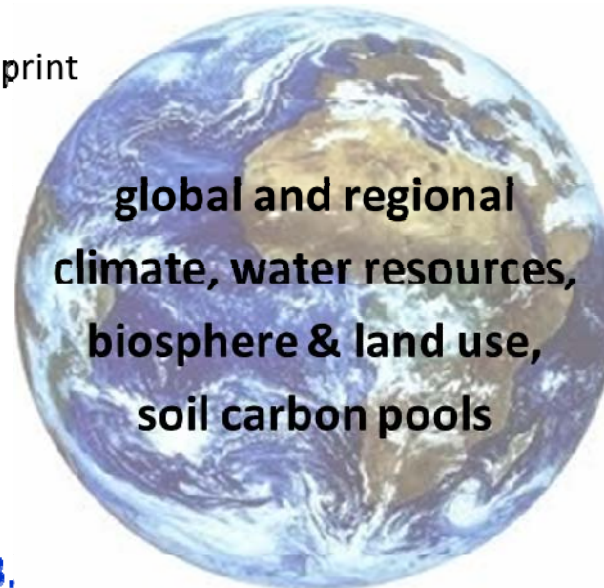
The BLUEGEM project

Advanced numerical modelling

climate models, downscaling methods, hydrological models, agro-economic models

Objective 1.

Establish the fingerprint of irrigation and groundwater



Objective 2.

Provide improved projections up to 2100

Objective 3.

Integrate expert knowledge and socio-economic data to

- explore pathways for sustainable management
- refine land use and irrigation scenarios used climate models.

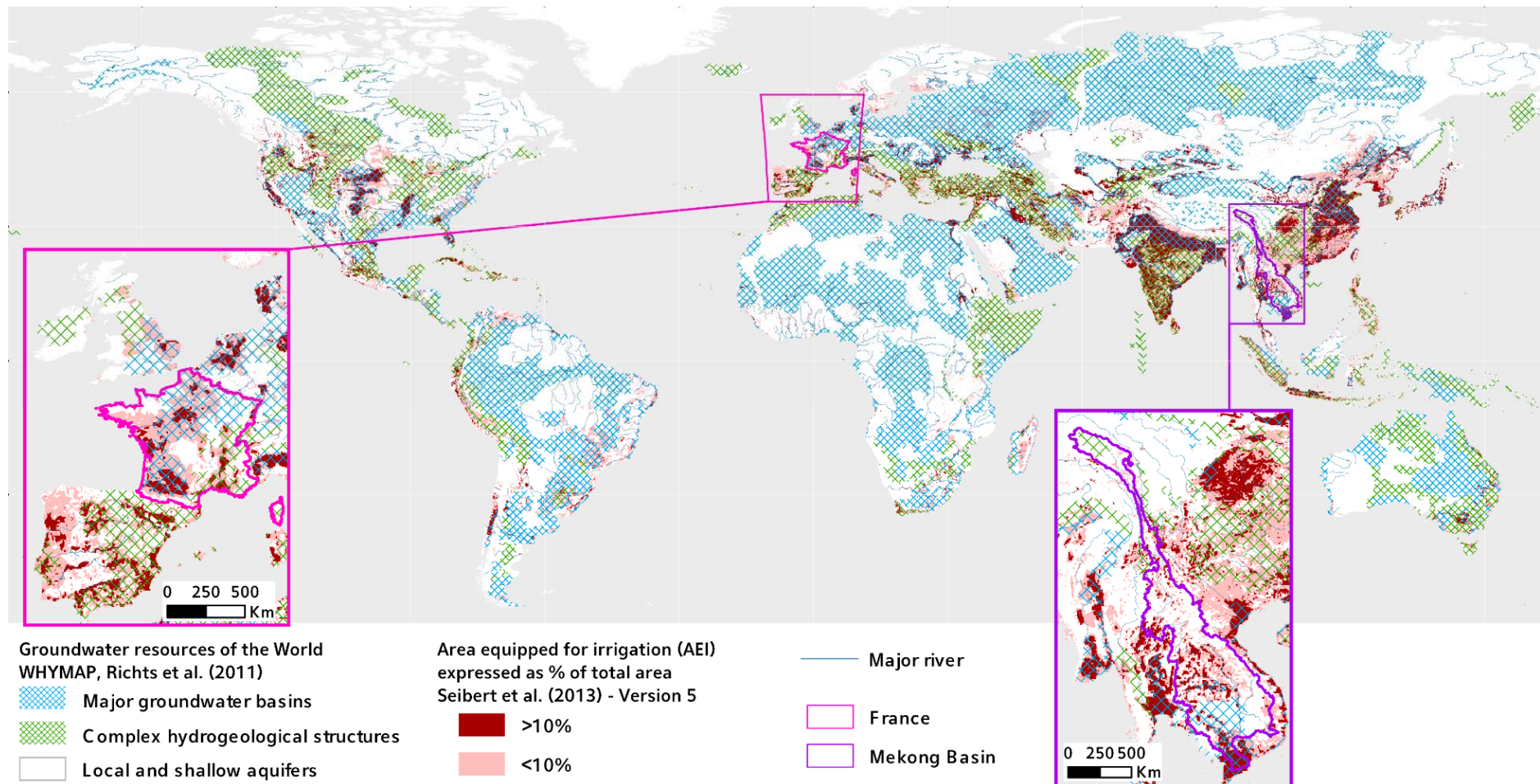
Various participatory methods with local and regional actors

participatory GIS, participatory cultural mapping, and storylines



The BLUEGEM project

Two scales and three geographic domains





The BLUEGEM project

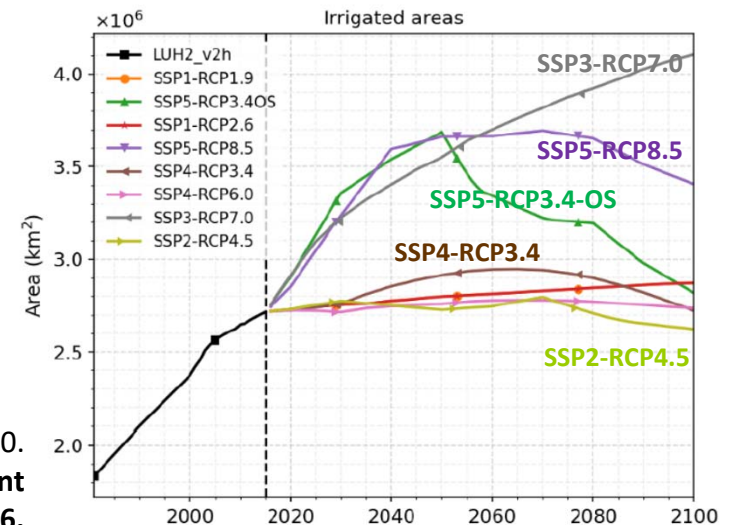
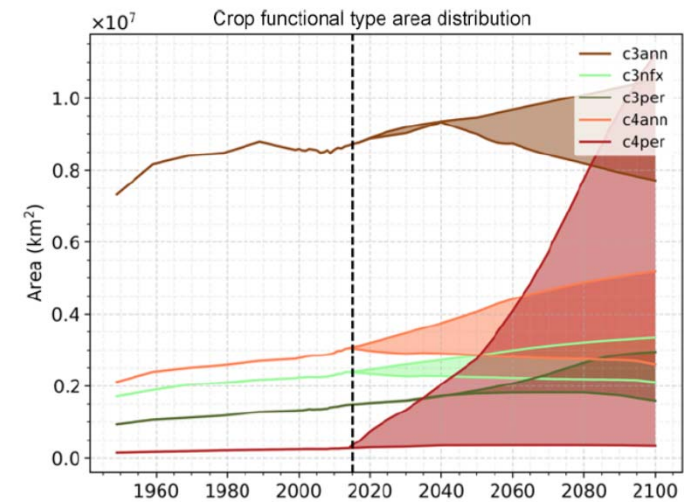
Improved climate change projections

- Two climate models with advanced representation of both groundwater and irrigation (CESM2 at NTU, IPSL-CM6 at IPSL)
- Water withdrawal failure if rivers or groundwater too low
- Among first climate projections with an evolution of irrigated areas

Which modulation of climate change trajectory ?

Tradoffs between irrigation and other water uses?

Tipping points?



Hurt et al. 2020.
Harmonization of global land use change and management
for the period 850–2100 (LUH2) for CMIP6.

Thank you

Merci 謝謝

