How compound extremes impact crops and what they mean for adaptation

WCRP Safe Landing Climates Discussion
20 November 2023

Lamont-Doherty Earth Observatory
COLUMBIA UNIVERSITY | EARTH INSTITUTE

DARTMOUTH | CLIMATE MODELING & IMPACTS GROUP


Crops are the boundary
conditions of the food system

A good harvest does not ensure food security

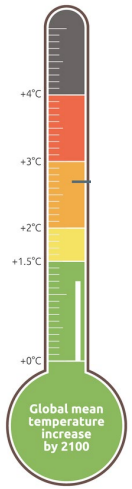
But a bad harvest does increase food security risk

A warming climate stresses crops in many ways

The evolving focus of climate impacts (in the IPCC)

IPCC 2nd Report:
Extremes **not mentioned** in agricultural impacts

+2°C



1990s 2000s 2010s 2020s

Mean changes

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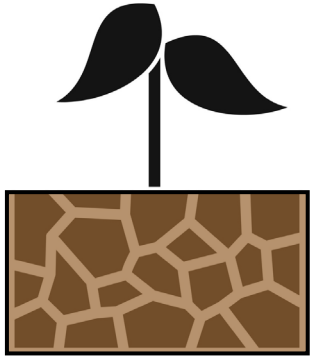

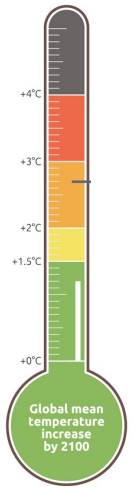

IPCC 3rd Report:
"Projected Changes in Climate Extremes could have **Major Consequences**"

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Mean changes **Extremes**

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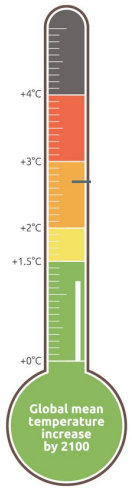
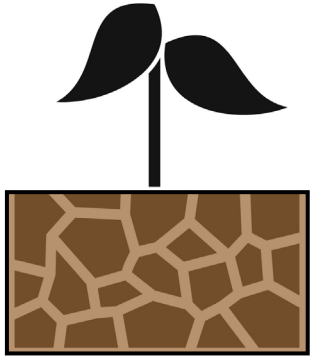
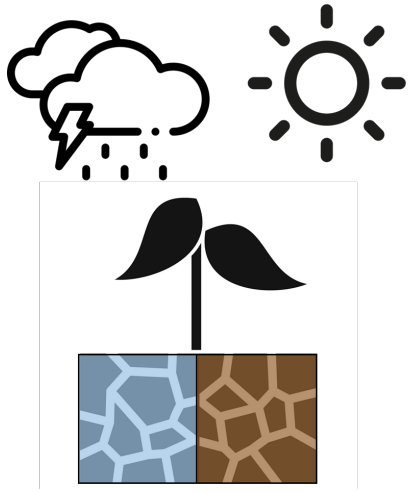




IPCC 3rd Report:
"Projected Changes in Climate Extremes could have **Major Consequences**"

IPCC 6th report:
First mention of **'compound extremes'**

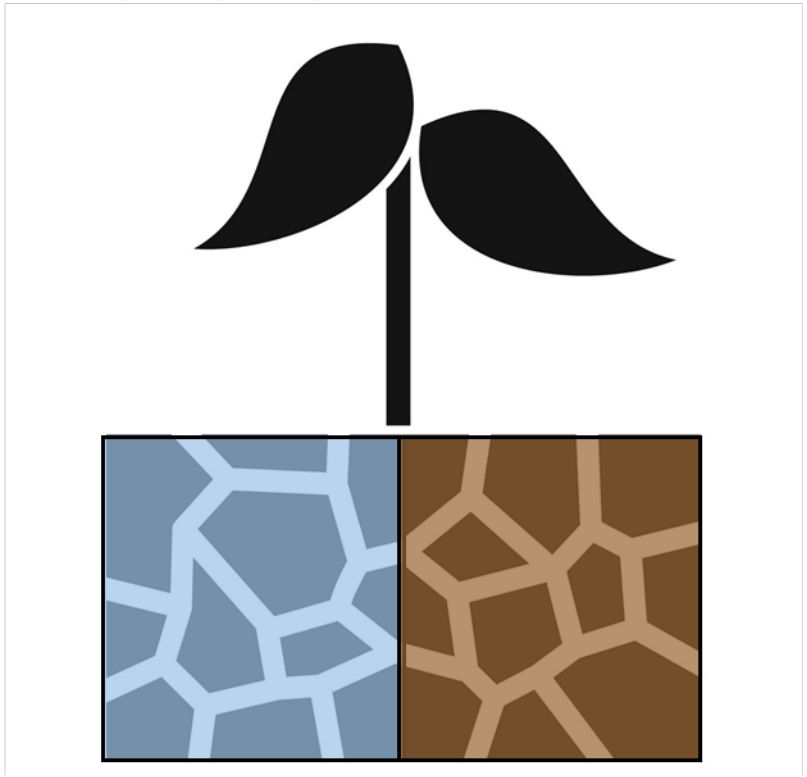


1990s 2000s 2010s 2020s

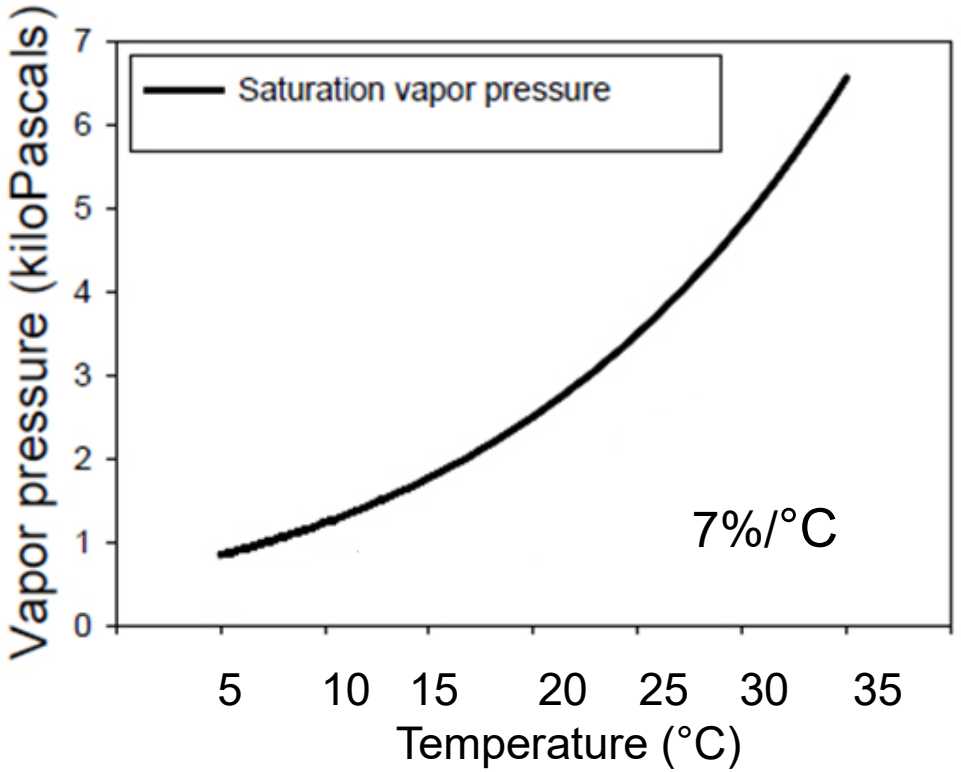
Mean changes **Extremes** **Compound extremes**

Under warming, crops are increasingly exposed to *multiple* stresses

Compound impacts
Distinct dynamics



Physically, warming implies more compound extremes



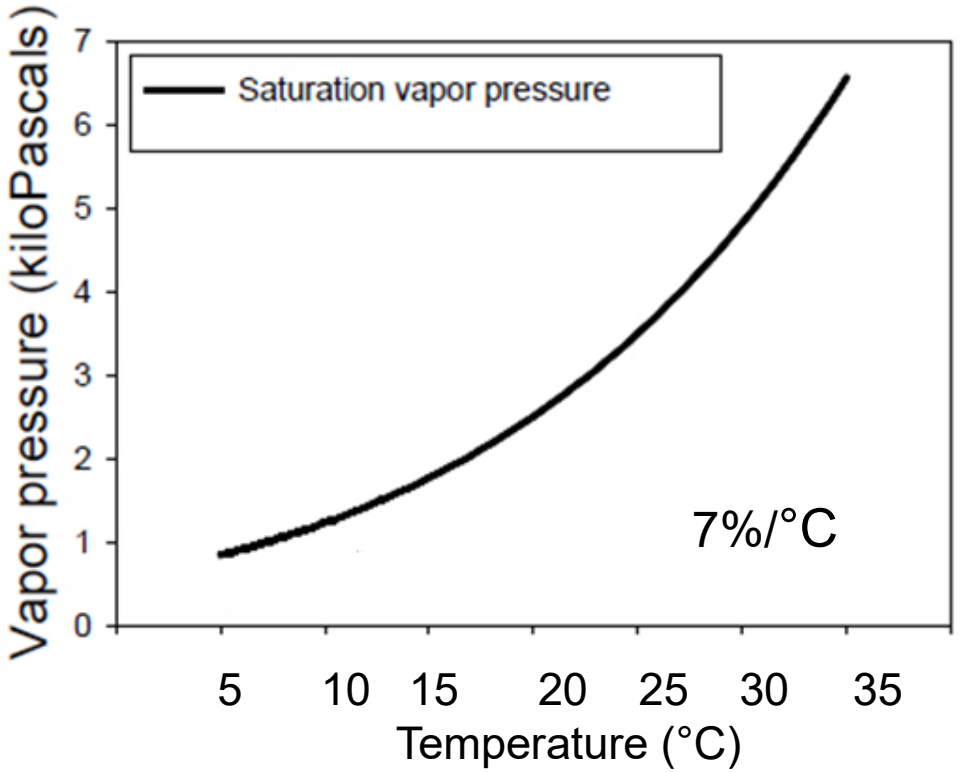
Warmer air holds more water vapor at saturation

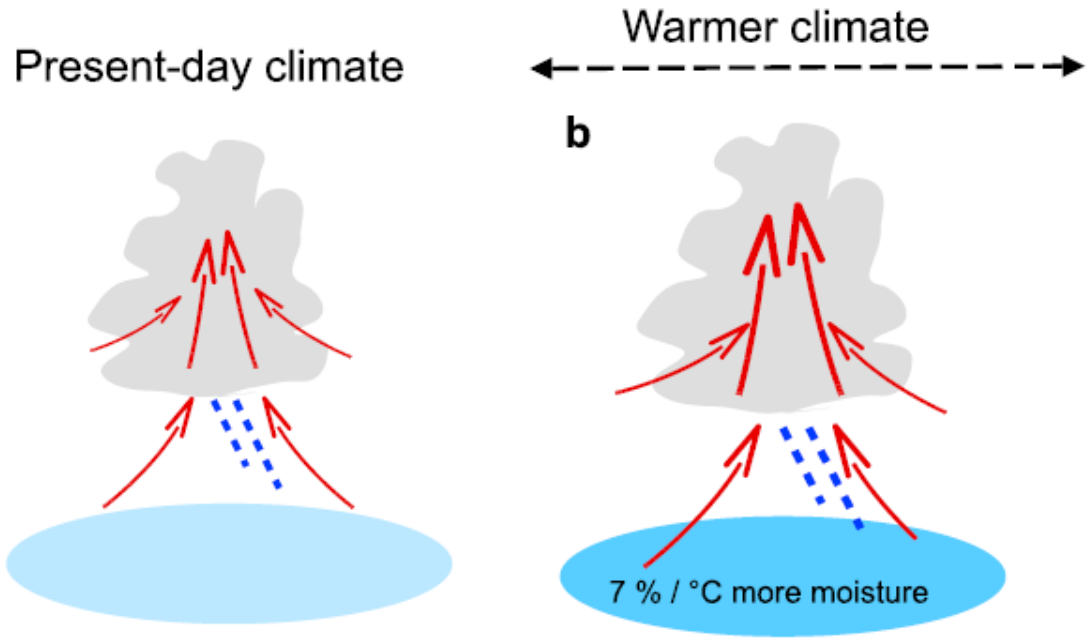
Steeply increasing (nonlinear)

A wetter atmosphere
A thirstier atmosphere

Westra *et al.* 2014

A wetter atmosphere ⟶ *More extreme rainfall*





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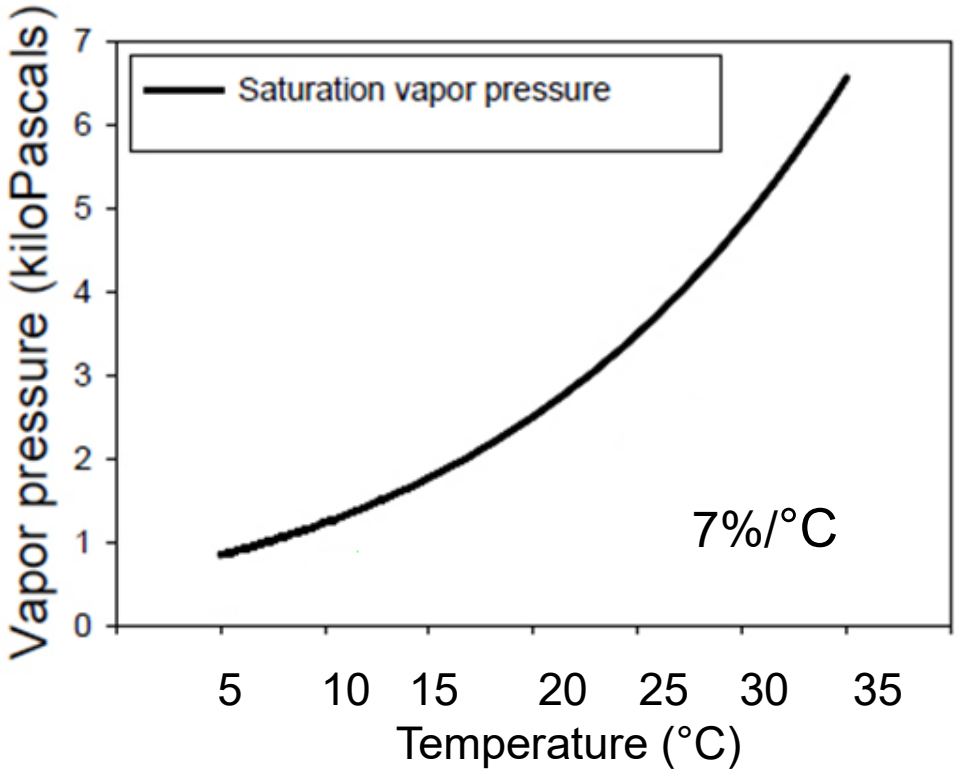
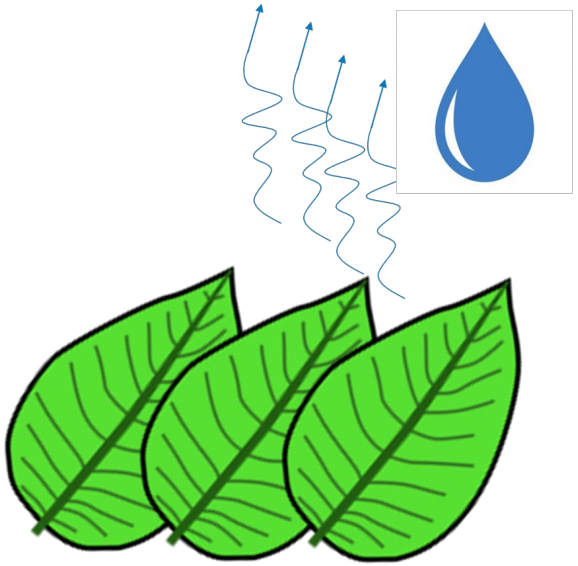
A thirstier atmosphere ⟶ *More moisture stress*





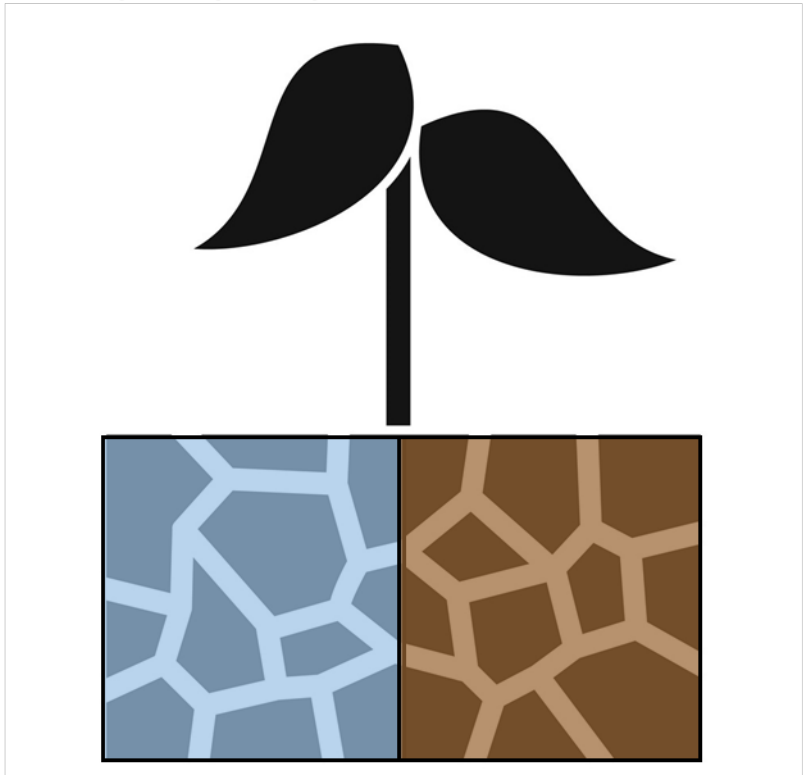
Grossiord *al.* 2020

Under warming, crops are increasingly exposed to *multiple* stresses

Warmer, more heat extremes

Also = more hydrologic extremes

Wet *and* Dry

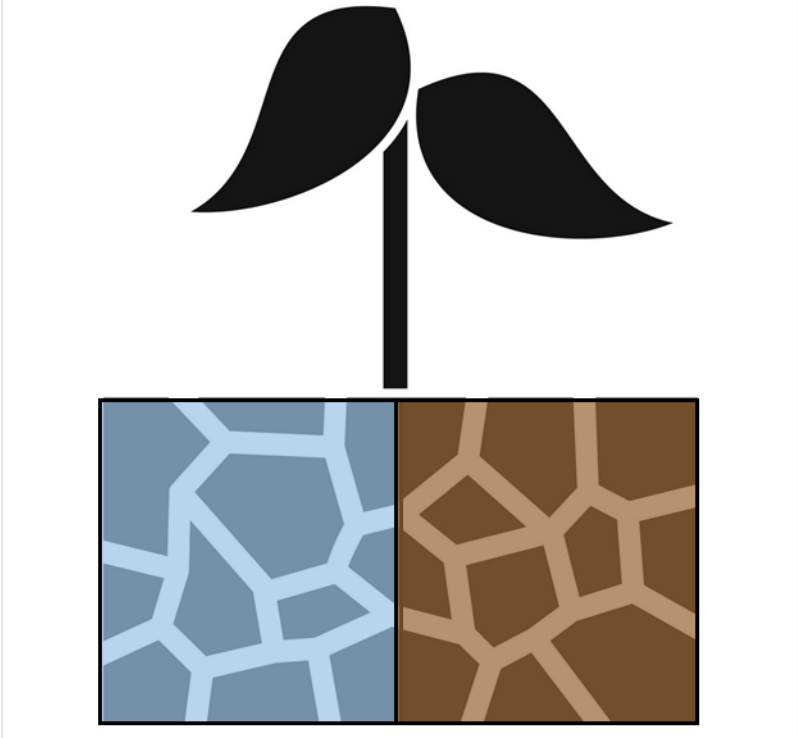


Crop impacts fairly well understood

Warmer, more heat extremes

Also = more hydrologic extremes

Wet *and* Dry



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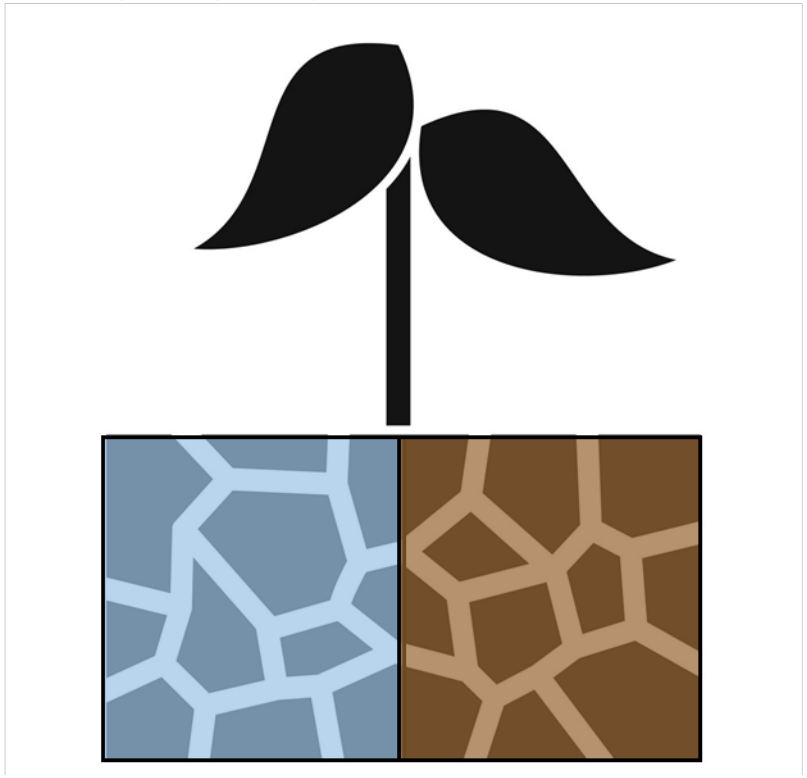
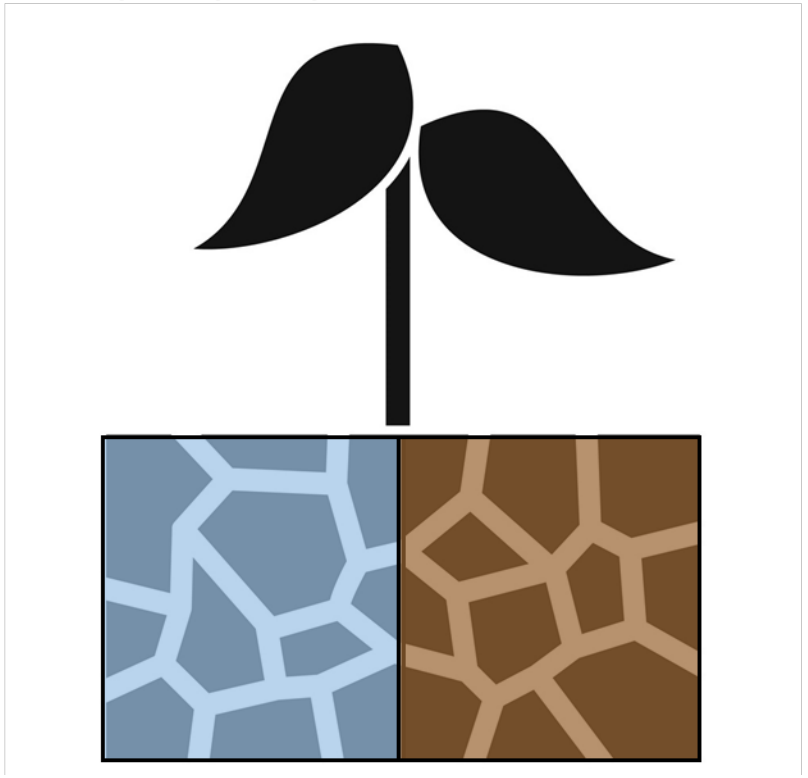


Crop impacts poorly understood

How do these compound stresses affect crop production?

More intense rainfall



Hotter droughts

Short answer (and the key message of this talk):

Increasingly compound heat+drought pose new risks to crops

Partially offset by more intense rainfall

Understanding these impacts clarifies how to effectively adapt

Rest of the talk:

1. Tools for understanding compound crop impacts
2. Crop impacts of **hotter droughts** and **more intense rainfall**
3. Implications for adaptation

Two ways to understand climate impacts on crops

1. Statistical models

Climate & Crop Data

↓

Regression

↓

Crop sensitivities

↓

Learning

Two ways to understand climate impacts on crops

1. Statistical models

Climate & Crop Data

Regression

Climate projections → Crop sensitivities → **Future impacts**

Crop sensitivities → **Learning**

Two ways to understand climate impacts on crops

2. Process-based models

Climate Projections

↓

Learning → *Key process equations*

↓

Future impacts

Two ways to understand climate impacts on crops

2. Process-based models

Climate Projections

↓

Learning → *Key process equations*

↓

Future impacts

In principle, the gold standard

But we don't understand key processes of ***compound stress***

Largely omitted from models

see Lesk et al. 2022, Nature Reviews Earth and Environment

Statistical modeling to learn how compound extremes impact crops

Climate & Crop Data

Regression

Climate projections → Crop sensitivities → **Future impacts**

Crop sensitivities → **Learning**

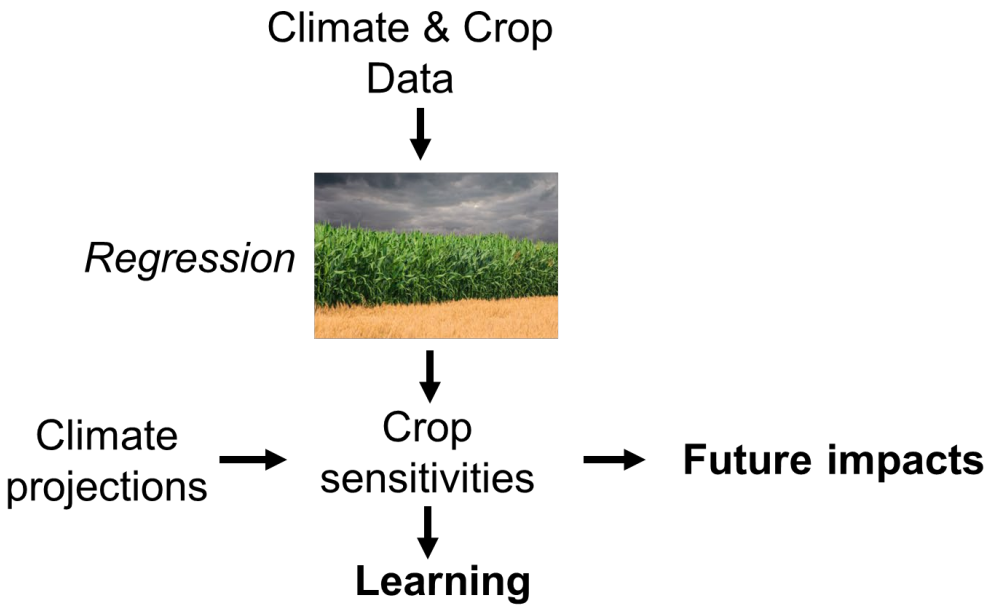
Understand missing key processes

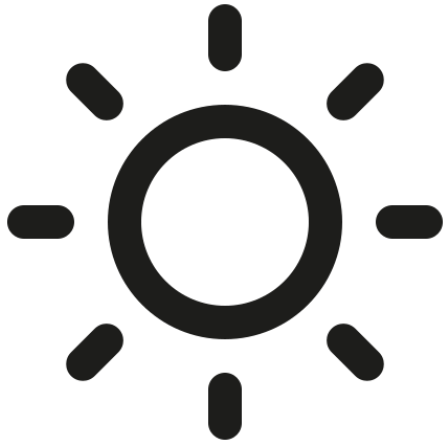
Learning → *Key process equations*

Climate Projections

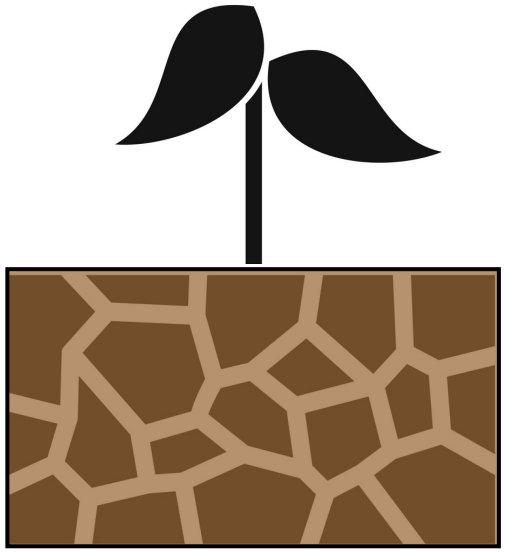
Future impacts

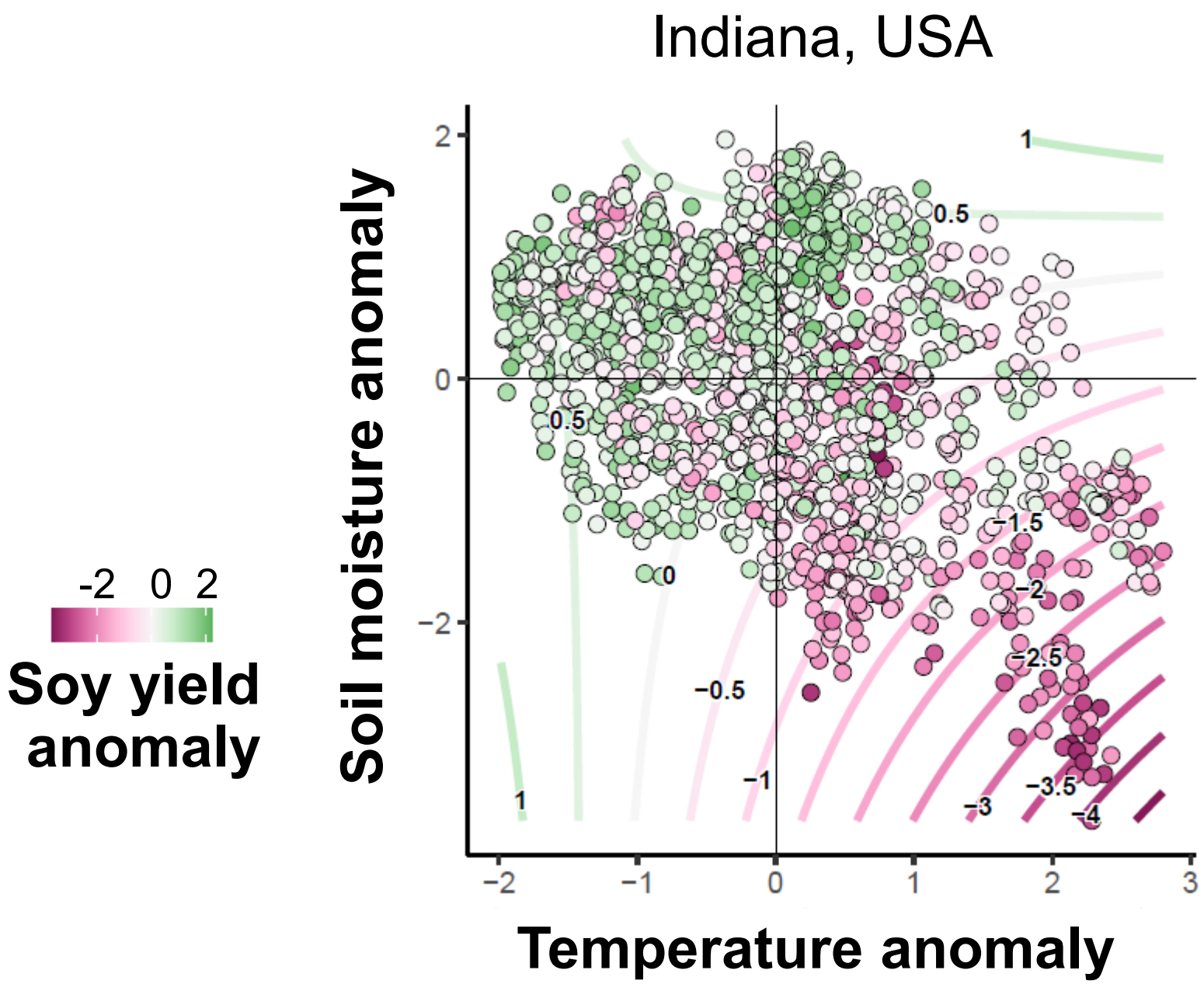
Statistical modeling to learn how compound extremes impact crops





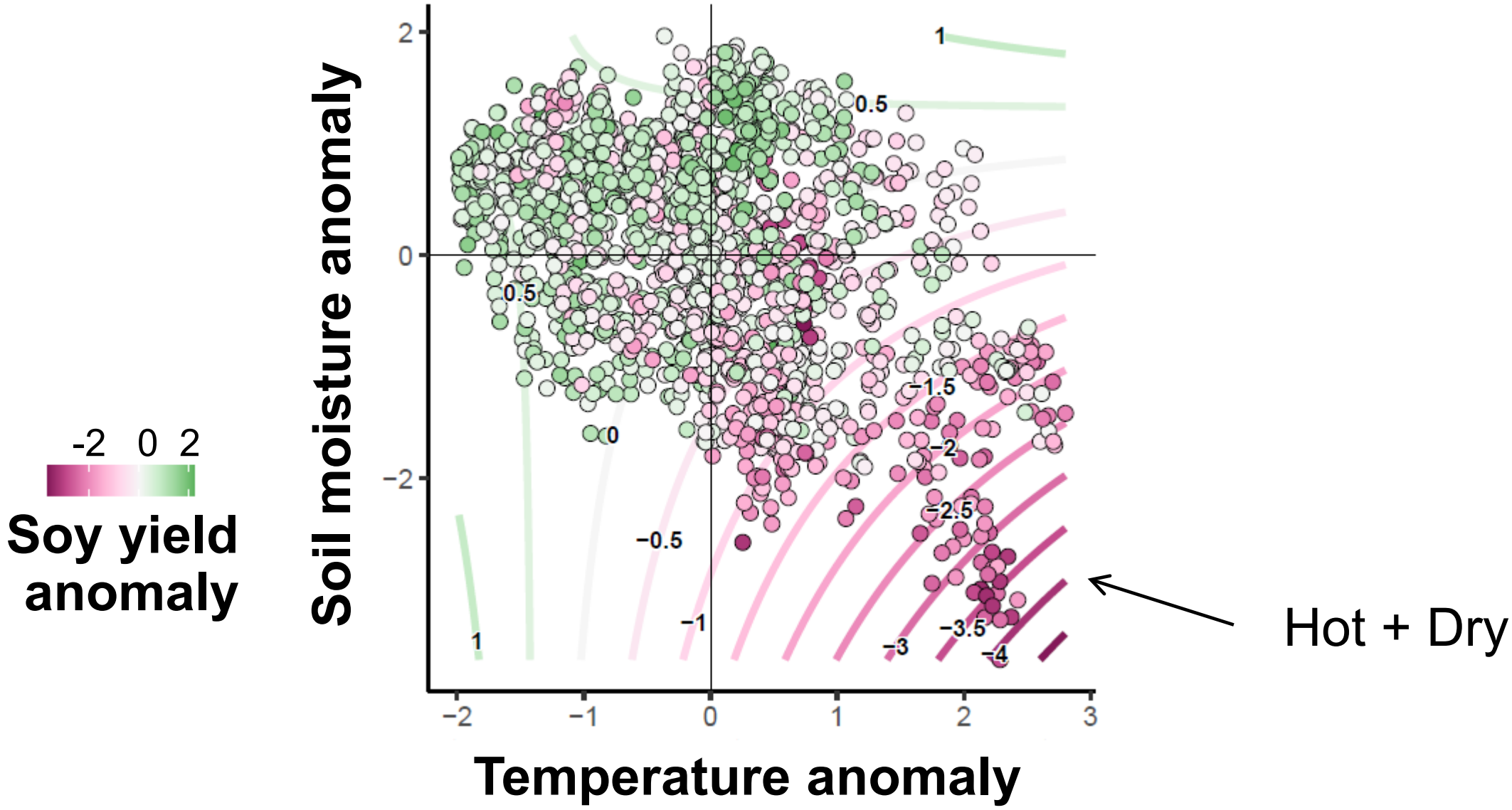
Hotter droughts





Two key processes

Hamed et al. 2022



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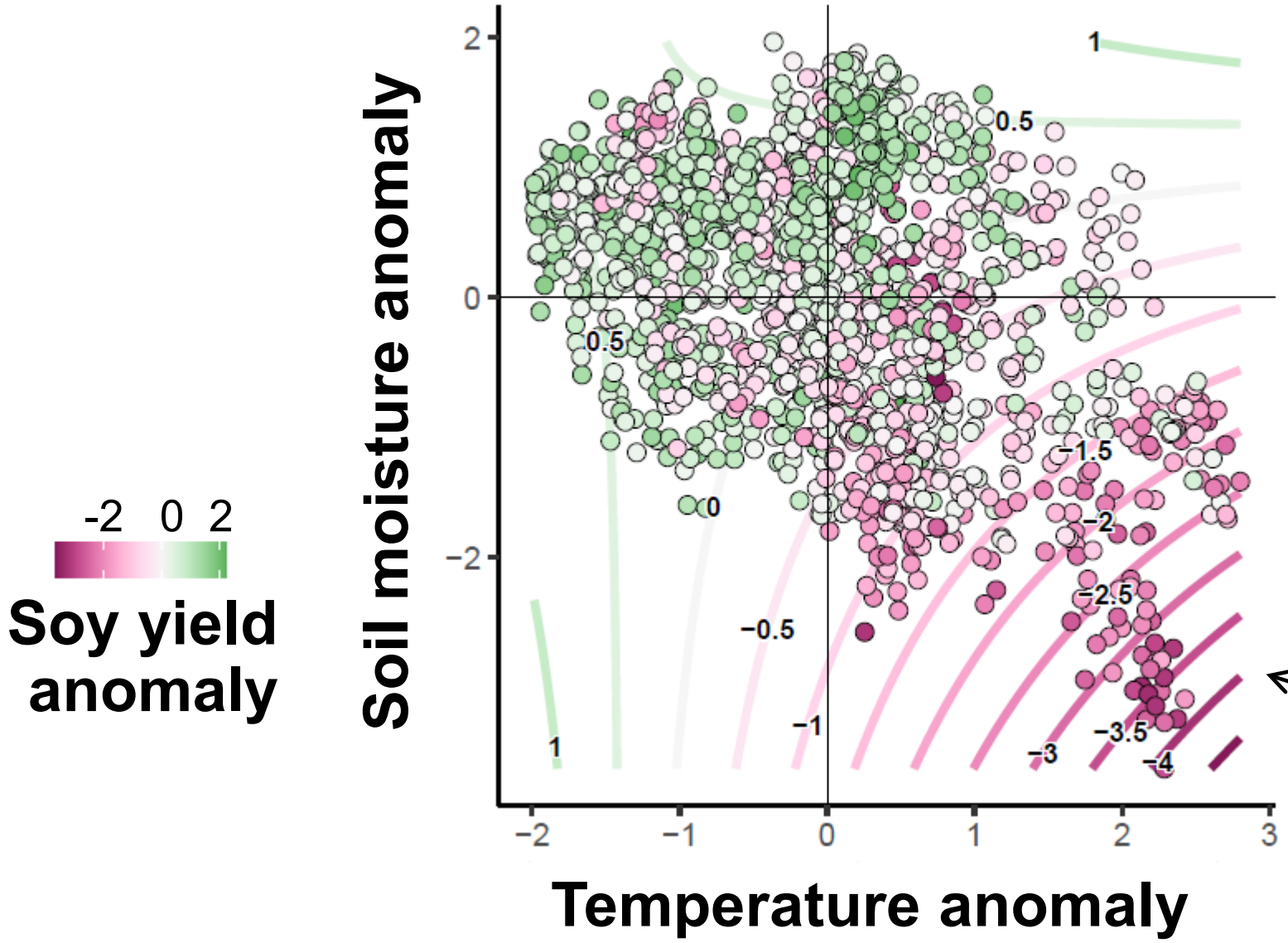
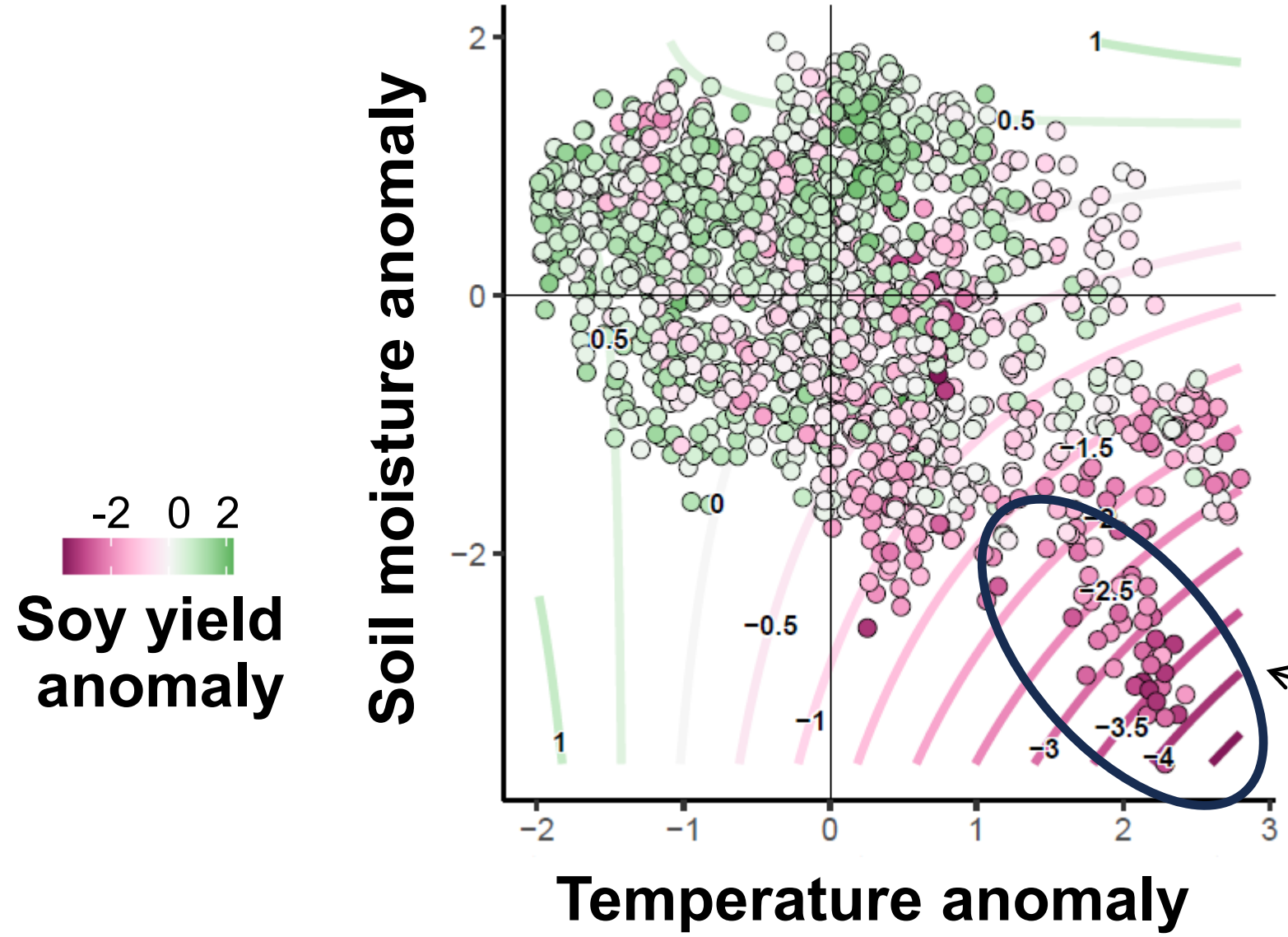


Historically, hotter droughts have strongest crop yield impact

Hamed et al. 2022

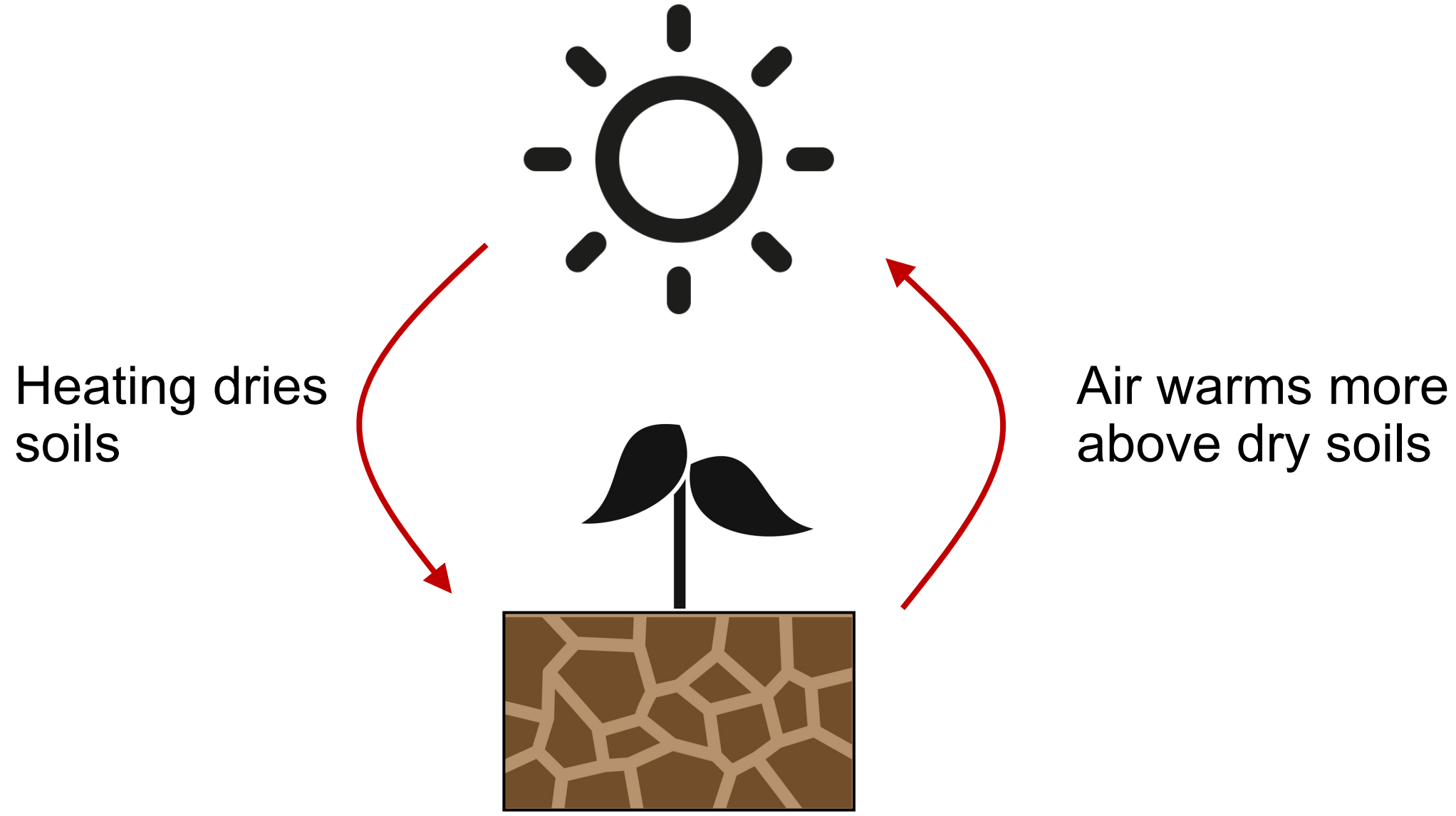


Also, heat + drought are connected

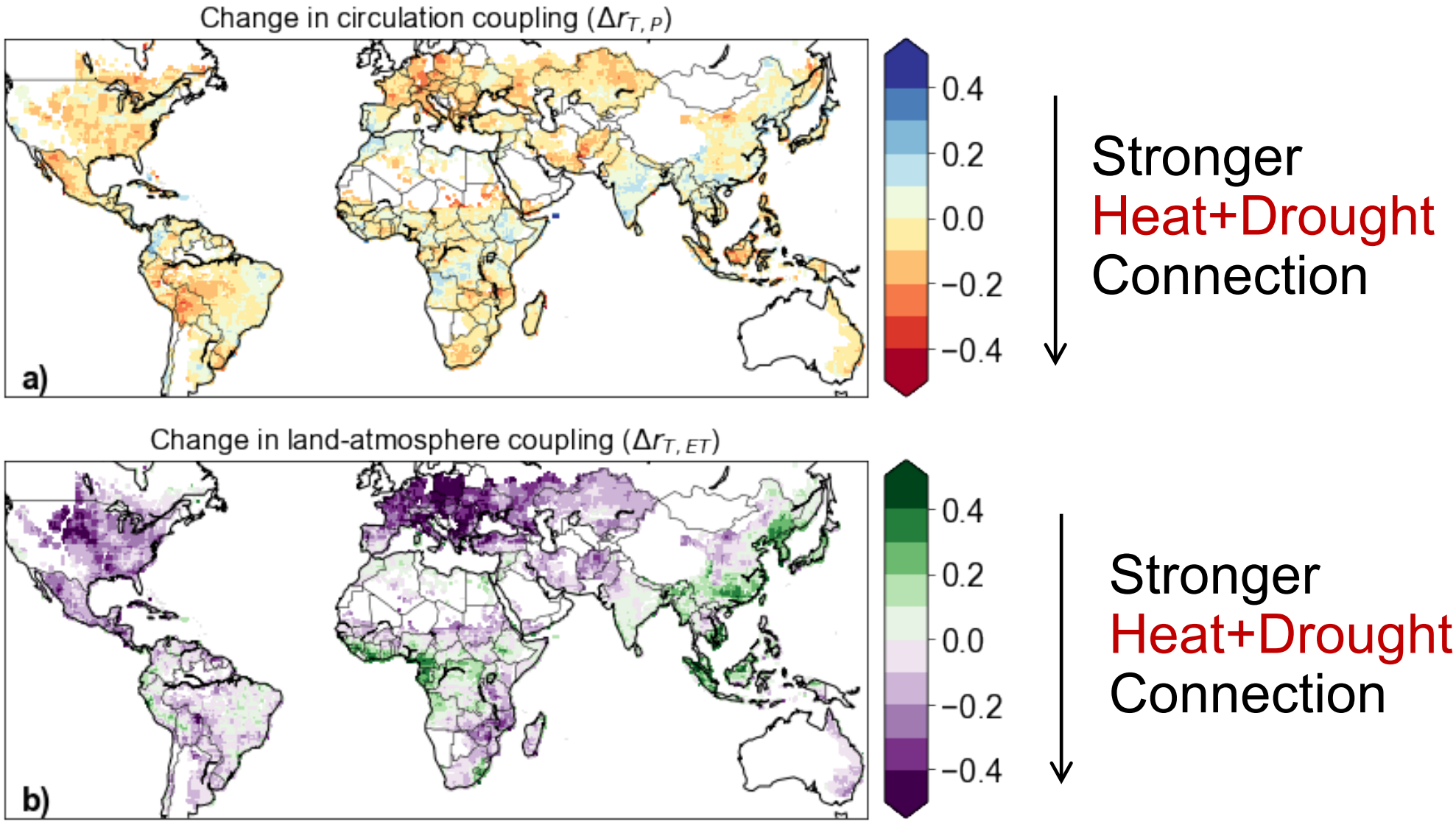
Mutual intensification

Hamed et al. 2022

Heat+Drought connections



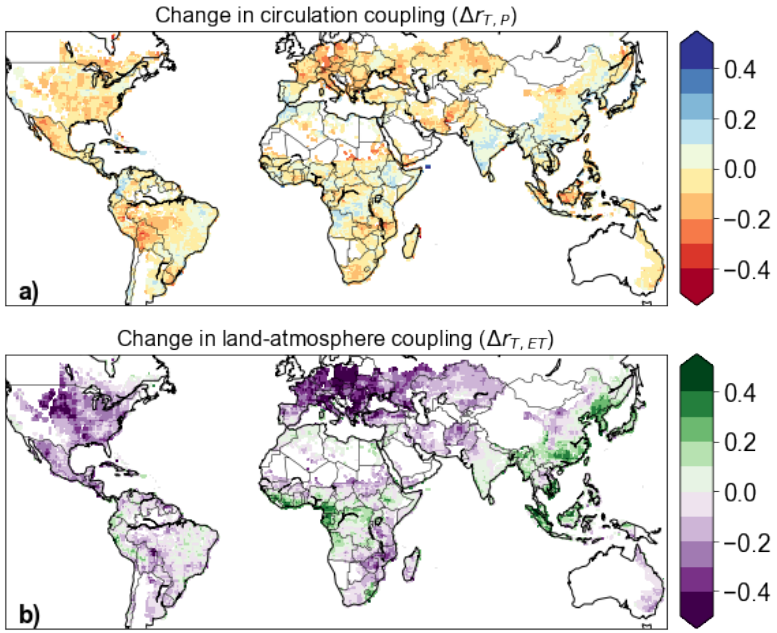
Stronger Heat+Drought connections under warming

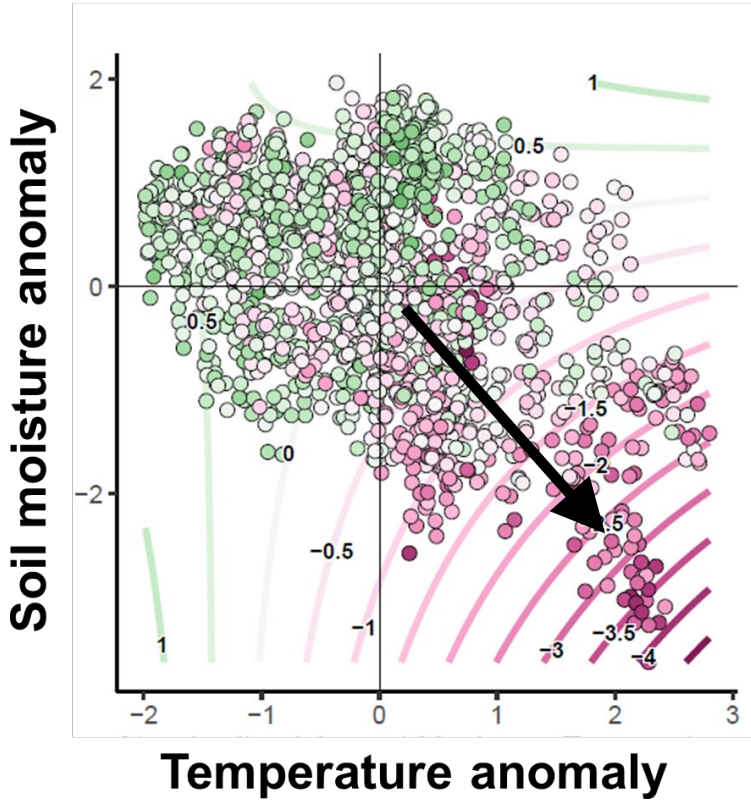


Lesk et al. 2021 *Nature Food*

Multi-model median of 12 CMIP6 GCMs/ESMs, SSP2-4.5, 2050-2100

Historical trends suggest enhanced couplings will increase heat sensitivity of crops

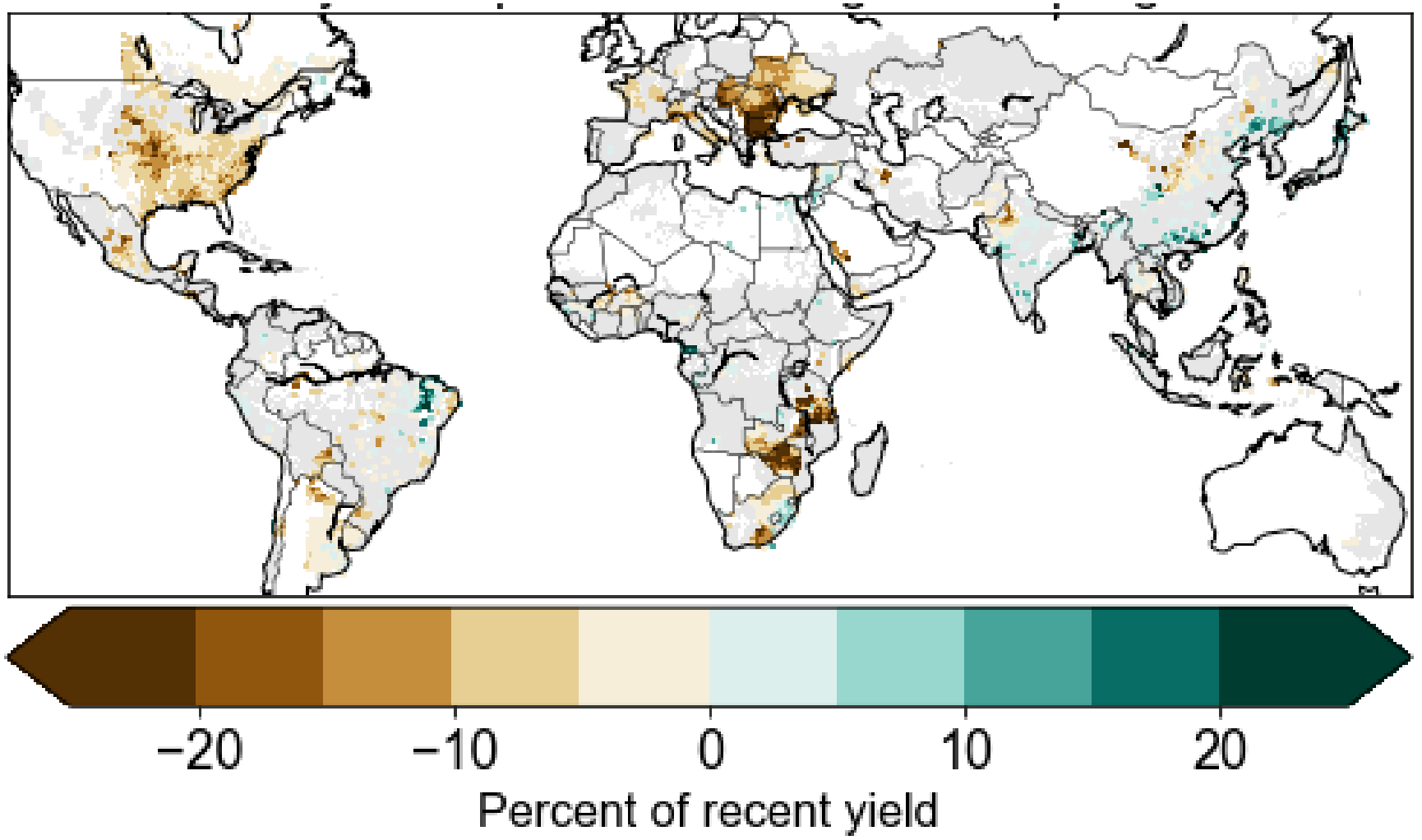




Multi-model median of 12 CMIP6 GCMs/ESMs, 2050-2100

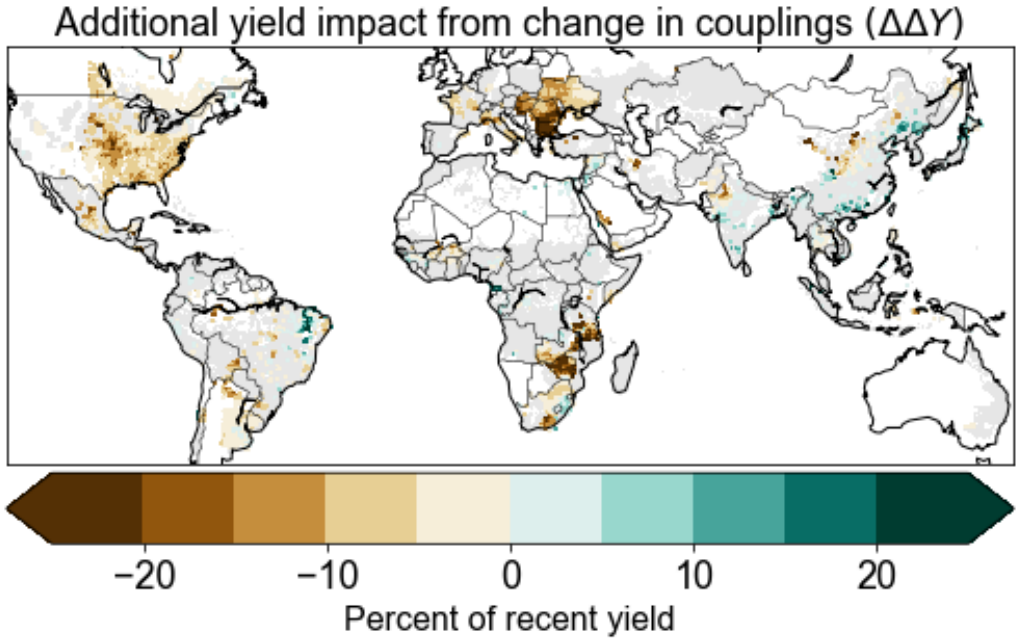
Future change in couplings exacerbates crop yield impacts of warming

Global average = 5%



Based on 12 CMIP6 GCMs/ESMs

Lesk et al. 2021 *Nature Food*

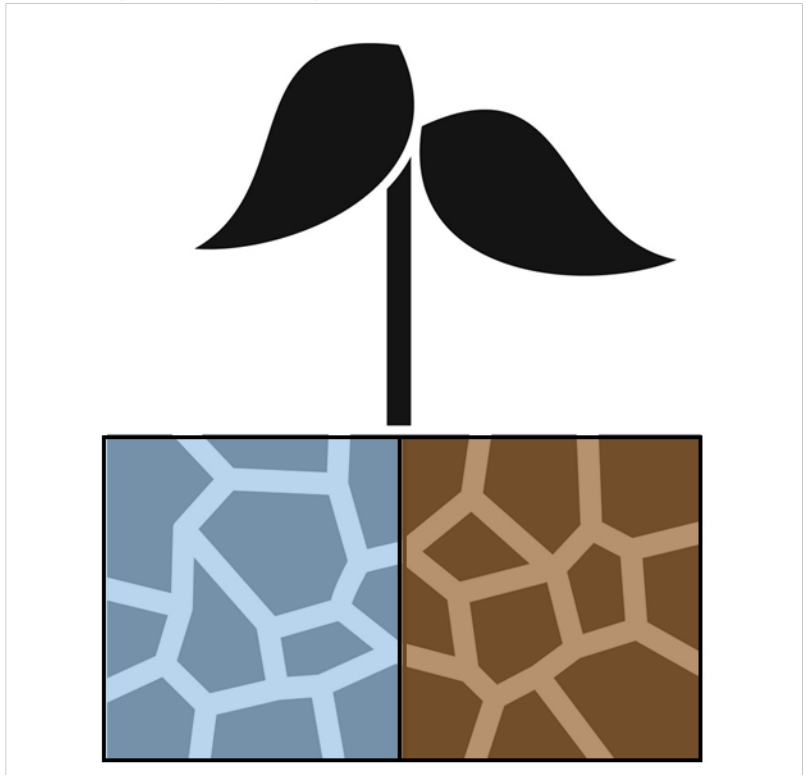


Not included in present risk assessments!
(for a variety of technical reasons we can talk about)

Lesk et al. 2021 *Nature Food*

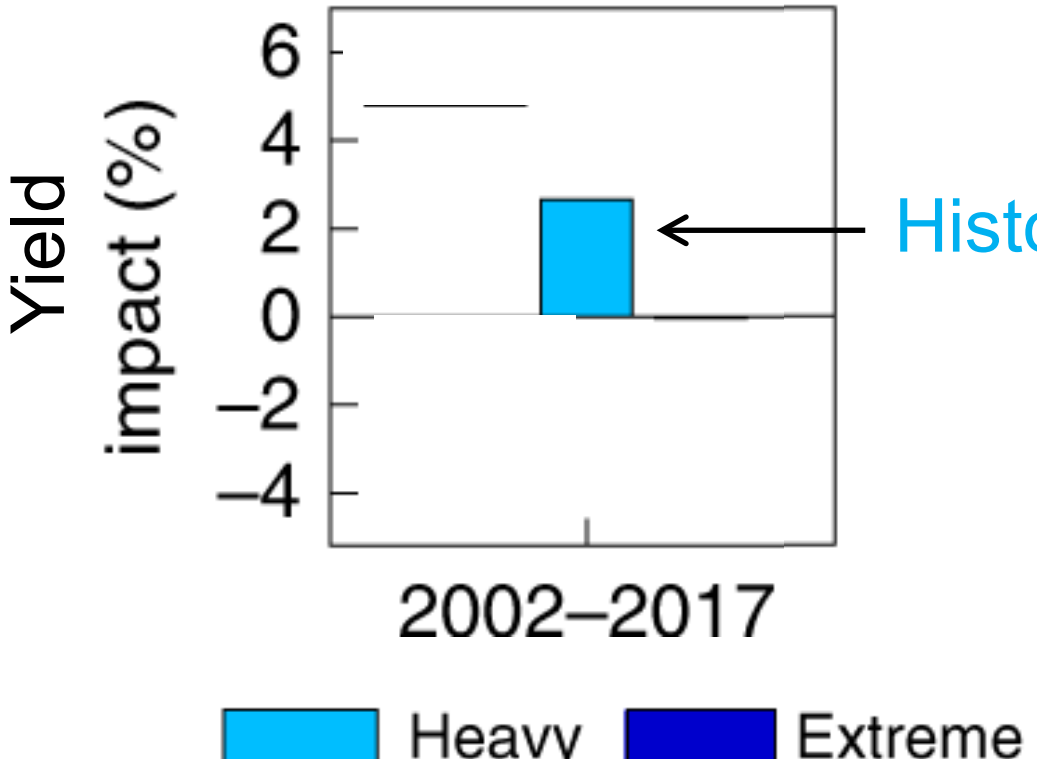
More intense rainfall

Will this help or hurt?



Hotter droughts

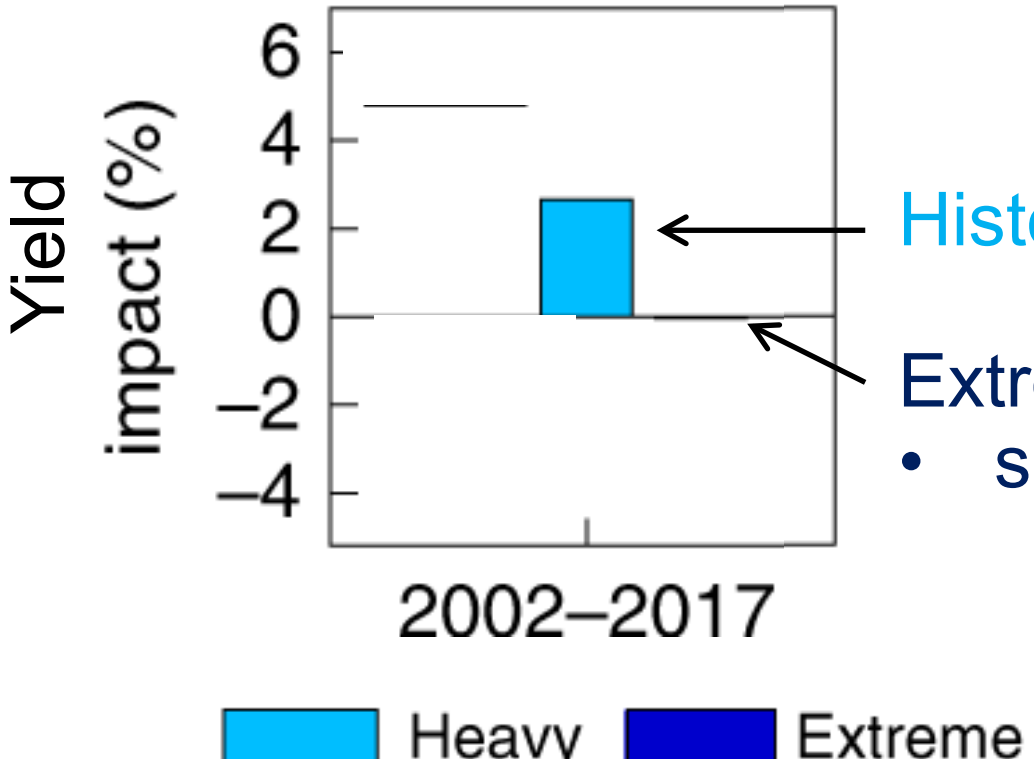
Maize and Soy



Historically, heavy rainfall benefits yields

Lesk et al. 2020 *Nature Climate Change*

Maize and Soy



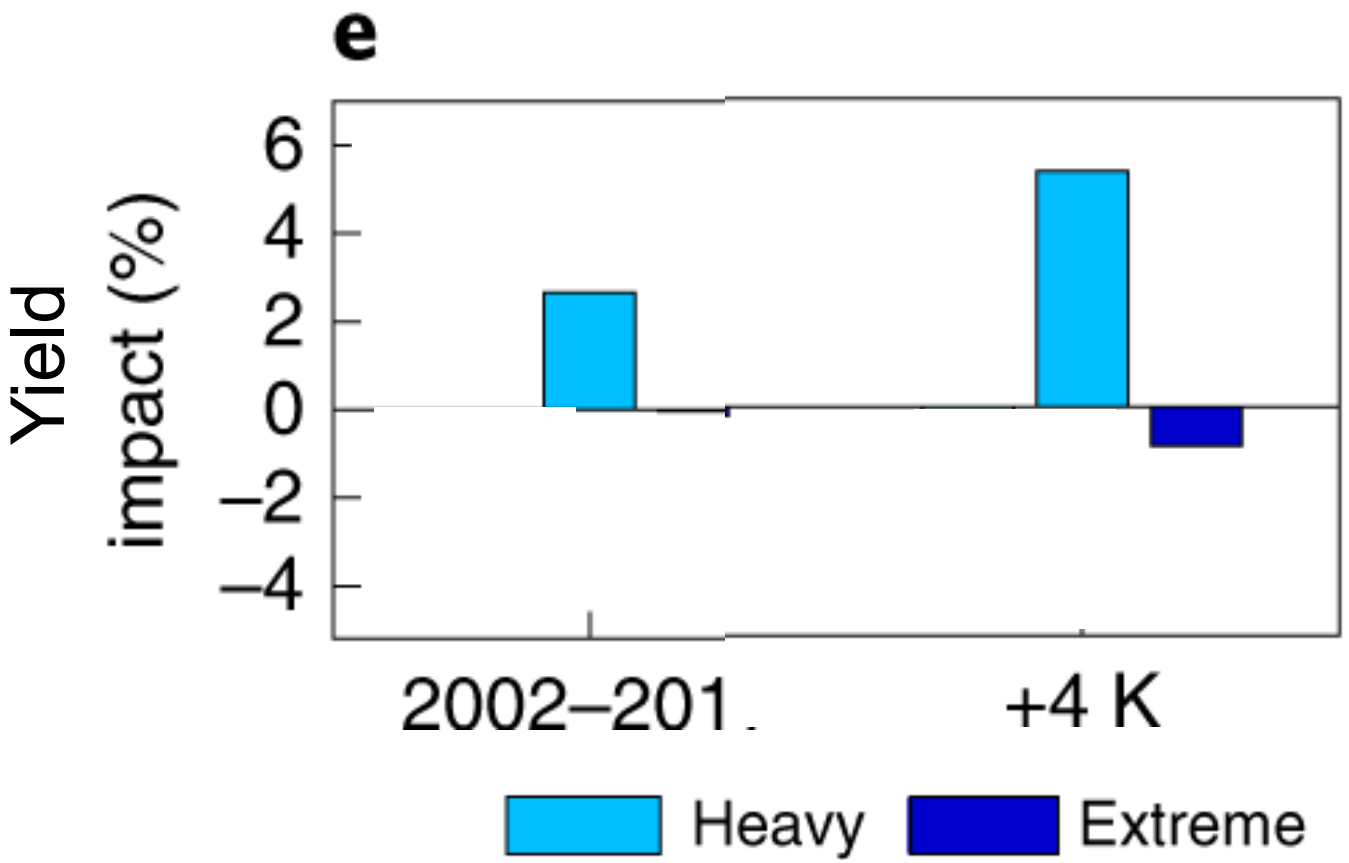
Historically, heavy rainfall benefits yields

Extremes are damaging, but very rare

- small impact, on average

Lesk et al. 2020 *Nature Climate Change*

Heavier rainfall will likely benefits yields (slightly)



Benefits of more heavy rain **outweigh** damages from more extremes

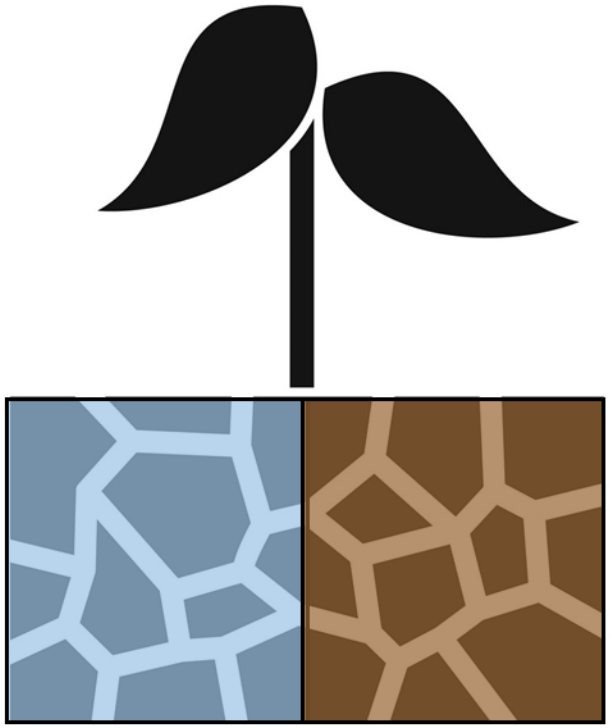
Yield gains around 2%

Lesk et al. 2020 *Nature Climate Change*

Additional crop risks from compound extremes

More intense rainfall

+2% yields



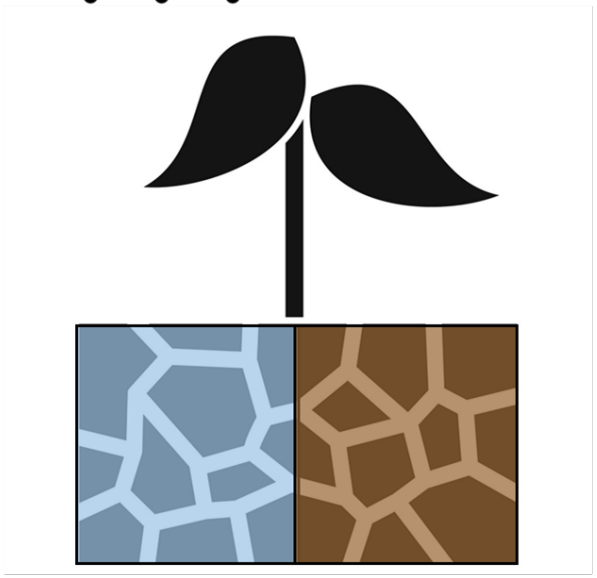
Hotter droughts

-5% yields

Additional crop risks from compound extremes

More intense rainfall

+2% yields



Hotter droughts

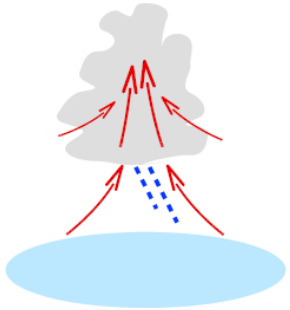
-5% yields

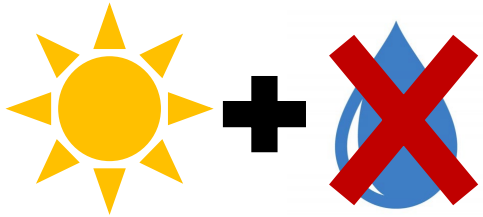
Only beginning to be considered in risk assessments

But clarifies effective adaptation

Multi-stress adaptation to climate change

Climate extremes are becoming increasingly compound



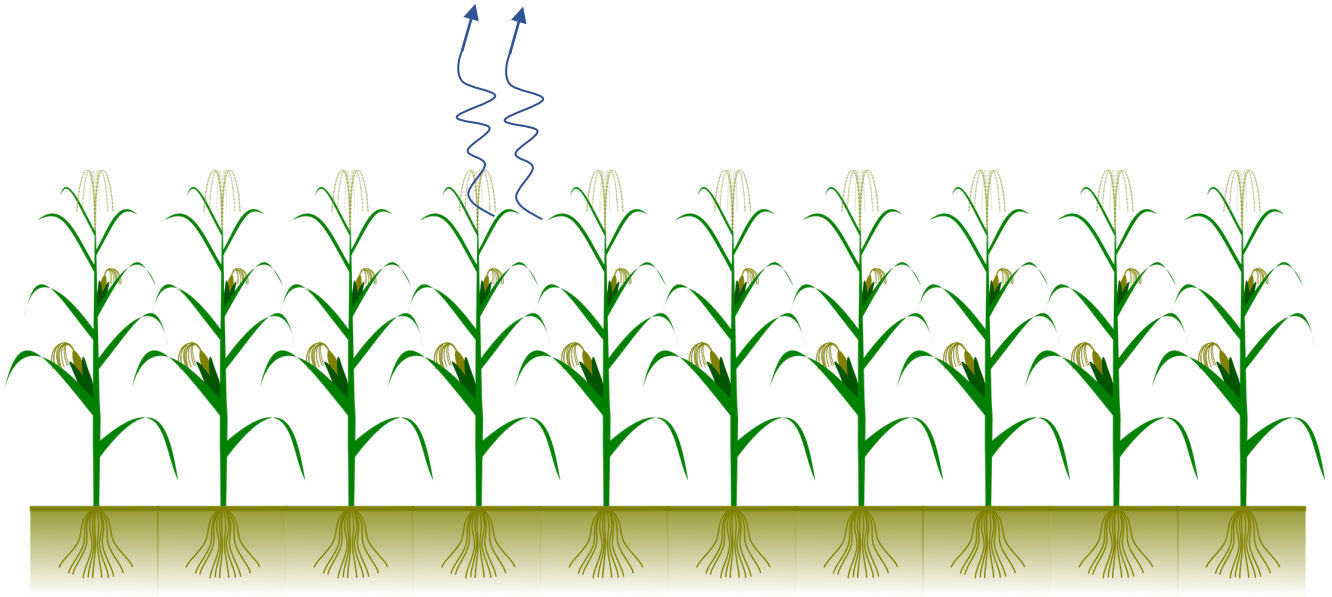


Some ‘traditional’ adaptation approaches may not work well

Breeding crops for drought: limit transpiration

Decrease water use
Maintain water status

Transpiration

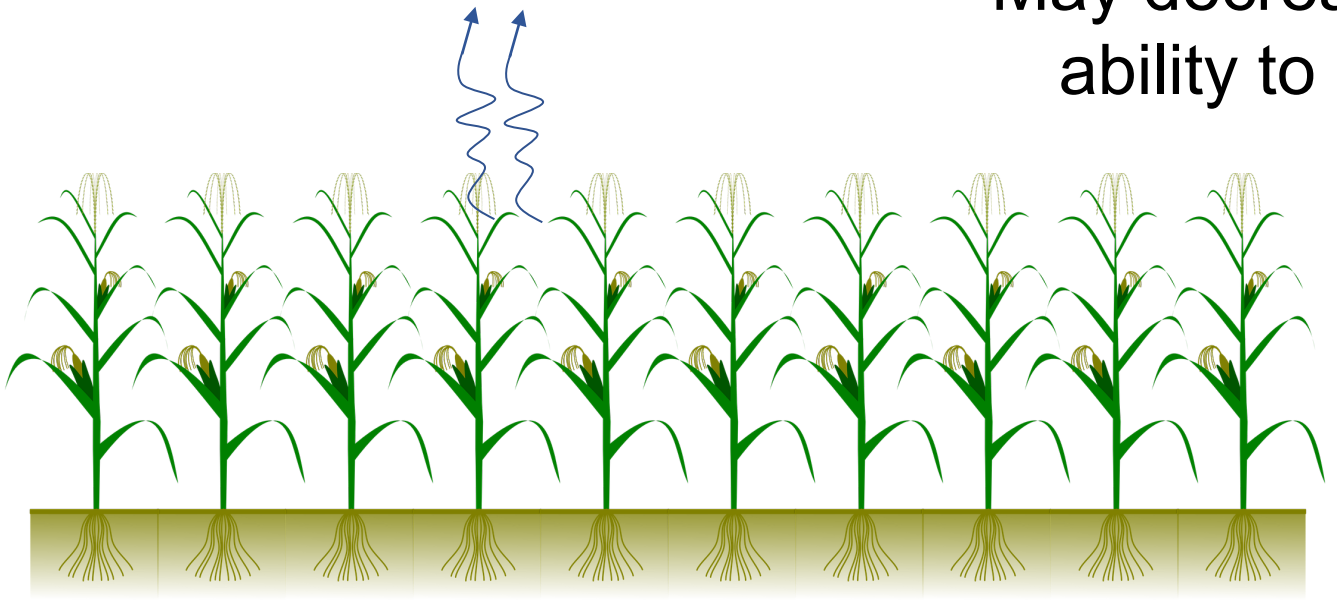


Breeding crops for drought: limit transpiration

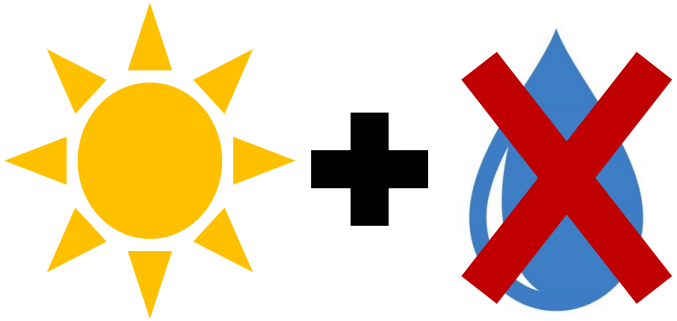
Decrease water use
Maintain water status

Transpiration

- But crops sweat
- May decrease a crop's ability to cool itself

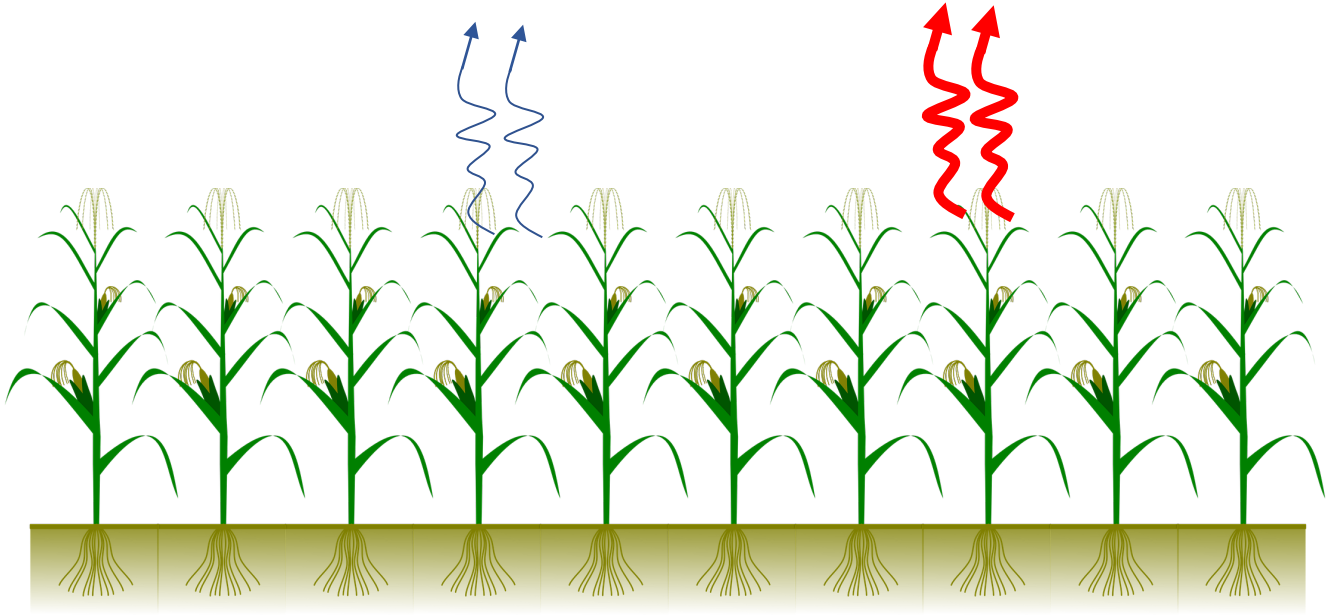


Potentially maladaptive for drought **and** heat

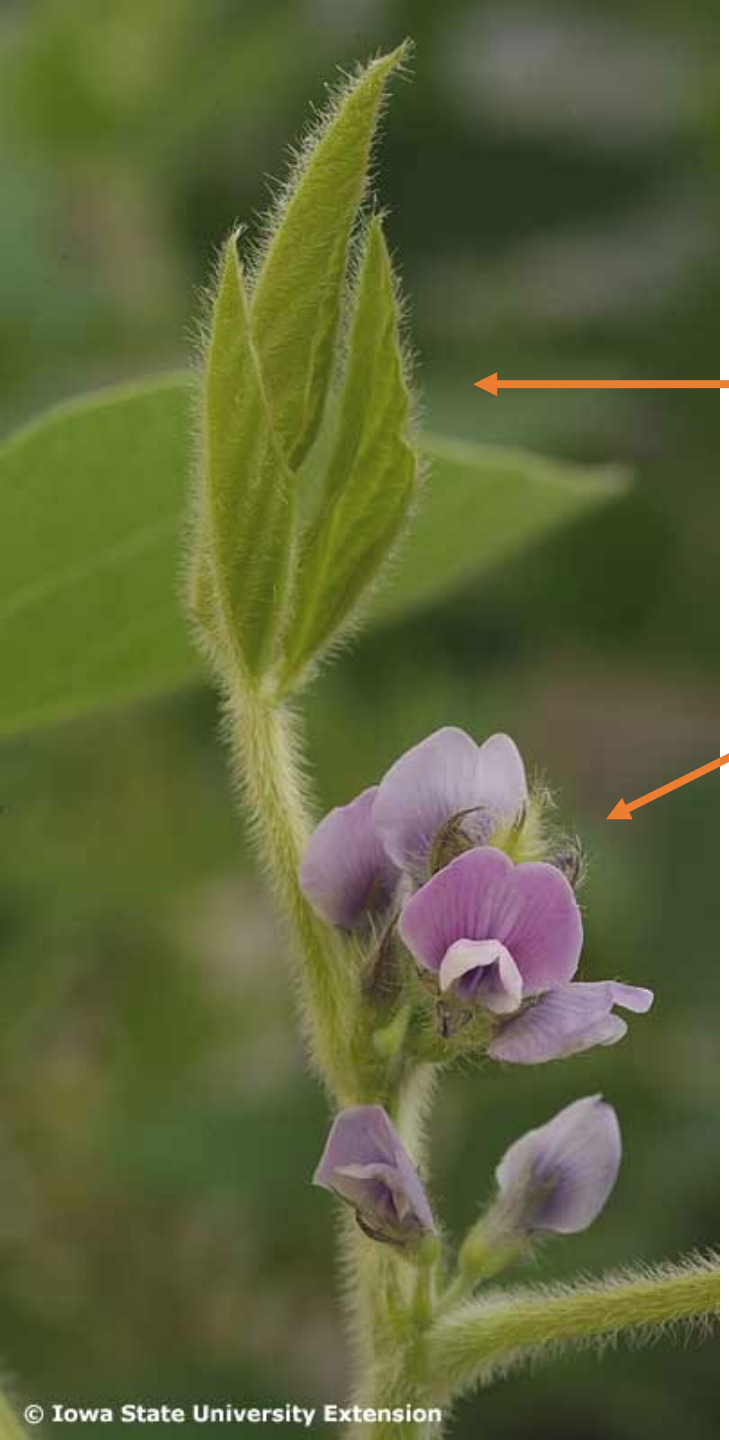


Drought adaptation amplifies heat stress

↓Transpiration ↑Crop temperature



Drought breeding targets **at odds with heat**!



But there are alternative targets!

Some soybean varieties limit leaf transpiration during combined heat and drought

But maintain flower transpiration (2-3°C cooling)

Flowers are very heat sensitive

Demonstrates wealth of genetic resources to breed for combined stresses

Sinha et al. 2022

But genetics are only a small piece

Plant-centric adaptations won't address wider food system vulnerabilities

Are these technologies available to subsistence farmers?

- Historically, mostly not
- If so, often at the expense of food security (debt)

As ever in the climate crisis,
no silver bullets

Check out review for more discussion →

nature reviews earth & environment

https://doi.org/10.1038/s43017-022-00368-8

Review article

Check for updates

Compound heat and moisture extreme impacts on global crop yields under climate change

Corey Lesk[1,2,3] ✉, Weston Anderson[4,5], Angela Rigden[6,7], Onoriode Coast[8], Jonas Jägermeyr[9,10,11], Sonali McDermid[9,12], Kyle F. Davis[13,14] & Megan Konar[15]

INSTITUTE neukom NEUKOM INSTITUTE FOR COMPUTATIONAL SCIENCE

NSF

Fonds de recherche Nature et technologies Québec

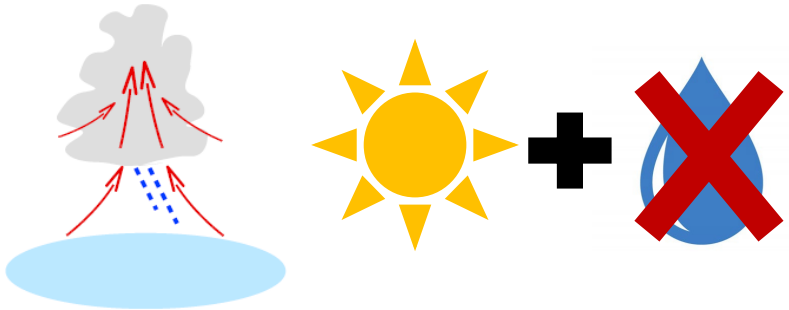
Thanks!

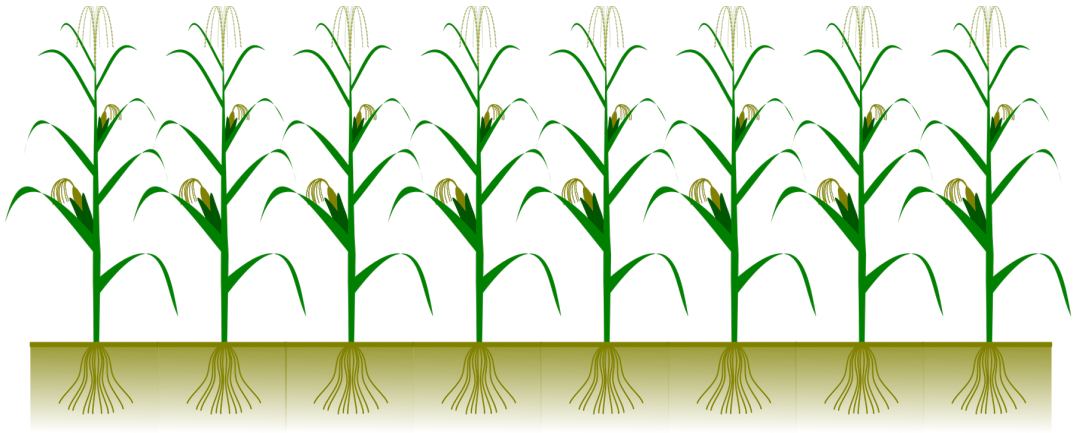
Corey.S.Lesk@dartmouth.edu

Collaborators: Radley Horton, Ethan Coffel, Jonathan Winter, Sonia Seneviratne, Jakob Zscheischler

2) Useful scholarship will need to be integrative

Concept of compound extremes goes much beyond heat and moisture

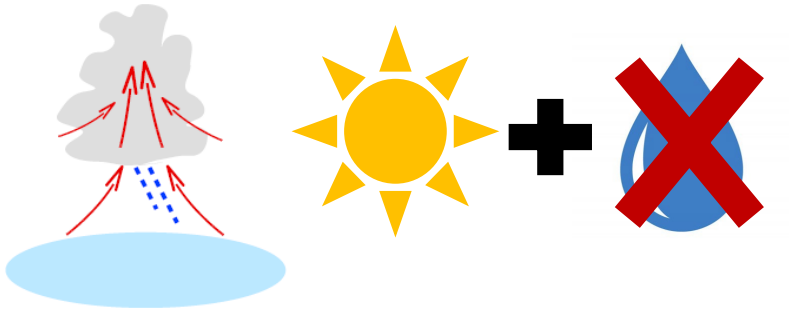




2) Useful scholarship will need to be integrative

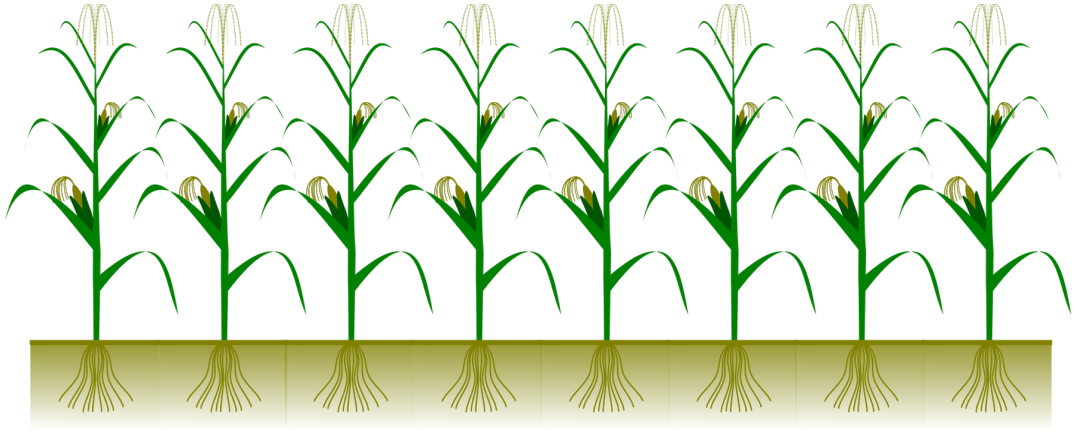
Compound extremes = interactions among:

Climate



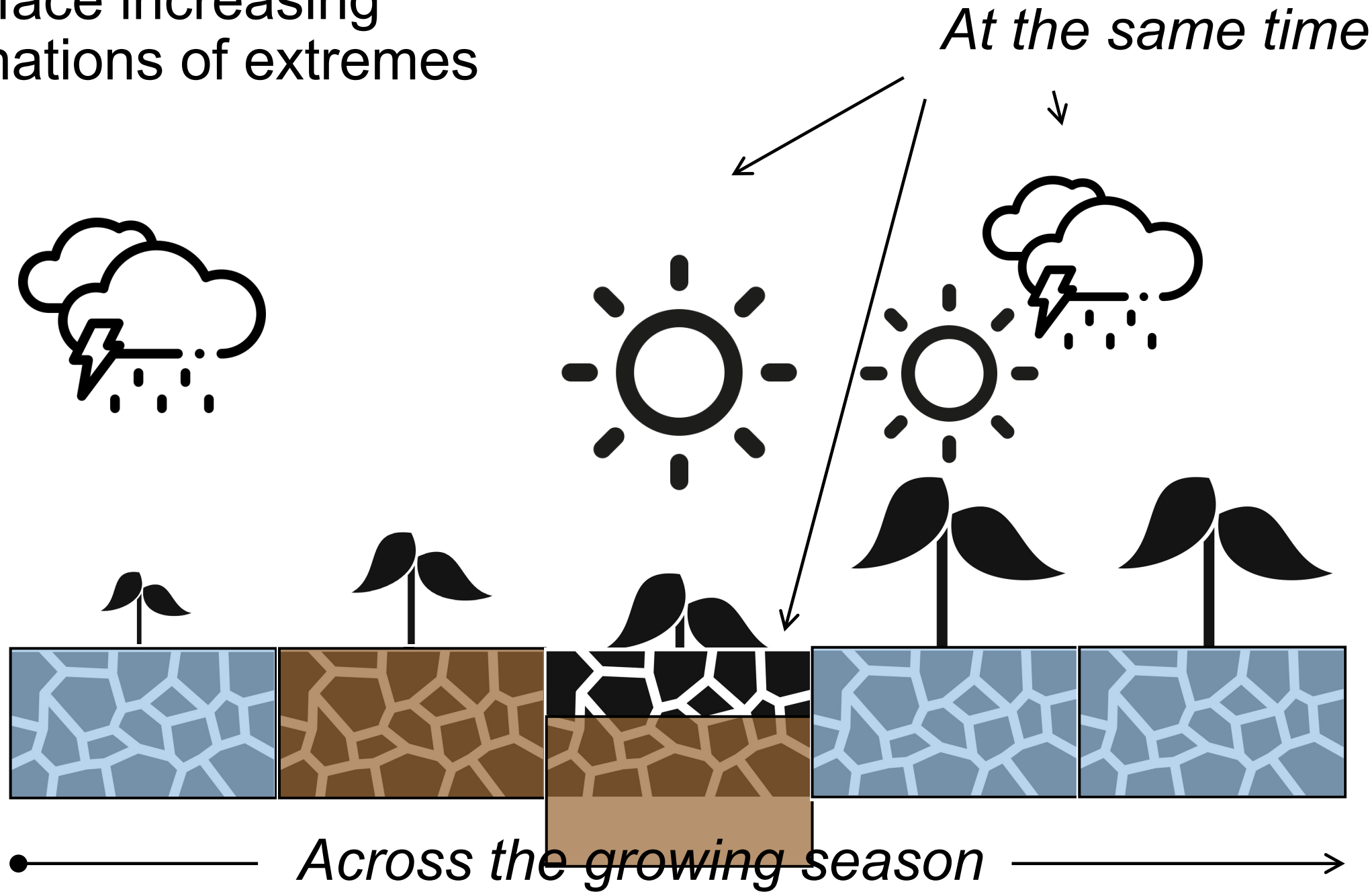
Crops (or other essential human-natural systems)

Soils

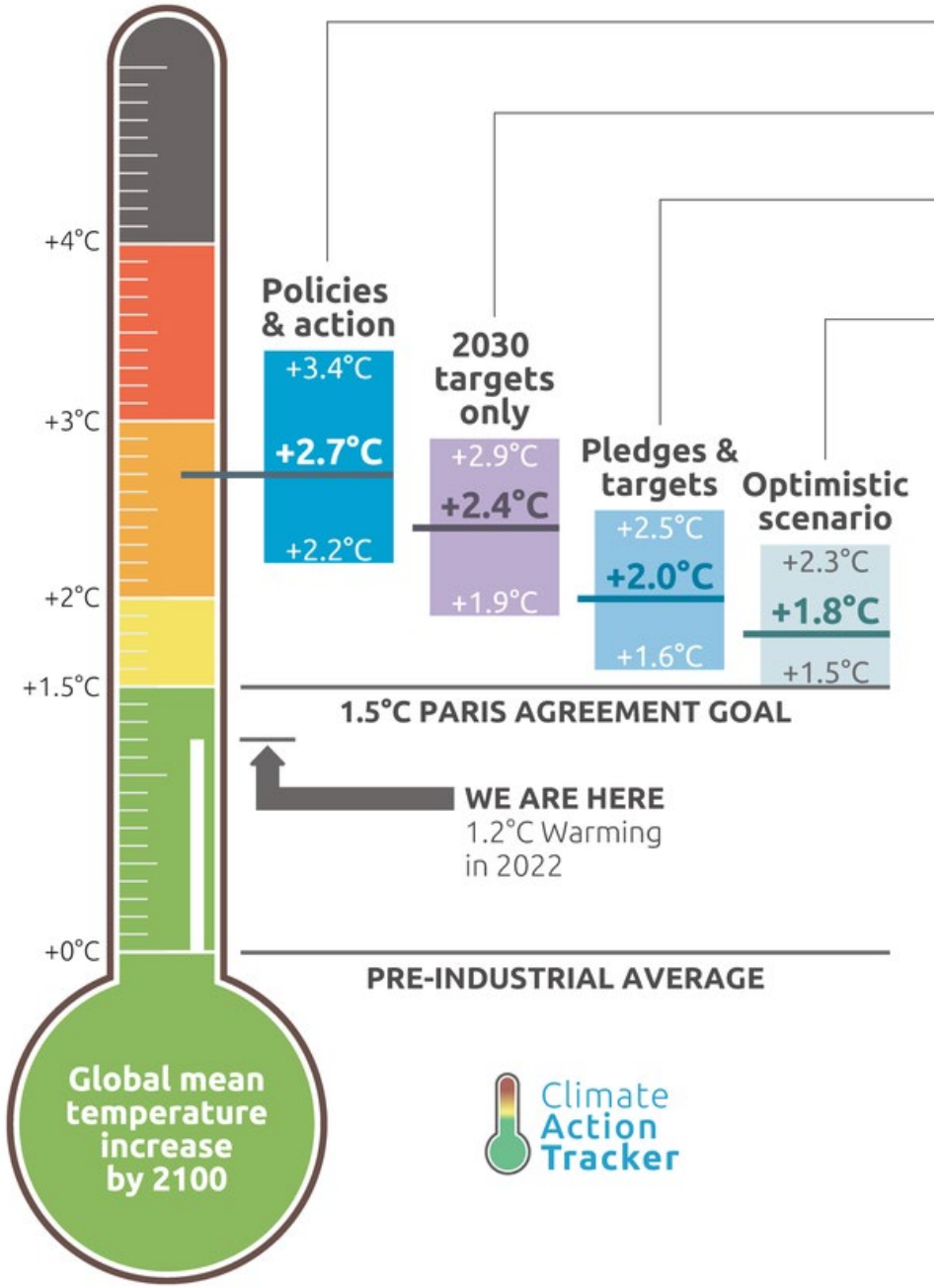


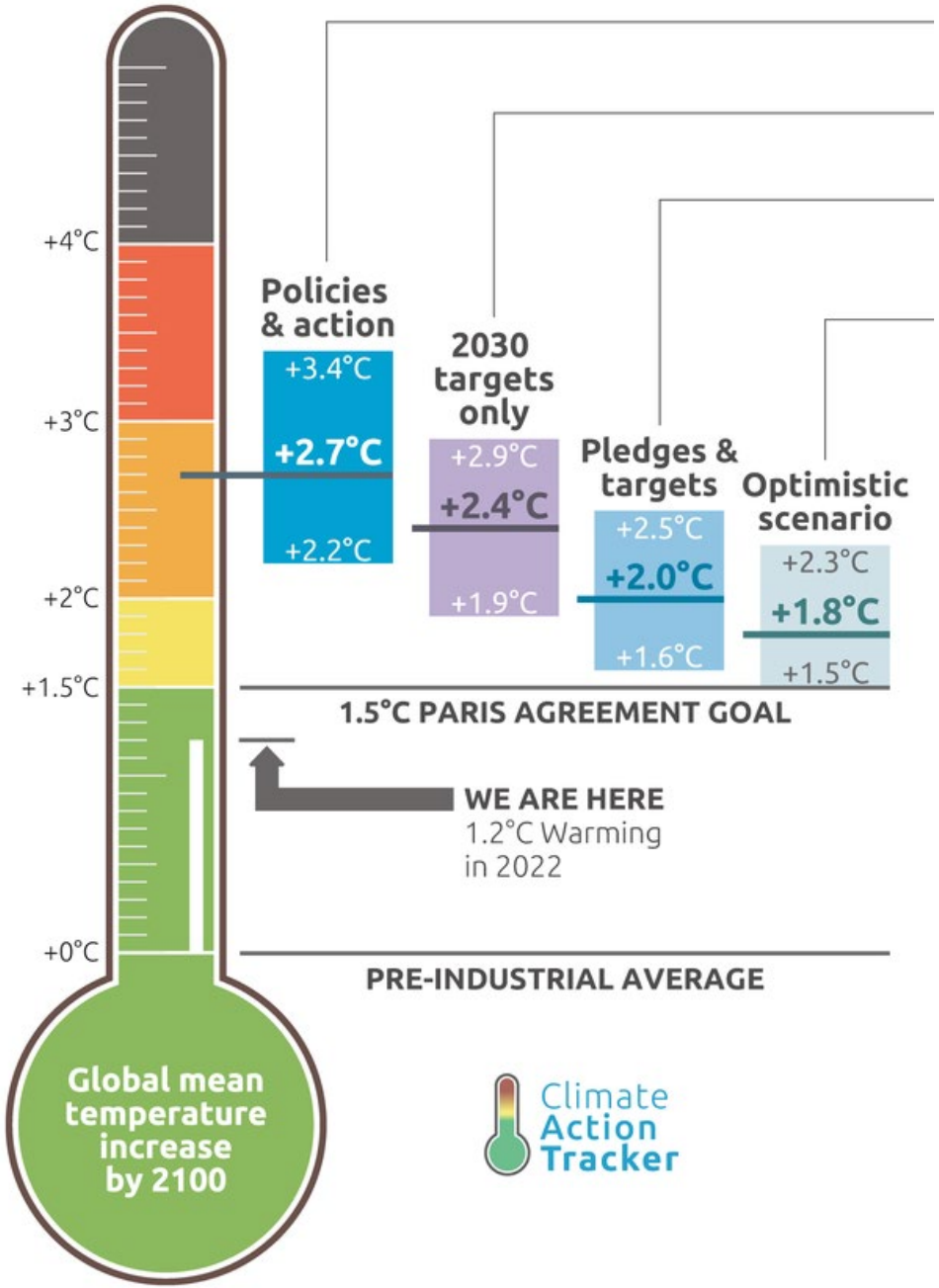
- Water resources
- Food trade
- Institutional/industrial science
- Geopolitics
- Mitigation tradeoffs

Crops face increasing combinations of extremes



Current policies and pledges put us in the range of 2°C warming by 2100





Current policies and pledges put us in the range of 2°C warming by 2100

How will that impact global crops?