Drought risk analysis

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Key factors

- **Precipitation deficit**
- **Surface air temperature**
- **Soil moisture**
- **River discharge**
- **Land use**
- **….**

On which time-scales?

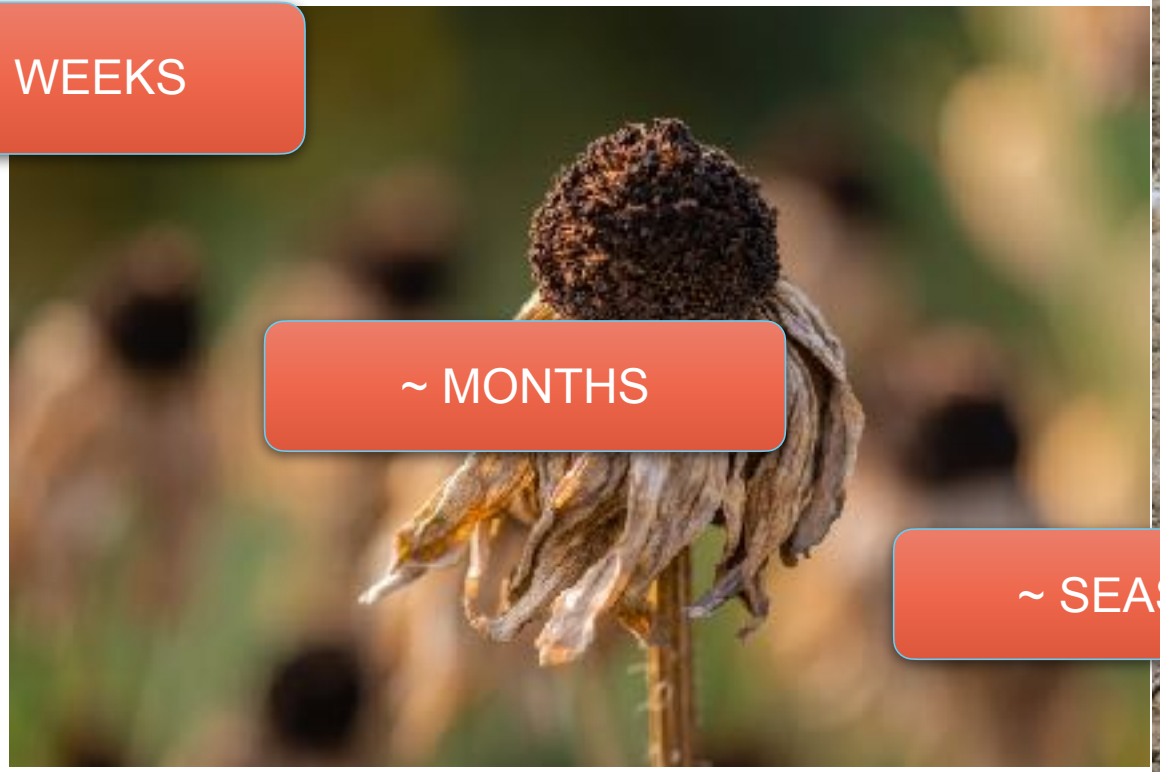
From flash drought to mega-drought

~ WEEKS

~ MONTHS

~ SEASONS

~ YEARS



@PawelCzerwinski-Unsplash

@MarkusSpiske-Unsplash

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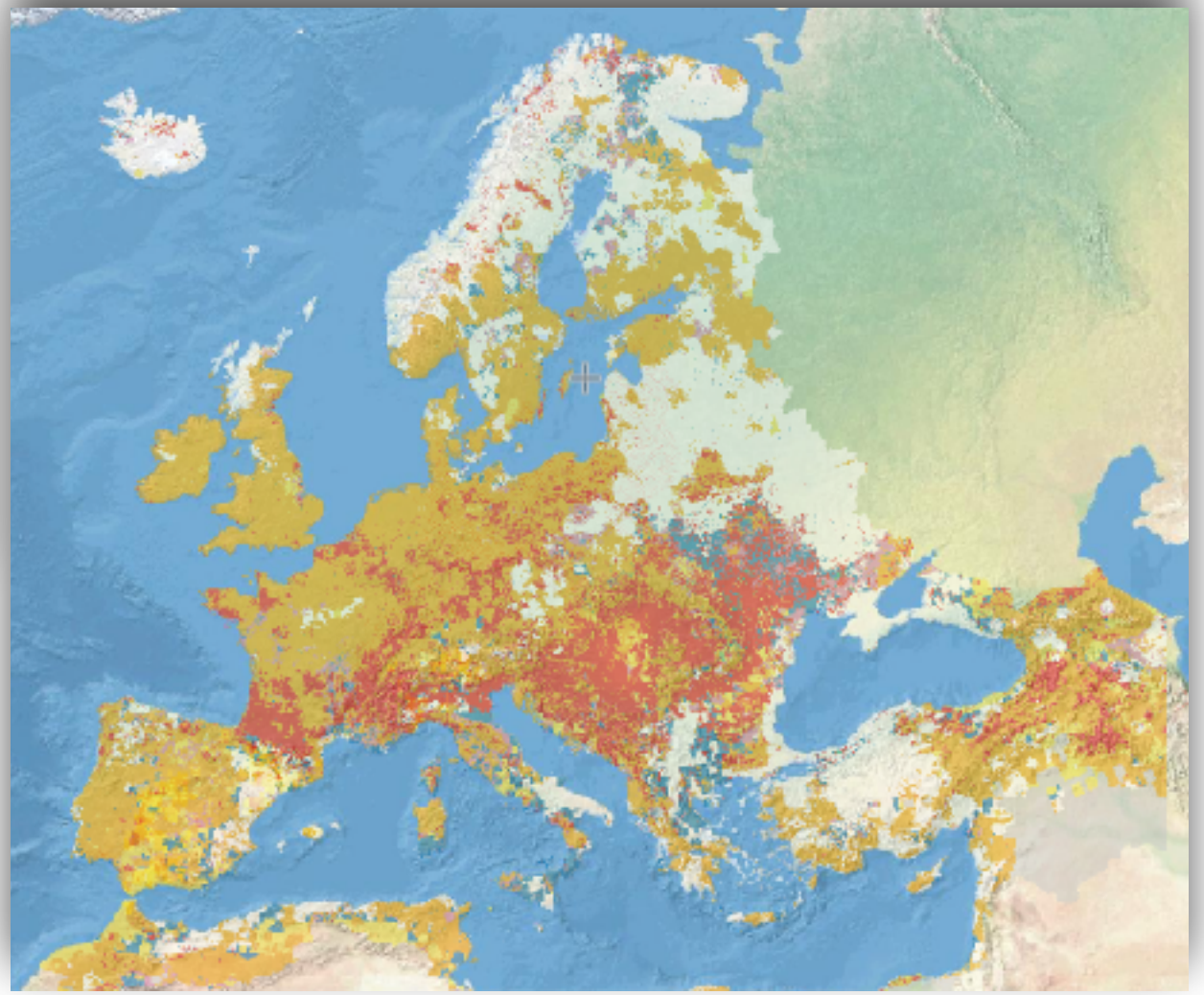
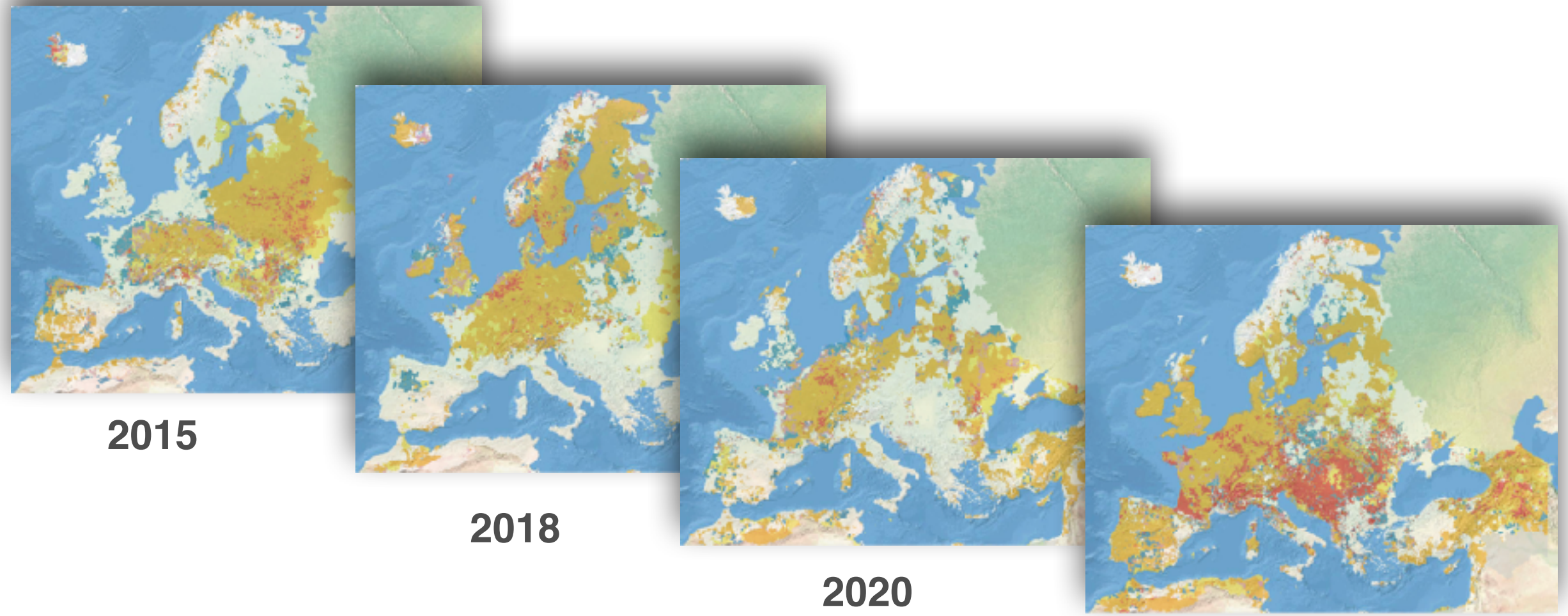
From local to continental



Recurrent events



2015

2018

2020

2022

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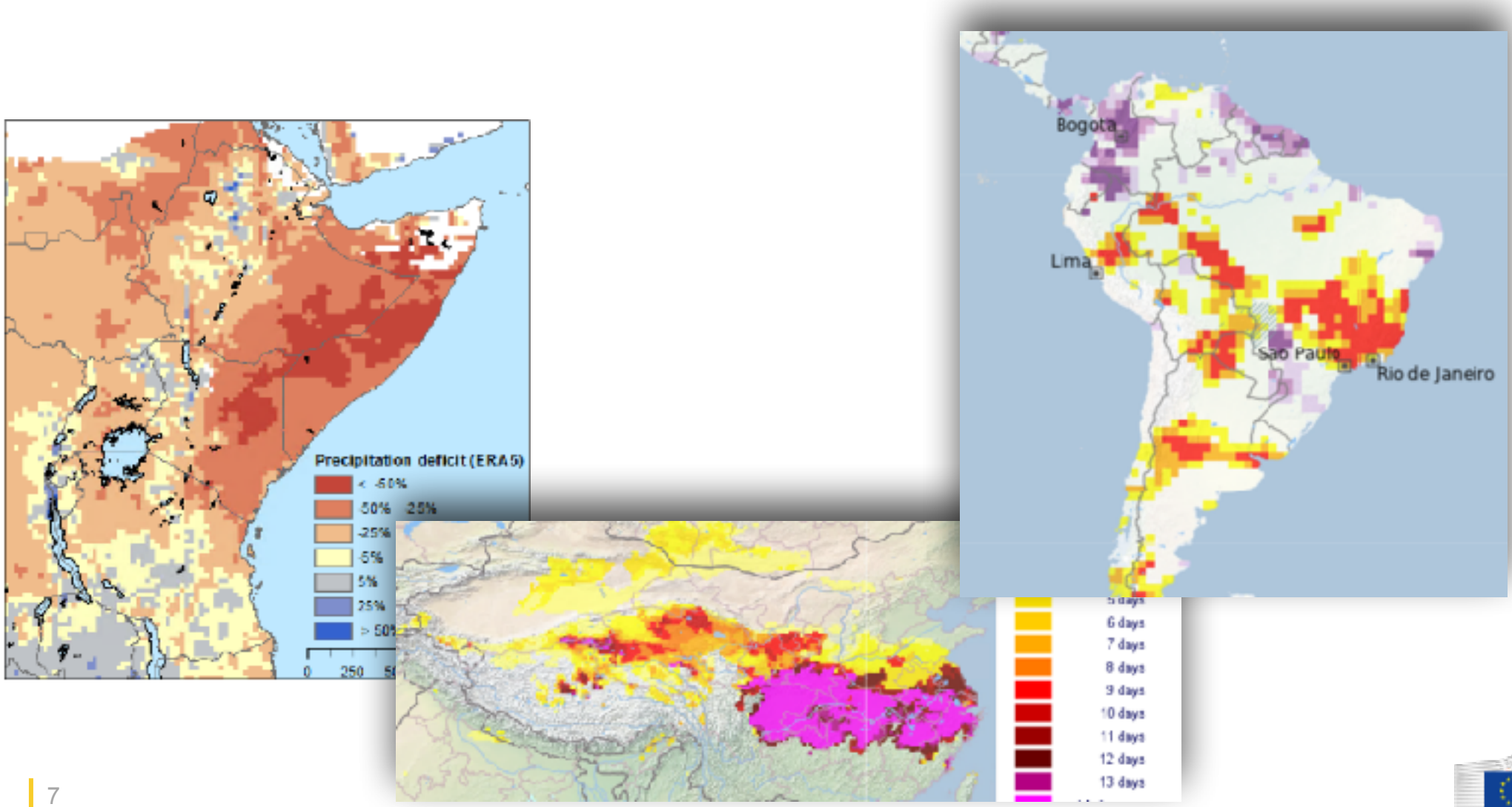
Concurrent events



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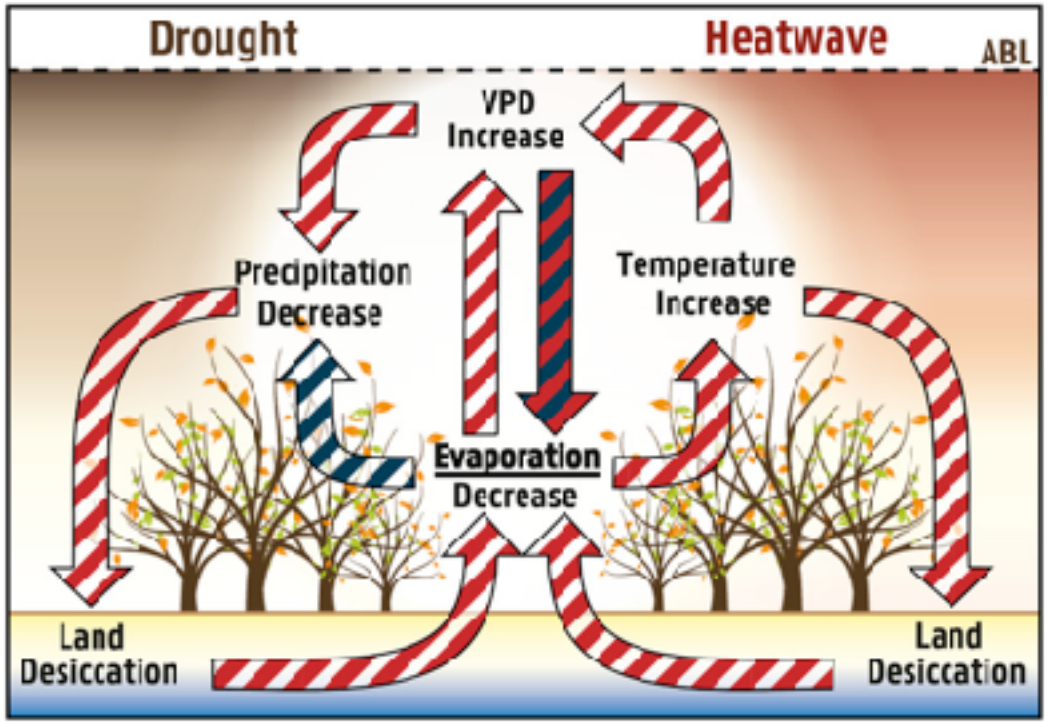
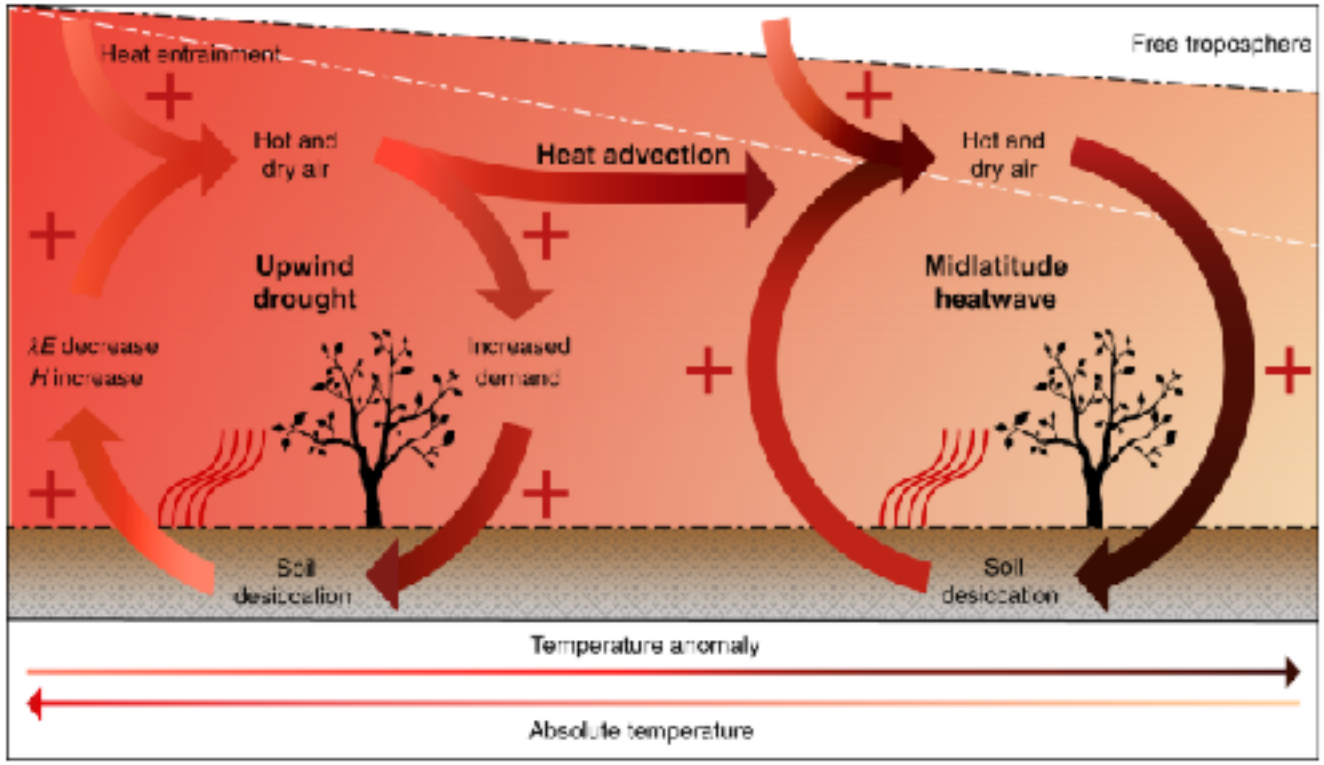
Compound events



MIralles et al. 2019., Ann. NY Academy of Sciences



Schumacher et al. 2019., Nat Geoscience

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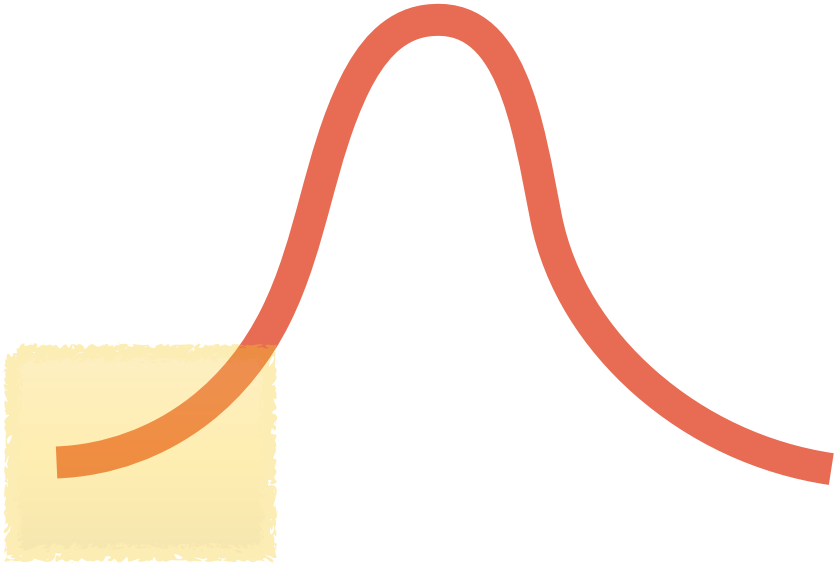
Defining a drought

Meteorological

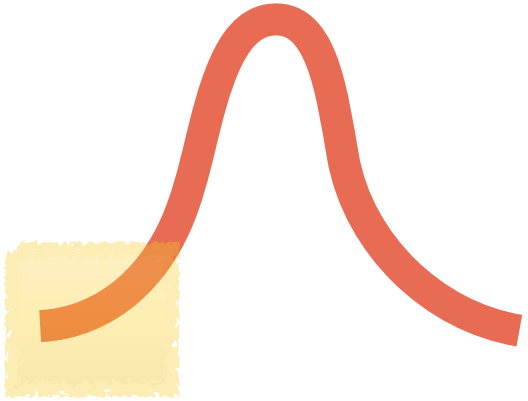
Agricultural

Hydrological

Need to define *normal* conditions and quantify anomalies



Standardised Precipitation Index



Define an accumulation period, e.g. 3 months

Infer a distribution $\mathcal{F}$

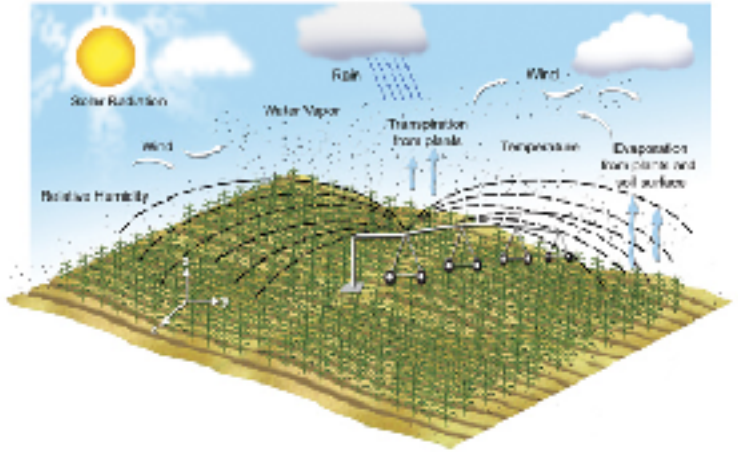
Parametric / non-parametric

$\mathcal{F}(X)$

Take care of the event-occurrence probability

Stand Normal Distr

@University of Nebraska–Lincoln, 2009



Integrating evapotranspiration

Different levels of complexity

$$E_p = 16 \cdot \left(\frac{10 \cdot T_{mean}}{J}\right) \cdot \frac{N \cdot n}{365}$$

Mean daylight length

Annual heat index

Thornthwaite as in Willmott et al., 1985

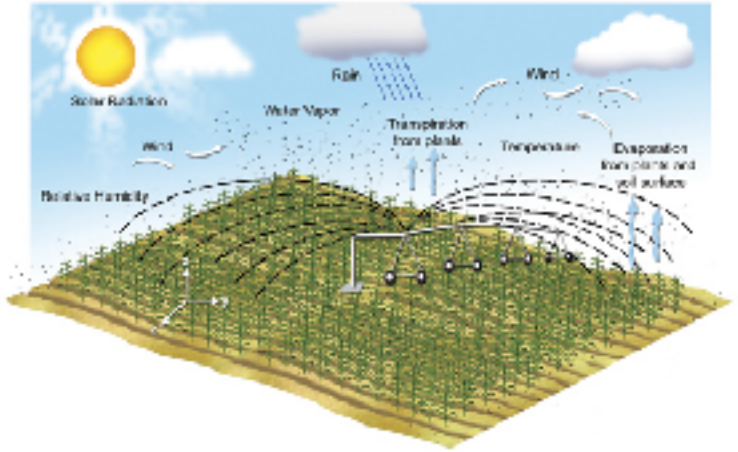
$$E_p = 23 \cdot 10^{-4} \cdot (T_{max} - T_{min})^{\frac{1}{2}} \cdot (T + 17.8) \cdot R_a$$

Extraterrestrial radiation

Hargreaves as in Hargreaves and Samani,1985

Integrating evapotranspiration

@University of Nebraska–Lincoln, 2009



Different levels of complexity

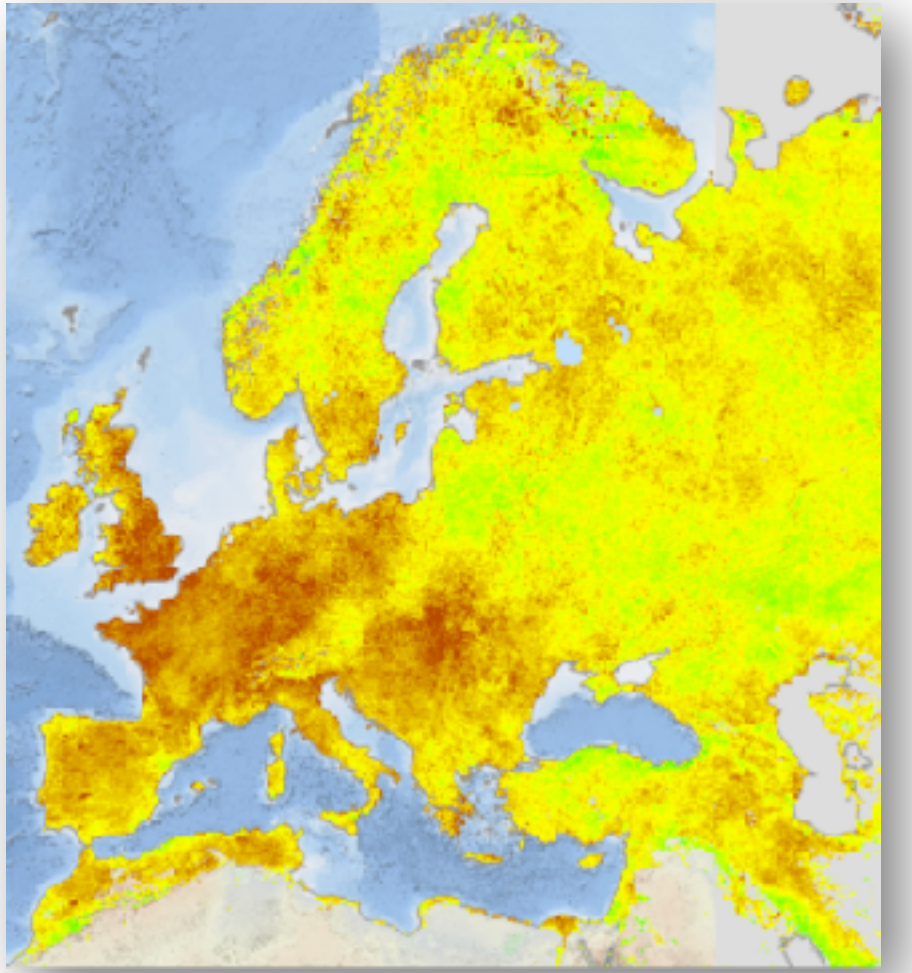
$$E_p = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

- Net radiation
- Soil heat flux
- Saturation vapour pressure deficit
- Slope vapour pressure
- Psychrometric constant
- Wind speed

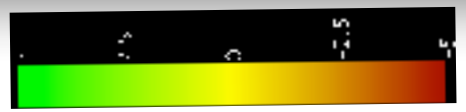
FAO 56 Penman Monteith

Theoretical reference surface with crop height = 1.2m, surface resistance = 70 s m^{-1}, albedo = 0.23

Evaporative stress index



ClimatServ. ESI July 2022



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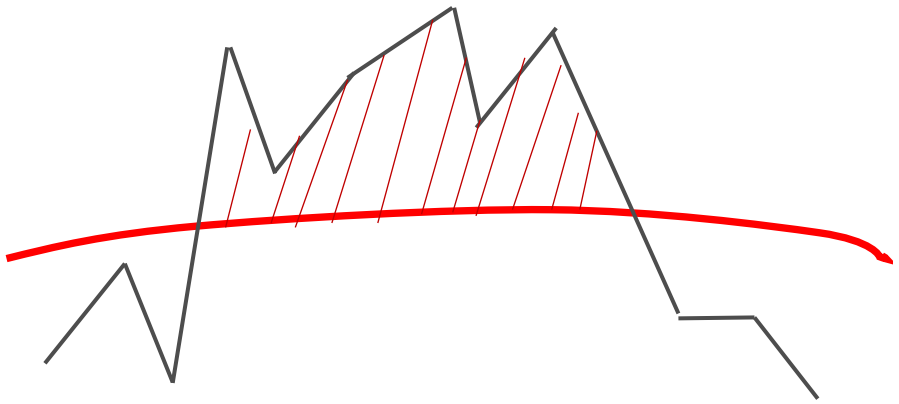
Heatwaves



Estimate daily 90th percentile with a window centred on the day of interest

↓

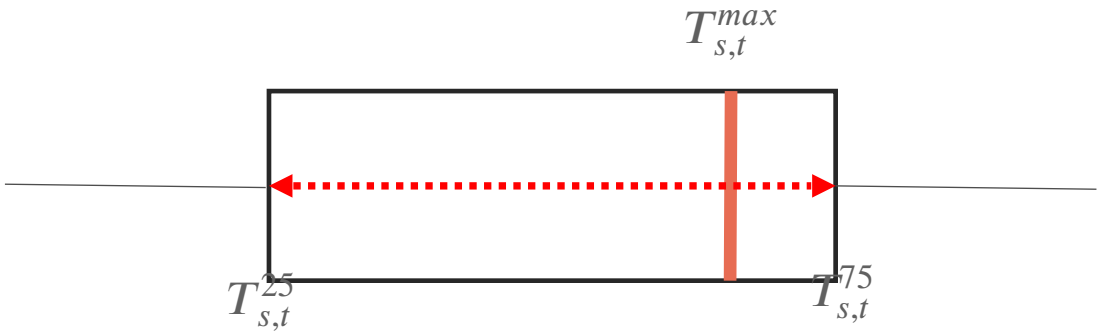
Smooth (temporally) the obtained values

↓

Identify heat waves adding a duration constraint (e.g. 3 days)

Estimate T^{25} and T^{75}

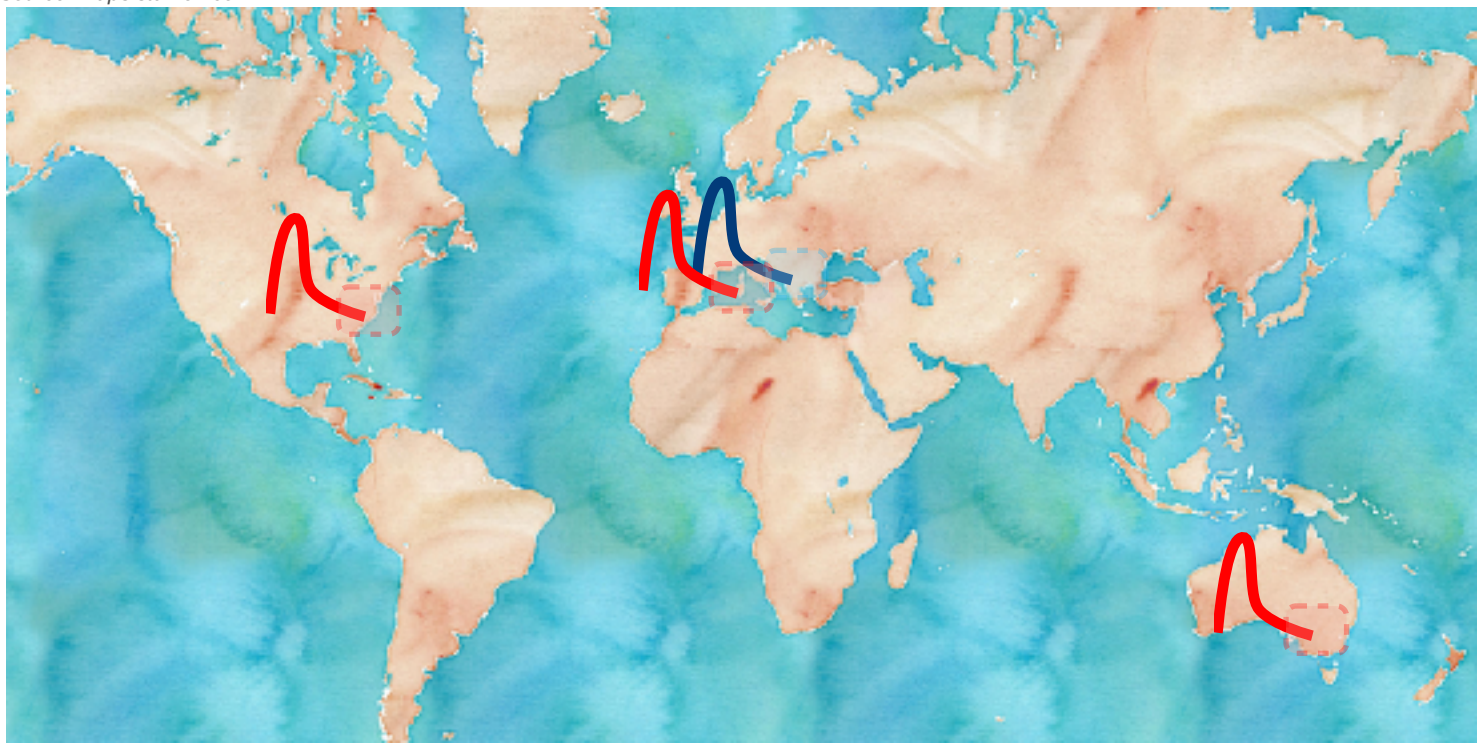
$$HMDI = \frac{T_{s,t}^{max} - T_s^{25}}{T_s^{75} - T_s^{25}}$$



Russo et al. 2015, ERL

Concurrent extremes

Source: maps.stamen.com



Large scale extremes of different types occurring at the same time (± lag) at the same place and/or in different regions of the world

Large scale extremes of the same type occurring at the same time (± lag) in different regions of the world and/or the same place

A new approach

Multi-type marked inhomogeneous point process

marks

time

$$Y = \{(t_i, r_i, c_i)\}_{i=1}^{N} \subseteq \mathcal{R} \times \mathcal{W} \times \mathcal{C}.$$

Dependence can be characterized by inhomogeneous J-summary statistic

Time distance between events

Nearest neighbour distance distribution function

$$J_{(B_1,C_1)\to(B_2,C_2)}(d) = \frac{1 - G_{(B_1,C_1)\to(B_2,C_2)}(d)}{1 - F_{(B_2,C_2)}(d)}, \quad d \geq 0.$$

Events with marks B_1, C_1

Events with marks B_2, C_2

Empty space function

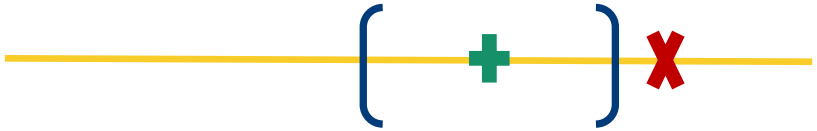
Toreti et al. 2019; Cronie and van Lieshout, 2016, 2018

A new approach

Events with marks B_2, C_2

Empty space function

Nearest neighbor distance distribution function



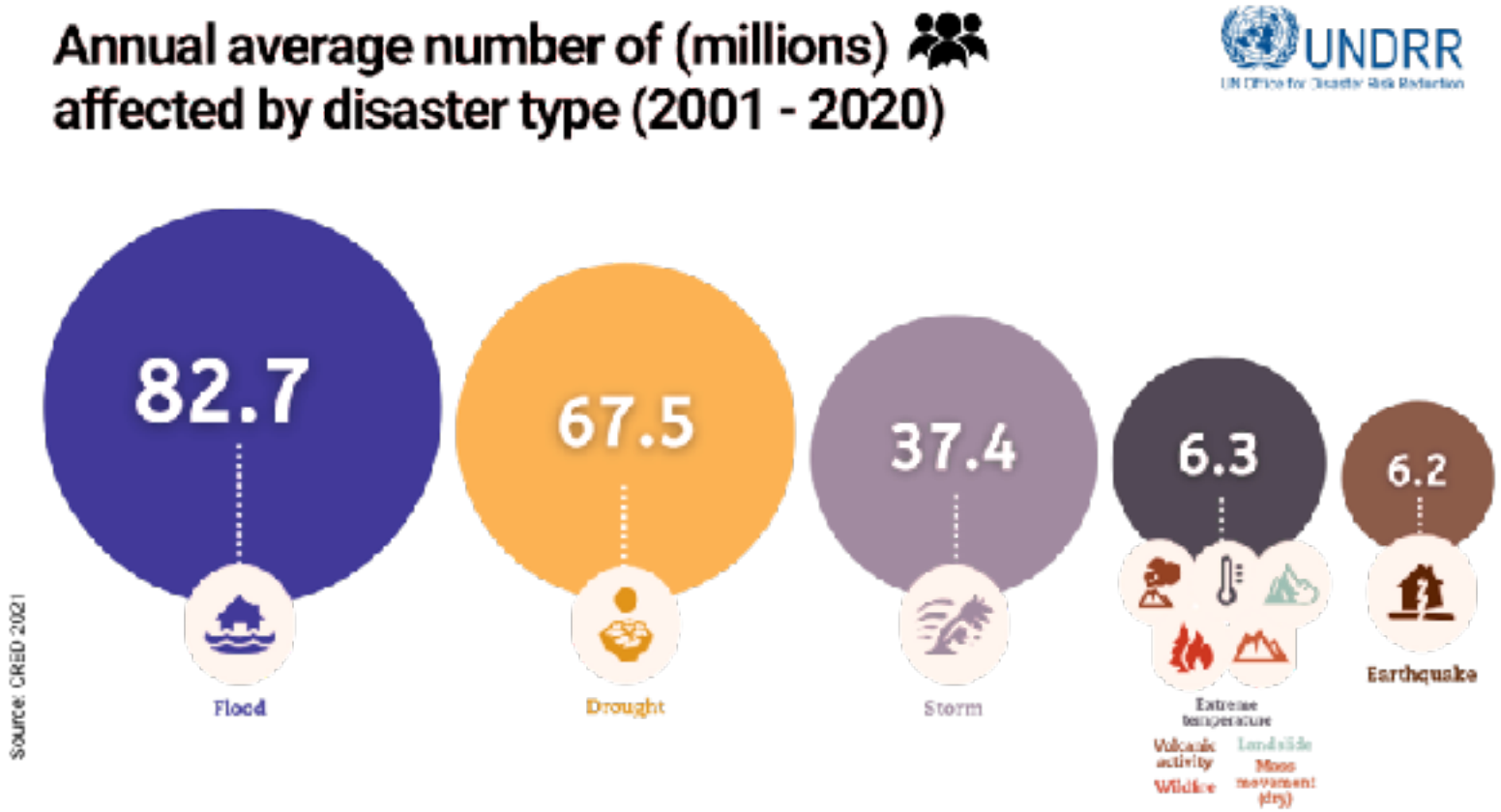
Events with marks B_1, C_1

…the non-homogeneous intensity function needs to be estimated

$$\mathcal{E}[|Y \cap A \times B \times C|] = \sum_{r \in B} \sum_{c \in C} \int_A \rho(t, r, c) dt$$

Source: Cronie and van Lieshout, 2016, 2018

Impacts



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Impacts on all key sectors + ecosystems

Agriculture

Public water supply

Energy supply

River transportation

Ecosystems

Rain fed agriculture

Irrigated agriculture

Hydropower

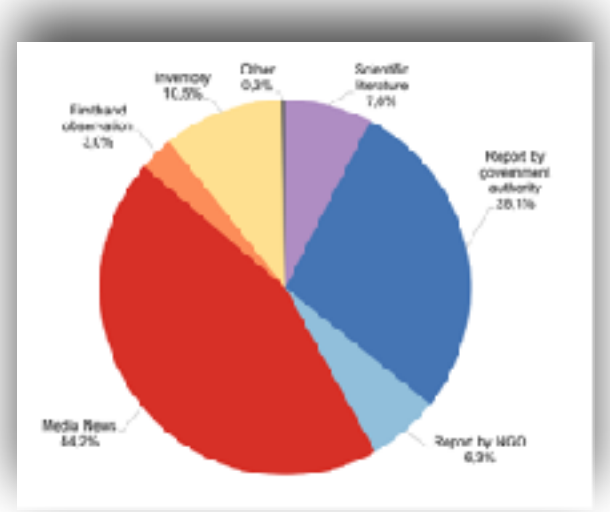
Nuclear

Terrestrial ecosystems

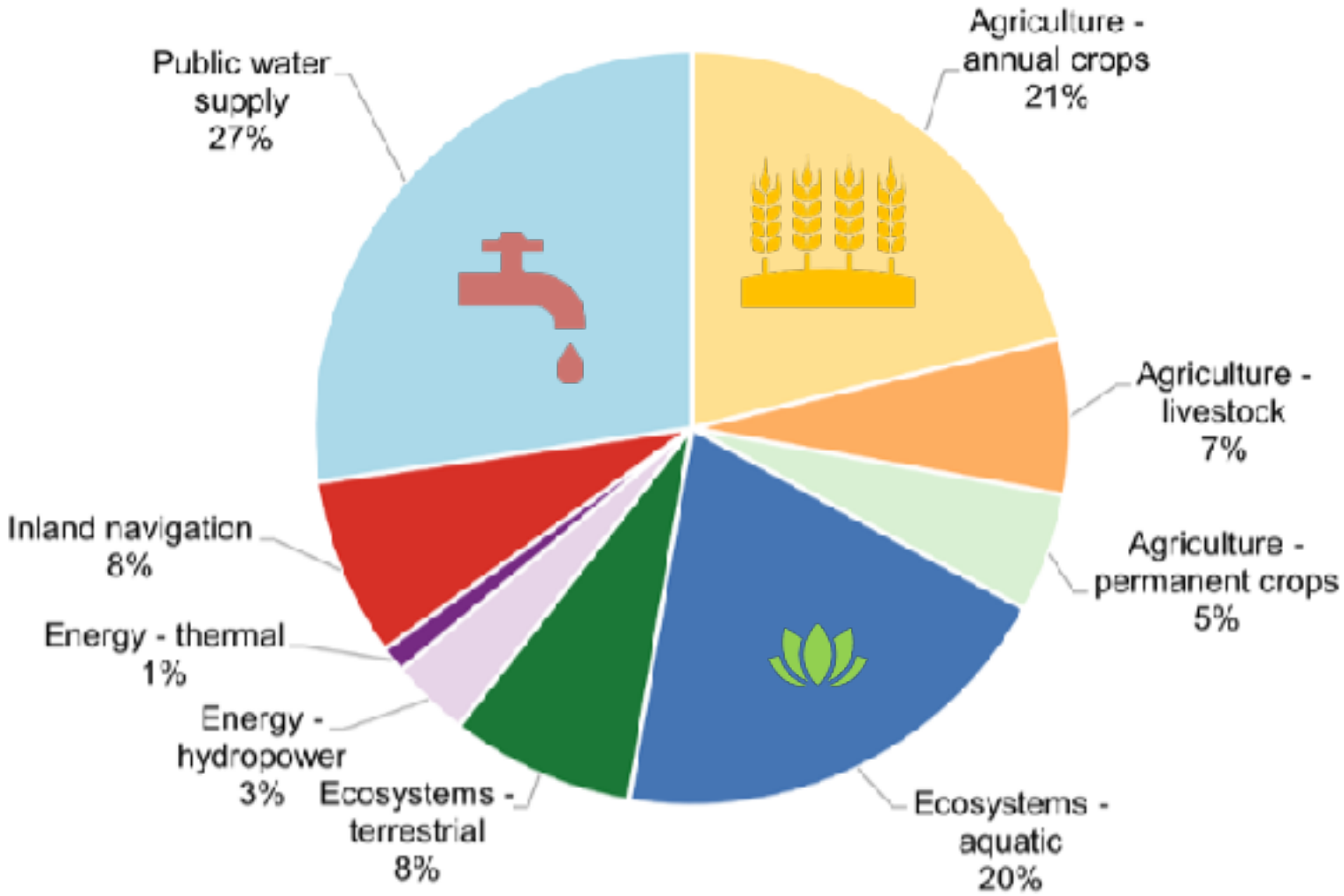
Freshwater ecosystems

European Commission

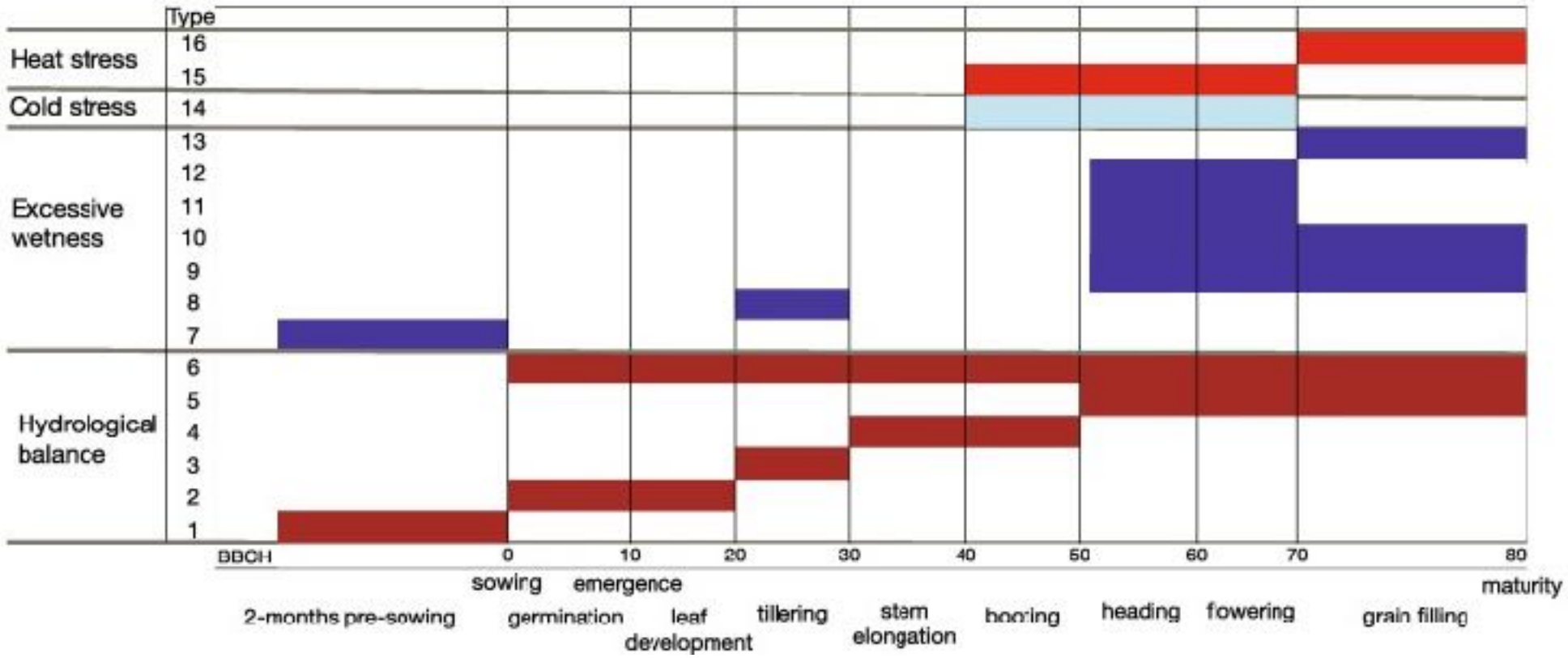
European Drought Impact Db



>20K *records*
1970-2022

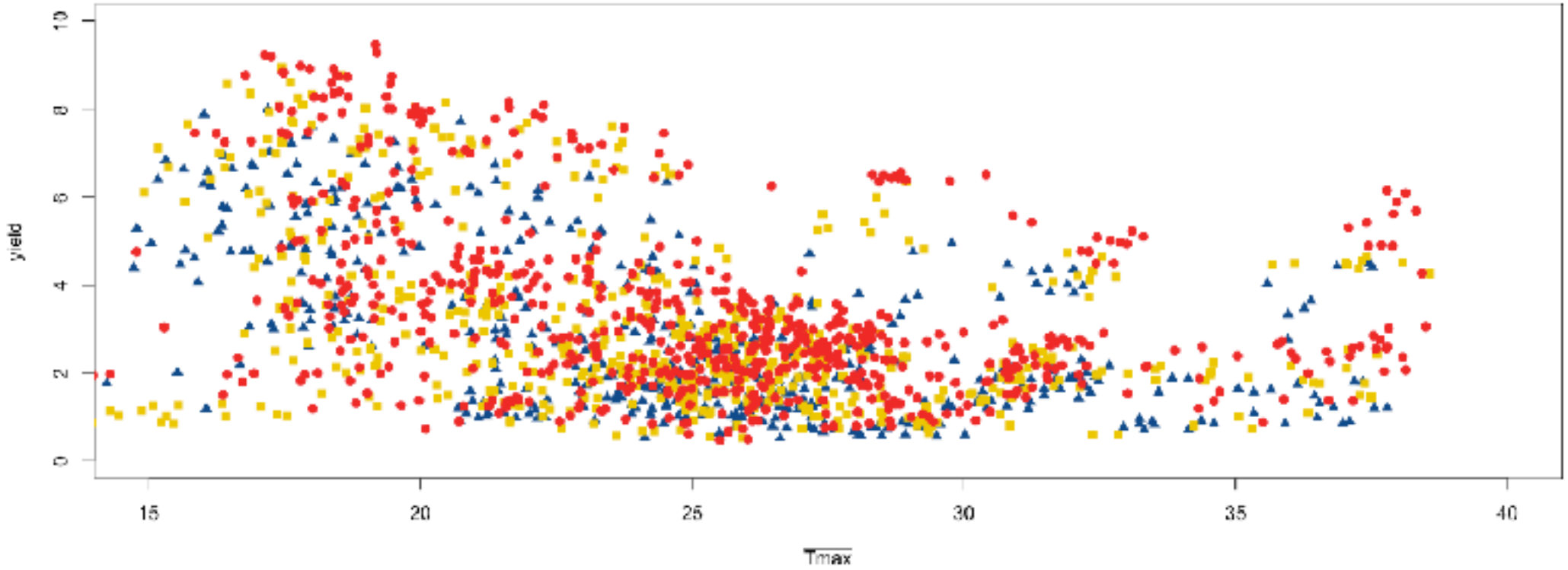


Time of occurrence matters



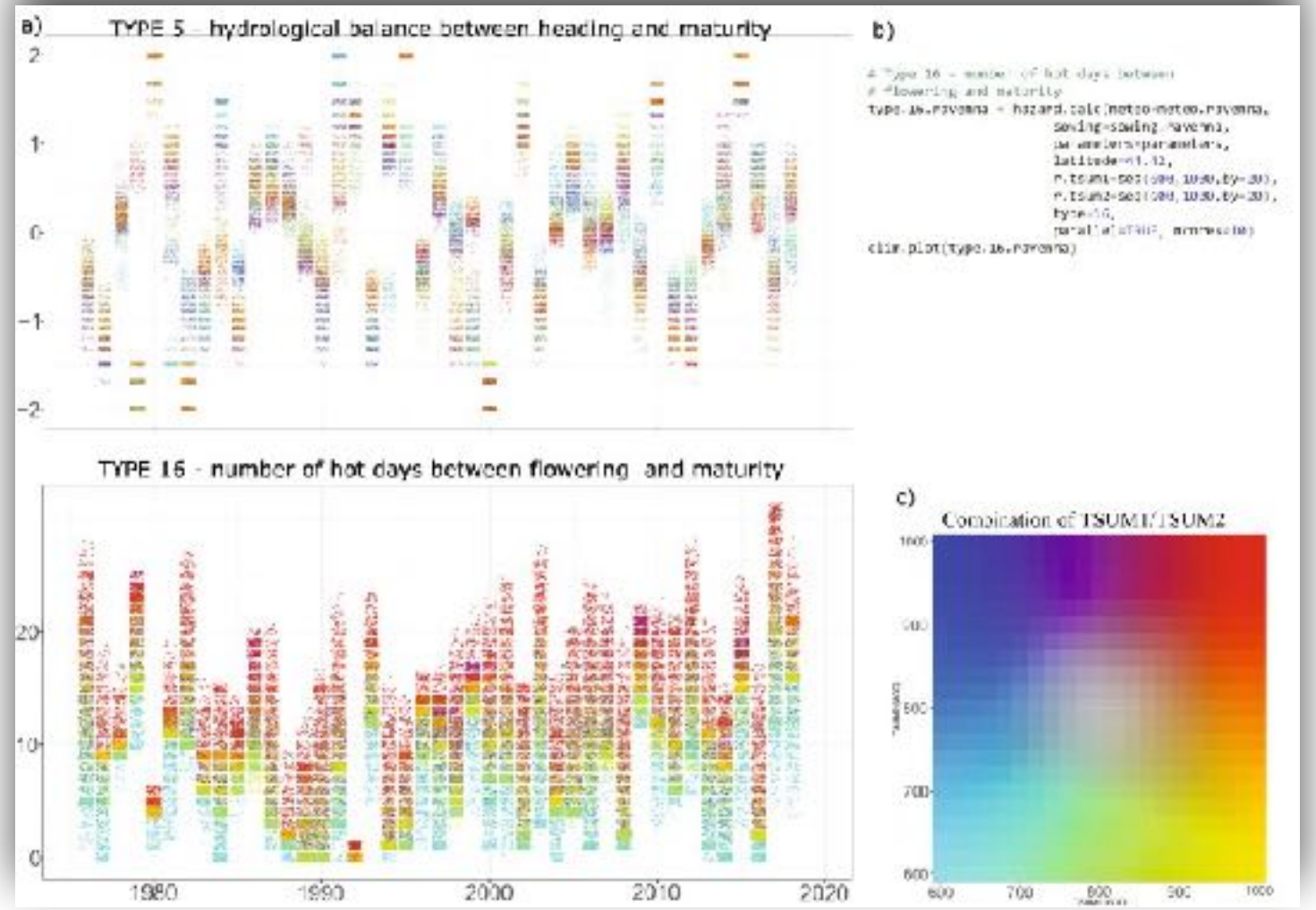
Ceglar et al. 2020, Clim. Services

There is not only climate



Toreti et al. 2019 (Encyclopedia of Food Security and Sustainability)

There is not only climate



Ceglar et al. 2020, Clim. Services 20

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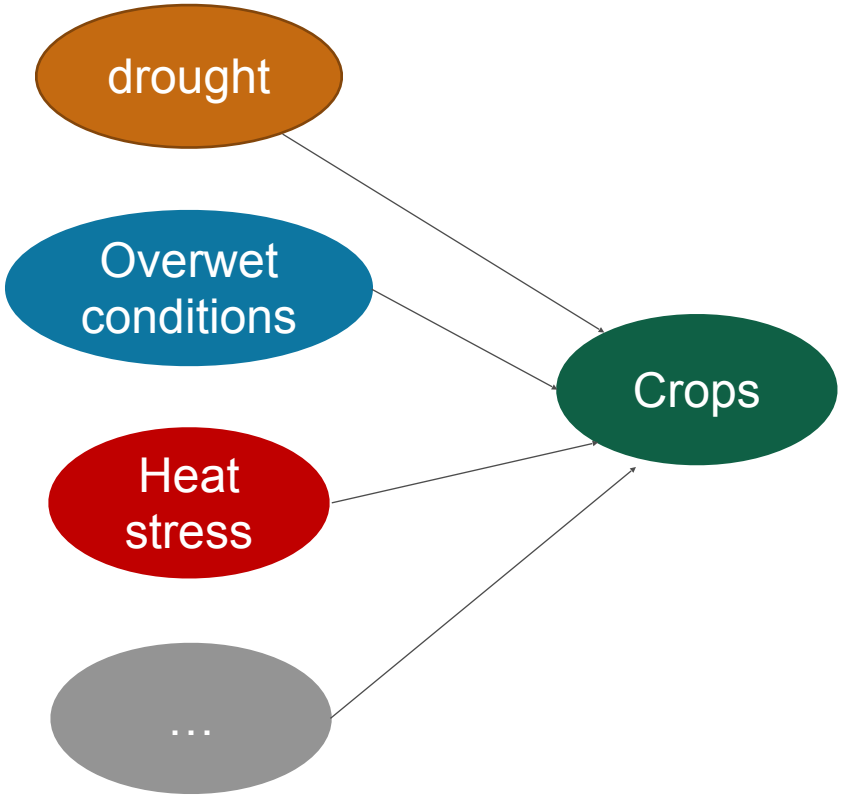
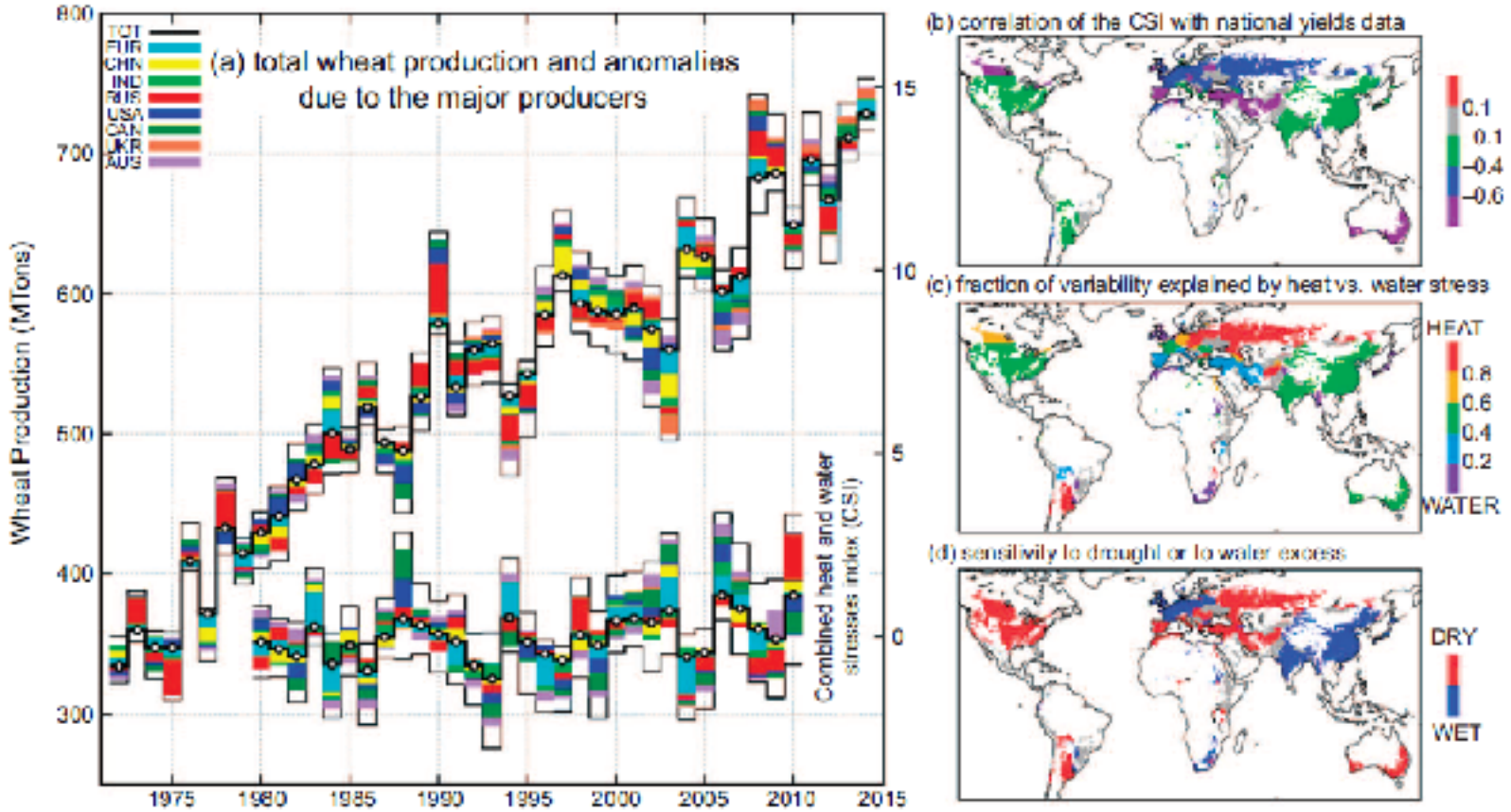
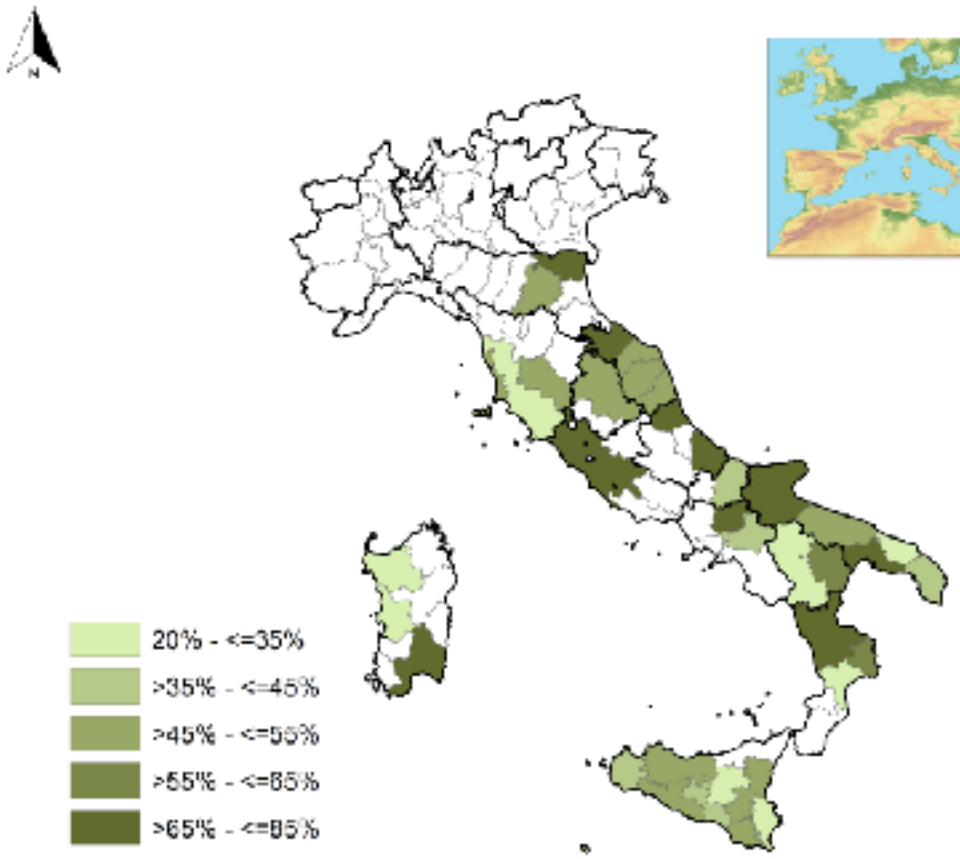
Learning from the past





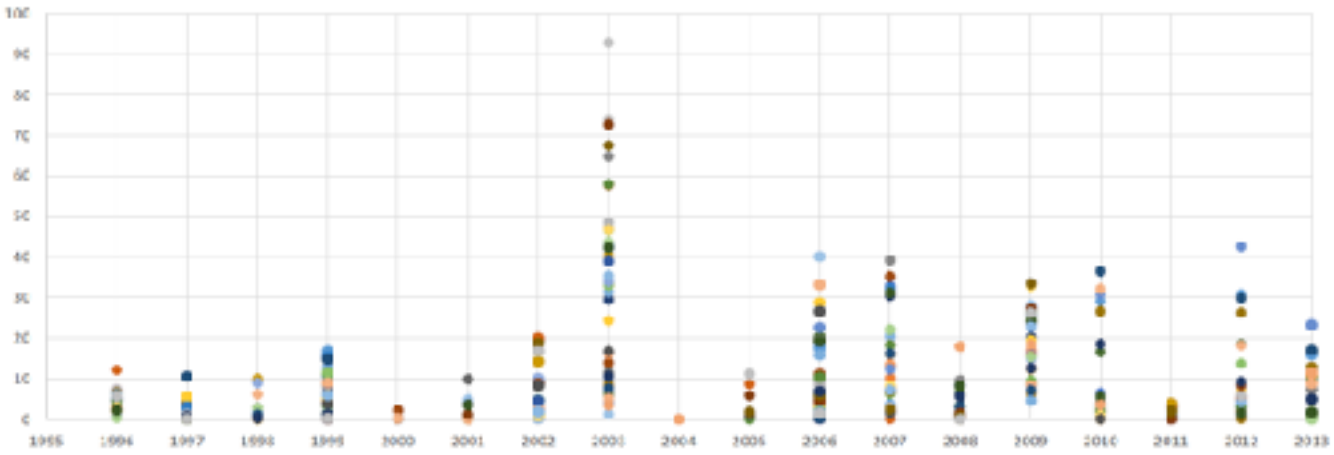
Zampieri et al. 2017, ERL

Learning from the past



Durum wheat

Early Heat Waves



Fontana et al., NHESS 15, 2015

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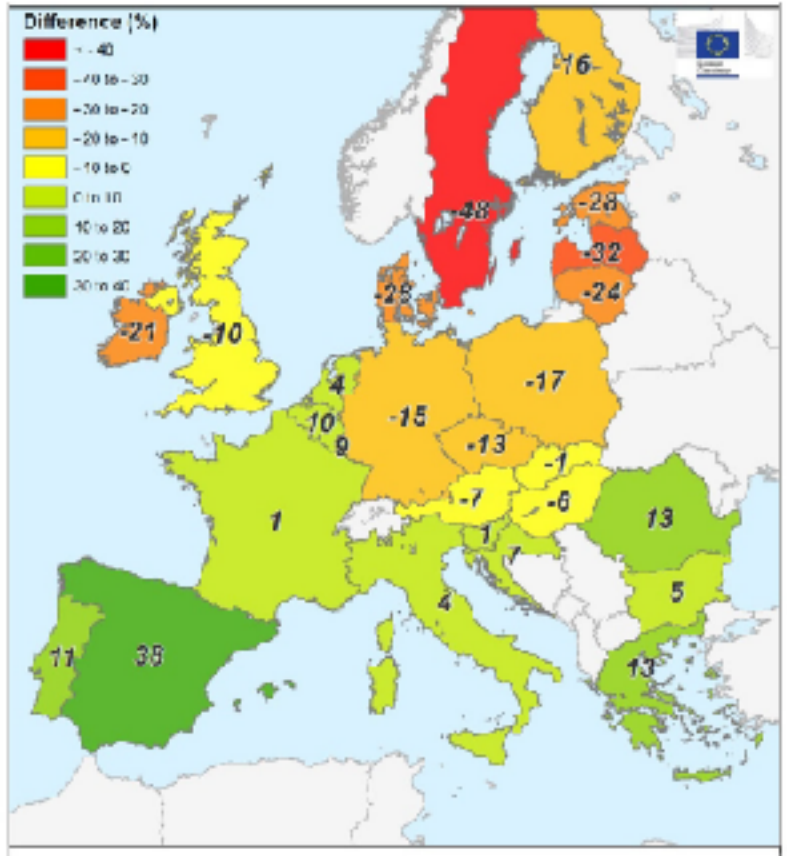
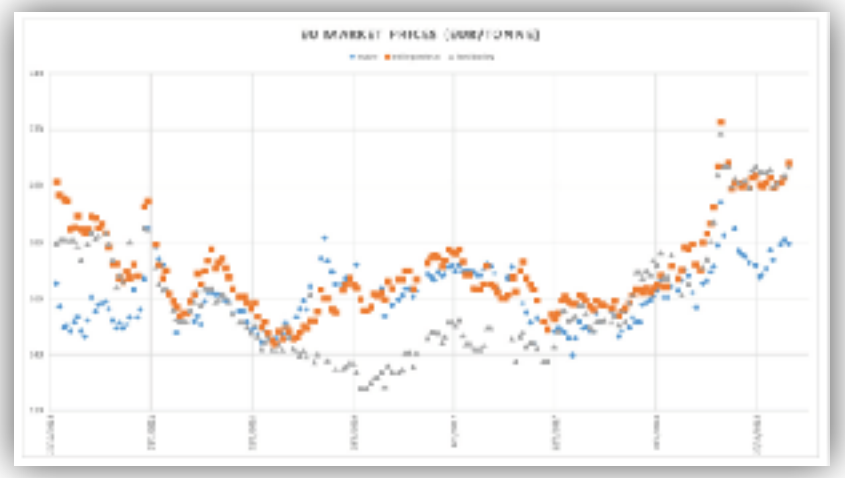
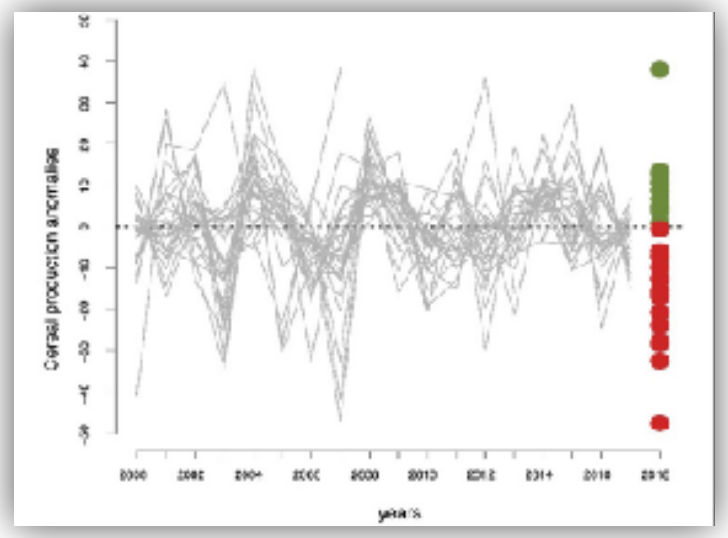
Learning from the past



The exceptional 2018 water seesaw





Toreti et al. 2021, Science for DRM 2020

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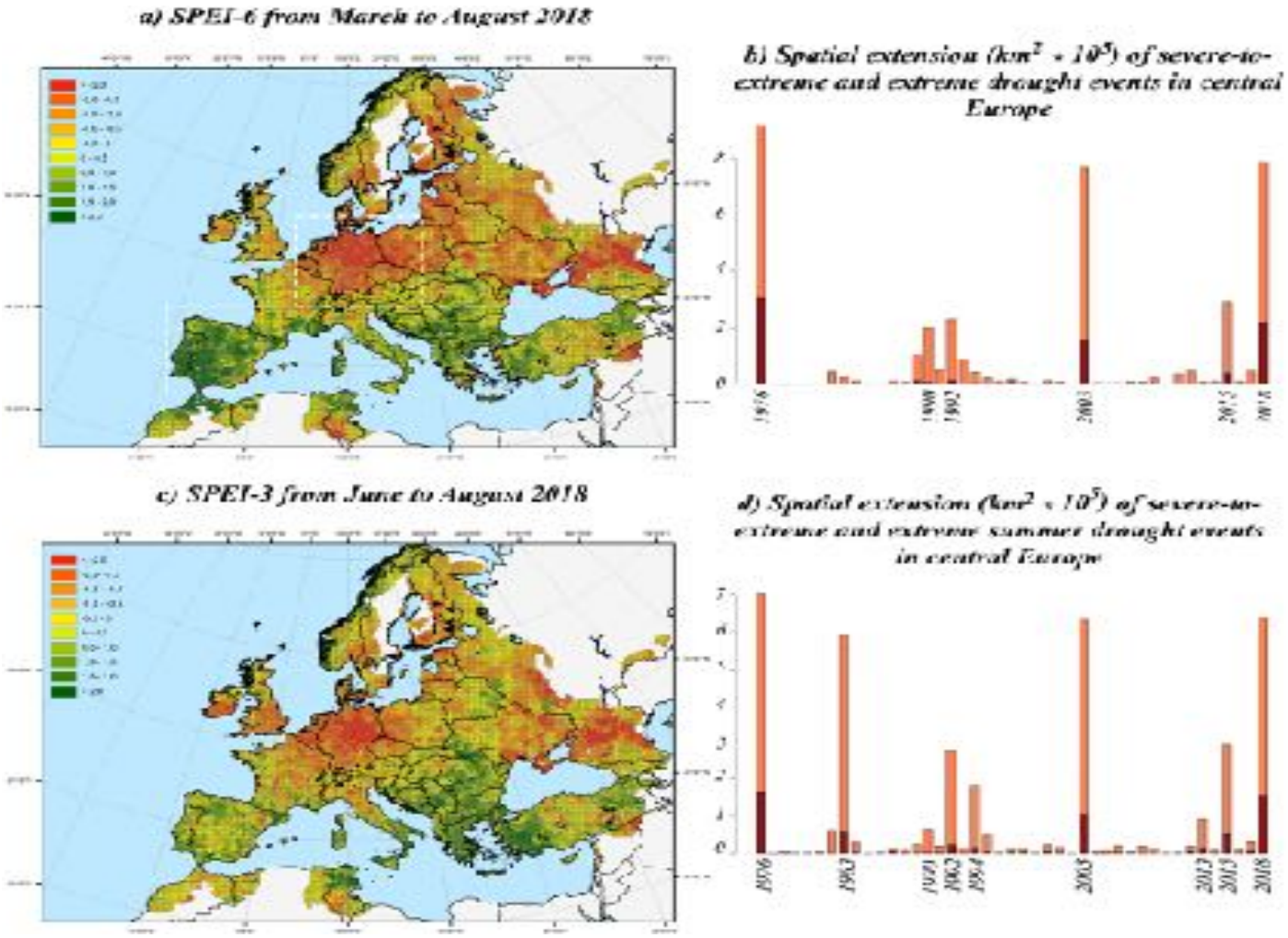
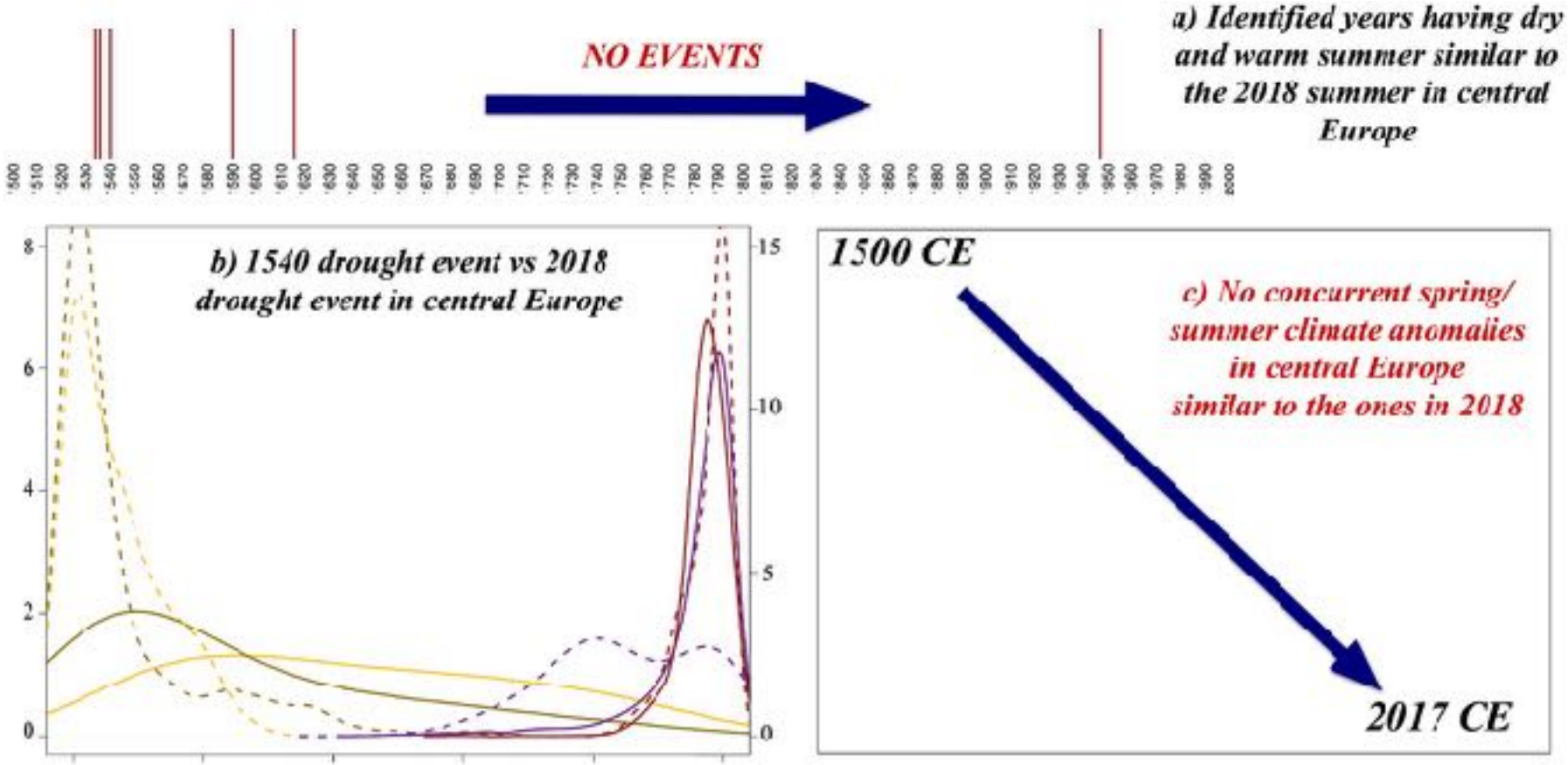
Learning from the past



Toreti et al. Earth's Future 2019

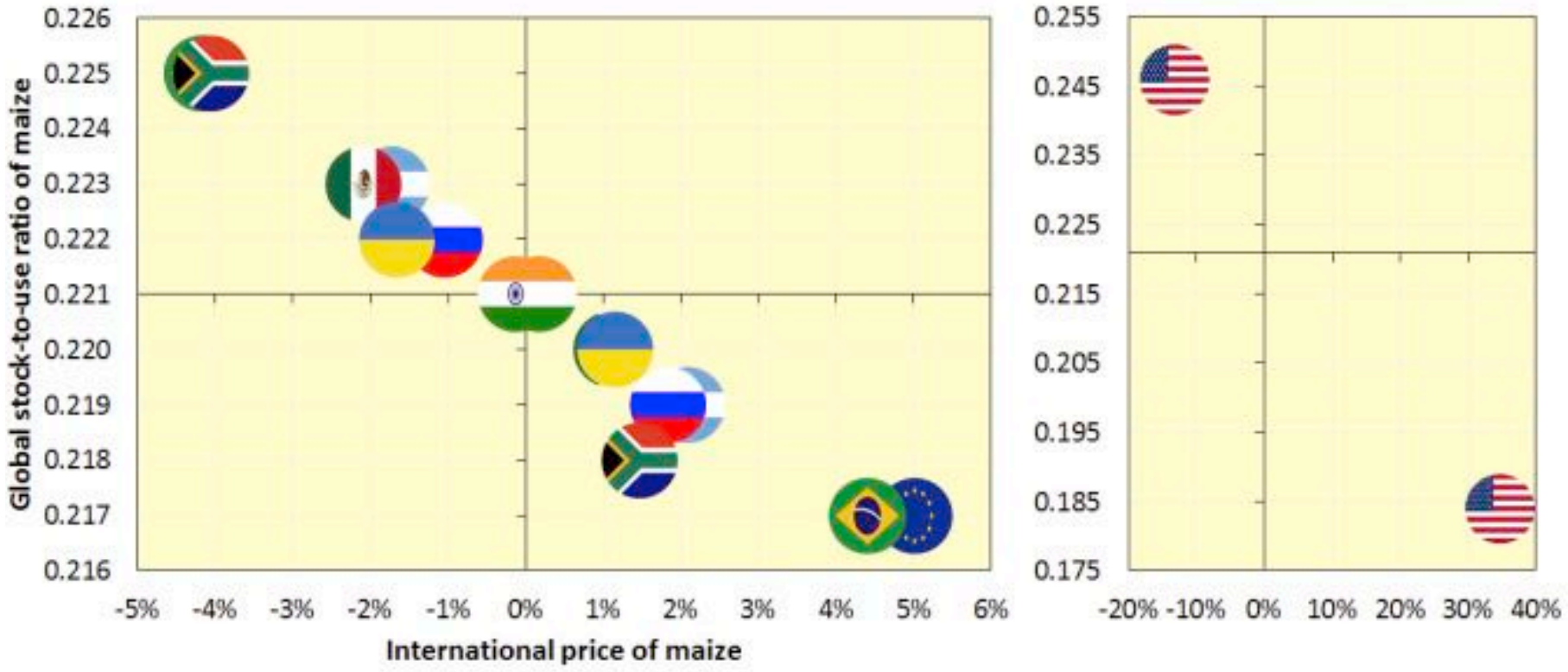
The extreme 2018



The 2018 drought: a compound event

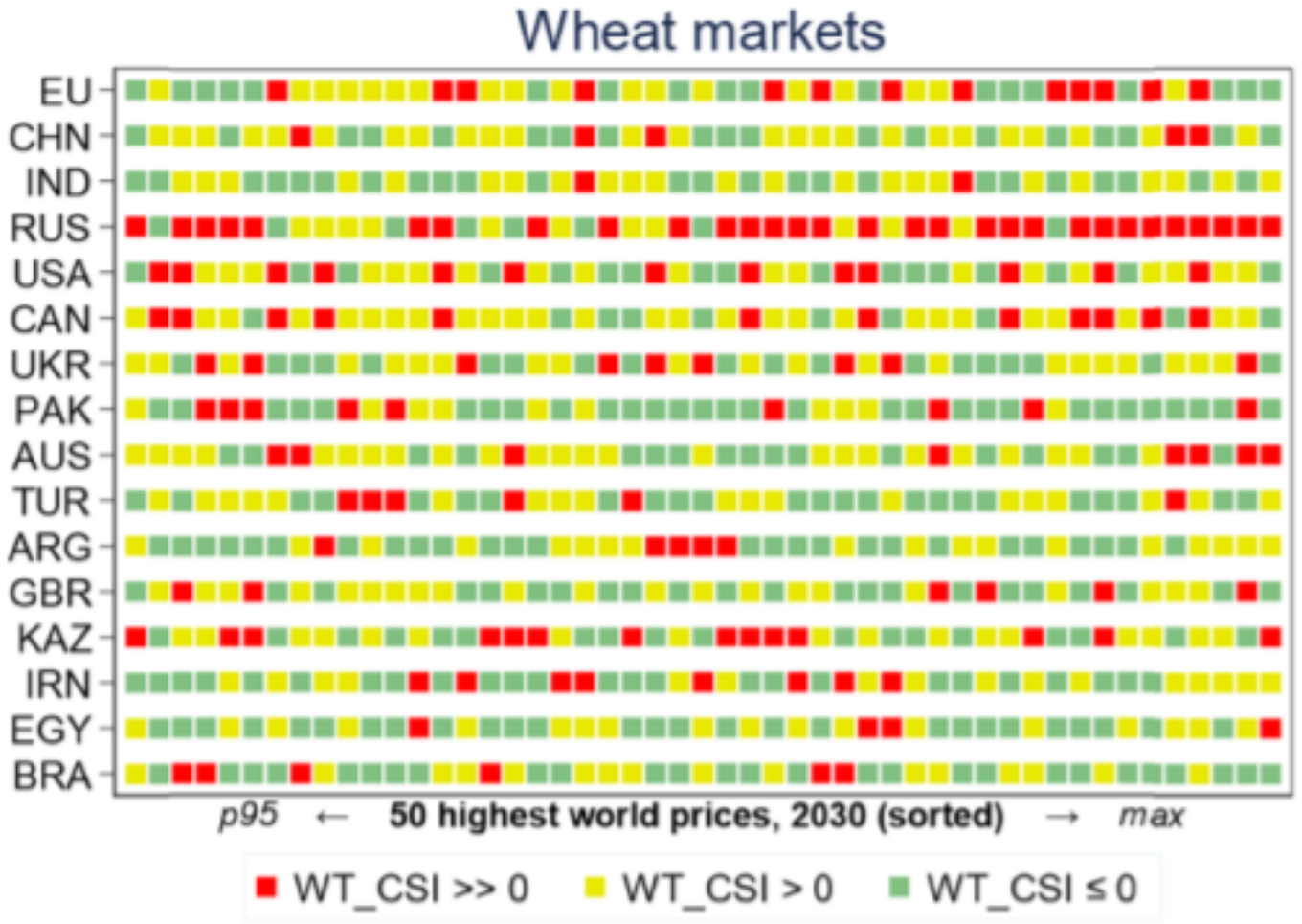
Toreti et al. Earth's Future 2019

Impacts on global markets



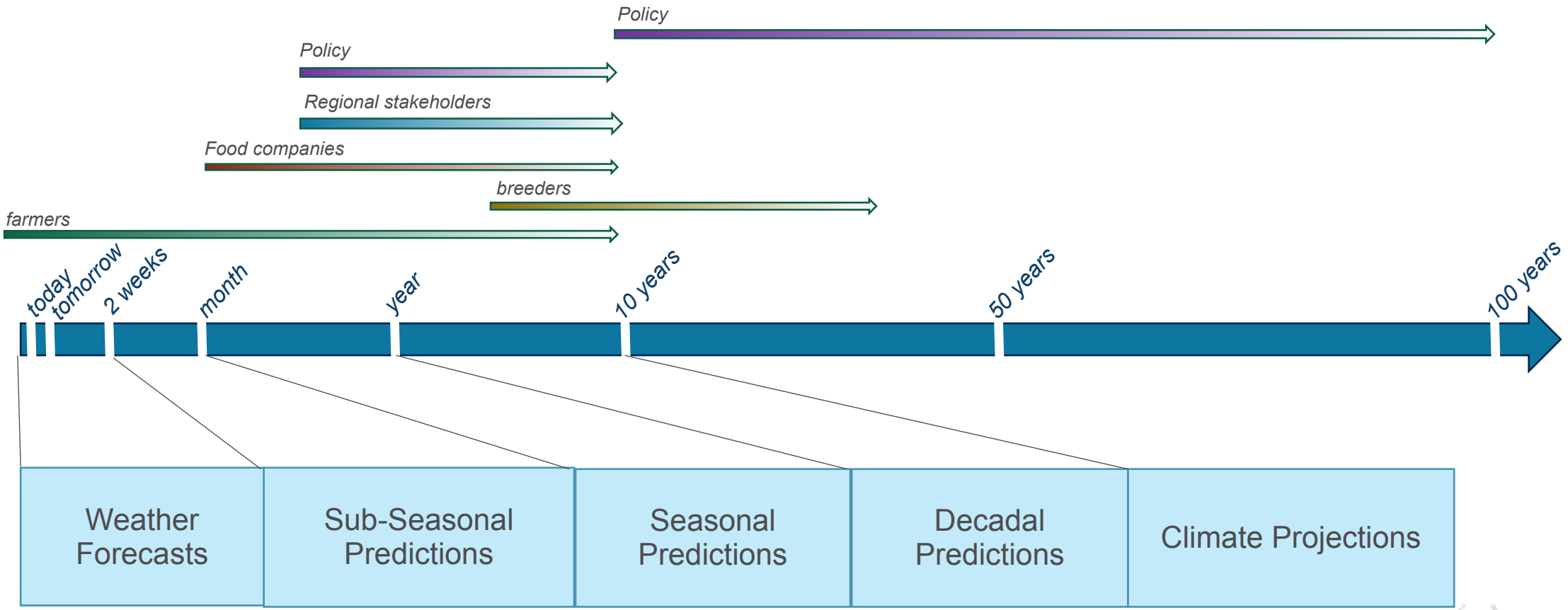
Chatzopoulos et al., 2020 Weather and Clim. Extremes

Impacts on global markets



Chatzopoulos et al., 2021 ERL

Predicting



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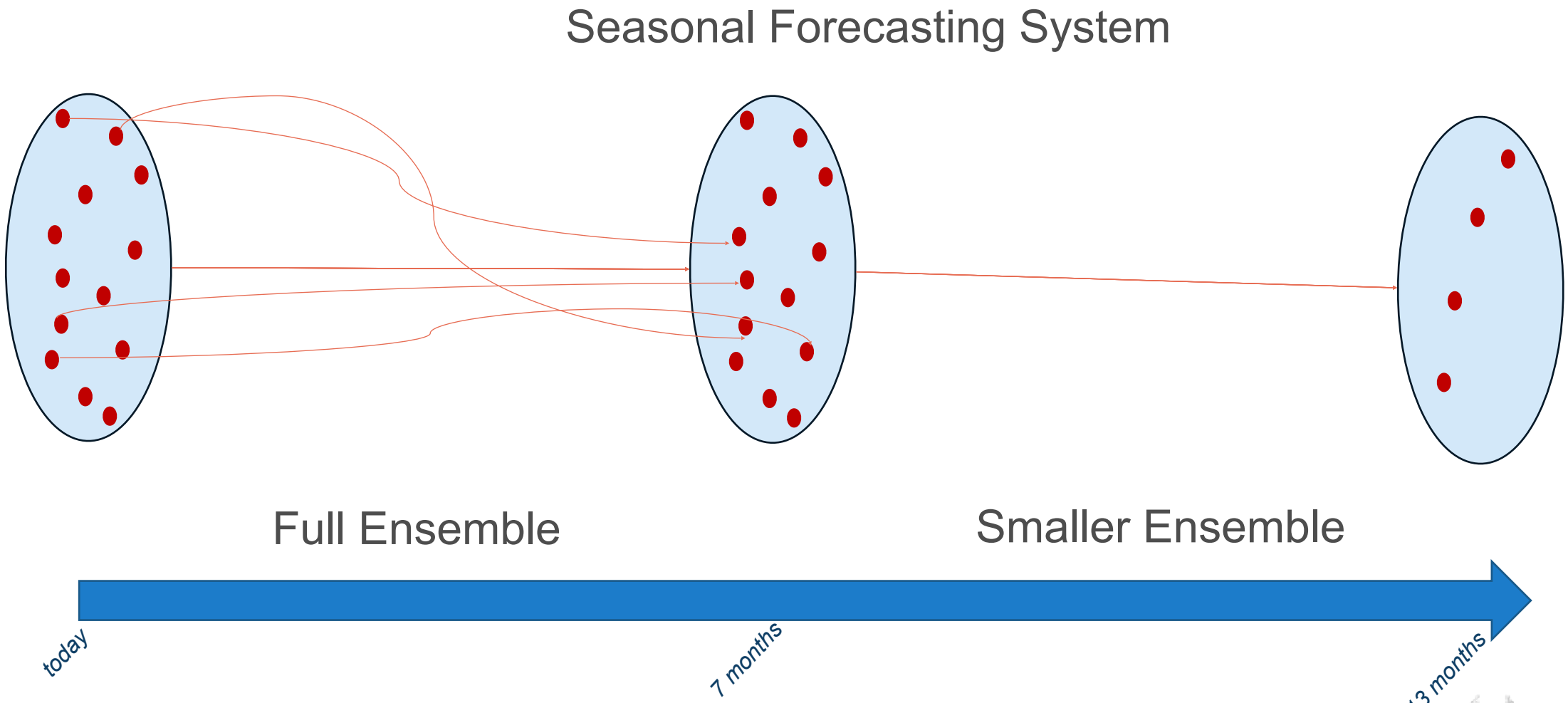

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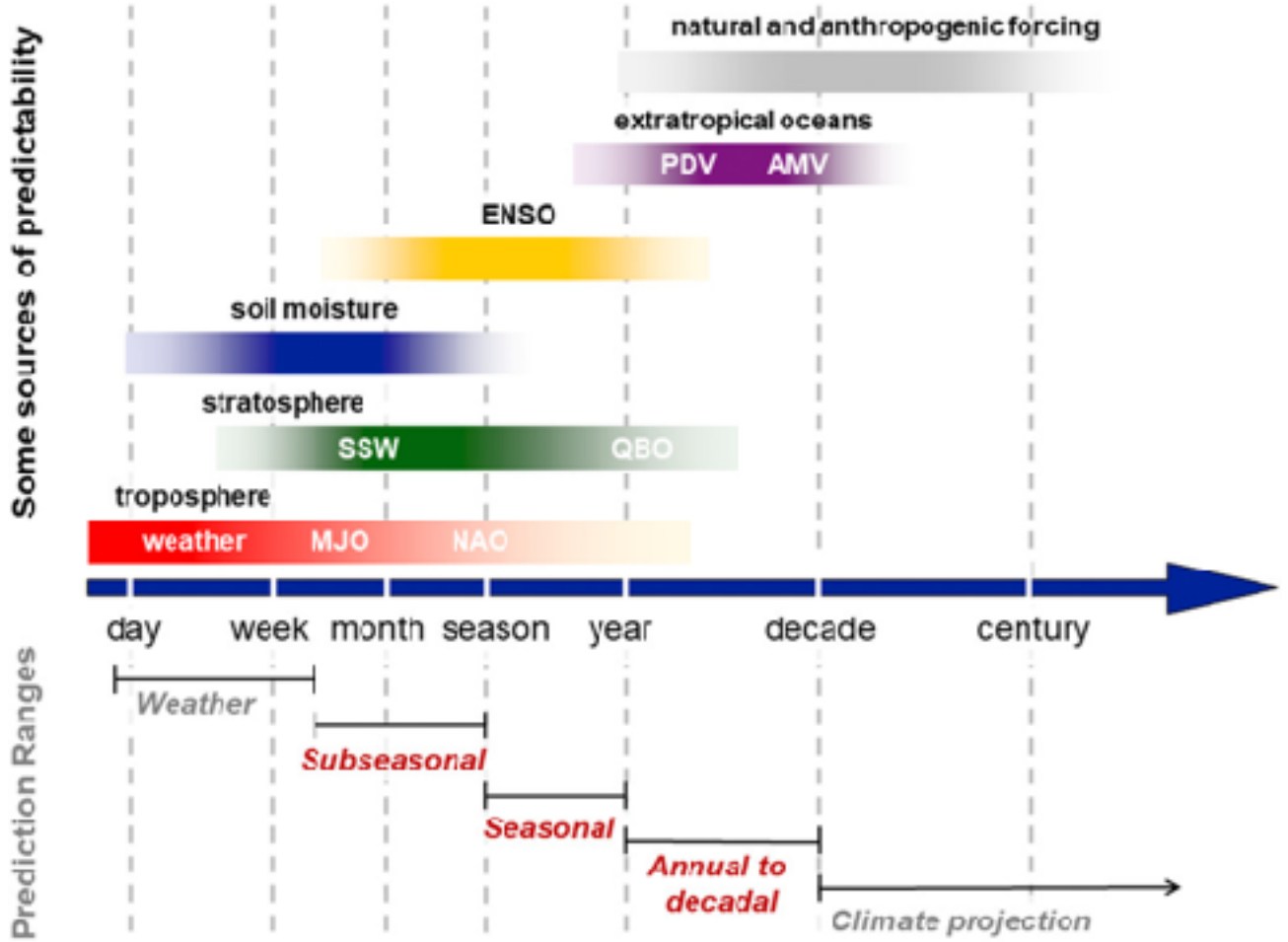
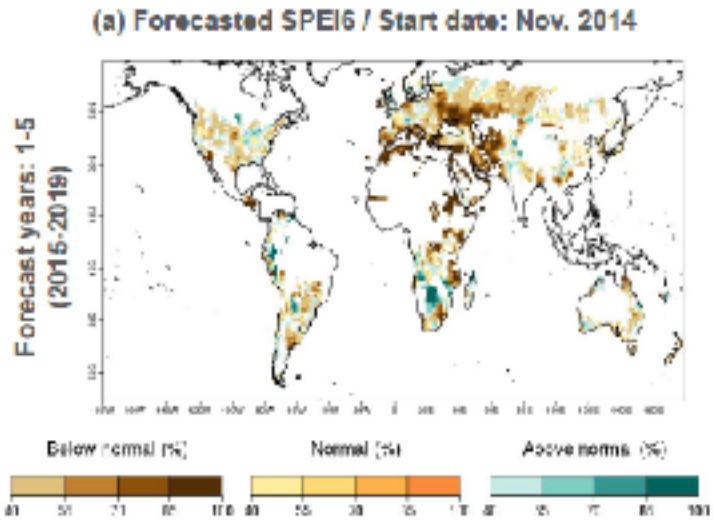


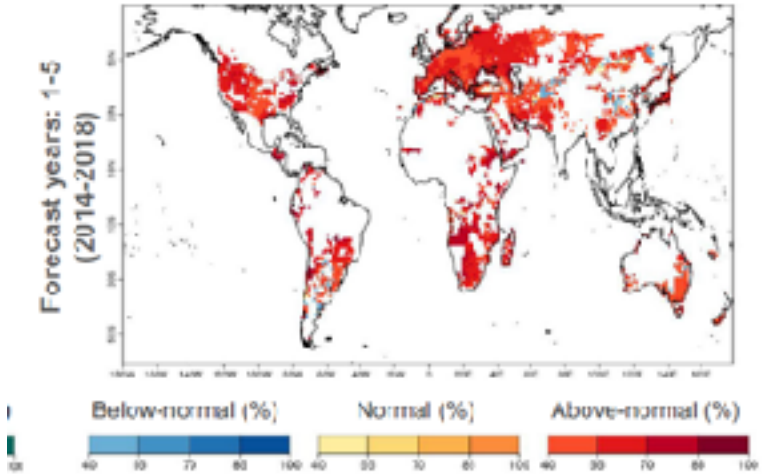
Merryfield et al., BAMS 101, 2020

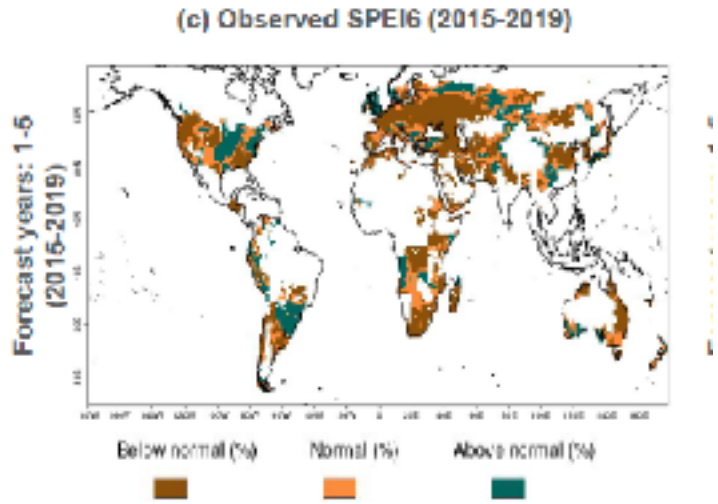
Seasonal forecast

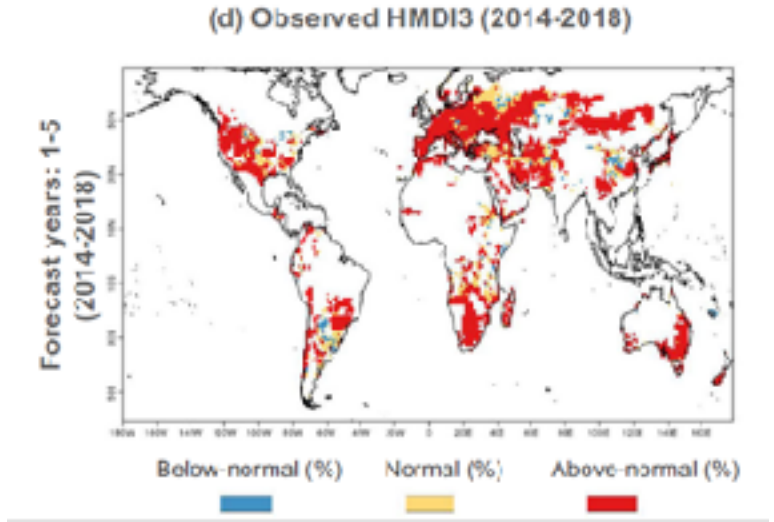
Source: Ceglar and Toreti, NPJ, 2021

Decadal forecast





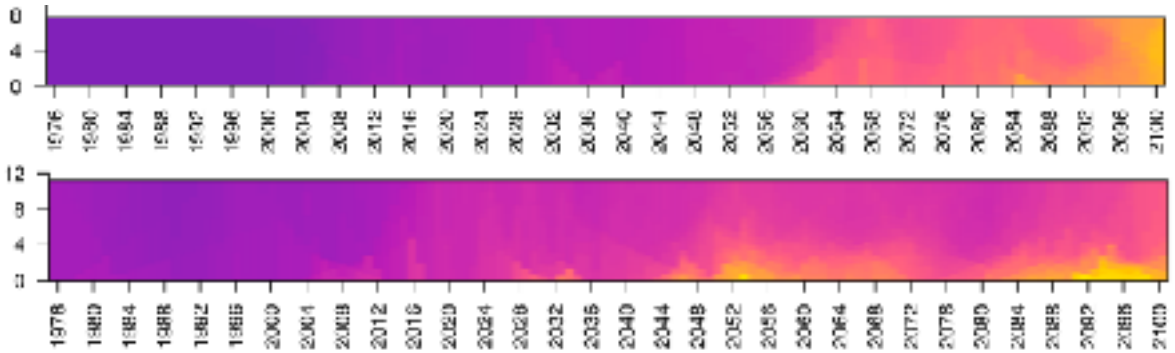


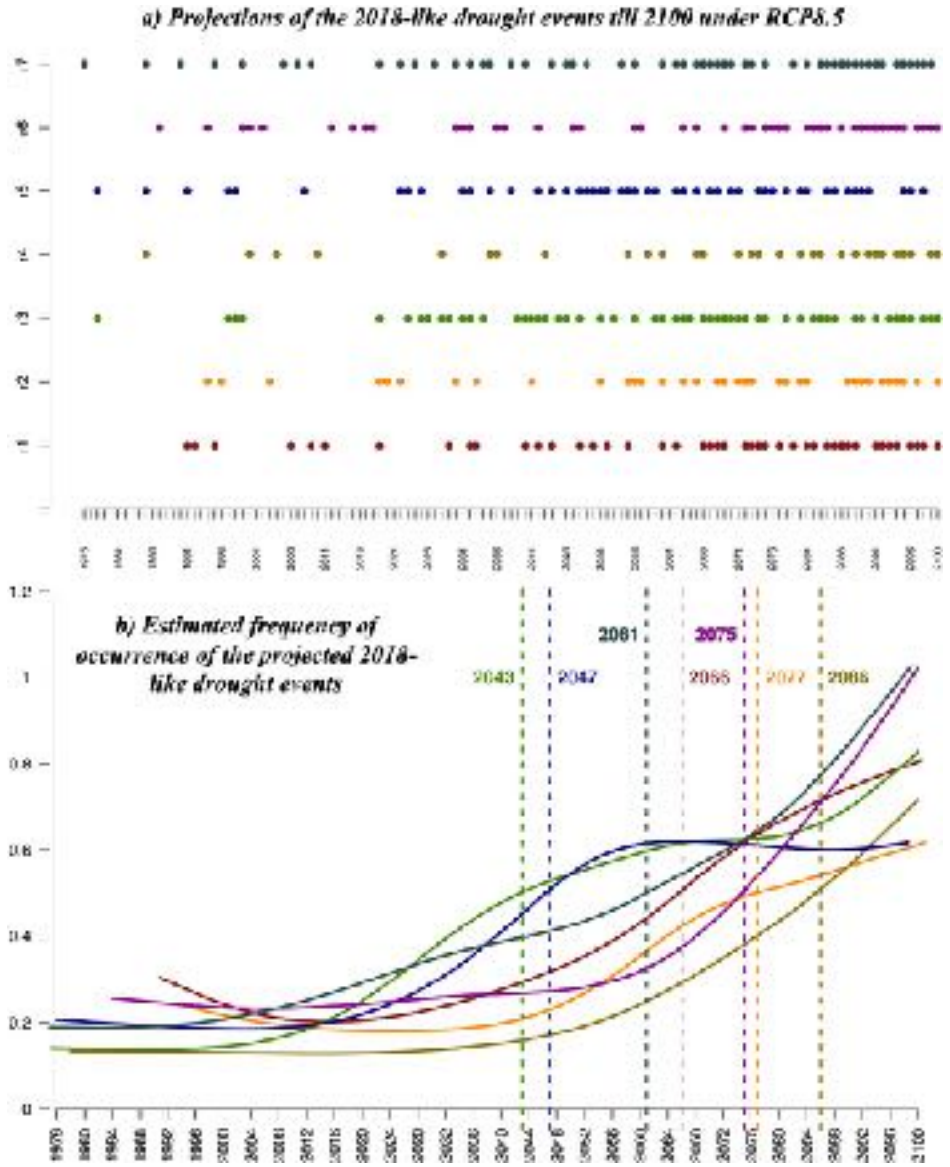


Source: Solaraju-Murali et al. NPJ, 2021

Projections

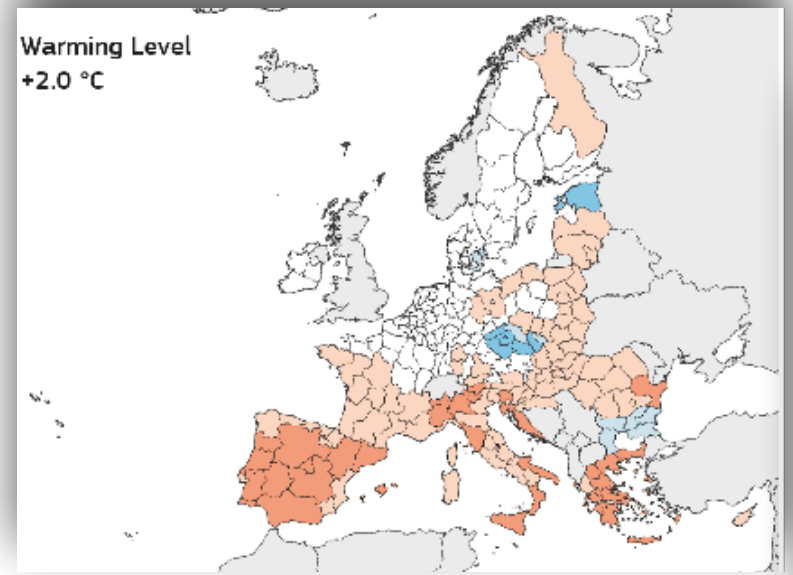
The 2018 extreme

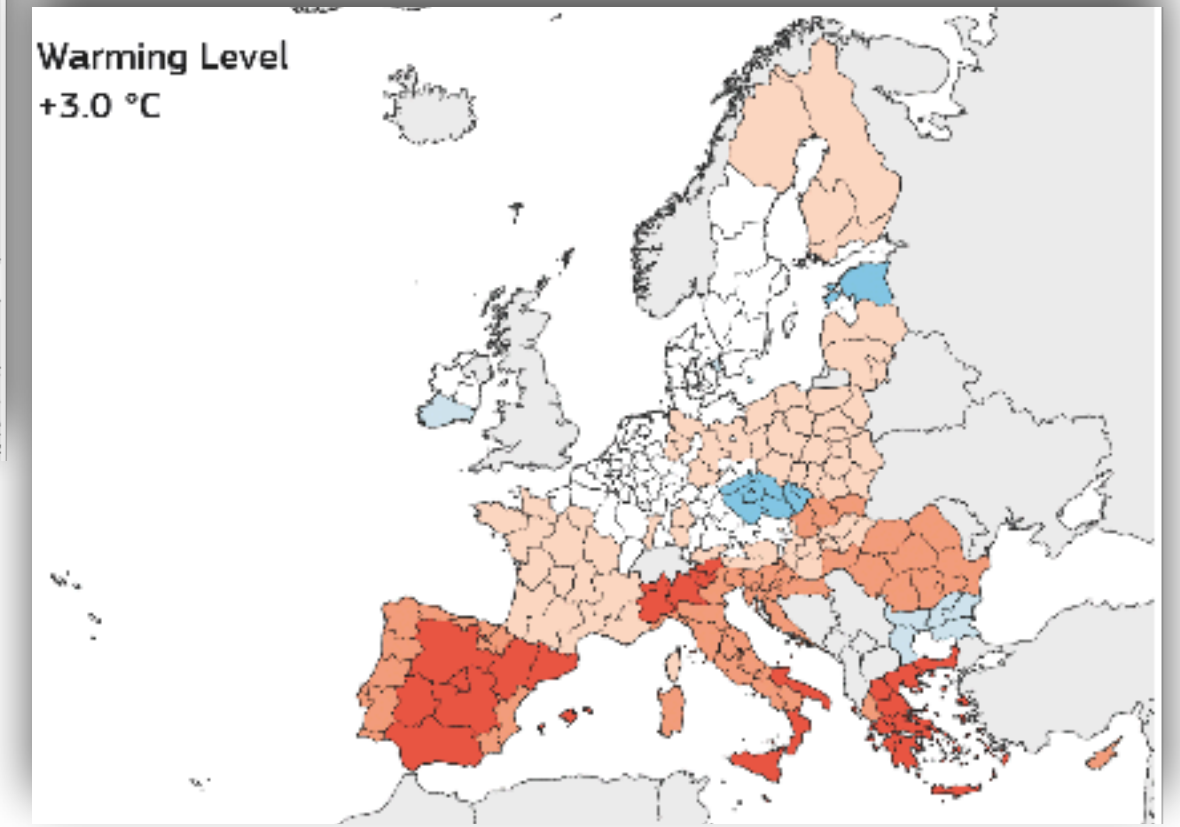




Source: Toreti et al., 2019

Public water supply - drought risk





Projected Loss / Current Loss

- reduction of more than 25%
- reduction between 10% and 25%
- no important variation
- increased by a factor of 1.1 to 1.5
- increased by a factor of 1.5 to 2
- increased by a factor of 2 to 3
- increased by a factor of 3 to 4
- increased by a factor of more than 4

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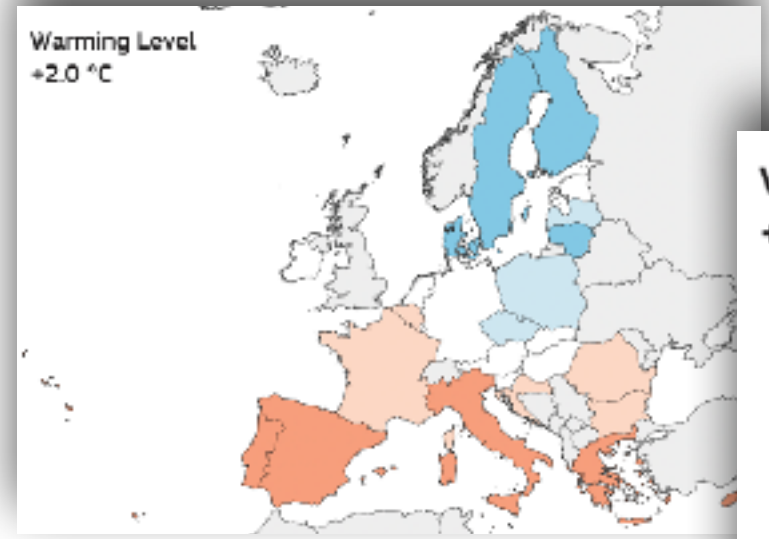
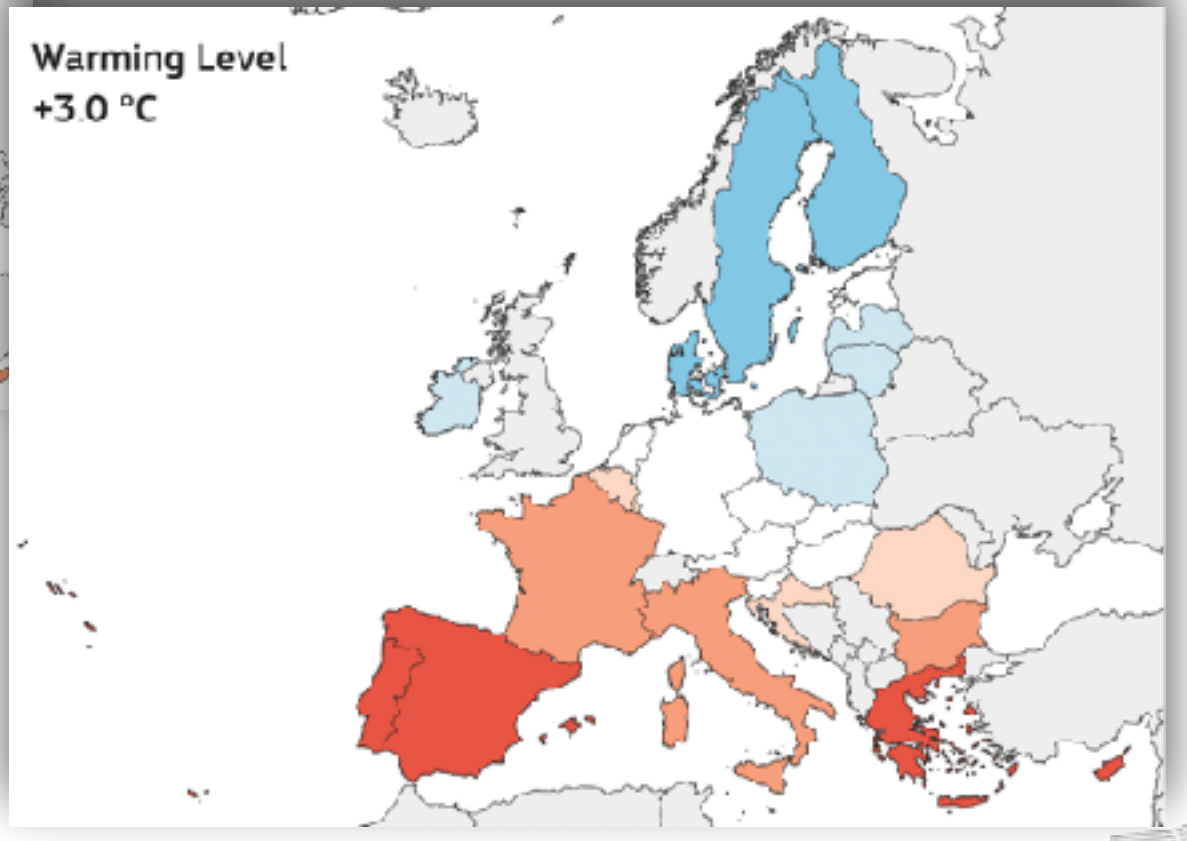
Hydropower - drought risk





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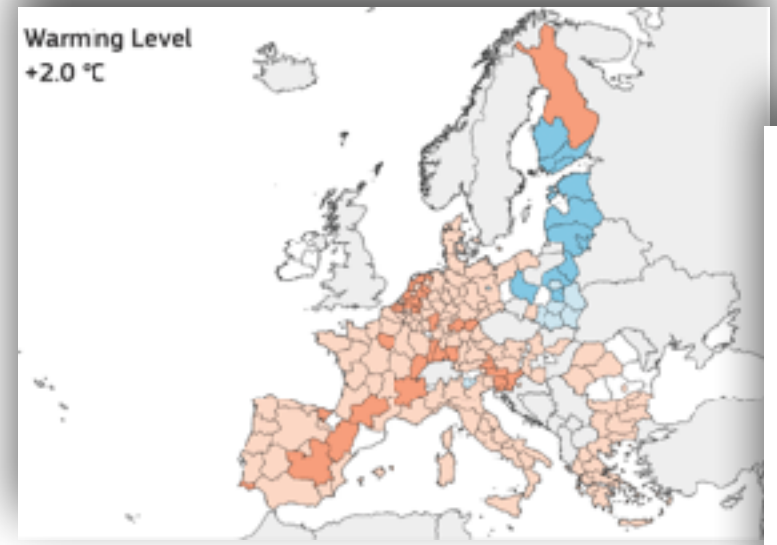
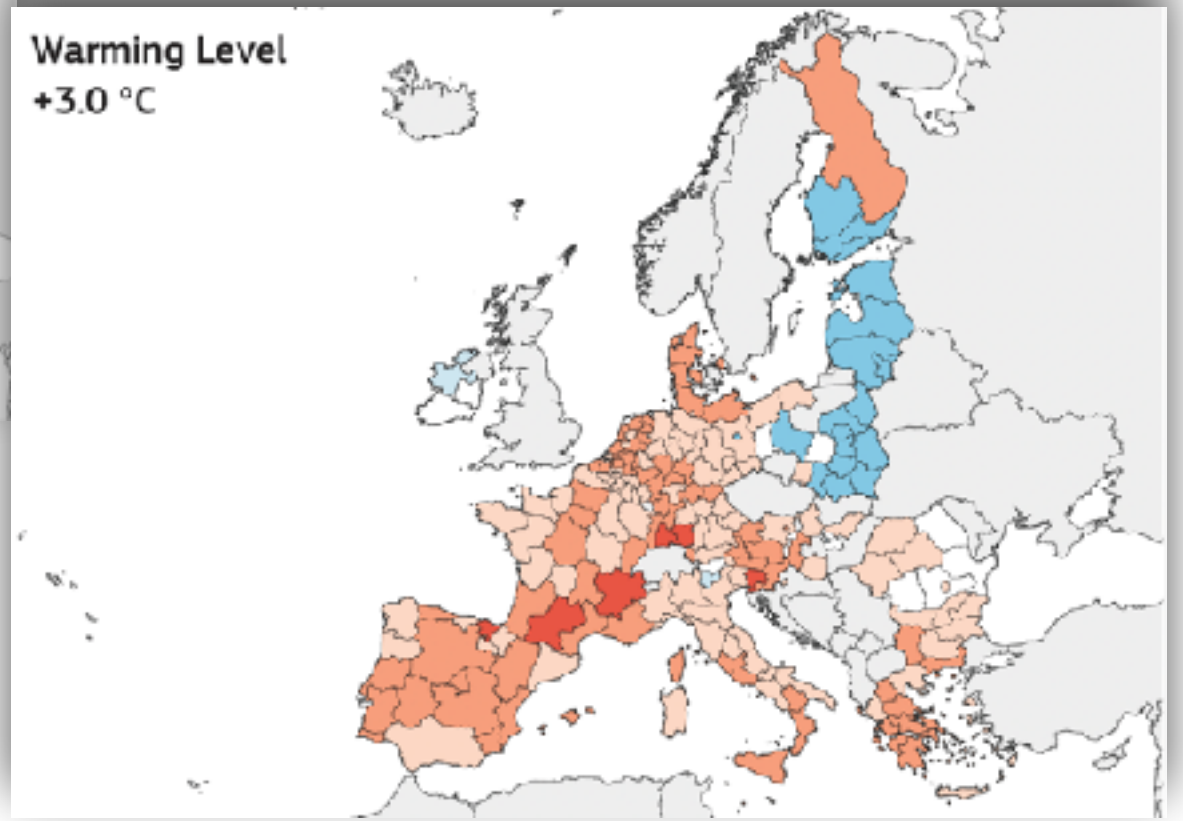
Agriculture (wheat) - drought risk





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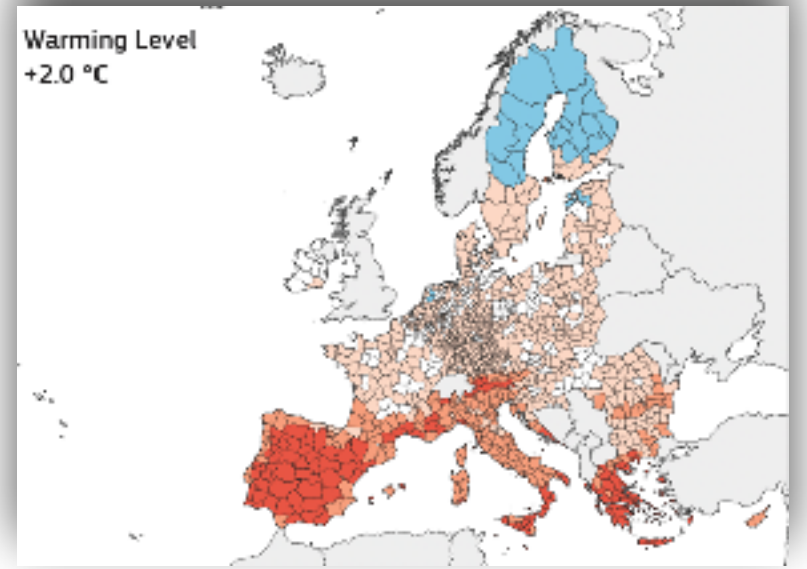
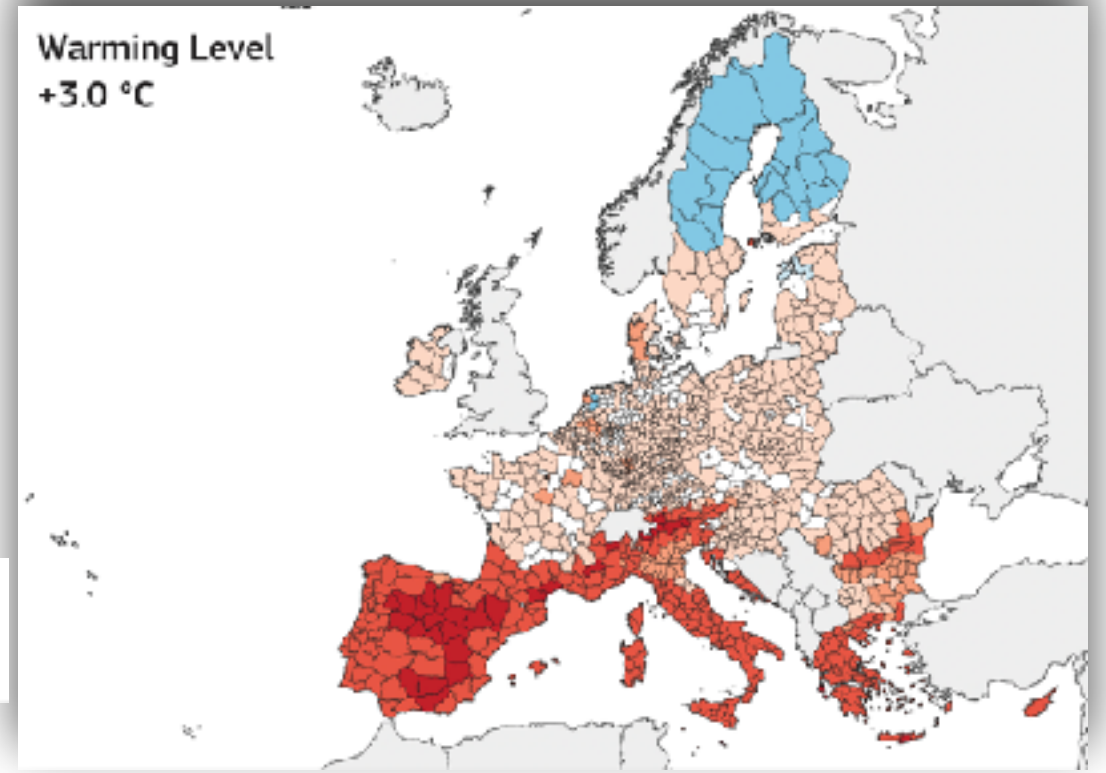
Ecosystems (terrestrial) - drought risk





Projected Loss / Current Loss

- reduction of more than 25%
- reduction between 10% and 25%
- no important variation
- increased by a factor of 1.1 to 1.5
- increased by a factor of 1.5 to 2
- increased by a factor of 2 to 3
- increased by a factor of 3 to 4
- increased by a factor of more than 4

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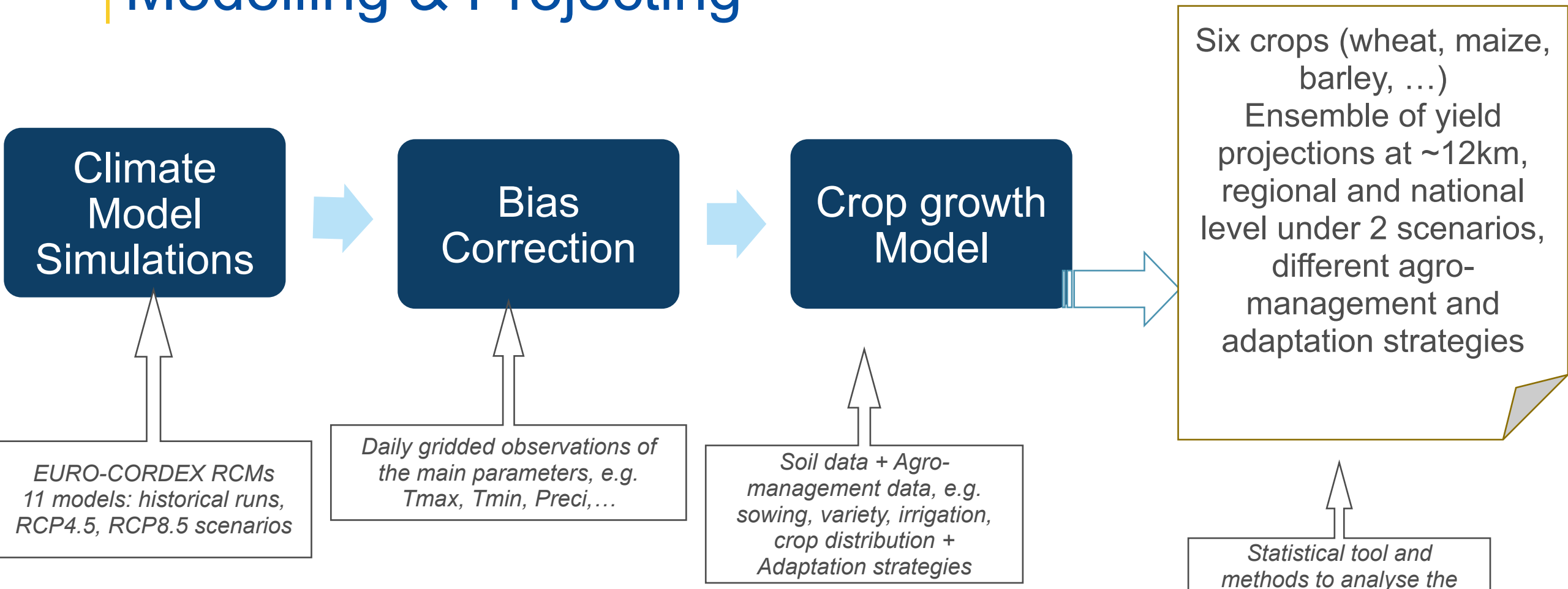
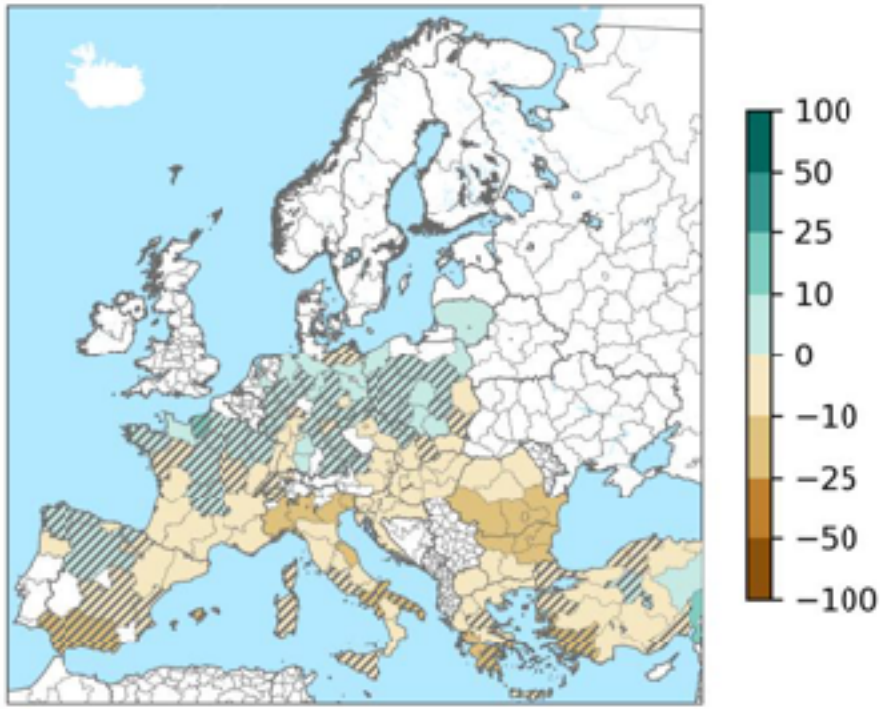
Modelling & Projecting



Modelling & Projecting

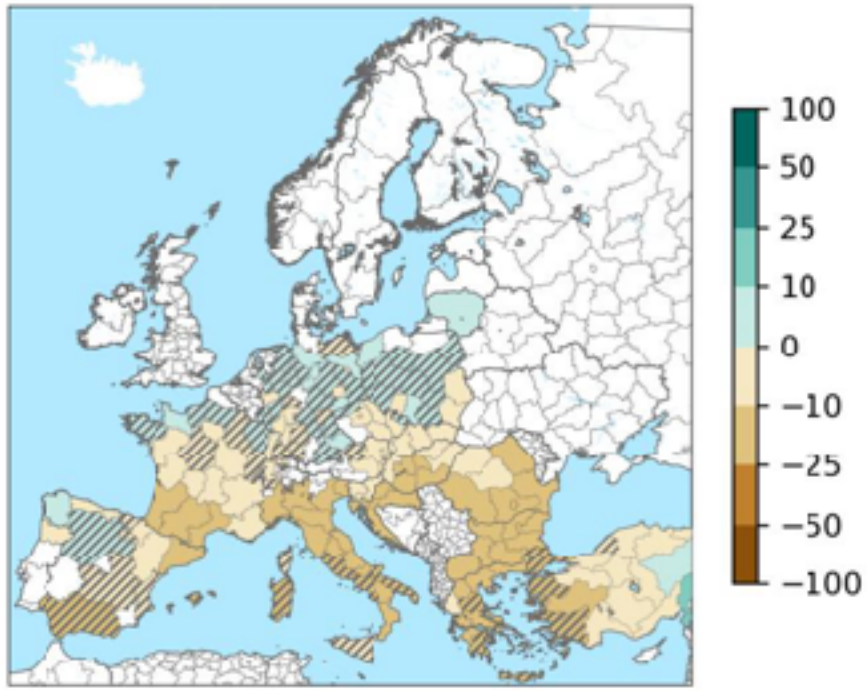
ENSEMBLE MEAN CHANGES RCP8.5

1.5 K



Maize

2 K

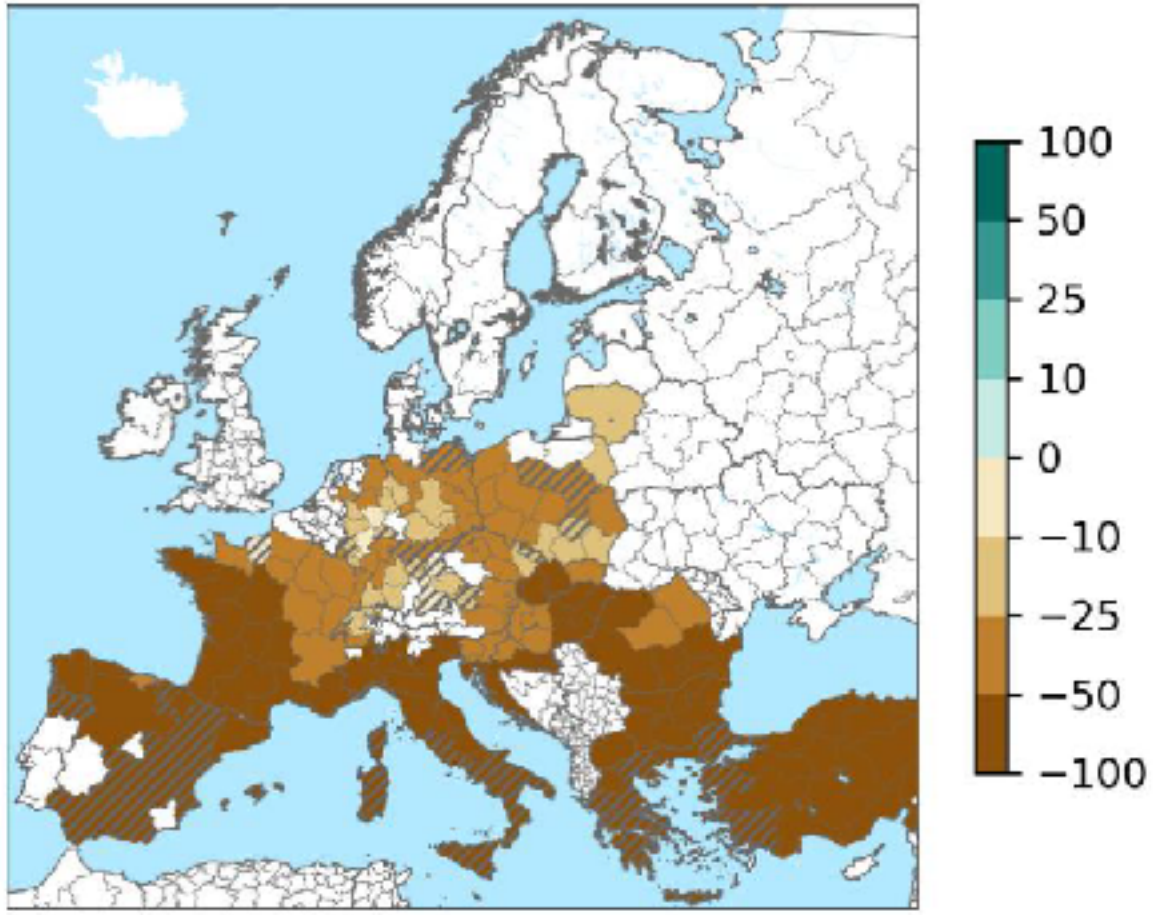


Source: Hristov et al., JRC119632, 2020

Modelling & Projecting

worst-case scenarios

No irrigation under future climate conditions



2K

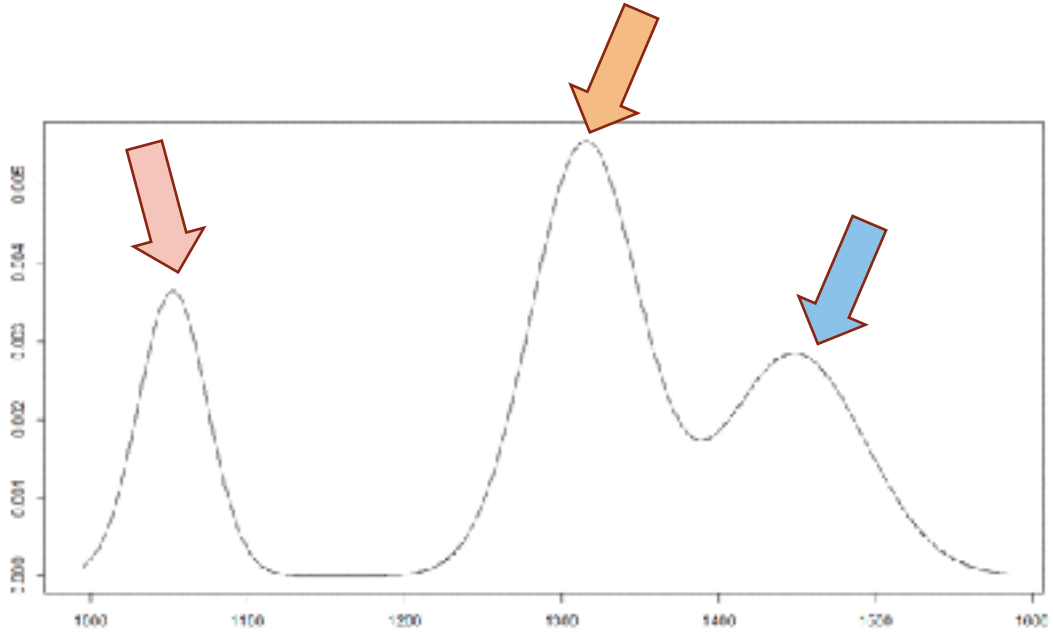
ENSEMBLE MEAN CHANGES RCP8.5

Maize

Source: Hristov et al., JRC119632, 2020

Modelling & Projecting

Experimental data: 189 durum wheat varieties tested in 8 sites in the Med



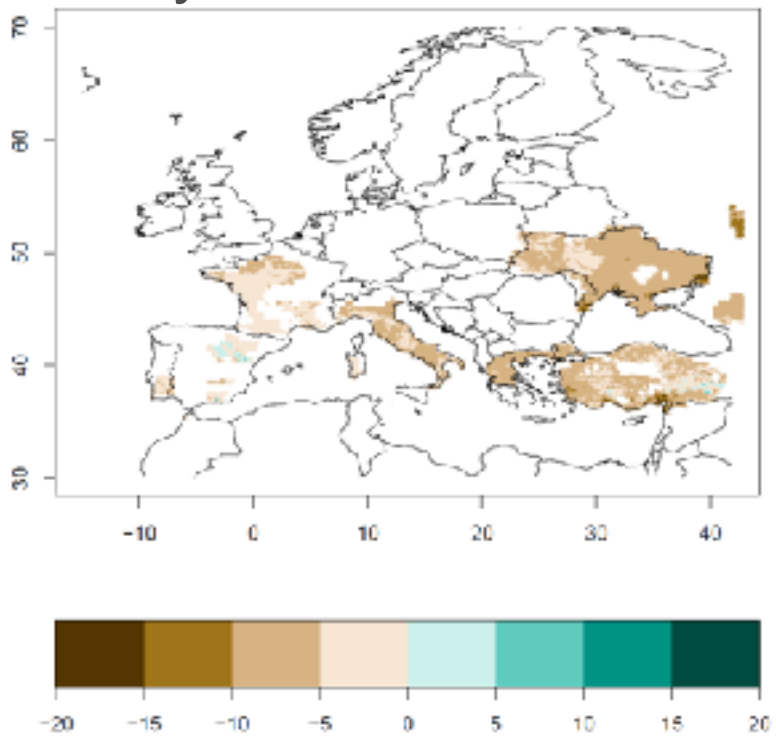
Representative sample of 18 ideotypes

ECroPS

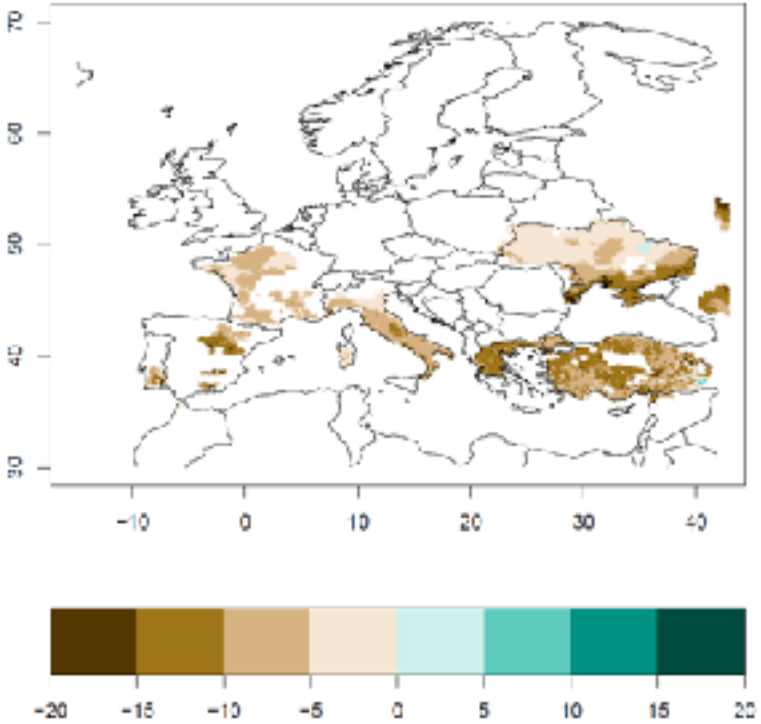
2021-2040 RCP8.5 scenario

Modelling & Projecting

early



late



Ensemble yield changes in %

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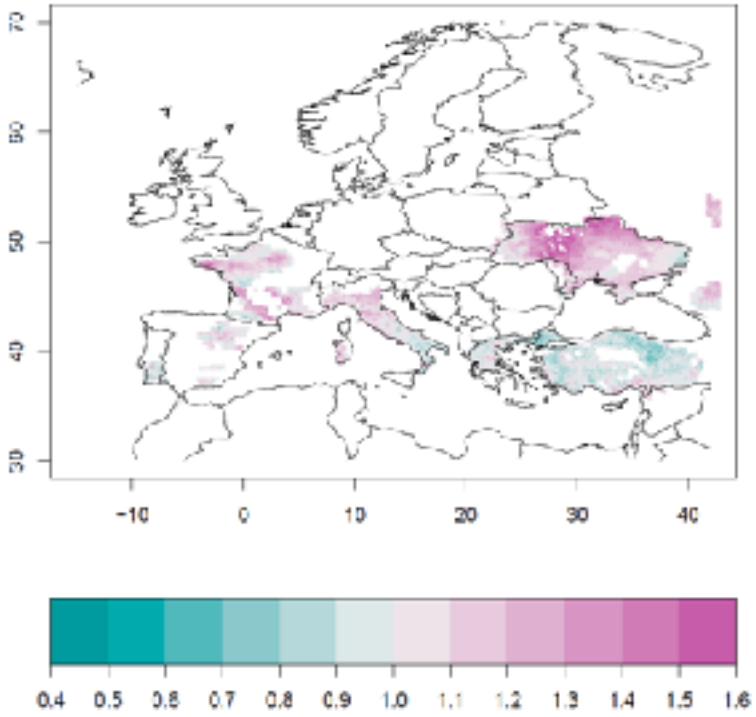
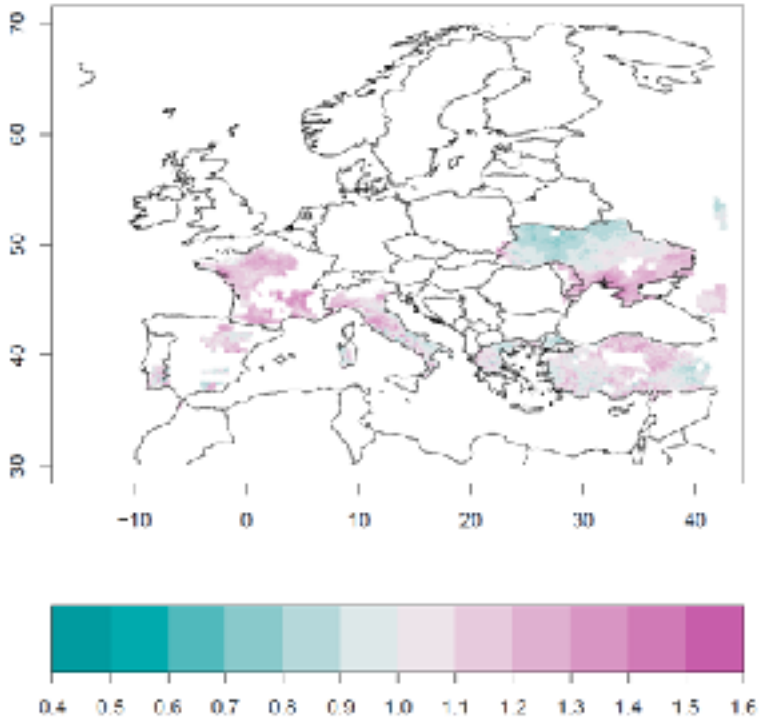
Modelling & Projecting

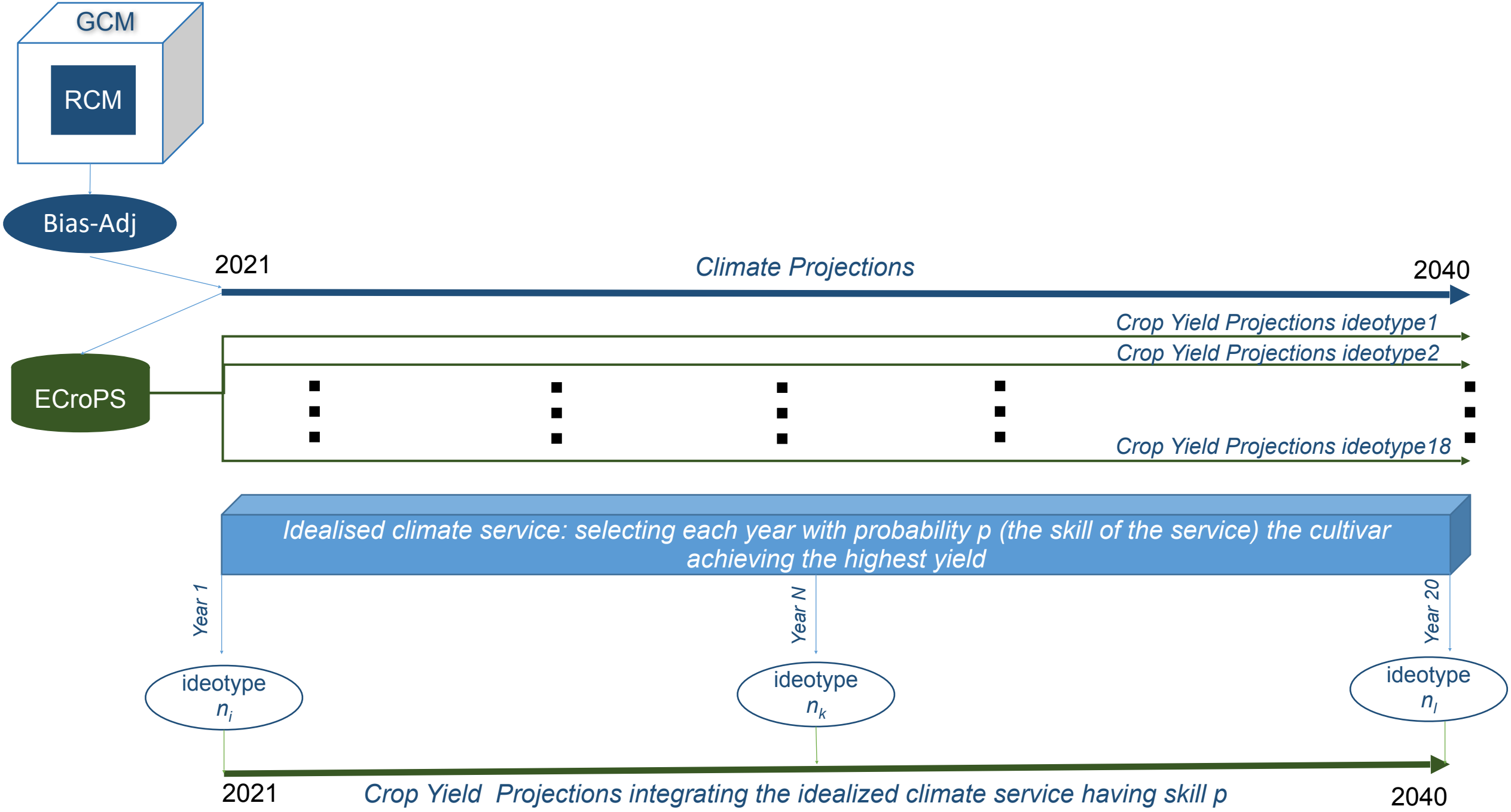
early



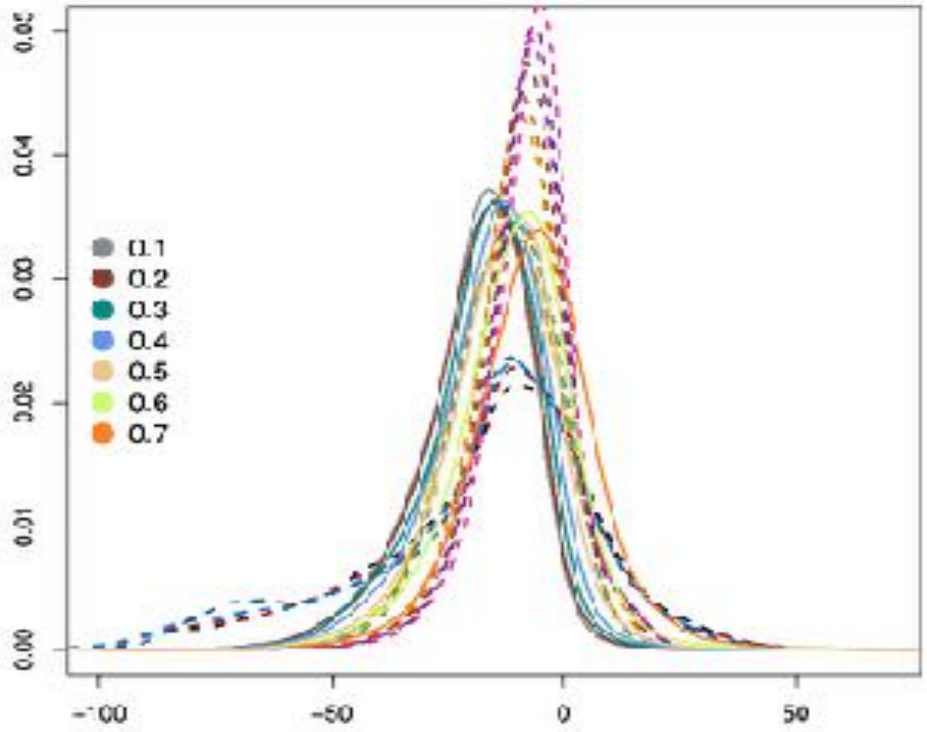
late



Changes in the interannual variability


GCM
RCM
Bias-Adj
2021
Climate Projections
2040
Crop Yield Projections ideotype1
Crop Yield Projections ideotype2
ECroPS
Crop Yield Projections ideotype18
Idealised climate service: selecting each year with probability p (the skill of the service) the cultivar achieving the highest yield
Year 1
Year N
Year 20
ideotype n_i
ideotype n_k
ideotype n_l
2021
Crop Yield Projections integrating the idealized climate service having skill p
2040

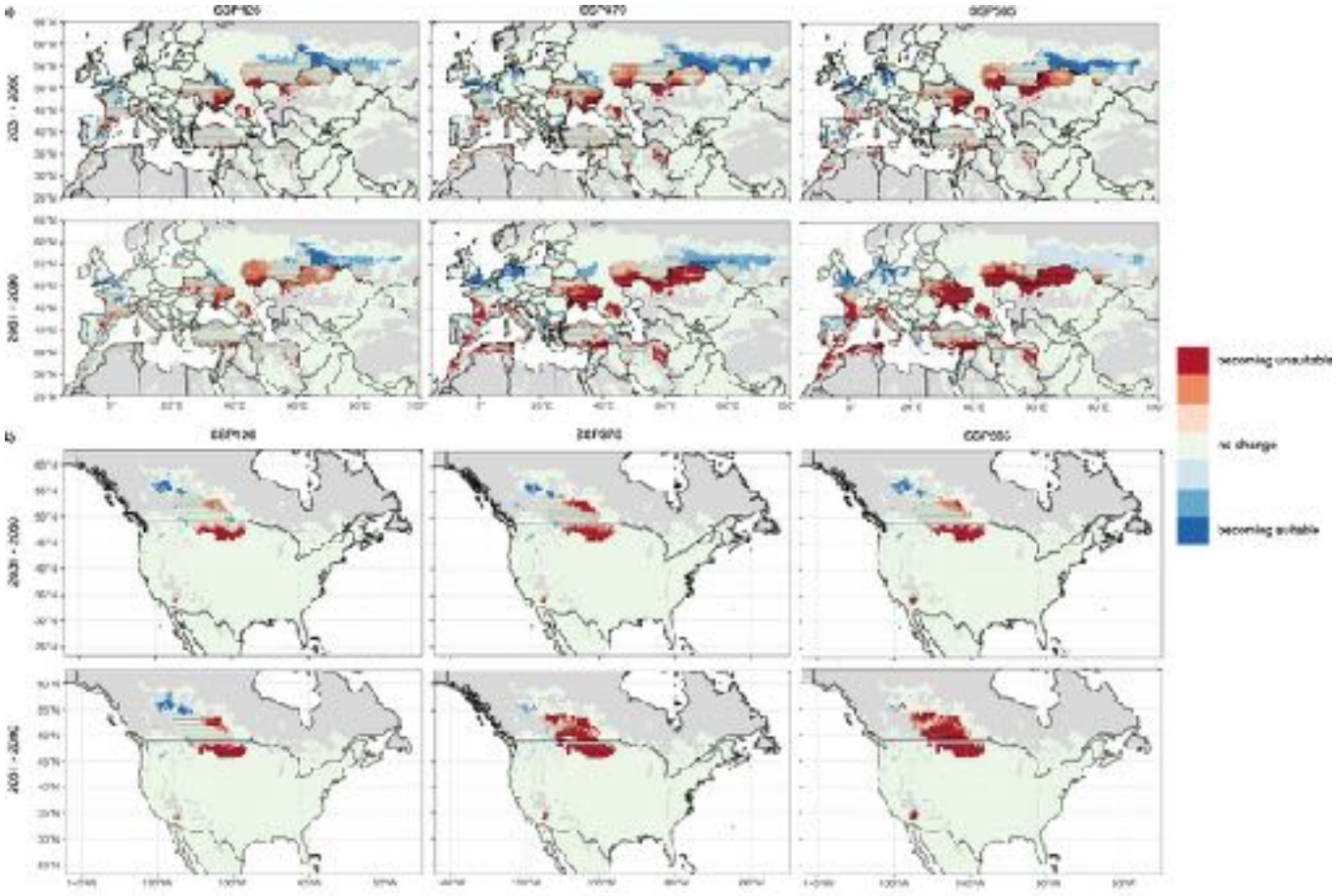
Modelling & Projecting

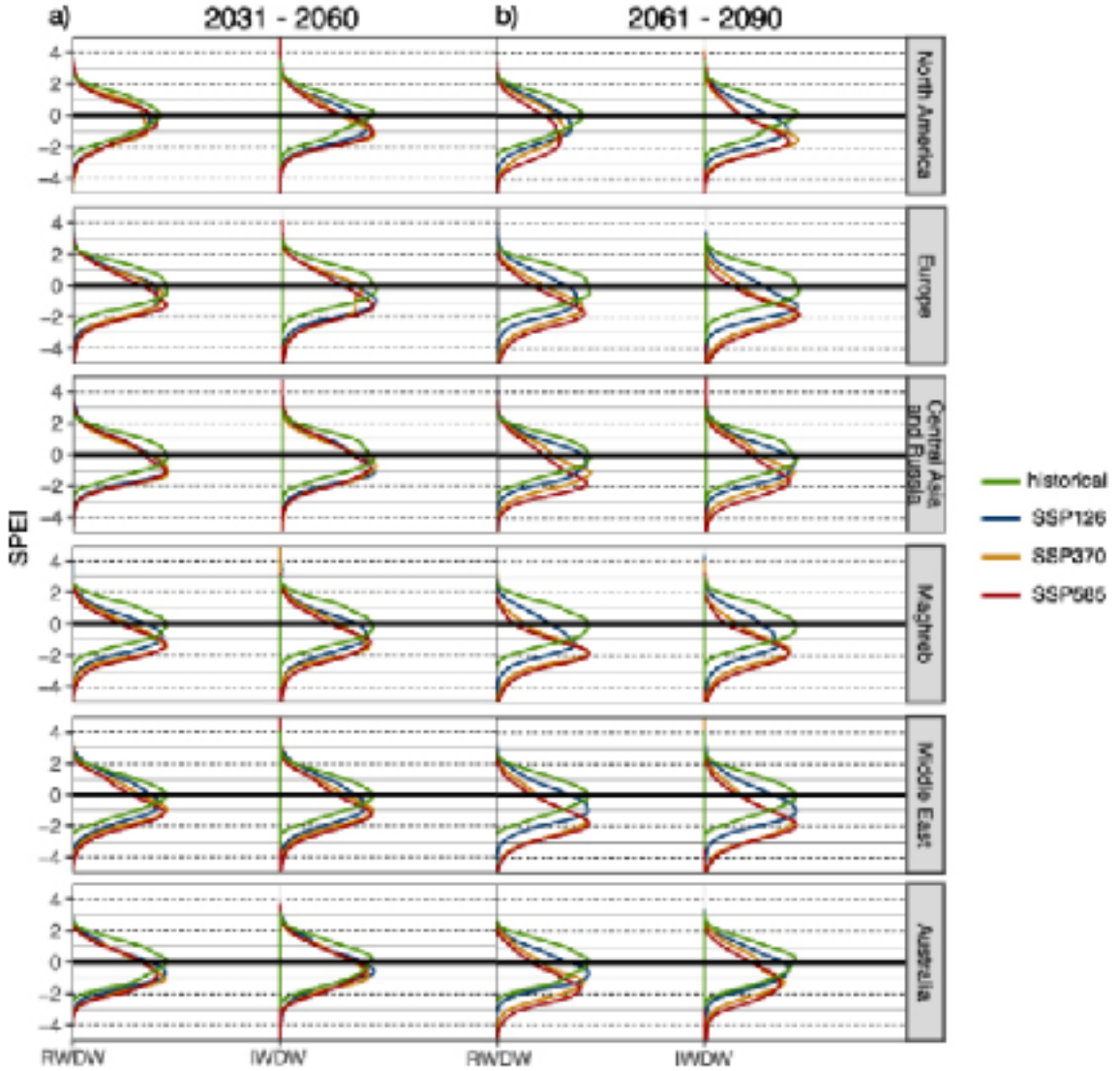


Climate change impacts on resilience (2021-2040 RCP8.5) with climate service in place informing on optimal crop variety at sowing

Source: Toreti et al. 2022 in review

Future impacts





Source: Ceglar et al. 2021

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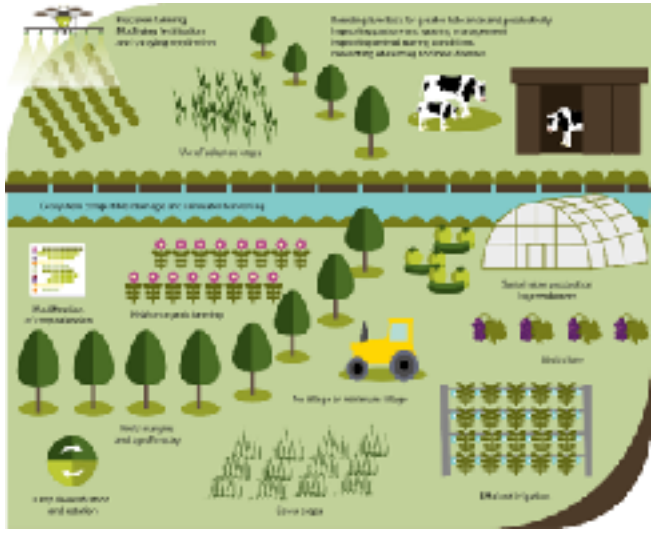
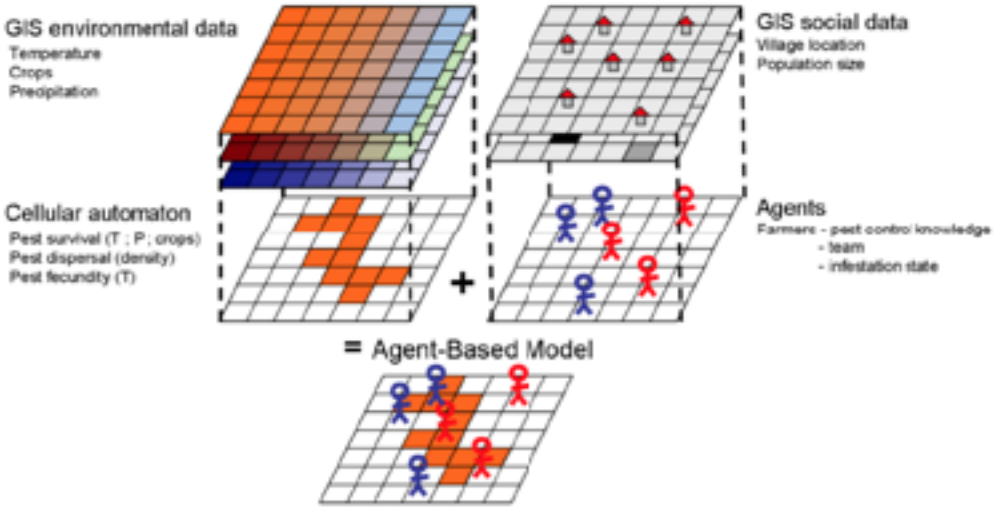
Adaptation

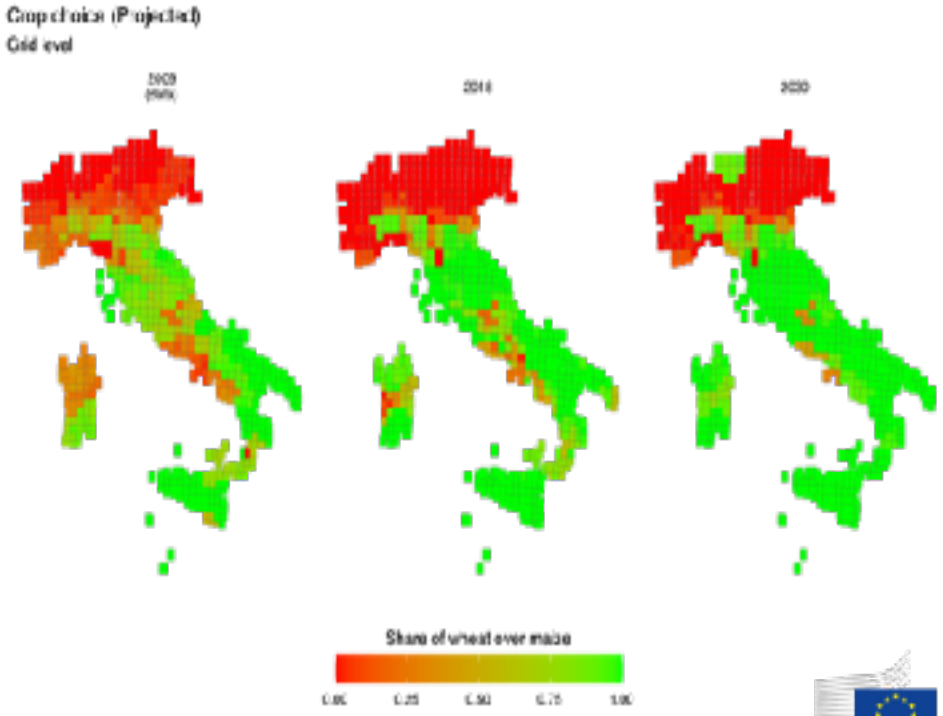
@Fraunhofer



Source: EEA, 2019



Source: Rebaudo et al. 2011



Source: Coronese et al. in preparation

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Ongoing initiatives and projects

CLINT
CLIMATE INTELLIGENCE

EXTREME EVENTS
HOTSPOTS
MACHINE LEARNING

XAIDA

Destination Earth

AIQCS
AI-enhanced Climate Services

ITU
UN environment programme

ITU/WMO/UNEP Focus Group on AI for Natural Disaster Management (FG-AI4NDM)

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Thank you

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