Hydro-meteorological extremes in a changing climate: Part two

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OPERANDUM
OPEn-air laboRAtories for Nature baseD solUtions to Manage hydro-meteo risks

Summer School on Nature-based Solutions for hydro-meteo hazards and climate change adaptation
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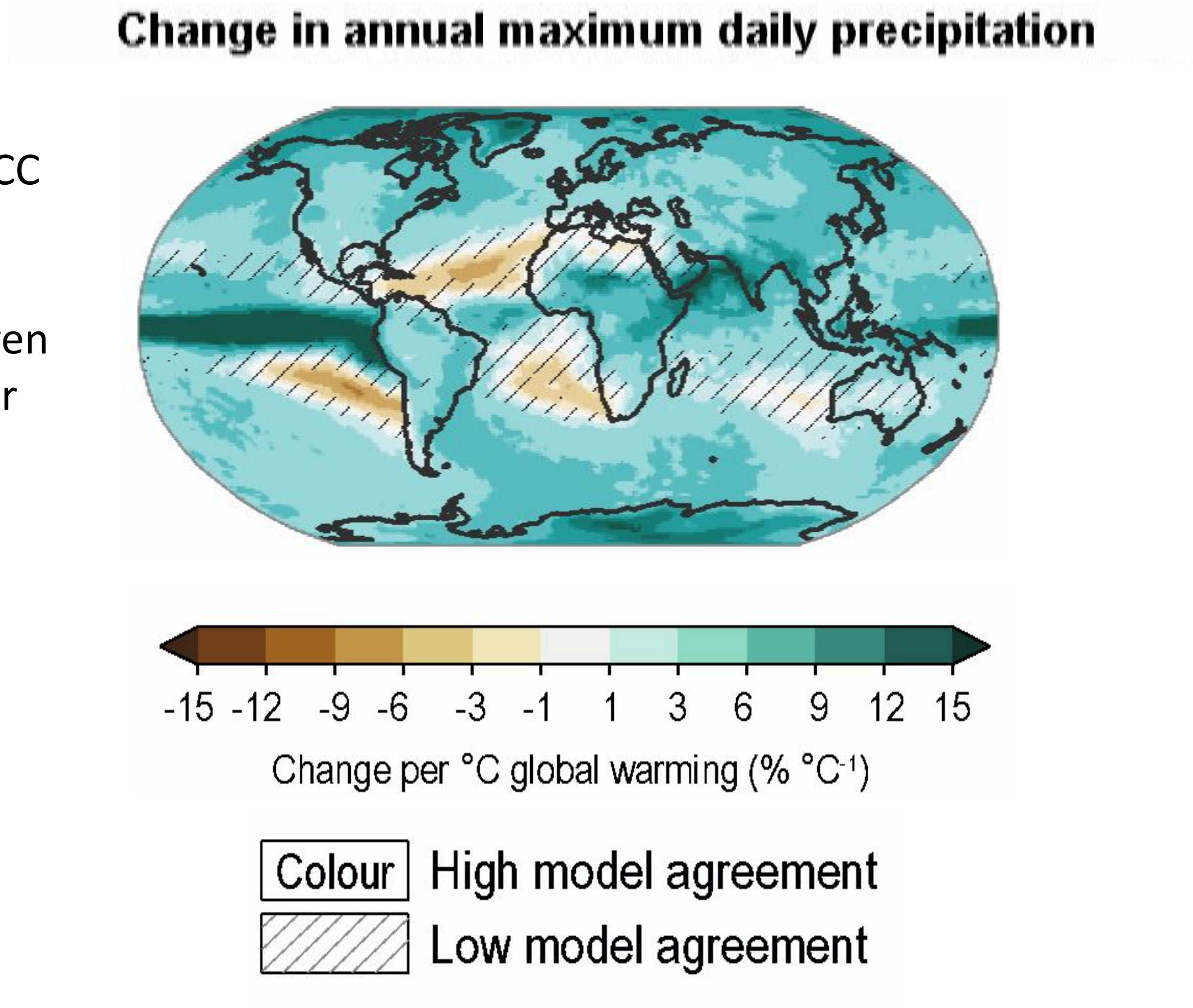
Impact of CC on extreme events

From the IPCC report
WG – I
Chapter eleven
On weather extremes

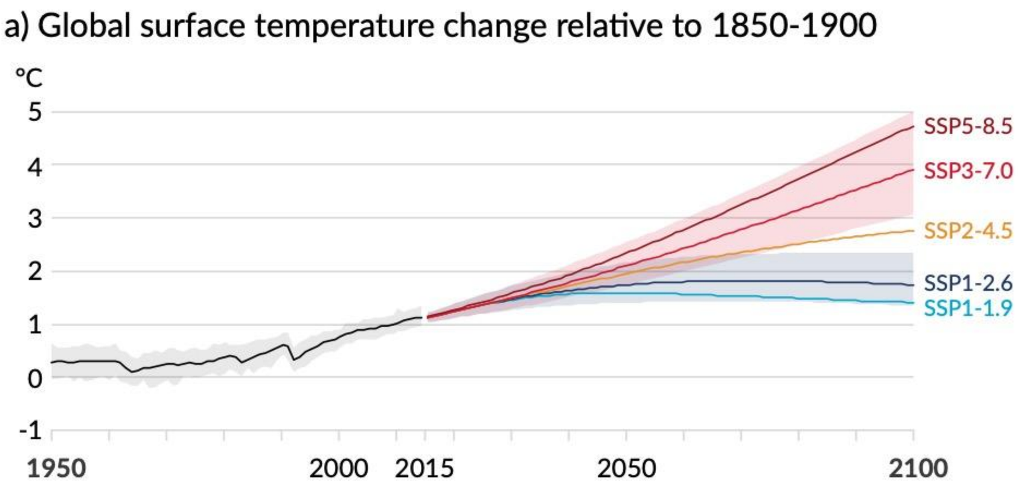


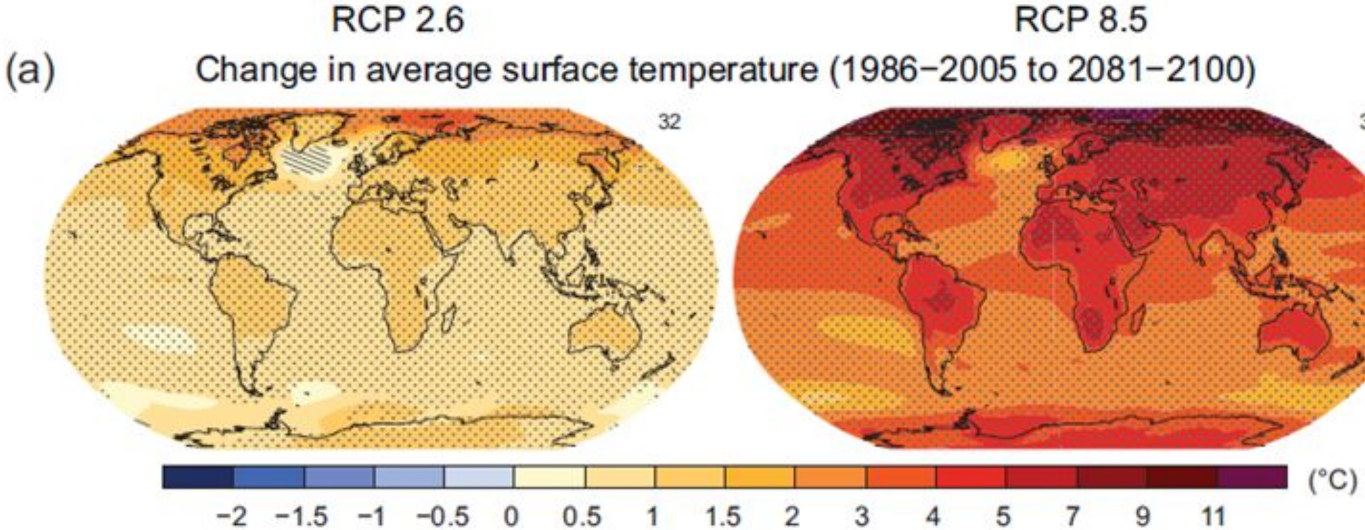
Aim and Outline

Introduce IPCC tools to explore projections of weather extremes and discuss fundamentals for their interpretation

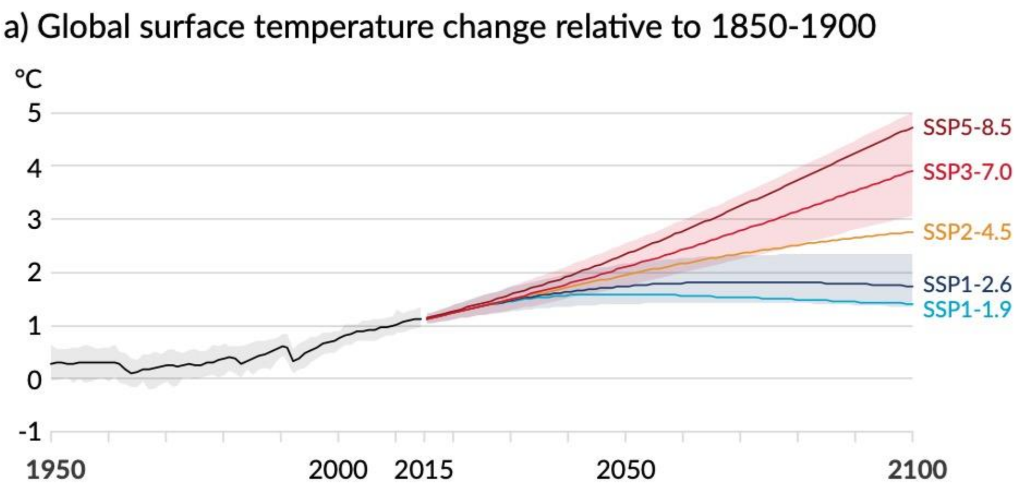
- Climatic Impact Drivers (CIDs)
- Signals and Uncertainty in climate projections of CIDs
- IPCC tools: Atlas and factsheets

Global warming

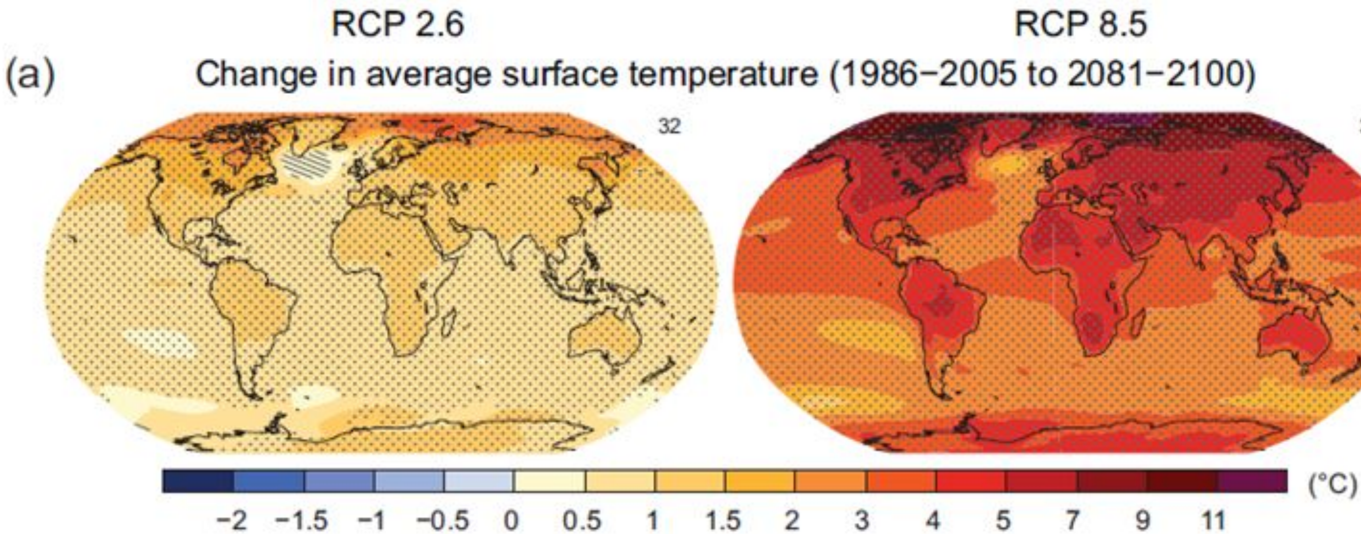




Global warming



We are not only interested in how warmer the planet will be (which is a rather direct consequence of radiative imbalance) but also in indirect impacts of climate change that are mediated by many and not always well understood physical processes.



Climatic Impact Drivers

Climatic impact-drivers (CIDs) are physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems.

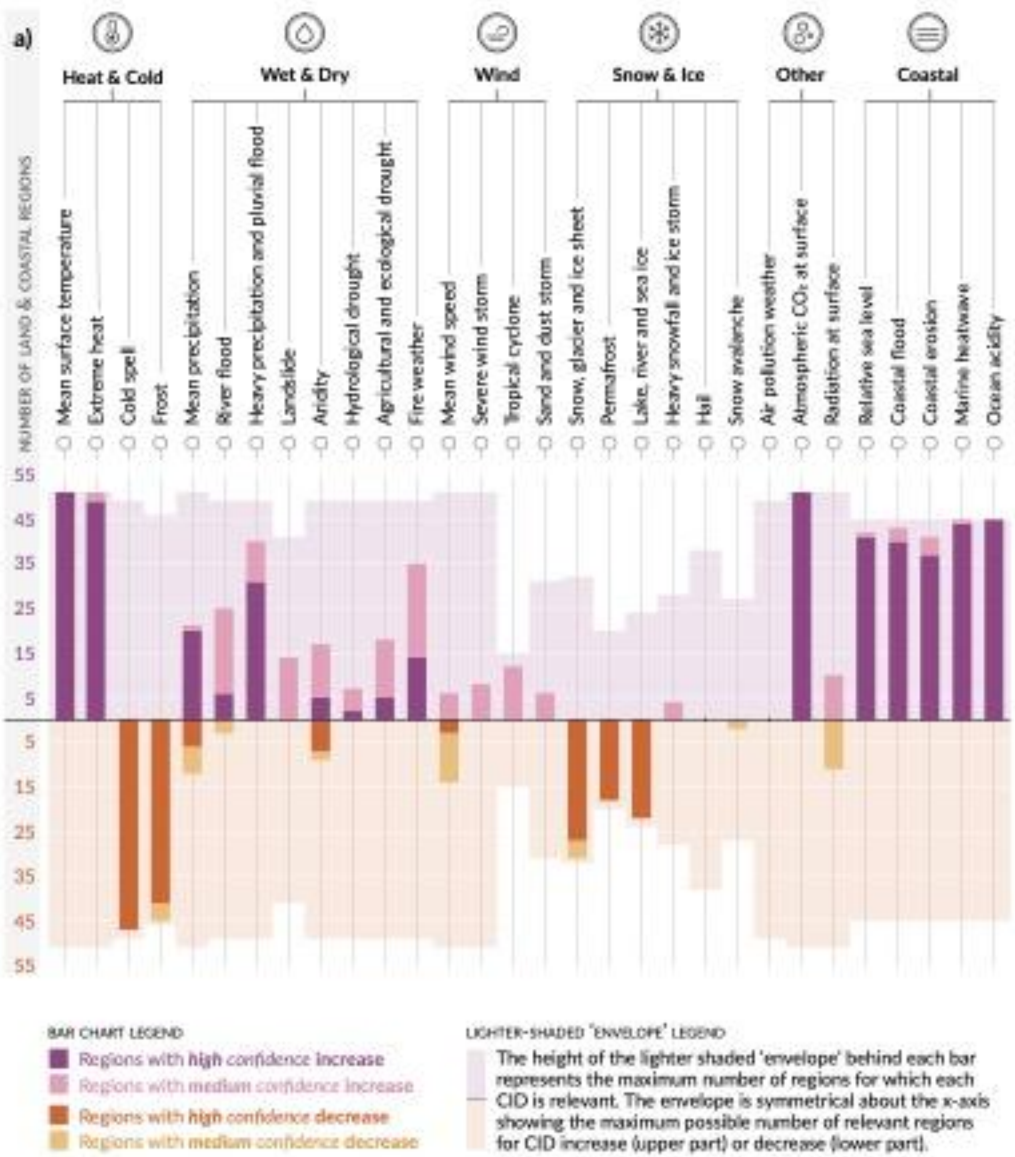
CIDs and their changes can be detrimental, beneficial, neutral, or a mixture of each across interacting system elements and regions.

[…]

All regions are projected to experience changes in at least 5 CIDs. Almost all (96%) are projected to experience changes in at least 10 CIDs and half in a least 15 CIDs.

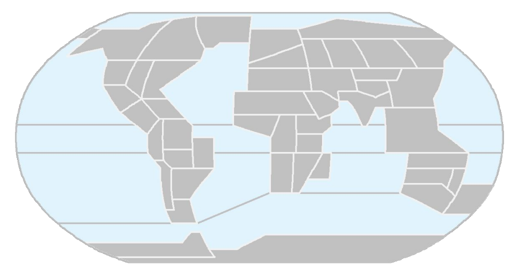
[…]

For many CIDs there is wide geographical variation in where they change and so each region are projected to experience a specific set of CID changes.



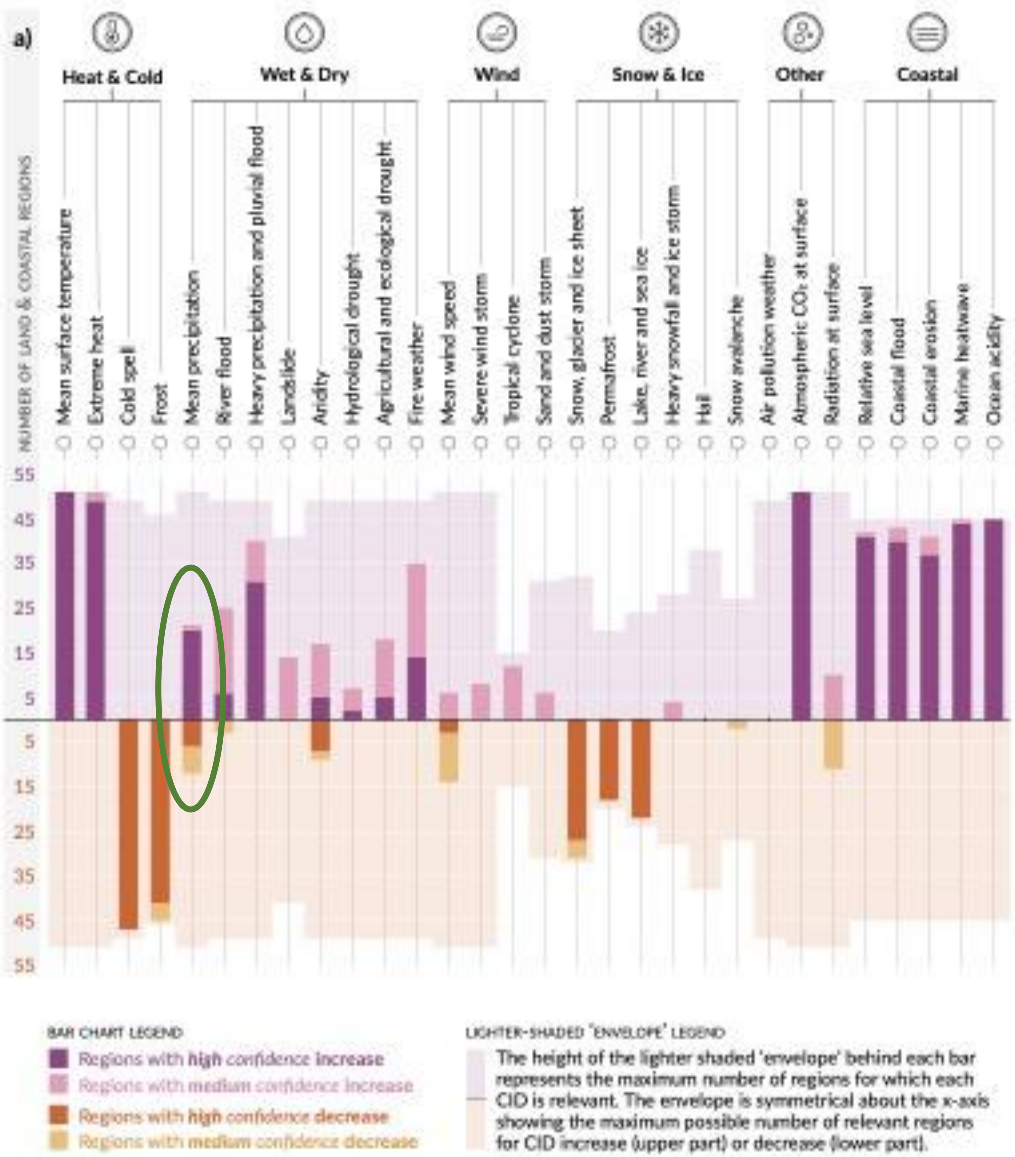
For each CID the figure shows the number of region that are expected to experience changes in that CID.

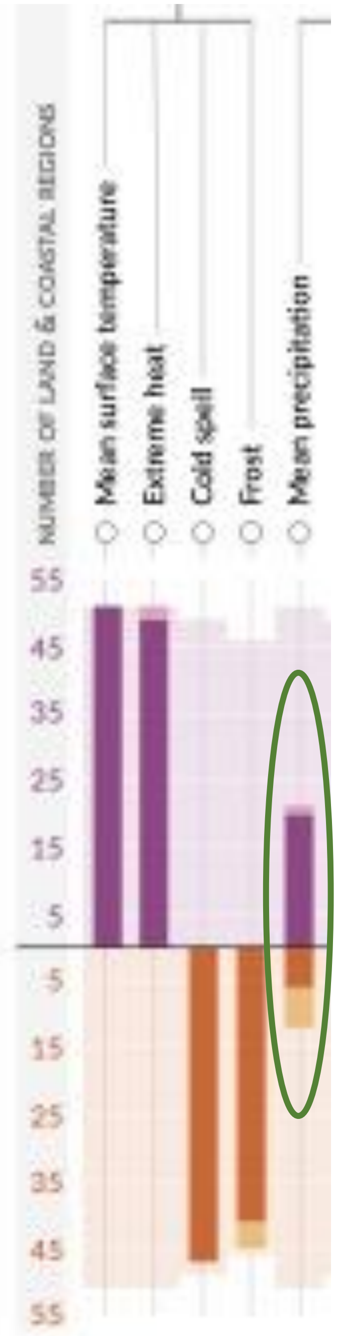
Each bar in the chart represents a specific geographical set of changes that can be explored in the WGI Interactive Atlas.



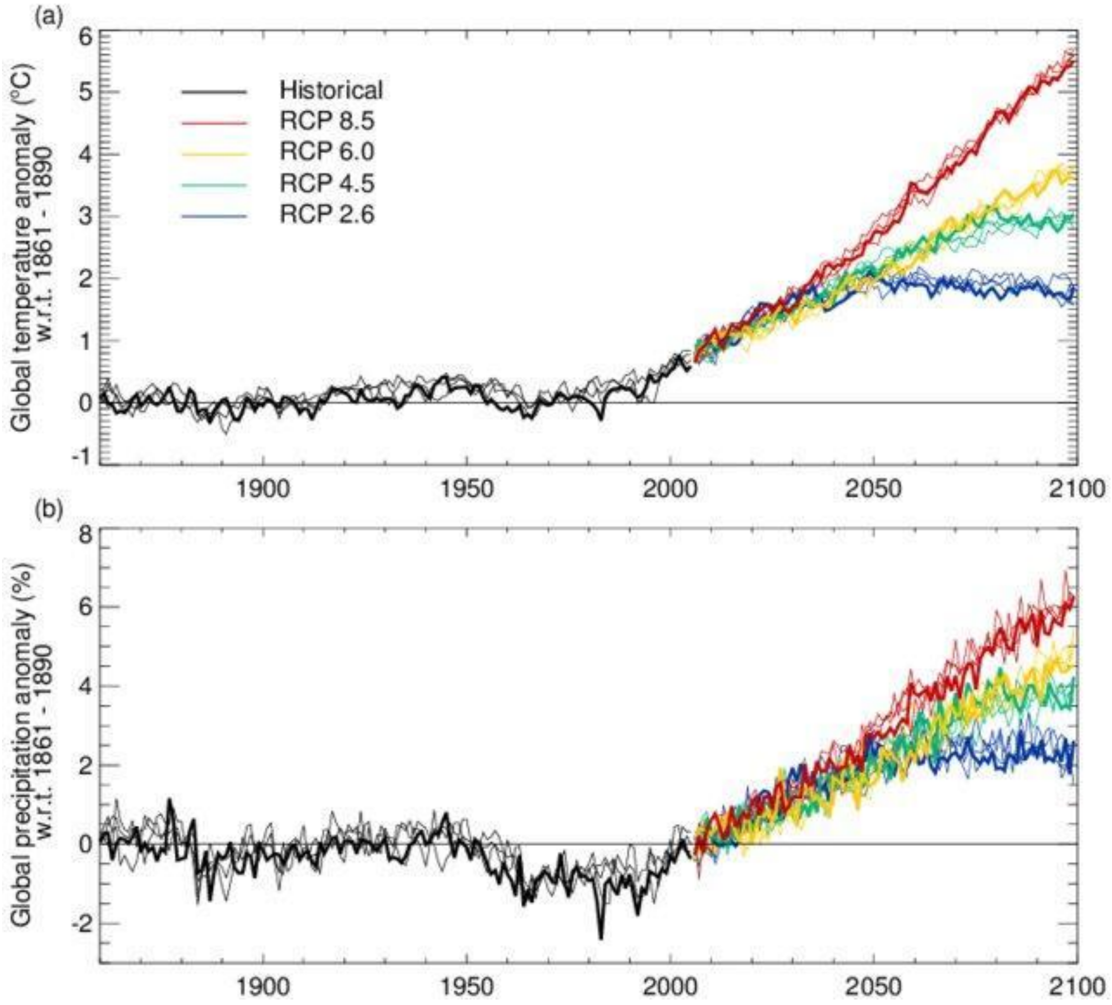
interactive-atlas.ipcc.ch

Number of land & coastal regions (a) and **open-ocean regions** (b) where each **climatic impact-driver** (CID) is projected to increase or decrease with **high** confidence (dark shade) or **medium** confidence (light shade)


a)
Heat & Cold
Wet & Dry
Wind
Snow & Ice
Other
Coastal
NUMBER OF LAND & COASTAL REGIONS
Mean surface temperature
Extreme heat
Cold spell
Frost
Mean precipitation
River flood
Heavy precipitation and pluvial flood
Landslide
Aridity
Hydrological drought
Agricultural and ecological drought
Fire weather
Mean wind speed
Severe wind storm
Tropical cyclone
Sand and dust storm
Snow, glacier and ice sheet
Permafrost
Lake, river and sea ice
Heavy snowfall and ice storm
Hail
Snow avalanche
Air pollution weather
Atmospheric CO_2 at surface
Radiation at surface
Relative sea level
Coastal flood
Coastal erosion
Marine heatwave
Ocean acidity
55
45
35
25
15
5
5
15
25
35
45
55
BAR CHART LEGEND
Regions with **high** confidence **increase**
Regions with **medium** confidence **increase**
Regions with **high** confidence **decrease**
Regions with **medium** confidence **decrease**
LIGHTER-SHADED 'ENVELOPE' LEGEND
The height of the lighter shaded 'envelope' behind each bar represents the maximum number of regions for which each CID is relevant. The envelope is symmetrical about the x-axis showing the maximum possible number of relevant regions for CID increase (upper part) or decrease (lower part).


NUMBER OF LAND & COASTAL REGIONS
Mean surface temperature
Extreme heat
Cold spell
Frost
Mean precipitation
55
45
35
25
15
5
5
15
25
35
45
55

What happens to global mean precipitation?

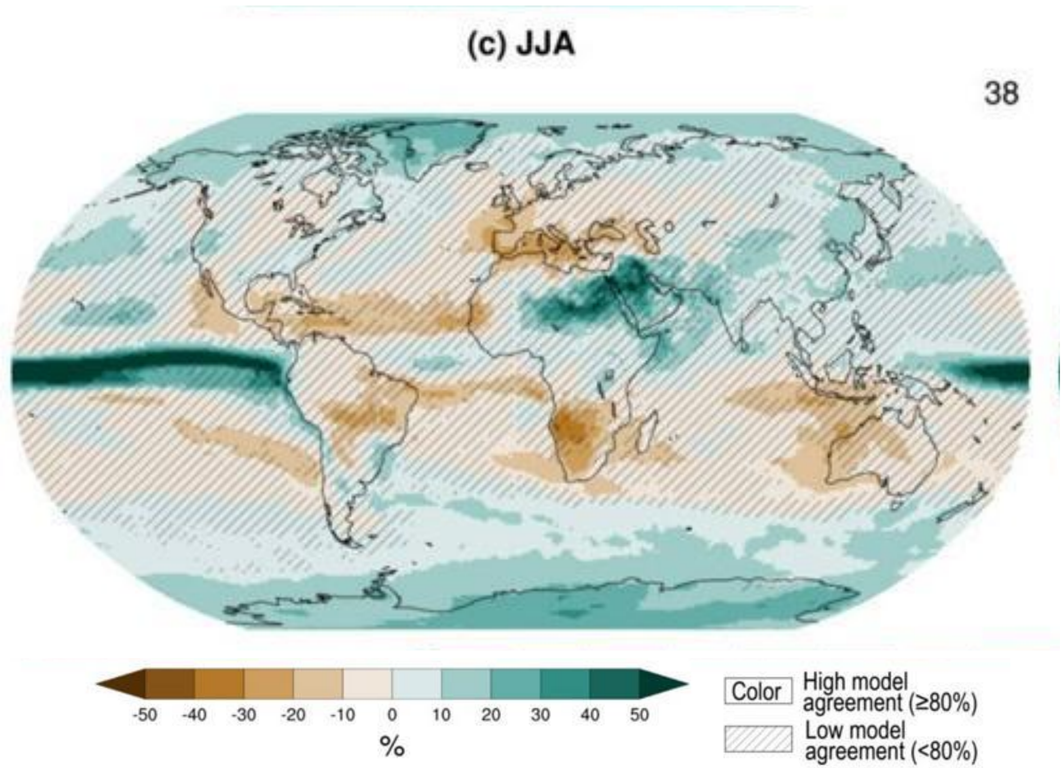


A warmer atmosphere can hold more water (Clausius-Clapeyron) with 1 °C of warming corresponding roughly to an increase of atmospheric water content about 7%.
This is one of the first robust scientific statements made about changes of the hydrological cycle.

Global mean precipitation increases at the rate of 1–3% per 1 °C of warming, governed also by changes in fluxes between atmosphere and surface.

What happens to global mean precipitation?

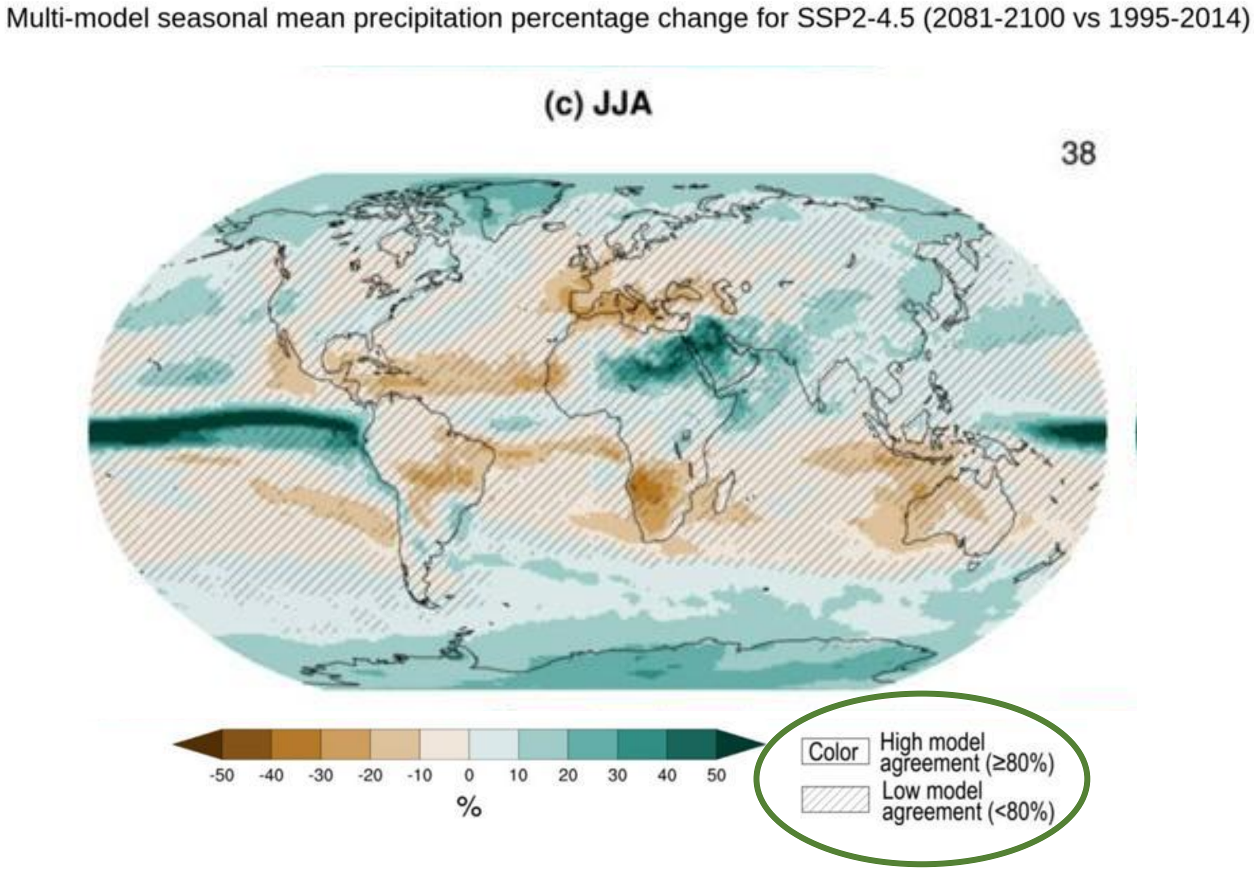
Multi-model seasonal mean precipitation percentage change for SSP2-4.5 (2081-2100 vs 1995-2014)



Regional changes involve more processes, including changes in the atmospheric circulation (expansion of the Hadley cell, storm track shifts, ...).

This leads to drying in certain regions and wetting beyond the global rate in others.

What happens to global mean precipitation?



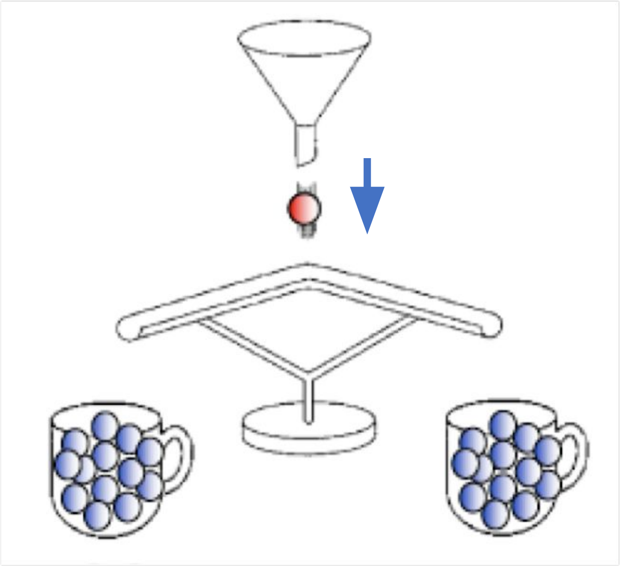
Regional changes involve more processes, including changes in the atmospheric circulation (expansion of the Hadley cell, storm track shifts, ...).

This leads to drying in certain regions and wetting beyond the global rate in others.

But this also introduces uncertainties in the problem

Source of uncertainty: stochastic

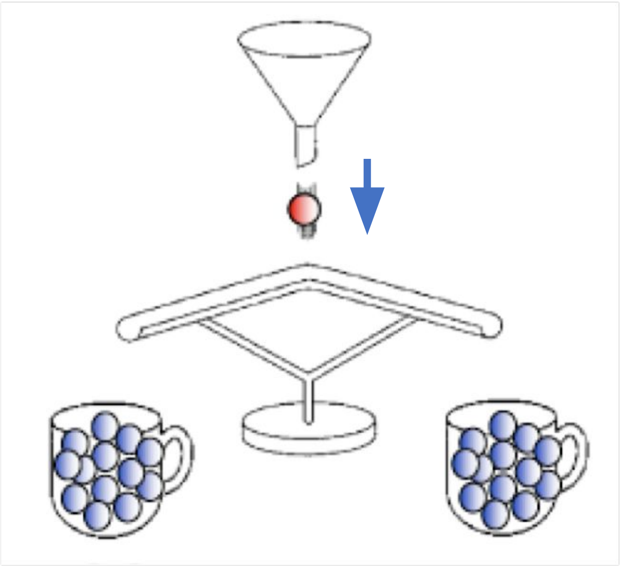
Analogy of a Weather forecast



Rain No Rain

Source of uncertainty: stochastic

Analogy of a Weather forecast



Rain

No Rain

We can predict the future state of atmospheric weather by knowing the initial conditions (position and velocity of the red ball)

And by knowing the physical laws that govern the system (in this case gravity and the double channel)

Doomed to fail beyond a couple of weeks ahead in time

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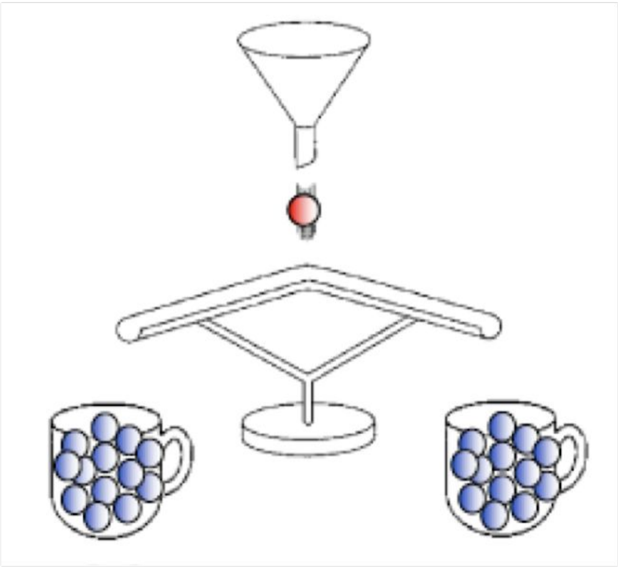
Source of uncertainty: stochastic

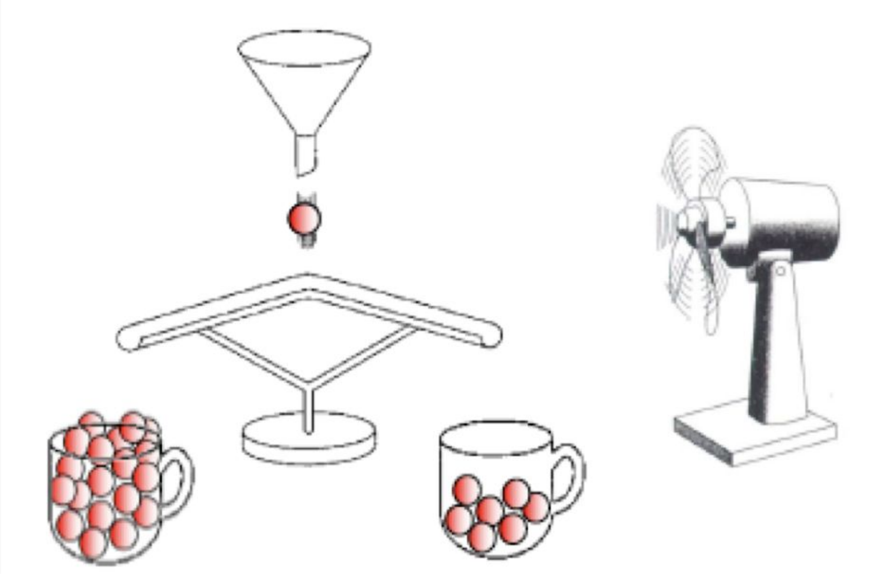
Weather forecast



Rain

No Rain

Climate projection



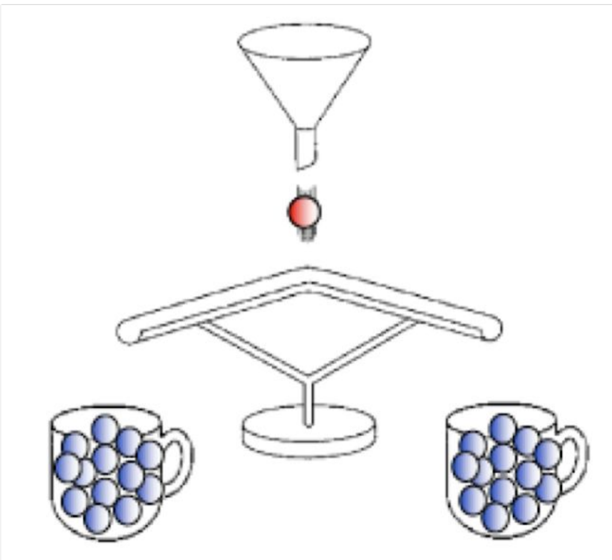
Rain

No Rain

In climate projections we exploit a deterministic forcing (the fan in our example) and try to understand how the statistics of weather will be under such an external forcing.

Source of uncertainty: stochastic

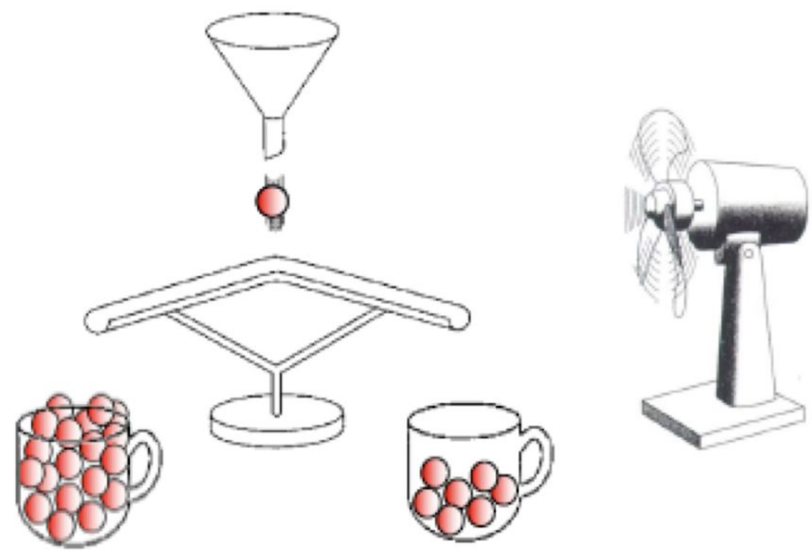
Weather forecast



Rain

No Rain

Climate projection



Rain

No Rain

Scientific questions about future weather events (including extremes) are intrinsically probabilistic.
Not all statements about climate change are probabilistic but the probabilistic nature of the problem is particularly relevant for future weather extremes.

Imperfect models

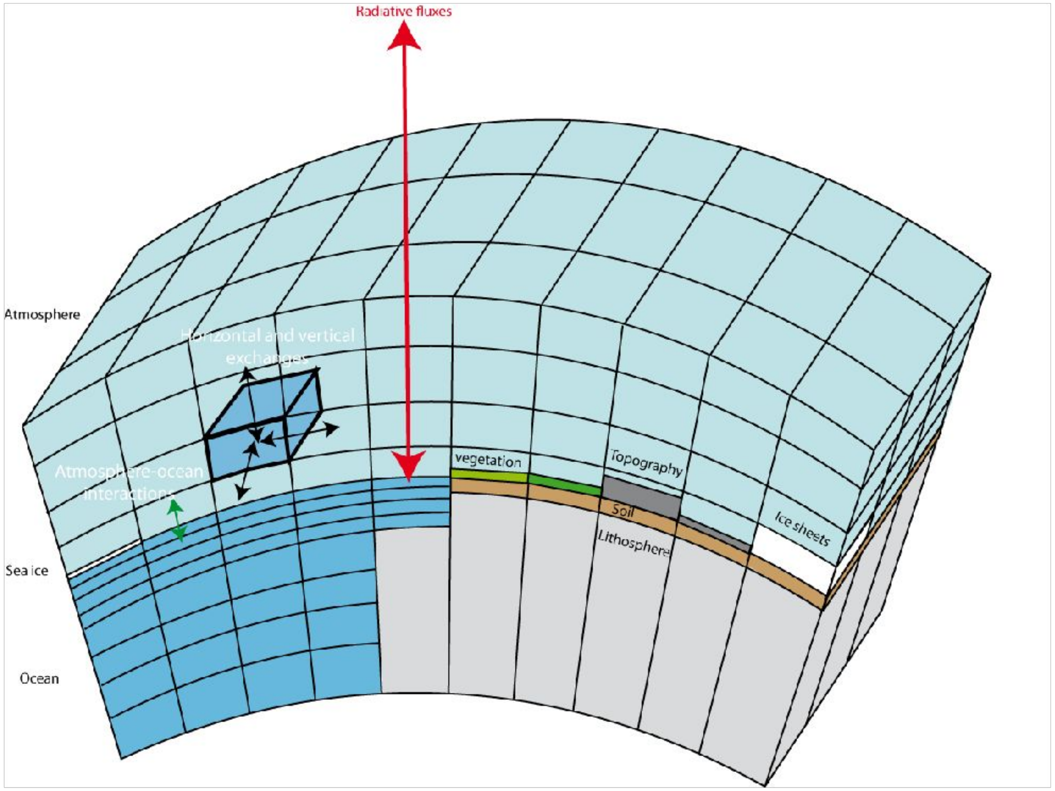


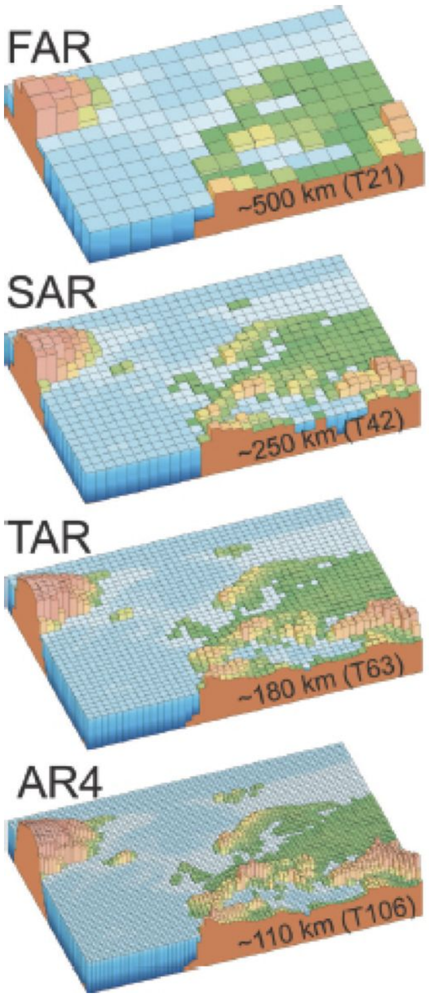
Figure 3.5: A simplified representation of part of the domain of a general circulation model, illustrating some important components and processes. For clarity, the curvature of the Earth has been amplified, the horizontal and vertical coordinates are not to scale and the number of grid points has been reduced compared to state-of-the-art models.

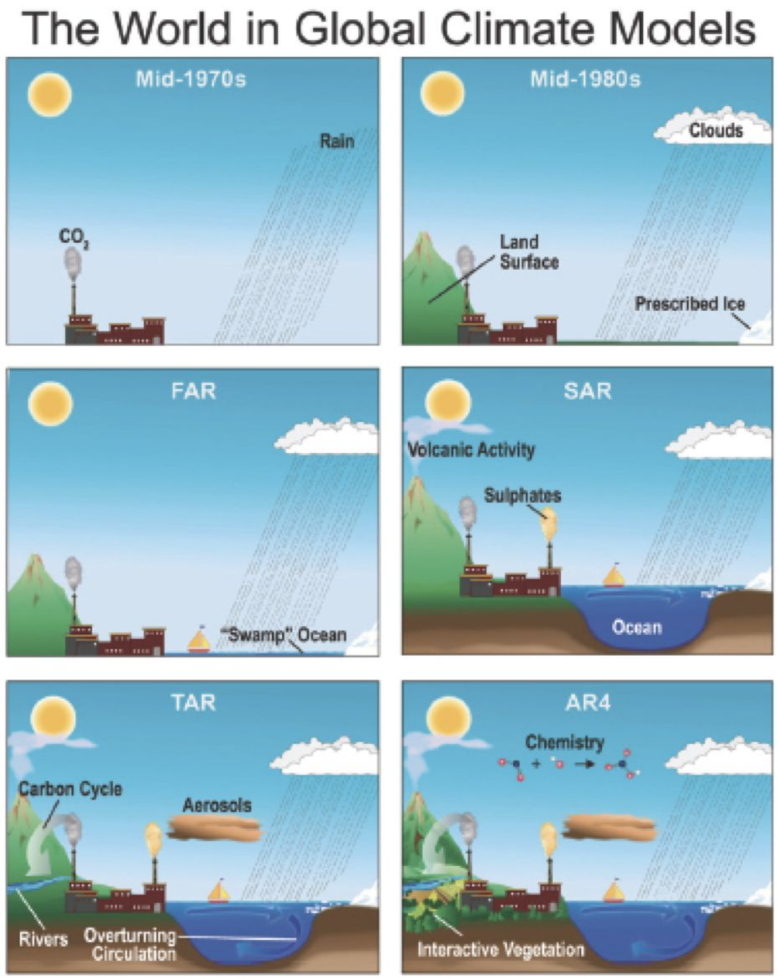
Our knowledge on future climate is based mostly on General Circulation Models

This is formally an attempt to solve 'an effectively infinite-dimensional non-linear system'* with an arbitrary finite truncation

*Palmer T. N.2016A personal perspective on modelling the climate systemProc. R. Soc. A.**472**2015077220150772

Source of uncertainty: epistemic





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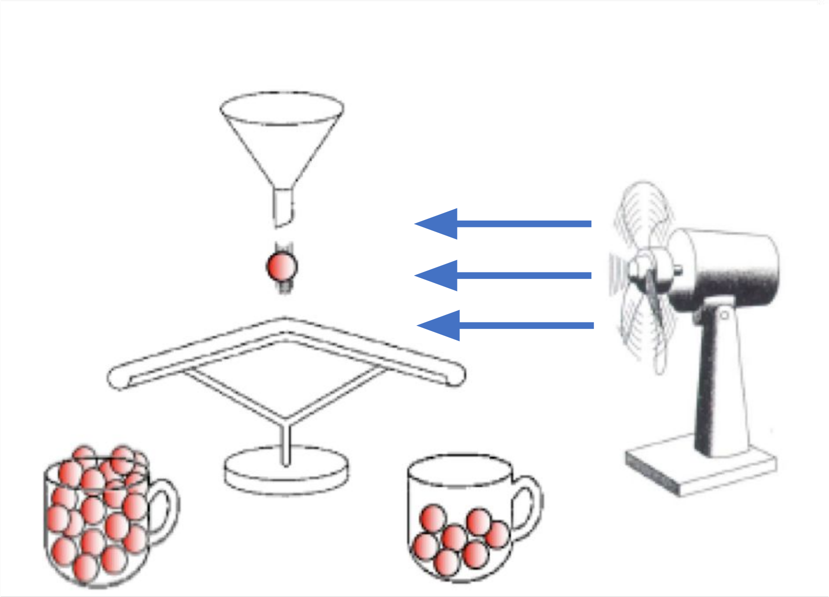
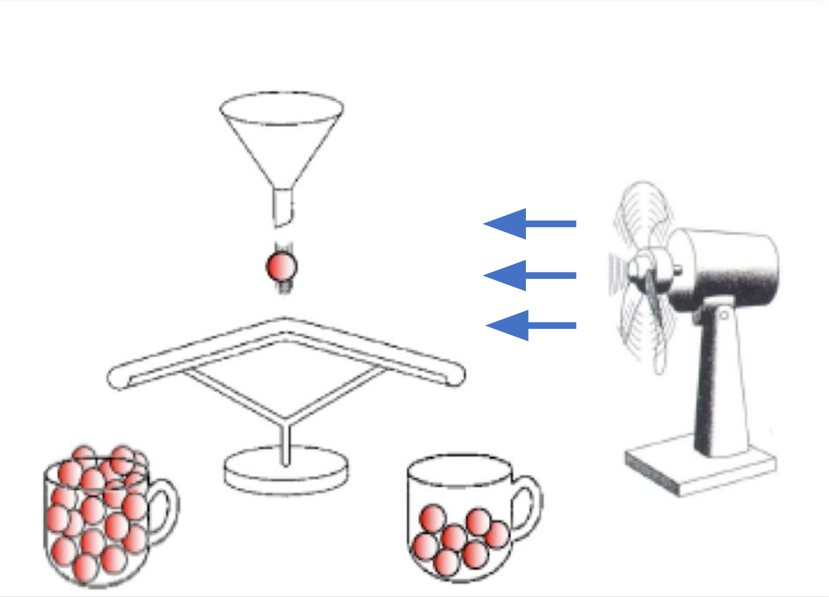
Source of uncertainty: scenario





The radiative forcing depends on unpredictable socio-economic drivers.

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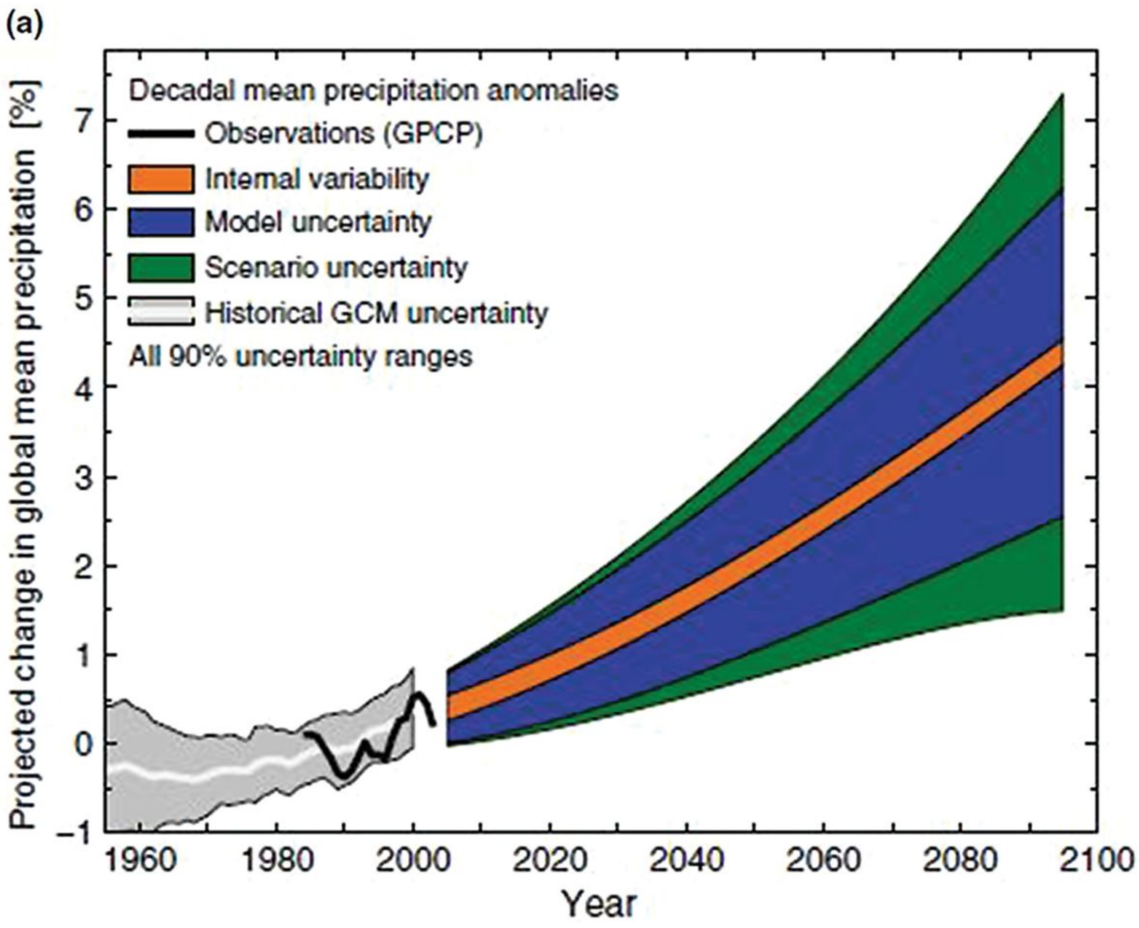
Uncertainty in climate projections



Intrinsic or internal
uncertainty
due to the stochastic nature of the problem

Epistemic or model
uncertainty
due to imperfect knowledge of the system

Scenario uncertainty
due to socio-economic pathways with unknown probability

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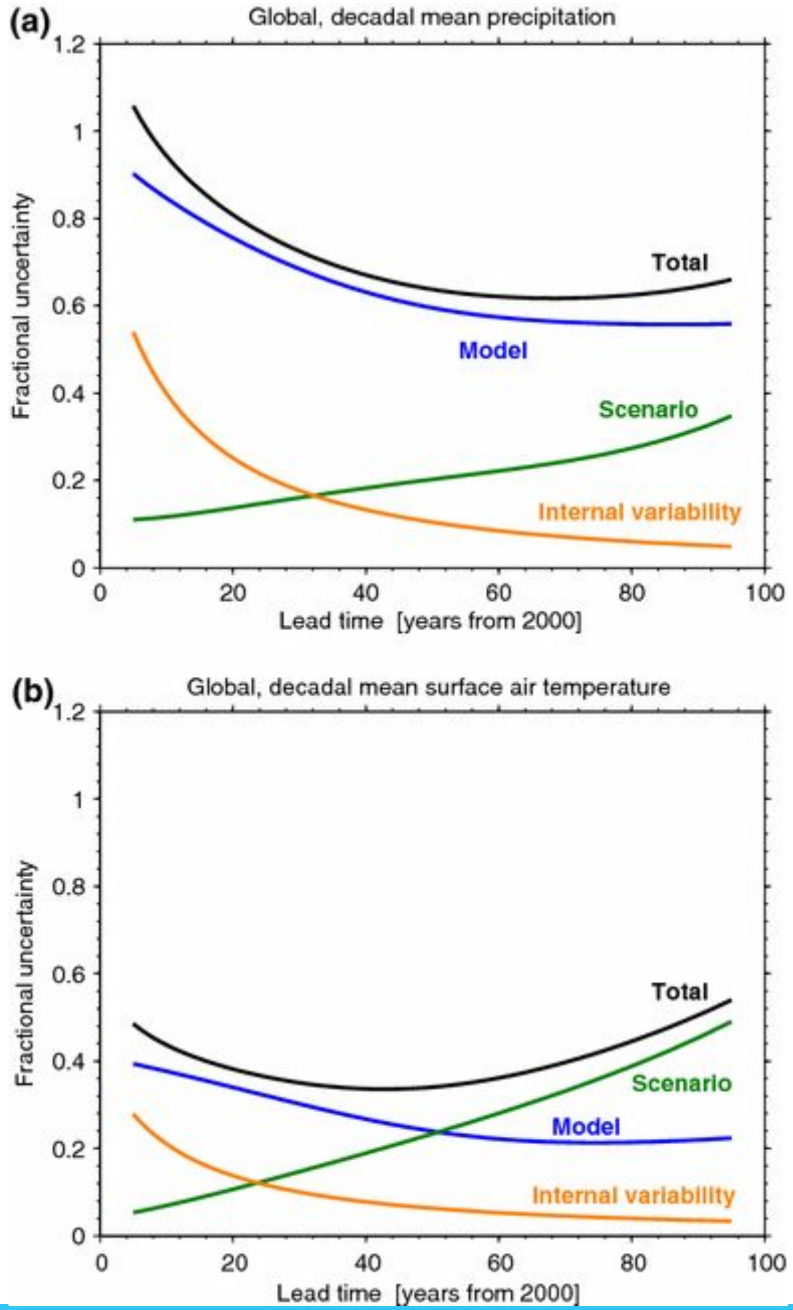
Noise-to-signal Ratio

(Uncertainty divided by Expected change)



Intrinsic or internal uncertainty *due to the stochastic nature of the problem*

Epistemic or model uncertainty due to imperfect knowledge of the system

Scenario uncertainty due to socio-economic pathways with unknown probability

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Uncertainty in climate projections

Uncertainty in climate sensitivity

+

Uncertainty in response of the General Circulation of Atmosphere and ocean

+

…

Intrinsic or internal uncertainty *due to the stochastic nature of the problem*

Epistemic or model uncertainty due to imperfect knowledge of the system

Scenario uncertainty due to socio-economic pathways with unknown probability

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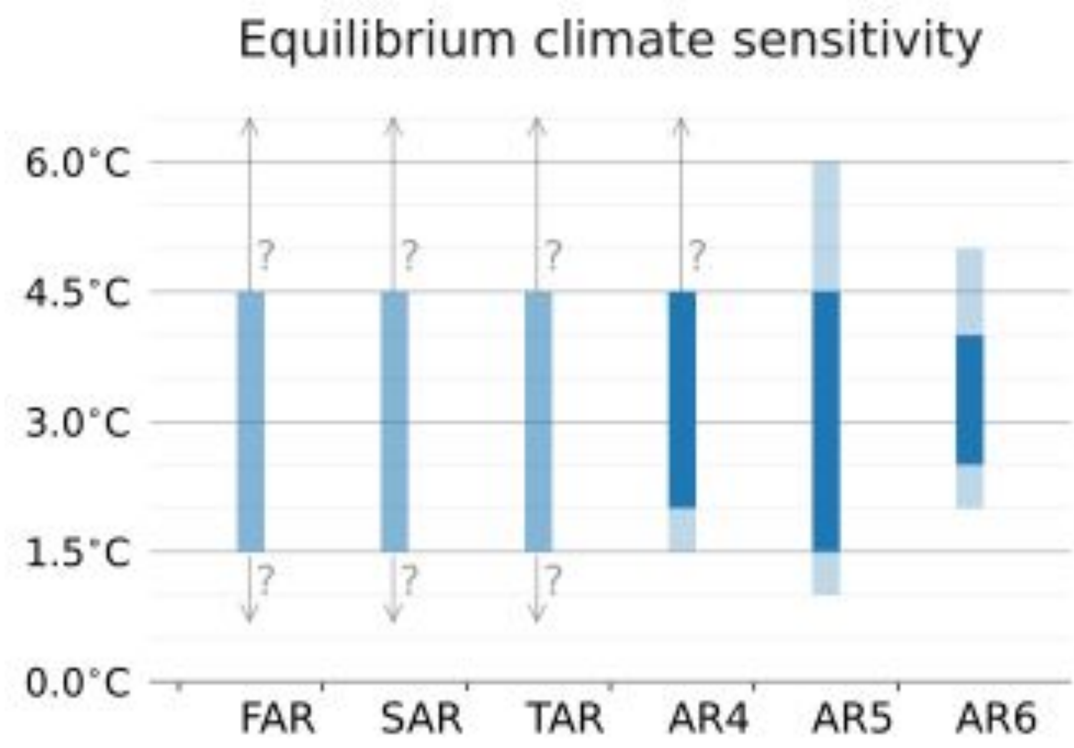
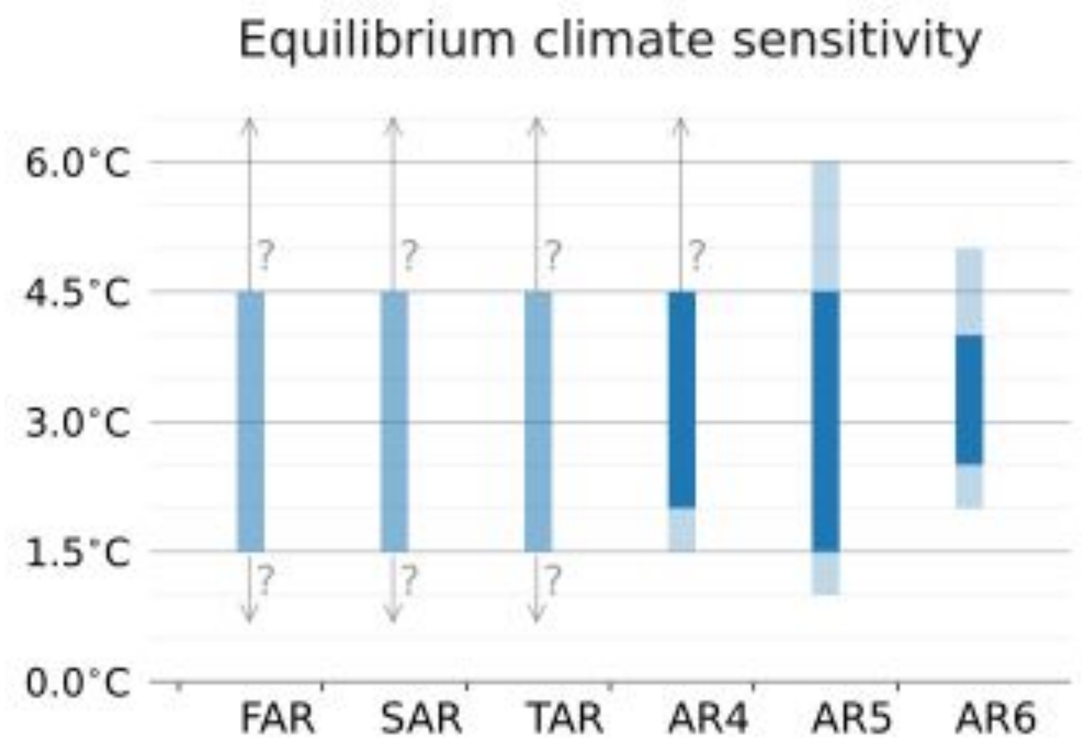
Uncertainty in climate sensitivity



Still large uncertainty on climate sensitivity (how fast the planet warms given a certain radiative forcing) after decades of scientific assessments

Global warming level



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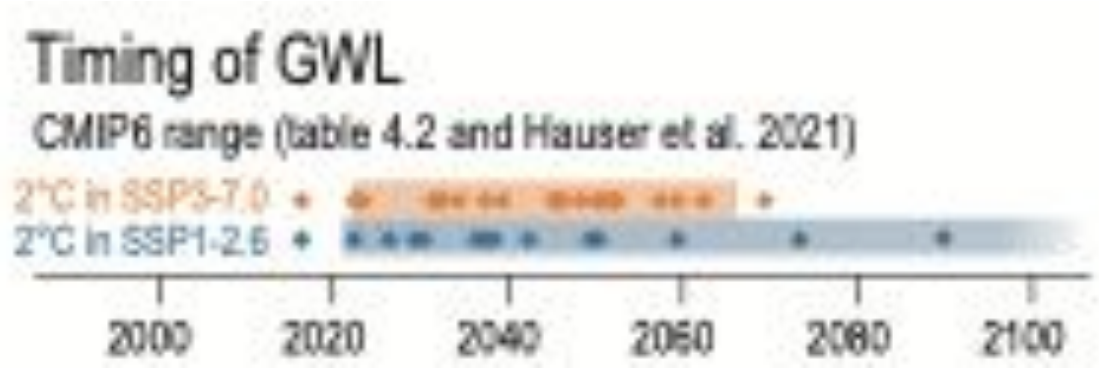
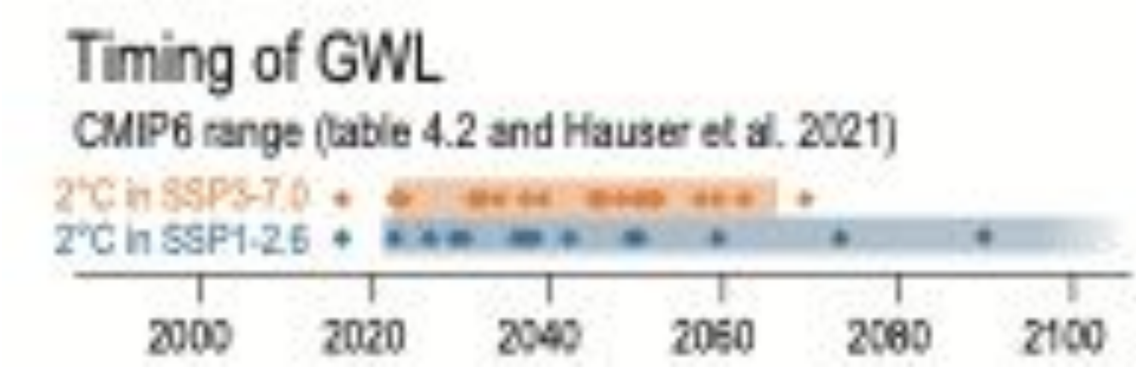
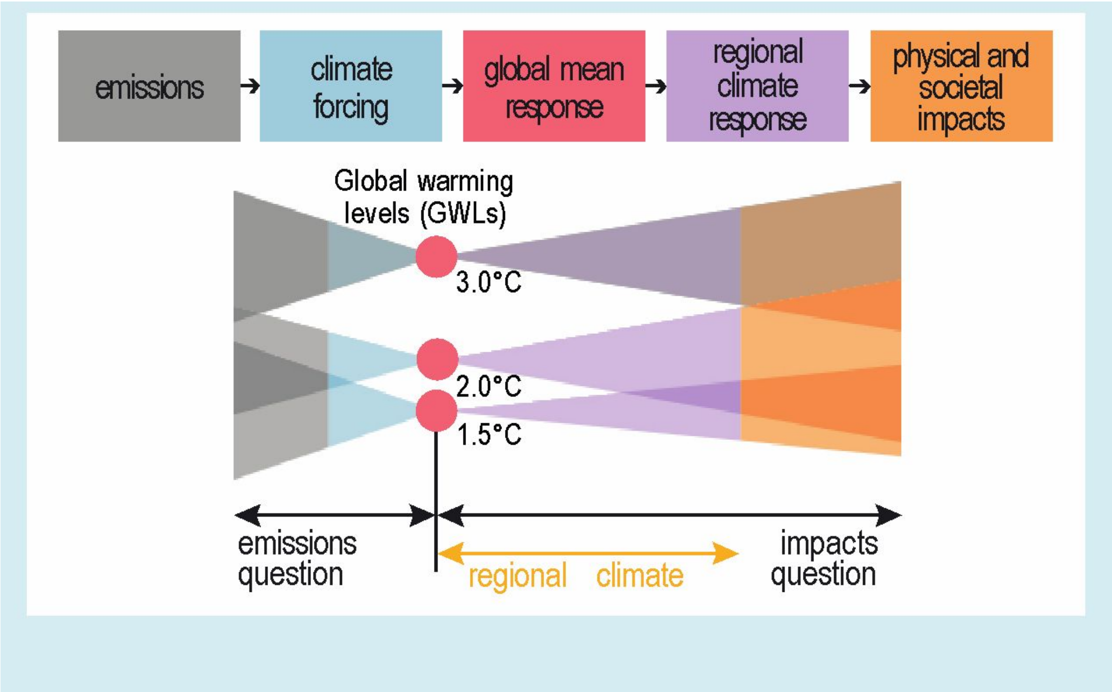


That translates into uncertainty in the timing of global warming level.

Global warming level





Split response of weather extremes into:
-the transient global warming response to scenarios
- the regional response as function of a given GWL, (regional climate sensitivity)

Became popular after Paris Agreement

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Impact of CC on extreme events

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WG – I
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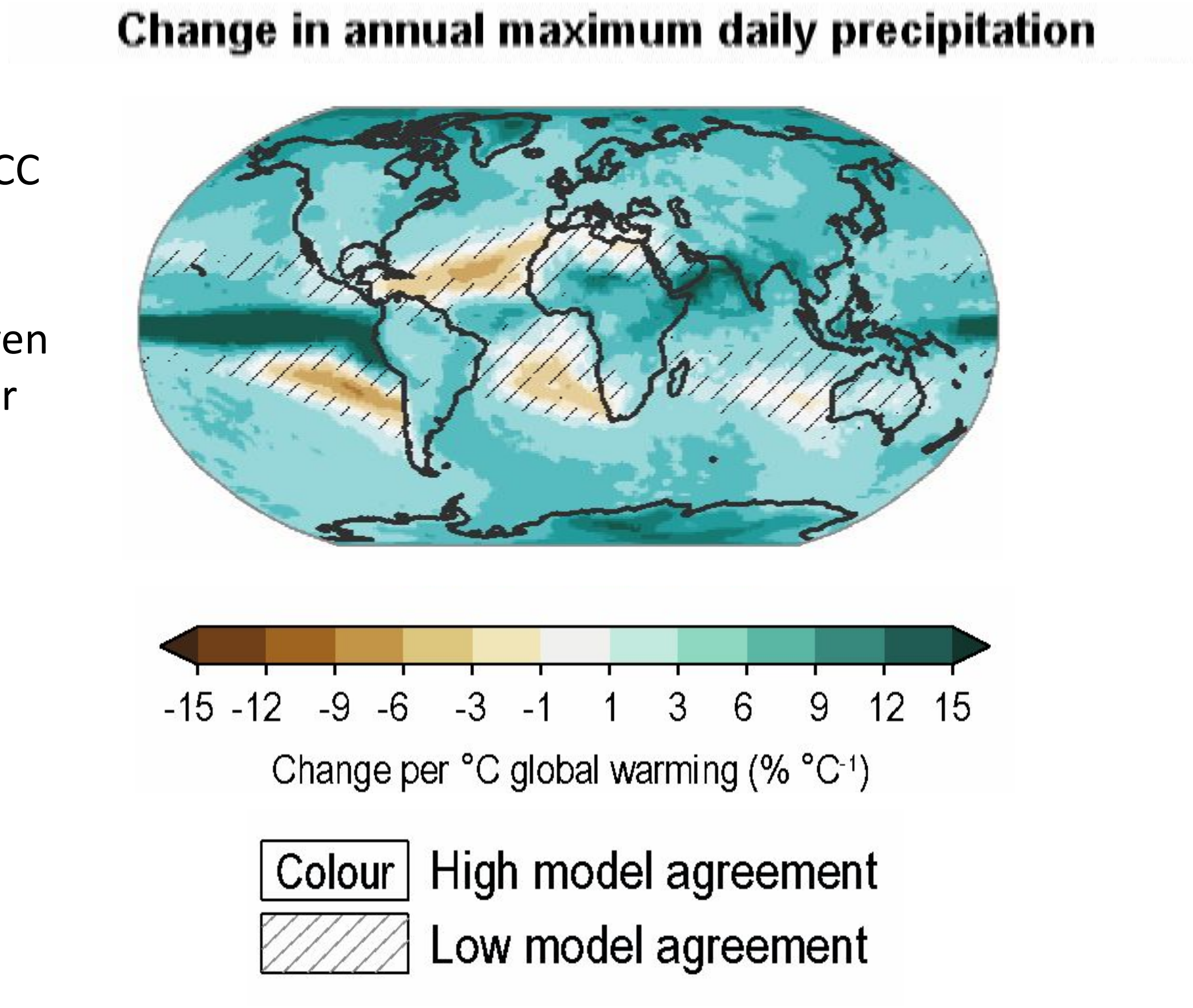
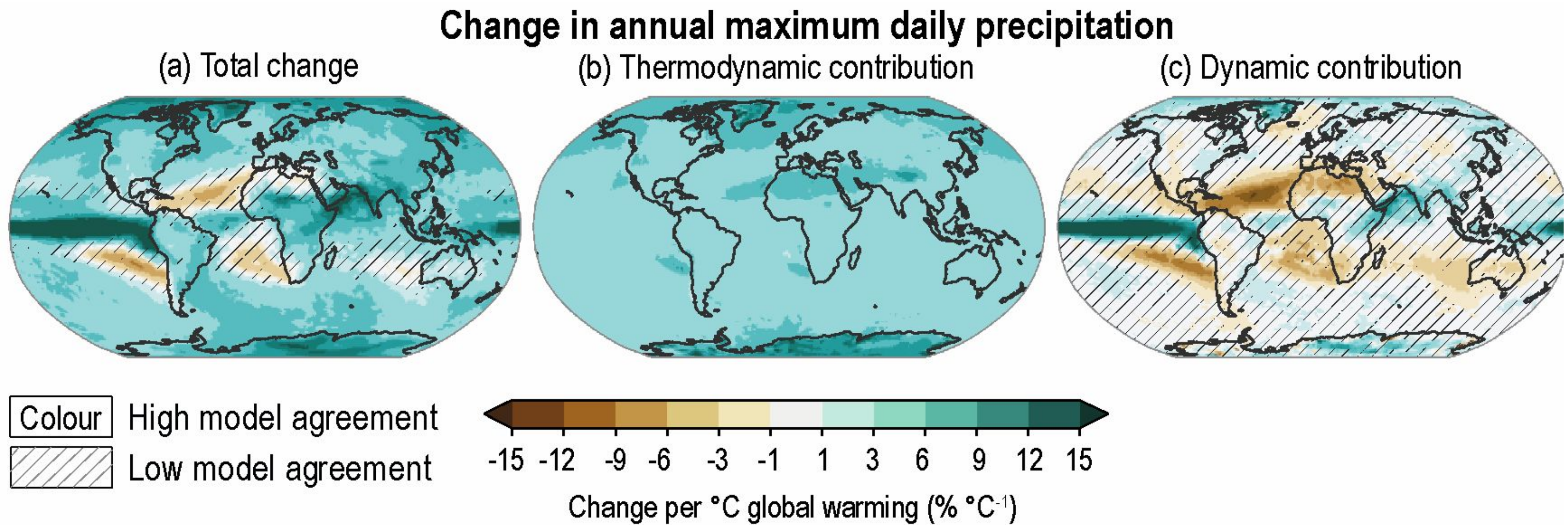


Dynamic and thermodynamics effects of CC on extreme events



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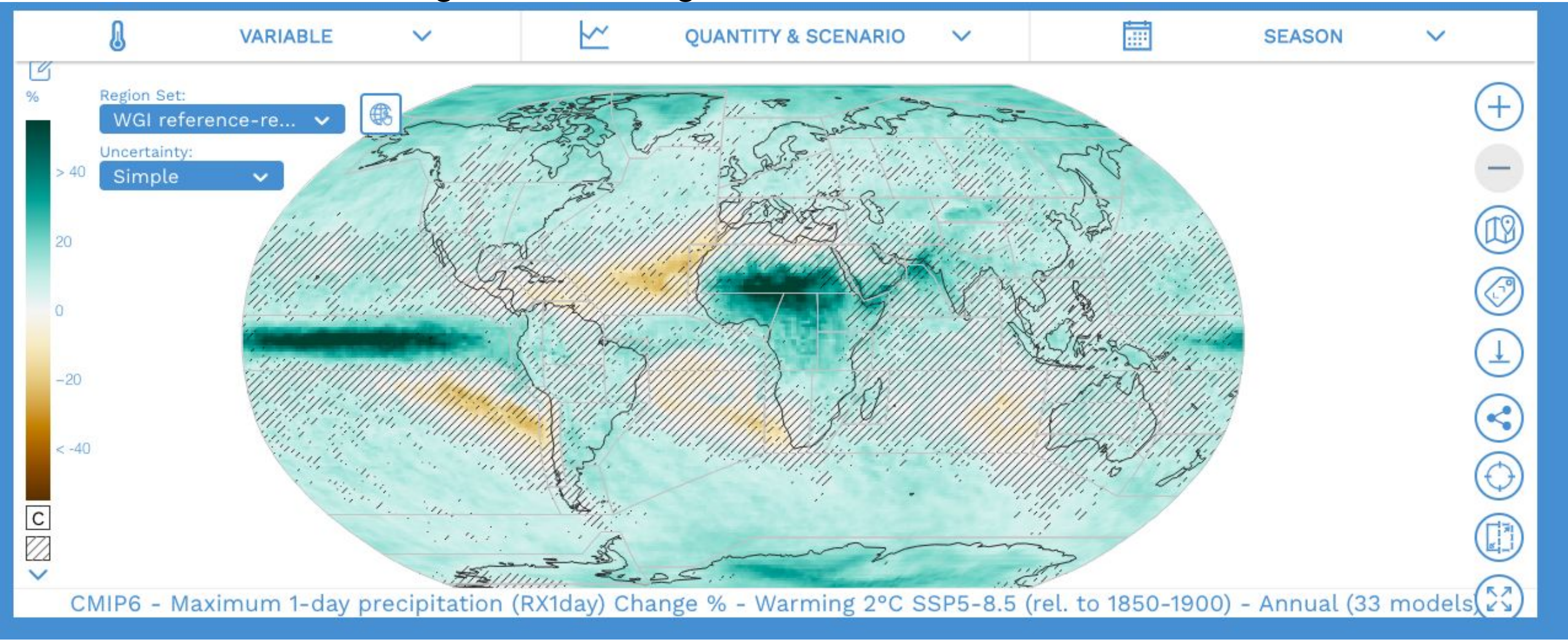
IPCC ATLAS

You can explore our current modelling estimates of climatic impact drivers
in scenarios and global warming levels in the IPCC Atlas



Likelihood and confidence

Table 11.2 | Synthesis table on projected changes in extremes. Note that projected changes in marine extremes are assessed in Chapter 9 and Cross-Chapter Box 9.1 (marine heatwaves). Assessments are provided compared to pre-industrial conditions.

Phenomenon and Direction of Trend	Projected Changes at +1.5°C Global Warming	Projected Changes at +2°C Global Warming	Projected Changes at +4°C Global Warming
Warmer and/or more frequent hot days and nights over most land areas Warmer and/or fewer cold days and nights over most land areas Warm spells/heatwaves; increases in frequency or intensity over most land areas Cold spells/cold waves: decreases in frequency or intensity over most land areas	*Virtually certain* on global scale *Extremely likely* on all continents Highest increase of temperature of hottest days is projected in some mid-latitude and semi-arid regions, and the South American Monsoon region, at about 1.5 times to twice the rate of global warming (*high confidence*) {11.3, Figure 11.3} Highest increase of temperature of coldest days is projected in Arctic regions, at about three times the rate of global warming (*high confidence*) {11.3} **Continental-scale projections:** *Extremely likely*: Africa, Asia, Australasia, Central and South America, Europe, North America {11.3, 11.9}	*Virtually certain* on global scale *Virtually certain* on all continents Highest increase of temperature of hottest days is projected in some mid-latitude and semi-arid regions, and the South American Monsoon region, at about 1.5 times to twice the rate of global warming (*high confidence*) {11.3, Figure 11.3} Highest increase of temperature of coldest days is projected in Arctic regions, at about three times the rate of global warming (*high confidence*) {11.3} **Continental-scale projections:** *Virtually certain:* Africa, Asia, Australasia, Central and South America, Europe, North America {11.3, 11.9}	*Virtually certain* on global scale *Virtually certain* on all continents Highest increase of temperature of hottest days is projected in some mid-latitude and semi-arid regions, and the South American Monsoon region, at about 1.5 times to twice the rate of global warming (*high confidence*) {11.3, Figure 11.3} Highest increase of temperature of coldest days is projected in Arctic regions, at about three times the rate of global warming (*high confidence*) {11.3} **Continental-scale projections:** *Virtually certain:* Africa, Asia, Australasia, Central and South America, Europe, North America {11.3, 11.9}
Heavy precipitation events: increase in the frequency, intensity, and/or amount of heavy precipitation	*High confidence* that increases take place in most land regions {11.4} *Very likely:* Asia, North America *Likely:* Africa, Europe *High confidence:* Central and South America *Medium confidence:* Australasia {11.4, 11.9}	*Likely* that increases take place in most land regions {11.4} *Extremely likely:* Asia, North America *Very likely:* Africa, Europe *Likely:* Australasia, Central and South America {11.4, 11.9}	*Very likely* that increases take place in most land regions {11.4} *Virtually certain:* Africa, Asia, North America *Extremely likely:* Central and South America, Europe *Very likely* Australasia {11.4, 11.9}

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Mediterranean (MED)

- Observed increase in hydrological and agricultural and ecological droughts (*medium confidence*), projected increase in aridity and fire weather conditions at global warming of 2°C and above (*high confidence*).
- Projected combination of climatic impact-driver changes (warming, temperature extremes, increase in droughts and aridity, precipitation decrease, increase in fire weather, mean and extreme sea levels, snow cover decrease, and wind speed decrease) by mid-century and at global warming of at least 2°C and above (*high confidence*).

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Effects of CC on extreme events

Charney report
1979

now be reasonably well simulated. At present, we cannot simulate accurately the details of regional climate and thus cannot predict the locations and intensities of regional climate changes with confidence. This situation may be expected to improve gradually as greater scientific understanding is acquired and faster computers are built.

IPCC AR6
2021
Factsheets

Mediterranean (MED)

- Observed increase in hydrological and agricultural and ecological droughts (*medium confidence*), projected increase in aridity and fire weather conditions at global warming of 2°C and above (*high confidence*).
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Summary

Some physical observables associated with socio-economic impacts (Climatic Impact Drivers) are affected by CC, this includes extreme weather.

CC can impact the statistics of hydro-meteorological hazards via a combination of thermodynamic and dynamical processes (some are robustly understood, some are questioned and debated).

Changes of extremes are often affected by large uncertainty (stochastic, epistemic, scenario-related). For some CIDs the epistemic uncertainty dominates.
Global warming levels useful to split epistemic uncertainty.

Our current scientific understanding allows probabilistic statements on regional climate change and extremes.
We need information relevant at the local scale to land management and adaptation plans.

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Useful link

IPCC AR6 WG I Chapter eight on water cycle changes
https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter08.pdf

IPCC AR6 WG I Chapter eleven on extremes
https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter11.pdf

IPCC Atlas
https://interactive-atlas.ipcc.ch/

IPCC Regional Factsheets
https://www.ipcc.ch/report/ar6/wg1/resources/factsheets/

Uncertainty in climate projections
https://royalsocietypublishing.org/doi/full/10.1098/rsta.2011.016

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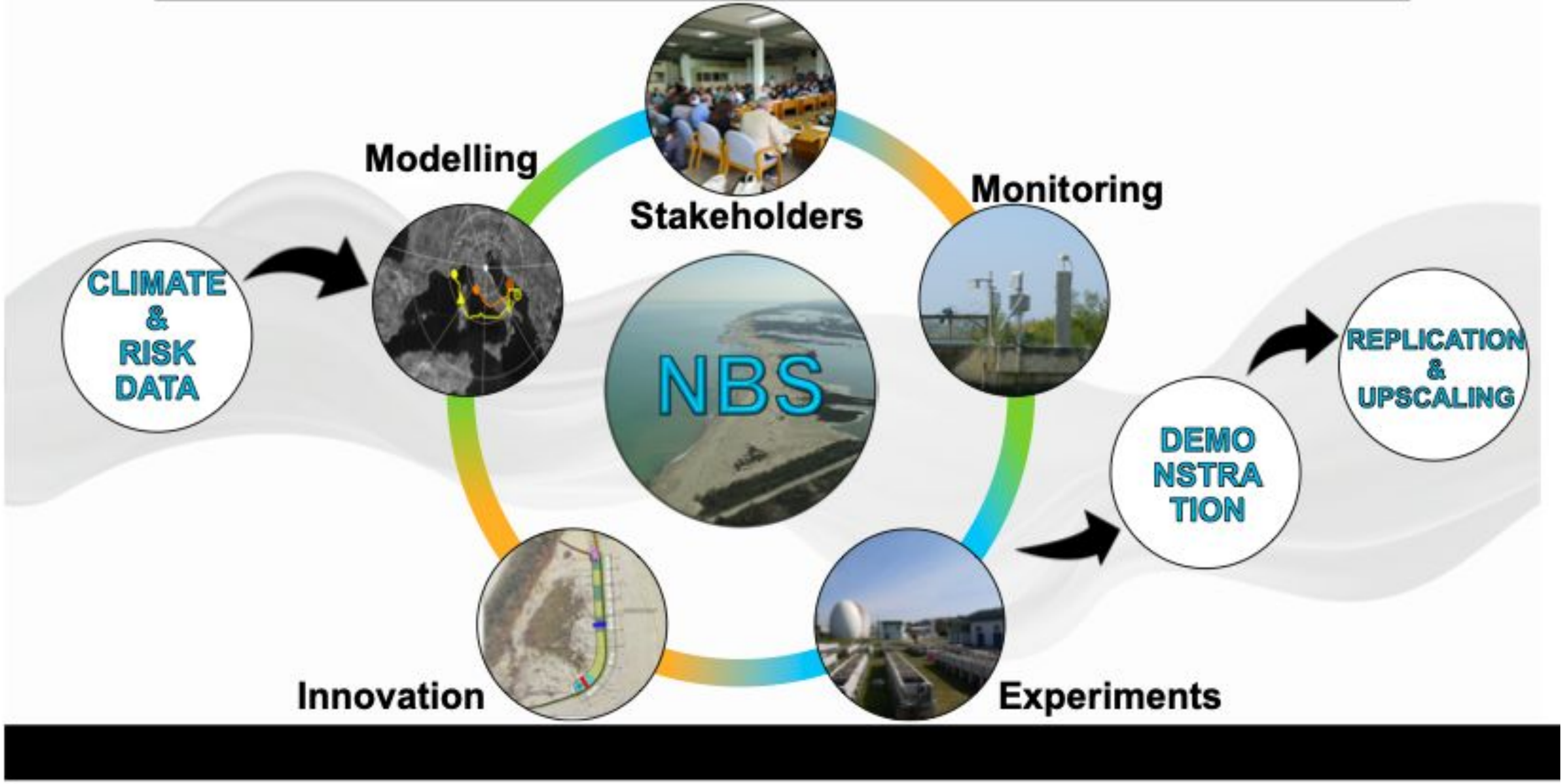
OPEN-AIR LABORATORY

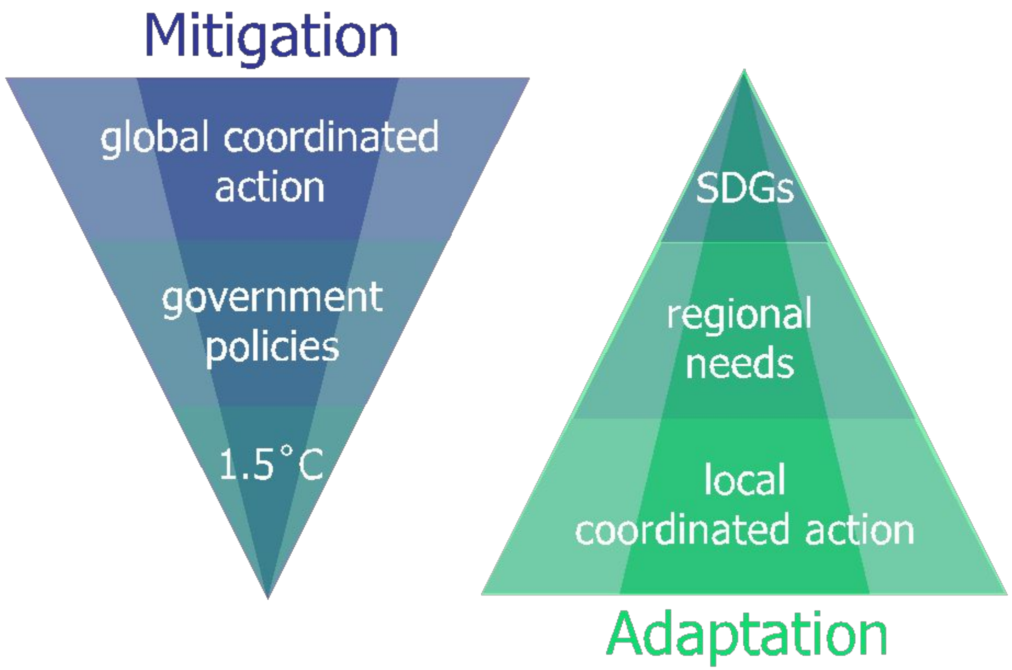


The Open-Air Laboratories (OALs) are ‘living labs’ where Nature-Based Solutions are **co-developed** and **demonstrated** with local stakeholders.
The OALs constitute an innovative approach to adaptation to climate change.

Coordinated climate research

The objective of the My Climate Risk Lighthouse Activity is to develop and mainstream a ‘bottom-up’ approach to regional climate risk, which starts from the decision context (and the decision scale) and enables relevant climate information to be brought into that context.

‘Lab’ approach to adaptation



‘The Activity will primarily use a case-study approach, in the form of labs (communities of practice), where labs are understood to be dynamic, exploratory, transdisciplinary environments, and not physical infrastructure’

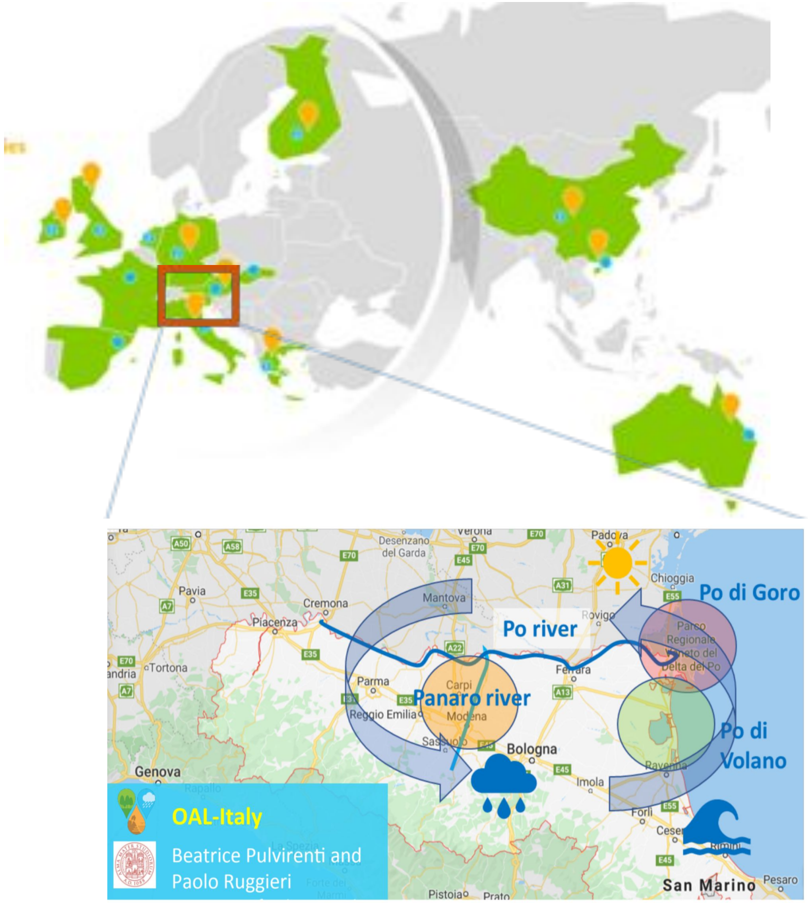
Fig. 1. Contrast between the “top-down” approach in climate-change science, which is needed for mitigation action, and the “bottom-up” approach needed for adaptation action.

Small is beautiful: climate-change science as if people mattered

Regina R. Rodrigues [a] and Theodore G. Shepherd[b]

EU funded project
GA no. 776848

The Open-Air Laboratory Italy



The 3 sites of the OAL-Italy

OAL-ITALY
IN NUMBERS

6 international partners

3 operational sites in real life environment

4 Nature-Based Solutions implemented, modeled and tested

10 monitoring, modelling and experimental initiatives

more than **40** among scientists and stakeholders involved

The operational sites

The Panaro Site

Target Hazards: River Flooding

NBS: Plantation of deep-rooted plants on the riverbank

The Po di Goro Site

Target Hazards: Salt wedge intrusion, drought

NBS: Plantation of halophytes plants

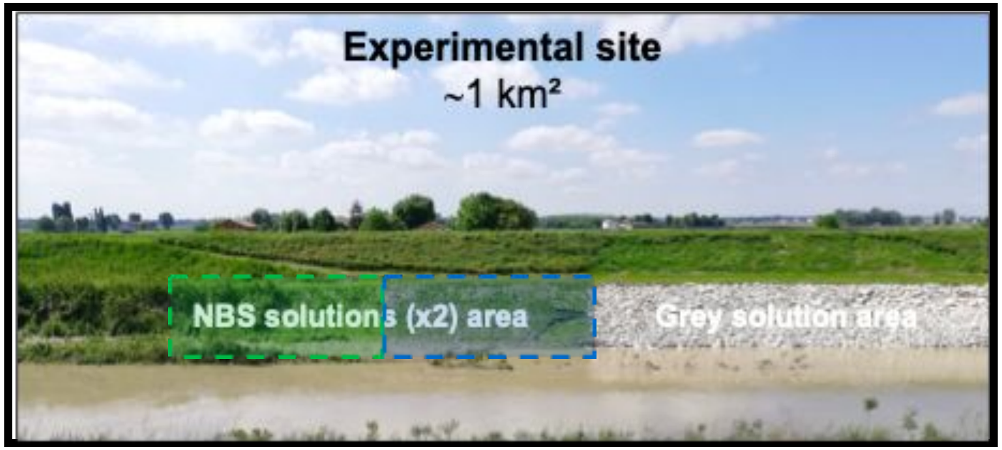
The Bellocchio/Volano Site

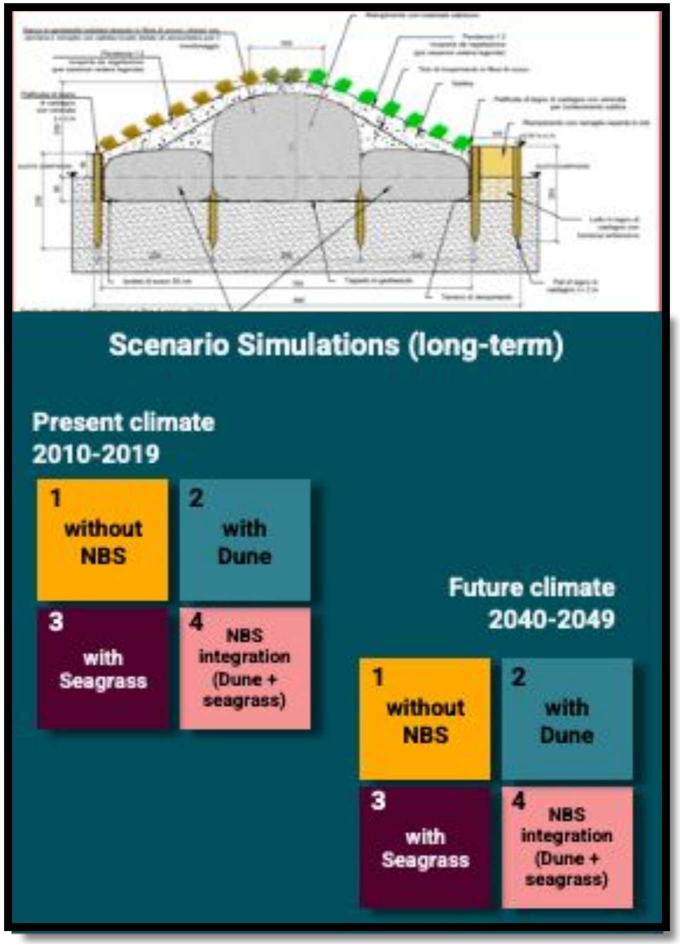
Target Hazards: Storm Surge and Costal Erosion

NBS: Artificial dune with natural material & seagrass

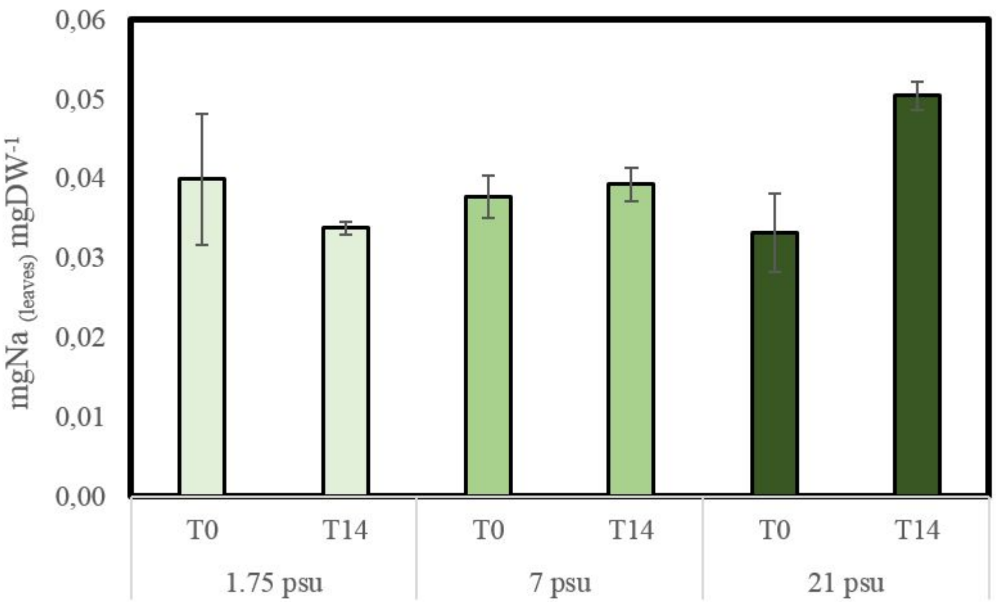
Highlights of the 4 NBS in OAL-Italy

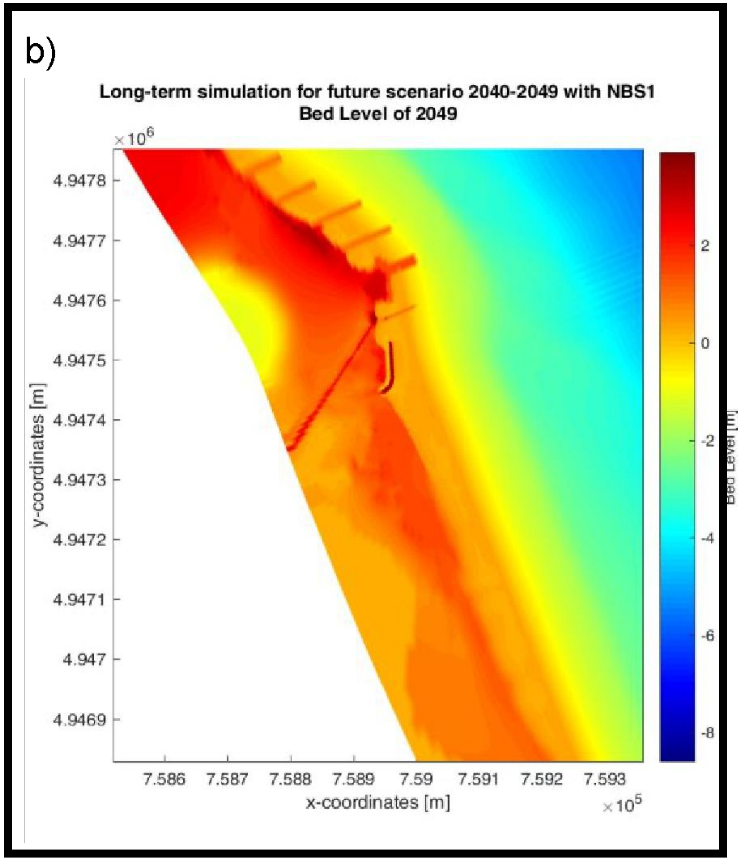
Urban River Lab (URL). Source: Naturalea

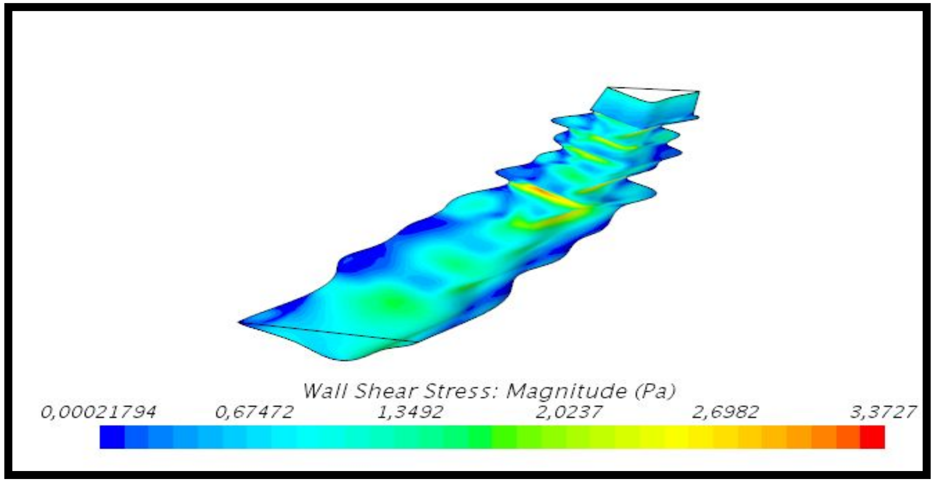




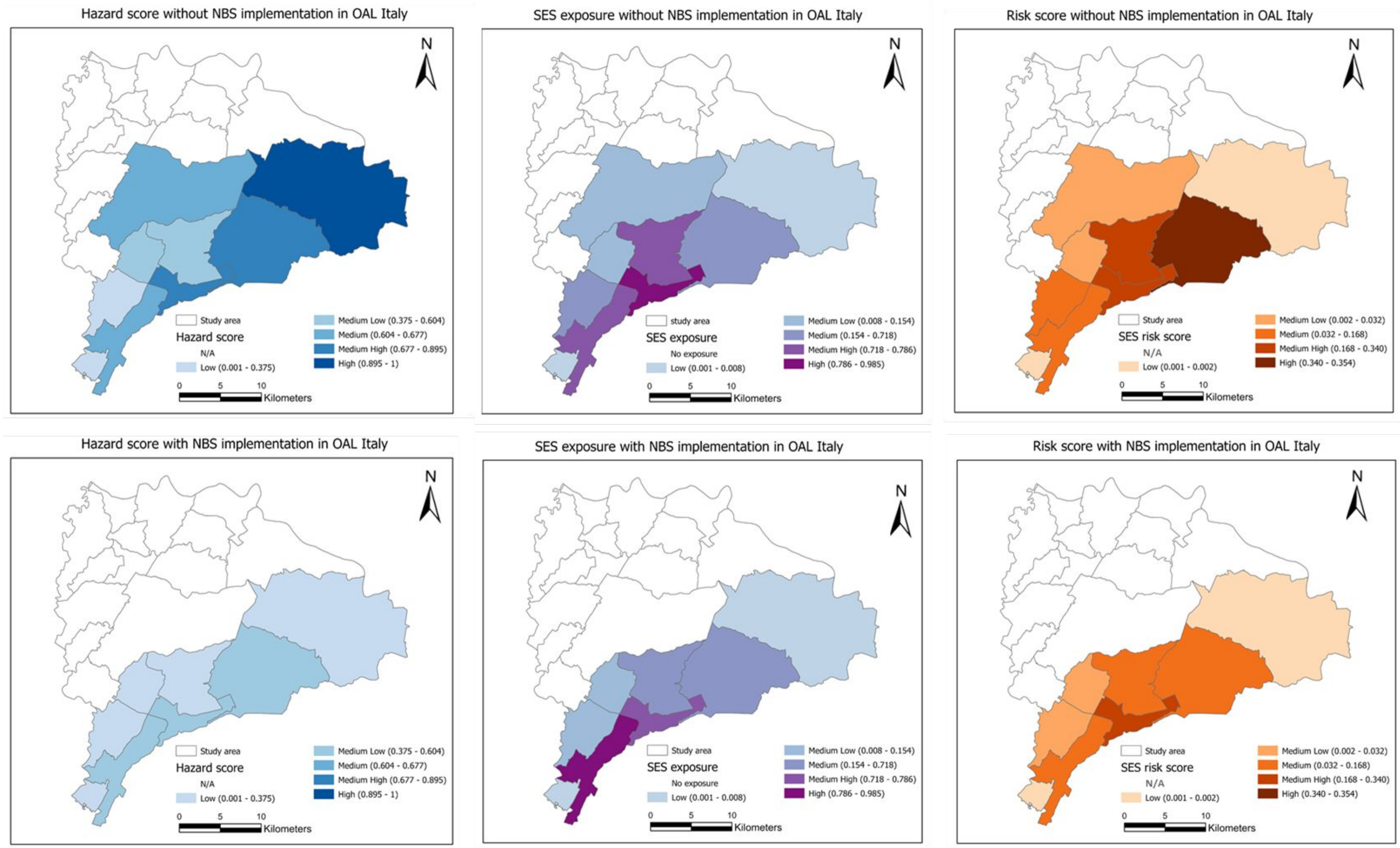
Monitoring and modelling results







Flood risk reduction with NbS - Panaro River, Italy, indicator-based approach



Draft results: SES hazard, exposure, and risk scores for a 200-year flood event in OAL Italy for with and without NBS scenarios

NBS expected damage reduction

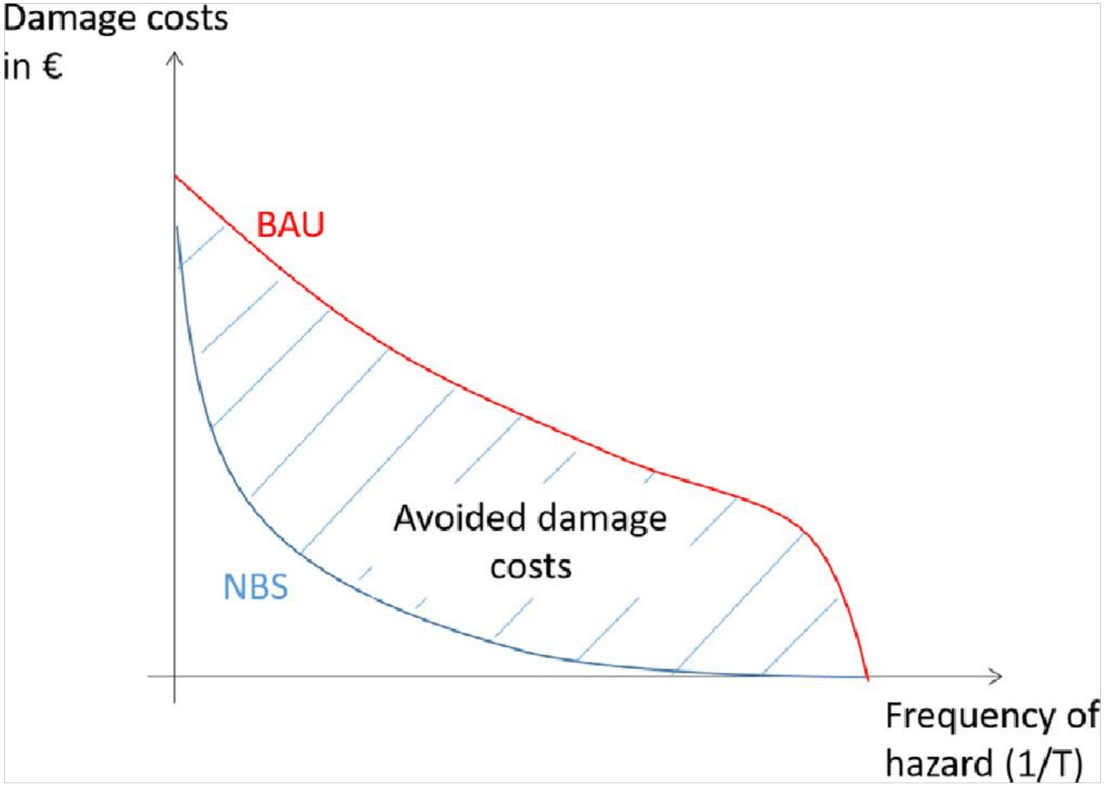
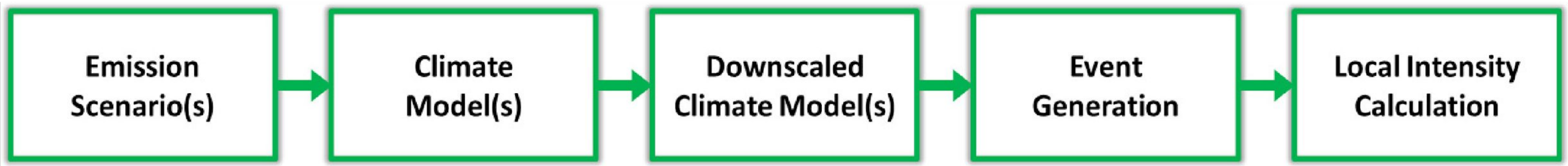


Fig. 2. The principle for assessing avoided damage costs.

Le Coent, Philippe, et al. "Is-it worth investing in NBS aiming at reducing water risks? Insights from the economic assessment of three European case studies." *Nature-Based Solutions*

Risk model with future hazard

A) Estimation of future frequency of hazard –
Ensemble climate impact modelling

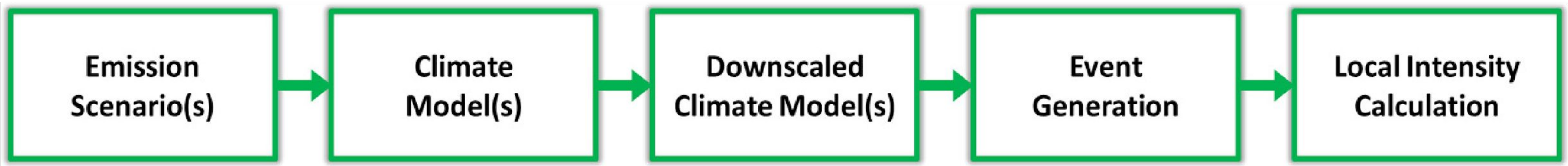


Cremen, Gemma, Carmine Galasso, and John McCloskey. "Modelling and quantifying tomorrow's risks from natural hazards." *Science of The Total Environment* (2021):

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Risk model with future hazard

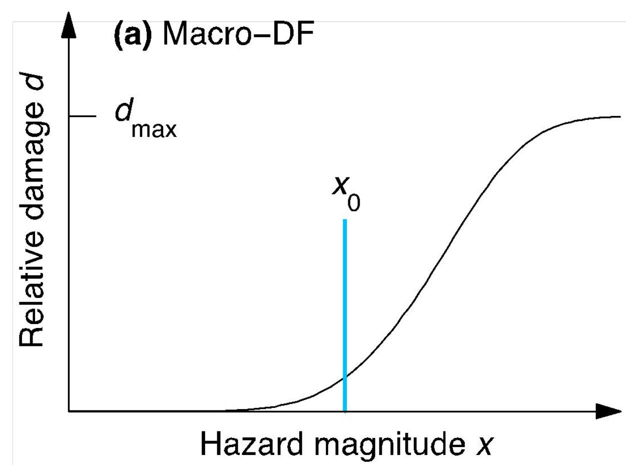
A) Estimation of future frequency of hazard – Ensemble climate impact modelling



Cremen, Gemma, Carmine Galasso, and John McCloskey. "Modelling and quantifying tomorrow's risks from natural hazards." *Science of The Total Environment* (2021):

B) Estimation of hazard-impact relationship – CAT model

- Mapping of event's hazard intensity (e.g. flood map)
- Assessment of the exposure of the assets/elements at risk (e.g. land cover)
- Damage functions/models.
- Modelling of protection measures



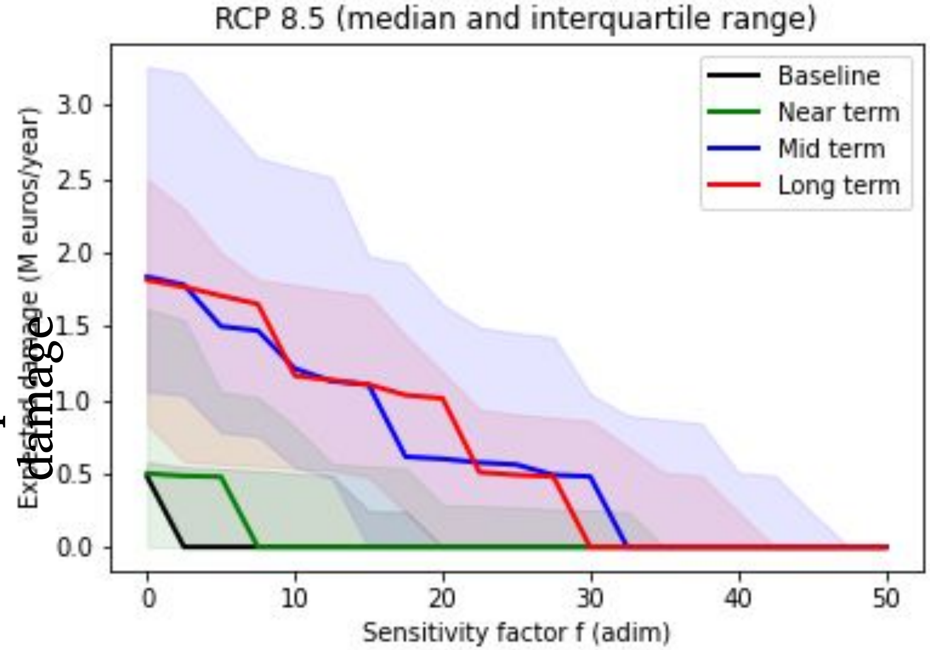
Prahl, Boris F., et al. "Damage functions for climate-related hazards: Unification and uncertainty analysis." *Natural Hazards and Earth System Sciences* (2016)

Risk model with future hazard

c) Expected damage reduction by adaptation action

By ‘parametrizing’ the effect of the NBS in this framework we can estimate costs and expected damage reduction
At the catchment scale

Expected damage



Actionable variable

Land Monitoring
COPERNICUS LAND MONITORING SERVICE
State of Play: In situ data requirements
Joint Research Centre
JRC
Climate Change Service

EU funded project
GA no. 776848