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REGIONAL CLIMATE CHANGE, WEATHER AND CLIMATE EXTREMES

Course: Climate change and its human aspect

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Definition of "Regional climate change" (IPCC AR6 WGI):

A change in climate in a given region identified by changes in the mean or higher moments of the probability distribution of a climate variable and persisting for a few decades or longer.

• a change in persistence or frequency of occurence of weather and climate extreme events

Causes of regional climate change:

- natural internal processes atmospheric internal variability + local climate response;
- changes in external forcings modulations of the solar cycle, orbital forcing, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere/land use.

Why regional information matters:

- Local decision-makers require region-specific projections (e.g., water resources, agriculture, infrastructure);
- Regional climate depends not only on global forcing but also on local processes, topography, land-atmosphere interactions, and ocean dynamics.





Sources of Regional Climate Variability and Change

Rising GHGs and aerosols modify temperature, precipitation, and extremes

Multi-year to decadal fluctuations like

Natural internal variability

Local physical

processes

Anthropogenic

forcing

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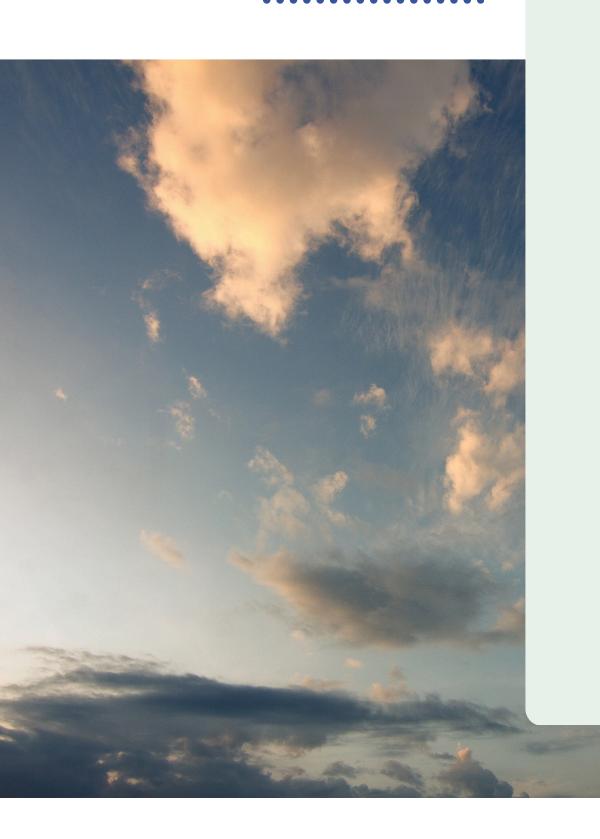
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Topography, coasts, land use, and complex terrain drive unique responses.

ENSO, AMO, PDO, monsoon variability.



REGIONAL CLIMATE CHANGE INFORMATION





The first of four chapters focused on regional climate change information

Diverse Methodology

How the regional

climate science is studied

Multiple Evidence

The regional climate science knowledge based on multiple pieces of evidence



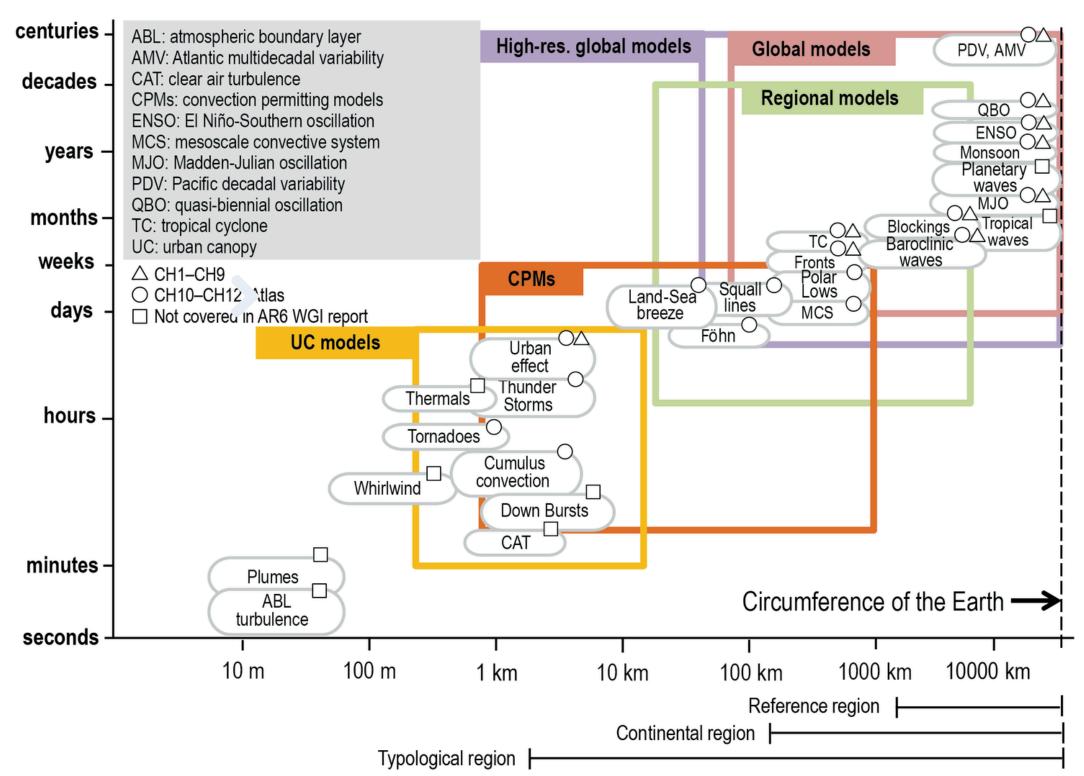
Linking Global to Regional Climate Change

IPCC AR6 Chapter 10

What is meant by regional:

Regional scales are defined as ranging from the size of sub-continental areas (e.g., the Mediterranean basin) to local scales (e.g., coastlines, mountain ranges and cities) without prescribing any formal regional boundaries.

Spatial and Temporal Scales



Regional climate change assessment must match the scale of the phenomenon:

Spatial scales

- Global scale: radiative forcing, greenhouse gas trends.
- Continental/sub-continental scale: monsoon systems, large-scale circulation changes.
- Local scale (10–100 km): mountains, coastlines, land use, cities.
- Micro-scale (<10 km): urban heat islands, local weather processes.

Temporal scales

- Short-term (annual to decadal): influenced by internal variability (e.g., ENSO).
- Mid to long-term (2050 onwards): strongly shaped by emission scenarios (SSPs), anthropogenic forcing.

Schematic diagram displaying interacting spatial and temporal scales relevant to regional climate change information. Source: IPCC AR6 WG1 (2021), Figure 10.3

Distillation of Regional Climate Information

Distillation steps:

1. Assess robustness of physical understanding

- Theory + observations + models.

2. Combine multiple evidence lines

- Global climate models (GCMs)
- Downscaled models (RCMs)
- Observational records
- Reanalysis datasets
- Attribution studies

3. Characterize uncertainties

- Emission scenario uncertainty
- Model uncertainty
- Internal variability

4. Translate into regional climate messages

- Clear statements about directional change, magnitude, and confidence.

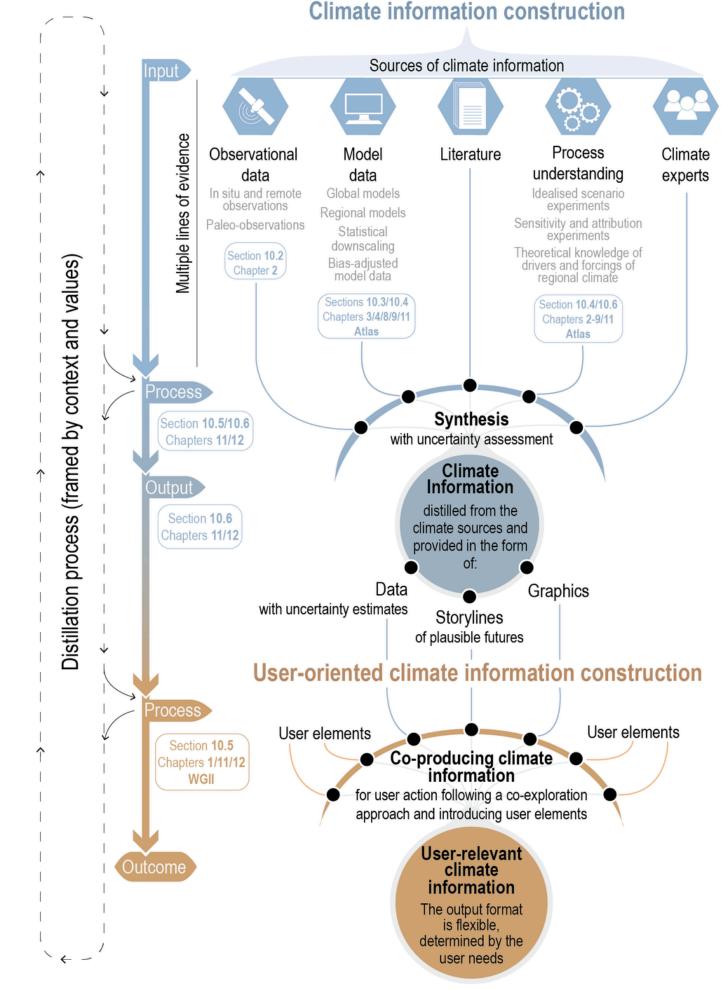
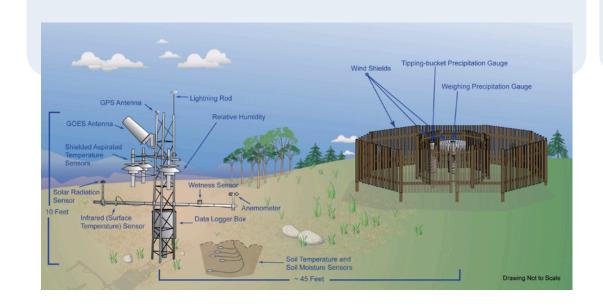


Diagram of the processes leading to the construction of regional climate infromation (blue) and user-relevant regional climate infromation (brown). Source: IPCC AR6 WG1 (2021), Figure 10.1

From the observational techniques:

In situ surface observations

Climate reference networks The data found is used to understand differences in regional climate as well as record major changes to it.



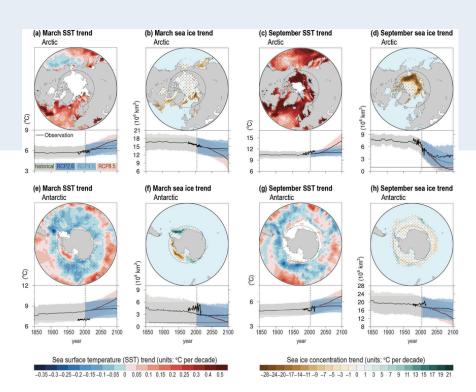
Satellite data

E.g. Low Earth Orbit (or LEO) satellites have been able to record data on a variety of different measures



Derrived products

take data already known and combine it with mathematical theory to create a new analysis.



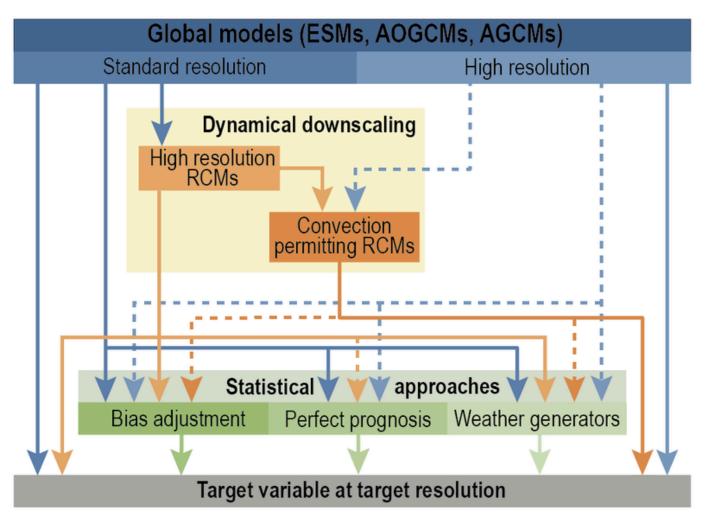


Figure 10.5 | Typical model types and chains used in modelling regional climate. Source: IPCC AR6 WG1 (2021)

Global Climate Change Models (GCMs)

Simulate both past and future climates at the global scale and are generally used to extract climate information for the entire Earth or at the continental level. Global climate models typically have spatial resolutions between 100-200 km.

Regional Climate Change Models (RCMs)

Can simulate dynamical climate elements, like global models, but are only applied over a specific region and at a higher resolution scale. The spatial resolution of these models is typically between 10-50 km. Regional models can be driven by global models, where the outputs of global models are inputs into the regional model. This is

known as dynamical downscaling.

From climate models simulations:

Statistical Models

Statistical models are an alternative to dynamical downscaling to obtain regional climate projections. Statistical approaches analyze the results from global climate models to produce information about regional climate.

Combining Approaches to Construct User-friendly Regional Information

Understanding and communicating regional climate change is important because:

- many of the specific impacts of climate change are going to occur at the regional level
- decisions about how to handle these challenges are often made on the regional level.

Some challanges when communicating the findings:

- What sources are selected
- What information is deemed relevant
- How to convey assumptions underlying the models and degrees of uncertainty
- What level of detail
- Conveying through a storyline or more numerically?
- information needs to be tailored to the relevant stakeholders

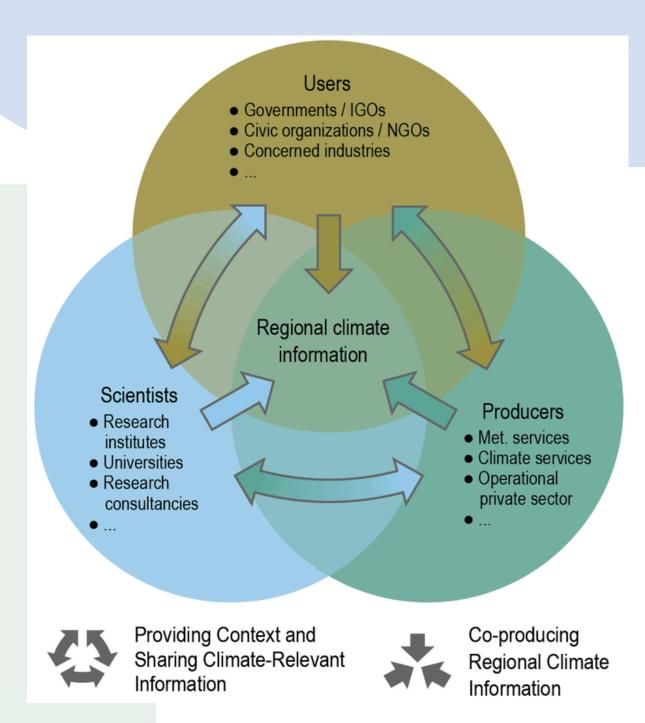


Figure 10.17 | Effective regional climate information requires shared development of actionable information that engages all parties involved and the values that guide their engagement. Source: IPCC AR6 WG1 (2021),



WEATHER AND CLIMATE EXTREMES







Extreme weather:

An event that is rare at a particular place and time of year.



Extreme climate:

A pattern of extreme weather that persists for some time, such as a season.



Division:

Relative thresholds and absolute thresholds.



Examined changes:

Changes in frequency and magnitude.

What are extremes?



Observational data

In situ station measurements

Provide local daily values for temperature and precipitation.

Reanalysis datasets

Combine observations with models to create gridded estimates of weather and climate variables.

Satellite data

Help fill gaps in regions with sparse observations and provide high-resolution measurements of rainfall or clouds.





- More warm days and nights, fewer cold days and nights.
- Heatwaves are becoming more frequent, more intense, and longerlasting worldwide.
- Cold extremes are declining, while both the hottest and coldest extremes are shifting to higher temperatures.
- Arctic regions experience the fastest rise in annual minimum temperatures.



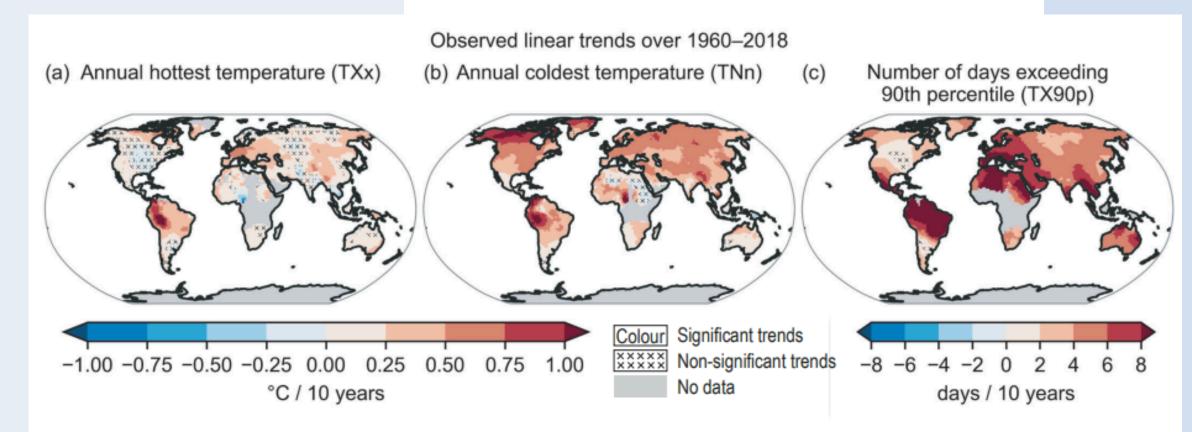


Figure 11.9 | Linear trends over 1960–2018 for three temperature extreme indices: (a) the annual maximum daily maximum temperature (TXx), (b) the annual minimum daily minimum temperature (TNn), and (c) the annual number of days when daily maximum temperature exceeds its 90th percentile from a base period of 1961–1990 (TX90p); based on the HadEX3 dataset (Dunn et al., 2020). Linear trends are calculated only for grid points with at least 66% of the annual values over the period and which extend to at least 2009. Areas without sufficient data are shown in grey. No overlay indicates regions where the trends are significant at the p = 0.1 level. Crosses indicate regions where trends are not significant. Further details on data sources and processing are available in the chapter data table (Table 11.SM.9).

Observed trends in annual maximum daily precipitation (Rx1day)

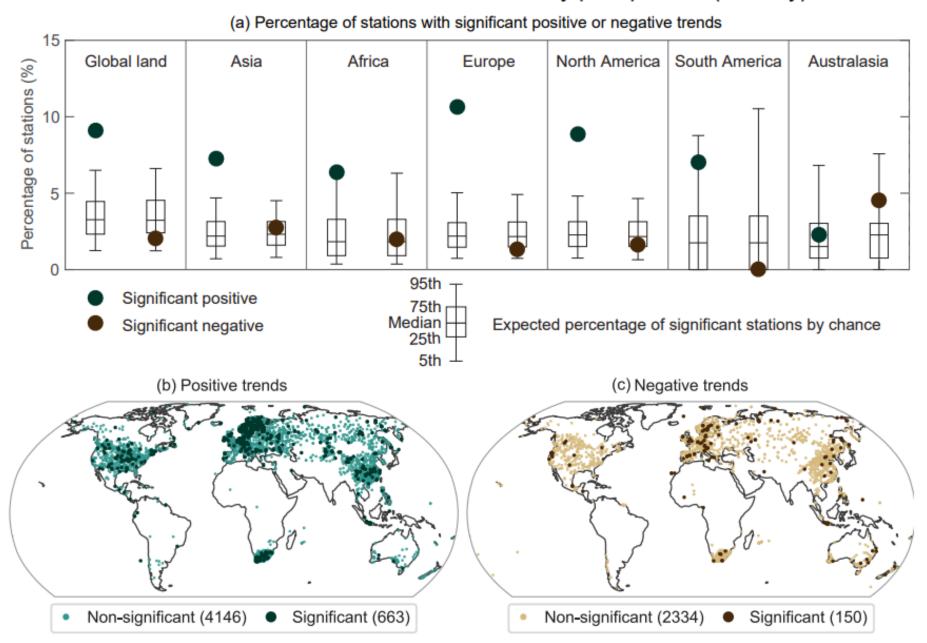


Figure 11.13 | Signs and significance of the observed trends in annual maximum daily precipitation (Rx1day) during 1950–2018 at 8345 stations with sufficient data. (a) Percentage of stations with statistically significant trends in Rx1day; green dots show positive trends and brown dots negative trends. Box and 'whisker' plots indicate the expected percentage of stations with significant trends due to chance estimated from 1000 bootstrap realizations under a no-trend null hypothesis. The boxes mark the median, 25th percentile, and 75th percentile. The upper and lower whiskers show the 97.5th and the 2.5th percentiles, respectively. Maps of stations with positive (b) and negative (c) trends. The light colour indicates stations with non-significant trends, and the dark colour stations with significant trends. Significance is determined by a two-tailed test conducted at the 5% level. Adapted from Sun et al. (2021). Figure copyright © American Meteorological Society (used with permission). Further details on data sources and processing are available in the chapter data table (Table 11.SM.9).

Heavy precipitation



- Heavy rainfall events have become more frequent and intense in many regions.
- 1-day extreme precipitation have increased across most land areas.
- More stations report increases in heavy rainfall than decreases, especially in North America, Europe, and Asia.
- Sub-daily extremes show increases in several regions, but global confidence is low due to limited data.

- Three main types meteorological, agricultural, and hydrological.
- Recent trends show more intense and frequent droughts in regions such as Mediterranean Europe, southern Africa, and parts of Asia.
- Higher temperatures increase evapotranspiration, worsening drought impacts even where rainfall declines are limited.

Droughts

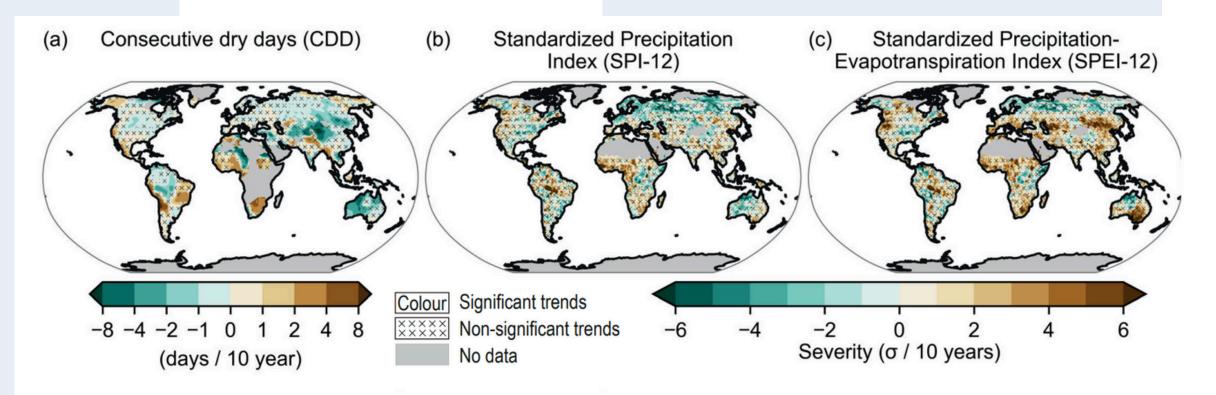


Figure 11.17 | Observed linear trend for (a) consecutive dry days (CDD) during 1960–2018, (b) standardized precipitation index (SPI) and (c) standardized precipitation-evapotranspiration index (SPEI) during 1951–2016. CDD data are from the HadEx3 dataset (Dunn et al., 2020), trend calculation of CDD as in Figure 11.9. Drought severity is estimated using 12-month SPI (SPI-12) and 12-month SPEI (SPEI-12). SPI and SPEI datasets are from Spinoni et al. (2019). The threshold to identify drought episodes was set at -1 SPI/SPEI units. Areas without sufficient data are shown in grey. No overlay indicates regions where the trends are significant at the p = 0.1 level. Crosses indicate regions where trends are not significant. For details on the methods see Supplementary Material 11.SM.2. Further details on data sources and processing are available in the chapter data table (Table 11.SM.9).

Extreme Storms

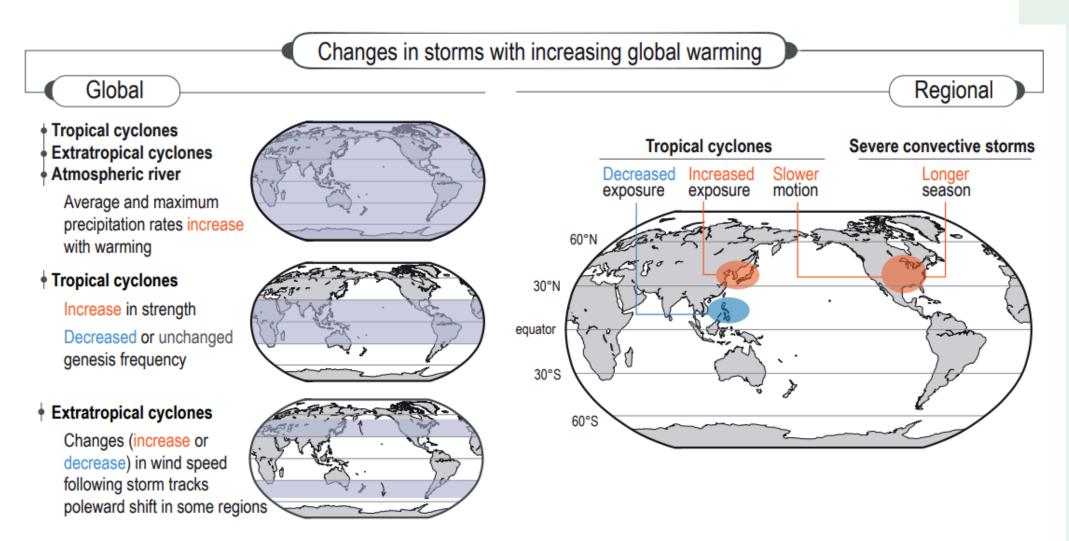


Figure 11.20 | Summary schematic of past and projected changes in tropical cyclone (TC), extratropical cyclone (ETC), atmospheric river (AR), and severe convective storm (SCS) behaviour. Global changes (blue shading) from top to bottom: (i) Increased mean and maximum rain rates in TCs, ETCs, and ARs [past (low confidence due to lack of reliable data) and projected (high confidence)]; (ii) Increased proportion of stronger TCs [past (medium confidence) and projected (high confidence)]; (iii) Decrease or no change in global frequency of TC genesis [past (low confidence due to lack of reliable data) and projected (medium confidence)]; and (iv) Increased and decreased ETC wind speed, depending on the region, as storm tracks change [past (low confidence due to lack of reliable data) and projected (medium confidence)]. Regional changes, from left to right: (i) Poleward TC migration in the western North Pacific and subsequent changes in TC exposure [past (medium confidence) and projected (medium confidence)]; (ii) Slowdown of TC forward translation speed over the contiguous USA and subsequent increase in TC rainfall [past (medium confidence) and projected (low confidence due to lack of directed studies)]; and (iii) Increase in mean and maximum SCS rain rate and increase in spring SCS frequency and season length over the contiguous USA [past (low confidence due to lack of reliable data) and projected (medium confidence)].

- Tropical Cyclones the most intense tropical cyclones (Cat 3–5) have become more frequent, rapid intensification is more common.
- Extratropical Cyclones overall cyclone numbers show no clear global trend, but storm tracks have shifted poleward since the 1980s.
- Severe Convective Storms includes tornadoes, hail, lightning, and mesoscale convective systems.
- Extreme Winds over land, many regions show long-term "stilling," while satellite observations over oceans indicate widespread increases in strong winds, especially at higher latitudes.



Compound events

Multiple extremes can occur together or in sequence, amplifying impacts

Concurrent Extremes in Coastaland Estuarine Regions

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Concurrent Droughts and Heatwaves

Compound events are harder to predict and manage due to their amplified combined effects



FUTURE PROJECTIONS OF REGIONAL CLIMATE

What This Section Covers

- Projected regional climate changes under +1.5 °C, +2 °C and +4 °C warming levels.
- Future shifts in extreme events, including heatwaves, droughts, floods and heavy precipitation.
- Compound and concurrent extremes and why multi-hazard events increase risk.
- Key uncertainties and confidence levels in regional climate projections.



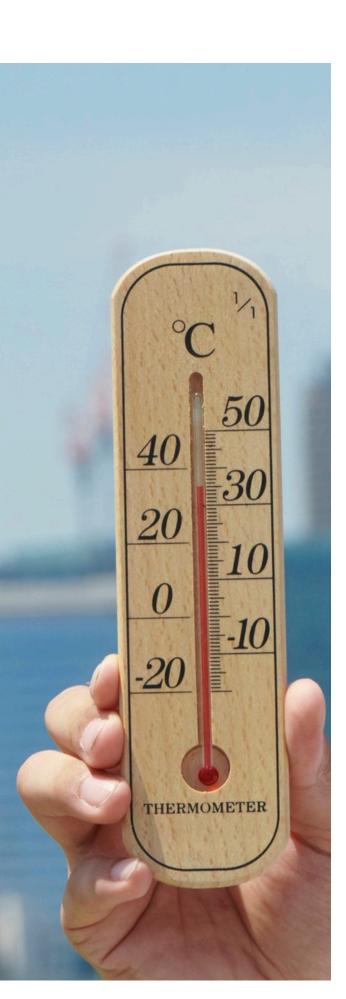
Why Regional Projections Matter

- Global warming affects each region differently
- Physical processes: circulation, land-sea contrast, topography
- Policy decisions require regional-level information





Warming Levels Approach (1.5°C, 2°C, 3-4°C)



1.5°C

More frequent heatwaves & heavy rain.

Early drying in Mediterranean, S. Africa, C. America.

Impacts still largely adaptable.

2°C

Sharp rise in extremes.

Stronger droughts (Med, S. Africa, W. N. America).

Intense rainfall in Asia & E. Africa.

High, region-specific risks.

4°C

Non-linear escalation.

Widespread compound extremes (heat + drought + fire).

Rare events become routine.

Some regions exceed adaptation limits.

Regional Temperature Projections

• Hot

intensify

Heatwaves

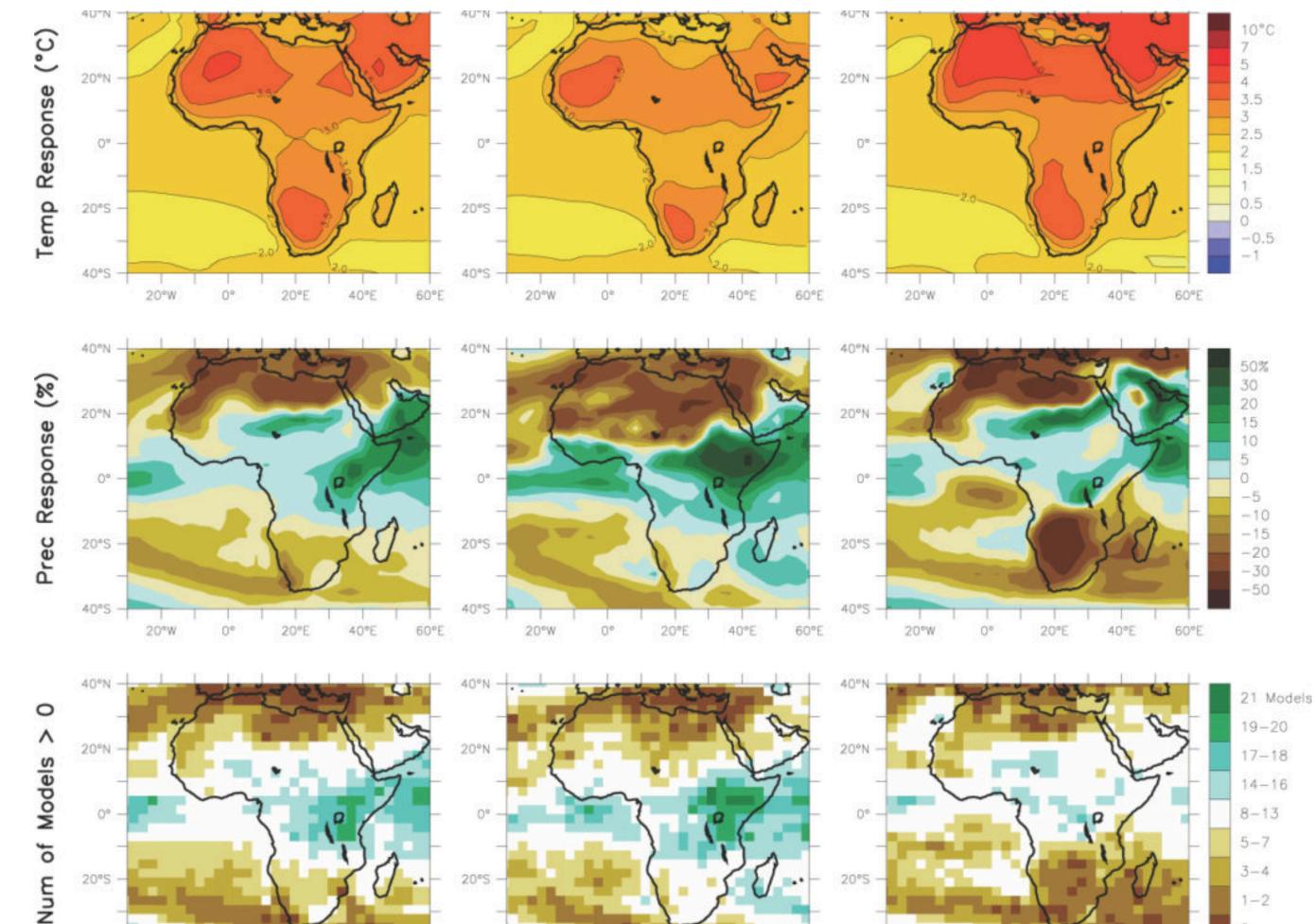
everywhere with

high confidence

become longer,

more frequent

extremes



Regional Precipitation Projections



Changes in large-scale atmospheric circulation and precipitation with each 0.5°C of warming (high confidence). Stable pattern of change over time and scenarios. Some departures from linearity possible at regional scale (*medium confidence*). Precipitation increase on land higher at 3°C and 4°C compared to 1.5°C and 2°C. Precipitation increases in large parts of the monsoon regions, tropics and high latitudes, decreases in the Mediterranean and large parts of the subtropics (high confidence).



Regional Ocean & Coastal Changes

- Sea level rise increases coastal flooding frequency
- Marine heatwaves become more frequent
- Tropical cyclone intensity increases (but frequency uncertain)
- Storm surges (eg. storm tide, storm flood) worsen due to higher sea level

(a) Change in 1-in-100 year river discharge per unit catchment area by mid-century, CORDEX RCP8.5

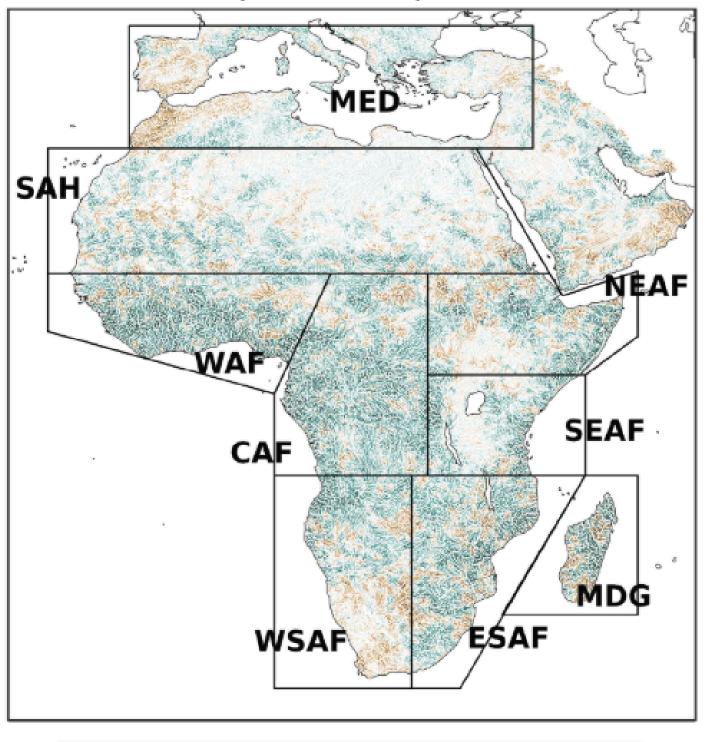
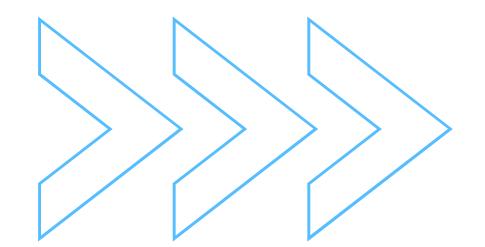


Figure 12.5 | Projected changes in selected climatic impact-driver indices for Africa.

-0.2 -0.1 -0.05 -0.02 -0.01 0 0.01 0.02 0.05 0.1 0.2 $$m^3\,s^{\text{-}1}\,km^{\text{-}2}$$

Compound & Concurrent Extremes



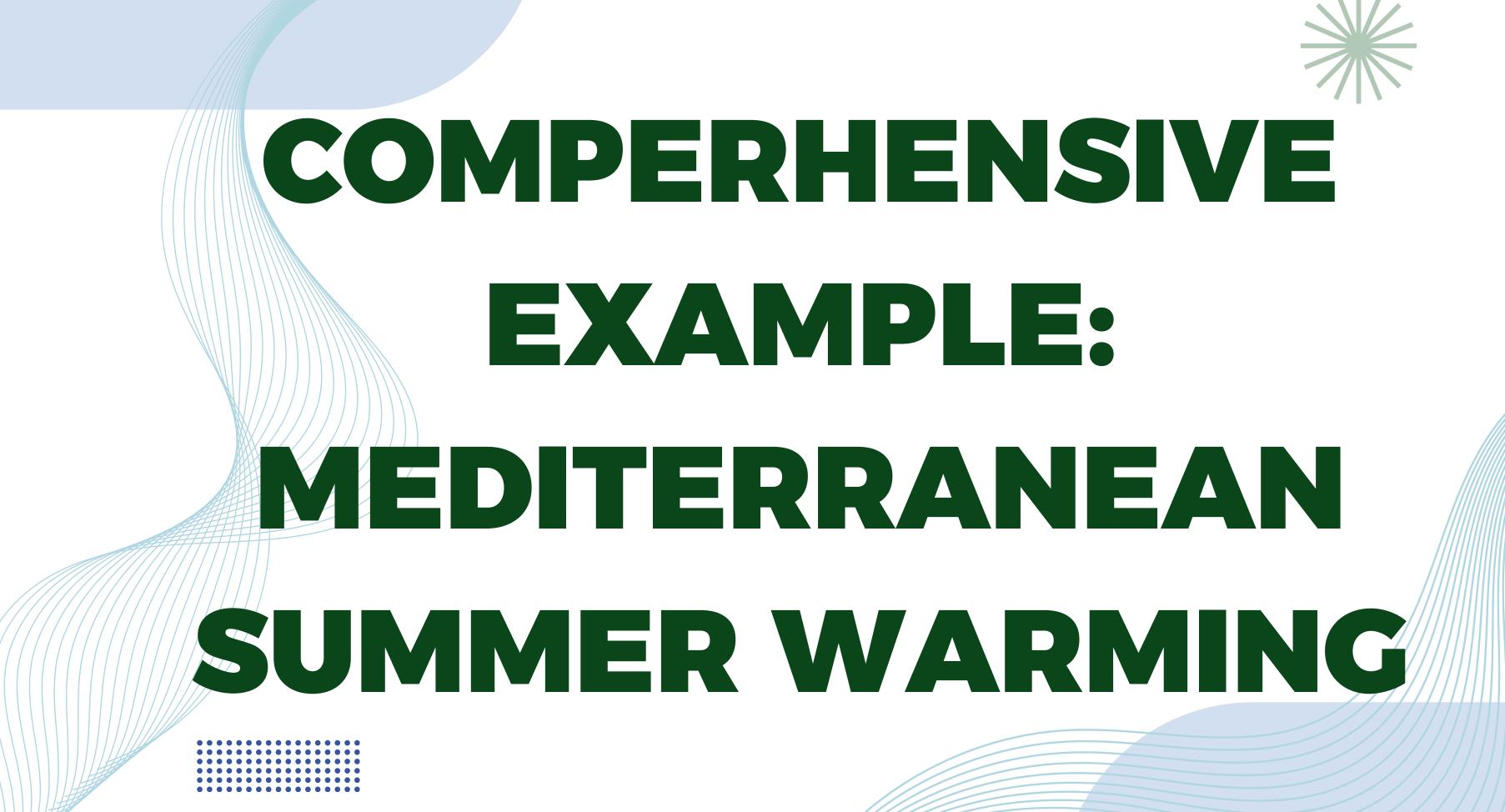
Examples with strong evidence:

Heat + drought (Mediterranean, Türkiye)
Heavy rain + storm surge (coastal Asia)
Heat + humidity extremes (South Asia)

Sub-region		OBS.	ATTR.	1.5°C	2.0	4°C	1.5°C	20	4°C
Sub-region				BASELINE: PRE-INDUSTRIAL			BASELINE: 1995-2014		
Mediterranean (same region as for Europe) MED	HOT EXT.	↑ V . L.	↑ L.	↑ V. L.	↑ E. L.	↑ V. C.	↑ L.	↑ V. L.	↑ V. C.
	HEAVY PRECIP.	LOW	LOW	↑ MED.	↑ HIGH	↑ HIGH	LOW	↑ MED.	↑ HIGH
	AGR./ECOL. DROUGHT	↑ MED.	↑ MED.	↑ MED.	↑ HIGH	↑ V. L.			
	HYDR. DROUGHT	↑ HIGH	↑ MED.	↑ MED.	↑ HIGH	↑ V. L.			
W.C.Asia WCA	HOT EXT.	↑ V. L.	↑ HIGH	↑ V. L.	↑ E. L.	↑ V. C.	↑ L.	↑ V . L.	↑ V. C.
	HEAVY PRECIP.	↑ MED.	LOW	↑ V. L.	↑ E. L.	↑ V . C.	↑ L.	↑ V. L.	↑ V. C.
	AGR./ECOL. DROUGHT	↑ MED.	LOW	LOW	LOW	↑ MED.			
	HYDR. DROUGHT	LOW	LOW	LOW	LOW	↑ MED.			

Confidence & Uncertainty in Regional Projections

- High confidence: temperature, heavy rain, sea-level rise
- Medium: some drought projections
- Low-medium: regional tropical cyclones
- Sources of uncertainty: regional feedbacks, internal variability, model limits



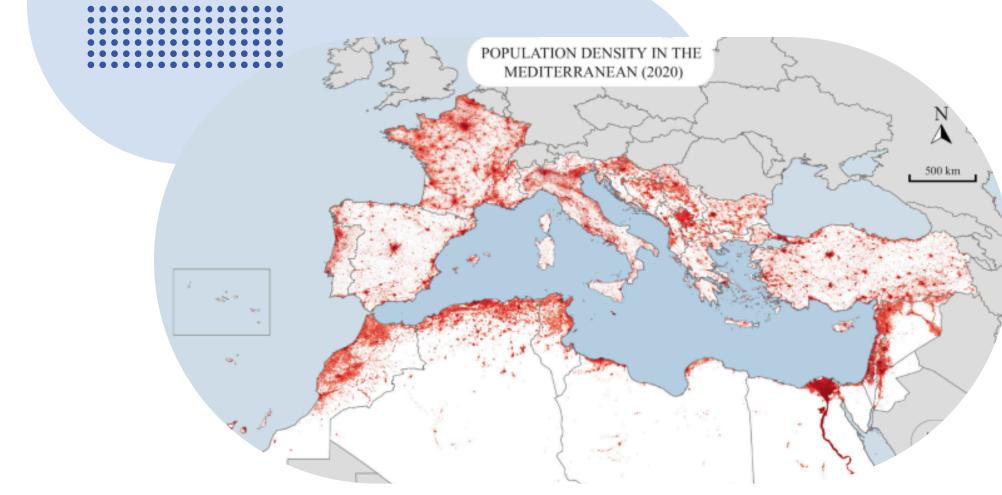


- 1. Motivation and regional context.
- 2. The region's climate.
- 3. Observational issues.
- 4. Relevant anthropogenic and natural drivers.
- 5. Model simulation and attribution over the historical period.
- 6. Future climate information from global simulations.
- 7. Future climate information from regional downscaling.
- 8. Storylines.
- 9. Climate information distilled from multiple lines of evidence.

Example of distilling regional climate information

Mediterranean Summer Warming: regional context





Regional characteristics

- complex orography
- strong land-sea contrast

Population

- relatively stable, declining during the past decades
- rise in the Middle East and Northern Africa during 1960-2015

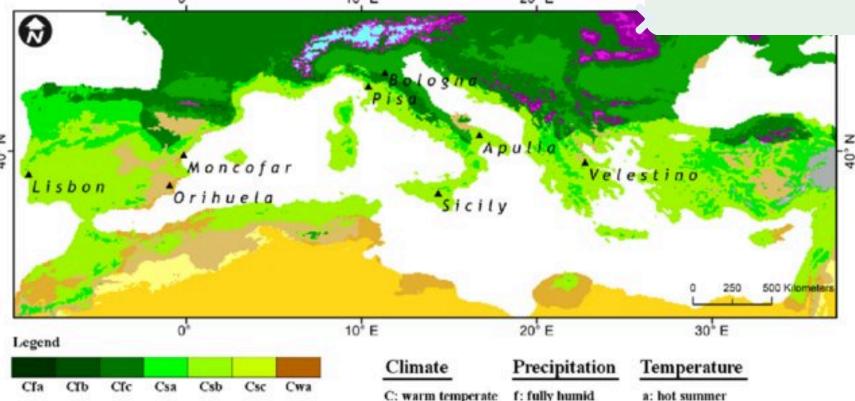
Urbanization

- rise from 35 to 64%between 1960 and 2015
- >5% during 2000-2020



Resolution: 0.5 deg lat/lon

The Medierranean has a heterogeneous, partly semi-arid climate.

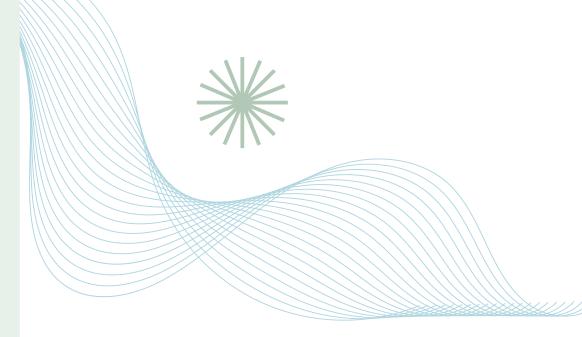


- Mild humid winters and dry warm or hot summers
- Circulation anomalies induced by topography
- Local cyclodenesis medicanes
- Regional winds due to channelling effect, extreme rainfall during autumn

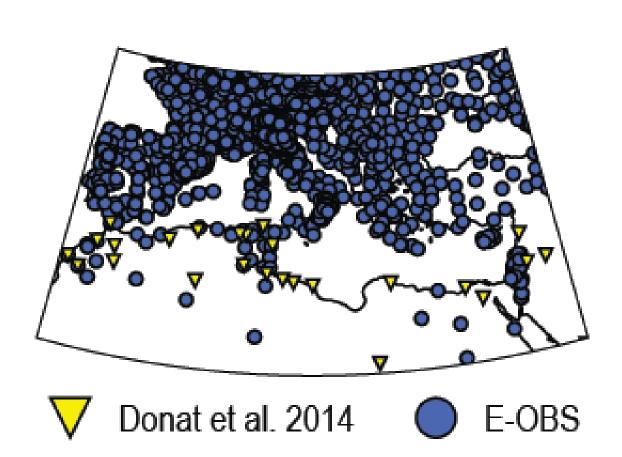
Relevant anthropogenic and natural drivers:

- Most dominant large-scale mode of natural variability: summer NAO (positive sNAO → upper level through over the Balkans → anomalously wet)
- AMV and Asian monsoon as drivers
- increase in GHGs + decrease of anthropogenic aerosols sonce 1980s → regional warming





Mediterranean Summer Warming: observational issues

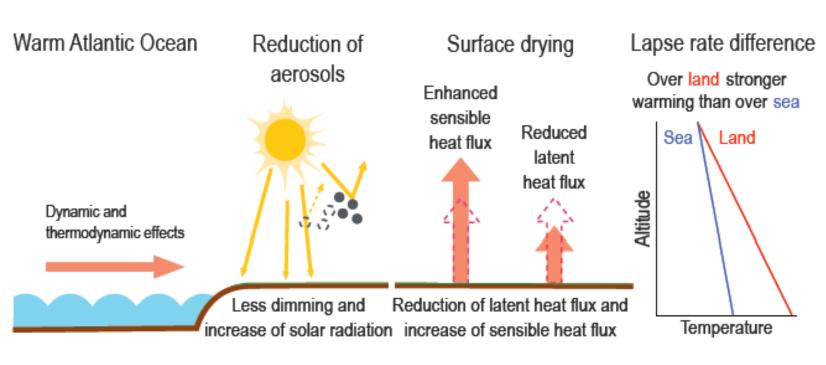


Locations of observing stations in E-OBS and Donat et al. (2014). Source: IPCC AR6 WG1 (2021), Figure 10.20b

- Southern part of the Mediterranean is sparsely covered by meteorological stations
- lack of homogeneous, quality controlled observational datasets (before 1970s)
- Sparse monitoring network in parts of the Mediterranean region strongly increases the uncertainty across different gridded datasets



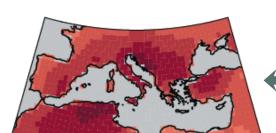
Mediterranean Summer Warming: model simulation



Baseline period is 1995-2014 HighResMIP **CORDEX EUR-44 CORDEX EUR-11** (၁) Berkeley Earth **CRU TS** HadCRUT5 1960 1980 1990 2010 1970 2000

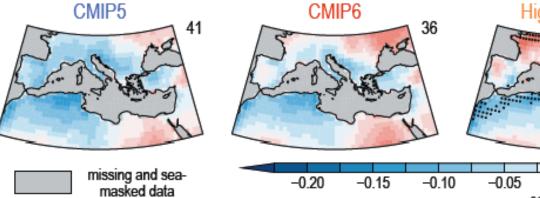
series of Time area averaged Mediterranean (25°N-50°N, 10°W-40°E) land point summer temperature anomalies (°C, baseline 1995-2014). Source: IPCC AR6 WG1 (2021), Figure 10.20e

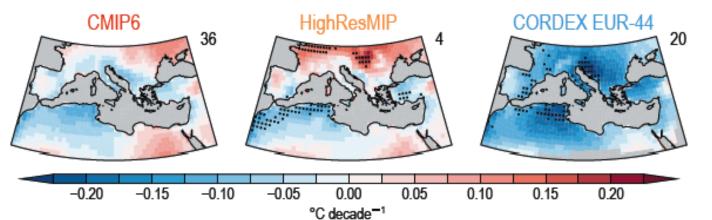
Mechanisms and feedbacks involved in enhanced Mediterranean summer warming.Source: IPCC AR6 WG1 (2021), Figure 10.20a

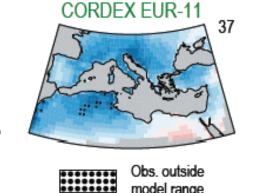


Past period (1960-2014)

Observed summer (June to August) surface air temperature linear trends (°C decade-1) over the 1960-2014 period from Berkeley Earth. Source: IPCC AR6 WG1 (2021), Figure 10.20d

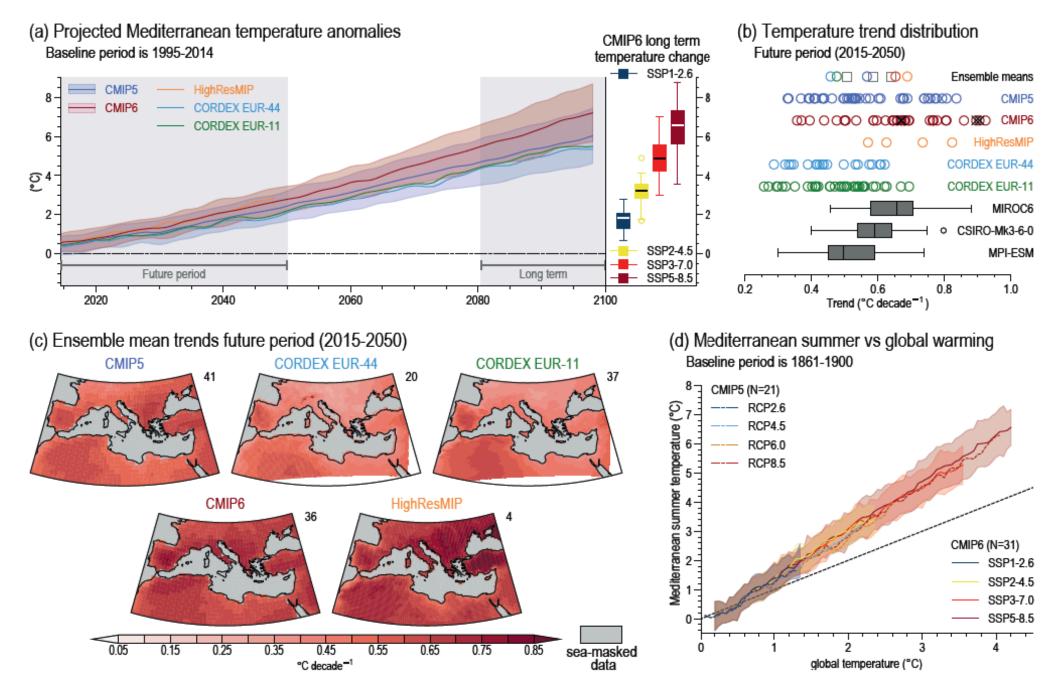






Ensemble mean differences with respect to the Berkeley Earth linear trend for 1960-2014 (°C decade-1) of CMIP5, CMIP6, HighResMIP, CORDEX EUR-44 and CORDEX EUR-11. Source: IPCC AR6 WG1 (2021), Figure 10.20g

Mediterranean Summer Warming: future projections



Projected Mediterranean summer warming. (a) Time series of area averaged Mediterranean (25°N-50°N, 10°W-40°E) land point summer surface air temperature anomalies (°C, baseline period is 1995–2014). (b) Distribution of 2015–2050 Mediterranean summer temperature linear trends (°C per decade). (c)Distribution of 2015–2050 Mediterranean summer temperature linear trends (°C per decade). (d) Projected Mediterranean summer warming in comparison to global annual mean warming. Source: IPCC AR6 WG1 (2021), Figure 10.21

"The Mediterranean is expected to be one of the most prominent and vulnerable climate change hotspots."

- → CMIP5, CMIP6, HighResMIP and CORDEX simulations all project a future warming for the 21st century that ranges between 3.5°C and 8.75°C for RCP8.5 at the end of this century for those ending at 2100
- → In terms of mean global warming: summer warming is projected to reach values up to 40–50% larger than the global annual warming, largely independent of models and emissions scenarios
- → Large regional differences: enhanced warming projected over Turkey, the Balkans, the Iberian Peninsula and North African regions

Future Climate Information from Regional Downscaling



Warming with temperature above 20°C is more than 60% larger under 2°C warming compared to 1.5°C



The frequency and duration of heatwaves and annual number of extremely hot days (T_max > 50°C) in the southern Mediterranean will increase substantially. For 2070–2099 with respect to 1971–2000 the latter might even reach 70 days for RCP8.5





Largest source of uncertainty in the temperature response over southern Europe: the choice of the driving global model; For summer precipitation the choice of the RCM dominates.

Reason: differences in solar radiation related to the absence of time-varying anthropogenic aerosols in RCMs → differences in cloud cover



Large agreement among future projections showing lower rates of warming in winter and spring, and higher ones in summer and autumn → obtained from statisical downscaling studies

Mediterranean Summer Warming: future projections

Mediterranean Summer Warming: climate information based on multiple lines of evidence

- → The Mediterranean region has experienced a summer temperature increase in recent decades that is faster than the increase for the Northern Hemisphere summer mean (*very high confidence*).
- → The projected Mediterranean summer temperature increase will be large than the global warming level, with an increase in the frequency and intensity of heatwaves (*very high confidence*).
- → Distillation process on regional or national level - non-comperhensive and heterogeneous sources of climate information
- → Global model–RCM matrix is still sparse and lacking a systematic design to explore the uncertainty sources (e.g., global model, RCM, scenario, resolution).

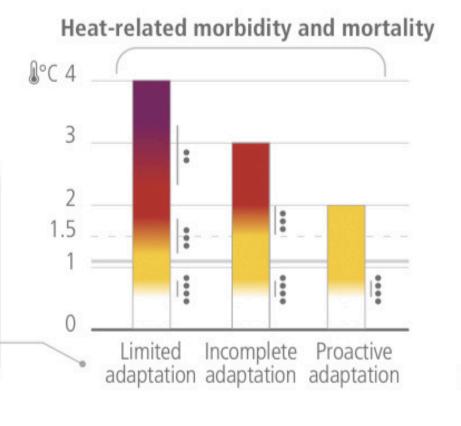


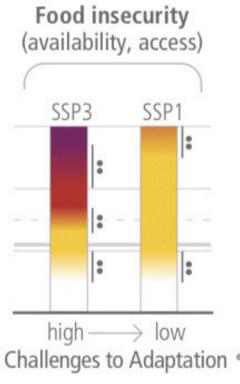


Effective Adaptation and Resilience strategies to each region



Limited adaptation (failure to proactively adapt; low investment in health systems); incomplete adaptation (incomplete adaptation planning; moderate investment in health systems); proactive adaptation (proactive adaptation management; higher investment in health systems)



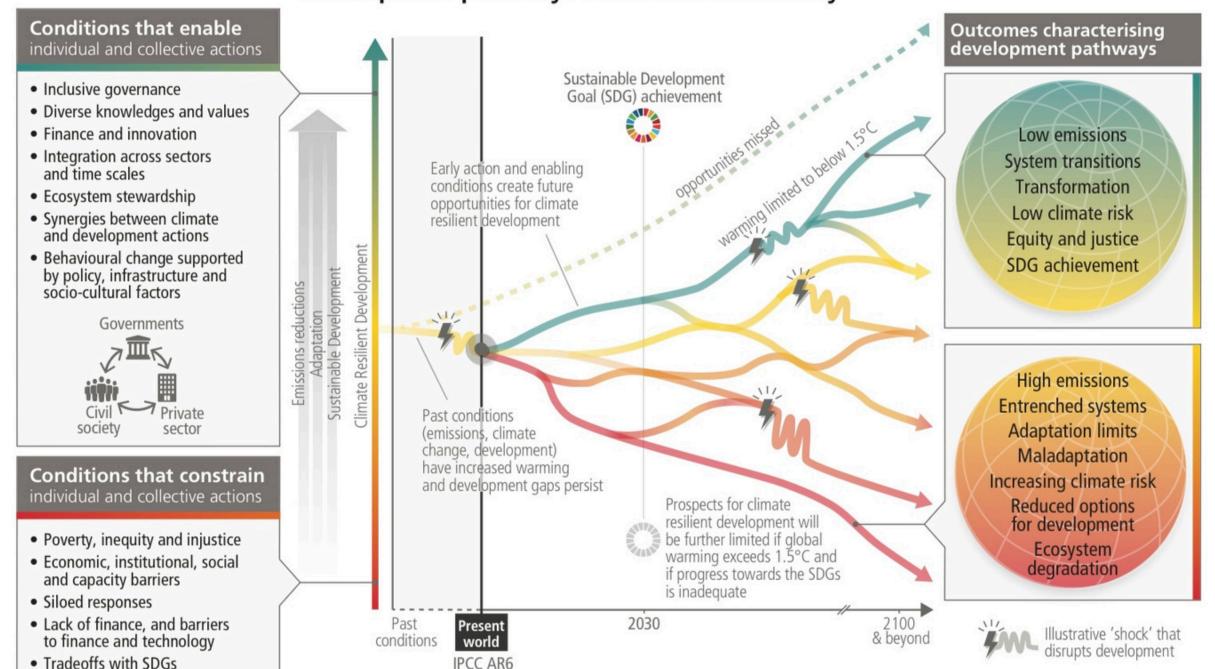


The SSP1 pathway illustrates a world with low population growth, high income, and reduced inequalities, food produced in low GHG emission systems, effective land use regulation and high adaptive capacity (i.e., low challenges to adaptation). The SSP3 pathway has the opposite trends.

The longer emissions reductions are delayed, the fewer adaptation options will be available

There is a rapidly narrowing window of opportunity to enable climate resilient development

Multiple interacting choices and actions can shift development pathways towards sustainability



- Diverse knowledge sources
- Limits to adaptation achievement global temperature rise above 1.5°C

Figure SPM.6(ipcc climate change 2023 synthesis report)

1: WATER-RELATED RISKS [ABOVE 2°C WARMING] (AFRICA, MEDITERRANEAN, SOUTH ASIA, ANDES)

Agriculture Sector

On-farm water management

water storage

soil moisture conservation

Irrigation

cultivar improvements

Agroforestry

farm diversitication

Agrisilvicultural systems (fao.org)



Drip Irrigation (openknowledge.fao.org)

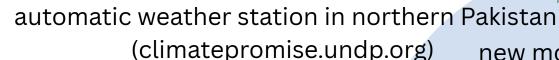
In-land flooding

Early-warning system

Zones or upstream forest management

<u>Community-based planing (ex: local water</u> governance)







new monitoring equipment for flood in Uzbekist (climatepromise.undp.org)

2: FLOODING (RIVERINE, MONSOON, FLASH FLOOD, MOUNTAIN REGION)

Eco-system based

- Restore wetlands and rivers- natural water retention ↑
- Upstream forest/mountain ecosystem management- runoff ↓

How natural floodplains and healthy watersheds reduce flooding Surface runoff Stream Peak flow Overbank flow Overbank flow A Rapid, higher flood flow (without natural infrastructure) I Surface runoff Stream A Rapid, higher flood flow (without natural infrastructure) B Attenuated, lower flood flow (without natural infrastructure)

Planning & Structural Measure

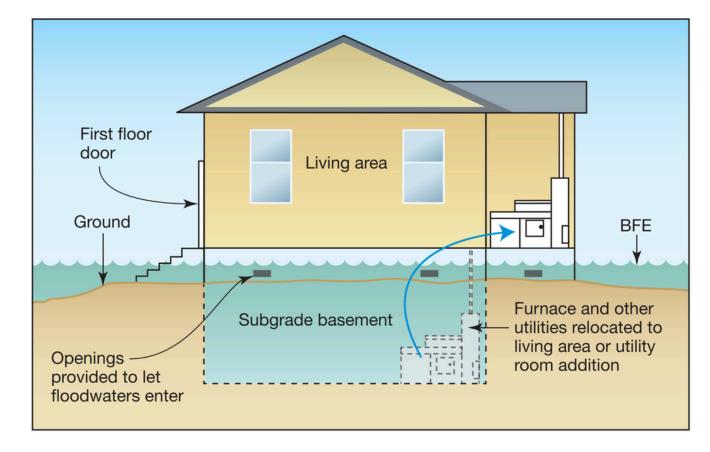
- Land-use planning (exclusion zones in floodplains)
 - Levees (*with eco-system based)



Levee <u>levees.sec.usace.army.m</u>

3: COASTAL VULNERABILITY (SMALL ISLAND, DELTA REGIONS. LAW-LYING COASTS)

- Flood-proofing buildings; elevated structures.
- Early warning systems for storm surge and coastal flooding.
- Managed retreat and risk-informed relocation (case-by-case, region dependent).
- Mangrove and coastal wetland restoration.



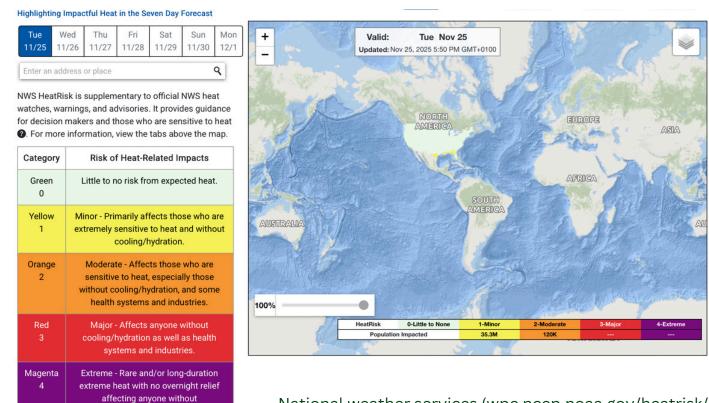
Flood-proofing building (fema.gov)

Some coastal households already face soft limits to adaptation due to governance and financial constraints.

4: EXTREME HEAT

(URBAN AREAS, SOUTH ASIA, MIDDLE EAST, MEDITERRANEAN, US SOUTHWEST)

- Heat Health Action Plans with early warning
- Cooling centers
- Communication protocols
- Urban greening and reflective surfaces heat islands
- Water and sanitation infrastructure upgrades -disease risk
- Work-shift adjustments for outdoor labor





Urban greening (greenplan.gov.sg)

National weather services (wpc.ncep.noaa.gov/heatrisk/)

! Effectiveness decreases sharply above 1.5°C in warm regions.

5: FOOD SECURITY (AFRICA, SOUTH AMERICA, ASIA)

- Agroecological farming (soil carbon, crop diversification, natural pest control).
- Climate services for farmers: seasonal forecasts, pest forecasts.
- Social safety nets, insurance, cash transfer programs for shocks.
- Improved storage and reduced food waste.





Timely and accurate climate updates via radio or mobile phones In Zimbabwe (climatepromise.undp.org)

Rice duck Agroecological farming in China (agroecologiynow.net)

Effectiveness decreases sharply above 1.5°C in warm regions.

Windhoek's future climate impacts & adaptations examples

Projections of the future climate from climate models show a range of outcomes for Namibia. Three plausible scenarios for the 2040s and their impacts on the city-region of Windhoek are described here:

1: Much hotter with a drier 2: Hotter with rainfall rainy season



- More than 2 deg C warmer
- Twice as many very hot days
- 1/3 less rainfall

later in the season



- 1.5 2 deg C warmer
- 50% more very hot days
- More rain later in the rainy season

3: Warmer with a similar rainy season



- 1 1.5 deg C warmer
- Annual average rainfall totals similar
- More intense rainfall

Water security & efficiency



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- In all climate futures evaporation from reservoirs increases as temperatures rise.
- Continued migration to Windhoek increases pressure on water resources which become more
- Adaptations could include additional water treatment or desalination plants.

Energy efficiency & renewable energy



- In climate futures 1 and 2, rainy days are fewer with more sunshine hours available for solar power.
- Increased temperatures sees greater demand for air conditioning.
- Local promotion of the National Energy Efficiency Programme and City of Windhoek's Renewable Energy Policy could help adoption of energy-efficient technologies and practices such as waste-to-energy power plants.

Healthy communities



- All climate futures are warmer, with many more very hot days in futures 1 and 2. Vulnerable people suffer from heat related illness.
- Flooding likely in climate futures 2 and 3 affecting sanitation. Cholera, Hepatitis B and similar diseases rise.
- Measures to improve sanitation services and general health of residents could help resilience to illness.

Biodiversity & Ecosystem goods & services



- Rises in temperature and changes to rainfall patterns likely in all climate futures with resulting biodiversity loss, shift in habitats and invasive species.
- Degradation to landscape or wildlife impacts on tourism.
- Game farming more resilient in a hotter future climate.
- Impacts mitigated through sustainable land management and conservation measures.



Climate Risk Narrative infographic developed through the FRACTAL Windhoek Learning Lab process. Figure adapted from Jack et al. (2020).

Final remarks: regional climate change



Distillation of Climate information

→ Regional climate change information is understood and communicated through a process of distillation from multiple sources and pieces of evidence.



→ Confidence in the distilled regional climate information is enhanced when there is agreement across these multiple lines of evidence.

Observations

→ The use of multiple sources of observations to evaluate climate model performance increases trust in future projections of regional climate (high confidence).



→Regional reanalyses provide realistic estimates of climate variables, which are particularly valuable in regions where direct surface observations are limited.

Climate Models

→ Global and regional climate models are important sources of climate information at the regional scale.



→ The performance of the models for future projections depends on their representation of relevant processes, forcings and drivers and on the specific context.

Human Influence

→ Human influence has been a major driver of regional mean temperature change since 1950 in many sub-continental regions of the world (*virtually certain*).



→ While it has contributed to multi-decadal mean precipitation changes in several regions, internal variability can delay emergence of the anthropogenic signal in long-term precipitation changes in many land regions (high confidence).



Final remarks: weather and climate extremes



Temperature extremes

→ The frequency and intensity of hot extremes (including heatwaves) have increased, and those of cold extremes have decreased on the global scale since 1950 (*virtually certain*).

→This also applies at regional scale, with more than 80% of AR6 regions showing similar changes assessed to be at least likely. This trend will continue in nearly all inhabited regions with increasing global warming levels.

→ Human-induced greenhouse gas emissions have led to an increased frequency and/or intensity of some weather and climate extremes since pre-industrial time, in particular for temperature extremes.

Heavy Precipitation

→ Heavy precipitation will generally become more frequent and more intense with additional global warming.

Droughts

→ Human-induced climate change has contributed to increases in agricultural and ecological droughts in some regions due to evapotranspiration increases (medium confidence). More regions are affected by these droughts with increasing global warming (high confidence).

→ Climate models can reproduce the sign (direction) of changes in temperature extremes observed globally and in most regions, although the magnitude of the trends may differ (high confidence).

→The probability of compound events has likely increased in the past due to human-induced climate change and will likely continue to increase with further global warming.

Extreme storms

→ The average and maximum rain rates associated with TCs, ETCs and atmospheric rivers across the globe, and severe convective storms in some regions, increase in a warming world (high confidence).

Key Takeaways & Final Message



- → Different regions respond differently to global warming.
- → Extremes intensify at all warming levels.
- → The Mediterranean region is a major hotspot.
- → Major changes become severe beyond 2°C.
- → Regional climate information is crucial for climate adaptation.

- → By mid-century, every region will face simultaneous changes in multiple climate impact drivers, many of which are already evident today as shifts in their magnitude, frequency, duration, seasonality, and spatial extent, challenging regional resilience and adaptation capacity.
- → Flexible, multi-sectoral, inclusion & long-term planning and implemention of action adaptations will benefit many sectors and systems and can deal with each climate extreme.





THANK YOU FOR YOUR ATTENTION!

