Department of Meteorology and Climatology,
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"Challenges of regional climate change over the Mediterranean - The added value from Regional Climate Models (RCMs)"

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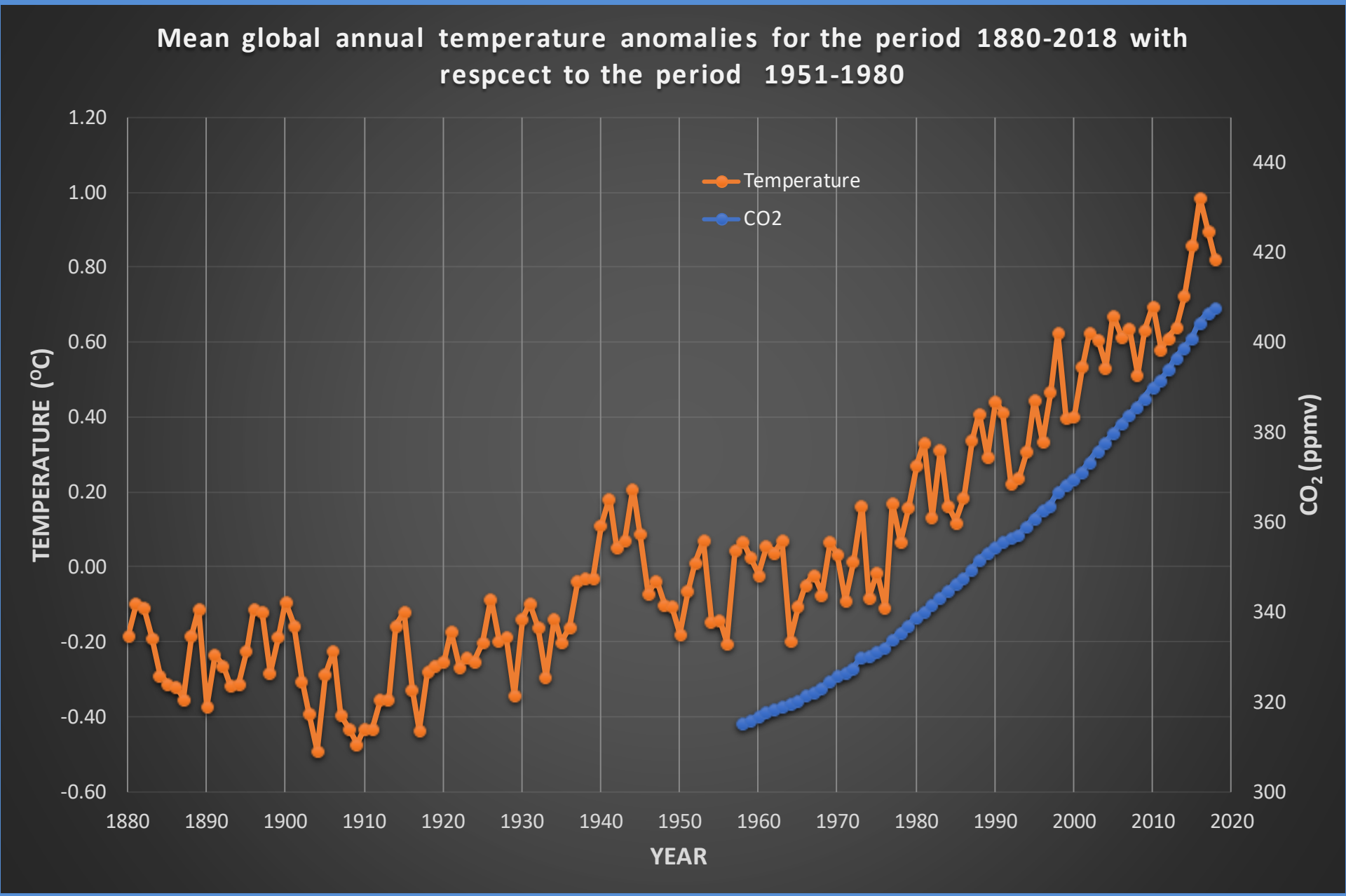
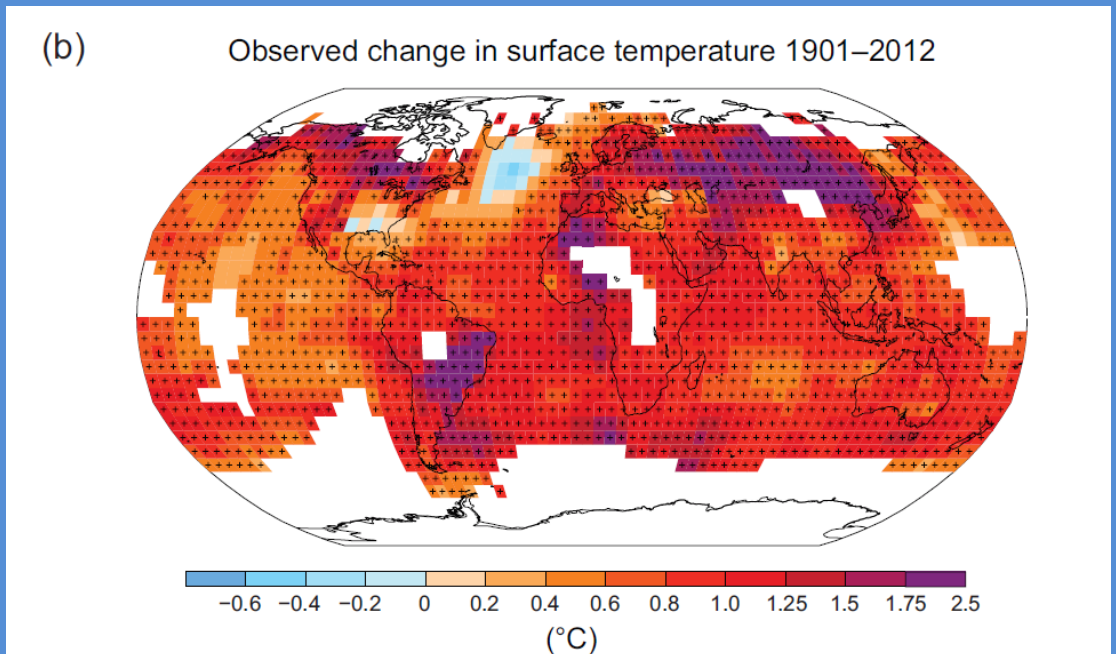
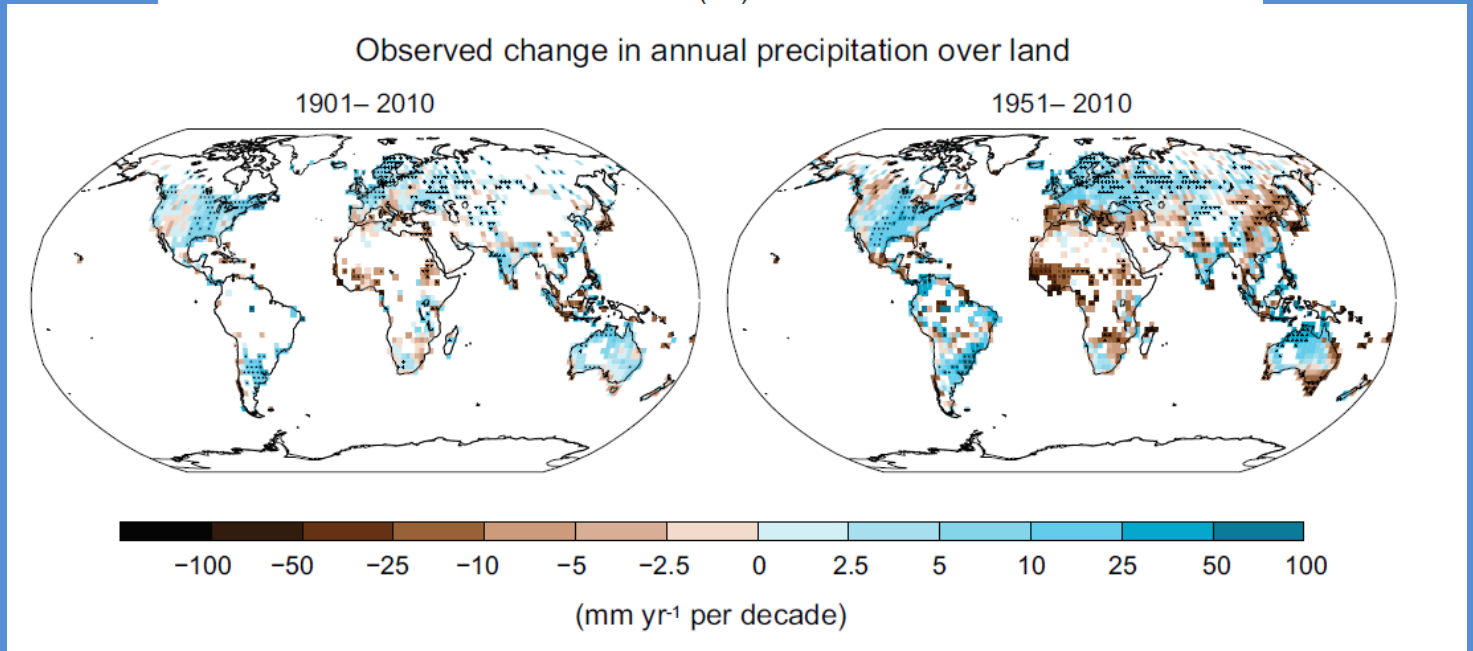
Professor

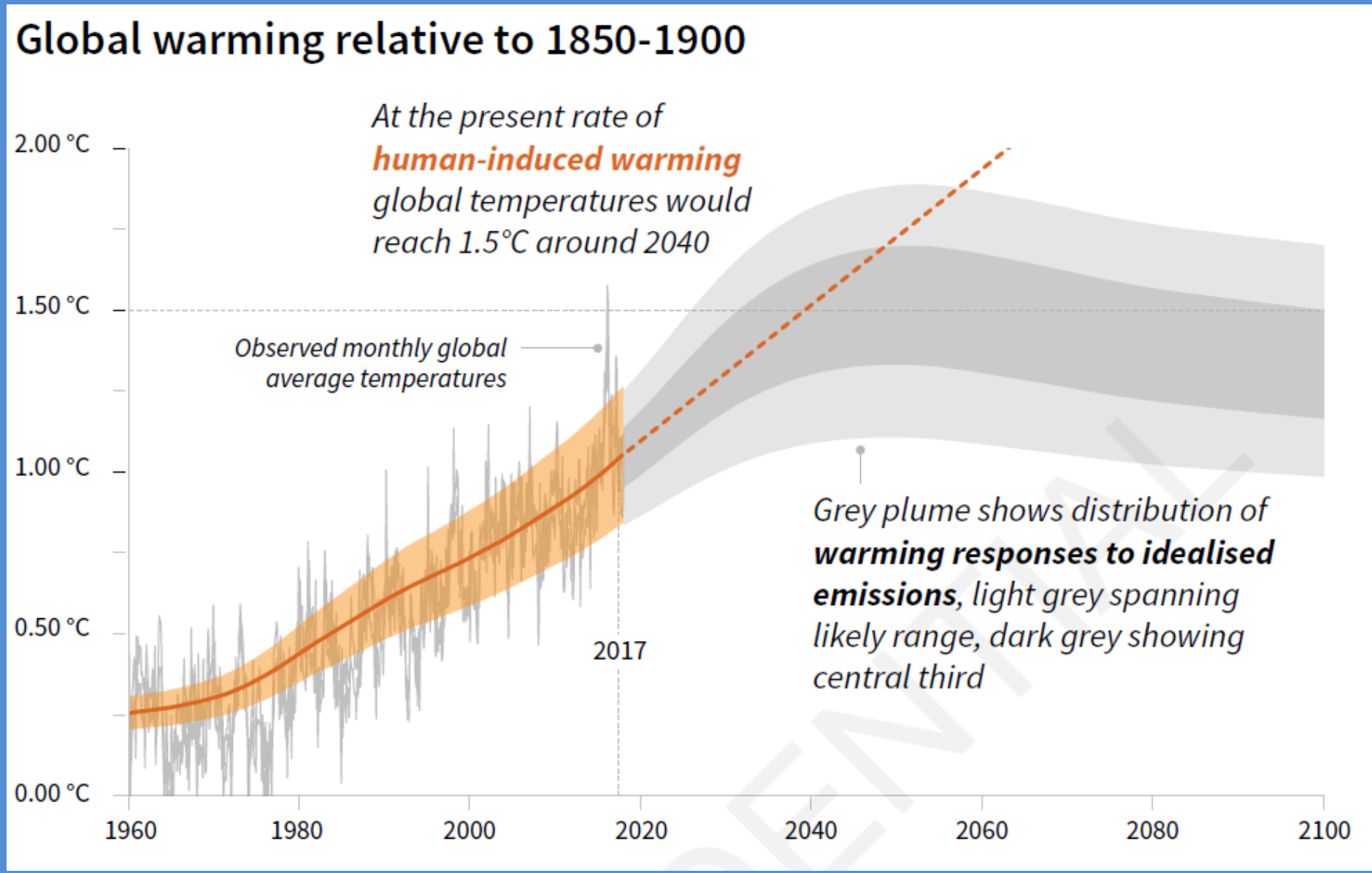
CLIMATE CHANGE IMPACT ON CULTURAL HERITAGE: FACING THE CHALLENGE, 21-22 JUNE 2019, ATHENS, GREECE


Mean global annual temperature anomalies for the period 1880-2018 with respcect to the period 1951-1980
Temperature
CO2
TEMPERATURE (°C)
CO2 (ppmv)
YEAR
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
440
420
400
380
360
340
320
300
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

Spatial distribution of temperature and precipitation changes over the recent past (IPCC, 2013)

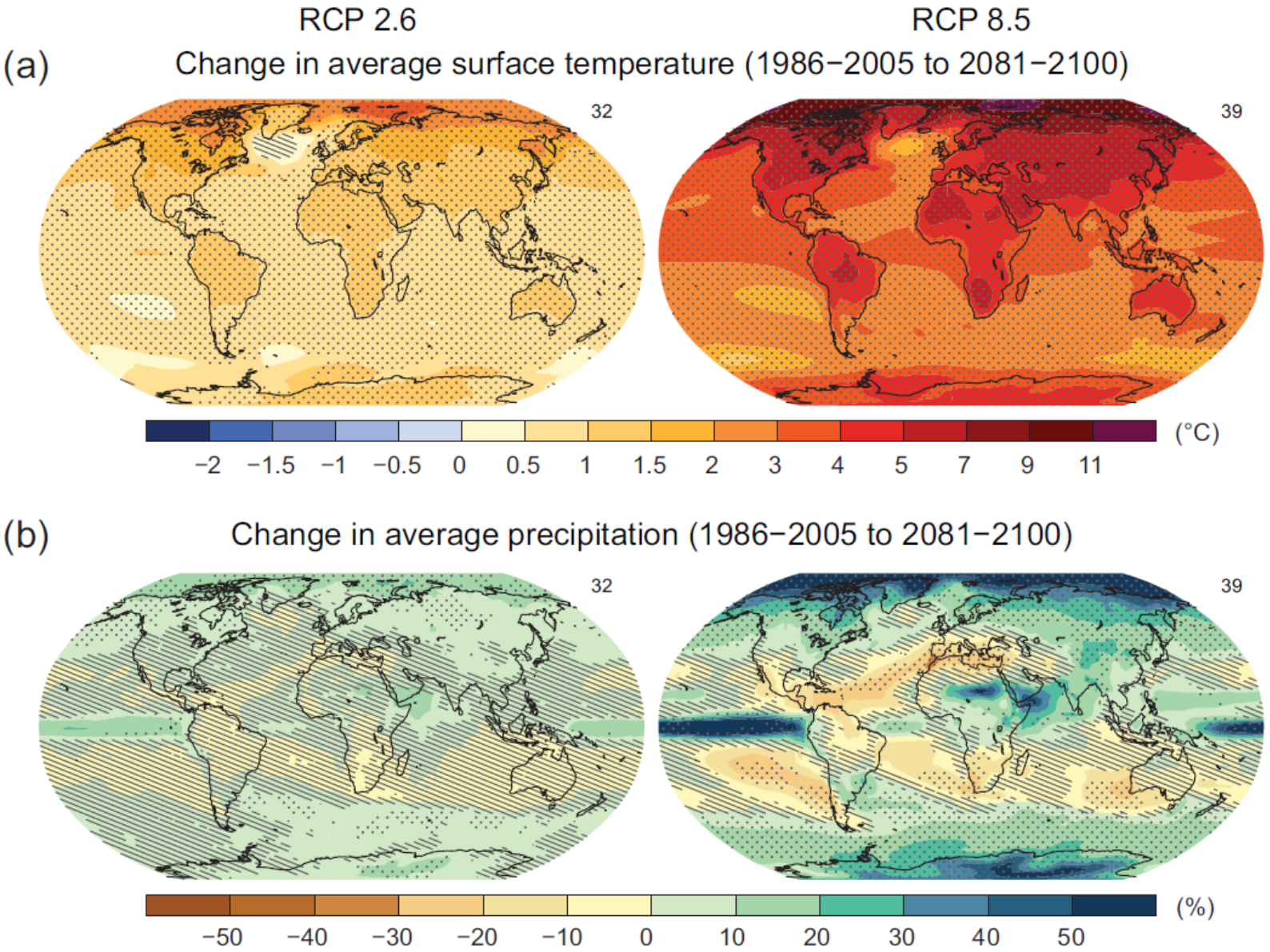




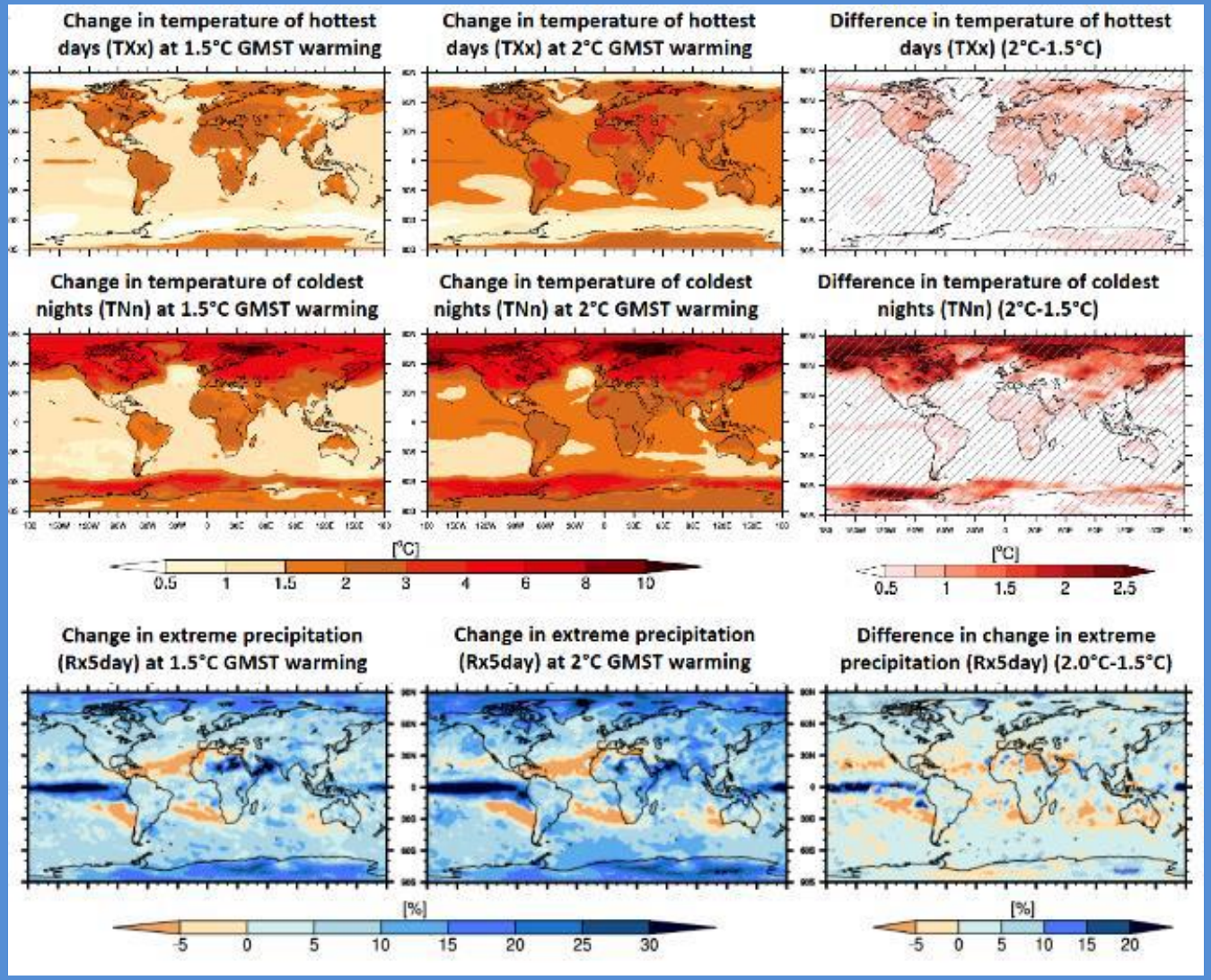


(source: IPCC SR1.5, 2018)

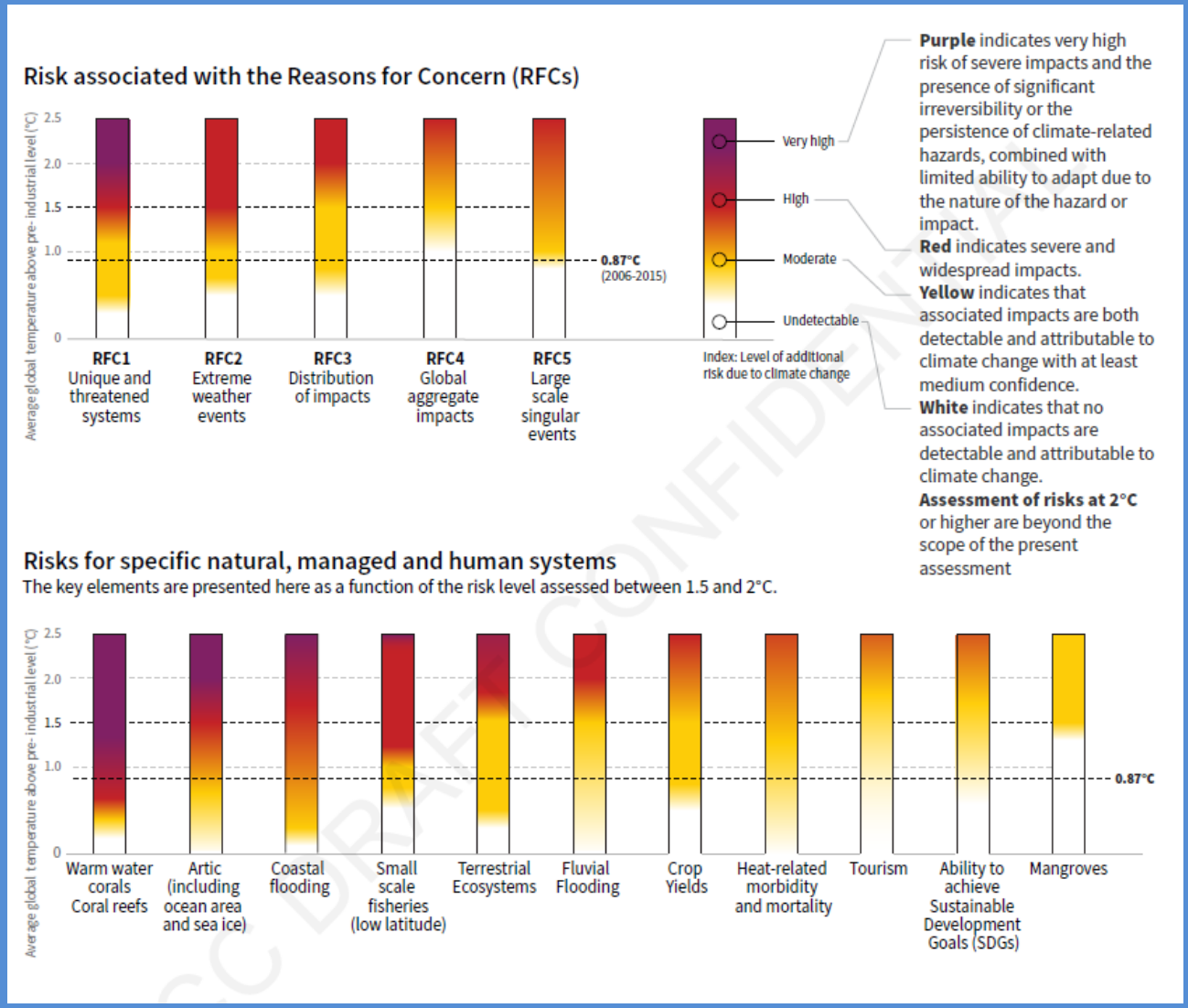
Future projections for temperature and precipitation



Climate change impacts



Projected change in extreme at 1.5°C global warming (left) and 2°C global warming (middle) compared to pre-industrial time period (1861-1880), and difference (right; hatching highlights areas in which 2/3 of the models agree on the sign of change): temperature of annual hottest day, TXx (top), and annual coldest day, TNn, (middle), and annual maximum 5-day precipitation, Rx5day (bottom). (source: IPCC SR1.5)



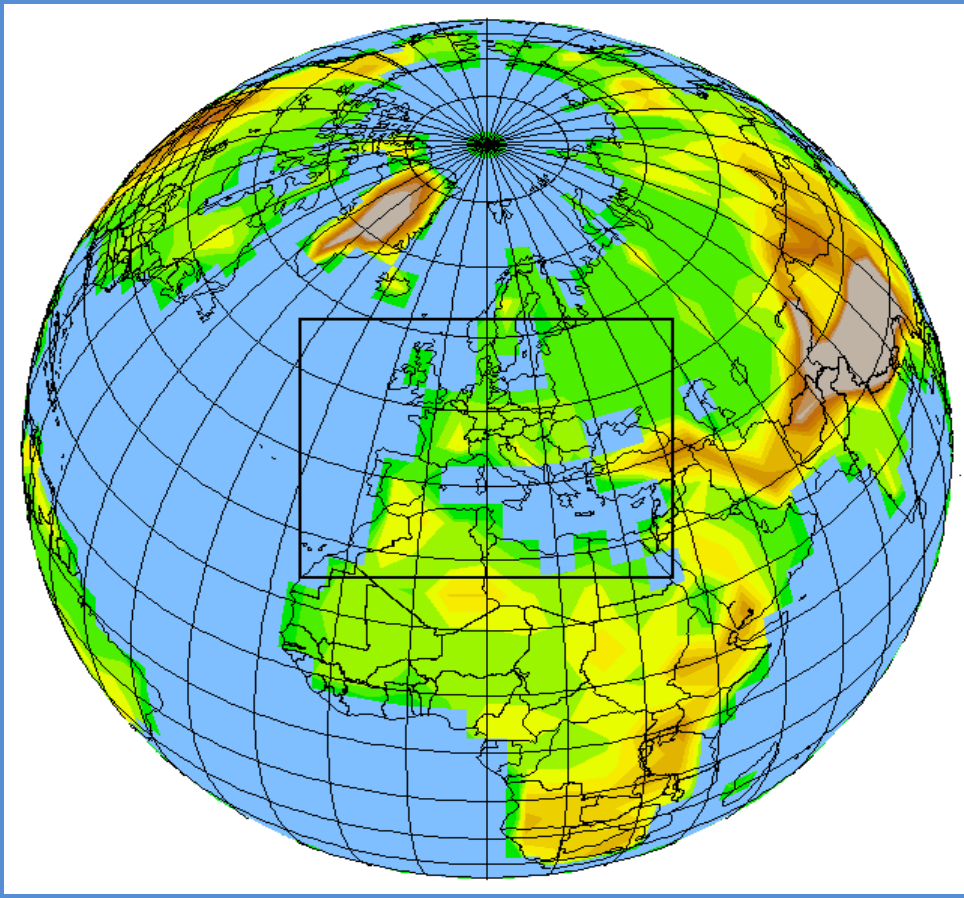
The dependence of risk on the extent of global warming for five Reasons for Concern (RFCs) together with a range of key elements of the Earth system, on the level of global warming. The colour shading indicates the additional risk due to climate change when a temperature level is reached and then sustained or exceeded. Comparison of the increase in risk across RFCs, or across elements, indicates the relative sensitivity to increases in global mean temperature above pre-industrial levels. The RFC component is updated from AR5 with a focus on levels of global warming between 0°C and 2°C global warming. Assessment of risks at higher than 2°C is beyond the scope of the present assessment. (source: IPCC SR1.5)

Impact of climate factors on cultural heritage

Climate parameters	Climate change risk	Physical, social and cultural impacts on cultural heritage
Atmospheric moisture change	• Flooding (sea, river) • Intense rainfall • Changes in soil chemistry • Ground water changes • Increase in time of wetness	• pH changes to buried archaeological evidence • Physical changes to porous building materials • Loss of stratigraphic integrity due to cracking and heaving from changes in sediment moisture
Temperature change	• Diurnal, seasonal, extreme events (heat waves, snow) • Changes in freeze-thaw and ice storms	• Deterioration of facades due to thermal stress • Freeze-thaw/frost damage
Sea level rises	• Coastal flooding • Sea water incursion	• Coastal erosion/loss • Permanent submersion of low lying areas
Wind	• Wind-driven rain • Wind-transported salt • Wind-driven sand • Winds, gusts and changes in direction	• Penetrative moisture into porous cultural heritage materials • Structural damage and collapse • Deterioration of surfaces due to erosion
Desertification	• Drought • Heat waves	• Erosion • Salt weathering
Climate and pollution acting together	• pH precipitation • Changes in deposition of pollutants	• Stone recession by dissolution of carbonates • Blackening of materials • Corrosion of metals
Climate and biological effects	• Proliferation of invasive species • Increase in mould growth • Decline of original plant materials	• Changes in the natural heritage values of cultural heritage sites • Changes in appearance of landscapes

Global Climate Models

- Coupled AOGCMs are the most advanced tools today available for climate simulation
- The resolution of present day AOGCMs (100 – 300 km) is still too coarse to provide fine scale regional climate information useful for impact studies.



Atmospheric Numerical Modeling

Dynamical processes

Wind Forecast Equations

1a. $$\frac{\partial u}{\partial t} = -u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} - \omega\frac{\partial u}{\partial p} + fv - g\frac{\partial z}{\partial x} + F_x$$

1b. $$\frac{\partial v}{\partial t} = -u\frac{\partial v}{\partial x} - v\frac{\partial v}{\partial y} - \omega\frac{\partial v}{\partial p} - fu - g\frac{\partial z}{\partial y} + F_y$$

Continuity Equation

2. $$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial \omega}{\partial p} = 0$$

Temperature Forecast Equation

3. $$\frac{\partial T}{\partial t} = -u\frac{\partial T}{\partial x} - v\frac{\partial T}{\partial y} - \omega\left(\frac{\partial T}{\partial p} - \frac{RT}{c_p p}\right) + \frac{H}{c_p}$$

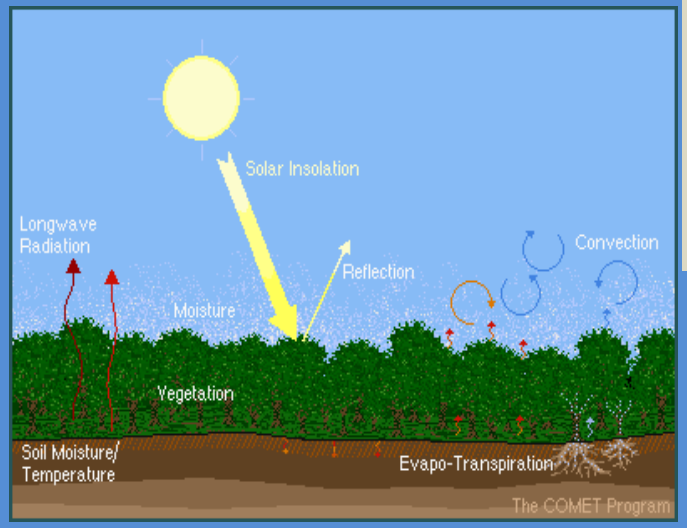
Moisture Forecast Equation

4. $$\frac{\partial q}{\partial t} = -u\frac{\partial q}{\partial x} - v\frac{\partial q}{\partial y} - \omega\frac{\partial q}{\partial p} + E - P$$

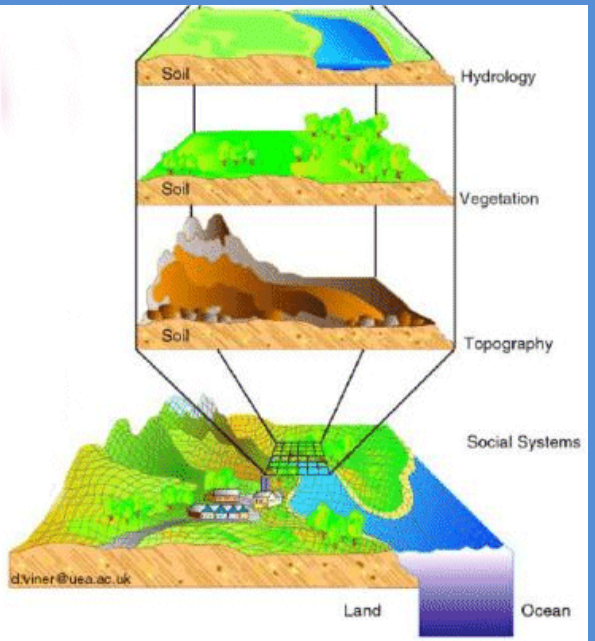
Hydrostatic Equation

5. $$\frac{\partial z}{\partial p} = -\frac{RT}{pg}$$

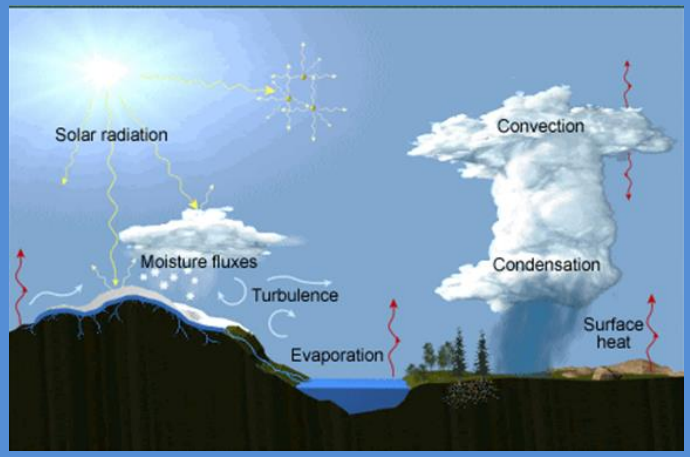
Radiative processes



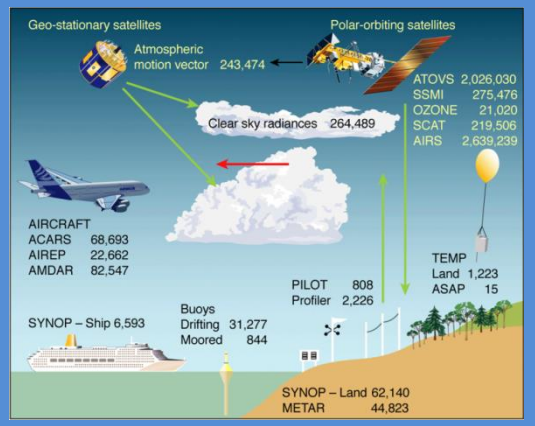
Land-atmosphere interactions



Cloud microphysical processes

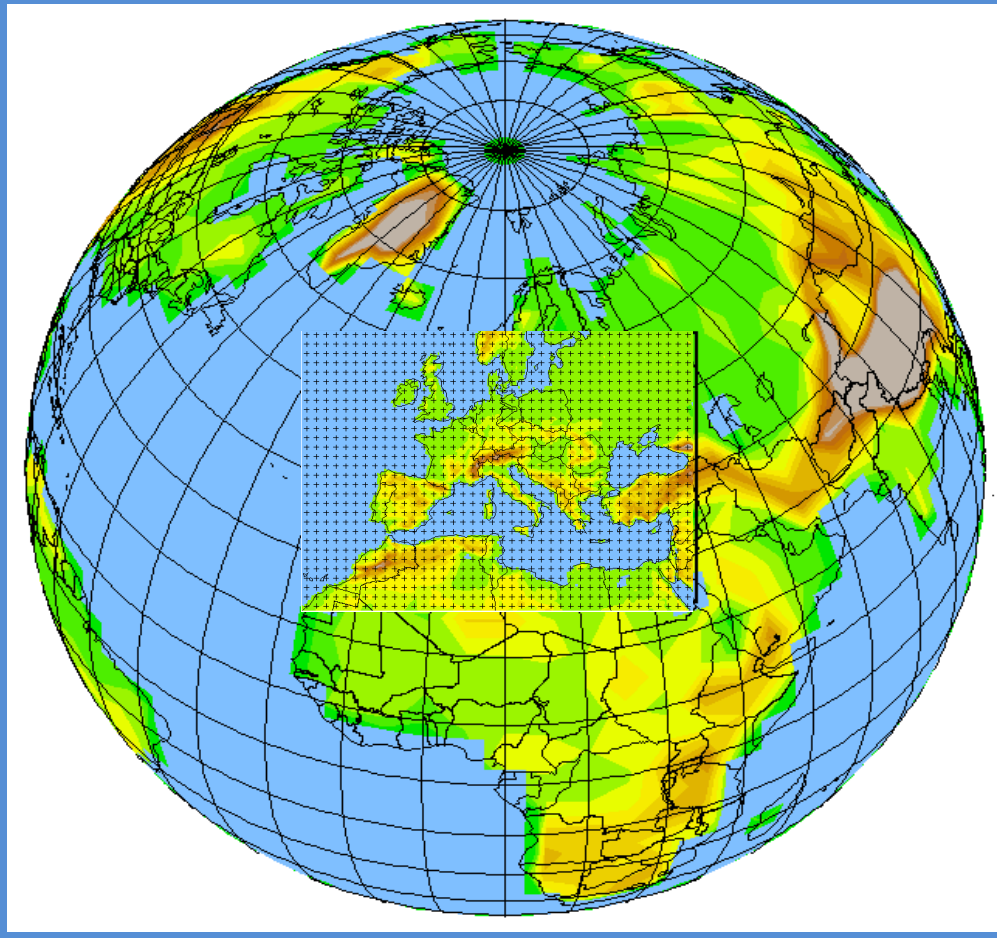


Initial conditions from measurements

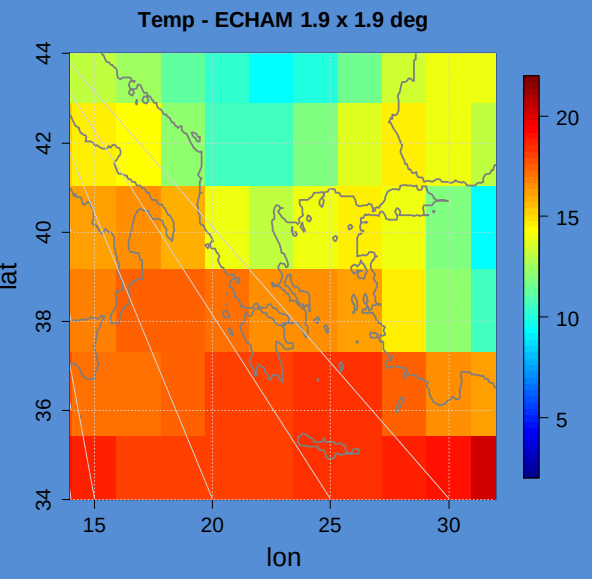


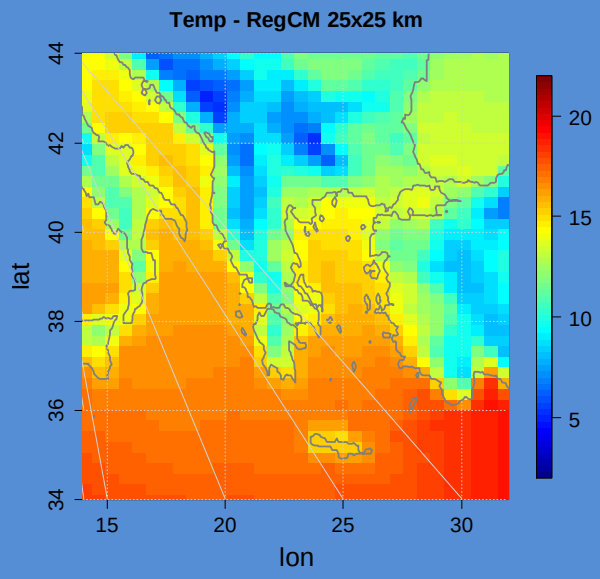
Regional Climate Models

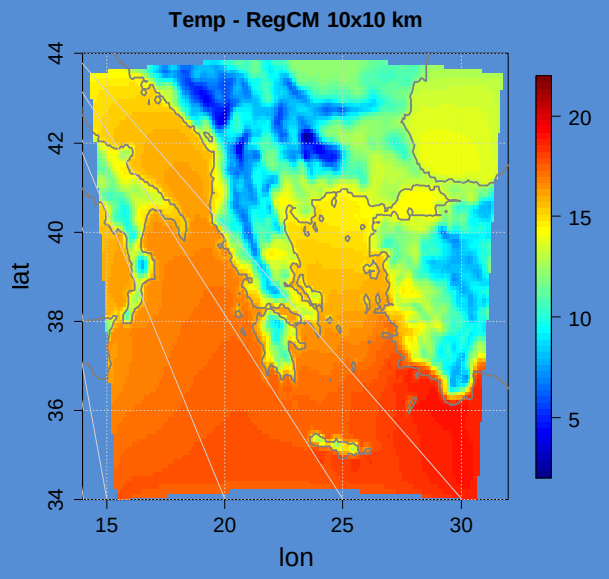
- Technique: A "Regional Climate Model" (RCM) is "nested" within a GCM in order to increase the resolution of a climate simulation.
  - Initial conditions (IC) and lateral boundary conditions (LBC) for the RCM are obtained from the GCM.
- Strategy: The GCM is used to simulate the response of the general circulation to large scale forcings, while the RCM is used to simulate the effect of sub-GCM-grid scale forcings and to provide fine scale regional information
  - The RCM is intended to only enhance the GCM information
- Technique inherited from NWP



Modelled temperature climatology (1975-2000) based on GCMs and RCMs: The effect of resolution



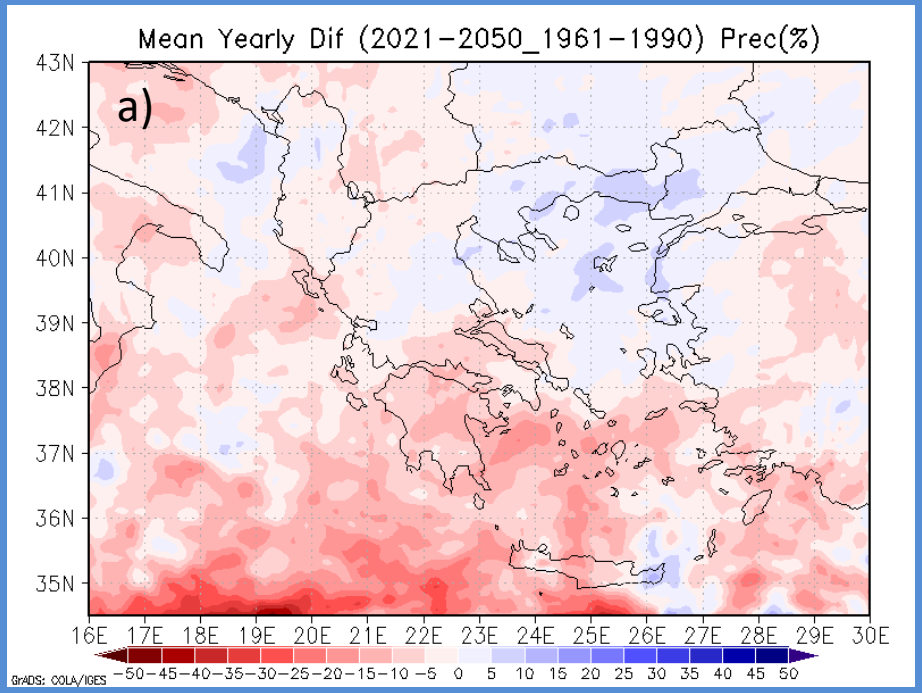


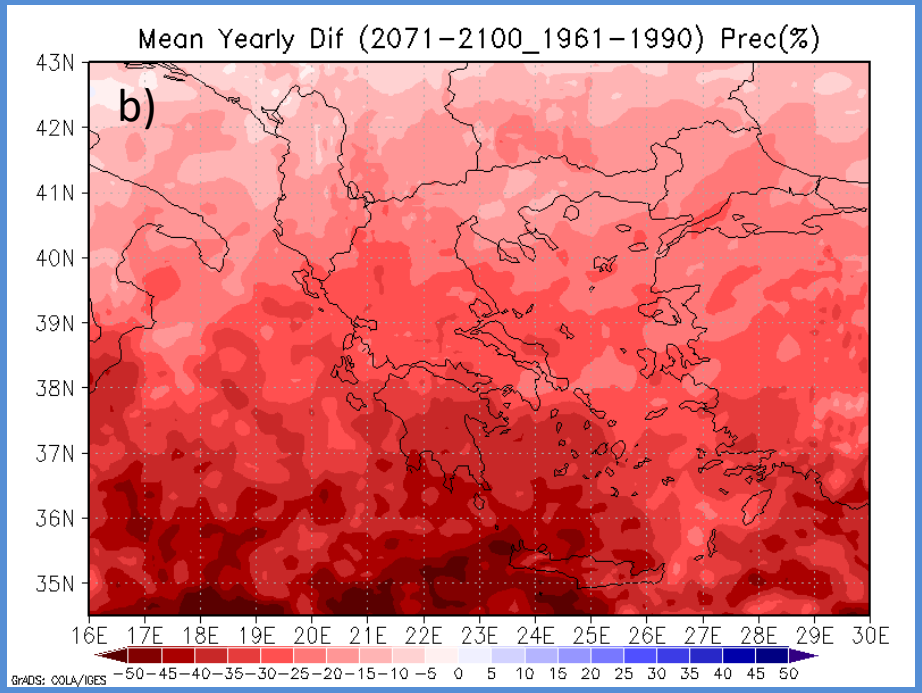


Climate on islands, mountains and coastal areas changes very differently around the Mediterranean Sea and it can only be properly highlighted using a RCM

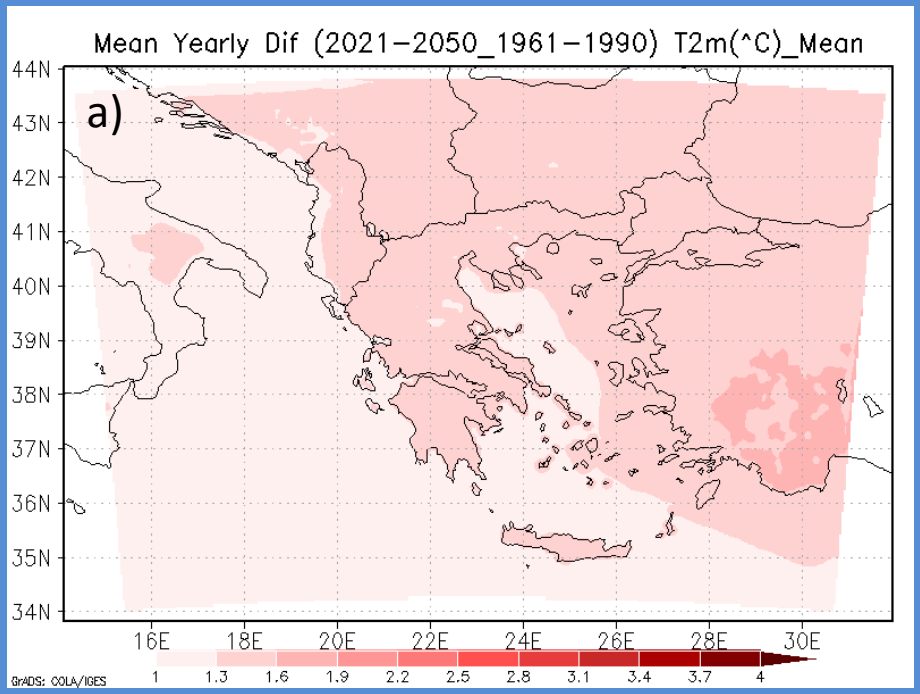
Source: Zanis et al., A transient high resolution regional climate simulation for Greece for the period 1960-2100: Evaluation and future projections, Climate Research, 64: 123–140, doi:10.3354/cr01304, 2015

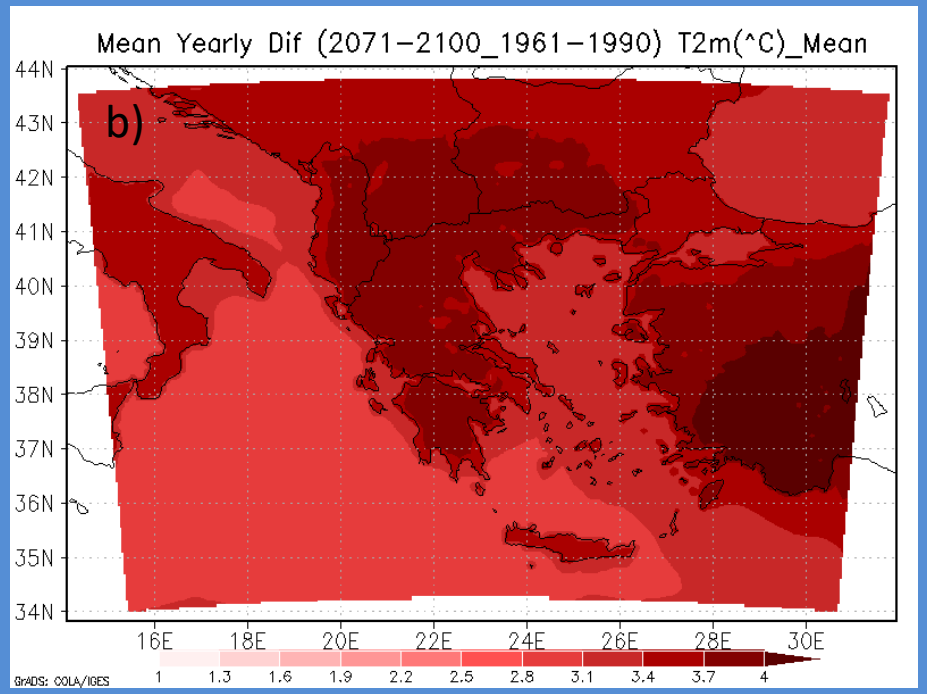
Precipitation changes over the 21st century based on RegCM simulation with 10 km x 10 km under A1B scenario



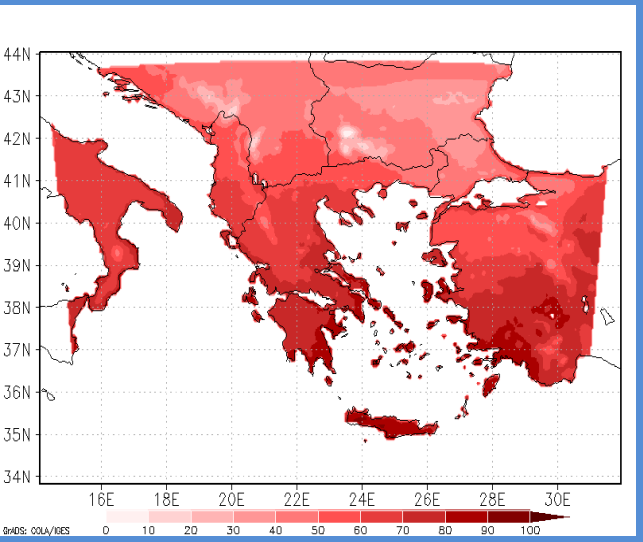


Temperature changes over the 21st century based on RegCM simulation with 10 km x 10 km under A1B scenario

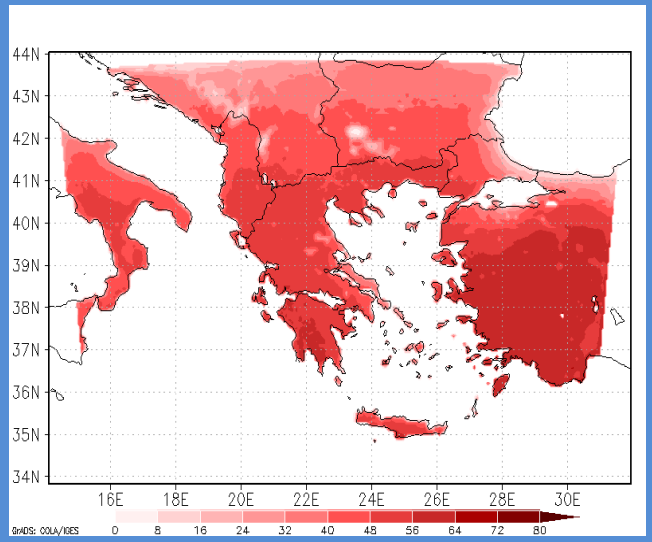




warm nightsTmin>20 ºC

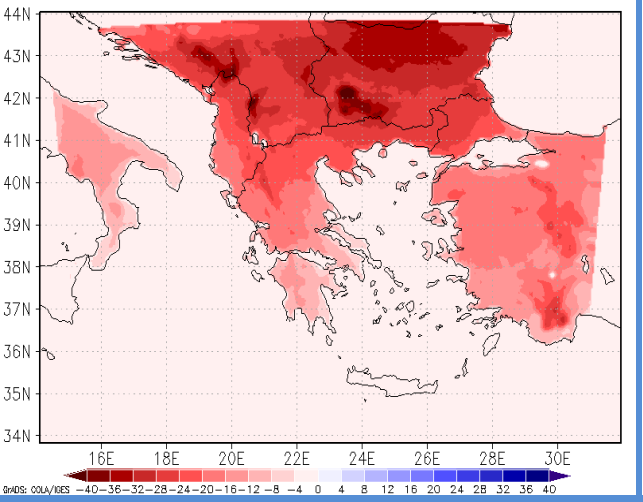


Hot days Tmax>35 ºC

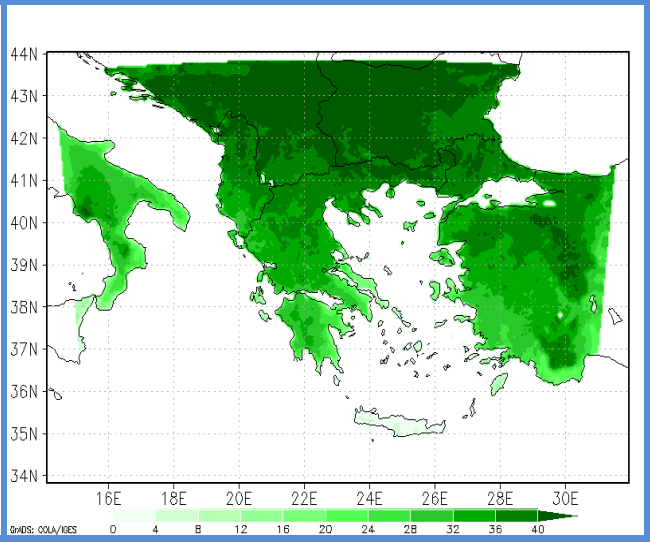


Changes in indices of extremes under A1B scenario 2071-2100 – 1961-1990 – (10 km x 10 km)

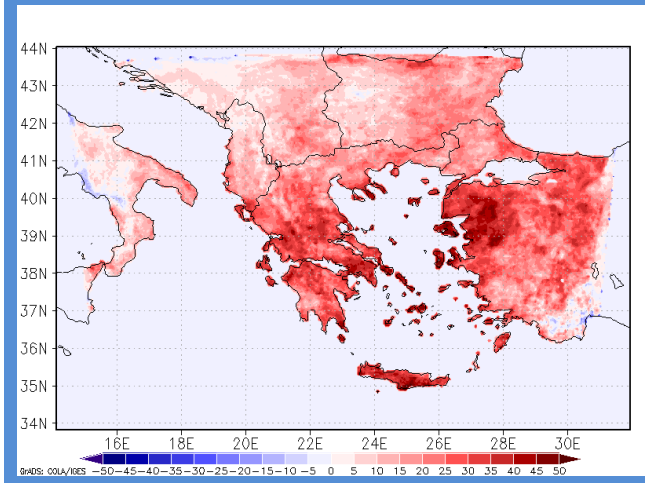
Frost nights Tmin<0 ºC



Growing season



Duration of dry period (PP<1 mm)



Challenges of regional climate change

The Mediterranean (and the surrounded regions) is one of the most sensitive and vulnerable to climate change regions on Earth.

The necessity to exploit the use of vast amount of data produced from existing infrastructures (e.g. earth observations and models , sectoral data) to support intermediary users and end-users and promote the uptake of relevant services and data in response to regional needs.

The need to integrate the different scientific disciplines involved in present and future environmental change in the region.

The need for a holistic approach to efficiently inform policy makers for the mitigation of the risks, support of adaptation strategies and plans, and advise society about the challenges of changing environment.

The need to address regional and local gaps and needs for new market opportunities under a changing environment and facilitate the engagement of regional stakeholders.

Challenges of regional climate change for adaptation and mitigation from the RCMs perspective

To support local/regional climate change impact studies as well as regional adaptation and mitigation strategies it is necessary to use **high resolution** future climate data from model projections based on **RCMs**.

There is plenty of climate change data from **RCMs** in open access databases but restricted usability from non-experts.

There is need for establishing **user friendly web application tools** for intermediary and end-users as well as policy decision makers.

DEAR-Clima

A Data Extraction Application for Regional Climate

http://meteo3.geo.auth.gr:3838/ or http://datahub.geocradle.eu/dataset/dear-clima

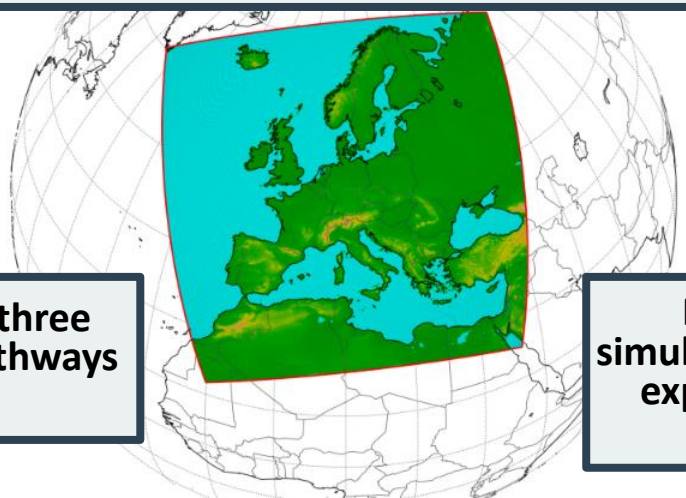
- **DEAR-Clima is a user friendly dynamical web application tool that extracts, visualizes and provides time series of essential climate variables and climate indices**

DEAR-Clima | Home | Domain | Experiments | Scenarios | Variables | Application | About | Contact

Domain

The domain of the application is the EURO-CORDEX domain which covers the greater area of Europe including the Mediterranean and a part of N.Africa. The spatial resolution of the CORDEX simulations used in this application is 11°x11°. The approximate center of the boundaries is 27°N-72°N and 22°W-45°E, while the center point of the domain lies is 49.68°N and 9.75°E. More information about the domain can be found in EURO-CORDEX website.

Extract Climate Information above Europe and N.Africa (EURO-Cordex Domain) in ~12 km resolution.



Future Projection are based on three Representative Concentration Pathways (RCPs)

More than 32 regional climate simulations to choose from the CORDEX experiments ranging for the period 1950-2100.

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Climate Variables

The climate projection application provides historical and future projections of the following essential climate variables.

$$Near\ surface\ daily\ Average\ air\ Temperature \quad (^{\circ}C)$$

$$Near\ surface\ daily\ Maximum\ air\ Temperature \quad (^{\circ}C)$$

$$Near\ surface\ daily\ Minimum\ air\ Temperature \quad (^{\circ}C)$$

$$Near\ surface\ Wind\ Speed \quad (m \cdot s^{-1})$$

$$Precipitation \quad (mm \cdot day^{-1})$$

$$Surface\ Solar\ Radiation \quad (W \cdot m^{-2})$$

$$Surface\ Air\ Pressure \quad (hPa)$$

$$Near\ surface\ Specific\ Humidity \quad (mg \cdot kg^{-1})$$

- Near surface stands for ~2m.
- Downward surface solar radiation is set to be positive.

8 Essential Climate Variable to extract and...

DEAR-Clima

A Data Extraction Application for Regional Climate

http://meteo3.geo.auth.gr:3838/

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Climate Indices

...13 Climate Indices related to Drought, Wet Heat and Cold days.

Drought

Consecutive Dry Days (CDD): Number of consecutive (C) days within a year where precipiration (RR) is lower than 1mm.

$$CDD = C(RR_{daily} < 1mm) \qquad (days)$$

Consecutive Dry Days Periods (CDDP): Number of periods within a year where precipiration (RR) is lower than 1mm. Each period is constituted of five consecutive (C) dry days.

$$CDDP = Periods(C(RR_{5days} < 1mm)) \qquad (periods)$$

Wet

Consecutive Wet Days (CWD): Number of consecutive (C) days within a year where precipiration (RR) is higher than 1mm.

$$CWD = C(RR_{daily} > 1mm) \qquad (days)$$

Consecutive Wet Days Periods (CWDP): Number of periods within a year where precipiration (RR) is higher than 1mm. Each period is constituted of five consecutive (C) wet days.

Summer Days (SU): Number of days within a year where daily maximum temperature (Tmax) is greater than 25C.

$$SU = Tmax_{daily} > 25^{\circ}C \qquad (days)$$

Consecutive Summer Days (CSU): Maximum number of consecutive (C) days within a year where daily maximum temperature (Tmax) is greater than 25C.

$$CSU = C(Tmax_{daily} > 25^{\circ}C) \qquad (days)$$

Hot Days (HD): Number of days within a year where daily maximum temperature (Tmax) is greater than 35C.

$$HD = C(Tmax_{daily} > 35^{\circ}C) \qquad (days)$$

Tropical Nights (TR): Number of days within a year where daily minimum temperature (Tmin) is greater than 20C.

$$TR = C(Tmin_{daily} > 20^{\circ}C) \qquad (days)$$

Cold

Frost Days (FD): Number of days within a year where daily minimum temperature (Tmin) is below 0C.

$$FD = Tmin_{daily} < 0^{\circ}C \qquad (days)$$

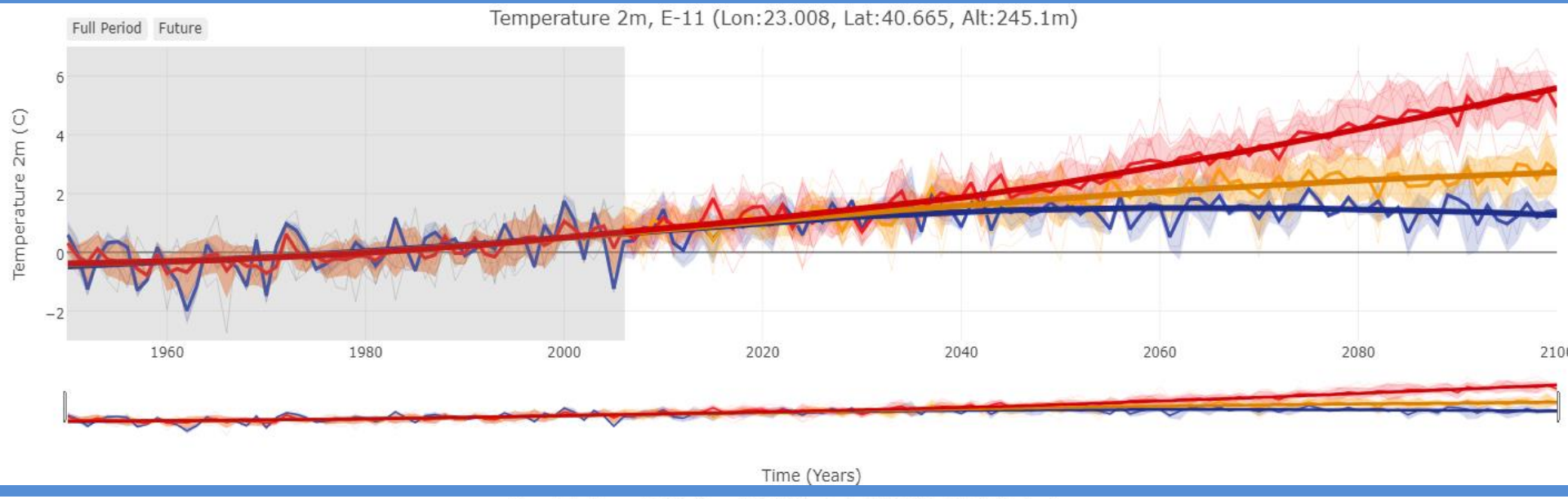
Consecutive Frost Days (CFD): Maximum number of consecutive (C) days within a year where daily minimum temperature (Tmin) is below 0C.

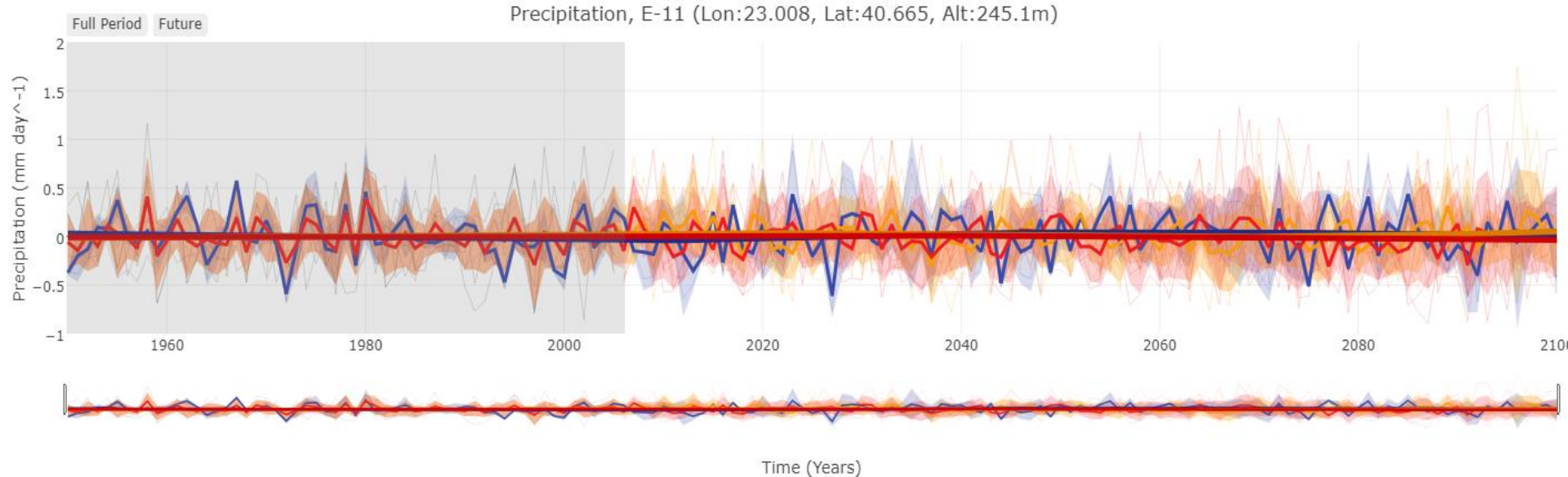
$$CFD = C(Tmin_{daily} < 0^{\circ}C) \qquad (days)$$

Ice days (ID): Number of days within a year where daily maximum temperature (Tmax) is below 0C.

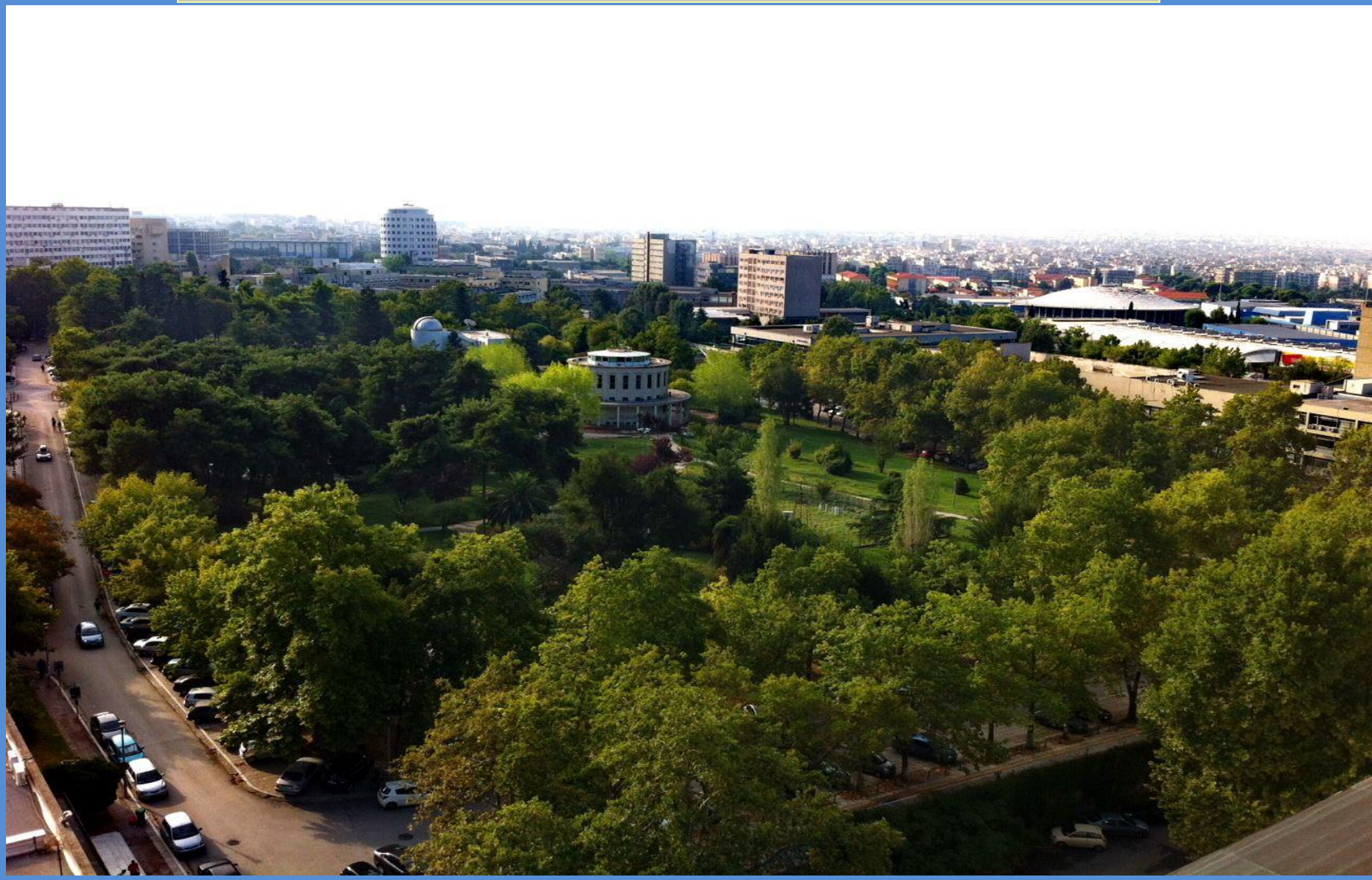
$$ID = C(Tmax_{daily} < 0^{\circ}C) \qquad (days)$$

Temperature change at Thessaloniki

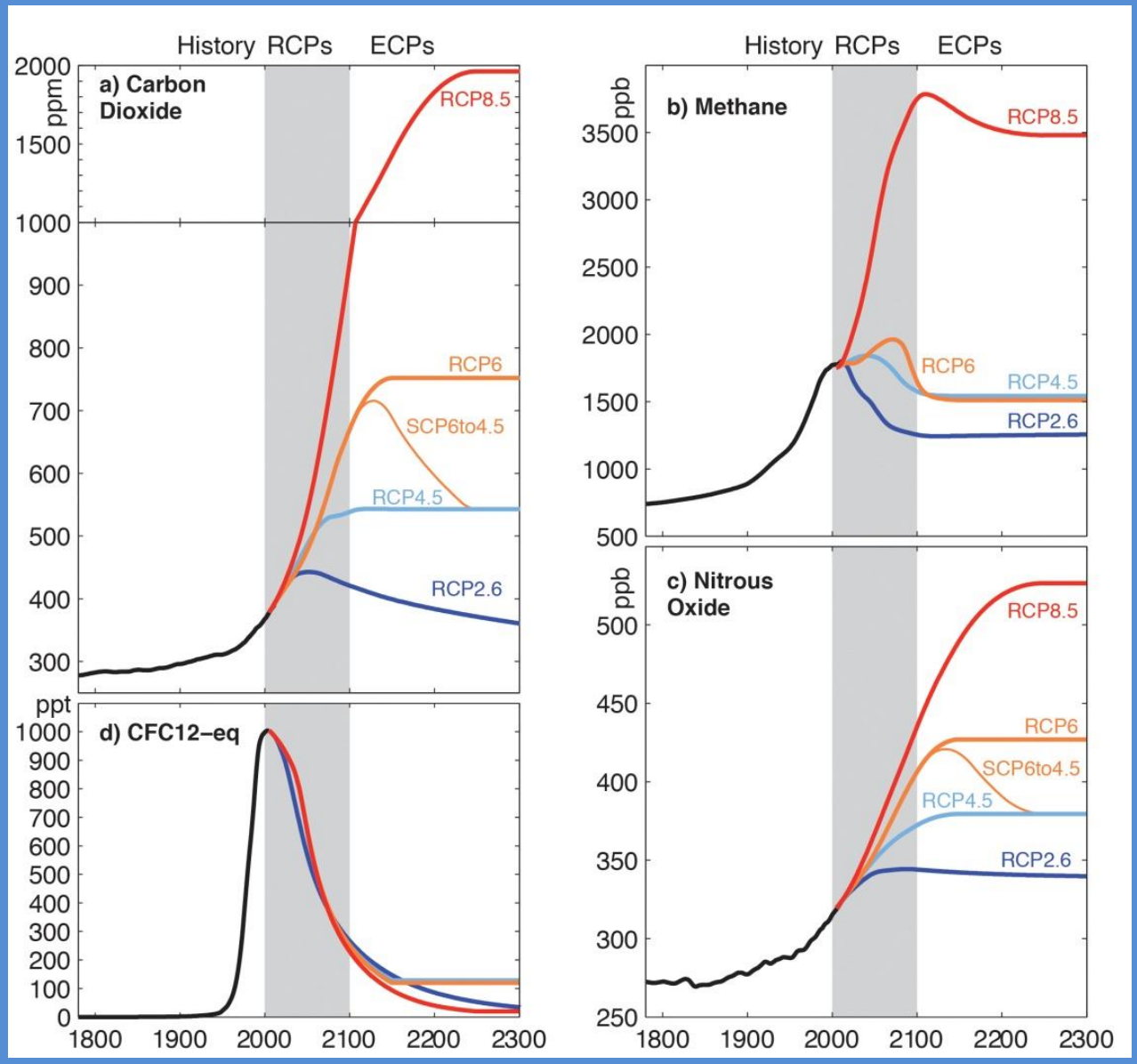




Thanks for your attention



Σενάρια Εκπομπών - IPCC 2013



Context and Objectives

Context

- **For Adaptation to Climate Change (ACC) is essential the use of high resolution future climate data from model projections.**
- **There is plenty of climate change data in open access databases but restricted usability from non-experts.**
- **There is need for establishing user friendly web application tools for intermediary and end-users.**

Objectives

- **The DEAR-Clima is a dynamical web application tool that visualizes and extracts time series of essential climate variables and climate indices for intermediary and end-users working on ACC as well as by researchers working on climate change impact studies.**
- **It can be also used for educational activities by students.**

The DEAR-Clima application tool

RCM projections EURO-CORDEX 1950-2100

- **The data are based on high horizontal resolution Regional Climate Model (RCM) simulations from the CORDEX research program with a high spatial resolution (0.11°) over the European domain and cover a time period from 1950 to 2100.**

- **The historical period of each experiment refers to 1950-2004, while the future period is 2006-2100 under the influence of three Representative Concentration Pathways (RCPs) adopted by the IPCC for its fifth Assessment Report (AR5); rcp26, rcp45 and rcp85.**

- **The simulation experiments are a product of various RCMs driven by several Global Climate Models (GCMs).**

Scenario	GCMModel	RCMModel
rcp26	CNRM-CERFACS-CNRM-CM5	CNRM-ALADIN53
rcp26	MPI-M-MPI-ESM-LR	MPI-CSC-REMO2009
rcp45	CNRM-CERFACS-CNRM-CM5	CLMcom-CCLM4-8-17
rcp45	CNRM-CERFACS-CNRM-CM5	CNRM-ALADIN53
rcp45	ICHEC-EC-EARTH	KNMI-RACMO22E
rcp45	IPSL-IPSL-CM5A-MR	IPSL-INERIS-WRF331F
rcp45	IPSL-IPSL-CM5A-MR	SMHI-RCA4
rcp45	MOHC-HadGEM2-ES	CLMcom-CCLM4-8-17
rcp45	MOHC-HadGEM2-ES	SMHI-RCA4
rcp45	MPI-M-MPI-ESM-LR	CLMcom-CCLM4-8-17
rcp45	MPI-M-MPI-ESM-LR	MPI-CSC-REMO2009
rcp85	CNRM-CERFACS-CNRM-CM5	CLMcom-CCLM4-8-17
rcp85	CNRM-CERFACS-CNRM-CM5	CNRM-ALADIN53
rcp85	ICHEC-EC-EARTH	KNMI-RACMO22E
rcp85	IPSL-IPSL-CM5A-MR	IPSL-INERIS-WRF331F
rcp85	IPSL-IPSL-CM5A-MR	SMHI-RCA4
rcp85	MOHC-HadGEM2-ES	CLMcom-CCLM4-8-17
rcp85	MOHC-HadGEM2-ES	SMHI-RCA4
rcp85	MPI-M-MPI-ESM-LR	CLMcom-CCLM4-8-17
rcp85	MPI-M-MPI-ESM-LR	MPI-CSC-REMO2009

DEAR-Clima application tool

List of Essential Climate Variables (ECVs) and Climate Indices (CI)

Climate Indices		Relevance
CI1	Mean near surface temperature	Fundamental
CI2	Precipitation rate	Fundamental
CI3	Maximum near surface temperature	Fundamental, extremes
CI4	Minimum near surface temperature	Fundamental, extremes
CI5	Wind speed at 10m, 50m, 100m and 200m	Fundamental, Energy, natural disasters
CI6	Surface absorbed solar radiation	Fundamental, Energy, Tourism, Agriculture
CI7	95th percentile of rain day amounts	Extremes, natural disasters
CI8	95th percentile of wind speed at 10 m	Extremes, natural disasters
CI9	Annual greatest 5-day total rainfall	Extremes, natural disasters
C10	Fraction % of total rainfall from events> long-term P90	Extremes, natural disasters
C11	Number of events > long-term 90th percentile of rain days	Extremes, natural disasters
CI12	Number of frost days Tmin < 0 degC	Extremes
CI13	Heat Wave Duration Index	Agriculture,Tourism
CI14	Standardized Precipitation Index (SPI)	Agriculture,Water resources
CI15	Potential evaporation	Agriculture
CI16	Growing season duration (GSD)	Agriculture
CI17	Tourism Climate Index (TCI)	Tourism
CI18	Snow depth (SnowD)	Tourism
CI19	Heating Degree Day (HDD)	Energy
CI20	Cooling Degree Day (CDD)	Energy