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Re-Gen
Risk Assessment of Ageing Infrastructure

Report of Climate Change Predictions (including key variables)

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Executive summary

According to climate change predictions Europe will go through dramatic changes in the near future. More floods, drier summers and wetter winters are expected, along with the rise of sea levels and increase of winds. The operational issues imposed on road networks by the change in temperature, precipitation, sea level etc. are already recognised. The goal of this report is to summarise the current available data on climate change predictions and its reliability, and also to state the direct impact that climate change effects have on infrastructure elements.

Chapter 1 provides an introduction to climate change effects, both on a global and a regional level, with negative and positive impacts to economy, society and especially infrastructure network.

Climate change predictions are presented in Chapter 2 of this report. General information on Assessment Reports and Climate Change Models is provided. Data gathered from IPCC's reports on climate change (contributions to 4th and 5th Assessment Report) is presented alongside data from European project ENSEMBLES.

Chapter 3 summarises the main challenges imposed on road networks. It brings together data gathered from the survey which was a part of CEDR's Adaptation to Climate Change report, in which crucial impacts are stated together with practical mitigation strategies.

It is concluded that a risk assessment tool which considers climate change effects will greatly help road owners/managers with prioritising and management of infrastructure impacted by the effects of climate change, but it is also stressed out that as a preventive measure in the future climate change effects must also be considered in the design phase. An appropriate risk framework to deal with these issues is a necessity.

1 Introduction

The terms “weather” and “climate” are often used interchangeably and are commonly mistaken for one and the same, when in fact, although intertwined, they have different connotations. The term weather is defined as the variable state of the atmosphere at a given time and place. Climate, on the contrary, refers to statistical weather conditions over a decade or a more.

According to IPCC’s Climate Change Report 2013, future climate conditions can be predicted without the need for accurate long-term weather forecasts (IPCC, 2013). Climate is often defined by the statistical long-term averages of rainfall and air temperatures in conjunction with the variability of these parameters (measured through the standard deviation). The term climatological averages refers to averages of climate variables over long-term period, months, years, decades etc. It is important to emphasise how climate predictions do not provide daily detailed forecasts for future periods, however weather forecasts do. Accurate weather forecasts rely on detailed information about the current state of the atmosphere.

Climate change is a term much talked about, while climate change impacts receive much less attention. In the last few decades, organisations at both national and international levels have made efforts to raise awareness by involving scientists from across the world to develop possible climate change scenarios, which are dependent on societal behaviour with respect to energy consumption and greenhouse gas emissions. IPCC’s reports state it is clear by now that even if patterns in energy usage were to change dramatically, some effects are irreversible and must be incorporated into the design of the infrastructure elements.

As noted by the IPCC’s reports there is strong evidence that most of the warming observed in the last 50 years is due to human activities.These changes have led to large-scale environmental hazards, such as: extreme weather, ozone depletion, loss of biodiversity, food producing system stress, and spread of global diseases (Gilbert et al., 2008). According to available published data much less research has been conducted on the impacts of climate change on health, food supply, economic growth, migration, security, societal change and public goods (drinking water) than to geophysical changes. The impacts of climate change on infrastructure network have also suffered from a lack of research.

Figure 1. Flooding in Deggendorf - Danube River taken from Spiegel Online (Getty Images, 2013)

Thresholds are exceeded more often, such as extreme weather events and/or abrupt climate change in combination to limited access to financial, technical, human resources. The photo of summer floods in Germany, presented above in Figure 1, shows a non-typical extreme weather event for the summertime period. Such events cause disruption to the transport system and can lead to human casualties and economic damage. Following the retreat of the flood water, additional infrastructure threats may emerge due to cascading and interdependent effects. For example, landslides may be triggered by instability caused by the changes in soil-water pressures or localised erosion. The consequences of such events may lead to additional infrastructure damage and distribution.

The term “climate injustice” is often used to capture the concept that the developing countries are far worse affected by climate change effects even though the last 50 developing countries of the world account for just over 1% of the worldwide greenhouse gas emissions, according to Global Humanitarian Forum (2009).

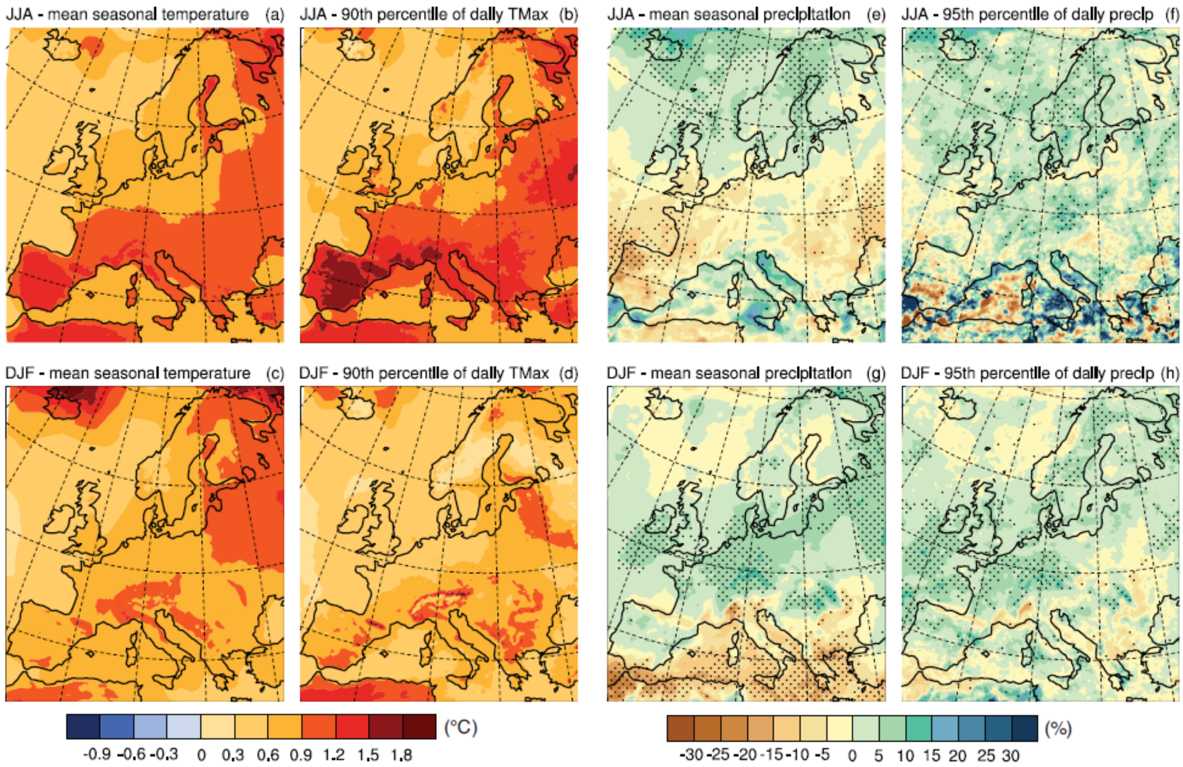

Figure 2. European-scale projections for ENSEMBLES project 2016-2035 relative to 1986-2005 for winter (DJF) and summer (JJA) period. According to IPCC, Climate Change 2013 (IPCC, 2013).

According to both global and regional models, climate change will impose a lot of operational issues for both road networks in Europe and worldwide as stated in Adaptation to Climate Change report (CEDR, 2012). Keeping in mind that global warming will not affect all the regions in the same manner and some road managers will actually benefit from positive effects; in the northern regions less snow fall will be expected and therefore less salt will be needed in the winter on their roads which will have a positive impact on several deterioration mechanisms. However on a European wide basis, the impacts of climate change on our society will primarily be negative. Adaptation to Climate Change, a report issued by CEDR also states that these impacts are expected to include more frequent natural hazards such as floods, wind/rain storms, and droughts, which then subsequently lead to landslides (CEDR, 2012). A lot of changes will not appear to have a hazardous impact in the first instance, but their repetitive long-term presence will have negative effects on the infrastructure elements in form of deterioration mechanisms which lead to degradation of elements built out of concrete, steel and earth. The relationship between these deterioration mechanism and climate change impacts are of main interest in Re-Gen project.

Regionally, the climate is expected to be changed in Europe during this century according to findings of ENSEMBLES project, shown in Figure 2 (ClimateCost, 2012). Mean annual temperature will rise by between 1ºC and 5.5 ºC. The annual precipitation is likely to increase in the North and decrease in the South, while mean annual wind speeds are expected to increase in the northern regions and decrease in the Mediterranean regions. Extreme wind speeds are likely to increase in Western and Central Europe as well as in the Northern Sea. Sea level is expected to rise by up to 90 cm, before the end of this century. Figure 2 shows projections for temperature and precipitation for period 2016-2035.

According to Adaptation to Climate Change, Europe will be divided into two regions when it comes to climate change: (i) Northern and Eastern Europe, where warmer and wetter winters with an increase in severe rain storms will be the main challenges and (ii) Southern, Western and Central will form another region where extremely warm and dry summers will be the dominant issue. Each of these regions will have their own challenges when it comes to impact of climate change effects on infrastructure elements (CEDR, 2012).

Greenhouse gas emissions have been a significant contributor toward climate change. According to distribution by economic sectors for year 2010 presented in IPCC's report Climate Change 2013 (Working Group 3), presented in Figure 3 transport contributed 14% by direct emission and 0.3% by indirect emission (IPCC, 2013). Transport is important for modern civilisation, and with ongoing growth in the Global population, we can anticipate emissions will increase further. Therefore the irreversible climate change effects must be incorporated into the design of future infrastructure elements.

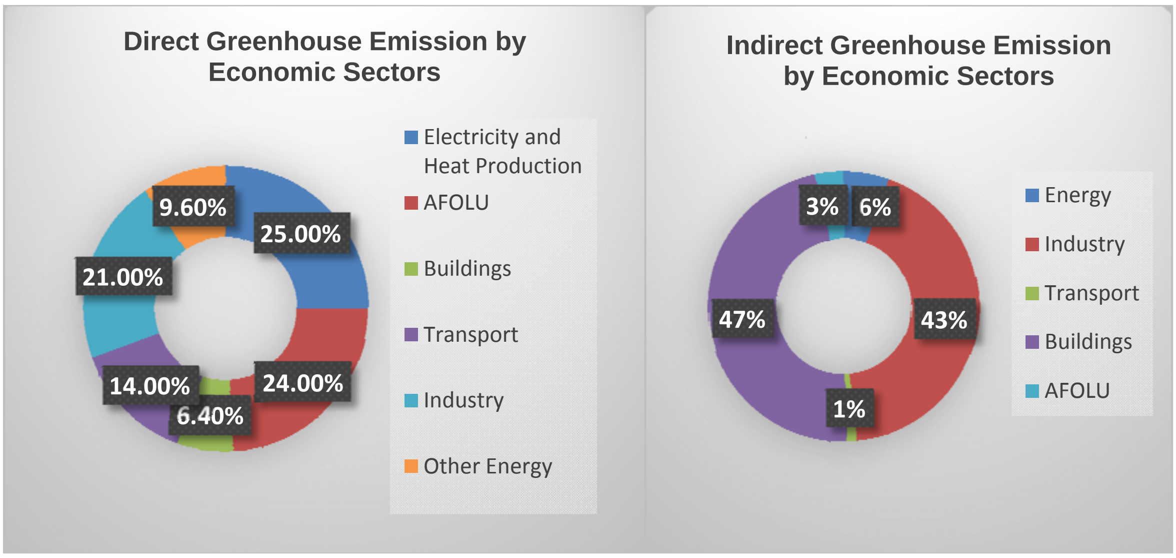

Figure 3. Greenhouse Gas Emissions by Economic Sectors according to data given by IPCC's report Climate Change 2013

Possible events of climate change on road infrastructure elements can be categorized in low, medium and high scenarios in order to help identify the probable risk of deterioration expected. The final product of Re-Gen project is a risk assessment tool, which will help road authorities with maintenance and operation of existing roads but also significantly contribute toward planning and design of future infrastructure elements. This tool will consider the impact of different climate change prediction scenarios.

2 Climate change predictions

2.1 Scope of report in relation to the Re-Gen project

The scope of work for this report is a desk study, which reviews recent findings and research on general climate change predictions and how climate change relates to infrastructure.

The purpose of this report is to summarise recent findings on climate change effects and to state their impact on infrastructure elements. The climate scenarios to be used in subsequent work packages, will also be defined within this deliverable.

This report is not concerned with weather forecasts and only considers climate change predictions. Some of the climate change scenarios considered in this report yield significant changes in the relevant parameters. The changes in temperature, precipitation and sea level will be of main interest for Re-Gen project as these parameters have the biggest influence on the deterioration of infrastructure elements.

This report primarily focuses on the given climatological data published by the IPCC in their Climate Change 2007 and Climate Change 2013 reports, respectively contributions to AR4 and AR5 and additional data from other European projects.

In short, climate projections indicate the response of the climate system to emission or concentration scenarios and are based on simulations by climate change models.

As predicted data will later be incorporated into a risk assessment tool, this report will also sum up some of the most common climate change effects and their consequential influence on infrastructure elements. Some of the common deterioration mechanisms are considered alongside the current adaption strategies in European countries. The flow path of relevant data is shown below in Figure 4.

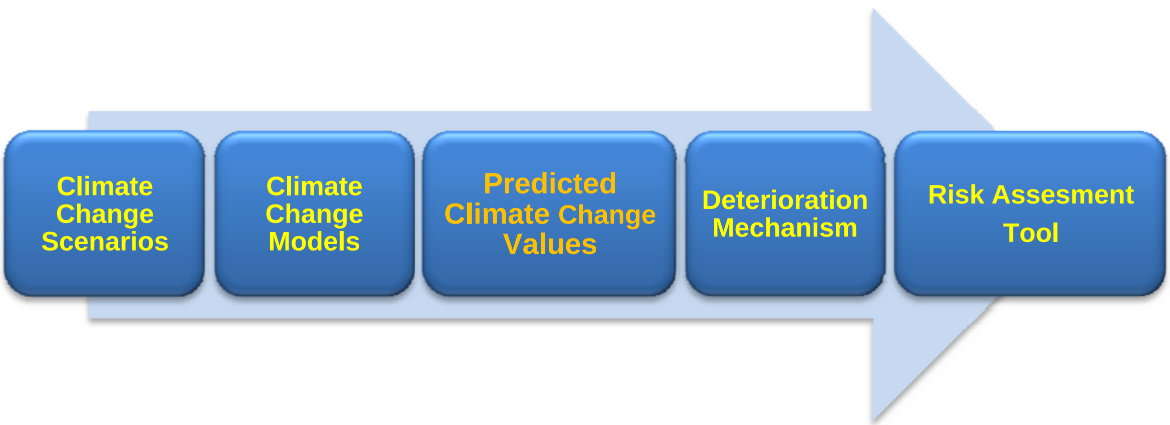

Figure 4. Flow chart for climate change data for Re-Gen project

2.2 IPCC reports overview

The Intergovernmental Panel on Climate Change (IPCC) is a scientific intergovernmental body supported by the United Nations Framework Convention on Climate Change (UNFCCC), which is the main international treaty on climate change with an objective to stabilise greenhouse gas concentrations in the atmosphere at a level that poses no threat to humans.
IPCC reports cover scientific, technical and socio-economic information relevant to understanding the impacts of climate change (Wikipedia, 2014). The IPCC is not involved in climate monitoring and does not carry out its own original research, but is based on published literature (IPCC, 2014). The increase in complexity of models used for the reports is shown in Figure 5.

Reports issued out by IPCC:

- **First assessment report (FAR, 1990)**
  This was the initial report that confirmed emissions from human activities were leading to increased greenhouse gas emissions. The consequential increase in global temperature was noted as 0.3ºC per decade. A supplementary report was added in 1992, following the Earth Summit in Rio de Janeiro, with an accent on improved time dependent simulations of climate change projections.

- **Second assessment report (SAR, 1995)**
  The report concluded that: greenhouse gas concentrations have continued to increase; anthropogenic aerosols continue to produce negative radiation; climate has changed since the late 19th century, air temperature has increased by 0.3-0.6ºC; there is a discernible human influence on global climate; and simulations confirmed that climate will continue changing.

- **Third assessment report (TAR, 2001)**
  This report concluded that human emitted greenhouse gases have increased substantially; warming over the 21st century is at more rapid rate than experienced in the last 10 000 years; some climate change effects will be beneficial, some ecosystems and species will be irreversibly damaged; GHG (Greenhouse gas) emission reduction will lessen the pressure on climate change; adaption to the effects of climate change will not prevent all damage but it will help to minimise potential negative effects.

- **Fourth assessment report (AR4, 2007)**
  AR4 (along with AR5) is based on published data gained by improved models which considers biogeochemical cycles important to climate change, as shown in Figure 5. AR4 notes that even if GHG emissions were reduced, sea levels would continue to rise due to the time scales associated with climate processes. If not lessened, climate change will lead to exhaustion of natural capacities. However climate change effects can be reduced, delayed and mitigated by changed societal behaviour.

- **Fifth assessment report (AR5, 2014)**
  The AR5 report concluded that changes since the middle of the last century are without a precedent, and include several decades with an increase of concentrations of greenhouse gases, such as carbon dioxide, methane, and nitrous oxide. Human influence was estimated 95-100% probability to be the dominant cause. It was noted that even if emission of GHG is reduced, already emitted concentrations will persist in

the environment for many centuries. Projections in AR5 are based on Representative Concentration Pathways (RCPs)

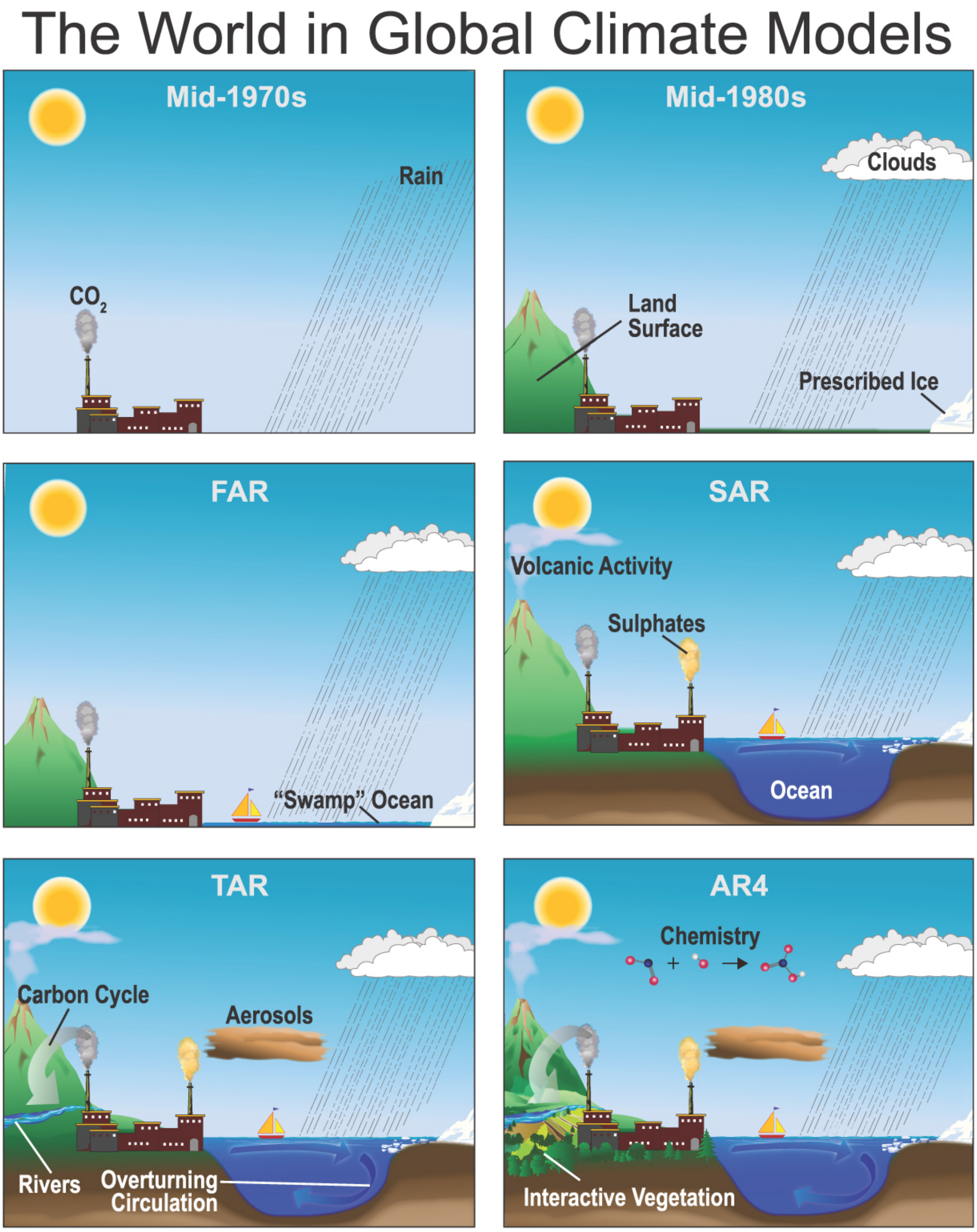

Figure 5. The increase of complexity of climate change predication models presented in Assessment Reports (IPCC, 2007)

2.2.1 Representative Concentration Pathways (RCPs)

The Intergovernmental Panel on Climate Change (IPCC) has produced several of assessment reports on climate change.

The fifth, currently final report, AR5, provides a clear and up to date view of scientific knowledge relevant to climate change. This report recognises that climate change predictions depend on greenhouse gas concentrations. Representative Concentration Pathways (RCPs) are trajectories of four greenhouse gas concentrations (not emissions) adopted by the IPCC for AR5 and are related to four possible climate futures. The concentration pathways are widely used for climate modelling and research. The four RCPs, RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m^2).

2.2.2 Special Report on Emission Scenarios (SRES)

The Special Report on Emission Scenarios (SRES), is an IPCC report, published in 2000. The greenhouse emission scenarios were used to make projections of possible future climate change. The SRES scenarios were used in the third assessment report (TAR, 2001) and once again in the fourth assessment report (AR4, 2007). The SRES scenarios had an economic and environmental focus with consideration of either globalisation or regionalisation in society as shown in Table 1.
The scenarios do not take into consideration possible future disasters and/or catastrophes such as wars and environmental collapse, and therefore are considered to be neutral.

Table 1. SRES Scenario Families composed according to IPCC's Special Report – Emission Scenarios 2000

SRES Scenario Families		
AR4	Economic Focus	Environmental Focus
Globalisation	**A1** rapid economic growth (A1T; A1B; A1FI)	**B1** global environmental sustainability
Regionalisation	**A2** regionally oriented economic development	**B2** local environmental sustainability

All A1 scenarios are characterized by rapid economic growth, and quick spread of new and efficient technologies, with an emphasis as it follows:

- A1FI - An emphasis on fossil-fuels (Fossil Intensive).
- A1B - A balanced emphasis on all energy sources.
- A1T - Emphasis on non-fossil energy sources.

2.3 Climate Change Models

2.3.1 General on global and regional models

Climate change models are the primary tools available for (i) investigating the response of climate system to various actions, (ii) for making climate predictions on seasonal to decadal time scales and (iii) for making projections of future climate over the coming century and beyond. These models use quantitative methods in order to simulate interactions between land surface, ocean, atmosphere and ice. The most common use of these models is to predict temperatures changes due to increasing in greenhouse gases concentrations in the atmosphere. Climate Change model types are presented in Table 2.

Table 2. Climate Change Model Types composed according to IPCC's report Climate Change 2013

Most Used Climate Change Models	Atmosphere – Ocean General Circulation Models
	Earth System Models & Earth System Models of Intermediate Complexity
	Regional Climate Models

Climate Change Models range from simple to complex:

AOGCMs=Atmosphere-Ocean General Circulation Models are considered to be standard models and predictions using this type of models were published in AR4. These models incorporate the dynamics of the physical components of the climate system such as atmosphere, ocean, ice etc. and make projections based on future GHG and aerosol forcings.

ESMs=Earth System Models are currently state of the art models and are the most comprehensive tools available. ESMs are more advanced versions of AOGCMs and they include various biogeochemical cycles (i.e. carbon and sulphur cycles).

EMICs=Earth System Models of Intermediate Complexity deal with certain scientific questions and at a lower level that the two previously stated models, but still we cannot call them simple because they realistically represent the large scale-geographical structures of the Earth, like the shape of continents and ocean basins, which is certainly not the case for simple climate models.

GSMs=Global Climate Change Models are coupled atmosphere/ocean/sea-ice general circulation models which provide a comprehensive representation of the climate system. Downscaling such models provides us with RCMs.

RCMs=Regional Climate Models are limited to a specific area. Usually global models are dynamically downscaled, in order to provide specified data for chosen location.
Since Re-Gen is focused on the European Road Network, European regional models will be of most interest.
Evaluation of the accuracy of various climate models was undertaken in the Coupled Model Intercomparison Projects (CMIP 3 & CMIP 5) which involved a set of coordinated and

consistent documented climate model experiments and provide form of quantification of model uncertainty by comparing predicted and observed values.

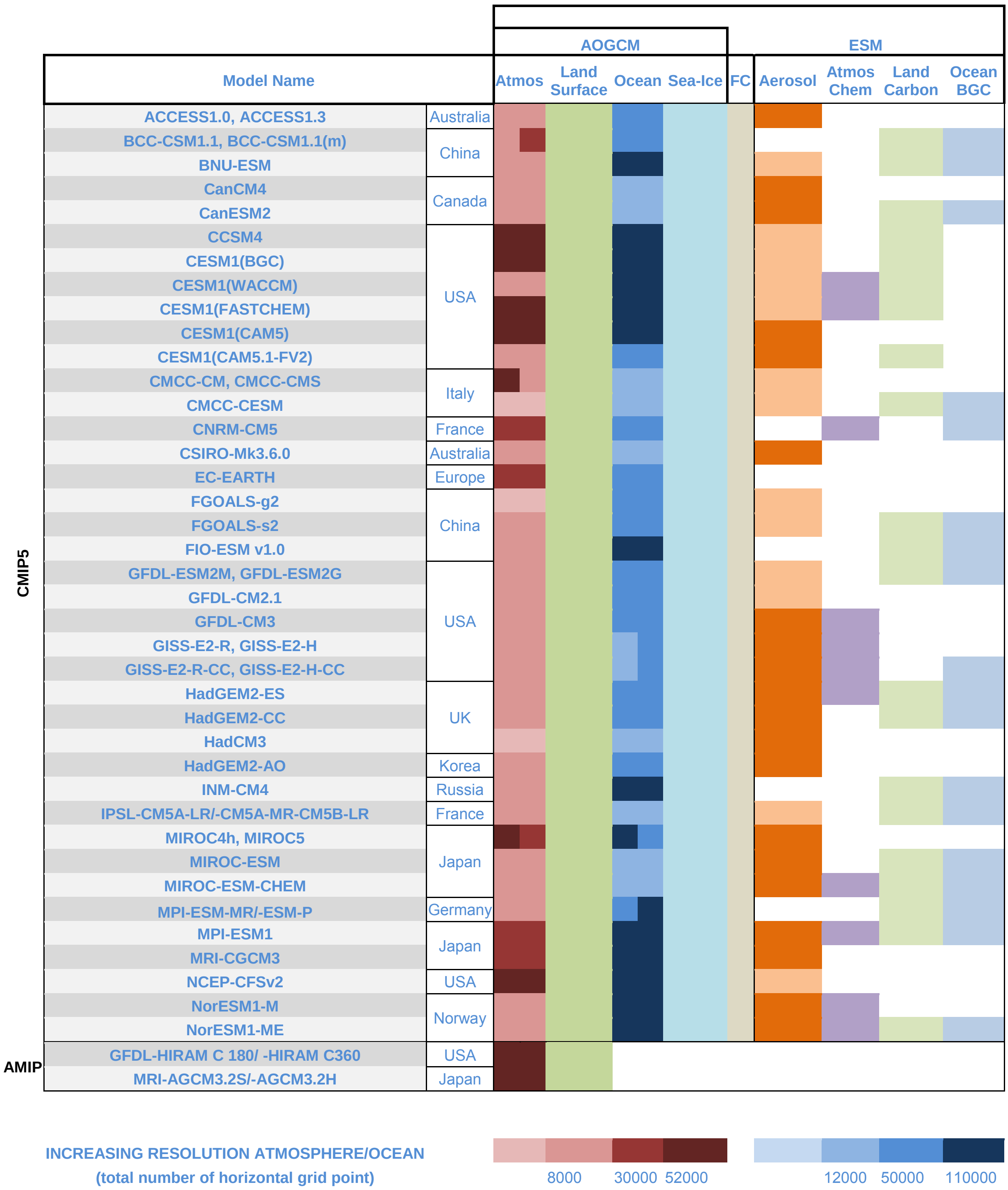

Figure 6. Coupled Model Intercomparsion Projects modified according to Climate Change 2013 (IPCC, 2013)

Figure 6 presents the main features (components and resolutions) of AOGCMs and ESMs which formed Coupled Model Intercomparison Project, Phase 5.

2.3.2 FP 6 project ENSEMBLES

ENSEMBLES, an integrated research project, was running from 2004 to 2009, and it has produced probabilistic projections of climate for Europe. Ensembles is also a term used for a group of parallel model simulations. For ENSEMBLES, A1B was chosen as the baseline scenario, due to the strong emission which is consistent with real emissions growth. Also a new stabilisation was developed, called E1, in order to limit the long-term radiative forcing to an equivalent of 450-ppm of CO_2 (estimated to limit global warming by 2 degrees). According to Summary of ClimateCost project results E1, projections only differ from A1B significantly in projection after 2040. Mean global temperature is projected to increase by 1 ºC in period 2011-2040 relative to period 1961-1990 which is taken as a baseline, this emphasises the need for adaption and mitigation (ClimateCost 2012).

Similar to CMIP 3, uncertainty was estimated by variation of results across the ensemble members. Ensembles which consist of the same model, but different initial conditions, only characterise the uncertainty associated with internal climate variability, where ensembles made out of several different models and simulations made by them, also include impact of model differences.

2.4 Climate change projections (globally and regionally for Europe)

2.4.1 General overview

IPCC and European funded research projects have provided us with a broad range of data on changes in temperature, precipitation, sea level, gas emission and other future predictions impacted by climate change. The climate change predictions that fall under the scope of this report are considered in the subsequent sections.

2.4.2 Temperature and Precipitation according to European and Global Climate Change projections (Summary of ClimateCost project results)

The ClimateCost project has considered three emission scenarios. A1B is considered to be a medium to high non mitigation (baseline) scenario; E1 is a mitigation scenario that stabilises global temperature change at 2ºC above preindustrial levels and RCP8.5, (previously discussed), as the high emission scenario (ClimateCost, 2012).

Figure 7 shows baseline for the A1B (red) and E1 (green) emissions scenarios. Results from the ENSEMBLES project GCM runs. The blue line shows the EC-Earth RCP8.5 model run, the narrow lines show individual models, and the thick red and green lines show ensemble mean.

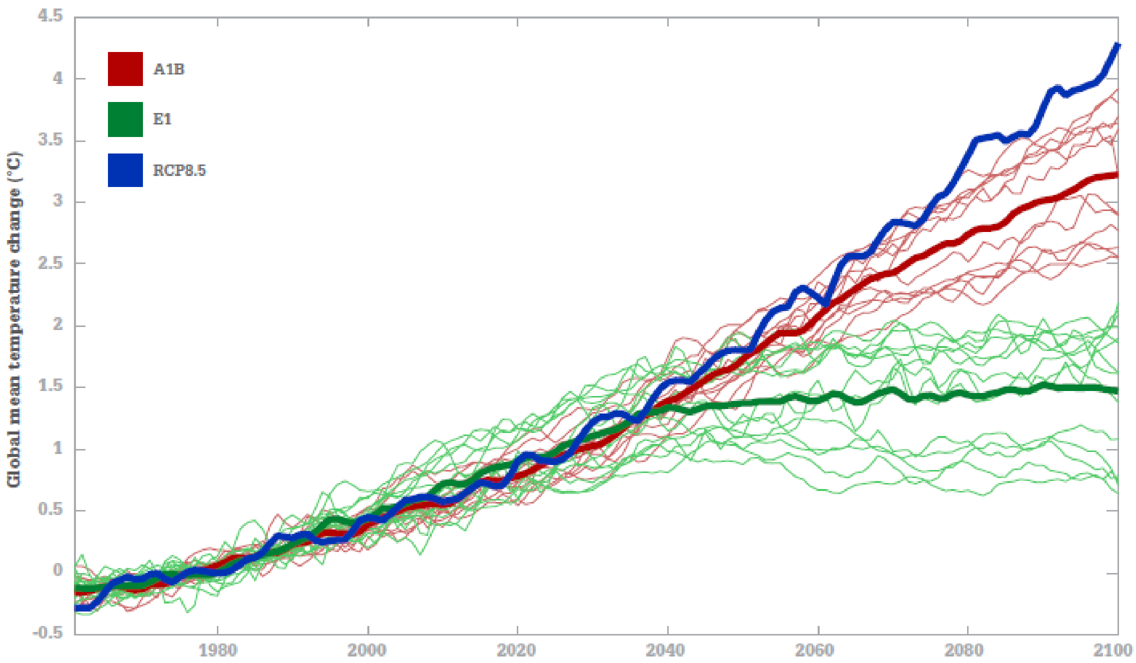

Figure 7. Projected change in global mean temperature (°C) with respect to the 1961-1990 taken from Summary of ClimateCost project *results* (ClimateCost 2012).

Figure 8 shows the trends 1) over time for the median A1B change from 1961-1990 for 2011-2040, 2041-2070 and 2070-2099, 2) for different scenarios with the A1B and E1 median scenarios for 2070-2099 and 3) the range across the alternative model projections for the same time period and emissions scenario (the central panel shows the central, the left the lowest and the right the highest of the models considered, all for the period 2070-2099 A1B).

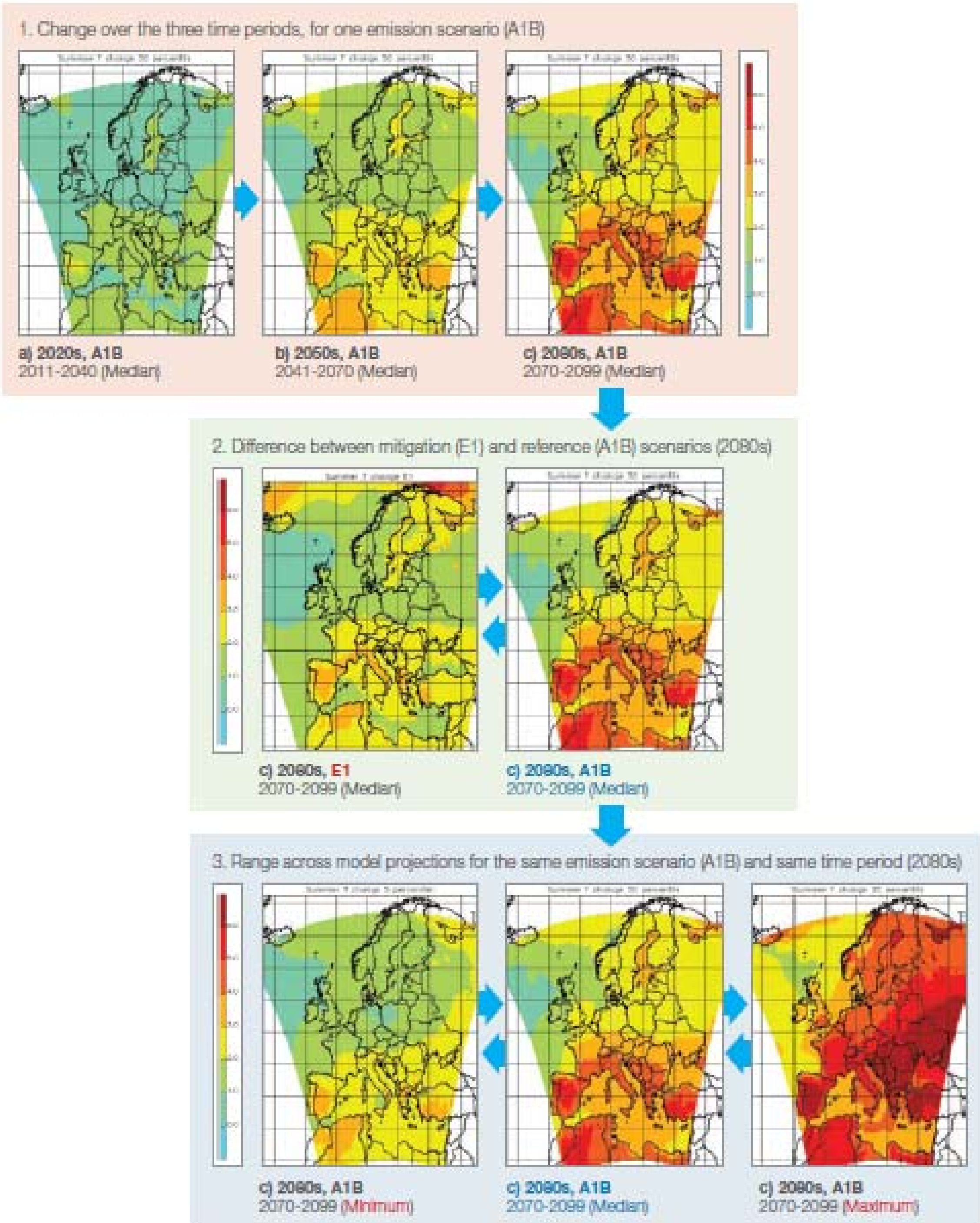

Figure 8. Change in surface air temperature (°C) for summer (June, July and August) in 11 RCM simulations from the ENSEMBLES archive taken from Summary of ClimateCost project results (ClimateCost, 2012).

Figure 9 shows baseline for the A1B (red) and E1 (green) emissions scenarios. Thin lines show individual models, thick red and green lines show ensemble mean and the blue line shows the EC-Earth RCP8.5 model run.

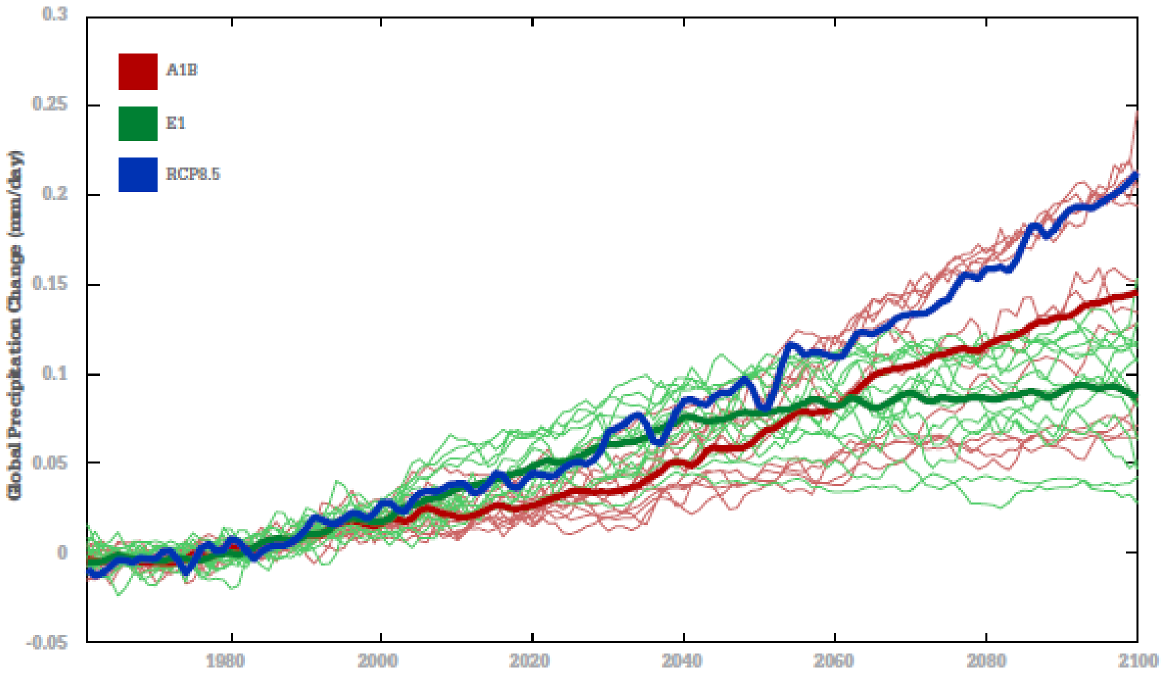

Figure 9. Projected change in global mean precipitation (mm per day) with respect to the 1961-1990, taken from Summary of ClimateCost project results (ClimateCost, 2012).

Figure 10 shows the trends 1) over time for the median A1B change from 1961-1990 for 2011-2040, 2041-2070 and 2070-2099, 2) for different scenarios with the A1B and E1 median scenarios for 2070-2099 and 3) across the alternative model projections for the same time period and emissions scenario (the central panel shows the central, the left the lowest and the right the highest of the models considered, all for the period 2070-2099 for A1B).

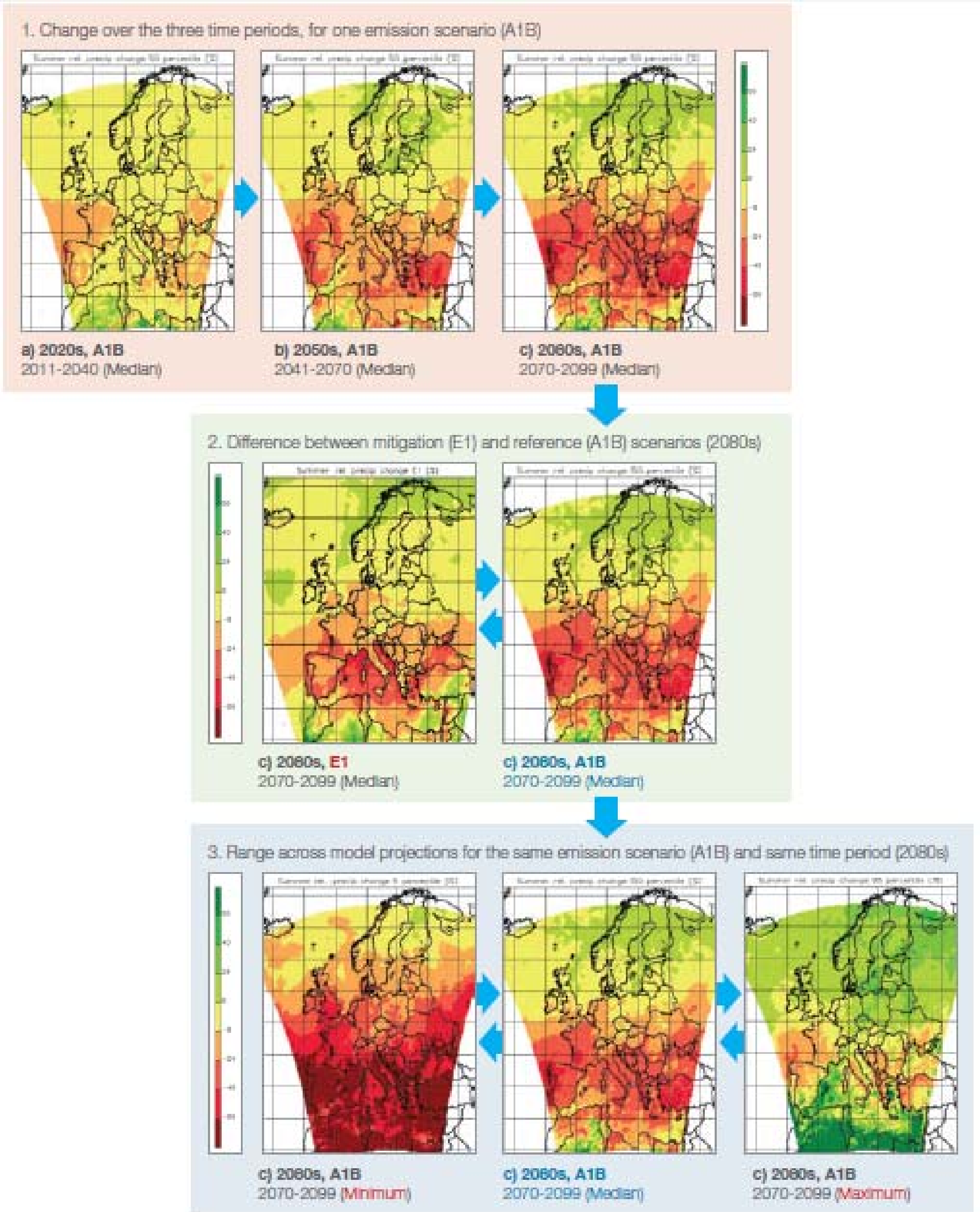

Figure 10. Relative change in summer precipitation (%) for summer (June, July and August) in 11 RCM simulations from the ENSEMBLES archive, taken from Summary of ClimateCost project results (ClimateCost 2012).

Figure 11 shows the trends 1) over time for the median A1B change from the 1961-1990 baseline for 2011-2040, 2041-2070 and 2070-2099, 2) for different scenarios with the A1B and E1 median scenarios for 2070-2099 and 3) across the alternative model projections for the same time period and emissions scenario (the central panel shows the central, the left the lowest and the right the highest of the models considered, all for the period 2070-2099 for A1B).

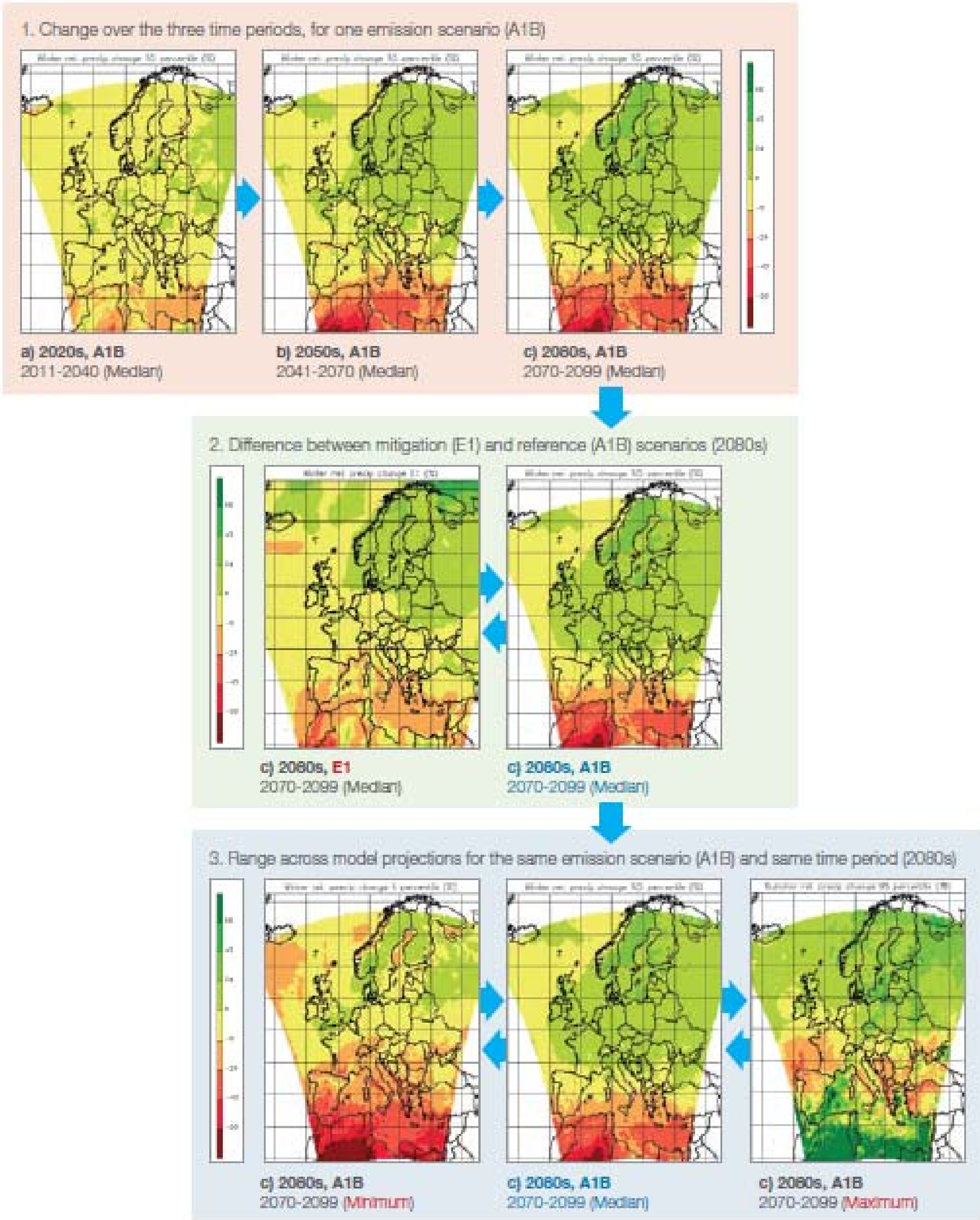

Figure 11. Relative change in winter precipitation (%) for winter (December, January and February) in 11 RCM simulations from the ENSEMBLES archive, (taken from Summary of ClimateCost project results (ClimateCost, 2012).

Table 3 shows summary of projected change data (2071-2100 is compared to 1961-1990 baseline) for global, Northern, Southern, Eastern and Western Europe. The minimum, mean and maximum values are provided for temperature and precipitation.

Table 3. Summary of projected change data for Temperature and Precipitation taken from Summary of ClimateCost project results (ClimateCost, 2012).

Actual climate change		Temperature (°C)		Precipitation (mm/ season)	
Scenario	Model run	Winter (DJF)	Summer (JJA)	Winter (DJF)	Summer (JJA)
A1B Global	Ensemble Minimum	2.52	2.20	-3.21	-4.51
A1B Global	Ensemble Mean	3.01	2.73	9.53	8.57
A1B Global	Ensemble Maximum	3.52	3.17	18.48	17.00
E1 Global	Ensemble Minimum	0.77	0.62	-0.70	-0.42
E1 Global	Ensemble Mean	1.53	1.40	4.00	4.34
E1 Global	Ensemble Maximum	2.09	1.85	11.03	10.73
A1B N Eur	Ensemble Minimum	3.74	2.12	22.29	-13.37
A1B N Eur	Ensemble Mean	4.46	2.74	42.37	0.58
A1B N Eur	Ensemble Maximum	5.17	4.44	54.88	10.07
E1 N Eur	Ensemble Minimum	1.20	0.94	3.30	-7.64
E1 N Eur	Ensemble Mean	2.98	1.86	15.10	5.56
E1 N Eur	Ensemble Maximum	4.22	2.74	29.12	28.58
A1B S Eur	Ensemble Minimum	1.78	3.10	-59.45	-60.61
A1B S Eur	Ensemble Mean	2.84	4.31	-28.97	-26.40
A1B S Eur	Ensemble Maximum	3.55	5.39	-4.57	-12.78
E1 S Eur	Ensemble Minimum	0.46	1.30	-32.04	-28.73
E1 S Eur	Ensemble Mean	1.65	2.44	1.32	-7.64
E1 S Eur	Ensemble Maximum	2.19	3.58	32.97	6.26
A1B E Eur	Ensemble Minimum	2.84	2.47	-9.78	-55.08
A1B E Eur	Ensemble Mean	3.95	3.95	7.70	-28.46
A1B E Eur	Ensemble Maximum	4.75	5.09	28.57	10.81
E1 E Eur	Ensemble Minimum	0.90	1.23	-13.53	-39.53
E1 E Eur	Ensemble Mean	2.21	2.45	6.00	-7.25
E1 E Eur	Ensemble Maximum	3.13	4.08	23.16	11.34
A1B W Eur	Ensemble Minimum	2.45	2.28	-26.06	-73.33
A1B W Eur	Ensemble Mean	3.16	3.67	21.22	-40.90
A1B W Eur	Ensemble Maximum	3.95	4.88	50.84	-12.06
E1 W Eur	Ensemble Minimum	0.80	1.25	-17.51	-30.87
E1 W Eur	Ensemble Mean	1.68	2.20	6.49	-11.85
E1 W Eur	Ensemble Maximum	2.24	3.61	23.19	8.64

2.4.3 Temperature, Precipitation and Sea-level change according to “Climate Change 2007 Report”, Contribution to AR4

According to IPCC, AR4 brings together observed changes in climate and the effects of past climate change on natural systems and human society. It also addresses the causes of change (both natural and anthropogenic drivers), updates on emission scenarios, it describes adaptation and mitigation options and covers the long-term perspective. It also gives climate projections shown in the following figures (IPCC, 2007).

Figure 12 shows annual mean winter and summer temperature change and annual winter and summer change in precipitation for period between the late 20th and early 21st century. It also provides number of models which provided the data

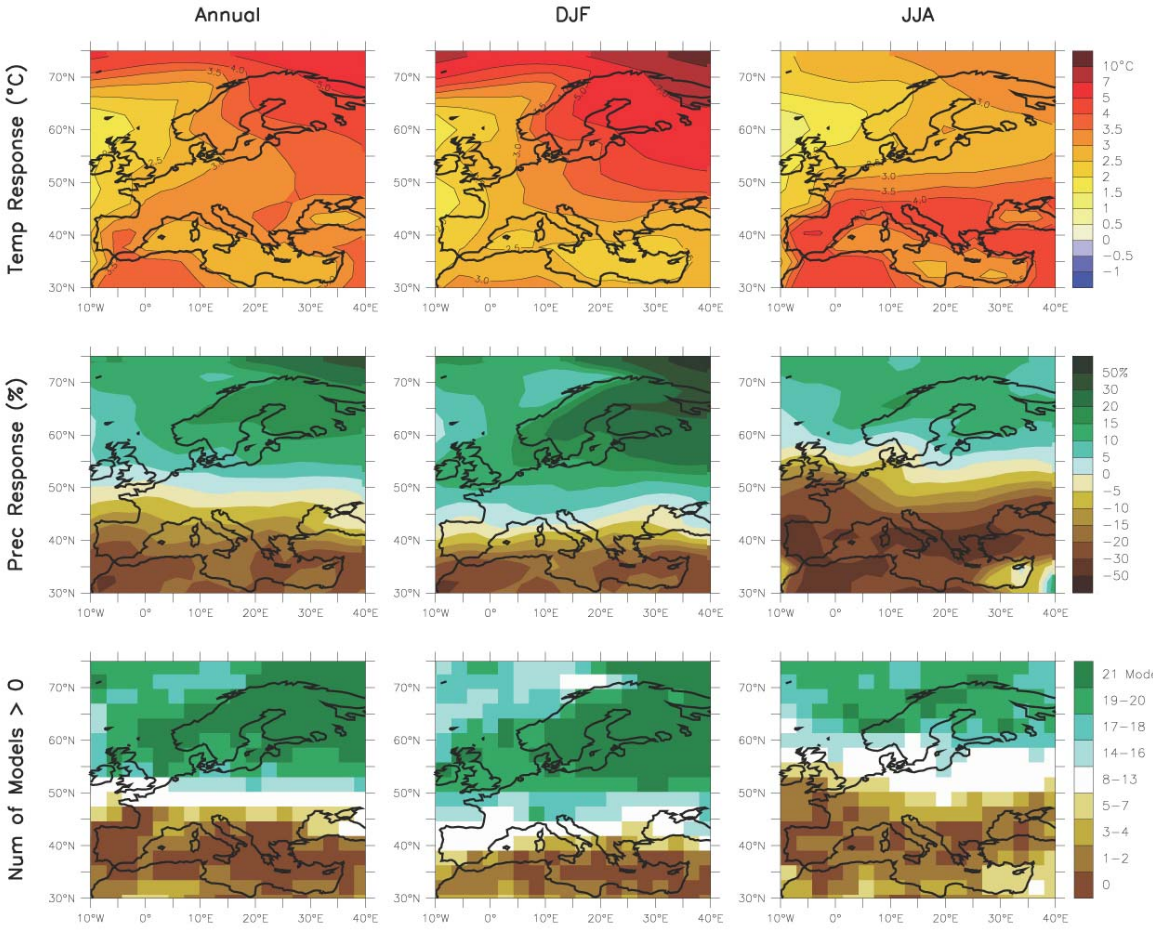

Figure 12. Annual mean winter (DJF) and summer (JJA) temperature change, annual meant winter (DJF), and summer (JJA) and number of models taken from IPCC’s report Climate Change 2007 (IPCC, 2007).

Global Average Surface Temperature Change (ºC) according to B1, A1B and A2, presented in Figure 13 show that in the near future there are no larger differences between the scenarios, looking into long term projections however B1 tends to give low values, A1B intermediate and A2 the highest.

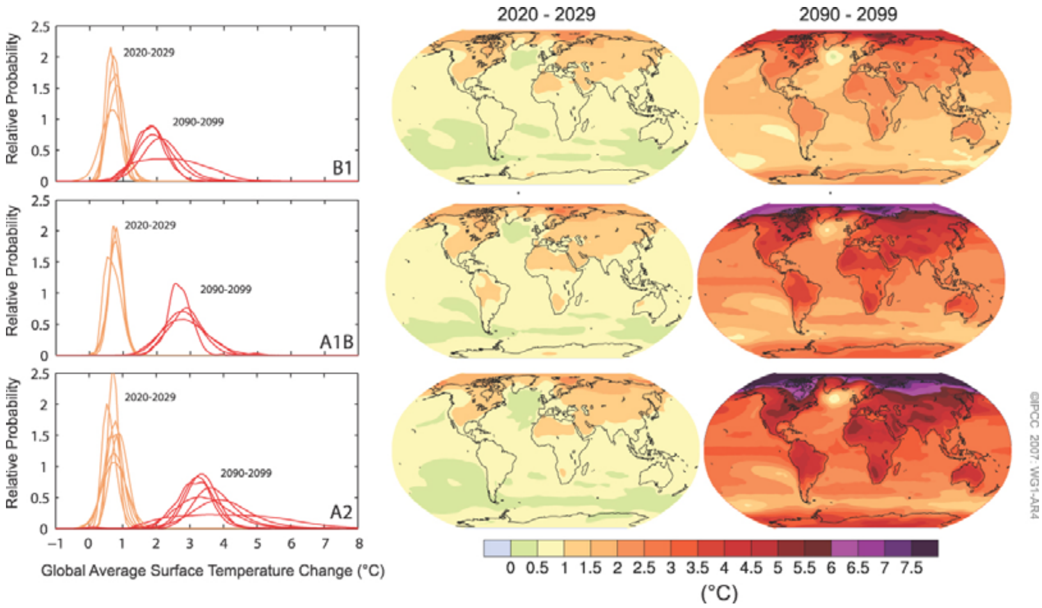

Figure 13. Global Average Surface Temperature Change (ºC) according to B1, A1B and A2 taken from IPCC's report Climate Change 2007 (IPCC, 2007).

Figure 14 shows comparison of results for global annual precipitation and surface air temperature according to different climate change models.

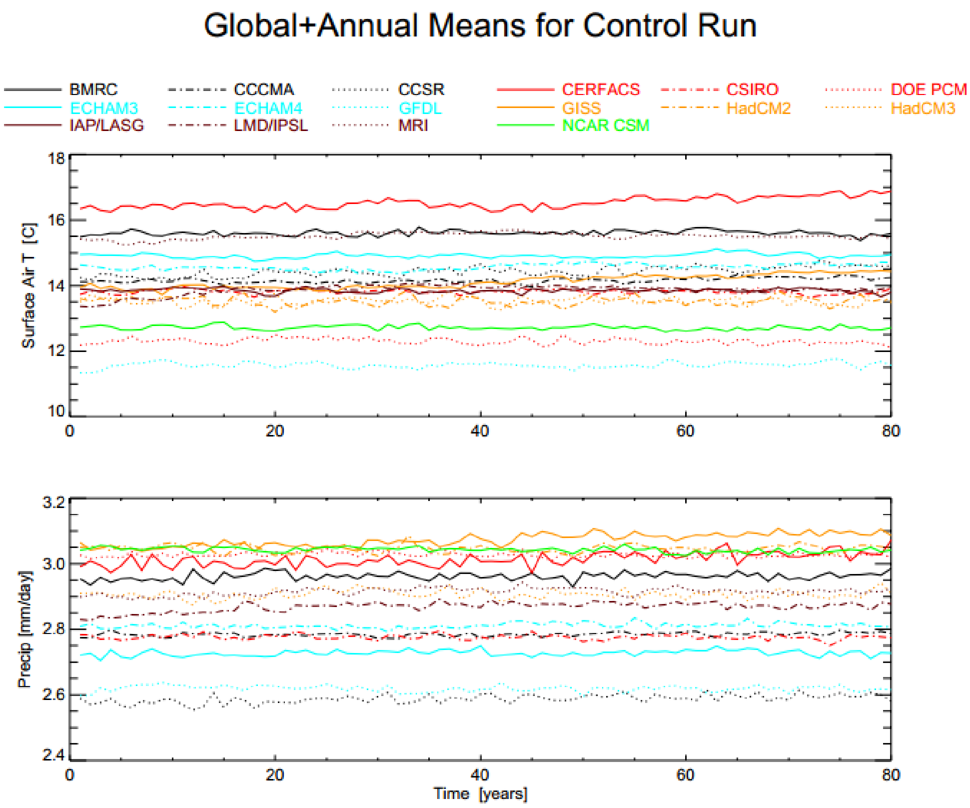

Figure 14. Global Annual Precipitation and Surface Air Temperature taken from IPCC's report Climate Change 2007 (IPCC, 2007).

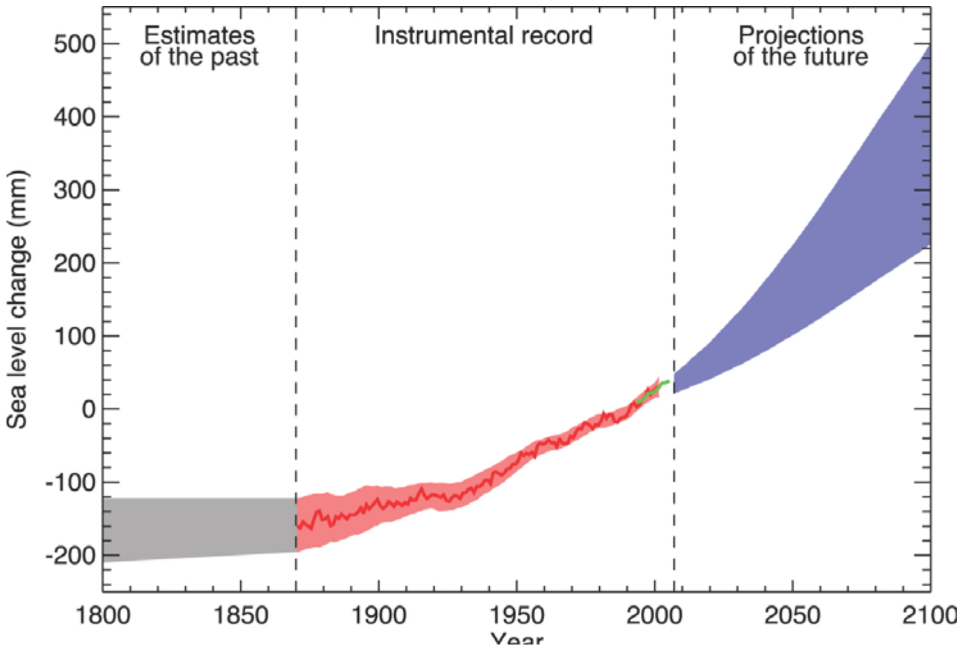

Figure 15. Sea level change (mm) values throughout the history and future projections taken from IPCC's report Climate Change 2007 (IPCC, 2007).

Figure 15 and Table 4 present data for sea level change. Figure 15 shows data distribution throughout the history, while Table 4 contains data for several different scenarios.

Table 4. Sea level rise linked to temperature changes (drawn up according to data from IPCC's report Climate Change 2007 (IPCC, 2007).

CASE	Temperature change (^{0}C at 2090-2099, relative to 1980-1999)		Sea Level rise (m at 2090-2099)
	Best Estimate	Likely Range	Model-based range excluding future rapid dynamical changes in ice flow
Constant year 2000 concentrations	0.6	0.3-0.9	Not available
B1 scenario	1.8	1.1-2.9	0.18-0.38
A1T scenario	2.4	1.4-3.8	0.20-0.45
B2 scenario	2.4	1.4-3.8	0.20-0.43
A1B	2.8	1.7-4.4	0.21-0.48
A2 scenario	3.4	2.0-5.4	0.23-0.51
A1FI scenario	4	2.4-6.4	0.26-0.59

Figure 16 shows the link between the changes in global temperature on a scale 0-5 ºC, to different socio-economic sectors, together with the predicted consequences for European Region.

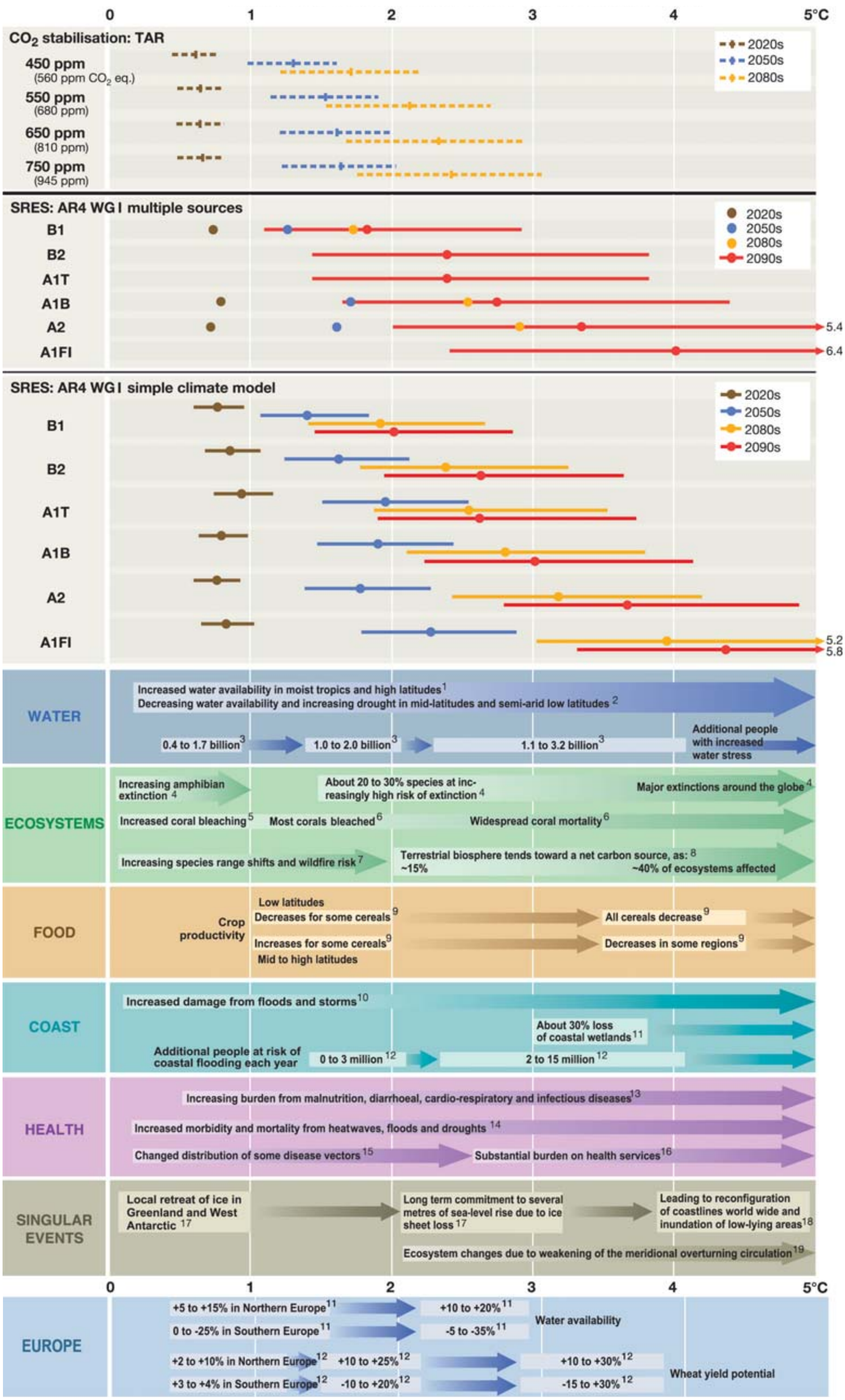

Figure 16. The link between the change in global temperature to different socio-economic sectors from IPCC's report Climate Change 2007 (IPCC, 2007).

2.4.4 *Temperature, Precipitation and Sea-level change according to "Climate Change 2013 Report", Contribution to AR5*

After some of the uncertainties were recognised in AR4, such as uneven treatment of risk across and within working groups, AR5 has been aiming to refine the information especially in regards to risk and to provide useful input for decision making on climate change. AR5 also puts a strong emphasis on mitigation strategies. The transport sector, being one of the main contributors to climate change, must turn to technological improvements and new technology-related practices to substantially mitigate against climate change effects (IPCC, 2013).

In Figure 17 for each point, the 25th, 50th and 75th percentiles of the distribution of the CMIP5 ensemble are shown; this includes both natural variability and inter-model spread. Hatching denotes areas where the 20-year mean differences of the percentiles are less than the standard deviation of model-estimated present-day natural variability of 20-year mean differences.

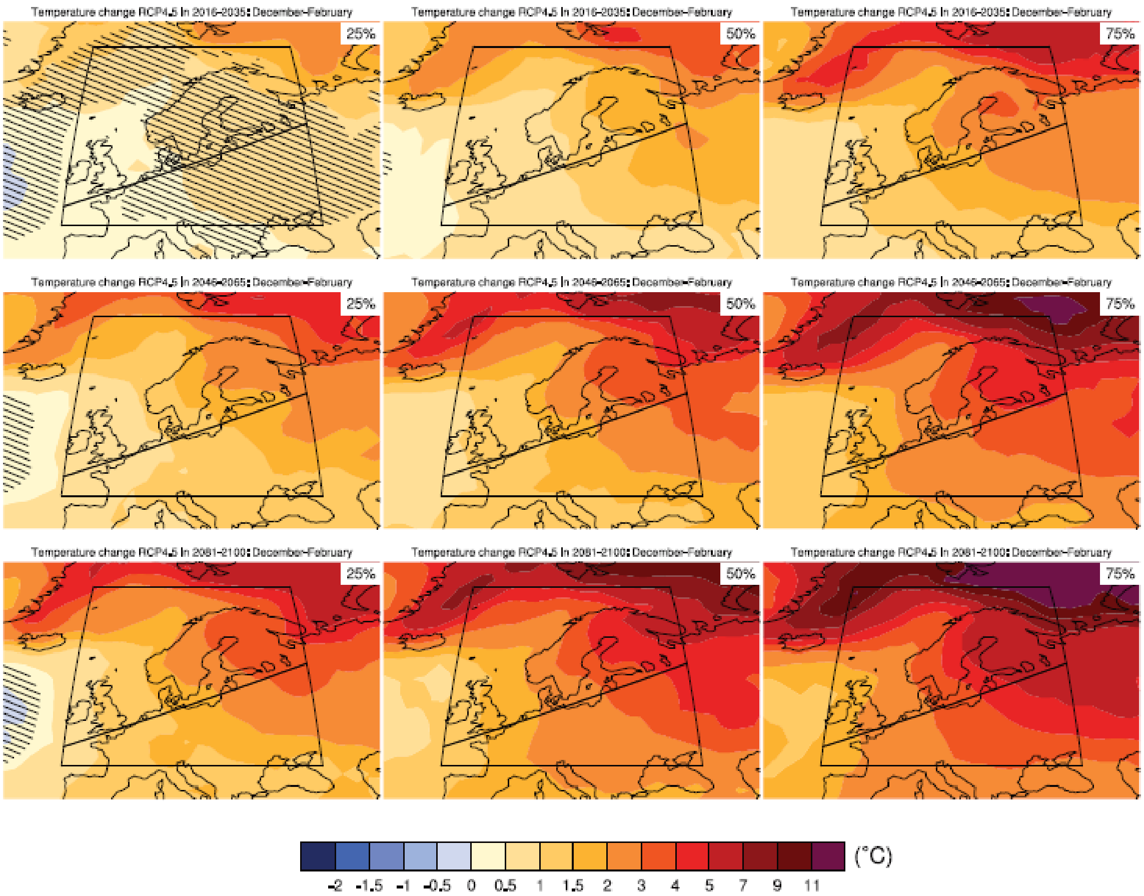

Figure 17. Maps of temperature changes in 2016–2035 (1st row), 2046–2065 (2nd row) and 2081–2100 (3rd row) with respect to 1986–2005 in the RCP4.5 scenario for Northern and Central Europe for DJF taken from IPCC's report *Climate Change 2013* (IPCC, 2013).

In Figure 18 for each point, the 25th, 50th and 75th percentiles of the distribution of the CMIP5 ensemble are shown; this includes both natural variability and inter-model spread. Hatching denotes areas where the 20-year mean differences of the percentiles are less than the standard deviation of model-estimated present-day natural variability of 20-year mean differences.

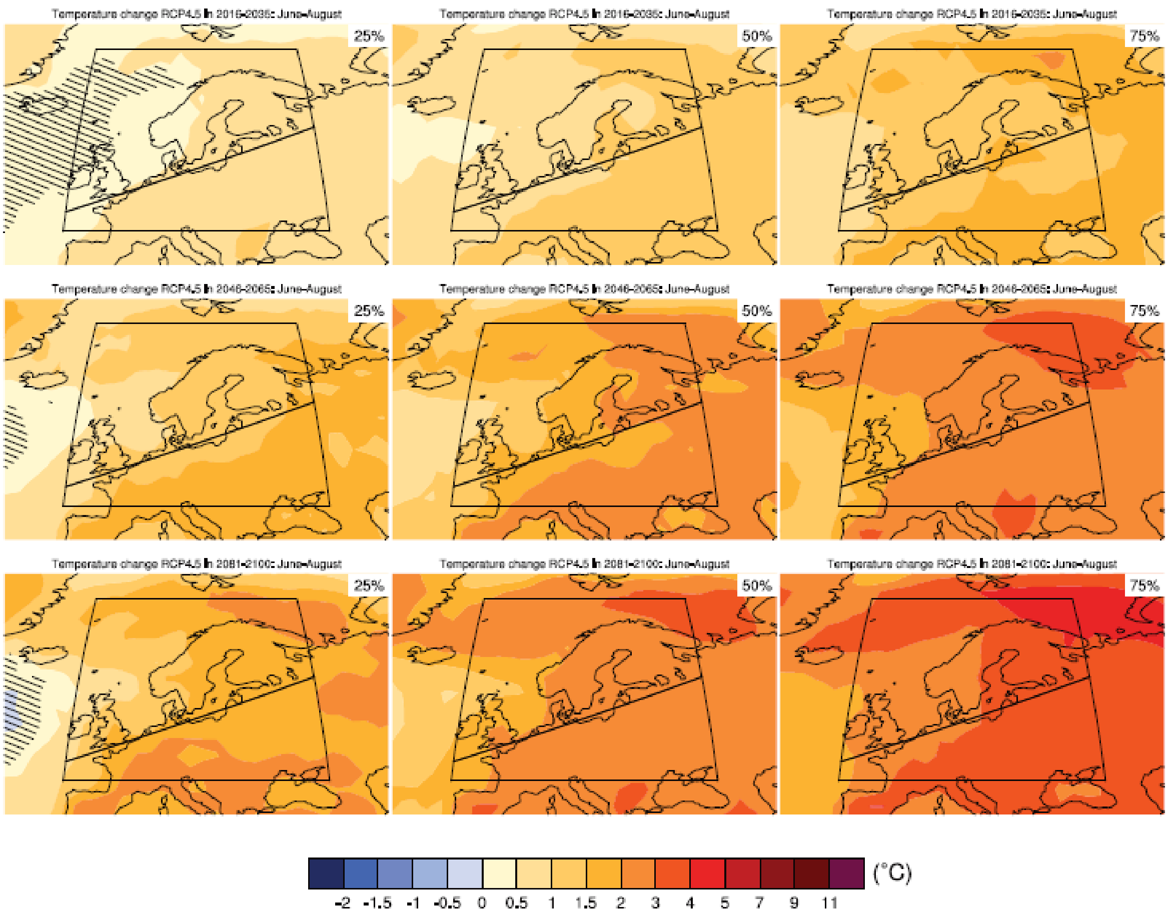

Figure 18. Maps of temperature changes in 2016–2035 (1st row), 2046–2065 (2nd row) and 2081–2100 (3rd row) with respect to 1986–2005 in the RCP4.5 scenario for Northern and Central Europe for JJA taken from IPCC's report Climate Change 2013 (IPCC, 2013).

In Figure 19 for each point, the 25th, 50th and 75th percentiles of the distribution of the CMIP5 ensemble are shown; this includes both natural variability and inter-model spread. Hatching denotes areas where the 20-year mean differences of the percentiles are less than the standard deviation of model-estimated present-day natural variability of 20-year mean differences.

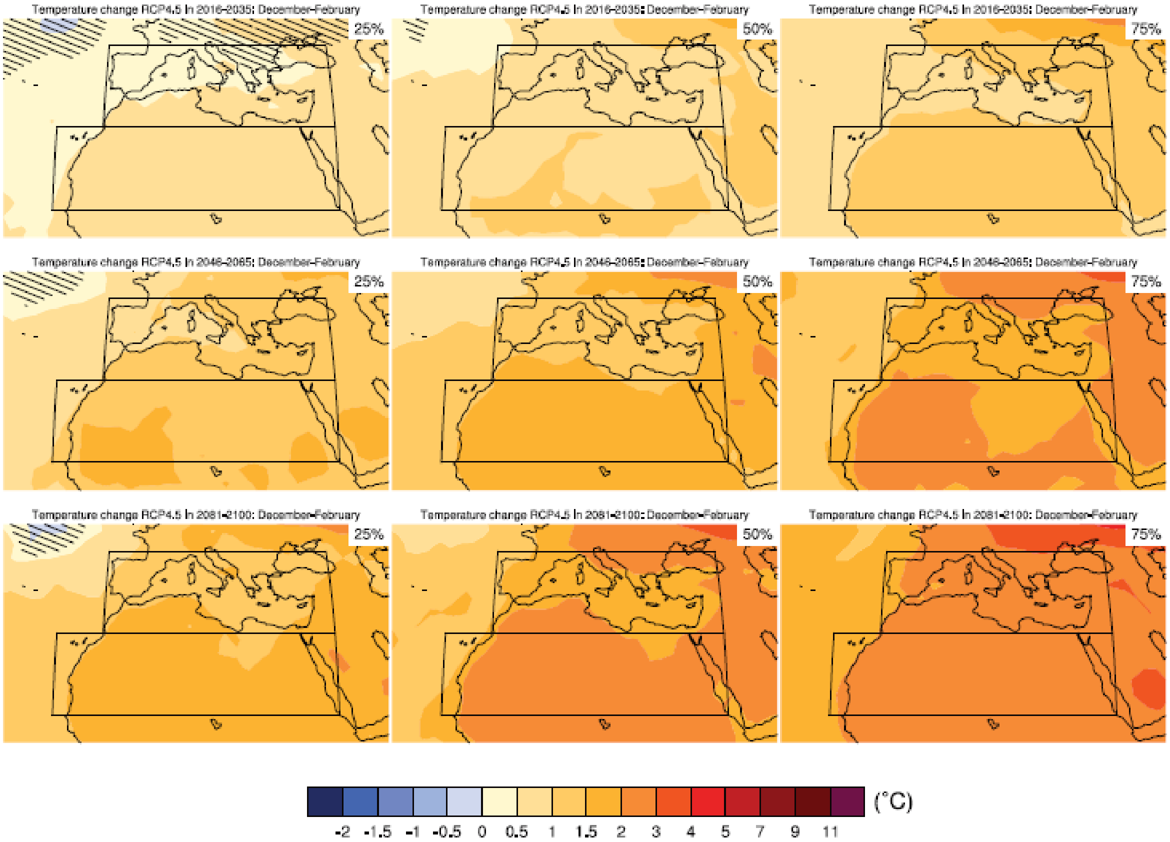

Figure 19. Maps of temperature changes in 2016–2035 (1st row), 2046–2065 (2nd row) and 2081–2100 (3rd row) with respect to 1986–2005 in the RCP4.5 scenario for Southern Europe for DJF taken from IPCC's report Climate Change 2013 (IPCC, 2013).

In Figure 20 for each point, the 25th, 50th and 75th percentiles of the distribution of the CMIP5 ensemble are shown; this includes both natural variability and inter-model spread. Hatching denotes areas where the 20-year mean differences of the percentiles are less than the standard deviation of model-estimated present-day natural variability of 20-year mean differences.

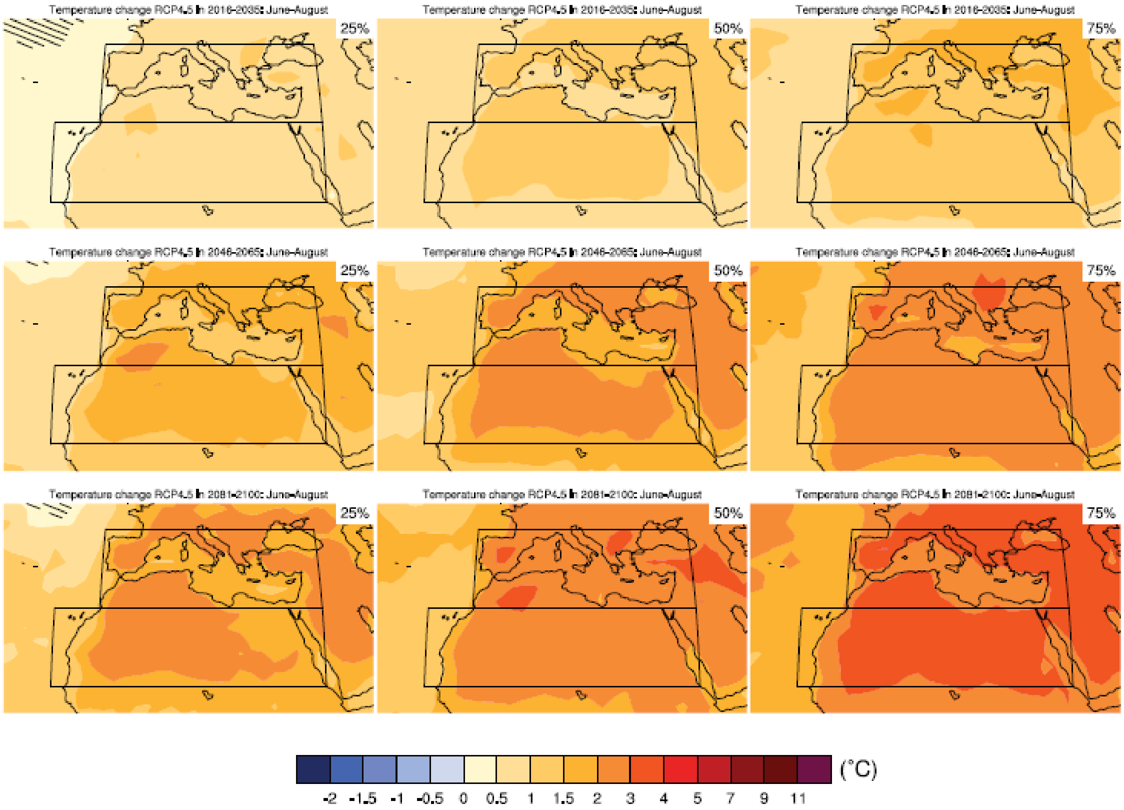

Figure 20. Maps of temperature changes in 2016–2035 (1st row), 2046–2065 (2nd row) and 2081–2100 (3rd row) with respect to 1986–2005 in the RCP4.5 scenario for Southern Europe for JJA taken from IPCC's report Climate Change 2013 (IPCC, 2013).

In Figure 21 for each point, the 25th, 50th and 75th percentiles of the distribution of the CMIP5 ensemble are shown; this includes both natural variability and inter-model spread. Hatching denotes areas where the 20-year mean differences of the percentiles are less than the standard deviation of model-estimated present-day natural variability of 20-year mean differences.

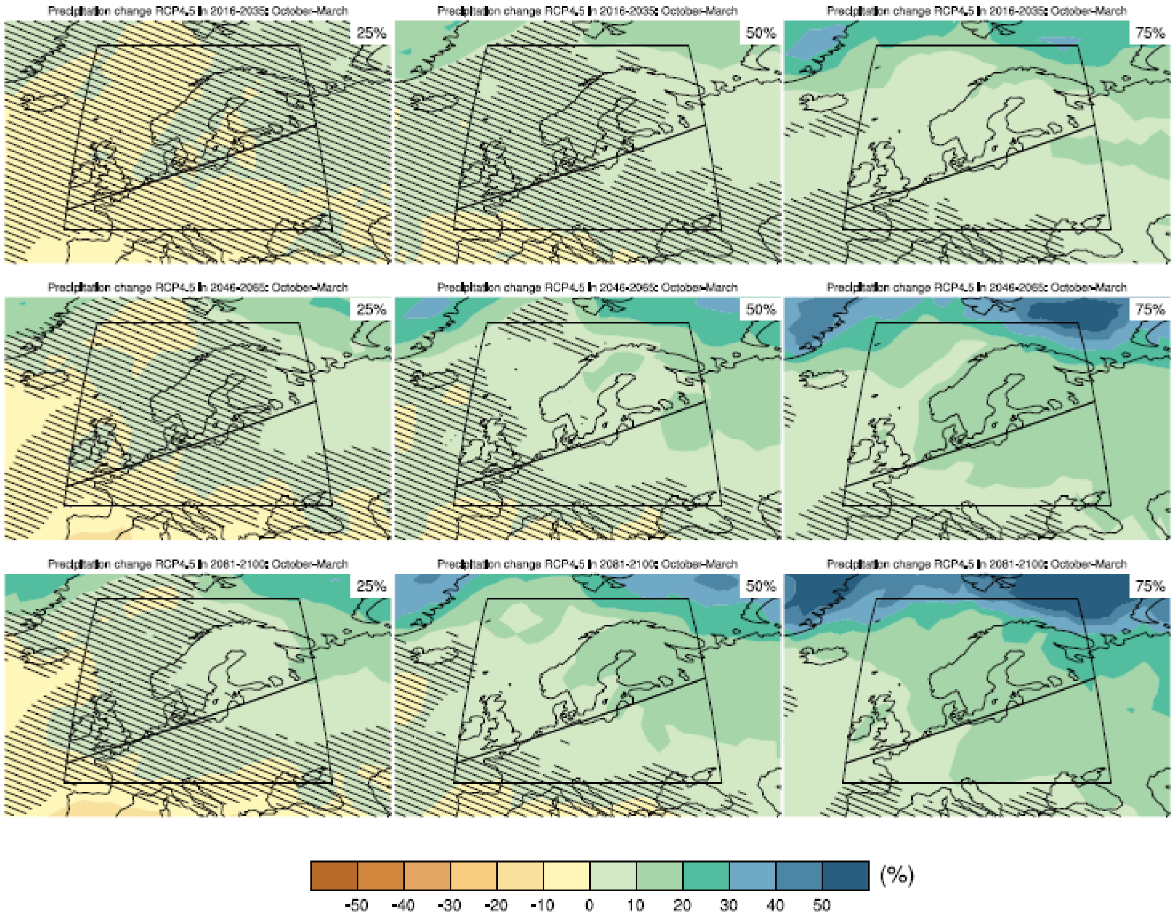

Figure 21. Maps of precipitation changes in 2016–2035 (1st row), 2046–2065 (2nd row) and 2081–2100 (3rd row) with respect to 1986–2005 in the RCP4.5 scenario for Northern and Central Europe for October-March taken from IPCC's report Climate Change 2013 (IPCC, 2013).

In Figure 22 for each point, the 25th, 50th and 75th percentiles of the distribution of the CMIP5 ensemble are shown; this includes both natural variability and inter-model spread. Hatching denotes areas where the 20-year mean differences of the percentiles are less than the standard deviation of model-estimated present-day natural variability of 20-year mean differences.

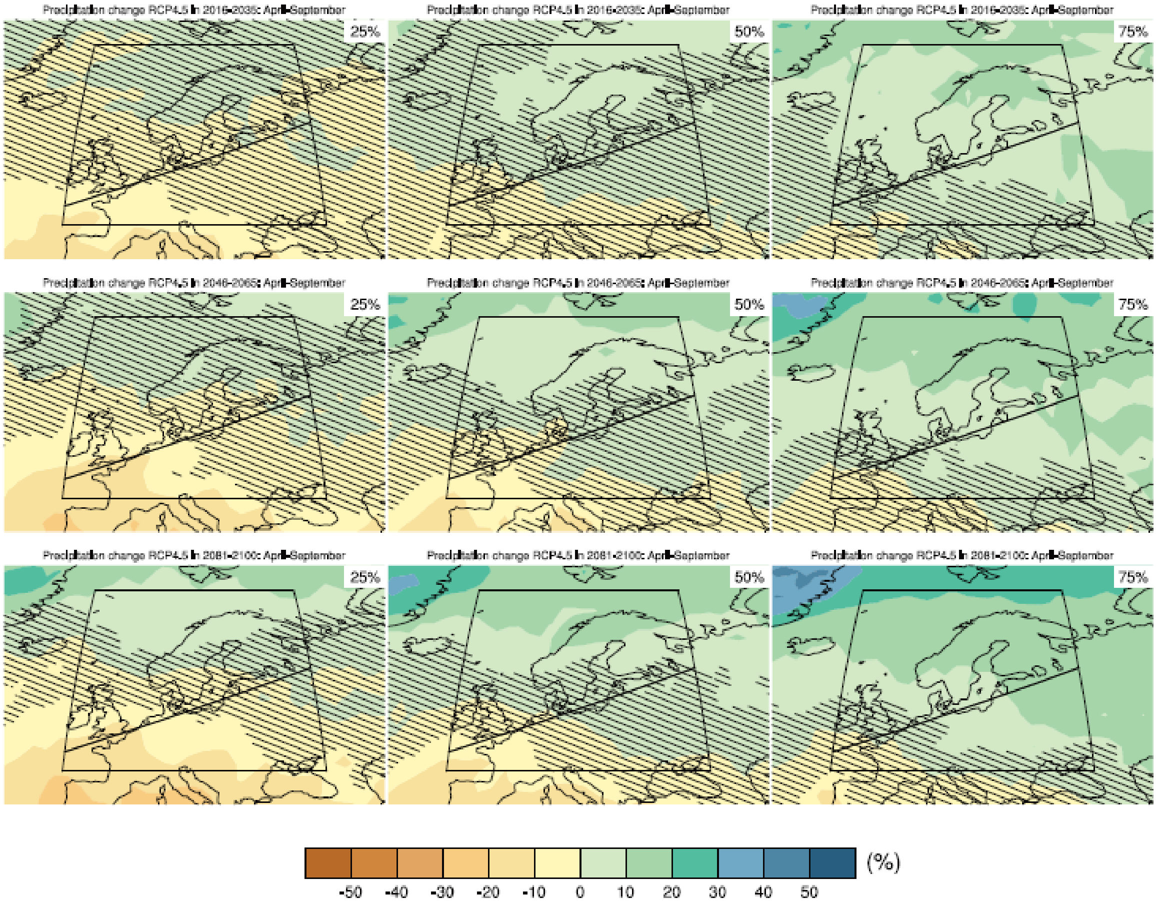

Figure 22. Maps of precipitation changes in 2016–2035 (1st row), 2046–2065 (2nd row) and 2081–2100 (3rd row) with respect to 1986–2005 in the RCP4.5 scenario for Northern and Central Europe for April-September taken from IPCC's report Climate Change 2013 (IPCC, 2013).

In Figure 23 for each point, the 25th, 50th and 75th percentiles of the distribution of the CMIP5 ensemble are shown; this includes both natural variability and inter-model spread. Hatching denotes areas where the 20-year mean differences of the percentiles are less than the standard deviation of model-estimated present-day natural variability of 20-year mean differences.

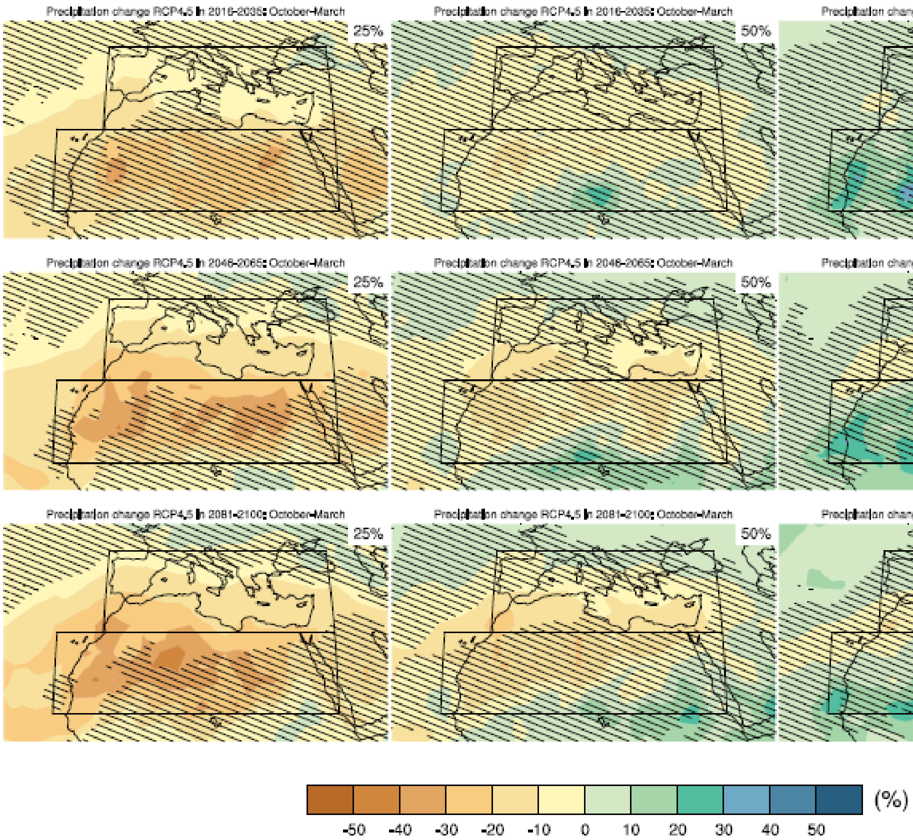

Figure 23. Maps of precipitation changes in 2016–2035 (1st row), 2046–2065 (2nd row) and 2081–2100 (3rd row) with respect to 1986–2005 in the RCP4.5 scenario for Southern Europe for October-March IPCC's report Climate Change 2013 (IPCC, 2013).

In Figure 24 for each point, the 25th, 50th and 75th percentiles of the distribution of the CMIP5 ensemble are shown; this includes both natural variability and inter-model spread. Hatching denotes areas where the 20-year mean differences of the percentiles are less than the standard deviation of model-estimated present-day natural variability of 20-year mean differences.

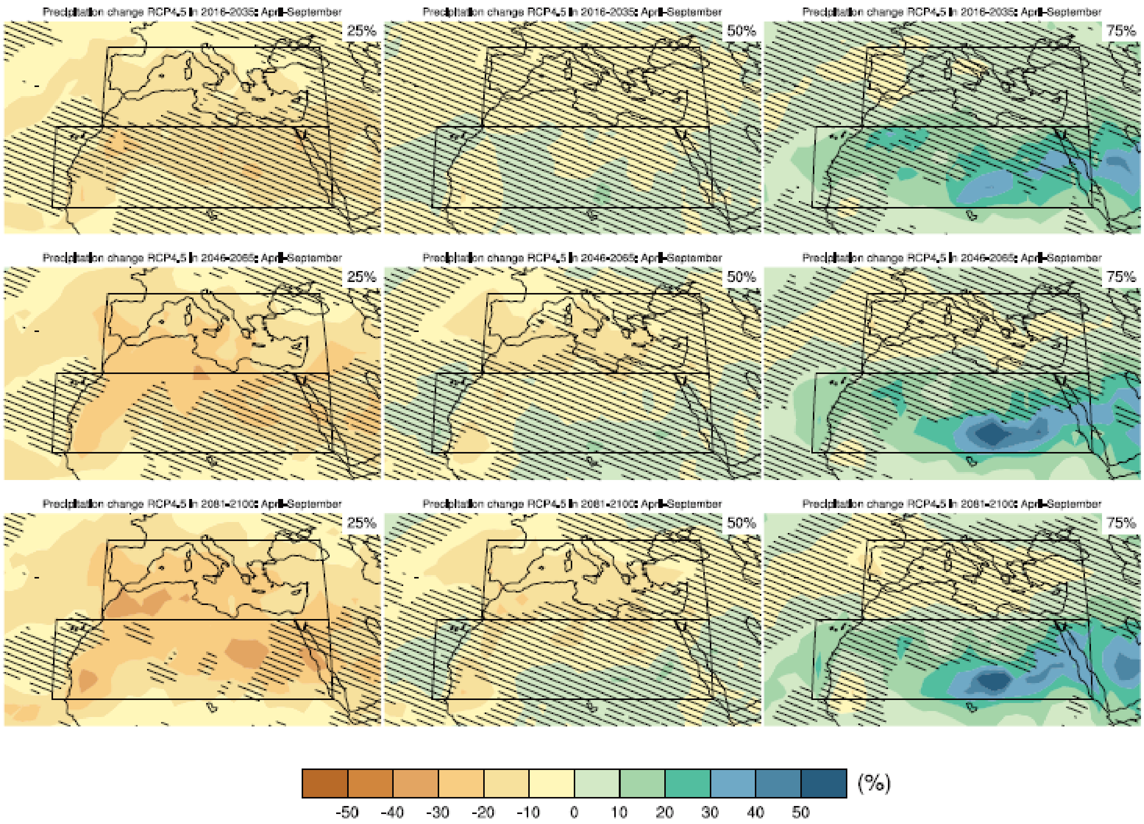

Figure 24. Maps of precipitation changes in 2016–2035 (1st row), 2046–2065 (2nd row) and 2081–2100 (3rd row) with respect to 1986–2005 in the RCP4.5 scenario for Southern Europe April-September taken from IPCC's report Climate Change 2013 (IPCC, 2013).

Projections in Figure 25 are grouped by forcing scenario as indicated on the plots. Results are plotted for a common time interval of 2011 to 2099. Colours correspond to particular model analyses: red = Marzeion et al. (2012a); blue = Slangen and van de Wal (2011); green = Radić et al. (2013); black = Giesen and Oerlemans (2013). Individual Atmosphere–Ocean General Circulation Model (AOGCM) projections are plotted for each analysis. In the panel showing results for RCP6.0 and A1B forcings, only Geisen and Oerlemans (black lines) use the A1B forcing.

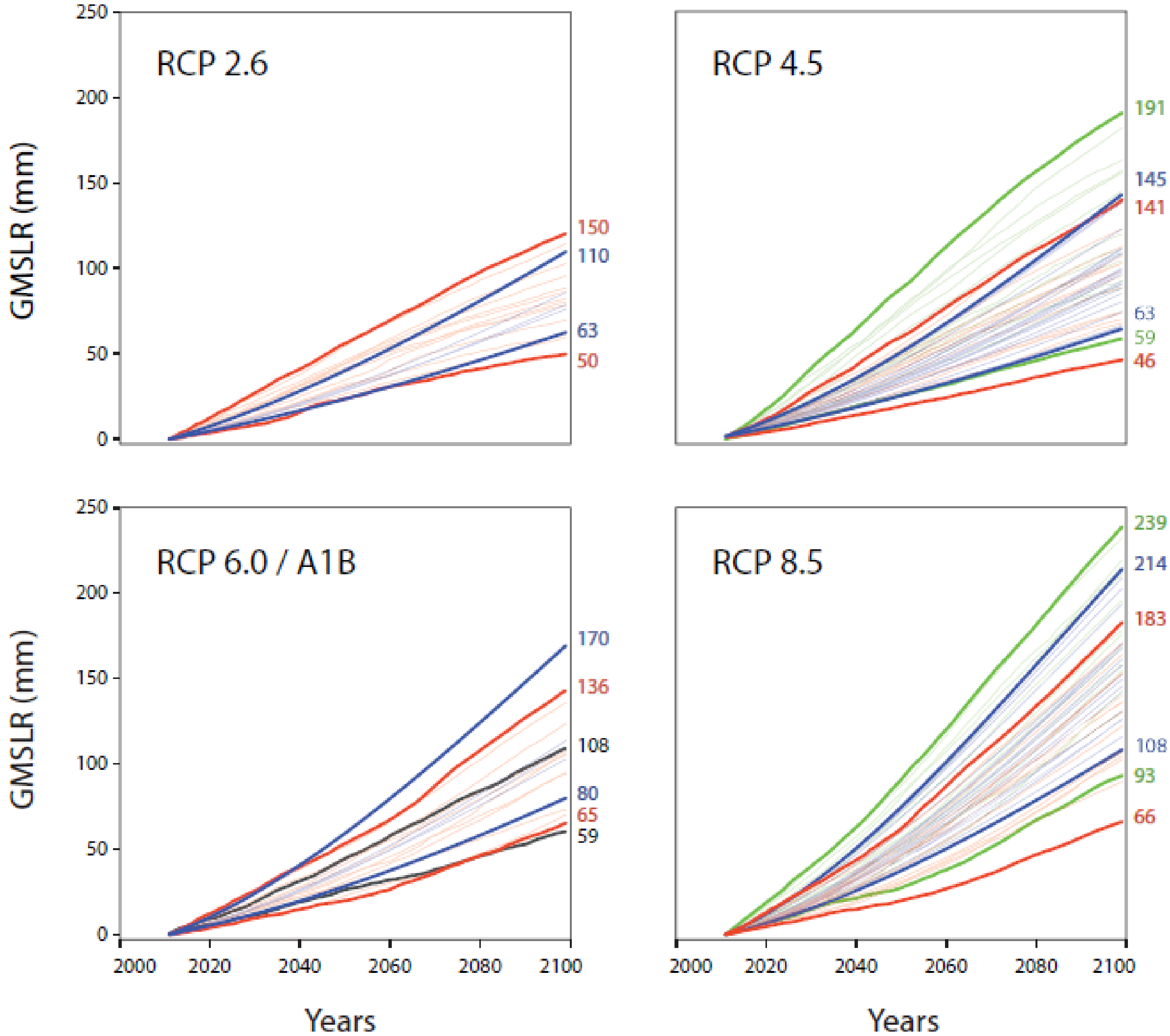

Figure 25. Time series plots for process-based model projections of sea level contributions from global glaciers (in mm), including peripheral glaciers surrounding the Greenland ice sheet but excluding the glaciers surrounding the Antarctic ice sheet taken from IPCC's report Climate Change 2013 (IPCC, 2013).

The contributions, in Figure 26, from ice sheets include the contributions from ice-sheet rapid dynamical change (ongoing dynamic responses of ice sheets to past forcings), which are also shown separately. The contributions from ice-sheet rapid dynamical change and anthropogenic land water storage are treated as having uniform probability distributions, and as independent of scenario (except that a higher rate of change is used for Greenland ice-sheet outflow under RCP8.5). This treatment does not imply that the contributions concerned will not depend on the scenario followed, only that the current state of knowledge does not permit a quantitative assessment of the dependence. Only the collapse of the marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level (GMSL) to rise substantially above the likely range during the 21st century. This potential additional contribution cannot be precisely quantified but there is medium confidence that it would not exceed several tenths of a meter of sea level rise taken from IPCC's report Climate Change 2013 (IPCC, 2013).

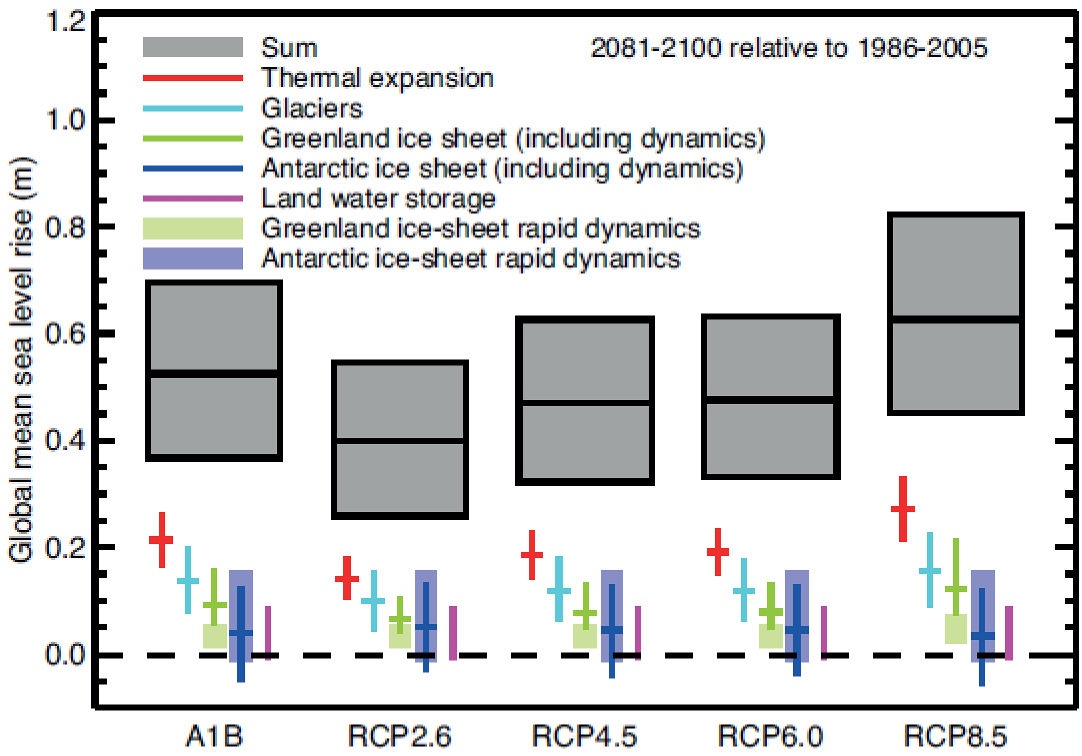

Figure 26. Projections from process-based models with likely ranges and median values for global mean sea level rise and its contributions in 2081–2100 relative to 1986– 2005 for the four RCP scenarios and scenario SRES A1B used in the AR4 (taken from IPCC's report Climate Change 2013 (IPCC, 2013).

3 Main effects of climate change and their consequences on infrastructure elements.

3.1.1 Main challenges

Several studies have shown that atmospheric concentrations of CO_2 had a stable range of 260-280 ppm before the industrial era began, with the dramatic increase from 280 ppm to 380 ppm occurring between the period of 1750-2005 (Wikipedia, 2014). CO_2 is a major component of GHG, and it has the ability to alter Earths long-wave radiation reflected back to space, which then leads to global warming and climate change. Climate change is usually described as change of mean values and variability of temperature, precipitation, and other climate variables, over a long time period. Carbon emission by humanity (economy, technology, energy production, agriculture etc.) have a direct impact on atmospheric concentration of CO_2. As described in chapter 3.1.2. The IPCC has included these emissions in the scenarios that have been developed.

As mentioned above due to global warming, temperatures will rise, which will have an impact on precipitation, winds, sea levels etc. Northern and Eastern Europe in comparison to Southern, Western and Central Europe will have different issues. Scandinavia for example, will be effected by higher winter temperatures from which they will benefit in the form of reduced salt usage throughout the winter and lower maintenance when it comes to snow ploughing, but conversely will be disadvantaged by the increase of free-thaw cycles which lead to structural deterioration. Chloride induced deterioration mechanism will be replaced by freeze-thaw weathering cycles. In the southern regions, higher temperatures will have a major negative impact on pavement durability. Higher temperatures throughout the Mediterranean will also increase the risks of wildfires which will lead to disruptions in transport and to higher operational costs. Roads in coastal areas will be impacted by higher sea levels, increasing the upper limit of the splash zone, thus increasing risk of chloride induced deterioration mechanism on areas of concrete and steel structures not designed for splash zone exposure. In conclusion different countries will be exposed to different type of climate change effect which will result in different problems.

There is a wide range of challenges which could be imposed on infrastructure elements by climate change, as listed below in Table 6.

Table 6. List of Challenges and their impact on infrastructure elements

Challenges	Impact
Flooding and erosion	Impact on drainage systems, and erosion protection (Slopes and retaining walls alongside bridge piers and abutments).
Landslides and avalanches	Extreme flooding intensifies landslide risks.
Droughts	Deterioration of concrete; steel structures, and embankments.
Sea Level Rise	Increased risk of chloride induced deterioration mechanism at areas above the designed splash zone.
Snowfall	Winter maintenance and operation (May also cause structural collapse in some types of structures).

Concrete structures are the most common structures according to material type and are widely represented in infrastructure and severely impacted by climate change as follows:

- INCREASE OF CARBON CONCENTRATION – will lead to acceleration in carbonation and also increases carbonation depth in concrete. This leads to further reinforcement deterioration and structural damage.
- CHANGE OF TEMPERATURE- leads to acceleration in carbonation, chloride penetration and corrosion rate of reinforcement elements.
- CHANGE OF HUMIDITY – if the level of humidity is lowered it may reduce or even stop carbonation and chloride penetration, if increased it may increase its occurrence in regions in which it is currently negligible
- CHANGE OF SEA WATER SALINITY-an increase will lead to acceleration of chloride ingress in concrete structures.
- CHANGE OF AIR POLLUTION-a change can lead to increase/decrease of corrosion.

For steel structures which also cover an important part of infrastructures corrosion is the main degradation factor and this is also governed by the factors described above for concrete structures. However for steel structures air pollution, especially from sulphur, is a main governing factor. For the old industrialized world pollution is reduced significantly and corrosion rate for steel structures can be expected to reduce significantly for these areas.

Table 5. Score according to assumed probability and severity of individual threats (CEDR, 2012)

Points	Probability	Severity of risk (Consequence)
3	Verifiable risk	Extremely severe
2	Probable risk	Severe
1	Slight probability	Less severe
0	Improbable	Not relevant

According to Adaptation to Climate Change report (CEDR, 2012), the RIMMAROCC project developed a risk matrix approach, where most common challenges are graded according to the system shown in Table 5 for the probability and the severity risk. The overall risk is characterised by a colour code, according to Figure 27.

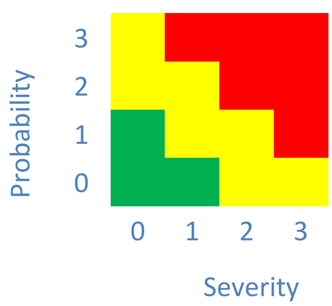

Figure 27. Coloured Schemed risk matrix for combined effect of both probability and severity (CEDR, 2012)

As a part of Task 16, Adaptation to Climate Change Report initiated by CEDR, in period 2009-2013 (CEDR, 2012) a survey was conducted among the member states involved in the project. Results from individual country surveys on the assessment and probability of effects and the severity of consequences are presented in Table 7. The survey also considered on-going work on adaption to climate change (information on climatological projections, adaptation strategies, main issues, potential beneficial effects, cost due to climate change effects, concrete on-going work and practice, related research etc.)

Table 7. Survey results for the assessment of the probability of effects and severity of consequences due to changes in climate parameters; P=probability and S=severity drawn up according to CEDR's Adaptation to climate change report survey (CEDR, 2012).

	HIGH TEMPERATURES		±0 TEMPERATURES		WIND		STORM		RAIN INTENSITY		INCREASED FLOW RATES IN RIVERS		FLOOD		DROUGHT		LANDSLIDES		AVALANCHES		SNOWFALL INTENSITY		SEA-LEVEL RISE	
	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
NORWAY	3	1	3		1		1		3	3	2	2	3	2	1	1	2	2	2	2	3	2	3	2
FINLAND	2	1	3	2	2	2	1	2	2	2	2	2	2	2	1	1	1	3	1	1	3	2	1	0
SWEDEN	2	2	3	2	1	2			3	3	2	2	3	2	1	1	3	3	1	1	1	2	2	2
DENMARK	2	2	1	1	2	1	1	1	3	2	2	1	2	2	2	1	0	0	0	0	1	1	2	2
UK	3	1	1	0	1	1	2	2	3	2	3	1	3	2	2	1	1	0	0	0	1	1	2	1
IRELAND	2	1	1	2	1	1	1	1	3	2	1	1	3	2	1	0	1	2	0	0	0	0	1	1
FRANCE	3	1	2	1	1	1	1	2	2	1	1	2	2	2	3	3	1	2	1	1	2	2	3	2
AUSTRIA	2	2	3	2	1	1	1	1	2	2	1	2	3	2	3	2	2	2	2	1	2	2	0	0
HUNGARY	3	2			2	1	3	2	3	2	3	2	3	2	3	1	2	1	0	0	3	2	0	0
ITALY	3	2	2	2	1	1	2	1	2	2			2	2	1	1	2	2			2	2	1	1
SPAIN	3	2	2	1	1	1	2	1	2	1	2	1	2	1	3	2	2	1	2	1	2	1	2	1

The survey shown in Table 7, suggests that floods induced by heavy rainfall and high temperatures in the summer period will be of most concerns to road managers and national road authorities.

3.1.2 List of possible deterioration mechanisms

Table 8 highlights the most common deterioration mechanism which are influenced by climate change effects, for bridges (concrete and steel), slopes (soil and rock) and retaining walls.

Table 8. List of most common deterioration mechanism for specific infrastructure elements

			DETERIORATION MECHANISM
TYPE OF STRUCTURE	BRIDGES	Reinforced Concrete	Chloride-induced corrosion
			Carbonation
			Sulphate attack
			Alkali-aggregate reaction
			Alkali-silica reaction
			Alkali-carbonate reaction
			Freeze-thaw cycles
		Steel	Corrosion
			Degradation of protective coating
			Fatigue
	SLOPES	Soil	Erosion by water, wind and gravity
			Structure decline by compaction
			Salting and waterlogging
		Rock	Weathering
	RETAINING WALLS		Assuming the high retaining walls taken into consideration are made of reinforced concrete or sheet piles; deterioration mechanisms are equivalent for those proposed for concrete bridges
			For the earth portion of the soil which is being retained the same deterioration mechanism as for soil slopes apply

The deterioration mechanism identified above are highly dependent on humidity, sea splash area and of course temperature, amongst other parameters. Any variability in climatological conditions will lead to consequential increase or decrease in the probability of certain deterioration mechanism occurring or will affect the rate of damage development.

Bridges and retaining walls which fall under the scope of this project are often made of reinforced concrete, where defects are usually linked to concrete durability (mostly in relation to the composition of the concrete) and the aggressive environment in which the concrete structure is placed.

The following deterioration mechanism are drawn up according to Bridge Inspection Manual, Part 2, Issued by the Queensland Government Department of Main Roads (Department of Main Roads Queensland Government, 2004).

- CORROSION of REINFORCEMENT: Alkali content in concrete usually protects the reinforcement from corrosion, but if oxygen/chlorides/moisture penetrate through the concrete and reach the reinforcement, the protection ceases to exist. Initially corrosion can be recognised as rust on concrete surfaces (sometimes this symptom is missing), afterwards the contaminated area also begins to form cracks, and in final stages heavily corroded reinforcement elements are exposed (Figure 28).

- CARBONATION: Atmospheric CO_2 can be dissolved in moisture located within the pores of concrete element, where it reacts with $Ca(OH)_2$-calcium hydroxide in the cement to form a neutral $CaCO_3$-calcium carbonate. Over time this slowly lowers the alkalinity of the concrete which covers the steel reinforcement and hence reduces the passive oxide layer which surrounds the steel. Through the acidic environment (concrete goes from neutral to acidic when pH level drops below 9) the steel reinforcement becomes prone to rust.

- ALKALI SILICA REACTION: Alkali-silica gel is of expansive nature and is produced when aggregates react with the alkalies in cement. In moist conditions this reaction leads to cracking and therefore deterioration of the concrete element. In this deterioration mechanism the cracking zone extends throughout the entire mass of the concrete. This kind of reaction is slow, and can develop throughout the decades.

- STEEL CORROSION: The most common deterioration mechanism occurring in steel structures is corrosion. It is defined as a chemical or electro-chemical reaction which results from exposure to air, moisture, industrial fumes, chlorides (marine or from de-icing) and other chemicals in the environment. The corrosion/rusting will only occur if steel is not protected by protective coating or if the coating is damaged or poorly maintained. Corrosion results in progressive loss of the steel thickness and will reduce fatigue resistance (Figure 28).

Figure 28. Examples of reinforced concrete and steel bridge deterioration; left photo available at www.nace.org, right photo available at www.rollanet.org)

Following statements are summarised from thesis by Viet Tran The (2011) Slope Stability Assessment of Manmade Slopes; Landslides are usually caused by topography, geology, and change in water conditions etc., where manmade slopes fail (Figure 29) during the engineering life-time due to weathering (Hack & Price). According to Ollier (1969): "Weathering is the breakdown and alterations of materials near the earth surface to products that are more in equilibrium with newly imposed physic-chemical conditions". Weathering can be physical, chemical or biological, and conditions which control them are either internal, external or geotechnical (designed: slope angle, height, drainage measures), according to Huat et al. (2004).

Figure 29. Example of slope deterioration, photo taken from Newcastle University webpage.

Prolonged exposure to rain, wind, sun or imposed additional loading can lead to erosion of slopes, which leads to further degradation of the soil body. The time required for soil deterioration time can vary dramatically, it can be immediate, for example after heavy rainfall or it can build up over geological timescales.

Salting is the process of accumulation of soluble salts, this is characteristic for lowland areas. Salt content has an influence on water conditions and flows and indirectly changes conditions within the soil body and can lead to soil collapse.

Figure 30. Example of retaining wall failure in Austria photo taken from "oe24" newspapers website.

Deterioration mechanisms which can lead to retaining wall failure (Figure 30) are the same to those already mentioned for reinforced concrete and steel structures and slopes.

Deterioration mechanisms will be further addressed in Task 2.3 Vulnerability Processes and Model Ranking. Relevant deterioration processes will be gathered from previous European framework projects and incorporated into risk models for critical infrastructure elements.

3.1.3 Possible mitigation/adaptation strategies

Most European countries have their own national strategy for adaption to climate change and mitigation strategies, according to European Climate Adaptation Platform (Figure 31). The level of refinement depends mostly on available funds and governmental policy. The best solution is to address climate change effects at the earliest possible stage throughout planning, design and construction or maintenance and operation. Research studies and research projects are also a big part of improvement when it comes to incorporation of climate change effects in infrastructure network.

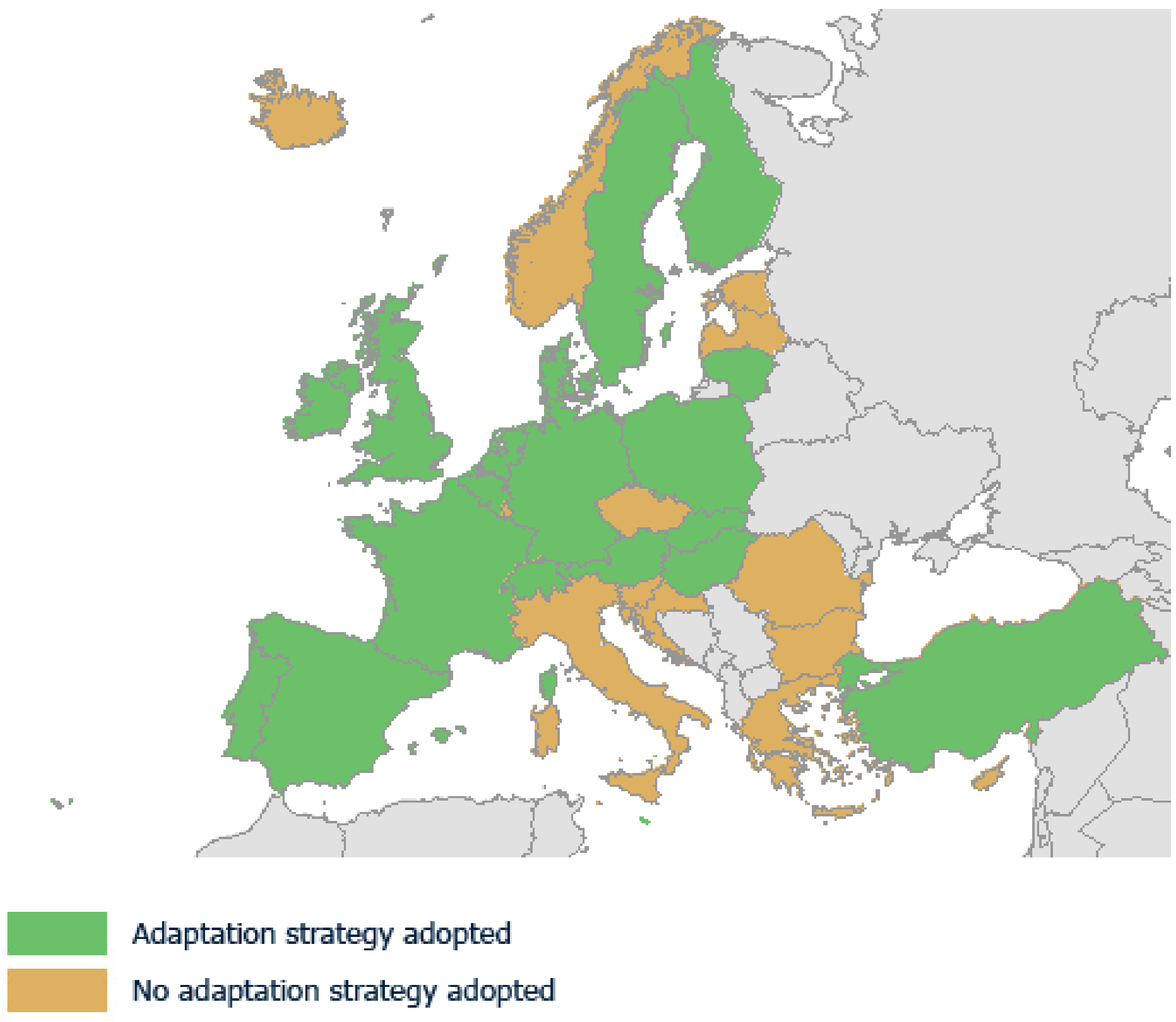

Figure 31. Adaptation strategy adoption image taken from European Climate Adaptation Platform website (CLIMATE-ADAPT, 2014)

Prioritising is important when it comes to road management, especially in maintenance of the existing inventory. This risk tool will help with that specific task. A set of practical adaptation scenarios are usually developed for each possible outcome by which road managers will act in order to prepare for the upcoming unfavourable events.

Table 9 gives a summary of some of the practical activities, which were covered in Adaptation to climate Change report (CEDR, 2012) of European Countries on adaptation work to climate change.

Table 9. Practical adaption to climate change effects throughout the Europe.

COUNTRY	ADAPTATION/MITIGATION	BENEFIT
Denmark	**ERA-NET ROAD –** Geographical Information system tool for analysis and prediction of floods. The objective is an overall guideline on identification of so called blue spots, the places where flooding occurs in extreme precipitation events.	All road administrations
Denmark	**Blue spot map -** Storm water prevention. The methods to predict flooding on and near road pavements in lowland areas, which is a consequence of sea-level rise.	Planning, operation, maintenance and repair
United Kingdom	**National Flood Register –** The register was launched in order to provide better emergency access to motorways. As a result Emergency Customer Welfare Strategy was improved in order to provide delivery of basic emergency welfare to stranded motorists.	Planning and design
Denmark, Norway and Sweden	**Design rule adjustment for climate change adaption -** The return periods for precipitation are being readjusted; introduction of climate factors; the source of data for precipitation and precipitation intensity and requirements for minimum dimensions.	To ensure drainage capacity, flood protection
Norway	**Landslide and avalanche alert system -** The Directorate of Water and Energy Resources (NVE) is establishing services that will warn of avalanche danger at regional level, with an aim of reducing number of accidents, casualties and damage.	Public safety, roads and railways, tourism
Austria	**Hazard zone planning -** The risk assessment of natural hazards takes into account probable risk developments due to climate change. The time perspective is long enough to cover rare and very severe events.	Active and passive protection against natural hazards with economical account taken into account. This tool finds best alignment of new infrastructure with respect to natural hazards.

COUNTRY	ADAPTATION/MITIGATION	BENEFIT
Austria	**Simulation and prognosis of natural hazards -** Simulation models contribute to improvement of protection measures and the prognosis of hazardous events.	Improvement of protection measures
European level	**ROADEX (Implementing Accessibility) -** Focused on general road condition management issues in harsh climates.	All road administrators
France	**Vulnerability of transport infrastructure to coastal hazards -** identification of low-lying areas that might be impacted by coastal flooding; simulation of climate change effects by investigation of sea-level rise.	Planning, Risk Assessment and Maintenance
Coordinator Finland (ERA-NET ROAD)	**IRWIN -** The main objective is to develop an improved winter road index capable of assessing the implications of climate change in various weather parameters and also related road maintenance actions.	Winter Maintenance, Road Management
Coordinator Sweden (ERA-NET ROAD)	**RIMAROCC (Risk Management for Roads in a Changing Climate) - The** objective was to develop a common method for risk analysis and risk management with regards to climate change. The methodological guidebook helps user to identify the climatic risks and to implement optimum action plans that maximise the economic return to road owner, taking into account construction cost, maintenance and environment.	All road administrations
France	**GeRiCi (Gestion des risques lies au changement climatique pour les infrastrucutres/Management of Risk Related to Climate Change) -** Risk assessment tool can be used for systematic screening of infrastructure with respect to vulnerability to different climatic threats.	Risk assessment and real-time monitoring for emergency planning
Norway	**Risk and susceptibility analyses of assets on the road network -** Helps define procedures for better risk and susceptibility analysis which consider weather and climate -related challenges with focus on climate change	Risk Management and Road Maintenance
Sweden	**Estimating costs related to climate change -** Increase in temperature and precipitation cause higher floods levels.	Planning, prioritising

4 Conclusions

In the immediate future the European Continent will go through dramatic changes caused by climatic factors. The negative effects (or consequences) of climate change will have many socio-economic impacts (Figure 32). The operational issues which climate change effects will impose on road infrastructure elements are the primary objective of Re-Gen project. Assessing the risks climate change effects impose on retaining walls, bridges and steep slopes and providing mitigation strategies is the ultimate goal.

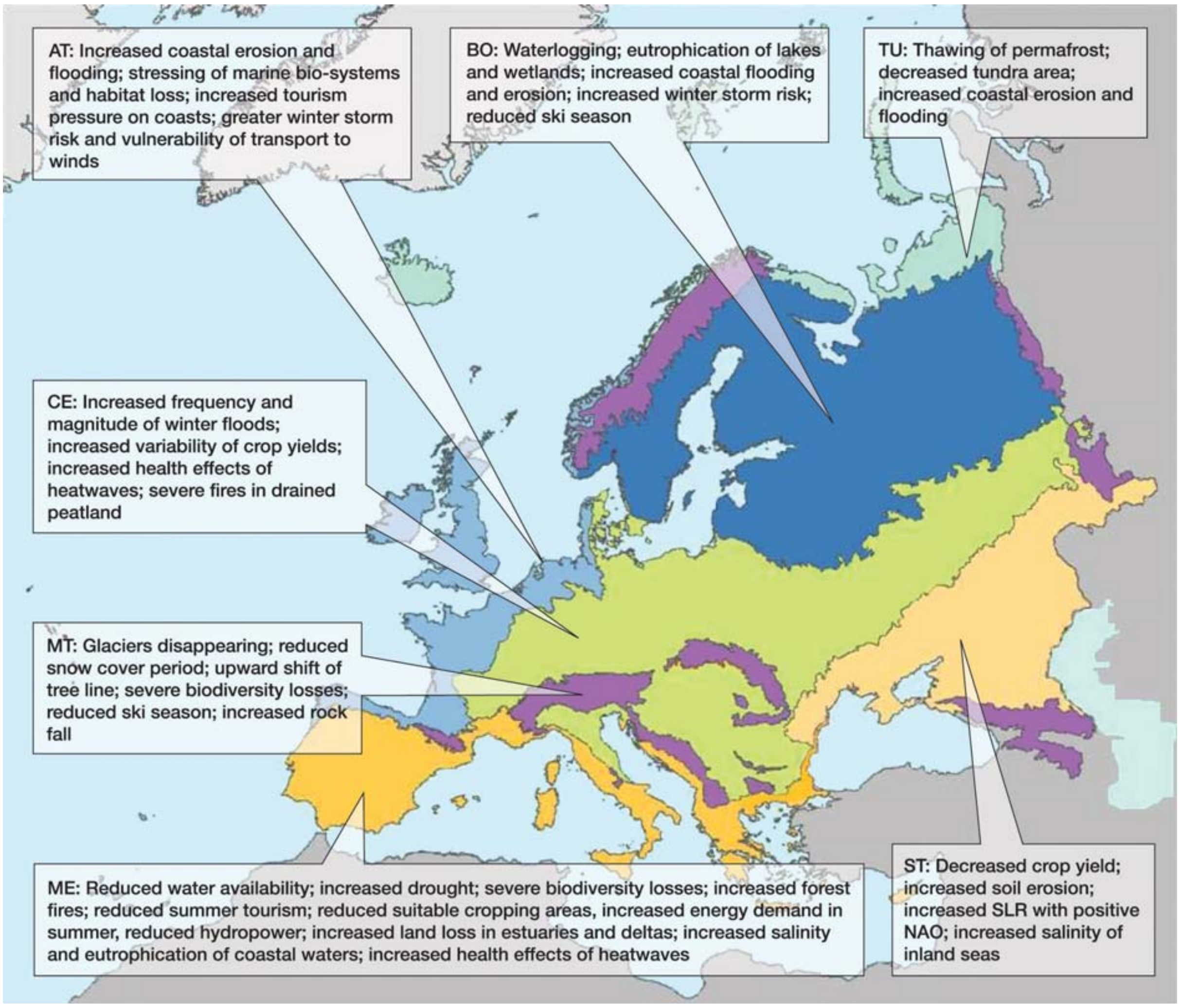

Figure 32. Predicted negative effects of climate change in Europe photo taken form IPCC's report Climate Change 2007, contribution to AR4 (IPCC, 2007)

According to the climate change research findings published in AR4, all of Europe will be affected negatively in one way or another (IPCC, 2007). The British Isles alongside Benelux countries and Northwest of France will be affected by the increased coastal erosion and flooding. This, together with increased winter storms and winds will of course have a negative impact on the transport network. The mountainous terrain throughout the Europe, e.g. Scandinavia, Alps or Dinarides will deal with the melting of glaciers, thus reducing snow cover and increasing rock falls. Scandinavia and the Baltic will experience cases of waterlogging, higher risk of winter storms, coastal flooding and erosion. Most of Continental Europe will also be affected by the increased events of floods in summertime and the

Mediterranean will experience higher heatwaves in the summer period, reduction of hydropower and increase of salinity. As stated in CEDR's report Adaptation to climate change we can form two regions: (I) the Northern and Eastern Europe and (II) Southern, Western and Central Europe. The former will be impacted by wetter winters and the latter by dryer summers (CEDR, 2012).

Aging is just one of the many factors which affect the performance of infrastructure. Its robustness, maintenance and management are often challenged by natural forces, and those forces are constantly changing in line with the climate. In other words environmental factors are seriously contributing to the aging and could lead to possible infrastructure failures.

In order to provide the road owners/managers with a risk assessment tool which will greatly help them with prioritising, decision-making and management, we must investigate possible climate change effects which have a direct impact on deterioration mechanism and ultimately lead to deterioration of infrastructure elements and incorporate them into the design tool, but also take them into consideration for the design and/or retrofitting of infrastructure in the future. In the risk assessment tool, these climate change effects will be incorporated in a probabilistic manner, taking account for the uncertainties of these effects. This report has given a comprehensive overview of the uncertainties to be expected over the next decades.

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