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Climate change projections for Albania

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Report for

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Executive Summary

This report presents climate change projections for Albania for the 2020s, 2050s and 2080s. The projections are taken from nine of the most up-to-date global climate models used in the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4), for a range of greenhouse gas emissions scenarios.

This work has been designed to complement research already undertaken in Albania, which provides observed trends in climatic conditions over the second half of the 20th century and future climate projections from a small number of climate models.

The projections for Albania in the 2020s and 2050s are summarised in the table below.

	Range of projected changes compared to 1961-1990 baseline [a]			
	2020s		2050s	
Climate variable	**Summer**	**Winter**	**Summer**	**Winter**
Temperature (°C)	Hotter +1.3 to +1.7	Hotter +0.5 to +1.1	Hotter +1.9 to +3.5	Hotter +1.1 to +2.1
Precipitation [b] (mm/day)	Drier -0.15 to 0.0 (-0.45 to +0.2) [b]	Mixed -0.25 to 0.0 (-0.2 to +0.45) [b]	Drier -0.35 to -0.05 (-0.45 to +0.05) [b]	Mixed -0.25 to +0.05 (-0.45 to +0.25) [b]
Windspeed [c] (ms^{-1})	Little change 0.0 to +0.1	Little change -0.05 to 0.0	Little change +0.05 to +0.1	Little change 0.0 to +0.05
Relative humidity [d] (%)	Less humid -6 to -2	Little change -1 to 0	Less humid -10 to -5	Little change -1 to 0
Cloudiness (%)	Less cloudy -5 to -2	Little change -2 to 0	Less cloudy -8 to -6	Little change -3 to 0
Sea surface temperature [d] (°C)	Warmer +0.9 to +1.1	Warmer +0.5 to +0.9	Warmer +1.3 to +2.1	Warmer +0.9 to +1.7
Sea level rise (cm)	According to the IPCC AR4, thermal expansion of the oceans and melting of ice could contribute 18 to 59cm to *global* sea levels by the 2090s compared to the baseline period 1980-1999. Since the AR4 was published, a growing number of scientists have stated that the AR4 projections are likely to be an underestimate. There are significant uncertainties regarding projections of sea level rise at the Albania coast, due to local processes such as land subsidence and uplift.			

Notes:

(a) Unless otherwise indicated, the ranges provided are the average across 9 climate models, under 3 greenhouse gas emissions scenarios.

(b) Figures shown in brackets are the ranges across the 9 individual climate models, under a single greenhouse gas emissions scenario.

(c) Projections for windspeed are highly uncertain. Only 1 greenhouse gas emissions scenario has been examined.

(d) For relative humidity and sea surface temperature, 2 emissions scenarios have been examined.

Uncertainties in the projections

Most global climate models operate at a course spatial resolution (2.5° x 2.5° is typical) which is insufficiently detailed for quantitative risk assessments and adaptation planning in small countries.

Furthermore, the agreement between the global climate models varies over Albania. For projections of changes in temperature, the nine models are in good agreement, and all show increasing temperatures over Albania in the coming decades. However, the model agreement is less good for projections of changes in precipitation, relative humidity and cloudiness. Projections of future changes in windspeeds are highly uncertain.

Future concentrations of atmospheric greenhouse gases are also uncertain, so this report provides projections based on a range of greenhouse gas emissions scenarios to help understand their influence. Natural variability will also clearly continue to be a feature of Albania's climate. Warmer and colder periods, wetter and drier periods, as seen in the past, will undoubtedly continue into the future. In any given year or season, this variability may add to, or subtract from, the effects of man-made climate change.

Based on the analysis undertaken for this report, it is clear that Albania would benefit from additional investment in downscaling of large-scale global climate models to scales of more relevance to river basin planning.

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List of acronyms

CMIP3	Coupled Model Intercomparison Project 3
DJF	December to February
GCM	Global Climate Model or, strictly speaking, General Circulation Model
GFDL	Geophysical Fluid Dynamics Laboratory, USA
HadRM3P	A version of the UK Met Office Hadley Centre's Regional Climate Model
HMI	Hydrometeorological Institute, Tirana Polytechnic University (now IWE)
IPCC AR4	Intergovernmental Panel on Climate Change Fourth Assessment Report
IWE	Institute for Energy, Water and Environment, Tirana Polytechnic University (formerly HMI)
JJA	June to August
MAM	March to May
NCEP	National Centers for Environmental Prediction, USA
SON	September to November
SRES	Special Report on Emissions Scenarios
SST	Sea surface temperature
WCRP	World Climate Research Programme

1. Introduction

This report sets out projected climatic changes for Albania and South East Europe in the decades of the 2020s, 2050s and 2080s, providing annual average changes and changes for the four standard seasons (December to February, March to May, June to August, and September to November).

As agreed with the World Bank, this report has been designed to complement, rather than replicate, the climate analyses for Albania which have already been published. The key published reports and presentations have been produced by Dr Eglantina Bruci, formerly of HMI/IWE, now at UNDP, and are as follows:

- **Observed climate variability and trends in Albania** (Bruci, 2008). This report provides data on observed climatic conditions, based on data recorded at meteorological and hydrological stations in Albania, mostly over the second half of the 20th century. It is the best available source of information on observed climatic conditions for the country. The climatic variables covered are temperature, precipitation, solar radiation, sunshine, wind, runoff and extreme precipitation events (heavy rain, strong winds, snow depth, flooding, drought and forest fires).
- **Climate change projections for South Eastern Europe** (Bruci, 2007). This report provides projections of annual average changes in temperature and precipitation for the 2080s at 5° x 5° spatial resolution from the UK Met Office Hadley Centre's climate model, for a broad range of greenhouse gas emissions scenarios. It also provides projections of annual average and seasonal average temperature and precipitation changes for the 2080s at the same spatial resolution from four climate models, for the A2 emissions scenario[1], as well as 2080s projections from one regional climate model, HadRM3P, at 50km x 50km spatial resolution.
- **Climate variability and expected changes in Albania** (Bruci, 2009). This presentation, delivered at the World Bank workshop on 10 March 2009, provides observed climate data presented in Albania's First National Communication to the United Nations Framework Convention on Climate Change (Islami *et al*, 2002), as well as the climate change projections generated for Albania's Second National Communication, due to be published later in 2009. The latter describe projected changes in temperature and precipitation for 2025, 2050 and 2100.

In addition, a report by Voynov and Hancock (2007) describes weather variability in South East Europe and Central Asia based on analyses of a 17-year model run of global climate undertaken by the Geophysical Fluid Dynamics Laboratory (GFDL) at 2.5° x 2.5° spatial resolution. Using these data, it investigates variability in temperature and precipitation on 3-10 day timeframes. It also presents analyses of variability in runoff data based on NCEP (National Centers for Environmental Prediction) reanalysis data at 1.9° x 1.9° spatial resolution, as well as some information on extremes of wind and drought.

Based on the above work, and through discussion with Dr Bruci, it was felt that our analysis could add value by presenting outputs from a broader range of the most up-to-date climate models used in the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4, Meehl *et al*, 2007), for a range of greenhouse gas emissions scenarios.

It is clear, however, that Albania would benefit from additional investment in downscaling of large-scale global climate models, which typically work at 2.5° x 2.5° spatial resolution, to the scales of more relevance to river basin planning.

[1] See Appendix A for descriptions of the emissions scenarios

1.1 Data presented in this report

Future climate change for the world or for specific regions is estimated from climate models. These models are forced with changing gaseous atmospheric compositions which result from greenhouse gas and other emissions. Since these emissions cannot be known from first principles, several possible agreed emissions scenarios have been established and used globally, and these are referred to as the SRES scenarios (Special Report on Emission Scenarios) (Nakićenović and Swart, 2000).

Most global climate models operate at a course resolution (2.5° x 2.5° is typical) which is insufficiently detailed for risk assessments and adaptation planning in small countries. As a result, methods have been developed to downscale the climate information to finer resolution, though these have only been applied in a small number of locations and often only provide results for the end of the century. In the absence of coordinated efforts to undertake climate downscaling for Albania, the global models, when studied at the regional scale, offer the best currently available guide to future Albanian climate conditions.

In this report, data from nine global climate models (GCMs) which formed part of the IPCC AR4 are evaluated over Albania. Projections of changes in the following climate variables are provided:

- Temperature,
- Precipitation,
- Windspeed,
- Relative humidity,
- Cloudiness,
- Sea surface temperature,
- Sea level rise.

Together with information on observed climatic conditions in Albania (Bruci, 2008), they help to provide an indication of future climatic conditions which will be experienced in the country, and which will affect the energy sector.

2. Data, methods and uncertainties

During 2007 the IPCC AR4 was released. As part of this effort an international, coordinated set of climate model runs was established under the World Climate Research Programme (WCRP) leading to a dataset which is referred to as CMIP3 (Coupled Model Intercomparison Project 3).

Some 22 climate models form this data set, but several of these 22 are replications of very similar versions of the same model. For this report, 9 demonstrably independent models have been selected. These are:

1. CGCM3.1 from the Canadian Center for Climate Modelling and Analysis – http://www.cccma.bc.ec.gc.ca/eng_index.shtml
2. CM3 from the French Centre National de Recherches Météorologique – http://www.cnrm.meteo.fr/gmme/
3. Climate Model Mark 3.0 from the Australian Commonwealth Scientific and Industrial Research Organisation – http://www.csiro.au/science/EMM.html

4. CM2 from the US Geophysical Fluids Dynamical Laboratory – http://www.gfdl.noaa.gov/research/climate/
5. ECHAM5 from the German Max Planck Institute for Meteorology – http://www.mpimet.mpg.de/en/home.html
6. GCCM2.3.2a from the Japanese Meteorological Research Institute – http://www.mrijma.go.jp/Dep/cl/cl.html
7. The Climate Model from the German Meteorological Institute of the Rheinische Friedrich-Wilhelms Universität, Bonn – http://www.meteo.uni-bonn.de/index.en.html
8. CCSM3 from the US National Center for Atmospheric Research – http://www.ccsm.ucar.edu/
9. HadCM3 from the UK Met Office – http://www.metoffice.gov.uk/research/hadleycentre/index.html.

The results from these 9 models have been interpolated to a common grid and the results shown in this report are based mainly on an average of all 9 models. For precipitation, we have also presented results from individual climate models, to establish how well the models agree with each other.

In all cases, the differences between the future time period (2020s, 2050s or 2080s) and the standard baseline period 1961-1990 are shown.

In interpreting the results of this assessment it is important to be aware of the uncertainties involved in making these projections. Climate models are the only approach available for making projections, but, despite continual improvements, models have their limitations and are particularly challenged when used to provide detailed regional and national projections. Other factors, including the future concentrations of atmospheric greenhouse gases, provide further uncertainties in the projections. Efforts have been made to address these uncertainties, but it should be borne in mind that no unique and definitive statements regarding future climates, shorn of all uncertainties, can be made.

Three pertinent sources of uncertainty associated with the projections presented in this report are:

Future atmospheric greenhouse gas concentrations are indeterminate for various reasons, not least the fact that future emissions will depend on numerous international, national and individual actions. In this assessment estimates have been presented for three SRES emissions scenarios, to cover a range of possible future. The three scenarios are:

1. SRES A2 – a 'medium-high' emissions scenario that results in a best estimate global temperature change of ~3.4°C by 2100,
2. SRES A1B – a more middle-of-the-road 'medium' emissions scenario giving ~2.8°C global temperature increase by 2100,
3. SRES B1 – a 'low' emissions scenario giving ~1.8°C global temperature increase by 2100.

These are referred to in this report as the 'medium-high', 'medium' and 'low' scenarios. For further details on these scenarios, see Appendix A.

Regional climate change is less well modelled and understood than global change. One of the limitations of current climate models is their relative inability to prescribe detail on the regional scale as compared to their abilities at the global scale; the IPCC has recognised this as a prime area for continuing research.

Natural climate variability will continue to be a feature that makes interpretation of anthropogenically-forced climate change complex. No single climatic event, past or future, can or could be attributed unequivocally to man-made climate change. Natural climate variability will continue to complicate interpretation. Warmer and colder periods, wetter and drier periods, features of the past, will undoubtedly continue into the future. A drier future climate overall does not signify that heavy precipitation events will *not* occur, while, equivalently, a wetter climate does *not* necessarily mean that the extra precipitation will be delivered in more powerful events, nor that droughts will not happen. Multi-year trends of warming or cooling, wetting or drying, have been observed in the past, and will continue to be a feature in the future.

3. Key global warming trends

To provide this report with a broader context, the characteristics of global trends are summarised below:

- Warming of the global climate system is unequivocal, with global average temperatures having risen by nearly 0.8°C since the late 19th century, and rising at about 0.2°C/decade over the past 25 years.
- It is "very likely" (>90% probability) that anthropogenic greenhouse gas emissions caused most of the observed global temperature rise since the mid-20th century.
- Globally each of the 12 warmest years on record have all occurred since 1990.

4. Projected changes over South East Europe including Albania

Based on the GCMs described in Section 2, projections of changes in climatic variables over South East Europe, including Albania, are discussed below.

4.1 Temperature

Temperature changes for the mean of the nine CMIP3 models are shown in Figures 1-5 for annual, June to August (JJA), December to February (DJF), March to May (MAM) and September to November (SON) respectively.

Warming is evident in all the decades and for all scenarios. Annual average warming is greatest (approx 4.5°C) in the 2080s and for the medium-high scenario. Warming is lowest in the 2020s, when the greenhouse gas concentrations are not markedly higher than present. The differences between the warming across the three SRES scenarios are insignificant for the 2020s but are evident and significant from at least the 2050s onwards.

Warming is greatest in June to August and lowest in December to February and March to May. In June to August warming exceeds 5°C over South East Europe by the 2080s in the medium-high emissions scenario, with Albania marking the axis between high warming to the north and more moderate warming in the Mediterranean to the south. In all seasons, the warming projected for the 2080s in the low emissions scenario is similar to the warming shown for the 2050s in the other two scenarios. This is a clear indication of the benefits of mitigation of emissions.

The amount of warming shown the Figures 1-5 is very likely an underestimate of the warming that will occur. The global model grids generally have the effect of reducing the land area in this part of the Mediterranean and increasing the area given over to ocean. The ocean warming is generally lower than the land warming. Regional models, which are better able to represent the land-ocean boundaries, suffer much less from this problem.

Overall the most significant components of the projected temperature increases are those for June to August. Summers in Albania are already hot, with very high values of evaporation, dangerous heat waves and wild-fire risk. Summers which are 5°C warmer than the current heat waves would impose severe risks.

For comparison, modelled baseline temperature projections for 1961-1990 are shown in Figure 29, although, as noted in Section 1, the observed baseline data for Albania (Bruci, 2008), is the best available description of baseline conditions.

4.2 Precipitation

Precipitation changes for the mean of the nine CMIP3 models are shown Figure 6-10 for annual, June to August (JJA), December to February (DJF), March to May (MAM) and September to November (SON) respectively. The results show a spatially coherent and moderate to strong tendency towards drying across the region. Taking the 2050s and 2080s together, only one scenario (low) and one season (DJF) shows a moderate increase in precipitation. For all other seasons and scenarios in these decades there is drying which is particularly marked in June to August in the 2080s. This drying, which is about 25% of the observed mean precipitation by the 2080s, coupled with the marked increase in temperature noted in the previous section, amplifies the exposure to reduced run-off, increased wild-fire and heat-waves. Some of these changes, for example drier soil moisture conditions, feedback on the climate system to increase the heating by, in this case, decreasing the cooling influence of latent heat and increasing the sensible heat flux from the surface to the atmosphere.

In the 2020s, during the transition seasons (March to May and September to November) the mean projections show a moderate increase in precipitation in the medium-high and medium scenarios. Winter and summer for this decade shows drying for all scenarios.

In general, precipitation is poorly handled in climate models. The process of precipitation occurs at scales much smaller than the model grid box and needs to be highly parameterised. As a result of the models using different parameterisation schemes, estimates of model precipitation differ greatly between models. The eastern Mediterranean, however, is one region for which most global models produce a similar result, which is one of drying in the 21st century.

So, although confidence in projections of precipitation is generally low, the South East Europe region is something of an exception. The large-scale anomalous descent serves as the key mechanism for damping precipitation production in this region. In essence, the region becomes much more strongly subtropical.

For comparison with the future projections, modelled baseline precipitation projections for 1961-1990 are shown in Figure 30, although, as noted in Section 1, the observed baseline data for Albania (Bruci, 2008), is the best available description of baseline conditions.

To better understand the agreement between the climate models, Figures 11-14 show the projections for precipitation for the 9 individual models (instead of the ensemble mean) for summer 2020s, winter 2020s, summer 2050s and winter 2050s respectively. Table 1 summarises the sign of change for these projections over Albania. Summers are projected to be drier in the 2020s by a majority of 6 out of the 9 models, with 1 model showing wetter summers and 2 models indicating a mixed signal. None of the models projects a wetter summer by the 2050s, with 8 out of 9 models showing drier summers and one model showing a mixed signal.

The winter precipitation change is less certain and by the 2020s, 4 of the 9 models indicate drier winters, 3 show wetter winters and 1 shows a mixed signal. A similar situation is seen in the 2050s, where 5 of the 9 models indicate drier winters and 4 show wetter winters.

One approach to evaluating the quality of climate models is to compare model simulations for the 20th century to observed climatic conditions over the same time period. Those models that perform best, i.e. that are closest to the actual 20th century climate conditions, are more likely to be reliable in their projections of future change.

Table 1: Summary of projected Albanian precipitation change (compared to 1961 – 1990 baseline) by the number of global climate models

Trend in future projection compared to baseline	2020s summer	2020s winter	2050s summer	2050s winter
Dry	6	4	8	5
Wet	1	3	0	4
Mixed	2	2	1	0
Ensemble mean	**Dry**	**Dry**	**Dry**	**Dry**

4.3 Windspeed

Windspeed changes for the 2020s, 2050s and 2080s are shown in Figures 15-17 respectively for the medium-high emissions scenario. On the whole, the picture which emerges for windspeed is complicated and low confidence should be attached to projected changes in this variable. There is no simple, multi-seasonal or multidecadal response. Instead by the 2080s, there is a slight projected decrease in windspeed for the year as a whole and during June to August, December to February and particularly September to November. For the 2050s, windspeed is projected to increase for the year as a whole and during June to August, December to February and March to May, and to decrease during September to November. A possible reason for the lack of clarity in the windspeed plots is that the different climate models tend to place the centres of pressure systems in slightly different places, leading to non-linear differences in the detailed structure of the wind systems between the models.

4.4 Relative humidity

Relative humidity changes for the annual mean, June to August, December to February, March to May and September to November are shown in Figures 18-22 respectively. Taken over the year as a whole, relative humidity decreases slightly in all three decades. Drying is clearest in summer in association with the decreased rainfall in this season. The mechanism for drying relates to increased subsidence of dry, upper tropospheric air over a large region of the Mediterranean.

4.5 Cloudiness

Cloud cover changes for the annual mean, June to August and December to February are shown in Figures 23-25 respectively. Cloud cover decreases in all seasons, all scenarios and all decades but is most marked (approaching 10%) in summer in the 2080s, in conjunction with the changes reported for precipitation and relative humidity.

4.6 Sea surface temperature

Sea surface temperature (SST) changes are shown for the annual mean, June to August and December to February in Figures 26-28 respectively. Sea surface temperatures throughout the eastern Mediterranean increase in all seasons, decades and scenarios. By the 2080s in the medium-high scenario, SSTs have increased by more than 3°C. Warming is greatest in summer, when the atmosphere to ocean heat flux is at a maximum. Warming in the 2020s is in the region of 1°C and approaches 2°C by the 2050s, except in the low emissions scenario, with a maximum again in summer.

The ocean domain revealed in Figures 26-28 shows that some land areas are designated as ocean in the global climate models. In essence, every 2.5° x 2.5° grid square has to be assigned in the climate model either as 'land' or as 'ocean', depending on whether land or ocean dominates the area. The land-ocean grid is not common to each model and as a result, details of these figures should be interpreted with caution. In some models, elements of the grid will be ocean, in others they will be land. Interpolation to a common grid and the subsequent averaging process therefore leads to edge effects which are not simple to identify.

4.7 Sea level rise

Global climate models provide a basis for estimating the large-scale (global) rise in sea level as a result of thermal expansion of the oceans and melting of ice. Regionally and locally, sea levels are affected by atmospheric, oceanographic and geological processes, such as land subsidence or uplift.

According to the IPCC AR4, thermal expansion of the oceans and melting of ice could contribute 18 to 59cm to global sea levels by the 2090s compared to the baseline period 1980-1999. However, since the AR4 was published, a growing number of scientists have stated that the AR4 projections are likely to be an underestimate.

Sea level trends from the 21 longest records (>35 yr) are smaller in the Mediterranean (0.3 ± 0.4 to -0.7 ± 0.3 mm yr^{-1}) than in the neighbouring Atlantic sites (1.6 ± 0.5 to -1.9 ± 0.5 mm yr^{-1}) for the period 1960–2000(Marcos and Tsimplis, 2008a). Decadal sea level trends in the Mediterranean are not always consistent with global values, in particular for the 1990s, during which the Mediterranean has shown enhanced sea level rise of up to 5 mm yr^{-1} compared to the global average (Marcos and Tsimplis, 2008a). Analysis of 12 ocean general circulation models for the 21st century in the Mediterranean (Marcos and Tsimplis 2008b) has emphasised the great uncertainties in interpreting the changes locally.

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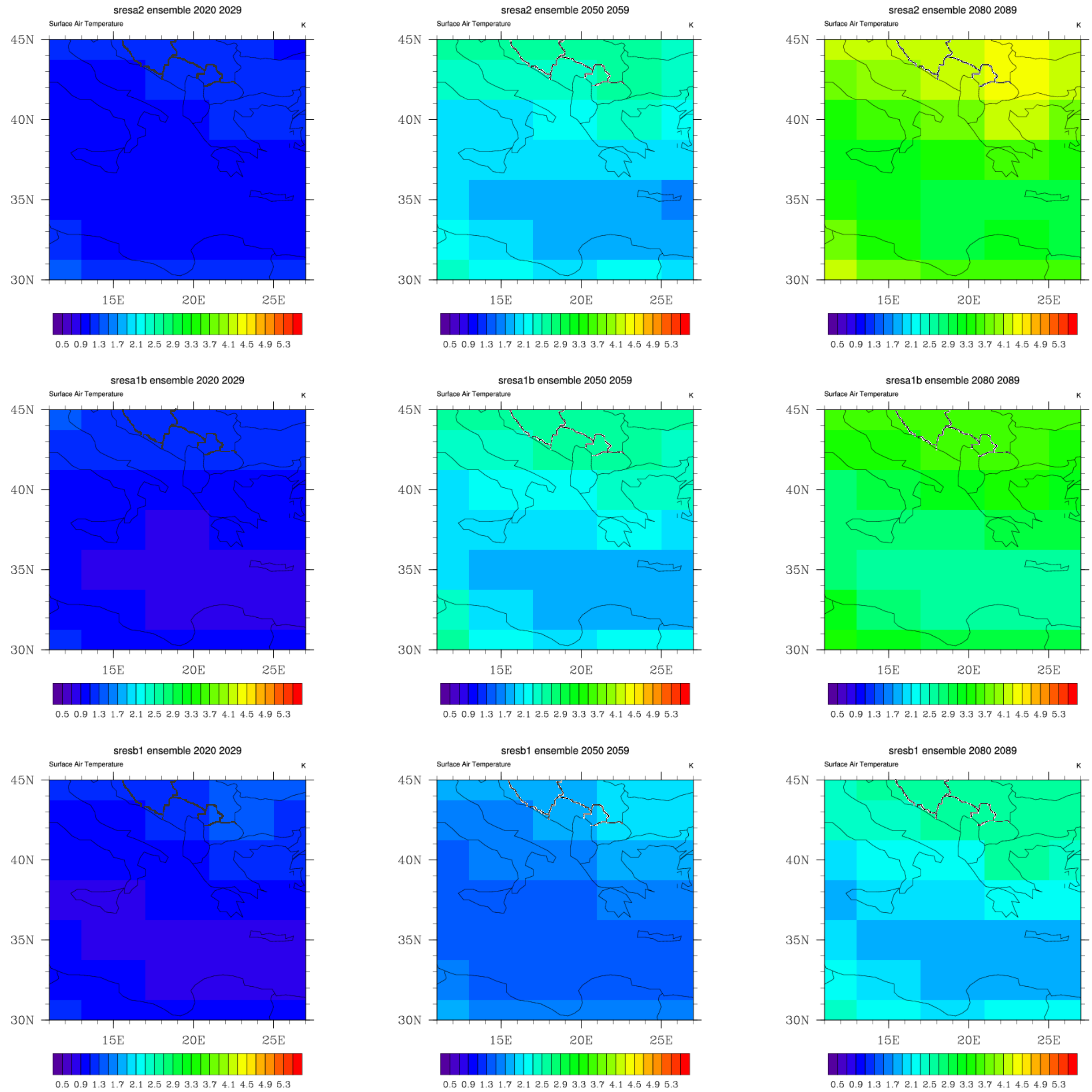

Figure 1: Projected annual surface temperature changes (ºC) from the 1961-1990 mean averaged across 9 IPCC AR4 global climate models for 2020s (left), 2050s (middle) and 2080s (right) for medium-high scenario (top), medium scenario (middle) and low scenario (bottom).

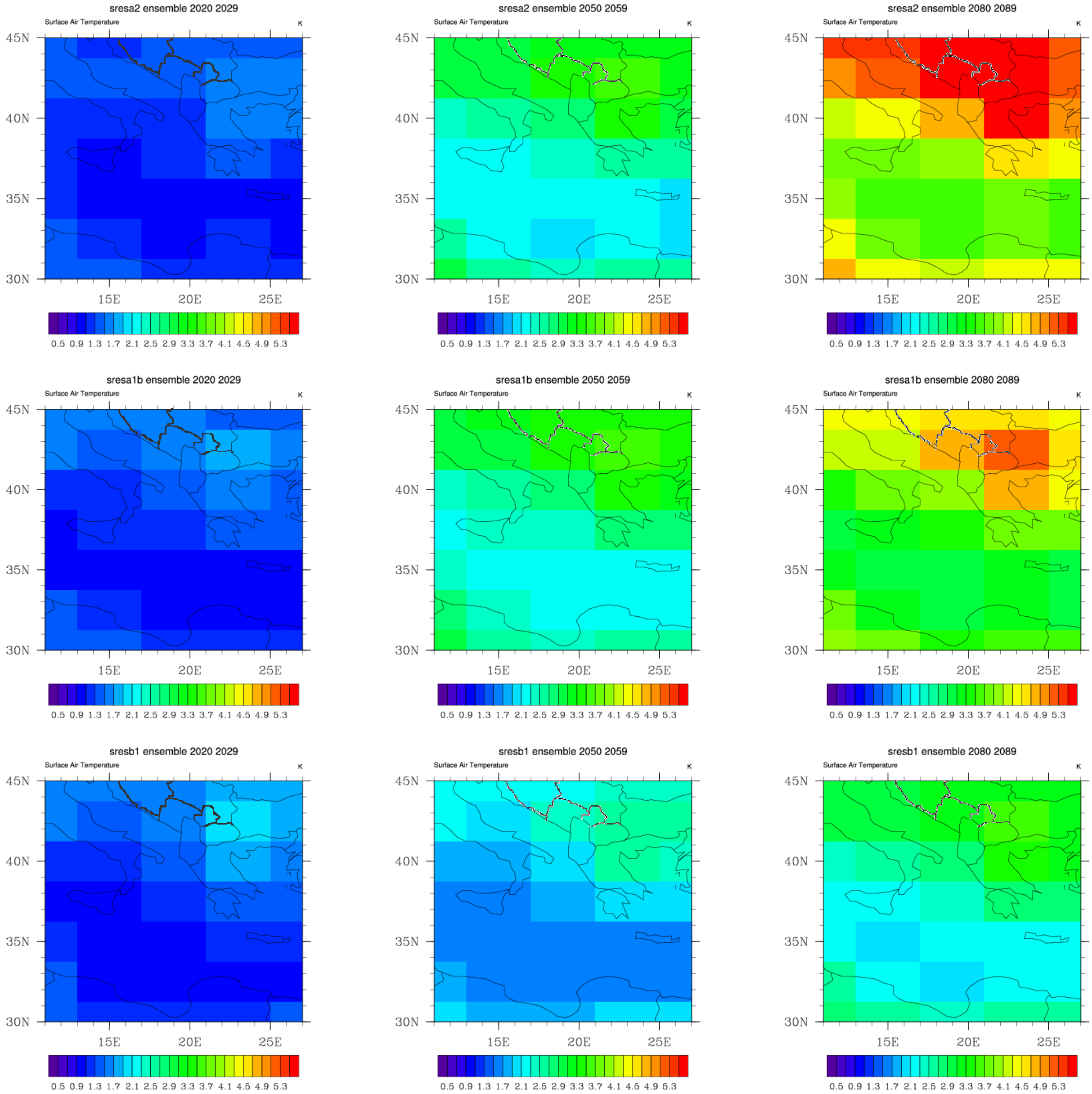

Figure 2: Projected June to August surface temperature changes (°C) from the 1961-1990 mean averaged across 9 IPCC AR4 global climate models for 2020s (left), 2050s (middle) and 2080s (right) for medium-high scenario (top), medium scenario (middle) and low scenario (bottom).

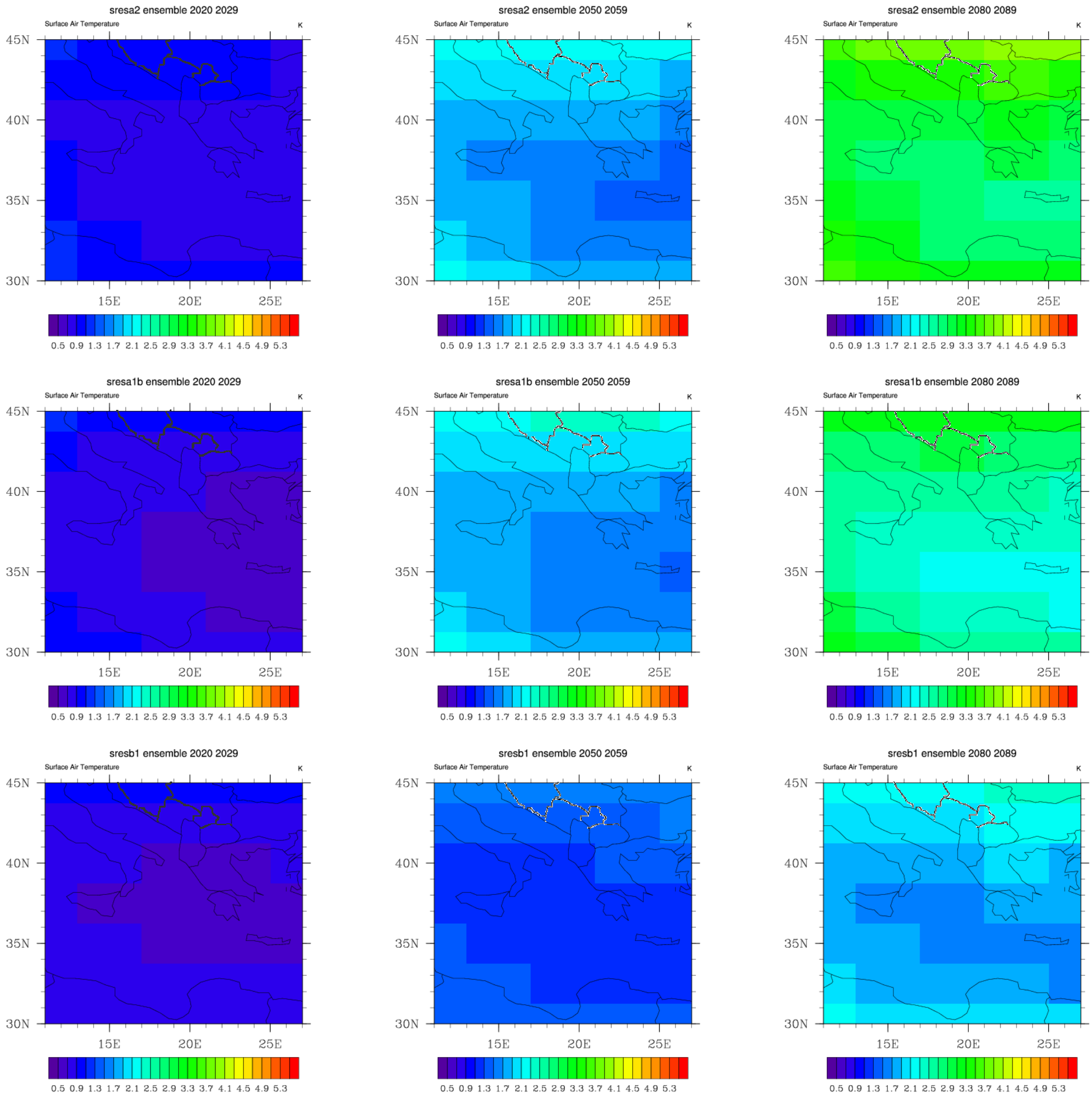

Figure 3: Projected December to February surface temperature changes (ºC) from the 1961-1990 mean averaged across 9 IPCC AR4 global climate models for 2020s (left), 2050s (middle) and 2080s (right) for medium-high scenario (top), medium scenario (middle) and low scenario (bottom).

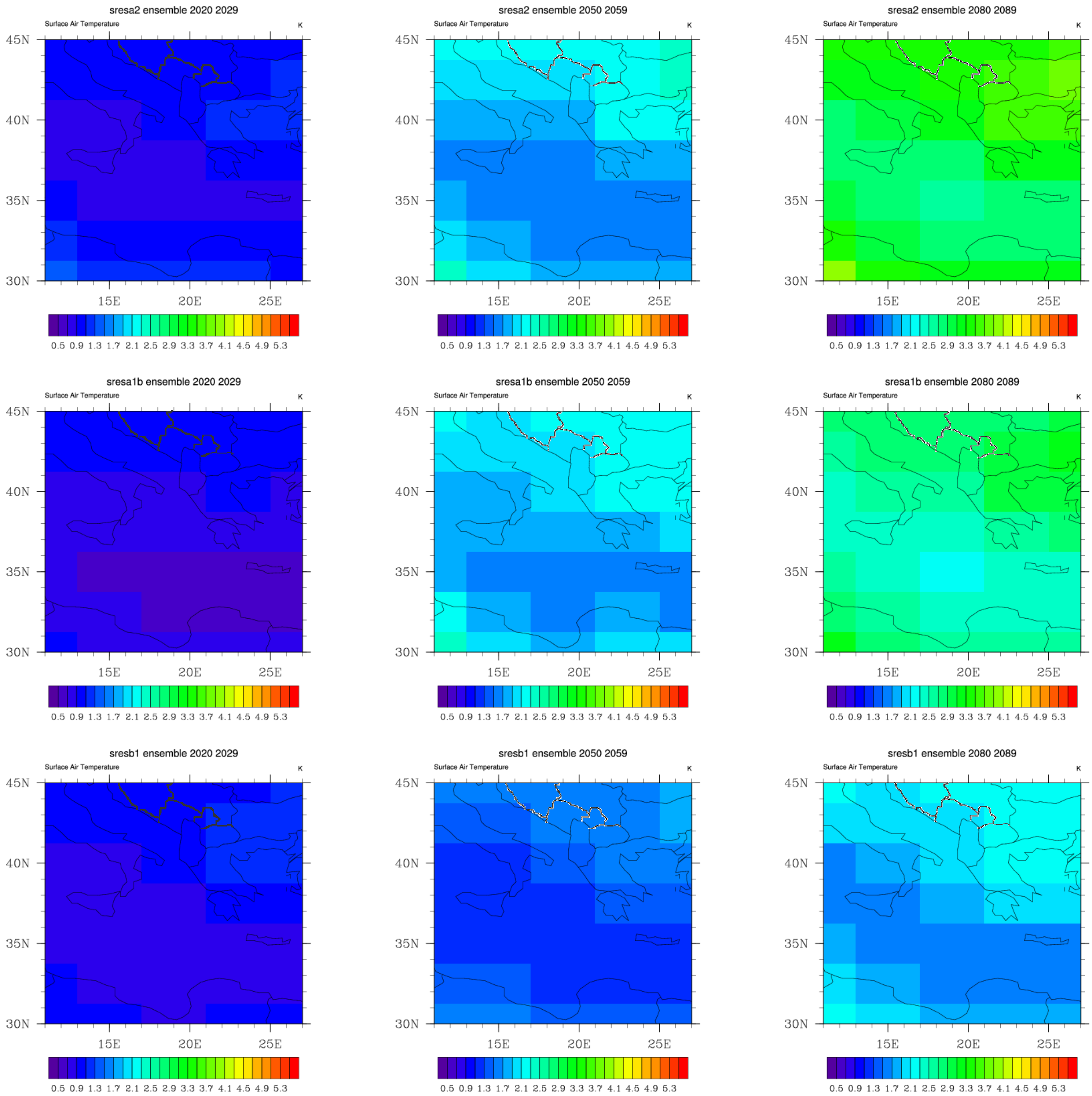

Figure 4: Projected March to May surface temperature changes (ºC) from the 1961-1990 mean averaged across 9 IPCC AR4 global climate models for 2020s (left), 2050s (middle) and 2080s (right) for medium-high scenario (top), medium scenario (middle) and low scenario (bottom).

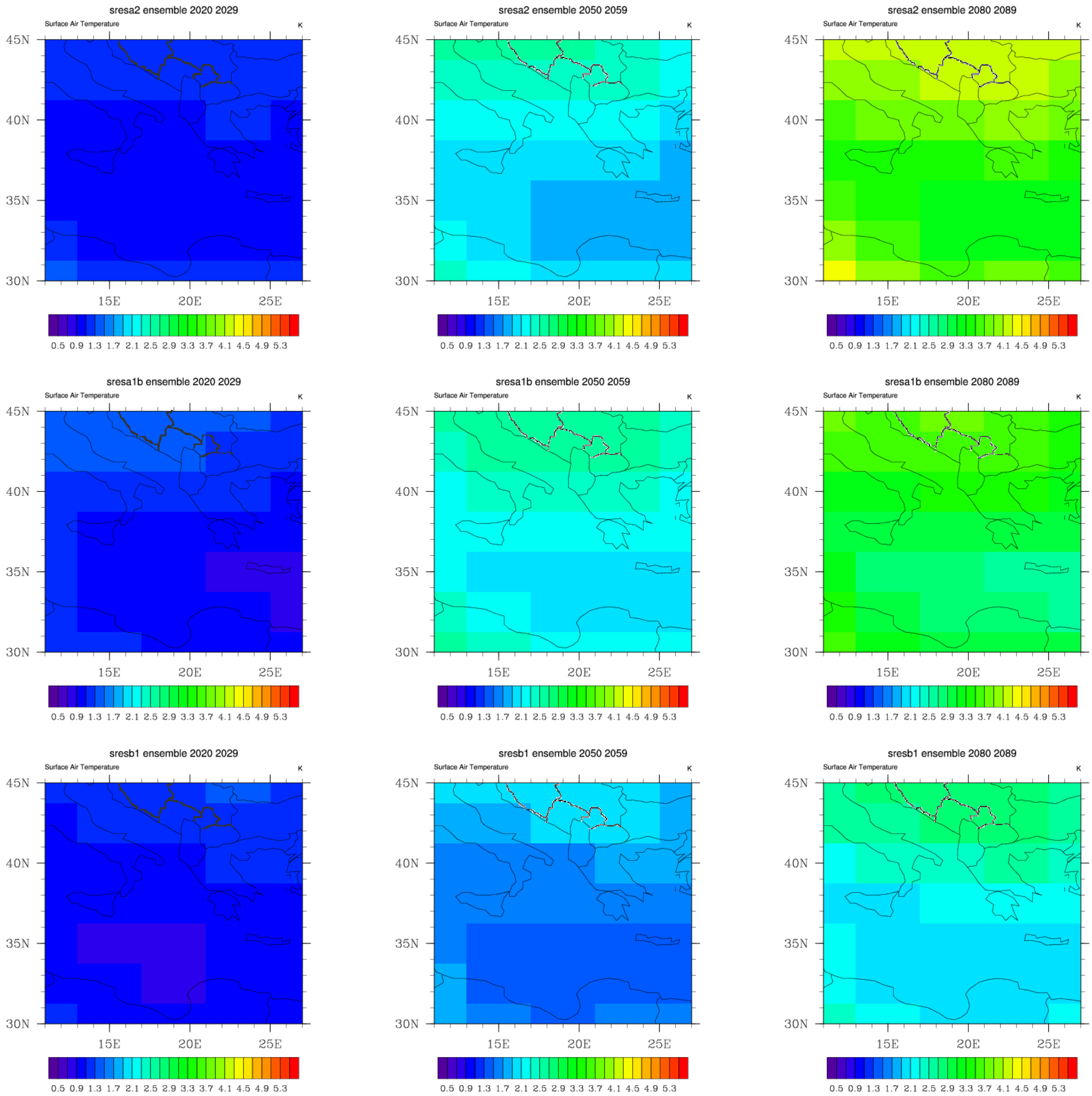

Figure 5: Projected September to November surface temperature changes (ºC) from the 1961-1990 mean averaged across 9 IPCC AR4 global climate models for 2020s (left), 2050s (middle) and 2080s (right) for medium-high scenario (top), medium scenario (middle) and low scenario (bottom).

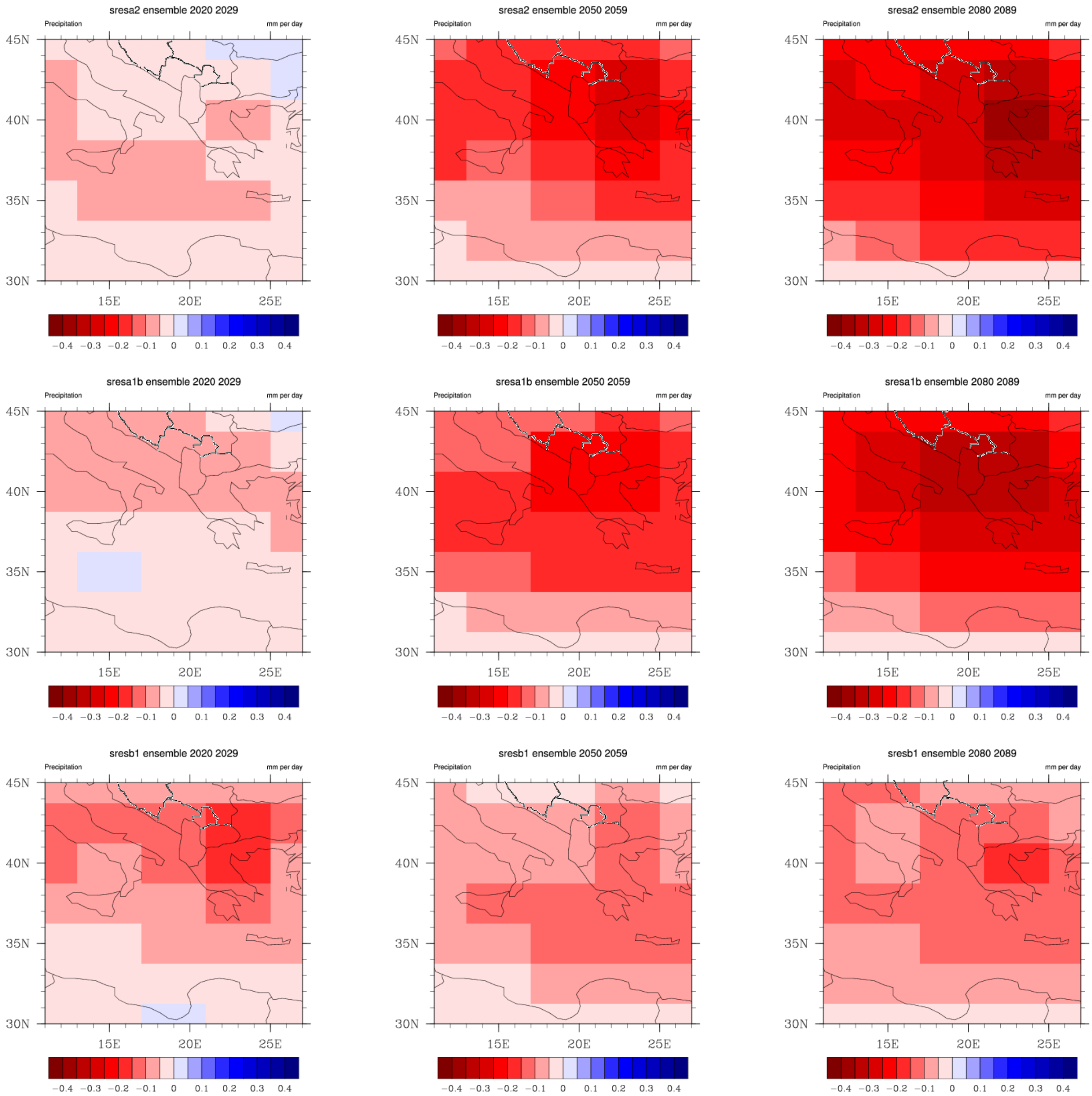

Figure 6: Projected annual precipitation change (mm/day) from the 1961-1990 mean averaged across 9 IPCC AR4 global climate models for 2020s (left), 2050s (middle) and 2080s (right) for medium-high scenario (top), medium scenario (middle) and low scenario (bottom).

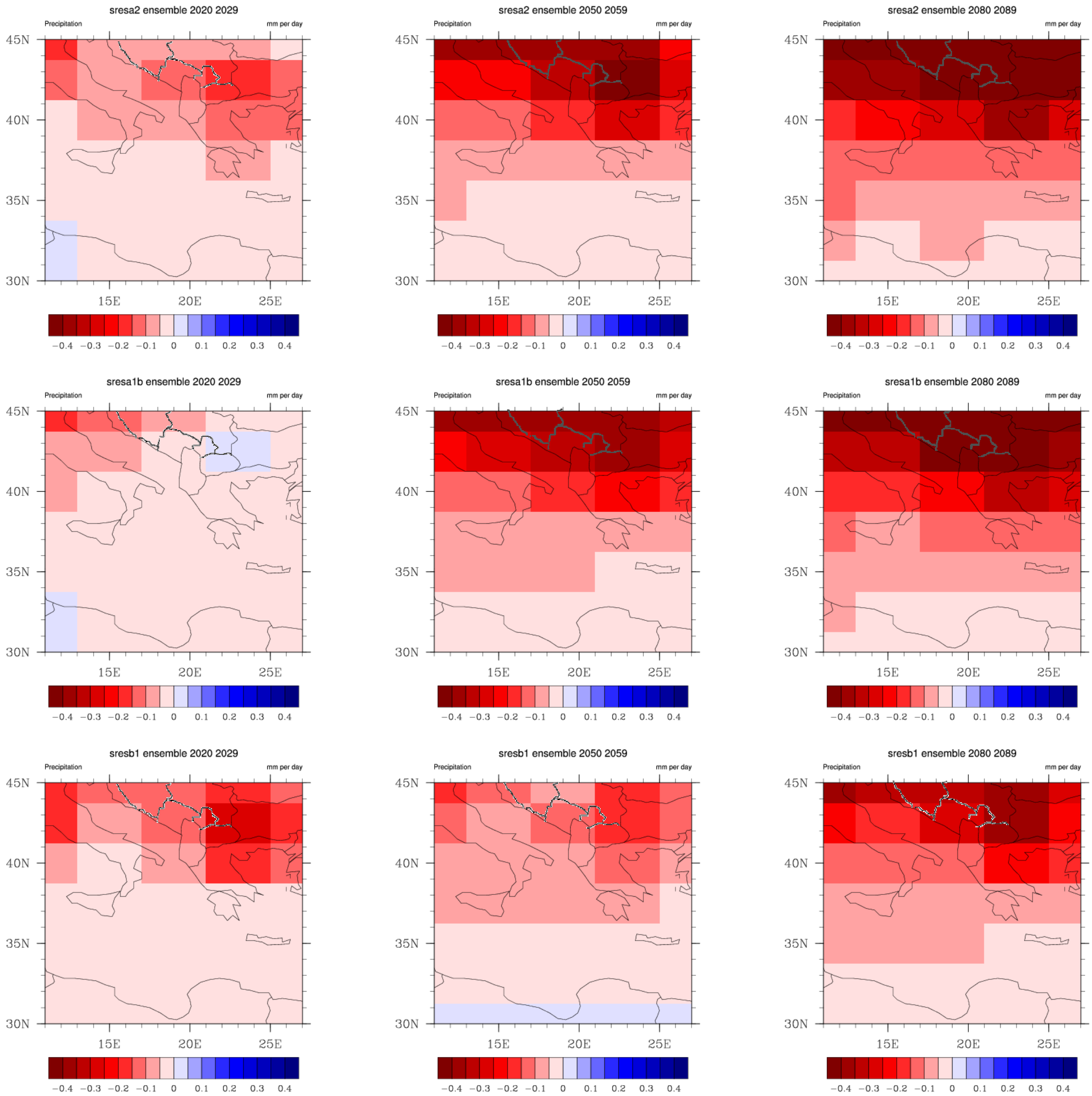

Figure 7: Projected June to August precipitation change (mm/day) from the 1961-1990 mean averaged across 9 IPCC AR4 global climate models for 2020s (left), 2050s (middle) and 2080s (right) for medium-high scenario (top), medium scenario (middle) and low scenario (bottom).

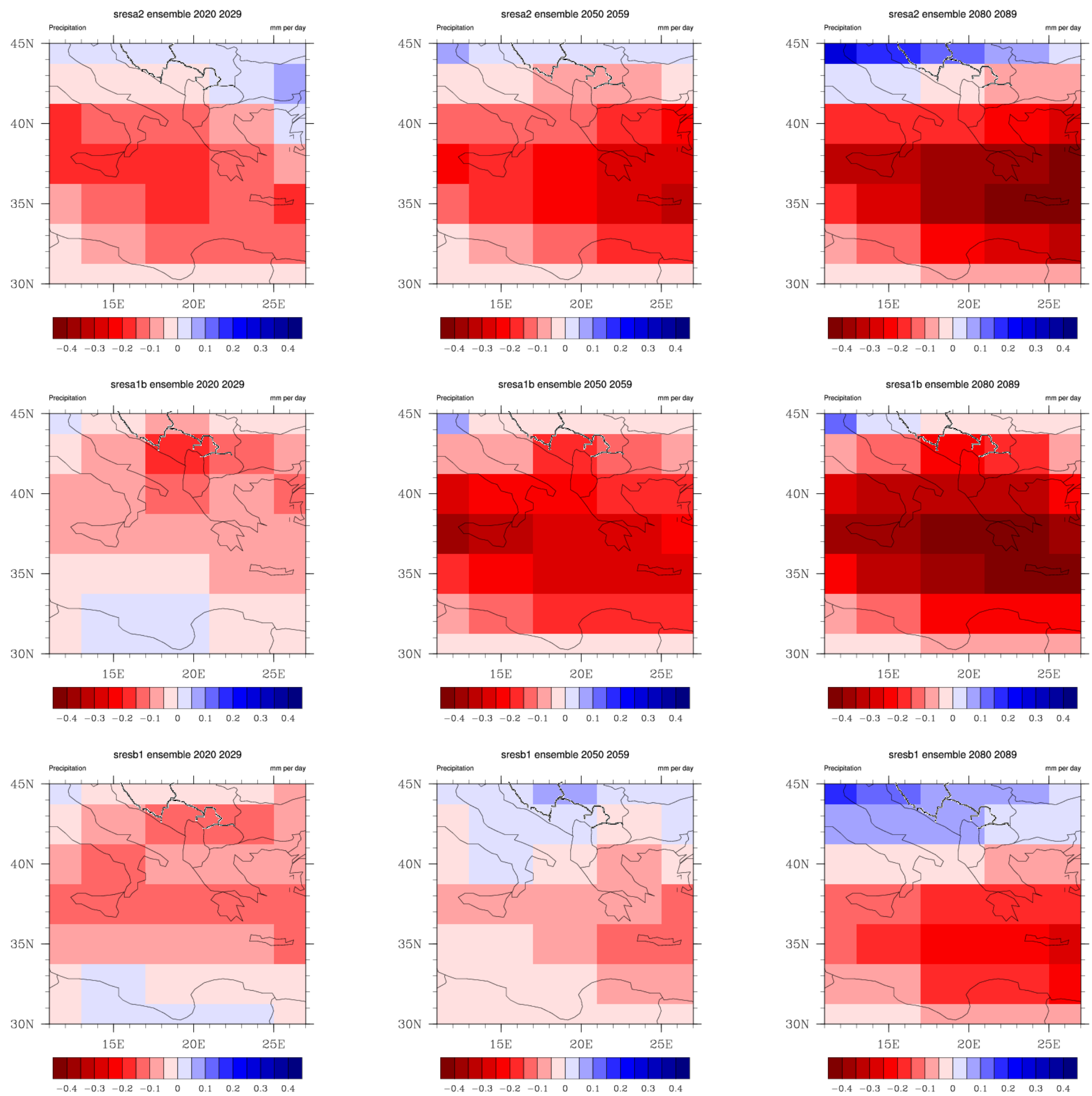

Figure 8: Projected December to February precipitation change (mm/day) from the 1961-1990 mean averaged across 9 IPCC AR4 global climate models for 2020s (left), 2050s (middle) and 2080s (right) for medium-high scenario (top), medium scenario (middle) and low scenario (bottom).

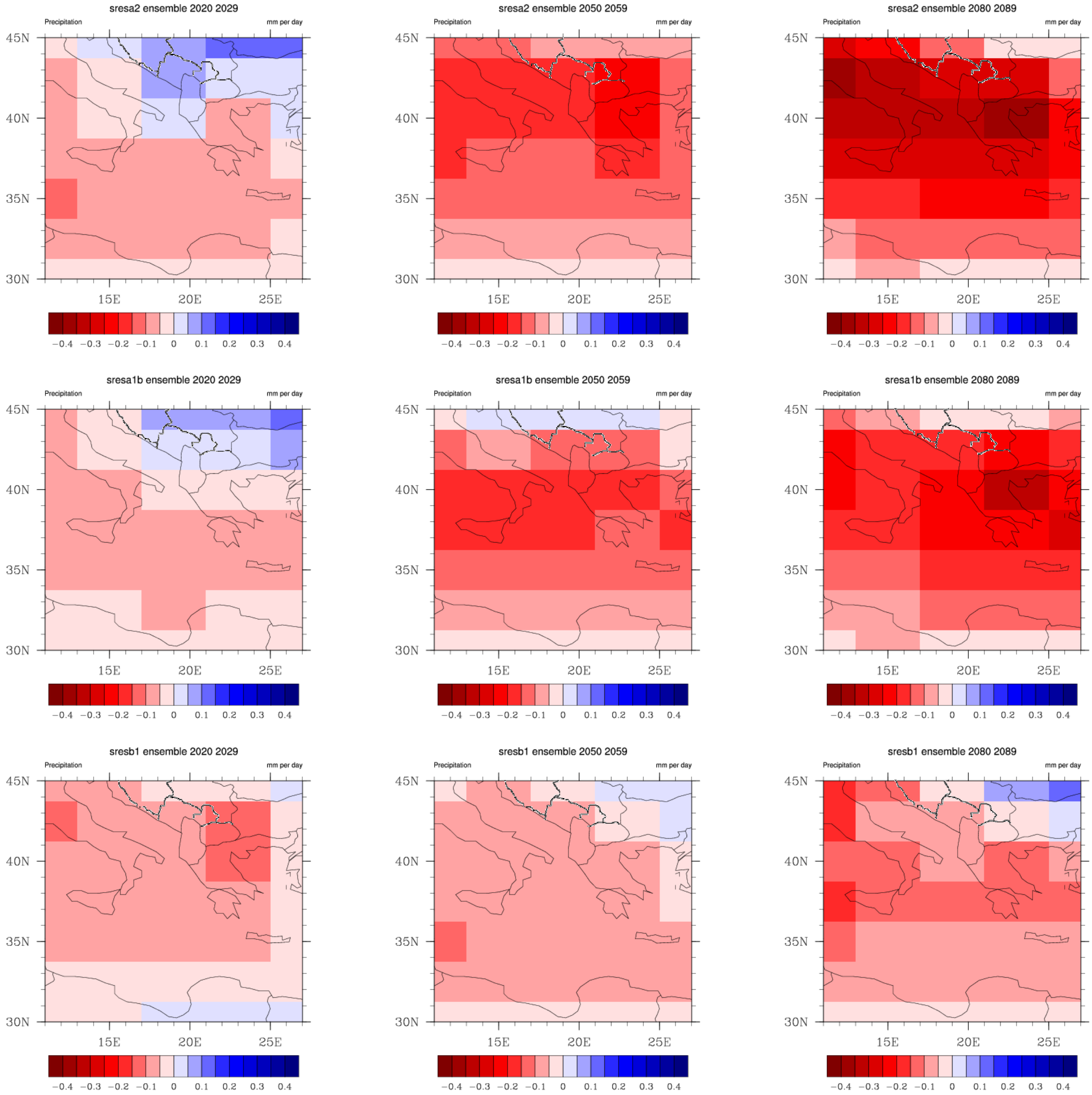

Figure 9: Projected March to May precipitation change (mm/day) from the 1961-1990 mean averaged across 9 IPCC AR4 global climate models for 2020s (left), 2050s (middle) and 2080s (right) for medium-high scenario (top), medium scenario (middle) and low scenario (bottom).

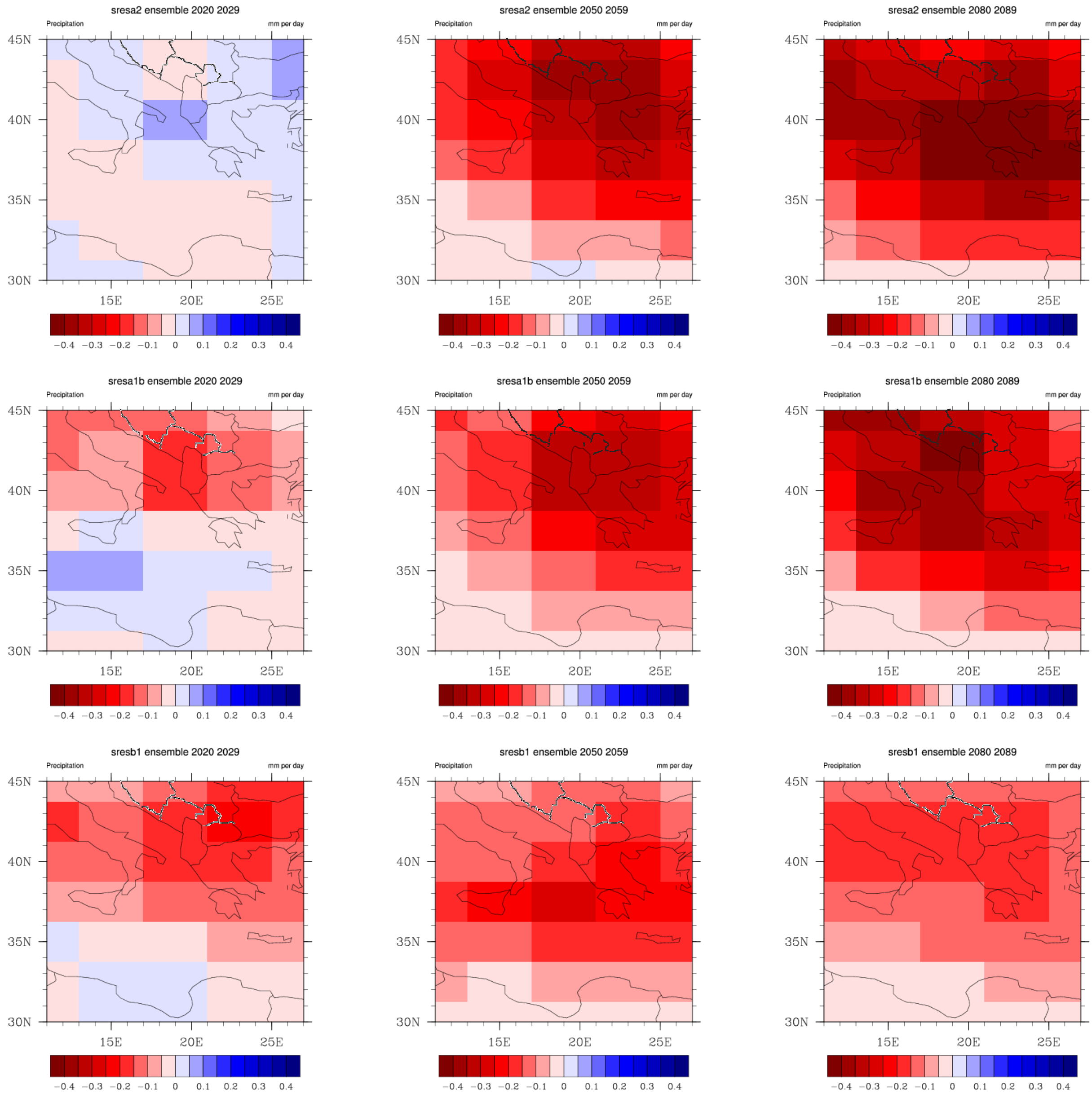

Figure 10: Projected September to November precipitation change (mm/day) from the 1961-1990 mean averaged across 9 IPCC AR4 global climate models for 2020s (left), 2050s (middle) and 2080s (right) for medium-high scenario (top), medium scenario (middle) and low scenario (bottom).

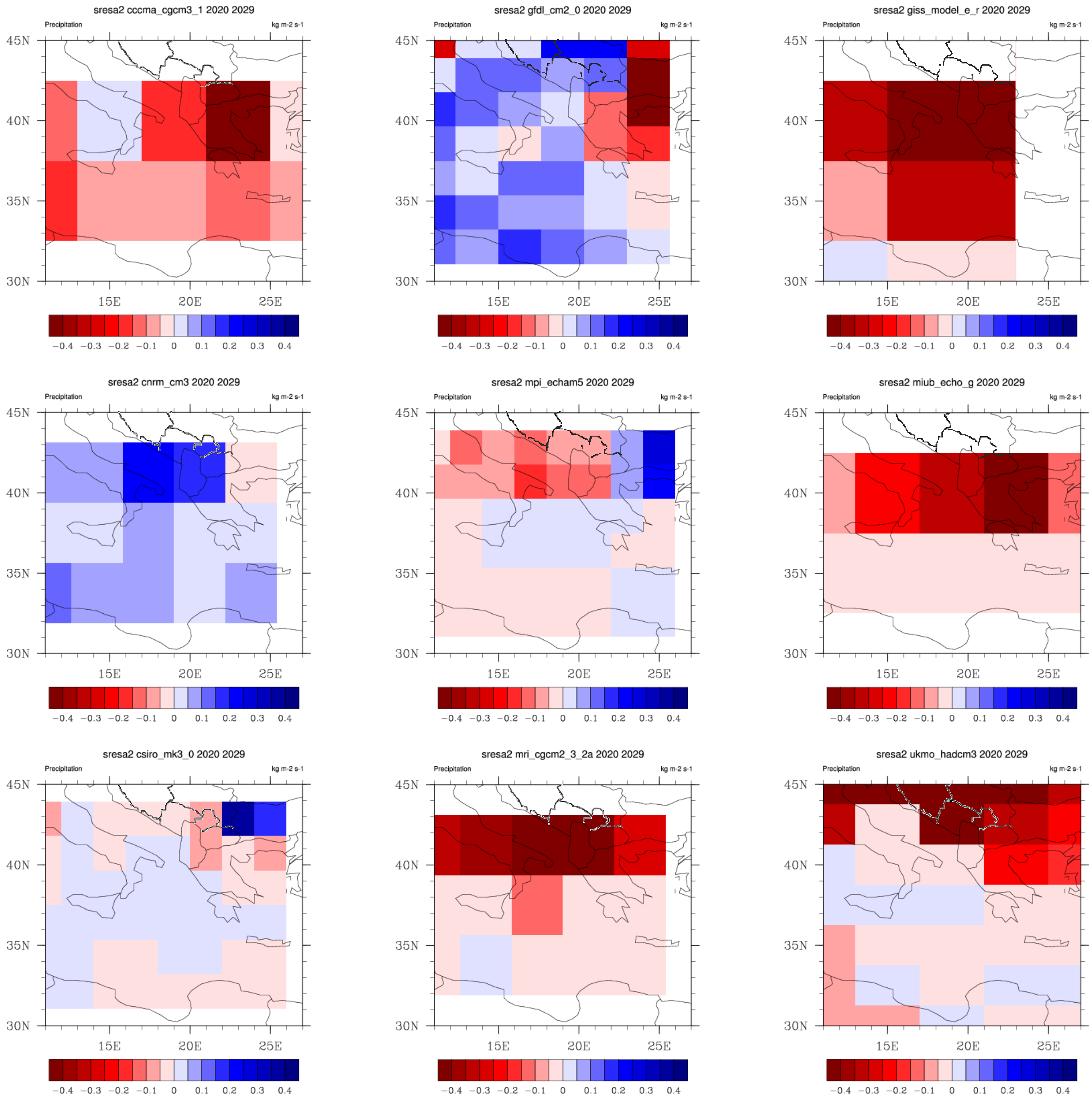

Figure 11: Projected June to August precipitation change (mm/day) from the 1961-1990 mean for 9 individual IPCC AR4 global climate models for 2020s for medium-high scenario.

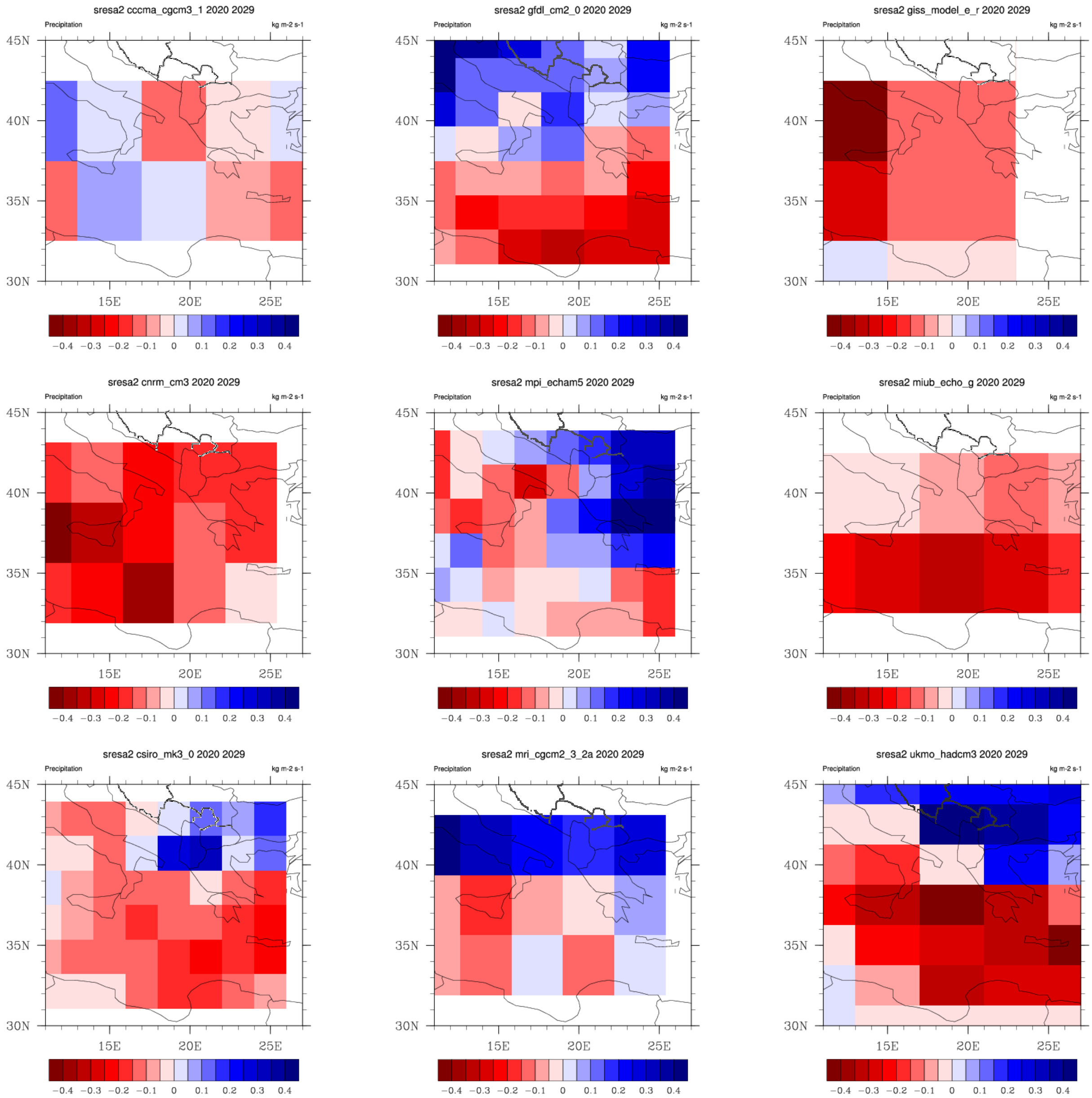

Figure 12: Projected December to February precipitation change (mm/day) from the 1961-1990 mean for 9 individual IPCC AR4 global climate models for 2020s for medium-high scenario.

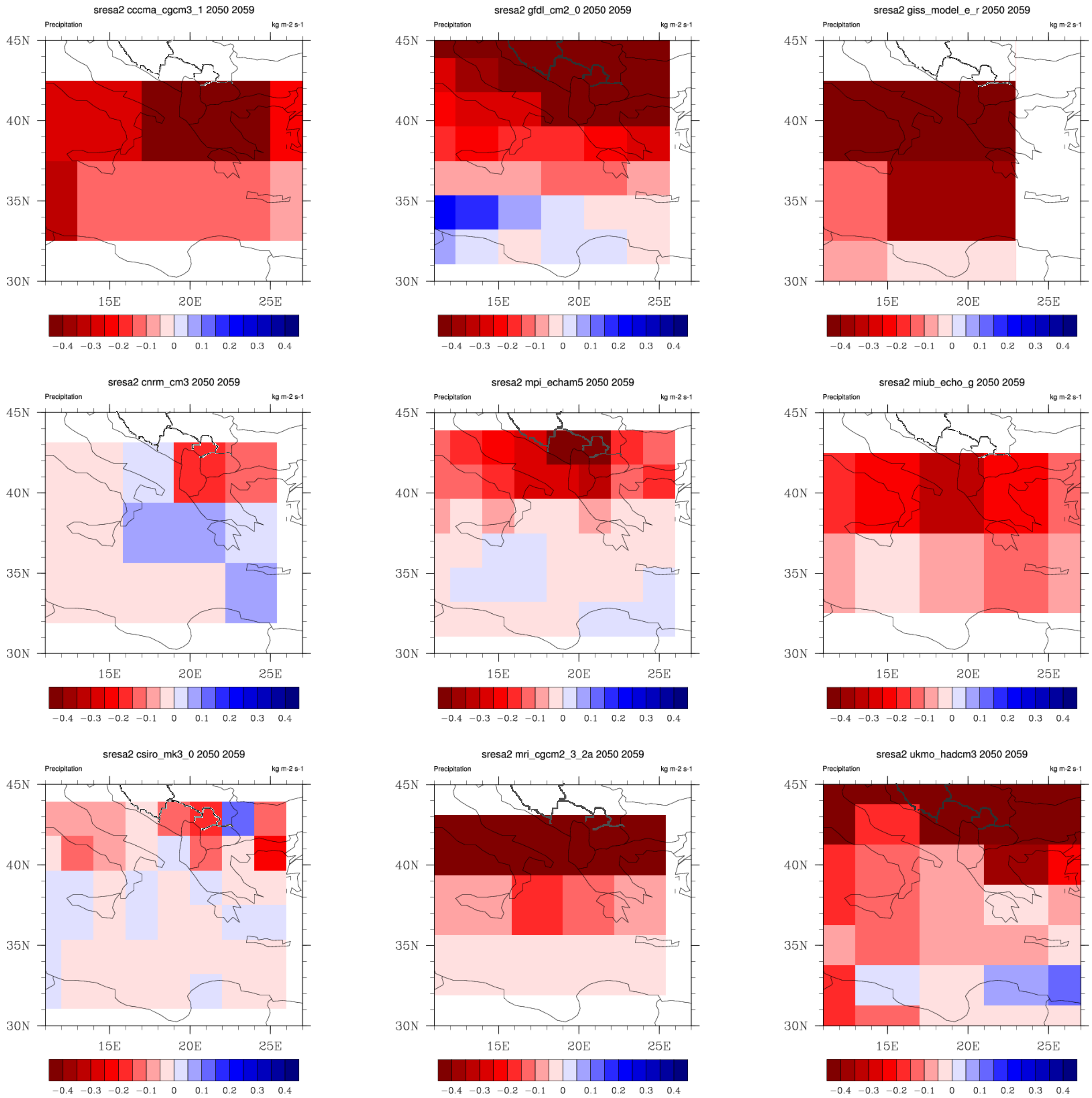

Figure 13: Projected June to August precipitation change (mm/day) from the 1961-1990 mean for 9 individual IPCC AR4 global climate models for 2050s for medium-high scenario.

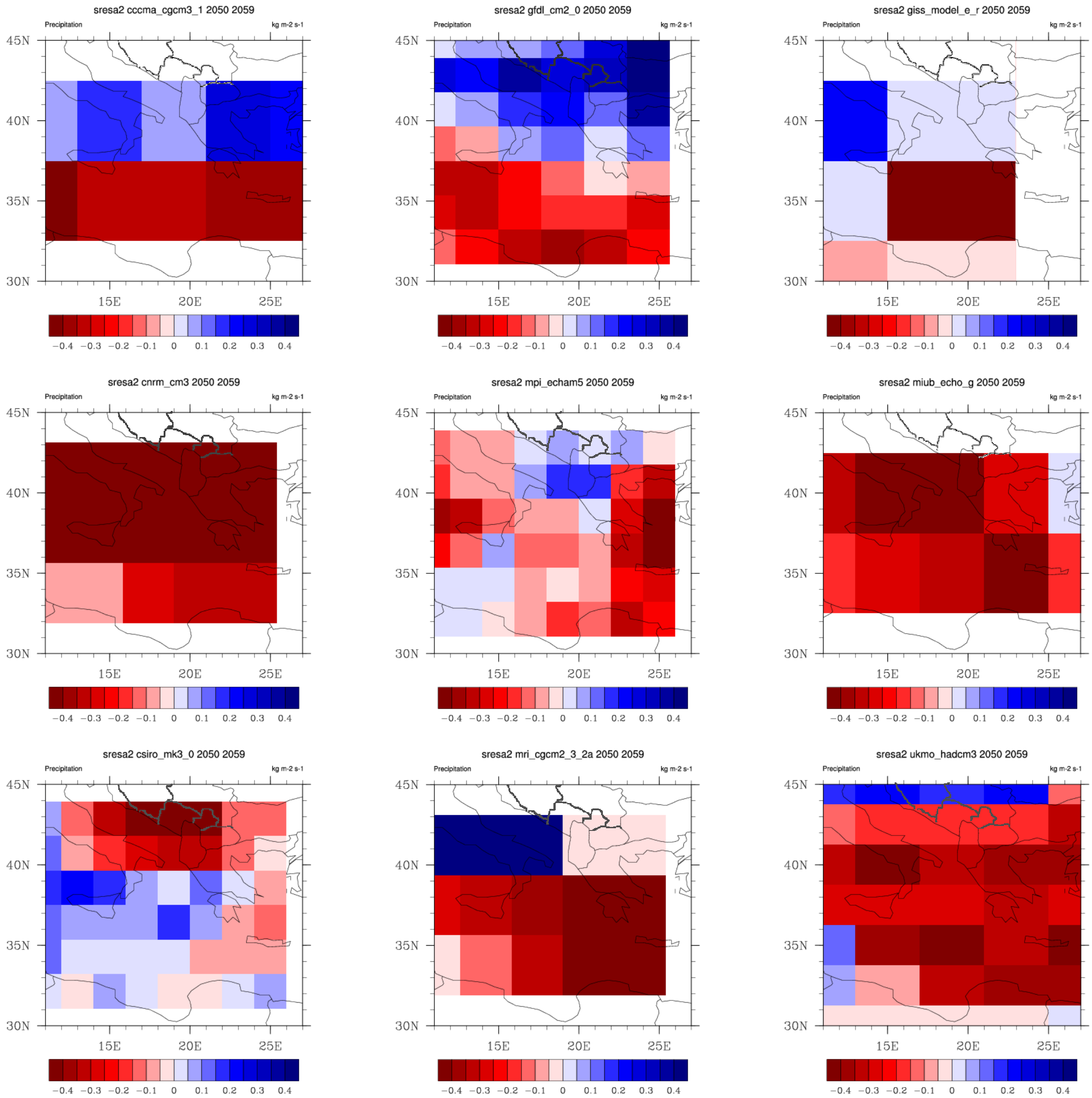

Figure 14: Projected December to February precipitation change (mm/day) from the 1961-1990 mean for 9 individual IPCC AR4 global climate models for 2050s for medium-high scenario.

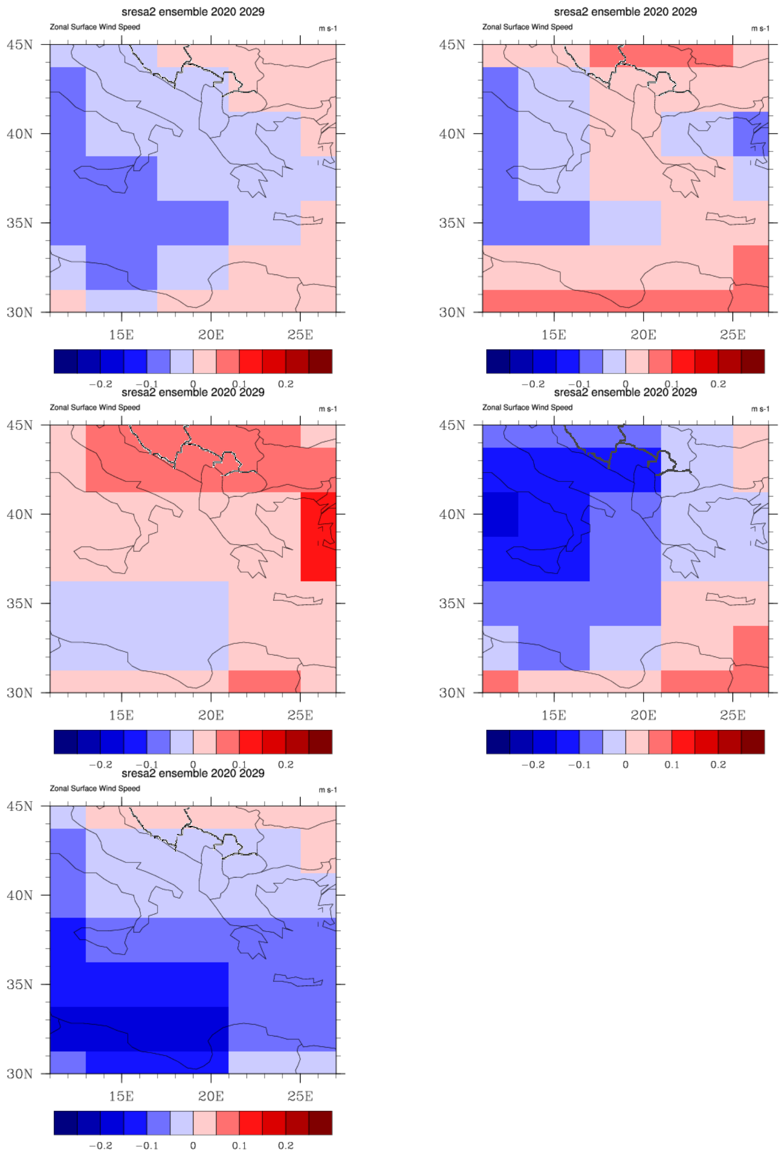

Figure 15: Projected windspeed change (m/s) from the 1961-1990 mean averaged across 9 IPCC AR4 global climate models for the 2020s for the medium-high scenario for annual (top left), July to August (middle left), December to February (bottom left), March to May (top right) and September to November (middle right).

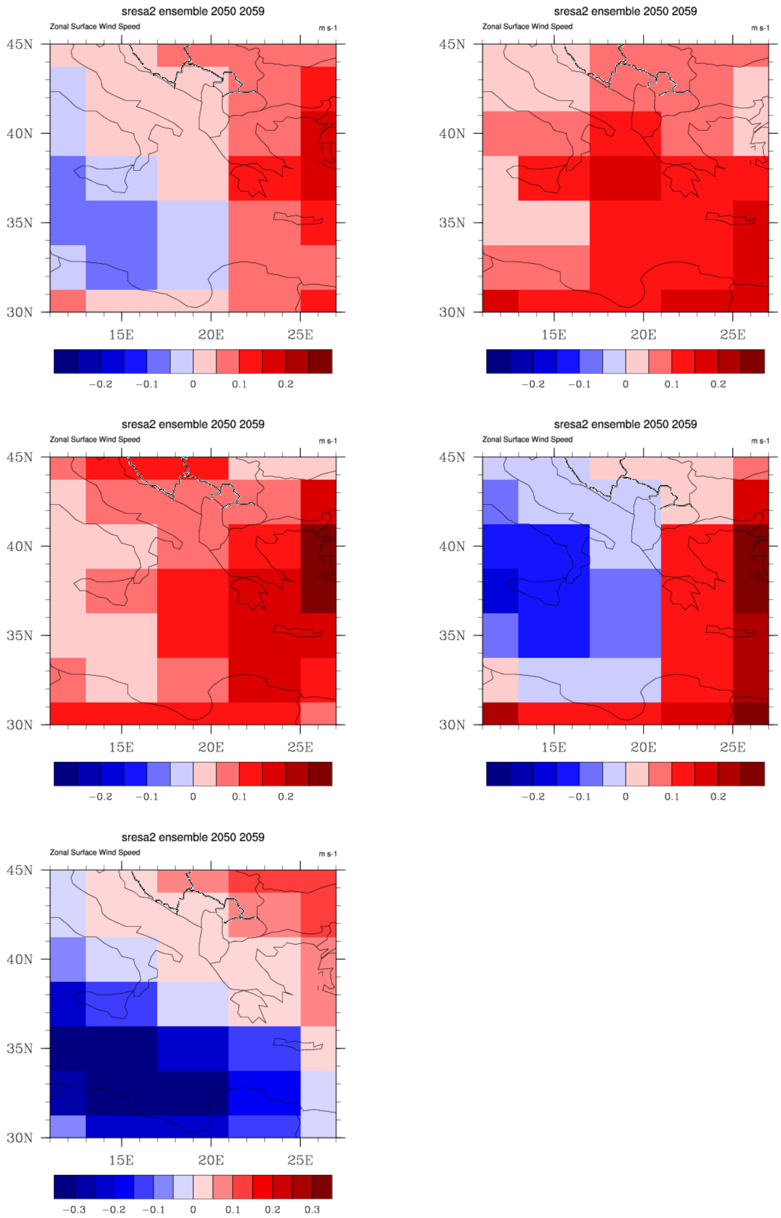

Figure 16: Projected windspeed change (m/s) from the 1961-1990 mean averaged across 9 IPCC AR4 global climate models for the 2050s for the medium-high scenario for annual (top left), July to August (middle left), December to February (bottom left), March to May (top right) and September to November (middle right).

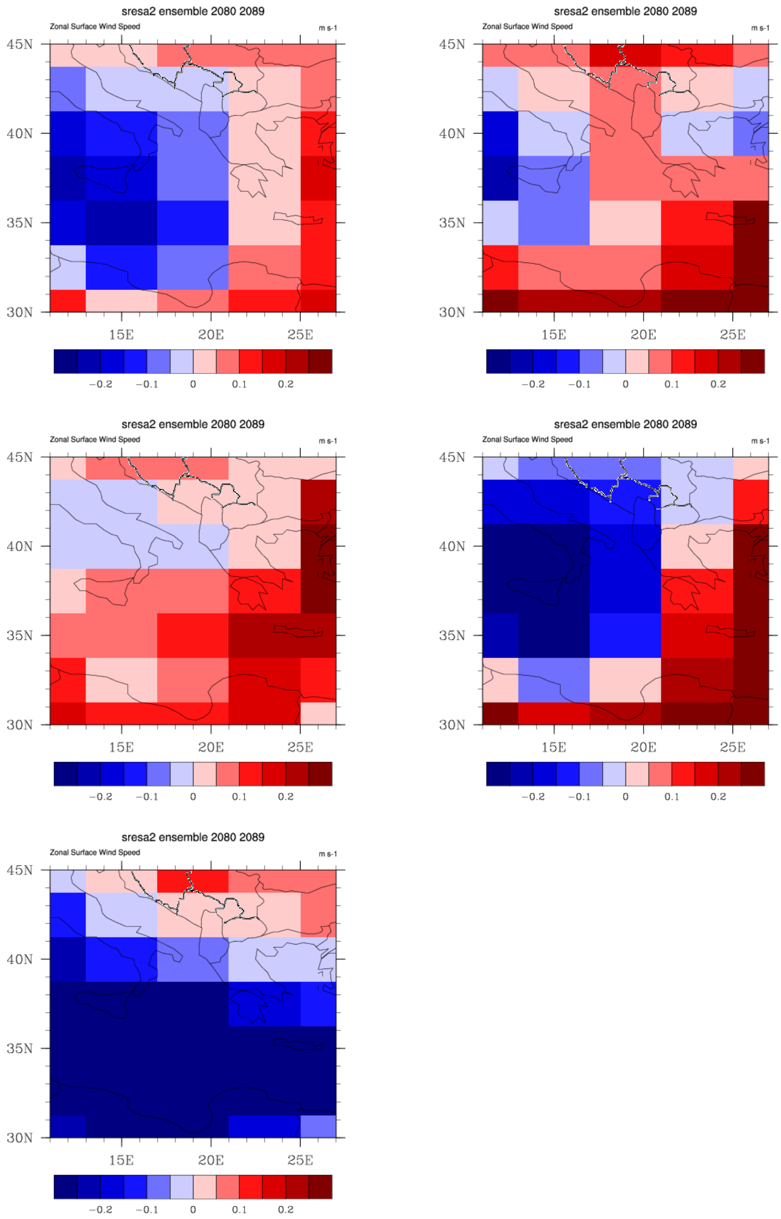

Figure 17: Projected windspeed change (m/s) from the 1961-1990 mean averaged across 9 IPCC AR4 global climate models for the 2080s for the medium-high scenario for annual (top left), July to August (middle left), December to February (bottom left), March to May (top right) and September to November (middle right).

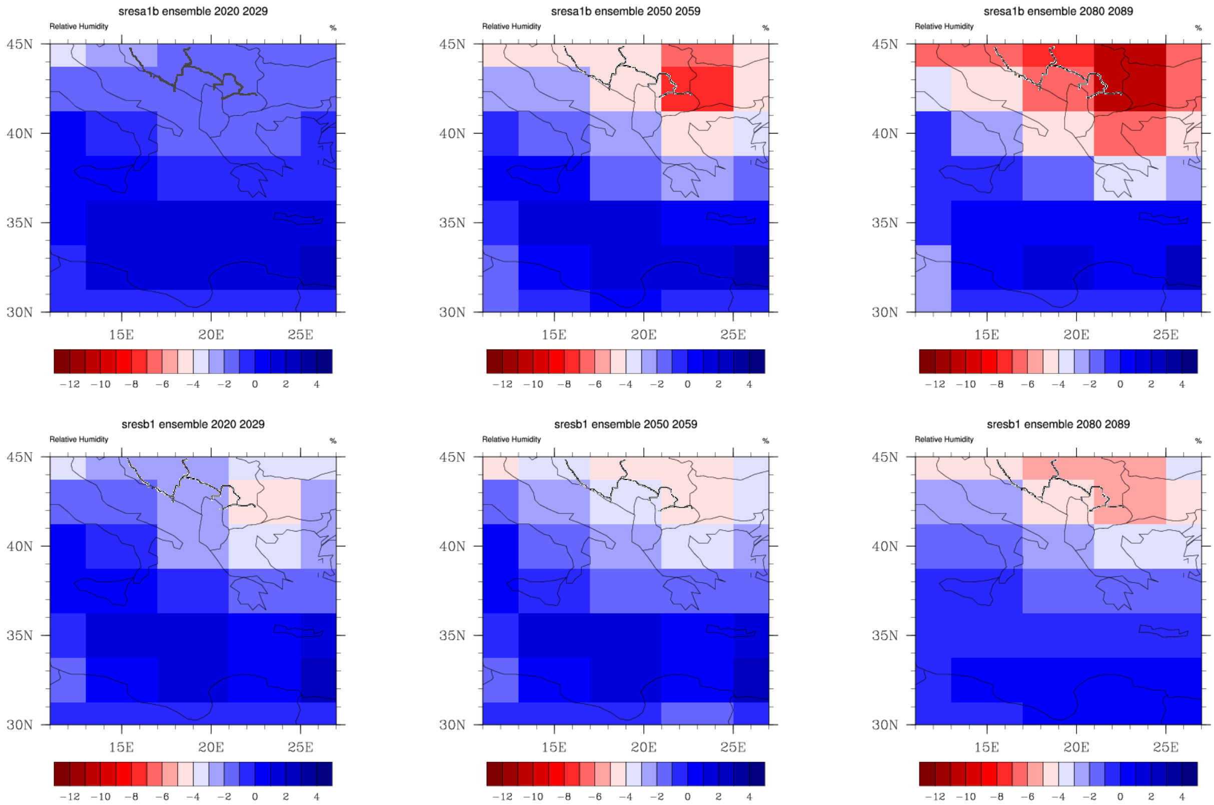

Figure 18: Projected annual relative humidity change (%) from the 1961-1990 mean averaged across 9 IPCC AR4 global climate models for 2020s (left), 2050s (middle) and 2080s (right) for medium scenario (top) and low scenario (bottom).

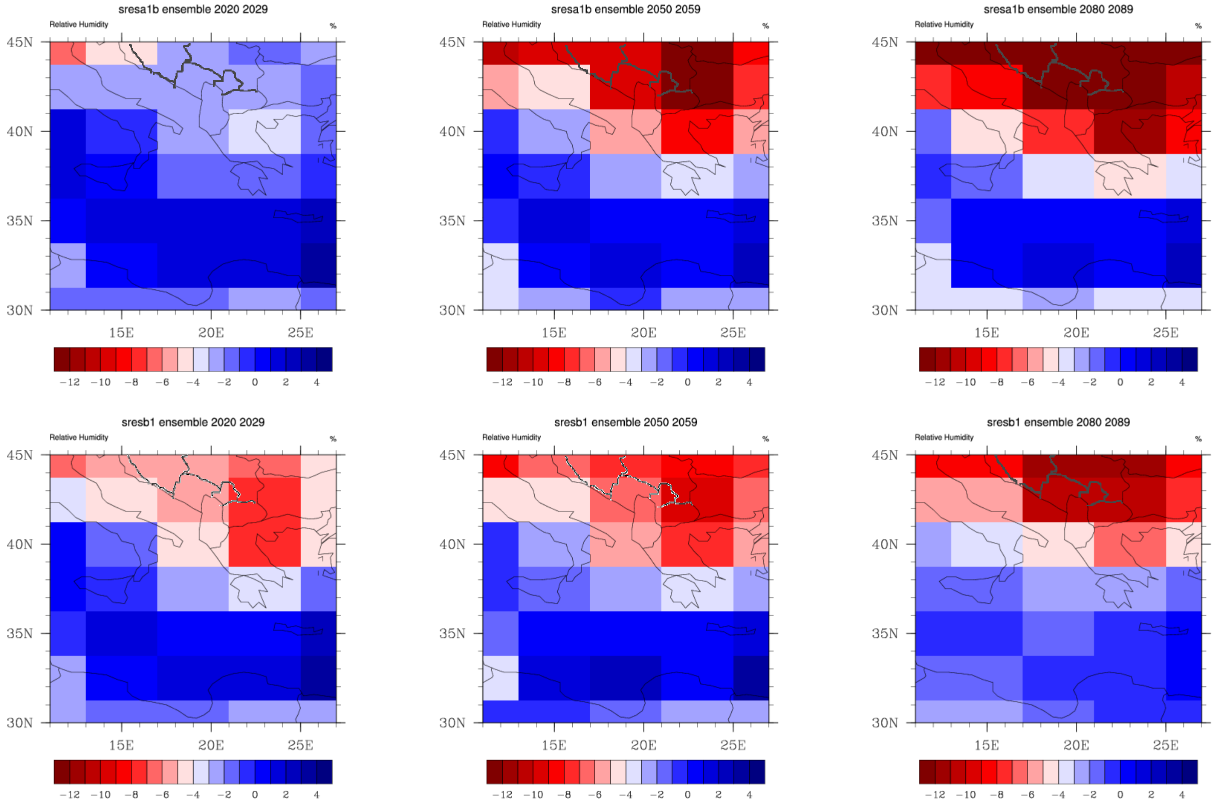

Figure 19: Projected June to August relative humidity change (%) from the 1961-1990 mean averaged across 9 IPCC AR4 global climate models for 2020s (left), 2050s (middle) and 2080s (right) for medium scenario (top) and low scenario (bottom).

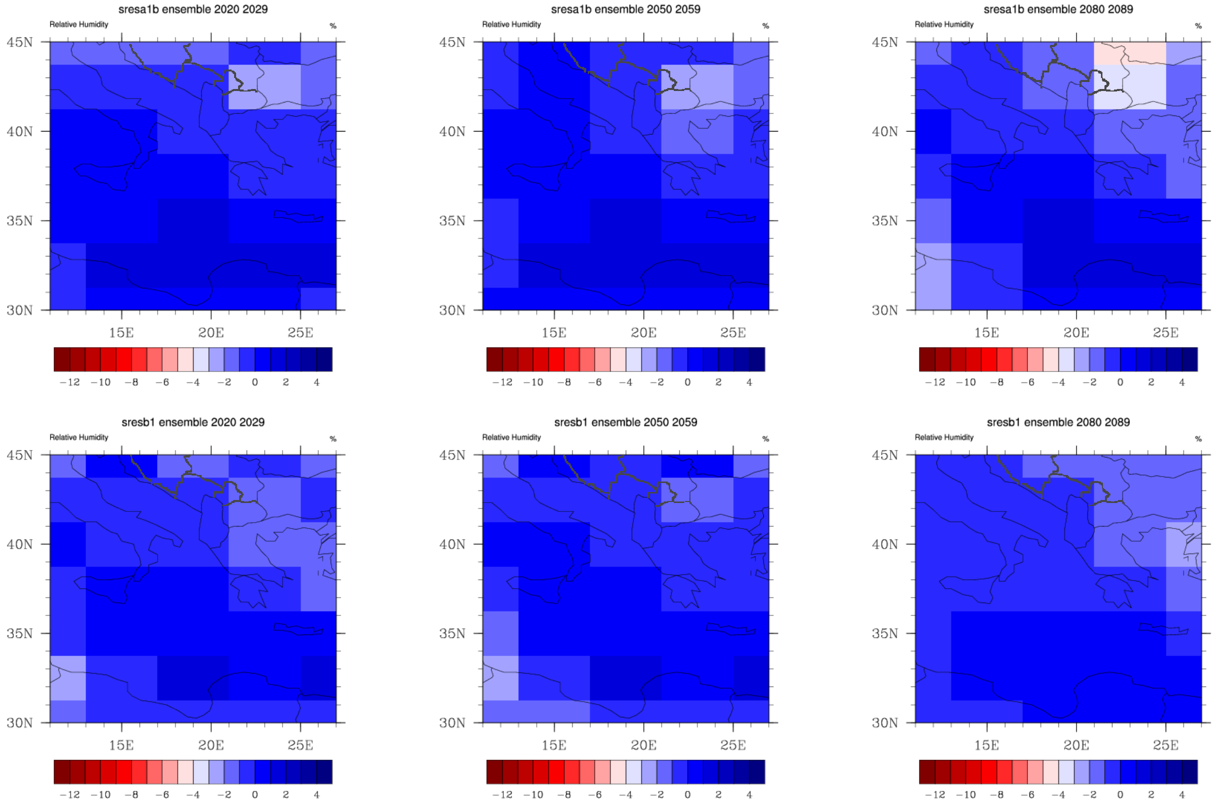

Figure 20: Projected December to February relative humidity change (%) from the 1961-1990 mean averaged across 9 IPCC AR4 global climate models for 2020s (left), 2050s (middle) and 2080s (right) for medium scenario (top) and low scenario (bottom).

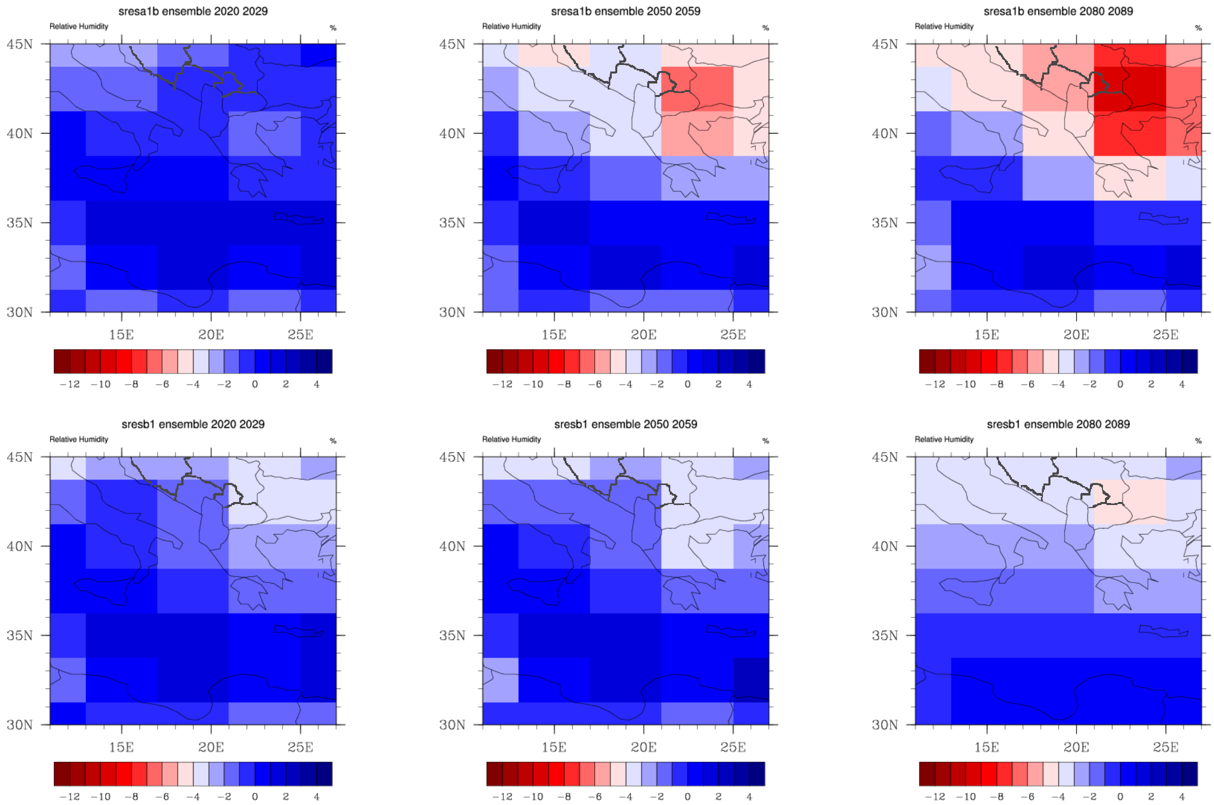

Figure 21: Projected March to May relative humidity change (%) from the 1961-1990 mean averaged across 9 IPCC AR4 global climate models for 2020s (left), 2050s (middle) and 2080s (right) for medium scenario (top) and low scenario (bottom).

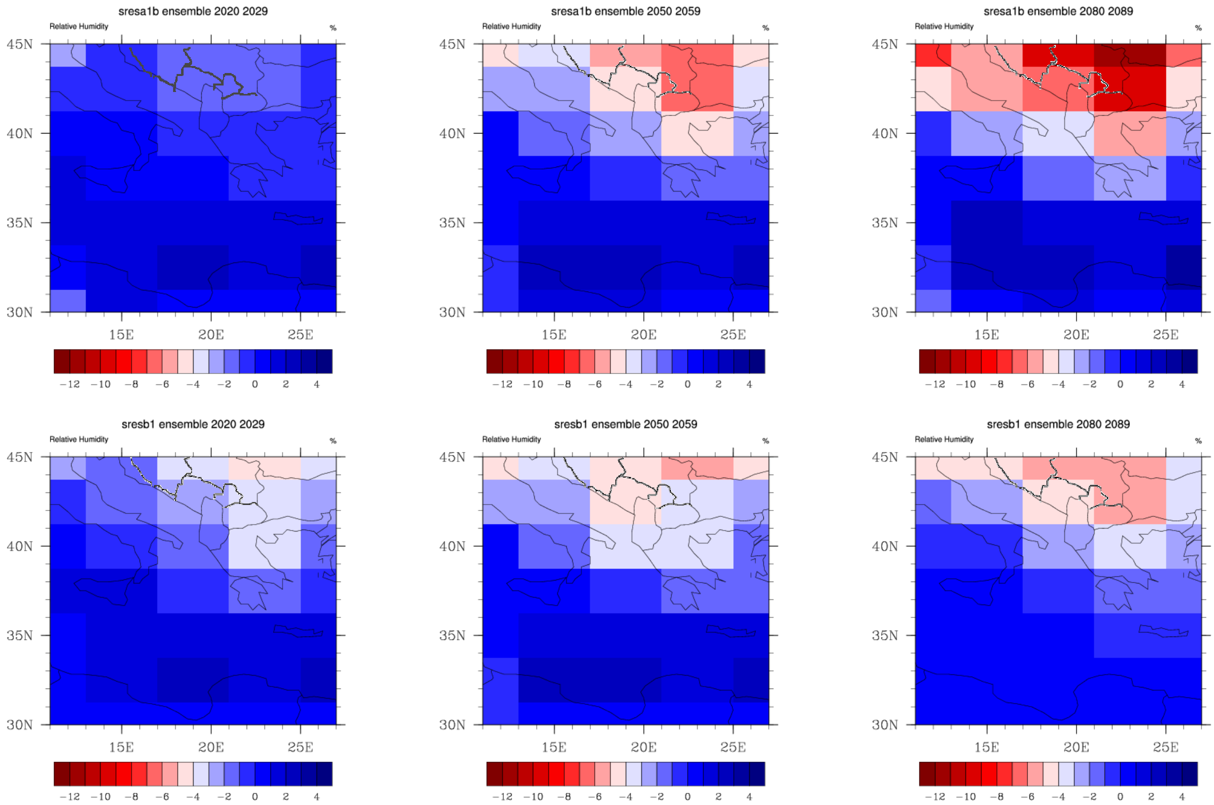

Figure 22: Projected September to November relative humidity change (%) from the 1961-1990 mean averaged across 9 IPCC AR4 global climate models for 2020s (left), 2050s (middle) and 2080s (right) for medium scenario (top) and low scenario (bottom).

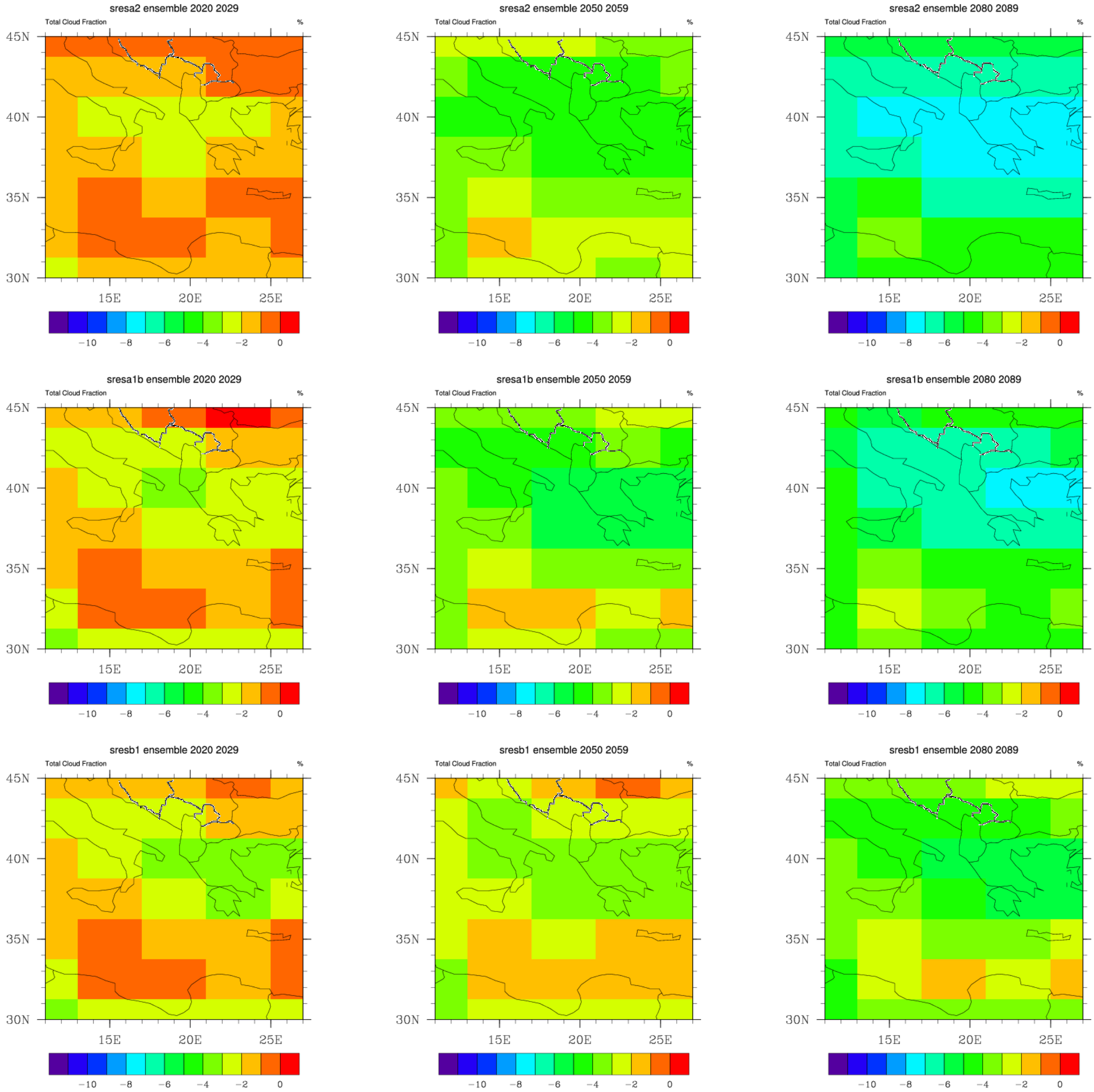

Figure 23: Projected annual cloudiness change (%) from the 1961-1990 mean averaged across 9 IPCC AR4 global climate models for 2020s (left), 2050s (middle) and 2080s (right) for medium-high scenario (top), medium scenario (middle) and low scenario (bottom).

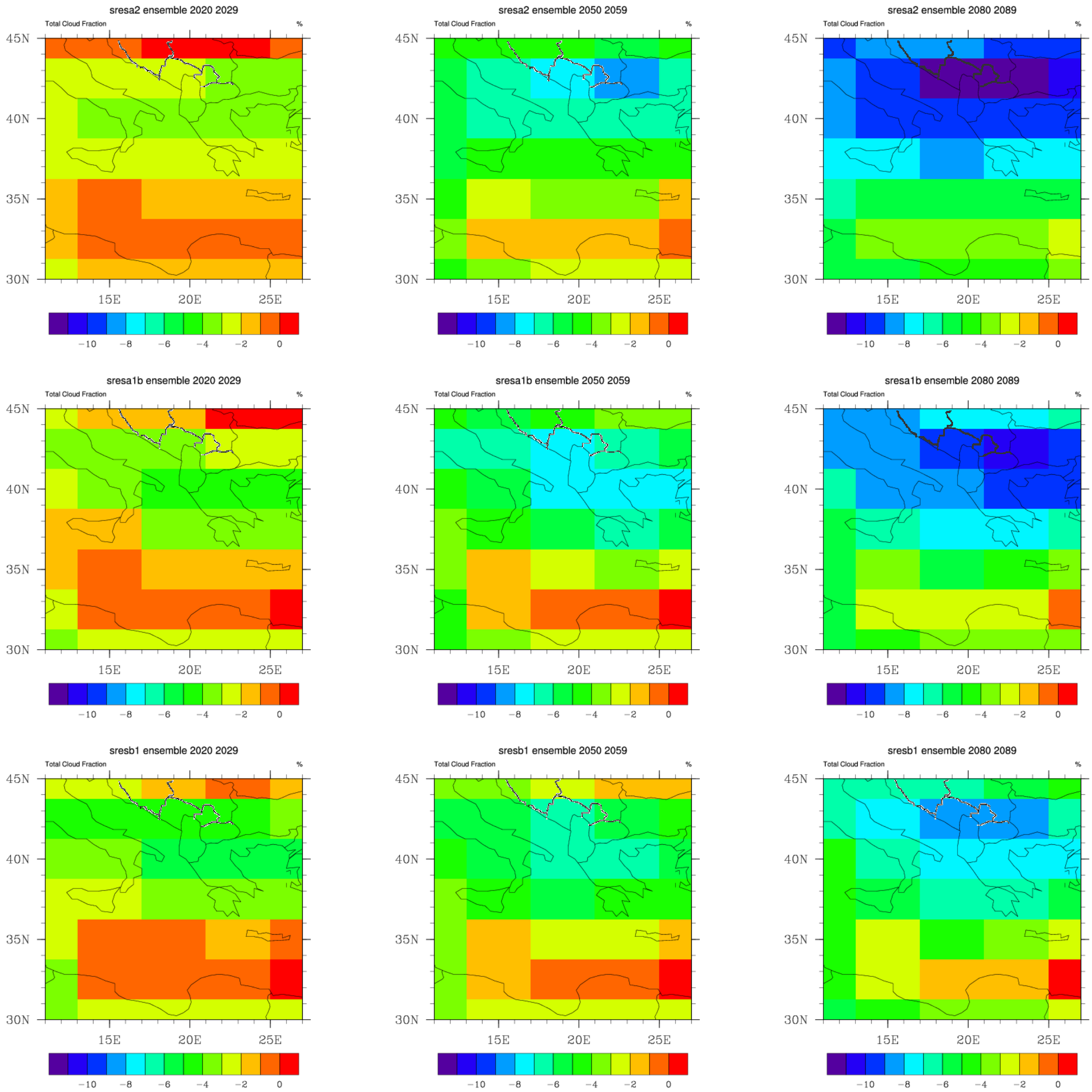

Figure 24: Projected June to August cloudiness change (%) from the 1961-1990 mean averaged across 9 IPCC AR4 global climate models for 2020s (left), 2050s (middle) and 2080s (right) for medium-high scenario (top), medium scenario (middle) and low scenario (bottom).

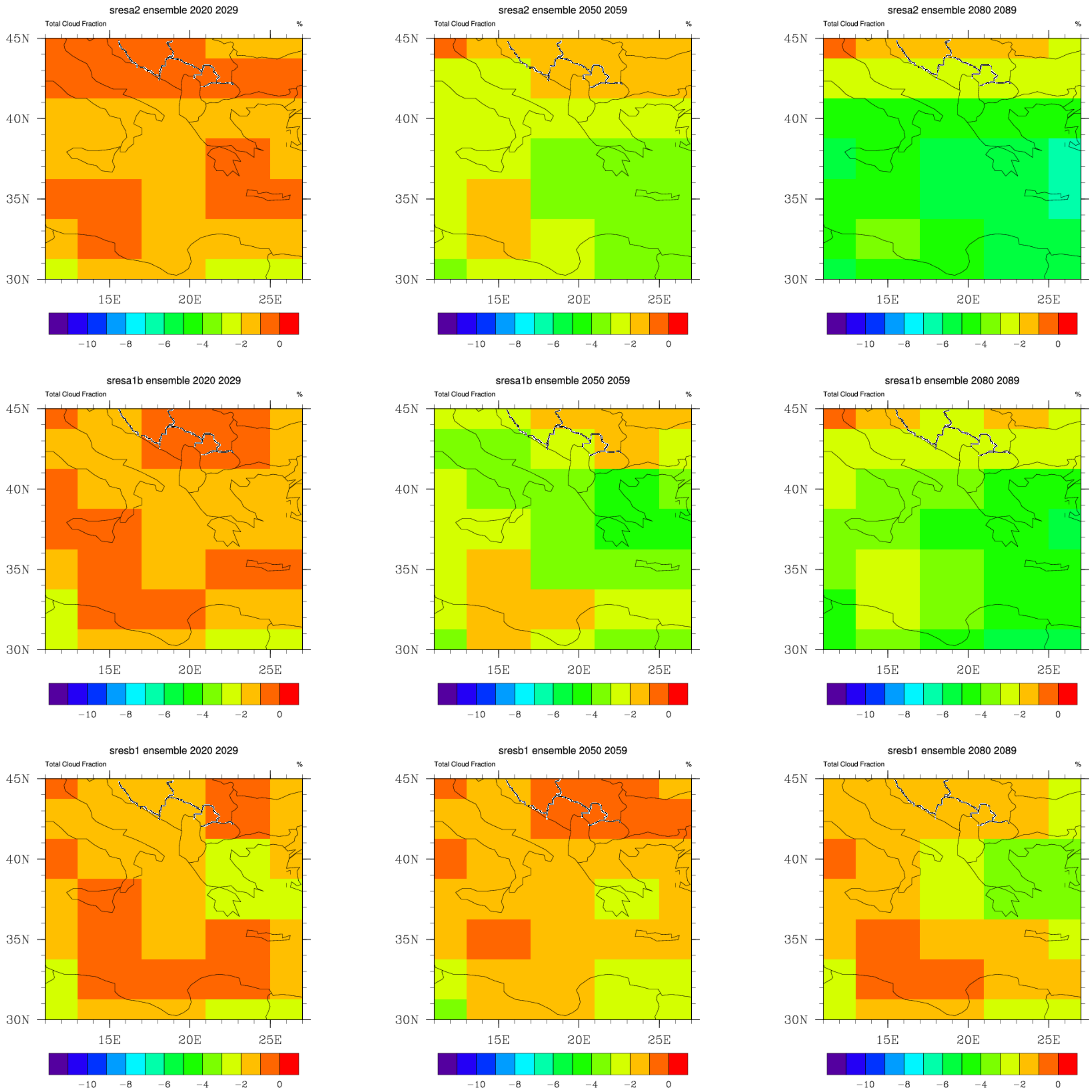

Figure 25: Projected December to February cloudiness change (%) from the 1961-1990 mean averaged across 9 IPCC AR4 global climate models for 2020s (left), 2050s (middle) and 2080s (right) for medium-high scenario (top), medium scenario (middle) and low scenario (bottom).

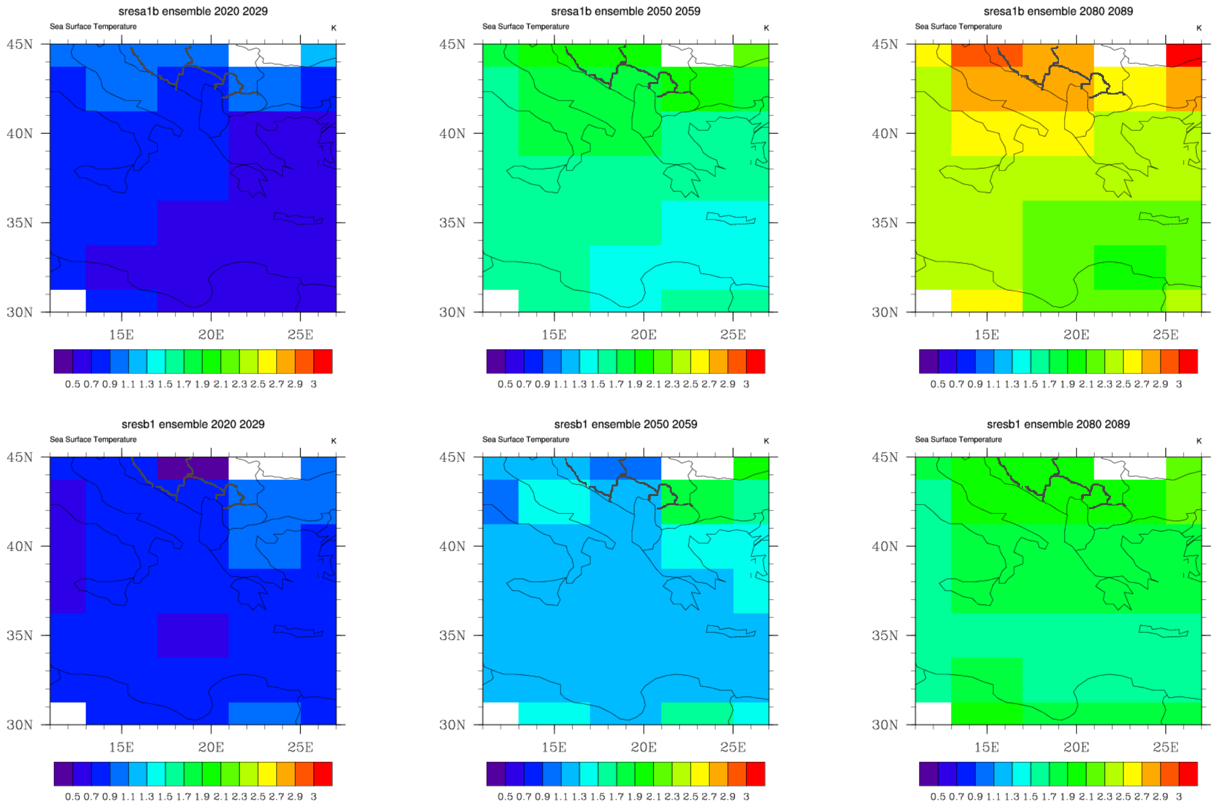

Figure 26: Projected annual sea surface temperature change (°C) from the 1961-1990 mean averaged across 9 IPCC AR4 global climate models for 2020s (left), 2050s (middle) and 2080s (right) for medium scenario (top) and low scenario (bottom).

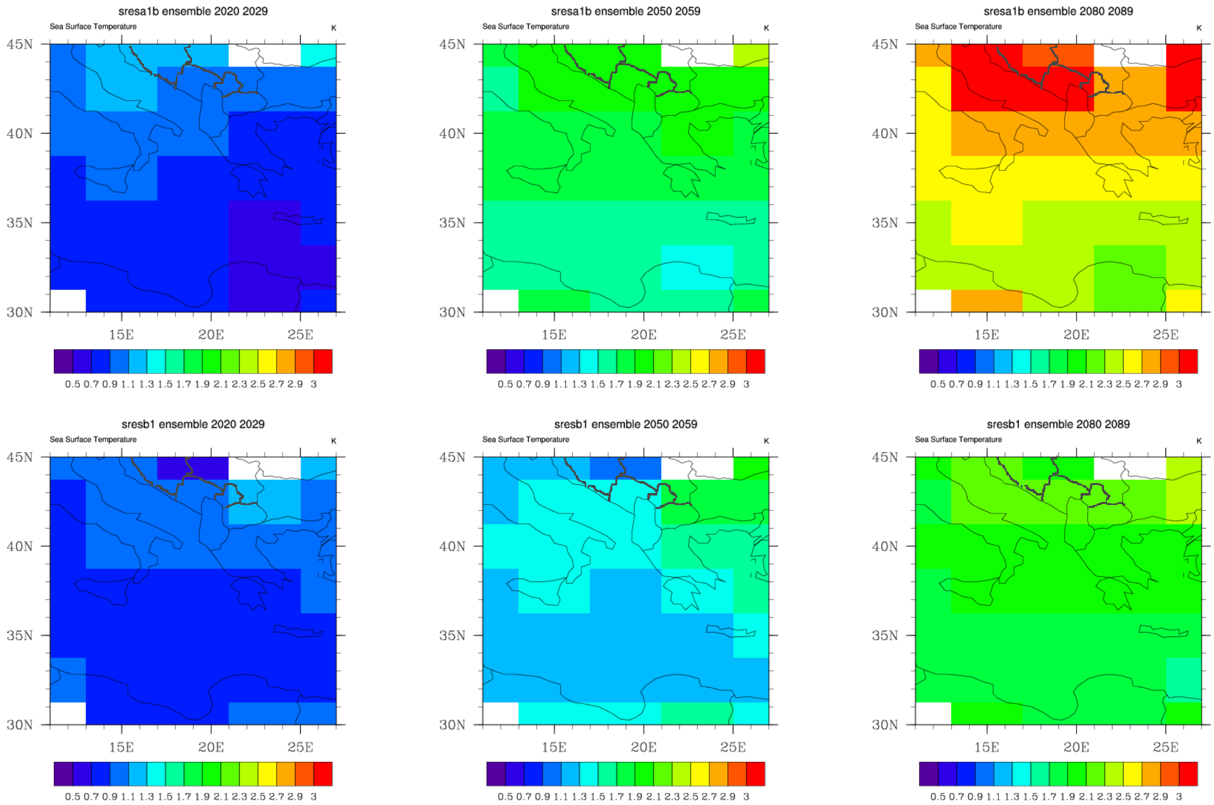

Figure 27: Projected June to August sea surface temperature change (ºC) from the 1961-1990 mean averaged across 9 IPCC AR4 global climate models for 2020s (left), 2050s (middle) and 2080s (right) for medium scenario (top) and low scenario (bottom).

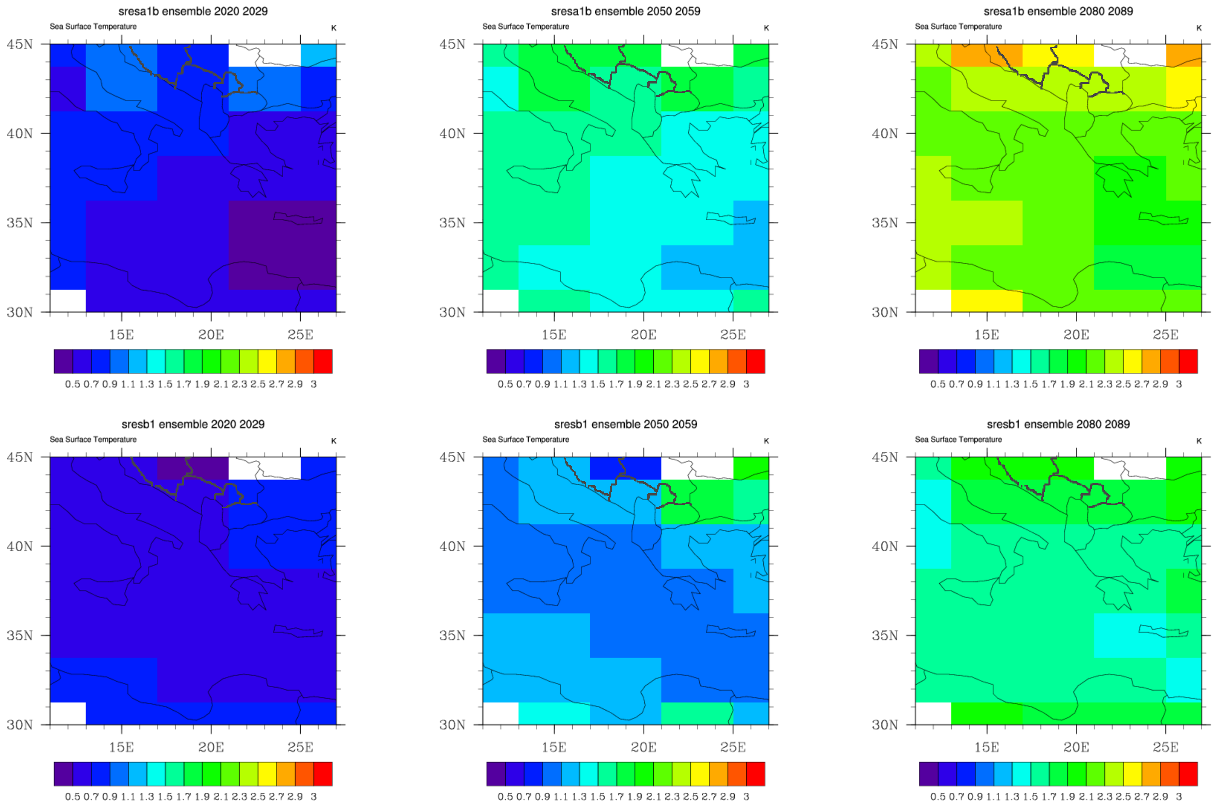

Figure 28: Projected December to February sea surface temperature change (°C) from the 1961-1990 mean averaged across 9 IPCC AR4 global climate models for 2020s (left), 2050s (middle) and 2080s (right) for medium scenario (top) and low scenario (bottom).

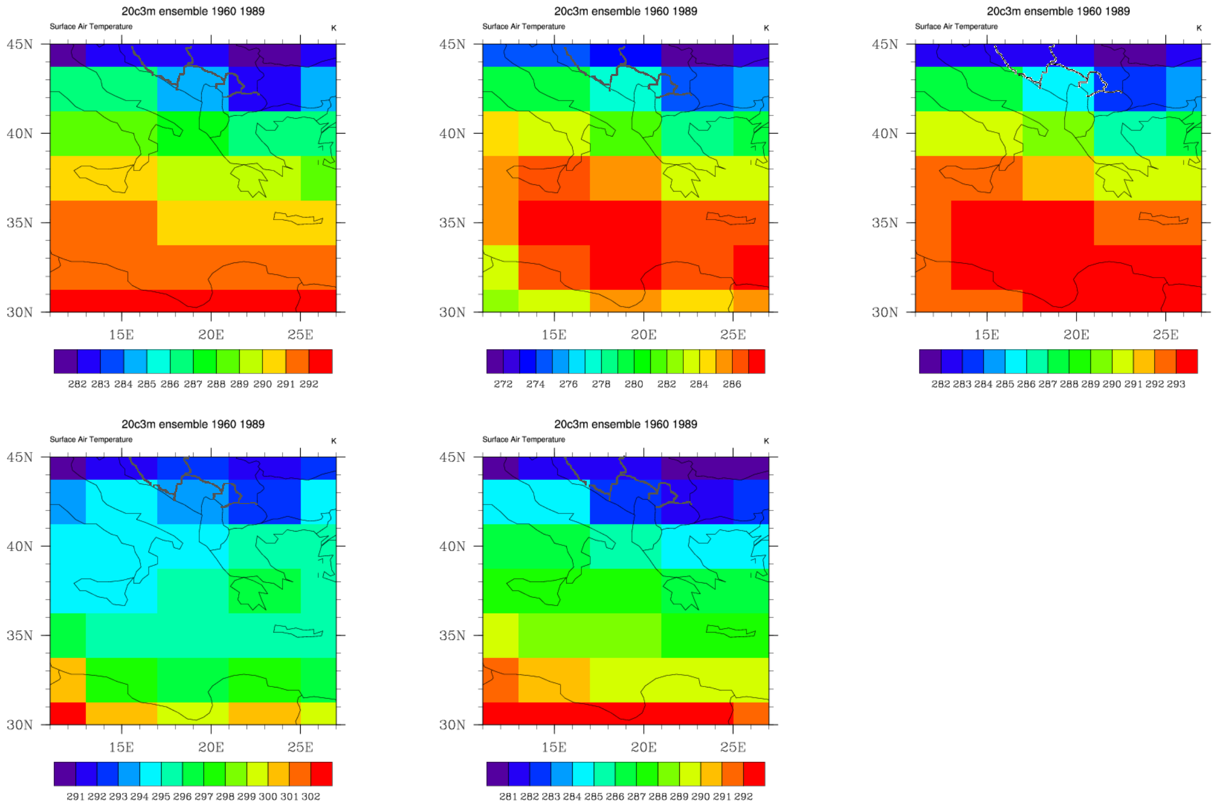

Figure 29: Modelled baseline temperature (K) averaged across 9 IPCC AR4 global climate models for annual mean (top left), June to August (bottom left), December to February (top middle), March to May (bottom middle) and September to November (top right). (Note: To convert temperatures from Kelvin (K) into °C, subtract 273 from the values shown.)

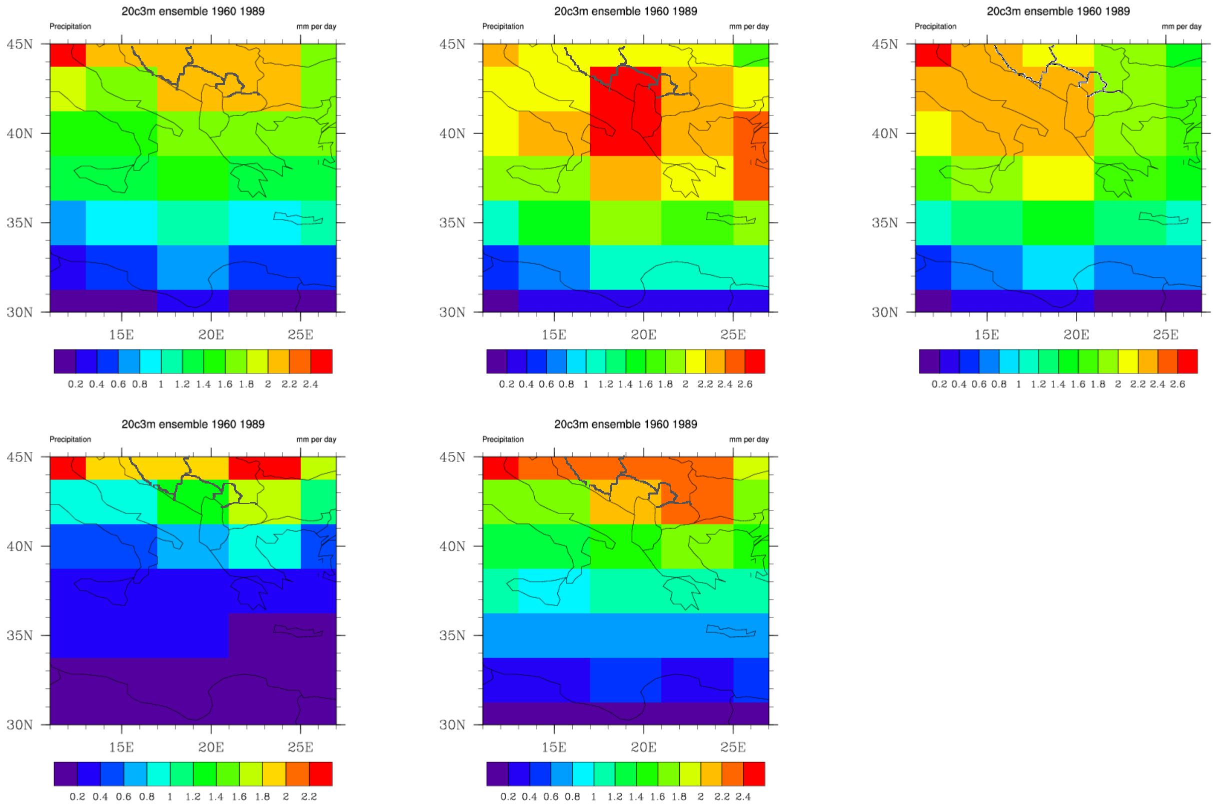

Figure 30: Modelled baseline precipitation (mm/day) averaged across 9 IPCC AR4 global climate models for annual mean (top left), June to August (bottom left), December to February (top middle), March to May (bottom middle) and September to November (top right).

Appendix A: Emissions scenarios

To provide a basis for estimating future climate change, the Intergovernmental Panel on Climate Change (IPCC) prepared the Special Report on Emissions Scenarios (Nakićenović and Swart, 2000), detailing 40 greenhouse gas and sulphate aerosol emission scenarios that combine a variety of assumptions about demographic, economic and technological factors likely to influence future emissions. Each scenario represents a variation within one of four 'storylines': A1, A2, B1 and B2. Further details of the storylines are provided in Box A1. Projected carbon dioxide, methane, nitrous oxide and sulphate aerosol emissions based on these scenarios are shown in Figure A1 below for six 'marker scenarios'. All the scenarios are considered equally sound by the IPCC and no probabilities are attached.

Box A1: Storylines for scenarios of greenhouse gas emissions

A1: The A1 storyline describes a future world of very rapid economic growth, a global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 storyline develops into three scenario groups that describe alternative directions of technological change in the energy system. They are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources and technologies (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).

A2: The A2 storyline describes a very heterogeneous world. The underlying theme is self reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

B1: The B1 storyline describes a convergent world with the same global population as in the A1 storyline (one that peaks in mid-century and declines thereafter) but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives, i.e. it does not include implementation of the United Nations Framework Convention on Climate Change or the Kyoto Protocol.

B2: The B2 storyline describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in B1 and A1. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

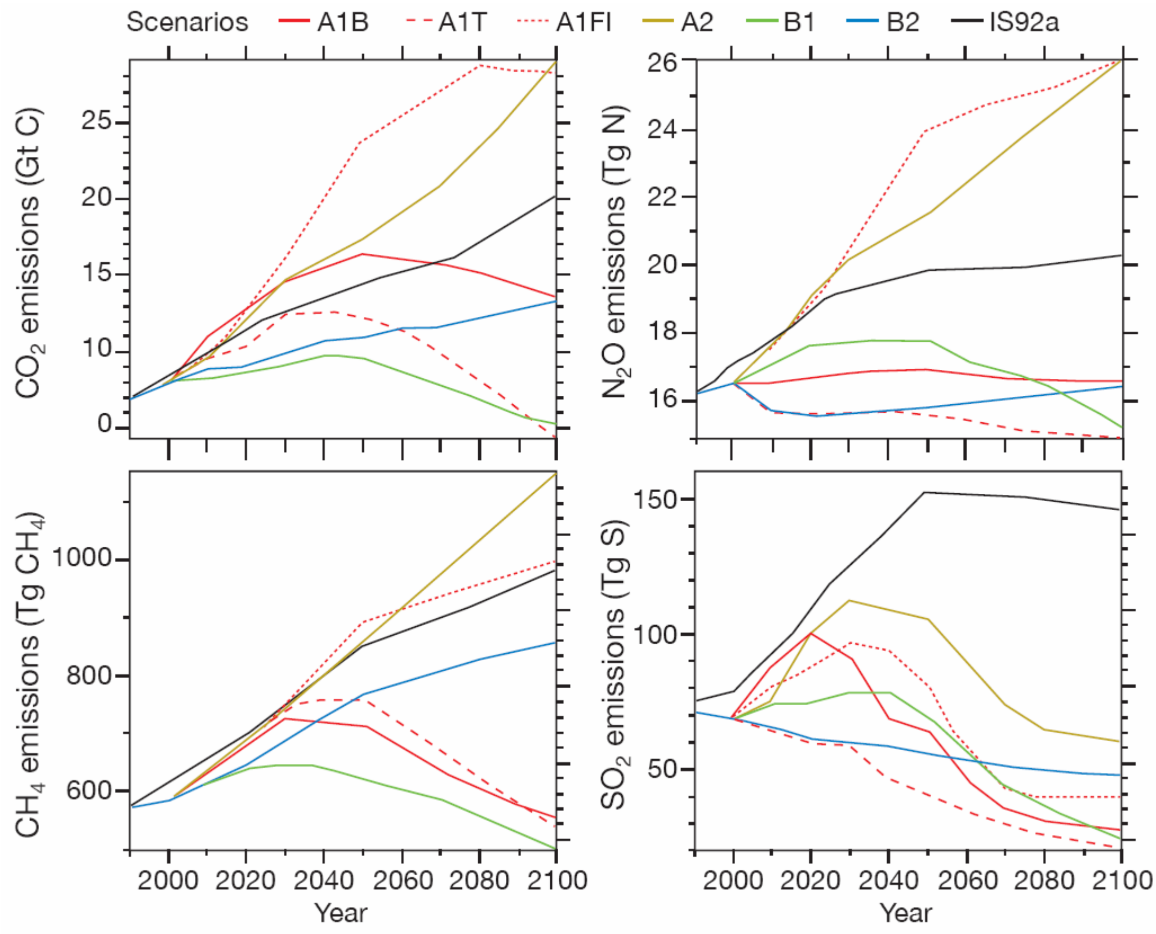

Figure A1: Anthropogenic emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and sulphur dioxide (SO_2) for six SRES scenarios (see Box A1) and the IS92a scenario from the IPCC Second Assessment Report in 1996 for comparison (Nakićenović and Swart, 2000).