Call: H2020-SC5-2014-two-stage

Topic: SC5-01-2014

PRIMAVERA

Grant Agreement 641727

PRocess-based climate sIMulation: AdVances in high resolution modelling and European climate Risk Assessment

Deliverable D5.4

SCENARIOS FOR EUROPEAN CLIMATE OF THE NEXT DECADES

<table>
<tr><td>Deliverable Title</td><td colspan="2">Scenarios for European climate of the next decades</td></tr>
<tr><td>Brief Description</td><td colspan="2">A set of multi-model experiments are designed to assess the possible influence and relative weight of oceanic modes, regional phenomena, and direct radiative forcing of greenhouse and aerosols projected evolutions, on the European climate changes of the next decades.</td></tr>
<tr><td>WP number</td><td colspan="2">5</td></tr>
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<tr><td>Creation Date
Version Number
Version Date</td><td colspan="2">16/07/2020</td></tr>
<tr><td>Deliverable Due Date
Actual Delivery Date</td><td colspan="2">24/07/2020
24/07/2020</td></tr>
<tr><td rowspan="4">Nature of the Deliverable</td><td>X</td><td>R - Report</td></tr>
<tr><td></td><td>P - Prototype</td></tr>
<tr><td></td><td>D - Demonstrator</td></tr>
<tr><td></td><td>O - Other</td></tr>
<tr><td rowspan="4">Dissemination Level/ Audience</td><td>X</td><td>PU - Public</td></tr>
<tr><td></td><td>PP - Restricted to other programme participants, including the Commission services</td></tr>
<tr><td></td><td>RE - Restricted to a group specified by the consortium, including the Commission services</td></tr>
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Version	**Date**	**Modified by**	**Comments**
1	16/07/2020		

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1. Executive Summary

Combined with the effects of direct radiative forcing of greenhouse and aerosols projected evolution, a set of multi-model experiments are designed and performed within PRIMAVERA to assess the possible influence and relative importance of oceanic modes and regional phenomena on the European climate changes of the next decades. To this aim, the European climate responses under the present (1995-2014) and future (2020-2039) climates are compared. To assess the role played by the model spatial resolutions, two distinct sub-samples are created and compared: one grouping those models with coarser resolutions (hereinafter denoted as LR) and a second one grouping those models with higher resolutions (hereinafter denoted as HR).

The results obtained indicate a widespread warming of European continent during the next decades. This warming is robust for both, LR and HR models, but the amplitude is different for certain regions depending on the model nominal resolution. The possible role played by the Atlantic Multidecadal Variability (AMV) as modulator of this warming has been assessed. This role can be described as *minor* due to the modest amplitude of the AMV-related impact on European temperature in comparison to the total warming identified. The impact on rainfall has been also analysed. In this case noticeable differences are identified among distinct sub-regions of Europe (Mediterranean, central and northern Europe) and between LR and HR models. However, the inter-model spread is higher than in the case of temperature, which obliges to interpret with caution.

2. Project Objectives

With this deliverable, the project has contributed to the achievement of the following objectives (DOA, Part B Section 1.1) WP numbers are in brackets:

No.	Objective	Yes	No
A	To develop a new generation of global high-resolution climate models. *(3, 4, 6)*		X
B	To develop new strategies and tools for evaluating global high-resolution climate models at a process level, and for quantifying the uncertainties in the predictions of regional climate. *(1, 2, 5, 9, 10)*		X
C	To provide new high-resolution protocols and flagship simulations for the World Climate Research Programme (WCRP)'s Coupled Model Intercomparison Project (CMIP6) project, to inform the Intergovernmental Panel on Climate Change (IPCC) assessments and in support of emerging Climate Services. *(4, 6, 9)*		X
D	To explore the scientific and technological frontiers of capability in global climate modelling to provide guidance for the development of future generations of prediction systems, global climate and Earth System models (informing post-CMIP6 and beyond). *(3, 4)*		X

E	To advance understanding of past and future, natural and anthropogenic, drivers of variability and changes in European climate, including high impact events, by exploiting new capabilities in high-resolution global climate modelling. *(1, 2, 5)*	X	
F	To produce new, more robust and trustworthy projections of European climate for the next few decades based on improved global models and advances in process understanding. *(2, 3, 5, 6, 10)*	X	
G	To engage with targeted end-user groups in key European economic sectors to strengthen their competitiveness, growth, resilience and ability by exploiting new scientific progress. *(10, 11)*		X
H	To establish cooperation between science and policy actions at European and international level, to support the development of effective climate change policies, optimize public decision making and increase capability to manage climate risks. *(5, 8, 10)*		X

3. Detailed Report

3.1 Comparison between present and future European climates

The difference between 1) the averaged conditions in the period 2020-2039 from the *highres-future* simulations (hereinafter denoted as "future") and 2) the averaged conditions in the period 1995-2014 from the *1950-historical* simulations (hereinafter denoted as "present"), is calculated for both, rainfall and surface temperature. This comparison of the present and future climates has been carried out from a multi-model analysis of PRIMAVERA models. Although some of these models had more members available, one member is used for each model to create an unbiased estimation of the multimodel mean. In particular five LR models (HadGEM3-LL, CNRM-CM6-1-LR, MPI-ESM1-2-HR, EC-Earth3P LR, CMCC-CM2 HR4) and five HR models (HadGEM3-MM, CNRM-CM6-1-HR, MPI-ESM1-2-XR, EC-Earth3P HR, CMCC-CM2 VHR4), are considered. The results obtained, for winter (DJF) and summer (JJA) seasons, are shown in Figure 1 and Figure 2, respectively.

In winter (Fig. 1), a warmer climate is found at surface level for the next twenty years. This warming is, however, more pronounced in HR than in LR models. In both, the increase of surface temperature is stronger in the northeastern Europe and weaker in the western Europe and the Mediterranean region. Regarding rainfall, wetter conditions are expected in the future for the Mediterranean region in LR models (increase of more than 20% for certain areas) and for the northern Europe in HR models (increase of about 20% in the Scandinavia peninsula). A considerable inter-model spread is however found.

In summer (Fig. 2), a noticeable warming is also detected over the continental areas of Europe, being stronger in the eastern part of the continent and, particularly, north of the Black Sea. The latter is characterized, as Iberia and certain areas over the Mediterranean Sea, by drier conditions in the future. On the contrary, an increase of rainfall is found over central Europe and Scandinavia. Nevertheless, as in winter, the consistency among models is limited. Thus, the results for rainfall must be interpreted with caution.

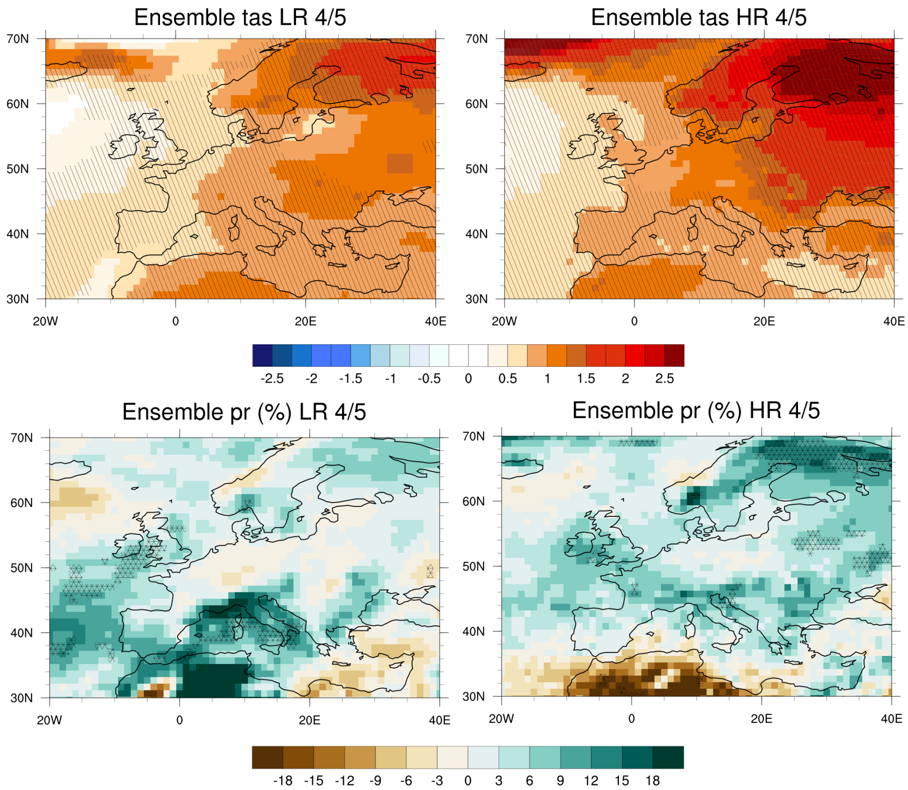

Figure 1: Difference of DJF average between “Highres-future (2020-2039)” and “hist-1950 (1995-2014)” simulations within PRIMAVERA. Top panels show the surface temperature (tas; units in *K*). Bottom panels show the surface rainfall (pr; units in % of change). From left to right: LR models and HR models. Hatching highlights areas with a certain number of models with a common sign (see ratio in the corresponding title).

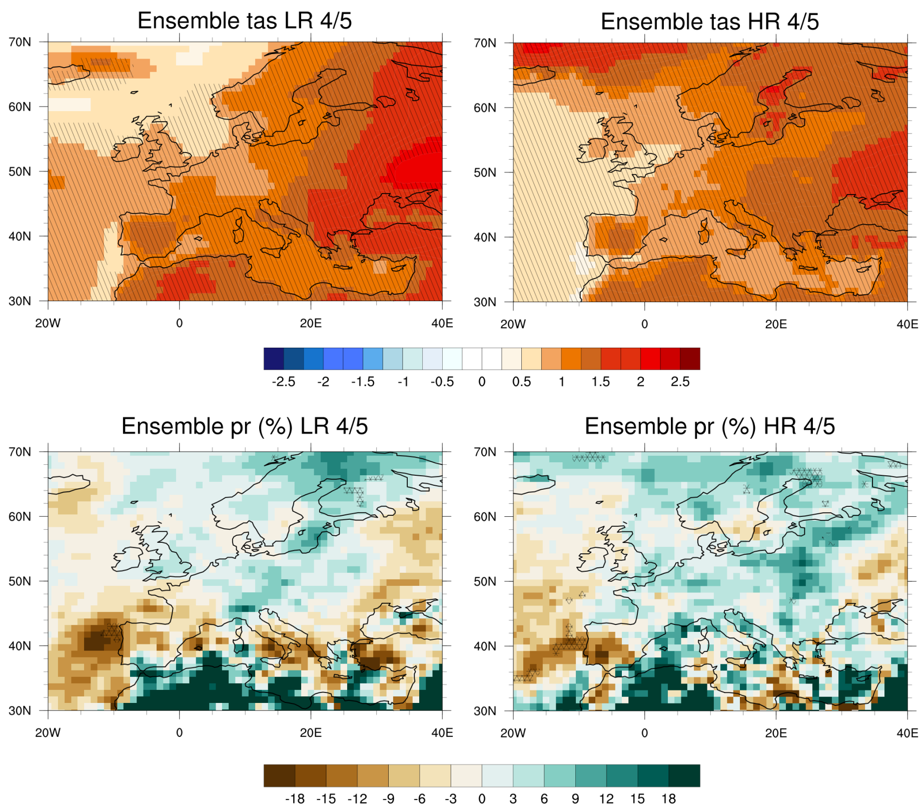

Figure 2: As Figure 1 but for summer season (JJA).

3.2 Role of the AMV variability

As known, the forced signal associated with the anthropogenic global warming occurs together with internal variability of the climate system at multidecadal timescales. The link among them is of huge interest, as the future evolution of internal variability could reinforce or mitigate, depending on the decade considered, the future changes associated with the forced variability. In this context, the analysis of the so-called Atlantic Multidecadal Variability (AMV) emerges as an important step for a better understanding of the future European climate. To this aim, the signature of AMV on the European rainfall and surface temperature has been analyzed from the PRIMAVERA DCPP-AMV experiences. These DCPP-like experiments are performed with a two-times (compared to CMIP6 protocol) AMV SST pattern, both for positive and negative phases (AMV+/AMV-). In particular, five LR models (CNRM-CM6-1-LR, EC-Earth3P LR, MetUM-GOML2-LR, MPI-ESM1-2-HR, ECMWF-IFS-LR) and four HR models (EC-Earth3P HR, MetUM-GOML2-HR, MPI-ESM1-2-XR, ECMWF-IFS-HR), are used. A total number of 100 members is considered for each model in summer (JJA) and 90 members for each model in winter (DJF). As in the previous section, some models had more members available, but we preferred to use a fix number of members for all of them in order to create an unbiased estimation of the multimodel mean. The results, for winter and summer season, are shown in Figure 3 and Figure 4, respectively.

In winter (Fig. 3; upper panels), the AMV signature (AMV+ minus AMV-) on European surface temperature is limited but broadly coherent with the observed impact (Arthun et al. 2018). Some noticeable differences are found between LR and HR models. While for LR models a warming is identified over the whole European continent, a slight cooling is detected over northern Europe in HR models. Considering the periodicity of the AMV and its current positive AMV phase, this warming (cooling) over northern Europe for LR (HR) models indicates that AMV may already be reinforcing (mitigating) the warming expected for the next future (Fig. 1). Please note, however, how the amplitude of the AMV-related impact (Fig. 3) is weaker than that of the forced impact (Fig. 1). Over the Mediterranean region both LR and HR models present a modest but consistent warming associated with positive AMV phases. This suggests a possible modulation of the forced signal by the AMV signal in that region as well. Regarding rainfall (Fig. 3; bottom panels), wetter conditions are detected over central Europe and specially over the Mediterranean Sea. This increase in surface rainfall is more prominent in HR models (~10%) than in LR models (~5%) but, as in the case of the forced signal, the consistency among models is limited and the results must be interpreted with caution.

In summer (Fig. 4; upper panels), the AMV signature on European surface temperatures present strong similarities with that obtained for winter time (with the exception of the cooling over northern Europe identified in HR models). The influence over the Mediterranean region is, however, stronger than that for the winter season. It is worth also mentioning how, in the case of HR models, a reinforced and more consistent impact over central Europe is detected in summer season than in winter season (Fig. 3). Regarding rainfall (Fig. 4; bottom panels), a decrease of more than the 10% is identified over the eastern Mediterranean. This response is stronger and opposite than that found in winter (Fig. 3). On the contrary, over northern Europe a consistent increase (of about 10% for LR models and 5% for HR models) is obtained. Thus, no major differences are identified among the AMV signatures on European continent in LR and HR models, being both of them coherent with the observed pattern (Sutton & Dong 2012).

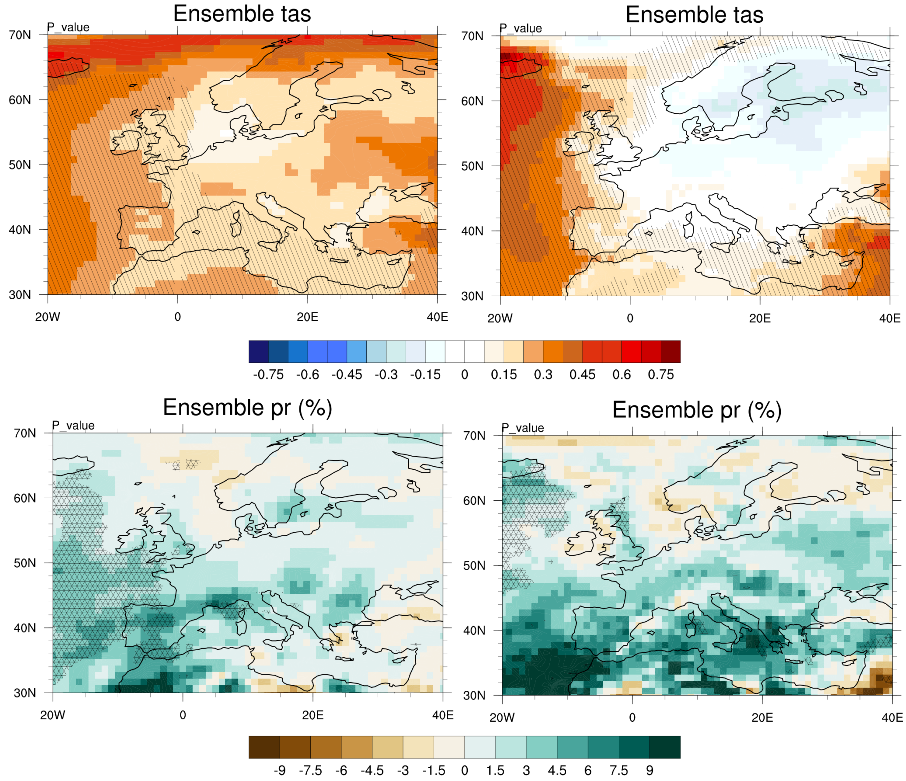

Figure 3: Difference of DJF average between “AMV-POS” and “AMV-NEG” simulations within PRIMAVERA. Top panels show the surface temperature (tas; units in K). Bottom panels show the surface rainfall (pr; units in % of change). From left to right: LR models and HR models. Hatching highlights statistically significant areas (at a level of 5%) from a two-sided Student’s t-test.

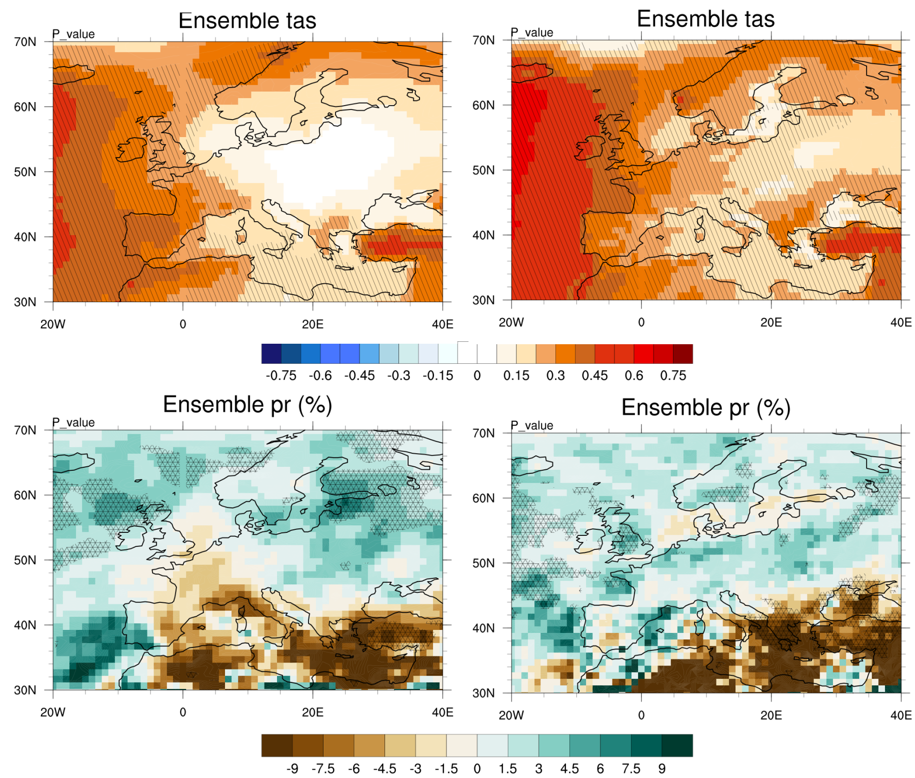

Figure 4: As Figure 3 but for summer season (JJA).

3.3 Averaged trends over the continental areas

A marked positive trend is identified, from the 1990's onwards, in the annual, winter, and summer averages of the European surface temperatures computed over the continental areas (for northern Europe in Fig. 5 and for southern Europe in Fig. 6). It is interesting to note how, in the historical period, the background conditions in LR models seem to be warmer than in HR (please compare the red lines with the observed values in green, which are common for both LR and HR panels). By carefully observing the multi-model spread from 2015 onwards (see boxplots to the right of each panel) we can conclude that increasing nominal resolution of models do not produce a direct improvement of this spread. Furthermore, by comparing the multi-model variability of our continental averages with the AMV amplitudes shown in Figures 3 and 4 (please note the red/blue points within the boxplots in Figs. 5 and 6) we can infer that the AMV plays a minor role as modulator of the forced warming.

At first glance, a clear difference among the trends obtained from the rainfall continental averages (Figs. 5 and 6) and those obtained from the temperature continental averages (Figs. 7 and 8) is the fact that the resultant trends are less marked in the former case. An interesting aspect from rainfall analysis emerges from the distinct signs of these trends among seasons, being slightly positive in winter but slightly negative in summer. These characteristics are common in both, LR and HR models. In addition, in winter time the models tend to overestimate rainfall (please compare blue and purple lines) while in summer they tend to slightly underestimate rainfall. The latter feature seems to be slightly corrected in HR models. Regarding the multi-model spread, and as in the case of surface temperature, no direct improvement is found in HR models with respect to LR models. The amplitude of the AMV signal, although small, is comparable with the trends obtained. Thus, a modulating role of the AMV should not be ruled out in the case of European rainfall.

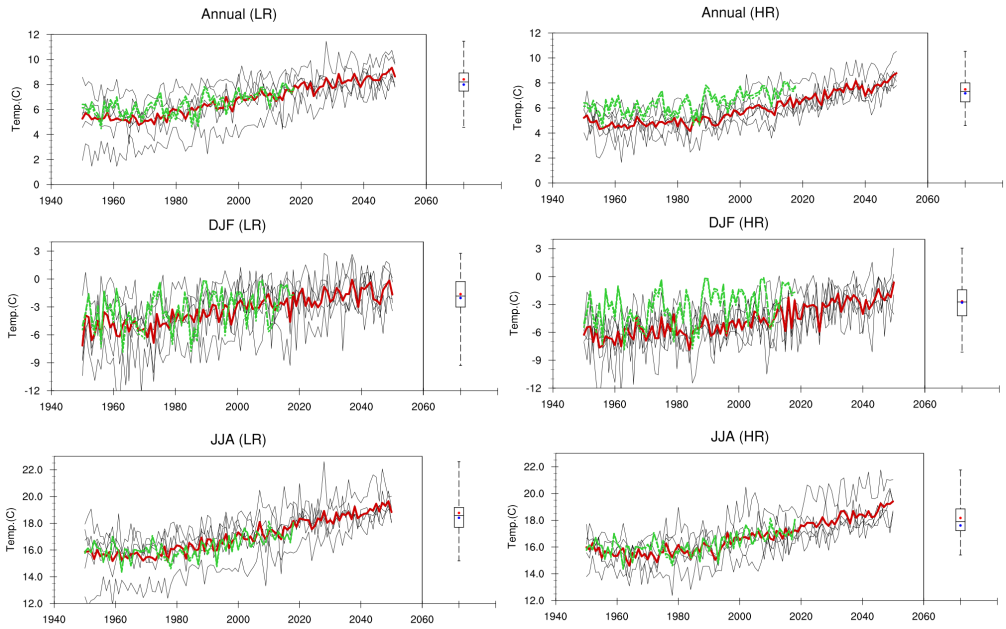

Figure 5: **Temperature over northern Europe**: Continental averages of surface temperature (tas; units in K) over northern Europe (10W-40E, 47N-65N). Black lines represent ensembles from different models while red line represents the multi-model ensemble. Green lines show the same averages from two distinct datasets: CRU (dashed green line) and EOBS (dotted green line). To the right of each panel the multi-model distribution [min, 25%, 50%, 75%, max] and the corresponding amplitude of the AMV around the mean (red and blue points for positive and negative AMV phases respectively). From top to bottom: annual averages, DJF average and JJA average. From left to right: LR models and HR models.

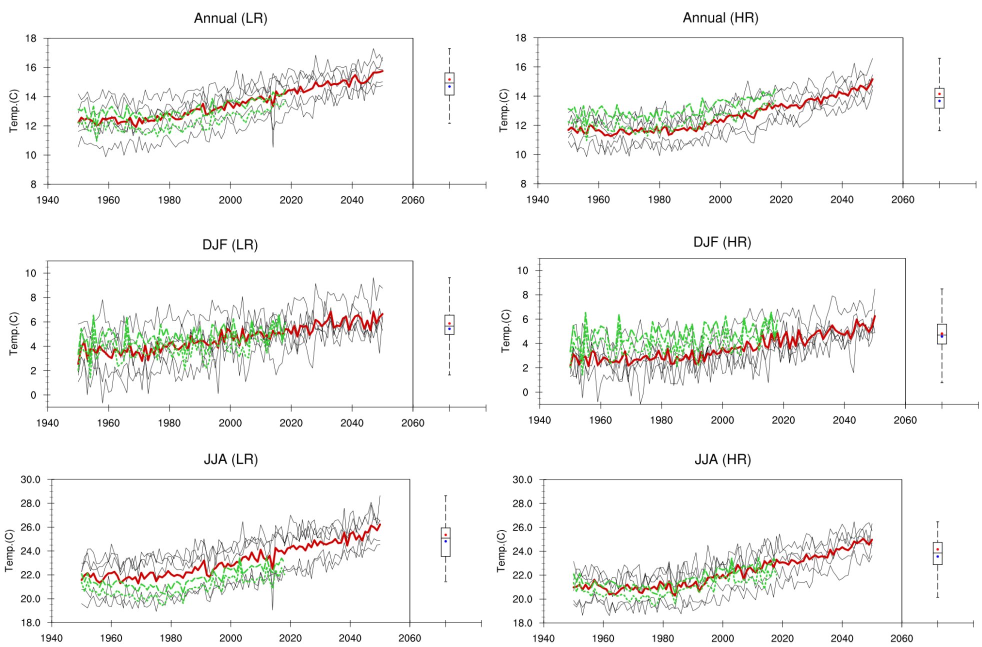

Figure 6: **Temperature over southern Europe**: As Figure 5 but for southern Europe (10W-40E, 35N-46N).

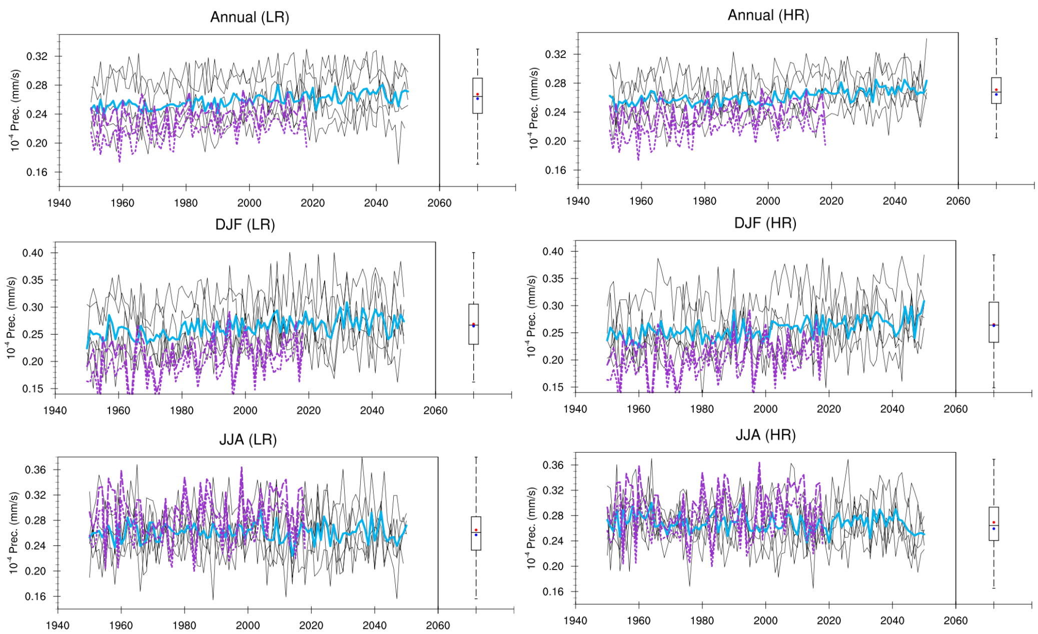

Figure 7**: Rainfall over northern Europe**: As Figure 5 but for rainfall (units in 10^{-4} Kg m^{-2} s^{-1}). In this case the multi-model ensemble appears in blue and the observational datasets in purple.

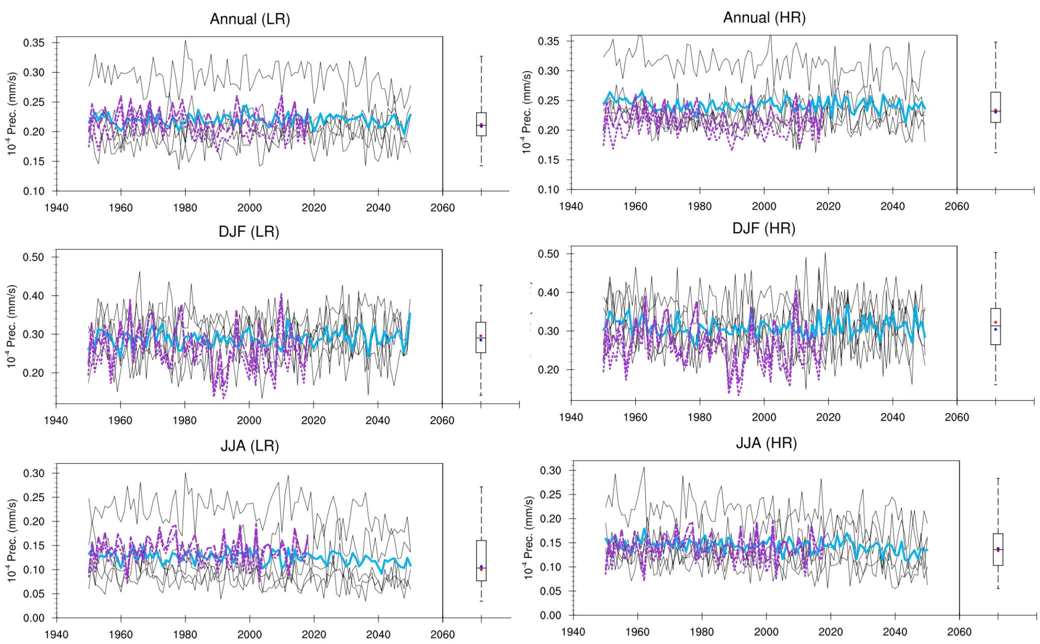

Figure 8: **Rainfall over southern Europe**: As Figure 7 but for southern Europe (10W-40E, 35N-46N).

3.4 References

Årthun, M., Kolstad, E. W., Eldevik, T., & Keenlyside, N. S. (2018) Time scales and sources of European temperature variability. Geoph. Res. Lett., 45, 3597–3604. https://doi.org/10.1002/2018GL077401

Sutton RT & Dong B (2012) Atlantic Ocean influence on a shift in European climate in 1990s. Nat Geosci 5:788–792. doi:10.1038/ ngeo1595

4. Lessons learnt

- A widespread warming of European continent is identified for the next decades. This warming is robust for both, LR and HR models, but the amplitude is different for certain European sub-regions depending on the model nominal resolution.

- Depending on its phase the AMV reinforces (AMV+) or mitigates (AMV-) this warming expected for the next future. Some differences are identified in this AMV-related impact over northern Europe between LR and HR models.

- Although a generalized increase of summer rainfall is expected for the next decades over most of continental Europe, some areas of eastern Europe and the Mediterranean will experience a decrease of rainfall in summer season. In winter the increase of rainfall is a widespread phenomenon over Europe, being however stronger over the Mediterranean (northern Europe) for LR (HR) models.

- Positive (negative) AMV phases increase (decrease) the winter rainfall over southern Europe. This response is particularly marked in HR models. Positive (negative) AMV phases decrease (increase) the summer rainfall over southern Europe and increase (decrease) the summer rainfall over northern Europe. The former response is comparable in LR and HR models whereas the latter response is stronger in LR models.

- Thus, the AMV could be modulating the forced signal on both, temperature and rainfall fields. This modulating role is only relevant for some specific sub-regions where the amplitude of the AMV-related signal is comparable to the total change expected for the next decades (~30% for temperature and ~50% for rainfall). For other sub-regions of Europe the amplitude of the AMV signal (and hence its modulating role) is much more limited.