Projections of selected temperature and precipitation extremes inferred by CMIP3 models (CES D2.4 deliverable task iv)

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Introduction

The territory of Northern Eurasia is characterized by complex and still insufficiently understood climate processes and feedbacks, contributing to the challenge, which the region poses from the viewpoint of climate modeling. Increased levels of atmospheric greenhouse gases will have a larger effect on climate in Northern Eurasia, particularly in its cold regions, than in most of other regions of the Earth. Russia, that occupies most part of Northern Eurasia, is the world's coldest country with its annual mean area averaged temperature of -4.1ºC.

Projections with the global climate models provide a physically consistent quantitative picture of climate change through the 21st century. The model projected mean warming will plausibly be accompanied by changes in the extremes that exhibit considerable interregional differences. The extremes at limited modeling resolution are manifested in large-scale slowly evolving climate (weather) anomalies that can be utilized to feed different impact models for more practical assessment. For analysis purposes the climate extremes can be expressed in terms of indicators (indices) that can describe an observed (simulated) variable (e.g. temperature, precipitation) behavior at the tails of its statistical distribution in changing climate. The set of such indices that describe impact related climate variability properties includes durations of threshold exceedances, annual/seasonal number of days with anomalously low or high surface air temperatures, number of days with very heavy precipitation accumulations within a season or year, etc.

To estimate a possible future change in climate extremes over the territories of European Russia (ER) and Europe (EU) an ensemble of 9 CMIP3 [1] comprehensive global (coupled atmosphere-ocean) climate models is used in this assessment (Table 1); so called A2 scenario is considered. Both A2 and A1B scenarios are similar in terms of resulting global mean warming up to the mid-21st century IPCC [2]. The projected changes in ER and EU in many cases continue the tendencies already observed, while their magnitudes as well as interscenario differences are increasing towards the end of the 21st century.

Table 1

	Model, country	Resolution atmosphere/ocean
1	CGCM3.1(T47), Canada	T47L31/1.9°×1.9°L29
2	CNRM-CM3, France	T63L45/0.5-2°×2°L31
3	CSIRO-Mk3.0, Australia	T63L18/0.8°×1.9°L31
4	ECHAM5/MPI-OM, Germany	T63L31/1.5°×1.5°L40
5	ECHO-G, Germany/Korea	T30L19/0.5-2.8°×2.8°L20
6	GFDL-CM2.1, USA	2.0°×2.5°L24/0.3-1.0°×1.0°
7	IPSL-CM4, France	3.75°x2.5°L19/2°x1°L31
8	MIROC3.2 (medres), Japan	T42L20/0.5-1.4°×1.4°L44
9	MRI-CGCM2.3.2, Japan	T42L30/0.5-2.0°×2.5°L23

Modeling output involved to calculate extreme indices includes gridded daily distributions of surface air temperature maxima and minima and daily precipitation totals. The output spans 1980-1999 (baseline) and 2046-2065 time slices. Projected changes in the indices of temperature and precipitation extremes are evaluated as arithmetic differences between 21st century and baseline indices. The changes in the following indices are considered below: annual maxima and minima temperatures and their difference (annual extreme temperature range), heat and cold wave durations in summer and winter, duration of dry periods and fraction of very heavy precipitation (exceeding 90th quantile) and its duration in summer. The definition of the indices is explained in more detail below. To assess the robustness of simulated changes in the extremes the following metrics are employed: signal-to-noise (a ratio between ensemble mean change and its standard deviation across the ensemble) and sign agreement (a percentage of models in the ensemble that project the same sign of changes as the entire ensemble does).

Analysis

In Fig.1a shown are simulated changes in the annual extreme temperature range calculated as difference between 20 yr mean absolute annual maxima and minima temperatures in baseline and future scenario periods. The range tends to decrease in warmer climate over the central and eastern parts of the region, however, only the changes (by 2-4ºC) over Scandinavia as well as in north-western and southern Russia appear to be confident. There is a slight increase (by 1-3ºC) is expected over southern Europe be due to pronounced increase of extremely high daily temperature maxima in summer. The decrease in annual extreme temperature range can be explained by faster increase of low and extremely low temperatures during cold season as compared against relatively slow increase of extremely high temperatures in summer. The simulated warming in the annual minima temperatures is projected to be twice larger as compared against warming in the annual maxima (Fig.1b-c).

Fig.2a displays changes of heat wave duration in summer by mid 21st century. A heat wave is defined as a total number of days within the intervals of at least 6 consecutive days with daily maximum temperatures exceeding maximum temperature normal by 5ºC in summer averaged over 20 yr period. As inferred from ensemble simulation the heat waves will likely be more durable throughout the region. The simulated heat waves in baseline period range from 1-3 days in the southern regions of EU to 4-6 days over central ER (Fig.2b). Most significant increase in the durations (by 8-12 days) can be found over the southern areas of EU, eastern Europe and southern ER and further eastwards indicating at possible future formation of xeric belt in southern mid-latitudes during warm season. This issue is supported by projected prolongation of dry periods over these areas (see below). The models agree reasonably well on heat wave changes greater than 6 days over most part of the region. In Fig. 2c shown are changes for cold wave duration in winter. The cold waves have been estimated using daily minimum temperatures not exceeding 5ºC threshold below daily minimum temperature normal in winter. In the late 20th century the ensemble mean cold wave duration ranges from 1-3 to more than 10 days throughout the region (Fig. 2d). In contrast with changes in heat waves, the most pronounced changes (decrease) in cold wave durations can be distinguished in northern areas of the region notably over northern EU and north-western ER (by 6-8 days), and Russian Far North (by 8-10 days).

The spatial picture of changes in heat and cold wave durations shown in Fig.2 is generally in agreement with that obtained for changes in summer and winter mean temperatures (not shown). This suggests that simulated changes in seasonal mean temperatures could be used as predictors for expected changes in heat/cold wave durations.

The changes of the extreme precipitation indices are demonstrated in Fig.3-4. While northern midlatitudes will likely undergo little change in dry summer periods, one can find that the southern regions of EU and ER will likely experience longer dry periods with consecutive daily precipitation accumulations below 0.1 mm (Fig.3). This picture is in agreement with projected decrease in summer mean precipitation over these regions.

Similarly to the mean summer precipitation and dry period length, simulated precipitation fraction from daily precipitation events above baseline 90th quantile in summer decreases (Fig 4a) along with the total number of such extreme events (Fig.4b) in the southern EU and ER. However, the models indicate that the total number of extreme events decreases at considerably higher rate (by 10-25%) as compared against that of extreme precipitation fraction (by 5-15%). This implies, under considerable uncertainty, that although days with heavy precipitation will be fewer in the mid-21st century during summer in the southern regions of EU and ER, their intensity will not decrease as much as the mean precipitation.

Resume

State-of-the-art climate projections for EU and ER have different credibility for different indices of climate extremes – e.g., higher for temperature and lower for precipitation. Given attention to the extremes, a more ambitious strategy for ensemble climate simulations is needed in order to better address the problem of natural climate variability and how it may be affected by a global climate change. Changes in the distribution of climatic events are as interesting as changes in the mean when the impacts of climate change are considered.

It has been shown that the changes in selected temperature indices are prone to moderate uncertainty due to inter-model differences at least for the particular modeling set, scenario and periods considered. However, over the most of the region not only the magnitude of changes in precipitation extremes but even the sign of these changes cannot be estimated at a reasonable level of confidence.

In order to decrease the uncertainties of the projections (including those due to natural variability, model sensitivity to prescribed forcings and due to forcings themselves), much larger samples of simulations are apparently required. Estimates of extreme events and their frequencies of occurrence require massive ensemble simulations. In addition, it would be advantageous to increase model resolution to better capture physical processes at finer scales and to better describe sharp spatial gradients, which are often in the regions where extreme events occur. Therefore, there is also pressing need to further investigate the impact related aspects of regional climate changes over the region using ensembles of regional climate model simulations at 10-50 km resolution. Both types of improvements (increasing resolution and ensemble size) are highly computer-intensive. Owing to the great diversity of climatic conditions in the region further research is needed to find a reasonable balance between ensemble size, modeling spatial resolution, complexity of incorporated physical parameterizations and additionally, in case of regional climate modeling, optimum domain size.

References

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USA.

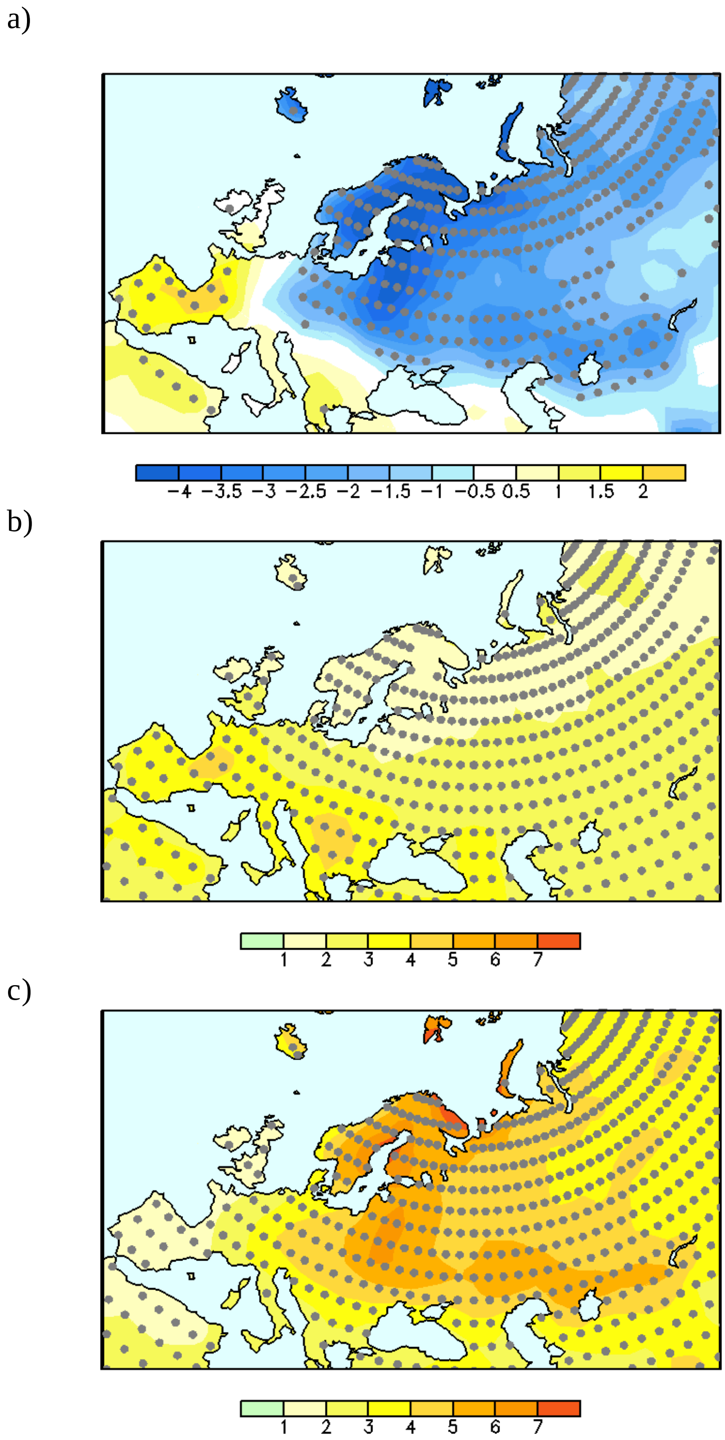

Fig.1 Change of annual extreme temperature range (a) annual maximum temperature (b) and annual minimum temperature (c) as simulated by the ensemble of 9 CMIP3 AOGCMs for 2046-2065 relative to 1980-1999. Units are K. Dots denote grid boxes for which signal-to-noise ratio is greater than 1.

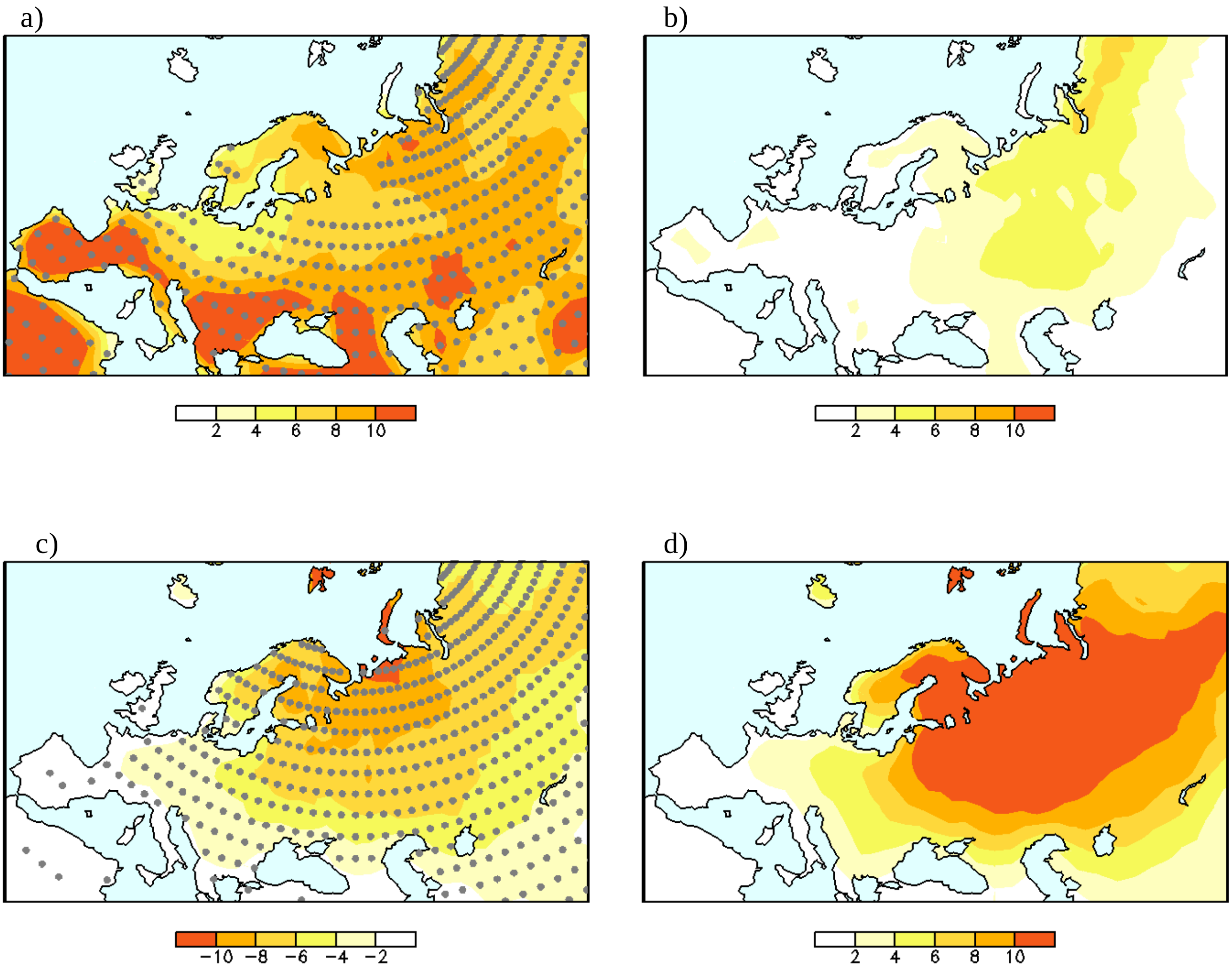

Fig.2 Same as in Fig.1 but for changes in heat (a) and cold (c) wave duration (days) in summer and winter, respectively. Shown are also heat (b) and cold (d) wave durations as simulated for the baseline period.

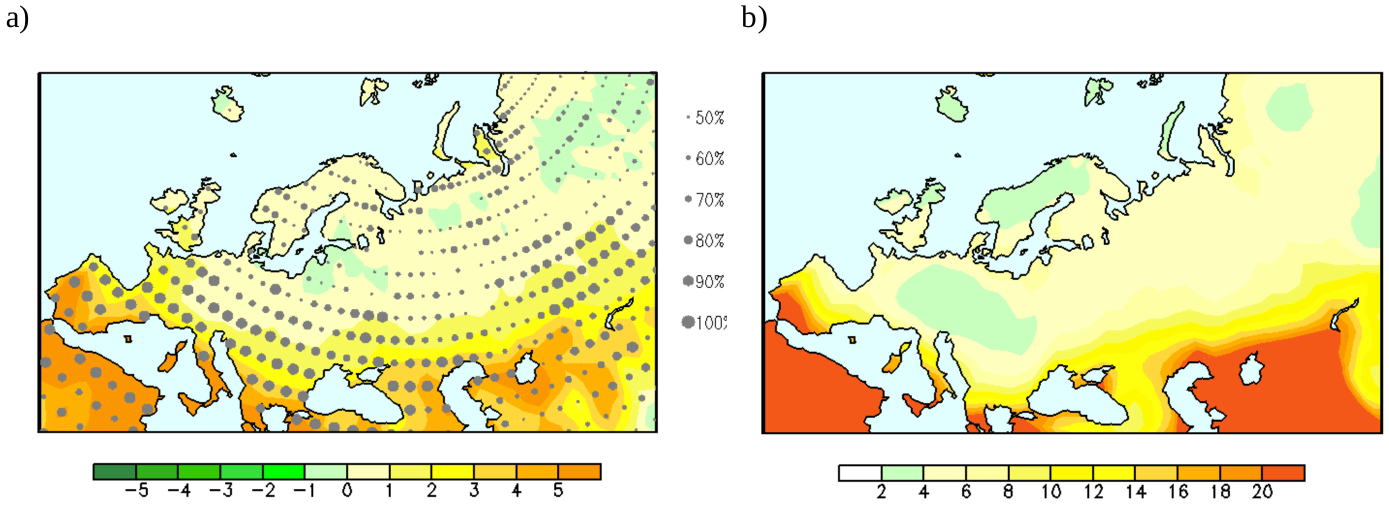

Fig.3 Ensemble mean changes (days) in maximum number of consecutive dry days (daily precipitation totals <0.1 mm) in summer (a) and its baseline distribution (b). Filled circles denote percentage of models in the ensemble that locally agree on the sign of simulated changes.

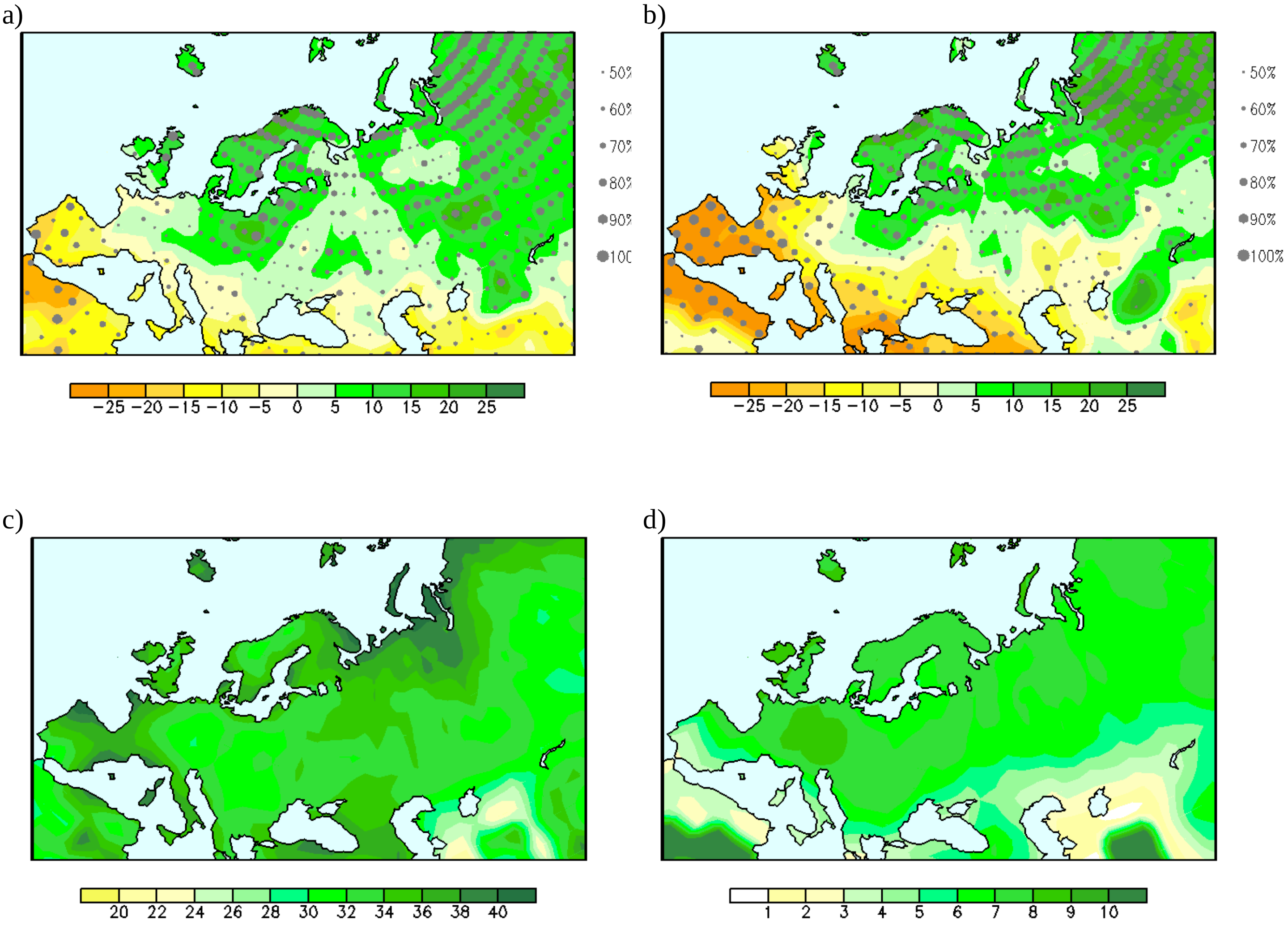

Fig.4 As in Fig.3 but for the relative changes (%) in summer fraction of precipitation above baseline 90th quantile (a) and total duration of such precipitation (b). In Fig.4cd shown are the baseline fraction (c) and duration (d). Units in (c,d) are percent and days, respectively.