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Thematic Priority: Global Change and Ecosystems

Deliverable D6.15. Assessing the uncertainty in projected changes in climate extremes and their impacts on the following sectors: health, forestry, flood risk, property damage, agriculture

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Lead Partner: SYKE: Finnish Environment Institute, Helsinki, Finland*
Contributing Partners: FMI: Finnish Meteorological Institute, Helsinki, Finland; FUB: Freie Universit"at Berlin, Institut für Meteorologie, Berlin, Germany; NAO: Institute for Environmental Research and Sustainable Development, National Observatory of Athens, Greece; PAS: Institute for Agricultural and Forest Environment, Polish Academy of Sciences, Poznań, Poland; ULUND: Departments of Ecology, Plant Ecology and Systematics and Physical Geography and Ecosystems Analysis, Lund University, Sweden; SMHI: Swedish Meteorological and Hydrological Institute, Norrköping.

* The original representative of Lead Partner, UEA, withdrew from this Work Package in 2008
Assessing the uncertainty in projected changes in climate extremes and their impacts on the following sectors: health, forestry, flood risk, property damage, agriculture

Introduction

The new set of climate model projections for Europe produced in the ENSEMBLES project offers new opportunities for estimating the potential impacts of climate change and their associated uncertainties. Some of the most damaging and costly impacts of climate change are expected to be manifest through extreme weather events. These are weather occurrences such as heavy rainfall, drought, severe cold, heatwaves and storms that can result in damage to natural ecosystems, forests, agriculture, infrastructure or human health and welfare. Extreme events, by definition, are rare, but in a changing climate their frequency and/or intensity may alter. Impact models have been used in ENSEMBLES to define the nature of these extreme events in different sectors under present-day climate, and then to evaluate how these may change in the future, using projections from the latest generation of global and regional climate models (Figure 1).

Figure 1. Use of impact models for estimating impacts of extreme events based on ENSEMBLES AOGCM and RCM climate projections. The types of impacts investigated are listed on the right of the diagram. The use of probabilistic projections for evaluating impact risks is also shown (in grey) and reported as Milestone M6.14.

Five examples are presented here: property damage due to windstorms in western and central Europe, effects of climate warming on potential energy demand for space heating and cooling in the Mediterranean, forest fire risk in Fennoscandia, forest damage due to low temperature and pests in Sweden and potential impacts of extreme weather in Poland. The results obtained in each of these examples are critically dependent on daily or sub-daily time scale information from climate models, and each example highlights new insights gained by applying ENSEMBLES climate simulations. Further details of these studies as well as other examples of modelled impacts of extreme weather events, are provided in the supporting references.

1 Timothy R. Carter, Finnish Environment Institute, Helsinki, Finland (SYKE)
Example 1: Property damage due to windstorms

Multiple projections from GCMs and RCMs produced in ENSEMBLES were analysed with respect to future changes in wind storm risk (Leckebusch et al., 2008; Donat et al., 2009; in prep. A) and related loss potentials (Donat et al., 2009; in prep. B). In most simulations, as well as in the ensemble mean of multi-model simulations, increased extreme wind speeds are found over northern parts of Central and Western Europe under increased greenhouse gas forcing. Decreased values of extreme wind speeds are projected for Southern Europe. Storm loss potentials are calculated by applying a storm loss regression model. Consistent with the changes in extreme wind speeds, higher storm losses are estimated for Western and particularly for Central Europe, assuming that no adaptation to the changed wind climate takes place (Figure 2).

Figure 2. Relative changes (%) of mean annual storm loss potential based on nine GCM (upper row) and eight RCM (bottom row) simulations for the end of the 21st century (2071-2100) relative to recent climate conditions (1961-2000), assuming the SRES A1B emissions scenario. Values in parentheses are inter-model standard deviations. Source: Donat et al. (in prep. B).

Uncertainties in the range of changes in loss potential are accounted for using two different measures. First, the standard deviation of the change signals across the different climate model simulations have been computed (parentheses in Figure 2), revealing values of the same order as the mean changes for most regions considered. However, as an uncertainty measure the standard deviation is strongly influenced by outliers. An alternative measure of uncertainty considers the arbitrariness of the multi-model ensembles used in the study. There are numerous combinations of model outputs that might have been selected as ensembles.

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among the nine GCM and eight RCM simulations, in addition to the 9-member and 8-member ensembles. For example, if only eight of the nine GCMs had been chosen as ensembles, there are nine possible combinations of these; selecting ensembles of seven GCMs from nine gives 36 possible combinations, and so on. Overall there are 511 possible ensemble combinations comprising between one and nine GCM members. Consideration of the signals from all of these combinations results in a relatively symmetrical distribution of possible change signals around the ensemble mean and further allows for the construction of probabilistic information about the range of expected changes (Figure 3). For example, extending this analysis to include additionally the eight RCM simulations produces 131,071 different sub-ensembles based on 17 individual model simulations. Using this distribution, as calculated for grid boxes over Germany for the end of the 21st century, a mean increase in loss potential of 25% can be estimated, with a 90% confidence interval of between +13% and +37%.

![ACC frequencies GER 2071-2100 - 1961-2000](image)

**Figure 3.** Anthropogenic climate change (ACC) signal in storm loss potential over Germany by 2071-2100 relative to 1961-2000 under an A1B emissions scenario, expressed probabilistically based on ensembles comprising all possible combinations of available ENSEMBLES simulations by GCMs (red curve), RCMs (green dotted curve) and all models (blue dotted curve). Source: Donat et al. (in prep. B).

Note, however, that these probabilities are conditional on the range of GCM projections provided in the ENSEMBLES project. This range of projections is not as wide, for example, as the range sampled in the IPCC Fourth Assessment Report, which considered around 20 GCMs and three emissions scenarios (Meehl et al., 2007). Furthermore, the ensembles formed using both GCM and RCM outputs cannot all be regarded as independent, as some of the RCM simulations made use of boundary conditions provided by one of the GCMs.
Example 2: Potential energy demand for space heating and cooling in the Mediterranean

In the Mediterranean region under present-day conditions the maximum values of energy consumption are related to cold weather in winter (for heating) and hot weather in summer (for cooling). With higher temperatures under a changing climate it would therefore be logical to expect decreased heating demand during the colder part of the year and increased cooling demand in the warmer part. This hypothesis has been examined using daily temperature outputs from simulations conducted in ENSEMBLES with six regional climate models (RCMs) assuming the A1B emissions scenario. Simulated temperatures representing the present (for 1960-1989) and the future (2021-2050) were extracted for the Mediterranean region at a horizontal resolution of 25 x 25 km.

A measure that is commonly used as a proxy for energy demand is accumulated temperature. This can be defined here as the difference of mean daily temperature from a threshold or base temperature at which energy consumption is at a minimum. During the warmer part of the year, temperatures commonly exceed a base temperature above which cooling is activated. By accumulating the daily exceedances during a given period, an indication of total energy demand can be estimated for that period (Cooling Degree Days or CDD). Similarly, the sum of daily temperature departures below a temperature threshold below a temperature threshold is a useful proxy for heating demand in the colder part of the year (Heating Degree Days or HDD). In this study, based on earlier work in southern Europe, 15°C is used as the base temperature for estimating HDD, and 25°C as the corresponding threshold for CDD.

Figure 4 presents changes in annual CDD and HDD up to 2021-2050. An increase in cooling requirement is indicated in all regions, with large increases over southern Spain, eastern Greece and western Turkey, and the largest increases over Cyprus and North Africa. Smaller changes are estimated for Sardinia, Corsica and the Aegean islands (Figure 4a). In contrast, heating demand, declines over much of the region (Figure 4b), less so in the coastal regions that do not currently experience cold winters.

(a) Change in Cooling Degree Days  (b) Change in Heating Degree Days

Figure 4: Projected change in potential annual energy demand between 1960-1989 and 2021-2050 for (a) cooling and (b) heating, based on accumulated temperature (°Cd). Source: Giannakopoulos et al. (2009a).

Another dimension of cooling demand is illustrated in Figure 5, which shows mean change in the number of days requiring cooling of more than 5°C by 2021-2050 (Figure 5a) as well as the standard deviation of the changes as a measure of inter-model spread (Figure 5b). Over north Africa more than one additional month of heavy cooling would be required, while over

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3 Christos Giannakopoulos, Institute for Environmental Research and Sustainable Development, National Observatory of Athens, Greece
parts of southern Spain and Italy, eastern Greece, western Turkey and Cyprus, 20 more days would be needed. In both cases this represents more than a doubling compared to today, suggesting a need to plan for additional generating capacity to meet the extra demand. The inter-model standard deviation is considerably smaller than the mean change in most regions, implying that the signal of change is fairly robust.

(a) Mean change in heavy cooling days

(b) Standard deviation of change

Figure 5: Mean change in the number of days with a large cooling demand (> 5°Cd) between the baseline and 2021-2050 periods (a) and inter-model standard deviation of the changes (b). Source: Giannakopoulos et al. (2009a).

Example 3: Forest fire risk in Fennoscandia

Fire is one of the dominant forms of disturbances in the boreal forest and in the transition zone between forest and tundra. During most of the year there is no risk of forest fire due to the extended presence of snow cover and the increased moisture of the surface during autumn. However, from May until August there are periods when the forest fire risk is high. The climate changes anticipated for the boreal zone in the future could influence both fire frequency and severity as summers become warmer and evaporation increases.

An assessment of the fire danger rating has been conducted applying the Finnish Forest Fire Index (FFI). In computing the index, the volumetric moisture of a 60 mm thick surface layer is estimated using precipitation and potential evaporation data. The surface moisture is scaled to forest-fire index values that vary between 1 and 6; index values above 4 (corresponding to a volumetric moisture of 20%) represent a high forest fire risk, while an index value above 5 corresponds to a very high fire danger. Projections from a 100-year simulation with the SMHI-RCA regional climate model starting from 2001 were used for determining future changes in fire danger over Finland, Sweden and the Baltic region focusing on the fire season, April-September. In addition, 16 locations have been selected and further statistical analyses have been performed in order to obtain the regional and temporal variation in fire danger. Time series of the annual number of days with FFI above 4 and 5 have been studied both for these stations and using gridded data for the entire region.

Based on the analysis, a distinct trend towards an increased danger of fire can be observed. For all 16 stations the projected change in fire risk index by 2100 is statistically significant at the 95% confidence level. The number of days with very high fire risk is estimated to almost double during this century under the A2 emissions scenario (Figure 6, left). The changes indicated for a B2 emissions scenario are slightly moderated (Figure 6, right). The largest increases are registered for the northernmost stations (north of latitude 65°N).

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4 Ari Venäläinen, Finnish Meteorological Institute, Helsinki, Finland
Example 4: Forest damage due to low temperature and pests in Sweden

Regional climate projections provide information on changes in temperature and precipitation regimes, including the frequency and severity of extreme events. The changes can alter the basic conditions for tree growth and the risk of large-scale ecosystem disturbances (Smith et al., 2007). Norway spruce, which is an economically important forest tree species in northern and central Europe, has two main vulnerabilities related to weather: frost damage after bud burst, and spruce bark beetle attacks following windstorm damage. Both these damage types are related to specific weather situations rather than general climatic conditions, and an ensemble approach is useful to increase the sample size of weather situations and to get a measure of model variation.

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Figure 6: Number of days with very high forest fire risk projected for northern Europe during the 21st century. Results for latitudinal zones are averages from station data. Source: Kilpeläinen et al. (2009).

Figure 7: Projected changes in frequency of frost events after onset of vegetation processes for the periods 2011-2040 and 2070-2098 compared to the reference period 1961-1990, based on climate projections from one

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5 Anna Maria Jönsson, Department of Ecology, Plant Ecology and Systematics, Lund University & Lars Bärring, Department of Physical Geography and Ecosystems Analysis, Lund University and SMHI, Sweden
regional climate model (SMHI-RCA3) nested in seven global climate models. Source: Jönsson and Bärring (in prep., A).

In a warmer climate the spring onset of vegetation processes begins earlier in the season when the sun is still low. Thus the earlier budburst exposes trees to increased risk of radiation frost during long nights as well as winter cold air outbreaks, in some geographical areas actually increasing the frost risk despite generally warmer winters (Figure 7).

The spruce bark beetle can kill millions of trees during large outbreaks, which occur after windstorm damage that produces ample breeding substrate. Warm weather conditions allow for a rapid development of the new generation (Jönsson et al. 2009). A warmer climate can therefore lead to increased frequency of late summer swarming, producing a second generation in southern Scandinavia and a third generation in central Europe (Figure 8).

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Figure 8: Projected changes in swarming frequency of the first and second generation of spruce bark beetle for the periods 2011-2040 and 2070-2098 compared to the reference period 1961-1990, based on climate projections from one regional climate model (SMHI-RCA3) nested in seven global climate models. Source: Jönsson and Bärring (in prep., B).
**Example 5: Potential impacts of changes in extreme weather on crop yields, water resources and health in Poland**

The Institute for Agricultural and Forest Environment of the Polish Academy of Sciences used projections from six ENSEMBLES regional climate model simulations to quantify selected extreme-weather indices for Poland, of importance for the agricultural, water and health sectors, for two time horizons – a reference period (1961-1990) and a future period (2061-2090). Climate changes, and in particular increases in temperature and changes in rainfall, have strong impacts on agriculture in Poland and crop yield depends critically on water availability during the plant development phase. For two important crops: potatoes and wheat, decreases of yield are projected for most of the country. The national means of change in yield are: -2.175 t/ha and -0.539 t/ha, respectively.

Increasing water deficit problems are projected in Poland under a changing climate. Already in the present climate, during summer, evapotranspiration exceeds precipitation over most of the country, hence the water storage (in surface water bodies, groundwater and soil) is depleted (Figure 9A). Summer precipitation deficit is projected to increase considerably in the future (Figure 9B), so that the additional water supplies (above precipitation) needed to realise the full potential for crop production are estimated to increase by half between the reference and future time periods (not shown).

![Figure 9](image)

**Figure 9**: Changes of climatic water balance in summer in Poland. Period 1961-1990 (A) versus 2061-2090 (B). Source: Szwed et al. (submitted).

As regards climate and health, the value of a composite index (computed as the product of the number of senior discomfort days recording a high heat index and the number of senior citizens aged 65 years or more) is projected to increase 2-6 fold in a hundred years. This is an effect of both increase in the number of senior-discomfort days (nearly four times) and the number of seniors (over two times).

**Discussion**

The case studies described above highlight the wide application of climate model information in impact studies across sectors and at different scales. The multiple climate model simulations conducted in ENSEMBLES have yielded a wide range of projections for Europe, facilitating the most rigorous treatment of uncertainties yet to be undertaken for this or any

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other region of this size. The study of wind storms (Example 1) illustrates how multi-model ensemble projections can begin to offer the prospect of estimating relative likelihoods of certain types of key impacts (in this case property damage). Furthermore, the spatial resolution of downscal ed information from RCMs is now fine enough (25 km in the majority of runs) to capture, with some confidence (Christensen et al., 2008; Kostopoulou et al., 2009), future changes in many extreme weather events of importance for impacts. This has encouraged analyses to be conducted of high temperature impacts on energy demand in the Mediterranean region (Example 2), on the health of the elderly in Poland (Example 5) and on pest breeding potential in Sweden (Example 4), as well as drought effects on agriculture and water resources in Poland (Example 5). The demands of model projections are greater still when considering composite weather events, such as damaging frosts affecting trees following mild spring conditions (Example 4), or enhanced fire risk due to combined drought and high potential evaporation (Example 3). Here, the combination of robust models as well as multi-model (ensemble) simulations, provides a firmer basis for capturing different sources of uncertainty and for establishing an improved appreciation of impact risk.

Many of the studies reported here, along with some others not shown, are being prepared for publication in a Special Issue of the journal Natural Hazards and Earth System Sciences (NHESS), scheduled to appear in 2010.

References


Jönsson, A.M. and Bärring, L. Warming up for spring backlashes in Norway spruce forests (in preparation, A)


