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Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)
The ENSEMBLES project aims to quantify the uncertainty in long-term predictions of climate change. ENSEMBLES is a collaborative venture involving 67 institutes to provide a reliable quantitative risk assessment of long-term climate change and its impacts. Particular emphasis is placed on probable future climate changes in extremes, including storms, intense rainfall, drought and climate ‘shocks’. To focus on the needs of policymakers, ENSEMBLES considers impacts on timeframes ranging from seasonal to decadal to centennial, and at local, regional and global spatial scales. Impact sectors studied include agriculture, forestry, energy, insurance, tourism and health.

A multi-model system of regional climate models (RCMs) has been developed and applied for Europe at a horizontal resolution of 25 km. Fourteen modelling groups have made evaluation simulations of the period 1961-2000. Scenario simulations are underway.

Several European global forecast systems have been used to assess, for the first time, the impact of model uncertainty on forecast error in climate predictions at seasonal, annual and interannual time scales. Those systems have produced an unprecedented set of re-forecasts over the period 1960 to 2005, including initialized decadal climate forecasts for the decade 2006-2015.

Funded by the European Commission and coordinated by the Met Office Hadley Centre, the ENSEMBLES project aims to quantify the uncertainty in long-term predictions of climate change. ENSEMBLES is a collaborative venture involving 67 institutes to provide a reliable quantitative risk assessment of long-term climate change and its impacts. Particular emphasis is placed on probable future climate changes in extremes, including storms, intense rainfall, drought and climate ‘shocks’. To focus on the needs of policymakers, ENSEMBLES considers impacts on timeframes ranging from seasonal to decadal to centennial, and at local, regional and global spatial scales. Impact sectors studied include agriculture, forestry, energy, insurance, tourism and health.
What are Climate Models?

Climate models use a computer representation of the laws of physics describing the transport of mass and energy in the atmosphere. These equations are solved at predefined time intervals for a number of grid points across the surface of the Earth, into the atmosphere, and down through the oceans. Climate models work at different spatial scales. Global Climate Models (GCMs) simulate the climate over the whole Earth. One problem with GCMs is their coarse spatial resolution. To overcome this, and hence improve the model simulation of real conditions, Regional Climate Models (RCMs) have been constructed at a much higher spatial and temporal resolution than a GCM. The much finer detail of model orography makes it possible to simulate smaller-scale weather features than is possible with the relatively coarse GCMs. In order to simulate future climates, modellers have to make some assumptions about how future atmospheric concentrations of the greenhouse gases will evolve. In order to make realistic assumptions, there has to be a story, or scenario, of how human societies, economies and technologies will evolve into the future.

More information about climate models can be found on the ENSEMBLES website for the Public Understanding of Science: http://www.cru.uea.ac.uk/projects/ensembles/pus/CLIMATE_MODELS.html

Figure 1: Summary characteristics of the four SRES storylines (Modified from IPCC, 2007)
TEMPERATURE

Global mean changes

The multi-model ensemble global annual mean warming for year 2099 under the B1 scenario amounts to 1.9°C to 3.0°C for A1B scenario and to 3.9°C for A2 scenario. The time series show a high signal-to-noise ratio indicating a robust signal of global warming (Figure 2).

The multi-model ensemble mean warming for 2011-2030 amounts to approx. 0.6°C for all three SRES scenarios, with respect to the reference period (1980 to 1999). Insignificant differences in ensemble mean changes for this time period reflect the close agreement between the scenarios on atmospheric greenhouse gas concentrations in the next two decades. The spread of global mean temperature in the model projections in each scenario amounts to approximately 0.3-0.4°C for the 2011-2030 period.

For the last two decades of the 21st century (2080-2099) the projections of the three SRES scenarios give in the ensemble average considerably different global mean temperature anomalies (1.8°C, 2.8°C and 3.3°C). The multi-model ranges of global warming for 2080-2099 mean above the 1980-1999 mean for B1, A1B and A2 are 1.4-2.3°C, 2.2-3.3°C and 2.7-3.6°C respectively. Projected multi-model spread of temperature changes triples for the time period 2080-2099 compared to the 2011-2030 period (approx. 1°C vs. 0.3°C).

TEMPERATURE

Patterns of change

Average changes over the 20-year time period (2080 to 2099) with respect to the reference period (1980 to 1999) in the corresponding simulations of the 20th century climate have been calculated (Figure 3). A robust pattern of temperature changes was revealed among the contributing models. The largest temperature increase occurs over the Arctic in boreal winter (DJF). Warming over land is larger than over ocean enhancing the land-sea contrast in near surface temperature. Less warming is simulated over the Southern Ocean. In boreal summer (JJA) the warming is more confined to continents and sea ice covered areas of the Southern Ocean.

The patterns of warming are very similar for different emission scenarios but differ in their magnitude. As expected, the most pronounced warming is found for the A2 scenario, whereas the weakest warming is shown in the B1 scenario. Large temperature changes in the Arctic are related to the changes in sea ice extent and volume.

IN A FUTURE WARMER CLIMATE:

- The multi-model ranges of global warming for 2080-2099 compared to 1980-1999 for B1, A1B and A2 are 1.4-2.3 degrees, 2.2-3.3 degrees and 2.7-3.6 degrees respectively.
- Heat waves will become hotter and last longer over much of Europe.
- The cold season will be much shorter.
IN A FUTURE WARMER CLIMATE:

- The multi-model global annual mean precipitation rise for the year 2099 relative to the reference period (1980-1999) amounts approximately to 3%, 4% and 5% for scenarios B1, A1B and A2 respectively.

- Mid-to high latitudes in Europe will experience an increase in rainfall especially in winter.

- The Mediterranean and the subtropics in general will experience reductions in precipitation in both summer and winter.

The precipitation change projected by the models follows a quasi-linear relationship between global precipitation and temperature changes (Figure 4). Thus, all models simulate a global mean precipitation increase (Figure 5), but with a weaker signal to noise ratio than for the temperature signal.

The multi-model global annual mean precipitation rise for the year 2099 relative to the reference period (1980-1999) amounts to 3.4% for scenario B1, to 4.6% for scenario A1B and to 5.4% for scenario A2.

Figure 4: Global annual mean precipitation changes [%] versus global annual mean temperature changes [°C] for scenario A1B for the models in ENSEMBLES project.

Figure 5: As in Figure 2 except for Precipitation changes.

Figure 6: Winter (left) and summer (right) mean precipitation change (mm/day) for the “medium emission” scenario A1B and the time period 2080-2099 relative to the 1980-1999 mean for the multi-model ensemble mean.
Precipitation Patterns of change

In winter the models show reduction of the precipitation over Central America, Northern Africa and the Mediterranean. In summer the precipitation is reduced over the continents in the temperate zones. In the Mediterranean the precipitation decrease is extended further northward and eastward compared to the winter pattern. A large precipitation reduction is seen over the Caribbean Sea and parts of North America. The monsoon in Southern and Eastern Asia intensifies (Figure 6).

In general, the models agree on a precipitation increase along the Intertropical Convergence Zone (ITCZ) and on decreasing precipitation in the subtropics. A robust feature across all models is mid- to high-latitude precipitation increase (most pronounced during winter of each hemisphere) associated with increased water holding capacity of the warmer atmosphere and poleward moisture transport.

Wind

High wind speeds in Europe are associated with large depressions, otherwise known as extra-tropical cyclones, which develop across the North Atlantic and generally tend to track along an axis from southwest to north-east across the ocean into Europe. These systems tend to be relatively short duration hazards but are still capable of causing significant damage and disruption. Many studies have found, during the latter part of the 20th century, an increasing trend in the frequency of damaging windstorms developing across the North Atlantic. However, no consistent trends across 100 years of data were detected.

Cyclones developing across the North Atlantic were identified and tracked from observed and climate model gridded data. For all systems, irrespective of intensity, the analysis found that storm track density in the future, under the A2 scenarios, is reduced, particularly over Northern Europe. For the more intense/severe systems the track density is found to increase over northwestern Europe.

In a future warmer climate:

- Under most climate projections, fewer storms in total are expected in the future.
- However, the number of severe winter storms over western Europe is expected to increase in the future in response to human-induced climate change.
Global climate change represents a great threat for European agriculture. As an example, in 2003, European agriculture was severely affected by the heat wave that began in early June and continued through until August. Crop development was accelerated by 10–20 days resulting in earlier ripening and maturity. High temperatures and solar radiation resulted in increased crop water consumption causing acute depletion of soil water and an eventual lowering of crop yields. Cereal production was badly affected across the whole of Europe and yields fell by 23 Mt compared to 2002. As a consequence, the low cereal harvest had to be covered by more than 6 Mt of imports under mandatory quotas and more that 10 Mt from carry-over stocks.

Projected rising temperature may negatively impact yields of herbaceous crops, such as cereals, by shortening the duration of growing season. Moreover, reduction in rainfall and longer duration of dry spells will make the situation worse. By the other hand, increase in CO₂ air concentration level plays an important role to counterbalance temperature and rainfall negative impacts.

The relevant intensity of these effects may vary with time, therefore the patterns of risk of low crop productivity will change depending on which of these effects will prevail. Here a wheat crop model is run driven by the output from the global perturbed physics climate change model for present and A1B future greenhouse gases scenarios. The initial improvements (in parts of the region) are due to carbon dioxide fertilization. The smaller changes in the last plot of figure 7 (bottom right) may be explained by greater uncertainty in climate projections for the end of the century.

With the exception of Portugal and Southern Spain, in the next 30 years risk of shortfall shows an overall reduction due to fertilizing effect of CO₂ increase. Thereafter, the risk progressively increases all around the Basin. Maximum risk was estimated in 2050-2070 when strong reductions in yield were accounted all over the Mediterranean area.

Slight reductions in risk were accounted for the end of the next century, probably due to the greater uncertainty of the future data. The results show that southern Portugal, southern Spain and Peloponnesus are the most vulnerable areas showing increase in risk probability up to +60% Risk probability in Galicia, Slovenia, Croatia and central-southern France always appear lower than today.

These effects are expected to be greatest over the southern Mediterranean and North Africa.
**Water**

Water is vital for life on earth. It sustains health, ecosystems and economic growth. A wide range of sectors, e.g., agriculture, industry, energy, and tourism depend on it. Increasingly, there is an imbalance between the geographical and seasonal demand for and availability of water. Using projections of future climates as input for a global hydrological model we are able to analyze the impact on long-term water availability in European river basins. Water availability is hereby defined as the amount of total renewable water resources accessible to anthropogenic uses.

Between now and the 2050s, annual water availability is likely to increase by overall 5%–12% in northern European basins. The change in annual water availability in two northern European basins (Thames and Seine) is ambiguous with values of change between -7% to +8% depending on the climate input. Basins in southern Europe show a tendency towards decreasing annual water availability by overall -5% to -20% for the 2050s.

While elevated water availability increases the risk of floods, lower water availability can affect water quality and water stress. Projected climate changes will intensify the water stress situation especially in the Tiber, Guadalquivir and Rhine basins based on a number of water stress indicators.

Figure 8: The arrows show the direction of change in long term average water availability between current conditions (1961-1990) and the 2050s (2035-2065). Results are based on calculations with the integrated global water model “WaterGAP”. The percentages give the span of changes that result from the use of an ensemble of climate model outputs as input to the hydrological model.

**Forestry**

Every year approximately 45,000 forest fires break out across Europe. The long hot summer of 2003 was a bumper year for forest fires, with more than half a million hectares of woodland destroyed across Mediterranean Europe. According to the European Commission, each hectare of forest lost to fire costs Europe’s economy between 1000 and 5000 €. Fires cause considerable damage in terms of loss of life and in environmental terms through the destruction of fauna and flora. They also have serious economic implications: destruction of habitats, forest damage, costs of fire-fighting and so on. Most of these fires are caused by people. However, there are many natural factors such as drought, wind speed and topography, which influence the spread of fires and govern their devastating effects.

In a future warmer climate, there may be an increase in the meteorological risk of fire. This increase can be attributed to a higher number of dry and hot days, areas with temperatures greater than 30°C and relative humidity below 20% longer hot and dry spells and a longer fire risk season. The areas most at risk are in hilly, continental regions.

**Mediterranean Forest Fires**

- In future, an increased risk of forest fire is expected due to:
  - a higher number of dry and hot days
  - longer dry and hot spells
  - a longer season with fire risk

- The increased risk will be greatest in continental and upland areas.
Strong winds blow down and break trees resulting in large economic losses in timber and ecosystem productivity. For example, in the UK, the Great Storm of October 1987 felled 15 million trees and the windy winter of 1989/90 blew down 100 million m$^3$ of timber throughout western and central Europe. More recently, on the 8th January 2005, a severe hurricane hit the southern part of Sweden, with inland gusts exceeding 35 m/s. This resulted in devastating forest damages which far exceeded previous records. The Swedish National Forest Board estimated the losses at about 75 million m$^3$ of timber, three times the previous record of 25 million m$^3$ which occurred during one of two large storms in 1969.

Current discussions about climate change impacts on forests have often focused on the assumed increased growth encouraged by a warmer climate. However, extremes may be of greater importance. The combination of a raised mean temperature and an increase in extreme weather events will have negative effects on boreal forests in several ways.

Predictions based on regional climate model data point toward an increased risk for frost damage in Norway spruce. In a milder climate, tree dehardening will begin up to two months earlier in southern boreal forests. Large temperature variations may occur earlier in the year, increasing the risk of freezing temperatures below the hardiness level.

Summer dry spells are likely to increase in Europe, especially in the western and central parts of the boreal forest zone. Trees suffering from drought decrease in vitality and will be more susceptible to frost damage and attacks by pests and disease.

In southern Scandinavia and western Europe, the risk of wind throw is projected to increase.

Currently, the Norway spruce bark beetle (Ips typographus) is the pest causing the most economic losses in spruce. Related to warmer temperatures, bark beetle damage is likely to become even worse in the future, since there is increased risk of an additional generation each year.

Forest management would have a large impact on susceptibility to storm damage and bark beetle damage.

Bark beetles are the major damaging insects to European forests. The IPS model simulates the effect of temperature on the population dynamics. The model has been applied to south Swedish conditions, and will be applied to Northern European conditions using ENSEMBLES regional climate model data.
Under future climate change, demand for heating decreases and demand for cooling increases. Around the Mediterranean, two to three fewer weeks a year will require heating but an additional two to three (along the coast) to five weeks (inland areas) will need cooling by 2050, relative to 1961 to 1990 levels. Summer space cooling needs will particularly affect electricity demand. Peaks in electricity demand during summer heatwaves are very likely to equal or exceed peaks in demand during cold winter periods.

More recently, during the summer of 2003, record high temperatures across Europe resulted in problems with power plant cooling due to water shortages and warm river waters. For example, German nuclear power plants on the Upper Rhine and the Neckar River were forced to reduce their power production by 20% for several days in August due to river (cooling) water temperatures in excess of 26°C. In the case of the Obrigheim plant on the Neckar, this had to be completely turned off due to insufficient cooling water. The potential for Germany to face blackouts was high at this time and several power plants had to obtain special permission from the German water resources management administration to exceed the limits of cooling temperatures to which they are restricted by law.

During the space heating season, there is evidence of a strong relationship between air temperatures and the consumption of electricity and gas. In both forms of energy, increases in temperature lead to a reduction in demand. As a result, the decreases in energy consumption can be expected to become larger through time as the climate change signal becomes stronger. The size of the reduction is expected to vary across Europe along a northwest-southeast gradient; smallest in maritime regions and largest in the southernmost parts of continental Europe where the greatest degree of warming is expected to occur.

In contrast, the results from the space cooling season are more mixed. An analysis of electricity consumption during the warmer months of the year suggests a relationship between temperatures and consumption. This relationship varies on a north-south transect across Europe, changing from an inverse linear function in the north to a quadratic function with a breakpoint around 18°C in the south. The behaviour of gas consumption across Europe also indicates the existence of an inverse linear relationship, which remains constant across the entire region.

Temperature rise is likely to increase energy demand for air conditioning in the summer, particularly in southern Europe. Such extra power demand, compounded by climate change induced reduction in hydro-production and problems with cooling water availability, could cause disruption to energy supplies.
Property Insurance

Storm damage is a major component of insurance claims costs and can cause operational problems through the handling of large volumes of claims and the difficulty in obtaining tradesmen and materials to carry out repairs. As an example of the huge losses that can be incurred following large storm events, in 1990 four large wind storms affected Europe resulting in insured losses of 7.2 billion EUR, and economic losses of approximately 10.5 billion EUR, and more recently in 1999 a series of three storms produced 4.5 and 9.3 billion EUR in insured and economic losses, respectively.

An estimation of potential future loss due to winter wind storm suggests an increasing loss potential for property damages for wide parts of Western Europe (e.g. England, France, and Germany) up to 15% This is comparing the 2070-99 period to the baseline of 1961-90 for the A2 scenario. This estimation already takes adaptation to possible future conditions into account. Without adaptation the increase will be approximately 20%.

Figure 10: Comparison of calculated storm loss based on ERA-40 with insurance data for Germany. Correlations between calculated loss and insurance data rate between 0.85-0.9

Tourism

Conditions for tourism are expected to improve in northern and western Europe. It has been indicated that an arbitrary climate change scenario of 1°C would lead to a gradual shift of tourist destinations further north and up mountains affecting the preferences of sun and beach lovers from western and northern Europe. Mountainous parts of France, Italy and Spain could become more popular because of their relative coolness. Higher summer temperatures may lead to a gradual decrease in summer tourism in the Mediterranean but an increase in spring and perhaps autumn. Mediterranean countries will probably experience a lengthening and a flattening of their tourism season by 2030. Occupancy rates associated with a longer tourism season in the Mediterranean will spread demand more evenly and thus alleviate the pressure on summer water supply and energy demand.

The ski industry in central Europe is likely to be disrupted by significant reductions in natural snow cover especially at the beginning and end of the ski season. The most sensitive elevation in the Alps is 600 m in winter and 1400 m in spring and with no snowmaking adaptation considered, a 1°C rise leads to four fewer weeks of skiing days in winter and six fewer weeks in spring. A 2°C warming with no precipitation change would reduce the seasonal snow cover in the Alps by 50 days/yr, and with a 50% increase in precipitation by 30 days.
Changes in frequency and intensity of extreme weather and climate events could pose a serious threat to human health. These threats may either be direct, such as heat waves and flooding, or indirect, for example by the spread of tick-borne diseases. Particularly vulnerable sections of the population would be elderly people with limited access to health care services.

Heat-related deaths were defined as the number of deaths occurring in excess of the number that would have been expected for that population in the absence of stressful weather.

The observed/expected analysis, under both approaches, showed that hotter days were associated with greater mortality risk. Heat-related deaths were not discernible below 34°C. Substantial heat-related deaths occurred at very high temperatures.

Climate change can affect human health by direct weather/climate exposures, indirect exposures through climate driven environmental changes, and climate-induced economic and social disruptions. Figure 12 shows the pathways by which climate change can affect health as well as the concurrent direct-acting and modifying influences of environmental, social and health system factors. The severity of climate change impacts will vary from region to region, depending on physical vulnerability, the degree of socio-economic development, natural and human adaptive capacity, health services, and disaster surveillance mechanisms. The effects of high temperature increases and reduced precipitation in areas already coping with water scarcity is one of the most problematic climatic changes likely to affect human health in the Mediterranean region.

Direct weather/climate health impacts result from exposure to temperature extremes and other extreme weather events such as storms, floods, intense rainfall, floods and droughts. The heatwave of 2003 in Europe showed how vulnerable humans are to extreme temperatures. It is estimated that this heatwave killed over 35,000 people. Mediterranean countries were most affected by this heatwave. The threshold level above which mortality increases has a geographical heterogeneity. For example, thresholds are 31.8°C in Milan, 30.3°C in Rome, 27°C in Turin and 34°C in Athens.
The ENSEMBLES project (contract number GOCE-CT-2003-505539) is supported by the European Commission's 6th Framework Programme as a 5 year Integrated Project from 2004-2009 under the Thematic Sub-Priority "Global Change and Ecosystems".

http://www.ensembles-eu.org

In 2009 there will be several Ensembles workshops for stakeholders on climate change and its impacts. These aim to engage the stakeholder community (the users of climate change information) with the science community who are researching climate change and its impacts. The aim of these meetings is to provide relevant and useful information about Ensembles results and wider climate change information to stakeholders. If you want more information or are interested in attending such an event please contact: martin.beniston@unige.ch.