IMPACTS OF CLIMATE CHANGE



INTERNET PORTAL ClimateImpactsOnline

Potsdam Institute for
Climate Impact Research

P I K

Impacts of climate change for Germany:

www.klimafolgenonline.com
www.climateimpactsonline.com

Contact ClimateImpactsOnline portal:
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The capacity to innovate

Through the appropriation of highly concentrated energy from the sun – stored for millions of years – humankind has become a driving force in the Earth system. This force, founded on the advance of scientific understanding, and today increasingly apparent in rising greenhouse gas emissions, is already affecting society in some sectors – as scientific evidence can ever more clearly demonstrate. Science is now unequivocal that the unfolding Global Change is caused by humans. And increasingly we see it happening in our own backyards.

In all this, it was technological progress – the human capacity for innovation – which made possible the energy transition from water power and solar energy stored short-term in the form of biomass, to the use of more highly concentrated sources of energy like coal and oil. The coupling of the steam engine to the mechanical loom in Manchester around the year 1785 can justly be seen as the innovation which set in motion the cascade of increasing production, supply and demand and which has gone down in history as the Industrial Revolution. Use of the steam engine increased the efficiency of coal mining and so fired further progress, which spread out via the continually expanding rail network of the inexhaustible steam railway – again coal-driven. When finally Winston Churchill as First Lord of the Admiralty decided just before the start of World War I to upgrade the British war fleet from coal to oil power, this fossil fuel, too, stepped onto the stage of human history and thereby also that of our Earth: As a result of the large-scale burning of fossil fuels, the concentration of carbon dioxide in the atmosphere has been driven up ever more rapidly, currently to a level 40% higher than at the start of the Industrial Revolution.

The effects on the global climate observed today and projected for the future have not come without warning: the Swedish scientist Svante Arrhenius described the possibility of human induced global warming as long ago as 1896, and thus to some extent foresaw the present day. Arrhenius was still working with pen and paper. In today's world, data collection and numerical computer simulation not only confirm his theory, but allow us further insights into the causes and expected effects of climate change. One of the most important relevant data series is the so-called Keeling Curve. Scientists under the leadership of Charles David Keeling began in 1958 on Mauna Loa, Hawaii, to continuously measure the concentration of carbon dioxide in the atmosphere. Measurements are ongoing and show a rise of about 315 ppm (parts per million) to around 396.78 ppm in May 2012 since the start of the programme. Computer simulations make it possible to estimate future impacts of climate change. Thus, through the virtual network of researchers and research results, an ever-clearer picture emerges, allowing us to perceive the globe in its present phase as markedly shaped by mankind. Here too, it is technological progress which marks this further step in the history of humankind – by providing us with the means to recognize the extent of our own force.

Technological progress based on scientific insights – is it a curse or a blessing? Certainly, such simplistic classification would be mistaken. Yet with regard to climate change and its impacts, innovations can be seen as both their initiator and the medium of our understanding: the innovations of the 18th century set the stone in motion as regards the exploitation of fossil fuels; the innovations of the 20th century have allowed us to measure the trail the stone has carved out.

And it will be the innovations of the 21st century which will allow us to take the next step – to reduce or even prevent the dangerous backlash climate change would have on human societies. Innovations in the realm of renewable energies are just one example here – although they are bound to play a key role. Concerning adaptation to unavoidable climate impacts, too, technology must work together with science to chart out the scope of future impacts and develop adequate answers to the challenges ahead.

The European Institute of Innovation and Technology (EIT) represents a courageous endeavour to face up to this social responsibility in its vision and structure. Its goal is to promote innovation which specifically supports sustainable growth. In three Knowledge and Innovation Communities (KICs), scientists collaborate with representatives of the worlds of business and education to develop marketable products which will be the heralds of intelligent innovation for Europe, pointing the way forward to a sustainable future. Synergies of high potential are forming among these networks of players, whose common aim is to address societal challenges. The focus of the Climate-KIC is explicitly on climate change and its impacts.

Governing anthropogenic climate change should encompass the intelligent combination of mitigation and adaptation. Reducing the vulnerability of humankind to the impacts of climate change is an absolute necessity, especially in developing countries. These countries were not historically responsible for climate change, yet are disproportionately affected by its impacts and at the same time often possess the least capacity for adaptation. The question of justice comes in here: both in developing technological innovations and making them available, Germany and Europe can share in assuming global responsibility.

And yet, it would be foolish to optimistically assume that technology can solve the problem. Technology can only be part of the solution. In the first place the global community whose collective action will impact even the most remote regions and future generations must be prepared to recognize itself for what it is: A network of human beings whose actions affect one another. Although here again new innovations open novel pathways towards identification (such as via the internet and the global networks created by it), we cannot avoid facing the question of responsibility that arises from such recognition. The responsibility we take or fail to take will ultimately rely on a decision taken by each one of us – do we care or do we not? Science – in partnership with technological progress – can deliver the foundations and instruments by providing us with options and choices; it is us who must decide to act on these.

If dangerous consequences for humanity are to be avoided, dealing with climate change will require a multifaceted strategy uniting innovations in the area of mitigation and adaptation, debate on ethical questions, and a strong political will. The technological progress of the past has both helped produce our problem-ridden present-day situation and has helped us to recognize it for what it is. Now it can help us resolve it: Innovations can point us the way to a sustainable future. But we as global citizens must walk it ourselves.

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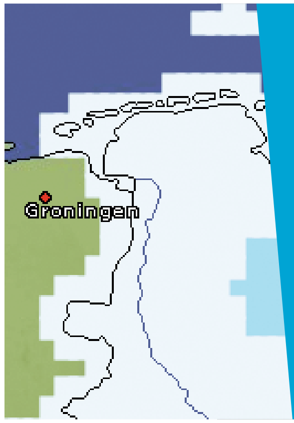
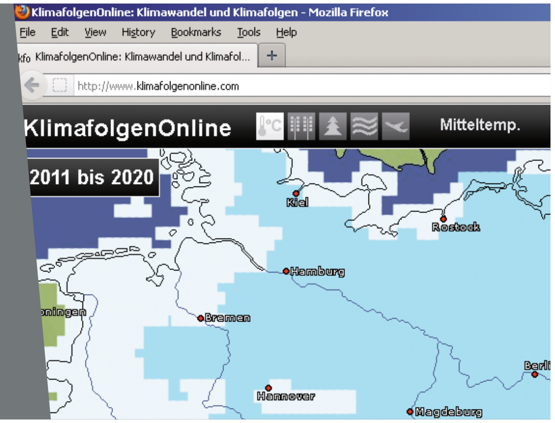


Climate change and climate impacts presented coherently

The consequences of climate change are not yet widely known. How can these impacts be presented to the general public? How can one simultaneously make available key information to specialist users in the private and public sector? And how can such information be successfully disseminated to a wide audience?



Numerous individual studies on climate impacts in Germany have been prepared by various institutions. These studies differ in terms of their aim, region and time period of interest. The goal of ClimateImpactsOnline is to present the regional impacts of global climate change on hydrology, agriculture, forest, energy, tourism and health sectors.

The results as prepared by the Potsdam-Institute for Climate Impact Research (PIK) are available at multiple scales in space and time. By using a standardized foundation, this approach will facilitate a new level of synthesis describing the interactions between sectors.

In the meantime, climate change is widely known but there is often uncertainty about the specific effects. One of the key tasks, therefore, consists of not only discussing the impact of climate change in specialist groups, but also presenting these to a wider audience. In that respect, decision-makers in the public sector in particular but also directly affected professional groups should be able to simply obtain information.

These groups are not made up of specialist scientists. This gives rise to two challenges:

- The information must be presented such that it is commonly understood.
- Access to the information must be easy. Interested parties do not have time to familiarize themselves over a lengthy period, but rather want to immediately work with the information.

In particular, potential users do not want to have to put together long-winded information from various sources, and even possibly have to go to great lengths to link them.

Two strong project partners

To satisfy this requirement, Potsdam Institute for Climate Impact Research (PIK) and WetterOnline have jointly developed an internet portal that is easy to use, groups together interesting information about climate impact and offers it in a directly usable form. The two project partners complement each other perfectly. The PIK has expertise in climate change and climate impacts, while WetterOnline has a wealth of experience in providing weather data to the general public.

A strong portal

The ClimateImpactsOnline portal for Germany will be available from 1 December 2012 at ***www.KlimafolgenOnline.com***

The sole precondition for using the internet portal is an up-to-date internet browser. Anyone can use the portal. Administrative or technical hurdles have been dispensed with (registration or plugins for the browser are not required). The information is available to users free of charge.

The stated aim is to win over the largest possible number of users – it is envisaged that all members of the general public who are interested can access it.

CLIMATE IMPACT AS CONTENT

ClimateImpactsOnline provides information about climatic changes such as changes in temperature, precipitation or solar radiation. However, the key element is the fact that information about the consequences of climate change is available at the click of a mouse.

A farmer can consider local information about temperature and precipitation changes regarding his field and accordingly directly consider the effects on income for the various crops or the harvest risk. Data no longer needs to be collected from various sources and matched with the local territory – a click of the mouse is now all that is required.

Specific information is made available about the climate, agriculture, forestry, hydrology and other (tourism, energy) sectors.

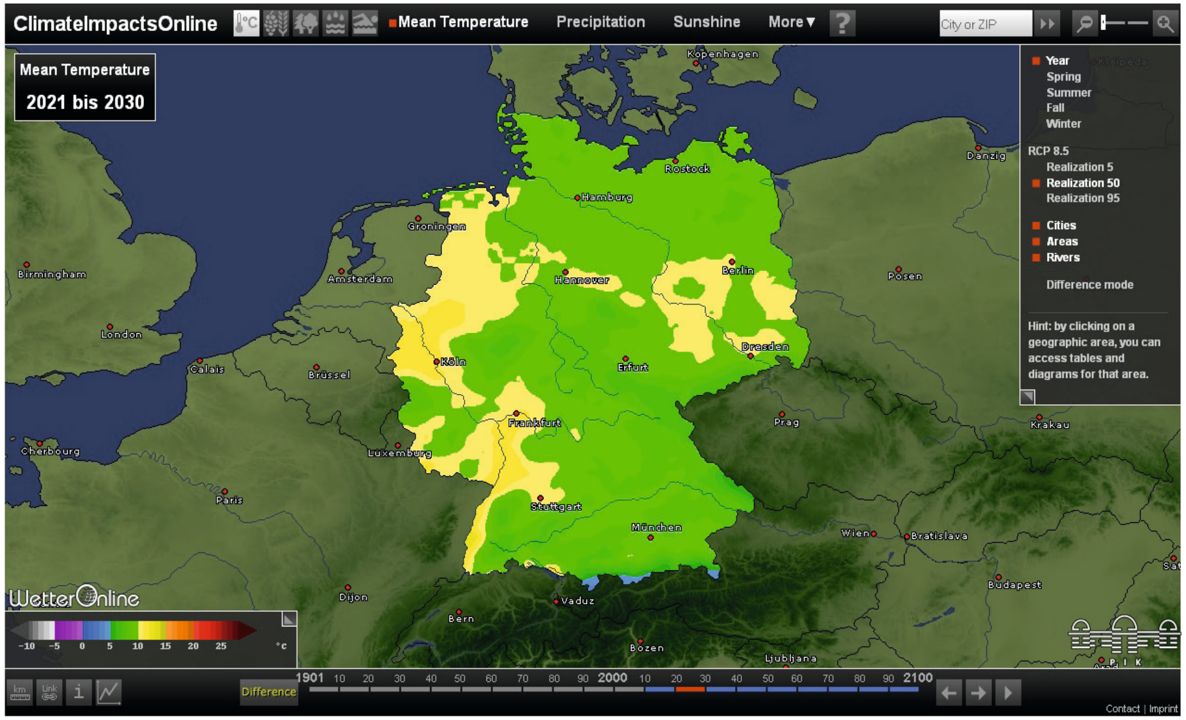


Figure 1 Colour maps:
The geographical distribution of various parameters, such as mean air temperature, is illustrated in maps.
Various enlargements are planned to provide a good overview of Germany, the German Federal states or districts.

In that respect, detailed information can be viewed in various formats depending on which illustration is best suited for the specific question:

- Colour maps (Figure 1) to illustrate the variations, for example of mean air temperature, in Germany,
- Tables to consider various parameters which, for example, are relevant to tourism, for a certain decade for a German Federal state,
- Series graphs (Figure 2) to show the development over time, for example of the yields of crops for selected destricts.

GUIDELINES – LOCAL OR THROUGHOUT GERMANY

Various users have different viewpoints on climate impacts. While a forester is interested in the local woods, an employee at a German Federal ministry deals with forests throughout Germany.

Therefore, the portal provides information about the whole of Germany, the individual Federal states or districts. In that respect, catchment areas or partial catchment areas of rivers are proposed for the hydrology sector.

A powerful search function facilitates the identification of these areas in the portal (Figure 3). For example, the search function proposes various candidates even while the user is entering the name of a city. Users can select a city with the click of

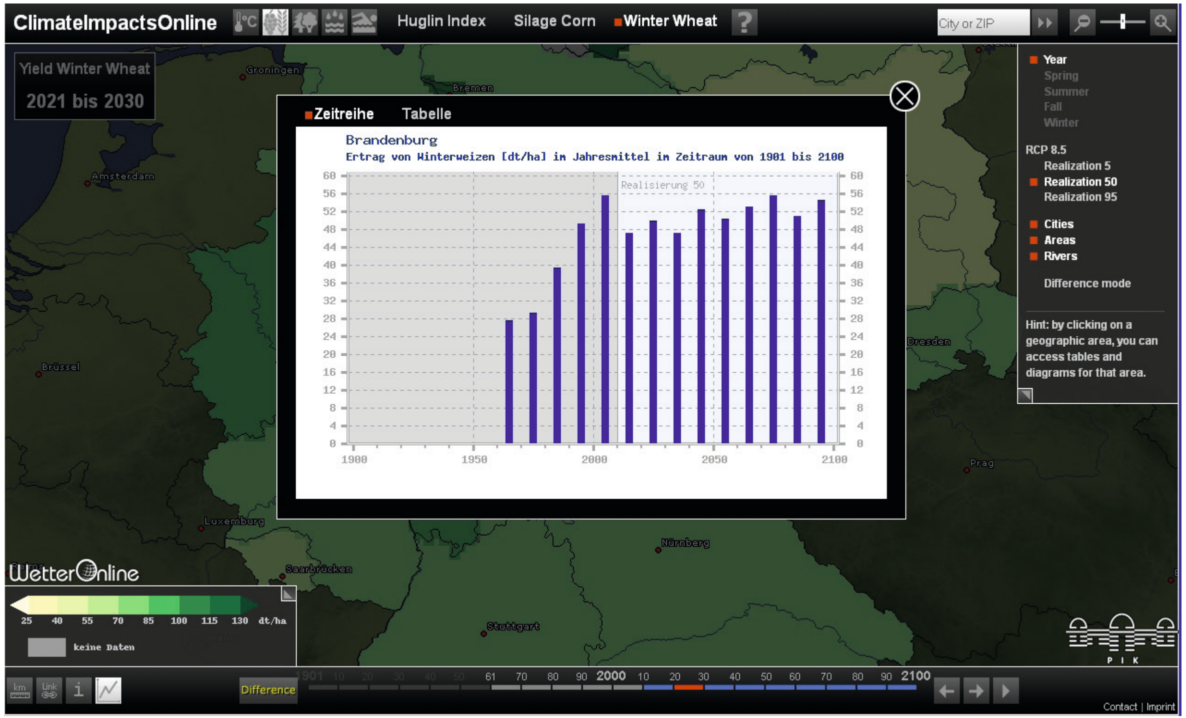


Figure 2 Series graphs:
Illustration of the development in terms of time of climate impacts in diagrams for the whole of Germany, for the individual Federal state and for each district

a mouse and will be directed to the surrounding district or partial catchment area.

Features such as rivers, cities or borders of German Federal states are displayed on the charts. In that respect, the information density of the current resolution of the chart is adjusted so as to avoid too many elements covering the relevant facts. Users can also remove features that are currently not of interest.

OVER TIME

However, not only are spatial features important, time is too. In that respect, the constantly visible time bar allows the displayed decades to be quickly amended, and at a glance identify which decades are currently displayed. If the user is interested in the difference between two decades, these are also marked in the time bar and can be easily shifted. This is accomplished through the option of displaying animations to consider the development over a period of decades.

VARIETY OF INFORMATION, BUT EASILY ACCESSIBLE

The wealth of information (for various locations, parameters, decades and scenarios etc.) runs the risk of overwhelming the user with choices. Therefore, great importance was attached to keeping the many options set out in a clear manner where possible. Decades, scenarios, illustrated geographical information, notification intervals and parameters can be selected independent of each other and in a manner that is easy to understand. There are very many parameters. Therefore, they are grouped together in sectors with related topics: Climate, Agriculture, Forestry, Water and Others (including Tourism and Energy) to increase the sense of clarity.

To make it easier for users to classify information, supporting texts are available that can be called up on a context-sensitive basis. Therefore, finding an explanation for individual parameters is easy. However, general information about the portal and the data method is also available.

EXCHANGING IDEAS WITH OTHERS

If a user has identified something of interest he can easily share it with others. By clicking on the mouse he can access a link with which he can notify others, for example by e-mail or social media. The recipient can view the portal in exactly the same mode in which the sender viewed it – same map sections, same parameters, same scenarios, where applicable the same diagram or the same table. This is a great help when exchanging ideas because there are no complications in having to describe how information is accessed. Instead a simple link is sent. Such links can also be set up on other websites, and then refer to ClimateImpactsOnline. On the one hand, this means those visiting other websites can access certain information. On the

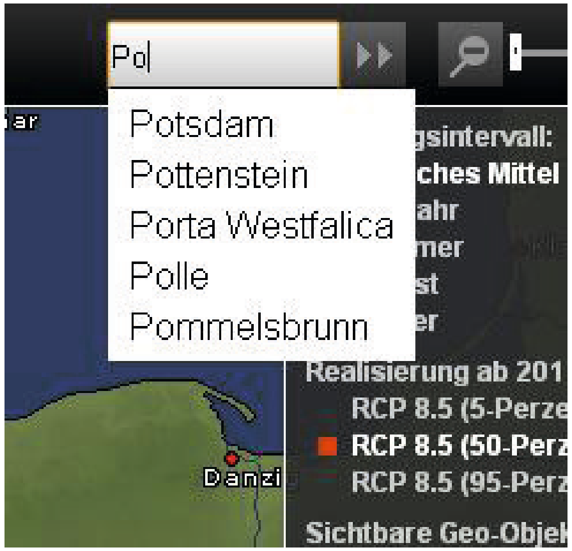


Figure 3 Easy search:
The search function automatically provides proposals even as data are entered

other, such visitors can explore the content of ClimateImpactsOnline themselves to obtain further information. This promotes an understanding of the correlations between climate change and its consequences.

GLOBAL FUTURE

Climate change and its consequences are global. Even though KlimafolgenOnline.com focuses, in particular, on Germany, it is already geared towards application for other countries.

This starts with the portal being accessible in several languages. For now, only German and English are available, but more languages can be added with little labour input.

The portal can easily present data for countries other than Germany, including outside Europe. The technology that forms the basis of the portal was designed with international use in mind. WetterOnline incorporates its experience with foreign weather portals, for example for China.

The Climate Sector

What was the climate like in the 20th century?

What is the nature of the current climate?

How can we look to the future?

How will the future climate develop in Germany?

The fact that the climate changes, and constantly, is common knowledge. The interesting question behind it is: at which location, in which time and with what degree of intensity do such changes occur? Such statements can be made quite accurately for the past. Climatologists' tools include ice cores, sediments, tree rings, records and measurements that are used to obtain the information in that respect. Of course only the evaluation of observation data is meaningful in respect of the question of current climate development. If we want to look to the future, on the one hand we need a model that precisely illustrates the past, where possible, and can simultaneously calculate future developments. On the other we need plausible projections for the future development that are incorporated in the model (e.g. the CO_2 development). Models will always only provide a limited illustration of reality, and not record all the features of the original (in this case those of the physical condition of the atmosphere). Therefore, we do not make a forecast for the future, but rather a scenario. This means that a scenario is the draft, considered or calculated by way of certain projections, of a situation or an expected development. Any number of scenarios can be considered. This automatically poses the question of which of the scenarios is the „right one". In principle, this question cannot be answered. The scenario by way of which a certain question can be answered is normally selected. For example, if we want to know what may occur in the future climate development in an extreme case, or how the climate reacts when certain measures are adopted? Or merely the median circumstances during the next few decades of interest?

The first question is: how did the climate in Germany develop between 1901 and 2010, and how will it develop further between 2011 and 2100 if we make certain scenario projections? The resulting outcome will, in turn, provide the basis for the second question: what influence does climate change exert on agriculture and forestry, on the hydrological situation or on the energy industry?

THE DATA

Germany has a very dense network of meteorological stations of which a relatively large number have been in operation since the start of the previous century. Building on this, a complete and homogeneous data set has been prepared of daily values for the period 1901-2010 for all available climate and precipitation stations. Recordings include air temperature (daily maximum, mean and minimum), the daily total of precipitation, the sunlight duration and the degree of overcast skies with clouds. On this basis monthly values, annual values and values for decades were calculated, which were then interpolated on a grid of 0.11° x 0.11°. The ten-year average (or totals) from the records of all stations located in the respective Federal state (and by the same token the German average) was used for the statistical description of the spatial structure for the German Federal states. The data of the stations in the surrounding areas were interpolated to central points of the individual districts.

STARS MODEL

The STARS model (STatistical Analogue Resampling Scheme) (Orlowsky et al. 2008) is a statistical regional climate model. It calculates regional climate projections of daily meteorological variables for the next 60 to 100 years. The model uses historical observations from weather stations and a prescribed future trend of a meteorological variable (in this case the annual mean of the air temperature, spatially distributed in the area of interest) in order to assemble a new meteorological data set that fulfils the trend prescription. Observed meteorological data associated with the trend variable are maintained so that the temporal and spatial consistency in the future data set is assured. Because of the very modest demands in computational resources, the STARS model is able to

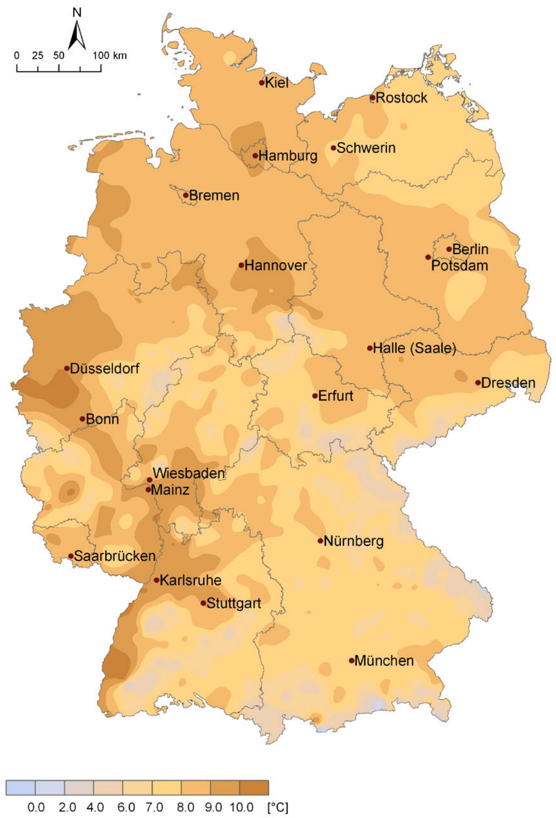


Figure 4
Annual mean air temperature, Germany 1901-1910[1]

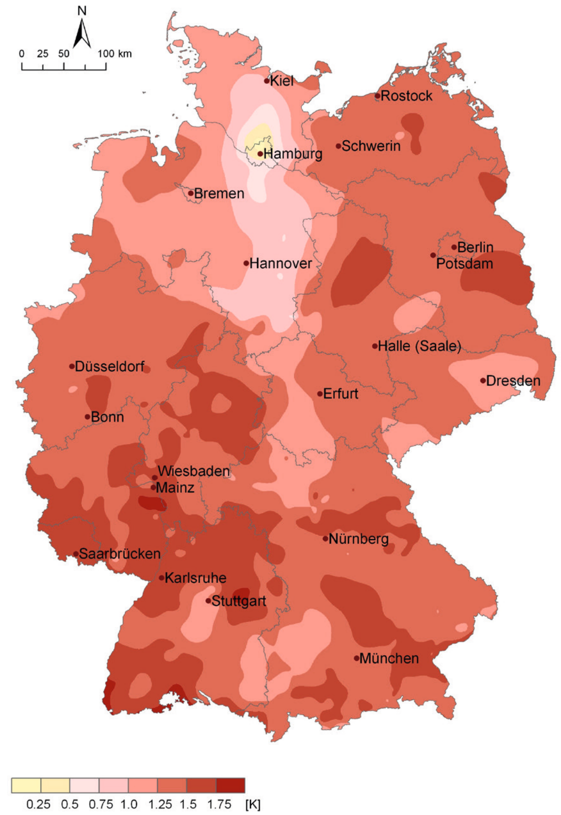


Figure 5
Differences in annual mean air temperature in Germany between the periods 2001-2010 and 1901-1910

[1] All periods in the diagrams of the chapters were selected on a different basis to highlight the time range of the overall assessment

simulate a large number of such data reassemblies, called realizations, for a given future trend of a meteorological variable. This allows the uncertainty of the simulations to be assessed. A detailed description of the STARS model can be found in the publication referenced below.

Based on the assumption that climatic conditions in the near future will not be very different from conditions that have been observed in the past, it can be assumed that past weather situations will occur again in the future, or that a future weather situation will be similar to past ones. The task of the STARS model is to find those weather situations and rearrange their time sequence in such a way that it results in a plausible climatic development. The larger the number of past observations, the better the result.

In a first step, the station data from the observation period are re-arranged by means of a random number generator in such a way that the resulting mean annual air temperature fulfils the prescribed temperature trend as accurately as possible. The first realization of the scenario is successful if this rearrangement of the data „hits" the trend exactly. This is usually not the case and the simulated temperature trend needs to be adjusted in line with the prescribed trend. This is done by exchanging so called „data blocks" within the simulated future years. The „blocks" are mean temperature data for

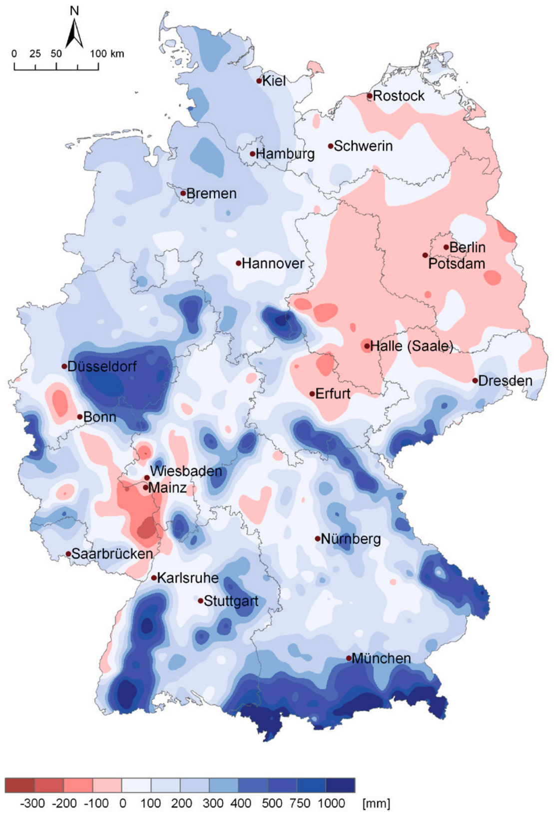


Figure 6
Mean annual total of climatic hydrological balance 2001-2010

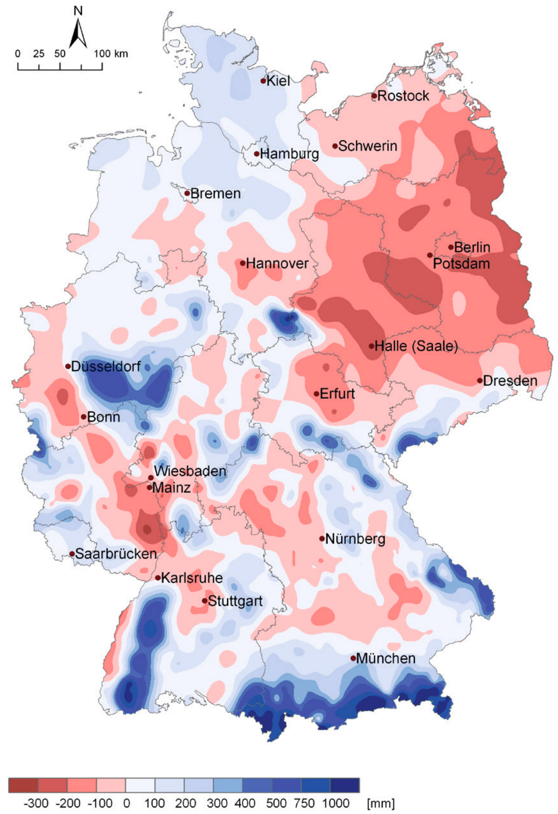


Figure 7
Mean annual total of climatic hydrological balance 2041-2050

12-day time periods, grouped by means of cluster analysis according to their temperature characteristics. This data exchange allows the mean annual air temperatures of individual years to be adjusted in such a way that the future temperature trend is reflected by the simulations as closely as possible. The procedure is carried out in an iterative manner in space for certain reference stations until the temperature trend is reflected with a prescribed accuracy. The reference stations are preselected, also through cluster analysis, and represent the climatology of a subregion.

Every „data block“ is tied to an actual date in the past. The STARS model delivers a time sequence of dates in addition to the temperatures for each realization. The meteorological variables other than air temperature that are associated with those dates are also attributed to the future data. This procedure ensures that the meteorological data for each realization of the scenario are consistent with respect to observations.

If the corresponding data basis is available, the model can be used in almost all areas of the world (at present model trials are under way in South and East Africa, China, South America and Europe).

Therefore, the STARS model is suitable as a data supplier for a variety of regional models for estimating the climate impacts. However, the model cannot be used for solving questions regarding the development of physical processes in the atmosphere. In that respect, climatologists rely on the regional dynamic models.

SCENARIO SELECTION

For the Fifth IPCC assessment report, new scenarios were crafted to be used in the medium term as successors to the SRES scenarios.

In contrast to the SRES scenarios, these new scenarios are not prepared by the IPCC (Intergovernmental Panel on Climate Change) but rather by the scientific community in self organization. In a first key step, Representative Concentration Pathways (RCPs) with coupled energy-economics-climate-land use models (called Integrated Assessment Models) were developed. These models include all drivers for anthropogenic greenhouse gases and transfer these into consistent scenarios of future emissions and the accompanying radiative forcing.

There are four different pathways altogether, three of which are characterized by anthropogenic radiative forcing of 8.5 W/m² (very high), 6 W/m² (high) and 4.5 W/m² (medium) in the year 2100. In the fourth pathway the (relatively low) anthropogenic radiative forcing reaches a maximum of 3 W/m² before 2100, and after that declines again.

Depending on the RCP selected, global climate models simulate new projections of the possible change of the climate in the 21st century and beyond. In addition to the development of RCPs and climate predictions, the scenario process, as suggested by the scientific community, also comprises a series of other components that particularly concern and support the integrated assessment of prevention, adaptation and climate impacts.

In ClimateImpactsOnline, the impacts of the RCP8.5 CO_2 emissions scenario are presented (Meinshausen et al. 2011). Although the RCP8.5 scenario was ranked by the IPCC as extreme at its inception, it is used here since, of all the IPCC emissions scenarios, it matches the current development of CO_2 emissions most closely. If the trend in actual CO_2 emissions since the year 2006 should continue, the CO_2 emissions will be even higher than assumed in the extreme scenario.

This gives rise to a spatially differentiated temperature increase for Germany of between 3.6°C and 4.1°C in the period 2011-2100 if one takes the scenario series of the global models that are currently available as a basis.

At this point, attention is again expressly drawn to the fact that the results of the scenario calculations for the period 2011-2100 are not a forecast in the customary sense, but rather constitute a potential future under the given underlying conditions.

THE RESULTS

Two examples are used to demonstrate what has changed in Germany in terms of climate, and what is to be expected on the assumption of the scenario RCP8.5 by 2100.

The first example documents the temperature development between 1901-1910 and 2001-2010. Figure 4 shows the spatial distribution of the annual mean temperature for the period 1901-1910. If the mountains are not taken into consideration, the annual mean temperature in this period is roughly between 7°C and 12°C depending on the region. In that respect it is clear that the Upper Rhine Valley and the Cologne basin are the warmest regions in Germany. Figure 5 shows the temperature development up to the decade 2001-2010, and for Germany states a temperature increase between 0.25°C and 2°C. Therefore, the temperature development in Germany is following the global warming that is currently unfolding.

The second example shows how the climatic hydrology balance, which is the difference between fallen precipitation and calculated evaporation, will develop up to the period 2041-2050. Figure 6 illustrated the current means (period 2001-2010) for the climatic hydrology balance. Negative values are found in large areas in eastern Germany and in a strip along the Rhine that spans the north eastern end of the Upper Rhine Valley to the Cologne basin. Figure 7 illustrates the climatic hydrology balance for the period 2041-2050. At first glance it becomes apparent that the territories with a negative climatic hydrology balance have increased significantly. In some regions the values have dropped by up to 300 mm.

The two examples show that significant climate changes have occurred in Germany since the start of the 20th century. If the development continues as is assumed in the case here in the scenario RCP8.5, the climatic changes to be expected will increase considerably.

The Hydrology Sector

How will climate change impact the hydrological processes and water resources in the various regions in Germany up until the middle of this century?

The water budget of a landscape is directly linked to the regional climate and, therefore, is highly sensitive to changes in the climatic conditions. The key influencing factor is, naturally, precipitation. Evaporation is of similar significance to the local hydrological balance, in particular in the dry regions, for example in many areas in eastern Germany.

As a result of the increase in temperature the precipitation quantities and distribution may change on the one hand. On the other the evaporation is stimulated by way of the additional energy and because of an extension of the vegetation period and a resulting increase in water requirements of plants. Both then exert an influence on the regional water budget (Hattermann et al. 2011).

SWIM MODEL

The effects of climate change on the hydrological processes and the water resources are estimated based on the climate scenarios and with the help of the SWIM model (Krysanova et al. 1998).

SWIM (Soil and Water Integrated Model) is a temporally continuous, semi-distributed watershed model. It integrates hydrological processes, vegetation growth, erosion and nutrient dynamics (nitrogen and phosphorus) at the river basin scale on a daily time step. The spatial units are sub-basins, which are derived from digital elevation data. The sub-basins are further subdivided into hydrotopes, defined as hydrologicaly homogeneous units with uniform land use and uniform soil properties. The model is linked to meteorological data, land use data, soil information and information on land management activities (such as crop rotation, fertilization).

RESULTS

Figure 8 shows the area-wide change in evaporation, the total formed runoff quantity (total surface and interim runoff and recharge) and the recharge. Evaporation increases at all locations where, under scenario conditions, enough water is available since more energy is available under warmer conditions. Plant growth also occurs earlier in the year and lasts longer into late autumn, as a result of which the water consumption of the vegetation may increase significantly. The impact on the local runoff formation is particularly strong where changes in the evaporation and in the precipitation are additive. The recharge is diminishing regionally because only the water that either has not run off on the surface or has not been absorbed by plants enters the groundwater. Under these conditions the groundwater table may drop considerably depending on the region and distance to the nearest surface groundwater.

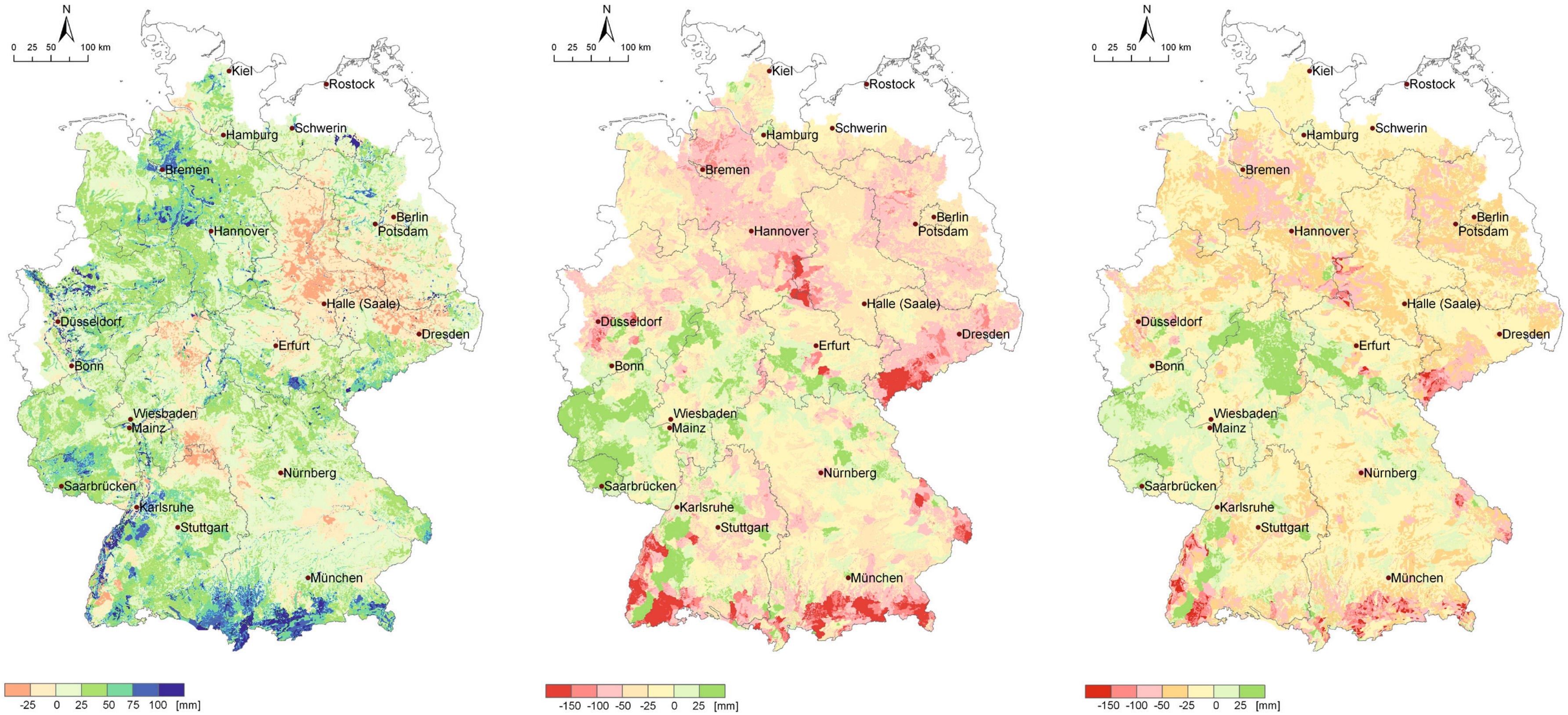
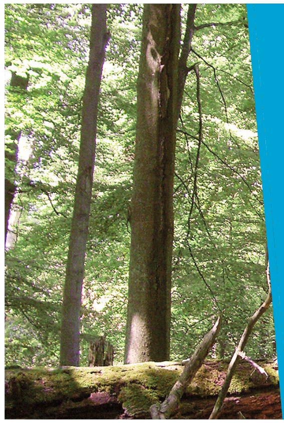


Figure 8
Area-wide illustration of the change in the annual totals for evaporation (left), the total runoff (middle) and the recharge (right), by comparing the averages for 1991-2010 and 2031-2050 for the major river catchment areas



The forest sector

How will Germany's forests grow? What risks are associated with the expected climate change? Answers to these questions are of importance to forestry to maintain the sustainability of the forests. However, they are of interest to all citizens who appreciate the functions of the forests.

The forests in Germany, and the associated forestry industry, perform a series of important functions in society and in the landscape. Wood and non-wood products, a varied recreational area and living space for animals and plants are made available. Furthermore, they play a part in erosion and avalanche control; they protect the global, local and regional climate; they function as a noise filter, dust filter and reduce pollutants, and not least provide a source of employment.

Forests are a source and a sink of carbon. They provide the most far-reaching CO_2-neutral building materials and substances and the regenerative energy source wood. In view of the expected climate change, the forests are assigned a special role because they are influenced by the climate changes, but also provide options for adapting to and avoiding the impact of climate change.

4C MODEL

The impact of climate change on forests in Germany will be analysed by using the climate scenarios delivered by STARS and the forest growth model 4C developed by PIK (Lasch et al. 2005).

The model 4C (FORESEE - FORESt Ecosystems in a Changing Environment) is a physiologically-based forest growth model which describes the establishment, growth and mortality of tree cohorts (Lasch et al. 2005). Productivity and growth are simulated for cohorts of trees of the same species, tree dimensions (height, diameter at breast height) and age. Competition among trees for light, water, and nutrients affects growth, mortality, and regeneration in the forest stand. The water, nutrient, and carbon budget of the forest stand is computed daily as a function of soil conditions, stand characteristics and weather data. The model has been validated for the main tree species in Germany: beech (*Fagus sylvatica* L.), Norway spruce (*Picea abies* L. Karst.), Scots pine (*Pinus sylvestris* L.), oaks (*Quercus robur* L., and *Quercus petraea* Liebl.), and Douglas-fir (*Pseudotsuga menziesii* (Mirb.)) at different forest sites (Level II sites in Germany and EUROFLUX sites in Europe). It has been used in various regional studies in Germany as well as BMBF and EU projects.

RISKS FOR THE FORESTS

Increasing temperatures, coupled with diminishing precipitation in the spring and summer months, may significantly change the climatic conditions regarding the risk of forest fires. An index developed by H. Käse (1969) has been calculated for the climate scenario to prove this. It expresses the climate-related risk of forest fires, and was used in a similar form as a forest fire risk index by Deutscher Wetterdienst to forecast the daily risk of forest fires from March to October. At all stations for which the climate scenario RCP8.5 was created, this index was calculated annually for both the current climate and the scenario periods, and determined over the corresponding period (Figure 9). In the area now demonstrating the highest climatic forest fire risk, the Northeastern German Lowland, in particular Brandenburg, the climatic forest fire risk increases by up to 16 percent, and therefore particularly significantly. The lowest change occurred in the areas currently demonstrating low forest fire risks, such as the Alps, in part the Alp foothills and northwestern Germany. The spread of the regions with a median index in excess of two increases significantly in the northeast and southwest, above all in the area of the Upper Rhine Valley.

This projection of the climatic forest fire risk need not necessarily give rise to greater damage as a result of forest fires. They may be high where other conditions favour forest fires, for example pine mono-cultures and very dry site conditions. Otherwise, ever more modern methods of combating forest fires are being applied, for example the forest fire early warning system „Fire Watch“ in Brandenburg.

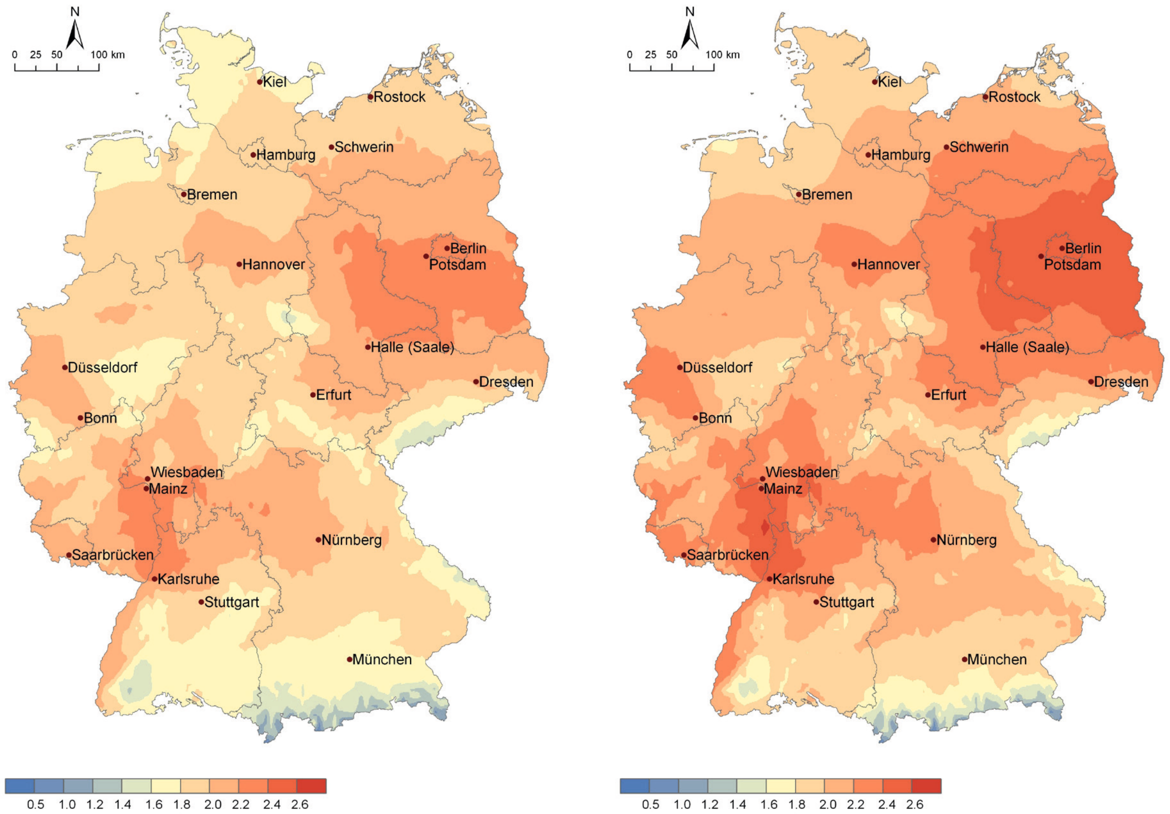


Figure 9
Climatic forest fire risk index, calculated and averaged for 1991-2010 (left) and 2031-2050 (right)

Effects of climate change on agriculture in Germany

How will climate change alter the natural preconditions for agricultural production in Germany? Is a climate-related decline in agricultural production to be expected?

Like in all parts of the earth the agricultural production in Germany depends on natural conditions and reacts to these. Their productivity is determined by the temperature and water condition, and by the soil. On the other hand, the intensity of agriculture, for example as is reflected in the use of fertilizers, exerts an influence on the soil, the water quality as well as the climate.

As of 2007, Germany had 11.8 million hectares of arable land, representing 70% of the total agricultural area (DESTATIS 2012). The major crops are winter wheat and maize (BMELV 2012). The risks to yield due to climate change for these critical winter and summer crops, respectively, are calculated with the IRMA statistical model, using the RCP8.5 scenario.

Another emphasis of the agricultural sector is the impact of climate change on phenology and its influence on the quality of grapes. Phenological parameters such as bud burst, flowering, veraison (onset of ripening) and harvest, as well as parameters that characterize the suitability for growing grape varieties specified by their temperature demand, are estimated.

IRMA MODEL

Agricultural yield predictions were developed using IRMA (Integrated Regional Model Assessment). A regression equation was calculated for every administrative district (Landkreis) to assess the effect of weather parameters within specific yearly time periods on yield changes. With the mean of the observed yields from 2001-2010 as a basis, the simulated yield differences from 2012 onwards were used to calculate the wheat and maize yields per district. Aggregations were then undertaken to the level of German states.

RESULTS

Within a warmer climate the potential transpiration of plants will increase. Even if the annual rainfall maintains the same level, the climatic water balance as the difference between rainfall and potential evapotranspiration, will degrade, especially during the main growing season (May – October).

This may lead to stress for summer grown plants like maize, summer barley, potatoes and sugar beets, especially in these areas in Germany where the water availability is limited by lower water balances as in most parts of eastern Germany. Decreases in maize yields therefore may be expected in these regions, such as the German states Brandenburg and Sachsen-Anhalt and differences in maize yields among states might become clearly recognizable (Figure 10).

Agricultural crops which are grown for longer periods like winter wheat, winter barley and rape seed will be less influenced by the decreasing water supply in summer. The crops might profit from increased precipitation during the winter season. The simulations show rising yield potentials in future decades for winter wheat.

Due to increased temperatures and sunshine hours as indicated by the STARS 8.5 scenario the production of grapes may be extended in Germany and the quality of wine may be enhanced. Simulations of a temperature index which describes the suitability of different grape varieties, the chances of growing white grape varieties like ‚Riesling' will shift to northern locations.

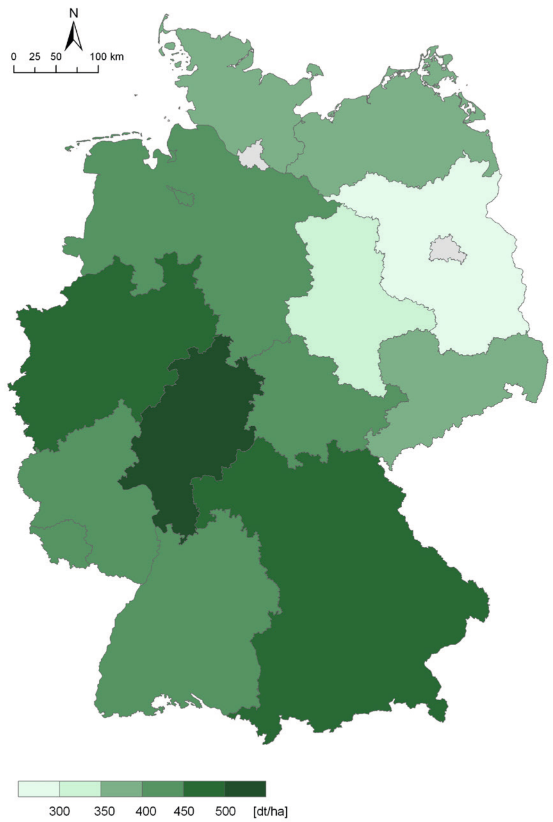


Figure 10
Simulated mean maize yield from 2041 to 2050 by counties

ClimateImpactsOnline portal – presentation of results

The following table lists the sectors of the ClimateImpactsOnline portal and the presented variables.

All variables have been condensed to annual mean, minima and maxima values averaged over decades.

Sector	Climate	Hydrology	Forest	Agriculture	Health, Energy and Tourism
Realized variables	Air temperature	Groundwater recharge	Climatic forest fire risk (developed by Käse (1969))	Wheat and maize yields per district	Annual number of hot and humid days
	Precipitation	Surface runoff	Bud burst for the main tree species in Germany	Huglin index (characterizes the suitability for growing grape varieties)	Potential number of bathing days
	Air pressure	Evapotranspiration		Bud burst of grape	Photovoltaic potential
	Relative humidity			Flowering of grape	
	Incoming solar radiation				
	Water vapour pressure				
	Sunshine duration				
Planned variables	Information on the uncertainty of the presented results, simulation of realizations for additional scenarios, presentation of event days, Walter-Lieth diagram for administrative units	Floods and low flows at selected discharge gauges	Species-specific annual drought stress index, species-specific annual net primary productivity for the main tree species in Germany, mean values and frequencies of forest fire danger classes	Yield and yield risks for more crops	Wind energy, Hydro-electric power

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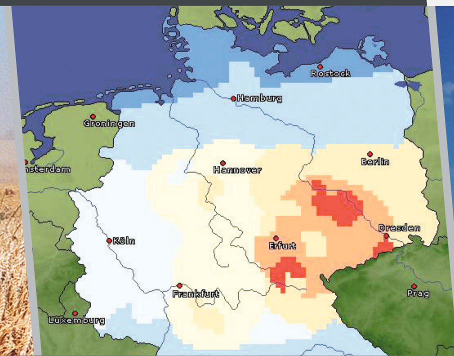

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