CEDR Transnational Road Research Programme
Call 2012: Road owners adapting to Climate Change

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Climate projection data base for roads: CliPDaR

Guidelines on ensemble climate projection data

Deliverable D 2.2

The **CliPDaR** Consortium:

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CEDR TRANSNATIONAL ROAD RESEARCH PROGRAMME
Call 2012

Design guideline for a transnational database of downscaled climate projection data for road impact models – *CliPDaR*

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Executive summary

Within this report the so-called 'ensemble approach' is introduced and discussed. A classification according to practical criteria is done, which is explained on the basis of examples. The application of the concept is demonstrated within the field of transport infrastructure and some additional thoughts are presented at the end of the report.

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1 Preliminary remark

Concerning the CEDR Call 2012 "Road owners adapting to Climate Change" the Project CliPDaR ("Design guideline for a transnational database of downscaled climate projection data for road impact models" (long title)) refers exclusively to the objective "A.1 – Review, analysis and assessment of existing (regional) Climate Change projections regarding transnational highway networks (TEN-T) needs". Regarding the questions of this objective the project CliPDaR is engaged in

- Assessment of statistical/dynamical downscaling: to facilitate a proper procedure that deals with the uncertainties of the future climate with respect to the needs of future budgets and maintenance issues

- Assessment of ensemble simulations and climate projections as well as the definition of a pragmatic data provision for decision making

- Assessment of return periods of e.g. cold winters or hot summers.

Because of the given short time line a provision of data is not foreseen within the frame of this project and emphasis is given to the results from already ongoing projects, in particular VALUE and KLIWAS, to contribute to a paper of recommendations for the involved national road agencies.

The mission of CliPDaR is creating a design guideline setting standards for the handling with climate change data and downscaling methods used in pan-European traffic infrastructure risk assessment.

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2   Introduction

2.1 The nature of General Circulation Models

Figure 1 is a constant companion of the CliPDaR reports. This report focuses on the third and fourth column. In this context the main focus is on the uncertainty involved in the derivation of local scale climate change projections driven by large scale models, i.e. Global Circulation Models (GCM), which are the basis for impact assessment. To discuss the ensemble approach, which is the aim of this report we have to highlight some of the main features of GCMs first. GCMs represent the climate system in a virtual world by describing the states of its components and their controlling processes. As elaborated in D1.3 GCMs solve physical equations on three-dimensional grids representing the atmosphere and the ocean. These grids typically have a width of hundreds of kilometres in the horizontal and consist of several dozens of vertical layers (down into the oceans and up into the atmosphere). Due to the coarse resolution, sub-grid scale processes, for instance related to the hydrological cycle in terms of convective precipitation and evaporation or river runoff, are not explicitly solved but parameterized. This means that too small or complex processes are replaced by simplified mechanisms, which are accounted for in the equations. Examples for such processes are the radiative energy transfer through the atmosphere, cloud-forming and small scale processes caused by complex topography.
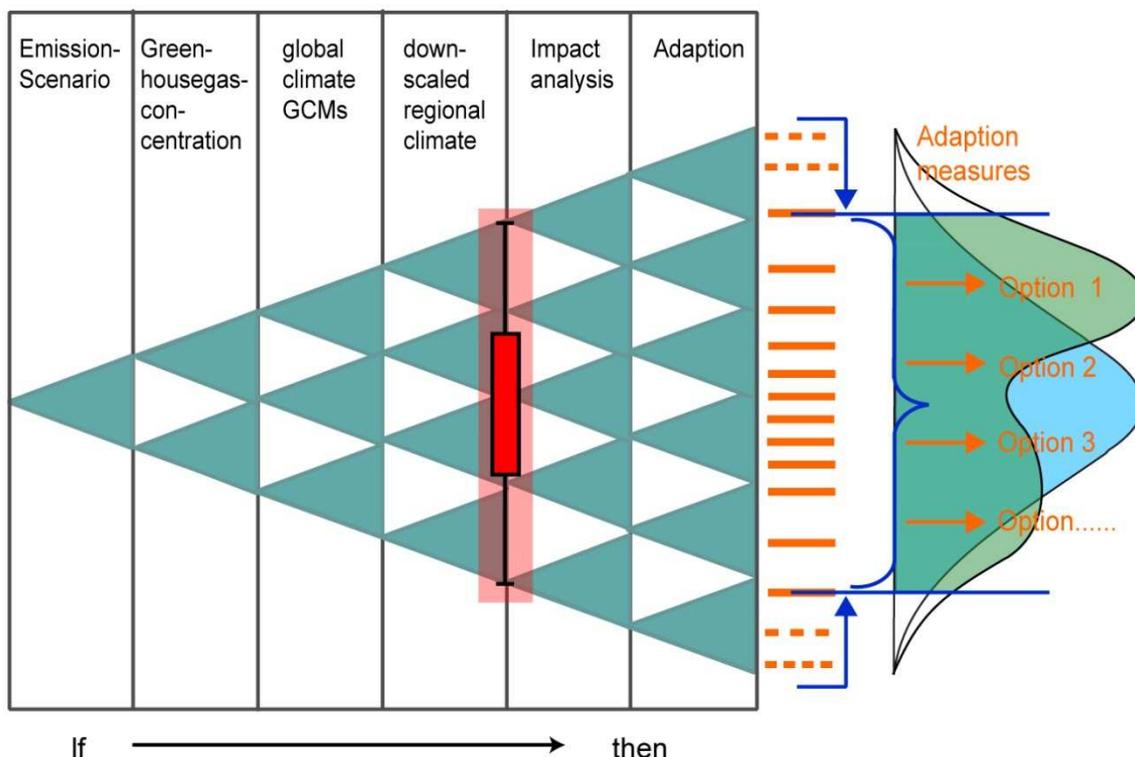
Figure 1: *Starting from a particular emission scenario (see deliverable D1.1) the uncertainty grows with every step that is necessary to derive different adaptation measures to mitigate the impact of climate change (schematic diagram). Source: DWD, after Viner 2002.*

GCM simulations are carried out to gain knowledge about future climate states, to model the climate of the past, to better understand the functioning of the climate system or to further improve the models themself. The most popular application of GCMs is the generation of future climate change projections driven by socio-economic scenarios describing possible emission pathways of mankind. These projections, however, come along with large uncertainties (as indicated in Figure 1) and have already been discussed in D1.2 or in Matulla et al. 2013.

3 The ensemble approach and the problem of internal climate variability

One important point is that GCM simulations depend on a list of factors. One factor is the already mentioned temporal uncertainty in the development of the forcing mechanisms. However, it turns out that also differences in the initial conditions the GCM simulations are started from have an impact on the evolution of the simulation. This is related to interactive coupling of the different components of the climate system, mostly important the interaction between the slow-varying ocean and sea ice with the more vivid varying atmosphere. This concept is widely known as internal climate variability. This means the state of the climate system can vary within certain bounds and albeit the states are different they all are the outcome of processes obeying the same physics (we will come later back to that, when discussing *the physical ensembles*).

3.1 Real-world analogue for the ensemble approach

In a certain sense Galton's board may serve (ii) as a simple example for this kind of behaviour; (ii) for the purpose of motivating the ensemble approach. Galton's board consist of quite some layers of pins. The pins of two successive layers are horizontally staggered by half the gap between the pins. On top of the Galton's board balls are tossed in and as they fall down they bounce left and right when hitting the pins. When they bounce right n times on their way down they will end up in the nth 'one-ball-bin' at the bottom. This experiment teaches quite some things about statistics, but here we focus on two things: (i) two balls that are tossed in almost the same way on top can end up in different 'one-ball-bins'. Albeit this is very different in complexity this may give a hint why after n calculation steps the state of the atmosphere is not the same for two simulations that were started from slightly different initial conditions. Second, it shows that a single ball dropped in on top of the board does not tell much about the probability to be in a particular 'one-ball-bin' (a single ball in a bin does not tell much about its probability to be occupied).

3.2 Classifications of the ensemble approach

As there is no such thing as 'best GCM' it is sensible to make use of a group of GCM projections when answering so called 'if-then' questions (see e.g.D1.3). Groups of projections are called ensembles. An ensemble of projections can help to display the range of results to be expected. It is known from experience that the mean of a multitude of experiments (e.g. measurements of a physical quantity) displays reality (e.g. the electrical resistance) in general better than a single experiment. Hence, it is common practice in climate research to consider the ensemble mean or the median respectively of climate change projections (driven by a particular socio-economic scenario) as the most probable reaction of the climate system to this scenario. However, every single projection is considered as a physically plausible state of the

climate system. Hence it is scientifically sound to consider the variance of the ensemble next to its average.

There are different kinds of ensembles depending on the physical problem to address. Three different types of ensembles used in the literature (e.g. Stainforth et al. 2007) are listed in **Table 1** are commonly used:

Table 1: *A proposal for a practical classification of different ensembles.*

'initial conditions vary'-ensemble	initial condition ensemble	Ensembles that fix the socio-economic scenario and the GCM but vary the initial conditions are used to assess the possible rage caused by the climate variability of a GCM. This is sometimes called an 'initial-conditions-ensemble'.
'models & initial conditions vary'-ensemble	physics and initial condition ensemble	In case just the socio-economic scenario is fixed but the physics as well as the initial conditions are varied ('multi-model initial condition' ensemble) the output describes possible reactions of the climate system to this particular pathway of mankind. Such ensembles are important to answer the question whether two particular pathways result in distinguishable reactions of the climate system. If this is not the case it is difficult to argue in favour of the pathway bringing more changes to societies.
'socio-economic scenarios & models & initial conditions vary'-ensemble	total ensemble	Ensembles varying everything: they make sense to picture the unavoidable or, in other words, the impossible/unreachable.

3.3 Tailoring ensembles

3.3.1 General remarks

To evaluate given uncertainties in the model chain (see Fig. 1) sufficiently, an ensemble of climate projections should be used normally. That means, that the user of climate projections should not trust in the results of only one climate projection, but in the analysis of ranges of possible states of the climate system using a greater number of climate projections. Based on this ranges, the most likely changes of relevant climate parameters can be deduced from the used ensemble. Because a set of climate projections does not necessarily span the full possible range of uncertainty, a chosen ensemble is also denoted as a "collection of models" or as an "ensemble of opportunity" (Kreienkamp et.al. 2012). Therefore all the GCM-RCM-combinations of a chosen ensemble have to be listed e.g. in a Table which always has to be presented together with the results. In addition, all available impact models should be used to simulate the uncertainty on the "impact level".

If an ensemble consists of not more then eight members, the spread of the results - in combination with a reference based on monitored data - can be

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represented by all ensemble members with e.g. a 3x3-matrix of figures. If the chosen ensemble covers more than eight members, the span of the results should be illustrated by extremes, e.g. the minimal and maximal values, or by the representation of statistical properties of the ensemble. The averaging period must not be shorter than 10 years and, concerning the last mentioned case, the ensemble statistics can be represented by e.g. Box-Whisker-plots.

3.3.2 Integral view: Using percentiles

Thus, when using an ensemble approach, a multitude of different model combinations, i.e. GCM – RCM (Regional Climate Models), guarantees the statistically most reliable results. For example, if an ensemble consisting of 20 different combinations of global and regional models is used, the single outcomes of the ensemble members may vary considerably, e.g. maybe even variations from a future projected cooling to a future projected warming of the atmosphere. To overcome such kind of ensemble inherent uncertainties the statistical measures of percentiles can be used.

Given a data set that has been ordered in increasing magnitude, the median, first quartile and third quartile can be used to split the data into four pieces. The first quartile is the point at which one fourth of the data lies below it. The median is located exactly in the middle of the data set, with half of all of the data below it. The third quartile is the place where three fourths of the data lies below it.

If the data has to be split into more than just four pieces we can generalize the idea of a quartile to that of a percentile. The nth percentile of a set of data is the point where $n\%$ of the data is below it. If an ensemble of m members is used, then the finest splitting possible is $n\%=(100 \ k/m)\%$. Reflecting the above mentioned ordered data set in increasing magnitude, normally for the "outlier fraction" at the lower and upper bounds of the distribution ($1/m$ and $1-1/m$ resp.) a minimal number of $k=3$ ensemble members will be chosen. At least a number of $k=2$ ensemble members has to be requested. Thus an ensemble with a minimum number of 17 members "allows" calculating 15th and 85th percentiles.

Thus, percentiles are a good measure to quantify potential outliers in the model ensemble and furthermore lead to an increased confidence in the ensemble results. Therefore the ensemble should have a sufficiently number of members to be able to calculate as possible for the quite extreme 15th and 85th percentiles or for more "extreme" percentiles (e.g. the 10th and 90th percentile). In the case of 15th and 85th percentiles 70% of the investigated ensemble is covered between these two thresholds and can be understood as a range in which occurrence can be expected in this scenario.

3.3.3 How to reduce the ensemble volume

Provided that the time necessary for computing is reasonable, the application of a greater ensemble of regional climate projections should be preferred as input for

impact models. In cases were the entire volume of the chosen ensemble could not be used to his full extent, the ensemble has to be reduced in a determined and justified manner. This may be the case in projects of climate impact research for roads where the impact models may be too complex to be processed with input data given from all regional climate projection of the "greater ensemble". Therefore, a procedure for a justifiable, targeted reduction of the available ensemble of regional climate projections is desirable. As there exists no generally applicable method to reduce large climate projection ensembles and the selection always depends strongly on the underlying problem, we propose an approach of three steps (from A to C):

A - Decide for an emission-scenario and for climate projections which furthermore have been computed for the projection time period you want to investigate, normally the whole 21st century. As a third criterion, it is meaningful to choose projections which do cover your entire investigation area.

B – Define a so-called *integral parameter* as an outcome of used impact models (for road adaptation purposes - for example the road surface temperature), which can be used for the analysis of the spread of the available projections. Because adaptation strategies are normally developed on the basis of impact models (see Fig. 1) the integral parameter should be drawn from an impact model which is of central interest for the project or all subprojects. Because of computational time the impact model is consuming it has possibly to be simplified (e.g. by using a statistical model with e.g. multiple linear regression than e.g. a thermodynamical numerical model) before it is used for all climate projections from step A. Thus, the ensemble can be reduced further with respect to quantitative criteria (average, maximum, minimum of the chosen integral parameter in a near future time period 2021-2050 and a far future time period 2071-2100).

C – To evaluate the effect that individual elements exert on the model chain, it is appropriate to include combinations of GCMs/RCMs in the ensemble such that both one RCM is forced by more than one GCM and one GCM forces several RCMs (Fig. 2).

This "three step"-approach has been used in the recent joint research programme KLIWAS and will be presented here as an example. The greater ensemble could be stated in this example as "all available SRES-projections of the EU-FP7-programme ENSEMBLE":

a – From the pool of available climate projections only those have been included in the reduced ensemble of KLIWAS, which had been run on the basis of the emission scenario SRES-A1B, and which furthermore had been computed for the whole 21st century. As a third criterion, the projections have to cover the KLIWAS investigation area. A total of 17 regional climate projections was included in the ensemble with respect to these criteria (Table 2).

b – As integral parameter the average run-off Q was defined (an output of a hydrological run-off impact model).

c – At least four regional climate projections were extracted complying the rule "C" for the combinations of GCMs/RCMs (Table 2, column "Q")).

From a larger 17 member ensemble, in the project KLIWAS a new smaller ensemble was generated for special purposes under consideration of points (b) and (c) and, in addition, with the request of "doubling" step 'c' ending up by 8 members (Table 2, column "KLIWAS-8").
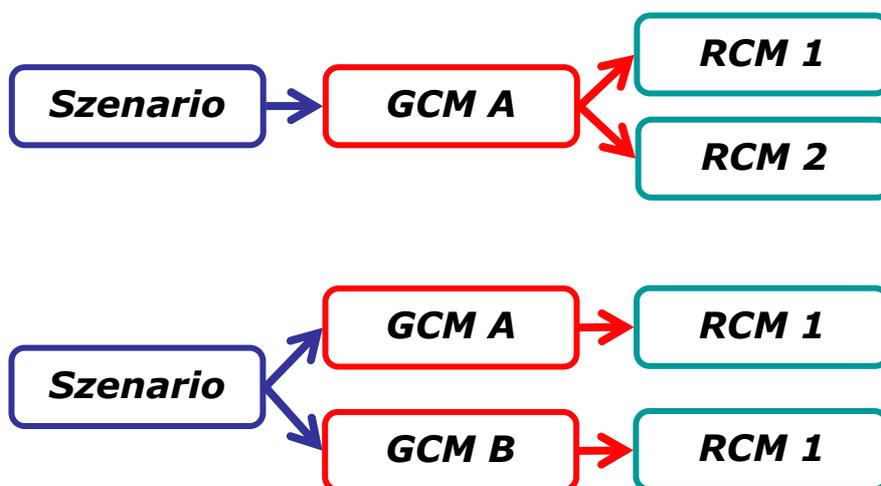
Figure 2: *GCM-RCM- Formation scheme for a „small ensemble" based on one emission-scenario*

3.3.4 Case study

Recently the available regional climate projections provide data with a maximal spatial and temporal resolution of about 25 km and daily values respectively. If it is necessary to use an impact model e.g. with hourly data then it might be that only one climate projection can be given. In this case no ensemble can be used to derive a span of possible impacts for developing adaptation measures and the project should be denoted as a *case study*. It is reasonable to compare the properties of the chosen climate projection, e.g. with regard to special climate indices, with the statistical properties of a greater ensemble.

If more than one impact model is available then they should be used to compute even a moderate span of results. This should be done to describe the uncertainty on the impact level with respect to the given model chains ("GCM-RCM-impact model_1..n").

Table 2: *Used climate projections for the analysis of the ensemble. The combinations of the global and regional climate models on the basis of the A1B-emissionscenario are represented. The examples for a reasonable "reduced ensemble" are given in columns 'Q' and 'KLIWAS-8'.*

SRES scenario	KLIWAS 17		reduced ensembles	
	GCM	RCM	Q	KLIWAS 8
A1B	ARPEGE	HIRHAM5 RM5.1		
	BCM2	HIRHAM5 RCA3		X
	ECHAM5r1	CLM2.4.11	X	X
	ECHAM5r2	CLM2.4.11		
	ECHAM5r3	HIRHAM5		X
		RACMO2	X	X
		RCA3		
		RegCM3		X
		REMO5.7	X	X
	HadCM3Q0	CLM2.4.6		X
		HadRM3Q0	X	X
	HadCM3Q3	RCA3 HadRM3Q3		
	HadCM3Q16	RCA3 HadRM3Q16		

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4 Added value of the ensemble approach and potential fields of application

4.1 Introductory Remarks

Ensembles of projections are important for planning and designing adaption measures as they attach probabilities to the extent of the changes and hence countermeasures can be considered. We will come back to that later when discussing the *added value* generated by ensembles of climate models. This discussion will include a further extension of the example of rutting, which was already introduced in earlier CliPDaR reports.

4.2 Potential field of applications

Before that however the above described different kinds of ensembles are introduced by examples. The first example shows the potential of ensembles to assign a cause to a particular effect (attribution). In this example the particular effect is the historical development of global temperature. Since the middle of the 19th century temperature measurements spread all over the planet are available on a sufficiently dense station grid to calculate the global average temperature. The 'global warming' debate which started in the outgoing 20th century was dominated by the question whether it is possible to attribute the observed warming to human activity or not. Due to the high complexity of the climate system, with its many exchange processes within and in between the components of the climate system, it was believed (even in the 1990s) that the human impact on the system will not emerge clearly enough from the noise to be detectable and attributable soon.

In 2001, however, the IPCC Third Assessment Report (TAR) presented Figure 2. It shows that the observed (red) temperature development (presented here as values relative to the mean temperature of the period from 1880 to 1920) can be properly reproduced by an 'initial conditions vary' ensemble only if natural and anthropogenic forcings are taken into account (rightmost panel). The ensemble driven by natural (solar and volcanic) forcings alone (left panel) clearly fails to reproduce the warming from the 1980s on, while the ensemble driven by anthropogenic (greenhouse gases, ozone and aerosols) forcings alone produces largest deviations from the 1940s to the 1970s (middle panel). This way an initial condition ensemble helped to assign the recent warming to anthropogenic activities by demonstrating that the observed temperature evolution can only be reproduced when taking anthropogenic and natural forcings into account. Here, each ensemble consists of four ensemble simulations starting from different initial conditions taken from a pre-industrial control run.

The next IPCC Assessment Report (AR4) in 2007 used a 'models & initial conditions vary'-ensemble consisting of 58 GCM runs carried out by 14 GCMs. This

means only the two emission-scenarios are fixed but 'the physics' and the initial conditions vary.
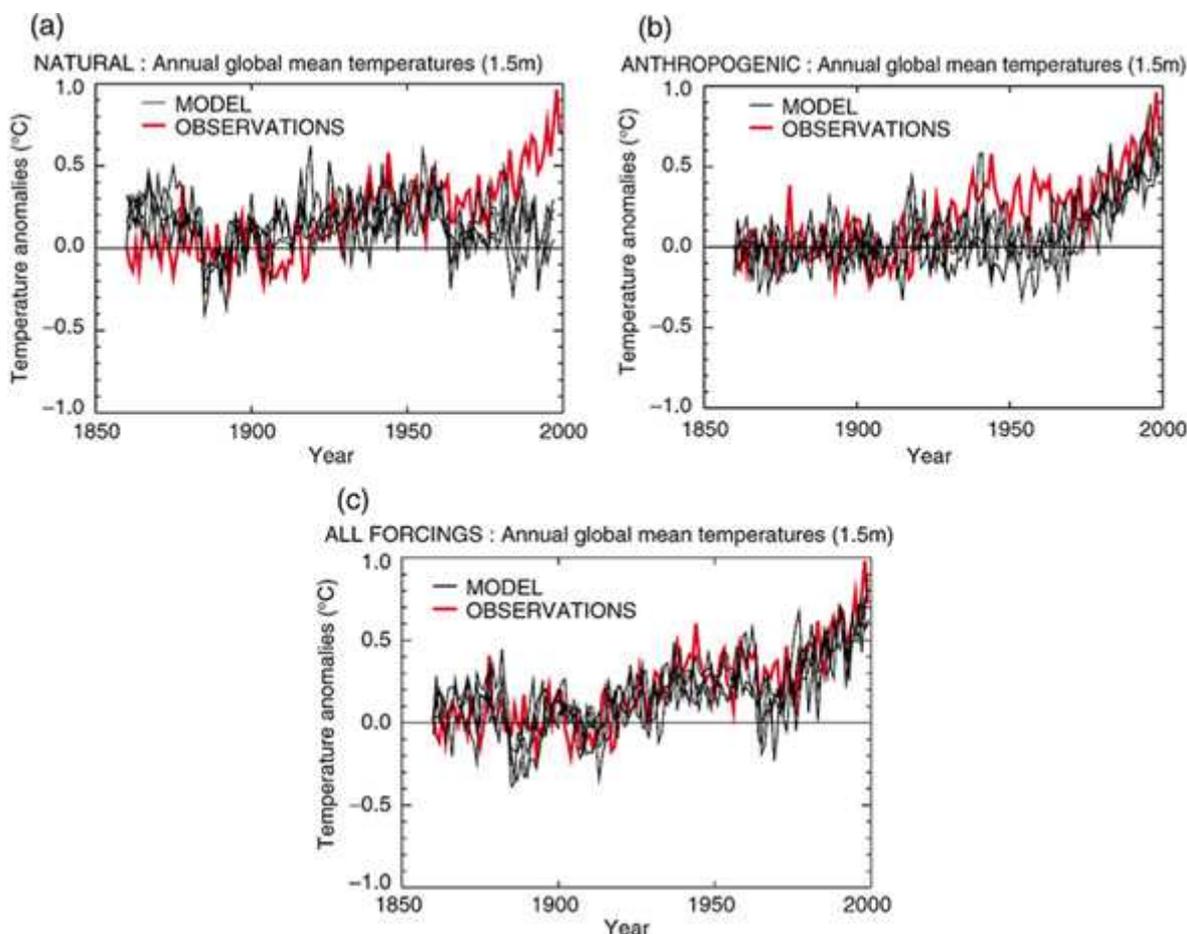
Figure 3: *Global mean surface temperature anomalies relative to the 1880 to 1920 mean from the instrumental record compared with ensembles of four simulations with a coupled ocean-atmosphere climate model (from Stott et al., 2000b) forced (a) with solar and volcanic forcing only, (b) with anthropogenic forcing including well mixed greenhouse gases, changes in stratospheric and tropospheric ozone and the direct and indirect effects of sulphate aerosols, and (c) with all forcings, both natural and anthropogenic. The thick line shows the instrumental data while the thin lines show the individual model simulations in the ensemble of four members. Note that the data are annual mean values (from IPCC 2001).*

One emission scenario follows the evolution of the natural forcings alone (blue), the second scenario describes the development of all forcings (natural + anthropogenic, pink). The black line represents the observations, which can be reproduced only if the anthropogenic forcings are considered next to the natural forcings on all spatial scales. This prove of the human impact on the climate system is possible due to the application of a 'multi-model initial condition' ensemble.
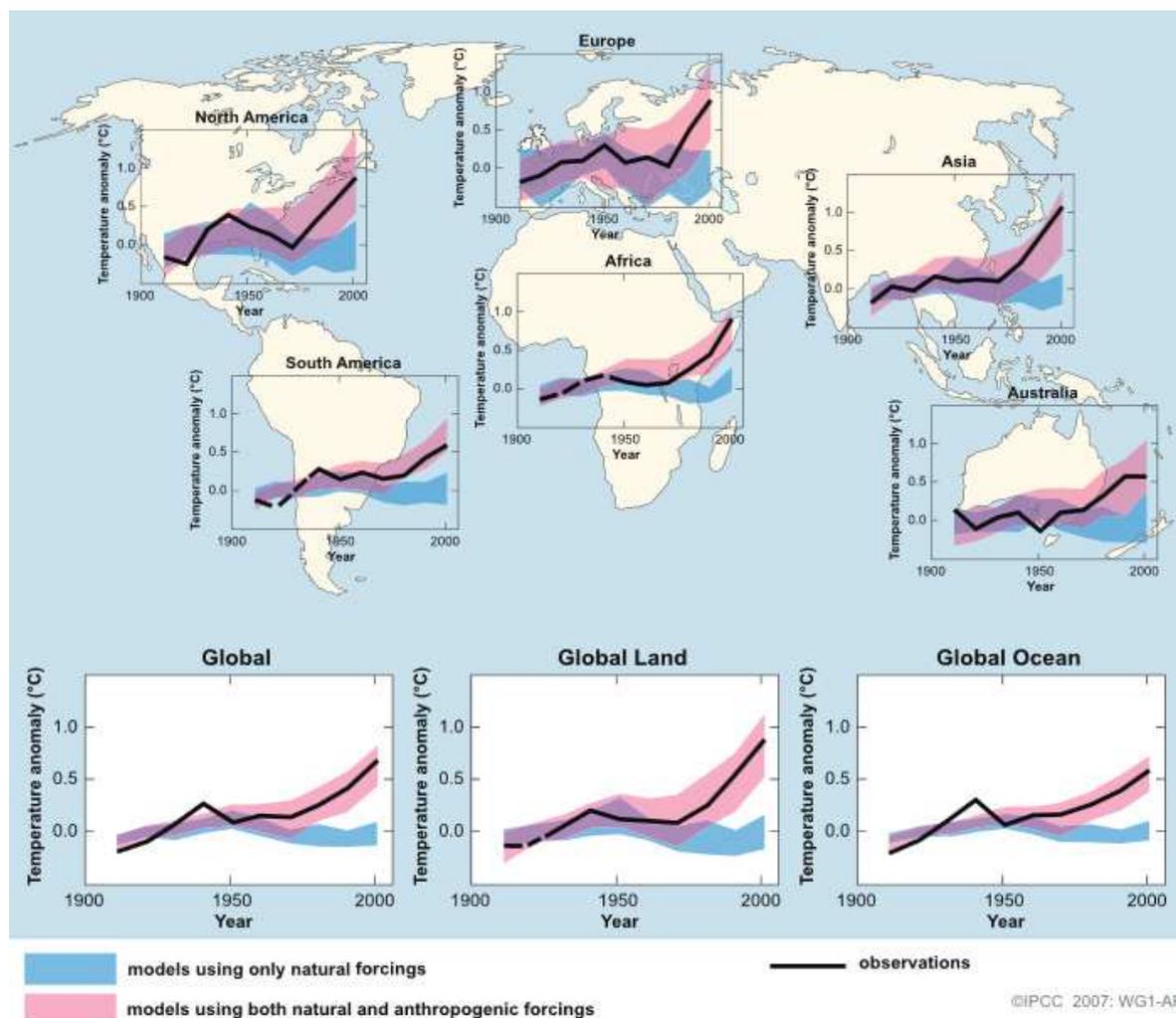
Figure 4: *Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906 to 2005 (black line) plotted against the centre of the decade and relative to the corresponding average for 1901–1950. Lines are dashed where spatial coverage is less than 50%. Blue shaded bands show the 5–95% range for 19 simulations from fi ve climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5–95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings.*

There is another aspect depict in **Figure 4** worth mentioning. In the CliPDaR report D1.3 we stressed the fact that GCMs produce (by construction) findings that are valid for large geographic areas as continents, but not for smaller regions, which is why Downscaling is required to derive small scale climate change projections. **Figure 3** and **Figure 4** demonstrate the detection on the global and the continental scale, respectively. Investigations of the human impact on smaller scale climate change would require the application of Downscaling.
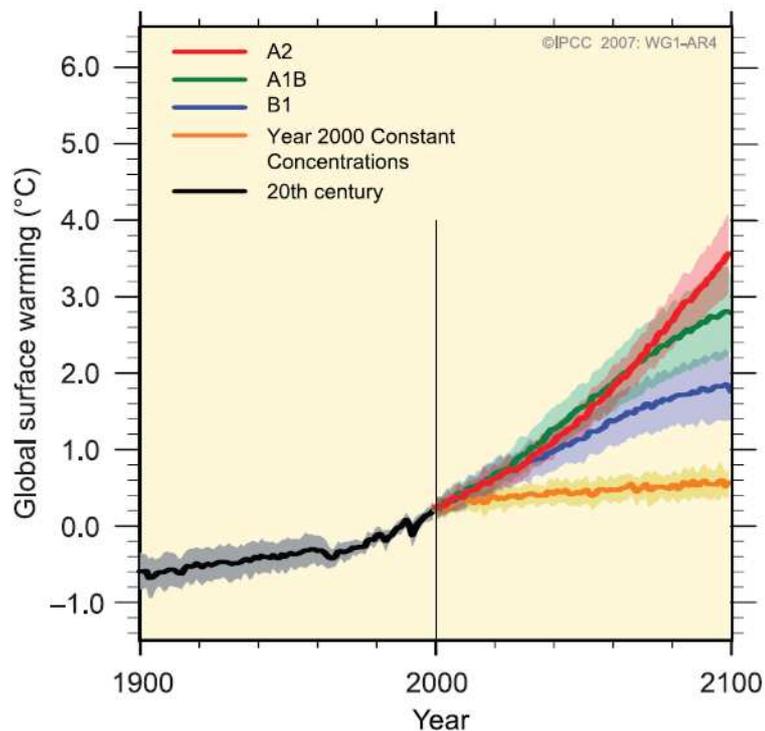
Figure 5: *Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the ±1 standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values.*

Figure 5 is the outcome of a 'total ensemble'('socio-economic scenarios & models & initial conditions vary'-ensemble). Time runs on the abscissa from 1900 to 2100. The black solid line displays the global average temperature reconstructed from observations and the coloured curves refer to different socio-economic scenarios. They correspond to socio-economic scenarios described in (Nakicenovic et al. 2000). **Table 3** gives a brief description of those shown in **Figure 5**.

Table 3: *The emission scenarios of the IPCC Special Report on Emission Scenarios (SRES, taken from the IPCC Summary for Policy Makers, 2007).*

A1	B1
The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil-intensive (A1FI), non-fossil energy sources (A1T) or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).	The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.
A2	**B2**
The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is selfreliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.	The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.
An illustrative scenario was chosen for each of the six scenario groups A1B, A1FI, A1T, A2, B1 and B2. All should be considered equally sound.	
The SRES scenarios do not include additional climate initiatives, which means that no scenarios are included that explicitly assume implementation of the United Nations Framework Convention on Climate Change or the emissions targets of the Kyoto Protocol.	

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5 An application concerning the European Transport Infrastructure

Within this Section we are going to extend the example on rutting, which we introduced in earlier reports, towards the ensemble approach.

The crucial point is, as will be demonstrated below, that the ensemble approach helps to improve the basis on which decision making -- regarding the planning and design of adaption measures - is done.
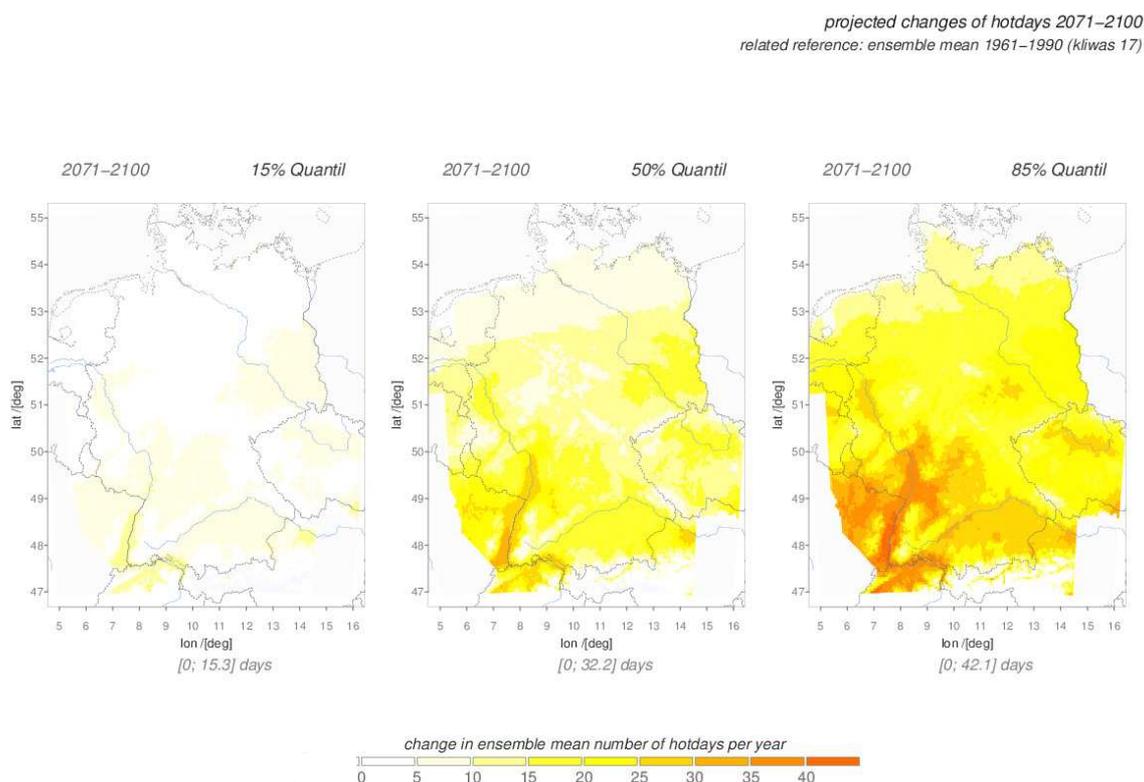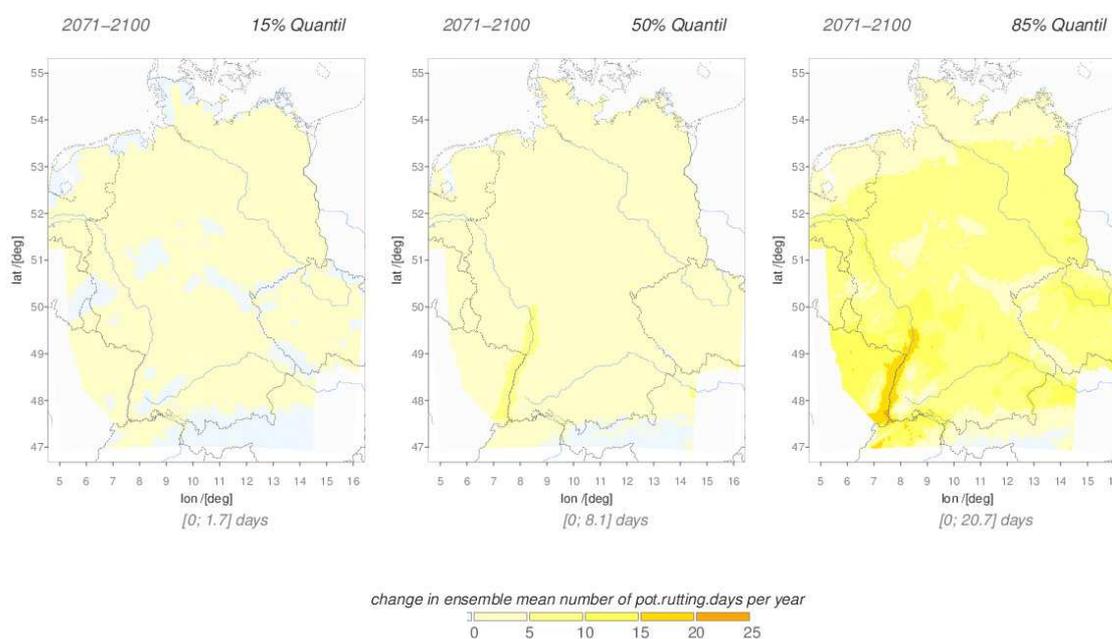

Figure 6: *The increase of hot days ($T_{max}>30°C$) shown by comparing the period 2071-2100 to the climate normal period 1961-1990 (as defined by the WMO). The Figure is based on the so called KLIWAS17 ensemble which is a 'models & initial conditions vary'-ensemble (see Table 1). The panels show the 15th, 50th and 85th percentile (from left to right).*

Within the range spanned by the left and the right panel of **Figure 6** are 70% of the small scale climate change projections contained within the KLIWAS17 ensemble (see Imbery et al. 2013). Largest changes are to be found in the South-West of the displayed region. They spread east and west across the Rhine valley along the border between Germany and France (and to a lesser extent south of the Danube). These increases are in the order of one month, meaning on top of today's heat days there will be one additional month of heat days more simulated by the median of the considered 'models & initial conditions vary'-ensemble (see **Table 1**). From statistical expertise it is known that the median of a sample is rather robust compared to a single draw or even the mean of a sample. So, the median has a higher probability assigned to it than a single projection. Anyway, about thirty more heat days is a lot.

Especially when considering that days potentially exceeding 30°C are concentrated in summer, which consist of 92 days in total. Several main highways (5, 6, and 8) are within the affected area along the Rhine and south of the Danube (3, 9, 7, and 8). This region shows the largest increases of all regions already presently exposed to comparably large heat stress (compared to most other regions shown within the panels). This year there were accidents with blow ups caused by excessive heat and some of them caused fatalities

projected changes of pot.rutting.days 2071–2100
related reference: ensemble mean 1961–1990 (kliwas 17)

Figure 7: *The increase of rutting days (see text for the definition of the assigned CI) shown by comparing the period 2071-2100 to the climate normal period 1961-1990 (as defined by the WMO). The Figure is based on the so called KLIWAS17 ensemble which is a 'models & initial conditions vary'-ensemble (see Table 1). The panels show the 15th, 50th and 85th percentile (from left to right).*

Here we focus on a CI that is characterized by high daily temperatures (≥30°C, Hot Days) together with T_{min} ≥20°C (Tropical Nights). Such days bear the potential of harming road surfaces like rutting. For the example of the far future time slice (2071-2100) the increase of "potential rutting days" varies from less than 5 days and for nearly the entire investigated region for the 15th percentile (left panel of **Figure 7**) up to more than 20 days in the upper Rhine valley with a north-south spatial gradient for the 85th percentile. In northern Germany the coastal regions remain in the class "less than 5 days" (right panel of **Figure 7**).

6 Further thoughts on the application of the ensemble approach to European transport infrastructure

One important implication in the context of the assessment of infrastructural stresses caused by climate change is that the different model-chain components, i.e. the individual structure of the GCM-RCM combination, is important for a proper simulation of the present-day climate.

For this so called forward modelling specific variables or quantities should therefore be simulated reasonably well in the RCM output. For roads this relates for instance to the number of frost events versus non-frost events within the diurnal cycle, the number of hot days during summer or the number of precipitation events causing flooding.

A validation of the downscaled GCM-RCM output is therefore necessary with present-day data (re-analysis or observational) for the historical period (e.g. 1960 - 2000). Although for most RCMs this validation has been carried out using re-analysis data (ERA40) as forcing, the GCM might impose profound biases changing results obtained for the re-analysis forced simulations (cf. also Pfeiffer and Zängl, 2011). Moreover, these biases can be especially large in areas where potential of damage to road or traffic infrastructure might be expected such as in mountainous areas or in regions affected by flooding caused by extreme rain or periods of increased rain spells.

A further approach to reduce the large number of GCM-RCM realizations is therefore to test the specific bias structure for the target variable that is crucial for the forward model (i.e. simulation of rutting) like frost/non-frost spells or the number of extreme temperature events.

Recommendations from the forward models (impact models) would be that they are efficient in modelling a larger ensemble of simulations. If already forward models exist that could theoretically be driven with the output of GCM-RCM ensembles. However, the according interfaces linking the model output with the forward models must be efficient. Given that the forward models on the application side are too complex and too computational demanding it might be an option to represent only the most important processes in the forward models if possible. The strongest guideline should however be related to maintain the skilful model chain in terms of a meaningful balance between complexity, efficiency and plausibility.

In carrying out the selection for the best GCM-RCM simulations on the one hand and establishing new forward models on the other hand also the process understanding should contribute from both sides in the context of changes in single/extreme weather events versus changes in the mean, for instance related to frost spells versus non-frost spells.

Given that not all GCM-RCM simulations could be taken into account for forward modelling, for specific well-performing combinations at least some sensitivity

experiments should be carried out for the initial ensemble. Especially for the near future, the different paths of the emissions scenarios do not show as clear-cut differences as for longer term periods and the slow varying components of the climate system might have not yet picked up certain signals or they might be disguised by internal variability. This is however also a crucial point as all realizations might have similar probability which could have important consequences for short-to-mid term planning and adaption strategies.

7 Concluding remarks

CliPDaR will establish a design guideline treating climate change scenarios, downscaling techniques and statistical methods necessary for the generation of regional scale scenarios across Europe. This sets the basis for consistent, Europe wide risk assessments of road infrastructure regarding climate change.

As such it is important to identify climate indices (e.g. long term rain events, heat spells) harming road assets. This is to be done in cooperation with the road administrations, people in charge and constructional engineers. The Austrian - German Workshop in Vienna (6th to 8th May 2013) is devoted to that issue. Additionally, interviews with road experts have been arranged. Thus CliPDaR will address this with workshops, interviews and participation in international meetings (e.g. FEHRL FIRM13 in Brussels). Next to that, KLIWAS and VALUE as well as the German Adaptation Strategy (DAS), the Austrian Adaptation Strategy and the IPCC Recommendations (IPCC 2007) regarding adaptation measures will be taken into account.

These sources will be completed by the German Federal expert discussions on "Climate impacts" and on "guidelines 'dealing with climate projection data'". All these documents will be considered when preparing the CliPDaR guidelines.

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10 List of Figures and Tables