# CONSEQUENCES DES CHANGEMENTS CLIMATIQUES SUR LE DEVELOPPEMENT D'ORNIERES

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## RÉSUMÉ

L'orniérage est une dégradation très fréquente sur les chaussées bitumineuses. L'apparition d'ornières est dépendante d'un grand nombre de facteurs différents. La capacité de résistance du bitume aux déformations permanentes est une grandeur d'influence très importante concernant la formation d'ornières. Cette résistibilité dépend des caractéristiques mécaniques de l'asphalte. D'autres paramètres, qui influencent la formation d'ornières, sont à chercher du côté du chargement. Ainsi la formation d'ornières augmente trivialement avec l'augmentation du trafic. Une autre grandeur d'influence est la température. Le danger de formation d'ornières augmente aussi avec l'augmentation de la température du bitume. Des suites de changements climatiques futurs tout aussi bien globaux que locaux, le paramètre d'influence « température » ne va cesser de gagner en importance en ce qui concerne l'orniérage. Le changement climatique appartient depuis quelques années à l'un des thèmes les plus abordés dans notre société. La thématique restait jusque-là inexploitée dans le domaine de la construction routière. Ce travail contributoire s'intéresse à cette problématique et analyse les conséquences de changements climatiques futurs sur la formation d'ornières dans les chaussées bitumineuses à partir de scénarii climatiques prédéfinis.

## 1. INDRODUCTION

Global climate change is one of our society's most current and controversial topics. The causes of climate change occurring today are many; however, it is clear that the changes are, at least in part, most likely due to human activity. During the 2nd half of the 20th century, one could observe the in-crease in both maximum and minimum air temperatures, and that the rise in daily minimum air temperatures was higher than that of maximums. In addition, the number of hot days increased, while the number of cold and freezing days decreased. It is highly probable that this development will continue through the 21st century [1]. What has been largely overlooked to date is the relation between the coming climate changes and structural road design. The effects of climate change on asphalt road design will be particularly noticeable. Because of the strongly temperature-dependent mechanical properties of asphalt as a building material, climate shifts in the surrounding environment may have a considerable effect on the durability of asphalt pavement structures. This pertains not only to conspicuous damage such as the development of ruts, the appearance of which will increase in summer due to climate-induced rises in temperatures, but also to the damage (fatigue) to the actual material of the asphalt pavement structures. First investigations about the impacts of climatic change on the fatigue resistance of asphalt and the substantial damage of asphalt pavements have been carried out in [2] and [3]. The service life of asphalt pavements will be significantly reduced probably for the analysed climate scenario as well as the analysed region in Germany according these investigations. Generally the impacts of climatic change on reduction of the service life of asphalt pavements can be influenced with specific variation of the thermal asphalt properties [2, 3]. However the tendency of reduction of service life can not be stopped. In the future the usage of forecasts and simulations will be more important in consequence of continuously increasing traffic volume and climatic changes. Only then durable asphalt pavements and hence an efficient utilisation of the limited finances can be achieved. This article shows the impacts of climatic changes on formation and progress of permanent deformations (ruts) in asphalt pavement.

## 2. CLIMATE-RELATED CHANGES

The extensive measurement and monitoring of significant climate-related parameters clearly shows that the global mean temperatures of the near-surface strata have risen since instrumentals records started (1850). The mean temperature increase in the 20th century was approximately 0.6 K +/-0.2 K. Moreover it is observed that the rise in night-time daily minimum air temperatures is double (approximately 0.2 K per decade) the rise in day-time daily maximum air temperatures. In many regions this resulted in shorter frost periods.

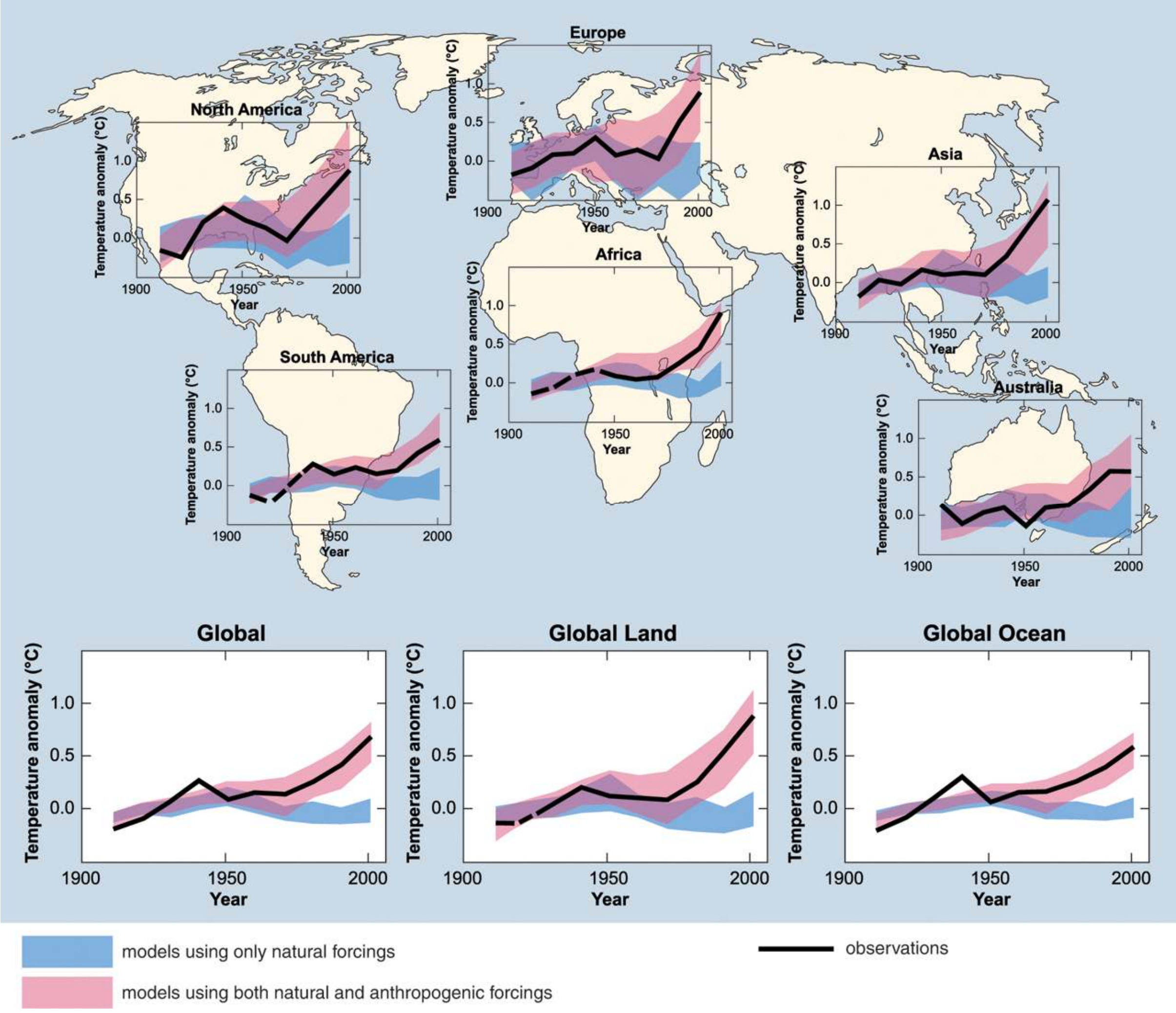
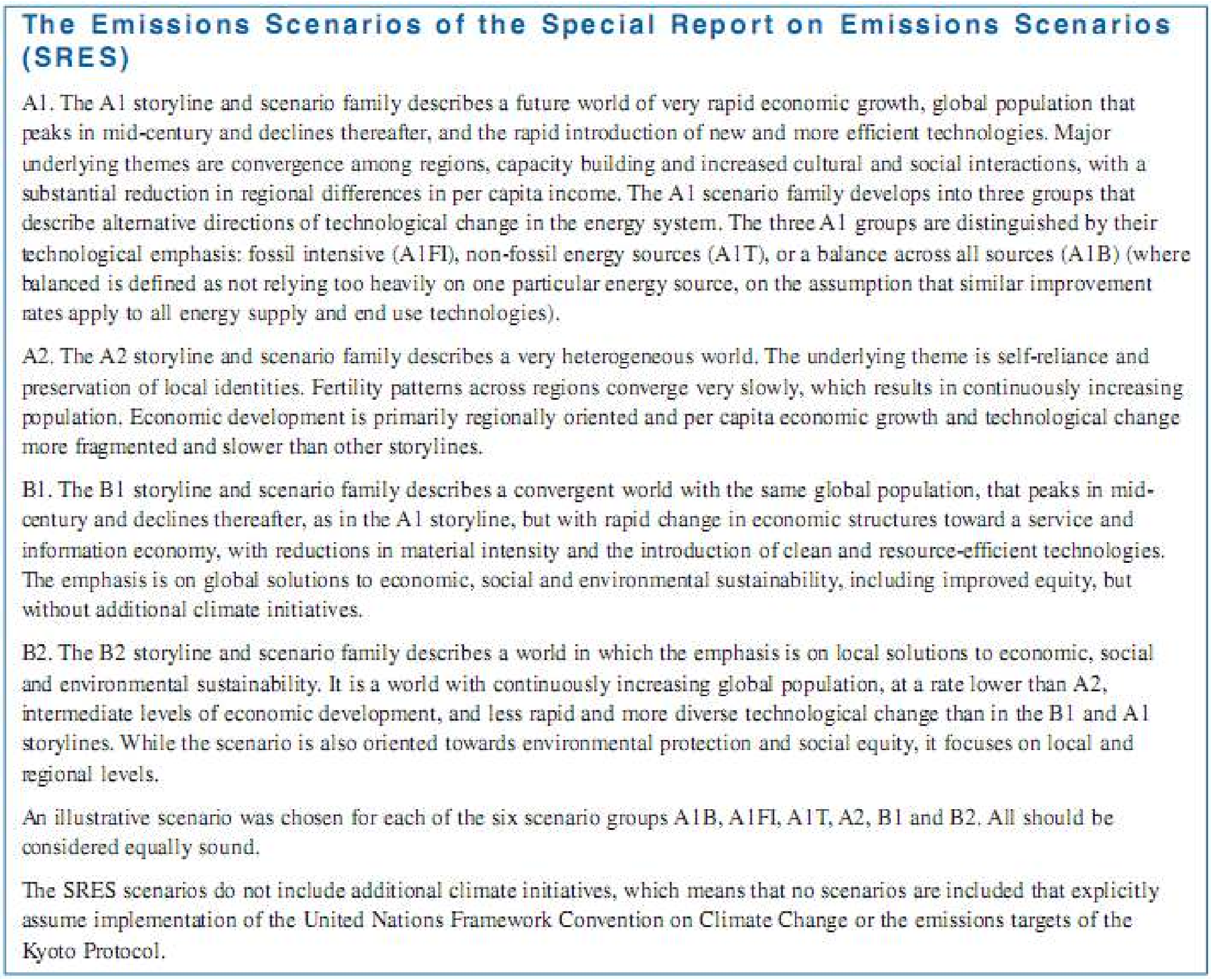


Figure 1 Comparison of monitored changes of land surface temperature (LST) on continental and global scale with the results calculated from climate models on the basis of natural and anthropogenic forces. The decade means for the monitoring period are plotted for the years 1906–2005 in the centre of the decade and relatively to the corresponding mean of 1901–1950. Dashed lines indicate spatial coverages of less than 50%. source: [1]

This temperature rise due to global warming has become markedly noticeable mainly for the last decades. For example, at least eleven years of the period of 1995 to 2006 were recorded as the twelve warmest years since 1950 [1]. Precipitation in the northern hemisphere (>30°N) increased by 0.5 % to 1.0 %. With +2 % to +4 %, the rise in the frequency of occurrence of very heavy precipitation events in these regions was far more distinct [1]. According to [1] it is probable that the observed climate changes can be attributed to anthropogenic factors to a considerable extent. The distinct rise in greenhouse gas concentrations since the 1950s and their impact on the energy balance of our climate system resulted in a positive radiative forcing with subsequent warming of the near-surface strata. Climate changes may have rather different impacts on different regions (Figure 1). While the global mean of ground level air temperatures has in-creased by approximately 0.6 K [1] in the 20th century, the European mean increased by even 0.8 K [4]. In Germany, an analysis of climate development for the same period reported an increase of 0.9 K [5, 6]. To predict the future development of our climate system, [1] gives various emission scenarios (Special Report on Emissions Scenarios - SRES) (Figure 2). These emission scenarios rest on predictions of the future development of the world economy. The scope of the scenarios is wide and includes an approach assuming rapid economic growth with intense use of fossil energy sources and also an assumption of decreased material consumption, the use of clean and resource-efficient technologies and environmental sustainability. All scenarios neglect influences that result from the implementation of the United Nations Framework Convention on Climate Change - UNFCCC or the Kyoto Protocol.



**The Emissions Scenarios of the Special Report on Emissions Scenarios (SRES)**

A1. 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).

A2. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance 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.

B1. 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.

B2. 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.

Figure 2 Description of IPCC Emissions Scenarios; source: [1]

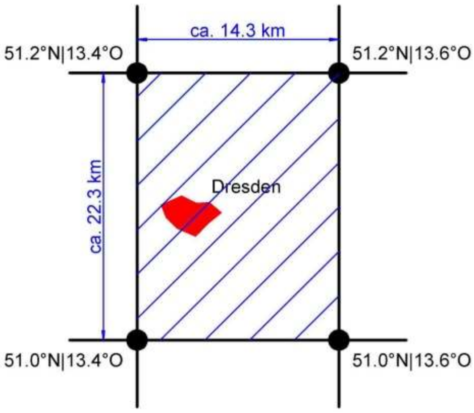
Mathematical modelling and the prediction of future climate developments show that global warming will continue to rise by approximately 0.1 K / per decade even without a further increase of greengas concentrations and thus constant radiative forcing taking the year 2000 as a basis. If, however, green-house gas emissions will increase in accordance with the IPCC scenarios, we expect an average global warming of approximately 0.2 K to approximately 0.4 K.

## 3. THERMAL PREDICTION SIMULATIONS FOR ASPHALT CONSTRUCTIONS

Special simulations are necessary to estimate the effects of prospective climate changes on the durability of asphalt road constructions. Starting from the development of relevant climate parameters predicted by the related IPCC scenarios, the future thermal conditions in asphalt pavement structures can be simulated using the heat balance equation. The climate parameters relevant to the simulation of the thermal conditions of circulation areas in accordance with the heat balance of road surfaces include:

- global radiation
- near-surface air humidity
- wind speed
- amount of precipitation
- cloud amount

Initial tests made at the chair of road construction at TU Dresden analysed possible effects of future climate changes on the thermal stress of asphalt road pavements and their material durability. The thermal simulations will be conducted with the climate data predicted and provided by the models and data group of the Max Planck Institute of Meteorology, Hamburg, and the IPCC emission scenario A1B [7]. This scenario starts from rapid economic growth and a balanced utilisation of energy sources. The research staff at the Max Planck Institute of Meteorology in Hamburg carried out model computations for emission scenario A1B in two runs (A1B run 1 and A1B run 2) with different start conditions. The result is a range of future developments of the climate environment. The predicted changes of the ambient climatic conditions of the two model computations of scenario A1B were used to numerically compute the surface temperatures and the temperatures in the asphalt pavement. The simulations have been carried out for the region Dresden and surroundings (longitude; 13.6° - 13.8°; latitude: 51.0° - 51.2°) for the period 2001 – 2069 (Figure 4 – left). The selected region has a total of four grid points and covers an area of approximately 318.9 km². The presented results of the thermal simulations are obtained with the mean values of the relevant climate parameters of the four grid points and are thus averaged over the area. The climate simulations C20 (Climate of the 20th Century) for the period 1980 – 2000 was integrated as reference values for the assessment of the thermal stress changes of asphalt pavement structures resulting from the modelling of scenario A1B [8]. Due to the complexity of the heat balance equations and the long simulation period of 90 years, the simulations were limited to a one-dimensional road construction-atmosphere system. A road construction with an asphalt pavement thickness of 34 cm were chosen. Three parameter variants of the thermo-physical material characteristics (Figure 4 – right) were analysed. The individual parameters of the three variants were defined that the influence of the climatic ambient conditions on the temperatures of the asphalt road construction is as strong as possible (VAR3) and as weak as possible (VAR1) in relation to the reference variant (VAR2). The different thermal properties for the individual layers of the whole asphalt pavement system – asphalt covering, bonding course and base course – have not been taken into account.



| variant-ID | VAR1 | VAR2 | VAR3 |
|---|---|---|---|
| *parameters for asphalt* | | | |
| reflectance (short-wave solar radiation) [-] | 0.800 | 0.850 | 0.900 |
| reflectance (long-wave terrestrial radiation) [-] | 0.975 | 0.950 | 0.925 |
| thermal conductivity [W/m/K] | 1.25 | 1.05 | 0.75 |
| specific heat capacity [Ws/kg/K] | 1,000 | 878 | 650 |
| density [kg/m³] | 2,500 | 2,240 | 2,000 |
| conductibility of temperature [cm²/h] | 18.00 | 19.22 | 20.77 |
| *parameters for sub base* | | | |
| conductibility of temperature [cm²/h] | 42.68 | 42.68 | 42.68 |
| *parameters for sub grade* | | | |
| conductibility of temperature [cm²/h] | 46.54 | 46.54 | 46.54 |

Figure 4 left: Schematic diagram of the examined region; right: thermo-physical material properties of the three parameter variants

## 3.1. Changes of climatic parameters relevant to the simulation

The analysis of the climatic development predicted by the Max Planck Institute of Meteorology in Hamburg for emission scenario A1B for the area under investigation (Dresden and its surroundings) shows noticeable climate changes in the future. For example, it is expected that the 30-year mean, near-surface air temperatures will continually increase in the future. On the basis of the 30-year mean temperatures for the period 1980 to 2009 it is expected that the 30-year mean air temperatures will increase by approximately 0.9 K by the end of the first half of this century and by approximately 1.6 K to 1.8 K by the end of the investigation period (2069) (Figure 5 – top left).

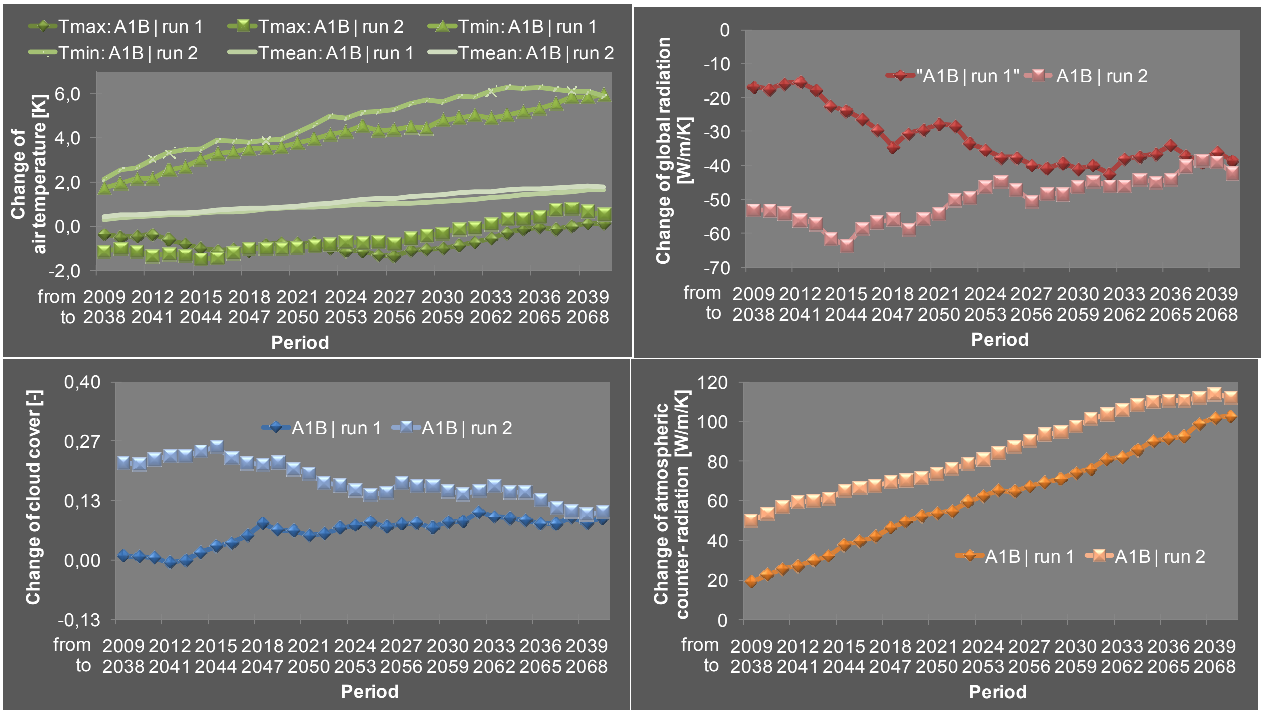


Figure 5 Predicted absolute changes of different climatic parameters related to the mean value of the period 1980-2009; top left: absolute changes of the 30-year near-surface mean air temperatures (annual mean temperature – Tmean; annual minimum temperature – Tmin; annual maximum temperature – Tmax); top right: absolute changes of the 30-year mean annual global radiation sum; bottom left: absolute changes of the 30-year mean annual cloud cover bottom right: absolute changes of the 30-year mean of the annual sums of the atmospheric counter-radiation.

The development of the 30-year mean air temperature minima will be far more drastic. An increase of approximately 1.7 K to 2.1 K is predicted already for the next 30 years. The increase will be even 5.9 K by the end of the investigation period (2069) (Figure 5 – top left). As far as the 30-year mean air temperature maxima in the area under investigation are concerned, increases are expected only in the second third of this century. By the end of the investigation period (2069), however, the 30-year mean air temperature maxima will increase by approximately 0.1 K to 0.5 K according to predictions (Figure 5 – top left).

According to the predictions of emission scenario A1B, a decrease of the global radiation intensity is expected (Figure 5 – top right). This is a reduction of a significant component of the energy input into the road surface. This radiation decrease can be explained by increasing cloudiness (Figure 5 – bottom left). Increasing cloudiness causes the atmospheric counter-radiation to increase as a result of the higher emissivity of the atmosphere for infrared radiation (Figure 5 – bottom right). At the same time, it intensifies the greenhouse effect thus warming the earth's climate and further intensifying the atmospheric counter-radiation.

## 3.2. Changes of thermal stress in asphalt pavement structures

Some significant changes of the climate parameters relevant for thermal simulations of asphalt pavement structures are expected in the next years of this century assuming the IPCC scenario A1B. Since these climate parameters have a direct effect both on the surface temperatures of the pavement and the temperatures in the individual asphalt layers, it is expected that the thermal stresses in asphalt pavement structures will change, too.

The impacts of climate changes concerning the emission scenario A1B on temperature in the asphalt pavement will be analysed in [2] and [3]. For example the mean pavement surface temperatures for parameter variant VAR2 (reference variant) for the next 30 years (2010-2039) are approximately 0.3 K to 0.4 K and for the years 2030 to 2059 approximately 1.0 K to 1.4 K above that of the period 1980 to 2009 [x, y]. During this century a continuous increase in these 30-year mean temperatures can be expected [x, y]. As for the surface near air temperatures distinct changes are predicted for the 30-year mean minima of the pavement surface temperatures [2, 3]. These temperatures are approximately 1.4 K to 2.2 K higher in the next 30 years (2010 – 2039) than in the reference period (1980 to 2009) [2, 3]. Predictions assume the increase of the 30-year mean minima of the pavement surface temperatures at the end of the considered period of even up to 5.2 K in comparison with the reference period 1980 to 2009 [2, 3]. The 30-year mean maxima of the pavement surface temperatures, however, will change less markedly [2, 3].

Only Specific temperature ranges are authoritative for the prognosis of rut formation. Temperatures higher than 15 °C will be included for the prognosis of ruts according to the procedure described in chapter 4. The absolute frequency changes (15 years mean of frequencies) at the selected temperature range concerning the mean frequency of the period from 1980 to 2009 (reference period) are presented in figures 6 – 8. The temperature range from +15°C to +60°C is authoritative for prognosis of rut formation. The frequencies of occurrence of this entire temperature range will increase (figure 6). The frequencies of the higher temperature ranges in the reference period will only be achieved as from the first third and will only be exceeded as from the second half of this century (figure 7 and figure 8). The reasons for this are the contrary trends of global radiation and atmospheric counter-radiation (figure 5).

The real warming effect is reflected in the low temperature range. The different thermo-physical material properties which underlying the simulations have a significant influence on the higher temperature range.

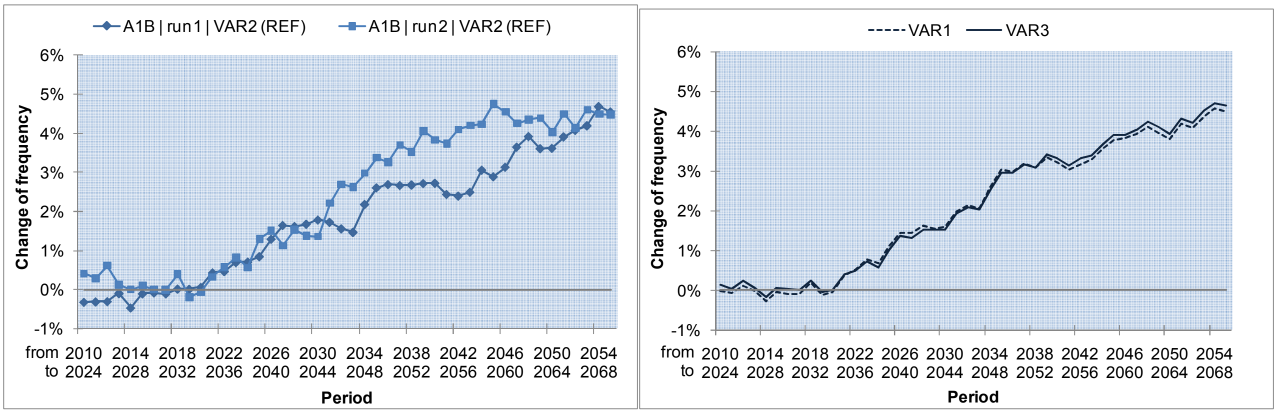


Figure 6 Predicted absolute changes of 15-years mean frequencies for T > 15°C related to the mean frequencies of the period 1980-2009; left: for the different runs of the scenario A1B using reference parameter variant VAR2; right: average of run 1 and run 2 with parameter variants VAR1 and VAR2

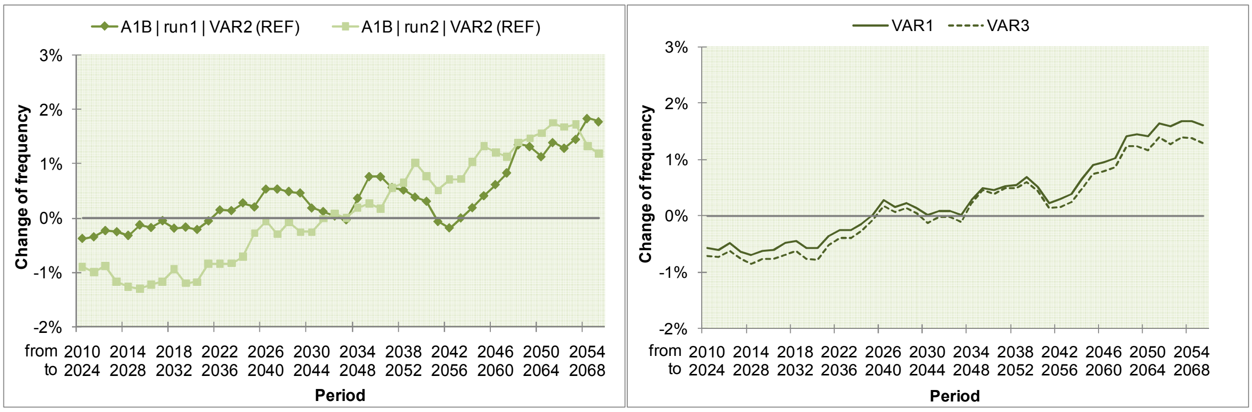


Figure 7 Predicted absolute changes of 15-years mean frequencies for T > 30°C related to the mean frequencies of the period 1980-2009; left: for the different runs of the scenario A1B using reference parameter variant VAR2; right: average of run 1 and run 2 with parameter variants VAR1 and VAR2

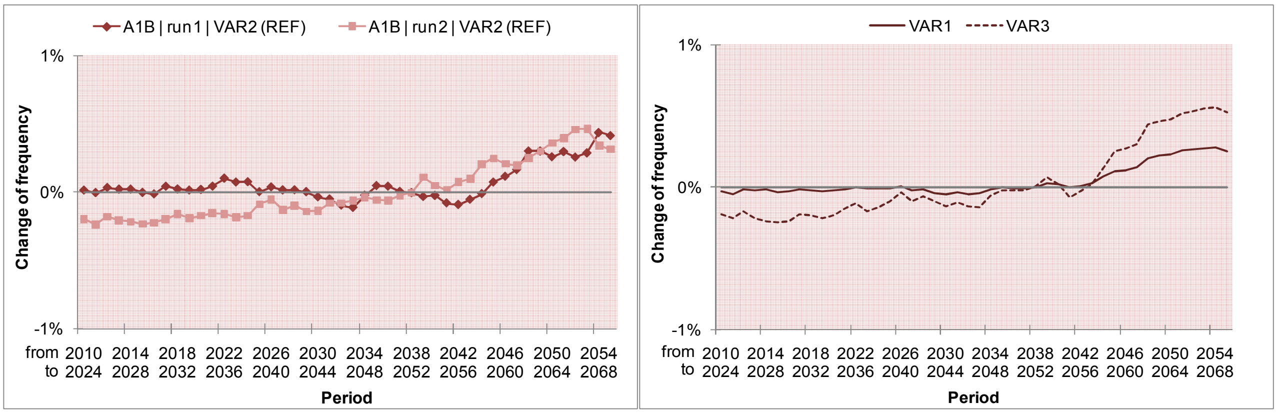


Figure 8 Predicted absolute changes of 15-years mean frequencies for T > 45°C related to the mean frequencies of the period 1980-2009; left: for the different runs of the scenario A1B using reference parameter variant VAR2; right: average of run 1 and run 2 with parameter variants VAR1 and VAR2

## 4. PROCEDURE FOR SIMULATION AND PREDICTION OF RUTTING

This method is based on results of a research project, which had been funded by the German Federal Ministry for Education and Research - BMBF [9]. The basic principles of the method are the results from multiaxial compression tests with swelling loading on asphalt samples on the one hand and the calculated multiaxial stress conditions in the asphalt structure on the other hand. These stress conditions can be calculated using appropriate models and methods. The results are depending on different input variables (load, temperature conditions).

### 4.1. Determination of the impulse creep curves

The impulse creep curves are necessary to forecast the rutting and to describe the trend of the permanent axial deformation of an asphalt specimen in a compression test with swelling loading as a function of the applied load cycles under defined stress conditions. The impulse creep curves will be determined using the results of triaxial tests which allow to generate user-defined multiaxial stress conditions. Due to the three-dimensional stress conditions the triaxial test is particularly suited to investigate the material behaviour experimentally as realistically as possible. Figure 9 shows the schematic configuration of the triaxial apparatus used at TU Dresden.

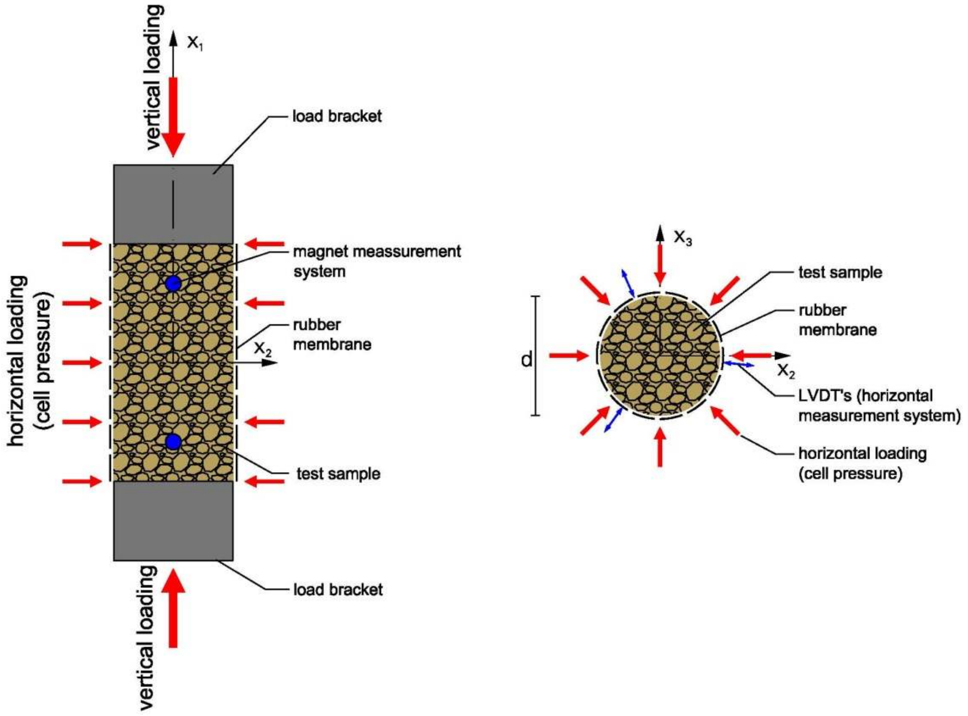


Figure 9: Schematic configuration of the triaxial apparatus used at TU Dresden for the triaxial tests [10]

The axial loads and the horizontal pressure will be applied swelling in the experimental procedure for determining the impulse creep curves. The accumulated permanent axial deformations are recorded contactlessly by a magnetic measurement system. Based on the measured deformations considering the distance between each pair of stacked magnets, the accumulated permanent strain can be calculated. Because of the relatively large expense associated with specimen preparation and experimental procedure triaxial tests cannot be performed for all stress conditions occurring in pavement structures, which are relevant for a realistic prediction of rutting. The basis of following statistical modelling of deformation behaviours are the experimentally accomplishable stress conditions.

## 4.2. Statistical modelling of deformation behaviours

Each impulse creep curve is based on a defined stress condition which is realized in the triaxial tests and will be approximated according to equation (1). The material parameters depend on the stress conditions and the temperature during the test and must be determined individually for each asphalt by fitting to the experimental results.

$$\epsilon = A \cdot \ln(N+1)^{B} \tag{1}$$

Where ε = permanent strains [‰]; N = number of load cycles [-]; A, B = material parameters [-].

## 4.3. Calculated stresses in pavement structure

Different material properties must be determined in the laboratory for these calculations depending on the used material model. Due to computing time, a linear elastic material model will be used for the stress calculations. The necessary material parameter is the stiffness modulus. This corresponds to the absolute value of the complex modulus. The stiffness modulus can be determined using the indirect tensile test [11] for different temperatures and loading frequencies and will be described in the form of a stiffness modulus-temperature function in the following sections. For a defined structure of an asphalt pavement, the stresses in the layers / elements of the structure model will be calculated using the stiffness modules. These relate always to a defined load condition, which is characterized by a defined traffic load and a defined temperature distribution along the individual construction layers. The stress calculations are carried out for different loading conditions. These must be relevant for the forecast of rutting. A detailed compilation and description of the temperature conditions and the traffic loads has been carried out in [12], [13] and [14]. These are the basics for the characterization of the required load conditions.

## 4.4. Simulation and prediction of rutting development

The method for simulating and predicting the development of rutting in asphalt pavements with consideration of random processes is a further development of the procedure developed in [9]. The further development of this procedure includes:

- all load cycles $N(b_n)$ of a stress condition $b_n$ will be divided into single packages (load packages) ω with $\omega = 1 \ldots k_\Omega$
- definition and implementation of temperature intervals
- the combination of the stress variables temperature and traffic load is random
- the order in which the stress conditions and load packages respectively can occur is random

These load packages describe the maximum number of consecutive load cycles of a stress condition. Thereby the chronological load situations of roads can be reproduced more realistically. To take into account seasonal changes in the asphalt surface temperatures and thus to prevent that implausible temperature, time series will be generated by the random process.

Additional classification criteria should be introduced. For this, the whole temperature range, which is relevant for evaluating rutting will be divided into different intervals Γ (Figure 10). The necessary temperature packages will be determined, based on the temperature distribution, the membership function as well as the number of load cycles.

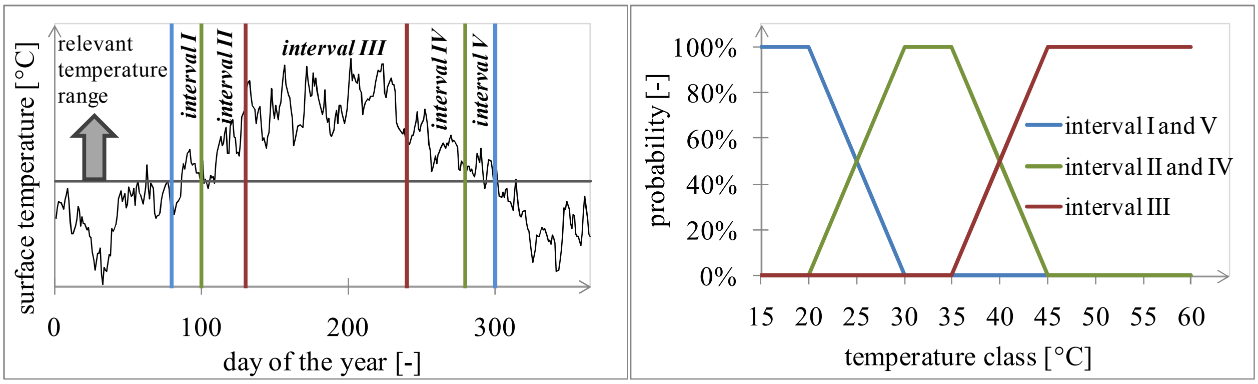


Figure 10: Schematic representation of the temperature intervals related to the annual surface temperature course (left) and the membership functions related to the temperature intervals (right)

The combination of the stress variables temperature and traffic load is random and the order in which the individual load conditions and load cycle packages will be considered within this accumulation processes will be defined quasi-randomly (Figure 11). This quasi randomness will be realized by a pseudorandom generator „Mersenne-Twister". The „Mersenne-Twister" has been developed by Matsumoto/Nishimura [15].

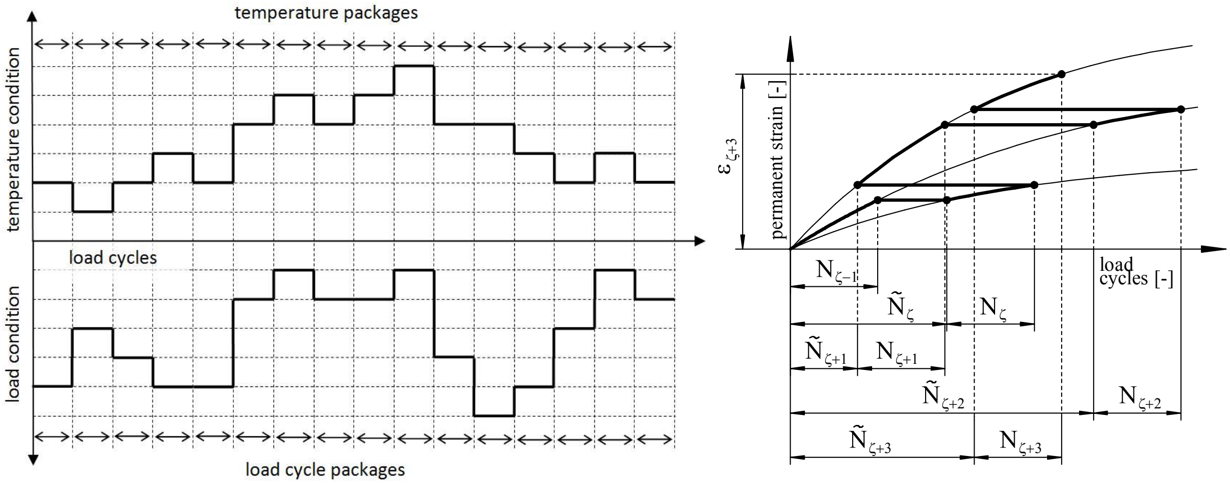


Figure 11: Schematic representation of the random combination of stress variables temperature and traffic load, the random order of the stress conditions and load packages respectively (left) and the resulting accumulation process exemplary for three load conditions and five load packages (right).

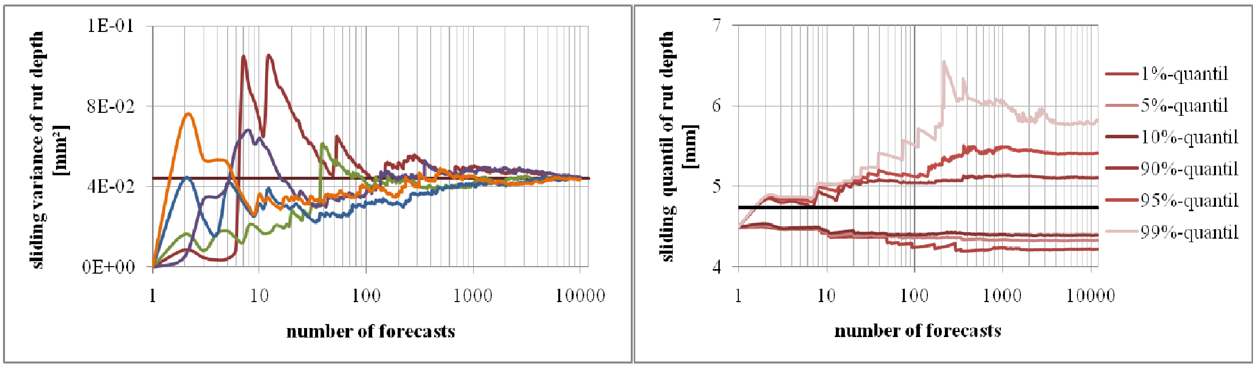


Figure 12: Statistical parameters (left: variances, right: quantiles) depending on the number forecasts / single predictions (left: load package size = 250 load cycles, right: load package size = 1,000 load cycles)

1,000 single predictions using this procedure are needed to determined stabile statistical parameters (figure 12).

## 5. MODEL CACULATION – SIMULATION AND PREDICTION OF RUTTING

The analysis of impacts of climate changes of the rut formations have been carried out using selected boundary conditions. These boundary conditions are described shortly in the following table.

Table 1: Boundary conditions for the model calculations

| **Pavement** | | |
|---|---|---|
| ***layer*** | ***thickness*** | ***material properties*** |
| *asphalt surface layer* | 4 cm | stiffness modulus of asphalt surface layer, asphalt binder and asphalt base course according [16]<br>Poisson's ratio = 0.35<br>adhesion between asphalt base course and frost blanket course = none (otherwise - all) |
| *asphalt binder course* | 8 cm | |
| *asphalt base course* | 22 cm | |
| *frost blanket course* | 56 cm | modulus of deformation = 120 N/mm²<br>Poisson's ratio = 0.5 |
| *formation* | ∞ | modulus of deformation = 45 N/mm²<br>Poisson's ratio = 0.5 |
| **Traffic loading** | | |
| *first year of forecast* | 2,500,000 load cycles | |
| *annual growth rate* | 5.0 % | |
| *axle load distribution* | axle load distribution for long distance traffic [16] | |
| **Temperature conditions** | | |
| *temperature profiles* | 204 absolute characteristic temperature profiles [12] | |
| *frequency of profiles* | results of thermal prediction simulation using scenario C20 as well as A1B run 1 and run 2 | |
| **Simulation conditions** | | |
| *simulation period* | 15 years per prediction | |
| *temperature intervals* | 5 temperature intervals according figure 10 | |
| *load package size* | 1,000 load cycles per load package | |
| *Number of forecasts* | 2,000 single predictions | |

The loading situations of asphalt pavements will be sorted randomly using the rut forecast procedure described in chapter 4. For each forecast 2,000 single predictions have been carried out to deduce statistical parameters. The results of the rut forecasts are probability distributions of rut depth after a defined service life. Figure 13 shows the probability distributions of rut depth after a service life of 15 years for both runs of emission scenario A1B as well as for two different service life periods. The corresponding rut formations are presented in figure 14 as a box-plot. Thereby the median and the range of 50% and 95% respective results (predicted rut depth) are presented. Both figures show that significant differences of rut formations can be expected in consequence of the different climatic conditions of both periods. The rut depth after a 15 years service life is greater in the second period than in the first. The variability of rut depth will also be increased in consequence of the randomness of the axle load and the temperature state.

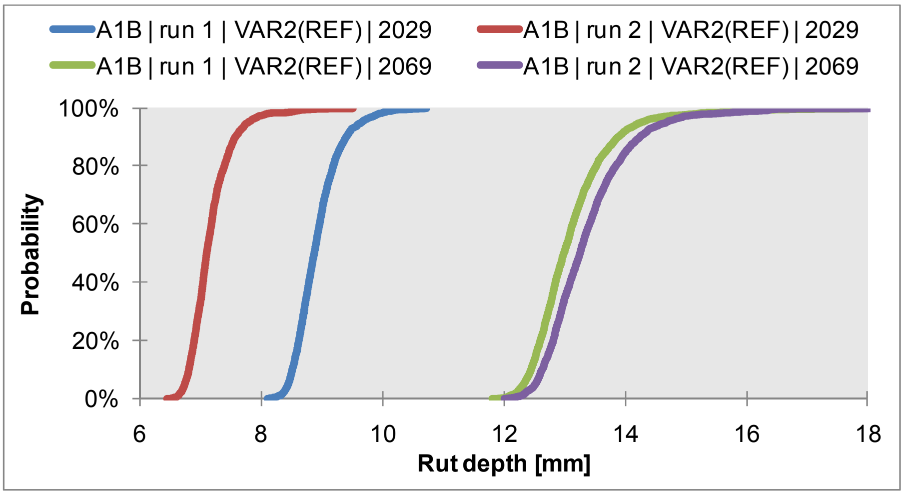


Figure 13: Probability distribution of rut depth after a service life of 15 years

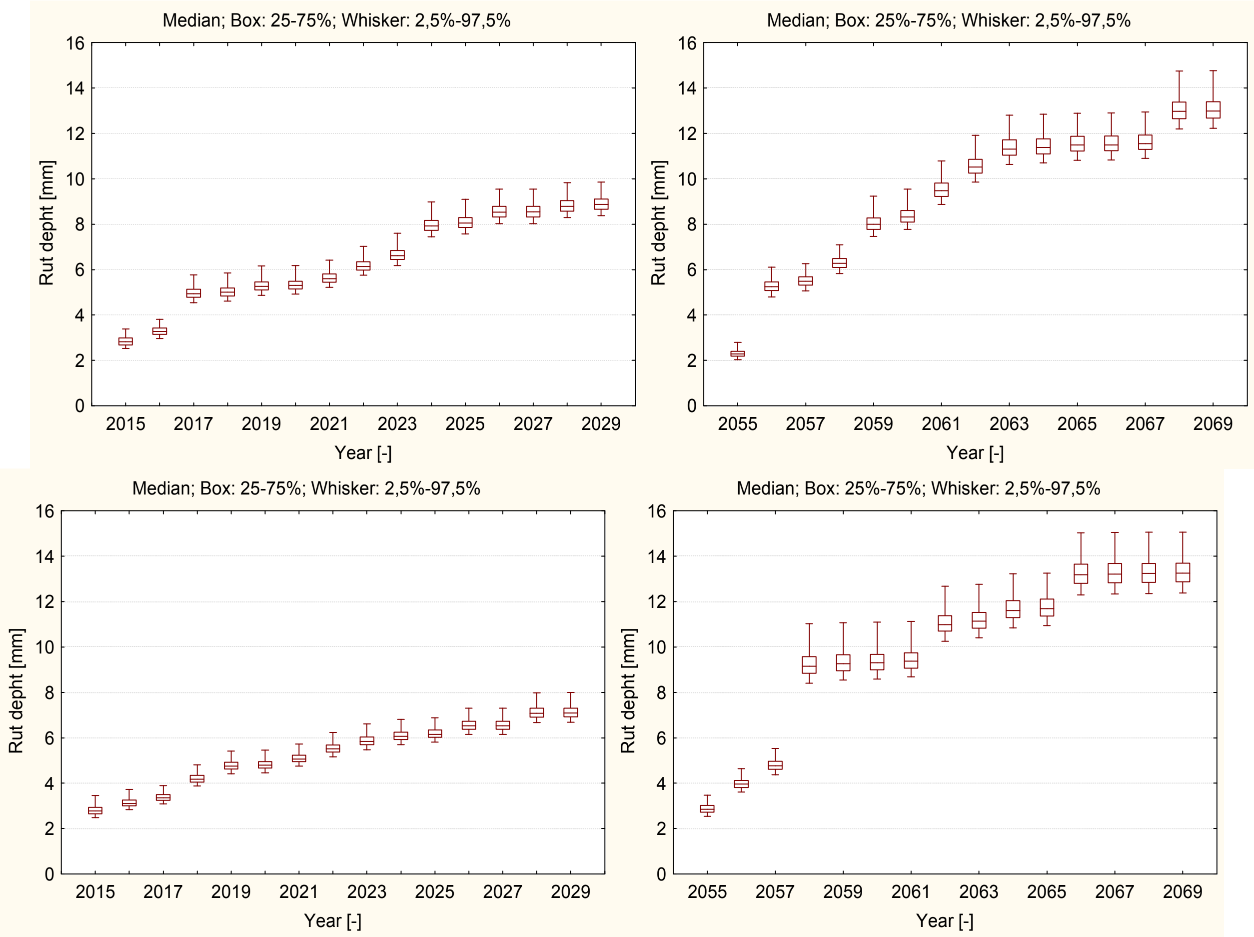


Figure 14: Rut formations of different periods (left: 2015 – 2029; right: 2055 – 2069) and two runs of the scenario A1B (left: A1B run 1; right: A1B run 2) using variant 2 of the thermo-physical parameters - range of the annual rut depth where being 50% and 95% of all predicted ruts

Figure 15 shows the relative trends of the 15 years rut depth within the period 2010 – 2069 concerning to the average value of the period 1980 – 2009. The rut depth can be significant increased in consequence of the climatic change considering the scenario A1B. The forecast indicates a magnification of the rut depth by a factor from 1.4 to 1.6.

The results show that climatic changes in first half of this century have little or no influence of rut formation. A significant increase of rut depth will be noticeable only in the second half of this century. This trend correlates with the trend of the relevant temperature ranges for rut formations (figures 7 and 8) and can be verified with the contrary trends of global radiation and atmospheric counter-radiation (figure 5).

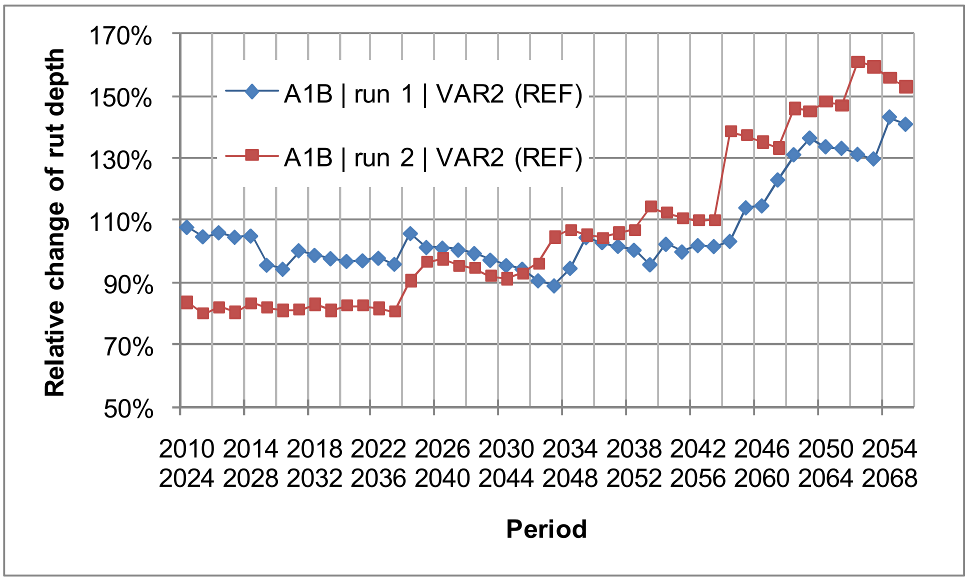


Figure 15: Rut depth after a service life of 15 year for the period 2010 - 2069 using variant 2 of the thermo-physical material properties

The different thermo-physical material properties which are the basis of the rut simulations and forecasts have a significant influence on the rut formations. The rut formations (95%-quantiles) depending on the three analysed parameter variants (figure 4) are presented in figure 16 for two different periods (15 year service life) exemplary.

The ruts after a service life of 15 years will be forecasted with a depth (95%-quantile) of about 10 mm (period: 2015-2029) and about 14 mm (period: 2055-2069) using the reference variant (VAR2). However, the rut depth (95%-quantile) for the variants VAR2 and VAR3 will be forecasted with 7 mm and 10 mm (VAR1) and 16 mm and 20 mm (VAR3) respectively. The forecasted rut depth using VAR3 are about 50% deeper compared to the reference variant VAR2 and even about 100% than VAR1.

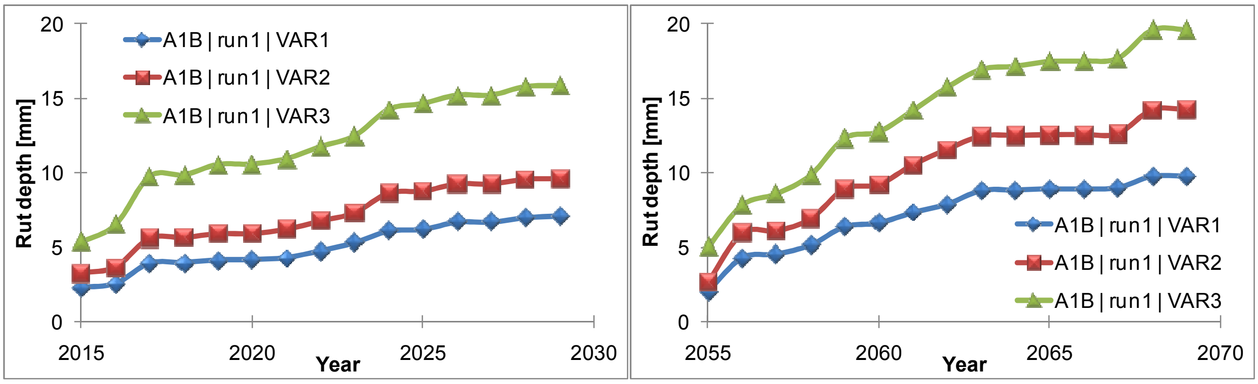


Figure 16: Rut formations (95%-quantile) for a 15 year service life depending on parameter variants of the thermo-physical material properties

The variability of single predictions for each forecast process will be influenced considerably by the thermo-physical material properties used at rut forecast. Figure 17 shows the variances of rut depth after a service life of 15 years depending on different parameter variants and prediction periods.

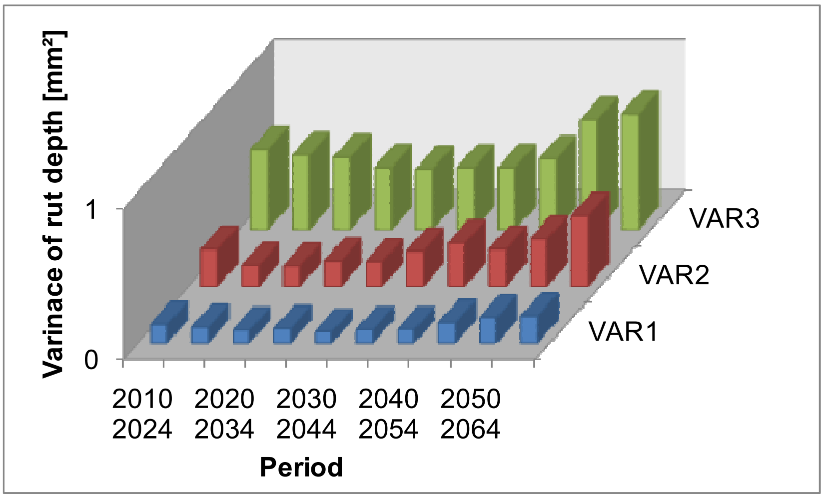


Figure 16: Variances of rut formations (95%-quantile) for different periods with a 15 year service life depending parameter variants of the thermo-physical material properties (emission scenario A1B run 1)

## 6. SUMMARY

Road damages have a significant influence on the usability of a road. One of the most frequently occurring damage is permanent deformation of pavement surface as a result of the deformation of individual layers. Among other issues, an accurate forecast and evaluation of ruts will be the basis for effective maintenance management. The bases of such forecast are adequate prediction and material models as well as considering the load variables (axle load and temperature condition) as accurately as possible.

On basis for forecasting the future rutting development are thermo-physical simulations, which are used to determine thermal loads of the asphalt construction in dependence of different climate parameters and their changes according to the selected climate scenario. On the other hand a statistic-mechanical model simulates the rutting progress depending on traffic and thermal loads as well as on material characteristics. The latter are determined from complex triaxial pressure-swell-tests.
From the rutting forecast model results statistical conclusions of the rut progress depending on traffic loads, mechanical asphalt characteristics and the future climate and temperature conditions.

It is most likely, that the climate will be changed in this century. If we assume the occurrence of emission scenario A1B, it is highly probable that the thermal stresses acting on asphalt pavement structures will drastically increase in some cases. It is also most likely, that the rut formation will be significant increase in consequence of changing thermal condition in asphalt pavement structures. However, the negative effects of the climatic changes on rut formation will only be detected in the second half of the century. The extent of the permanent deformations of asphalt pavements can be affected significantly influencing thermo-physical material properties specifically.

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