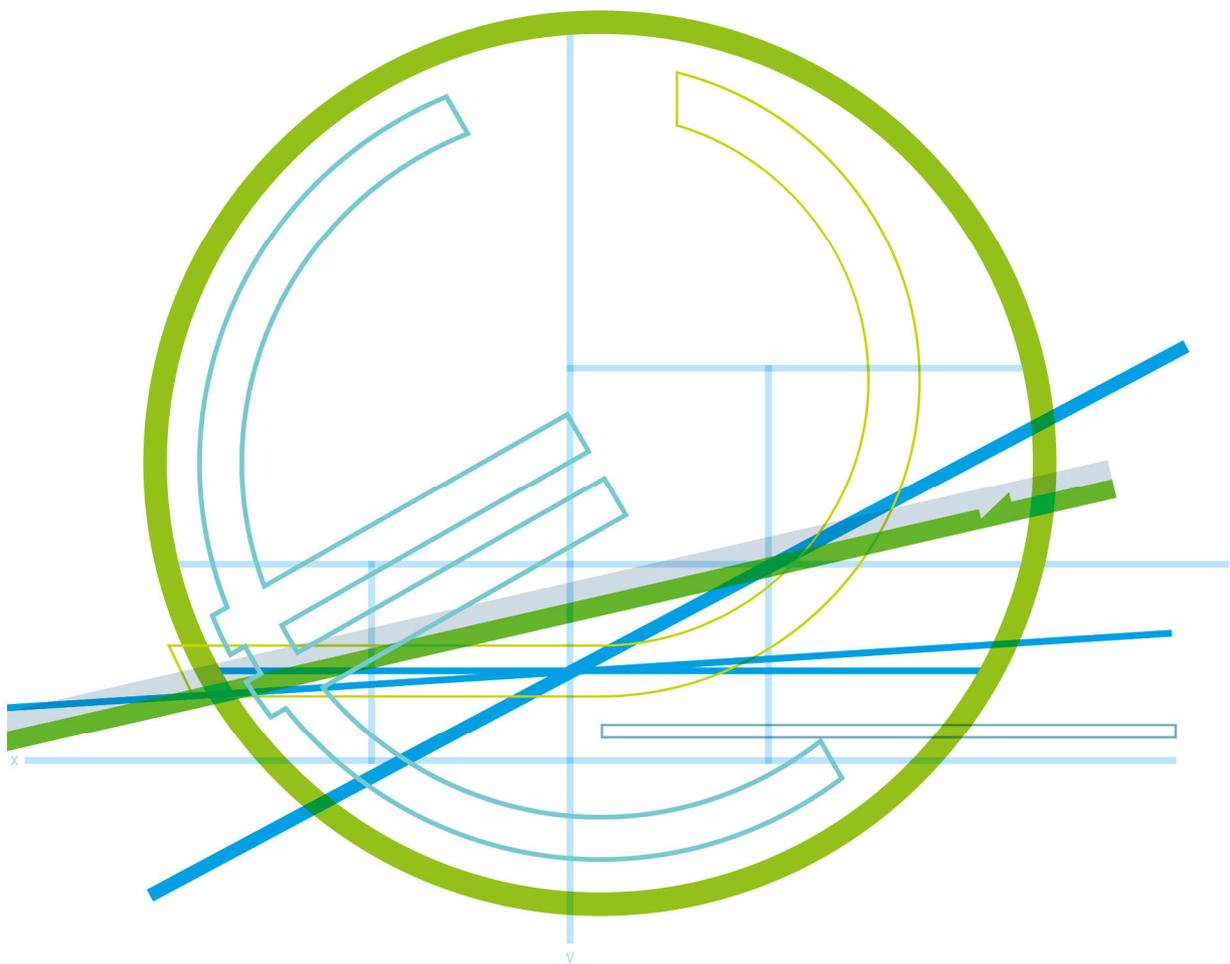


Direct Attribution of the Anthropogenic climate signal to Phenological observations



PREFACE

The **BLUE GLOBE REPORT** shows the competence and variety of approaches chosen by Austrian industry and research in striving to come up with solutions for the central tasks of the future. The Climate and Energy Fund has made it its strategy to provide specific impulses through long-term subsidy programs, programs to create an excellent starting position for Austrian companies and institutions in international competition.

Each year the Climate and Energy Fund has a budget of up to 150 million euros for promoting sustainable energy and transport projects in line with the climate protection goals. These funds are used to support ideas, concepts and projects in the areas of research, mobility, and market penetration.

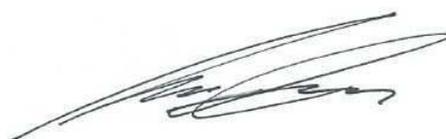
The Climate and Energy Fund's **BLUE GLOBE REPORT** informs about project results thus supporting the application of innovation in practice. In addition to technological innovations in energy and transport it also discusses social topics and the scientific base for political planning processes. The **BLUE GLOBE REPORT** is made available to the interested public via the www.klimafonds.gv.at website and invites readers to a critical discussion.

The current report documents the results of a project from the „ACRP“ research program with the goal of providing the scientific basis for increasingly important decisions on climate adjustment measures and as such constituting a solid basis on which stakeholders can base their decisions.

We are the right partner for whoever decides to take a sustainable part in the future. The Climate and Energy Fund promotes innovative solutions for the future!



Theresia Vogel
CEO, Climate and Energy Fund



Ingmar Höbarth
CEO, Climate and Energy Fund

B) Project overview

1 Executive Summary

Introduction

The global mean temperature has risen by $0.74^{\circ}\text{C} \pm 0.18^{\circ}\text{C}$ over the last 100 years (1906 – 2005). Observed responses to that temperature increase are found across a wide range of systems as well as regions. During the last 30 to 50 years a general shift of spring phases by about 2.3 to 5.2 days/decade has been documented predominantly in the mid to higher latitudes of the Northern Hemisphere. The shift of the phenological entry dates to earlier occurrences appears consistent with temperature increases over the same time period in the same region. At this stage one might be interested in testing the hypothesis that the increasing temperatures and the associated reaction of the biological systems have both the same underlying cause, the human-induced increase of greenhouse gas concentrations. To formally link cause and effect, two concepts, called detection and attribution, have been created. Detection is the process of demonstrating that an observed change is significantly different (in a statistical sense) from a change that can be expected by natural variability only. In this study the method of direct attribution has been applied, which requires an 'end-to-end' modelling system that includes the simulation of the phenological entry dates as function of temperature. It is able to simulate the response of the phenological entry dates to greenhouse-gas increases. The output of this modelling system can then directly be compared with observed changes in natural systems and thereby the reason for the observed changes may be isolated.

Our study is an end-to-end analysis of the human impact on the seasonal vegetation cycle or phenology in Central Europe. It includes the detection of the near surface temperature variability and the variability of phenological time series in relation to their natural variability and the attribution to the climate forcing scenarios "historical" (all forcings = natural + anthropogenic forcings) and "historicalNat" (only natural forcings) via consistency tests. For that purpose a phenology module was developed, which was fed by the results of the regional climate model COSMO-CLM and global climate models, which were driven by the various forcing scenarios. By comparing observations with model results the anthropogenic impact on phenology in Central Europe could be quantified.

Detection temperature

The piControl (pre-industrial forcing of the climate) runs are assumed to represent a first approximation to the natural internal climate variability, not influenced by human activities. Generally the observed trends are found in the upper range of the natural variability given by the piControl runs. The observed change is in a statistical sense significantly different from the change that can be expected from natural variability alone. The observed winter trends fall into the range of the piControl trends, whereas the observed spring and autumn trends might be termed unusual (trends $p_{95\%}$ piControl < trends observed < trends piControl max) and the summer trends exceptional (trends observed > trends piControl max).

Attribution temperature

The selected GCM model ensembles clearly show a difference between the historical and historicalNat runs, even when restricting the region to Central Europe and restricting the time to individual seasons. The variability of winter time series and trends is rather large and the difference between the piControl, historical and historicalNat cases is least clear. In case of spring, summer and autumn one finds the trends of the piControl and historicalNat runs to be consistent, also those of the historical runs and the observations, whereas those of the piControl and historicalNat runs are inconsistent with those of the historical runs and observations. The observed temperature changes in the climate system over Central Europe are consistent with the estimated response (historical) and not consistent with alternative, physically plausible explanations (e.g. historicalNat).

Detection phenology

A main restriction for the consistency analysis of the phenological time series is their shortness, because the phenological time series only start in 1951. The maximum observed trends of 16 of the 18 selected phenological phases reach beyond maximum trends of both piControl runs (CanESM2 and CNRM-CM5). The observed change is in a statistical sense significantly different from the change that can be expected from natural variability alone. The observed phenological trends can be termed unusual in 2 cases (trends $p_{95\%}$ piControl < trends observed < trends piControl max) and exceptional in 16 cases (trends observed > trends piControl max).

Attribution phenology

Attribution results demonstrate the consistency between historical runs and observations and between historicalNat and piControl runs. Also the inconsistency between historical and historicalNat runs is obvious. These features can be observed for all 18 phases.

The observed shift of phenological phases to earlier entry dates in Central Europe is consistent with the estimated response of phenological phases to the regional temperature increase caused by the additional anthropogenic forcing (historical runs) and not consistent with alternative, physically plausible explanations that exclude the regional temperature increase (e.g. historicalNat runs).

Conclusions

- Detection and attribution can be done based on a consistency approach and on GCMs over a restricted area for temperature and phenological entry dates as impact variable.
- This study shows on basis of climate model simulations that there is a human influence on climate visible, which has impacted temperature and phenology in Central Europe during the last decades.

Outlook

Based on the encouraging results of DATAPHEN one could extend generalise the detection and attribution study and quantify the human influence on the climate at regional and local scales. Or in other words: how far has the anthropocene, that is the observed climate influenced by man, already moved away from its natural state because of human interference. Therefore it would make very much sense to continue with similar studies for Central Europe, the Alps and Austria. Suggested are for instance an atmospheric multivariable study based on the HISTALP dataset (<http://www.zamg.at/histalp/>), a repetition of this study with the Austrian phenological record and an application of detection and attribution to length and volume of Alpine glaciers.

2 Background and objectives

Introduction

The global mean temperature has risen by $0.74^{\circ}\text{C} \pm 0.18^{\circ}\text{C}$ over the last 100 years (1906 – 2005). Observed responses to that temperature increase are found across a wide range of systems as well as regions. During the last 30 to 50 years a general shift of spring phases by about 2.3 to 5.2 days/decade has been documented predominantly in the mid to higher latitudes of the Northern Hemisphere. The shift of the phenological entry dates to earlier occurrences appears consistent with temperature increases over the same time period in the same region. At this stage one might be interested in testing the hypothesis that the increasing temperatures and the associated reaction of the biological systems have both the same underlying cause, the human-induced increase of greenhouse gas concentrations. To formally link cause and effect, two concepts, called detection and attribution, have been created (Mitchell and Karoly, 2001, Rosenzweig et al., 2007 and 2008). Detection is the process of demonstrating that an observed change is significantly different (in a statistical sense) from the change that can be expected by natural variability only. The unequivocal attribution of climate change to anthropogenic causes (i.e., the isolation of cause and effect) would require controlled experiments with the climate system,

which is impossible. Instead a statistical analysis is required and the careful assessment of the evidence to demonstrate that the observed changes in both the climate and the natural system:

- are unlikely to be entirely due to natural variability alone,
- consistent with the estimated responses of either physical or biological systems to a given regional climate change and
- not consistent with alternative, physically plausible explanations of observed change that exclude regional climate change.

Summarising the large amount of literature concerning the attribution problem the AR4 (Hegerl et al., 2007) states that most of the observed increase in global average temperatures since the mid-twentieth century is very likely to be due to the observed increase in anthropogenic greenhouse gas concentrations. Up to this stage attribution has been applied to establish a statistical link between external forcings and the reaction of the climate system. Now the concept of attribution has to be carried one step further, linking external forcings with impact phenomena via the climate system. The method of direct attribution requires an 'end-to-end' modelling system that includes explicit representations of all of the main processes (climatic and non-climatic) that contribute to the variability of the system under study. It is able to simulate the response to greenhouse-gas increases as well as other factors that can cause changes in the observed impact. The output of such a modelling system can then directly be compared with observed changes in natural systems and thereby the reason for the observed change may be isolated.

Overall objective

The overall objective of this project is the application of the above described direct attribution approach to identify the anthropogenic impact on the observed shift of phenological events in Central Europe to earlier entry dates. For that purpose a phenology module was developed, which was fed by the results of the regional climate model CCLM and global climate models, which were driven by essentially two forcing scenarios, "historicalNat", where only natural forcings are applied and "historical", where natural and anthropogenic forcings are applied. By comparing observations with model results the anthropogenic impact on phenology in central Europe could be quantified.

Main topics

In order to achieve the above described overall objective, a number of steps had to be worked on.

The first part of the study dealt with a number of technical questions, which prepared the basis for the subsequent consistency study. Among the activities in this project phase have to be enumerated the preparation of the phenological and climate model data sets, the interpolation of the TSM (Temperature Sum Model) parameters to the CCLM model grid points, the interpolation of the global climate model temperature time series to the ECSN (European Climate Support Network) station coordinates, the calculation of the TSM parameters at the ECSN stations, running of the TSM at the ECSN stations fed with climate model data, and many more.

During the second part of the work the statistical methods for detection and attribution had to be developed, at first for temperature and then for phenology also. Based on the results of this section conclusions could be formulated.

3 Project contents and results

Work done and methods used

Our study is an end-to-end analysis of the human impact on the seasonal vegetation cycle or phenology in Central Europe (Fig. 1). It includes the detection of the near surface temperature variability and the variability of phenological time series in relation to the natural variability and the attribution to the climate forcing scenarios

“historical” (all forcings = natural + anthropogenic forcings) and “historicalNat” (only natural forcings) via consistency tests. There are a number of detection and attribution methods applied in literature, the most quantitative of them being called the optimum fingerprint technique, and less quantitative methods, like consistency tests (Hegerl and Zwiers, 2011). An adaptation of the latter appeared to be the kind of method best suited for the purposes of this project.

Data sets

For this project phenological entry dates from PEP725 are available, spanning 59 years from 1951 to 2009. A set of 36 selected phenological phases has been saved in a netCDF file. After checking the quality of the TSM, 18 phases have been excluded, leaving 18 phases, which can be modelled by the TSM with reasonable quality (Tab. 1, Fig. 3 and 4). The spatial distribution of the observations is more or less focused on Germany with some additional data from Austria, Lithuania, Slovenia, and Slovakia (Fig. 2).

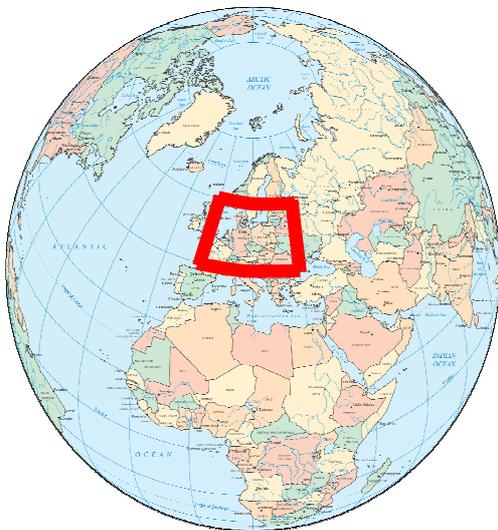


Fig. 1. The study region of this project is marked by the red square.

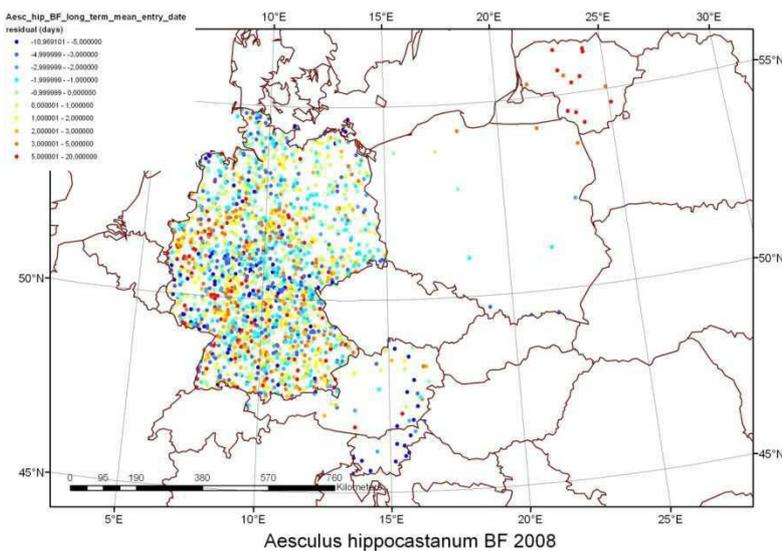


Fig. 2: Map depicting the spatial distribution of stations with valid data for *Aesculus hippocastanum* Beginning of Flowering in 2008. The colours represent the residuum of the multiple regression between the entry dates and the station coordinates (lambda, phi and zet).

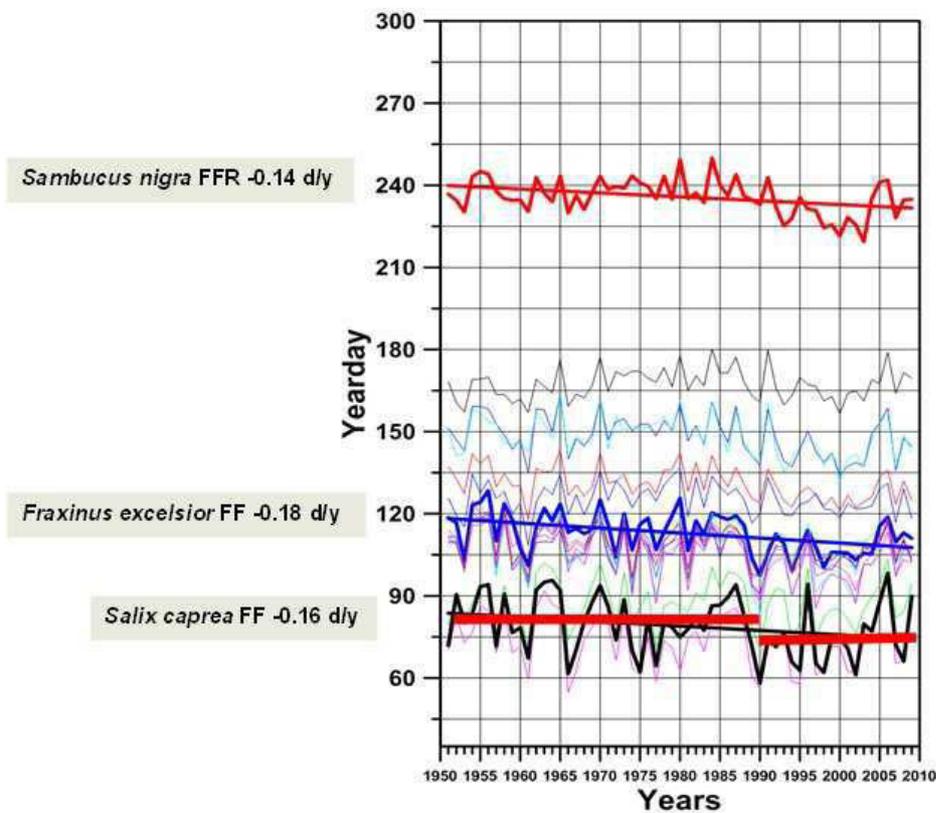


Fig. 3: Time series of the 18 phenological phases selected for this study. For demonstration purposes three of them have been plotted with bold curves and trend regressions added (days/year from 1951 – 2009), *Salix caprea* (goat willow) first flowers open, *Fraxinus excelsior* (common ash) first flowers open, *Sambucus nigra* (black elder) first ripe fruits. The red bars over the time series of *Salix caprea* first flowers open indicates the discontinuity of the trend, which can be found in a number of phenological time series.

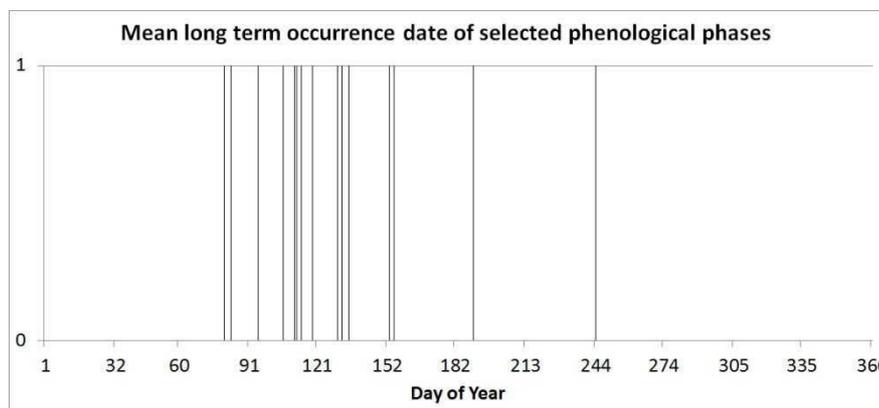


Fig. 4: Mean long term occurrence date of the selected phenological phases (see Tab. 2).

Tab. 1: List of phenological phases selected for this study. The second column shows the mean long term entry date of the phase over all available European stations (station elevation taken into consideration via height reduction).

	Day of year	Phenological phase
1	112.40	Aesculus hippocastanum: Leaf unfolding(first visible leaf stalk)
2	130.70	Aesculus hippocastanum: First flowers open
3	111.40	Alnus glutinosa: Leaf unfolding(first visible leaf stalk)
4	111.70	Betula pendula (B. verrucosa, B. alba): Leaf unfolding(first visible leaf stalk)
5	155.40	Sambucus nigra: First flowers open
6	244.80	Sambucus nigra: First ripe fruits
7	80.39	Tussilago farfara: First flowers open
8	112.10	Acer platanoides: First flowers open
9	95.08	Anemone nemorosa: First flowers open
10	119.30	Fraxinus excelsior: First flowers open
11	106.10	Larix decidua: First needle unfolding
12	153.30	Robinia pseudoacacia: First flowers open
13	83.22	Salix caprea: First flowers open
14	135.80	Sorbus aucuparia: First flowers open
15	132.70	Syringa vulgaris: First flowers open
16	111.10	Taraxacum officinale: First flowers open
17	190.10	Prunus avium (Cerasus avium) (late cultivar by name): Fruits ripe for picking
18	114.20	Ribes rubrum: First flowers open

The data had to be interpolated to the rotated grid of the CCLM with a resolution of 50 km or about 0.5°. In order to increase the limited spatial extent of the phenological observation networks, we extrapolated the phenological data somewhat by applying height reduced inverse distance weighting with an interpolation radius of 500 km and a minimum number of 3 neighbouring stations.

The daily mean 2 m temperatures are available from the ECA&D website (Haylock et al., 2008), as station time series as well as time series on various grids. The data cover most of Europe. Station time series are available from 1st of January 1950 with a near real time update.

A gridded ECA&D data set was interpolated to the rotated CCLM grid at the ZAMG by Ivonne Anders.

The climate model data set relies mainly on publicly available CMIP5 runs, which are supplemented by 6 ECHAM5 runs (the originally chosen one, 3 “historical” and 3 “historicalNat” runs) and 3 ECHO-G runs (3 “historicalNat” runs, thanks to Sebastian Wagner from the GKSS):

- 2 piControl runs (CNRM-CM5 and CanESM2)
- 27 runs „historicalNat“ (7 models)
- 36 runs „historical“ (6 models)

- 65 model runs all together

From these model runs the near surface temperature TAS (equivalent to the 2 m temperature) was extracted in monthly (1850 – 2005) and daily (1951 – 2005) resolutions.

Deduction of TSM parameters

Phenological entry dates were simulated with a 3 parameter temperature sum model (TSM), which uses daily mean temperature time series as input. The input may be observed temperature data, temperatures from reanalysis projects or climate models. In the latter case the impact of climate scenarios on vegetation, pollen emission or the growing season can be assessed.

In case of the TSM the entry date t_2 is a function of the starting date of temperature accumulation t_1 , the temperature sum F between t_1 and t_2 above the temperature threshold T_b : $t_2 = f(t_1, T_b, F)$. The state of forcing F (forcing units usually in degree days) is represented by

$$F = \int_{t_1}^{t_2} R_f(T(t)) dt \quad (1)$$

where t_1 is the starting date of temperature accumulation, t_2 the entry date of the phase and R_f the rates of forcing, which is defined as

$$R_f(T) = \begin{cases} 0 & \text{if } T < T_b \\ T - T_b & \text{if } T \geq T_b \end{cases} \quad (2)$$

where T is the daily mean temperature and T_b the temperature threshold. After the starting date of temperature accumulation the difference between the daily mean temperature T and the temperature threshold T_b is determined and summed up until the date t when the temperature sum F is reached. In the best case, this date should coincide with the observed phenological entry date t_2 . The optimum TSM parameters (t_1, T_b, F) were determined via the LUT (Look Up Table) method at each ECA&D station.

Regional climate model simulations

We used the CCLM regional climate model to provide the required climatological information for the phenological modelling. A set of GCM scenarios with and without anthropogenic forcing has been selected as drivers for the CCLM simulations (Tab. 3). To meet the requirements of the phenological model, the CCLM domain was setup to cover Europe with 50 km resolution. The time span of simulations was set to 1958 – 2002 for the reanalysis and 1940 – 2000 for the differently forced GCM runs so as to cover the phenological observational period.

It might be tempting to calculate the phenological entry dates simultaneously during the climate model runs, but that would have meant quite some effort to implement the temperature sum model into the CCLM source code. Therefore this idea had to be abandoned. Alternatively, running the CCLM simulations independently without the phenological model is much more flexible.

Table 2: Selection of CCLM forcing datasets.

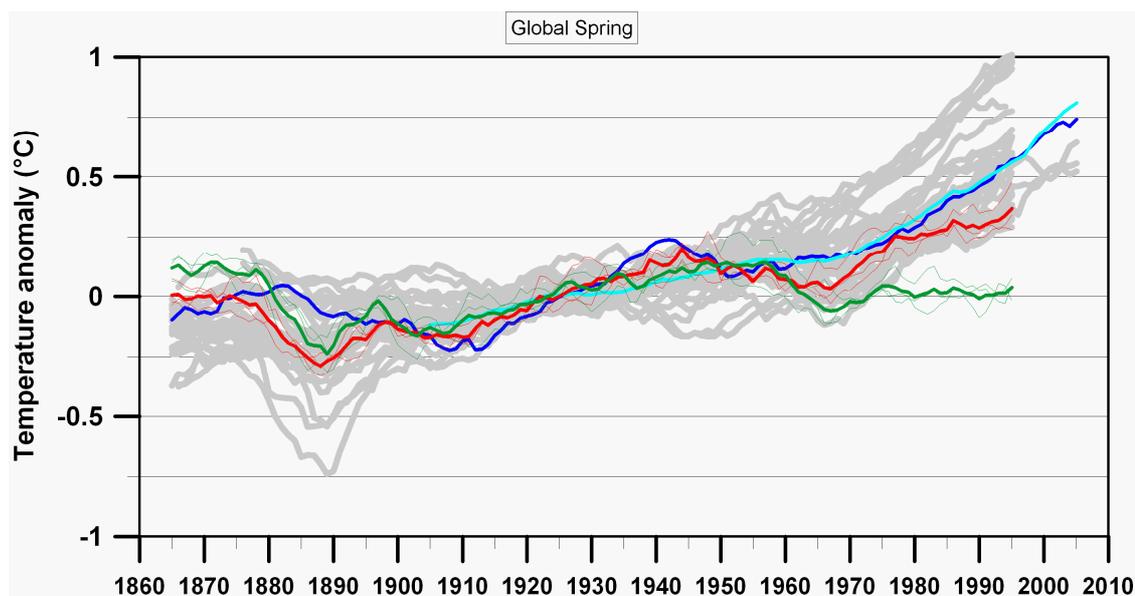
Exp	Scenario	Forcing	Link for model output	Remark/CERA dataset
1	Reanalysis	ERA40	ZAMG reclip:century	missing period 1948-1961 and 2002-present
2	Natural only (included SC-VA)	ECHAM5-MPI-OM run no.1	hurrikan.dkrz.de:/ut/m/m214002/EXP600/run608	IPCC MPI-ECHAM5_T63L31 MPI-OM_GR1.5L40_20C3M_nat,run no.1
3	Natural only (included SC-VA)	ECHAM5-MPI-OM run no.2	hurrikan.dkrz.de:/ut/m/m214002/EXP600/run609	IPCC MPI-ECHAM5_T63L31 MPI-OM_GR1.5L40_20C3M_nat run no.2
4	Natural only (included SC-VA)	ECHAM5-MPI-OM run no.3	hurrikan.dkrz.de:/ut/m/m214002/EXP600/run610	IPCC MPI-ECHAM5_T63L31 MPI-OM_GR1.5L40_20C3M_nat run no.3
5	Anthropogenic + natural (included SC-VA)	ECHAM5-MPI-OM run no.1	hurrikan.dkrz.de:/ut/m/m214002/EXP500/run586	IPCC MPI-ECHAM5_T63L31 MPI-OM_GR1.5L40_20C3M_all run no.1
6	Anthropogenic + natural (included SC-VA)	ECHAM5-MPI-OM run no.2	hurrikan.dkrz.de:/ut/m/m214002/EXP500/run588	IPCC MPI-ECHAM5_T63L31 MPI-OM_GR1.5L40_20C3M_all run no.2
7	Anthropogenic + natural (included SC-VA)	ECHAM5-MPI-OM run no.3	hurrikan.dkrz.de:/ut/m/m214002/EXP500/run589	IPCC MPI-ECHAM5_T63L31 MPI-OM_GR1.5L40_20C3M_all run no.3

The CCLM model runs

All 7 planned CCLM runs could be completed. The downscaled reanalysis ERA-40 run was provided within the reclip:century project. The simulations based on ECHAM5-MPI-OM output with “natural” forcing and “anthropogenic + natural” forcing were conducted on Supercomputer IBM Cluster at the ECMWF in Reading. The input data have been extracted from the CERA database at the DKRZ and transferred to ECMWF MARS tape system. Optimal number of nodes vs. computing billing units were tested. The required output from climate simulations is the daily mean 2m-temperature, which has been prepared for phenological modelling as gridded dataset in NetCDF format and as time series for approximately 60 selected ECSN monitoring stations in ASCII format.

Results

The anthropogenic climate signal is clearly visible in the GCM runs (Fig. 5). The restriction of the spatial extent to Europe and a particular season enhances the variability and makes a clear separation of the realisations difficult. This GCM behaviour is in fact translated down to the CCLM runs (Fig. 6). If one restricts the global ECHAM5 runs to Europe, autumn and winter subjectively show some idea of a difference between historical and historicalNat runs, but in spring and summer there are no differences obvious.



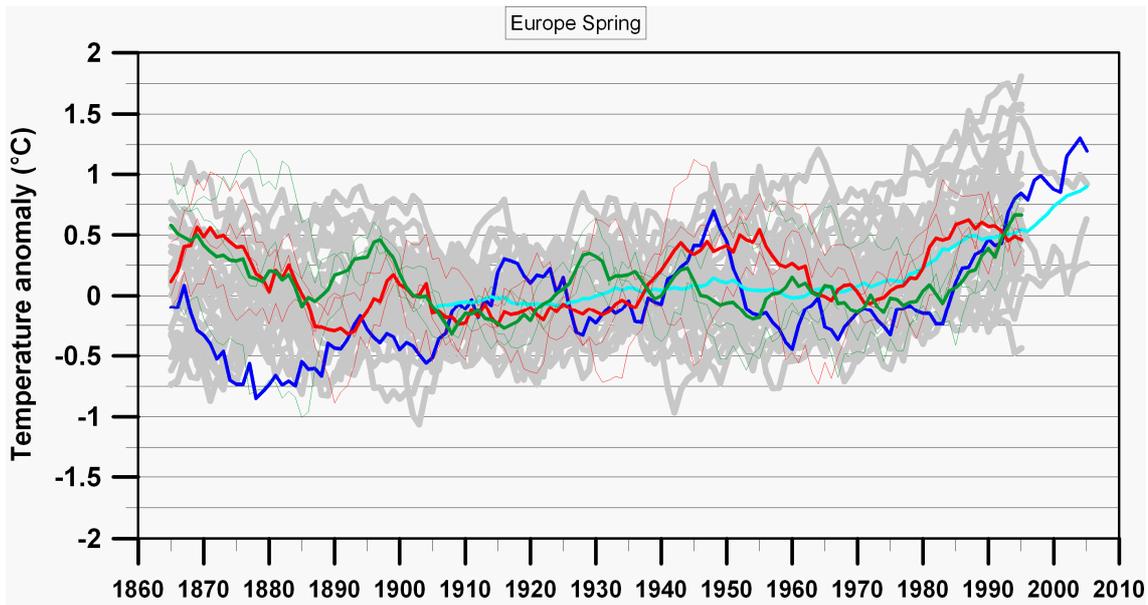


Fig. 5: Spring 2 m temperature anomalies relative to 1901 – 1950, smoothed with an 11 year moving average. KNMI Climate Explorer historical (all forcings) ensemble (32 members, grey) and ensemble mean (light blue) and CRU observational data set (blue); 3 ECHAM5 runs historical (red, ensemble mean thick line), historicalNat (natural forcings only, green, ensemble mean thick line); global (top) and Europe (0-25E, 45-55N, bottom).

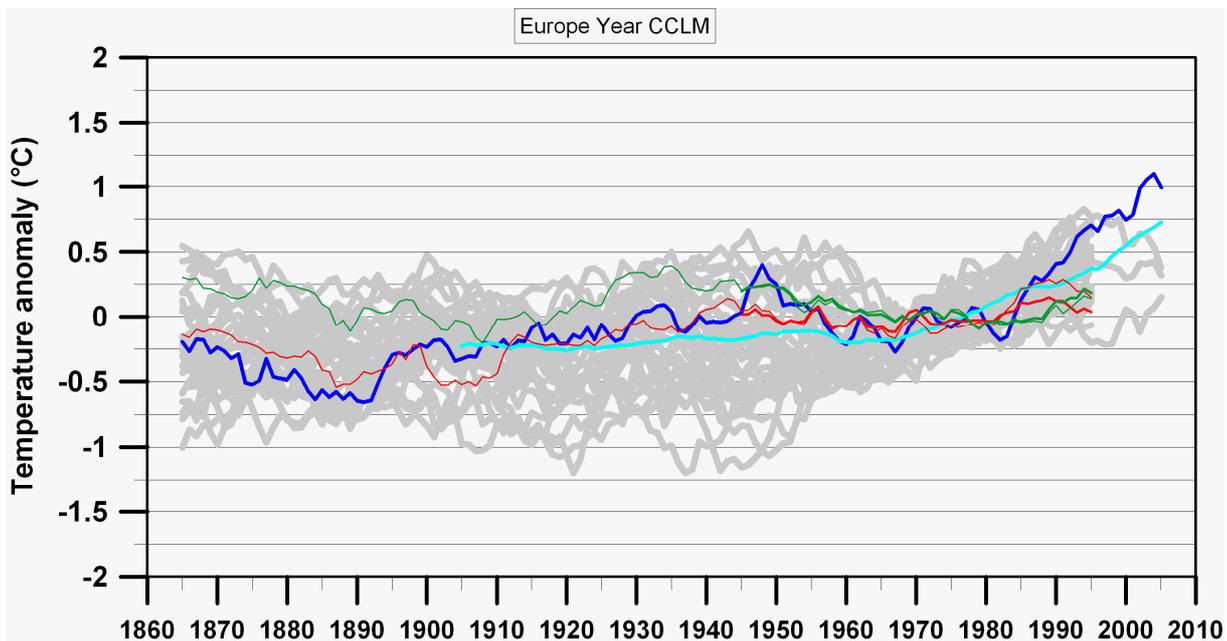


Fig. 6: Yearly mean 2 m temperature anomalies relative to 1961 – 1990, smoothed with an 11 year moving average. KNMI Climate Explorer historical (all forcings) ensemble (32 members, grey) and ensemble mean (light blue) and CRU observational data set (blue); 3 ECHAM5 runs historical (red, ensemble mean thin line), historicalNat (green, ensemble mean thin); ensemble mean CCLM based on ECHAM5 runs historical (thick red line), historicalNat only (thick green line); Europe (0-25E, 45-55N).

Conclusions from the global analysis

- Trends of observations and ensemble means are quite close, except that the models are not able to reproduce the maximum around 1940.
- Observed temperature increase begins around 1970, modelled temperature increase starts 5 – 10 years earlier.
- The trends of the ECHAM5 historical simulations are in the lowest range of the KNMI model ensemble from 1970 – 2000, the last 30 model years.
- The ECHAM5 historicalNat only ensemble mean is always clearly sticking out of the KNMI ensemble showing no temperature increase after 1970.

Europe year and seasons

- In the yearly mean temperature case ECHAM5 historical shows no trend or a slightly decreasing trend from 1985 to 1995, in contrast to observations and the KNMI ensemble mean. The ECHAM5 historicalNat ensemble mean does show a small trend, moving its temperature curve to the lower margin of the KNMI ensemble.
- Winter. Variability of all curves high. ECHAM5 historicalNat are clearly in the lower margin. Modelled and observed trends are similar.
- Spring. No difference between ECHAM5 historical and historicalNat. If the curves were not coloured, one could not relate them to their model runs. The observed trend is much larger than any modelled trends after 1980. This is the most decisive season for phenology, so, if the pheno models are fed with the temperature time series of this phase only based on the ECHAM5 runs, there is no difference to be expected between the various forcing scenarios.
- Summer. ECHAM5 historicalNat is in the lower range of model ensemble. The observed trend is much larger than any modelled trends after 1980. Models appear to have difficulties simulating the observed trend during spring and summer.
- Just for comparison purposes the CCLM temperature time series are also plotted here (Fig. 6). There is no essential difference between the ECHAM5 and CCLM time series.

Conclusion from the above comparisons

We urgently needed more climate model runs. The ECHAM5 runs are rather atypical compared with other climate model runs. This meant a change of the original work plan, there was no time and means to dynamically downscale a greater number of global climate model runs and we had to continue our work with global climate model runs.

Consistency analysis applied to temperature

The selected model ensembles clearly show a difference between the historical and historicalNat runs, even when restricting the region to Central Europe and restricting the time to individual seasons (Fig. 7).

If a consistency test should make sense, one has to make sure that the piControl run used as a reference for the natural climate variability is in fact close to the observed natural variability. Just for demonstration purposes, the actual time series of means and trend values for the piControl and the observed temperature time series have been plotted (Fig. 8).

Dean and Stott (2009, p 6224) formulate the basic idea of a comparison of the piControl run variability with the observed variability thus: "However, if the observational standard deviation lies within this confidence interval of the model deviations, then we have some evidence that the model can be said to have variability over these selected time scales, which is consistent with the observational record" and restrict the usefulness of this approach a few lines later: "Given the very short observational record it is not possible to determine definitely whether the models are able to capture the real world variability of 50-yr temperature trends". A look at the autocorrelation of the piControl and especially the observed time series underlines the correctness of their last statement. The observational time period of 150 years is in fact too short to guarantee a sufficiently large set of independent 50 year trends. We do not know anything about natural variability in the time scales necessary, in order to evaluate the recent trends. So the surrogate of the natural variability based on piControl runs is a rather difficult substitute for reality.

In spite of the mentioned restrictions, a comparison was done between the observed and the modelled natural climate variability. Two 1000 year piControl runs (CanESM2 and CNRM-CM5) were resampled in 100 year time segments, which advanced by 50 years. The mean, maximum and minimum standard deviation of mean and trend values over a range of sub-periods (year-to-year, 10, 20, 30, 40 and 50 years) within the 100 year period has been plotted in Fig. 9. For comparison purposes the blue dots represent the standard deviation of the respective quantities of the HadCRUT3 observational data set over the 100 year period from 1850 to 1949, which is thought to be least influenced by human activities. From Fig. 9 one has to conclude that the standard deviation values of the piControl runs and the observations are comparable, although for instance 30 and 50 year trend periods of the piControl runs show on average a higher standard deviation than those of the observed temperature time series. If the standard deviations of the means and trends of the piControl runs and the short observed time series are similar, one could be confident to use the piControl runs as reference for the variability of the natural background, as a frame for what can be expected from the natural background.

The largest of the observed trends range beyond the 95% percentile of any of the piControl runs, except for winter (Fig. 10 and 11). Generally the observed trends are found in the upper range of the natural variability given by the piControl runs. In case of the observed summer trends, they appear to be exceptional in the sense that they are larger than the maximum trends of all three piControl runs.

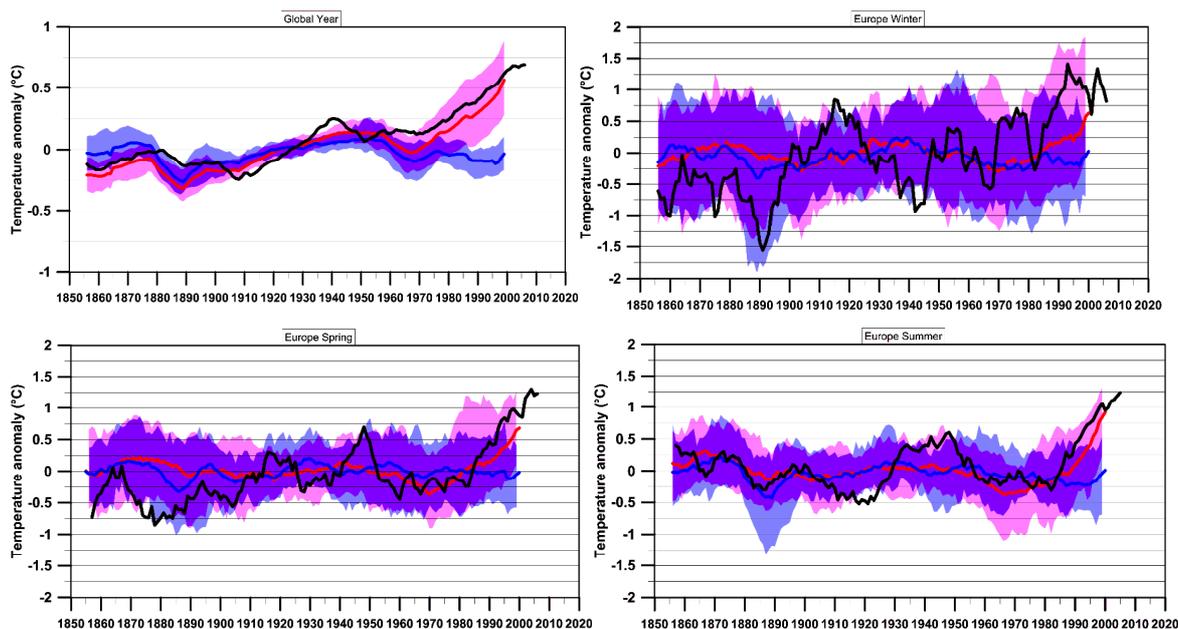


Fig. 7: 5% and 95% quantiles (coloured areas) and means (as curves) of climate model simulation time series in comparison, 11 year moving average, with historical (pink) and historicalNat (blue) forcings. Models according to Tab. 2. Observations (black) from the HadCRUT3 data set.

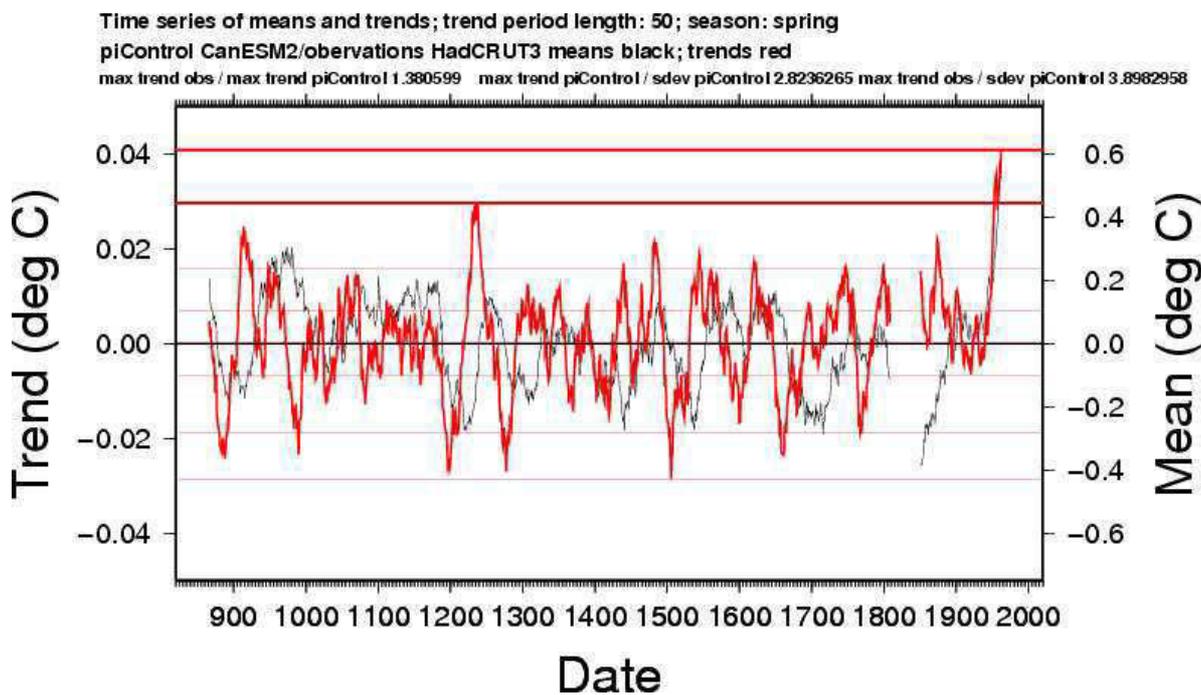


Fig. 8: European time series of means (black) and trends (red) for yearly advancing time periods of 50 years of the CanESM2 piControl (up to 19th century) run and of the observational time series HadCRUT3. The gap in the 19th century separates the CanESM2 piControl run and the HadCRUT3 observational time series. Horizontal lines from bottom to top: minimum, 5%, 25%, 50%, 75%, 95%, maximum (thick red line) trend of the piControl run. The lower thick red line represents the maximum trend of the piControl run, the upper thick red line the maximum trend of observations HadCRUT3 1951 - 2011.

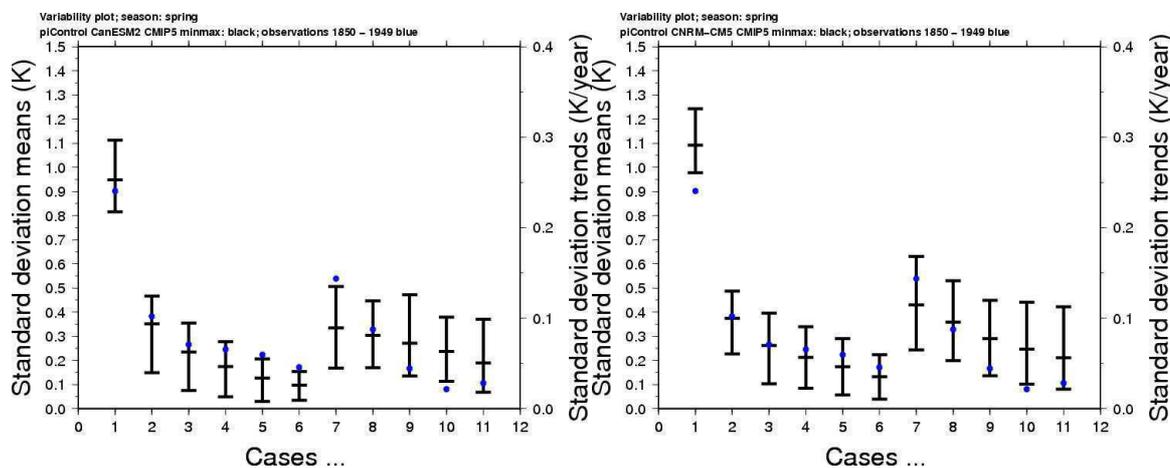


Fig. 9: Standard deviation of mean and maximum values over various sub-periods for spring, piControl with CanESM2 left, piControl with CNRM-CM5 right. The 1000 year piControl runs have been resampled over 100 year section advancing in 50 year steps. The mean standard deviation over all samples, the minimum and maximum values are displayed. Observations were taken from the HadCRUT3 data set for the 100 year time period from 1850 to 1949 (blue dots). The x-axis: the year-to-year variability (case 1), then of means of 10 (decadal, case 2), 20 (case 3), 30 (case 4), 40 (case 5) and 50 years (case 6) and the variability of trends over 10 (case 7), 20 (case 8), 30 (case 9), 40 (case 10) and 50 years (case 11). This was done for Europe (0°-30°E and 45°-60°N).

Fig. 12 confirms the conclusions from Fig. 11 and adds the attribution information. The attribution is less clear in winter, as was the case for detection. The variability of winter time series and trends is rather large and the difference between the piControl, historical and historicalNat cases is least clear. From a consistency point of view, one finds the trends of the piControl and historicalNat runs to be consistent, also those of the historical runs

and the observations, whereas those of the piControl and historicalNat runs are inconsistent with those of the historical runs and observations.

Following the established way to argue, we summarise our findings for temperature:

Detection

The observed change is in a statistical sense significantly different from the change that can be expected from natural variability alone. The observed temperature trends might be termed unusual (trends p95% < trends observed < trends piControl max) to exceptional (> piControl max).

Attribution

The observed changes in the climate system over Central Europe are consistent with the estimated response (historical) and not consistent with alternative, physically plausible explanations (historicNat).

Consistency analysis applied to phenology

A main restriction for the consistency analysis of the phenological time series is their shortness, because the phenological time series only start in 1951. There are a few longer phenological time series available, which could be used in a future study, like the Swiss cherry flowering.

For demonstration purposes Fig. 8 has been repeated for horse chestnut beginning of leaf unfolding (Fig. 13). Compared with temperature, the phenological trends appear inverted, because a temperature increase is linked with earlier occurrence dates.

The maximum observed trends of 16 phenological phases reach beyond maximum trends of both piControl runs (Fig. 14). The exceptions are *Tussilago farfara* (coltsfoot) and *Salix caprea* (goat willow). At the moment there is no obvious explanation for that.

The length of observed time series and trends is just enough to perceive the temperature increase and shift of phenological phases to earlier dates as unusual to exceptional. Each further year added to the data set may strengthen the shift towards the exceptional.

A sample of the attribution results is given by Fig. 15, which clearly demonstrates the consistency between historical runs and observations as well as between historicalNat and piControl runs. Also the inconsistency between historical and historicalNat runs is obvious. These features can be observed for all 18 phases.

The anthropogenic forcing has to be added to the external forcings of the climate system in order to create a consistency between the modelled and observed phenological trends in Central Europe. Model runs driven with natural forcings alone are not able to explain the observed phenological trends over the last decades.

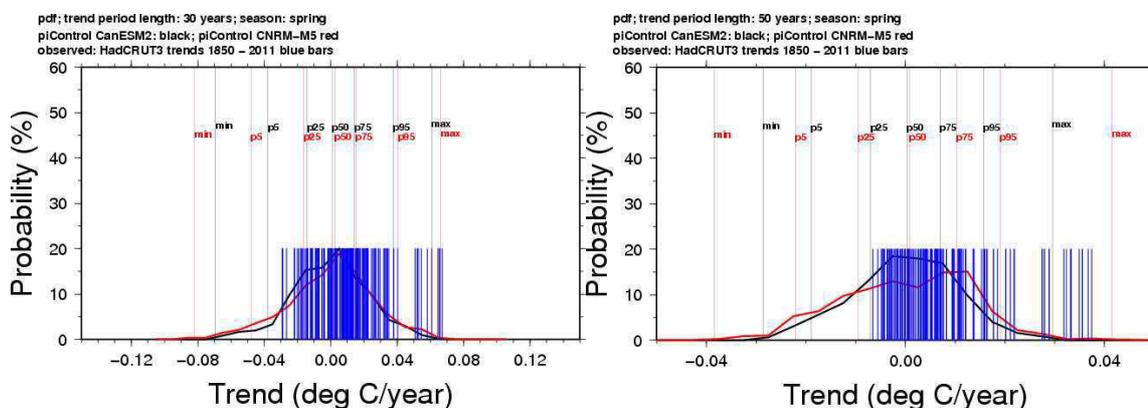


Fig. 10: Histograms of trends of piControl runs (CanESM2 model black, CNRM-CM5 model red) and trends of observations (HadCRUT3, 1850 – 2011). Trends have been calculated moving through the time series in yearly steps over the selected region over Europe. Spring, 30 year trend period (left), 50 year trend period (right).

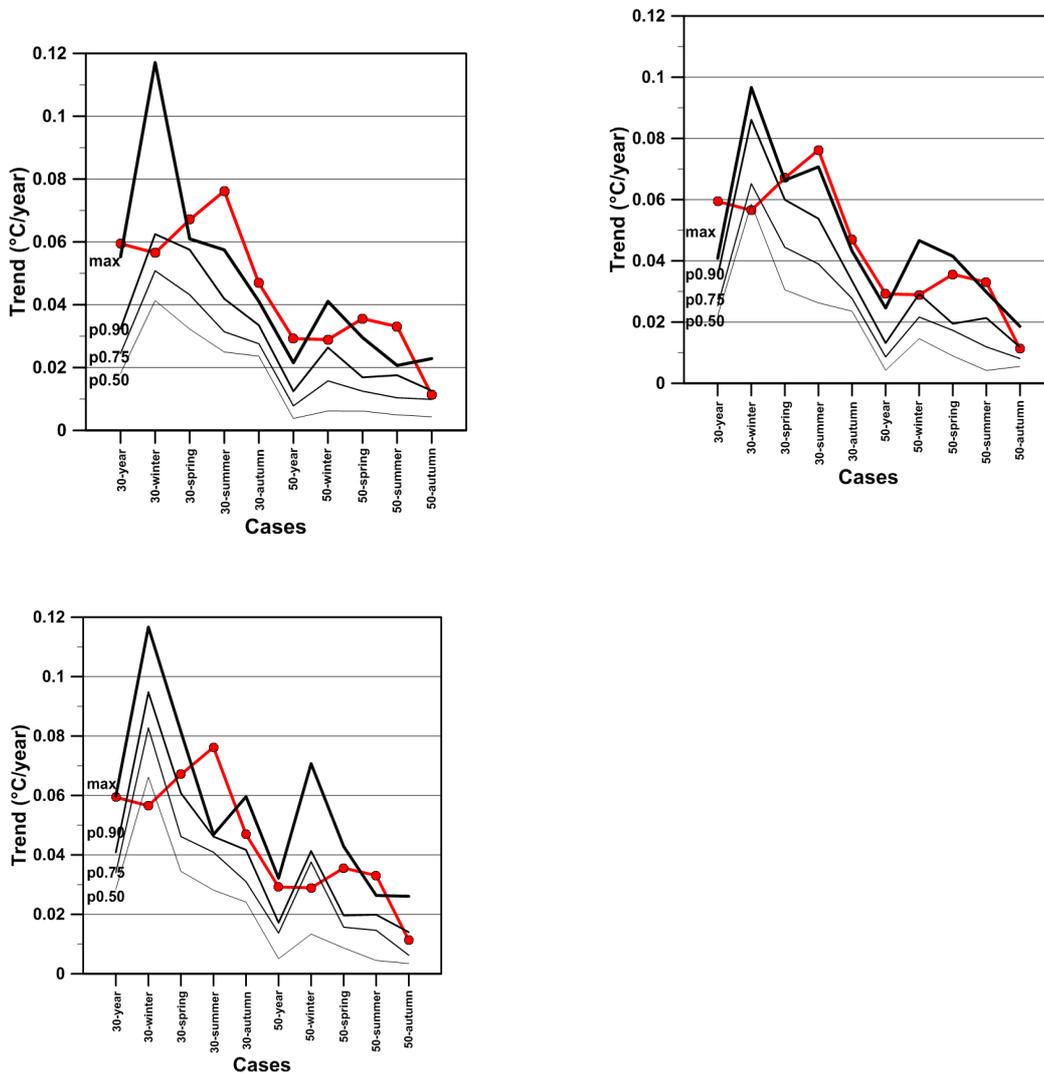


Fig. 11: On the x-axis various cases are listed, where the numbers give the trend period lengths in years (30 and 50) and the year resp. seasons are iterated for each trend period length. Maximum trend values from the HadCRUT3 observational data set from the 59 year period 1951 – 2009 (red). The piControl runs have been resampled over 59 year periods advancing by 30 years. For each of the 59 year periods the maximum trend value was determined and percentiles calculated (black curves). piControl runs: top left CanESM2, top right CNRM-CM5 and bottom left HadGEM2-ES.

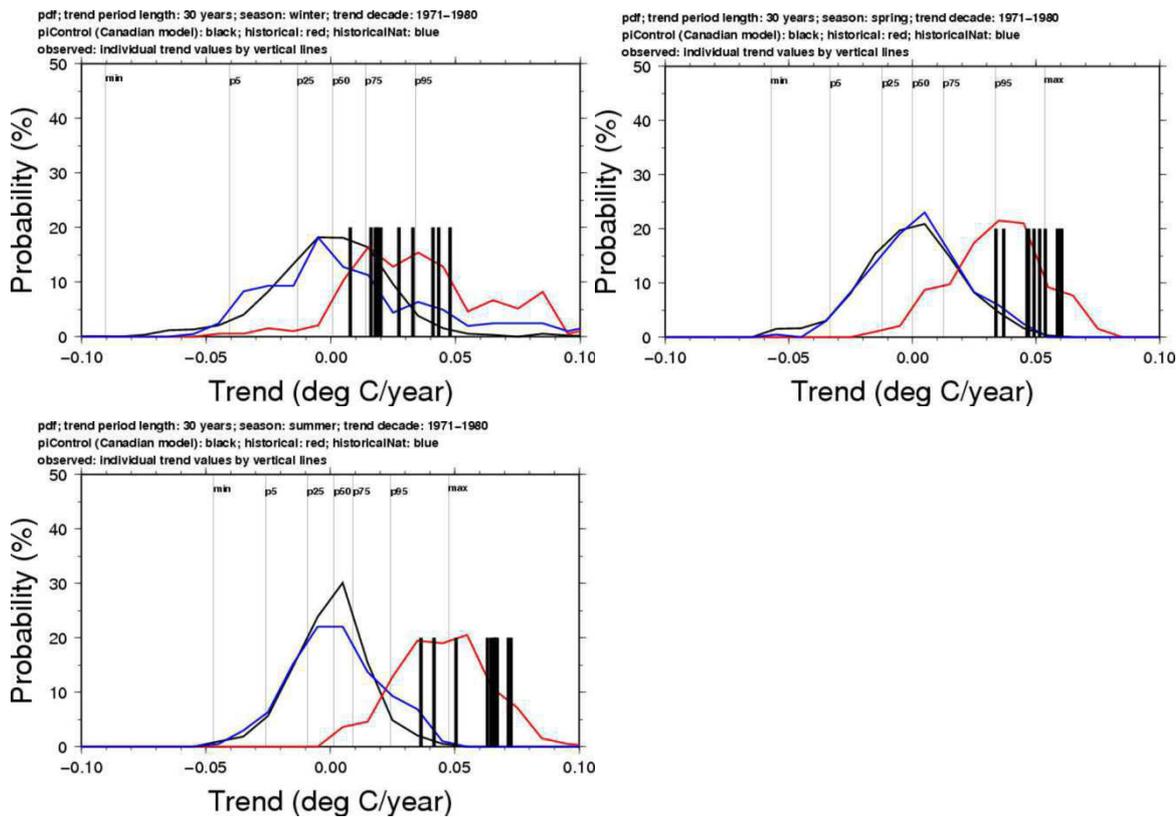


Fig. 12: Histograms of all trend values over all 30 year periods starting in the decade 1971 – 1980 (1971 – 2000, 1972 – 2001, etc.). Plotted are the histogram of the 30 year trends of the piControl run over the total piControl time period of about 1000 model years (black curve), of 36 historical runs (red curve), of 27 historicalNat runs (blue curve) and 30 year trend values of the observational time series (black bars). Winter (top left), spring (top right) and summer (bottom).

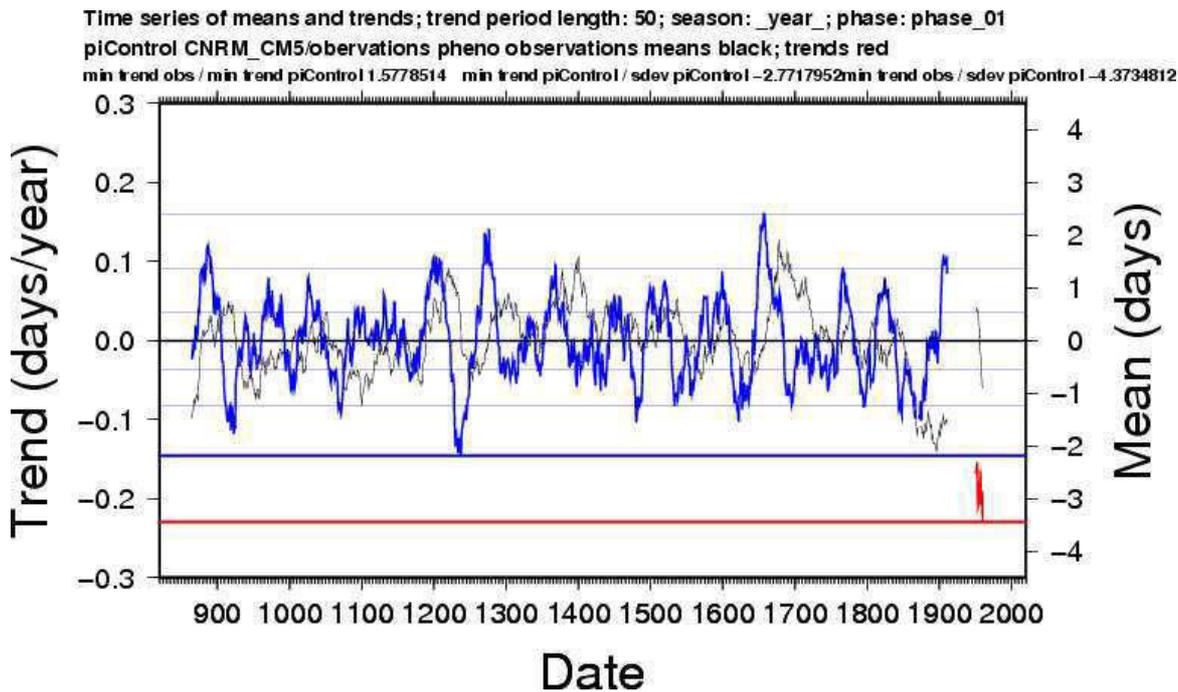
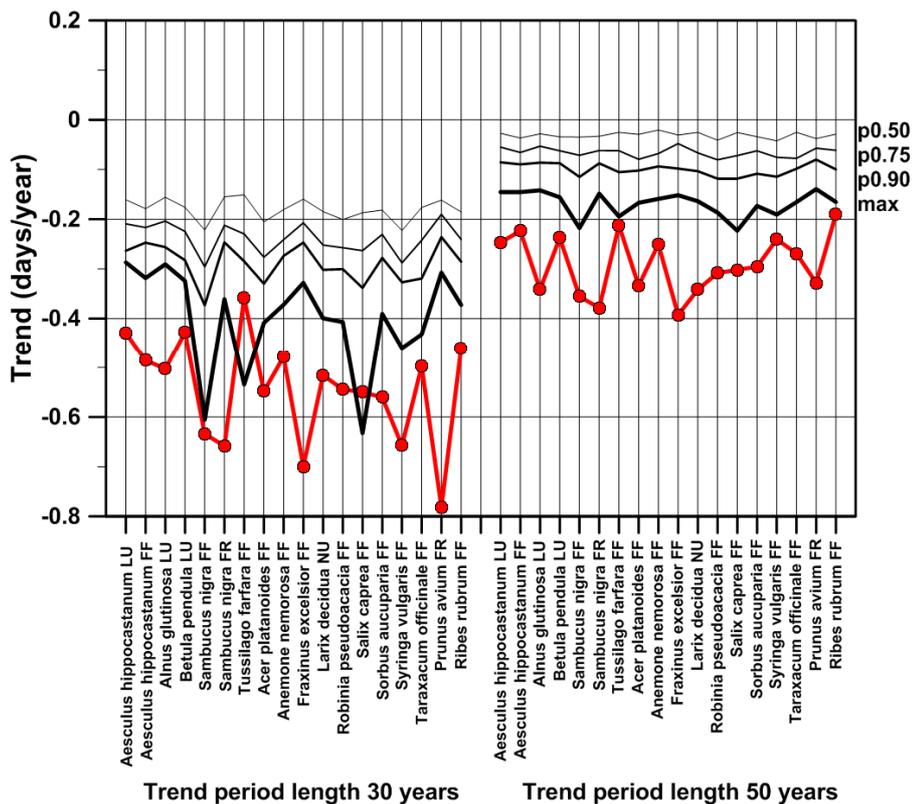


Fig. 13: Pheno time series, mean over all European stations, phase 1, *Aesculus hippocastanum* beginning of leaf unfolding Europe Time series of means (black) and trends (blue for piControl/red for observations) for the trend period length of 50 years means and trends of CanESM2 piControl (up to 19th century) observational time series PEP725. Horizontal lines from bottom to top: minimum (blue thick line), 5%, 25%, 50%, 75%, 95%, maximum trend of piControl, thick red line, minimum trend of pheno observations 1951 - 2009.



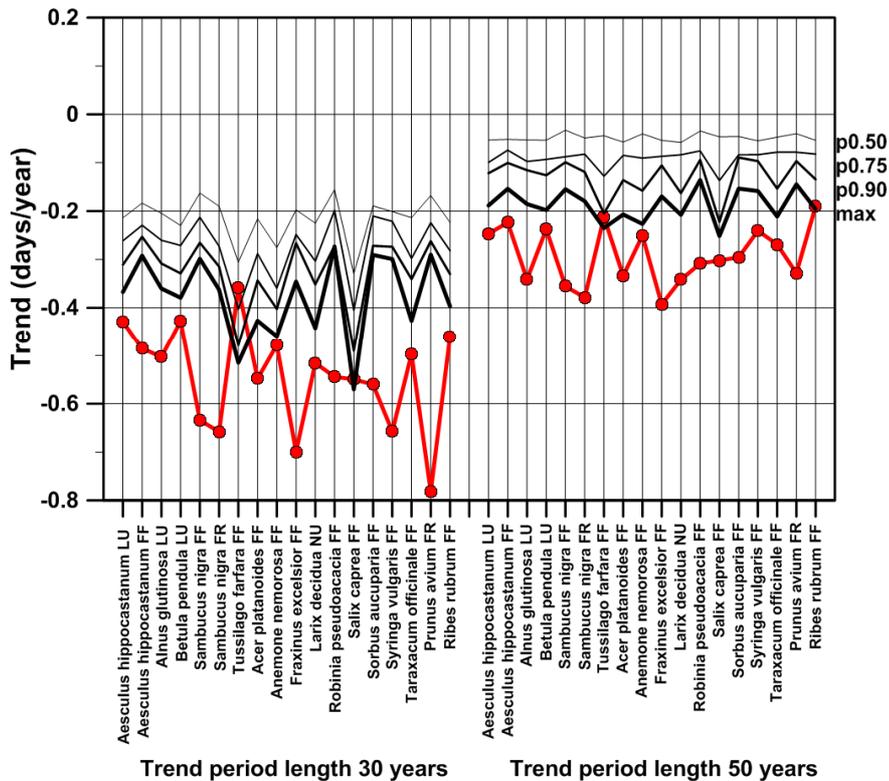


Fig. 14: Maximum trends of the piControl runs and phenological observations in comparison. On the x-axis the phenological phases are listed (LU = leaf unfolding, FF = first flowering, FR = beginning of fruit ripening, NU = needle unfolding) for trend period lengths of 30 and 50 years. The piControl runs have been resampled over 59 year periods advancing by 30 years. For each of the 59 year periods the minimum trend value was determined (thick black line) and the p10, p25 and p50 (black lines with reduced thickness). Top CanESM2, bottom CNRM-CM5.

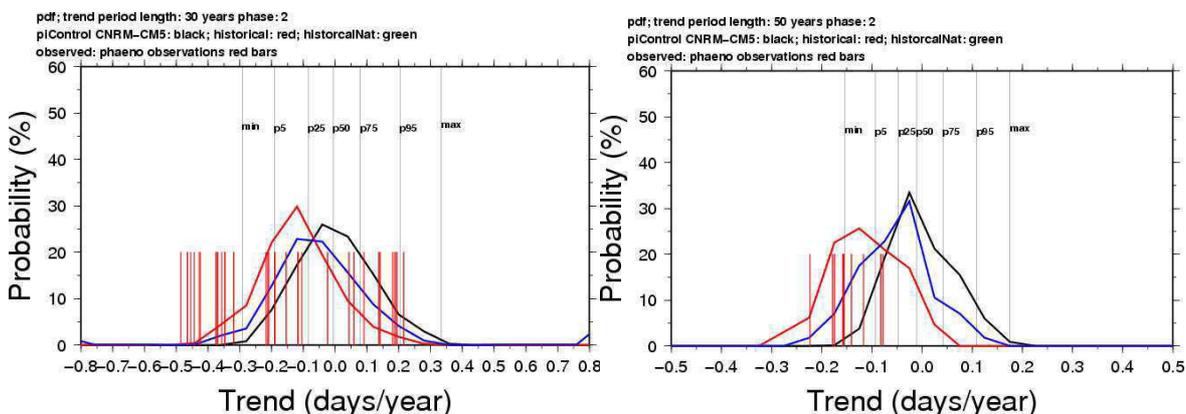


Fig. 15. Histograms of all trend values over 30 (left) and 50 (right) year periods within the time period from 1951 – 2009 for the observations (red vertical bars), the historical runs (red curves) and the historicalNat runs (blue curves). The black curve represents the frequencies of all trends values of the piControl run (CNRM-CM5) over the total piControl time period of about 1000 model years. The minimum, maximum and indicated percentile values of the piControl run are given by vertical black lines.

Following the established way to argue, we summarise our findings for the phenological phases:

Detection

The observed change is in a statistical sense significantly different from the change that can be expected from natural variability alone. The observed phenological trends can be termed unusual in 2 cases ($< \pi_{\text{Control max}}$) and exceptional in 16 cases ($> \pi_{\text{Control max}}$).

Attribution

The observed shift of phenological phases to earlier entry dates in Central Europe is consistent with the estimated response of phenological phases to the temperature increase caused by the additional anthropogenic forcing (historical runs) and not consistent with alternative, physically plausible explanations that exclude the regional temperature increase (historicNat runs).

3 Conclusions and Recommendations

Specific conclusions

- Before selecting GCMs for downscaling, one would have to check their suitability for the study and the added value of dynamically downscaling the chosen variables. Both questions cannot be answered a-priori without a closer look.
- Detection and attribution can be done based on a consistency approach and on GCMs over a restricted area for temperature and phenological entry dates as impact variable.
- This study shows on basis of climate model simulations that there is a human influence on climate visible, which has impacted temperature and phenology in Central Europe during the last decades.

How to continue with this line of work

Based on the encouraging results of DATAPHEN one could extend and generalise the detection and attribution study as well as quantify the human influence on the climate at regional and local scales. Or in other words: how far has the anthropocene, that is the observed climate, already moved away from its natural state because of human interference? Therefore it would make very much sense to continue with similar studies for Central Europe, the Alps and Austria.

In case of temperature the detection and attribution problem is comparatively straight forward, it is less clear for other atmospheric variables and especially problematic in case of ecosystem variables. Here follows a number of suggestions, how one could continue such kind of studies with special relevance for the Alps and Austria:

- An atmospheric multivariable study based on the HISTALP dataset (<http://www.zamg.at/histalp/>, 20120611, air pressure, temperature, precipitation, moisture, sun shine duration and cloudiness, Auer et al., 2007). One would have to check, in how far climate models are able to reproduce the observed climate over the Alpine area (historical runs) and then subtract the human influence from the observed state. This approach would be a rather strict test of climate models, global or regional, to reproduce observed climate over decades up to centuries.
- Repeat this study with the Austrian phenological record. The area would be restricted to Austria, the station elevation ranges from 100 to 1400 m above sea level (higher than the PEP725 data set) and there would be more phases available to describe the vegetation period. In some cases trends of phenological phases appear even stronger in Austria compared to other places in Europe. This could be done within the frame of a master or doctoral thesis.
- Glaciers are an intensely studied climate impact phenomenon at ZAMG. With the support of glacier models driven with input from climate models, methods of detection and attribution could also be applied to glacier length and volume (.).

Methods could also be improved. More rigorous statistical methods should be developed and the application of optimal fingerprint methods should be explored.

Relevance and use of the results of this study for specific target groups

- This study demonstrates that detection and attribution studies can be done for restricted areas, for selected seasons, for atmospheric and impact variables via an end-to-end modelling system, thereby encouraging like detection and attribution studies for other atmospheric and impact variables.
- The results of DATAPHEN substantiate the human impact on temperature and phenology in Central Europe.
- The confrontation of climate models with observations during the historical time period reveals something about the reliability of climate modelling and can tell something about their uncertainty in regard to future climate scenarios.

C) Details of the project

4 Methods

Our study is an end-to-end analysis of the human impact on the seasonal vegetation cycle or phenology in Central Europe (Fig. 1). It includes the detection of the near surface temperature variability and the variability of phenological time series in relation to the natural variability and the attribution to the climate forcing scenarios "historical" (all forcings = natural + anthropogenic forcings) and "historicalNat" (only natural forcings) via consistency tests. There are a number of detection and attribution methods applied in literature, the most quantitative of them being called the optimum fingerprint technique, and less quantitative methods, like consistency tests (Hegerl and Zwiers, 2011). An adaptation of the latter appeared to be the kind of method best suited for the purposes of this project.

There are no standard methods available to solve the technical problems and answer the questions raised. The backbone of this study are a number of data bases, like the PEP725 European phenological data base or the CMIP climate model data base. The work itself rests mainly on software tools, like the regional climate model CCLM, a few standard statistical procedures and a greater number of custom made software tools. With existing and new Fortran 90 codes, tcl scripts, netCDF subroutines and other proven and tested software packages the work was accomplished. Selected statistical routines from for instance the IMSL library and from the "Numerical recipes" of Press et al., 1992 supported the work.

5 Work and time plan

The work programme of the project has been accomplished through three work packages. Work package 1 and 2 prepare a number of deliverables, which are input for the final analysis in work package 3. Here the actual work flow is being described, which deviates in some points from the original work packages. The main reason for these deviations was the weak anthropogenic signal of the originally chosen ECHAM5 climate simulations, which renders any subsequent phenological modelling useless. For the further work the dynamical downscaling with the CCLM was skipped in favour of a great number of global climate model scenarios.

WP 1 Phenology

- Extraction of the phenological and temperature data from the respective data bases and storing the data in the netCDF file format.
- Interpolation of the observed PEP725 phenological time series to the coordinates of 494 ECSN stations.
- Depending on the spatial distribution of the phenological stations, about 50 to 80 ECSN stations remained, where the TSM model parameters could be deduced and validated.

WP 1 Phenology revised

In order to remain as closely as possible at the stations, where the TSM have been deduced, the rather complicated and error prone interpolation of the TSM parameters to the climate model grid points was avoided. As an alternative the GCM (Global Climate Model) temperature data were interpolated from the closest 9 model grid points to each individual station. This is a mere technicality, which is not intended to stretch the spatial abilities of the GCMs beyond their skill resolution. The analysis relies completely on time series averaged over all stations of the region.

WP 2 Preparation of the regional climate model runs

- Prepare the model domain and identify the proper model resolution
- Attach the phenological temperature sum model to the regional climate model
- Select appropriate GCM control runs and prepare the nesting options

WP 3 Regional and global climate model runs and analysis of the results

- Conduct the model runs with the CCLM
- Check the output of the regional climate model runs for differences between runs with various forcing scenarios.
- The TSM models were run at ECSN stations for all GCM models, which resulted in more than 2000 phenological time series.
- Then follows the detection and attribution - consistency analysis of the calculated temperature and phenological time series.

5 Publications and dissemination activities

Zuvela-Aloise M, Matulla C, Lexer M, Scheifinger H, Anders I, Auer I, Böhm R. (2010): Downscaling climate change simulations for impact assessment studies within the Alpine region. Proceedings 11th International Meeting on Statistical Climatology, Edinburgh, 172, 2010.

Zuvela-Aloise M, Matulla C, Auer I, Böhm R, Lexer M, Scheifinger H. (2010): Comparing empirical downscaling methods within different kinds of terrain applied on the edge to climate impact research. European Geosciences Union General Assembly 2010 (EGU, May 2-7, 2010), Vienna, Austria

Scheifinger, H., C. Matulla, M. Zuvela – Aloise, T. Schöngaßner: Direct Attribution of the Anthropogenic climate signal to PHENological observations – DATAPHEN. 12. Öst. Klimatag, 21-22.09.2011. Tagungsband V20.

Scheifinger, H., C. Matulla, M. Zuvela-Aloise and T. Schöngaßner (2011): Direct Attribution of the Anthropogenic climate signal to PHENological observations – DATAPHEN. *Geophysical Research Abstracts*, **13**, EGU2011-1399, EGU General Assembly 2011.

Scheifinger, H., T. Schöngaßner, M. Zuvela-Aloise and C. Matulla (2012): Direct Attribution of the Anthropogenic climate signal to PHENological observations – DATAPHEN. *Geophysical Research Abstracts*, **14**, EGU2012-7398, EGU General Assembly 2012.

Zuvela-Aloise M, Anders I, Haslinger K, Matulla C, Scheifinger H, 2011. CCLM 20th-century simulations for climate impact assessment in European ecosystems, COSMO/CLM User Seminar, DWD BTZ Langen, Germany, March 2011.

[http://www.dwd.de/bvbw/generator/DWDWWW/Content/Forschung/FE1/Seminare_Tagungen/2011/COSMO_User2011/FU_COSMO_User_2011_Abstracts,templateId=raw,property=publicationFile.pdf/FU_COSMO_User_2011_Abstracts.pdf\(20120611\)](http://www.dwd.de/bvbw/generator/DWDWWW/Content/Forschung/FE1/Seminare_Tagungen/2011/COSMO_User2011/FU_COSMO_User_2011_Abstracts,templateId=raw,property=publicationFile.pdf/FU_COSMO_User_2011_Abstracts.pdf(20120611)).

Scheifinger, H., C. Matulla, M. Zuvela – Aloise, T. Schöngaßner: Direct Attribution of the Anthropogenic climate signal to PHENological observations – DATAPHEN. 13. Öst. Klimatag, 14. – 15. Juni 2012.

Scheifinger, H., C. Matulla, M. Zuvela – Aloise, T. Schöngaßner: Direct Attribution of the Anthropogenic climate signal to PHENological observations – DATAPHEN. Mezinárodní Konference Bioklima, Usti nad Labem 29th – 31st August 2012.

6 References

Dean, S. M., and P. A. Stott (2009): The Effect of Local Circulation Variability on the Detection and Attribution of New Zealand Temperature Trends. *Journal of Climate*, **22**, 6217–6229.

Hegerl, G., and F. Zwiers (2011): Use of models in detection and attribution of climate change. *WIREs Climate Change*, **2 (4)**, 570 – 591. DOI: 10.1002/wcc.121

Matulla C., Watson E., Wagner S. and W. Schoener (2009): Downscaled GCM projections of winter and summer mass balance for Peyto Glacier, Alberta, Canada (2000-2100) from ensemble simulations with ECHAM5-MPIOM, *International Journal of Climatology*, 29, 1550-1559, [doi:10.1002/joc.1796](https://doi.org/10.1002/joc.1796).

Mitchell, J. F. B. and D.J. Karoly (2001): Detection of Climate Change and Attribution of Causes. In: Climate Change 2001: The Scientific Basis [J.T. Houghton, Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Maskell and C.A. Johnson (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Springer C., Matulla C., Watson E., Wagner S., Schöner W., R. Steinacker (2012): Downscaled GCM projections of winter and summer mass balance for Central European glaciers (2000-2100) from ensemble simulations with ECHAM5-MPIOM. *International Journal of Climatology*, [doi:10.1002/joc.3511](https://doi.org/10.1002/joc.3511)

Rosenzweig, C., G. Casassa, D.J. Karoly, A. Imeson, C. Liu, A. Menzel, S. Rawlins, T.L. Root, B. Seguin, P. Tryjanowski, (2007), Assessment of observed changes and responses in natural and managed systems. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 79-131.

Rosenzweig, C., D. Karoly, M. Vicarelli, P. Neofotis, Q. Wu, G. Casassa, A. Menzel, T. L. Root, N. Estrella, B. Seguin, P. Tryjanowski, C. Liu, S. Rawlins and A. Imeson (2008): Attribution physical and biological impacts to anthropogenic climate change. *Nature*, **453**, p 353 – 358.

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Author

ZAMG – Zentralanstalt für Meteorologie und
Geodynamik

Helfried Scheifinger
Hohe Warte 38, 1190 Wien
Phone: +43 1 36026 2226
E-Mail: Helfried.Scheifinger@zamg.ac.at

Owner, publisher and media owner

ClimateandEnergy Fund
Gumpendorfer Straße 5/22
1060 Wien
office@klimafonds.gv.at www.klimafonds.gv.at

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