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# Final report of Action B5

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# Climate change indicators and vulnerability of boreal zone applying innovative observation and modelling techniques

Data Project

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# 1 Summary

This report describes use of JSBACH and PREBAS models in producing regional scenarios of the state of land ecosystems during this century. The adjustments of the models, the applied running setups and sequences are first reported and then the retrieval of the climate change indicators is explained with selected examples.

# 2 Introduction

This action produced trancient ecosystem model runs through years from 1981 to 2100 with regionally bias-corrected climate scenario driving data from five global climate models and three representative concentration pathways (RCPs) of the CMIP5 project. The timeseries and trends of the climate change indicators were consequently retrieved from the model results. The impact models used in our project are land ecosystem models JSBACH (FMI) and PREBAS (Luke and UHel). The land ecosystem models were run in relatively high spatial resolutions of approximately 10km and the models were operated with daily driving data. The target climate change indicators retrieved from the model results are the duration of a yearly vegetation active period (VAP), vegetation carbon uptake rate (i.e. gross primary production, GPP), vegetation and ecosystem respiration rates (i.e. autotrophic and heterotrophic respiration), methane emission rate, evapotranspiration (sum of surface evaporation and plant transpiration), soil moisture drought, length of soil frost period, snow cover and surface albedo.

# 3 Model developments

## 3.1 JSBACH

JSBACH is a land surface model (LSM) of an earth system model of Max Planck institute for meteorology (MPI-MET) implemented and operated in FMI. During the project the JSBACH model domain and the respective surface data source were upgraded for several aspects; First, formerly our regional JSBACH domain was set to accord with a regional climate model providing the climatic drivers for JSBACH but as in this project down-scaled and bias-corrected global scenarios are used as driving data, conformance with a climate model domain is not needed. Consequently, it was possible to reduce the lateral extension of the domain and limit it to Finnish territory thus diminishing the fraction of unnecessary land area in the model runs.

Secondly, a new Finnish CORINE land cover data CLC2012 was made available since the beginning of the project (Corine 2012 Final Report). Finnish CLC2012 is of higher resolution and more detailed nomenclature than its European counterparts priorly used by the team. It contains also information about soil type providing thus a soil information consistent with the vegetation cover information, while earlier these data was collected from separate data sources. Furthermore the CLC2012 has been developed for Finland with local expert knowledge.

Finally, FMI has lately adopted a new standard for gridded meteorological data product that is produced into a approximately 10 km grid (Aalto et al 2013). In order to maximize consistence between the new domain and gridded data available for down-scaling purposes, we decided to adopt the same grid for our regional modeling. The grid resolution is also somewhat improved in the revision and is currently 0.1°x0.1°.

Simultaneously with a new domain and up to date surface data a new model version was adopted. The updated version has 5-layer soil moisture description (Hagemann and Stacke, 2013) and the Yasso soil carbon module (Goll et al., 2014) implemented. Additionally for our scenario simulations we adopted the state of acclimation (S) formulation, whose performance is demonstrated in the *2dn progress report*s *of Action B4: Methodologies developed, implemented and tested.* The state of acclimation delays the beginning of photosynthetic activity of evergreen species in spring that is not limited by the bud burst. Because according to Böttcher et al (2016) the start date of the photosynthetically active season (SOS) of coniferous evergreens in the model is ahead of the observed, an air temperature sum based downregulation of photosynthetic capacity was implemented to JSBACH. Moreover, Böttcher et al. (2016) showed that the modeled SOS of deciduous broadleaf species in Finland is generally behind the observed and thus the threshold temperature of the temperature sum regulating the bud-break was decreased from 4°C to 2°C in the model.

Furthermore, a condition that reduces stomatal conductance under supersaturation – that is, under very high air humidity – is removed because it falsely prohibits photosynthesis at all under such situations that are not infrequent in such an off-line coupling set-up that we're running the model.

## 3.2 PREBAS

For making regional simulations with PREBAS we need climate drivers to run the model and a description of the initial state of the forest and soil to start the simulation. The climate variables were produced by FMI as described above, so the same grid resolution was used (0.1°x0.1°). PREBAS used daily values of weather data on this grid.

For calculating the initial state, we utilised the multisource inventory data from LUKE. Here the country is covered by a fine-scale grid with 16 m x 16 m grid cells. Each grid cell has information about species (*Pinus sylvestris*, *Picea abies* and *Betula* ssp), mean height, mean diameter, basal area and leaf area, which are the inputs to PREBAS. We aggegated this information into grid cells 8 km x 8 km for regional calculation, containing 500 x 500 original grid cells. Within the larger grid cell we further defined forest categories on the basis of species and size class. We assigned each original grid cell to one of these categories and aggregated them to areas of categories in each larger grid cell. The simulations were carried out by category for each grid cell and aggregated to grid cell totals each year, which is the time resolution of the growth submodel of PREBAS. If one forest grid cell was covered by more than one climate grid cell (where the borders did not match), we used averaged weather data from the grid cells covering the forest grid cell.

## 3.3 Methane model HIMMELI

A methane production and transport model HIMMELI was developed and calibrated in collaboration between University of Helsinki and Finnish Meteorological Institute during the project. In its current state HIMMELI is a point-wise model that uses soil temperature, leaf area index of gas transporting vegetation, water table depth (WTD) and anaerobic carbon decomposition that can be derived from NEE as driving data. The model simulates microbial and transport processes that take place in the peat column, keeping track on the concentration profiles of $CH_4$, $O_2$ and $CO_2$. The output is fluxes of $CH_4$, $O_2$ and $CO_2$ between the soil and the atmosphere. Driving data can be derived either from observations or from a model. In MONIMET we adopted the drivers from JSBACH climate scenario runs averaged for 13 ecological regions (forest growth zones, see Figure 1.) in Finland.

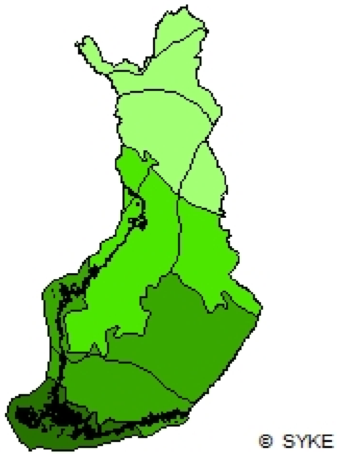


Figure 1. Finnish forest growth zones Hemiboreal, Southern boreal, Middle boreal and Northern boreal indicated with green tones from dark to light. Light lines indicate further division into sub-zones.

# 4 Scenario forcing data production

Other driving variables but long-wave radiation were down-scaled to a 0.2°x0.1° longitude-latitude grid by bias-correction methods utilizing gridded FMI meteorological data (Aalto et al. 2013). For PREBES the down-scaled data provided appropriate driver sets as such. For JSBACH the bias corrected data was further downscaled to a grid corresponding to the new domain. Moreover, because no gridded observation data exists for long-wave radiation the raw data adopted from CMIP5 database was interpolated to the new domain by bilinear interpolation method. Global mean $CO_2$ concentrations from the RCPs 4.5 and 8.5 were linearly interpolated to monotously increase through the calendar years. The Figure 2 shows the changes of temperature and precipitation from a baseline period 1981-2010 to periods 2011-2040, 2041-2070 and 2071-2099 in Finland indicated by data from down-scaled CMIP5 climate models. See the *Report on climatic data processing* of this action for more details on extraction of driving data from CMIP5 database and its preparation for driving the land ecosystem models.

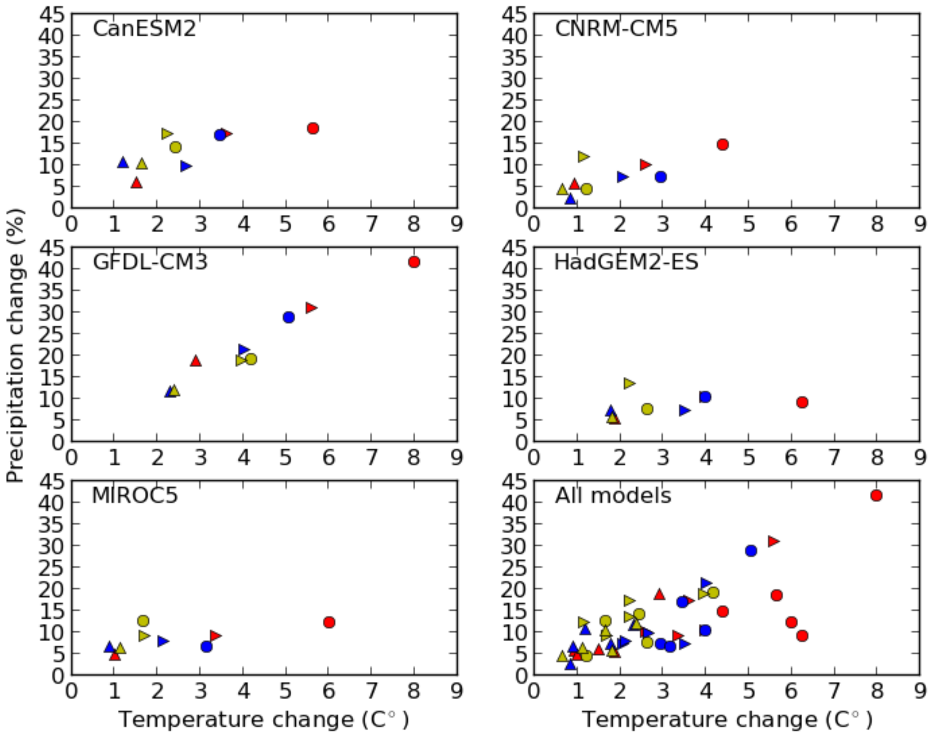


Figure 2. Changes of precipitation against changes of temperature during the scenario periods 2011-2040 (circle), 2041-2070 (triangle pointing right) and 2071-2099 (triangle pointing up) in comparison to the baseline (1981-2010) as predicted by RCP 2.6 (yellow), RCP 4.5 (blue) and RCP 8.5 (red).

# 5 Scenario run set-up and running sequence

## 5.1 JSBACH

To comply with the time step of the scenario driving data JSBACH was run in a daily forcing mode in which the model generates the daily cycles of the driving variables. Model internal timestep was set to 3600 seconds (1 hour). The spatial resolution of the model run was that of the surface boundary data (0.1°x0.1°). Number of soil layers was set to five and that of plant functional types (PFTs) to 22 out of which less than half exists in Finland.

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The running sequence consisted of four different spin-up phases that were run prior to the transient production run throughout the forcing data timeseries. In the first phase the CO2 concentration was set to that of the year 1852 (285 ppm) and the model was run for 30 years with the climate from 1980 to 2010. This round was made to make sure that the relatively slowly changing state variables in the system reached a semi-equilibrium with the current day climate. The second phase was started from the equilibrium reached during the first round. The atmospheric CO2 concentration and the climate were equal to those of the first round and the purpose of this round was to produce thirty years of driving data for the following phase. The third phase of the spin-up was performed to develop soil carbon storages using the net primary productivity (NPP) estimated at the second phase. In this phase soil carbon model YASSO was run offline from the other biogeochemical and biophysical processes in JSBACH model framework.

The fourth running phase used the carbon, water and energy states equilibrated with CO2 concentration of mid 19th century and current day climate during the previous steps. In this phase the climate from 1981 to 2010 was circulated for 120 years with the increasing atmospheric CO2 concentrations from 1851 to 1979.

Finally the production run from 1980 to 2099 is started from the state reached at the fourth spin-up phase. The first year 1980 is excluded from the analysis in order to have a continuous driving data series preceding the first included year 1981. This is important in a northern region where seasonal snow-cover starts to accumulate in the end of the previous calendar year.

## 5.2 PREBAS

The regional scenario runs with PREBAS were carried out in four 30-year time intervals, starting in 1981. Each time interval was initiated with the same forest cover (multisource measurements from 2013). The rationale for this was that because we also considered forest management, which has a large impact on the forest cover and thus the indicators, but which is dependent on forest policies and largely uncertain, the re-initialisation would make the four periods comparable with each other. We are thus projecting potential developments of the same forest cover under different climatic forcing and $CO_2$ concentration.

We defined three different management scenarios:

1) Current management recommendations with clear cut at mean breast height diameter (DBH) about 26 cm, regeneration with the same species
2) Current management recommendations but with the assumption that 30% of final harvests are delayed to DBH = 36 cm, regeneration with the same species
3) No management

We initialised soil carbon in the Yasso model separately for each management scenario and grid cell. The initialisation is a “spin-up” that runs the model to steady state using appropriate litter input from the reference period. We used the plant litter that was simulated by PREBAS, given the management scenario in each grid cell.

The results of the simulations were aggregated to the 8 km x 8 km gid cells. Results on photosynthesis, evapotranspiration and soil water content were obtained as daily totals, from which we extracted indicators of phenology on the basis of their definition. Other indicators were given as annual totals or annual daily means (for example GPP, ET, NEE, volume growth).

# 6 Extracting climate change indicators

The climate change indicators were described in the *1st progress report of Action B5: Retrieving climate change indicators by models.* A limited set of indicators (GPP, TER, NEE, the beginning, the end and the duration of VAP) was also processed for Climateguide.fi. For Climateguide.fi purposes the yearly values were averaged over four 30 year periods: 1981-2010, 2011-2040,2041-2070 and 2071-2099. Additionally, changes of the indicators from the first period that is considered as a baseline were calculated. For Climateguide.fi also JSBACH results that are originally in geographical coordinates were transformed into plane coordinates.

For visualization purposes in addition to the grid cell wise data we synthesized the results for 13 forest eco-sub-regions in Finland. While with a regional map it is possible to visually inspect one dimensional variables such as trends or time averages, regional averaging enables showing time series with associated statistics. In Figure 3 there are shown GPP time series averaged for one southern and one northern Finnish forest growth region (see Figure 1) together with the start and the end days of VAP.

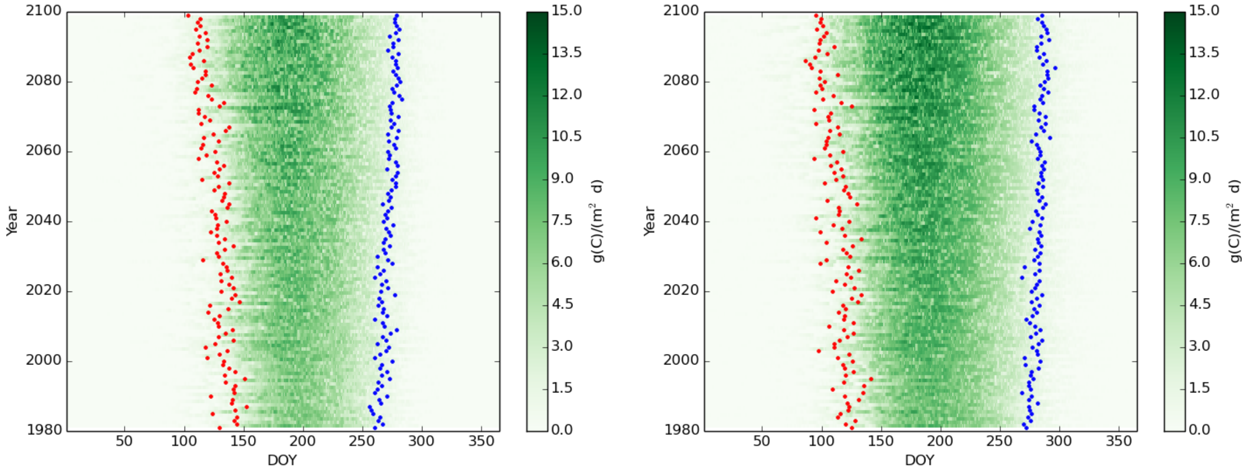


Figure 2. GPP (in green) produced with climatic drivers from GFDL-CM3 under RCP4.5. The dots framing the start (in red) and the end (in blue) of VAP is indicated with dots. At left a northern and at right a southern forest growth region.

# 7 Example climate change indicators

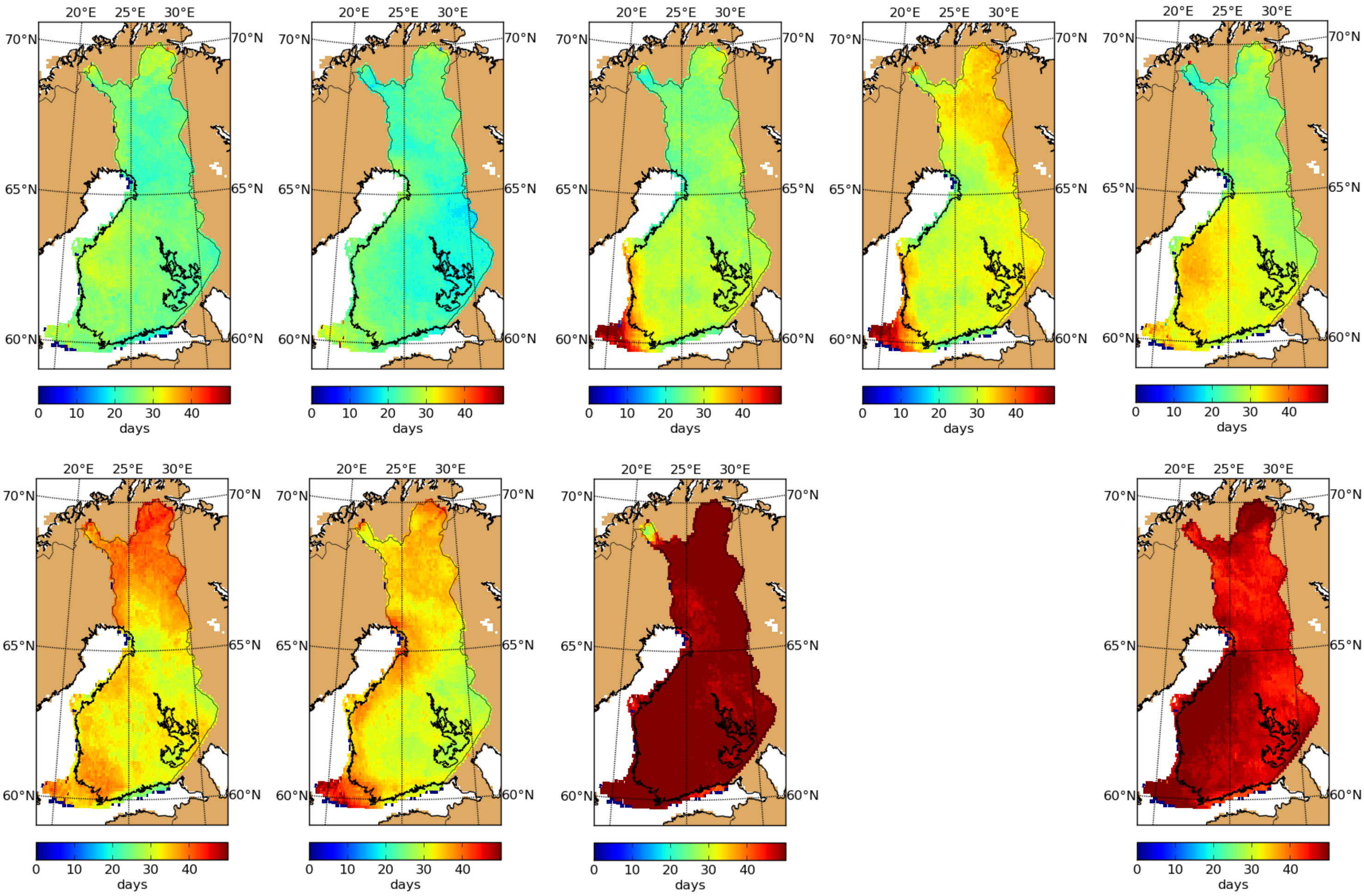


Figure 4. Change of VAP length in days from the baseline period 1981-2010 to the third scenario period 2071-2100 according to JSBACH model. Driving climate models from left to right: CanESM2, CNRM-CM5, GFDL-CM3, HadGEM2-ES and MIROC5. RCP 4.5 in the upper row and RCP 8.5 in the lower row.

Changes of VAP by the end of the current century in comparison to the baseline vary strongly according to the driving model and RCP (Figure 4). The differences of VAP among the two impact models are not as large as the differences among the driving models (not shown) even though both yearly GPP and NEE predictions from the two impact models deviate (Figures 5 and 6). The deviations increase towards the end of the century.

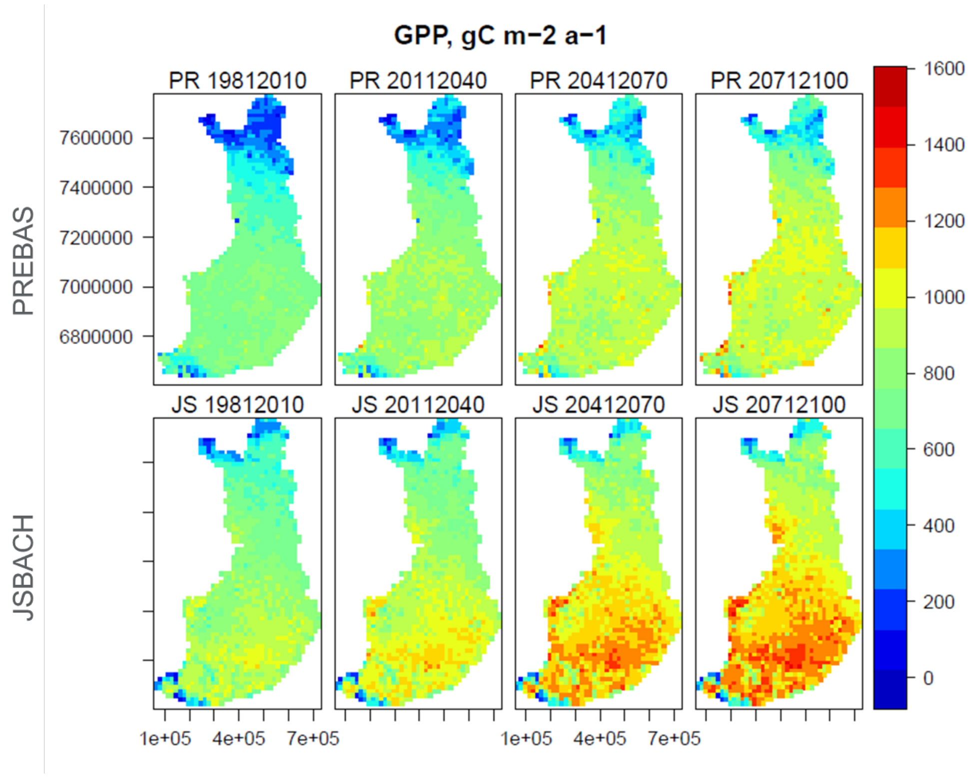


Figure 5. Mean yearly GPP for the baseline and three scenario periods predicted by both impact models PREBAS and JSBACH. Climatic drivers are from (CanESM2 RCP4.5).

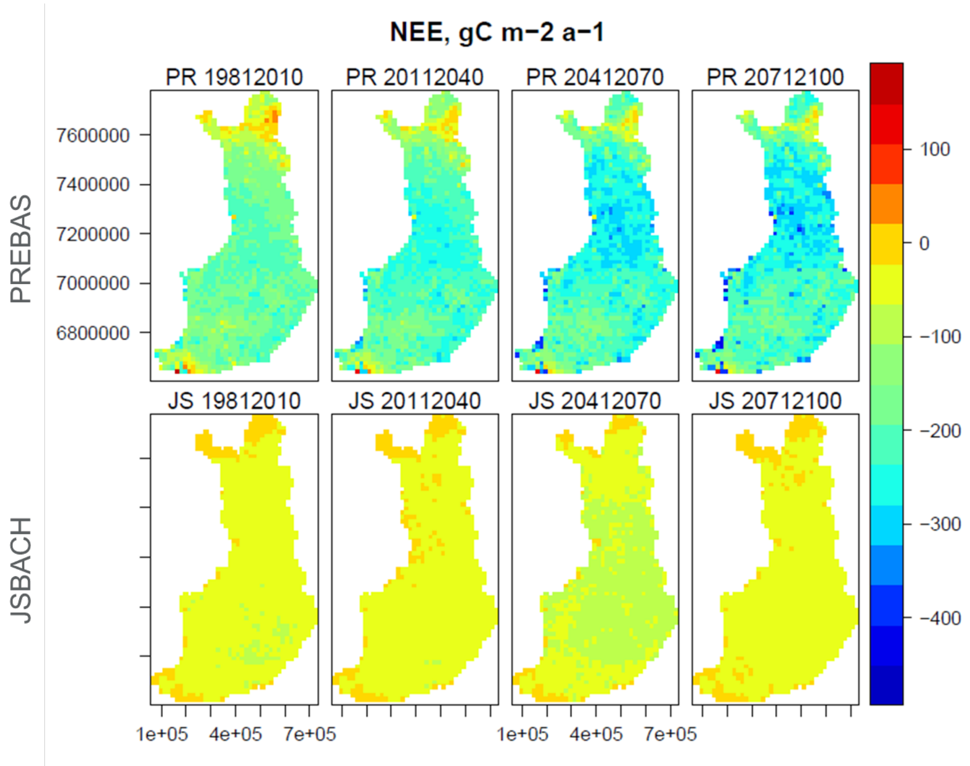


Figure 6. Mean yearly NEE for the baseline and three scenario periods predicted by both impact models PREBAS and JSBACH. Climatic drivers are from (CanESM2 RCP4.5).

The number of soil frost days shows significant decreasing trend throughout the years 1981-2100 (Figure 7). Strongest decreasing trend is predicted with forcing GFDL-CM3 whose temperature change was the largest (Figure 2) and who also showed the largest increase in the VAP duration (Figure 4).

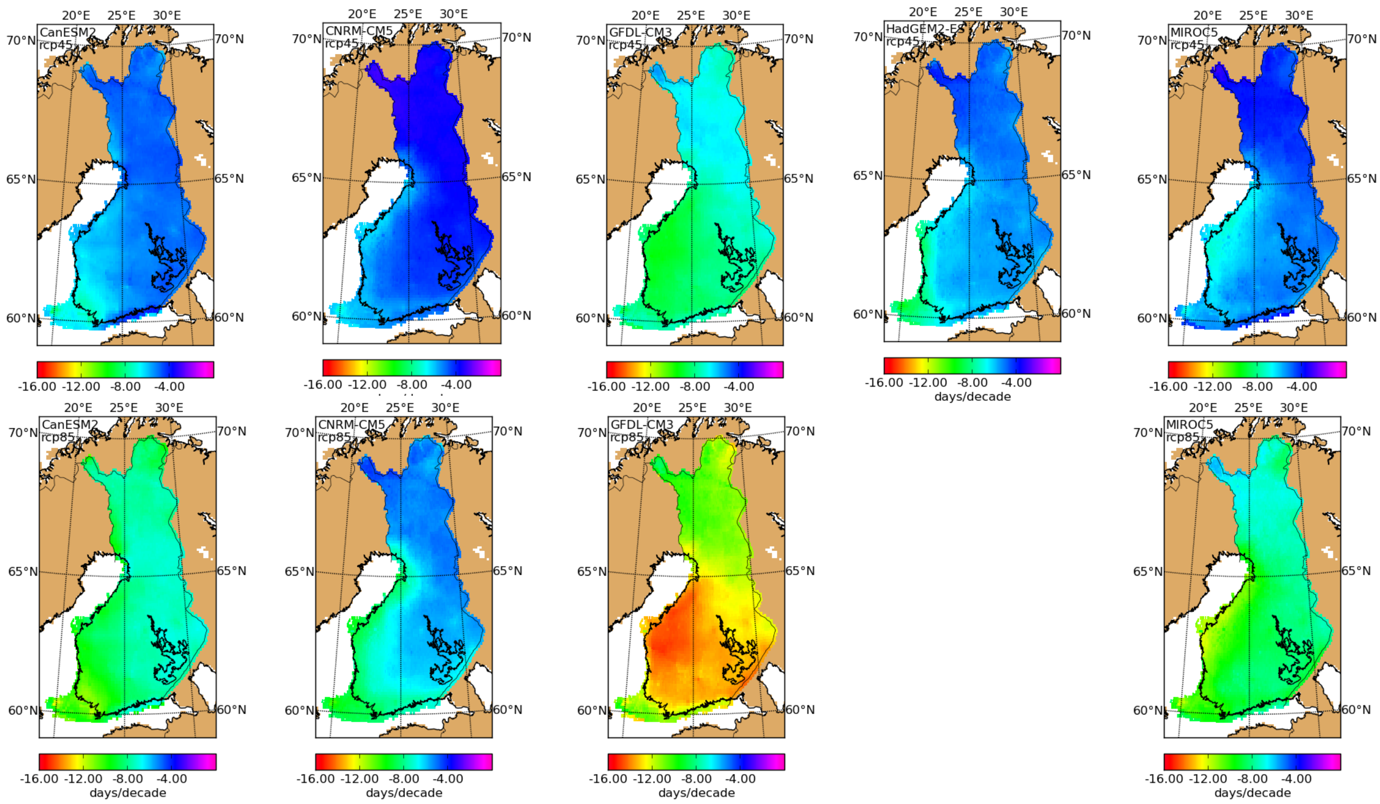


Figure 7. Trend of soil frost days from JSBACH through 1981-2100 (days/decade). Driving climate models from left to right: CanESM2, CNRM-CM5, GFDL-CM3, HadGEM2-ES and MIROC5. RCP 4.5 in the upper row and RCP 8.5 in the lower row.

For the number of summer drought days a linear fitting as a function of year does not typically indicate a significant trend in July and August who are the months most susceptible to drought. This is because the number of years with no days of severe drought remains relatively hight. Meanwhile, however, the duration of dry periods seem to increase in the years indicating some drought. Thus instead of trends, for number of extreme summer drought days a regional multimodel mean, median and percetiles 5, 25, 75 and 95 were calculated for baseline and scenario periods. For instance for the middle boreal zone covering the central

Finland in Figure 1, the median of number of drought days is almost 6-fold during the last scenario period under RCP8.5 while the mean is only double of that of the baseline (Table 1.).

Table 1. Summer drought days from JSBACH: Driving model mean of the number of summer season (June-August) days dryer than the driest 5% of the baseline period in Finnish middle boreal zone.

| Scenario | Years | Mean | Median | 5 pct | 25 pct | 75 pct | 95 pct |
|---|---|---|---|---|---|---|---|
| RCP 4.5 | 1981-2010 | 4.61 | 1.05 | 0.00 | 0.03 | 4.98 | 19.77 |
| RCP 4.5 | 2011-2040 | 5.19 | 2.05 | 0.24 | 0.33 | 8.56 | 19.77 |
| RCP 4.5 | 2041-2070 | 7.98 | 1.70 | 0.24 | 0.30 | 13.31 | 30.57 |
| RCP 4.5 | 2071-2100 | 9.30 | 4.95 | 0.24 | 0.73 | 11.14 | 35.86 |
| RCP 8.5 | 1981-2010 | 4.61 | 1.05 | 0.00 | 0.10 | 4.81 | 19.77 |
| RCP 8.5 | 2011-2040 | 5.95 | 2.40 | 0.24 | 0.85 | 9.63 | 19.98 |
| RCP 8.5 | 2041-2070 | 8.51 | 1.92 | 0.24 | 0.37 | 14.76 | 31.44 |
| RCP 8.5 | 2071-2100 | 9.31 | 5.92 | 0.24 | 1.04 | 10.58 | 35.86 |

Methane fluxes were estimated for mires in sub-regions shown in Figure 1 and further aggregated to south, middle and north boreal zones (Figure 8). Regional estimates show clear trend towards the end of the century. However, also the uncertainty deriving from driving models also increases towards the end of the century being 5.5 gCH4/m2/a during the baseline and 9.0 gCH4/m2/a during the last scenario period (average over all the boreal zones).

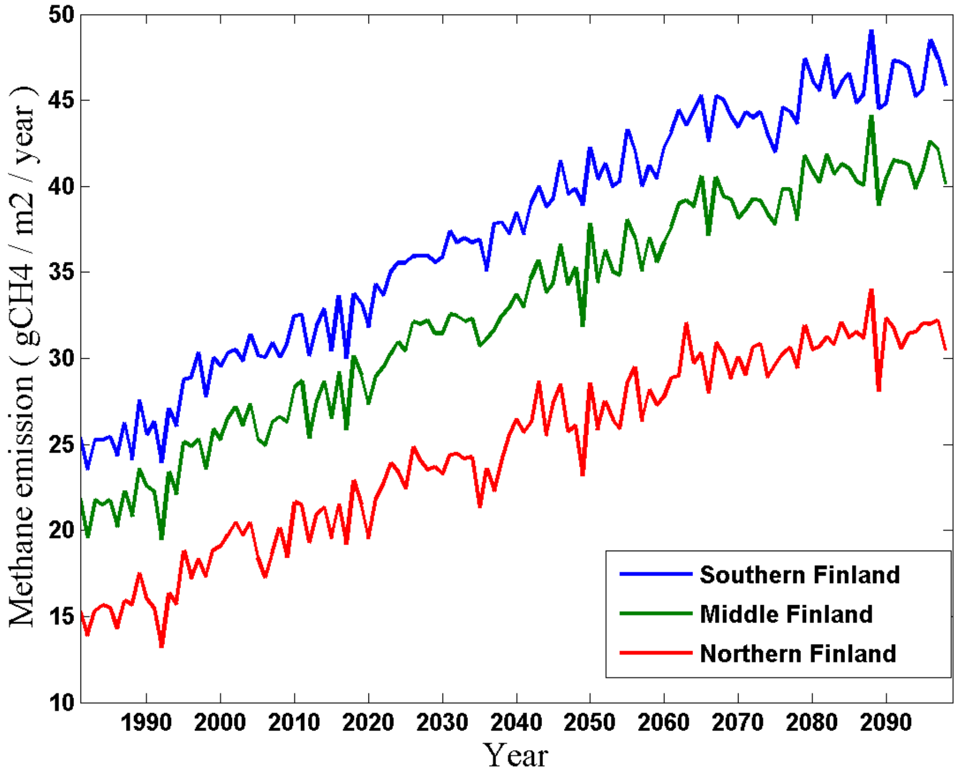


Figure 8. Mean yearly wetland methane emissions predicted with all RCP4.5 climatic drivers for three boreal zones.

## 8 References

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