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M6.6 Sensitivity analysis and construction of preliminary impact response surfaces for selected impact models

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PU	Public	
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Milestone 6.6

Sensitivity analysis and construction of preliminary impact response surfaces for selected impact models

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1 Introduction

A useful way of illustrating the modelled sensitivity of an exposure unit to changes in different climate variables is to construct impact response surfaces. These can be constructed by conducting multiple model simulations across a wide range of plausible future climates as well as for the present-day conditions, and then plotting the estimated impacts (e.g. crop yield, runoff) against key climate variables (e.g. see examples in section 2). Impacts to be studied in this way in the project include: soil moisture, soil temperature, crop productivity, nitrogen use efficiency, nitrogen leaching, soil carbon storage, stream discharge, and water availability. There are different methods of constructing and analysing response surfaces, and these are discussed further in sections 2.4 and 2.3, below, using examples from ENSEMBLE partners in WP 6.2. Response surfaces will be used later in the project in combination with probabilistic representations of future climate generated by ENSEMBLES partners in other Research Themes. Probability density functions (pdfs) will be computed, based on multi-model (ensemble) climate simulations, for changes in the same key climate variables and over the same regions used in constructing the impact response surfaces.

The importance of a given impact can be evaluated by defining *impact thresholds*. These are being selected by modelling groups to illustrate possible levels of tolerance to climate change, the exceedance of which may be regarded as unacceptable by decision makers (thus addressing an important element of Article 2 of the UN Framework Convention on Climate Change[1]). For example, a drying trend may reduce groundwater levels below threshold levels for long-term sustainable use, thus jeopardising supplies to consumers. Thresholds are sector-, system- and region-specific, and can be based either on historical impacts, or according to established operational conditions (e.g. minimum stream discharge for hydroelectric production).

2 Preliminary response surfaces

WP 6.2 is applying a range of different models to examine the potential impacts of climate change on crops, water resources, forests, energy supply, and human health (*cf*. Carter & Fronzek 2006). Some of the models will be used with the response surface method. Table 1 lists the impact models with which response surfaces will be calculated. Other partners in WP6.2 may conduct similar exercises at a later stage.

Table 1: Impact models, sectors and scales of analysis using the response surface method employed by partners in Work Package 6.2.

Partner	**Local**	**Catchment/national**	**Europe-wide**
DIAS	Temperate crops/N/Soil C	Temperate crops/ N/Soil C	
DISAT	Mediterranean crops	Mediterranean crops	
SMHI		Runoff/stream discharge	
SYKE		Temperate crops, subarctic palsa mires	
UNIK			Water availability/ water quality

The following sections show some preliminary example response surfaces constructed with the various impact models employed in WP 6.2.

2.1 DIAS: Risk of having the sowing dates for crops after a certain day

The Daisy model (Hansen et al., 1990, Abrahamsen and Hansen, 2000) was used for the sensitivity analyses and construction of response surfaces. Areas in Europe with high agricultural production were selected from

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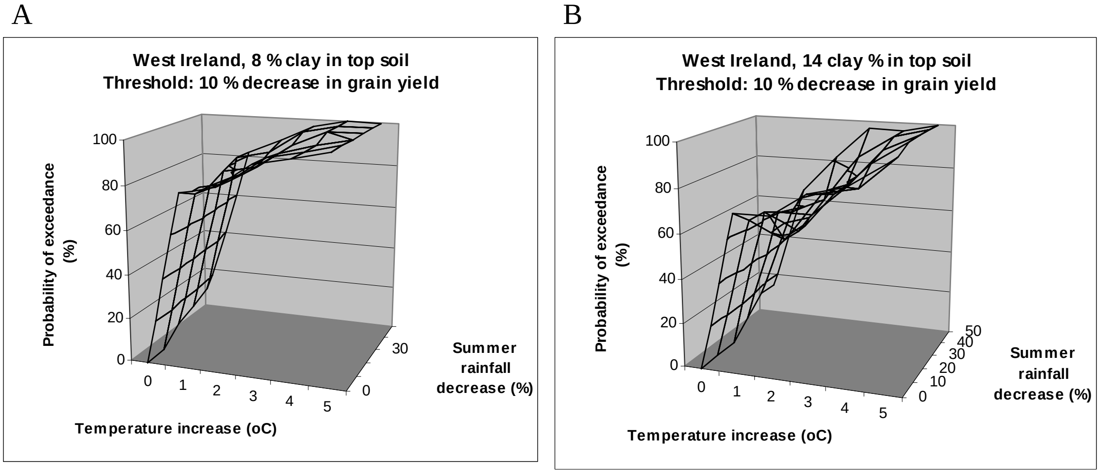
[1] "The ultimate objective …. is to achieve …...stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." (UNFCCC, 1999). The exploration of alternative tolerance thresholds can provide useful information for decision makers needing to interpret what constitutes "dangerous anthropogenic interference".

information on land use from EUROSTAT. Baseline climate data from the MARS/STAT database from Joint Research Centre (JRC), 1976-2004 was used as input data for the model. The climatic elements, i.e. air temperature and precipitation were modified. Soil data was from the European Soil Database, version 2.1.0.0 from JRC, and the model was run with two representative soil types for each climate grid. The fertilisation rate was calculated from the simulated maximum yield and a regression between maximum yield and optimal N rate. The regression was found from simulations with 5 soil types, 9 European climates and 5 N rates (50, 100, 150. 200 and 250 kg N/ha). A delay in sowing date of 5 days for each 1oC increase in mean temperature was used. It was necessary to change the vernalisation demand in the Daisy model, when increased temperatures were applied. We have made the vernalisation dependent on the mean temperature in December. This probably reflects both some weaknesses in simulation of vernalisation in the model, and the need for adaptation of vernalisation in varieties under warmer climates.

Preliminary sensitivity analyses have been conducted and a method to construct impact response surfaces was tested. The Daisy model was used to simulate winter wheat yields and nitrogen leaching for selected climate grid in some of the pilot areas. The temperature was changed with steps of 1oC to +5oC and summer (March-August) precipitation was decreased with steps of 10 % from 0 to –50%. The probability of exceeding a threshold of 10 and 20 % reduction in yield compared to baseline was calculated. Also the probability of exceeding a threshold of nitrogen leaching larger than 25 kg N/ha was calculated. Figures and 2 show results from two grids in Ireland and Portugal and for two soil types. The analysis will be extended with other impact thresholds and other combinations of future climates (temperature, rainfall, CO2 concentrations). Simulations with spring barley will also be included in the analysis.

It will also be necessary to investigate the combined response of changes in temperature, summer rainfall, winter rainfall and CO2 concentration. However, this gives multidimensional response surfaces and ways of simplifying these relationships will be investigated.



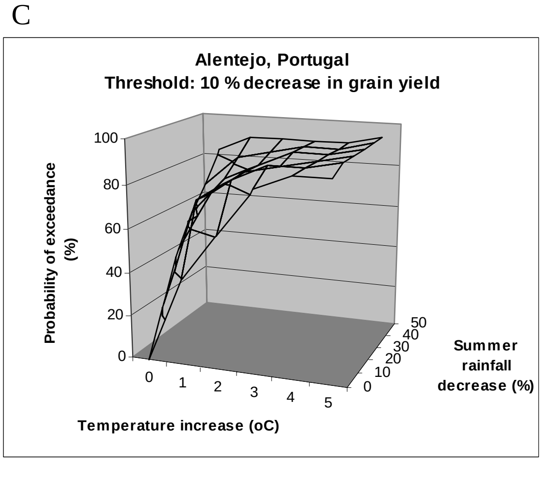
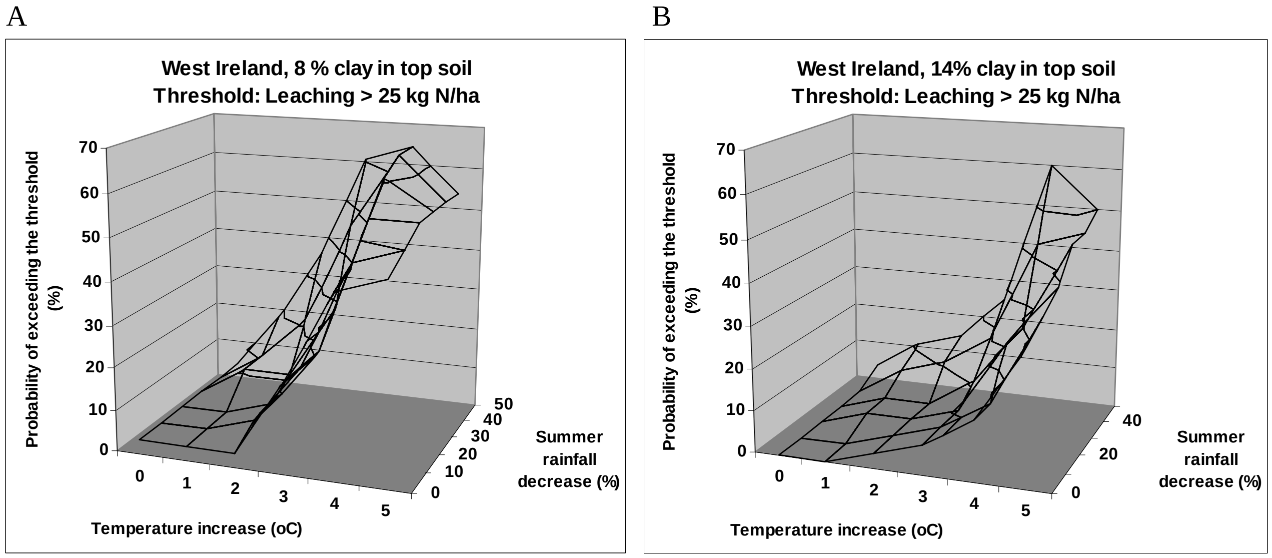


Figure 1. Response surfaces showing the probability of exceeding a threshold value of 10% increase in yields compared to baseline as function of changes in mean annual temperature and summer rainfall (A: West Ireland, 8% clay in top soil, B: West Ireland, 14% clay in top soil and C: Alentejo, Portugal).



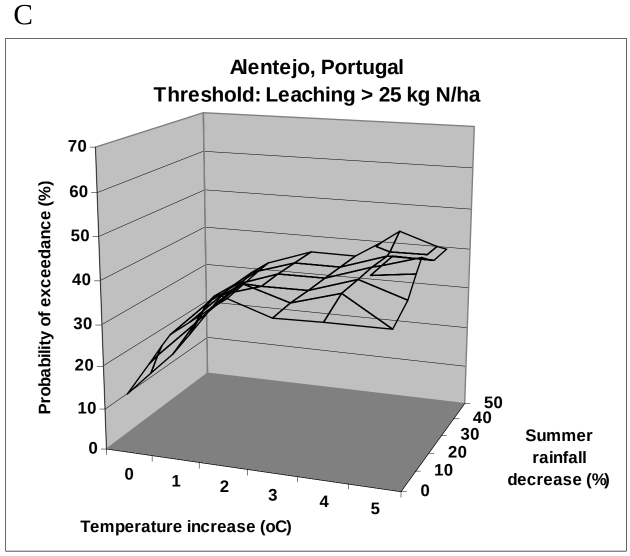


Figure 2. Response surfaces showing the probability of exceeding a threshold value of leaching > 25 kg N/ha as function of changes in mean annual temperature and summer rainfall. (A: West Ireland, 8 % clay in top soil, B: West Ireland, 14 % clay in top soil and C: Alentejo, Portugal).

2.2 DISAT: Risk of having the sowing dates for crops after a certain day

With the aim to test the “sensitivity analysis and response surface” methods for linking probabilistic climate information to impact model, the calibrated crop growth model (Stockle et al. 2003) was used to simulate wheat phenology for Milano, Roma and Foggia over the last century to provide a baseline scenario for risk assessment. Three weather historical series (minimum and maximum temperature and rainfall) (1858-2003 for Milano, 1862-2003 for Roma and 1901-2003 for Foggia) were used as input data to run the model. Radiation was calculated according to Bristow and Campbell model using RADEST software. The risk of having the sowing dates after a certain day (1st Dec. in Milano, 15th Dec. Roma and 1st Jan. Foggia) was investigated under a wide range of plausible future climate changes. More specifically, each time series was modified by changing both temperature and rainfall over the range –5° + 5° for minimum and maximum temperature (1°C as step) and +30% -30% for annual rainfall (10% as step). The surface responses of the probability of exceeding the selected threshold for the sowing dates were reported in Fig. 6.

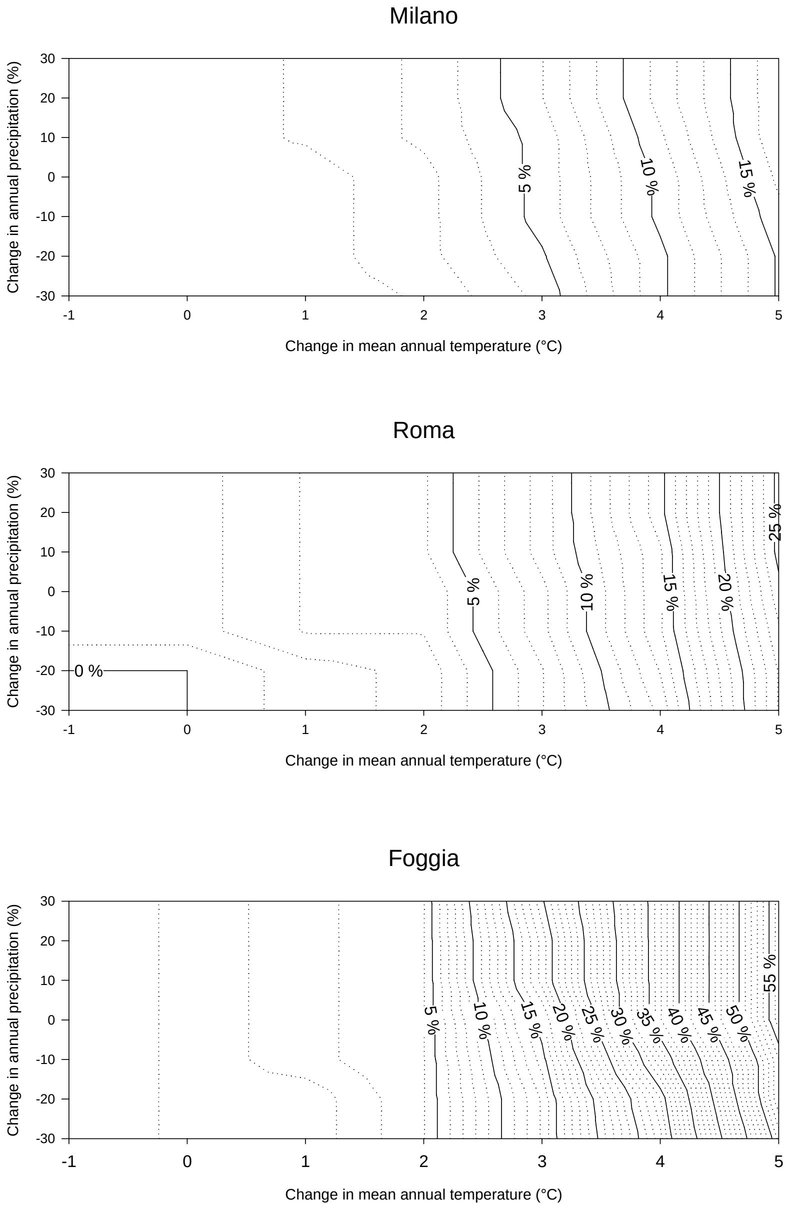


Figure 3: Risk response surfaces showing the probability of exceeding a threshold data for sowing, as function of changes in mean annual Temperature and Precipitation in 3 locations (A: Milano; B: Roma; C: Foggia).

2.3 SYKE: Response surfaces of changes in sub-arctic palsa mire distribution

Palsa mires are northern mire complexes with permanently frozen peat hummocks, located at the outer limit of the permafrost zone. They are currently degrading throughout their distributional range, probably because of regional climatic warming. The current distribution was mapped on a 10’ x 10’ regular grid over northern Fennoscandia (Luoto *et al.*, 2004). Using climate variables derived from the CRU 1961-1990 climatology (giving values for mean monthly temperature and precipitation) on the same spatial resolution, the palsa mire distribution was then modelled with five climate envelope techniques (generalized linear modelling, generalized additive modelling, classification tree analysis, artificial neural networks and multiple adaptive regression splines) (Fronzek *et al.*, 2006).

These distribution models were used to construct response surfaces for changes in the area that offers suitable climatological conditions for palsa mires. A sensitivity analysis was carried out with respect to changes in mean annual temperatures and annual precipitation sum. The sensitivity analysis was conducted for precipitation changes between –30% and +30% and temperature changes between -1°C and +7°C applied uniformly across all months of the year. Most climate models agree that future warming in northern Europe is strongest during the winter months. We therefore repeated the sensitivity analysis by using an annual cycle for the temperature changes that was calculated as the average from the simulated changes of six global climate models between the periods 1961-1990 and 2071-2100 (northern European grid cell values, A2 scenarios).

Figure 4 shows the response surfaces of these two approaches for one of the distribution models. The loss of area suitable for palsa mires is demonstrated with increasing temperatures and decreasing precipitation. For the same increase in mean annual temperature the model results show a greater loss of palsas in the response surface that was calculated for seasonally varying temperature changes (Figure 4, right), indicating the importance of changes during the winter.

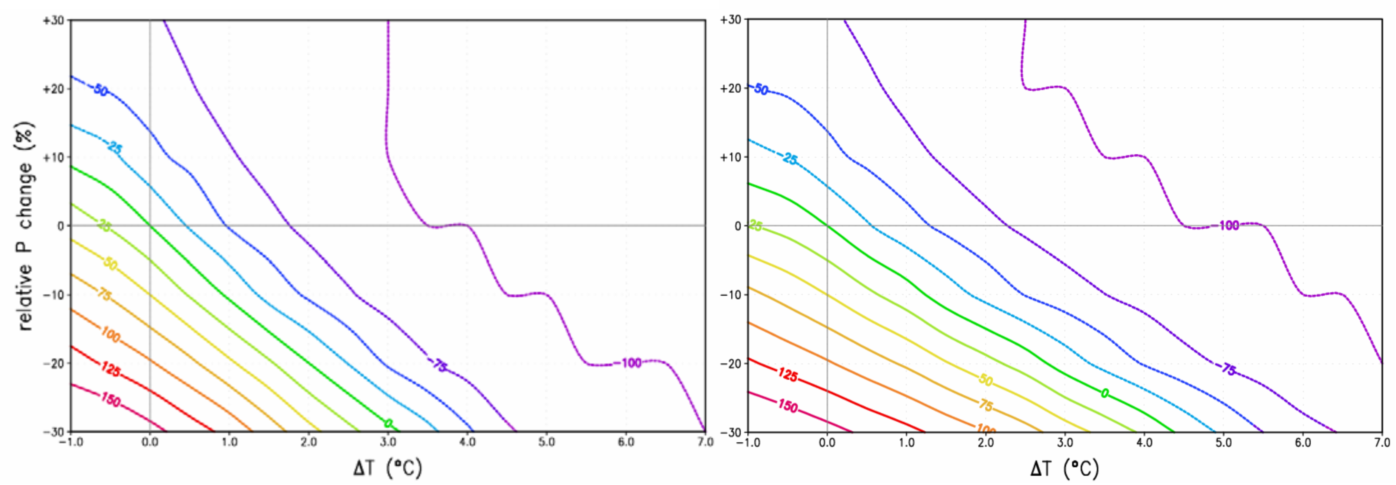


Figure 4: Percentage change of 10' resolution grid boxes predicted to be suitable for palsa formation in northern Fennoscandia using generalized additive modelling. Values are plotted for combinations of mean annual precipitation and temperature changes relative to the 1961-1990 baseline. Calculations assumed: (left) uniform climate changes throughout the year; (right) seasonally varying temperature changes based on projections averaged across six global climate models (preliminary, unpublished results).

2.4 UNIK: Response surfaces of water availability for river basins

This section is explained in more detail in UNIK (2006).

In order to investigate the behaviour of water availability for river basins in various climatic zones under modified climates, climate data with modified climatic elements, i.e. variations in monthly mean temperature and monthly mean precipitation, have been fed into an integrated water availability model. The impact on the annual river discharge was computed at the outlet cell of each selected river basin, which describes the sum of the basin discharge. Calculations were carried out with WaterGap (Water – Global Assessment and Prognosis).

WaterGap, developed at the Center of Environmental Systems Research at the University of Kassel, is an integrated global water model to compute current and future water availability and water use. It consists of a global hydrology model to simulate the terrestrial water cycle and a global water use model to simulate the anthropogenic interference with the water cycle. The hydrological model calculates the daily water balance on a 0.5° x 0.5° (geographical latitude and longitude) grid cell basis. It takes into account physiographic characteristics, e.g. soil, vegetation, slope, aquifer type, the inflow from upstream cells, and the influence of lakes, reservoirs and wetlands. The total runoff is divided into fast surface and subsurface runoff, and groundwater recharge. Discharge is routed through the basin according to a drainage direction map. The water use model computes water uses for three sectors: domestic, industry and agriculture. The domestic sector includes municipal and household uses; the industry sector is subdivided into electricity production and manufacturing facilities; the agriculture sector is subdivided into irrigation and livestock uses. For each sector, water intensities are calculated and multiplied by the appropriate driving force, which are e.g. population in the domestic sector; electricity production for electricity generation, and GVA for manufacturing in the industry sector; area of irrigated land, climate change and number of livestock in the agriculture sector (Alcamo *et al.*, 2005).

Model calculations are first carried out based on the climate normal period (1961-1990) using data from New *et al.* (2000). The mean river discharge of the whole basin is computed. Water use is excluded at this stage, in order to calculate the potential water availability. This option has been chosen to compute solely climate-change based responses. The 30-year monthly mean climate is gradually modified as follows, where constant changes of climate are equally applied to all months of the year: the monthly mean temperature is varied in the range of –5 to +5 degrees Celsius-deviation from the climate normal. Monthly mean precipitation is decreased in discrete steps by 25% and 50% and increased by 25%, 50%, 75%, and 100% relative to the climate normal. This results in a 11x7 data matrix of water availabilities (z_i). In order to display the impact of climate change on the water availability, response surface diagrams are used. For each river basin, a 3D- surface is fitted of the form Z = F(X,Y) by gridding the 11x7 data matrix (11 points for temperature and 7 for precipitation alterations) to a 45x45 mesh and interpolating z_i (the water availability) using Delauney triangulation (cubic interpolation).

Preliminary results

All selected river basins show a significant response to a variation of the monthly mean precipitation and temperature. The dimension of this response, however, differs based on basin specific geographical and climate factors. A change in precipitation leads in all European catchments to a stronger response in the water system, i.e. the change in the average annual river discharge is higher than the initial change in precipitation. An increase of precipitation by 100% causes increases in the range of 150% - 500% in annual river discharges, depending on the basin. A decrease of the precipitation by 50% leads to decreases between 70% to almost 100%.

The discharge in all river basins shows a stronger response to a change in precipitation than to a change in temperature. This is not surprising, when considering the fact that precipitation directly influences river discharge in WaterGAP while temperature is a second order variable and influences discharge via evaporation and snow.

Temperature variations cause up to 30% changes in average discharges if the precipitation is kept constant (at the reference value). The impact of temperature change amplifies in combination with a simultaneous increase in precipitation. It becomes less relevant for decreased precipitation values. If the precipitation is altered concurrently, changes can reach dimensions of up to 80% to 90% at maximum and 1% at minimum.

The topography of the river basin has an influence such that higher altitudes lead to a bend in the discharge curve with a peak around minus 1 to minus 3 degrees, which can be attributed to an increasing number of snow days in these areas due to seasonally lower temperatures. However, this peak is most distinctive in combination with increased precipitations. It is observed at snow or ice impacted basins.

The 18 river basins have been divided into three classes of North, Central, and South European basins. In the following, the results will be discussed further with respect to this classification. Figure 5 shows response surfaces for representative river basins of these three classes. Response surfaces for all 18 river basins are shown in an appendix to the full report (UNIK, 2006).

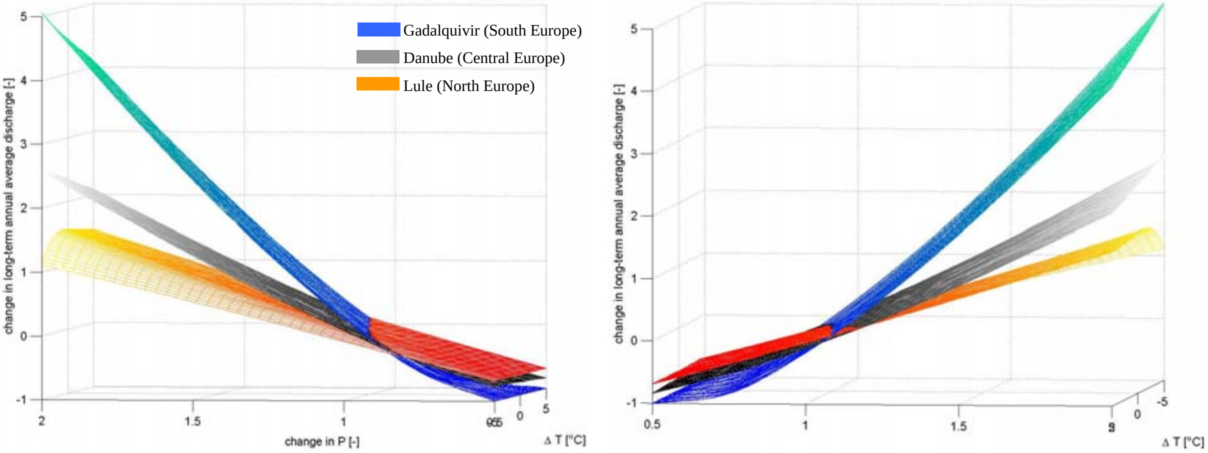


Figure 5: Different views of response surfaces for North-, Central-, and South-European river basins

The North-European river basins (Glomma. Kemijoki, Lule, Angermann) show the weakest response to a change in precipitation or temperature, compared to the other European basins. The changes in annual mean discharge reach app. +150% to +200% at maximum and app. –75% at minimum. A bend of the surface due to the influence of mountains is visible at the Glomma, Lule and Angermann catchments. The number of snow days dominates the discharge in cold North-European climates: additional precipitation is mostly stored as snow. With increasing precipitation, the duration at which water is stored as snow extends because WaterGap assumes the daily snowmelt for temperatures above zero to be constant. This leads to a lower increase in discharge for increasing precipitation in comparison to other climates. Because average temperatures are already low in Northern Europe, the temperature modifications of -/+ 5°C have a rather low impact on discharges and the response surfaces show a lower gradient.

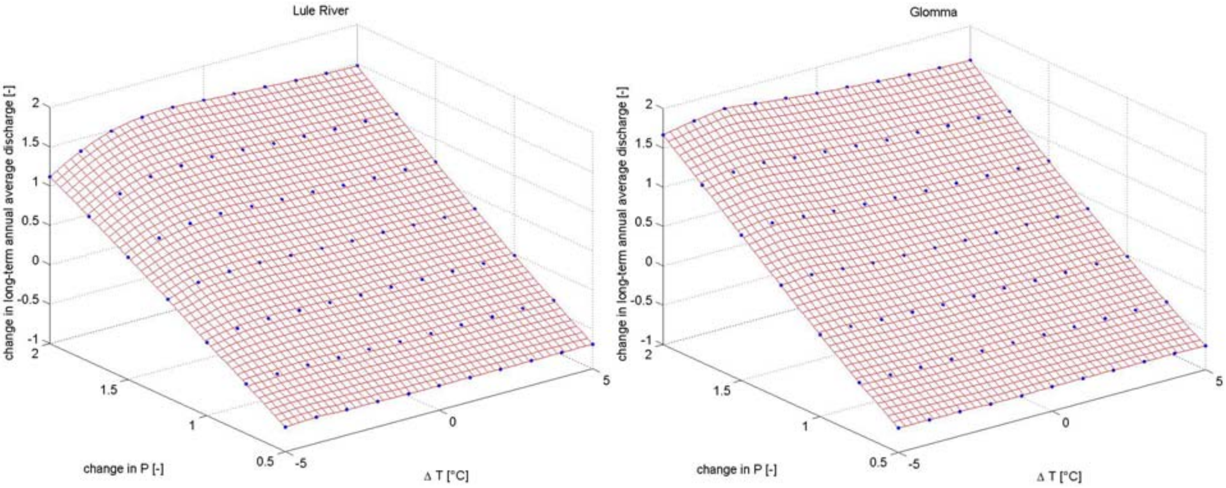


Figure 6: North-European river basins

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