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Impact analysis of climate data aggregation at different spatial scales on simulated net primary productivity for croplands

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ABSTRACT

For spatial crop and agro-systems modelling, there is often a discrepancy between the scale of measured driving data and the target resolution. Spatial data aggregation is often necessary, which can introduce additional uncertainty into the simulation results. Previous studies have shown that climate data aggregation has little effect on simulation of phenological stages, but effects on net primary production (NPP) might still be expected through changing the length of the growing season and the period of grain filling. This study investigates the impact of spatial climate data aggregation on NPP simulation results, applying eleven different models for the same study region (~34,000 km^2), situated in Western Germany. To isolate effects of climate, soil data and management were assumed to be constant over the entire study area and over the entire study period of 29 years. Two crops, winter wheat and silage maize, were tested as monocultures. Compared to the impact of climate data aggregation on yield, the effect on NPP is in a similar range, but is slightly lower, with only small impacts on averages over the entire simulation period and study region. Maximum differences between the five scales in the range of 1–100 km grid cells show changes of 0.4–7.8% and 0.0–4.8% for wheat and maize, respectively, whereas the simulated potential NPP averages of the models show a wide range (1.9–4.2 g C m^{-2} d^{-1} and 2.7–6.1 g C m^{-2} d^{-1} for wheat and maize, respectively). The impact of the spatial aggregation was also tested for shorter time periods, to see if impacts over shorter periods attenuate over longer periods. The results show larger impacts for single years (up to 9.4% for wheat and up to 13.6% for maize). An analysis of extreme weather conditions shows an aggregation effect in vulnerability up to 12.8% and 15.5% between the different resolutions for wheat and maize, respectively. Simulations of NPP averages over larger areas (e.g. regional scale) and longer time periods (several years) are relatively insensitive to climate data

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aggregation. However, the scale of climate data is more relevant for impacts on annual averages of NPP or if the period is strongly affected or dominated by drought stress. There should be an awareness of the greater uncertainty for the NPP values in these situations if data are not available at high resolution. On the other hand, the results suggest that there is no need to simulate at high resolution for long term regional NPP averages based on the simplified assumptions (soil and management constant in time and space) used in this study.

1. Introduction

Net primary production (NPP) is a crucial variable characterising the condition of an ecosystem (Pan et al., 2014) and it is sensitive to climate change. Spatial NPP is difficult to measure and is often biased and uncertain (Pan et al., 2014), because measurements show several limitations (indirect determination, spatially and temporally limited). Spatial modelling is an important tool for interpolation and extrapolation of measurements or for providing spatially distributed projections at regional (Reich et al., 1999; Zaehle et al., 2006; Bandaru et al., 2013; Liu et al., 2015), continental (Ciais et al., 2010) and global scales (Hemming et al., 2013; Friend et al., 2014). The regional scale is relevant for policy makers to analyse adaptation and mitigation strategies, but NPP data at this scale are often derived by extrapolating measured information from the site scale to a region by applying models developed at site scale (Zhang et al., 2015). This model-based up-scaling requires a balance between accuracy and simulation time.

Spatial modelling of NPP relies on spatially distributed input and driving data like weather data and information on soil, land use and management characteristics. Depending on environmental parameters, ecosystem characteristics and the chosen resolution, the impacts of extrapolation or interpolation may be great or small since there is a higher uncertainty for high relief areas compared to relatively flat areas, as shown by Pierce and Running (1995). For this reason, estimates of error and uncertainty arising from data aggregation across scales needs to be quantified.

Several studies have highlighted the impact of data aggregation on simulation results (Cale et al., 1983; Rastetter et al., 1992; Ewert et al., 2015; Zhao et al., 2015). de Wit et al. (2005) and Hoffmann et al. (2015) investigated the impact of climate data aggregation on crop yields. While de Wit et al. (2005) varied precipitation and solar radiation only on the resolutions 10 km and 50 km, Hoffmann et al. (2015) differentiated between five different resolutions between 1 and 100 km and also considered aggregation effects of temperature for 13 models. Both studies found only slight impacts of data aggregation on simulated yield over longer time periods at a regional scale. van Bussel et al. (2011) investigated the impacts of climate aggregation on croplands and focused on phenological stages rather than primary production, but they also found minor effects on simulated average values. The impacts of climate data aggregation on NPP were tested by Nungesser et al. (1999) and Pierce and Running (1995), for American forests. In both studies, the impact was minor for averages over the entire study area, but showed impacts for smaller areas, especially for areas dominated by strong relief changes (Pierce and Running, 1995). In both studies, the effects were tested by one model and for two resolutions of 10 and 50 km grid cells in Nungesser et al. (1999), and 1 km and 110 km in Pierce and Running (1995). The latter study investigated the effect for different input variables (relief, climate and soil) and found that climate data aggregation was the dominant variable affecting scale differences of NPP. They also observed larger scale effects for shorter time periods, which could be an indication of extreme weather events that average out over larger areas or longer time periods. Overall, regional simulation results over longer periods seem to be little affected by climate data aggregation. Over longer periods, changes of NPP even out and the impact of extreme events may not be obvious in a long term average, but relevant for shorter periods. Reichstein et al. (2013) describe the importance of temporal and spatial scale for detecting impacts of extreme weather conditions on the carbon balance, and highlight the risk of missing extreme weather conditions by integration of weather data across scales. Impacts of extreme weather also depend on the temporal scale, which has not so far been tested for impacts on NPP. However, studies determining the effect on NPP simulations of croplands are rare, and no study to date has analysed the potential to miss extreme events with climate data aggregation.

The objective of this paper, therefore, is to quantify error and uncertainty of NPP simulations of croplands caused by climate data aggregation across five resolutions (1, 10, 25, 50 and 100 km grid cell side length). This study addresses the three questions: (i) what are the impacts on long term NPP averages over the entire region?, (ii) how does the aggregation effect change over shorter time periods?, (iii) is the aggregation effect more pronounced in years with extreme weather conditions compared to "normal" years? These questions are answered by using a simulation approach involving eleven different models. Additionally, a vulnerability analysis helps to identify the impact of climate data aggregation for years with extreme weather conditions. Thus, we provide the first systematic analysis considering the impact of spatial weather data aggregation on NPP using five resolutions and 11 different models.

2. Methods

2.1. Aggregation effect

Crop models are generally designed and parameterised for a specific spatial resolution, which can be for points, plots, fields, map grid cells, or larger areas. When a model is run at a resolution different from that for which it was designed, inputs must be spatially aggregated or dis-aggregated, which will cause errors in outputs if the model is nonlinear. Most crop models are complex nonlinear point models. When such models are used to evaluate yield potential in large regions, lack of input information and computational constraints means that they need to be run at coarser resolution. The ensuing aggregation error is difficult to predict because of model complexity and our limited knowledge of the spatial heterogeneity underlying our aggregated input values. Input aggregation thus adds to the uncertainty associated with model predictions (Heuvelink and Pebesma, 1999). One way of reducing uncertainty about input aggregation error is to evaluate models at different resolutions for areas where high-resolution input data are available. In such cases, we are able to block-average the inputs and quantify the effect that the aggregation has on model outputs. Building up experience with such case-studies may help us assign probabilities to different degrees of aggregation error in comparable areas. In this study, we quantify the effect of climate data aggregation on the simulation of NPP, and define the aggregation effect ($E_{aggregation}$)