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How will climate change affect the vegetation cycle over France? A generic modeling approach

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ABSTRACT

The implementation of adaptation strategies of agriculture and forestry to climate change is conditioned by the knowledge of the impacts of climate change on the vegetation cycle and of the associated uncertainties. Using the same generic Land Surface Model (LSM) to simulate the response of various vegetation types is more straightforward than using several specialized crop and forestry models, as model implementation differences are difficult to assess. The objective of this study is to investigate the potential of a LSM to address this issue. Using the SURFEX ("Surface Externalisée") modeling platform, we produced and analyzed 150-yr (1950–2100) simulations of the biomass of four vegetation types (rainfed straw cereals, rainfed grasslands, broadleaf and needleleaf forests) and of the soil water content associated to each of these vegetation types over France. Statistical methods were used to quantify the impact of climate change on simulated phenological dates. The duration of soil moisture stress periods increases everywhere in France, especially for grasslands with, on average, an increase of 9 days per year in near-future (NF) conditions and 36 days per year in distant-future (DF) conditions. For all the vegetation types, leaf onset and the annual maximum LAI occur earlier. For straw cereals in the Languedoc-Provence-Corsica area, NF leaf onset occurs 18 days earlier and 37 days earlier in DF conditions, on average. On the other hand, local discrepancies are simulated for the senescence period (e.g. earlier in western and southern France for broadleaf forests, slightly later in mountainous areas of eastern France) for both NF and DF. Changes in phenological dates are more uncertain in DF than in NF conditions in relation to differences in climate models, especially for forests. Finally, it is shown that while changes in leaf onset are mainly driven by air temperature, longer soil moisture stress periods trigger earlier leaf senescence over most of France. This shows that developing *in situ* soil moisture networks could help monitoring the long-term impacts of climate change.

1. Introduction

Adapting agriculture and forestry to climate change in a global context of rising demand for food and energy will be a key objective in the next decades. The basic information needed to build adaptation strategies is provided by impact models able to simulate vegetation growth in response to climate variables (Tubiello et al., 2007). The latter are provided by climate models. Both climate and impact models are affected by uncertainties, which have to be described and quantified as much as possible (e.g. Déqué and Somot, 2010; Soussana et al., 2010). In many European countries, agricultural and forestry practices

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present local differences related to soil characteristics and, also, often related to local climates. Therefore, downscaling the large scale information given by global climate models is key. Moreover, an important component of adaptation is the development of new ground networks able to monitor biophysical indicators such as soil moisture (Calvet et al., 2007) and methods permitting the identification of vulnerable areas where the added value of such networks would be high.

In this study, we focus on metropolitan France, and we address local aspects of the impact of climate change on vegetation growth using the SURFEX (''Surface Externalisée'') modeling platform (Masson et al., 2013). The IPCC climate simulations, either CMIP3 A1B or CMIP5 RCP, show significant trends towards more precipitation in northern Europe and less precipitation in southern Europe and the Mediterranean basin (Jacob et al., 2014). From this point of view, France lies in an area between northern and southern Europe, where trends in precipitation are less pronounced. However, the marked increase in air temperature (T_{air}) may enhance evapotranspiration in spite of the antitranspirant action of CO_2 on plants. This may trigger a soil water deficit at springtime, earlier than under the present climate, and increase the irrigation demand (Calvet et al., 2008).

In order to simulate the impact of climate change on cultivated plant species, Brisson and Levrault (2010) used specific crop and forestry models over 12 sites representative of the main climatic regions in France. Their simulations suggested that wheat yields and the forage production could slightly increase in the future. On the other hand, the viability of forests, vineyards, and summer crops such as maize could be impacted by more frequent droughts in many regions. Loustau et al. (2005) used several forestry models over 5 locations in French plains. Their simulations indicated ''a slight increase in potential forest yield until 2013–2050, followed by a plateau or a decline around 2070–2100''. These trends were more or less pronounced from one location to another and from one tree species to another.

As past studies have focused on a limited number of sites in France, there is a need for more extensive evaluation of the plant phenology response across species. Models able to represent various vegetation types have been developed in the last two decades. They rely on generic approaches permitting the simulation of land surface water, energy and CO_2 fluxes, together with soil moisture and vegetation biomass. In this study, we used the Interactions between Soil, Biosphere, and Atmosphere model (ISBA) developed by Meteo-France for meteorological, hydrological and climatic applications. The CO_2-responsive version of this model (Calvet and Soussana, 2001; Gibelin et al., 2008) is able to simulate plant growth and carbon storage. The model uses relatively few parameters while representing key processes. In particular, drought-avoiding and drought-tolerant plants can be distinguished thanks to a refined representation of the effects of soil water deficit on photosynthesis parameters (e.g. mesophyll conductance). Phenology is directly driven by photosynthesis and, using satellite leaf area index (LAI) products, Szczypta et al. (2014) showed that realistic LAI simulations can be obtained over Europe.

This work aims at assessing uncertainties of future trends on biophysical variables (leaf onset, leaf senescence, maximum LAI) for four vegetation types (rainfed straw cereals and grasslands, broadleaf forests, needleleaf forests) over a large number of sites representative of the agricultural and forest regions in France. Maize and vineyards are not considered as they are not explicitly represented in our simulations. As a key objective of this study is to quantify the impact of uncertainties in climate simulations, we use an ensemble of eleven climate models (Fig. 1) to drive the ISBA model. We apply classical statistical methods to assess: (1) trends in time series of downscaled simulations of biophysical variables and plant phenology indicators, (2) the consistency of the various climate simulations at a given location. Finally, the analysis of the spatial variability of the response of plant growth to climate change is investigated and the main spatial patterns identified in this study are summarized.

The climate simulations and the ISBA land surface model are presented in Section 2, together with the design of the simulations of biophysical variables. The results are shown in Section 3 and discussed in Section 4. The conclusions of this study are summed up in Section 5.

2. Material and methods

2.1. Climate simulations

The downscaled climate simulations used in this study are derived from the SCRATCH2010 database (http://www.cerfacs.fr/~page/scratch/), which has been used in various climate change impact studies in France (e.g. Gouache et al., 2012; Habets et al., 2013). SCRATCH2010 climate simulations are generated using a statistical downscaling method applied to global large-scale climate simulations. The methodology is described in Boé et al. (2006), and in Boé and Terray (2008). It is based on weather-typing and builds on the physical links between the large-scale circulation and the local scale climate, from which statistical relationships can be derived. The spatial scale of representation is changed but the temporal distribution of weather variables is close to the parent global simulation. This statistical downscaling method is used to produce climate projections at a fine scale over France (8 km by 8 km), at a hourly time step. It is first trained on a reference period using observations to define the statistical relationships, and then applied to the climate simulations. The reference atmospheric reanalysis used to train the method is ''Système d'Analyse Fournissant des Renseignements A la Neige'' (SAFRAN) (Durand et al., 1993; Quintana-Segui et al., 2008). SAFRAN provides hourly values of liquid and solid precipitation, incoming solar radiation, incoming longwave radiation, air temperature, air humidity, atmospheric pressure, and wind speed over France. Boé et al. (2006) showed that the climatology derived from the downscaled climate simulations for past decades is very close to the observed climatology. The original large scale climate simulations correspond to the CMIP3 Special Report on Emission