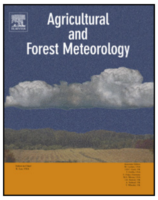
Agricultural and Forest Meteorology 232 (2017) 247–264

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet



Bias correction of dynamically downscaled precipitation to compute soil water deficit for explaining year-to-year variation of tree growth over northeastern France

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ARTICLE INFO

Article history:
Received 7 November 2015
Received in revised form 22 August 2016
Accepted 29 August 2016
Available online 1 September 2016

Keywords:
Regional climate modelling
WRF
Quantile mapping
Water balance
Soil water deficit
Douglas-fir
Common beech

ABSTRACT

This paper documents the accuracy of a post-correction method applied to precipitation regionalized by the Weather Research and Forecasting (WRF) Regional Climate Model (RCM) for improving simulated rainfall and feeding impact studies. The WRF simulation covers Burgundy (northeastern France) at a 8-km resolution and over a 20-year long period (1989–2008). Previous results show a strong deficiency of the WRF model for simulating precipitation, especially when convective processes are involved. In order to reduce such biases, a Quantile Mapping (QM) method is applied to WRF-simulated precipitation using the mesoscale atmospheric analyses system SAFRAN («Système d'Analyse Fournissant des Renseignements Adaptés à la Nivologie») that provides precipitation data at an 8 km resolution. Raw and post-corrected model outputs are next used to compute the soil water balance of 30 Douglas-fir and 57 common Beech stands across Burgundy, for which radial growth data are available. Results show that the QM method succeeds at reducing the model's wet biases in spring and summer. Significant improvements are also noted for rainfall seasonality and interannual variability, as well as its spatial distribution. Based on both raw and post-corrected rainfall time series, a Soil Water Deficit Index (SWDI) is next computed as the sum of the daily deviations between the relative extractible water and a critical value of 40% below which the low soil water content induce stomatal regulation. Post-correcting WRF precipitation does not significantly improve the simulation of the SWDI upon the raw (uncorrected) model outputs. Two characteristic years were diagnosed to explain this unexpected lack of improvement. Although the QM method allows producing realistic precipitation amounts, it does not correct the timing errors produced by the climate model, which is yet a major issue to obtain reliable estimators of local-scale bioclimatic conditions for impact studies. A realistic temporality of simulated precipitation is thus required before using any systematic post-correction method for appropriate climate impact assessment over temperate forests.

1. Introduction

Numerous studies highlighted that extreme or recurrent drought events, especially when combined to a heat wave, constitute one of the main climate hazard causing dieback in temperate forests (Lévy et al., 1987; Bréda and Badeau, 2008; Allen et al., 2010). Drought events may induce large-scale tree decline episodes since water availability severely constrains forest ecosystems productivity (Bréda et al., 2006; Ciais et al., 2005). In France, the 2003 drought and heat wave was exceptional both in its duration and intensity. After this event, forest declines with diffuse mortality were reported throughout Western Europe for both coniferous and broadleaved species (Lorenz et al., 2007). In Burgundy (northeastern France), coniferous species like Douglas-fir which were more severely affected than broadleaved species, presented visual

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http://dx.doi.org/10.1016/j.agrformet.2016.08.021
0168-1923/

symptoms such as abnormal coloration and needle loss as direct responses, and delayed symptoms like abnormal tree mortality (Sergent et al., 2012). Altered coloration of needles was caused by warm surface temperatures, occurring after a long period of reduced tree transpiration due to stomatal closure, induced by a very early soil water deficit (Bréda et al., 2006). A reduction of the net primary productivity and radial growth of common Beech trees was also reported after the summer 2003 heat wave over northeastern France (Granier et al., 2007).

In the context of anthropogenic climate change, an increase of the exposure to soil water deficit is expected in the Northern Hemisphere, especially in spring and summer, that is, the main vegetative period (IPCC, 2007). Over northeastern France, climate projections using the Weather Research and Forecasting (WRF) regional climate model and the Intergovernmental Panel on Climate Change (IPCC) A2-Special Report on Emissions Scenario (SRES-A2 – Meehl et al., 2007) have shown a warming of up to 3 °C for 2030–2050 and 5 °C by the end of the century (Xu et al., 2012). Over Burgundy, the mean annual temperature for the year 2003 was about 3 °C higher than the 1970–2000 climatology (Xu et al., 2012). Thus, the 2003 episode can be seen as an extreme event under current climate, and is an example of possible forthcoming forest-impacting hazards in a near future (Bréda et al., 2006; Betsch et al., 2010). Regional adaptation to global change through mitigation and adaptation of sylvicultural strategies is a key issue for the agro-forestry community. Future drought episodes inducing recurrent diebacks may reduce forest productivity and affect species distribution (Parmesan and Yohe, 2003; Mueller et al., 2005).

As a region extensively covered by forests (over 30% of the land area), Burgundy is particularly sensitive to such environmental changes. Besides oaks, Douglas-fir and common Beech are two highly represented species. The radial growth of these species is highly driven by soil water deficit (Lebourgeois et al., 2005; Betsch et al., 2010; Sergent et al., 2012), indicative of the intensity of drought episodes. Future climate changes are therefore a potential threat for the productivity of these forest stands.

During the last decade, numerous studies attempted to document the future of French forests potential distribution, productivity and risk of dieback. But these depend on ecological parameters such as soil water availability, which show large variations at both the local and the regional scales (Loustau et al., 2005). Impact models often need input climatic data at a resolution finer than 10 km and require thus a downscaling step of the climate information provided by the global climate models (Boé et al., 2007). Previous works proposed projections of forest potential areas using niche-based models (Pyatt et al., 2001; Piedallu et al., 2009; Badeau et al., 2010) based on statistical downscaling of climate data (Hewitson and Crane, 2006; Solomon et al., 2007; Christensen et al., 2007; Ning et al., 2012a,b). Such statistical downscaling considers empirical relationships linking the large-scale atmospheric variables to local or regional-scale variability and do not take into account auto-correlation between climatic variables (von Storch and Zwiers, 1999; Wilks, 2006).

In this study, we propose to use a daily lumped water balance model fed with climate information derived from a RCM, in order to calculate soil water deficit and its relationship to tree growth. Physiological indices, such as the Soil Water Deficit Index (SWDI) are used rather than climatic data to allow biological interpretations of the growth response to climate. These indices could be better correlated with radial growth than monthly climatic variables because soil water availability is a major limiting factor for tree growth (Michelot et al., 2012). Furthermore, using impact models as an additional source of information for evaluating climate models or post-correction methods can provide many benefits, but the use of impact indicators to test them is infrequent (Stéfanon et al., 2015; Boulard et al., 2015).

Among the process-based models, the daily water balance model Biljou© (Granier et al., 1999) is dedicated to forest stands, and allows calculating elementary water fluxes (tree transpiration, understorey evapotranspiration, rainfall interception, drainage) as well as the daily soil water content under forests. The model quantifies the intensity, the duration and the starting date of drought experienced by the stand. It has already been successfully applied to different stands (Bréda et al., 2006; Gandois et al., 2010; Van der Heijden et al., 2011; Michelot et al., 2012) and over parts of Burgundy (Sergent et al., 2012; Van der Heijden et al., 2013; Boulard et al., 2015). Requested climatic data to compute the water balance include 2-m air temperature and relative humidity, 2-m wind speed, solar radiation and precipitation.

With the aim of obtaining more reliable estimations of these variables close to the sites of interest, coarse global reanalyses data is downscaled at a sensibly higher resolution using the non-hydrostatic WRF model. Although RCMs are powerful tools for describing regional and local scale climatic conditions, they still feature systematic errors, and small-scale patterns of daily precipitation are highly dependent on the model resolution and physical parameterizations (Giorgi and Mearns, 1991; Laprise, 2008). Biased representation of precipitation intensities and associated temporal and spatial variability often prevent RCM precipitation outputs to be directly used for climate change impact assessment (Fowler et al., 2007; Maraun et al., 2010). A previous analysis documenting the capability of the WRF model to regionalize near-surface atmospheric variables over Burgundy concluded on good skills for simulating the first four aforementioned variables (Boulard et al., 2015), but a clear tendency to over-estimate precipitation amounts, especially those of convective nature (Marteau et al., 2014).

In order to obtain reliable estimators of local-scale bioclimatic conditions, precipitation biases need thus to be post-corrected. Among the empirical-statistical downscaling and error correction methods, the Quantile-Mapping (QM) method (Piani et al., 2010; Heinrich and Gobiet, 2011; Themeßl et al., 2011, 2012; Gudmundsson et al., 2012; Maraun, 2013) adjusts the distribution of modelled data to observed ones and generally shows high efficiency, particularly for high quantiles (Themeßl et al., 2011).

This study aims thus at (i) documenting how accurately the QM method corrects the WRF precipitation errors, critical for soil water deficit computations; (ii) evaluating the relevance of post-corrected WRF outputs to be used as climatic input data for environmental impact assessment. This is achieved by forcing a forest water balance model that computes a SWDI over the Burgundy region. In order to evaluate the performance of post-corrected precipitation, comparisons are done between water balances of 30 Douglas-fir and 57 common Beech stands computed from both raw and post-corrected WRF outputs, as well as mesoscale SAFRAN («Système d'Analyse Fournissant des Renseignements Adaptés à la Nivologie») atmospheric analyses. SAFRAN analyses (Quintana-Seguí et al., 2008) produce surface atmospheric variables covering France on a regular grid at an 8 km resolution using observations from the automatic, synoptic and climatologic Météo-France station networks, and ECMWF reanalyses (Szczypta et al., 2011).

This paper is organized as follows. Section 2 presents the data used and the experimental setup for WRF simulations. Section 3 evaluates the improvement of the post-corrected precipitation upon the raw WRF precipitation. Section 4 focuses on the computation of the water balance, including the Relative Extractable Water (REW) and the Soil Water Deficit Index (SWDI) of the Douglas-fir and common Beech stands, and their relationship to observed radial growth indexes. Results are finally discussed and summarized in Sections 5 and 6 respectively.