Agricultural and Forest Meteorology 263 (2018) 100–106

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

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

Using high-resolution simulated climate projections in forest process-based modelling

J.H.N. Palma[a,*], R.M. Cardoso[b], P.M.M. Soares[b], T.S. Oliveira[a], M. Tomé[a]

[a] Forest Research Centre, School of Agriculture, University of Lisbon, Tapada da Ajuda, 1349-017, Lisboa, Portugal
[b] Instituto Dom Luiz, CGUL, Universidade de Lisboa, Lisboa, Portugal

A R T I C L E I N F O

Keywords:
CORDEX
WRF
RACMO
Eucalyptus
Regional climate models
Climate change

A B S T R A C T

Forest management decisions often rely on forest growth process based models. These models require climate data at a time-scale and a time-frame that is frequently not available in the area of interest. With the purpose of evaluating the use of modelled climate as a replacement for observational data, we compared the performance (efficiency, precision and bias) of a forest growth process based model (3-PG) when the inputs of the observational climate data were replaced by modelled climate data. Based on previous research, we focused on two promising regional climate models: 1) the Regional Atmospheric Climate Model (RACMO) and 2) the Weather Research and Forecast Modelling System and Program (WRF).

Results suggest that when using simulated climate data there are minor losses of performance in the forest growth model predictions with a general growth overestimation, with RACMO providing the best results. A deeper analysis suggests that improving the temperature accuracy of the model will reduce the overestimation of the predictions.

The use of simulated climate data with RACMO and WRF is therefore recommended when observed climate is scarce or inexistent. The use of these datasets can certainly widen the usage of forest growth process based models, improving the support for decision-making in forest management, especially when considering climate change, one of the cornerstones for which modelled climate is developed.

1. Introduction

Process based models (PBMs) offer insights into tree growth that is useful for both forest management and applied research (Korzukhin et al., 1996; Johnsen et al., 2001). Their use and application has increased in recent years due to the need to consider productivity under climate change, becoming an important tool to support adaptive forest management and planning (Bugmann and Trasobares, 2013; Garcia-Gonzalo et al., 2014; Mcmurtrie and Wang, 1993; Valentine et al., 1997).

In order for PBMs to project reliable estimates of forest growth, the model parameters need to be calibrated and the estimates need to be validated against observed data, using both physical drivers (soil and climate) and tree growth measurements. Although computers and software capacities allow a wide use of PBMs, the availability of climate data remains a challenge. Typically, climate data for modelling is collected from a meteorological station located near the place where the tree measurements are gathered (e.g. an installed meteorological station). In its absence, e.g. due to lack of budget, data from the nearest available climate station is used.

Climate data is frequently difficult to retrieve, in particular when no meteorological station has been installed and measurements from meteorological station networks have to be used. Even when data from these networks exist, other problems persist such as a lack of climate measurements during certain time periods, the distance between the climate station and the tree measurements is too far, or the climate data is too expensive to buy, especially in the case of models requiring daily weather data for long periods (e.g. to simulate the growth of slow growing trees).

The development of regional climate models (RCMs) in the recent decades has provided meteorologists with a powerful tool to characterise past and future, and regional to local, climates (Giorgi and Mearns, 1999; Laprise, 2008; Rummukainen, 2010). Although able to represent physically consistent regional and local atmospheric circulations, their accuracy is highly dependent on the quality of the boundary conditions, the physical parameterisations (Evans et al., 2013; Flaounas et al., 2011; Liang et al., 2008), the horizontal and vertical resolutions used (Boberg et al., 2010; Rauscher et al., 2010; Soares et al.,

* Corresponding author at: Forest Research Centre, School of Agriculture, University of Lisbon, Tapada da Ajuda, 1349-017, Lisboa, Portugal.
E-mail address: joaopalma@isa.ulisboa.pt (J.H.N. Palma).

https://doi.org/10.1016/j.agrformet.2018.08.008
Received 11 January 2018; Received in revised form 23 July 2018; Accepted 13 August 2018

2012a,b,c), on the horizontal domain size (Colin et al., 2010) and on the error measures selected to analyse their performance (Soares et al., 2015, 2017).

The European climate community has, in recent years, been involved in the construction of regional climate datasets for the whole continent at increasingly higher resolution. The latest project, EURO-CORDEX (Jacob et al., 2014), is a consortium of several climate centres which has performed regional climate simulations for a common European domain at 12 km and 50 km resolutions for present and future climates. The compliant set of simulations includes:1) a hindcast simulation, forced by ERA-Interim reanalysis (Dee et al., 2011), for the 1979–2009 period, representing a synchronized present climate dataset, thus suitable for describing the actual climate and be fully evaluated against observations at the full range of output temporal and spatial scales; 2) a historical simulation forced by a free running Global Circulation Model (GCM), for the period 1971–2000, therefore only statistically comparable to observations; and (3) future climate simulations, covering the period from 2006 to 2100, following the Representation Concentration Pathways (RCP) future emissions scenarios. Kotlarski et al. (2014) analysed the near surface temperature and precipitation from the hindcast simulations and detected a cold and wet bias in almost all of the European domain and in most of the seasons; nevertheless, the different RCMs were able to capture the spatial and temporal variability of the European climate.

Similarly to the EURO-CORDEX project, a set of 9 km resolution simulations for the Iberian Peninsula has also been performed by the University of Lisbon using the Weather Research and Forecast (WRF; Skamarock et al., 2008) regional climate model. The hindcast simulation has been evaluated against point observations for maximum and minimum temperatures and precipitation in Portugal (Soares et al., 2012a,b,c) and Iberian solar irradiance (Magarreiro, 2016), as well as gridded datasets for Iberian precipitation (Cardoso et al., 2013; Rios-Entenza et al., 2014), and onshore and offshore wind (Nogueira et al., 2018; Soares et al., 2014). In all cases remarkably good results were obtained. Additionally, these hindcast simulation results were used for fire propagation studies (Sá et al., 2017) and investigations on the climatic cooling potential for Iberian buildings (Campaniço et al., 2016).

This work explored the potential of using such simulated climate data to predict forest growth.

The main objective was to evaluate the performance of process based model estimations when replacing observed climate data with simulated climate data. If the performance observed previously using simulated climate datasets can be transposed to forest modelling applications, it would widen the range of application of both simulated climate datasets and forest growth models to a greater extent in two important research areas. One is the calibration and validation of forest PBMs where currently scarce or no weather measurements are available, and another is the combination of both PBMs and modelled climate data considering future scenarios, to deepen the knowledge for strategic decisions for adapting the sustainable forest management in the future (e.g. Garcia-Gonzalo et al., 2014; Palma et al., 2015).

2. Materials

To compare the performance of real and simulated climate data we used a forest growth PBM where the evaluation consisted of the comparison of predicted forest growth against tree measurements when using 1) observed climate data and 2) regional climate simulated data. As the resolution of the simulated datasets is getting finer, we further assessed if there was an advantage of having such finer resolution by testing simulated data from a grid coordinate a) near the observed weather station and b) near the tree measurements.

2.1. Forest growth process based model (PBM)

The model 3-PG - Physiological Principles in Predicting Growth – is a simple, process based model (PBM) developed with the intention of bridging the gap between the simpler empirical models and the more complex physiological based ones, giving stand-level information of interest for forest management (Landsberg and Waring, 1997; Sands and Landsberg, 2002). The model is well-documented, the code is freely available and it has already been calibrated for *Eucalyptus* plantations in Portugal (Fontes et al., 2006). It is a forest stand level model that works on a monthly time step where the main outputs are the biomass values for stem, foliage and roots, but it also estimates stem volume, basal area, stand density, mean stem diameter at breast height, mean annual stem volume increment, available soil water, stand transpiration and leaf area index.

The 3-PG implemented in Excel (with integrated visual basic for applications), version 2.7 was used (available at http://booksite.elsevier.com/9780123744609/?ISBN=9780123744609) with the parameter values for eucalyptus stands in Portugal from Fontes et al. (2006).

2.2. Tree measurements and soil data

Field data was collected from 1988 to 2013 from different experimental plots located in different regions representing wide climate and soil variation in the eucalyptus expansion region in Portugal (Fontes et al., 2006; Oliveira, 2015). All the plots were of first rotation stands of non-clonal *Eucalyptus globulus* Labill. The trees were measured for diameter at breast height while height was measured on at least the dominant trees. When necessary, tree height was estimated with the equation from Soares and Tomé (2002). Volume was calculated using the equations from Tomé et al. (2002) while aboveground biomass and biomass per tree component (stem wood, stem bark, branches and leaves) were estimated using the equations developed by Antonio et al. (2007). A total of twelve sites were used (Supplementary material #1 - Fig. 1). Tree measurements covered a wide range of stand ages, densities and site indices (dominant height at age of 10). A total of 2682 trees in 125 plots were measured between 1988 and 2013 (Supplementary material #1).

For each site, a soil pit was dug and profiled to collect information on soil texture, depth, available soil water and other soil-related data needed for the 3-PG model (see details in Oliveira, 2015).

2.3. Observed climate data

The climate data used, covering the growth period of the stands, was partially collected from SNIRH (Sistema Nacional de Informação de Recursos Hídricos http://snirh.pt/) and partially acquired from the Instituto Português do Mar e da Atmosfera (IPMA) (Fig. 1).

Climate data from 1988 to 2004 and from 2009 onwards was acquired from IPMA, while climate data from 2005 to 2009 was collected from SNIRH. SNIRH had a network of climate stations covering Portugal mainland and all data is freely available; however from 2009 to 2014 the stations stopped working due to a lack of budget, so data from 2009 onwards was completed with data purchased from IPMA.

The nearest stations for each site was chosen to collect climate data (Supplementary Material #1 and Table 1) that included monthly mean minimum and maximum daily temperatures, accumulated precipitation, number of days with rain > 1 mm (wetdays) and frost days and yearly solar radiation (Supplementary material #2).

2.4. Simulated climate data – regional climate models

The climate data used included the highest resolution climate regional simulation dataset available covering all of Iberia, and the KNMI RACMO model results generated in the framework of the EURO-CORDEX project, at 12 km resolution. The higher resolution regional climate dataset was produced using the Weather Research and Forecasting (WRF) model, at 9 km, forced by the ERA-Interim