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Application of BIOME-BGC to simulate Mediterranean forest processes

M. Chiesi[a,*], F. Maselli[a], M. Moriondo[b], L. Fibbi[a], M. Bindi[b], S.W. Running[c]

[a] IBIMET-CNR, Via Madonna del Piano 10, 50019 Sesto Fiorentino, Italy
[b] DISAT-Università degli Studi di Firenze, Italy
[c] University of Montana, Missoula, USA

ARTICLE INFO

Article history:
Received 27 February 2006
Received in revised form
20 February 2007
Accepted 28 March 2007
Published on line 7 May 2007

Keywords:
BIOME-BGC
C-Fix
Mediterranean forest
Spot-VGT
GPP
Monitoring

ABSTRACT

The current work investigates on the applicability of a widespread bio-geochemical model (BIOME-BGC) to estimate seasonal photosynthesis and transpiration within water limited Mediterranean forest environments. The use of the model required a preliminary calibration phase, aimed at setting its ecophysiological parameters to properly simulate the behavior of three Mediterranean species (*Quercus ilex* L., *Quercus cerris* L. and *Pinus pinaster* Ait.). For each of these species, the calibration of BIOME-BGC was performed by adjusting the monthly gross primary productivity (GPP) estimates of 10 forest plots to those of a simplified parametric model, C-Fix, which is based on the use of satellite and ancillary data. In particular, BIOME-BGC was run modifying the eco-physiological parameters controlling stomatal conductance, in order to identify the best model configurations to reproduce the spatial, intra- and inter-annual GPP variations simulated by C-Fix. Next, the fraction of leaf nitrogen in Rubisco was adjusted to fit also the magnitudes of the C-Fix GPP estimates. The subsequent testing phase consisted of applying the original and calibrated versions of BIOME-BGC in independent forest sites where the three species considered were dominant and for which field measurements of photosynthesis and transpiration were available. In all cases the use of the calibrated BIOME-BGC versions led to notably improve the GPP and transpiration estimation accuracy of the original model. The results obtained encourage the operational application of BIOME-BGC in Mediterranean forest environments and indicate a possible strategy to integrate its functions with those of C-Fix.

1. Introduction

Forest ecosystems are an environmental and economic resource which is still widely spread. Some authors suggest that their extension is about 40% of the Earth's ice-free land surface and that this is less than the potential extension due to human disturbances (Waring and Running, 1998). Forests are able to provide numerous wood products (e.g. timber, paper products, etc.), prevent soil erosion, contribute to maintain biodiversity and are often used for recreational purposes; additionally they have a great role both in the water and carbon cycles (Waring and Running, 1998). Hence, the estimation of forest ecosystem processes and their variations in time and space is one of the main objectives of applied ecological studies. In general, such estimation is necessary to advance towards sustainable management of forest resources, both on a local and on a regional scale. Specifically, the necessity for monitoring and quantifying the

* *Corresponding author*. Tel.: +39 055 5226023; fax: +39 055 444083.
E-mail address: m.chiesi@ibimet.cnr.it (M. Chiesi).

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doi:10.1016/j.ecolmodel.2007.03.032

amount of carbon accumulated within forests has recently increased also in view of the application of the Kyoto Protocol and related documents (IPPC, 2001).

Numerous studies have been recently conducted and trials have been performed to produce estimates of forest processes on different spatial and temporal scales using various instruments (i.e. eddy-covariance techniques, satellite images, biogeochemical models, etc.). Among the proposed methodologies, those based on the use of remote sensing data and ecosystem simulation models are particularly promising. More specifically, the former have been demonstrated to be efficient in providing direct estimates of vegetation conditions (e.g. LAI, FAPAR, etc.) related to global forest productivity (Waring and Running, 1998; Maselli et al., 2006). Ecosystem simulation models are instead efficient means to combine data from different sources (meteorological and soil measurements, structural and eco-physiological information, etc.) for a more complete characterization of vegetation processes (transpiration, photosynthesis, respirations, allocations, etc.).

The application of both tools, however, encounters specific difficulties in Mediterranean environments, which are characteristic for their climatic and human-induced features. Mediterranean climate is in fact unique for its warm and dry summer season and for its mild and relatively rainy winter. To adapt to such conditions, Mediterranean vegetation has developed specific morphological and physiological features (Odum, 1971). Moreover, Mediterranean environments are characterized by mosaic landscapes generated by a long history of human activities (Van der Leew, 1998). These characteristics cause extreme spatial and temporal heterogeneity of these environments, which makes their study particularly complex (Lacaze et al., 1996; Bolle et al., 2006).

Building on these premises, the current investigation aimed at evaluating the possibility of routinely modelling major forest processes (i.e. photosynthesis and transpiration) in a typical Mediterranean region (Tuscany, Central Italy). The research was not directed to inter-compare the performances of different models of forest ecosystem processes, which was the subject of previous investigations (e.g. Cramer et al., 1999; Coops et al., 2001). Instead, the focus was on the development of a robust methodology to apply one of the most known of these models, BIOME-Bio Geochemical Cycles (BGC). This model was selected among the possible alternatives due to its specific suitability to provide information on the water, carbon and nitrogen cycles within forest and non-forest ecosystems (Running and Hunt, 1993; White et al., 2000). Additionally, the model is the natural evolution of FOREST-BGC, which was found to be capable of properly simulating transpiration and photosynthetic processes of Mediterranean forest ecosystems (Chiesi et al., 2002, 2005; Anselmi et al., 2004).

BIOME-BGC, however, has found only a few and incomplete applications in Mediterranean areas (Mollicone et al., 2003). Thus, a primary effort was directed to develop a calibration procedure capable of adapting the model to environments different from those for which it was originally created. This procedure relies on the use of monthly GPP estimates derived from an NDVI-based parametric model (C-Fix), which was recently demonstrated to accurately depict productivity features of existing Italian forests (Maselli et al., 2006). The procedure was applied to modify the original BIOME-BGC configurations and simulate the productivity features of three Mediterranean forest species which are typical of Tuscany (Central Italy). Next, the performances of the model were evaluated against existing transpiration and GPP measurements available for the selected three BIOME types.

The current paper first introduces the two models used, C-Fix and BIOME-BGC. This is followed by a description of the study areas and data considered. Next, the data processing and results sections are presented, divided into the following two steps:

1. The first, the calibration phase, is directed to identify optimal BIOME-BGC configurations to characterize the three chosen Mediterranean forest types (*Quercus ilex* L., *Quercus cerris* L. and *Pinus pinaster* Ait.). To this aim, 10 forest plots for each species were selected all over Tuscany and monthly GPP values of 5 years were computed for all of them by using C-Fix. These GPP values were used as reference to calibrate the original BIOME-BGC configurations.
2. The second, the validation phase, consists of applying the original and calibrated versions of BIOME-BGC in three additional forest sites (one for each forest species considered) and evaluating their outputs against independent series of field data (i.e. transpiration and GPP measurements).

The paper concludes with a discussion of the problems encountered and of the future perspectives of the work.

2. Models of forest ecosystem processes

Several models of forest ecosystem processes have been developed and applied to estimate regional and global productivity. They are generally based on various simplifying assumptions and use different formulations and input environmental variables (Cramer et al., 1999). As reported in Matsushita et al. (2004), these models have been categorized into three groups:

- statistical models,
- parametric models and
- process models.

Each group of models has its strengths and limitations. Statistical models are well known for their simplicity but limited generality (Lieth, 1975); parametric models take the advantage of using remote sensing data, but, relying on empirical relationships/constants (e.g. light-use efficiency), lose the link to some critical ecological processes (Potter et al., 1993); process models are based on current knowledge of major ecological/biophysical processes, but suffer from high complexity, difficult calibration, and great computational intensity (Foley, 1994; Liu et al., 1997).

The current approach tends to exploit the advantages of a parametric model (C-Fix) to guide the calibration of a process-based model (BIOME-BGC). The latter is then used to estimate forest photosynthesis and transpiration in a Mediterranean region. The main features of these two models are described in the next sections.