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SCOPE model applied for rapeseed in Spain

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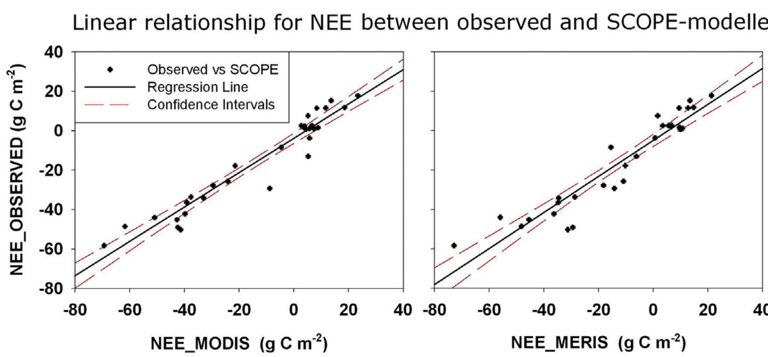
HIGHLIGHTS

- SCOPE uses a two-source model to calculate energy fluxes and CO_2 exchanges.
- The integrated model SCOPE revealed great results in simulating CO_2 fluxes.
- Characteristic photosynthetic parameters (V_{cmax}, J_{max}) for rapeseed were obtained.
- A sink behaviour for rapeseed was also found when simulating NEE with SCOPE.

GRAPHICAL ABSTRACT



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ABSTRACT

The integrated SCOPE (Soil, Canopy Observation, Photochemistry and Energy balance) model, coupling radiative transfer theory and biochemistry, was applied to a biodiesel crop grown in a Spanish agricultural area. Energy fluxes and CO_2 exchange were simulated with this model for the period spanning January 2008 to October 2008. Results were compared to experimental measurements performed using eddy covariance and meteorological instrumentation. The reliability of the model was proven by simulating latent (LE) and sensible (H) heat fluxes, soil heat flux (G), and CO_2 exchanges (NEE and GPP). LAI data used as input in the model were retrieved from the MODIS and MERIS sensors. SCOPE was able to reproduce similar seasonal trends to those measured for NEE, GPP and LE. When considering H, the modelled values were underestimated for the period covering July 2008 to mid-September 2008. The modelled fluxes reproduced the observed seasonal evolution with determination coefficients of over 0.77 when LE and H were evaluated. The modelled results offered good agreement with observed data for NEE and GPP, regardless of whether LAI data belonged to MODIS or MERIS, showing slopes of 0.87 and 0.91 for NEE-MODIS and NEE-MERIS, and 0.91 and 0.94 for GPP-MODIS and GPP-MERIS, respectively. Moreover, SCOPE was able to reproduce similar seasonal behaviours to those observed for the experimental carbon fluxes, clearly showing the CO_2 sink/source behaviour for the whole period studied.

1. Introduction

The dynamics of the various ecosystems has been widely studied. Knowledge of this dynamic behaviour can help to quantify the role played by the different types of ecosystem in the global carbon, energy, and hydrological cycles. The enormous relevance in different scientific applications of the various biophysical processes at land surface level,

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or relating atmosphere and surface/ecosystem, has thus led to the development of models able to reproduce a wide range of such processes, in particular those related to energy, carbon, and water exchange.

Radiative transfer models based on the radiative transfer theory were developed as a tool to describe canopy behaviour with regard to its interaction with radiation (Liang et al., 2012; Clough et al., 2005; Kötz et al., 2004; Dorigo et al., 2007). The most well-known and widely studied radiative transfer models are probably those used in SCOPE (**S**oil, **C**anopy **O**bservation, **P**hotochemistry and **E**nergy fluxes): SAIL (Verhoef, 1984; Verhoef et al., 2007) and PROSPECT (Jacquemoud and Baret, 1990; Jacquemoud et al., 2009).

Energy balance models are commonly divided into one or two-source models (Gonzalez-Dugo et al., 2009; Kustas et al., 1996; Kalma et al., 2008; Li et al., 2009; Song et al., 2016; Tang et al., 2013). A formulation developed for two-source models was described by Shuttleworth and Wallace (1985). The model assimilated the ecosystem as a system defined through two resistances. Since then, several approaches to this formulation have been widely studied and applied (Norman et al., 1995). As described in Wallace and Verhoef (2000), when several sources are taken into consideration when developing SVAT (Soil-Vegetation-Atmosphere Transfer) models, various resistances should be calculated to fully describe the system, as is the method applied in SCOPE, differentiating between soil and canopy. If interaction between the various fluxes is considered, all the different components considered in this approach have different aerodynamic and surface resistances characterizing their influence.

The simplest biochemical model uses a single layer approach (known as the big-leaf model), although new models using two-leaf or multilayer approaches have also been widely studied (Kremer et al., 2008). Chen et al. (1999) present Farquhar's model (Farquhar et al., 1980) as one of the most successful in modeling canopy photosynthesis and summarize the different approaches used to enhance the original model. In two-leaf model calculations, the canopy is divided into sunlit and shaded leaves (Xin et al., 2015). The various fluxes and photosynthesis rates are thus estimated separately for each leaf type. One such approach, the one used in this study, applies the separation into sunlit and shaded leaves (Wang and Leuning, 1998) when simulating energy and CO_2 fluxes.

The 1-D SCOPE model was proposed (Van der Tol et al., 2009) as an integrated radiative transfer, photochemistry, and energy balance multilayer model. The main purpose of this model is to estimate the most important biophysical processes involved in an ecosystem. The SCOPE model based on Farquhar's model could thus be used to evaluate the response of various crops to changes in CO_2 concentration, which is known to be increasing (IPCC, 2013). Previous studies evaluating SCOPE have mainly focused on sun-induced (chlorophyll) fluorescence (Thum et al., 2017; Du et al., 2017; Verrelst et al., 2015) rather than on carbon fluxes. When carbon fluxes have been evaluated, they have been applied to crops or types of vegetation (Liu et al., 2017) different to the one studied in this paper. Rapeseed (*Brassica napus* L.) is a crop that has gained importance by considerably increasing both its harvested area and production over the last twenty years (FAOSTAT, http://www.fao.org/faostat/). This increase has been particularly noticeable in Spain since 2001 (MAGRAMA, http://www.mapama.gob.es/es/estadistica/temas/publicaciones/anuario-de-estadistica/). Moreover, rapeseed is a crop which has scarcely been analysed thus far, thereby increasing the interest of the present study. This study therefore aims to evaluate the reliability of SCOPE regarding energy fluxes and carbon exchange on an agricultural ecosystem where rapeseed was grown. The objectives of this paper are:

1) to obtain carbon and energy fluxes by applying the SCOPE model,
2) to compare them against experimental measurements in order to calibrate the model for the ecosystem evaluated in this paper, and
3) to retrieve the characteristic parameters describing the various processes by calibrating the model.

2. Study area and instrumentation

2.1. Study area

The study area (41°46′44.4″ N, 4°52′19.19″ W, 849 m a.m.s.l.) is located on the central Spanish plateau. The farmland where measurements were performed is located in a semi-arid area, some 30 km north west of Valladolid (Fig. 1) in Castilla y León (Spain). The climate characterizing this region is Mediterranean-Continental with low temperatures in winter months, and warm and dry summers. Air temperature usually peaks in July or August with values around 36 °C, whereas minimum values are found in January or December, and may drop to as low as −10 °C. Precipitation is seasonally distributed with an average sum of 450 mm for a 35-year period. Precipitation events occur mainly in spring (April to June) and again in October, November, or December depending on the year. The yearly accumulated precipitation for the full year of 2008 reached 497 mm. The maximum crop growth (hereafter referred to as MIP -Maximum Interest Period-) was considered from March to June in this study, with accumulated precipitation of 237 mm for this period. Two clearly differentiated periods can be considered in the study area, namely a wet period and a dry period. The dry period was determined by the last precipitation event, after the harvest, followed by at least 15 days without precipitation. This period covered 24 June 2008 to 6 October 2008. Accumulated precipitation for this period was 34 mm, and the average air temperature was 17 °C. The remainder of the yearly period was defined as a wet period.

The farmland where measurements were performed is divided into single plots where a rotation scheme is carried out under reduced tillage management. One of those single plots, covering an area of about 36 ha, was the place chosen to carry out the measurements (Fig. 1). The large size and horizontal homogeneity of the terrain, coupled with the fact that the main wind direction (WSW-NE) concurs with the orientation of the study plot, yielded eddy covariance (EC) measurements representing the whole study plot (Burba and Anderson, 2010; Leclerc and Foken, 2014).

The rotation cycle in the single plot usually includes several of the most representative non-irrigated crops in the region such as: rapeseed, wheat/barley, peas, rye, and sunflower. The typical growth period for these crops usually covers from seedtime to mid-July the following year when the crop is harvested. The rest of the time, soil only presents residue coverage, characteristic of reduced tillage practices. The rapeseed studied in this paper was seeded in mid-September 2007 and harvested in mid-July 2008. Soil composition is sandy loam with a content of between 60% to 65% sand, 20% clay, and about 15% silt.

2.2. Instrumentation

Measurements have been conducted continuously since March 2008 in the sampling plot. The validation period considered in this study covered from March 2008 to October 2008. Two towers were installed to perform these measurements. The first tower incorporates the EC system which uses a 3D sonic anemometer (USA-1, METEK, Germany) measuring wind speed and direction, and an open path infrared gas analyzer –IRGA– measuring carbon and water densities/concentrations 3.5 m above the surface (Li-7500, Li-Cor Inc., Lincoln, NE, USA). This instrumentation records instantaneous data with a 10 Hz sampling frequency. A tower located a few metres from this first tower is equipped with the meteorological instrumentation. Wind speed and direction (Wind sentry Model 03002, Young, Campbell Scientific, Inc.), air temperature and humidity (model STH–5031, Geónica, Spain), net radiation (net radiometer type 8110, Ph. Schenk), and soil temperature and moisture (model STS–5031, Geónica, Spain; model 6545, Type ML2x, ThetaProbe) are measured. A quantum sensor (LI–190Sz, Li–Cor Inc., Lincoln, NE, USA) is also located in this tower to measure PAR (Photosynthetically Active Radiation). The soil heat flux is averaged from two soil heat flux plates (HFP01, HukseFlux, Delft, The Netherlands), one