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Scaling-up leaf monoterpene emissions from a water limited *Quercus ilex* woodland

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ABSTRACT

Mediterranean ecosystems are large emitters of biogenic volatile organic compounds (BVOC), and recent studies illustrate how water stress can decrease these emissions even during hot summer. We present here a spatially explicit modelling experiment of BVOC emissions in a water-limited Mediterranean Region in Southern France dominated by *Quercus ilex* forests. Emission rates were estimated daily using a leaf-level emission model with appropriate up-scaling procedures. The model was based on Guenther's empirical equations, where we inserted effects for water limitation and seasonality observed from field measurements. Up-scaling from leaves to canopy was performed using Sellers' theory. For each grid cell, climate variables were interpolated daily from meteorological stations. Incoming solar radiation was measured at one site and extrapolated for the all region based on slope and aspect. Soil properties were derived from pedological maps as well as a digital elevation model, while soil water content was evaluated daily using a bucket-type model.

We estimated monoterpene emissions from *Q. ilex* woodlands to be 16 kt yr^{-1} (on average), with most emissions occurring in the summer. When including the water-limitation module, yearly emissions were 50% of the initial estimates, with a significant decrease in the number of days with BVOC high emission peaks. This result highlights the importance of water control on determining air pollution peaks in Mediterranean areas and the need for scaling procedure in this area with its large range of strong emitter species.

1. Introduction

"Biogenic Volatile Organic Compounds" (BVOCs) include all the atmospheric organic trace-gases (except methane) emitted from natural sources. They influence tropospheric air chemistry because of their high reactivity, and their contribution to the atmospheric non-methane VOC budget is significant, even in urban and suburban regions with high anthropogenic VOC emissions (Parra et al., 2004; Francois et al., 2005). BVOCs (predominantly terpenes) are emitted by woody plants and influence the tropospheric oxidation capacity, the concentration of greenhouse gases and, in turn, change the atmospheric radiation budget through production of ozone and OH radicals (See Monson and Holland, 2001 for a review). They are also involved in the formation and growth of Secondary Organic Aerosols (e.g. Mentel et al., 2009).

Understanding the temporal and spatial variability of BVOC emitters is essential to be able to characterize the circulation of their oxidation products and derivatives in the atmosphere. BVOC emissions are usually studied at the leaf level, and scaling procedures are needed to extrapolate BVOC emissions at the stand or ecosystem level. Only these up-scaled BVOC emissions can be used as comprehensive inputs for statistical procedures and/or mechanistic air chemistry models to investigate their impact on global chemistry and climate (Sanderson et al., 2003; Wiedinmyer et al., 2006). Regional air quality models also require these procedures for air pollution control strategies (Thunis and Cuvelier, 2000; Solmon et al., 2004; Francois et al., 2005).

Empirical leaf-level BVOC emission models are often used in conjunction with canopy radiation models and land cover data to generate flux estimates over large spatial and temporal scales (e.g. Parra et al., 2004; Guenther et al., 2006; Simon et al., 2006). The most widely used leaf model adjusts a static, species-specific standardized emission rate (E_S) to ambient light and temperature

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conditions using correction factors that are based on the short-term response of isoprene and monoterpene emissions to light and temperature (Guenther et al., 1993). As outlined by a recent review (Niinemets et al., 2010), the strength of these algorithms has been the conceptual simplicity provided to modellers which allows them to insert into the model the effects of environmental factors recently highlighted such as seasonality (e.g. Guenther, 1997) or water limitation.

Under Mediterranean conditions, water availability is a major environmental constraint for plant functionality during the recurrent summer drought periods, and largely contributes to the annual pattern of vegetation activity, together with air temperature and solar radiation (Di Castri et al., 1973). Emissions of all investigated volatile terpenes are usually reduced under severe drought stress but there is no clear relationship yet between emission rates and water stress (See Penuelas and Staudt, 2010, for a review). However, water limitation is often cited as a hypothesis in modelling studies to explain an over (or under) estimation when simulations and measurements are confronted (e.g. Bertin et al., 1997). Only two models incorporate a negative effect of water limitation on biogenic emissions. Parra et al. (2004) relied on Llusia and Penuelas's works (1998, 2000) and reduced empirically the E_S for three species during summer months. Guenther et al. (2006) incorporated into MEGAN, a direct effect linked to the soil moisture and an indirect effect linked to the increase of leaf temperature, according to the results of Pegoraro et al. (2004).

Our goal in this modelling approach was to propose a regional up-scaling method for monoterpene (MT) emissions on Mediterranean-type ecosystems with its recurrent drought events and the presence of a large variety of terpene emitters (BEMA project, see Seufert et al., 1997) – under water-limited conditions, to test i) how important water limitation is on the estimation of biosphere/atmosphere MT emissions and ii) what are the temporal and spatial variations of MT emissions based on the coupled effects of high temperature and water limitation in the Mediterranean region. We conceptualized and developed here a model on a daily basis with a 1 km spatial resolution, based on the reference of Guenther's algorithm, and compute the daily water budget from accurate information on vegetation, soil and climate at the same resolutions. Moreover, we integrate water limitation into the MT emission module based on Lavoir et al. (2009) results for *Quercus ilex*, an evergreen tree species, dominating the tree species distribution and BVOC emission in the study area.

2. Model description

2.1. Modelling domain and study species

The study area is the Languedoc–Roussillon administrative region in southern France covering 27,787 km^2. It is delimited by the Rhone flood plain to the East, the Massif Central foot hills to the North, the Pyrenees Mountains to the Southwest and the Mediterranean Sea to its southern bound. Altitudes range from sea level at the Mediterranean coast to 2921 m (Pic Carlit, Pyrenees). We will further use the five administrative departments within the administrative region for better local focus (Fig. 1). From the North to the South there is: Lozère (L), Gard (G), Herault (H), Aude (A), Pyrénées-Orientales (PO).

Forests and shrublands (called "garrigues") cover 14,887 km^2 (54% of the total land area), among which *Q. ilex* woodlands occupy 2804 km^2 as open woodland or dense forest (IFN, Inventaire Forestier National, reference database for forestry activity in France). Soils are essentially Jurassic limestone and cretaceous cracked limestone.

The climate is Mediterranean with dry and hot summers with a high inter-annual variability and extreme events (winter frost,

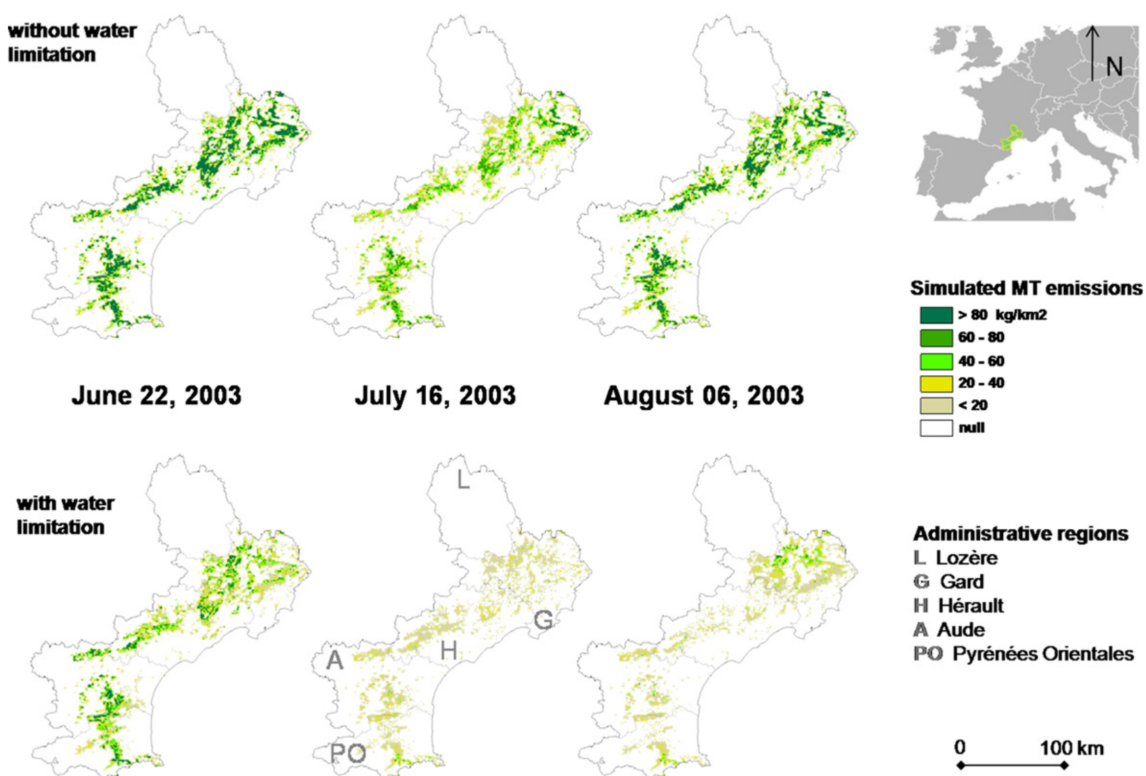

Fig. 1. Daily monoterpene emissions rates (kg km^{-2}) from *Quercus ilex* forest in Languedoc–Roussillon for three selected dates in 2003 (June the 22nd, July the 16th, August the 6th). Simulations were applied integrating a water stress effect (lower panel) or not (upper panel). From North to South, administrative regions are Lozère (L), Gard (G), Hérault (H), Aude (A) and Pyrenees-Orientales (PO).