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Intensive measurements of gas, water, and energy exchange between vegetation and troposphere during the MONTES campaign in a vegetation gradient from short semi-desertic shrublands to tall wet temperate forests in the NW Mediterranean Basin

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HIGHLIGHTS

- We present a multidisciplinary biosphere-atmosphere field campaign.
- We measured a gradient from semi-desertic shrublands to wet temperate forests.
- A wide range of instruments and vertical platforms were used.
- Land cover strongly influenced emissions of BVOCs and gas, energy and water exchange.
- Vegetation has strong potential for feed-back to atmospheric chemistry and climate.

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ABSTRACT

MONTES ("Woodlands") was a multidisciplinary international field campaign aimed at measuring energy, water and especially gas exchange between vegetation and atmosphere in a gradient from short semi-desertic shrublands to tall wet temperate forests in NE Spain in the North Western Mediterranean Basin (WMB). The measurements were performed at a semidesertic area (Monegros), at a coastal Mediterranean shrubland area (Garraf), at a typical Mediterranean holm oak forest area (Prades) and at a wet temperate beech forest (Montseny) during spring (April 2010) under optimal plant physiological conditions in driest-warmest sites and during summer (July 2010) with drought and heat stresses in the driest–warmest sites and optimal conditions in the wettest–coolest site. The objective of this campaign was to study the differences in gas, water and energy exchange occurring at different vegetation coverages and biomasses. Particular attention was devoted to quantitatively understand the exchange of biogenic volatile organic compounds (BVOCs) because of their biological and environmental effects in the WMB. A wide range of instruments (GC–MS, PTR-MS, meteorological sensors, O_3 monitors,...) and vertical platforms such as masts, tethered balloons and aircraft were used to characterize the gas, water and energy exchange at increasing footprint areas by measuring vertical profiles. In this paper we provide an overview of the MONTES campaign: the objectives, the characterization of the biomass and

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Monoterpenes
VOCs
CO_2
N_2O
CH_4
O_3
Vertical profiles
Tethered balloons
Aircraft
Masts
Boundary layer

gas, water and energy exchange in the 4 sites-areas using satellite data, the estimation of isoprene and monoterpene emissions using MEGAN model, the measurements performed and the first results. The isoprene and monoterpene emission rates estimated with MEGAN and emission factors measured at the foliar level for the dominant species ranged from about 0 to 0.2 mg m^{-2} h^{-1} in April. The warmer temperature in July resulted in higher model estimates from about 0 to ca. 1.6 mg m^{-2} h^{-1} for isoprene and ca. 4.5 mg m^{-2} h^{-1} for monoterpenes, depending on the site vegetation and footprint area considered. There were clear daily and seasonal patterns with higher emission rates and mixing ratios at midday and summer relative to early morning and early spring. There was a significant trend in CO_2 fixation (from 1 to 10 mg C m^{-2} d^{-1}), transpiration (from 1–5 kg C m^{-2} d^{-1}), and sensible and latent heat from the warmest–driest to the coolest–wettest site. The results showed the strong land-cover-specific influence on emissions of BVOCs, gas, energy and water exchange, and therefore demonstrate the potential for feed-back to atmospheric chemistry and climate.

1. Introduction

Woodlands and the atmosphere are coupled. Climate and atmospheric composition determine vegetation distribution, cover, biomass and functioning, and at the same time are sensitive to composition and conditions in woodlands. Woodlands act as a sink for CO_2, absorb ozone and other pollutants such as CH_4, SO*x* or NO*x*, play a crucial role in the water cycle and emit biogenic volatile organic compounds (BVOCs), which can lead to the formation of ozone and aerosols (Claeys et al., 2004). These aerosols, in turn, can scatter solar radiation and act as condensation nuclei for precipitation. Thus, woodlands are strongly affected by atmospheric and climatic changes, but at the same time in a strong feedback interaction play a major mediating role in determining the composition and climate of the atmosphere. In particular, land cover and biomass alter climate through the effects of biogeochemical processes (especially photosynthesis and carbon sequestration) and physical properties (mainly surface energy and water balance) of the vegetated land surfaces.

CO_2 uptake is the main biogeochemical process involved in this woodland–atmosphere interaction, but it is not the only one. A larger green biomass increases CO_2 uptake but also further increases the total biogenic volatile organic compounds (BVOC) emissions (Claeys et al., 2004). The increased fixing of CO_2 in the biosphere decreases its concentration in the atmosphere and thus reduces its influence on the greenhouse effect (IPCC, 2007). The increases in the emissions of BVOCs might also make a significant contribution to the complex processes associated with global warming (Claeys et al., 2004). Until recently, the short lifetime of BVOCs was thought to preclude them from having a significant direct influence on climate. However, there is emerging evidence that this influence might be important at different spatial scales, from local to regional and global, through aerosol formation and direct and indirect greenhouse effects. BVOCs generate large quantities of organic aerosols (Laaksonen et al., 2008; Jiang et al., 2009; Spracklen et al., 2010) that could affect climate by forming cloud condensation nuclei. The result should be a net cooling of Earth's surface during the day because of radiation interception. Furthermore, the aerosols also diffuse the light received by the canopy increasing CO_2 fixation. However, the BVOCs also increase ozone production and the atmospheric lifetime of methane, thus enhancing the greenhouse effect of these gases. Whether the increased BVOC emissions will cool or warm the climate depends on the relative weights of the negative (increased albedo and CO_2 fixation) and positive (increased greenhouse action) feedbacks (Claeys et al., 2004).

A larger presence of the green cover should also alter physical processes such as surface albedo, latent and sensible heat, and turbulence processes that influence boundary layer meteorology and climatology more immediately and more regionally than does a change in CO_2 concentration. With larger leaf biomass, latent heat flux increases and the Bowen ratio (the ratio of sensible to latent heat) decreases. There is also a more efficient coupling between the land and the atmosphere attributable to an increase in surface roughness, which lowers aerodynamic resistance and can thus also lead to a cooler wetter atmospheric boundary layer (Bonan, 2008).

The larger presence of green cover and biomass may thus generate a cooling by sequestering more CO_2 and increasing evapotranspiration. However, this carbon fixation and evaporative cooling may decline if drought becomes more frequent, or when water availability decreases later in the summer season. In fact, an early onset of vegetation green-up and a prolonged period of increased evapotranspiration seem to have enhanced recent summer heat waves in Europe by lowering soil moisture (Zaitchik et al., 2006; Fischer et al., 2007). The depletion of summer soil moisture strongly reduces latent cooling and thereby amplifies the surface temperature anomalies (Peñuelas et al., 2009). In wet regions and seasons, additional water vapor may form clouds that contribute to surface cooling and increased rainfall in nearby areas, whereas in drier conditions, a higher presence of the green cover may warm regional climate by absorbing more sunlight without substantially increasing evapotranspiration.

There are many unknowns in the final balance that all these biogeochemical and biophysical impacts have on local, regional and global atmosphere composition and climate. One problem is that our knowledge of vegetation influence on climate comes mostly from models that are abstractions of complex physical, chemical and biological processes in the land-atmosphere system. Plant physiological and phenological formulations of current models used in global climate simulations are highly empirical and employ a few local-scale findings representing only a fraction of the global bioclimatic diversity. In consequence, a quantification and a more realistic mechanistic representation of the effects of having different biomasses covering land surface on the changes in temperature and water exchange, and finally on the atmospheric composition and dynamics are needed. In particular, landscape scale evaluations are required to assess the reliability of these models.

In recent decades, climate, chemical composition of the atmosphere, and land-use are experiencing rapid changes. These changes are likely to have a great influence on woodland biomasses and coverages and therefore in woodland–atmosphere interactions, but little experimental evidence is available. The actual roles of these woodland–atmosphere interactions at the local, regional and global scales are still poorly understood, as pointed