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Turbulence scales for eddy covariance quality control over a tropical dry forest in complex terrain

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ABSTRACT

The assessment of the potential for carbon sequestration in tropical dry forests has lagged behind the work done in other tropical environments; the particularities of the carbon dynamics in these ecosystems are largely absent from models of global primary productivity and effects of climate change on vegetation. In Mexico, the largest portions of preserved tropical dry forests have been confined to conservation areas on hilly terrain where productive activities like agriculture are difficult. The location of these remnants of original tropical dry forest in complex terrain presents an operational challenge to directly assess CO_2 exchange between the forest and the atmosphere by means of the eddy covariance (EC) technique. We installed and maintained an EC system over an intact tropical dry forest in the Chamela-Cuixmala Biosphere Reserve in the lowlands of the Pacific Coast of Mexico, to assess the suitability of this technique to measure CO_2 flux, sensible heat and latent heat flux over moderately complex topography in a remote location. The quality of the datasets produced was evaluated through the degree of energy balance closure achieved. Modelling the incoming and outgoing radiation to take into account the slope and aspect of the underlying terrain raised the energy balance closure from 71% to 75%. We also compared the effect of applying three different filters to discriminate conditions of well-developed turbulence: the friction velocity u_*, the standard deviation of the vertical wind σ_w, and two dimensionless indices based on a modified turbulence intensity scale u_{TKE}. u_* and σ_w discriminated fluxes coming from topographically complex areas, according to a flux footprint model, but the filtered subset of data did not showed higher energy balance closure compared to the unfiltered dataset. The u_{TKE}-based filters were more effective screening out periods dominated by horizontal or vertical advective transport instead of turbulence exchange, and raised the slope of the energy balance regression in the filtered data between 3%–17% – depending on the season-,compared to the unfiltered dataset. Together, these procedures of quality assurance and control produced a flux dataset of quality comparable to those obtained in more ideal surfaces.

1. Introduction

Tropical dry forests are ecosystems that, from a potential distribution, cover 47% of all tropical environments. These forests, as defined by Sánchez-Azofeifa et al. (2005), have a mean annual temperature around 25 °C, and a prolonged dry season (less than 100 mm rain per month) that can last from four to six months of the year. During the dry season, 80–100% of plant species are characterized by a deciduous leaf habit. Three well defined phenological seasons can be identified in the vegetation of tropical dry forests: maturity, senescence, and leafless canopy. These phenological events are mostly controlled by soil moisture availability. Tropical dry forests currently have an extension of about 500,000 km^2 in the Americas, have high deforestation rates, and their landscape is mostly a combination of agricultural fields and primary and secondary forests (Portillo-Quintero and Sanchez-Azofeifa, 2010). Major threats to their survival are the conversion of the land to pasture for livestock, and the advance of the agricultural frontier where the soil is fertile.

Among the current available carbon flux measurement systems in the FLUXNET database, only 5 of 517 sites are reportedly located in tropical dry forests. In the Americas, two of them are located in the lowlands of the Pacific coast of Mexico: Chamela-Cuixmala Biosphere Reserve, and Tesopaco, Sonora (Pérez-Ruiz et al., 2010) and one more in Costa Rica (Santa Rosa Environmental Monitoring Super Site,

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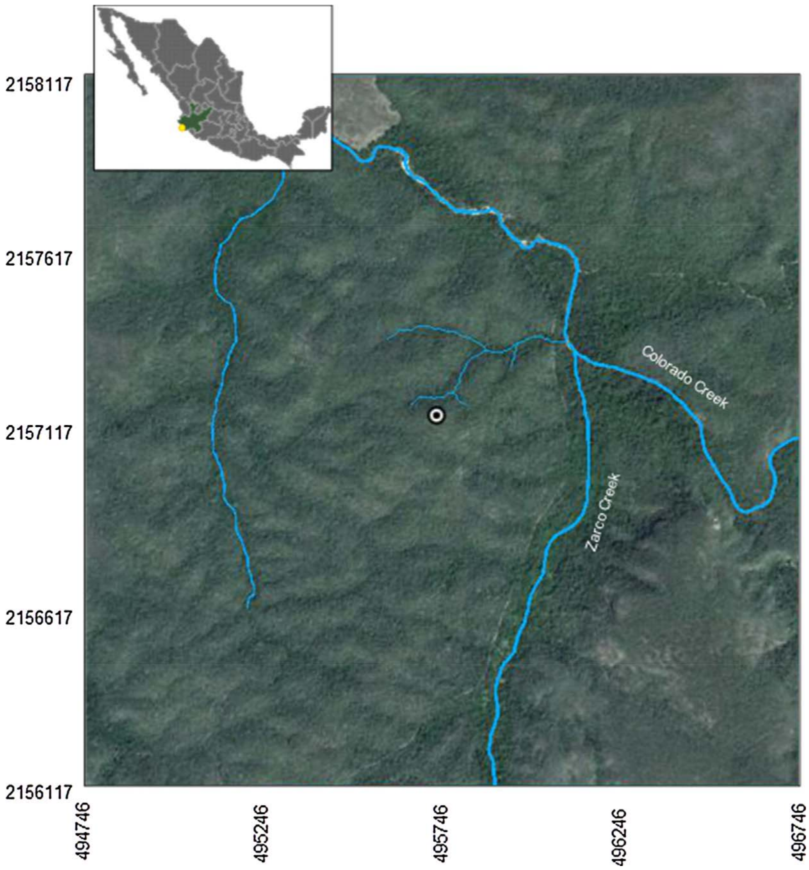

Fig. 1. Location of the Chamela region (yellow dot on insert) in the state of Jalisco (green area on insert), and topographical features of the terrain surrounding the tower (white dot) in an area of 2 × 2 km. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Guanacaste). The Chamela-Cuixmala Biosphere Reserve tower operated between 2007 and 2015. These three stations cover a wide annual precipitation range going from 650 mm and 800 mm at the Sonora and Chamela-Cuixmala sites, respectively, to 1445 mm for the Santa Rosa Super Site.

The Chamela-Cuixmala site was situated in a moderately complex topographic terrain and therefore represented a distinct operational challenge. Estimations of carbon sequestration by tropical ecosystems in general have been conducted in relatively flat sites, covered mostly by tropical rainforest, specifically in the Amazon basin (e.g. Mahli et al., 1998; Saleska et al., 2003). In contrast, work on tropical dry forests has lagged behind research done at other tropical ecosystems, in spite of their extension and high deforestation rates (Sánchez-Azofeifa et al., 2005). In Mexico, the most extensive remnants of well-preserved TDF in North and Central America are located in Western coast of Mexico (Ceballos and Garcia 1995; Trejo and Dirzo 2000), in hilly terrain that has not been cleared yet because is not apt for agricultural purposes. Estimates of aboveground biomass increments and CO_2 emissions to the atmosphere during conversion of these forests to other land uses suggest these systems might be sites of substantial CO_2 exchange (Martinez-Yrizar et al., 1996; Kauffman et al., 2003; Jaramillo et al., 2003), however their contribution to the global carbon budget both as intact or secondary forests and as areas subjected to high rates of land use change has only started to receive attention (e.g. Pérez-Ruiz et al., 2010; Verduzco et al., 2015).

With the wider aim to further the understanding of the role that these forests play in the sequestration and storage of CO_2, here we present an exploration of the suitability of the eddy covariance technique to evaluate the carbon exchange at a tropical dry forest located on moderately complex topography, the type of terrain in which most of the remnants of tropical dry forests of Mexico and the Americas in general persist. Over a flat, homogeneously-covered surface, only the storage and the collective covariance terms of the conservation of mass species equation must be measured to account for total transport of CO_2 or other scalar, since the horizontal and vertical advection terms are negligible with respect to the magnitude of turbulent transport (e.g. Paw U et al., 2000). Over non-flat terrain, however, both horizontal and vertical gradients of scalar and mean wind velocities develop, not only because the wind follows the terrain, but also because even when the cover is homogeneous, the uneven growth of vegetation over such topography inevitably results in a non-uniform distribution of leaf area, so sources and sinks of C develop within the canopy and produce scalar concentration gradients. The contribution of the mean flow to the total exchange of the scalar in a control volume can no longer be neglected in such conditions, and should be measured or estimated. Advection of CO_2, water vapor or temperature has proven to be difficult to measure directly in the field, so a lot of research has focused instead on identifying filtering criteria to discriminate periods or conditions of well-developed turbulence, when the advective fluxes to total transport of scalars are relatively negligible. Here we examine the use of three different turbulence scales as indicators of atmospheric conditions when turbulent mixing is adequate. We hypothesize that the effectiveness of each scale to filter out periods when advection dominates can be assessed by evaluating its impact on the energy balance residual (EBR) and closure, and that a dataset of comparable quality to those obtained under more ideal terrain conditions can be constructed by identifying and discarding periods when advective fluxes cannot be ignored. We also hypothesize that over undulating terrain, the available energy for turbulent transport is overestimated if the incoming radiation flux is not corrected to account for the fact that it strikes on sloping surfaces, increasing the estimated energy balance residual. Both the filtering scheme and the radiation correction are applicable to a variety of terrain and vegetated surfaces and need only measurements already available at most eddy covariance study sites.