Numerical sensitivity study of the nocturnal low-level jet over a forest canopy and implications for nocturnal surface exchange of carbon dioxide and other trace gases

The development of a wind speed maximum in the nocturnal boundary layer, commonly referred to as a low-level jet (LLJ) (Blackadar, 1957), is a common feature of the vertical structure of the atmospheric boundary layer (ABL) and impacts the meteorology and the local climate of a region. A variety of mechanisms has been suggested to characterize the development and evolution of LLJs including inertial oscillations, baroclinicity over sloping terrain, and land-sea breeze effects (Stull, 1988). Although pure inertial oscillations attributed only to the diurnal oscillation of eddy viscosity are rare and are typically intertwined with other contributing factors, they constitute an important cause of jet formation. This mechanism is the only one that can be simulated by one-dimensional atmospheric boundary-layer model. This mechanism is a strong function of the distribution of surface energy properties which in turn depends on the time of day, latitude of location, and underlying surface characteristics. These parameters influence the jet height, maximum speed of the jet, and the duration of the wind speed maximum. The present study uses the numerical model SCADIS described by Sogachev et al. (2002) in its one-dimensional mode, to examine specific effects of tall vegetation on the structure of nocturnal jets. The unique feature of the model, based on a two-equation closure approach, is the treatment of buoyancy and plant drag effects in a way that does not require a predefined mixing length (Sogachev 2009). A battery of sensitive tests was carried out to examine the response of the low-level jet to forcing mechanisms at the air-forest interface. Results show that SCADIS captures the most prominent features of the LLJ, including its vertical structure as well as its diurnal phase and amplitude: i.e. the stronger the temperature inversion, caused by different radiative forcing, the more intense the LLJ. In a dense forest, the surface roughness increases the frictional forcing, thereby increasing the degree of supergeostrophic wind and the height of the LLJ. Besides the generation of turbulence in the nocturnal boundary layer, several studies demonstrated the role of nocturnal jets in transporting moisture, ozone, and other trace gases between the biosphere and the lower atmosphere (Mathieu et al., 2005; Karipot et al., 2006; 2007; 2008; 2009). This study suggests that SCADIS, because of its simplicity and low computational demand, has potential as a research tool regarding surface–atmosphere gaseous exchange in the nocturnal boundary layer, especially if carbon dioxide, water vapor, ozone and other gases are released or deposited inside the forest canopy.

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