Numerical simulation of future low-level jet characteristics

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Abstract
In this paper, results of numerical simulations of low-level jet (LLJ) characteristics are presented. By forcing a boundary layer model with the results of a regional climate model, long time series have been calculated which are analyzed with special regard to the night-time wind regime. The simulated LLJ statistics are compared qualitatively with available observations and show overall good agreement. The frequency distributions for jet height and jet speed at the end of this century show light changes with a tendency to an increased jet height.

1 Introduction
A characteristic feature of the nocturnal boundary layer is a wind speed maximum near the ground which is called low-level jet (LLJ). This phenomenon has been known for many years (e.g. BLACKADAR, 1957; BONNER, 1968; RIDER and ARMENDARIZ, 1971) and was observed in different parts of the world (e.g. STENSRUD, 1996). Due to the combination of strong night-time thermal stratification and remarkable wind shear in the lower part of the atmosphere, the LLJ is of importance e.g. for aviation, wind energy and transport of pollutants.

Recent developments in remote sensing technology have increased our knowledge of the LLJ. Probing the lower part of the atmosphere with acoustic and optical techniques has resulted in a large number of observations for a wide variety of synoptic situations. Meanwhile the data base is large enough to calculate LLJ climatologies and statistics (e.g. BANTA et al., 2002). Regardless of the specific site, all observations show very similar statistics concerning jet speed, jet height or diurnal occurrence. However, it should be mentioned here, that a unique definition of LLJ does not exist and all authors use similar, but different definitions.

Early attempts to simulate the nocturnal LLJ have been published e.g. by WIPPERMANN (1973). He demonstrated the influence of thermal stratification and baroclinicity on LLJ development for ideal synoptic situations. For real situations, including the wide variety of boundary layer effects (e.g. waves, radiation divergence) with their interactions, modelling of the nocturnal boundary layer with a LLJ wind regime is still a challenge (e.g. KRAUS et al. 1985; ZHANG et al. 2001; CONANGLA and CUXART 2006; STORM et al., 2009).

We expect a change in our local environment due to global warming in the coming decades. Downscaling the global change by using regional models (JACOB et al., 2007) result in information for different meteorological variables with a high resolution in space and time. The results of such a regional climate model for the next 100 years are adopted to force a boundary layer model which is able to capture the main features of the LLJ. Because of the wide variety of uncertainties of regional climate models, the simulated long-term results have been used to calculate LLJ statistics and possible changes in the future only and no individual weather situations or wind extremes are considered here. However, as has been shown by LARSEN et al. (2010), the simulated winds of regional climate models are very consistent with observations regarding wind speed as well as other statistical measures. These findings encourage the use of the results of a regional climate model as reasonable estimates for further studies. Especially in wind energy applications, an estimate of on-site LLJ statistics is of great importance for planning purposes. With increasing hub heights of 150 m and more, the wind turbines operate completely in the range of the low-level jet with the benefit of greater night-time energy yield, albeit with an increased risk of damages due to the very complex wind shear.

2 The low-level jet
The low-level jet has been observed and described in many studies. Since this boundary layer phenomenon is embedded into a specific synoptic situation and superimposed by local and regional wind systems, a perfect picture of this regular night-time feature is not always given. The key mechanism for the development of the LLJ seems to be a decoupling of the nocturnal surface layer from the air above. This is caused by a strong decrease of turbulence due to night-time surface cooling and consequently a strong increase in thermal stability. This mechanism disturbs the day time balance of pressure gradient, Coriolis force and friction resulting in an inertial oscillation with a wind speed maximum at the top of the nocturnal inversion (STULL, 1988).