Vertical Motion in the Nocturnal Low-Level Jet Arising from a Spatially-Varying Initial State

by Alan Shapiro, Evgeni Fedorovich, and Joshua Gebauer

It has long been recognized that nocturnal low-level jets (LLJs) can provide thermodynamic and dynamical support for nocturnal convection over the Great Plains of the United States. A LLJ can augment southerly moisture transport and facilitate lifting at its northern edge or in the vicinity of its intersection with frontal boundaries. However, the relation between a LLJ and many occurrences of convective initiation (CI), particularly involving elevated CI in regions removed from obvious frontal boundaries or other mesoscale structures, remains elusive. In such cases CI often happens in association with a LLJ, but it is not clear if the LLJ is a causative agent or if the LLJ and CI arise independently from nocturnal boundary layer processes and simply occur within overlapping domains at similar times.

A theory is presented for the vertical motion induced by a class of spatially variable LLJs. The theory does not address CI per se, but makes a case for how a LLJ associated with (i) horizontally varying geostrophic winds (a special case of east-west variation of a southerly geostrophic wind is considered) or (ii) horizontally varying surface buoyancy can force broad zones of mesoscale ascent within and above the atmospheric boundary layer (ABL), thus creating a favorable environment for CI.

We consider the development of a LLJ from the sudden relaxation of the frictional constraint in the ABL around sunset (mechanism proposed by Blackadar, but augmented with a buoyancy effect arising from a differentially heated surface). Horizontal variations in the free-atmosphere geostrophic wind and ABL buoyancy, as accounted for in the initial (sunset) conditions, drive a spatially variable LLJ and associated horizontal divergence and vertical motion fields. The focus of our analysis is a fourth order partial differential equation for the vertical velocity field obtained from the linearized equations of motion, thermal energy, and mass conservation under the Boussinesq approximation. This equation is solved via the method of Laplace transforms.

Results are obtained using a free-atmosphere geostrophic wind in the form of a mean southerly flow with a superimposed wavy (varying in horizontal direction x) component, and an ABL buoyancy that varies horizontally with a similar wavy structure. The sensitivity of the solution is explored with respect to the free-atmosphere Brunt-Vaisala frequency, Coriolis parameter, ABL depth, and the amplitude and lateral wavelength of the free-atmosphere geostrophic wind and ABL buoyancy perturbations. In the cases of strong forcing and weak stratification the vertical displacements of parcels in the ABL are found to be as large as 500 m to 1 km over the course of the ascent phase of the oscillation.