Nocturnal jet simulation under neutral conditions by theoretical model

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Resumo

O jato noturno, ou jato de baixos níveis, ocorre normalmente em noites de céu claro, i.e., sob condições estáveis. Aqui é analisada a ocorrência do jato noturno em condições neutras por meio de um modelo teórico.

1. The nocturnal jet

The nocturnal jet, or low level jet (LLJ), is a meteorological phenomenon with space scale varying from meso up to synoptic, depending on the forcing. Usually, the formation occurs during the night and there are many methodologies to identify it, see for example Blackadar (1957), Bonner (1968), and Brook (1985). In most cases, a standard procedure is to identify the longitudinal velocity wind peaks (supergeostrophic values) from the LLJ. During the daytime, the wind in the mixed layer tends to be subgeostrophic, due to the surface friction and vigorous mixing. At sunset, pressure gradients tend to accelerate the wind towards geostrophic value. During the process, the Coriolis force induces an inertial oscillation on the wind, producing a supergeostrophic wind at night (Blackadar, 1957). Such process is more easily verified under stable conditions, when the lower half of the Planetary Boundary Layer (PBL) close to the ground becomes stably stratified, and the upper half part of the PBL becomes more susceptible to external forcings (larger meteorological scale systems).

2. Inertial oscillation under neutral conditions

Considering the simplified momentum equations for the boundary layer and the transversal wind component as zero ($V_g = 0$), we have (Stull, 1988):

$$\frac{d\overline{U}}{dt} = f_c \overline{V} - f_c F_u \qquad (1)$$

$$\frac{d\overline{V}}{dt} = f_c \left(\overline{U}_g - \overline{U}\right) - f_c F_v \qquad (2)$$

where U_g is the longitudinal geostrophic wind component, f_c is the Coriolis force, $\partial\left(\overline{uw}\right)/\partial z = f_c F_u$ and $\partial\left(\overline{vw}\right)/\partial z = f_c F_v$, with F_u and F_v given in units of velocity. In the stable layer case, one considers that friction suddenly disappears above the surface layer at sunset, remaining zero throughout the night (Stull, 1988). For the neutral case, we consider that friction remains active, but varying linearly with time: it can be seen through $\overline{wu}$ profiles simulated by LES model (not showed here). Defining

$$C_{Fu} \equiv \frac{dF_u}{dt} \qquad (3)$$

where C_{Fu} is a constant, and combining (1) and (2) follows

$$\frac{d^2\overline{U}}{dt^2} = -f_c^2\left(\overline{U} - \overline{U}_g + F_v + C_{Fu}\right). \qquad (4)$$

By means of scale analysis (based on LES data), one can –neglect the third term RHS. The solution for the longitudinal component is:

$$\overline{U}_n = \overline{U}_g + A\sin\left(f_c\, t\right) + B\cos\left(f_c\, t\right) - C_{Fu} \qquad (5)$$

where $A = F_{uD}$ and $B = -F_{vD}$, D designates daytime (convective boundary layer, CBL) and *n* designates night time (neutral layer). We can note that the LLJ equation for neutral layer is the same LLJ equation for the stable boundary layer (see Stull 1988, equation 12.5.3d) with addition of the C_{Fu}. Taking into account: $A\sin\left(f_c\, t\right) > \left[B\cos\left(f_c\, t\right) - C_{Fu}\right]$ we probe the presence of the LLJ $\left(\overline{U}_n\right)$ under neutral conditions. Moreover, as $C_{Fu} > 0$ one observes that the jet under neutral conditions tends to be less intense than the jet in stable conditions.

3. Results and discussion

In the LLJ model (equation 5) the vertical momentum flux and the surface wind are extracted from LES data. Here, we used the LES model described by Moeng (1984) and Sullivan et al. (1994). The LES simulation for the neutral conditions is executed after the CBL simulation (followed by a decay and neutral phase), in order to guarantee the quasi-stationary state.

Figure 1 shows the time-integrated vertical profiles of the longitudinal wind component. In the Figure, the time $t=0$ identifies the starting point for the neutral phase, z is height above the ground and z_i is a standard top height (1000 m). Here, we define the occurrence of LLJ whenever the wind value is supergeostrophic, i.e., greater than $U_g = 10ms^{-1}$. In this way, the LLJ occurrence is observed after some time period of the neutral phase process, located near the top of the PBL. This means that while wind increases near the top, it decreasing slowly in the interior of the layer, i.e., the wind profile changes from logarithmic (in CBL) to almost linear (in the neutral layer). We also verify (LES simulation output, not shown here) that the jet tends to weaken and disappear when the convection restarts in the morning.

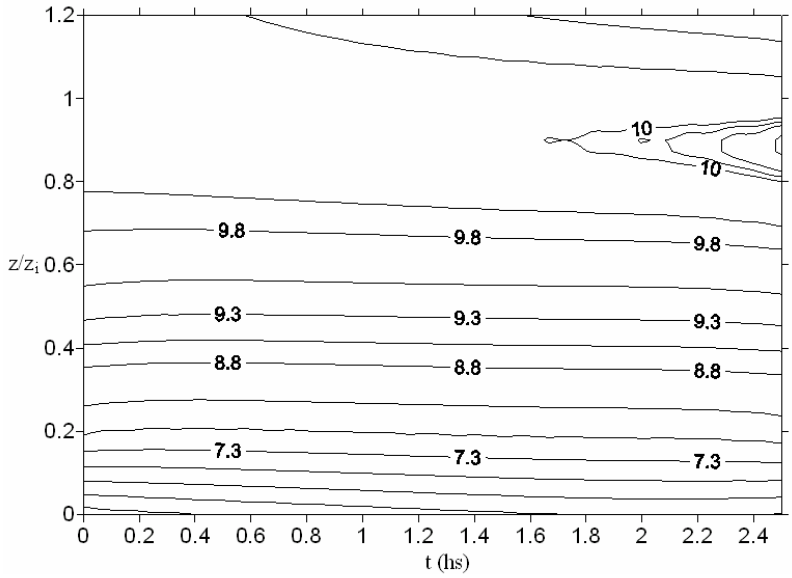

Figure 1. Time-integrated longitudinal wind component.

Finally, despite from the simplicity of the mathematical model, the model results have a good agreement with the LES output.

4. References

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