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Comment on "Do stable atmospheric layers exist?" by S. Lovejoy et al.

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[1] *Lovejoy et al.* [2008] (hereinafter referred to as L08) used fine resolution drop sonde data from NOAA Winter Storms 2004 experiment to demonstrate that "apparently stable layers in the atmosphere are composed of a hierarchy of unstable layers themselves with embedded stable sub-layers''. Here I examine the credibility of the stable atmospheric layer concept (SALC) of the state-of-the-art meteorology using fine resolution turbulence-resolving model. I found that the SALC is indeed viable and that L08 arguments against it are due to misinterpretation of the drop sonde readings in terms of atmospheric layers.

[2] The drop sondes provide time series of temperature and velocity readings during their descent through the atmosphere. Their vertical and temporal resolutions are about 5 m and 0.5 s correspondingly. L08 compared two such time series obtained by sondes dropped $\sim$30 m apart. Referring to high correlation between these two time series, L08 associated each sonde reading to an atmospheric layer. A convenient definition of a layer could be as follows: "a relatively thin sheet-like expense or region lying over or under another'' (http://www.thefreedictionary.com). In meteorology, the expense of the layer is reasonable to define having in mind scales of the atmospheric processes resolved by contemporary models. Currently, models have the horizontal resolution of a few kilometers and larger. Hence, to be useful, the SALC should characterize the horizontal expense of about 10 km and larger and the corresponding vertical thickness of a few tens of meters. The stability properties of the layer could be measured with e.g. a squared Brunt-Vaisala frequency $N^2 = g\beta\partial\theta/\partial z$ where g = 9.81 m s^{-2} is the gravity acceleration, $\beta = 0.003$ K^{-1} is the air thermal expansion coefficient, and θ is the potential temperature. This layer definition is suitable for contemporary meteorological models. L08 questioned the existence of such layers and found the SALC untenable in their drop sonde analysis.

[3] The L08 criticism is crucially based on two facts: high short-distance correlations between two drop sonde time series; and high variability of the local stability. L08 interpreted variations in the local and instant atmospheric stability as representative of variations in stability of the entire atmospheric layer. Hence, to advocate the SALC, one has to show that these variations are largely of local and transient nature. If so, the instant profile correlations should deteriorate at larger than δ = 30 m separations but high correlations of temporally averaged stability profiles should persist. I used fine mesh three-dimensional turbulence-resolving simulations with the LESNIC code [*Esau*, 2004; *Esau and Zilitinkevich*, 2006] to support viability of the SALC. The LESNIC data was taken from E. Fedorovich et al. (Entrainment into sheared convective boundary layers as predicted by different large eddy simulation codes, paper presented at the 16th Symposium on Boundary Layers and Turbulence, American Meteorological Society, Portland, Maine, 2004) study so the quality of the simulations could be easily assessed against other state-of-the-art turbulence-resolving models and atmospheric measurements. Albeit idealized, the LESNIC numerical experiment on the mesh 256 by 256 by 128 nodes had several advantages. It was run under horizontally homogeneous, steady-state, barotropic conditions. Nothing but turbulence and internal gravity wave dynamics modify initially prescribed stability profile with N = 9.4 10^{-3} s^{-1}. Homogeneous constant surface potential temperature flux 0.1 K m s^{-1} and the geostrophic wind 20 m s^{-1} were applied. It caused development of a sheared convective boundary layer with strong turbulence, a capping strongly stably stratified inversion and a residual, turbulence free atmosphere open for eventual passing of detached eddies and gravity waves [*Zilitinkevich*, 2002]. The run vertical resolution of 20 m was something coarser than the vertical drop sonde resolution but the horizontal resolution of 39 m was comparable with drop sonde separation of L08.

[4] Despite the idealization and coarser resolution of the LESNIC data, two instant and local stability profiles in Figure 1a reveal remarkable similarity in amplitude of wiggles. The profiles have been randomly chosen within the simulation domain. Blue and red profiles are at the minimum possible δ = 39 m. Their correlation is high. Green profile is separated from the other two by the maximum possible δ = 7071 m. Its correlation with the blue and red profiles is low. For all possible pairs of instant profiles in the stable residual layer and the capping inversion, the mean correlation at δ = 39 m was 0.85. The correlation rapidly falls with δ saturating at $\delta \sim$ 300 m at 0.48.

[5] The correlation of $\sim$0.5 is still non-negligible so it is interesting to look at the structure of the correlated part of the stability profiles. To elucidate this structure, 30 three-dimensional temperature fields were sampled with one minute time interval from the LESNIC data. The sampled data were processed with an empirical orthogonal function (EOF) analysis [e.g., *Obukhov*, 1960; *Craddock*, 1973; *Esau*, 2003]. The first EOF corresponds to the most

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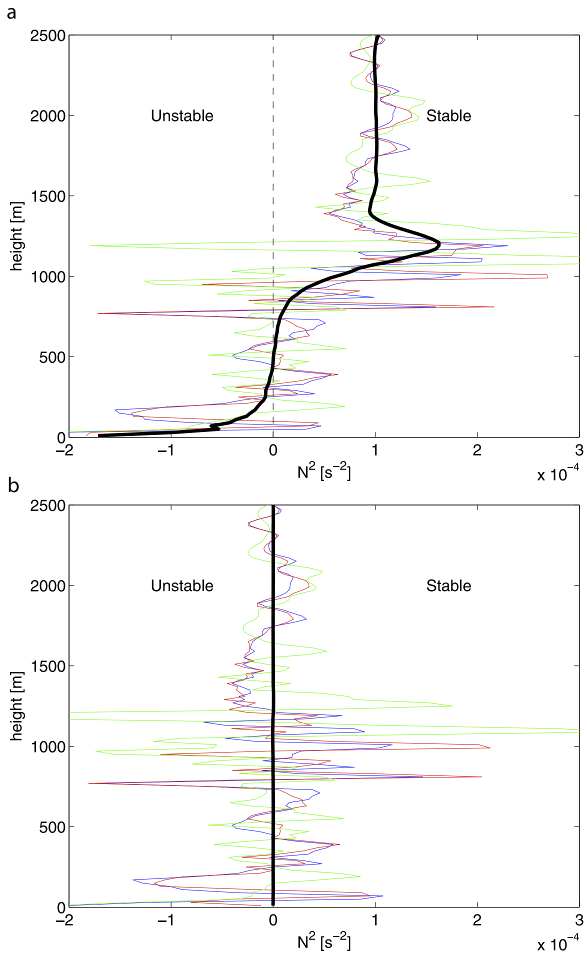

Figure 1. Instant and local (blue, red and green curves) vertical profiles of the atmospheric stability from the LESNIC data (GC case) and the stability profiles of the 1st potential temperature EOF (bold black curve): (a) the original data; (b) the data with subtracted the 1st EOF. See details in text.

common for all local profiles, structure of potential temperature. The structure is practically indistinguishable from either temporally or spatially averaged temperature profile. It is important to note that the 1st EOF comprises 99% of the total variability. The N^2 profile (bold black curve in Figure 1a) obtained from the 1st EOF is smooth, deprived of wiggles and preserves the initially prescribed stability in the turbulence-free atmosphere, somewhat stronger stability $N \sim 1.2\ 10^{-2}\ \mathrm{s}^{-1}$ in the capping inversion, near-neutral stability $N \sim 0.0\ \mathrm{s}^{-1}$ in the convective layer, and super-adiabatic stability $N \sim -5.0\ 10^{-3}\ \mathrm{s}^{-1}$ in the surface layer. It unambiguously determines the stability structure of the atmospheric layers, which is in excellent accord with the SALC.

[6] The wiggles in the local stability profiles remain in the instant data after subtraction of the 1st EOF (see Figure 1b). As one can observe the variability of N^2 has about the same amplitude as the original variability. But, the 30-minutes averaged temperature fluctuations are of just 0.2 K in the capping inversion and 0.05 K in the other layers. The numbers are about order of magnitude smaller than instant temperature excursions occurring at every grid node. The instant temperature excursions are almost averaged off over 30 minutes and hence their mean duration should be not larger than ~10 minutes. For all possible pairs of instant profiles in this data, the mean spatial correlation drops from 0.75 (δ = 39 m) to zero (δ = 600 m) at 96% level of confidence.

[7] Summarizing, the analysis suggests that the stability fluctuations are of transient (a minute scale) and local (500 m scale) nature. Such fluctuations and their mean effect on the layer's stability cannot be singled out in the drop sonde data but can be analyzed with tethered balloons and kites [*Balsley et al.*, 1998; *Muschinski et al.*, 2001; *Frehlich et al.*, 2003] as well as with the turbulence-resolving simulations. In the latter case, they are unambiguously attributed to passing turbulent eddies or gravity waves as there are no other sources of disturbances in the LESNIC data. Besides, as noted by my Reviewer, the gravity waves cannot propagate through unstably stratified layers. The waves are ubiquitously observed in the atmosphere [*Nappo*, 2002]. If however their wave length is much larger than the size of unstable, turbulent sports, the wave propagation remains undisturbed due to the effect of wave diffraction. Being interesting work as such, L08 however is not directly applicable to judge the validity of the stable atmospheric layer concept. The drop sonde data are appropriate to describe the instant and local stability but not the layer's stability. The observed similarity between drop sonde data and instant and local profiles in the LESNIC data and the above analysis of the data support the robustness of the stable atmospheric layer concept when hour and kilometer scales are considered.

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