Average thickness of the atmospheric convective boundary layer

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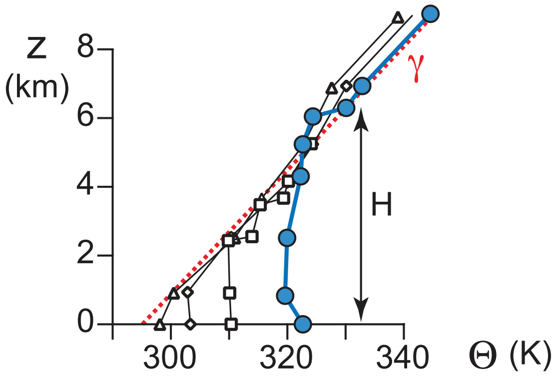
In the context of the size selection of giant aeolian dunes [1], we have shown that the typical thickness of the atmospheric convective layer, averaged at the seasonal time-scale, is mostly determined by the ground temperature (at least in the tropical desert regions). At this scale, the nocturnal/diurnal cycles, as well as the daily variation of cloud cover and weather conditions can be averaged out, allowing for a semi-quantitative description from elementary scaling law arguments.



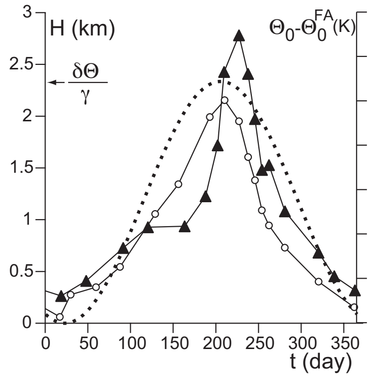


Fig. 1: (a) Typical vertical profiles of the virtual potential temperature $\Theta(z)$ measured by sounding balloons at noon, in Sulayel (Saudi Arabia), at different seasons (blue circles: 07/27/1978, squares: 10/22/1978, diamonds: 12/01/1977, triangles: 02/12/1978). (b) Depth of the ML (triangles) and ground temperature difference $\Theta_0 - \Theta_0^{\rm FA}$ (circles), in Ouargla (Algeria), averaged over 10 days, as a function of the day number. Dashed line: Eq. (1).

The typical vertical structure of the atmospheric boundary layer (ABL) in desert regions ideally follows a simple convectively driven situation: a well-mixed layer (ML) of thickness H lies below the stratified free atmosphere (FA). The air density profile is roughly constant in the ML, and linearly stratified in the FA. In agreement with the classical Boussinesq approximation, so is that of the virtual potential temperature Θ (Fig. 1a). We call Θ_0 the temperature in the ML and $\gamma \equiv d\Theta/dz$ the temperature gradient, which is found positive and constant $\gamma \simeq 4$ K/km. Extrapolating the temperature Θ_0^{FA} on the ground from the FA by the linear profile, one finds $H \simeq (\Theta_0 - \Theta_0^{\rm FA})/\gamma$.

As shown in Fig. 1a, the ML is thicker in summer when the temperature difference $\Theta_0 - \Theta_0^{\rm FA}$ is larger: the summer profile shows a $\simeq 6$ km thick convective layer, whereas the winter profile is stably stratified almost down to the ground. Using meteorological data from the Integrated Global Radiosonde Archive [2] as well as airports weather data base [3], we find that the seasonal time variation of H is fairly well reproduced by

$$H \sim \frac{\delta\Theta}{2\gamma}\left[1 + \sin(2\pi t/Y + \varphi)\right], \tag{1}$$

as shown in Fig. 1b. In this expression, time t is expressed in days ($Y = 1$ year) and $\delta\Theta$ is the RMS value of Θ on the ground, extracted from ground temperature time series. The fitted phase φ corresponds to a maximum in the mid-summer.

References

[1] B. Andreotti, A. Fourrière, F. Ould-Kaddour, A.B. Murray & P. Claudin, Giant aeolian dune size determined by the averaged depth of the atmospheric boundary layer, *Nature* **457**:1120, 2009.
[2] I. Durre, R.S. Vose & D.B. Wuertz, Overview of the Integrated Global Radiosonde Archive, *J. Climate* **19**: 53 (2006). See also IGRA web site: `http://www.ncdc.noaa.gov/oa/cab/igra/`.
[3] Weather archives: `http://meteo.infospace.ru/wcarch/html/index.sht`.

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