Comparison of some theoretical atmospheric boundary layer profiles with 5 years of SIRTA data

THEORY

- Context:
  In atmospheric CFD computations, the boundary conditions for wind speed profiles in neutral conditions follows a logarithmic law:

$$\overline{u}(z) = \frac{u_*}{\kappa} \ln\left(\frac{z}{z_0}\right)$$

  It would be useful to have theoretical profiles for stable and unstable conditions too.
- Monin-Obukhov similarity theory (MOST) [1]:

$$\frac{\mathrm{d}\overline{u}}{\mathrm{d}z} = \frac{u_*}{\kappa z}\varphi_m\left(\frac{z}{L}\right)$$

  Valid theory only within the surface layer.
- Gryning et al. extension [2]:

$$\frac{\mathrm{d}\overline{u}}{\mathrm{d}z} = \frac{u_{*0}}{\kappa}\left(1-\frac{z}{z_i}\right)\left(\frac{\varphi_m(z/L)}{z} + \frac{1}{L_{MBL}} + \frac{1}{z_i - z}\right)$$

  Extension of MOST within the whole atmospheric boundary layer.

DATA ANALYSIS

- Data description:
  To validate the previous theories, 5 years of SIRTA data were used, from 2012 to 2017.
  - 2 sonic anemometers (10m and 30m) and 2 lidar (from 40m to 2000m);
  - 10Hz measurements and average on 10min;
  - Filter on wind direction (265° - 295°) to avoid obstacles around the site: 12700 measurements left.
- Data processing:
  - Parameters computation:

$$\begin{cases} u_* = \left(\overline{u'w'}^2 + \overline{v'w'}^2\right)^{1/4} \\ \dfrac{1}{L} = -\dfrac{\kappa \dfrac{g}{\theta_0}\overline{w'\theta'}}{u_*^3} \end{cases}$$

  Measurements at 10m for $\overline{u'w'}$, $\overline{v'w'}$, $\overline{w'\theta'}$ and θ_0.
  - Filter to keep only data for which:
    - $u_* > 0.2$m/s for stable conditions;
    - $u_* > 0.3$m/s for unstable conditions

    6400 measurements left.

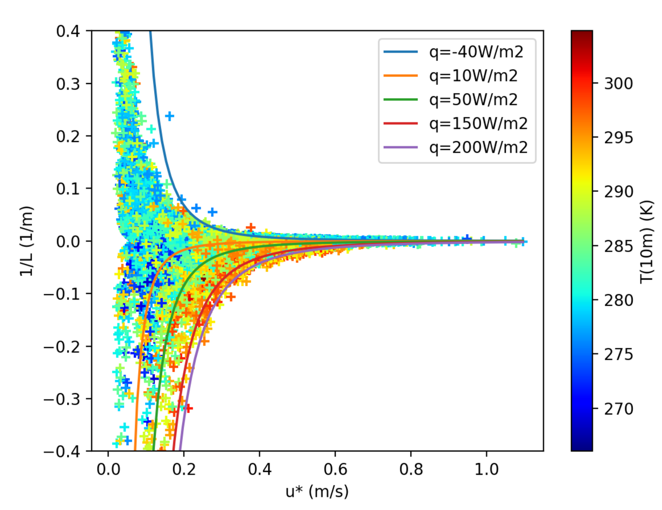

Figure 1 : $1/L$ against u_*. +: measurements; lines: iso-heat flux computed with the mean temperature $\theta_0 = 25°$C

  - Roughness length computation: z_0 was determined using the formula, fulfiled in neutral conditions:

$$z_0 = z\exp\left(-\kappa\frac{\overline{u}(z)}{u_*}\right)$$

  The roughness length was computed with mesurements for which $|L| > 1000$m and the median value of these computations were used.

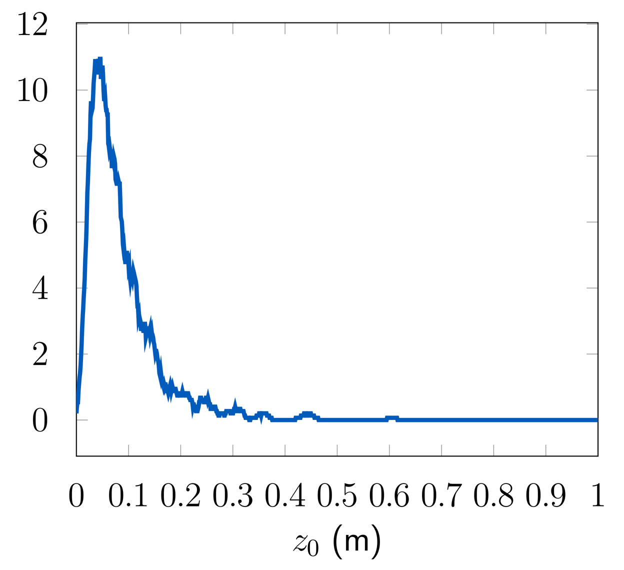

Figure 2 : PDF of z_0. The median value is $z_0 = 0.066$m

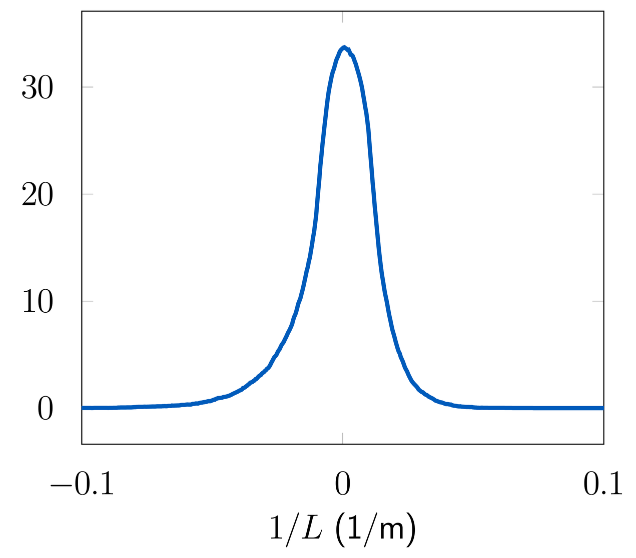

Figure 3 : PDF of $1/L$

  Length scale of the middle boundary layer computation: L_{MBL} was computed for each sample using the parameterization given in Gryning et al. [2]:

$$\frac{u_{*0}}{fL_{MBL}} = \left(-2\ln\left(\frac{u_{*0}}{fz_0}\right) + 55\right)\exp\left(-\frac{\left(\dfrac{u_{*0}}{fL}\right)^2}{400}\right)$$

  Atmospheric boundary layer height computation: z_i was computed with Zilitinkevich parameterization [3] for stable conditions:

$$z_i = 0.4\sqrt{\frac{u_{*0}L}{f}}$$

  and with neutral parameterization for neutral conditions ($|L| > 1000$m):

$$z_i = 0.2\frac{u_{*0}}{f}$$

  - Classification of data into 6 categories following the value of $1/L$. For each category, mean and median of $\overline{u}(z)/u_*$ were computed for all heights and median value of L, L_{MBL} and z_i were computed (for unstable conditions, z_i was set between 1200m and 2000m for weakly to strongly unstable conditions).

References

[1] Monin, A. S., Obukhov, A. M., 1954.

[2] Gryning, S. E. et al. Boundary-Layer Meteorology, 2007.

[3] Zilitinkevich, S. S. Boundary-Layer Meteorology, 1972.

[4] Hartogensis, O. K., De Bruin, H. A. R., Boundary-Layer Meteorology, 2005

RESULTS

- Monin-Obukhov similarity theory:

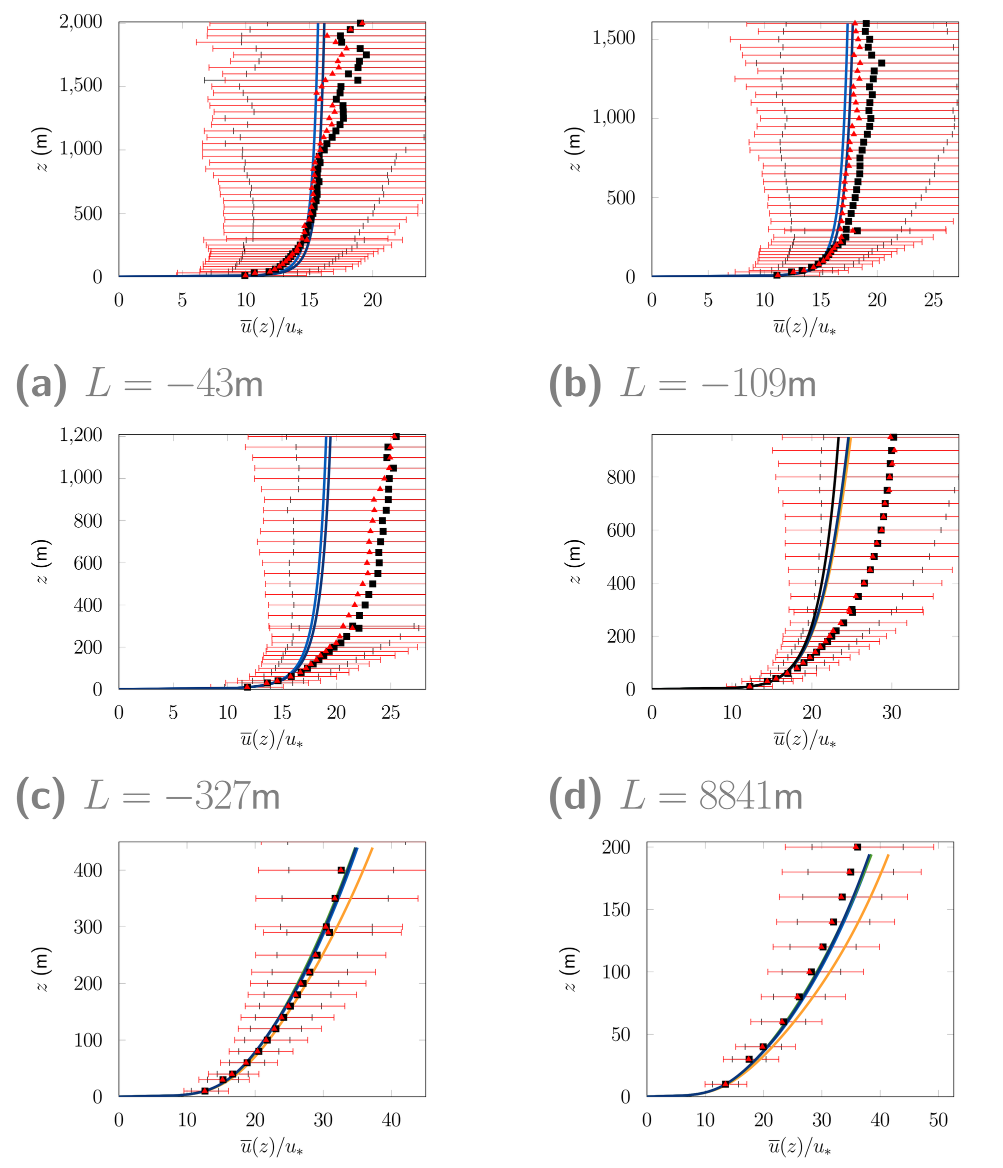

Figure 4 : Plot of the wind speed using MOST. Mean: •; Median: •; $HO88$: —; $CB05$: —; $HB05$ [4]: —; $B71$: —; log: —

Figure 4 shows that Monin-Obukhov profiles aren't far from the measurements for low altitudes but they postpone with height.

- Gryning et al. extension:

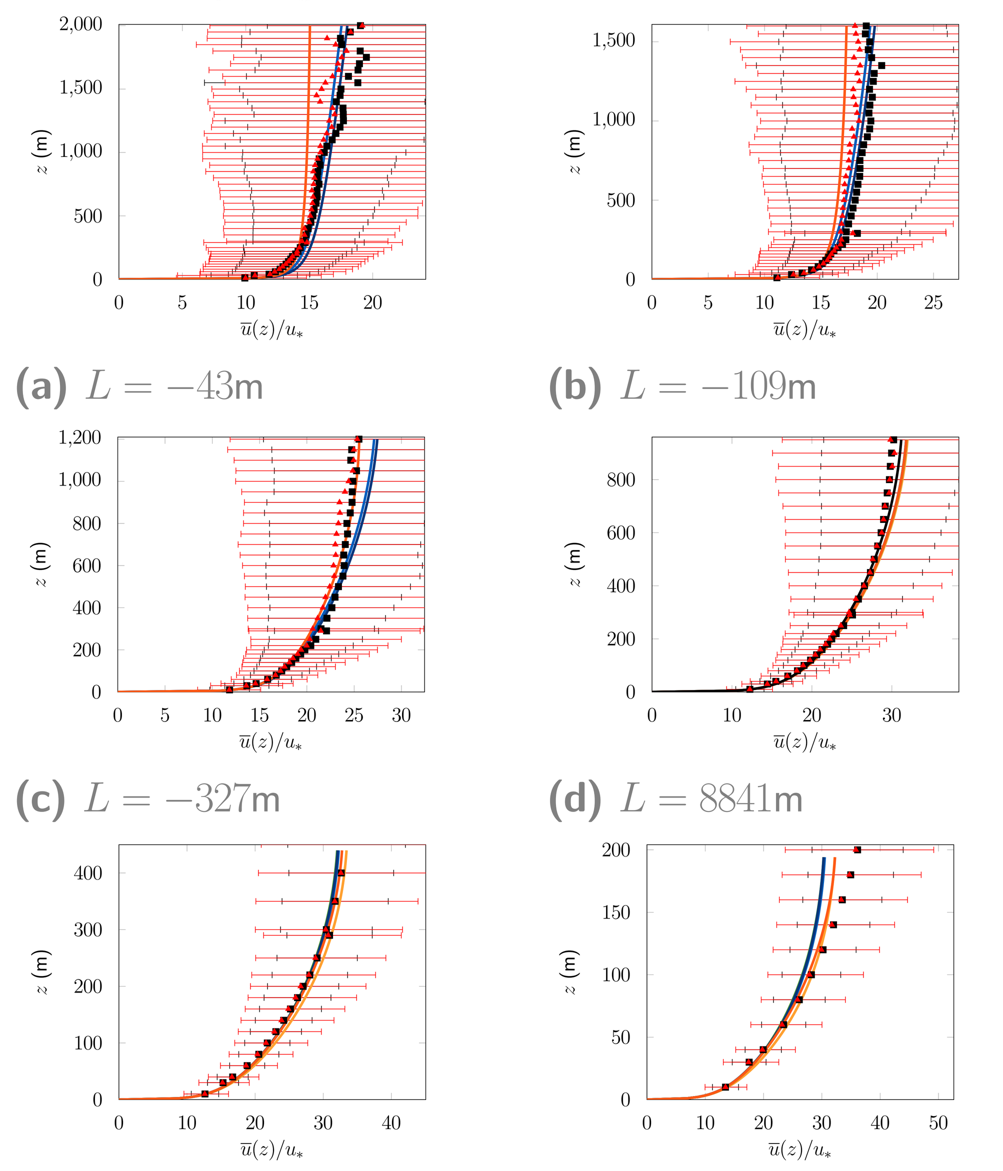

Figure 5 : Plot of the wind speed using MOST. Mean: •; Median: •; $HO88$: —; $CB05$: —; $HB05$ [4]: —; $B71$: —; $G07$: —; log: —

Figure 5 shows that Gryning et al. extension theory allows to bring the theoretical profiles closer to the measurements.

CONCLUSION, PERSPECTIVES

- Interest to find a parameterization of z_i for unstable conditions or to use z_i estimation based on lidar or ceilometer measurements;
- Interest to know which theory gives the most realistic profiles for CFD codes

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