The vertical structure of turbulence in the atmospheric boundary layer: observations at Ny Alesund and preliminary analyses

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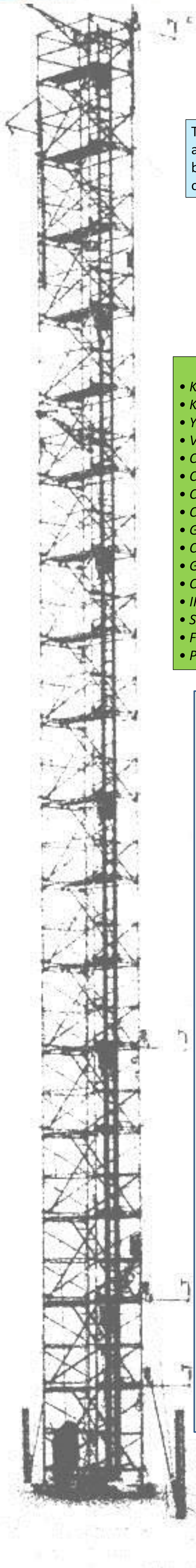
http://www.isac.cnr.it/~radiclim/CCTower/



The Arctic land areas are subject to warming faster than other region on earth. The "Arctic amplification" may be due to feedback mechanisms from loss of sea ice or changes in atmospheric and oceanic circulations. To deepen the knowledge of such mechanisms a 32 m high platform named Amundsen-Nobile Climate Change Tower (CCT) has been set up at Ny Ålesund - Svalbard on 2009 by Italian CNR. Multiple levels of fast and slow response instruments are provided to investigate the processes related to the energy balance and to the mean and the turbulent characteristics of the planetary boundary layer (PBL) under different conditions. Purpose of this research is to exploit the in-depth use of measurements in the PBL to understand its dynamics, highlighting the capability of such instrumental setup. This study aims to update present parameterizations of momentum and heat fluxes at the surface, necessary to improve weather forecasts, air quality assessment and climatic simulations.

The unique data set collected at the CCT allows to test similarity predictions and address some questions for:
• CBL: does exist or can be recognized the transition from dynamic to free convection layers (Kader and Yaglom, 1990)? This transition occurs only for vertical velocity variance or also for the mean velocity?
• SBL: Can 'traditional' and 'upside-down' (Mahrt and Vickers, 2002) structures be recognized from tower data? Is the BL height univocally defined?

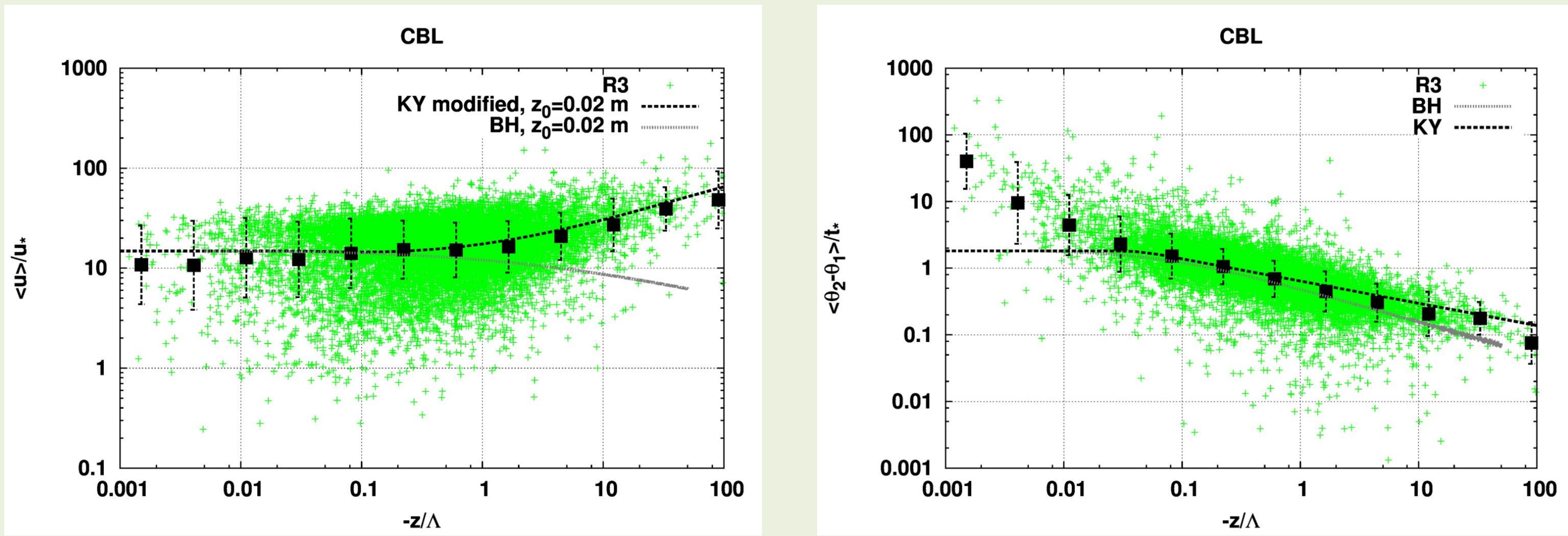
• u_* friction velocity
• $\tau = u_*^2$ momentum flux
• $\langle w\theta \rangle$ heat flux
• t_* temperature scale
• Λ Obukhov length
• TKE turbulent kinetic energy
• h_m, s_m momentum scale height
• h_h, s_h heat scale height
• h_{TKE}, s_{TKE} kinetic energy scale height

CCT INSTRUMENTATION SETUP

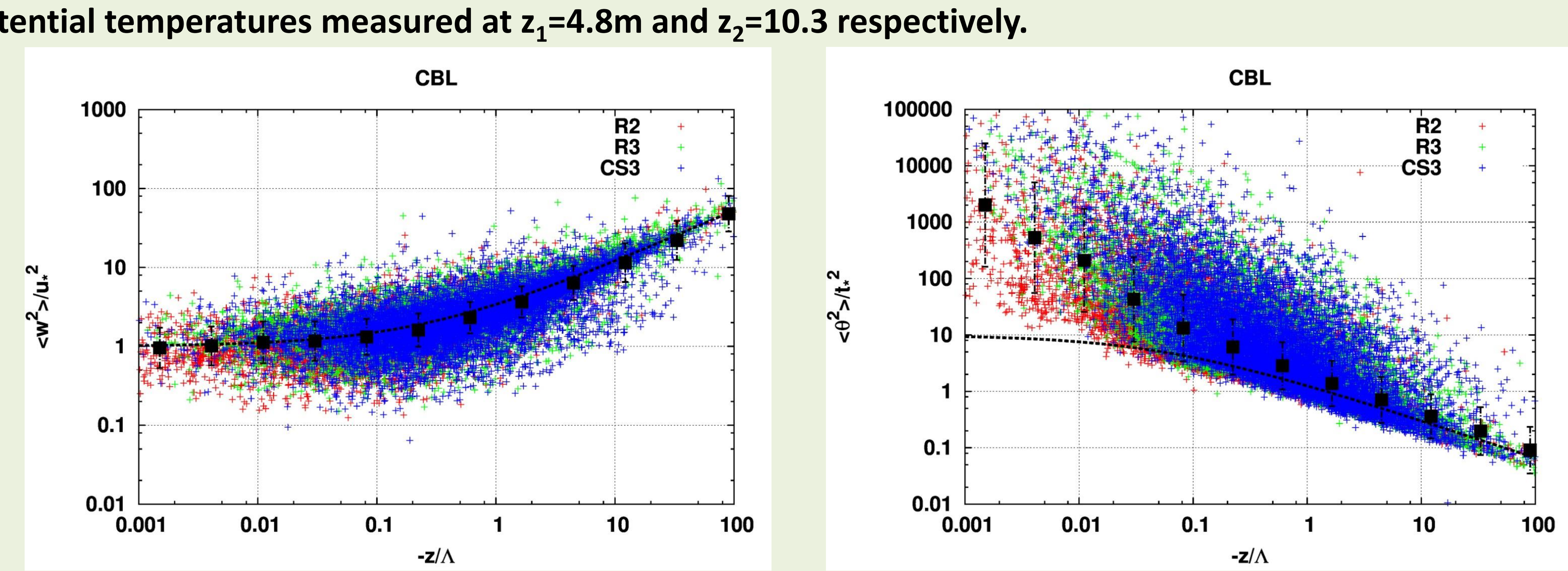
- *K&Z CNR 1 net radiometer* ***[33 m]***
- *K&Z CM11 and CGR4 upwelling first class radiometers* ***[25 m]***
- *Young propeller anemometers* ***[33m, 10m, 5m and 2m]***
- *Vaisala HMP45 thermo-hygrometers* ***[33m ,10m, 5m and 2m]***
- *Campbell CSAT3 sonic anemometers* ***[21 m]***
- *Campbell EC150 fast hygrometer* ***[21 m]***
- *CH4 and CO2 open path analyzers* ***[21 m]***
- *CRDS inlet for gas measurements* ***[21 m]***
- *Gill R50 Solent sonic anemometer* ***[7.5 m]***
- *Campbell Kh-20 fast hygrometer* ***[7.5 m]***
- *Gill R2 Solent sonic anemometer* ***[3.7 m]***
- *Campbell Kh-20 fast hygrometer* ***[3.7 m]***
- *IR120 infrared sensor for snow skin temperature* ***[5m]***
- *SR50 sonic range sensor for the snow height* ***[5m]***
- *Flux plate at the interface soil-snow* ***[at surface]***
- *PT100 in the snow layer and into the ground* ***[15 , 5, -5, -15 cm]***

In present work two period of measurements are selected **25 May - 17 August 2012** and **15 June -11 Nov 2013.**
The analysis uses the four level of conventional instruments, Young anemometers and Vaisala thermo-hygrometers, and the three level of fast response sensors, Campbell CSAT3, Gill R50 Solent and Gill R2 Solent sonic anemometers. The data are averaged over 10 minutes.
The data have been classified according to the following definitions:
• stable cases (SBL): $z/\Lambda > 0$ for all sensors (24%; 2501 observations)
• unstable cases (CBL): $z/\Lambda < 0$ for all sensors (76%; 8109 observations)

Unstable cases



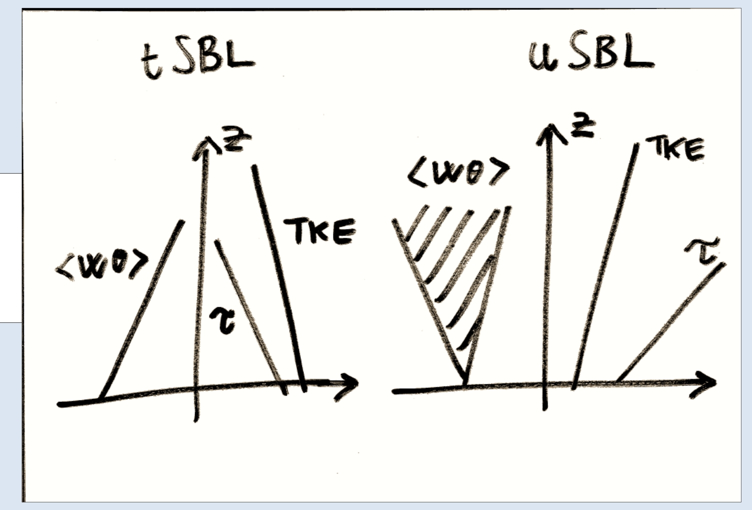
Normalized wind velocity (left) and temperature difference (right): Beljaars and Holtslag (1991) and Kader and Yaglom (1990, coefficients reevaluated) formulations are reported. Green symbols: data; grey squares: geometric averages and standard deviations after binning. Z_0 = 0.02m is the roughness length, θ_1 and θ_2 are potential temperatures measured at z_1=4.8m and z_2=10.3 respectively.



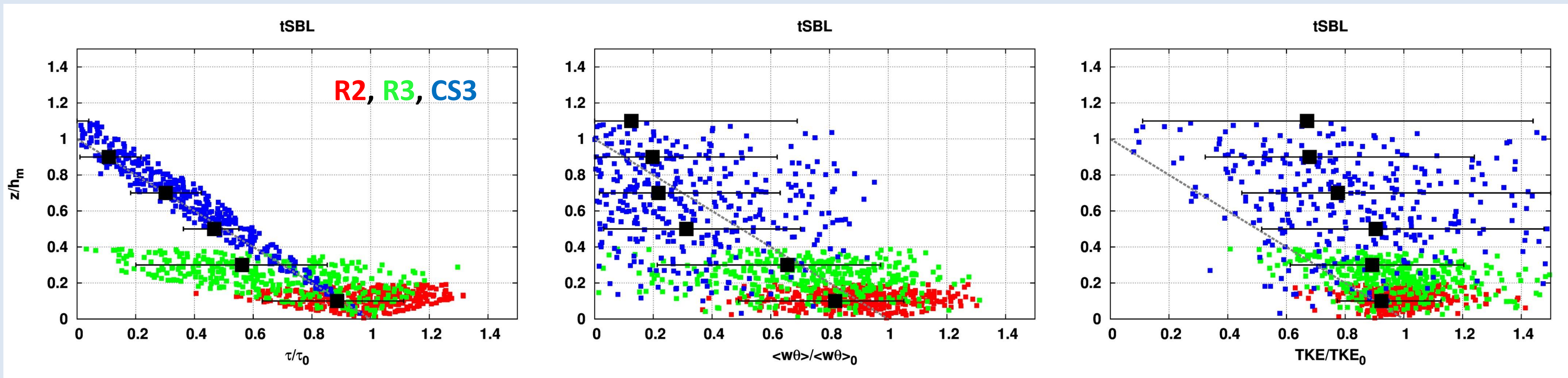
Normalized variance of the vertical velocity (left) and temperature variance (right). The theoretical curves are slightly modified from Tampieri et al. (2009).

Stable cases

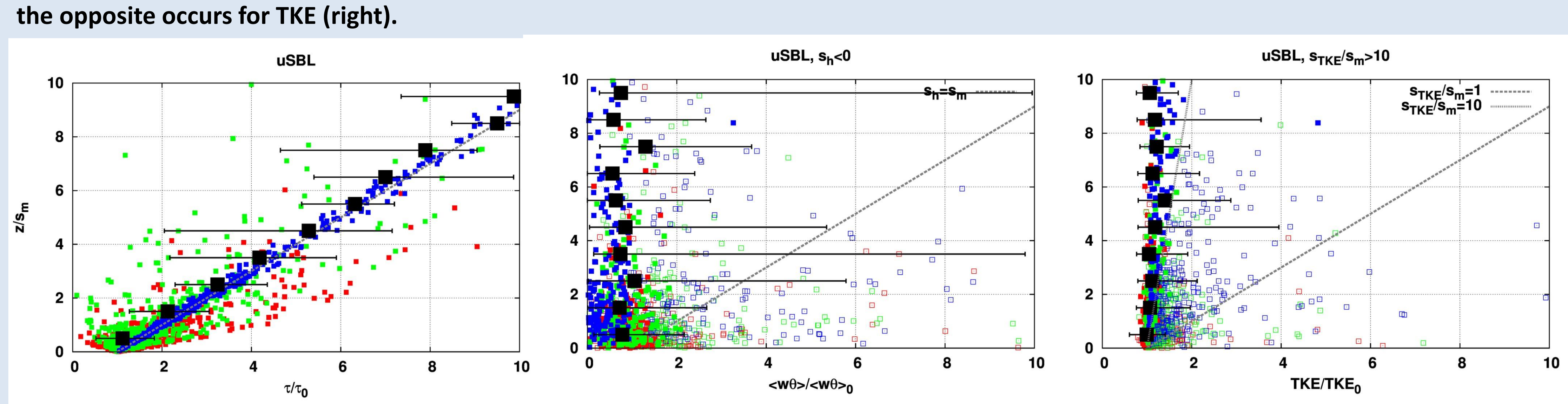
Simplified sketch for the SBL structure: traditional (left, tSBL) and upside-down (right, uSBL).
For tSBL τ and TKE decrease with height, <wθ> increases with height.
For uSBL τ and TKE increase with height, <wθ> presents both behaviors.



Second order momenta have been linearly fitted: y = a + b*z where y stays for τ, <wθ> or TKE.
For tSBL, scale heights h_m, h_h and h_{TKE} were defined as the height where τ, <wθ> and TKE go to zero (h = -a/b).
For uSBL, similarly to the tSBL case, s_m, s_h and s_{TKE} were defined as scales of variation of τ, <wθ> or TKE (s = a/b, positive for τ and TKE, while for <wθ> it can be positive or negative (see sketch).



For tSBL, the momentum flux (left) is fairly well fitted by the linear relation, although the lower data show a wide spread (power laws like in Nieuwstadt (1984) could be more suited); the heat flux (center) goes to zero at heights smaller than the momentum flux ($h_h < h_m$), while the opposite occurs for TKE (right).



For uSBL, the momentum flux (left) is fairly well fitted by the linear relation. Concerning the heat flux (center), a wide range of profiles can be found: full symbols for <wθ> increasing with height; open symbols <wθ> decreasing. Cases with <wθ> changing less than τ with height are more frequent (points above the line $s_h = s_m$).
TKE (right) increases less than τ with height. For TKE the full symbols refer to cases in which $s_{TKE} > 10\ s_m$.
The black squares represent the median values, together with 10th and 90th percentiles.

References:
Beljaars, A. and A. A. M. Holtslag, 1991: Flux parameterization over land surfaces for atmospheric models. J. Appl. Meteorol., 30, 327–341.
Kader, B. A. and A. M. Yaglom, 1990: Mean fields and fluctuation moments in unstably stratified turbulent boundary layers. J. Fluid Mech., 212, 637–662.
Mahrt, L. and D. Vickers, 2002: Contrasting vertical structures of nocturnal boundary layers. Boundary-Layer Meteorology, 105, 351–363.
Nieuwstadt, F. T. M., 1984: The turbulent structure of the stable, nocturnal boundary layer. J. Atmos. Sci., 41, 2202–2216.
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Conclusions:
• for unstable cases, the standard results for temperature and vertical velocity variance are retrieved. It is worth to note that for mean wind the profile by Kader and Yaglom (1990) gives the correct dependence in convective conditions;
• for stable cases, on the basis of the slopes derived from fits, both tSBL and uSBL situations have been identified;
• for tSBL: the heights derived from second order moments are different, and preferably $h_{TKE} > h_m$;
• for uSBL: TKE is increasing typically at a smaller rate than momentum flux; the heat flux may be increasing or decreasing.