Diurnal Behaviour of Turbulence in the Summer PBL at Dome C: Sodar and In-situ Observations

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INTRODUCTION

A long-term experiment to study turbulence in the atmospheric boundary layer (ABL) over the Antarctic plateau was carried out in 2011-2015 at the French-Italian Concordia station (Dome C). The behaviour of thermal turbulence was observed remotely using a specially developed high-resolution sodar – HRS (vertical resolution better than 2 m, time resolution of 2 s, first range gate of ≈ 3 m). Observations were made using both sodar and in-situ instruments (ultrasonic thermometer-anemometers, wind and temperature sensors near the surface and on a 45-m tower, radiometers and radiosoundings). The results presented here are restricted to the summer period from December 2014 to January 2015, when accurate turbulence measurements by a high-quality ultrasonic thermometer-anemometer HS-50 (Gill Instruments Ltd) were performed in synergy with the other instruments.

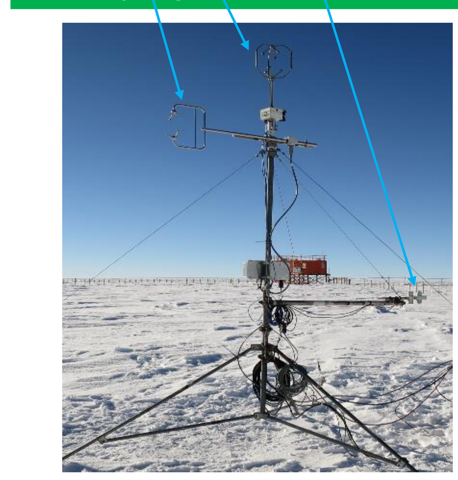
An accurate calibration of the sodar C_T^2 measurements was performed to refine the sodar results obtained previously. The diurnal behaviour of the height dependence of C_T^2 together with the mixing layer height was determined for the entire diurnal cycle.

The behaviour of turbulence spectra at high-frequency range (especially, their slopes) under stable stratification was determined correctly and compared with previous results. Relationships between thermal and mechanical turbulence intensities under different stability conditions were considered.

INSTRUMENTATION

High-resolution SODAR (HRS)
measures vertical profiles of the strength of thermal turbulence
from ≈2 m, with a step of <2 m to 200 m
Antenna system: three transmitting horns and one receiving shielded parabolic dish
Carrier frequency: 4850 Hz
Pulse duration: 10 ms
Pulse repetition: 2 s

1. Ultrasonic **thermometer-anemometers:**
1) USA-1 by Metek (Height: 3.5 m)
2) HS50 by Gill (Height: 2.9 m)
Sample rate: 10 Hz
2. Net **Radiometer**
CNR1 by Kipp&Zonen
Height: 1.5 m
Sampling rate: 1 minute



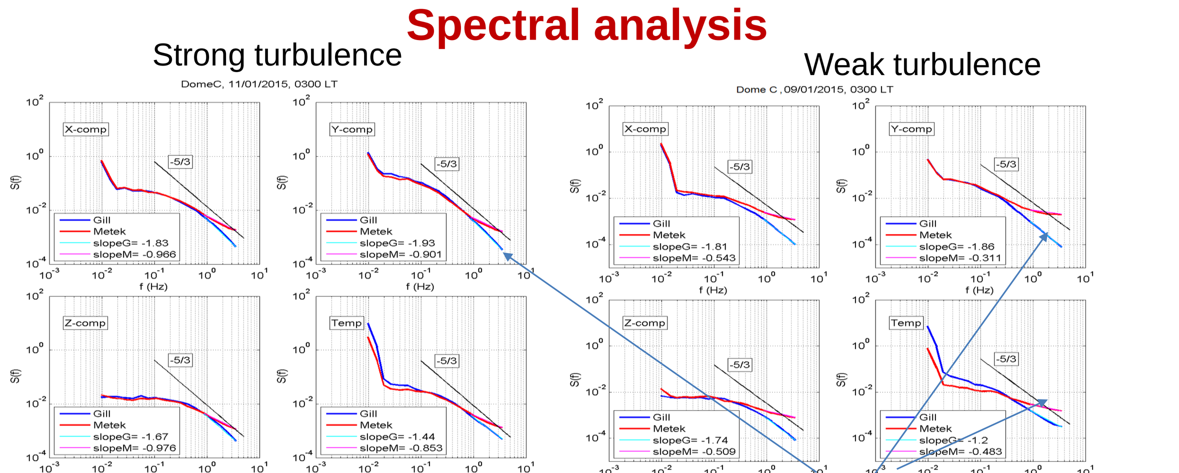
Sonic quality characterisation

Comparison of the instruments showed that they have both advantages and disadvantages:

1) USA-1 Metek generates elevated electronic noise signal at > 1 Hz that distorts spectrum slopes and structure parameter estimates (especially for temperature).
2) HS50 Gill produces at low temperatures (< -30 °C) trends and jumps in temperature in a random way that could distort flux estimates.
3) HS50 Gill has an overestimation of temperature measurements of ~ 2-6 K depending on temperature.

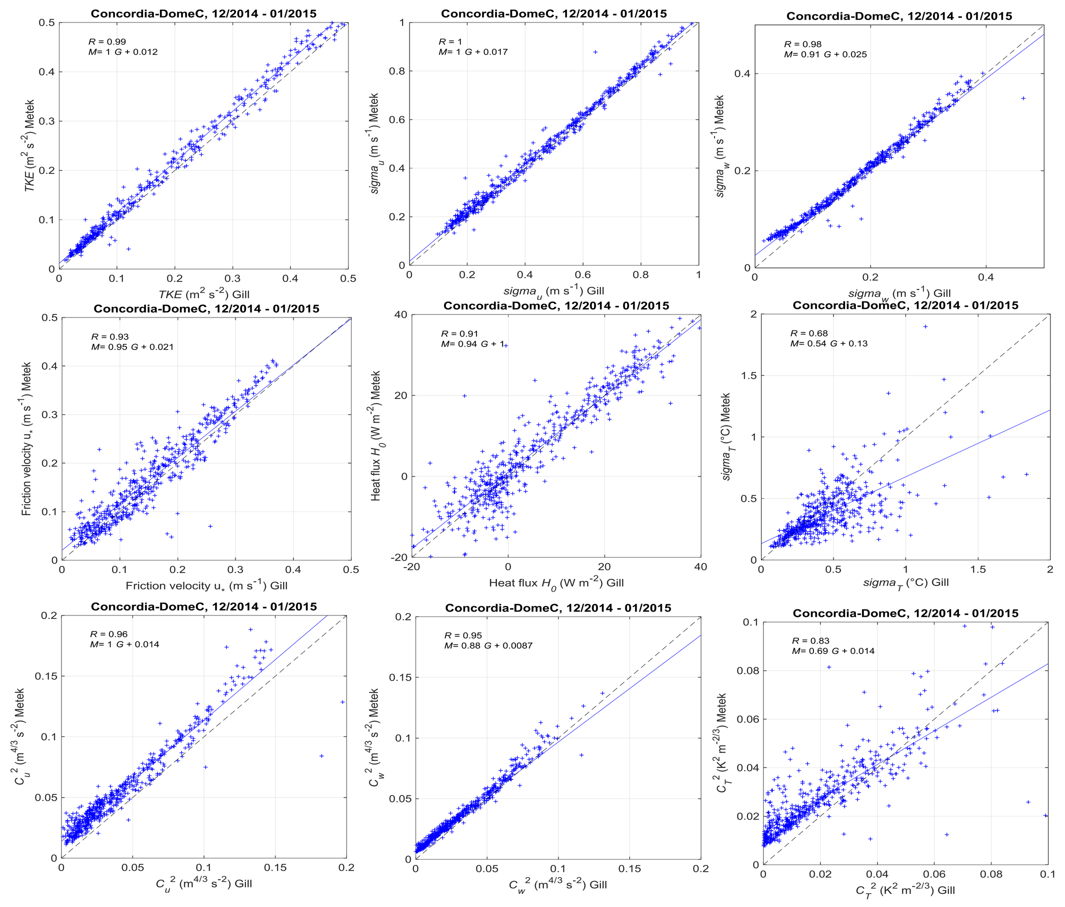
Till now, accurate measurement of turbulent parameters under weak turbulence at low temperatures in the stable boundary layer remains a difficult problem of polar studies. Careful preliminary analysis is extremely needed when data processing to eliminate erroneous data with outliers and low frequency trends caused by non-atmospheric reasons.

Spectral analysis



Spectra of all parameters obtained from Metek data show overestimation at frequencies > 0.3 Hz, while Gill data provide spectra close to the theoretical ones with slopes of ~ -5/3. The difference is quite evident for weak turbulence conditions (right panels).

Correlation between Metek and Gill measurements



Essential difference is observed between Metek and Gill measured temperature structure parameter C_T^2 and temperature standard deviation. Also, there is some difference in the range of negative heat fluxes H_0.

Summarized diurnal behaviour of sonic measured mean and turbulent parameters

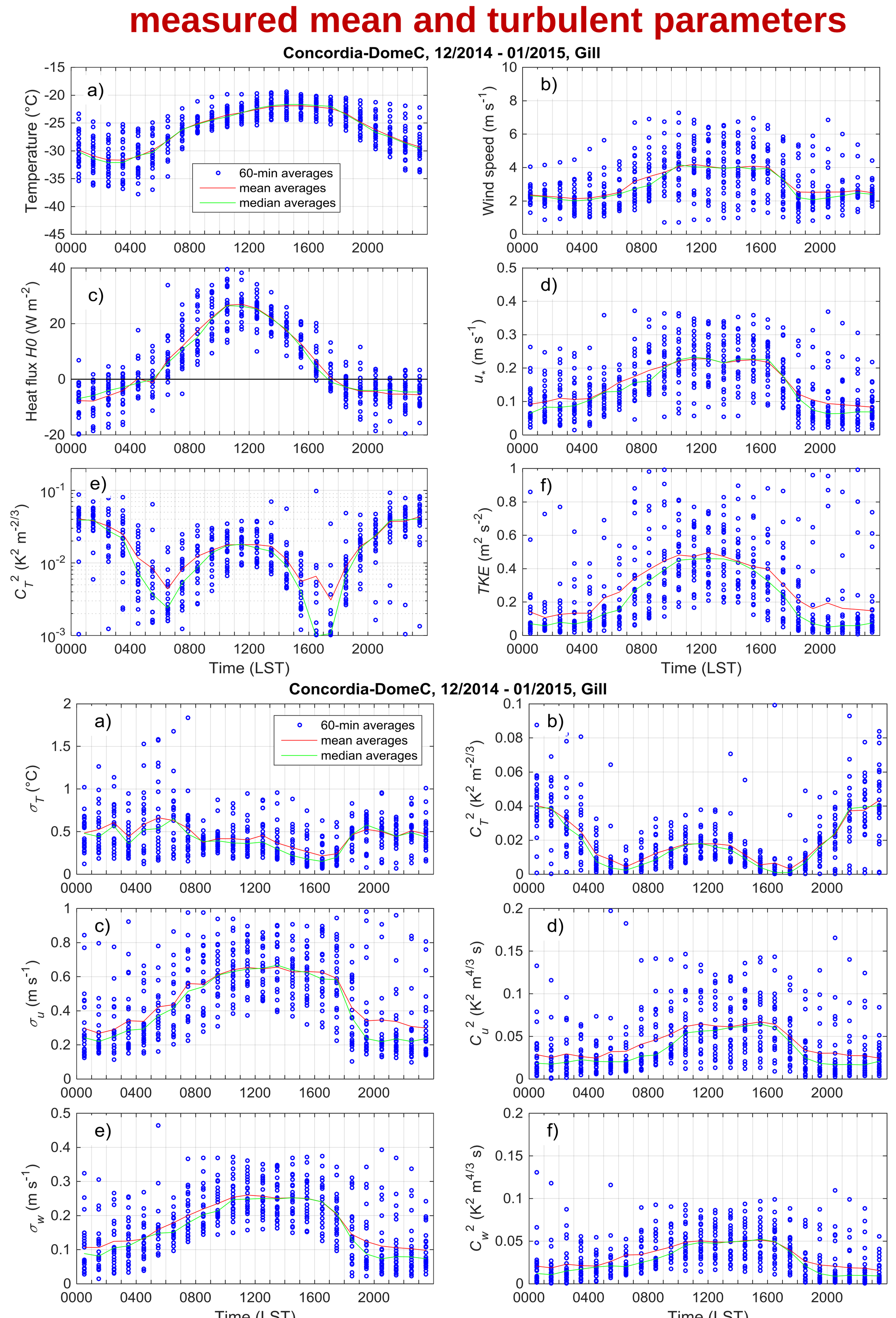
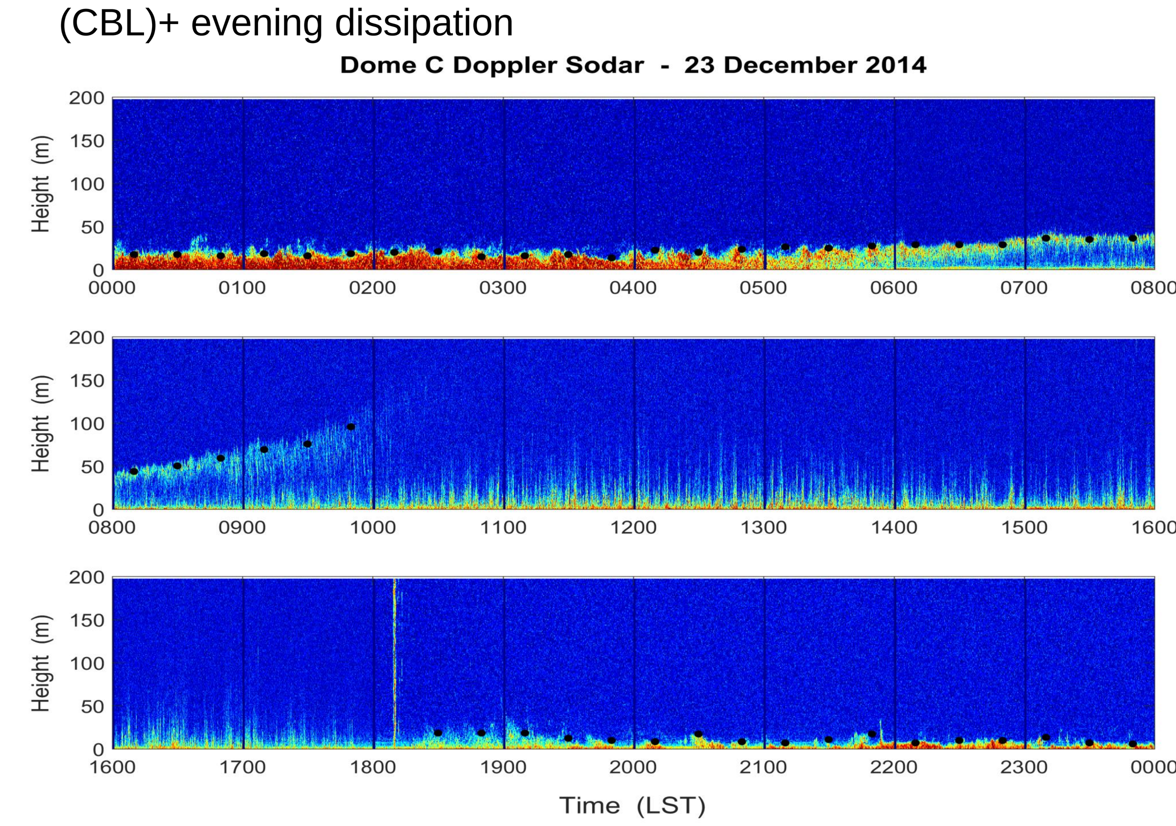


Fig. Diurnal behaviour of some variables measured with a sonic thermometer-anemometer Gill HS50 at a height of 3.5 m during summer 2014-2015. **a** Temperature, **b** wind speed, **c** sensible heat flux H_0, **d** friction velocity u^*, **e** temperature structure parameter C_T^2 , **f** turbulent kinetic energy TKE. Circles are the 30-min averaged values for individual days. Solid lines show the averaged values over the all days. Red and green lines show arithmetic and median averages, respectively.

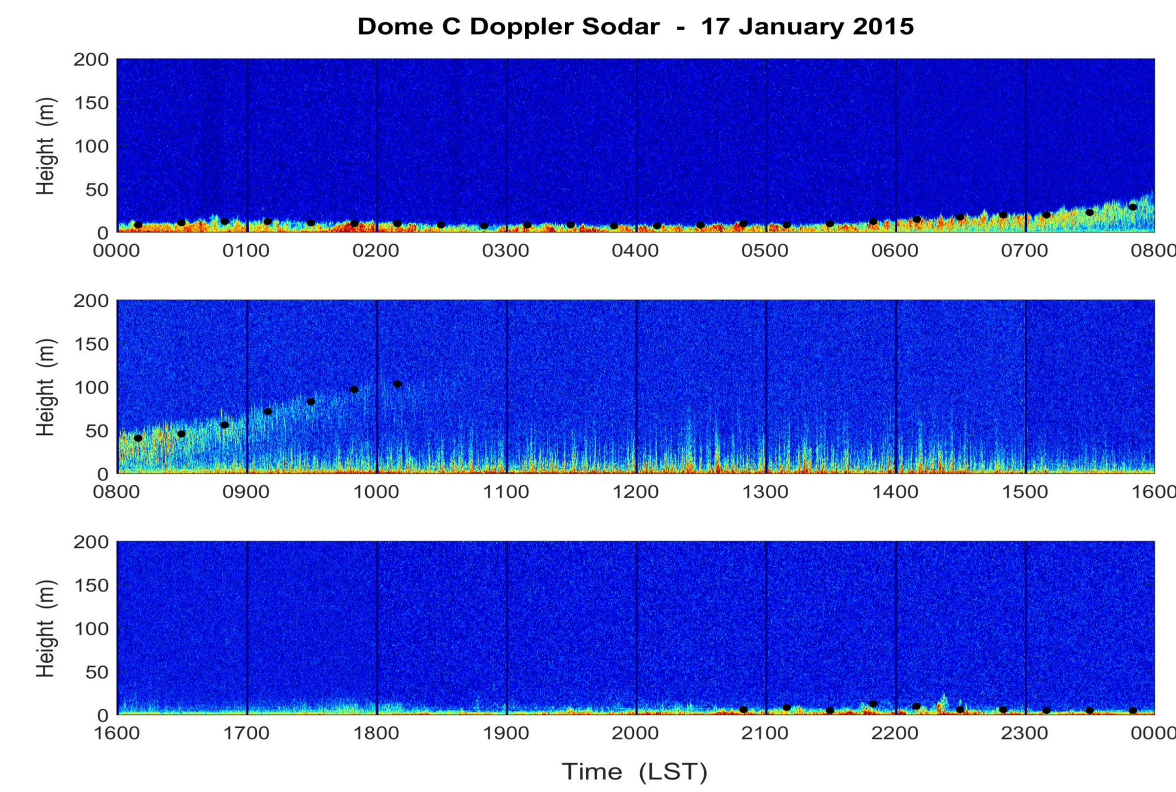
Typical diurnal behaviour of the spatio-temporal structure of the ABL (shown by the sodar) and of relevant atmospheric parameters in summer-time at Dome C

Examples of the typical sodar echogram in summer time at Dome C with morning development of the convective BL. The color intensity is proportional to $\ln C_T^2$.

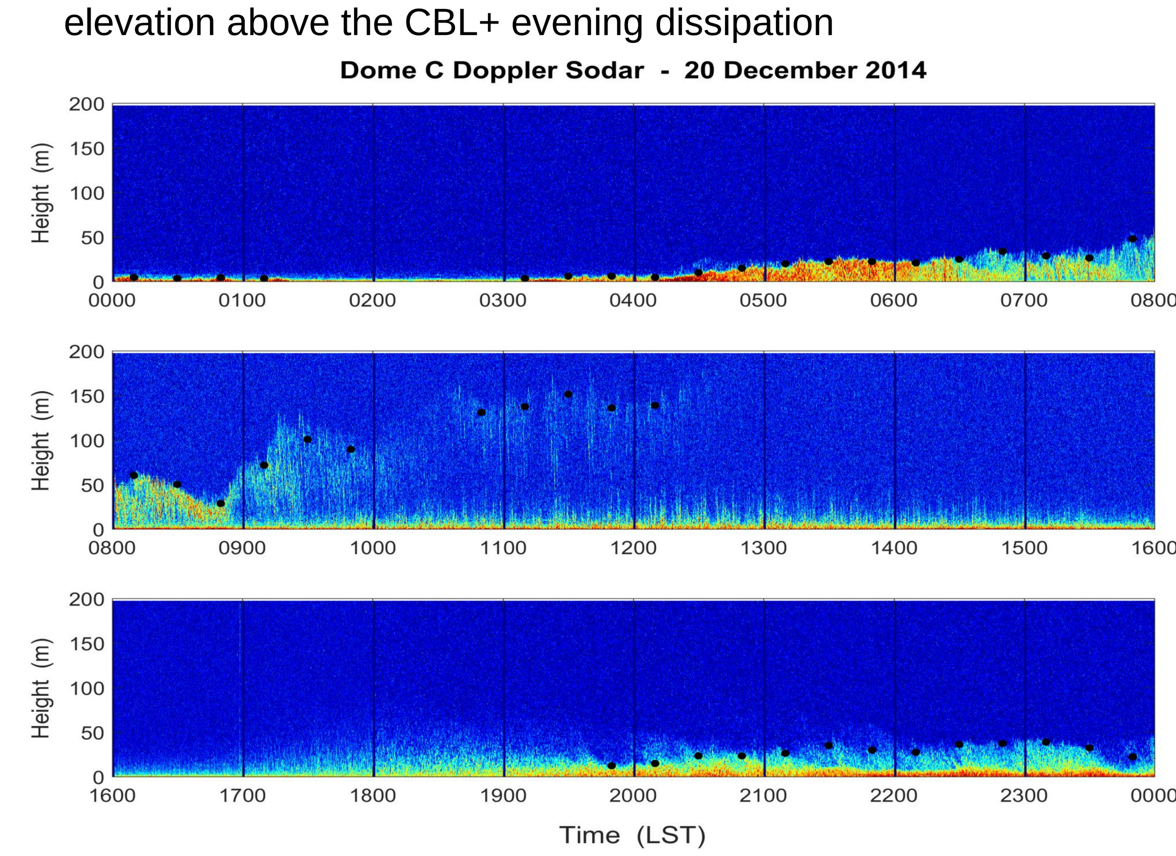
Very shallow Nocturnal Surface-based Turbulent Layer (NSTL) + with sequent monotonous elevation above the Convective Boundary Layer (CBL)+ evening dissipation



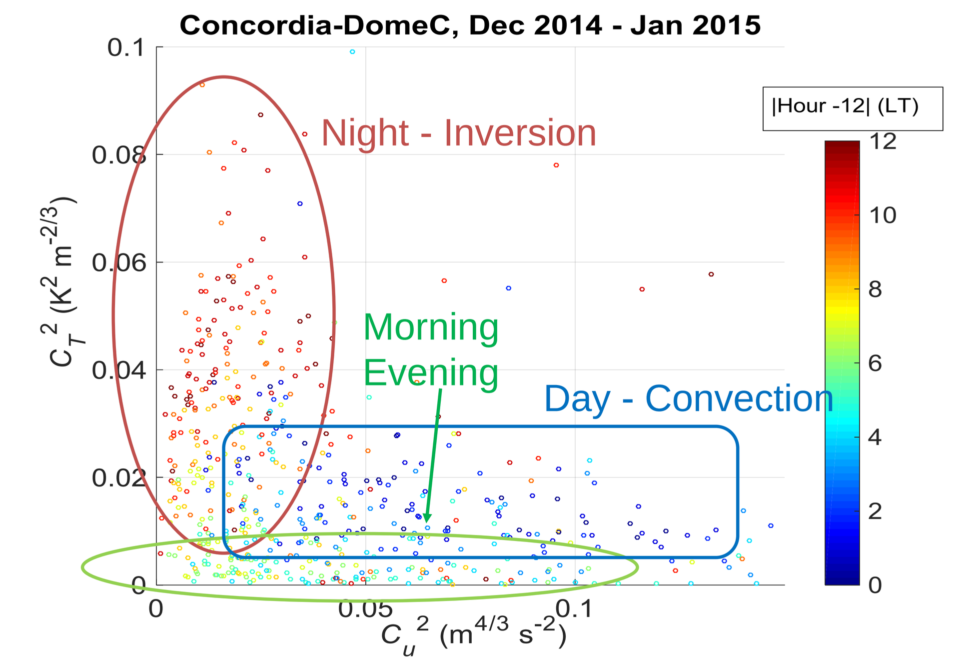
Moderately deep NSTL + with sequent NONmonotonous (with stopping for ≈1 h) elevation above the CBL+ evening dissipation

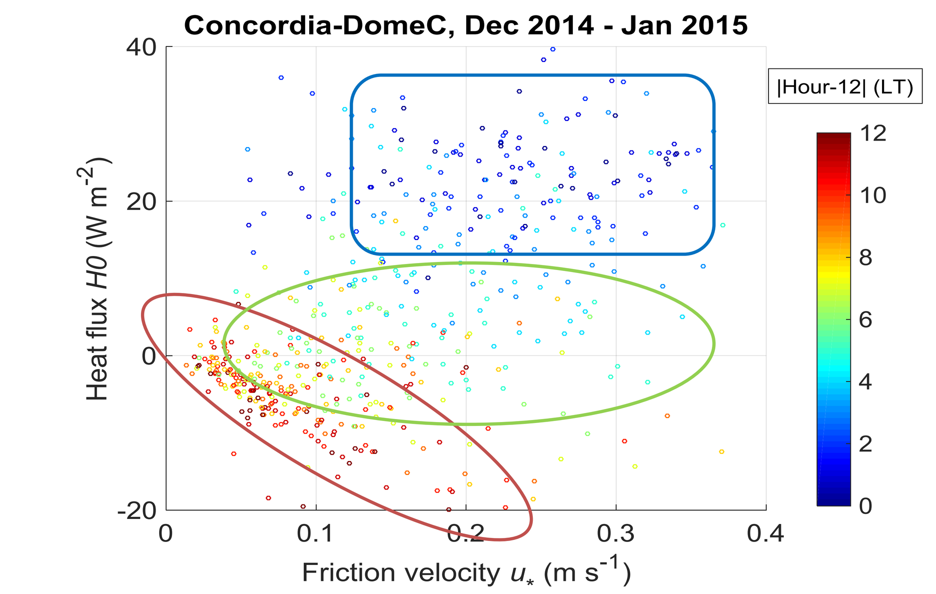


Growing NSTL + with sequent NONmonotonous (with ocsillations) elevation above the CBL+ evening dissipation



Relationship between thermal and mechanical turbulence





Temperature structure parameter C_T^2 vs wind speed structure parameter C_V^2 (upper panel). Sensible heat flux H0 vs friction velocity u_* (lower panel). 23 Dec 2014 - 17 Jan 2015.
Red colours show time around midnight, blue – around midday, green – morning and evening hours.
NB!!! Relationship between temperature and wind speed fluctuations is not universal, but depends on stratification

CONCLUSIONS

A representative diurnal cycle of the ABL turbulence structure and of the relevant atmospheric characteristics was documented using sodar and *in situ* measurements in December 2014 – January 2015 at Dome C. This diurnal course indicates the alternation of a surface-based temperature inversion and convection capped by the inversion layer. The temperature structure parameter C_T^2 (from both sodar and sonic) diurnal behaviour shows higher values during “nighttime” and remarkable recurrence during “daytime”.

Accurate measurement of turbulent parameters under weak turbulence at low temperatures in the stable boundary layer remains a difficult problem of polar studies.

The use of the advanced high-resolution sodar allowed us to reveal some new features in the BL, which indicates clearly the presence of undulation processes accompanying the development of convection during morning hours. Inside the elevated turbulent layer, which ascends with the development of the convective layer close to the surface, the regular wavy fine-scale layers forming the braid pattern in the sodar echogram are present.

The minimum in CT2 of ~ ??? are observed at earlier morning 5-6 LT and evening 16-18 LT hours. The lowest CT2 values observed by HS50 Gill device are about one order lower than those measured earlier by other sonic device models.

Relationship between intensities of small-scale thermal and mechanical turbulence characterized by structure parameters CT2 and CV2, respectively, is not uniform

Acknowledgements. This research was supported by the Italian National Research Programme (PNRA), and the French Polar Institute (IPEV) (project COMPASS). Also, the Russian Foundation for Basic Research (project 13-05-00846) and Russian Science Foundation (project No. 14-27-00134) partly supported the data analysis. The authors thank the staff of the Meteo-Climatological Observatory and the logistics staff of the Concordia station for its active help during the field work.

EMS2018-433, Sec UP1.2
3-7 September 2018, Budapest