Fine-scale wavelike structures in the surface-based turbulent layer at Dome C, Antarctica

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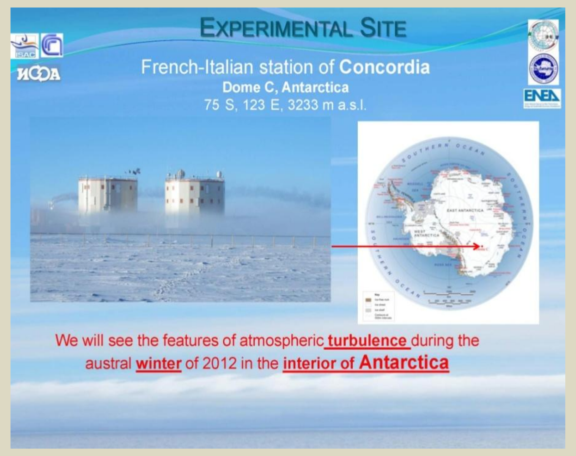


INTRODUCTION

During January-November 2012, observations were carried out at the French-Italian station of Concordia (Dome C, Antarctica) to study the behaviour of atmospheric turbulence in the boundary layer (BL). The behaviour of thermal turbulence was observed remotely using a specially developed high-resolution sodar. In contrast to the previous observations, the turbulence pattern in the BL was observed by sodar beginning from ≈2m and with vertical resolution <2 m. Sodar observations were accompanied by in-situ measurements of the mean and turbulent atmospheric characteristics.

Thank to the high-resolution sodar measurements, it was found that in the surface-based turbulent layer (STL), a distinct wave activity occurs very often. Mainly, the form of wavelike fine-scale turbulent layers is classified as "braid" (or "herringbones") pattern. They can be associated with internal gravity-shear waves attributed to the Kelvin-Helmholtz instability. Some characteristics (spatial and temporal scales, vertical extension) of the wavelike structures are determined and presented.

FEATURES OF THE PRESENTED RESULTS

"**Quasi-LABORATORY**" experiment –
minimally influenced by external factors

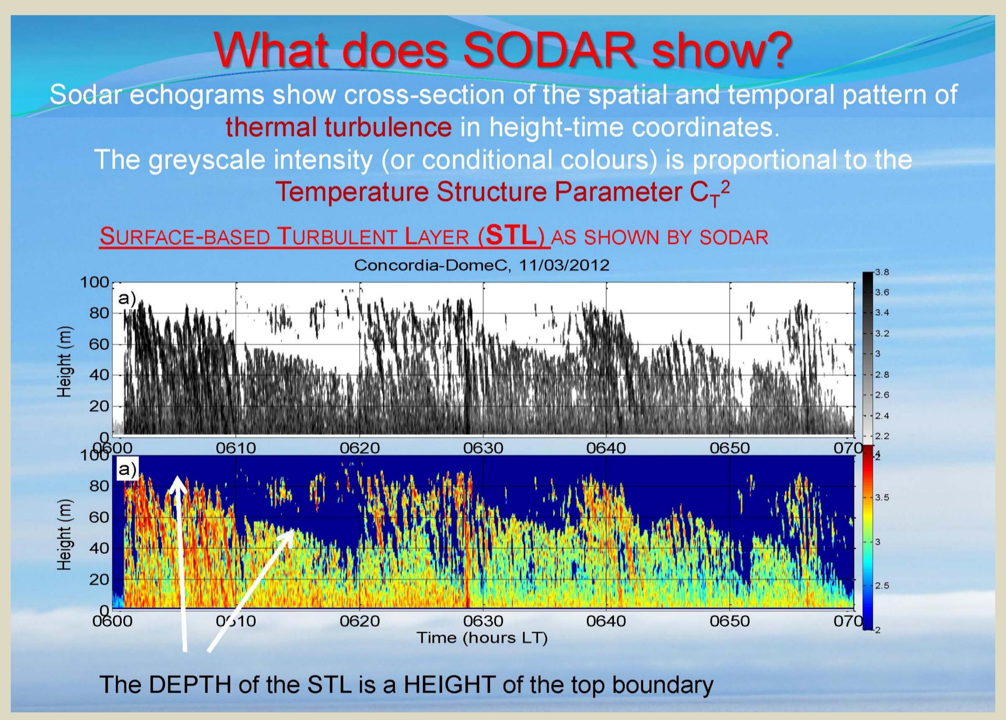
1. Horizontal HOMOGENEITY - NO OROGRAPHY influence (flat surface with a slope < 0.1%)
2. NO external HEAT sources (almost no Sun)
3. (almost) NO DIURNAL VARIATIONS
4. Periods of NO SYNOPTIC perturbations are considered

INSTRUMENTATION

High-resolution SODAR measures vertical profiles of the strength of thermal turbulence
from ≈2 m to 200 m with a step of <2 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 **thermoanemometer**
USA-1 produced by Metek
Height: 3.5 m
Sample rate: 10 Hz

2) Net **Radiometer**
CNR1 by Kipp & Zonen
Height: 1.5 m
Sampling rate: 1 minute^{-1}



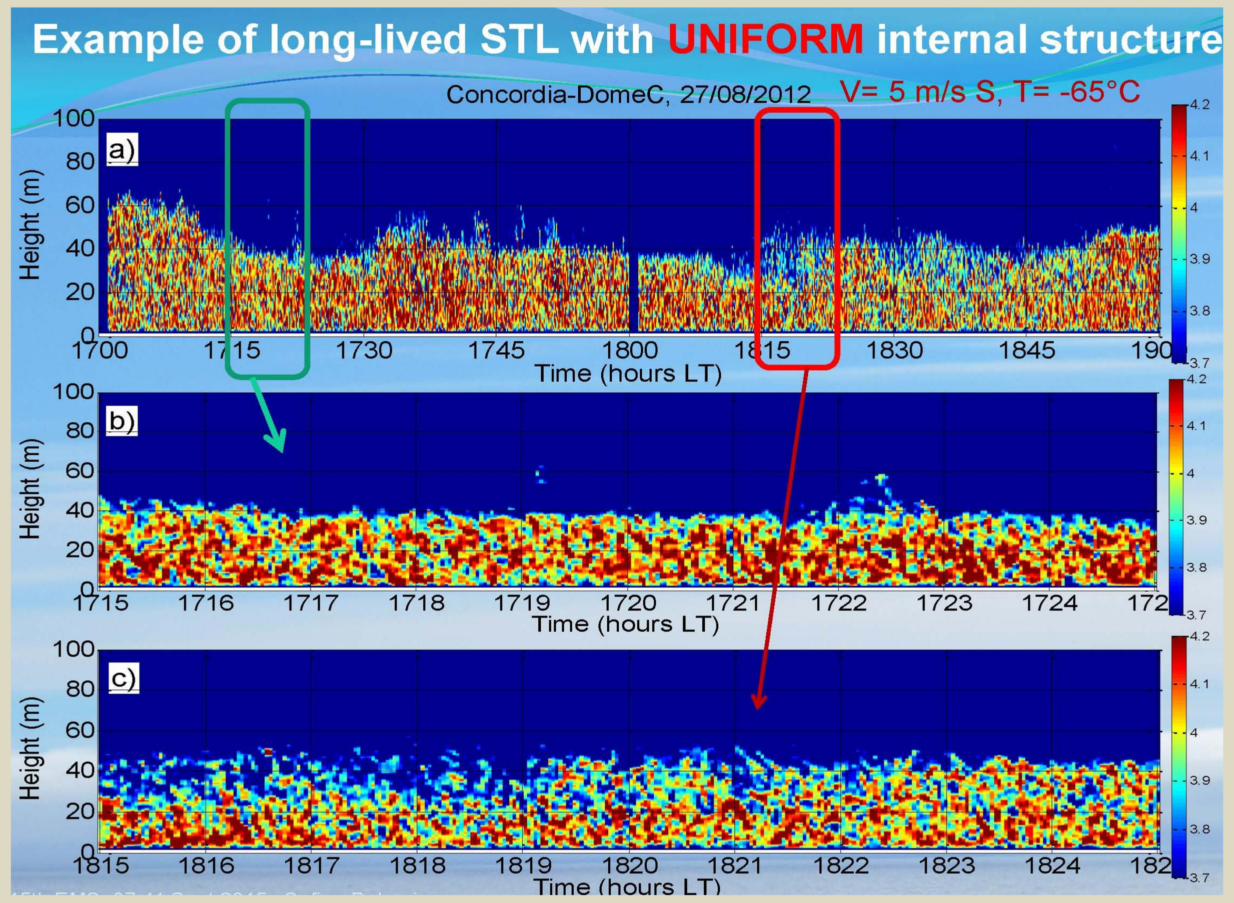
Smoke layer with undulation

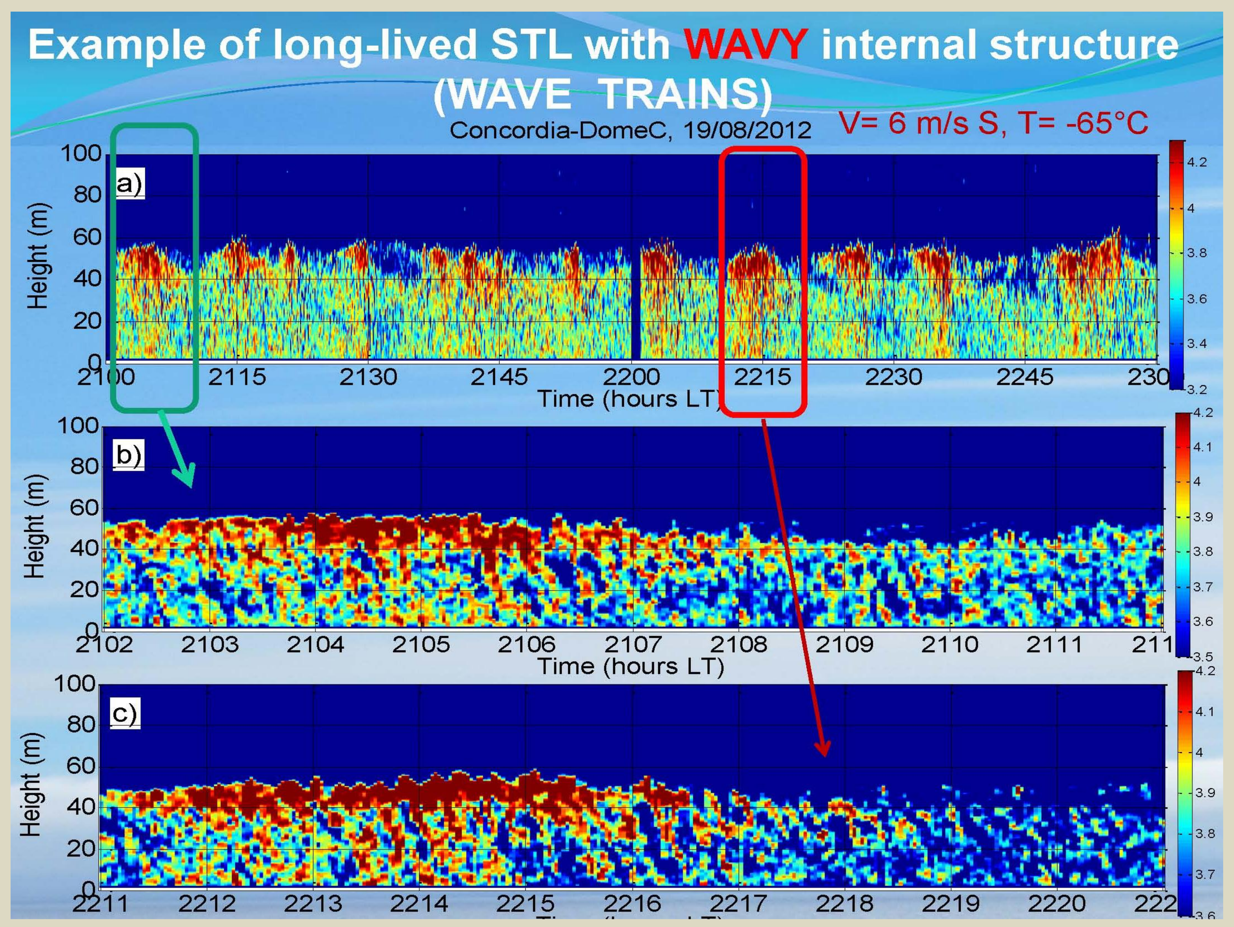
FEATURES OF TURBULENCE DURING THE WINTER AT DOME C:

In spite of
1) **the absence of the Sun and very low temperatures,**
2) **extremely high static stability and strong temperature inversion extending up to 100-300 m with a strength reaching 30-40 C,**
3) **the absence of orography features**
4) **relatively long periods of steady weather conditions,**

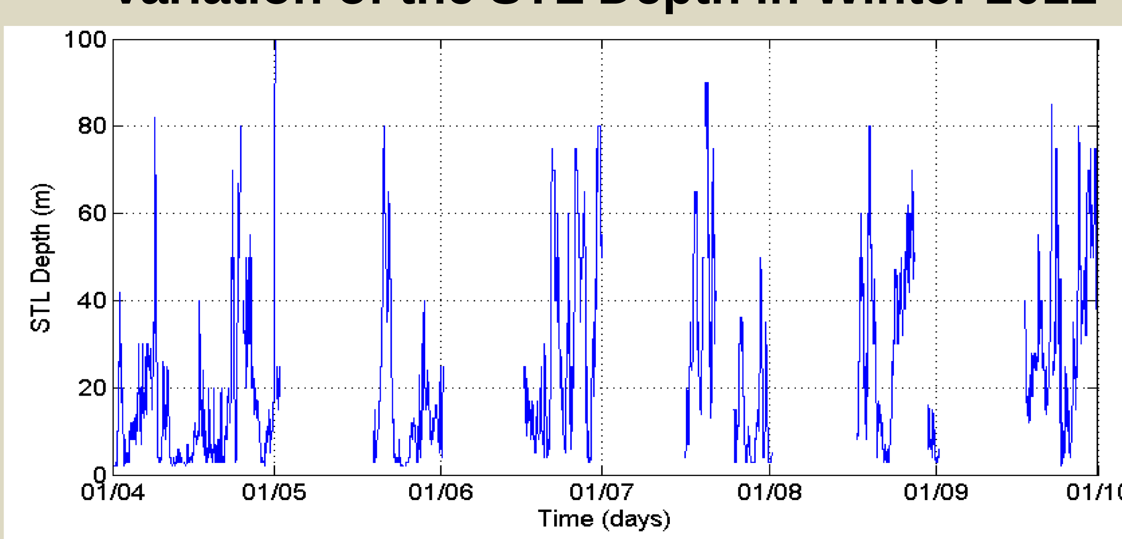
TURBULENCE is quite VIVID and LIVELY
and shows different and variable spatio-temporal structures

Typical spatial and temporal structure of the STL in winter-time at Dome C





Variation of the STL Depth in Winter 2012



Occurrence of STL Depth:

0-10 m	33%
10-30 m	37%
30-50 m	17%
> 50 m	13%

CLASSIFICATION of STL

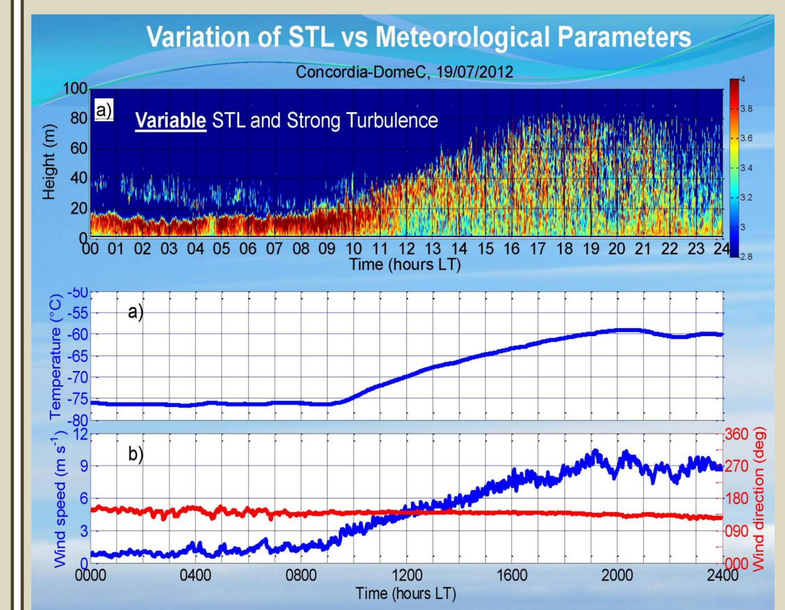
STL can be characterized by its DEPTH and INTERNAL STRUCTURE
The observed STLs can be subdivided into several groups according to their depth and internal structure.

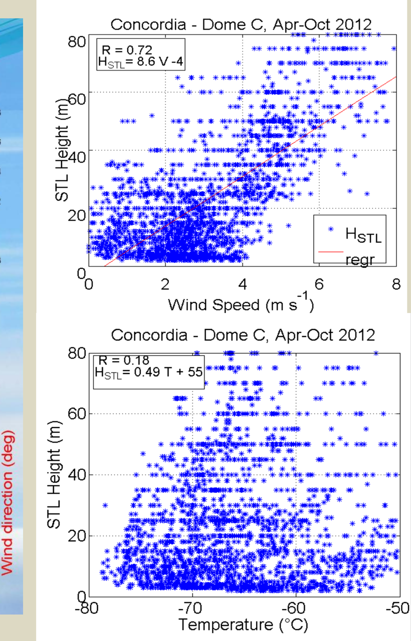
"Shallow" :
1) Depth <20 m without any visible regularity of the internal structure.
2) Depth <20 m with a wavy internal sub-layer.

"Deep" :
1) Depth of 20-60 m with uniform internal structure
2) Depth of 20-60 m with wavy internal structure of a braid form with periods of 60-300 s (Kelvin-Helmoholtz instability)
3) Depth of >60 m with wavy internal structure with periods of 60-120 s through the whole depth
4)* Depth of 30-60 m with periodical (of ≈10-12 minutes) alternation of wave trains (with internal periods of ≈20-30 s and duration of ≈4-5 minutes) and zones with uniform internal structure.

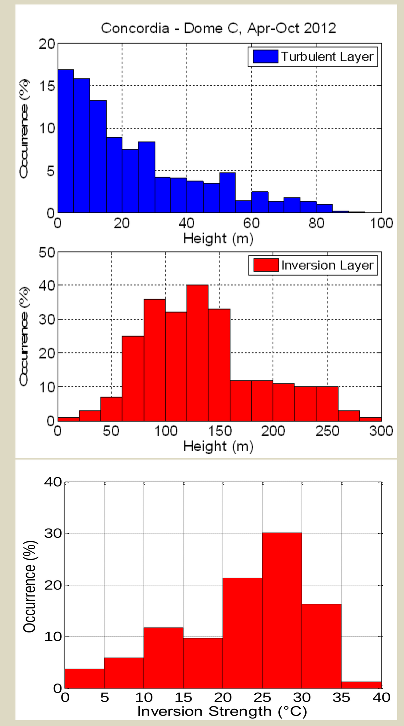
* This case is more complicate and often occurs.

STL Depth vs Wind Speed and Temperature





Depths of the Surface-based Turbulent Layer (from sodar) and of the Inversion Layer (from radiosonde)



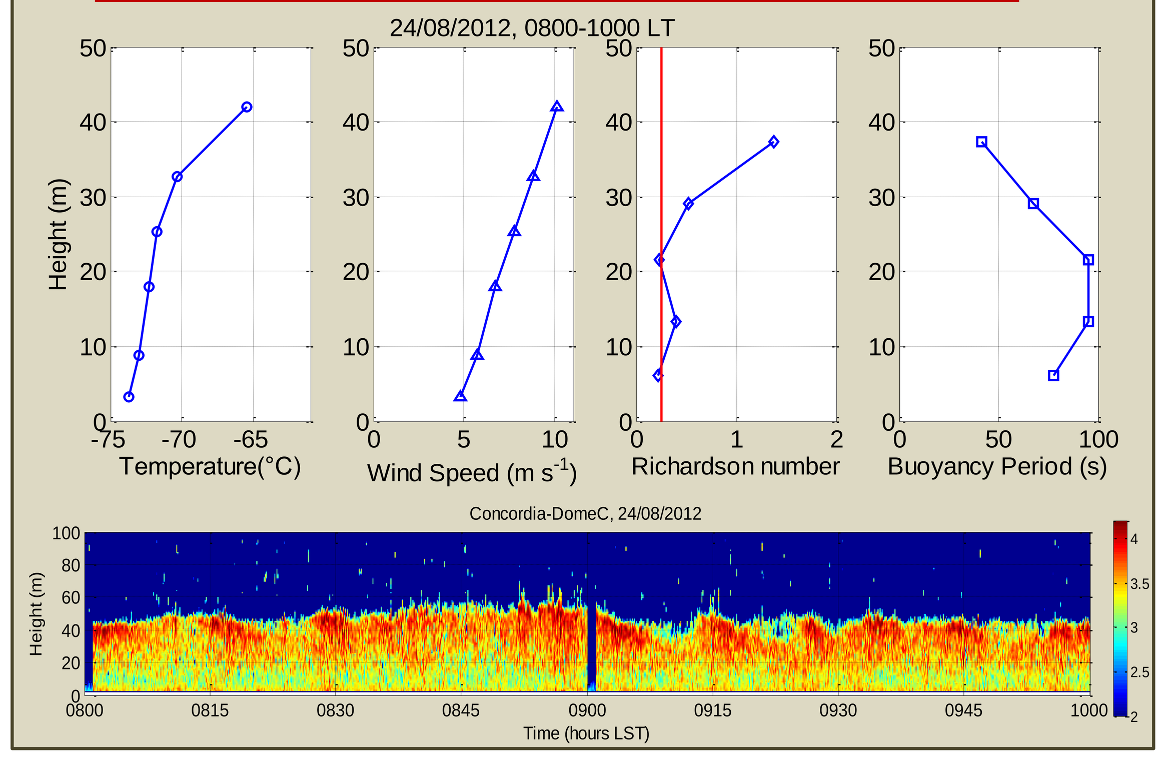
Surface-based Turbulent Layer occupies only the lowest 10-20% of the whole inversion layer.

This is the main difference between the turbulence in the **long-lived** stable boundary layer and the usual **nocturnal** inversion layer

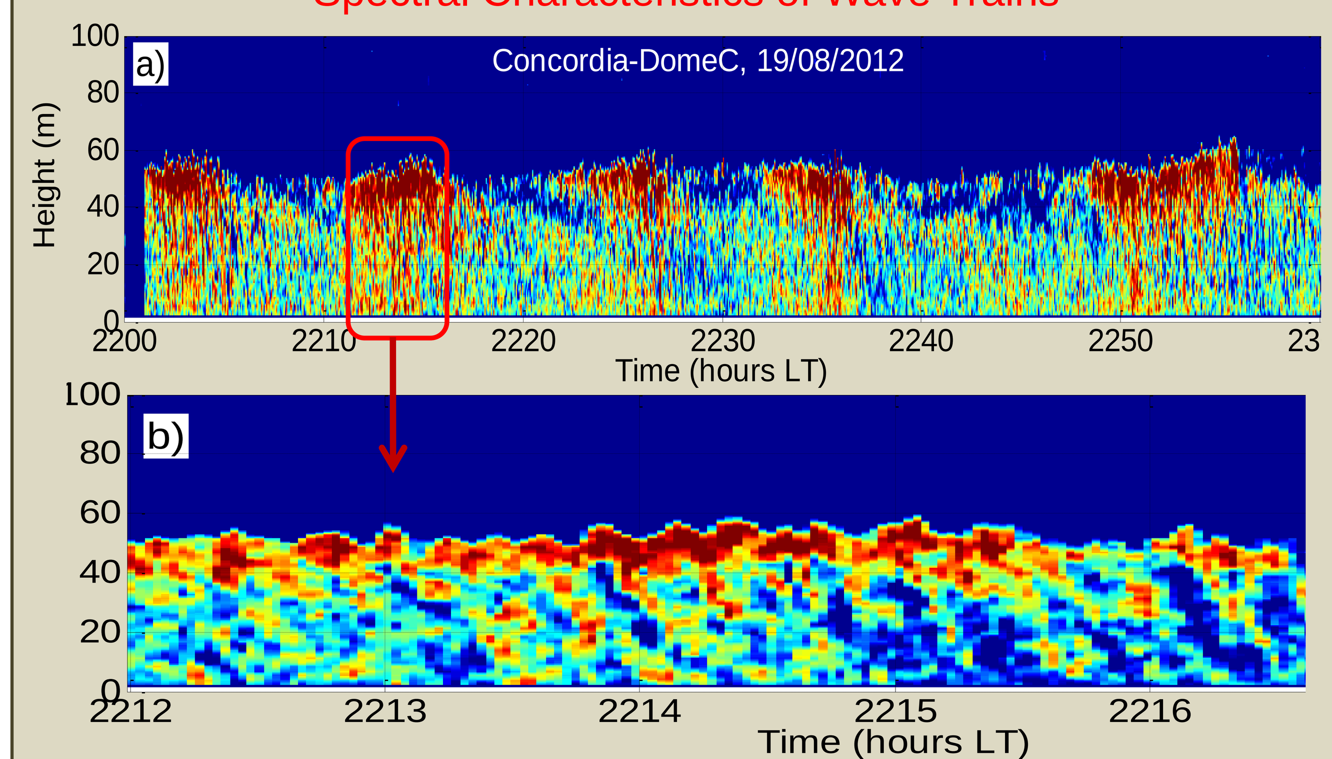
Heights of Surface Turbulent Layer and Inversion Layer averaged over Apr-Oct 2012

Heigth (m)	Mean (m)	Median (m)	Std (m)
Turbulent Layer	23	16	20
Inversion Layer	133	125	63

RICHARDSON NUMBER from TOWER DATA

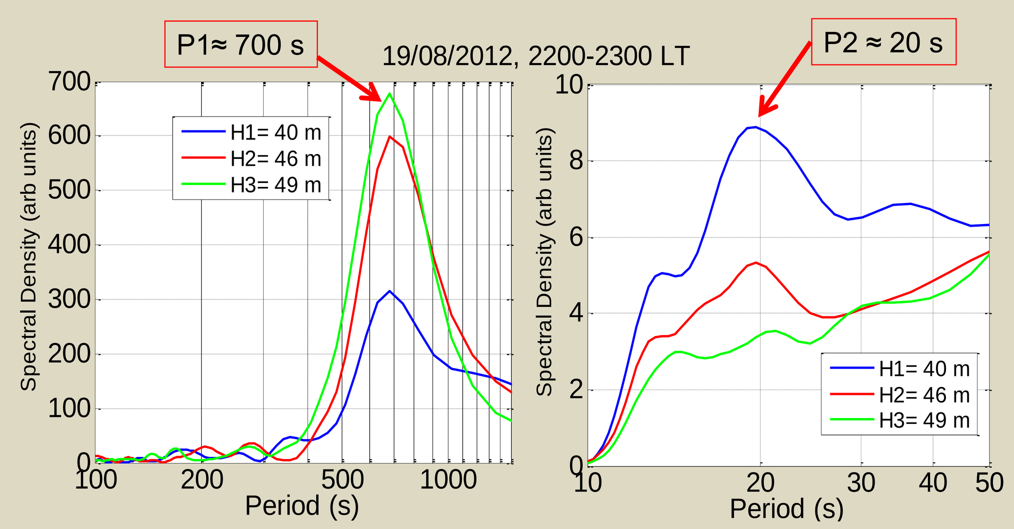


Spectral Characteristics of Wave Trains



Low-Frequency part
P1 is the period of **trains**

High-Frequency part
P2 is the period of **waves**



For the temperature gradient of 6.5°C/km measured by the radiosonde in the free atmosphere, the **buoyancy period ≈ 520 s**

CONCLUSIONS

In spite of the high static stability due to the strong temperature inversions, considerable thermal turbulence often occurs and extends up to several tens of metres forming the Surface-based Turbulent Layer (STL) at the Antarctic plateau during the austral winter.

Typical patterns of the spatial and temporal structure of turbulence observed using the advanced high-resolution sodar are presented and analyzed.

Statistics of the STL depth and the inversion height are presented. The STL occupies only the lowest 10-20% of the whole inversion layer.

The STL depth increases with **wind speed that** seems to be the most relevant variable influencing the structure and intensity of thermal turbulence in the polar STL under very stable stratification.

Distinct **wave activity** within the STL occurs during a large part of the time and can be assumed to be the main feature of the STL occurring under very stable stratification.

Richardson number within the STL estimated from temperature and wind speed gradients at 45-m tower shows values close to the critical one = 0.25 and sometimes exceed it.

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 inside the surface-based turbulent layer.

It is characterised with regular wavy fine-scale layers forming the braid pattern in the sodar echogram

The periods of the observed wavy structures range between 20 and 30 s. The horizontal thickness of individual wavy fine-scale layers was estimated to be of 30 to 50 m; their vertical thickness was of 3-5 m. The entire depth of the turbulent layer containing waves varied from 20 to 40 m. The observed undulations are not due to buoyancy, as the buoyancy (Brunt-Vaisala) periods being estimated from radiosonde are of 520 s.

The presented results call for the development of new theoretical approaches taking into account wave processes in the generation of turbulence. The challenging problem in atmospheric physics concerning the vertical transfer from the near-surface to the overlying atmosphere unlikely can be resolved without consideration of **wave processes**.

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