Boundary layer structure of fronts observed in Helsinki

Victoria A. Sinclair, Division of Atmospheric Sciences, Department of Physics, Helsinki
Leena Järvi, Division of Atmospheric Sciences, Department of Physics, Helsinki

HELSINGIN YLIOPISTO
HELSINGFORS UNIVERSITET
UNIVERSITY OF HELSINKI
MATEMAATTIS-LUONNONTIETEELLINEN TIEDEKUNTA
MATEMATISK-NATURVETENSKAPLIGA FAKULTETEN
FACULTY OF SCIENCE

Objective: Determine from observations what is the turbulent structure within the transition zone of synoptic-scale fronts

1. Introduction

Numerical modeling studies have shown that boundary-layer mixing modifies the structure of synoptic-scale fronts. However, few observations of either the vertical structure of synoptic-scale fronts in the boundary layer or the turbulent characteristics of frontal zones exist to validate modeling results against.

Fig.1. Location of Helsinki

Observations from within frontal zones over a six year period from Helsinki, Finland (25°E 60°N) are examined. Mast measurements of temperature and wind allow the vertical structure of fronts to be determined and turbulent kinetic energy (TKE) and turbulent dissipation rate (ε) quantify the extent of turbulence within frontal zones.

2. Motivation

Knowledge of TKE and ε can be used to verify and improve boundary-layer parameterization schemes in numerical weather prediction models.

It is unclear what physical processes control the minimum cross-front horizontal scale of synoptic-scale fronts. Blumen and Piper (1999) suggested that kinetic energy dissipation opposes frontogenesis and proposed a linear relationship between ε and frontal width but this relationship is yet to be verified.

3. Data and Methods

A 6-year climatology of synoptic fronts was manually created based on significant weather charts (SWC) and observations. SWCs are produced every 6 hours by forecasters at the Finnish Meteorological Institute. 10-minute observations of temperature and wind from multiple levels on the 327m tall Kivenlahti mast were analyzed and exact times of all fronts were determined. Composite warm and cold fronts were calculated by averaging all observed fronts (275 cold fronts, 208 warm fronts) and a frontal frequency climatology (not shown here) was created.

Eddy covariance data and standard meteorological measurements from the Station for Measuring Ecosystem-Atmosphere Relationships (SMEAR) III were analyzed. 1-minute averages of TKE and 10-minute averages of dissipation rate, calculated using the inertial dissipation technique, were analyzed for all cold fronts.

4. Turbulence in cold fronts versus non-frontal zones

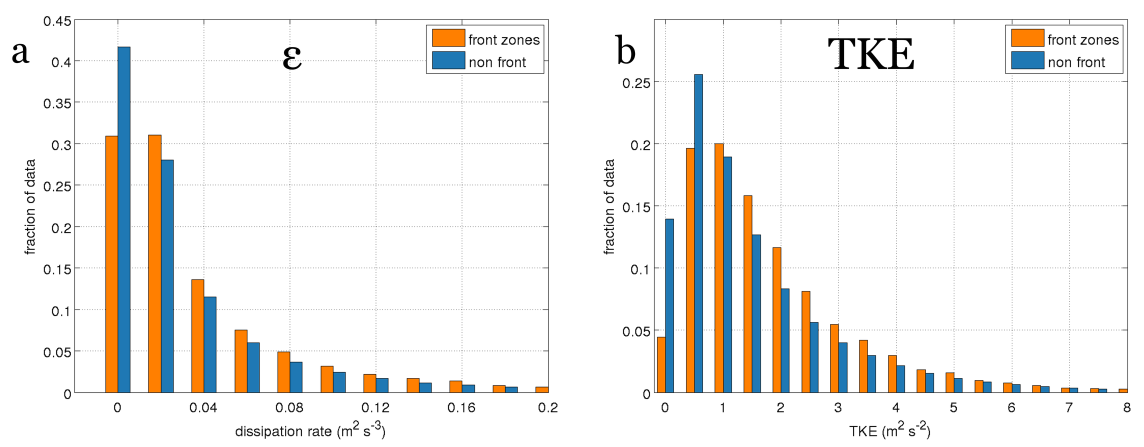

Fig.2. Histogram of (a) ε and (b) TKE for cold frontal zones and non-frontal zones. Histograms include 6 years of 10-minute averaged observations

5. Examples of cold fronts observed in Helsinki

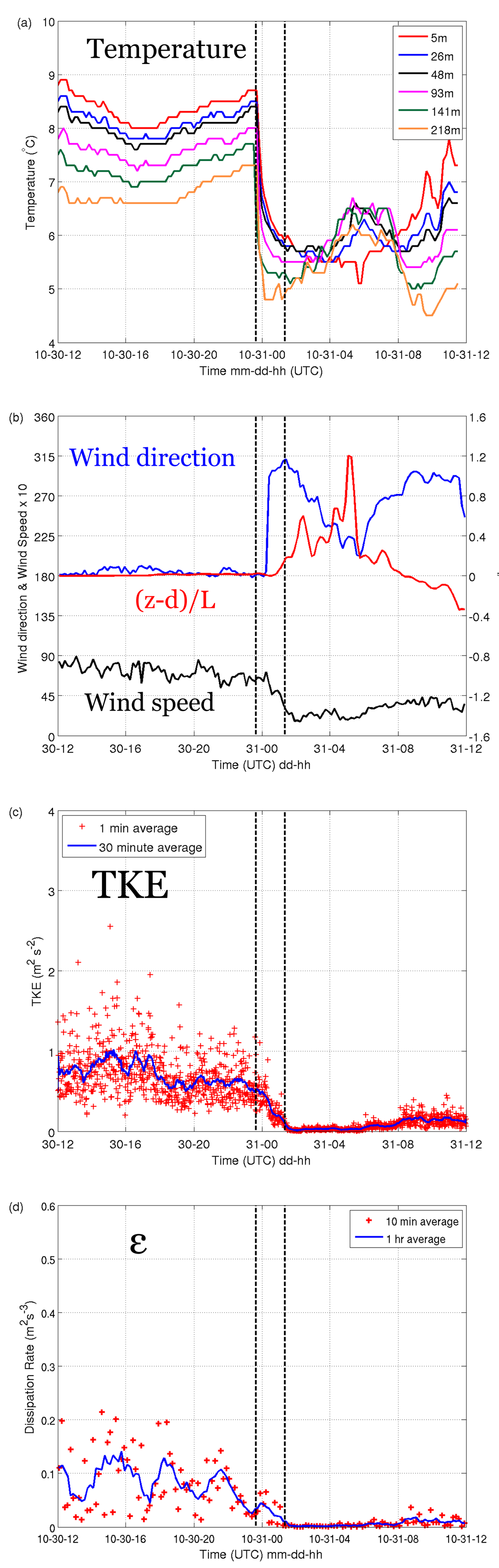

Fig.3. Observations of a cold front on 30 Oct 2007. (a) Temperature, (b) wind speed and direction and (z-d)/L, (c) TKE and (d) ε. Vertical dashed lines indicate the frontal zone

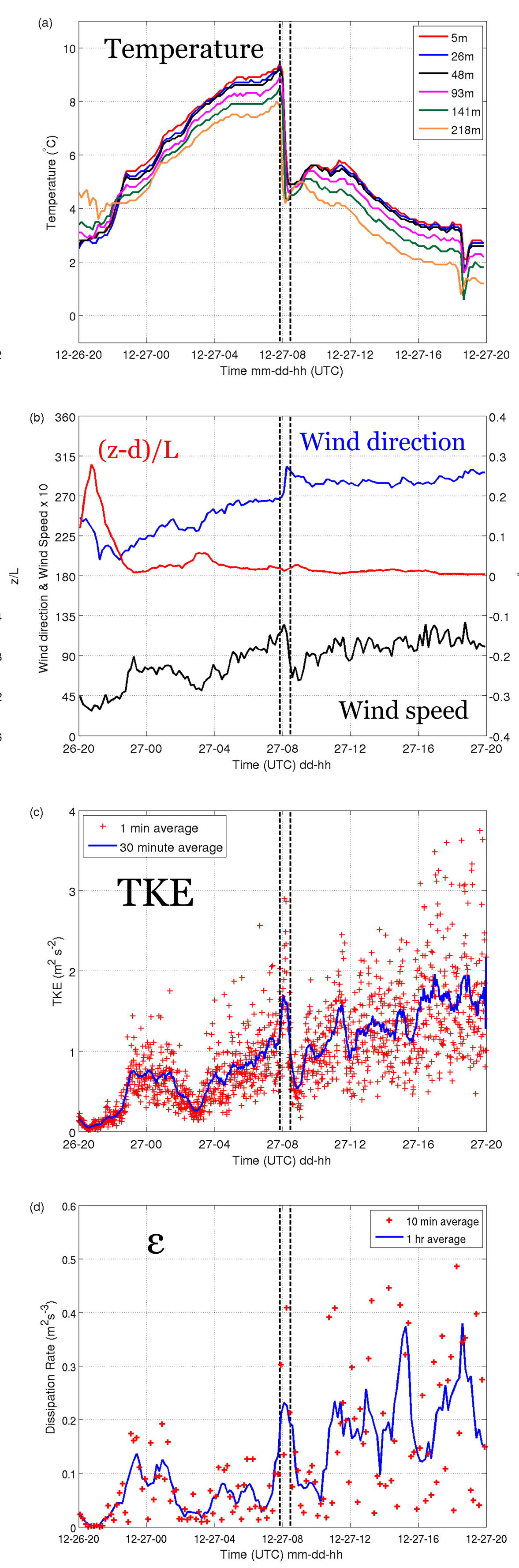

Fig.4. Same as Fig. 3 except for 27 Dec 2011

6. Composite of all (275) cold fronts

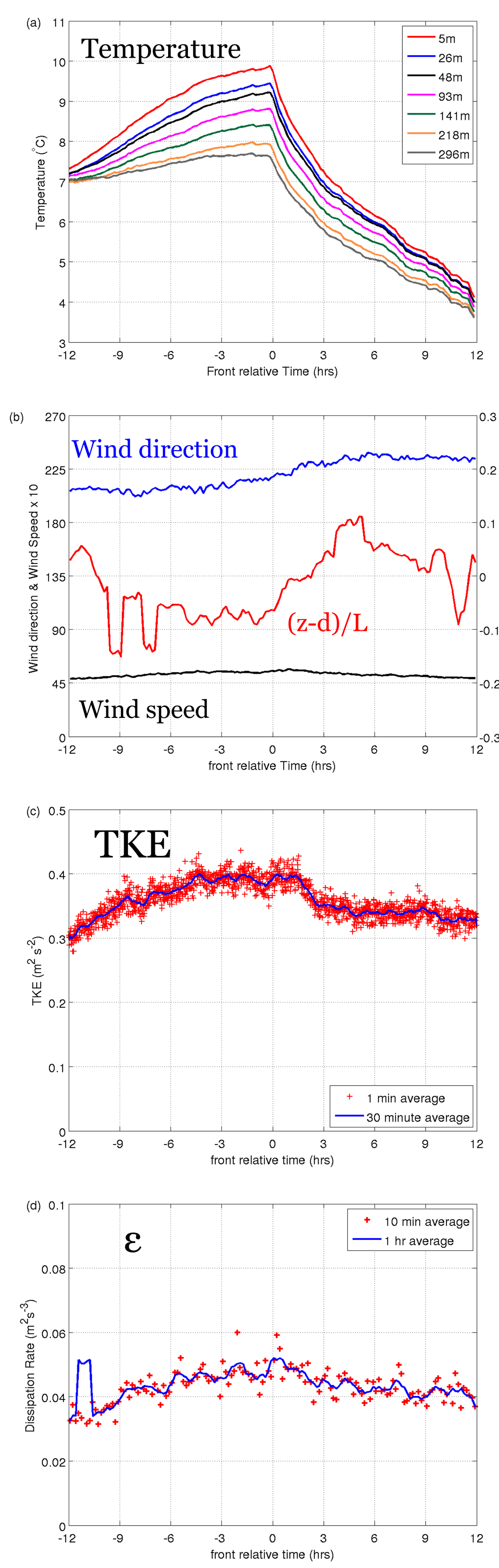

Fig.5. Same as Fig 3 except for a composite of all observed cold fronts. Note that scales on the y-axes differ to those in Figs. 3 and 4.

Cold fronts modify the stability of the surface layer and consequently the turbulent characteristics differ between the pre-frontal and post-frontal boundary layers.

Temperature observations of cold fronts reveal case-to-case variability in frontal width, temperature decrease and vertical structure.

TKE and ε in cold frontal zones display significant variability between different fronts.

In some cold fronts, ε was enhanced relative to the values both ahead of and behind the front, as was found by Piper and Lundquist (2004), but this feature does not appear in the composite cold front.

7. Stability effects

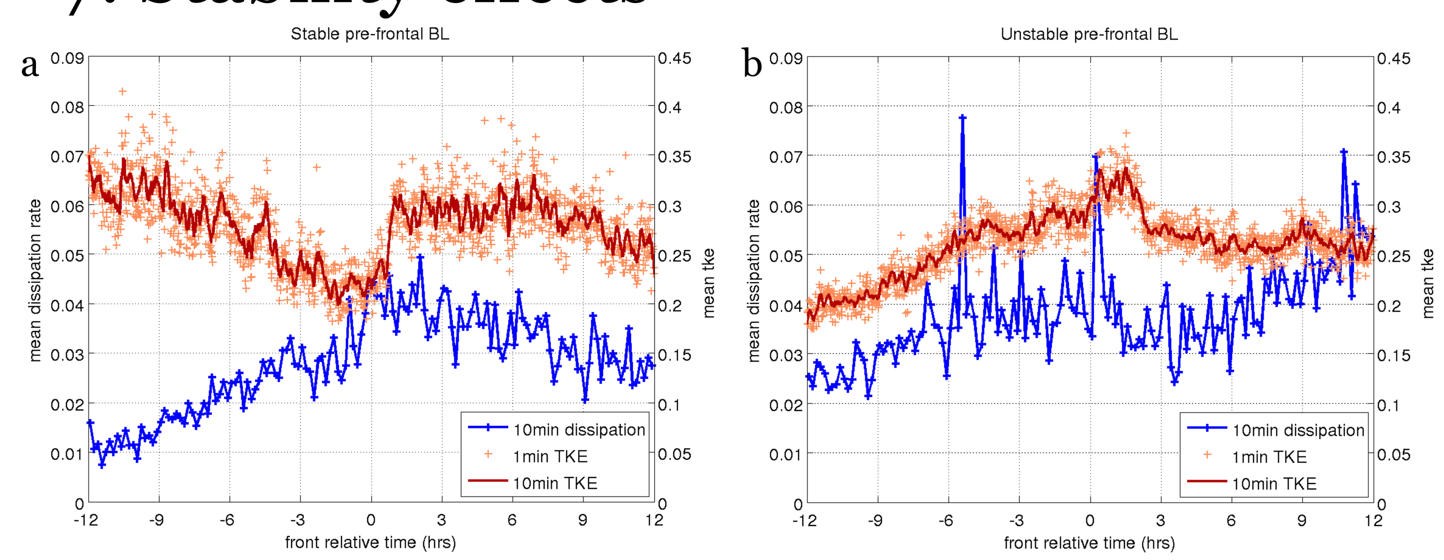

Fig.6. Composite of TKE and ε across cold fronts for fronts which had a (a) stable and (b) unstable pre-frontal boundary layer. Stability was determined by averaging (z-d)/L for the 3 hours before the front was observed. An average (z-d)/L>0.1 was classified as stable and (z-d)/L< -0.1 was classified as unstable.

When the pre-frontal BL is stable, cold fronts lead to a rapid increase in TKE but a much more gradual increase in ε.

When the pre-frontal BL is unstable, TKE increases slightly due to the cold front and has a pronounced maximum for 2-3 hours. ε has a short, sharp maximum co-located with the cold front.

8. Conclusions

I. On average, TKE and ε are larger in cold frontal zones than in non-frontal zones, but not all cold frontal zones have elevated TKE and ε.

II. TKE in frontal zones is high due to strong shear production of turbulence.

III. The composite cold front has a clear temperature signal but creating composites of TKE and ε does not work well due to the greater variability.

IV. Stability of the pre-frontal boundary layer and of the frontal zone strongly affect TKE and ε.

Please contact me:
Victoria.Sinclair@helsinki.fi
www.atm.helsinki.fi/~vsinclai

References

Blumen,W., and M. Piper, 1999: The frontal width problem. *J. Atmos. Sci.*, ***56*, *3167–3172*.**

Piper, M and Lundquist, J. K., 2004: Surface Layer Turbulence Measurements during a Frontal Passage, *J. Atmos. Sci.*, ***61* *1768–1780***

Acknowledgements

The work was funded by Finnish Academy grant 126853. We also acknowledge Pasi Aalto (University of Helsinki) for providing SMEAR III meteorological data, Ari Aaltonen (FMI) for providing the Kivenlahti mast observations and Eveliina Tuovinen (FMI) for providing the significant weather charts.