Surface layer simulations with WRF single-column model in stable nocturnal conditions

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Abstract

The numerical weather modelling of the planetary boundary layer is extremely challenging, especially in stable or near neutral stratification conditions. At night, when the turbulent motions are absent, the boundary layer processes are mostly determined by the surface fluxes. The surface fluxes and the boundary layer schemes are coupled by surface layer schemes. This coupling affects daily minimum temperature predictions throughout the year over continental, landlocked areas. We have a limited knowledge on surface layer and numerical weather prediction models cannot afford large-eddy-scale computations, therefore the estimations of exchange processes require simplifications. Similarity functions based on Monin–Obukhov similarity theory are usually used.

A series of multicopter, tethered balloon and flux measurements were made in southern Hungary over a 5-day-long period in the scope of the Pannonian Atmospheric Boundary Layer Experiment in 2015 (PABLS'15). The measurements were taking place over a flat, homogeneous area in the middle of the Pannonian Plain. The aim of the measurements was to analyse the night-time stable environment of the boundary and surface layer. These datasets were used as validation for our study and for determining the surface information, the soil and vegetation parameters. The WRF single column model is used to test different parameterization schemes. Simulated fluxes were tested against the continuous flux measurements. The model setup used 61 atmospheric vertical layers, where 22 layers are found in the lowest 200 meters. Altogether 26 combinations of available parameterizations were chosen and analysed. Results show that the different physical parametrizations' performance in the near-surface layer depends on the simulated meteorological variable. The vertical gradient of the temperature is captured, but the moisture flux is not. A cluster analysis on the errors also show that in case of 1st and 1.5 order closure schemes the choice of surface layer scheme results is small variances, but in case of 2nd order closure, the choice of surface layer parameterization is an important factor. Results also show that even with using the same soil and vegetation parameters the estimated Noah and Noah-MP surface schemes perform significantly different during daytime conditions.

Data

Validation data was measured within the PABLS'15 (Pannon Atmospheric Boundary Layer Experiment Szeged – 2015) research project near Szeged, Hungary in the summer of 2015.

Lower atmospheric soundings took place by three different instruments, OWL, BOU and ELTE. The soundings started from the ground (87 m) to about 150 m high above sea level. Flux measurements are also available from PABLS'15. The data for initialization is from the daily atmospheric radio soundings in Szeged and from the Global Forecast System.

PBL code	Planetary Boundary Layer (PBL) scheme	Closure order and type	Method
1	Yonsei University	1.0 non-local	K-profile
2	Mellor–Yamada–Janjić	1.5 local	TKE
3	NCEP Global Forecast System (GFS)	1.0 non-local	K-profile
4	Eddy-diffusivity Mass Flux QNSE	1.5 local	TKE
5	Level 2.5 Mellor–Yamada–Nakanishi–Niino	1.5 local	TKE
6	Level 3 Mellor–Yamada–Nakanishi–Niino	2.0 local	TKE
7	Asymmetrical Convective Model 2	1.0 local/non-local	K-profile
8	Bougeault–Lacarrère	1.5 local	TKE
9	University of Washington	1.5 local	TKE
11	Shin–Hong „scale-aware"	1.0 non-local	K-profile
12	Grenier–Bretherton–McCaa	1.5 local	TKE

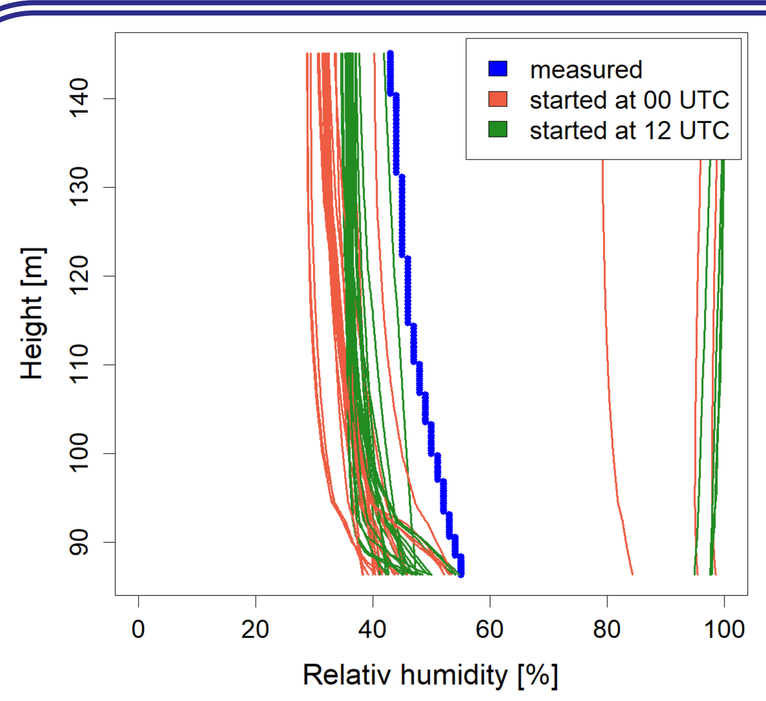
PBL/SFC			
1.	1/1	14.	7/1
2.	1/91	15.	7/7
3.	2/2	16.	7/91
4.	3/3	17.	8/1
5.	4/4	18.	8/2
6.	5/1	19.	8/91
7.	5/2	20.	9/1
8.	5/5	21.	9/2
9.	5/91	22.	9/91
10.	6/1	23.	11/1
11.	6/2	24.	11/91
12.	6/5	25.	12/1
13.	6/91	26.	12/91

Combinations of Planetary Boundary Layer Schemes and Surface Layer Schemes

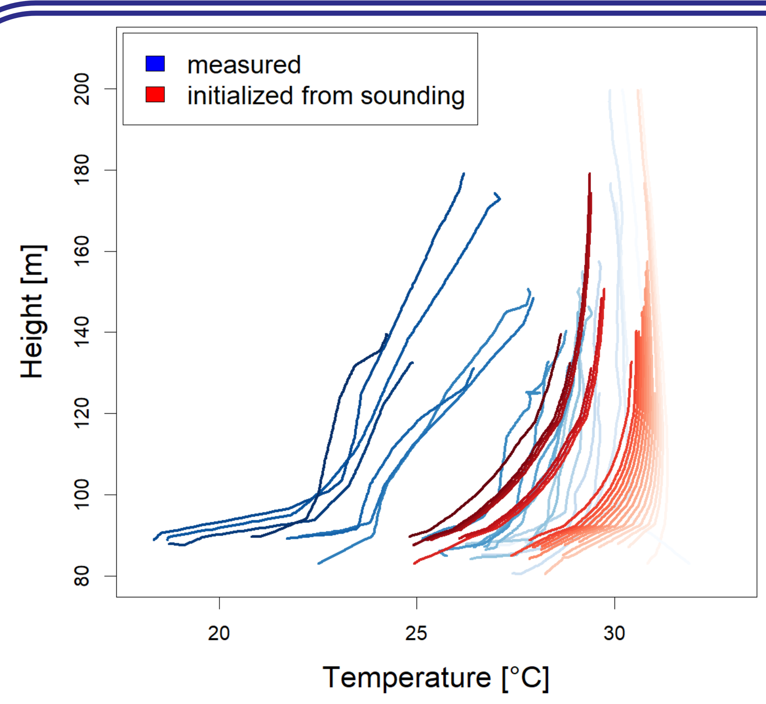
WRF Single Column Model

- Uses different modules and scripts, different results with different settings
- Useful for testing physics and parameterization schemes of the WRF model without the influence of the three-dimensional atmospheric dynamics
- Our settings:
  - 1 km horizontal resolution, 61 vertical levels, 30 s time step, 48 hours long forecast
  - 2 different initial value database (soundings and GFS), multiple launching times
  - 26 combinations of planetary boundary layer schemes and surface layer schemes (indicated with numbers)
  - unified Noah land surface model and Noah-Multiparametrization land surface model

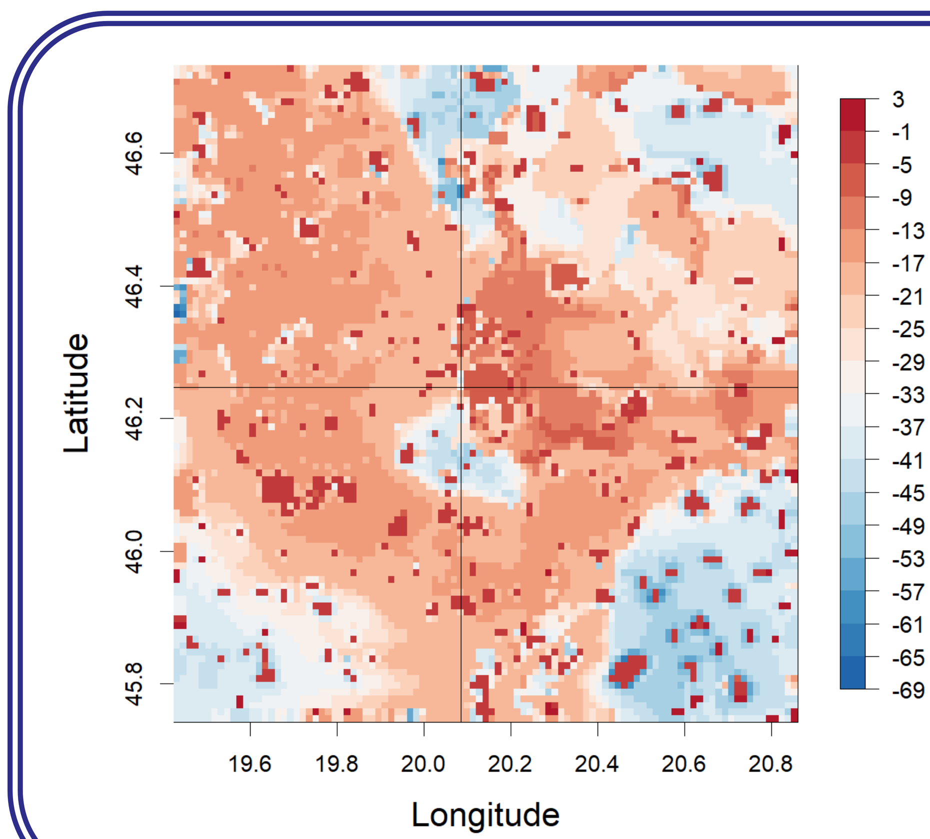
SFC code	Surface Layer (SFC) scheme
1	Revised MM5 Monin–Obukhov
2	Monin–Obukhov (Janjić)
3	NCEP Global Forecast System (GFS)
4	QNSE surface layer
5	Mellor–Yamada–Nakanishi–Niino
7	Pleim-Xiu
91	Old MM5



The relative humidity in the near-surface layer at July 16. 19.20 with radio sounding initial values, simulations started at two different times, 26 combinations



The temperature in the near-surface layer at night of July 16. with radio sounding initial values, simulations started at 12 UTC, 1. PBL/SFC combination, all measurements

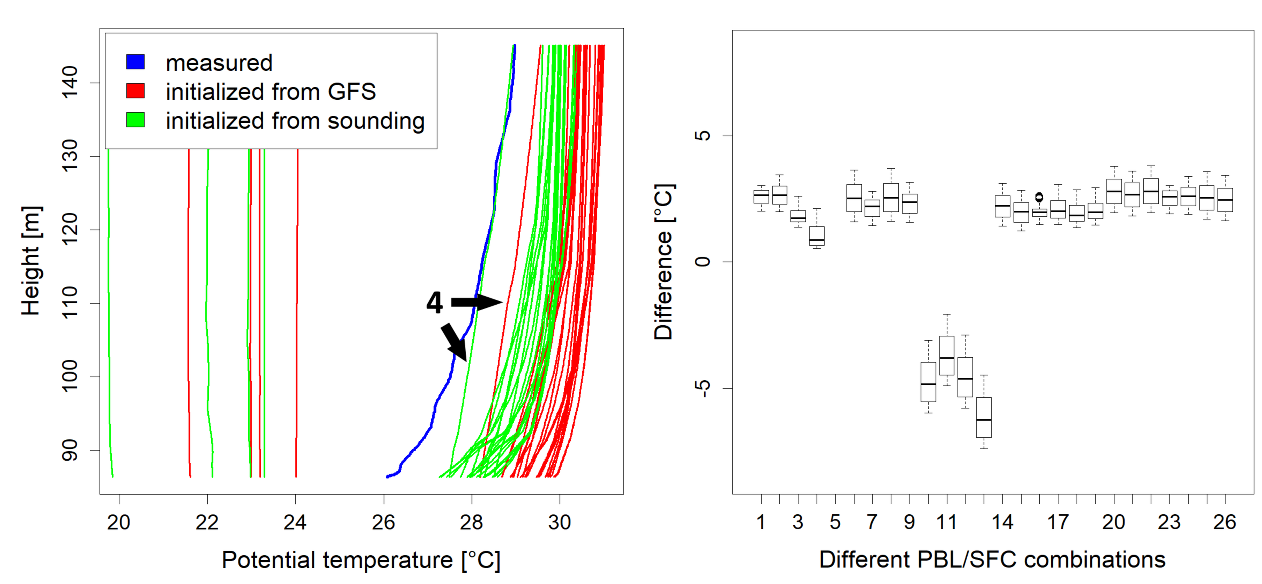


The sensible heat flux at July 16. 20.00 UTC with GFS initial values and the 4. PBL/SFC combination. The simulation was made with 3-dimensional WRF model. The grid distance is ≈ 1 km. The marked point shows the place of the measurements and vertical analysis. Sensible heat flux significantly depends on land cover and soil texture. Higher values show inhabited areas.

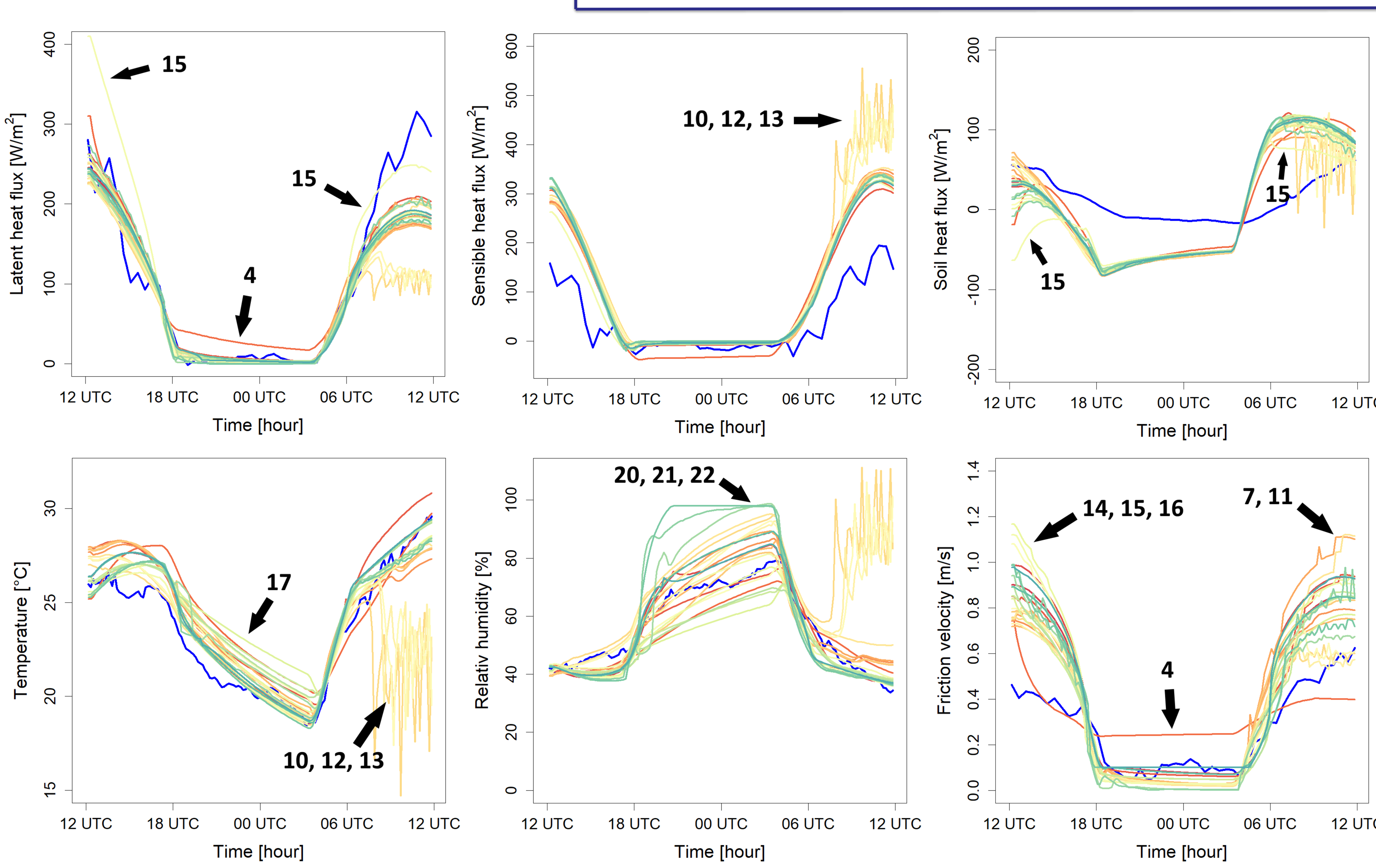
Validation

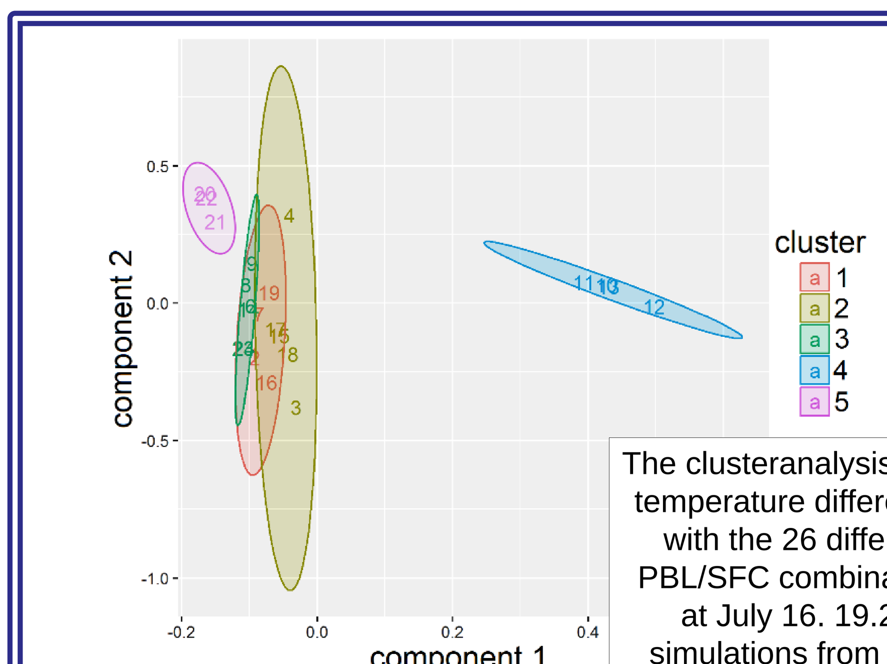
After simulations were made, prepared and interpolated, we validated the results with PABLS'15 data. We analysed the differences between different fluxes during 24 hours and the vertical profiles of meteorological variables in the low atmosphere. Vertical gradient and mean difference were also calculated.

The potential temperature in the near-surface layer at July 16. 19.20 and difference between measurements and simulations from GFS initial values, simulations started at 12 UTC



The changes of different fluxes, temperature and relative humidity between July 14. 12 UTC – July 15. 12 UTC, the initial values are from radio sounding, simulations started at 12 UTC, blue line shows the measurements





The clusteranalysis of the temperature differences with the 26 different PBL/SFC combinations at July 16. 19.20, simulations from GFS initial values started at 00 UTC

Clusteranalysis

The combinations with the same PBL schemes are contained in the same clusters after principal component analysis, except PBL scheme 6, where combination 11 usually belong to a different cluster.

Results

- The different physical parametrizations' performance in the near-surface layer depends on the simulated meteorological variable.
- The vertical gradients of the simulated variables are similar to the measured profiles, but differences between values are considerable.
- Different initial values and starting times have great effects on the results. There are greater differences in earlier started simulations.
- Choosing the planetary boundary layer scheme is a key point against choosing the surface layer scheme in forecast models.
- When using schemes with higher closure order (PBL scheme 6), the importance of surface layer scheme increases.
- The surface model's role is extremely important, especially when calculating evapotranspiration.
- Using the detailed settings of the single column model for 3-dimensional WRF model doesn't make such good results.