Field experiments and numerical simulations for investigating soil and planetary boundary layer interrelationships in Hungary – WRF case studies

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Abstract

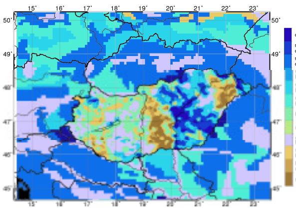
Partition of surface energy budget components is strongly dependent upon both soil moisture content and the soil hydraulic properties mainly via evapotranspiration. This partition determines the state of near surface air, therefore the turbulent transport of momentum, heat and moisture. The transported energy via turbulent mixing also considerably affects the planetary boundary layer (PBL) height.
In this study, two soil datasets were considered, both refer to Hungary. One is called MARTHA (Hungarian Detailed Soil Hydrophysical Database), in which the number of soil samples is 15 times higher than in the other, the HUNSODA (Unsaturated Soil Hydraulic Database of Hungary), though the spatial resolution is only five times denser. Because of the amount of soil samples the main hydraulic properties as the wilting point, the field capacity and the saturated soil moisture content significantly differ, which determine both the evapotranspiration and the PBL height. Simulations of the PBL height were conducted over the Carpathian basin on a 3 km horizontal resolution. The calculated PBL heights are compared to windprofiler and radiometric observations on a synoptic station in Hungary. In order to analyze in depth the soil/PBL height relationships on mesoscale, a 160 km x 160 km size nest was applied. The resolution of the one-way nest is 1 km with the center of the chosen synoptic station. Quantifying the relationships, a significance test which refers to the diurnal course of PBL height and latent heat flux was applied as well.

Model

- WRF-ARW v3.1 (Skamarock et al., 2008)
- Modeling features
  - resolution: 3 km mother domain, 1 km nest, 50 eta levels;
  - domain size: 235x211; 160x160 gridpoints;
  - simulation time step: 15 s, 5s;
  - strong wave propagation in nest => use of 6th order diffusion;
  - simulation time 18 hours, from 00 UTC;
  - no assimilation of measurements.
- parameterizations
  - RRTM (Mlawer et al., 1997);
  - Bougeault-Lacarrère (1989);
  - Thompson (2005);
  - Noah (Chen & Dudhia, 2001);
  - No cumulus parameterization.

Soil texture

- FAO (Food and Agriculture Organization) 12 type soil texture,
- in Hungary:
  – Digital Kreybig Soil Information System (Pásztor et al., 2010), 1:25000 resolution,
  – spatial interpolation of soil particle size distribution with FAO classification to 30" resolution grid used by the WRF model (Pásztor et al., 2011; Bakacsi et al., 2010).
- FAO-STATSGO distribution (5') in surrounding countries.



Soil texture distribution in the model area.

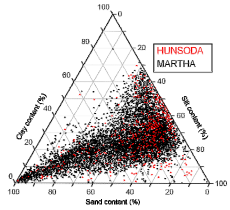
Soil database

HUNSODA: Nemes (2002), Várallyay (1980)
- 476 soil samples,
- one sample per soil horizon,
- soil moisture retention curves in the whole suction range (pF 0, 0.4, 1, 1.5, 2, 2.3, 2.7, 3.4, 4.2 and 6.1),
- samples only from plains.

MARTHA: Makó and Tóth (2008)
- ≈7500 soil samples, ≈2300 sample sites,
- samples from the whole country,
- soil moisture retention curves at least for standard pF values: 0, 2.5, 4.2 and 6.2.

Soil texture	b (2.7-5.3)	Θ_w [mm/m] (24-132)	Θ_f [mm/m] (225-427)	Θ_s [mm/m] (422-491)	$\Theta_f - \Theta_w$ [mm/m] (200-303)
sand	**-0.34**	**-5**	**-73**	**85**	**-68**
loamy sand	**-0.87**	**-48**	**-194**	**172**	**-146**
sandy loam	-0.57	-12	-42	37	-30
silt loam	-0.49	-2	-3	5	-1
silt	0.64	15	-54	29	-69
loam	-0.43	-13	-29	-1	-16
sandy clay loam	-0.27	18	6	-6	-12
silty clay loam	-0.67	-17	-31	21	-14
clay loam	**-0.42**	**-41**	**-86**	**114**	**-45**
sandy clay	0.17	34	17	85	-17
silty clay	**1.13**	**10**	**78**	**-34**	**68**
clay	-0.88	-13	-48	48	-35

HUNSODA – MARTHA differences in the main soil parameters (b – pore size index, Θ_s – saturated soil water content, Θ_f – field capacity, Θ_w – wilting point) (interval of MARTHA parameters in brackets).



Soil triangle of soil samples for HUNSODA and MARTHA.

Measurements

Measurement site

Vertical profiling measurements for this study were conducted at the observatory of the Hungarian Meteorological Service in Szeged (46.25572N, 20.09023E). The site is surrounded by agricultural cultivations (corn, barley), outside the city. During the measurement period (August 1-31, 2011), the precipitation was only 1.9 mm, 1/30 of climatic average.

Instruments

Radiometrics MP-3000A, ground-based microwave radiometer:

- continuous temperature, humidity, liquid water profiling to 10 km height,
- 21 calibrated channels in 22-30 GHz (K-band) and 14 in 51-59 GHz (V-band),
- sensors for surface temperature, relative humidity, and pressure.

Vaisala LAP®-3000, lower atmosphere wind profiler with radio acoustic sounding system (RASS):
- vertical profiles of horizontal wind speed and direction, and vertical wind velocity up to an altitude of 4 km,
- operating frequency: 915 MHz,
- time steps: every 15 minutes, the average of preceding 30 minutes,
- range resolution: ≈ 220m.

Estimation of PBL height

- Model: level of diminishing turbulence from turbulent kinetic energy, average of nearest 4 grid values to the measurement site;
- Windprofiler: height of maximum signal-to-noise ratio (SNR);
- Radiometer:
  - nighttime: level of disappearing inversion,
  - daytime: level of 0.4K/100m gradient in potential equivalent temperature.

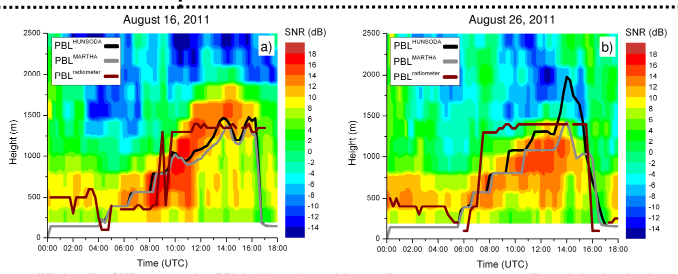
Measurement comparison

Radiometer:
- daytime temperature gradient close to dry adiabat during the measurement period,
- daytime PBL height variation is low,
- fast change to and forth inversion at dawn and sunset.

Windprofiler:
- change in wind direction with height is closer to level of negative SNR.

Model validation

- Model estimated heights show good correlation with PBL height measurements (SNR and $PBL^{radiometer}$),
- effect of soil parameters with synoptic conditions,
- $PBL^{HUNSODA} - PBL^{MARTHA} \approx$ 50 – 500m,
- overshooting with HUNSODA because of higher sensible heat flux,
- more stable stratification with MARTHA.



Windprofiler SNR compared to PBL height estimated form radiometer temperature profile and simulated using HUNSODA and MARTHA soil parameters on a) August 16, 2011, b) August 26, 2011.

Case studies

August 16, 2011:
- cold front passing the day before, high pressure system to the west,
- high and mid level clouds until midday,
- T_{min} = 16-19°C, T_{max}=25-30°C.

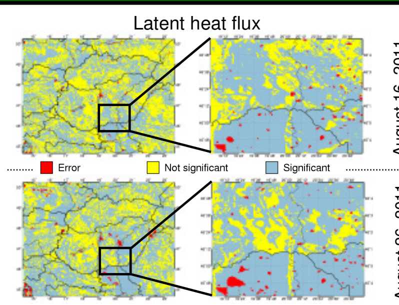
August 26, 2011:
- between anticyclone to the northeast and approaching cold front => strong southerly winds on lower levels,
- no clouds,
- T_{min} = 17-22°C, T_{max}=32-37°C.

Significance test

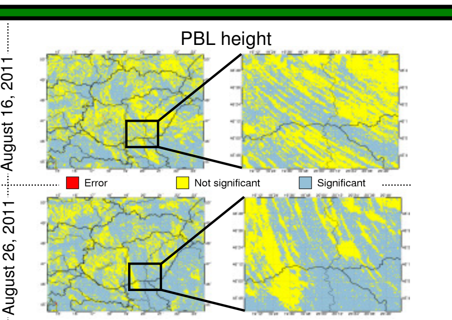
Diurnal change of PBL height and latent heat flux is an autoregressive stochastic periodic process in a statistical sense and depend mainly on the incoming radiation. In order to separate the effect of soil parameters in the diurnal courses, the natural diurnal course had been alienated from the simulated quantities with Fourier-series analysis. The significances were tested to p<0.01 probability. Errors are found where the simulated PBL height has low daytime change.

Latent heat flux:
- highly dependent on soil texture and land use,
- over cities the PBL height doesn't have a diurnal course => errors in significance calculations,
- nest results correspond to mother domain.

PBL height:
- spatial distribution of change in PBL height show little correlation to latent heat flux change => differences in surface heat flux is transported,
- nest show microstructures of flow,
- daytime PBL height differences vary from 10 – 500 m, ≈ 150 m on average.



Spatial distribution of significant (p<0.01) PBL height differences using soil hydraulic parameters determined from different soil databases.



Spatial distribution of significant (p<0.01) PBL height differences using soil hydraulic parameters determined from different soil databases.

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