Planetary boundary layer height sensitivity to soil hydraulic parameters: MM5 simulations

Hajnalka Breuer[a*], Ferenc Ács[a], **Borbála Laza[a]**, Ákos Horváth[b],
István Matyasovszky[a], Tamás Weidinger[a], Kálmán Rajkai[c]

[a] Department of Meteorology, Eötvös Loránd University, Pázmány Péter sétány 1/a., H-1117 Budapest, Hungary
[b] Hungarian Meteorological Service, Vitorlás u. 17., H-8600 Siófok, Hungary
[c] Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences, Budapest, Hungary

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Introduction

In our study, we examine the relationship between the planetary boundary layer (PBL) and the soil hydraulic properties by using MM5 weather prediction system. The simulations were performed on six days using a horizontal resolution of 6 km. The days were in summer, fall and winter when weak convection was prevailing with almost no cloud formation. In the simulations two soil databases were used: one global, the USDA (United States Department of Agriculture), and one regional, the Hungarian HUNSODA (Unsaturated Soil Hydraulic Database of Hungary) (Nemes, 2002; Várallyay, 1980) (Fig. 1). Soil hydraulic parameter differences between the two datasets cause differences in evaporation and temperature of the surface. These differences can be sensed in a more or less unstable atmosphere, in the upper PBL layers due to turbulent mixing.

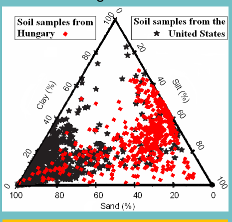

Fig. 1: Distribution of soil samples across the soil textural triangle.

Soil Texture	Θ_s (m³/m³)	Θ_f (m³/m³)	Θ_w (m³/m³)	Ψ_s (m)	b	K_s (m/s)
Loamy Sand	0.598	0.479	0.080	0.126	3.900	2.52E-05
Sandy Loam	0.476	0.379	0.064	0.143	3.990	1.14E-05
Loam	0.468	0.406	0.088	0.207	4.200	4.58E-06
Sandy Clay Loam	0.439	0.354	0.061	0.206	4.210	7.98E-06
Clay Loam	0.580	0.479	0.139	0.234	4.740	3.05E-06
Clay	0.541	0.489	0.147	0.224	6.210	8.00E-07

Soil Texture	Θ_s (m³/m³)	Θ_f (m³/m³)	Θ_w (m³/m³)	Ψ_s (m)	b	K_s (m/s)
Loamy Sand	0.421	0.383	0.028	0.036	4.26	1.41E-05
Sandy Loam	0.434	0.383	0.047	0.141	4.74	5.23E-06
Loam	0.439	0.329	0.066	0.355	5.25	3.38E-06
Sandy Clay Loam	0.404	0.314	0.067	0.135	6.66	4.45E-06
Clay Loam	0.465	0.382	0.103	0.263	8.17	2.45E-06
Clay	0.468	0.412	0.138	0.468	11.55	9.74E-07

Table 1: Used soil hydraulic parameters derived from HUNSODA and USDA (Θ_s – saturated soil water content, Θ_f – field capacity, Θ_w – wilting point, Ψ_s – saturated soil water retention, b – pore size index, K_s – saturated hydraulic conductivity).

Soil properties

The degree of the soil samples texture which were taken into account and the differences in the definition of the soil textural classes cause differences in the soil parameter values.

Main differences in soil database:

- Number of soil samples: ≈ 1400 USDA, 470 HUNSODA,
- sand-silt-clay content of samples: 78-10-12% USDA, 38-42-20% HUNSODA.

Main differences in soil parameters:

- Porosity index: half in HUNSODA for clayey soils compared to USDA;
- available soil moisture content: $(\Theta_f-\Theta_w)^{HUNSODA} > (\Theta_f-\Theta_w)^{USDA}$ => HUNSODA defined soils are drier,
- clay texture differs in the highest degree in soil.

Model

MM5 v3 non-hydrostatic
Resolution: 6 km horizontal, 27 vertical levels (9 in the planetary boundary layer (PBL))
Time step: 18 s
Simulation time: 24 hours, from 00-24 UTC
Parameterizations:
- Cumulus – Grell (Grell, 1994),
- PBL – **Eta** (Janjic, 1990, 1994)/ **MRF** (Hong & Pan, 1996)
- Microphysics – Reisner (Reisner et al., 1998),
- Radiation – RRTM (Mlawer et al., 1997),
- Land-surface – Noah (Chen & Dudhia, 2001).

Initial and boundary conditions: ECMWF MARS (**E**uropean **C**entre for **M**edium-**R**ange **W**eather **F**orecasts's **M**eteorological **A**rchive and **R**etrieval **S**ystem) data base, with 0.25° horizontal resolution; updated hourly.

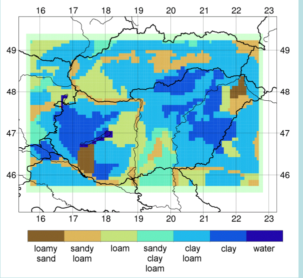

Fig. 2.: Soil texture distribution in the model domain.

Days	Weather conditions	Tmax (°C)	Tmin (°C)	Cloud	Rain	Sunshine [hrs.]
19.07.2006	anticyclone to the west	34	11	Ci	-	13-15
12.09.2006	anticyclone to the east	27	5	-	-	10-12
10.10.2006	anticyclone to the west	23	1	Fog	<1mm	10
15.01.2007	anticyclone to the west	13	-9	Ci, Fog	-	7-8
18.07.2007	pre-cold frontal	41	14	-	-	13-15
26.07.2007	anticyclone to the west	31	7	-	-	10-15

Table 2.: Summarized weather conditions of the case studies.

Case studies

- 6 days: 3 in summer, 2 in autumn, 1 in winter
- Typical weather condition: weak convection, almost no cloud formation
  - Height of PBL depends on: sensible heat flux, lapse rate of the morning residual layer, wind shear (Santanello et al., 2005)
  - Sensible heat flux depends on incoming solar radiation and land surface properties
  - Analyzing the effect of soil parameters to PBL height, requires clear sky weather situation

Methods – Significance test

The differences in PBL height evolution are treated by a significance test which takes into account the stochastic properties and the typical diurnal evolution of the PBL.

1.) Determination with Fourier series for the two cases (HU, US)
a.) the expected values
b.) the deviation
c.) the standardized values of the PBL height
d.) deviation of the difference of PBL height and expected PBL height (g(t))

2.) Determination of the autocorrelation coefficient (α),

$$\alpha=\frac{\sum_{t=2}^{T}\left[(Z_t-\overline{Z})\cdot(Z_{t-1}-\overline{Z})\right]}{\sum_{t=2}^{T}(Z_{t-1}-\overline{Z})^2}$$

where $\overline{Z}$ is the average of the expected values.

3.) Null hypothesis: no difference between two PBL height values (HU, US).

4.) Calculating of
a.) the expected variance (s^2):

$$s^2=\frac{1}{T}\sum_{t=1}^{T}(Z_t-\overline{Z})^2$$

b.) the standardized value of difference of PBL heights (Z_t^*):

$$Z_t^*=\frac{HU_t-US_t}{g(t)}$$
;

where T is the count of time steps.

5.) Examination of the P_t statistic:

$$P_t=\frac{\overline{Z^*}}{\sqrt{\frac{1+\alpha}{1-\alpha}\cdot\frac{s^2}{T}}}$$

6.) 4 significance level (P<0,1; 0,05; 0,01; 0,001).

Methods - Mixing diagram

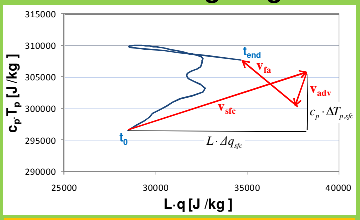

Fig. 3.: Diurnal evolution of 2m-potential temperature (c_pT_p) and 2m-humidity (Lq) on 18.07.2007. using Eta PBL scheme and HU soil parameters between 5:00 and 17:00 UTC.

- „Mixing diagram": special analysis method described by Betts et al. (1984, 1992).
- The evaluation of sensible and latent heat flux (2m potential temperature, 2m humidity) can be used to examine the land-atmosphere interactions, so the effect of soil on the PBL evolution.
- 2m potential temperature (T_p) and 2m humidity (q) are the most capable variables: they are easy to measure and model, as well as provide information about processes at the top of the PBL.
- From sunrise (t_0) to sunset (t_{end}) the course of 2m T_p and q is represented (blue curve).
- The tendency of an arbitrary variable (ξ) in the PBL (T_p, q) can be described (Betts et al., 1992):

$$\frac{\partial\langle\overline{\xi}\rangle}{\partial t}=-\underbrace{\left(\langle\overline{u}\frac{\partial\overline{\xi}}{\partial x}\rangle+\langle\overline{v}\frac{\partial\overline{\xi}}{\partial y}\rangle\right)}_{\text{advection}}+\frac{1}{\langle\overline{\rho}\rangle Z_i}\left[\underbrace{\overline{\rho}\,\overline{w'\xi_s'}}_{\text{surface}}-\underbrace{\left(\overline{\rho}\,\overline{w'\xi_i'}+\overline{\rho}\cdot\left(\frac{\partial Z_i}{\partial t}-w_i\right)\cdot\left(\overline{\xi}_i-\langle\overline{\xi}\rangle\right)\right)}_{\text{entrainment}}\right]$$

(u, v, w: wind vectors, Z_i: PBL height, i: level of entrainment, s: surface)

- Surface by Santanello (2009):

$$c_p\cdot\Delta T_p=\frac{\overline{H}\cdot\Delta t}{\overline{\rho}_m\cdot\overline{PBL}} \qquad L\cdot\Delta q=\frac{\overline{LE}\cdot\Delta t}{\overline{\rho}_m\cdot\overline{PBL}}$$

($\overline{H}$: average sensible heat, Δt: elapsed time, $\overline{\rho}_m$: average air density in the PBL, $\overline{PBL}$: average PBL height, $\overline{LE}$: average latent heat)

- Advection: from the model
- Entrainment: residual term

There are 3 vectors on the diagram to represent these terms: the effect of surface (v_{sfc}), the advection (v_{adv}) and the entrainment (v_{ent}) to the PBL evolution.

Results – Mixing diagram

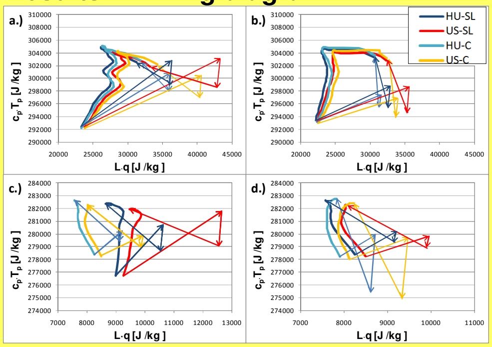

Fig. 4.: Diurnal evolution of 2m-potential temperature (c_pT_p) and 2m-humidity (Lq) for two soil types (SL: sandy loam, C: clay) on a.) 19.07. 2006 using Eta PBL, b.) 19.07.2006 using MRF c.) 15.01.2007 using Eta PBL d.) 15.01.2007 using MRF scheme.

- Every day and run shows
  - drier soil by HU parameters.
  - less q and more T_p fluctuation in HU cases.
- Summer days: from sunrise q and T_p is increasing until midday, followed by a decrease in q, which after 15 UTC is rising again while T_p is decreasing with both schemes.
- Winter day: diurnal course from 8:00 to 13:00 UTC shows during the day decreasing q and increasing T_p except for sandy loam using Eta PBL scheme (HU, US).
- Surface flux dominates above sandy loam.
- Advection's role is more pronounced above sandy loam on 19.07.2006, while at winter day using MRF scheme shows the opposite.

Results – Significance test

Results show that:

- the sensitivity of PBL height to soil parameters is significant (p<0.01) in most cases,
- more significant cases with MRF respect to the Eta PBL scheme,
- there are three areas where the number of significant days are less than the average.

- (between 1-4 by Eta PBL and 3-5 by MRF scheme), caused by small soil parameter differences,
- relative PBL height difference averaged for 6 days is around 10-15% (not shown) for MRF and Eta schemes.

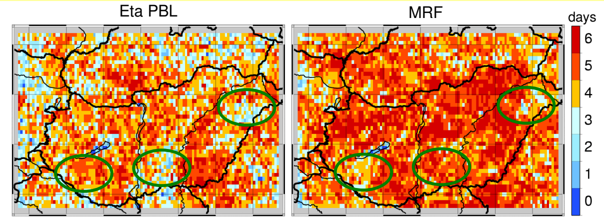

Fig. 5.: The sensitivity of PBL height to soil parameters for the 6 analyzed days using a.) Eta PBL b.) MRF scheme.

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NEW SZÉCHENYI PLAN

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***Corresponding author: Hajnalka Breuer, bhajni@nimbus.elte.hu**