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Sensitivity of local convective precipitation to parameterization of the field capacity and wilting point soil moisture contents

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Abstract — Sensitivity of local convective precipitation to parameterization of the field capacity (θ_f) and wilting point (θ_w) soil moisture contents was analyzed. The analysis was performed using simulation results of the Penn State – NCAR MM5 Modeling System obtained on nine days in 2006 and 2007. 24-hour accumulated precipitation fields over the territory of Hungary were considered. Precipitation fields were statistically analyzed. The observed fields were obtained from rain gage data applying a kriging interpolation technique. The agreement between simulated and observed fields was estimated using categorical and continuous verification indices. Significance tests were done to estimate how large (important) or small the obtained differences were.

The main results are as follows. In average, 20 percent relative differences in the θ_f resulted in about 5 – 10 percent relative differences in the true skill statistic (*TSS*) categorical verification index. In several cases these *TSS* differences are significant on the 10% level. Similarly, in average, 50 percent relative differences in the θ_w resulted in about 10 – 50 percent relative differences in the *TSS*. These *TSS* differences were significant on the 10% level on eight from the nine days.

The results obtained can be useful in quantifying the strength of the soil moisture – precipitation feedback mechanisms.

Key-words: convective precipitation, field capacity, wilting point, MM5 modeling system, Hungary, true skill statistic categorical verification index, significance test

1. Introduction

The impact of biophysical mechanisms on atmospheric processes is revealed by *Charney* (1975). Since then an array of different sensitivity studies was performed to show the type and rate of the land-surface-atmosphere interaction processes (e.g., *Wolker* and *Rowntree*, 1977; *Deardorff*, 1978; *Shukla* and *Mintz*, 1982; *Sud et al.*, 1988; *Xue*, 1997; *Betts*, 2001; *Betts* and *Viterbo*, 2005). Recently, there are serious efforts not only to explain, but also to quantify the strength of the feedback mechanisms. Among these studies, it could be mentioned the numerical experiment performed by *Koster et al.* (2004) for present-day climate conditions and the study of *Seneviratne et al.* (2006) which was performed for near-future climate conditions in Central Europe.

Among feedback mechanisms, the soil moisture – precipitation feedback is one of the most important (e.g., *Yeh et al.*, 1984; *Oglesby* and *Erickson*, 1989; *Beljaars et al.*, 1996). For a complete analysis, all relevant processes have to be considered: processes occuring in the soil (water transport) and in the planetary boundary layer (triggering of convection), as well as the cloud physical (convection and microphysic) processes (*Hurk van den*, and *Blyth*, 2008). It could not be said that any of these processes is more important than the other one; this hierarchy of the processes according to the importance is highly case-dependent. The importance of soil hydraulic processes is well recognized (*Seneviratne et al.*, 2006), but there is no fully comprehensive analysis. An extensive analysis is made by *Guo et al.* (2006). They argued that the effect of soil moisture (θ) on precipitation should be examined in two distinctly separated parts: (1) when soil moisture affects evaporation and (2) when evaporation affects precipitation. According to *Guo et al.* (2006), the model results are highly dependent on the processes related to the first part. This statement is also confirmed by *Ács* (2002, 2003). Therefore, in this study we investigated the soil – convective precipitation relationship.

From the meteorological point of view, among soil features, soil hydraulic properties are the most important. Among them, the field capacity (θ_f) and the wilting point (θ_w) soil moisture contents have a special role. They depend not only on soil type, but also on the parameterization of soil hydraulic functions (soil water retention and soil water conductivity functions) and the criteria applied in their estimation procedure (*Ács*, 2005). At the same time, θ_f and θ_w are relevant for estimating evapotranspiration (*Chen* and *Dudhia*, 2001). One can pose the question whether local convective precipitation – via sensitivity of evapotranspiration – is also sensitive to the parameterization of θ_f and θ_w. To the best of our knowledge, this question is not discussed to date in the scientific community.

The investigation was made by performing a total of nine one-day case studies during a storm season period in Hungary. Simulations were made by the Penn State – NCAR MM5 modeling system (fifth generation mesoscale model).

The results obtained are statistically evaluated and validated with rain gauge measurements.

2. Model description

2.1. General characteristics of the nonhydrostatic model MM5

Numerical simulations were performed by the version 3 of the Penn State – NCAR MM5 (Fifth-generation Mesoscale Model) modeling system (*Dudhia*, 1993). The model applies a terrain-following sigma coordinate system. The predictive variables are: pressure perturbation, the three momentum components, temperature, specific humidity, and the mixing ratio of the different types of hydrometeors (cloud water, cloud ice, rain, snow, and graupel particles). The partial differential equation system is solved by using a relaxation lateral boundary condition and a radiation upper boundary condition. Model runs were performed using horizontal resolution of 6×6 km, and 26 vertical levels.

Scheme of *Grell et al.* (1994) was applied for parameterization of convection based on rate of destabilization or quasi-equilibrium. A simple single-cloud scheme with updraft and downdraft fluxes and compensating motion determining heating/moistening profile was used. Formation of cloud and precipitation elements are simulated with an explicit bulk microphysical scheme (*Reisner et al*., 1998) with five different types of hydrometeors: cloud water, cloud ice, rain, snow, and graupel particles. Collision coalescence processes between different types of hydrometeors, furthermore, the diffusion of vapor, freezing of liquid elements, and melting of ice particles are simulated. The equation of conservation is not only solved for the mixing ratios of hydrometeors but for the concentration of cloud ice as well.

The planetary boundary layer (PBL) is described by the local mixing PBL scheme based on the work of *Janjic* (1990, 1994). Compared with other non-local or high-order closure schemes, this PBL scheme proved to be more efficient, because it needs less computer capacity.

2.2. Basic characteristics of the OSU LSM

Land-surface processes are simulated by the OSU LSM (Oregon State University Land-Surface Model). The model consists of a multilayer soil model (*Mahrt* and *Pan*, 1984), a single-layer snow model (*Chen* and *Dudhia*, 2001), and a canopy model (*Pan* and *Mahrt*, 1987).

Evapotranspiration of soil-plant system is estimated as the sum of transpiration and evaporation from the soil and the wetted parts of vegetation. Both transpiration and soil evaporation depend on θ_f and θ_w. They are estimated from soil hydraulic functions (soil water retention (Ψ) and conductivity (K) functions) parameterized after *Campbell* (1974) using *Clapp* and *Hornberger*'s

(1978) parameter values, and supposing inhomogeneous areal distribution of soil moisture content.

Detailed description of the model can be found in the work of *Chen* and *Dudhia* (2001).

2.3. Parameterization of θ_f and θ_w

θ_f and θ_w depend not only on soil texture but also on many other factors which are relevant in their estimation: for instance, soil type, transpiration, areal distribution of soil moisture content, and parameterization of soil hydraulic functions. Therefore, their values are quite uncertain.

In this study, soil hydraulic functions referring to Hungarian soils were estimated using *Campbell's* (1974) parameterization and *Clapp* and *Hornberger*'s (1978) parameter values. θ_f values were estimated in two steps as in *Chen* and *Dudhia* (2001): in the first one, the so-called homogeneous (areal distribution of soil moisture content is homogeneous) θ_f values (θ_f^h) were calculated according to the following criteria:

$$pF = \log_{10}[\Psi(\theta_f^h)] = 2.3, \tag{1}$$

$$K_S \left(\frac{\theta_f^h}{\theta_S} \right)^{(2b+3)} = 0.5 \text{ mm day}^{-1}, \tag{2}$$

where θ_S is the saturated soil moisture content, K_S is the saturated soil water conductivity, and b is a dimensionless fitting parameter. The pF value and the corresponding θ_f^h value in Eq. (1) were experimentally determined using the method of *Várallyay* (1973). This criterion applied together with the Várallyay method was common for estimating of θ_f^h in Hungary. Eq. (2) is used for USA soils by *Chen* and *Dudhia* (2001). The effect of the inhomogeneous areal distribution of θ is taken into account as follows:

$$\theta_f = \theta_f^{inh} = \frac{\theta_S}{3} + \frac{2}{3} \cdot \theta_f^h, \tag{3}$$

where Eq. (3) implicitly expresses the fact that the slope of transpiration curve obtained for inhomogeneous distribution of θ is considerably smaller than the slope of transpiration curve obtained for homogeneous distribution of θ (*Ács*, 2003).

θ_w values were also estimated in two steps: as above, the so-called homogeneous θ_w values were calculated according to the following criteria:

$$pF = \log_{10}[\Psi(\theta_w^h)] = 4.2, \tag{4}$$

$$\theta_w^h = 5\rho_b hy, \tag{5}$$

where ρ_b is the bulk soil density and *hy* is the so-called hygroscopic coefficient. *hy* is determined by exposing a thin soil layer to an atmosphere saturated with water vapor for a period of about a day. As in Eq. (1), the *pF* value and the corresponding θ_w^h value in Eq. (4) were experimentally determined using the Várallyay method. In most cases, this expression serves for estimating θ_w^h. If there are no $\Psi(\theta)$ measurements, θ_w^h is usually estimated by expressions like Eq. (5) (*Stefanovits et al.*, 1999). Similarly to the former case, the effect of the inhomogeneous areal distribution of θ is taken into account as

$$\theta_w = \theta_w^{inh} = 0.5\,\theta_w^h. \tag{6}$$

Eq. (6) has the same meaning as Eq. (3). It expresses the fact that the slope of transpiration curve obtained for inhomogeneous distribution of θ is considerably smaller than the slope of transpiration curve obtained for homogeneous distribution of θ (*Ács*, 2003).

3. Data and numerical experiments

The nine days chosen for analysis include: June 27, 2006, August 1, 2006, August 7, 2006, May 5, 2007, May 22, 2007, June 1, 2007, June 2, 2007, August 10, 2007, and August 20, 2007. On all nine days the weather prevailed was favorable for evolution of local convective storms when the land-surface – air interaction is strong.

3.1. Rain gage data

24-hour accumulated precipitation data for Hungary was acquired from the Hungarian Meteorological Service (HMS). Information was created using data of stations whose type and number varied. In two cases only the main, approximately 100 stations' data were used, in the remaining 7 days the non-automatic gage (about 560 stations) data were incorporated if there was a measurement, otherwise the precipitation was taken as 0. To avoid errors from the rounding and calculation of coordinates, only those stations were added that were more than approximately 6 km from the actual measurements. Overall, on all days the Kriging interpolation error was below 0.5% at the gridcells located in Hungary.

3.2. Basic land-surface parameters

In this study, the USGS-25 category land use dataset was used. Vegetation characteristics in the model domain for May, June, and August are as follows: vegetation cover veg (vegetated part of one complete grid cell) changes between 0.5 and 1.0. In the Carpathian Basin, the prevailing vegetation type is type 2, "dryland, cropland, and pasture". The lowest veg values can be found in the case of type 2. Towards mountain regions, the "grassland" type increases. *veg* is estimated on the basis of leaf area index (LAI). Details concerning the specification of vegetation parameters are described in the work of *Chen* and *Dudhia* (2001).

Table 1. Main physical characteristics of the Hungarian soils

Soil texture	No. of samples	Clay fraction (%)	Sand fraction (%)	Silt fraction (%)	ρ_b (g cm^{-3})
Sand	7	3.84	91.61	4.54	1.32
Loamy sand	20	8.03	78.28	13.69	1.09
Sandy loam	32	14.39	60.29	25.33	1.44
Loam	28	25.36	41.18	33.47	1.45
Sandy clay loam	2	28.80	57.80	13.40	1.55
Clay loam	3	41.53	26.53	31.93	1.3
Clay	37	51.21	6.63	42.19	1.49
Heavy clay	24	60.20	5.37	34.43	1.32
Silt loam	181	19.42	23.33	57.26	1.41
Silty clay loam	154	36.87	9.05	54.08	1.46
Silt	6	5.77	8.05	86.18	1.46

Soil hydraulic properties are obtained from a Hungarian soil data set. Dataset comprises soil data from 576 samples collected in Hungary. Beside hydraulic properties, some other important physical characteristics are also measured. Their mean values for ten different soil textural classes are presented in *Table 1*. Soil textural classes are determined according to criteria given by *Filep* and *Ferencz* (1999). Bulk soil density varies from 1.09 g cm^{-3} for loamy sand to 1.55 g cm^{-3} for sandy clay loam soils. Note, that in the Hungarian soil database there are only two samples for sandy clay loam, three samples for clay loam, and six samples for silt. Noteworthy, that there are only three clay loam samples from the clay loam areas which are quite large in Hungary. Dataset does not contain information about the single map units, that is, we do not know how large the area is to which they are representative. Therefore, it is impossible to upscale this data. Soil hydraulic functions were obtained using results of *Nemes* (2003) and *Fodor* and *Rajkai* (2005).

In this study, θ_f and θ_w values were estimated using all equations. Equation combinations are presented and discussed in the section „Experimental design". The obtained θ_f and θ_w values are presented in *Table 2*. All other soil hydraulic parameters used in this study are presented in *Table 3*. Note that these soil parameter values can slightly differ from the ones given in the work of *Horváth et al*. (2007). This is caused since slightly different soil data sets and estimation procedures were applied. Soil parameter values represent grid point values. Grid cell values were calculated from the grid point values, but no subgrid-scale variability was considered.

Table 2. Field capacity and wilting point soil moisture content values and the corresponding relative differences for different soil textures estimated by different equation combinations

Soil texture	**Θ_f (m^3 m^{-3})**			**Θ_w (m^3 m^{-3})**		
	Eqs (1), (3)	**Eqs (2), (3)**	**Rel. diff.**	**Eqs (4), (6)**	**Eqs (5), (6)**	**Rel. diff.**
Sand	0.325	0.272	0.163	0.029	0.068	1.345
Loamy sand	0.479	0.348	0.273	0.080	0.141	0.763
Sandy loam	0.379	0.288	0.240	0.064	0.045	0.297
Silt loam	0.408	0.316	0.225	0.080	0.043	0.463
Silt	0.437	0.312	0.286	0.069	0.027	0.609
Loam	0.406	0.296	0.271	0.088	0.044	0.500
Sandy clay loam	0.354	0.273	0.229	0.061	0.032	0.475
Silty clay loam	0.435	0.355	0.184	0.119	0.071	0.403
Clay loam	0.479	0.387	0.192	0.139	0.081	0.417
Sandy clay	0.340	0.330	0.029	0.055	0.056	0.018
Silty clay	0.340	0.273	0.197	0.113	0.032	0.717
Clay	0.489	0.406	0.170	0.147	0.132	0.102
Average	**0.406**	**0.321**	**0.205**	**0.087**	**0.064**	**0.509**

Table 3. Hungarian soil hydraulic parameters as used in the OSU LSM. θ_S = saturated soil moisture content, Ψ_S = saturated soil water retention, K_S = saturated water conductivity, b = dimensionless fitting parameter

Soil texture	***b***	**ψ_s (m)**	**K_s (m s^{-1})**	**Θ_s (m^3 m^{-3})**
Sand	3.02	0.060	3.26E-05	0.507
Loamy sand	3.90	0.126	2.52E-05	0.598
Sandy loam	3.99	0.143	1.14E-05	0.476
Silt loam	4.18	0.182	2.73E-06	0.487
Silt	3.54	0.223	2.00E-06	0.496
Loam	4.20	0.224	4.58E-06	0.468
Sandy clay loam	4.21	0.132	7.98E-06	0.439
Silty clay loam	5.04	0.234	6.20E-07	0.491
Clay loam	4.74	0.207	3.05E-06	0.580
Sandy clay	3.58	0.890	4.58E-06	0.500
Silty clay	4.06	0.324	1.05E-06	0.453
Clay	6.21	0.228	8.00E-07	0.541

In all runs, that areal distribution of soil texture was used which was originally implemented in the MM5. According to this distribution six textural classes are used from the ten textural classes presented in *Table 1*. They are as follows: loamy sand, sandy loam, loam, sandy clay loam, clay loam and clay.

3.3. Initializations

Initial conditions for MM5 model runs were obtained from the ECMWF analysis and forecast. 00 UTC data were used for all nine days. 100 hPa layer was chosen for the top level of the MM5. Initial soil data (temperature and soil moisture) were also taken from the ECMWF analysis. According to soil moisture content values (about 180–300 mm m^{-3}) in the surface layer, on all nine days $\theta_w < \theta < \theta_f$.

3.4. Experimental design

In the comparative analyses, three runs were performed. The conditions used in the runs are presented in *Table 4*. Run 1 is the reference run. In this run, θ_f was parameterized using Eqs. (1) and (3), while θ_w by Eqs. (4) and (6). Run 2 differs from run 1 only in the parameterization of θ_f. In run 2, θ_f was parameterized using Eqs. (2) and (3). Run 3 and run 1 are different only in the parameterization of θ_w. In run 3, θ_w was parameterized by Eqs. (5) and (6). Comparing the results of runs 1 and 2 (comparison 1), we can analyze how important the parameterization of θ_f is. Comparing the results of runs 1 and 3 (comparison 2), we get an insight into how important the parameterization of θ_w is.

Table 4. Brief description of the conditions in the runs used in the study

	Definition of Θ_f	**Definition of Θ_w**
Run 1	Eqs. (1), (3)	Eqs. (4), (6)
Run 2	Eqs. (2), (3)	Eqs. (4), (6)
Run 3	Eqs. (1), (3)	Eqs. (5), (6)

4. Validation, comparison, and discussion

Storm events occurring on all nine days were analyzed. The model was running for 30 hours to ensure a 6-hour spin-up time. In all cases, the model was started at 00 UTC. 24-hour accumulated precipitation fields were obtained from +6 and +30 hours accumulated precipitation fields. The domain considered has 115 × 49 grid points (in total 5635 grid points). Precipitation fields were statistically analyzed in detail. Statistical analysis is performed only for the territory of Hungary (area of Hungary: 2288 grid points). First, the simulated and observed fields were compared. Observed fields were estimated from rain gage data applying the ordinary block kriging interpolation technique. In the second step, the agreement between simulated and observed fields was estimated using a categorical and a continuous verification index. At the end, significance tests were also done to estimate how large (important) or small the obtained differences are.

Kriging interpolation technique was used because this method is an approved method for interpolating precipitation data (*Rubel*, 1996). Among the various categorical verification indices, true skill statistics (*TSS*) was chosen. It is based on the two dimensional contingency table (*Table 5*). *TSS* is computed as

$$TSS = \frac{hz - fm}{(h+m)(f+z)}. \tag{7}$$

TSS changes between –1 and +1. For perfect simulation, it tends towards +1. This is a perfect verification measure, because it is independent from the fraction of rain/no rain events. Root mean square error (*RMSE*) was chosen as the continuous verification index. Significance tests were made by using the Student t-test hypothesis. This is appropriate for independent, small-number samples with Gaussian distribution. In the following, we will be dealing with the validation and sensitivity experiments.

Table 5. Contigency table for the calculation of true skill statistics. Symbols: h = hits, f = false, m = misses, z = zero, n = h + f + m + z

	Observation YES	**Observation NO**	**Forecast TOTAL**
Forecast YES	h	f	h + f
Forecast NO	m	z	m + z
Observation TOTAL	h + m	f + z	n

4.1. Validation results

Distribution of the nine-day mean values of the true skill statistics obtained by run 1 (reference run) for different precipitation threshold limits is presented in *Fig. 1a*. Threshold limits denote precipitation intervals from the threshold to its maximum value. Three ranges can be separated. For small threshold limits (small and large precipitation together), the *TSS* values are quite low, about 0.2. For large threshold limits (referring to large precipitation events), the *TSS* values obtained are also small, between 0.05 and 0.2. The distinct break in the values of *TSS* at 13 mm·day^{-1} is caused by the dropout of one day, since there were no precipitation over that threshold. In between (from about 5 to 12 mm day^{-1}), the

TSS values estimated are somewhat larger, about 0.3. The same distribution but obtained on May 5, 2007 is presented in *Fig. 1b*. The main difference with respect to *Fig. 1a* can be observed for small threshold limits. In this case, the *TSS* values are larger, somewhere between 0.4 and 0.7. Note, that abrupt decrease from threshold limit of 13 mm day^{-1} does not exist. Distribution of the nine-day average values of the root mean square errors (*RMSE*) obtained using the reference run for different precipitation threshold limits is presented in *Fig. 2a*. *RMSE* values are smaller (about 10 mm day^{-1}) for larger and larger (about 11–12 mm day^{-1}) for smaller *TSS* values. The same behaviour can also be observed for *RMSE* values calculated on May 5, 2007. This is presented in *Fig. 2b*. In this case, the largest *RMSE* values are about 14 mm day^{-1}.

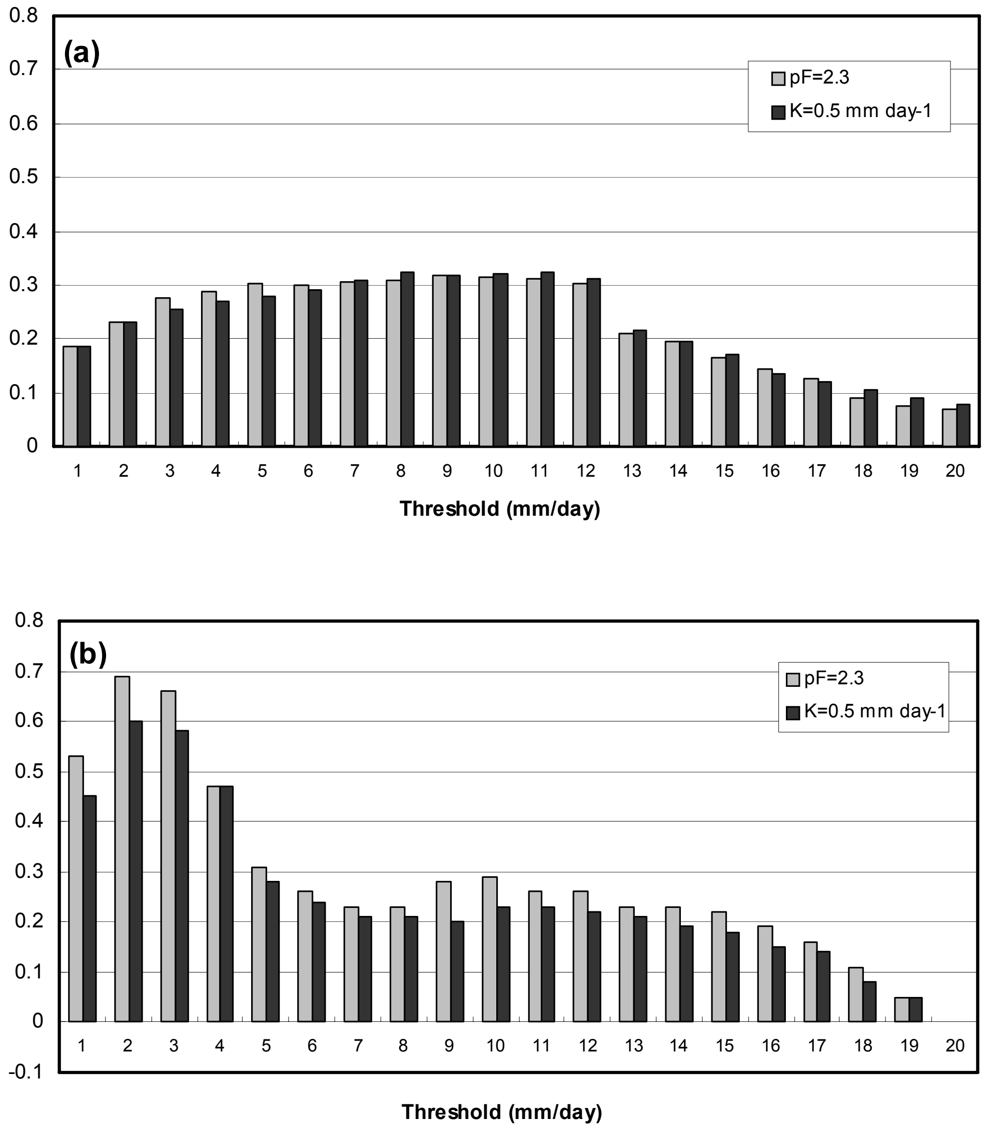

Fig. 1. Distribution of (a) nine-day mean values and (b) actual values on May 5, 2007 of the true skill statistics obtained using run 1 ($pF(\theta_f)$ = 2.3 and $pF(\theta_w)$ = 4.2) and run 2 ($K(\theta_f)$ = 0.5 mm day^{-1} and $pF(\theta_w)$ = 4.2) for different precipitation threshold limits.

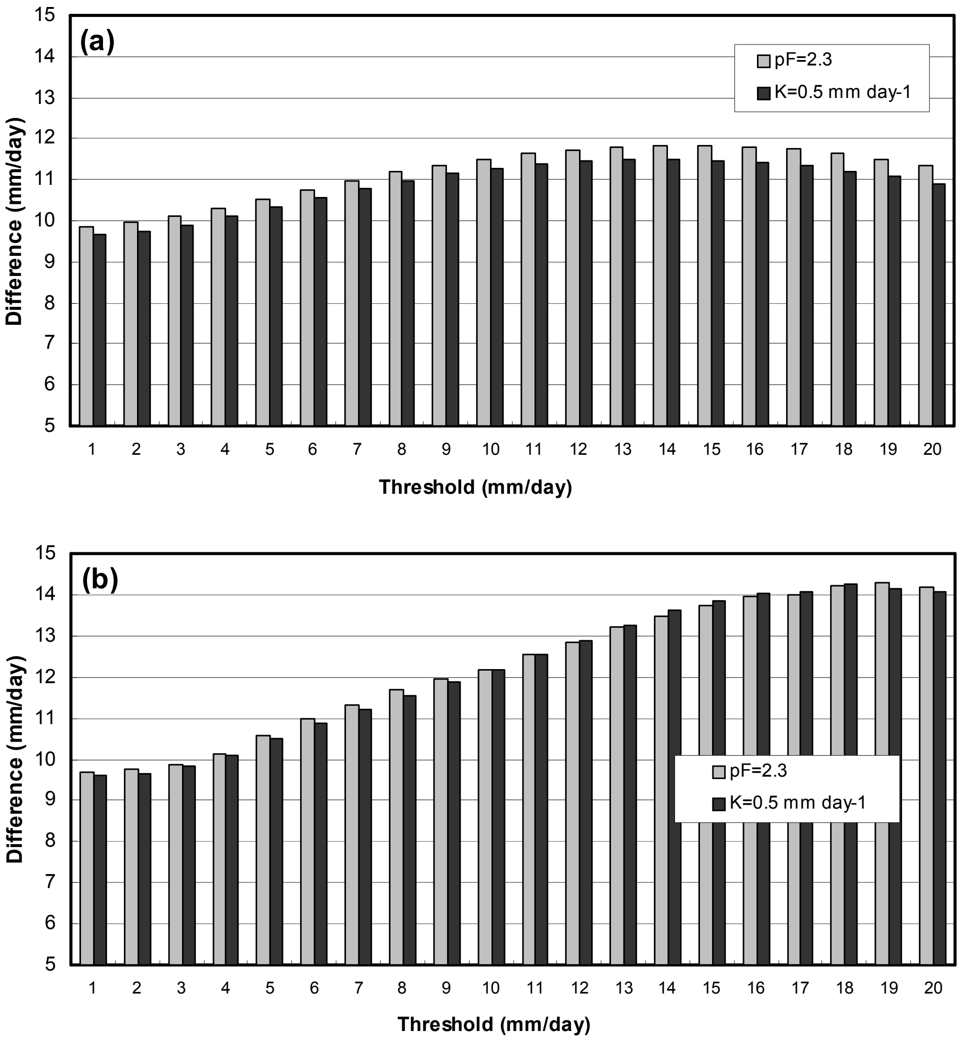

Fig. 2. Distribution of the of (a) nine-day mean values and (b) actual values on May 5, 2007 of the root mean square error obtained using run 1 ($pF(\theta_f) = 2.3$ and $pF(\theta_w) = 4.2$) and run 2 ($K(\theta_f) = 0.5$ mm day^{-1} and $pF(\theta_w) = 4.2$) for different precipitation threshold limits.

4.2. Sensitivity to θ_f parameterization

Comparing results of runs 1 and 2 (comparison 1), we can analyze the effect of θ_f parameterization upon precipitation field prediction. This is presented in *Fig. 1* for *TSS* and in *Fig. 2* for *RMSE* values. According to *Fig. 1*, the sensitivity (difference between the gray and dark columns) seems to be negligible. In average, the relative differences ($[TSS^{pF}-TSS^{K}]/TSS^{pF}$) are under 10 percent. However, according to significance test results, the obtained differences were significant on the 10% level on six from the nine days. That is, relative differences which seem to be small, can be significant. It is also obvious that there is no tendency in the distribution of the *TSS* values obtained by using runs 1 and 2. TSS^{pF} values were higher than TSS^{K} values on three from the six significant days. The sensitivity on a day, when the differences were significant on the 10% level is presented in *Fig. 1b*. In some cases, for instance for threshold values of 9 and 10 mm day^{-1}, relative difference between the *TSS* values is about 20 percent. Though, it is obvious that these cases are rare. The sensitivity of *RMSE* to θ_f parameterization seems to be also small. In these cases no significance tests were performed.

4.3. Sensitivity to θ_w parameterization

Comparing results of runs 1 and 3 (comparison 2), we can analyze the effect of θ_w parameterization upon precipitation field prediction. Distribution of the nine-day mean values of the true skill statistics obtained using runs 1 and 3 for different precipitation threshold limits is presented in *Fig. 3a*.

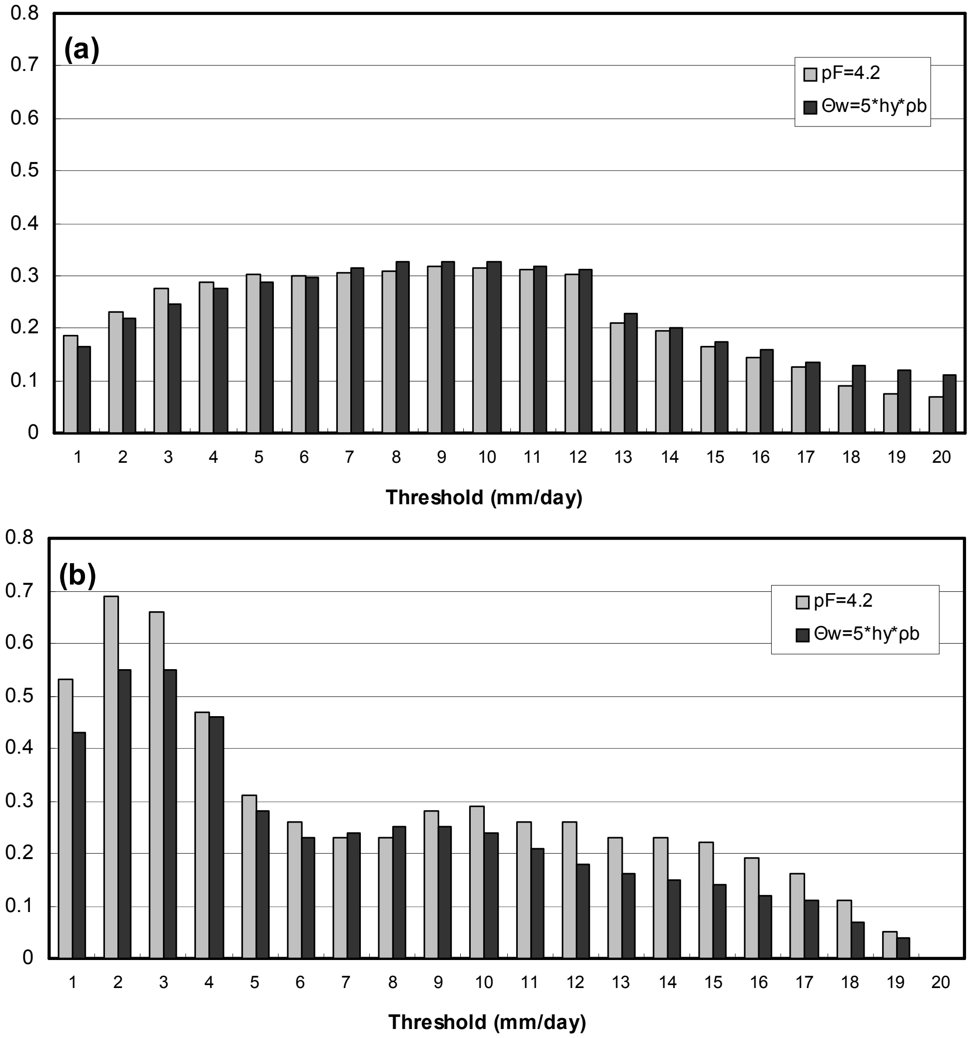

Fig. 3. Distribution of (a) nine-day mean values and (b) actual values on May 5, 2007 of the true skill statistics obtained using run 1 ($pF(\theta_f)$ = 2.3 and $pF(\theta_w)$ = 4.2) and run 3 ($pF(\theta_f)$ = 2.3 and θ_w estimated by *hy*) for different precipitation threshold limits.

As in the former case, the obtained relative differences ($[TSS^{pF}-TSS^{K}]/TSS^{pF}$) seem to be small (under or about 10 percent), but in some cases they were especially large. For instance, for large threshold values (above 17 mm day^{-1}), relative differences amount 50 percent. According to significance test results, the obtained differences were significant on the 10% level on eight from the nine days, that is, on almost all days. TSS^{hy} values were higher than TSS^{pF} values on five from the eight significant days. The same distribution but obtained on May 5, 2007, when the differences between the *TSS* values were significant, is presented in *Fig. 3b*. In this case, there are large relative differences not only for large (about 30 percent) but also for small threshold values (about 15 percent). Distribution of the nine-day mean values of the *RMSE* for different precipitation threshold limits is presented in *Fig. 4a*. The obtained differences are very small. Distribution of the *RMSE* on May 5, 2007 is presented in *Fig. 4b*. Differences obtained in this case are obviously larger with respect to the differences obtained in *Fig. 4a*. As in the former case, these differences were not analyzed from the point of view of significance tests.

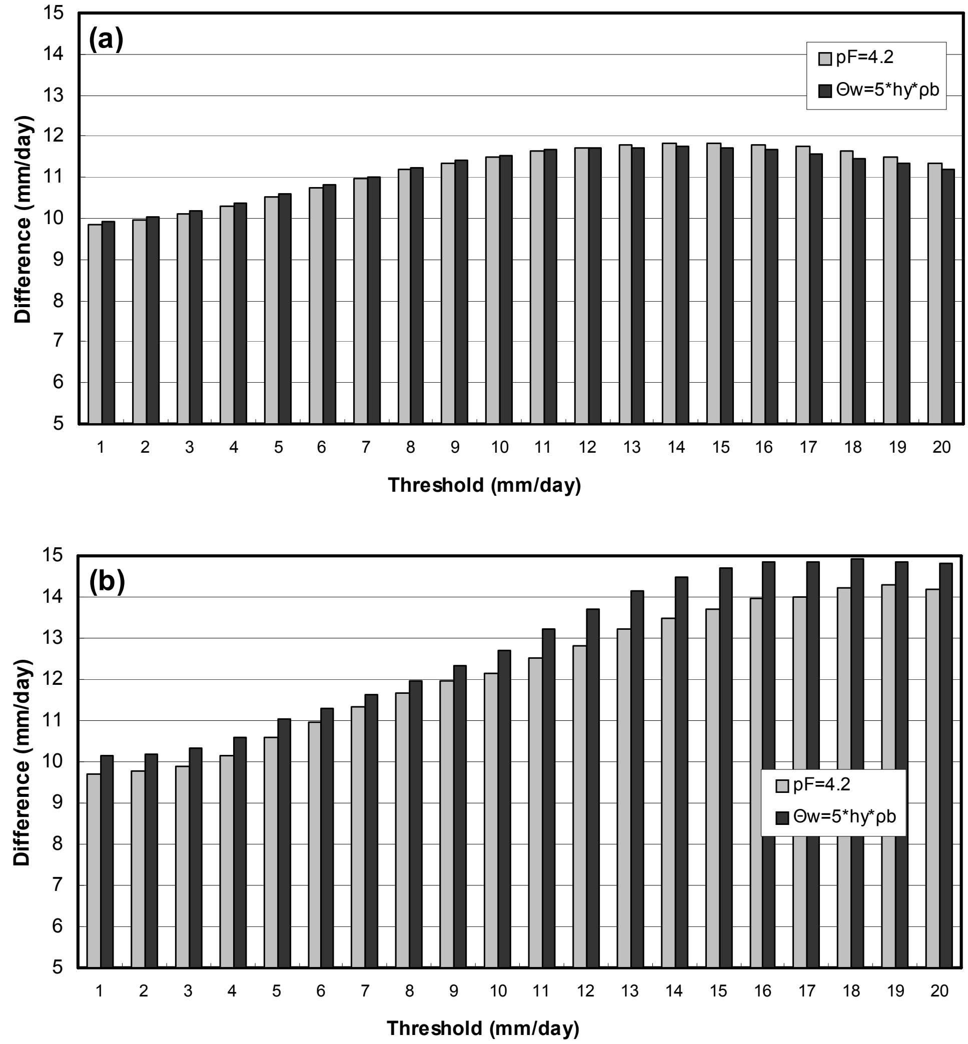

Fig. 4. Distribution of (a) nine-day mean values and (b) actual values on May 5, 2007 of the the root mean square error obtained using run 1 ($pF(\theta_f)$ = 2.3 and $pF(\theta_w)$ = 4.2) and run 3 ($pF(\theta_f)$ = 2.3 and θ_w estimated by *hy*) for different precipitation threshold limits.

4.4. Significance tests applied to other skill measures

Since *TSS* differences were significant on the level of 10% in many cases (for θ_f in six, while for θ_w in eight from the nine days), we decided to performe significance tests for various skill measures. Differences on the level of 10 percent were evaluated for each day separately for in total nine skill measures. The skill measure used were as follows: *POD* = probability of detection ($POD = h/(h + m)$), *FAR* = false alarm ratio ($FAR = f/(h + f)$), *TSS* = true skill statistics, *PC* = proportion of correct hits and misses ($PC = (h + z)/n$), *CSI* = critical success index ($CSI = h/(h + f + m)$), *ORSS* = odds ratio skill score ($ORSS = (hz - fm)/(hz + fm)$), *CHI* = χ2-measures of association ($CHI = (hz - fm)^2/((h + f)(m + z)(h + m)(f + z))$, *CR* = correspondence ratio, and *HSS* = Heidke skill score ($HSS = 2(hz - fm)/((h + m)\cdot(m + z) + (h + f)\cdot(f + z))$.

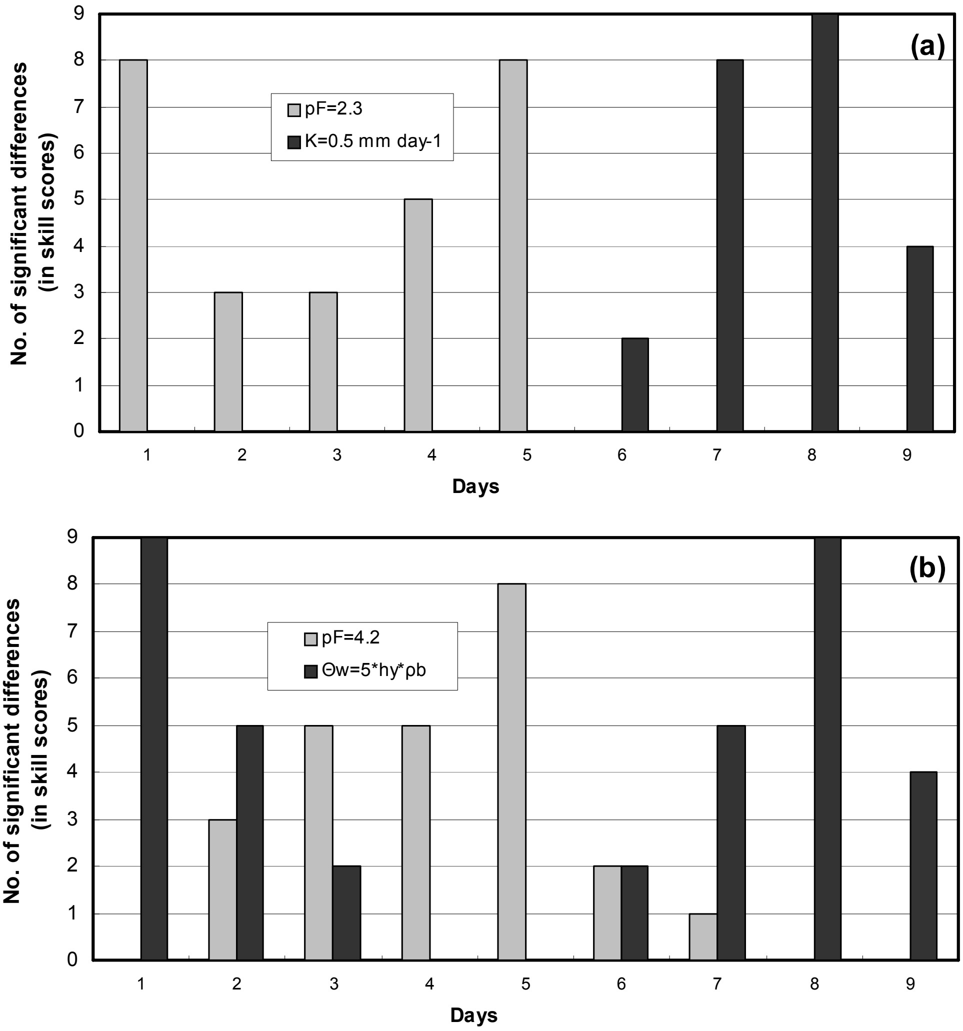

Fig. 5. Number of significant differences on the level of 10% between the skill scores (in total nine) obtained by using conditions (a) in run 1 and run 2 and (b) in run 1 and run 3 for each day separately. Grey column: simulated precipitation obtained by run 1 is closer to the observation, dark column: simulated precipitation obtained by run 2 is closer to the observation.

Number of significant cases for each day separately obtained analyzing the effect of the parameterization of θ_f is presented in *Fig. 5a*. All cases were significant on the eight day (this is August 10, 2007). In all nine cases, results obtained in run 2 were better with respect to the results obtained in run 1. On the first, fifth, and seventh days, the differences were in eight cases significant. Nevertheless, on the 1st and 5th days, the results obtained in run 1 were better than those obtained in run 2. Note that on the sixth day, the differences were only in two cases significant. The same distribution but for θ_w is presented in *Fig. 5b*. The number of significant differences is obviously higher than in the former θ_f case. Differences between all skill measures were significant on the first and the eighth days. The lowest number of the significant differences (in total four) can be observed on the 6th and 9th days. There is no tendency in the distribution of the number of significant cases obtained by using runs 1 and 3.

5. Conclusions

The impact of θ_f and θ_w parameterization upon convective precipitation fields was analyzed. The analysis was performed using simulation results of the Penn State – NCAR MM5 Modeling System obtained on nine days in 2006 and 2007. On all days, actual soil moisture content in the surface layer was higher than θ_w but lower than θ_f.

The considered domain covers the territory of Hungary. Convective precipitation fields were statistically analyzed in detail. First, the simulated and observed fields were compared. The observed fields were obtained from rain gage data applying a kriging interpolation technique. Agreement between the simulated and observed fields was estimated using categorical and continuous verification indices. Significance tests were done to estimate how large (important) or small the obtained differences are.

According to the results, MM5 simulates in an acceptable manner the formation of local convective precipitation field in Hungary. *TSS* values obtained are about 0.2–0.3 on average. We also showed that local convective precipitation is to some degree sensitive to the parameterizations of θ_f and θ_w. What does "to some degree" mean? It can be seen that on average, 20 percent relative differences in the θ_f ($[\theta_f^{pF} - \theta_f^{K}]/\theta_f^{pF}$) (see *Table 2*) caused on average about 5–10% relative differences in the *TSS* ($[TSS^{pF} - TSS^{K}]/TSS^{pF}$). However, in many cases these *TSS* differences were significant on the level of 10%. Similarly, on average, 50 percent relative differences in the θ_w ($[\theta_w^{pF} - \theta_f^{hy}]/\theta_f^{pF}$) (see *Table 2*) caused about 10–50 percent relative differences in the *TSS* ($[TSS^{pF} - TSS^{hy}]/TSS^{pF}$). These *TSS* differences were significant on the level of 10% on eight days. This latter result suggests that sensitivity to θ_w seems to be somewhat higher than sensitivity to θ_f.

Results obtained can be useful in quantifying of the strength of the soil moisture – precipitation feedback mechanisms. It should be mentioned that models used for scientific and operative purposes have completely different soil parameterizations, so different θ_f and θ_w calculation procedures. This study showed that uncertainties in the parameterization of θ_f and θ_w could considerably contribute to scatter of the simulation results (*Koster et al.*, 2004).

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