THE EFFECT OF SOIL HYDROPHYSICAL PROPERTIES ON CONVECTIVE PRECIPITATION AND ON COMPONENTS OF THE WATER BUDGET: METEOROLOGICAL AND CLIMATOLOGICAL ANALYSES IN HUNGARY

Theses of the PhD dissertation

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INVESTIGATED PROBLEMS

The land-surface was always an object of analysis in modern meteorology as the lower boundary condition of the atmosphere. Its notability changed during the decades, however with the appearance of mesoscale models its role has increased. The land-surface properties unequivocally determine its energy budget, so indirectly also the processes in the near surface atmosphere. The latent heat flux is the most complex component of the energy budget. Its rate is controlled by the water use of vegetation and the soil moisture content aside the atmospheric demands. Furthermore, the soil moisture content depends on the soil physical properties and on the parameterization of some soil parameters. Changes in the surface energy budget affect mainly the near surface temperature and dew point, which determine the stability of the atmosphere. The evaporation has also an effect on heat, moisture and momentum transport via turbulent exchange processes. As a result of these two effects, the soil moisture affects both the convection and the precipitation formation.

The analyses of the effect of soil moisture and soil properties on planetary boundary layer and convective precipitation are quite diversified. The sensitivity to initial soil moisture content, different soil textures, pedotransfer functions referring to soil parameters and to the spatial distribution of soil properties was investigated. However, these relationships were analyzed with models of different complexity, coupled or uncoupled with the atmosphere using different spatial resolutions. Beside these investigations, the sensitivity to soil database was rarely analyzed. Since the knowledge of latent and sensible heat flux is particularly important in mesoscale modeling, it is also relevant from the meteorological point of view to compare a globally used and a local soil database.

AIMS

The aim of my research was to analyze the effect of soil hydrophysical properties on convective precipitation and some components of water budget. The hydrophysical properties have been estimated from the HUNSODA (briefly HU) and USDA (briefly US) soil databases containing Hungarian and North-American soil samples, respectively. The parameters from USDA are used all around the world in the MM5 and WRF models. Thus, a comparison with a regional database is an interesting and important task. The parameters from the HUNSODA have been determined by me. The MM5 numerical weather prediction model has been used for analyzing convective precipitation. The simulated intensity and spatial distribution of precipitation have been compared to measured fields. The water budget of Hungary for the 20^{th} century has been estimated with an own constructed multi-layer soil moisture model using the CRU TS 1.2 database. In these runs, the water budget dependence on soil database is also analyzed.

APPLIED METHODOLOGY

The foremost task in the thesis was to determine the soil hydrophysical parameters from the HUNSODA database. Only those have been calculated which are needed for the MM5 model, the methodology of their determination follows the Hungarian standards. As a result, the soil texture categorization from soil particle sizes and the determination of field capacity differs from the methodology of USDA parameter definition.

Simulations with the MM5 model have been verified on a daily scale. For this, the measurements were represented in a form comparable to the simulations. The daily rain gauge measurements have been interpolated to a grid resolution three times smaller than the simulations (≈18 km) with Kriging interpolation technique. The coarser resolution was needed because of the interpolation technique requirements: at least one measurement point is needed to have in a grid cell. The simulated fields on finer resolution have also been interpolated to the coarser resolution with Kriging.

Comparison of the precipitation fields has been done using a non-parametric correlation coefficient and a skill score. Not only the measured and simulated fields but also the simulations themselves have been compared during the sensitivity analysis. For the correlation coefficient, significance test has also been made.

In developing of the water budget model, it was important to use as much information as possible beside soil and land use data as well as weather data with monthly time step. Soil texture dependent wilting point (Θ_w), field capacity (Θ_f), saturated soil moisture content (Θ_s), porosity index (b), saturation matric potential (Ψ_s) and saturated water conductivity (K_s), as well as land use dependent leaf area index and minimal stomatal resistance and the depth of topsoil have been used.

In the water budget model, due to Richards equation, 30 minutes long time step have been applied, though the estimation of evapotranspiration requires only daily or 12 hourly temperature and air humidity data. Since the database used for Hungary contained only monthly data, downscaling have been applied. In case of temperature and air humidity, a simple linear calculation was used. In case of precipitation, the average frequency and intensity have been determined form daily measurements. This was applied to 4 Hungarian cites (Budapest, Szeged, Szombathely and Debrecen) for the 20th century. The downscaling was created to a 12 hour interval using the previous data. Water budget model verification has been performed on the daily time scale for one year and on the monthly time scale for 13–20 year long period. Soil moisture content measurements at 11 stations in Illinois State (USA) and at the Agrometeorological Observatory of Debrecen were used as reference data.

RESULTS AND CONCLUSIONS

New results concerning soil hydrophysical properties are as follows:

1) I determined the values of those soil hydrophysical parameters which are contained in Campbell's parameterization using the Hungarian HUNSODA soil database and Filep and Ferencz's (1999) soil texture classification.

2) Comparing the HU and US parameter values, I showed that b^{US} is about twice as large as the b^{HU} for clay texture. Furthermore, Θ_s^{HU} and Θ_f^{HU} are on average 60 mm/m larger than the Θ_S^{US} and Θ_f^{US} for all soil textures. Similarly, the available soil moisture content (Θ_f - Θ_w) for HU parameters is on average 55 mm/m larger than for US parameters. From the 12 analyzed soil textures, the greatest differences can be found for clay loam and loamy sand.

Results concerning the sensitivity of the numerical weather prediction model to soil hydro-physical properties can be summarized as follows:

3) Differences in soil hydraulic properties result in maximal value of 100 W/m^2 latent and sensible heat flux difference in summer. These differences cause about ±1°C change in near surface temperature and dew point which depend on the weather situation. The dew point depression difference is about twice as much.

4) The effect of soil and vegetation parameters on the convective available potential energy and precipitation intensity is comparable.

5) The differences in soil moisture content induced by soil parameter changes non-linearly affect the precipitation amount and its spatial distribution. The simulated precipitation systems are usually offset to each other. This shift is about 50 km.

6) Soil texture and parameter value changes resulted significant differences in the spatial distribution of precipitation. The magnitude of difference depends on the amount of daily precipitation. The largest differences were found in the 3-5 mm/day interval, which are the most frequent occurring amount of precipitation.

7) Among soil parameters a ranking could be made concerning the magnitude of their effect on precipitation field. The largest difference is caused by the change of all parameter values. This effect is followed by the spatial distribution effect of soil texture in the modeled domain and by the spatial distribution effect of soil moisture in the grid cell.

8) Change in only one soil parameter doesn't result significant change in the precipitation.

9) Local (in this case Hungarian) soil data (soil texture distribution and soil parameter values) improve the skill of the locally simulated precipitation with respect to global soil data.

New results concerning the use of water budget model are as follows:

10) The model simulates the monthly water content well (R=0.75–0.8) using a few year averages and excellent (R=0.96–0.99) using decade long averages.

11) The annual course of water budget components doesn't depend on soil database, in this case the land surface and soil properties are more dominant.

12) Concerning annual sums, the HUNSODA/USDA differences for infiltrated water are 20–40 mm, while for runoff 10–30 mm. The spatial differences in water budget components caused by soil database change can be attributed to the difference in the available soil water content and soil water drainage.

Summarizing, it can be said that soil database use considerably influences both the simulated convective precipitation and the water budget components on monthly or yearly time scales. Therefore we suggest to use instead global, regional or local scale soil parameter values in land surface – atmosphere exchange studies.

PUBLICATIONS RELATED TO THE DISSERTATION

Journal papers:

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