Experiments in soil physics – case study

Grzegorz Duniec, Andrzej Mazur

Institute of Meteorology and Water Management
National Research Institute.
Department of Numerical Meteorological Forecast COSMO
61 Podlesna str, PL-01-673 Warsaw, Poland

grzegorz.duniec@imgw.pl; andrzej.mazur@imgw.pl

Abstract

A project "New approach to parameterization of Physical Processes in soil in numerical model" started in August 2012 at IMWM-NRI. Basing on overhaul physical phenomena in soil, new parameterizations are being prepared taking into consideration physical processes in soil (microphysics processes in soil, fluid dynamics in porous media, soil dynamics), water cycle in soil and soil-plant-water relation. Parameterizations these are intended to further improve current parameterizations of the TERRA_ML in COSMO model.

At the moment authors are working on new mathematical description of the parameterization of bare soil evaporation, vertical and horizontal soil water transport and the runoff from soil layers. Before incorporating new parameterizations into the TERRA_ML several test cases is being prepared with different soil data sets. In this paper results from testing current TERRA_ML parameterization of the bare soil evaporation for a chosen season are presented. In the first experiment forecasts from COSMO model over the Poland area were compared with the satellite data , received from Satellite Remote Sensing Centre Institute. In the second experiment we tested a "point injection" of the initial soil condition. Later, the results of the 24th hour forecast form the COSMO model were compared with data from meteorological stations.

1 Introduction

Current parameterization of soil processes in meteorological TERRA_ML COSMO model was introduced in the '70s and '80s when the resolution of computational mesh in numerical models was much coarser than today - see Dickenson, 1984 for a comprehensive overview of these parameterizations. Finer resolution demands improved parameterization of the soil and vegetation processes which influence the meteorological forecast. Dickenson was pointed out that his parameterization has a lot deficiencies and although more recently many improvements were incorporated to the original formulation of Dickenson's parameterizations, TERRA_ML still has several weak points (e.g. Duniec and Mazur, 2012, 2013, 2014).

According to Dickenson (1984), parameterization of evaporation is based on:

a) dimensional analysis
b) physical reasoning
c) detail structure was inferred from trial and errors numerical integration

and has several recognized by Dickenson deficiencies , including

a) overestimation of evaporation during morning hours and for wet soil
b) underestimation of evaporation during afternoon hours and for dry soil
c) overestimation of evaporation for wet soil
d) underestimation of evaporation for dry soil
e) it was prepared for low mesh resolution but current version of model has a high mesh resolution (e.g. with grid size of 2,8 km) but the same, "old" soil parameterization schemes

Details of the present parameterizations in TERRA_ML can be found in documentation of COSMO model "*A Description of the Nonhydrostatic Regional Model LM, Part II: Physical Parameterization*".

In the current paper we are presenting results from the numerical experiments which were set in the preparation to improve parameterization of the evaporation processes in the TERRA_ML model. Because knowledge about forecast of agrophysical and meteorological fields in soil of the COSMO model is very limited, in the first step it was decided to compare numerical forecast with observation data from meteorological stations using the original formulations from the current TERRA_ML model. Soil observation data from meteorological stations belong IMWM - NRI were very poor so it was decided to use an analysis data from two sources. The first set was received from the Satellite Remote Sensing Center Institute of Meteorology and Water Management - National Research Institute, the second - from Institute of Agrophysics Polish Academy of Science.

2 Analysis based on data from Satellite Remote Sensing Center Institute

Satellite Remote Sensing Center receives soil data from satellite MetOp-A . Example of orbit MetOp-A element indicates that it is a pole satellite. Below is an example of element of orbit for epoch 22 of August 2013, 19:37:55 UTC:

- Eccentricity: 0.0000457
- Inclination: 98.7074^o
- perigee height: 819 km
- apogee height: 821 km
- right ascension of ascending node: 293.6326^o
- argument of perigee: 183.6942^o
- revolutions per day: 14.21488536
- mean anomaly at epoch: 176.4232^o

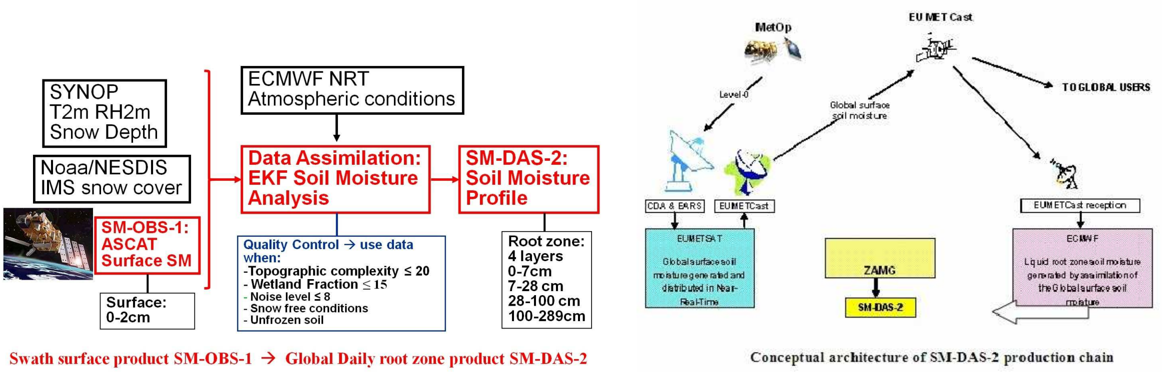


Figure 1: Conceptual schemes architecture of production chain figures from:“Product User Manual for product H14 – SM-DAS-2”.

At figure 1 a conceptual schemes architecture of production chain (Information come from Product User Manual – PUM – 14, Product H14 – SM-DAS-2, “EUMETSAT Satellite Application Facility on Support to Operational Hydrology and Water Management”, documentation page 6) is shown. Product operational characteristics form the satellite observations are as follow:

- observing cycle: 24 h,
- timeliness: 36 h,
- horizontal resolution: 25 km.

The soil profile is computed for four layers:

a) from surface to 7 cm,

b) 7 cm to 28 cm,

c) 28 cm to 100 cm,

d) 100 cm to 289 cm.

The statistic score of the available for the comparison data is:

a) Mean Bias: 0,043.

b) Standard Deviation: 0,246.

c) Correlation Coefficient: 0,203 or 0,047 m3/m3.

d) Root Mean Square Difference: 0,71.

To the analysis we have selected data from different seasons, keeping in mind a diversity of soil conditions (January, April, August, December in 2012). Next we compared results (forecast) from COSMO model with satellite data, analyzing standard statistic parameters such as Standard Deviation (SD), Correlation Coefficient (CC), Root Mean Square (RMS) and vertical and horizontal profiles. Only selected results for winter season are presented in this paper, namely the case of December 5th, 2012. In the Figure 2 below a synoptic situation in Europe is shown. During this time Poland was under influence of the atmospheric fronts connected with low system pressure with centre on the Baltic Sea, in the result soil was wet and frozen in many regions.

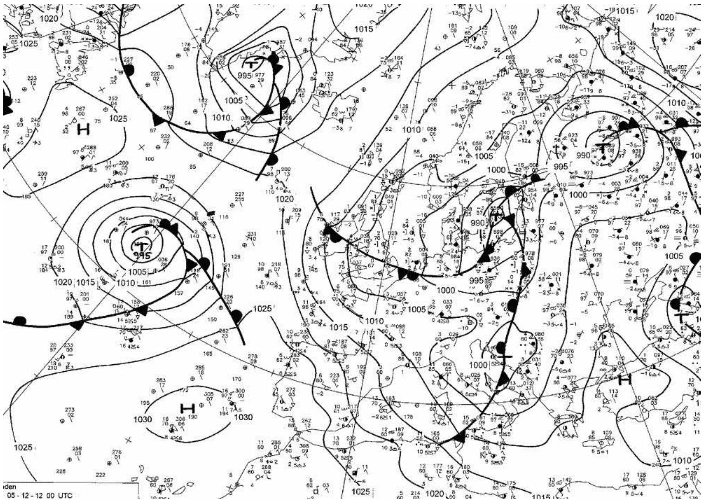


Figure 2: Synoptic situation for December of 5, 2012 for 00 UTC.

At the first step we chose areas with different sort if soil. These area were marked by letter A, B and C (fig. 3) to be further assessed in our numerical experiments.

A - Embryonic soil - Soil in the initial phase of formation, with small level of organic soil. Embryonic soils can be formed usually as a result of erosion of background on hard and loose flowing. Due to low fertility and low resistance to mass movements seldom used in agriculture. Embryonic soils are characterized by a shallow (10 cm) layer of soil with a bedrock located directly below (Uziak et al.). A characteristic feature of initial soil are relatively big rock fragments in the soil, particularly in the lower, less developed layer. In mountain areas an appearance of these soil is temporary due often mass transport down the slope (Skiba et al, 2009). Embryonic soils do not have a distinctive color. It depends on the surrounding rocks that originally form a soil (Uziak et al.).
The most common is the soil profile (A) CC - this abbreviation reads (Trzcinski, 1989):

- A - humus horizon
- C - the level of bedrock

Some authors distinct a separate thin organic layer and then profile description is O-C-AC (Skiba et al.)

B - Fawn (loess) soils - fertile brown soils with A-Eet-Bt-C profile. A characteristic feature of this type is washed-out colloidal clay, transported without decomposition to the lower level of Bt. It can found in the temperate (marine) and transitional zone - in Western and Central Europe, including Poland. It occurs under deciduous and mixed forests.

C - Brown soils - formed in temperate climate, primarily under a vegetation of deciduous and mixed forests. They are formed from various geological origin and various grain, from rocks rich in bases or acids (eg. weathered granite or gneiss) and from dusts (loess and loess-like tracks) . The pH of these soils are strongly acidic.
The brown color of the soils is a result of iron compounds and of brown humus compounds coating grains of soil in a form of thin shells.
In brown soils a cambic subsurface diagnostic level (Bbr) occurs, while in fawn soils - subsurface luvic (Eet) and argillic (Bt) levels (Mocek et al., 2000).

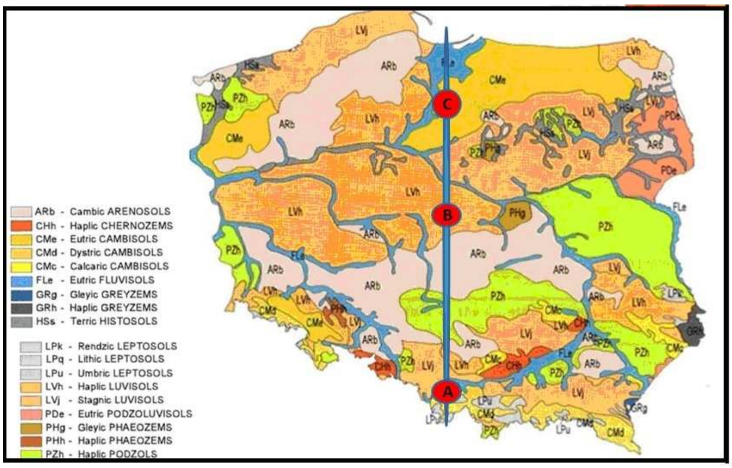
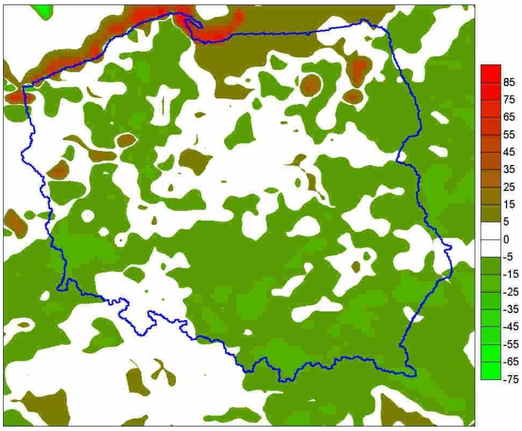
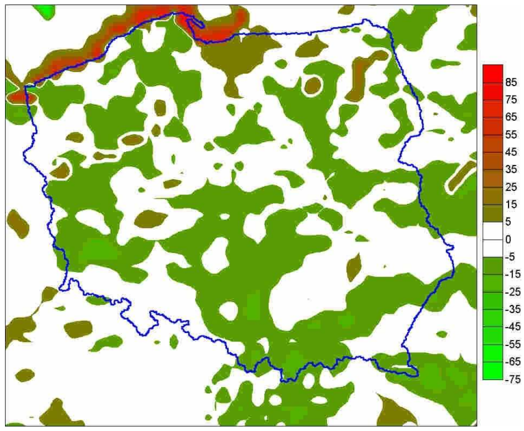


Figure 3: Points selected for analysis.

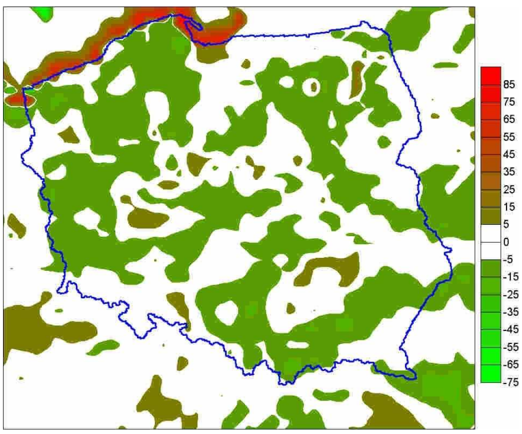
Next we compared forecast from COSMO model with results from satellite measurements for four soil layers. At figure 4, differences between results from COSMO model and satellite data are shown with green colors indicating areas where values of the Soil Water Content (SWC) from COSMO model was lower in comparison with values from satellite measurements (red colors -higher, respectively).



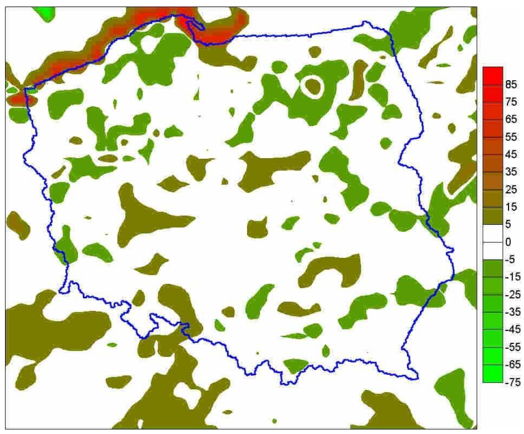
(a) 0-7 cm



(b) 7-28 cm



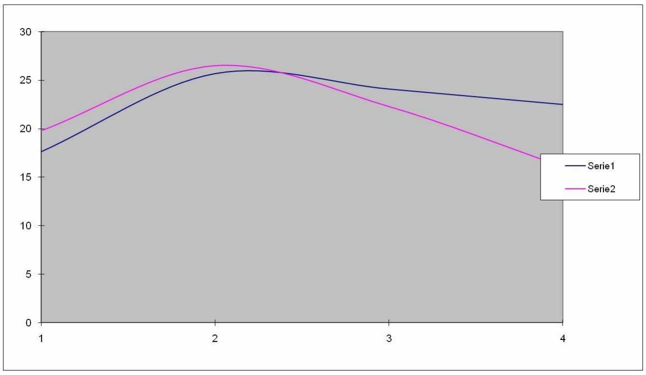
(c) 28-100 cm



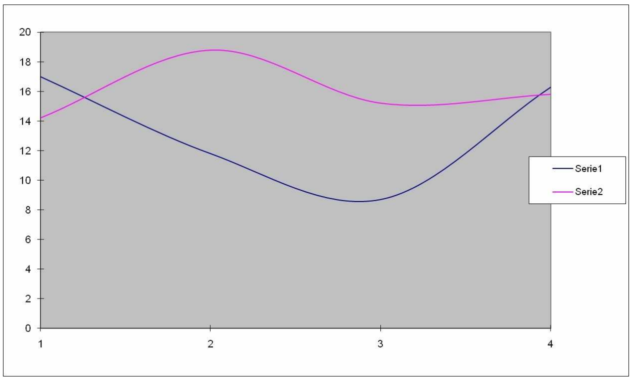
(d) 100-289 cm

Figure 4: Results for December 5th, 2012 – difference of values of SWC in layer

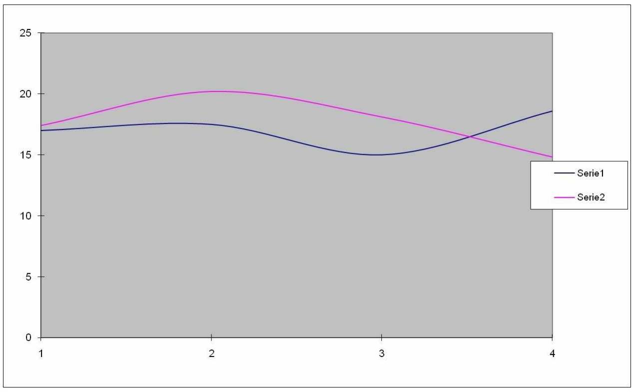
Next we analyzed vertical profiles of SWC for three chosen point (fig. 5). For the first and second layer COSMO model overestimate SWC in comparison with data from satellite. In deeper layer the opposite results were seen- SWC was underestimated in comparison with satellite data. At the point B only in the upper part of soil humidity was overestimated by COSMO model. In deeper layers situation change to opposite. At the region C, SWC was overestimated by COSMO model only in the fourth layer.



(a) profile of SWC in point A



(b) profile of SWC in point B



(c) profile of SWC in point C

Figure 5: Results for December 5th, 2012. Blue line represent values SWC from COSMO model and violet line represent data from satellite. Y axis – SWC in percent. X axis – layer number (centre of layer).

In the next step we analyzed cross-section horizontal profile for the four layers (fig. 7) along “blue line”, as showed at fig. 6. Along cross-section are following kind of soil: Umbric Leptosols, Haplic Luvisols, Haplic Podzols, Cambic Arenosols, Eutric Cambisols, Eutric Fluvisols.

In the central part of Poland the SWC was underestimated by COSMO model. In the marine area values of SWC were overestimated by COSMO model in comparison with satellite data. In mountain areas values of the SWC are very similar. In the second layer (fig. 7(b)) the SWC was overestimated by COSMO model in comparison with satellite measurements only in coastal region. In the third layer (fig. 7(c)) situation was very similar as for second layer, except that in mountain area values from COSMO model and from satellite measurements were almost identical. In the deepest layer (fig. 7(d)) results from COSMO model were very similar in comparison with results from satellite, except for coastal region where SWC was overestimated.

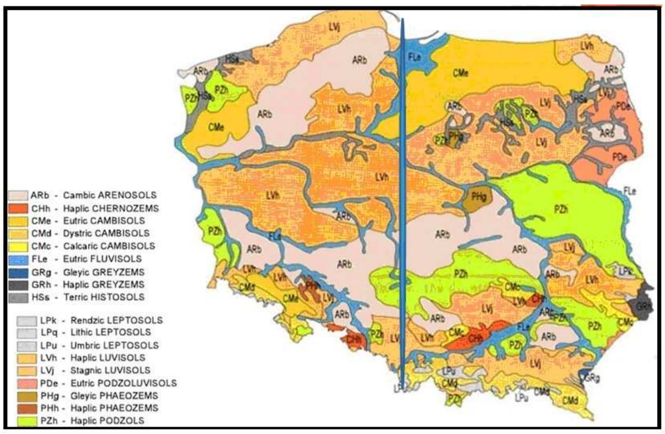
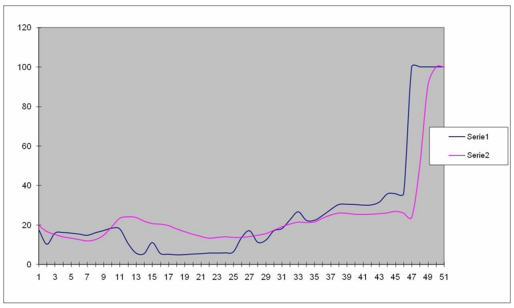


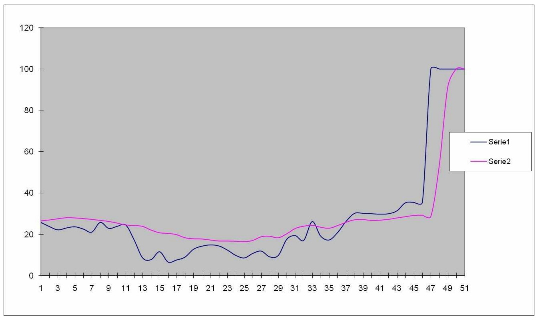
Figure 6: "Blue" vertical line indicate cross-section profile of SWC for the four soil layers.

Basing on numerical experiment for all cases we can summarize this part of the results:

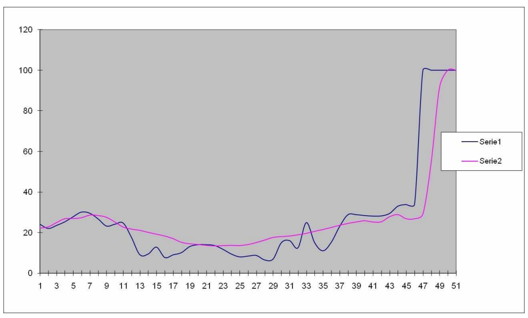
- **Generally for all data:**
  a) Overestimated SWC in coastal area.
  b) Underestimated SWC in mountain area and central part of Poland.
- **In detail for the different soil types:**
  a) Overestimated or underestimated SWC, depending on type of soil and of plant cover, seasons etc.:
  b) for Stagnogleyic Luvisols, Haplic Phaeozems, Haplic Podzols, Cambic Arenosols, – underestimated,
  c) for Eutric Cambisols, Haplic Luvisols – overestimated.



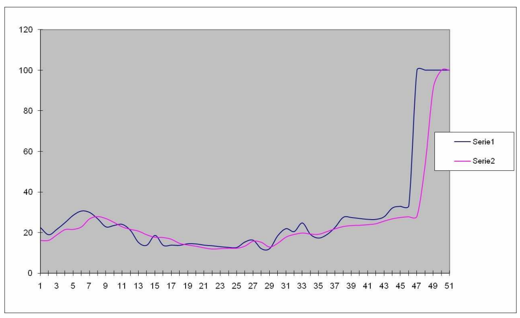
(a) 0-7 cm



(b) 7-28 cm



(c) 28-100 cm



(d) 100-289 cm

Figure 7: Results for December 5th, 2012 – cross section profile of SWC in layer. Blue line represent values SWC from COSMO model and violet line represent data from satellite. Y axis – SWC in percent. X axis – "y" coordinate of COSMO model (small domain).

3 Analysis based on data from Institute of Agrophysics Polish Academy of Science

Second set of data was gained from the Institute of Agrophysics, Polish Academy of Science. That data was received in the frame of formal cooperation established between both Institutes.

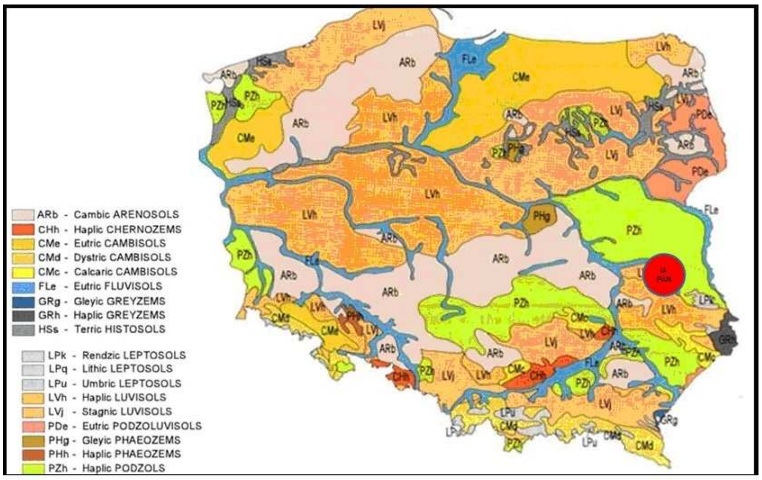


Figure 8: Red circle marks area of measurement.

At the experiment area following parameters were measured:

a) Temperature at 10 cm below ground level

b) Soil water content at 10 cm below ground level

The first set of data was gathered from January 2008 to December 2009.
Data come from the following four different locations in Poland:

a) $\lambda = 23^o06'14.2''$ $\phi = 51^o28'55.2''$ deep soil measurements; soil: sand in pinery,

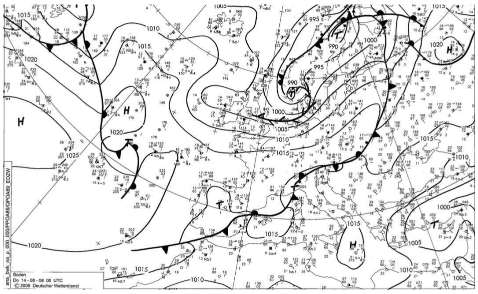
b) $\lambda = 23^o06'50.5''$ $\phi = 51^o28'23.7''$ surface soil measurements; soil: peat,

c) $\lambda = 23^o07'35.5''$ $\phi = 51^o27'40.1''$ surface soil measurements; soil: peat under grass,

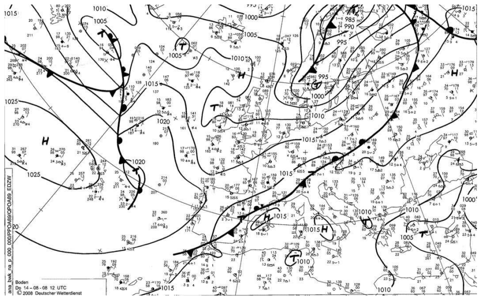
d) $\lambda = 23^o08'6.542''$ $\phi = 51^o27'12.424''$ deep soil measurements; soil: rendzic.

The initial soil conditions for COSMO model were replaced by the field data from Institute of Agrophysics in these four locations. Next, results from "reference" COSMO model with results received after changing initial data (so called COSMO – PAN – version) were compared. We analyzed standard statistic parameters including Mean Bias (MB), Standard Deviation (SD), Correlation Coefficient (CC), Root Square Difference (RMSD) and vertical and horizontal profiles.

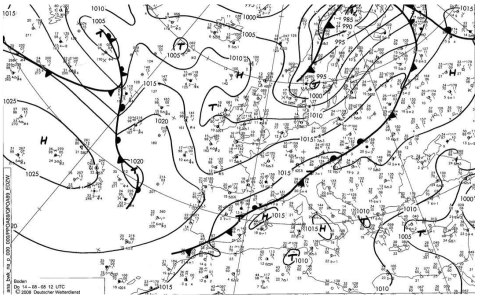
Selected data from August 14, 2008 are presented below. Poland was under influence of low system pressure with atmospheric front in the south-eastern part of country (fig. 9). During this day measured soil condition was warm and wet.



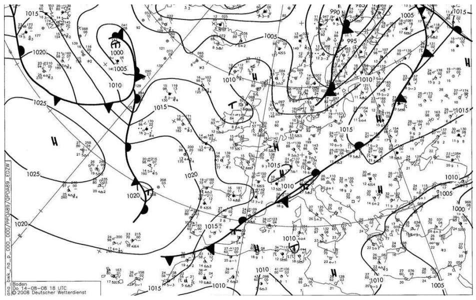
(a) 00 UTC



(b) 06 UTC

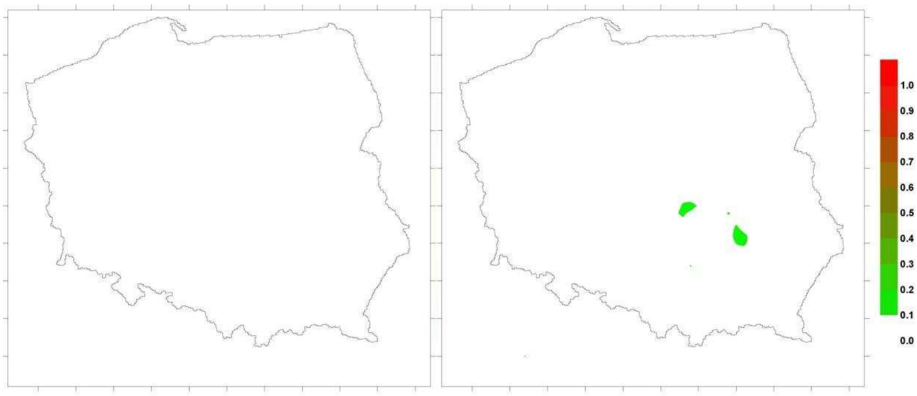


(c) 12 UTC

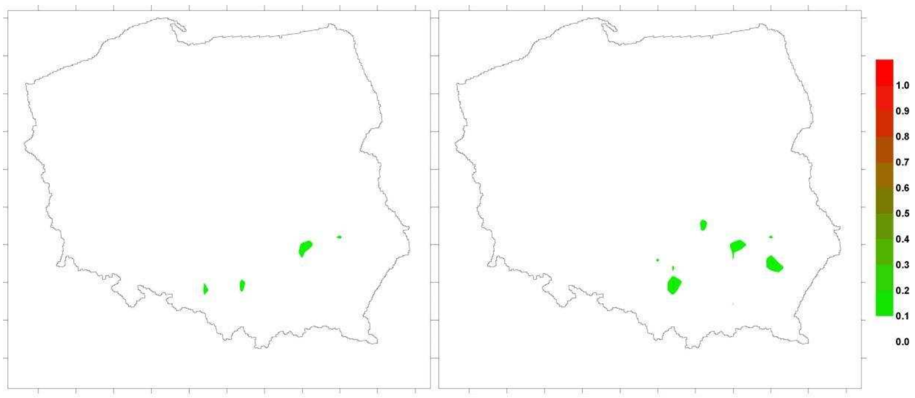


(d) 18 UTC

Figure 9: Synoptic situation for August 14th, 2008.

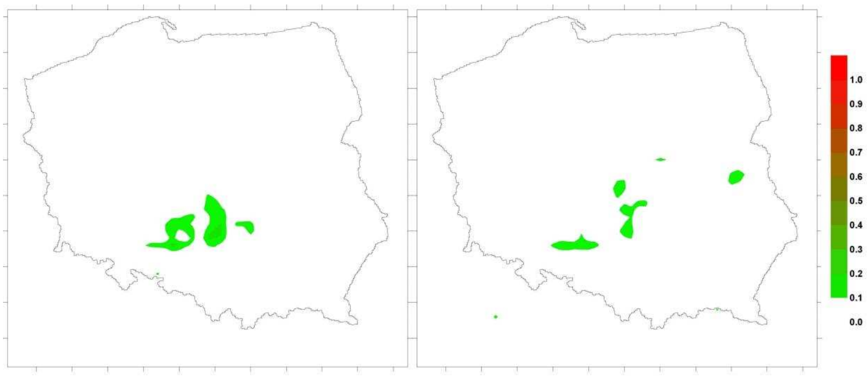


(a) 9th hour

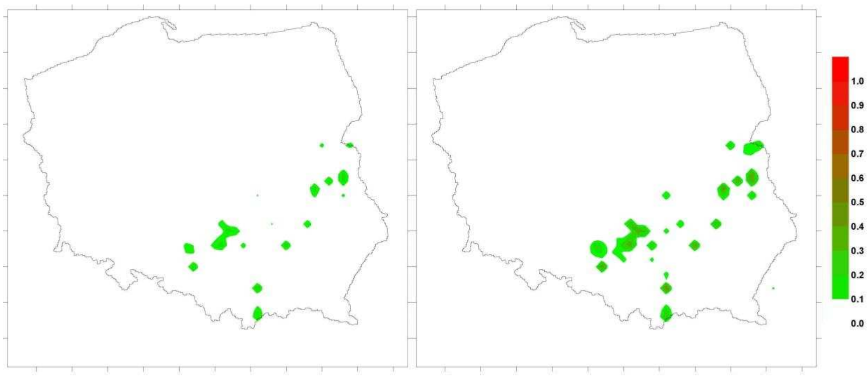


(b) 12th hour

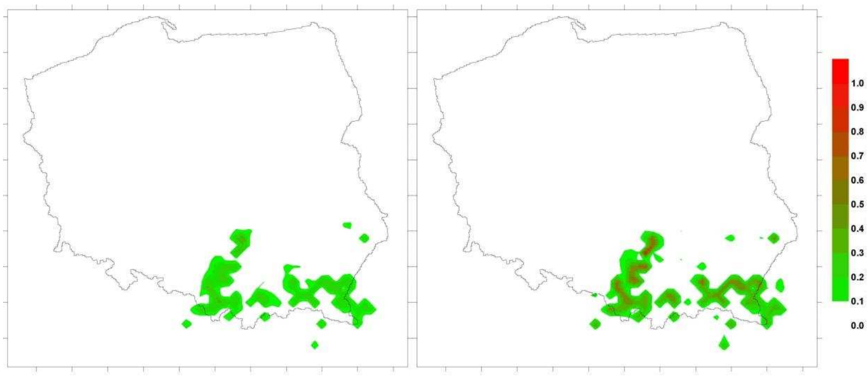
Figure 10: 9th hour and 12th hour forecast for: temperature at 2 m. a.g.l. (left) and temperature of soil surface (right panels). Forecast started at 00 UTC August 14th, 2008.



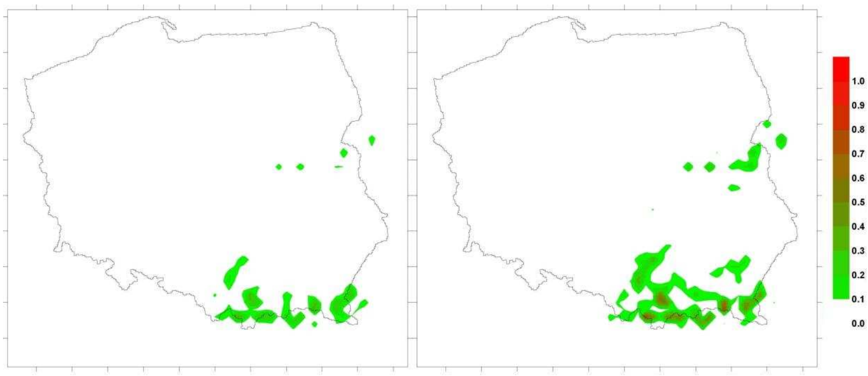
(a) 15th hour



(b) 18th hour



(c) 21st hour



(d) 24th hour

Figure 11: The 15th, 18th, 21st, and 24th hour of forecast for temperature at 2 m. a.g.l. (left) and temperature of soil surface (right). Forecast started at 00 UTC August 14th, 2008.

4 Summary

In this paper preliminary results of the numerical experiments of TERRA_ML model were presented. Current parameterization of soil processes in TERRA_ML COSMO numerical meteorological model give unsatisfactory forecasts of the agrophysical fields like as Soil Water Content (SWC), moisture flux which are very important and influencing on quality of meteorological fields. At first step we studied results from COSMO model and compared them with the data from observations. To make this comparison we used experimental data sets from two sources. The first one was from Satellite Remote Sensing Center, the second – received from the Institute of Agrophysics Polish Academy of Sciences.

Basing on numerical experiment which were made at Institute of Meteorology and Water Management, it was inferred for all cases that Soil Water Content (SWC) were overestimated in coastal area, SWC were underestimated in mountain area and central part of Poland (generally for all data). Consideration results in detail for the different soil types were observed overestimated or underestimated SWC, depending on type of soil and of plant cover, seasons etc.: for Stagnogleyic Luvisols, Haplic Phaeozems, Haplic Podzols, Cambic Arenosols, - underestimated,for Eutric Cambisols, Haplic Luvisols - overestimated. Generally, this effect depends on the type of soil, the plant cover as well as on the season of year.

A very interesting phenomenon can be seen using the second data set. “Point injection” of the initial conditions caused propagation of differences between “modified” and “reference” results, in large distance from the source these changes. The first differences appeared at ninth hour of forecast for temperature of soil at the surface and for twelfth hour of forecast for air temperature at 2 m. a.g.l. This test case will be elaborated in more details in the further studies.

Detailed results will be presented during the next COSMO meeting.

Acknowledgements authors would like to thank prof. C. Slawinski and Dr. K. Lamorski for providing experimental data in the frame of cooperation between IMWM and the Institute of Agrophysics Polish Academy of Sciences.

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