COTEKINO Priority Project – Results of Sensitivity Tests

Grzegorz Duniec, Andrzej Mazur

Department for Numerical Weather Forecasts. Institute of Meteorology and Water Management - National Research Institute. PL-01-673 Warsaw, 61 Podlesna str

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

Summary

Results of preliminary and detailed sensitivity tests of model output sensitivity to changes in soil-related parameters are presented in the paper. Conclusions and propositions regarding construction of "soil-parameters-based" ensemble(s) as a part of more general, lower-boundary-conditions-based EPS are an outcome of this case study.

1 Introduction

Moist atmospheric processes are clearly sensitive to soil conditions, as it was shown in many studies (see e.g. Sutton et al. 2006 or Cloke et al., 2012). At the Institute of Meteorology and Water Management – National Research Institute (IMWM-NRI) a simple method was proposed to assess a possibility to produce reasonable number of valid ensemble members, taking into consideration predefined soil parameters. The first phase is based on tentative analysis of the influence on a reference results from various model set-ups (e.g. parameter configurations, numerical schemes, physical parameterizations etc.) combined with rough changes of the selected soil-related model parameters (like surface-area index or bottom of the last hydrological active soil layer). This analysis provides an answer about "importance" of mentioned soil parameters and a possibility to neglect "less significant" ones. The proposed tests should answer, how small perturbations of selected parameter(s) are sufficient to induce most significant changes in the forecast of the state of atmosphere, and, thus, to provide qualitative selection of a "proper" member of an ensemble.

So far, the first two phases were applied in the analysis - a predefined group of different model configurations/set-ups was tested providing the first selection of soil-related parameters which will be used in our further ensemble experiments. Then detailed sensitivity test was carried out in order to establish test-bed environment used to assess validity of the selection of ensemble member(s) in a quasi-operational mode. Finally, these experiments should result in preparing a well-defined ensemble based on the soil parameters perturbation to be introduced in the COSMO model operational work.

2 Basic Methodology

COTEKINO sensitivity test setup

Due to convection-permitting grid resolution used in the simulations, shallow convection scheme was chosen as a basic (and invariant) setup to subsequent studies. Other physical parameterizations and numerical schemes selected for the test were as follows (see Schattler et al. 2008, for details):

- The various formulations of the advection:
  - Leapfrog: 3–timelevel HE-VI (Horizontally Explicit – Vertically Implicit) Integration. This scheme is used as a default setup in Poland for 7km resolution operational model instance, as well as for the COSMO-EU in DWD.
  - Runge - Kutta: 2-timelevel HE-VI Integration (irunge_kutta=1). This scheme is used for the COSMO-DE.
  - Runge - Kutta: 2-timelevel HE-VI Integration (irunge_kutta=2) - variant scheme with Total Variation Diminishing.
- Vertical turbulent diffusion:

  - 1-D diagnostic closure (used in combination with leapfrog scheme only).
  - 1-D TKE-based diagnostic closure(used in COSMO-EU and in COSMO-DE).
- Parameter to select the type of parameterization for transpiration by vegetation:
  - Bucket version.
  - BATS version.

All the above gives total of 9 basic (reference) set-ups. Then soil-related parameters to be evaluated in the sensitivity test were chosen as follows:

- c_soil (with relation to c_lnd) – surface-area index of evaporating fraction from 0 to c_lnd (surface-area index of gridpoints over land, default 1.0),
- crsmin – minimum value of stomatal resistance (used in connection with BATS version only) from 50 to 200 (default 150.0),
- pat_len – length scale of subscale sfc parameters over land from 0 to 10000 (500 m),

all the above in TUNING namelist and

- czbot_w_so – depth of bottom of last hydrological active soil layer, from 0.0 to last soil level depth (default 2.0 meters) in PHYCTL namelist.

General assumption for the preliminary assessment was to choose three to four values from a given parameter range, including minimum and maximum ones.

Output fields selected for comparison were:

- Soil – soil temperature at 0 cm down (surface temp.).
- T2m – air temperature at 2m above ground level.
- Water – water + ice content of soil layers 1cm down the surface.
- U10m – zonal wind component, 10m above ground level.
- V10m – meridional wind component, 10m above ground level.

Statistical characteristics selected for sensitivity analysis were as follows:

- point-to-point difference pattern (field) with center of mass of field of differences, defined as

$$\vec{r}_d = \frac{\sum_{r_x} t_x \cdot r_x}{\sum_{r_x}} \tag{1}$$

  with t_x being value of field at point r_x.
- average difference (over entire domain)
- RMS of difference (over entire domain)
- maximum difference of values (MDV) defined as

$$MDV = \max |t_r(i,j) - t_c(i,j)| \ \mathrm{sign}|t_r(i,j) - t_c(i,j)| \tag{2}$$

  where, r and c – reference and changes, respectively)
- normalized difference of values (NDV)

$$NDV = \frac{\langle T_c \rangle - \langle T_r \rangle}{\langle T_r \rangle} 100 \tag{3}$$

  where $\langle T_x \rangle$ being

$$\langle T_x \rangle = \frac{\sum_{i=1}^{i_{max}} \sum_{j=1}^{j_{max}} t_x(i,j)}{i_{max} \cdot j_{max}} \tag{4}$$

  and

- R (Pearson) correlation coefficient (over entire domain)

$$R = \frac{\sum_{i=1}^{i_{max}} \sum_{j=1}^{j_{max}} (t_c(i,j) - \langle T_c \rangle) \cdot (t_r(i,j) - \langle T_r \rangle)}{\sqrt{\sum_{i=1}^{i_{max}} \sum_{j=1}^{j_{max}} (t_c(i,j) - \langle T_c \rangle)^2} \sqrt{\sum_{i=1}^{i_{max}} \sum_{j=1}^{j_{max}} (t_r(i,j) - \langle T_r \rangle)^2}} \quad (5)$$

As a case study basis eleven different synoptic situations were chosen (for Poland area); six of them tested before during COLOBOC priority project, and five new ones:

- 2009.02.01 (00 UTC) - low temperature, the ground was frozen solid
- 2009.02.22 (12 UTC) - sunny/fair day
- 2009.10.16 (00 UTC, 06 UTC) - ground covered with snow
- 2009.11.04 (12 UTC) - windy day with precipitation
- 2009.11.21 (06 UTC) - foggy day
- 2012.02.03 (00 UTC) - very cold day with air temperature below -20^oC, ground frozen solid after two weeks of low air temperatures
- 2012.05.18 (00 UTC) - sunny/fair day, ground temperatures below 0^oC
- 2012.07.01 (00 UTC) - sunny/fair/hot day
- 2020.12.14 (12 UTC) - again, very cold day with air temperature below -10^oC
- 2020.12.16 (12 UTC) - right after previous, some warming in the air (higher temperature)

3 First outcomes, preliminary conclusions

After completed model runs for mentioned terms and subsequent statistical computations following conclusions were drawn:

- There were no significant differences (sensitivities) with changes of numerical schemes (HE-VI, RK1 and/or RK2). Hence it was suggested in further study to limit to operational configuration of COSMO (which is 3-order standard Runge-Kutta scheme, 2-timelevel HE-VI integration with irunge_kutta=1, similar to COSMO-DE).
- "czbot_w_so" has a noteworthy impact on values of water and ice content down to 1458 cm below ground level.
- Parameter "c_soil" has a noteworthy impact on values of air temperature at 2m agl., dew point temperature and relative humidity at 2m agl., wind speed and direction at 10m agl. and surface specific humidity
- Other parameters have rather insignificant impact on tested values against reference ones.

Concerning all the above results, we decided to proceed with sensitivity tests with following assumptions:

1 Due to the (convection-permitting) scale of problem and space resolution of model domain shallow convection scheme is accepted as basic.

2 Basic numerical scheme would be 3-order standard Runge-Kutta scheme (see above).

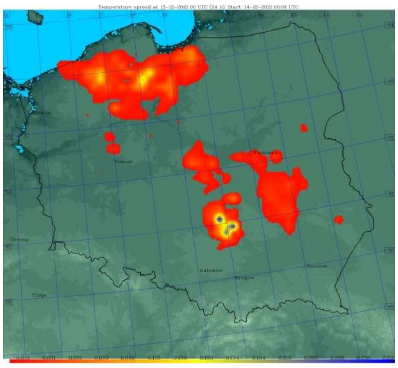
3 All eleven test cases (different synoptic situations) as listed above were consequently used to study the variability of the "c_soil" parameter within the range from 0 to 2.0 with step of 0.1 and of "czbot_w_so" parameter, within the range of 0.0 to 5.0m with step of 0.25m.

4 Results

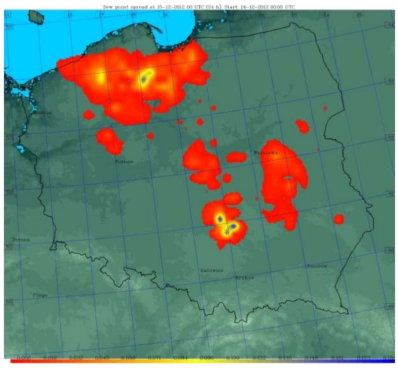
Following figures show selected results of sensitivity tests. All of results are described in terms of spatial distribution of "spread" – i.e. standard deviation of result against reference (default value) of selected parameter - and presented as the "spread" of the temperature (a; upper left), dew point (b; upper right), wind speed (c; lower left) and precipitation (d; lower right chart).

1 "c_soil" sensitivity test results (Figures 1–4).

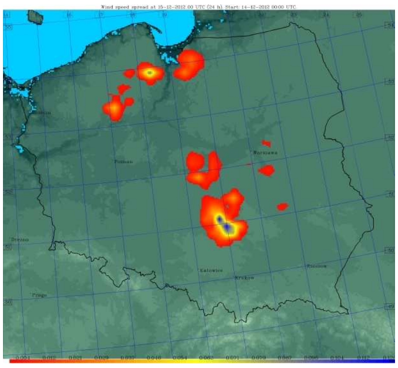
2 "cz_bot_w_so" sensitivity test results (Figures 5–8).



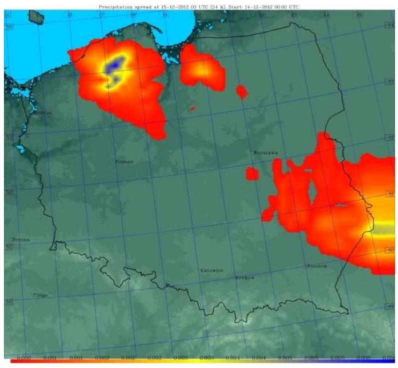
(a)



(b)

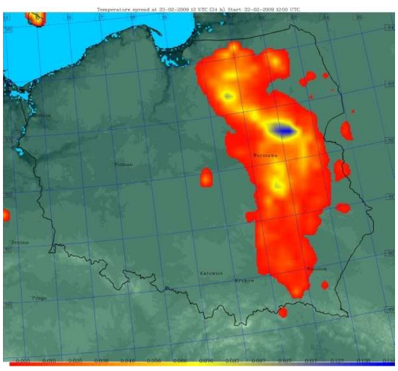


(c)

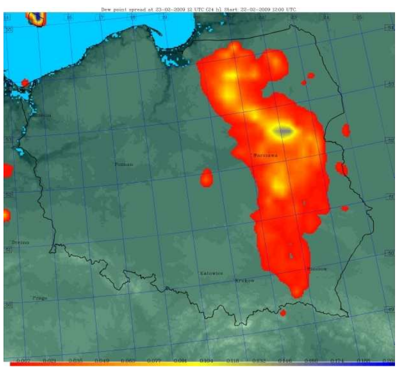


(d)

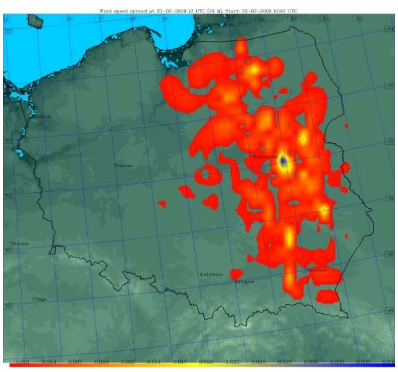
FIGURE 1: Winter case (December 14th, 2012)



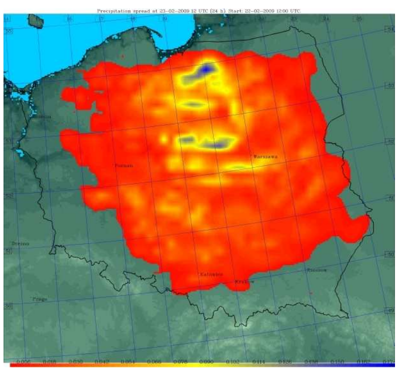
(a)



(b)

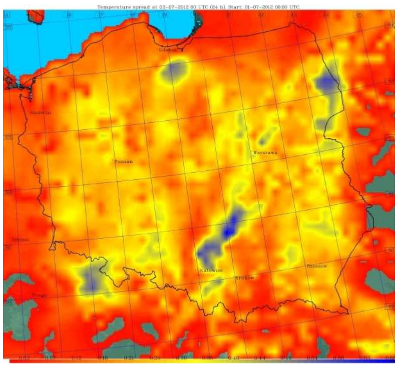


(c)

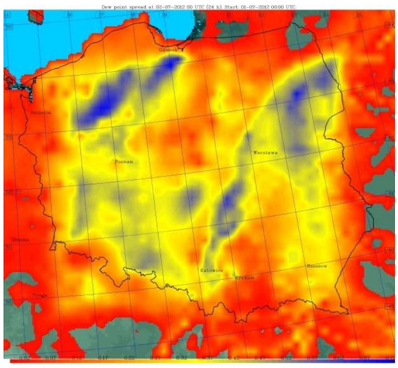


(d)

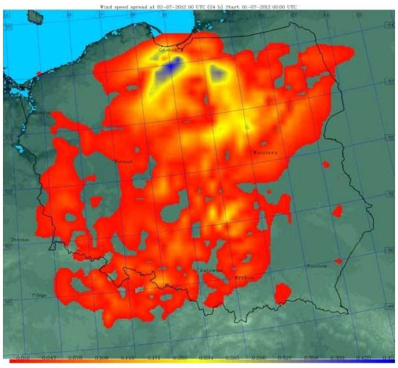
FIGURE 2: Spring case (February 22nd, 2009)



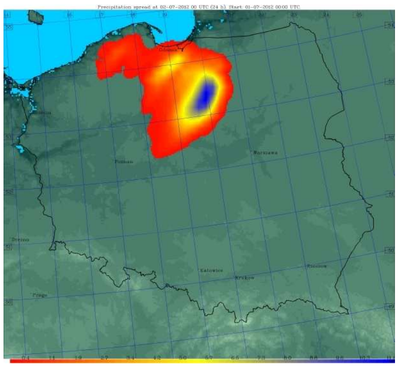
(a)



(b)

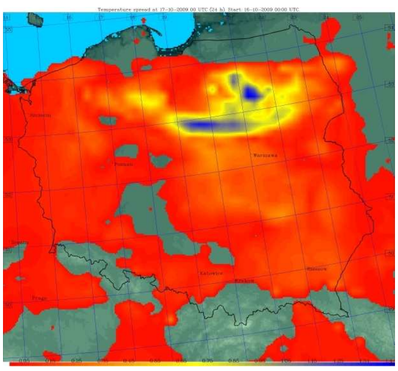


(c)

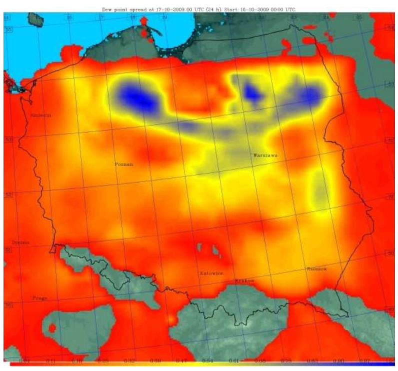


(d)

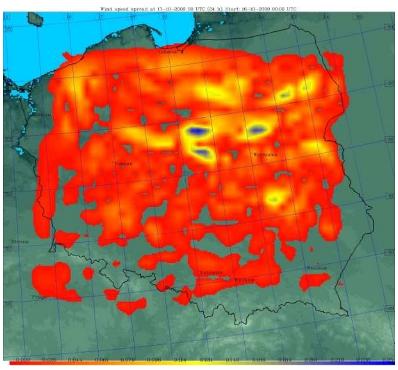
FIGURE 3: Summer case (July 1st, 2012)



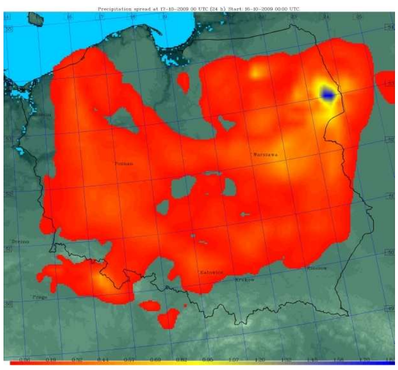
(a)



(b)

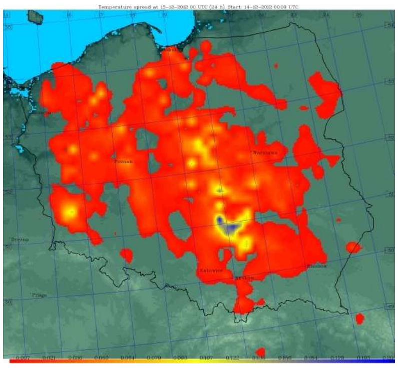


(c)

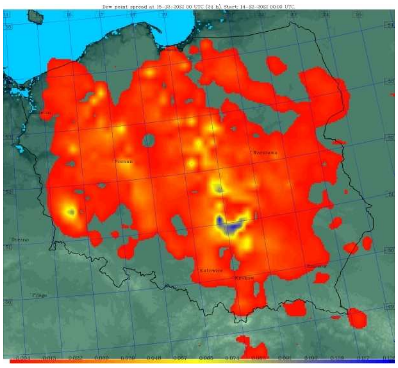


(d)

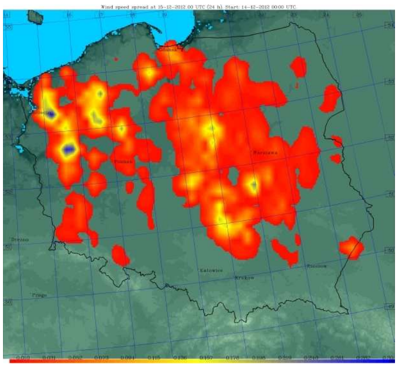
FIGURE 4: Fall case (October 16th, 2009)



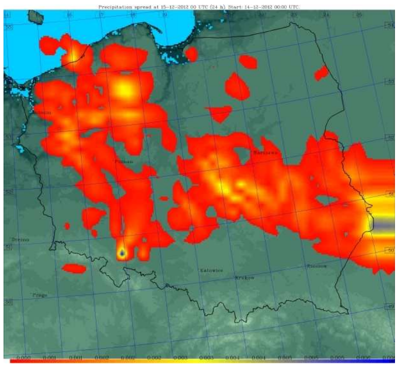
(a)



(b)

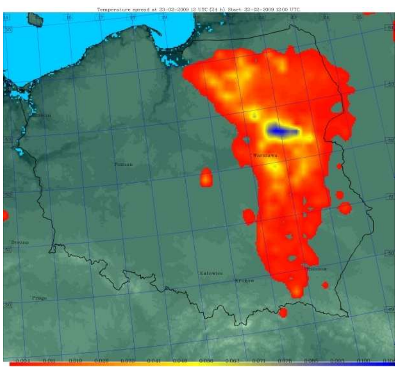


(c)

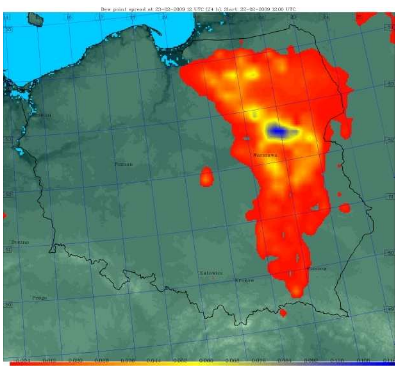


(d)

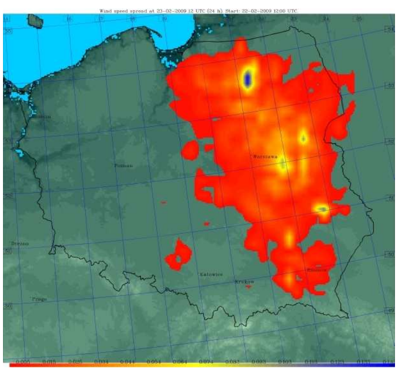
FIGURE 5: Winter case (December 14th, 2012)



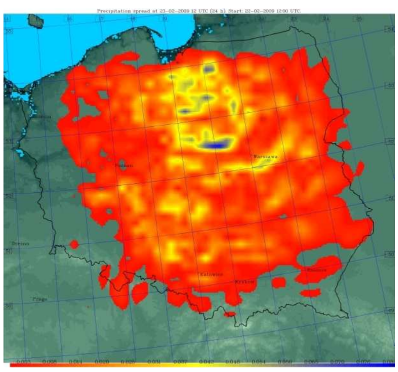
(a)



(b)

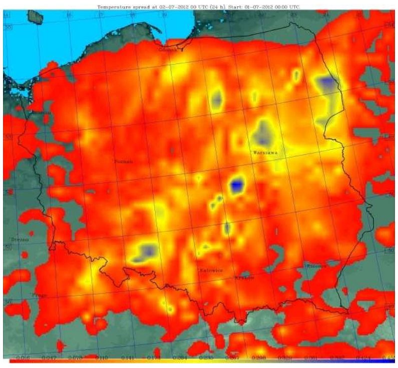


(c)

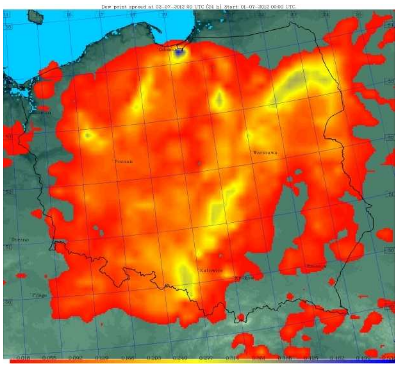


(d)

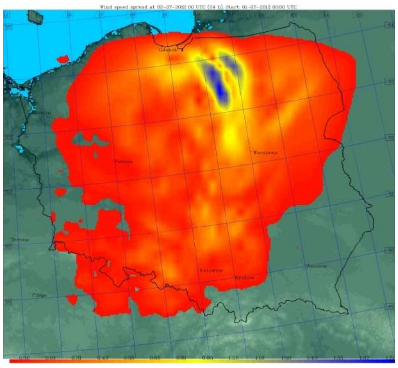
FIGURE 6: Spring case (February 22nd, 2009)



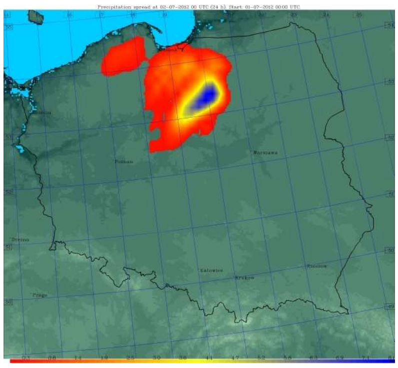
(a)



(b)

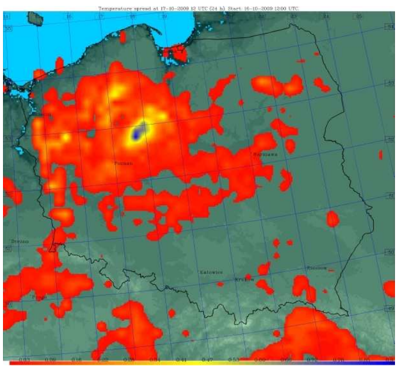


(c)

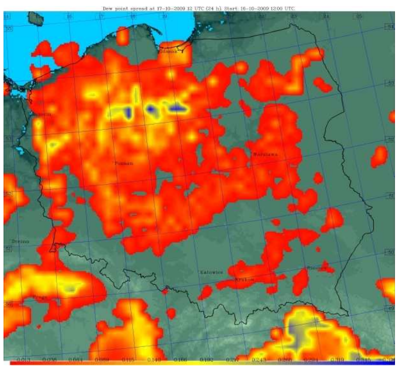


(d)

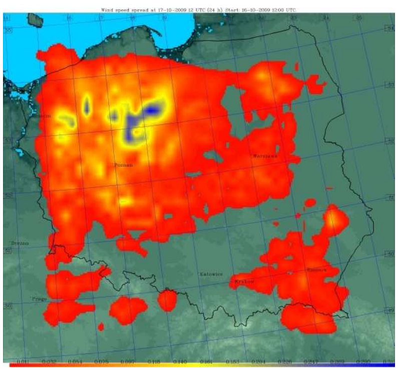
FIGURE 7: Summer case (July 1st, 2012)



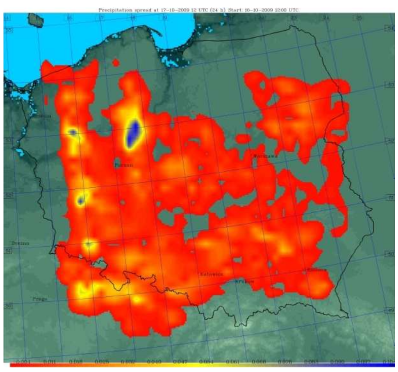
(a)



(b)



(c)



(d)

FIGURE 8: Fall case (October 16th, 2009)

5 Discussion

As in preliminary computations it should be stressed that changes of "czbot_w_so" had a noteworthy impact on values of "deep soil" parameters, like water/ice and water content, temperature of soil layers etc. down to 1458 cm. This influence varied from 10 to 25 percent of original (reference) value, and seemed to enlarge with increase of czbot_w_so Impact on values of lower-atmosphere parameters like air temperature, dew point, precipitation amount or wind speed most likely to be neglected. On the opposite, changes of "c_soil" seem to induce significant changes of values of air temperature, dew point temperature and relative humidity at 2m agl., wind speed/direction at 10m agl. and surface specific humidity forecast against reference ones. The maximum "spread" (standard deviation of values against reference one) – is as big as 2^oC (in case of temperature or dew point) or 1.5 m/s (wind-speed). Mean difference (over the entire domain) between maximum and minimum values was about 0.1^oC and 0.07 m/s, respectively. This order of changes pertained mostly to "warm" cases (late spring, summer, early fall), since for obvious reasons soil is at this time much more "subtle" to "stimuli" from a boundary layer. Thus, all the changes seemed to be much more visible during warm season as above defined. Impact on values of soil parameters like water/ice and water content, or soil layers temperature is rather irrelevant.

In the frame of COTEKINO priority project it is planned to study a possibility to prepare sufficiently representative ensemble in two different ways. It would be a random setting of a one value of c_soil/czbot_w_so globally/uniformly for the entire domain, which is easier to perform (required change(s) in namelist only), and there's no need for modification of the source code. This approach is, in general, a logical consequence of research described in this paper. The second approach proposed to assess is a more "stochastic" one: a valid ensemble could be prepared via modification of the source code to modify values of c_soil/czbot_w_so from gridpoint to gridpoint over the domain in a random way. Subsequent activities are planned to gain ensemble(s) in both ways and to compare results of these approaches.

References

[1] Cloke,H., Weisheimer,A., Pappenberger,F., 2011; Representing uncertainty in land surface hydrology: fully coupled simulations with the ECMWF land surface scheme. *Workshop on Model Uncertainty*, 20-24 June 2011, ECMWF, Reading (UK).

[2] Doms,G., Schattler,U., 2002; A Description of the Nonhydrostatic Regional Model LM, Part I: Dynamics and Numerics, DWD.

[3] Doms,G., Forstner,J., Heise,E., Herzog,H.-J., Raschendorfer,M., Reinhardt,T., Ritter,B., Schrodin,R., Schulz,J.-P., Vogel,G., 2007; A Description of the Nonhydrostatic Regional Model LM, Part II: Physical Parameterization, DWD.

[4] Rewut,B., 1980; Soil physics (in Polish: Fizyka gleby), PWRiL.

[5] Schattler,U., Doms,G., Schraff,C., 2009; A Description of the Nonhydrostatic Regional Model LM, Part VII: User's Guide, DWD.

[6] Sutton, Hamill,T., Warner,T., 2006; Will perturbing soil moisture improve warm-season ensemble forecasts? A proof of concept. *Mon. Weather Rev.* 134, **3174-3189**.