Ensemble Prediction System (EPS)-based forecast prepared from perturbations of soil conditions

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1 Summary

The significance of Ensemble Prediction System (EPS)-based forecasts is now greater than ever. Perturbations of the lower boundary state (i.e. of soil and - the boundary between soil and lower atmosphere) applied to EPS are also believed to play an important role at any resolution. The aim of this study was to develop, test and verify a simple method of preparing an ensemble of forecasts using a perturbation of selected soil parameters. The first phase involved tests of specified group of different model set-ups and pre-selection of parameters to be used in further experiments.

Then, sensitivity tests were carried out to verify the correct selection of ensemble members in a quasi-operational mode. The aim of the tests was to obtain a response whether a small perturbation of soil-related parameter(s) would be considerable efficient to cause significant changes in the forecast and create "proper" ensemble. Two methods of preparing a well-defined ensemble based on the soil parameters perturbation were evaluated for (potential) operational implementation in the COSMO model.

2 Introduction and methods

As a part of COSMO Towards Ensembles at the Km-scale In Our Countries (COTEKINO) priority project of Consortium for Small-scale Modeling (COSMO) at the Institute of Meteorology and Water Management – National Research Institute (IMWM-NRI) a simple method was proposed to produce reasonable number of valid ensemble members, taking into consideration predefined soil-related model parameters. The first phase was based on tentative analysis of the influence on a reference results from various model set-ups (i.e. parameters, numerical schemes, physical parameterizations, etc.) combined with rough changes of these parameters, like the surface-area index or bottom of the last hydrological active soil layer. The analysis provided an answer about "importance" of soil parameters and a possibility to neglect "less significant" ones. Having results of this approach as a first step (see Duniec and Mazur, 2014; Mazur and Duniec, 2014), in the second phase further sensitivity tests were performed. This allowed for detailed selection of various configurations and for assessing methods of perturbation of important soil parameters.

After completion of numerous model runs following conclusions were drawn: (i) climatological layer depth (cz_bot_w_so) had a noteworthy impact on values of water and ice content down to lower boundary of soil model; (ii) surface area index of evaporating fraction (c_soil) had a noteworthy impact on values of relative humidity, air and dew point temperatures at 2m agl. and on the wind speed and direction at 10m agl.; (iii) other parameters had rather insignificant impact on forecast values in comparison with reference ones. Thus, sensitivity tests were set-up with the following numerical schemes applied: (a) a shallow convection parameterization was set as a basic convection scheme, and (b) a 3-order Runge-Kutta advection.

Changes of cz_bot_w_so had a significant impact on water and ice content as well as soil temperature down to 1458 cm, but its impact on the lower atmosphere fields, such as temperature, precipitation, dew point temperature and wind speed was relatively small. Moreover, this parameter, as of an integer type -from 1 to 7 - was not very useful for a preparation of an ensemble. On the other hand, perturbation of c_soil has a significant influence on the air temperature, dew point and humidity at 2 m a.g.l., and wind speed/wind direction at 10 m a.g.l., as well as on surface specific humidity. As a floating-point number it may be equal to any value from its range of variability (ie. from 0 to 2.0). So c_soil is (potentially) a much better candidate for base of an ensemble. Thus, all selected cases were studied in detail regarding changes of c_soil parameter (Mazur and Duniec, 2014).

Representative ensemble members could be prepared using two methods:

- Random set the one value of c-soil, globally, on the whole domain (easier to perform, you need to change the namlists) do not need to change the model code.

- An alternative approach -by modifying the source code may distribute the random values of the c-soil from point to point over the entire model domain.

All of results are described in terms of spatial distribution of forecast “spread” – i.e. the standard deviation against mean value.

3 Results and discussion

As a case study basis, eleven selected terms (dates of the start of forecast) were chosen, covering four season and diversity of synoptic situations. In the following figures results of an application of the point-to-point method mentioned above, as a sample preparation method of an ensemble are presented.

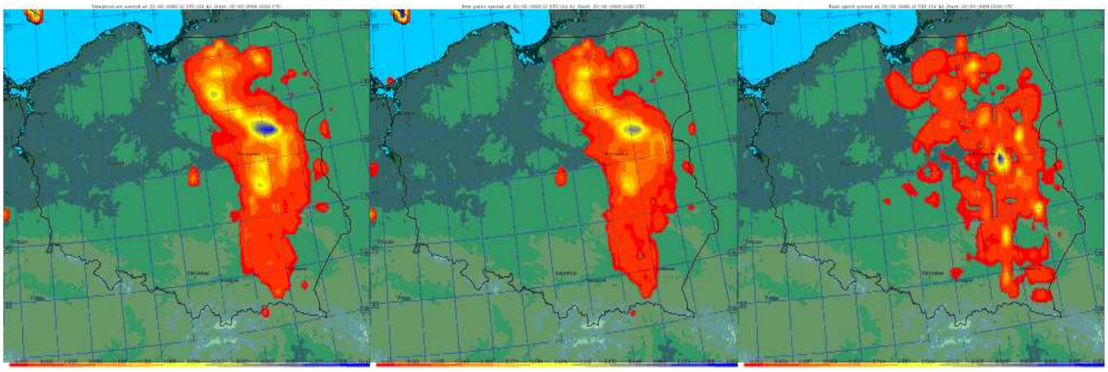

Figure 1: Spread of selected meteorological field over a c_soil based ensemble; winter case (February 22nd, 2009). Left chart - temperature (max spread value - 0.2^oC), middle - dew point temperature (max spread value - 0.2^oC), right - wind speed (max spread value - 0.1 m/s).

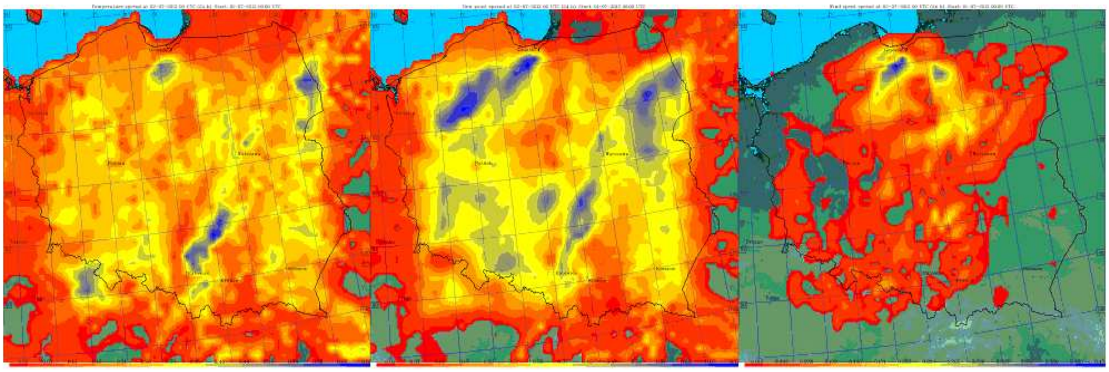

Figure 2: Spread of selected meteorological field over a c_soil based ensemble; summer case (July 1st, 2012). Left chart -temperature (max spread value -0.7^oC),middle - dew point temperature (max spread value - 0.9^oC), right - wind speed (max spread value -1.0 m/s).

In the following figures results of the comparison of ensemble forecasts with measurements at meteorological stations (seashore station Leba, midland station in Warsaw and Poznan, mountain station Zakopane) are shown for selected (winter and summer) cases.

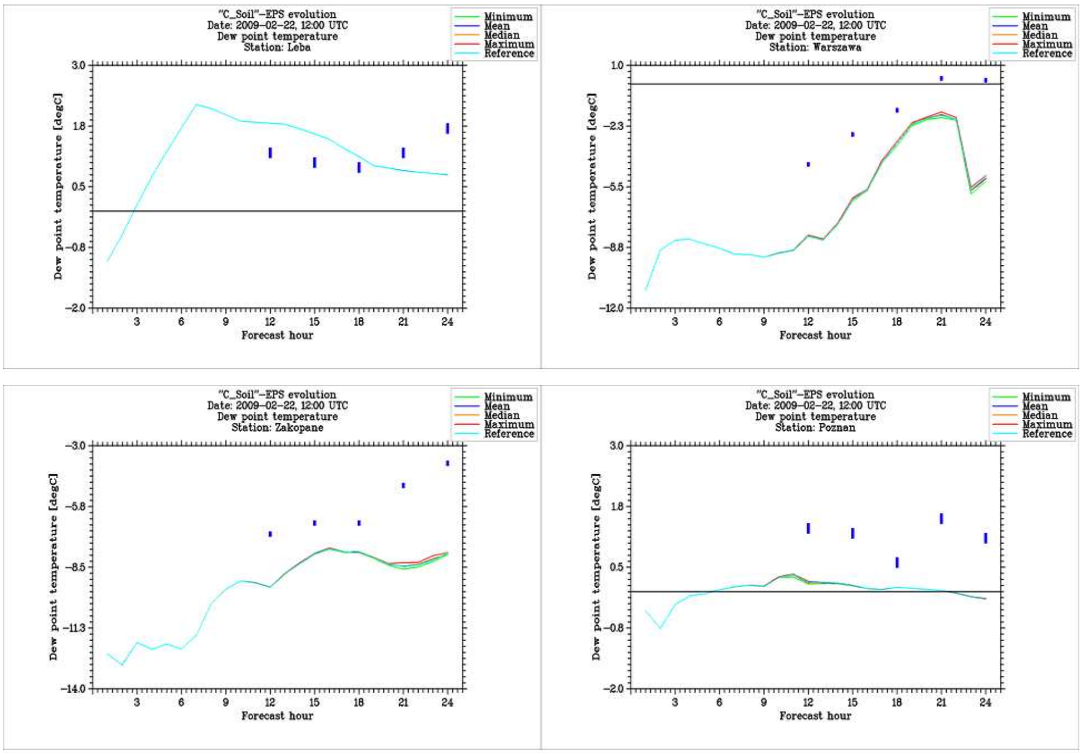

Figure 3: Ensemble forecast with c_soil, for the winter case, February 22^{nd}, 2009. "Spaghetti-plots" against values measured at meteorological stations (vertical bars). Dew point temperature forecast at the following stations:upper left – Leba, upper right – Warsaw, lower left – Poznan , lower right – Zakopane.

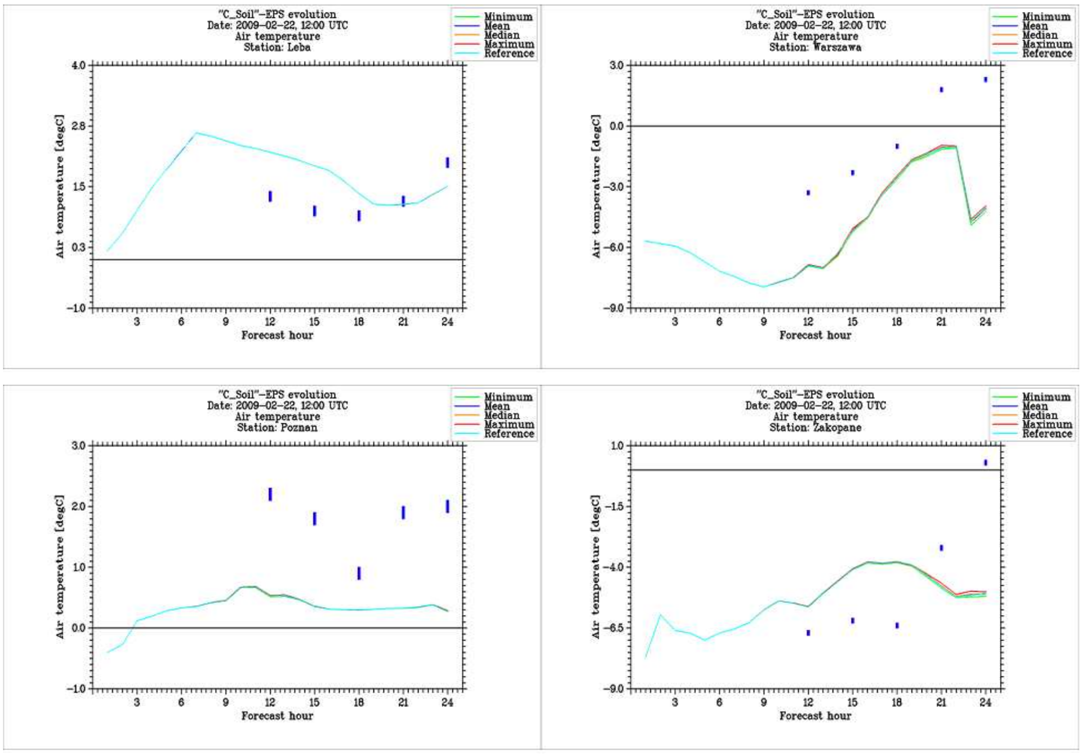

Figure 4: Same case as on Fig.3 but for, air temperature forecast.

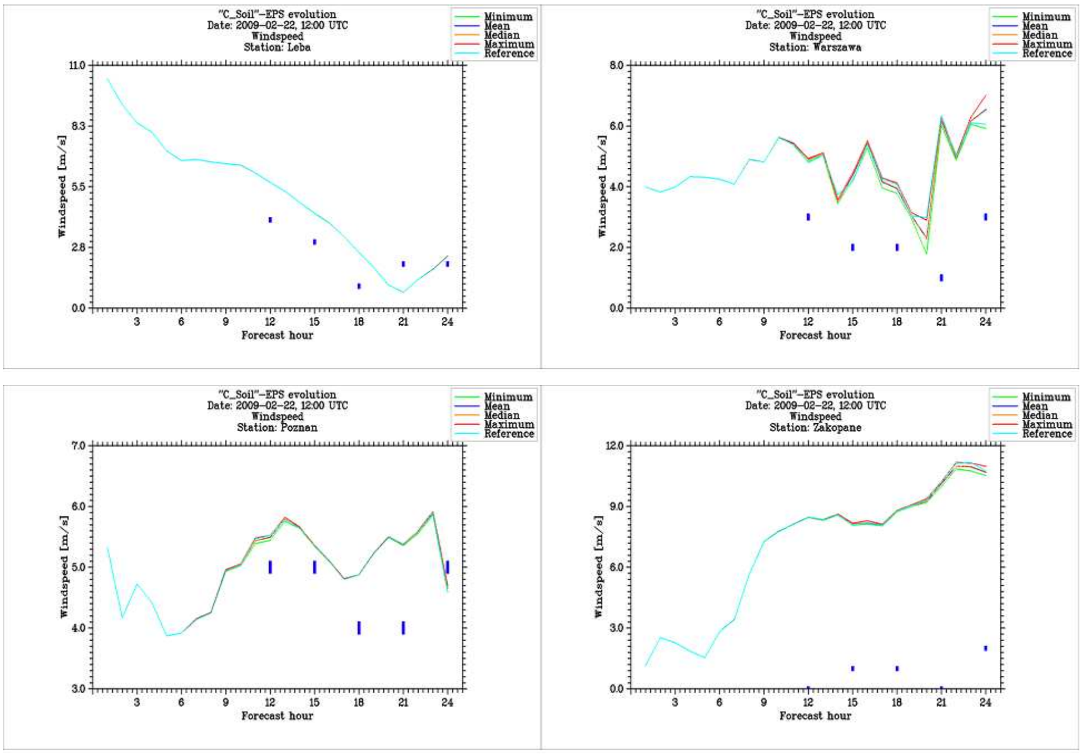

Figure 5: Same case as on Fig.3 but for wind speed forecast.

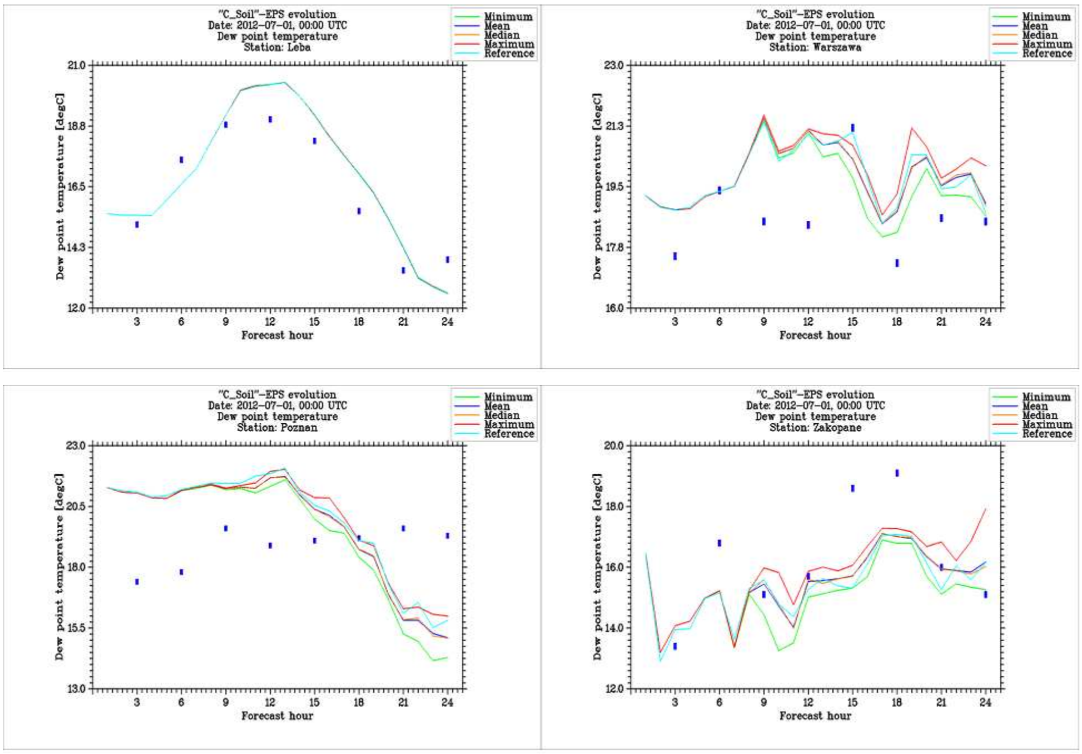

Figure 6: Ensemble forecast with c_soil, summer case, July 1^{st}, 2012. “Spaghetti-plots” against values measured at meteorological stations. Dew point temperature forecast at stations: upper left – Leba, upper right – Warsaw, lower left – Poznan , lower right – Zakopane.

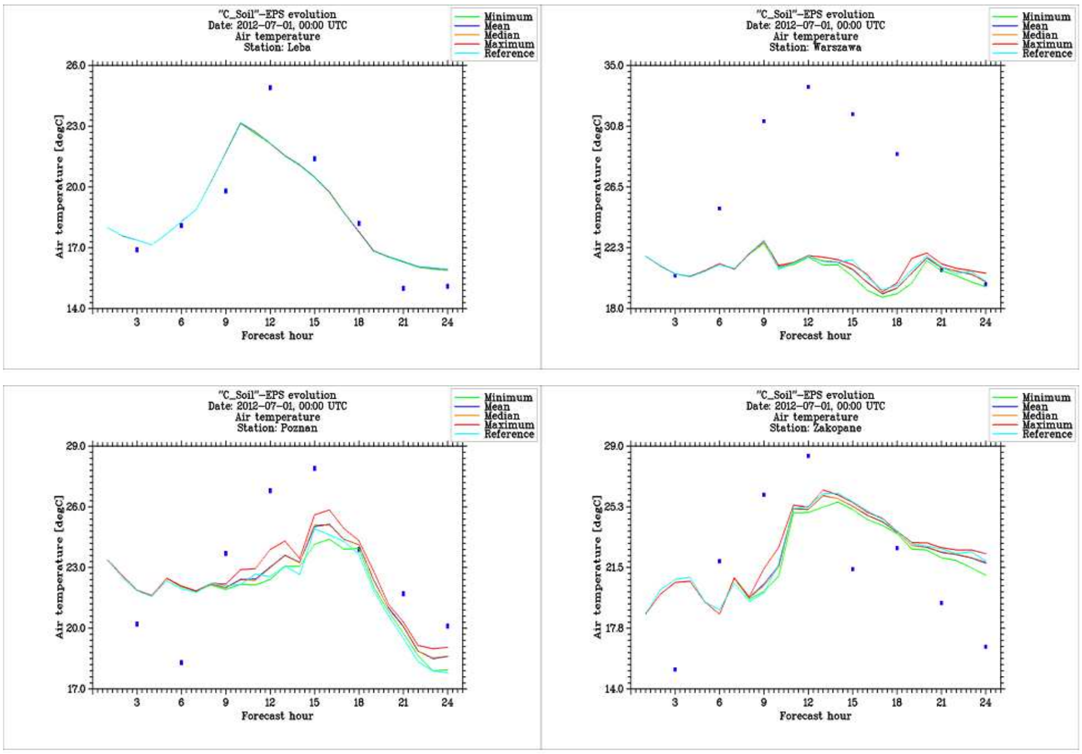

Figure 7: Same case as on Fig.6 but for air temperature forecast.

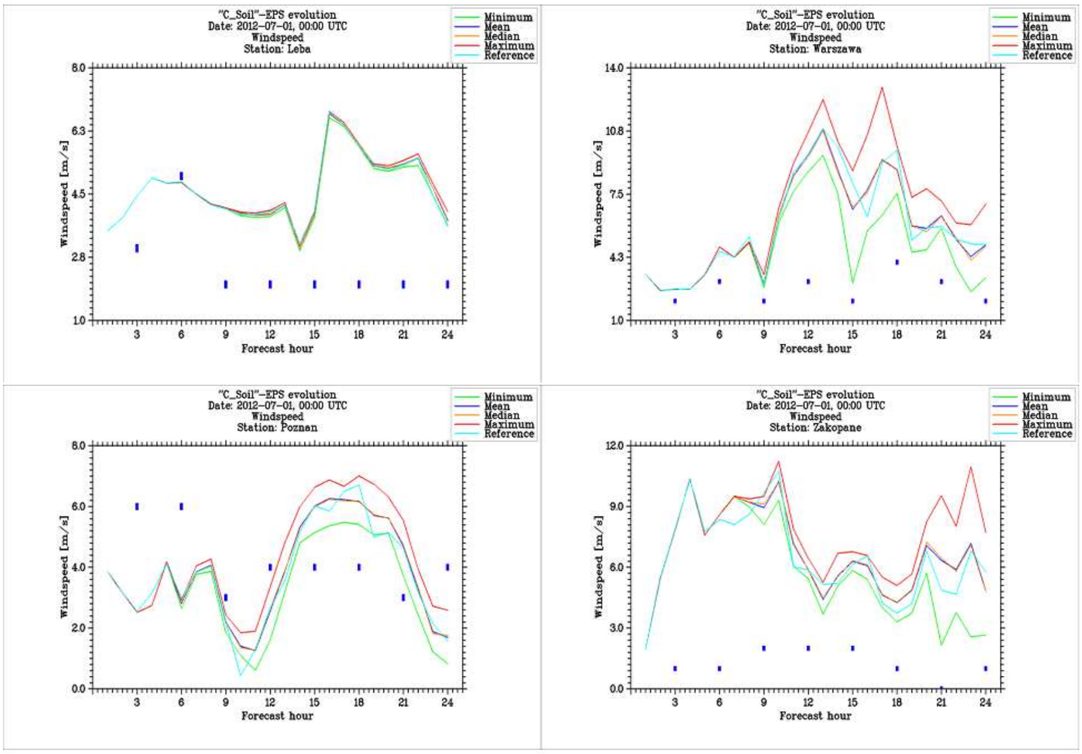

Figure 8: Same case on Fig.6 but for wind speed forecast.

The last part of the study presented here was a combination of changes of soil processes parameterization (Duniec and Mazur 2014) with the preparation of soil-based ensemble forecasts. After replacing the Dickinson equation with the temperature-dependent Darcy equation, similarly to deterministic forecasts, further improvement in forecasts can be seen. Examples of the results are shown in the following figures. Actual values, measured at stations are “closer” to the forecast spread calculated for appropriate hour.

This improvement can be seen to a big extent in forecast of wind speed, especially in central part of Poland, like Warsaw and Poznan, rather than these located at the seashore (Leba) or in mountain regions (Zakopane). This effect is most likely correlated with type or nature of soil in these locations (luvisols in central part of Poland, small land fraction at the sea cost or gravel/pebble settlements in southern Poland).

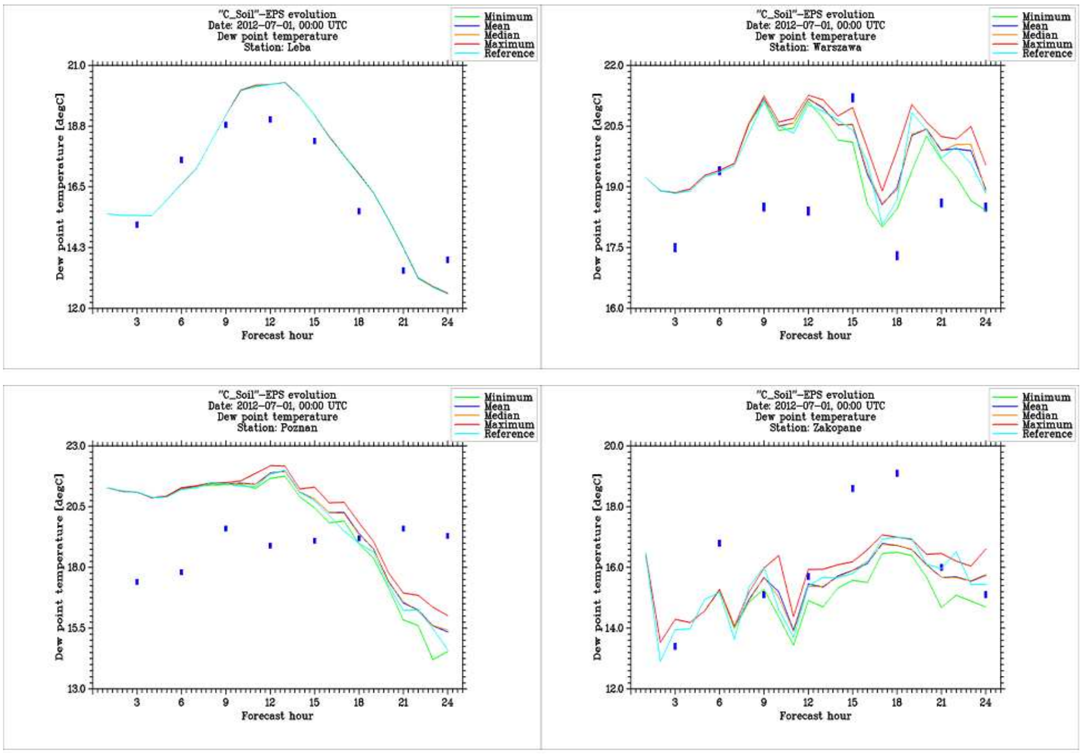

Figure 9: Ensemble forecast with c_soil, summer case, July 1^{st}, 2012, combined with altered soil processes parameterization. “Spaghetti-plots” against values measured at meteorological stations. Dew point temperature forecast at the following sations: upper left – Leba, upper right – Warsaw, lower left – Poznan , lower right – Zakopane.

Last figures show quantitative effect of changes of soil processes parameterization on a forecast quality.

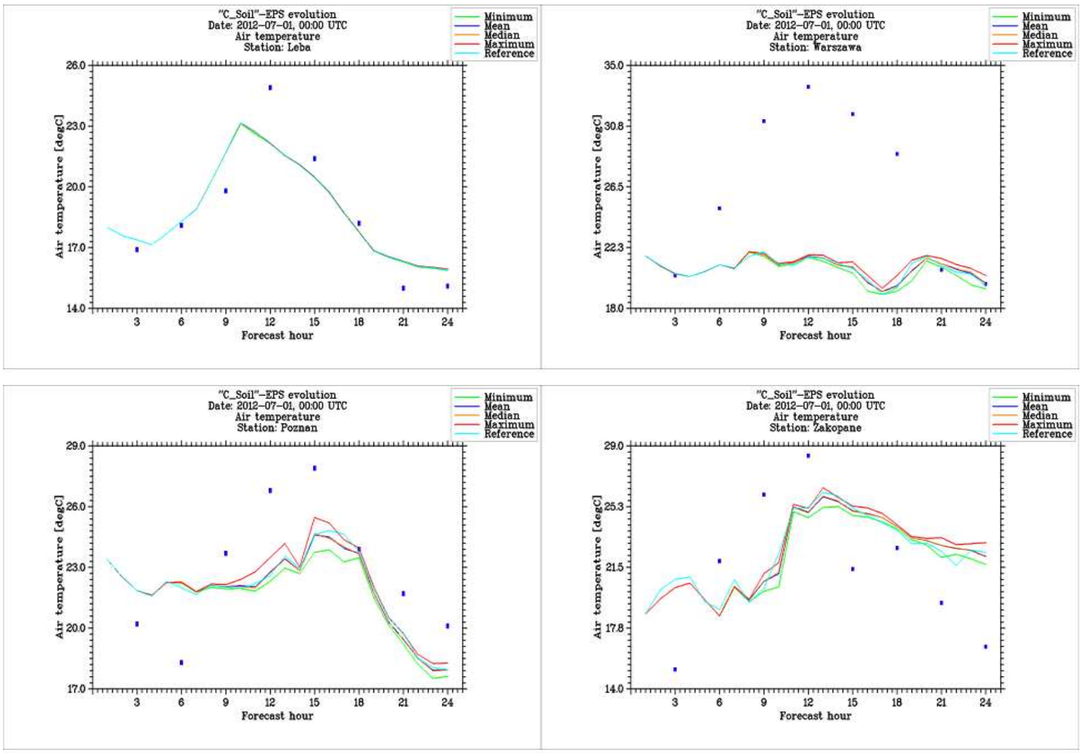

Figure 10: Same case as on Fig.9 for the altered soil processes parameterization, and air temperature forecast.

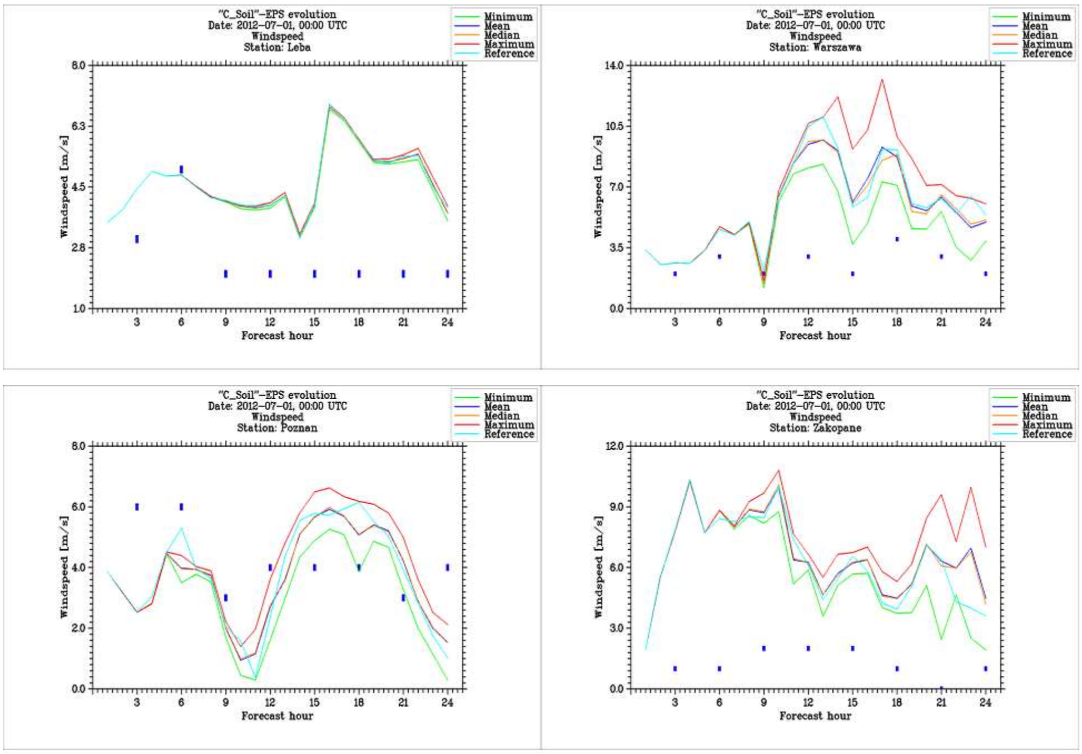

Figure 11: Same case as on Fig.9 for the altered soil processes parameterization and wind speed forecast.

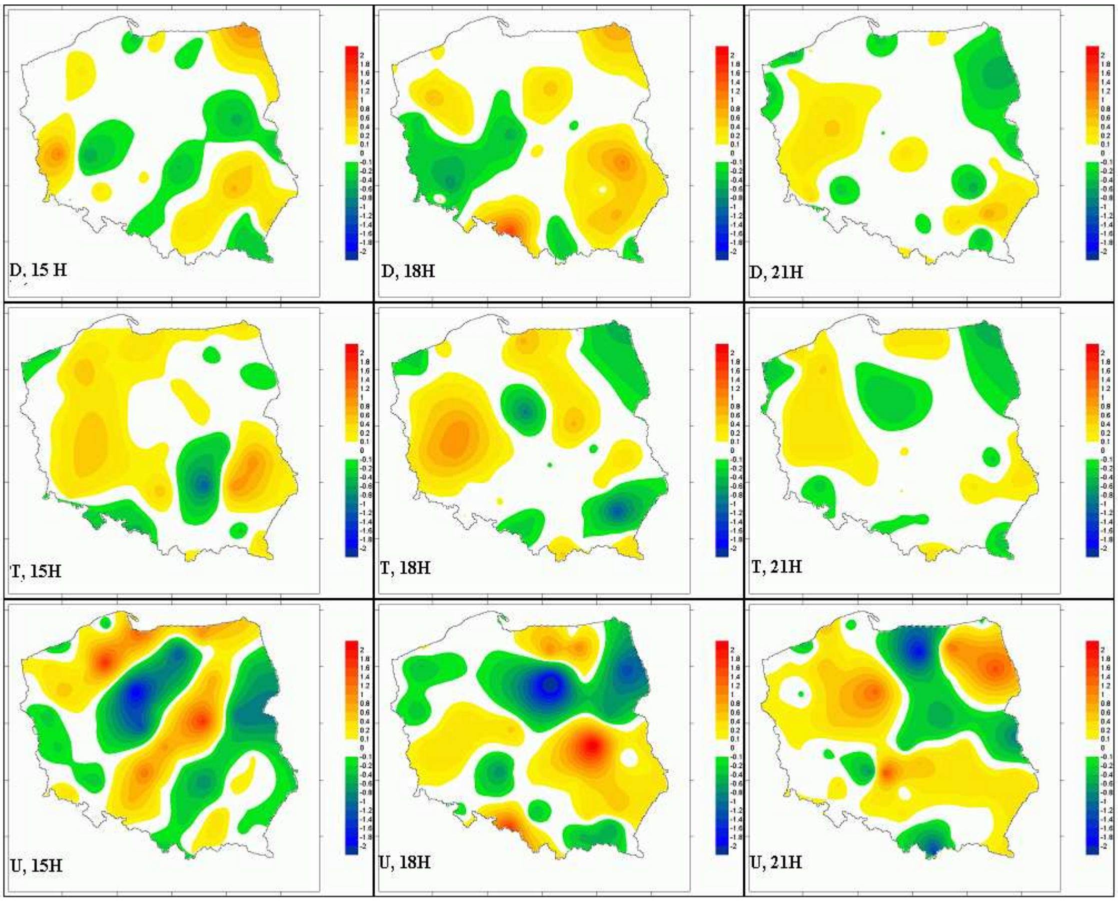

Figure 12: Comparison of "regular" c_soil-based ensemble forecast with the one combined with altered soil processes parameterization. Summer case, July 1st, 2012. Upper row – prediction of dew point temperature for 15th, 18th, and 21st hour of forecast. Middle row - temperature forecast, similarly. Lower row - wind speed forecast, similarly. Areas with "warm" colors represent improvement of forecast, areas with "cold" colors - worsening of forecast (see further explanation in text) due to change of soil processes parameterization.

A comparison of these two types of forecasts was carried out by computation a “distance” of a real value, measured at SYNOP stations, from an interval defined by a forecast’s spread, understood as a difference between minimum and maximum values over an ensemble. If the real value was located in the interval, this “distance” was identified as equal to zero. In the figure, areas with “warm” colors (from yellow to red) represent improvement of forecast (i.e., decrease of a “distance” forecast’s spread from real values) caused by change of parameterization, whereas areas with “cold” colors (from blue to green) – worsening of forecast.

An overall improvement (spatially computed, mean value of this “distance”) for every element shown above was recognized. In case of dew point and air temperature, significant improvement can be especially seen in central and south-eastern part of Poland. In case of wind speed forecasts, the “area of improvement” was moving with forecast hour, in general, from west to east. It should also be stated, however, that this improvement can hardly be seen in a beginning of a forecast(s). It seems that the soil parameterization need some “spin-up” time to have a significant impact on a quality of an ensemble forecast of atmosphere’s state.

4 Conclusions

Tests proved that small perturbations of selected parameter(s) were sufficient to induce significant changes in the forecast of the state of atmosphere and to provide qualitative selection of a valid member of an ensemble. However, perturbations have had almost negligible impact in the areas with land fraction much less than one and during the cold season (perhaps due to the specific soil conditions, e.g. frozen ground). A detailed (seasonal/annual) performance analysis is needed for stochastic forecasts. Comparison of ensemble forecasts with observations at meteorological stations showed that, as in the case of deterministic forecasts, introduction of altered soil processes parameterization slightly improved forecasts, mainly in the central/southern part of Poland, rather than closer to the sea or in mountain regions.

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