# Tests of TILES/MOSAIC parametrisation in COSMO model

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## 1 Summary

In COSMO model (Consortium for Small-Scale Modelling) physical processes occurring between lower atmosphere and upper soil layers were parameterized via soil model TERRA and TERRA/LM (Doms et al., 2007). Since 2009 at the Institute of Meteorology and Water Management (IMGW) two new parameterizations, MOSAIC and TILE, (Ament 2006, 2008 and Ament and Simmer, 2010, Duniec and Mazur 2011) have been tested. These parameterizations have taken into account non-homogeneities of the soil in a single grid. In 2009 and 2010 MOSAIC parameterization has been intensively tested (Duniec, Mazur, 2011), and tests were continued in 2011 with TILE parameterization. Tests were carried out using selected data from days with specific synoptic conditions. Different versions of the model code with both TILE and MOSAIC parameterizations implemented were used for tests, using various numerical and convection schemes.

## 2 Introduction

Physical processes occurring in the soil and the bottom layer of the atmosphere (in boundary layer of atmosphere), are interlinked. In soil, there is a set of hydrological and thermal processes (Warner, 2011):

- Capillary and gravitational transport of water, drainage of surface and subsurface runoff.
- Vertical transport of water vapor in the atmosphere via convection and molecular diffusion.
- Withdrawal of water in soil by plant roots (trees, grass, etc.).
- Freezing and melting and/or condensation and evaporation of water, release of absorbed latent heat due to these processes.
- Thermal conductivity.
- Precipitable water, water from melting snow, dew which penetrates into deeper layers of soil.
- Evaporation of water from the ground into the atmosphere.
- Heat exchanged between the ground and atmosphere.
- Transport of water in the roots, herbaceous, etc.
- Precipitation on the (covered or not covered - bare-soil) surface with vegetation.
- Drips of water on a surface or other plants.

- Snowfall and its excess on a soil surface covered with and on bare soil.
- Melting and sublimation of snow and frost and any accompanying thermal processes.
- Dew and frost on a soil covered or with vegetation or bare soil, release of latent heat.
- Surface mist (soil covered with vegetation and bare soil).
- Evaporation of water from the surface of the leaves of plants, transpiration, any accompanying thermal processes.

Many factors affects on thermal and hydrological processes in soil. These factors are related to:

**a)** soil type (clay, sand, silt, mud, sludge, etc., with different physical properties such as thermal conductivity, porosity, etc.),

**b)** soil cover (water, ice, snow),

**c)** type of vegetation covering a ground (grass, forest, etc.),

**d)** spatial distribution of vegetation coverage,

**e)** type of region (cities, villages, fields, meadows, etc.),

**f)** season (soil may be frozen, moist, dry, snow-covered etc. due to synoptic situation),

**g)** physical processes that occur in the lower atmosphere.

Since that these processes occur on a scale smaller than the resolution of model grid they must be parameterized. At present two parameterizations are applied in the COSMO model, namely soil and vegetation models TERRA and TERRA_LM (Doms et al., 2007), that assume that surface of the Earth in a single model grid is uniform. Since 2009 at IMGW two other parameterizations, TILE and MOSAIC, are tested. Both account for ground non-uniformity (Ament, 2006, 2008, Ament and Simmer, 2010, Duniec and Mazur 2011). Tests were carried out for several terms (selected dates). Selection was made on the basis of miscellaneous criteria, namely, season of a year, different conditions of soil - frozen, unfrozen, clamp, loose, etc.), synoptic situation (sunny, foggy, windy, cloudy day etc.), and atmospheric phenomena, (at ground surface, e.g. snow cover). In 2009 and 2010 tests of MOSAIC parameterization were conducted for six selected synoptic terms (Duniec, Mazur 2011) while in 2011 TILE and MOSAIC parameterizations were tested for nine (actually, six previously chosen and three additional) terms.

During tests various versions of model code model were used (4.08 and 4.14 with parameterizations MOSAIC and TILE implemented), with miscellaneous numeric and convection schemes. Approach MOSAIC and TILE is described in the work of (Ament 2006, 2008; see Ament and Simmer, 2011 and Duniec and Mazur 2011).
Following meteorological fields were selected for tests:

- TE2M - air temperature at 2m above ground level.
- TD2M - dew point temperature at 2m agl.
- TSOI - soil temperature at 0 cm.

- U10m - zonal wind component, 10m agl.
- V10m - meridional wind component, 10m agl.
- QV2M- specific water vapor content, 2m agl.
- QVSF - specific water vapor content at surface.
- PR - atmospheric pressure.

Data from nine terms with various soil- and synoptic conditions were selected for analysis, as follows: 01.02.2009, 00 UTC, 22.04.2009, 12 UTC, 22.07.2009, 00 UTC, 16.10.2009, 00 UTC and 06 UTC, 04.11.2009, 12 UTC, 21.11.2009, 06 UTC, 10.01.2010, 00 UTC, 25.02.2010, 00 UTC and 18.11.2010, 00 UTC.

Description of synoptic conditions in 01.02.2009, 22.04.2009, 16.10.2009, 04.11.2009 and 21.11.2009 one can find in (Duniec and Mazur 2011).

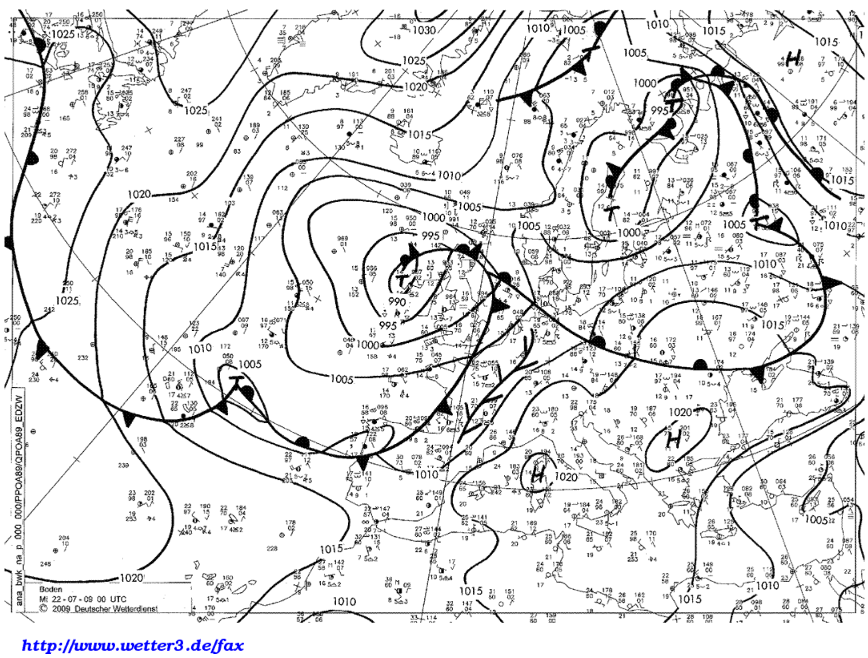


Figure 1: Synoptic situation of 22.07.2009, 00 UTC.

*Meteorological conditions in 22.07.2009, 00:00 UTC (Fig. 1).*
Weather in Western and Central Europe was influenced by fronts related to set of low-pressure centers. Southern Europe was in range of a high pressure center of 1020 hPa over Greece and Sardinia. South of Poland was up under an influence of a warm front associated with the atmospheric low-pressure center of 990 hPa over Ireland. Air temperature from 10.2 C to 20.8C. Wind form 0 to 10m/s over Baltic Sea in over western part of Sudety Mountains.

*Meteorological conditions in 10.01.2010, 00:00 UTC (Fig. 2).*
Northern Europe was in range of wide high-pressure center of 1040 hPa over southern Scandinavia. Western Europe was under an influence of high-pressure center of 1020 hPa over the Iberian Peninsula. The rest of Europe was in the range of low-pressure centers and atmospheric fronts. Southern Poland was in range of a warm front associated with the low-pressure

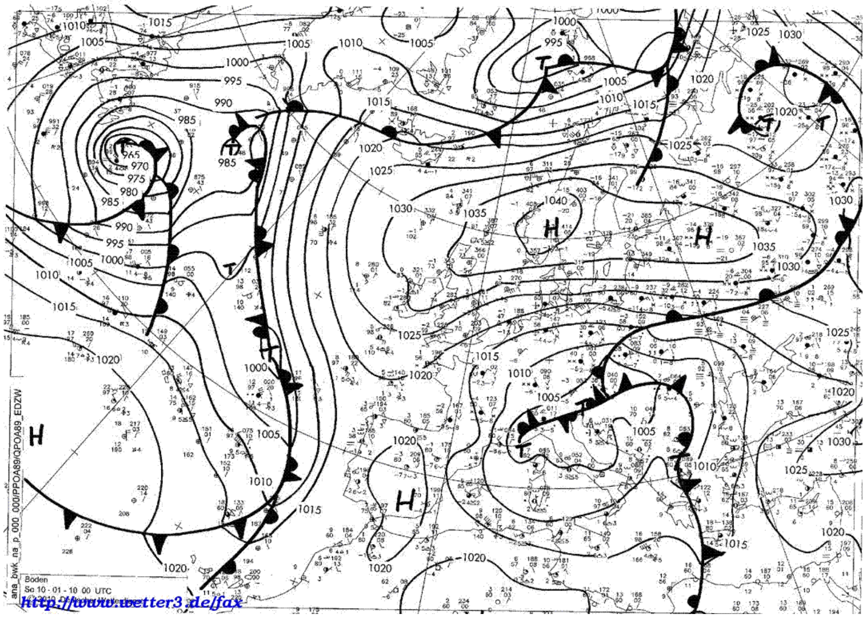


Figure 2: Synoptic situation of 10.01.2010, 00 UTC.

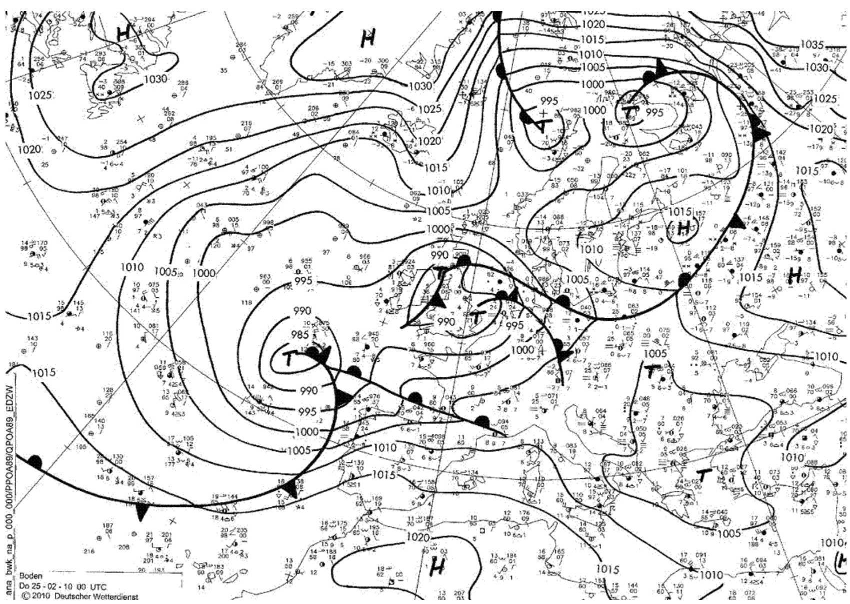


Figure 3: Synoptic situation of 25.02.2010, 00 UTC.

center of 1005 hPa over southern Europe. Wind from 1 m/s (midlands) to 21 m/s over Baltic Sea. Air temperature from -9.2C (north) to 1.9C in south.

*Meteorological conditions in 25.02.2010, 00:00 UTC (Fig. 3).*
In Western and Central Europe dominated systems of low pressure with atmospheric fronts. Poland was in the zone of warm atmospheric front associated with low-pressure center of 995 hPa over northern Scandinavia. Wind: weak all over the country. Air temperature from approximately -4.0C in mountain region of Poland to 3.5C.

*Meteorological conditions in 18.11.2010, 00:00 UTC (Fig. 4).*
Low-pressure center of 980 hPa over Ireland prevailed in Western Europe, and an atmospheric

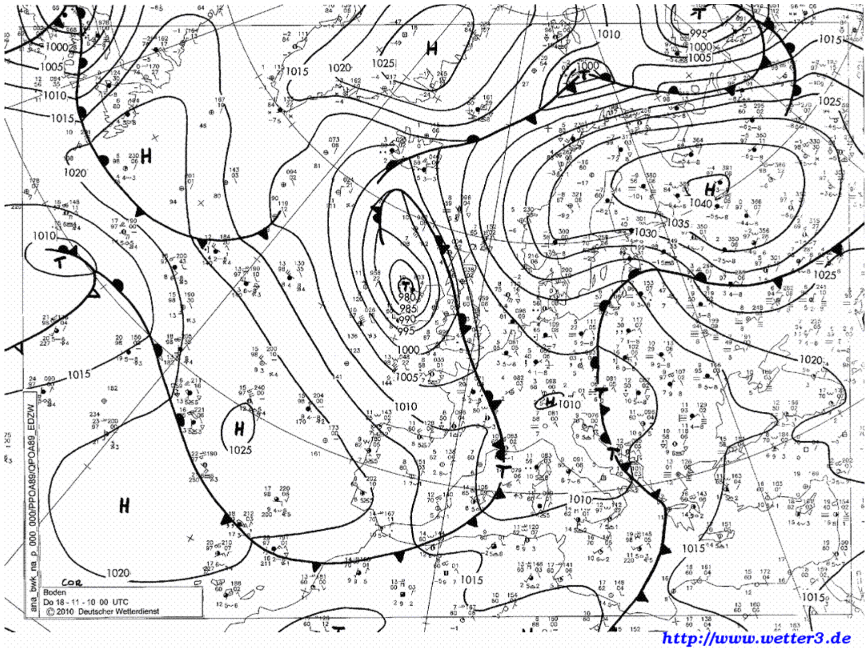


Figure 4: Synoptic situation of 18.11.2010, 00 UTC.

front in Central Europe. In the north-eastern part of Europe occurred high-pressure system with a center of 1040 hPa over the northern Russia. Poland was in the zone of warm front. Wind from 1 m/s to 11 m/s over the Baltic Sea. Air temperature from 3.0C to 9.0C.

## 3 Methodology

Several versions of COSMO model code were prepared and tested as follows:

- 4.08 - fundamental version of code, COSMO v. 4.08 - MOSAIC parameterization NOT implemented.
- 4.14 - fundamental version of code, COSMO v. 4.14 - TILE parameterization NOT implemented.
- MOSA - code of COSMO ver. 4.08 - with MOSAIC parameterization implemented.
- TILE - code of COSMO ver. 4.14 - with TILE parameterization implemented.
- NSUBS - modified code, TILE parameterization implemented but switched-off.
- SUBS1 - modified code, TILE parameterization implemented, accounting for presence/absence of snow cover in a single grid
- SUBS3 - modified code, TILE parameterization implemented, accounting for presence/absence (more or less 50% of) lake surface
- Three convections schemes were applied for every version as above:
- KAFR - Kain-Fritsch's scheme.
- SHAL - Tiedtke's scheme for shallow convection.
- TIED - regular Tiedtke's scheme.

. . . together with four numerical schemes (Doms et al., 2007):

- HEVI - leapfrog, 3-timelevel HE-VI integration.
- LFSI - leapfrog, 3-timelevel semi-implicit.
- RKN1 - Runge-Kutta, 2-timelevel HE-VI integration, irunge kutta=1.
- RKN2 - Runge-Kutta, 2-timelevel HE-VI integration, irunge kutta=2.

Numerical experiments were carried out for every chosen term using code versions prepared as described above. First, a comparative analysis was performed on three different ways:

1. To compare results obtained for the different versions of the code model COSMO for the same numerical and convection schemes as follows: 4.08 - 4.14, 4.08 - MOSA, 4.08 - TILE (NSUB, SUB1, SUB3), 4.14 -MOSA, 4.14 - TILE (NSUB, SUB1, SUB3), MOSA - TILE (NSUB, SUB1, SUB3), TILE (NSUB - SUB1, NSUB - SUB3, SUB1 - SUB3).
2. To compare results obtained using various numerical schemes but with fixed convection scheme for each version of the model code (e.g. MOSA, convection scheme Tiedtke, different numerical schemes).
3. To compare results obtained using different convection schemes but with fixed numerical scheme for each version of the model code (e.g. MOSA, numerical scheme Runge-Kutta, different convection schemes).

Afterwards correlation coefficient and standard deviation were calculated and analyzed for all possible combinations of numerical and of convection schemes.

## 4 Results and discussion

The results were divided into two categories, "the best configuration" and "the worst configuration". The first one contained results for which resulting correlation coefficient has the highest value, while the second - lowest value. The highest value of the correlation coefficient indicated that the parameterization either insignificantly or not at all influenced on examined meteorological field, and the smallest value of correlation coefficient suggests a high sensitivity of meteorological field to soil processes parameterization. It should be stressed out that terms "the worst" and "the best" did not reflect in any way a quality of parameterization, but described in a qualitative manner changes (from the most significant to the less ones) which can be seen comparing to reference runs.

The worst results were received from experiment code v. 4.08, 4.14, MOSA, TILE VIEW (SUB1, NSUB, SUB3) of 18 November 2010 for the following combinations: 4.14 - TILE (SUB1), 4.14 - TILE (NSUB), 4.08 - TILE (SUB1), 4.08 - TILE (NSUB), TILE (NSUB) - TILE (SUB3), TILE (NSUB) - TILE (SUB3), TILE (SUB1) -TILE (SUB3), MOSA - TILE (SUB1), MOSA - TILE (NSUB) (Tab. 1, Fig. 5-7).

The best results have been received for numerical experiment using the code v. 4.08 and the MOSA version for February 1, 2009 and 18 November 2010, for all analyzed meteorological fields, and for February 1, 2009 using the TILE version with NSUB and with SUB1. Correlation coefficient was equal to 1 for all convection schemes. It suggests that meteorological fields are insensitive to soil processes parameterization regardless of numerical and of convection schemes applied.

| Numerical schemes → | HEVI | LFSI | RKN1 | RKN2 |
|---|---|---|---|---|
| **Convection schemes ↓** | **Comparison of 4.14-TILE-SUB1** | | | |
| **KAFR** | 0,9278 | 0,9300 | 0,9317 | 0,9316 |
| **SHAL** | 0,9277 | 0,9302 | 0,9315 | 0,9316 |
| **TIED** | 0,9276 | 0,9290 | 0,9312 | 0,9312 |
| | **Comparison of 4.14-TILE-SUB** | | | |
| **KAFR** | 0,9278 | 0,9300 | 0,9317 | 0,9316 |
| **SHAL** | 0,9277 | 0,9302 | 0,9315 | 0,9316 |
| **TIED** | 0,9276 | 0,9290 | 0,9312 | 0,9312 |
| | **Comparison of 4.08-TILE-SUB1** | | | |
| **KAFR** | 0,9280 | 0,9302 | 0,9326 | 0,9325 |
| **SHAL** | 0,9279 | 0,904 | 0,9326 | 0,9326 |
| **TIED** | 0,9278 | 0,9294 | 0,9330 | 0,9330 |
| | **Comparison of 4.08-TILE-SUB** | | | |
| **KAFR** | 0,9820 | 0,9302 | 0,9326 | 0,9325 |
| **SHAL** | 0,9279 | 0,9304 | 0,9326 | 0,9326 |
| **TIED** | 0,9278 | 0,9294 | 0,9330 | 0,9329 |
| | **Comparison of TILE-NSUB-TILE-SUB3** | | | |
| **KAFR** | 0,9322 | 0,9341 | 0,9318 | 0,9318 |
| **SHAL** | 0,9321 | 0,9343 | 0,9317 | 0,9317 |
| **TIED** | 0,9318 | 0,9334 | 0,9314 | 0,9314 |
| | **Comparison of TILE-SUB1-TILE-SUB3** | | | |
| **KAFR** | 0,9322 | 0,9341 | 0,9318 | 0,9318 |
| **SHAL** | 0,9321 | 0,9343 | 0,9317 | 0,9317 |
| **TIED** | 0,9318 | 0,9334 | 0,9314 | 0,9314 |
| | **Comparison of MOSA-TILE-SUB1** | | | |
| **KAFR** | 0,9280 | 0,9302 | 0,9326 | 0,9325 |
| **SHAL** | 0,9279 | 0,9304 | 0,9326 | 0,9326 |
| **TIED** | 0,9278 | 0,9294 | 0,9330 | 0,9329 |
| | **Comparison of MOSA-TILE-NSUB** | | | |
| **KAFR** | 0,9280 | 0,9302 | 0,9326 | 0,9325 |
| **SHAL** | 0,9279 | 0,9304 | 0,9326 | 0,9326 |
| **TIED** | 0,9278 | 0,9294 | 0,9330 | 0,9329 |

Table 1: Correlation coefficient (soil temperature, 18.11.2010) for different model versions, convection and numerical schemes.

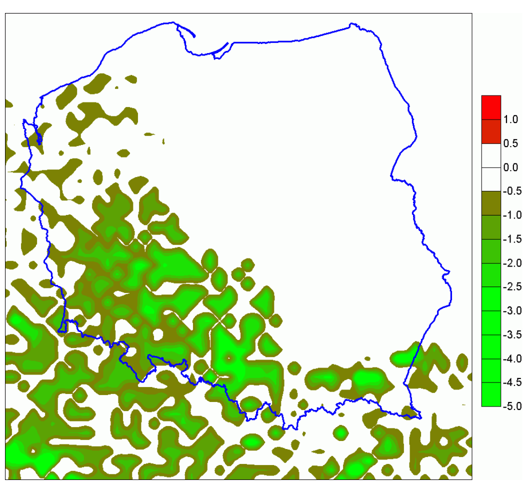


Figure 5: Differences of values of soil temperature at 2m agl., 18.11.2010 r. Comparison between 4.14 - TILE (SUB1), numerical scheme HE-VI, convection scheme Kain-Fritsch.

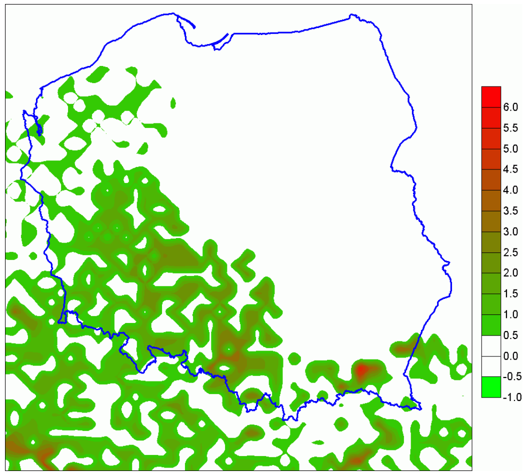


Figure 6: As in Fig. 5. Comparison between TILE SUB1 and SUB3, numerical scheme Runge-Kutta, convection scheme Tiedtke - shallow convection.

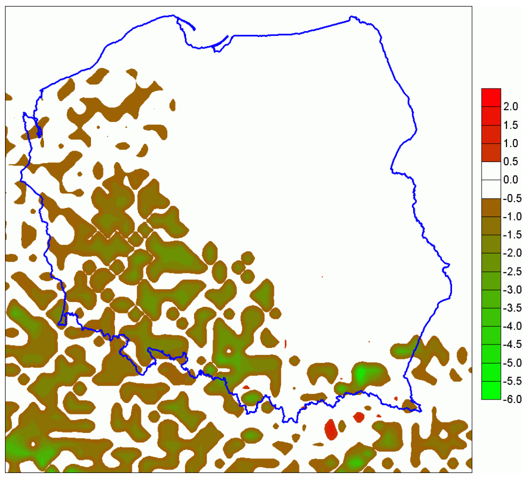


Figure 7: As in Fig. 5. Comparison between MOSA - TILE NSUB, numerical scheme Runge-Kutta 2, convection scheme Tiedtke.

The analysis of data shows that surface temperature is the most sensitive of meteorological field to MOSAIC and/or TILE parameterization (see tables 1-8). Correlation coefficients for this field are the lowest in comparison with correlation coefficients for others. It seemed that synoptic situation of 18.11.2010 was a main reason of it. During this day the entire area of Poland was under an influence of a warm front, which was accompanied by rainfall causing high amount of moist in a surface layer of soil and, subsequently, changes in physical properties of soil (e.g. thermal conductivity). It has caused soil surface temperature to be very sensitive to applied parameterizations. The change of physical properties of soil affected also on heat and moisture fluxes from soil surface to atmosphere and - indirectly -on other meteorological fields such as air temperature, dew point temperature and humidity. A sensitivity of these fields on the parameterizations of soil processes is smaller compared to sensitivity of soil surface temperature. Changing numerical and convection schemes one could not significantly affect results - differences in values of correlation coefficients was in the range of 0.01 to 0.06.

A sensitivity of meteorological fields for MOSAIC and/or TILE parameterization depends on a synoptic situation that affects current weather conditions. When in a given area there are homogeneous synoptic conditions meteorological fields are more sensitive to MOSAIC parameterization with numeric schemes leapfrog and leapsemi. This sensitivity was not observed for Runge-Kutta schemes, regardless of the applied schema types. When there is non-homogeneous set of meteorological conditions it was not stated explicitly which parameterization has a more significant influence on meteorological fields.

In Figures 8-10 and in tables 2 and 3 there are values of correlation coefficients of results obtained for the numerical experiment of 1 February 2009. On that date there were significantly different meteorological conditions. Poland was under the influence of high-pressure with center over mid Russia. There were no precipitation at all and ground surface was covered with snow. Using numeric schemes leapfrog and leapsemi, air temperature at 2m agl. seemed to be the most sensitive to soil parameterizations (to a lesser extent, dew point, sensible heat flux and humidity).

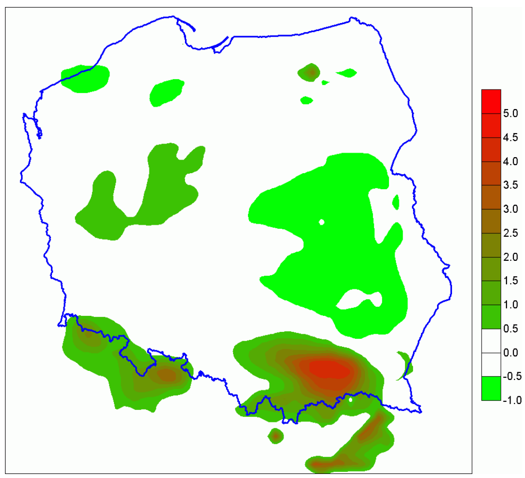


Figure 8: Differences of values of air temperature at 2m agl., 01.02.2009. Comparison between 4.14 - TILE (SUB3), numerical scheme HE-VI, convection scheme Kain - Fritsch.

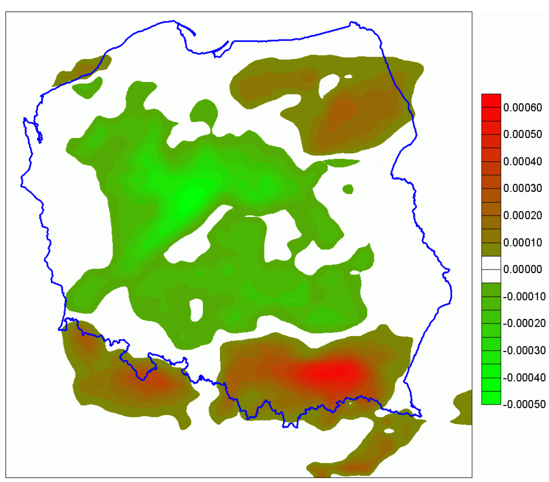


Figure 9: Differences of values of specific water vapor content at 2m agl., 01.02.2009. Comparison between 4.08 - TILE (SUB1), numerical scheme HE-VI, convection scheme Kain - Fritsch.

| Numerical schemes → | HEVI | LFSI | RKN1 | RKN2 |
|---|---|---|---|---|
| Convection schemes ↓ | Comparison of 4.14-TILE-SUB3 | | | |
| **KAFR** | 0,9696 | 0,9708 | 0,9954 | 0,9954 |
| **SHAL** | 0,9699 | 0,9708 | 0,9954 | 0,9954 |
| **TIED** | 0,9711 | 0,9711 | 0,9972 | 0,9972 |
| | Comparison of 4.14-TILE-SUB1 | | | |
| **KAFR** | 0,9677 | 0,9686 | 0,9986 | 0,9985 |
| **SHAL** | 0,9683 | 0,9688 | 0,9985 | 0,9985 |
| **TIED** | 0,9679 | 0,9673 | 0,9986 | 0,9986 |
| | Comparison of 4.14-TILE-NSUB | | | |
| **KAFR** | 0,9677 | 0,9686 | 0,9986 | 0,9985 |
| **SHAL** | 0,9683 | 0,9688 | 0,9985 | 0,9985 |
| **TIED** | 0,9679 | 0,9673 | 0,9986 | 0,9986 |
| | Comparison of 4.08-TILE-SUB3 | | | |
| **KAFR** | 0,9695 | 0,9704 | 0,9939 | 0,9939 |
| **SHAL** | 0,9697 | 0,9706 | 0,9939 | 0,9939 |
| **TIED** | 0,9710 | 0,9710 | 0,9942 | 0,9943 |
| | Comparison of 4.08-TILE-SUB1 | | | |
| **KAFR** | 0,9676 | 0,9684 | 0,9970 | 0,9970 |
| **SHAL** | 0,9682 | 0,9688 | 0,9970 | 0,9970 |
| **TIED** | 0,9679 | 0,9636 | 0,9960 | 0,9960 |
| | Comparison of 4.08 - TILE-NSUB | | | |
| **KAFR** | 0,9676 | 0,9684 | 0,9970 | 0,9970 |
| **SHAL** | 0,9682 | 0,9688 | 0,9970 | 0,9970 |
| **TIED** | 0,9679 | 0,9674 | 0,9960 | 0,9960 |
| | Comparison of TILE-NSUB - TILE-SUB3 | | | |
| **KAFR** | 0,9800 | 0,9765 | 0,9949 | 0,9949 |
| **SHAL** | 0,9802 | 0,9774 | 0,9949 | 0,9949 |
| **TIED** | 0,9820 | 0,9786 | 0,9965 | 0,9965 |
| | Comparison of MOSAIC - TILE-SUB3 | | | |
| **KAFR** | 0,9695 | 0,9704 | 0,9939 | 0,9939 |
| **SHAL** | 0,9697 | 0,9706 | 0,9939 | 0,9939 |
| **TIED** | 0,9710 | 0,9710 | 0,9942 | 0,9943 |
| | Comparison of MOSAIC - TILE-SUB1 | | | |
| **KAFR** | 0,9676 | 0,9684 | 0,9970 | 0,9970 |
| **SHAL** | 0,9682 | 0,9688 | 0,9970 | 0,9970 |
| **TIED** | 0,9679 | 0,9674 | 0,9960 | 0,9960 |

Table 2: Correlation coefficient (air temperature, 01.02.2009) for different model versions, convection and numerical schemes.

| Numerical schemes → | HEVI-LFSI | HEVI-RKN1 | HEVI-RKN2 | LFSI-RKN1 | LFSI-RKN2 | RKN1-RKN2 |
|---|---|---|---|---|---|---|
| Convection schemes/fields ↓ | Comparison of TILE-NSUB | | | | | |
| KAFR-QV2M | 0,9872 | 0,9713 | 0,9714 | 0,9782 | 0,9782 | 0,9999 |
| KAFR-TE2M | 0,9830 | 0,9655 | 0,9655 | 0,9579 | 0,9579 | 0,9999 |
| SHAL-TE2M | 0,9845 | 0,9660 | 0,9660 | 0,9578 | 0,9578 | 0,9999 |
| TIED-TE2M | 0,9823 | 0,9651 | 0,9655 | 0,9658 | 0,9658 | 0,9999 |
| | Comparison of TILE-SUB1 | | | | | |
| KAFR-QV2M | 0,9872 | 0,9713 | 0,9714 | 0,9782 | 0,9782 | 0,9999 |
| KAFR-TE2M | 0,9830 | 0,9655 | 0,9655 | 0,9579 | 0,9579 | 0,9999 |
| SHAL-TE2M | 0,9845 | 0,9660 | 0,9661 | 0,9578 | 0,9578 | 0,9999 |
| TIED-TE2M | 0,9823 | 0,9655 | 0,9655 | 0,9658 | 0,9658 | 0,9999 |

Table 3: Correlation coefficient (for selected meteorological fields in 01.02.2009) TILE version, NSUB and SUB1), for selected convection and numerical schemes.

### 5 Conclusions

In this article results of tests carried out using a new soil processes parameterizations - MOSAIC and TILE in COSMO model COSMO are presented. Tests were carried out with different convection and numerical schemes to assess how parameterization(s) contributes to a forecast of meteorological fields or which one of them exhibits stronger influence. Statistical analysis was carried out and an analysis of the differences between the results obtained with parameterizations MOSAIC or TILE switched on and off. Results were divided into two groups. The first group includes results with the highest correlation coefficient (so called "the best case"), and the other - results with lowest correlation coefficient ("the worst case"). Best case suggests that the parameterization MOSAIC or TILE does not affect (almost at all) the forecast. The "worst case" is an opposite situation, describing strong influence of parameterization an forecast.

The analysis shows that: (a) synoptic situation that determines a weather in a given area, is also a main factor determining an influence of parameterization of soil processes on meteorological field(s). The manner of this influence would be a topic of on-going tests at IMGW; (b) MOSAIC parameterization has a more significant influence on meteorological fields in the case of homogeneous meteorological conditions prevailing in the area of interest and (c) in the case of "heterogeneous" weather, resulting in a diversification of physical characteristics of the soil - such as variations in the coverage of the snow surface of the soil - one cannot explicitly specify a schema for parameterization of the processes of soil that would have more significant influence on a meteorological field. At the moment detailed work on this issue is in progress.

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