COLOBOC - MOSAIC parameterization in COSMO model v. 4.8

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Summary

Processes occurring on borderline between ground and bottom layer of the atmosphere in COSMO model vs. 4.8 might be parameterized in two different ways using MOSAIC and TILE parameterizations. Multiple test should be performed to allow operational use of one of these parameterizations. Authors implemented the MOSAIC approach. The tests were carried out on specially selected data. Terms were selected to cover the various physical conditions prevailing in the atmosphere and in soil. In the course of the tests different numerical and convection schemes were applied.

1. Introduction

The interaction between the Earth surface and the atmosphere is a very important source of water vapor and energy in atmosphere. Therefore it is very important to correctly parameterize physical processes that occur between the ground surface and the bottom layer of the atmosphere. The Earth surface is not homogeneous but covered with various types of vegetation and other elements of ground coverage. Ground can consist of various types of soil (clay, silt, mud, sands, sludge, etc.) characterized by differing physical properties such as thermal conductivity, porosity etc. To concern a non-homogenous ground surface a numerical model can include two parameterizations - MOSAIC and TILE approach.

2. MOSAIC approach

In MOSAIC approach (Ament 2006, 2008; Ament, Simmer 2008) every single grid of computing domain consists of n equal sizes located geographically. For every grid an average value of streams of latent heat, sensible heat, speed and humidity is calculated. For example, the flow of latent heat is computed using the following formula:

$$E_0 = -\frac{1}{N} \sum_{i=1}^{N} \rho_i K_{h,i} |v_h| \left(q_{atm} - q_{s,i} \right)$$
(1)

where: v - wind speed, ρ - total air density, q_{atm} humidity in the air, qs - humidity at the surface of the Earth, K_h - turbulent transfer coefficient, and the flow of sensible heat is

$$H = -\frac{1}{N} \sum_{i=1}^{N} c_p \rho_i K_{h,i} |v_h| \left(\theta_{atm} - \theta_{s,i}\right)$$
(2)

where: v - wind speed, ρ - total air density, K_h - turbulent transfer coefficient, c_p - specific heat at constant pressure, θ_{atm} - air temperature, θ_s - the temperature of the Earth's surface.

Other streams are calculated in a similar way. Exchange rates are determined using the local parameters, roughness and the Earth surface temperature, taking into account air temperature and wind speed. Radiation processes are calculated in two steps. In the first step it is calculated for each column using the average coefficient of albedo and emission of infrared (long-wave) radiation.

In the second step of the designated average net radiation processes for every grid are spread over the components using the local albedo and temperature coefficient for all sub-grids.

3. TILE approach

In a TILE approach we are dividing a surface inside the mesh grid computing on n classes. Contrary to MOSAIC, where a grid has been split into n identical items, in TILE approach each item has (or may have) different size. For each class of the surface the physical processes are calculated separately.

Latent heat flux is calculated from the formula:

$$E_0 = -\sum_{i=1}^{N} f_i \rho_i K_{h,i} |\vec{v_h}| (q_{atm} - q_{s,i})$$
(3)

and sensible heat flux:

$$H = -\sum_{i=1}^{N} f_i c_p \rho_i K_{h,i} |\vec{v_h}| \left(\theta_{atm} - \theta_{s,i}\right)$$

$$\tag{4}$$

where: f_i - coefficient of surface coverage of the class. Other streams are calculated in a similar way.

In both methods there is a simplifying assumption of homogeneous soil conditions inside every grid. Consequently, same values of temperature and humidity of soil are used in sub-grids in MOSAIC approach or for all classes of soil used in the TILE approach. Only parameters of surface roughness or surface resistance used to calculate the individual streams are equal.

4. Numerical Tests

In Institute of Meteorology and Water Management a MOSAIC approach has been implemented.

Meteorological fields selected from results of COSMO model to comparisons were as follows:

- T2M air temperature, 2 m a.g.l and TD dew point temperature, 2 m a.g.l,
- TSO soil surface temperature, and WSO soil water content,
- U10 zonal wind component and V10 meridional wind component, 10 m a.g.l.

Dates of experiments - selected data from six terms: 1.II.2009 - 00:00 UTC, 22.IV.2009 - 12:00 UTC, 16.X.2009 - 00:00 UTC and 06:00 UTC, 04.XI.2009 - 12:00 UTC, 21.XI.2009 - 06:00 UTC.

The above covered prevailed yet different weather conditions. Below one can find a brief description of these weather conditions together with synoptic situations.

The domain of experiments is shown in Figure 1. It covers Poland and its vicinity, with the basic grid size of 7 km.



Figure 1: Domain for experiments

Meteorological conditions on 1 February 2009 at 00:00 UTC

Synoptic situation: Western Europe was in a range of low pressure zone with fronts. The eastern part of the continent was under the influence of widespread high pressure center. Over Poland, the weather was due to high pressure centre of 1035 hPa above the Gulf of Finland.



Figure 2: Synoptic situation, 1 February 2009, 00:00 UTC

Clouds: Stratocumulus, Stratus, scattered Cumulonimbus, Altocumulus and Altostratus. Cloud cover: 100%. Phenomena: snow, fog, fog freezing into rime.

Pressure reduced to sea level: from 1016.2 hPa to 1027.7 hPa.

Wind: weak and moderate, strong in mountains, mostly from east.

Air temperature: from -14.1° C to -1.5° C (mountains).

Meteorological conditions on 22 April 2009 at 12:00 UTC

Synoptic situation: Poland was under the influence of high pressure zone with center of 1025 hPa over Latvia and Belarus. In the western part of Europe - high pressure zone with center over southern Wales. Between these two zones - an occurrence of front passing over Poland during the next 24 hours and giving precipitation.



Figure 3: Synoptic situation, 22 April 2009, 00:00 UTC.

Clouds: Cumulus humilis and mediocris (locally Cumulonimbus), Altocumulus perlucidus, Cirrus fibratus and spissatus, Cirrostratus. Cloud cover from 0 to 75%. Phenomena: locally rainfall showers and storms (Świnoujście, Szczecin, Slubice) Pressure reduced to sea level: 1015 hPa 1020 hPa. Wind: weak and moderate (1-8 m/s), variable direction.

Air temperature: from 3.9° C to 18° C.

Meteorological conditions on 16 October 2009 at 00:00 and 06:00 UTC

Synoptic situation at 00:00 UTC: Central Europe, the Balkans as well as part of the Ukraine and Belarus were in a mass of cold air. Poland was in the range of low pressure zone with center of 1015 hPa over eastern Poland.



Figure 4: Synoptic situation, 16 October 2010, 00:00 UTC

Clouds: Stratus fractus and nebulosus, Stratocumulus, scattered Cumulonimbus, Altocumulus, Cirrus, Altostratus.

Cloud cover mostly 100%.

Phenomena: rain showers, locally heavy rain with snow, snow, fog and mist.

Pressure reduced to sea level: from 1013 hPa to 1019 hPa.

Wind: weak and moderate, variable directions, mostly from west.

Air temperature: from -2.7° C to 5.9° C

Synoptic situation at 06:00 UTC: as above

Cloud: Stratus fractus and nebulosus, Stratocumulus, Cumulus, Altocumulus, Altostratus, scattered Cumulonimbus.

Cloud cover 100%.

Phenomena: rain showers, locally heavy rain with snow, snow, fog and mist.

Pressure reduced to sea level: from 1010 hPa to 1019 hPa.

Wind: weak and moderate, variable.

Air temperature: from -11.2° C to 4.2° C.

Meteorological conditions on November 4, 2009 at 12:00 UTC

Synoptic situation: Poland was under the influence of high pressure zone with center over Russia, occlusion front passing from west to east.

Clouds: Stratocumulus, Stratus, Altocumulus, Altostratus, scattered Cumulonimbus and Cumulus.

Cloud cover mostly over 75%.

Phenomena: rain showers, rain with snow, snow, locally heavy rain with snow and freezing rain.

Pressure reduced to sea level: from 987.5 hPa to 1007.6 hPa.

Wind: weak in lowlands, strong in mountains to the strong lowland, variable direction, mostly from south.

Air temperature: from $-7.3^{\circ}\mathrm{C}$ to $6.7^{\circ}\mathrm{C}.$



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Meteorological conditions on 21 November 2009 at 06:00 UTC

Synoptic situation: Southern Europe was in under the influence of high pressure zone with the center over Switzerland. Poland in warm low pressure zone with the center of 980 hPa over Iceland.



Figure 6: Synoptic situation, 21 November 2009, 00:00 UTC

Clouds: locally Stratocumulus, Altocumulus, Cirrostratus, Cirrus. Cloud cover: mostly sunny. Phenomena: mist. Pressure reduced to sea level: from 1014.9 hPa to 1029.2 hPa. Wind: weak and moderate, from western and south-western direction Air temperature: from 1.8° C to 12.2° C.

5. Methodology and results

Following numerical schemes are implemented in COSMO model (Doms 2002, Schattler 2009, Jacobson 2000):

- three-point integration: explicit in horizontal plane, implicit in vertical (hereinafter referred to as leapdef with Tiedtkes convection scheme or as leapdef1 with Kein-Fritschs convection scheme)
- three-point, "leapfrog"-type semi-implicit integration (referred to as leapsemi with Tiedtkes convection scheme or as leapsemi1 with Kein-Fritschs convection scheme)
- two-point, third order Runge-Kutta scheme: explicit integration in the horizontal plane, implicit integration in vertical (default and standard, irungekutta=1, referred to as RungeKutta1)
- two-point, third order Runge-Kutta scheme: explicit integration in the horizontal plane, implicit integration in vertical (variant of the method with reduction of the total variation TVD, Total Variation Diminishing, irungekutta=2, referred to as RungeKutta2)

The following tests were carried out using:

- original version of COSMO v. 4.8 code referred to as orig
- modified version of code with of subs procedure fully disabled referred to as ctrl
- modified version of code with of subs procedure enabled, nsubs = 4, low-resolution input data only, identical sub-pixels referred to as twins
- modified version of code with of subs procedure fully enabled, nsubs = 4, high resolution referred to as subs

The results were afterwards statistically analyzed. In the first step a comparison (for all possible combinations of numerical schemes and convection) between orig and ctrl, orig and subs, orig and twins, twins and ctrl, subs and ctrl, twins and subs, was carried out. In the second step a statistical parameters like correlation coefficient, deviation, covariance, variances etc. were calculated for all possible combinations of numerical schemes and convection. Finally, any possible difference occurred was analyzed comparing pairs of results as above.

Results were divided into two categories of "best configuration" and "the worst possible configuration". The first category contains results for which the highest value of correlation coefficient was obtained, and the second the lowest ones.

$The \ best \ configuration$

The best results have been obtained for the field of water content in the soil (Table 1) for the data from 1 February 2009, 22 April 2009, 21 November 2009, with shallow convection switched on and off correlation coefficient was equal to 1.

The best results for meridional wind component were obtained for 22 April 2009 (Table 2). The lowest value of the correlation coefficient equal to 0.991 was obtained for leapsemil

Correlation coefficient WSO						
	leapdef	leapdef1	leapsemi	leapsemi1	RungeKutta1	RungeKutta2
orig-twins	1	1	1	1	1	1
orig-subs	1	1	1	1	1	1
orig-ctrl	1	1	1	1	1	1
ctrl-twins	1	1	1	1	1	1
ctrl-subs	1	1	1	1	1	1
subs-twins	1	1	1	1	1	1

Table 1: Correlation coefficient - water in soil (01.02, 22.04, 21.11.2009)

scheme and combination orig-subs, ctrl-subs and for subs-twins. For leapsemi and the same combinations result was slightly better and equal 0.992. For remaining combinations orig-twins, orig-ctrl, ctrl-twins and for all numerical schemes, correlation coefficient was equal to 1.

Correlation coefficient WSO						
	leapdef	leapdef1	leapsemi	leapsemi1	RungeKutta1	RungeKutta2
orig-twins	1	1	1	1	1	1
orig-subs	0.999	0.998	0.992	0.991	0.999	0.999
orig-ctrl	1	1	1	1	1	1
ctrl-twins	1	1	1	1	1	1
ctrl-subs	0.999	0.999	0.992	0.991	0.999	0.999
subs-twins	0.999	0.999	0.992	0.991	0.999	0.999

Table 2: Correlation coefficient, zonal wind component (22.04.2009)



Figure 7: Differences between subs and twins, leapsemi1, zonal wind component (22.04.2009). Correlation coefficient 0.991

High value of the correlation coefficient for the dew point temperature (Table 3) was obtained for 1 February 2009. These results were obtained with shallow convection switch on. Values of a correlation coefficient were equal to 0.998 for leapsemi scheme with combination of origsubs, ctrl-subs and subs-twins and for RungeKutta1 scheme with combination ctrl-subs. For

Correlation coefficient - TD with shallow convection				
	leapdef	leapsemi	RungeKutta1	RungeKutta2
orig-twins	1	1	1	1
orig-subs	0.999	0.998	0.999	0.999
orig-ctrl	1	1	1	1
ctrl-twins	1	1	1	1
ctrl-subs	0.999	0.998	0.998	0.999
subs-twins	0.999	0.998	0.999	0.999

combinations orig-twins, orig-ctrl, ctrl-twins for all schemes correlation coefficient was equal to 1.

Table 3: Correlation coefficient, dew point temperature (01. 02.2009)



Figure 8: Differences between subs and twins, leapsemi, dew point temperature (22.04.2009). Correlation coefficient 0.998

The best results for air temperature were obtained for 16 October 2009 with shallow convection switched on (Table 4). For a combinations orig-twins, orig-ctrl, ctrl-twins and numerical schemes leapdef, leapsemi, RundeKutta1 and RundeKutta2 correlation coefficient was equal to 1. For combinations orig-subs, ctrl-subs and subs-twins and same numeric schemes a value of the correlation coefficient was in a range from 0.996 to 0.998.

Correlation coefficient - T2M with shallow convection				
	leapdef	leapsemi	RungeKutta1	RungeKutta2
orig-twins	1	1	1	1
orig-subs	0.998	0.998	0.998	0.998
orig-ctrl	1	1	1	1
ctrl-twins	1	1	1	1
ctrl-subs	0.998	0.998	0.998	0.998
subs-twins	0.998	0.998	0.998	0.998

Table 4: Correlation coefficient for air temperature (16.10.2009)

The best results for a surface temperature of the soil was obtained for the data of 1 February, 2009 with shallow convection switched on (Table 5). The correlation coefficient values vary in similar range as of air temperature. For a combination of the orig-twins, orig-ctrl, ctrl-twins and numerical schemes leapdef, leapsemi, RundeKutta1 and RundeKutta2 correlation coefficient was equal to 1. For other combinations of the orig-subs, ctrl-subs and subs-twins and same numeric schemes a value of the correlation coefficient was in a range from 0.997 to 0.998.

Correlation coefficient - TSO with shallow convection				
	leapdef	leapsemi	RungeKutta1	RungeKutta2
orig-twins	1	1	1	1
orig-subs	0.998	0.997	0.997	0.998
orig-ctrl	1	1	1	1
$\operatorname{ctrl-twins}$	1	1	1	1
ctrl-subs	0.998	0.997	0.997	0.998
subs-twins	0.998	0.997	0.997	0.998

Table 5: Correlation coefficient for surface temperature (01.02.2009)

Correlation coefficient - V10 with shallow convection				
	leapdef	leapsemi	RungeKutta1	RungeKutta2
orig-twins	1	1	1	1
orig-subs	0.999	0.999	0.999	0.999
orig-ctrl	1	1	1	1
$\operatorname{ctrl-twins}$	1	1	1	1
ctrl-subs	0.999	0.999	0.999	0.999
subs-twins	0.999	0.999	0.999	0.999

Table 6: Correlation coefficient for meridional wind component (16.10.2009, 06:00 UTC)

Worst case

The worst results were obtained for all the fields of meteorology (T2M, TD, TS, U10, V10, WSO) for data from 4 November 2009, for all numerical schemes and with shallow convection both disabled and enabled, for combinations orig-twins, ctrl-twins, and subs-twins.

Tables 7 and 8 show the case for which the value of the correlation coefficient was the lowest. The worst results were obtained for the air temperature T2M. In the case of shallow convection switched off the correlation coefficient value varied from 0.026 for numerical scheme leapdef, RundeKutta1, RundeKutta2 with combinations orig-twins, ctrl-twins, subs-twins to 0.049 for combinations orig-twins, ctrl-twins and a combination of subs-twins and leapsemi scheme.

As far or the other meteorological fields are concerned, correlation coefficients were slightly bigger but do not differ significantly from the values presented in Table 7, while with shallow convection switched on they were lower. For leapdef, the combination of orig-twins, ctrl-twins, subs-twins correlation coefficient yielded a value 0.02. For the RundeKutta1 and RungeKutta2 schemes with same combinations the value of the correlation coefficient was about 0.024. For leapsemi and combination of orig-twins, ctrl-twins, correlation coefficient was equal to 0.037 and for a combination of subs-twins about 0.044. So low value of the correlation might be most likely caused by numeric errors.

Correlation coefficient - T2M without shallow convection					
	leapdef	leapsemi	RungeKutta1	RungeKutta2	
orig-twins	0.026	0.049	0.026	0.026	
orig-subs	0.999	0.992	0.999	1	
orig-ctrl	1	1	1	1	
ctrl-twins	0.026	0.049	0.026	0.026	
ctrl-subs	0.999	0.993	1	1	
subs-twins	0.026	0.057	0.027	0.028	

Table 7: Correlation coefficient for air temperature (04.11.2009)



Figure 9: Differences between subs and twins, leapdef, air temperature T2M (04.11.2009). Correlation coefficient - 0.026

Correlation coefficient - T2M with shallow convection					
	leapdef	leapsemi	RungeKutta1	RungeKutta2	
orig-twins	0.020	0.037	0.024	0.024	
orig-subs	1	0.997	1	1	
orig-ctrl	1	1	1	1	
$\operatorname{ctrl-twins}$	0.020	0.037	0.024	0.024	
$\operatorname{ctrl-subs}$	1	0.997	1	1	
subs-twins	0.020	0.044	0.026	0.026	

Table 8: Correlation coefficient for air temperature of the air, with shallow convection (04.11.2009)

As far or the other meteorological fields are concerned, correlation coefficients are of similar level. Only for 4 November 2009 there were extreme low value of the correlation coefficient.

There was also the initial comparison of the results obtained with the values of observation (measurements of meteorological stations) carried out. The following figure and Table 9 shows the results of the comparison for schemes leapdef and leapsemi for air temperature.



Figure 10: Results (T2M) vs. measurement values. Top: leapdef, bottom - leapsemi

Correlation coefficient (T2M)				
	leapdef	leapsemi		
orig	0.9030	0.8990		
twins	0.9085	0.9058		
subs	0.9101	0.9097		

Table 9: Comparison of observation results with COSMO/COLOBOC results obtained for air temperature with schemes leapdef and leapsemi the correlation coefficients

6. Conclusions

In this paper the results of tests carried out using the new MOSAIC parameterization in the meteorological numerical model COSMO, vs. 4.8, were presented. The tests were carried out using different convection parameterizations and numerical schemes. The correlation between the results obtained for specific fields of meteorology seems to be satisfactory. The value of the correlation coefficient varies in range of 0.85 to 1. Only for 4 November 2009 data there has been actually null correlation, caused most likely by numeric errors.

In the future it is planned to carry out tests using more different initial conditions to examine the impact of the parameterization on the structure of bottom layer of the atmosphere. The results will be compared with the values of actual measurements.

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