Testing of Snow Parameterization Schemes in COSMO-Ru: Analysis and Results

E.Kazakova[1,2], I.Rozinkina[1]

1: Russian Hydrometeocenter, Russia
2: Moscow State University, Russia

1. Introduction

Interaction between atmospheric and underlying surface blocks in the mesoscale model COSMO very significantly impacts the success of the 2m air temperature prediction. Snow cover presence is quite common in mid latitudes in winter. The snow parameterization TERRA_ML (called "EH" [1]) is utilized in the model COSMO. A new snow parameterization scheme is developed for potential use in the COSMO model (called "EM" or just "new" [4], [5]).

In this paper we analyze the results of two snow parameterization schemes comparison during the snow accumulation period with special focus at the snow melting processes at the end of the cold period. The issues related to the 2 m air temperature (T2m) forecasting depending on snow cover characteristics simulation are discussed. Experiments were conducted for the European Part of Russia for the periods of March 2009, December 2009 - February 2010, March 25-31 2010, April 1-10 2010.

2. Tools, data and area of study

The snow parameterization scheme "EM" was developed by E.Machulskaya and V.Lykosov [4], [5]. The heat and moisture transfer processes within the snow cover and snow - atmosphere heat and moisture fluxes are considered in this scheme.

The main differences between the "EM" scheme in relation to "EH"scheme in TERRA_ML model are:

1. multi-layer approach;
2. radiation is calculated explicitly (following exponential extinction law). Direct solar radiation penetrates into the snow cover heating not only the snow surface, but also the underlying layers. In case of low albedo (melting snow) this effect may be significant.
3. water phase conversion accounting the melted water's percolation with the following freezing and consequent heat release;
4. gravitational compaction is considered as well as metamorphic compaction.

Both schemes can operate within the multi-layer soil and vegetation model TERRA_ML, which generates turbulent fluxes and includes parametrization of snow and water fractions within the cell.

The schemes were numerically tested in the COSMO-Ru14 model with horizontal resolution 14 km. The objective verification of the scheme "EM" versus the traditional version of snow scheme "EH" with TERRA_ML within the model Cosmo-Ru in different weather conditions was executed for the periods mentioned above.

The results of consecutive 3-days forecasts were examined using the initial and boundary conditions from DWD which were applied as an initial data for COSMO-Ru model experiments during the studied periods. Short periods of integration (78 hours) was not sufficient to identify and prove any considerable differences between two schemes, therefore the predicted fields of surface pressure, precipitation, cloudiness, wind and geopotential were practically identical for both schemes.

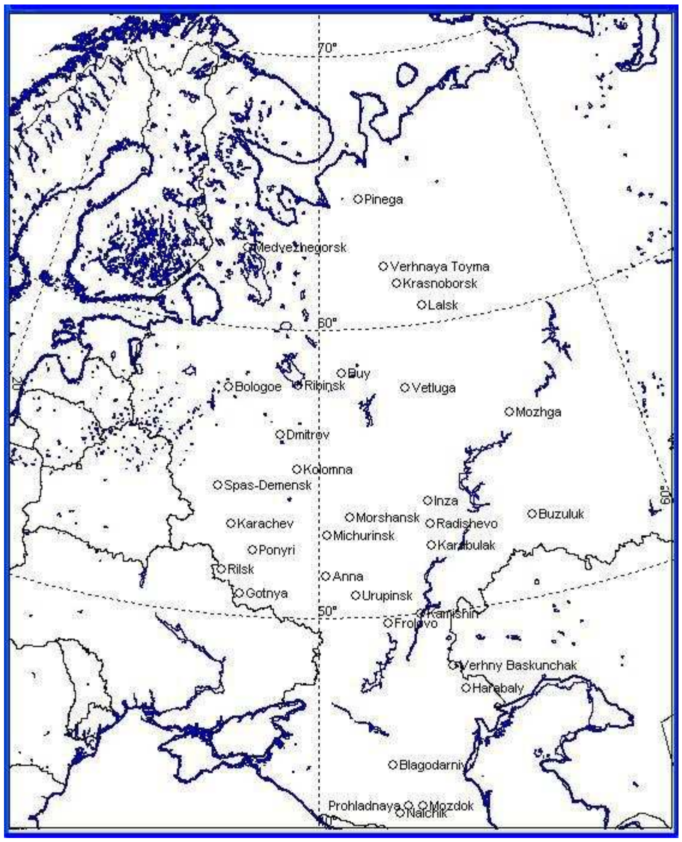

Figure 1: Stations selected for analysis

The forecasts were analyzed for day and night separately for the following elements:

- snow water equivalent (SWE),
- snow depth,
- air temperatures at 2 m (from atmospheric model).

Observation data from 33 specialized meteorological stations (Fig.1) for snow depth, water equivalent, 2m air temperature and precipitation were used for verification. In meridian direction the area exceeded 2000 km. Stations were segregated in three groups: "north", "centre", and "south". For northern stations no snow melting was observed for the entire period of February-March, for central stations the partial melting was registered, however, not resulting in complete disappearance of snow cover, for southern stations snow cover was unstable during the entire period.

3. Results of two snow parameterization schemes testing

3.1. Simulations of snow water equivalent

It was found that for almost all stations snow was observed practically during the entire winter cold period ($T \leq 0^oC$). The values of snow water equivalent (SWE) simulated by both schemes were very close, except for the period of snow cover melting during last several days of a cold season (Figs. 2, 3, 4). During this period the differences were significant. In southern area, when the amount of snow was small, with often alternate periods of melting-freezing, water equivalent differed insignificantly for both schemes. In the scheme "EM" snow melting occurs more slowly (Fig. 2).

The biggest errors for water equivalent calculated by both snow schemes (Fig.3) were most likely connected with essentially overestimated initial values of snow density obtained from DWD model. At the same time, the initial data of snow depth had a good correspondence to the data of direct measurements. In the system of initial fields calculation in DWD model water equivalent is calculated using the snow depth measurements data (snow depth is daily measured at all standard meteorological stations, though water equivalent is calculated only at few stations). The algorithm of these calculations may use the wrong values of snow density, which results in the errors of water equivalent in the model initial fields gives the overestimation of snow weight are 2-3 times in comparison with the reality at the end of winter and in single forecasts.

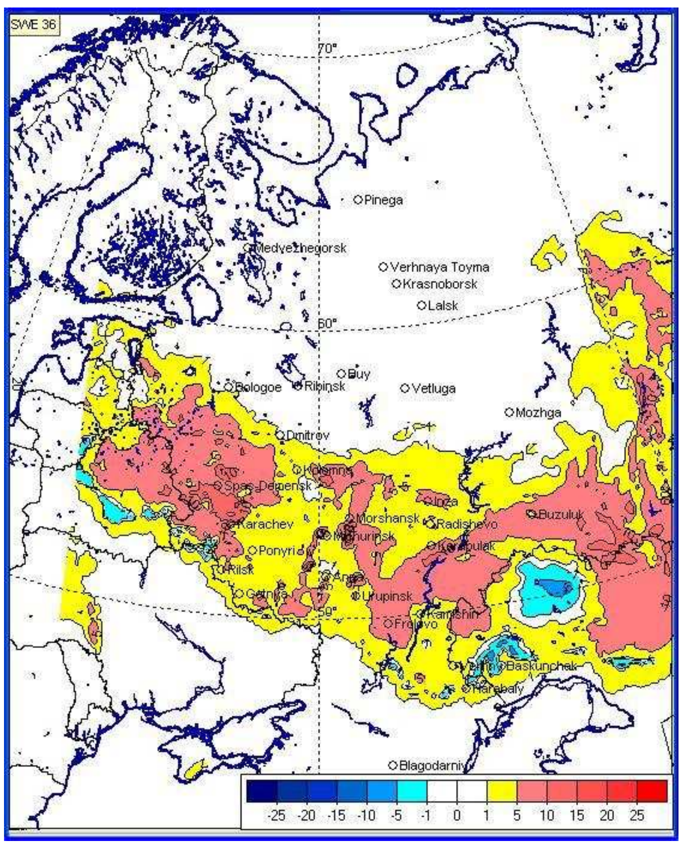

Figure 2: Difference of water equivalent forecasts (mm) on 36 h between different snow schemes (EM-EH) during the snow melting period. March 12, 2009.

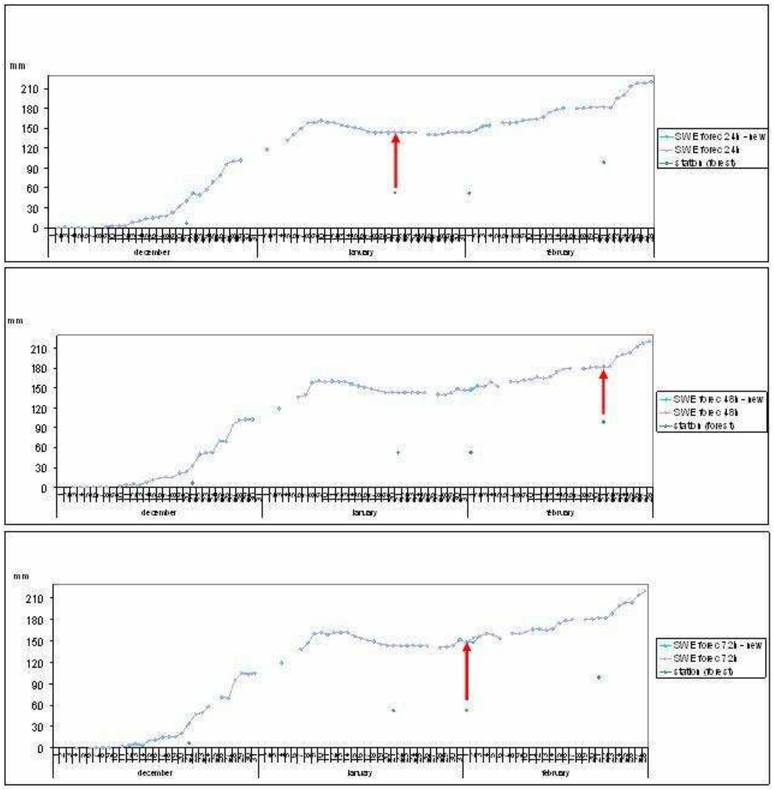

Figure 3: Difference of water equivalent forecasts (mm) on 36 h between different snow schemes (EM-EH) during the snow melting period. March 12, 2009.

Values of water equivalent forecasts are decreasing when the snow cover is melting, so that differences between forecast and measurements are decreasing as well (Fig.4). However, relative differences between two schemes become bigger in comparison with the winter period.

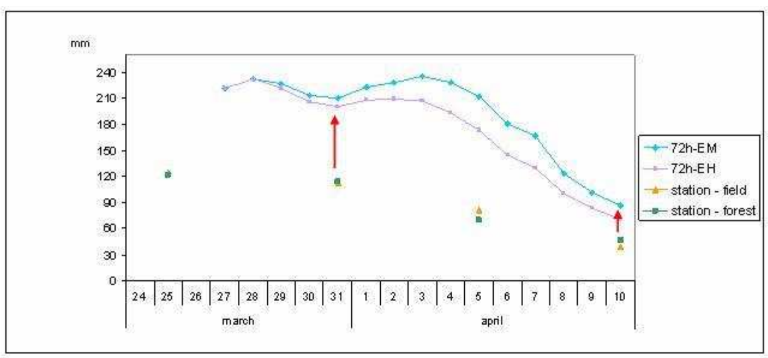

Figure 4: The example of snow water equivalent forecasts for one of the stations in the centre region for "EH" and "EM" schemes.

3.2. Snow depth simulation

On the basis of analyzed sets of forecasts it was determined that snow depth was stably well simulated by both schemes (Fig.5). Meanwhile, the "EM" scheme regularly overestimated the snow depth related to snowfalls, therefore the "EM" scheme had differences in the modeled snow depth essentially bigger in relation to direct measurements than scheme "EH" (Fig.5). Cases of snowfalls were studied in details. In absence of snowfalls, snow becomes more dense in the "EM" scheme, and the errors of snow depth values decrease. In southern regions when snow precipitation occurred at temperatures of 1-3 degrees below zero, both schemes calculated snow depth in a similar way and essential distinctions between them were not identified. In the experiments with the "EM" scheme snow completely descended more slowly than in the control "EH" run. Such conclusion confirms the previous received results on the detailed verification based on the observations at two observatories [3].

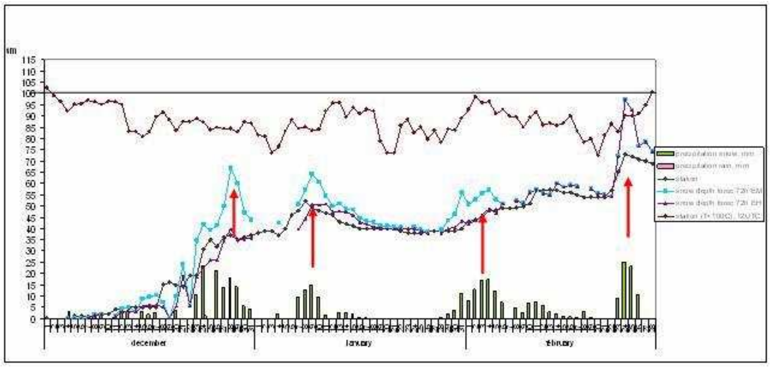

Figure 5: Example of snow depth forecasts (72 hours) for one of the stations in the northern region.

3.3. Snow density

The realistic simulation of snow depth, as well as big distortions in SWE simulations, significantly depends on the quality of the initial data used for integration. Snow depth is regularly measured at the majority of the WMO meteorological stations while SWE measurements are rare. Snow depth observations are transferred via communication channels in SYNOP-code and can be assimilated without distortion for model initial data generation. In order to have SWE initial data it is necessary to convert the snow depth (direct measurements) considering the snow density (estimated) into SWE. Therefore in order to understand the reason for big errors in SWE initial data assimilation we analyzed available measurements of snow density at the stations.

According to the measurements conducted with 5-10 days intervals, snow density changed during the 2009-2010 winter period: there were no very significant differences between the snow density in the forest and at the opened surface. Generally, the snow was most dense at the central region while at the south the highest snow compaction was registered at the end of snow period. The variability of snow density in the northern region was insignificant (tables 1 and 2).

The snow density was also calculated using 72h forecasts of snow depth and SWE for "EH" and "EM" schemes (tables 3, 4).

Version "EM" gives more friable snow during winter period then version "EH" and its values are close to measurements at the stations. However, both schemes are overestimating the snow density versus the measurements (Figs. 6, 7). During the snow melting period, "EM" scheme produces more significant snow density versus EH, which causes slower melting in the "EM" scheme.

The tables below show that there is a big dispersion in snow density data and using it directly as a constant during the whole season and for the entire region is not relevant.

region	Date														
	December			January						February					
	10	20	31	5	10	15	20	25	31	5	10	15	20	25	28
north		193					178		193		197		203		195
center		85					158		195	251	188	214	216	249	248

Table 1: Average snow density for the forest areas, kg/m^3

region	Date														
	December			January						February					
	10	20	31	5	10	15	20	25	31	5	10	15	20	25	28
north		170					197		199		201		196		196
center		137	198		197		209		210		217	230	240	244	255
south				105			136		184		195	229	308		

Table 2: Average snow density for the opened surface, kg/m^3

region	Date														
	December			January						February					
	10	20	31	5	10	15	20	25	31	5	10	15	20	25	28
north		217	241		273	358	380	377	368	383	376	351	373	292	373
center		177	251		263	347	376	359	301	351	345	344	363	347	385
south								123	299	292	349	391	413		

Table 3: Average snow density from EM: 72h forecast, kg/m^3

region	Date														
	December			January						February					
	10	20	31	5	10	15	20	25	31	5	10	15	20	25	28
north		356	351		375	389	396	396	395	396	376	351	373	292	373
center		294	339		350	389	394	388	380	387	345	344	363	347	385
south								208	347	331	341	372	410		

Table 4: Average snow density from EH: 72h forecast, kg/m^3

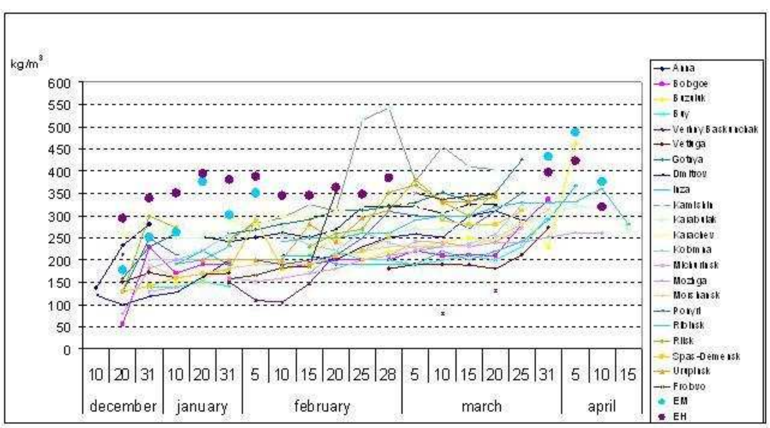

Figure 6: "Center" region's snow density according to field station measurements and 72h forecasts of EM and EH versions for the winter 2009-2010 period and March 25-April 10 2010.

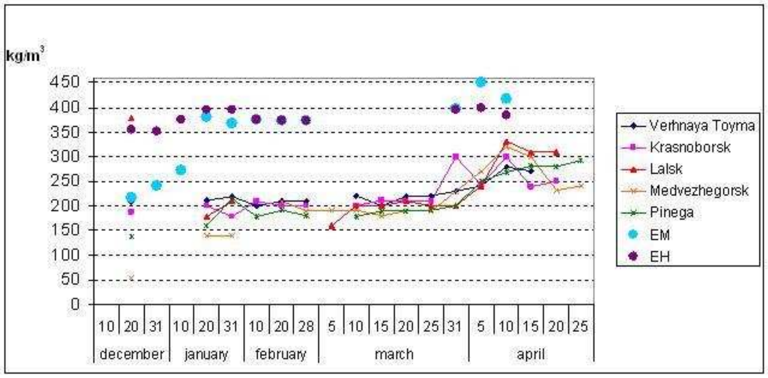

Figure 7: "North" region's snow density measured at the forest stations 72h forecasts by EM and EH for the winter 2009-2010 period and March 25-April 10 2010.

3.4. 2m air temperature simulation

One of the most important criteria of the correct work of Land-Surface Schemes (LSS) is the successful forecast of the temperature at 2 meters above the surface (T2m). The skill of this parameter forecast reflects the quality of the reproduction of all components of the land surface heat balance and the integral heat exchange between land surface and air in a model.

The "EM" scheme effects the simulated 2m temperature only in the regions of snow melting [2]. The northern and northeastern regions where no snow melting was observed or simulated both schemes gave similar results for T2m.

In the areas of snow melting the greatest positive effect in the simulation of T2m occurred at night during freezing of snow water melted in daytime. In these cases the nocturnal cooling of snow surface (and air temperature at 2 meters) occurred considerably less frequently, and the errors of T2m simulation were at 1.5 - 2^oC lesser in the "EM" scheme. This was typical for anticyclone cloudless conditions with the high daytime insulation when temperature during the day was higher than 0^oC (Fig.8). At the same time the direct sun radiation partly penetrates into snow layer and can slightly warm it in scheme "EM", as well as at night hours.

In the cases of cold weather without day snow melting and night water freezing the T2m in the experiments was practically identical for both schemes. At night hours with the clear sky conditions both schemes simulated the significantly greater cooling (up to 5-7^oC) than observed (Fig.8).

Most significant errors in T2m simulation in both schemes (new and control) occurred in the presence of snow in the cell, which didn't allow the temperature simulated by the model to fall below 0^oC (Figs.9, 10) while the real near-surface air was significantly warmer (up to 10-15 degrees). This happens in the cases when the direct solar radiation heated (at the time of light cloudy weather) the snow-free cells (roads, houses, branches of trees, etc.). This effect was especially perceived for the urbanized territories.

The updating of parameters determining the fraction of a cell covered with snow did not give the noticeable result for T2m improvement. (These numerical experiments were aimed to reproduce an effect of air heating in the snow-free parts of cells). Some effect was visible in a very narrow zone near the boundary of a snowcovered and snow-free areas. However, the effect in this zone was significant - the temperature increased 5-7 degrees, and for the stations within this area the temperature forecasts were considerably improved (Fig.11). The

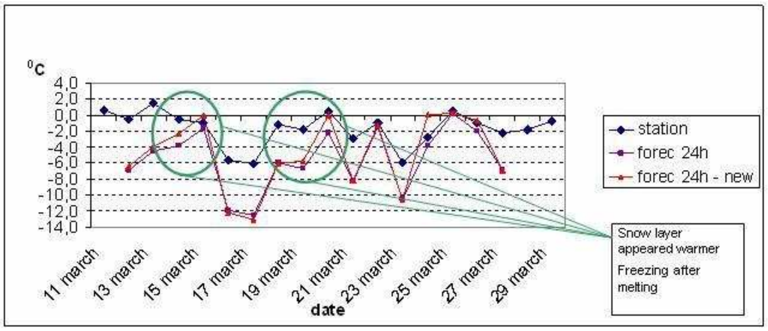

Figure 8: Typical sets of night T2m forecasts (24 hours) using the 'EM' (red line) and 'EH' (violet) schemes in comparison with observations (dark blue line).

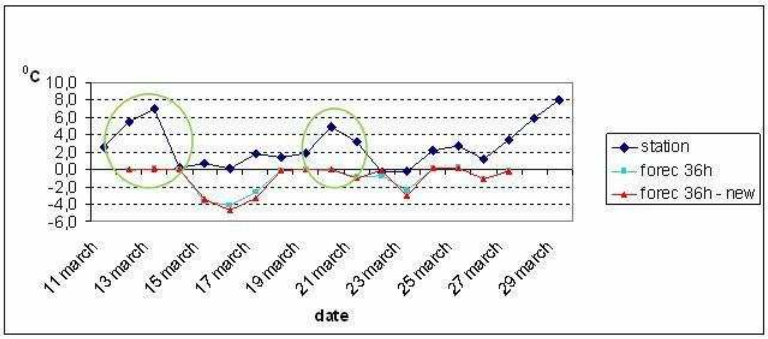

Figure 9: Typical rows of daily T2m forecasts (for 36 hours) with the use of "EM" (red) and "EH"

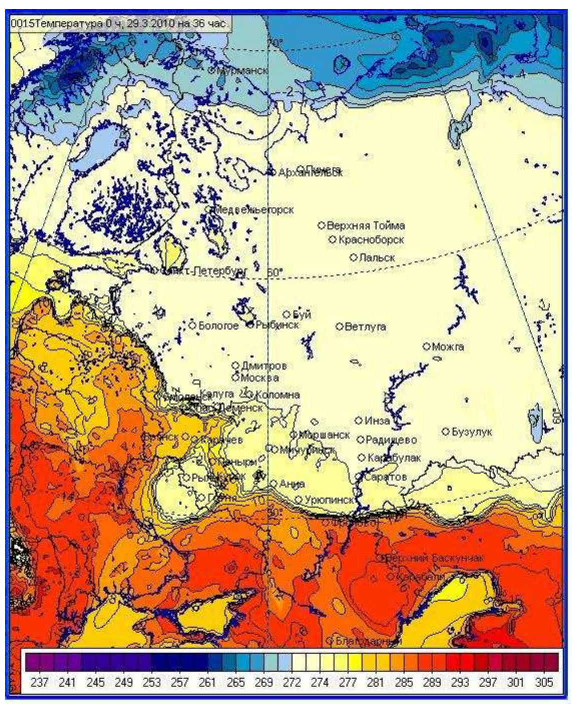

Figure 10: COSMO-Ru 2m 36 hours forecast: (color scale in K, isolines in ^oC), start: March 29, 2010. Practically at all the European part of Russia snow melted, while the forecasted T2m for huge area were "pasted" to zero value.

part of grid covered element was calculated as a function of water equivalent and parameter $cf_{snow}(zrss) = \max(0.01, \min(1.0, \frac{zwsnow}{cf_{snow}}))$, see COSMO code src_soil_multlay.f90 and [2]), SWE used in the model as initial data significantly differed from observations. Therefore updating the algorithm of parameterization of fractional covering without the functional dependence on a water equivalent (for example, with the replacement it with the functional dependence of snow depth or of air temperature) seems to be reasonable. Using snow depth initial data for fractional parameter will be more reliable since the snow depth is measured at meteorological stations and contain less mistakes then calculated SWE.

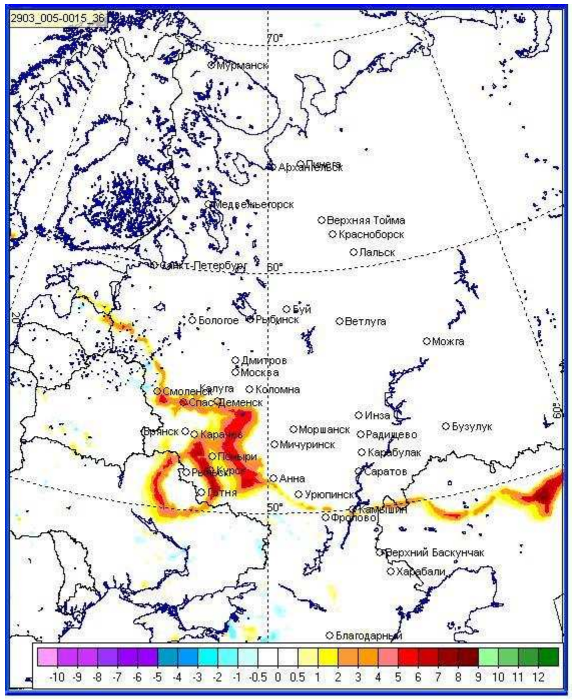

Figure 11: Difference in forecasts 2m (^oC) at maximal change of parameter of a fractional covering. In a narrow zone the temperature essentially increased.

5. Summary

The main results of the study are:

- SWE forecasts are considerably overestimated by both versions of model COSMO-Ru. It was caused by inaccuracy of SWE, and therefore the snow density initial data assimilated by the model, while the snow depth initial data was quite close to reality.
- During snow accumulation period the scheme tends to overestimate snow depth after snowfalls.
- During snow melting period snow scheme reproduce more realistically the following parameters:
  - time dependence of SWE;
  - T2m at night (due to using snow scheme "EM" there is the improvement of T2m forecast by 1.5-2^oC).

  It is related to the fact that snow scheme "EM" considered the freezing of daily melted water and following release of heat as well as heating of deeper snow layers during day-time resulted from penetration of solar radiation into snow.

- During snow melting period the biggest differences of T2m forecasts occured in vast regions for both versions (up to $10^{o}C$). It happened since the surface temperature in the cells with the presence of snow could not be higher than $0^{o}C$.
- Modifications of the snow fractional cover algorithm allowed to reduce the area with significant mistakes in air temperature.

6. Outlook

The 5 months statistics of the model skill T2m forecasts versus observations at different points at the European part of Russia demonstrated that the cumulative effect from transition the new snow scheme in TERRA_ML is especially positive for the areas where snow melts. This is mostly noticeable at night.

In order to improve the work of the scheme the following actions are suggested:

- The correction of algorithms of newly fallen snow density calculations in scheme "EM" (in "EM" scheme newly fallen snow is much more "friable" in comparison with "EH" scheme and the reality).
- The correction of algorithm of SWE initial data calculation using improved values of snow density.
- It seems reasonable to incorporate the scheme into the TERRA_ML model. The advantages of this scheme give positive effect which is most significant during snow melting periods even at short integration intervals, however, it is necessary to modify the algorithm of calculation of newly fallen snow density after snowfalls.

- It is necessary to optimize the snow density data considering the geographical differences calculating it as a function of temperature. It is important for receiving the initial information of snow.
- A problem the TERRA_ML model itself has - parameterization of fractional cell coverage depending on water equivalent. It seems reasonable to improve the algorithm taking into account snow-free surfaces during snow melting periods.

References

[1] Doms G., Heise E. et al., 2007: A Description of the Nonhydrostatic Regional Model LM, part 2: Physical Parameterization, *www.cosmo-model.org*.

[2] Kazakova E., Machulskaya E., Rozinkina I., 2010: Results of testing of the new snow parameterization scheme in spring snow melting conditions. Proceeding of State Institution Hydrometeorological Research and Development Center of Russian Federation . Issue 344. *Atmospheric physics and weather forecast*, pp.**147-164**.

[3] Machulskaya E., 2009: An examination of the quality of a new snow parameterization scheme combined with the COSMOs land surface scheme TERRA. *Research activities in atmospheric and oceanic modelling, CAS/JSC WGNE, WMO*, No. 39, p. **5.13-5.14**.

[4] Machulskaya E.E., Lykosov V.N., 2008: An advanced snow parameterization for models of atmospheric calculation, *COSMO Newsletter*, No.8, pp.**10-16**.

[5] Volodina E. E., L. Bengtsson, Lykosov V. N., 2000: Parameterization of heat and moisture transfer through snow pack for simulation of seasonal variations of land-surface hydrologic cycle, *Russian Journal of Meteorology and Hydrology*, No. 5, pp. **5-14**.