Smoothing of Soil Wetness Index (SWI) in ALADIN/LACE domain

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Introduction

During the period 15th – 20th June 2002 Slovakian colleague Jan Mašek noticed that during the day hot spots appear in the 2m Temperature field (http://www.shmu.sk/aladin_lace/). The spots occur in the flat areas, e.g. N Austria, SW Slovakia and Hungary. Hot spots do not move and they can be observed on the same place for several days. There is no corresponding pattern in 925 hPa level. In these areas, 2m Temperature was affected by the too warm soil. The cause of the hot spots problem in ALADIN/LACE is very probably the same as the cause of similar problems observed already in ARPEGE and ALADIN-France. The explanation is in the too strong horizontal variability of the soil moisture in the model. The origins of this variability are multiple: long time scale evolution of total soil moisture and necessity of using switching conditions in the soil moisture analysis since the correlation's between 2m errors and soil moisture errors are mostly situation dependent.
In Figure 1, 2m Temperature field and Soil Wetness Index for June 18th 2002 15 UTC are shown, 15 hours forecast. There is a good correlation between areas with high 2m Temperature and very dry areas.

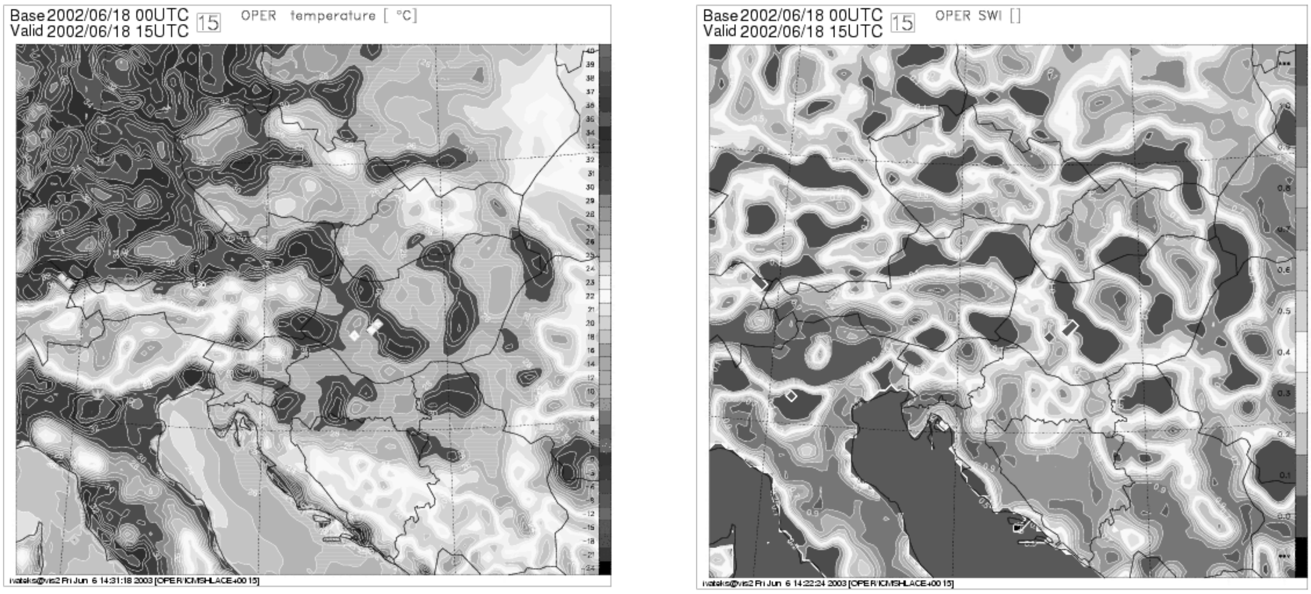


Figure 1 2m Temperature and Soil Wetness Index for June 18th 2002 15 UTC, 15 hours fcst

The aim of this work is to reduce the current unrealistic spatial heterogeneity of soil moisture by smoothing spatially the Soil Wetness Index (SWI). That heterogeneity caused hot spots in forecasted 2m Temperature during period 15th –20th June 2002 in ALADIN/LACE forecast. This period was tested first, with different combinations of smoothed SWI. Afterwards, a few chosen combinations were tested on six cases in year 2003; January-3 days, April-2 days and May-1 day.

How Optimum Interpolation surface analysis works?

The Optimum Interpolation (OI) surface analysis is operational analysis in the global model ARPEGE. As input for the OI, surface observations of 2m Temperature and Humidity are used. As it is known, in ALADIN or ARPEGE model, we do not have level that corresponds to that height, and vertical interpolation is required to compare the model fields with the 2m observations. The procedure interpolates the surface and the lowest model layer values, supposing that the fluxes are calculated according to the Monin Obukhov theory. Analysis is sequential, with the frequency of 6 hours, during the analysis observations are assimilated to correct the background field.

After the OI, surface analysis of 2m SYNOP observations are interpolated at the model grid-point (by a 2m analysis). Because we don't have the model level on 2m, correction of the surface parameters using 2m increments ($\Delta T_{2m} = T_{2m}^{a} - T_{2m}^{f}$ & $\Delta RH_{2m} = RH_{2m}^{a} - RH_{2m}^{f}$) between the analysed and forecasted values is needed. The Surface parameters changed according the increments of 2m Temperature and Humidity are Ts – Surface temperature, Tp – Mean soil temperature, Ws – Superficial (liquid) soil water content and Wp – Total liquid soil water content.

In the figure on the right hand side evolution of Total soil water content according the increments of 2m Temperature and Humidity is shown. Increments for surface prognostic variables are defined by the following expressions:

- for Temperatures:

    $Ts^{a} - Ts^{f} = \Delta T_{2m}$ &

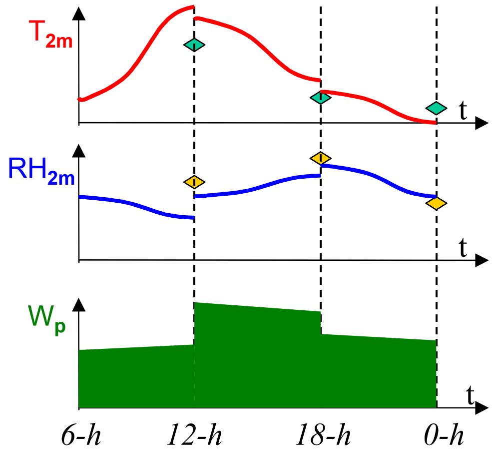
    $Tp^{a} - Tp^{f} = \Delta T_{2m}/2\pi$.

- for Soil water contents:

    $Ws^{a} - Ws^{f} = \alpha_{WsT}\,\Delta T_{2m} + \alpha_{WsRH}\,\Delta RH_{2m}$ &

    $Wp^{a} - Wp^{f} = \alpha_{WpT}\,\Delta T_{2m} + \alpha_{WpRH}\,\Delta RH_{2m}$.

OI coefficients $\alpha_{Wp/sT/RH}$ are functions of the local time, the percentage of vegetation, LAI/Rsmin, texture and atmospheric conditions.



After the Analysis is finished, only the surface data are stored as the model variables, and the 2m variables are recalculated from the lowest model level and surface variables. The measurements are not distributed homogeneously; the surface analysis and forecast of connective precipitation have high degree of uncertainty, which produces small-scale features in the soil moisture. The Surface analysis is done in ARPEGE (resolution from 20-200 km).

Soil Wetness Index (SWI)

The initialisation of the soil moisture is very important in meteorological models since the repartition between sensible and latent heat fluxes at the surface depends on the quantity of water in the ground available for evapotranspiration.

The soil moisture in the LSS ISBA is represented by the superficial soil moisture $\mathbf{W_s}$ (quantity of water in 1 cm) and the total soil moisture $\mathbf{W_p}$ (quantity of water in the total reservoir depth $\mathbf{dz}$). The total soil moisture is much more important to be initialised than $\mathbf{W_s}$ since the superficial reservoir has small capacity and $\mathbf{W_s}$ is relaxed towards $\mathbf{W_p}$ with a time scale of 2 days. The volumetric soil water content ($\mathbf{W_p/dz}$) is not the best field to compare the available soil moisture for transpiration between the grid-points. We often prefer the Soil Wetness Index (SWI), which represents the hydric stress of the vegetation. If SWI ≤ 0 that means the transpiration of the plants is zero (dry soils) and if SWI ≥ 1, the vegetation evaporates at the potential (maximal) rate (wet soils). Definition of SWI is shown bellow:

$$\mathbf{SWI} = \frac{\mathbf{W_p + W_{pi} - W_{wilt}}}{\mathbf{W_{fc} - W_{wilt}}},$$

where is:

- $\mathbf{W_p}$ - Total soil water content liquid (water),
- $\mathbf{W_{pi}}$ - Total soil water content frozen (ice),
- $\mathbf{W_{wilt}}$ - Soil water content at wilting point,
- $\mathbf{W_{fc}}$ - Soil water content at field capacity.

Because the SWI field has big gradients, it is possible to find completely dry and saturated soil on a distance of a few grid-points (~100 km), what is not realistic. The SWI field evolves on very long time scales, like $\mathbf{W_p}$, because of the large capacity of the total soil reservoir in ISBA.

Smoothing is performed with the subroutine elislap, which smoothes a field by adding its laplacian times a constant factor (a length scale). Smoothing is performed just for the land points, without the snow cover

and without the ice in the ground, in the ALADIN model. The laplacian is calculated using the data from the 5 nearest grid-points.
After that, because there is not **SWI** in ALADIN files, it was needed to convert SWI_{smooth} back to $(W_p)_{smooth}$ in the ALADIN file. $(W_p)_{smooth}$ is calculated with these formulae:

$$(W_p)_{smooth} = SWI_{smooth} \cdot W_{fc} + (1 - SWI_{smooth}) \cdot W_{wilt},$$

and two more checks:

$$\text{if } (W_p)_{smooth} \le veg \cdot W_{wilt} \text{ then } (W_p)_{smooth} = \max(W_p, (W_p)_{smooth})$$

$$\text{if } (W_p)_{smooth} \ge W_{fc} \text{ then } (W_p)_{smooth} = \min(W_p, (W_p)_{smooth})$$

$$(W_p)_{smooth} = \max(\max(W_S, dz), (W_p)_{smooth})$$

where is:

veg - Percentage of vegetation,
W_S - Surface soil water content liquid (water),
dz - Soil depth or reservoir depth.

To be able to make the calculation of SWI, the following fields are necessary in ALADIN or ARPEGE FA-file: Land/sea mask (SURFIND.TERREMER), Snow depth (SURFRESERV.NEIGE), Frozen deep soil wetness (PROFRESERV.GLACE), Percentage of vegetation (SURFPROP.VEGETAT), Soil depth (SURFEPAIS.SOL), Percentage of clay within soil (SURFPROP.ARGILE), Liquid (water) surface soil wetness (SURFRESERV.EAU), Liquid (water) deep soil wetness (PROFRESERV.EAU)
Smoothing is performed just for the land points (Land/sea mask SUFRIND.TERREMER=1), points without snow cower (SURFRESERV.NEIGE=0), and without ice in the ground (Frozen deep soil wetness PROFRESERV.GLACE=0).
There is no important change between an analysis and the forecasts of the SWI. Dry areas remain dry and wet areas remain wet after 15 hours of forecast (not shown here). Using the smoothing of SWI we would like to reduce the current unrealistic spatial heterogeneity of the soil moisture.
When the radius of smoothing is increased, the smoothed area and the amplitude are increased. Beyond the threshold value, further increase in the radius of smoothing does not bring a change of SWI any more. For the LACE domain with 12.2 km resolution results are the same for 8.1 and 6.1 km radius. In ALADIN, smoothing is performed with the data from just the 5 nearest grid points while in ARPEGE 7 grid points are used. The idea is to smooth the SWI field just over the land only if there is no ice in the ground or snow cover. This means that the impact will be high during the summer and low or none during the winter.

Results

Forecasts with the operational version of ALADIN, AL25T1_op2 in Croatia were done. 12 days were chosen for the testing, 6 days in June 2002 and 6 days in year 2003, 3 days in January, 2 days in April and 1 day in May.
From the results (not shown here) it may be conclude that the impact on the T2m for the winter and early spring examples is really small, the same is valid for the H2m. For the late spring period (not shown here) impact of smoothing of SWI is relatively big.
The period from 15th to 21st of June 2002 was a very hot period with the temperatures of more than 30 °C in the Central Europe. The measured values were the highest ever. The period was also very hot for the West Europe but not during the whole period.
For the examples from the problematic period the improvement in 12 and 36 hrs forecast of the T2m is really big in the areas where a very big gradient of surface temperature was noticed, in some points for more than 2 °C. Radius of smoothing of 6.1 km was used. The results are similar if the smoothing is

applied to the SWI field 21 or 30 times. The T2m field gradient field is not as big as it is in the Operational run.

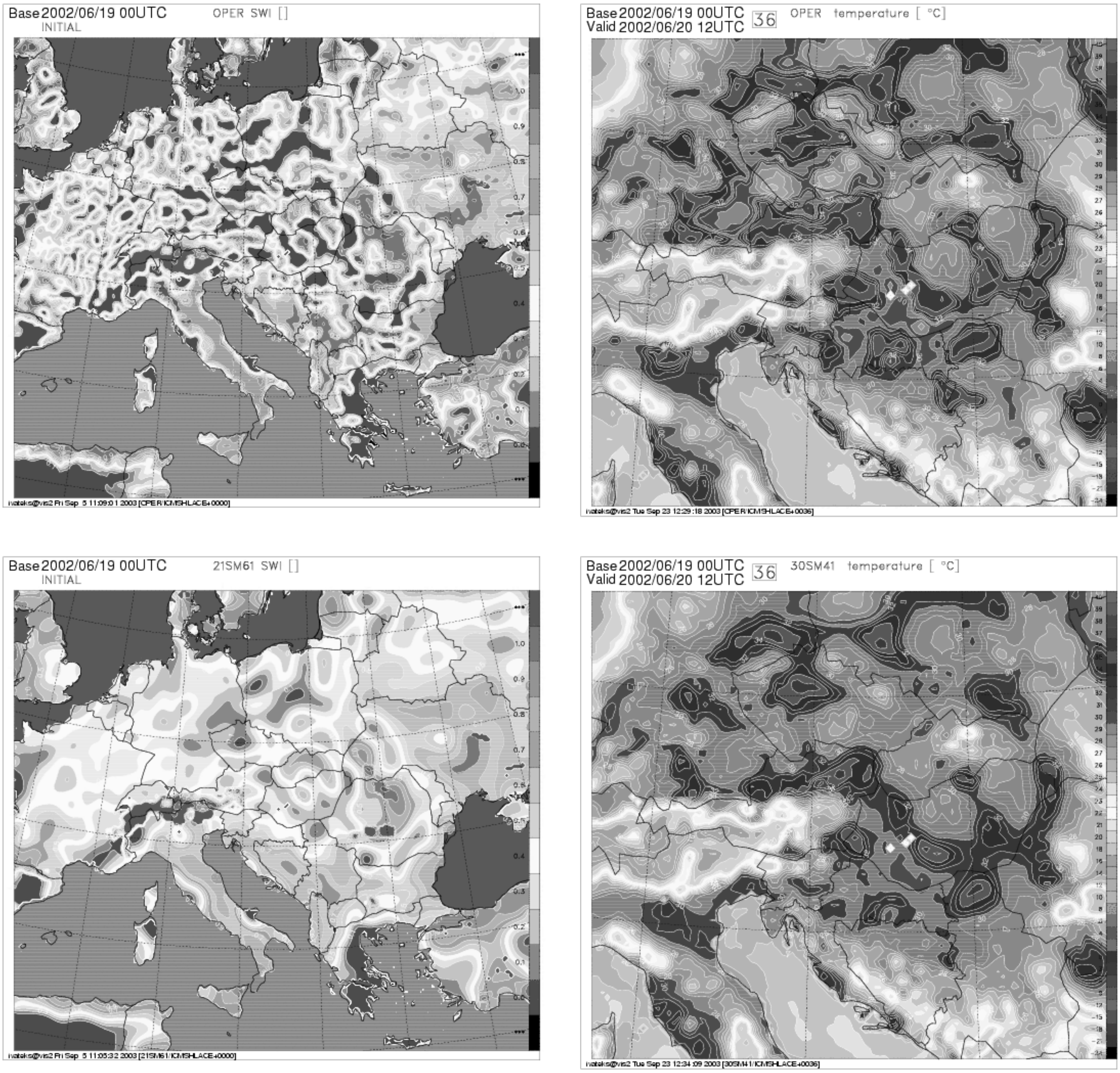


Figure 2 SWI from Analysis and T2m 36 hours forecast from the Operational run and with the 21SM61 smoothing set-up of SWI (21 times smoothing with radius of smoothing 6.1 km - half of the grid size) are shown, start June 19th 2002 00 UTC.

During the January and the beginning of April there are no significant changes in the RMS and BIAS. During the warm period RMS is usually better for the smoothed run while BIAS is better for the Operational run.
If there is some impact on the BIAS of T2m, there is an opposite impact on the BIAS of H2m (in the term of sign). This is the case for all warm situations.

In the following tables, comparison of the 21SM61 smoothing with the OPER run and the other smoothing set-ups for the period in June 2002 is shown. The number of the better (D<0) and the worse (D>0) points (in terms of absolute error) is shown. In the Tables 1 and 2, the grey background in the first tree rows in the tables (D<0) means that the forecast is improved in more points than it is worsened for the set-up 21SM61. The grey background in the last tree rows (D>0), in the Tables 1 and 2, mean that the smoothed set-up 21SM61 gives more points with the worst forecast. With the 21SM61 smoothing set-up, the number of points with the better forecast is highest.

Table 1 The number of points with the better and worse T2m forecast, 20SM61 is compared with the other runs (OPER and other smoothing: 10SM61, 21SM41, 30SM41 and 30SM61), sum for all the forecast hours: 00, 06, 12… 48 UTC, and for the whole period, 15th-20th of June 2002

T2m 00,06,...,48	|2161|-|OPER|	|2161|-|1061|	|2161|-|2141|	|2161|-|3041|	|2161|-|3061|
T2m_all_D <= -2 C	433	39	45	13	9
-2 C < D <= -1 C	1228	259	290	119	50
-1 C < D <= -.5 C	2287	857	916	532	400
-.5 C < D < .5 C	27179	32090	31920	33013	33318
.5 C <= D < 1 C	1849	743	798	440	374
1 C <= D < 2 C	1008	220	235	100	66
2 C <= D	238	14	18	5	5

Table 2 The number of points with the better and worse T2m forecast, 20SM61 is compared with the other runs (OPER and other smoothing: 10SM61, 21SM41, 30SM41 and 30SM61), sum for all the forecast hours: 00, 06, 12… 48 UTC, and for the whole period, 15th-20th of June 2002

H2m 00,06,...,48	|2161|-|OPER|	|2161|-|1061|	|2161|-|2141|	|2161|-|3041|	|2161|-|3061|
H2m_all_D <= -10 %	1269	159	179	78	57
-10 % < D <= -5 %	2755	792	884	407	303
-5 % < D <= -2 %	4522	3230	3288	2419	1624
-2 % < D < 2 %	20219	27102	26744	28992	29753
2 % <= D < 5 %	3227	2167	2328	1763	1974
5 % <= D < 10 %	1430	488	517	330	305
10 % <= D	651	135	133	84	57

If all the forecast hours and the whole period, are compared the smoothing set-up 21SM61 is better than others are. Smoothing set-ups 30SM41 and 30SM61 are better for some classes.
For all the forecasts: 06, 12, 18, 24, 30, 36 and 48, 21SM61 smoothing set-up is usually better than other smoothing set-ups, with an exception of 31SM61 for a some classes.
When just the improvement in the T2m and H2m forecast is considered it is not clear which smoothing set-up is better. If more weight is given to the bigger improvement, the results are better for the 21SM61 set-up, it is especially the case for H2m.

Conclusion

During the hot summer days, hot spots appear in the 2m Temperature field, caused by the small-scale features in the soil moisture. These features are the consequence of the switching condition in the surface analysis and of convective precipitation, both of which have high degree of uncertainty. More over, this smoothing is coherent with the soil moisture analysis, which is not able to connect spatial scales lower than 100 km because of the Surface Observations network. The Surface analysis is made in ARPEGE.

With the smoothed SWI, big gradients in T2m field from the Operational run are reduced. In some points for more than 2 °C. Radius of smoothing of 6.1 km was used. The results are similar if the smoothing is applied to the SWI field 21 or 30 times.
For June 2002, with the very high temperatures, RMS of T2m and H2m is better when SWI is smooth. Maximum improvement of RMS for H2m is 0.022. and of T2m is 0.334 °C. The differences are the highest for 12, 36 and 18 hrs forecast. The BIAS is usually better for the operational forecast with maximum difference 0.024 for H2m.and 0.369 °C for T2m. BIAS is negative formost of the experiments.

If there is wish to smooth the SWI, the proposed setting is 21SM61, 21 means that the smoothing procedure is applied 21 times and 61 is for the radius of smoothing 6.1 km (half of the horiz. grid-size).
A longer parallel test during the late spring and summer is needed to conclude if the impact of SWI smoothing will improve the 2 m scores. The best solution is to improve assimilation in ARPEGE or to apply smoothing of SWI in ARPEGE, and then it is not needed in ALADIN.