LACE/Météo France stay report

Extensive validation and verification of using Land SAF albedo assimilation in ALADIN NWP model and Exploring possibilities of using satellite information for snow analysis in combination with improved CANARI snow analysis

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1. Introduction

The work done during a three month stay at Meteo France was split into two parts.

First part was a continuation of topic started two years ago: usage of Land SAF albedo retrieval for assimilation in ALADIN NWP. In this part, the report is closely related to the previous report produced two years ago by the same author.

Second part was devoted to exploration of possibilities of combining Land SAF snow cover information with CANARI OI for snow to gain an improved snow analysis.

2. Albedo

After promising results obtained during previous stay at MF, the goal was to recode the algorithms in a more compact and transparent way that would allow easy operational usage, to perform validation of system in some locations where there have also been extensive measurement campaigns and to produce an entire year of forecasts for verification.

To get a detailed description of the simple Kalman filter based algorithm for albedo assimilation, see (Cedilnik, 2008). Here I only mention that the algorithm was basically not modified but only recoded with the operational aspect in mind. The additional fields required for assimilation and cycling of the data (albedo projected to LCC grid, analysis error, etc.) are now stored in the FA file for easier access by the system.

The entire experiment is now performed in a fully consistent manner: only the climatology values from the model are used (e.g. no use of "third party" information from ECOCLIMAP...) and the entire process is performed on LCC grid of the model after the satellite data have been projected to it (by the nearest neighbor method). That means that only one interpolation is required (from the satellite view projection to model grid).

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2.1 Validation

The algorithm was validated by examining the time evolution of assimilation related variables in a few chosen points that correspond to stations where several atmospheric fluxes were measured during a campaign related to CO_2 fluxes. Time series of retrieved albedo and analyzed albedo for the entire year of 2007 are shown in **Figure 1**. The concept of Kalman filter approach can be well verified in the behavior of analyzed albedo values in autumn months, when in certain locations no good retrieval was obtained and therefore the analyzed albedo started drifting towards climatological value. Most of such cases happen in Hesse (middle left of **Figure 1**), where the climate is perhaps closest to continental and therefore days with persistent cloudiness limit the albedo retrieval. On the other side, the Mediterranean location of Puechabon (bottom left) has hardly any missing albedo retrievals through the entire year.

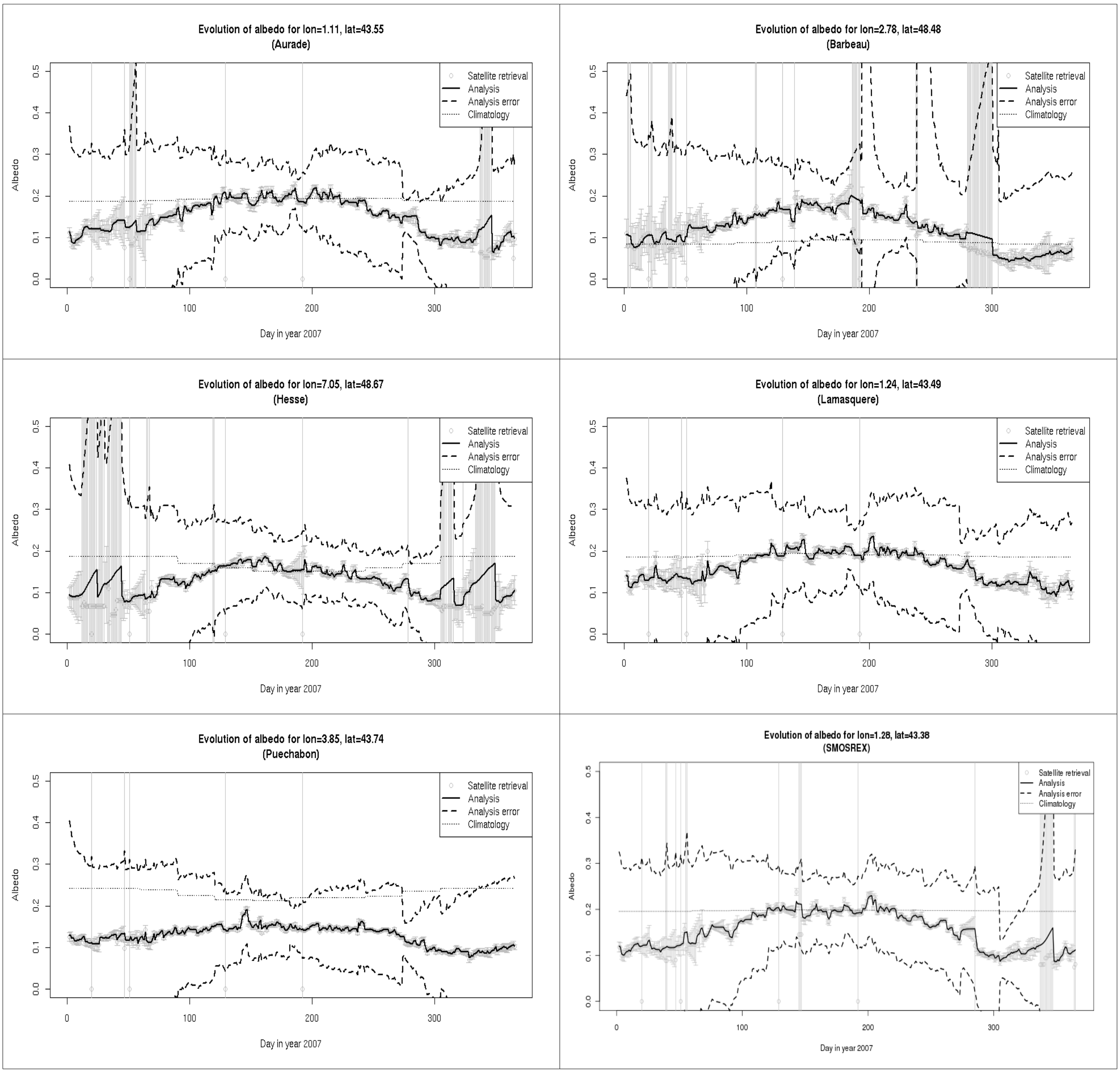

Figure 1: Albedo evolution for 6 stations (see titles of individual graphs): circles with error bars are albedo retrieval values (after interpolation to model grid), dotted lines are model climatology values (change only from month to month), solid black line is the best albedo estimate and dashed black lines are its uncertainty.

The next point in validation was to see how the modified albedo changes the model fluxes related to short wave radiation. The same stations as above were chosen and a comparison has been performed between the measured and modeled net radiation, **Figure 2**. Clearly, most of the time the impact is neutral.

However, in one location (Barbeau, second from top on **Figure 2**) the fluxes in experiment run are farther from observations than net radiation fluxes of the reference run. This is true for spring and summer time and the impact is neutral for the rest of the year. In other stations, there is some sign of improvement in spring and autumn period, with the exception of Puechabon, where the fluxes in the experiment run are much closer to observations throughout the entire year and the effect is the least pronounced in the colder part of the year. This vast impact can be attributed to a much more different satellite retrieved albedo compared to the climatology (again see **Figure 1**, bottom left).

The assimilation of albedo impact is more pronounced on surface temperature related fields for colder part of the year whist during warmer period this is projected also on the height of the PBL. This is probably due to more frequent stable conditions in winter time and consequence of this is less mixing in the atmosphere, so that the surface information is not propagated in the vertical. In summer time, on the other side, the atmosphere is less stable and the modification of albedo has more impact on the height of the PBL rather then on surface temperature itself. **Figure 3** shows time-series of PBL height evolution and the sensible heat flux (which is in the opposite correlation to PBL height) for the same 6 stations as in **Figure 1**.

It is not completely clear, whether such comparison of model analyzed PBL height has any merit, but the algorithm to compute the PBL height is model intrinsic and is the same for both runs. To some extent, this is avoided by focusing on sensible heat flux and PBL height difference opposed to the absolute values themselves.

The difference in albedo values can also be seen on precipitation fields. Due to differences in diabatic heating, differences occur in distribution of convective precipitation and in latent heat flux distribution and magnitude. **Figure 4** shows such relative difference for average daily latent heat flux for warmer part of the year (from April until October) and in **Figure 5** there is the absolute difference in convective precipitation for months April until October. The differences in convective precipitation values mostly come in pairs of two of the opposite sign (similar to dipoles). This is explained by the fact that the convection is triggered slightly away from the reference position. However, on the average, there is a non-negligible difference of latent heat flux over the entire domain, see **Figure 6**. This domain average difference can reach values higher than 1 W/m2, which is of the order of magnitude of the anthropogenic forcing on climate change estimate.

Besides the difference in domain averaged latent heat flux there is also a non-negligible difference in convective precipitation domain average shown on **Figure 7**. The relative values of this difference are up to a few percent. The difference in the stratiform part of precipitation (not shown) is of a few orders of magnitude lower compared to the convective part.

Contrary to a simple guess, the impact of modification in albedo need not be in negative correlation with surface (or 2m) temperature. This rather surprising fact was established after a painstaking trial to search for the biggest difference in temperature after 12 hours of integration. The biggest differences occur as single spots and are very suspicious for a careless observer. However, when observing when such differences occur, the fact the this is a three dimensional model has to remembered.

These values get so high when there is a difference in the distribution of convective precipitation (mostly in late spring and summer period) and a small difference in the distribution and value of albedo can lead to very small differences in the distribution of surface temperature which in turn change the behavior of the convective scheme, causing a different distribution of convective precipitation and a great difference in surface temperature. If a shower or a thunderstorm

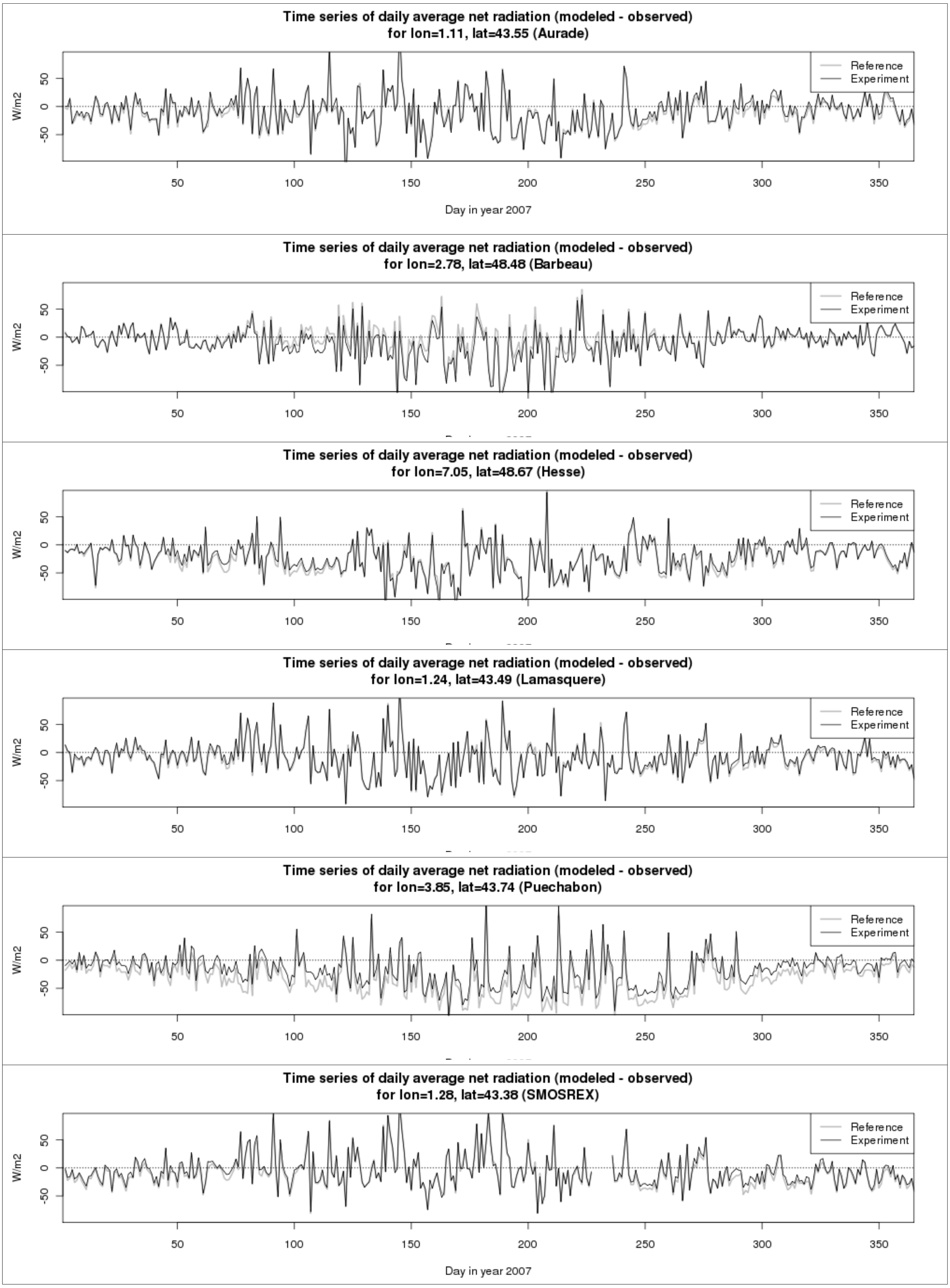

Figure 2: Daily net radiation time-series for year 2007 for six stations (same as in Figure 1 – see titles of individual graphs). Shown is difference between model and observation for experiment run (with LSAF albedo assimilation) – bold line and the reference – light gray line. Closer to zero is better.

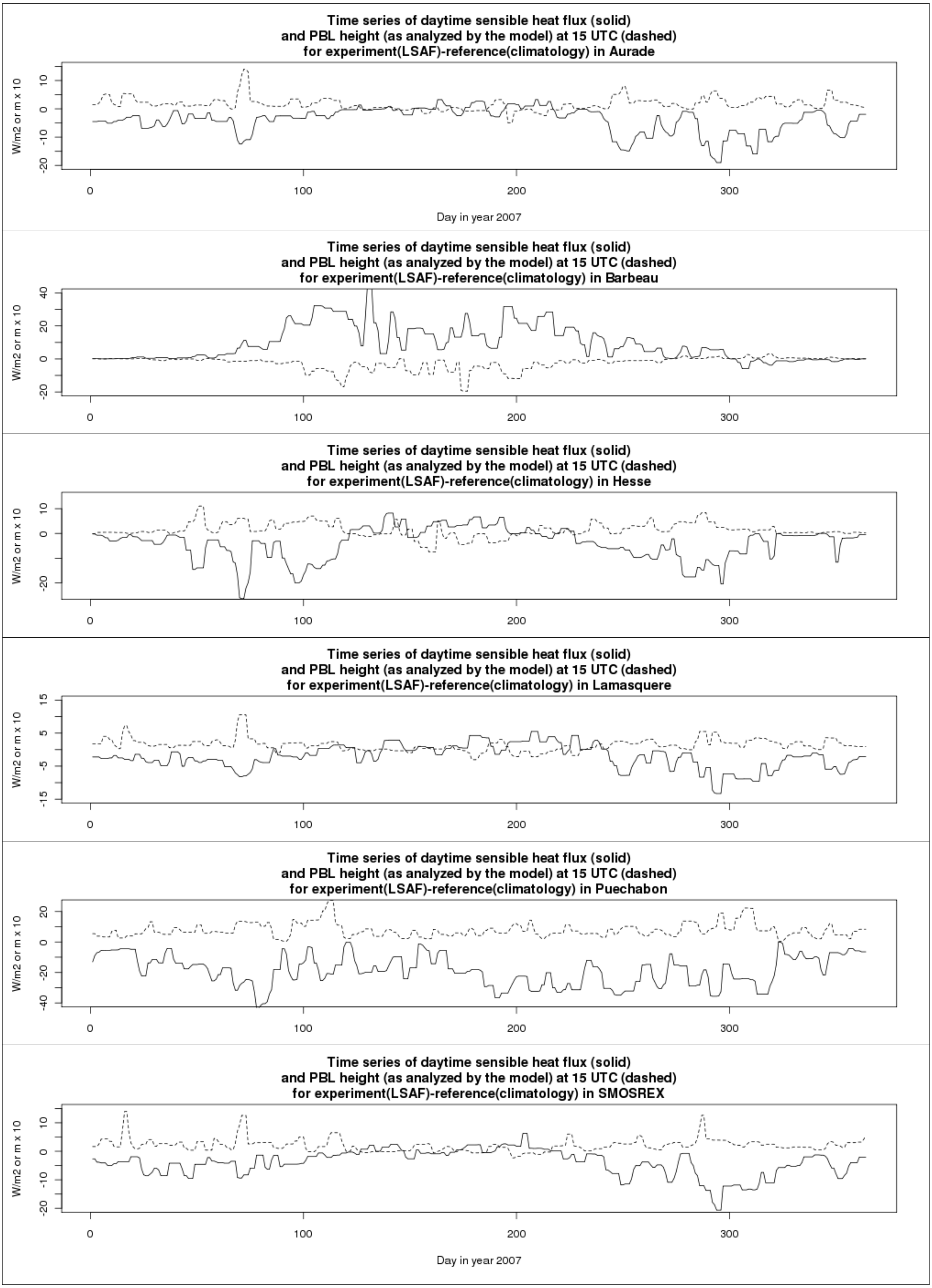

Figure 3: Time-series of sensible heat flux during the day (between 9 and 15 UTC) and PBL height as analyzed by the model at 15 UTC for the difference between the experiment (LSAF assimilation) and reference run.

in a model appears in a different place, rain will cool the ground in another gridpoint. Or it comes to difference in temporal distribution of rain, which means that the experiment run is cooling a certain gridpoint sooner (later) than in the reference. This is nicely shown in **Figure 8** for a gridpoint close to Vienna, where the rain started slightly later in experiment run and therefore, the cooling did not take place at the same time as in the reference model. Ultimately, this led to surface temperature positive correlation with albedo modification of the magnitude of around 10 degrees C.

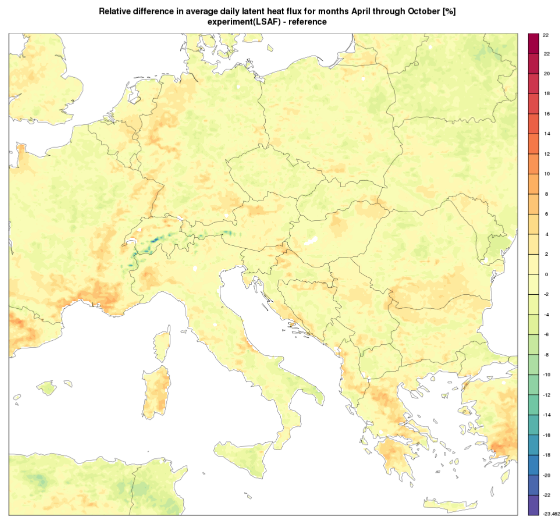

Figure 4: Relative difference for daily average latent heat flux (for month from April until October) in percents.

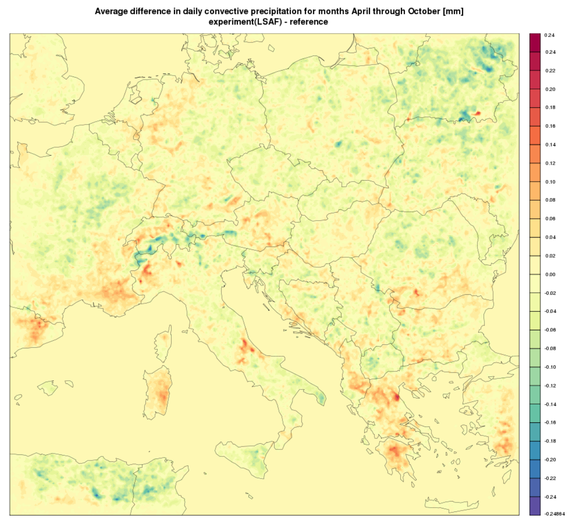

Figure 5: Average daily convective precipitation difference (for months from April until October).

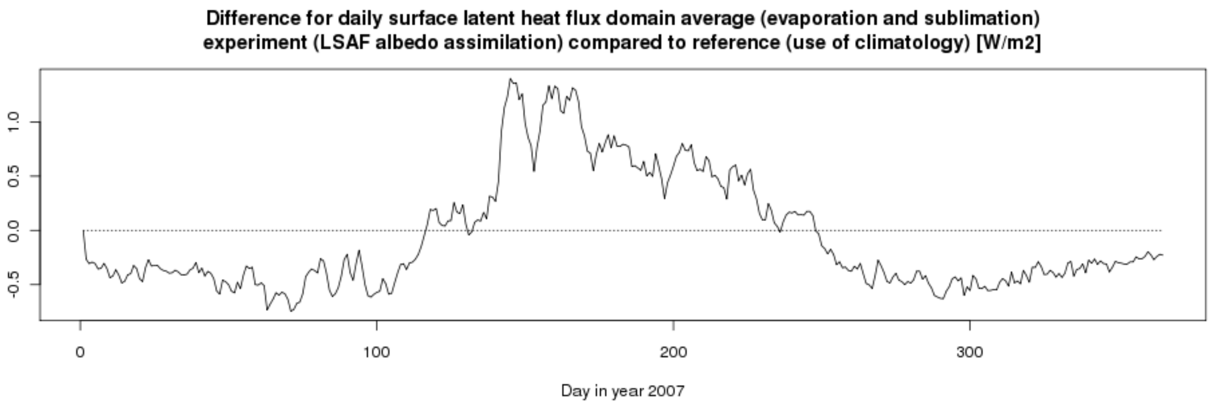

Figure 6: Domain averaged difference for surface latent heat flux time-series. Positive values are when the latent heat flux in the experiment (with LSAF albedo assimilation) is greater compared to reference.

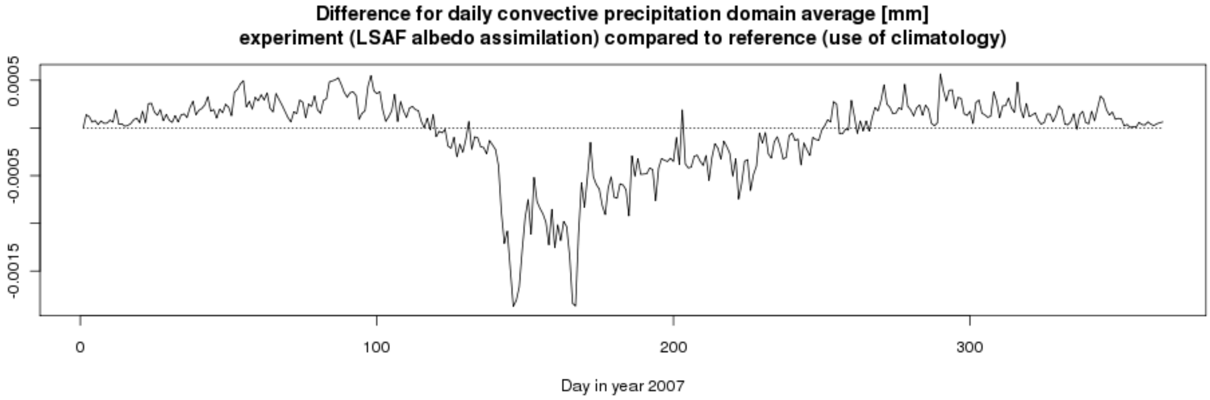

Figure 7: Domain averaged difference for convective precipitation, positive values are when there is more convective precipitation in the experiment (with LSAF albedo assimilation) compared to reference.

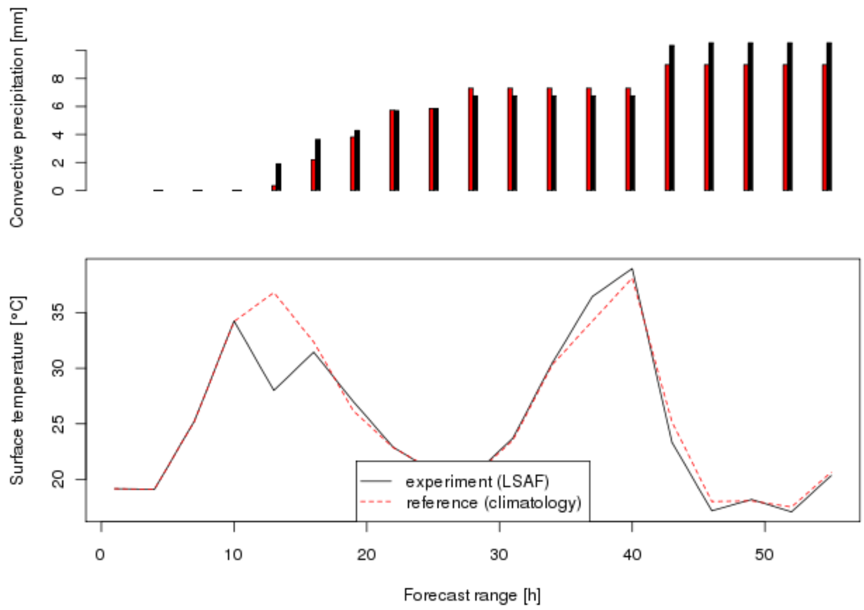

Figure 8: Forecast of convective precipitation (above) and surface temperature (below) for a gridpoint near Vienna for experiment (black) and reference (red). The difference at +12 hours is around 9°C and is correlated in positive way with albedo difference since it is not a direct consequence of difference in radiative forcing but in precipitation (convection) spatial and temporal distribution.

2.2 Verification

Verification was performed with the standard Météo France / Compass software, some further details (domain size etc.) can again be found in report from 2008.

In this report I will focus on thoroughly presenting all the obtained results for the entire year: the break down is first done by month and forecast range (for forecast ranges 12, 24, 36 and 48) (dependence on date – **Figures 9** through **12**) and then by month only (dependence on forecast range – **Figure 13**). What is shown are only the temperature at 2m scores, since there is not much impact on any other variable and on the free atmosphere. When comparing the top right image in **Figure 9** and **Figure 10** or from **Figure 13** in general, it can be clearly seen that the impact is greater at forecast times +12 and +36 then at +24 or +48. This makes sense and it is due to the fact that the integration runs are always initialized at 00 UTC and so these two ranges are always during the maximum of short wave radiation. This daily impact is sometimes kept also for the night time (on **Figures 10** and **12** for months of March and September). This is in accordance with the analysis on month per month basis (**Figure 13**) which shows that in general, the greatest impact is in the colder part of the year – from September until March, and there is hardly any impact in summer time (June, July, August). All this is goes quite hand in hand with the results of validation, for example **Figure 2**.

One possible explanation of why the impact on temperature is the largest in that period is that this is when there are the greatest variations in albedo in general (season changes, snow melting...) for the kind of climate in this computational domain.

Probably greater impact would occur in more dry climates (e.g. over Spain or northern Africa), when the albedo can change more rapidly and vividly. For example, if rain falls in a desert this should contribute to significant change in albedo value.

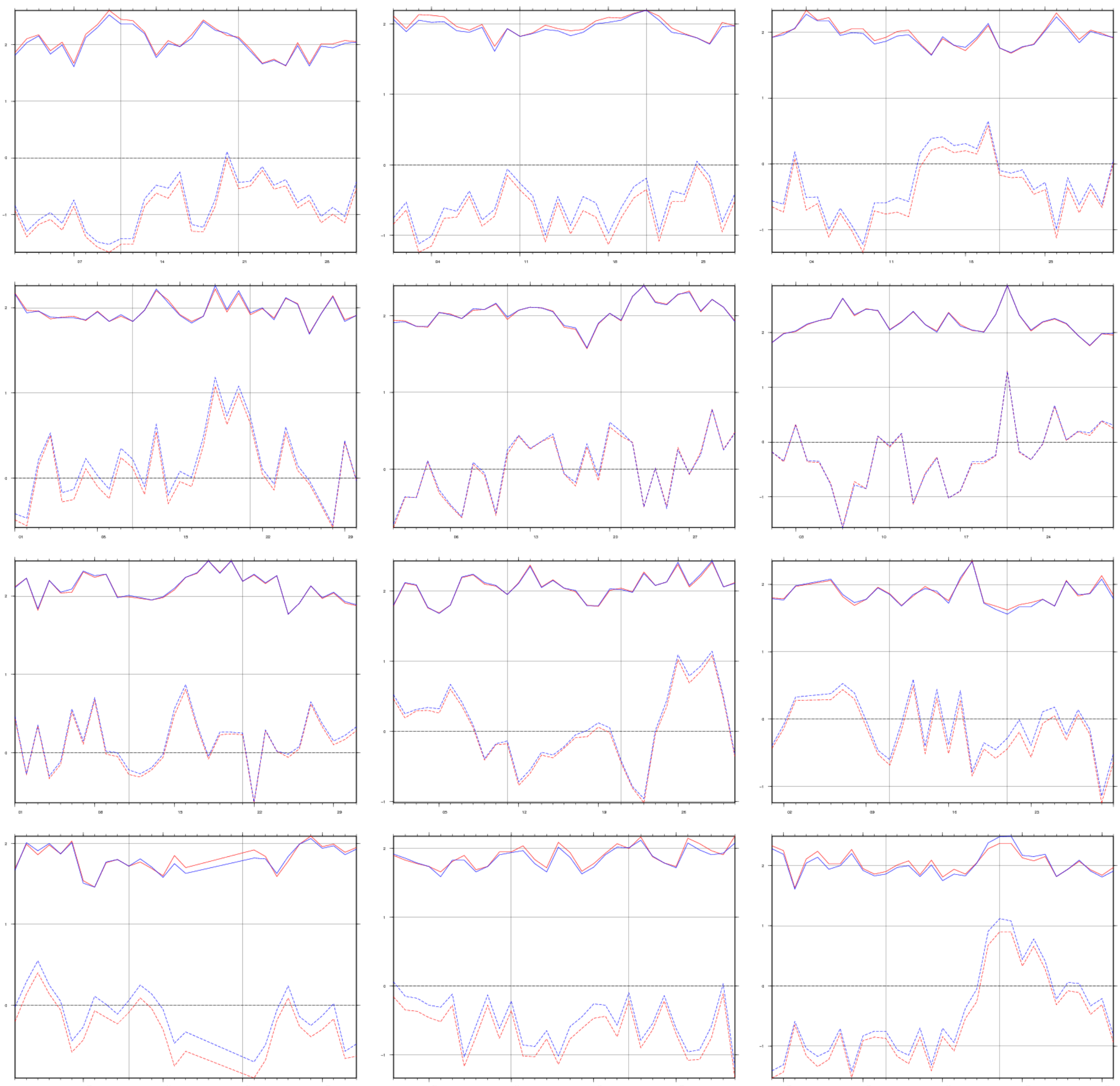

Figure 9: Scores for temperature at 2 meters after 12 hours of intergration for January, February and March (top row), April, May and June (second row), July, August and September (third row) and finally for October, November and December (bottom row), day in month are on the x axis. The top curve on each graph is RMSE and the bottom one is bias. Blue line is for experiment with Land SAF albedo assimilation and red one is for the reference run.

The scores indicate that the albedo assimilation is mostly a more or less systematic correction of cold bias. It seems it is not selective and therefore it is not only removing cold bias but in some cases introducing additional warm bias, see for example top right image in **Figure 9**, for March 2007.

However, on the average for year 2007, there is an improvement – top blue line is generally below top red line in **Figure 13**, indicating that the RMSE of the albedo assimilation run is lower compared to reference. Same goes for bias, which is generally of the order of a few tenths of a degree smaller and always corrected in positive sense (reduction of cold bias).

As this correction is non-selective, it is sometimes too overacting. This can not be seen on average scores of **Figure 13**, but rather in **Figures 9 and 11,** top and bottom right (March and December), where it seems that this too extensive correction is linked to a particular time period and therefore to a special weather phenomena. Either this can be attributed to a difference in vegetation or melting of snow or using old albedo values during long and spatially extensive cloudy periods. This is one thing that awaits further investigation.

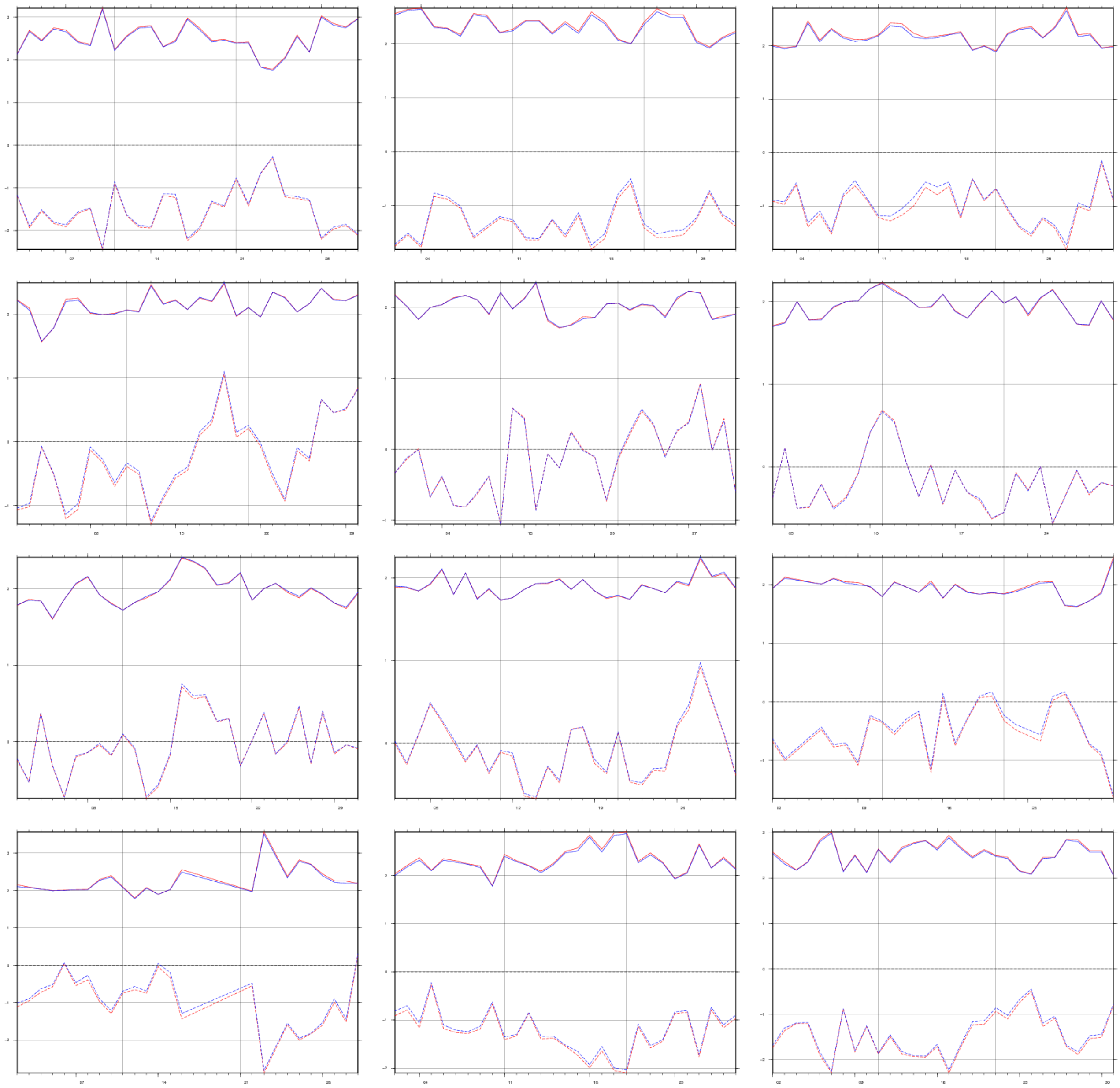

Figure 10: Same as **Figure 9**, but for forecast time of 24 hours.

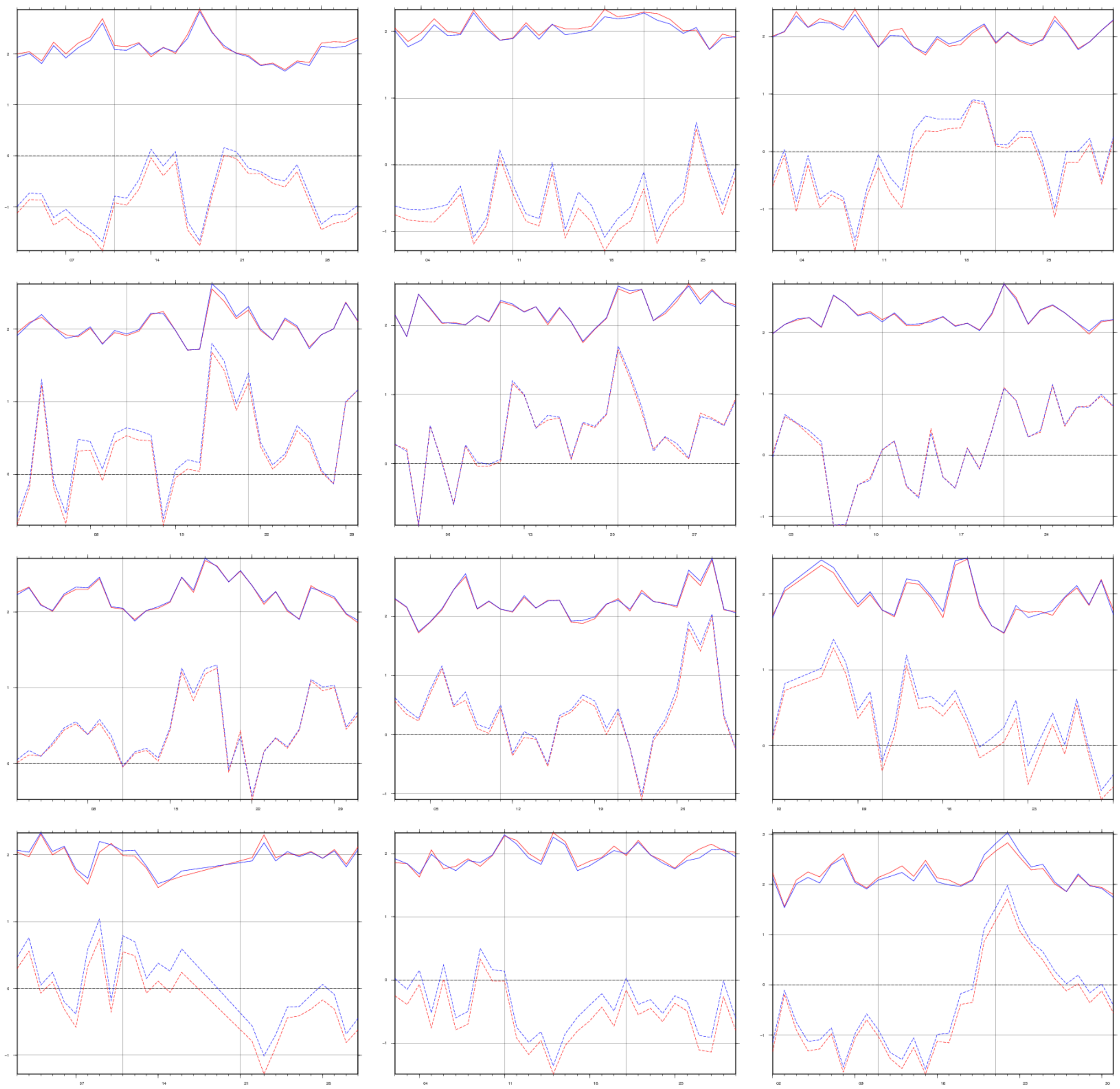

Figure 11: Same as **Figure 9**, but for forecast time of 36 hours.

The non-selective bias correction property of the Land SAF assimilation was further investigated. Another experiment over a shorter period was constructed, where the surface fields are not initialized with ARPEGE every run, but with the first guess from the previous ALADIN run. This could also be called a surface assimilation system with no observation. The idea behind this is that perhaps reinitialization every day (with ARPEGE surface) is causing the surface variables into some rather unbalanced state inconsistent with the new albedo value. An even more daring assumption was that such first guess initialization in combination with albedo assimilation would act similarly as the CANARI OI for surface, which is also reducing bias, but rather acting aposteriori. The results (not shown) didn't confirm such hypothesis and were worse compared to the reference of the initial experiment.

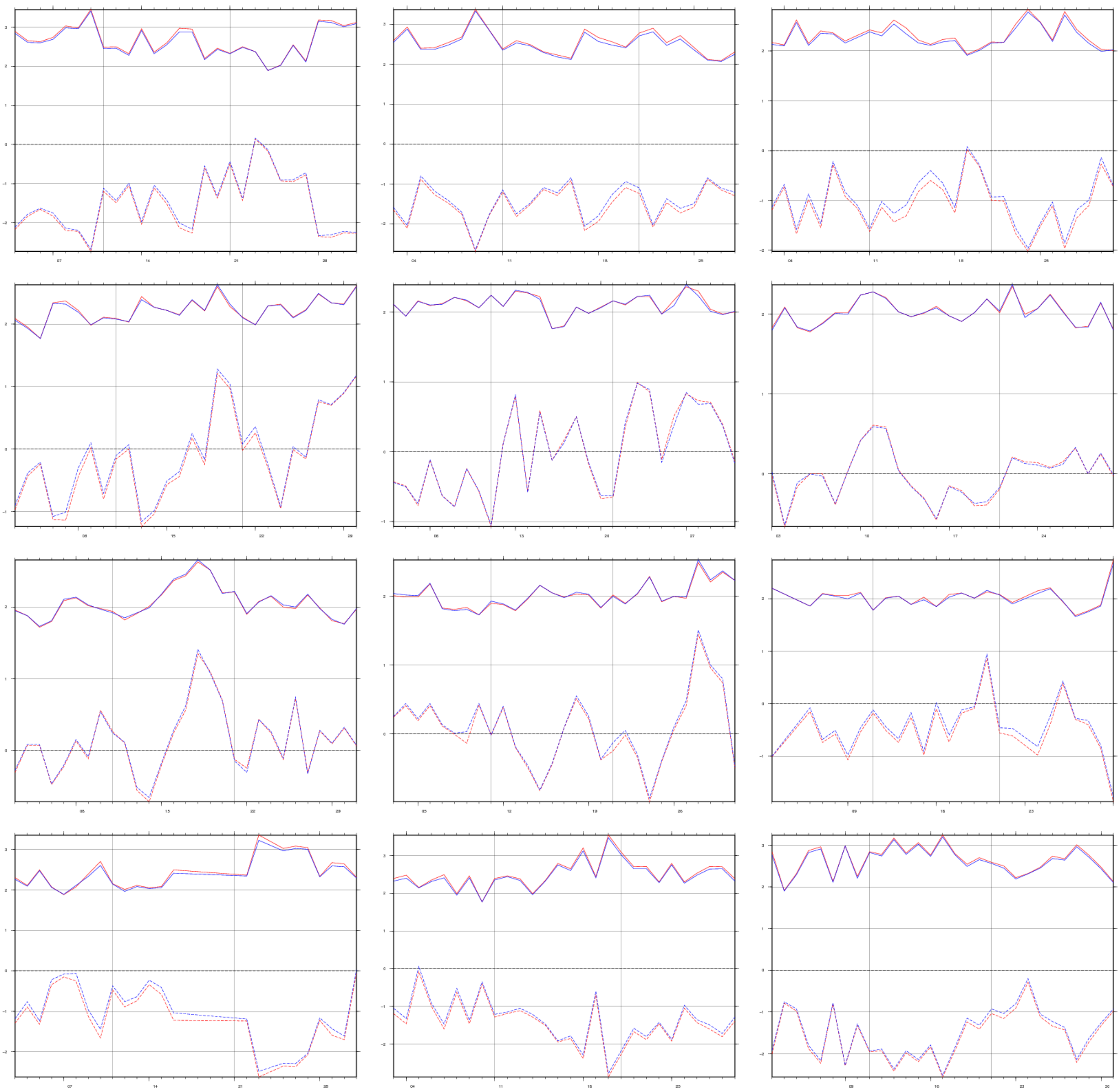

Figure 12: Same as **Figure 9**, but for forecast time of 48 hours.

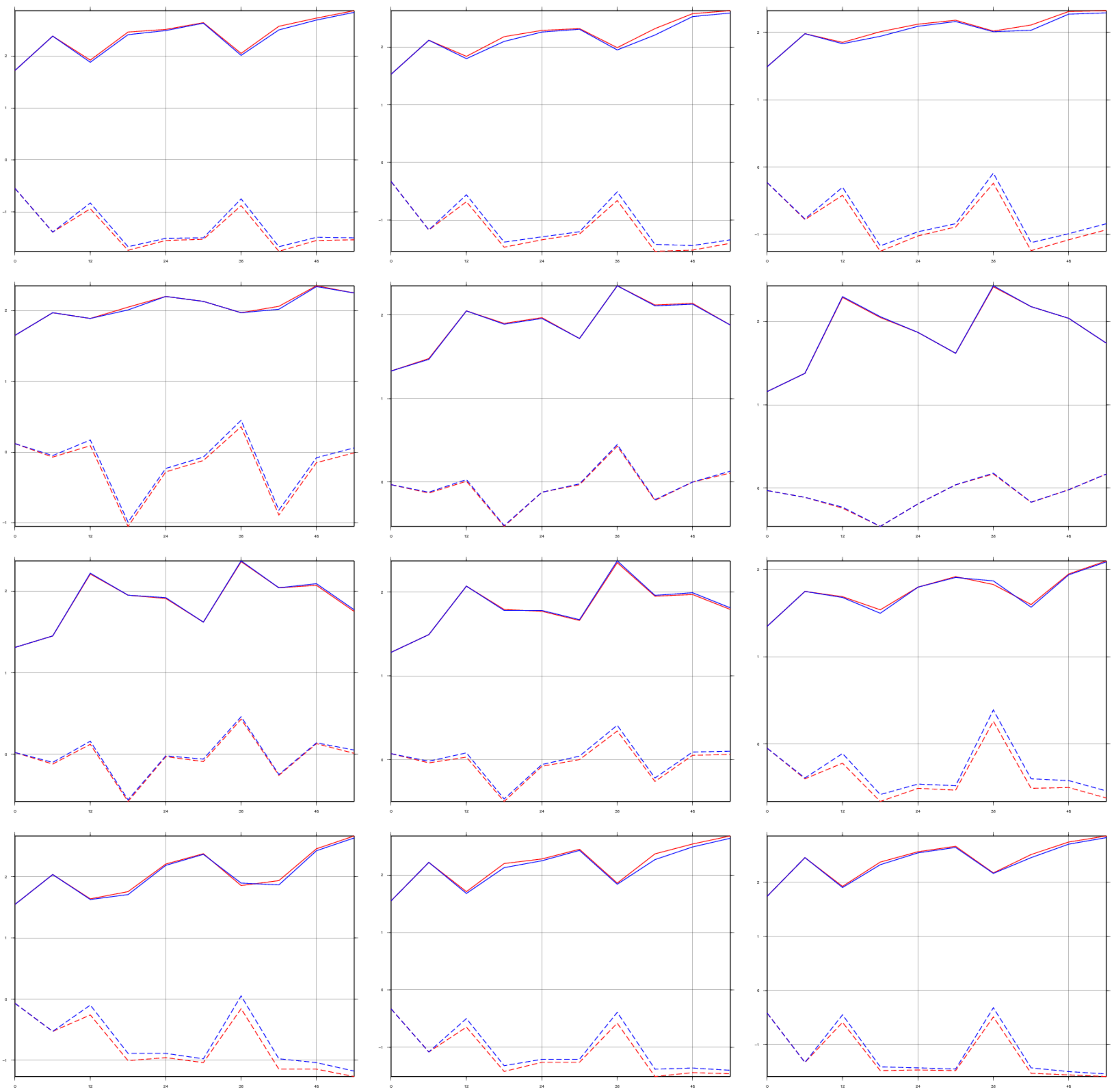

Figure 13: Temperature at 2m scores depending on forecast range for every month of year 2007 (top row is for January, February and March, second row is for April, May and June, third row is for July, August and September and bottom row is for October, November and December. Blue line is for experiment with Land SAF albedo assimilation and red is the reference.

3. Snow

3.1 Description of technique

The first step in work on snow assimilation was to correctly set-up existing snow assimilation in CANARI (in model experiment with full 3Dvar). This consisted of replacing snow mass assimilation (snow water equivalent or SWE – snow height was simply multiplied by 0.01 to obtain snow water equivalent in kg/m2) with snow height assimilation, where values for density are taken from first guess (model snow density).

Further, CANARI code was modified in such way to allow for cycling of errors of analysis. This required only minor modifications in the code, since some time ago, such error cycling has already been used for CANARI upper air OI. The analysis error is stored in a separate file and then read again in the initialization at the next step of assimilation cycle as the background error.

The next big step was to recode and adopt the algorithm which defines snow cover based on values of LSAF albedo. This algorithm was developed by Dominique Carrer and it is close to the SnowCover LSAF product, but offers some more flexibility and better defines regions with possible snow cover (not only regions where there is high certainty for snow cover).

Finally, all three pieces were linked together in an assimilation procedure in the following order:

- snow cover extend is extracted from the LandSAF satellite product by a simple algorithm and merged with first guess with the following simple set of rules:
  - when there is no snow in the model and snow cover in satellite retrieval:
    → 10 cm of snow is added,
  - when there is snow in the model and no snow in satellite imagery:
    → snow is removed,
- the new background error for snow height is obtained in the following way:
  - previous analysis error is used as basis
  - physical fluxes related to precipitation are added (in absolute value) to it:
    - precipitation flux
    - sublimation flux
    - snow melting flux.

This addition of physical fluxes is supposed to keep the value of error under control, so that it would not drift too low. No test was performed on which model physical fluxes and in what way should be used, so this item is open for further investigation.

Only then is the CANARI snow assimilation (in snow height) performed based on satelitte modified first guess and, unless in case of a cold start, the background error values are read from the separate file, after they were modified as explained above.

3.2 Validation

Unfortunately, there was no time to perform a longer and extensive test over several weeks similar to the one for albedo, instead only an example of one such combined assimilation sequence was performed and is presented here. The author believes that such a combination should be used for further development with some modifications and improvements.

This example for one case is explained in **Figures 14, 15** and **16**. First the impact of purely modifying the snow obs operator is shown in **Figure 14**. The snow water equivalent (SWE) analysis was replaced with snow height analysis, since snow height is the quantity measured by SYNOP stations. To achieve this, snow density model field was put into one of the arrays for snow climatology which are accessible in snow obs operator routine – so that the obs operator for snow computes snow height. The snow climatology arrays were handy, since they were only used for Urban formula vertical interpolation of snow height, which is now considered deprecated and shouldn't be used.

One relies on model snow height value for this operator, but the author believes that such a treatment is better than to assume constant snow to water density ratio of 1:10 as in case of SWE analysis. The comparison of snow height fields coming from SWE or snow height analysis can be seen in **Figure 14**. The time of analysis shown on this figure is 00 UTC and consequently there aren't many stations outside Germany reporting snow height, so the place to look for differences is mostly over Germany.

After testing snow height analysis and the ability of CANARI OI to save and re-read the error of analysis (minor code changes were needed here as well), the next step was to bring the

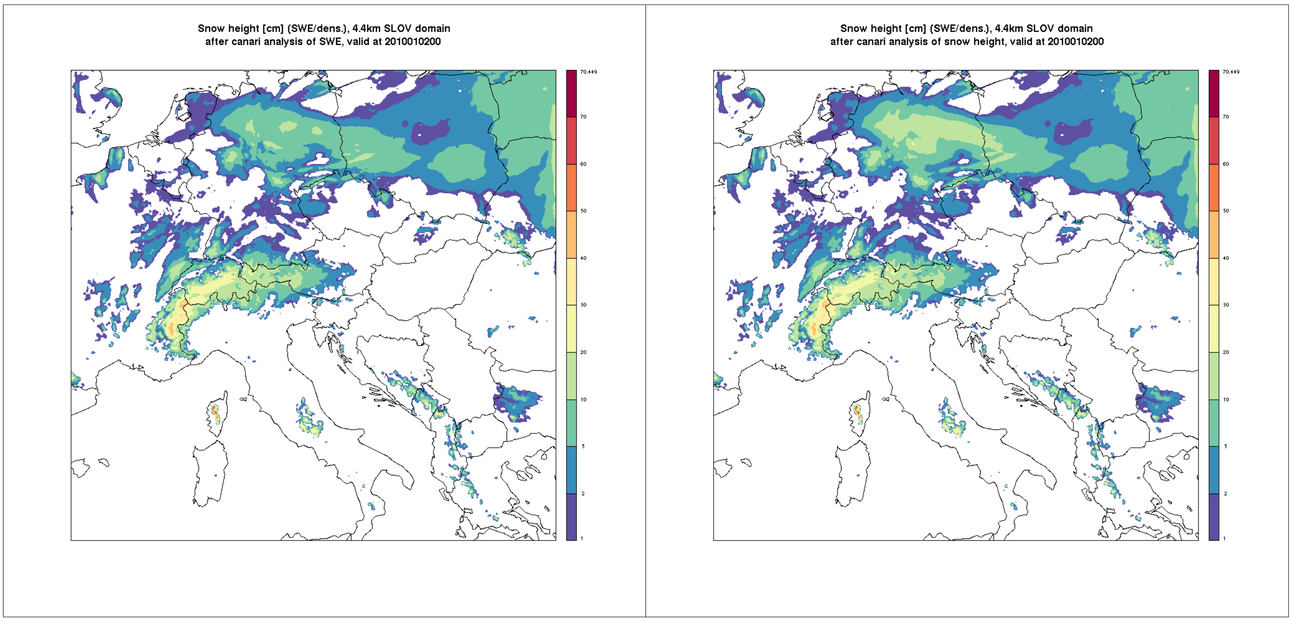

Figure 14: The impact of modifying obs operator for snow: snow height [in cm] after snow water equivalent analysis (left) compared to snow height [in cm] after snow height analysis where model guess snow density was used in obs operator. Note: at the time of analysis (00 UTC) only few observation are used, mainly in Germany.

satellite snow information on model grid. The algorithm to obtain this is based on two sub-algorithms: one is a simple Land SAF albedo quality flag, which specifies snow covered ground (coming from nowcasting SAF) and the other is a simple algorithm based on albedo values using various thresholds and conditions. The latter can be tuned to one's needs and, as it was used in this case, it is believed to provide some more information on the snow cover on the ground.

The final snow cover information, based on both algorithms and already projected to LCC model grid is shown in **Figure 15**, on the top left. The interpolation method used to project the satellite data on the model grid was a simple nearest neighbor interpolation, for which I constructed look-up tables in advance. In this place, one should stress that it is very important what are the resolutions of the two grids – in this case the space projection grid of SEVIRI and the model LCC grid. If model grid is much coarser than the SEVIRI one, the nearest neighbor method would leave out many satellite grid points and the information obtained in the model would be less complete than it could be, on the other hand, if the model grid is finer than the SEVIRI grid, some of the model grid points would share the same neighbor in the SEVIRI grid. But the latter is less problematic than the former. In my case the resolution of the model used is 4.4 km, while the approximate SEVIRI resolution for the target latitude is around 5 km. We therefore didn't expect any problems coming from interpolation.

As seen from the top left image in **Figure 15**, only minor part of the computational domain has some information and the larger part is with no data. This is due to the fact, that there is a lot of cloud coverage obstructing the view of the ground. Unfortunately, snow on the ground and extensive cloud cover are rather temporally correlated.

After the process of subtraction and addition of snow cover according to rules described above, the impact of using snow cover information from the satellite on the new CANARI snow height analysis can be seen in two bottom images of **Figure 15**: left is without usage of satellite information and below right is with Land SAF snow cover. Notice the parts of snow cover in Poland and Germany, where snow was removed and then later introduced by CANARI analysis (due to its relatively large radii of impact). Probably a better tactics would be to perform another snow removal after OI.

The modifications of analysis/background error are shown in **Figure 16**: the left image is the analysis error after the first analysis at 00 UTC. Due to the fact that there is much less stations reporting snow height at that time, the analysis error is reduced only there and where the analysis

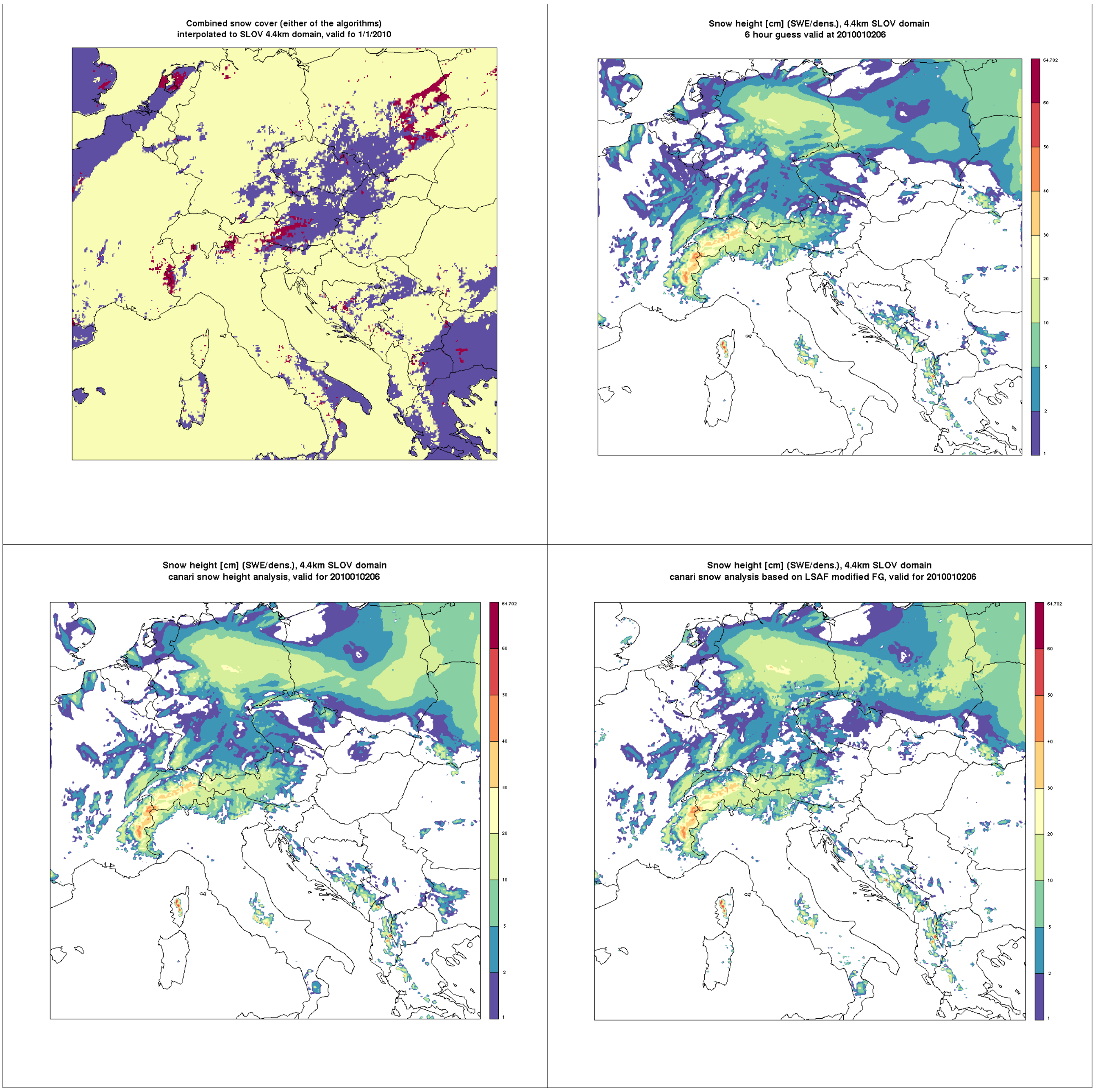

Figure 15: Comparison of LandSAF satellite information impact on CANARI snow assimilation. Top left is the information extracted from the satellite product and projected on model grid (bluish color is now snow, redish is snow and pale yellow is no data), top right is snow cover from first guess and the bottom images are snow cover after two different analysis: left is reference CANARI OI and right is CANARI OI with first guess modified by LandSAF information).

has no effect, the initial background error is preserved (5 cm in my case). After addition of various model fluxes coming from first guess (again see above), the new background error is in the middle image of **Figure 16**. At the first glance it seems that the values added are too high, since the average value of error is generally higher then what would be the default background error (5 cm), so probably this step needs further experimenting and tuning to improve performance. After

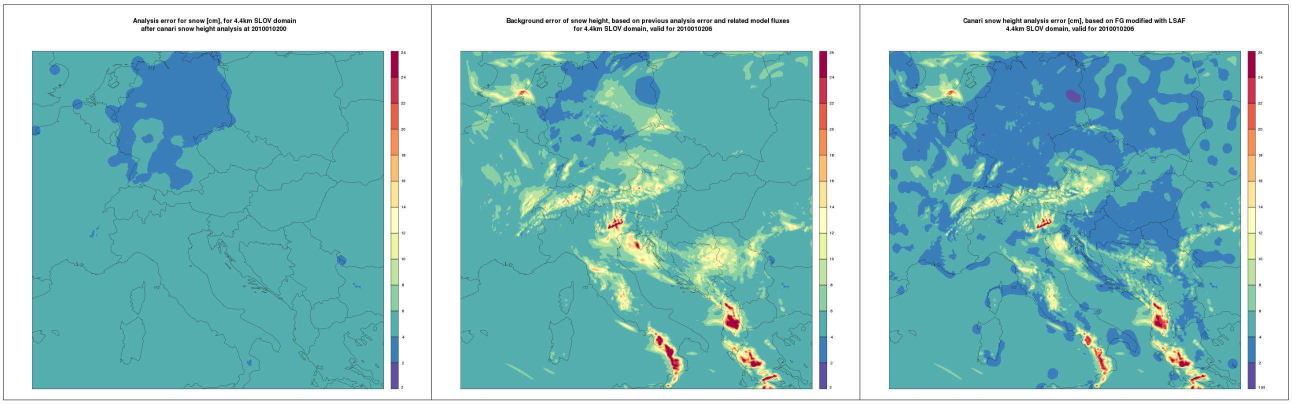

Figure 16: Evolution of snow height uncertainty: left is error of analysis after 00 UTC analysis, middle is the "evolved error" at 06 UTC which is a combination of previous error of analysis and snow related model fluxes, which is then used as the next background error for analysis at 06 UTC and in the right is analysis error after 06 analysis.

3.3 Conclusions

A serious drawback of described technique is the difference in temporal resolution of model analysis and satellite retrievals. The observation window for a daily satellite product is too large. What is more, it is not covering the night time.

Namely the snow cover obtained by the satellite should be considered as an average of the sunny part of the day and its time stamp is not as definite as a time stamp of an analysis is. To make matters worse, the snow that would fall during the night is not seen by the last satellite image, because you need daylight for snow or albedo retrieval. This snow will only show up on the next satellite retrieval, provided the cloudiness conditions will allow it. At the time of the 6 UTC analysis – when most of the stations are providing snow data, the latest satellite retrieval available is the one from the day before and this one doesn't include the snow that fell during the night. The example of such an error or rather mistake is also seen in **Figure 15**, where the first guess (top right) provides snow cover in the Netherlands, northern Belgium, northern France and in some areas of southeast England. This snow cover is then removed from the first guess using satellite retrieval and after that, this snow was not reintroduced by the SYNOP analysis (**Figure 15**, bottom left).

With this in mind, one could conclude that this technique is more promising for analysis at 18 UTC (this is another time, when lots of data are available; of course, providing that the retrieval is also already available at that time – this would theoretically be possible for winter time). Or one should rather completely focus on 15 minutes retrievals, which would contain less information usable, but due to much shorter validity there would be almost no chance of assimilating any faulty information. As such an algorithm, based on only one satellite image time slot would have a much lower yield, the assimilation of such data would need to be more frequent. This points in direction of using RUC (rapid update cycle) with both 3Dvar and surface OI and perhaps the appropriate retrievals could still be aggregated over a 3 hour time scale and this would still not introduce much error.

All this would imply that the retrievals need to be performed locally, using raw satellite data to produce a tailored product for one's need.