Use of geostationnary SEVIRI radiances in ALADIN 3D-Var

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ABSTRACT

The pre-operational French ALADIN 3D-Var configuration, that includes an Ensemble Jb formulation, has been used to assimilate geostationary SEVIRI radiances during a 15 days test period. A cloud type product developed by CMS (Centre de Météorologie Spatiale, Lannion, France) is used to keep channels non contaminated by clouds in the assimilation process, including those whose weighting function peaks over the cloud top. The near IR 3.9 µ and ozone 9.7 µ channels are blacklisted. One pixel out of 5 has been used with thinning boxes of 66 km^2, constant biases are applied and empirical observation error variances are used. The monitoring shows stable features in RMS error and bias for each channel. The (obs–analysis) RMS error is much smaller than the (obs-guess) one, meaning that a lot of information coming from the assimilated channels is taken into account in the variational process. The resulting mid-to-high tropospheric humidity increments present realistic mesoscale patterns. Scores against radiosoundings show positive impact up to 12 h of forecast, compared to the dynamical adaptation version of ALADIN. Biases are however observed for humidity and high level temperature. The information brought out by SEVIRI allows to predict realistic amount of total rain between 12 and 6 h of forecast for all the precipitating events of the test period.

1. Introduction

An operational version of the ALADIN 3D-Var will hopefully start at the beginning of 2005 at Météo-France. Details about its first configuration and results can be found in Fischer et al. (2004). It shows in particular that, compared to NMC-type formulations, the **B** matrix computed from an ensemble of ARPEGE/ALADIN analyses/forecasts (Stefanescu and Berre, 2004) has shown the best behaviours : mesoscale correlation lengths and appropriate vertical covariances that allow to correct model errors, notably the temperature bias below the tropopause. This first configuration has been adapted to study the impact of geostationary radiances observed by SEVIRI on board Meteosat-8 (ex-MSG). After a presentation of the product that is sent and stored operationally in Météo-France at Toulouse in section 2, the pre-processing of the data will be described in section 3. Monitoring and impact on analyses will be addressed in section 4. Forecast scores and impact on the prediction of precipitations will finally be presented in section 5.

2. Presentation of the product

Since May 2004, the CMS (Météo-France/ Centre de Météorologie Spatiale, Lannion, France) is sending to Toulouse a SEVIRI/MSG product of particular interest for ALADIN. This product is received and stored in GRIB format every hour. It is composed of different fields at full-resolution covering all European ALADIN domains (18°S to 65°N, 25°W to 40°E) :

- ✔ The 8 IR SEVIRI channels, from 3.9 µ to 13.4 µ,
- ✔ The associated date, latitude-longitude position, angles of sight,
- ✔ A cloud type (CT hereafter) and the cloud top pressure with the associated quality flags.

As described in the next section, the latter fields permit to keep in the assimilation process channels whose weighting function peaks above the cloud top. These cloud products have been developed by CMS in the SAF/NWC MSG framework. Complete documentations can be found at *http://www.meteorologie.eu.org/safnwc/* . The CT product contains information on the major cloud classes : fractional and semitransparent clouds, high, medium and low opaque clouds (including fog) for all the pixels identified as cloudy in a scene. The set of thresholds to be applied depends mainly on the illumination conditions, whereas the values of the thresholds themselves may depend on the illumination, the viewing geometry, the geographical location, and NWP data describing the water vapour content and a coarse vertical structure of the atmosphere.

Fig. 1 gives an example of this product and its associated cloud top pressure for the 18th of July 2004. It has to be noticed there is no separation between cumuliform and stratiform clouds currently done in the CT product.

3. Pre-processing of the data

The SEVIRI radiances assimilated in the configuration of ALADIN 3D-Var presented in this report are pre-processed in the following way :

- ✔ To keep the observations relatively uncorrelated, one pixel out of 5 is extracted from the database, which gives approximately a 25 km horizontal resolution over France, and thinning boxes of 66 km^2 are applied during the screening.

a)

b)

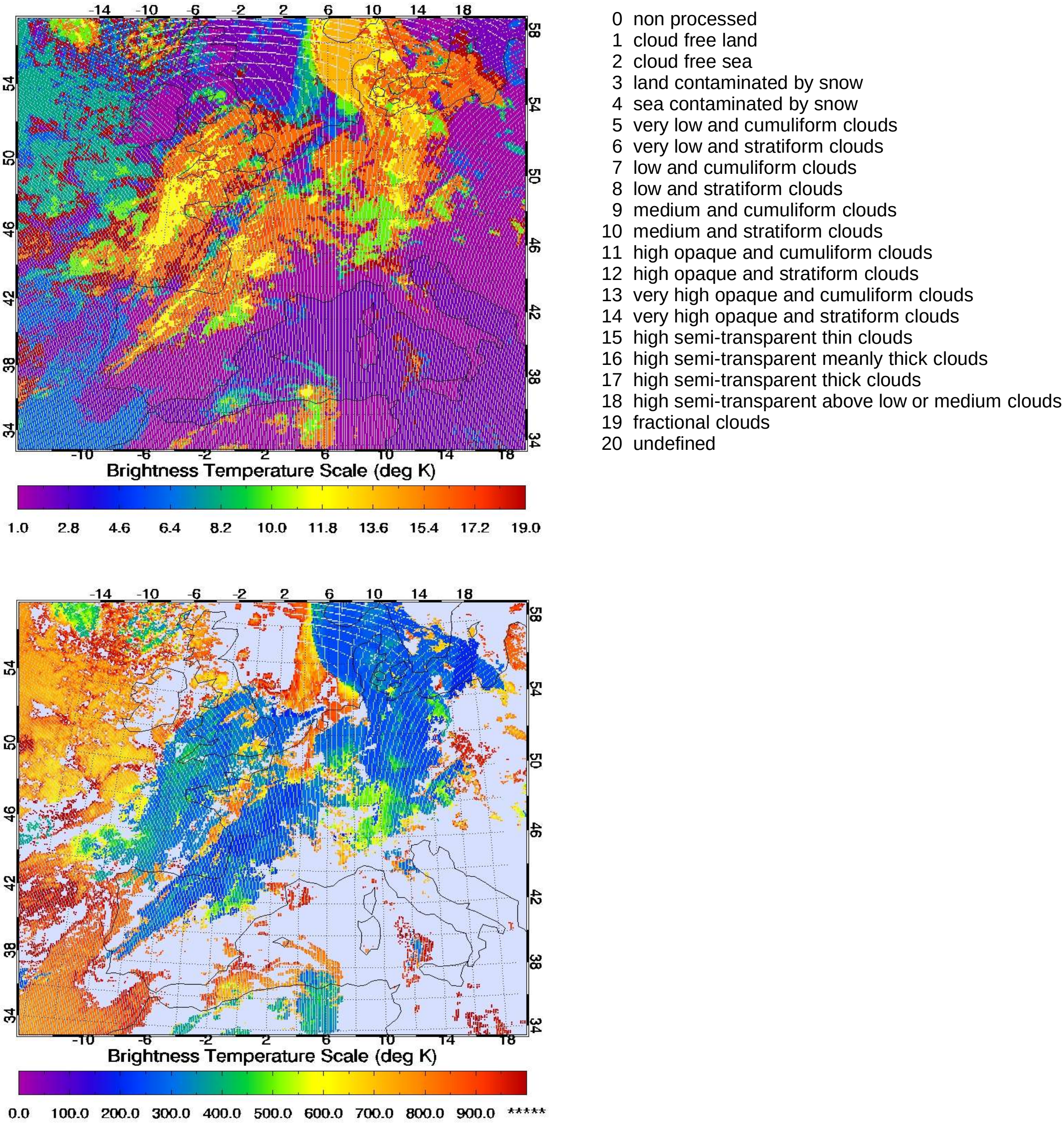

Figure 1 : a) Cloud types and b) cloud-top pressure for the 18th of July, 2004.

- The near IR 3.9 μ and the ozone 9.7 μ channels are blacklisted. The broad 3.9 μ channel is not used because RTTOV has troubles to simulate it (Roger Saunders, personal communication).
- Since the domain of interest is relatively small, a constant bias is assumed as a first hypothesis for the remaining channels.
- The observed brightness temperature error for each channel has an empirical value, based on measurements errors and errors due to RTTOV. 1.05 and 1.7 K have been chosen respectively for the IR and the WV channels. As a matter of fact, the uncertainty of the humidity estimation in the troposphere leads to take a larger σ_O for the two WV channels.
- A quality control is applied to reject data whose (obs-guess) value exceeds the sum of the background and the observation error variances times an empirical constant.
- The CT product presented in the previous section is used to select channels : the low

peaking IR channels 8.7 µ , 10.8 µ and 12 µ are kept only in clear-sky conditions, the 13.4 µ is also kept above very low clouds and the two WV channels are considered even above mid-level clouds.

4. Impact on analyses

A test period of 15 days with 4 daily assimilations has been performed from the 6th to the 22nd of July, 2004. In order to study the relative impact of SEVIRI data within ALADIN 3D-Var, a control experiment (CNTRL hereafter) has been run. This experiment follows the configuration presented by Fischer et al. (2004) : an Ensemble **B** matrix (STEFANESCU and BERRE, 2004) has been used with an a-posteriori tuning of the REDNMC factor, to 1.8. It assimilates the same complete set of observations as ARPEGE at that time (AMSU-B microwave radiances and the sea-wind scatterometer on board QuikSCAT are in particular not taken into account in these experiments), within an assimilation window of +/- 3 hours. 36 h forecast have been run from each analysis time with digital filter initialization applied.

An experiment that presents the same characteristics than CNTRL but with the addition of SEVIRI radiances (SEV hereafter) has then been run during the same period. Assimilation statistics plotted in Fig. 2 show that a lot of information coming from the 6 assimilated channels is taken into account in the analyses. The (obs-analysis) root-mean-square (RMS) errors over the whole test period are indeed much lower than the (obs-guess) ones. The relative error decrease is however less pronounced for the 13.4 µ channel as noted in MONTMERLE (2004) which is probably due to the broader shape of its weighting function and/or the choice of a non-optimal observation error variance. The mean biases have values less than 0.2 K which seems to justify the values of the constant bias correction.

Monitoring has been performed and results are plotted on Fig. 3 for the six assimilated channels. It shows firstly a strong negative bias of about –2.6 K for the WV 6.2 µ channel, which is well corrected by the flat bias correction. As for the 3.9 µ channel which is blacklisted, this bias is due to its broad spectral resolution that is badly taken into account by the radiative transfert model RTTOV. The bias-corrected channels present very stable features during the period. A diurnal cycle is visible for the biases and the number of active data for the low peaking channels. For each analysis time, about 1500 observations from the WV channels, 1000 for the 13.4 µ one and between 500 and 1000 for the three other channels are considered in the variational process. The (obs-guess) RMS error presents also a weak oscillation for the WV 6.2 µ that coincides with two peaks of convective activity at the beginning and at the end of the test period.

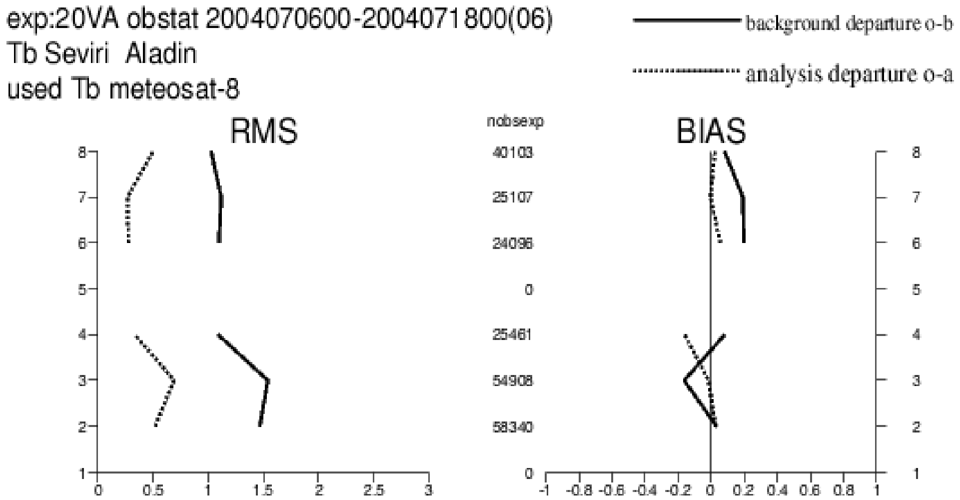

Figure 2 : Assimilation statistics of the SEV experiment computed considering every analysis times over the July 2004 test period. The vertical axis denotes the channel number, the left panel the RMS error and the right panel the bias between (obs – guess) (plain line) and (obs-analysis) (dashed line) for brightness temperature. The number of assimilated data is plotted between two panels.

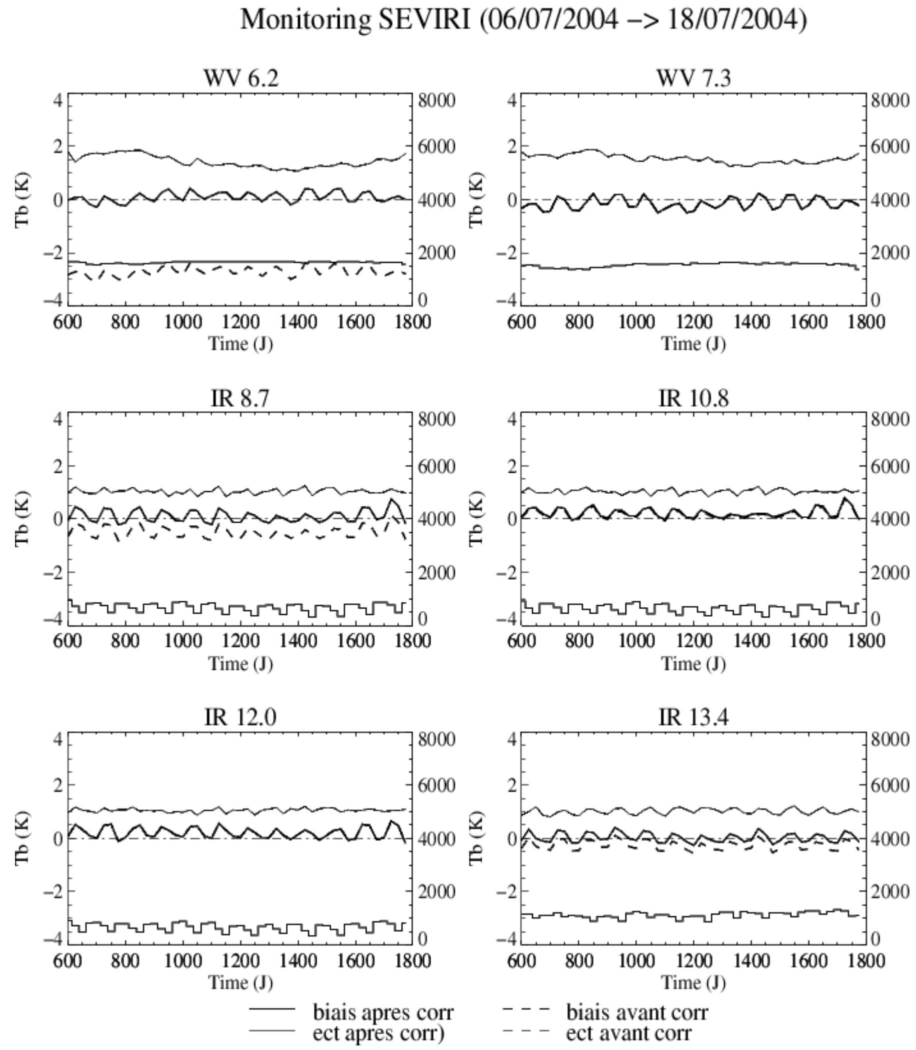

Figure 3 : Monitoring for the 6 assimilated SEVIRI channels for the SEV experiment from the 6th to the 18th of July, 2004. Histograms on bottom of figures (associated with the right vertical axis) represent the number of active data that enter the minimization.

5. Impact on forecast

5.1 Forecast scores

DA.r12/TP – SEV.r12/TP
(15 cases, 06/07/2004 12UTC -> 22/07/2004 12UTC)
Std Dev RMS BIAS

Geopotential
(1 m)

T
(0.05 K)

q
(1 %)

Wind
(0.2 m/s)

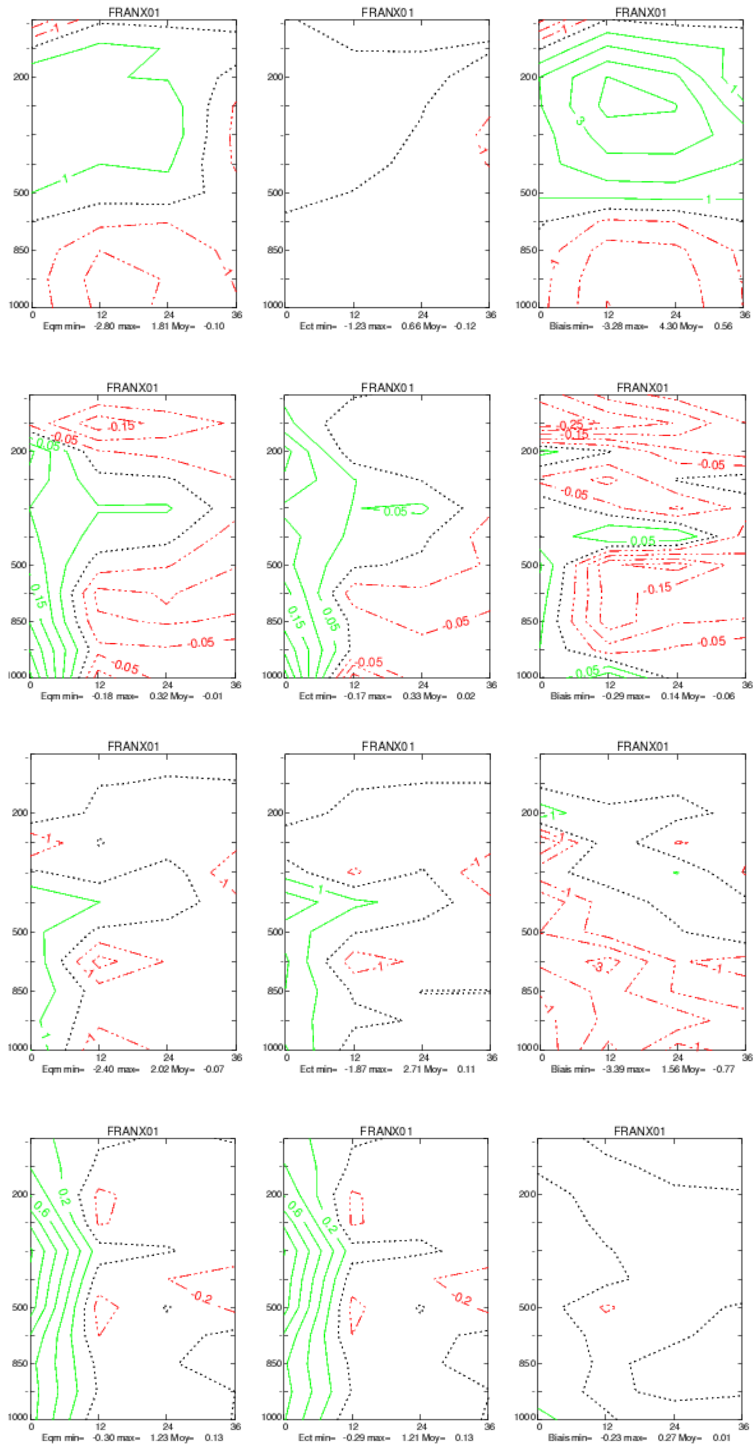

Figure 4 : Differences in forecast scores against TEMP observations : DA vs SEV, over the ALADIN-France domain for the July 2004 test period. Left column is the standard deviation, middle the RMS error and right the bias. Green isolines denote positive impact of SEV.

Forecast scores have been computed relatively to the dynamical adaptation version of ALADIN (DA) and are plotted in Fig. 4. For the geopotential height, the assimilation of SEVIRI data reduces the bias against radiosoundings of about 4 m between 12 and 24 h of forecast above 600 hPa, and increases it slightly below. This impact induces logically negative bias on sea-level pressure during the forecast, which is difficult to explain since no negative bias is present in the analyses. For the temperature, SEV brings a diminution of RMS error on all vertical levels before 12 h and up to 24 h near 300 hPa. Negative bias are however present from the start above 300 hPa and in the middle troposphere after 6 h. The RMS error for humidity is slightly improved before 6 h of forecast and up to 12 h near 400 hPa. The analyses for this quantity show however small biases at all vertical levels that propagate downward with time. Finally, SEV show better scores than CNTRL on RMS error of the wind intensity in mid- to-high troposphere (CNTRL scores are not shown).

Globally, the scores of CNTRL against radiosoundings have been slightly degraded. This can be explained by the fact that the large amount of SEVIRI data added in the assimilation process has slightly taken away the analysis from radiosoundings observations which are the main source of observation in CNTRL. To give better weight to the different observation types, the tuning of the observation error variances will be undertaken in the near future, following Chapnik (2004).

5.2 Total rainfall forecast

Case of the 18th July 2004

The total rain forecasted between 6 and 12 hours by DA, CNTRL and the SEV experiments from the 00 UTC analysis time are plotted on Fig. 5 and compared to rain-gauge values over France. DA missed the NE/SW orientation of the main rain band. CNTRL produces the good orientation and the SW part of the line seems realistic, although a little bit too South. The use of SEVIRI data allows to forecast the observed second cell of intense precipitations located in the NE part of the line, with a slightly overestimated amount (> 20 mm). The maximum over the Bordeaux region is however located too South but with an amount of 40 mm comparable to rain-gauge observations. The secondary line of precipitation is also quite well captured over the NE of France with realistic shape and amount.

To understand why SEV produces the observed second cell of intense precipitations in the north-eastern part of the line contrary to CNTRL, increments of humidity and temperature at 700 hPa for the 00 UTC analysis have been plotted for the two experiments (Fig. 6). The most striking difference between the two is that increments produced by SEV present more realistic and mesoscale patterns than for CNTRL, where the main source of information seems to come mainly from radiosoundings. In particular, SEVIRI data are cooling and humidifying the mid-to-low troposphere pre-convective area located upstream of the frontal rain band over western France, which produces intense rain 6 hours later.

At each analysis time, a large amount of IR radiances coming from SEVIRI is taken into account in the assimilation process compare to ATOVS data for example. The ratio of the number of data that enters the screening for these two observation types is varying indeed between 10 and 25. It has however to be noted that for both CNTRL and SEV, ATOVS data have been assimilated using the screening features of ARPEGE. For HIRS for instance, 1 pixel out of 5 have been extracted and thinning boxes of 250 km^2 have been applied which is not comparable to SEVIRI. In the near future, the impact of a higher density of ATOVS data will be tested in 3D-Var using two complementary approaches :

- ✔ Extraction and thinning at higher horizontal resolutions,
- ✔ Use of the "EARS-Lannion" data that are already used in the operational ARPEGE suite. Their shorter reception time delay allows indeed to get more data within the +/- 3 hours assimilation window considered in ALADIN 3D-Var.

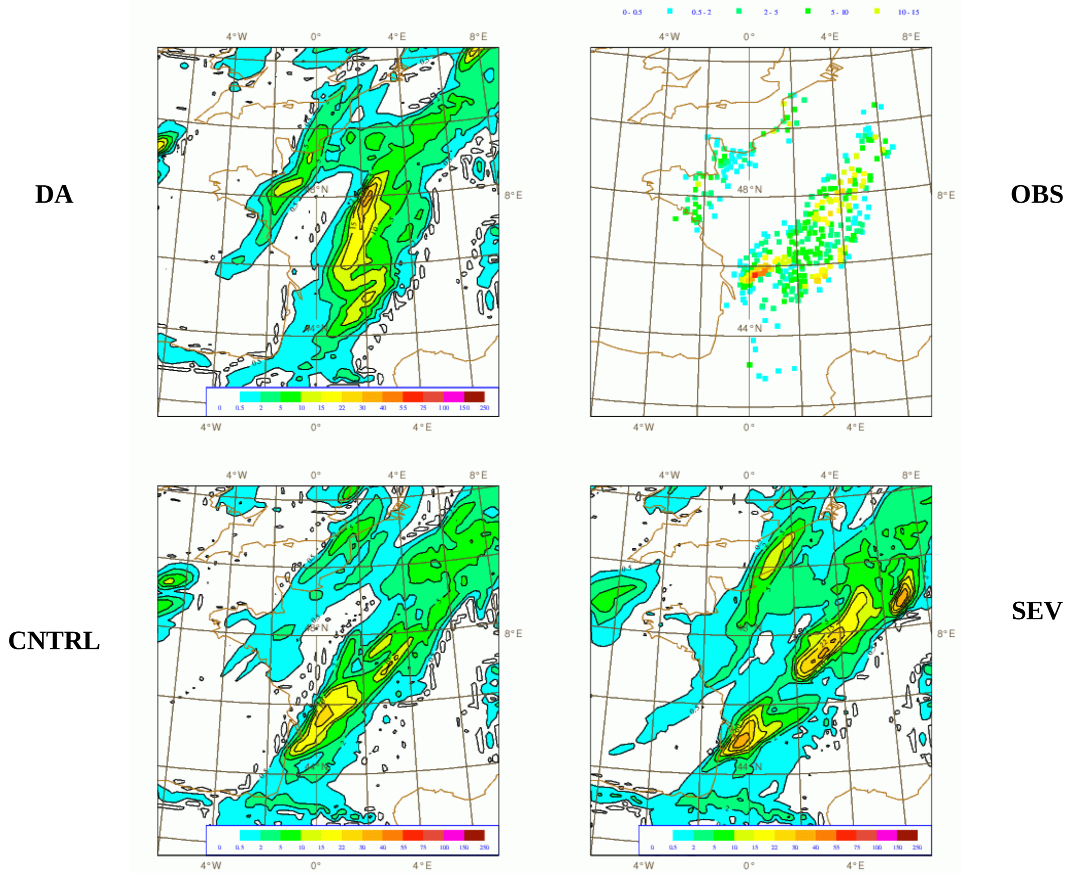

Figure 5 : Rain-gauge observation (top right) and simulated total rainfall between 6-12 h of forecast for July 18th, 2004.

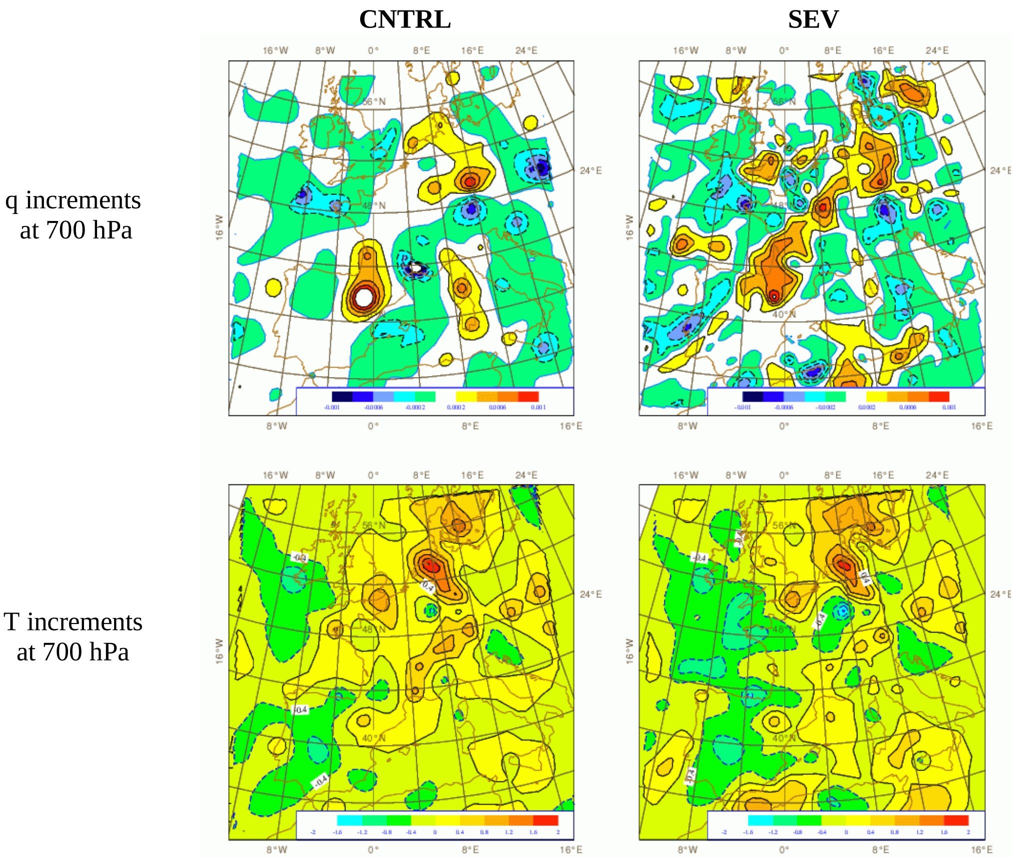

Figure 6 : Specific humidity (top panels) and temperature increments (bottom panels)
for CNTRL (left) and SEV (right), for July 18th, 2004, at 00 UTC.

Case of the 8th of July 2004

The total rain forecasted between 6 and 12 hours of simulation by CNTRL and SEV, compared to rain-gauges and DA are displayed on Fig. 7. DA produces unrealistic large amounts (over 40 mm) of rain over NE of France contrary to the two 3D-Var experiments that are more comparable to observations. CNTRL reproduces well the shape and intensity of the northern part of the N-S oriented line of heavy precipitations located in eastern France, whereas DA totally missed it. The addition of SEVIRI data allows to enhance realistically precipitations in its southern part with amounts up to 20 mm and to produce light rain over the centre of France that are observed by rain gauges.

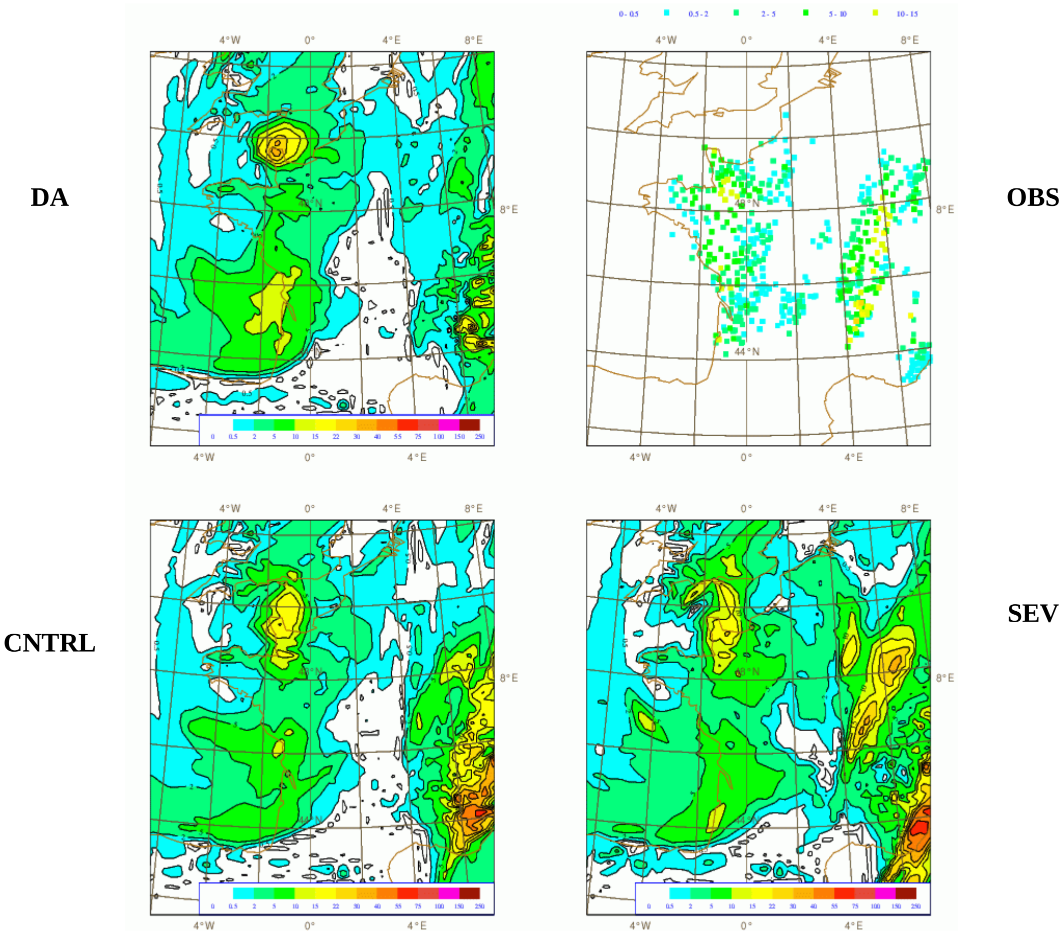

Figure 7 : same as Fig. 5 but for the 8th of July 2004.

Case of the 22nd of July, 2004 : for that case, DA underestimates strongly the precipitations that occur over the western part of France (Fig. 8). The use of a cycled 3DVar allows to correct this failing. Shapes and intensities of the precipitating cells as forecasted by SEV seem moreover in better agreement with rain gauges observations and rain rates derived by radars over the sea (not shown) where amount greater than 30 mm were measured.

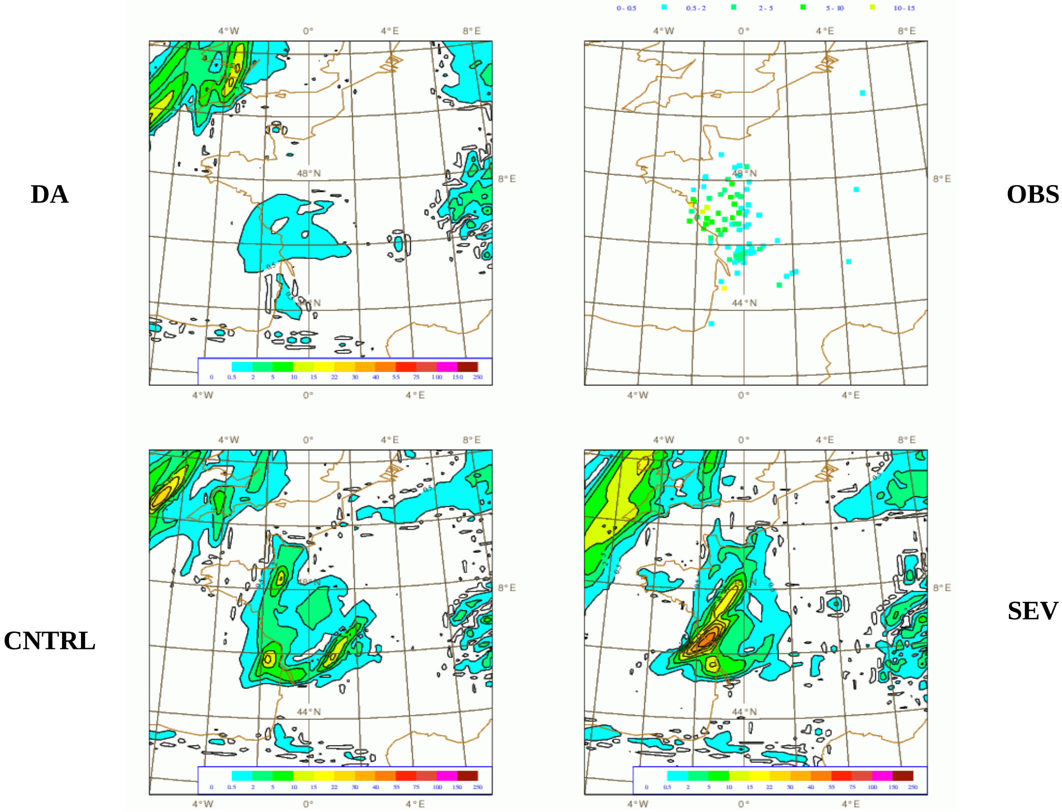

Figure 8 : same as Fig. 5 but for the 22nd of July 2004

5.3 QPF scores

Quantitative Precipitation Forecast (QPF) scores were computed for the July test period for different thresholds. The observations used to compute those scores are the 6 hours total rain measured by rain gauges.

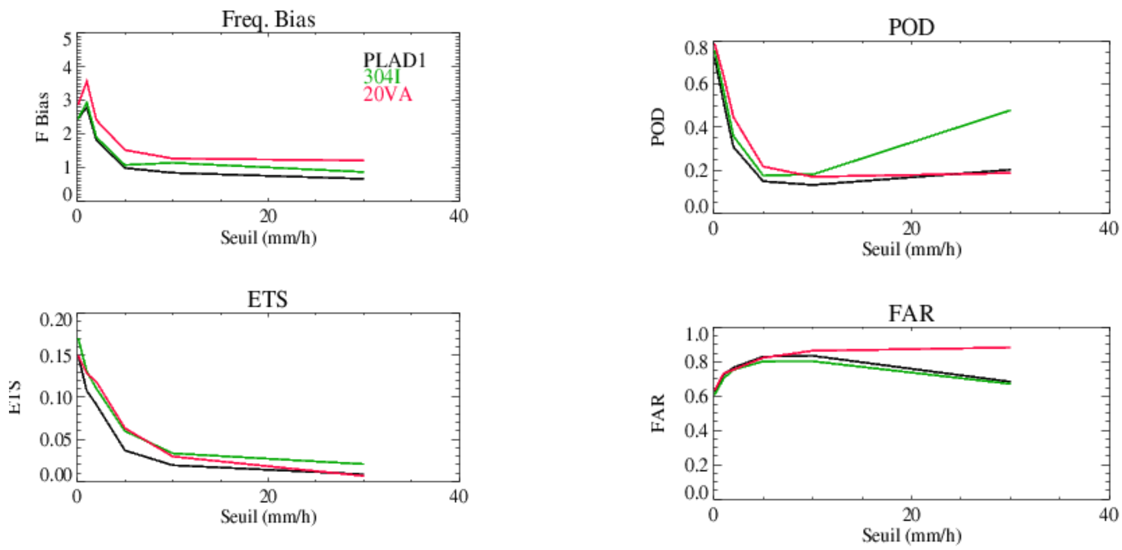

Figure 9 : QPF scores for **DA**, **CNTRL** and **SEV** computed for the whole July period for the total rain forecasted between 12 and 6 h, from the 00 and the 12 UTC analyses. Precipitation thresholds are 0.1, 1, 2, 5, 10 and 30 mm. FBIAS : Frequency Bias, POD : Probability Of Detection, ETS : Equitable Threat Score, FAR : False Alarme Rate

The two detection scores (ETS and POD) displayed in Fig. 9 are higher for the experiments that are using an assimilation scheme. The ETS is comparable for CNTRL and SEV and shows values almost twice greater than DA for the 5 mm threshold. The addition of SEVIRI data permits to perform a better detection of precipitating events mostly for the 2 and the 5 mm thresholds, with respective POD of 0.46 and 0.23 compared to 0.34 and 0.16 with CNTRL. However, this better detection is made to the detriment of the FBIAS : SEV produces to much precipitations for all thresholds. For small thresholds, the overestimation of the number of simulated precipitating pixels shown by DA and CNTRL is accentuated for SEV. For thresholds greater than 5 mm, the FBIAS are comparable for the 3 experiments although slightly greater than 1 for SEV. Finally, the FAR is greater for SEV for the 30 mm threshold. Since a very small number of observed/simulated pixels are characterized by values greater than this threshold, QPF scores are weakly representative at this level.

Assimilating SEVIRI data using the first configuration defined in this report seems thus to produce too much precipitation, particularly light rain. The weight of the information given by these radiances during the assimilation step has to be weaken to limit this drawback through the tuning of the observation error variances and/or the use of larger thinning boxes.

6. Conclusions and future work

SEVIRI data have then been assimilated in ALADIN 3D-Var following the configuration defined by Fischer et al. (2004) to study their relative impact. Channels 3.9 µ and 9.7 µ have been blacklisted, 1 pixel out of 5 has been used, a constant bias has been applied for each channel and empirical error variances have been chosen in the first configuration. The cloud-type classification computed by CMS in the SAF/NWC framework has been used to keep data non contaminated by clouds in the variational process, which includes channels that peak over the cloud top. The monitoring shows stable features for all channels during the whole test period. A lot of information coming from SEVIRI radiances is taken into account in the analyses through the 3D-Var, producing realistic increments. Results deduced from the 15 days test period are encouraging notably for the short term (i.e < 12 h) precipitation forecasts, where the addition of these kind of data allows to simulate realistic precipitation patterns, in shape and intensity. Forecast scores are slightly degraded compared to the control experiment, probably because of the large amount of additional data that move slightly away the analyses from radiosoundings. Moreover, QPF scores have shown that the experiment that includes SEVIRI radiances has better rain detection scores but produces spatially too much light precipitations.

One priority in the near future will thus be to tune error statistics and/or thinning to lower the relative impact of SEVIRI in the analyses. Methods based on the use of the DFS (Degrees of Freedom for Signal) related quantities will be applied to improve covariances matrices (Desroziers and Ivanov, 2001; Chapnik, 2004). In parallel, studies will be addressed to the use of additional ATOVS data by considering radiances coming from EARS extracted with a better sampling. In particular, the impact of AMSU-B data is one major concern. Finally, the cloud-top pressure product sent by CMS and a convection-detection algorithm will be used to compute proxy humidity profiles for convective clouds for assimilation purposes.

The first configuration of ALADIN 3D-Var (including SEVIRI radiances) is scheduled to become operational hopefully around March 2005. Further tests are envisaged on this operational suite, including the use of a 3D-Var FGAT (First Guess at Appropriate Time) and shorter assimilation cycles (typically 3 hours).

7. References:

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