Assimilation of satellite data in a regional mesoscale model

by Thibaut Montmerle[1]

Météo-France/CNRM: 42, av. G. Coriolis 31057 Toulouse, France

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- Evaluation of the operational ALADIN 3Dvar
- Impact of SEVIRI and of denser ATOVS data in the operational ALADIN
- Assimilation of SEVIRI's CSR in the global model ARPEGE

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[1] corresponding author's address: montmerle@cnrm.meteo.fr

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1. Introduction

Since July 2005, Météo-France is running operationally the limited area model ALADIN/France with four daily updates towards observations using a 3D-Var data assimilation system. This system provides short-range precipitation forecasts at mesoscale over Western Europe, with a 10 km horizontal resolution. This preliminary step precedes the data assimilation at high resolution that will be performed for the non-hydrostatic AROME model over the French mainland. An overview and the evaluation of pre-operationnal versions of this complete assimilation/forecast system have already been presented in the two previous reports (referred as M2004b and M2005 hereafter). The specific set-up is also discussed in Fischer *et al.* (2005) (F2005 hereafter). M2004b firstly described the following steps that have been necessary to prepare the configuration of the initial pre-operational version. The specification of the error covariance matrix is especially discussed in this paper and has lead to the selection of ensemble based covariances that were sampled from an ensemble of ALADIN forecasts, with initial conditions taken from an ensemble of analyses from the coupling model ARPEGE (Ştefănescu *et al.*, 2005). It has also been shown in this report, that successive cycled assimilations of SEVIRI clear air radiances allow to reduce the mid-tropospheric humidity and temperature forecast error and to get better forecast scores during the first 12 hours than the former operational version of ALADIN, which is simply the dynamical adaptation of the global model ARPEGE (or “spin-up model”, i.e. without data assimilation). However, different drawbacks appear while comparing with in-situ or radiosonde data, reflecting balance problems partly due to badly tuned and/or biased observations.

Several studies have then been carried out by M2005 to correct those drawbacks. An air-mass dependent bias correction has been computed for SEVIRI radiances, IR channels have been removed over land. The sensitivity of the analysis to observations has been studied through the use of the Degrees of Freedom for Signals. This diagnostic has shown that the analysis was too much controlled by SEVIRI data, as well as it permits to point out the respective influence of different channels and different types of data. Error variances tuning coefficients as defined by Desroziers and Ivanov (2001) have also been computed. They have allowed to confirm the relevance of the thinning lengths that have been chosen for SEVIRI and to tune the global background error variances. Finally, ground based data have been added in the assimilation process. Great complementarity has been found with SEVIRI WV channels over land by avoiding increments induced by the latter to spread out too much in the boundary layer. This new version including these improvements has been evaluated during 2 months (June and July 2005), and finally decision has been made to turn it operational the 25th of July, 2005.

The first part of this final report focuses on a work that has been done in parallel, which consists in a preliminary study of the assimilation of SEVIRI Clear Sky Radiance (CSR) product in the 4Dvar data assimilation system of Météo-France’s global model ARPEGE. One of the main goal of such a study is to bring more consistency between the coupling files that are provided by ARPEGE and ALADIN physical fields whose initial values are partly controlled by SEVIRI data. The operational ALADIN 3Dvar is then evaluated in section 3 by showing monitoring results and forecast scores. Observation Study Experiments (OSEs) based on this operational suite have then been undertaken in order to study the relative impact of SEVIRI and of denser ATOVS data in this system. The main conclusions about this study are discussed in section 4 and represent the core of an article that will be submitted to QJRMS soon.

2. Assimilation of SEVIRI CSR in Arpège

EUMETSAT produces routinely a Clear Sky Radiance (CSR) product for Meteosat-8. This product is generated by cloud classifying every pixel in an image and finding the average radiance for groups of 16x16 pixel square, summing over cloud free pixels. These data are provided with the cloud free fraction for each segment and a number of quality indicators. Details can be found in Köpken et al. (2004). An example of CSR product for channel 10.8 μ is plotted in fig. 1. Following the positive impact of their assimilation at ECMWF shown by Szyndel *et al.* (2004), it has been decided to test the impact of these CSR at Météo-France using the global model ARPEGE and its 4Dvar. The second reason of this study is to ensure a better consistency with ALADIN, which considers high resolution SEVIRI data (see section 3), through the coupling files.

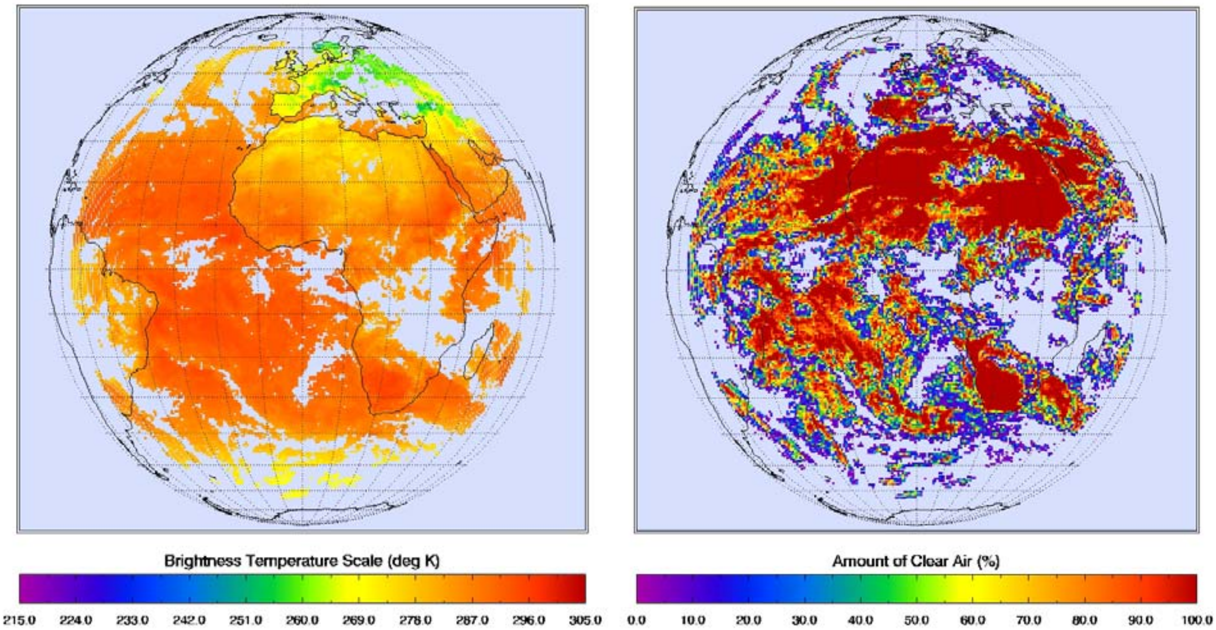


Fig. 1: *SEVIRI CSR for channel 10.8 μ (left panel) and the associated percentage of cloud free (right panel).*

2.1 Data Processing

For the experiment presented herein, the same data processing than Szyndel *et. al* (2004) has been chosen :

- Hourly observations are considered
- only the two WV channels are assimilated in the 4Dvar
- pixels are kept only if %clear > 70%
- the same thinning lengths than for ATOVS is used (260 km)
- the observation error variance σ_o = 2 K for the two assimilated channels
- an air-mass dependent bias correction (Harris & Kelly, 2001) with 3 predictors (optical thicknesses between 1000 and 300hPa and between 200 and 50 hPa, Total column Water Vapor) has been applied on a 1 month dataset. The surface Temperature has not been considered as predictor as in ALADIN because no IR low-peaking channels are taken into account.
- a first-guess quality control is applied to remove too large innovations

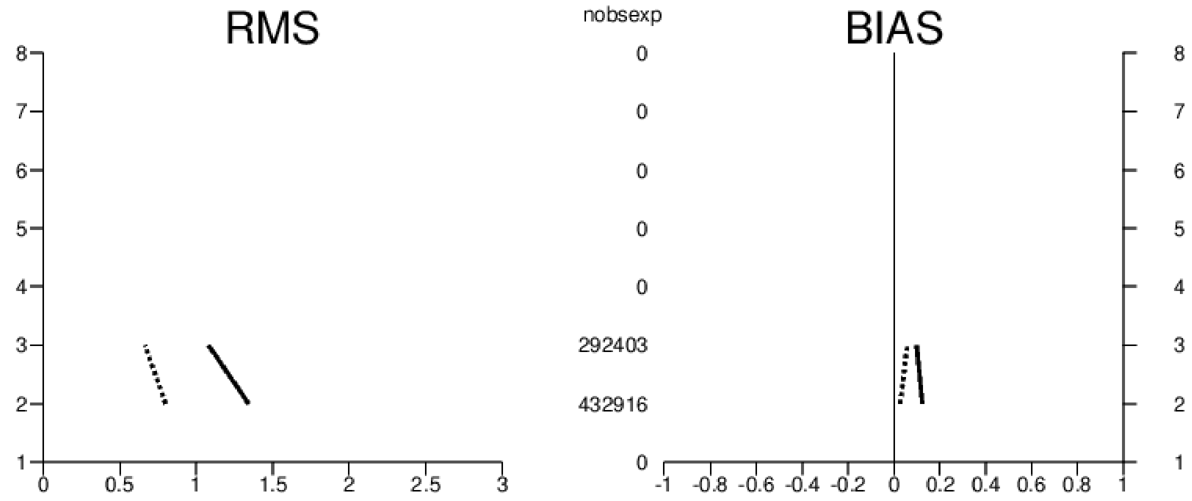
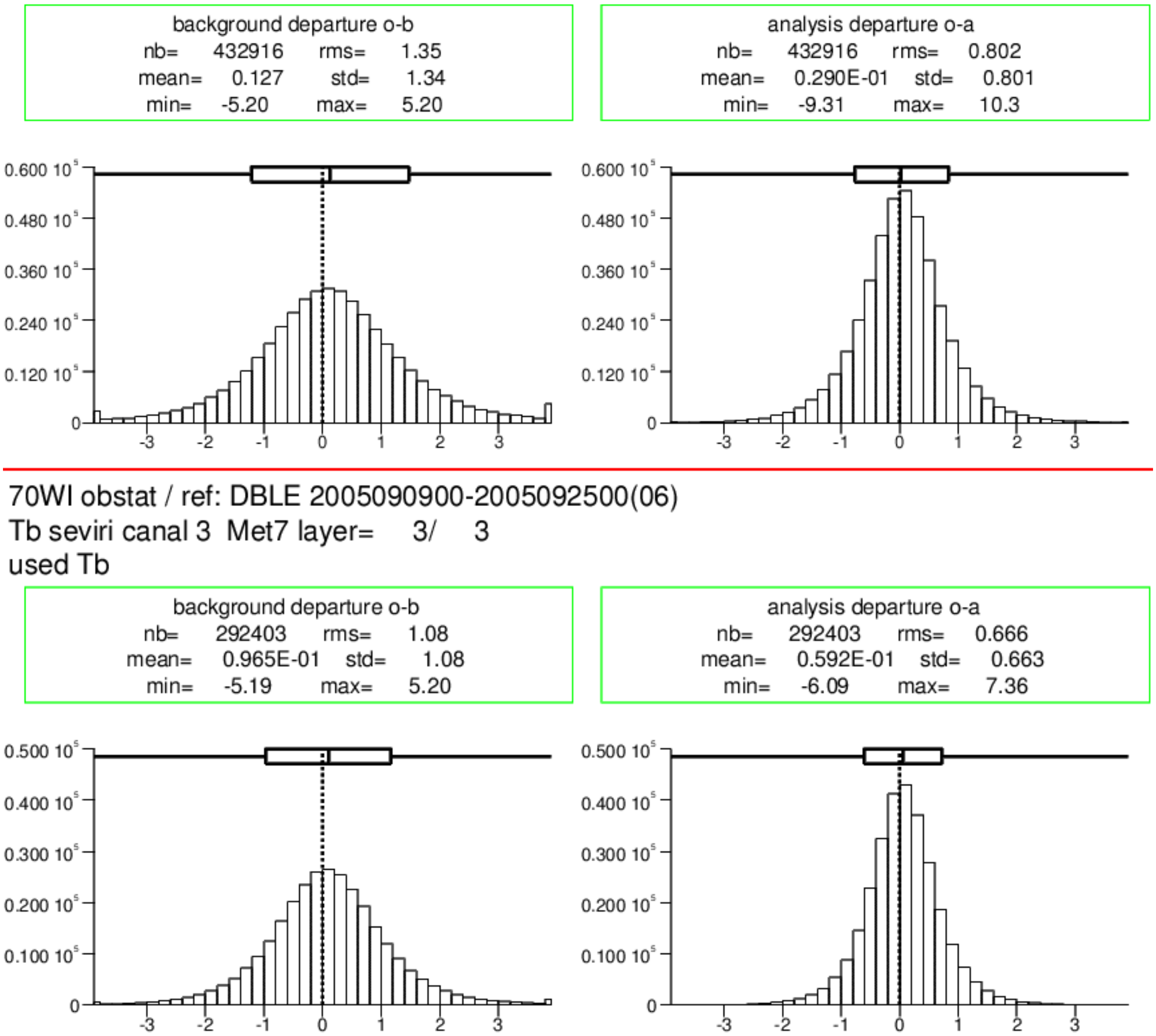


Fig. 2 : *RMS error and bias for (obs-guess) (solid line) and (obs-anlysis) (dashed line) after the assimilation of SEVIRI CSR between the 9th and the 25th of September., 2005. The vertical axis represents the channel number and numbers in the middle the amount of assimilated data.*



background departure o-b
nb= 432916 rms= 1.35
mean= 0.127 std= 1.34
min= -5.20 max= 5.20

analysis departure o-a
nb= 432916 rms= 0.802
mean= 0.290E-01 std= 0.801
min= -9.31 max= 10.3

70WI obstat / ref: DBLE 2005090900-2005092500(06)
Tb seviri canal 3 Met7 layer= 3/ 3
used Tb

background departure o-b
nb= 292403 rms= 1.08
mean= 0.965E-01 std= 1.08
min= -5.19 max= 5.20

analysis departure o-a
nb= 292403 rms= 0.666
mean= 0.592E-01 std= 0.663
min= -6.09 max= 7.36

Fig. 3 : *Histograms of (obs-guess) (left panels) and (obs-analysis) (right panels) values (in °K) for SEVIRI's channels WV 6.2 μ (top) and WV 7.3 μ (bottom)*

2.2 Impact on analyses

Assimilation statistics plotted in Fig. 2 show that a lot of information coming from the 2 assimilated channels is taken into account in the analyses. (obs-analysis) rms errors over the whole test period are indeed lower than the (obs-guess) ones. Compared with the assimilation of high resolution radiances in ALADIN (Fig. 11 of M2004b), this variance reduction is less pronounced, probably because of the greater number of assimilated observations which are sensitive to mid to high tropospheric humidity in ARPEGE (especially HIRS, AMSU-B and radiosounding data) that push the cost function toward an alternative solution. Innovations and analysis departure histograms displayed in Fig. 3 show Gaussian distributions reflecting respectively efficient bias correction/data quality control and uniform variance reduction through the variational process.

2.3 Impact on forecasts

Forecast scores of geopotential height against radiosoundings are plotted in Fig. 4. Mixed results are shown : a mid to high tropospheric reduction of the bias accompanied with an degradation above is visible for the three Northern Hemispheric sub-domains (AMNORD, EUROPE, NORD20). This degradation is present from the analyses and lasts for the whole forecast period. Over SUD20 (areas whose latitudes are < 20S), the assimilation of CSR reduces slightly the rms error, as over Asia after 72 h of forecast. Weak degradation of the bias is also visible above 200 hPa over the tropics and Asia.

More promising features are displayed while comparing to ECMWF outputs (Fig. 5). High tropospheric biases are indeed notably reduced for all forecast ranges and for every sub-domains. Reduction of rms error is also visible over Asia and Europe around 72h.

This experiment is still continuing in order to have more cases to build reliable statistics.

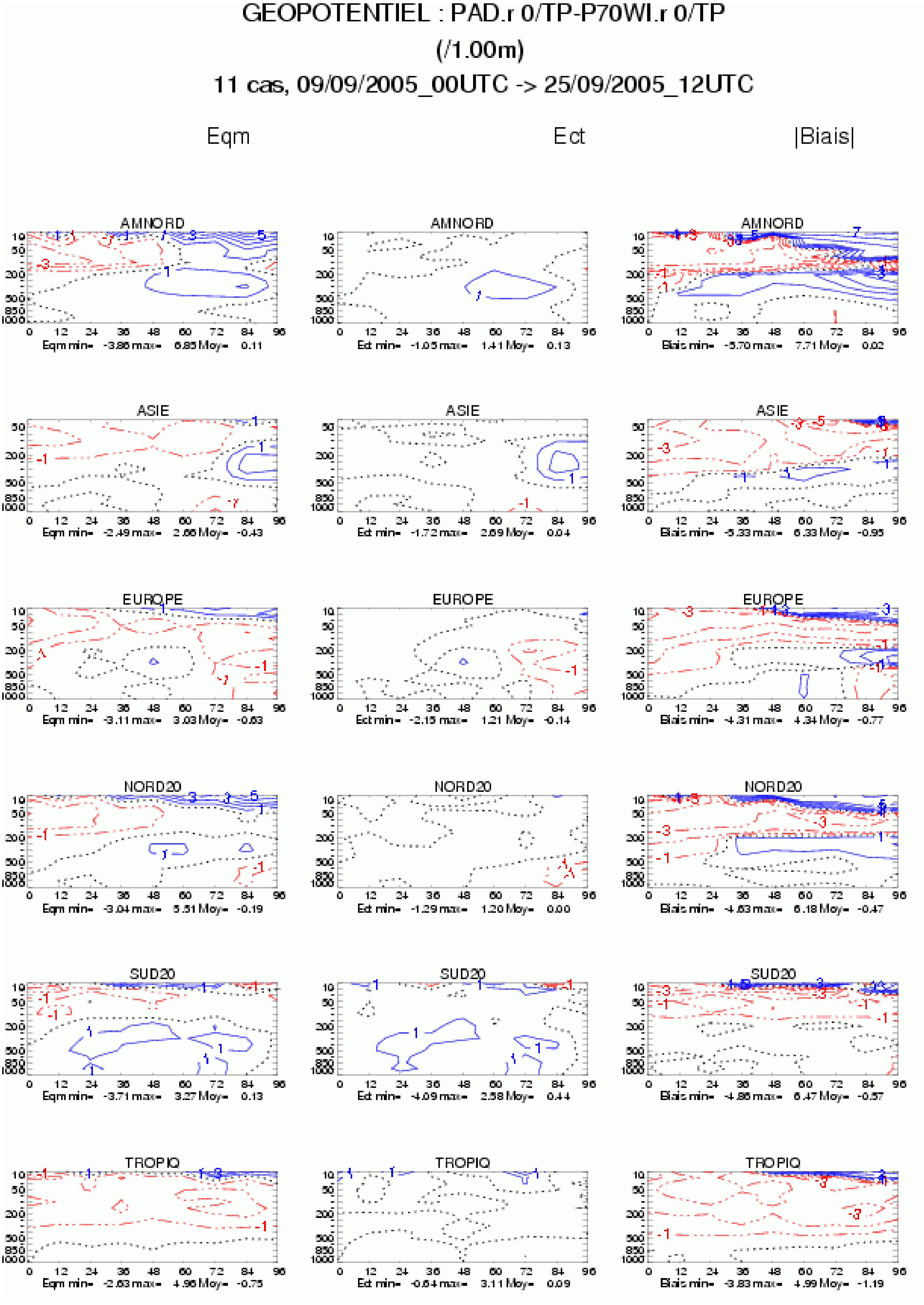


***Fig.4 :** Forecast scores for the whole experiment period of ARPEGE Pre-OPER against radiosoundings minus 70WI (ARPEGE pre-OPER+CSR) against radiosoundings for 6 geographical areas (lines) displayed as standard deviation (left column) rms error (middle column) and bias (right column). The horizontal axis shows the forecast term and the vertical axis the pressure level. Blue isocontours denote positive impact brought by the SEVIRI CSR.*

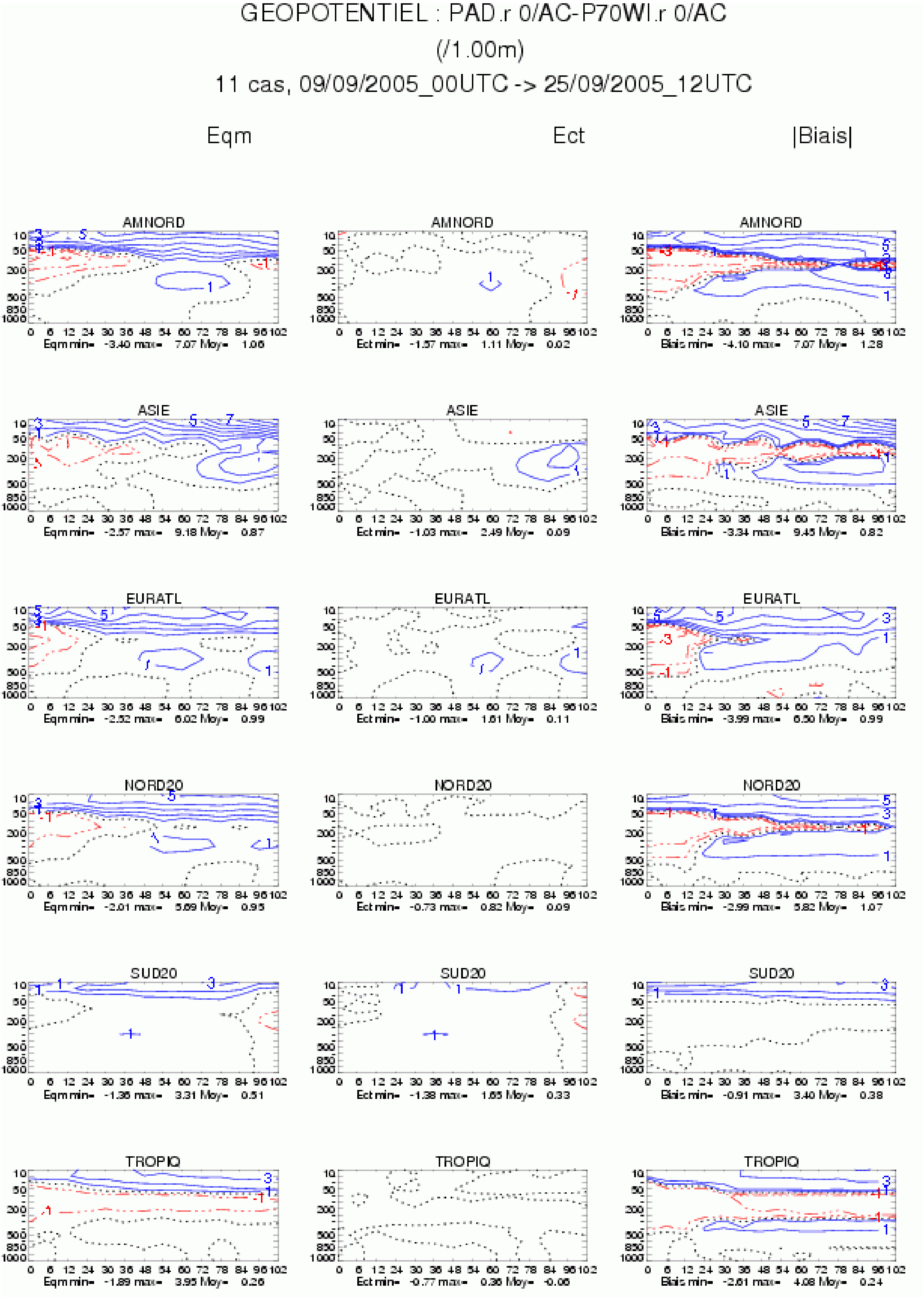


***Fig.5 :** same as Fig.4 but for ECMWF model against radiosoundings minus 70WI against radiosoundings. Blue lines denote a positive impact of SEVIRI CSR assimilation.*

3. Evaluation of the operational ALADIN 3DVar

3.1 General configuration

The difference between the pre-operational configuration of the ALADIN 3Dvar presented in M2005 and the operational one (OPER in the following) is that the production cycle allows now to run four daily forecasts instead of one at 00 UTC, as it is shown in Fig. 6 below. As in the pre-operational suite, the ALADIN/France assimilation cycle is coupled with its ARPEGE counterpart based on long cut-off times. Four analyses are produced per day which allow to run 6 h forecasts that are used as background for the next assimilation step, for both assimilation and production suites. The latter is coupled with its ARPEGE counterpart that uses short cut-off times and permits to obtain 36 to 54h forecasts depending of the assimilation time. It has to be noted that for the moment the surface analysis comes from ARPEGE.

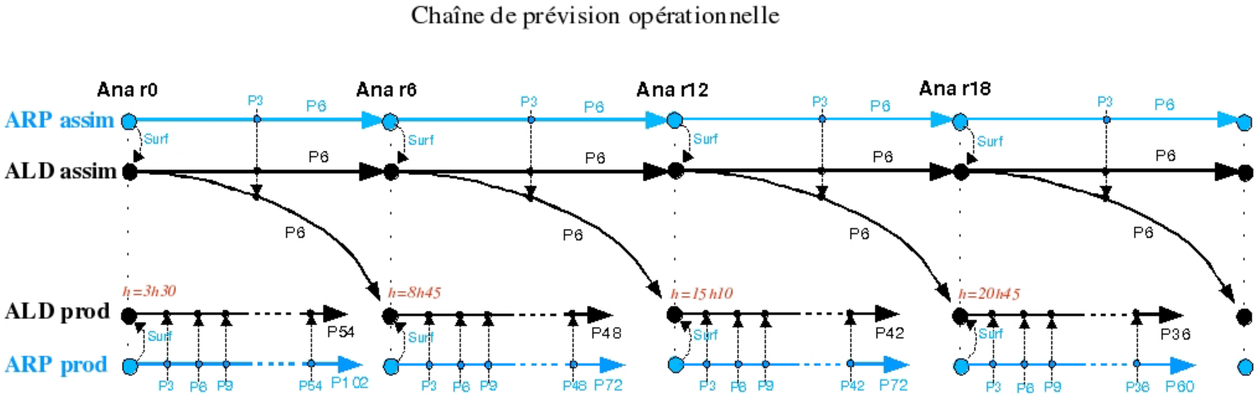


Fig. 6 : *Cycling in OPER. « Assim » and « prod » denote long and short cut-off times respectively, ALD and ARP stand for ALADIN and ARPEGE.*

As explained in detail in M2004b, ALADIN 3Dvar is based on an incremental formulation that heavily relies on the ARPEGE/IFS system (Courtier *et al.*, 1994). As already mentioned in the introduction, the backbone of this 3Dvar is an ensemble-based background error covariance matrix (Ştefănescu *et al.*, 2005) that allows to represent the effect of the analysis and of the short forecast ranges in an accurate way. We refer also to M2004b for a brief presentation of this **B** matrix that is used by ALADIN at each analysis step.

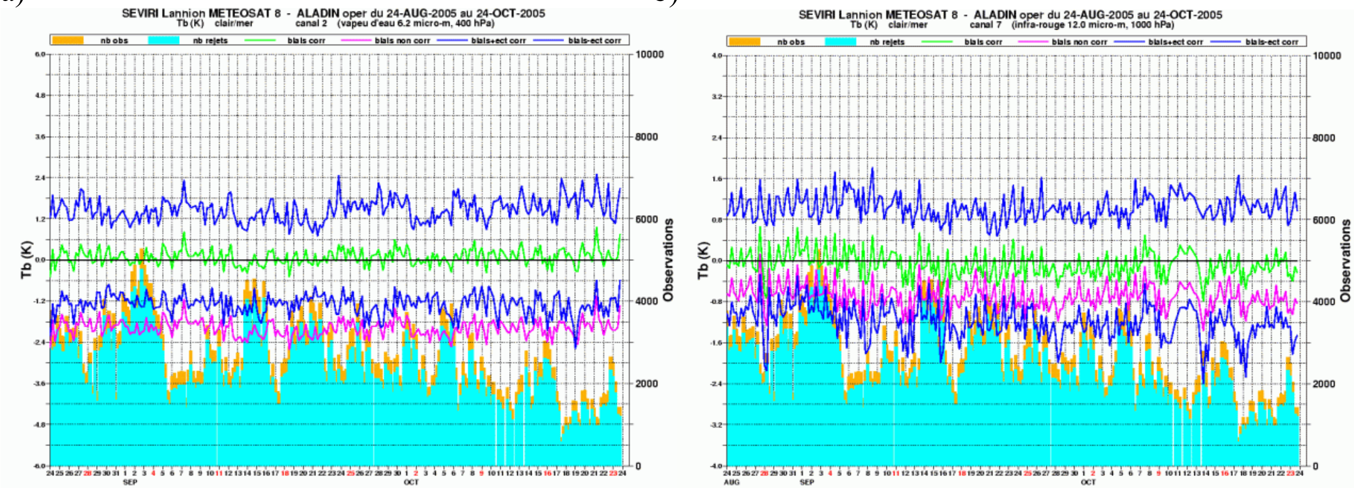
The same types of observations as in ARPEGE are considered in the variational process. These observations are, among others, radiosondes, ground station and airplane measurements, horizontal wind retrieved by geostationary satellites, AMSU-A radiances from NOAA-15, NOAA-16 and AQUA, AMSU-B radiances from NOAA-16 and NOAA-17, and HIRS radiances from NOAA-17. High-resolution Meteosat-8/SEVIRI radiances are considered as additional data and are sent hourly by the CMS (Centre de Météorologie Spatiale, Lannion, France). The same data processing than in M2005 is used :

- Use of 1 pixel over 5 (~25 km horizontal resolution over France)
- Thinning within 70 km boxes

- Near IR 3.9µ channel blacklisted because of possible solar contamination and bad simulation by the fast radiative transfer model RTTOV-8 (Saunders *et al.*, 1999) (Roger Saunders, personal communication)
- Ozone 9.7 µ channel blacklisted because of poor representation of the stratosphere in the model
- CO_2 13.4 µ channel blacklisted because of poor bias correction, as discussed in the following
- Empirical observation standard deviations: 1.25 K and 2 K for the IR and WV channels respectively. Higher values have been chosen for WV channels because of the larger uncertainty for retrieving mid to high tropospheric humidity.
- Use of the cloud classification product, computed by the CMS in the SAF/NWC MSG framework, for the channel selection: Channels IR 8.7 µ, 10.8 µ , and 12 µ are used only in clear air over sea; WV 6.2 µ and 7.3 µ are kept above low-level clouds.
- Innovation (i.e obs-guess) biases have been computed following an air-mass dependent bias correction (Harris & Kelly, 2001), that uses multiple linear regressions over three weeks of uncorrected (obs-guess) values with 4 predictors : 1000-300 hPa and 200-50 hPa Thickness, T_S and total column WV.

Results of the bias correction can be seen in Fig. 7 that shows more than 2 months of monitoring of the corrected innovation biases for OPER for channels WV 6.2µ, IR 10.8µ and IR 13.4µ. This figure shows that WV channels are more stable than IR ones, although the WV 6.2 µ channel is characterized by a –1.6 K bias before correction due to its broad spectral resolution that is poorly represented by RTTOV. For all the assimilated channels except the 13.4 µ , the corrected

a) b)



c)

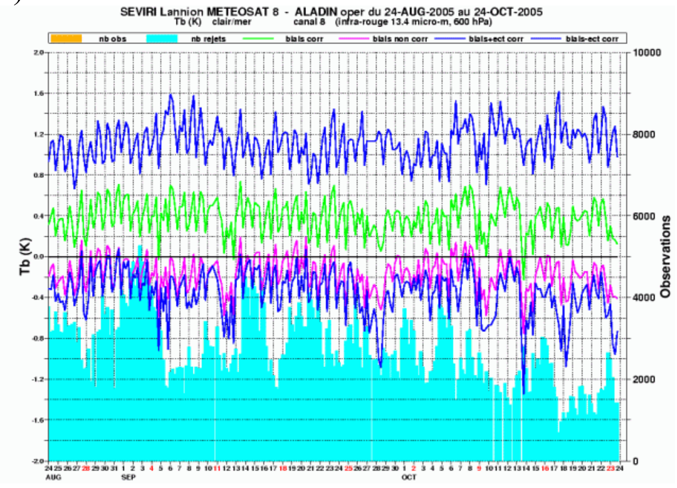


***Fig. 7 :** Monitoring of the (obs-guess) bias before (purple) and after (green) correction for SEVIRI (a) WV 6.2µ , (b) IR 12 µ and (c) IR 13.4µ channels, from the 24th of August to the 24th of October. 2005. RMS error are plotted in blue. Blue histograms, related to the right vertical axis, show the number of rejected data, orange the assimilated ones.*

innovation biases present a narrow Gaussian distribution well centered over zero. For the CO_2 13.4 µ channel (Fig. 7.c), this distribution is constantly centered around + 0.4 K, perhaps because of unsuited predictors for this particular channel that is sensitive to the temperature throughout most of the troposphere. As a consequence, this channel has been put temporarily on blacklist. Tests have been made using weighted Planck functions and the corresponding RT coefficients compatible with RTTOV8 (provided by Pascal Brunel, CMS, Lannion, France). The resulting innovation bias is slightly reduced but not enough to prevent from blacklisting.

It has to be noted that a radical change of weather regime over the limited area covered by the model is able to degrade the results, the regression coefficients being misfited. In that particular case, new coefficients need to be computed (typically every new season).

As in the pre-operational version of the 3Dvar, surface observations have also been added in the analysis for OPER (work done by L. Auger of CNRM, see M2005 for more details). Two meters observations of temperature and humidity T_{2m} and q_{2m} of the French RADOME network and from other European measurement sites are now operationally taken into account. It has been shown experimentally that the assimilation of these ground level observations shows great complementarity with SEVIRI data. It allows to reduce the positive bias for precipitations, which was one of the main drawback of the assimilation of SEVIRI radiances. As discussed in M2004b, this bias was mainly due to humidity increments produced by the assimilation of SEVIRI's WV channels over land that spread out too much towards the boundary layers through the background error vertical correlations.

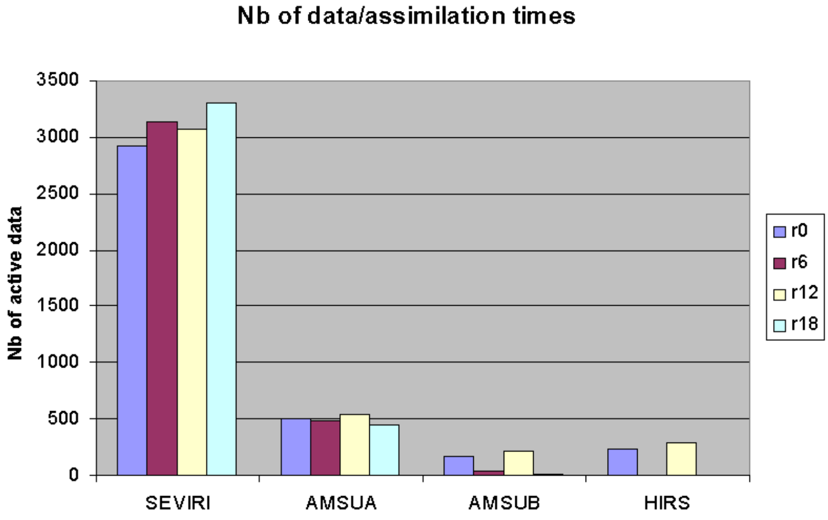


***Fig. 8 :** Number of assimilated satellite data for the four daily analysis steps*

Fig. 8 displays an example of the number of geostationary and polar orbiting satellite data that enters the minimization. No HIRS and almost no AMSU-B data are considered at the 6 and the 18 UTC analysis times, while almost 3000 SEVIRI and 500 AMSU-A pixels are present for each of the four daily analyses. It has however to be noted that, for the moment, the same thinning interval than in ARPEGE (~260 km) is applied for ATOVS data (results of the OPER configuration used with extra ATOVS data and finer thinning lengths are discussed in section 4). The fact that those radiometers are onboard polar-orbiting satellites makes the number of available data over Western Europe strongly dependent of the daytime. This shows that the high temporal resolution and the fast reception of SEVIRI radiances are an obvious advantage compared to polar orbiting satellite for data assimilation at regional scale, since it allows continuous observations in space and time over the region of interest.

3.2 Impact on analyses

As in M2005, the DFS (Degree of Freedom for Signal) has been computed for each type of observation. Details about its theory and its practical computation are discussed in M2005. This quantity gives an insight of the relative reduction of the variance during the analysis brought by each type of observation. Fig. 9 gives such DFS values at the 00 UTC analysis time for four different days, in order to have a sufficient number of uncorrelated samples (see section 4 for a discussion about this particular topic). This figure shows that, for the 00 UTC assimilation time, SEVIRI radiances are as informative as ground based data (SYNOP) and radiosonde data (TEMP). Other satellite observations (HIRS, AMSUA and AMSUB) have much less impact in the analyses, mainly because of their low number.

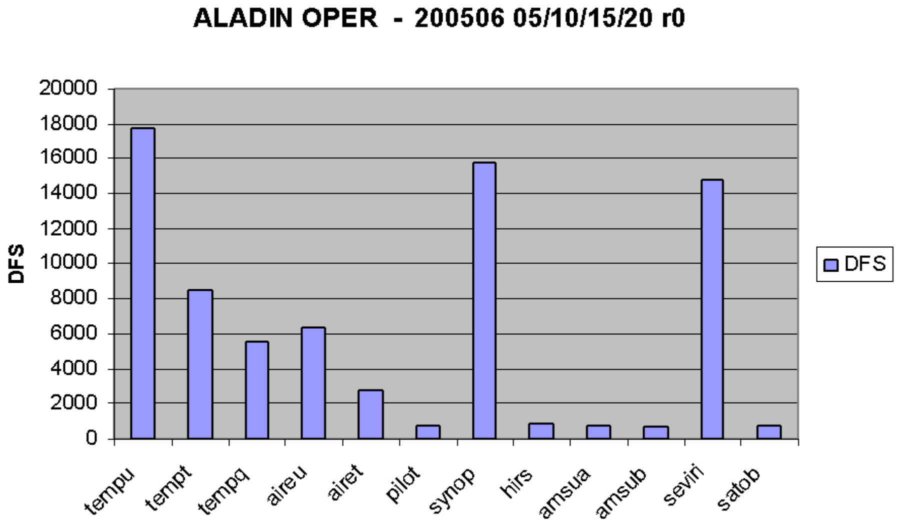


Fig. 9 : Histograms showing DFS values for each type of assimilated observations in the operational ALADIN/France at 00 UTC for four days. TEMP denotes radiosoundings, AIRE aircraft data, PILOT and SYNOP surface data, SATOB atmospheric moving vectors.

3.3 Impact on precipitation forecasts

Examples of precipitation forecasts between the spin-up model and the 3Dvar with and without SEVIRI data have been studied in M2004a and M2004b. It has been shown in the latter that the use of SEVIRI radiances in the assimilation process allows to get realistic mid to high tropospheric increments of specific humidity and temperature that leads in a number of situations to better rain forecasts.

A typical example with the operational configuration of the 3Dvar is displayed in Fig. 10. This case corresponds to a NW/SE oriented line of convective cells that was propagating SW, producing locally strong amounts of rainfall up to 50 mm/6h, as shown on the raingauge observations. The 3Dvar reproduces well the main precipitation patterns, although the small scales of the observed convective events cannot be predicted by the model's 10 km horizontal resolution. The system however simulates well the dry region located between the Pyrenees and the precipitating line, as well as the stronger amount of rainfall observed in the south-eastern edge of the line near the Mediterranean sea. As displayed on the 750 hPa specific humidity increment, these features are respectively due to the drying and the humidification of the concerned areas, due mainly to the assimilation of radiosondes and SEVIRI WV channels over land. The spin-up model (i.e ALADIN without data assimilation) is unable to reproduce the observed features and shows more uniform precipitations all over the area.

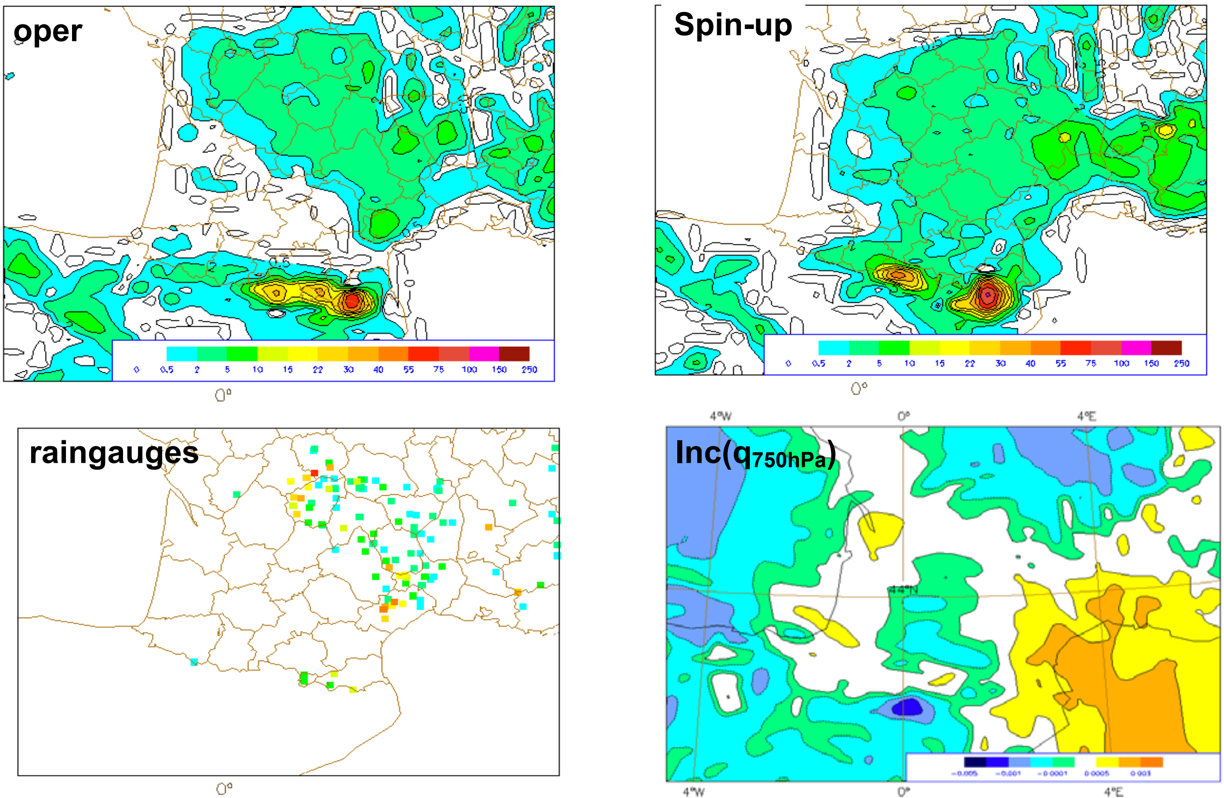


Fig. 10 : *Cumulated rain between 12 and 18 h of forecast for the 21st of June, 2005, over SW of France for the operational 3Dvar (top left) and the spin-up model (top right). Corresponding raingauge observations are plotted on bottom left and humidity increments at 750 hPa for the 3Dvar at 00UTC the same day on bottom right.*

3.4 Forecast scores

Fig. 11 displays scores over one month of experiment against ground based measurements compared with the spin-up model. OPER shows very positive features by reducing the initial RMS errors and biases of humidity and 3h cumulated precipitations up to 18h of forecast. A neutral impact is visible for the temperature, although the bias is slightly degraded for the 12 and the 18 h forecast times. Scores against wind measurements show also neutral impact (not shown).

Scores against radiosondes are displayed in Fig. 12. No noticeable impact is shown for the geopotential height, except a weak bias reduction below 500 hPa associated with a weak degradation above. The RMS error is reduced all over the troposphere for the temperature before 12 h of forecast, while a degradation of the bias is displayed above 200 hPa (brought during the model integration (M2004b)) and near the surface at all forecast ranges. Concerning the humidity, the 3Dvar allows to reduce the RMS error and the bias respectively in the mid and in the low-troposphere, while the bias is slightly degraded around 200 hPa before 6 h. Finally, a reduction of RMS error all over the troposphere up to 12 h is shown for the wind field intensity.

3.5 Forecaster's feedback

During the first two months following the launch of the operational suite, a subjective evaluation has been made by forecasters. Results are summarized below in Table 1. Positive impact of the 3Dvar has been noted for 13 cases out of the total 34 studied cases, 5 before and 8 after 9 h of forecast. 19 cases have been classified as neutral, and only 5 have shown worst behaviour than the spin-up model.

The lessons that can be drawn from our experience are as follows:

- Before 3h of forecast, results should be taken with caution (impact of initialization, of unbalances …)
- Between 3 and 12 h, the assimilation cycles produce their own solution that is more realistic in most cases
- the limit of predictability is somewhere between 12 and 24 h, mostly because of the growing influence of the lateral boundary conditions

	Positive impact < 9h	Positive impact > 9h	Neutral	Negative impact
Nb of cases	5	8	19	5

***Table 1:** result of the subjective control performed for OPER*

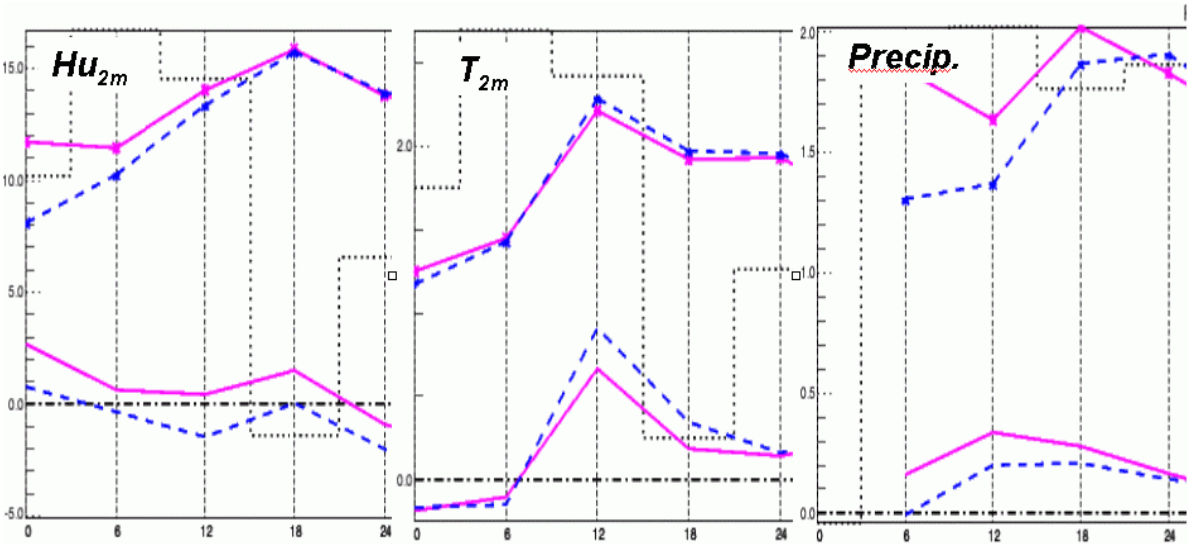


***Fig. 11 :** Mean biases (bottom lines) and rms error (top lines) of the spin up Model (plain purple line) and OPER (dashed blue lines) against ground based observations for Humidity at 2m (left) Temperature at 2m (middle) and 3h cumulated precipitations (right) over the ALADIN domain from the 6th of June to the 24th of July 2005. Horizontal axis denotes forecast time.*

DA.r0/TEMP – OPER.r0/TEMP
(48 cases, 06/06/2005 00UTC -> 24/07/2005 00UTC)

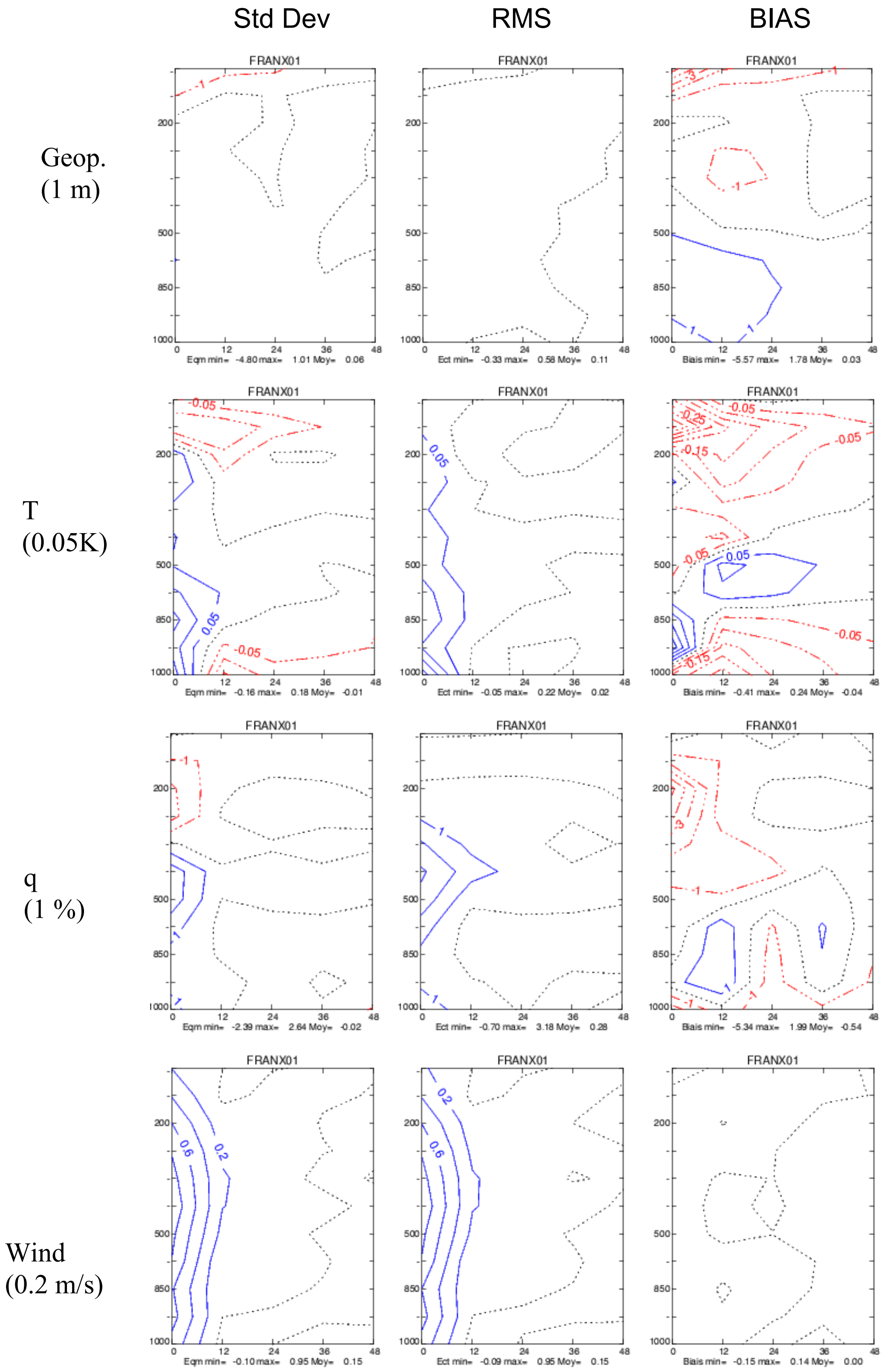


***Fig. 12 :** Forecast scores of the spin-up model (DA) vs. radiosoundings minus OPER vs. radiosoundings over the ALADIN domain from the 6th of June to the 24th of July 2005. Left column is the standard deviation, middle the rms errors and right the bias. Blue isocontours denote positive impact of OPER compared with the spin-up model.*

4. Impact of SEVIRI and of denser ATOVS data in OPER

To evaluate the impact of a specific observation type on the forecast, Observing System Experiments (OSEs), which consist in comparing forecast scores of experiments that consider different observation deployment scenarios, are typically performed. The drawback of such a method is the large amount of computational ressources that is required. Some methods have been furthermore implemented to diagnose the impact of observations on analyses, i.e to infer the statistical variance reduction induced by the variational assimilation of one particular type of observation. These methods are mainly based on measurements of the so-called *DFS* (for Density of Freedom for Signal) already used in the previous section. The theory and the practical computation of this quantity have been presented in M2005. This chapter focuses on the use of OSE and DFS to infer the relative impact of SEVIRI and extra ATOVS data in the operational ALADIN France.

4.1 Observation System Experiments

Two extra Observation System Experiments (OSE) have been carried out in this study :

- **moreATOVS** corresponds to OPER with additional ATOVS data used with a finer thinning. For this experiment, every AMSU-A pixel have been extracted (1/2 for OPER), 1/2 for HIRS (1/4) and 1/3 for AMSU-B (1/6), which gives approximately one pixel every 70 km for the three instruments. A thinning length of 80 km has been used, while OPER uses 260 km. For the 00 UTC assimilation step, this configuration allows to consider in the assimilation process 2, 8 and 10 times more HIRS, AMSU-A and AMSU-B data respectively.
- **noSEV** corresponds to OPER without SEVIRI data.

These experiments have been run for 3 weeks, from the 5th to the 23rd of June, 2005, with the same cycling strategy than OPER. As it is displayed in Fig. 13, moreATOVS uses a coverage for

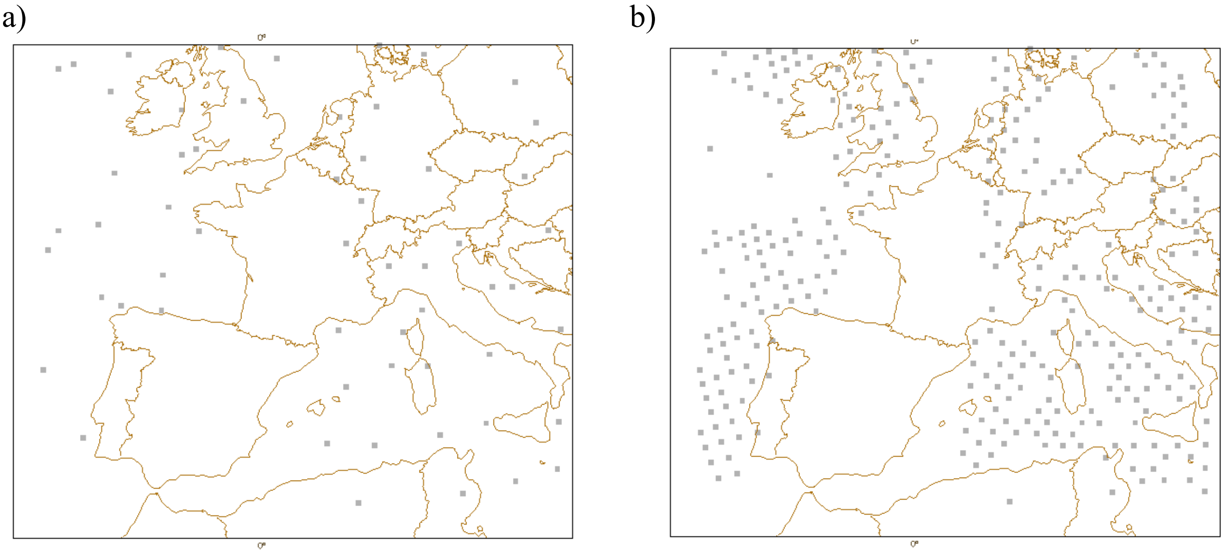


***Fig. 13 :** example of the localization of active AMSU-A data that enter the minimization at 00 UTC for (a) OPER, (b) moreATOVS.*

ATOVS data that seems better suited for studies at regional scale within the ALADIN domain. However and as it is shown in the following, the shape of the structure functions, correlations between adjacent pixels as well as the presence of other redundant observation types that are sensitive to the same atmospheric component can relativize the impact of a high spatial resolution in the analysis. This is particularly the case for WV channels of AMSU-B, HIRS and SEVIRI radiometers whose weighting functions are plotted in Fig. 14. Mid to high tropospheric humidity sensitive HIRS's channels 11 and 12, AMSU-B's channels 3 and 4 and SEVIRI's channels 2 and 3 are for instance characterized by weighting functions that have close shapes and intensities. As a consequence, the individual impact of one single observation from one of these instruments should be comparable. On the other hand, the AMSU-A's channels are sensitive to high tropospheric/low stratospheric temperature variations, and thus should be less coupled to the three remaining radiometers.

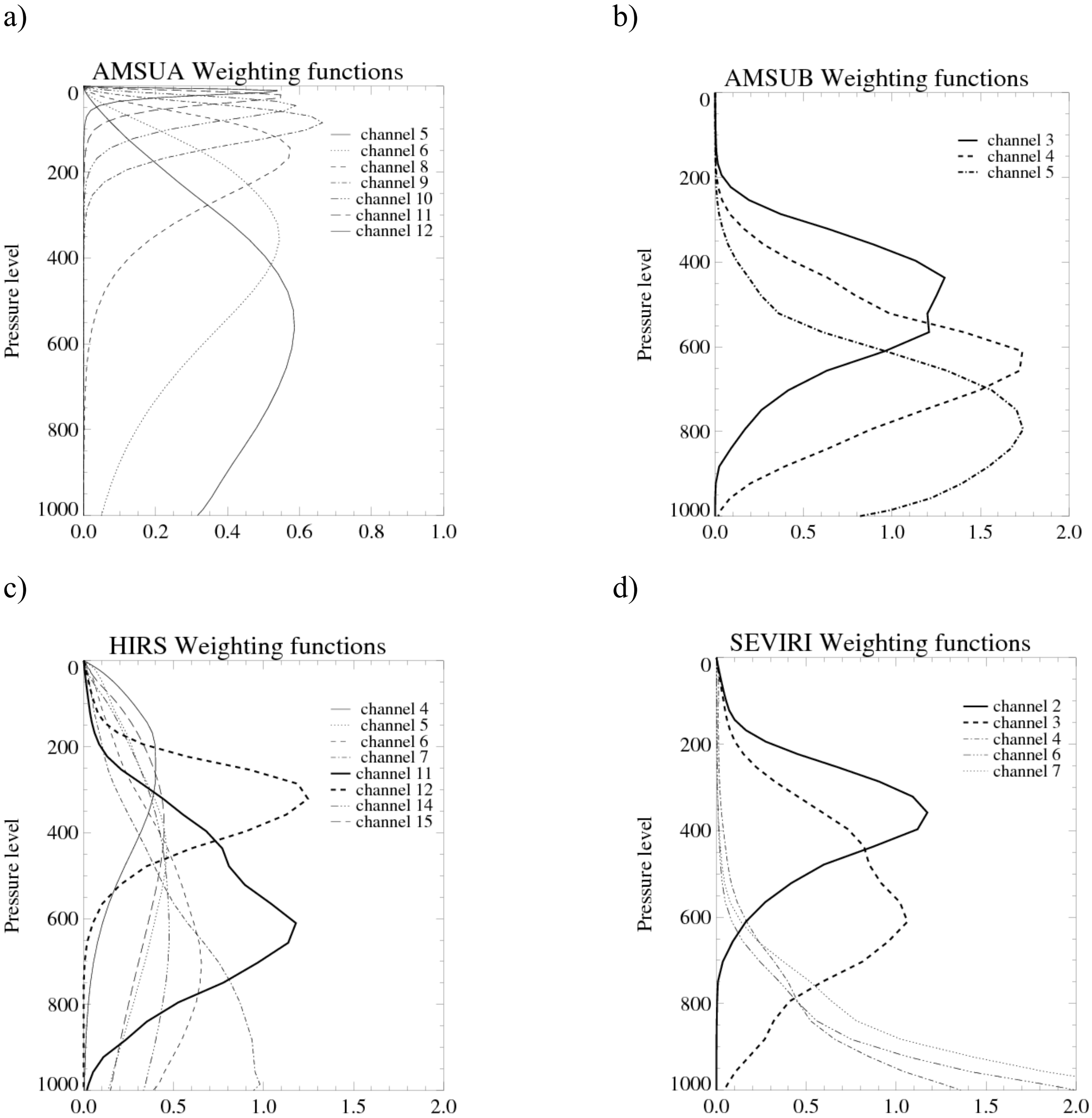


Fig. 14 : *Mean Weighting functions computed with RTTOV 8.5 for 20 mid-latitude summertime profile for (a) AMSU-A, (b) AMSU-B, (c) HIRS and (d) SEVIRI. WV channels are in bold lines.*

4.2 Verification versus ATOVS and SEVIRI observations

For the two experiments noSEV and moreATOVS, the fit of the model first guess and analysis to conventional observations remains mostly unchanged compared with OPER. Discrepencies appear however for statistics involving AMSU-B and HIRS channels because of their spectral behaviours that have been put forward above. Fig. 15 shows such statistics for noSEV compared with OPER. For HIRS's channels 11 and 12 and AMSUB, smaller background departure rms errors are displayed for OPER, which indicates that 6 hour forecasts are closer to that kind of observations while considering SEVIRI radiances. The corresponding analysis departure rms errors are on the contrary larger for OPER than for noSEV because of the high number of assimilated SEVIRI data that highly constrains the cost function towards an alternative solution. Finally, HIRS # 5,6 and AMSUB # 3,4 are badly bias corrected. The monitoring (not shown) displays highly variable features, mainly because of the low number of data that are taken into account in the statistics. In OPER however, adding correctly bias corrected SEVIRI data minimizes the potential harmful effect of this point, the latter being almost 10 times more, depending on the analysis time (Fig. 8).

The same statistics are plotted on Fig. 16 for moreATOVS compared with OPER. Concerning background and analysis departure RMS errors, the same characteristics than for noSEV are displayed, but in a much less pronounced manner: adding extra ATOVS data to an experiment that considers high resolution SEVIRI data have much less impact than adding SEVIRI data to an experiment that uses only sparse ATOVS data. Furthermore, it seems that (obs-guess) biases are degraded while using more ATOVS data for HIRS, but smaller values for AMSUB # 3 and 4 are shown. That point seems to indicate that the background becomes less and less good through the cycling of biased and/or correlated data. As a matter of fact, statistics computed for the initial analysis time show smaller biases and background departures for moreATOVS than OPER, whereas the contrary is shown for the last analysis time (not shown). This drawback could be partly solved by the use of greater observation error variances σ_o for ATOVS data in order to decrease their weight in the minimization. For that purpose, tuning factors could be computed as in M2005b. Another issue when using denser ATOVS data would be to compute the regression coefficients used for the bias correction specifically over the ALADIN-France domain, in order to ensure a better fit with predictors, instead of using coefficients computed over the global ARPEGE domain as it is the case for the three OSEs.

4.3 Sensitivity to the analysis

This section focuses on the computation of the DFS ("Density of Freedom for Signals"), whose theoretical aspects have been exposed in M2005. Let us just recall that, in an optimal case, we have : $DFS = Tr(\mathbf{HK})$, where Tr denotes the trace operator, **H** is the tangent linear of the observation operator in the vicinity of the background state, and **K** is the Kalman gain matrix. The estimation of this quantity is made difficult because of the sizes of the involved matrices and because the analysis error covariance matrix is not available in a variational scheme. The same Monte-Carlo-like method than in Chapnik *et al.* (2005) has been used.

As pointed out by Sadiki and Fischer (2005), to provide a reliable estimate of the $Tr(\mathbf{HK})$ with this Monte Carlo method, one needs to have a sufficient number of samples. While calculating this estimate for a particular set of data (humidity from radiosondes for instance), this number can drop and corrupt the result. To solve this potential problem, the Monte Carlo estimate has been generalized for a serie of trace operators valid for four different analysis dates (the 5th, 10th, 15th and 20th of June at 00 UTC), by simply adding all the individual random estimates to one another. The five days period between analysis dates that has been chosen follows the recommandation given by Sadiki and Fischer (2005) to ensure the ergodicity of the signal that require the data of each analysis step to be uncorrelated. This decorrelation time probably results from the meteorological variability over Western Europe and from the propagation time of a synoptic system inside the computational domain.

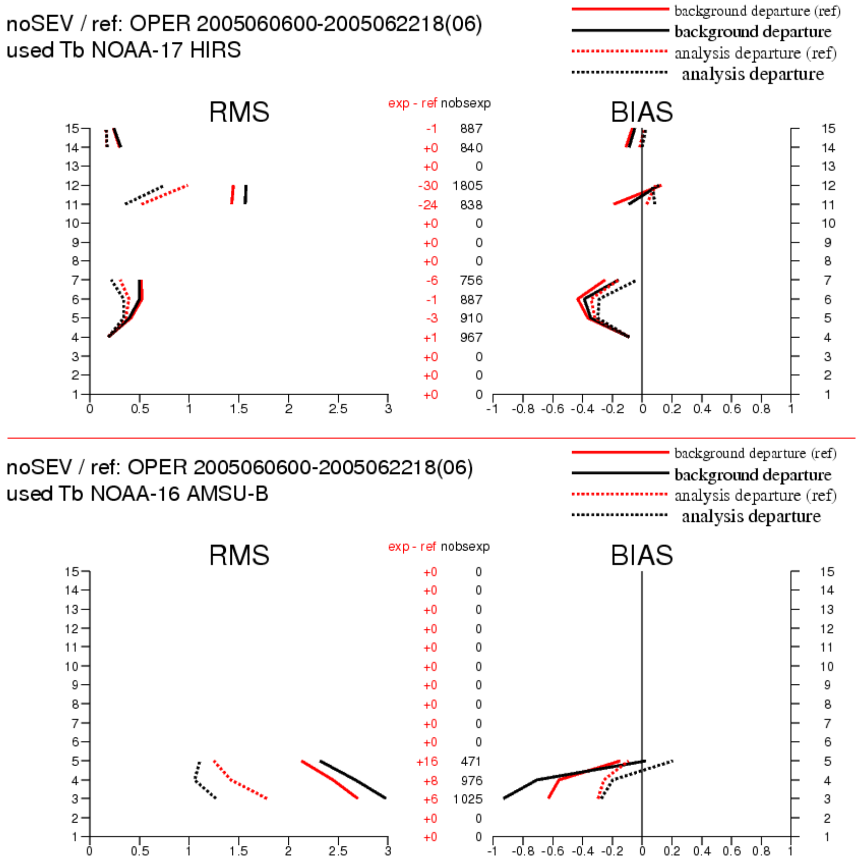


Fig. 15 : *RMS error and bias for (obs-guess) (solid line) and (obs-anlysis) (dashed line) for noSEV (black) and OPER (red lines) between the 6th and the 22nd of June, 2005, for HIRS onboard NOAA-17 (top panels) and AMSUB onboard NOAA-16 (bottom panels). The vertical axis represents the channel number and numbers in the middle the amount of assimilated data.*

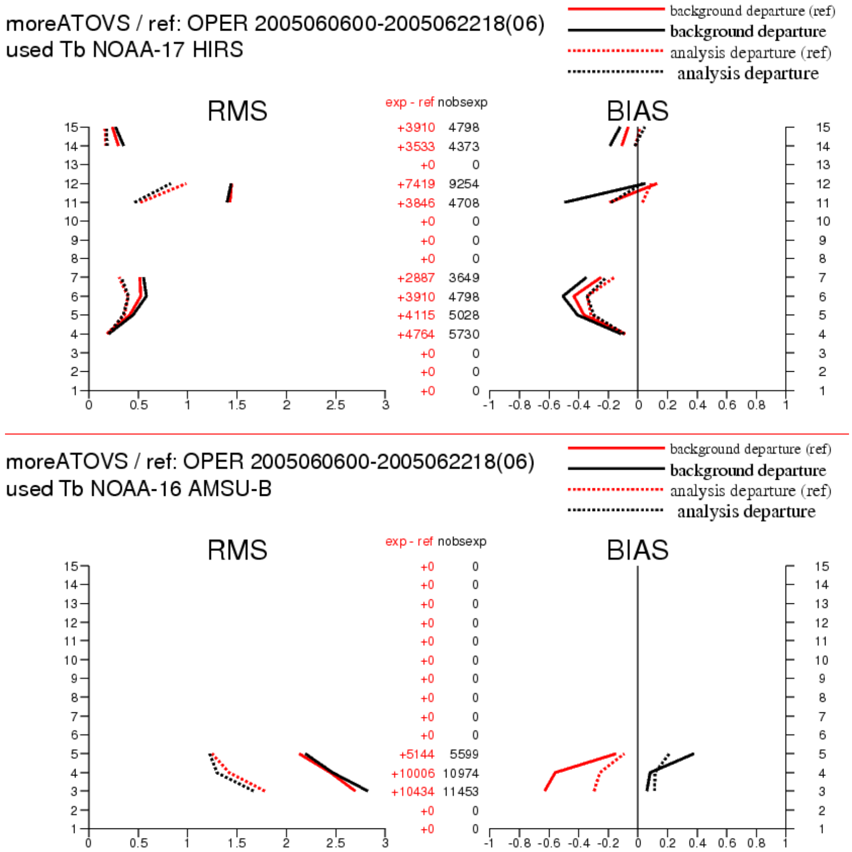


Fig. 16 : *as Fig.14 but for moreATOVS and OPER*

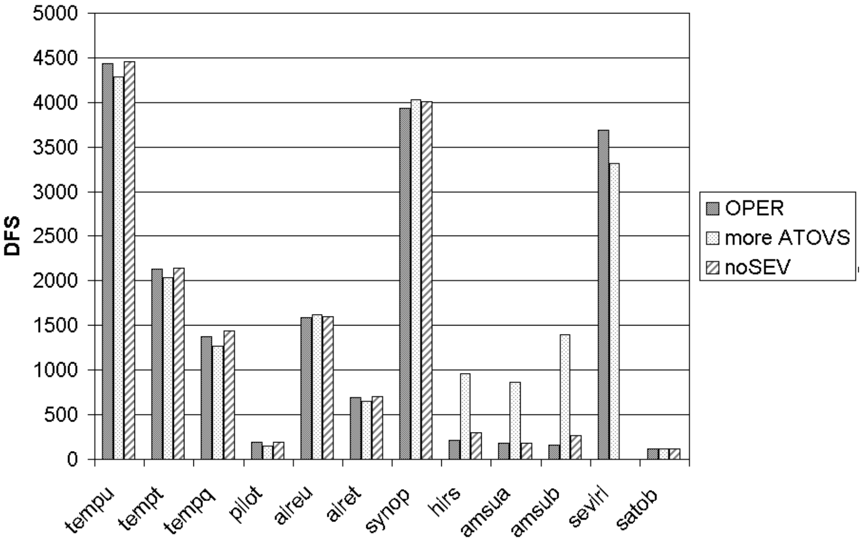


Fig. 17 : DFS values per obstype for OPER, moreATOVS and noSEV

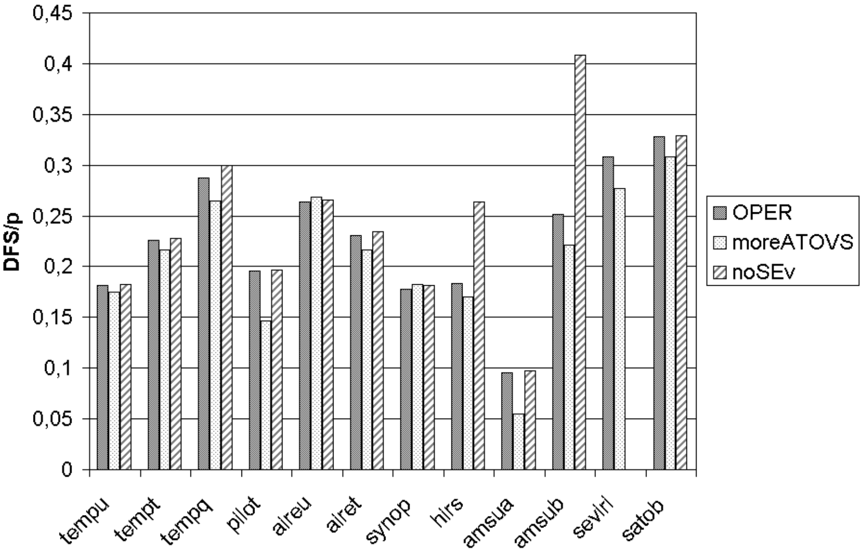


Fig. 18 : DFS values per obstype normalized by the number of observations for OPER, moreATOVS and noSEV

Fig. 17 shows DFS values per obstype for the three experiments. As it has been already shown in section 3.2, SEVIRI radiances are as informative as ground based data (SYNOP) and radiosonde data (TEMP) in the mid-troposphere for OPER and for the 00 UTC assimilation time. Other satellite observations (HIRS, AMSUA and AMSUB) have much less impact in the analyses. As it is stated in section 3.1, it has however to be noted that, for ATOVS data, the same thinning lengths than ARPEGE have been kept (~250 km) which reduces drastically the number of radiances entering the minimization.

The moreATOVS experiment displays comparable DFS values than OPER for conventional data. As it was expected, ATOVS data, and especially AMSU-B data, have however more impact in the analyses. On the contrary, SEVIRI data show weaker values in that case. This can be explained by the fact that new observations, notably radiances from HIRS and AMSU-B that are sensitive to the mid to high tropospheric humidity, are entering the minimization and thereby decreasing the influence of SEVIRI's WV channels. For the same reason, adding more ATOVS data implies to reduce the impact of one single radiance, as it is plotted in Fig. 18 that shows the DFS normalized by the number of associated observations. For AMSU-A, this reduction is accentuated because this radiometer is sensitive mostly to temperature variations in the high tropoposphere to low stratosphere, which are characterized by broad structure functions (Berre *et al.*, 2005) that "dissolve" the information brought by one single pixel.

When not using any SEVIRI radiances, the DFS associated to HIRS and AMSU-B almost doubles (Fig. 17). But contrarily to moreATOVS, the DFS per single observation notably increases (Fig. 18), especially for AMSU-B. The impact of humidity from radiosondes (TEMPQ) also increases slightly. This shows the complementarity between datasets that are sensitive to the same atmospheric component. For the 6 and 18 UTC analysis times, where no HIRS and AMSU-B data are available, SEVIRI observations allow nevertheless to obtain realistic humidity increments. On the contrary, when all radiances are available, the information brought by each pixel becomes somehow redundant and their respective impact become smaller.

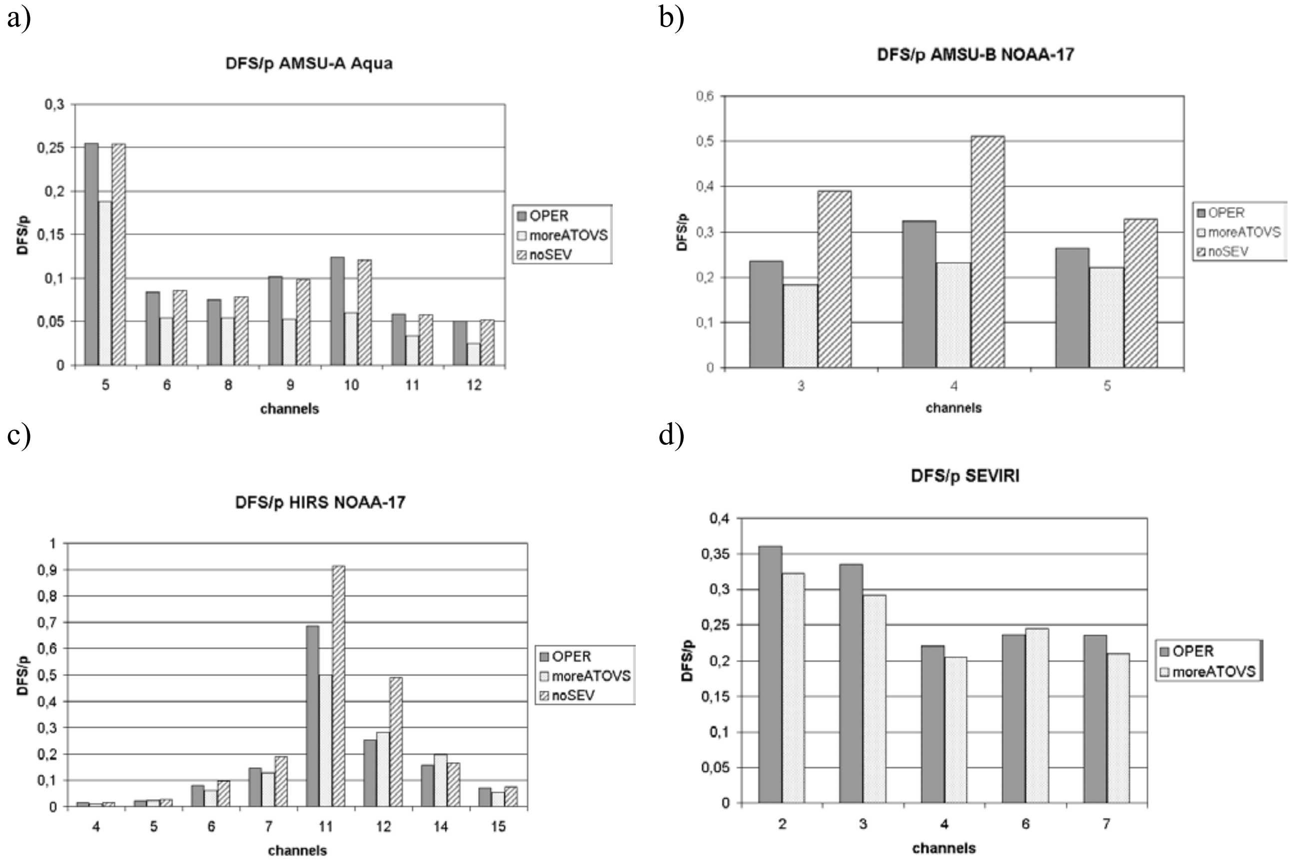
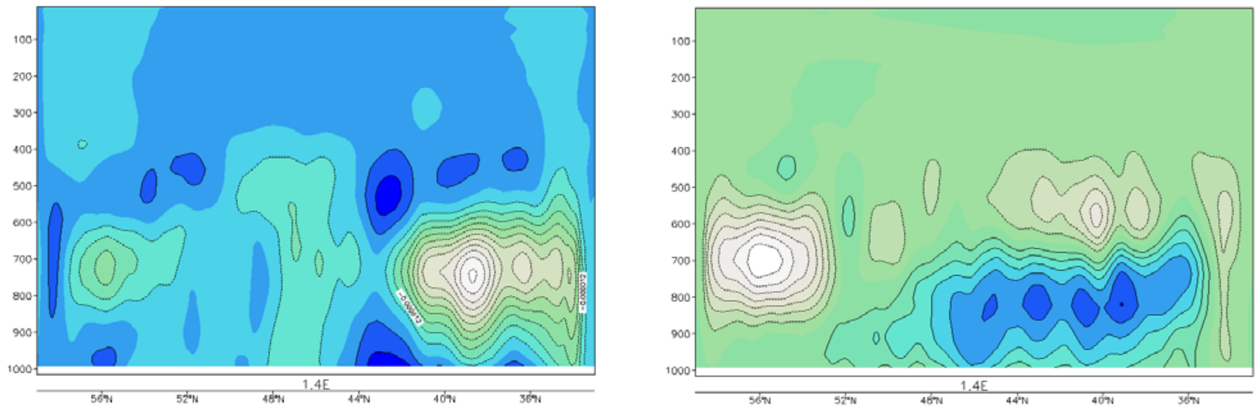


***Fig. 19 :** As Fig 18 but for each channel of (a) AMSU-A, (b) AMSU-B, (c) HIRS and (d) SEVIRI*

DFS is also useful to study the sensitivity of the analysis to different channels for a particular radiometer (Figs. 19). As one could expect it, the two WV channels are the most informative for SEVIRI, especially the 6.2 μ (Fig. 19.d). The three remaining IR channels have almost the same DFS values. For moreATOVS, these values slightly decrease. As shown in Fig. 19.c, WV channels 11 and 12 have the largest DFS for HIRS, especially channel 11. This confirms results by Cardinali et al. (2004) for the ECMWF data assimilation system. For noSEV, the DFS associated to the latter HIRS channels have greater values, which denotes higher impact of these particular channels whose spectral responses are close to the 7.3 μ and 6.4 μ SEVIRI channel respectively (c.f. Fig. 14). The large number of additional AMSU-B data in moreATOVS (10 times more than OPER), coupled with ALADIN/France structure functions, implies a loss of individual potential information for every channel (Fig. 19.b). As for HIRS, the AMSU-B pixels that are the more comparable to SEVIRI WV channels (channels 3 and 4) become more informative in noSEV. For each AMSU-A channel, the impact of a single observation is inversely sensitive to the number of pixels that enter the minimization, but do not depend on SEVIRI observations, since it is not sensing the same atmospheric levels (Fig. 19.a).

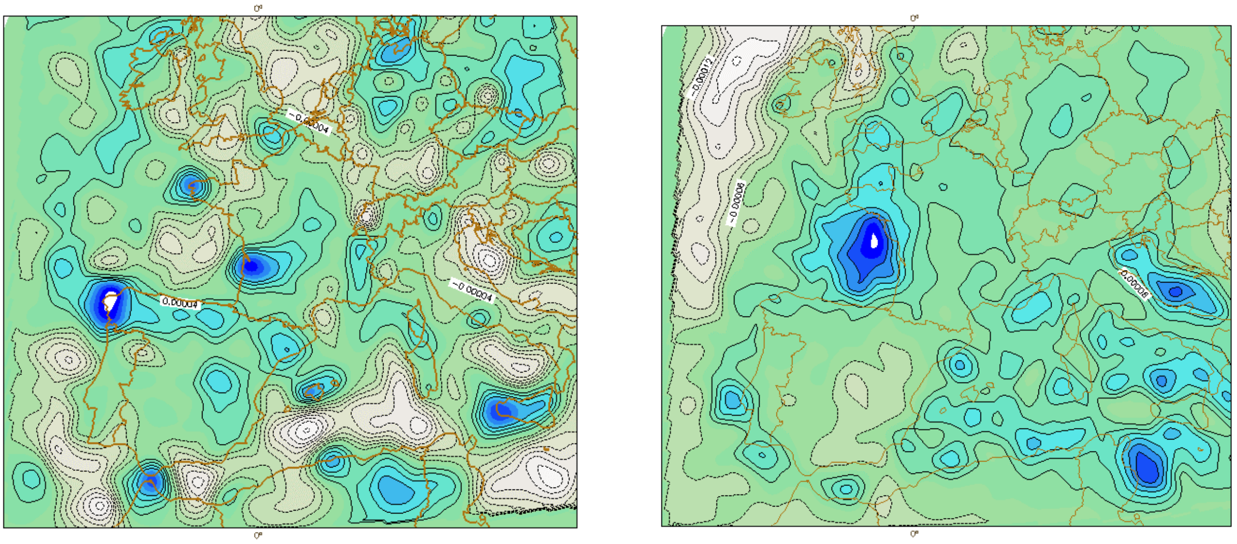
4.4 Impact on specific humidity increments

Zonal average of mean increments for specific humidity have been computed over the three weeks period considering every analysis steps. Fig. 20.a shows the difference between OPER and noSEV of such a quantity. Adding SEVIRI data produces strong mid-tropospheric negative increments mainly over the sea below 42°N, and positive humidity increment spots around 500 hPa. The horizontal cross section at 700 hPa of the corresponding mean increment difference plotted on Fig. 21.a exhibits that the mid-tropospheric drying brought by SEVIRI data occurs mainly over the Mediterranean sea and over the Atlantic West of Portugal. On the other hand, the extra ATOVS data show tendency to counter this drying by adding, in average, positive humidity increments in that particular area for the low to mid-tropospheric levels (Figs. 20.b and 21.b).


a)

b)

Fig. 20 : *Zonal Average of the difference of the mean specific humidity increment for (a) (OPER–noSEV) and (b) (moreATOVS–OPER) between the 5th and the 23rd of June, 2005 (Isocontours every 2.10^{-5} kg/kg).*


a)

b)

Fig. 21: *Horizontal cross section at 700 hPa of the mean specific humidity increment between (a) (OPER-noSEV) and (b) (moreATOVS-OPER) between the 5th and the 23rd of June, 2005 (Isocontours every 2.10^{-5} kg/kg).*

These additional data accentuate also the mid-tropospheric drying over the inflow region located west of Ireland.

4.5 Forecast scores

Comparisons between radiosounding data and forecasts interpolated at the observation's location show very comparable behaviour for the three OSEs at every forecast range. Adding SEVIRI data or denser ATOVS observations has no particular impact on that kind of score. A weak degradation of the humidity bias around 300 hPa up to 12 h of forecast is however visible while adding SEVIRI data, which indicates that SEVIRI data are constraining the analyses towards a new solution that is, in average, slightly different than what the sounding observations indicate (not shown).

Figs. 22 show the only significant discrepancies between the three experiments for forecast scores against ground based data over the whole test period. Considering SEVIRI data allows to get better short-range forecast (i.e before 12h) of 3h cumulated precipitation over France (Fig. 22.a). For the 6 h forecast range, the corresponding rms error is indeed significantly reduced. For the 18 and 24 h forecast ranges however, this tendency is reversed, but mainly because of two cases. As pointed out in section 3.5, forecasts are furthermore more sensitive at those ranges to lateral boundary conditions. The probable non-optimality of moreATOVS, already pointed out in section 4.2, seems to be the cause of worst scores compared with OPER : using a better ATOVS coverage do not improve the short-range precipitation detection (Fig. 22.b) and slightly degrades the mean sea level Pressure bias before 12 h of forecast (Fig. 22.c). Scores for temperature, humidity and wind show however same values for the three OSEs, meaning that the additional mid to high-tropospheric information brought by new satellite data has no significant impact on the model's first vertical levels.

4.6 Impact on precipitation forecast

It has already been shown in section 3.4 that the 3Dvar allows to get better scores than the spin-up model for 3 h cumulated precipitations up to 18 h of forecast. For the precipitating cases of the studied period, the three OSEs are producing their own solution. However, some redundant behaviours can be drawn from the examination of the precipitating patterns that are simulated. For example, Fig. 23 shows cumulated rain that have been forecasted between 12 and 18 h of simulation the 23rd of June, 2005, by the three experiments, compared with rain gauges observations. This case was characterized by Easterly and south-easterly wind in the South East of France bringing unstable moist air from the Mediterranean sea over the South of France. During the day, these unstable conditions have supported convective activity, mainly over the mountains of the Massif Central, the Pyrenees and the Alps.

For that particular case, the spin-up model generally underestimates the precipitations, especially over the Massif Central. The strong convective activity that has developed along a NS oriented convergence line that links the Pyrenees to the Massif Central is well represented in intensity, but is located too far East. These drawbacks (see also the case displayed on Fig. 10 which is described in the previous section) are typical for the spin-up model that often captures the large scale precipitation pattern but is less accurate for smaller scales. For all the precipitating cases of the three weeks experiment, OPER and moreATOVS show very close solutions for the simulated precipitation patterns. Figs 23.a and 23.d display for example comparable forecasts. These two experiments are representing quite well the main bow-shaped precipitation line with realistic amounts, which has been confirmed by better QPF scores than the spin-up model and noSEV over France (not shown). As noticed in section 4.3, adding extra ATOVS data reduces the individual impact of each ATOVS and SEVIRI pixel, because of the structure functions, of information redundancy and probably because of observation correlations between adjacent pixels. In the case where SEVIRI data are present at high resolution in the assimilation process as in OPER, using denser ATOVS data thus seems not to be a real issue (especially in the case of poor bias correction applied for ATOVS data). Finally, noSEV seems to be less accurate for that particular case than the two other OSEs: an unrealistic cell of more than 40 mm/6h is displayed in the South Western part of the Massif Central and precipitations over the Toulouse region is underestimated. The low number of observation types that are sensitive to mid to high tropospheric humidity is truly prejudicial not only for that case, but also for the other precipitating events of the studied period.

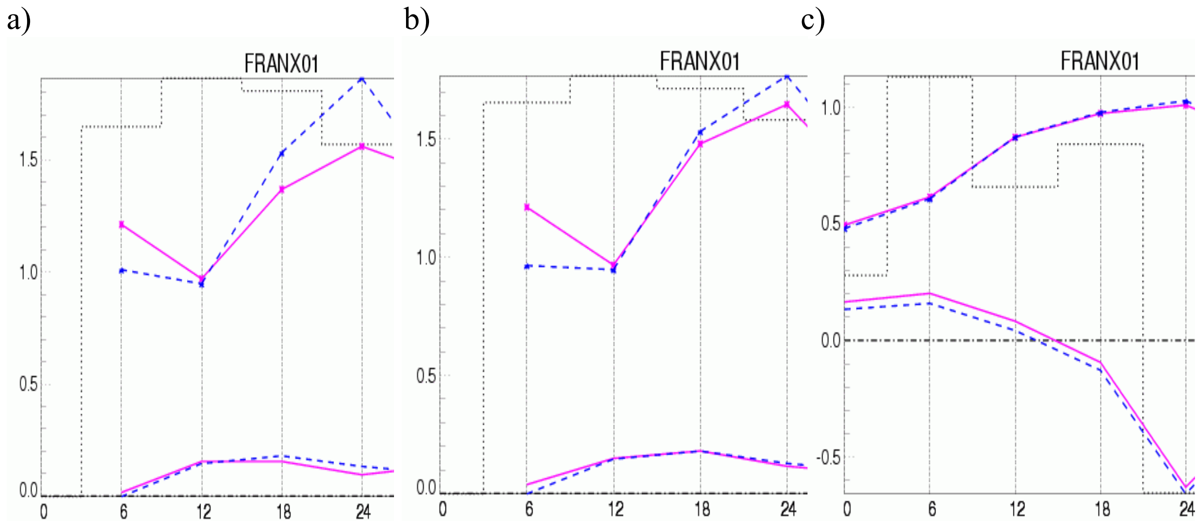


Fig. 22 : *Mean biases (bottom lines) and rms error (top lines) of OPER (dashed blue lines) against ground based observations of 3h cumulated precipitations compared with (a) noSEV (plain purple lines) and (b) moreATOVS (plain purple lines), and (c) against observations of mean sea level Pressure compared with moreATOVS (plain purple lines) over the ALADIN domain from the 6th of June to the 24th of July 2005. Horizontal axis denotes forecast time.*

5. Conclusions and future work

In this final report, we have firstly presented preliminary results of the assimilation of SEVIRI's Clear Sky Radiance (CSR) product in the global model ARPEGE. This study has been motivated by the positive results on forecast scores at the global scale that have been obtained at ECMWF by Szyndel *et al.* (2004), and also in order to bring more consistency between the coupling files that are provided by ARPEGE to the limited area model ALADIN, whose initial state is partly controlled by SEVIRI data through its 3Dvar data assimilation system. Promising results on forecast scores have been obtained, especially compared with ECMWF outputs. However, more cases should be performed in order to get more robust statistical results.

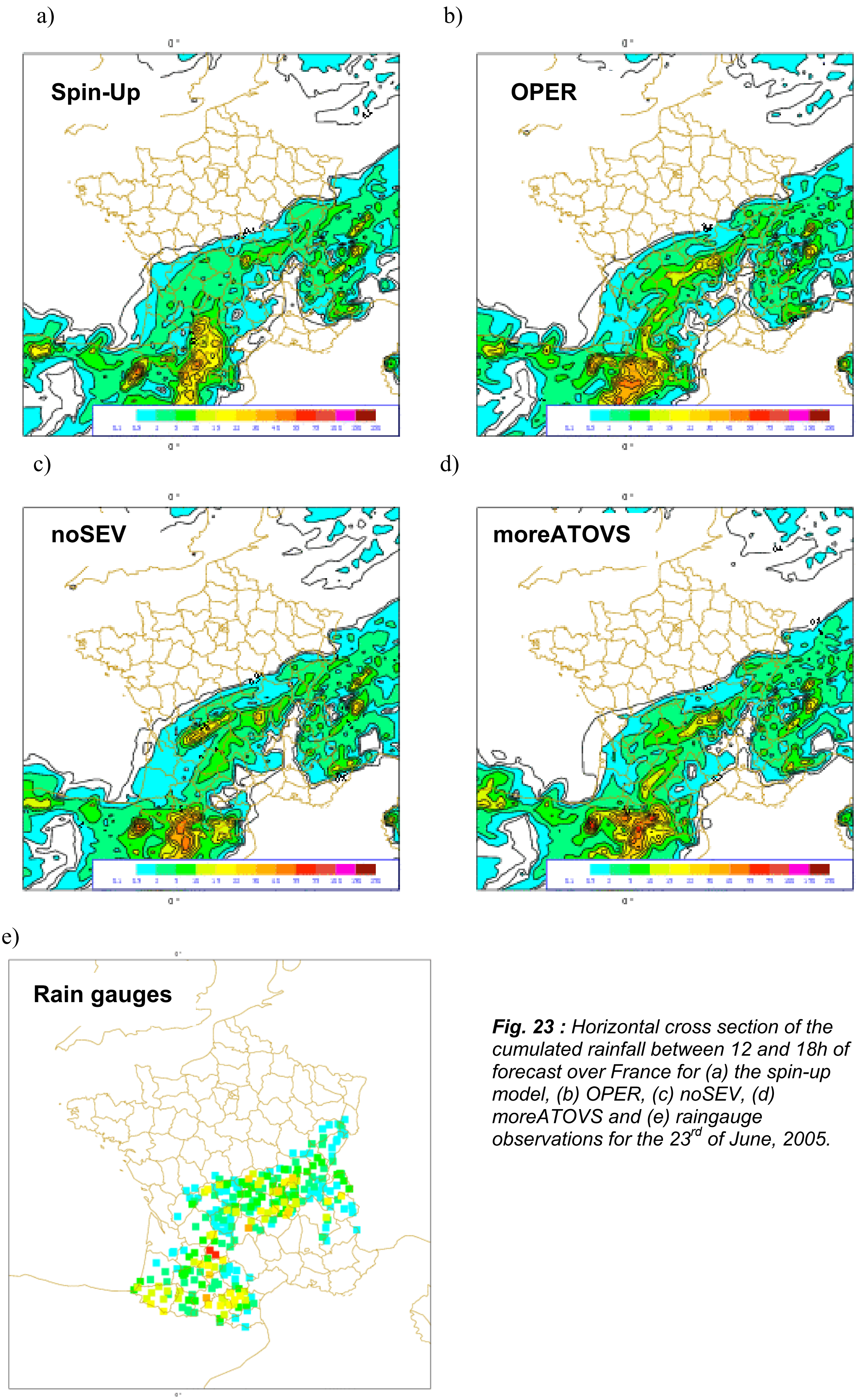


Fig. 23 : Horizontal cross section of the cumulated rainfall between 12 and 18h of forecast over France for (a) the spin-up model, (b) OPER, (c) noSEV, (d) moreATOVS and (e) raingauge observations for the 23rd *of June, 2005.*

The general framework of the recently operational complete assimilation/forecast suite based on ALADIN-France and its 3Dvar has then been presented. This system is the results of studies presented in M2004a, M2004b and M2005, in which the potential benefit of SEVIRI data for weather prediction at regional scale, the choice of the configuration and the tuning have been discussed. The operational 3DVar is distinguishable from ARPEGE mainly because of its ensemble based background error covariance matrix that provides structure functions better suited for analyses at regional scale, and by the use of specific observation types that are the 2 m temperature and humidity and the SEVIRI data at high resolution. The latter data are taken into account using a cloud type classification to keep only data non-contaminated by clouds in the variational process. A specific air-mass dependent bias correction scheme and a quality control are then applied on the remaining pixels, which allows to obtain realistic mesoscale increments though the 3Dvar that leads in most of cases to realistic precipitation pattern forecast. Forecast scores against ground based data and radiosoundings show better behaviour for the operational suite than the spin-up model (i.e ALADIN without data assimilation), especially for precipitations. From its launch at the end of July 2005, this system is evaluated by forecasters on a daily basis, and for the moment the feedback on subjective control is positive.

Observation System Experiments (OSEs) based on this operational system have then been performed, in order to infer the potential impact of SEVIRI and denser ATOVS data. A strong complementarity has been shown between satellite observations that are sensitive to the same atmospheric component, namely AMSUB, HIRS and SEVIRI WV Channels. As a consequence, the high temporal resolution of SEVIRI allows to get information about the mid to high tropospheric humidity even when no AMSUB and HIRS data are present, which is especially the case for the 06 and 18 UTC analysis times. Inversely, ATOVS observations could bring precious information if transmission problems occur for SEVIRI data at the 00 or 12 UTC analyses times. In that particular case, having more ATOVS data (1 pixel within a thinning box of 70 km instead of 260 km for example) would surely be very interesting. On the contrary, if SEVIRI data are already present at high resolution, the redundancy of information, the shape of the structure function and the potential observation correlation between adjacent pixels lower the individual potential impact of denser ATOVS data on analyses. As a matter of fact, no real improvement on forecast scores nor on simulated precipitation patterns have been found for that particular OSE. Another consequence of the complementarity between satellite data is that, in the case of the operational suite, the high number of geostationary data allows to decrease the potential harmful affect of badly bias corrected ATOVS data. Tuning of observation error variances should however be carried out for every new observation type that is taken into account in the system in order to ensure the best possible optimality during the minimization.

Further studies are planned to improve the actual operational ALADIN model : 3DVar using FGAT (First Guess at Appropriate Time), use of a new variational term in the cost function to relax the analyses towards large scale, revisit the formulation of humidity analysis as at ECMWF, assimilation of cloudy radiances, get a better estimation of surface emissivity and surface temperature to assimilate IR channels over land. All these studies are preparing the assimilation at convective scale that will be performed for the AROME model. As a matter of fact, Météo-France has undertaken by year 2008 to run an operational data assimilation and forecasting system, called AROME (Applications of Research to Operations to MesoscalE), with non-hydrostatic dynamics, an horizontal resolution of 2 to 3 km over the French mainland, explicit representation of strong convective events and associated precipitation, detailed depiction of actual weather, interfacing with hydrological, land-surface and atmospheric chemistry models.

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