The sensitivity of the HARMONIE/Norway forecasts to the IASI data

Roger Randriamampianina and Andrea Storto
Norwegian Meteorological Institute
PO Box 43 Blindern, N-0313 Oslo, Norway
www.met.no
rogerr@met.no

Abstract

The HARMONIE assimilation and forecasting system is being implemented at the Norwegian Meteorological Institute (Met.no). Since we intend to make this system operational at Met.no in the near future, we need to improve our understanding of its functionality. Concerning the assimilation part, we have to decide how and what kind of observations to use, and how to define a better representation of the background error for the system. The classical way to study the impact of different observations is by performing observation simulation experiments (OSEs). The OSE is a clean study, but very expensive, since we have to repeat the experiments as many times as many parameters or observation types we want to evaluate. In this study we were using a relatively cheap technique to substitute the expensive OSE experiments. The method is based on moist total energy norm cost functions. It has been applied to analyse the sensitivity of the forecast to different combinations of the IASI channels. We used a localisation operator for evaluating the most sensitive channels or group of channels in a specific sub-area of the limited area model. These specific areas could be those over land or Sea, or areas influenced by different meteorological conditions (e.g. convective area or polar lows) as well as various vertical subregions of the atmosphere. We found, that the IASI channel groups have different impact in different cases. The sensitivity of the forecasts to the IASI data was higher in unstable or convective synoptic situations.

Introduction

In the frame of the IPY-THORPEX/Norway, aiming to improve the accuracy of the high-impact weather forecasts over the Arctic region, we decided to assimilate the Infrared Atmospheric Sounder Radiometer (IASI) data. After a successful implementation of the ALADIN/HARMONIE system for the Norwegian domains of interest, our next step was to look at the observations processing and the choice of the background error statistics further used in the assimilation system. Our earlier study (Randriamampianina and Storto, 2009) showed a positive impact of the IASI data in the conditions with and without the additional campaign data (dropsondes were operated during the campaign for studying some polar synoptic conditions). Our case studies showed that the IASI data can be very efficient in forecasting polar lows. Since we are using relatively small amount of IASI channels, we are interested to know the contribution of different IASI channels or group of the IASI channels on the HARMONIE/Norway forecasts. We have tested a new, relatively cheap approach, to evaluate the sensitivity of the forecasts. The method is based on moist total energy norm cost functions. It has been tested first with the system without IASI radiances (Storto and Randriamampianina, 2010).

In this paper we describe the application of the moist total energy norm approach to assess the sensitivity of the HARMONIE forecasts to 3 groups of IASI channels. The active IASI channels are divided into three groups up to their peaking levels (see Figs 2.).

Further, this paper is organised the following way: after the short description of the assimilation and forecast system, we briefly give the basic of the applied approach, which followed by its application to study the contribution of the IASI data in the moist energy of the HARMONIE forecasts. Then, before concluding the experiments and the results are discussed.

The HARMONIE/Norway assimilation and forecast system

The assimilation system consists of i) updating the Sea Surface Temperature (SST) by using the ECMWF global SST analysis, ii) performing a surface Optimal Interpolation for updating soil moisture and skin temperature fields through a univariate analysis of 2 meters temperature and relative humidity using the synoptic stations network (SYNOP); iii) performing a spectral upper-air three dimensional variational data assimilation, which takes advantage of the SYNOP stations from ships and land for the surface pressure and for the 10 meters wind over sea only, the radiosonde network for the multi-layer observations of wind, temperature, humidity and geopotential, the wind profilers for the multi-layer observations of wind, the air-borne observations of temperature and wind, the surface pressure measurements from the oceanographic buoys, the wind vectors deducted from cloud-drift satellite images (Atmospheric Motion Vectors, AMV), the microwave radiances from AMSU-A, AMSU-B/MHS and IASI from the polar-orbiting satellites of NOAA and from MetOp (Table 1).

Type	Parameter (Channel)	Bias correction	Thinning
TEMP	U, V, T, Q, Z	Only T using ECMWF tables	No
SYNOP	Z	No	Temporal and spatial
PILOT (Europrof.)	U, V	No	Redundancy check against TEMP
DRIBU	Z	No	Temporal and spatial
AIREP	U, V, T	No	25 km horizontal
AMV	U, V	No-Use of quality flags	25 km horizontal
AMSU-A	5 to 13	Variational	80 km horizontal
AMSU-B, MHS	3, 4, 5	Variational	80 km horizontal
IASI	41 channels	Variational	80/120 km horizontal
GPS	available but not used in	Static	No
MSG/SEVIRI	this experiment	Variational	60 km horizontal

Table 1. Use of Observations in the ALADIN-HARMONIE/Norway

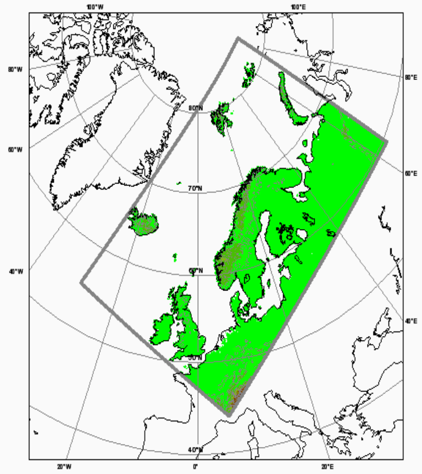


Figure 1. The ALADIN-HARMONIE/Norway domain, 11 km horizontal resolution

Methodology

The impact of the initial conditions on the forecasts at a given forecast time t may be described through a cost function J (*Rabier et al.*, 1996) given by:

$$J = \frac{1}{2} \langle x_t^{exp} - x_t^{ref} , x_t^{exp} - x_t^{ref} \rangle \tag{1}$$

where x_t^{ref} are forecasts initialised with reference initial conditions, and x_t^{exp} are the ones initialised, in general, with some modifications or perturbations of the initial conditions, and $\langle \ldots, \ldots \rangle$ is a norm operator used for verification purposes. Thus, similarly to Equation (1), it is possible to define a cost function for any subset of observations *i* which have been excluded from the assimilation system:

$$J^i = \frac{1}{2} \langle x_t^i - x_t^{ctr}, x_t^i - x_t^{ctr} \rangle . \qquad (2)$$

Here, x_t^i is the forecast initialised without assimilating the observations belonging to the *i*-th subset and x_t^{ctr} is the control forecast with all the observations assimilated, which is assumed to give the best verifying forecasts. It is also possible to introduce a localisation operator **P** to study the sensitivity of forecasts in specific areas inside the model domain extension, e.g. for evaluating the impact between open-sea and inland areas apart, or in vertical sub-regions of the atmosphere. In this case, Equation (2) becomes

$$J^i = \frac{1}{2} \langle P(x_t^i - x_t^{ctr}), P(x_t^i - x_t^{ctr}) \rangle . \qquad (3)$$

The norm used for evaluating the observations impact is the moist total energy norm (Ehrendorfer *et al.*, 1999). For more details about the applied approach, see *Storto and Randriamampianina* (2010). The impact on the quality of the forecasts is assessed by the metric in Equation (3) only if the simultaneous use of all the observations is proved positive. If the assimilation of some observation types is detrimental in some areas or at some verification times, the cost function provides information on the sensitivity without any information on the improvements caused by such observations. The cost function provides a measure of the quality loss when an observation type is not assimilated. Repeating the computation of the norm for many independent simulations, we define the sensitivity of the forecasts to the *i*-the group of observations. The results presented in the next section use simulations apart enough to ensure ergodicity of the sensitivity, as recommended in *Sadiki and Fischer* (2005), and give the same weight to all the cases (for simplicity) to have an average of the cost function over the cases.

Application – evaluating the sensitivity of the forecasts to the IASI data

As it was described above the 41 IASI channels were separated into three groups. The vertical description of the "high-", "middle-", and "low-peaking" IASI channels are shown on Figs. 2.

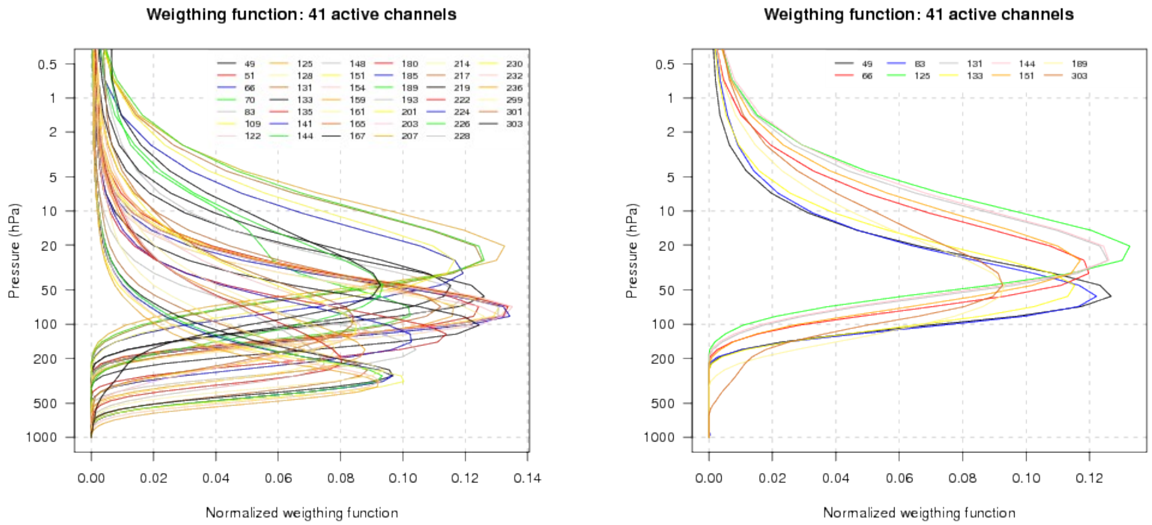


Figure 2a. Separation of IASI channels: The full set (left) and the "high-peaking channels (right).

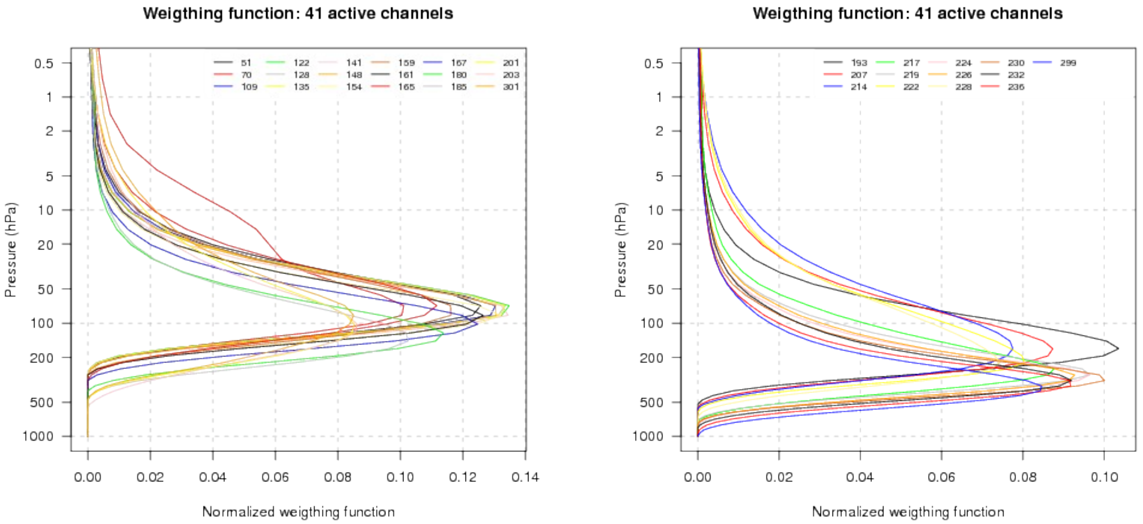


Figure 2b. Separation of IASI channels: The middle-peaking (left) and the "low-peaking channels (right).

The vertical definition of the studied sub-regions is described in table 2.

Vertical region	Region Bottom	Region Top
Low-troposphere	850 hPa	600 hPa
Middle-troposphere	600 hPa	350 hPa
High-troposphere	350 hPa	150 hPa
Stratosphere	150 hPa	20 hPa

Table 2. Definition of vertical sub-regions of the atmosphere used the localisation operator.

The experiments and results

We performed a series of data assimilation and 48-hour forecasts with 6 hour cycling using the full set of observations (Table 1). The experiment started on February 20 and lasted until March 17, 2008. The following dates and times were chosen for the data denial experiments: 25.02.2008 (12UTC), 03.03.2008 (00 UTC), 10.03.2008 (12UTC), and 16.03.2008 (00 UTC). Taking into account our earlier study (*Storto and Randriamampianina*, 2010), only the most impacting observations were investigated together with the IASI channels groups. Data denial experiments were then conducted also with all the aircraft (AIREP), the radiosonde (TEMP), the AMSU-A, and the AMSU-B observations.

According to our results, the relative contribution of the IASI channels group on the forecasts, averaged over the cases is relatively small over the whole HARMONIE/Norway domain (Figs 3).

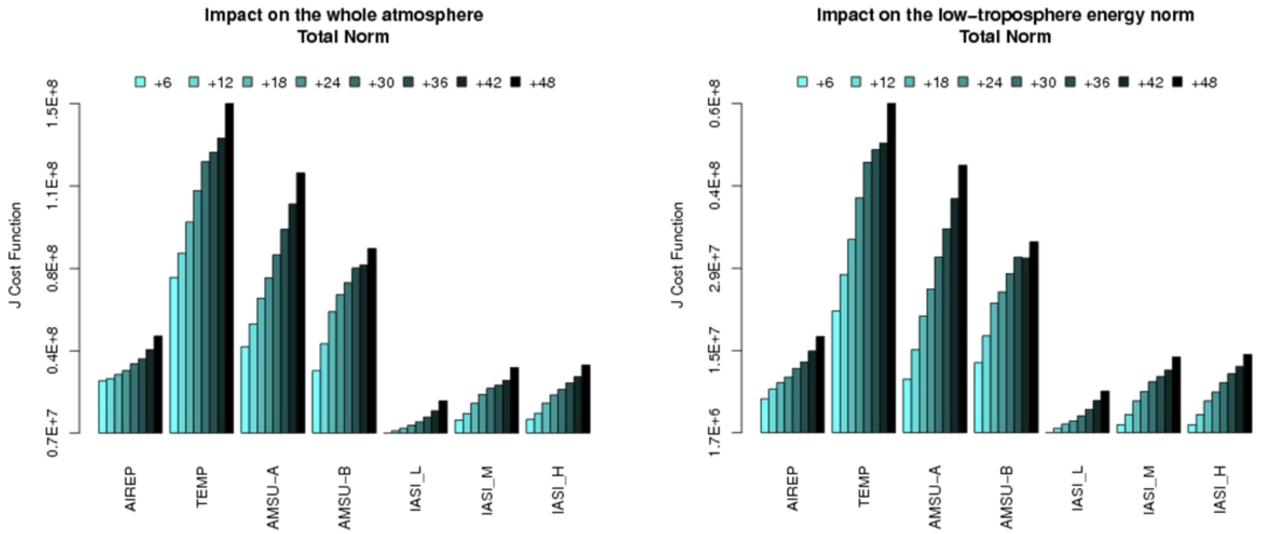


Figure 3a. Total energy norm impacts for the whole atmosphere (left), and for the lower troposphere (right). The forecast ranges are shown with different colours.

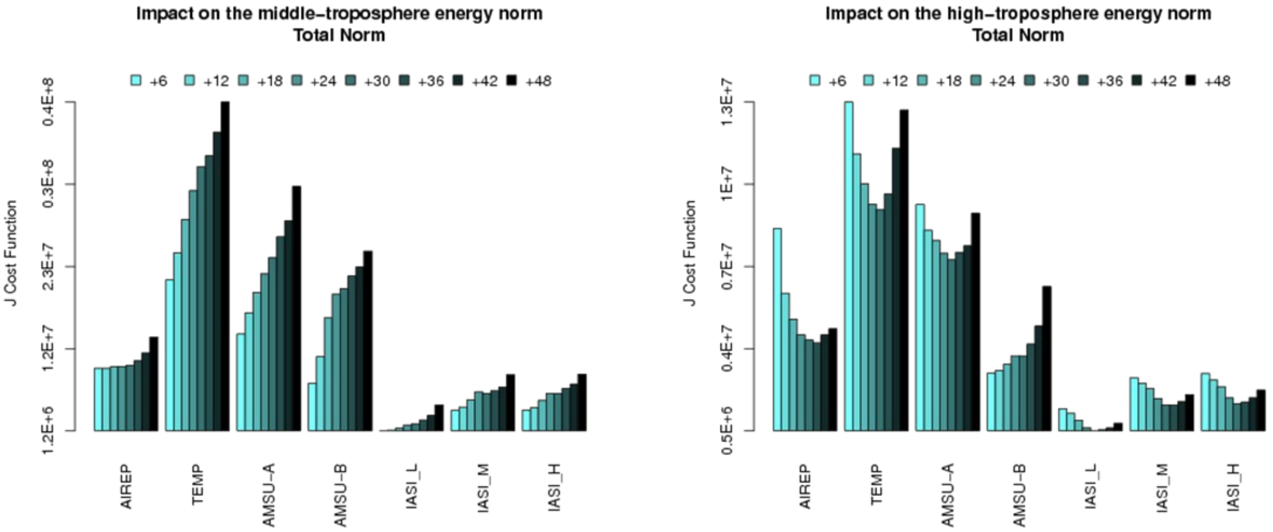
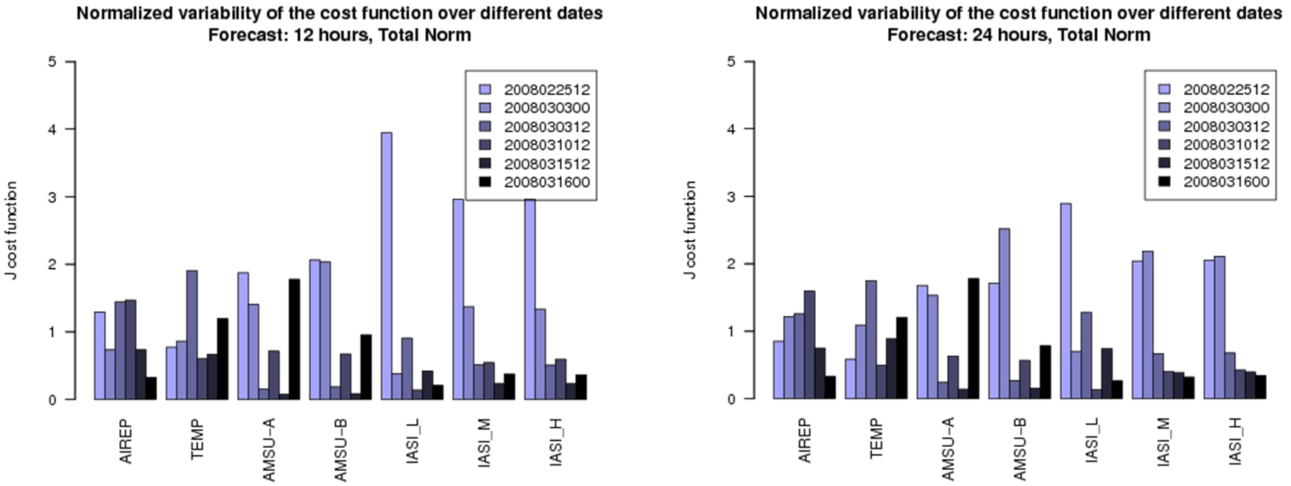


Figure 3b. Same as Fig.3a but for the middle (left) and the high troposphere (right).

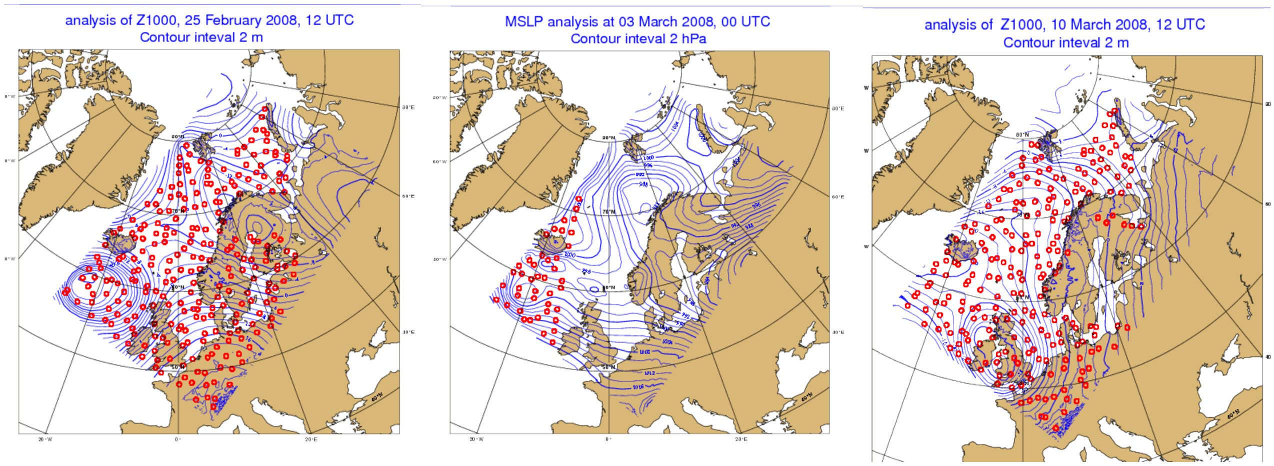
Comparing separately the normalised day-by-day variability of the cost functions over the cases, we can observe large variation of the contribution of the different observations (Figs 4). It is interesting to see that there are cases when the IASI channels groups could provide higher impact on the forecasts (cases of February 25th (12 UTC) for the 12-hour forecast, and March 3rd (00 UTC) for the 24-hour forecast, for example) than the other observations used in the system. Checking the synoptic conditions inside the HARMONIE domain for the investigated cases, we concluded that the radiances, in particular the IASI data, had the highest impact in case of unstable situations. On Figs 5 the horizontal distribution of the active IASI channels are plotted on top of the synoptic charts.

We can see that for the 00 UTC analysis, the IASI observations cover only one part of the HARMONIE/Norway domain. For the case of 3rd of March (00 UTC), although a polar low was developing north-west of the Lofoten Islands, the relatively high contribution of the IASI data was only thanks to the "perturbations" developing in the south-western part of the domain. More interesting situation was observed on 25th of February (12 UTC), because on top of the full observation coverage of the AMSU-A and AMSU-B (not shown), the IASI data (having good coverage over the domain in this case) can still have higher relative contribution on the forecasts. Note that the synoptic condition over the HARMONIE/Norway domain at this case was quite complex. The case of 10th of March (12 UTC) seems to have quite "stationary" synoptic situation over the domain, except a mature cyclone situated in the southern part of the domain.


Normalized variability of the cost function over different dates
Forecast: 12 hours, Total Norm

Normalized variability of the cost function over different dates
Forecast: 24 hours, Total Norm

Figures 4. The normalised variability of the cost functions over different dates. Note that the normalisation was done separately case by case. So, one should compare the relative contribution of the observations with respect to the same days.


analysis of Z1000, 25 February 2008, 12 UTC
Contour inteval 2 m

MSLP analysis at 03 March 2008, 00 UTC
Contour inteval 2 hPa

analysis of Z1000, 10 March 2008, 12 UTC
Contour inteval 2 m

Figures 5. Examples for forecasts sensitivity case studies. Red circles represent the active IASI pixels.

Conclusions

Comparison against observations and ECMWF analyses showed statistically significant positive impact of the IASI data on the HARMONIE forecasts. The horizontal distribution of the errors is well spread over the HARMONIE domain (not shown in this paper).

We evaluated the sensitivity of the HARMONIE/Norway forecasts using an energy norm-based approach. We found that the evaluation is highly dependent on the studied cases. Hence, for obtaining any "representative/overall" information about sensitivity of the forecasts to various observations, we need to select carefully the cases that that we take into account.

We concluded that the IASI channel groups have different impact on different synoptic situations and that the sensitivity of the forecasts to the IASI data is higher in unstable or convective synoptic situations.

References

Ehrendorfer M, Errico RM, and Raeder KD., 1999: Singular-vector perturbation growth in a primitive equation model with moist physics. *Journal of Atmospheric Sciences* **56**: 1627–1678.

Rabier F, Klinker E, Courtier P and Hollingsworth A., 1996: Sensitivity of forecast errors to initial conditions. *Quarterly Journal of the Royal Meteorological Society* **122**: 121–150.

Randriamampianina, R and Storto A, 2009: Impact of IASI data on forecasting polar lows, *EUMETSAT Meteorological Satellite Conference*, Bath, United Kingdom 21 - 25 September 2009.

Storto A. and Randriamampianina R., 2010: The Relative Impact of Meteorological Observations in the Norwegian Regional Model as determined using an energy norm-based approach, *Atmospheric Science Letters.*

Sadiki W and Fischer C., 2005: A posteriori validation applied to the 3D-VAR Arpège and Aladin data assimilation systems. *Tellus* **57A**: 21–34.