Assimilation of IASI radiances in AEMET operational suite

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1 Introduction

Infrared Atmospheric Sounder Interferometer (IASI) is an infrared Fourier-transform spectrometer on board the MetOp polar orbiting meteorological satellites which make up the EUMETSAT Polar System (EPS) series.

IASI measures in the infrared part of the electromagnetic spectrum at a horizontal resolution of 12 km over a swath width of about 2,200 km, in a sun-synchronous mid-morning orbit (9:30 Local Solar Time equator crossing, descending node), providing global observations twice a day. It provides information on the vertical structure of the atmospheric temperature and humidity in an accuracy of 1° Kelvin and a vertical resolution of 1 kilometre and profiles of humidity with an accuracy of 10% and a vertical resolution of 1-2 kilometres, which has given significant positive forecast impact at NWP centers in both global and regional models (Collard and McNally, 2009, or Randriamampianina et al. 2011).

The aim of this short contribution is to present the implementation and assessment of the assimilation of IASI clear-sky radiances from METOP-B in the AEMET HARMONIE-AROME system. First, IASI radiances assimilation has been prepared by executing an experiment where these data were assimilated passively. Then, these data have been actively assimilated to test their impact on model forecasts.

2 IASI passive data assimilation experiment

The current HARMONIE-AROME cycle 40h1.1 (Bengtsson et al., 2017) operational suite in AEMET that runs on the local HPCF. The model runs at 2.5 horizontal resolution and 65 vertical model levels extending up to 10 hPa, over two domains: one centered on the Iberian Peninsula that includes the Balearic Islands (called AIB), and other centered on the Canary Islands (called AIC). AEMET HARMONIE-AROME is based on a 3DVar data assimilation with a 3h cycle. Until recently, it assimilated conventional observations from SYNOP, SHIP, DRIBU, AMDAR, and TEMP reports, GNSS ZTD data, and ATOVS satellite radiances from AMSUA and AMSUB/MHS instruments. A later major update of this system added the assimilation of radar reflectivities, scatterometer winds, and 2-meter temperature and relative humidity data in upper air, and activated the large-scale mixing with ECMWF fields in the first guess also for humidity (Sánchez-Arriola et al., 2020). Now, clear-sky IASI radiances from METOP-B have been incorporated to the assimilation system at 09, 12, and 21 UTC for AIB and at 00, 09, 12, and 21 UTC for AIC. A thinning distance of 80 km is used to reduce the original spatial resolution of IASI data.

The preparation of IASI data assimilation has mainly consisted in selecting the set of channels to be assimilated, checking the cloud detection scheme results and tuning the bias correction variational algorithm (VarBC). Passive assimilation of IASI radiances in a parallel experiment to the operational configuration has allowed to perform it.

Data and initial channel selection

The IASI L1c product (provided by EUMETCAST) contains 8461 channels (between 645.0 cm-1 and 2760 cm-1 at 0.5cm-1 resolution). For numerical weather prediction data assimilation purposes, this high volume of data was reduced to 366 channels by Collard (2007) and Collard and McNally (2009).

This large number of channels must be checked and evaluated for each model. This is a hard task which we decided not to perform initially. Instead, we used the reduced channel selection performed by MetCoOp that is available in the HARMONIE-AROME set-up. This comprises 30 channels for the long-wave CO2 band and 25 channels for the water-vapour band (see Table 1). In this study IASI data from METOP-B satellite are used.

Table 1: Selection of IASI channels used for passive IASI data assimilation experiments.

Band	Peaking Level	Channel
CO2	High	38, 51, 63, 85, 104, 109, 167
	Middle	173, 180, 185, 193, 199, 205, 207, 212, 224, 230, 236, 239, 242, 243, 249, 296, 386
	Low	333, 337, 345, 352, 389, 432
Water vapour		2701, 2819, 2910, 2919, 2991, 2993, 3002, 3008, 3014, 3098, 3207, 3228, 3281, 3309, 3322, 3438, 3442, 3484, 3491, 3499, 3506, 3575, 3582, 3658, 4032

Variational bias correction and cloud detection scheme

Satellite bias for IASI radiances is corrected using a Variational Bias Correction scheme (VarBC) in a similar way as for ATOVS radiances (Campins et al., 2017). We use a set of 6 predictors (0, 1, 2, 8, 9, and 10; see Table 2) which were initialized from a cold-start and updated with a 24-h cycling.

Table 2: Description of predictors used in VarBC.

Number	Predictor
0	Constant
1	1000-300 hPa thickness
2	200-50 hPa thickness
8	Nadir viewing angle
9	Nadir viewing angle **2
10	Nadir viewing angle **3

As the current assimilation of IASI deals with clear-sky radiances, the cloud contaminated channels must be rejected. To discriminate between clear-sky and cloud-affected channels the scheme described by McNally and Watts (2003) was used. This algorithm works with observation minus first-guest departures, but these departures must be unbiased. However, that is not the case for a cold start passive assimilation, until regression bias correction coefficients are updated. Biased data can be evaluated as cloudy data and rejected through quality control checks, mainly for low and middle peaking channels. To diminish this issue, we followed the procedure described in Benacek (2013). It mainly consists in selecting a few clear sky days to relax cloud detection algorithm and accelerating the bias coefficients convergence during these days in order they may adapt faster. The objective is to prevent in subsequent assimilation cycles, when both cloud detection and bias coefficients are reset to their default values, that cloud detection decisions may reject radiances affected by strong biases.

Final channel selection

The aim of passive assimilation is to spin-up VarBC coefficients and to ensure the suitability of the IASI observations that will be further assimilated as active. For all channels in Table 1, time series of (bias corrected) observations minus first guess were examined. We expect a bias reduction in time, from zero (cold-start) to a small mean value of observation minus guess (OMG) departures (i.e., 0.1-0.2 K). After the 40-day period this is the case for almost all the channels, except for some low-peaking levels as 333, 352, 389, and 432 (see the difference between channel 205 and 389 in Figure 1). For these low-peaking channels (more affected by cloud contamination) the number of observations is very low, preventing an appropriate bias correction. For this reason, these channels are discarded in both domains. Besides, channel 85 exhibits a large OMG standard deviation in the AIB domain, and it seems reasonably to reject it too. As a consequence, the final channels selection is reduced to 50 channels for AIB and 51 channels for AIC.

We have not found any significant difference between corrected first-guess departures over land and sea, thus the selected channels are assimilated over both surfaces.

The assimilated clear-sky radiances for different channels were validated against cloud-top-pressure images (a product derived from MSG-SEVIRI by EUMETNET Nowcasting-SAF) along the passive, and active data assimilation periods. Overall, cloud detection scheme and variational bias correction are able to identify clear channels and reject those affected by clouds, specially in the mid and upper troposphere.

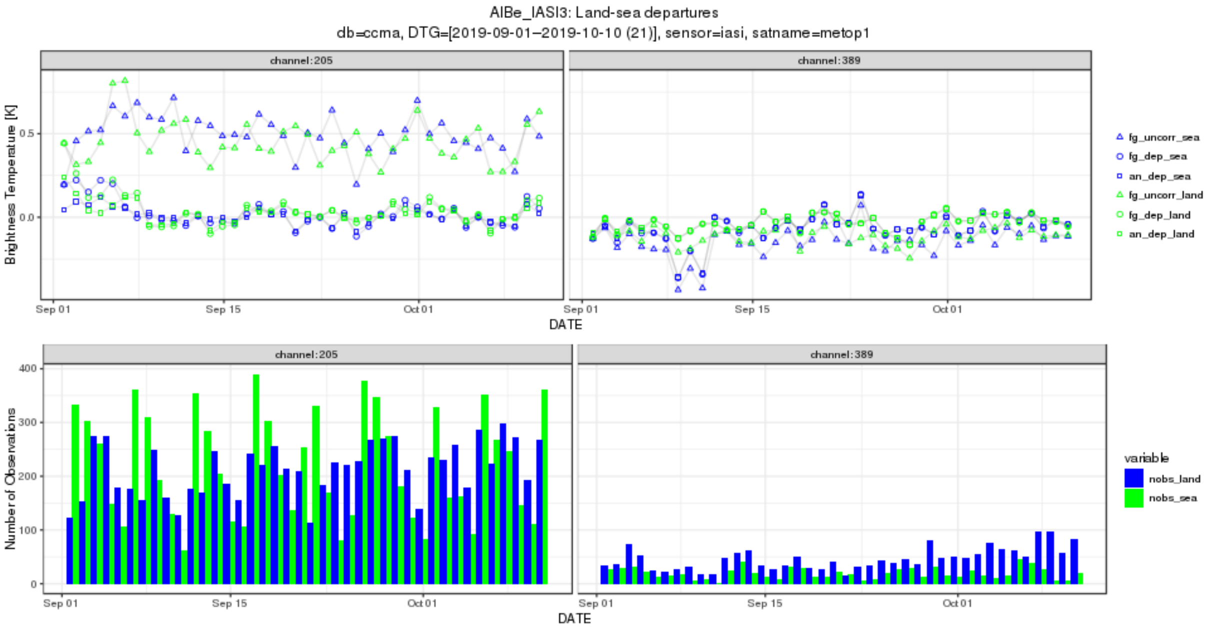

Figure 1: Time series of: top) uncorrected and corrected first-guess departures (fg_uncorr and fg_dep), and analysis departures (an_dep), and bottom) number of assimilated observations for channel 205 (left), and channel 389 (right) over land (in green) and sea (in blue) at 21 UTC.

3 IASI active data assimilation experiment: impact on the forecast

Once the bias for clear-sky IASI radiances is being corrected properly because bias coefficients are tuned, the next step is to assimilate these observations in active mode, and to evaluate their impact on the forecast. Two parallel experiments have been run, one without IASI radiances (which is used as control), and another one assimilating actively IASI radiances in long wave CO2 and water vapour bands. This procedure is applied over the Iberian Peninsula domain (AIB vs AIBe), and Canary Islands domain (AIC vs AICe) over a long study period. For the first domain, forecast verification is split in two consecutive periods (from 10th June to 31st August 2020, and from 1st to 30th September 2020), and for the second domain forecast verification is performed over one single period (from 10th June to 9th September 2020). The forecast lead time is 24 hours for analysis time at 00, 06, 12 and 18 UTC; and 3 hours for analysis time at 03, 09, 15, and 21 UTC.

It should be mentioned that previously the impact of the assimilation of only CO2 band radiances had been evaluated in a different shorter period. The best scores obtained when the radiances of the two bands were assimilated decided the final configuration of the experiments presented here.

The impact of the assimilation of IASI data has been assessed through the forecast objective verification of the parallel experiments against SYNOP and TEMP observations, and for both domains.

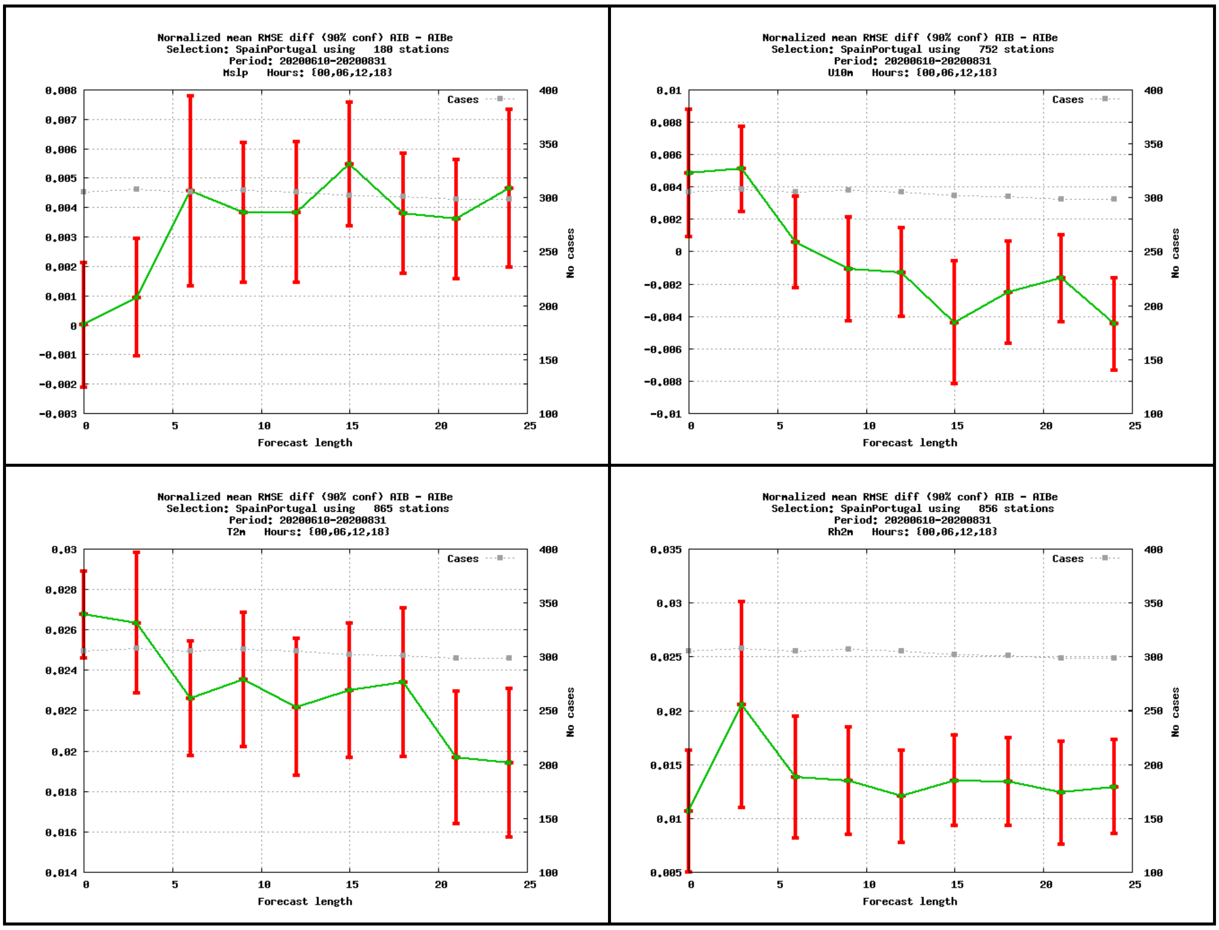

Figure 2: Normalized mean Root Mean Square Error (RMSE) difference between AIB and AIBe for mean seal level pressure (top-left), 10-meter wind (top-right), 2-meter temperature (bottom-left), and 2-meter relative humidity (bottom-right).

AIB-AIBe: 10th June to 31st August 2020

The impact of the active assimilation of clear-sky ASI radiances on surface parameters is shown in Figure 2, where normalized mean Root Mean Square Error (RMSE) differences between AIB and AIBe are calculated for different forecast lengths (positive/negative values correspond to larger/lower RMSE for AIB respect to AIBe). For mean sea level pressure (top-left), and 2-meter temperature and relative humidity the impact found is positive, and it is statistically significant for most of the forecast lengths (bottom panels). For 10-meter wind (top-right), the impact found is positive only for short forecast lengths (H+0 and H+3, statistically significant), but negative thereafter.

At upper-air, vertical profiles of temperature and wind speed verification scores do not reveal any impact on forecast during this summer period, but for relative humidity a slight positive impact can be underlined (Figure 3).

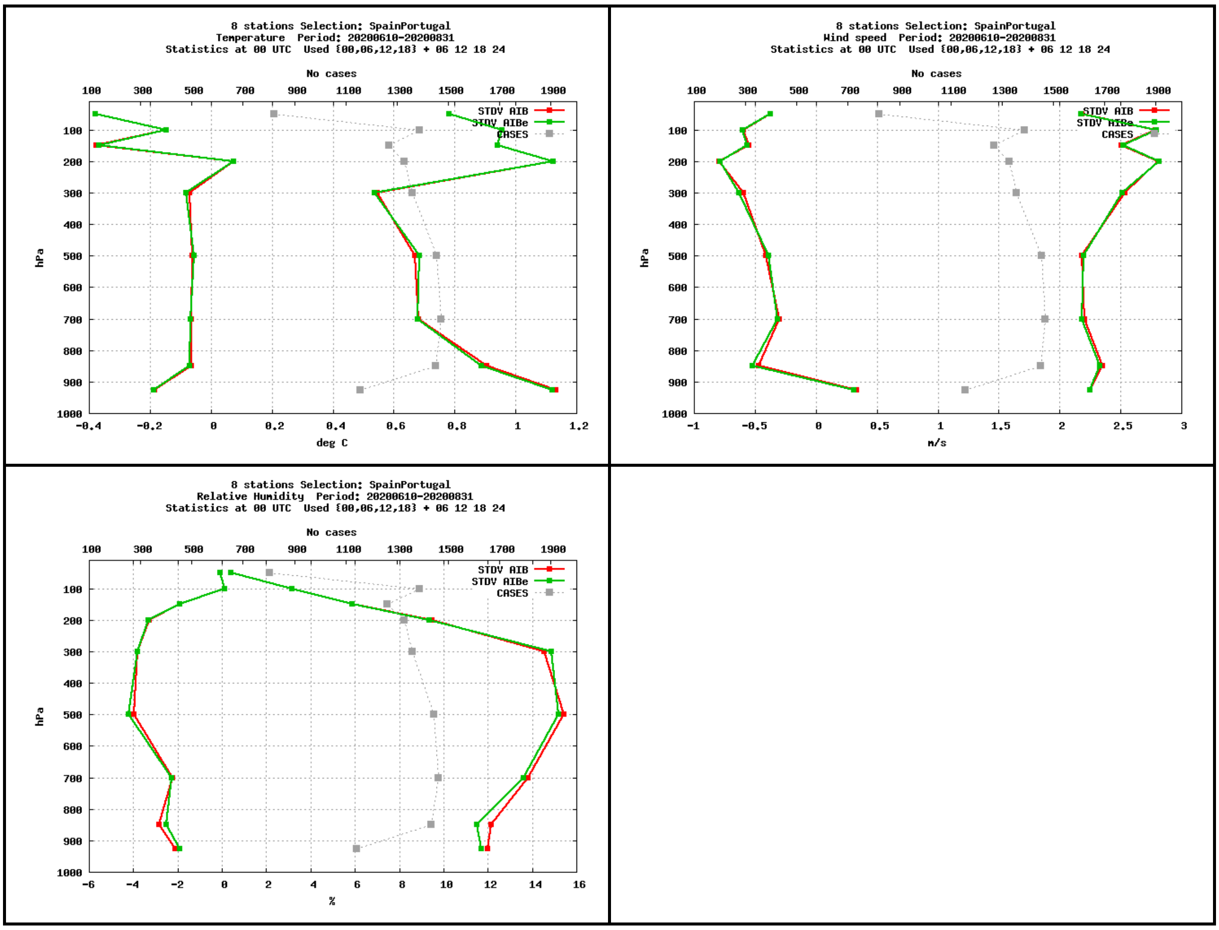

Figure 3: Vertical profiles of standard deviation and mean error for temperature (top-left), wind speed (top-right), and relative humidity (bottom-left) for AIB (in red) and AIBe (in green) at 00 UTC.

The skill of precipitation forecasts is very similar for AIB and AIBe, except for high precipitation amounts (> 60 mm in 6 and 12 h) where the active assimilation of IASI observations improves the forecast (not shown). Similar results are obtained in this period for False Alarm Ratio and Probability of Detection (not shown).

AIBe-AIB: 1st to 30th September 2020

Forecasts objective verification has been carried out for this month separately because it is representative of rainy conditions over Spain. For this period, the impact of IASI data assimilation has shown to be slightly positive for mean sea level pressure, statistically significant for some forecast lengths (not shown). On the contrary, for 10-meter wind the overall impact is negative (statistically significant), but it seems related to light winds, which are dominant, while for strong winds the impact is positive (not shown). For 2-meter temperature and relative humidity the impact is either positive or negative depending on the forecast length (not shown).

The assimilation of IASI data slightly improves precipitation forecasts. As an example, in Figure 4, the forecast skill (measured by the Equitable Skill Score) and the probability of detection for 6h accumulated precipitation are presented. The improvements are obtained at almost all the accumulated precipitation amount intervals.

Along this period the impact of IASI data assimilation is found to be neutral for all the upper air parameters (not shown).

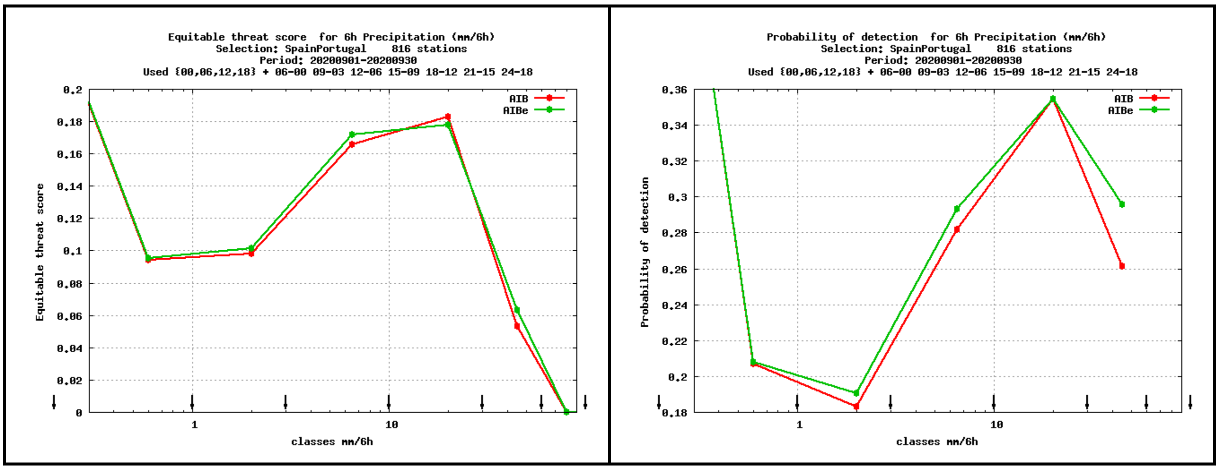

Figure 4: Equitable Threat Scores (left) and Probability of detection (right) of 6h accumulated precipitation for AIB (in red) and AIBe (in green).

AIC-AICe: 10th June to 9th September 2020

The impact of IASI data assimilation in the Canary Islands forecasts is very similar to that obtained for the Iberian Peninsula domain. That is, IASI data assimilation slightly improves mean sea level pressure, 2-meter temperature and relative humidity forecasts, but impact is found to be negative on 10-meter wind (statistically significant for almost all forecast times; Figure 5). Verification scores for vertical profiles of meteorological parameters indicate no impact neither at temperature nor at relative humidity, but a small improvement is observed for low-level wind speed (not shown).

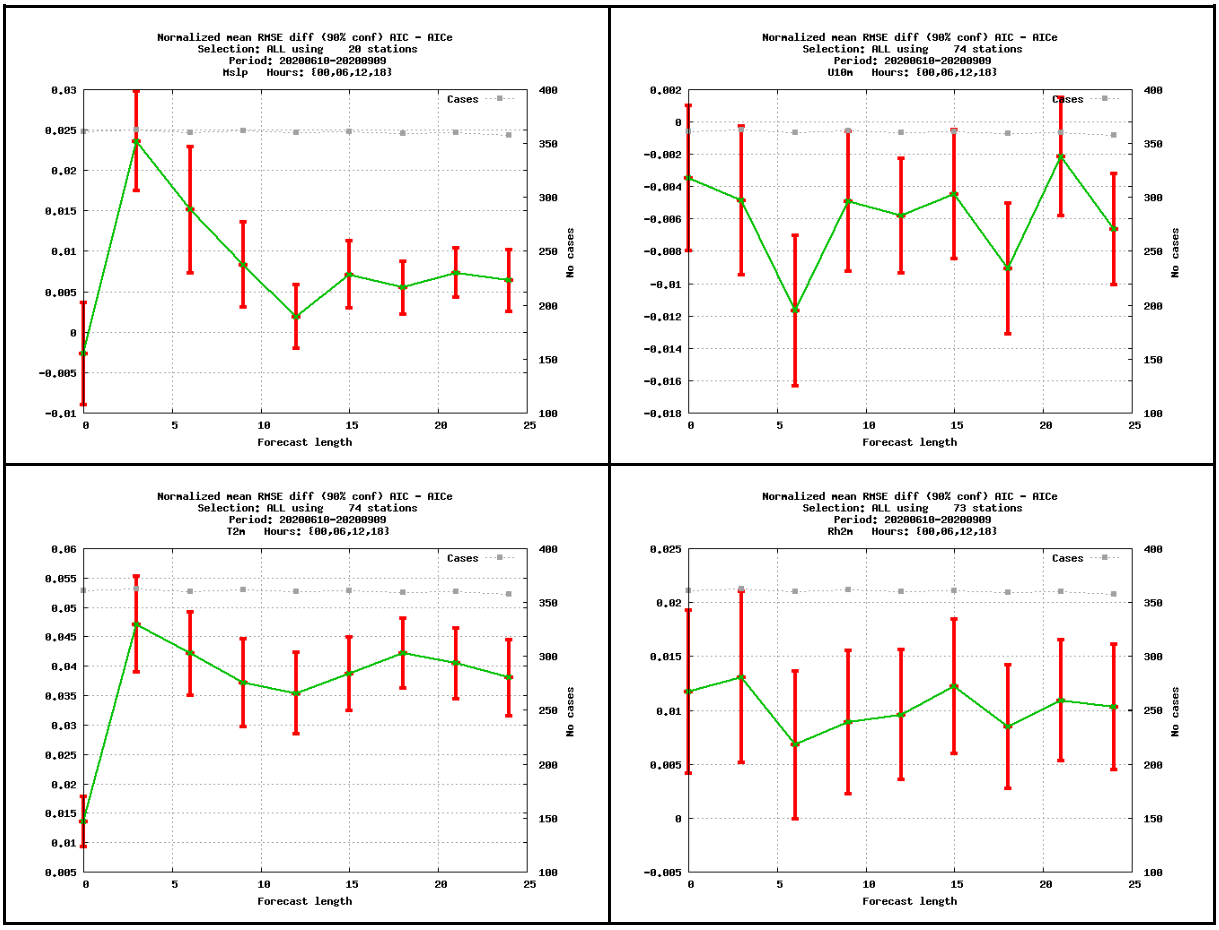

Figure 5: As Figure 1 for AIC and AICe.

4 Conclusions and outlook

We shortly presented the implementation of clear-sky IASI radiances from Metop-B into the AEMET HARMONIE-AROME system. Firstly, we passively assimilated a pre-selected set of channels to spin-up and update bias coefficients included in VarBC files. Then, the quality of bias correction over these channels was investigated, and a few channels (most of them low-peaking) were discarded. Radiances from the final selection of channels were actively assimilated during a long period, and we have assessed their impact on forecasts. These two steps were done over the two domains used in the actual AEMET set-up.

Overall, the assimilation of IASI radiances from long-wave CO2 and water vapour bands channels has a neutral or slight positive impact on forecasts for both domains. In more detail, for surface parameters, there is an improvement on mean sea level pressure, and 2-meter temperature and relative humidity, but the impact is negative on 10-meter wind. Vertical profiles of verification scores for upper air parameters do not show any impact, except a slight positive one for relative humidity at the Iberian Peninsula domain, and for low-level wind at the Canary Islands domain. Finally, it is observed that precipitation forecasts are slightly improved over the Iberian Peninsula domain (the Canary Islands domain was not evaluated due to the small number of cases).

Accordingly, the assimilation of IASI observations became operational in AEMET on 15th December 2020.

AEMET is currently implementing the cycle43 of HARMONIE system. This new run is being prepared to additionally assimilate METOP-C ATOVS radiances, METOP-B IASI and Doppler radar radial wind data. It is also foreseen to run this new cycle over a single geographical domain covering the current AIB and AIC geographical areas.

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