Assimilation of clear-sky SEVIRI radiances in AEMET HARMONIE-AROME model

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1 Introduction

Radiance data from geostationary satellites have been assimilated in global numerical weather prediction models since a long time (Köpken et al., 2003; Szyndel et al., 2004). Their high spatial and temporal coverage are particularly beneficial on global scales and in regions with a lack of ground-based measurements. As an example, the assimilation of radiance data from Meteosat-8 and Meteosat-11 continues to be of value to the ECMWF system (Burrows, 2020). Similarly, limited area models can benefit from these radiances. In fact, some operational centres assimilate radiance data from geostationary satellites in their convective-scale numerical weather prediction models (Gustafsson et al. 2018).

The present contribution describes the implementation and evaluation of the radiances assimilation of two water vapour channels (WV6.2 and WV7.3) and an infrared channel (IR13.4) of SEVIRI instrument, in the AEMET HARMONIE-AROME system. The impact of using clear-sky radiances from the geostationary satellite Meteosat-11 has been assessed separately through different parallel experiments covering two geographical domains (Iberian Peninsula and Canary Islands) over two study periods.

The main features of the data processing are described. Special care has been devoted to bias correction, in particular to the number of variational bias correction predictors. After the control and experimental suites are presented, the impact studies carried out are introduced and some aspects of the analysis performance are shown. An objective verification of all the experiments has allowed to assess the impact on forecasts, with emphasis on the shorter lead times to better understand the influence of the assimilation of these SEVIRI channels.

2 Experimental framework

Control suite

The setup of the AEMET HARMONIE_AROME suite is based on cycle 43h.2.1.1 on the local HPC. The model runs at 2.5 km horizontal resolution and 65 vertical model levels extending up to 10 hPa, and over two domains: one centred on the Iberian Peninsula that includes the Balearic Islands (called AIB), and other centred on the Canary Islands (called AIC).

The upper-air assimilation uses a 3DVar scheme with a 3-hr cycle using 70 minutes cut-off time for the observations. Many types of observations are assimilated, including conventional measurements (radiosonde, aircraft, buoy, ship, and synop, 2-meter temperature and relative humidity), Global Navigation Satellite System (GNSS) Zenith Total Delay (ZTD) data, weather radar reflectivity information, as well as scatterometer data and passive microwave and infrared (IR) clear-sky radiances from various satellite platforms. Scatterometer data are provided by Metop-B and C satellites. Passive microwave radiances are provided by the Advanced TIROS Operational Vertical Sounder (ATOVS) from AMSU-A and MHS instruments on board of NOAA-18 and 19, and Metop-B and C satellites.

And finally, the IR radiances are sensed by the Infrared Atmospheric Sounding Interferometer (IASI) placed on board the Metop-B satellite.

For the surface analysis, CANARI optimal interpolation with conventional observations (snow depth, 2-meter temperature and relative humidity) is used. The large scale from the host model is included in the analysis through a scale selection method (LSMIX) for temperature and wind, but not for humidity.

As lateral boundary conditions, Global forecasts provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) are used. These forecasts are launched every 6 h with a 1 h output frequency.

SEVIRI radiances: Instrument, channels, and pre-processing

The Spinning Enhanced Visible and InfraRed Imager (SEVIRI) is the Meteosat Second Generation primary instrument. It has twelve spectral channels, eight of them take measurements in the infrared band of the spectra, the rest for the visible channels (one of them in high resolution). The horizontal resolution is 3 km, except for the high resolution visible channel that is 1 km. Time resolution is one image every 15 minutes.

Table 1: Infra-red SEVIRI channels and their main characteristics.

SEVIRI Channels	Main characteristics
IR 3.9	It is used at night to detect fog and very low clouds Window channel of CO_2
WV 6.2	Water Vapour Channels
WV 7.3	
IR 8.7	Window channel of H_20
IR 9.7	Ozone absorption channel. Not suitable to data assimilation
IR 10.8	Window channel of H_20
IR 12.0	
IR 13.4	CO_2 absorption band

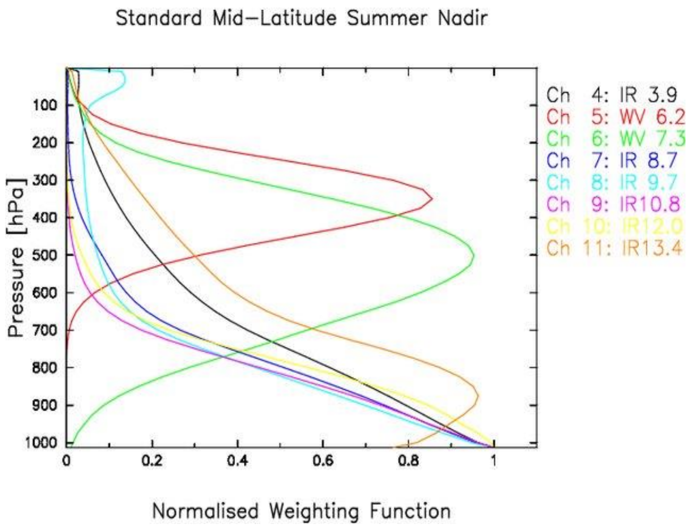

Figure 1: Normalised Weighting Function of SEVIRI Infrared channels. Source EUMETSAT.

The Figure 1 shows the normalised Weighting Function for the Infrared channels for SEVIRI. According that, Channels IR3.9 and IR9.7 are not suitable for data assimilation purposes, IR3.9 has a contribution of solar radiation during the day time and IR 9.7 gives information of stratospheric ozone. Channels IR8.7, IR10.8, IR12.0 are low–peak channels and have a strong influence of surface, so even in some meteorological services are assimilated them over sea (Montmerle et al, 2007 and Kelly 2008) we decided not using for the time being. The WV channels give information about humidity at high and mid-levels and the sensitivity of surface is minimum, so they are the most valuable channels for us. Also IR13.4 even it has a strong relation with surface, the maximum value of the normalised weighting function is over 850 hPa so we decided to take it into account.

The radiances assimilated must be over clear sky. The method employed to discriminate cloudy pixels from non-cloudy pixels use the Nowcasting SAF (NWCSAF) products Cloud Type (CT) and Cloud Top Temperature and Height (CTTH).

The SEVIRI pre-processing software reduces the resolution of the files, only takes one pixel out of 5, changes the format of the original files from NetCDF to GRIB and generates a single file ready to be read by HARMONIE-AROME. This single file includes the brightness temperature for all infrared channel, CT and CTTH products from NWCSAF.

The observations used in this study are taken in the SEVIRI instrument on board of Meteosat-11 (MSG-4), located on the longitude 0º over the Ecuador.

Bias correction of SEVIRI radiances

Background departures for radiance observations present biases that can be due to systematic errors in the satellite instrument itself, deficiencies in the radiative transfer model, or bias in the first guess. In HARMONIE-AROME, bias correction for radiances is carried out using the Variational Bias Correction scheme (VarBC), which is a particular adaptive scheme that is embedded inside the assimilation system. Bias is estimated by means of a multivariate linear regression implemented into the assimilation cycle (Auligné et al., 2007). While the number of bias predictors is fixed, the bias coefficients are updated in each assimilation cycle. In the reference system, a set of 5 predictors (p0, p1, p2, p3 and p4) are used for SEVIRI WV channels, where p0 = 1 to allow a constant component for the bias, p1 and p2 depend on the atmospheric state at the observed location (that is 1000-300 hPa and 200-50 hPa thickness), p3 is the skin temperature, and p4 is the total column water at the observed location.

The convergence of the bias coefficients to a certain timescale is set by means of the stiffness parameter (NBG_MSG_HR in this case), which depends on the number of assimilated observations and the cycling strategy. In the reference system NBG_MSG_HR is set to 5000, but in our initial tests, as the mean number of assimilated observations is large, NBG_MSG_HR was reduced to 2000. For radiances, the cycling strategy is set to 24 hours.

The VarBC method itself cannot distinguish the origin of the bias, and so, it can convert any model error into an observational bias. As the analysis process uses redundant information given by other observing systems to decide what is the most probable error source, the use of not biased observations like TEMP and AMDAR reports (called 'anchoring data') acts as a constraint on the assessment of the control variable and, in particular, of the VarBC bias predictors. In those cycles where there are not anchoring observations (or only a few), bias correction can be affected by the presence of model errors. Moreover, taking into account that some bias predictors are related to the model temperature and that this variable is biased (especially at low levels), the use of 5 bias predictors can be questioned. For this reason, the reference set of 5 bias predictors was compared with the simplest approach consisting in only 1 bias predictor (a constant bias-offset).

Experimental design

To evaluate the impact of SEVIRI radiances in the AEMET HARMONIE-AROME limited-area NWP system a set of parallel data assimilation and forecast experiments were designed. The aim was both to find the best set of predictors in VarBC when only the two WV channels were assimilated and to study the impact of assimilating together the two water vapour channels and the IR13.4 channel. Different experiments were run for AIB and AIC domains. In all suites, SEVIRI observations were only assimilated over the sea. In the first tests, radiances over land were also assimilated for WV channels, but despite the major contribution of these channels comes from mid and upper troposphere, the bias correction was negatively affected and the impact on the forecast was clearly detrimental. For this reason, we decided in both areas to use only radiances over sea.

- Testing the set of predictors for VarBC

The following experiments were run:

CONTROL: Data assimilation settings as the reference system and observation usage as described previously. The SEVIRI WV channels were passively assimilated.

SEV_WV_5p: Like in CONTROL. In addition to the observations assimilated in CONTROL, radiances of SEVIRI WV-channels were also actively assimilated. As in the reference system, a set of 5 predictors were used. This experiment started with initial state and VarBC predictor coefficients from CONTROL.

SEV_WV_1p: Like in CONTROL. In addition to the observations assimilated in CONTROL, radiances of SEVIRI WV-channels were also actively assimilated. Only one VarBC predictor used (predictor 0, i.e. constant). This experiment started from cold-start with passive assimilation during a month. Later, WV channels were assimilated in active mode.

The set of parallel experiments was performed for a summer period, during a month. To allow for minor adjustments to the VarBC between newly introduced and existing assimilated radiances in SEV_WV_1p and SEV_WV_ 5p, the first nine days were excluded from the verification. During the study period forecasts up to a range of 24 h were launched four times a day, at 0000, 0600, 1200 and 1800 UTC.

- Active assimilation of IR13.4 channel

The following experiments were run:

CONTROL: Data assimilation settings as the reference system and observation usage as described previously.

SEV_WV_1p: As described previously.

SEV_WV_IR_1p: Like in SEV_WV_1p. In addition to the channels assimilated in SEV_WV_1p, radiances of SEVIRI IR13.4 channel was also actively assimilated. This experiment started with both initial state and VarBC predictor coefficient from SEV_WV_1p.

This set of parallel experiments was run for the same summer period as the previous one. Additionally, a second period was also evaluated, only for CONTROL and SEV_WV_IR_1p. This second period was a wet period, which extended along one month. For this experiment, VarBC predictor coefficients were extracted from CONTROL. To adjust the VarBC predictor coefficients to the new period, all SEVIRI channels were assimilated as passive during the previous fifteen days. Then, WV6.2, WV7.3 and IR13.4 channels were actively assimilated. Again, to allow for minor adjustments the first nine days were excluded from the verification. During this period, forecasts up to a range of 24 h were launched four times a day, at 0000, 0600, 1200 and 1800 UTC.

3 Analysis performance

When SEVIRI radiances are actively assimilated, the fit of the model first guess to observations can change compared to when they are not assimilated (or they are passively assimilated). To analyse this effect, the bias and the standard deviation of brightness temperature observation minus first guess (ob-fg) values are calculated for: SEVIRI radiances, microwave radiances (AMSU-A and MHS), and infrared radiances from IASI, for different experiment runs over AIB domain.

The active assimilation of observations of SEVIRI channels seems to reduce the standard deviation of first guess departures for these channels compared with CONTROL, where observations of these channels are assimilated as passive. Table 2 shows that standard deviation of brightness temperature innovations is smaller when channels WV6.2 and WV7.3 are actively assimilated (SEV_WV_1p and SEV_WV_5p). However if IR13.4 channel is also assimilated as active (SEV_WV_IR_1p), standard deviation is practically the same as in the other experiments. In all channels and experiments the bias is close to zero, indicating in all cases the good performance of the variational bias correction.

Table 2: Bias and standard deviation (sd) of ob-fg for different SEVIRI channels for AIB and summer period. Analysis time: 00 UTC.

Channel	WV6.2		WV7.3		IR13.4	
Experiment	Bias	Sd	bias	sd	bias	sd
CONTROL	-0.05	1.15	-0.04	1.07	-0.02	0.54
SEV_WV_1p	-0.01	0.99	-0.01	0.94	-0.09	0.53
SEV_WV_5p	-0.02	0.99	0.0	0.95	-0.02	0.53
SEV_WV_IR_1p	-0.02	0.99	-0.01	0.93	-0.01	0.52

For AMSU-A radiances, bias and standard deviation of ob-fg values are almost the same for experiments which assimilate SEVIRI observations and CONTROL (not shown). This indicates that the assimilation of SEVIRI observations has no impact on background departures for AMSU-A radiances.

Table 3: Bias and standard deviation (sd) of ob-fg for different MHS channels for AIB and summer period. Analysis time: 21 UTC.

Channel	3		4		5	
Experiment	bias	sd	bias	sd	bias	sd
CONTROL	-0.44	2.10	-0.37	1.92	-0.22	1.47
SEV_WV_1p	-0.38	1.92	-0.32	1.78	-0.19	1.34
SEV_WV_5p	-0.37	1.91	-0.313	1.77	-0.19	1.34
SEV_WV_IR_1p	-0.38	1.94	-0.32	1.78	-0.19	1.33

In Table 3, the bias and standard deviation of ob-fg of three MHS channels for different experiments in summer period at 21 UTC are displayed. Negative bias and standard deviation for all three MHS channels are reduced in SEV_WV_1p, SEV_WV_5p and SEV_WV_IR_1p compared to CONTROL.

However, negligible differences are observed in bias and standard deviation between experiments SEV_WV_1p, SEV_WV_5p and SEV_WV_IR_1p.

Observation and first guess departures are also calculated for the assimilated IASI radiances. For IR-CO2 channels results are similar to those obtained for AMSU-A, i.e. the impact of assimilating SEVIRI observations is not significant (not shown). However, some differences are obtained for IR-H_2O channels (Figure 2). In this case, bias and standard deviation of ob-fg from different experiments present a positive impact for all channels when SEVIRI radiances are assimilated, the bias and standard deviation of first guess departures are reduced. In particular, for channels ranging from 6.6 to 7.6 microns (close to WV6.2 and WV7.3), the assimilation of SEVIRI radiances allow for an un-biased first-guess departures. Like MHS, no differences are obtained between SEV_WV_1p and SEV_WV_IR_1p, reflecting the small impact of SEVIRI IR13.4 channel. Besides, negligible differences are found between variational bias correction performed with 1 or with 5 predictors (not shown).

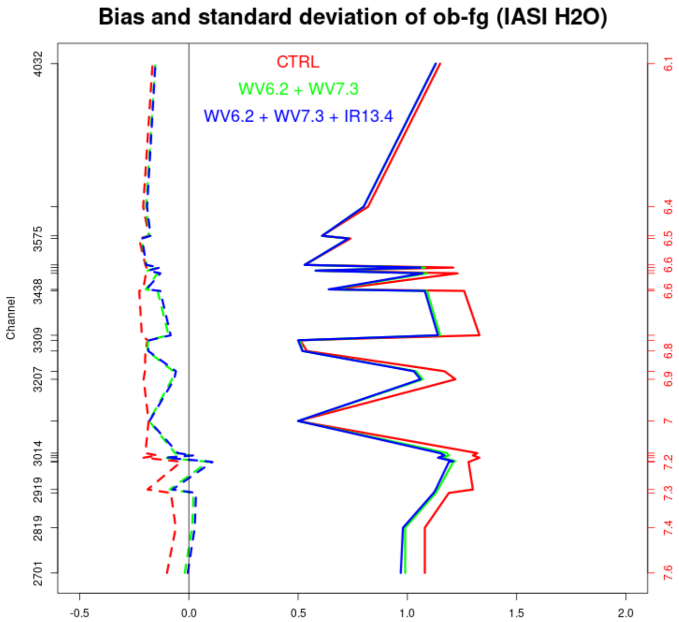

Figure 2: Vertical profile of bias (discontinued lies) and standard deviation (solid lines) of ob-fg for IASI-H_20 channels and different experiments. Analysis at 21 UTC for AIB and summer period.

DFS

The impact of observations on the analysis system can be evaluated using the degrees of freedom for signal (DFS) diagnostic. DFS is the derivative of the analysis increments in observation space with respect to the observations used in the analysis system. However, it is important to recall that DFS does not measure whether this impact is positive or negative.

Here we compare the DFS values for the experiment SEV_WV_IR_1p against CONTROL for a subset of three separated days in the wet period in AIB. All eight assimilation cycles within the three selected days are included in calculations.

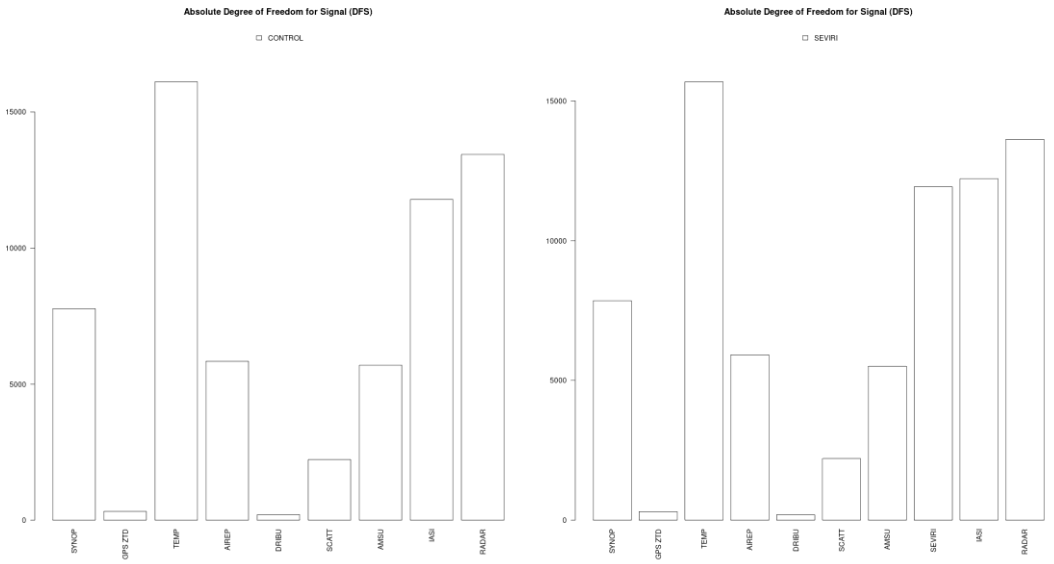

Figure 3: Absolute DFS for the experiments CONTROL (left) and SEV_WV_IR*_1p (right) subdivided for various observation types. Data for a set of cycles in the wet period in AIB.*

In Figure 3, we present the absolute DFS subdivided into various observation types for CONTROL (left panel) and for experiment SEV_WV_IR_1p (right panel). Results show very similar values for all the observation types, except for SEVIRI type in experiment SEV_WV_IR_1p. Graphics show that TEMP observations exhibit the highest impact on the analyses, but radar reflectivity and IASI radiances also influence on the analyses. For SEV_WV_IR_1p, DFS value for SEVIRI is comparable to IASI, but as the number of assimilated observations is smaller for SEVIRI than for IASI, the relative impact of SEVIRI data is larger than IASI ones (not shown). Absolute DFS value for SEVIRI data includes the contribution of WV6.2, WV7.3, and IR13.4 channels. A separated absolute DFS analysis (not shown) demonstrates that for SEVIRI type, almost all the contribution come from the WV6.2 and WV7.3 (96.7 %), and IR13.4 slightly contributes to the impact (3.3 %).

4 Observation impact on the forecasts

The impact of the SEVIRI assimilation has been assessed through the forecast objective verification of all the experiments against SYNOP and TEMP observations during two test periods and for both domains. All the experiments which assimilated SEVIRI radiances were compared with CONTROL in their corresponding study periods.

Overall, in all the experiments which assimilated SEVIRI radiances a slight positive impact was obtained. There are not noticeable differences between the scores obtained for AIB and AIC, neither between the summer and wet study periods. In more detail, for upper-level parameters, for AIB and AIC and in both study periods, the forecast impact was neutral for almost parameters and levels, except for mid-level relative humidity and wind speed where it was slightly positive (Figure 4 and Figure 5).

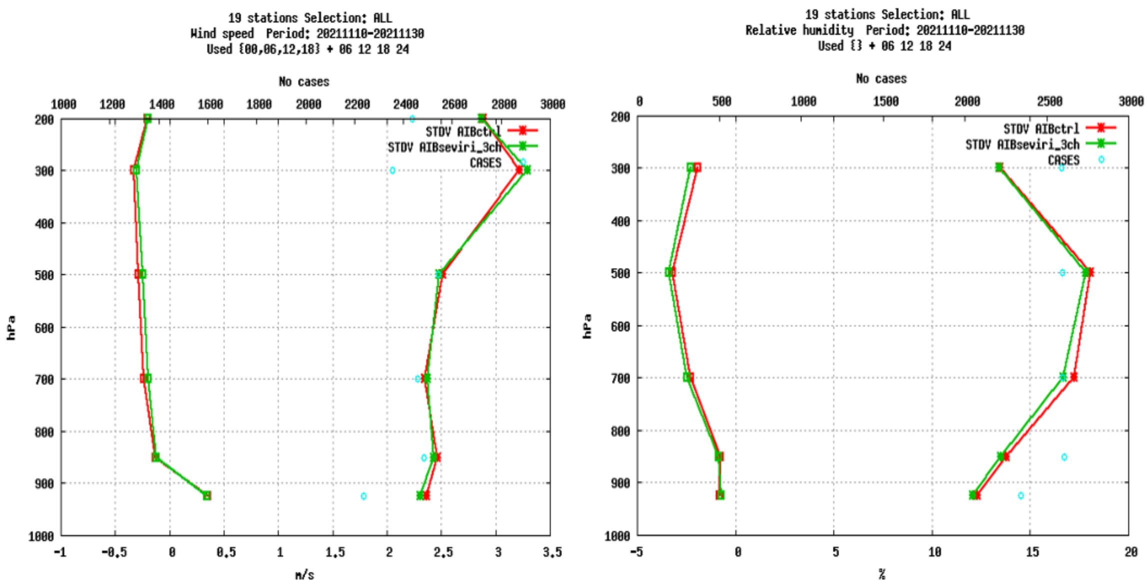

Figure 4: Bias and standard deviation of vertical profile of wind speed (left panel), and relative humidity (right panel) forecast for CONTROL (red) and SEV_WV_IR_1p (green). Scores for the AIB domain and for the wet period.

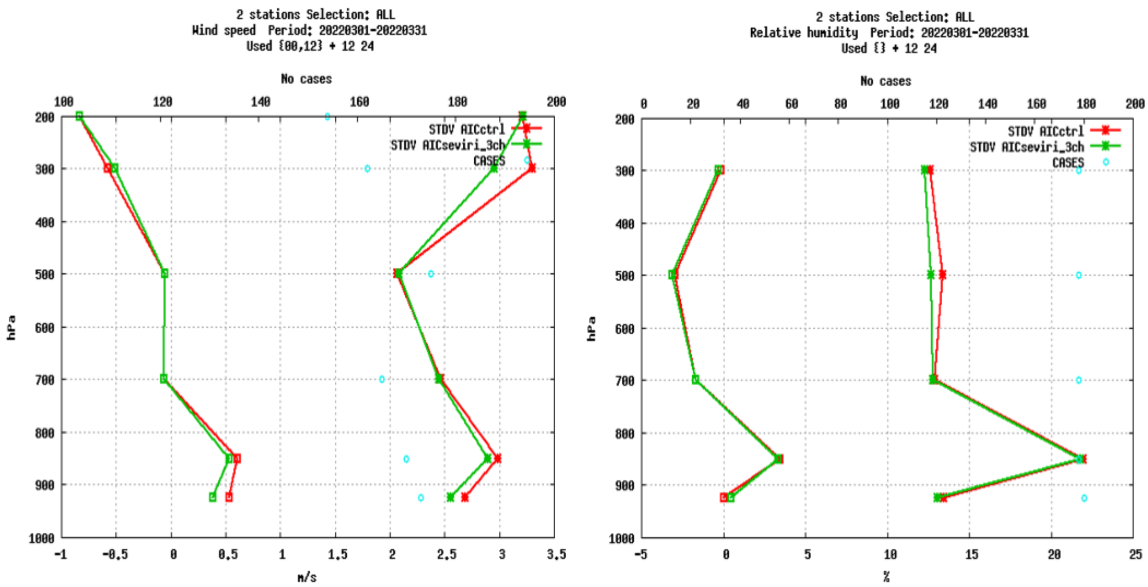

Figure 5: Bias and standard deviation of vertical profile of wind speed (left panel), and relative humidity (right panel) forecast for CONTROL (red) and SEV_WV_IR_1p (green). Scores for the AIC domain and for the wet period.

The overall impact for surface parameters was also neutral for AIB and AIC, except in AIC for the wet period, when a small reduction of the bias for mslp can be observed (not shown). For precipitation, no impact was noticed in low and moderate amounts and not conclusive results were found for larger amounts of accumulated precipitation.

5 Summary

We shortly presented the performance of assimilating a few SEVIRI channels into the AEMET HARMONIE-AROME system. First, the handling of clear-sky SEVIRI radiances was described. Radiances were pre-processed in order to reduce the size and change the format of the files using the NWCSAF products to discriminate between clear-sky and cloudy pixels. Later, the control and different parallel experiments were presented. An important issue was the set-up of the bias correction so that two particular configurations were compared: one using five VarBC predictors (the default) and the other one using only one predictor (the constant one). Besides, the approach of assimilating only the two water vapour SEVIRI channels (WV6.2 and WV7.3) or adding a third channel (IR13.4) was also evaluated. This set of parallel runs were done over the two domains used in the actual AEMET set-up.

The impact of assimilating clear-sky SEVIRI radiances was positive on the analyses and the forecasts in any all those experiments that assimilated SEVIRI radiances (compared to CONTROL). Thus, first-guess departures were reduced for other assimilated observations as for MHS channels and those IASI humidity channels. The impact on the forecast was neutral for surface and upper level parameters, except a slight positive impact on mid-level relative humidity and wind speed. Although the impact is small, it shows to be consistent for the two geographical domains over the two study periods.

When comparing the impact on the analyses and forecast of all the parallel experiments assimilating SEVIRI data, very small differences can be underlined. So, any of them could be a valid option to include in the next operational suite. However, as bias correction is an essential task in the assimilation, the simplest choice, that is one predictor (the constant offset), seems to be preferable. On whether it is better to assimilate not only the WV channels but also the IR13.4 one, again the conservative choice seems the best option. The inclusion of IR13.4 has no impact on the analyses and the forecasts, but this channel has an important contribution from the surface and low troposphere, which may not be accurately enough described by the forecast model. For these reasons, the set-up used for SEVIRI_WV_1p, based on a single VarBC predictor for SEVIRI radiances and that only assimilates data from WV6.2 and WV7.3 channels, is actually running in pre-operational mode.

6 Acknowledgements

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7 References

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