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**POTENTIAL BENEFITS OF ASSIMILATING METOP COMBINED
RETRIEVAL L2 PRODUCTS IN AROME-FRANCE**

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Abstract

EUMETSAT developed Metop level 2 products as combined retrieval from IASI and microwave sensors which are on board Metop satellites, from a piece-wise linear regression. They now are calculated at each local acquisition centre, such as Lannion (Satellite Meteorological Centre of Météo-France) in Brittany, France.

Level 1 radiances from IASI, AMSU-A and MHS are operationally assimilated in the convective-scale model AROME-France of Météo-France for almost 10 years, with a positive impact (Guidard et al., 2011) on the forecast quality. Nevertheless, recent changes in AROME-France included a lowering of the model top (to 10 hPa), which led to the rejection of numerous IASI channels that were previously assimilated in AROME-France, from 123 to 44 channels.

The present study first describes the evaluation of these Metop level 2 products in terms of temperature and humidity compared to AROME-France short-range forecasts. Then, the first assimilation experiments of the Level 2 products in AROME-France in replacement of level 1 radiances are evaluated using objective scores on observation assimilation and forecast scores.

INTRODUCTION

The satellite data have been one of the main sources of observations used in the Numerical Weather Prediction (NWP) models, these data have been used in the NWP together with other observations such as radiosondes, synop data, radar and others. In the last decades, the satellite data have been assimilated directly in the NWP models (radiance/brightness temperature), however information from these data can also be assimilated as a retrieval profile.

The Advanced Microwave Sounding Unit (AMSU)-A and B, Microwave Humidity Sounder (MHS), High Resolution Infrared Radiation Sounder (HIRS), Advanced Technology Microwave Sounder (ATMS), Atmospheric Infrared Sounder (AIRS), Cross-track Infrared Sounder (CRIS) and Infrared Atmospheric Sounding Interferometer (IASI) are the main sensors that have been used in the operational NWP systems.

IASI is a hyperspectral sensor with 8641 channels. It is capable to provide humidity and temperature profiles from the atmospheric emission spectra. These profiles are retrieved with a high accuracy and vertical resolution (EUMETSAT, 2017). IASI sensor is onboard Metop-A and B satellites. For a NWP purpose, a subset of IASI channels (Collard, 2007) are disseminated on the Global Telecommunication System (GTS), which reduces the redundancy in information and the computational cost in using all IASI channels in the NWP.

The current Applications of Research to Operations at MESoscale (AROME) version has had the top

model changed from 1 to 10 hPa (Brousseau et al., 2016). As a result, the quality of the simulation of channels having a strong contribution from the atmosphere above 10 hPa decreased. In this way, a large number of channels were removed from the assimilation process in the regional model.

The Metop combined retrieval L2 product, hereafter referred to as L2 product, is a statistical combined retrieved product. The L2 provides temperature and humidity information on the whole atmosphere, with a high vertical resolution (109 levels below 10 hPa).

AROME-France

AROME is the operational convective-scale model at Météo-France since 2008 (Seity et al., 2011). In the current AROME version, the horizontal and vertical resolutions are 1.3 km and 90 levels, ranging from 5 m to 10 hPa. Figure 1 shows the AROME orography and the domain, which contains 1440 x 1536 points on Lambert projection centered at 47.5 °N and 2 °E over France (Brousseau et al., 2016).

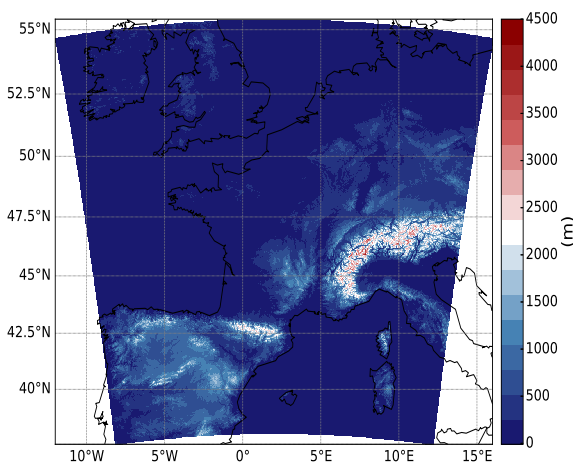


Figure 1: AROME domain and orography in shaded.

The initial conditions of the AROME model are provided by a 3D-Var assimilation scheme, which has one-hour assimilation cycle and one-hour assimilation time window (± 30 minutes). In the AROME assimilation cycle scheme the long range forecast is launched at 00, 06, 12 and 18 UTC. The forecast range at 00 and 12 UTC is 48 hours and at 06 and 18 UTC is 42 hours. The boundary conditions are given by the forecast fields from the French global model, *Action de Recherche Petite Echelle Grande Echelle* (ARPEGE).

In the system, observations from different sources are assimilated, such as radar measurements (Doppler wind and reflectivity), surface stations, buoys, ship, aircrafts, wind profilers, radiosondes and satellite observations. The satellite observations include data from infrared and microwave sensors on board geostationary and polar-orbiting satellites. The sensors operationally assimilated in AROME are AMSU-A on board Metop-A and B, NOAA-15, 18 and 19 and AQUA; AMSU-B (MHS) on board NOAA-18 and 19 and Metop-A and B, ATMS on board NPP, SSMIS (DMSP-17 and 18), GMI (GPM), IASI on board Metop-A and B, SEVIRI from Meteosat 11 and scatterometer (Metop-A and B). The GNSS data from ground-based stations are also assimilated.

Some observations are bias corrected and thinned in the AROME system due to misrepresentation of their error and information redundancy. The bias correction coefficients applied to the radiance data come from ARPEGE, except the ones applied to SEVIRI, these are calculated in AROME. The thinning applied to the IASI data is 80 km, to the AMSU-A is 100 km and to the MHS is 80 km. In AROME, the IASI channels peaking above 200 hPa and below 600 hPa over land are not assimilated. Relative humidity profiles from radiosondes are not assimilated above 300 hPa. In the ARPEGE model 129 IASI channels are assimilated, however because of the AROME top level (10 hPa) some channels are discarded, remaining 44 channels (20 temperature, 20 water vapour and 4 surface channels) over sea and 8 water

vapour channels over land (figure 2) peaking in the mid and upper troposphere. The IASI, AMSU-A and MHS, together, represent around 5% of the data assimilated in the AROME, this amount depends of the weather conditions (clear or cloudy sky)

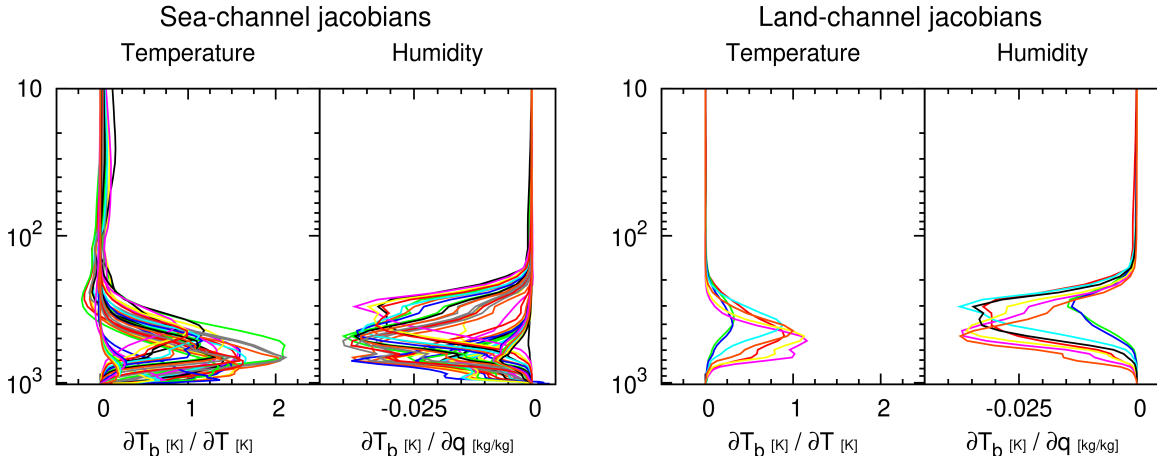


Figure 2: Jacobians of the IASI used channels over sea and over land by AROME model. Extracted from Andrey-Andrés (2017).

The experiments have been carried out with the same AROME version introduced previously, however some modifications have been applied in order to configure appropriately the system. These differences are described in detail in the experiments setups.

Metop combined retrieval L2 product

The L2 product come from a statistical retrieval, which combines retrieval products from IASI and microwave sensors (AMSU-A and MHS) on board Metop satellites. The L2 operational processor and its components were presented in EUMETSAT (2018). This product contains atmospheric profiles of pressure, temperature, water vapour mixing ratio and ozone, some surface parameters (surface temperature, surface emissivity at 10 wavenumbers, surface mean elevation in the pixel and standard deviation of surface elevation in the pixel) and information about the profile quality.

In this study, the profiles of temperature, pressure and water vapour mixing ratio, surface mean elevation in the pixel and the quality control indicator (QCI) for temperature and humidity were used for the assessment and for assimilating these data. The evaluation performed in this work includes the period from August 2017 to February 2018. Only the L2 data from locally received observations in Lannion in real time. The L2 data from Metop-A and Metop-B are available from 08 UTC to 12 UTC (AM), and from 19 UTC to 23 UTC (PM) only for Metop-B.

In the assimilation system the interest is to assimilate the best L2 products profiles available for a specific position and time. For this reason, the evaluation was made for the profiles for which the temperature quality indicator (provided by EUMETSAT with the L2 data) values were less than 2 K and the humidity QCI were less than 3 K for temperature of dew point.

The goal of this paper is to assess the potential benefit and study the practicalities of assimilating L2 temperature and humidity profiles in a regional model in replacement of IASI and AMSU radiances. To target the objectives some tasks were executed. The evaluation of the level 2 products was performed with AROME-France short-range forecasts, which are used as background state in the assimilation process. The configuration of the assimilation experiments using the Level 2 products in AROME-France in replacement of level 1 radiances were then defined. Finally the assessment of the assimilation experiments was performed by comparing Baseline, without Metop satellite sounders, with L1 and L2 assimilation experiments.

EVALUATION OF METOP COMBINED RETRIEVAL L2 PRODUCTS

The assessment was performed for all profiles with the QCI defined before. There are differences between the elevation provided with the L2 (surface mean elevation in the pixel) and the orography used in the AROME model. These differences can be greater than 500 meters. The profiles located at points where the altitude differences are large should have an atmosphere with different characteristics. In order to exclude these profiles, a filter was applied to discard profiles with an absolute difference between altitudes greater than 25 meters.

Figure 3 shows the monthly variation of mean differences and standard deviation of differences from August 2017 to February 2018 for temperature and specific humidity of L2 products over AROME domain. Mean differences for temperature have a large variation near surface, values vary between -3 and -0.5 K, and between 300 and 200 hPa, where the values vary from -0.9 to 0.4 K (figure 3 on left column). February is the most different month, for which the mean differences have a positive peak between 1000 and 900 hPa (more than 0.5 K). All months present the same behavior of the standard deviation of differences, except near surface where it is possible to notice that there is a monthly variation (1.73 to 2.6 K). The standard deviation of differences increased between 300 and 200 hPa (1 to 1.5 K), in this layer, as shown before, the mean differences also increase.

The specific humidity also presents a monthly variation (figure 3 on right column). The mean differences are negative in most cases. In December, below 950 hPa, mean difference is positive, the other months present a negative mean differences near surface (-0.9 g/kg in August to -0.04 g/kg in October). The standard deviation of differences have strong variation linked to the seasonal variation of the absolute atmospheric moisture content. In August the value is 1.9 g/kg at 975 hPa, which is larger than the one in February for the same level (0.77 g/kg), for example.

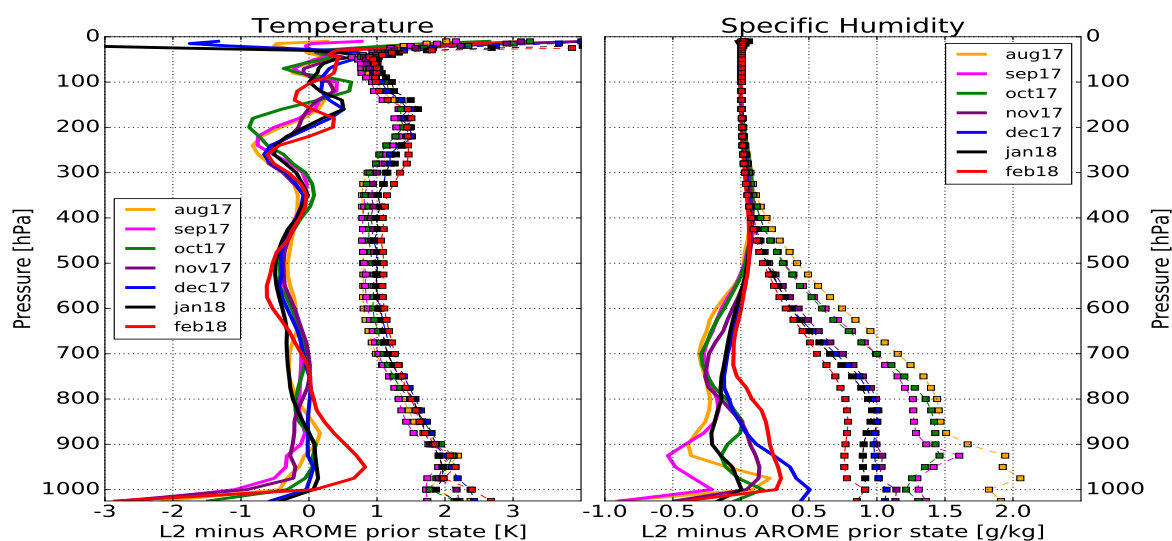


Figure 3: L2 minus AROME-F first-guess statistics for seven months. Mean differences are in solid lines, standard deviations of differences are in dashed lines with squares. Yellow: August/2017, magenta: September/2017, green: October/2017, purple: November/2017, blue: December/2017, black: January/2018 and red: February/2018. Left column for temperature, on right one for specific humidity.

Define the L2 product observation error (σ_o)

The L2 data will be assimilated as pseudo-radiosoundings in AROME and the L2 observation error (σ_o) must be determined. The radiosondes and aircraft (AIREP) data have the same σ_o for temperature (the humidity profiles from aircraft are not assimilated in the AROME). Their σ_o was used as a guide for estimating the σ_o for the L2 data. The humidity data from radiosondes above 300 hPa are not assimilated into operational AROME, but for this comparison, the whole profiles were considered. The observations (radiosondes and aircraft) first guess departure (observation minus one-hour forecast) are used to calculate the mean differences and standard deviation of differences. The data used in this evaluation is from January 2018.

The L2 data (red lines) and radiosondes (black lines) mean differences for temperature have opposite sign near the surface (figure 4 on left column), the mean difference for L2 data is -0.5 K and the one for radiosondes is 0.5 K. The three observations types are in good agreement for the mean differences amplitudes. The standard deviation of differences get closer when going up in the atmosphere (above 700 hPa), near the surface, the L2 standard deviation is greater than 2 K and for radiosondes it is 1.5 K. The figure 4 on right column shows the specific humidity mean differences, and it is possible to notice that there is an agreement between the two data over the whole atmosphere. The standard deviation are different, but above 700 hPa the lines start to get closer.

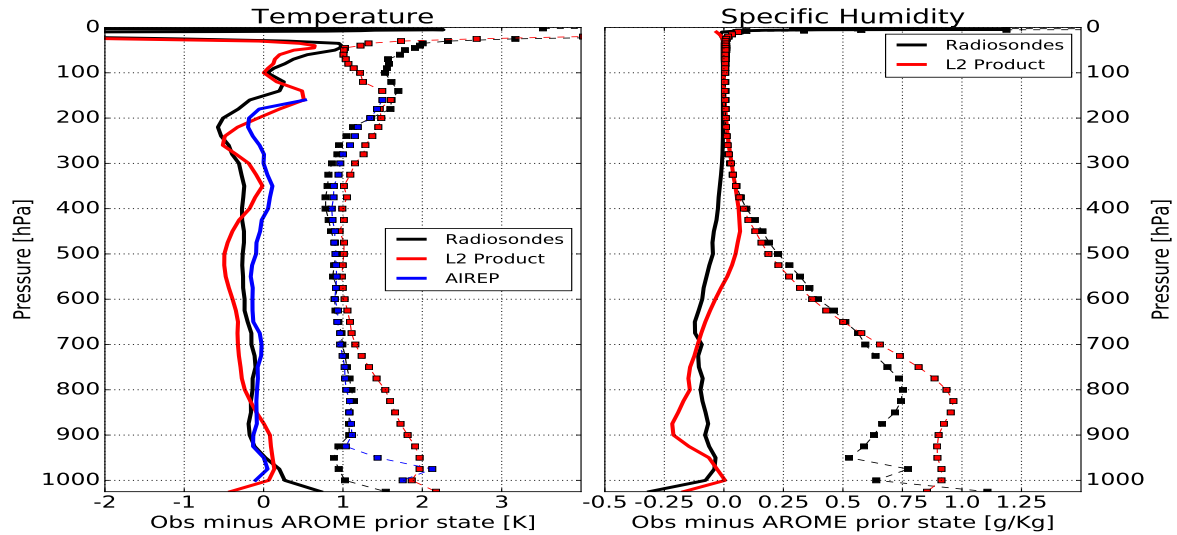


Figure 4: L2 product, radiosondes and AIREP minus AROME-F first-guess statistics for January/2018. Mean differences are in solid lines, standard deviations of differences are in dashed lines with squares. Black lines: radiosondes, red: L2 product and blue: aircraft (AIREP). There are no assimilated specific humidity profiles from aircraft data. Left column for temperature, on right one for specific humidity.

This evaluation and others (not included in this document) helped to estimate the L2 product observation error, where for the L2 temperature profiles the estimate error is 1.2 times of the radiosondes error. Specific humidity uncertainty assigned to L2 product is 15 % of the relative humidity, in comparison, 12 % relative humidity is usually specified to assimilated radiosondes measurements. Figure 5 shows the profile of the observation error for temperature, on the left, and for specific humidity.

PRELIMINARY RESULTS OF THE ASSIMILATION EXPERIMENTS

Experiment Setups

The L2 data evaluation with respect to AROME short-range forecast, aircraft (AIREP) and radiosondes helped to build the data assimilation experiment using the L2 product. The horizontal thinning applied to the L2 data was defined as 160 km (one observation per 160x160 km box is considered) and the vertical thinning was one level every three levels. This means that 36 data for temperature and humidity per profile could be assimilated. The L2 product was also evaluated separately over different surfaces (over land, sea and high altitudes). Based on this, three filters were applied in the L2 experiment to avoid some discrepancies found in this L2 data assessment (table 1).

Region	Filter
Sea	Use data only above level 1000 hPa
Land, orography below 1 km	Use data only above level 900 hPa
Land, orography above 1 km	Use data only above level 700 hPa

Table 1: Filters applied to L2 data.

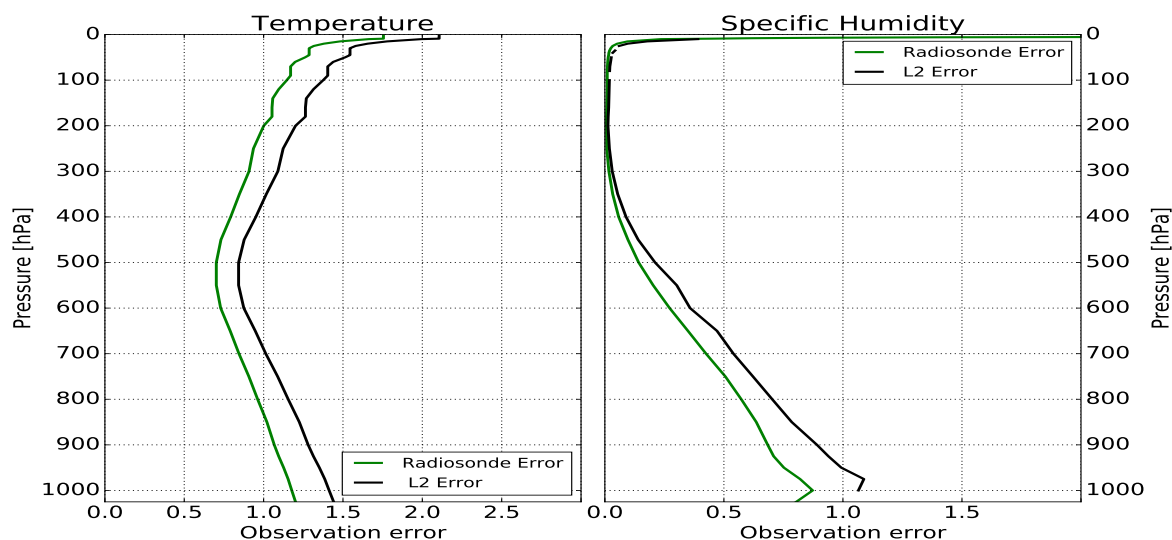


Figure 5: L2 product and radiosondes observation error. Black lines: L2 observation error, green: radiosondes observation error. Left column for temperature, on right one for specific humidity.

Table 2 presents the experiments and their configuration. The baseline experiment uses the same observations than the operational AROME-France, except for the IASI, AMSU-A and MHS data, which were removed. The control experiment assimilates the data used in baseline experiment and L1 radiances from IASI data from Lannion, AMSU-A and MHS data from EUMETSAT. The L2 experiment makes use of the observations present in the baseline experiment together with the L2 product. The three experiments were performed during 35 days (January, 1st to February, 04th 2018).

Experiment	Configuration
Baseline	No IASI, AMSU-A and MHS data
Control	Baseline + IASI from Lannion (only), AMSU-A and MHS data from EUMETSAT.
L2 Experiment	Baseline + L2 product from Lannion

Table 2: Experiments configuration and period.

Impact of the Metop combined retrieval L2 products use on observation statistics

The first evaluation was the impact of assimilated the L2 data on other observation types assimilation statistics. Figure 6 shows the vertical profiles of mean first guess (solid lines) and analysis (dashed lines) departure from temperature (aircraft observations) and specific humidity (radiosondes observations). In the L2 experiment (blue lines) the first guess departure is reduced in the lower troposphere for both observation types. This reduction is also present in the analysis departure from the aircraft temperature (figure 6 on left column). However, the standard deviation profiles do not present differences (not shown).

Forecast verification

The quality of forecast generated in the L2 experiment was assessed using the vertical profile of the bias and Root-Mean-Square Error (RMSE) of the temperature (figure 7) and relative humidity (figure 8) 24 hour forecast. These metrics were calculated using an independent analysis, e.g., the European Centre for Medium-Range Weather Forecasts (ECMWF) analyses.

Figure 7 on left column shows the evaluation of the control experiment (black lines) against the baseline experiment (red lines). In the figure there is no differences between the two curves. The comparison between the bias and RMSE of L2 (blue lines) and baseline (red lines) experiments does not show large differences (figure 7 on right column). However, there are red (levels with a degradation) and green (levels with an improvement) dots in the RMSE profiles, which means that, at these levels, the differences between the two experiments are statistically significant with 95 % of confidence (according a t-student

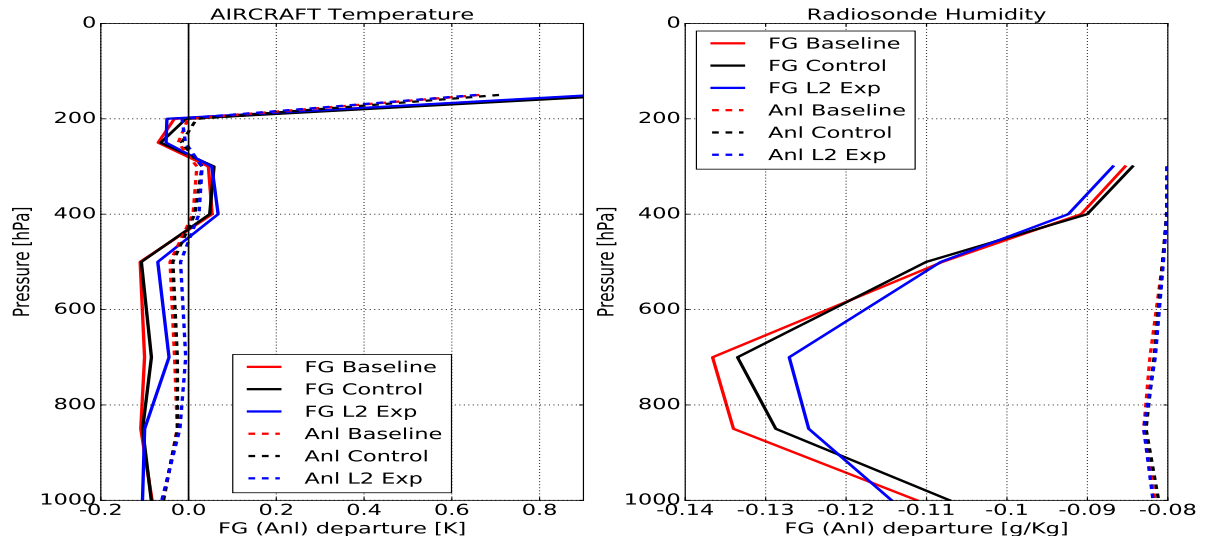


Figure 6: Vertical profile of the first guess (solid lines) and analysis (dashed lines) departure. The red lines are the baseline experiment, the black the control and the blue ones is the L2 experiment. Figure on left column is the temperature profile from aircraft (AIREP) observations and on right column is the specific humidity profile from the radiosondes. These profiles are the mean values of the period between January, 1st 2018 to February, 4th 2018.

test).

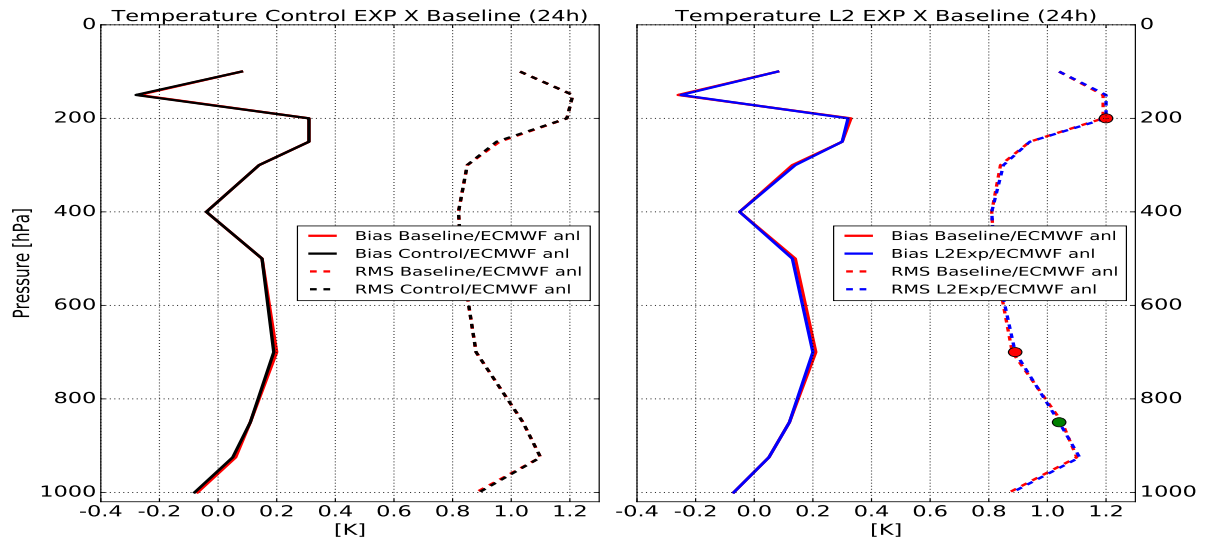


Figure 7: Vertical profiles of RMSE (dashed lines) and bias (solid lines) from scores for temperature 24 hour forecast. Left figure is the control (black lines) versus baseline experiment and the right one is L2 experiment (blue lines) against baseline (red lines). The dots represent that the differences between the experiments are statistically significant with 95 % level of confidence (t-student test), red dots represent that reference (baseline experiment) is better than the experiment and the green dots mean the opposite, e.g., the experiment is better than the reference. ECMWF analyses was the independent analysis used. The period evaluated was 35 days starting on January, 1st 2018. Left column for control against baseline, on right one for L2 experiment against baseline.

The verification of the relative humidity 24 hour forecast shows an improvement in the RMSE of the control experiment when compared with the baseline, this is represented by the green dots at 250 and 700 hPa in the figure 8 on left column. The L2 experiment presents a degradation (red dots at 250, 300 and 1000 hPa). Both comparisons, control versus baseline and L2 experiment versus baseline, do not present large differences between the two experiments. This means that the experiments have a similar RMSE and bias when evaluated using the ECMWF analysis.

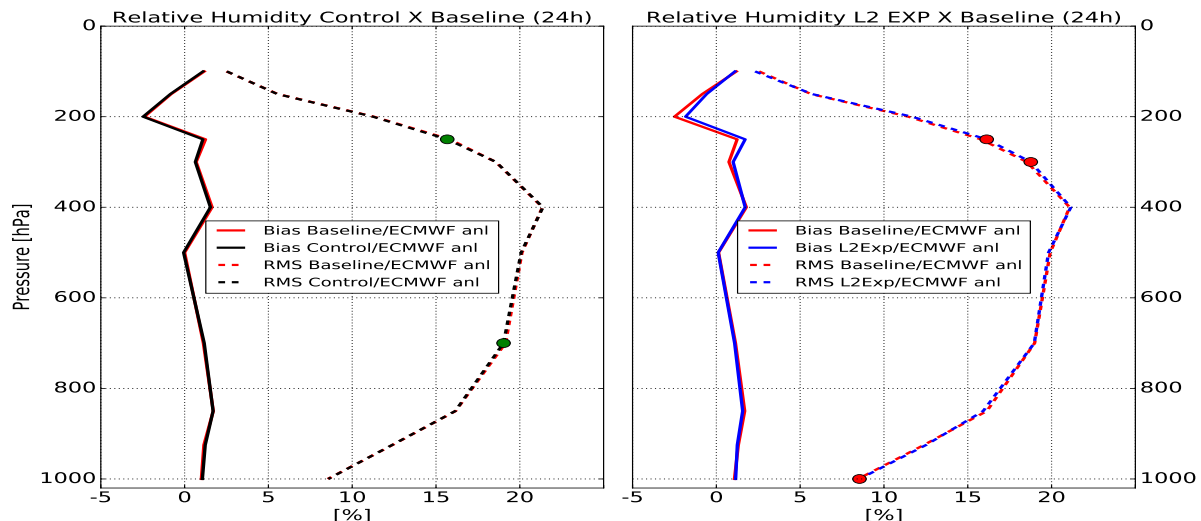


Figure 8: As in figure 7, but for relative humidity.

CONCLUSION

This study evaluated the potential benefits of assimilating Metop combined retrieval L2 products in the mesoscale AROME-France model. The results showed that the L2 products are suitable for assimilation in NWP models. The L2 experiment helped to decrease the first guess and analysis departures from aircraft temperature and radiosondes humidity. The L2 experiment also has scores comparable with the control (L1 product) experiment.

The next steps of the present study are to perform the experiments over other periods of the year and to adapt further the experiment settings to optimise the L2 impact (vertical thinning, observation errors, etc).

ACKNOWLEDGEMENTS

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