

# Improved assimilation of IASI land surface temperature data over continents in the convective scale AROME France model

Niama Boukachaba, Vincent Guidard, Nadia Fourrié

CNRM-GAME, Météo-France and CNRS, 42 Avenue Gaspard Coriolis, 31057 Toulouse Cedex, France

niama.boukachaba@meteo.fr

## Abstract

The current high-spectral resolution advanced infrared sounder generation includes in particular IASI (Infrared Atmospheric Sounding Interferometer, developed by CNES / EUMETSAT) onboard polar orbiting MetOp satellites. These sounders provide a large amount of information allowing to describe accurately surface parameters (such as land surface temperature 'LST' and surface emissivity on a wide range of wavelengths). However, the forecast of continental surface temperature is not realistic enough to use the infrared information in the lower troposphere and close to the surface over continents because radiances sensitive to this region are strongly affected by the variation of surface parameters (e.g. LST, surface emissivity and humidity) and cloud cover. The aim of this work was to study the impact of retrieved LST from IASI channel on the assimilation in the convective-scale AROME model in clear sky conditions following the work by [Guedj et al. \[2011\]](#) and [Vincensini et al. \[2013\]](#). For that, LST was extracted from radiances using radiative transfer equation inversion [[Karbou et al., 2006](#)] and RTTOV model. Then, retrieved LST from IASI was compared with retrieved LST from SEVIRI (Spinning Enhanced Visible and Infrared Image) channels using various channels. These comparisons in AROME model enable us to study the complementarity between polar and geostationary satellite. The IASI channel 1191 was selected for LST retrievals. The retrieved LST from this channel was then used in RTTOV model to improve the simulation of IASI surface-sensitive infrared observations in the AROME-France assimilation system.

## 1. Introduction

LST plays an important role in surface-atmosphere exchange [[Niclòs et al., 2009](#)]. It is one of the key surface parameters which indicates the energy balance at the Earth's surface and is particularly relevant for domains such as agriculture, climatology, hydrology and weather forecasts [[Kerr et al., 2004](#)]. An essential component of the numerical weather forecast is the analysis of the atmosphere state, a necessary step for the definition of the initial conditions of forecasts. This analysis uses in-situ data as well as satellite observations. The convective scale weather numerical prediction AROME model of Météo-France (Figure 1) benefits from an assimilation system based on short cycles of three-dimensional variational assimilation (3D-Var) [[Seity et al., 2011](#)]. Météo-France now uses in operations a new configuration of AROME model with 1.3 km horizontal resolution and 90 vertical levels where the top level is around 10 hPa. For the assimilation, AROME model uses hourly 3DVar data assimilation with long-range 36 h forecasts every 3h.

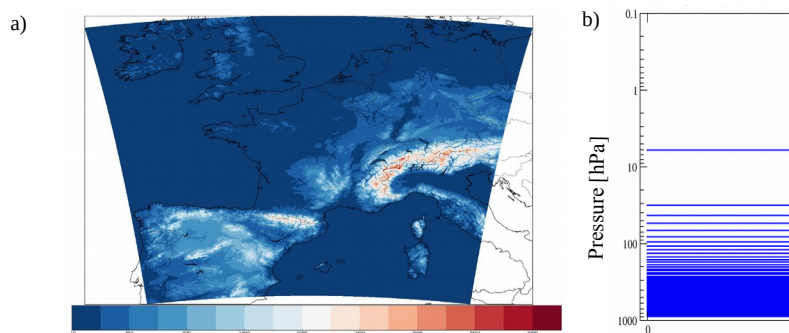


Figure 1: The geographical domain (a) and vertical levels (b) of AROME model (colours indicate orography in the model).

The assimilation of IASI in the AROME model is already well developed as it benefits from the assimilation of IASI in the global ARPEGE model [Guidard et al., 2011]. More research is still needed to allow an increase of its use. By pursuing the approach developed by Vincensini [2013] to find the LST from a combination of IASI channels, a new selection of channels over land was built, to better analyse the lower layers of the atmosphere, in particular in term of temperature. This work shows the results of the best surface-sensitive IASI channel selection for LST retrieval and the impact of this retrieved LST on the assimilation in AROME model. For that, we first compared LST from IASI MetOp A & MetOp B. Then, we compared background (which is a short-range forecast of AROME model) LST with retrieved IASI channels LST. We also performed inter-channels IASI LST comparisons. After that, we compared IASI LST vs SEVIRI LST. Finally, we studied the impact of LST retrieved from IASI channel selected on the IASI simulation and on the other assimilated observations.

## 2. LST retrievals from IASI

### 2.1. Methodology for LST retrieval

IASI is an IR hyperspectral sensor onboard polar orbiting satellites MetOp A and MetOp B. It contains 8461 channels operating between 645 and 2760  $\text{cm}^{-1}$  but less than 200 channels are assimilated in NWP centres. The spatial resolution of IASI is 12 km at nadir. SEVIRI sensor is onboard Meteosat Second Generation geostationary satellites. It contains 12 channels measuring between 0.6 and 12  $\mu\text{m}$ , with 4 km spatial resolution over Europe. To retrieve LST, we should have the best surface-sensitive channel. For that, we chose five surface IASI channels and three SEVIRI channels. The five IASI channels selected for retrieving LST are: 1027 (901.5  $\text{cm}^{-1}$ ), 1191 (942.5  $\text{cm}^{-1}$ ), 1194 (943.25  $\text{cm}^{-1}$ ), 1271 (962.5  $\text{cm}^{-1}$ ) and 1884 (1115.75  $\text{cm}^{-1}$ ). For SEVIRI, we selected: channel 1 [IR3.9 (2564.10  $\text{cm}^{-1}$ )], channel 4 [IR8.7 (1149.43  $\text{cm}^{-1}$ )] and channel 7 [IR12.0 (833.33  $\text{cm}^{-1}$ )]. All these channels are sensitive to surface and clouds.

The same approach used in the Guedj et al 2011 study was chosen for the computation of LST using radiative transfer equation inversion (Equation (1)):

$$LST = L \left[ \frac{R_v(\theta) - L_v^\uparrow(\theta) - \Gamma_v(\theta)(1 - \varepsilon_v(\theta))L_v^\downarrow(\theta)}{\Gamma_v(\theta)\varepsilon_v(\theta)} \right]^{-1} \quad (\text{Eq.1}) \quad [\text{Karbou et al., 2006}]$$

Where  $\varepsilon_v$ ,  $\Gamma_v$ ,  $L_v^\uparrow$  and  $L_v^\downarrow$  represent the surface emissivity, the atmospheric transmission, and the atmospheric upwelling and downwelling radiances at channel  $v$ , respectively. The value of  $\Gamma_v$ ,  $L_v^\uparrow$  and  $L_v^\downarrow$  can be computed using the RTTOV model v 11 [Saunders et al., 2012] given a priori knowledge of the atmosphere (short range forecasts of air temperature and humidity) [Borbos et Ruston, 2010].

The AVHRR (Advanced Very High Resolution Radiometer) gives an information about cloud cover. This information is an essential prerequisite to retrieve LST. For IASI retrievals, we compared two types of emissivity: constant emissivity (0.98) and variable emissivity developed by the Space Science and Engineering Center at University of Wisconsin [Borbos et al., 2007]. The use of this emissivity atlas has allowed to obtain a more realistic LST compared to the results using constant emissivity. In this paper, we present only the results using atlas emissivity (of 2013) for a study period from the 15<sup>th</sup> January 2015 till the 28<sup>th</sup> February 2015. To choose the best surface-sensitive channel we have relied on several conditions: 1) a good surface representation with lower sensitivity to clouds and atmospheric molecules, 2) lower bias and Standard deviation (StdDev) between background LST and retrieved LST and 3) the best correlation with other IASI and SEVIRI channels LST.

### 2.2. Comparison of retrieved LST IASI MetOp A vs MetOp B

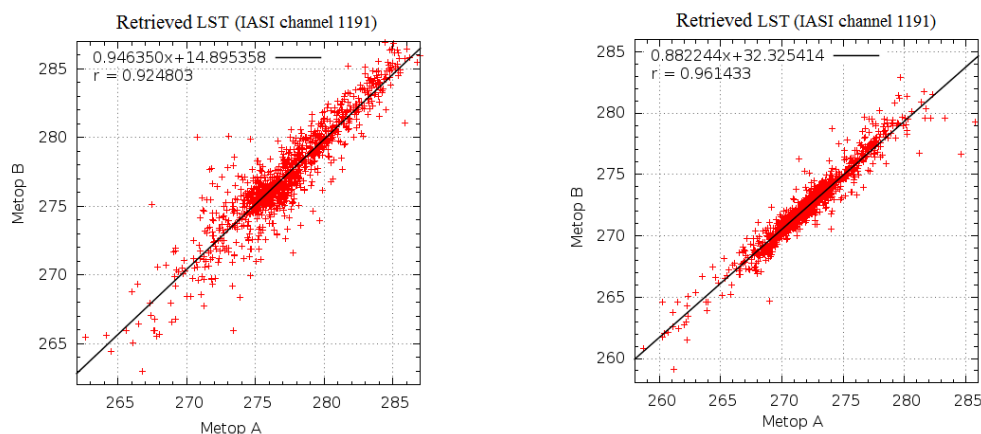
MetOp A & B satellites are on the same orbit with a 180° shift which induces a 50 minute temporal shift. Before comparing retrieved LST IASI from MetOp A and MetOp B, we carried out a study based

on cloud cover from AVHRR over a 3-week period (from the 1<sup>st</sup> to the 21<sup>st</sup> February 2015) which corresponds to the ground track repeat cycle of IASI (Table 1). The goal of this study was to have an idea about the percentage of clear/cloudy IASI observations which affected the number of used data, as we retrieved LST only for clear cases. The result of this comparison shows that around 80% of IASI from MetOp A & MetOp B are affected by clouds at day and more than 50% at night. Note that we had 10% cloudy detection differences between MetOp A and B at night. Also, we had more clear sky at night for both satellites (maybe because the channels used for cloud detection are different during daytime (VIS + IR) and night-time (IR)).

	MetOp A		MetOp B	
	Clear	Cloudy	Clear	Cloudy
Day	20%	80%	21%	79%
Night	43%	57%	33%	67%

**Table 1:** Comparison between cloud cover IASI MetOp A vs MetOp B (according to AVHRR) for the period from 1<sup>st</sup> February to 21<sup>st</sup> February.

We also compared retrieved LST from MetOp A & B during the whole period, we present for example the results for IASI channel 1191 (Figure 2). The results showed that for all IASI channels we had a very good correlation higher than 0.9 especially at night.



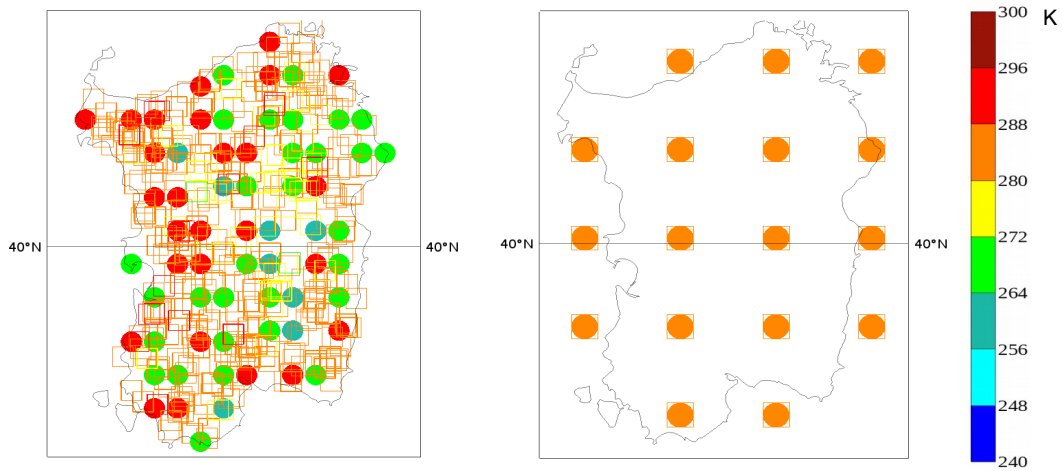
**Figure 2:** Comparison of retrieved LST IASI MetOp A vs MetOp B (in Kelvin) for IASI channel 1191 at day (left) and at night (right).

In order to maximise the number of IASI observations, we combined data from MetOp A & B satellites to retrieve LST.

### 2.3. Comparison between background and retrieved LST IASI

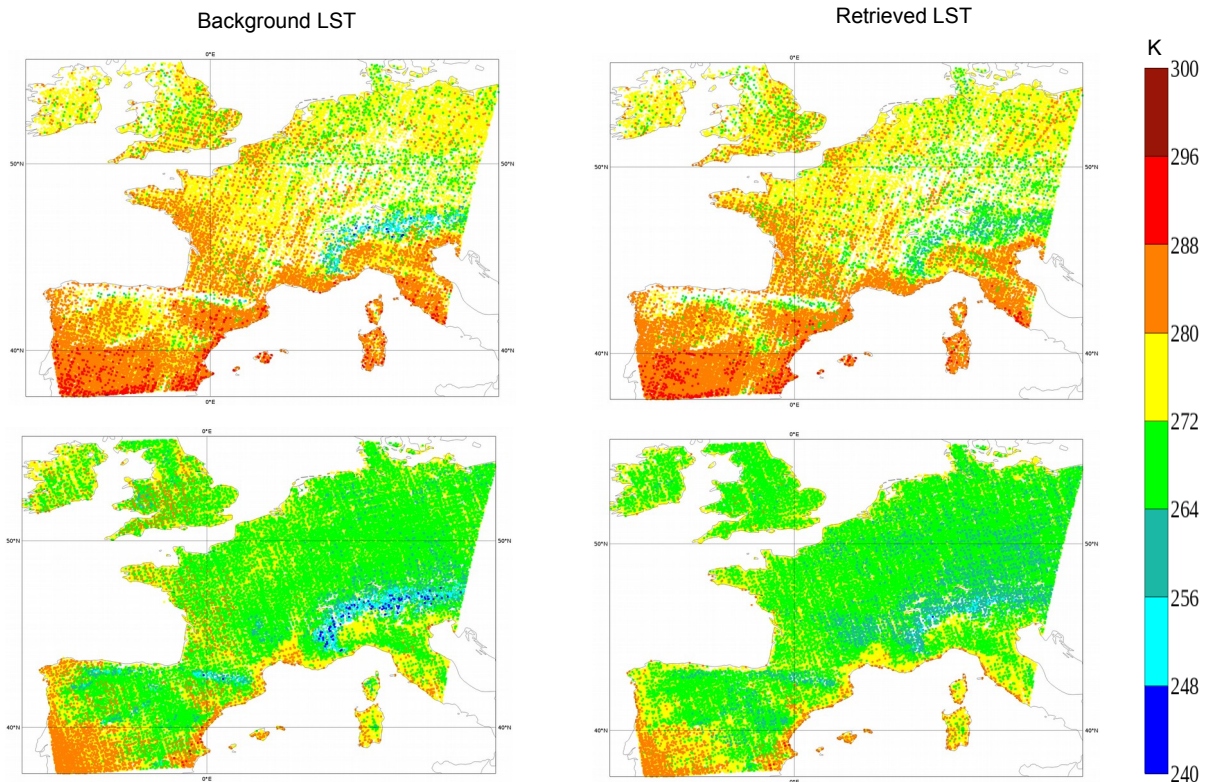
IASI and SEVIRI channels have different spectral and spatial resolutions, also different total observation numbers (e.g. 1,277,674 SEVIRI observations against 161,890 IASI observations from January 15<sup>th</sup> to February 28<sup>th</sup> 2015 over the AROME France domain).

To be able to compare them to each other, we calculated the mean of LST in boxes of 0.5° squared (Figure 3). We chose this spatial resolution because it is the best one giving enough IASI and SEVIRI observation number per box.



**Figure 3:** Retrieved LST from IASI channel 1191 (squares) and from SEVIRI channel 04 (circles) for all observations (left) and mean retrieved LST IASI and SEVIRI channels by box of 0.5° squared (right) over Sardinia at daytime from January 15<sup>th</sup> to February 28<sup>th</sup> 2015.

After that, we compared background and retrieved IASI LST at daytime and night-time (Figure 4). We observed that the largest difference between background and retrieved LST is located over the Alps and the Pyrénées mountains where background LSTs is colder than retrieved LST especially at night (more than 8 -16 K). Also, background and retrieved LSTs are warmer on the South-Western part of the domain (between 272 K and 288 K).



**Figure 4:** Comparison between background (left panels) and retrieved (right panels) LST IASI channel 1191 at daytime (top) and at night-time (bottom).

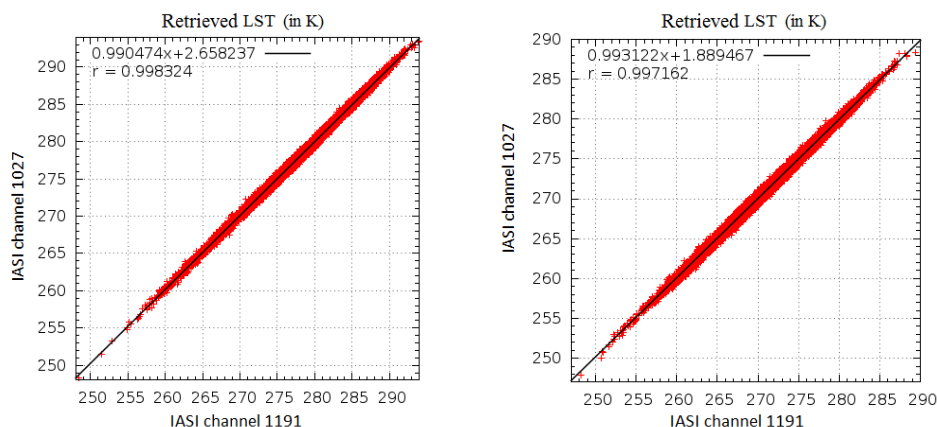
The mean difference between background and retrieved LST for the five IASI channels (Table 2) shows that we have less than 1 K of difference at day and at night, except for IASI channel 1884 at night because this channel is in a spectral band different from the other IASI channels. The standard deviation (StdDev) is around 2 K at daytime and 3 K at night-time. Also, the correlation is much better at day (0.88 instead of 0.72).

Even if the total number of observation is larger at night-time (96070 against 66191 during day time), table 2 shows better agreement at daytime. The algorithm used for the AVHRR cloud detection is not totally consistent between both periods which may degrade the results at night.

Channel number	Day			Night		
	Mean	StdDev	Correlation	Mean	StdDev	Correlation
1027	0.161	2.238	0.876	-0.695	2.936	0.718
1271	0.337	2.177	0.881	-0.524	2.902	0.722
1191	0.165	2.217	0.877	-0.678	2.938	0.716
1194	0.212	2.194	0.879	-0.615	2.901	0.722
1884	-0.324	2.191	0.879	-1.327	3.108	0.690
Total observation	66191			96070		

**Table 2: Statistics of the differences between background and retrieved LST from 5 IASI surface-sensitive channels at daytime and night-time.**

Then, we performed IASI inter-channel comparison of retrieved LST and we found a very good correlation, almost equal to 1. Figure 5 shows an example between IASI channel 1191 and channel 1027 with correlations higher than 0.997.

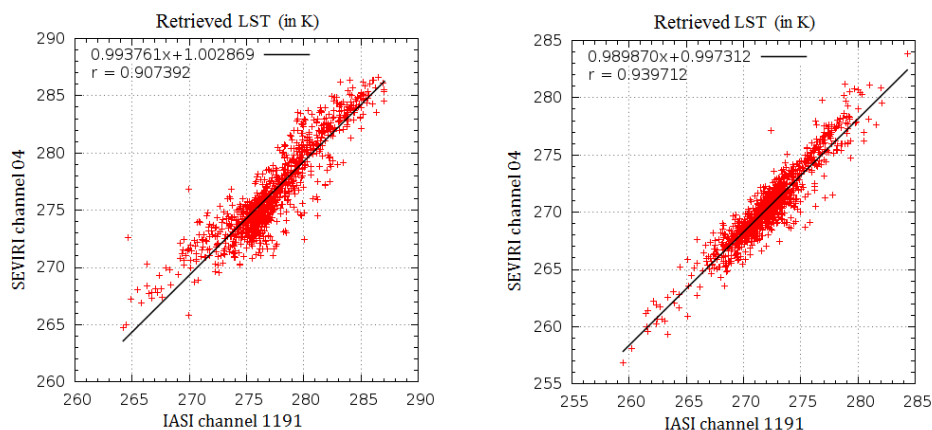


**Figure 5: Scatterplot of LST Retrieved from IASI channel 1191 and channel 1027 at daytime (left) and at night-time (right).**

#### 2.4. LST IASI vs LST SEVIRI

In order to evaluate the quality of the IASI retrieved LST, we made a comparison with LST retrieved from SEVIRI channel 4 in a grid with in 0.5° squared boxes (Figure 6). We found a very good correlation higher than 0.9. This correlation was slightly better at night-time (because there is a higher dispersion during daytime).





**Figure 6: Comparison between LST Retrieved from IASI channel 1191 and SEVIRI channel 04 (by box of 0.5° squared) , at day (left) and night (right).**

After that, we looked at the LST spatial differences between both sounders (not shown). During day time, SEVIRI LST presented higher temperatures than IASI LST in the South East part of Europe: the difference was around 2 K. At night we saw the opposite, SEVIRI LST was colder than IASI LST: the difference was included between 2 K and 6 K in the North East of AROME domain, also over UK and Ireland.

The mean difference (Table 3) was lower than 0.8 K at day and 2 K at night. The StdDev was around 2 K with a very good correlation higher than 0.9, even for IASI channel 1884 which presented a very good correlation with 04 SEVIRI channel. Both channels are located in the same spectral band which differs from the one of the other chosen surface channels (IASI and SEVIRI).

SEVIRI Channel	IASI channels	Day			Night		
		Mean	StdDev	Correlation	Mean	StdDev	Correlation
04	1027	0.711	1.682	0.906	1.736	1.153	0.939
	1271	0.897	1.663	0.908	1.910	1.154	0.939
	1191	0.724	1.666	0.907	1.757	1.150	0.940
	1194	0.775	1.671	0.907	1.818	1.160	0.939
	1884	0.268	1.604	0.914	1.127	1.110	0.940
Total observation		1089			1090		

**Table 3: Statistics of the differences between retrieved LST IASI channel 1191 and SEVIRI channel 04 (by box of 0.5° squared) from January 15<sup>th</sup> to February 28<sup>th</sup> 2015.**

According to all conditions that we fixed to select the best surface-sensitive channel in methodology for LST retrieval section and the results obtained in section 2.2 and 2.3, we chose IASI channel 1191 to retrieve LST. In fact, this channel provided good compromise with the other IASI and SEVIRI channels in terms of bias, mean difference and correlation.

### 3. The impact of LST retrieved from IASI on the brightness temperature simulation in the assimilation

To study the impact of LST retrieved from IASI channel 1191 on the IASI simulation and assimilation we ran two experiments. The first one called **EXP** where we used LST retrieved from IASI surface channel for all IASI brightness temperatures (BT) simulations. The second one is the **REF** where LST provides from AROME forecast (similar to the operations) used for IASI BTs simulation. This paper shows the results of two days of assimilation from the 15<sup>th</sup> to the 16<sup>th</sup> January 2015 and using only clear observations according to AVHRR imager. These results are presented only for the IASI channels used for cloud detection [McNally & Watts, 2003] in LW temperature band (brown rectangle in Figure 7) in AROME.

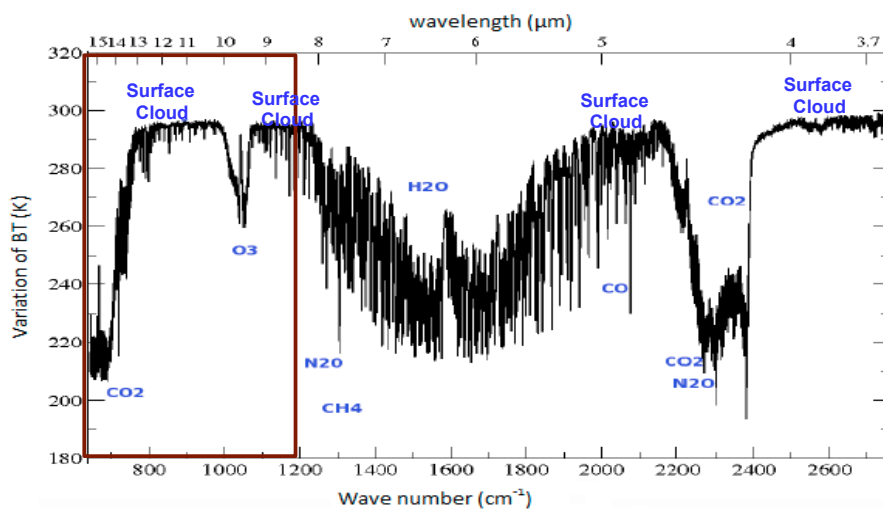
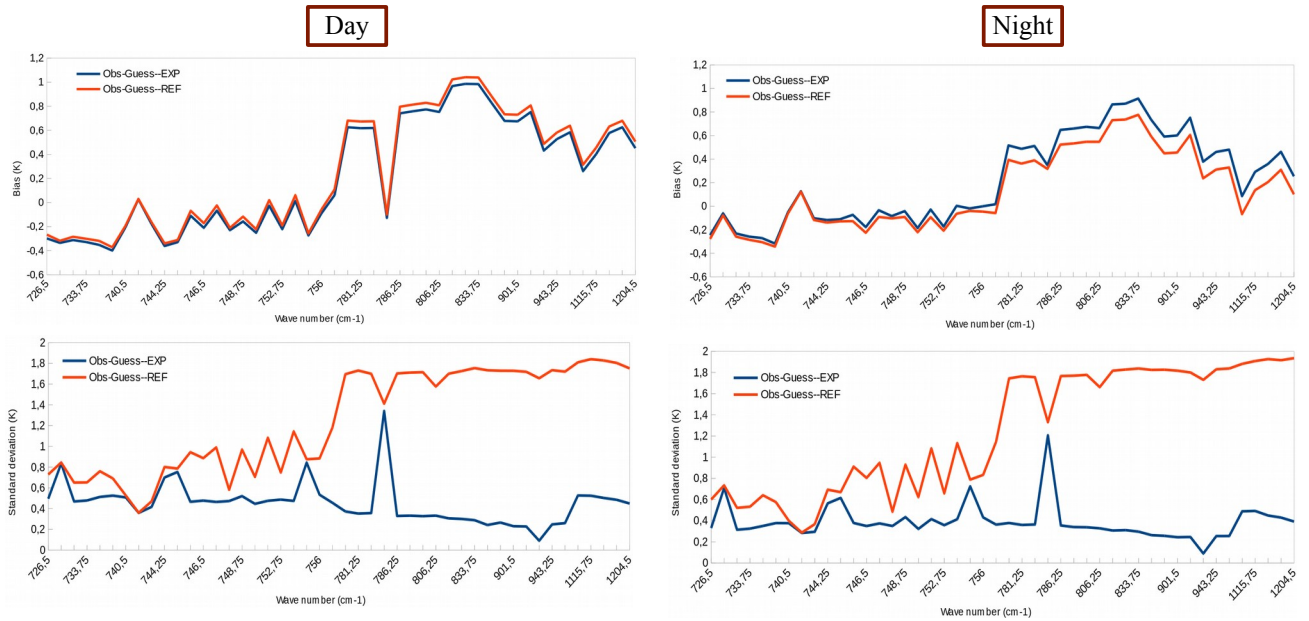


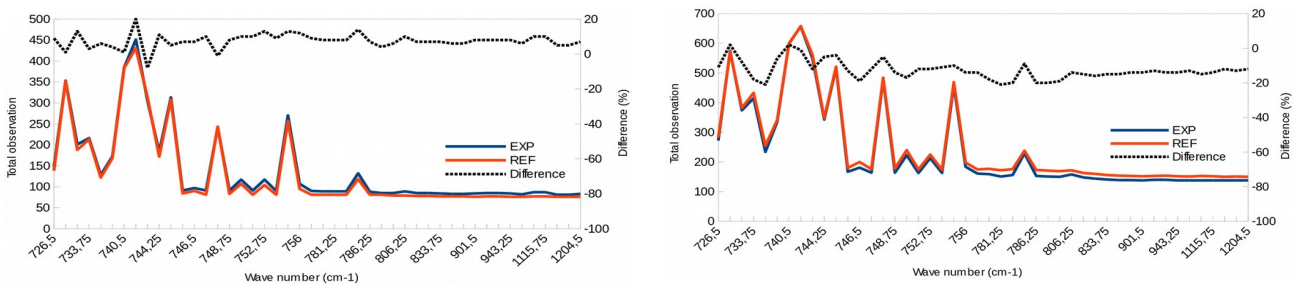
Figure 7: Example of a IASI spectrum in clear sky conditions [Fourié, 2010].

Figure 8 shows the bias and StdDev of the differences between observation and background simulation (Obs-Guess) of EXP and REF (combining IASI data from MetOp A & B). The Obs-Guess of EXP and REF was very similar at daytime and at night-time. A small difference was observed for surface-sensitive channels (0.05 K at daytime and around 0.15 K at night-time for channels located between 773.5 cm<sup>-1</sup> and 1204.5 cm<sup>-1</sup>). The StdDev was reduced in EXP compared to REF for both cases (around 0.85 K) with large difference in surface-sensitive channels (1.30 K at daytime and 1.40 K at night-time against 0.25 K and 0.3 K respectively for the other channel).



**Figure 8:** Bias (top) and standard deviation (bottom) between Obs-Guess of EXP (blue) and REF (red) at day (left) and at night (right) for all IASI clear observations according to AVHRR.

After that, we looked the impact on cloud detection. Figure 9 describes the total clear channels according to McNally and Watts algorithm within to clear pixels according to AVHRR. At daytime, the impact on cloud detection provides more clear channels in EXP than in REF (about +5%). At night-time, the clear channel number is decreased (around -10%, varying with respect to channels). This may be due to the increase of the OBS-Guess value in EXP.



**Figure 9:** Total clear observation according to AVHRR and McNally & Watts algorithms at day (left) and at night (right).

#### 4. Conclusions and perspectives

In order to prepare the assimilation of the new hyperspectral sensors such as IRS (which will be onboard Meteosat Third Generation and will supply for the first time measures in thousands of channels, at high-temporal frequency “every 30 minutes” over Europe) and IASI-NG (IASI-New Generation) over continents in AROME model, we performed a comparison between current sensors. For that, we chose to work with IASI and SEVIRI. We first compared LST retrieved from IASI MetOp A & MetOp B. Then, we compared background LST with retrieved IASI channels LST. We also performed inter-channels IASI LST comparisons. After that, we compared IASI LST vs SEVIRI LST. Finally, we studied the impact of LST retrieved from IASI channel selected on the IASI simulation and on the other assimilated observations.



The results of this study has shown that IASI from MetOp A & MetOp B produces similar LST retrievals. The use of an emissivity atlas has allowed to obtain a more realistic LST compared to the results using constant emissivity (not shown). The comparison between channels in regional AROME model has enabled to select one IASI channel for LST retrieval: channel number 1191, because it provided the best results in terms of lower difference between background and retrieved LST, correlation with other retrieved LST from IASI and SEVIRI channels (we found similar results in the global ARPEGE model, not shown). The comparison between IASI and SEVIRI retrievals presented good results allowing to study the complementarity between polar and geostationary satellites. The use of retrieved LST for IASI BT simulation leads to a decrease of the standard deviation of the differences between observations and background simulations, especially for surface-sensitive channels. Finally, the first results of assimilation are encouraging and present a slightly positive impact on some other observation such as temperature from radiosoundings (not shown).

This preliminary results should be confirmed with the whole period of the study in order to be statistically significant. Subsequently, we will select IASI surface-sensitive channels to be assimilated over land and evaluate the improvement of assimilation and forecasts in the AROME-France domain. After that, the methodology that we adopted will be applied to assimilate recent sensors like CrIS.

## 5. References

- Borbas, E. E. and Ruston, B. C. 2010.** The RTTOV UWiremis IR land surface emissivity module. Mission Report EUMETSAT NWPSAF-MO-VS-042.
- Borbas, E.E., Knuteson, R. O., Weisz, S. W. E., Moy, L. and Huang, H.-L. 2007.** A high spectral resolution global land surface infrared emissivity database. Joint 2007 EUMETSAT Meteorological Satellite Conference and the 15th Satellite Meteorology & Oceanography Conference of the American Meteorological Society, Amsterdam, The Netherlands, 24-28 September 2007.
- Guedj, S., Karbou, F., and Rabier, F. 2011.** Land surface temperature estimation to improve the assimilation of SEVIRI radiances over land. *J. Geophys. Res.*, 116 :18.
- Guidard, V., Fourrié, N., Brousseau, P. and Rabier, F. 2011.** Impact of IASI assimilation at global and convective scales and challenges for the assimilation of cloudy scenes. *Q. J. R. Meteorol. Soc.* 137: 1975–1987. DOI:10.1002/qj.928.
- Karbou, F., Gérard, E., and Rabier, F. 2006.** Microwave land emissivity and skin temperature for AMSU-A and -B assimilation over land. *Quart. J. Roy. Meteor. Soc.*, 132 :2333–2355.
- Kerr, Y. H., Lagouarde, J. P., Nerry, F., et Ottlé, C. 2004.** Land surface temperature retrieval techniques and applications. *Thermal Remote Sensing in Land Surface Processing*, pages 33–109.
- Niclòs, R., Valiente, J.A., Barberà, M.J., R., Estrela, M.J., Galve, J.M., Caselles, V. 2009.** Preliminary results on the retrieval of land surface temperature from MSG-SEVIRI data in Eastern Spain. *Proceedings p.55, EUMETSAT Meteorological Satellite Conference, Bath, UK, 21-25 September 2009*, 8 p.
- McNally, A. P., and Watts, P. D. 2003.** A cloud detection algorithm for high-spectral-resolution infrared sounders. *Q. J. R. Meteorol. Soc.* (2003), 129, pp. 3411–3423.
- Vincensini, A., Fourrié, N., Rabier, F., and Guidard, V. 2013.** Data assimilation of IASI radiances over land. 18<sup>th</sup> International TOVS Study Conference, 21-27 March 2012, Toulouse, France.
- Saunders, R., Hocking, J., Rayner, P., Matricardi, M., Geer, A., Bormann, N., Brunel, P., Karbou, F.,**

**et Aires, F. 2012.** RTTOV-10 Science and Validation Report. EUMETSAT, NWPSAT-MO-TV-023, page 31.

**SEITY, Y., BROUSSEAU, P., MALARDEL, S., HELLO, G., BENARD, P., BOUTTIER, F., LAC, C. and MASSON, V. 2011.** The AROME-France Convective-Scale Operational Model. American Meteorological Society. Volume 139, pages 976-991.