DATA ASSIMILATION OF IASI RADIANCES OVER LAND.

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Abstract

Observations from satellite infrared measurements have large atmospheric and surface information contents and are known to improve Numerical Weather Prediction. However, the use of these observations is still not optimal over land because of uncertainties about land emissivity and skin temperature. Currently, radiances are assimilated only when they are not affected by the surface. Previous studies on microwave and infrared observations have shown that the use of land emissivity climatologies together with land surface temperature retrievals improves the assimilation system. As a first step toward the assimilation of Infrared Atmospheric Sounding Interferometer (IASI) data over land, the aim of this study is the improvement of the simulation of the IASI data over land in the ARPEGE model of Météo-France. The provision of spatial and temporal variations in emissivity is studied. The impacts on simulation of a constant emissivity, emissivity climatologies from the IASI Level-2 products from EUMETSAT and atlases computed from MODIS (Moderate Resolution Imaging Spectroradiometer) emissivity products are compared.

1. INTRODUCTION

Infared instruments provide relevant observations permitting to improve the initial conditions for short-range forecasts. However, the use of these observations is still not optimal in Numerical Weather Prediction (NWP). Satellite retrievals of atmospheric variables, such as temperature and water vapor partly depends on surface parameter estimation. The surface contribution to the simulated radiances is limited by the uncertainties about land emissivity and skin temperature. Thus data from infared instruments are more exploited over sea than over land and only radiances that are not affected by the surface are currently assimilated. Indeed the surface temperature is much more variable over land than over sea and the land surface emissivity varies with wavelength, surface types, roughness and moisture [1] [2]. Satellite infrared observations permit to estimate with accuracy these properties of land sufaces and provide a global coverage in space and time. Over sea, the emissivity is provided by the Infrared Surface Emissivity Model (ISEM) [3]. This model computes a surface emissivity for the channel of interest at the given viewing angle.

At the moment, the emissivity is set at a constant value 0.98 in operations and the surface temperature is poorly estimated. Previous studies, on microwave observations from AMSU-A and AMSU-B [4] or on infrared observations from SEVIRI [5], have shown that the use of land emissivity climatologies together with land surface temperature retrievals improves the assimilation system. A similar work will be realized with the Infrared Atmospheric Sounding Interferometer (IASI) observations. IASI, on board MetOp, is a high-spectral-resolution sounder that provides accurate information about the atmospheric temperature and the composition of the atmosphere at a high vertical resolution. It measures the infrared radiation emitted from the surface of the Earth and the atmosphere. IASI has 8461 spectral channels distributed between 645 and 2760 cm^{-1}. Since the beginning of 2007, IASI data have been available and assimilated in NWP [6], [7].

The aim of this preliminary study is the improvement of the brightness temperature simulation of the IASI data over land using high spectral resolution emissivity databases. This step is required before carrying out any assimilation experiments using an accurate representation of emissivity and surface temperature in the ARPEGE NWP of Météo-France. Recently several land surface emissivity databases have been developed in order to be used as first guess in the retrievals of infrared sounder observations. These datasets are obtained from different intruments and method at different spectral, spatial and temporal resolution. A global high spectral resolution (HSR) infrared land surface emissivity database have been developed by Seemann et al [8]. Emissivity is derived using input from the Moderate Resolution Imaging Spectroradiometer (MODIS) operational land surface emissivity product. The IASI Level-2 (L2) products from Eumetsat are retrievals of geophysical parameters from the radiance measurements. The surface emissivity is retrieved by regression [9]. The impacts on simulation of a constant emissivity, emissivity climatology from the IASI L2 products from EUMETSAT and atlas computed from MODIS emissivity products are compared. In a next step, these land surface emissivities will be used as input parameters of the radiative transfer model to retrieve the land surface temperature.

2. THE IMPACT OF EMISSIVITY ON BRIGHTNESS TEMPERATURE

The surface emission depends on surface parameters: emissivity and temperature. In order to increase atmospheric retrieval accuracy in the atmospheric thermal infrared window, it is necessary to improve the knowledge of land surface emissivity and its spectral, spatial and temporal variations. The figure 1 shows the differences between simulated brightness temperature with the constant emissivity used in operations (equal to 0.98) and the simulated brightness temperature for other constant values of emissivity. These results are averaged on the whole globe for July 1st, 2011 at 0 UTC. This figure shows that a difference of 1 % in emissivity (from 0.98 to 0.97) corresponds on average to a difference of brightness temperature of 0.4 K in the surface wavebands between 773 and 962 cm^{-1} and between 1091 and 1168 cm^{-1}. A difference of 6 % in emissivity (from 0.98 to 0.92) corresponds on average to a difference of brightness temperature of 2.3 K in these wavebands.

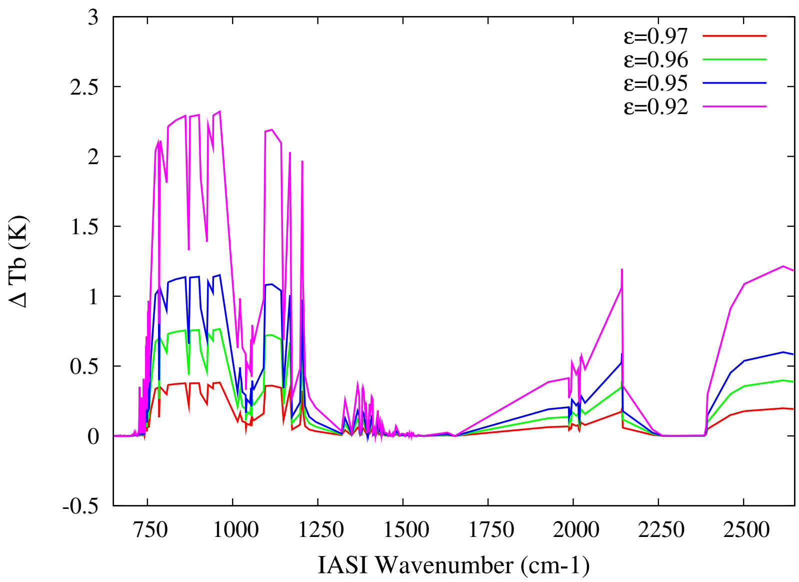


Figure 1: Differences between simulated brightness temperature for the constant emissivity 0.98 used in operations and simulated brightness temperature computed for different constant emissivity values (0.92, 0.95, 0.96, 0.97). These results are for July 1st, 2011 over a 6-hour window around 0 UTC.

A small difference on emissivity may have a significant impact on the simulated brightness temperature.

3. LAND SURFACE EMISSIVITY DATABASES

3.1. The global high spectral resolution (HSR) IR land surface emissivity database

An infrared emissivity atlas and high spectral resolution emissivity algorithm based on MODIS and laboratory measurements have been developed by Seemann et al. [8] and Borbas et al. [10]. The emissivity is derived using the input from the MODIS operational land surface emissivity product (MOD11). Six emissivity wavelengthes are available in MOD11. The emissivity in the database is available globally at 10 wavelengthes (3.6, 4.3, 5.0, 5.8, 7.6, 8.3, 9.3, 10.8, 12.1 and 14.3 μm) with 0.05° spatial resolution thanks to the baseline fit method using laboratory measurements of surface emissivity. In order to retrieve atmospheric parameters from infrared sounders with accuracy, a global database of land surface emissivity with broad spectral coverage and fine spectral resolution is required. The University of Wisconsin (UW) has developed an approach deriving high spectral resolution (HSR) infrared emissivity measurements from measurements made at selected wavelengths. This is the UW HSR algorithm. The algorithm provides HSR infrared land surface emissivity from 3.6 to

14.3 μm using input from a monthly composite database defined globally at 0.05° spatial resolution. The HSR infrared emissivity spectrum is derived using an eigenfunction representation of high spectral resolution laboratory measurements of selected materials applied to the UW/CIMSS 4 Baseline Fit (BF) global infrared land surface emissivity database [8]. The figure 2 shows the land surface emissivity as a function of the selection of 314 IASI wavenumbers for July 2007 for five points on Earth. The spatial and spectral variations of land surface emissivity are emphasized in this figure.

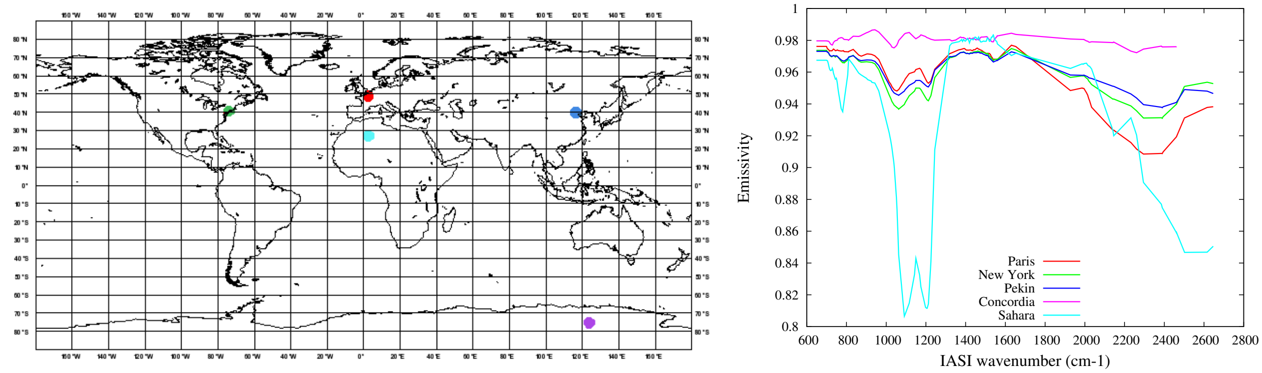


Figure 2: Land surface emissivity from the atlas derived from MODIS for July 2007 for 5 points on Earth for the selection of 314 IASI channels.

In this study, the global HSR emissivity atlas has been reconstructed with a 0.5° spatial resolution in order to have an acceptable resolution for the integration into the ARPEGE model. This atlas is available and used for the month of July 2007.

3.2. IASI Level-2 products from Eumetsat

The IASI Level-2 (L2) products from Eumetsat are retrievals of geophysical parameters from the radiance measurements [11]. The surface emissivity is retrieved by regression [9]. From the ten retrieved emissivity principal component scores, a full emissivity spectrum for all 8461 IASI channels can be constructed. In the products, the emissivity is only provided at 12 selected wavenumbers. Using the emissivity eigenvectors, it is possible to compute the underlying scores and thereby the full emissivity spectrum from these selected values. In order to construct this atlas, a monthly average in July 2011 has been calculated and only clear sky cases in the data files have been considered. The atlas has been constructed with a 0.5° spatial resolution. In order to do that, data are averaged in boxes of 0.5°x0.5°. The figure 3 shows the land surface emissivity as a function of the selection of 314 IASI wavenumbers for July 2011 for 5 points on Earth. The spatial and spectral variations of land surface emissivity are emphasized in this figure. Moreover, the spectral variations of the emissivity in the IASI L2 products are very different from those in the atlas derived from MODIS in particular in the Sahara desert and in Concordia.

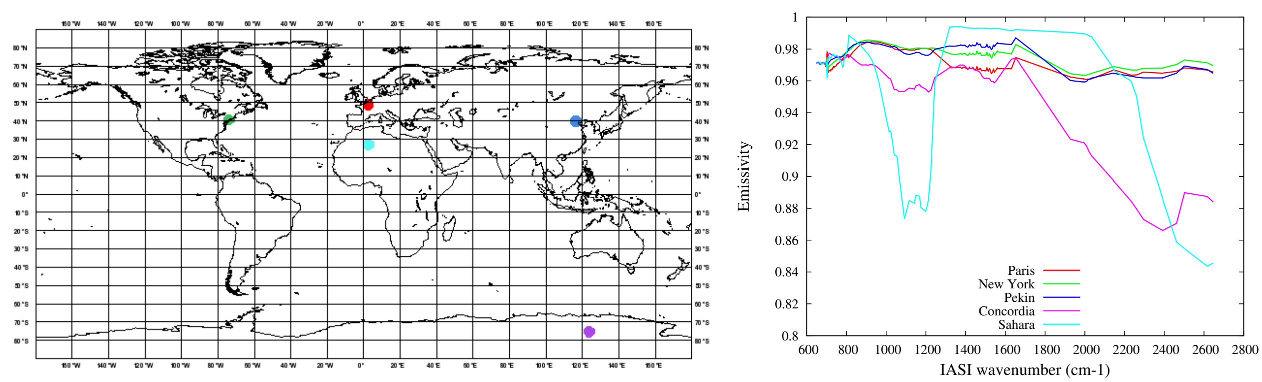
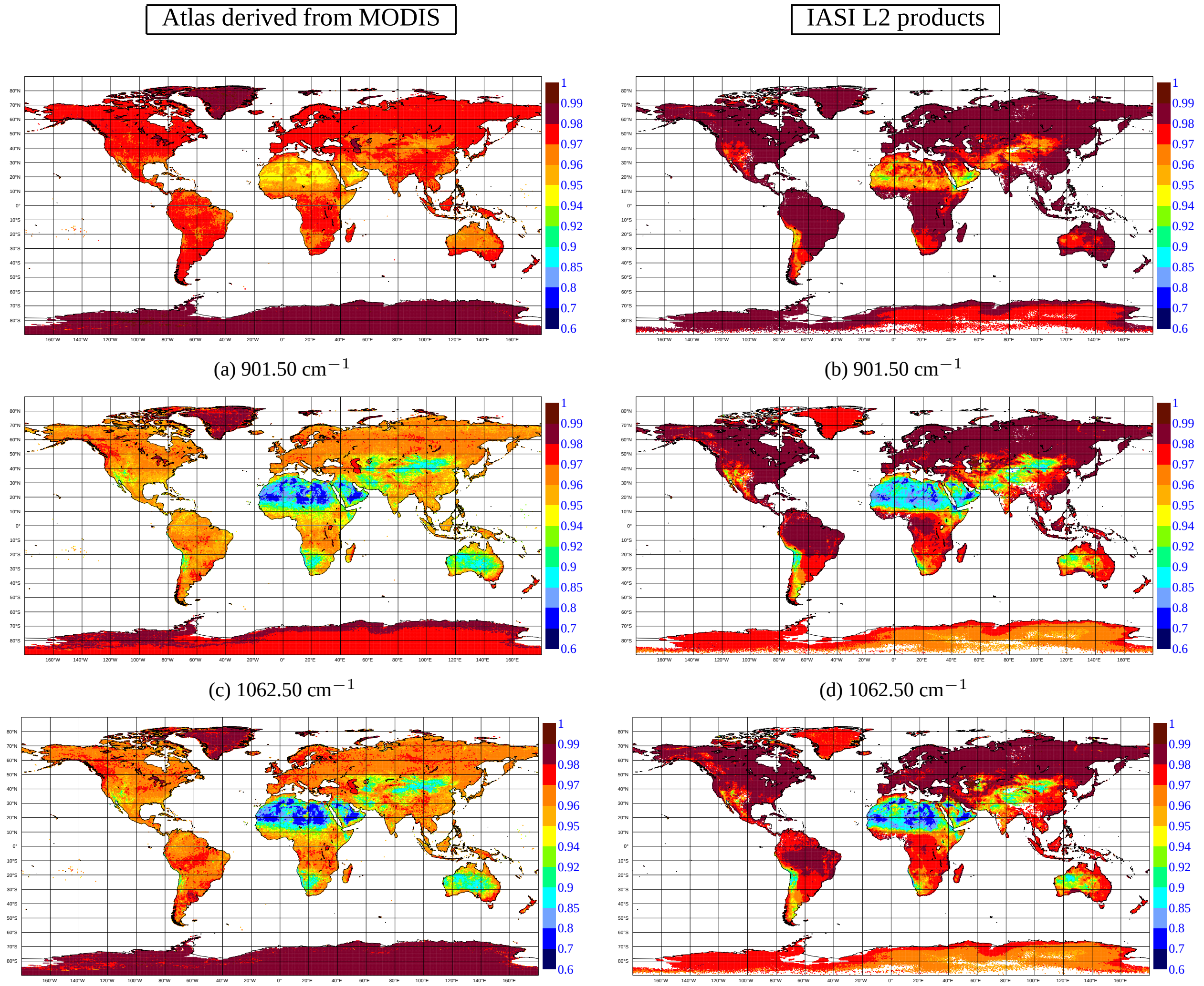


Figure 3: Land surface emissivity from the IASI L2 products for July 2011 for 5 points on the Earth for the selection of 314 IASI channels.

4. COMPARISON OF THE ATLAS DERIVED FROM MODIS AND THE IASI L2 PRODUCTS

The global land surface emissivity have been plotted on figure 4 for three different channels chosen among the selection of 314 IASI wavenumbers: a surface channel (901.50 cm^{-1}), a channel sensitive to ozone (1062.50 cm^{-1}) and a water vapor channel (1225 cm^{-1}).



(a) 901.50 cm^{-1} (b) 901.50 cm^{-1}

(c) 1062.50 cm^{-1} (d) 1062.50 cm^{-1}

(e) 1225 cm^{-1} (f) 1225 cm^{-1}

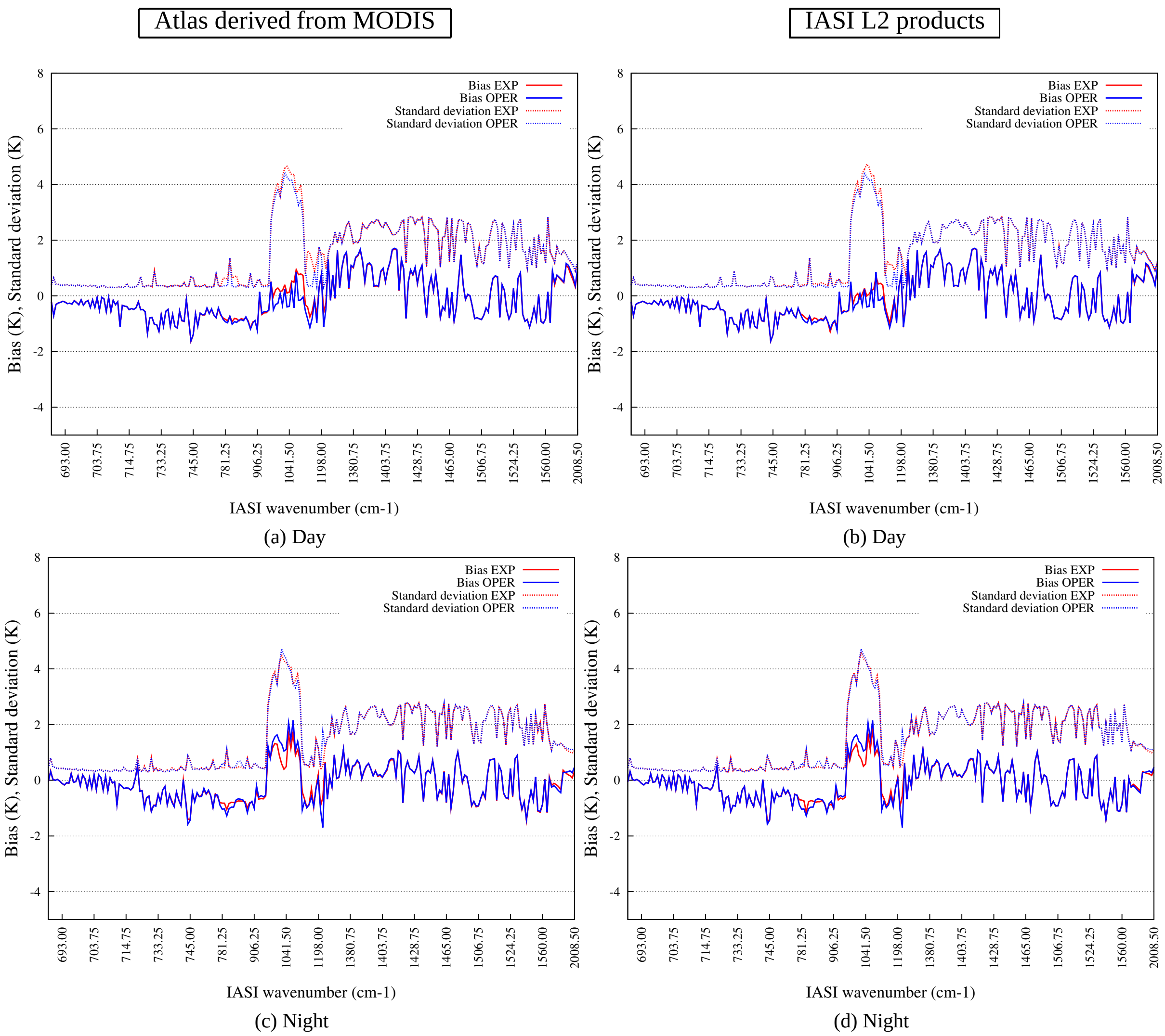
Figure 4: Land surface emissivity for the atlas derived from MODIS (on the left) and for the IASI L2 products (on the right) for three different wavenumbers.

These atlases are very different from each other (figure 4) as pointed out in the EUMETSAT technical note (Surface Emissivity within IASI L2 PPF v5) in which the emissivities retrieved by the IASI L2 PPF v5 with monthly maps provided by Dan Zhou is compared with the Global Infrared Land Surface Emissivity Database from the University of Wisconsin. The emissivities from the atlas derived from MODIS are generally smaller than the ones from the IASI L2 products.

5. COMPARISON OF THE RESULTS OF SIMULATION

The impacts on simulation of the emissivity climatologies from the IASI L2 products from EUMETSAT and the atlas computed from MODIS emissivity products have been studied over the whole Earth in clear sky conditions. The number of clear cases over the whole Earth is determined according to the cloud detection scheme developped by McNally and Watts [12]. This test enables the detection of cloud-free channels in any given pixel. The cloud signature is identified by the difference between observations and simulations from the background state. Channels are first reordered into a

vertically ranked space according to the height of the lower tail of their respective weighting function. A search for the channel at which a monotonic increase in the magnitude of the first guess departure begins indicates the first channel being contaminated by a cloud. All other less sensitive channels are flagged cloud-free and the more sensitive channels are flagged cloudy. In these calculations of simulated IASI radiance, the background surface temperatures from the ARPEGE model are used. The temperature and humidity profiles also come from ARPEGE. The surface temperatures are poorly estimated and have a significant impact on the cloud detection. Clear-sky observations can be declared as cloudy because of these bad surface temperatures. This preliminary study only aims to see the impact of an accurate emissivity on simulation, the background surface temperature is not improved.
Using this cloud detection, the numbers of clear cases are very low in the surface wavebands between 773 and 962 cm^{-1} and between 1091 and 1168 cm^{-1} for the experiment with a constant emissivity but also for the experiments with both atlases. Indeed, in July 2011, on average, only 0.5% of the total number of observations are considered as clear during the day and 1.5% during the night in these wavebands. The figure 5 presents the monthly mean differences between IASI observations and simulated brightness temperatures for a constant emissivity (OPER), for the IASI L2 products and the atlas derived from MODIS (EXP) for clear cases of July 2011. The background surface temperature used in the calculation of simulated brightness temperature comes from ARPEGE for each experiment. For both atlases, the bias is slightly reduced compared to the operational experiment by around 0.1 K for the surface wavebands between 773 and 962 cm^{-1} and between 1091 and 1168 cm^{-1} for day and night. The standard deviation is slightly increased in these two surface wavebands during the day and is almost equal during the night.



(a) Day (b) Day

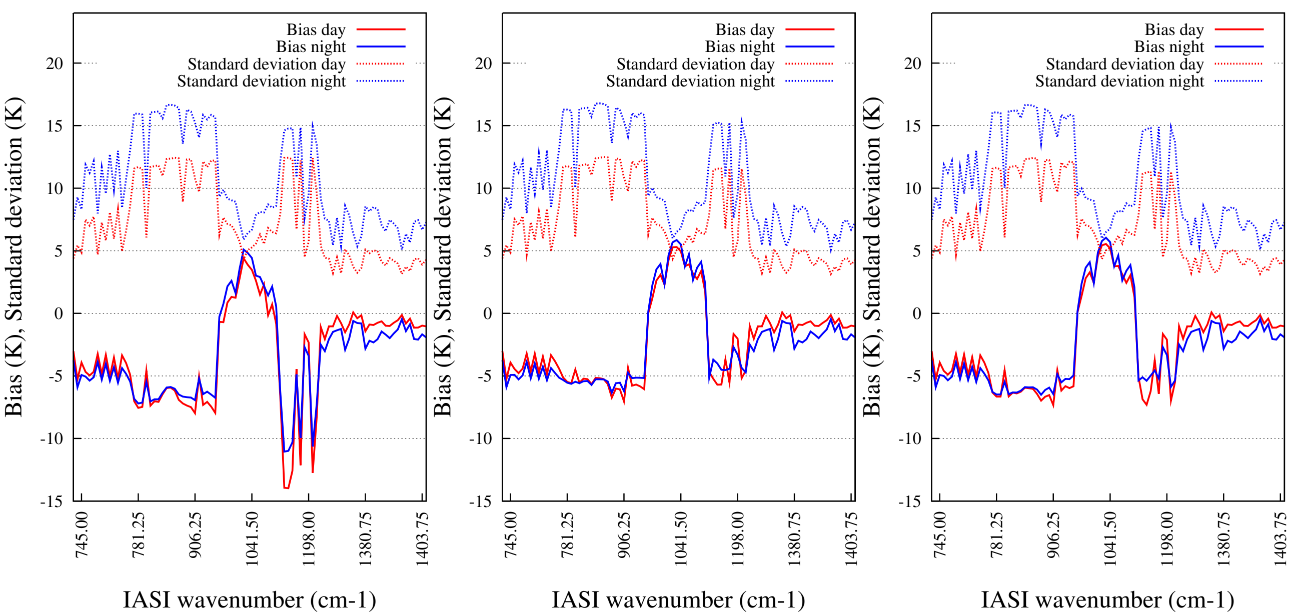
(c) Night (d) Night

Figure 5: Monthly mean differences (solid lines) over the globe, depending on the IASI wavenumber, between IASI observations and simulated brightness temperatures for a constant emissivity as in operations (OPER) and between IASI observations and simulated brightness temperatures using atlases (EXP). Dotted lines represent the associated standard deviations. Only clear cases are considered. The results for the atlas derived from MODIS are on the left and those for the IASI L2 products are on the right.

According to the figure 5, the impact of both atlases is not significant over the whole globe. Moreover the number of clear cases is very low. This result can be explained by a bias in the surface channels that affects the diagnosis of the cloud detection.

Thus the impacts on simulation of both atlases have been studied over the desert of Sahara and Saudi Arabia (for latitude from 12°N to 38°N and longitude from 18°W to 55°E). These locations are characterized by a lesser proportion of cloud. The cloud detection is not used for this location. The figure 6 shows the monthly mean differences, depending on the IASI wavenumber, between IASI observations and a) simulated brightness temperatures with a constant emissivity as in operations and between IASI observations and simulated brightness temperatures using the atlases b) derived from MODIS and c) constructed with the IASI L2 products for the day (in red) and for the night (in blue). For both atlases, the bias is reduced by around 1 K compared to the results for a constant emissivity in the surface waveband between 773 and 962 cm^{-1} for day and night. In the surface waveband between 1091 and 1168 cm^{-1}, the bias is reduced by around 7 K for the IASI L2 products and around 8 K for the atlas derived from MODIS. Thus in this area, emissivity atlases have a significant impact on brightness temperatures. For both atlases, the standard deviation does not vary compared to the experiment with a constant emissivity.

Moreover figure 6 shows important differences between the results for day and night with differences up to 4 K in the surface wavebands for the operational experiment and up to 2.5 K for the experiments with atlases. The calculated biases are smaller (in absolute values) during the night in the surface wavebands. However the value of the bias may show a remaining cloud contamination. The standard deviations are reduced by around 5 K in the daytime compared to the night for all experiments. The emissivity used during day and night is the same but the background surface temperature is, on average, better estimated during the night than during the day. This result emphasizes the fact that a good estimate of surface temperature is necessary to the brightness temperature simulation process. So, in a future work, the land surface emissivities from atlases will be used as input parameters in the radiative transfer model to retrieve the land surface temperature.



(a) Constant emissivity (OPER) (b) Atlas derived from MODIS (c) IASI L2 products

Figure 6: Monthly mean differences (solid lines) over Sahara and Saudi Arabia, depending on the IASI wavenumber, between IASI observations and simulated brightness temperatures with a constant emissivity as in operations (a) and between IASI observations and simulated brightness temperatures using emissivity atlases: the atlas derived from MODIS (b) and the IASI L2 products (c). Dotted lines represent the associated standard deviations. The red lines represent the results for the day and the blue ones are for the night. .

6. CONCLUSION

The simulations of IASI observations using atlases (atlas derived from MODIS and IASI Level-2 products) for July 2011 over the whole globe in clear sky conditions have not permitted to underline the impact of an accurate emissivity. The results are quite similar to those obtained for a constant emissivity. However, because of a bias of around 5 K in the surface channels, the diagnosis of the cloud detection is affected and the number of clear cases is very low (around 1% of the total number of observations). Thus the same simulation experiments have been made over Sahara and Saudi Arabia, characterized by the absence of cloud. This study has shown a significant impact on the brightness temperature simulation. The use of a surface emissivity atlas has shown a reduction in the difference between IASI observations and simulated brightness temperatures compared to the results obtained with a constant emissivity. Moreover the surface emissivity atlas calculated from MODIS for July 2007 provides better results than with the surface emissivity atlas from the IASI L2 products for July 2011. This study has also permitted to emphasize the necessity of an accurate surface temperature in the simulation process. These land surface emissivities from atlases will be used as input parameters of the radiative transfer model to retrieve the land surface temperature. After that, assimilation experiments will be run using a better representation of emissivity and surface temperature.

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