ASSESSMENT OF IASI RADIANCES DURING THE SALSTICE CAMPAIGN

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Abstract

This paper presents the results of the comparison between the Infrared Atmospheric Sounding Instrument (IASI) observations and the radiance measurements performed during the SALSTICE (Semi-Arid Land Surface Temperature and IASI calibration Experiment) validation campaign with the Fourier transform spectrometer ARIES (Airborne Research Interferometer Evaluation System). Nine flights have been considered from 11th to 25th May 2013, four of them over Arizona being dedicated to land-surface processes, the others over ocean in the Gulf of California, all of them in coincidence with overpasses from one or both Metop platforms.

The comparisons between both instruments, whose spectral characteristics are slightly different, have been performed into a set of spectral windows in which the effect of the instrument function is negligible. AVHRR (Advanced Very High Resolution Radiometer) images taken at the time of the overpass have been used in order to assess the possible presence of clouds and to assess scenes homogeneity. Some more refinements (using surface or humidity channels) have been made to provide consistent comparison. We have found that there is an overall good agreement between IASI and ARIES which agree within 1K over sea. It appeared, however, that ARIES brightness temperatures are systematically warmer than IASI ones. The comparison over land turned out to be less successful, probably hampered by the large difference in the spatial resolution of the instruments.

I. INTRODUCTION

As part of the Calibration/Validation activities of satellite sensors, field campaigns play a crucial role in determining the performances of the system and its ability to reach its objectives. After the launch of Metop-A in October 2006, the JAIVEx (Joint Airborne IASI Validation Experiment) campaign was held in April/May 2007 aiming at the radiometric and spectral calibration of the IASI instrument [1]. As a follow-up, the campaign SALSTICE has been planned after the launch of Metop-B not only for the validation of IASI but also for investigating the large biases between satellite-derived surface temperatures and their equivalent in numerical weather prediction models [2].

SALSTICE was conducted in May 2013 by a UK/US team including, among others, members from the MetOffice-UK and the NASA Langley Research Center and took place in the South-West of the USA.Two aircraft were involved: the ER-2 aircraft from NASA and the BAe 146 from the FAAM. Flights were performed both over Arizona and Gulf of California so that they were in coincidence with IASI on the two Metop platforms and CrIS on Suomi-NPP overpasses. Both in-situ and remote sounding measurements were performed during the flights: dropsondes for the characterization of vertical profiles of atmospheric temperature and humidity, lidar for estimating aerosols profiles, in-situ measurements of aerosols, clouds, temperature and humidity along the flight path and finally IR spectrometry using the ARIES interferometer onboard the FAAM aircraft.

In this paper, we will only focus on ARIES observation whose spectra can be compared to IASI level 1c ones. ARIES (Airborne Research Interferometer Evaluation System) is a Fourier transform spectrometer designed for airborne measurements that has been used by the MetOffice-UK since 1994 in several field experiments. It provides spectra from 550 to 3000 cm-1 with a resolution of 1 cm-1 and a spectral sampling of 0.4822 cm-1. The field of view of 2.5 degrees yields a spatial resolution of about 350 meters at nadir when the instrument is flown at an altitude of 8km.

IASI nomally performs measurements across track along a swath of 2200 km width. However, in order to support the campaign, IASI on Metop-B has been put in a special mode where the instrument is viewing nadir only. Over the twenty-four overpasses in such a mode that have been planned, eight were actually programmed and only on one occasion (on 24th May) a flight could be performed in coincidence (Table 1).

11 May 1822	Pacific Ocean (126ºW, 34ºN)
12 May 1800	Californian coast (120ºW, 38ºN)
13 May 0519	Pacific Ocean (123ºW, 34ºN)
13 May 1739	Californian coast (116ºW, 37ºN)
14 May 0458	Californian coast (117ºW, 34ºN)
14 May 1718	Californian coast (111ºW, 37ºN)
15 May 0435	Gulf of California (110ºW, 26ºN)
16 May 1818	Pacific Ocean (125ºW, 35ºN)
17 May 0537	Pacific Ocean (128ºW, 35ºN)
17 May 1757	Californian coast (120ºW, 35ºN)
18 May 0515	Californian coast (121ºW, 32ºN)
18 May 1735	Californian coast (110ºW, 39ºN)
19 May 0455	Californian coast (115ºW, 35ºN)
19 May 1715	Californian coast (110ºW, 35ºN)
21 May 1815	Pacific Ocean (124ºW, 33ºN)
22 May 0534	Pacific Ocean (128ºW, 37ºN)
22 May 1753	Californian coast (118ºW, 37ºN)
23 May 0512	Californian coast (121ºW, 34ºN)
23 May 1732	Californian coast (113ºW, 37ºN)
24 May 0451	Californian coast (116ºW, 34ºN)
24 May 1711	Californian coast (108ºW, 37ºN)
26 May 1811	Pacific Ocean (123ºW, 35ºN)
27 May 0530	Pacific Ocean (126ºW, 36ºN)
27 May 1749	Californian coast (117ºW, 38ºN)

Table 1: List of SALSTICE overpasses in which IASI on Metop-B was planned to be put in nadir-viewing geometry. Due to flight cancellations, only the highlighted (in purple) IASI overpasses were indeed performed in this mode and only on 24th May a coincident file could be performed.

This paper will give an overview of the inter-comparisons between IASI and ARIES spectra. As a first step, an overview of the method of the methodology used to perform the comparison of spectra coming from two instruments with different spectral resolution will be exposed. We will then present results of the comparison on some selected cases both for IASI on Metop-A and on Metop-B, and both over land and sea. An analysis of the observed difference using modelled radiances will conclude the paper.

II. METHODOLOGY

Because IASI and ARIES have a different spectral sampling, namely 0.25 cm^{-1} and 0.4822 cm-1 respectively, comparing the measurements would require transforming IASI spectra into ARIES-like equivalents taking into account the response functions of the instruments. We have used a different approach, making use of the possibility is to compare spectra into a set of micro-bands, chosen so that the average spectral transmission within them is flat. In such windows, the effect of the instrument function is negligible and the radiances can thus be compared directly. Sixty-one of such bands have been selected, most of them being located in regions where the spectral radiance is maximum (low atmospheric transmission). Figure 1 shows, as an example, the location of the first 8 micro-bands overplotted on a typical IASI spectrum.

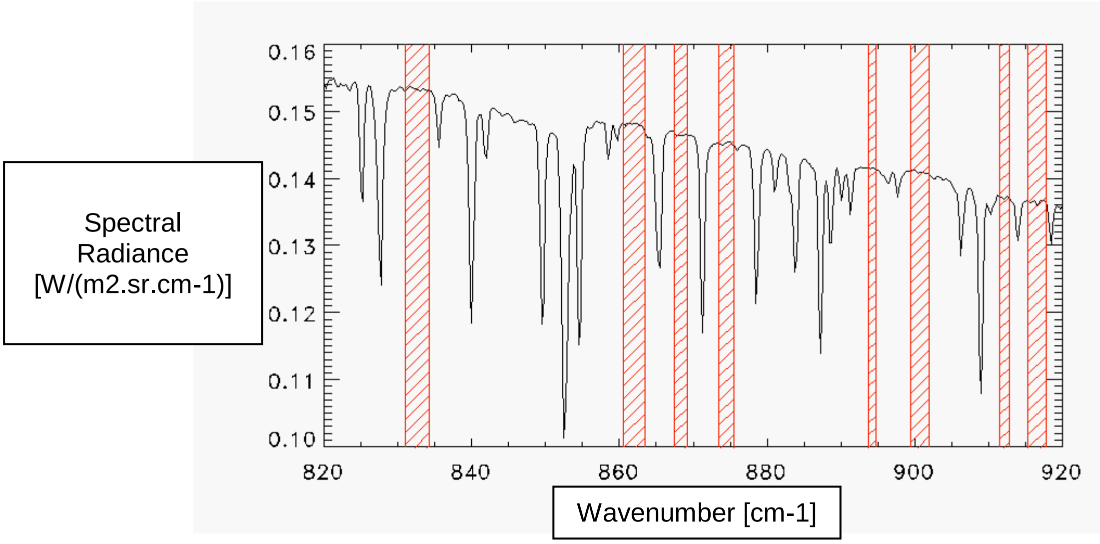

Figure 1: location of the first 8 micro-bands used for the ARIES/IASI inter-comparison over a IASI spectrum.

However, in order to increase the range of radiances retained for the computation, some bands located where the atmospheric absorption is high have been added.

III. CASE STUDIES

A total of nine flights have been performed from 11 to 25th May 2013 either over land or over the Gulf of California, all of them in clear or slightly cloudy conditions (Table 2). We present in this section a selection of case studies as an overview of the comparisons that have been performed. We will first discuss the land cases for both IASI-A and IASI-B, followed by sea cases also for both instruments including the case of the 24th May on which IASI-B was put in nadir-viewing mode.

Day in May 2013	11	12	15	16	19	21	23	24	25
Scene	Land	Land	Ocean	Ocean	Land	Ocean	Ocean	Ocean	Land
Metop	A & B	A	B	A	B	A	B	B	A & B
Comment	Cloudy	Cloud-free			No ARIES meas. at the time of the overpass	Cloud-free	Cloud-free	IASI in nadir-viewing mode	Cloudy

Table 2: list of the ARIES/Metop coincidences during the SALSTICE campaign.The cases highlighted in red are the ones discusssed in this paper.

1. Land case: 12th May 2013 (comparison with IASI-A)

The flight on the 12th May was dedicated to land-surface and was performed over Arizona, east of Tucson. Metop-A overflew the zone almost at zenith at 17:06 UTC; Metop-B, on the other hand, was at most 30 degrees above the horizon at 18:01 UTC. The quite complicated flight track is plotted on Figure 2 along the IASI-A footprints over a GoogleEarth view of the area while Figure 3 shows the ARIES radiance measurements in micro-band 6 (900 cm^{-1}) along with the corresponding IASI observations in the same band plotted over a RGB composite of the AVHRR images. Some small clouds are visible on the latter in the south-eastern part of the area.

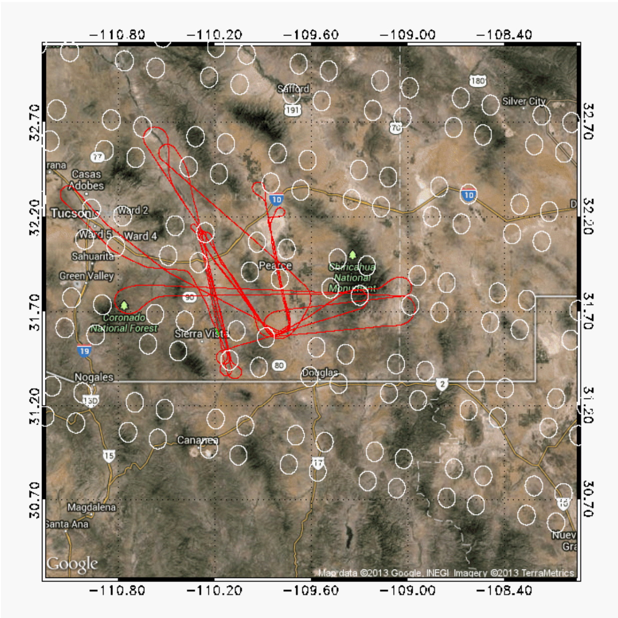

Figure 2: track of the 12 May flight (in red) along with IASI-A footprints (in white). The section of the flight corresponding to the Metop-A overpass (that occurred at 17:06 UTC) is shown in green (at -110.20 degrees longitude and 31.50 deg. latitude).

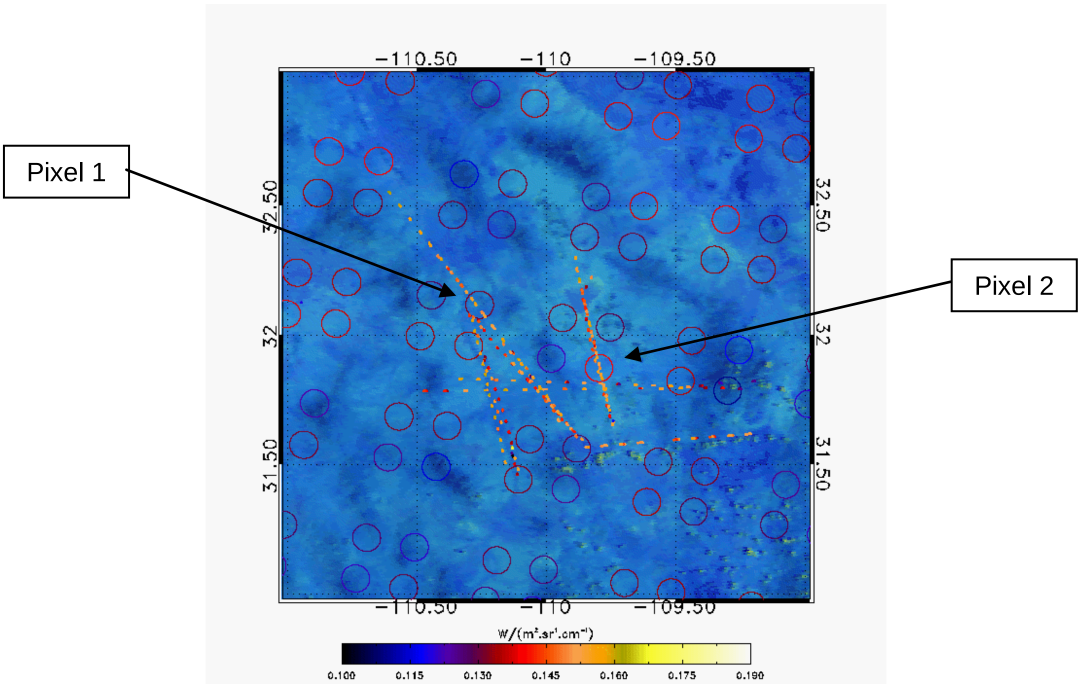

Figure 3: IASI-A measurements of the brightness temperature at 900 cm-1 (ellipses) along with the corresponding ARIES measurements (dotted line) over an RGB composite of AVHRR. The two IASI pixels for which we have performed a comparison are marked.

We have chose 2 IASI pixels to perform the comparison (identified on Figure 3). In each of them the IASI spectrum is compared with the average of several ARIES spectra. The spectral difference IASI-ARIES for pixel 1 is plotted on Figure 4. It appears that the brightness temperature difference in the window channels between 800 and 900 cm-1 ranges from -15 to -20 K due to the difference in the spatial resolutions of the instruments: over heterogeneous terrains, ARIES measurements, with their spatial resolution of the order of some hundred meters, cannot be directly compared to IASI spectra, averaged over more than 10 kilometres. The difference in the water vapour channels is, on the other hand, much lower and almost zero, denoting clear sky conditions as both instruments “see” the same water vapour content although being at different altitudes.

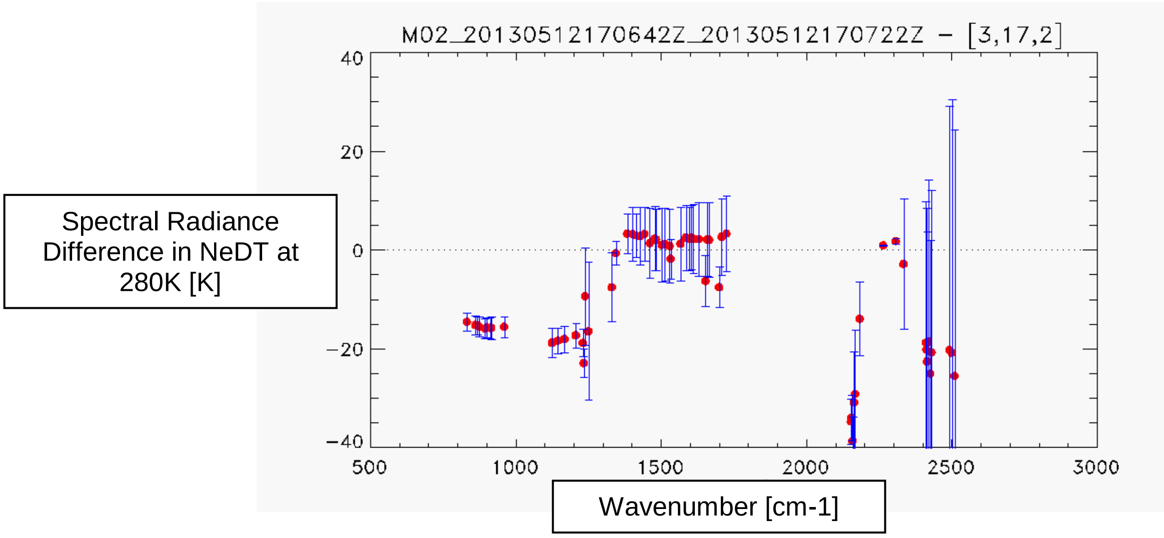

Figure 4: Radiance difference IASI-ARIES expressed in NeDT at 280 K in 61 micro-bands for pixel 1 on Figure 3.

On the other hand, if we focus now on the IASI pixel 2 located in the centre of the image (see Figure 3), it turned out that the difference between IASI and ARIES is large (of the order of -30 K) in the water vapour channels while there is a very good agreement in the surface channels although with a very high variability (Figure 5).

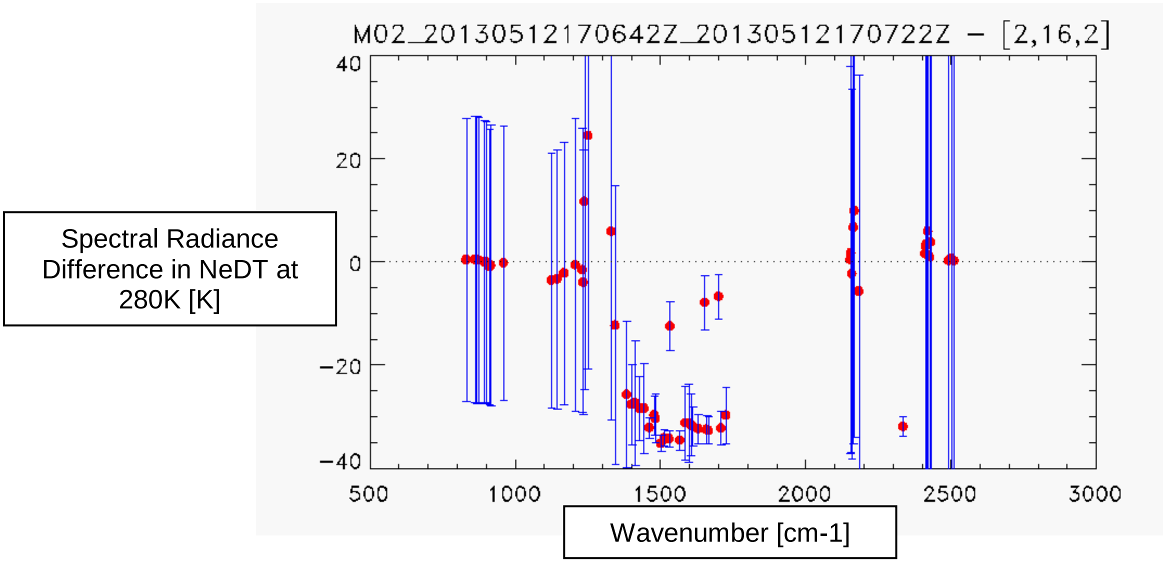

Figure 5: Radiance difference IASI-ARIES expressed in NeDT at 280K in 61 micro-bands for pixel 2 on Figure 3.

Because one IASI spectrum is compared to an average made of several ARIES spectra acquired over several passes, the differences observed can be attributed to:

- Surface heterogeneities seen by ARIES thanks to its much better spatial resolution (350 m as compared to 12 km);
- Changes in atmospheric conditions between successive ARIES passes.

Indeed, in each pass the brightness temperatures measured by ARIES range from 314 to 324 K.

This also explains the large error bars on the difference in this spectral domain. On the other hand, the huge gap between IASI and ARIES in the water vapour region suggests contamination by clouds: even if the IASI pixel is only partially covered by clouds, the average temperature detected by IASI will be lower than the one detected by ARIES at the same wavenumber if it's taken in clear sky conditions.

2. Land case: 19th May 2013 (IASI-B)

On 19th May, a flight was performed over Arizona (see flight track on Figure 6) in coincidence with a close Metop-B overpass that occurred at 17:17 UTC (metop-B was then almost at an elevation of 85.5 degrees i.e. almost at zenith).

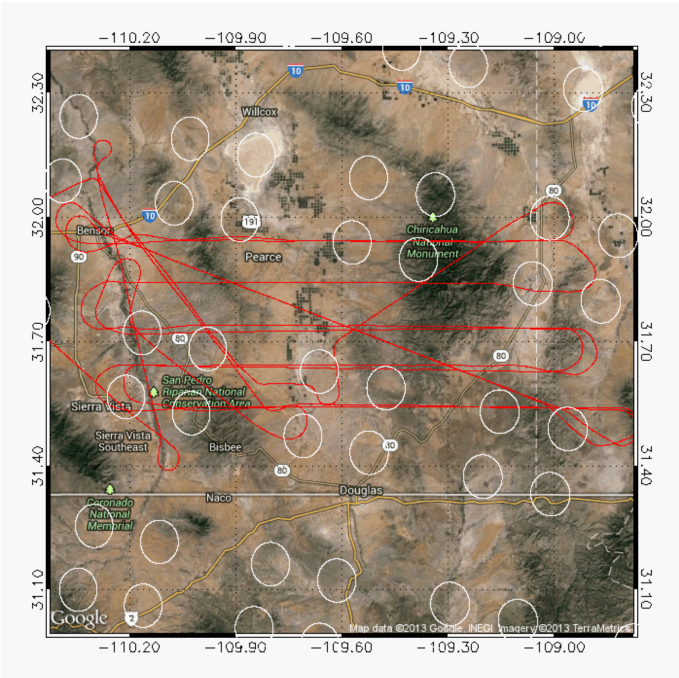

Figure 6: track of the 19th May flight (in red) along with IASI-B footprints (in white) over a GoogleEarth view of the area. Metop-B overpass occurred at 17:17 UTC.

Although the AVHRR composite does not reveal the presence of any clouds, ARIES measurements seem again to be slightly warmer than the corresponding IASI ones, especially in the south-west quadrant of the area (figure 7).

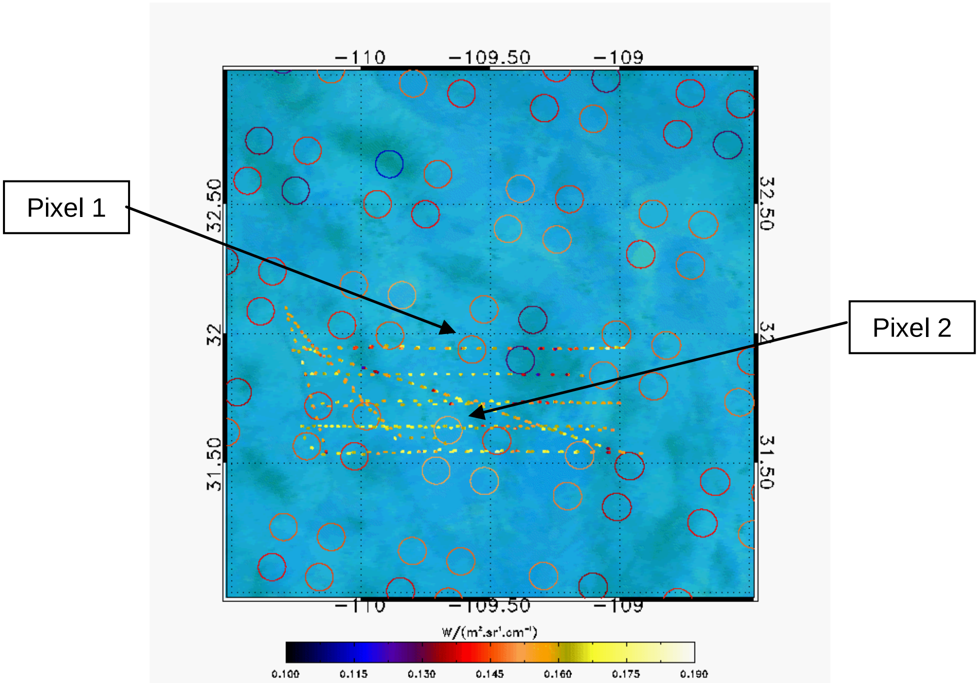

Figure 7: IASI-B measurements of the brightness temperature at 900 cm-1 (ellipses) along with the corresponding ARIES measurements (dotted line). The two IASI pixels for which we have performed a comparison are marked.

This is especially visible on the spectral difference IASI-ARIES for pixel 1 (Figure 8). It must be noted however that ARIES measurements performed in the area covered by this particular IASI footprints are made up of essentially two passes: one around 20:00 UTC when the brightness temperatures at 900 cm-1 range from 324 to 332 K and another one much later, around 21:50 UTC, during which the brightness temperature at 900 cm-1 were ranging between 303 to 324 K. All ARIES measurements have thus been made in this area significantly later than the IASI overpass (17:17 UTC). This could indicate the presence of clouds at some point during the day. It is thus not possible to draw significant conclusions from this particular comparison.

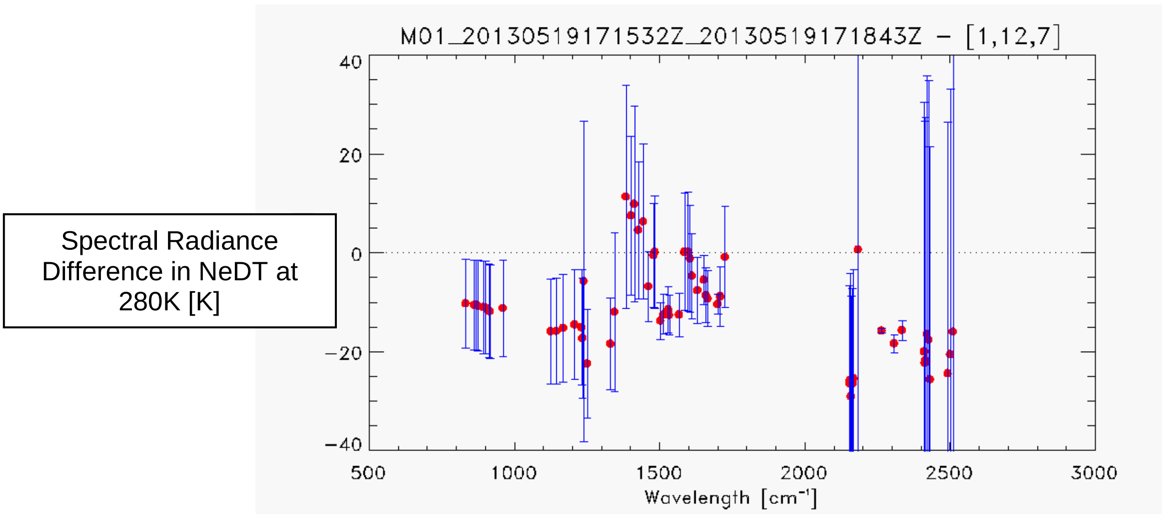

Figure 8: difference IASI-ARIES expressed in NEDT in 61 micro-bands for 1 IASI-B pixel 1 on Figure 7.

We consider now the IASI pixel 2 (see Figure 7). ARIES measurements obtained in the area corresponding to the footprint were obtained at 19:00 UTC and 20:50 UTC, again significantly after

IASI overpass; also, the temperatures measured at 20:50 are lower than the earlier ones but the dispersion is lower: temperatures at 900 cm-1 range from 326 to 331 K for the first pass and from 324 to 327 K for the second pass. The spectral difference (Figure 9) exhibit the same discrepancy in the surface channels as noted previously with a temperature difference ranging from -10 to -15 K. The difference in the water vapour channel is of the same order however.

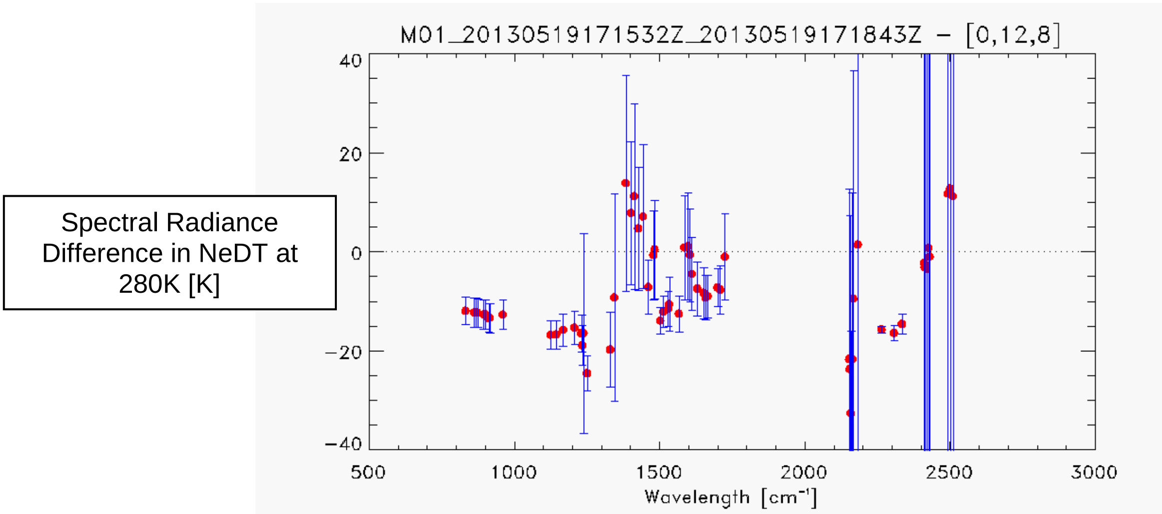

Figure 9: spectral difference IASI-ARIES expressed in NEDT in 61 micro-bands for 1 IASI-B pixel 2 on Figure 7.

3. Sea case: 23[rt] May 2013 (IASI-B)

The flight of the 23[rd] May was performed over the Gulf of California when a good overpass by Metop-B occurred (80 degrees elevation at 17:34 UTC); the flight track and IASI footprints are plotted on Figure 10.

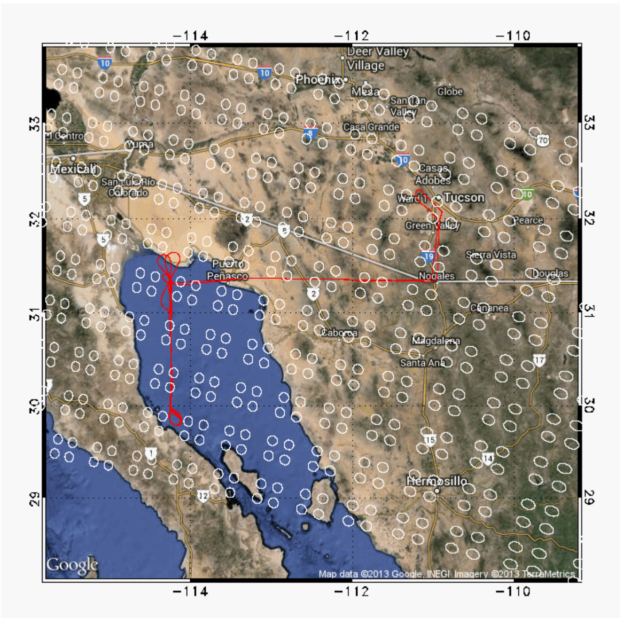

Figure10: track of the flight of the 23rd May (in red) along with IASI-B footprints (in white). The section of the flight corresponding to the Metop-B overpass (that occurred at 17:34 UTC) is shown in green.

There are no signs of clouds on the corresponding AVHRR composite (Figure 11).

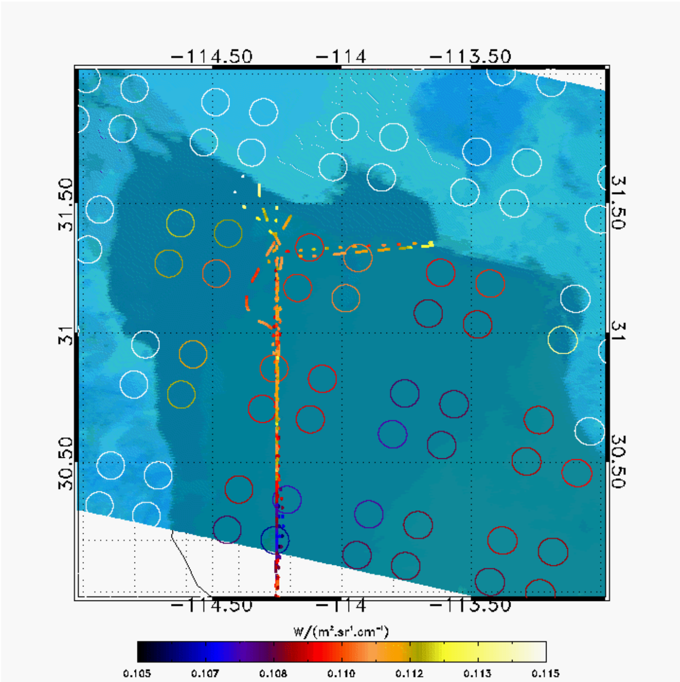

Figure 11: IASI-B measurements of the brightness temperature at 900 cm-1 (ellipses) along with the corresponding ARIES measurements (dotted line).

Figure 12 shows the radiance measured by both instruments at 900 cm-1 as a function of latitude; only the IASI measurements performed along the track have been plotted. There is a good agreement between both series at least south of 31.2 degrees latitude when the measurements are performed at a constant altitude; this is the part we will focus on.

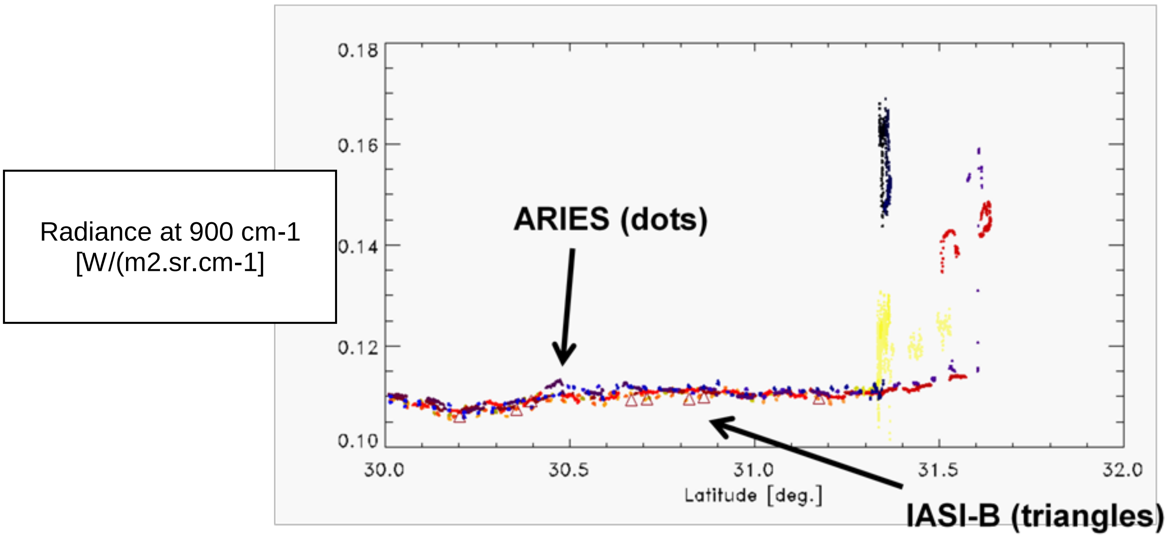

Figure 12: IASI-B (triangles) and ARIES (dots) measurements of the radiance at 900 cm-1 as a function of latitude. The colours correspond to the time after the start of the flight.

When plotting the the radiance measured by ARIES as a function of time (Figure 13), we see that the temperatures measured at the beginning and end of the flight were much higher than those obtained between 17:00 and 18:00 UTC i.e. at the time of the Metop overpass. Furthermore, during this interval, the ARIES brightness temperatures at 1503 cm-1 are quite comparable to the value measured by IASI. The comparison is thus done by focusing on this time interval, around the IASI overpass. The resulting spectral difference is plotted on Figure 14, showing a better agreement between the two instruments in comparison with the land cases.

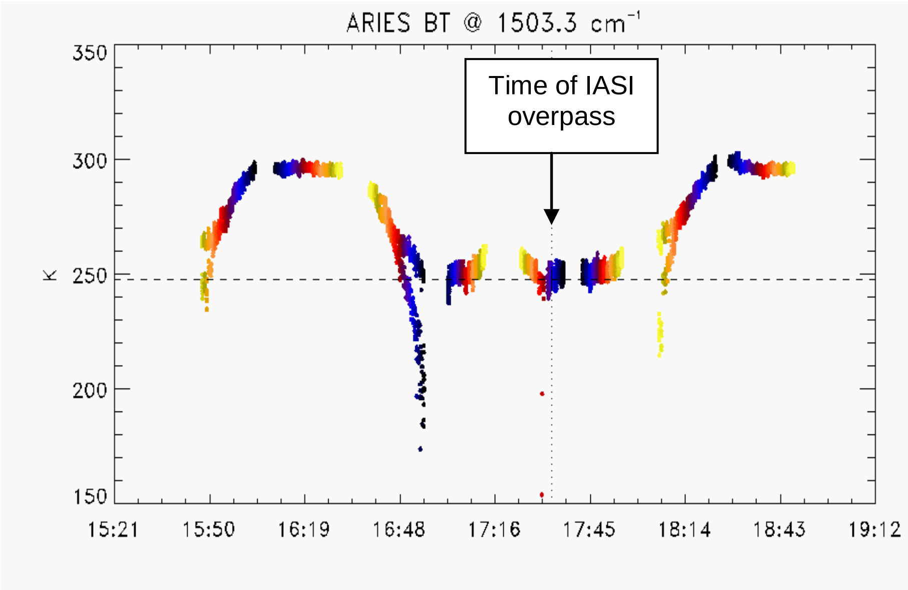

Figure 13: time series of the brightness temperature at 1503.3 cm-1 (6.65 µm) measured by ARIES on the 23rd May in the latitude range 30-31.2 degrees; the colours denote the latitude. The vertical dotted line marks the time of the Metop-B overpass while the horizontal dashed line is the average temperature measured by IASI at the same wavenumber; the standard deviation of IASI measurements is 5K.

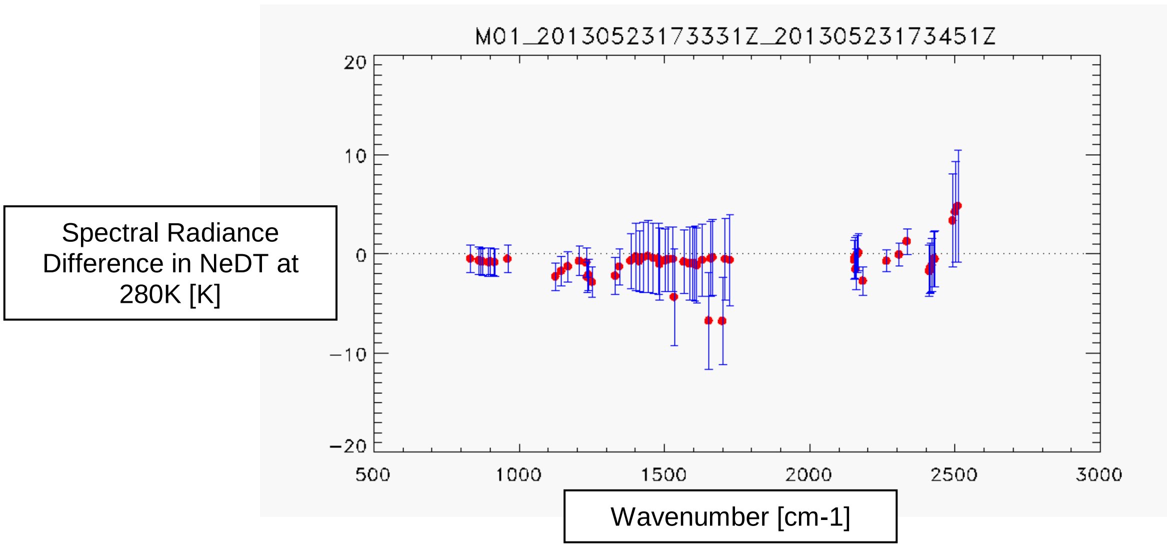

Figure 14: spectral difference IASI-A - ARIES expressed in NEDT in 61 micro-bands, averaged over the 7 IASI footprints intercepting the flight track, taking only ARIES measurements performed between 17:00 and 18:00 UTC into account.

4. Sea cases: 24th May 2013.

The flight on the 24th May deserves special attention. It was also performed over the Gulf of California and IASI on Metop-B was put in external calibration mode. All measurements are then performed at nadir. The flight plan was chosen so that the flight path follows the satellite track as seen on Figure 15.

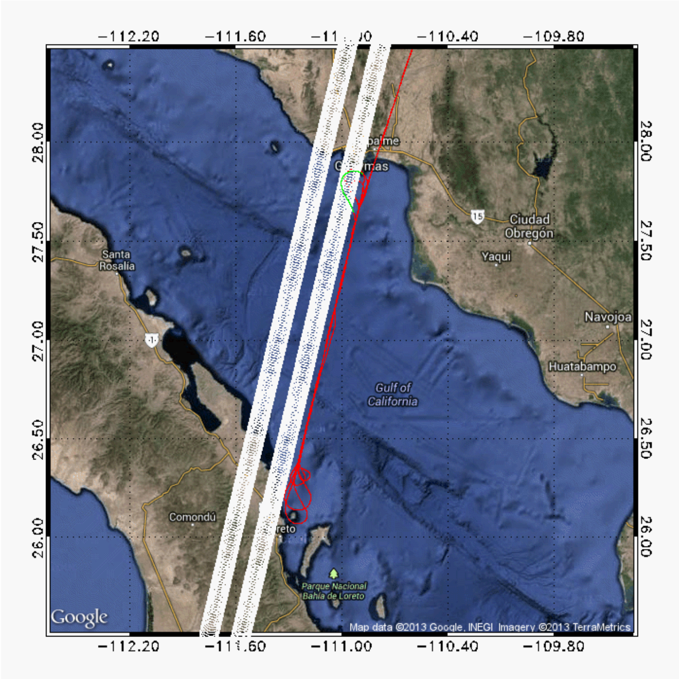

Figure 15: track of the flight of the 24th May (in red) along with IASI-B footprints (in white). The section of the flight corresponding to the Metop-B overpass (that occurred at 17:13 UTC) is shown in green.

On Figure 16 are plotted the brightness temperatures measured at 900 cm-1 by both instruments over an AVHRR composite. Some cirrus are visible in the northernmost part of the area, north of 27.4 degrees in latitude. IASI temperatures exhibit a slight variation with latitude that is not visible in ARIES measurements.

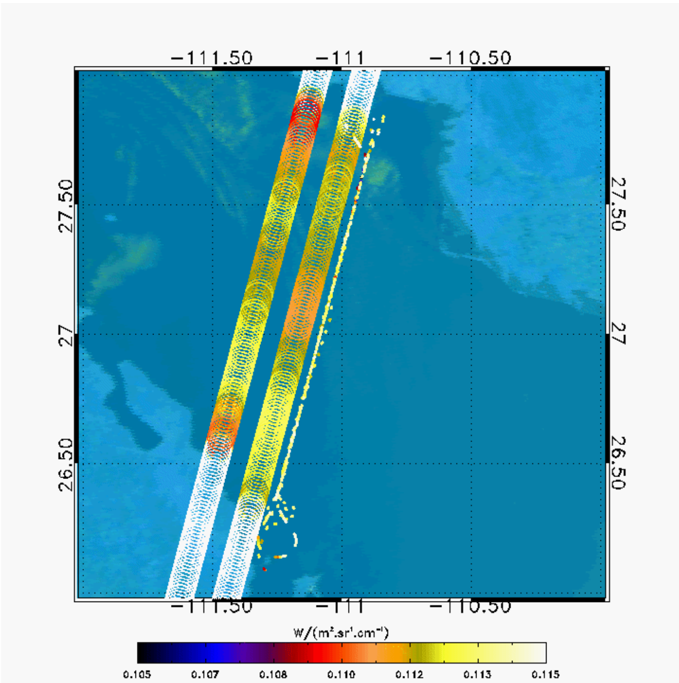

Figure 16: IASI-B measurements of the brightness temperature at 900 cm-1 (ellipses) along with the corresponding ARIES measurements (dotted line).

The flight however was performed from 15:50 to 18:50, period in which the brightness temperature at 900 cm-1 over ocean exhibits some variations (Figure 17). In order to compute the spectral difference, we thus focused on the 10 minutes before and after the IASI overpass and excluding the measurements taken north of 27.5 degrees latitude where cirrus seem to be present.

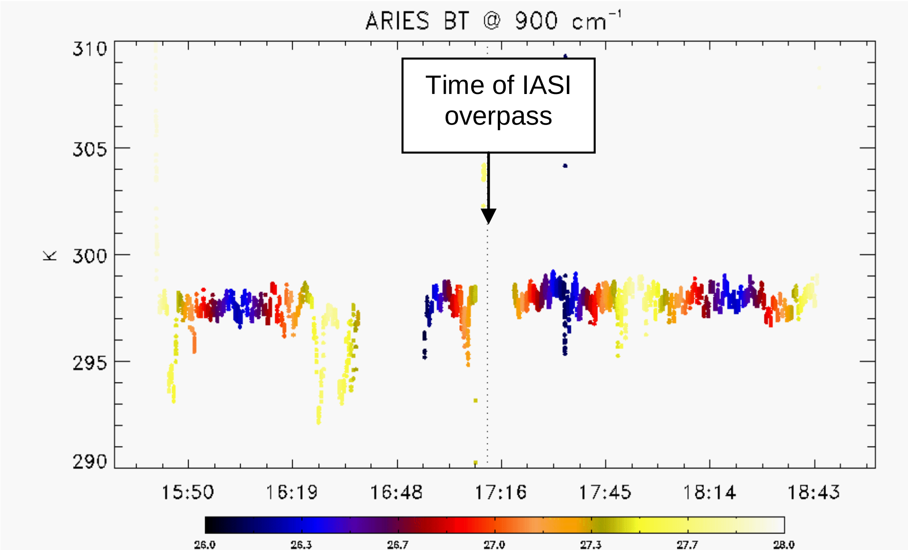

Figure 17: timeseries of the brightness temperature measured by ARIES at 900 cm-1 as a function of time on the 24th May. The points are coloured according to their longitude. The vertical dotted line marks the time of the Metop overpass

It is shown on Figure 18 which exhibits a good agreement between both instruments although ARIES appears to be warmer by about 1 or 2K depending on the wavenumber. It can be noted that this is the only spectral difference in this series computed from 92 IASI pixels, making it statistically more significant.

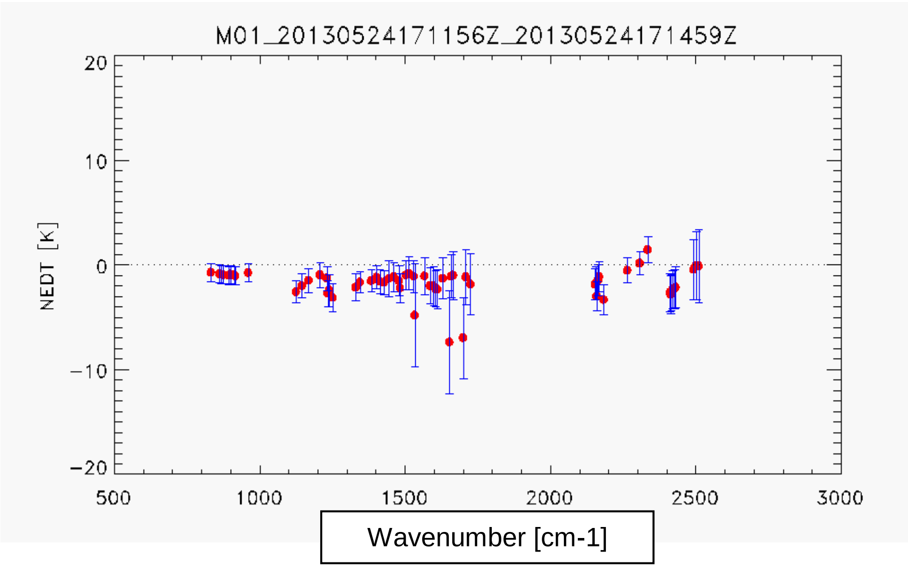

Figure 18: difference IASI-A - ARIES expressed in NEDT in 61 micro-bands averaged over 92 IASI pixels on 24th May 2013.

IV. MODELLING OF THE OBSERVED BIAS BETWEEN IASI AND ARIES

The systematic bias between IASI and ARIES brightness temperatures can be attributed to the difference in observation level: ARIES measurements were indeed performed between 8000 and 10000 m altitude that is lower than the tropopause. This could explain why ARIES is always slightly warmer since it does not see the coldest regions of the atmosphere. In order to assess the validity of this hypothesis, we have simulated synthetic spectra as they would be observed over sea by IASI at both 10 km and 800 km altitude. We didn't attempt to simulate ARIES spectra for the lack of information about the instrumental response function.

The synthetic spectra have been computed using the software package 4A/OP that is the operational version - developed by NOVELTIS with the support of CNES - of the 4A forward radiative transfer model from Laboratoire de Meteorologie Dynamique (LMD). The 4A calculations rely on a multi-dimensional interpolation of pre-built optical thickness databses called „Atlases" created from the line-by-line model STRANSAC using the spectral line catalogue GEISA [3].

4A/OP has been fed using the vertical profiles of temperature, humidity and ozone from the ERA-Interim reanalysis by ECMWF. Computations have only been done over sea and under clear-sky conditions. Figure 19 shows two synthetic IASI spectra computed for the 24th May 2013 over the Gulf of California at 800 km altitude (in red) and 10 km altitude (blue).

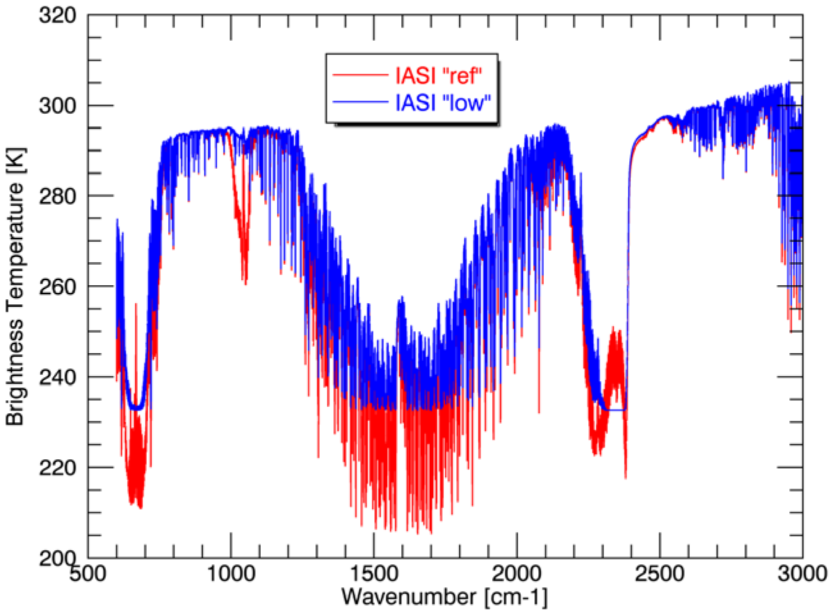

Figure 19: synthetic IASI spectra simulated with 4AOP with an observation height of 10km (blue) and 800km (red).

Figure 20 shows the spectral difference between the two synthetic spectra at full resolution. Clearly apparent is the fact that the „low" IASI does not see the airmass above 10 km altitude with respect to the „reference" IASI in the water vapour channels (between 600 and 700 cm-1 and 1300-2000 cm-1) and especially in the ozone channels (between 1000 and 1100 cm-1) where the difference is the highest and reach more than 20 K.

In the comparisons presented above, the difference IASI minus ARIES has been computed in a set of micro-windows in which the radiances of both instruments are averaged. Repeating the same methodology for comparing the synthetic spectra yields the difference shown on Figure 21 that represents the lowest possible difference in brightness temperature that can be observed when comparing two identical instrument flying one at 10 km the other at 800 km altitude. The difference is zero in the surface channels, of the order of 1 K in the water vapour channels (warmer at 10km) that is of the order of what we observed when we compared IASI and ARIES in clear sky conditions over sea (Figure 14 or 18).

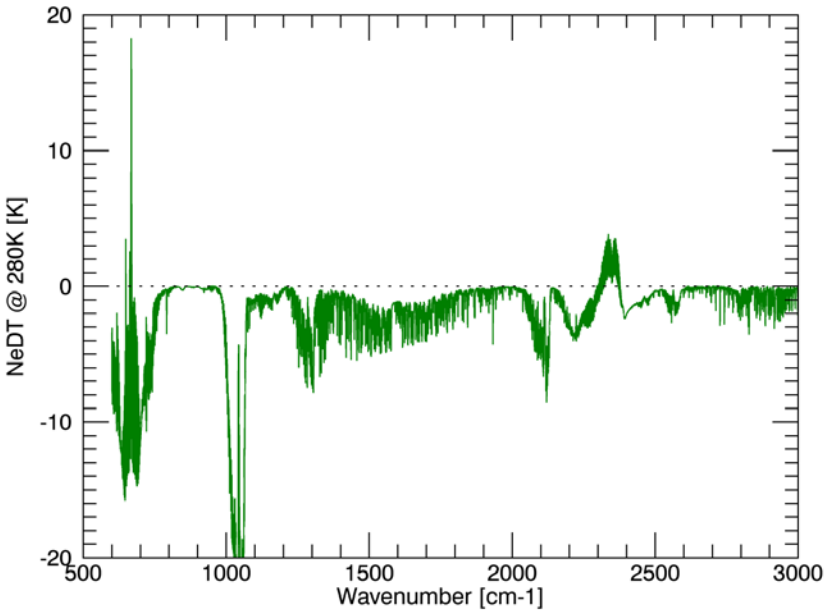

Figure 20: spectral difference between two synthetic IASI at 10km (blue) and 800km (red) at full resolution.

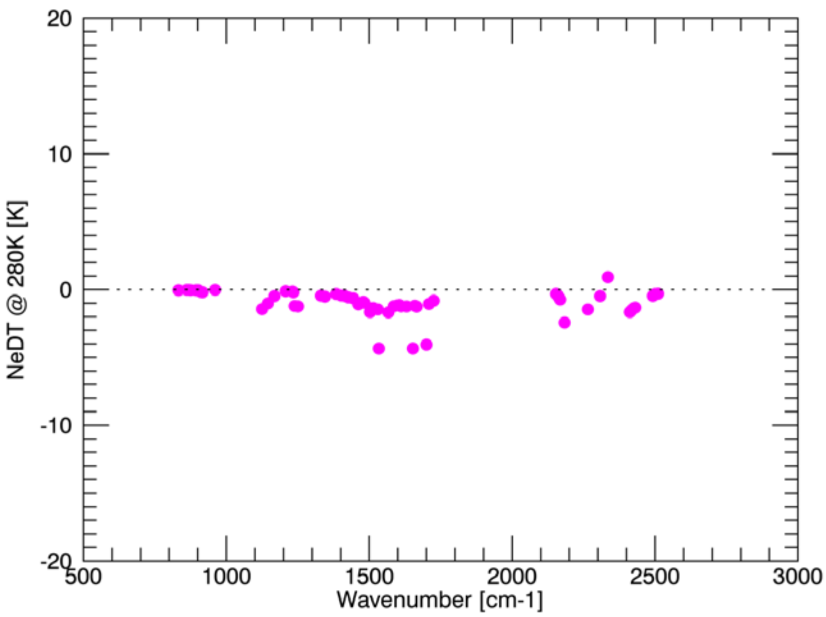

Figure 21: spectral difference between two synthetic IASI at 10km (blue) and 800km (red) in the set of 61 micro-windows used in this study.

V. CONCLUSION

Nine flights have been performed from 11 to 25 May 2013, four of them over Arizona being dedicated to land-surface processes, the others over the Gulf of California. All flights have been performed in clear or almost clear sky conditions.

For each flight, we have plotted the flight track along the corresponding IASI footprints during at the time of the overpass, a RGB composite from the AVHRR image taken at the time of the overpass in order to assess the possible presence of clouds and or differences in surface temperature, as well as a comparison of the radiance measured by both instruments.

The main findings are summarized in Table 3. Overall it appears that:

- In all cases: the comparisons that we have performed show that ARIES brightness temperatures are warmer than IASI ones.
- Over Land: IASI with ARIES radiances do not match: even in the surface channels, ARIES is warmer than IASI by about 10K. Due to the difference in the spatial resolution of both instruments, such a comparison is very challenging over heterogeneous terrains.
- Over Sea: IASI and ARIES observations exhibit a much better agreement. In those cases, we have found that both instruments agree within 1K, ARIES being still slightly warmer than IASI.
- No differences were observed when the comparison was performed with IASI-A or with IASI-B; both instruments appear to be very similar.

Date In May 2013	Scene	Metop	Comparison IASI-ARIES	Comments	Pertinence for this study
11	Land	A, B	Very poor: • -10K in surface channels • -40K in water vapour	Cloudy	Not relevant
12	Land	A	Difficult to conclude: some pixels show very good agreement in surface channels and very bad in water vapour, some just the other way around.		Inconclusive
15	Ocean	B	Good: • -1K in surface channels • -2K in water vapour	All ARIES measurements have been taken, including those performed at more than 1 hour from the time of the overpass	Good case with some issues in the WV
16	Ocean	A	Good: • -1K in surface channels • -2K in water vapour	Id.	Good case with some issues in the WV
19	Land	B	Very poor: • -15K in surface channels • Maybe slightly less in water vapour channels but very high variability	No ARIES measurements at the time of the overpass	Hardly conclusive
21	Ocean	A	Very good: • -1K in surface channels • Large error bars in water vapour		Good comparison
23	Ocean	B	Excellent: • -1K everywhere		Very good comparison
24	Ocean	B	Very good: • -1K in surface channels • -2K in water vapour	IASI in special mode; Some clouds	Very good comparison
25	Land	A and B	Poor: • -5K in surface channels • -20K in water vapour	Cloudy	Hardly conclusive

Table 3: summary of the comparisons IASI-ARIES for each flight

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