INTERCOMPARISON OF IASI AND CRIS SPECTRA

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Abstract

The spectral characteristics of the Cross-track Infrared Sounder (CrIS) instrument are very close to those of the two Infrared Atmospheric Sounding Interferometer (IASI) flying on Metop-A and Metop-B. We have taken advantage of this property to set up a monitoring of the quality of the CrIS products disseminated by EUMETSAT. Direct comparisons over Simultaneous Nadir Observations (SNOs) as well as indirect comparisons using the double differences technique provide us with an assessment of the relative consistency of both instruments.

This paper reviews the methods and observations that we have used. The analysis of the IASI and CrIS differences over the past months is presented, showing that both instruments are radiometrically consistent within less than 0.2 K.

INTRODUCTION

In the frame of its agreement with NOAA, EUMETSAT is distributing products from the Cross-track Infrared Sounder (CrIS) instrument to the users via the EUMETCAST network. No processing is performed at EUMETSAT, except decoding the original files and repacking data into BUFR files. This distribution has taken place since August 2012 and was further improved in spring 2013 with the inclusion of the cloud fraction measured in each CrIS pixel by the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument: VIIRS and CrIS products are decoded, collocated and merged into a single file, then pushed to the users. EUMETSAT is thus distributing about 2700 CrIS/VIIRS products a day.

CrIS and VIIRS are flying on the Suomi National Polar-orbiting Partnership (NPP) satellite since October 2011. CrIS is a Fourier transform spectrometer sounding the atmosphere with 1305 spectral channels from 4.64 µm to 15.38 µm (650 to 2155 cm-1). From its spectral characteristics but also spatial resolution (CrIS measurements consist in 30 Earth-views over a 2200km wide swath, each view providing 9 pixels with a spatial resolution of 14km at nadir), CrIS is very similar to the two Infrared Atmospheric Sounding Interferometer (IASI) flying on Metop-A since July 2006 and on Metop-B since September 2012. This eases the assessment of the radiometric consistency between these hyperspectral IR sounders.

Inter-calibrating IASI and CrIS has two objectives:

- To monitor the quality of the CrIS/VIIRS products that EUMETSAT is disseminating. Indirectly, such a monitoring also provides a feedback on the quality of IASI;
- To provide a new inter-calibration using IASI that could be used in the GSICS framework: IASI-A has indeed proved an excellent reference and the commissioning of IASI-B has shown that both instruments are of similar quality.

Such an inter-comparison can be performed using two approaches:

- A direct comparison of coincident measurements when the tracks of the two satellites cross at high latitudes .i.e. the so-called simultaneous nadir overpasses (SNOs). IASI/CrIS pairs pixel pairs can thus be selected so that both instruments are observing the same scene at the same time;
- An indirect comparison using a third reference, namely the double-differences technique. Several studies have been conducted using SST observations from a third satellite, often

geostationary, as reference (see for instance, Wang *et al*., 2010). We have chosen to use instead radiative transfer calculations fed with NWP fields.

SPECTRAL CONVOLUTION

While IASI has a uniform spectral sampling of 0.25 cm^{-1} over its whole spectral range, CrIS sampling is different in each of the three bands that form a CrIS spectra: it is of 0.625 cm^{-1} in band 1, 1.25 cm^{-1} in band 2 and 2.5 cm^{-1} in band 3. Comparing the measurements thus requires transforming IASI spectra into CrIS-like equivalents taking into account the response functions of the instruments. It consists in resampling and apodising IASI measurements with the CrIS instrument function, as shown on Fig. 1.

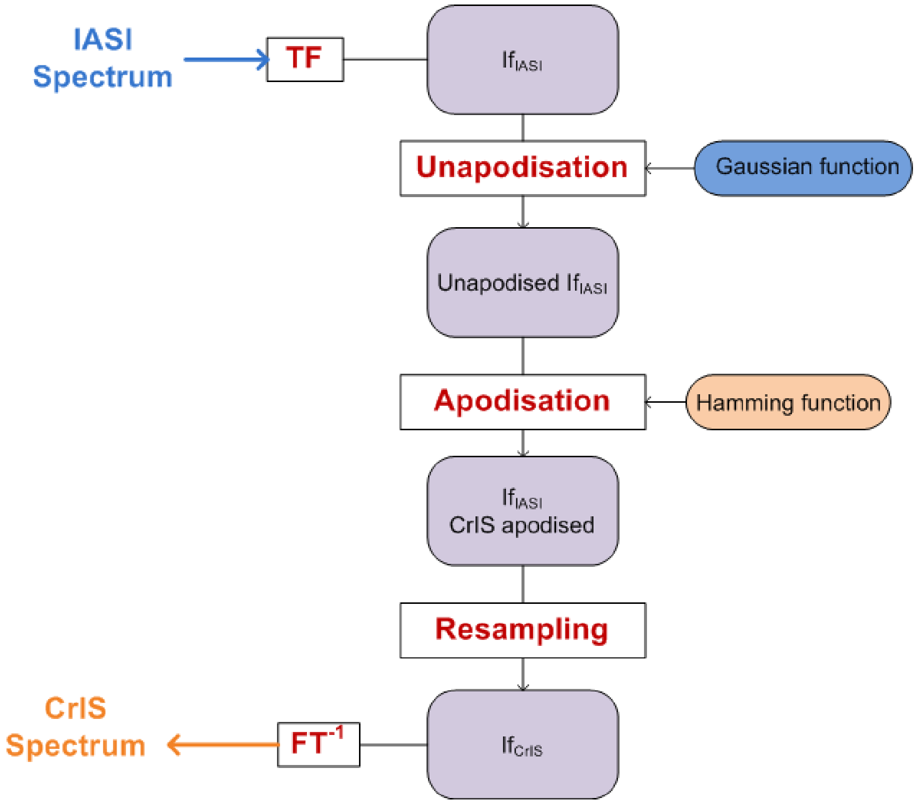

Figure 1: **flowchart of the transformation of a IASI spectrum into its CrIS-like equivalent.**

SIMULTANEOUS NADIR OBSERVATIONS

Suomi-NPP is orbiting at an altitude of 825 km, the local time of the ascending node crossing being 13:30. The two Metop are slightly lower, 817 km, and the local equator crossing time at the ascending node is 21 hours 30. The two orbits are thus not in the same plane and the tracks cross at high latitudes so that CrIS and IASI can see the same regions at the same time.

IASI and CrIS pixels are considered as pairs if:

- they are separated by a distance smaller than 6.5 km;
- they are separated by less than 2 minutes;
- the satellite zenith angles are similar, namely linked by the relation
- the IASI pixel (that is larger than the corresponding CrIS one) is either clear (cloud coverage less than 1%) or completely cloudy (cloud coverage larger than 99%).

The first two criteria are driving the occurrence frequency of the SNOs. With these values, we have SNOs every orbit for about 1 day, i.e. about 1000 IASI/CrIS pixel pairs both in northern and southern polar latitudes, every 7 weeks for a given Metop.

An example of the geographical distribution of CrIS and IASI pixels during such an event is shown on Fig. 2 over an AVHRR image over Siberia in July 2013. The crossing point of the satellites tracks is in the centre of the image, where most of the pairs are located due to the restriction that the satellite zenith angle should be similar.

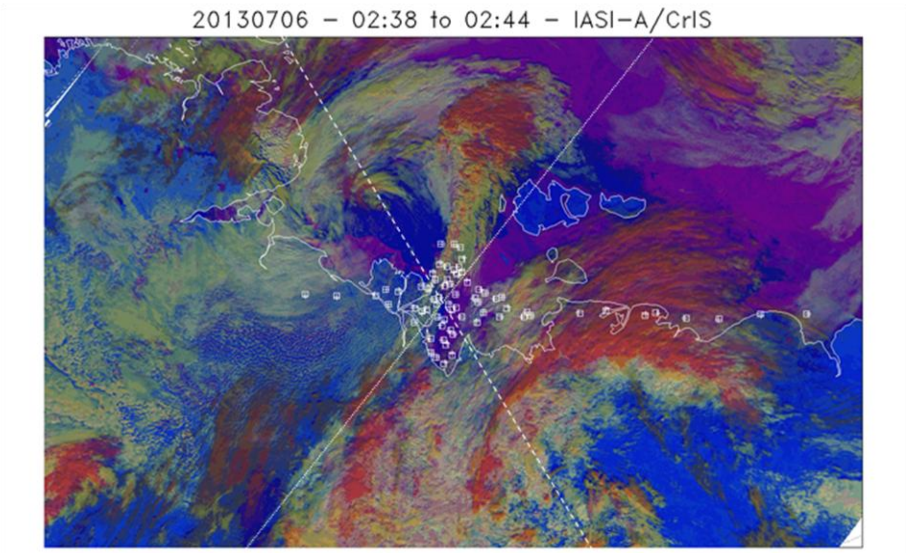

Figure 2: **geographical distribution of the IASI (+ signs) and CrIS (squares) pixels selected for the comparison during a single SNO event between Metop-A and NPP on 6th July 2013 around 02:40. The straight lines are the satellite tracks. The background in an AVHRR image in false colours in which sea appears as deep blue, land as light blue, sea ice as purple and clouds are in white-green-red.**

The spectral radiances of each instrument are then averaged over all selected pixels pairs and, possibly, over several SNO events. In addition, we distinguish between northern and southern coincidences as, depending on the season, either one or the other could be contaminated by the permanent solar light making the comparison difficult. The difference can then be calculated provided that the averaged IASI spectrum is transformed into the CrIS-like equivalent using the method described above. Fig. 3 shows this difference for IASI-A over the boreal summer 2013 cumulating the IASI-A/NPP SNOs of the 6 July and 26-27.

The following features are noteworthy:

- An overall excellent agreement between IASI-A and CrIS: the spectral difference indeed never exceeds 0.2 K;
- An excellent agreement between northern and southern SNOs except in band 3 that is very sensitive to solar light;
- A definite tendency of CrIS to be slightly warmer at longer wavelength: the spectral difference IASI-CrIS exhibits a slope in band 1 for both Metop-A and Metop-B and for both northern and southern SNOs.

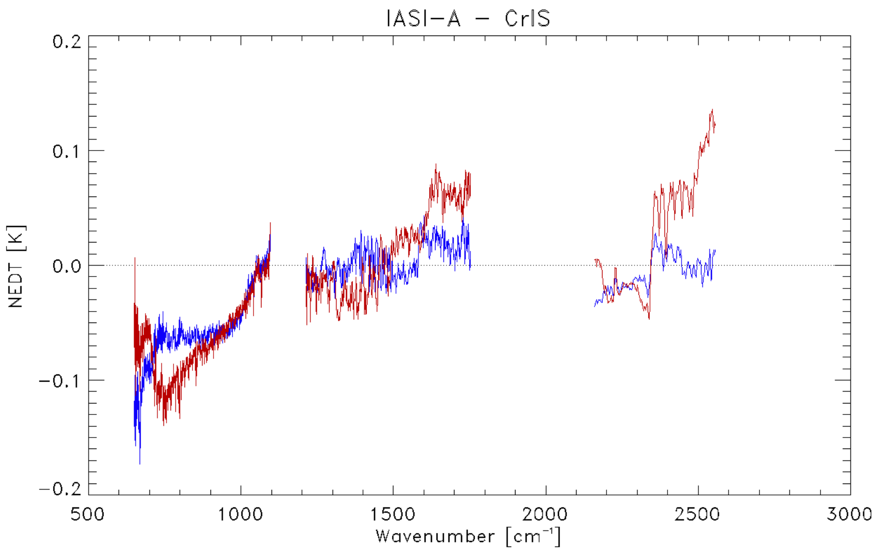

Figure 3: **average IASI-A - CrIS spectral difference expressed in NeDT for the northern (red) and southern (blue) coincidences.**

Figure 4 shows the spectral difference between both IASI-A and IASI-B and CrIS where we have merged the results of the northern and southern SNOs. Both differences agree remarkably well, emphasizing the excellent consistency between the IASI instruments aboard the two Metop. The features previously noticed when comparing IASI-A and CrIS thus still apply: an overall very good agreement between IASI and CrIS with the latter being slightly warmer in band 1. Noteworthy enough is the fact that the slope of the difference in band 1 is observed to be the same, being computed either with IASI-A or IASI-B. This would tend to indicate a flaw in the CrIS calibration process, possibly in the non-linearity correction.

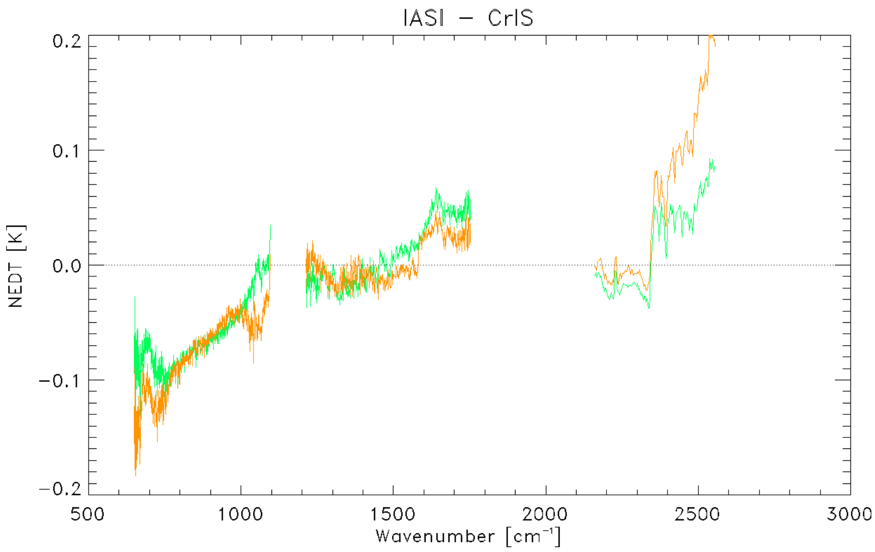

Figure 4: **average IASI-CrIS spectral difference for summer 2013 expressed in NeDT for Metop-A (green) and Metop-B (orange).**

DOUBLE DIFFERENCES

The double differences technique using synthetic spectra has been previously used in the past to assess the radiometric consistency of IASI and AIRS (see for instance Elliott et al. [2009]). It is a useful complement of the SNOs method as it permits to extend the comparison to a broader geographical area; also the evaluation of the radiometric consistency can be performed every day, without waiting for the SNOs to occur, thus allowing a daily monitoring of its quality.

In this method, IASI and CrIS spectra are simulated using RTTOV 10.2 fed with temperature and humidity taken from ECMWF forecast fields; as no information were available in the ECMWF fields on the distribution of trace gases, we have used standard profiles. These spectra, referred to as “CALC”, are compared with the corresponding observations (“OBS”). Assuming that there is no differences between the errors induced by the use of ECMWF fields as well as by the RTM in the simulation of both IASI and CrIS spectra, these errors cancel to first order when doing the double difference i.e. we have in average:

$$(\mathrm{OBS\text{-}CALC})_{\mathrm{IASI}}\text{-}(\mathrm{OBS\text{-}CALC})_{\mathrm{CrIS}} \cong \mathrm{OBS}_{\mathrm{IASI}}\text{-}\mathrm{OBS}_{\mathrm{CrIS}}$$

In this method, it is important to use the same criteria to select the scenes from both instruments. We have selected CrIS and IASI scenes obtained in the following conditions:

- close to nadir (satellite zenith angle lower than 10 degrees);
- by night time (sun zenith angle larger than 120 degrees);
- in mid-latitudes or the tropics (latitude lower than 60 degrees);
- over sea;
- by clear sky.

The selection of clear scenes has proven to be the most problematic criterion to implement. It indeed turned out that the cloud fraction provided in CrIS products available at EUMETAST is not really useable as illustrated in Fig. 5: most of CrIS pixels (about two-third, depending on the day) do not have a defined value of the cloud fraction. This is due to a time constraint when generating the merged CrIS/VIIRS products at EUMETSAT: the user specification was not to wait that all VIIRS files are available to generate and distribute the combined CrIS/VIIRS products; when VIIRS data are missing, the cloud fraction is set to “undefined”.

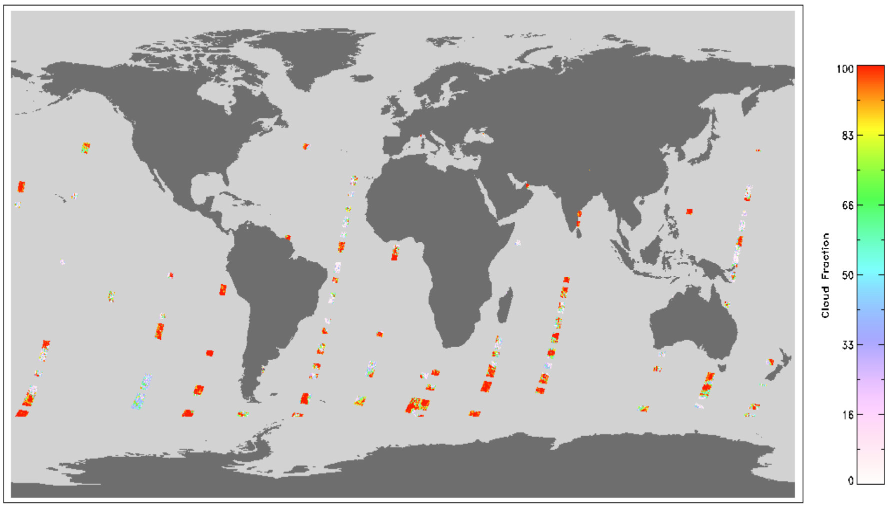

Figure 5: **Cloud fraction extracted from the combined CrIS/VIIRS products generated at EUMETSAT for the 28th August 2013.**

In order to alleviate this problem, we have implemented a cloud detection scheme that can be used on both IASI and CrIS spectra, mainly based on the brightness temperatures differences. Namely, we consider that a pixel is clear if:

- the brightness temperature at 11 microns (“surface channel” hereafter referred to as BT11) is larger than 280 K;
- the difference between BT11 and the surface temperature is larger than 0 and lower than 5K;
- the difference between BT11 and the brightness temperature at 3.9 microns is larger than -3K and lower than 1.5K;

- the difference between the observed and the computed spectra is lower than 1K in the channel corresponding to BT11.

Most of these criteria have already been used in previous studies. An overview is given in Ackermann *et al*. 2010. The last criterion, based on the OBS-CALC difference at 11 microns, is actually used in the cloud detection scheme of the IASI level 2 processing. Tentatively, the method described by Serio *et al*. 2000, based on a comparison of the autocorrelation of the spectra, has been implemented but did not give useable results when applied on CrIS due to the slightly too low spectral resolution of this instrument.

Applying these criteria yields two similar populations of observed IASI and CrIS spectra as illustrated on Fig. 6 that shows a comparison between the distribution of the brightness temperature at 900 cm-1 of the selected CrIS and IASI pixels. We have decided to run the comparison over four consecutive days in order for the geographical coverage of the datasets to be more homogeneous in both latitudes and longitudes. Doing so, the statistics of the OBS-CALC is performed over a sample of about 20000 CrIS pixels and 10000 pixels for each IASI (this difference is due to the fact that the spatial resolution of CrIS is better than the one for IASI).

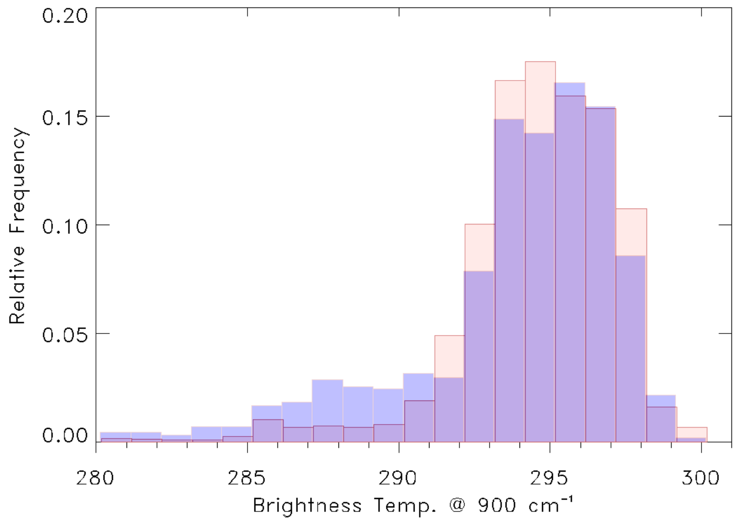

Figure 6: **Distribution of the brightness temperature at 900 cm-1 for the selected CrIS (in red) and IASI (in blue) pixels.**

Fig. 7 shows the spectral difference OBS_{IASI}-OBS_{CrIS} computed from the OBS-CALC residuals for IASI-A and CrIS using four days in August 2013. It can be seen that:

- there are some peaks in the spectral difference: they are attributable to the fact that standard profiles of trace gases were used when computing the residuals. The signature of ozone is in particular clearly visible;
- if we ignore the peaks, there is an excellent agreement between IASI-A and CrIS, at least in band 1 and 2 (red lines on the figure). As already noted when using the SNOs, the maximum difference is of the order of 0.2K in band 1 and much less in band 2.
- the difference IASI-CrIS varies linearly with wavenumber in band 1. This is a confirmation of the result obtained with the SNOs, although the level is not exactly at the same. This must be investigated;
- the difference IASI-CrIS is slightly higher in band 3. It must be noted however that the spectral sampling of CrIS is ten times the spectral sampling of IASI in this region. Both instruments thus not sample the same atmospheric layers and transforming IASI into a CrIS-like equivalent cannot solve the problem. The comparison in this band is thus not meaningful.

Fig. 8 shows the difference between IASI-B and CrIS. Not surprisingly (as we know that IASI-A and IASI-B extremely close), we get a result very similar to the IASI-A case.

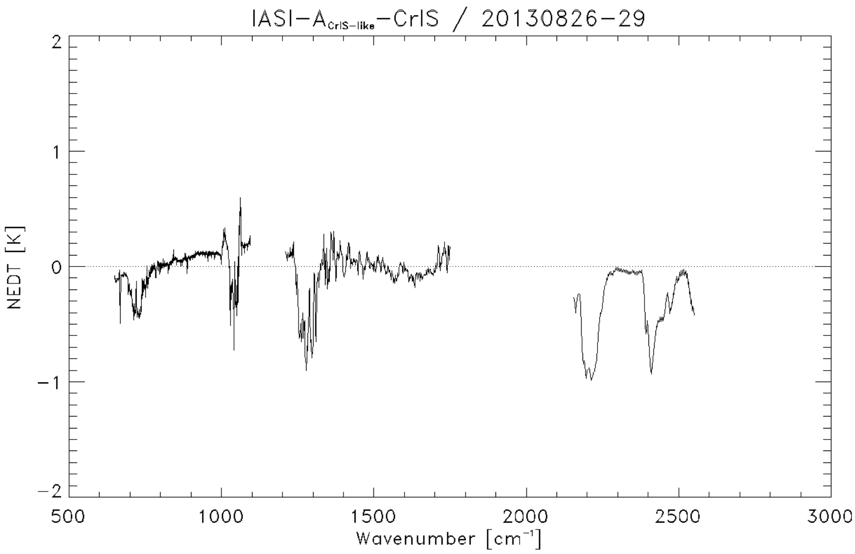

Figure 7: **Spectral difference IASI-A – CrIS computed from the residuals OBS-CALC for both instruments for four days in August 2013.**

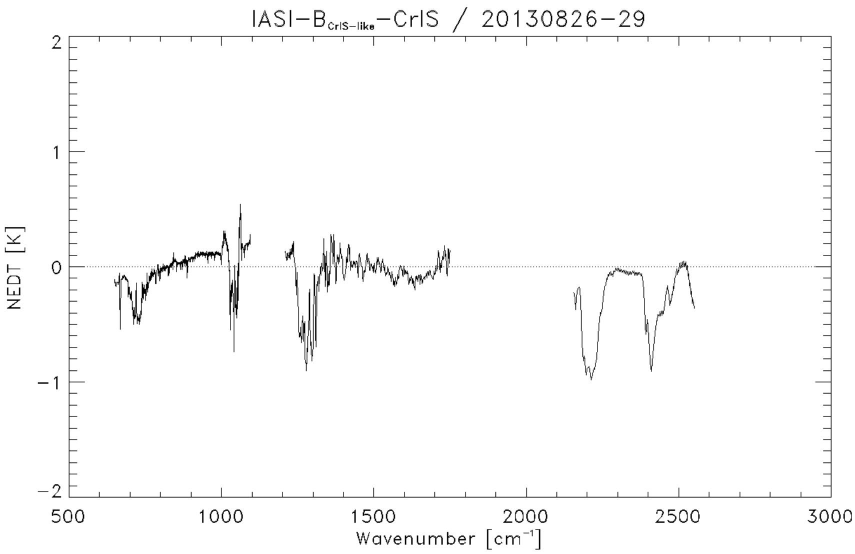

Figure 8: **Spectral difference IASI-B – CrIS computed from the residuals OBS-CALC for both instruments for four days in August 2013.**

CONCLUSION

In order to monitor the quality of the CrIS products disseminated by EUMETSAT, we have set-up a tool to compare CrIS spectra with IASI measurements. Using this tool, we are able to perform:

- a routine assessment of CrIS products through monitoring the difference IASI-CrIS. This difference is indirectly computed using the residuals OBS-CALC for both IASI and CrIS;
- a direct comparison of the measured radiance in polar region when SNOs occur.

The first method requires that only clear scenes are selected for the processing. We have found that the cloud fraction in the CrIS/VIIRS products is not useable for reasons linked to the timeline of the distribution. We thus had to define reliable criteria to select clear cases using brightness temperature differences. This method is not specific to IASI or CrIS and could be used with any hyperspectral measurements.

Both methods show that:

- there is a good radiometric consistency between IASI and CrIS. Indeed the difference expressed in noise equivalent differential temperature at 280K is at most 0.2K.
- some inter-calibration issues remain, in particular:
    - a possible non-linearity correction needed in CrIS band 1;
    - Larges discrepancies in band 3 could be attributed to the large difference in the spectral sampling of CrIS and IASI in this region. Such discrepancies have however not been noted in other studies (e.g. Wang *et al.*, 2010). This will need to be investigated.

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