VALIDATION OF ECMWF ANALYSES AND IASI L2 PROFILES WITH SALSTICE

Xavier Calbet, Marc Crapeau, Thomas August

EUMETSAT, Eumetsat Allee 1, 64295 Darmstadt, Germany

Abstract

For the validation of IASI L2 retrievals or ECMWF profiles with reference ground based or in-situ instruments, like sondes, an initial radiance consistency check is proposed. This will give a high confidence that the co-location is adequate and the reference measurements are of high quality for the validation comparison. The consistency is verified by certifying that the IASI observed minus calculated radiances lie within three sigma IASI instrumental noise. Calculated radiances are computed by feeding the reference profile into a radiative transfer model. The statistics of the reference profile versus the IASI L2 retrievals or NWP fields comparison show a significant improvement when IASI fields of view are selected according to the consistency check. The consistency verification provides additional results like verifying the bias corrections in sonde humidity measurements or hinting on potential problems in the radiative transfer model.

INTRODUCTION

Recent infrared hyperspectral retrieval algorithms have achieved a high degree of quality when validated with Numerical Weather Prediction (NWP) model fields. These fields constitute convenient reference profiles as they are usually quite accurate, are available everywhere and therefore are easy to co-locate with hyperspectral observations. It is also known that NWP fields do not represent the atmosphere perfectly, therefore, if retrievals are to be validated with potentially better representations of the atmosphere, other independent types of atmospheric measurements, such as sondes or ground based remote sensing instruments, should be used.

There is also an increasing trend to use these same NWP fields as training sets for regression retrievals or as background for optimal estimation retrievals. This is based on the positive properties of the NWP fields mentioned above. The retrievals performed in this way should improve upon the NWP fields. These type of retrievals and the NWP fields themselves should be validated with independent sources of atmospheric information, such as, sondes or ground based remote sensing instruments.

In all of the above cases, it is becoming apparent that the next frontier to improve infrared hyperspectral retrievals, and also NWP fields, will be to use local measurements of the atmosphere for validation. Unfortunately, such measurements are not easy to use. Sondes and ground based remote sensing instruments are difficult to properly co-locate with hyperspectral soundings and, often, the instruments suffer from biases which need to be corrected for. This paper will propose a method to make the comparison of reference sonde measurements with hyperspectral retrievals or ECMWF profiles viable and will highlight the biggest problems when performing these validations.

RETRIEVAL VALIDATION STRATEGY

Given a set of hyperspectral retrievals or NWP fields and a collection of reference measurements (sondes), the standard or usual strategy to validate hyperspectral retrievals is the following:

1. Co-locate the reference profiles with the hyperspectral observations with particular criteria.
2. Compare the reference profiles with the hyperspectral retrievals or NWP fields, usually by means of the difference between both.
3. Obtain a final representation of the comparison, like for example, the vertical profile of the differences statistics (bias, standard deviation, RMS, correlation, etc...).

The main disadvantage of this strategy is that there are many uncontrolled variables in the comparison. Many issues could remain unanswered like, how big are the co-location errors?. Do the reference measurements suffer from a potential bias, like the humidity measurements from the sondes? In the worst case scenario it could well happen that the co-location error is much bigger than the retrieval error or the reference measurement uncertainty, in which case the comparison statistics will directly reflect the co-location error and will have little to do with retrieval or NWP uncertainty determination.
Because of all this, an additional step in the strategy can be introduced with the aim of making the complete validation exercise consistent and to increase confidence in the retrieval uncertainty estimation. The complete alternative validation strategy would be defined as follows:

1. Co-locate reference profiles with hyperspectral observations.
2. Perform a consistency check, which consists in assessing the adequate co-location and quality of the reference measurements by doing an observed versus calculated radiance comparison. It is worth noting here that, in order to have an reference profile which is independent from the retrieval, the calculated radiances should be computed with no retrieval elements or, if this is not possible, the fewest retrieval elements as possible.
3. Profile comparison.
4. Obtain statistical results.

The importance of the consistency check resides in that it gives a very high confidence that the reference sonde is properly co-located and that it is also of high accuracy, since it is highly unlikely that the radiances do match if there is a problem in any of these two issues. The same statement can be made in a negative way: if the radiances are not consistent or, in other words, compatible, it will be very difficult to obtain a retrieval that is similar to the reference measurement.

SALSTICE CAMPAIGN

The Semi-Arid Land Surface Temperature IASI Cal/val Experiment (SALSTICE) is a follow on campaign to the JAVIEX airborne campaign, which was performed during 2007 right after the Metop-A satellite was launched. SALSTICE aims to calibrate and validate the instruments on the newly launched Metop-B and on the still operative Metop-A satellites, mainly their on board IASI instrument. The campaign took place in May 2013 and used the UK's FAAM Bae 146-301 and the NASA's ER-2 aircraft. A few of the instruments on board of the aircraft which are worth mentioning are: a Michelson interferometer with similar resolution and spectral range as IASI, instruments to measure in-situ temperature, humidity, trace gases, cloud and aerosol particle properties, a backscatter lidar and dropsondes. The measurements with which we will be concerned with in this paper are exclusively the humidity and temperature ones measured by the dropsondes. Dropsondes were of the Vaisala RD94 type, which are equipped with RS80 type sensors for temperature and RS92 type sensors for humidity.

APPLICATION OF THE ALTERNATIVE VALIDATION STRATEGY TO SALSTICE

Co-location of reference profiles with IASI measurements

The first step in the proposed alternative validation strategy is to co-locate the dropsondes with the IASI measurements. For this, all IASI measurement fields of view which are less than 25 km in distance and 30 minutes in time to the SALSTICE dropsondes are selected for the validation exercise.

Consistency check

The radiosonde profile, an assumed surface emissivity and skin temperature are fed first into a radiative transfer model for clear sky scenes to obtain what is known as the calculated radiances (CALC). In a second step, the observed IASI radiances (OBS) are subtracted to the calculated ones. These OBS – CALC radiances are then revised to verify whether they are mostly within the three sigma IASI instrument noise or not. For brevity, in this paper, the consistency check will be applied only to the spectral region between 1500 and 1800 cm^{-1}, whereas for a complete consistency, the whole spectral region should be verified. This greatly simplifies the verification since most of this

region is unaffected by low level lying clouds or by surface parameters, and therefore there is not need to estimate surface properties to a high precision.
Fig. 1 left shows a spectra that qualifies as a consistent reference measurement. The OBS-CALC radiances in Fig. 1 right, on the other hand, are quite far away from the three sigma IASI noise and hence the reference profile is not compatible with the IASI measurement and the corresponding retrieval should not be validated with this sonde data.

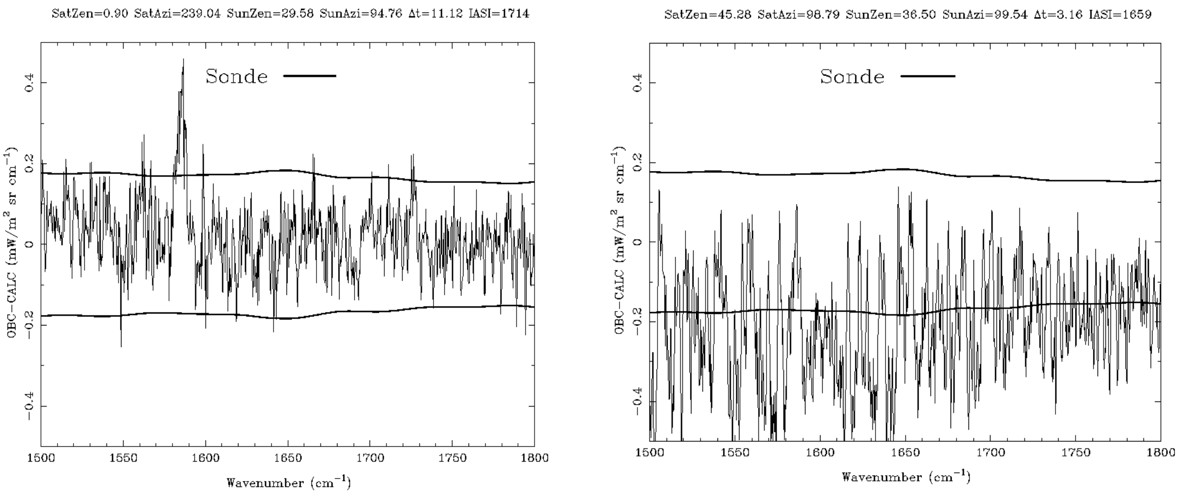

Figure 1: **Examples of Observed – Calculated (sonde+radiative transfer model) radiance. Nearly horizontal flat line is the three sigma IASI instrument noise. In the left figure, the difference falls neatly within the three sigma IASI noise, which is not the case in the right one.**

From previous experience with the EPS/Metop campaign in Sodankylä (Calbet et al. 2011), there are three critical points when trying to match observed versus calculated radiances: an adequate spatial or temporal interpolation, proper humidity bias correction of the sondes and the presence of clouds.
A temporal or spatial interpolation was difficult to achieve, mainly because the campaign was not designed with this concept in mind and the humidity field is very inhomogeneous in the region of interest, as is shown in the retrievals of Fig 2. Because of this and for simplicity, in this paper no temporal or spatial interpolation was attempted.

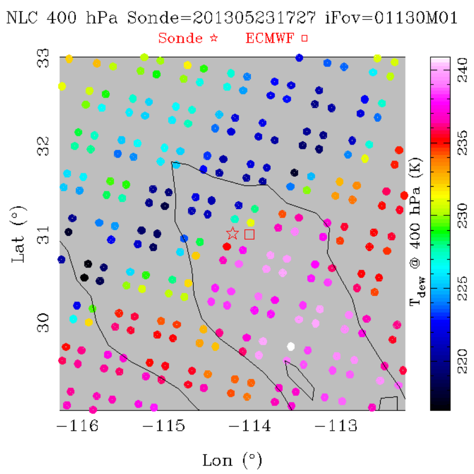

Figure 2: **Non-linear regression retrievals of the humidity field showing a huge inhomogeneity at 400 hPa within the region of interest.**
The campaign data also lacked from any reliable humidity reference measurement, like a Cryogenic Frost point Hygrometer (CFH), with which to calibrate the dropsonde humidity sensor. The dropsondes were launched during daytime, and having an RS92 type of humidity sensor they are expected to have

a significant bias. The bias correction applied to them here is the one that performed well during the Sodankylä campaign for the applied radiative transfer model (OSS). This is the Kivi et al. (2009) bias correction plus an added 2% in relative humidity in the whole profile. This bias correction was applied to the dropsonde humidity measurement with the hope that it would also work for SALSTICE dropsondes just as they worked for the Sodankylä campaign.
The presence of clouds was determined by visual inspection of the AVHRR infrared and visible images. One such image is shown in Fig. 3. To avoid additional complications, only clear fields of view were used.

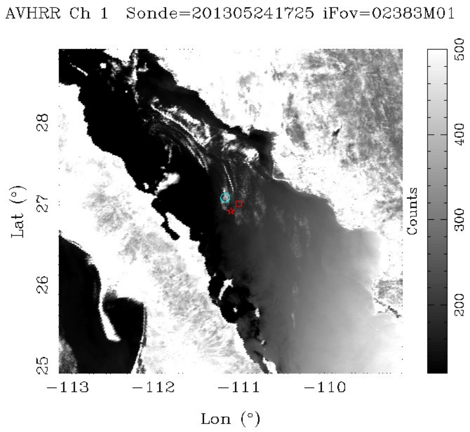

Figure 3: **AVHRR Channel one image showing the presence of clouds in the region of interest. IASI field of view is shown as a cyan circle, dropsonde launch location as a read star and ECMWF grid point as a red square.**

Ideally, if the right temporal or spatial interpolation and the correct humidity bias corrections are used, all co-locations should have proper matching OBS-CALC radiances. Because of the above explained simplified analysis of the SALSTICE data (co-location and humidity bias correction issues), not all co-located reference measurements do lie within three sigma IASI noise. Therefore, a criterion to select good matches needs to be sought. For that purpose, the OBS-CALC radiances are divided by one sigma IASI instrument noise and the average and standard deviation of the OBS-CALC difference in the spectral range between 1500-1540 and 1660-1700 cm^{-1} is calculated. A scatter plot of these two parameters is shown in Fig. 4. The matches that are finally selected for further analysis are the ones showing a low bias and standard deviation (co-locations lying within the red rectangle in Fig. 4). Overall, 56% of the match-ups are retained.

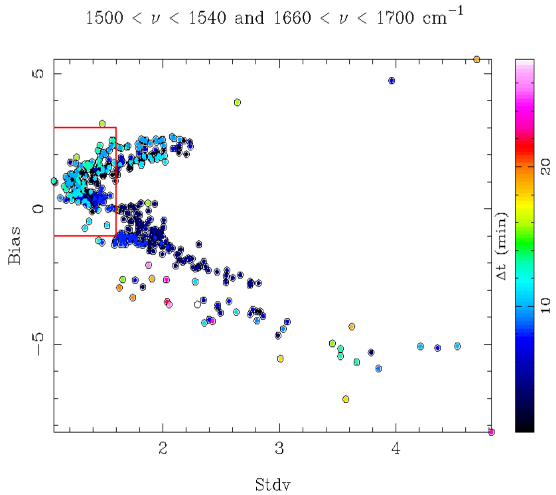

Figure 4: **Scatter plot of average (bias) and standard deviation of (OBS-CALC)/(1 sigma IASI noise) in the spectral range between 1500-1540 and 1660-1700 cm^{-1}. The color code shows the co-location time difference in minutes. Co-locations that lie within the red rectangle are the ones selected for further analysis.**

Comparison of profiles with retrievals and its statistics

Once the co-locations are consistent they can be compared. Sonde profiles are smoothed with a top hat kernel to simulate, in a simple way, the averaging kernels. They should ultimately be smoothed with the averaging kernels of the retrievals. ECMWF profiles are not smoothed and are compared directly to the sondes.

One of the retrievals tested in this paper are the non-linear regression retrievals from the MTG-IRS prototype version 0. These regression retrievals have been trained with the Chevallier climatology and the OSS radiative transfer model (Camps-Valls et al., 2012). The other retrievals explored in this paper are the EUMETSAT operational IASI L2 version 5 ones (August et al., 2012), which are also based on climatology as either training dataset or background.

Vertical statistics results are shown in Fig. 5 with the fields of view selected according to the consistency check described above (left) and with all the fields of view (right). It can be seen that the overall statistics improve significantly when the consistency check selection is used, and, obviously, the number of cases decreases (from 117 to 66). The retrieval statistics of the humidty are, for the selected fields of view, in some levels, better than ECMWF profiles. The temperature RMSs for the consistency checked retrievals are also unusually high, which could be explained by the lack of consistency of the spectra in the CO2 band, where most of the temperature information is obtained from the spectra (Fig. 6).

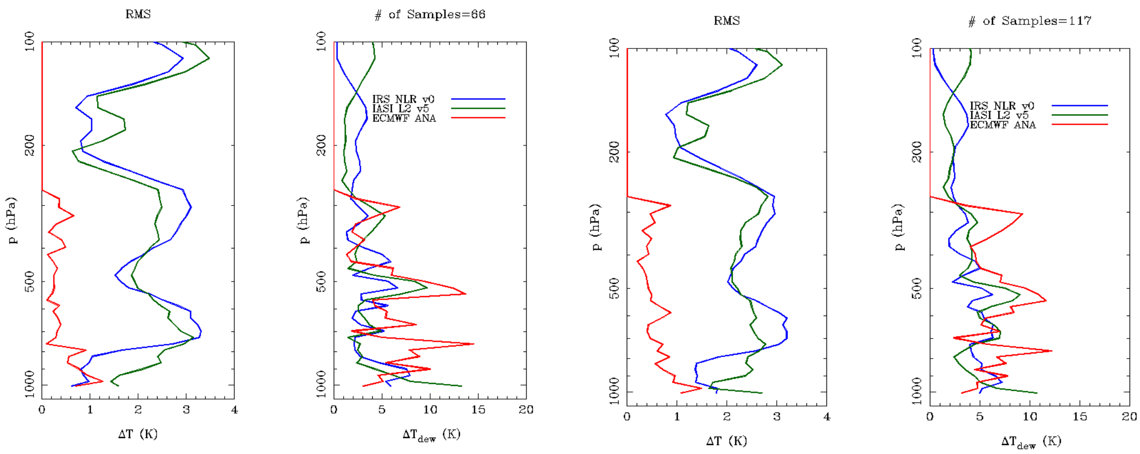

Figure 5: **Vertical comparison statistics of the reference profiles with the retrievals or ECMWF profiles for the consistency checked selected profiles (left) and all the available co-locations (right).**

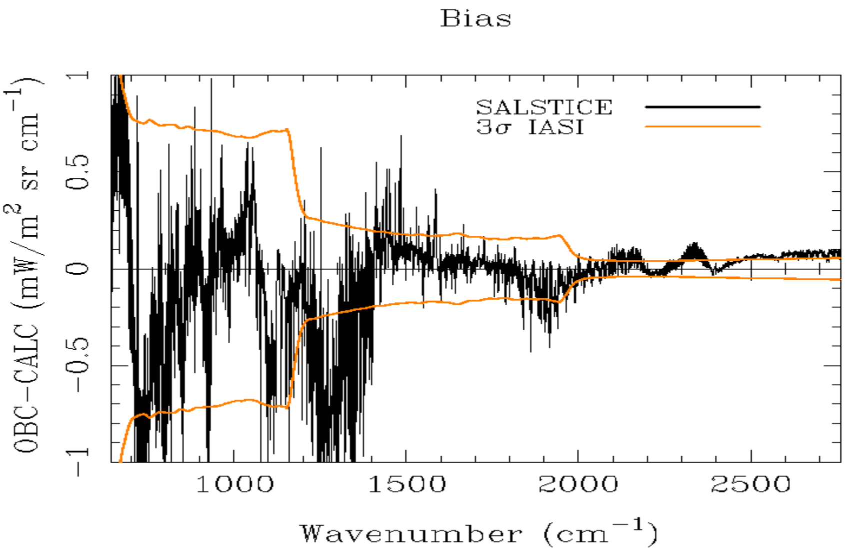

Figure 6: **Average OBS-CALC of the consistency checked profiles. There is a big deviation in the CO2 band (wavenumbers smaller than 750 cm^{-1}). Only the region between 1500 and 1800 cm^{-1} has been checked for consistency.**

ADDED VALUE

The OBS-CALC average or bias of all the sondes might show features that can be useful to detect problems in the complete radiative transfer modelling. For example, it is still under investigation how to accurately model the water vapour continuum in the infrared spectrum. Surprisingly enough, the OBS-CALC bias shows the same behaviour around 1500 cm^{-1} for the SALSTICE data as for the Sodankylä data (Fig. 7). It is worth noting that these biases are derived from two very different set of humidity profiles, ranging from very humid ones, as is the case for SALSTICE data, to very dry Arctic ones, as is the case for Sodankylä data. This could be corrected by using a different water vapour continuum in the radiative transfer models (Newman, 2012).

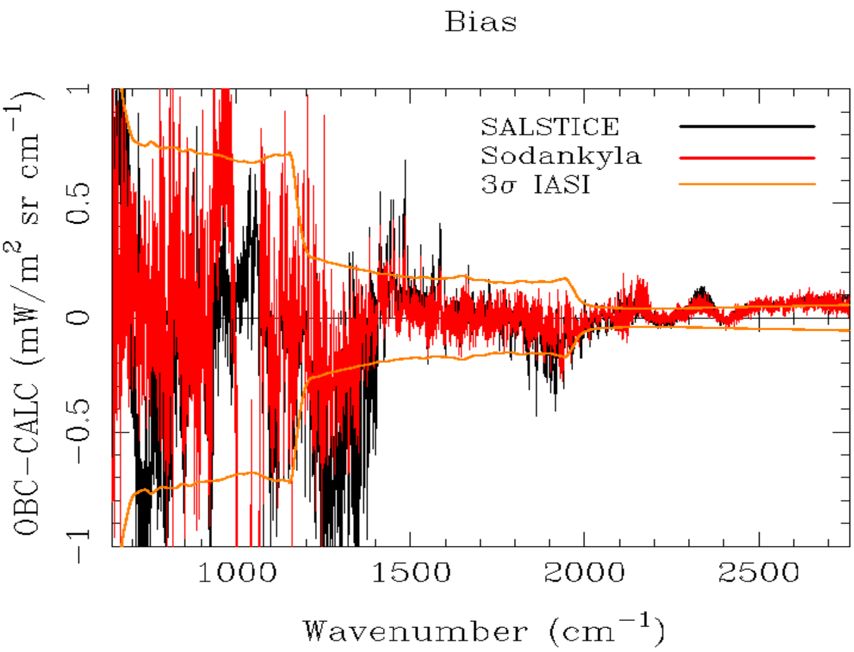

Figure 7: **Average OBS-CALC of the consistency checked profiles for the SALSTICE campaign (black) and for the Sodankylä campaign (red). Note the remarkable agreement in the water vapour band and particularly around 1500 cm^{-1} where there are still issues with the water vapour continuum in the radiative transfer models.**

CONCLUSIONS

The following conclusions can be drawn from this study:

1. Retrieval vertical statistics significantly improve when the fields of view are consistency check selected.
2. Temperature bias for IASI retrievals needs to be investigated since it is too high, although no consistency check has been made in the CO2 band.
3. For some levels, IASI climatological based humidity retrievals might perform better than ECMWF.
4. The selected dataset could be used for further IASI L2 related studies.
5. The comparison of OBS-CALC radiances also gives an indication whether the applied humidity bias correction is valid for the given humidity sensors.
6. They also give an indication of potential problems in the radiative transfer models.

It would also be advisable to continue this study to verify if a better radiance matching can be found when some type of time or spatial interpolation is applied.

ACKNOWLEDGEMENTS

The principal investigators (PIs) for SALSTICE were Drs. Chawn Harlow and Stuart Newman at the Met Office. Airborne data were obtained using the BAe 146-301 Atmospheric Research Aircraft (ARA) flown by Directflight Ltd and managed by the Facility for Airborne Atmospheric Measurements (FAAM), which is a joint entity of the Natural Environment Research Council (NERC) and the Met Office. The authors are grateful to the Instituto Nacional de Estadística y Geografía (INEGI), Dr. Jaime Garatuza of the Technical Institute of Sonora, and Dr. Chris Watts of the University of Sonora for their important contributions to the campaign. The efforts Dr. Allen Larar of NASA and Dr. Bill Smith of the University of Wisconcin in flight and campaign planning are also greatly appreciated. EUMETSAT provided part-funding of the campaign via contract EUM/COS/LET/12/681794.

REFERENCES

August, T., Klaes, D., Schlüssel, P., Hultberg, T., Crapeau, M., Arriaga, A., O'Carroll, A., Coppens, D., Munro, R., Calbet, X. (2012). IASI on Metop-A: operational level 2 retrievals after five years in orbit. Journal of Quantitative Spectroscopy and Radiative Transfer, 113, 11, 1340-1371.

Calbet, X., Kivi, R., Tjemkes, S., Montagner, F., and Stuhlmann, R. (2011). Matching radiative transfer models and radiosonde data from the EPS/Metop Sondakylä campaign to IASI measurements. Atmospheric Measurement Techniques, 4, 1177-1189.

Camps-Valls, G., Laparra, V., Muñoz-Marí, J., Gómez-Chova, L, Calbet, X. (2012). IEEE Trans. On Geoscience and Remote Sensing, 50, 1759-1769.

Kivi, R., Kujanpä, J., Calbet, X., Montagner, F., and Vömel, H. (2009). Observations of water vapor profiles over Northern Finland by satellite and balloon borne instruments, in: Proceedings: 2009 EUMETSAT Meteorological Satellite Conference, 21–25 September 2009, Bath, UK, EUMETSAT P.55.

Newman, S. M. (2012). Report on the impact of changes in the water vapour continuum arising from the CAVIAR consortium on satellite remote sensing. Met Office RC13C Key Deliverable Report, February 2012.