Inter-calibration of METEOSAT IR and WV channels using HIRS

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Abstract. We present a strategy to inter-calibrate the complete time series of Water Vapour (WV, 6.3 µm) and Infrared (IR, 11.8 µm) channel radiances from the MVIRI instrument on Meteosat First Generation and the SEVIRI instrument on Meteosat Second Generation. Two different inter-calibration methods are evaluated i.e., (1) inter-calibrate to a homogenised time series of HIRS observations, and (2) inter-calibrate using the so called double differencing methodology. The latter method compares, for instance, observations from two Meteosat instruments to observations of one HIRS instrument, and then calculates the difference between the two Meteosat instruments, or vice versa. Both methods are validated against reference observations, for which observations from the IASI instrument are used. In addition, the stability of the HIRS on Metop is investigated with Metop IASI observations. We have analyzed the uncertainties introduced in both methods by changes in filter functions, collocation scene variability, instrument noise and calibrations drift. A systematic review of spectral conversion functions, which often dominate the errors, indicates that the best set up is to use collocations under all conditions, i.e., all latitudes covered by the collocated observations, all atmospheric situations including cloudy scenes, and all viewing angles. Estimates of spectral conversion uncertainties have been computed among pairs of different instrument types (HIRS/2, HIRS/3, MVIRI and SEVIRI), and are almost an order of magnitude larger for the WV than the IR channel. For the WV channel spectral conversions from HIRS/2 to HIRS/3 and HIRS/4 have an uncertainty of approximately 1 K, whereas the conversion uncertainties from MVIRI to SEVIRI are about 0.5 K. With some exceptions the conversions among the same type of instruments, such as HIRS/3 to HIRS/4 or SEVIRI to SEVIRI, have uncertainties of less than 0.1 K.

Keywords: Fundamental Climate Data Records, inter-calibration, infrared radiances.
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INTRODUCTION

Climate change is one of the greatest challenges facing mankind in the twenty-first century. Observations from space provide unique information of the climate system, so it is evident, that the future of the global climate observing system depends critically upon a major satellite component [1]. This has also been recognised by the UNFCCC and its subsidiary bodies.

Satellite operators are responsible for the development and operations of the satellites and its instruments, and the processing of satellite data, from which satellite products can be generated in an operational mode (e.g. Near Real Time processing of data supporting weather forecast applications). It is recognised, that higher level applications, such as climate variability and change analysis, require long time series of satellite data that are well calibrated and homogeneous over time. Satellite data of such kind are referred to as Climate Data Records (CDRs) and are generated through careful recalibration and reprocessing activities. Such activities have been considered by the EUMETSAT member states as the main focus of EUMETSAT's activities in support to Climate Monitoring [2].

Observations from EUMETSAT's series of Meteosat First Generation (MFG) and Meteosat Second Generation (MSG) geostationary satellites span a period from 1982 till today for satellites operated over the Atlantic Ocean (sub-satellite longitude 0 degrees), and from 1997 till today for satellites operated over the Indian Ocean. The applicability of these time series of satellite data for climate analysis at multi-decadal scales is hampered by inherent temporal heterogeneities due to successive radiometers having different filter functions and changes in the calibration methodology. To improve the quality of these time series, EUMETSAT has initiated an activity to inter-calibrate their data to community references, following the principles of the Global Space-based Inter-Calibration System (GSICS).

The uncertainty of inter-calibration of Meteosat instruments vs. HIRS has three major components: (1) due to spectral conversion, (2) due to noise of the pixel collocations and (3) due to instrument drift. These uncertainties need to be characterised to have a final uncertainty estimate for the homogenised time series.

In this paper we present a strategy to inter-calibrate the complete time series of Water Vapour (WV, 6.3 µm) and Infrared (IR, 11.8 µm) channel radiances from the Meteosat Visible and InfraRed Imager (MVIRI) instrument on MFG and the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) instrument on MSG. As a reference, observations from the High resolution Infrared Radiation Sounder (HIRS) on NOAA satellites are used. The uncertainties of spectral conversion functions have been assessed through a systematic review. The inter-calibration method proposed uses the so called double differencing methodology. The latter method compares, for instance, observations from two Meteosat instruments to observations of one HIRS instrument, and then calculates the difference between the two Meteosat instruments, or vice versa.

DATASETS

As reference data the observations from the High resolution Infrared Radiation Sounder (HIRS) will be used. The HIRS instrument is an atmospheric sounder that measures infrared radiances in 19 channels, and has been operated onboard the series of NOAA satellites since 1978. During the period 1982 till date three types of HIRS instruments have been operated, i.e., HIRS/2 on NOAA 1-14, HIRS/3 on NOAA15-17 and HIRS/4 on NOAA-18 and Metop-B. For these three types of HIRS instruments the number of channels remained unchanged, but their characteristics changed with respect to their central wave numbers, channel width and spectral response functions. Beside instrument changes, there are also satellite-to-satellite variations between similar types of HIRS instruments that have to be accounted for.

The monitored data in this study are the water vapor channel at 6.8 µm and infrared channel at 10.8 µm from the MVIRI and SEVIRI instruments onboard of EUMETSAT's series of MFG and MSG geostationary satellites, respectively. The observations from these satellites span the period 1982 till today for the zero degree longitude sub-satellite position and the period 1997 till today for the Indian Ocean sub-satellite position, which makes them pre-eminently suited for climate analysis at multi-decadal scale. Heterogeneities in the time series are introduced due to successive radiometers having different filter functions and due to changes in calibration methodology over time.

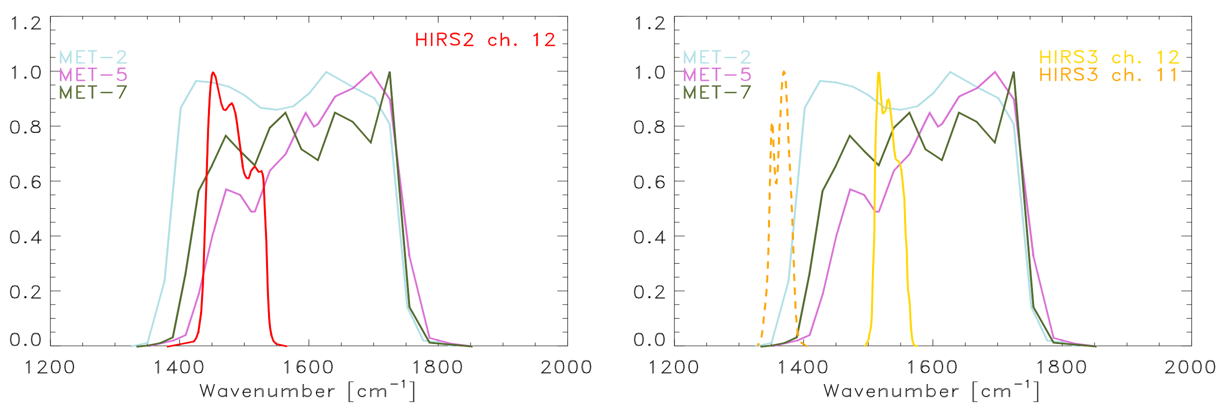

FIGURE 1. Spectral response functions (SRF) for the water vapour channel of MVIRI vs. HIRS/2 channel 12 (a), MVIRI vs. HIRS/3 Channel 11 and 12 (b).

Figure 1 shows that the MVIRI Spectral response functions (SRFs) differ from satellite to satellite. The HIRS instrument series consists of three different instruments where a big change in spectral position and width was introduced with the launch of the HIRS/3 instrument. An inter-calibration method for both series needs to convert radiances to one reference channel.

SPECTRAL CONVERSION FUNCTION UNCERTAINTIES

The inter-calibration errors are often dominated by uncertainties of spectral conversion functions. Simulated brightness temperatures from the references (HIRS) and monitored (Meteosat) instruments have been used to assess spectral conversion uncertainties due to fitting method, scene selection, viewing angle restriction and number of reference channels used. This assessment indicates that the best set up is to use collocations under all conditions, i.e., all latitudes covered by the collocated observations, all atmospheric situations including cloudy scenes, and all viewing angles. The spectral conversion uncertainty for the WV channel is much larger (almost one order of magnitude) than the uncertainty in the infrared window channel. For the WV channel the conversions have uncertainties of about 1 K, whereas the conversions of the IR channel have uncertainties of about 0.1 K.

Estimates of spectral conversion uncertainties have been computed among pairs of different instrument types (HIRS/2, HIRS/3, MVIRI and SEVIRI). Table 1 gives the mean RMSD as brightness temperature [K] for the WV channel for all spectral conversion among the different types of Meteosat and HIRS instruments using a quadratic fit with multiple HIRS channels. Lowest RMSDs are always found for the same instrument class. Among different instruments the HIRS/2 – MVIRI combination gives the lowest uncertainties, whereas conversions from HIRS/2 to HIRS/3 (1.03K) and HIRS/4 (1.07) show the highest uncertainties. Uncertainties for transfers from HIRS to MVIRI and SEVIRI are small for HIRS/2, but reach values of 0.74K for HIRS/4 to MVIRI (Met 4-7) and 0.57K for HIRS/4 to SEVIRI.

TABLE 1). Uncertainties due to spectral conversion using multiple channels for each class of instruments for the water vapour channel. The left column is the reference instrument. Numbers represent the mean RMSD of Tb in Kelvin.

	HIRS/2 (NOAA6-14)	**HIRS/3** (NOAA15-17)	**HIRS/4** (NOAA18-MetopB)	**MVIRI** (Meteosat 1-3)	**MVIRI** (Meteosat 4-7)	**SEVIRI** (Meteosat 8-11)
HIRS/2 (NOAA 6-14)	0.04	1.03	1.07	0.07	0.16	0.41
HIRS/3 (NOAA 15-17)	0.78	0.05	0.06	X	0.67	0.51
HIRS/4 (NOAA 18-MetopB)	0.84	0.06	0.03	X	0.74	0.57

ASSESSMENT OF INTER-CALIBRATION METHODS

There are different methods of transferring calibrations from one instrument to the other. The most common approach is to create an inter-calibrated series of HIRS radiances by transferring calibrations from HIRS to HIRS, and uses this series as reference for each Meteosat instrument. Disadvantage of this approach is that the uncertainty due to the spectral conversion increases with each step. Taking into account that an individual satellite overlaps with several other satellites one may use less spectral conversions to reduce the number of steps. Another approach is to use double differences [3] and employ one Meteosat and two HIRS at a time to determine the difference between the HIRS instruments, or two Meteosats and one HIRS to determine the differences between the Meteosats, as illustrated in Figure 2. The reference instrument needs to be stable over time. Both approaches need a reference instrument as standard for which the IASI instrument is the most appropriate. Direct collocation with all SEVIRI instruments and MVIRI on Meteosat-7 can be achieved and provide the anchor point for the time-series. Observations from Metop IASI and Metop HIRS can be used to investigate the stability of HIRS on Metop.

For our inter-calibration the double differencing approach is proposed to recalibrate the WV (6.8 μm) and IR (10.8 μm) channels from the MVIRI instrument onboard MFG and SEVIRI instrument onboard MSG using HIRS data as a reference. The double differencing has the advantage that it achieves a more quantitative evaluation of intra-satellite consistency. Double-differencing is often used to remove the phase ambiguity between satellites, which is achieved by differencing the satellite measurements twice. Another advantage of double differencing is that this method cancels out or minimizes the effect of systematic errors and instabilities in satellite data arising from, for example, collocation errors, and systematic biases. To perform double differencing three data sets are required. This can either be three satellite data sets, or two satellite data sets and simulated satellite measurements. When using one monitored instrument and two reference instruments the double differencing equation looks as follows:

$$DD = (O_m - O_{r1}) - (O_{r1} - O_{r2}) \qquad (1)$$

where O_m is the observed monitored data and O_{r1} and O_{r2} is the observed reference data from reference instrument 1 and reference instrument 2, respectively.

For the period 1983-date both HIRS and MVIRI or SEVIRI instruments were operated simultaneously, see Figure 2. Thus, the infrared channels of MVIRI and SEVIRI can be recalibrated with a double differencing approach using one monitored and two reference data sets (equation 1).

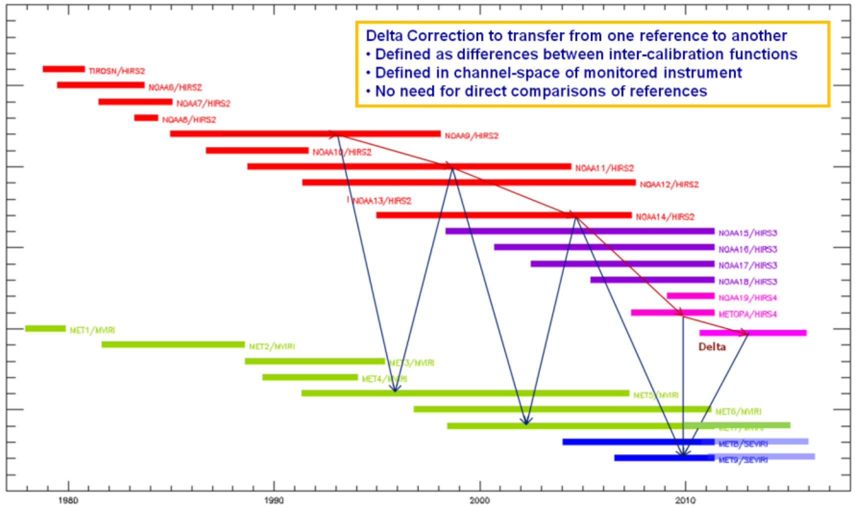

FIGURE 2. Schematic representation of the “Zipper” approach using double differences to transfer the calibrations.

SUMMARY

The uncertainties in the approach are introduced by the different filter functions of MVIRI/SEVIRI and HIRS, different filter functions within both the MVIRI/SEVIRI and HIRS instrument series, noise in the collocation of instrument pixels due to spatial and temporal variability in imperfectly matched scenes, radiometric noise as well as potential orbital and instrumental drift. A systematic review of spectral conversion functions indicates that the best set up is to use collocations under all conditions, i.e., all latitudes covered by the collocated observations, all atmospheric situations including cloudy scenes and all observation conditions such as viewing angles.

The assessment of the inter-calibration approaches indicated that double differencing can be applied for inter-calibrating the Meteosats with HIRS. Since there is an overlap between satellites operating the HIRS and IASI instruments, IASI can be taken as the calibration standard.

Works for further research include investigation of the effects of calibration transfer uncertainties and drifts in reference transfer standards. Hereafter the approaches described in this paper shall be implemented, and the generation of Fundamental Climate Data Record of infrared radiances from the Meteosat instruments covering the period 1982 till date can start.

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