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Common Reference Channels for Metrological Comparability

In this article we discuss the effect of the choice of reference during calibration on later use of the calibrated results, and how a reference should be chosen to support later use of the data. Starting from the concept of metrological comparability we will formulate the purpose of calibration in metrology, and discuss the difference from a traditional (statistical) view. We derive some requirements for calibration, and especially for the choice of a useful reference. The calibration of a geosynchronous (GEO) instrument with a low spectral resolution against a low-earth-orbiting (LEO) instrument with a much higher spectral resolution used as a reference, as is currently done in GSICS, raises the question how the processing of the data from the reference sensor is affecting the aim of calibration.

One of the fundamental concepts in metrology is linked to the term *metrological comparability* (VIM 2008). It is always possible to compare any two numbers, but any pair of measurement results can only be compared if and only if they are traceable to the same unit(s) or reference(s). A prerequisite is that they share the same dimension. Comparability does not mean that the measurement results are of the same magnitude. For example the distance between the earth and the moon can be metrologically compared with a distance between two locations on earth if both distances are traceable to the same unit (SI meter definition).

One objective of the calibration of a measurement system is to establish a traceable link to a stated reference(s), which is important if one wants to use its results produced thereafter. One important use of measurement results is comparison and since comparison is only possible with common references, it is necessary to understand the usage of the results to determine a useful reference during calibration.

For all physical quantities that are part of the SI system of units, there is a developed and maintained system of reference standards available from the international network of standards organizations. For measurement systems being calibrated on Earth, the choice of reference is easy: one chooses the SI system of units whenever possible. Calibration services to support these references are available around the globe. These results are comparable in time and space (on Earth). As a result many quantities are currently metrologically comparable. But one should not forget that a huge effort is needed worldwide to establish and to maintain the SI system of units.

If one moves to outer space the choice of reference is not that easy, because calibration out there is not a simple service that can be bought from a provider. Calibration becomes a huge effort and simple concepts like regular re-calibration against arbitrary references are often close to impossible to implement.

Nevertheless, establishing a useful satellite inter-calibration system is a valuable mission. Without calibration one cannot metrologically compare any two results. So it is impossible to compare data from sensor A with data from sensor B, and if the data are not comparable then it is impossible to combine or verify the data. The ultimate consequence is that uncalibrated data is useless from a metrological point of view. Uncalibrated data might not even be comparable with itself in time if one does not have means to prove that a sensor is stable enough (not drifting).

For the inter-calibration of the GEO sensors (e.g., MSG) one can choose LEO sensors (e.g., IASI) as a reference. Figure 1 shows a block diagram of the metrologically relevant data processing of such a calibration. During the inter-calibration, collocations are chosen where the views of both sensors are sufficiently similar.

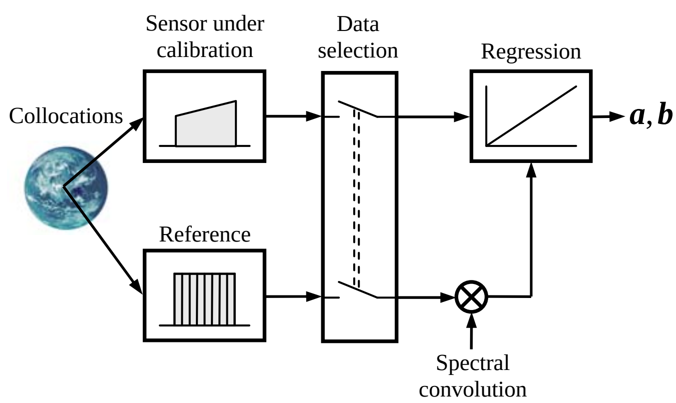

Figure 1: Block diagram of the metrological data processing for the inter-calibration of broad-band GEO sensors and high spectral resolution polar-orbiting sensors, such as IASI.

It can therefore be assumed that the sensor input to both sensors for any collocation is the same (within an uncertainty). A proper data selection method can ensure this. Since the spectral resolution of the two sensors is very different it is necessary to perform a spectral convolution in the data path of the high resolution reference sensor. A linear regression is used to combine the convoluted data from the reference sensor and the data from the sensor under calibration. The results are the offset *a* and the scale factor *b*.

The calibration parameters *a* and *b* are used later to correct the raw data of the calibrated sensor. The corrected data is then traceable to the reference results (IASI). The "accuracy" of the corrected results depends on the calibration of the reference sensor. Even if the reference sensor is uncalibrated but sufficiently stable then the calibrated (corrected) results traceable to the same reference are metrologically comparable.

Figure 2 shows a block diagram of the existing calibration scheme of the MSG sensors against IASI, flown on Metop. The spectral convolution in the reference path is "matched" to the particular sensor under calibration (MSG). This almost eliminates any spectral mismatch between reference sensor and the sensor under calibration.

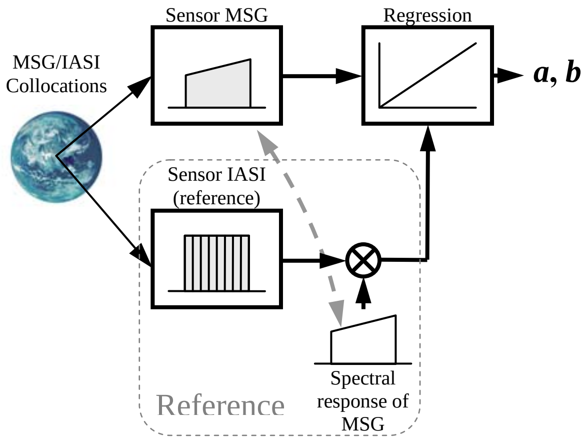

Figure 2: Existing calibration scheme of MSG sensors against IASI. The spectral convolution is "matched" to the individual MSG sensor.

However, since the matched spectral response is sensor specific, the reference for different sensors is systematically different and therefore the sensors are not traceable to the same reference. It is well known that one has to include a systematic error term because of the differences in the reference path when the results need to be compared. But the error term is unique for any pair of sensors and it is difficult to establish without detailed knowledge of the spectra of the sensor input.

But the corrected results based on this calibration are comparable to themselves and therefore it is possible with this kind of calibration to "transfer" the stability of the IASI sensor to the MSG results with the smallest possible uncertainty. This calibration method has an important value as long as the usage is limited to this case.

To achieve the goal of metrologically comparable results between different sensors, it is necessary to eliminate the sensor-specific processing in the reference path and to establish *Common Reference Channels* with a common spectral convolution for all sensors. Figure 3 shows the general calibration scheme where the processing of data in the reference path is independent of the sensor under calibration. The spectral convolution is reduced in this case to limiting the bandwidth.

The difference in the spectral response between the sensor path and the reference path causes what we call the *Spectral Mismatch* δL_r. The effect is dependent on the difference in the spectral response and the spectral variability of the target (Earth) for a given intensity or brightness temperature.

Because of the high spectral resolution of the reference sensor, some knowledge about the spectrum is available during calibration which can be used to evaluate an uncertainty specification (guard band) for the *Spectral Mismatch* δL_r. The associated uncertainty $u(\delta L_r)$ might dominate the final uncertainty in case that the sensor's Spectral Response Functions is significantly different from the spectral response in the reference path (e.g., flat top).

In case sensors with similar spectral response need to be compared, it might be useful to establish a common response in the reference path which matched the behaviour of the set of sensors more closely to reduce the uncertainty of the additional component δL_r for all sensors.

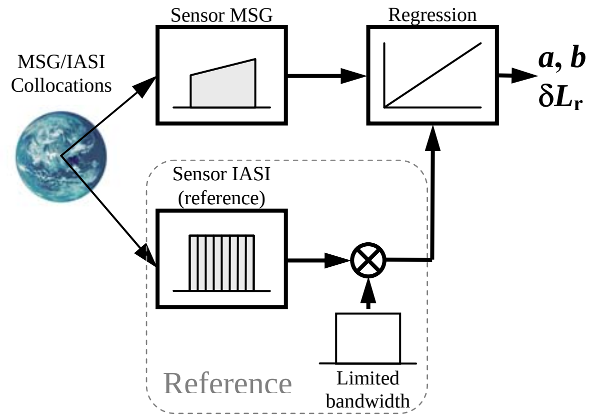

Figure 3: Proposed calibration scheme for MSG sensors against a polar-orbiting sensor (IASI). The spectral convolution is reduced to limit the bandwidth. δL_r is an additional component to describe the *Spectral Mismatch* and its uncertainty.

Until a system of standard references can be established in space for all quantities of interest, it might be useful to operate with multiple references here which can be defined on a practical basis. But it is important that the user clearly distinguishes them and that he does not compare "apples and oranges". One solution would be to provide the observations (raw data) and multiple calibration functions for different purposes and let the user apply the functions to the raw data. The user would be responsible for the application of the calibration and that the calibration matches the intended use of the measurement results.

Reference

BIPM 2008, International Vocabulary of Metrology – Basic and General Concepts and Associated Terms. VIM, 3rd edition, JCGM 200:2008. http://www.bipm.org

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