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Editorial

Calibration and Verification of Remote Sensing Instruments and Observations

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Satellite instruments are nowadays a very important source of information. The physical quantities (essential variables) derived from satellites are utilized in a wide field of applications, in particular in atmospheric physics and geoscience. In contrast to ground measurements the physical quantities are not directly measured, but have to be retrieved from satellite observations. Satellites observe hereby the reflection or emission of radiation by the Earth's surface or atmosphere, which enables the retrieval of respective physical quantities (essential variables). The physical basis for the retrieval is the interaction of the radiation with the Earth's atmosphere and surface. This interaction is defined by radiative transfer, which favors the use of radiances and their respective units within retrieval methods.

However, the primary measurement quantity (unit) of the sensors consists of voltage or digital counts. Hence, calibration has to be applied in order to relate the digital counts (voltage) given by the sensor to the incoming radiances, consequently, the physical units of interest. The relation between the digital counts and the radiances (calibration coefficients) can be derived by comparison of the sensor signal with an absolute standard reference prior to launch. Nowadays, satellite instruments are usually well designed and calibrated prior to launch. Unfortunately, no matter how sophisticated the instruments are, once in space they degrade with time, e.g., due to thermal, mechanical or electrical effects or exposure to UV radiation. Yet, for the majority of remote sensing retrievals and applications calibrated data are essential. Sensor re-calibration (hereafter referred to as calibration) is therefore the basis of reliable remote sensing and ensuring the quality of the derived variables and products. However, after-launch comparison with reference standards of known accuracy is difficult to manage in terms of metrology. On-board calibration units being interpreted as the reference standard are subject to degradation processes as well, especially in the visible spectra. Moreover, many satellite sensors (especially in the visible spectra) are not adjusted by on-board calibration. Hence, in any case, post launch calibration is quite a challenging task, but is essential for physically defined retrieval of essential variables.

A central and important method for post-launch calibration is often referred to as vicarious calibration. Vicarious calibration refers to methods that make use of “invariant” natural targets of the Earth for the post-launch calibration of sensors. The "invariant" target approach enables the definition of a reference standard for the observed reflections. Vicarious calibration is addressed in several manuscripts of this Special Issue, including uncertainty assessment and discussion of calibration methods.

Mishra *et al.* [1] report of improvements to an empirical absolute calibration model using a Libya 4 pseudo invariant calibration site (PICS). The approach is based on the use of the Terra MODIS as radiometer to develop a calibration model for the spectral channels covered by this instrument from visible to shortwave infrared.

In Chen *et al.* [2], vicarious calibration of Beijing-1 Multispectral Imagers is performed. Within this study three vicarious calibration methods (*i.e.*, reflectance-based, irradiance-based, and cross-calibration) were investigated, systematic and accidental errors, and the overall uncertainty was assessed for each individual method. The irradiance based method is finally used to derive the calibration coefficients.

In the study of Chen *et al.* [3], deep convective clouds (DCC) are used as an invariant target to monitor the degradation of the FY-3A/MERSI (Medium Resolution Spectral Imager) reflective solar bands (RSBs). The FY-3A/MERSI degradation results derived from DCC are compared with Aqua/MODIS (Moderate Resolution Imaging Sepetroradiometer) inter-calibration, multi-site invariant earth target calibration and the CRCS (Chinese Radiometric Calibration Site) Dunhuang desert vicarious calibration method. Respective comparison results are analyzed and discussed.

In Bhatt *et al.* [4], invariant desert (Libya4) and deep convective cloud targets are used to assess the NASA calibration stability of CERES VIIRS reflective solar bands. Stability is needed in order to provide climate quality TOA flux data sets as a pre-requisite for the consistent retrieval of cloud properties throughout the data record.

Decoster *et al.* [5] analyze the spectrally dependent aging of the Meteosat First Generation satellites in the visible. Within this scope the reflections of a set of clear-sky and cloudy targets are analyzed and a spectral aging model is applied and discussed. The manuscript also contains an extensive description of the Meoteosat imagery and its errors and traps.

Odongo *et al.* [6] provide an assessment of a site in Turkey (Tuz Gölü) for the radiometric vicarious calibration of satellite sensors. Its spatial homogeneity in the visible and near-infrared (VNIR) wavelengths over a 25-year period (1984–2009) is analyzed and discussed.

The specific difficulties of satellite calibration require proof and improvement of calibration methods. The assessment of uncertainties of sensor calibration methods and their improvement is therefore another important task within the scope of calibration of satellite sensors. This important issue is discussed in several manuscripts of the special issue.

In Xu *et al.* [7], the accuracies of radiometric calibration in the thermal infrared channels (TIS) are evaluated for VIRR on-board FY-3A and FY-3B. In Yang *et al.* [8], the near real-time NRL global tropical cyclone (TC) monitoring system, based on multiple satellite passive microwave (PMW) sensors, is improved with a new inter-sensor calibration scheme to correct the biases caused by differences in these sensors high frequency channels. In Fernandes *et al.* [9], analysis and inter-calibration of large data sets of total column water vapor products from scanning Micro-Wave-Radiometers is performed within the scope of a wet tropospheric correction for CryoSat-2

In Döring *et al.* [10], a new method is applied for the systematic derivation of calibration uncertainties of synthetic aperture radars. This is an important step toward traceable radiometric calibration of these systems.

For some years now satellite data has been established within climate studies and initiatives. This is also reflected in publications in this Special Issue, e.g., [5,11,12] and references therein. Use of satellite data within climate applications usually requires long data records extending the lifetime of a single remote sensing satellite. Cross-calibration (multi-sensor) and inter-calibration is therefore needed to provide a spatial and temporal homogeneous data set, e.g., [5,11,12]. Cross-calibration or inter-calibration is usually performed by comparison and subsequent adjustment of radiances observed from different sensors for simultaneous nadir overpasses (SNO), or more generally, identical targets. The radiances observed by the different satellites are then adjusted relative to a reference instrument. The inter-calibration of Meteosat First Generation satellites for the construction of a climate data record of Top of Atmosphere radiation from visible images is discussed in Decoster *et al*. [5].

In Karlsson *et al.* [12], inter-comparison of several satellites is performed and discussed within the scope of the Climate Change Initiative of the European Space Agency. In this study radiances from the MODIS, AVHRR, AATSR, and MERIS sensors are inter-compared using the SNO approach over a three-year demonstration period, covering 2007–2009. This is an important and required step for the construction of an AVHRR-heritage cloud product dataset for climate monitoring and analysis.

In Bosch *et al*. [11], a multi-mission cross-calibration is performed by adjusting an extremely large set of single- and dual-satellite crossover differences of altimeter systems. This is the basis for the construction of a consistent long-term data record from a sequence of different, partly overlapping altimeter systems. Systematic errors, modifications in the algorithms and geo-centering of the orbits are identified by sophisticated analysis methods; also data problems of rather new missions (such as HY-2A), but also weaknesses and unresolved issues of past missions (such as GFO or Jason-1) are discussed.

The question of calibration stability is of course also closely related to climate studies. This topic is addressed by, e.g., Bhatt *et al.* [4].

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Conflicts of Interest

The author declares no conflict of interest.

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