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Spectral band unification and inter-calibration of Himawari AHI with MODIS and VIIRS: Constructing virtual dual-view remote sensors from geostationary and low-Earth-orbiting sensors

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ABSTRACT

Through band unification and inter-calibration this paper develops and presents a method to construct virtual dual-view sensors from compatible geostationary and low-Earth-orbiting (LEO) sensors such that spectrally unified and radiometrically consistent observations from two different angles can be acquired using these virtual sensors. Results for three virtual dual-view sensors constructed from Himawari-8/AHI (one of the next generation of geostationary sensors) paired with MODIS (Aqua and Terra) and VIIRS are reported. Over 1270 representative Hyperion passes were used to reproduce, by spectral band integration, "simultaneous" observations by the three pairs of sensors, and linear relationships between AHI-MODIS and AHI-VIIRS were established, allowing the conversion of MODIS bands and VIIRS bands to AHI bands. For 95% of the sample pixels, a maximum reflectance conversion error < 0.004 was achieved. Following band conversion, inter-calibration was conducted using a ray-matching technique, involving up to 2100 matchup areas from 20 months of imagery. Overall the final calibration accuracy is high as indicated by high correlation r^2 (~0.98), small estimated parameter errors, small regression errors and negligible regression biases. The temporal drifting of the paired-sensors over a 20 month period was also analysed. It shows that all the involved sensors are very stable. Accurate inter-calibration not only provides an economical solution for the calibration and validation of remote sensors, it is also essential for synergetic multi-sensor applications. Lack of sufficient information from single-view sensors has been a common bottleneck in many remote sensing applications. Constructing virtual dual-view sensors using the presented method provides an effective way to overcome the limitations of single-view sensors, without incurring extra costs. The method can be applied to other next generation geostationary sensors leading to near global coverage and enhanced products. Inter-calibration between geostationary sensors, such as Himawari AHI – and GOES-R ABI, may be conducted using the LEO sensors as bridges.

1. Introduction

In recent years a series of new generation geostationary (GEO) remote sensors have become, or soon will become, available. These sensors provide major capability advances in terms of spatial, temporal and spectral resolutions. The Advanced Himawari Imager (AHI) (Bessho et al., 2016; Da, 2015; Okuyama et al., 2015) is on-board the Himawari-8 satellite in a geostationary orbit above 140.7°E. Launched on 7 October 2014, this sensor is capable of capturing the full disk every 10 min, with moderate spatial resolution (0.5 to 2 km) and 16 spectral bands from visible (0.47 μm) to thermal infrared (13.3 μm). In comparison, the previous MTSAT-1/2 sensors covering this region had 1-hour frequency, a single visible band with 1 km spatial resolution, and 4 infrared bands with 4 km spatial resolution. Other next generation GEO sensors with capabilities similar to Himawari-8/AHI are under development globally or recently launched: for the Americas the GOES-R/ABI (Schmit et al., 2005) at 89.5°W, for Europe/Africa the MTG-I/FCI (Durand et al., 2015) at 9.5°E, and for Asian-Oceania region the FY-4/AGRI (Lu and Shou, 2011) consisting of two operational missions (named FY-4-East and FY-4-West, to be located at 86.5°E and 105°E respectively) to provide wider coverage (https://www.wmo-sat.info/oscar/satelliteprogrammes/view/54) and GEO-KOMPSAT-2A/AMI at 128.2°E (https://www.wmo-sat.info/oscar/satellites/view/34).

By pairing the very high temporal resolution of these new GEO sensors with compatible low-Earth-orbiting (LEO) sensors, such as MODIS (Guenther et al., 1998), VIIRS (Cao et al., 2014) and SGLI

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(Second Generation Land Imager, launched on-board GCOM-C in December 2017; Honda and Kajiwara, 2013) a unique opportunity to acquire near-simultaneous dual-view observations is presented. Taking advantage of the different viewing geometries of the GEO and LEO sensors, via BDRF (Bidirectional Reflectance Distribution Function) model inversion means that combining these sensors afford opportunities to increase the information content.

Insufficient observations from single-view sensors is a common limitation to many remote sensing applications (Emelyanova et al., 2013; Jarihani et al., 2014; Vanhellemont et al., 2014; Wang et al., 2014). Near-simultaneous dual-view observations, when the observation targets (i.e., atmosphere and surface) can be assumed unchanged, would substantially increase the information content for BRDF modelling, thereby increasing the likelihood and accuracy to retrieve target properties, in applications such as forests (Chopping et al., 2010) and aerosol retrievals (Di Girolamo et al., 2004; Grey et al., 2006; Qin et al., 2015). Multi-view observations can be obtained from multi-angle sensors, such as POLDER (Deschamps et al., 1994), CHRIS (Cutter et al., 1999), MISR (Diner et al., 2010; Diner et al., 1989), AATSR (Smith et al., 2001) and SLSTR (Coppo et al., 2010). However, these multi-angle data are not widely available and the temporal coverage is often very limited. For example, both MISR and AATSR have 3 to 5 days revisit time. By using a dual-satellite constellation, SLSTR on Sentinel-3a and 3b (to be launched) (Fletcher and European Space Agency., 2012) can reduce the revisit time to 1 day.

Unifying GEO and LEO acquired imagery would provide a cost-effective and flexible alternative to multi-angle sensors, with significantly higher temporal resolution. For example, by combining MODIS/Aqua, MODIS/Terra and VIIRS the revisits of the same location will be increased to ~3 times daily. The number of daily visits can be further increased by using more LEO sensors such as SGLI.

To combine data across sensors requires calibration, which is the foundation of quantitative remote sensing (Ma et al., 2015; Mishra et al., 2016; Pahlevan and Schott, 2012; Santer et al., 2003; Steven et al., 2003; Wang et al., 2011). Additionally, unifying near-simultaneous multiple single-view GEO and LEO sensor data provides another source of information to monitor the long term changes in the spectral response of the involved sensors themselves. This complements the substantial efforts made to ensure the high quality of calibration, such as that of the MODIS sensors on both the Aqua and the Terra platforms, where a range of techniques including on-board calibrators, lunar observations, and stable ground sites are utilized (Wu et al., 2013; Xiong et al., 2010). Benefiting from experiences and lessons from MODIS calibration, VIIRS is expected to be even better calibrated (Eplee et al., 2015; Vermote et al., 2014; Xiong et al., 2014). Inter-calibration is also widely used between LEO sensors to calibrate one sensor using another well calibrated sensor as a reference and/or to validate the calibration consistency between two sensors. As examples, Angal et al. (2013) verified the consistency between MODIS and ETM+ using long term data over a pseudo-invariant site. Chander et al. (2013) used near-simultaneous ALI, ETM+ and MODIS observations over 4 calibration sites. Pahlevan and Schott (2012) validated L7/ETM+ calibration over a low reflectance area using Terra-MODIS as reference. Vermote and Saleous (2006) calibrated AVHRR using MODIS as reference over a stable Sahara desert site. Gao et al. (2015) described the cross-calibration of the HSI (hyper-spectral imager) using Hyperion as the reference.

Our objective is to develop a method for the construction of spectrally unified, radiometrically consistent and cost-effective virtual dual-view sensors by paring GEO–LEO sensor data, to enable the development of enhanced products through use of the richer measurements of higher frequency provided by these virtual dual-view sensors. Here AHI will be paired with the two MODIS sensors and the VIIRS sensor.

2. Method

To achieve our objective two steps are implemented: (i) spectral band conversion; and (ii) radiometric cross-sensor calibration (Fig. 1). The methods involved in the two steps are documented in Sections 2.1 and 2.2, respectively. Herein LEO refers to collectively the two MODIS sensors and the VIIRS sensor. The AHI bands will be referred to as AHI b1, AHI b2 etc., and the MODIS bands will be referred to as MODIS b01, MODIS b02 etc. For VIIRS, there are two sets of bands: the imagery bands (referred to as VIIRS I01 etc.) and moderate resolution bands (referred to as VIIRS M01, VIIRS M02 etc.).

2.1. MODIS and VIIRS to AHI spectral band conversion

Fig. 2 shows the spectral response functions of the five visible and near infrared AHI bands (from top to bottom), together with the MODIS and VIIRS bands in the same spectral regions. It shows that, despite the similarities between some AHI and LEO bands such as AHI b3–VIIRS I01 and AHI b4–MODIS b02, there are differences between the sensors in terms of their spectral response functions, with the AHI b2 at 510 nm

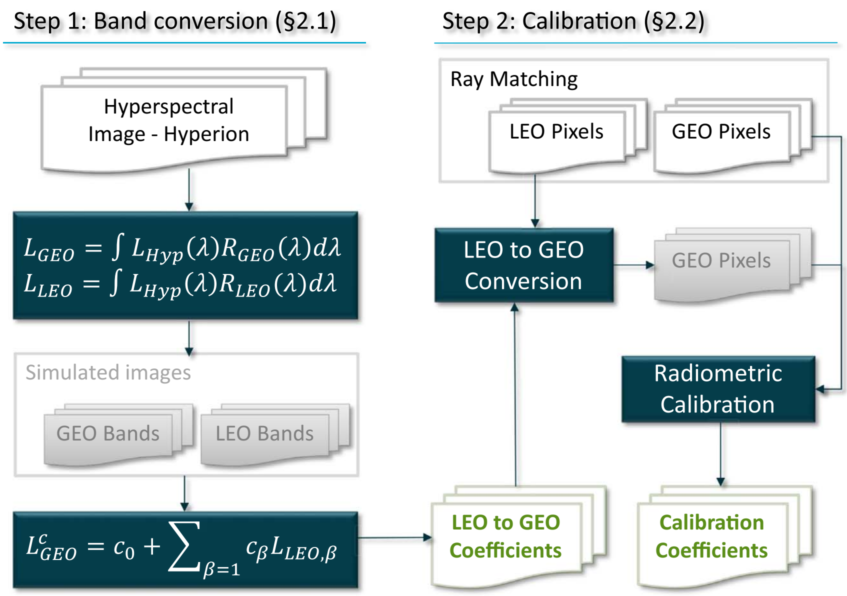

Fig. 1. Flow chart showing a process towards constructing dual-view sensors from GEO-LEO sensors. White boxes represent the input images, and green texted boxes are the outputs of the process. In this work the GEO sensor is AHI, and LEO refers collectively to the two MODIS sensors and the VIIRS sensor. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)