Author: Dr. Joan-Cristian Padró Garcia[1]

Grumets Research Group, Dep. Geografia, Edifici B, Universitat Autònoma de Barcelona, 08193 Bellaterra, Catalonia, Spain. JoanCristian.Padro@uab.cat

Contribution to REMOTE SENSING 101 TEXTBOOK INITIATIVE

TOPIC: Atmospheric corrections

Radiometric and atmospheric corrections to compare images from different sensors and captured in different atmospheric conditions.

To be bully comparable between them, images from different satellite sensors must be corrected and harmonised in a single spatial and radiometric frame, but also atmospheric effects must be corrected to obtain trustable measurements of the earth surface reflectance, independently of the satellite sensor being used. In other words, given the ideal case of two images captured exactly at the same time and over the same place by two different satellite sensors (e.g. OLI-2 Landsat-9 and MSI Sentinel-2A), they must have the same surface reflectance pixel values after all the radiometric and atmospheric corrections. Even more, assuming the same surface unaltered, the same surface reflectance values must be obtained in different atmospheric conditions.

Harmonizing satellite missions from different countries

International associations and governments have been creating an increasingly efficient Earth observation (EO) network in order to guarantee access to high-quality data systems. For these purposes, an increasing temporal availability of EO resources is arising from political will and collaboration. To maximize efforts in terms of scientific, social, and economic benefits, spatial agencies advance together through initiatives as the Global Earth Observation System of Systems (GEOSS). In GEOSS, the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA), among others, collaborate in the acquisition of high spatial resolution (SR) multispectral imagery, with the Landsat Data Continuity Mission (LDCM) and the Copernicus Sentinel-2 (S2) programs, respectively. The synergistic use of different satellite missions implies that images must have similar characteristics (spatial, spectral, radiometric, etc.). In fact, the design of several missions in recent years has gone in this direction, such as the aforementioned LCDM and Copernicus, currently with two Landsat (Landsat-8 (L8) and Landsat-9 (L9)) and two Sentinel-2 (Sentinel-2A (S2A) and Sentinel-2B (S2B)) satellites in orbit. The Sentinel constellation was designed to support the Landsat Program and provide continuity to the SPOT program by embedding sensors with similar spatial and spectral resolution features. The temporal orbit cycle of Sentinel-2 platforms was specifically thought to maximize combined consecutive observations with Landsat, thereby increasing their joint monitoring possibilities.

Spectral surface reflectance and atmospheric correction

Nevertheless, these efforts are still considered insufficient as long as the sensed raw data cannot be ensured to receive radiometric correction that allows the combined use of the different platforms and sensors intended to act in a coordinated way. The backbone of the radiometric correction of satellite data is the proper modelling of the atmospheric parameters affecting each captured image. Perhaps the most interesting physical magnitude to be obtained after an atmospheric correction of remote sensing optical imagery is spectral surface reflectance (ρs_λ; dimensionless), which can be defined as the proportion of reflected radiant flux over the incident radiant flux in a given wavelength. Indeed, surface reflectance is an essential variable for characterizing main land cover types with maximum accuracy. Besides atmospheric correction, topographic correction is also interesting for properly managing terrain incident angles, shadows, and so forth. Therefore, to this end, it is implemented in several radiometric correction processors (e.g., Sen2Cor-SNAP) using a digital elevation model (DEM) as auxiliary data. The DEM can also be used for other purposes, such as modelling the transmittance as a function of the terrain height, assuming a higher atmospheric transmittance at higher altitudes (e.g., 6S-LaSRC).

Official agencies provide surface reflectance products of Landsat and Sentinel-2 data by using specifically designed radiometric correction processors. For L8, the United States Geological Survey (USGS) uses an adaption of the Second Simulation of the Satellite Signal in the Solar Spectrum (6S), namely Landsat Surface Reflectance Code (6S-LaSRC). For S2, ESA uses an adaption of the Atmospheric Correction (ATCOR3) processor, also implemented in Sentinel's Application Platform (Sen2Cor-SNAP). Additionally, both official agencies work together towards harmonizing surface reflectance products to support the creation of time series combining L8 and S2 data (Harmonized Landsat and Sentinel (HLS)). Other works in this field have analysed the geometric adaption of both grid origins and different spatial resolution grids and the combined use of L8 and S2 data. In recent years, international projects have been focusing on the radiometric coherence between sensors, and particularly between L8 and S2 products, developing and comparing atmospheric correction processors (Atmospheric Correction Intercomparison Exercise (ACIX)). Thanks to these efforts, radiometric correction methods today provide an acceptable level of coherence, as can be validated by field spectroradiometric data captured almost simultaneously with satellite data.

Atmospheric correction physical description

Reaching a higher level of precision, a typical Sentinel-like optical sensor measures spectral radiance (Ls_λ; W m^{-2} sr^{-2} μm^{-1}), including both the land surface-reflected radiance, which usually is the main interest, and the atmospheric spectral radiance ($Latm_\lambda$), composed by the upwelling spectral radiance and the reflection of the downwelling spectral radiance of the atmosphere. Atmospheric spectral total optical depth ($\tau_{0\lambda}$; dimensionless) weakens the downwelling solar spectral irradiance ($E_{0\lambda}$; W m^{-2} μm^{-1}) and the upwelling surface-reflected radiance. At-sensor received radiance is also widely known as Top-Of-Atmosphere (TOA) radiance, and combining this with the solar radiance, its is possible to calculate the TOA reflectance.

Surface reflectance validation

For years, satellite remote sensing has been attempting to relate the images with field spectroscopy data. Field spectroradiometric measurement of surface reflectance at the satellite overpass is practically unaffected by atmospheric effects. Moreover, it is a valuable source of information for assessing and reinforcing the accuracy of radiometric correction. Currently, in situ measurements are carried out by operators using portable field spectroradiometers, sometimes with elevator devices. However, they face various challenges, such as trying to access high tree canopies or water surfaces, or the impossibility of measuring in dangerous or restricted areas. Another important restriction of conventional field spectroradiometry is the specific covered area and the sampling method themselves, since during the acceptable time of 20 min before and after the satellite overpass, a skilled operator can scan up to a reasonable area equivalent to 20 pixels of OLI 30 m, 45 pixels of MSI 20 m, or 180 pixels of MSI 10 m. Moreover, it is advisable to adapt sampling strategies to a predetermined satellite pixel size and origin, followed by a resampling of the pointer field data to the different satellite pixel sizes, which is neither a trivial nor easy task by any means. For example, although ground-sampling data is usually georeferenced in an accurate way, in some situations, such as the forest understory, it can be difficult to achieve accurate georeferencing. In this context, imagery acquired with hyperspectral or multispectral sensors onboard manned or unmanned aerial systems (UAS) is expected to complement field data, as the aerial platform can access those hardly accessible areas in a faster way than human operators and systematically sample the surface with higher spatial accuracy.