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Improving the SMAC atmospheric correction code by analysis of Meteosat Second Generation NDVI and surface reflectance data

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ABSTRACT

In order to obtain high quality data, the correction of atmospheric perturbations acting upon land surface reflectance measurements recorded by a space-based sensor is an important topic within remote sensing. For many years the Second Simulation of the Satellite Signal in the Solar Spectrum (6S) radiative transfer model and the Simplified Method for Atmospheric Correction (SMAC) codes have been used for this atmospheric correction, but previous studies have shown that in a number of situations the quality of correction provided by the SMAC is low. This paper describes a method designed to improve the quality of the SMAC atmospheric correction algorithm through a slight increase in its computational complexity. Data gathered from the SEVIRI aboard Meteosat Second Generation (MSG) is used to validate the additions to SMAC, both by comparison to simulated data corrected using the highly accurate 6S method and by comparison to *in-situ* and 6S corrected SEVIRI data gathered for two field sites in Africa. The additions to the SMAC are found to greatly increase the quality of atmospheric correction performed, as well as broaden the range of atmospheric conditions under which the SMAC can be applied. When examining the Normalised Difference Vegetation Index (NDVI), the relative difference between SMAC and *in-situ* values decreases by 1.5% with the improvements in place. Similarly, the mean relative difference between SMAC and 6S reflectance values decreases by a mean of 13, 14.5 and 8.5% for Channels 1, 2 and 3 respectively. Furthermore, the processing speed of the SMAC is found to remain largely unaffected, with only a small increase in the time taken to process a full SEVIRI scene. Whilst the method described within this paper is only applicable to SEVIRI data, a similar approach can be applied to other data sources than SEVIRI, and should result in a similar accuracy improvement no matter which instrument supplies the original data.

1. Introduction

When examining the Earth's surface from a space-based remote sensing platform, the atmosphere is a large factor in the uncertainty associated with a surface reflectance measurement. On its path from the Sun to the surface and onwards to the sensor, a photon can be disturbed from its course through the influence of atmospheric absorption and scattering. The former of these decreases the radiance measured at satellite level whilst the latter can, depending upon atmospheric conditions, either increase or decrease the measured radiance. Atmospheric components such as aerosol or water vapor content can substantially modify the top of atmosphere (TOA) radiance as seen by the satellite (Herman and Browning, 1975; Richards and Jia, 2006). In addition, the View Zenith Angle (VZA) and Solar Zenith Angle (SZA) also play a major role in determining the effects of the atmosphere. If the zenith angle is far from nadir then the photon must travel through a much larger portion of the atmosphere, and thus the chance of an absorption or scattering event greatly increases. Conversely for angles close to nadir the path length is greatly reduced, as is the uncertainty in radiance due to the atmosphere.

The goal of an atmospheric correction scheme is to nullify this atmospheric influence by modifying the TOA radiance measurement recorded by a sensor in accordance with calculated values for the atmospheric absorption and scattering along the path travelled by incident light. This results in a surface radiance, or after further computation, a surface reflectance that is free from influence by atmospheric scattering and absorption. Whilst no atmospheric correction scheme can completely remove the effects of the atmosphere, a considerable amount of work has been done into improving the accuracy and quality of correction. One particularly accurate scheme is

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the Second Simulation of the Satellite Signal in the Solar Spectrum, 6S (Vermote et al., 1997). This method is at heart a radiative transfer code, but can be operated in reverse to function with an atmospheric correction scheme to derive a surface reflectance from a top of atmosphere reflectance. It treats the problem of atmospheric perturbations to a satellite signal in great detail, accounting for the effects of a substantial number of atmospheric gases and particulates as well as other factors such as the polarisation of incoming light and — if required — the properties of the target itself. Kotchenova et al. (2006) detail the validation process for 6S and show that in most circumstances the 6S scheme is of high accuracy when compared to other atmospheric correction methods. One other commonly used method is that described by Rahman and Dedeiu (1994), known as the Simplified Method for Atmospheric Correction (SMAC). It has been designed to emulate the accuracy of 6S whilst reducing complexity and enabling the atmospheric correction to be quickly performed on a large data set. A substantial number of simplifications are made to the calculation method used within the SMAC, and a number of the more complex components that are modelled within 6S are not included in the SMAC. This enables the SMAC to perform, on average, almost 3000 times faster than 6S, but naturally results in a decrease in the accuracy of the atmospheric correction. As shown in Proud et al. (submitted), under a wide range of conditions the SMAC-corrected surface reflectances for a SEVIRI/MSG sensor are substantially different from the 6S surface reflectances. These differences reduce the value of the SMAC in correcting for atmospheric perturbations, and are discussed in more detail in Section 4.1.

The Spinning Enhanced Visible and InfraRed Imager (SEVIRI) that flies aboard the geostationary Meteosat Second Generation (MSG) series of spacecraft is a multispectral sensor that records one full disk Earth image every 15 min, a subset of which is shown in Fig. 1. Of primary interest within this study are the three Visible and Near InfraRed (VNIR) wavelength bands centred at 635, 810 and 1640 nm (Aminou, 2002), more commonly known as Channels 1, 2 and 3 respectively. Typically these bands are used for examining aerosol optical depth (AOD), cloud detection, soil moisture content or vegetation parameters such as NDVI (Cadau and Laneve, 2008; Fensholt et al., 2006b; Schmetz et al., 2002). Channel 1 is particularly affected by ozone content, whilst channels 2 and 3 are mostly affected by water vapour content (Vermote et al., 2006). Therefore they are very useful for studying the effects that any changes made to the SMAC have upon its accuracy when dealing with those two gases. The 15 min scan time is one of the highest temporal resolutions available from geostationary orbit and enables accurate monitoring of events such as changes in plant water stress due to water availability or the evolution of cloud cover over the course of the day (Fensholt et al., 2009; Roebeling et al., 2008). For areas that experience frequent cloud cover this high temporal resolution also increases the probability of gaining a cloud free look at any particular pixel. As SEVIRI scans once per 15 min, the Sun will move by a small amount in each scene, meaning that solar angles must be calculated for each image and cannot be precomputed. These changes in solar angles for different pixels and times-of-day have a substantial impact upon the top of atmosphere reflectance that is measured by the sensor, and must be accounted for within the radiative transfer correction code.

Fig. 1. A typical MSG-SEVIRI scene, with the Dahra and Nairobi field locations highlighted.

Due to the large area covered by the SEVIRI and the high temporal resolution, it is not usually possible to use a full radiative transfer code (such as 6S) on the received data, as this would require too much time and computational resources. As described in Proud et al. (submitted) there are a number of issues with the SMAC when correcting in particular atmospheric conditions. Channels 1 and 2 display very poor quality correction (when compared to 6S) under almost all atmospheric and angular conditions. Channel 3 is of much higher quality but still differs from 6S under some key conditions, such as high water vapor content. Changes to the way in which the SMAC computes its correction values are therefore required in order to make the code as useful and as accurate as possible.

The SMAC is designed to allow modifications to its method with ease. This can be done either through changing the values of the various sensor specific coefficients that the SMAC requires as an input or by changing the actual atmospheric correction calculations that are made within the code. Although it is possible to improve accuracy simply by changing the coefficients, this study examines the more complex case of code alteration. The advantage of altering the calculation code itself is that the range of conditions under which the SMAC operates successfully can be extended. For example, the original SMAC is unable to produce high quality channel 1 surface reflectance values for conditions where the VZA or SZA exceeds 30° (Proud et al., submitted). By adding additional calculations to the code this limit can be extended to beyond 30° and therefore increase the range of conditions for which the SMAC is suitable. In order to determine the nature of the changes that were required it was decided that the SMAC calculations should attempt to mirror the 6S calculations as closely as possible (as was the case for the original SMAC). Mathematical models were constructed that mapped the divergences between the SMAC and 6S results for a variety of atmospheric conditions. Based upon these models, changes were made to the SMAC calculation method in order to reduce any differences that arose between the two correction techniques. The details of this approach are discussed within Section 4.

This study examines one method of increasing the accuracy of the SMAC, particularly in channels 1 and 2 — and thereby also increasing the accuracy of NDVI measurements. The changes made to the SMAC will be briefly discussed and results shown that provide feedback on the success of the SMAC changes. This feedback will be examined through analysis of both long and short timescale datasets at field sites operated in Dahra, Senegal and near Nairobi, Kenya. This allows the success of the changes made to the SMAC to be determined for seasonal trends such as the rainy and dry seasons as well as for diurnal trends due to the varying Sun angle. Also discussed are the effects of these changes upon the speed at which the SMAC can correct for atmospheric effects. One of the prime goals of the SMAC was to enable fast correction of data, so it is important that it retains this capability.