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SPECTRAL TRANSFORMATION OF METEOSAT-VISIBLE-BAND SURFACE ALBEDO TO BROAD-BAND SURFACE ALBEDO AND ITS DEPENDENCY ON SOLAR ZENITH ANGLE

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ABSTRACT: Surface albedo has been calculated in the METEOSAT-4 VIS band and in a squared broad band (0.25-2.5 μm) for a set of surfaces from the EFEDA Project. In the albedo estimation, incident and reflected radiances were simulated by means of the 5S code, assuming Lambertian behaviour. A MATLAB program was developed to handle large amounts of data needed in simulations. Calculated albedos were correlated to get a spectral transformation from METEOSAT VIS band (filtered albedo) to broad band (meteorological albedo). The obtained relationship is linear to a good approximation but its dependency on solar zenith angle is weak in the interval 0 - 60°.

INTRODUCTION

Surface albedo is one of the important parameters of the Earth-Atmosphere system radiation balance. Meteorological albedo may be defined as the ratio of reflected to incident radiation, both spectrally and hemispherically integrated and depends on surface type and solar zenith angle. An advantageous way to obtain albedo is from satellites, with wide spatial and temporal availability. Very often, these data are limited to the sensor spectral filter and viewing angle. Thus, it is necessary to transform filtered albedo to broad band albedo. Determination of this spectral correction for the METEOSAT VIS band as a function of solar zenith angle is the object of this work.

If the surface can be assumed Lambertian, its reflectance may be expressed as

$$\rho(\lambda) = \frac{\pi\ L(\lambda)}{\mu_s\ E_s(\lambda)} \tag{1}$$

where $L(\lambda)$ is the reflected spectral radiance (W m^{-2} sr^{-1} μm^{-1}), $\mu_s = \cos \theta_s$, with θ_s the solar zenith angle, and $E_s(\lambda)$ the spectral solar irradiance (W m^{-2} μm^{-1}) reaching the surface normally to the illumination direction.

Spectral albedo α in any spectral band may be defined as the hemispherical reflectance integrated with respect to the wavelength defined for that band and may be expressed as

$$\alpha = \frac{\pi\ L}{\mu_s\ E_s} \tag{2}$$

L is now the integral of the spectral radiance weighted by the spectral band filter function (W m^{-2} sr^{-1}) and E_s the weighted integral of the spectral solar irradiance (W m^{-2}):

$$\pi\ L = \int_{\lambda_{inf}}^{\lambda_{sup}} \pi\ L(\lambda)\ S(\lambda)\ d\lambda \tag{3}$$

$$\mu_s\ E_s = \int_{\lambda_{inf}}^{\lambda_{sup}} \mu_s\ E_s(\lambda)\ S(\lambda)\ d\lambda \tag{4}$$

where $S(\lambda)$ is the spectral response of the filter function and λ_{inf} and λ_{sup} the extreme wavelength values of the spectral band.

The objective of this work is to calculate the relationship between both band albedos. The METEOSAT VIS channel has a triangular shape regarding wavelength (0.4-1.1 μm), and the broad band filter is constant from 0.25 to 2.5 μm. The procedure is to carry out simulations by using a modified version of the 5S radiative transfer code, taking advantage of this powerful tool that controls a large number of parameters representing a wide range of atmospheric, geometrical, surface and spectral conditions. Surface spectral data proceed from reflectance field measurements from the EFEDA Project, to make more realistic simulations. We present a relationship for both albedos according to surface type and globally, and we carry out a detailed study of this spectral correction as a function of solar zenith angle.

METHODOLOGY

Radiative Transfer Model. The 5S radiative transfer code calculates the different components of atmospheric radiance and is able to simulate the signals observed by different satellites in the solar spectrum, assuming a cloudless atmosphere and a surface Lambertian behaviour. The code divides the solar spectrum in 750 intervals from 0.25 to 4.00 μm thus providing a good resolution for our purposes. The input parameters may be selected from standard conditions pre-defined in the code (satellite spectral bands and observing angles, surface types, aerosol types, distribution and sizes, atmosphere profiles) or defined by the user. The code calculates apparent reflectance, gas transmittance, surface irradiance, and the different contributions to the radiance observed by the satellite, taking into account the main atmospheric effects produced by gas absorption (water vapour, oxigene, CO_2 and ozone) and molecule and aerosol scattering. It also contemplates the possibility of homogeneous and non-homogeneous surface and offers the results spectrally integrated.

Surface Reflectance Models. In the context of the EFEDA Project, we measured spectral reflectance of the most representative surfaces of Castilla-La Mancha, in April and June, 1991. Some of these measurements are suitable to make more realistic simulations. The spectral signatures of the different surfaces were obtained by using a GER-SIRIS spectroradiometer (0.4-3.0 μm) with a spectral resolution of 2 and 4 nm depending on the diffraction grating. Twenty three surfaces were selected for this study, nine correponding to different bare soils, nine to natural vegetation and five to different green healthy crops. Fig. 1 shows their reflectance spectra overimposed to the filter bands.

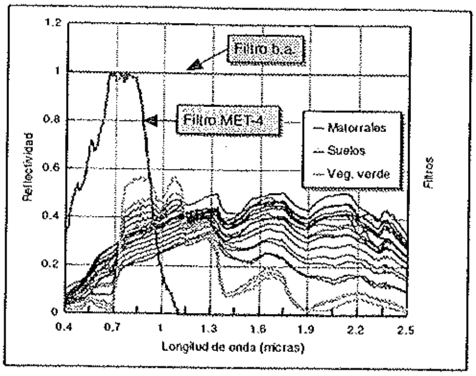

Fig.1)- Spectral signatures overimposed to the spectral filters object of the study.

Data Input and Output of the Simulations. The MATLAB Environment. To run 5S, it is necessary to edit an input file with all spectral, atmospheric, geometrical and surface condition data. Since the code has been slightly modified to make it iterative, it seemed suitable to develop a user friendly computer MATLAB programme permitting not only to automatically edit and handle large data input files in an interactive way, but also to retrieve the result matrix and facilitate its analysis in graphical form. The MATLAB programme helps to solve different problems, avoiding to keep order, positions, formats and values in the input file in a rigid way. The user may introduce geographical coordinates in different formats, define and select other filters not implemented in the code, introduce radiosounding data, reflectance spectra, filter functions, etc. In addition, when running the code iteratively, the user may define the range and variation steps of the changing parameters.

This work aims to obtaining the albedo spectral correction from METEOSAT band to broad band. The relationship has been studied at the surface level by using the 5S code and spectral reflectance measurements selected from EFEDA. 5S is explicitly used to estimate surface irradiance spectral distribution. Spectral band albedo is obtained from the calculated spectral irradiance and the selected spectral reflectances assuming surface Lambertian behaviour. The interest of this work is to determine the dependency of the spectral transformation on surface type and solar zenith angle. The large number of data needed to study this dependency demanded the development of a MATLAB programme to facilitate the use of 5S iteratively.

RESULTS AND CONCLUSIONS

Isotropic albedo is obtained by spectrally integrating surface incident irradiance, $E_s(\lambda)$, and reflected radiance, $L(\lambda)$, both weighted with the filter function, $S(\lambda)$:

$$\alpha = \frac{\pi \int_{\lambda_{inf}}^{\lambda_{sup}} L(\lambda)\, S(\lambda)\, d\lambda}{\mu_s \int_{\lambda_{inf}}^{\lambda_{sup}} E_s(\lambda)\, S(\lambda)\, d\lambda} \qquad [5]$$

From Eq. (5), we shall call α_{MET} the albedo calculated for METEOSAT-4 VIS band and α_{BB} the albedo calculated for a squared broad band from 0.25 to 2.5 μm.

The selected surface spectra are representative of an agricultural continental region. Clouds and snow were not included and water was shown in graphics to observe a larger albedo range, not for analytical calculations. Atmospheric conditions were: standard midlatitude summer atmosphere, continental aerosols, and visibility of 17 km. Geometrical conditions corresponded to solar zenith angle variation from 0 to 60°.

Spectral Transformation of Albedo as a Function of Surface Type. The results of the simulation for all the surfaces are shown in Fig. 2 in terms of broad band albedo versus METEOSAT albedo with a good correlation between both. The figure also shows that the solar zenith angle dependency produces a characteristic scattering for each surface type. Particular behavior for three specific surfaces, bare soil, natural vegetation and green crop may be seen in Fig. 3 in more detail. A solar zenith angle variation from 0 to 60° produces a linear scattering approximately paralell to the diagonal. Fig. 3 which is an enlargement of a region of Fig. 2, also shows that both albedos increase with solar zenith angle. Note that the slope associated to this gowth actually depends on the specific surface type.

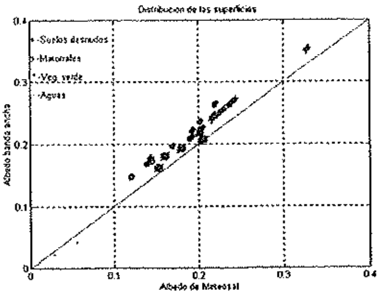

Fig.2)- Relationship between METEOSAT albedo and broad band albedo

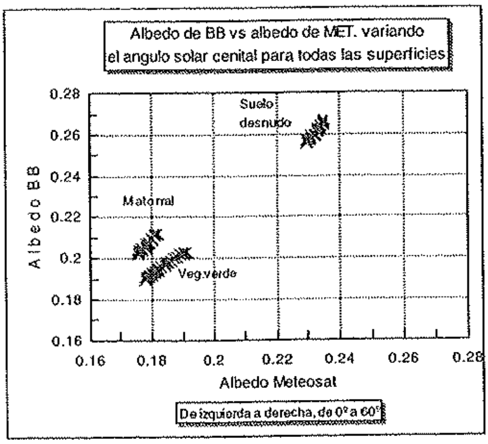

Fig.3)- METEOSAT albedo vs broad band albedo, for solar zenith angle 0 to 60°.

As a preliminary conclusion, the spectral transformation of METEOSAT albedo to broad band albedo depends on surface type and solar zenith angle. However, this dependency is not very large according to Fig. 2. For a particular surface type, the effect of solar zenith angle variation only produces a linear scattering in the same direction as the correlation between both albedos. Thus, we have obtained linear relationships for the different surface types, and they are shown in Table I and Fig. 4 together with the linear relationship for all the surfaces as a whole.

Table I. Linear relationships between METEOSAT albedo and broad band albedo as $\alpha_{BB} = M\, \alpha_{MET} + N$. (R = correlation coefficient, STD = standard deviation).

SURFACE	M	N	R	STD
Bare Soil	0.94	0.038	0.998	4.46
Nat. Veg.	1.06	0.015	0.982	3.44
Geen Crop	0.89	0.031	0.949	1.89
ALL	1.10	0.0009	0.988	6.62

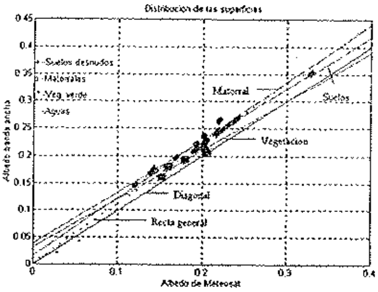

Fig.4)- METEOSAT to broad band spectral correction according to surface type

According to standard deviation, the best linear fit corresponds to green vegetation. The linear regressions for each surface type have smaller errors than the linear regression for all surfaces as a whole. However, the low resolution of the METEOSAT observation (2.5 x 2.5 km^2 at nadir) does not permit a pixel classification which in the end may be considered in fact as a combination of the three basic surface types. This justifies the usefulness of the general regression in spite of its larger STD value.

Spectral Transformation of Albedo as a Function of Solar Zenith Angle. The interest now is to try to formulate a transformation valid for all kinds of surfaces, including the dependency with the solar zenith angle. The transformation should be linear for the albedo whereas the dependency with the solar zenith angle should be in the regression coefficients. Eq. (6) below shows the spectral transformation obtained from our simulation, and Fig. 5 shows the 3-dimensioonal of the data obtained in the simulation and the surface given by Eq. (6).

$$\alpha_{BB} = a(\theta)\, \alpha_{MET} + b(\theta) \qquad [6]$$

where $a(\theta) = 1.09$;
$b(\theta) = -3.67\times10^{-4} + 1.23\times10^{-4}\theta +$
$+5.55\times10^{-3}\sin(x) + 2.18\times10^{-3}\cos(x)$;
$x = 2.32\times10^{-2}\theta + 2.53$
and θ is expressed in degrees.

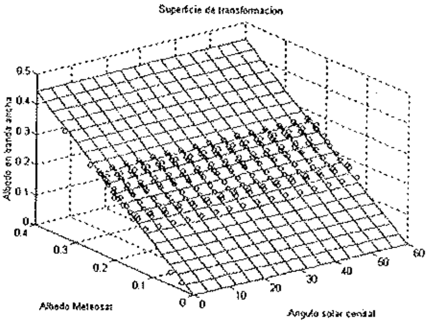

Fig.5)- Spectral correction of METEOSAT albedo to broad band albedo as a function of solar zenith angle.

The angular dependency in the a(θ) coefficient is minimum (its value is a constant in Eq. (6)). The maximum error for this coefficient not considering solar zenith angle dependency is about 0.7%, which practically coincides with the accuracy associated to the 5S code which is about 0.5%. The coefficient b(θ) was adjusted by means of a set of functions of different angular dependency, obtaining the best correlation with a sine function (R = 0.988). The range for b(θ) between 0 and 60° is 0.0020 and 0.0096, respectively, showing that the solar zenith angle dependency is necessary. However, by considering that the usual albedos are above 0.1, the correction from the b(θ) is not exceedingly large.