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TWELVE MONTHLY MAPS OF GROUND ALBEDO PARAMETERS DERIVED FROM MODIS DATA SETS

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ABSTRACT

The National Aeronautics and Space Administration (NASA) of the USA is making available to anyone worldwide maps of ground albedo parameters that are derived from the MODIS (Moderate Resolution Imaging Spectroradiometer) instrument. The first parameter *fiso* describes the isotropic part of the bidirectional reflectance distribution function (BRDF); the two other parameters *fvol* and *fgeo* are linked to the viewing and illuminating geometry and describe the anisotropic part of the BRDF. These maps exhibit missing values. This communication describes a series of 12 monthly maps of the BRDF parameters with no missing values available on the Web. In addition, a method for computing the ground albedo is proposed that does not require the a priori knowledge of the ratio of the direct to the global irradiance.

Index Terms— surface solar irradiance, agrometeorology, climate, ocean, albedo

1. INTRODUCTION

The downwelling solar irradiance observed at ground level on horizontal surfaces and integrated over the whole spectrum (total irradiance), is called surface solar irradiance (SSI). It is the sum of the direct irradiance, from the direction of the sun, and the diffuse irradiance originating from the rest of the sky vault, and is also called the global irradiance [1]. The SSI is an Essential Climate Variable (ECV) as established by the Global Climate Observing System in August 2010 [2]. Knowledge of the SSI and its geographical distribution is of prime importance for numerous domains as e.g. weather, climate, biomass, and energy. Part of the diffuse irradiance is composed of photons that are once or more reflected by the ground and then by the atmosphere, cloudy or not, towards the receiving horizontal surface [1]. Hence the diffuse irradiance and the global irradiance E are a function of the ground albedo ρg. As a consequence, ρg must be known to assess the SSI.

Such knowledge is not easily available worldwide, with the exception of the National Aeronautics and Space Administration (NASA) of the USA which is making available to anyone worldwide maps of ground albedo parameters that are derived from the MODIS (Moderate Resolution Imaging Spectroradiometer) instrument. However, two difficulties are encountered when using these NASA data sets. The first one is that the computation of ρg depends on the diffuse irradiance, which in turn depends on ρg due to the multiple reflections between the ground and the atmosphere, cloudy or not. The second one is that the maps proposed by the NASA have missing values. This communication discusses how to compute ρg and proposes 12 monthly maps of ground albedo parameters that are dense, tractable and accurate enough at least for computing the SSI in an operational chain.

2. THE THREE MODEL PARAMETERS FOR ALBEDO FROM MODIS

MODIS is an instrument aboard the Terra and Aqua satellites of the NASA. It acquires data in several spectral bands, from which among others, three parameters describing the ground albedo can be derived. These three parameters are called *fiso*, *fvol*, and *fgeo* [3]. *fiso* describes the isotropic part of the bidirectional reflectance distribution function (BRDF); the two other parameters are linked to the viewing and illuminating geometry and describe the anisotropic part of the BRDF. The directional hemispherical reflectance, also known as black-sky albedo ρbs [4], and the bihemispherical reflectance, also known as white-sky albedo ρws, are computed from the BRDF using the following formulas [3], where θ_S is the solar zenith angle:

$$\rho ws(\theta_S) = fiso + fvol\,(-0.007574 - 0.070987\,\theta_S^2 + 0.307588\,\theta_S^3) + fgeo\,(-1.284909 - 0.166314\,\theta_S^2 + 0.041840\,\theta_S^3) \quad (1)$$

$$\rho bs(\theta_S) = fiso + 0.189184\,fvol - 1.377622\,fgeo \quad (2)$$

Denoting B and E respectively the beam and global irradiances, the ground albedo ρg is given by:

$$\rho g = \rho ws + [B / E(\rho g)]\,(\rho bs - \rho ws) \quad (3)$$

3. COMPUTING THE GROUND ALBEDO

The ratio of the beam B to global $E(\rho g)$ appears in Eq. (3). Since the global $E(\rho g)$ is the sum of the beam B and the diffuse $D(\rho g)$ irradiances, knowing this ratio is equivalent to knowing the ratio $D(\rho g)$ to $E(\rho g)$. The multiple reflections between the ground and the atmosphere, cloudy or not, contribute to $D(\rho g)$. As a consequence, the ratio D/E depends on ρg and solving Eq. (3) for ρg requests D/E. This communication proposes a heuristic approach to solving Eq. (3) assuming that *i)* B is known and *ii)* $E(\rho g)$ is known for three specific values of ρg: 0.0, 0.1 and 0.9. Let $E0$ denote the solar irradiance received on a horizontal plane at the top of atmosphere. $E0$ is easily calculated by trigonometric functions [5]. The clearness index KT, also known as the global transmissivity of the atmosphere, or atmospheric transmittance, or atmospheric transmission, is defined by:

$$KT(\rho g) = E(\rho g) / E0 \quad (4)$$

The direct clearness index KT_B is defined in the same way:

$$KT_B = B / E0 \quad (5)$$

The formula of Vermote et al. [6]:

$$KT(\rho g) = KT(\rho g{=}0) / (1 - \rho g\, S) \quad (6)$$

describes the change in KT as a function of the ground albedo ρg and the atmospheric spherical albedo S. S is unknown and, in principle, it can be computed using Eq. (6) knowing $KT(\rho g)$, or equivalently $E(\rho g)$, for any value of ρg. In practice, it is sufficient to know $E(\rho g)$ for three values of ρg: 0.0, 0.1, and 0.9, and S can be computed for any ρg by linear interpolation and extrapolation [8]:

$$a = [S(\rho g{=}0.9) - S(\rho g{=}0.1)] / 0.8$$
$$b = S(\rho g{=}0.1) - 0.1\, a$$
$$S = a\, \rho g + b \quad (7)$$

Denoting $\Delta = (\rho ws - \rho bs)$, and combining the above equations, one obtains a second-order equation in KT which is the quantity of interest:

$$a\, \Delta^2 KT_B^{\,2} + KT\, [KT(\rho g{=}0) + (2\, a\, \rho ws + b)\, \Delta\, KT_B] + (a\, \rho ws^2 + b\, \rho ws - 1)\, KT^2 = 0 \quad (8)$$

All quantities, but KT, are known in this equation. Therefore, Eq. (8) can be used to compute KT by keeping the solution $KT > KT_B$, Eq. (4) provides $E(\rho g)$, and Eq. (3) provides ρg.

4. CONSTRUCTING MONTHLY MEANS OF BRDF PARAMETERS

The MCD43C1 and MCD43C2 data, derived from MODIS images, are 16-day composites provided as a level-3 product projected to a 0.05° grid in latitude/longitude, approximately 5.6 km at Equator. A product is composed of 3600 x 7200 pixels. They are produced every 8 days with 16 days of acquisition, where the given date is that of the first day of the 16-days period. These data sets contain the three model parameters *fiso*, *fvol*, and *fgeo*. The difference between the MCD43C1 and MCD43C2 products is that MCD43C2 is a snow-free version of MCD43C1. Both products are worldwide but restricted to land. Both products exhibit other irregular data gaps in time and space. Considering the period 2004-2011, it is found that 26.2% of the pixels have at least one valid value per month in the products MCD43C1 and only 18.4% for MCD43C2. Approximately 3.3% of the pixels bearing a valid value differ in value between MCD43C1 and MCD43C2, i.e. 96.7% known pixels agree. The difference is small between both products, except that MCD43C1 has more known pixels.

The European-funded projects MACC and MACC-II (Monitoring Atmosphere Composition and Climate) have several objectives, including the development of an operational chain for the assessment of the SSI. It has been decided for operational reasons to use only multiannual means of monthly averages of the BRDF parameters computed over the period 2004-2011. Lefevre et al. [7] find that using multiannual monthly means instead of the product MCD43C2 did not change noticeably the accuracy of the retrieved SSI and make operations more tractable. Therefore, the mean values of the three BRDF parameters from MCD43C1 product were computed for each of the twelve months of the year over the period 2004-2011. Each mean value was allotted to the 15th of each month. From an operational point of view, the values for the current day are computed by linear interpolation between the nearest means modulo 12.

Additional efforts have been made on the completion of data which are missing mostly in water-covered areas. The “Land Cover Type” product is a MODIS product named MCD12C1 using the same grid than MCD43C1. It identifies pixels containing water and the proportion of water in these pixels. Let W denote the binary mask for water; W is set to 1 if the pixel has been classified as “water” at least once for the given month during the period 2001-2009 covered by the “Land Cover Type” product, and is 0 otherwise. The typical triplet *fW=(fiso, fvol, fgeo)* for water areas is defined by the mode of the valid triplets *f=(fiso, fvol, fgeo)* for water pixels comprised between latitudes -45° and + 45°. Let P be the average proportion of the water. *fW* was allotted to each unknown water pixel for which $P=1$. Then, if a water pixel exhibits a valid triplet *f* and a proportion of water P less than 1, *f* is replaced by the linear combination: $P\, fW + (1-P)\, f$. A moving average of +/- 1 month is then applied followed by a median filter of 11x11 pixels to replace unknown pixels. This two-steps filtering is repeated but with a window of +/- 2 months. Then, a median filter of 21x21 pixels is applied to replace unknown pixels. The few pixels still unknown were located in the middle of the ocean, extreme southern part of the Antarctic Ocean, and Greenland and were individually treated manually and were allotted the mean value of the triplets *f* averaged in their neighborhood.

Figure 1 displays the maps of *fiso* for July and December.

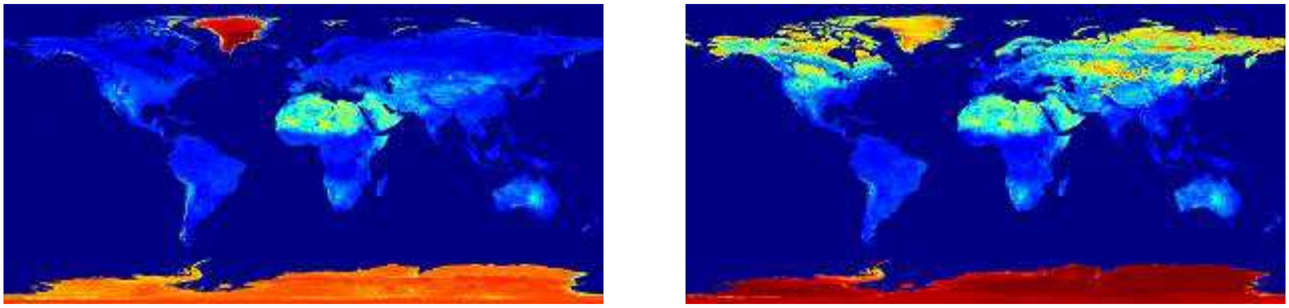

Fig. 1. Maps of *fiso* for July and December. Values increase from dark blue to red and dark red. Color table is the same for both maps.

5. CONCLUSION

A series of 12 maps of the BRDF parameters have been computed. They are in operational use for computing the SSI worldwide in clear-sky conditions [8] and in Europe and Africa for any condition. These maps are available in HDF5 format at http://www.oie.mines-paristech.fr/Valorisation/Outils/AlbedoSol/ under a Creative Commons license (CC-BY). These maps were created for SSI computation but are useful in many other applications, such as climate or agrometeorology.

The computation of the ground albedo ρg from these BRDF parameters depends on the diffuse irradiance, which in turn depends on the albedo because of the multiple reflections between the ground and the atmosphere, cloudy or not. The computation method proposed here does not require the a priori knowledge of the ratio of the diffuse to the global irradiance.

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