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Simulating clear-sky reflectance of the Earth as seen by satellite radiometers with a radiative transfer model

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Introduction

Reflectances at the top of atmosphere of the Earth (TOA) are fundamental data derived from satellite radiometers.

By comparing measurements of such instruments with radiative transfer simulations of clear-sky (*i.e.* cloudless) situations, it is possible to isolate cloud properties or else atmospheric or surface characteristics, that are not accounted by the simulator. Notably, we aim at using such simulations to assess from satellite data a cloud index for surface solar irradiance retrievals.

We developed a fast way to routinely simulate TOA reflectances in the visible range of the electromagnetic spectrum. The method is summarized in Fig. 1.

Our method is here tested for the SEVIRI radiometer on board the Meteosat-9 geostationary satellite (MSG, for Meteosat Second Generation), and for the EPIC radiometer on board the DSCOVR satellite which orbits at the Sun-Earth L1 Lagrange point, 1.5×10^6 km distant from Earth.

Results are summarized in Fig. 4 and 5 and Tables 2 and 3.

Methods

Visible channels of EPIC and SEVIRI radiometer are very different (Fig. 3). The large bandwidth of SEVIRI visible channels leads to expensive running time for nm-resolved radiative transfer simulations. We therefore use the spectral approximation by [Kato et al., 1999], initially designed for broadband shortwave surface irradiance estimates.

The anisotropy of the ground reflectance is taken into account, by using the Ross-Li model of bidirectional reflectance distribution function (BRDF), along with BRDF parameters derived from satellite measurements (*cf.* Fig. 1). Cloudy measurements have been manually filtered out from satellite data (Table 1).

The method is tested for 8 sites (7 for MSG) with different characteristics, viewing geometries, climates and surface types.

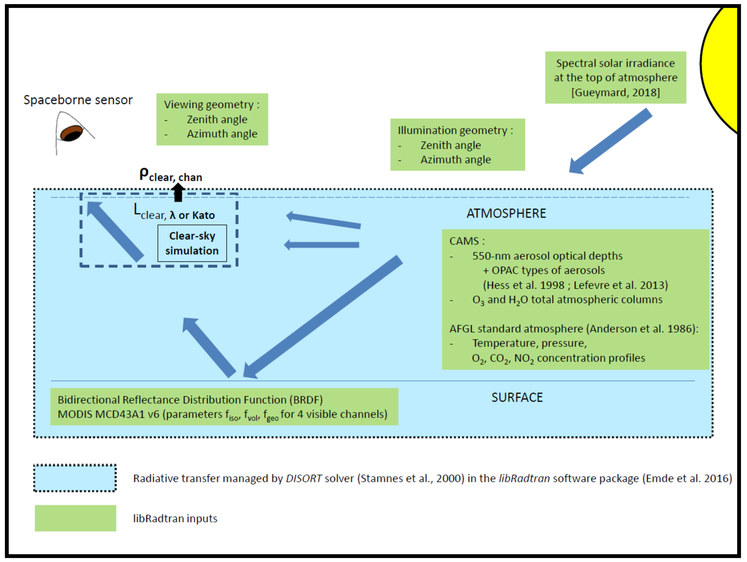

Fig. 1: Description of the method. Lclear are simulated clear-sky TOA upwelling radiances. **λ** or **Kato** indicate the use of libRadtran full spectral resolution, or [Kato et al., 1999] spectral approximation. Reflectances ρ_{clear} are derived from L_{clear}, considering spectral response functions of the radiometric channel.

	MSG/SEVIRI	DSCOVR/EPIC
Time period	2011/06/20 – 2011/08/20	2017/06/01 – 2017/06/29
Simulated channels	VIS1 (0.6 µm) ; VIS2 (0.8 µm)	388 ; 443 ; 688 ; 780 nm
Spectral approximation based on [Kato et al. 1999]	Yes	No
Number of data (per spectral channel)	9678	1181
Locations considered	All except GOB	All 8 locations

Table 1: Considered satellite data sets and spectral resolution for radiative transfer computations.

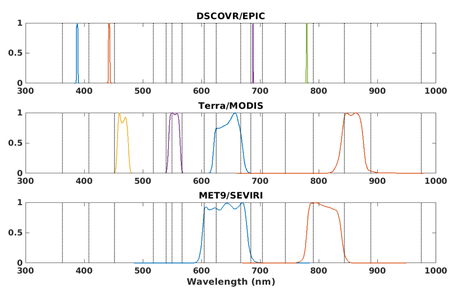

Fig. 3: Spectral response functions for channels of satellite data used in this study. Vertical datched lines indicate boundaries of wavelength intervals defined by [Kato et al., 1999]

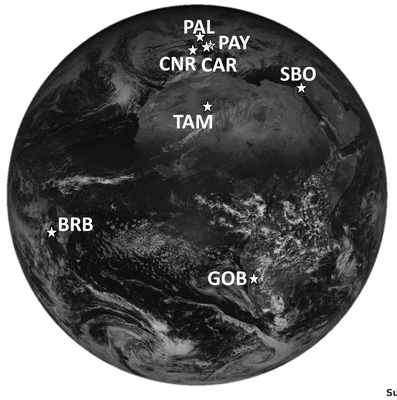

Fig. 2: Locations considered for comparisons between measurements and simulations, here shown with a Meteosat/SEVIRI/VIS1 picture as a background

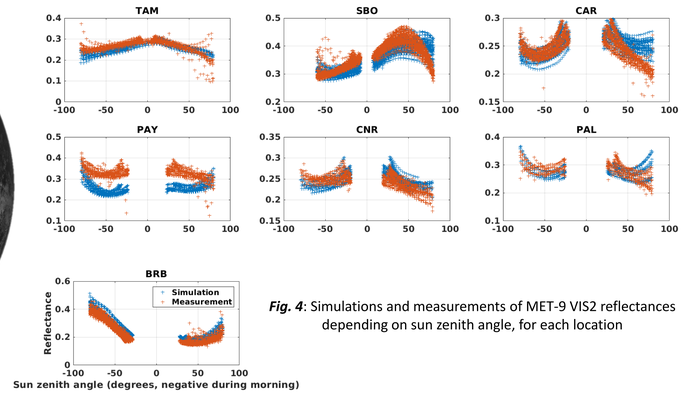

Fig. 4: Simulations and measurements of MET-9 VIS2 reflectances depending on sun zenith angle, for each location

Results

Clear-sky TOA reflectances are simulated with different levels of quality, depending on the spectral channel. Fig. 4 shows how reflectance diurnal patterns are well reproduced for each site. Simulations on sites like Payerne and Palaiseau are affected by significant biases. Also, EPIC channels 688 nm and 780 nm are not well simulated, in particular the diurnal cycle (not represented here). However, for both satellite radiometers, a RMSE of 12.5 % is reached for at least one visible channel (Table 2 & 3). This quality allows us to use such an approach for our solar energy applications.

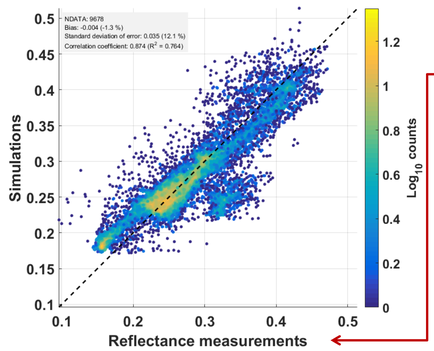

Fig. 5: 2D histogram of MSG VIS2 clear-sky reflectances, all sites considered.

Table 2: Statistics for MSG simulations

METEOSAT-9/SEVIRI Location	Number of data points	Mean bias error VIS1 (VIS1 %) VIS2 (VIS2 %)	Standard deviation of the error VIS1 (VIS1 %) VIS2 (VIS2 %)	Root mean square of the error VIS1 (VIS1 %) VIS2 (VIS2 %)
Tamanrasset (TAM, Algeria) (Surface type: desert, rock; Topography type: flat, rural)	1116	0.004 (1.6 %) -0.010 (-3.6 %)	0.018 (8.1 %) 0.022 (8.1 %)	0.019 (8.2 %) 0.024 (8.9 %)
Sde Boker (SBO, Israel) (Surface type: desert rock; Topography type: hilly, rural)	2579	0.004 (1.2 %) -0.010 (-2.6 %)	0.024 (7.8 %) 0.028 (7.6 %)	0.025 (7.9 %) 0.029 (8.0 %)
Carpentras (CAR, France) (Surface type: cultivated; Topography type: hilly, rural)	1537	0.009 (7.5 %) 0.006 (2.3 %)	0.009 (7.3 %) 0.017 (7.0 %)	0.012 (10.5 %) 0.018 (7.3 %)
Payerne (PAY, Switzerland) (Surface type: cultivated; Topography type: hilly, rural)	895	0.035 (36.3 %) -0.071 (-21.7 %)	0.014 (15.0 %) 0.033 (10.1 %)	0.038 (39.2 %) 0.079 (23.9 %)
Cener (CNR, Spain) (Surface type: asphalt; Topography type: mountain valley, urban)	1007	0.025 (17.3 %) 0.006 (2.4 %)	0.012 (8.4 %) 0.015 (6.3 %)	0.028 (19.2 %) 0.017 (6.8 %)
Palaiseau (PAL, France) (Surface type: concrete; Topography type: flat, urban)	471	0.034 (29.0 %) 0.001 (0.5 %)	0.021 (17.7 %) 0.034 (12.1 %)	0.040 (34.0 %) 0.034 (12.1 %)
Brasilia (BRB, Brazil) (Surface type: concrete, since 2015: shrub; Topography type: flat, rural)	2073	0.031 (23.2 %) 0.023 (10.1 %)	0.026 (19.4 %) 0.021 (8.9 %)	0.041 (30.2%) 0.031 (13.5 %)
Sum of stations	9678	0.017 (9.1 %) -0.004 (-1.3 %)	0.024 (12.9 %) 0.035 (12.1 %)	0.030 (15.8 %) 0.035 (12.2 %)

Table 3: Statistics for EPIC simulations

DSCOVR/EPIC Spectral channel	Number of data points	Mean bias error	Standard deviation of the error	Root mean square of the error
Sum of stations, 388 nm	1362	-0.002 (-0.9 %)	0.027 (12.5 %)	0.027 (12.5 %)
Sum of stations, 443 nm	1312	0.036 (19.6 %)	0.027 (15.1 %)	0.045 (24.8 %)
Sum of stations, 688 nm	1346	0.120 (124.8 %)	0.044 (46.0 %)	0.128 (133.0 %)
Sum of stations, 780 nm	1354	-0.076 (-25.9 %)	0.080 (27.5 %)	0.110 (37.8 %)

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Meteosat-9 data are provided by EUMETSAT, https://www.eumetsat.int