ASSESSMENT of six different methods for the estimation of surface Ultra-Violet FLUXES at one location in Uruguay

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Abstract

This communication assesses six methods estimating Ultra-Violet A and B (UV-A and UV-B) fluxes from satellite imagery, numerical weather models or ground measurements. The UV estimates from each method are compared to coincident 15 minutes in-situ measurements collected at one location in Uruguay from September 2015 to January 2019. The first method "LAAM" (Locally-Adapted Antón Martínez) combines Global Horizontal Irradiance (*G*) measured on site with satellite-derived daily Ozone concentration. The second method "Wald" uses an empirical model onto satellite-retrieved solar broadband irradiance at the surface (SSI) produced by HelioClim-3 version 5 (HC3v5) to derive UV fluxes. The third method named "CAMS-UV", is one of the outputs of ECMWF numerical weather model. The three remaining methods are respectively named "Weighted_Kato HC3v5", "Discretized _Kato HC3v5" and "DWD SARAH-3". They rely on more sophisticated modelling of the atmosphere in cloud-free conditions using radiative transfer modelling combined to a cloud modification factor (or cloud extinction) derived from HC3v5. Outside an underestimation observed for the UV-B range for both CAMS-UV (-20 %) and for the empirical model (-29 %), methods demonstrated their ability to collect the temporal variability of the signal of the instrument on-ground; biases ranges from -2 to 4 % for UV-A and from 0 to 10 % for UV-B, RMSE are close to 15 % and almost all correlation coefficients exceed 0.96. This analysis gives precious elements for discussion about the performance of models mainly developed and validated over Europe and Africa.

Keywords: UV-A and B, CAMS, HelioClim-3, surface solar irradiance, radiative transfer modeling, numerical weather model, ground measurements

1. Introduction

Solar Ultra-Violet (UV) radiation at ground level has beneficial but also negative effects on human health and ecosystems. UV-B radiation, which ranges in [280, 315] nm, is the most energetic part of the solar spectrum that reaches the ground; and is responsible for instance for the damage of DNA leading in rare cases to skin cancers and melanomas (Coste et al., 2015; Fortes et al., 2016, Savoye et al., 2016). Interest is growing in the role of UV-A [315, 400] nm and UV [280, 400] nm in their benefit for diverse brain diseases such as migraines (Lisicki et al., 2017), Parkinson's disease (Kravietz et al., 2017), and other diseases such as thyroid cancer (Mesrine et al., 2017) or sclerosis (Orton et al., 2011). UV plays a significant role in water disinfection as one of the three common water treatment technologies (Kosjek et al., 2009).

Researchers would ideally like to handle long-term, homogeneously distributed and available worldwide UV datasets. Unfortunately, due to high cost of UV radiometers and maintenance, these measurements are scarce. Alternatives have consequently been developed to derive UV radiation from broadband Global Horizontal Irradiance (*G*) or from numerical weather models. This communication presents the validation results of 6 different methods to assess UV-A and UV-B at 1 site in Uruguay. It represents a unique opportunity to investigate how models originally developed and validated over Europe and Africa perform for this site in South America.

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2. Ground measurements

Ground measurements are maintained by the laboratory of solar energy, University of the Republic, Montevideo, Uruguay. The geographical coordinates of the site are -31.2821° for the latitude, -57.9176° for the longitude, and finally 50 m for the altitude. It is located in the North West quarter of Uruguay, close to the Uruguay River as a natural border between Uruguay from Argentina. Figure 1 depicts the location of the Uruguayan site in the world map of Köppen-Geiger climate classification (Peel et al., 2007). This classification proposes to divide climates into five main climate groups, with each group being divided based on seasonal precipitation and temperature patterns. The site is located in the center of a “Cfa” code zone (green), corresponding to a humid subtropical climate.

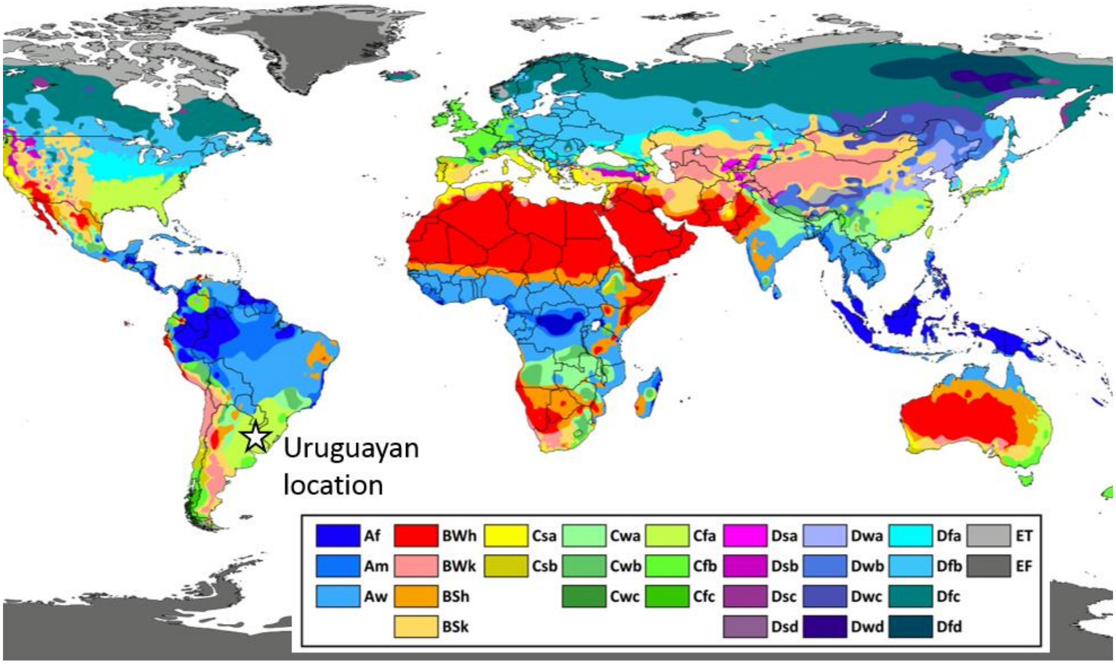

Fig. 1: Location of the Uruguayan site in the world map of Köppen-Geiger climate classification. The location corresponds a humid subtropical climate (code “Cfa”, Peel et al., 2007)

In-situ measurements corresponds to 15 minute UV-A and UV-B measurements collected with Kipp and Zonen UV radiometers with controlled temperature. UV-B data are available from June 2017 to Jan. 2019, and UV-A from Oct. 2015 to Jan. 2019, with a gap from Nov. 2016 to June 2017. Data are irradiances in W m^{-2} in local time (universal time minus 3 hours). 15 min irradiances were generated by averaging 1 minute samples only if more than 66 % of the 1 minute samples were available, corresponding to a minimum of 10 slots for the synthesis of the 15 minute dataset. 1 minute irradiances are the results from the averaging of 6 instantaneous measurements collected every 10 seconds, once again only if 100 % of the 10 second samples were available (no gaps).

UV-A and UV-B measurements are considered only when the solar elevation angle is above 7°, and when *G* measured at the same location exceeds 15 W m^{-2}. As the site is equipped with high quality instruments and the station is daily maintained and calibrated every year, the visual inspection didn’t emphasize the need an additional quality check algorithm.

3. Description of the six methods estimating UV irradiances

3.1. Method #1: Locally-Adapted Antón Martínez (LAAM)

Antón Martínez is the name of the author of the method and is described in his PhD dissertation (2007). The parametrization of this empirical model applies onto in-situ *G* and satellite-derived (OMI/TOMS) daily ozone concentration. We expect that this method outperforms other methods.

3.2. Method #2: Wald

Global set of coefficients has been empirically designed to derive UV-A and UV-B from broadband *G* (Wald 2012), produced by the surface solar irradiance (SSI) HelioClim-3 version 5 (HC3v5) using the model Heliosat-2 (Blanc et al., 2011, Rigollier et al., 2004). This method has been applied in the past for instance to generate monthly average maps of UV daily doses within the EUROSUN project, a public health project for the quantification of sun exposure in Europe and its effects on health and funded by the EU Public Health Programme from 2003 to 2008. This model has also been exploited for the analysis of the influence of UV radiation in the occurrences and intensity of migraines (Lisicki et al., 2017).

3.3. Method #3: CAMS-UV FMI

The CAMS-UV processor is part of a global model running on ECMWF servers. It produces global UV index (UVI) and spectral UV forecasts on demand to users. The CAMS-UV spatial resolution is approximately 80 km before 21st June 2016 at 12 UTC and approximately 40 km later on. It does not depend on the geographical point. These data are provided with a temporal sampling rate of 1 hour for UVI and 3 hours for UV-A and UV-B. For the sake of this analysis, the temporal sampling rate has been artificially decreased to 15 minutes by using a temporal linear interpolation of the 1-hourly UVI cloud modification factor i.e. ratio between all-sky UVI and clear-sky UVI, and 15 min clear-sky UV estimates derived from Modified Lambert-Beer approach (Mueller et al., 2004) applied on two closest 3-hourly UV estimates. Of course, this means that the 3-hourly estimates are more reliable than high temporal resolution estimates. A complete description of the CAMS-UV processor and quarterly validation reports are regularly updated on the CAMS website (active in Aug. 2019): https://atmosphere.copernicus.eu/

3.4. Method #4a: Weighted_Kato HC3v5 and Method #4b: Discretized_Kato HC3v5

These methods rely on the assumption that broadband *G* can be accurately retrieved from a reduced number of spectral bands (Kato et al., 1999, Lefèvre et al., 2013). CAMS McClear uses several look up tables (LUT) computed by the Radiative Transfer Model libRadtran for selected values of inputs and provides the irradiance in cloud-free conditions for each of the 32 spectral intervals. The Weighted_Kato method (Wandji Nyamsi et al., 2017) corresponds to weights applied on the 6 first Kato bands to supply UV-A and UV-B datasets. The Discretized_Kato method proposes a spectral resampling to refine the results based on a few additional parameters and interpolations. An all-sky version of these methods is obtained by extracting a cloud modification factor (or clear-sky index) from HC3v5, with the underlying assumption that clouds are not spectrally sensitive.

3.5. Method #5: DWD SARAH-3

Very similar in principle to Weighted_Kato method, SPECMAGIC also consists of LUT generated for each of the 32 Kato bands (Mueller et al., 2012). Its cloud-free estimates are combined with spectrally-resolved cloud transmission values derived with radiative transfer corrections of the broadband cloud transmission. Spectral irradiances are scheduled to be available together with the next generation of broadband SSI provided by the Climate Monitoring Satellite Application Facility (CM-SAF) in 2021.

Figure 2 provides a recapitulative scheme of the assessment of the performance of these 6 UV-methods.

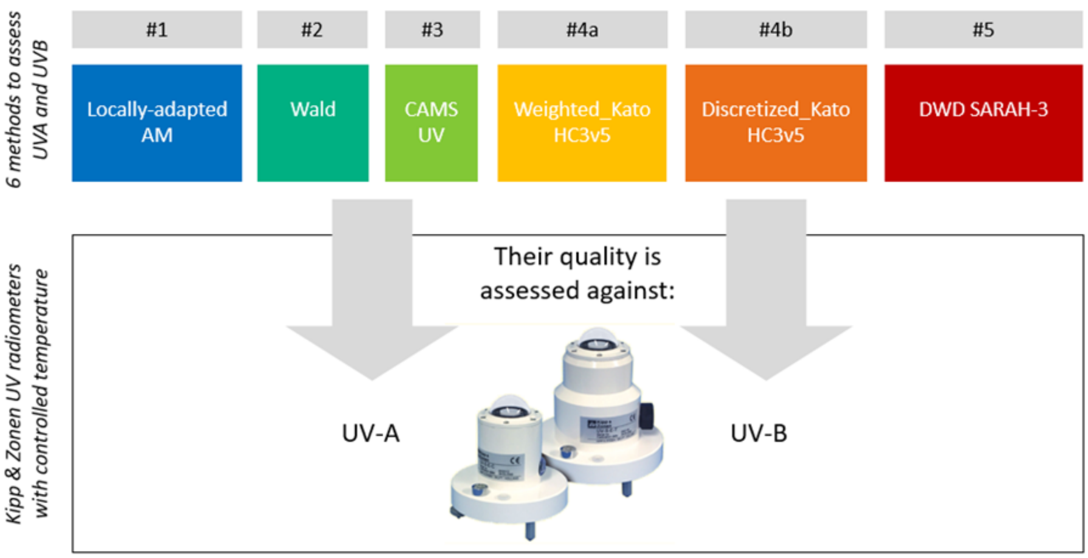

Fig. 2: Recapitulative scheme of the quality assessment of the 6 methods to derive UV-A and UV-B, against the measurements at a site in Uruguay.

4. Validation protocol and results

The selected protocol is the usual one; time and space coincident estimates are compared to the corresponding measurements. Night values are discarded. Correlation coefficients (CC) are computed. The sets of differences (estimates minus measurements) are computed and summarized by their bias and the standard deviation (STDEV) as these two indices are fully independent. Relative values are computed by dividing the bias or the STDEV by the mean of the measurements and are given in percent. Results are available in Tab. 1 and 2 for UV-B and UV-A respectively. 2-D histograms between measurements and estimates are displayed in Fig. 3 and 4. Green color highlights best results while orange color highlights the worst ones, excluding results of the method #1.

Tab. 1: UV-B in [280, 315] nm, number of coincident measurements: 19936. Mean of the in-situ measurements: 0.9 W/m2. Green color highlights best results while orange color highlights worst ones without results of the method #1

Method		Bias (W/m2) and relative value	STDEV (W/m2) and relative value	CC
#1	LAAM	0 (0 %)	0 (4.4 %)	0.997
#2	Wald	-0.2 (-28.5 %)	0.3 (38.6 %)	0.930
#3	CAMS-UV	-0.2 (-19.3 %)	0.2 (27.2 %)	0.931
#4a	Weighted_Kato HC3v5	0.1 (6.2 %)	0.1 (16.3 %)	0.971
#4b	Discretized_Kato HC3v5	0 (4.1 %)	0.1 (15.1 %)	0.972
#5	DWD SARAH-3	0.1 (10.1 %)	0.1 (15.6 %)	0.978

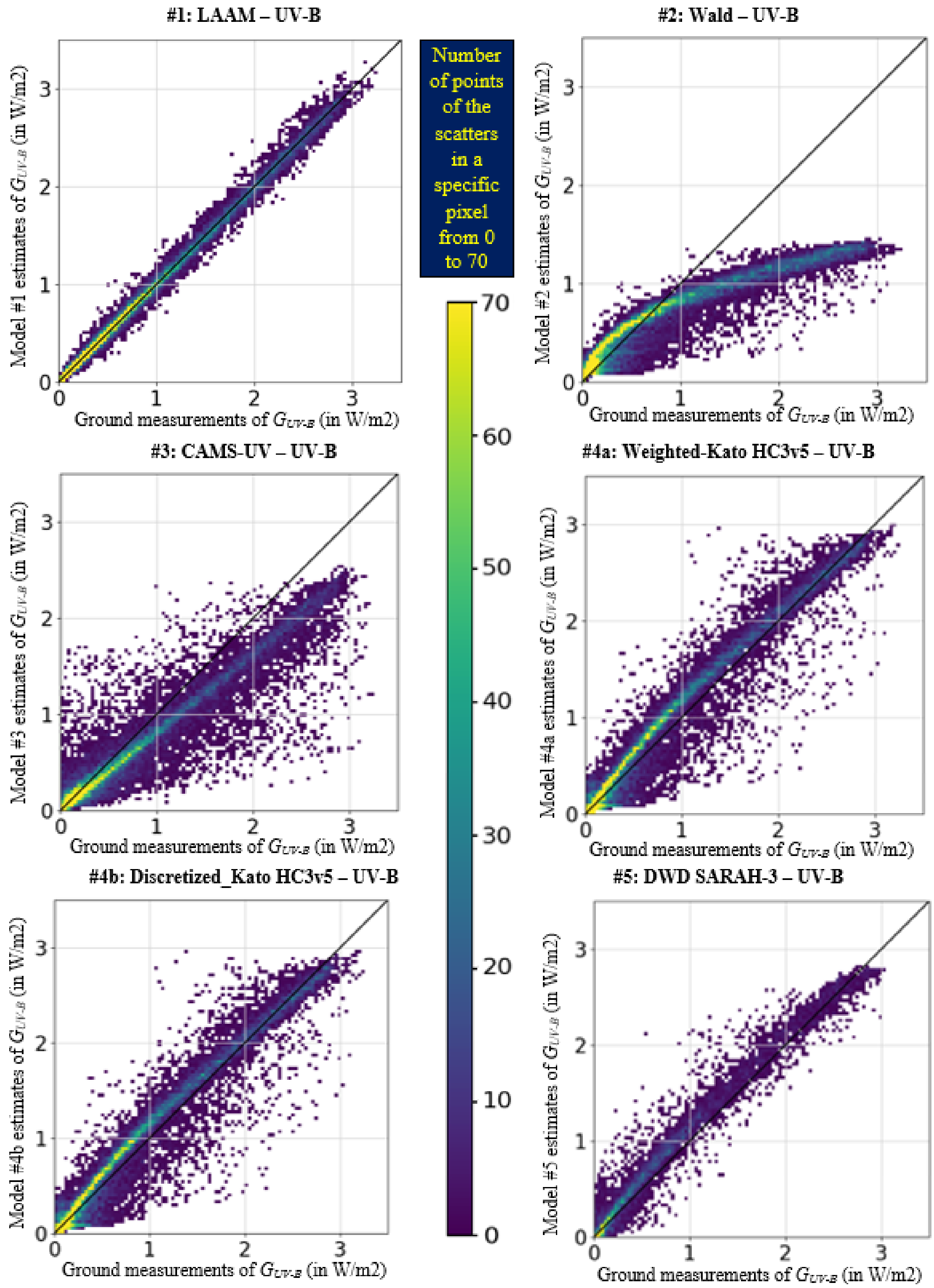

Fig. 3: 2-D histograms of the UV-B derived from the 6 different models (vertical axes) and UV-B in-situ measurements (horizontal axis). Models are respectively: #1 LAAM, #2 Wald, #3 CAMS-UV, #4a Weighted_Kato HC3v5, #4b Discretized_Kato HC3v5, and #5 DWD SARAH-3

Tab. 2: UV-A in [315, 400] nm, number of coincident measurements: 32269. Mean of the in-situ measurements: 24.9 W/m2. Green highlights best results while orange highlights poorest ones outside method #1

Method		Bias (W/m2) and relative value	STDEV (W/m2) and relative value	CC
#1	LAAM	0 (0 %)	1.06 (4.3 %)	0.997
#2	Wald	0 (0 %)	3.37 (13.6 %)	0.959
#3	CAMS-UV	-0.6 (-2.3 %)	5.87 (23.5 %)	0.856
#4a	Weighted_Kato HC3v5	0.2 (0.6 %)	3.57 (14.4 %)	0.961
#4b	Discretized_Kato HC3v5	-0.4 (-1.6 %)	3.39 (13.6 %)	0.961
#5	DWD SARAH-3	1 (4.2 %)	3.58 (14.4 %)	0.964

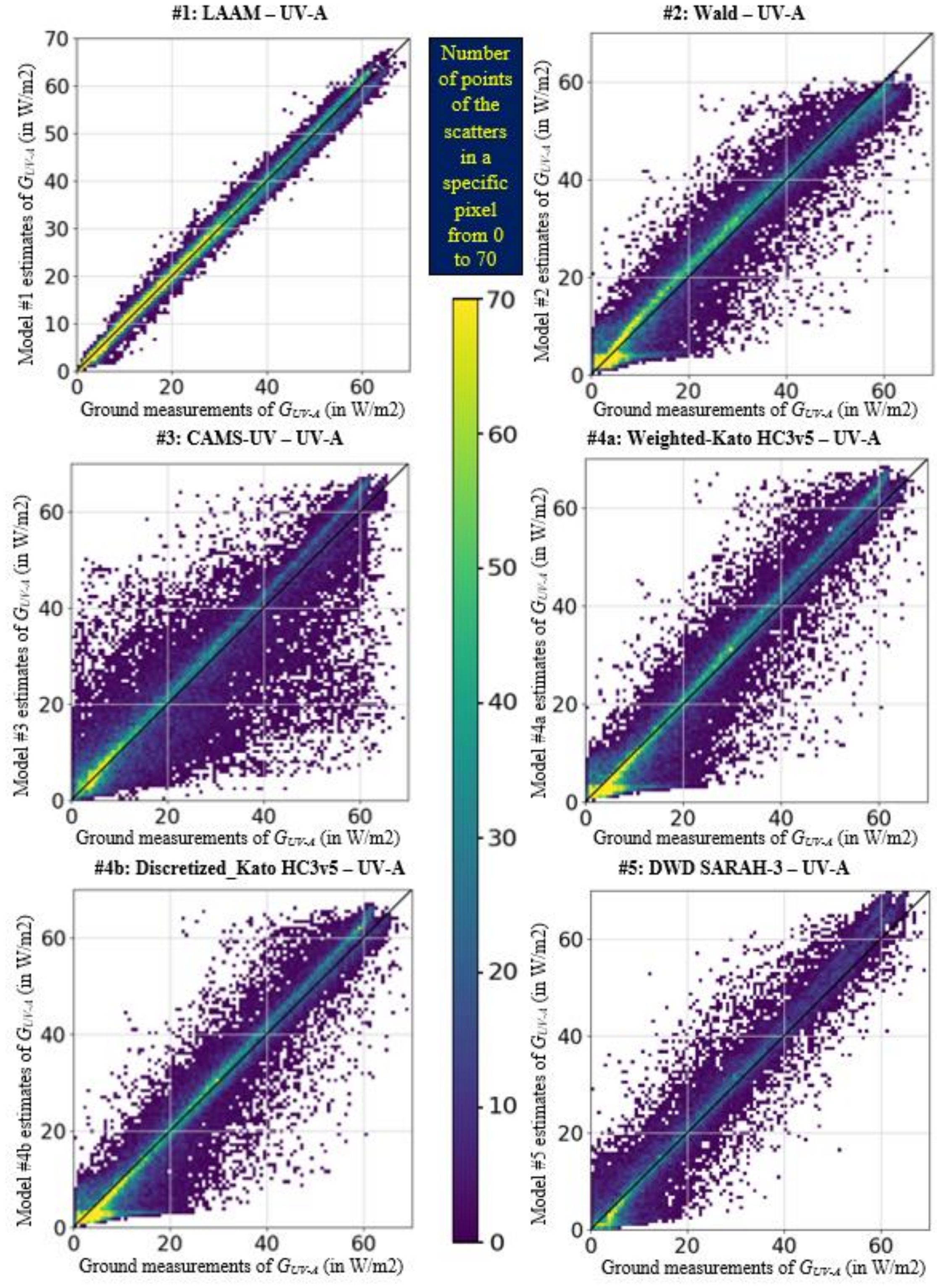

Fig. 4: 2-D histograms of the UV-A derived from the 6 different models (vertical axes) and UV-A in-situ measurements (horizontal axis). Models are respectively: #1 LAAM, #2 Wald, #3 CAMS-UV, #4a Weighted_Kato HC3v5, #4b Discretized_Kato, and #5 DWD SARAH-3

5. Validation protocol and results

The analysis of the performance of the methods has been carried out by the laboratory of solar energy in Uruguay.

As expected, method #1 (LAAM) outperforms others for both UV-B and UV-A spectral ranges. The good fit between the model and the in-situ measurements is characterized by a narrow cloud of points well-aligned along the diagonal on the 2-D histograms. Statistical indices show a null bias, a STDEV of about 4 % and CC close to its ideal value of 1 with 0.997. This method requires a preliminary training of the parameters using in-situ *G* which offers the possibility to appropriately capture the local temporal variability, leading to an almost excellent fit with the in-situ UV measurements. However, this method has been tuned with high quality measurements available on site. As a consequence, the scarcity of such high quality input parameters measured at ground level limits the use of the method at other locations in similar conditions.

Method #2 (Wald) shows an eyebrow shape on the 2-D histogram for the UV-B range. Despite a good correspondence of low irradiances, large UV-B irradiances are strongly underestimated. This discrepancy is confirmed by the lowest performances in all statistical results: Bias is -0.2 W/m2 corresponding to a relative bias of -28.5 %, STDEV is 0.3 W/m2 (38.6 %), but with still a good correlation with a value of 0.93.

Wald method depicts surprisingly very good results for the UV-A range, with a null bias and a STDEV of 3.4 W/m2 (13.6 %). CC is lower than expected with a value of 0.959. An explanation of this loss of correlation is the presence of a yellow cluster of points for low UV-A irradiances, as if a threshold of 5 W/m2 was applied onto satellite UV-A irradiances. This phenomenon is also observed on UV-A 2-D histograms for both Weighted_Kato HC3v5 and Discretized_Kato HC3v5. The common parameter is the use of the broadband *G* from HC3v5. One of the potential reasons for such artefact could be the reflection of the light on the Earth's surface in the satellite direction, also named "sun glint". This phenomenon has a drastic effect on the Heliosat-2 methods (Blanc et al., 2011, Rigollier et al., 2004) used to update HC3 in real time. Indeed, white reflectances in Meteosat images are considered as clouds, leading to erroneously low irradiances at ground level. It affects all surfaces like snow, sands, and land, but mainly water areas (seas, oceans, reservoirs, lakes and rivers). Even though the site is not coastal, it sits on the bank of a large reservoir or artificial lake. A further analysis would consist in identifying and discarding instants potentially affected by the sun glint in order to inspect the impact on 2-D histograms.

The 2-D histogram for the method #3 (CAMS-UV) and for the UV-B range shows a line which goes through the point (0, 0), but with an underestimation of the large UV-B irradiances. The angle between the diagonal and the line of the cloud of points is approximately 5°. The underestimation is confirmed by a negative bias of -0.2 W/m2 (-19.3 %). The scatter of the cloud of points is quite large with a STDEV of 0.2 W/m2 (27.2 %). CC is close to that of Wald UV-B with 0.931. This observation concerning the large scatter of the points is also valid for the UV-A range; despite a small bias of -0.6 W/m2 (-2.3 %), STDEV is the largest one compared to all methods with 5.9 W/m2 (23.5 %), and CC is the poorest with 0.856. This can be explained by the fact that CAMS-UV is one of the outputs of ECMWF numerical weather model which operates on a coarser grid (80 km before 21st June 2016 at 12 UTC and approximately 40 km later on) than satellite ones with a spatial resolution of approximately 7 km for this location.

Methods #4a (Weighted_Kato HC3v5) and #4b (Discretized_Kato HC3v5) rely on the same method, while method #4b applies a refinement compared to #4a with the objective to reach a better representation of the solar spectrum. In that perspective, results should be similar, with a slight enhancement of #4b. Validation results for UV-B coincide with this observation, with a bias for method #4a of 0.1 W/m2 (6.2 %) and for method #4b 0.03 W/m2 (4.1 %), STDEV values are very close, with a value of approximately 0.1 W/m2 (16 %) and CC of 0.97. For the UV-A range, method #4a obtains a low bias of 0.2 W/m2 (0.6 %), whereas #4b slightly underestimates the in-situ measurements with a bias of -0.4 W/m2 (-1.6 %). STDEV and CC, very similar for both methods, are 3.4 W/m2 (14 %) and 0.961 respectively. In any case, the fact that biases are below a few percent means than the models are close to the uncertainty of the ground instrument, and consequently can be considered excellent, as was already the case for the Wald method for the UV-A range.

As for the two previous methods, Method #5 (DWD SARAH-3) is also based on the 32 wavelength intervals of the solar spectrum as defined by Kato et al. (1999). Consequently, it is coherent to observe a similar scatter of the points in the 2-D histograms, in agreement with STDEV values respectively of 0.1 W/m2 (15.6 %) for UV-B and 3.6 W/m2 (14.4 %) for UV-A. This method shows a lower performance in terms of bias with values of 0.1 W m^{-2} (10.1 %) for the UV-B range and 1 W/m2 (4.2 %) for UV-A. It is nevertheless very important to notice the increase of performance if one only focuses on CC, with values of 0.978 and 0.964 for respectively the UV-B and the UV-A ranges. The inspection of the 2-D histograms gives essential clues on the interpretation of the results. For UV-A histograms for the three Kato-based methods, one observes that all clusters of points are almost identical and modelled by a line located slightly above the diagonal, as an indication of slight overestimation. For #4a and #4b, the overestimation is counterbalanced by the underestimation of low values due to the artefact explained in a previous paragraph. This artefacts impacts CC directly, and that is why method #5 outperforms the two other methods, if CC is used as the only performance criterion.

6. Perspectives

Method #1 (LAAM) differs from the other methods because it is adjusted on local measurements. The performance of this method will be evaluated using satellite SSI retrievals and numerical weather outputs instead of locally measured parameters.

Method #2 (Wald) is straightforward, by applying coefficients directly onto the broadband *G* of a SSI. Consequently, it is computationally economic, and could run easily in real time for the monitoring of a large number of locations. As the Wald method provides excellent results for the UV-A range, one may explore the possibility to correct model parameters to rectify the eyebrow shape of the 2-D histogram in the UV-B range.

The quality of method #3 (CAMS-UV) is continuously assessed during the on-going CAMS project, and this current work is supporting this activity.

Method #4b (Discretized_Kato HC3v5) requires a discretization every 1 nm of the Method #4a (Weighted_Kato HC3v5) as a step further for a better adequacy in the results. According to the similarity of the results, this refinement turns out to be unnecessary. This observation should be confirmed at other locations.

Method #5 (DWD SARAH-3) is currently being implemented to provide both UV and Photosynthetically Active radiation values within the framework of the next SARAH-3 release. These preliminary results are promising and complete validation efforts carried out by DWD.

Another perspective of improvement for this work is the investigation of the potential issue of sun glint that could affect HC3v5 for this location, which indirectly impacts methods #2, #4a and #4b mainly for UV-A range.

An extension of this validation work is planned to check if conclusions drawn at this site in Uruguay could be generalized to other sites and under other climates. In that perspective, several collaborations have been initiated with research centers and universities to retrieve other UV in-situ measurements. For instance, the collaboration with Colette Brogniez, Fanny Minvielle and Frédérique Auriol from the Laboratory of Atmospheric Optics is a vector to access spectral measurements in the UV range at three sites located in Lille (north of France), Observatoire of Haute Provence (south east of France), and La Réunion Island (France). A contact with Alexandr Aculinin from the Laboratory of Materials for Photovoltaics and Photonics, Kishinev in Moldova is promising to add to this validation activity long term spectrometer measurements collected at the site of Kishinev. Finally, we will also pay attention to other networks providing high quality UV datasets such as FLUXNET and AEMET.

7. Conclusion

This paper proposes a unique opportunity to confront six methods to assess UV for a humid subtropical climate at one site in Uruguay. The method LAAM provides the best results as expected, since a preliminary training of the parameters is required based on local measurements.

All other methods are either based on satellite imagery or numerical weather model. For the UV-B range, all methods based on the Kato decomposition of the solar spectrum propose very promising results. The output CAMS-UV from ECMWF numerical weather model gives also satisfactory results outside an underestimation that could easily be corrected by a post-bias adjustment. The Wald method would require also a more complex adjustment to correct the underestimation to reach satisfactory results. This work could be worthy as this method is compatible with an operational exploitation in real time.

In the UV-A range and despite a larger scatter of the CAMS-UV histogram, one may conclude that all methods provide a trustful representation of the local temporal variability of the irradiances.

This work is part of a larger project of comparison of methods to assess different methods to supply UV estimates for several sites in the world. The plan is to extend this validation for other sites in France and in the United-Kingdom.

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