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RED DE MONITOREO DE LA IRRADIANCIA SOLAR UV-TOTAL EN ARGENTINA“SAVER-NET”

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RESUMEN

El monitoreo simultaneo de la radiación solar localizada en diferentes rangos espectrales de banda ancha tiene varias ventajas importantes sobre el monitoreo aislado, tanto para la investigación básica como aplicada. Su integración en una red bajo protocolos estandarizados tiene a su vez valiosos beneficios, incluida la posibilidad de caracterizar geográficamente los niveles de radiación solar en grandes regiones. Recientemente, se ha desplegado en Argentina una red integrada de monitoreo de irradiancia solar UV-Total en 8 estaciones con nuevos instrumentos, sitios de medición y protocolos en el marco del proyecto Saver-Net (Japón, Argentina y Chile) llevado a cabo durante el período 2013- 2018. La red es administrada por el Servicio Meteorológico Nacional (SMN) de Argentina y el Instituto de Investigaciones Científicas y Técnicas para la Defensa (CITEDEF - UNIDEF). En este trabajo se describe la estructura y capacidad de la red y varios logros iniciales de la red argentina de monitoreo de irradiancia solar UV-Total con el objetivo de dar a conocer a la comunidad científica y poner a disposición estas bases de datos para su amplio uso en la investigación básica y aplicada. Además, se presenta la caracterización de los sitios donde se encuentra cada nodo de monitoreo de la red. Se observan valores extremos por encima de 1000 Wm^{-2} para la irradiancia solar Total, 60 Wm^{-2} para la irradiancia solar UVA e índices UV por encima de 9, aún en los sitios ubicados de la red Saver-Net ubicados más al sur, con su consecuente significancia en aplicaciones prácticas como la generación de energía solar e implicancias en la salud de las personas como el riesgo de contracción de eritema.

Palabras clave: Red de monitoreo de irradiancia, Saver-Net, Argentina.

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SAVER-NET UV-TOTAL SOLAR IRRADIANCE MONITORING NETWORK IN ARGENTINA

ABSTRACT

Simultaneous localized solar radiation monitoring in different broadband spectral ranges has several important advantages over isolated measurements for both basic and applied research. Its integration into a network under standardized protocols has, in turn, worthy benefits including the possibility to characterize geographically the solar radiation levels in large regions. Recently, an integrated UV-Total solar irradiance monitoring network has been deployed in Argentina in 8 stations with new instruments, measurement sites, and protocols into the frame of the Saver-Net project (Japan, Argentina, and Chile) carried out during the period 2013-2018. The network is managed by the Argentine Servicio Meteorológico Nacional (SMN) and Instituto de Investigaciones Científicas y Técnicas para la Defensa (CITEDEF - UNIDEF). In this paper, the structure, capability and several initial achievements of the Argentine UV-Total solar irradiance monitoring network are described with the aim to make these databases available to the scientific community for their broad use in basic and applied research. In addition, the irradiance characterization at each monitoring node of the network is presented. Extreme values over 1000 Wm^{-2} of Total solar irradiance, 60 Wm^{-2} of UVA solar irradiance and UV Index of 9 are registered even in the southernmost stations, with their consequent signification for the practical applications of the solar energy and health implications such as the risk to cause erythema.

Keywords: Solar irradiance monitoring Network, Saver-Net, Argentina

1. INTRODUCTION

Starting with its definition as a "source of life" since the origins of our planet (e.g. Rapf and Vaida, 2016), solar radiation at the Earth's surface has been historically one of the main geophysical parameters to measure. Its local knowledge is crucial for many purposes, but the implementation of a geographically-distributed measurement network expands these possibilities to large-coverage regions. Total shortwave (300-3000 nm) and UV (280-400 nm) solar radiation ranges have by themselves many implications and applications in human health and industry. The study of optical parameters of the atmospheric components constitutes a subject by itself, as they depend on the wavelength to different degrees. For these reasons, reliable simultaneous localized measurements of both UV and Total solar radiation in stations with the maximum possible geographical coverage within a given region are valuable either for basic and applied research.

Solar radiation levels reaching the Earth's surface are affected in different spectral ranges due to global phenomena such as stratospheric ozone depletion and greenhouse effect increase, among others (Barnes et al., 2019). The most direct effect of the ozone depletion is the increase in tropospheric UVB (280-320 nm), mainly in polar and sub-polar latitudes where the greatest depletion occurs (Wolfram et al., 2012; Orte et al., 2017; Orte et al, 2019b), although mid-latitudes and tropical regions are also affected (Pinheiro et al, 2012; Bresciani et al., 2018; Bittencourt et al., 2018). Ozone depletion has also contributed to the Southern Hemisphere climate change through modifications in the tropospheric dynamics, especially by the "Antarctic ozone hole" (AOH), with synergistic consequences (Hossaini et al, 2015; Nowack et al, 2015; Bandoro et al, 2014). In turn, the increase in the greenhouse effect modifies the amount of atmospheric solar radiation throughout the wavelength ranges by changes in the cloudiness and surface albedo patterns (Damiani et al, 2015). The surface solar shortwave radiation budget is a parameter included within the six core 'Surface atmosphere' Essential Climate Variables (ECV's) selected by GCOS (WMO, 2019), considered as "a fundamental component of the surface energy budget which is crucial to nearly all aspects of climate, and needs to be monitored systematically" (`https://gcos.wmo.int/en/essential-climate-variables/surface-radiation`). Hence, reliable monitoring of solar irradiance is particularly important for many applications, but also as local proxies of the global atmospheric changes in course.

Networks for UV and/or Total solar irradiance measurement in Argentina enabled a series of relevant scientific studies on UV and simultaneous UV-Total irradiance analysis (Cede et al., 2002a; Cede et al. 2002b; Cede et al. 2002c; Cede et al., 2004; Luccini et al., 2006; Utrillas et al., 2018). In turn, Total shortwave solar irradiance capabilities have been developed for decades in Argentina with different types of instruments and are being reinforced (Righini et al., 2010). These capabilities allowed, for example, the characterization of the solar radiation energy resource along the country (Grossi Gallegos and Righini, 2007) and also in specific Antarctic sites (Luccini et al., 2005). Following these previous efforts, Argentina has recently deployed an integrated simultaneous UV and Total solar irradiance measurement network incorporating new monitoring sites, new instrumentation, and updated measurement protocols with sustained data acquisition and calibration at eight geographically distributed stations. The Saver-Net network was developed into the framework of the Saver-Net project (`http://www.savernet-satreps.org/es/`) carried out by CEILAP (Centro de Investigaciones en Láseres y Aplicaciones, CEILAP (CITEDEF-UNIDEF), Argentina) together with the UMAG (Universidad de Magallanes, Chile), and the ISEE (Institute for Space-Earth Environmental Research, Japan) during the period 2013-2018 and it is managed by the Argentine National Weather Service. Other stations, namely La Quiaca (22.10°S, 65.60°W, 3468 m a.s.l.), Mendoza (32.89°S, 68.87°W, 836 m a.s.l.), Puerto San Julián (49.31°S, 67.80°W, 50 m a.s.l.) and Ushuaia (54.85°S, 68.31°W, 18 m a.s.l.) count with solar radiometers whose databases formed part of several mentioned studies, but their measurement protocols are still in course of standardization with Saver-Net network.

In this work, the structure and capabilities of the Argentine integrated UV-Total monitoring network developed during the Saver-Net project are detailed. Section 2 describes the geographical location, instruments and available datasets, presents a characterization of surface total shortwave, UVA and UVI at each station, and details recent goals in research studies with this network's data. Finally, conclusions and future perspectives are summarized in section 3.

2. THE SAVER-NET UV-TOTAL SOLAR IRRADIANCE MONITORING NETWORK

2.1. DESCRIPTION

Figure 1 shows the geographical location of the eight stations that constitute the Argentine UV-Total monitoring network deployed under the Saver-Net project during 2013-2018. Different methodologies which take into account the spatio-temporal variation of the irradiance have been developed to optimize the distribution of solar irradiance monitoring stations for new networks or to determine the optimum location for augmenting an existing one (Davy and Troccoli, 2014; Yang and Reindl, 2015). However, the large territorial extension of Argentina, their large altitudinal gradients, and the limited number of stations included in the Saver-Net network difficulties the implementation of these techniques. Hence, the stations of the network were strategically deployed from 26°S to 52°S, covering a latitudinal range that is scarcely covered at similar latitudes in the rest of the Southern Hemisphere and includes four stations in Patagonia, the closest continental region to Antarctic Continent. Logistical and maintenance facilities were also aspects considered to determine the placement of the stations. The equipment and measurements

Figure 1: Geographical location of the Argentine Saver-Net UV-Total solar irradiance network stations.

of each station are specified in Table I. The Saver-Net UV-Total network regularly measures surface broadband global solar irradiance on a horizontal plane: in the Total shortwave range with pyranometers Kipp&Zonen CM-11 (310-2800 nm) and Kipp&Zonen CMP-21 (285-2800 nm), UVA range (315-400 nm) with Kipp&ZonenserieUV-S-A-T and YES UVA-1 radiometers, and erythemal UV (UVE: UV filtered with the erythema reference action spectrum ISO/CIE 17166:2019) with Kipp&Zonen SUV-E, YES UVB-1, and EKO UVB radiometers. From the UVE values, the UV Index (hereinafter UVI) is calculated as follows (WHO, 2002):

$$UVI = UVE\left(\frac{W}{m^2}\right) \cdot 40\left(\frac{m^2}{W}\right) \quad (1)$$

Where UVE (erythemal UV) is defined as:

$$UVE = \int_{250}^{400} E_\lambda \cdot s_{er}(\lambda)\, d\lambda. \quad (2)$$

E_λ is the solar spectral irradiance, while s_{er} (λ) is the action spectrum for each wavelength λ. As an example, Figure 2 shows the set of three instruments (Pyranometer CMP-21, radiometer YES UVA-1 and radiometer YES UVB-1) installed in Bariloche station.

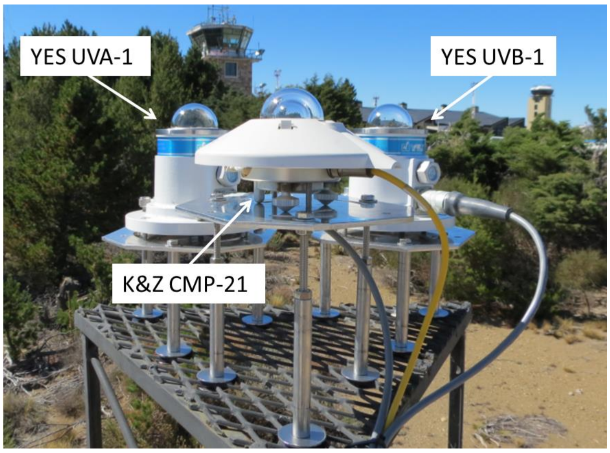

Figure 2: Set of UV-Total solar irradiance instruments installed in Bariloche.

2.2. DATA MANAGEMENT

As detailed in Table I, the whole set of instruments at each station are connected to the same datalogger recording automatically data with a temporal resolution of one minute that results from averaging instantaneous

Station City (Province)	Location (altitude)	Instruments (SN)	Range [nm]	Datalogger (SN)	Start of database
Tucumán (Tucumán)	26.79ºS, 65.21ºW (456 m a.s.l.)	K&Z CMP-21 (140455)	285-2800	CR-1000 (70404)	27/03/2017
		K&Z UV-A (170143)	315-400		15/11/2017
		K&Z UV-E (170213)	UVE*		15/11/2017
Pilar (Córdoba)	31.68ºS, 63.87ºW (330 m a.s.l.)	K&Z CMP-21 (140454)	285-2800	CR-1000 (70405)	18/04/2017
		K&Z UV-A (170144)	315-400		01/11/2017
		K&Z UV-E (170212)	UVE*		01/11/2017
Villa Martelli (Buenos Aires)	34.58ºS, 58.48ºW (25 m a.s.l.)	K&Z CMP-21 (120926)	285-2800	CR-800 (13764)	05/09/2014
		YES UVA-1 (120214-4)	315-400		31/08/2014
		YES UVB-1 (130804)	UVE (280-320)		31/08/2014
Tandil (Buenos Aires)	37.32ºS, 59.08ºW (205 m a.s.l.)	K&Z CM-11 (830288)	310-2800	CR-800 (21629)	03/10/2018
		EKO UVB (S97088.02)	UVE (280-320)		03/10/2018
Neuquén (Neuquén)	38.95ºS, 68.14ºW (270 m a.s.l.)	K&Z CMP-21 (120924)	285-2800	CR-800 (21633)	01/09/2014
		YES UVA-1 (060428-2)	315-400		14/12/2016
		YES UVB-1 (60703)	UVE (280-320)		14/12/2016
Bariloche (Neuquén)	41.15ºS, 71.16ºW (846 m a.s.l.)	K&Z CMP-21 (120928)	285-2800	CR-800 (21632)	16/08/2013
		YES UVA-1 (120214-1)	315-400		16/03/2016
		YES UVB-1 (130805)	UVE (280-320)		16/03/2016
Comodoro Rivadavia (Chubut)	45.78ºS, 67.50ºW (43 m a.s.l.)	K&Z CMP-21 (120925)	285-2800	CR-800 (21630)	01/09/2014
		YES UVA-1 (120214-3)	315-400		19/01/2016
		YES UVB-1 (130803)	UVE (280-320)		19/01/2016
Río Gallegos (Santa Cruz)	51.60ºS, 69.32ºW (15 m a.s.l.)	K&Z CMP-21 (120927)	285-2800	CR-800 (21631)	13/10/2014
		YES UVA-1 (120214-2)	315-400		15/09/2014
		YES UVB-1 (130806)	UVE (280-320)		15/09/2014

Table I: Details on the equipment and start of measurement date at the stations of the Argentine UV-Total monitoring network.

registers every 1 second. The raw signals from each site are stored in a common data server. Subsequently, dark-signal correction using nighttime registers taken for solar zenith angles (SZA) > 100° and conversion of all raw signals to irradiance values complete the data reliability process. Pyranometer raw signals are converted to irradiance values through a single absolute calibration constant, having an efficient cosine response close to 1 even for large solar zenith angles. UVA raw signals are converted to irradiance values through a single absolute calibration constant and a cosine correction as a function of the SZA. UVB raw signals are converted to UVE irradiance values through an absolute calibration constant, a cosine correction as a function of the SZA, and a correction matrix as a function of the SZA and the total ozone column (e.g. Cede et al, 2002; Hülsen and Gröbner, 2007). Then, it is converted to units of UV Index (UVI) using the Equation 1. Finally, the output calibrated irradiance data are stored in text format files with their corresponding security back-ups. A full data processing description can be found in Orte et al. (2018a and 2018b).

2.3. DATABASES

The whole network's available solar irradiance datasets in Total shortwave (black), UVA (red, factor 10), and UVI (blue, right y-axis) ranges at each station are shown in Figure 3. All the sites account for measurement in the mentioned three broadband wavelength ranges except Tandil where only Total solar irradiance and UVI are measured. Tucumán station registered temporary test data during the period 2017-2019 and it is planned to transform it into a permanent measurement station. Seven of the eight UVI databases present a gap of missing data at beginning of 2018 as these instruments were moved to Buenos Aires for a calibration campaign during February and March (Nollas et al., 2019). The UVE radiometer at Tandil station was intercompared against two calibrated radiometers Kipp&Zonen SUV-E (SN70404 and SN70405) before its installation in October 2018 (Orte et al. 2018b; Wolfram et al. 2019). Once assured the mentioned data acquisition and storage, no systematic quality-control algorithm (e.g. Long and Shi, 2006; Roesch et al., 2011; Zo et al., 2017) is employed at this stage since the strong variability effects caused by clouds in both enhancing and attenuation of solar irradiance can led to erroneous exclusion of valid data in 1-minute databases. In the same way, in order to not confuse data generated by different sources, it is opted by to leave data gaps uncovered since this action can be made by data users with own-selected methods like satellite, modeled or reanalysis algorithms after its validation (e.g. Salazar et al., 2020).

2.4. IRRADIANCE CHARACTERIZATION

In order to characterize the solar irradiance levels at noon in the three measured ranges (Total, UVA, UVI) at each station, the 1-minute data were averaged in 30-minutes intervals around the solar noon for each day as recommended by Cede et al. (2002b). They are shown in Figures 4, 5, and 6 as the result of applying a 31 day moving median centered at every day in the year for each database containing at least two complete annual cycles of data (more than 60 days into each moving window). For this reason, Tucumán station was not characterized since this site was operative for less than two years. The 16-84 % percentile (dark shaded area), and 5-95 % percentiles (light shaded area) are also shown. As mentioned, the present characterization is based on the procedure by Cede et al. (2002b) but, at users' consideration, other algorithms can be applied to generate statistical data from these available databases (e.g. Roesch et al., 2011).

Extreme values over 1000 Wm^{-2} of Total solar irradiance are registered even in the southernmost stations, with their consequent signification for the practical applications of the solar energy. Additionally, irradiance values over 60 Wm^{-2} in UVA and UV Index over 9alert on severe biological implications and human health risk including erythema, eye damage or altering plant growth and aquatic ecosystems, as well as aging effects on exposed materials (Lucas et al., 2006).

As expected, the all station present the minimum of the solar irradiance median values in winter and an increase towards December, except for Río Gallegos and Comodoro Rivadavia where the median noon values remain constant between November and December. This behavior is attributed to the high presence of cloudiness at noon in those regions.

On the other hand, the known fact that clouds affect the Total solar irradiance more strongly than the UV solar irradiance in both the enhancing and the attenuation cases (e.g. Cede et al 2002c) is sensitive to the considered lapse time. So, sustained attenuation by large-cloud-optical-depth is generally associated with a high fraction of cloud coverage, as made evident in the 5-16 % percentile ranges of Figures 4, 5 and 6 which are based on 30-minute and monthly averages. It is observed that the

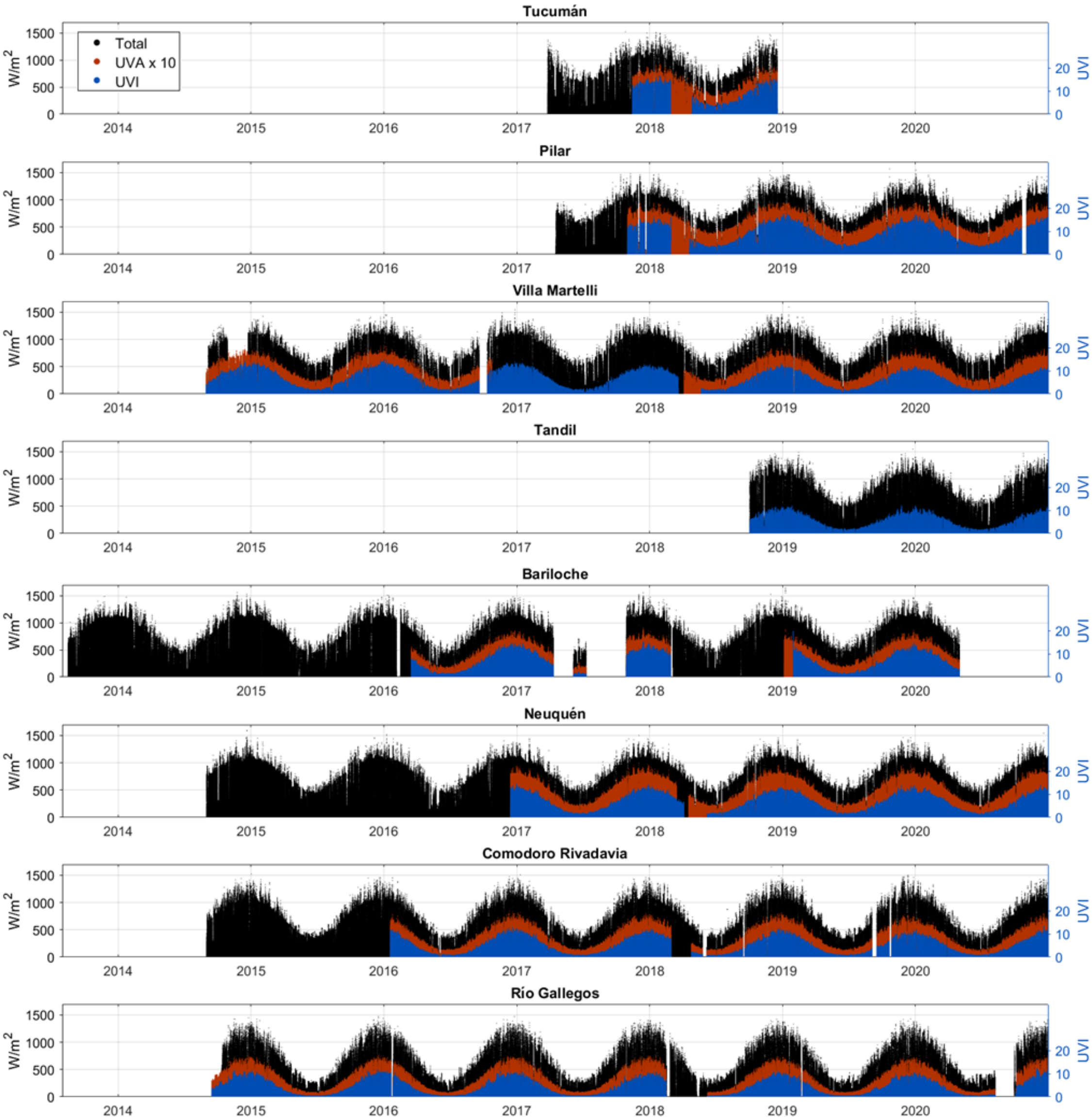

Figure 3: Time series of the whole available solar irradiance measurement database in the Total shortwave (black), UVA (red, factor 10) and UV Index (right-blue y axis) ranges at each station of the Argentine Saver-Net UV-Total solar irradiance network. Tandil station has no UVA measurements.

range between the median value and the 5 % percentile is larger in Villa Martelli, Tandil and Pilar which describe that the mentioned attenuation impact is stronger in those sites than the southernmost ones. Contrarily, solar irradiance enhancing is generally related to broken clouds, a short-term phenomenon which is less evident on time lapse averaging of 30 minutes and moving monthly window as can be seen in the 84-95 % percentile ranges. Nevertheless, it is important to note that the available 1-minute databases in Saver-Net network allow this type of detailed studies like short-term solar irradiance enhancing (e.g. Wolfram et al. 2018).

The Saver-Net UV-Total solar irradiance network's data have been used in several recent

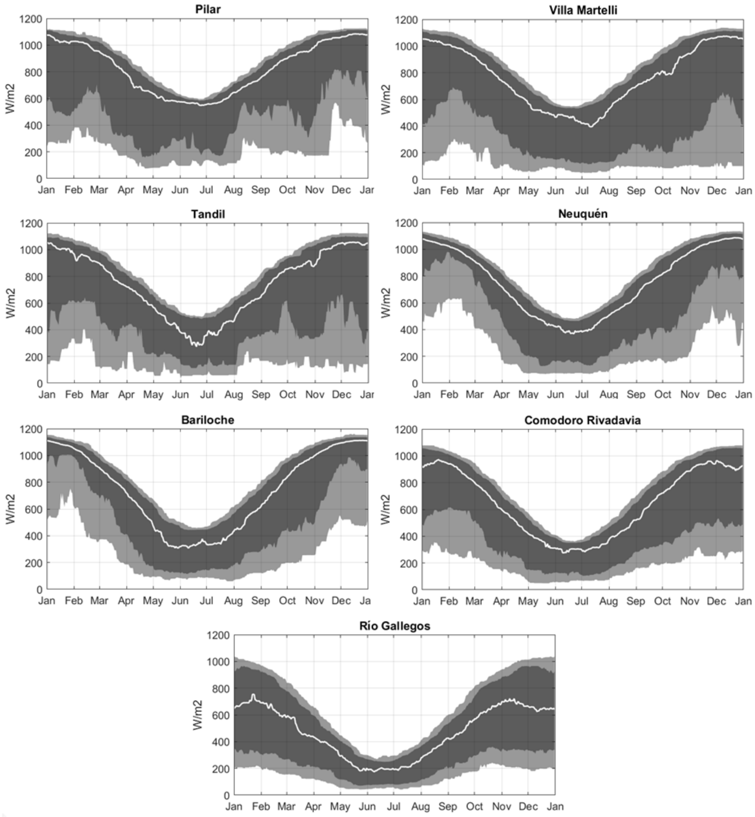

Figure 4: Daily time series of the median noontime Total solar irradiance at each station of the Argentine Saver-Net network, on the base of a 31-days moving window in steps of 1 day during the year. Dark and light grey areas denote the 16-84 % and 5-95 % percentiles, respectively.

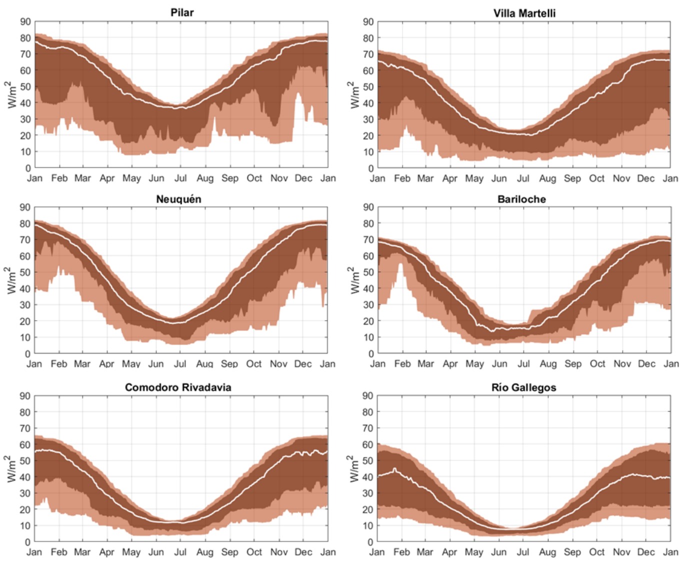

Figure 5: Daily time series of the median noontime UVA irradiance at each station of the Argentine Saver-Net network, on the base of a 31-days moving window in steps of 1 day during the year. Dark and light orange areas denote the 16-84 % and 5-95 % percentiles, respectively.

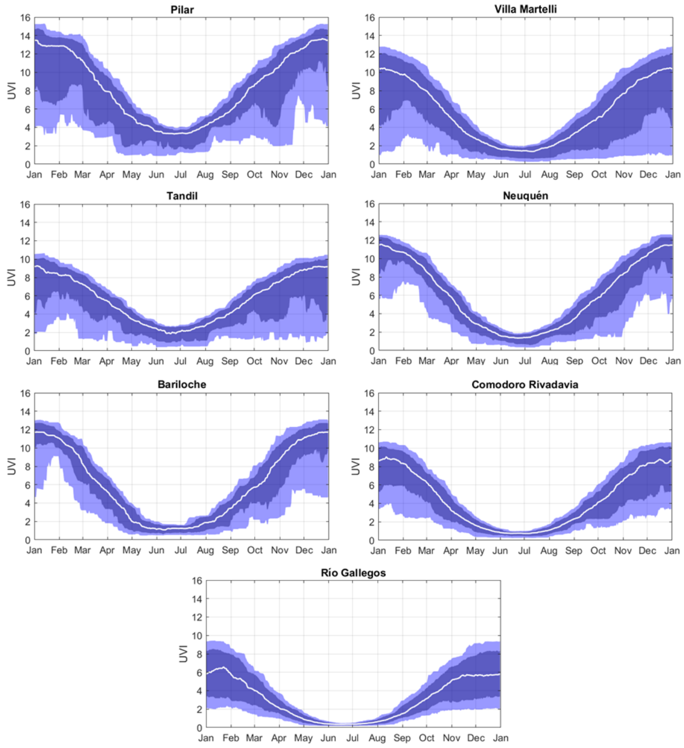

Figure 6: Daily time series of the median noontime UV Index at each station of the Argentine Saver-Net network, on the base of a 31-days moving window in steps of 1 day during the year. Dark and light blue areas denote the 16-84 % and 5-95 % percentiles, respectively.

relevant studies along Argentina. Orte et al. (2019b) analyzed the impact of stratospheric low-ozone-content air masses, related to AOH intrusions over the UVI in the continental sub-polar regions during November 2014. The intrusion of low-ozone air masses were observed over Río Gallegos station (Observatorio Atmosférico de la Patagonia Austral) using Millimetre Wave Radiometer, SAOZ (Systeme d'Analyse par Observation Zenithale), and OMI (Ozone Monitoring Instrument) measurements, reaching unusually low values of 230DU, below 2SD from the climatological value. The impact over the surface UVI was analyzed using the daily maximum UVI time series (near noon) reflecting extreme values of 11.5, above the 95 % percentile of the UVI characterization at Río Gallegos site (figure 6). On the other hand, CERES (Clouds and the Earth's Radiant Energy System, `https://ceres.larc.nasa.gov/index.php`) satellite-retrieved Total shortwave solar irradiance was validated against this network's high-quality solar irradiance measurements to elaborate updated solar radiation Atlas and effective cloud cover maps along Argentina (Carmona et al., 2018). The daily solar global radiation and monthly mean daily solar global radiation data (CERES_SYN1deg product) were compared with the same parameters retrieved from the pyranometers measurements installed in five Saver-Net sites. High correspondence between satellite and ground-based measurements was shown. A similar validation of CERES satellite-retrieved UVA solar irradiance was performed with the aim to develop UVA surface irradiance monthly maps over Argentina (Orte et al., 2019a). CERES monthly means of daily UVA (CERES_SYN1deg product) reflected good agreement with ground-based UVA measurements at four sites of the Saver-Net network (Villa Martelli, Bariloche, Comodoro Rivadavia, and Río Gallegos) (Figure 1).

Additionally, industrial photovoltaic power generation is highly conditioned by the sudden variability in irradiance levels caused by clouds (e.g. Reindl et al., 2017; Gueymard, 2017). The high temporal resolution of the irradiance acquisition in the network, with the complement of simultaneous all-sky camera images, allowed a pilot study of the short-term Total solar irradiance variability in the lapse of 1 to 5 minutes (ramp-rate events) for the Buenos Aires area (Wolfram et al. 2018), and it is planned to extend it to other Saver-Net sites.

3. CONCLUSIONS AND PERSPECTIVES

The conformation, equipment and available datasets in the Argentine Saver-Net UV-Total solar radiation monitoring network have been detailed. Their deployment has been pushed with the development of the Saver-Net project (Japan, Argentina, and Chile) during the period 2013-2018, widening the geographical coverage and possibilities for basic and applied radiative studies including climatology, cloud effects, quantification of solar shortwave radiation budget, photovoltaic energy production, health-risk prevention, validation of satellite data, among others, emphasizing that traceable ground-based monitoring is the most reliable technique for obtaining local surface solar irradiance information. With this purpose, a characterization of the median irradiance and variability range levels along the year was provided at each station, together with a summary of the research precedents with these data. For scientific purposes, data are freely available upon request.

The present structure of this solar irradiance monitoring network can be shortly enlarged with the incorporation of stations that count with both UV and Total irradiance radiometers but still request adhering to the standardized measurement protocols detailed in this work.

Data availability. For ground-based datasets and further information, please contact via email the corresponding author Facundo Orte (`porte@citedef.gob.ar`) and Elian Wolfram (`ewolfram@smn.gob.ar`).

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