

# A Database of 10 min Average Measurements of Solar Radiation and Meteorological Variables in Ostrava, Czech Republic

Marie Opálková<sup>1</sup>, Martin Navrátil<sup>1</sup>, Vladimír Špunda<sup>1</sup>, Philippe Blanc<sup>2</sup>, Lucien Wald<sup>2</sup>

<sup>1</sup>Department of Physics, Faculty of Science, University of Ostrava, Ostrava, 70200, Czech Republic

5 <sup>2</sup>MINES ParisTech, PSL Research University, CS 10207 – 06904 Sophia Antipolis CEDEX, France

*Correspondence to:* Marie Opálková (opalkovamarie@seznam.cz)

**Abstract.** A database containing 10 min means of solar irradiance measured on a horizontal plane in several ultraviolet and visible bands from July 2014 to December 2016 at three stations in the area of the city of Ostrava (Czech Republic) is presented. The database contains time series of 10 min average irradiances or photosynthetic photon flux densities measured in the following spectral bands: [280, 315] nm (UVB); [315, 380] nm (UVA); [400, 700] nm (photosynthetically active radiation, PAR); [510, 700] nm; [600, 700] nm; [610, 680] nm; [690, 780] nm; [400, 1100] nm. A series of meteorological variables including relative air humidity and air temperature at surface is also provided at the same 10 min time step at all three stations, precipitation is provided for two stations. Air pressure, wind speed, wind direction and concentrations of air pollutants PM<sub>10</sub>, SO<sub>2</sub>, NO<sub>x</sub>, NO, NO<sub>2</sub> were measured at the 1 h time step at the fourth station owned by the Public Health Institute of Ostrava. The details of the experimental sites and instruments used for the measurements are given. Special attention is given to the data quality and the original approach to the data quality which was established is described in detail. About 130 000 records for each of three stations are available in the database. This database offers a unique ensemble of variables having a high temporal resolution and it is a reliable source on radiation in relation with environment and vegetation in highly polluted areas of industrial cities in the of north middle latitudes. The database has been placed on the PANGAEA repository (<https://doi.pangaea.de/10.1594/PANGAEA.879722>) and contains individual data files for each station.

## 1 Introduction

Solar radiation is the crucial factor which influences the life on Earth. The intensity and spectral characteristics of incident solar radiation are important properties which cause physiological responses of plants, animals, and humans. Incident solar radiation, especially in ultraviolet UVB [280, 315] nm, UVA [315, 400] nm and visible (VIS) [380, 760] nm spectral regions, is the key factor influencing plants. Although plants can adapt to changing environmental conditions, excessive radiation causes them acute damage because of over-excited photosystems and evolution of free radicals (Reddy & Raghavendra, 2006). Reversely, a lack of radiation is an important stress factor as well (Lambers et al., 2008). Plants use

different spectral regions of solar radiation in different processes in their metabolism. Solar radiation can be a source of energy for plant photosynthesis, mainly the blue and red components of photosynthetically active radiation (PAR, [400, 700] nm) (Ohashi-Kaneko et al., 2007; Johkan et al., 2010). It is also a source of information (UVB, UVA, blue and red components of PAR) as plants contain photoreceptors which are capable of recognizing individual spectral regions: UVR8  
5 photoreceptor for UVB radiation (Tilbrook et al., 2013), cryptochromes and phototropins for UVA radiation (Verdaguer et al., 2017); cryptochromes, phototropins and phytochromes for PAR (Casal, 2013). UVB is mostly harmful and plants try to avoid damage, by using, for example, UV shielding by producing chemical compounds which absorb UVB radiation (Meijkamp et al., 1999). UVA and the blue component of PAR are involved in phototropic reactions, in stomata activity, growth and plant development (Barillot et al., 2010). Plants are also significantly affected by the green light (Materová et al.,  
10 2017). Ratios of spectral regions of incident solar radiation, e.g. UVB/PAR or UVA/PAR, and ratio between diffuse and global radiation, have also important effects on plants (Behn et al., 2010; Grifoni et al., 2008). Diffuse radiation spreads into the environment without a specific direction and is therefore able to penetrate within the plant canopy more effectively. Moreover, diffuse radiation is known for having different blue/red ratio compared to direct radiation (Navrátil et al., 2007), so diffuse radiation influences photosynthesis of plant canopies in different ways than the direct radiation. Although  
15 irradiance is lower in conditions when diffuse radiation is dominant, photosynthesis is more effective than under conditions of prevailing direct radiation. Because air pollutants increase the diffuse fraction, industrial areas have a tendency to exhibit greater diffuse fractions than natural areas and interactions between radiation and plants will be different between these two areas. Since changes in both spectral composition and intensity of incident solar radiation can affect physiological processes in plants, detailed measurements of radiation in several spectral bands in UV and VIS ranges in highly polluted areas of  
20 industrial cities are useful for further understanding of these processes.

Solar radiation passing through the atmosphere is influenced by absorption and scattering due to gas, liquid and solid particles contained in the atmosphere (Wald, 2007). The character of cloudiness and smog periods in industrial urban areas cause considerable changes in the radiation environment compared with clean air areas. These changes can directly affect the photosynthetic activity and reduce the resistance of plants to other abiotic stresses. However, systematic measurements of  
25 radiation in UV and VIS spectral bands, which would allow finding and studying patterns of changes of intensity and spectral quality of incident solar radiation in urban areas, are still missing. Several studies deal with a similar topic (e.g. Jacovides et al., 2004; Zhou & Savijärvi, 2014), but there is a lack of continuous measurements of irradiance in particular spectral regions of PAR, mainly blue ([400, 510] nm), green ([510, 600] nm) and red ([600, 700] nm) radiation, which are important for plants.

30 Ostrava is the third largest city in the Czech Republic with long industrial history. Current industrial production is focused mainly on metallurgy and mechanical engineering and produces air pollutants emitted into the atmosphere. The Ostrava industrial region experiences a great occurrence of smog periods during winter months, but concentrations of air pollutants are noticeable up to severe during the whole year (Jančík et al., 2013). Approximately 20% of the area of Ostrava is covered by public green areas including forests (EEA, 2017). This number is low in comparison with cities of similar size in the

Czech Republic, but is comparable to that found in other cities of similar size in the world. The combination of these factors makes Ostrava a good place for studies of interactions between vegetation and meteorological factors. The detailed measurements spanning several vegetative seasons performed at Ostrava aim at supporting a comprehensive analysis of the changes in intensity and spectral composition of incoming irradiation in relation with air quality characteristics and other meteorological variables and further of the impact of air pollution on the radiation regime in that region.

The database discussed here is nearly connected with studies of plant photosynthesis and metabolism because this is the main research topic of the group of Biophysics at the Department of Physics at the University of Ostrava. The original goal of performing measurements of solar radiation was to inform on solar irradiances in different spectral regions during different meteorological conditions and to use these data in experiments on plants in artificial conditions in growth chambers. In addition, the database can be used for any environmental modelling, e.g. for atmospheric chemistry models, or urbanistic studies.

Because of existence of systematic errors in radiation measurements (e.g. Muneer & Fairouz, 2002; Younes et al., 2005), particular attention was devoted to a careful quality check (QC) on the measurements (e.g. Journée & Bertrand, 2011; Roesch et al., 2011) before releasing the data for further analyses.

The aim of this paper is to describe a database elaborated in cooperation between the University of Ostrava (Department of Physics, Faculty of Science) and the research centre Observation, Impacts, Energy of MINES ParisTech. The database covers the period 2014–2016 and includes quality-checked 10 min averages of seven spectral regions within UV and VIS as well as the broadband irradiance at three measuring stations situated at two locations within the wider area of the city of Ostrava. Meteorological variables, such as air temperature and relative air humidity, are also included in the database for all three measuring stations, and precipitation is included for two measuring stations. Other meteorological variables, such as air pressure, wind direction, wind speed and concentrations of several air pollutants, are included for one location.

This paper is organized as follows: the study area and details about sensors for radiation measurements are given in Sect. 2, the QC procedures applied to the measurements are described in Sect. 3, their results and the structure of the database are detailed in Sect. 4. Finally, a summary and perspectives are given in Sect. 5. The quality-checked database is available in PANGAEA (<https://doi.pangaea.de/10.1594/PANGAEA.879722>) under Creative Commons Attribution 3.0 Unported International Public License (CC-BY 3.0).

## 2 Ground stations and measurements

### 2.1 Locations of the measurement sites

The city of Ostrava is located in the north-eastern part of the Czech Republic. Mean elevation of the city is 244 m a.s.l. and the countryside is flat or slightly undulating (Weissmannová et al., 2004). According to the Köppen-Geiger classification, Ostrava belongs to the Dfb climate subtype (Peel et al., 2007) – mild warm climate, in addition with urban influences. Weissmannová et al. (2004) reported that summers at Ostrava are long, warm and mildly dry, winters are short, mildly warm

with a short duration of snow cover (50–60 days), and the mean annual sunshine duration is 1 594 h. From our data, we computed a mean annual air temperature of 10.3 °C and a mean annual sum of precipitation of 585 mm.

Three identical systems of sensors were installed at two different locations. Two systems (stations S1 and S2) were installed very close to each other, 3 m apart, in the Botanical Garden of the University of Ostrava (BGOU) in the Radvanice district in

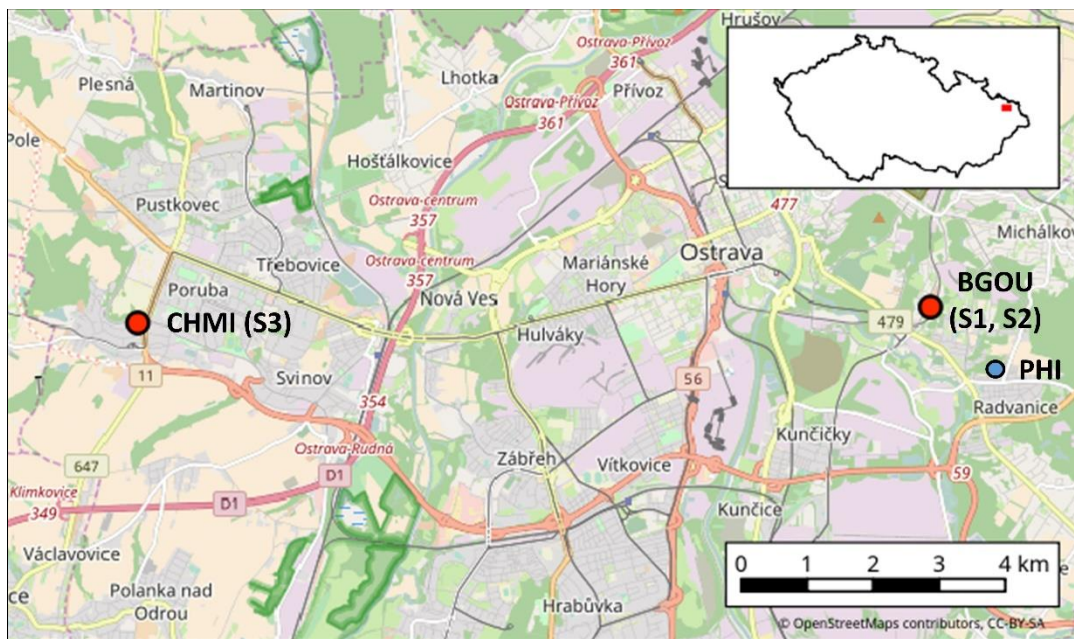
5 Ostrava (235 m above sea level; Tab. 1, Fig. 1; Figs. 1–3 in the Appendix). When the study was planned, it was believed that it was desirable to have two identical systems (i.e. sets of irradiance sensors) at the same place at one location to better assess custom-made sensors and the quality of the measurements. The third system (station S3) was installed in the Czech Hydrometeorological Institute (CHMI) in the Poruba district in Ostrava (240 m above sea level; Tab. 1, Fig. 1; Figs. 4–6 in the Appendix). BGOU is situated approximately 3 km apart from an industrial area which produces large amounts of air  
10 pollutants (Jančík et al., 2013) and concentrations in air pollutants are greater at BGOU (stations S1, S2) than at CHMI (station S3), especially in the winter months (Tab. 2). Jančík et al. (2013) reported that the main source for air pollution at BGOU is industry while it is the road traffic at CHMI.

It was desirable to locate the stations in a very open space area but this was not possible in this project due to necessity of a fenced and easy-to-visit area. There are some shrubs and trees in the surroundings of measuring stations (S1, S2) at BGOU  
15 and other measuring devices in the surrounding of measuring station (S3) at CHMI. Their shading effects were studied and included in the database. Shaded and non-shaded data were determined visually by coloured plots of the irradiance as a function of the solar azimuth and elevation angles (figures with details are included in the datasets and in the Appendix, Fig. 7–9). These horizons were confirmed by the analysis of the digital elevation model found in Google maps.

Several meteorological variables (air temperature, relative air humidity, air pressure, wind speed and wind direction) and  
20 concentrations of air pollutants (PM<sub>10</sub>, NO, NO<sub>2</sub>, NO<sub>x</sub>, SO<sub>2</sub>) were measured at the measuring station owned by Public Health Institute of Ostrava (PHI). The PHI has a network of 4 permanent measuring stations; the nearest PHI station to BGOU is located approximately 1.7 km from BGOU (49.819031°N, 18.340355°E; Fig. 1).

25 **Tab. 1: List of measuring stations owned by University of Ostrava with some details. “BGOU” means Botanical Garden of University of Ostrava, “CHMI” means Czech Hydrometeorological Institute.**

Station	Abb.	Location	District	GPS	Start of measurement	End of measurement
Station 1	S1	BGOU	Radvanice	49.82754°N, 18.32618°E	1. 7. 2014 00:00 UTC	31. 12. 2016 22:50 UTC
Station 2	S2	BGOU	Radvanice	49.82751°N, 18.32615°E	2. 7. 2014 08:00 UTC	31. 12. 2016 22:50 UTC
Station 3	S3	CHMI	Poruba	49.82521°N, 18.15932°E	7. 7. 2014 13:00 UTC	31. 12. 2016 22:50 UTC



**Fig. 1: Locations of the measuring stations. CHMI: Czech Hydrometeorological Institute area (station S3); BGOU: Botanical Garden of the University of Ostrava (stations S1 and S2); PHI: measuring station of Public Health Institute of Ostrava.**

**Tab. 2: Average concentrations of PM<sub>10</sub>, NO<sub>x</sub> and SO<sub>2</sub> measured by the Public Health Institute of Ostrava close to Radvanice (stations S1, S2) and by the Czech Hydrometeorological Institute at Poruba (station S3). All values are given in  $\mu\text{g m}^{-3}$ .**

	Radvanice (S1, S2)			Poruba (S3)		
	PM <sub>10</sub>	NO <sub>x</sub>	SO <sub>2</sub>	PM <sub>10</sub>	NO <sub>x</sub>	SO <sub>2</sub>
annual average 2015	33.8	25.0	13.3	30.6	25.1	5.2
annual average 2016	33.3	24.1	14.0	26.9	22.2	4.3
winter average 2015	43.9	32.9	16.7	37.4	30.7	6.0
winter average 2016	41.8	31.0	18.3	32.3	27.2	4.7

## 2.2 Sensors, measurements, data storage, maintenance and calibration

Several types of sensors were installed to measure the **downwelling** solar radiation or the photosynthetic photon flux density (PPFD) received at the ground level on a horizontal plane in different spectral bands. **All used sensors were placed at 2 m**

**above ground.** The database contains measurements from July 2014 to December 2016. Data loggers collected signals from the sensors each minute. The raw data was stored as 10 min averages to ease further numerical processing.

At all three stations, there were sensors which measured global radiation in UVB, UVA, broadband, and the PPFD at various wavelength ranges within the PAR band: [400, 700] nm, [510, 700] nm, and [600, 700] nm, and spectral bands around 660 nm and 730 nm (Tab. 3). The data were collected by data loggers Edgebox V12 from the EMS Brno company (<http://www.emsbrno.cz>). At all three stations, air temperature and relative air humidity were measured (Tab. 3),

precipitation was measured by the tipping bucket rain gauge only at S1 and S3. Tab. 1 and Fig. 10 in the Appendix summarize the technical characteristics of the radiation sensors and their relative spectral responses.

Maintenance of sensors was performed every month in winter, when heavy loads of dust particles in the atmosphere are frequent, and every two months during the rest of the year. The sensors were cleaned with pure ethanol and the silica gel for removing air humidity within the data logger was changed at each maintenance.

The sensors were calibrated before the start of the measurements in 2014. EMS Brno recommends recalibration of their own sensors once per five years since all sensors are equipped with glass diffusers, which allow accurate measurements for a long time. To check the long-term stability of the sensors, measurements from each of them were compared to the measurements performed in the broadband range and linear regressions were computed in the whole measuring period and for each individual year. No significant changes in the values of the regression parameters were observed. In addition, at BGOU, measurements made by identical type of sensors were compared to check the temporal consistency as the 2 stations S1 and S2. Coefficients of determination were in the interval [0.94, 0.98], thus confirming the expected similarity in data between S1 and S2. No significant systematic biases were observed and the least square linear regression provided a cross-calibration correction of less than 5%. Differences between them could be caused by variable irradiance during partly cloudy days, i.e. one measuring station can be brightened by the Sun, but second measuring station can be shaded by clouds, or by technical properties of sensors. For example, sensors measuring radiation in the intervals [510, 700] nm and [600, 700] nm contain cut-off filters which have the S-shaped transmission curve and it causes a little bit different measured values. Based on these tests, we can conclude that no long-term decrease of the sensitivity of solar sensors is noticeable.

**Tab. 3. Basic technical description of the sensors. Measurement owner: “OU” means University of Ostrava, these instruments were used at stations S1, S2, and S3. “PHI” means Public Health Institute Ostrava, these instruments were used at the measurement station of PHI. “CM” means custom made sensors.**

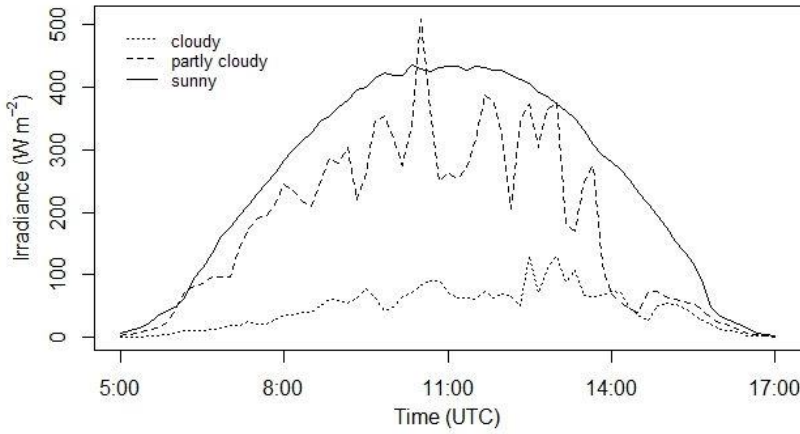
Measured quantity	Bandwidth [nm]	Unit	Type	Company	Measurement owner
Broadband irradiance	400–1100	W m <sup>-2</sup>	EMS 11	EMS Brno, CR	OU
UVB	280–315	W m <sup>-2</sup>	SKU 430	Skye, UK	OU
UVA	315–380	W m <sup>-2</sup>	SKU 420	Skye, UK	OU
PAR	400–700	μmol m <sup>-2</sup> s <sup>-1</sup>	EMS 12	EMS Brno, CR	OU
510–700 nm	510–700	μmol m <sup>-2</sup> s <sup>-1</sup>	CM	EMS Brno, CR	OU
600–700 nm	600–700	μmol m <sup>-2</sup> s <sup>-1</sup>	CM	EMS Brno, CR	OU
660 nm	610–680	μmol m <sup>-2</sup> s <sup>-1</sup>	SKR 110	Skye, UK	OU
730 nm	690–760	μmol m <sup>-2</sup> s <sup>-1</sup>	SKR 110	Skye, UK	OU
Air temperature	-	°C	EMS 33R	EMS Brno, CR	OU
Relative air humidity	-	%	EMS 33R	EMS Brno, CR	OU
Precipitation	-	mm	370C/372C	MetOne Instruments, USA	OU
Air temperature	-	°C	resistive sensor	Thies Clima, Germany	PHI



Relative air humidity	-	%	hygrometer	Thies Clima, Germany	PHI
Air pressure	-	hPa	anaeroid	Thies Clima, Germany	PHI
Wind speed and direction	-	$\text{m s}^{-1}$ ; °	Windsonic	Gill Instruments, UK	PHI
PM <sub>10</sub>	-	$\mu\text{g m}^{-3}$	5030	Sharp, Japan	PHI
NO	-	$\mu\text{g m}^{-3}$	APNA 370	Horiba, Japan	PHI
NO <sub>2</sub>	-	$\mu\text{g m}^{-3}$	APNA 370	Horiba, Japan	PHI
NO <sub>x</sub>	-	$\mu\text{g m}^{-3}$	APNA 370	Horiba, Japan	PHI
SO <sub>2</sub>	-	$\mu\text{g m}^{-3}$	APSA 370	Horiba, Japan	PHI

Concentrations of air pollutants and meteorological variables were provided by PHI as 1 h averages. The measurements were part of a routine process for monitoring air quality in Ostrava. In this routine, series of measurements are checked twice per day, each station is physically checked three times per week, the check and calibration of all sensors is performed by certified companies once per year, and the calibration of sensors in the calibration laboratory takes place once every two years. Measurements are controlled in three different procedures that occur *i*) daily, *ii*) once per month before sending to air pollutants database ISKO, and *iii*) once per year. Air quality data measured by CHMI are not available for free usage. This is the reason why the database does not contain additional meteorological variables for the CHMI (station S3). This problem may have been overcome by using the PHI network but there was no PHI station near the CHMI station.

- 10 Three additional pieces of information are included in the database. The first piece is the season when the measurement was done: spring for the term 21<sup>st</sup> March–20<sup>th</sup> June, summer for the term 21<sup>st</sup> June–22<sup>nd</sup> September, autumn for the term 23<sup>rd</sup> September–20<sup>th</sup> December, and winter for the term 21<sup>st</sup> December–20<sup>th</sup> March. This information was added for potential analyses of solar radiation during different year seasons. The second piece is the prevailing cloudiness conditions – called “weather category” in the database – or each record with three categories: cloudy, partly cloudy and sunny. It was determined by the analysis of the daily profile of the 10 min broadband irradiance as exemplified in Fig. 2 which presents daily profiles for three different days in March 2015; sunny days offer a bell-shaped profile, cloudy days have flat low profiles and partly cloudy exhibit large variability within the day. The information about prevailing cloudiness conditions was allotted to the whole day including night. The third piece is the air pollution category and is available only at S1 and S2. It was established on the basis of intervals of concentration of PM<sub>10</sub> in the air at the measuring station of PHI following the
- 20 five categories proposed by Elshout et al. (2008): very low air pollution (0–11  $\mu\text{g m}^{-3}$ ), low (12–24  $\mu\text{g m}^{-3}$ ), medium (25–49  $\mu\text{g m}^{-3}$ ), high (50–99  $\mu\text{g m}^{-3}$ ) and very high (greater than 100  $\mu\text{g m}^{-3}$ ).



**Fig. 2. Example of daily profiles of the 10 min broadband irradiance for three different days in March 2015: cloudy day on 14th, partly cloudy day on 15th and sunny day on 17th.**

### 3 Quality check applied to radiation data

5 To the best of the knowledge of the authors, there has not been published and accepted procedure for checking the quality of irradiances in the spectral bands of interest yet. In the absence of such a procedure, we have adapted the approach of Korany et al. (2016) which applies to measurements of global and diffuse total irradiances. In our specific case, the quality check (QC) of Korany et al. consists in checking that each measurement  $E(t, \Delta\lambda)$  falls into the range  $[0.03 E0(t, \Delta\lambda), E0(t, \Delta\lambda)]$ , where  $t$  is the time of measurement,  $\lambda$  the wavelength,  $\Delta\lambda$  the spectral range,  $E(t, \Delta\lambda)$  the measurement, and  $E0(t, \Delta\lambda)$  the corresponding irradiance or PPFD at the top of the atmosphere (TOA). Given a typical spectrum  $E0(\lambda)$  (Kurucz, 1992) of the irradiance at TOA, the ratio of the irradiance at TOA for a given spectral band  $E0(\Delta\lambda)$  to the total irradiance at TOA  $E0$  was computed for each spectral band (Tab. 4). It was checked that these ratios are fairly constant by performing similar calculations with other reference spectra of irradiance at TOA found in LibRadtran software (Mayer & Kylling, 2005). In addition, the Kurucz spectrum was converted into spectral PPFD in  $\mu\text{mol m}^{-2} \text{s}^{-1} \text{nm}$  using the equation  $E0(\lambda) = h c / \lambda$ , where  $E0(\lambda)$  is the spectral irradiance,  $h$  is the Planck constant and  $c$  is the velocity of the light. The PPFD  $E0(t, \Delta\lambda)$  in  $\mu\text{mol m}^{-2} \text{s}^{-1}$  was obtained when needed by summing up the spectral PPFD within the band (Tab. 4). The coefficient for the unit conversion for each spectral band was obtained by ratioing the irradiances expressed in both units (Tab. 4). Finally, the final coefficient for converting  $E0$  into  $E0(\Delta\lambda)$  was computed by multiplying the ratio to the total irradiance by the coefficient for the unit conversion (Tab. 4). Time series of the total irradiance at TOA in a 1 min step were downloaded from the website soda-pro.com (<http://www.soda-pro.com/web-services/radiation/cams-radiation-service>) for BGOU and CHMI sites and then averaged every 10 min to match the measurements. By applying the appropriate coefficients for each spectral range, corresponding time-series of  $E0(t, \Delta\lambda)$  were obtained against which the measurements  $E(t, \Delta\lambda)$  may be compared for the first step of the QC.



The second step was performed aiming at flagging measurements that are significantly different from 0, i.e. measurements that are greater than 1.5 times the measurements uncertainty given by the World Meteorological Organization (WMO, 2012). As this uncertainty is based on 95% probability, multiplying it by 1.5 and assuming a Normal law for uncertainty means that there is a 99.7% chance that a measurement greater than this threshold is significantly different from 0. The WMO guide provides relative uncertainty in percent for hourly values of total irradiance and irradiance is expressed in MJ m<sup>-2</sup> while our measurements are in W m<sup>-2</sup> or μmol m<sup>-2</sup> s<sup>-1</sup>. We have estimated the threshold for each spectral band as follows. The relative uncertainty for daily irradiation of good quality is set to 5% in the WMO guide if the irradiance is greater than 8 MJ m<sup>-2</sup>, which corresponds to an hourly mean of irradiance of 220 W m<sup>-2</sup> for an average day length. The 95% relative uncertainty for hourly values in the WMO guide is 8%, i.e. approximately 18 W m<sup>-2</sup>. Multiplying by 1.5 yielded the threshold for the total irradiance: 27 W m<sup>-2</sup> reported in Tab. 4. In a similar way to step 1, the threshold for each spectral range was computed by multiplying the threshold for the total irradiance by the final coefficient (Tab. 4).

**Tab. 4. Irradiance for each spectral band at the top of the atmosphere (TOA, in W m<sup>-2</sup>), its ratio to the total irradiance, conversion coefficients from W m<sup>-2</sup> to μmol m<sup>-2</sup> s<sup>-1</sup> when needed, final coefficients for calculation of irradiance in spectral bands, and resulting upper thresholds.**

Spectral band	TOA Irradiance W m <sup>-2</sup>	TOA Irradiance μmol m <sup>-2</sup> s <sup>-1</sup>	Ratio to total irradiance	Unit conversion coefficient	Final coefficient, including unit conversion	Thresholds
Total irradiance	1365.780	-	1	-	1	27 W m <sup>-2</sup>
Broadband 400–1100 nm	908.205	-	0.665	-	0.665	18 W m <sup>-2</sup>
UVB	20.386	-	0.0149	-	0.0149	0.4 W m <sup>-2</sup>
UVA	65.355	-	0.0479	-	0.0479	1.3 W m <sup>-2</sup>
400–700 nm	534.311	2432.153	0.39121	4.552	1.7808	48 μmol m <sup>-2</sup> s <sup>-1</sup>
510–700 nm	327.785	1644.228	0.24000	5.016	1.2039	33 μmol m <sup>-2</sup> s <sup>-1</sup>
600–700 nm	160.760	870.742	0.11771	5.416	0.6375	17 μmol m <sup>-2</sup> s <sup>-1</sup>
660 nm	131.406	701.406	0.09621	5.338	0.5136	14 μmol m <sup>-2</sup> s <sup>-1</sup>
730 nm	95.673	578.752	0.07005	6.049	0.4238	11 μmol m <sup>-2</sup> s <sup>-1</sup>

The QC for air temperature and relative air humidity was done by checking if data belong to the interval of values which were trustable for the measuring period at measuring places (nonsense values were eliminated). The QC for additional meteorological data and air quality measurements has been described in Sect. 2.2.

4 Results

4.1 Results of the quality check

There were a total of 131 142 records for station S1 (BGOU), 131 558 records for station S2 (BGOU), and 130 659 records for station S3 (CHMI) from July 2014 to December 2016. Percentage of data greater than thresholds is greater than 30%, except UVB (Tab. 5, column 2). This low percentage is explained by the fact that the records also include the night measurements which were close to zero and that were rejected in step 2 as not different from 0. The greatest percentages are observed in broadband, PAR, and UVA. The lowest percentage of data greater than threshold value is observed in UVB region: 17.8%. This fact was likely due to a too high threshold value for this spectral region ( $0.4 \text{ W m}^{-2}$ ), but measurements of UVB radiation are known to be difficult (e.g. Sayre & Kligman, 1992).

Average percentage of data greater than the threshold and passing QC based on the interval  $[0.03 \cdot E_0, E_0]$  was 98.8% (Tab. 5, column 4). The data at S3 had less percentage of data which successfully passed QC than stations S1 and S2. Differences are less than 3%; there is no apparent explanation.

Tab. 5. Data success rate for the QC of measured values of spectral irradiances. Rates are expressed as percentage. First row contains the number of column. *TR* means threshold values from Table 4. The column *>TR* gives the percentage of data greater than *TR* calculated from all records. *iQC* means the interval  $[0.03 \cdot E_0, E_0]$ . The column *>TR + <iQC* gives the percentage of data  $<0.03 E_0$  calculated from numbers of data *>TR*. The column *>TR + iQC* gives the percentage of data belonging to *iQC* calculated from numbers of data *>TR*. The column *>TR + >iQC* gives the percentage of data  $>E_0$  calculated from numbers of data *>TR*.

1	2	3	4	5
	>TR	>TR + <iQC	>TR + iQC	>TR + > iQC
	%	%	%	%
S1 (BGOU)				
Broadband	43.32	0.03	97.79	2.19
PAR	41.88	0.03	99.97	0.01
510–700 nm	41.48	0.03	99.97	0.01
600–700 nm	40.83	0.03	99.97	0.00
660 nm	28.95	0.59	99.42	0.00
730 nm	30.25	0.48	99.52	0.00
UVA	38.63	0.06	99.95	0.00
UVB	17.31	1.38	98.62	0.00
S2 (BGOU)				
Broadband	43.51	0.02	97.01	2.97
PAR	41.83	0.03	99.97	0.00
510–700 nm	41.81	0.03	99.96	0.01
600–700 nm	41.21	0.03	99.96	0.01

660 nm	28.77	0.59	99.41	0.00
730 nm	29.92	0.44	99.56	0.00
UVA	38.92	0.06	99.95	0.00
UVB	17.84	1.30	98.68	0.02
<hr/> S3 (CHMI) <hr/>				
Broadband	44.02	0.00	94.74	5.25
PAR	42.53	0.01	99.76	0.24
510–700 nm	42.37	0.01	99.73	0.27
600–700 nm	41.92	0.03	99.70	0.27
660 nm	31.22	0.71	99.29	0.00
730 nm	32.22	0.62	99.40	0.00
UVA	38.74	0.08	99.92	0.00
UVB	18.40	1.34	93.22	5.45

## 4.2 Additional comments

Some values are greater than the corresponding irradiance at TOA. These values were usually connected with partly cloudy weather, when multiple scattering on the cloud edges could increase incident solar irradiation (Mims & Frederick, 1994).

- 5 Because of noticeable shading effects experienced by the three stations, the direct component of the radiation is extinguished when the sun is below the local horizon. In addition, a part of the sky is always shaded, so a part of diffuse radiation is always missing in the measurements, whose magnitude depends on the day and time of the day and atmospheric constituents. Moreover, these objects reflect the downward radiation and part of the reflected radiation may contribute to the measured radiation. This effect can potentially increase the measured radiation. It is very difficult to quantify it as it depends on optical
- 10 properties of the reflecting object, day and time of the day and atmospheric constituents. Therefore, our measured data **are** influenced by these effects and **they** can be used only for purposes where these effects may be neglected.

**All used sensors were equipped with cosine correctors which allow to gain final values of irradiance without necessity of recalculations because of changing solar elevation angle (SEA). In technical manuals, it is said that these correctors work properly when SEA is greater than 5°. We made an analysis of data variability dependent on SEA and low variability of data**

15 **was confirmed for SEA greater than 8°. It means that only data with SEA greater than 8° should be used in further analyses.**

## 4.3 The database: description and where to access it

One file containing 10 min averages of spectral irradiances, meteorological variables and air quality observations was created for each of the three surface stations for each of the three years. These nine files can be downloaded from the

Pangaea website using a unique identifier (<https://doi.pangaea.de/10.1594/PANGAEA.879722>). To avoid confusion, time stamps are given for both the beginning and the end of each 10 min averaging period. These files are self-explanatory and contain 40 columns for station S1, 29 columns for station S2 and 29 columns for the station S3 with variables mentioned in Tab. 6.

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Tab. 6. A list of variables contained in the database. PHI means Public Health Institute Ostrava.

Code for station	S1, S2 (BGOU), S3 (CHMI)
Date/time start/end	in UTC
Solar azimuth angle	values in the interval (0; 360), in °
Solar elevation angle	values in the interval (-63.6; 63.6), in °
Mask shadow	0 (influenced by shade), 1 (not influenced by shade)
Season	spring, summer, autumn, winter
Weather category	cloudy, partly cloudy, sunny
Air pollution category	very low, low, medium, high, very high (according to the concentration of PM <sub>10</sub> )
PM <sub>10</sub> , NO <sub>x</sub> , SO <sub>2</sub> , NO, NO <sub>2</sub>	in µg m <sup>-3</sup> , measured by PHI
Meteorological variables measured by PHI	air temperature, relative air humidity, air pressure, wind direction, wind speed
Meteorological variables measured by OU	air temperature, relative air humidity, precipitation
Radiation variables in W m <sup>-2</sup>	broadband [400, 1100] nm, UVA [315, 380] nm, UVB [280, 315] nm
Radiation variables in µmol m <sup>-2</sup> s <sup>-1</sup>	PAR [400, 700] nm, [510, 700] nm, [600, 700] nm, 660 nm [610, 680] nm, 730 nm [690, 760] nm

For each spectral band, there is one column with a quality flag, which gives information if measured value of spectral irradiance passed quality check: “1” means that the measurement falls in the interval [0.03 E<sub>0</sub>, E<sub>0</sub>], and “0” means that it is outside. All data including night measurements are present in the datasets. Figures depicting the influence of the horizon on the measuring stations are included in each dataset and in the Appendix. Dataset for the station S1 contains additional columns with meteorological data measured by PHI (Tab. 6). Data of air pollutants and meteorological variables measured by PHI had a native 1 h resolution, so they were copied to all six 10 min records of data measured by the University of Ostrava for each hour. These data can be connected with the dataset for station S2 because of identical location of stations S1 and S2 (BGOU).

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### 5 Summary and perspectives

A homogeneous database of 10 min measurements of downward solar irradiance in several ultraviolet and visible bands has been assembled. Currently, the data cover the period from July 2014 to December 2016 and originate from three ground stations representing two locations in the Ostrava city (Czech Republic) with different air pollution conditions. These quality-checked data are available online at <https://doi.pangaea.de/10.1594/PANGAEA.879722>. The data provide an insight

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to a spatial and temporal variability of solar radiation in spectral bands [280, 315] nm (UVB), [315, 380] nm (UVA), [400, 700] nm (PAR), [510, 700] nm, [600, 700] nm, [610, 680] nm (660 nm), [690, 760] nm (730 nm), and [400, 1100] nm (broadband). These spectral intervals were selected according to their significance for the plant physiology and development. It is possible to calculate the PPFD in blue [400, 510] nm (the PAR PPFD minus the PPFD in [510, 700] nm) or in green [510, 600] nm (the PPFD in [510, 700] nm minus the PPFD in [600, 700] nm). Hence, changes and differences in irradiances and PPFDs in these spectral bands can be studied in different meteorological and air pollution conditions. Because of the specific environmental conditions of the stations, these data have some limitations that should be taken into account before use. Because of their high temporal resolution and the period spanning more than two years, these data constitute a precious tool for the estimation of the radiation environment in an industrial city in Central Europe and they can be used as input data for any environmental modelling, e.g. for atmospheric chemistry models, or urbanistic studies. One of the goals is to characterize the influence of atmospheric pollution on the spectral composition of incident solar radiation with a focus on analyses of differences between measured values. For example, analyses of relationships between some spectral ratios (e.g. UVB/PAR, UVA/PAR, Blue/PAR, Blue/Red, etc.) and concentrations of air pollutants are planned. Based on preliminary results, changes in spectral composition of incident solar radiation induced by individual air pollutants can be specific and they could differently influence physiological processes in plants. Thus, the understanding of the radiation environment is crucial in relation to vegetation and its ecological services in cities. The measurements of solar irradiation will continue and new data can be added to this database later, thus longer and detailed studies of time series will become available for this location of an industrial city in Central Europe.

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## Author contributions

L. Wald suggested possibilities of data quality check. P. Blanc determined a shading effect on measuring stations according to combinations of solar zenithal and elevation angles and horizon. L. Wald, P. Blanc, M. Navrátil and V. Špunda participated in the manuscript preparation. M. Opálková did the operation and maintenance of the sensors and designed the data set, made a data quality check and prepared the manuscript with contributions from all co-authors.

## Competing interests

The authors declare that they have no conflict of interest.

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