Validation of longwave downward radiation estimated by ERA5 reanalysis using measured BSRN INO station data

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Longwave downward radiation (LWDR) from the ERA5 reanalysis was validated against pyrgeometer measurements at the Baseline Surface Radiation Network (BSRN) INO station in Magurele, Romania, for 2021–2022. Hourly comparisons show excellent agreement, with R = 0.94, a slope of 0.98 ± 0.003, and a small intercept (1.6 ± 0.9 W m⁻²). The mean bias (+4.8 W m⁻²), MAE (13 W m⁻²), and RMSE (18.5 W m⁻²) confirm ERA5 accuracy. Seasonal differences reveal underestimation during winter, while summer values agree within ±5 W m⁻². ERA5 provides reliable LWDR estimates for South-Eastern Europe, with strong potential for climatological, energy-balance, and optoelectronic applications.

1. Introduction

Solar radiation reaching the Earth's surface consists primarily of solar shortwave radiation (300–4000 nm), while atmospheric gases such as water vapor, carbon dioxide, and ozone absorb part of this energy and re-emit it as longwave radiation (>4.5 μm) [1, 2]. The component of this flux directed downward to the surface, known as longwave downward radiation (LWDR), is a key element of the surface radiation budget and plays a critical role in regulating the surface energy balance [3, 4]. Accurate LWDR estimates are essential not only for understanding greenhouse-gas effects and climate change but also for practical applications in hydrology, evapotranspiration modelling, weather forecasting, and building energy design [2-4, 5]. In addition, accurate determination of longwave downward radiation is directly relevant to optoelectronic applications in atmospheric studies, as it provides essential input for the calibration and performance assessment of infrared detectors, radiometers and other photonic devices. Direct measurement with pyrgeometers is the most accurate method of determining LWDR [2]. Pyrgeometers use passive thermal sensing elements, named thermopiles, which determine the absorbed solar irradiance by converting the temperature difference sensed by the elements [6]. Another approach in determining LWDR is to use atmospheric reanalysis data [3]. However, ground-based observations are limited in spatial coverage. Reanalysis products, such as the fifth-generation ERA5 dataset from the European Centre for Medium-Range Weather Forecasts (ECMWF), offer spatially and temporally continuous estimates of atmospheric variables by assimilating global observations with model output [7]. ERA5 provides high-resolution fields of radiative fluxes and has been shown to outperform satellite products for LWDR over land [3]. Despite technological progress, globally consistent and spatio-temporal continuous LWDR data are needed to ensure further improvement of LWDR practical applications [5]. Moreover, the accuracy of estimation methods needs to be tested, as the methods can be affected by poor spatial representativeness, uneven spatial distribution [8] or uncertainties in relation land observations [9], and must be validated at global scale [3]. Also, precise estimation of surface net radiation flux components is essential in areas where in situ measurements are not available and photovoltaics technology can be used, considering recent advancements in material design [10], architecture [11, 12], and output [13]. Therefore, validation against independent observations remains necessary to assess the reliability of ERA5 for local and regional applications.

Eastern Europe is underrepresented in LWDR validation studies, despite being a region influenced by strong seasonal variability, frequent temperature inversions, and high aerosol and pollution loads. The Baseline Surface Radiation Network (BSRN) station at Magurele (INO), located south of Bucharest, Romania, provides high-quality pyrgeometer observations [14] that can be used for such evaluation. In this study, we compare two years of ground-based LWDR measurements at

Magurele with corresponding ERA5 reanalysis data. To our knowledge, this represents the first validation of ERA5 LWDR products in Romania, providing insights into their accuracy under the climatic and atmospheric conditions of South-Eastern Europe.

2. Methods

In situ LWDR observations were obtained from the Baseline Surface Radiation Network INO station (44.34°N, 26.01°E; 80 m a.s.l.), located ~10 km south of Bucharest, Magurele, Romania. The station is equipped with a Kipp & Zonen CGR4 pyrgeometer, installed on a Kipp&Zonen Solys2 solar tracker with shading to avoid shortwave contamination, for longwave downward irradiance measurements. A full description of the instrumentation and setup is provided by Carstea and Fragkos [14]. The data are recorded at 1 Hz frequency using a Campbell Scientific CR1000X data-logger. From these high-frequency measurements, one-minute averages are calculated along with standard deviations, and maximum and minimum values. The one-minute data were further averaged into 15-minute, 1-hour and then daily intervals. Data from 2021 and 2022 were used to calculate the monthly means. In order to undertake the QA/QC analysis, the BSRN recommended tests were applied [15, 16].

ERA5 is a comprehensive global atmospheric reanalysis produced by the European Centre for Medium-Range Weather Forecasts (ECMWF). It provides hourly data from 1940 to near real time by combining model forecasts with a large number of assimilated observations, using the Integrated Forecasting System (IFS) coupled with a land-surface model [7]. In this study, hourly ERA5 LWDR data were retrieved for 2021–2022, extracted at $0.25° \times 0.25°$ spatial resolution, and interpolated to the location of the INO station.

The comparison between measured and ERA5-derived LWDR was assessed using a set of standard statistical metrics: mean absolute error (MAE), root mean square error (RMSE), Pearson correlation coefficient (R), and interquartile range (IQR). These indicators allow evaluation of the systematic bias, random error, and correlation between reanalysis and ground-based observations.

3. Results and discussions

The temporal variability of the measured LWDR data for the period 2021-2022 has been discussed in detail by Carstea and Fragkos [14]. Here, we focus on validating ERA5 estimates against pyrgeometer observations from the BSRN INO station. Fig. 1 shows the hourly variation of measured and modelled LWRD together with their differences. The highest measured LWDR value was recorded on 2021-08-05 18:00 UTC (441.5 W m^{-2}) and the lowest on 2021-02-13 06:00 UTC (180.9 W m^{-2}). The highest estimated ERA5 value was found on 2022-07-27 13:00 UTC (442.7 W m^{-2}) and the lowest on 2021-02-13 07:00 UTC (183.2 W m^{-2}). The two datasets overlap closely, but differences are seasonally dependent: smaller in summer and larger during autumn and winter.

Monthly averages (Fig. 2) highlight this seasonal dependence of the differences more clearly. Differences are the highest during November–March period, when cloud cover and boundary-layer stability are the strongest.

The largest absolute differences between ERA5 LWDR data and measured data were 82.5 W m^{-2} on 2021-12-19 04:00 UTC and 85 W m^{-2} on 2022-03-21 22:00 UTC. Such large seasonal differences are not usually visible in global evaluations, where data are aggregated across all conditions [3, 17]. Nevertheless, the seasonal cycle of LWRD at Magurele is well captured by ERA5, with both datasets showing maxima in summer (~380–390 W m^{-2}) and minima in winter (~260–270 W m^{-2}). The overall phasing and amplitude of the seasonal variability are reproduced very accurately. However, systematic differences emerge in certain periods: ERA5 tends to underestimate LWRD during the colder months (November–March) by 10–20 W m^{-2}, consistent with the influence of nocturnal inversions and underestimated boundary-layer humidity in winter [8, 18]. In contrast, ERA5 shows better agreement during late spring and summer, when clear-sky conditions dominate, with differences reduced to within ±5 W m^{-2}. These results are consistent with previous evaluations indicating that ERA5 performs best under clear-sky conditions, when longwave fluxes are primarily controlled by surface temperature and integrated water vapor, while larger discrepancies are linked to cloud and boundary-layer representation errors under cold-season conditions [3, 17].

The regression analyses of the hourly data are shown in Fig. 3. A highly significant correlation was found between modelled and measured LWDR data (R = 0.94) while the regression slope is close to unity (0.98).
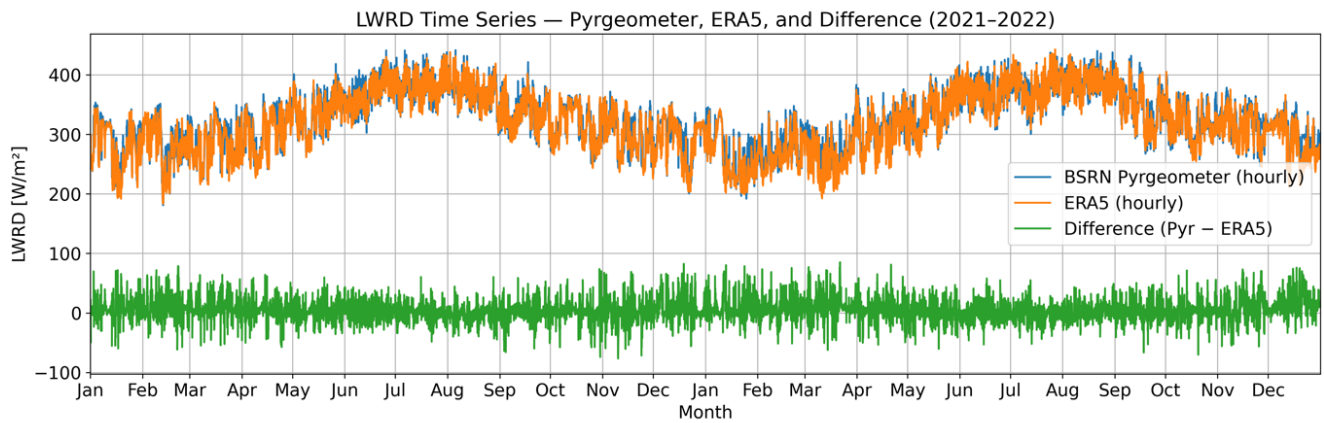
Fig. 1. Hourly variation of the measured and modelled LWRD data, and the difference between the two datasets (pyrgeometer measured – ERA5 estimations), from January 2021 to December 2022 (colour online).
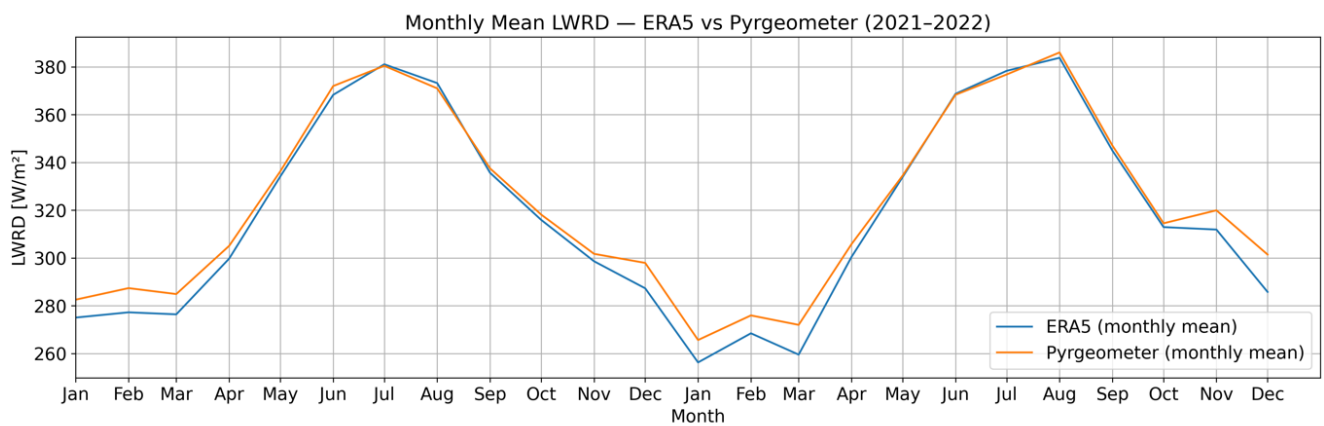

Fig. 2. The comparison between the monthly means of estimated ERA5 LWRD and the measured LWRD data for 2021 and 2022 (colour online).

The distribution of differences between measured LWDR data and ERA5 estimations, and its associated statistical analysis are shown in Fig. 4. The ERA5 reanalysis underestimates, in most cases the LWDR, as more differences were found in the positive range. The mean bias is modest ($+4.8$ W m^{-2}), with a mean absolute error of 13 W m^{-2} (indicating that the model slightly underestimated the measured data) and a root-mean-square error of 18.5 W m^{-2}. These values are consistent with previously reported global evaluations, where ERA5 biases were typically within ± 10 W m^{-2} and RMSE values were ~20–30 W m^{-2} against BSRN and SURFRAD networks [3, 8, 17]. The accuracy of the model was reasonable with a RMSE of 18.5 W m^{-2}, which was better than those found by Tang et al. [3] when comparing LWDR data retrieved from ERA5 reanalysis and satellite, and measured data from 49 BSRN stations. Moreover, the IQR was 16.8 W m^{-2}, showing that the distribution of the differences was tight, after removing outliers and tail values. The error distribution is approximately Gaussian, although extreme deviations exceeding ± 40 W m^{-2} occur,

particularly under cloudy conditions and during winter/spring months. This pattern highlights the well-known challenges in reanalysis products, where uncertainties in cloud representation and near-surface humidity are the dominant contributors to LWRD biases [19]. Clear-sky conditions, on the other hand, are generally well captured, consistent with the strong physical dependence of LWRD on temperature and integrated water vapor that ERA5 represents effectively [18]. Overall, our results confirm that ERA5 is a reliable source of LWRD for climatological and energy-balance applications, although caution is warranted in cloud-affected periods where errors can locally exceed ± 50 W m^{-2}.

Fig. 5 plots the differences at hourly frequency and indicates the values that exceeded the 5th and 95th percentiles. The hourly differences showed that there were less values outside of the range in summer compared the other seasons, due to a larger number of clear sky days. Higher underestimations, close to 80 W m^{-2}, were observed in the winter months, while overestimations

peaked in November (close to -80 W m^{-2}), in both years. However, there were more instances of minor overestimations compared to underestimations, throughout the year, potentially due to changes in cloud cover and cloud characteristics. The small but systematic differences observed between ERA5 and pyrgeometer measurements at the BSRN INO station can be attributed to several factors. First, uncertainties in cloud representation are the dominant source of longwave flux errors: ERA5's parameterized cloud fraction, base height, and optical thickness may not fully capture local variability, particularly for thin cirrus or low stratus layers, leading to deviations of up to ±50 W m^{-2} in all-sky conditions [17, 19]. Second, biases in near-surface humidity affect the radiative transfer scheme, as longwave radiation is highly sensitive to water vapor content in the lower troposphere; underestimations of column water vapor typically lead to negative LWRD biases [3, 20]. Third, boundary-layer processes at Magurele, especially nocturnal inversions and stable stratification, are often smoothed in the reanalysis vertical structure, resulting in weaker downward longwave flux compared to ground observations [8]. Fourth, station–grid mismatches (ERA5 grid elevation vs. actual site altitude of 80 m) and the assumption of uniform surface emissivity may also introduce small systematic offsets [18]. Finally, in specific cases, aerosols and pollution, which are significant in the Bucharest metropolitan area [21], can contribute additional absorption and re-emission in the infrared, effects not fully represented in ERA5 [22].
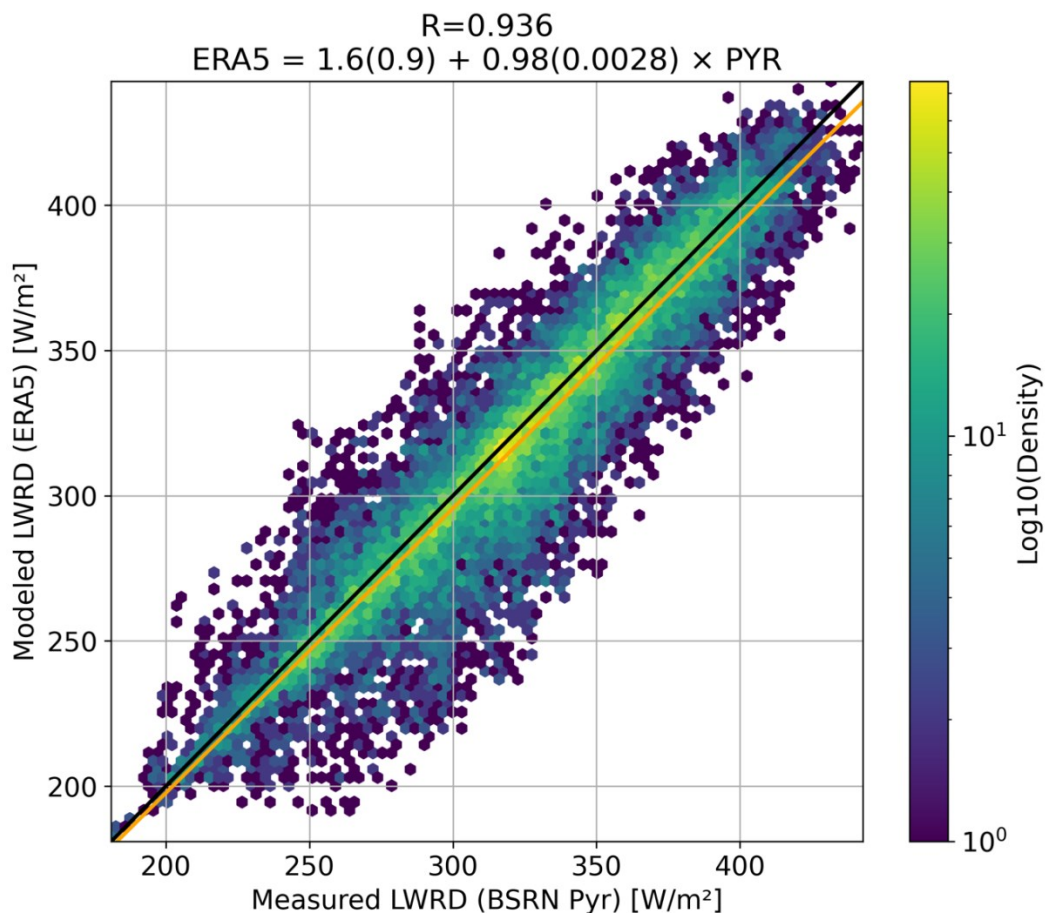

Fig. 3. Validation of the ERA5 LWDR estimated data using the measured LWDR data. Black line represents 1:1 line while the orange line represents the linear fit (colour online)

N=17482, Mean=4.8, STD=17.9
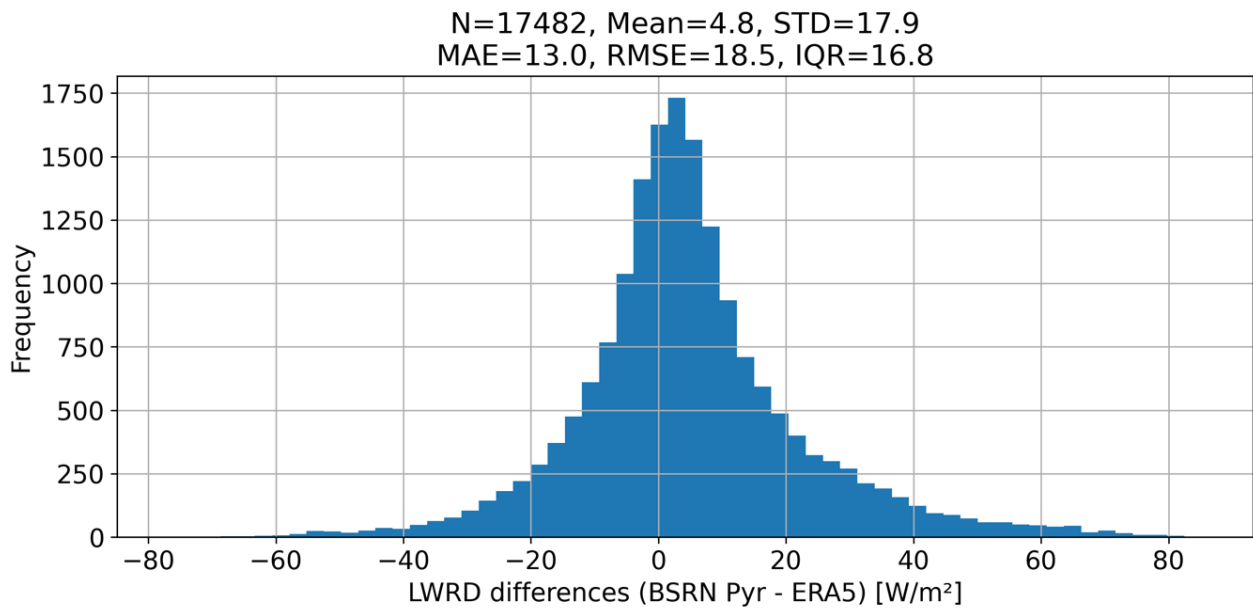MAE=13.0, RMSE=18.5, IQR=16.8

Fig. 4. The distribution of the differences between the modelled and measured LWDR data.
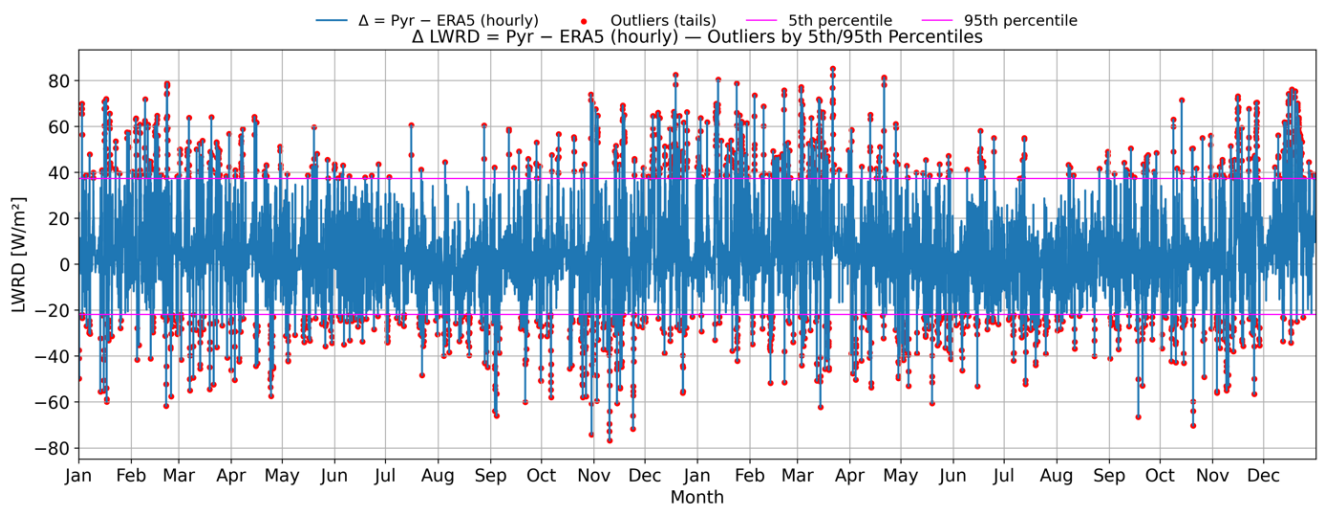

Fig. 5. The differences between hourly LWDR, modelled and measured, and the associated 5th and 95th percentiles.
The values outside of this range are marked with red circles (colour online).

4. Conclusions

Longwave downward radiation (LWDR) estimated by ERA5 was evaluated against pyrgeometer measurements at the Magurele BSRN station (south of Bucharest) for 2021–2022. Regression analysis of hourly data demonstrated excellent agreement, with a correlation of 0.94, a regression slope of 0.98 ± 0.003, and a negligible intercept (1.6 ± 0.9 W m^{-2}). Seasonal analysis revealed that differences between model and measurements are larger during the winter months (November–March), likely due to greater uncertainties in ERA5 related to cloud cover, boundary-layer stability, and humidity profiles. On average, ERA5 underestimates LWDR during colder months, whereas agreement is much improved in summer under predominantly clear-sky conditions. Overall, the mean bias is modest, and both MAE and RMSE indicate small errors between the datasets. Outlier analysis further confirms that extreme deviations are concentrated in winter. These results demonstrate that ERA5 provides high-quality LWDR estimates for South-Eastern Europe, with strong reliability for climatological, energy-balance, and optoelectronic applications, although caution is warranted in cloud-affected winter periods.

Data availability

The BSRN INO Magurele station radiation measurements can be accessed from the PANGEA website: https://www.pangaea.de/?q=BSRN&f.author%5B%5D=Carstea%2C+Emil

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