# Variability of solar UV radiation in the northern mountains of the Czech Republic, 2020–2021

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## Abstract
Solar ultraviolet (UV) radiation has a crucial role in many atmospheric processes and a huge impact on living organisms. Its main positive effect is the synthesis of vitamin D, but it also causes problems such as sunburn, skin cancer or eye cataracts. In the mountains, high doses of UV frequently occur due to a specific combination of atmospheric and geographical factors such as a high ground reflection as a consequence of a large number of days with snow cover, or a lower concentration of atmospheric pollutants in comparison to lowland urban regions. This study used measurements of erythemal UV radiation from two high altitude areas: the Hrubý Jeseník Mountains (Vysoká hole meteorological station, 1 464 m a.s.l.) and the Giant Mountains (Luční bouda meteorological station, 1 413 m a.s.l.) in the Czech Republic, during 2020 and 2021. We evaluated the daily and monthly changes in erythemal dose and UV index. The maximum daily dose of 5.0 kJ.m$^{-2}$ (8.9 of UV index) was measured on 28 June 2020 at Vysoká hole. The maximal UV index of 10.1 was observed at Luční bouda on 5 July 2020, while the maximum daily dose of 4.9 kJ.m$^{-2}$ occurred on 14 June 2021. The main factors that caused changes in solar UV radiation were the amount of cloud cover as well as the total ozone column.

***Key words:*** erythemal dose, UV index, ozone, cloud cover, Hrubý Jeseník, Giant Mountains

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***Abbreviations*****:** CMF – Cloud modification factor, DU – Dobson unit, ECMWF – European Centre for Medium-Range Weather Forecasts, ESRI – Environmental Systems Research Institute, EUV – Erythemally weighted ultraviolet, GMAO – Global Modelling and Assimilation Office, CHMI – Czech Hydrometeorological institute, LB – Luční bouda station, MERRA – Modern-Era Retrospective Analysis for Research and Applications, NASA – National Aeronautics and Space Administration, SZA – Solar zenith angle, TOC – Total ozone column, UV – Ultraviolet, UVI – UV index, VH – Vysoká hole station, WHO – World Health Organization, WMO – World Meteorological Organization

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## Introduction

Solar ultraviolet (UV) radiation is a part of the electromagnetic light spectrum and has a wavelength of 100 to 400 nm. Depending on the wavelength, UV radiation can have both beneficial and harmful effects on living organisms. Exposure to UV radiation may cause serious diseases such as skin cancer and eye cataracts, but on the other hand, it is critical in the synthesis of vitamin D (Lucas et al. 2019, Vaníček et al. 1999). In humans, sensitivity to UV radiation is defined by the action spectra, *e.g.* the erythemal action spectrum (McKinlay and Diffey 1987), which describes the reaction of the skin to UV radiation, or the action spectrum of vitamin D synthesis (CIE 2006[1], Vaníček et al. 1999). Moreover, UV radiation has different beneficial/ harmful effects and impacts on plants, terrestrial fungi and bacteria (Vanhaelewyn et al. 2020). UV-induced changes in the DNA of plants have harmful effects on growth, overall development and flowering (Hollósy 2002). A common method used to express the amount of UV radiation is the UV index (UVI), which is defined as the erythemally weighted UV (EUV) radiation in $mW.m^{-2}$, divided by 25 (Vaníček et al. 1999, WHO 2002[2]). UVI values can be grouped together based on the effect they have on living organisms and there are recommendations to improve public awareness and understanding of the potential risks (*see* WHO 2002[2]).

The intensity of the incident solar UV radiation on the Earth's surface depends on various atmospheric and geographical factors, such as solar zenith angle, surface elevation, cloud cover, total ozone column (TOC), reflectivity (albedo), and aerosols (Kerr and Fioletov 2008, Vaníček et al. 1999). In the mountains, the combined effect of the factors that affect UV radiation may be more pronounced, especially in early spring or late winter, when the stratospheric ozone is highly variable due to atmospheric dynamics. The annual variation in TOC over the Czech Republic ranges from ~280 DU in September, to ~400 DU in March (Čížková et al. 2018). The presence of snow cover results in an increased surface albedo (Pribullová and Chmelík 2005, Simic et al. 2011).

The effect of altitude and albedo on the daily clear-sky UVI maximum in the Czech Republic was studied by Metelka (2018), who reported the difference between a mountain and lowland site (Labská bouda and Hradec Králové, respectively). The paper reported that in spring, the UVI was approximately 25–50% higher at the mountain station than at the lowland station. Nevertheless, due to the decrease in the density of molecular and aerosol particles with increasing altitude, extremely high UV radiation doses can occur at mountain sites throughout the year, so close monitoring of UV radiation levels in these areas is necessary (Diffey 2002, Metelka 2018, Pribullová and Chmelík 2005).

In addition to mountainous areas, extremely high UV radiation doses are also prevalent in the polar regions, mostly due to a combination of ozone depletion and high surface reflectivity (*e.g.*, Cordero et al. 2022, 2014). In the polar regions the UVI reaches different peak values in the Northern and Southern hemisphere. At selected stations within the Arctic Circle in Canada and Europe the highest values of UVI measured were between 4 and 6 during the summer months of 1990–2019 (Bernhard et al. 2020). Most of the high readings were recorded at the Sodankylä station where, between 1990 and 2015, a UVI of 6 was measured twice, once in the summer of 2011 and again in the summer of 2013 (Lakkala et al. 2017). At the northernmost sites (near 80 °N), the maximal UVI was ~3, but below the Arctic circle, *e.g.*, at Scandinavian stations, it could reach up to ~9 (Bernhard et al. 2020, Svendby et al. 2023). By contrast, UV radiation in

Antarctica can reach extreme values, such as a UV index of 11 or more measured at the coastal station Marambio on 5 days between 2000 and 2010 (Lakkala et al. 2018).

The intensity of UV irradiance in polar and mountainous regions is driven by a similar set of factors, all of which are affected by various processes and feedback mechanisms in the climate system. Moreover, the ecosystems in both the polar and mountainous regions may be more significantly affected by future changes in UV radiation related to the consequences of global climate change (*e.g.*, Barnes et al. 2023). Therefore, it is crucial to continue UV radiation research in such areas.

In the Czech Republic, there are four meteorological stations operated by the Czech Hydrometeorological Institute (CHMI), which have been recording UV radiation levels as part of the Solar Radiation Network since 1994 (Vaníček 2001). Moreover, a reconstructed time series of UV radiation is available for Hradec Králové from 1964 (Čížková et al. 2018). There are three mountain stations in the Czech Republic, which have been making solar UV radiation observations since 2004. At the Labská bouda station, located in the Giant Mountains, UV radiation monitoring is carried out by the Giant Mountains National Park Administration. The second station in the Giant Mountains is Luční bouda (1 413 m a.s.l.), which has been operated by the CHMI since 2019. The Vysoká hole station (1 464 m a.s.l.), located in the Hrubý Jeseník Mountains, was established by Masaryk University, with the UV monitoring programme launched in April 2019.

The solar UV radiation measurements from these stations have been subject to a preliminarily assessment (Metelka 2018, Tomanová and Pokorná 2021), however, not enough attention has been paid to mountainous locations in the Czech Republic. The aim of this study is to broaden the knowledge of UV radiation levels at mountainous sites in the Czech Republic through an analysis of the daily and monthly variation in UV radiation levels at the Luční bouda and Vysoká hole meteorological stations located in the Giant Mountains and the Hrubý Jeseník Mountains during 2020 and 2021.

## Data and Methods

The meteorological station on Vysoká hole (50.0596 °N 17.2314 °E; VH) is located ~450 m southwest of Vysoká hole (the second highest peak of the Hrubý Jeseník Mountains) at an altitude of 1 464 m (Fig. 1, Table 1). It is a sprawling summit with a flat mountain plateau and an unobscured (open) horizon. The southeast hillside is part of the Velká Kotlina mountain basin. The vegetation cover of the site is described as alpine grassland. There was also an allochthonous dwarf pine plantation (Zeidler and Banaš 2020), which, however, did not shade the solar radiation measuring instruments. From April 2019 solar UV radiation measurements have been performed by the Department of Geography, Masaryk University, Brno using a broadband UV-S-E-T radiometer (Kipp & Zonen, the Netherlands). The mean annual air temperature at the nearest meteorological station (Šerák, 16.7 km from the VH station) was 3.2°C between 1991 and 2020 (Dolák et al. 2023).

At the Luční bouda station (50.7353 °N 15.6979 °E; LB), UV radiation has been measured using a 501A UV-Biometer broadband radiometer (Solar Light, USA) since October 2019. The station is located at an altitude of 1 413 m in the Giant Mountains, in the proximity of ~3 km from the Sněžka Mountain, the highest summit in the Czech Republic. It also looks out over an unobstructed (open) horizon, the area is dominated by alpine grassland, mainly matgrass with dwarf pine and northern structured peat bogs (KRNAP 2024[3]). The mean annual air temperature at the LB station was 1.6°C in 1961–2000 and 2.6°C in 2001–2016 (Kliegrová and Kašíčková 2019).

Both instruments are calibrated every year at the Solar and Ozone Observatory, CHMI, according to international standards based on the Guide to Instruments and Methods of Observation, World Meteorological Organization (WMO 2023[4]). Over the study period, there were only a few missing values due to technical issues; at the VH station on 6–7 September 2020 and 16–29 April 2021, and at the LB station on 18 July 2021.

| Station | Instrument | Period | Altitude (m a.s.l.) | Coordinates | Surface Characteristics | Mountains |
|---|---|---|---|---|---|---|
| **Luční bouda** | UV-Biometer 501A (Solar Light) | 2020–2021 | 1413 | 50.7353 °N 15.6979 °E | alpine grassland | Giant Mts. |
| **Vysoká hole** | UV-S-E-T (Kipp & Zonen) | 2020–2021 | 1464 | 50.0596 °N 17.2314 °E | alpine grassland | Hrubý Jeseník |

**Table 1.** Characteristics of the Luční bouda and Vysoká hole meteorological stations.

For the UV radiation analysis, daily EUV dose, maximal daily UVI, TOC, and theoretical (modelled) clear-sky UV radiation were used for the period of 2020 to 2021. For each month the UVI distribution, categorized as per the WHO (2002), the daily and monthly EUV dose and related statistical characteristics were calculated.

The theoretical 10-min EUV irradiance (in $mW.m^{-2}$) for clear-sky conditions was obtained from the libRadtran software package (Emde et al. 2016, Mayer et al. 2020), using the RTES DISORT algorithm. The input parameters for the calculation were:

- daily mean value of TOC in Dobson Units (DU), measured using a Brewer spectrophotometer (MkIII, double monochromator, no. B184) at the Solar and Ozone Observatory in Hradec Králové, Czech Republic
- daily mean albedo – snow albedo from the ERA5 Land reanalysis (ECMWF 2024[5]), corrected for snow cover height and the state of the soil at the LB and Šerák CHMI station (for the VH site). The shortwave albedo was then recalculated as the albedo for UV radiation (according to Čížková et al. 2018),
- daily mean value of total column water vapour in $kg.m^{-2}$, obtained from ERA5 reanalysis (ECMWF 2024[5]),
- solar zenith angle (SZA) calculated at 10-min intervals to correspond with the UV radiometer measurements.

Moreover, the cloud modification factor (CMF), expressed as a ratio of the measured and theoretical (modelled) values of EUV radiation (Calbó et al. 2005), was determined with a 10-min resolution and used to compute the daily mean CMF, calculated for SZA < 80°. Three days, the 2–3 and 6 April 2020, were selected for further evaluation of the cloud cover and TOC effect due to the prevailing synoptic situation. Attention was also paid to the period with the highest daily dose and the maximal daily UVI (28 June and 5 July 2020). All the map outputs needed for the case studies, including cloud cover, geopotential height and total ozone column in Europe, were downloaded from the Giovanni database (NASA 2024[6]) and processed using the ArcGIS Pro software package (ESRI 2024[7]). The plots were generated using the ggplot2 library in the R programming language (Wickham 2010[8]).

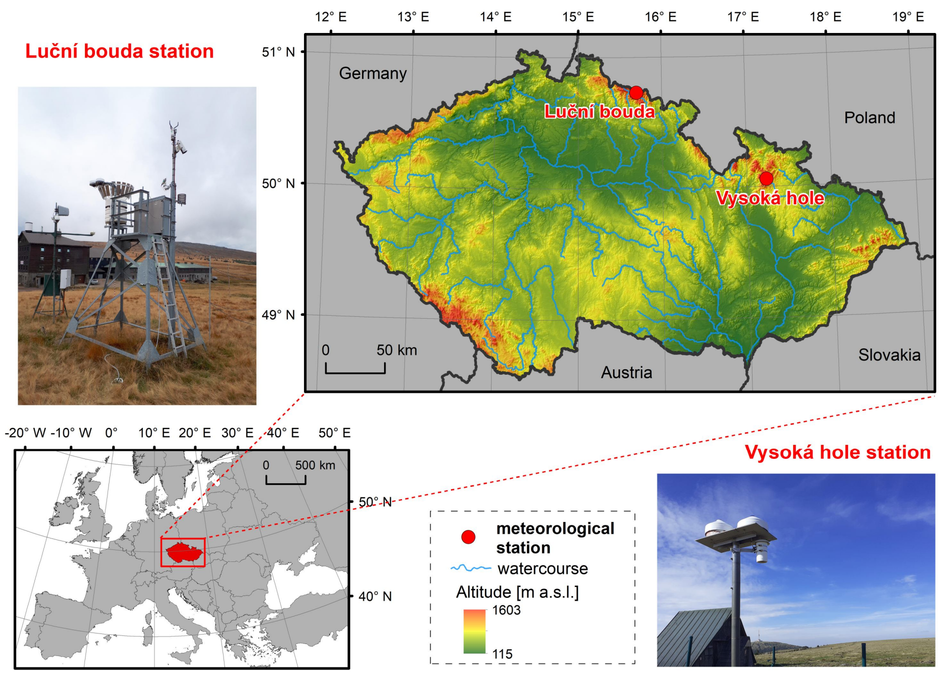


**Fig. 1.** Location of the Luční bouda and Vysoká hole meteorological stations in the Czech Republic and Central Europe.

## Results

### *Solar UV radiation, total ozone and cloud cover variation*

The high variability of the maximal daily UVI and EUV doses at the VH and LB stations during the period 2020–2021 can be seen in Fig. 2A–D. The mean maximal daily UVI over the entire period at VH was 3.0, while at LB it was 3.5. In summer, the UVI varied between 0.7–10.1 at LB and 1.2–8.9 at VH with a mean UVI of ~6.0. The highest UVI at the LB station, 10.1, was measured on 5 July 2020, and the highest UVI at the VH station, 8.9, was measured on 28 June 2020 and 28 July 2020. The highest daily EUV dose at VH (5.0 kJ.m$^{-2}$), was also recorded on 28 June 2020. At LB, the highest EUV doses over the period of study were measured on 14 June 2021, 4.9 kJ.m$^{-2}$, with a UVI of 7.9. At VH, a lower intensity of incident UV radiation was recorded on the same day with a daily dose of 3.4 kJ.m$^{-2}$ (UVI of 5.9).

The theoretical clear-sky UVI and daily EUV dose, calculated using the libRadtran radiative transfer model, are shown in Fig. 2A–D. The measured UVI was higher than the theoretical clear-sky, *i.e.* CMF > 1, on 45 days at LB, 25 days in 2020 and 20 days in 2021, but only on 24 days at VH, 18 days in 2021 and 6 days in 2021. In 2020, a very high UVI came from the model between 12 and 17 May due to the high albedo (> 60%) at both stations; this was associated with snow cover that lasted for days during this period. The assessment of the observed and modelled UVI, using CMF changes (Fig. 2E–F), showed similar seasonal changes in 2020 and 2021, with a lower CMF found at VH compared to LB. The annual mean CMF at the VH station was 0.61, with a range of 0.59 (2021) and 0.63 (2020), while at the LB station it was 0.70 for both years, indicating that the cloud cover at VH caused a greater degree of attenuation of the UV radiation than at LB.

The annual course of the daily TOC had its minima in autumn/winter and maxima in spring (Fig. 1G). The maximum TOC in Hradec Králové was 469.1 DU on 4 March 2020. The lowest TOC of 226.9 DU was measured on 18 November 2020. A significant decrease in TOC, by 76 DU, was observed in the first half of April 2020 (*see* section Effect of selected factors on UV Index – a case study).

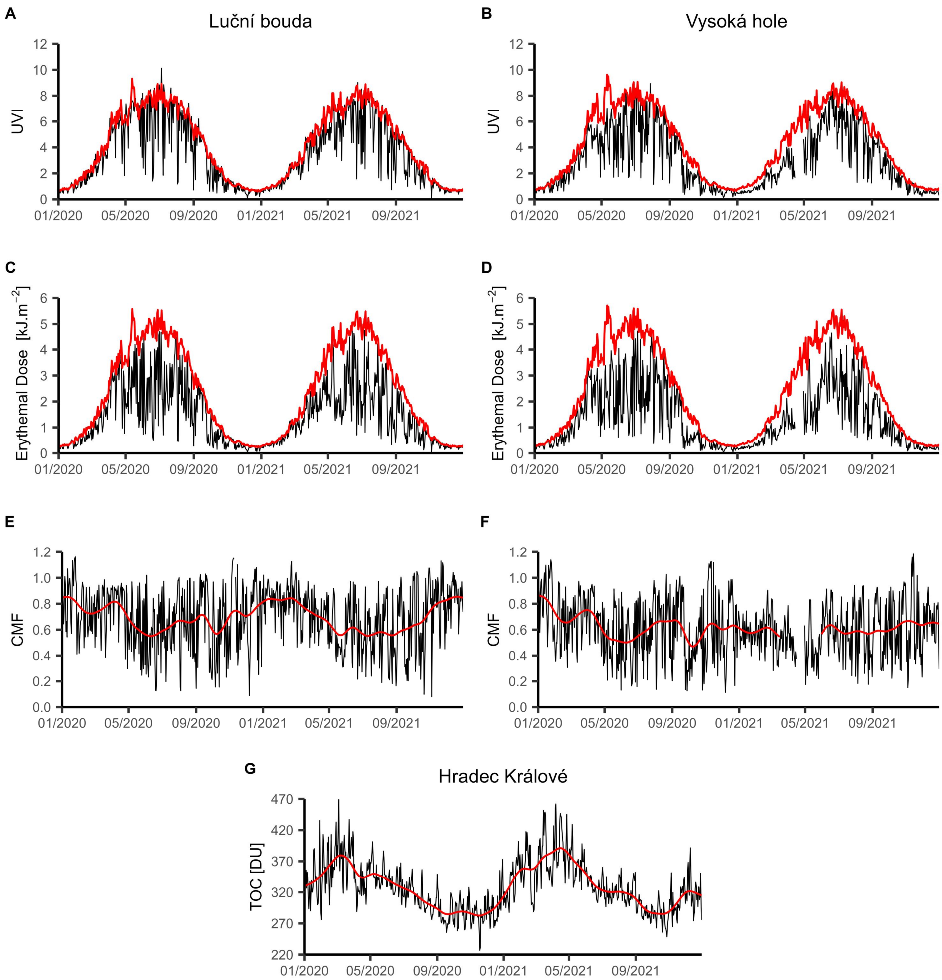


**Fig. 2.** Maximum daily UV index (A, B), daily erythemal UV doses (C, D) with theoretical clear-sky values (red); cloud modification factor (E and F) at the Luční bouda (left) and Vysoká hole (right) stations and the total ozone column (TOC) from the Solar and Ozone Observatory in Hradec Králové over the period of 2020–2021 (G) smoothed using a Gaussian window function (red).

### *UV Index distribution*

The relative frequency of the maximal daily UVI categories, as per the WHO (2002), during the individual months of 2020 and 2021 showed considerable seasonal changes at both stations (Fig. 3A–D). At the two study sites, very high UVI values frequently occurred from May to August. At the VH station, very high UVI values were observed from June to August 2020 and in June and July 2021. In contrast, at LB, very high UVI values were recorded from May to July in both years and the occurrence of very high values of UVI was also more frequent. At the LB station, there was also a greater proportion of high UVI values in April 2020 when compared to the VH station. In general, at VH there were around 3–13% more days with low UVI and 3% more days with moderate UVI, but 4–5% less days with high UVI in comparison to LB.

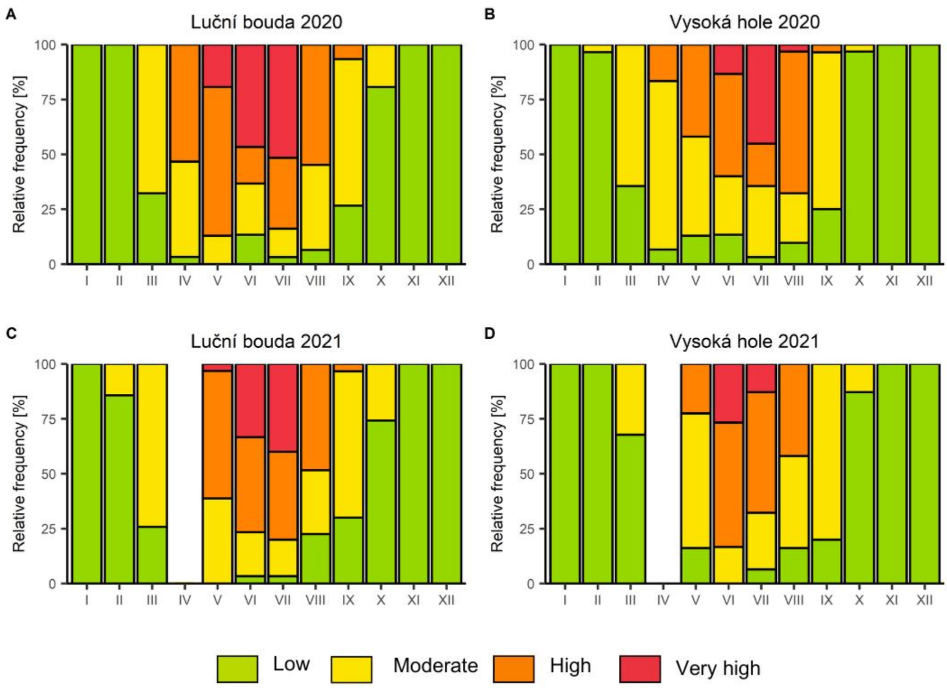


**Fig. 3.** Relative frequency of maximal daily UV index at the Luční bouda (left) and Vysoká hole (right) stations in the individual months in 2020 (A, B) and 2021 (C, D).

### *Variability of erythemal UV doses*

The mean daily EUV dose was 1.34 kJ.m$^{-2}$ at VH and 1.43 kJ.m$^{-2}$ at LB, which was 26.8–29.5% of the maximum daily dose at the stations. The maximal mean monthly EUV dose at the VH station occurred in June 2021 (3.06 kJ.m$^{-2}$), in the same month as the maximal monthly EUV dose (91.79 kJ.m$^{-2}$). At the LB station, the maximal monthly dose occurred in July 2020 (86.13 kJ.m$^{-2}$), which is 6.2% lower than the maximal monthly EUV dose at the VH station.

Over the majority of the study period, higher monthly EUV doses were recorded at LB, but in July and August 2020, and June to September 2021, VH recorded higher monthly EUV doses (Fig. 4A–B). In April 2020, the monthly EUV dose (72.70–80.78 kJ.m$^{-2}$) measured at both stations was higher than that in May (65.86–78.98 kJ.m$^{-2}$). The May value (78.98 kJ.m$^{-2}$) was also greater than that measured in June (75.64 kJ.m$^{-2}$). A possible explanation is that in April 2020, there were 16 days with a CMF ≥ 0.9 at LB and 6 at VH, but only 3 days at LB and 1 day at VH in May 2020; 2 days at LB and no days at VH in June 2020, indicating that there was more cloud cover in the latter two months. In addition, a decrease in TOC was observed at the beginning of April 2020, which may also have contributed to the recorded increase in EUV dose (Fig. 2G).

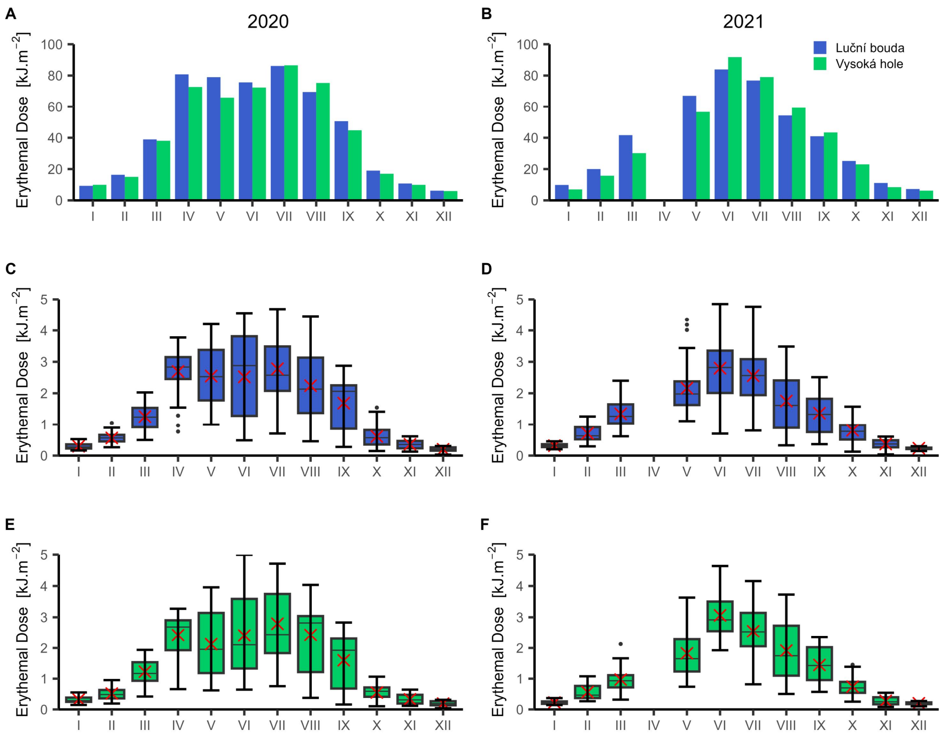


**Fig. 4.** Monthly dose of erythemal UV radiation (A, B) and monthly box plots of the daily erythemal dose (C, D, E, F) at the Luční bouda (blue) and Vysoká hole (green) stations in 2020 (left) and 2021 (right). The horizontal line in each box represents the median (red cross shows the mean value); the hinges represent the 25 and 75 percentiles, while the whiskers represent 1.5 times the interquartile range; dots represent values outside this interval.

The statistical characteristics of the daily EUV dose (Fig. 4C–F) indicate some differences between the stations, and also between 2020 and 2021. From May to September 2020, a greater degree of variability (standard deviation, interquartile and variance range) in the daily EUV dose was observed compared to 2021. A higher monthly minimum of the daily EUV dose from January to May (0.16–1.11 kJ.m$^{-2}$) was recorded at LB in both years. On the other hand, in June 2021, the minimum daily dose was higher at VH (1.93 kJ.m$^{-2}$) than at LB (0.71 kJ.m$^{-2}$). In June and July 2020, higher monthly maxima of the daily EUV dose were observed at VH (4.71 to 5.00 kJ.m$^{-2}$), but in the summer 2021, the monthly maxima at VH were lower (4.16 to 4.64 kJ.m$^{-2}$).

### *Effect of selected factors on UV Index – a case study*

From 2 to 6 April 2020, there was a decrease of almost 76 DU in TOC observed in the Czech Republic (Fig. 5A–F). During this period, snow cover was recorded at both stations, and albedo ranged from 0.54 to 0.67. Both the 2 and 6 April 2020 were classified as clear days, given that the CMF at each station exceeded 0.9.

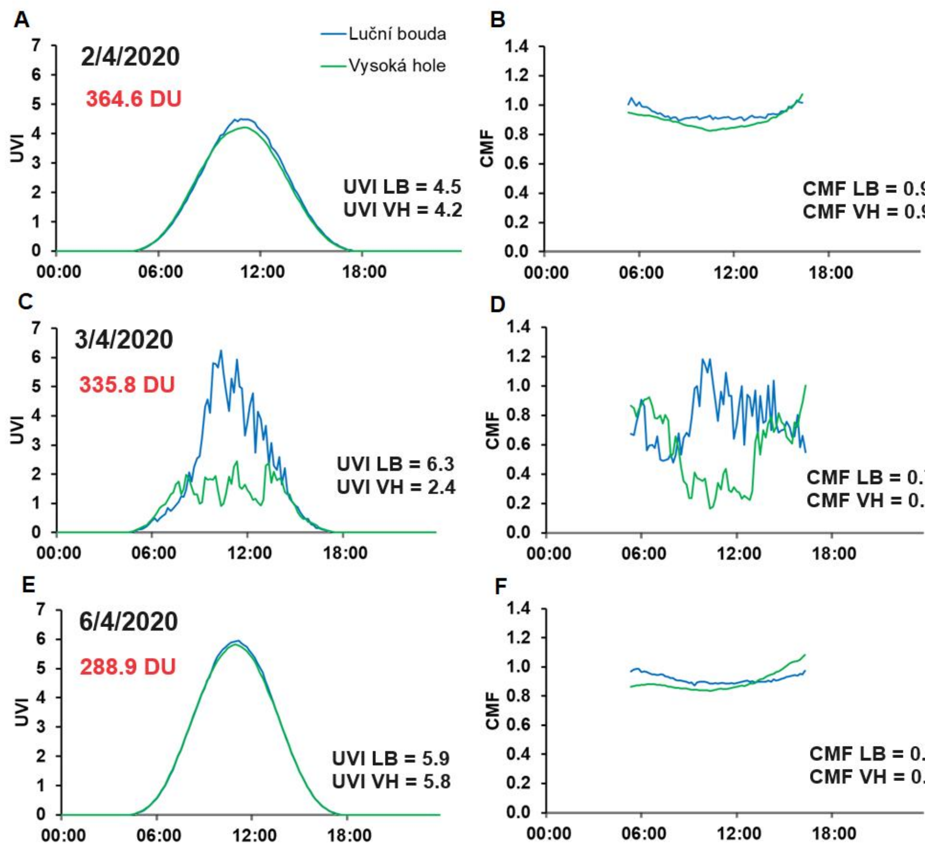


**Fig. 5.** Variability of UVI (left) and cloud modification factor (right) at Luční bouda (blue) and Vysoké hole (green) on 2 April 2020 (A, B), 3 April 2020 (C, D), and 6 April 2020 (E, F), supplemented by the daily mean TOC (in red), and maximum daily UVI and daily mean CMF at Luční bouda (LB) and Vysoká hole (VH). Time is given in UTC (Coordinated Universal Time).

When compared to 2 April (TOC = 364.6 DU, *see* Fig. 5A), an increase in the maximum daily UVI of 37% at LB and 38% at VH was recorded on 6 April 2020 (TOC = 288.9 DU, Fig. 5E). The difference in the maximum daily UVI between these two days was 1.6 (VH) and 1.4 (LB). Similarly, the daily EUV dose was higher on 6 April with 0.8 $kJ.m^{-2}$ at LB and 0.9 $kJ.m^{-2}$ at VH.

In addition, on 3 April 2020 (Fig. 5C), a significant difference in the cloud cover over the stations was observed, the daily mean CMF at VH was 0.55 and at LB 0.77. There was also, at LB, a higher maximal daily UVI measured (6.3, at 10:20 UTC) than on 6 April ($UVI_{max}$ = 5.9, at 11:00 UTC). Between approximately 9:50 UTC and 10:20 UTC, the UVI at LB on 3 April exceeded the UVI on 6 April by 2–10%. As the CMF was 1.1–1.2 at the time, the potential cause was the reflection of UV by the clouds. However, throughout the day, the UVI at LB was on average 34% lower on 3 April when compared to 6 April 2020, and the difference was 46% at the VH station.

The highest daily EUV dose over the whole study period was recorded at the VH station on 28 June 2020 (Fig. 6A–B), and the highest maximum daily UVI was observed at LB on 5 July 2020 (Fig. 6C–D). On 28 June 2020, the daily maximum UVI at VH was 8.9, and the daily EUV dose was 5.0 $kJ.m^{-2}$. The highest daily UVI at LB was lower at 8.5, as was the daily EUV dose, 4.0 $kJ.m^{-2}$. The reason for the difference between the stations on this day was likely the presence of cloud cover over LB in the afternoon (the cloud cover was 5/8 at 13:00 and 8/8 at 15:00 UTC at the Pec pod Sněžkou meteorological station, located approximately 5.3 km away from LB).

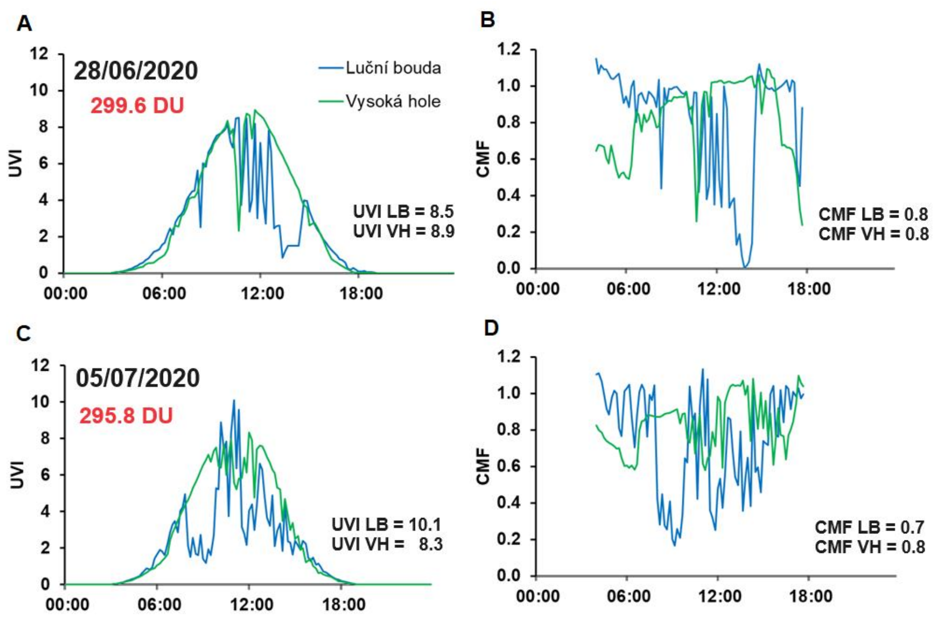


**Fig. 6.** Variability of UVI (left) and cloud modification factor (right) at Luční bouda (blue) and Vysoká hole (green) on 28 June 2020 (A, B) and 5 July 2020 (C, D), supplemented by the daily mean TOC (in red), and the maximum daily UVI and daily mean CMF at Luční bouda (LB) and Vysoká hole (VH). Time is given in UTC (Coordinated Universal Time).

On 5 July 2020, the maximum daily UVI at LB was 10.1, but at VH, it was only 8.3, 1.8 lower than at LB. However, on this day, the daily EUV dose was also higher at VH, at 4.7 kJ.m$^{-2}$ in comparison to LB at 3.5 kJ.m$^{-2}$. This may be explained by the variable cloud cover over both stations (Fig. 7 and 8), which attenuated a portion of the UV radiation at LB. However, it may also have contributed to the very high UVI value by reflecting and therefore enhancing the incoming UV radiation. The difference in TOC between the two days was only 3.8 DU (299.6 DU on 28 June and 295.8 DU on 5 July), but these values were 7–10% lower than the June and July averages. The relatively low TOC values, in comparison with the June and July averages, were caused by the advection of ozone-poor air from lower latitudes (*see* Fig. 7A, 7C). The influx of ozone-poor air masses, which coincided well with the observed pattern in the 100hPa geopotential height and prevailing southwestern advection associated with a high-pressure system over the Mediterranean and northern Balkans. Moreover, less cloud cover, between 0 and 40%, was connected with edge of this high-pressure system that extended over central Europe (*see* Fig. 7B, 7D).

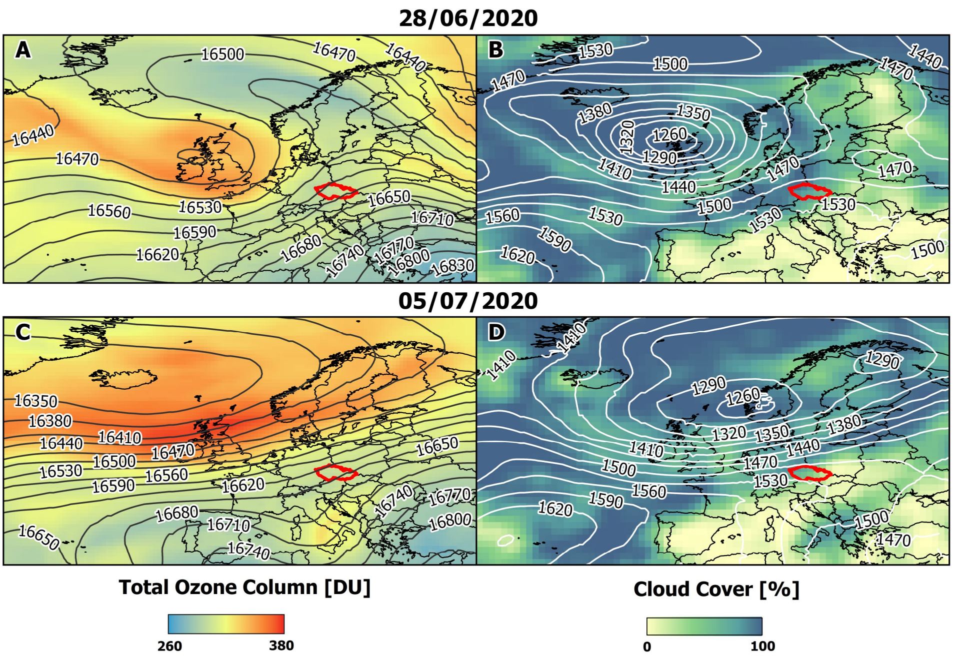


**Fig. 7.** Spatial distribution of daily mean TOC (A, C; left) and daily mean cloud cover (B, D; right), supplemented with the geopotential height at 100 hPa (left; black line) and 850 hPa (right; white line) on 28 June 2020 (A) and 5 July 2020 (B). The border of the Czech Republic is highlighted in red.

## Discussion

The maximal daily values of UVI and daily EUV doses at the VH and LB mountain stations in 2020 and 2021 were highest in the summer months, when the northern midlatitudes experience the lowest SZA of the year. A similar pattern of EUV radiation and UVI values has been observed across the mountainous regions of Central Europe, *e.g.*, at the Schauinsland station (1 206 m a.s.l.) in Germany and Zugspitze (2 962 m a.s.l.) in the Alps (Vitt et al. 2020). The UVI maxima recorded by the Czech mountain stations (up to about 10) are even comparable with the coastal Antarctic stations (*e.g.*, Marambio, Palmer, Troll), where UVI can reach or exceed 10 on rare occasions (Aun et al. 2020).

However, the UVI or EUV doses in the Alps (including Zugspitze) or the Tatra Mountains, Slovakia, can be even higher (Pribullová and Chmelík 2008, Vitt et al. 2020, Vuilleumier et al. 2021). In the Tatra Mountains (Slovakia), the maximum EUV dose can reach 4–7 $kJ.m^{-2}$ (modelled EUV doses based on 10 year climatology), with a maximal monthly mean of about 4.8 $kJ.m^{-2}$ at the Skalnaté Pleso station (1 778 m a.s.l.) between 2002 and 2004 (Pribullová and Chmelík 2008). Also, in Davos (1 610 m a.s.l.), Switzerland, the mean monthly EUV dose reached a maximum of around 4 $kJ.m^{-2}$ in the summer months of 2004–2018 (Vuilleumier et al. 2021), which is about 1 $kJ.m^{-2}$ higher than in the northern Czech mountains. Similarly, the maximal noon UVI in Zugspitze (2 962 m a.s.l.) was close to 11 over the period of 1983–2015 (Vitt et al. 2020). These locations are at higher altitude than the LB and VH stations, which could be the main reason for the differences, as the alpine stations exhibit high surface albedo, even in the summer months (Schmucki et al. 2001), and multiple reflections from inclined snow-covered surfaces can further increase the incident UV radiation (Kerr et al. 2003).

Contrary to the dependency of UV radiation intensity on SZA, in 2020, the maximal monthly EUV dose at both stations under study came in July, not in June, when SZA is at its lowest. This was most likely a consequence of a greater degree of cloud cover in June, as the mean monthly CMF was lower in June than July at both stations (in June 2020, CMF was 0.50 ± 0.23 at VH and 0.55 ± 0.25 at LB, whereas in July, CMF reached 0.62 ± 0.20 at VH and 0.65 ± 0.19 at LB). Also, in April 2020, there were more days when the CMF exceeded 0.90, which may also have contributed to the higher monthly EUV dose in comparison with May 2020.

The environmental conditions at both stations are favourable for high values of UVI and high doses of EUV radiation. Very high values of UVI were measured at these stations in both 2020 and 2021 and they were more frequent at the LB station, where the maximum UVI (10.1) was observed. The difference in the distribution of very high UVI levels between these stations may be due to the different amount and type of clouds, which in turn cause differences between the measured UVI or EUV doses and the theoretical clear-sky levels. The effect of cloud cover on UV radiation depends, amongst other things, on the cloud type, spectral dependence and SZA dependence of cloud effects (Calbó et al. 2005). Scattering and reflection of radiation by the cloud edges (that very often occur when there are partly cloudy skies) has the most pronounced effect on UV radiation, due to the increase in the diffuse radiation that reaches the surface of the ground, although the direct solar radiation most often remains unchanged (Antón et al. 2012). The increase in UV radiation under these types of atmospheric conditions may only take a few minutes, nevertheless maximum UV irradiance levels tend to be higher than on clear-sky days (Sabburg and Wong 2000).

Cloud cover variability may account for regional differences in UVI which have been described, for example, by Fioletov et al. (2003), who observed a higher mean midday UVI in Western Canada in comparison to Eastern Canada at the same latitude in July 1979–1987. Other important factors that affect UV radiation are the geographic location of the stations, the local topography, and the ground surface characteristics of the various mountains, in the case of this study, the Hrubý Jeseník and Giant Mountains (Dolák et al. 2023, Kliegrová and Kašíčková 2019).

An increase in solar UV radiation, attributed to a 79 DU decline in TOC over the course of 5 days, was observed at both of the study sites. A significant episode of extensive stratospheric ozone depletion, in the late winter and early spring of 2020, was also documented at other stations in the Northern Hemisphere (Bernhard et al. 2020, Petkov et al. 2023, Tichopád et al. 2024). This reduction in TOC can be explained by atmospheric dynamics and the anomalous cold and persistent stratospheric polar vortex, which created favourable conditions for chemical ozone loss (Petkov et al. 2023).

These types of episodes with low ozone may cause a significant increase in the levels of solar UV radiation (Hlavinka et al. 2007, Schwarz et al. 2018). In our study, the 37–38% increase in UV radiation measured between 2 and 6 April 2020 was due to the combination of two factors – TOC and cloud cover. Fig. 8A–F shows the gradual influx of ozone poor air from higher latitudes over the Czech Republic, as well as clear-sky conditions on 2 and 6 April 2020. The spatial distribution of the mean daily values of TOC coincides well with the findings of Petkov et al. (2023), who studied ozone dynamics across Europe during the spring of 2020, and Bernhard et al. (2020), who observed the highest relative UVI anomaly in the first week of April at the European Arctic stations (Sodankylä, Ny-Ålesund, Andøya). However, absolute UVI anomalies for March and April were very small (< 1 unit of UVI). In our study, the difference in the maximum daily value of UVI over two days (connected with changes in TOC) was 1.6.

A high maximal daily UVI value of 6.3 was also measured on 3 April 2020 at the LB station, but it was likely not caused by the previously mentioned reduction in TOC (which was 335.8 DU on that day), but primarily by variable cloud cover (*see* Fig. 8A–F). Solar UV radiation can be scattered by clouds (*e.g. Cumulus*) and this can lead to a short-term increase that can even exceed the clear-sky values (Antón et al. 2012, Calbó et al. 2005, Podstawczynska 2010, Vaníček et al. 1999). Most likely, even the highest level of UVI measured in this study (10.1 at LB on 5 July 2020) was the result of cloud enhancement.

Another factor, which can have a significant influence on the incident UV radiation, is surface albedo. In the study period, long-lasting spring snow cover was noted at both stations. During the case study in April 2020 snow cover was recorded at both stations, which can also increase the UV radiation levels. For example, Kylling et al. (2000) found that the increase in the monthly EUV dose can be more than 20% when snow cover is present. Furthermore, Philipona et al. (2001) and Schmucki et al. (2001) confirmed that a rise in the daily EUV dose of up to ~30% is possible at any time of the year thanks to the high albedo of snow-covered surfaces. In the High Tatra Mountains an increase in the UV-B irradiance of 13–16% was detected at an SZA of 55–65° (Pribullová and Chmelík 2005). Due to the relatively low SZA in the spring in comparison to the winter, the springtime albedo-related enhancement of UV irradiance in the Czech mountainous areas may present a potential danger for organisms including humans (Schmucki et al. 2001).

Future trends and changes in UV radiation will mainly depend on the effects and changes in the many factors that affect UV radiation intensity, including cloud cover, TOC, aerosols, surface albedo, greenhouse gas concentrations, and air pollutants (Bais et al. 2019). Some simulations of UV radiation in high latitudes suggest that by the end of the 21$^{st}$ century, recovery of the ozone layer (in combination with changes in the reflectivity of the Earth's surface) could result in a 5–15% decrease in the summer and autumn UV radiation levels in the Northern Hemisphere (Bais et al. 2019, Fountoulakis and Bais 2015, Litynska et al. 2012). However, it is difficult to predict the UV radiation levels in the future, as UV projections are very sensitive to emission scenarios that affect all the factors that influence UV radiation, including ozone (Bais et al. 2019). Therefore, it is important to continue monitoring UV radiation and the factors that affect it using both ground-based and satellite-based instruments.

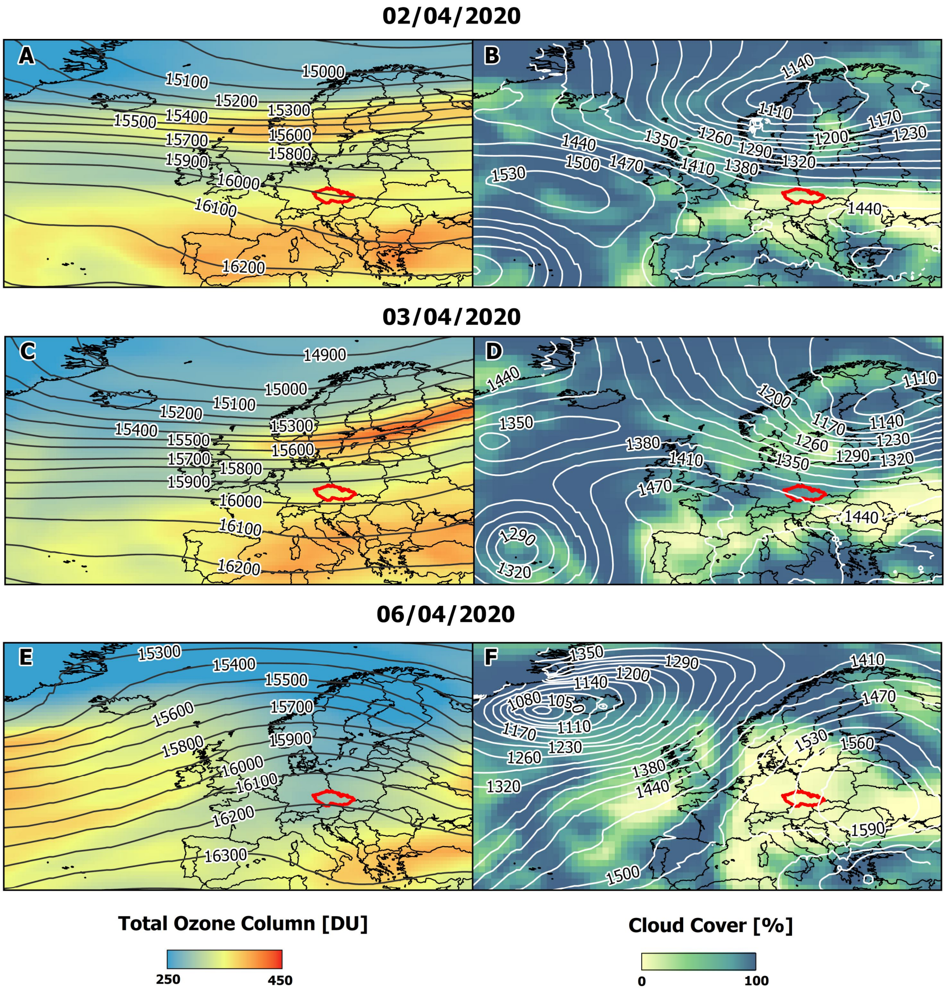


**Fig. 8.** Spatial distribution of the daily mean TOC (A, C, E; left) and daily mean cloud cover (B, D, F; right), supplemented by the geopotential height at 100 hPa (left, black line) and 850 hPa (right; white line) on 2 April 2020, 3 April 2020, and 6 April 2020. The border of the Czech Republic is highlighted in red.

## Conclusion

This study presents an analysis of the first two years of UV radiation monitoring at the Vysoká hole and Luční bouda stations, the Czech Republic. The variability of the maximal daily UVI and daily EUV dose at Vysoká hole and Luční bouda was evaluated for 2020 and 2021.

The maximum values of UVI were recorded at both stations in the summer of 2020. The highest UVI, 10.1, was measured at Luční bouda on 5 July 2020, while the maximum daily dose of 4.9 kJ.m$^{-2}$ occurred on 14 June 2021. The maximum UVI at the Vysoká hole station was lower (8.9), and it was observed on 28 June 2020, together with the maximum daily EUV dose reaching 5.0 kJ.m$^{-2}$.

This study shows that very high UVI values can be observed especially in the first half of the summer when SZA is low, and can be further conditioned by low TOC, cloud-free skies or variable cloud cover, which can cause multiple reflection and enhancement of UV radiation. High albedo and low levels of aerosols also contribute to the high UV radiation levels observed.

The combined effect of these factors can lead to high UVI and daily erythemal doses in the mountainous areas of the Czech Republic. As the UVI at the Czech mountainous sites can exceed 10+, due consideration should be given to protection from EUV radiation, especially during the summer and periods with snow cover (late winter and spring). Additional precautions when visiting mountainous areas with extreme levels of UV radiation is crucial and this study can also act as a basis for further dermatological research into the effects of UV radiation on human health.

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