Comparative measurements of solar UV irradiation at the high-mountain stations of BEO-Moussala (BG) and NAO-Rozhen (BG)

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Abstract. Damaging UV radiation is an important object of investigation related to its impact on biological species. Data acquired at high-altitude stations reveal dangerous events of incident UV radiation reaching the Earth surface. Continuous multi-UV spectral measurements by open-source equipment could further deepen the knowledge of solar light propagation and the events of radiation transfer and atmospheric absorption processes. This report describes recent results on high-resolution UVA, UVB, UVC measurements of solar UV radiation at the mountain stations in Bulgaria.

1. Introduction
Recent climatic changes and temperature records have raised the attention to environmental monitoring and to the correlations between unusual atmospheric events and the Sun activity. The UV range of the sunlight spectrum has been investigated for long years but is still the object of research due to the complexity of input factors as well as the fast-growing improvements in ICT and sensors technologies.

The Sun variability is strongly wavelength-dependent. The variability on the 27-day solar rotation scale is mostly related to the appearance and disappearance of active regions on the solar surface. The main goal of these applied studies is to evaluate accurately the risks and to forecast events, thus preventing damages to the infrastructure and to animals and humans. At high altitudes, UV monitoring is an important method of evaluating potential risks to human skin. In mountains, the accumulated UV dose is higher due to the higher transparency, the lower thickness of the atmospheric layers and to other dynamic optical effects, as “cloud passing” and corresponding additional UV light reflections. In

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this paper, recent achievements in the design of open-source scientific tools and solar UV measurements are reported.

2. Equipment implementation
The general idea was to develop an open-source tool capable of operating under the severe mountain conditions and of being easily improved and upgraded using low budget. The Internet of Things (IoT) is a concept that can solve the problem. IoT’s challenge is to bridge the physical world, such as temperature and humidity sensors readings, and the information world, such as data processing and storage of data via machine-human interfaces. Communication protocols for data acquisition that can be used are the HTTP and MQTT (Message Queuing Telemetry Transport) protocols both running on TCP. MQTT uses a publish/subscribe pattern and provides some advantages, such as low energy consumption [1]. The MQTT protocol is specifically designed for "machine to machine" communication. A common system of MQTT requires two main software components: MQTT Broker serves to handle publishing and subscribing for data; the sensor unit is defined as MQTT Client.

In this study, a UV sensor system was designed capable of measuring solar UV-A and UV-B irradiation. This system sends the sensor data over the internet to the open-source “cloud” ThingSpeak. It consists of digital UV sensors, a micro-controller (Arduino platform), a Wi-Fi device (ESP 8266), and an independent supply unit – a solar charger with a Li-ion battery pack. The system is wirelessly connected to LAN and is able to read and send multiple sensor data to both LAN storage every two seconds and “cloud” storage every 20 seconds. In the last version, messages are transmitted from MQTT Client (sensors) to Mosquitto MQTT broker, installed on Odroid C2 Ubuntu Linux platform, and then transferred to another MQTT client, which is configured for storage as a subscriber.

Several identical UV monitoring systems were fabricated and installed at different locations in order to perform comparisons and data analyses. A modular design approach was adopted. The measuring unit, shown at figure 1, is designed and programmed to capture UV-A and UV-B irradiation using a VEML 6075 sensor. At BEO-Moussala, the UV sensor system contains an additional UV-C sensor (240 – 280 nm) based on a visible-blind gallium-phosphide (GaP) photodiode which is incorporated in the sensor head. All sensors are calibrated with reference to Class II UV sensors. In order to save battery charge during night-time, a WatchDog/DeepSleep circuit is implemented. The WatchDog is essentially a small timer that will force the full system to reset and restart if any application or the microcontroller freeze, hang, stall or crash.

![Figure 1. UV sensor unit and main components.](image-url)
The charger unit delivers DC electricity using a 5-Wp solar PV module, an MPPT controller and DC/DC converters. An 18650 type Li-ion rechargeable battery block (19.2 Ah) supplies 3.3 V for all components.

3. Measurements
The high UV season in the northern hemisphere is expected in the summer aphelion (near 04 July) due to the minimum distance between the planet Earth and the Sun. This is why in this study the UV irradiation was measured in three successive years (2017-19) during the period 26 June – 04 July). Indicative days have been selected for comparisons with different cloud cover and wind speed. For example, UV Index (UVI) data during a typical clear sky day is presented in figure 2a, while a partially cloudy day is illustrated in figure 2b. In order to ensure data logging with higher resolution, the data is stored locally on an SD card in the UV sensor unit. The data is transferred later with lower resolution to a cloud server for visualization and data manipulation.

4. Results and discussion
The solar UV radiation passes through a dynamic atmospheric filter and is subjected to the effects of multiple reflection and absorption mechanisms. Thus, the on-ground UV spectrum is influenced by reflection from atmospheric water droplets and by UV-absorbing aerosols, including regional-scale aerosols associated with smog generated ozone and plumes of burning biomass (soot). Stratospheric ozone is another important factor (20 – 50 km above sea level); it is produced by a series of reactions between molecular oxygen O₂ and singlet oxygen O in the presence of N₂ and high energy UV-C radiation (< 242.2 nm or 5.11 eV). It is postulated that, if normally distributed, the stratospheric ozone absorbs nearly all of the UV-C radiation. However, the recent UV measurements by our group revealed abnormal behavior and exceptionally high daily UVI peaks at high-altitude locations in Rila Mountain (BG).

At first, exceptional UV peaks (UVI > 12-15) were observed at BEO-Moussala (2925 m), as can be seen at figure 2b. The highest UVI values were observed in partially cloudy days.

Figure 2. UV index value measurements at BEO Moussala on June 30, 2019, and on July 01, 2019.
According to our observations, the additional UV component is the result of optical reflection from the rounded edges of solid clouds, rather than of “lenses” effect of clouds, as illustrated in figure 3.

The cumulative effect of the UV irradiation in the presence of dispersed clouds with vertical development (as measured on 30 June) exceeds by 15% the relevant UVI values under clear sky conditions, (measured on the next day, 01 July). Stratocumulus and cumulus clouds could be blamed for the effect. Depending on the accumulated dose, UV irradiation can weaken or enhance the human immune system. Overexposure to UV irradiation in summer contributes to ocular and skin diseases (skin cancer and eye cataracts), while underexposure in winter results in ailments associated with vitamin D deficiency [2].

Secondly, wavelength-dependent dynamic optical filtering appears when vertical motion of air masses occurs. One would expect that in mountainous areas the strong winds and turbulence may contribute to more transparent vertical air channels. The quasi-simultaneous readings of UV-A and UV-B sensors as illustrated in figure 4 a, b, reveal temporal deviations in the peak UV irradiation values depending on the wavelength. The individual narrow wavelength channels and short trigger intervals contribute to distinguishing a “real dynamic UV irradiance picture”. Abnormally low total ozone columns (TOC) have been frequently observed throughout the mid-latitudes of both hemispheres and have been labeled “ozone mini-holes” [3, 4].

The additional UV-C sensor located at the BEO-Moussala station (2925 m) detects the UV-C radiation (240 – 280 nm) incident on the Earth surface, as can be seen in figure 4a. This implies that in short temporal intervals the higher energy UV-C component is not absorbed fully by the atmospheric ozone. As presented at figure 4, quasi-simultaneous measurements in the UV-A, UV-B and UV-C ranges reveals the optical absorption’s dynamic behavior. It is interesting to mention that at the altitude of 2925 m during daytime UV-C peaks exist aside from the UV-A and UV-B peaks.

Using the ThingSpeakTM application, comparative measurements were performed of the solar UV irradiation data streams at BEO Moussala and NAO Rozhen locations. The application was chosen because with MATLAB analytics inside ThingSpeak one can write and execute MATLAB code to perform preprocessing, visualization and analyses. Two different channels are used to store data sent from two Wi-Fi UV sensor units. Screenshots of visualized sensors data are presented at figure 5 and figure 6.
Figure 5. UV data streams from BEO Moussala for a day with partial clouds (12 July 2019).

Figure 6. UV data streams from NAO Rozhen for a full-cloudy day (02 August 2019).

The direct day-by-day comparison of the UV irradiation shows a UVI value in NAO-Rozhen lower by approximately two points compared to the BEO-Moussala measurements. These findings cannot be attributed only to Rozhen location’s lower altitude, or to the presence of different cloud formations; one should account for the existence of thick forests, i.e., the higher oxygen generation leading to a
higher local tropospheric UV absorption. This hypothesis is partially confirmed by the simultaneous comparative UV measurements in Sofia city and at Belogradchik Observatory (figure 7). At lower altitudes in an urban area or in rocky cliffs surroundings, the UVI is higher due to a polluted or a thinner oxygen layer. Probably, oxygen produced by forests plays a positive role for UV protection of humans in mountainous areas.

![Figure 7. UV data streams from Belogradchik Observatory for a cloudy day (12 August 2019).](image)

5. Conclusions
The lower atmospheric layers were investigated as a dynamic UV optical filter at high-mountain sites. The rapidly changing atmospheric conditions result in consecutive dramatic fluctuations in the UV irradiation. Not only “passing clouds”, but also the wind speed are factors contributing to the UV absorption. Clouds with expressed vertical structure enhance the reflection of UV sunlight on the cloud edges. A 15% increase in the UV index and, correspondingly, in the UV-A and UV-B irradiation, were registered in partially cloudy days in comparison to representative clear-sky days. Unexpectedly, UV-C irradiation was detected at Moussala peak. The existence of UV-C radiation incident on the Earth surface raises also the question of adequate actions to alleviate the effects of the damaging UV radiation. Currently, erythema action spectrum, 295 nm to 320 nm peaking near 305 nm is accepted for the calculation of the UV index [5], but the UV-C radiation is not included. The data collected is intended to be of assistance in seeking a correlation between the UV fluctuations and the clouds’ shape using artificial intelligence and machine learning.

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References
[1] Vergara E J, Prihodko M and Nadjm-Tehrani 2013 e-Energy S 289-90
[2] Stamnes K and Stamnes J 2008 Transport of Solar Radiation through the Atmosphere: Aspects relevant for Health, Solar Radiation and Human Health The Norwegian Academy of Sciences and Letters
[3] Newman P A, Lait L R and Schoeberl M R 1988 Geophys. Res. Lett. 15 923–6
[4] James P 1998 Int. J. Climatology 18 1287 – 1303
[5] McKinlay A F and Diffey B L 1987 CIE Journal 6 17-22