Chapter 24
BEO Moussala: Complex for Environmental Studies

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Abstract The main areas of research at the Basic Environmental Observatory (BEO) Moussala, Rila Mountain, are the aerospace and terrestrial environment. The interactions between cosmic rays and the Earth's atmosphere, global change parameters and climate research, and natural hazards and technological risks are the objectives of the investigations.

Real-time measurements of basic parameters of space and atmosphere are carried out. The information is transmitted via a high-frequency radio-telecommunication system to the Internet and is stored in a database for further analysis within GAW, EURDEP, EUSAAR (ACTRIS), RECETOX, and UNBSS international networks.

On-line data and detailed information about BEO Moussala are available at: http://beo-db.inrne.bas.bg

In 2014, the scientific research carried out at peak Moussala celebrated its 55th anniversary.

Keywords High mountain observatory • Cosmic ray research • Greenhouse and reactive trace gases • Aerosols • Persistent organic pollutions • Environmental monitoring • Atmospheric processes

24.1 Introduction

The mountainenvironment as a field for climate studies and recently for climate change has become a global issue. The first high mountain research station in Europe, the High Alpine Research Station Jungfraujoch in the Swiss Alps, which was set up in 1932, laid the foundation for a chain of similar research stations.

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The peak Moussala is the highest peak of the Balkan Peninsula: 2925.4 m a.s.l. (42°10′45″N, 23°35′07″E). It is remote from industrial and vehicle pollution. Peak Moussala is reached by both Mediterranean and continental air masses because of its dominant geographic position over a vast area. Therefore, it provides prospects for complex and comparative research of the impact of multiple influences.

BEO Moussala (Stamenov et al. 2007) was built as a facility with a modern infrastructure and all basic appliances for scientific investigation. Local and long-range air transport (fine and ultrafine aerosols, coarse particles, and gas pollutants), gamma-ray background, climate change, and cosmic rays—all these phenomena are monitored. Data for 38 substantial atmospheric and space parameters are stored in a database for retrospective analyses and modeling.

Real-time data are provided via the local measurement system and the telecommunication system to the database.

24.1.1 Climate Notes

The peak Moussala is the coldest place in Bulgaria. Positive average temperatures occur for about 3 months annually. The average wind speed is one of the highest in Bulgaria. The absolute humidity is very low but the relative humidity is high (Table 24.1).

24.1.2 The Station Chronology

1959: Cosmic Ray Station was set up on peak Moussala
1983: Cosmic Ray Station destroyed by fire
1993: French-Bulgarian integrated project OM2 was started for monitoring and management of high mountain ecosystems
1999: Cosmic Ray Station was reconstructed and renamed the Basic Environmental Observatory Moussala
2002: BEO Moussala given Centre of Excellence Award
2003: BEO Moussala attained ISO certification
2007: BEO Moussala became a Pan-European Research Infrastructure
2010: BEO Moussala became a Regional GAW station

Table 24.1 Basic meteorological parameters

Meteorological parameter	Value
Annual mean temperature	−3.1 °C
Prevailing wind direction[a]	N–NE
Monthly mean wind speed	4.9–10.5 m/s
Annual mean wind speed	7.5 m/s
Annual mean rainfall	1000–1300 mm

[a]BEO measurements (2003–2014)

The idea of constructing a Cosmic Ray Station on the peak Moussala was proposed by the prominent Bulgarian scientist Acad. G. Nadjakov and the famous Hungarian physicist Acad. L. Yanoshi. It was realized in 1959. The Bulgarian School of Cosmic Rays was developed during a long period of productive common scientific work with the Hungarian group of physicists. The names of the leading scholars Prof. L. Mitrani, Prof. N. Ahababyan, Prof. I. Kirov, and Prof. J. Stamenov stand out in this group. Unfortunately, in 1983 the Moussala Cosmic Ray Station was destroyed by fire.

The station was rebuilt in 1999 with the financial support of the Bulgarian Ministry of Environment and Water and has become a modern research facility. The measurements restarted, keeping up the tradition in cosmic ray research and adding environmental monitoring via the French-Bulgarian project OM2 (funded by the French Ministry of Exterior and Centre National de la Recherche Scientifique).

From 2003 BEO Moussala was certified by ISO 9001 "Quality Management" (No. 3312/0) and ISO 14001 "Environmental Management" (No. 357/0).

In July 2007 BEO Moussala was validated by EC and European Science Foundation (ESF) survey as Research Infrastructure (# 563) of pan-European importance.

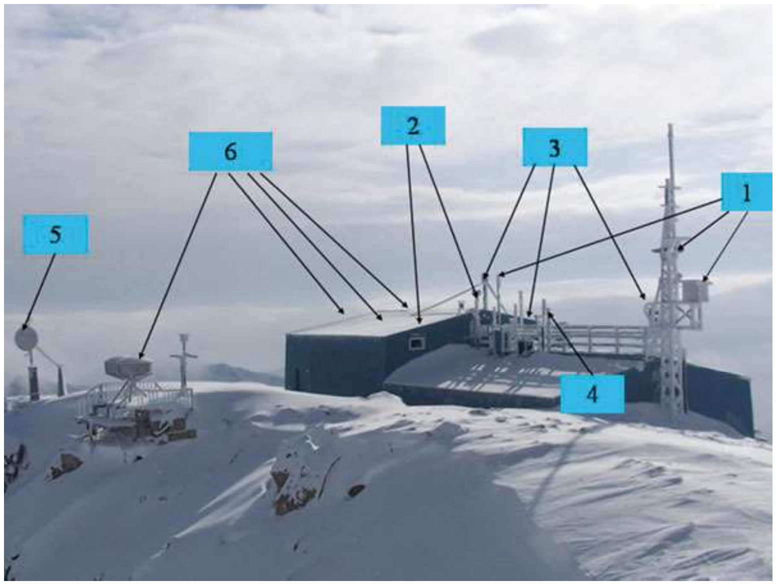
The technological status of the Observatory was improved substantially consequent to the successful implementation of the HIMONTONET FP5 and BEOBAL FP6 projects. The participation in FP6 EUSAAR and ACCENT projects has created the basis for further development of applied monitoring methods. BEO Moussala received the Center of Excellence Award in 2002. For its unique location in Eastern Europe, as well for the high-quality measurements it carried out, the station was accepted as a Regional Station (2010) in the GAW network. A team of physicists, engineers, and technicians came together and contributed to the scientific findings at BEO Moussala.

The main feature of BEO Moussala station, after this long history and experience, is its complexity: from cosmic rays investigation to high-mountain monitoring and environmental research.

24.2 Environmental Measurements at BEO Moussala

The aerosols, the greenhouse gases, reactive trace gases, and persistent organic pollutants (POPs) are responsible for the radiation forcing of the atmosphere and hence they affect the climate. The precise measurement of these parameters is the main objective of BEO Moussala and provides prospects for climate change studies.

The measurement systems at BEO Moussala (Photograph 24.1) were basically set up in the period 2003–2007 in the frame of the EC projects. Some new devices (SMPS, SEVAN) were installed in 2008 and 2009 (see the following text). Since the beginning, the automatic measurement equipment has been connected to a local network, and the telecommunication system BEO-INRNE has provided real-time data to the Internet.



Photograph 24.1 BEO Moussala measurement station. *1* Automatic Weather Station (Vaisala), *2* atmospheric gas analyzing system (Environnement S.A.), *3* aerosol measurement system (TSI, Itf-Leipzig), *4* gamma background measurement (Technidata), *5* telecommunication system (2.4 GHz) INRNE-BEO, *6*Cosmic Rays Research Systems

Since December 2013 a new international project has been launched, with more than 20 participants, including BEO Moussala (BACCHUS: Impact of Biogenic versus Anthropogenic emissions on Clouds and Climate: toward a Holistic UnderStanding). Also an agreement was signed to participate in another international project involving a network of high mountain observatories named VAO-II (R & D): Trends of greenhouse gases and aerosols, and spatiotemporal deposition of persistent environmental pollutants (TP I/02), launched in May 2014.

24.2.1 Vaisala Automatic Weather Station (AWS)

The Vaisala AWS has been operating since August 2003. It is equipped with basic sensors for air temperature and relative humidity, atmospheric pressure, wind speed, wind direction, and precipitation. The AWS provides important information for atmospheric conditions for the other systems. The sensor collector transmits the

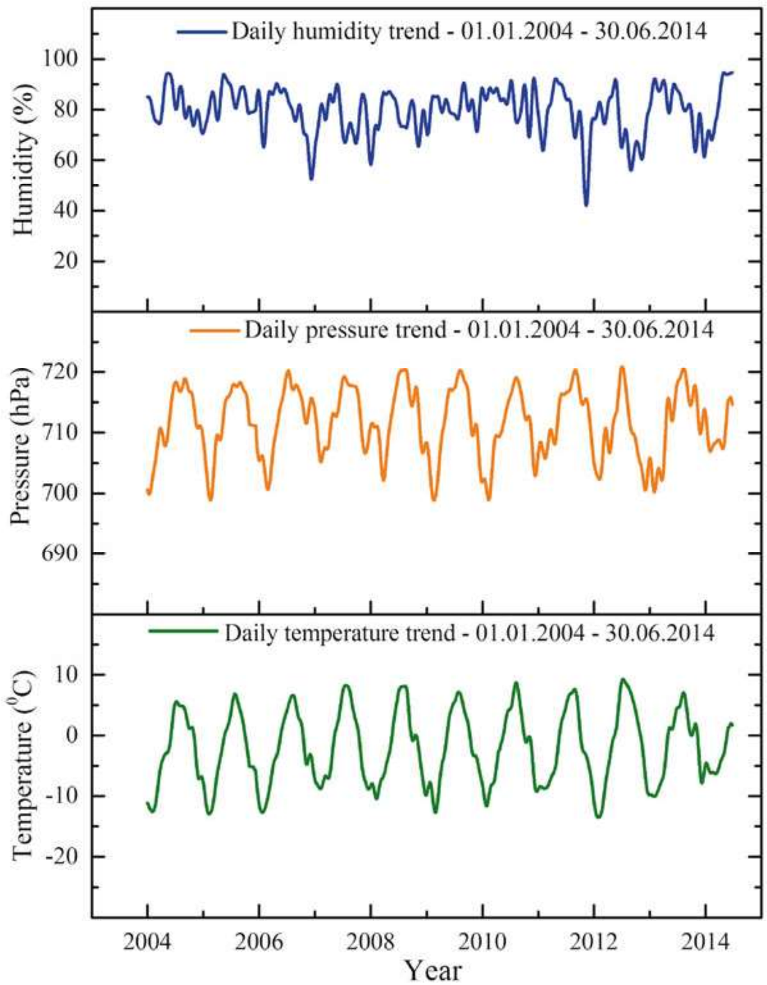


Fig. 24.1 Seasonal variation of meteorological parameters at the Basic Environmental Observatory (BEO) Moussala, 2004–2014

data to the computer. Data acquisition and transfer repeat every 10 min. The AWS is designed for heavy weather conditions. Figure 24.1 shows the trends from 2004 to 2014. Wind rose data up to 2014 show that the prevailing wind direction was north-northeast (Fig. 24.2).

A new color camera rotating 360° is installed at the station to view cloud cover on the peak.

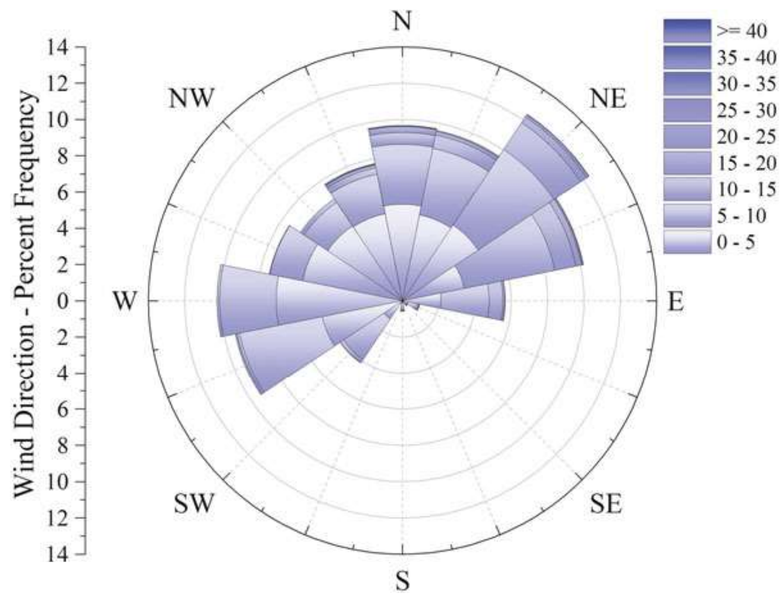


Fig. 24.2 BEO Moussala wind rose, 2004–2014

24.2.2 POPs Passive Air Sampling

Since 2009, passive air samplers (Photograph 24.2) have been installed in the frame of the international project MONET (MOnitoring NETwork) for measurement of POP compounds in the ambient air. This network has been organized by the Research Centre for Toxic Compounds in the Environment (RECETOX), Masaryk University, Brno, the Czech Republic, where the collected filters are analyzed.

Because of their harmful effect on the environment and human health, it is important to monitor pollutant origin and air transport over Europe. The passive air samplers consist of two protective stainless-steel hemispheres with different diameters (30 and 24 cm) mounted on a common axis, with a filter mounted on the equatorial plane between them. The air flows freely in the opening between the spheres and through the filter, with the pollutants being trapped within it. The filters are made of white polyurethane foam (PUF) with a density of 0.030 g cm^3 (type N 3038; Gumotex Breclav, the Czech Republic) acting as a sorbent. The filters are of circular shape, 15 mm thick, with a diameter of 150 mm.

Passive sampling yields information on the long-term pollution at specific locations (Pribylova et al. 2012; Klanova et al. 2006) and is thus a suitable tool for estimating the spatial and temporal variations and trends of the POPs atmospheric concentrations. Polyaromatic hydrocarbon (PAH) levels in the atmosphere are presented in Fig. 24.3.

Photograph 24.2 Passive air samplers at BEO Moussala

24.2.3 Atmospheric Gas Analysis System

Greenhouse and trace gases measurements, which are important for climate change investigation, are performed by an atmospheric gas analyzing system (Table 24.2). BEO Moussala was named a regional GAW Station in 2009 and provides data from the gas analyzers and from the meteorological measurements to WDCGG (http://gaw.kishou.go.jp/wdcgg/). The first results of ozone data analyses were published, showing a possible method for pollutants tracking.

24.2.4 BEO Moussala Aerosol Measurement and Devices

Scattering and backscattering coefficients of aerosols and aerosol size distribution are measured by integrating the Nephelometer and Scanning Mobility Particles Sizer (SMPS).

24.2.4.1 Scanning Mobility Particles Sizer

The SMPS is a spectrometric scanning measurement system for fine and ultrafine particles that was put into operation in November 2008. The measurement range is from 10 nm to 1 μm (Fig. 24.4). Its sensitivity and measuring range allow measuring

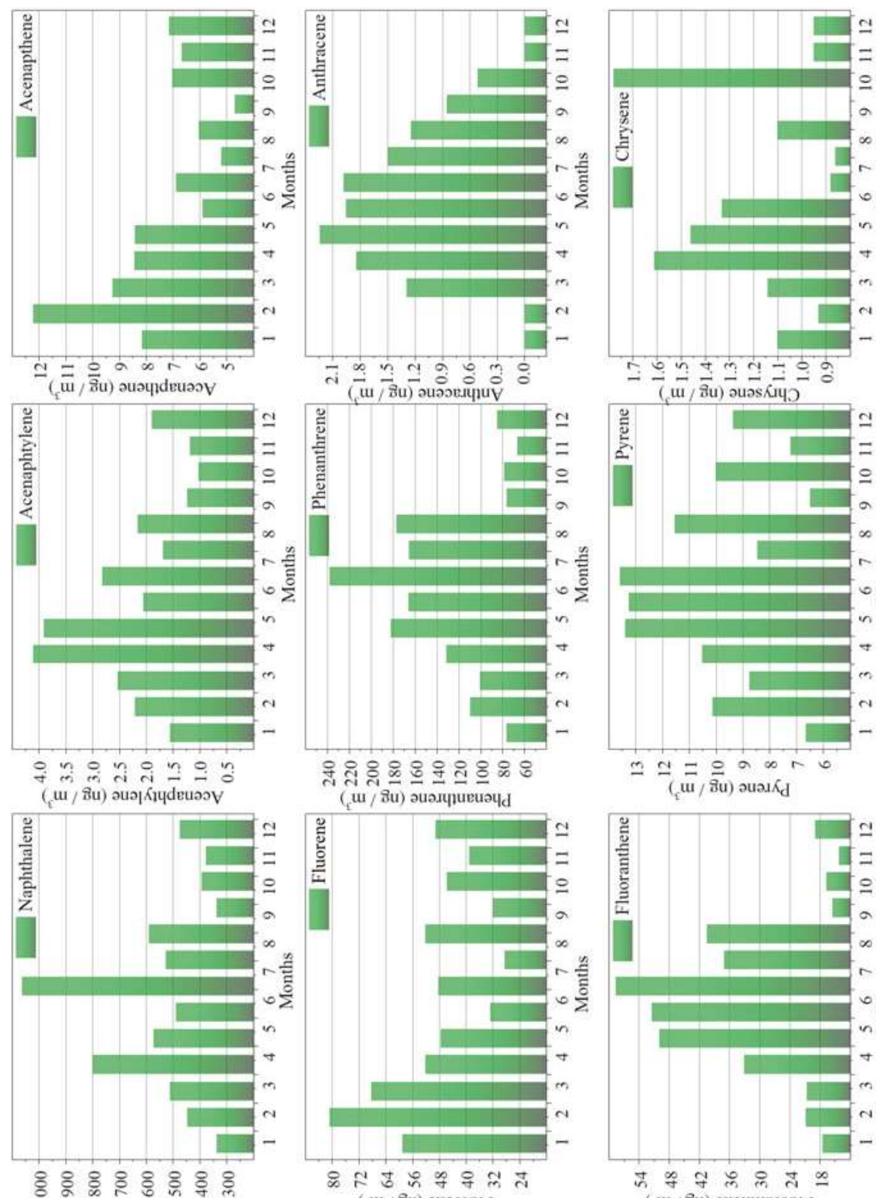


Fig. 24.3 Seasonal variability of polyaromatic hydrocarbons (PAH) levels in 2009–2011 (ng/m^3)

Table 24.2 BEO Moussala gas analyzers

Gas	Device	Measurement range
NO	AC32M	NO-NO_2-NO_X from 0.4 ppb to 20 ppm
CO	CO12M	CO from 50 ppb to 200 ppm
SO_2	AF22M	SO_2 from 0.5 ppb to 10 ppm
O_3	O342M	O_3 from 0.4 ppb to 10 ppm
CO_2	CO12M	CO_2 from 1 ppm to 2000 ppm

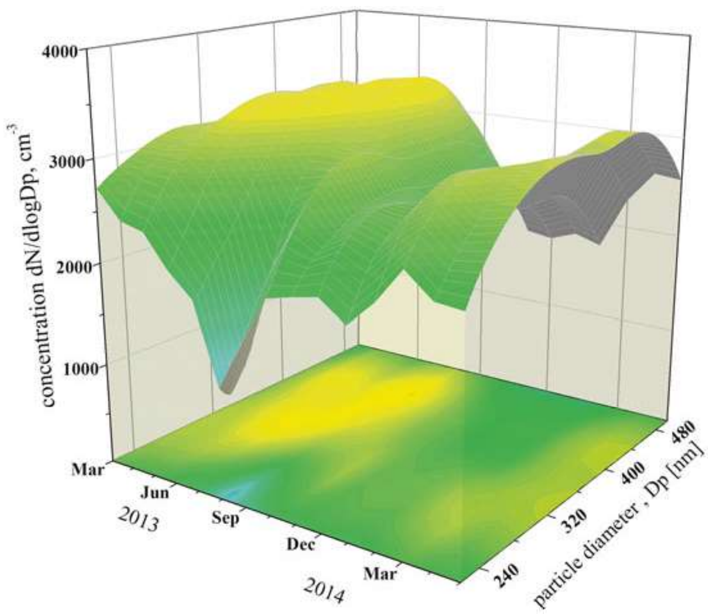


Fig. 24.4 Seasonal aerosol size distribution at BEO Moussala, 2004–2014

of the most sensitive part of the atmospheric composition, subject to local and distant pollutants.

24.2.4.2 Nephelometer TSI 3563

The TSI 3563 is a measurement device for scattering and backscattering coefficients of ambient aerosols/pollutants. It was put into operation in March 2007. Light scattering gives precise data for the amount of particulates/dust in the air. TSI 3563 measures at three wavelengths, 450 nm (blue), 550 nm (green), and 700 nm (red), which are sensitive to different particle size scattering and pollutants.

Since June 2012, thanks to the project ACTRIS and a signed agreement for a long-term loan from the GMD division of NOAA, an absorption photometer, CLAP (Continuous Light Absorption Photometer), for real-time measurements was installed at BEO Moussala. CLAP is a filter-based instrument to derive information on aerosol absorption coefficients that indicated increased absorption during the Saharan dust event, March 31, 2013 (Fig. 24.5).

24.2.5 System for Measurements of Radioactivity in Aerosols

The system includes an air turbine, a filter device, a press for preparing the samples for measurement, a Ge spectrometer, and a program for analysis of the gamma spectra. All these components have been developed in INRNE. The air turbine allows 1500–1800 m^3 per hour to pass through the fiber filter, which is type FPP-15-1.5 with high efficiency, 94–99 %. The filter size is 50×50 cm. After sampling, the filter is

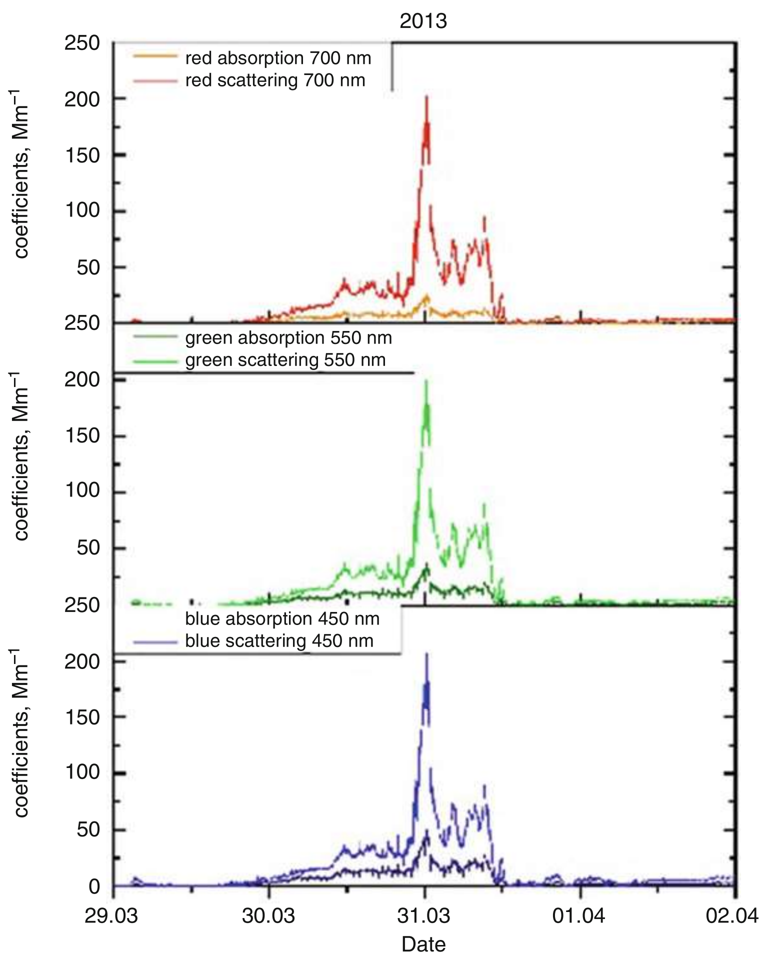


Fig. 24.5 Absorption coefficient during Saharan dust event, March 31, 2013

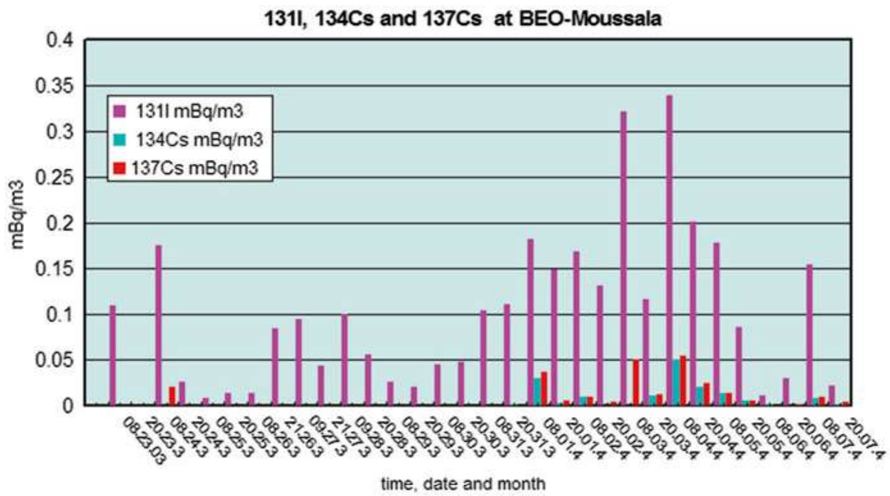


Fig. 24.6 Measured activities of some isotopes from the Fukushima accident at BEO Moussala

compressed to a pill with diameter of 57 mm and thickness of 15 mm. The appearance in the atmosphere of ^{7}Be is a result of a deep spallation reaction as a process of interactions between high-energy cosmic particles with the atmosphere. The quantity of ^{7}Be gives information for a powerful atmospheric process, the intrusion of high atmospheric layers. From the results obtained during recent years, several conclusions can be drawn:

– ^{7}Be integral quantity for a specific place is determined by several factors, mainly by atmospheric processes (including intrusion from stratosphere to troposphere), and changes in the intensity of cosmic rays (solar and galactic).
– ^{7}Be quantity (as a tracer for air mass origin) could serve as additional information for short-term meteorological prognoses

Activity of the U-Th products was detected in the aerosols at peak Moussala, including ^{7}Be, which is a well-known product of the cosmic rays. Typical products of human activity, such as ^{134}Cs, ^{137}Cs, and ^{131}I, were been detected after the Fokushima accident (on 23 March 2011, 2 weeks after the accident) (Fig. 24.6).

24.2.6 BEO Moussala Gamma Background Measurement

24.2.6.1 IGS421B1 Gamma Probe

Ambient equivalent dose rate is measured by the IGS421B1 gamma probe consisting of three Geiger-Muller counting tubes with a sensitivity range from 10 nSv/h to10 Sv/h. Data from gamma-ray background monitoring during the Fukushima accident are shown on Fig. 24.7. This figure shows that the background radiation is within acceptable limits.

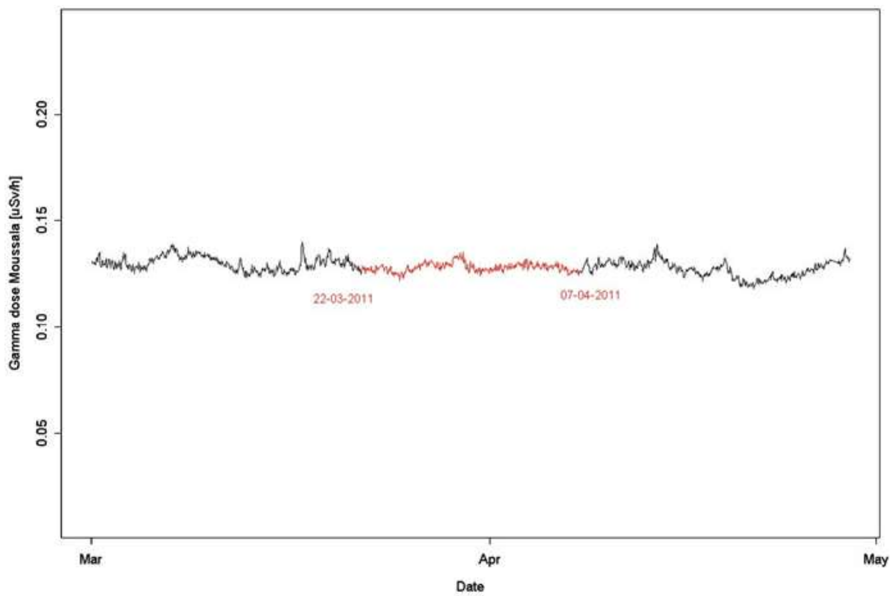


Fig. 24.7 Gamma-ray background near Moussala peak during the Fukushima accident

24.2.6.2 Online Measurement of the Spectrum of Gamma Rays at Moussala Peak

An Na(I) spectrometer was installed in BEO Moussala for online measurement of the spectrum of gamma rays in the air at peak Moussala. The size of the detector is ~ф50 × 50 mm, energy resolution ~8–10 %, and measured interval of gamma rays 100–6500 keV. Using such an energy interval it is possible to observe the main isotopes of natural and human-origin radioactivity, including those possible from nuclear accidents. At the same time the background of cosmic gamma rays with energy 2800–6500 keV is also monitored. All systems work automatically, and every 2 h one spectrum is recorded. The measurements could be controlled, changed, and observed from everywhere by means of the Internet with a program for remote management. A typical spectrum is shown in Fig. 24.8.

The intensities of gamma rays at 609 keV, 1120 keV, 1764 keV, and others, which arise from the daughter nuclei of ^{222}Rn, manifest changes with time. There are two possibilities for such behavior: the first could be seasonal fluctuation, and the second is possibly some connection with seismic activity. The continuous background of cosmic gamma rays in the interval 2800–6500 keV also has some changes in intensity. There are possible connections with astrophysical processes in space or in the upper layer of the atmosphere. More long-term monitoring, about 2 to 3 years, and comparison with data from other devices at BEO-Moussala will help to clarify an explanation of the observed phenomena.

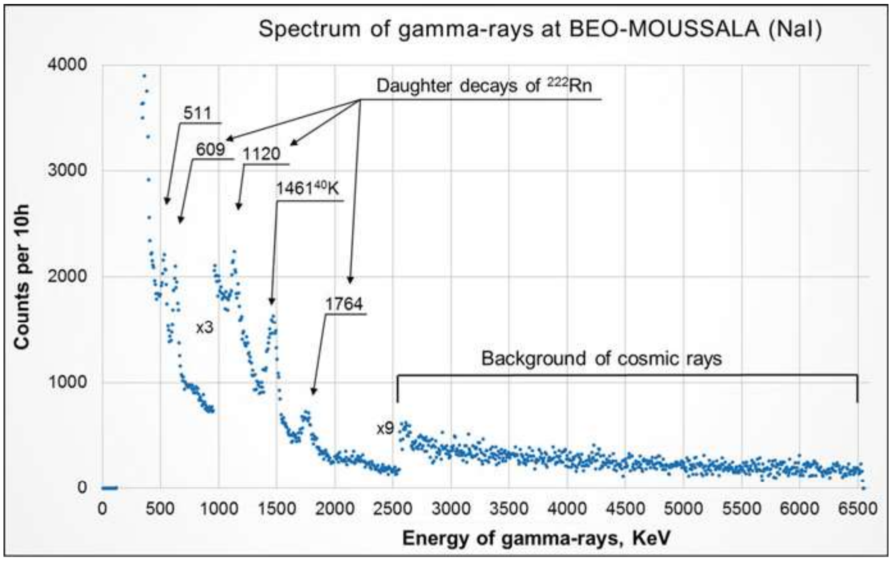


Fig. 24.8 Typical spectrum of gamma rays at BEO Moussala (NaI)

24.3 Cosmic Ray Research at BEO Moussala

24.3.1 Muon Telescope

The telescope has been operating since August 2006. It has a surface of 1 m^2 and an energy threshold of 0.5 GeV. The time variations of cosmic ray muon flux are measured continuously in five directions. Connecting the instrument to the existing networks (Neutron Monitors and Muon Detectors Network) for cosmic rays and space weather studies, after the upgrade of the data acquisition software, is planned. These data are also used for probable correlations research between cosmic ray (CR) intensity and environmental parameters.

As a new beginning of the old cosmic rays station, the first observations of space weather were performed in 2012. This event coincided with the period of the most active solar activity since the Muon telescope became fully operational, as a part of the current 24th solar cycle observations. There are registered Forbush events with different magnitude, caused by particle flux decrease resulting from the impact of solar flares and arrival of cosmic mass ejections (CMEs) on modulation of galactic cosmic rays. The time of arrival and extreme values of the largest Forbush events detected with the Muon telescope and SEVAN are shown in Table 24.3.

The biggest challenge for BEO Moussala is to complete uninterrupted and precise measurements with both detectors, the Muon telescope and SEVAN, until the end of the current 24th solar cycle and to extend observations beyond it into the next cycle. For this purpose, a full maintenance and data acquisition system upgrade of the Muon telescope was completed in August 2013 (Tchorbadjieff et al. 2012).

Table 24.3 List of the largest Forbush events, detected on Moussala in 2012

Event began: time in hours UTC	Time of extreme hours UTC	Magnitude of extreme (%)	Solar event
24.01: 16:00	24.01: 21:16	4 %	M8/2b flare
08.03: 11:30	08.03: 22:35	5+ %	X5/3B flare
12.03: moon	13.03: 01:38	3 %	M8 flare
23.04: evening	26.05: 03:50	4 %	C-Class CME
04.09: 01:00	05.09: 00:34	2.5+ %	M1 and C8/2f flares
31.10: 17:00	01.11: 15:26	2 %	B9/Sf flare + 2CMEs

24.3.2 SEVAN

This cosmic ray detector is a part of the developing SEVAN network (until now including Armenia, Bulgaria, and Croatia). The SEVAN detector and the network have been developed in the CRD–YPI as an element of the Instrument Development Program for the International Heliophysical Year.

One of the major advantages of this multi-particle detector is probing of the different populations of the primary cosmic rays, which initiate particle cascades in the terrestrial atmosphere. Fluxes of neutrons and gammas, charged components of low energy, and high-energy muons are measured by a basic detector of the SEVAN network. This diverse information provides the opportunity to estimate the energy spectra of the highest energy solar cosmic rays and distinguish very rare events of direct solar neutron detection.

24.4 Cosmic Rays and Climate

The influence of CRs on the climate was suggested lately as a topic in many scientific reports as explaining the variations in the climate through the processes of the cloud cover formation.

One of the main features of BEO Moussala is complex research of cosmic and environmental parameters. The correlation between CRs and the initiation of lightning is recently being investigated (Chilingarian et al. 2009; Erlykin et al. 2010; Gurevich and Zybin 2002; March and Svensmark 2000; Ney 1959; Svensmark and Friis-Christensen 1997; Stozhkov 2003).

Data obtained from the new device, the BOLTEK EFM-100 Atmospheric Electric Field Monitor, could be used for research on the relationship between the intensity variations of cosmic rays and thunderstorms (Fig. 24.9).

Figure 24.9 shows the measured values of normal, high, and very high electric fields, and the moment of the thunder event.

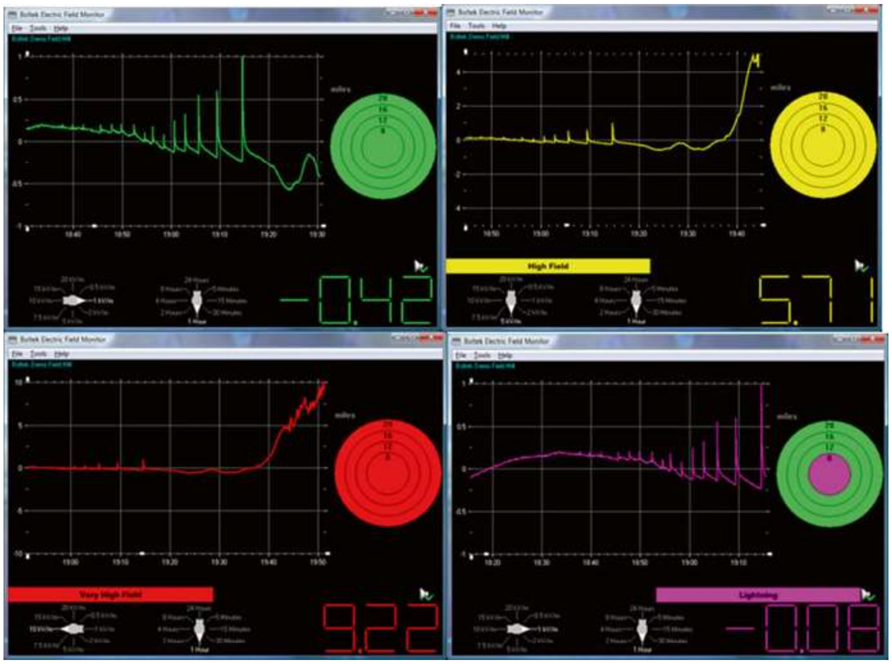


Fig. 24.9 BOLTEK EFM-100 Atmospheric Electric Field Monitor

24.5 Telecommunication and Information System INRNE-BEO

The main task of the telecommunication system is to collect, transmit, and archive the measured data in the SAP database (MaxDB), which is enlarged by the following:

- Stored data retrieval in accordance with the needs and permissions of the users
- Packing/unpacking
- Compressing/decompressing
- Raw data processing for visualization and presentation in human-readable format

The information system is a complex software system providing data flux control, data storage, and data quality control. In state of implementation is the Data Acquisition Quality Assurance System (DAQAS). The system was developed in the UFS Zugspitze GAW station for improved data flow control and calibration processes.

24.6 Conclusion

The peak Moussala is an important reference point for assessment of anthropogenic influences in the large Southeast European region. BEO Moussala is a facility with modern infrastructure for scientific investigations. Data for 38 parameters are stored for real-time retrieval, retrospective analyses, and modeling.

The BEO Moussala is a research complex, and data quality is an issue that remains focus needing persistent and continuous efforts.

The devices for cosmic rays research, the AWS, and the gas and aerosol measurement systems allow carrying out precise study of atmosphere parameters and cosmic rays. The connection between the atmospheric events and cosmic ray flux is a prospective field for investigation.

The BEO Moussala information system including the measurement systems, the high-frequency telecommunication system, and the database can be used in situ or by remote access by the international scientific community.

The BEO Moussala has a long tradition as a high mountain scientific facility, and its future mostly depends on the process of scientific collaboration and integration in the global research area.

The study of high mountain environmental parameters (meteorology, atmospheric physics and chemistry, background radiation, and cosmic rays) measured at BEO Moussala provides the possibility for complex evaluation of anthropogenic and biogenic impacts on the climate.

Acknowledgments BEO "Moussala" is one of the four mountain observatories in Europe at this altitude and unique in its southeastern part. It was established by the large international projects BEOBAL, EUSAAR, and ACTRIS, and is supported by the Bulgarian Ministry of the Environment and Water.

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