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Ultraviolet and infrared emission from lightning discharges observed at Aragats

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Abstract. The ultraviolet and infrared optical sensors previously used at RELEC space missions were installed at the high-altitude research station Aragats at 3200 m above the sea level. The spectral composition and temporal structure of the recorded optical signals and measurements of the electrostatic field and atmospheric discharges obtained by "fast" and "slow" field sensors have been compared. Measurements of lightning and related to them phenomena observed at the mountain altitude and on board of orbiting satellites are compared.

1. INTRODUCTION

The thundercloud electrical structure and its evolution during thunderstorm have not been yet described and classified. The thunderstorm dynamics, lightning initiation, and electron acceleration in the cloud, multiple atmospheric discharges and their optical counterparts have to be measured simultaneously, and a non-trivial correlation in the measurements can shed light on the underlying physical models.

The discovery of the so-called transient optical phenomena in the upper atmosphere observed between thunderclouds and ionosphere increased the interest to the study of the electric discharges in the electric circuit formed in the cloud - ionosphere-near earth space. To study the properties of the electric discharges and their interaction with particle fluxes, it is necessary to perform measurements within a single storm system at the mountains. A low elevation of the clouds allows to locate sensors just inside the cloud during a thunderstorm.

On the other hand, to observe the global phenomena of thunderstorms we need sensors located on board of satellites having a polar orbit. These two methods of surface and space research complement each other. Studies at the mountains have the advantage to be in close proximity to the thunderclouds where the electric charge is accumulated and distributed and very complicated processes of the self-organizing of discharges are triggered. Such measurements are performed at Aragats Space Environmental Station (ASEC, Chilingarian et. al., 2005) of the Yerevan Physics Institute with the help of a broad variety of particle detectors that measure the neutral and charged particle fluxes, also using field meters, weather stations and lightning detectors. The data collected on numerous nearby thunderstorms accompanied by huge particle flux enhancements (so-called Thunderstorm ground enhancements, which are the subject of the study at Aragats station, Chilingarian et al., 2010 and 2011) can be useful for the analysis of the global data obtained from satellites, which are far above the thunderstorms.

2. DETECTOR FOR UV AND IR EMISSION AND DETECTORS OF ARAGATS COSMIC STATION USED FOR JOINT OPTICAL AND TGE MEASUREMENTS.

The measurements of the transient optical flashes were performed by a detector of ultraviolet and red-infrared emissions (DUVIR), which contains of UV (wavelength 240-380 nm) and IR detectors (wavelength, 610-800 nm) (Garipov et al., 2006). R1463 photomultipliers with a multialkali photocathode and an ultraviolet glass window have been used as photo sensors of ultraviolet and infrared radiation. The bandwidth in the ultraviolet region of the photomultiplier is limited by filter UFS-2; in the infrared region - by filter KS-11 with a thickness of 2.5 millimeters each. Crosstalk between IR and UV sensor signals is less than 0.05 percent. Crosstalk between UV and IR sensor signals is less than 1 percent. Selected were such multialkali photocathodes which could maintain their parameters over a wide range of illumination of the atmosphere, day and night, and also maintain stable sensitivity for a long exposure time. The block diagram of the detector electronics is shown in Fig.1.

The signals from the photomultiplier are amplified by the charge-sensitive preamplifiers with an integration time of ~20 microseconds and fed to the 2-input multiplexer with a switching frequency of 0.5MHz. The output signals from the multiplexer and ADC are transmitted to the programmable logic FPGA unit. This unit selects useful events, implements the scientific program algorithms, performs PMT gain control, and transmits the useful information to an on-line PC. The selected events are recorded in a waveform that is comprised of 256 measurement points each with duration of record time of 128 milliseconds. A waveform of a signal with the largest amplitude is selected every 20 seconds and transmitted to the PC for further processing. Adjustable high voltage power supply provides tuning of the PMT high voltage supply in a way to keep the average current in the middle of the dynamic range of the ADC under all expected levels of the illumination of the atmosphere.

The selected time constant of the automatic adjustment of the high voltage is a few seconds which is considerably larger than the duration of the expected signals, so that the PMT gain remains constant during the signal registration.

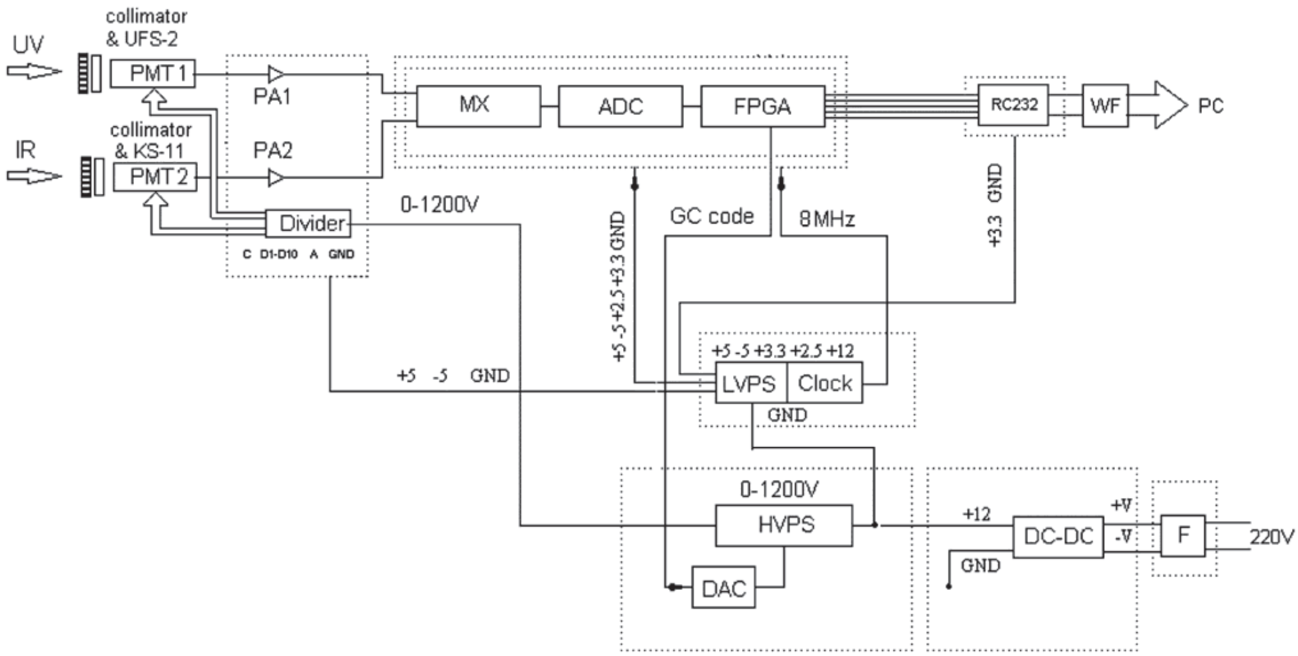

Figure 1. Diagram of the electronics of the DUVIR device.

PMT 1 and PMT 2 are the photomultiplier tubes, PA1 and PA2 - charge sensitive amplifiers, MX - analog multiplexer, ADC- analog to digital converter, FPGA - a logic programmable unit, RS232- communication port, WF- communication line, LVPS- low voltage power supplier, HVPS - controlled high-voltage PMT power supplier, DAC- digital to analog converter for the PMT gain control, DC-DC - common galvanic isolation transformer and circuit of preliminary voltage stabilization, F- noise protection filter

3. DETECTION OF UV AND IR RADIATION AT ARAGATS STATION AND ON BOARD OF VERNOV SATELLITE.

On 15 June 2015 at 18:00 -18:48 a huge storm with numerous lightnings occurred above the Aragats station. The electric field disturbances were prolonged and deep, reaching -28 kV/m; the lightning activity was strong and some of the lightnings were within 5 km from the station. The network of three EFM-100 electric mills monitored the near-surface electric field. The devices operated according to the “atmospheric electricity” sign convention (a positive electric field at ground is produced by positive charge overhead and negative electric field on the ground is produced by negative charge overhead). Thus, the recorded positive field change corresponds to negative lightning, which decreases the negative charge overhead and negative field change corresponds to positive lightning, which decreases the positive charge overhead. The heavy-duty storm that started at ~18:00 was followed by copious positive lightnings lasting until ~18:45 (Fig. 2). In Fig. 3 (zoomed from Fig. 2) we show the electric field disturbances measured by the electric mills during 10 minutes when the UV and IR radiation was detected by DUVIR device.

The pattern of rapid decrease of the electric field was approximately the same for 3 electric mills located at a maximal distance of ~300 m from each other. The abrupt decrease of the near-surface electric field followed by a relatively slow recovery is an indication for the neutralization of the positive charge in the thundercloud, i.e. the positive lightning. However, the operation of the in-cloud charging engine permanently recovers the positive charge in the thundercloud. After very-well-pronounced 5 positive lightnings at 18:29 – 18:32, another, a negative lightning started at 18:34:90 after a prolonged recovery and continued as a positive one with a very long recovery time. At the same time very strong light flash was registered at the station.

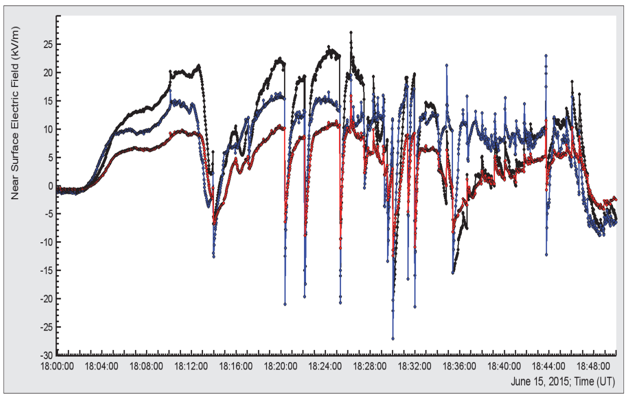

Figure 2. Disturbances of near-surface electrostatic field measured by the network of EFM-100 type electric mills at Mt. Aragats on June 15 2015

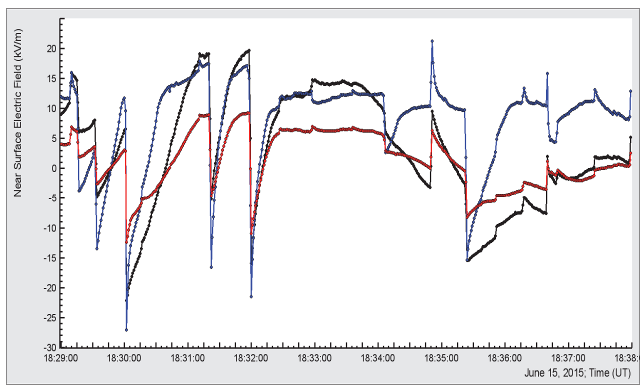

Figure 3. Disturbances of near-surface electrostatic field measured by the network of EFM-100 type electric mills at Mt. Aragats on June 15 2015 (zoomed version of 10 minutes from Fig.2)

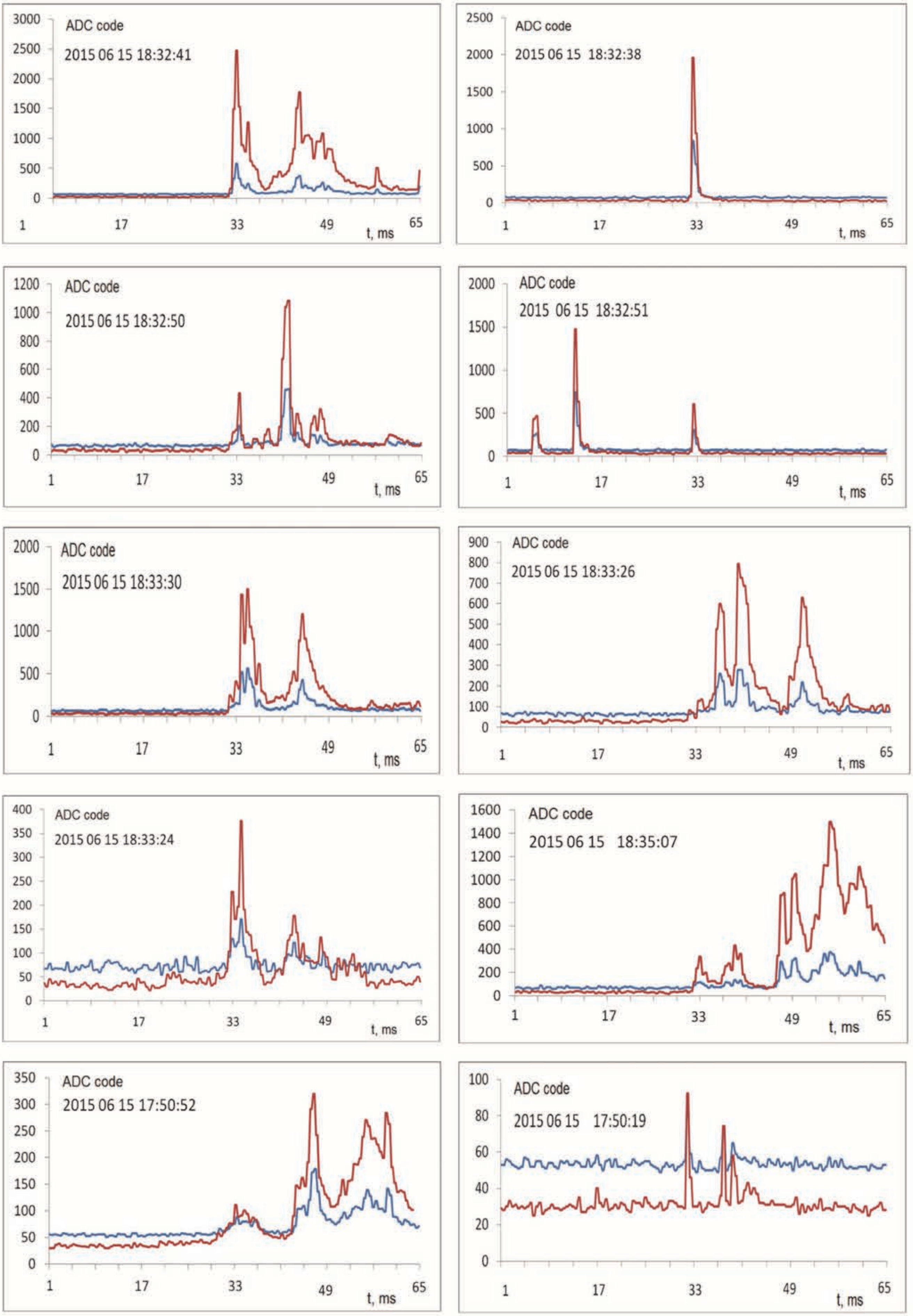

Figure 4. UV and IR radiation from the lightning flashes registered at Aragats station on 15 June 2015

Unfortunately, at that time the on-line computer of DUVIR was not connected to the synchronized NTP computer network of ASEC. That is why we cannot identify each episode of UV/IR radiation with a particular lightning on the millisecond time scale. However, the selected episode of storm shown in Fig. 3 overlaps with the UV/IR radiation peaks.

In Figs. 5 and 6 we show negative and positive lightnings overlapping in time with another episode of intense UV/IR radiation on 4 October 2015 at 16:07 – 17:28.

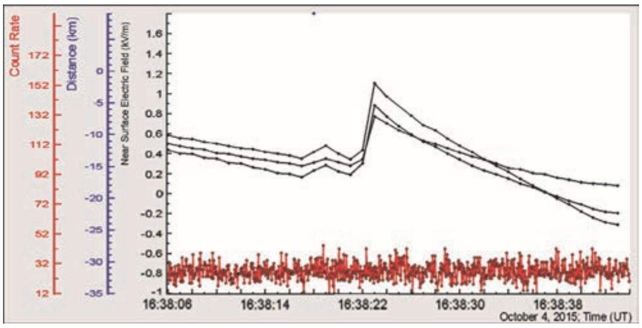

Figure 5. Negative lightning detected by the network of electric mills and particle count rate (at the bottom)

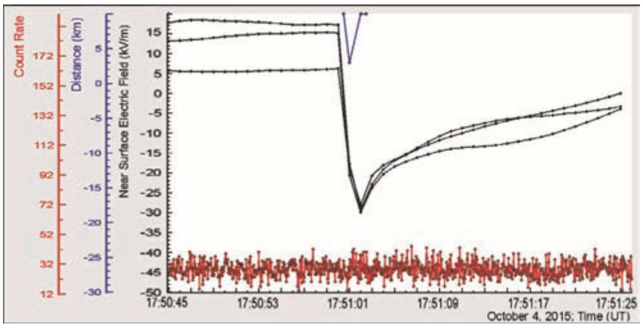

Figure 6. Positive nearby lightning detected by the network of electric mills and particle count rate (at the bottom)

At the bottom of the pictures we show 50-msec time series of count rates of the 1 m^2 plastic scintillator located outdoors at an altitude of 3200 m.

The selected lightnings shown in Figs. 5 and 6 coincide within 1sec with the UV/IR radiation spikes (Fig. 7). In Fig 8. we show zoomed pictures of the fast wave forms registered from atmospheric discharges (see details in Chilingarian et all., 2016) coinciding with one of the episodes of UV/IR radiation.

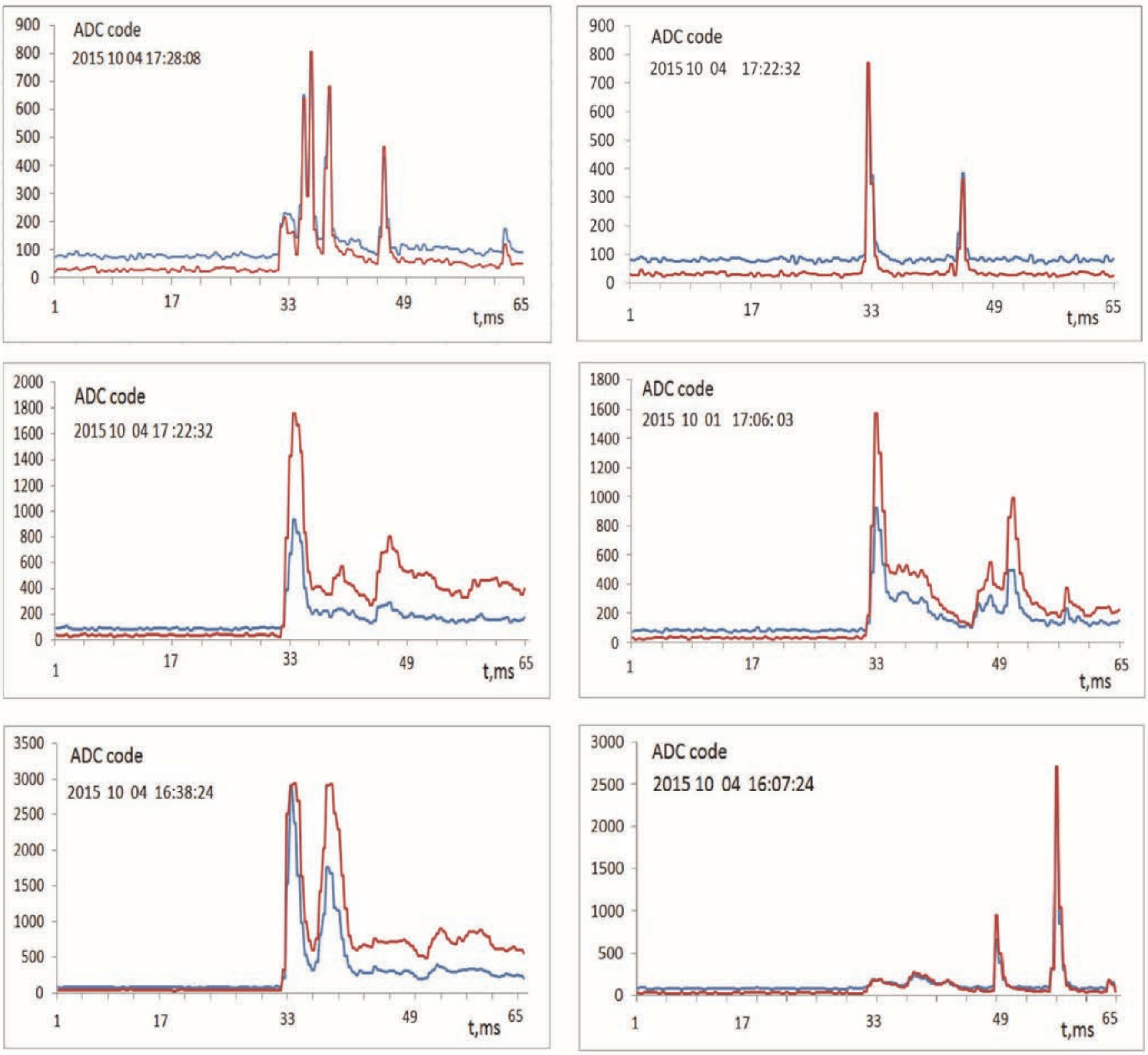

Figure 7. UV and IR radiation from the lightning flashes registered at Aragats station on 4 October 2015

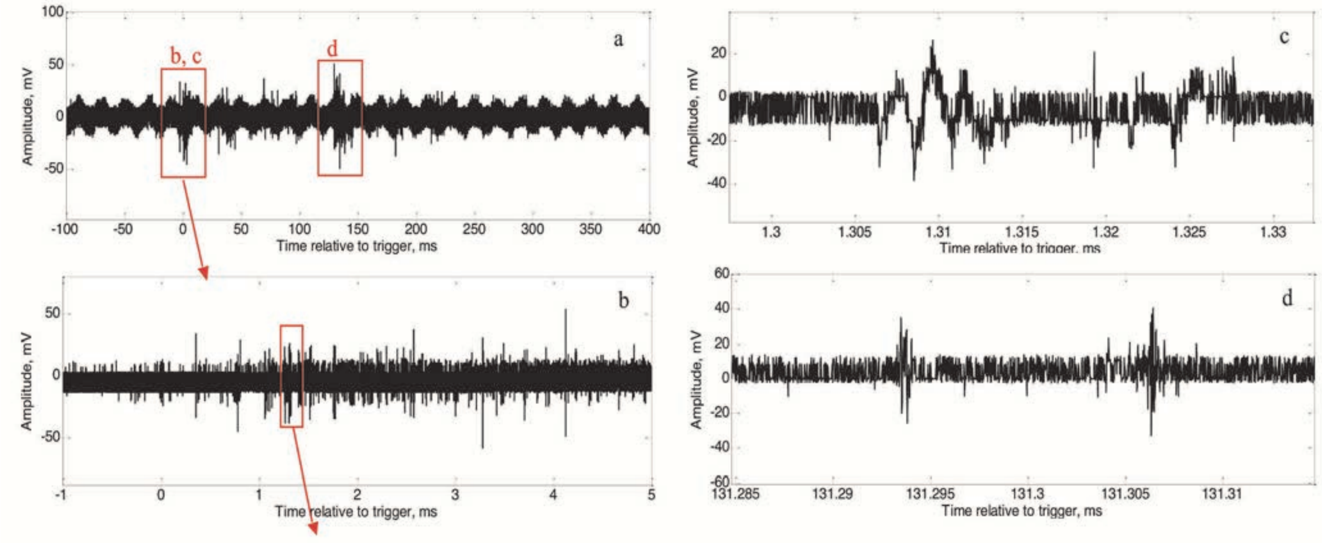

Figure 8. Fast waveforms registered on October 4 2015 at 17:51:01

In Fig. 9 we show UV/IR transient flashes in the Earth's atmosphere registered by the DUVIR device on board of Vernov satellite (Garipov et all., 2015).

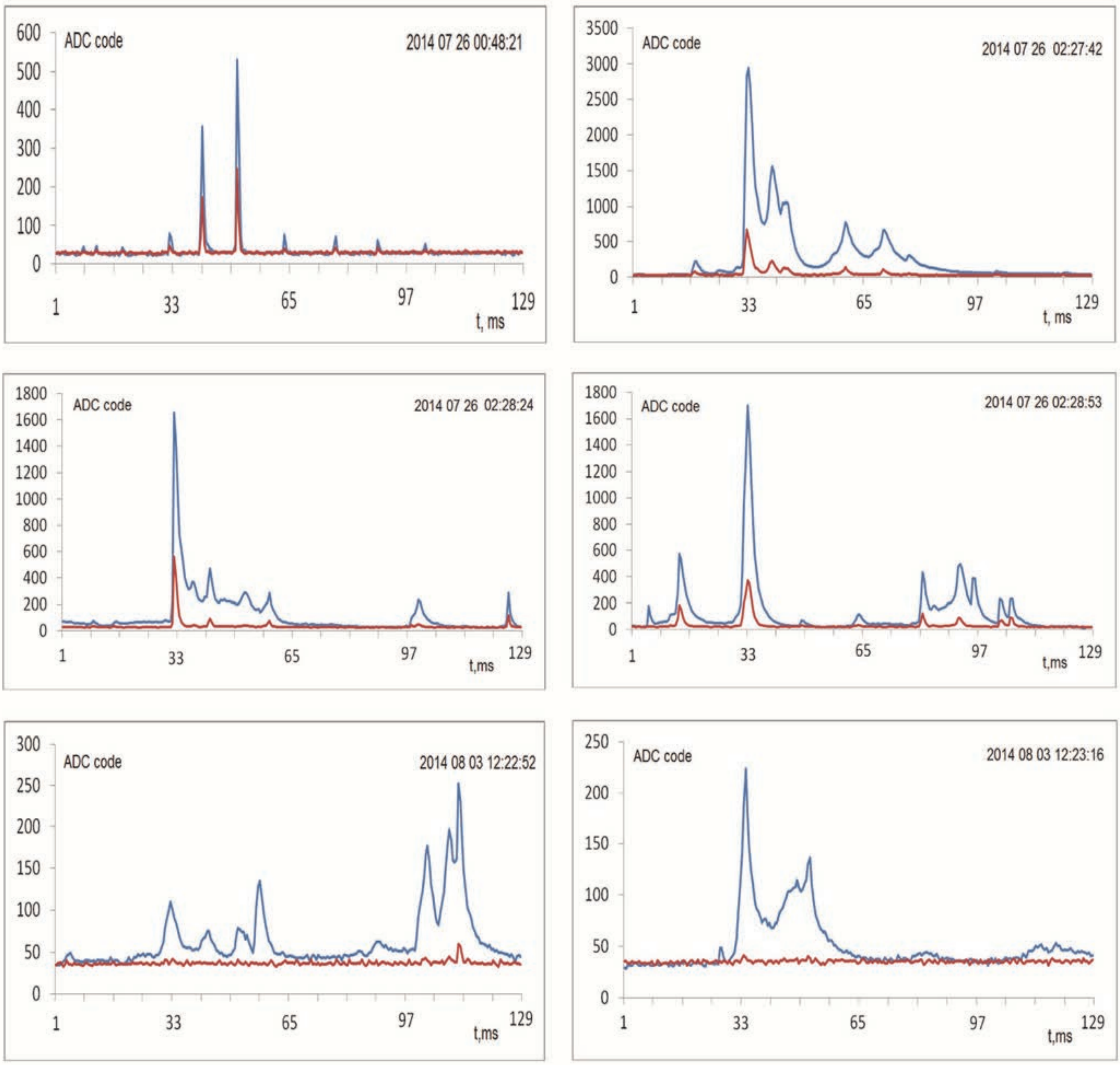

Figure 9. Examples of the waveforms of lightning flashes recorded on board of the "Vernov" satellitte.

4. DISCUSSION AND CONCLUSION

We have presented the preliminary results of the operation of a device designed to register the UV/IR radiation from the lightnings that occur above the Aragats research station in Armenia. The temporal structure of the lightnings as measured by the DUVIR device consists of random pulses of ultraviolet and infrared radiation between which there is no delay. In most of the coincident in time pulses, the infrared signal by the amplitude exceeds the ultraviolet radiation; in some of the pulses their amplitudes are equal. The variations of the amplitudes of the coincident pulses of infrared and ultraviolet radiation are caused by scattering and absorption on the way to the detector and by reflection and scattering of the lightning light in the stormy atmosphere.

It is evident that the temporal structure of the lightning observed at Aragats station and that observed from the orbit are very similar. In the flashes recorded on Aragats, there is somewhat less ultraviolet radiation as compared with the infrared radiation, which is explained by the non-ideal transparency of the lower atmosphere. In some flashes observed from space, the ultraviolet radiation sometimes appears in the absence of infrared radiation; it points to the difference in the discharge properties of the transient luminous events and conventional lightnings. This phenomenon has not been observed on high mountains, possibly due to insufficient statistics of the recorded events.

In the 2016 observations we plan to attach DUVIR to myRio board produced by National Instruments Company (see Figs. 10 and details in Pokhsraryan, 2016). With the help of this board we plan to register UV/IR emissions, fast waveforms from atmospheric discharges and particle fluxes on the nanosecond time's scale.

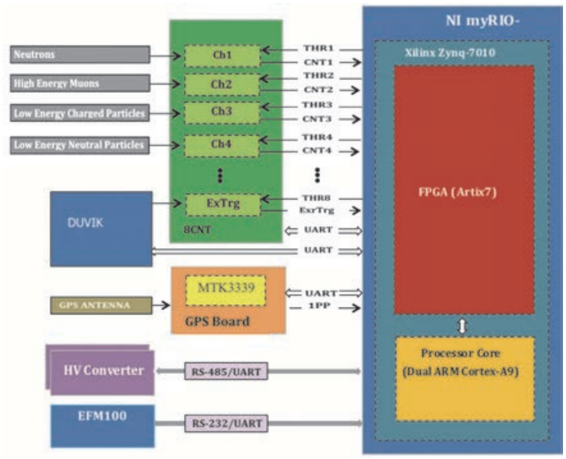

***Figure 10.** National Instruments myRio board for the synchronized detection of particle fluxes, UV and IR radiation and disturbances of the near-surface electrostatic field.*

The myRio board keeps the GPS absolute time with an accuracy not worse than a few tens of nanoseconds. This accuracy can be improved down to a few nanoseconds by using calibration signals from the aircrafts or drones (Aab et al., 2016). Thus, files with microsecond scale waveforms of UV/IR radiation (DUVIR trigger) and files with nanosecond resolution from 5HGz frequency oscilloscope (fast waveform trigger) will be synchronized at least on the microsecond time's scale. As well we plan to synchronize fluxes of electrons, gamma rays and neutrons from TGEs. Moreover, arrival time of each particle in a time span of 100 msec before trigger and 400 msec after trigger will be enumerated also with a nanosecond accuracy. It will give us the possibility to check the hypothesis if the lightnings themselves are the source of high-energy particles. We are planning to use another myRio board that will be triggered by the Extensive air Showers (EAS), so that we can finally check the hypothesis on the relation between EASes and lightnings (RB-EAS hypothesis of Alex Gurevich et al., 1999).

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