Atmospheric monitoring at the Yakutsk EAS array

Stanislav Knurenko and Artem Sabourov
Yu.G. Shafir Institute of Cosmophysical Research and Aeronomy SB RAS
E-mail: s.p.knurenko@ikfia.ysn.ru

Abstract. There are several instruments at the Yakutsk EAS array which are used for monitoring of atmospheric conditions. Here we present the results of perennial observations of the atmospheric spectral transparency, seasonal variations of aerosol optical depth, stratospheric temperature and ground-level electric field. These characteristics are used during the processing of primary data obtained by the EAS array.

1. Introduction
The interest in atmosphere monitoring is not only associated with long-term and middle-term weather forecasts, but also with studying of the thermal regime change on the planet. There are several possible factors causing such deviations. One of them is usually associated with Solar activity. It is widely accepted, that during solar flashes a huge amount of energy is released and transferred to near-Earth space by solar wind, where it interacts with magnetosphere and Earth’s ionosphere and, by channels yet to discover, passes further into stratosphere and troposphere. Another contribution may come from high and ultra-high energy cosmic rays (UHECR) passing through thick layers of the atmosphere. Such particles ionize the medium and may form clusters of hydroxyl groups, thus opening additional channels of solar energy entrance.

In 2005 an observational site, registering atmospheric parameters started operating at the Yakutsk EAS array. Its instrumentation includes detectors of Cherenkov light from cosmic rays, 532 nm lidar, photometer CE318, sensors for electric field and storm activity and alpha- and beta-radiation detectors. The whole system tracks atmospheric response to processes associated with space physics and anthropogenic disasters.

2. Experiment description
The Yakutsk array is a complex setup designed to register electromagnetic, muonic and Cherenkov components of extensive air showers (EAS) [1]. Integral and differential Cherenkov light detectors are used for measurements in optical wavelength range. A Photomultiplier (PMT) with a large photocathode is used as a light receiver. PMT sensitivity range is 300 – 800 nm with maximum at $\lambda = 430$ nm.

A station of atmosphere monitoring is operating since 2005. The structure of this point includes the small Cherenkov array, a lidar, monitoring atmospheric transparency and a photometer CE-318, recording aerosol content in the atmosphere. Registration system also includes electric field sensor, antennas for measuring $E$- and $H$-components of electric field. On constant basis the system records signals from atmospheric noise field in optical wavelength during nighttime, variations of charged particles background measured with surface scintillation
3. Results

3.1. Low-energy cosmic rays (Cherenkov radiation)
It was shown in works by [2] and by [3], that Cherenkov radiation from EAS with energy $\sim 10^{15}$ eV is generated mainly near the upper boundary of the troposphere and in the absence of a strong atmosphere turbidity is registered at the sea level without significant losses. Any significant content of aerosol in the atmosphere, especially below the maximum of Cherenkov light generation, changes the light flux and hence, a frequency of shower occurrence. This feature is used to estimate the atmosphere optical passing function. A seasonal trend of spectral transparency was established at operational wavelength (see fig. 1). It occurs virtually every year and is associated with the change in temperature distribution at heights $0 - 4$ km.

3.2. Lidar measurements
Preliminary data on spectral transparency at $\lambda = 532$ nm obtained with the lidar during different observational periods do not contradict the conclusions made from cosmic ray registration [4].

Fig. 2 shows an example of possible lidar utilization for tracking the atmosphere state during intense volcanic activity (or ground nuclear explosions). It is seen on Figure 2, that several aerosol layers are observed which scatter laser radiation at $\lambda = 532$ nm. This record, within the shift in time, coincides with volcanic eruption on Kamchatka and visually demonstrates how this technique could be used for tracking the man-induced processes.

3.3. Stratospheric warming
It is still unknown what exactly causes the warming of climate and this problem requires a complex approach. It is proposed that for climate of Yakutia a great effect has the so-called...
western transfer — stable movement of air masses in all atmosphere thick from east to west, and routes of cyclones connected with it. The absence of strong pollution sources (except natural ones) on the territory of Yakutia, especially on winters, allows to observe the aerosols and polluting substances transferred by air masses from other regions. Hence, they appear as indicator for routes of air masses.

4. Photometric measurements of atmospheric aerosol

Optical features of the atmosphere are connected with aero-dispersion ability of the medium, containing aerosol particle of natural and artificial origin. Aerosol of the Earth’s atmosphere is discriminated by altitude (near ground, tropospheric, stratospheric, etc.) and by geographic region (continental, nautical, arid and so on). Such a classification allows to pick out peculiar sources of atmospheric aerosol with main processes of aerosol transformation under the influence of geophysical factors.

In the border atmospheric layer the aerosol is affected by underlying surface, season of year, daytime and meteorological factors (mainly — by humidity and wind regime). Various atmospheric situations — such as hazes, fogs, clouds, smoke from fires, industrial throw outs, dust storms, volcanic eruptions — point at variety of physical-chemical features, forms and size ranges of particles in the atmosphere. This is why regular atmospheric observations are important for atmosphere clearance monitoring and for studying the atmosphere physics.

For example, the data recorded near Yakutsk with CE-318 photometers during one of summer months are demonstrated on Figure 3. It is seen that on some days atmospheric optical thickness (AOT) takes extraordinary high values associated with meteorological situation in the region. Figure 4 shows seasonal dependency of AOT values averaged over the month. One can note that starting from May till August mean AOT in the region of Yakutsk equal to 0.18 ± 0.02 and have a tendency of decreasing to 0.13 ± 0.02 in September-November. Observations during five years show seasonal trend in AOT distribution.

Detailed analysis of such characteristics as AOT, spatial non-uniformity and dispersion contents of aerosol, performed using the data obtained with photometer CE-318 have shown that following facts are peculiar during summer near Yakutsk: 1) minimal atmospheric turbidity, AOT values are smaller, then in other Siberian regions such as Tomsk and Novosibirsk, 2) special for several days maximal selectivity of AOT spectral trend, indicating relatively high content of a small-disperse aerosol in the atmosphere, 3) smaller content of absorbing matter in the aerosol, 4) not only small concentration of main aerosol fractions, but other characteristics — modal and effective radii, imaginary component of refraction index [6].

As it’s seen from Figure 4, in pre-thunderstorm and thunderstorm periods AOT rapidly increases in all spectral intervals which could be associated with excessive concentration of liquid micro-particles in the atmosphere at the moment.

5. Features of atmosphere during thunderstorms

On Figure 5 an example is shown of a rapid drop in electric field during thunderstorm cloud passage over the Yakutsk EAS array. The duration of this process equals to time of thunderstorm
Figure 4. Annual trend of aerosol during 2004-2008 (average values at 500 nm wavelength).

Figure 5. Ground-level electric field during a thunderstorm. Changes of electric field (dE) are denoted with red color, $E_{RMS}$ is denoted with black color.

Figure 6. Temporal trend of signals from scintillation detectors with different energy threshold during the passage of a thunderstorm cloud. Event from Jun 17, 2009, UT 10:30:37.

active phase with discharge to the ground.

Temporal trend of signals intensity from scintillation detectors recorded during the passage of thunderstorm clouds is shown on Figure 6. The figure demonstrates long-term increase of intensity, associated with precipitation. As we see, relative value of scintillation signal intensity is significantly higher from detectors with low energy threshold $E_{thr} \geq 1.8$ MeV (by $\sim 20\%$) than that from detectors with high threshold. This result confirms that long-term increase is connected with gamma radiation and significant dose in radiation causing this increase consists of high-energy (order of MeV’s) gamma-photons. They are those photons that must be released during radioactive decay of radon and its products.

Acknowledgments
The work is supported by the Russian Ministry of science, state contract # 16.518.11.7075.

References
[1] Artamonov V P, Afanasiev B N, Glushkov A V 1994 Izv. RAN ser. fiz. 58 12 92–97
[2] Dyakonov M N, Knurenko S P, Kolosov A V et al. 1993 Proc. 23th ICRC. 3 303
[3] Knurenko S P et al. 2001 Proc. 27th ICRC. 1 177
[4] Knurenko S P, Nikolashkin S V, Sabourova A V et al. 2006 Proc. of SPIE. 6522 65221-U1
[5] Geinz Yu E, Zemlyanov A A, Zuev V Ye et al. 1999 Nel'metnaya optika atmosfernogo aerosolya (Novosibirsk: SO RAN)
[6] Sakerin S M, Kabanov D M, Panachenko M V et al. 2005 Optika atmosfery i okeana 18 11 968–975
[7] Knurenko S P, Sleptsov I Ye 2004 Proc. Int. Symp. “Atmosphere and ocean optics. Atmosphere Physics” 181–182