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MONITORING OF BIOLOGICAL (DNA-DAMAGING) EFFECTS OF SOLAR UV RADIATION IN MIDDLE AND HIGH LATITUDES

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Abstract. We show that biological dosimeters applied for long-term solar UV monitoring are promising tools for the assessment of biological hazards in relation to space weather activity over polar areas. For comparing solar UV induced DNA-damage at high latitudes in Arctic regions and in central and southern Europe we started in 2004 the measurement campaigns with the facilities of the Polar Geophysical Institute (PGI) of the Russian Academy of Sciences in Barentsburg, Spitsbergen (78° N) and in Apatity (68° N). We present the first preliminary results of these field experiments and discuss planned future experiments, which will be conducted in 2005.

1. Introduction

Solar UV radiation was a driving force for organic chemical evolution on the Earth and possibly on other planets (e.g., Mars). Special studies on the UV environment of the Achaean era on the early Earth, 2.5 – 3.8 Gyr ago, showed that the Earth's atmosphere was essentially anoxic, resulting in ozone column abundance insufficient for protecting the Earth surface in the UV-B and UV-C range (Walker et al., 1983; Lowe, 1994; Holland, 2000; Cockell and Horneck, 2001). Geographical locations in high latitudes, where the ozone content is strongly variable and effected by penetrating energetic solar particles and meteorological conditions, can be used as a kind of test for studies related to UV associated biological effects. The results of such studies may help us to understand how simple organisms on the early Earth may have reacted to stronger exposure of UV-B and UV-C and how the radiation affects living systems in polar regions in general. The stratospheric ozone concentration has been investigated by several methods, e.g., determinations of the ozone layer using a network of ground based spectrophotometers of the Dobson and the Brewer types. These data indicate a significant decrease of the ozone layer superimposed by much larger seasonal changes at specific geographical locations. The stratospheric ozone plays an important role in the attenuation of the short-wavelength components of the solar spectrum, thus the consequence of the decreased ozone layer is an increased UV-B level.

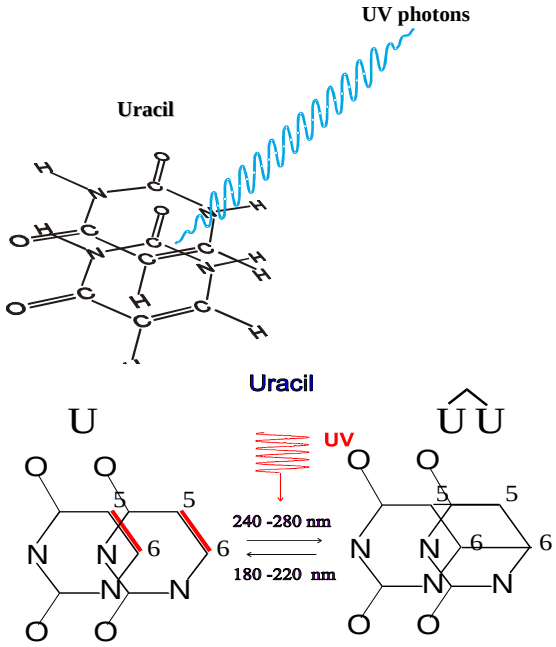

Fig. 1: Uracil thin layer , as a part of the living RNA, can be a model of DNA damage. UV radiation causes two main processes: binding of two uracil molecules (dimerization), or breaking apart a dimer into monomers (monomerization). The photoeffects highly depend on the wavelength of the radiation. Shorter wavelength UV radiation – below about 220 nm – is strongly effective in monomerization, while the longer wavelengths refer to the production of dimer. In the case of polychromatic light the two processes run parallel.

Various pyranometers measuring the biological effect of environmental UV radiation have been constructed with spectral sensitivities close to the erythema action spectrum defined by the CIE. Using these erythemally weighted broad-band instruments to detect the tendency of UV-B radiation, controversial data have been found. To quantify the biological risk due to environmental UV radiation it is reasonable to weight the solar spectrum by the spectral sensitivity of the DNA damage taking into account the high DNA-sensitivity at the short wavelength range of the

solar spectrum. Various solar UV sensitive biological dosimeters have been developed e.g., polycrystalline uracil thin layer (Fig. 1). These are usually simple biological systems or components of them. Their UV sensitivity is a consequence of the DNA-damage. In living systems nucleic acids are the most important targets of photons, which are present in solar UV radiation and they are essential components of all living systems. The structural and functional stability of nucleic acids is therefore of special interest for our study. Fig. 2 shows the biological sensitivity and the present solar UV irradiance in the UV-C, UV-B and UV-A range compared to the irradiance on the early and present Earth.

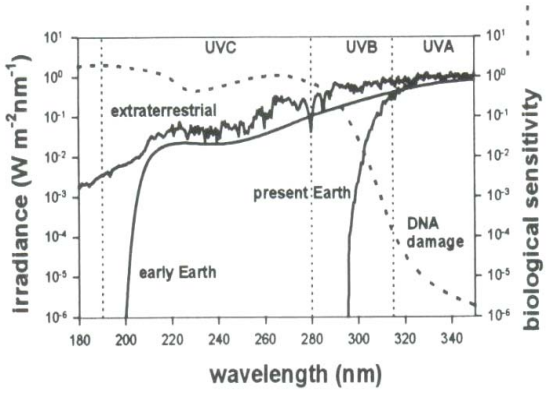

Fig. 2: UV-C, UV-B and UV-A part of the solar UV irradiance compared to the irradiance on the surface on early and present Earth. One can also see the wavelength dependent DNA damaging potential of the solar UV radiation (Rettberg et al., 2001).

The biological effective irradiance E_{eff} can be written as

$$E_{eff} = \int E_{\lambda}(\lambda) S_{\lambda}(\lambda) d\lambda, \qquad (1)$$

where E_{λ} is the solar spectral irradiance, S_{λ} the biological action spectrum and λ the wavelength. By integrating E_{eff} with time t one obtains the biological effective dose rate *BED:*

$$BED = \int E_{eff}(t) dt. \qquad (2)$$

2. Preparation of uracil samples

The uracil thin layers for the biodosimeters were produced by vacuum evaporation. An Auto 306 Vacuum Coater from Edwards Ltd. West Sussex was used to evaporate uracil on quartz sheets. The production facility shown in Fig. 3 consists of a bell jar vacuum chamber and an oil-diffusion pump ensuring the required pressure, about 10^{-6} mbar. A built-in rotating spherical work-holder dome was installed, which enables to rotate the quartz sheets (2) around the axis. Uracil is evaporated from the special boat (3) by heating (1) up to 180 ˚C. A built-in film-thickness monitor (4,5,7) consists of a quartz crystal head (in the inner part of 4) situated in the vacuum area, which is connected to an oscillator circuit (5). The evaporated uracil creates a deposit on the crystal head, changing the frequency of the oscillation. A microprocessor (7) converts the frequency-shift into the thickness of the coating films. After reaching the desired thickness of layer, the heater (1) is switched off, and the evaporation terminates.

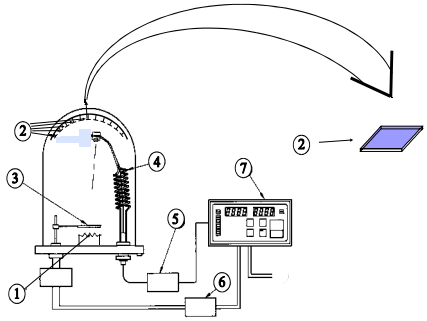

Fig. 3: Illustration of the uracil sample production facility.

3. Location of field experiments

Two biodosimeters were located at the top of a PGI field station near Barentsburg, Spitsbergen during the International Conference “Geophysic Research in Spitsbergen Archipelago” on June 02, 2004. The geographical location shown in Fig. 4 of this research facility is 78° Lat. Two biodosimeters were exposed to solar UV radiation from the beginning of June to the beginning of July.

Fig. 4: Photos of biodosimeters and the geographical location of the field experiments which were carried out at PGI field stations in Barentsburg, Spitsbergen and Apatity, Russian Federation.

Another four biodosimeters were exposed to solar UV radiation at a second PGI research facility at the Kola Peninsula near Apatity, Russian Federation during June and July (two) and August and September (two) 2004.

4. Sunshine hours over Apatity and Spitsbergen

Fig. 5 shows the sunshine hours observed over Apatity during June to October, 2004 and Fig. 6 shows the sunshine hours in Barentsburg, Spitsbergen between May and August.

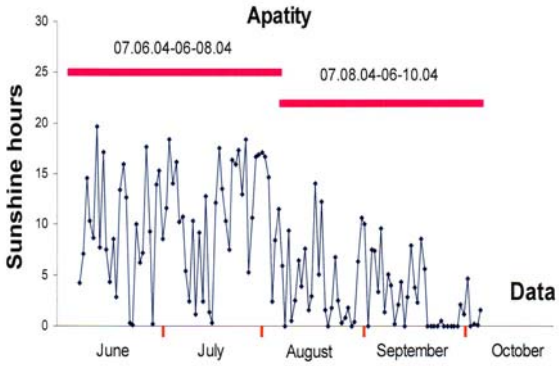

Fig. 5: Sunshine hours in Apatity, Russian Federation between June and October, 2004. The data were obtained by the Murmansk Hydrometeorology Department.

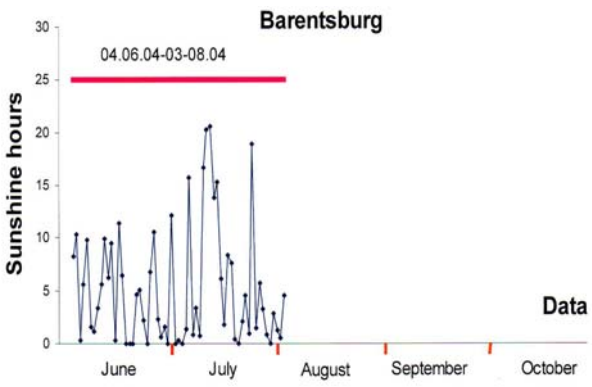

Fig. 6: Sunshine hours in Barentsburg, Spitsbergen between May and August, 2004.

The horizontal lines in Figs. 5 and 6 correspond to the solar UV exposure times of the uracil biodosimeters.

5. Cumulative uracil dose rates

Figs. 7 show the cumulative uracil dose rates obtained due to the solar UV exposure of the biodosimeters in Apatity and Barentsburg, respectively. One can see in Fig. 7 that the cumulative uracil dose rate is about 5 times larger during June 2004 in Apatity compared to the results obtained in Barentsburg at the same time period. The dose rate measured in Apatity is comparable to dose rates measured in Budapest, Hungary between April and June in 2002 (Fig. 8).

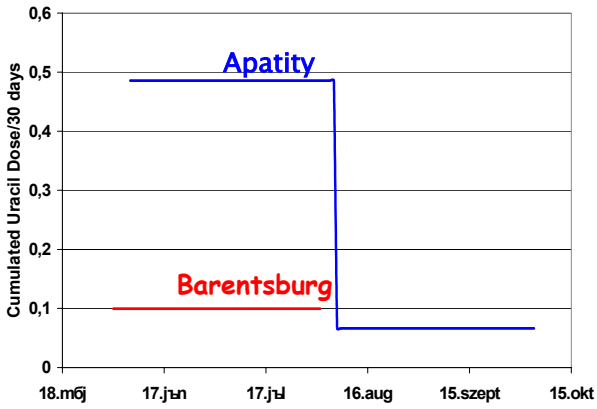

Fig. 7: Cumulative uracil dose rates measured in Apatity, Kola Peninsula, Russian Federation, during June to September 2004 and Barentsburg, Spitsbergen during June and July, 2004.

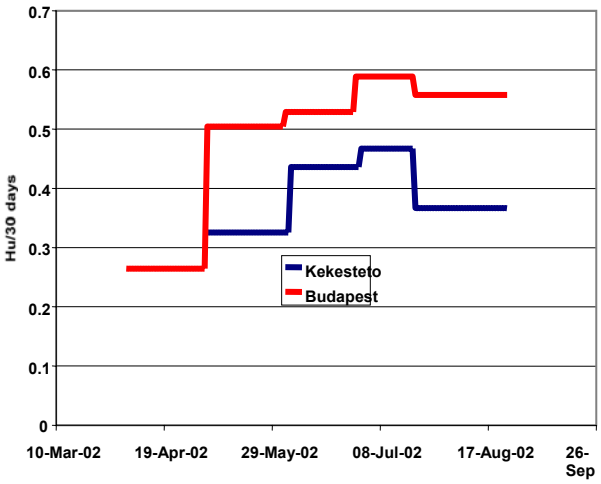

Fig. 8: Cumulative uracil dose rates measured in Hungary between April to September, 2002. One can see that the dose rate reached similar values in Apatity during the period of June to July, 2005, which is normal in central Europe but unusual in Arctic regions.

For identifying the exact time period where the uracil got its highest damaging dose, more observations with biodosimeters in shorter time ranges and parallel observations of the ozone, NO_x contents and UV spectrum are planned during future experiments.

6. High energetic solar particle events

There is much evidence that the unusual high dose rate measured with the biodosimeters in Apatity during June and July may be related to an observed decrease of the stratospheric ozone layer (Fig. 9), caused by the production of NO_x radicals due to high energetic solar particle events. One can see a strong decrease in the atmospheric ozone content at the end of June, 2004. Upper stratospheric enhancements in NO_X (NO and NO_2) were observed at high northern latitudes from March through at least July of 2004. The enhancements were a factor of 4 higher than nominal at some locations, and are unprecedented in

the northern hemisphere since at least 1985. Randall et al. (2005) observed reductions in ozone contents of

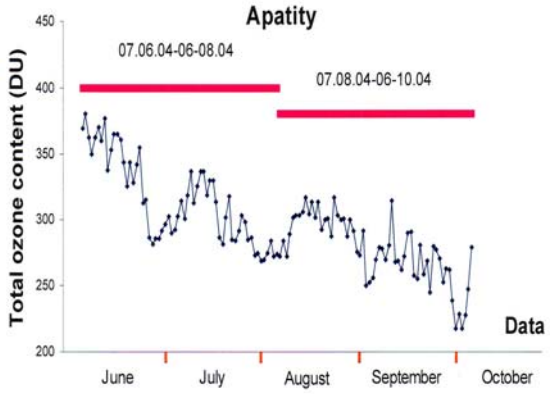

Fig. 9: Total ozone content over Apatity between June and October. One can see a huge decrease followed by an increase at the end of June 2004. The lower ozone content between August and September correlated also with less sunshine hours shown in Fig. 5 during the same time period.

more than 60 % in some cases. Energetic particle precipitation led to substantial NOx production in the upper atmosphere beginning with the strong solar particle events in late October 2003 and possibly persisting through January. Downward transport of the excess NOx, facilitated by unique meteorological conditions in 2004 that led to an unusually strong upper stratospheric vortex from late January through March, caused the enhancements (Randall et al., 2005).

7. Conclusions

DNA damage experiments carried out with uracil biodosimeters at research facilities of the Polar Geophysical Institute (PGI), of the Russian Academy of Sciences in Barentsburg, Spitsbergen and Apatity, Kola Peninsula, showed unusual high cumulative uracil dose rates in Apatity during June and July, 2004. This time period agrees with independently observed high NO_x and NO_2 production, caused by high energetic particle events, which originated at the Sun. By late January satellite data indicate a systematic descent of NO_x-rich air in the vortex that finally led to unprecedented NO_x enhancements and ozone reductions in the upper stratospheric vortex from March to May 2004. The anomalies declined as the stratospheric vortex broke up, but were still evident even in July. However, one should note that our measurements are preliminary, because a new observation campaign with more uracil biodosimeters is carried out during 2005. The obtained data are planned to be correlated with measurements of the UV spectrum obtained by a spectrum-radiometer, as well as ozone and NO_x measurements carried out by the PGI at the Kola Scientific centre in Apatity.

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