INCLUSION OF ENVIRONMENTAL ISSUES INTO SCIENCE EDUCATION
SUPPLEMENTARY MATERIAL

(To make the introduction to the paper shorter, the explanation below had been summarized in just several sentences within the very paper; the full original text is below. This file in two versions, double-spaced and a easier-to-read single spaced ones, together with all materials regarding the paper, like commented images from the activities, as well as the presentation from the conference are available at the site http://amper.ped.muni.cz/gw/activities/.)

Basic Radiation Literacy

What affects the temperature of the Earth? Why is it bound to rise lot in coming decades? If students will find answers to these questions and will understand them, it may influence their views on many other human activities. They may begin to regard science as an indispensable tool to tackle the many problems arising due to the changed composition of the atmosphere.

The major obstacle to grasp the current thermal evolution of the atmosphere is the missing experience and understanding of various bands of electromagnetic radiation. A common blunder is that some radiation is heat transport, whereas another one – the light – "is not", that there is something as "cold light". Few people are aware that most of energy fluxes around us are those from ordinary environments, not from the extremely hot ones, and that their propagation has some similarities to light, but also some profound differences. That the invisible properties of the atmosphere, and their change, determine the fate of the life on our planet. That the amount of longwave infrared radiation, that with $\lambda > 3$ µm, abbreviated IR-C sometimes ("Infrared," 2012), coming to the ground from the air itself is larger than the insolation, in a yearly average. Having a qualitative, and then even quantitative knowledge about radiative fluxes in various spectral intervals should be a matter of course after all – these fluxes are driving all what happens on Earth, and enable our lives too.

From a set of proposed activities, some of which may be performed by students outside school lessons as well, we show just a small selection here: observations, measurements, experiments.

On (solar) Illuminance and Irradiance

Do we perceive light amounts? Not really, we notice just ratios of luminances in differing directions or changing quickly during time. Just when the light levels around us are really low, like at the end of civil twilight, we become aware of it – ceasing to see tiny details and then even colours. Many people are surprised that PV cells don't produce enough electricity to feed some toys under "so strong" lights indoors. Nobody sees that even under winter overcast sky in daytime, the light amounts are easily ten times or hundred times larger outdoors. Our vision adapts. But PV cells or plants depend on the absolute amounts, not on ratios. Revealing that illuminance of a luxmeter sensor changes from a centilux to a tenth of a megalux in various common night and day environments is a useful exercise.

How does that span correspond to irradiances? Could a luxmeter be used as a proxy for solar irradiance? Common instruments analogous to luxmeters say that somehow, let's call them *solarmeters* here. How do they differ from a luxmeter? And from a true pyranometer? A luxmeter gives a very good proxy for a photopic light flux density, having a spectral sensitivity very similar to daytime human vision. A true pyranometer measures radiative heat flux density in a spectral interval broad enough to capture almost all incident solar radiation, typically from 300 nm to 2800 nm, using a black surface and a thermopile. A solarmeter is an analogy of a luxmeter, registering photon flux density as filtered by some spectral sensitivity curve. It differs from a luxmeter by mostly having a "raw" sensitivity curve, using all the photoelectric capability of a silicon sensor, which is rather flat in a photon count domain running from 400 nm to 1000 nm. However, due to photon energy being inversely proportional to its wavelength, it is almost 3× less sensitive at its shortwave end then at longwave end, when expressed in energy domain. Even if it would be possible to filter the longer wavelenghts to approach an energy-proper sensitivity, it is mostly not done, as such instruments are meant to be a reference for PV power plants, which are responsive to photon flux, not to energy flux, to solar heat. But even true pyranometers have their problems (Gueymard & Myers, 2009), and well usable PV "pyranometers" can even ignore solar IR (Martínez, Andújar, & Enrique, 2009).

Comparing readings by luxmeter and solarmeter might be revealing. For clear sky daylight, it will soon appear that luxmeter is a good proxy for PV-relevant solar irradiance too, the ratio being about 100 lx/(W/m^2). This is due to the fact that solar radiation from the clear sky has no very strong spectral features which would vary. The ratio rises a bit for overcast sky – the obvious answer is, water droplets absorb infrared radiation. But for radiation returned back skywards by the terrain, the ratio of their readings may be very different, provided the surface is coloured or "coloured", the latter being a non-visual feature of IR reflectivity being very different from visual reflectivity – vegetation is the best example. There is a huge difference of luxmeter/solarmeter reading ratio for outdated hot bulbs, which emit lots of shortwave IR radiation, and for fluorescent and semiconductor (LED) light sources, which don't. IR trasmissivity of glass, measuring by closed and opened windows, is also easy to demonstrate; not all glazings are the same in this respect, due to varying iron content or coatings reflecting longwave infrared radiation, as these coatings absorb the shortwave IR quite a lot. This compares with their different temperature due to sunshine – the more absorbing ones are warmer, easy to feel by touching them.

On Longwave Infrared

There is no obvious way how to experience the huge invisible radiances of the order of 100 W/(m^{2}sr) valid for all directions in our terrestrial environment. The reason is that we radiate too, and just the difference of absorbed and emitted radiation can be perceived. Pyrgeometers, reporting the longwave irradiance in watts per square metre, are not common among citizens or in schools. Explaining the theory, perhaps in a way using a logarithmic scale for wavelengths (Marr & Wilkin, 2012), seems to be necessary. However, feeling warmer or colder surfaces or air "at distance" is a useful illustration that there have to be large fluxes, if even their small disbalance becomes apparent. And, almost everybody knows infrared "thermometers" now, instruments which measure radiance inside a band of wavelengths, mostly within a range from 7 μm to 15 μm (or rather 8 μm to 14 μm only and similarly in the above bounds, always denoted as LWIR – the real limits are never sharp anyway).

References

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