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CORRECTING ERRORS ASSOCIATED WITH UNDERWATER SPECTRAL IRRADIANCE MEASUREMENTS

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Abstract. Some sources of errors associated with measurements with a single LI-1800 UW spectroradiometer are discussed. These sources include the effects of the variation in the incoming radiation and surface waves on the measuring results. It is shown that the effects of the variation of direct solar and diffuse irradiance above the water level can be minimized by using the measured intensity of the global radiation to standardize the measured underwater spectra to some specific level of incoming radiation. The effect of the wind waves can be minimized by filtering the high resolution spectra (resolution of 2 nm). Also polynomial fit can be used. These procedures are not suitable if high resolution corrected spectra are needed.

Key words: underwater irradiance spectra, wind, waves, global radiation.

INTRODUCTION

In order to obtain consistent measurements of underwater spectral irradiance at different times the spectral irradiance above the water surface must be known. Because the spectral distribution of the incoming irradiance does not vary significantly within the time span of noon ± 3 hours, the intensity of the global radiation can be used as the indicator for the spectral irradiance. As the global radiation may vary considerably due to the variation in the cloud cover this radiation ought to be measured at the same time and preferably at the same place as the underwater irradiance, either in the same boat or the nearby shoreline.

The effect of wind waves on the underwater spectral measurements is another serious source of error. In our case the only method for the correction is smoothing of the spectrum. In case of more modern instruments that can measure an irradiance spectrum very quickly the effect of wind can be eliminated by measuring the spectrum several times and then computing an average over these spectra. This is clearly a better method than smoothing. However, there are large numbers of spectra measured in wavy conditions with slower instruments the results of which should be used also.

MEASURING PROCEDURE

The measuring device was an LI-1800 UW spectroradiometer. Its range of wavelengths is 300–850 nm in the water. Typically we used the spectral resolution of 2 nm. The duration of the measurement of a single spectrum was 40 s. Depending on the water depth the depths of the measurements used were 0.5, 1, 1.5, 2, 2.5, 3, 4, and 5 m. All measuring series were taken twice, one spectrum when lowering the instrument and the other when raising it. The measurements during which the global radiation differed more than 20% from the average global radiation of the respective measurement series were rejected. Altogether the percentage of the rejected measurements was about 20 to 30 of all the measurements. The number of measuring series in one day varied between 2 and 8 and the number of corresponding irradiance spectra varied between 24 and 100.

In order to correct the data for variable incoming radiation one minute values of global radiation were measured with an LI-200 SA pyranometer. This instrument was placed on board the boat where the underwater measurements were made in large lakes and on the shoreline in case of smaller lakes.

The measurements for this study were made in connection with the Finnish–Estonian project SUVI and the EU project SALMON in five Estonian and seven Finnish lakes. Some of the lakes had several measuring sites, the total number being 29. In most of the lakes two measuring expeditions were made during the summer of 1997.

CORRECTION FOR THE EFFECTS OF WAVES

It was shown earlier (see Dera, 1992, pp. 281–292) that waves cause errors in underwater optical measurements whose periods are of the order of or less than the period of wind waves. This comes from the fact that the water surface is disturbed by several types of waves besides wind waves and surface tension waves and the light beam is refracting from different points of the surface to the measuring device.

For smoothing out the effects of the wind waves two methods were used: filtering with a low pass filter and a polynomial fitting to the measured spectrum. Because the error seems to be proportional to the level of irradiance, smoothing was applied to logarithmically transformed spectra.

The irradiance spectrum in a wavelength domain can be considered as a spectrum in the time domain, the wavelength interval 2 nm corresponding to the time interval of $2 \times 40/550$ s = 145 ms. Because the period of wind waves is about 1–2 s, the effect of waves can be filtered by a low pass filter with the limit period of the order of 2 s. We used a Butterworth recursive filter (see Krauss et al., 1994, pp. 2–22) with a length of 3. It includes 5 parameters and filtering was made twice, first advancing with the increasing time and then in the opposite direction. The parameters of the filter depend on the selected cut off frequency.

Another possibility of smoothing the measured spectrum is to apply polynomial fitting to the data. It was observed that a polynomial having degree 14 or 15 should be used.

Figure 1 shows the original data as well as results of the smoothed data for Lake Vesijärvi. In this case the results were corrupted by the effects of wind waves. It can be seen that fitting with the polynomial of degree 15 gives almost the same results as low pass filtering. The results deviate in some details.

In order to get a better idea of the accuracy of the smoothed series some simulated logarithmically transformed spectra were used. It was necessary to calculate logarithms, because the errors were proportional to the level of the spectra. The simulated series were obtained by summing up the error series and some measured spectrum with no wind wave error. The error series were obtained as the difference between the measured spectrum disturbed by wind waves and its low pass filtered spectrum (Vesijärvi, depth 0.5 m, Fig. 1) multiplied with some constant. As there seems to be weak periodicity in the disturbance, this kind of error series describe the real disturbance better than for example some Monte Carlo simulation with random data. Because filtered series do not follow all short period changes in the data (Fig. 1), only values of the spectrum in the smooth part between 450 and 700 nm were used repeatedly in order to get a right number of data.

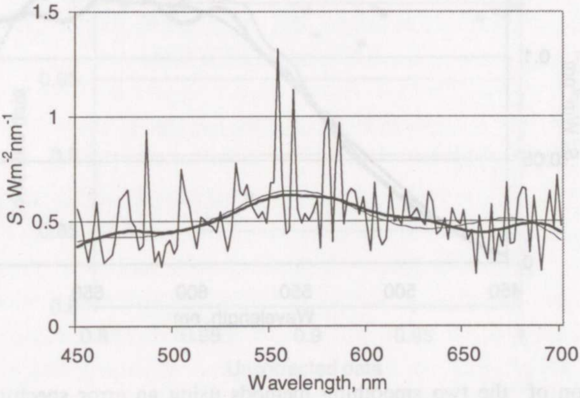

Fig. 1. Smoothing with filtering and polynomial fitting. Medium line: the measured spectral irradiance S at a depth of 0.5 m in Lake Vesijärvi; thick line: filtered spectrum, cut off frequency 0.025 nm^{-1}; thin line: polynomial fit, degree 15.

The simulation procedure is illustrated here:

$$S_s(\lambda) = \exp[\ln(S_0(\lambda)) + k\ln(er(\lambda))],$$

where $S_s(\lambda)$ is the simulated spectrum, $\ln(S_0) + k\ln(er(\lambda))$ is the simulated logarithmically transformed spectrum, $S_0(\lambda)$ is the original spectrum with a low level of error, k is a simulation coefficient, and $er(\lambda)$ is the error spectrum.

Figures 2a and 2b show some results of the correction for wind wave effects. The figures suggest that when the disturbance is low the low pass filtered series seems to give better consistency with the measured series than the polynomial fit, but in case of higher disturbance the situation is almost the opposite. However, the difference between these two smoothing methods is not big.

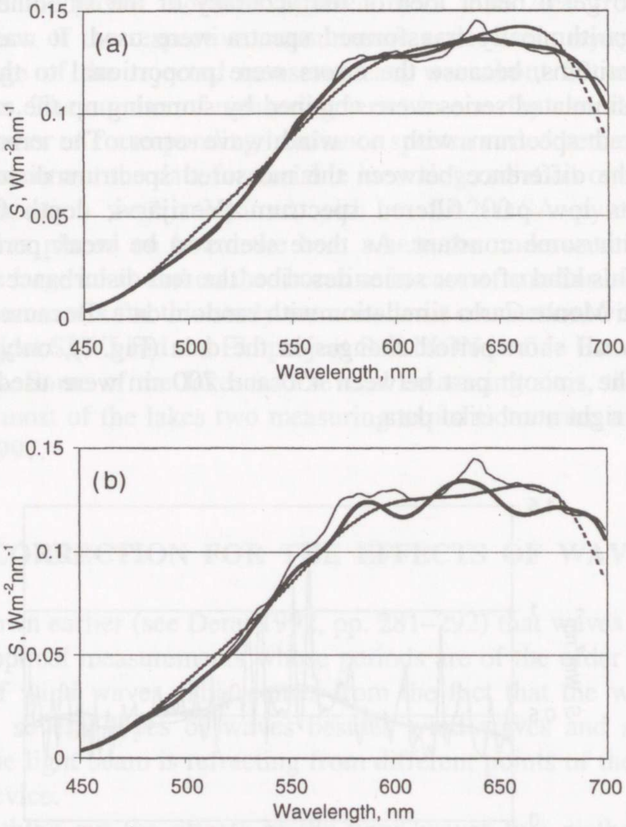

Fig. 2. Comparison of the two smoothing methods using an error spectrum with a simulation coefficient $k = 0.5$ (a) and $k = 4.0$ (b). Thin line, measured spectrum at a depth of 1 m in Lake Pääjärvi; thick line, filtered simulated spectrum, cut off frequency 0.025 nm^{-1}; dashed line, polynomial fit of simulated spectrum, degree 15.

CORRECTION OF DATA FOR VARIABLE INCOMING RADIATION

To get consistent data in a situation of variable incoming radiation the data must be corrected. The procedure has been described earlier (Virta & Blanco Sequeiros, 1995). The correction procedure is simple:

$$S_{0\lambda} = S_{\mathrm{m}\lambda} \frac{H_0}{H_{\mathrm{m}}},$$

where S_λ is the spectral irradiance at the wavelength λ and H is the global incident radiation. The subscript m means measured and 0 designates the level of the global radiation into which the correction is to be made. The correction is based on the measured 1 min averages of the global radiation H_{m} . Some errors may arise because the boat is not a fixed platform, which would be necessary for the global radiation measurements, besides it is possible that rapid changes in the input radiation are not occurring at the same time on the boat and on the shoreline. The following analysis was made to clarify whether it is sensible to correct the data with these approximate global radiation measurements.

Independent measurements with light attenuation meters indicated to an approximately linear dependence between the depth and the logarithm of the irradiance at a specific wavelength and independence of the irradiance attenuation coefficient from the depth. Thus the estimation of the quality of the radiation correction can be based on the comparison of depth–irradiance correlation before and after the correction.

Figure 3 shows correlation coefficients at the wavelength of 570 nm of corrected data plotted against uncorrected ones for 22 cases. It can be seen that in most cases corrected data give better correlation than uncorrected data. There are

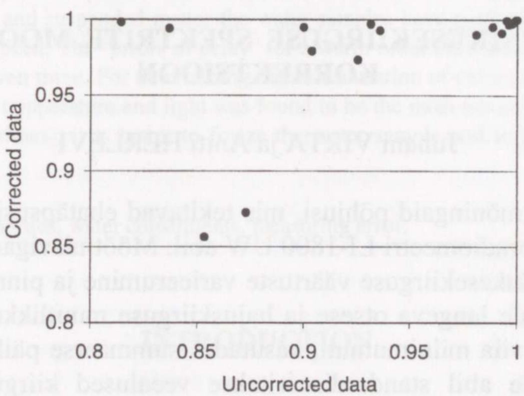

Fig. 3. Absolute values of the correlation coefficient between the depth and logarithm of the spectral density of corrected data at the wavelength of 570 nm plotted against the corresponding coefficients computed with uncorrected data.

clearly two exceptions with corrected correlation coefficients less than 0.9. Both of these cases were measured in Lake Verevi where independent measurements showed vertical inhomogeneity of the water and thus there may exist a depth dependence of the irradiance attenuation coefficient.

CONCLUSIONS

It may be concluded that the effect of waves on the underwater spectral irradiance measurements can be smoothed in cases when the spectrum has been measured with high resolution (2 nm) and a detailed spectrum is not needed. The effect of the variation of the incoming radiation can be taken into account and the spectra can be corrected, but care must be taken in timing – the measurements of the incoming radiation and an underwater spectrum must be made at the same time, and if possible also in the same place.

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VEEALUSE PÄIKESEKIIRGUSE SPEKTRITE MÕÕTMISVIGADE KORREKTSIOON

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On vaadeldud mõningaid põhjusi, mis tekitavad ebatäpsusi veealuse kiirguse mõõtmisel spektroradiomeetri LI-1800 UW abil. Mõõtmisvigade allikaks on veepinnale langeva päikesekiirguse väärtuste varieerumine ja pinnalainete mõju. On näidatud, et pinnale langeva otsese ja hajuskiirguse muutlikkuse poolt tekitatud vigu on võimalik viia miinimumini, kasutades summaarse päikesekiirguse mõõtmisandmeid, mille abil standardiseeritakse veealused kiirgusspektrid pinnale langeva kiirguse mingi fikseeritud taseme jaoks. Tuule tekitatud pinnalainete mõju kiirguse mõõtmistulemustele vähendatakse filtreerides kõrge lahutusvõimega (2 nm) spektrid või kasutades polünoomlähendit. Need protseduurid pole rakendatavad, kui eesmärgiks on saada kõrge lahutusvõimega spektreid.