

De-noising spectral signatures from shallow water bodies for water quality determination purposes

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Abstract: Spectral signatures collected by means of field spectrometer from shallow water bodies are noise contaminated from the atmosphere or the sensor itself. Existing spectral analysis methods are based on the variation within the data; therefore, they are very sensitive to noise effects. Noise can obscure important features such as peaks, valleys, or peak widths, or make calculation of signal features such as slopes, areas and peak widths difficult. The filter approach should maintain the sharpest absorption/reflectance features in the original signal.

The level of the noise highly depends on the atmospheric conditions during data acquisition such as clouds and wind. Each spectral signature even when taken from the same water body but on another date is processed and filtered according to noise level.

The application of the methods is based on the criteria that the selected model must smooth out high frequency noise while maintaining the smallest features that could be associated with biophysical attributes of the water (absorption troughs and reflectance peaks).

We found that the higher polynomial or wavelet orders do not provide more optical information than the lower ones; simple models were selected accordingly. For normal weather conditions, it is best to use the DWT filter with *sym5* or *sym8* Symlet wavelet depending on noise level. Symlet wavelet seeks to preserve shapes of reflectance peaks and essentially performs a local polynomial regression to determine the smoothed value for each data point. This method is superior to Adjacent Averaging because it tends to preserve features such as peak height and width, which are usually 'washed out' by Adjacent Averaging. At the same time, in case of windy weather, the best filter was application of Savitzky-Golay filter with lower frame size (e.g. 17) and subsequent application of Discrete Wavelet Transformation with *sym5* wavelet. In all filters a polynomial degree of 3 preserved best the shape of the spectra and has been used for all data.

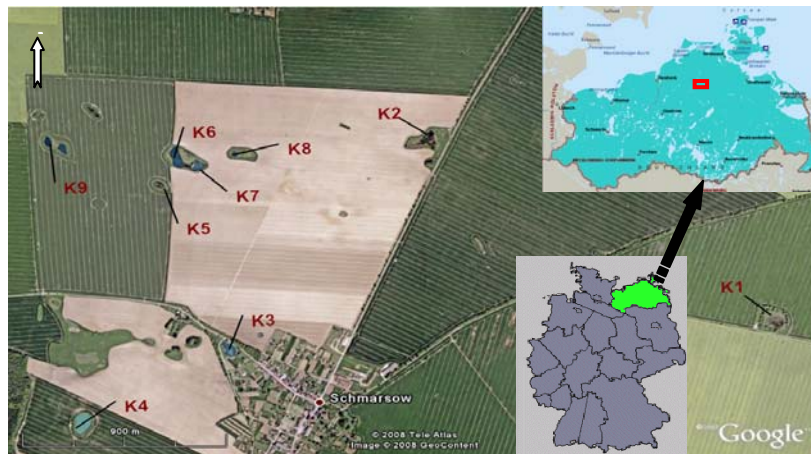
1. Introduction

The European Water Framework Directive [Eu00] aimed a 'good ecological status' for all water bodies until 2015 by establishing of long-term water quality objectives and revising existing monitoring programs. In North-Eastern Germany more than 15,000 kettle holes (small digressional lentic waters or wetlands usually less than <1 ha) can be found mostly within arable land and forest. They are characterized by a wet-dry-cycle and, therefore, provide a high potential for structural and species diversity. Furthermore, shores of kettle holes are a source for enhanced greenhouse gas emissions due to eutrophication [Me02]. However, kettle holes are subject to pollution, drainage, and structural alteration by intensive land use practices.

Recent research in the Southern Baltic region demonstrated the tight relation between discharge generation and nutrient export [Tie06]. Prompt by climate change raising temperature induces more winter precipitation and subsequently winter discharge which leaches more nutrients to surface water bodies including kettle holes [Tie08].

Remote sensing can provide useful information for water quality monitoring in agricultural young moraine landscape in North-Eastern Germany. Especially field spectroscopy has been applied successfully toward establishing relationships between the spectral response and water-quality parameters including algal chlorophyll in many studies [De93, Al04 and Wia06]. Contrary to satellite and aircraft altitudes, the close-range spectroscopy has an important advantage in acquiring of wide range spectral information from the desired un-mixed object with negligible atmospheric attenuation [Han98]. However, spectral signatures of shallow water bodies are noise contaminated from the atmosphere or the sensor itself. Existing spectral analysis methods are based on the variation within the data; therefore, they are very sensitive to noise effects. [De93, Ge06]. The level of the noise highly depends on the atmospheric conditions during data acquisition such as clouds and wind [Al04]. Each spectral signature even when taken from the same water body but on another date is processed and filtered according to noise level.

The objective of this study was to show the usefulness of several de-noising techniques applied to spectral signatures with different noise level for water quality determination.



(Figure 1. Test area located close to the village Schmarsow, Demmin suburbs (FRG), with kettle holes numeration [Goo08].)

2. Methodology

The test area is located close to the city of Demmin, about 150 km north of the city of Berlin and covers approximately 10 km² (Figure 1). Monitoring program included 6 sampling stations. Field data was collected in the period of June-October 2007 (total of 7 data sets, 5 out of which with spectral data) and May – September, 2008 (total of 10 complete data sets).

A field spectroradiometer (ASD FieldSpec HH ultraviolet/visible and near-infrared (UV/VNIR)) was used to measure the upwelling radiance of the water at each sampling station during water sampling. The instrument records a continuous spectrum with 25° FOV in 512 bands, ranging from 274 nm to 1085 nm with 1.587 nm spectral resolution [ASD08]. Upwelling radiance from the water body is being retrieved as relative reflectance in relation to down welling radiance spectrum measured from a reference panel (Spectralon with approximately 100% reflectance, 25-30 cm above the panel). At each sampling station, the reference panel was scanned first. Depending on the depth and size of the kettle hole, the spectral measurement took place either on the board of a boat or at the shoreline. The measuring unit was oriented to the boat side within the light propagation to minimize sun glint from waves, but far enough not to be affected by the boat shadow. Same rules were applied for the shoreline measurements. In both cases data was collected at or close to the central part of the kettle hole at the height of ≈ 30 cm in vertical downward direction between 10 am and 2 pm. At least ten measurements were taken from each kettle hole repeatedly, which were afterwards averaged to minimize random effects and to enhance the signal to noise ratio.

3. Results

Spectra taken from the field trips needed to be filtered to produce the data that are uncontaminated by noise from the atmosphere or the sensor itself. Existing spectral analysis methods are based on the variation within the data [Git00, Kne04]; therefore, they are very sensitive to noise effects. Noise can obscure important features such as peaks, valleys, or peak widths, or make calculation of signal features such as slopes, areas and peak widths difficult [Wia06]. The filter should maintain the sharpest absorption/reflectance features in the original signal.

Mean and Savitzky-Golay filter (SGolay), Discrete Wavelet Transformation (DWT) and none-decimated DWT were used by [Sch04] to smooth vegetation spectra. The same methods were applied by [Wia06] to the volumetric reflectance from Michigan inland lakes and it was found that Savitzky-Golay filter proved to be best compared to other approaches. The application of the methods is based on the criteria that the selected model must smooth out high frequency noise while maintaining the smallest features that could be associated with biophysical attributes (absorption troughs and reflectance peaks). We found that the higher polynomial or wavelet orders do not provide more optical information than the lower ones; simple models were selected accordingly.

All spectra were filtered using MatLab 7.0 software applying Savitzky-Golay filter and Discrete De-noising Wavelets. We found that for normal weather conditions, it is best to use the DWT filter with *sym5* or *sym8* Symlet wavelet depending on noise level. Symlet wavelet seeks to preserve shapes of reflectance peaks and essentially performs a local polynomial regression to determine the smoothed value for each data point. This method is superior to adjacent averaging because it tends to preserve features such as peak height and width.

Ratio between minimum near 670 nm and maximum near 700 nm was successfully applied to data obtained in highly diverse aquatic ecosystems dominated by different algal assemblages [Thi02]. The height of the peak above a baseline between 670 nm and 750 nm depends mainly on phytoplankton density and was used as its quantitative

measure [Git00]. Therefore, the region near 700 nm requires precise and accurate de-noising procedures.

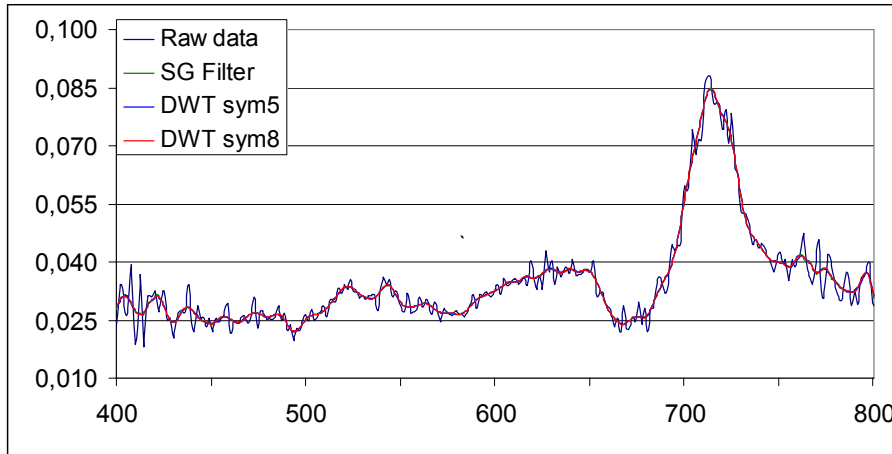


Figure 2. De-noised spectra taken from kettle hole K2 at 29.07.2008 (a).

Figure 2 shows performance of all smoothing filters in the range of 400nm and 800 nm performed well. This de-noising is done without ‘noise decreasing’ procedure while spectra taken in normal weather condition.

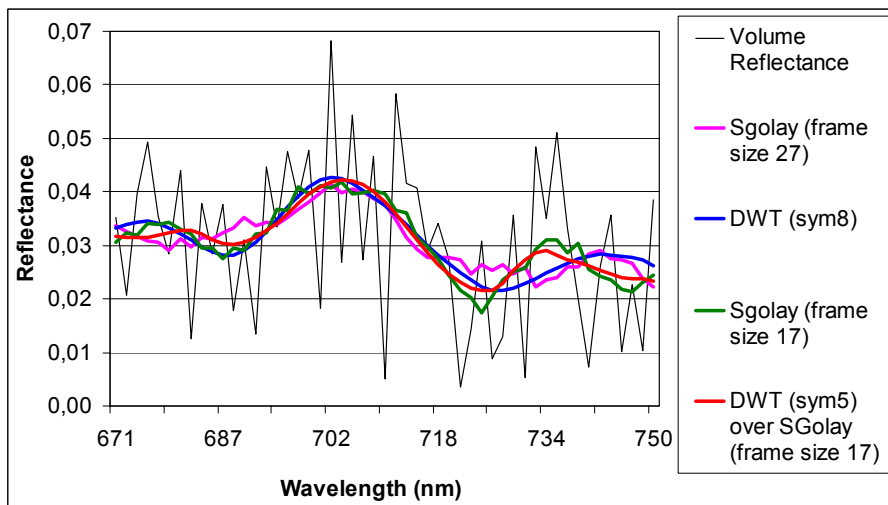


Figure 3. Comparison of noise removal filters for volumetric reflectance. The best performing filter is a combination of first Savitzky-Golay Filter with small frame size (e.g. 17) and then Discrete Wavelet Transformation with *Sym5* de-noising wavelet.

In case of windy and overcast weather, the best performing filter was a combination of first Savitzky-Golay filter with a small frame size (e.g. 17) and then Discrete Wavelet Transformation with *sym5* wavelet (Figure 3).

In all filters a polynomial degree of 3 best preserved the shape of the spectra and has been used for all data.

4. Conclusion

There are advantages and disadvantages to every de-noising technique. However, it is shown that wavelets are superior for field spectra smoothing. Symlet wavelet smoothing techniques preserving sharp peaks and troughs because the filter calculated a local polynomial for every determined wavelength range.

Symlet *sym8* shows the best de-noising for spectral signatures taken in normal weather conditions. For spectra taken in overcast conditions sequential application of Savitzky-Golay Filter and Discrete Wavelet Transformation produces best de-noising performance.

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