EXPERIMENTAL DETERMINATION OF ADJACENCY EFFECTS OVER AN EUTROPHIC LAKE USING A HELICOPTER MOUNTED SPECTRORADIOMETER FOR THE CORRECTION OF IMAGING SPECTROMETER DATA*

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ABSTRACT

The amount of adjacency effect present in imaging spectrometer data over lakes is determined using a helicopter mounted spectroradiometer. The experiment – carried out over an eutrophic lake in Central Switzerland – included extensive ground data collection including water quality assessment and underwater spectroradiometric measurements. The experiment is flown over the same transect in 11 different altitudes above the lake. The radiometric measurements are converted to reflectance values using a Spectralon panel and a sun photometer. The contribution of the green vegetation on both ends of the transects to the water signal is measured and discussed.

1.0 INTRODUCTION

Adjacency effects present in imaging spectrometer data lead to an overestimation of the effective signal of the observed object. In the special case of green vegetation and water bodies, the overlay of three effects contributing to the observed total chlorophyll signal in a lake can be discriminated. First the sensors signal is influenced by the macrophytes chlorophyll content in shallow water as long as the sensor penetrates the first few meters of the water body. Second the adjacency effects originating from the lake's surrounding vegetation contributes to the total signal. Finally the dissolved chlorophyll in the water itself is the parameter of investigation and shall be used to monitor chlorophyll concentration distribution within the lake.

According to fig. 1, the adjacency effect is considered as the summation of the radiant components of 2, 3 and 4 (whereas 1 is the ground direct reflected radiance, 2 & 5 the path scattered radiance, 3 the adjacency effect with interaction of the object, 4 the trapping effect, and 5 the intrinsic atmospheric radiance) [KAUFMAN, 1989, TANRÉ, 1989, PROY, 1989]. In horizontal areas, the major contribution arises from 2, whereas 3 increases with increasing slope and aspect of the sun.

2.0 EXPERIMENT DESCRIPTION

An eutrophic lake (Lake Zug) in Central Switzerland is selected as reference test site for this experiment. The flight line for the helicopter is chosen based on the different kind of vegetation types and the slope of the hills at the start and the end point of the transect (meadows and flat on the eastern border, forests and steep on the western border). On September 25 1996 the same transect is flown using a helicopter mounted spectroradiometer at 11 different altitudes ranging from 100 m to 1800 m above the lake. At the same time two boats measured different limnological parameters in the lake. For the monitoring of the atmosphere a sun photometer is used.

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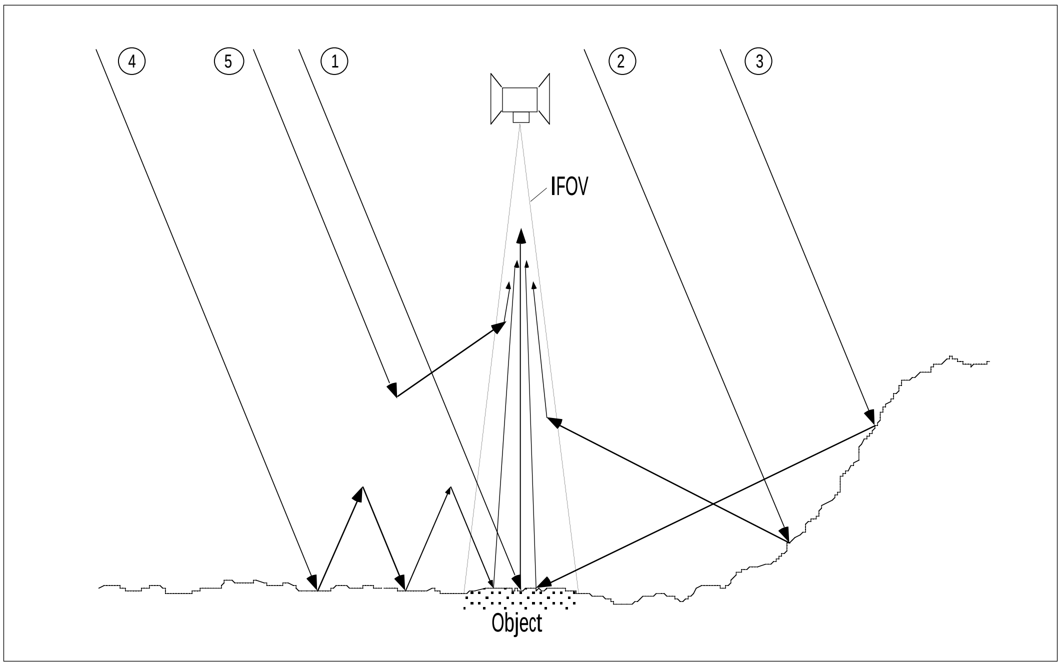

Figure 1. Radiation Contributing To The Adjacency Effect

2.1 AIRBORNE MEASUREMENTS

The helicopter is equipped with navigation and measurement instruments. For the navigation the internal system of the helicopter is used to determine the flight altitude with an active altimeter and the heading using a compass. The heading of the flight lines was determined to be at 111° and 291°. The absolute position of the helicopter while taking a measurement is recorded using a differential GPS system. The differential signal is supplied over an external FM/RDS–pager that is connected to the GPS receiver. The pager decompresses and decodes the differential signal and corrects the GPS system accordingly. The expected accuracy lies between 15–30 meters. The GPS is only used to record the position at each measuring point and not to navigate the helicopter. The navigation of the helicopter is based on compass readings, altimeter readings and visual navigation using landmarks only.

Due to vibrational problems the helicopter had to fly at a constant speed (19.7 m/s) during data acquisition. This results in a ellipsoid GFOV of the radiometer which it modelled for the different transect altitudes. The radiometer has a round field of view of ± 1.4°. For a flight altitude of 1800 m above lake level this yields to an ellipsoid of 78.5 m and for 100 m above the lake of 4.3 m.

A standard SLR camera with a fixed focus lens of 84.8 mm is mounted just next to the spectroradiometer in the helicopter. The angular field of the SLR camera is 28.5°. For a flight altitude of 1800 m above lake level this yields to a ground field of view of 760.7 x 507.1 m and 42.2 x 28.1 m respectively. Both, the radiometer and the camera have been adjusted using a digital level meter resulting in a parallel pointing direction. With every measurement a picture was taken simultaneously to reconstruct the FOV on the ground after the flight.

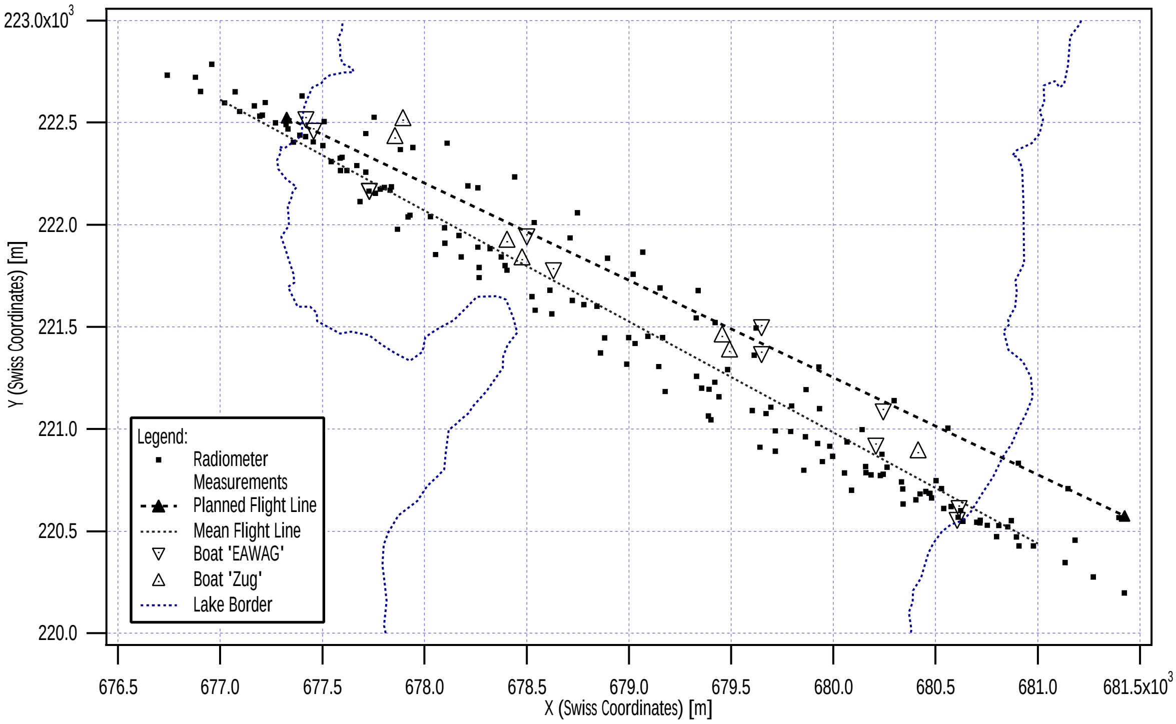

Figure 2. Measurement Point Distribution Of The Transect Flown

The radiometric measurements are taken with a GER3700 spectroradiometer. This radiometer covers the wavelength range from 400 – 2450 nm with 704 channels. The spectral sampling interval is 1.5 nm in the VIS, 6.8 nm in the SWIR I and 8 nm in the SWIR II portion of the spectrum. The radiometer is mounted in the helicopter on an anti–vibrational shock mount that reduces interference from helicopter vibrations. The instrument is connected over a cable with the controlling laptop computer. In total 162 spectra have been recorded on 11 different altitudes above the lake.

The calibration of the spectroradiometer is performed using a Spectralon reference panel (PTFE). This panel is located just next to the sun photometer. Before, in the middle and after the helicopter flight, the panel is measured with the radiometer still built in the helicopter. The sun photometer monitors changes of the atmosphere which allows to convert the raw measurements of the radiometer into time consistent reflectance values.

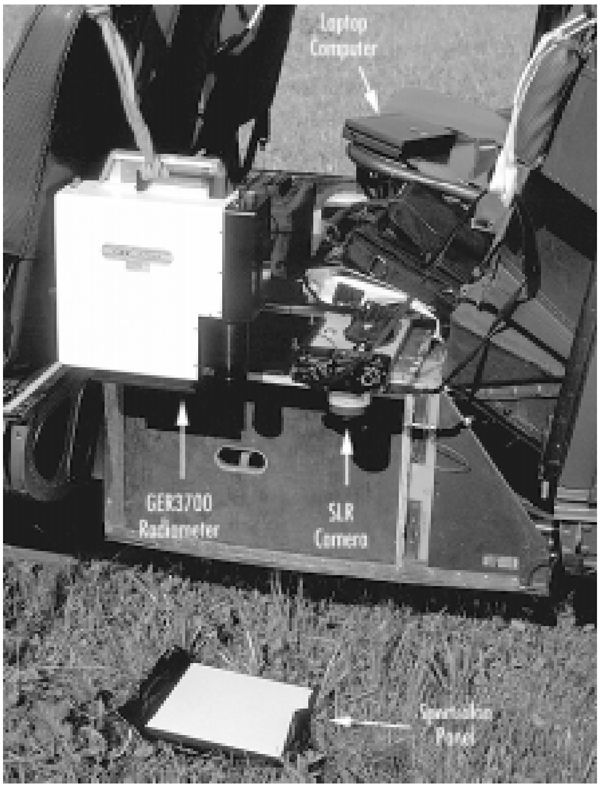

Figure 3. Helicopter Instrument Setup And Calibration Panel

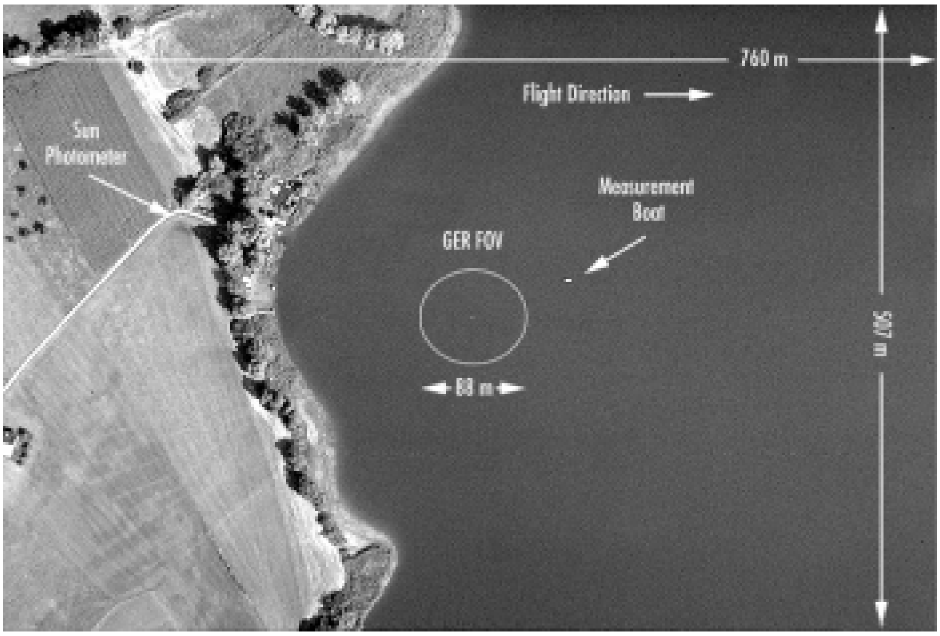

Figure 4. FOV Of The Radiometer And The SLR Camera On 1800 m.a.g.

2.2 LIMNOLOGICAL MEASUREMENTS

Limnologic parameters are measured using two boats. The absolute position of the boats is determined with the same DGPS technology as described in the airborne measurements. One group measured the water spectral signatures, the other classic limnological parameters.

A Licor LI-1800UW underwater spectroradiometer is used to measure downwelling irradiance on four different spots upon the water surface (+0.5 m) and under the water surface in several depths (-0.5 m, -1.0 m, -2.0 m, -3.0 m, -4.0 m, -5.0 m). Because of fluctuations of the signal during the data acquisition, several scans are taken and averaged (5 scans in -0.5 m and -1.0 m, 3 scans in -2.0 m, 2 scans in -3.0 m).

The Secci depth is also measured. This is the maximum depth from which an observer on a boat is able to see the reflected light of a white coloured disc (Secchi disc). This is also the maximum depth where particulate and dissolved matter, and the bottom of the lake influence the spectral signature of a radiometer above the water surface.

Water constituents are determined using samples on 6 different sites in 3 different depths (-0.5 m, -2.0 m, -5.0 m). Suspended matter of 3 water samples are filtered directly on the boat. In the laboratory chlorophyll a, DOC (dissolved organic carbonate) and the particle size distribution of particulate matter are measured and the algal class composition is determined. In addition in-situ chlorophyll fluorescence is measured to retrieve information about the vertical chlorophyll distribution within the water.

2.3 ATMOSPHERIC MEASUREMENTS

A Reagan sun photometer [EHSANI, 1992] is positioned at the calibration site to record data of the optical thickness of the atmosphere and to measure water vapour contents. The Reagan sun photometer is a sun-looking radiometer, measuring the direct solar irradiance at 10 wavelengths between 380 and 1030 nm. It is continuously monitoring the state of the atmosphere and allows conclusions on atmospheric stability and daily developments of aerosol contents. The visibility on ground level is quantified by inverting the sun photometer data using the MODTRAN model.

3.0 REFLECTANCE MODELLING OF THE HELICOPTER MEASUREMENTS

A comparison between two radiometer measurements can only be performed if the radiance values are converted to reflectance values. This is normally done using a Spectralon reference panel. In the special case of this experiment Spectralon measurements are only realized on the lake level. The altitude differences between the transects introduce an increased single and path scattered radiance. These contributions must be known for the determination of the adjacency effect. The amount of direct radiance does not depend on the flight altitude assuming constant radiation over time. The maximum variance of the single and path scattered radiance is modelled using MODTRAN.

Due to technical constraints, it was not possible to take a reference measurement for each measurement on the transects. Thus only three Spectralon measurements have been taken during the whole flight time of 2 h. Because the atmospheric conditions changed significantly between each reference measurement on the ground, the Spectralon radiance is modelled over time using the sun photometer measurements. In a first modelling attempt, the modelling of the radiometer channels is limited to the sun photometer channels. Since neither the radiometer nor the sun photometer are absolutely calibrated, the following equation is used to model the reflectance:

$$\rho(\lambda,t_1) = \frac{\phi_r(\lambda,t_1)}{\phi_0(\lambda,t_1)} = \frac{\phi_r(\lambda,t_1)}{\phi_0(\lambda,t_0)\cdot\frac{T(\lambda,t_1)}{T(\lambda,t_0)}} = \frac{\phi_r(\lambda,t_1)}{\phi_0(\lambda,t_0)\cdot\frac{\phi^{SPM}(\lambda,t_1)}{\phi^{SPM}(\lambda,t_0)}}$$

where: ρ is the reflectance, λ is the wavelength, t is the time, and ϕ is the uncalibrated radiance (the index r refers to the reflected radiance, the index 0 to the reference measurements of the Spectralon, and the index SPM to the sun photometer).

Based on this formula, the following restrictions apply:

- Model uncertainties occur to the spatial extent in x, y and z between the position of the sun photometer and the radiometer.
- The suggested time interval for taking a reference measurement of the Spectralon between two measurements (< 15 min.) is exceeded by far.
- The measurements of the sun photometer (measures the sun disk only) are not directly comparable to the diffuse properties of the Spectralon reference panel.

It can be shown that if the diffuse radiation during the reference measurement is larger (smaller) than during the target measurement and assuming that the direct radiation is constant, the modelled reflectance values are underestimated (overestimated). In general a complicated behaviour between the direct and the diffuse radiation is expected. The modelling of the diffuse contribution using MODTRAN will partly remove the adjacency effect and therefore remove the subject of investigation.

4.0 RESULTS

The reflectance values are calculated for 669 and 779 nm. These channels are selected because the reflectance values for water and vegetation show a minor disagreement at 669 nm and a major at 779 nm.

4.1 LIMNOLOGICAL MEASUREMENTS

There are only small horizontal differences between the 6 different measuring sites in the lake. Secchi depth ranges from 1.8 to 2.6 m. The chlorophyll concentrations range from 8.1 to 9.5 µg/l directly under the surface and from 9.6 to 11.2 µg/l in the larger depths.

4.2 REFLECTANCE AS A FUNCTION OF THE DISTANCE TO THE LAKE BORDER

All reflectance values of the transects are plotted against the distance to the lake border. The result of this calculations is visualized in fig. 5.

The following points are to be mentioned:

(1) As expected at 779 nm the values are higher over land than over the lake. At 669 nm this is only true for the western border. On the eastern border most values over land are lower than over the lake because of shadow, lower spectral reflection of roads, the darker forest signature, and the slope of the hills on this side of the lake.

(2) The changing atmospheric conditions (i.e. atmospheric transmission) influence the results and must be taken into account when interpreting them.

(3) The determination of the distance where the adjacency effect influences the signal is difficult because of the spatial sampling interval of the measurements. On the eastern border the first measurements show no significant contribution of the expected adjacency effect. On the western side, the same phenomena can be observed for lower altitudes. For the 1800 m transect a slightly higher value at a distance of 300 m from the lake border can be observed.

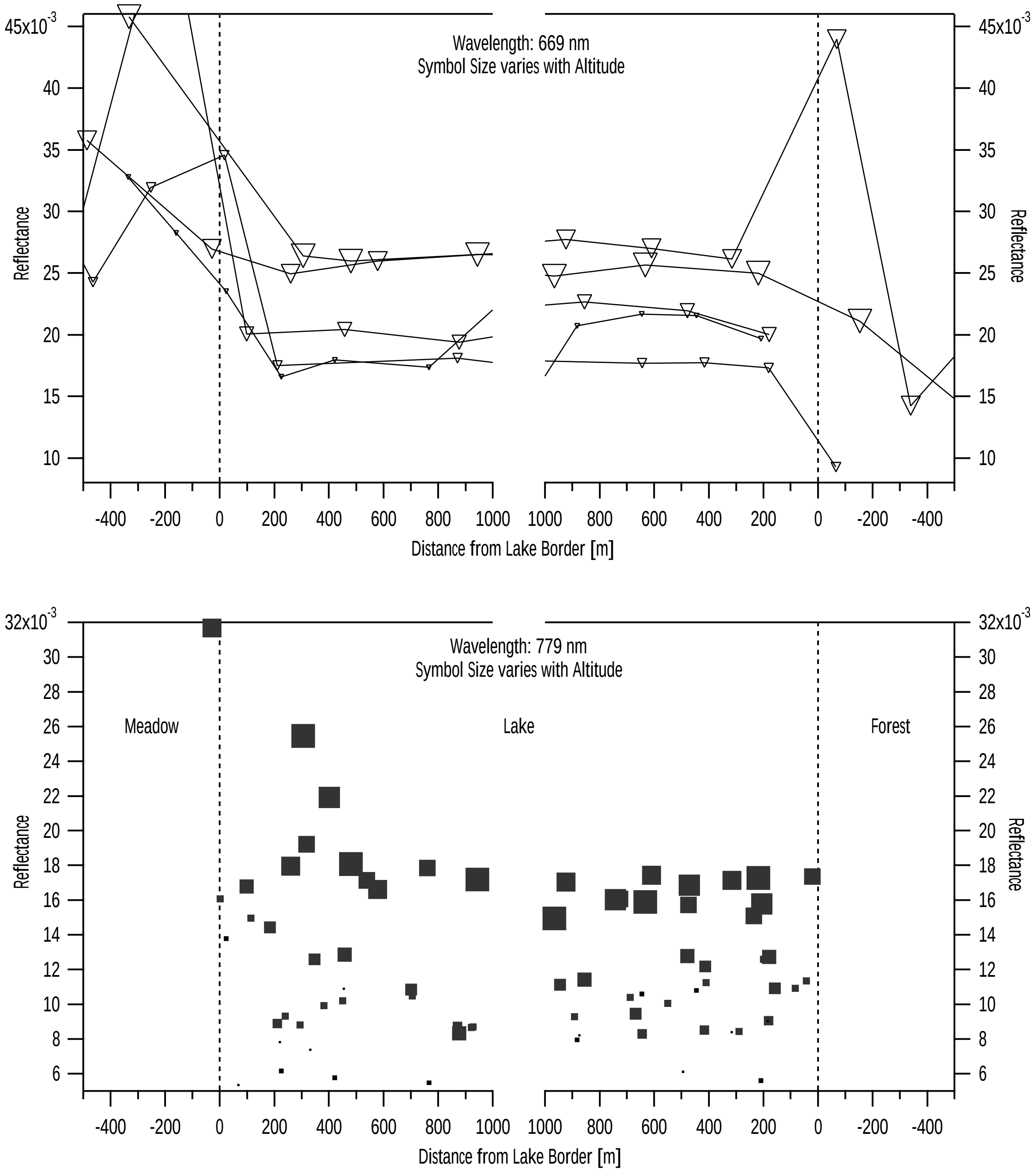

Figure 5. Reflectance Modelling Using 669 and 779 nm

(4) The “apparent” reflectance increases with increasing altitude. This is caused by the single– and path–scattered radiance and by the adjacency effect. This result is expected because with increasing altitude the diffuse light increases too. Using a radiative transfer model (MODTRAN) the contribution of the single– and path–scattered radiance to the total radiance is modelled. At a height of 100 m over the lake and a visibility of 16 (33) km the attenuation is in the order of 1%

(2%), at a height of 1800 m in the order of 10-15% (15-20%) for both wavelengths. The direct reflected radiance is independent of the flight altitude.

5.0 DISCUSSION

A higher amount of adjacency effect was expected to be present at a distance over several 100 m from the lake border. Only weak effects are detected on the 1800 m transect in a distance of 300 m from the lake border. The modelling of the contribution of the adjacency effect to the total signal measured is helpful to identify the limitations of non–imaging data acquisition. A major problem are the temporal and spatial differences between the radiometric measurements introduced by the changing of the atmospheric conditions and the limitation of the reference measurements to one altitude only. For an exact determination of the adjacency effects the separation of direct and diffuse radiation present in each pixel must be modelled very carefully, taking into account all the mentioned restrictions.

6.0 CONCLUSIONS AND OUTLOOK

This adjacency experiment has identified a number of problems arising from non–imaging data acquisition. The spatial, spectral and temporal inhomogenities that occur due to the experiment setup require special modelling attempts using radiative transfer codes. The amount of changes observed give a good estimate of the complexity of the subject investigated. For a better determination of the adjacency effect more measurements near the lake border with better spatial resolution are needed. The next step will be an approach to parameterize the adjacency effect as a function of object distance and observer altitude. The important task of the determination of the water constituents is improved using this modelling approach. Further investigations will also focus on the information content of spectral signatures influenced by adjacency effects.

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