TOTAL SUSPENDED MATTER MAPS FROM CHRIS IMAGERY OF A SMALL INLAND WATER BODY IN OOSTENDE (BELGIUM)

Barbara Van Mol[(1)] and Kevin Ruddick[(1)]

[(1)]*Management Unit of the North Sea Mathematical Models (MUMM), Royal Belgian Institute for Natural Sciences (RBINS), 100 Gulledelle, B-1200 Brussels, Belgium. Email:B.VanMol@mumm.ac.be*

ABSTRACT/RESUME

It has been already established that total suspended matter (TSM) can be retrieved from CHRIS imagery for turbid coastal waters, but what about inland waters?
Because of the high resolution of CHRIS/PROBA images, inland waters not visible by sensors like SeaWiFS, MERIS and MODIS become detectable and are expected to become a key new application domain for optical remote sensing. In the Oostende test site there is a small (800m*1400m) inland water body with an average depth of 1.5m called the Spuikom. On 6 July 2004, a cloud free CHRIS acquisition of the Oostende test site occurred with simultaneous in situ measurements.
The reprocessed dataset is evaluated and analyzed. Data from CHRIS show abnormally high near infrared (NIR) reflectance in the lake, especially near the borders. This does not significantly affect TSM maps but does contaminate the chlorophyll maps deduced from CHRIS imagery. This high NIR reflectance is probably caused by adjacency effects, although the possibility of bottom reflection must also be assessed. In the summer of 2005 a measurement campaign is planned to investigate further the influence of nearby land and bottom reflection in order to provide a benchmark dataset for testing of algorithms to detect and correct for such effects. CHRIS images will be an important component of this dataset.

1. INTRODUCTION

The Management Unit of the North Sea Mathematical Models (MUMM) received since 2002 until now 14 CHRIS/PROBA mode 1 image sets of the test site Oostende (centre coordinates: 51.28°N, 2.88°E) for mapping chlorophyll *a* (CHL) and total suspended matter (TSM) in coastal waters. During nine of the acquisitions there were simultaneous in situ measurements but there are only 2 cloud free images sets with in situ measurements (Fig. 1).
Before the 2nd CHRIS/PROBA workshop in 2004 a processing chain was developed including destriping based on a 5 column moving average, atmospheric correction based on a darkest pixel approach and georeferencing with ground control points [1].

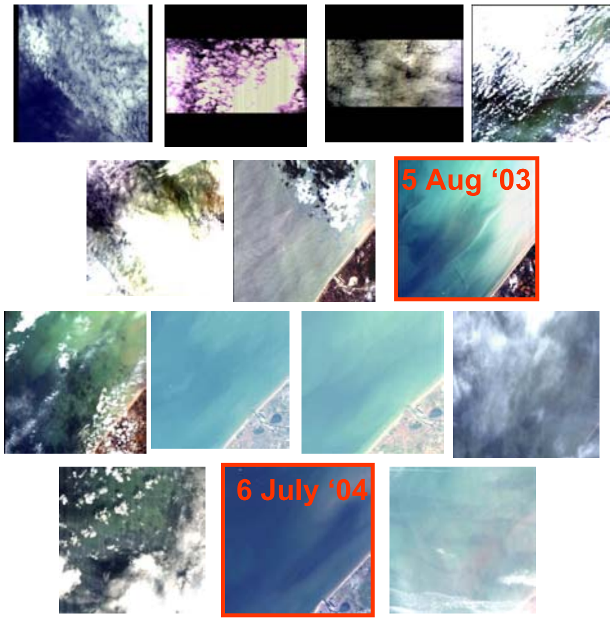

Fig. 1. CHRIS/PROBA quick looks of the Oostende test site. Red frame: cloud free and simultaneous in situ measurements. The images are approximately 13 km² and are not georeferenced.

CHRIS/PROBA images have been evaluated for mapping chlorophyll *a* (CHL) and total suspended matter (TSM) in coastal waters and the conclusion was that CHRIS/PROBA images are good enough to create useful TSM maps but the possibility to create CHL maps needed further research [1].
The question arises if CHRIS/PROBA mode 1 could also be used to map TSM in small inland waters.
Recently a new calibration was applied by Sira[1] to the CHRIS/PROBA images which solves e.g. the problem of abnormally high radiances at 411 nm.
This paper outlines the improvements of the new calibration and assesses the possibility of mapping SPM and chlorophyll in small inland waters.

[1] Company that developed the CHRIS sensor. More info about Sira can be found on www.sira.co.uk

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2. NEW CALIBRATION

Since the first data acquisition of CHRIS/PROBA, Sira has improved the processing before the images are delivered to the principal investigators. The reprocessing of cloud free images of the Oostende test site occurred at the end of 2004. In order to assess the difference with the previous version, a comparison of spectra is made.
Fig. 2 shows the comparison of sample spectra extracted from the CHRIS/PROBA nadir viewing image of 6 July 2004 (with real observation zenith angle equal to 24.88°) before and after reprocessing with the new calibration.

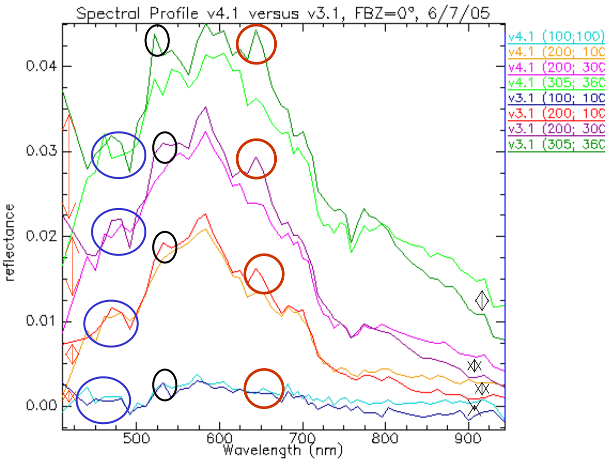

Fig. 2: Comparison of water leaving reflectance spectra before (darkest colours) and after (lightest colours) reprocessing.

The reprocessed images show lower reflectance values in the blue wavelengths, higher values in the near infrared (NIR) wavelengths and less pronounced peaks.

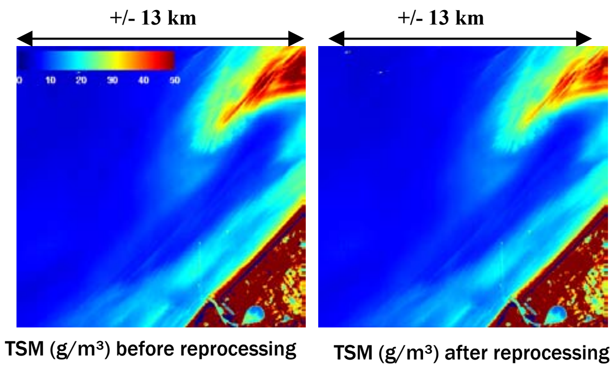

Fig. 3: Comparison of TSM maps derived from CHRIS imagery of 6 July 2004 with fly-by zenith angle and observation zenith angle equal to 0° and 24.88° before and after reprocessing. The images are approximately 13 km² and are not georeferenced.

The total suspended matter (TSM) maps created from the reprocessed images show slightly lower concentrations. This is because the reflectance values at 670 nm, used for the calculation of TSM, are also slightly lower (Fig. 3).
The chlorophyll maps obtained are unreliable for both versions.

3. INLAND SMALL WATER BODY: THE SPUIKOM

3.1. In situ measurements

Almost simultaneous with the CHRIS/PROBA acquisition of 6 July 2004 (13h00 local time) 3 in situ measurements were made in the Spuikom, a small (800m * 1400m) inland water body with an average depth of 1.5 m in Oostende (Fig. 4):

- SP1 in the middle of the Spuikom at 13h09
- SP2 in the west side of the Spuikom at 13h20
- SP3 in the east side of the Spuikom at 13h40

In contrast to coastal water, water in the Spuikom is not strongly influenced by the tides (only inflow of water at average high tide but the water level is regulated). These measurements are therefore assumed to represent the situation at the CHRIS/PROBA overpass.

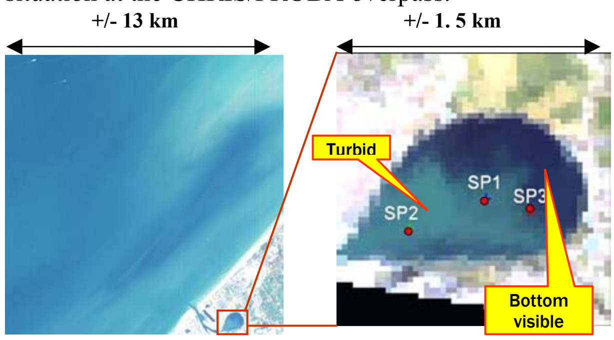

Fig. 4: Measurement points in the Spuikom. The left image is not georeferenced, the right image is georeferenced

The measured parameters are water leaving reflectance, total suspended matter, chlorophyll, secchi depth and metadata including position and weather circumstances.
The water leaving reflectance is calculated from the water leaving radiance, sky radiance and downwelling

Fig. 5: TriOS optical sensors mounted on the Rigid Inflatable Boat, called the Tuimelaar.

radiance measured by the TriOS optical sensors mounted on a Rigid Inflatable Boat (Fig. 5). Technical specifications of the TriOS-RAMSES sensors can be found on www.trios.de. TriOS wavelengths range from 350 nm to 950 nm with a bandwidth of about 10 nm. Chlorophyll and total suspended matter are analyzed in the lab after filtration of the water samples.

3.2. Reflectance

The reflectance spectra derived from CHRIS imagery are compared with the in situ TriOS reflectance measurements in Fig. 6 for the nadir viewing image.

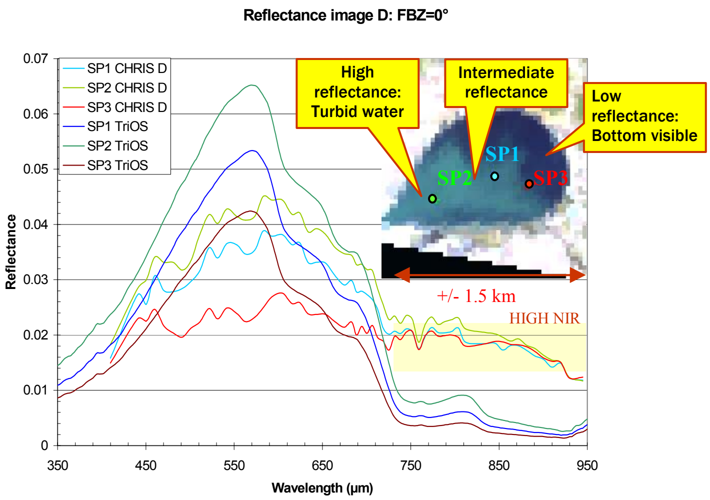

Fig. 6: Comparison of CHRIS and TriOS reflectance spectra.

The highest reflectance is found in the west of the Spuikom for both sensors. This is due to the high turbidity in this area. The lowest reflection is found in the east. Here the water is clear and shallow and the bottom is visible.
The CHRIS-derived reflectance is lower than TriOS reflectance for visible wavelengths. This can be explained by the simple atmospheric correction based on the darkest pixel which subtracts the spectrum of the darkest water pixel from all spectra assuming that the water reflectance in the darkest water pixel is zero and that the sensor reflectance there is entirely atmospheric. As this assumption is not entirely accurate, the atmospheric reflectance is overestimated which leads to an underestimation of the water leaving reflectance [1].
The most striking feature of Fig. 6 is the high CHRIS reflectance in the near infrared (NIR). In previous studies [1] and in Fig. 7 (the black line) the CHRIS water leaving reflectance spectra at sea were found to have a shape comparable to in situ measurements of water leaving reflectance i.e. with reflectance decreasing almost monotonically from a peak in the range 550-600 nm to values a factor 2 or more lower at 711 nm with further decrease by a factor 2 or more to 800 nm and a further decrease to 900 nm because of the corresponding increase in pure water absorption. This difference between spectra at sea and for the lake suggests that the high inland water near infrared reflectance does not result from sensor calibration. The typical water leaving reflectance spectral form is expected to be valid for all water bodies except perhaps for very shallow water (< 1m) where the reflectance from the bottom may contribute to the surface reflectance at red and near infrared (NIR) wavelengths. The TriOS measurements made in the Spuikom confirm such a spectral shape (Fig. 6).

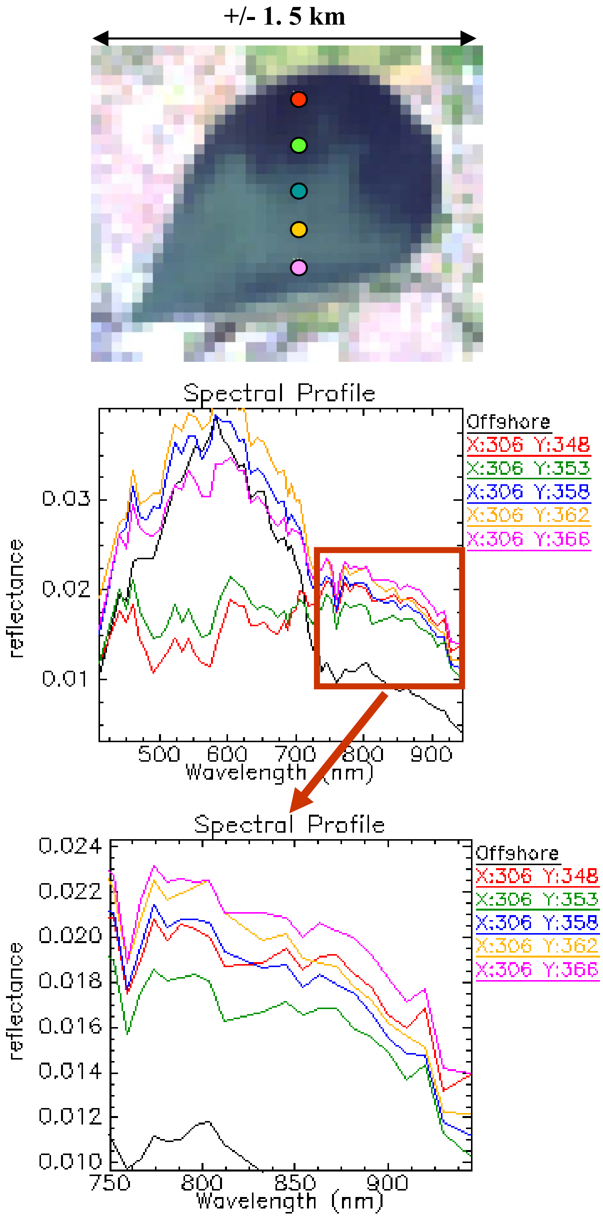

Fig. 7: CHRIS reflectance spectra

Comparing CHRIS-derived reflectance spectra in different places on a line from north to south through the Spuikom (Fig. 7and 8) shows that the highest values in the NIR are found close to the borders of the Spuikom (the pink and red spectra).

A possible explanation of these high NIR could be bottom reflection [2]. However, this hypothesis is questionable. Such features will clearly affect the water-leaving reflectance for blue and green wavelengths, since they are visible to the human eye. However, bottom reflectance becomes rapidly absorbed for all but the shallowest water for red and near infrared wavelengths. For example the absorption of water is about $0.8 m^{-1}$ at 709nm and rises to $4.2 m^{-1}$ at 850nm [3] with the result that even for clear water the surface signal of bottom reflectance is attenuated to a factor 0.45 and 0.015 or smaller at 709nm and 850nm respectively for water of 1m depth. Moreover these factors will be squared if the water depth doubles i.e. the bottom reflectance at 850nm is reduced to less than 0.022% of its bottom value by passage through water of 2m depth [4]. Inspection of the decrease in reflectance for the wavelengths 709nm–850nm in the Northern portion of the Spuikom shows a relatively similar decrease in reflectance for all wavelengths as water depth increases, which is contrary to the stronger decrease that would be expected at higher wavelengths for the case of bottom reflectance. This and the fact that these high NIR reflectances are not found in the in situ reflectance measurements and are found also on places where the bottom is not visible, suggests that bottom reflectance cannot explain entirely the abnormally high reflectance found for these wavelengths.

According to the alternative hypothesis of adjacency effects [5] (also called environmental stray light), some of the light reaching the sensor along the viewing direction for a water pixel could arise not from the water pixel itself but from an adjacent land pixel after small angle forward scattering in the atmosphere. An alternative and similar effect could arise in the absence of atmospheric scattering from imperfect blocking by the sensor of light outside the instantaneous field of view [6], though it is thought that the CHRIS sensor is sufficiently focused to avoid such effects and that this is less likely than environmental stray light.

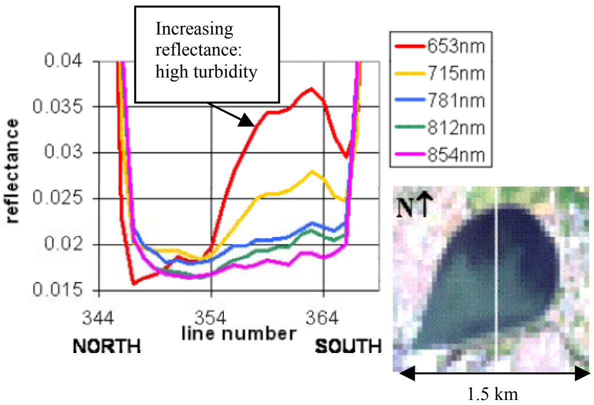

Fig. 8: Profile of CHRIS reflectance across the Spuikom from North to South along the white line.

The rapid and similar decrease of near infrared reflectances going away from the shore of the lake is consistent with a decrease in atmospheric forward scattering (for increasing scattering angle) (Fig.8).

3.3. Total Suspended Matter maps of the Spuikom

Total suspended matter (TSM) maps are calculated from the water leaving reflectance (ρ_w) based on Eq. 1

$$SPM\,(g/m^3) = B_Q + A_Q * \frac{\rho_{w,670nm}}{0.187 - \rho_{w,670nm}} \quad (1)$$

where A_Q and B_Q are wavelength dependent and calibrated using the method of [7]. For the production of TSM maps the wavelength 670 nm was chosen with A_Q = 81.43 g/m³ and B_Q = 4.50 g/m³.

In Fig. 6 it can be seen that the CHRIS reflectance at 670 nm is similar to the TriOS reflectance. This results in similar estimates of TSM concentrations (table 1). Total suspended matter maps derived from CHRIS imagery of 6 July 2006 are shown in Fig. 9 for 3 different viewing angles. The variation between the calculated TSM concentrations, (both from the TriOS reflectance and from CHRIS imagery) and the in situ TSM measurements is smaller then the target 30 percent which means that the TSM maps derived from CHRIS imagery give a realistic representation of the reality (table 1) in this case.

Table 1: Comparison of the calculated and measured total suspended matter concentrations (mg/l) in the 3 measurement points in the Spuikom.

	CHRIS FBZ=-36° (670 nm) image C	CHRIS FBZ= 0° (670 nm) image A	CHRIS FBZ=36° (670 nm) image B	TriOS (670nm)	In-situ
SP2	23.48	23.41	23.69	24.00	Rejected by QC
SP1	19.83	19.95	19.21	18.35	25.5
SP3	16.41	15.28	13.04	14.45	14.67

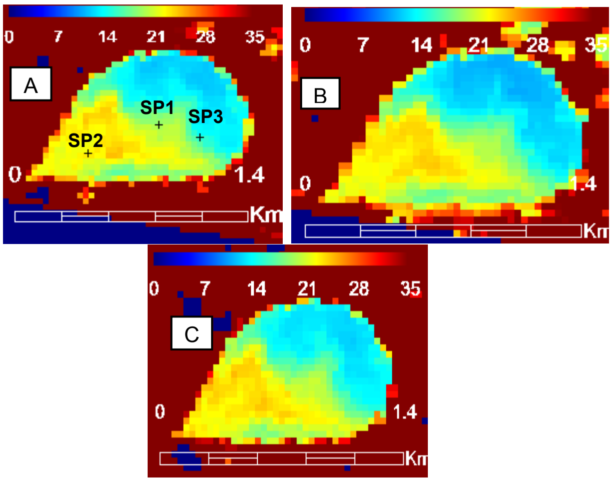

Fig. 9: TSM maps derived from CHRIS imagery of 6 July 2004 with fly-by zenith angles and observation zenith angles for image A=0° and 24.88°, image B=36° and 31° and image C= -36° and 35.88°.

Chlorophyll concentration is calculated by applying Eqs. 2-4 based o the work on [8].

$$b_{b0} = 1.2 * 2.69 m^{-1} * \frac{\rho_{w,778nm}}{0.187 - \rho_{w,778nm}} \quad (2)$$

$$\gamma = \frac{\rho_{w,708nm}}{\rho_{w,664nm}} \quad (3)$$

$$CHL(mg/m^3) = \frac{1}{0.0146 m^2 mg^{-1}} * \left[\gamma * (0.699 m^{-1} + b_{b0}) - 0.402 m^{-1} - b_{b0} \right] \quad (4)$$

However mapping of chlorophyll concentrations in the Spuikom needs more research as the values retrieved for CHRIS imagery unreliable (Fig. 10, table 2).

Table 2: Comparison of the calculated and measured chlorophyll concentrations (µg/l) in the 3 measurement points in the Spuikom.

	CHRIS FBZ=-36°	CHRIS FBZ= 0°	CHRIS FBZ=36°	TriOS	In-situ
SP2	11.36	9.24	6.55	3.24	7.07
SP1	10.51	8.48	7.71	2.64	2.6
SP3	15.46	16.13	18.28	1.71	2.65

Calculated chlorophyll concentrations reaches near the shore values of 50 µg/l and more. This could be due to a combination of too simple atmospheric correction, spectral noise, adjacency effects and maybe bottom reflection.

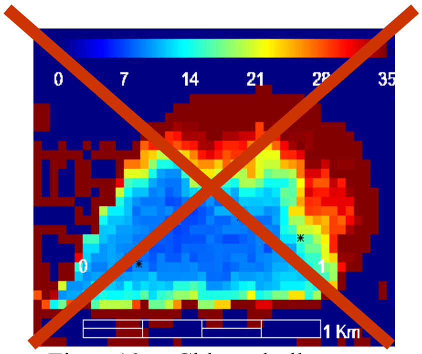

Fig. 10: Chlorophyll map derived from CHRIS imagery of 6 July 2004 with observation zenith angles = 24.88°

4. FUTURE PLANS: BRADEX

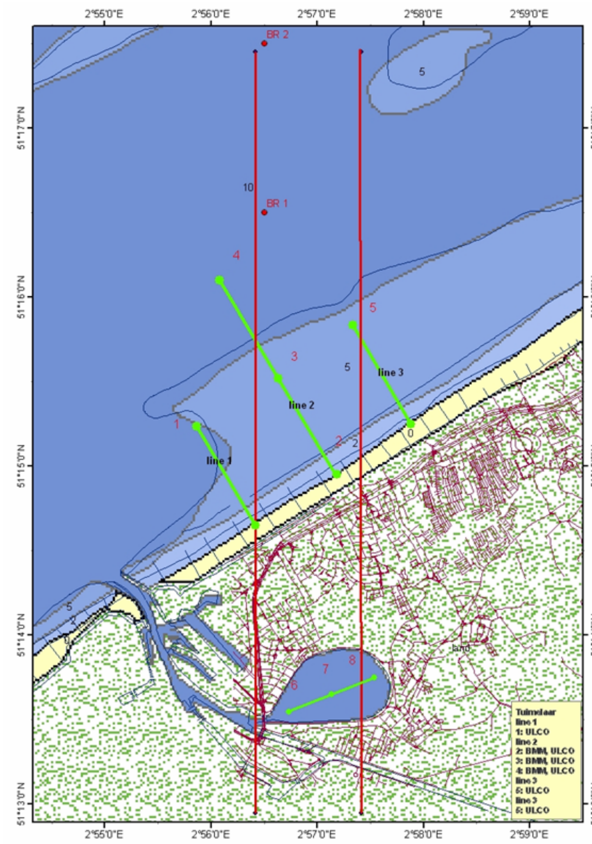

Fig. 11: Measurement plan of the BRADEX project.
Red lines = flight lines for the AHS 160 hyperspectral reflectance measurements
Green lines = ship track for water leaving reflectance measurements
Green dots = sampling points

MUMM is coordinator of the Bottom Reflection and Adjacency Effects Experiment (BRADEX) for Belgian coastal and inland waters. This small project aims to improve the scientific basis for processing of optical remote sensing imagery in shallow coastal and inland waters, where bottom reflectance and/or adjacency effects (also called environmental straylight) may be significant. Through BRADEX a benchmark dataset will be acquired for developing and testing algorithms for detection and correction of bottom reflectance and adjacency effects in optical remote sensing imagery. In June 2005 hyperspectral airborne reflectance measurements will be made by VITO using the AHS 160 instrument over the Spuikom and Oostende coastal waters (see Fig. 11) in combination with in situ measurements of water leaving reflectance, TSM, Chlorophyll and secchi depth. Atmospheric measurements will be made by the Université du Littoral Côte d'Opale. CHRIS images will be an important component of this dataset and could help considerably to test adjacency effect algorithms.

5. CONCLUSIONS

The newly processed CHRIS imagery is the result of an improved calibration by Sira. The abnormally high reflectance measured at 411 nm before reprocessing has disappeared and some irregular peaks in the reflectance spectra are now smoother. In the near infrared there is a small increase of reflectance.

CHRIS reflectance spectra in the Spuikom, a small inland water body in Oostende, show remarkably high near infrared reflectances which tend to be highest near the shores of the lake. This is probably caused by adjacency effects, although bottom reflection can not be excluded completely. In June 2005 a measurement campaign is planned to set up a database for developing and testing algorithms for detection and correction of bottom reflectance and adjacency effects in optical remote sensing imagery. CHRIS imagery is a useful addition to this dataset and can be used to test adjacency effect algorithms eg. for MERIS.

These adjacency effects have no significant influence on the total suspended matter mapping of inland water bodies from CHRIS data which proved to be reliable. For chlorophyll mapping the influence may be more significant when near infrared bands are used.

6. ACKNOWLEDGEMENT

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7. REFERENCES

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