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CHRIS/PROBA SUPERSPECTRAL DATA FOR INLAND WATER QUALITY STUDIES

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ABSTRACT

Remote Sensing techniques have been used for various environmental research with increasing frequency for last years. Specialised environmental satellites are placed on the Earth's orbits and dedicated to specified investigations. The current technology trends to placing of small, compact satellites, which are to perform particular tasks. One of examples is the PROBA Mission, financed and managed by the European Space Agency (ESA). The superspectral scanner, placed on its board, allows acquisition for investigations of the natural environment, performed with increased accuracy. The paper presents the current progress and the first results of the CHRIS/PROBA experiment for the MAZURY Test Site, which has been included in the MEMAMON Project (MONitoring of the Mecklenburg and Masurian Lake Districts) carried out by the GFZ Potsdam.

Keywords: CHRIS/PROBA, superspectral data, water quality

INTRODUCTION

Increasing of spatial and spectral resolution of remote sensing data facilitates monitoring, evaluation and analysis of changes, which occur in various ecosystems. In the case of terrestrial measurements of water quality (limnological and hydrobiological parameters) we always deal with point measurements, the frequency of which is very low and it is often insufficient for many analyses. On the other hand remote sensing techniques allow to acquire information of the continuous nature in space and repeatable in time, what, in turn, allows to perform real monitoring of changes, which occur in various ecosystems.

Quality investigations of surface waters, which use satellite data have been performed all over the world in order to improve methods of water quality monitoring, but works, which have been performed, concerned utilisation of multispectral, broadband data of Landsat MSS and TM, SPOT XS, and IRS 1C type. The analysed group of parameters, which characterise the surface water quality, was limited to the basic, general parameters. Such limitation was the result of the low number of recorded spectral bands and of their broadband nature. With the increase of precision of determination of spectral characteristics of objects, super- and hyperspectral data should also improve the possibility to determine additional water quality parameters and their relations with the structure of the catchment area.

Investigations of usefulness of hyperspectral data for various analyses, which concern the natural environment, including inland and coastal waters, have been performed recently all over the world. Satellite systems, which allow to acquire photographs in several or in several dozens of spectral bands, include, among others ASTER/TERRA, MODIS/TERRA, MERIS/ENVISAT and CHRIS/PROBA. The majority of such systems acquire photographs in one, nadir position of a scanner. However, the latter sensor, CHRIS/PROBA, is a new generation system. Such systems acquire superspectral and narrow band data under different view angles, what should eliminate influences of the illumination angle and directional reflectance on the intensity of radiation reflected by the Earth's surface. Besides, the CHRIS acquires data in various modes of operation, which are specially adapted to investigations of the land surface, waters and atmospheric aerosols. Such data allows to obtain quasi-continuous spectral characteristics of analysed objects, with consideration of their diversified nature.

Uniqueness of remote sensing CHRIS/PROBA data, which was already mentioned, allows to perform investigations, which could not be performed before basing on satellite photographs. Utilisation of such data for evaluation and analysis of water quality parameters is an important step toward operational use of remote sensing.

CHRIS/PROBA MISSION

The PROBA Mission, i.e. The Project for On-Board Autonomy is the mission of the European Space Agency, financed within the ESA's General Support Technology Programme. The PROBA Project is managed and coordinated by the ESA (Control and Data Systems Division, Department of Electrical Engineering). The Project was started in the middle of 1998 and on October 22, 2001 the PROBA satellite was placed on the Earth's orbit with the use of Antrix/ISRO PSLV-C3 rocket, launched from Sriharikota station in India. At the beginning the mission was planned for one year, but it has been still operating and even the next mission, PROBA 2 is planned, which is to be placed on the orbit in 2005. IN general, it is to be the continuation of the improved PROBA technology, but the PROBA 2 Project assumes successive miniaturisation of the satellite.

PROBA is a small satellite, weighting 94 kg; its dimensions are 60×60×80 cm. It moves on the polar, Sun-synchronous orbit (inclination 97,9o), at the altitude of 561-681 km above the Earth's surface, with the period of 96-97 minutes. After 16 days the satellite flies through the same location on the orbit.

Eight instruments are placed on the board; its total weight equals to 25 kg. They are: CHRIS – Compact High Resolution Imaging Spectrometer, HRC – High Resolution Camera,WAC – Wide Angle Camera, SREM – Space Radiation Environment, DEBIE – Debris In-orbit, SIPs – Smart Instrument Points, MRM - Miniaturised Radiation Monitor, PASS - Payload Autonomous Star Sensor.

CHRIS COMPARED TO OTHER SATELLITE SENSORS

CHRIS, i.e. the **C**ompact **H**igh **R**esolution **I**maging **S**pectrometer is a compact device, which weights about 15 kg. It was specially designed for environmental investigations. In the case of CHRIS it is possible to programme the area to be registered, as well as spectral channels to be used, which may be specially selected depending on the subject of investigations.

Moving on the orbit of the average altitude of 600 km, CHRIS acquires images on a swath of the approximate width of 14 km with the average spatial resolution of 18×18 m. This value is slightly changing as a result of variations in the orbit altitude, which varies between 561 and 681 km, with the nominal scanner field of view of 1.3^{o}.

CHRIS images are normally acquired as a set of five scenes of the same fragment of the Earth's surface recorded along the track, for different view angles, in an „almost-real" time. (2-3 minutes).

CHRIS acquires images with 12-bit sampling, for the spectral range between 410 nm and 1050 nm; it is possible to achieve 63 spectral bands with the spatial resolution of 36×36 m or 18 spectral bands with the so-called, full spatial resolution, i.e. 18×18 m. Spectral resolution varies from 1.3 nm for 410 nm to 12 nm for 1050 nm and it depends on wavelengths of the electromagnetic radiation.

The discussed scanner is a highly "flexible" instrument; many variants of acquisition of spectral bands allows for its better utilisation for many purposes. In the case of higher spatial resolution it is possible to acquire images in the following modes: „Land/Aerosols" (18 bands marked as L), „Water" (18 bands marked as W), „Chlorophyll" (18 bands marked as C) and „Land" (36 bands marked as H, acquired for a half of the nominal band of scanning). The variant of lower resolution includes 36 spectral bands, marked as A („All sites" in English). In the case of data acquisition dedicated to investigations of water, CHRIS acquires more visible spectral bands than in the case of data registration for the needs of land investigations (Table 1). Only three spectral band fall within the infrared radiation.

Table 1: Spectral ranges registered by CHRIS Scanner in the „Land/Aerosols" and „Water" modes.

Band	λ_{min} [nm]	λ_{max} [nm]	dλ[nm]
L1	438.0	446.8	8.8
L2	485.6	494.8	9.2
L3	525.6	534.2	8.6
L4	546.4	556.1	9.7
L5	566.3	573.4	7.7
L6	626.6	636.0	9.4
L7	655.8	666.3	10.5
L8	666.3	677.2	10.9
L9	694.3	700.1	5.9
L10	700.2	706.2	6.0
L11	706.2	712.4	6.2
L12	738.2	745.0	6.8
L13	745.0	751.9	6.9
L14	773.3	788.4	15.1
L15	863.1	881.3	18.3
L16	890.7	900.2	9.5
L17	900.2	909.8	9.7
L18	1002.7	1035.5	32.9

Band	λ_{min} [nm]	λ_{max} [nm]	dλ [nm]
W1	405.6	415.2	9.6
W2	438.0	446.8	8.8
W3	485.6	494.8	9.2
W4	504.5	514.8	10.3
W5	525.6	534.2	8.6
W6	556.1	566.3	10.2
W7	566.3	573.4	7.7
W8	584.6	596.4	11.8
W9	617.5	626.6	9.0
W10	645.7	655.8	10.1
W11	666.3	677.2	10.9
W12	677.2	682.8	5.6
W13	682.8	688.5	5.7
W14	700.2	712.4	12.2
W15	751.9	758.9	7.0
W16	773.4	788.4	15.0
W17	863.1	881.3	18.3
W18	1002.7	1035.5	32.9

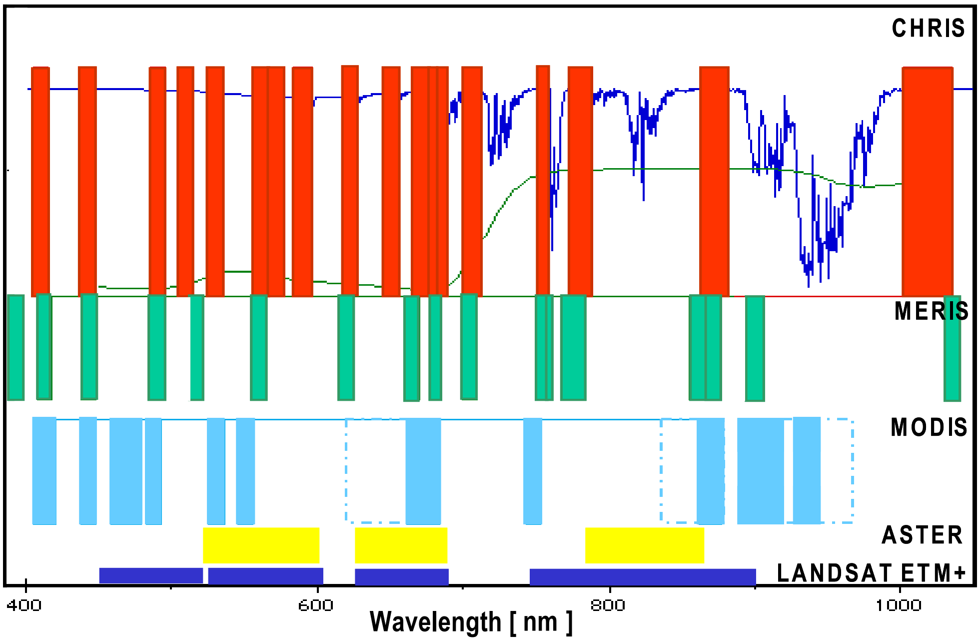


Figure 1: Comparison of spectral ranges registered by selected multi- and superspectral satellite sensors.

Comparing to other multi- and superspectral scanners, which are currently used on the Earth's orbits, CHRIS scanner also seems to be very useful for investigations of surface water properties. In general, it has more spectral bands, which are useful for those applications (Figure 1). What refers to the spectrum of recorded radiation and the number of spectral bands, it may be compared to MERIS scanner (Placed on board of ENVISAT satellite), but it has worse spatial resolution, 300×300 m. Such spatial resolution results in a general view concerning the water quality in the case of investigations of lake waters, and it does not allow to perform more accurate analyses. The similar situation occurs in the case of MODIS/TERRA scanner. The spatial resolution of 250×250 m allows, in general, to perform investigations of sea coastal and oceanic waters.

CHRIS has another feature, which may turn to be useful. It is data registration in five scanner positions, what has been already mentioned; this feature allows to perform atmospheric correction with high reliability, and this should allow to achieve results, which better represent properties of terrestrial objects.

4. POSSIBILITIES TO DETERMINE LAKE WATER PARAMETERS BASING ON SUPERSPECTRAL CHRIS DATA

Possibilities to use CHRIS data for investigations of lake water quality are the subject of a research project, performed within the frames of the Research Project no **5 T12E 006 24** financed out of funds of the Committee for Scientific Research, which is implemented in co-operation with ESA and GFZ Potsdam. A fragment of the Masurian Lake District, located between the geographic coordinates 53°56' N, 53°48' N and 21°22' E, 21°34' E has been selected as the test site for this project (Figure 2).

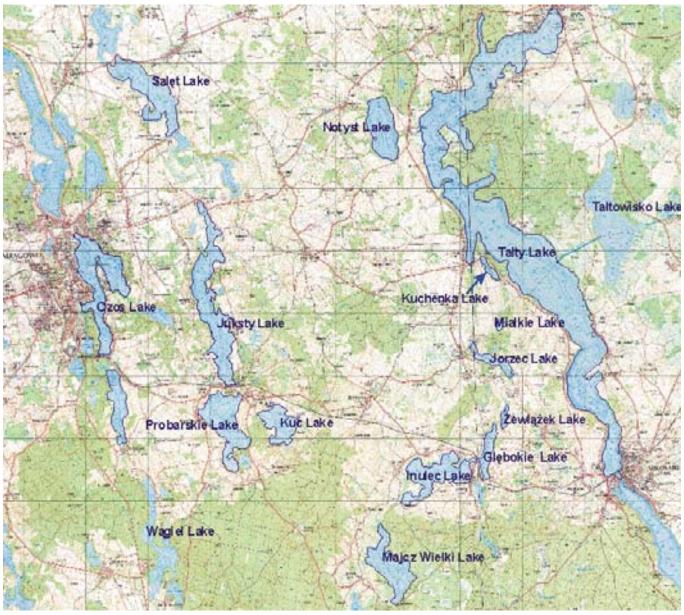


Figure 2: „Mazury" test site.

The area of investigations is characterised by occurrence of lakes of diversified size, depth and trophic features, as it is also the case in other lake districts. Catchment areas of water reservoirs are characterised by hummocky terrain relief, composed of post-glacial materials, such as: loams, loamy sands and sands. The lowest point is located on the bank of Tałty Lake – 116 m above the sea level, and the highest point is situated between the villages of Użranki and Zalec – 186.5 m above the sea. The land use structure includes about 80% of agricultural areas: arable lands and meadows, and about 20% of forests.

The investigated lakes belong to the group of large lakes – about 600 ha (Tałty and Ryńskie Lakes), medium-size – about 100 – 330 ha (Inulec, Notyst, Salęt, Czos, Wierzbowskie, Probarskie, Kuc and Majcz Wielki Lakes), small lakes – about 40 ha (Jorzec, Głębokie), as well as very small lakes – about 5 – 15 ha (Miałkie, Kuchenka). The deepest lakes (deeper than 30 m) are: Ryńskie, Tałty, Czos, Głębokie and Probarskie Lakes and the most shallow lakes (about 10 m and less) are Inulec, Zełwążek, Kuchenka and Miałkie Lakes.

The „Mazury" Test Site was classified in 2003 by the ESA as a priority area for acquisition of CHRIS satellite images. However, the weather during two recent measurement seasons did not permit to acquire at least three cloud-free images for that area, in periods which were important for limnological purposes.

Together with acquisition of satellite images, *in situ* measurements are performed, which concern the oxygen content in water, water temperature and Secchi disk transparency, as well as taking surface water samples (0-25 cm) for further testing. Geographical coordinates are measured by means of a GPS receiver for each point of water sampling. Measurements of the oxygen content in water are performed by means of an oxygen probe produced by the WTT. Hydrobiological and chemical analyses of water samples are performed by the Field Station of the Centre for Ecological Investigations of the Polish Academy of Science (PAN) in Mikołajki.

The following parameters are determined for non-dripped samples:

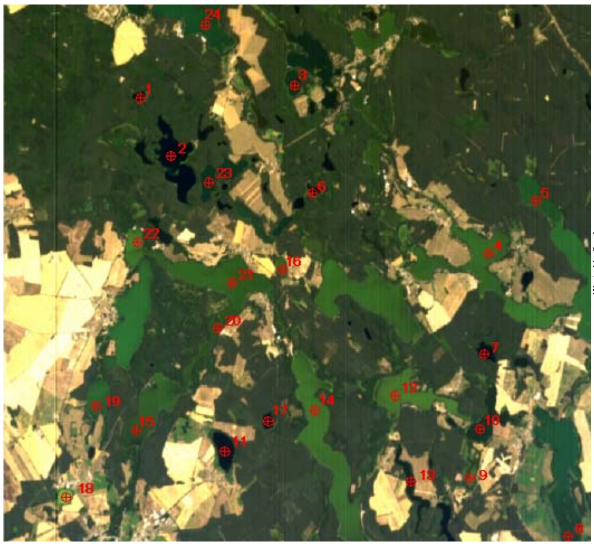
- Chlorophyll-a concentration (or pheophytin) by acetone method,
- Concentration of suspended matter by weight-and-filter method,
- Concentration of total phosphorus by the method of extraction in perchloric acid and by the colorimetric method,
- Concentration of total nitrogen by the method of extraction in sulfuric acid and by the colorimetric method.

The following parameters are determined for samples filtered by the mineral Whatmann GF/C filter:

- Concentration of mineral phosphorus by the colorimetric method,
- Concentration of nitrates by the colorimetric method.

The investigations performed aim at development of the methodology of determination of various parameters which characterise the lake water quality basing on remote sensing data. Selection of data processing methods for CHRIS superspectral images, which would allow to obtain the possibly most reliable values of parameters, which describe the water quality in inland water reservoirs is particularly important for further utilisation of results obtained. Those parameters may be later utilised for modelling and forecasting of changes in water reservoirs. Therefore, it is also important to perform appropriate atmospheric corrections; in the case of CHRIS data the existing, advantageous conditions allow to perform that process.

The first results of analysis of lake water quality, which have been obtained for another test site, are promising. As it was mentioned, due to atmospheric conditions, it was not possible to acquire a complete set of images for the „Mazury" Test Site. Therefore, testing for the season of 2003 was mainly performed for „Rheinsberg" Test Site, located in Meklemburg in Germany.



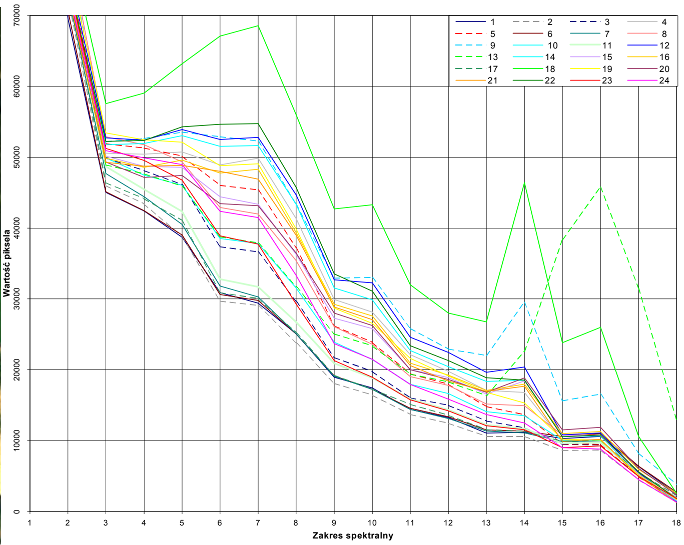


Figure 3: The colour composite (RGB=W10 W7 W4) based on data recorded on August 10, 2003 with spectral characteristics of selected lakes within the „Rheinsberg" Test Site (W1 spectral band has been excluded due to high signal noise).

The basic analysis which may be performed using a set of superspectral images is analysis of spectral characteristics; it is presented in Figure 3 above. High variability of lake water colours may be already observed on a colour composite, which contains information from three spectral bands only (RGB=W10 W7 W4).

This variability is further stressed by spectral characteristics. It is very well visible that the highest diversification of water properties occurs in green and red parts of spectrum. Since the blue part is highly influenced by radiation scattered by particles suspended in the atmosphere, differentiation of values recorded by the scanner is low. The channel W1 has been excluded from graphical presentation since utilisation of this channel resulted in low readability of the diagram.

In the infrared parts of spectrum very low reflection from the water surface is usually visible. Considerably higher values of reflection of radiation, comparing to other places, may be observed only in two cases. Those lakes are probably characterised by water blossoming, which results in high reflection in near infrared bands. Index processing performed for various bands within the green and red parts of spectrum also leads to interesting results. At present, works concerning detailed analysis of obtained results are performed.

Typically eutrophic lakes located within „Rheinsberg" Test Site are: Bramin, Dollgow and Schmidt. Wumm Lake is a typical, oligo-and-mezotrophic lake of the depth of 36 m. Zootzen and Zechlin Lakes are mezotrophic lakes. Other lakes located within the discussed area are in intermediate phases. Figure 4 presents those features very clearly. That figure presents results of principal component analysis.

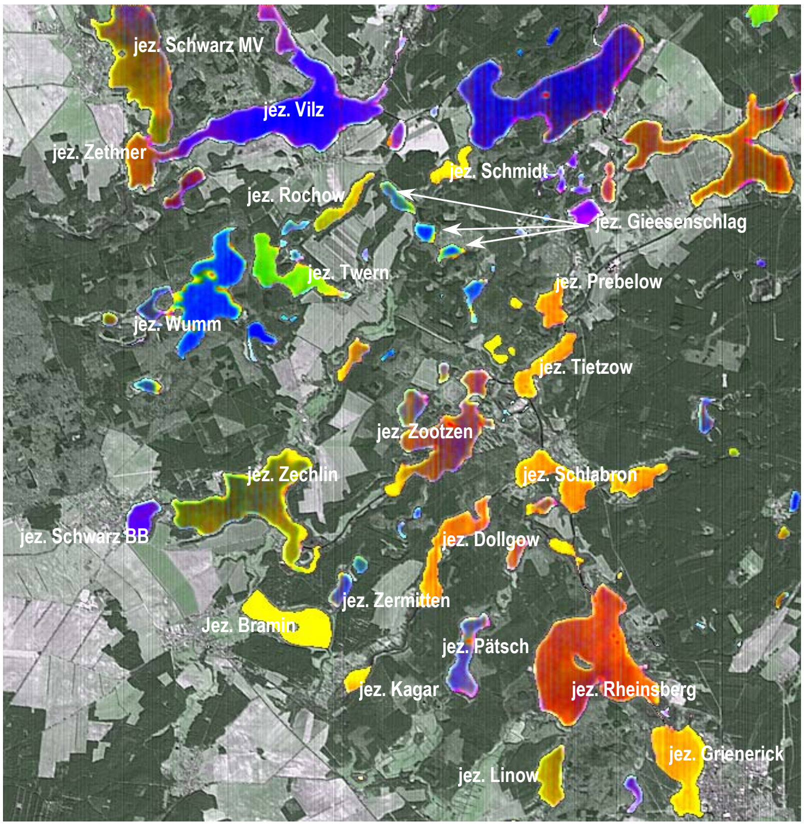


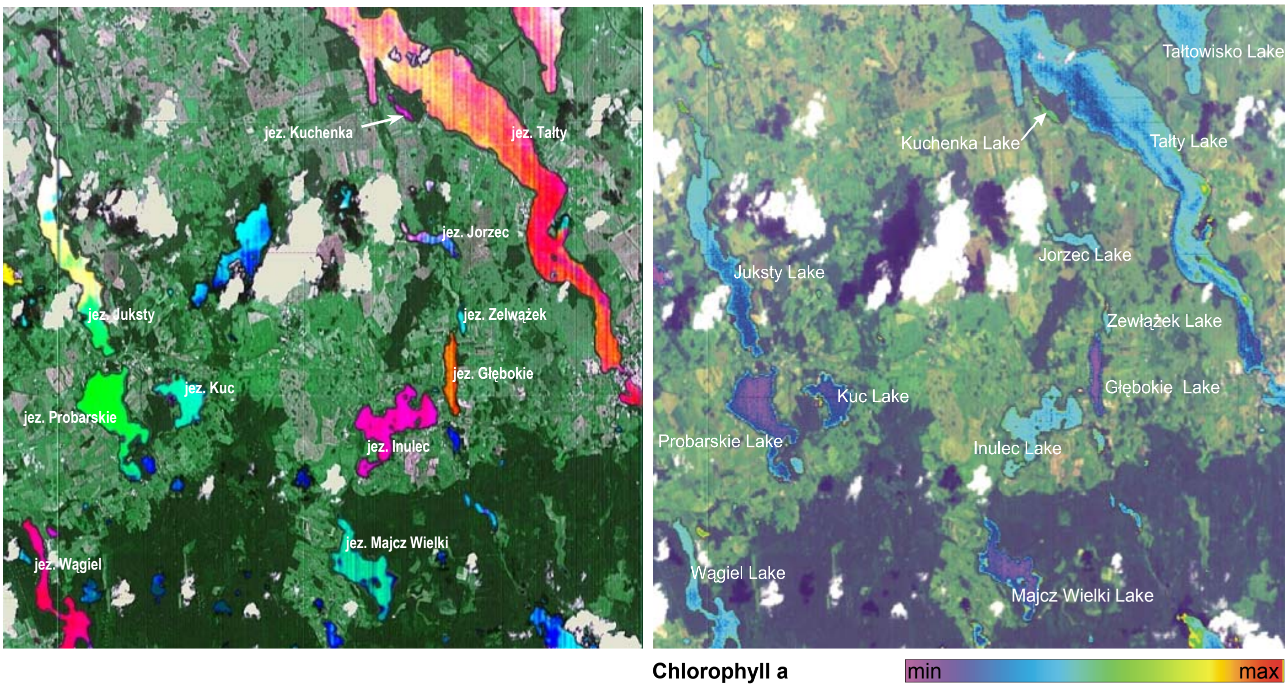
Figure 4: The „Rheinsberg" Test Site – processing of visible bands of CHRIS superspectral images recorded on April 23, 2003, which stresses diverse properties of lake waters.

At present, satellite images for „Mazury" Test Site are processed and analysed. Preliminary results are illustrated in Figure 5. It presents an image acquired on August 4, 2004, processed according to the methodology which aimed at stressing diversification of spectral characteristics of lake waters.

The global approach to statistical analyses of images, covering both, lands and lakes, screens subtle variations in spectral characteristics of waters. Separation of objects of LAND/WATER types is possible with the use of near infrared bands (W15, W16, W17 and W18) and may be performed by means of various processing techniques. It may be achieved, among others, by unsupervised classification (clustering) or masking with the use of infrared spectral bands.

Detailed analysis was performed for separated areas of waters. At the beginning, W1 and W2 spectral bands were rejected; the level of instrumental noise for those bands was unacceptable. W16 and W17 bands were also rejected; high scanning error values and saturation of detectors occurred for those bands. Other channels (11 spectral bands) were processed by Hotteling (PCA) method; orthogonalisation of the variance-covariance matrix was only performed for fragments of images covering lakes. Five PCA components contains more than 99.5% variance of input data. The following figure 5a presents the composite of the first three components of PCA procedure. Figure 5b shows chlorophyll-a distribution (August 4, 2004) calculated based on satellite data.

Table 2 includes parameters, which were measured *in situ*.



a. *b.*

Figure 5: The „Mazury" Test Site – processing of visible bands of CHRIS superspectral images of August 4, 2004.

Table 2: Chosen measurement data of lakes investigated within „Mazury" Test Site (26.08.2004).

Lake	Maximum depth [m]	Mean depth [m]	Secchi disk transparency [m]	Chlorophyll a concentration [mg/l]	Suspended matter [mg/l]	O_2 [mg/l]	**Total phosphorus** [mg/l]	**Trophic state**
Tałty	44.7	15.6	1.75	3.8 – 35.0	3.6 – 5.2	8.05	36-48	Eutrophic
Miałkie	2.7	1.0	1.40	33.9	5.2	5.0	47	Eutrophic
Kuchenka	4.5	1.9	1.00	35.3	-	8.4	-	Hipertrophic
Jorzec	11.6	5.5	1.50	16.9	3.6	7.8	57	Eutrophic
Zełwążek	7.4	3.7	2.30	19.7	4.0	7.6	51	Eutrophic
Głębokie	34.3	11.8	2.20	0.6	2.8	9.1	25	Eutrophic
Inulec	10.1	4.6	1.50	16.9	5.2	5.5	44	Eutrophic
Probarskie	31.0	9.2	4.1	7.1	0.8	8.6	19	Mezotrophic b[2]
Kuc	28.0	8.0	5.4	0.6	1.2	7.9	19	Mezotrophic a[1]
Juksty	38.6	8.0	4.6	2.6	2.0	7.4	21	Mezotrophic b[2]

[1] mezotrophy a – similar to oligotrophy
[2] mezotrophy b – similar to eutrophy

As a results of applied CHRIS images processing the following lakes were distinguished very well: hipertrophic Kuchenka Lake, eutrophic Kuc lake, mezotrophic Probarskie and Juksty Lake as well as oligotrophic lakes. Further detailes analysis and satellite data processing are continued.

It turns out from literature analysis, the most useful for determination of the majority of parameters, which characterise the surface water quality, are, first of all, spectral bands of green and red parts of spectrum [among others Ritchie, Cooper, 1991; Ritchie, Cooper, 2001; Thiemann, Kaufmann, 2002]. Basing on analysis of spectral reflection of chlorophyll-a – one of parameters used for description of the lake water quality – it may be seen that it may be best determined with the use of radiation of the length of 650-690 nm. CHRIS registers four spectral bands in this interval; this should influence the increase of precision of description of that parameter.

CONCLUSION

Within research works, included in the international MEMAMON Project (MONitoring of the Mecklenburg and Masurian Lake Districts) in the seasons of 2003 and 2004, experiments concerning registration of CHRIS/PROBA satellite images for „Mazury" Test Site were undertaken. Unfortunately, of the and intensive cloud cover which occurs for this particular geographical latitude, results in great difficulties in this respect. Satellite passes about 10 a.m. often occur at the same time when cumulus clouds are developed. Decision concerning registration of images must be made at least 24 hours in advance; even in the case of advantageous weather forecasts such circumstances highly complicate data acquisition. Within three summer months it was theoretically possible to make 9 passes with satisfactory geometric features (satellite passing the centre of the test site), but due to cloud cover only three, partially clouded areas were recorded in 2004: on July 10, August 4 and August 11. Effectiveness of data acquisition may be increased by programming every of 9 satellite passes. In the case of the discussed project, only those passes, for which the limnological situation was interesting, were programmed. In the case of operational utilisation of satellite data such difficulties should be considered. Although, analysing the last 20 years, it is usually possible to register a satellite image at least for two acquisition dates, interesting form investigations of water quality.

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