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DESIGNING SATELLITE IMAGE ANALYSES FOR THE LAKE TANGANYIKA RESEARCH PROJECT

by

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PREFACE

The Research for the Management of the Fisheries on Lake Tanganyika project (LTR) became fully operational in January 1992. It is executed by the Food and Agriculture Organization of the United Nations (FAO) and funded by the Finnish International Development Agency (FINNIDA).

LTR's objective is the determination of the biological basis for fish production on Lake Tanganyika, in order to permit the formulation of a coherent lake–wide fisheries management policy for the four riparian States (Burundi, Tanzania, Zaïre and Zambia).

Particular attention are given to the reinforcement of the skills and physical facilities of the fisheries research units in all four beneficiary countries as well as to the build–up of effective coordination mechanisms to ensure full collaboration between the Governments concerned.

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LIST OF ABBREVIATIONS

AVHRR: Advanced Very High Resolution Radiometer
ESA : European Space Agency
GMT : Greenwich Mean Time
NDVI : Normalized Difference Vegetation Index
NOAA : National Oceanic and Atmospheric Administration
PC : Personal Computer
SPOT : Système Probatoire d'Observation de la Terre
TM : Thematic Mapper

1. INTRODUCTION

Remote sensing works is an important tool in FAO/FINNIDA Lake Tanganyika Research Project (LTR) as it will provide information of the spatial and temporal variations of surface water conditions of the Lake Tanganyika. In favourable conditions, this method enables to obtain data of lake temperature and it also gives, at the same time, indication of the relative vegetation index, all over the lake. This is not possible by any other field sampling programme. The image analysis, which needs to be calibrated with actual ground-truth measurements, can thus be used to estimate the relative physical and biological differences between the surface areas of the lake. Remote sensing gives also complementary data to other research sub-components of the LTR Scientific Sampling Programme (=SSP).

We hope to use remote sensing to observe the occurrence and extent of the expected upwelling events, especially at the southern end of the lake but also elsewhere. These observations will be related first to the hydrological model of the lake. Further, we also hope to use the images for areal comparisons between different parts of the lake and relate them to possible differences in its limnology and biological production at large. The two parameters we are employing now are surface temperature and the so-called vegetation index.

Satellite based remote sensing has been used in environmental research since the early 1970's. During the past few years, however, its use has been greatly expanded, partly due to the easier accessibility of satellite images and to the decreasing cost of acquiring them. Also, the imaging characteristics have been greatly improved during the past two decades.

One of the first tasks of this study was to find out the feasibility and suitability of different satellite sensors and their channels for LTR use. The other objective was to establish the methodology for analyses of satellite images and, accordingly, to process some sample images of Lake Tanganyika for preliminary investigation of the lake water dynamics. In this report, basics of satellite imagery are described. Further, the criteria for selection of NOAA AVHRR images as well as the first image analyses of Lake Tanganyika are given. Lastly, the initial results and future plans are discussed.

2. BASICS OF REMOTE SENSING

2.1 Basic aspects

In the satellite-borne remote sensing, the channels of images describe the distribution of the light reflected from the earth surface or the heat radiated by the earth. Each channel sees the earth through a narrow window in the electromagnetic spectrum. On the visible region of the spectrum, the satellite image corresponds to the situation where the globe was observed through a coloured filter. On the channels of the longest wavelengths the images give distribution of the surface temperature. In Figure 1, the absorption spectrum of chlorophyll *a* is given; in addition, the channel 1 as well as the beginning of channel 2 of the NOAA AVHRR imager are shown.

By properly designing the wavelength range for the satellite image channels, the desired results/information can be achieved. For example, in order to obtain an estimate of chlorophyll *a* concentration, one channel should be around the top of the chlorophyll absorption peak and another (reference) channel on the wavelength region where chlorophyll *a* has no effect. From Figure 1, one can see that the band at 650 – 680 nm could be the first channel and the other band could be located anywhere from 450 nm to 600 nm. In case of the NOAA satellites the spectral bands can not be chosen at will. Instead, they are fixed with only one band which is within the visible region of electromagnetic region as shown in Figure 1. This band covers a much larger band and thus includes information from other diverse vegetation as well. Therefore, all measurements from these images are referred to as indicating "vegetation" instead of chlorophyll *a*.

2.2 Satellite alternatives

Three of the present earth-orbiting satellites could be considered for LTR, *i.e.* Landsat, NOAA, and SPOT. The sensors of Landsat and SPOT satellites provide much better spatial and somewhat better spectral resolution but they overpass the lake less frequently than NOAA 11. NOAA 11 passes over the lake once around the noon (at 1:30 p.m., GMT) and once at midnight (at 1:30 a.m., GMT). Another drawback is that the images of Landsat and SPOT are much more expensive. Consequently, the NOAA AVHRR images were chosen. Some general characteristics of the AVHRR images of NOAA are given in Table 1.

Further reference on the basis of remote sensing as well as the characteristics of the satellite imagers are given in Lillesand & Kiefer (1987) and in Meaden & Kapetsky (1991).

The spatial resolution of NOAA AVHRR (1.1 km x 1.1 km) is not as good when compared to that of Landsat TM (30 x 30 m). But since the area of Lake Tanganyika is so large and as it lacks complicated shore lines and small islands the AVHRR resolution is good enough for the task. In Figure 2, an enlargement of one AVHRR-image is shown in order to provide an example of its spatial resolution. In Figures 3a through 3e all 5 channels of a NOAA AVHRR-imager are shown, separately.

Table 1.

The characteristics of the NOAA AVHRR images.

Channel	Wavelength (nm)	
1	580 - 680	(green - red)
2	720 - 1 100	(near IR)
3	3 550 - 3 930	(middle IR)
4	10 500 - 11 500	(thermal IR)
5	11 500 - 12 500	(thermal IR)

(1 000 nm = 1 micrometer)

Spatial resolution on the ground: 1.1 km x 1.1 km, at nadir

Passes over Lake Tanganyika: NOAA-11, NOAA-12

2.3 Sources of images

The NOAA AVHRR images can be obtained from two commercial sources *i.e.* from (1) Eurimage in Frascati (Rome), Italy which cooperates with the European Space Agency (ESA), and from (2) Satellite Applications Centre in Pretoria, South Africa. The UK/SADC Lake Fisheries Project on Lake Malawi used to receive the AVHRR images by its own receiver and it may be possible to obtain some images from that project, for comparison.

All images for the LTR have been bought from Eurimage, and in addition, a set of images has now been ordered from the Satellite Applications Centre, Pretoria. In the images from Eurimage, the country borders as well as every fifth latitudinal and longitudinal line have been overlaid on the image (see an example in Figure 4).

3. SATELLITE IMAGE ANALYSIS

3.1 Vegetation index

Ideally, the satellite image analysis should be based on the original reflectance spectrum of the ground target. To determine an index (chl *a*) to describe the amount of chlorophyll *a* in one pixel of any image, one should calculate the object reflectances at 705 nm and 670 nm and then calculate the following ratio at that pixel:

$$chl\ a = \frac{R\,(705)}{R\,(670)} \tag{1}$$

The relation of this index to the concentration of chlorophyll *a* has been studied elsewhere and is well known.

As shown before, this computation is not possible when NOAA satellites are used due to restricted possibilities in selected channels. The wavelength widths of the channels are so large that the reflectance values on a specific wavelength cannot be determined. NOAA satellites have been constructed for weather forecasting but lately and despite of these limitations they have been also used for 'vegetation studies'.

Instead of formula (1) we have used in this study the formula:

(2) $$NDVI_1 = \frac{CH_2 - CH_1}{CH_2 + CH_1}$$

where NDVI is the so called "normalized difference vegetation index", and where CH_i is the intensity of the channel i in the satellite image (Los, 1993). Here channel 1 includes one absorption peak of chlorophyll *a* and channel 2 as a reference channel does not.

Two different methods were tested for the image calibration. According to the first one, the NDVI values are scaled to positive values by taking the darkest point (=lowest value) of the image in both channels as a scaling (=offset value) pixel. This is effectively one kind of atmospheric correction and is based on the principle that the radiance in at least one pixel in every image is equal to zero and thus the value in the lowest point is due to reflectance from the atmosphere. This method is not always reliable, since it is sometimes difficult to ascertain that the lowest value is not an erroneous one, artefact, or otherwise corrupted. Furthermore, this method gives only relative values of the NDVI.

The calibration tables from NOAA are used (Los, 1993) in the second method to determine the real pixel reflectances of the images:

(3) $$NDVI_2 = \frac{R_2 - R_1}{R_2 + R_1}$$

3.2 Lake surface temperature

The lake surface temperature is the other important attribute computed from the images. As stated before, it can be determined directly from the thermal channels of the satellite image. In the AVHRR imager, there are two thermal channels (channels 4 and 5). The spectral response curve is an important characteristic of each channel. A curve for the channels 4 for the AVHRR imager is shown in Figure 5.

When computing the actual temperature, it is important to know the functional dependence between surface temperature and surface radiance. For the AVHRR imager this dependence is almost linear for both of the two thermal channels. The radiance *L* can be computed from the pixel values (measured intensities) *N* with the equation (similar equation for each channel):

$$L_i = g_i N_i + o_i \tag{4}$$

where g_i is the gain and o_i is the offset for channel i of the measuring instrument. The temperature is related to the radiance by the following equation:

$$L = \int_{\nu_1}^{\nu_n} B(\nu) W(\nu) \mathrm{d}\nu \tag{5}$$

where *W* is normalised response function of a channel, υ_1 and υ_n are the radiation frequencies of the beginning and end of the channel (Lauritson *et al.*, 1979) and *B* is the classical Planck function:

$$B = \frac{2hc^2\nu^3}{e^{hc\nu/kT} - 1}$$

where h is the Planck constant, c is the speed of light, k is the Bolzmann constant and *T* is the temperature to be calculated by cumbersome iterative numerical methods. Alternatively, when the function W is known for a channel, values of *L* at different temperatures *T* can be calculated given thus numerically the function *L*=*L*(*T*), which may be tabulated and inverted to give *T*=*T*(*L*), *i.e.* temperature as a function of *L*, which is given by (4).

4. RESULTS

4.1 Vegetation index and surface temperature

Nine NOAA AVHRR images were obtained from Eurimage. The acquisition dates, times, and the scene Ids (Eurimage reference code) are shown in Table 2. The complete data in digital form are available at the Department of Applied Physics of the University of Kuopio, Finland.

For the data acquisition the hardware that includes Silicon Graphics UNIX workstation was set up at the University of Kuopio, Finland. The image processing software Khoros from the University of New Mexico was used. A personal computer has been used for graphics crafting and word processing.

To pre-process the images, C-programs were written. The necessary information was extracted from the files. The lake area was clipped out of the original images, which covered also large land areas around the lake. The computation of the NDVI and the temperature from the images as described above were executed with the aid of Khoros software.

The vegetation index, $NDVI_2$ (according to Eq. 3) and the surface temperature using the channel 4 and chiefly by Eq. 5 were computed from all the images received. The spatial distributions of the results calculated from the first entry in the Table 2 are shown in Figures 6 and 7.

The images also indicate that the central parts of the lake are rather poor on "chlorophyll", with 'green' belt extending in

Table 2.

The data information of images obtained from the Eurimage and the list of the images ordered from the Satellite Applications Centre. The list includes acquisition dates, times, and reference number of each organisation.

ESA/ESRIN, Frascati, Italy

Satellite	Date & Time		Scene id.
NOAA-11 AVHRR	29.06.1991	12:50	NB119106291250
NOAA-11 AVHRR	26.05.1992	13:18	NB119205261318
NOAA-11 AVHRR	03.06.1992	13:24	NB119206031324
NOAA-11 AVHRR	04.06.1992	13:12	NB119206041312
NOAA-11 AVHRR	23.07.1992	13:28	NB119207231328
NOAA-11 AVHRR	31.07.1992	13:33	NB119207311333
NOAA-11 AVHRR	11.09.1992	13:30	NB119209111330
NOAA-11 AVHRR	12.09.1992	13:19	NB119209121319
NOAA-11 AVHRR	19.09.1992	13:35	NB119209191335

SAC MIKOMTEK/CSIR,Pretoria, South Africa

Satellite	Date & Time		SAC Refer.
NOAA-11 AVHRR	29.07.1993 1:21		IDD93363-004
NOAA-12 AVHRR	12.08.1993	17:14	IDD93363-006
NOAA-11 AVHRR	19.08.1993 2:07		IDD93363-002

the littoral zone. It is further possible that nutrients enter the lake also with airborne dust.

4.2 Upwelling

Upwelling of waters is one interesting phenomenon which is under investigation in the satellite images. The only apparent upwelling image at the southern end of the lake is from June 29, 1991, with some secondary upwellings elsewhere in the littoral zone. In this case the apparent upwelling event can be seen in the vegetation index but not in the temperature pattern. In the images obtained in 1992 no such events were clearly observed. This may indicate that the upwelling event is a rare one, or its surface effects are modest at best, or they disappear quickly. Preliminary limnological and hydrological data indicate that the lake water may mix deeply even after a short high wind, but the stratification is also restored quickly, in matter of hours or days.

4.3 Cloudiness over Lake Tanganyika

Along with the study of NOAA AVHRR images mentioned above, the cloud cover over the lake during January-June 1991 was followed through the so called quick-look images of AVHRR at the European Space Agency (ESA), Frascati, Italy. The 1991 survey was based on images taken weekly between 1.1.1991 and 14.4.1991 and again between 5.6.1991 and 29.6.1991.

The 1993 images were obtained by Kuopio from the University of Edinburgh through Internet computer network. This source is based on the geostationary Meteosat satellite, which is located above the equator and which covers half of the globe including Africa. These "quick-looks" show roughly the target area and its cloud cover. An example of a Meteosat image is shown in Figure 8. The 1993 survey was based on the images taken every tenth day between 4.1.1993 and 7.6.1993. A subjective categorisation for both studies is given in Table 3.

Table 3.
A subjective categorisation of cloudiness over Lake Tanganyika in the spring 1991 and spring 1993.

	cloudy or very cloudy	moderate	clear
1991	14.1.– 8.3.	15.3.–14.4.	5.6.– 29.6.
1993	4.1.– 29.3.	19.4.–17.5.	28.5.– 7.6.

5. DISCUSSION

The results and preliminary interpretations of the analyses will have to be verified by measurements directly at the corresponding positions on the ground (="ground-truth data").

The seasonal window (*i.e.* clear sky) for satellite imaginary over Lake Tanganyika is generally from May through September, although occasional opportunities for cloudless days may also occur at other times. This is fortunate as it corresponds with the season when the upwellings are expected to occur.

The temperature results obtained through satellite images have not been yet checked with simultaneous "ground truth" measurements. The results are, however, of the right order (to the nearest degree of ′C) when compared to the temperatures recorded during the same month and what is indicated in the past literature. Our temperature results are based on the calibration of data and thus the reliability is also limited by the imager itself. More temperature data are also needed from night-time satellite passes to further complement the ground-truth data. We have now ordered night-time images from SAIC and they will be analyzed during the spring 1994.

The determination of "chlorophyll" is more problematic compared to the temperature. Instead of "chlorophyll" we are rather dealing with a vegetation index, which actually describes the reflective colour of the object (the object looks green, when red light is absorbed, Figure 1). The values of vegetation index are relative, since we have not yet used any calibration "ground-truth" data. The validity of this relative "chlorophyll map" will be clarified by the ground-truth comparisons. It is possible, nevertheless, that image correlations with actual chlorophyll *a* concentrations will be difficult, considering that the Secchi disc values in Lake Tanganyika may vary between 2 and 22 m. A priori there are some doubts about the possibility to detect chlorophyll *a* from the NOAA AVHRR images. Nakayama (1994), however, gives promising results of using AVHRR channel 1 for water quality monitoring.

An important source of errors, however, is the lack of the atmospheric correction, which has not yet been done. This atmospheric correction affects both the vegetation index and the temperature. The weather and climate over the long lake vary both daily and seasonally. The lake itself has a length of 650 km, and, therefore local meteorological data are needed to compare different regions of the lake. We shall rely on the meteorological stations of the LTR on and around the lake. Around these stations the calculated atmospheric corrections are expected to be most accurate.

The satellite data from the littoral zone shall be evaluated critically, since those pixels contain information both from the lake and the land.

For the moment we have established the routine analysis of the Eurimage images. We have also received images from the South African station, and we are setting up the analysis routine for them as different routine is required since the image format is different from that of Eurimage.

Despite much work done in the field of remote sensing and many methods developed for deriving information from the raw satellite image data, it is argued that the algorithms are not universal and that regional algorithms are required for getting the desired information in each specific case (Sullivan *et al.*, 1993).

To make ground truth measurements and validate the satellite image information, a measurement protocol will be defined. For the time being the images bought from the Eurimage are processed several weeks after their acquisition and thus they are not very useful at this phase of the study. It should be worthwhile to try to negotiate with Eurimage an agreement of faster delivery of some specified images. Another possible source of the images is in South Africa as they seem to be able to deliver the images faster. Therefore, the ground truth calibration should be based on images from this South African source. If the South African receiving station is able to produce the images according to their information, which states that any NOAA AVHRR image will be mailed within a few days, we can plan the concurrent ground truth and satellite measurements at will.

Since the sampling grid (the pixel size) in a AVHRR image is 1.1 by 1.1 km, the ground truth measurements should be related to this. Therefore, the distance between consecutive measurement points should be of the order of 500 m. If the conditions on the lake are stable, the time for measurements before and after the passing time of the satellite can be prolonged. On the average, the satellite image will be acquired from Lake Tanganyika at 3:30 p.m. and 3:30 a.m. (Burundian time). To get an exact fly-over time of the NOAA satellite, the project has a PC program, which can be used for planning the timetable.

The measurement scheme

The surface vegetation and temperature shall be measured over the 500 m x 500 m sampling grid and in several, distant locations over the lake from as many points as possible during the satellite fly-over. The area covered by these measurements depends on the lake surface stability and the vessel availability. There should be at least six 1.1 km x 1.1 km squares included. The measurements shall be done during the daytime fly-over around noon. The meteorological data shall also be recorded in the same time at the meteorological stations around the lake.

It should be possible to transform the images into some common coordinate system to combine the pixels in the image and the measurement points on the lake. For the moment, we are not able to do this but the software in the image analysis system is used for this purpose. The vessels on the lake use the accurate satellite global positioning system (GPS) for the navigation. The accuracy of the available charts and maps is, however, not the best one.

In the future, a more accurate measurement of the chlorophyll *a* in the lake surface shall be possible because the acquisition of more detailed spectrum of the ground surface radiation will be possible. This is made possible by the new environmental satellites, whose spectral accuracy due to the new imagers will be very high (Ustin *et al.*, 1991). The launchings of such satellites are expected to be accomplished at the end of the current decade.

Another current possible alternative in data acquisition is the spectrum measurement from an aeroplane. This can be realised using the presently known technology and along with the chlorophyll it would also give many other parameters about the lake surface. In this case, the waters next to lake shore could also be included in the measurements.

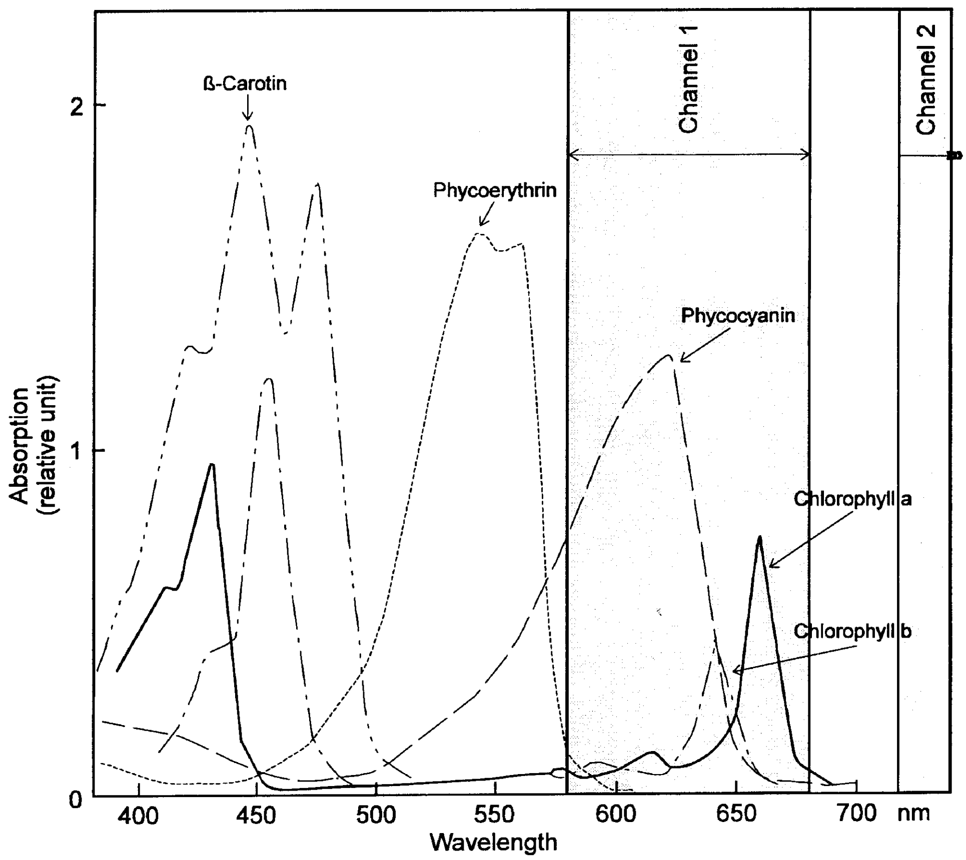

Figure 1. The absorption spectrum of the chloropyhll *a* (Hoppe W., *et al.*, 1978) and the NOAA AVHRR channels covering that spectral region.

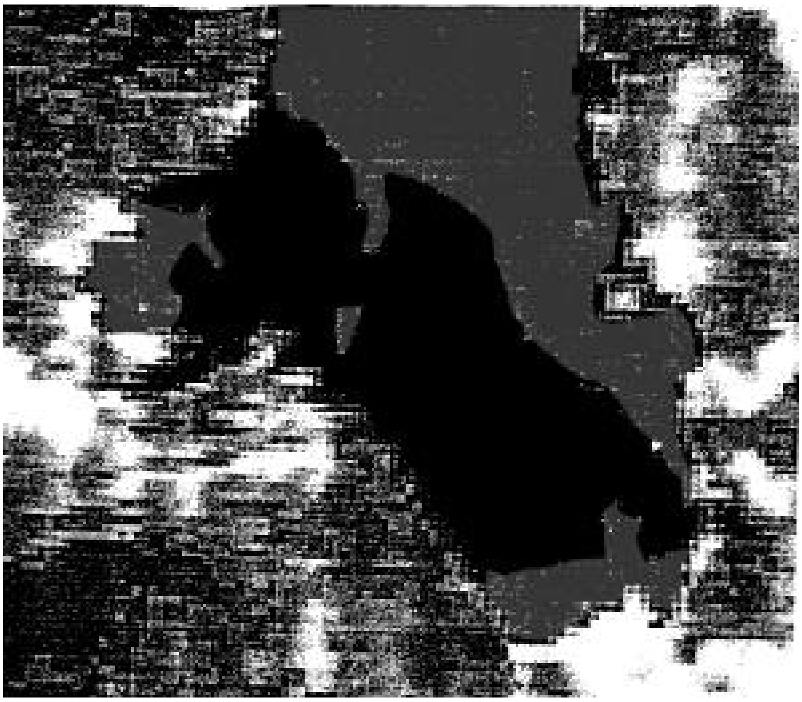

Figure 2. Enlarged NOAA AVHRR image of the southern part of Lake Tanganyika showing the actual spatial resolution.

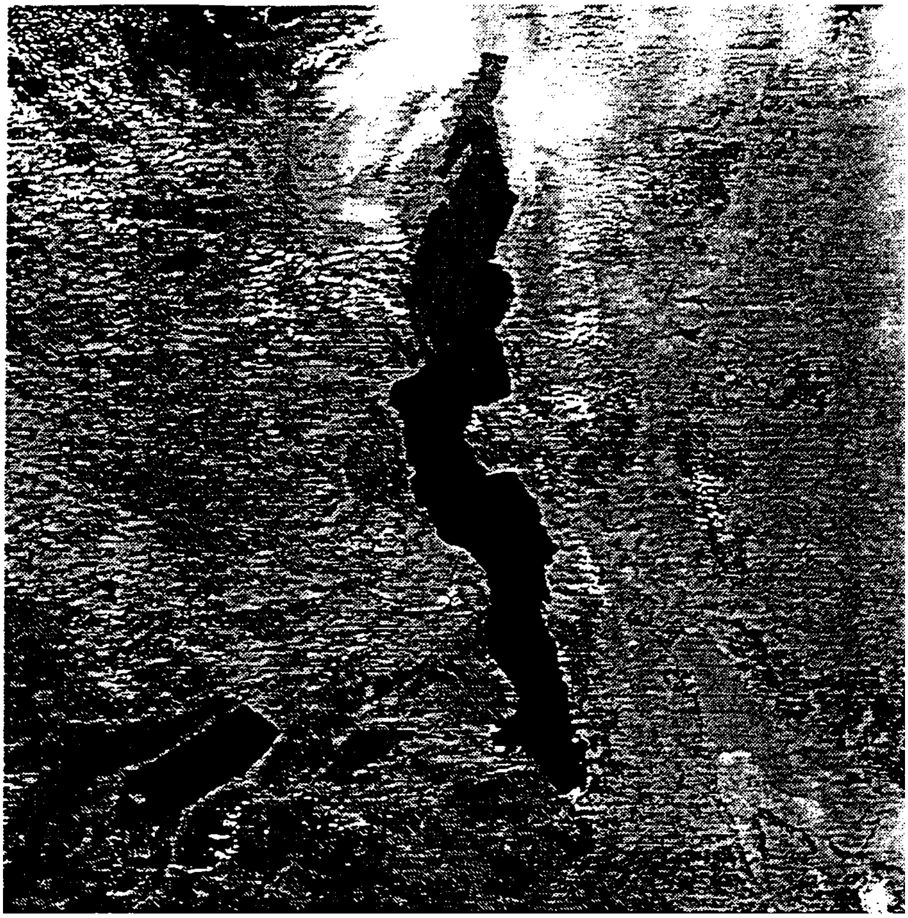

Figure 3a. The NOAA AVHRR image (Channel 1) of Lake Tanganyika (26.9.1991). (The image was delivered by Eurimage.)

Figure 3b. The NOAA AVHRR image (Channel 2) of Lake Tanganyika (26.9.1991). (The image was delivered by Eurimage.)

Figure 3c. The NOAA AVHRR image (Channel 3) of Lake Tanganyika (29.6.1991). (The image was delivered by Eurimage.)

Figure 3d. The NOAA AVHRR image (Channel 4) of Lake Tanganyika (29.6.1991). (The image was delivered by Eurimage.)

Figure 3e. The NOAA AVHRR image (Channel 5) of Lake Tanganyika (29.6.1991). (The image was delivered by Eurimage.)

Figure 4. Lake Tanganyika with the overlaid state borders and the 5th and 10th S latitude and the 30th E longitude (Source: Eurimage).

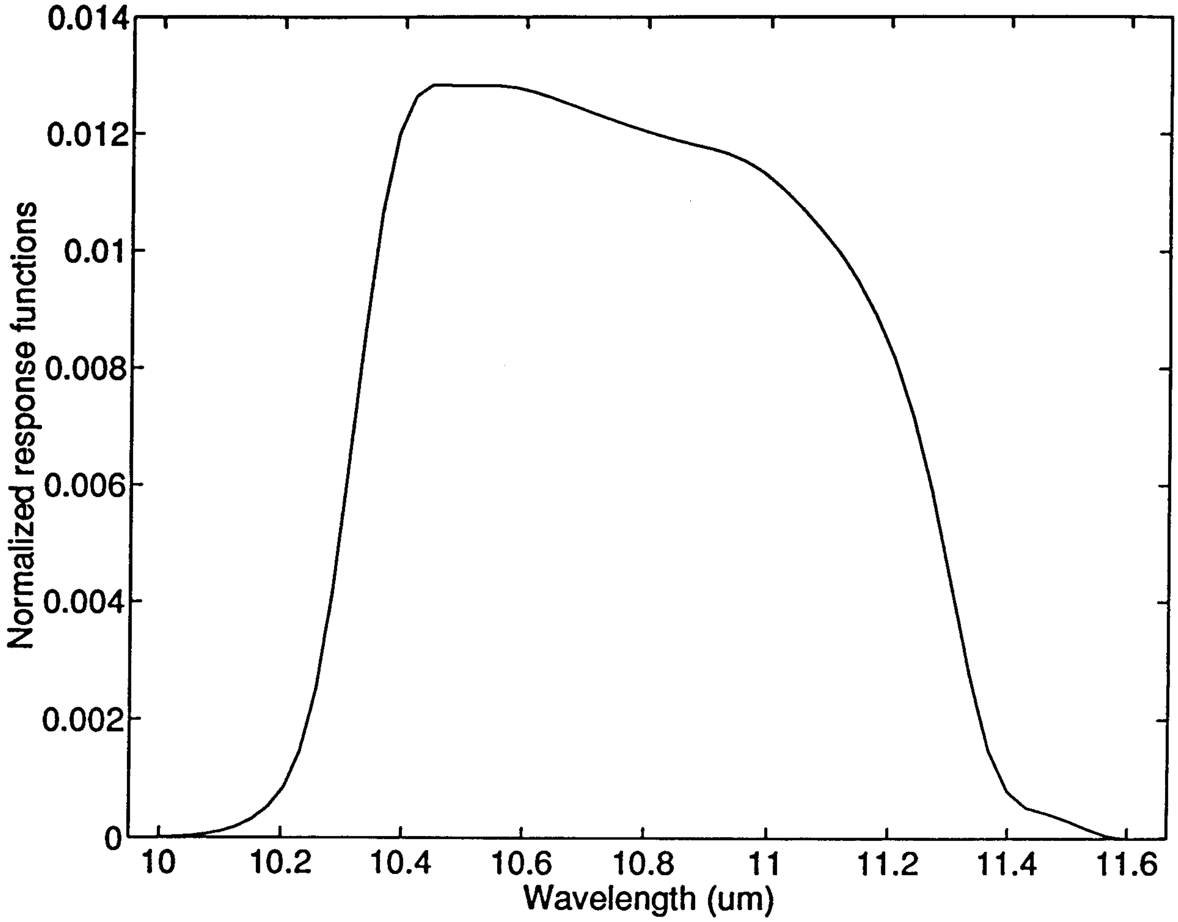

Figure 5. The spectral response curve for the channel 4 for the AVHRR imager.

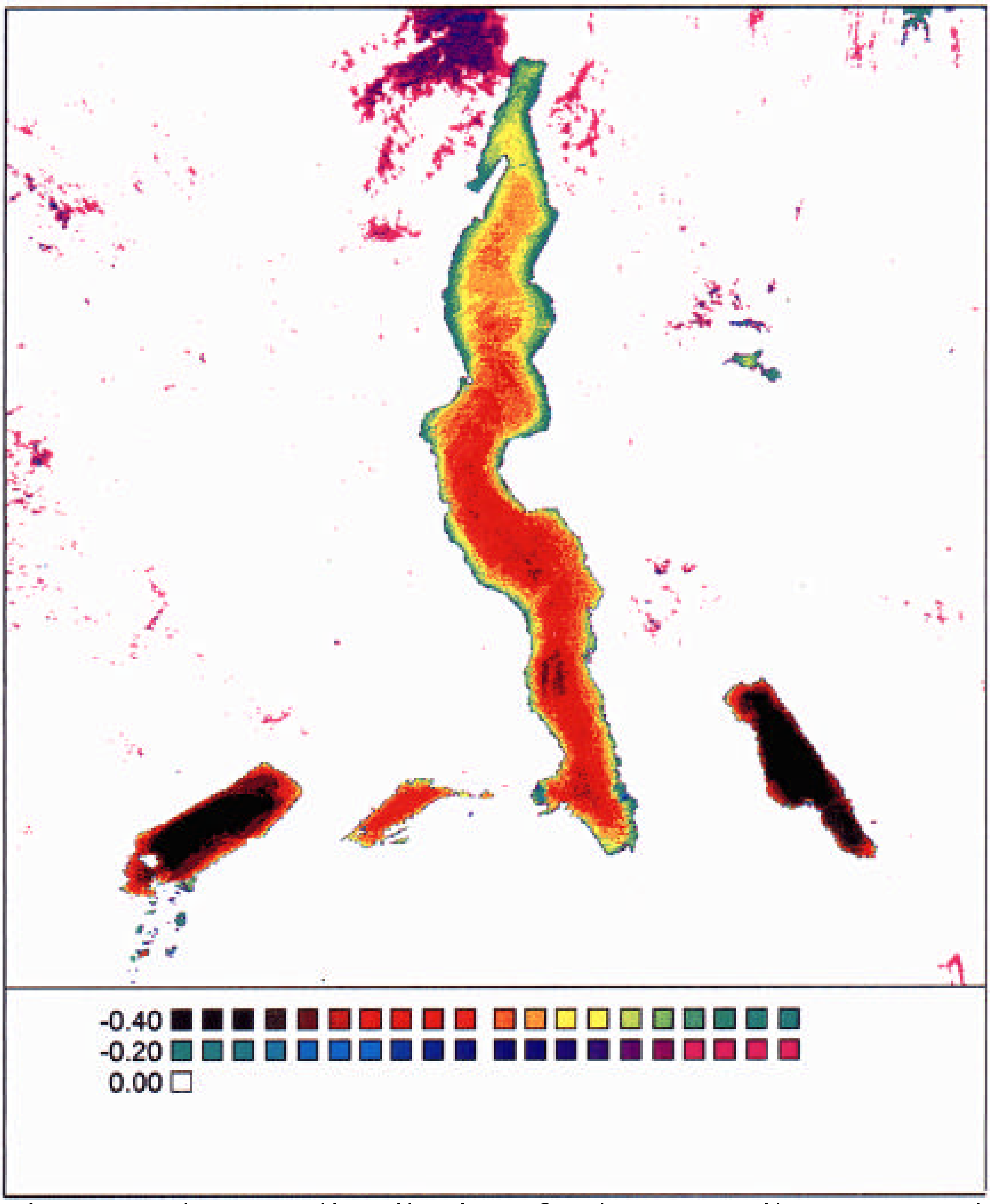

Figure 6. The NDVI distribution of Lake Tanganyika. Computed from the NOAA AVHRR image acquired on 29.6.1991.

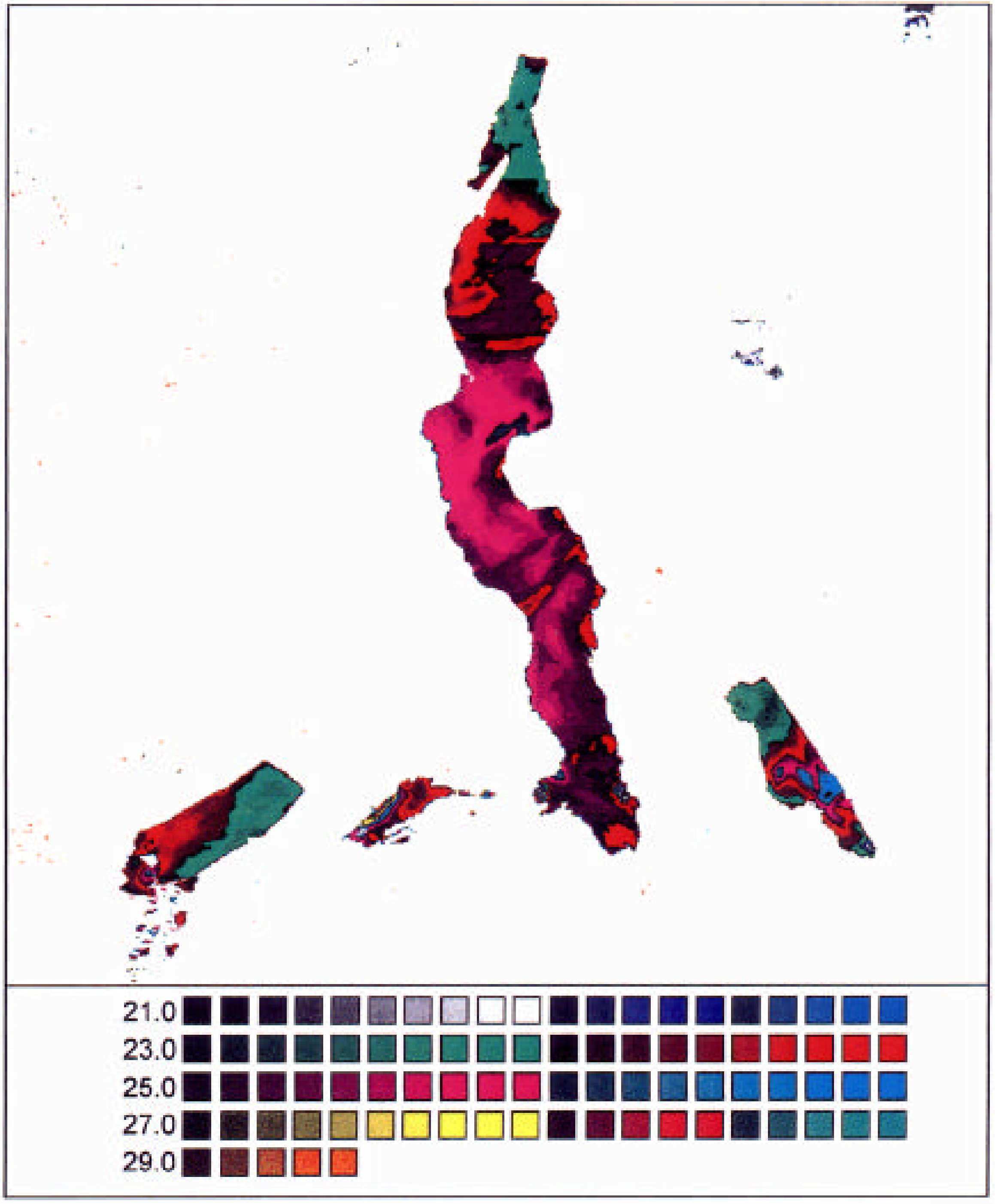

Figure 7. The temperature distribution of Lake Tangnayika. Computed from the NOAA AVHRR image acquired on 29.6.1991.

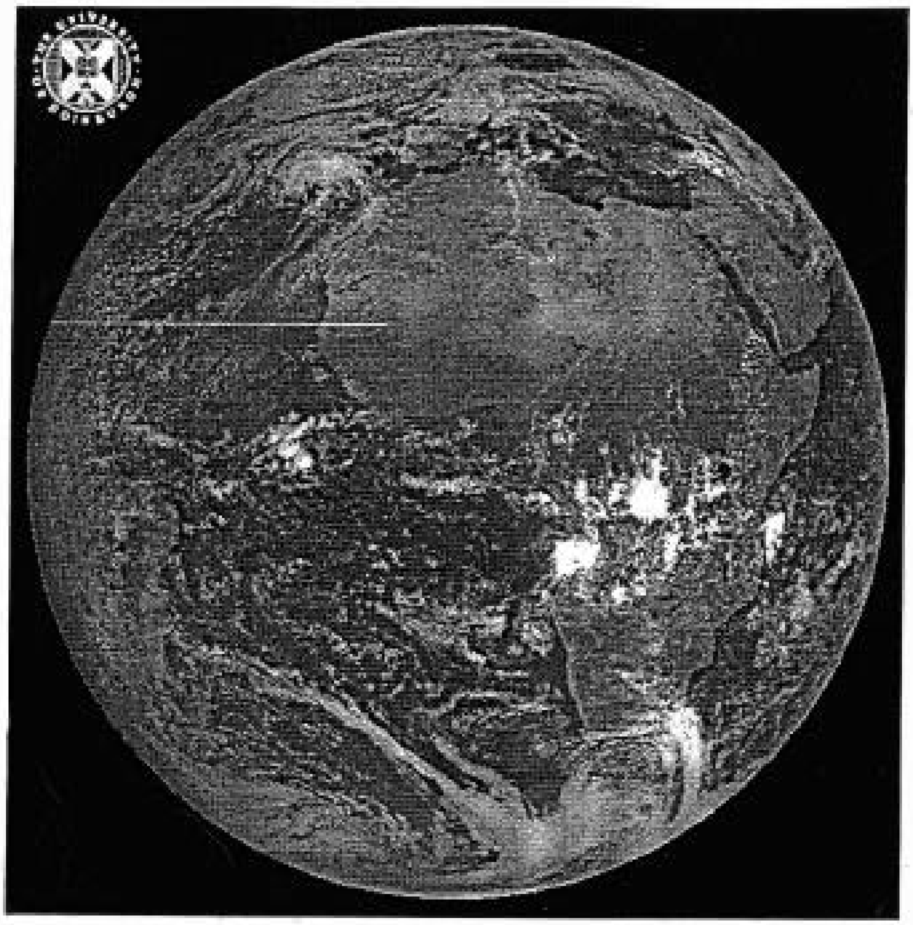

Figure 8. A Meteosat image on 15.3.1993.

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