RAMSES

A modular multispectral radiometer for light measurements in the UV and VIS

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ABSTRACT

Solar radiation is the energy source for all photosynthetic life-forms. Due to their individual pigment compositions only a specific part of the spectrum can be used by the single species for photosynthesis. Therefore multispectral radiation measurements are helpful for their investigation and monitoring. With the background of increasing ultraviolet radiation due to the decreasing ozone layer in the atmosphere, the measurement of the UV-A and UV-B part of the spectrum is of increasing interest to people.
In the RAMSES project (Radiation Measurement Sensor with Enhanced Spectral Resolution), founded by the German Ministry of Research and Technology, a new subminiature multispectral radiometer is under development. This new instrument allows spectral measurements in the range from 250 to 720 nm. A modular concept of the instrument, combined with very low power consumption, allows to use the instrument in profiling systems as well as in stand-alone applications, such as moorings, monitoring systems or weather stations. Sensor heads with different detection characteristics are available, and up to 16 of them can be combined to a single instrument for simultaneous measurement, e.g for up-welling and down-welling light.
Typical applications of this instrument are satellite calibration and validation, UV measurements, biology, ecosystem modelling, water quality and even climatology.

Keywords: multispectral, spectrometer, underwater light field, ultraviolett, visible, radiation, radiometer, light sensor

1 INTRODUCTION

Measurement of solar radiation in the water column is a well-known method in marine science. The *in situ* light field is influenced by absorption and scattering of different substances and life-forms like phytoplankton, yellow substance, contaminants and by the water itself (Jerlov, Morel and many other).
In biology works PAR (**P**hotosynthetically **A**vailable **R**adiation), as the integral value of the irradiance from 400 to 700 nm, is most commonly used to characterise the conditions for photosynthesis of phytoplankton communities. Due to the individual pigment composition of different species the usefulness of a given light field for photosynthesis is not a simple function of the total intensity of PAR. It depends also on the spectral distribution of quanta, especially with regard to the absorption spectrum (Fig.1) of the phytoplankton. To account for this Morel (1978) introduced the concept of PUR (**P**hotosynthetically **U**sable **R**adiation), which is a modified PAR obtained by weighting it across the spectrum with the specific absorption spectra of phytoplankton.
Fig. 2 a-b shows the spectral distribution and the vertical decrease at two selected wavelengths of the down-welling irradiance in the presence of a deep chlorophyll maximum at different water depths at a station in the western Arabian sea. Fig. 2 c represents the chlorophyll fluorescence which has been measured simultaneously to the irradiance. The bold lines in Fig's. 2 a and b represent the curve calculated for the absence of chlorophyll. The figures clearly shows the spectral selective light absorption by the phytoplankton and therefore the necessity of multispectral radiation measurements.

Studies of the behavier of different life-forms on ultraviolet radiation shows non-repairable damages. In view of increasing ultraviolet radiation due to decreasing ozone in the atmosphere, it becomes more and more interesting to extend the spectral light measurements from the visible to the UV-A and UV-B parts of the spectrum. To meet these requirements, a new multispectral radiometer series with a modular concept is under development. The performance of these instruments includes:

- high resolution multispectral detection in the UV and VIS from 250 - 720 nm
- up to 16 multispectral sensors in a single system
- specialized UV detection modules

- sensors with different detection characteristics for the measurement of different parameters
- low power consumption to make the instrument suitable for handheld and moored applications
- modular setup for customized sensor configurations
- operation down to 3000m for use in multiparameter probing systems

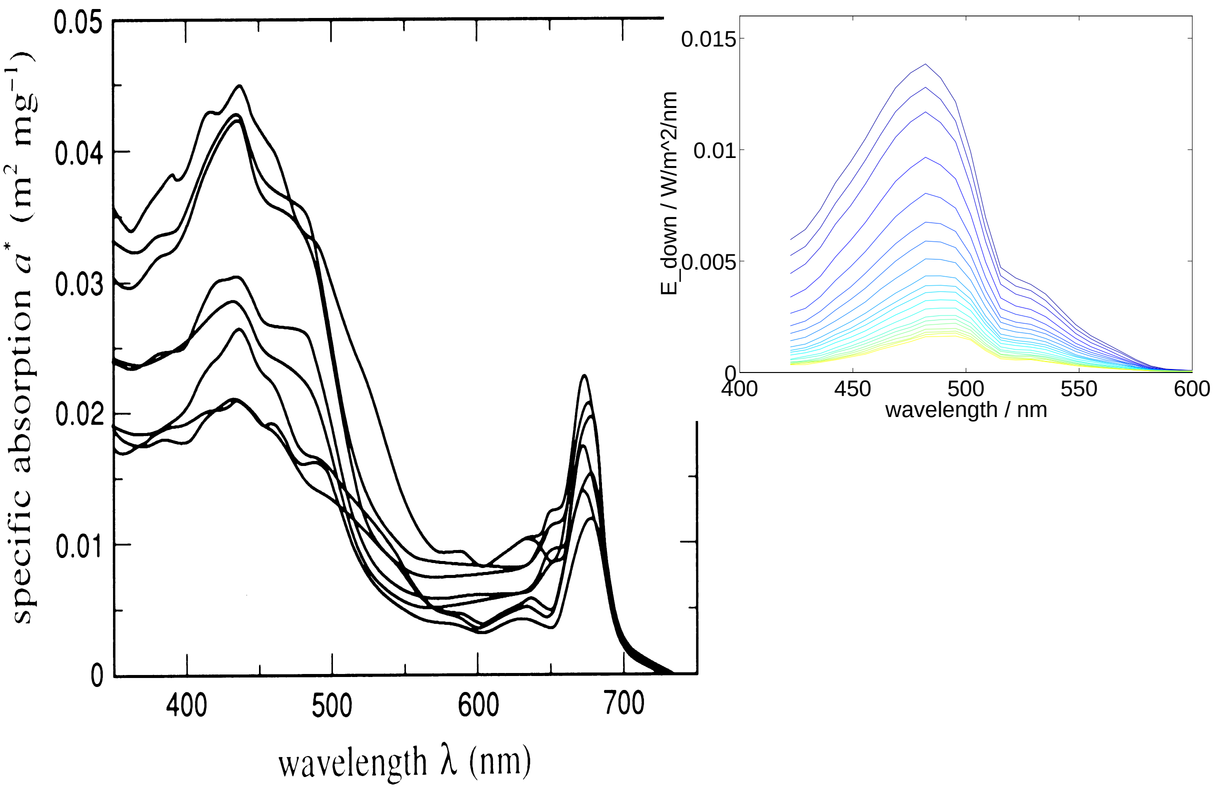

Fig.1: (a) Specific absorption spectra of the main phytoplankton classes (after Mobley,1994); (b) Down-welling irradiance at water depths between 40 and 70 m with 2 m intervals at a station in the western Arabian sea taken in May 1997 on board RV Sonne.

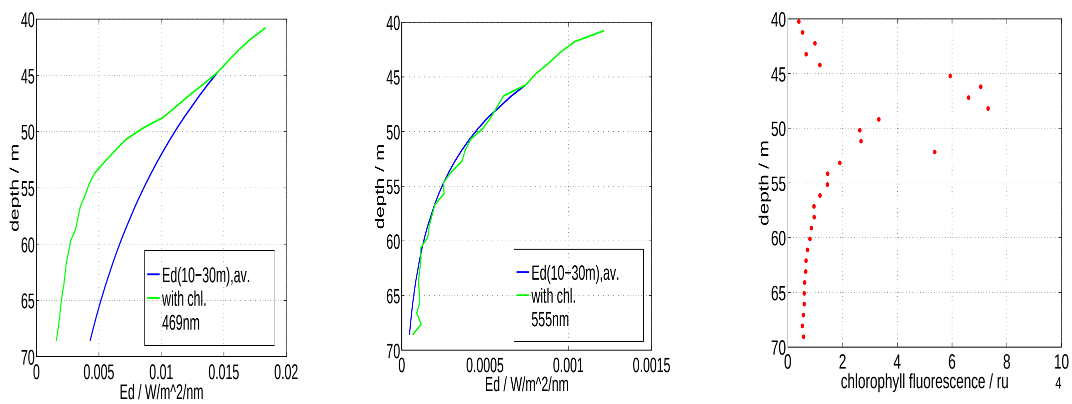

Fig.2: Down-welling irradiance at 469 nm (a) and 555 nm (b) from 40 to 70 m taken from the same profile as shown in Fig 1b. The full lines are the calculated values for a situation without a deep chlorophyll maximum between 40 and 50 m (according to values from 10-30 m). (c) distribution of *in situ* chlorophyll fluorescence measured simultaneously with the radiation.

2 TECHNICAL REALIZATION

2.1 Modular concept

The main concept of the RAMSES radiometer family is to divide the functionality of the whole instrument into a set of individual modules, which can be easily combined to customized instruments. This offers the highest flexibility for a wide field of applications. The functions of these modules are, e.g. spectra aquisition, data storage, data interfacing, time scheduler, analog output, etc. Each module is taxable via specific control commands. These modules are connected through a two-wire serial bus. Fig. 3 illustrates this serial network of single modules.

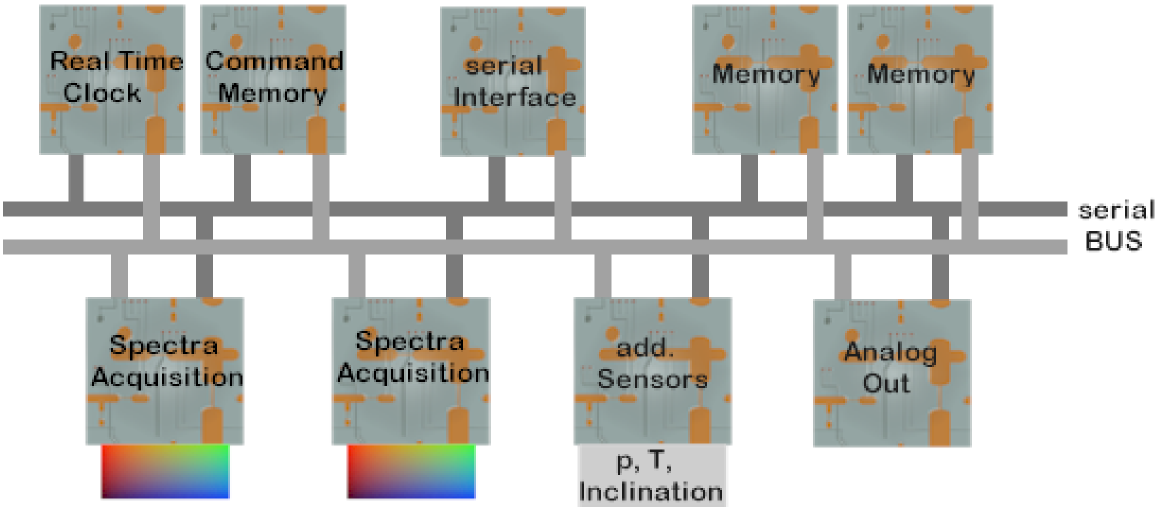

Fig.3: Schematic diagram of the serial network of the RAMSES radiometer

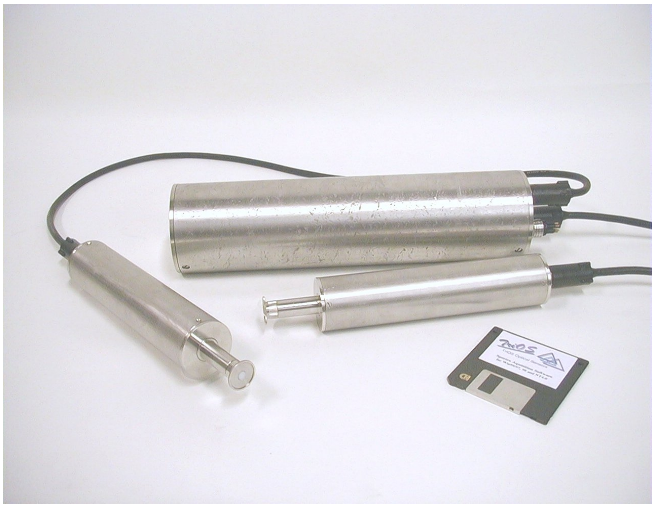

Fig. 4: Two multispectral light sensors for plane irradiance measurement connected to a data storage and acquisition unit (with internal battery pack).

The multispectral light sensor modules are mounted in small pressure resistant housings for operation depths of down to 3000m. This maximum operation depth is of course not valid for radiation measurement, but makes the instruments suitable for the use in multiparameter systems without unmounting them for deep sea operations. The possibility of individual positioning of each detector allows them to be used in open ocean water, where the shading by other instruments must be avoided, as well as in highly turbid waters, where measurement of up-welling and down-welling light must be done with sensors positioned at identical depth. An additional module with a two-axis inclinometer and a pressure sensor can be added to each light sensor module. Up to 16 multispectral light sensors can be assembled in to one instrument using a central data storage and acquisition unit (Fig. 4).

2.2 Multispectral light sensors

A monolithic miniature spectrometer, manufactured by Carl Zeiss, Germany, is integrated in each multispectral light sensor. This spectrometer consists of a quartz fibre bundle with a circular arrangement of the single fibres at the entrance and a linear one at the other end. The linear end forms the entrance slit of a spectrograph. A silicon photodiode array with 256 diodes is used as a detector. Fig. 5 shows a module mounted on an electronic circuit, developed within this project. This highly integrated circuit generates all signals required for operation of the diode array, signal processing, data conversion and the interface to the sensor network. The use of components with low power consumption and the integrated power management in each module reduces total energy requirements of a complete module to 0.85 W in full operation mode. Most energy is needed for the analog part of the electronics. Therefore the integrated microcontroller switches the analog part off after a measurement. This reduces the power consumption to 20 mW. Analog to Digital conversion is done by a 16 bit ADC (+/- 2 LSB). Together with a switchable integration time for the diode array in the range from 4 ms up to 8 s, the total dynamic range is 25 bit.

The miniature spectrographs are available in an UV/VIS version (190-735nm; 2.2nm/pixel) and a specialized UV Version (200-400nm; 0.8 nm/pixel). The stray-light discrimination in the UV modules is an order of magnitude better than the UV/VIS versions. In combination with the higher spectral resolution they are suitable for high accuracy UV measurements. Table 1 shows the summarized characteristics of both modules.

Technical specifications		
	UV/VIS	**UV**
optical		
wavelength range	250-720 nm	250-400 nm
detector type	256 channel silicon photodiode array	
spectral sampling	2.2 nm / pixel	0.8 nm / pixel
spectral accuracy	0.2 nm	0.2 nm
stray light	$< 1x10^{-3}$	$< 5x10^{-4}$
usable channels	230	190
electrical		
A/D resolution	16 bit A/D converter, 14 bit specified	
integration time	4 ms - 8 sec.	
dynamic resolution	25 bit	
telemetry interface	RS-232 or Serial Bus	
data rate (RS-232)	1,200 - 19,200 baud (user selectable)	
power requirements	1.5-11 VDC 0.85 W (data acquisition active) 20 mW (interface active) 0.5 mW (standby modus)	
connector	SUBCONN-Micro 5 pins, male (others on request)	
optional sensors	pressure, 2-axis inclinometer, internal temperature	
physical		
size	∅ 4.7 cm x 18.0 cm (without detector) ∅ 4.7 cm x 23.0 cm (with optional sensors)	
weight in air	0.5 kg (coated aluminium) 1.3 kg (stainless steel)	
depth rating	300 m (coated aluminium) 3000 m (stainless steel)	
operation temperature	-10 to +40 °C	

Table 1: Technical specifications of the multispectral light sensors. Optical specifications following the data sheets of Carl Zeiss, Germany.

For measuring different radiometric parameters, like scalar irradiance, vector irradiance or radiance, different collectors are needed in front of the fibre bundle of the spectrometers. In a first step three collector versions have been developed (Table 2).

MCC	MSC	MRC
plane irradiance E	scalar irradiance E_0 vector irradiance $\vec{E}$	radiance L
E_d or E_u up-welling or down-welling irradiance	E_0 and $\vec{E}$ (requires two modules)	baffled Gerhun tube, field of view: 10° in water

Table 2: The different collectors for the multispectral light sensors
The spectral transmission of the collector material limits the usable UV spectral range of the modules to wavelengths greater than 250 nm. Therefore, not all of the 256 diodes of the detector array can be used for radiation measurement and the number of useful diodes depends on the type of spectrograph used.

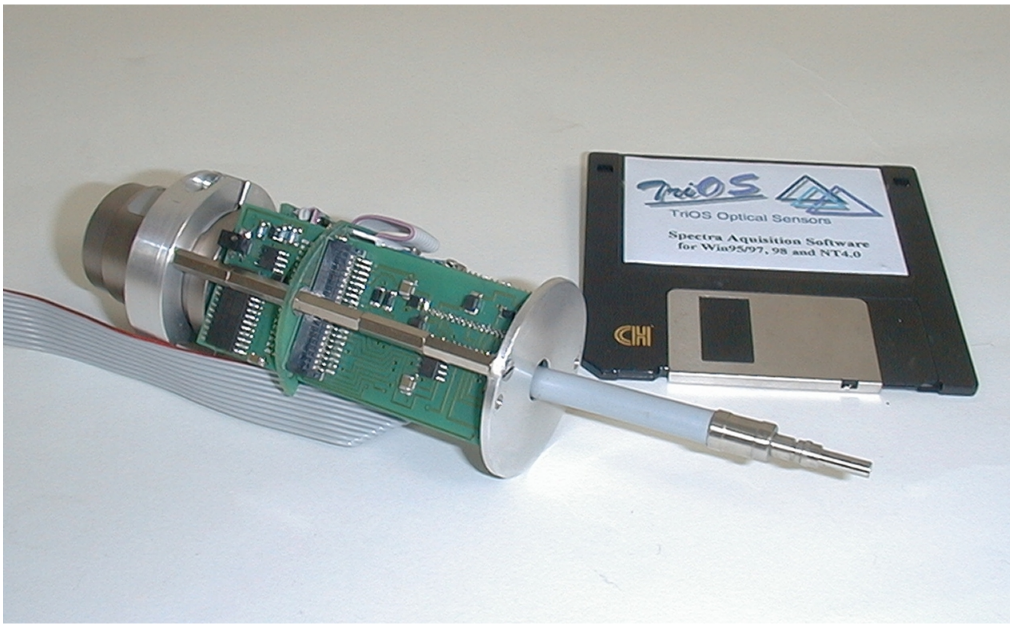

Fig 5: Miniature spectrometer with fibre optic bundle and highly integrated electronic.

2.3 Calibration

Quantitative measurements require a careful correction of the spectral sensitivity of each module, including the collector. This is done by using calibrated deuterium lamps for the UV and tungsten lamps for the VIS part of the light spectrum, driven by stabilized power supplies. The emission of these lamps has been put in to quantitative terms before by calibrating them with primary standard lamps, following the NIST standard (Oriel).

2.4 Software

Part of the RAMSES radiometer is an easy-to-use Windows based software. Main features of this software are:

- measurement control
- data recording
- online calibration of raw spectra
- different data display modes such as single spectra, time series, depth profiles
- online calculation of standard radiometric parameters
- different pre-defined functions for online display of integral values of specified spectral ranges, like PAR, UV-A, UV-B, or to fit interference filters used in satellites
- user defineable algorithms for data processing

3. PRELIMINARY RESULTS

First measurements of a profiling system containing two multispectral light sensors and a data acquisition unit have been carried out on board the RV *Heincke* during a cruise in the German Bight in March 1999. A third multispectral light sensor was mounted on board the ship as a deck reference for continuous measurement of the incident light. Fig. 6 represents the incident irradiation at three selected wavelengths from the deck reference sensor. A depth profile of the ***in situ*** instrument is shown in Fig. 7 as a three-dimensional plot.

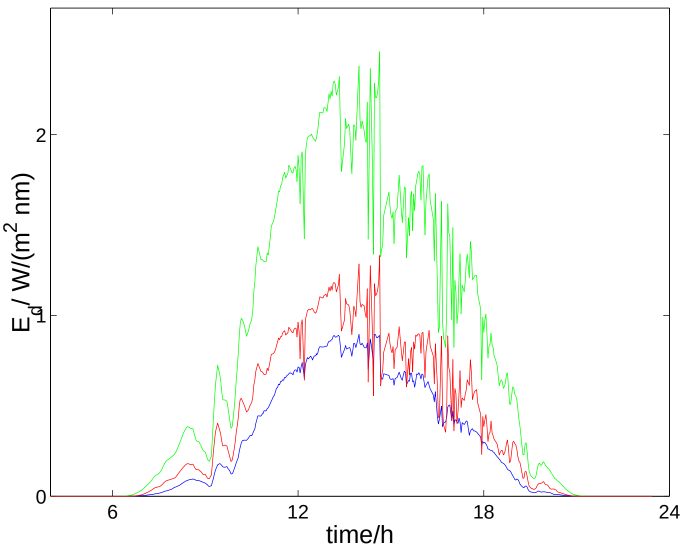

Fig. 6: Incident irradiance at three selected wavelengths (320, 460 and 640 nm) over a period of 1 day.

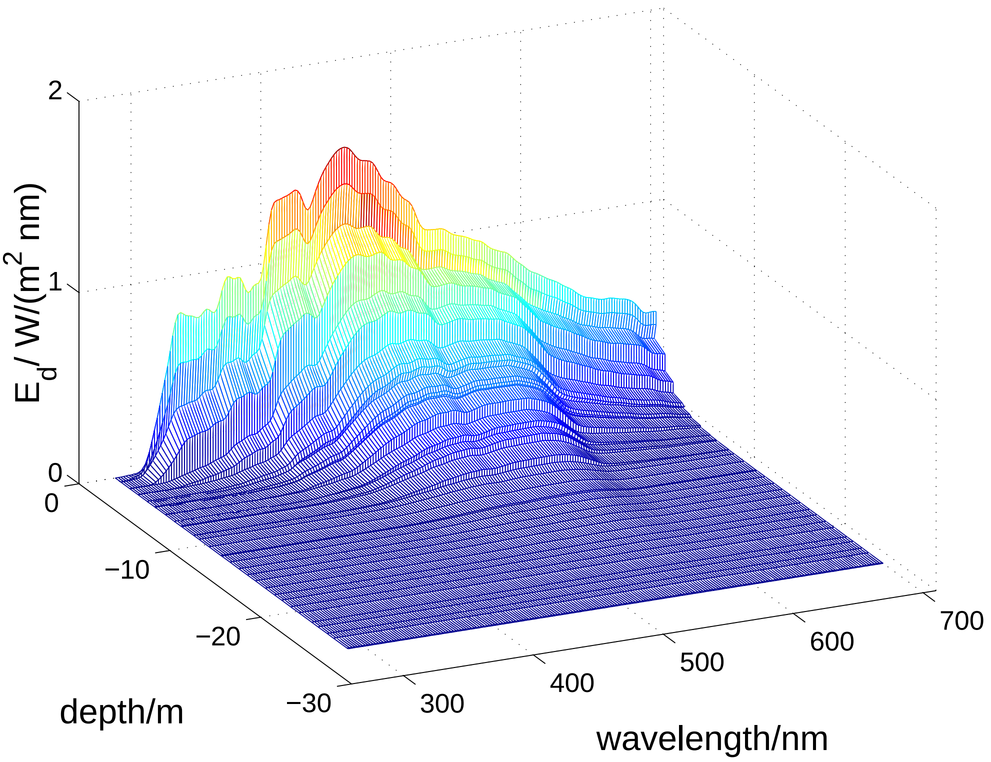

Fig.7: Depth profile of the down-welling irradiance taken on board RV *Heincke* during a cruise in the German Bight.

4. ACKNOWLEDGEMENT

The development of the RAMSES modular multispectral radiometer is supported by a grant from the Federal Minister of Research and Technology, Bonn.

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