

## OPERATIONAL AIRBORNE HYDROGRAPHIC LASER FLUOROSENSING

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### ABSTRACT

Airborne lidar systems have frequently been used to measure hydrographic parameters under various conditions during the past two decades. Since 1993, a Do228-212 aircraft, equipped with a laser fluorosensor for detailed analysis of oil spills, has been used for maritime surveillance of the German territory in the North and Baltic Seas. This operational task offers the possibility to monitor hydrographic parameters. In this paper, the power of operational hydrographic measurements with an airborne laser fluorosensor is investigated. Essential features of the recently developed concept of automated distribution among different participants of a monitoring programme will be presented, especially the graphical user interface developed for easy access and evaluation of hydrographic laser fluorosensor data. Recent results from the winter and spring periods of 1999/2000 will be presented. Prominent features are the distribution of gelbstoff related to water masses and the onset of phytoplankton bloom in the German Bight and the western Baltic Sea. The paper concludes with a brief discussion of the results and possible improvements, which underline the demand for a long-term operation.

### INTRODUCTION

The investigation of hydrographic processes in coastal regions is important for effectively monitoring the marine environment. The detection of distinct events like harmful algae blooms or transport of chemicals and other pollutants with the water masses is of special interest. Passive optical radiometers on-board satellites show remarkable results in detecting, for example, the chlorophyll distribution over the open ocean. However, in coastal areas the algorithms for discriminating phytoplankton contents in the water from colour ratios must carefully consider other water constituents like gelbstoff (coloured dissolved organic matter) and suspended particles. This results in a much more complex theory of radiative transfer and, consequently, in larger uncertainties (1). An additional serious problem for the North and Baltic Seas, the focus of this work, is the high cloud probability during the year which inhibits the gathering of continuous information on hydrographic parameters by spaceborne techniques over a large area.



**Figure 1. Maritime surveillance aircraft (Do228LM57+01) operated by the 3<sup>d</sup> Naval Air Wing on behalf of the German Ministry of Transport, Building, and Housing.**

A possible solution to this could be the operational application of airborne lidar measurements (for an overview of lidar application see (2)). The capability of this active remote sensing technique along the track of a low-flying aircraft has been shown in previous works, see, for example (3,4,5,6). These measurements are, in principle, independent of clouds and weather conditions and can be made during the day and at night. The application of an aircraft limits the measurements to distinct flight tracks, while large areas can be covered by satellite swaths. Recently, it has become possible to get a nearly synoptic survey of a limited region like the German Bight within a flight time of 2 hours, which is considerably shorter than a tidal period.

German areas of jurisdiction in the North and Baltic Seas have been under operational airborne survey for maritime pollution since 1985. At present, two Do 228-212 aircraft (Figure 1), especially equipped with side-looking airborne radar (SLAR) for detecting oil slicks over large distances and ultraviolet (UV) as well as infrared (IR) line scanners for mapping the sea surface in the nadir range are operated by the 3<sup>rd</sup> Naval Wing „Graf Zeppelin“ in Nordholz on behalf of the German Ministry of Transport, Building, and Housing (Figure 2). One of these aircraft operating around the clock is additionally equipped with a microwave radiometer (MWR) and a mapping laser fluorosensor (LFS). These sensors allow for a more detailed analysis of oil spills in terms of film thickness, and hence discharged volumes(7). The LFS uses a XeCl excimer laser as an active radiation source in the UV (at 308 nm). It detects the spectral fluorescence signal emitted from the upper water column and can yield information on the type and quantity of the spilled substance (8,9). Moreover, hydrographic parameters such as gelbstoff, chlorophyll in phytoplankton, and seawater turbidity can be measured (10).

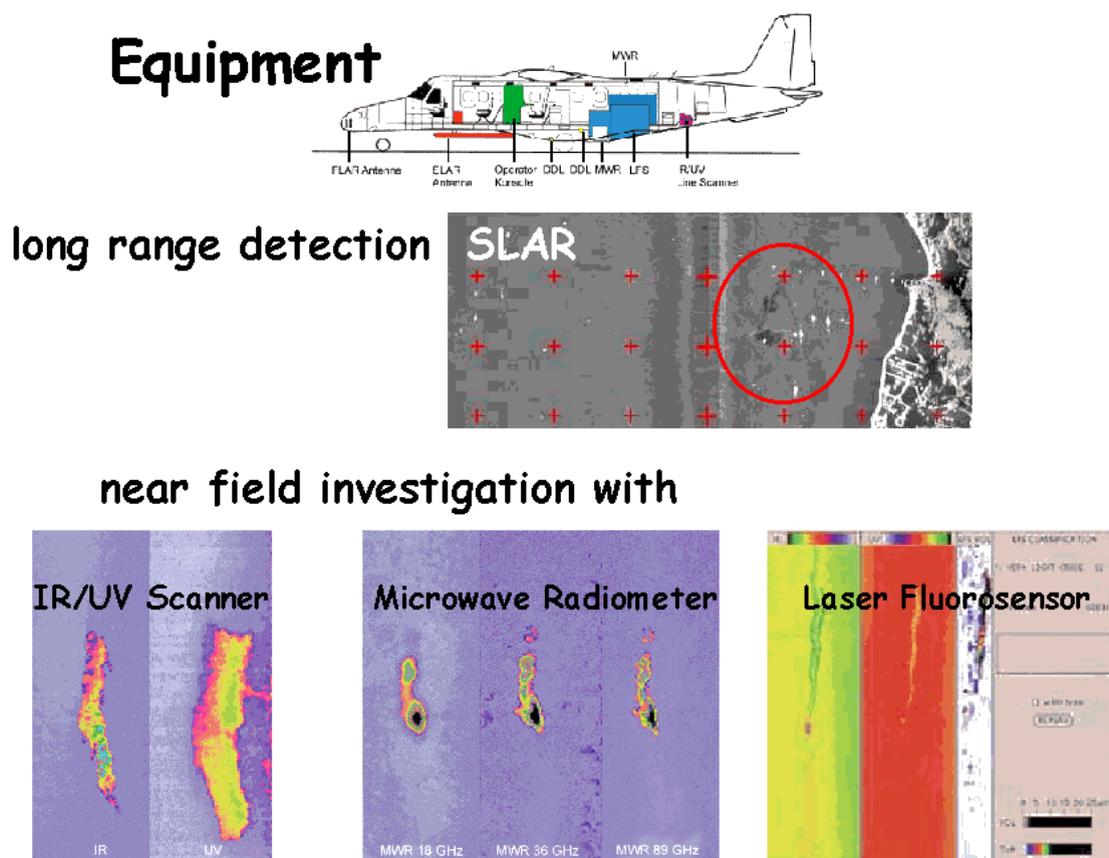
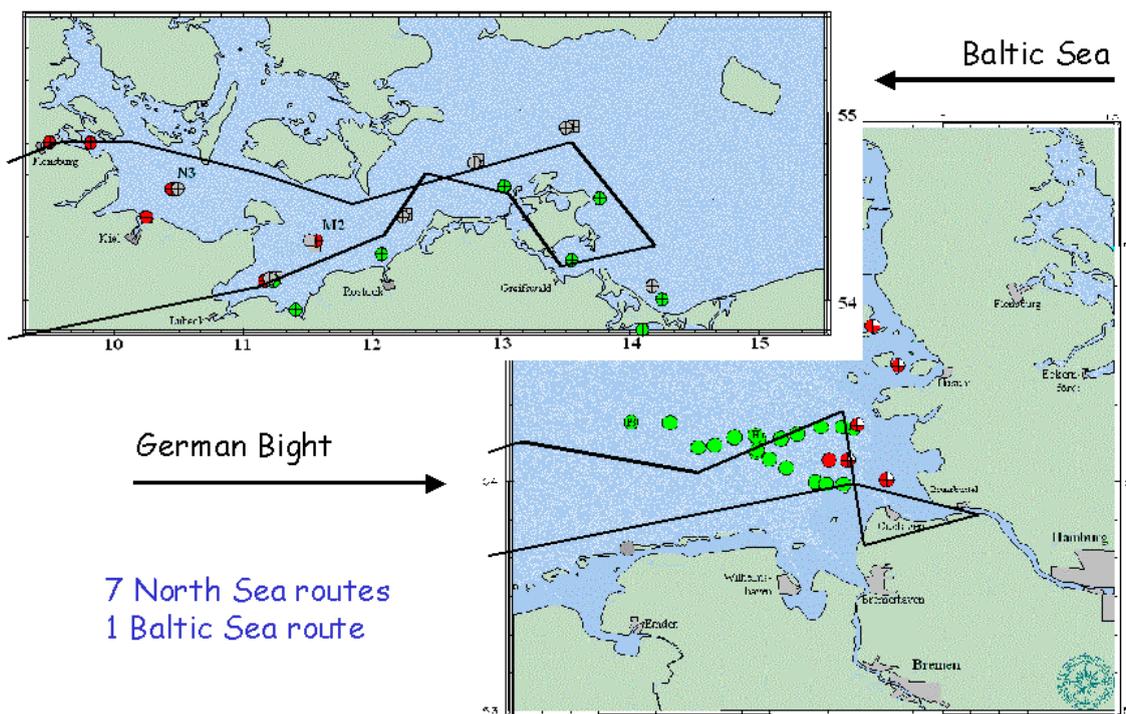


Figure 2. Sensor equipment aboard the German maritime surveillance aircraft Do228LM57+01.

Since it is the objective of this paper to investigate the power of an operational application of the maritime surveillance patrols for hydrographic measurements as a contribution to the “federal and state monitoring programmes for the marine environment“ in German coastal waters (Figure 3), the following section will describe the instrumentation and methodology. Section 3 will stress the importance of a fast and easy-to-use data conversion for a successful operation and essential features of the recently developed concept to answer these demands will be presented. Recent results from the winter and spring periods of the years 1999/2000 are shown in Section 4. Finally, Section 5 will discuss these results and conclusions will be drawn on the suitability of using the airborne surveillance system for long-term monitoring.



**Figure 3. Flight routes over the North and Baltic Seas compared with phytoplankton sampling sites of the “federal and state monitoring programmes”. Out of the 7 North Sea routes, only one is selected for illustration.**

### METHODOLOGY OF THE LFS

The LFS, as one of the most complex remote sensing instruments for quantitative measurements operated on an aircraft, is designed with two high energy pulse lasers in the UV at 308 nm (XeCl-excimer laser, 150 mJ pulse energy, 20 ns pulse length) and 383 nm (dye laser, 20 mJ, 15 ns). The stimulated fluorescence as well as the scattering of the laser light at the water surface and within the water column are detected with a 20 cm telescope and then spectrally separated into 12 detection channels (detection wavelengths at 332, 344, 365, 382, 407, 441, 471, 492, 551, 592, 650, and 684 nm with a typical optical bandwidth of 10 nm). The operational altitude is between 100 and 300 m resulting in a surface swath width of 150 to 450 m, utilizing a conical scanner. For more details on the LFS design see (11).

The main features of the laser fluorosensor in its original design for oil spill measurements are:

- estimation of oil film thickness between 0.1 and 10  $\mu\text{m}$ ,
- calculation of the oil volume on the water surface,

- identification and classification of the oil through its spectral signature,
- discrimination between natural and mineral oil films and
- detection of oil below the water surface.

For the hydrographic measurements, the focus of this paper, a simplified scan pattern of one laser pulse ahead of the aircraft and one to the rear was applied. This allows for long-term operation along the complete flight route (3-5 hours) with low energy consumption. Since the dye laser was not available at the time, ultraviolet excitation at 308 nm was used throughout the campaign. Having spectral characteristics of chlorophyll *a* in mind (see e.g. Kirk, 1994:12), this is quite far from the absorption maximum at about 430 nm. However, eye safety regulations demand a UV light source and the 308 nm excitation yields an excitation energy seven times higher than the dye laser normally used for the 383 nm laser pulse. This compensates lower absorption characteristics within the phytoplankton. However, it has to be the subject of future experiments to find out to what extent chloroplasts and pigment centres are affected by this UV radiation and what kind of relation exist between the LFS chlorophyll fluorescence signal detected and the phytoplankton species and concentrations monitored.

Data obtained by the LFS were corrected for system characteristics, background illumination, and scan geometry in advance (for a detailed description of algorithms and methodology see Reuter et al., 1993). Gelbstoff fluorescence was then derived from the signal intensity at 365 nm, divided by the Raman signal at 344 nm (both signals background corrected, see also Bristow et al., 1981). Chlorophyll fluorescence, as observed by the LFS, was calculated by the same method, applying the 684 nm channel of the detector and the 344 nm Raman normalization. This is not optimal, as the Raman signal is proportional to the volume observed and the penetration depths for 344 and 684 nm differ significantly in water. A dye laser, for example with a 450 nm excitation and a resulting Raman wavelength at 533 nm, would yield lower errors due to differential absorption, and therefore would be more appropriate for chlorophyll detection in the water column. In Section 3 we will, however, show that acceptable results for the monitoring of phytoplankton distributions were achieved even under these non-optimal conditions for chlorophyll fluorescence detection.

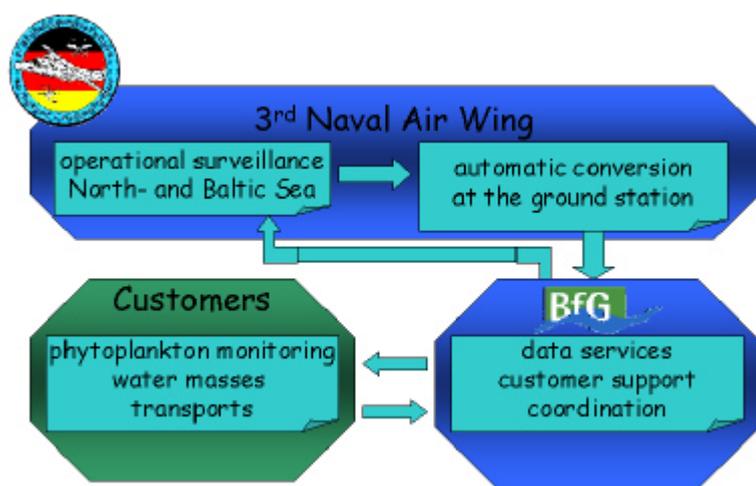


Figure 4. Elements of the operational laser fluorosensor application as a part of the routine oil spill surveillance. BfG stands for “Bundesanstalt für Gewässerkunde” (Federal Institute of Hydrology).

### LFS AS PART OF THE OPERATIONAL MONITORING PROGRAMME

Apart from the methodological aspects of laser fluorosensing of the marine environment, the fast – and easy access to this information is of great importance to the customers of operational monitoring (Figure 4). In the case presented here, the German Federal Ministry of Environment together with the German Federal States located along the North and Baltic Seas, carry out a monitoring programme for the marine environment. The agencies and institutions involve sampling, e.g., phytoplankton at different sites throughout the year with an increased frequency during spring

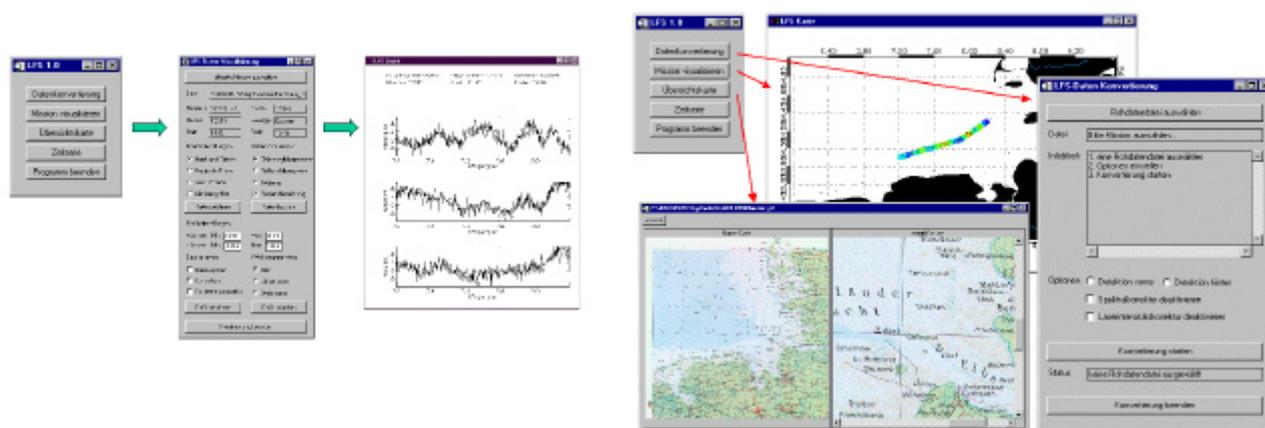
phytoplankton at different sites throughout the year with an increased frequency during spring and summer periods. However, these measurements are based on single sampling with water samplers and subsequent laboratory analysis. No information is available for the areas between the sampling sites or sampling times. Therefore, long-term monitoring and forecasting require additional spatial and time-resolved information, like airborne hydrographic laser fluorosensor data. It is important to understand that the participants (customers) of these monitoring programmes are not interested in raw data or calibration procedures. Methods and tools have to be developed for a fast distribution of results

- from the 3<sup>rd</sup> Naval Air Wing as the operator of the surveillance flights,
- via the Federal Institute of Hydrology as the executive agency and acting in its role as the centre for value adding and mission planning
- for the customers with their specific demands for information.

To establish a rapid distribution among the participants, a two-step data conversion was realized:

- Nearly automatic conversion of original data sets (using a complex binary structure) into ASCII-based raw data with easily interpretative header information about wavelength selection and data structure plus the complete raw data from the aircraft navigational interface and the laser fluorosensor.
- Transformation of the raw data into information on gelbstoff, chlorophyll fluorescence, and turbidity applying a graphical user interface (Figure 5) for the required information and provision of a first visualisation of results. Data are again stored in ASCII files that can be imported into other standard visualisation and calculation tools.

The first step is carried out automatically following the flight at the ground station of the 3<sup>rd</sup> Naval Air Wing. Data are reduced by the pre-selection of data sets from about 100 to less than 10 megabytes and could be drastically reduced by compression tools due to their purely textual nature. The archived raw data will be sent to the Federal Institute of Hydrology (BfG) via e-mail, where it will be pre-analysed and distributed among the participants. The second step, the transformation of raw data into usable information, could therefore take place at the BfG and on the customer's desk, taking into account his specific needs and parameter selections. The data volume is again reduced by a factor of five, so that finally a mission lasting two hours with a ground track of about 200 km length requires about 1 megabyte of disk space, with a sampling distance of about 70 m. During the experiments in the winter of 1999 and the spring of 2000, the results of which will be described in the following, step 1 was still performed at the equipment service company; however, the automated conversion tools are now ready for implementation at the ground station.

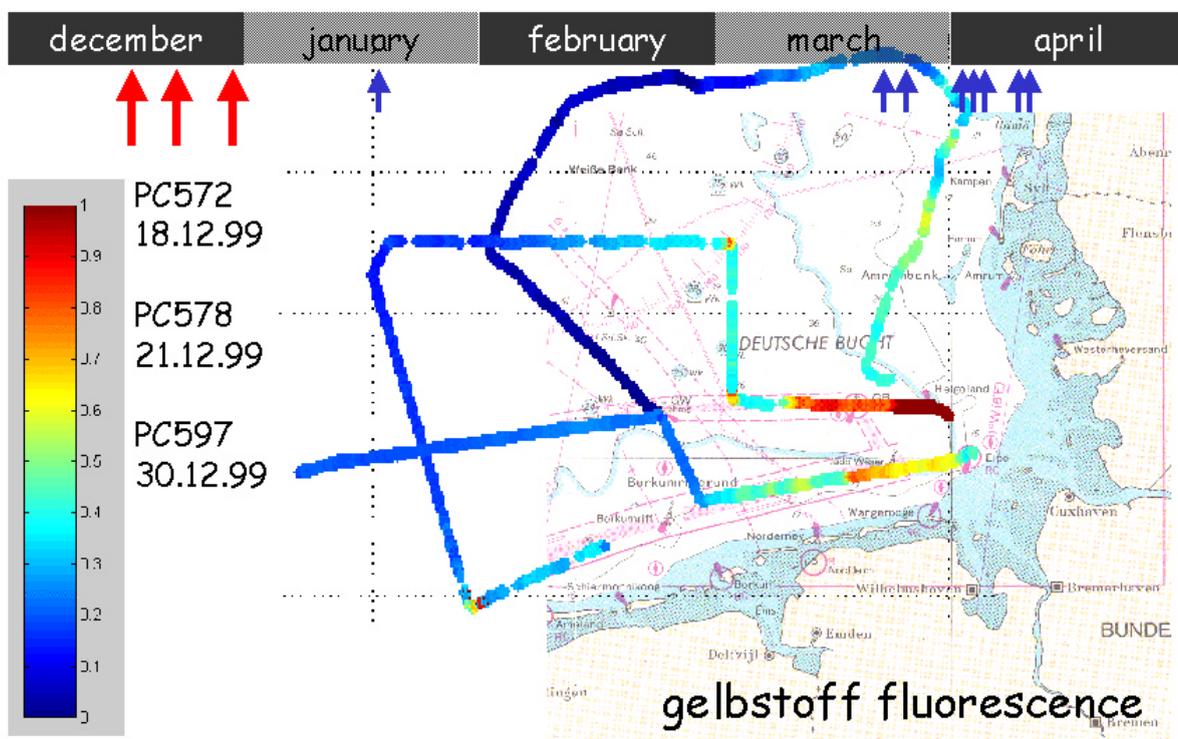


**Figure 5. Screenshots from the graphical user interface for hydrographic LFS-data analysis and**

visualisation.

**EXPERIMENTAL RESULTS**

The experimental survey of hydrographic parameters started in mid-December 1999, when three laser fluorosensor data sets were gathered over the German Bight as part of the regular surveillance activities. Biological primary production during this winter period was low, therefore chlorophyll fluorescence information provided no hint on increased phytoplankton abundance. However, the hydrographic situation could be clearly identified by the distribution of gelbstoff fluorescence throughout the German Bight (Figure 6). Gelbstoff content increases towards the coast and reaches its maximum in the south-eastern part of the area, where the run-off from the river Elbe can be observed. This is in good agreement with previous experiments (5) and oceanographic observation given by the literature (13).

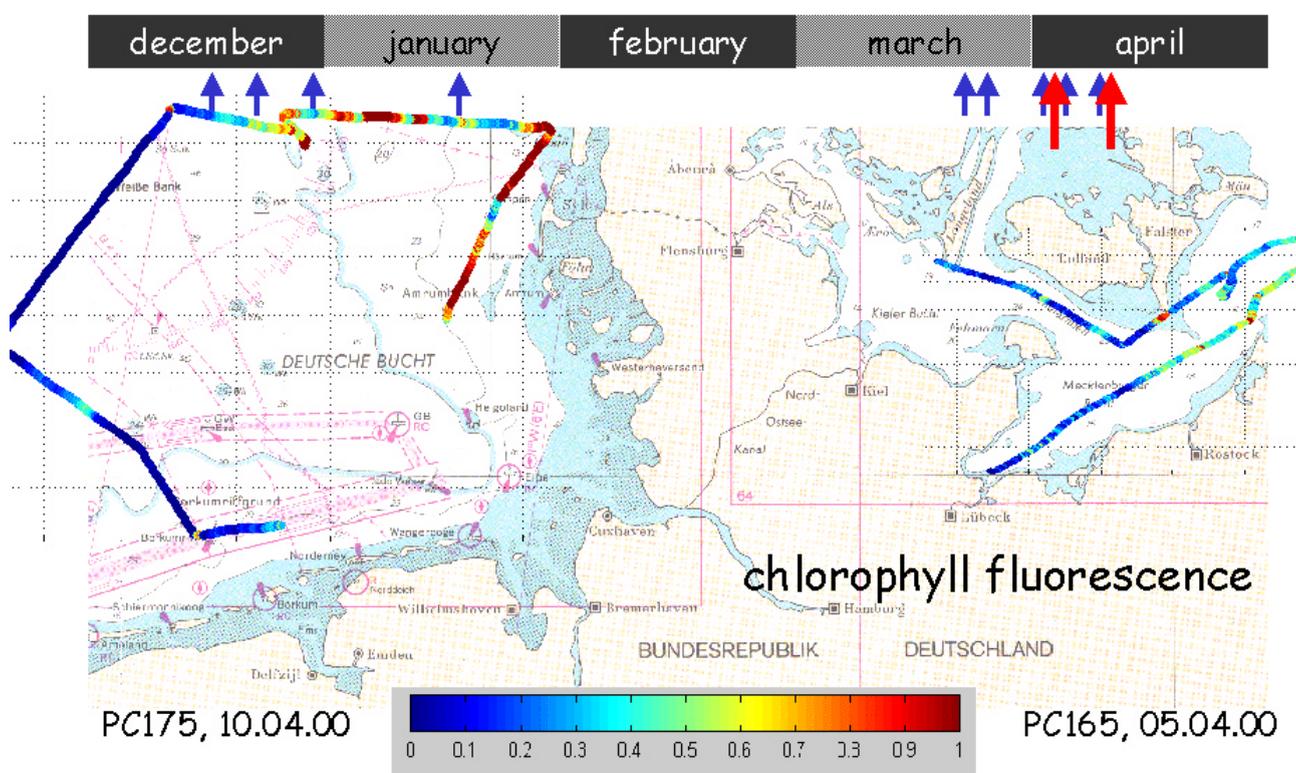


**Figure 6. Gelbstoff fluorescence distribution within the German Bight from three flights in winter 1999.**

From January until mid-March weather conditions were bad, so that almost no laser fluorosensor data were available. In some cases, this was not a short-coming of the measurement principle, but a problem of flight security. LFS data are normally obtained from an altitude of about 300 m, flying below the clouds. At night or under moderate visibility conditions this implies an increased risk to the flight crew, who therefore choose an altitude of 1,000 to 1,500 m which is above the clouds and allows for permanent observation by the regional radar control. This altitude does not affect the operational task of oil spill surveillance based on the long-range observation with the side-looking airborne radar, but it affects the availability of hydrographic laser fluorosensor data. Additionally, regular maintenance work decreased the number of flights in February. One result of this experiment is that the number of available data sets of hydrographic measurements is, at present, much

lower than the number of surveillance flights performed. However, it can be expected that the regularity of data sets will improve significantly with the installation of a new LFS in the second surveillance aircraft scheduled for autumn 2001.

Starting with the good weather conditions at the end of March 2000, accompanied by increased solar radiation, the number of available measurements increased drastically, as did the phytoplankton population in the German coastal seas. Figure 7 shows the chlorophyll fluorescence distribution in the German Bight and the western Baltic Sea early in April. Especially in the north-eastern part of the area, a high chlorophyll fluorescence signal was detected along the track, which indicated that a phytoplankton bloom was starting in this area. Comparisons with observations by the “federal and state environmental monitoring programmes“ near the coast of Sylt in mid-April supported this suggestion. Unfortunately, no *in situ* data were available accompanying the experiment and therefore no ground truth information could be given for these laser fluorosensor data sets. An important further step will be to co-ordinate *in situ* sampling at fixed sites and during ship campaigns with the air surveillance flights.



**Figure 7. Chlorophyll fluorescence distribution within the German Bight and western Baltic Sea in April 2000.**

## CONCLUSIONS

As this paper represents a first feasibility study of hydrographic LFS as a by-product of the operational oil spill surveillance performed over German areas of jurisdiction, the potential of such information for environmental monitoring programmes could be clearly identified. Yet the operational status of these kinds of observations requires a fast and user-orientated information distribution and the frequent availability of good data sets. With the development of a two-step data conversion, an overall concept of data distribution and tools with easy-to-handle graphical user interfaces, the first demand has already been met. However, it turned out during the experiments that the availabi-

lity of hydrographic data sets is lower than the total number of performed surveillance flights due to weather conditions and maintenance activities. This will be partially overcome with the installation of a new LFS in the second German marine surveillance aircraft. Therefore, hydrographic laser fluorosensing is pre-operational at the present stage. It provides a valuable source of information on different parameters over long periods and large scales and is an excellent extension of the *in situ* sampling sites and the underlying monitoring of the marine environment. Further long-term observations accompanied by ground truth experiments are recommended in order to achieve a fully operational status in the near future.

#### ACKNOWLEDGEMENTS

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