Cyanobacterial blooms in the Baltic Sea

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Key Message

This summer, blooms of cyanobacteria were observed for more than two months period, from 29 June to 5 September. During 30 days from the 7 July, extensive blooms were seen, but the most massive accumulations stayed away this year. The Bothnian Sea which usually blooms in August, also had an unusually prolonged bloom.

This year's bloom was normal in an initial comparison with previous years; however, the normalized bloom intensity, extent and duration should not yet be compared with the blooms between 1997 and 2009 since the detection method used during 2010 & 2011 is new. Work is ongoing to harmonize the time series.

The detection new method that was introduced in 2010, combining MODIS and MERIS satellite data, has also been used in 2010.

However, even though the bloom observed for a long time the normalized bloom intensity, extent and duration was low compared to 2010. No comparison should not yet be made with the blooms between 1997 and 2009 since the detection method used during 2010 & 2011 is new. Work is ongoing to harmonize the time series.

Results and Assessment

Relevance of the indicator for describing developments in the environment

Nitrogen fixation by cyanobacteria is a significant source of nitrogen to the Baltic Sea.

The amount of available phosphate in the surface water, water temperature and weather conditions during the summer are important factors regulating the intensity of cyanobacterial blooms in the Baltic Sea. During 2011 phosphate concentrations were above normal in the whole Baltic Proper. (See SMHI, R/V Argos cruise reports 2011, www.smhi.se)

The weather in the Baltic region during the summer was unstable. Low pressure passages were common and strong winds dissolved the dense blooms accumulations. However, in between the lows, warm, calm and sunny weather favored bloom growths.

Assessment

The Baltic Proper

Following a few days with warm and sunny weather the first surface accumulations of cyanobacteria appeared in the Gulf of Finland 29 June. Signs of blooms were also seen east of Bornholm, and the next day surface accumulations were observed in the Gdansk Bay. The blooms were, as usual at this time, not very large.

A low pressure system dominated the weather on the first days of July. The bloom in the Gulf of Finland grew, but not until the 7 July more extensive surface accumulations were seen in the Baltic Proper. Up to the 12 July, a broad band with partly dense surface accumulations stretched from the Gulf of Finland past the western coast of Gotland towards Rügen.

On the 13 July a low with northerly winds passed and the algal belt was partly dissolved. A few cloudy days followed, but the 19 July, large blooms were again seen in the southern Baltic Proper as well as in a large part of the northern Baltic Proper. Much of the development for the rest of July was hidden under clouds, but the surface accumulations were still present.

The first week of August offered a solid high pressure over the Baltic Sea area which made the blooms increase in large parts of the Baltic Proper, for the first time also east of Gotland. Some media reports of algae drifting ashore along the Swedish east coast appeared during this week. A low pressure system swept in over the Baltic Sea the 7 August, and remained until the 11. As it withdrew, this year's large-scale blooms in the Baltic Proper had ceased. On the 23 August, a bloom unexpectedly turned up southeast of Gotland, and stayed until the 5 September.

The Bothnian Sea

The first signs of a bloom in the Bothnian Sea were seen already on the 22 July. At the end of the month the bloom had increased in size, but not formed any surface accumulations. They were visible on the satellite image the day after, the 1 of August. The bloom had its greatest extent around mid-August when a large surface bloom was floating in the centre of the Bothnian Sea. The bloom then declined, but remained until the end of the month.

In situ observations

On the SMHI expedition, 17-22 June, with the Swedish Coast Guard vessel KBV001 Poseidon the researchers found relative ample amounts of cyanobacteria of the genus *Aphanizomenon* when sampling in the southern Baltic, but not in blooming quantities. It would still take ten days before a bloom could be observed from satellite.

At the next expedition on 10-15 July, surface accumulations were observed at these stations and further northeast to the east of Gotland. The species *Nodularia spumigena* was commonly found in the surface accumulations, but *Aphanizomenon* and *Anabaena* dominated the water samples.

The last expedition of the summer on 1-7 August went through sheets of cyanobacteria filaments in much of the southern Baltic Proper as well as north of Gotland. Now, *Aphanizomenon flos-aqua* was again found to be the most abundant species.

Normalized indexes

To be able to compare blooms between different years, the definitions of bloom normalized **duration (T)**, **extent (A)** and **intensity (I)** have been developed. Based on the annual summaries (see example in Figure 1) where the area (a_i) is equal to the extent that is covered by surface accumulations of blooms during (i) number of days, the normalized duration and extent is given, with (i) ranging from 1 to the maximum number of days with bloom observations during the current year. The intensity is given in “extent days” or km^2days. (Hansson, 2006 & Hansson & Håkansson, 2007)

Although no comparison with the years 1997-2009 should be made since the detection procedure has changes and the time series not has been corrected, the normalized bloom intensity was 12526 km^2days and duration 3.5 days, while the normalized extent was 3550 km^2. The maximal extent (~65 000 km^2) was observed on the 4th August. Overall the bloom during 2011 can be considered to be below normal.

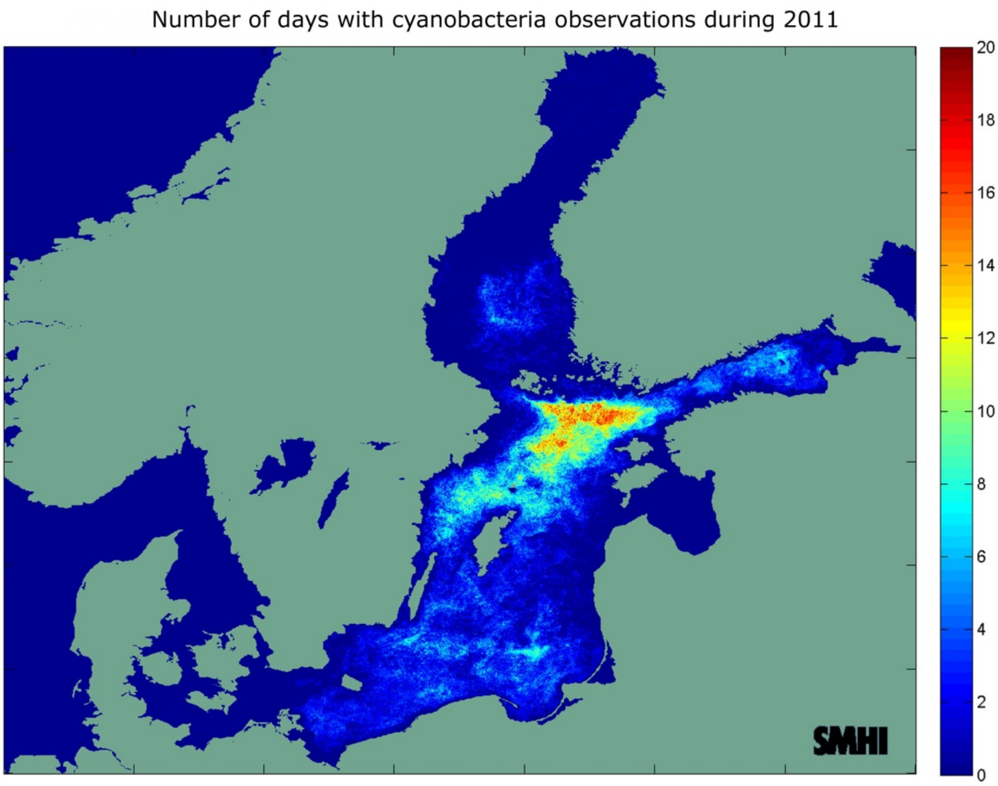

Figure 1. Number of days during 2011 with surface blooms of cyanobacteria observed in each pixel based on MERIS and MODIS satellite data.

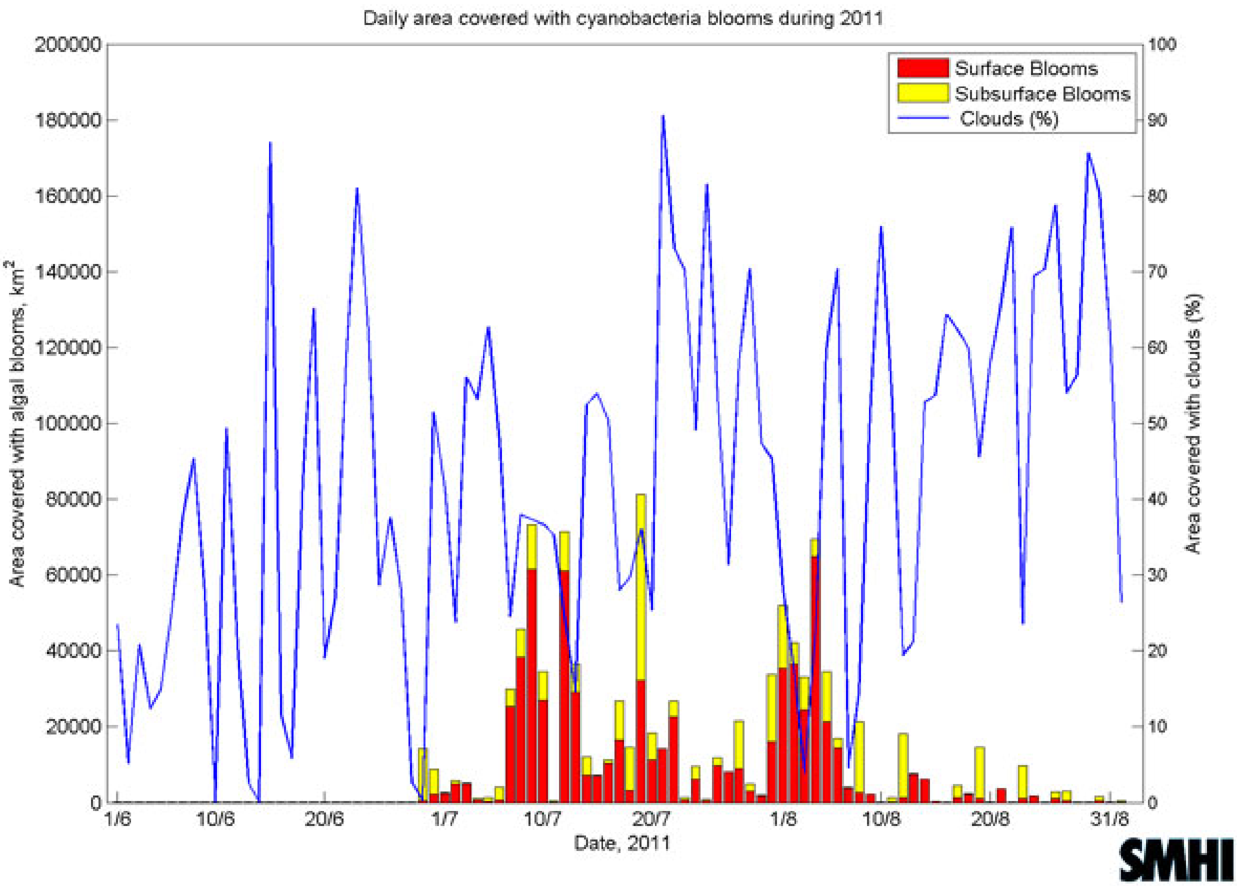

Figure 2. Daily extent of cyanobacteria blooms in the Baltic Sea during 2010, deteced by MODIS and MERIS satellite imagery. Red bars correspond to surface bloom and yellow bars indicate subsurface bloom. The blue line represents the integrated cloud cover (in percent of the total area) over the whole analyzed area.

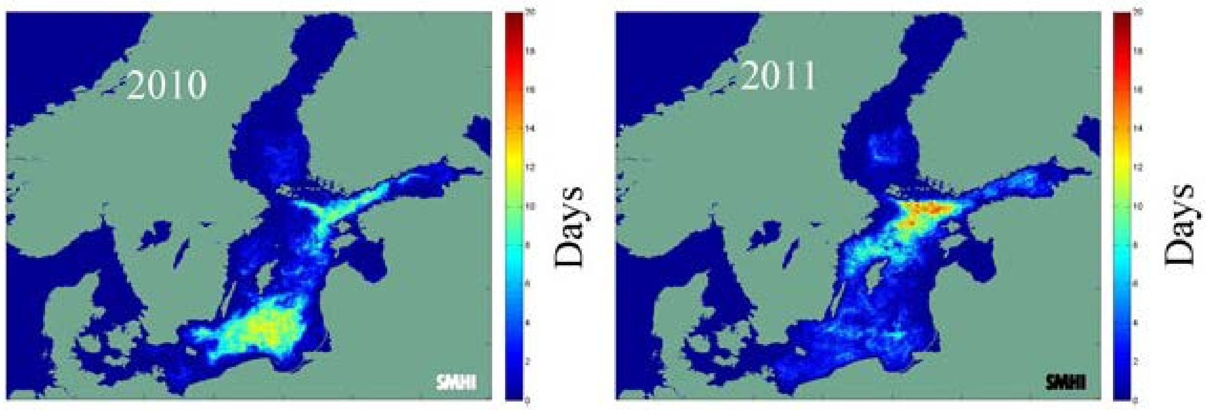

Figure 3. Summary of number of days with cyanobacterial observed in each pixel during the period 2010-2011. Note that comparison between these results and results from the period 1997-2009 is not possible since the detection method is different.

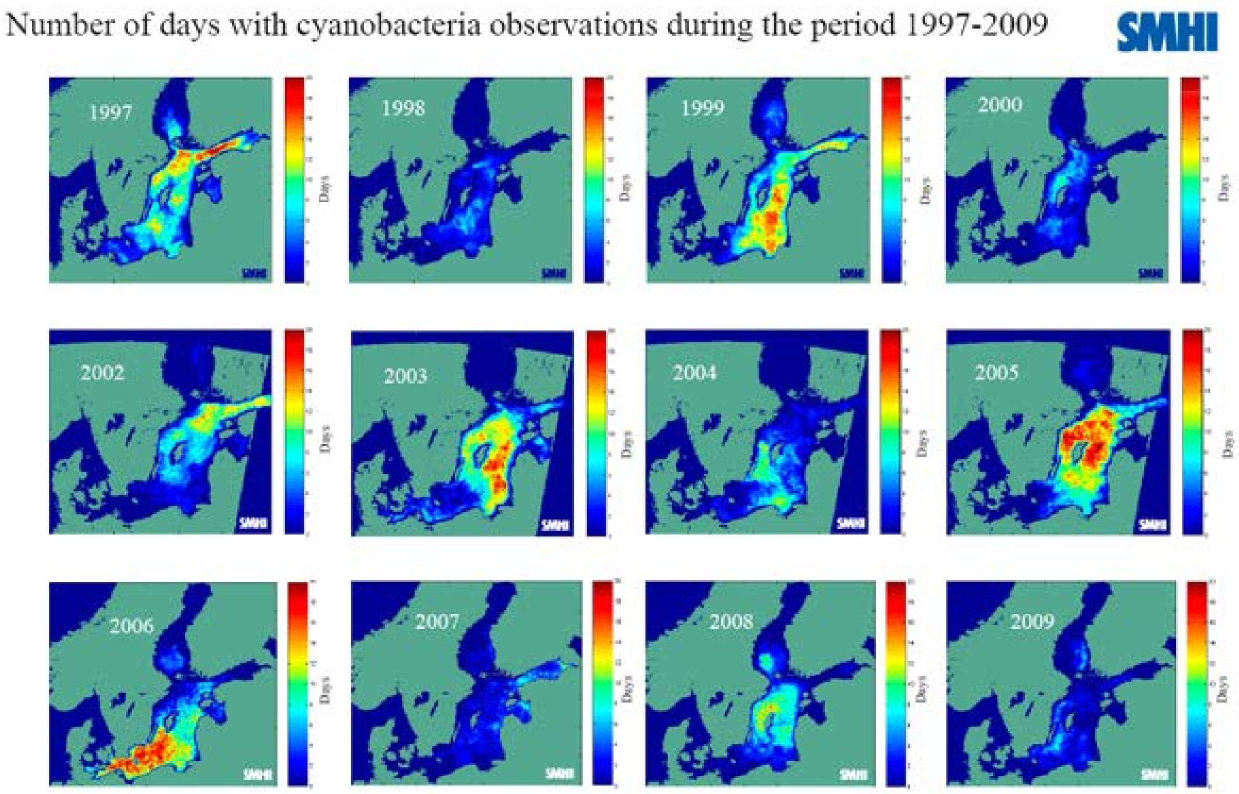

Figure 4. Summary of number of days with cyanobacterial observed in each pixel during the period 1997-2009, based on NOAA-AVHRR satellite imagery. Year 2001 is missing due to antenna malfunction at the receiving station. Note that comparison between the results of 2010 and 2011 with previous years is not possible since the detection method is different. Work is ongoing to make the time series harmonized.

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Data

All MERIS and MODIS L2 data covering the Baltic region that were available from the previous day area automatically collected via FTP-boxes (Near Real-Time service at OceanColorWeb, NASA and the MERIS rolling archive at ESA) to SMHI. Data from the previous day is convenient to use, since a new bloom map can be made available directly around 09:00 local time and the public and environmental managers can then get updated information about the algal situation early in the morning. It's also practical for the operator who does not need to wait for additional satellite data which can delay the daily production of bloom maps.

As a backup, the SMHI satellite receiving station in Norrköping collectes NOAA-AVHRR data, which can be used if data from both MODIS or MERIS are missing. Analysed satellite images showing the extent of surface and subsurface bloom in the Baltic Sea is presented at the following website. The images are updated on a daily basis during summer.
http://www.smhi.se/en/Weather/Sweden-weather/the-algae-situation-1.11631

Metadata

Technical information

1. Data source:

MERIS data is collected via ftp from the rolling archives at ESA and MODIS data is collected from the near real time service at OceanColorWeb at NASA.

2. Description of data:

Normalized water leaving radiance (nLw) from MODIS and MERIS L2 data is used. The AVHRR-sensor measures radiation in 5 broad wavelength bands ranging from visible to thermal infrared.

3. Geographical coverage:

The Baltic region; due to the longer revisit interval and the smaller swath width compared to AVHRR the two sensors MERIS and MODIS must be combined to achieve a daily coverage of the Baltic region during the bloom season.

4. Temporal coverage:

Data from the NOAA-AVHRR sensor have been available since the late 1970s. Karhu et al. (1994; 1997) has produced a compiled time series of satellite data for analysis of cyanobacterial blooms in the Baltic Sea from 1982 to 1994. In 2002, SMHI initiated the Baltic Algal Watch System (BAWS) that performs daily interpretations of satellite imagery during the summer. AVHRR data have also been analyzed between 1997 and 2000 by SMHI in the EU-project HABES (Harmful Algal Blooms Expert System).

5. Methodology and frequency of data collection:

Data are collected automatically via ftp to SMHI. Scenes from the Baltic regions are not always available on a daily basis since MODIS has a revisit interval of 1-2 days and MERIS 3 days. By combining these two sensors, daily coverage can be achieved.

6. Methodology of data manipulation:

Methods to detect surface accumulations of cyanobacteria in the Baltic Sea has been develop for several satellite sensors: CZCS, AVHRR, SeaWIFS [Kahru 1997, Kahru 2007], and MODIS data. The detection scheme to classify blooms in MODIS data [Kahru, 2007] relies on a combination of threshold value masking of normalized water leaving radiance (nLw) in two bands; 551 and 670 nm. For the 551 nm band, where the radiation penetrates a few meters down in the water column, [Kahru, 2007] estimated a threshold of nLw(551) > 0.8 mWcm-2µm-1sr-1 by visual inspection of RGB composite images. The water signal in this channel is sometimes affected by shallow depths which gives a false high signal from the bottom. It is also sensitive to turbid waters such as river plumes or sediment rich coastlines, which has a strong signal. Because of water's strong absorption properties at 670 nm the radiation does not penetrate as deeply as band 551 nm. Hence, this gives a signal from the water surface that can be used to detect surface accumulations and also to filter out bottom reflections when combine with the 551 nm band. For the 670 nm the authors [Kahru, 2007] used the turbid water flag of MODIS which corresponds to a threshold of nLw(670) > 0.18498 mWcm-2µm-1sr-1. The method can be used to distinguish between blooms at the surface and blooms present just below the surface; subsurface blooms.

This classification method for detection of blooms in MODIS imagery has been adopted for the similar 560 nm and 665 nm bands of the MERIS sensor full resolution level 2 data. By combining nLw data from MODIS and MERIS the problem with daily coverage of the Baltic region can be minimized.

MERIS data were FRS L2 products downloaded from EOLi (Earth Observation Link). This is the European Space Agency's client for Earth Observation Catalogue and Ordering Services. MODIS L2 data were collected from NASA's Ocean Color Web. MERIS surface reflectance (Rho_wn) data were converted to normalized water leaving radiance (nLw) by using Eq 1.

$nLw = (Rho\_wn * F0 * \cos(SzA))/\pi$, (1)

where F0 is the downwelling solar irradiance and SzA is the solar zenith angle (Pers. Comm. Ludovic Bourg, EOHelpdesk)

Two satellite data sets from one overpass are usually needed to cover the Baltic region. Depending on what data are available, the system can handle one or two data sets from each sensor. The MERIS surface reflectance data is converted to nLw using Eq. 1. and both MODIS and MERIS data are mapped to an equal area projection covering the Baltic Sea. Flags from both datasets are used to eliminate clouds or other conditions in which bloom detection is either not possible or likely to produce errors. Error pixels are marked as no data. The combined bloom maps present the occurrence of surface and subsurface blooms, clear water, clouds and areas with no data. When overlap exists, blooms observations are prioritized. Hence, surface bloom goes before subsurface and clouds and no data are only marked if they are detected in both data sets in overlapping areas or detected in non overlapping areas.

The operator quality controls the bloom map and writes a daily report, which is published on the web. A weekly composite, comprising of stacked images of the bloom observations during the last seven days is also published. If data from both MODIS and MERIS are absent due to satellite position, sensor or data delivery malfunction, data from NOAA-AVHRR can still be used in the service as a backup. This guarantees that a daily bloom map can always be produced during the bloom season.

Quality information

1. Strength and weakness:

Satellite data have high sampling frequency and allow a synoptic view. Monitoring is limited to open sea areas due to shallow water effects and land contamination of pixel data, and are also limited by cloud cover. However, the new method enables monitoring closer to land than previously and it is now possible to detect blooms through scattered clouds, which impossible when using AVHRR.

2. Reliability, accuracy, robustness, and uncertainty:

The new method has been tested on satellite data with well known blooms, such as 31st of July 2008 and 11th July 2005, with good results. The whole summer season of 2008 (1 June – 1 September) has also been tested to certify that results didn't drift throughout a season. The results and comparison with the previous method, which not yet have been published, show a good overall agreement between MERIS/MODIS and AVHRR. The detected area is slightly smaller with the new method since bloom patchiness is better represented. It is also evident from processing the bloom season 2008 that more blooms could be seen, since the cloud influence on the detection results was less with the new method.

3. Further work:

Up to now the main work has been to make the new combined MODIS and MERIS detection scheme operational. This work, funded by the National Swedish Space Board, is now finished but further work is needed to harmonize the time series from 1997 to 2009 with the new detection method. Future work will focus on the differences between MODIS and MERIS flags, since MODIS seems to be more restrictive than MERIS. The Maximum chlorophyll index (MCI) and Fluorescence Line Height (FLH) will also be evaluated to see if they are suitable contributing tools in the monitoring process.

Future work will also focus on availability of satellite data. Both MERIS and MODIS are operating beyond their technical lifetime so it is necessary to introduce other similar satellite data or include new missions into the service as soon as data are made available.

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