Cyanobacterial blooms in the Baltic Sea

Authors: Martin Hansson (Martin.Hansson@smhi.se) & Jörgen Öberg, Swedish Meteorological and Hydrological Institute

Key Message

This summer's cyanobacterial bloom in the Baltic Sea was restricted to the first three weeks of July and mostly affected the southeastern parts of the Baltic Proper. Blooms were frequently observed in the northern Baltic Proper, the outer parts of the Gulf of Finland and in the Hanö Bight. However, after three weeks the blooms scattered and only minor surface blooms where detected in August. As in previous years, blooms occurred in the central and eastern Bothnian Sea during the second half of August, but the surface accumulations were less prominent. 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 is new. Work is ongoing to harmonize the time series.

A new method to detect cyanobacterial blooms from satellite data has been developed during 2009 and 2010 and was used operationally during 2010. The method combines satellite data from two satellite sensors (ENVISAT-MERIS and EOS-MODIS). The detection technique (Kahru, 2007) was originally developed for MODIS data and has now been adapted and combined with MERIS data to minimize the cloud problem and to get daily coverage. MERIS and MODIS data offer a higher spatial and radiometric resolution compared to AVHRR which previous been used. With the new method it’s possible to detect blooms closer to land and through scattered clouds. The patchiness of the bloom is also monitored more accurately.

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 2010 phosphate concentrations were back to normal in the whole Baltic Proper. (See SMHI, R/V Argos cruise reports 2010, www.smhi.se)

The weather in the Baltic region during July started with a warm and dry period. The air temperature in the Baltic region exceeded 30°C in many locations; for example in Visby a new temperature record was set at 33.7°C. High temperatures could also be seen in the surface water, which was above normal temperature at all sampling stations in the Baltic Proper during the July cruise of R/V Argos (See SMHI, R/V Argos cruise reports 2010, www.smhi.se). These favorable weather conditions for cyanobacterial blooms continued during the first half of July. The end of July was more unstable with heavy rain and strong winds. August started with fine weather but from mid August more unstable autumnal weather prevailed. Water temperatures were back to normal during the cruise in August.

Assessment

The largest and most dense bloom could be observed from satellite images under an almost unchanging cloud-free sky, from the 2nd to the 22nd of July. The main part of the bloom was in the southeastern Baltic Proper, extending north into the Gulf of Finland and east to the Hanö Bight. At the end of July, cloud cover became more frequent, making it more difficult to detect the bloom from satellite. As the clouds dispersed, only fragments of the earlier bloom could be seen. These blooms were visible until the 2nd of August.

The Bothnian Sea usually blooms later than the Baltic Proper, and this year was no exception. The eastern Bothnian Sea bloomed from the 11th to the 23rd of August. Remains of the bloom could be seen into September.

Scientists aboard the SMHI cruise on R/V Argos from the 28th June to 3rd July mainly observed *Aphanizomenon* spp. but no coherent surface aggregations were seen. On the next expedition between the 19th and 24th July, dense surface accumulations covered large parts of the southern Baltic Proper, including in the Hanö Bight and the southern coast of Skåne. The toxic species *Nodularia spumigena* dominated.

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)

$$\text{Duration, T} = \frac{\sum a_i * i}{\sum a_i} \quad [days]$$

$$\text{Area, A} = \frac{\sum a_i * i}{\sum i} \quad [km^2]$$

$$\text{Intensity,} \quad I = A * T \quad [km^2\ days]$$

Although no comparison with previous years should be made since the detection procedure is new and the time series not has been corrected, the normalized bloom intensity was 24163 km^2days and duration 4.0 days, while the normalized extent was 5986 km^2. The maximal extent (~70 000 km^2) was observed on the 12th July. Overall the bloom during 2010 can be considered to be normal.

Another improvement in monitoring is the new ferrybox system that has been installed on the merchant vessel TransPaper, which traffics weekly between Gothenburg (Sweden) and Oulu (Finland). Data are collected continuously from a set of sensors, which among other parameters record, chlorophyll-a and phycocyanin pigments. Data are sent via satellite to SMHI. Water samples are also collected automatically and preserved for optical plankton analysis.

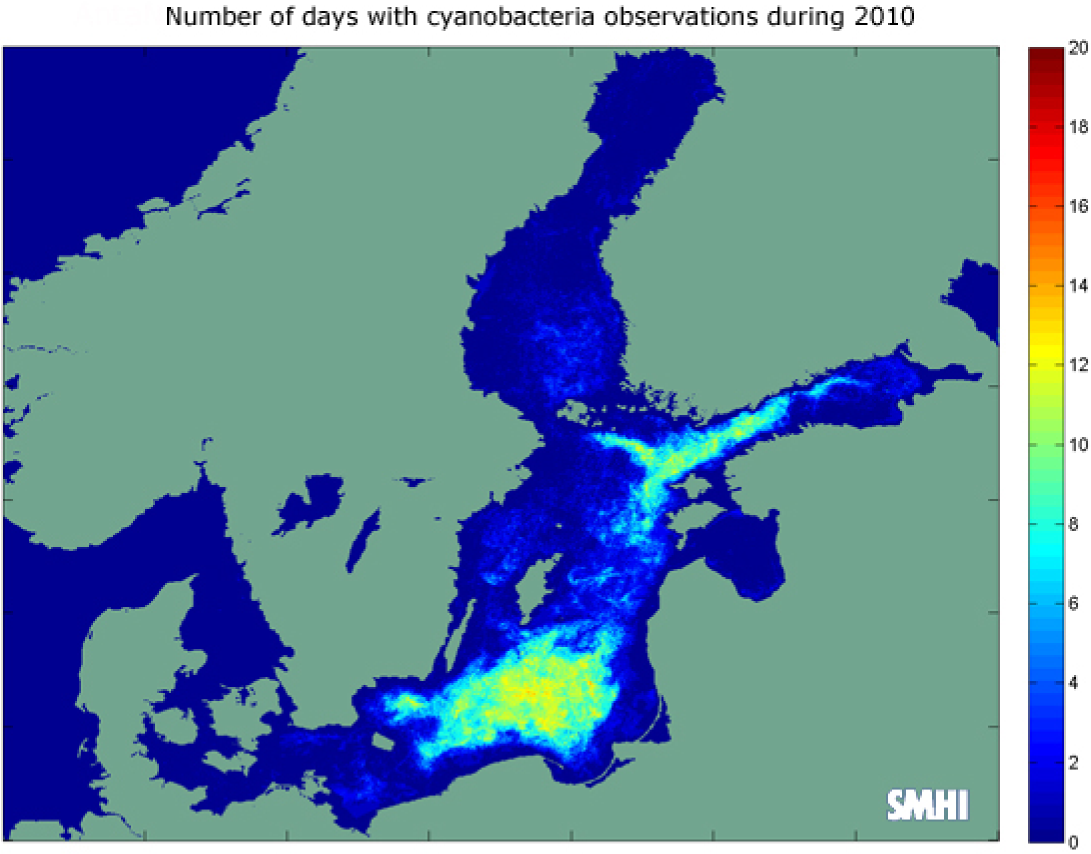

Figure 1. Number of days during 2010 with surface blooms of cyanobacteria observed in each pixel based on MERIS and MODIS satellite data.

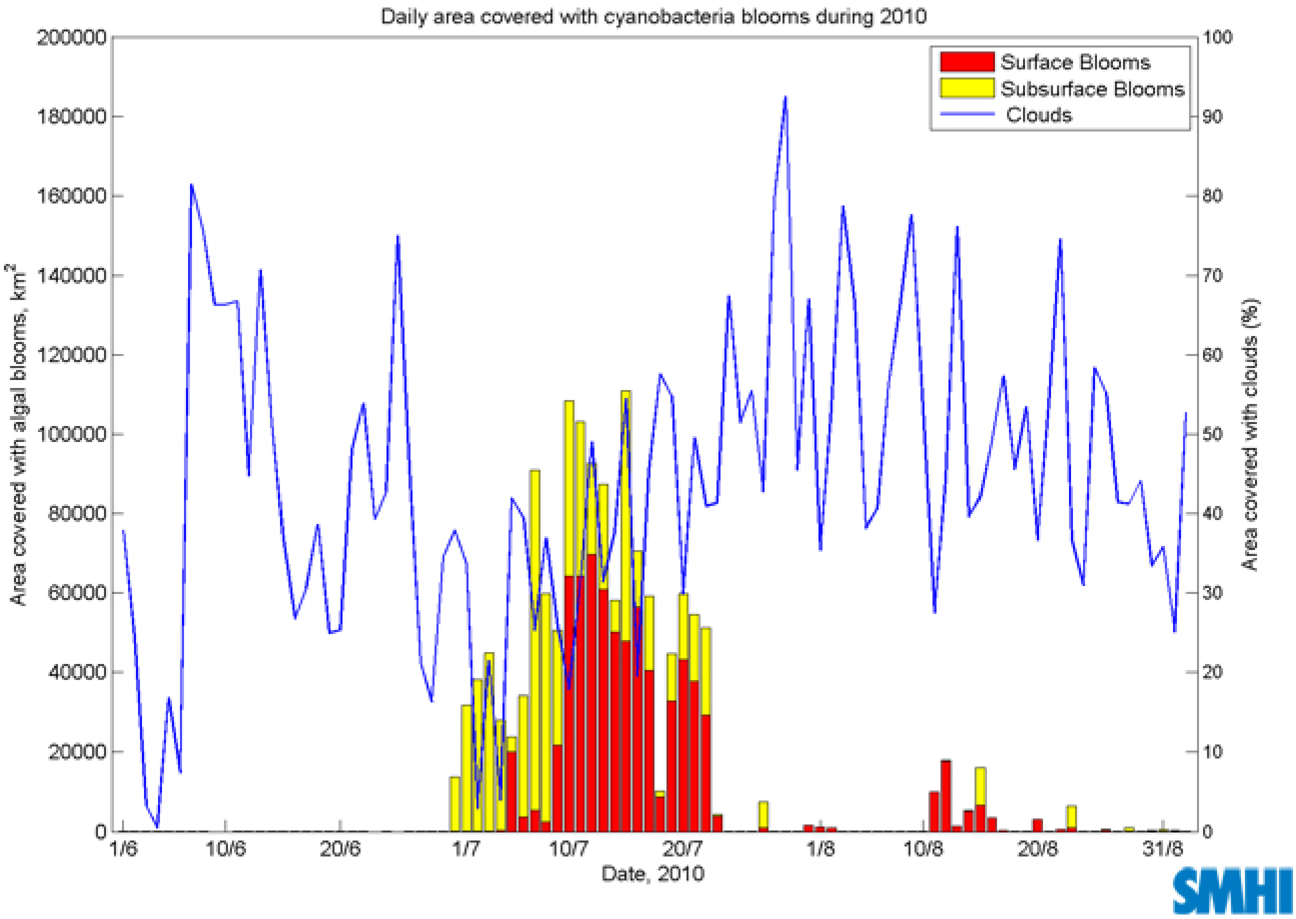

Figure 2. Daily extent of cyanobacteria blooms in the Baltic Sea during 2009, deteced by MODIS and MERIS satellite imagery. Red bars correspond to surface bloom and yellow bars indicate subsurface bloom. The blue line represents the integrated cloud cover (in percent of the total area) over the whole analyzed area.

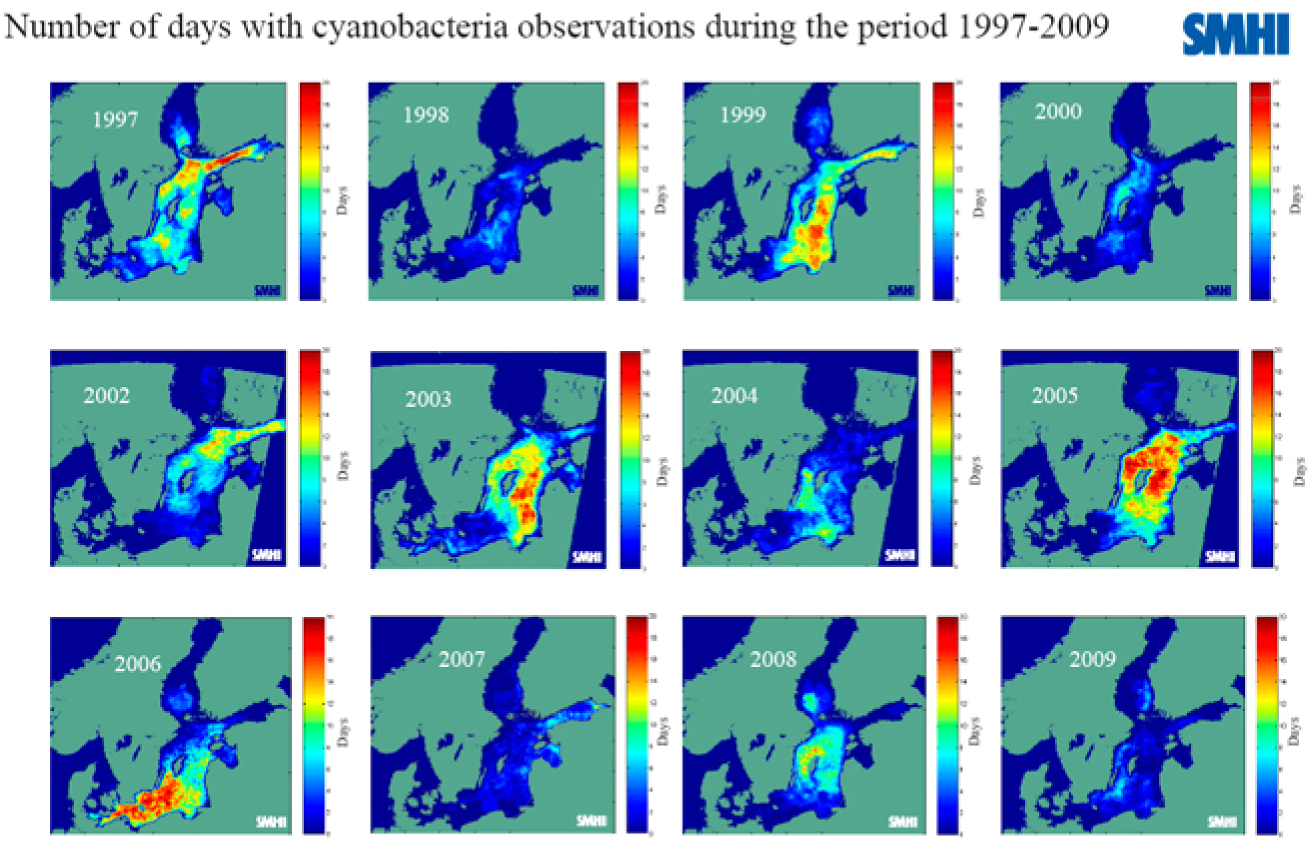

Figure 3. Summary of number of days with cyanobacterial observed in each pixel during the period 1997-2009, based on NOAA-AVHRR satellite imagery. Year 2001 is missing due to antenna malfunction at the receiving station. Note that comparison between the results of 2010 and previous years not is possible since a new detection method is used. Work is ongoing to make the time series harmonized.

References

Hansson, M., P. Pemberton, B. Håkansson, A. Reinart, K. Alikas. Operational nowcasting of algal blooms in the Baltic Sea using MERIS and MODIS. ESA Living Planet Symposium, Bergen 28-Jun to 02-Jul-2010, Special Publication SP-686, 2010.

Hansson, M., & B. Hakansson, 2007, "The Baltic Algae Watch System - a remote sensing application for monitoring cyanobacterial blooms in the Baltic Sea", *Journal of Applied Remote Sensing* 2007, 1(1):011507.

Hansson, M. Cyanobakterieblomningar i Östersjön, resultat från satellitövervakning 1997-2005, SMHI Oceanografirapport nr 82, 2006, ISSN: 0283-7714.

Karhu, M., O.P. Savchuk, and R. Elmgren, 2007, “Satellite measurements of cyanobacterial bloom frequency in the Baltic Sea: Interannual and spatial variability”. In Press.

Kahru, M., 1997, Using Satellites to Monitor Large-Scale Environmental Change: A case study of the Cyanobacteria Blooms in the Baltic Sea. Monitoring algal blooms: New techniques for detecting large-scale environmental change. Landes Bioscience.

Kahru, M., U. Horstmann and O. Rud, 1994, Satellite Detection of Increased Cyanobacteria Blooms in the Baltic Sea: Natural Fluctuation or Ecosystem change?, Ambio Vol. 23 No. 8.

Larsson, U., and L. Andersson, 2005, Varför ökar inte kvävet när fosforn ökar?, Miljötillståndet i Egentliga Östersjön, rapport 2005, Stockholms marina forskningscentrum.
SMHI, R/V Argos cruise reports & AlgAware, archive 2010.
http://www.smhi.se/oceanografi/oce_info_data/reports/havmiljoarkiv/oce_reportarchive10.html

Data

All MERIS and MODIS L2 data covering the Baltic region that were available from the previous day was 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. <u>By combining nLw data from MODIS and MERIS the problem with daily data coverage of the Baltic region can be minimized.</u>

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))/π, (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 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.

For reference purposes, please cite this Baltic Sea environment fact sheet as follows:

[Author's name(s)], [Year]. [Baltic Sea environment fact sheet title]. HELCOM Baltic Sea Environment Fact Sheets. Online. [Date Viewed], http://www.helcom.fi/baltic-sea-trends/environment-fact-sheets/.