Satellite studies of the Baltic Sea ecology

Mati Kahru

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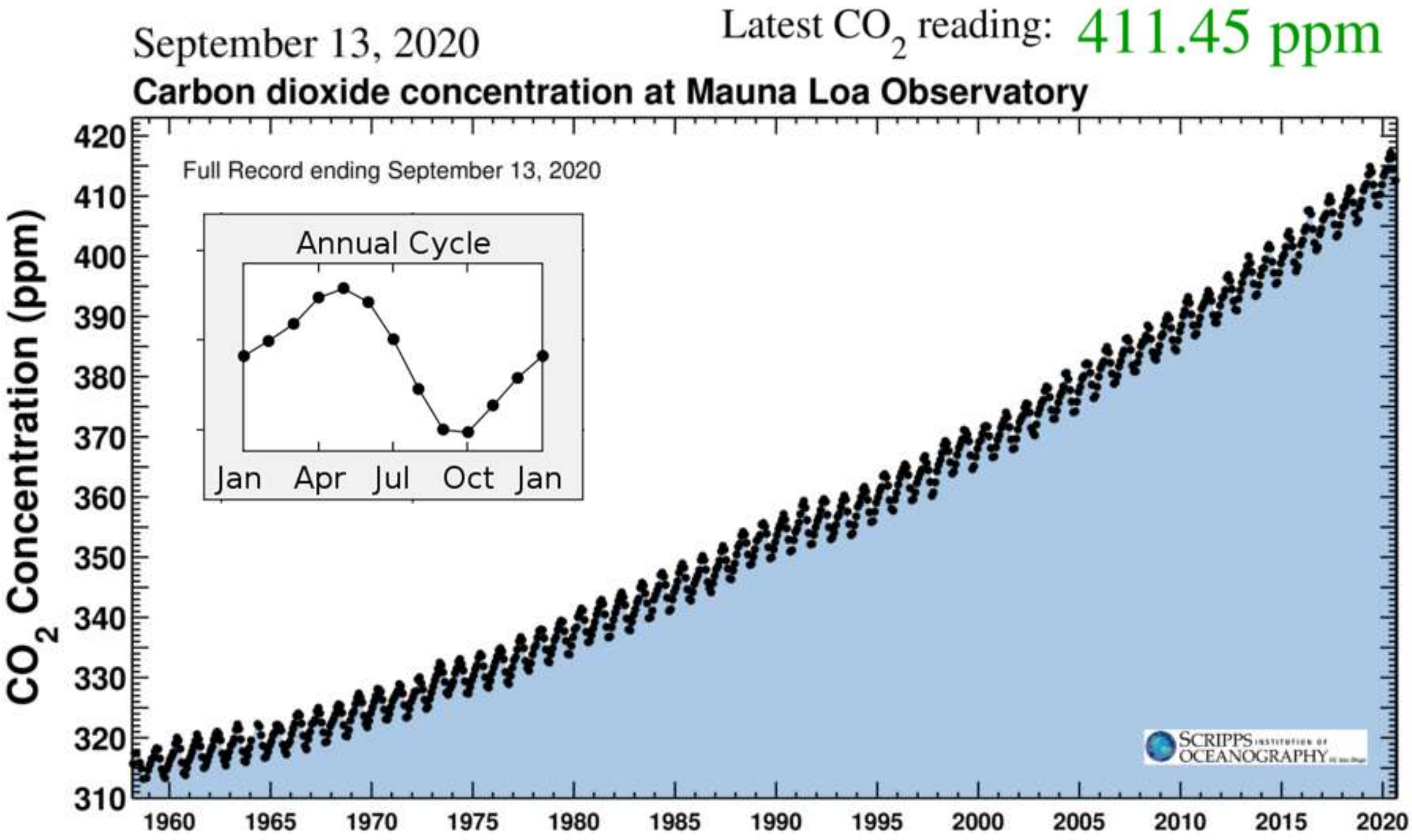
mkahru@ucsd.edu

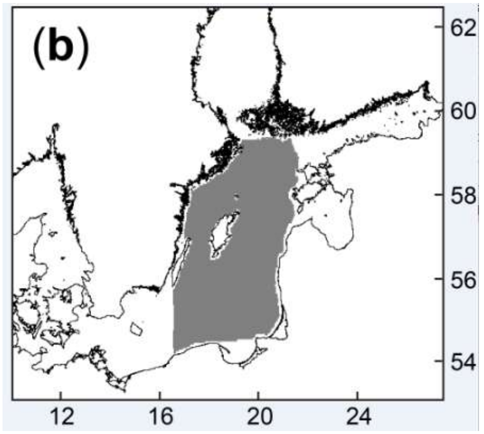
MODISA 2005/07/08

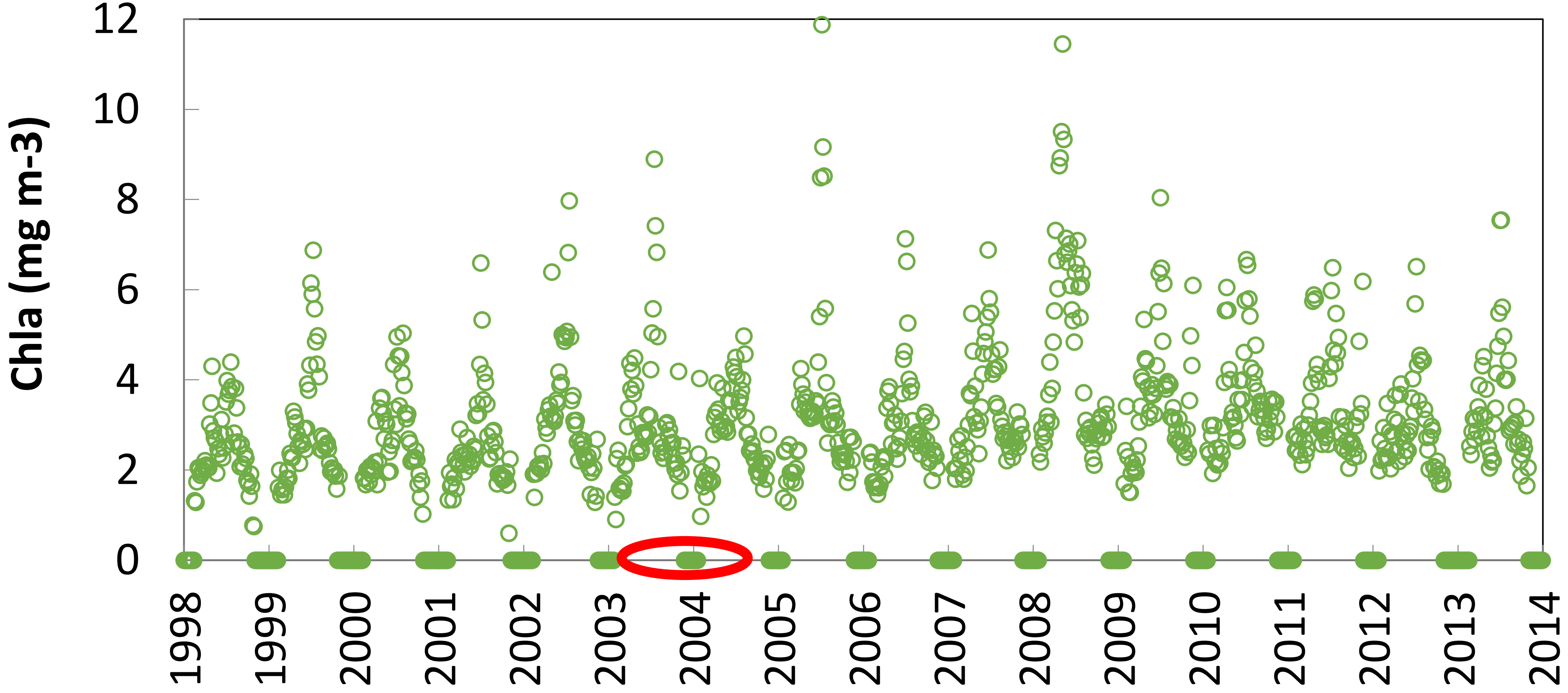
The “Keeling curve” Prof. Charles David Keeling; Prof. Roger Revelle

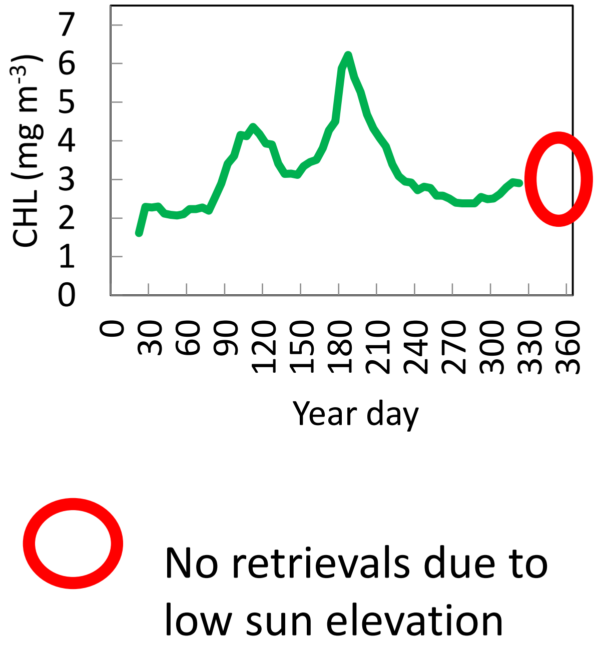


Chlorophyll-a (Chla) in central Baltic Sea

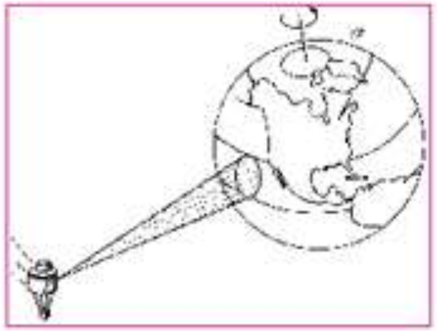
Time series of the 5-day mean CHL (mg m^{-3}) in the central Baltic Sea derived from the ESA-CCI processing of SeaWiFS, MERIS and Aqua-MODIS satellite data (Sathyendranath et al., 2014, 2015). Trend? Accuracy? What does it measure?







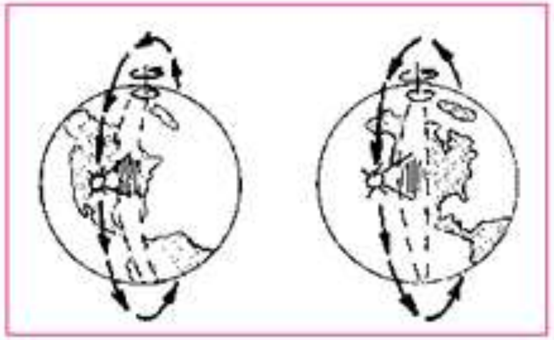
EO sensors are typically on:
polar orbits (often sun-synchronous, LEO);
geostationary orbits (GEO): **GOCI, METEOSAT, SEVIRI**
Polar orbiters ~700 km above ground. **Orbit repeat cycle** is ~14-16 days. However, sensors with wide swath (e.g. MODIS-Aqua – 2330 km) <2 day **revisit time**, 1-day revisit with a pair (tandem) sensors (MODIS Aqua & Terra, Sentinel-3 A & B)
High-res sensors with narrow swath have revisit time equal to repeat cycle ~14-16 days, Landsat, Sentinels 2A & 2B.



Geostationary Satellite
in equatorial orbit at
36,000 km altitude
stays over the same spot

can stare at evolving systems

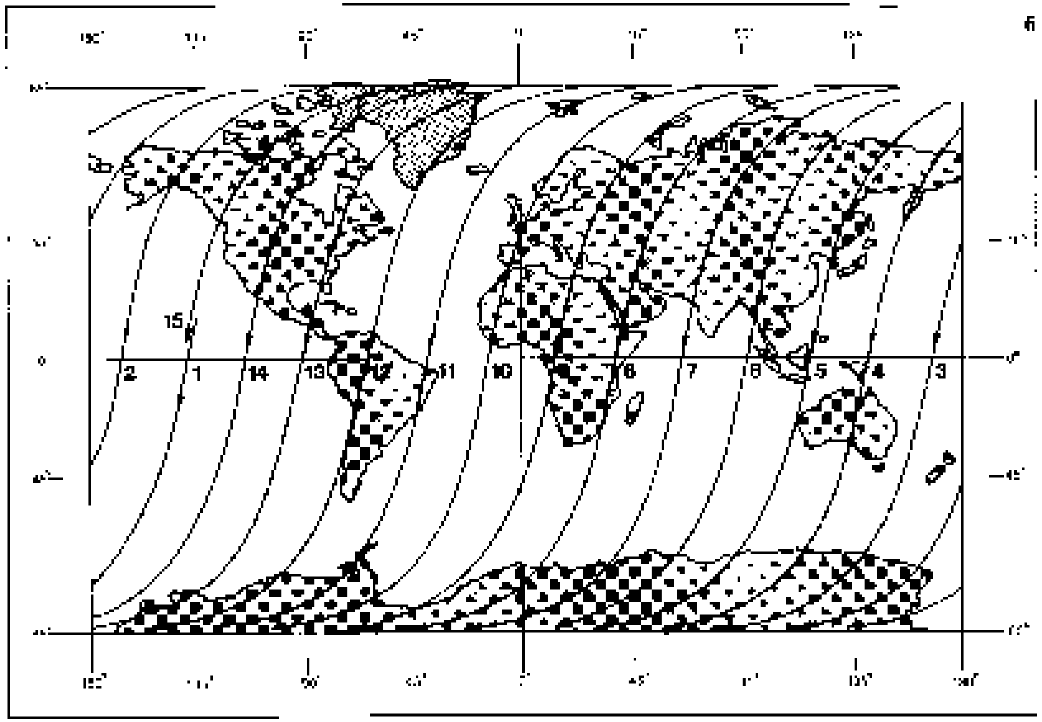
Lower spatial resolution



Polar-Orbiting Satellite
about 850 km altitude travels over both north and south poles. Earth rotates ~13° for each ~100 min orbit

can see whole globe at
high resolution

Sees only small portion
at any time



Satellite Oceanography (Ocean color, SST and altimetry) has been around for >40 years

- **CZCS** 1978-1986 (ocean color)**, AVHRR** 1979-…(SST)**, SeaSat** 1978 (altimetry), **Landsat** MSS (visible imagery),…
- **Fundamentally, ocean color sensors have not changed from 1978** (more bands, more bits/pixel, better algorithms)
- **Similarly, the principal technology behind SST and altimetry has not changed from about 1978**
- **Fundamental change in data access (PC, Internet!)**

Necessary components for satellite oceanography:

1. **Hardware** (satellite, sensor, antenna, computer, display)
2. **Software**
3. **Imagery** (data)
4. Cloud-free weather for visible and infrared imagery; microwave & scatterometry penetrate clouds

1. Hardware

Then: Receiving station (antenna, etc.): Scripps, Dundee, BSH, Tromsö. Manually directed horn-antenna in Stockholm University, 1992-93

Now: Don't need the antenna! Data through internet for free!

1. Hardware, continued

Then: Dedicated and expensive computers;

~30 yrs ago ~ $500,000… $1 million; VAX, HP, etc., specialized hardware

VAX 11/780, 6.2 m wide,
SMHI, Norrkőping, Sweden 1991-92

Now the minimum what is needed is a ~$300 PC and internet connection

2. Software

Then: Tailored for the specific hardware and very expensive (tens of thousands of $), using proprietary file formats

Now: generic, using high-level software layers, common high-level file formats (netCDF, HDF);

- **Free: SeaDAS, SNAP, Python, (BEAM)**
- **Inexpensive: Wimsoft, Matlab, IDL, ENVI**

3. Data (imagery)

Then:

Hard to get without owning a receiving station, stored and distributed on bulky tapes. Expensive! 1992-93 visited BSH to copy DAT cassette tapes

Now:

Mostly freely downloadable. Need internet and lots of storage (disk space)

Local (e.g. BSH) vs GHRSST

GHRSST
GROUP FOR HIGH RESOLUTION
SEA SURFACE TEMPERATURE

GROUP FOR HIGH
RESOLUTION SEA
SURFACE
TEMPERATURE

- real-time
- NRT - near real time
- NTC – delayed, reprocessed, climate quality

- Merging data from multiple sensors (NOAA-20 !) with changing calibrations and specifics, infrared + microwave, different resolutions, different overpass times (daytime, nighttime). Local provider OK for real-time and NRT, use GHRSST for long time series!

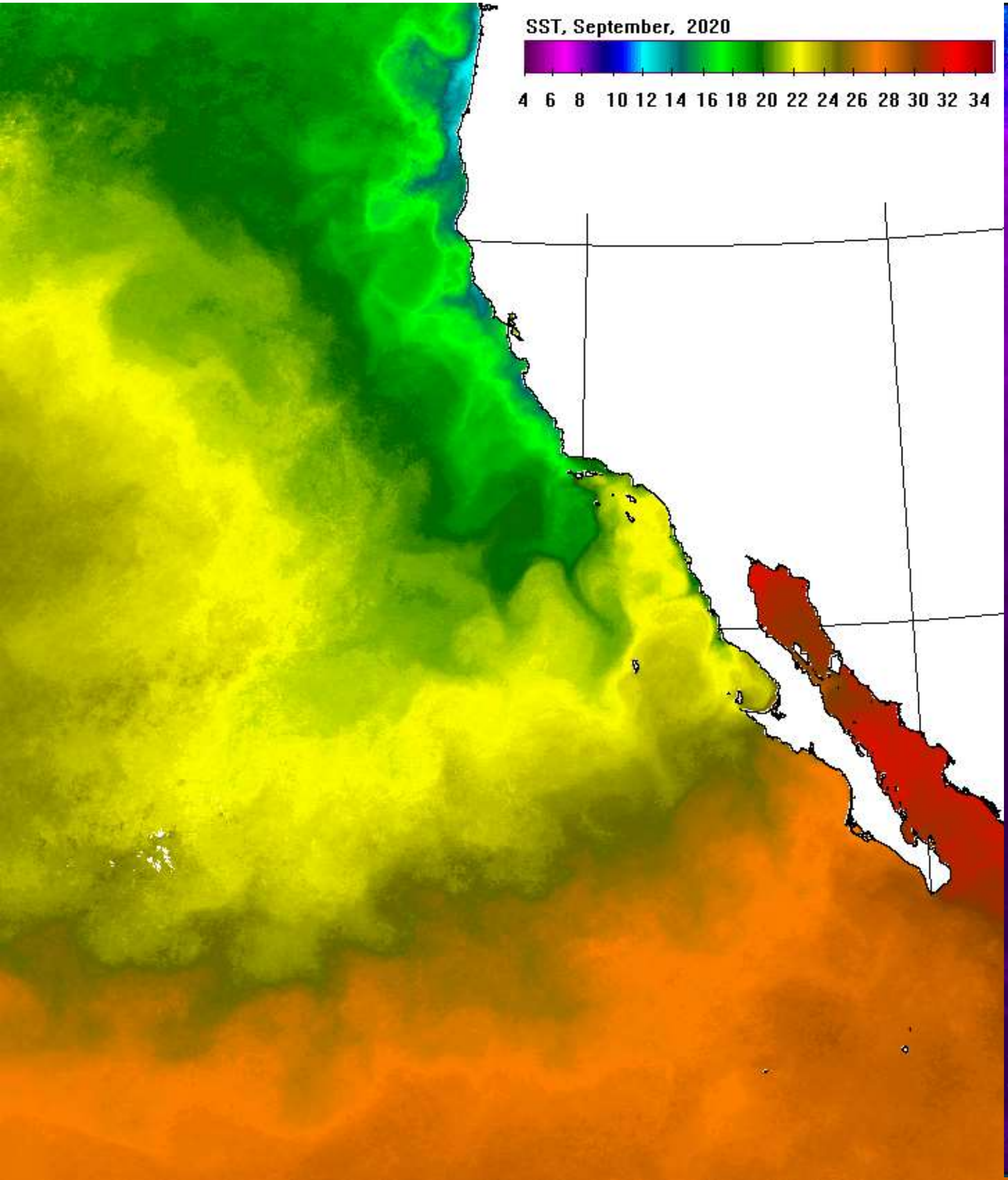
I am a data provider, mostly for N America West Coast, in the past Scotia Sea in Southern Ocean

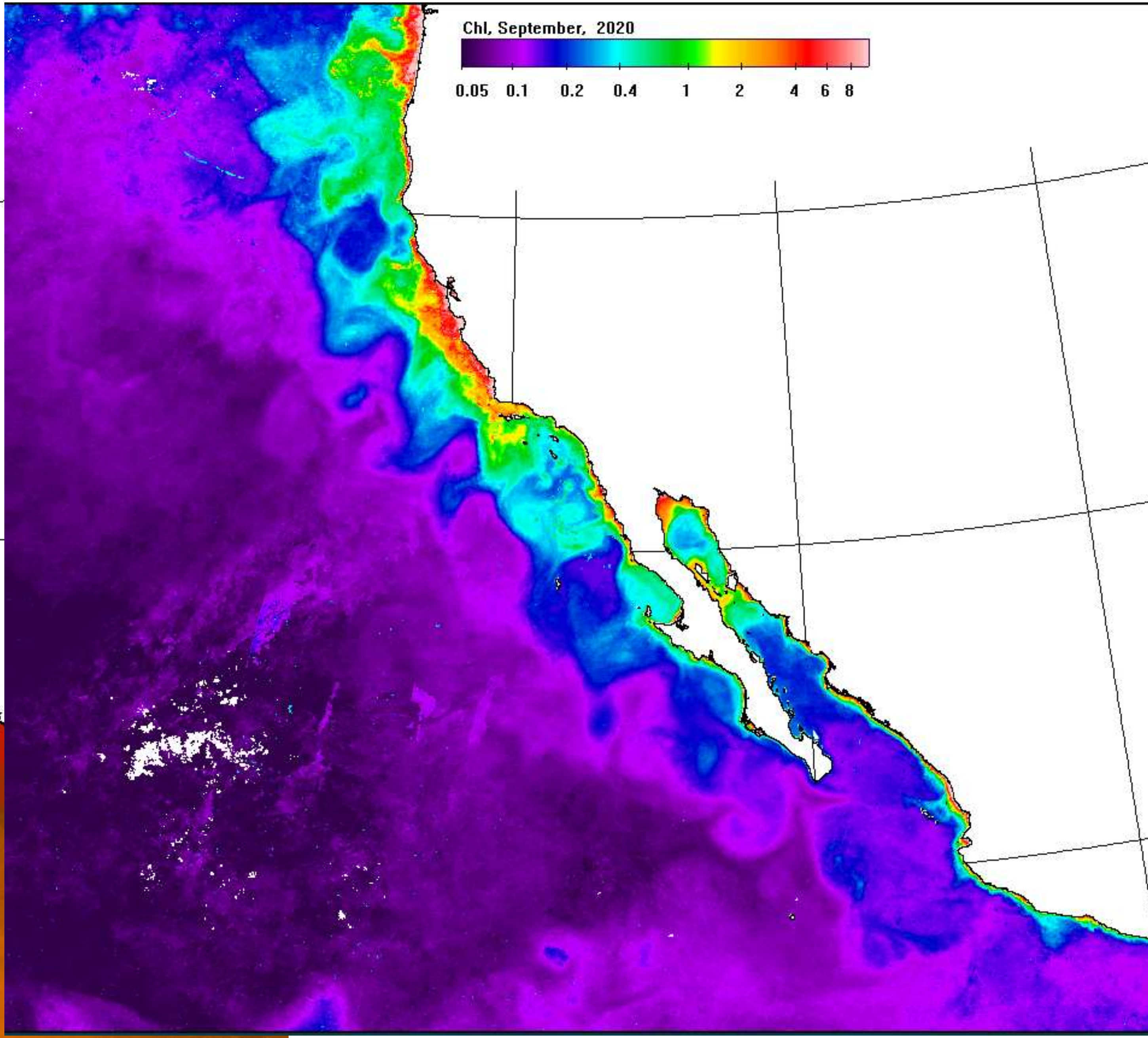
https://www.wimsoft.com/satellite.htm http://spg-satdata.ucsd.edu/

Year	Chl-a, POC	Sensor & processing version used for Chl-a	SST	Sensors used for SST	Notes / README
1978	X, 0	CZCS_v2014.0			updated 2016/02/12
1979	X, 0	CZCS_v2014.0			updated 2016/02/12
1980	X, 0	CZCS_v2014.0			updated 2016/02/12
1981	X, 0	CZCS_v2014.0			updated 2016/02/12
1982	X, 0	CZCS_v2014.0			updated 2016/02/12
....					
2018	X, X	MODISA_v2018.0, MODIST_v2018.0, VIIRS_v2018.0 OLCIA-WRR, OLCIB-WRR, VIIRS-JPSS1_v2018.0	X	MODISA_v2014.0.1, MODIST_v2014.0.1, VIIRS_v2016.0	updated 2020/03/06
2019	X, X	MODISA_2018.0, MODIST_2018.0, VIIRS_2018.0 OLCIA-WRR, OLCIB-WRR, VIIRS-JPSS1_2018.0	X	MODISA_R2019.0, MODIST_R2019.0, VIIRS_2016.2	updated 2020/05/12
2020	X, X	MODISA_2018.1, MODIST_2018.0, VIIRS_2018.0 OLCIA-WRR, OLCIB-WRR, VIIRS-JPSS1_2018.0, SGLI_2	X	MODISA_v2019.0, MODIST_v2019.0, VIIRS_v2016.2	updated ~weekly

- **Produced from Level-2**
- **Level 2 -** geophysical values, derived from Level-1A by applying sensor calibration, atmospheric corrections, and bio-optical algorithms, e.g. Chl-a, Rrs412, Rrs443,..
- **Level 3** – Level-2 data binned and mapped to a known projection or regular grid, here Albers Conic Equal Area 1 km^2 grid.

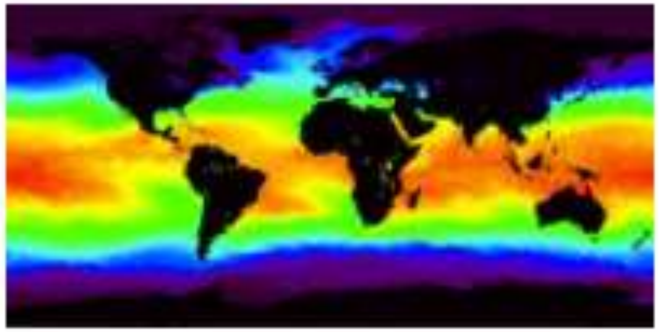
https://www.wimsoft.com/satellite.htm http://spg-satdata.ucsd.edu/





Monday, February 17, 2020

The PO.DAAC is pleased to announce that the GHRSST Multi-Scale Ultra High Resolution Sea Surface Temperature (MUR SST) data are now available in the cloud, as part of the NASA—Amazon Web Services (AWS) Space Act Agreement, executed by the Interagency Implementation and Advanced Concepts Team (IMPACT) for NASA's Earth Science Data Systems (ESDS) Program. The global, 1 km MUR SST dataset is available from June 2002 to present. Making these data freely available in the cloud is part of a larger effort by ESDS to enable researchers and commercial data users to access and work with large quantities of data quickly. These MUR SST data are optimized so that researchers can do large-scale analyses in the cloud.



GHRSST Level 4 MUR Global Foundation Sea Surface Temperature Analysis (v4.1)

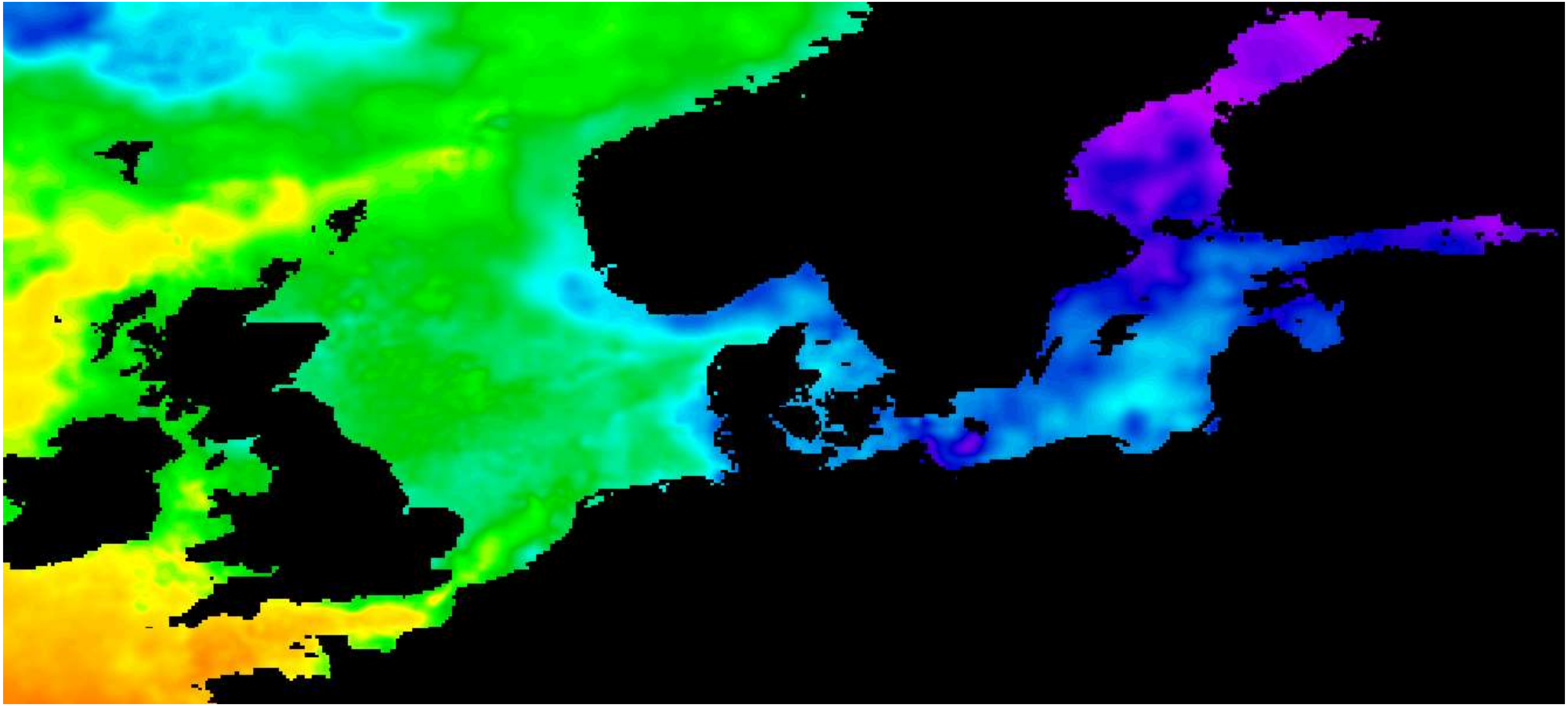
SHARE THIS PAGE

https://podaac.jpl.nasa.gov/dataset/MUR-JPL-L4-GLOB-v4.1

The version 4 **Multiscale Ultrahigh Resolution (MUR)** L4 analysis is based upon nighttime GHRSST L2P skin and subskin SST observations from several instruments including the NASA Advanced Microwave Scanning Radiometer-EOS (AMSR-E), the JAXA Advanced Microwave Scanning Radiometer 2 on GCOM-W1, the Moderate Resolution Imaging Spectroradiometers (MODIS) on the NASA Aqua and Terra platforms, the US Navy microwave WindSat radiometer, the Advanced Very High Resolution Radiometer (AVHRR) on several NOAA satellites, and in situ SST observations from the NOAA iQuam project

GHRSST
GROUP FOR HIGH RESOLUTION SEA SURFACE TEMPERATURE

GHRSST_Level_4_DMI_OI_North_Sea_and_Baltic_Sea_Regional_Foundation_Sea_Surface_Temperature



Cyanobacterial blooms cause heating of the sea surface

Vol. 101: 1–7, 1993 | MARINE ECOLOGY PROGRESS SERIES Mar. Ecol. Prog. Ser. | Published November 4

Mati Kahru[1], Juha-Markku Leppänen[2], Ove Rud[1]

[1]Stockholm University, Department of Physical Geography, S-106 91 Stockholm, Sweden
[2]Finnish Institute of Marine Research, PO Box 33, SF-00931 Helsinki, Finland

Example of biological-physical feedback!

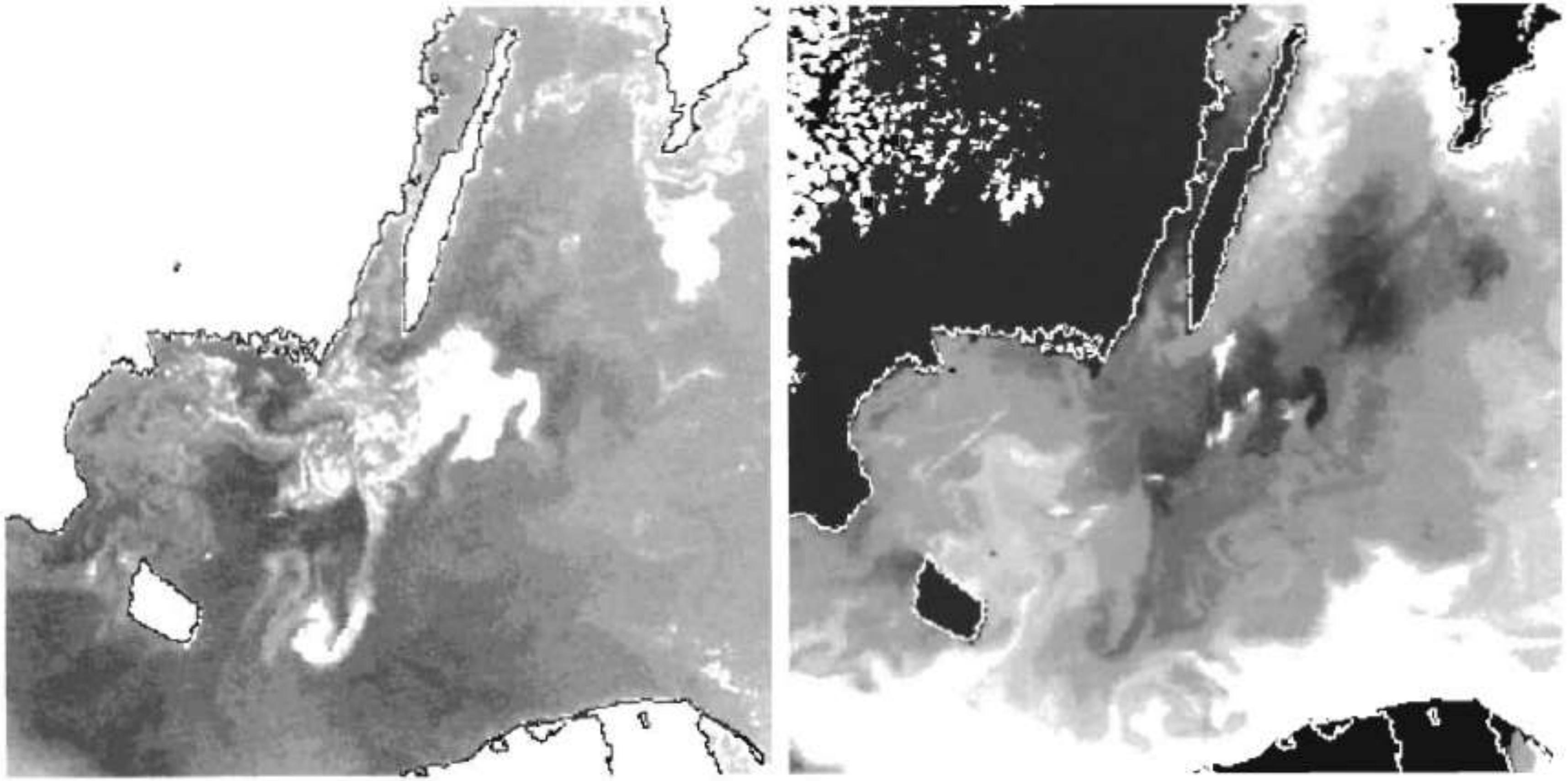


Fig. 2. NOAA-11 AVHRR images of Channel 1 albedo and Channel 4 temperature in the southern Baltic Sea, with surface-floating cyanobacterial accumulations. Coastlines have been overlaid with black (Channel 1) or white (Channel 4) contours. Lighter shades of gray represent higher albedo values and lower temperatures

Pergamon

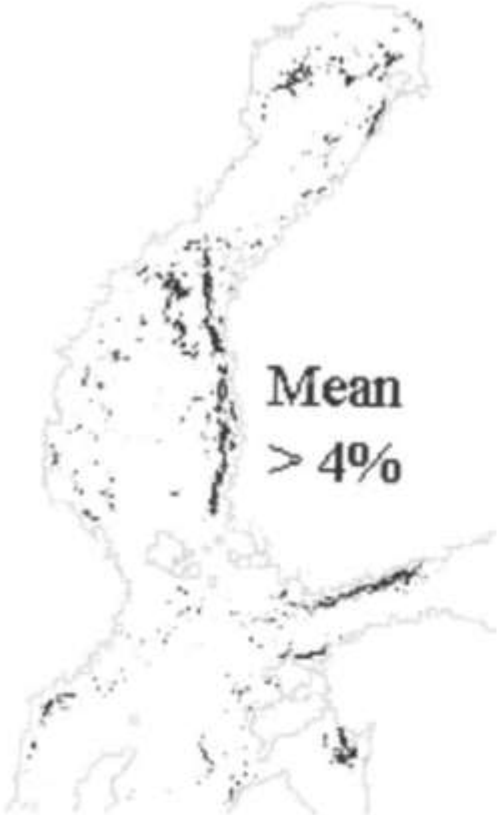
Continental Shelf Research, Vol. 15, No. 6, pp. 663–679, 1995

0278–4343/95 $9.50 + 0.00

0278–4343(94)E0030–P

Distributions of the sea-surface temperature fronts in the Baltic Sea as derived from satellite imagery

MATI KAHRU,*† BERTIL HÅKANSSON‡ and OVE RUD*



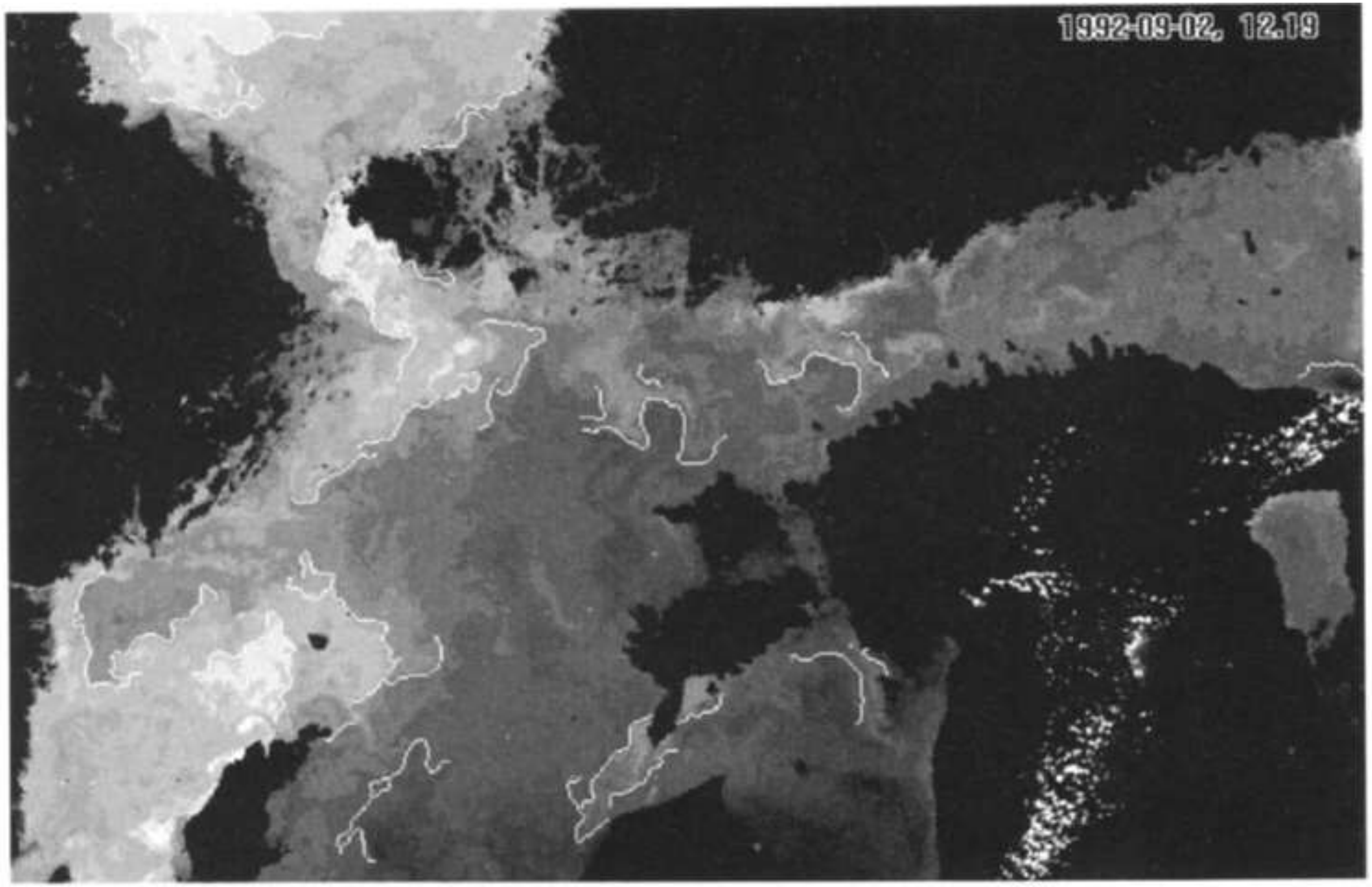


Fig. 2. Results of the front detection program on an AVHRR channel 4 subimage in the Northern Baltic Proper and western Gulf of Finland on 2 September 1992 (UTC 12.19). Brighter shades of gray correspond to colder, and darker shades to warmer, water. The detected fronts are overlaid as white contours. Land is considerably warmer and looks black. A few small scattered clouds are seen over land.

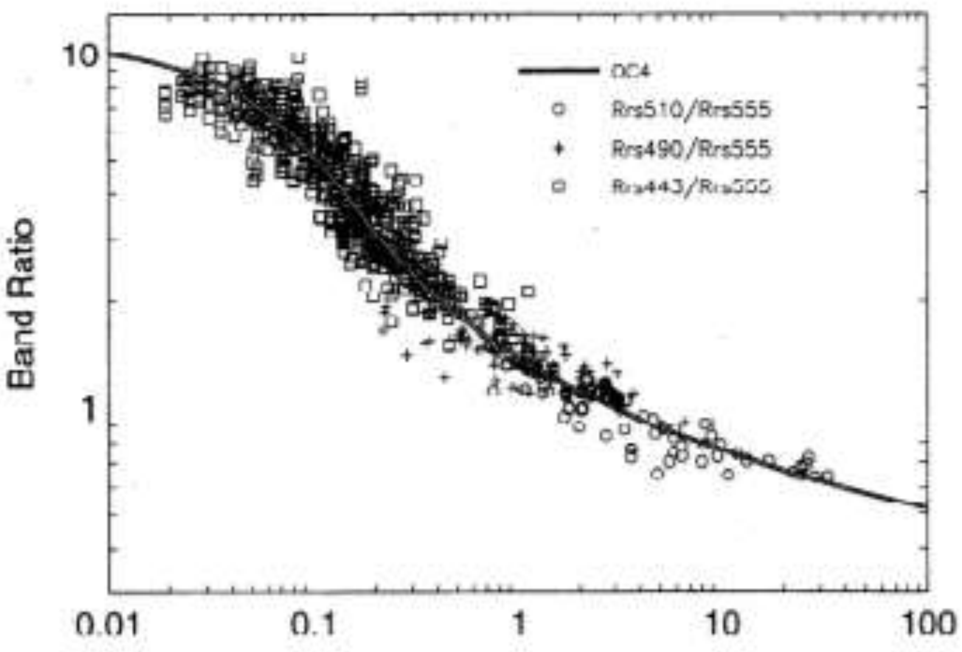
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 103, NO. C11, PAGES 24,937–24,953, OCTOBER 15, 1998

There is no Baltic-specific SST algorithm but there is a need for a Baltic-specific Chla algorithm!

Ocean color chlorophyll algorithms for SeaWiFS

John E. O'Reilly,[1] Stéphane Maritorena,[2] B. Greg Mitchell,[3] David A. Siegel,[4] Kendall L. Carder,[5] Sara A. Garver,[6] Mati Kahru,[3] and Charles McClain[7]

Abstract. A large data set containing coincident in situ chlorophyll and remote sensing reflectance measurements was used to evaluate the accuracy, precision, and suitability of a wide variety of ocean color chlorophyll algorithms for use by SeaWiFS (Sea-viewing Wide Field-of-view Sensor). The radiance-chlorophyll data were assembled from various sources during the SeaWiFS Bio-optical Algorithm Mini-Workshop (SeaBAM) and is composed of



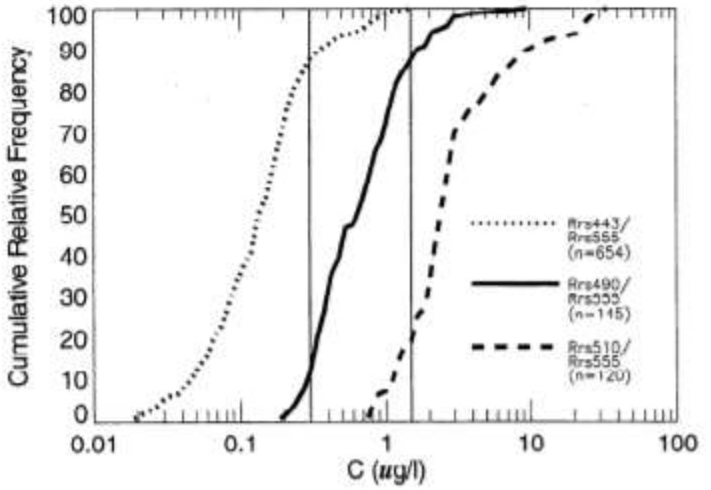
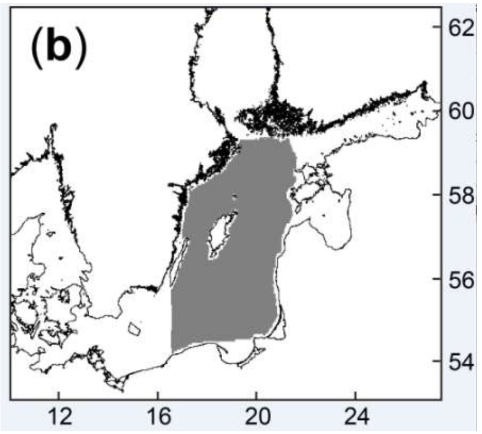


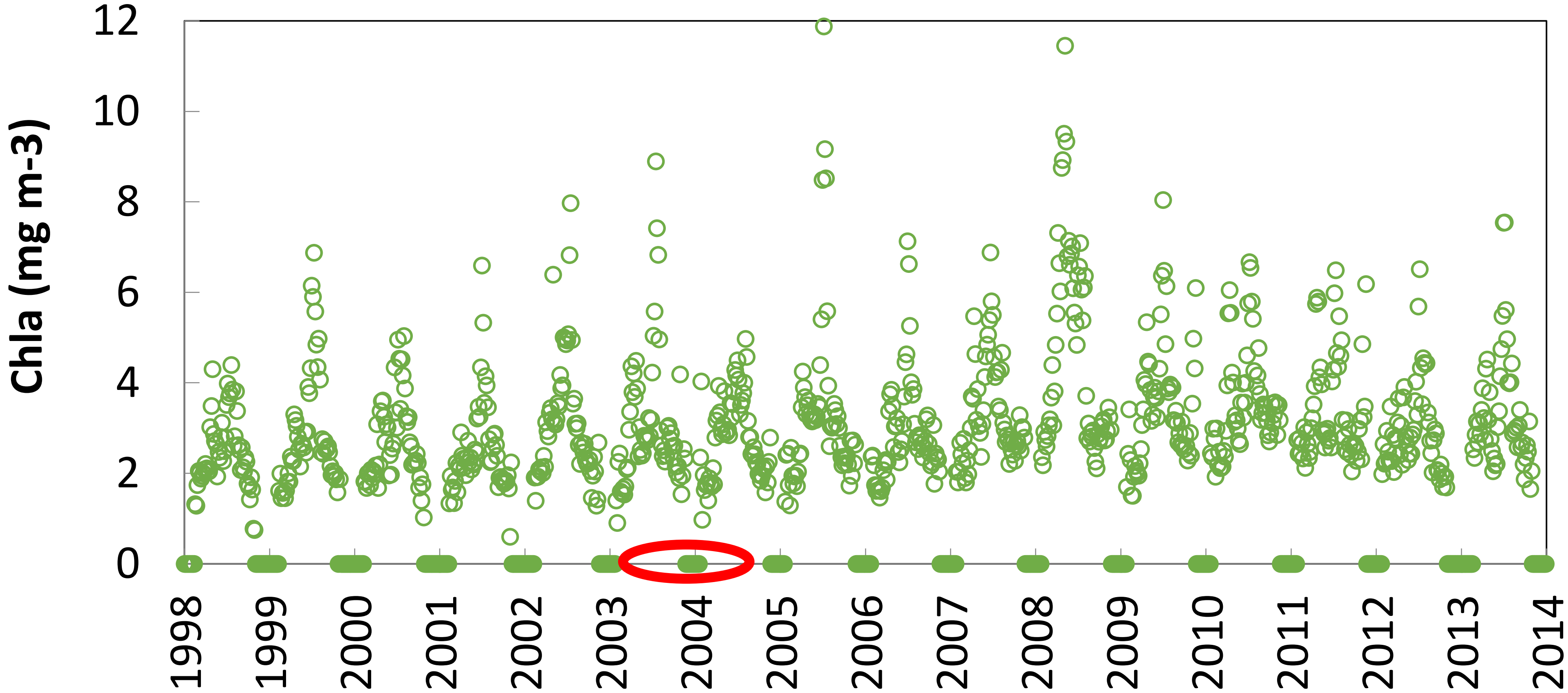
Figure 7. Ocean chlorophyll 4 algorithm. (top) In situ band ratio versus C. OC4 model is represented by curved line. The in situ data are represented by symbols indicating dominant band ratio. (bottom) Cumulative relative frequency distribution of maximum band ratios showing regions of dominance overlap between Rrs443 and Rrs490 and between Rrs490 and Rrs510 (vertical lines at 0.3 and 1.5 $\mu g\ L^{-1}$, respectively).

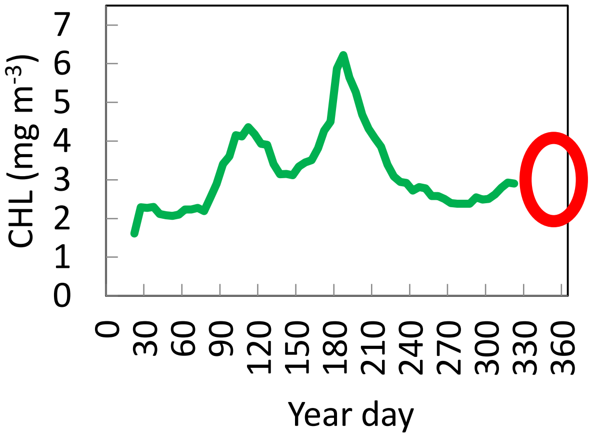
There is no Baltic SST algorithm but there is a need for a Baltic Chla algorithm!

Chlorophyll-a (Chla) in central Baltic Sea

Time series of the 5-day mean CHL (mg m^{-3}) in the central Baltic Sea derived from the ESA-CCI processing of SeaWiFS, MERIS and Aqua-MODIS satellite data (Sathyendranath et al., 2014, 2015). Trend? Accuracy? What does it measure?







No retrievals due to low sun elevation

Report

Mati Kahru, Ulrich Horstmann and Ove Rud

AMBIO vol. 23, N8, Dec 1994

Stockholm University

Satellite Detection of Increased Cyanobacteria Blooms in the Baltic Sea: Natural Fluctuation or Ecosystem Change?

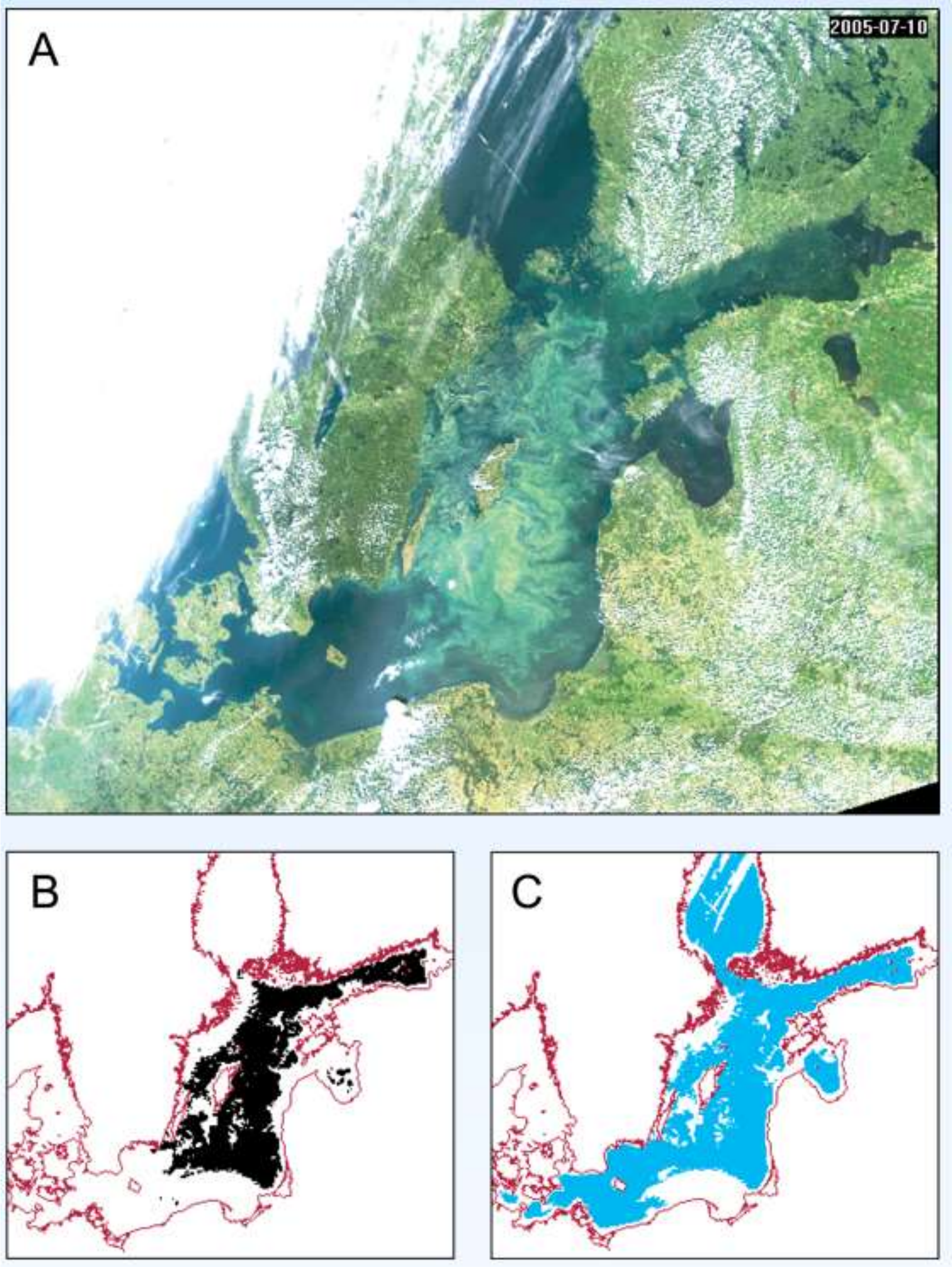
Using data from the Advanced Very High Resolution Radiometer (AVHRR) on the NOAA series of satellites, an increase in the area covered by cyanobacteria blooms in the Baltic Sea was detected. The time series of satellite data covers a period of 12 years from 1982 to 1993. The total area covered by surface-floating cyanobacteria (blue-green algae) has increased in the 1990s, reaching over 62 000 km in 1992. From 1992, visible accumulations appeared for the first time in the Gulf of Riga and reappeared, in the western Gulf of Finland, after being absent from 1984. Conspicuous surface blooms were also present in the early 1980s, coincident with a period of sunny and calm summers. However, when the influence of variable sunshine duration is taken into account, the increase in 1991–1993 is still distinct, indicating significant changes in the Baltic environment. The causal factors for the increased cyanobacteria blooms are still not clear.

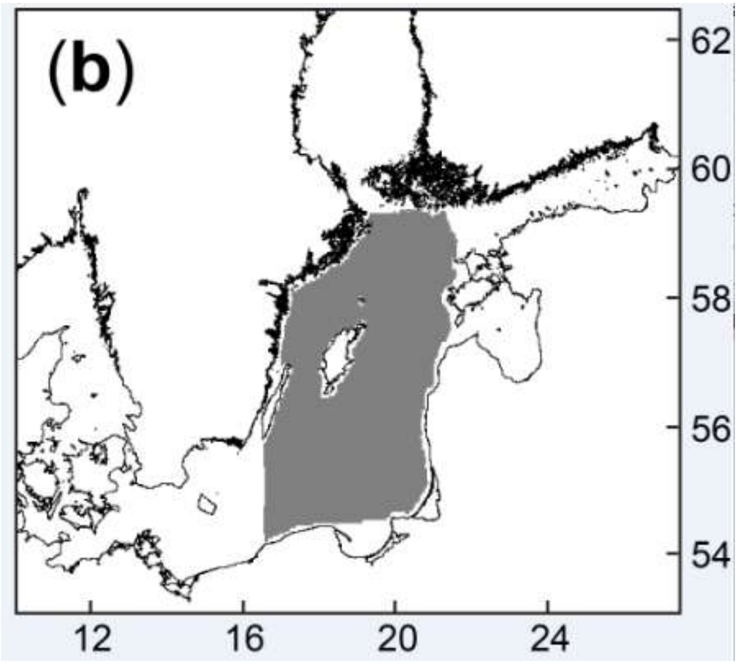
Frequency of cyanobacteria accumulations: FCA=N(detected) /N(valid)

(for each pixel, average over area)

A Quasi true color image using bands 1 (red), 3 (blue), 4 (green)
B Detected cyanobacteria accumulations (black)
C Valid ocean areas (blue)

TCA=Total Cyanobacteria Area, total area of all pixels where accumulations detected at least once





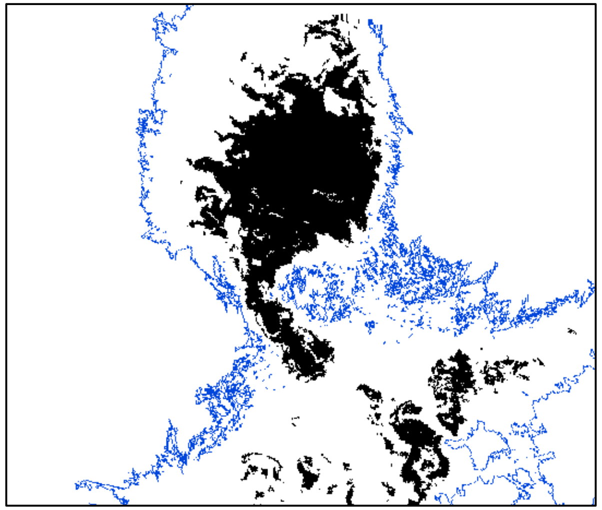
Frequency of cyanobacteria accumulations: **FCA** = N (detected) / N(valid) (for each pixel, average over area)

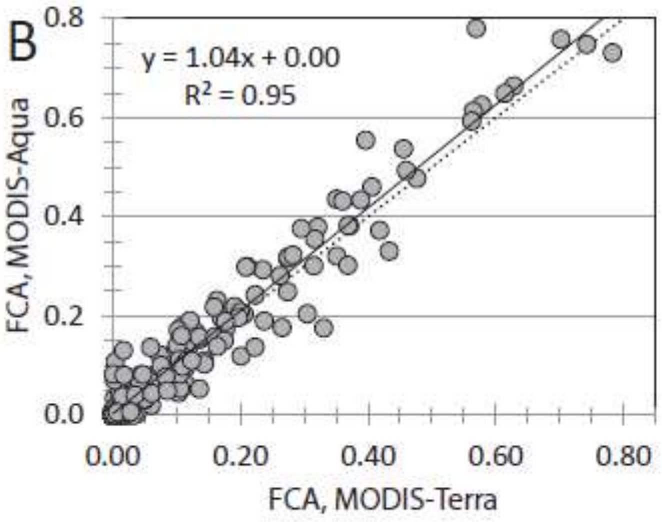
Currently using 4 sensors: MODIST (from 1999), MODISA (from 2002), VIIRS-SNPP (from 2012), VIIRS-NOAA20 (from 2018), each has 3 passes per day, examining 100 days – June – July – August - first 5 days of September

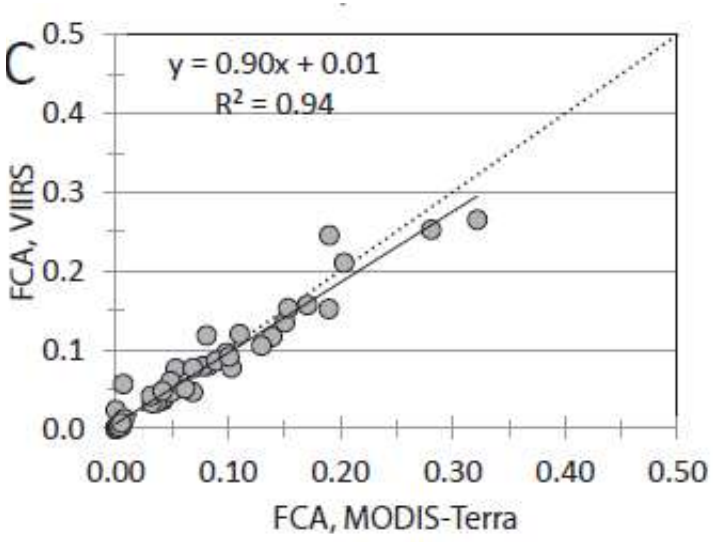
The number of Level-2 satellite datasets (each with ~10 bands like Rrs412, …, Rrs550, Rrs670, chlor_a, etc):

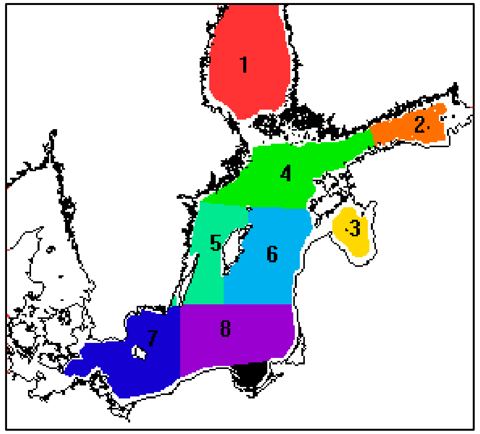
N = 100 days * 4 sensors * 3 passes = 1200 per year

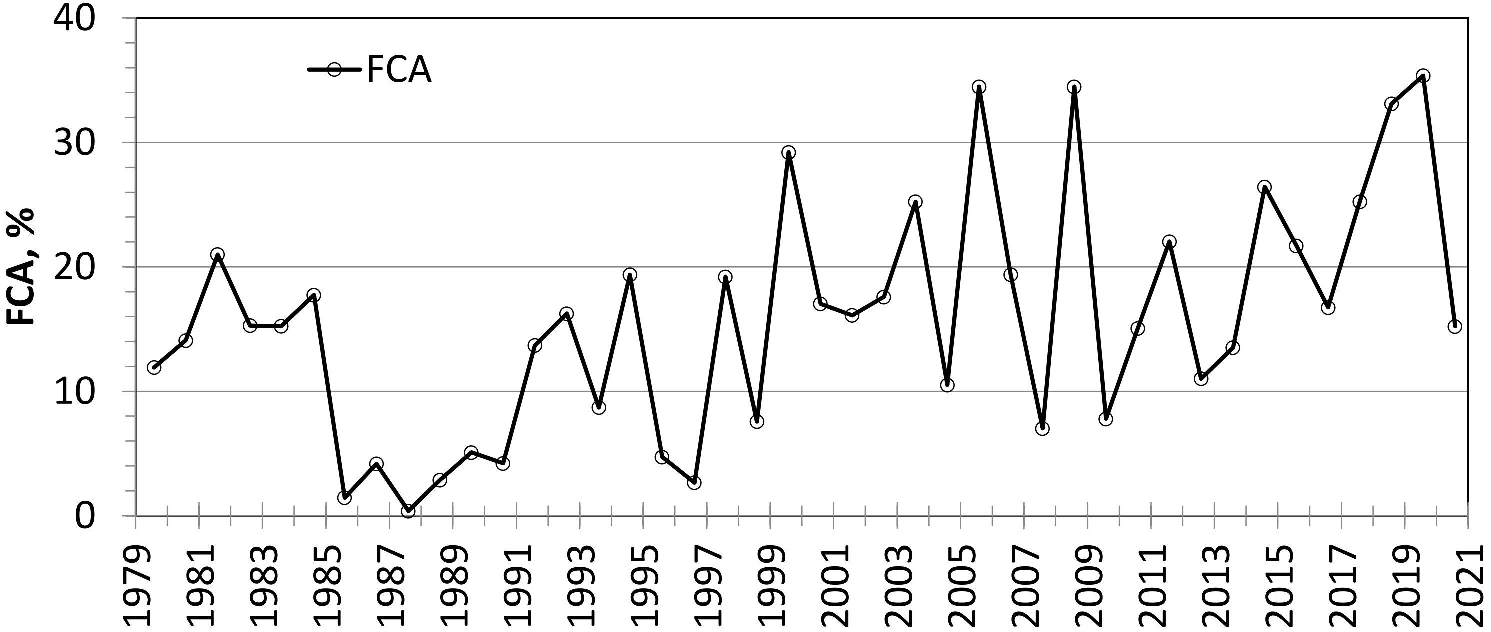
Time series starts in 1979 with CZCS. Longest satellite derived biological time series in the world!










FCA
FCA, %
0
10
20
30
40
1979
1981
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2005
2007
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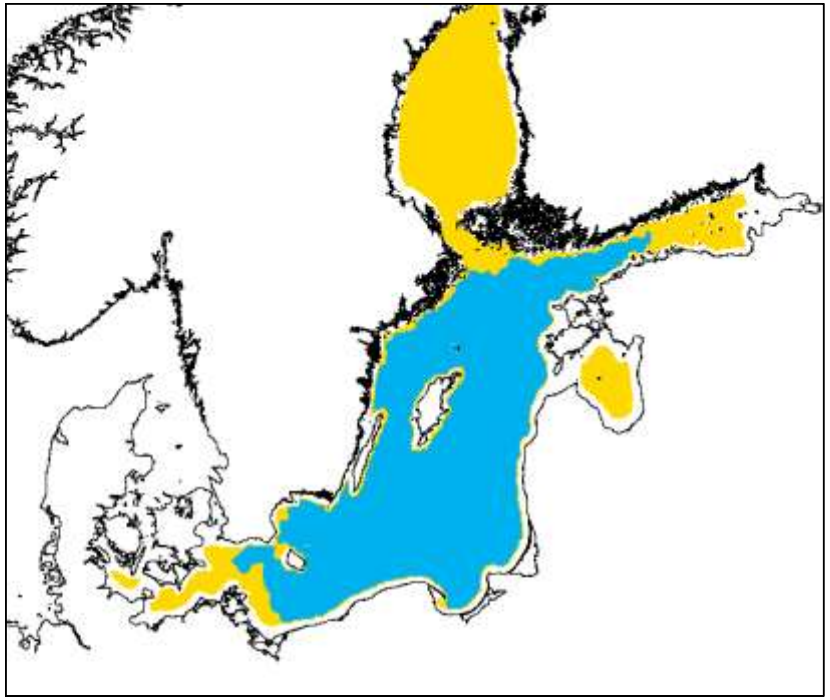
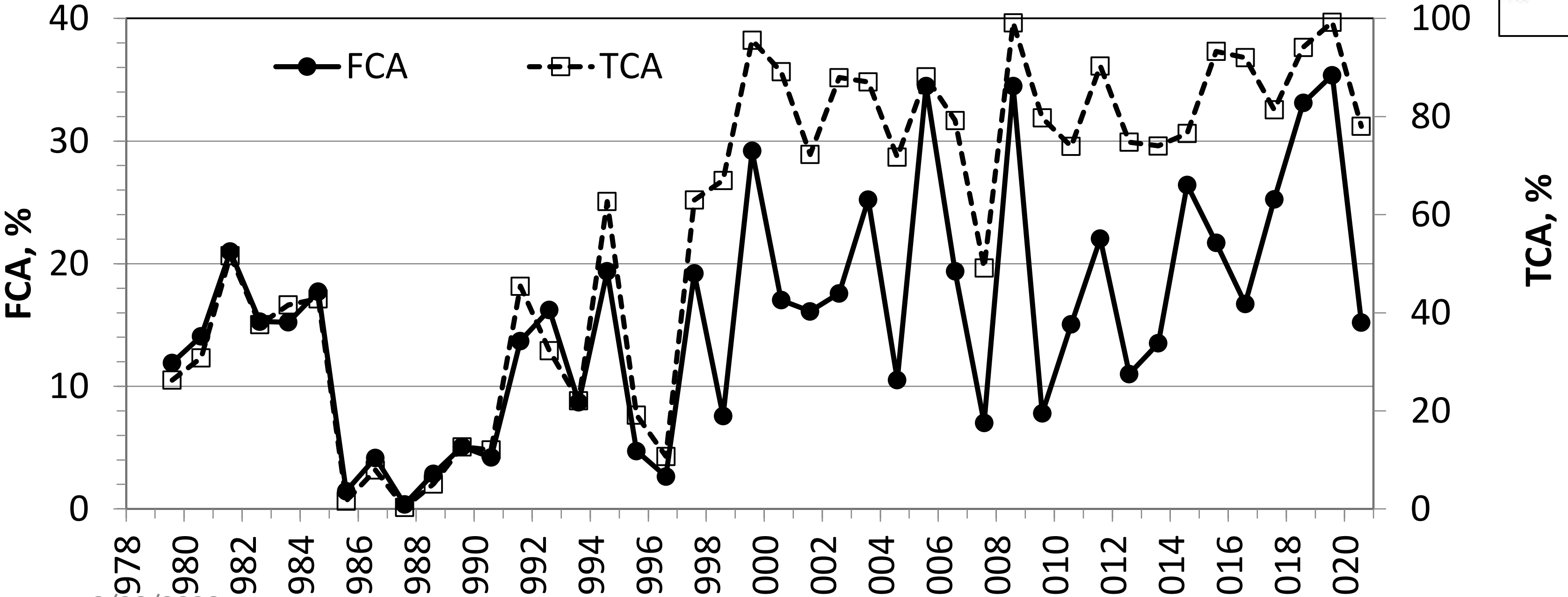
2019
2021




FCA
TCA
FCA, %
TCA, %
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20
30
40
0
20
40
60
80
100
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
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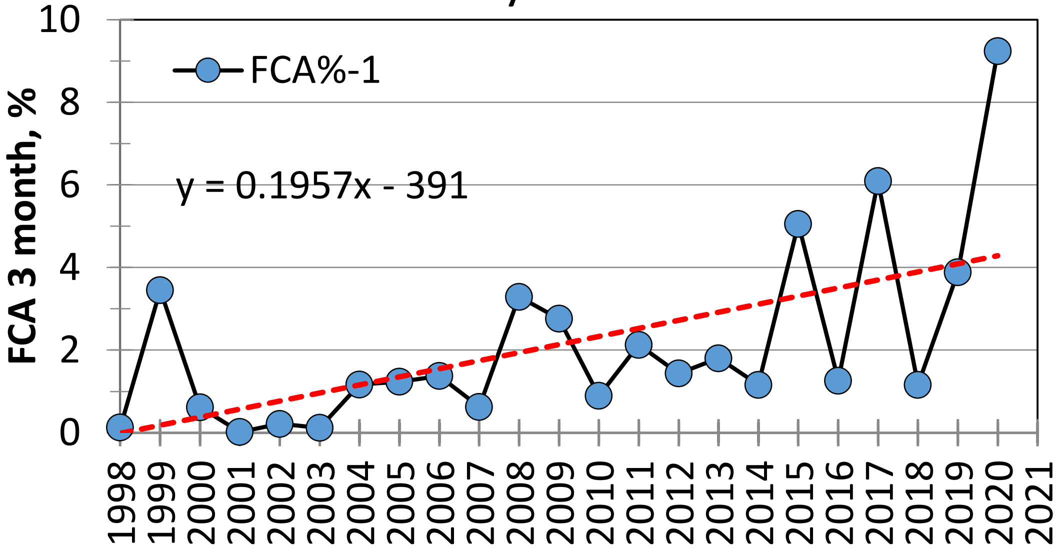
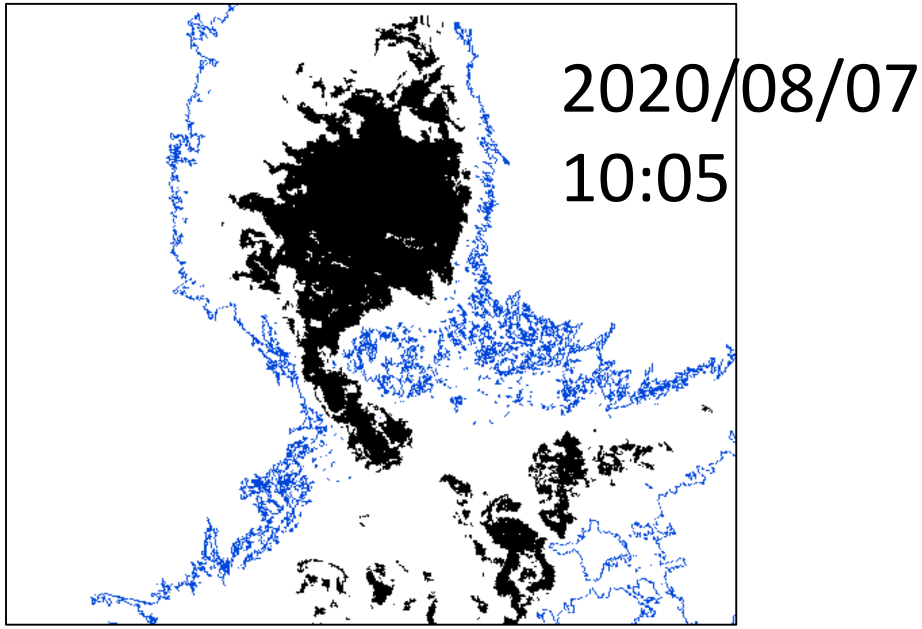
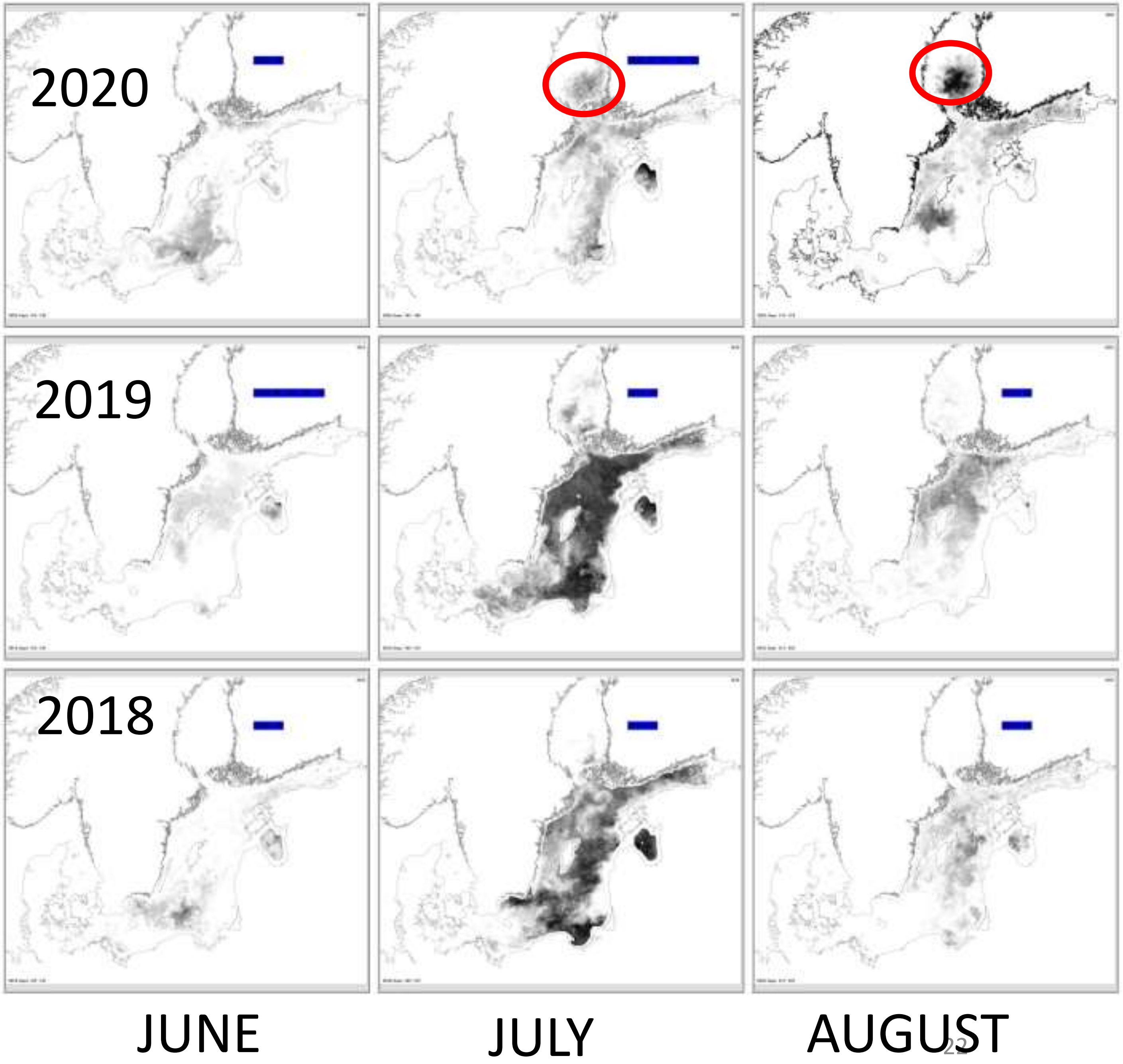
2012
2014
2016
2018
2020

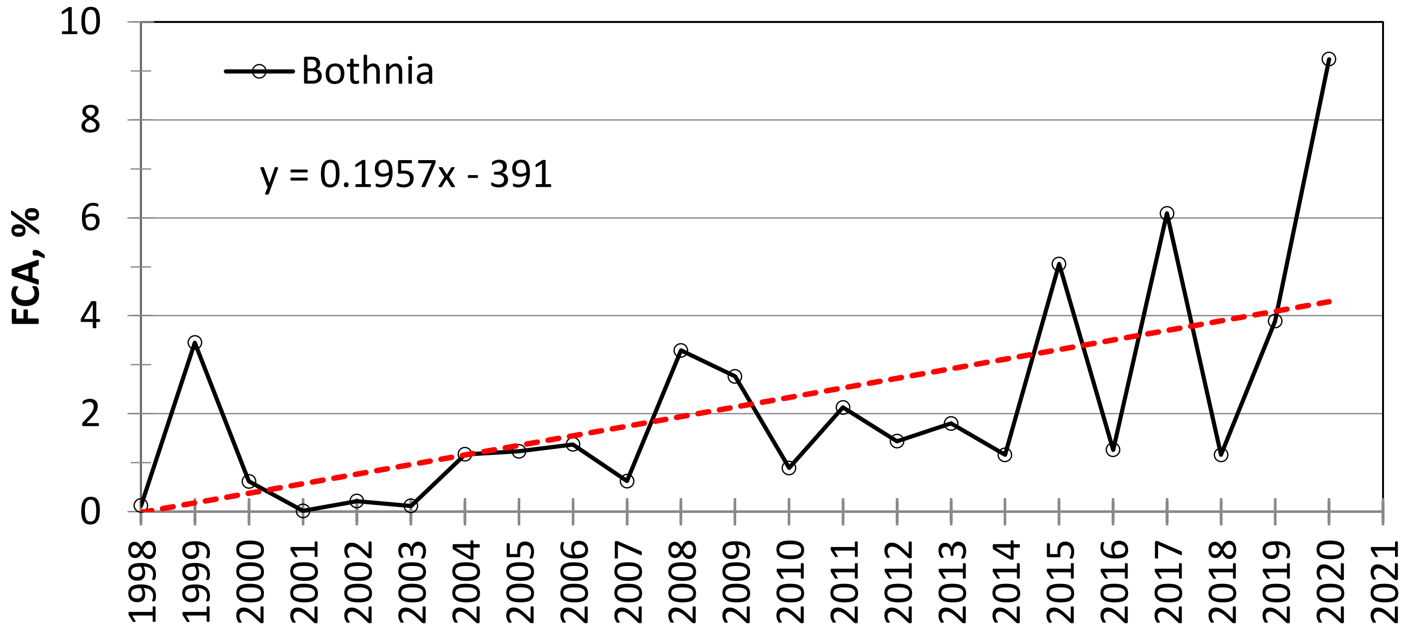
Bothnian Sea 2020!

Niemi 1979: no cyano bloom due to N:P ratio

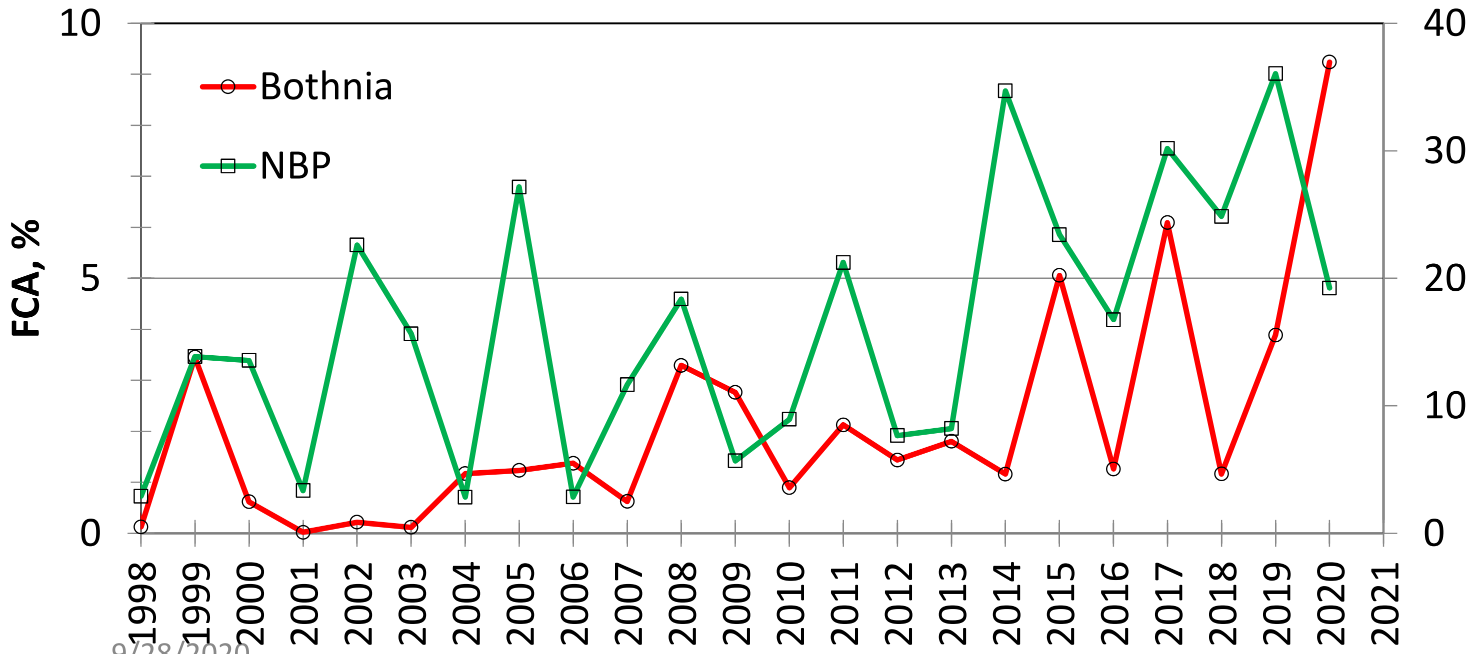








Bothnia
y = 0.1957x - 391
FCA, %
0
2
4
6
8
10
1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021



Bothnia
NBP
FCA, %
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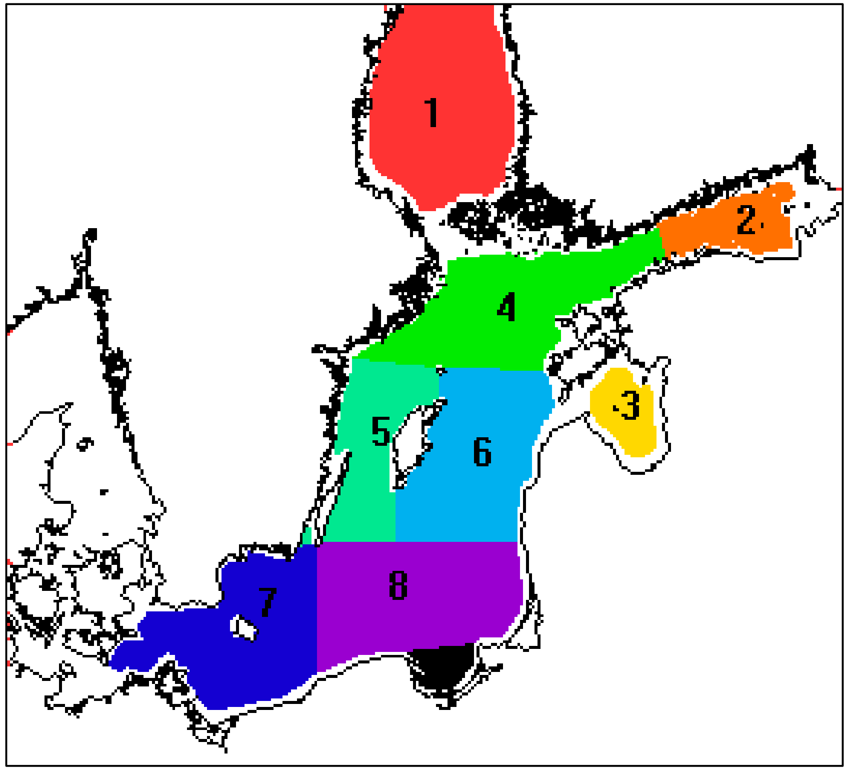
5
10
0
10
20
30
40
1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021



1
2
3
4
5
6
7
8

Biogeosciences, 13, 1009–1018, 2016
www.biogeosciences.net/13/1009/2016/
doi:10.5194/bg-13-1009-2016

Biogeosciences
Open Access

Changing seasonality of the Baltic Sea

Mati Kahru[1], Ragnar Elmgren[2], and Oleg P. Savchuk[3]

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[2]Department of Ecology, Environment and Plant Sciences, Stockholm University, Stockholm, Sweden
[3]Baltic Nest Institute, Stockholm University, Stockholm, Sweden

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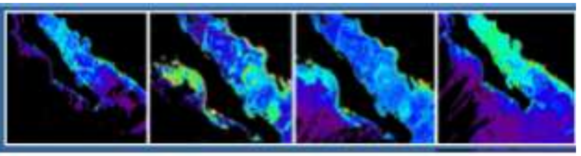
https://www.wimsoft.com/



☐ Home ■ Introduction ■ User's List ■ Functions ■ Satellite ■ Start ■ Manual
■ Download WIM ■ WIM Automation Module (WAM) ■ What's New ■ Contact

If you need to visualize and analyze satellite data from sensors like SeaWiFS, CZCS, MODIS-Terra, MODIS-Aqua, GLI, OCTS, MERIS, VIIRS, OLCI, the new SGLI on JCOM-C but also NOAA-AVHRR, MOS, AMSR-E, QuikSCAT, SSMI in different formats (mostly netCDF and HDF but also in binary and/or legacy formats CoastWatch, Terascan, ERDAS-LAN, NSIDC, etc.) in the Microsoft® Windows environment then you can use the easy to use but powerful Windows Image Manager = WIM.

Remote sensing professionals from universities, government agencies, environmental monitoring agencies, military R&D organizations, exploration and other business operations as well as casual users like geographers, oceanographers, marine biologists, fishermen in over 30 countries (see WIM User's list) are using WIM for its easy-to-use features (see WIM functions).
WIM runs under the current Windows operating systems.

If you are new to WIM, you may want to view the Introduction or browse through the User's Manual.
You can download different satellite images from many sources (see a limited list of satellite data).

WIM is NOT a tool for editing bitmap-type images (e.g. JPEG, GIF, PNG, TIFF, etc.).

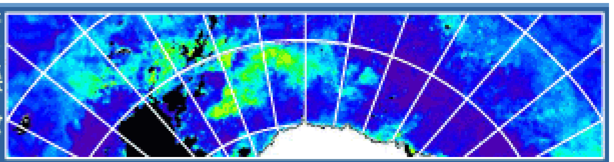
With WIM you can easily read scientific datasets (SDS) in Hierarchical Data Format (HDF4), netCDF and Terascan datasets, use special functions for ocean color imagery, SST, polar ice datasets, global and regional products, make composites, create overlays of coastlines and depth contours, and much more. Serious WIM users use **WAM** (=WIM Automation Module) that implements batch or script processing in an easy to use environment. Upgrade to the latest version as we upgrade often. Instructions on how to install WIM and get started are given here.

Check out What's New in the latest version and the release history.

To download a free evaluation version click here. For more information please send e-mail to wim@wimsoft.com To prevent SPAM you have to manually type the e-mail address. **Fight Spam!**

WIM functions can be automated with the WIM Automation Module (WAM)
Examples of WIM and WAM applications are available here.

https://www.wimsoft.com/satellite.htm



■ Home ■ Introduction ■ User's List ■ Functions ☐ Satellite ■ Start ■ Manual
■ Download WIM ■ WIM Automation Module (WAM) ■ What's New ■ Contact

Satellite Data and Projects

- *Satellite projects by Mati Kahru*
-
- *Mati Kahru*: Publications and Courses

Satellite data archives processed with Wimsoft (WAM)

- ***California Current*** **merged 1-km Chl-a, SST, POC data**
- ***California Current*** **optimally merged 4-km Chl-a, primary production, POC, export flux of Carbon, SST and other data**
- ***CalCOFI*** **area optimally merged Chl-a data**
- ***California EZ*** **merged 1-km Chl-a, and other data**
- ***Scotia Sea*** **merged 1-km Chl-a and SST data for the Southern Ocean - discontinued**

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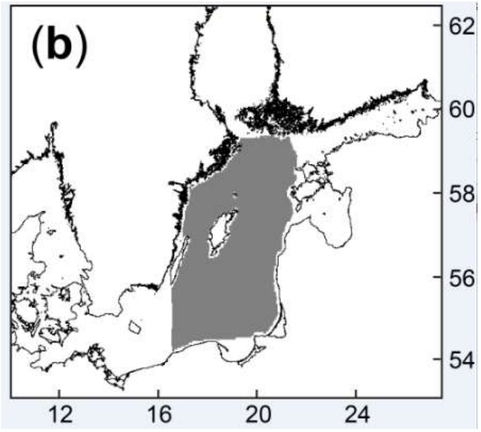
See some of my recent projects

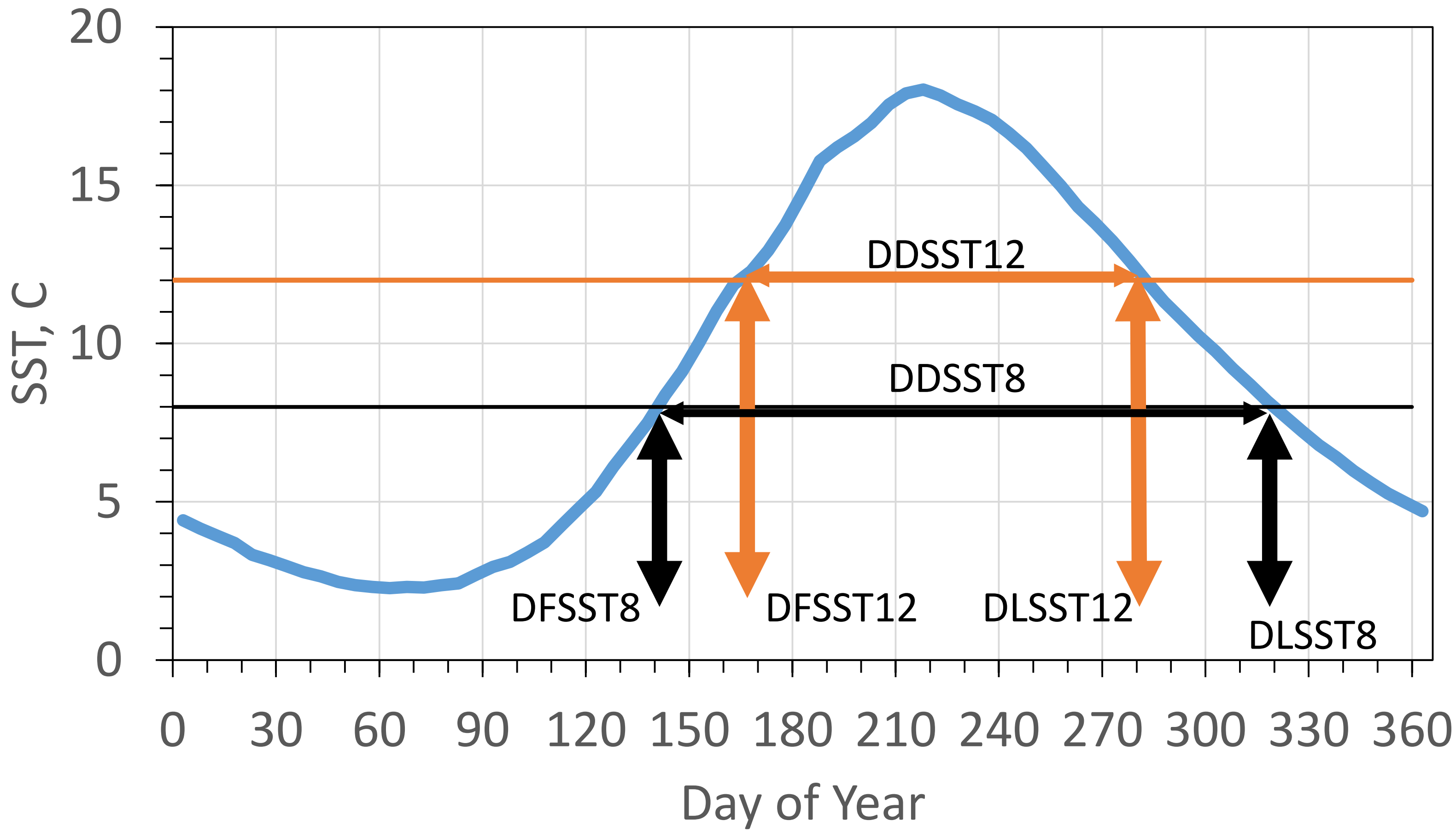
PUBLICATIONS:	INVITED LECTURES AND COURSES:
2018-2020	2018-2020

- Using **satellite** data to detect change
  - Satellite data are suitable for this task as they cover multiple (large) **areal scales** (local, basin, global); have consistent **frequency** (in general), are available for **free**; getting longer and more suitable for climate studies
- Trying to **separate** changes caused by **anthropogenic** effects from those due to **natural** climate variability – complicated!

Indices of SST phenology

Mean annual cycle of SST (AVHRROI, 1981-2018) in central Baltic;
Day of the year when 8˚C is first reached, DFSST8 = Day First SST 8, when 8˚C is last reached, DLSST8 = Day Last SST 9, same for 12˚C

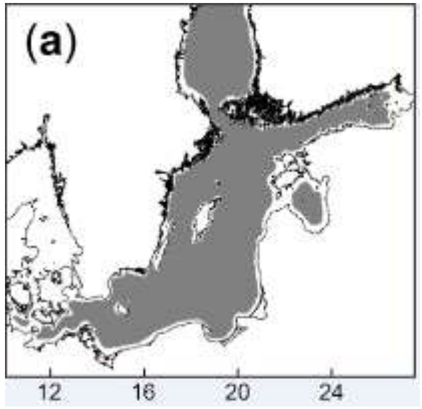




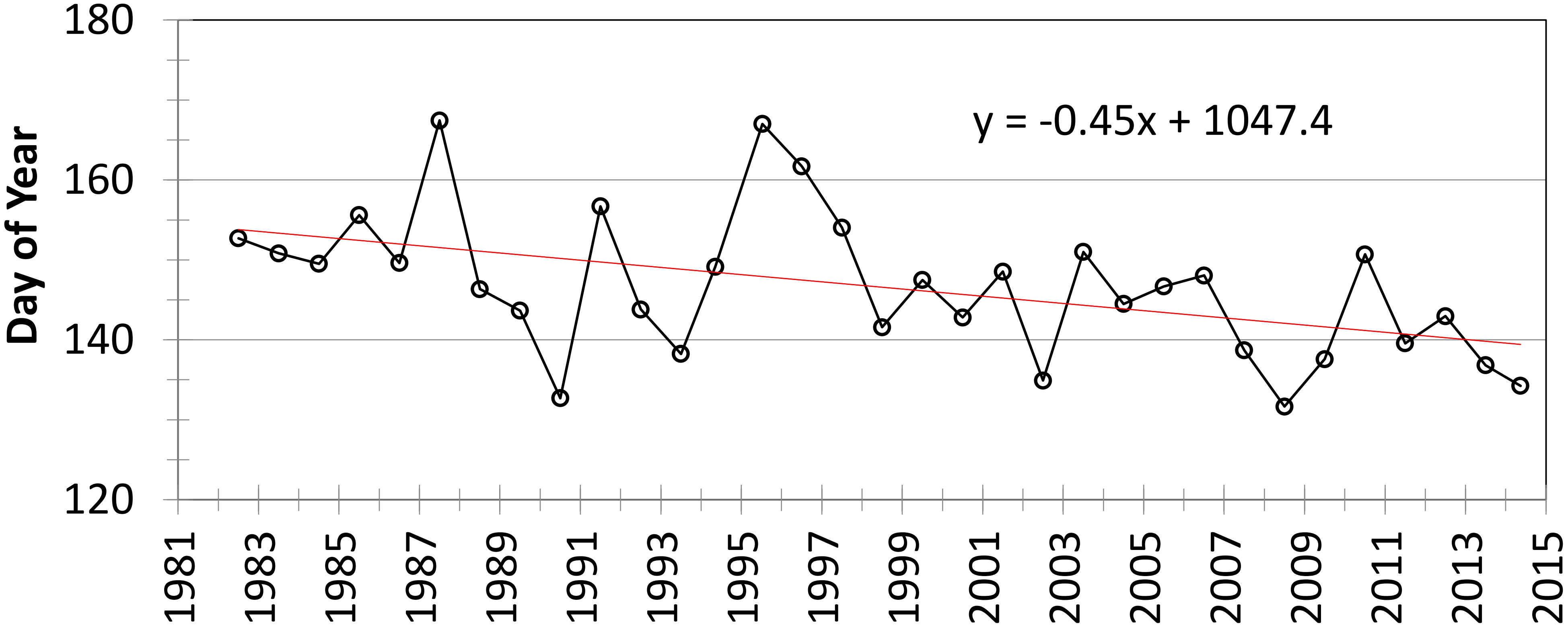
DFSST8 ~140; DLSST8 ~315
DDSST8 = DLSST8 – DFSST8 = 175

DFSST12 ~170; DLSST12 ~280
DDSST12 = DLSST12 – DFSST12 = 110

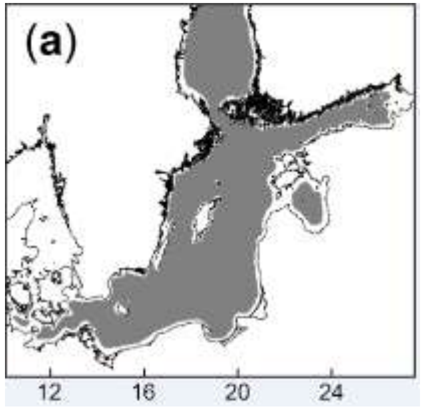
Trends in SST phenology: DFSST8



Day of the year when 8 ˚C is reached in spring
(DFSST8 = Day First SST 8C). Slope = -0.45, i.e. in 10 years 8 ˚C is reached 4.5 days earlier; in 40 years -> 18 days earlier



Phenology indices

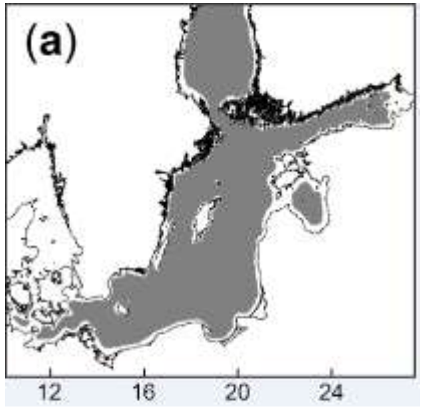


Explanation	Type	Example variable groups
First day of reaching a threshold	DF	DFSST, DFCHL, DFKED
Last day of reaching a threshold	DL	DLSST, DLCHL, DLKED
Duration of the period between DF and DL	DD	DDSST, DDCHL, DDKED
Count of days over the threshold	DC	DCSST, DCCHL, DCKED
Day of reaching the annual maximum	DM	DMSST, DMCHL, DMKED
First day of reaching a cumulative threshold	DFCUM	DFCUMSIS, DFCUMSST

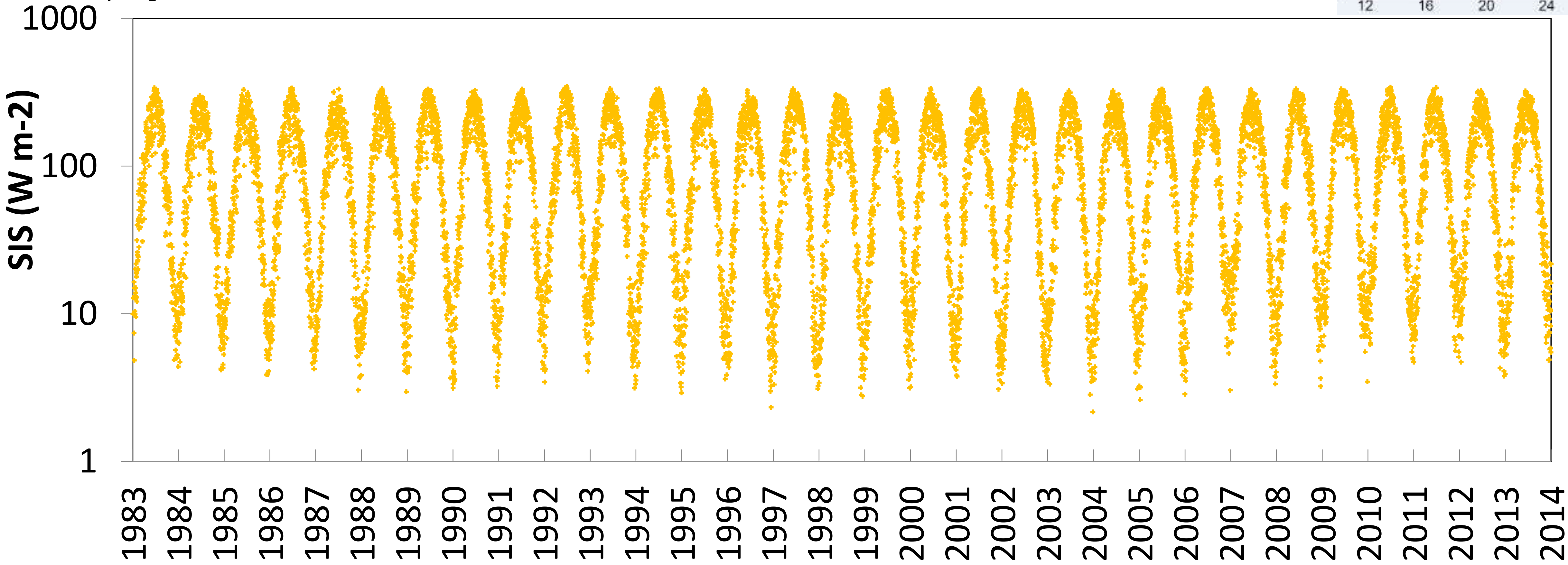
↔ Coral bleaching (DC)

↔ Radiative heating (DFCUM)

Surface Incoming Shortwave irradiance (SIS, W m^{-2}) from geostationary Meteosat sensors (Mueller et al., 2009, Müller et al., 2015).



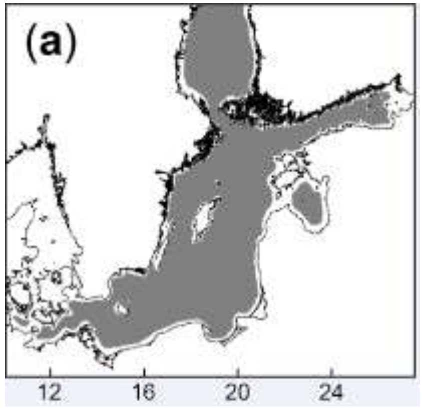
Extremely regular, no trends detectable in absolute values



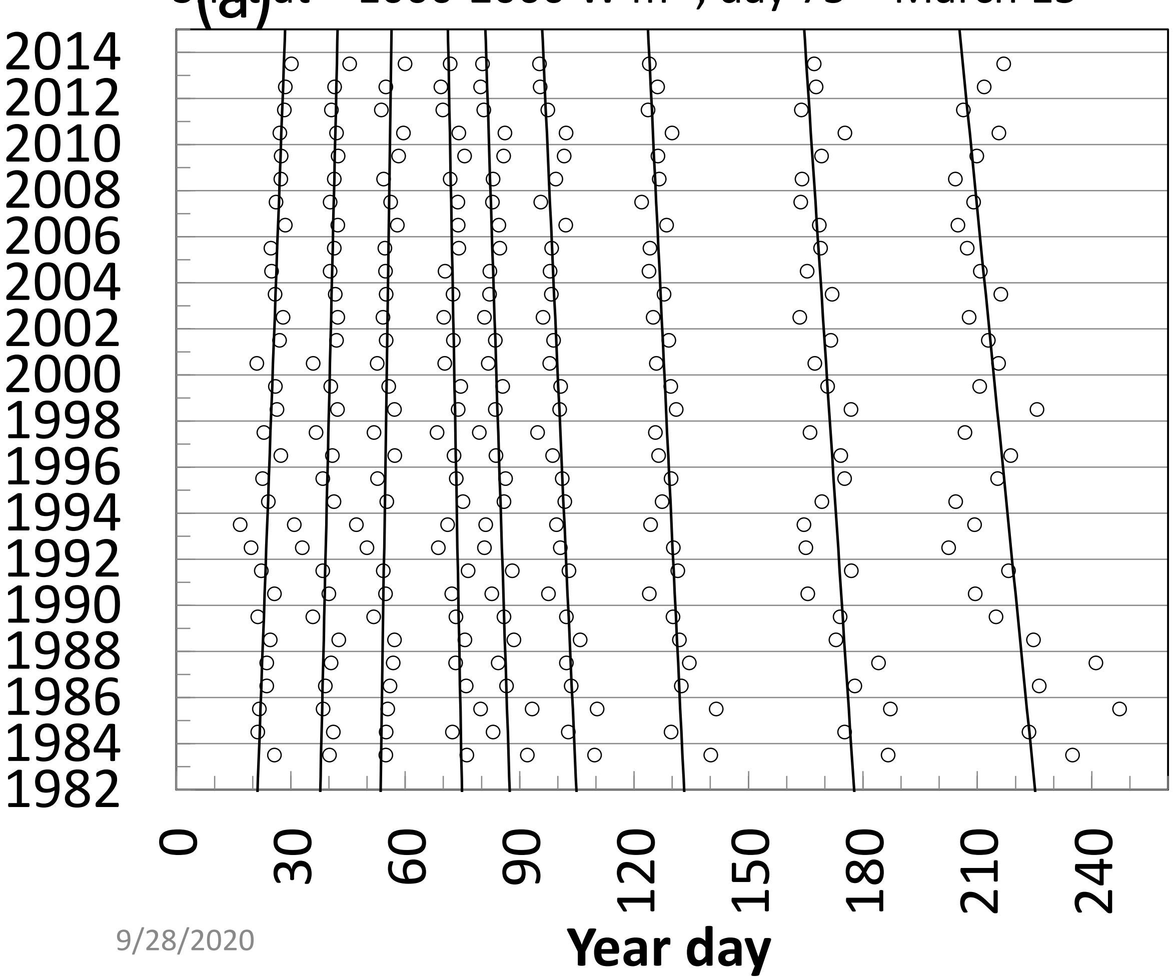
Trends in SIS (Surface Incoming Shortwave irradiance, W m^{-2})

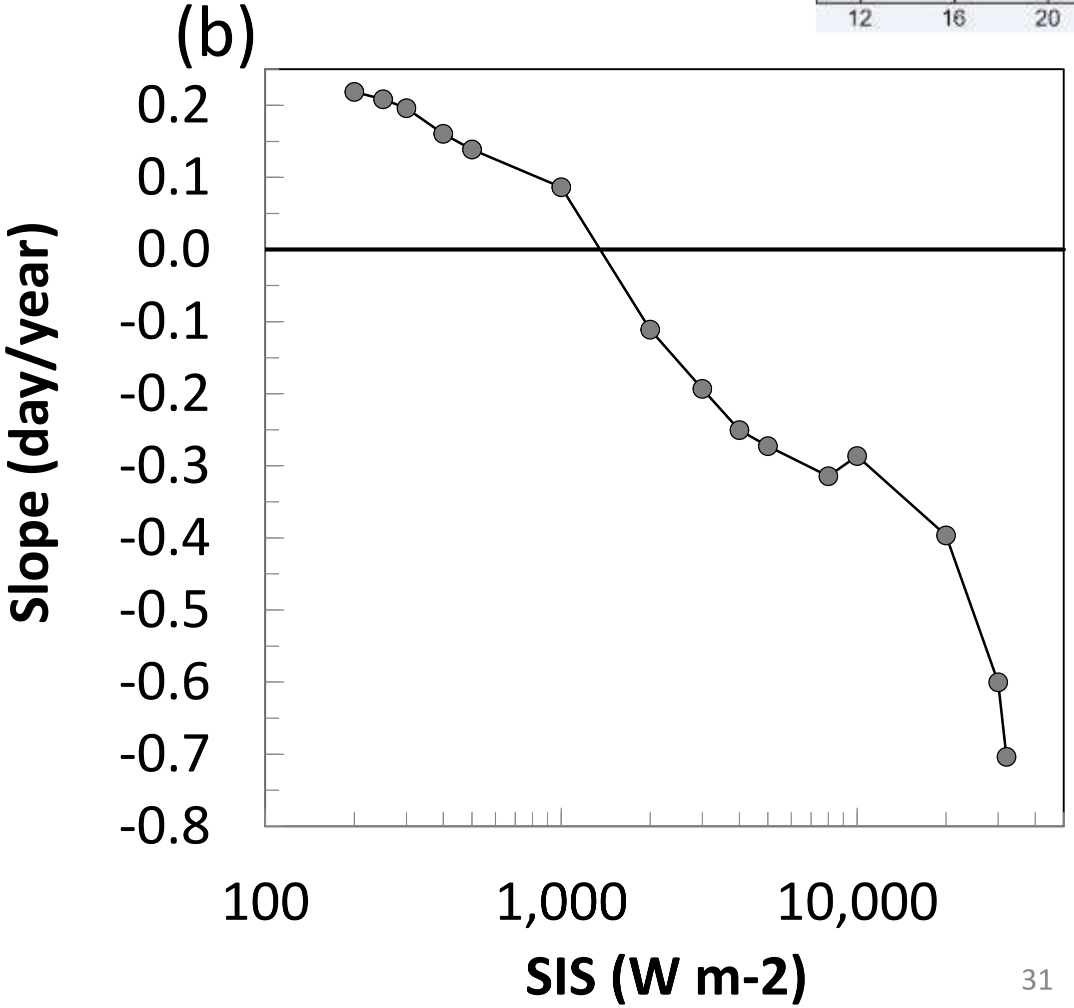
(a) DFCUMSIS, i.e. day of year when the annual sum of daily SIS reaches the following thresholds: 200, 500, 1000, 2000, 3000, 5000, 10000, 20000 and 30000 W m^{-2}. For each threshold the circles show the day of the year and the line shows the respective linear regression; (b) Slope of the linear regression.

DFCUMSIS 30K Wm^{-2} was reached ~day 237 in 1983 but on day 214 in 2014, i.e., 23 days earlier.



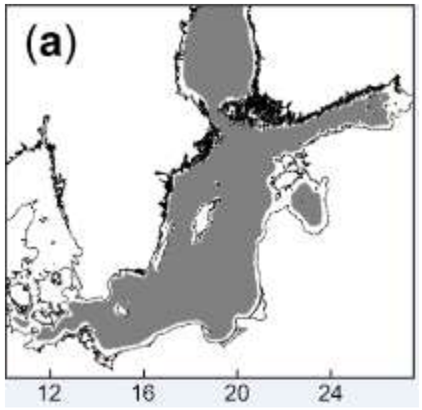
Shift at ~ 1000-2000 W m^{-2}, day 75 ~ March 15



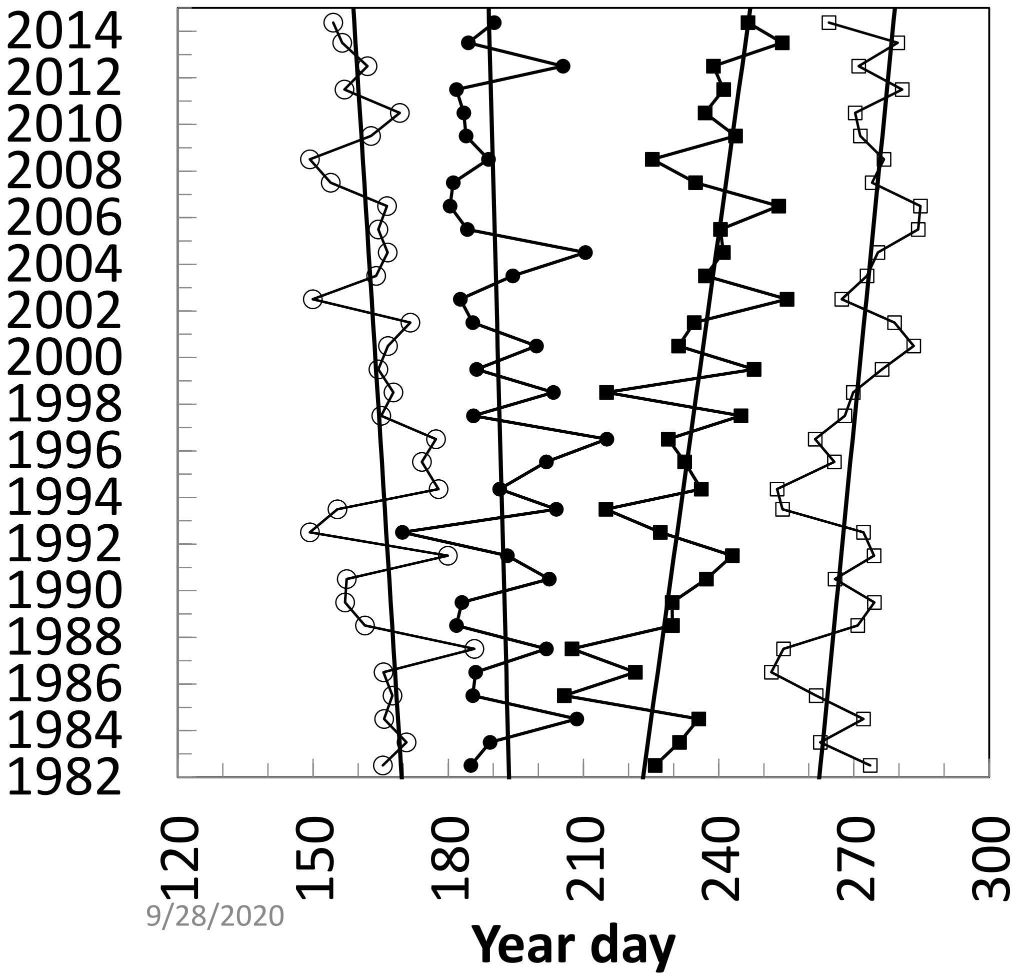


Trends in SST phenology

(a) The symbols and regression lines from left to right: first day when 12 ˚C is reached (DFSST12, open circles), first day when 17 ˚C is reached (DFSST17, filled circles), last day when 17 ˚C is reached (DLSST17, filled squares), last day when 12 ˚C is reached (DLSST12, open squares).



(a)

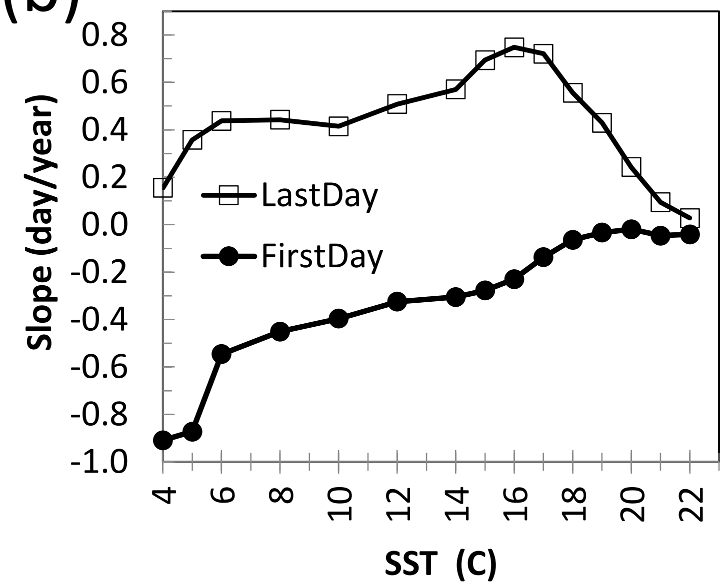


(b) Rate of change (day/year) in the day of year when a SST level is first reached (DFSST, filled circles) and when a SST level is last reached (DLSST, open squares) for the Baltic Sea.

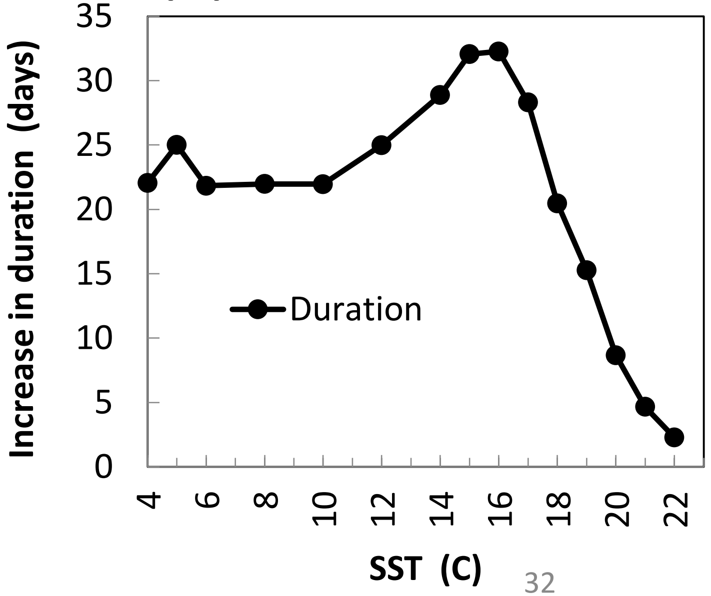
(c) Increase in the duration of a period with SST above a certain level (DDSST) from 1982 to 2014 (32 years). DSST17 increased > 1 month!

-> What does it mean for a fish or crab?

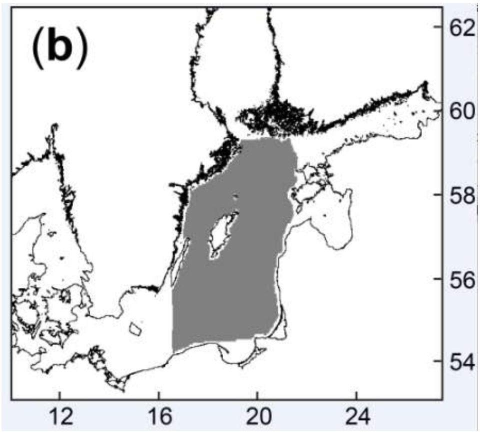
(b)



(c)

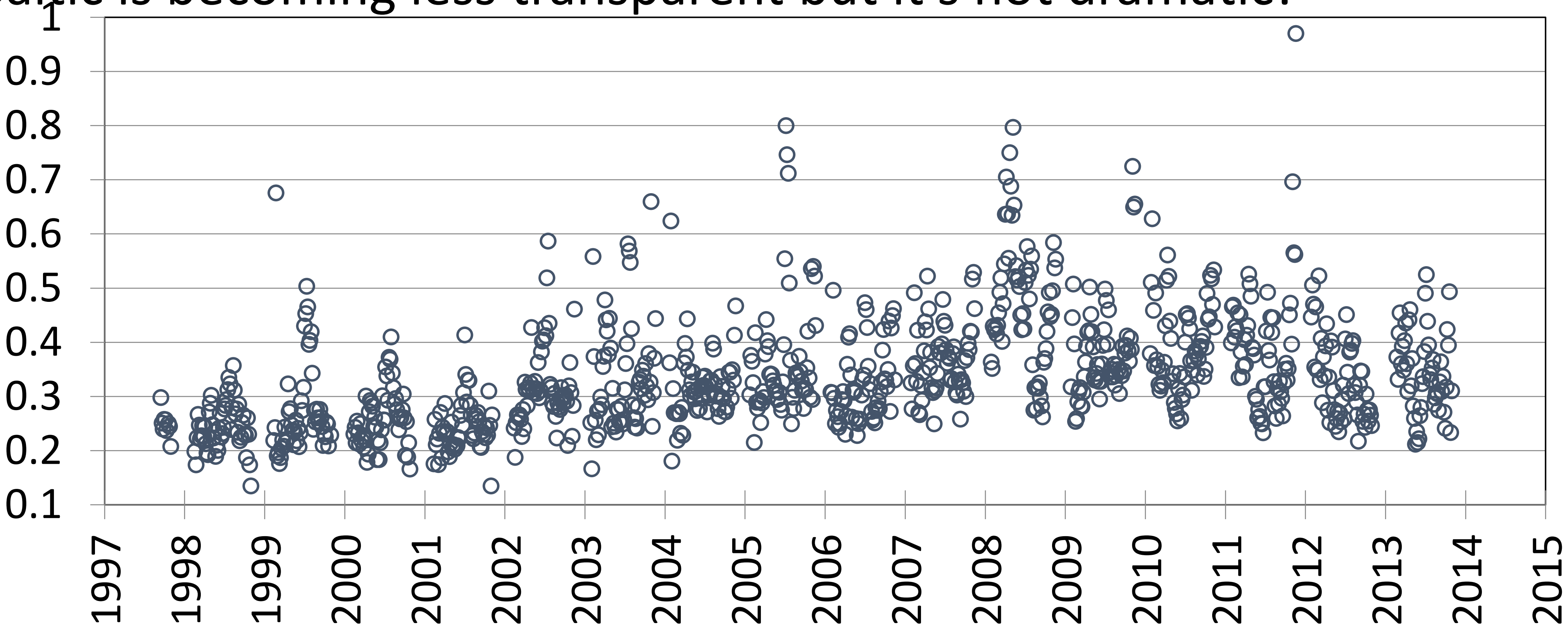


Coefficient of light attenuation (Ked490) in central Baltic Sea



Time series of the 5-day mean KED490 (m^{-1}) in the central Baltic Sea derived from the ESA-CCI processing of SeaWiFS, MERIS and Aqua-MODIS satellite data using the Lee algorithm.

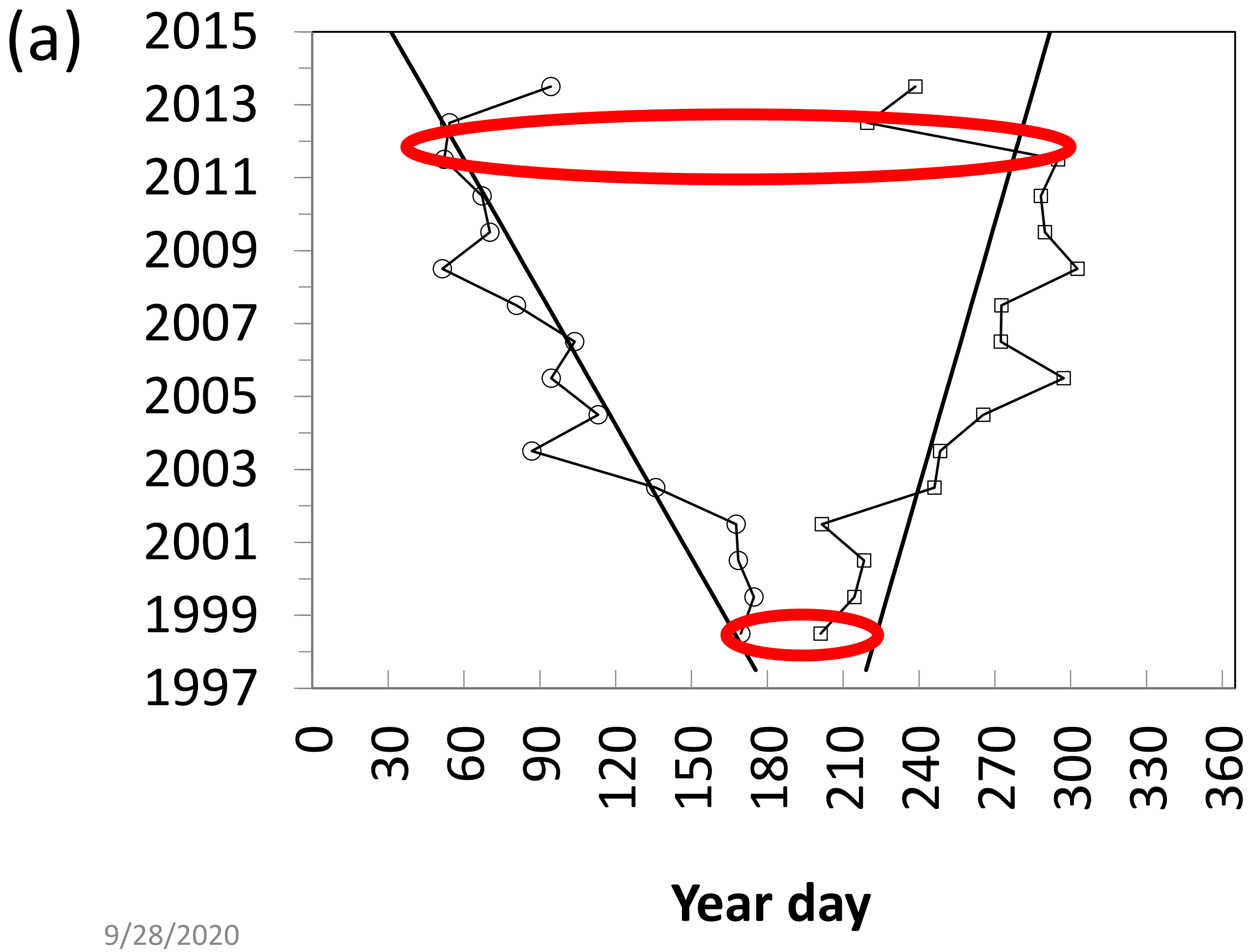
Baltic is becoming less transparent but it's not dramatic!

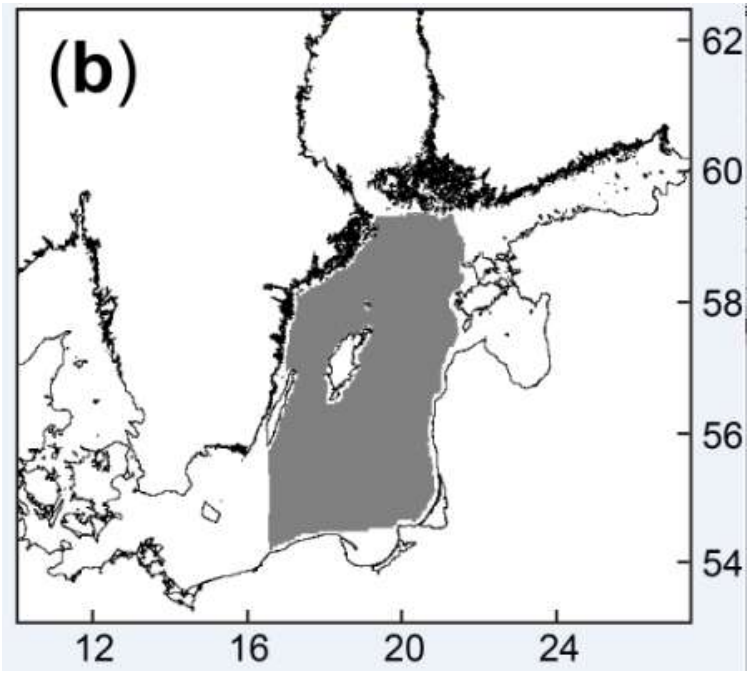


Trends in Ked490 phenology

Temporal changes in the start and end of Ked490 = 0.4 m^{-1} for central Baltic Sea (Fig b). Circles show the first day of the year (DFKED), squares show the last day of the year (DLKED) of Ked490 = 0.4. DRAMATIC CHANGES!

Turbid period has increased from <60 days to 240 days, 4x!
What does it mean for a fish?

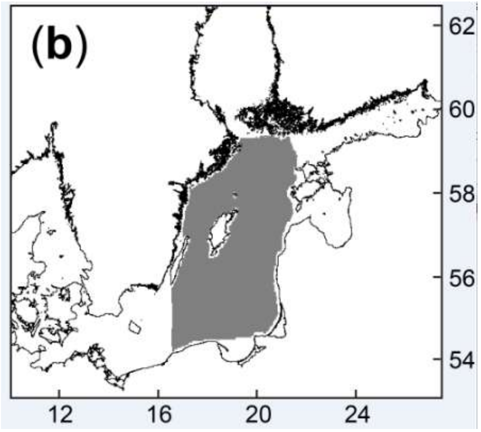


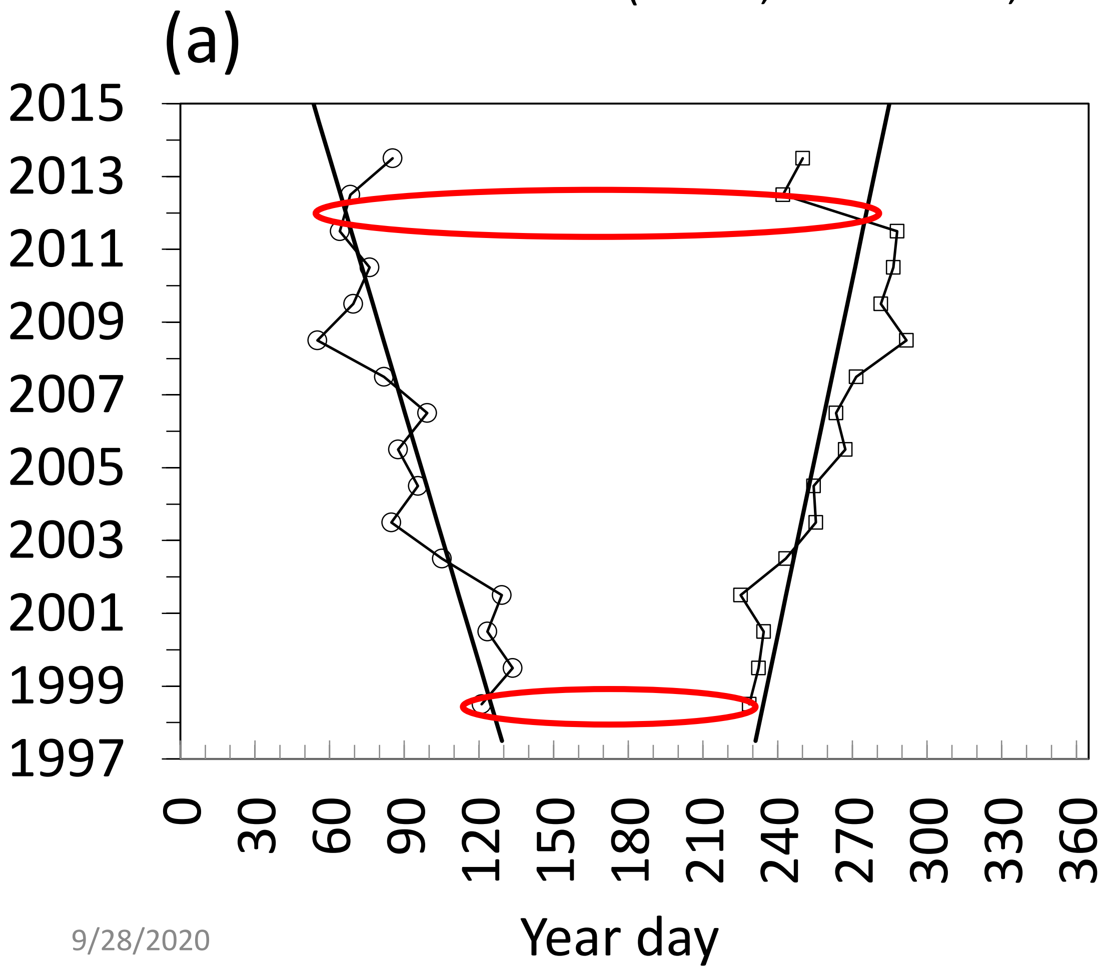


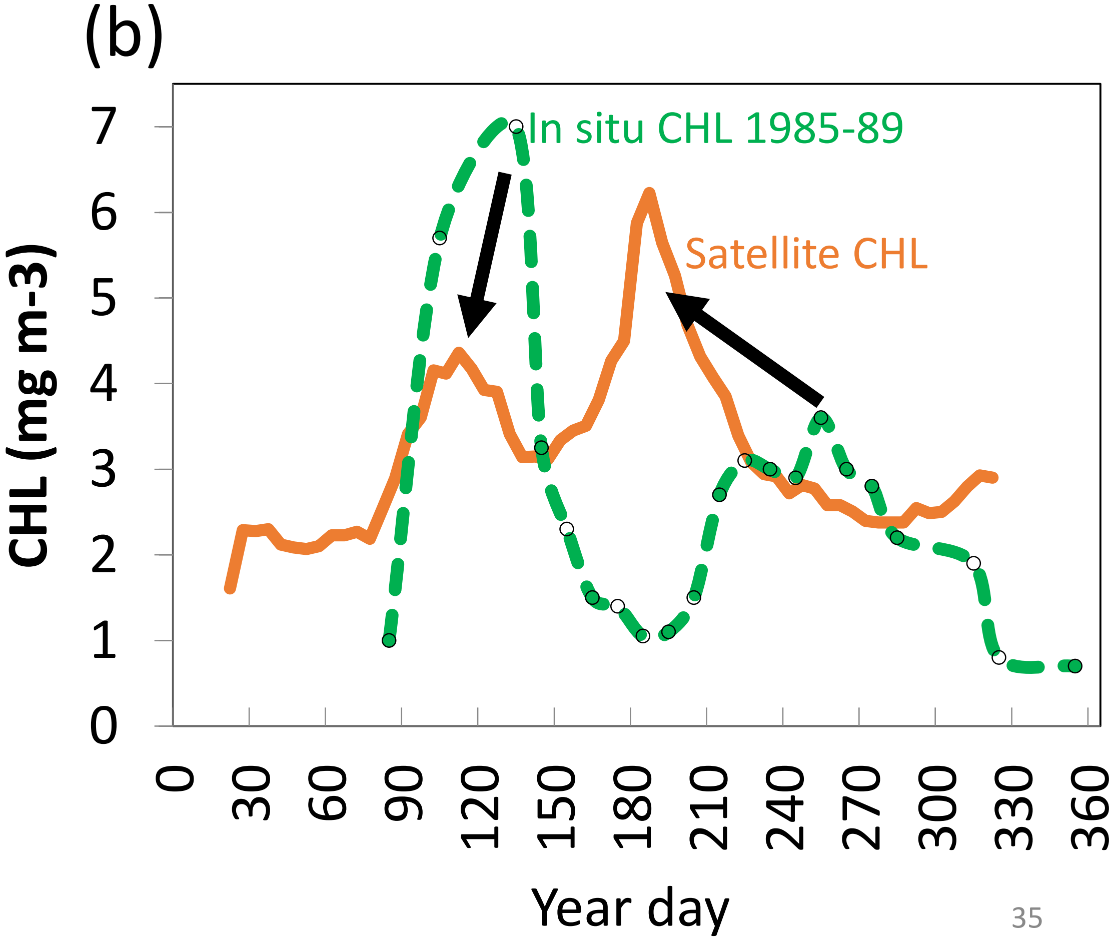
Trends in CHL phenology

(a) Temporal changes in the start and end of the "high chlorophyll season" (CHL >= 3 mg m^{-3}) in the Baltic Sea: day when CHL = 3.0 mg m^{-3} is reached first (DFCHL3, circles) and last (DLCHL3, squares) during the season.

(b) Mean annual cycle of CHL in central Baltic Sea for 1997-2013 (solid line) compared with CHL measured in situ in 1985-1989 (circles, dashed line, from Kahru et al., 1991). Max in May → July

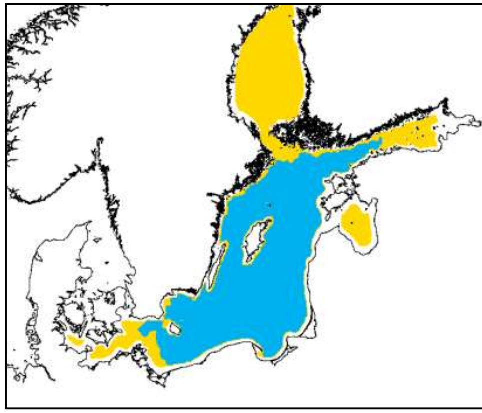


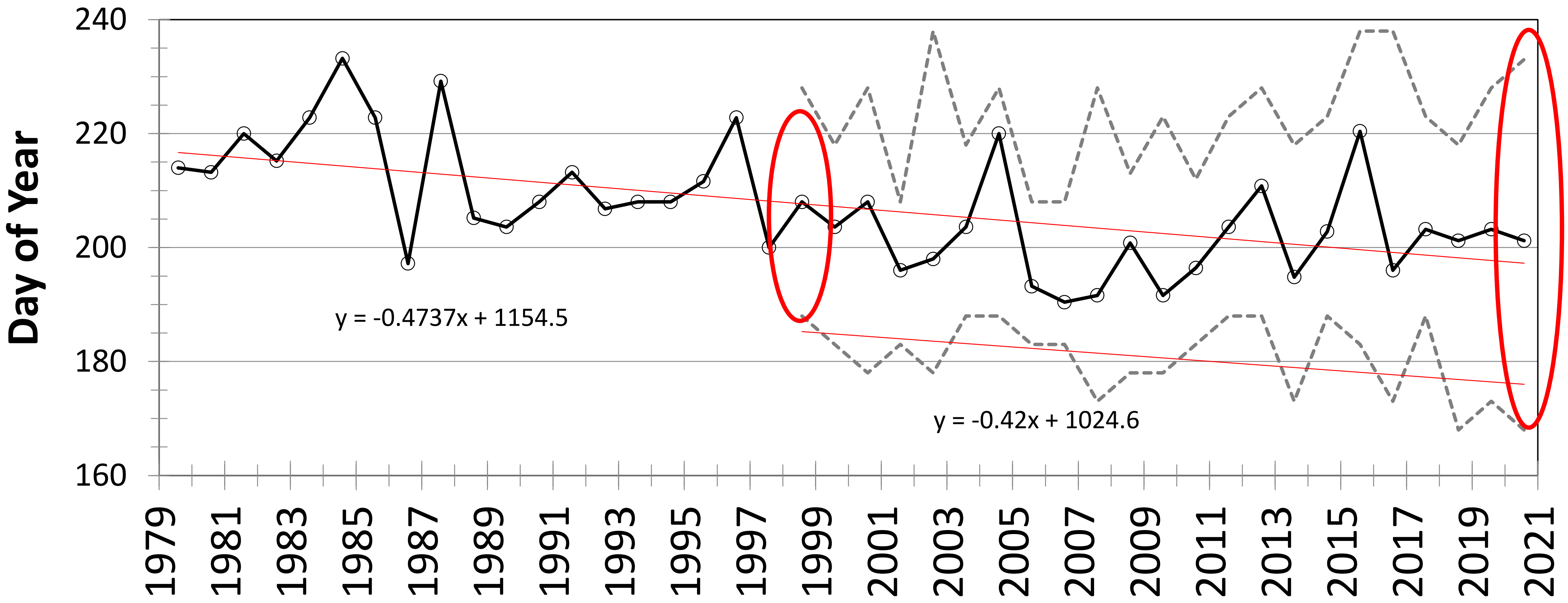




Timing of cyanobacteria accumulations

- Center of timing becoming earlier (1979->2020) but not since ~2006
- Duration becoming longer: starting earlier and lasting longer
- Shown: center of toming, start (first 10% percentile), end (last 90% percentile)
- Duration expanded (from ~day 160 = 06/08 or 06/09 to ~day 240 = 08/27 or 08/28)





Summary

- Phenological indicators are sensitive and can detect changes even when changes in absolute values are hardly detectable
- Some of the indicators, e.g. the duration of the growth season, have direct ecological significance. Timing also important for Match/mismatch between trophic interactions.
- The Baltic Sea has experienced drastic changes in the seasonality during the last decades in a many variables from physical to biological.
- For several ecologically important variables (Ked490, CHL) the length of the annual period of high values has increased by a factor of >2.
- The set of phenological indices can be applied to all kinds of variables but they are particularly suitable for satellite data that have consistent time interval and can be averaged over a spatial domain.

Some Conclusions

- The cumulative sum of 30K W m^{-2} of surface incoming shortwave irradiance (SIS) was reached **23 days earlier** in 2014 compared to 1983.
- The period with **SST ≥17 C has ~doubled** from 29 days in 1982 to 56 days in 2014. It's like the Baltic Sea has moved from Finland to Germany ☺
- The period of **low water transparency** (Ked490 over 0.4 m^{-1}) has increased from <60 days in 1998 to ~240 days in 2013, i.e. **4X**!
- The period of high satellite-detected **CHL (>3 mgm^{-3}) has doubled** from ~ 110 days in 1998 to 220 days in 2013.
- Both the phytoplankton **spring and summer blooms have become earlier**, and the annual CHL maximum may have switched from the spring bloom in the 1980s (in May) to the summer cyanobacteria bloom (in July).

THANK YOU!