

# Detection of Change in Arctic Phytoplankton Blooms

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## 1 Introduction

Detection of change is a hot topic due to the threat of global climate change. Arctic is the area where these changes appear to be strongest and drastic changes have been already been documented during the last decades.

Satellite data are rather short in time span but provide large scale coverage at frequent intervals and are therefore essential in detecting such change. In this tutorial we try several methods of change detection with WIM/WAM.

### 1.1 *Assembling a consistent time series*

In any time series analysis it is important that the data are consistent over the time span of the series. This is not easy to guarantee as sensors degrade in time, their calibration changes, time series often consist of data from multiple sensors that are never exactly the same. For a short description of the satellite-detected time series of chlorophyll-a see *Detection\_of\_Change.pdf* in the *Course* folder or the same at [http://www.wimsoft.com/Course/4/Detection\\_of\\_Change.pdf](http://www.wimsoft.com/Course/4/Detection_of_Change.pdf).

## 2 Detecting changes in time series of chlorophyll-a concentration

### 2.1 *Detecting Changes in Bloom Magnitude*

We will follow the example of a Kahru & Mitchell (2008) but with an extended and improved dataset. We will use global 5-day time series of chlorophyll-a concentration (Chla) to detect changes in bloom magnitude and timing. We want to make the time series as long as possible (1996-2012) but need to have complete sets for each year. We therefore skip OCTS data of 1996 as there were only 2 months (Nov-Dec) and these 2 months cannot be assumed to be representative of the annual maximum for the year. Note that in 1997 we miss the data for July-August. In the Baltic Sea the apparent Chla maximum is often due to cyanobacteria blooms in July-August and we therefore will miss these in 1997. For most other regions the annual Chla

maximum is not likely to occur in July-August and therefore missing Jul-Aug in 1997 will not likely affect the annual maximum.

We assume that the 5-day Chla data are in *C:\Sat\Merged\5day\ChlBlended\_25*.

Open some of the files in the folder with WIM by clicking or double-clicking on them and try to guess what the file names mean. Look at the file and dataset *Attributes* (the *Table*-like icon on the toolbar). The images have been reduced to 25 km resolution from their original 9-km resolution. Our first task is to find the annual maximum for each pixel for every year available in the time series of 1133 images. Imagine how long it would take by manually looking at images? ☺

Open the command prompt and *cd* to the top directory where you keep the results, e.g.

```
cd C:\Sat
```

Before we run the analysis, move the few 1996 files to separate folder, e.g. *Hide*. You can do that interactively or with the command line:

```
mkdir Merged\5day\ChlBlended_25\Hide
move Merged\5day\ChlBlended_25\O1996*.hdf Merged\5day\ChlBlended_25\Hide
```

Now find the annual maximum for each pixel for each year with the command:

```
wam_annual_max Merged\5day\ChlBlended_25\*.hdf
```

After the command finishes in a few minutes you should see output something like that:

```
C:\Sat>wam_annual_max Merged\5day\ChlBlended_25\*.hdf
1133 matching files found in Merged\5day\ChlBlended_25
=====
1133 files with years and mid-days selected
16 individual years found
Assuming valid Min = 0.0101 and valid Max = 64.56
ImageFileName,      YearIndex, Year, MiddleDay
A2011001.C2011005_ChIblended_comp_reduced3_Average.hdf: 14, 2011, 3
A2011006.C2011010_ChIblended_comp_reduced3_Average.hdf: 14, 2011, 8
.....
S2001356.S2001360_ChIblended_comp_reduced3_Average.hdf: 4, 2001, 358
S2001361.S2001365_ChIblended_comp_reduced3_Average.hdf: 4, 2001, 363
Saved Annual max in _hdf_Max.hdf
Saved Annual min in _hdf_Min.hdf
Saved valid count in _hdf_ValidCounts.hdf
Done with 1133 images!
Processing time: 00:05:06
```

Note that we are using global data with reduced resolution (25 km) instead of the maximum 1 km resolution. That makes it possible to make the calculations in relatively short time even on laptop computers.

As output, we get 3 files with the names derived from the command argument (*\*.hdf*). **Please rename** them to, respectively, *Max.hdf*, *Min.hdf*, *ValidCounts.hdf*.

```
rename _hdf_Max.hdf Max.hdf
rename _hdf_Min.hdf Min.hdf
rename _hdf_ValidCounts.hdf ValidCounts.hdf
```

As the names infer, these files have the annual maxima, minima and the number of valid months of each pixel for each year included.

**Note! In order to produce the timing information you need to let your computer run for about 4 hours!** The option *Slow* appended to the command produces an additional file *MaxDay.hdf* that contains the day number (year day or Julian day) of the maximum for each year and each pixel.

```
wam_annual_max Merged\5day\ChlBlended_25\*.hdf Slow
```

On a fast desktop it took 3 hours and 52 minutes to complete, on a slow laptop probably ~15 hours. **Do NOT use that option unless you can let it run for many hours!**

Kahru et al (2010) have shown that in certain areas of the Arctic covering nearly 10% of the Arctic Ocean with available chlorophyll data, the annual phytoplankton bloom (spring bloom) has become earlier due to earlier retreat of ice. Therefore, the *Slow* option is needed to show changes in the timing of the maxima.

It is **VERY IMPORTANT** to keep all the files well **ORGANIZED** in separate folders. You can use your own folder names but you need to be consistent. I recommend creating a new folder `C:\Sat\Merged\L3\5day\MinMax_25` for this project and move the 3 created files to that folder:

```
mkdir MinMax_25
move *Max.hdf MinMax_25
move *Min.hdf MinMax_25
move *ValidCounts.hdf MinMax_25
```

If you did run the *Slow* option, please rename `_.hdf_MaxDay.hdf` to *MaxDay.hdf* and move it also to the *MinMax\_25* folder as well. It has the year day of the year when the pixel had its annual maximum in Chla. Now, take a look at the files that you have just created. Before doing that, close WIM and open it again by clicking (double-clicking) on the newly created file *Max.hdf*. Each HDF file has 16 datasets corresponding to the 16 years that were included (1997-2012). We have several ways to visualize these results. For interactive visualization, load all 16 datasets in *Max.hdf* (in the correct order!) into WIM and use the *Examine-Spectral Plot* menu option. You should not have any other images in WIM at the same time. Of course, instead of a *spectral* plot we are actually having a time series plot. Each  $\times$  symbol on this plot corresponds to the maximum Chla in that year. Note: you need to **right-click on the Spectral Plot window** and drag the mouse pointer to the image without raising the button. For each pixel you are pointing, it shows 16 annual points corresponding to the time series of bloom magnitudes (1997-2012). If you point to somewhere in the Baltic Sea or the near Oregon/Washington coast of North America, you will see something like in Fig. 1.

Fig. 1 happens to show a significant increase in the apparent annual bloom magnitude from 1997 to 2012 in the Baltic Sea. In the Baltic Sea the Chla algorithm is not accurate as it reacts to the high concentrations of colored dissolved organic matter (CDOM) and to the floating mats of cyanobacteria (*Nodularia*) at the surface. Although the exact values of the apparent Chla cannot be trusted in the Baltic Sea, the apparent trend of the composite variable is obvious. Of course,

Of course, most areas do not show such a significant increase but a more or less random scatter. You can move the mouse pointer around and find areas that show interesting features.

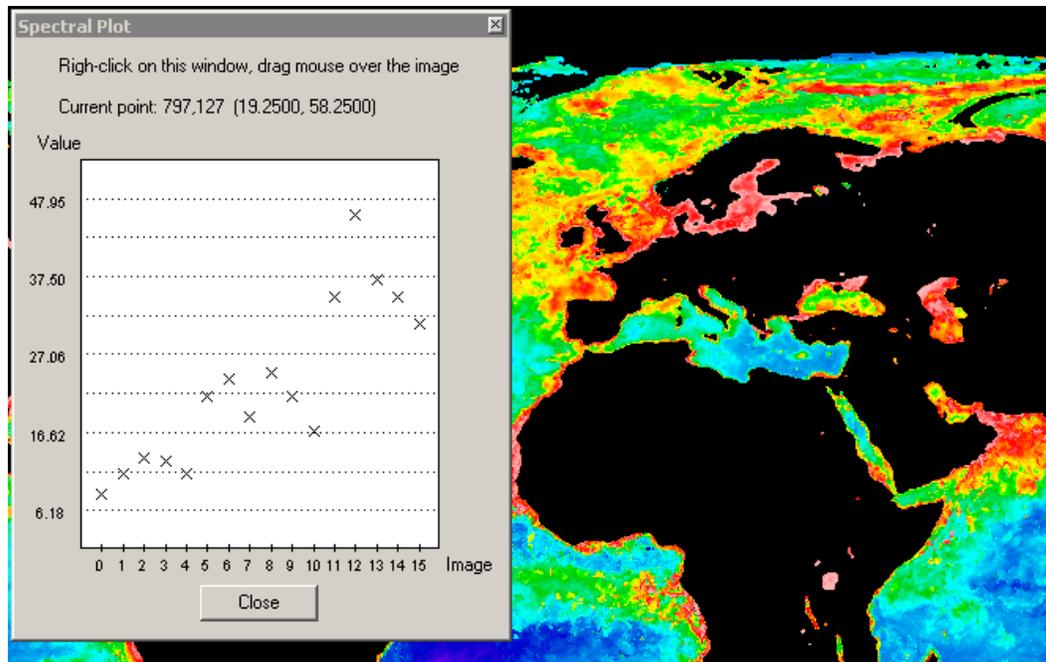


Fig. 1. Using the *Examine-Spectral Plot* in WIM to show interannual variations in bloom magnitude in the Baltic Sea.

The next task is to programmatically find the areas of significant increase or decrease. Again, imagine how much time it would take to evaluate each pixel in the images! ☺ We can use command *wam\_trend* for that. To see all the options, type the name of the command, e.g. *wam\_trend*, without arguments. The default *Significance* is 90% ( $p=0.1$ ), other *Significance* levels are 95% ( $p=0.05$ ), and 99% ( $p=0.01$ ). As the ocean color time series is relatively short (16 years used here), the detected trends are **not** usually highly significant. In the command window issue the following command:

```
wam_trend MinMax_25\Max.hdf Sen
```

Here we assume that the file with maximum values (*Max.hdf*) is in the folder *MinMax\_25*. You need to modify the command if you have it in a different folder. You should get the following output:

```
C:\Sat>wam_trend MinMax_25\Max.hdf Sen
Using the nonparametric Sen slope
Using Sen slope with Significance 90%, coefficient = 1.6449
Using Multi-SDS_file MinMax_25\Max.hdf
--- Using Anomaly palette file C:\Projects\WIM\LUT\anomaly.lut
=====
Assuming valid Min = 0.01035142 and valid Max = 64.56542
0, 1997_Max, mid year 1997.501
1, 1998_Max, mid year 1998.501
2, 1999_Max, mid year 1999.501
3, 2000_Max, mid year 2000.505
4, 2001_Max, mid year 2001.501
5, 2002_Max, mid year 2002.501
```

```

6, 2003_Max, mid year 2003.501
7, 2004_Max, mid year 2004.505
8, 2005_Max, mid year 2005.501
9, 2006_Max, mid year 2006.501
10, 2007_Max, mid year 2007.501
11, 2008_Max, mid year 2008.505
12, 2009_Max, mid year 2009.501
13, 2010_Max, mid year 2010.501
14, 2011_Max, mid year 2011.501
15, 2012_Max, mid year 2012.33
Please be patient, Expect 100 dots until done...
.....
.....Looking for best scaling...
Slope values will be multiplied by 62.4918022155762
  Saved Max_trend_sen_90.hdf
Processing time: 00:00:19
    
```

This command created a new file *Max\_trend\_sen\_90.hdf* where each pixel value has the slope of the estimated trend. The *Sen* option uses the nonparametric *Sen* trend estimate instead of the least squares *Linear* trend. *Sen* slope computes the slopes for all the possible pairs of time series points and then uses their median as an estimate of the overall slope. Similar estimates of the slope can be obtained with the more traditional linear least squares regression (*Lin* option instead of *Sen*) but the *Sen* slope estimator is preferable due to its less sensitivity to outliers. A palette file *anomaly.lut* is used by default and it shows areas of increased bloom magnitude in red and decreased bloom magnitude in blue (Fig. 2). If the image does not look like that in Fig. 2 (i.e. has totally different colors), click on the *Settings* (  ) icon, then *Misc* tab and uncheck *Override LUT in HDF*. Then close WIM and open again by clicking (double-clicking) on the same image file.

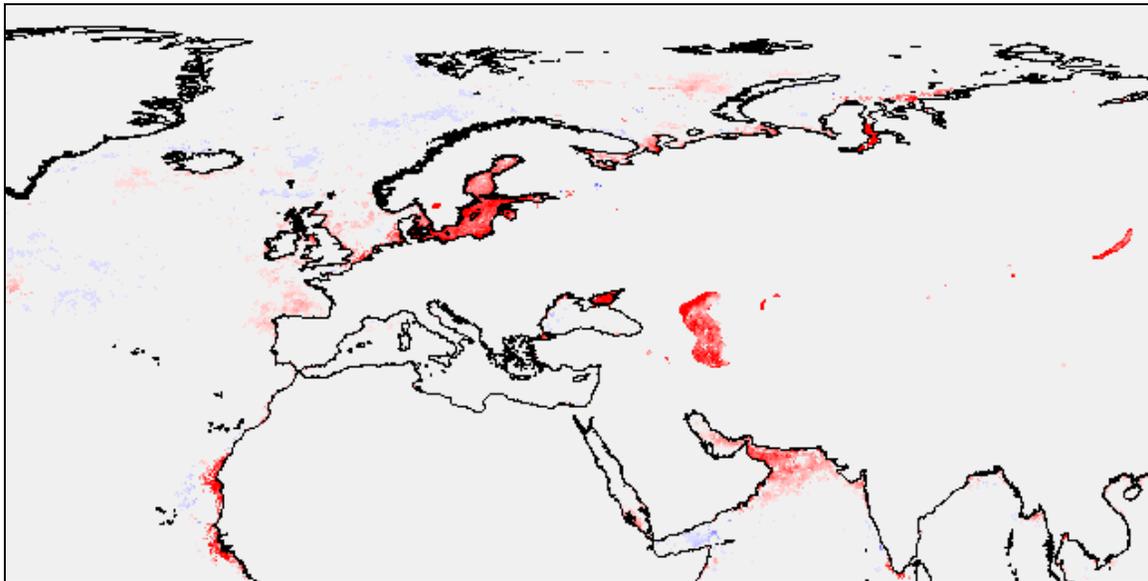


Fig. 2. Changes in bloom magnitude detected by the *Sen* slope estimator. Increased blooms are detected in areas shown in red, decreased blooms in areas in blue.

Now take a look at the specifics of the slope image. Press down the right mouse button and move the mouse around the white areas, e.g. over most of the open ocean. You can notice that pixel value 128 corresponds to the scaled slope value of 0.

You can stretch the colors with the  icon on the toolbar (Fig. 3) but you need to do it symmetrically up and down (for both the *Start* and *End* variables).

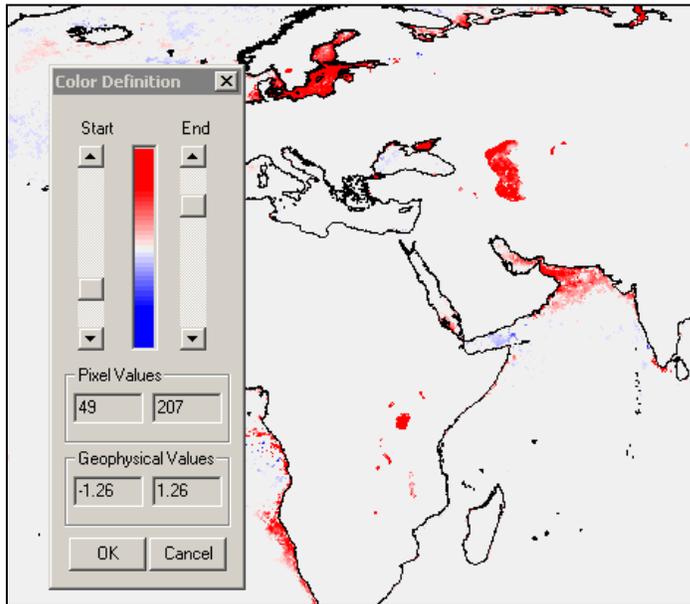


Fig. 3. Stretching the color scale.

The default is to evaluate the slope of each pixel at the 90% statistical significance. You can also specify significance at 95% and 99% level.

```
wam_trend MinMax_25\Max.hdf Sen 95
wam_trend MinMax_25\Max.hdf Sen 99
```

Evaluate the result of these commands. In general, the ocean color time series is too short to detect the existence of trends at high significance. On the other hand, by having thousands if not millions of pixels in the analysis almost guarantees that some of significant trends just by chance.

You can apply the same command (*wam\_trend*) to the annual minima file (*Min.hdf*) and the result would show trends in the annual minima. It appears that there are some areas where the minima have also increased or decreased but much less than the maxima.

The global map of the change in bloom magnitude, similar to what you just created but based on earlier and much shorter time series, is shown at <http://spg.ucsd.edu/blooms.png> and a Google Earth version of the same at <http://spg.ucsd.edu/blooms.kmz> and parts are in the EOS article (Kahru and Mitchell, 2008, see [pdf](#)). We will now try to make our images look a little better (like shown in the links above).

Load the Sen slope image (*Max\_trend\_sen\_90.hdf*) into WIM.

Create a coastline image with *Geo-Get Map Overlay* ( icon on the toolbar), use the full resolution coastlines *coast\_full.b* file in *C:\Program Files (x86)\Wimsoft\Maps*, check *Land* and *Lake*, set *Foreground* 1, *Background* 0. Set palette to Grayscale in Settings (the  icon on the

toolbar), stretch the colors with  icon on the toolbar, leave the *Start* color at 0 and scroll the *End* color to 6. The coastlines appear very dark gray and the rest is black.

Convert the image to RGB with *Transf-Convert to 24bpp (RGB)*.

Fill land with gray color with *Edit-Draw*, e.g. use gray with RGB components 213, 213,213. You can use *Define Custom Colors* to define your own colors by specifying the RGB components. Use the same color for both *Outline* and *Fill*. Be careful when filling some areas where the coastlines do not extend to the edge of the image, e.g. Asian continent near Bering Strait. You may need to use  to *Undo* the leaking color spill. You can manually extend the coastline and fill the gap with the *Paintbrush* tool in *Edit-Draw*. Filling all the islands with gray color takes some time. Sorry, currently there is no automated tool for that.

Now go back to the original slope image and convert to RGB with *Transf-Convert to 24bpp (RGB)*. Now overlay with the filled RGB coastlines image that you just created using *Multi-Overlay Image* (  on the toolbar).

You can save all images in WIM memory together (e.g. as *work.hdf* in *C:\Sat\MinMax25* - for the case that you want to use them again) or just save the final image both as HDF and as PNG (e.g. *slope\_edited.hdf* and *slope\_edited.png*). Always save as HDF if you need to edit the data again. Images saved as bitmaps (PNG, JPG, BMP, etc) cannot be read into WIM again and are “dead end”.

You can also generate detailed time series of the mean, median or other statistics of the image data in specified areas of interest, called masks. This can be done with *wam\_statist*. There is an exercise (4.3) on using *wam\_statist* in [Exercises\\_WIM\\_WAM.pdf](#). Only a short list of actions is presented here.

## 2.2 Detecting Changes in Bloom Timing

If you run *wam\_annual\_max* command with the *Slow* option:

```
wam_annual_max Merged\5day\ChlBlended_25\*.hdf Slow
```

you will also get a file named *\_.hdf\_MaxDay.hdf* with the year day of the annual Chla maximum for each year. Please note that this command will run for about **4 hours** on a fast desktop and much slower on a typical laptop. **Better to leave it run overnight!** When it is finished, rename *\_.hdf\_MaxDay.hdf* to *MaxDay.hdf* and move to *MinMax*. Note that for your convenience I have provided the file *MaxDay.hdf* in folder *Sat\Merged\5day\Done*.

Now evaluate possible trends in the timing of the annual maximum with the following commands:

```
cd C:\Sat
wam_trend MinMax_25\MaxDay.hdf Sen 90
```

This makes evaluates the significance of possible trends in timing at 90% significance level. We assume that that you moved *MaxDay.hdf* to the *MinMax\_25* folder. As output you should get a file called *MaxDay\_trend\_sen\_90.hdf* that has slope estimates of the trends in the day of the maximum. The default colors are somewhat bleak and we increase contrast by stretching the colors to something like -2.45 to 2.45 (Fig. 4). You should get something like Fig. 5.

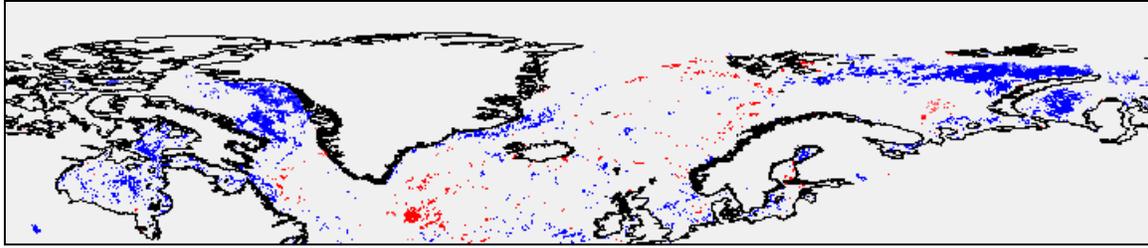


Fig. 4. Changes in the timing of the bloom maximum detected with the Sen slope estimator based on the GlobColour Chla data (1997-2010, from Kahru et al., 2010). Blue shows earlier bloom maximum (decreased year day) and red shows later bloom maximum (increased year day).

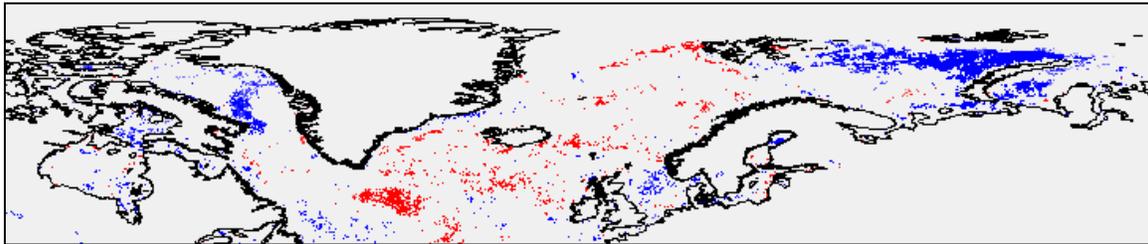


Fig. 5. Same as Fig. 4 but based on the blended and extended (1997-2012) Chla dataset.

We now remap this global image to polar stereographic projection that we take from any ice image in the *C:\Sat\Ice\nasateam\_final\_N\_mo* folder. Just load any ice image from there and use *Geo-Remap Projection* to that image. The output (after some modification) would look something like Fig. 7.

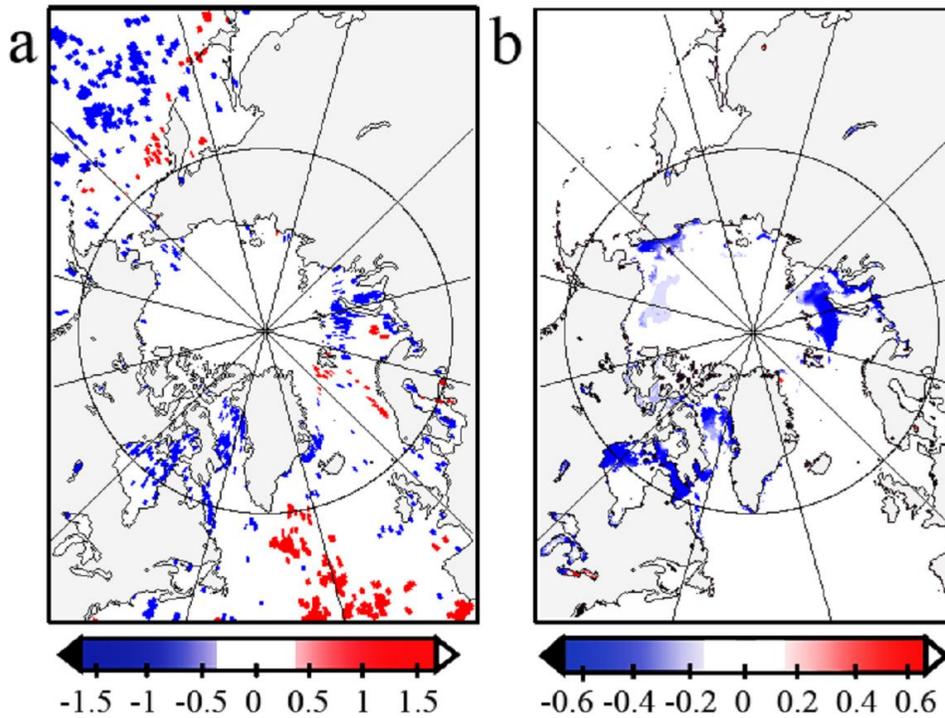


Fig. 6. Detected changes in timing of the annual *Chla* maximum (a, day/year). b, trends in early summer (June) ice concentration (ice fraction change per year, trend calculated for 1979 to 2007 using monthly ice concentrations from the Nimbus-7 SMMR and DMSP SSM/I passive microwave data) (from Kahru et al., 2010).

Figs. 5 and 6 show that the bloom maximum has become earlier in some ice edge areas of the Arctic while in other areas (e.g. North Atlantic) the maximum has become later. Fig. 7 shows time series plots of the day of maximum *Chla* in selected areas of the Arctic Ocean with the most significant change towards earlier blooms.

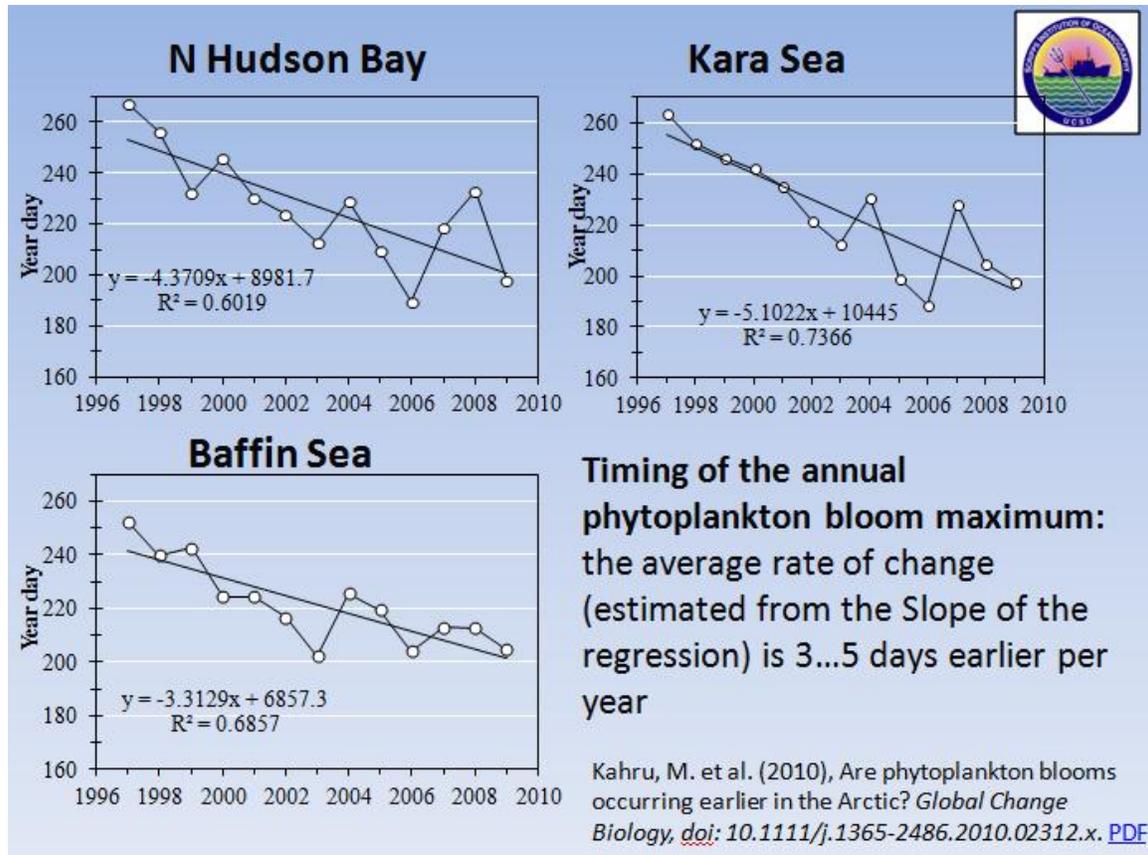


Fig. 7. Year-day of the annual *Chla* maximum in selected areas of the Arctic Ocean for 1997-2009 showing significant trends towards earlier maxima (from Kahru et al., 2010).

## References

- Kahru, M., B.G. Mitchell (2008) Ocean color reveals increased blooms in various parts of the World, *EOS, Trans. AGU*, Vol. 89, N 18, p. 170.
- Kahru, M., R. Kudela, M. Manzano-Sarabia and B.G. Mitchell (2009), Trends in primary production in the California Current detected with satellite data, *J. Geophys. Res.*, 114, doi:10.1029/2008JC004979.
- Kahru, M., V. Brotas, M. Manzano-Sarabia, and B. G. Mitchell (2010), Are phytoplankton blooms occurring earlier in the Arctic? *Global Change Biology*, doi: 10.1111/j.1365-2486.2010.02312.x.