Detection of Change in the Arctic, Blooms

Contents

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.

2 Assembling a consistent time series of chlorophyll-a concentration

The 1st satellite ocean color sensor (CZCS, 1978-1986) was experimental, the calibration was poor compared to current standards and the data recording was gappy. Modern ocean color time series starts with the short-lived OCTS (Nov-1996…Jun-1997) but the continuous series starts with SeaWiFS (1997-2010). In order to be able to detect changes, we want to assemble a time series as long as possible. SeaWiFS also had periods when it was not transmitting data (in 2008, 2009, 2010). We therefore use merged time series from up to four sensors: OCTS, SeaWiFS, MODIS-Aqua (MODISA) and MERIS. OCTS and NASA sensors were recently (2009-2010) reprocessed with consistent methods. MERIS (2003-present) data are also being reprocessed but the updated data have not been incorporated yet.

We can use either monthly or 5-day data for the time series covering years 1997-2010. In 1996 we only have 2 months (Nov and Dec) that are not enough to include this year. In 2002-2010 we have overlapping data from SeaWiFS, MODISA and MERIS. We increase the reliability and decrease the number of missing values by merging data from multiple sensors. Monthly data have the advantage of having less missing pixels due to clouds but are too coarse to detect any changes in timing. 5-day data have lots of gaps due to clouds. We use interpolation to fill in the missing pixels. We also use daily ice maps in order to prevent interpolating into ice covered areas. For this exercise we have assembled a 5-day merged chlorophyll-a (Chl) dataset from daily datasets obtained from NASA's Ocean Color website (http://oceancolor.gsfc.nasa.gov/) and the European Space Agency's GlobColour project (http://www.globcolour.info).

2.1 Example: Algal blooms and bloom magnitude

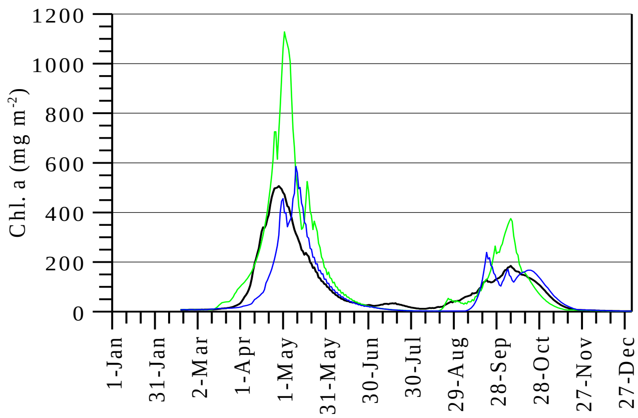

Fig. 1. Phytoplankton annual cycle and its inter-annual variation in the central North Sea: depth-integrated Chl-a in 1991 (green), 1997 (blue), mean for 1990-2000 (black). From Nielsen and St. John, 2003.

Fig. 1 shows that phytoplankton has a clear annual cycle with a maximum in biomass during the spring bloom. The magnitude of the annual maximum has large inter-annual variability. It is reasonable to assume that in years with very high and short spring bloom, a significant part of the newly produced biomass is not consumed by the next trophic level and sinks out of the top layer and may-be to the bottom. Respiration in the bottom layers consumes oxygen and can produce "dead zones" of oxygen-depleted waters, e.g. off Oregon [*Service*, 2004, 2007]. It is reasonable to assume that lower and longer spring bloom leads to more of the new biomass being consumed in the top layer and less being exported by the sinking flux whereas during a high and short bloom the consumers are probably not ready and a large portion of the algal biomass sinks out. The magnitude of the bloom is therefore an important variable to monitor as it can be related to the production of oxygen-depleted waters as well as to the removal of biogenic carbon from the surface layer.

2.2 Detecting Changes in Bloom Magnitude

We will follow the example of a recent paper [Kahru & Mitchell, 2008] but with an extended and improved dataset. We will use global 5-day time series of chlorophyll-a concentration (Chl-a) to detect changes in bloom magnitude and timing. We want to make the time series as long as possible (1997-2011) but need to have complete sets for each year. We skip OCTS data of 1996 as there were only 2 months (Nov-Dec) and these 2 months cannot 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 Chl-a maximum is often due to cyanobacteria blooms in July-August and we therefore will miss these in 1997. For most other regions the annual Chl-a 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 Chl-a data are in *C:\Sat\Merged\L3\5day\CHL_25_filled_deiced*.

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

```
cd C:\Sat\Merged\L3\5day
```

Take look at the files in the folder and try to guess what the file names mean. Note that the L3m_* files are based on merger of SeaWiFS, MODISA and MERIS data by the GlobOcean project. The images have been reduced to 25 km resolution. Some missing pixels have been filled with interpolation. The interpolation process has been controlled with ice map masks from SSM/I to prevent interpolating into ice-covered areas. The filename of the ice mask is recorded in the filename of the Chl-a data.

Our first task is to find the annual maximum for each pixel for every year available in the time series of 1009 images. Imagine how long it would take by manually looking at images? ☺

In the command window run the following command:

```
wam_annual_max  CHL_25_filled_deiced\*.hdf
```

(The option with *Reduce* is needed for bigger images if you don't have enough RAM in your computer.) After the command finishes in a few minutes you should see output something like that:

```
C:\Sat>wam_annual_max  Merged\L3/Monthly\CHL_9\*.hdf
 1009 matching files found in CHL_25_filled_deiced
14 individual years found
………………………………………………………………………….
Saved Annual max in _.hdf_Max.hdf
Saved Annual min in _.hdf_Min.hdf
Saved valid count in _.hdf_ValidCounts.hdf
Done with 1009 images!
Processing time: 00:04:13
```

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  CHL_25_filled_deiced\*.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* for this project and move the 3 created files to that folder:

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

If you did run the ***Slow*** option, please rename *_.hdf_MaxDay.hdf* to *MaxDay.hdf* and move it to the *MinMax* folder as well. It has the year day of the year when the pixel had its annual maximum in Chl-a. Now, take a look at the files that you have just created. Before doing that, clean the image stack in WIM, i.e. close WIM and open it again by clicking (double-clicking) on the newly created file, e.g. *Max.hdf*. Each HDF file has 14 datasets corresponding to the 14 years that were included (1997-2010). We have several ways to visualize these results. For interactive visualization, load all 14 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 × symbol on this plot corresponds to the maximum Chl-a 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 14 annual points corresponding to the time series of bloom magnitudes (1997-2010). 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. 3.

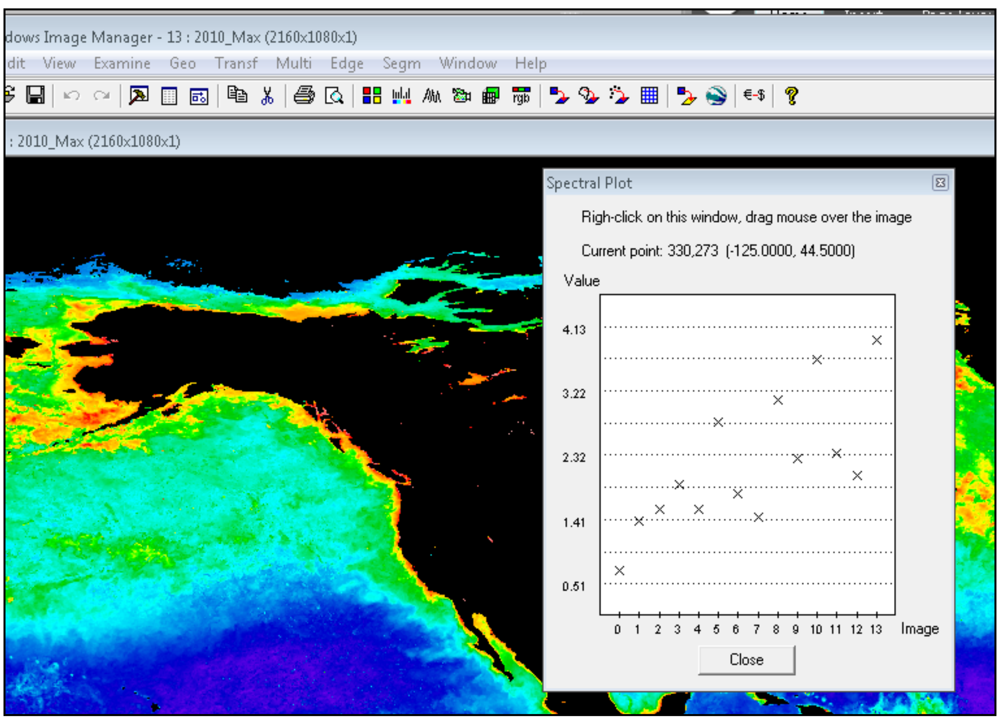

Fig. 2. Using the *Examine-Spectral Plot* in WIM to show interannual variations in bloom magnitude off Oregon.

Fig. 2 happens to show a significant increase in the annual bloom magnitudes from 1997 to 2010 off the Oregon/Washington coast of North America. 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.

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 very short (14 years used here), the detected trends are **not** usually highly significant. In the command window issue the following command:

```
wam_trend MinMax\Max.hdf  Sen
```

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

```
C:\Sat\Merged\L3\5day>wam_trend MinMax\Max.hdf  Sen
Using the nonparametric Sen slope
Using Sen slope with Significance 90%, coefficient = 1.6449
Using Multi-SDS_file MinMax\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 2000.501
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 2004.501
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 2008.501
12, 2009_Max, mid year 2009.501
13, 2010_Max, mid year 2010.501
Please be patient, Expect 100 dots until done...
..............................................................................
......................Looking for best scaling...
Slope values will be multiplied by 149.307708740234
  Saved Max_trend_sen_90.hdf
Processing time: 00:00:14
```

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 switches to the *Sen* slope instead of the *Linear* trend. Sen slope is a nonparametric estimate of the slope that involves computing slopes for all the pairs of time points and then using the median of these slopes 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. 3). If the image does not look like that in Fig. 3 (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.

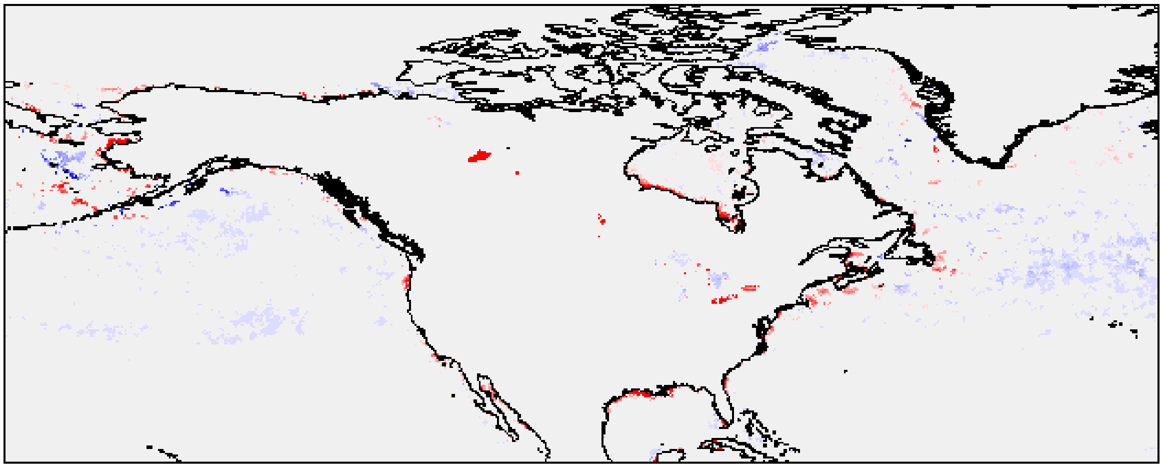

Fig. 3, A. Changes in bloom magnitude detected by the Sen slope estimator. Increased blooms are detected in areas shown in red, decreased blooms in areas in blue.

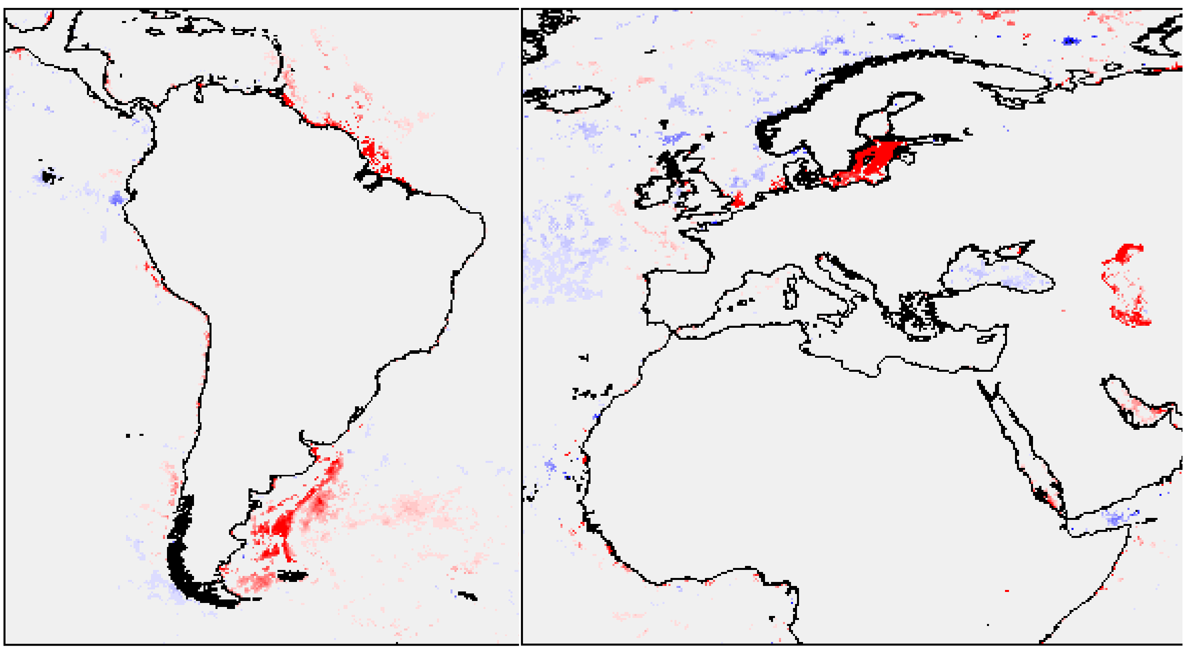

Fig. 3, B. Changes in bloom magnitude detected by the Sen slope estimator. Increased blooms are detected in areas shown in red, decreased blooms in areas in blue. Increased blooms are detected e.g. in the Baltic, Azov, Caspian seas. Modified from [Kahru and Mitchell, 2008, see pdf].

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 (Fig. 4).

Fig. 4. White areas with pixel value 128 correspond to the Sen slope of 0.0.

Now take a look at the scaling of the image by clicking at the icon on the toolbar.

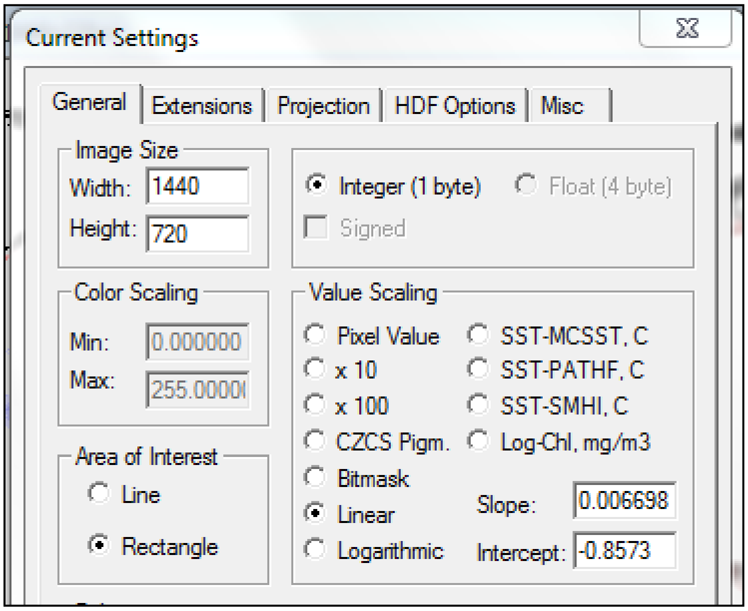

Fig. 5. Settings of the slope image.

As you can see, the *Intercept* is -0.8573 and the *Slope* is 0.006698. Please note that we have an image with the values of the *slope* of the trend in bloom magnitude. To scale this image, we use parameters such as *Intercept* and *Slope*.

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\Max.hdf Sen 95

wam_trend MinMax\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 rends 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, is also 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 FilesWimsoft\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\MinMax* - 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 a "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.

2.3 Detecting Changes in Bloom Timing

If you run the *wam_annual_max* command with the *Slow* option, you have the file *_.hdf_MaxDay.hdf* with the year day of the annual Chl-a maximum for each year. Rename it to *MaxDay.hdf* and move to *MinMax*. Now evaluate possible trends in the timing of the annual maximum with the following commands:

```
wam_trend MinMax\MaxDay.hdf Sen  90
wam_trend MinMax\MaxDay.hdf Sen  95
wam_trend MinMax\MaxDay.hdf Sen  99
```

This makes 3 versions of the trends in timing assuming significance levels 90%, 95% and 99%, respectively. We assume that that you moved *MaxDay.hdf* to the *MinMax* 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 from -2.62 to 2.63 (Fig. 6). You should get something like Fig. 6.

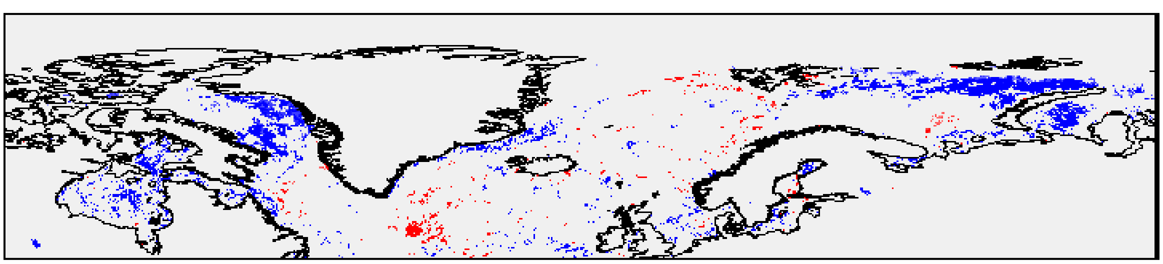

Fig. 6. Changes in the timing of the bloom maximum detected with the Sen slope estimator. Blue shows earlier bloom maximum (smaller year day) and red shows later bloom maximum (larger year day).

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.

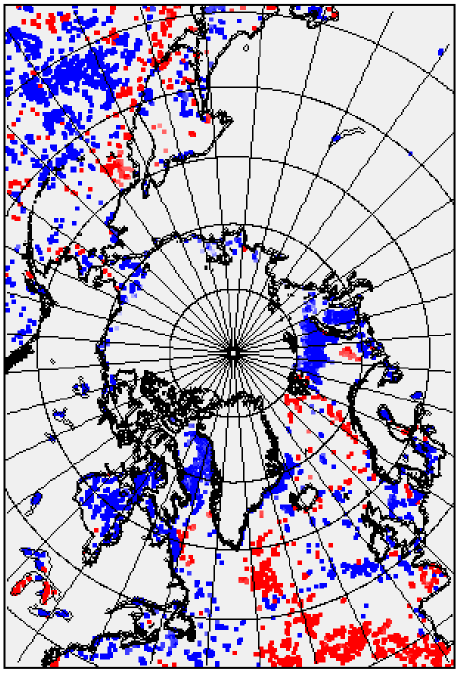

Fig. 7. Changes in the timing of the bloom maximum detected with the Sen slope estimator (as Fig. 6 but mapped to polar stereographic projection).

Figs. 6 and 7 show that the bloom maximum has become earlier in many ice edge areas of the Arctic while in many areas to the south of the Arctic the maximum has become later.

References

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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.

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