

# Detection of Change in the Arctic, Ice

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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 documented during the last decades.

Satellite data are rather short in time span but provide frequent and large scale synoptic coverage 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 sea ice data

It is important that the time series that we use for detecting trends is consistent. Sensors do not last very long and their calibrations and data processing algorithms change. This may cause fake trends or fake abrupt changes in the time series of satellite data. In this exercise we will use the “Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I Passive Microwave Data” distributed by the National Snow and Ice Data Center (NSIDC) (<http://nsidc.org/data/nsidc-0051.html>). This data set is generated from brightness temperature data derived from Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR) and Defense Meteorological Satellite Program (DMSP) -F8, -F11 and -F13 Special Sensor Microwave/Imager (SSM/I) radiances at a grid cell size of 25 x 25 km. The data are provided in the polar stereographic projection. This product is designed to provide a consistent time series of sea ice concentration spanning several decades and several passive microwave instruments. Sea ice concentration is defined as the fraction, or percentage, of ocean area covered by sea ice. The data are generated using the NASA Team algorithm (“nasateam”) developed at NASA Goddard Space Flight Center.

This dataset can be downloaded from (<ftp://sidacs.colorado.edu/pub/DATASETS/seaice/polar-stereo/nasateam/>). There are 3 versions of the data: *final-gsfc*, *preliminary* and *near-real-time*. The preferred data are under *final-gsfc* but it currently has only the time period from October-1978 to end of 2007. Later data are under *preliminary* (2008) and *near-real-time* (2009-2011). Under each version there are *daily* and *monthly* sections, except there is no monthly section under *near-real-time*. Therefore, in order to have a monthly time series until present you need to assemble the missing monthly data from the *preliminary* (2008) and the *near-real-time* (2009-2011). NSIDC distributes the data in the **binary** format that is not user-friendly. We can convert the binary files to user-friendly HDF files with *wam\_convert\_ssmi*. In fact, we have already converted all *final-gsfc* and *preliminary* monthly binary data to HDF format. We also converted the daily *near-real-time* data of 2009 and 2010 into daily HDF files and composited those daily HDF files into monthly mean ice concentration composites. In this exercise you have to convert the daily binary files of the most recent year (2011) to HDF. Practicing the conversion of the daily binary data to HDF and then compositing daily data into monthly composites will prepare you for independently downloading the daily binary data and creating an updated monthly dataset for your use in the future.

## 2.1 Converting binary sea ice data to HDF

We assume that you have copied the sample satellite data from the DVD to your hard disk, e.g. to *C:\Sat*. Open the command prompt and *cd* to the top directory where you keep ice data, e.g.

```
cd C:\Sat\Ice\nasateam_nrt_N_day
```

Familiarize with the directory structure and open some sample HDF files by clicking (or double-clicking) on the files. Double-click on any of the files in the *C:\Sat\Ice\nasateam\_nrt\_N\_day* folder. The image will be loaded into WIM and should look like the image on left panel of Fig. 1. If the colors look different then you may have to uncheck the check-box in *Settings-Misc-Override LUT in HDF* (see right panel of Fig. 1).

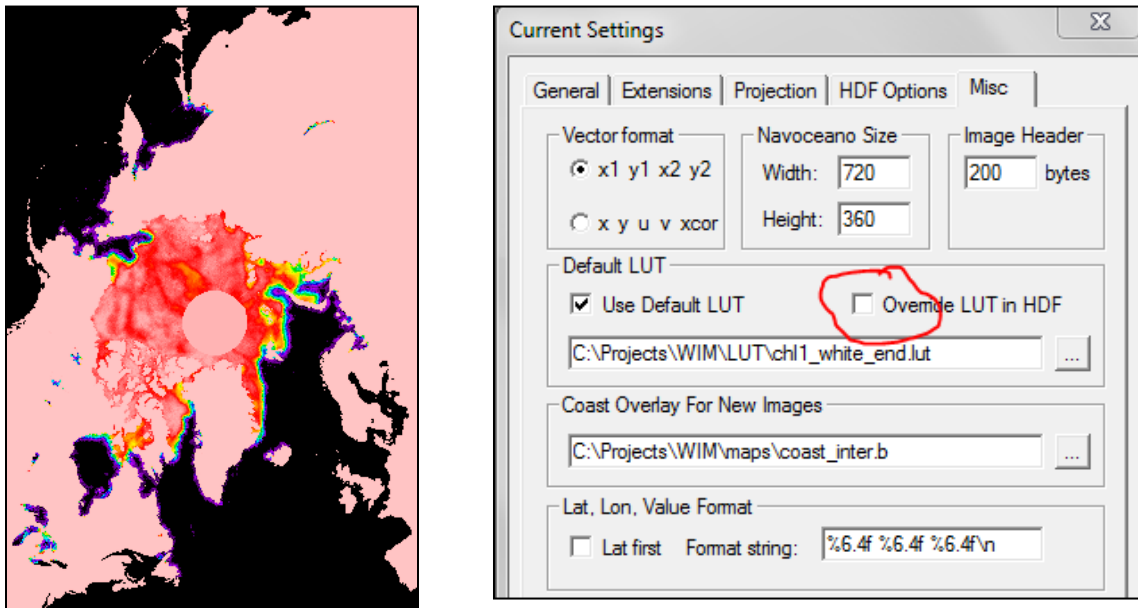


Fig. 1. Sample ice image (left) and the option to uncheck option to override LUT in WIM *Settings-Misc-Override LUT in HDF*.

Check out the binary files in `C:\Sat\Ice\nasateam_nrt_N_day\bin` and realize that there is no easy way to read them (i.e. without writing a program in some computer language).

Now use `wam_convert_ssmi` to convert the binary data to HDF. We will create a folder for 2011, convert the 2011 binary files and move to the folder 2011.


```
mkdir 2011
wam_convert_ssmi bin\nt_2011*.bin
move nt_2011*.hdf 2011
```

You can also use the batch file `convert_year.bat` in the same folder that you can need to edit it for years other than 2011. Please take a look at the batch file by opening it in *Notepad*. Don't click (double-click) in it as that would run the batch file.

## 2.2 Compositing daily sea ice data to monthly means

We now assume that you have converted the daily binary 2011 files and that the corresponding daily HDF files are in folder 2011 in `C:\Sat\Ice\nasateam_nrt_N_day`. We now use `wam_composite_month` to create monthly mean ice concentrations from daily data in HDF format, e.g.

```
wam_composite_month 2011\nt_*.hdf
```

Look at the output files and realize that the file naming convention is not similar to the NSIDC file naming. This is because `wam_composite_month` was designed to work with ocean color data and is not customized for the naming convention of NSIDC ice data. Ocean color data typically use sequential yeardays and not months to designate files. For example, the string "2011031" in filename `201101n2009031_nt_comp.hdf` means that the file is for January, 2011 as January ends with yearday 31. You can check all the file attributes (additional information) by opening the file and checking out the attributes (*View-Attributes* or the  icon on toolbar). Note the "Start Day" and "End Day" attributes that are used to make the monthly composites. We will just rename the files in order to keep a consistent naming convention (note that we are explicitly specifying month numbers instead of year days, e.g. 201101 for year 2011 and month 01):

```
rename nt_201101n2011031_nt_comp.hdf nt_201101_f13_nrt_n.hdf
rename nt_201102n2011059_nt_comp.hdf nt_201102_f13_nrt_n.hdf
rename nt_201103n2011090_nt_comp.hdf nt_201103_f13_nrt_n.hdf
rename nt_201104n2011120_nt_comp.hdf nt_201104_f13_nrt_n.hdf
rename nt_201105n2011151_nt_comp.hdf nt_201105_f13_nrt_n.hdf
rename nt_201106n2011181_nt_comp.hdf nt_201106_f13_nrt_n.hdf
rename nt_201107n2011212_nt_comp.hdf nt_201107_f13_nrt_n.hdf
rename nt_201108n2011243_nt_comp.hdf nt_201108_f13_nrt_n.hdf
rename nt_201109n2011273_nt_comp.hdf nt_201109_f13_nrt_n.hdf
```

Notice that for year 2011 we only have data from January to September and that the month of September is complete as it includes days until September 30 (last yearday 273). If you have time and interest, you can try to download and convert binary data after September 30, 2011, convert to HDF and make monthly composites. Now move the newly created and renamed monthly composites of 2011 to the folder where you have the full monthly time series, e.g.

```
C:\Sat\Ice\nasateam_final_N_mo.
```

```
move nt_2011*_nrt_n.hdf C:\Sat\Ice\nasateam_final_N_mo
```

Also move the monthly composites of the *nrt* data of 2009 and 2010 that have been produced and are in a folder *C:\Sat\Ice\nasateam\_nrt\_N\_mo*.

```
cd C:\Sat\Ice
move nasateam_nrt_N_month\*.hdf C:\Sat\Ice\nasateam_final_N_mo
```

Also move the monthly composites of the *preliminary* data (2008) to the same folder where you have the full monthly time series, e.g. *C:\Sat\Ice\nasateam\_final\_N\_mo*.

```
cd C:\Sat\Ice
move nasateam_preliminary_N_month\*.hdf C:\Sat\Ice\nasateam_final_N_mo
```

Now confirm that you have all the monthly composite files from Oct-1978 to Sep-2011, i.e. 396 months. You can right-click at the folder and choose *Properties*.

### 2.3 Detecting change interactively

You can use WIM interactively to look up pixel values and try to detect any changes between images. You will quickly realize that it is a daunting task. You can use the *Examine-Spectral Plot* function in WIM to see time series for individual pixels. As there is a strong annual cycle in ice concentration, it makes it easier to temporarily separate individual months into separate folders. For example, make a folder for July and move or copy all files corresponding to month 07 to that folder.

```
cd C:\Sat\Ice\nasateam_final_N_mo
mkdir July
move nt_???07*.hdf July
```

Now, take a look at the July folder and load all files into WIM. Before doing that, clean the image stack (i.e. all images) in WIM memory or close WIM and open it again. There are 33 individual July files there (from 1979 to 2011). You can load them all individually in correct order (!) but it is easier to load them all with *File-Open* and select all files in the folder. Open *View-Image list* and check that you have the files in chronological order. Note that if the last file is out of order, i.e. year 1997 happens to be the last and not the first, just delete the last image from WIM memory by clicking on the X icon of the image. You should not have any other images in WIM at the same time. Use *Examine-Spectral Plot*. 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 a time series of points corresponding to the images in memory, i.e. the July ice concentrations for years 1979-2011. If you deleted the 1979 image then the time series is for 1980 to 2011. If you point to the Kara Sea, you will see something like Fig. 2.

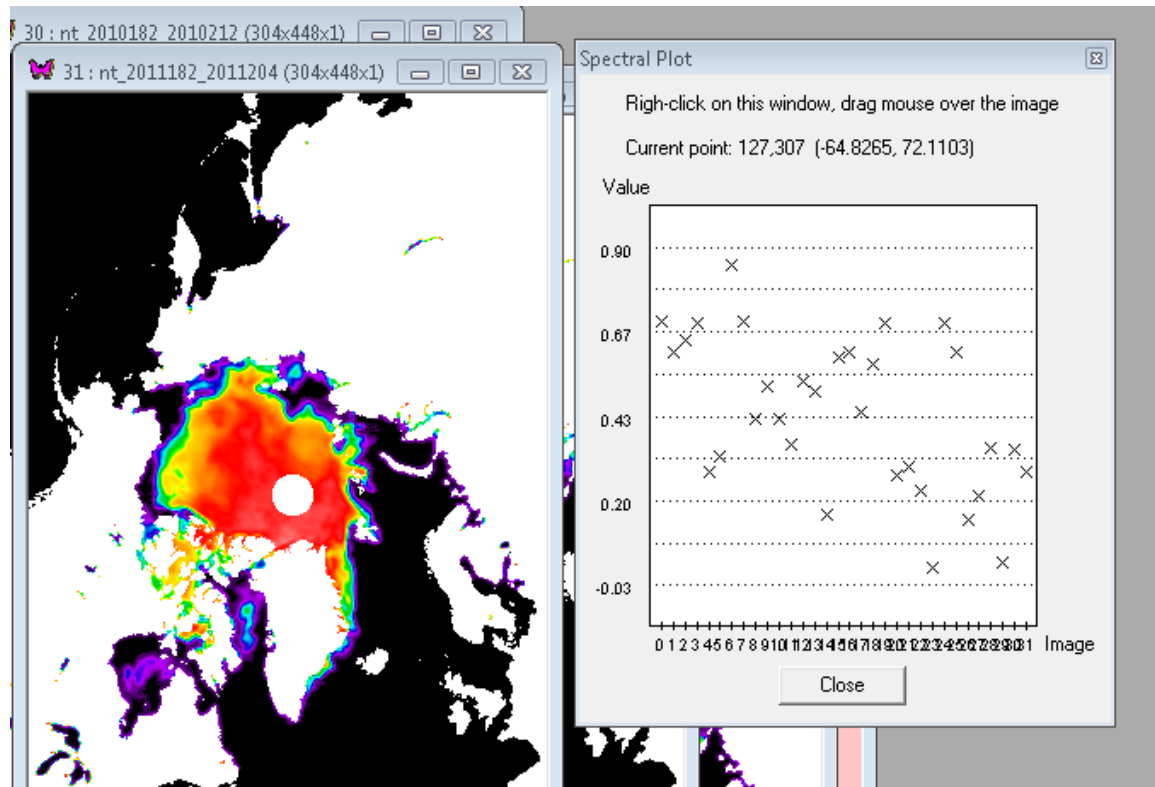


Fig. 2. Using the *Examine-Spectral Plot* in WIM to show interannual variations in July ice concentration in the Kara Sea (right plot) of the Arctic Ocean.

Fig. 2 happens to show a time series with a decreasing trend but you can also realize that the trend is not always present or is less obvious in other areas.

## 2.4 Detecting change with *wam\_trend*

In order to programmatically find areas of significant trends we use a special tool, *wam\_trend*. To see all the options, type *wam\_trend* without arguments. The default *Significance* is 90% ( $p=0.1$ ), other *Significance* levels are 95% and 99%. Before we run *wam\_trend*, move all the July files back to folder *nasateam\_final\_N\_mo*. Let's create a trend images for May, June and July ice concentrations. If you created the July folder and moved July images to that folder, move the images back and delete the July folder! Otherwise you will be missing the July images in the following trend analysis.

In the command window issue the following commands:

```
cd C:\Sat\Ice\
wam_trend nasateam_final_N_mo\nt_???05*.hdf Sen 95
wam_trend nasateam_final_N_mo\nt_???06*.hdf Sen 95
wam_trend nasateam_final_N_mo\nt_???07*.hdf Sen 95
```

Here we are creating trend image using the nonparametric Sen trend estimator with significance level 95% (0.05 error). Note that blue areas show significant decreasing trend, red areas

significant increasing trend and white (light gray) mean no significant trend at the selected level of confidence. Let's rename the output files to have better names:

```
rename nt_----05__trend_sen_95.hdf nt_1979-2011_may_trend_sen_95.hdf
rename nt_----06__trend_sen_95.hdf nt_1979-2011_jun_trend_sen_95.hdf
rename nt_----07__trend_sen_95.hdf nt_1979-2011_jul_trend_sen_95.hdf
```

Now let's create similar May, June, July trend images but using the *Linear* trend estimate:

```
wam_trend nasateam_final_N_mo\nt_????05*.hdf Lin 95
wam_trend nasateam_final_N_mo\nt_????06*.hdf Lin 95
wam_trend nasateam_final_N_mo\nt_????07*.hdf Lin 95
```

Let's rename the output files to have better names:

```
rename nt_----05__trend_lin_95.hdf nt_1979-2011_may_trend_lin_95.hdf
rename nt_----06__trend_lin_95.hdf nt_1979-2011_jun_trend_lin_95.hdf
rename nt_----07__trend_lin_95.hdf nt_1979-2011_jul_trend_lin_95.hdf
```

Open and examine the files in WIM. Compare and try to explain the differences, e.g. the donut-like circle in the *Linear* trend estimates.

You can create trends for other months besides May-July, may-be for all 12 months. Copy and paste the trend images into a document side by side, e.g. into a Word table or a PowerPoint file to get something like Fig. 3. You can add the Lon-Lat grid with *Geo-Grid* using *Lat step 10*, *Lon step 10* and *Value 1*.

You can create the color bar with *View-Annotate*. Do you find any areas with increasing ice concentration, i.e. red pixels? Try *View-Zoom* to zoom 16x and examine the image for red pixels.

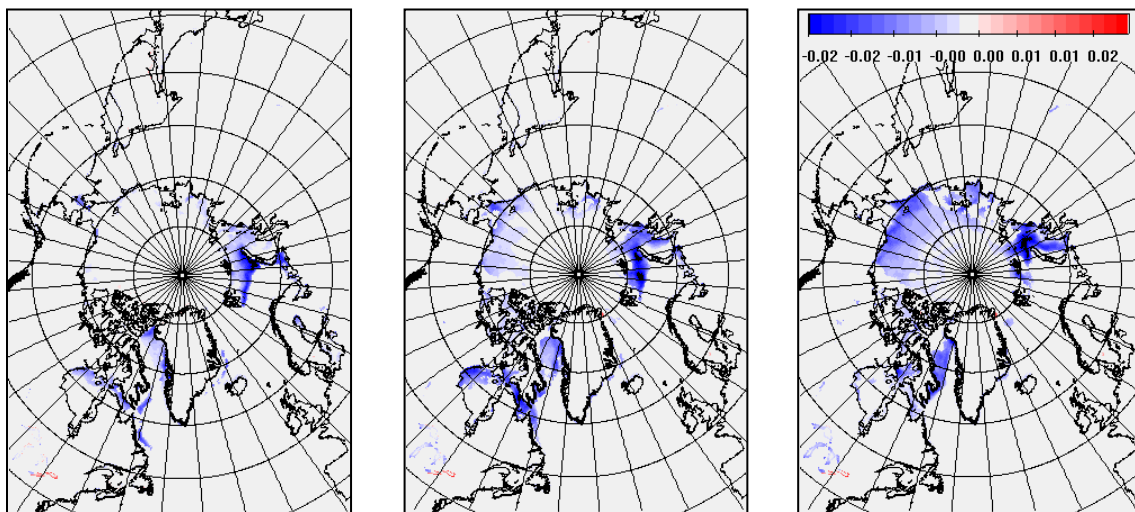



Fig. 3. Trends in ice concentration for May (left), June (middle) and July (right) for 1979-2011.

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

## 2.5 Creating time series with *wam\_statist*

You can generate detailed time series of the mean, median and other statistics of a series of images for any 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](#). Here we create single time series for a single mask in the Kara Sea south of the Novaya Zemlya island.

We can create a list of images with the following command:

```
dir /b /s C:\Sat\Ice\nasateam_final_N_mo > list_nasateam_mo.txt
```

Note that the list must not have any other filenames other than the monthly files that you want to use in the time series. You must delete all directories and other file names from that list, e.g. the July folder if you forgot to delete it! Open the list file (e.g. by double-clicking on it) in Notepad or any other editor and delete the names of any directories or other file names.

We can use a sample mask image *mask\_novzem1.hdf* and a log file *nasateam\_mo\_novzem1.txt* for *wam\_statist*. A screenshot for *wam\_statist* is given in Fig. 4. After running *wam\_statist* with log file *C:\Sat\Ice\nasateam\_mo\_novzem1.txt* you will create output file *C:\Sat\Ice\nasateam\_mo\_novzem1.csv*. Load it into *Excel* and create plots like Fig. 5.

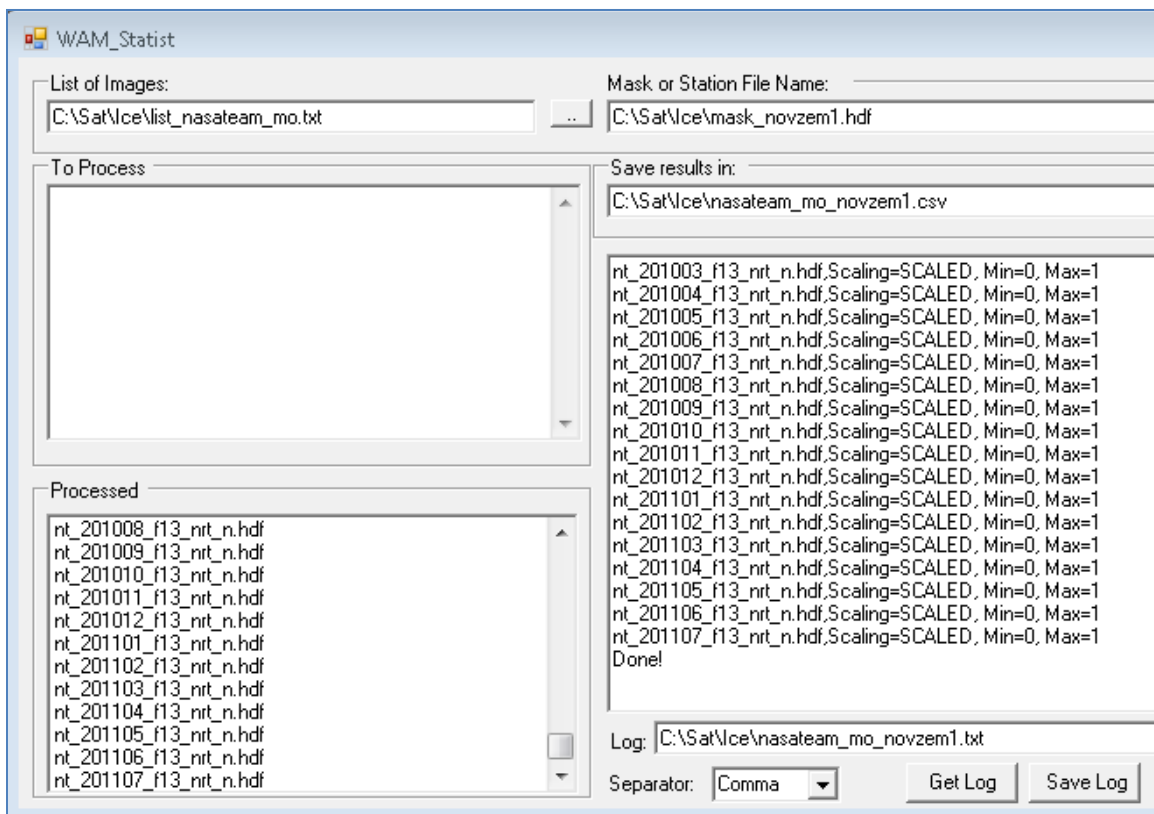


Fig. 4. Screenshot of *wam\_statist* creating a time series.

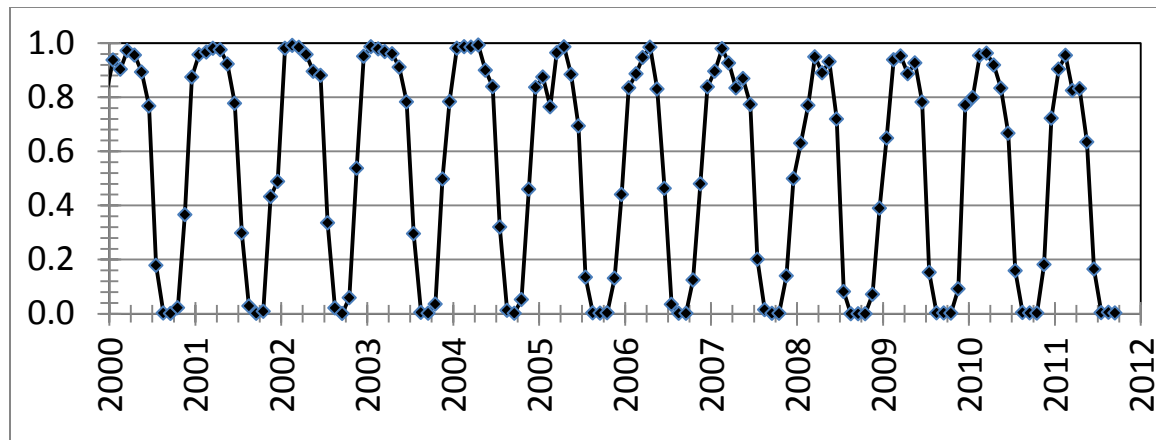


Fig. 5. Time series of the mean ice concentration in the Kara Sea.

## 2.6 Creating time series of anomalies with *wam\_anomaly*

As you can see in Fig. 5, the annual cycle in ice concentration is the completely dominates the time series. By calculating the anomalies we remove the mean annual cycle to see the interannual anomalies. You can issue the following commands:

```
cd C:\Sat\Ice\  
wam_anomaly nasateam_final_N_mo\*.hdf 12
```

This calculates monthly (argument 12) means and anomalies relative to the monthly means. Now create directories for the means and anomalies and move the means and anomalies to the respective directories.

```
mkdir anomaly  
move *anomaly.* anomaly  
mkdir means  
move *Means.hdf means  
move *Validcounts.hdf means
```

You can view individual monthly anomalies: red means higher than normal and blue means lower than normal ice concentration. The monthly anomalies have been calculated by subtracting the monthly mean ice concentration for each pixel from the actual monthly ice concentration. You can build time series of the anomalies with *wam\_statist* (see previous section). We need a list of images that are included in the time series. We create it with the following command:

```
dir /b /s C:\Sat\Ice\anomaly\*.hdf > list_anomaly_mo.txt
```

Note that you must delete all directories and other file names from that list! Open the list file (e.g. by double-clicking on it) in *Notepad* or any other editor and delete the names of any directories or other file names.

We can use the same sample mask image *mask\_novzem1.hdf* and modify the settings of *wam\_statist* to use *list\_anomaly\_mo.txt*, to save the output to *C:\Sat\Ice\nasateam\_mo\_anomaly\_novzem1.csv* and log to *C:\Sat\Ice\nasateam\_mo\_anomaly\_novzem1.txt*.

After running *wam\_statist* with log file *C:\Sat\Ice\nasateam\_mo\_novzem1.txt* you will create output file *C:\Sat\Ice\nasateam\_mo\_novzem1.csv*. Load it into *Excel* and create plots like Fig. 6.

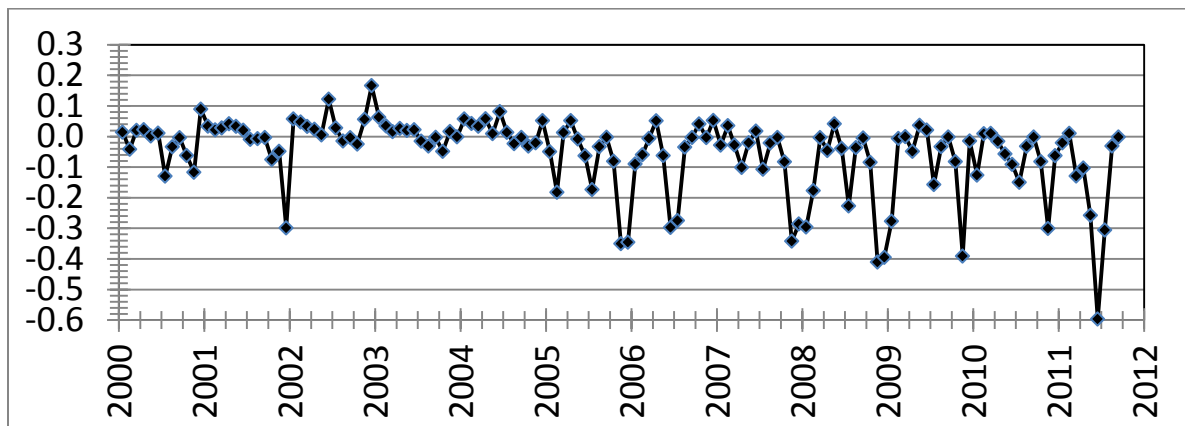


Fig. 6. Time series of the ice concentration monthly anomalies in the Kara Sea.

You can see that June, 2011 had an extremely low ice concentration (anomaly of -0.6) but ice concentration recovered in August-September. We should keep in mind that the 2009-2011 data are based on the less reliable near-real-term and not on the final data.

## 2.7 Detecting Change between two Images

You can use a simple command *wam\_change* to detect change between 2 images. The syntax is:

Usage: *wam\_change* File1 File2 [AnnotateX AnnotateY LUT]

AnnotateX and AnnotateY are, respectively, X and Y in pixels where to put the

Date annotation

The default LUT is *anomaly5.lut*

For example, to show the differences in ice distribution from June, 2000 to June, 2011 you can use the following command:

```
cd C:\Sat\Ice
```

```
wam_change nasateam_final_N_mo\nt_200006_f13_v01_n.hdf
           nasateam_final_N_mo\nt_201106_f13_nrt_n.hdf
```

(all in one line).

The output is shown in Fig. 7. They show that in most areas ice concentration decreased from June-2000 to June 2011, however, in a few areas like Hudson Bay and off NW Greenland ice concentration was higher in June-2011 compared to June-2000.

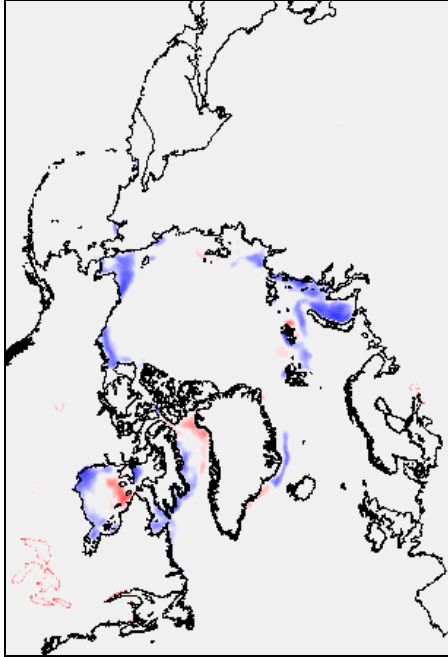


Fig. 7. Changes in ice concentration from June, 2000 to June, 2011.