

Detection of Change in Arctic Sea-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 relatively short in time but provide frequent and large scale **near-instantaneous** 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. For example, it is possible that a sensor's sensitivity deteriorates slowly over time. This would create a fake trend of a decreasing variable, e.g. ice concentration, over time. 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. These instruments measure microwave radiation emitted at different wavelengths. Ice and water surface emit differently at different frequencies that allows their detection. Because clouds are transparent

in the microwave spectral bands, ice detection using microwaves can be done through clouds. The NASA team algorithm uses the difference between two microwave channels and divides by their sum. Corrections are made to compensate or reduce errors caused by variations in surface roughness, waves, sea ice types, the presence of snow, variations in salt and moisture content, the presence of melt ponds, variations in surface temperature, etc. The data are provided on a grid in the polar stereographic projection with cell size of approximately 25 x 25 km. 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 NSIDC. There are currently 2 versions of the data: *final-gsfc* and *near-real-time*. The *preliminary* data of the past are currently no longer produced. The preferred data are under *final-gsfc* but it currently has only the time period from October-1978 to end of 2010. Northern and Southern hemispheres are in separate directories. There are *daily* and *monthly* sections under both *north* and *south* sections. For example, the monthly final *nasateam* data of the *north* can be downloaded from ftp://sidacs.colorado.edu/pub/DATASETS/nsidc0051_gsfc_nasateam_seaice/final-gsfc/north/monthly/. You may notice that for 2007 there are separate monthly files from separate instruments: f13 and f17.



Recent data are under near-real-time (NRT). The daily NRT data of the Northern hemisphere are at ftp://sidacs.colorado.edu/pub/DATASETS/nsidc0081_nrt_nasateam_seaice/north/. 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 yourself from the *near-real-time* (2011-2012). 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* monthly binary data to HDF format. We also converted the daily *near-real-time* data of 2011 and 2012 into daily HDF files and composited those daily HDF files into monthly mean ice concentration composites similar to the standard NSIDC monthly files. In this exercise you can practice how to convert the daily binary files of the most recent year (2012) to HDF. Practicing this and then compositing daily data into monthly composites will prepare you for independent downloading the most recent daily binary data and creating an updated monthly dataset for your use in the future.

2.1 Introduction to sea ice data in 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 *Windows Explorer* (e.g. by clicking on *My Computer*) and navigate to the folder with monthly ice data, e.g. to C:\Sat\Ice\nasateam_nrt_N_month.

Familiarize yourself with the directory structure and open some sample HDF files by clicking (or double-clicking) on any of the files. 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 are using a different color look-up table (LUT) and must uncheck the check-box in *Settings-Misc-Override LUT in HDF* (see right panel of Fig. 1).

You can examine the data in several ways. For example, to look up pixel values hold down the right button of your mouse and move the mouse on the image. In the top part of the image window frame you will see values in the format X;Y (Lon; Lat)=PV (SV) where X and Y are image coordinates (X = distance in pixels from the leftmost column, Y = distance in pixels from the top row), Lon and Lat are the corresponding longitude and latitude (note the order!), the pixel

value (PV) and the scaled value (PV in geophysical units). For example, pixel value 188 corresponds to ice fraction (geophysical variable) of 0.752. If you click at the Current Settings (the Hammer icon on the Toolbar), you can see that *Value Scaling* is *Linear* with *Slope* = 0.004 and *Intercept* = 0 which confirms that $188 * 0.004 = 0.752$. Note that invalid ice fraction over land (and over the North Pole) has PV=254 and the ice fraction that is above the possible limit of 1.0. You can also check the geo-location of the image by creating a coastline image and then overlaying it on top of the ice fraction image. Use the Map Overlay tool  in the Toolbar or select menu Geo – Get Map Overlay. Then pick a map file with global coastlines, e.g. *coast_inter.b*. When you do it for the first time you have to locate the map files folder (e.g. *C:\Program Files\WimSoft\Maps* or *C:\Program Files (x86)\WimSoft\Maps*). When creating a coastlines overlay use background pixel value 0 and the foreground pixel value is either 255 (for white) or 1 (for black). To overlay coastlines or other features on the background image, then on the Overlay icon  on the toolbar (or Multi –Overlay Image in the menu).

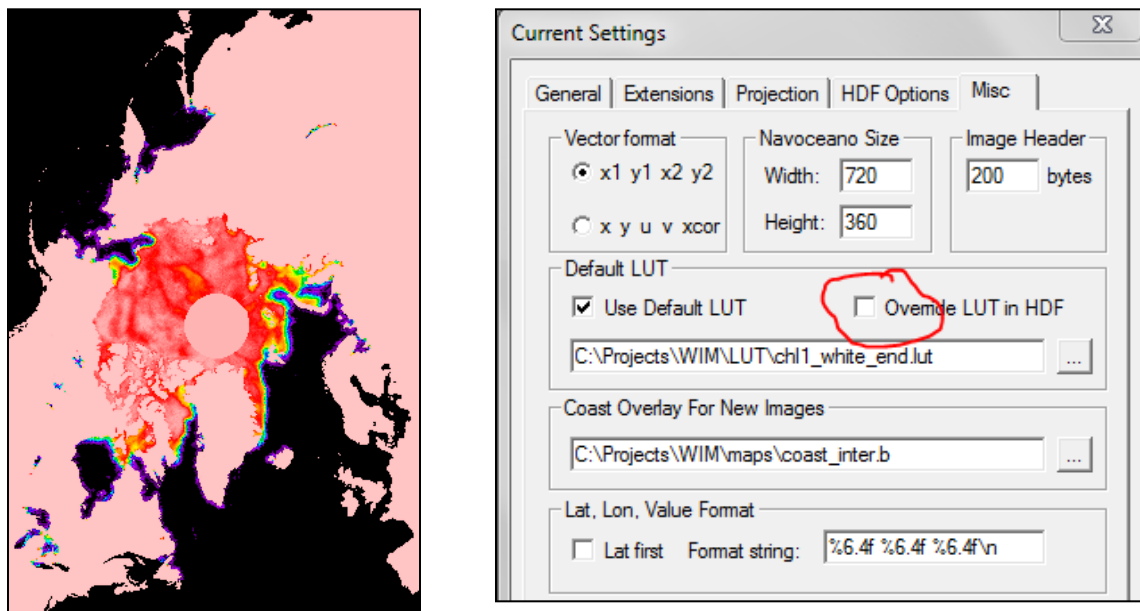



Fig. 1. Sample ice image (left) and the option to uncheck option to override LUT in WIM Settings-Misc-Override LUT in HDF.

2.2 Compositing daily sea ice data to monthly means

As the latest *final-gsfc* monthly data are not available to download from NSIDC, we have to create these ourselves. **If you have limited time and no interest for this kind of data processing, you can skip this section!** The monthly data of 2011 and 2012 are already composited from daily data and copied to folder *\Sat\Ice\nasateam_final_N_mo*.

We assume that you have the daily ice fraction HDF files of 2012 in folder *C:\Sat\Ice\nasateam_nrt_N_day\2012*. To make monthly composites from daily HDF files we can use the command line program *wam_composite_month*, e.g.

```
cd C:\Sat\Ice\nasateam_nrt_N_day
wam_composite_month 2012\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 “2012031” in filename *nt_201201n2012031_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 2012 files in order to keep a consistent naming convention. We can use a batch file *rename2012.bat* to rename the 2012 files easily.

Notice that for year 2012 we only have monthly data from January to September and that the month of September is incomplete. **Check what is the last day used in the September, 2012 image *nt_201209_f17_nrt_n.hdf* using the attributes!** After renaming the 2012 files, move the newly created and renamed 2012 monthly composites to the folder where you have the full monthly time series, e.g. *C:\Sat\Ice\nasateam_final_N_mo*.

```
rename2012
move nt_2012*_f17_nrt_n.hdf C:\Sat\Ice\nasateam_final_N_mo
```

If you have time and interest, you can download and convert the latest binary data beyond the data that are on the DVD. For example the near-real time northern hemisphere daily ice data are at [ftp://sidacs.colorado.edu/pub/DATASETS/nsidc0081_nrt_nasateam_seaice/north/](http://sidacs.colorado.edu/pub/DATASETS/nsidc0081_nrt_nasateam_seaice/north/). See Appendix 1 for details.

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 must be 34 individual July files there (from 1979 to 2012). 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 1979-2012. If you deleted the 1979 image from WIM memory then the time series is for 1980 to 2012, i.e. 33 years. If you point to the Kara Sea, you will see something like Fig. 2. Move around your mouse pointer and try to find interesting

trends or other types of change in ice concentration over the last 32-33 years. After you are done, move the July files back from the July folder.

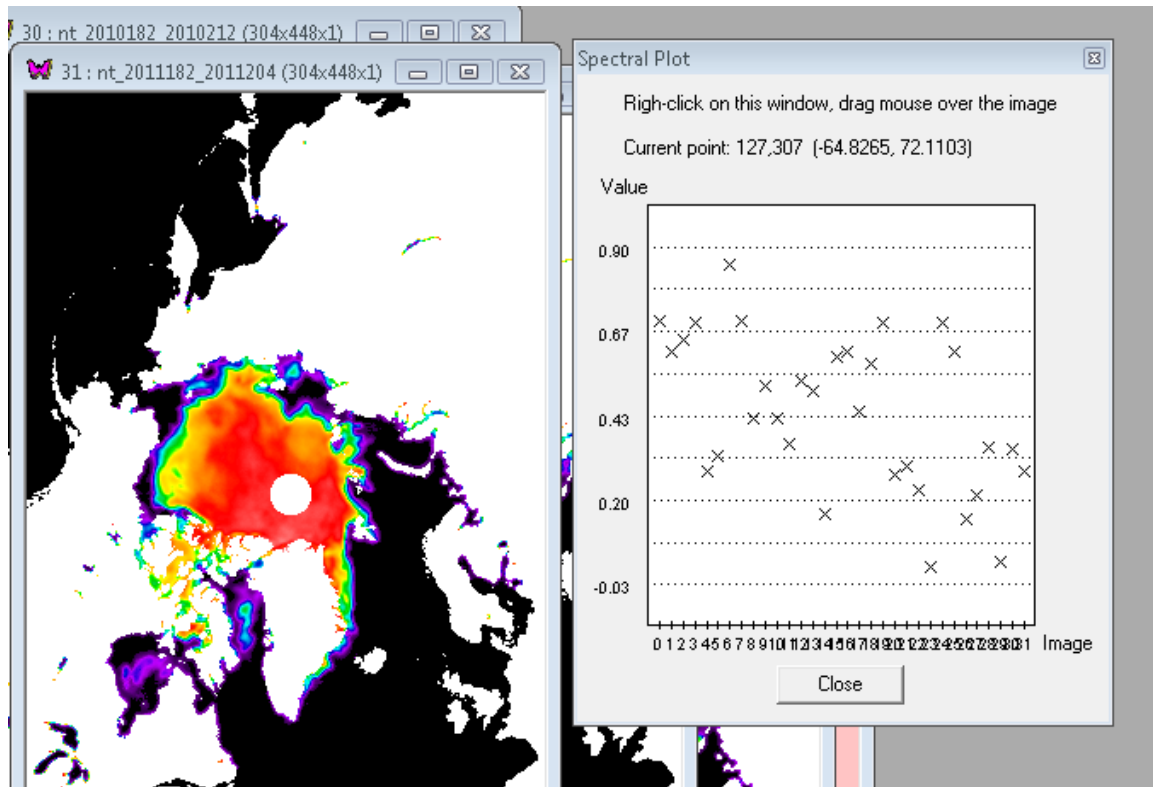


Fig. 2. Using the *Examine-Spectral Plot* in WIM to show interannual variations in July ice concentration in the Kara Sea (right plot) of the Arctic Ocean.

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 much less obvious in other areas. Make similar analysis of changes in another month, i.e. make a folder for that month, move the corresponding files to that folder and look interactively at time series.

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 empty 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_????03*.hdf Sen 95
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). Don't worry that output for the 2011 and 2012 images looks different from the others as these were created by us and we renamed the file names but not the image names. Note that *blue* areas show significant decreasing trend, *red* areas show 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_---03__trend_sen_95.hdf nt_1979-2012_mar_trend_sen_95.hdf
rename nt_---05__trend_sen_95.hdf nt_1979-2012_may_trend_sen_95.hdf
rename nt_---06__trend_sen_95.hdf nt_1979-2012_jun_trend_sen_95.hdf
rename nt_---07__trend_sen_95.hdf nt_1979-2012_jul_trend_sen_95.hdf
```

Open and examine the files in WIM. Stretch the colors to show areas with significant trends more clearly. Note: you have to stretch the colors symmetrically from both ends of the lookup table! Compare and try to explain the differences between months. What could be the reason for the donut-like circle around the North Pole in some trend estimates?

You can create trends for any month, 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 get rid of the donut artifact by masking it with pixel value of 128, i.e. of no trend. It appears that the donut disappears when we exclude the monthly data of 2011 and 2012, i.e. those created by ourselves from the NRT data. Obviously the NRT data have some distortions and need to be corrected before they are considered final.

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.

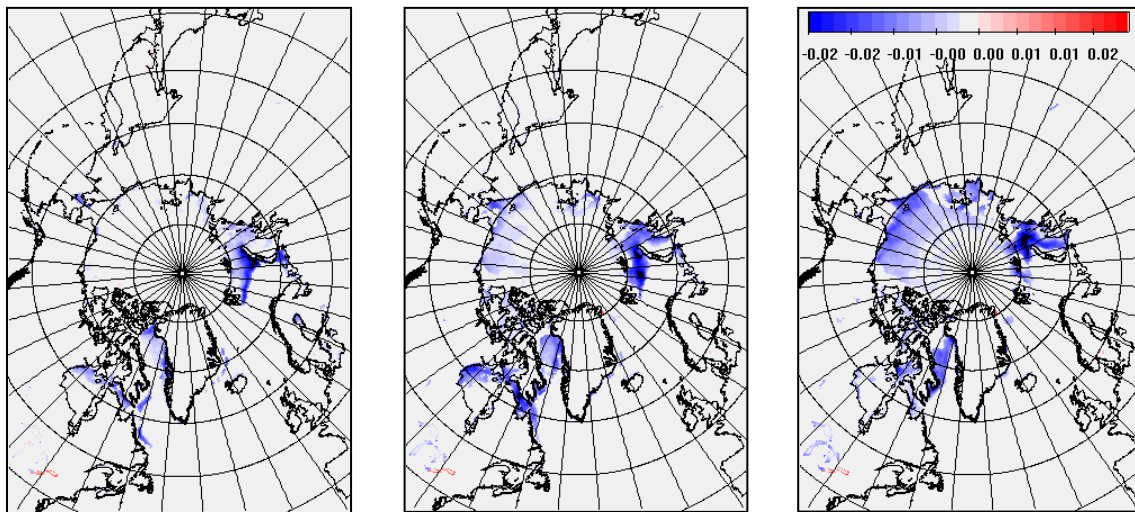



Fig. 3. Trends in ice concentration for May (left), June (middle) and July (right) for 1979-2011.

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 area of interest (mask) in the Kara Sea south of the Novaya Zemlya island.

We need (1) list of images to be used in a text file and (2) a mask image in an HDF file. We create the list of images with the following command (before doing that, make sure that you have moved the July and possibly other files back to the `nasateam_final_N_mo` folder and deleted the empty July folder):

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

This command lists all the files in that folder and dumps them into a text file. 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 can open the text file in *Notepad* and confirm that you have only the monthly HDF filenames in that list. Open the list file (e.g. by double-clicking on it) in *Notepad* or any other editor. You can now delete items from that list, e.g. the July folder if you forgot to delete it!

We have provided a sample mask image *mask_novzem1.hdf*. You can create your own mask file and use it but for the test let's use *mask_novzem1.hdf*. The settings of *wam_statist* are saved in a log file and you can load all the setting from *nasateam_mo_novzem1.txt* for our test run. A screenshot for *wam_statist* is given in Fig. 4. Note the button “Get Log” near the bottom. After running *wam_statist* with settings from log file `C:\Sat\Ice\nasateam_mo_novzem1.txt` you create output file `C:\Sat\Ice\nasateam_mo_novzem1.csv`. Load it into *Excel* and create plots like Fig. 5.

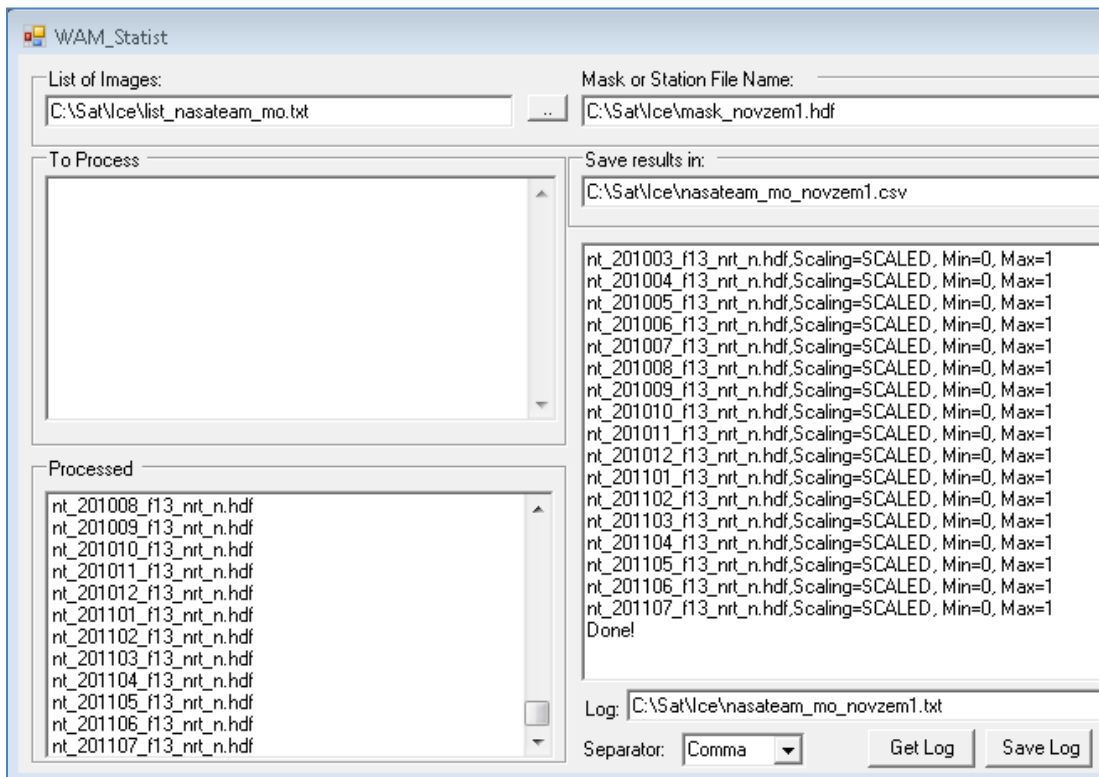


Fig. 4. Screenshot of *wam_statist* creating a time series.

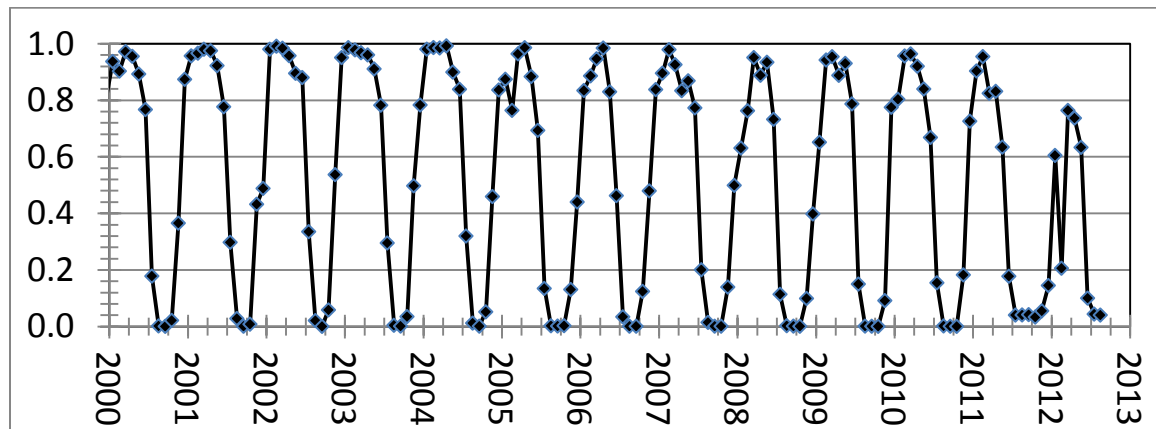


Fig. 5. Time series of the mean ice concentration in the Kara Sea.

Note that on Fig. 5 we have only plotted data since 2000 and not the full time series since 1978. Note the gradual decrease in the maximum ice fraction from 2008 and a sharp drop in 2012. Of course, we need to be cautious in interpreting these changes as the 2011 and 2012 data are based on preliminary NRT datasets and will be revised in the future.

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 dominates the time series. In order to see how each point compares to the mean annual cycle we can calculate anomalies relative to the mean annual cycle. Command `wam_anomaly` first calculates the mean annual cycle and then the anomalies. You can issue the following commands:

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

This calculates monthly means (due to argument 12) and then 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 fraction for each pixel from the actual monthly ice fraction. 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
```

Open the list file (e.g. by double-clicking on it) in *Notepad* and check that you have only the **anomaly.hdf* file in the list.

Now use *wam_statist* to create a time series using anomalies. We can use the same sample mask image *mask_novzem1.hdf* but a different list of images (e.g. *list_anomaly_mo.txt*). We 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*. It is important to change the name of the log file before clicking on “Save Log”.

After running *wam_statist* with *list_anomaly_mo.txt*, load the output file *nasateam_mo_anomaly_novzem1.csv* into *Excel* and create plots like Fig. 6.

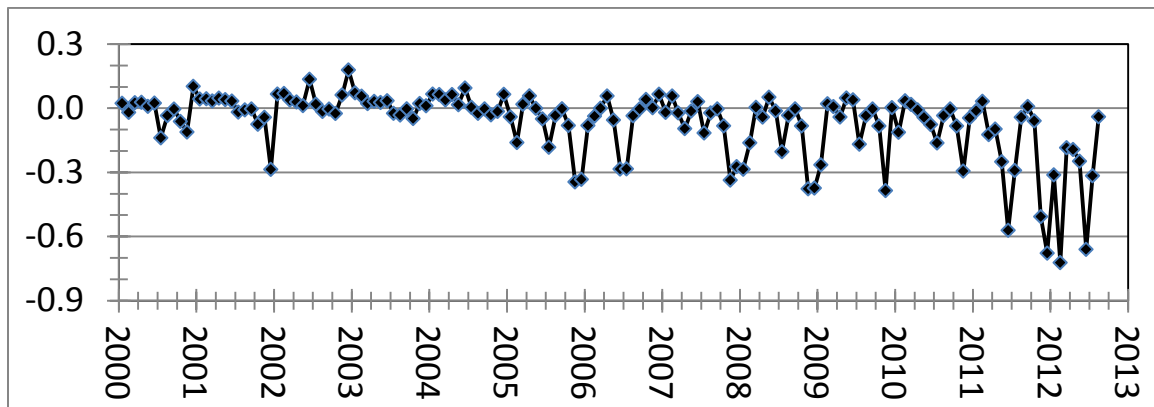


Fig. 6. Time series of the ice concentration monthly anomalies in the Kara Sea.

If you look at the full time series you can see several anomalously low values that seem like outliers but a whole cluster of very low values in 2011 and 2012. Again, we should keep in mind that the 2011-2012 data are based on the less reliable near-real-time 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 and then from June, 2011 to June, 2012 you can use the following commands:

```
cd C:\Sat\Ice
wam_change nasateam_final_N_mo\nt_200006_f13_v01_n.hdf
nasateam_final_N_mo\nt_201106_f17_nrt_n.hdf
```

(all in one line)

```
wam_change nasateam_final_N_mo\nt_201008_f17_v01_n.hdf
nasateam_final_N_mo\nt_201208_f17_nrt_n.hdf
```

(all in one line).

The output is shown in Fig. 7. They show that (left panel) 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. The changes from August, 2010 to August, 2012 were also mostly towards decreased ice fraction but the pattern is very different.

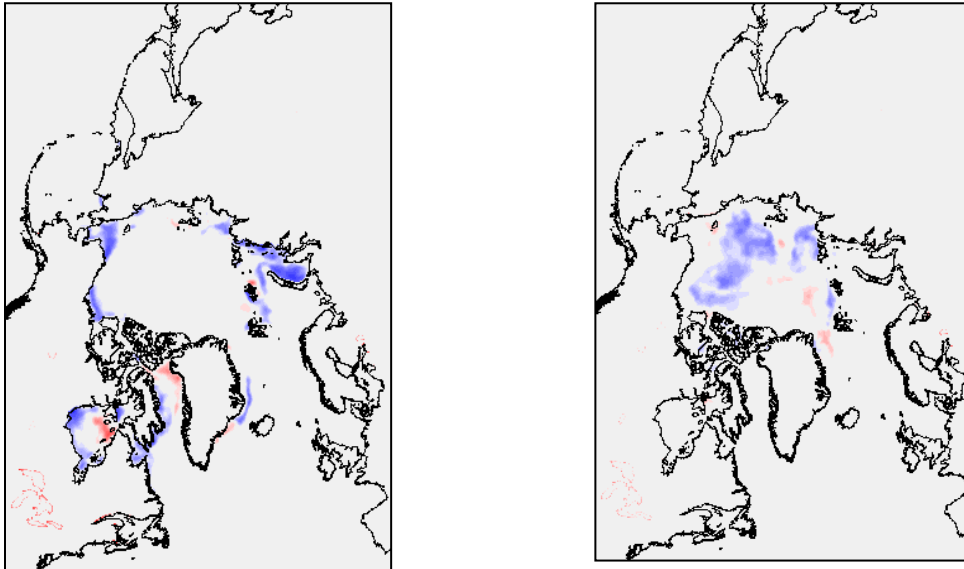


Fig. 7. Changes in ice concentration from Jun-2000 to Jun-2011 (left panel) and Aug-2010 to Aug-2012 (right panel).

3 Appendix 1. Converting binary ice files to HDF

Open the command prompt and *cd* to the directory where you have the downloaded binary ice data, e.g.

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

There is no easy way to read the binary files without using special program in some computer language. Therefore we are converting the binary files to HDF (Hierarchical Data Format) files that can be easily visualized by many software, e.g. WIM.

We will use a command line program *wam_convert_ssmi* to convert the binary data to HDF. We will create a folder for year 2012 one level up, convert all binary year 2012 files in the current folder and move the created HDF to the folder 2012.

```
mkdir ..\2012
wam_convert_ssmi nt_2012*.bin
move nt_2012*.hdf ..\2012
```

You can also use the batch file *runYear.bat* in the same folder that you can need to edit it for years other than 2012. 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.

4 Appendix 2. Making an animated GIF

You can easily make an image loop or animated GIF from the images. You can use the anomaly JPG files but here we use the monthly mean images that we created when we run *wam_anomaly*. We moved the HDF file with the monthly mean images to the *means* folder. First, find the file and rename it to *Means.hdf*., then we will separate (disassemble) the months into individual files which we will use with *Babarosa Gif Animator* to make an animated gif. Below are the commands. You may need to install *Babarosa* from the *Tools* folder of the DVD.

```
cd C:\Sat\Ice\means
rename _ .hdf_Means.hdf Means.hdf
wam_disassemble Means.hdf
```

You can use the anomaly JPG files to make a long animation but these files do not have an annotation that shows the time (month and year). You can read the corresponding anomaly HDF files with *wam_series*, overlay an annotation and save as PNG in the same folder. This requires some time to learn to use *wam_series*.