Practical Exercises with WIM and WAM:

Emphasis on ocean color and SST

April 2024

Contents

1 Purpose and Requirements

The exercises with WIM (=Windows Image Manager) and WAM (=WIM Automation Module) are designed for students who want to gain practical experience in using digital satellite imagery. While all the examples are using the WIM and WAM software, they should be useful for learning how to use satellite data in general.

Instructions for installing WIM and WAM are given in the end of this document.

2 WIM/WAM exercises at a glance

2.1 Exercises with WIM

Exercise Name	Details, requirements
Loading files	*File-Open* dialog is **NOT** the preferred method. Better use Click (or double click) on the file name. Reading multiple images at once. Associate WIM with data files. Samples: *composite.hdf, S2000*.hdf* in *Images\SeaWiFS\baja_2000_april*.
Right-click and left-click	Looking up pixel details (pixel value, scaled value, coordinates). Selecting areas of interest.
Basic operations	*Geo – Get Map Overlay; Multi –Overlay Image; List of Images; Current Settings; Examine-Statistics*, Valid data range; *Examine-Profiles, Examine-Histogram.*
Changing colors	Palettes, LUTs, *View-Set Colors*
Compositing images	*Multi-Composite* with *S2000*.hdf* images in *Images\SeaWiFS\baja_2000_april.*
Bathymetry image and depth contours	*Geo-Bathy Image* with *world_bathy_2min.dat*
Creating 3-component RGB images	SeaWiFS image *sw_l1a_mapped_byte.hdf* in *Images\SeaWiFS*
SeaWiFS Level-3 (SMI) images	All files in *Images\SeaWiFS\L3*
Calculating primary production from a set of 3 images (CHL, PAR, SST)	Use *Multi-Primary production* with *S20060322006059.L3m_MO_CHL_chlor_a_9km* and *S20060322006059.L3m_MO_PAR_par_9km* in *Images\SeaWiFS\L3 \Monthly* and SST image *200002.s04m3pfv50-bsst-16b.hdf* in *Images\SST*

Tracking in situ measurements on images	Using *composite.hdf* in *Images\SeaWiFS\baja_2000_april*, point file *ime9801.csv*. *Vector objects* table. *Geo – Distance*.
Utility for converting between dates and Julian days	julian YYYYMMDD julian YYYY JDAY
Utilities for compressing and uncompressing HDF files	wam_compress_hdf *.hdf wam_uncompress_hdf *.hdf
Remapping and overlaying images	Using SeaWiFS Level 3 chlorophyll with Polar Stereo projection from *Images\SSMI\S3ACOAST.HDF*.
Screen Level-3 images for best quality	Screen SST data by pixel quality *\Images\MODISA\L3\Monthly\ A20060602006090.L3m_MO_SST_4*, use operation *Multi-Mask w. Image*
Edge Detection in Sea-Surface Temperature Images	Find edges (fronts) in SST images using various methods, e.g. *Transf-Gradients-Sobel*, *Edge-Shade Edge*, *Edge-SIED*.
Compare MODIS and SeaWiFS chlorophyll products	Compare the SeaWiFS, MODISA and merged SeaWiFS-MODISA L3 CHL products.
SeaWiFS Level-2 data: “Black waters” of Florida	Red tide detection off Florida: *2001265175156.L2_HUSF.sub.map.hdf* in *Images\SeaWiFS\L2; Transf-Binarize*.
Using MODIS-Aqua Level-2 images	Download from http://oceancolor.gsfc.nasa.gov/cgi/browse.pl?sen=am
Combining RGB images with pseudo-color images	Combine RGB land (as a RGB overlay) with pseudo-color Chl-a or SST images converted from Level-2 data
QuikScat Level-2 products	Examine and composite wind speed data
Opening image files the hard way	Open NGSST raw binary file, manually set size, header, value scaling, projection and geo-location coefficients.

2.2 Exercises with WAM GUI applications

Exercise Name	**Details, requirements**
wam_series	Allows the user to selectively apply various operations to a series of images. Includes options for input and output formats, sub-area, filtering, overlays, converting, remapping, etc.
wam_match	Finding match-ups between in-situ data and satellite images. Creates a CSV text file with match-up statistics of a DX x DY pixel window corresponding to in situ measurements.
wam_statist	Use a series of masks (areas of interest) and a list of images to create time series of statistics for a series of images.

2.3 Exercises with WAM command-line applications

Exercise Name	Details, requirements
wam_composite	Reads a list of HDF4 or netCDF files, calculates mean composite and a count image from all valid pixels, saves as HDF4. Tries to create attributes so that the start and end periods correspond to the first and last images, respectively.
wam_anomaly	Reads all matching files, calculates monthly means or annual means, creates monthly or annual anomalies.
wam_npp	A batch process for creating primary production images from a set of component files (e.g. CHL, PAR, SST).
wam_statist_sta	Calculates statistics for 3x3 pixel windows of images from a list of images and a list of points (stations).
wam_screen	Batch process to screen images, i.e. excluding low quality pixels
wam_rgb_modis	Batch process to create true-color RGB images from MODIS bands 1, 4, 3, at resolutions 1 km, 500 m and 250 m.
wam_turbidity	Batch process to calculate turbidity images from MODIS bands 1 and 2 at 250 m resolution.
Merging Level-2 Chl-a and SST data	Batch process Level-2 SST and Chl-a data from multiple sensors into merged composites.

3 WIM exercises

The exercises use sample images from the *Images* folder. It is recommended that you copy the *Images* folder from the DVD to your hard disk. The *Images* folder is also available from the Google Drive at

https://drive.google.com/drive/folders/1JuK2xbfTWXm7ns2W8vOJ9PhZlWzwkD_s?usp=sharing

Do **not** copy it into your *Wimsoft* folder (e.g. to *C:\Program Files (x86)\WimSoft* on 64-bit Windows). You can copy *Images* to your root directory (e.g. *C:\Images*) or into another folder with write access. When using command line WAM programs it is important **not** to use **folder names with spaces** like "*Program Files*" or "*My data*". Therefore, when working with real data, it is recommended to use short folder names without spaces, e.g. *C:\Sat*, *C:\Sat\SeaWiFS\L3\Monthly\CHL_9*, i.e. sorted by sensor name, product level, period and variable name (the _9 means 9 km spatial resolution). You can certainly replace *C:* with another drive letter, e.g. *E:*.

3.1 Loading files

- You can load an image with the standard  *File-Open…* dialog in WIM (an icon on the toolbar) but it is much better to find files and navigate between the necessary image files with the *Windows Explorer,* and then load them by clicking (or double-clicking, depending on your Windows setup) on the filename. To be able to do that you need to associate WIM with the particular filename extension. Click (or double-click) on any HDF image file (e.g. *composite.hdf* in *Images\SeaWiFS\baja_2000_april*). Some HDF4 files do not have a *.*hdf* extension. For these files you need to associate that extension with *Wim.exe* and set WIM to open it as HDF. This was the practice with old NASA ocean color data. You should be able to just click (double-click) on a HDF4 file name in Windows Explorer and have WIM open it. Therefore *Wim.exe* (typically in *C:\Program Files (x86)\WimSoft*) must be associated with the particular file type (extension).
- You may have to select "***read as HDF***" for HDF4 type in WIM. If you choose a wrong file type then the file will not be correctly loaded. You can correct your error with *View – Settings - Restore Defaults* – that clears all previously set "*read as*" file types.
- If you load images with the *Open* icon on the toolbar (menu *File – Open…*) you need to pay attention to the type of images that you are trying to read. WIM can read and write many types of images but you have to select the correct ***Files of type*** in the dialog. The next time you are trying to read or write an image the type used last time is already selected as default for you. In each folder you will be shown **only** the files with the extension that has been selected to correspond to the selected file type. You must type * or *.* to see all the files. However, **it is better not to use the *File-Open* dialog at all and open files just by clicking or double-clicking on them in Windows Explorer.**
- The only advantage of using the *File – Open…* dialog is that you can read multiple files at once by clicking on the *Open* icon on the toolbar (menu *File – Open…*) and selecting multiple files. For example, you can read all the HDF files from *Images\SeaWiFS\baja_2000_april* in one step.
- Each file can contain multiple images of its own. For example, you can load 3 SeaWiFS Level-1A images from *sw_l1a_mapped_byte.hdf* in folder *Images\SeaWiFS*.
- Folder *Images\OLCI* has a folder with OLCI (on Sentinel-3A) reduced resolution (WRR) imagery and another folder with full resolution (WFR) imagery. Each folder has files in netCDF format. Click (double-click) on the file *chl_oc4me.nc* and associate *.*nc* files with *Wim.exe*. Note that the geo-location information is in a separate file *geo_coordinates.nc* in the same folder and needs to be loaded to get geolocation. Try to locate some known locations on these *CHL_OC4ME* images. Can you find Paracas Bay in Peru? Evaluate the differences between respective WRR and WFR images. A separate tutorial on OLCI data is at https://www.wimsoft.com/Course/2/OLCI_L2_data.pdf
- Folder *Images\SGLI* has a file in HDF5 (*.*h5*) format with SGLI (on GCOM-C) imagery. Click (double-click) on the file name and associate *.*h5* files with *Wim.exe*. Note that the file has many datasets. Select and load *Image_data/CHLA*. A separate tutorial on SGLI data is at https://www.wimsoft.com/Course/2/SGLI_L2_data.pdf

3.2 Right-click and left-click

- 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). If the image has no projection then the corresponding *Lat* and *Lon* are not shown. If the image has no scaling then the corresponding *PV* and *PV* are the same.

- Select an area of interest (e.g. a rectangle) by moving the mouse with the **left button** down. Assuming that you have successfully opened *composite.hdf*, select an area of interest and apply the *Histogram* function using the *Histogram* icon on the toolbar or menu *Examine – Histogram - Show*. Many functions (*Histogram, Statistics, Profiles,* etc.) operate on the selected area of interest (either a rectangle or a line).

3.3 Basic operations

- To create a coastline overlay for an 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*** or *coast_crude.b*. When you do it for the first time you have to locate the map files folder (e.g. *C:\Program Files (x86)\WimSoft\Maps*). WIM memorizes the location and will use it next time). When creating an overlay make sure that the background pixel value is 0 and the foreground pixel value is either 255 (for white) or 1 (for black).
- Create multiple coastline overlays (*Geo-Get Map Overlay*) using different coastline files (*coast_crude.b*, *coast_low.b*, *coast_inter.b*, *coast_high.b*) compare the resolutions, overlay them on the sample image. The recommended coastline file is the 1-km coastlines file *coast_inter.b*.
- To overlay coastlines or other features on an image, click on the image in WIM, then on the *Overlay* icon on the toolbar (or *Multi –Overlay Image* in the menu). Make sure the image number to be overlaid is correct. The current image is assumed when looking up values or performing operations (e.g. *Histogram*, *Statistics*). You can make an image current by either **left clicking** on it or **double clicking** on it in the *List of Images* box. Question to you: When should you use foreground pixel value 255 (white) or 1 (black)? Which one to use for *Images\SeaWiFS\L3* files? Which one to use for images in the *Images\SeaWiFS\baja_2000_april* folder?
- The basic information about an image is shown in the *List of Images* box but more detailed image attributes are shown when clicking on the *Attributes* icon on the toolbar (*View –Attributes* in the menu). Note the "*Processing Version*" attribute in the latest NASA products.
- Scaling and other settings of an image are shown in the in the *Current Settings* box (*Settings* icon on the toolbar or *View – Settings* in the menu). For example, check that the scaling for the *chlor_a* image in file *composite.hdf* is *Logarithmic* with *Slope* = 0.015 and *Intercept* = -2.0 (equivalent to the *Log-Chl* scaling) and the projection is *Linear*. Create an Excel spreadsheet to calculate scaled values from pixel values according to =POWER(10,A2*0.015-2). A2 here is assumed to be the cell with pixel value. What are the scaled values for pixel values 0, 1, 48, 200?
- Get statistics for an area of your choice (select a rectangle with the mouse) by using *Examine-Statistics*, report Min, Max, Mean, St.Dev, Median, N-in-range, N-out-range. Note and select a proper valid data range. Note how the **valid data range** influences the results.
- Select an area of interest by dragging the left mouse button. Draw profiles in the horizontal and vertical direction.
- Select an area of interest, calculate and plot Histogram (*Examine* - *Histogram*). Check out the *Values*, explain what the numbers mean.
- Familiarize yourself with various options of the *Settings* panels (*View* - *Settings*).

3.4 Changing colors

There are 3 ways to change colors in WIM.

- Change colors by linear stretch with - this uses the same palette of 256 colors but stretches them to be between the *Start* and *End* values in *Color Definition* dialog. Pixel values less than *Start* will have the first color (e.g. black) and pixel values larger than *End* will have the last color of the palette (e.g. white or pink, depending on the palette).
- Switch between one of the 3 types of palettes: *Rainbow*, *Grayscale*, *Custom*. The *Grayscale* and *Rainbow* are built in. The *Custom* palette is loaded automatically when WIM starts. It can be loaded manually with *File - Lookup Table - Load LUT*. The default palette can be set in *Settings – Special – Default LUT*. Now, switch between *Rainbow*, *Grayscale*, *Custom* palettes. HDF files can include their own palettes. If a palette is included in the HDF file then WIM can either use that one or use the default palette depending on if you have checked or unchecked *Settings – Special – Override LUT in HDF*.
- Set a suitable default palette (LUT) in *Settings – Special – Default LUT*, e.g. *LUT\chl1_white_end.lut.*

3.5 Compositing images

- Read all the *S2000*.hdf* images in *Images\SeaWiFS\baja_2000_april* at once by clicking on the *Open* icon on the toolbar (menu *File – Open…*) and selecting multiple files. Or read them one by one by clicking (double-clicking) on the filename.
- Create a composite with *Multi-Composite*. Pay attention to the *Valid Range* values. Try different options. The recommended values are 0.015 to 64 using the *Geophysical Values*. Explain the **pixel** and **geophysical values** in the resulting **two** new images.
- Compare your results with the existing composited image file *composite.hdf*. Observe the differences with *Multi - Difference*. The difference image should look mostly black (i.e. 0). However, there are some “dots” in the image. Observe their values with *Right-Click*. It is obvious that there are minor differences with the image in *composite.hdf* but the differences are minor. What could cause the differences? If your course covers also WAM exercises, you can do the same task later using the command line WAM program *wam_composite*.

3.6 Bathymetry image and depth contours

- Read *composite.hdf* or any other image with a projection. The projection is important – without it you cannot create a corresponding bathymetry image. Why? Use *Geo-Bathy Image*, select *world_bathy_5min.dat* (in the *Maps* folder) as the bathymetry data file. Now try the same with the 2-min bathymetry data (*world_bathy_2min.dat*). Observe and explain the differences between them.
- Create depth contours with *Examine - Contour Lines*. Select depth isobaths from 1000 m to 5000 m with a step of 1000 m and pixel value of 255. The depth contours show as white. Overlay the depth contours on the bathymetry image: the contours are not white, why? They are white on *composite.hdf*. Why? How to make them white on the bathymetry image?
- Convert the (2-byte) int16 bathymetry image to byte in *Logarithmic* scaling using *Transf – Convert – BYTE - Logarithmic-Slope = 0.015, Intercept = 0*. Check out the differences between pixel values and scaled (geo-physical) values between the int16 and byte images. What are the differences?
- Overlay the depth contours and possible coastlines on the scaled byte bathymetry image.

3.7 Creating 3-component RGB images

- Read 3 image bands from a sample mapped SeaWiFS Level-1A image *Images\SeaWiFS \sw_l1a_mapped_byte.hdf*.
- Use *Examine – RGB Image* to create a RGB composite of the 3 bands; experiment with various settings.
- To create a natural looking "true color" image use the red band (670 nm) for the *Red*, green band (555 nm) for the *Green* and blue band (412 nm) for the *Blue* component of the RGB composite.
- Try the following combination: *Red* = 100-255, *Green* = 40-255, *Blue* = 44-255. Note that the smaller number must be on the lower scrollbar and the higher number on the higher scrollbar
- You can save as JPEG, PNG, GIF or 24-bit Bitmap (BMP) and compare the colors of the saved file. Bitmaps saved with less than 24-bit color are slightly distorted.
- Please note that the more complex procedures of creating "true-color" RGB images with MODIS L1B data using *wam_rgb_modis* is described in a separate document *Exercises_modis_250m.pdf*.

3.8 SeaWiFS Level-3 (SMI) images

- Global SeaWiFS Level-3 images are usually referred to as Standard Mapped Images (SMI). With the nominal resolution of 9 km at the equator the image size is 4320 x 2160 pixels (4096 x 2048 in older versions). MODIS Aqua and other datasets are also distributed at 4 km nominal resolution with 8192 x 4320 pixels. SMI images are usually composited for daily, 8-day, monthly and annual time periods. Check out all files in *Images\SeaWiFS\L3*. Keep in mind that these files are in HDF4 format (*.hdf*) but in the old OBPG naming convention the extensions were used to show the period and resolution, e.g. **.L3m_MO_CHL_chlor_a_9km* for monthly 9-km Chl data. Since reprocessing of 2014 all OBPG files are in NetCDF4 with the **.nc* extension.
- Check out the attributes with and find the units and the time compositing time period (start year and day, end year and day). What month is that?
- What is the purpose of making composites with over time? Compare the coverage of daily, 8-day, monthly and annual CHL files. Explain the difference. Explain the patterns of missing data in the daily CHL image. Calculate the number of missing pixels for selected daily, 8-day, monthly and annual CHL images in 2000 using the *Histogram* tool ( ). Present these numbers in a table. What do they show? In the earlier version of the files the numbers of missing data pixels were 8,562,051; 6,011,440; 4,583,810; and 3,858,275 for, respectively, the daily, 8-day, monthly and annual CHL images. Find the increase in ocean coverage (i.e. % of ocean pixels with valid CHL values) from daily to annual composites. Tip: subtract the land and coastline pixels that you can get from *land_4320x2160.hdf* in *Images\SeaWiFS\L3*. Create a table (see below) with pixel counts and percentages for the daily, 3-day, monthly and annual images. Explain the changes.

	Number of Missing Pixels	**Number of Valid Pixels**	**Valid % of Total**	**Valid % of Ocean**	**Number of Total Pixels**
Daily					**Land**
8-day					**Coast**
Month					**Land + Coast**

Annual	Total Ocean

- Cut out rectangular subsets in your area of interest, create coastlines for them with *Geo - Get Map Overlay* with *coast_inter.b*. Which pixel value is best to use for coastlines? Why? Use to stretch the colors to best visualize the spatial structure in the ocean.

3.9 Calculating primary production from a set of 3 images (CHL, PAR, SST)

- Load a set of 3 monthly images: SeaWiFS chlorophyll image *S20060322006059.L3m_MO_CHL_chlor_a_9km.hdf* and SeaWiFS PAR image *S20060322006059.L3m_MO_PAR_par_9km.hdf in Images\SeaWiFS\L3\Monthly* and the corresponding AVHRR Pathfinder SST image *200002.s04m3pfv50-bsst-16b.hdf* in *Images\SST*. Note that they all represent monthly data from March, 2000. Confirm that all images represent the same time period. Check the Attributes (*View-Attributes,* icon on toolbar) of the images. Confirm each image's scaling.
- Use *Multi - Primary Production* (with default settings) to create a PP image. Make sure that you have selected the right image numbers for the CHL, PAR and SST images, respectively.
- Realize that the component images have to be of the same size. Use *Geo-Remap Projection* or the corresponding Toolbar icon to remap the SST image to the size of other images.
- Check the Pixel type and the size of the PP image from the *List of Images*, compare the attributes using the *Attributes* icon on the Toolbar. What are the units? Check the Attributes! Note that some of the attributes, e.g. *Units*, belong to the component images, e.g. CHL and not the PP image. The attributes corresponding to the PP image are specified by attribute *Owner PrimProd*. How can we calculate primary production per month?
- You can convert the (2-byte) int16 PP image to byte in *Logarithmic* scaling using *Transf – Convert – BYTE – Logarithmic – Slope = 0.015, Intercept = 0*.
- To calculate PP for many sets of images it is far better to use a WAM command-line program *wam_npp*. The command line program also includes a number of other PP models and their modifications. The command-line program is also far easier to modify, e.g. if you want to add your model of NPP. See the section on *wam_npp* in this document and a separate tutorial *Tutorial_Primary_Productivity.pdf*.

3.10 Tracking in situ measurements on images

- Load the Chl image of the Baja California area *composite.hdf* in *Images\SeaWiFS\baja_2000_april*; then load a sample point file *ime9801.csv* in the same folder with *Geo-Get Vector Objects-Point*. Make sure that you use the following options: *Bitmap Only, Geographic Lon, Lat, Float Lon Lat*. The points are actual stations from a Mexican cruise IMECOCAL 9801. If you don't see any stations on the image then you probably have the wrong setting for the *Longitude-Latitude* sequence. Make sure that in the *Settings* (on the toolbar or *View – Settings* in the menu), under tab *Misc*, you have *Lat, Lon, Value Format* **unchecked** "*Lat first*". The selected point file has columns of *Longitude-Latitude* (in that order) and if "*Lat first*" is checked then the coordinates are read incorrectly.

- Select a point in the *Vector objects* table and see which one is blinking. Select *Statistics* for the selected point. The statistics is calculated for a 3 x 3 pixel window centered at the point. Note ***Nin*** (= number of pixels in valid range) and ***Nout*** (= number of pixels out of valid range) values.
- You can select one, multiple or all the points and save the statistics for all selected points into a text file, e.g. *junk.csv* with the *Save Lat,Lon,Value* button. Note that in order to get correct statistics you need to set a correct valid data range. For Log-Chl scaling the valid data range is 0.011 to 64. Explain this! You can also change the valid data range in *Examine - Statistics*. Now load the saved file into a text editor, e.g. *Notepad*, or MS *Excel* and verify the file format. Note that you need to sect both *Tab* and *Space* as separators in *Excel*. Do not use the *Save* button that saves in an HDF file (it is not an image file that WIM can read). Select all the points in the *Vector objects* table and delete them all. You can also try to load the points from the saved point file *junk.csv* again. You can do that as the basic format of the file (*Longitude*, *Latitude*, *Value*) is the same.
- Familiarize yourself with the various vector object types (*Point*, *Transect*, *Rectangle*, *Drifter Track*, *Vector*), Coordinate (X-Y vs. Lon-Lat), drawing (bitmap vs. image buffer) options and with the *Vector Objects* table;
- Use *Geo- Get Vector Objects – Drifter Track* and select *drifter_track_test.csv* that represents an imaginary drifter track file. Note the start (circle) and end of the drifter track.
- Load more point objects and display with a different symbol (select other than *Standard* when reading the points). You can make the points with pixel value 255 (white) and then load and overlay the same points with a different symbol and different color (e.g. 220, red). This improves the combined symbol's visibility. Load an image from *2nd_ovl.hdf* in the *Program Files\Wimsoft* folder and try to reproduce it!
- Create some sample *Transect* objects with *Geo – Distance – Save – Close*. Save as a **.trk* file. Load the saved **.trk* file using *Geo – Tracking – Transect*. Select individual Transect objects, show their profiles, calculate statistics along the transect.
- For more automated finding of matches between many points and many images you can use the graphical WAM utility *wam_match* (see the exercise on *wam_match*). For automated point statistics use *wam_statist* or *wam_statist_sta*.
- See a separate tutorial on validation of satellite data [*Tutorial_Validation.pdf*](Tutorial_Validation.pdf).

3.11 Utility for converting between dates and Julian days

Many image file names use the day of the year (also called Julian day of the year) instead of the date. A simple command line utility *julian.exe* converts between a date and a Julian day.

Syntax: julian YYYYMMDD => converts date to Julian day

or: julian YYYY JDAY => converts julian day to date

For example:

```
julian 20011123
YYYYMMDD=20011123 => Julian Day=327
```

shows that November 23 of 2001 is Julian Day 327. Try the reverse calculation:

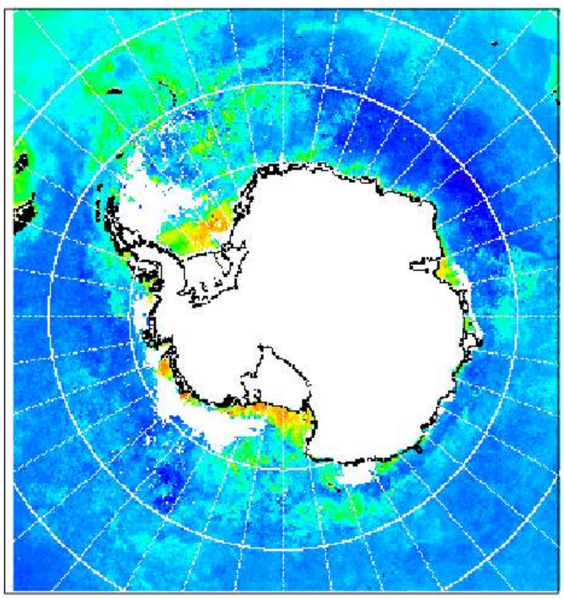
```
julian 2001 327
Julian Day=327 => Year=2001 Month=11 Day=23
```

3.12 Remapping and overlaying images

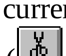
- Load any Level-3 standard mapped image (SMI, e.g. in *Images\SeaWiFS\L3\Monthly*) and another image from *composite.hdf* in *Images\SeaWiFS\baja_2000_april*. Using *Geo-Remap Projection* remap the SMI image to the projection of *composite.hdf*. Then do the opposite and remap the local image in *composite.hdf* to the projection of the SMI image. Try to find it by scrolling the big black image up and down and left to right. Now create a coastline overlay for it with *Geo-Get Map Overlay* with *coast_inter.b*, pixel value 255, overlay it on top of the last remapped image. Find the difference between the outcome when using either *Forward* or the (default) *Inverse* mapping.
- Try to create an image that looks like the following image. Note that the coastlines are black; latitude-longitude grid is white. Try to reproduce it as close as possible.

  Hint 1: Projection is *Polar Stereo (S3A)* of the SSMI products (*Images\SSMI\S3ACOAST.HDF*), the image is a SeaWiFS Level-3 chlorophyll image.

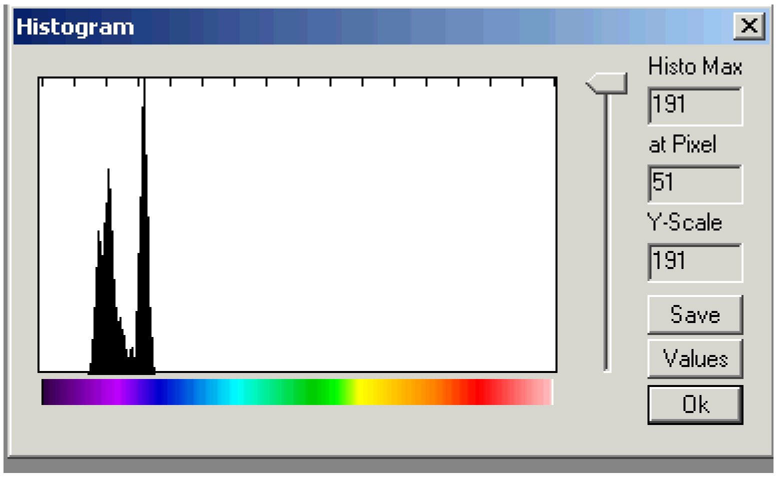
  Hint 2: use an annual composite or a monthly composite from a boreal winter month as during boreal summer (austral winter) there is no Chl data due to ice and low light conditions.

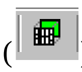


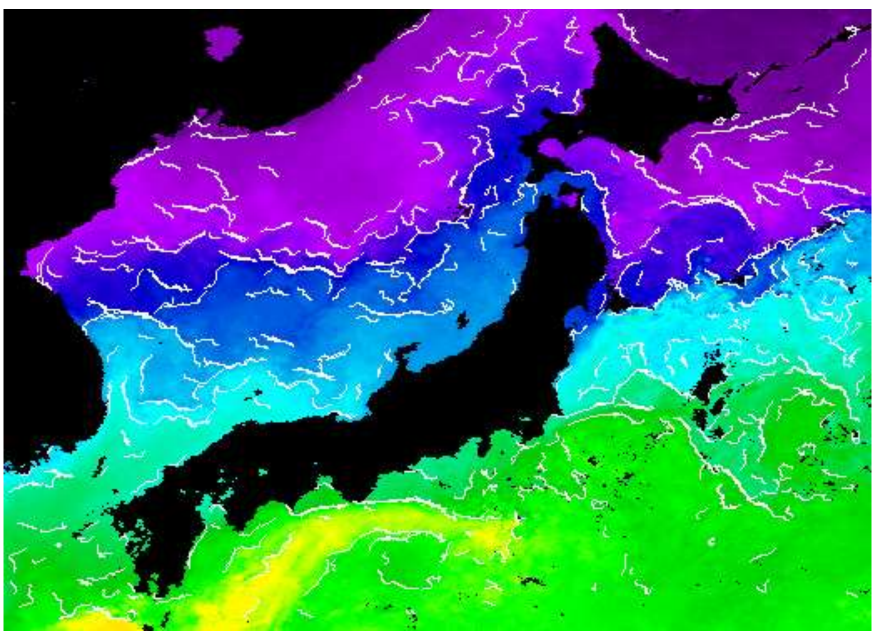
3.13 Edge detection in sea-surface temperature images

- More details on edge (front) detection with WIM and WAM are provided in *Exercises_WAM_Edge_Detection.pdf*. Here we test several edge detection methods with WIM.
- Load a MODIS-Aqua SST 4-km monthly data screened with WIM *A20060602006090.L3m_MO_SST_4_screened.hdf* in *Images\MODISA\L3\Monthly\SST_4*.
- Navigate to area around Japan, or the Gulf of Mexico/Florida, or another area with strong and large-scale SST gradients. The Gulf Stream and Kuroshio currents are well visible in these areas, respectively. Cut out a rectangular area with the Cut () tool. Apply the following edge detection methods:
- *Transf-Gradients-Sobel*

- *Edge-Shade Edge* (select *Min pixel value to use* 1 or higher to eliminate edges with land).
- *Edge-SIED* (try first the variable window and then a fixed window of size, e.g., 20).
- Evaluate the histogram in some well-defined frontal regions by selecting a rectangular area and then applying the *Histogram* tool (). Confirm that the histogram has two or more peaks that define the existence of a front in the SIED method.



- Overlay the detected edges onto the Cut image with the Overlay () tool.



- You can automate edge detection and compositing on many images with *wam_edge* and *wam_edge_accumulate* (see *Exercises_WAM_Edge_Detection.pdf*).

3.14 Compare MODIS and SeaWiFS chlorophyll products

- Several satellite sensors (e.g. SeaWiFS and MODIS-Aqua) can produce similar products, e.g. Chlorophyll-*a*. Also, a number of different algorithms can be used to produce different versions of the same product from the same sensor. In addition, data from different sensors can be merged to produce merged, multi-sensor products. As clouds tend to move in between the different overpass times of different sensors, these merged products have the potential to provide more data in case of variable cloudiness.

- Compare three monthly, 9-km Chl-a composites from February, 2006:
  - *S20060322006059.L3m_MO_CHL_chlor_a_9km.hdf* in *Images\SeaWiFS\L3\Monthly* (SeaWiFS)
  - *A20060322006059.L3m_MO_CHL_chlor_a_9km.hdf* in *Images\MODISA\L3\Monthly\CHL_9* (MODIS-Aqua)
  - Create a composite of the two images with Multi-Composite using valid Range Min=0.011 and Max=64. Delete the *Composite-Count* image.
- Examine the spatial coverage, i.e. the number of missing or bad data. You can calculate pixel distribution with the *Histogram* tool ( ), click on *Value* to see the number of pixels in each histogram class. The merged product has 2 bytes per pixel. Histogram calculation in WIM is implemented for Byte images that can have pixel values from 0 to 255. Convert the 2-byte per pixel product to byte with the Conversion tool ( ) using *Log-Chl* scaling. Calculate the total number of pixels in the highest pixel value class (255 or 253, i.e. the invalid pixel value). Which product has the best coverage, i.e. least number of invalid pixels? Rank the products in terms of coverage. Do you get numbers like those below? Explain the values.

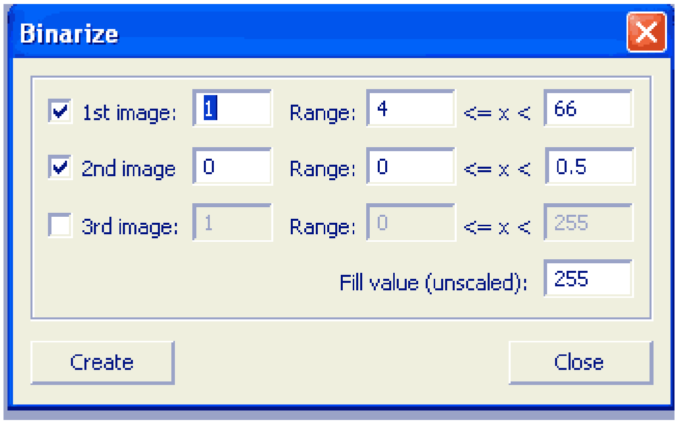
  5,207,151

  4,830,939

  4,593,241
- Calculate the percentage improvement of the merged product compared to the two individual products. Note that this is a monthly product and therefore the improvement in coverage is not dramatic. For 8-day and especially daily products the improvement is much better. Explain why.
- Examine how well the values correspond to each other in different products. Select a sub-area, do *Examine – X-Y Scatter*, experiment with different ranges. Evaluate the differences. Calculate statistics for some sub-area with *Examine-Statistics*. Which is higher, on average?
- Find the differences between images with *Multi-Difference* and *Multi-Subtract Image*. The calculated image is a Float32 image and needs adjustment for better visualization. Make the *Max* value in *Color Scaling* in *Settings* ( ) smaller, e.g. 1.

3.15 SeaWiFS Level-2 data: "Black waters" of Florida

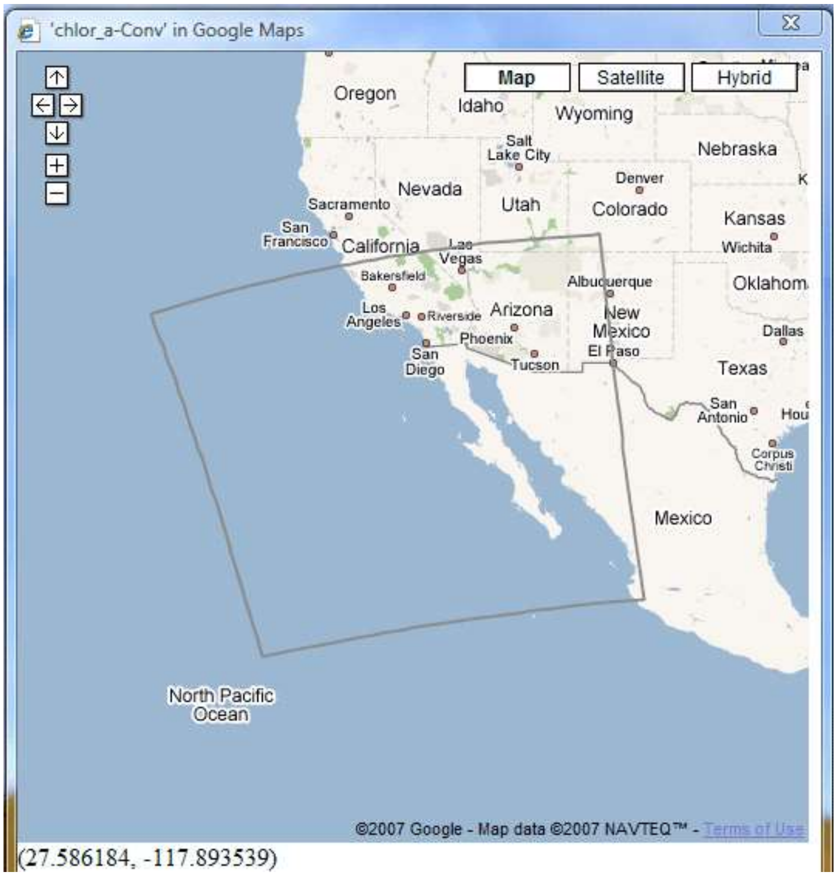
- More details on SeaWiFS Level-2 data are provided in a separate document *Exercises_detecting_habs.pdf*.
- Load SeaWiFS Level-2 data from *S2001265175156.L2_HUSF.sub.map.hdf* of 22-Sep-2001 in *Images\SeaWiFS\L2*, select *nLw_555, chlor_a*. Convert *chlor_a* to Byte with *Transf – Convert –* BYTE - Log-Chl.
- Use *Transf - Binarize* to find areas (pixel) that have LOW reflectance at 555 nm and at the same time HIGH chlor_a. For example, use the following conditions: 0<= nLw_555 < 0.5, 4 <= chlor_a < 66.

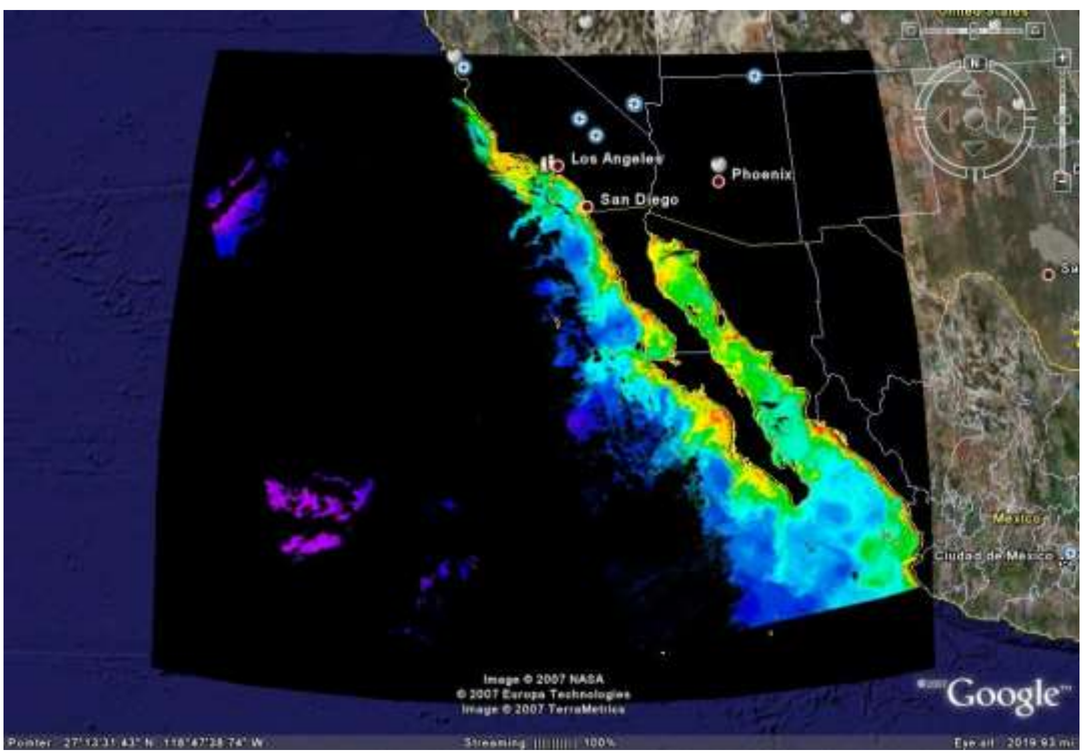


- Create coastlines with *Geo* - *Get Map Overlay* with *coast_inter.b*, coastlines value 1. Why 1? Overlay coastlines on the masked image, explain the distribution.

3.16 Using MODIS-Aqua Level-2 images

- More detailed instructions and examples on working with Level-2 ocean color data are provided in separate documents: *Exercises_Merging_L2_Chl_and_SST.pdf*, *2_Exercises_with_L2_satellite_data.pdf*, *2_Exercises_with_L2_satellite_data_commands.pdf* and *2_Exercises_with_L2_satellite_data_Your_area.pdf*.
- You can select, order and download various Level-2 (i.e. unmapped) ocean color data on the NASA ocean color website https://oceancolor.gsfc.nasa.gov/cgi/browse.pl?sen=am . You need to select the sensor (e.g. MODIS-Aqua), time and space range. You can download a full granule, i.e. 5 minutes of satellite data. As your area of interest may be near the border of the 5 minute granules and you don't need data outside your area of interest, it is better to order a whole set of data files that are **subset** (i.e. cut) for your selected spatial range.
- Download a suitable **Level-2** Ocean Color data file (**.L2_LAC_OC.nc*) by clicking on it. Note: Level-2 data files have file extension like *.L2_LAC_**. Do not download Level-0 or Level-1A data! Level-2 files are internally compressed in the netCDF file format. You can also get sample Aqua L2 data in *Images\MODISA\L2*.
- Load the *chlor_a* dataset from both of the **.L2_LAC* files in the *Images\MODISA\L2* folder. (The easiest way to do that is just to click (double-click) on the file. When you do it the first time you have to select WIM as the application to load the data file.) Resize the windows so that you can see both images at the same time and navigate both to the Gulf of California area. Why is the Gulf of California bigger on one and smaller on the other image? To make images from different passes comparable we have to remap the images to a standard projection. It is also recommended to convert the *chlor_a* images from the float32 format to the scaled byte format by using *Transf-Convert* ((icon on the toolbar) - *Log-Chl* scaling.
- If you have internet connection then you can display the map of the Level-2 swath in *Google – Maps* (, *Geo* - *View in Google Maps*). You can also select a rectangle on the image with the left mouse button and it will show in GM. In order to view the image in *Google Earth* (, *Geo – View in Google Earth*), it has to be in *Linear* projection. You can remap any image to a *Linear* projection, e.g. using *Geo-Remap Projection* with *Create new projection* and *Auto parameter setting*.

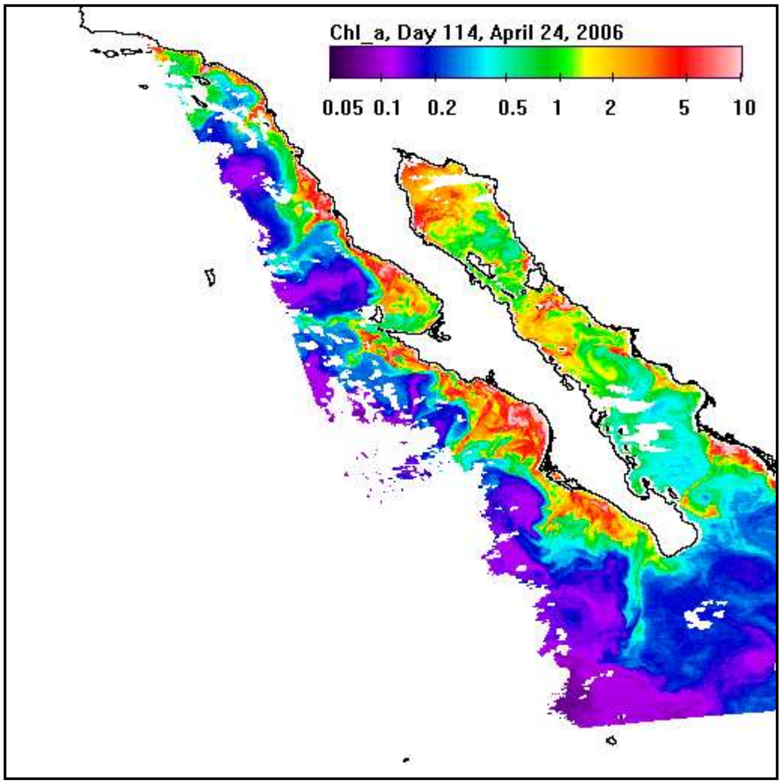

'chlor_a-Conv' in Google Maps
Map
Satellite
Hybrid
Oregon
Idaho
Wyoming
Salt Lake City
Nebraska
Nevada
Denver
Sacramento
Utah
Colorado
Kansas
San Francisco
California
Las Vegas
Wichita
Bakersfield
Albuquerque
Los Angeles
Riverside
Arizona
New Mexico
Dallas
Phoenix
El Paso
San Diego
Tucson
Texas
San Antonio
Corpus Christi
Mexico
North Pacific Ocean
©2007 Google - Map data ©2007 NAVTEQ™ - Terms of Use
(27.586184, -117.893539)


Los Angeles
Phoenix
San Diego
Image © 2007 NASA
© 2007 Europa Technologies
Image © 2007 TerraMetrics
Google

- In order to have a consistent projection of the images we need to remap them to some "standard" projection using *Geo - Remap Projection*. You need to spend some time to find the best target projection for your area of interest. The easiest projection is *Linear*. Check out the target projections (and overlay files at the same time) in *Images\MODISA\L2_processing*. The 512 x 512 pixel images were created using the HDF images in the *Images\SeaWiFS\baja_2000_april* folder. Note that the 512 x 512 pixel images have the pixel size of approximately 2.7 x 3.7 km in the center of the image. Measure the distance across the image with *Geo - Distance*, calculate the average pixel size using the distance and the number of pixels along the picked transect. You can also draw and open a square of size 100 x 100 pixels near the center of the image with *Edit – Draw* and measure the horizontal and vertical distance. The pixel size is now easy to calculate by dividing the distance with 100.
- You can create a new *Linear* projection with *File - New* and selecting the target image latitude-longitude range and pixel size or image size. Consider the pixel size in the target image compared to the pixel size in the source data.
- When you have decided on the target projection and image size you can add some standard features to the target image that you use as an overlay to create a series of annotated mapped images. For example, put coastlines, latitude-longitude grid, may-be some stations (e.g. use small filled red circles to designate stations) and the color scale to the target image. Most of this has been covered in previous exercises. To get the appropriate color scale set the scaling of the target image to *Log-Chl*, scroll the *Start* and *End* of color scaling to your preferred range. For example, to consistently display all the *chlor_a* images with the color range 0.05-10 mg m^{-3} use *Start* and *End* of 48 and 200, respectively. After that select a rectangular area somewhere on the image (where it does not cover the main features of interest) and use *View - Annotate*. You may have to experiment a few times to get what you are satisfied with. Do the same for SST; i.e. make a new overlay image, set the value scaling to SST-Pathfinder, set the *Start* and *End* pixel values to 120 and 255 (corresponding to SST of 15.0 and 35.25, respectively). There is a sample SST overlay file in *Images\MODISA\L2_processing*. Now you can use that target image not only as the standard projection but also as a standard overlay for the remapped images. The process of converting, remapping, annotating and overlaying images can be automated with a WAM program *wam_series* (see below in this document). Even more advanced results can be achieved with a WAM command line program *wam_l2_map*.
- Open the command window and navigate to the *Images\MODISA\L2 folder*. It is better to move the overlay files to a folder one level up (e.g. from *Images\MODISA\L2_processing*). Then type a command

```
wam_l2_map  A2006*.hdf  ..\L2_processing\cal_chl_48_200.hdf  215  17
```

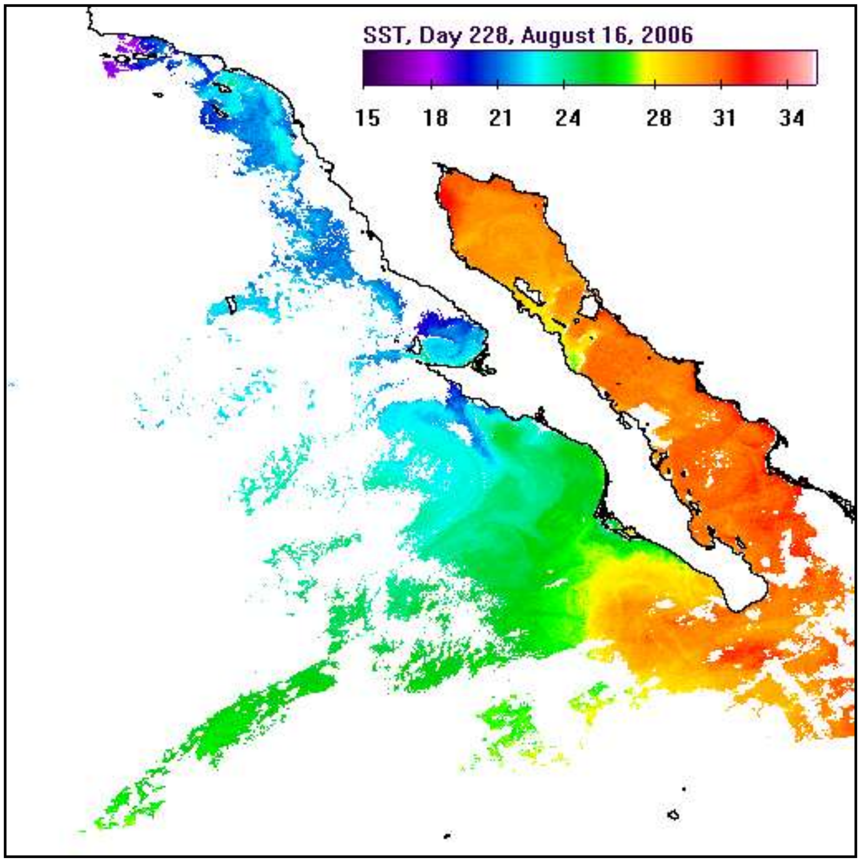
- Here the first argument is a set of matching **.hdf* files, then comes the target projection/overlay file, then the *X* and *Y* coordinates of the annotation. It is assumed here that the target projection file is in directory on level up. In the *Images* folder it is actually in a folder *L2_processing*. More details on this are in the separate documents *Exercises_Merging_L2_Chl_and_SST.pdf*, *2_Exercises_with_L2_satellite_data.pdf*, *2_Exercises_with_L2_satellite_data_commands.pdf* and *2_Exercises_with_L2_satellite_data_Your_area.pdf*.
- If the command finished successfully, you should have 3 chl-a files per matching file: a mapped HDF file, a mapped and annotated HDF file and a PNG file. Sample chl-a PNG file is shown below.



- To produce a quality-checked SST image you have to run the command with the SST files:

  wam_l2_map A2006*LAC_SST.hdf ..*L2_processing*\cal_sst_120_255.hdf 215 17

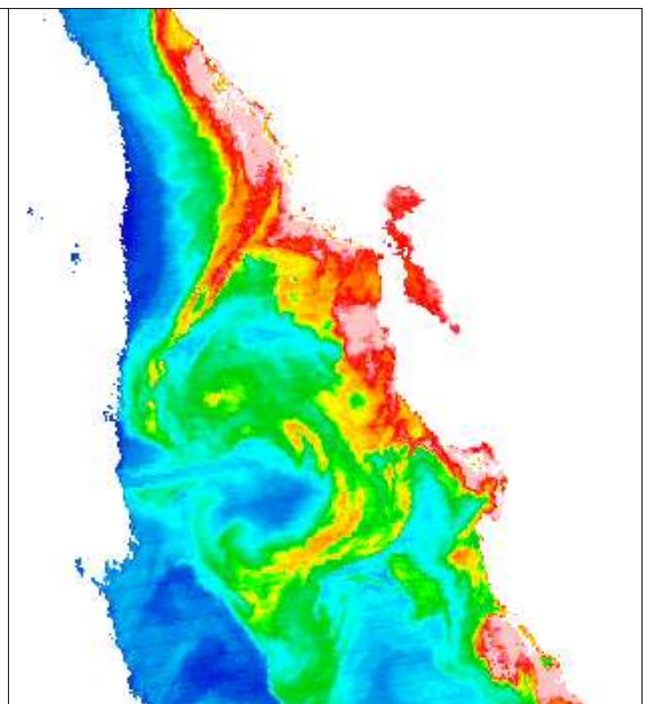
- Do not mix SST files with ocean color (OC) files in the same command! It is better to keep them in separate directories. If the command finished successfully, you should have 3 SST files per matching SST file: a mapped HDF file, a mapped and annotated HDF file and a PNG file. The PNG file is shown below.

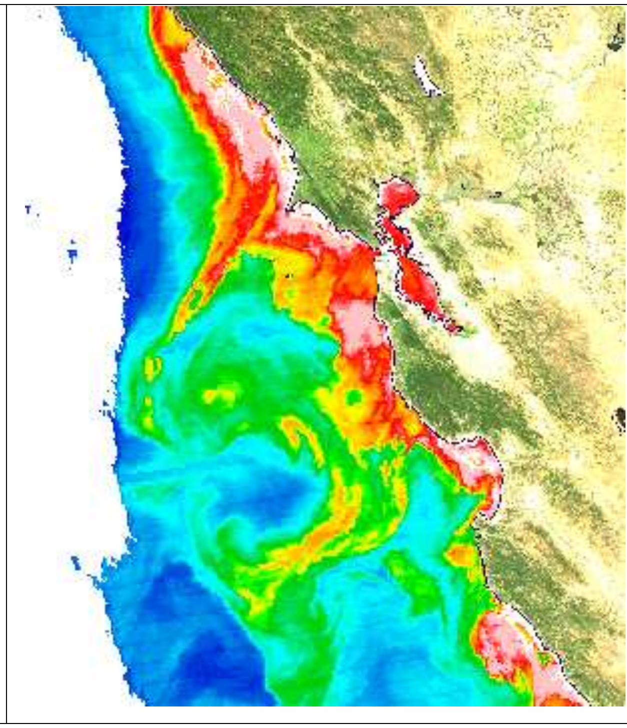


3.17 Combining RGB images with pseudo-color images

- The color images created in the previous exercise are called “pseudo-color” images as the colors are assigned using a rather arbitrary palette or lookup table (LUT). If we have a pseudo-color chlorophyll-a or SST image of the ocean then it is often appealing to cover land and the clouds with “true-color” like colors. In this exercise we will combine Level-2 ocean color images like those used in the previous exercise with a quasi-true-color image created from MODIS Level-1B data (see separate exercises in *Exercises_modis_250m.pdf*).
- Load a sample RGB image from *Images\MODISA\L1B*. This is a Aqua-MODIS RGB image from julian day 123 of 2004, mapped to a 500 m Albers conic projection.
- Load a sample Level-2 *chlor_a* image, e.g. from *A2004123212000.L2_LAC_OC.x.hdf* in *Images\MODISA\L2*, convert to *Log-Chl* scaling with *Transf-Convert*.
- Remap to the 500 m Albers conic projection of the RGB image.
- Stretch the colors to 48-220 (Chl-a concentration of 0.05-20 mg m^{-3}).
- Convert pixel value 0 (black) to 255 (white): first set *Value Scaling* in *Settings* to *Pixel Value*, then use *Transf – Replace Values* from 0-0 to 255).
- Create coastlines with *Geo – Get Map Overlay* with Foreground value of 1 and background value of 0 using coastlines file *coast_full.b*. Fill the ocean area with pixel value 1 using *Edit - Draw – Fill* and Convert to RGB using *Transf – Convert to 24bbp (RGB)* .
- Overlay this on top of the original RGB image using *Multi – Overlay Image*.

- Fill the ocean area with a RGB color of black (0-0-0) using *Edit - Draw – Fill*. Save this last image in HDF format to be used as a standard overlay file (in case you want to use it later for other images). We will call this image a “RGB overlay”.
- Convert the Chl-a (with white missing values) to RGB using *Transf – Convert to 24bbp (RGB)* and overlay the “RGB overlay” on top of it using *Multi – Overlay Image.*
- The coastlines will be “washed out” (not visible) as we used pixel value 255 for the coastlines and there is no ocean color data next to the coastlines (white). Therefore create different coastlines with pixel value 1, and overlay on top of our “RGB overlay” and use the new image with dark coastlines as the “RGB overlay”.
- The final image should have pseudo-color Chl-a data over the ocean, white pixels for clouds and quasi-true color pixels for land. Some of the intermediate and the final images are shown in the table below. Try to reproduce these images yourself!
- You can also add color bar, etc. to your “RGB overlay”. Try to create a similar RGB image for SST by combining the SST data from the same file (in pseudo-color) with true-color land. Use the color bar from *sf_sb_aco_500m_sst_80_120.hdf* in *Images\MODISA\L2_processing*. OOPS: the new OC file format does not include SST, therefore you cannot do that.
- As you see, the process of creating nice-looking RGB images with RGB land and pseudo-color ocean takes a number of steps and quite a bit of time. You can easily automate the process if you want to apply the same RGB overlay on many images. A WAM application *wam_series* can be used for that – see a separate section on *wam_series*. Sample log-files of *wam_series* for processing Level-2 Chl-a and SST data with RGB overlays (*log_chl_15day_RGB.txt* and *log_sst_15day_RGB.txt*) are in *Images\MODISA\L2_processing*. You may need to modify these settings in *wam_series* for your file locations.

3.18 QuikSCAT Level-3 products

- Global ocean wind data can be obtained from the SeaWinds scatterometer (a specialized radar) on the QuikSCAT satellite (see http://podaac.jpl.nasa.gov/).
- Open and examine a sample QuikSCAT file *QS_XWGRD3_2003230.20032311346*.hdf in *Images\QuikSCAT* that has the Level 3-derived multi-algorithm surface wind stress products. The file has many datasets (SDS).
- Load the ascending and descending average wind speed images, *asc_avg_wind_speed* and *des_avg_wind_speed*. Check their HDF attributes, e.g. units. If the image appears upside down, mirror it (*Transf-Mirror*) over the horizontal axis. Explain why we have the separate *Ascending* and *Descending* datasets! Can we have corresponding *Ascending* and *Descending* datasets for Chl-a and other ocean color products? Explain.
- Create a composite (average of valid values from ascending and descending passes) with *Multi-Composite* using reasonable (make your guess!) valid data range. Check out the Count image, do *Examine-Histogram-Values*. Explain the results, i.e. the meaning of the pixel values 0, 1 and 2. The following figure shows a part of the Count image. What do the patterns indicate?

4 WAM exercises with Graphical User Interface

The following exercises are with the WAM programs that use GUI (graphical user interface) in the form of Windows Forms. These programs are powerful utilities that incorporate many functions in a single program. You have more control over the individual components in the command-line WAM utilities (next section). Using WAM programs assumes that you have installed the .NET Framework (see section 6.3).

4.1 wam_series

A common scenario for WIM users is that they want to apply a series of operations to a series of image files. You can do simple operations interactively with WIM but doing many operations on many images is tedious and error prone. For example, you may have a large batch of global (SMI) images and you want to cut out a small sub-area or map it to another projection, overlay coastlines and/or station locations, change the scaling and convert to byte, stretch the color scale, annotate with year and date, and save in a number of different formats (e.g. HDF and JPG). This is where *wam_series* is used.

More information on *wam_series* is in the WAM manual (*WAM.pdf*). Start *wam_series.* You should begin with a few simple functions and proceed to more complex examples. As a start, run *wam_series* with the default settings. If you have copied the *Images* folder (e.g. from the WIM/WAM DVD) to *C:* then you can just click *Start* and check out the resulting JPEG files in the *C:\Temp* folder. The default option is to use the sample SeaWiFS Level-3 images, cut out a subset in the California region, overlay coastlines with pixel value 1, annotate with date, and stretch the colors from 20 to 220 and save the JPEGs of the output in *C:\Temp*. If you have sample files in a different location then you need to modify the *From dir* text box.

You can now start experimenting with *wam_series*. Let's pick the source files from *Images\SeaWiFS\L3\Monthly*. Open any file from there with WIM (by clicking or double-clicking on the filename) and select your area of interest. To be used in an animated GIF the area cannot be very large (images of about 400 x 400 pixels are OK). Note the latitude and longitude ranges. You should now type the latitude and longitude range into *wam_series* to the right of the *Cut subimage* check box. The north latitude goes to the top box, south latitude to the bottom box, west longitude to the left box, east longitude to the right box. Pick a folder where you are going to store the results, e.g. *C:\Sat\out* (create it if it does not exist). For temporary tests you can save the output to *C:\Temp* folder but for more useful results you can create a new folder, e.g. *C:\Sat\out*.

Wam_series has a number of inputs that specify the sources, outputs and operations. All selected options are stored in the registry just before processing starts, so even if you close the *wam_series* application or turn off the PC, the next run of *wam_series* will start with your last options selected.

If you want to save the settings of more than one set of parameters you can save these in separate log files and load these another time. In this way you will have a record of what you did; and you can repeat the same operations or modify them at a later time.

The following are the main options:

"**From dir**" specifies where your source images are. In the test you can use *C:\Images\SeaWiFS\L3\Monthly* but for a more useful exercise get a longer dataset, e.g. all the monthly SeaWiFS chlorophyll datasets *\Sat\SeaWiFS\L3\Monthly\CHL_9* or the merged SeaWiFS/MODISA images. It is convenient to navigate to the folder where your files are with Windows Explorer and copy and paste the folder name in the Address bar into the text box in *wam_series*.

"**File pattern**" is how you pick (match) the files in the input directory. For example, you can use S*CHL*. That would match all SeaWiFS *CHL* files. Be careful not to match too many images as it may take a long time to process!

"**To dir**" is the folder name where your output files will be written, e.g. *C:\Temp* or *C:\Sat\out*.

"**Input type**" as **HDF**, **SDS** as 0. With HDF files containing multiple images (scientific datasets = SDS) you can specify the sequence number of the image in the file. With single image HDF files this should be "0". Note that the numbering starts at 0 and not 1.

"**Save as**" is the output file type, e.g. JPEG or HDF.

"**Cut subimage?**" – check this and select your area of interest by the range: North (top box), South (bottom box), East (right box) and West (left box). Remember to use negative longitude for West longitudes and negative latitude for south latitudes. All values are in decimal degrees, e.g. latitude of 0.5 means 0 degrees and 30.0 minutes north. When *Statistics* is checked, no sub-image is produced and instead, the statistics is calculated. Uncheck all the other check-boxes and click **Start**.

When everything worked out as expected, start experimenting with more options. You can try **Median filter** with the window **size** (typically 3 or 5 pixels) to smooth the output image with a median filter of a specified size. Overlay coastlines by checking "**Coastlines**" with **Overlay Pixel Value** with *C:\Program Files\Wimsoft\Maps\coast_inter.b* and the pixel value of the coastline. Typically, you may want to use 255 (white) for the coastlines to be visible on black background or 1 (purple or black) on white background. Use 1 for the SeaWiFS Level-3 SMI images. Experiment with "**Color stretch**" to find the best "**Start**" and "**End**" values corresponding to the *View-Set Colors* (color definition) type of color stretch operation in WIM.

"**Overlay**" lets you use an overlay file that you have to generate WIM before running *wam_series*. For example, you may want to put a specific latitude, longitude grid with station locations, color bar or anything else on top of the images. Even bathymetry contours may be used in the overlay image. Remember that the overlay needs to be of the same size as the output files and the background (transparent on the overlay image) needs to have pixel value of 0. If you are using the specified overlay file you should not use *Coastlines* overlay.

Create an overlay file using one of your output files saved as HDF as the starting point. When you are done, saved as HDF, then specify that filename in the **Overlay** text box of *wam_series*.

"**Annotate**" with selectable **X** and **Y** values lets you specify where an annotation consisting of the year and start day of the image will be put. X means the distance in pixels from the left and Y means the distance in pixels from the top. If you use a negative values, e.g. "-1" for any of these, the default values corresponding to the top right corner will be used. The date annotation will be correct only if *wam_series* can find date (e.g. the *Start Year* and *Start Day* from the image attributes or name). This works for most common images.

"**Statistics**" with "**Valid Min, Max**" selects to calculate statistics for either the whole image or a sub-area specified by the "*Cut subimage*" values. The resulting output file of statistics for the whole series of images is saved in a text file *statistics.txt* in the current folder. The *Min* and *Max* values are important to get correct statistics. Pixels outside the valid range must be excluded from the statistics calculations. For example, in case of typical chlorophyll-a values the *Min* and *Max* should be 0.015 and 64.0, respectively.

"**Convert to byte?**" lets you convert multi-byte (e.g. Int16 and Float) images to simple scaled byte images that are easier to manipulate and visualize. The selectable scaling options are *Chlor_a, Logarithmic*; *SST-Pathfinder, Linear* and *Logarithmic*.

"**Remap to**" lets you remap the image to projection (and size) of another image. You can also change the mapping options (*Forward*, *Forward* with *Fill gaps* or *Inverse*) in *wam_series*.

One application of *wam_series* is to create sequences of images that can be viewed as an animation (movie loop). You can browse through the images with the *Windows Picture and Fax Viewer* and have the appearance of an animation. Animated GIFs can be created with simple software tools. These GIFs can be viewed by dragging the file to Internet Explorer. You can try the *Babarosa GIF animator* program in the *Tools* folder. Make your own animated GIF, set the time interval (e.g. to 1 second).

4.2 wam_match

The need to understand the relationships between satellite data and ground measurements is fundamental in any application of satellite measurements. The problem is that satellites never measure **exactly** the same variables as ground measurements and need validation. There is no one-to-one relationship between the remote and ground methods. An important source of discrepancy is the huge difference in the measurement footprint. Let's say you have a set of measurements that you want to compare with satellite images. You can just move the mouse pointer and by right-clicking in WIM see the geophysical values at a certain location of longitude and latitude. This can be realistically done if you have only a few points and a single image. However, usually we have a whole time series of images and a set of points. The number of all possible pairs of comparisons gets overwhelming.

The purpose of *wam_match* is to generate coincident datasets between satellite and *in situ* data. You can get more information on *wam_match* in the WAM manual (*WAM.pdf*).

An important restriction is the validity of the satellite data. Invalid or missing data within an image is caused, e.g. by clouds, and is usually flagged or masked with invalid pixel values. There are two ways of separating valid values from invalid values: using a valid range or a separate image of flags.

Valid range with Min and Max is the easiest way of defining valid pixels. The problem is that the valid range may not obvious and may change for different scalings. Also, when doing match-ups with multiple images in the same file (e.g. *chlor_a*, *Rrs_412*, *Rrs_443*, …) the valid range may be different for the individual images. Also, in some cases we may need to have more details in the classification of pixels based on their quality. Use 0.015 and 64 as the typical valid range for Chl-a data.

Using **flags** allows a more detailed characterization of the "quality" of match-ups. For each pixel a set of flags is generated in the Level-2 processing. Each flag indicates if a certain condition has been met. For example, SeaWiFS Level-2 images have 32 flags each of which can be on or off.

Before starting matching satellite images with **your** data you need to gain experience by reproducing the screenshot in the WAM manual.

- First use the default options that are loaded when you first start *wam_match*. These are set to "*C:\Program Files\Wimsoft\list_mapped_C.txt*" as the *List of Images*, and "*C:\Program Files\Wimsoft\match.csv*" as the *List of Point* data (point file). *Use flags* checkbox should be unchecked, use "*Time lag, hr*" of 28, "*Window, DX x DY*" of 3 x 3 and 5 for "*Min Valid Pixels*" (minimum number of valid pixels considered acceptable). Also select Band 0 to be used (the files in the selected list have only 1 SDS). Note that if you are using the Spanish version of Windows and have installed WIM in *C:\Archivos de programa* instead of *C:\Program Files* then you need to pick "*C:\Program Files\Wimsoft\list_mapped_spanish.txt*" as your *List of Images*. This assumes that you have copied the *Images* folder to the *Wimsoft* folder on your hard disk. If your Images folder is not at any of these locations you need to edit the *List of Images* file and provide the true paths to the image files.

- The separator can be selected as *Comma*, *Tab*, *Space*, or *Semicolon* and is used to separate the columns in the output file. Comma is easiest to use in the English (US) culture but not suitable for most European cultures where comma is used as the decimal point. Also, the Date format in the US is MM/DD/YYYY and is typically DD/MM/YYYY in European cultures. If decimal comma is detected in the *Longitude* column then it is also assumed that the date is in the typical European format (you can then use the provided sample file *match_pt.csv*).

- The sample list file expects the image files to be in C*:\Program Files\Wimsoft\ Images\SeaWiFS\baja_2000_april*. If you have the images in a different path then you need to edit the list file or use a different list file.

- After you click *Start* and the program finishes you should get 35 matches. Examine the output log by scrolling it up. Try to understand the output results.

- If any match-ups are found they are put into a *data-grid* and into the graph. You can select variables to be plotted from the point dataset (X-axis) versus variables from the satellite data (Y-axis) as well as the point's "Label" variable using respective up-down controls. The point's "Label" is shown in the "**Point Label**" text box. A "label" is actually any field in the point table (e.g. longitude, latitude, date, time, etc.) and can be selected in the "**Select Point Label**" domain up-down control. When moving the mouse cursor to a particular point you can see the point label in the "Point label" text box. Also, in the data-grid the corresponding row is selected. Vice versa, when a row is selected in the data-grid by selecting it with a mouse click, the corresponding point in the plot will be surrounded by a blue diamond frame. The value that is used to represent **missing values** in both the point and satellite data can be chosen (e.g. 0 or -9).

- You can select outliers for elimination and eliminate them from the plot by double-clicking on the point in the plot. As the plot ranges are picked by the min and max, eliminating outliers will likely create a more focused plot. Save the results as a CSV file. You can also save the plot images as PNG or EMF. The *Save as XML* option is not fully implemented yet. Examine the saved CSV file with MS *Excel*. Observe that the eliminated matches have been moved to a separate section.

You can experiment with *wam_match* by observing the effects of changing some parameters. For example, reduce the *Time lag*; note the changes to the number of matches. Explain. Check up the figure in *WAM.pdf* explaining the *Time lag*.

- If you want to create match-ups for your own data and images, you have to create your own *List* and *Point* files. Note that you need to have the full path name of image files, e.g. *C:\Sat\SeaWiFS\L3\Monthly\CHL_9\ S20062742006304.L3m_MO_CHL_chlor_a_9km* for each image file. The image list is easily generated by a command like this:

  ```
  dir/b /s S*.hdf > list.txt
  ```

  The /s option adds the full path to the filenames.

- In a special case where the geo-referencing data (LLA = longitude-latitude arrays) are in a separate file (e.g. MODIS L1B, GLI Level-2), the list file must have full path to the image file plus a comma and a short name of the geo-referencing file (i.e. without the full path). It is assumed that the geo-referencing file is in the same folder as the data file.

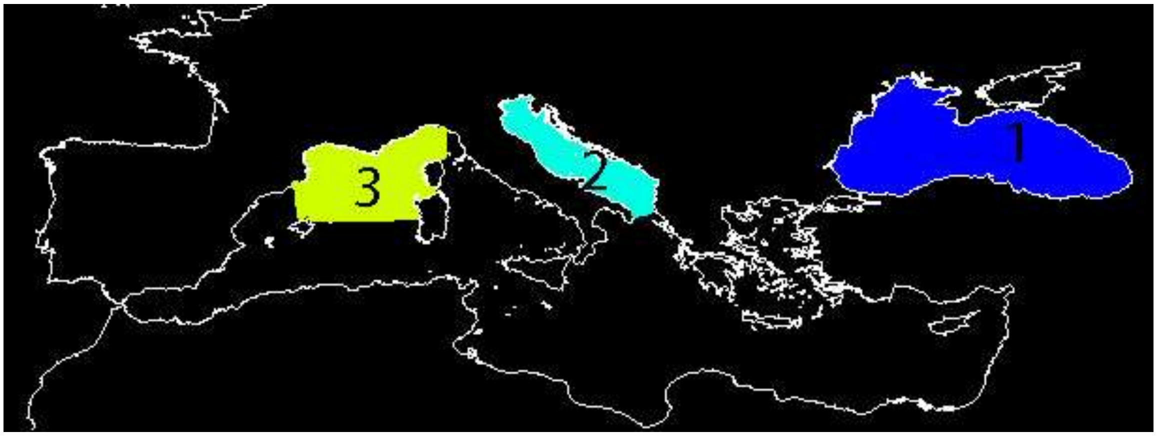
- Create your own "**List of Point data**", i.e. a WIM point file. The point file format has separated (by comma, tab, semicolon or space) columns of *longitude*, *latitude*, *date* and *time* followed by *station* and whatever measurements you have. See the sample file *match.csv*. The point file is best generated in *Excel* worksheet and saved as CSV file. In WIM point files have extension *.*csv* or *.*pnt*. The first line in a point file is a header and is not used for data.

4.3 wam_statist

Wam_statist calculates statistics of selected areas of a series of images. More information is provided in the WAM manual (*WAM.pdf*). *Wam_statist* uses masks of any shape to select areas of interest. You can have up to 255 different areas of interest that you are calculating statistics for. Of course, in a typical case the number of areas of interest is much smaller. *Wam_statist* calculates statistics for each masked area and, in addition, the sum of each pixel's value multiplied by the pixel area. This sum is calculated only for the commonly used *Global Equal Angle* projection where the pixel area is a simple function of latitude. Pixel area of an image in other projections is more complicated and has not been implemented. The standard mapped images (SMI) are in *Global Equal Angle* projection. In order to calculate meaningful statistics the program needs the range of valid values. Note that there are no options to manually specify the valid data range. It is assumed that *wam_statist* can correctly estimate the valid range for the set of images. This works for most common images but may need to be updated at the source code level for new types of images. The *fMin* and *fMax* values that *wam_statist* is using are reported. If these values are not correct for your images, please report to WimSoft with a sample image and we will update *wam_statist*. For example, in the Log-Chl (byte) scaling the valid chlorophyll-a values are between 0.011 and 65. All values outside this range are considered invalid and are not used in the statistics. As an output *wam_statist* saves a text file (CSV file) that can be importing into a spreadsheet program like MS Excel. It reports the following: *Image* (file name), *SYear* (start year), *EYear* (end year), *SDay* (start day), *EDay* (end day), *Mask* (mask number), *Nin* (number of valid pixels in the mask), *Nout* (number of invalid pixels in the mask), *Min, Max, Mean, StDev, Median, Total* (integral over the mask).

Wam_statist uses a mask image to define areas of interest. A mask image defines areas of interest with pixel values from 1 to 255 whereas pixel value 0 specifies an area not to be used. Mask images can be created with a number of different ways, e.g. drawing with the WIM functions *Edit-Draw*, *Transf-Binarize*, filling coastline contours, shifting coastline contours with *Multi-Shift Image* and then overlaying with the original coastlines, etc. Always start with a mask 1, then add mask 2, then add mask 3, etc. If you don't see that the colors of these masks are different then stretch the colors in WIM. Do not use masks like 100, 200 just because their colors look different nice without stretching.

A sample mask image before cleaning looks like this:



The mask numbers (pixel values) are shown only for demonstration here. Please note that the mask image has to be of the same size and projection as the images that are being used and that is easily dane by remapping to the data images. You can create the mask image following coastlines and saving as HDF. Before using the mask in *wam_statist* the the coastlines, grids, etc that have pixel value of 255 (white) need to be removed (converted to pixel value 0). Otherwise those pixels will also be considered as another area of interest and used in calculating statistics (for mask area 255). You can use *Transf - Replace Values - Replace range from* 255 *until* 255 with value 0. Remember that *Value scaling* should be *Pixel value* before running *Transf - Replace Values* (otherwise the scaled values will be used).

You also need a list of images that you are going to use. You can easily create lists of images with a DOS command, e.g. *dir/b /s *.hdf > list.txt*. This command lists all **.hdf* files in the current folder. Each file name must have its full path and the /s option does that for you.

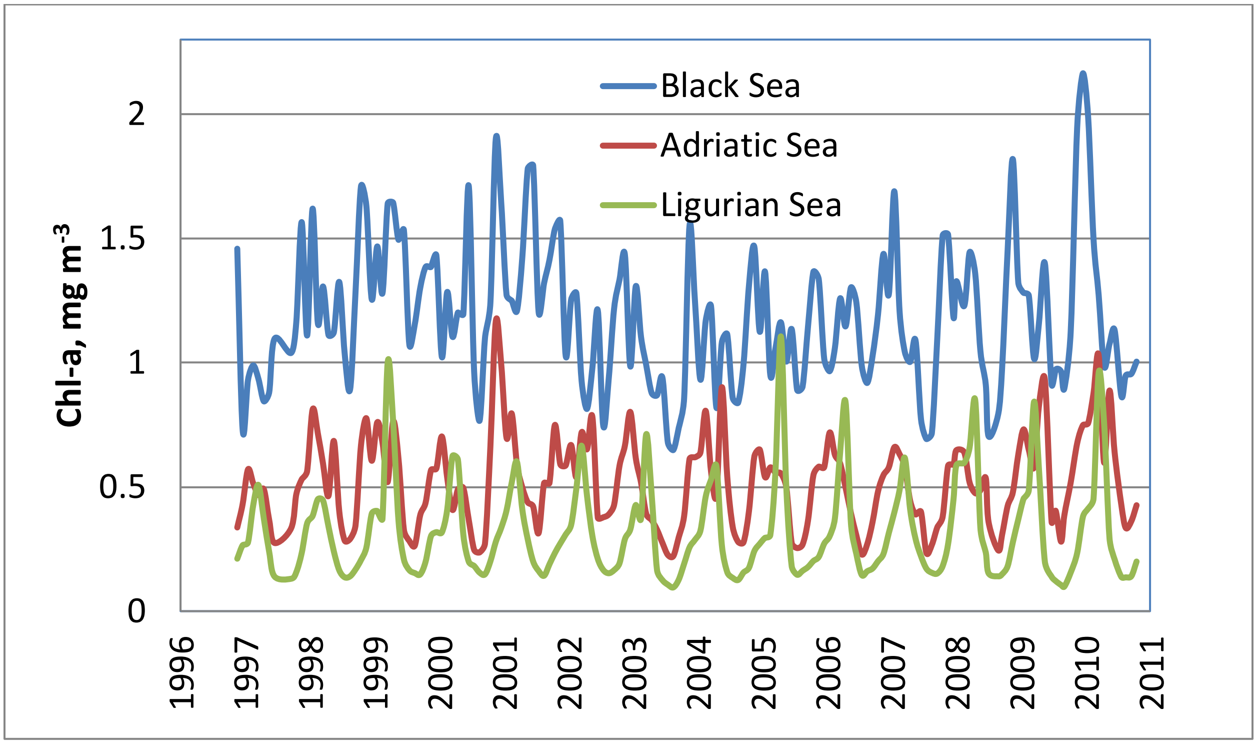
For a meaningful time series we need as many data points as possible. We can combine monthly Chl-a data from 3 sensors: OCTS (1996-1997), SeaWiFS (1997-2002) and merged SeaWIFS-MODISA (2002-2010).

The output from *wam_statist* is a text file where columns are separated by a separator. Comma is the default separator that works fine in the English (US) formatting. In many other cultures comma is used as the decimal point and therefore you should use either the tab or the semicolon as the separator between columns.

The output format is effective to produce but cumbersome when using simple plotting routines, e.g. MS *Excel*. You need to sort the output file by mask numbers in Excel or use a utility *sortmasks*. The syntax is

sortmasks input_file.csv

Sortmasks converts the input file into a sorted file **_sorted.csv*. The sorted file is ready to be imported to a spreadsheet like MS *Excel*. Time series of the mean chlorophyll-a concentration using monthly composites of OCTS, and SeaWiFS-MODIS merged data are shown below.



5 WAM exercises with command-line applications

Command-line programs may be hard to use for a computer novice but they are easy to write and modify and provide powerful functions for the more advanced user. Therefore most WAM applications are command line programs. The source codes of all the examples are included in the *WAM_samples* folder. You can modify the source code and recompile your own WAM programs. The source codes are in the C# language. The command-line C# compiler is part of the .NET Framework and is available for free. Visual Studio is needed for more productive work. When compiling your own WAM programs you can have the source code in any folder but the **executable should be built into the Wimsoft folder** because the various libraries that are needed are in that folder.

5.1 wam_composite

wam_composite is a utility for creating composites from various file types. You may want to make a composite Chl image of a certain 10-day period using available daily images but the official products are daily and 8-day images. Or may-be you want to make composite of all October images from 1997 to 2003. You can make the composites interactively with WIM but it is much more convenient to use *wam_composite*.

The files to be composited are selected either as a matching pattern from file names or from a list of the image files names. The matching pattern is easiest to use, e.g.

wam_composite *.hdf composite.hdf count.hdf

Having a list gives the additional benefit of having a record of the files used in the composite. You can create the list by simply doing dir/b /s on your image files and piping that to a list file, e.g.

dir/b /s S199*CHL* > list.txt

That creates a list file called *list.txt* and dumps all the matching filenames into it. You can skip files from being used in the compositing by preceding the file name with the # character. That allows you to keep the file name in the list in case you want to use it another time. Run *wam_composite* with:

wam_composite list.txt composite.hdf count.hdf

For example, run wam_composite with the sample files in the *\Images\SeaWiFS\baja_2000_april* folder:

cd C:\Images\SeaWiFS\baja_2000_april

wam_composite S*.L2_HMBR.submapped_scaled.hdf composite2.hdf count2.hdf

That creates two HDF files: a composite file and the corresponding count file. Explain the contents of the *count.hdf* image Check out the attributes of the resulting images. Do they make sense?

Please see a separate tutorial for compositing *Tutorial_Compositing.pdf*.

5.2 wam_anomaly

wam_anomaly is a powerful utility for creating mean and anomaly images from a series of images. It is a complex process with many options. Please also see a separate document *Exercises_Anomalies_EOF_PC.pdf* for more details.

1) Locate the SeaWiFS or the *Merged* monthly chlorophyll data on the DVD or your hard disk, e.g. *\Sat\SeaWiFS\L3\Monthly\CHL_9*. The file names have a pattern of *SYYYYDDDYYYYDDD.L3m_MO_CHL_chlor_a_9km* where S designates the sensor (SeaWiFS), YYYY are the start or end year, respectively, *DDD* are the start and end Julian days of the year, respectively. The "_9km" string in the end means the 9-km nominal resolution.

2) Create a work area for this project on the disk, e.g. *C:\sat\Projects\Medit*. We will use Mediterranean as our area of interest but you can use any area of interest. Make a sub-folder CHL for subsets of the standard *chlor_a*.

3) Using *wam_series* extract subsets covering the Mediterranean area and save as HDF. You can also save the JPEGs but that is not essential. The cut area could be, e.g. between latitudes 30 and 50 and longitudes -11 and 42.5.

4) Create a mask image for your subsets. Load any of the HDF cut images and create the coastlines (*Geo-Get Map Overlay* with *coast_full.b*). Fill land with a pixel value of 255 using *Edit-Draw.* Save the resulting image as HDF in your work area (*C:\Sat\Projects\Medit*) as *mask_medit.hdf*.

5) Create monthly means and monthly anomalies with *wam_anomaly*. Open a command window and navigate to your work area (cd *C:\Sat\Projects\Medit*). First create monthly means for each of the 12 months and monthly anomalies relative to the monthly mean. In case of chlorophyll the anomalies are calculated as ratio to the mean. The full scale of the anomalies is from 0.1 to 10 of the ratio, i.e. from 10 times below and 10 times above the mean. Below average values are blue, above average values are red. The intensity of the color shows the intensity of the anomaly (ratio value). In the command window type the following

wam_anomaly CHL.hdf 12 anomaly.lut false mask_medit.hdf no 160 22*

The number 12 here means that we are using the **Monthly** mode (12 months). *anomaly.lut* is the LUT file that we use. *mask_medit.hdf* represents the land mask that will be masked out. ***no*** means that we are not using a precomputed *Means* image but computing Means using the input data. Numbers 160 and 22 mean the location of the annotation (160 = distance from left in pixels, 22 = distance from top in pixels). Check the output. Rename the new files *_.hdf_Means.hdf* and *_.hdf_ValidCounts.hdf* to *Means.hdf* and

ValidCounts.hdf, respectively. Evaluate these files. Now evaluate the many anomaly images. Look at both the HDF and the JPEG files. You can also make an animated GIF from the JPEGs.

6) For clarity, make a new folder and move the anomaly images to the new folder called *CHL_anomalies*. Make another new folder called *CHL_means* (both under your work folder) and move the *Means.hdf* and *ValidCounts.hdf* there.

mkdir CHL_anomaly
*move *anomaly.* CHL_anomaly*
mkdir CHL_means
*move *Means.hdf CHL_means*
*move *ValidCounts.hdf CHL_means*

6) The next task is to study the *interannual* variability, i.e. compare the different years. For that we need to create annual composites that are representative for the year. You can make a composite of all the 12 months of each year or pick a certain season. You can use WIM interactively to make the annual composites but a much better way is to use *wam_composite*. Create annual composites for individual years using *wam_composite*, e.g. for 1997, 1998,…, 2010:

```
wam_composite CHL\?1997*.hdf  chlo1997.hdf   count1997.hdf
wam_composite CHL\?1998*.hdf  chlo1998.hdf   count1998.hdf
wam_composite CHL\?1999*.hdf  chlo1999.hdf   count1999.hdf
wam_composite CHL\?2000*.hdf  chlo2000.hdf   count2000.hdf
wam_composite CHL\?2001*.hdf  chlo2001.hdf   count2001.hdf
wam_composite CHL\?2002*.hdf  chlo2002.hdf   count2002.hdf
wam_composite CHL\?2003*.hdf  chlo2003.hdf   count2003.hdf
wam_composite CHL\?2004*.hdf  chlo2004.hdf   count2004.hdf
wam_composite CHL\?2005*.hdf  chlo2005.hdf   count2005.hdf
wam_composite CHL\?2006*.hdf  chlo2006.hdf   count2006.hdf
wam_composite CHL\?2007*.hdf  chlo2007.hdf   count2007.hdf
wam_composite CHL\?2008*.hdf  chlo2008.hdf   count2008.hdf
wam_composite CHL\?2009*.hdf  chlo2009.hdf   count2009.hdf
wam_composite CHL\?2010*.hdf  chlo2010.hdf   count2010.hdf
```

Move the annual means and counts into a new folder called *CHL_annual*:

```
mkdir CHL_annual
move chlo*.hdf CHL_annual
move count*.hdf CHL_means
```

9) Make interannual anomalies (and interannual mean) by issuing the following command:

```
wam_anomaly  CHL_annual\chlo*.hdf  1  anomaly.lut  false  mask_medit.hdf  no  160  22
```

The *chlo*.hdf* is a pattern that matches the newly generated annual images. The number 1 here means that we are using the *Interannual* mode (there is just one interannual mean that is the overall mean. You will now have new interannual mean called *chlo_.hdf_Means.hdf* and the interannual count image *chlo_.hdf_ValidCounts.hdf*. You can rename them into something more meaningful.Evaluate these files.

5.3 wam_npp

wam_npp is a command line program for creating primary production images in batch mode. Please see a separate tutorial *Tutorial_Primary_Productivity.pdf*. You can see the options by typing the command *wam_npp* without arguments. The main argument is a text file with a list of directory paths for the component files, e.g. Chl, PAR and SST. Examine the sample list file *list_calc_npp.txt* with the following content:

 # path for Chl files, matching pattern
C:\Images\SeaWiFS\baja_2000_april\,S2000.hdf*
 # path for PAR files, matching pattern
*C:\Images\SeaWiFS\L3\Monthly,*PAR**
 # path for SST files, matching pattern

Type *wam_npp* to see all the available options. You can calculate corresponding NPP images using the specified global monthly PAR and SST data. These images will be automatically mapped to the Chl images which will be the *base* images for NPP. Run the following command:

wam_npp list_calc_npp.txt

As you can see, *wam_npp* makes it easy to automate the calculation of primary production and test various NPP models and input data. Try to explain the output text and the output files!

5.4 wam_statist_sta

wam_statist_sta is another image statistics program. Please note it is probably easier to use the GUI program *wam_statist* instead of this command line program. It uses a list of points (stations) given by their longitude, latitude and name, and a list of images, to calculate statistics for 3 x 3 pixel areas centered at the stations for all the images. The syntax is:

wam_statist_sta StationsList Pattern [OutputFile]

where *StationsList* is a text file (CSV file) with longitudes, latitudes and optional date, time, station name (in that order), *Pattern* is matching pattern of HDF file names, *OutputFile* is the name of the output CSV file. The valid *Min* and *Max* values are determined automatically variables and cannot be changed from the command line. You can run a test with the sample file ime9801.csv in the folder *\Images\SeaWiFS\baja_2000_april*. Note that it contains 109 stations.

Run the following commands:

cd \Images\SeaWiFS\baja_2000_april

*wam_statist_sta ime9801.csv \Images\SeaWiFS\L3\Monthly\S2000*CHL*9km OutPut.csv*

Note that there is a single matching image file *S20000612000091.L3m_MO_CHL_chlor_a_9km*. With a single command we extracted statistics for 3 x 3 pixel neighborhoods corresponding to our list of 109 stations. The output file is in the CSV (comma separated values) format and has the following header:

Image,SYear,EYear,SDay,EDay,Station,Nin,Nout,Min,Max,Mean,StDev,Median,Pointvalue,Pixel_1,Pixel_2,Pixel_3,Pixel_4,Pixel_5,Pixel_6,Pixel_7,Pixel_8,Pixel_9

Here *SYear* and *EYear* specify, respectively, the start and end year of the image, *SDay* and *EDay* are the start and end day of the image, *Nin* and *Nout* are the number of pixels within the valid range and outside the valid range, respectively. *Pointvalue* is the pixel value in the nearest pixel that is the center of the 3 x 3 pixel area where statistics is calculated.

Note that the output is sorted first by image and then by station. For easy plotting of time series you need to sort by station. You can use a command *sortstas input_file*. Note that the statistics is extracted for all the matching images. For a related task where we want to extract the matching values from the image nearest in time there is another WAM command *wam_match_nearest* that does exactly that. See Course\4\Tutorial_Validation.pdf for details.

5.5 wam_screen

SST data may have data of various quality levels indicated by the corresponding quality index. It is often necessary to eliminate pixels of lower quality. The quality index may be different for different data formats. Versions of this program operate on SST Pathfinder data (*wam_screen_pf*), old type MODIS data (*wam_screen_modis*), and the new MODIS SST data by the Ocean Color Processing Group (*wam_screen_sst_ocpg*). The quality index is in a separate file for the old MODIS and SST Pathfinder data and in the same file (separate dataset) for the OCPG SST data.

As a result of screening, pixels with the corresponding best quality flag will retain their value while pixels with lower quality flags will be converted to 0. Different options may exist. See the WAM manual (*WAM.pdf*) for more details.

Find some MODIS Level-3 SST files and try the following command:

wam_screen_sst_ocpg S2.L3m_MO_SST_4*

5.6 wam_rgb_modis

See a separate document *Exercises_modis_250m.pdf*.

5.7 wam_turbidity

See a separate document *Exercises_modis_250m.pdf*.

5.8 Merging Level-2 Chl-a and SST data

See a separate document *Exercises_Merging_L2_Chl_and_SST.pdf*.