

Merging Level-2 Chl-a and SST data

1 Introduction

Level-2 datasets such as Chl-a concentration and normalized water-leaving radiances are derived geophysical quantities in sensor view geometries. Due to the Earth's curvature and the viewing geometry the ground projection of each satellite swath is different. In order to make individual swaths comparable to each other they need to be mapped to a common projection. Another important aspect is the need for image compositing. At any one time clouds cover a significant part of the ocean and make the ocean invisible for the ocean color sensor. By using cloud-free pixels from a number of passes it is possible to acquire more-or-less cloud-free images. Some areas are especially cloudy and more difficult for getting visible data. As clouds move around during the day it is possible to use holes in the clouds and composite data from multiple sensors and multiple passes during different times of the day to get maximum coverage. For example, we can composite data from MODIS-Terra with an overpass at 10:30, SeaWiFS at 12:00 noon and MODIS-Aqua at 13:30 to get enhanced coverage.

Global mapped ocean color data that can be downloaded from the NASA Ocean Color website <http://oceancolor.gsfc.nasa.gov/ftp.html> is at lower spatial resolution, at 9 km and 4 km. In order to create full-resolution (1 km) time series you need to download corresponding Level-2 (unmapped) datasets and do your own mapping and compositing. This exercise describes the procedures for creating a full resolution, merged Aqua-Terra-SeaWiFS chlorophyll time series of any area of choice using a suite of WAM programs. The same procedure is used to merge and composite SST data from Aqua and Terra sensors. The derived composites are better than the standard composites available globally as they (1) have higher spatial resolution; (2) provide flexible time of compositing; (3) merge data from multiple sensors of your choice.

2 Prerequisites

We assume that you are familiar with the basics of the command line, i.e. how to open the command window, change directory, issue a command, etc.

We also assume that you have installed WIM and WAM. (see section "Installing WIM and WAM" in Exercises_WIM_WAM.pdf.

3 Ordering and downloading the data

SeaWiFS, MODIS-Aqua and MODIS-Terra Level-2 data can be ordered from the Ocean Color Level-1 and 2 Browser website

<http://oceancolor.gsfc.nasa.gov/cgi/browse.pl?sen=am>. You can select the sensor (for SeaWiFS also the data type - MLAC or GAC), specify the boundaries of your area of interest, select a month or another time period and click on "Find swaths". Then click "Order data", enter your email address, select "Do extract my order for me", select

“Level 2”. Under Level-2 product types you should leave it open to get all product types (you need at least “chlorophyll a” and “Level-2 flags”). For SST you need to select “Level 2 SST (11 μm)”. I always unselect all the remind options (“Remind”, “Require” and “Notify”). After clicking on “Submit” you need to wait for an email and then respond to the email. You will then receive two emails: when processing of your order has started and when the files are ready for downloading.

4 Selecting the standard map projection

Before you start mapping the data you need to pick a suitable target map projection. The easiest projection to create with WIM is the *Linear* projection – you need to decide the latitude and longitude range and either the image size in pixels or the pixel size in meters. Other projections, such as *Albers Conic Equal Area* or *Mercator* projections may be preferable in some cases but are more complex to define. You need to consider the resulting pixel size of your target image. The nominal spatial resolution of ocean color data is typically about 1 km but at the edges of the swath the resolution is lower. During mapping to a target projection there is never going to be a one-to-one mapping of pixels. You can increase the apparent resolution of the target image by selecting a pixel size less than 1 km. A single pixel on a typical computer screen is so small that you may not notice the duplication of pixels. For example, you can increase the apparent resolution to about 500 m if you need a smaller area at higher resolution. Of course, those 500-m pixels will be filled by duplicating neighboring 1-km pixels.

In the following example I will choose a target projection that is a *Albers Conic Equal Area* projection generated with the Terascan (SeaSpace Corp) utility *master2* with the following parameters: `projection=albers min_lat=16 max_lat=45 min_lon=-135 max_lon=-100 corner_edges=yes square_aspect=yes num_samples=3840 est_center=yes`.

This target map covers the west coast of North America and the California Current. In this projection each pixel is 1 km². A *Linear* projection with the same area would have severe distortions and pixel size would be different in different parts of the image. For smaller areas the *Linear* projection is much more acceptable.

Output has remapped and composited data files in HDF, annotated images as both HDF as PNG. The annotated images can also be created afterwards with a program like *wam_series* but it is convenient to create them simultaneously with the data files. It is important that the quick-looks have all the required information like the Lat-Lon grid and the color scale. All the required information should be in an overlay file that is then overlaid on top of the data. The annotated images can be smaller than the data files. In the example below the data images are large (3840 x 3405 pixels) and the quick-looks will be reduced by 8 times. The image below shows the overlay image that was created with WIM. In this case the target overlay image was reduced 8 times, Lat-Lon grid was overlaid, and color scale was added. All these operations are part of the interactive WIM program and will not be covered here. It is important to note that in order to get the right numbers with the color scale you need to set the scaling type of the overlay to that of the resulting image (e.g. *Log-Chl*), stretch the color scaling as needed and only THEN use *View-Annotate* to create the numbers along the color bar. You can let WIM create the numbers for the color scale by using “Auto-Generated” or select the numbers individually

(separated by a comma) by using “Custom”. In the example below the color range was chosen 0.05–10 mg m⁻³ of Chl-a that corresponds to a range of 48–200 in pixel values. In the example below the land areas were filled with pixel value 255. The coastlines and the Lat-Lon grid were created with a pixel value of 1 (that makes them black). Please note that if you stretch the colors of this overlay between 48 and 200, the gridlines and labels will not be visible on the black. Don’t worry, they become visible in the quick-looks!

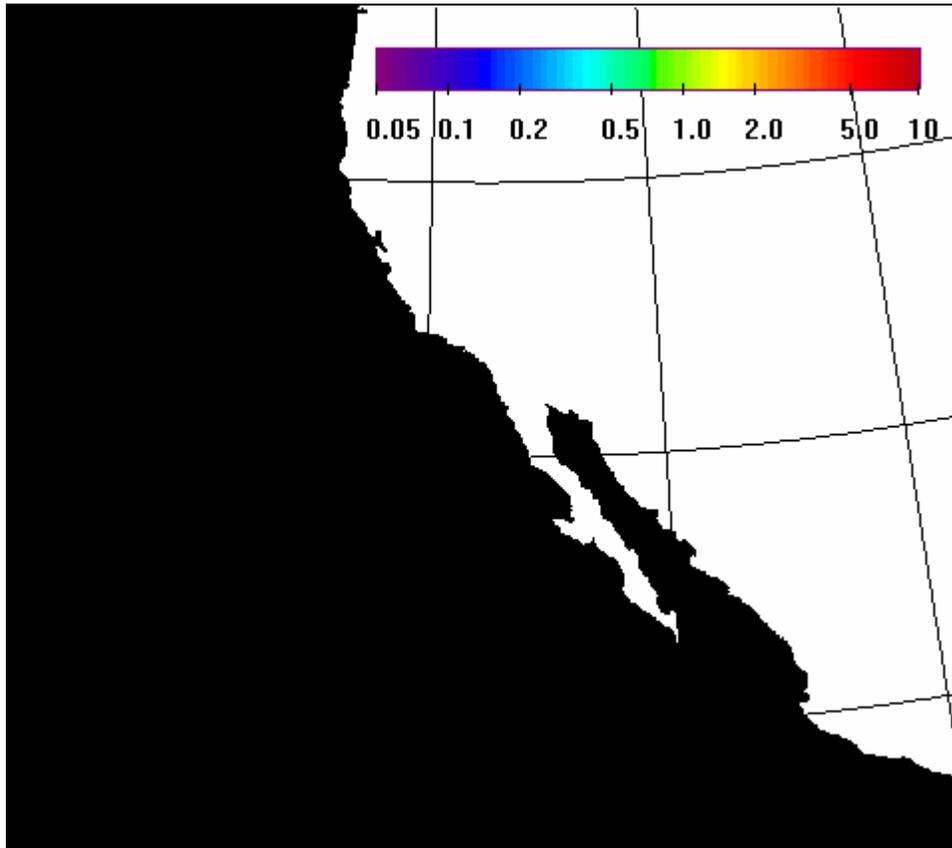


Fig. 1. The reduced Chl-a overlay image with color bar, latitude-longitude grid, and filled land. Colors have been stretched between 48 and 200 pixel values corresponding to Chl-a concentration of 0.05 – 10 mg m⁻³.

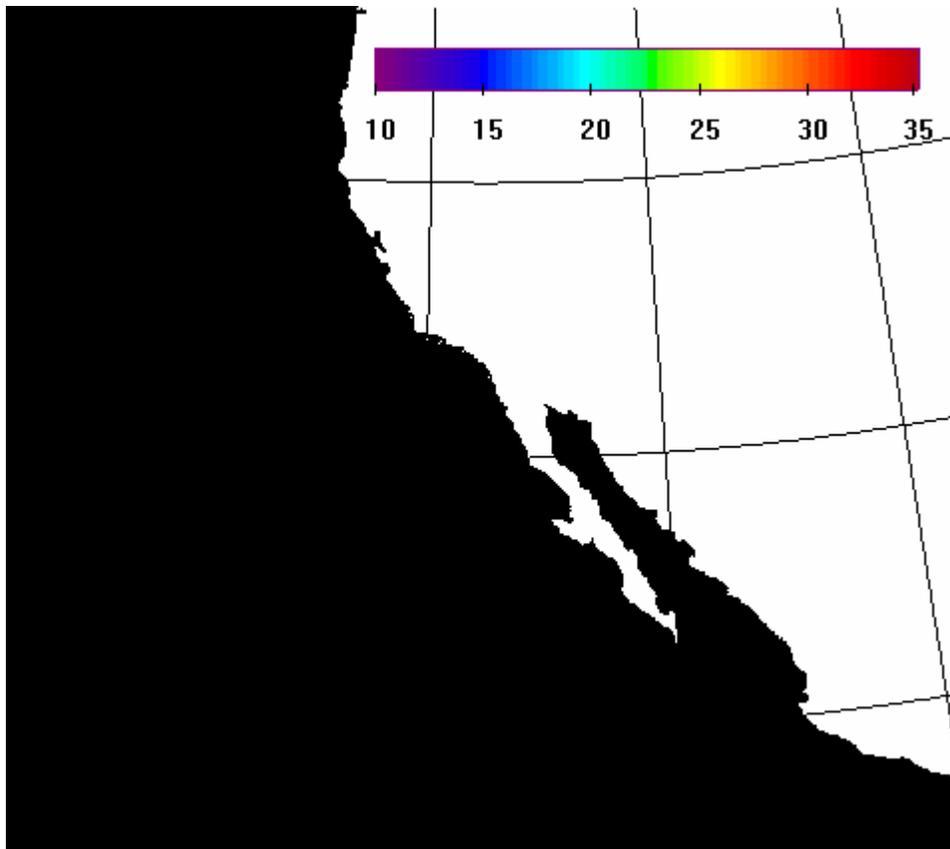


Fig. 2. The reduced SST overlay image with color bar, latitude-longitude grid, and filled land. Colors have been stretched between 87 and 255 pixel values corresponding to SST of 10.05 – 35.25 C.

5 Level-2 flags

Level-2 data have pixels with variable qualities specified by their Level-2 flags. In your final images you don't want to use pixels that are obviously wrong. Some flags indicate that the pixel is most probably bad while other flags indicate warnings that may be ignored.

In this example using both Aqua, Terra and SeaWiFS data I used flags `ATMFAIL`, `LAND`, `HIGLINT`, `HILT`, `HISATZEN`, `STRAYLIGHT`, `CLDICE`, `HISOLZEN`, `HITAU`, `LOWLW`, `CHLFAIL`, `NAVWARN`, `CHLWARN`, `DARKPIXEL`, `SEAICE`, `NAVFAIL` to eliminate low-quality pixels. Other flags (`BADANC`, `COASTZ`, `NEGLW`, `COCCOLITH`, `TURBIDW`, `ABSAER`, `TRICHO`, `MAXAERITER`, `MODGLINT`, `ATMWARN`, `FILTER`, `SSTWARN`, `SSTFAIL`) were ignored. It was found that the pixels marked with the latter flags were statistically not different from neighboring pixels while their elimination would have decreased the amount of usable data. In addition to eliminating the flagged pixels, the cloud image determined with the flag `CLDICE` was dilated (expanded) to eliminate contaminated pixels near cloud edges. Cloud edges are often associated with erroneously high chl-a values.

6 Processing steps

Preprocessing

The following operations are used after the data files have been downloaded.

- `bzip2 -d *.bz2`

This command uncompresses all `*.bz2` files in the current folder using the `bzip2.exe` utility. In many cases you have some very small files have either no data at all or have very small datasets of invalid pixels that are not worth remapping. The next operation will move the files with no data to a folder called “bad” and you can safely delete the whole folder “bad”. Keeping files with no data can stop the following operations from running and will waste disk space.

- `wam_compress_hdf *.hdf`

This command reduces the size of the data files considerably and also moves bad files with no data to a folder “bad”. Keeping HDF files with no datasets may crash the next step. Please note that this compression is applied within the HDF file itself and does not change the HDF file type or the file name (not like the `winzip`, `bzip2` or other compression programs do).

wam_l2_map

- `wam_l2_map PATTERN TARGET`

`wam_l2_map` is the program that remaps and composites all matching Level-2 datasets and creates daily mapped composites. The command above shows the basic form of `wam_l2_map` with `PATTERN` being a matching filename pattern (folder and filename pattern combined) and `TARGET` is the HDF filename with the target projection. If you want to create annotated quick-looks with a separate overlay and image dates then you need a more complex command. The full command syntax can be checked by typing the name of the command without arguments.

- `wam_l2_map PATTERN OVERLAY xPos yPos`

If your target map and overlay are of the same size then you can use your overlay file in place of the target map like in the command above. `xPos` is the x-coordinate (pixels from left) and `yPos` is the y-coordinate (pixels from top) where the annotation (date) is written. You have to pick a good position, e.g. over land, that would not cover useful data.

- `wam_l2_map PATTERN TARGET OVERLAY xPos yPos`

If your target map and overlay are different in size (overlay is typically smaller) then you need to specify both `TARGET` and `OVERLAY` separately like in the command above.

This command works through all the matching files and produces 3 files per **day**:

- `*_chl_a_mapped.hdf` (mapped daily data file),
- `*_chl_a_mapped_annotated.hdf` (annotated HDF file),
- `*_chl_a_mapped.png` (annotated PNG file).

The Level-2 MODIS data (*.L2_LAC.x.hdf or *.L2_LAC) of both Aqua and Terra include also SST data but no SST quality data. Therefore mapped SST images will not be generated from them.

- If you downloaded separate SST data (*.L2_LAC_SST.x.hdf or *.L2_LAC_SST) then please separate these from *.L2_LAC.x.hdf or *.L2_LAC files to a separate folder. I typically use folders like A2007 for Aqua L2 data and A2007_SST for Aqua L2 SST data and, respectively, T2007 and T2007_SST for Terra. For SST data the command syntax is the same but the overlay file should correspond the SST data with a different range and annotation) is specific to SST. The *.L2_LAC_SST files have a separate *qual_sst* dataset with the SST quality flags. It is missing in the general *.L2_LAC files.

wam_l2_map uses multiple passes to create the daily mapped images. If the target area is very large then you will probably have multiple non-overlapping passes. At high latitudes consecutive passes become close to each other and you can have many partly overlapping passes per day. A full list of actual working commands used to generate full-resolution California Current dataset (http://spg.ucsd.edu/Satellite_Data/California_Current/) is given in the end of this document.

wam_composite_2sensors

This step merges data from 2 sensors. For ocean color you can use L2 datasets from Aqua, Terra and SeaWiFS. SeaWiFS data have 2 types: GAC (global area coverage at 4 km resolution) and MLAC (merged local area coverage at 1 km resolution). It is usually best to merge SeaWiFS MLAC and GAC data with the same command (as if from different sensors). The GAC data normally guarantees the best coverage while MLAC data (if present) guarantees the best spatial resolution.

- `wam_composite_2sensors PATTERN1 PATTERN2`

The command above composites daily mapped images from 2 sensors.

- `wam_composite_2sensors PATTERN1 PATTERN2 OVERLAY xPos yPos Yes`

The command above composites daily mapped images from 2 sensors and uses `OVERLAY` image with the annotation positioned at `xPos`, `yPos`. The keyword *Yes* specifies that data in `PATTERN1` has preference over data in `PATTERN2`. This is used in case you are merging data with different resolution or quality. For example, when merging SeaWiFS MLAC (higher resolution) with GAC data (lower resolution) or MODIS-Aqua data (higher quality) with MODIS-Terra data (lower quality) you should use the lower quality/resolution data as `PATTERN2` and the *Yes* keyword.

The best strategy seems to be the following sequence of merging data from 4 datasets (SeaWiFS MLAC, SeaWiFS GAC, MODIS-Aqua and MODIS-Terra):

1. SeaWiFS MLAC with SeaWiFS GAC with MLAC priority into SeaWiFS merged.

2. MODIS Aqua with MODIS Terra with Aqua priority into MODIS merged.
3. MODIS merged with SeaWiFS merged with equal priority into merged multisensor Chl-a.

Please note that the first letter of the filenames may change as a result of merging data from different sensors/datasets. The rules of change are:

1. SeaWiFS MLAC with SeaWiFS GAC – no change (keep “S”).
2. MODIS Chl-a merged with SeaWiFS Chl-a – change to “C” (for Chl).
3. MODIS Aqua with MODIS Terra – change to “M” for MODIS (for both Chl-a and SST).

If datasets 1 and 2 have equal priority then corresponding valid pixels will be averaged. If priority keyword *Yes* is used then the lower priority PATTERN2 data is used only if PATTERN1 data is missing or invalid.

A full list of actual working commands used to generate full-resolution California Current dataset (http://spg.ucsd.edu/Satellite_Data/California_Current/) is given in the end of this document.

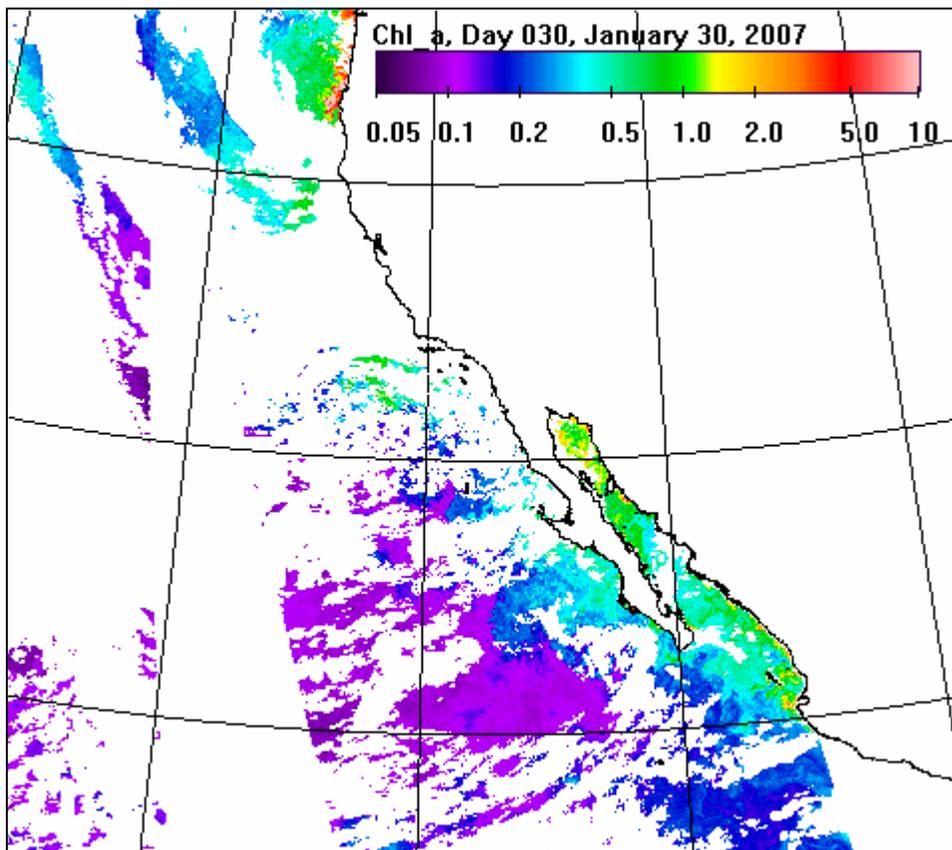


Fig. 3. Aqua Chl-a for January 30, 2007. 23.7% of the ocean pixels are valid (i.e. not cloudy).

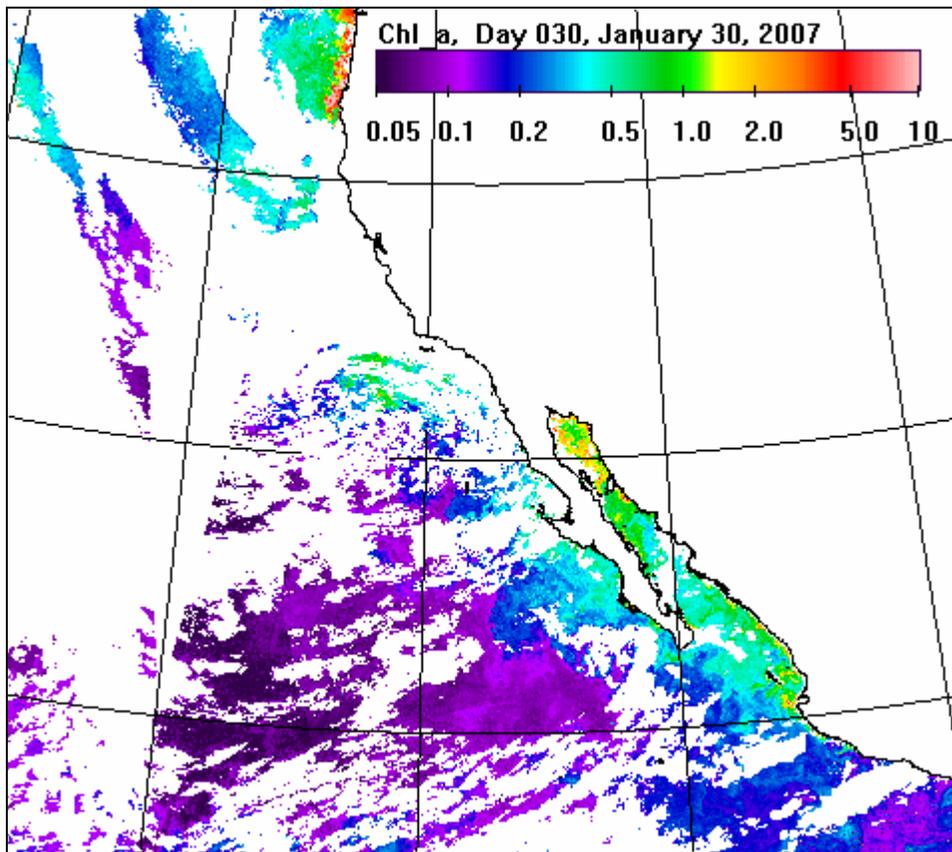


Fig. 4. Merged Aqua and SeaWiFS Chl-a for January 30, 2007. 34.1% of the ocean pixels are valid, an increase of over 10% compared to Aqua alone.

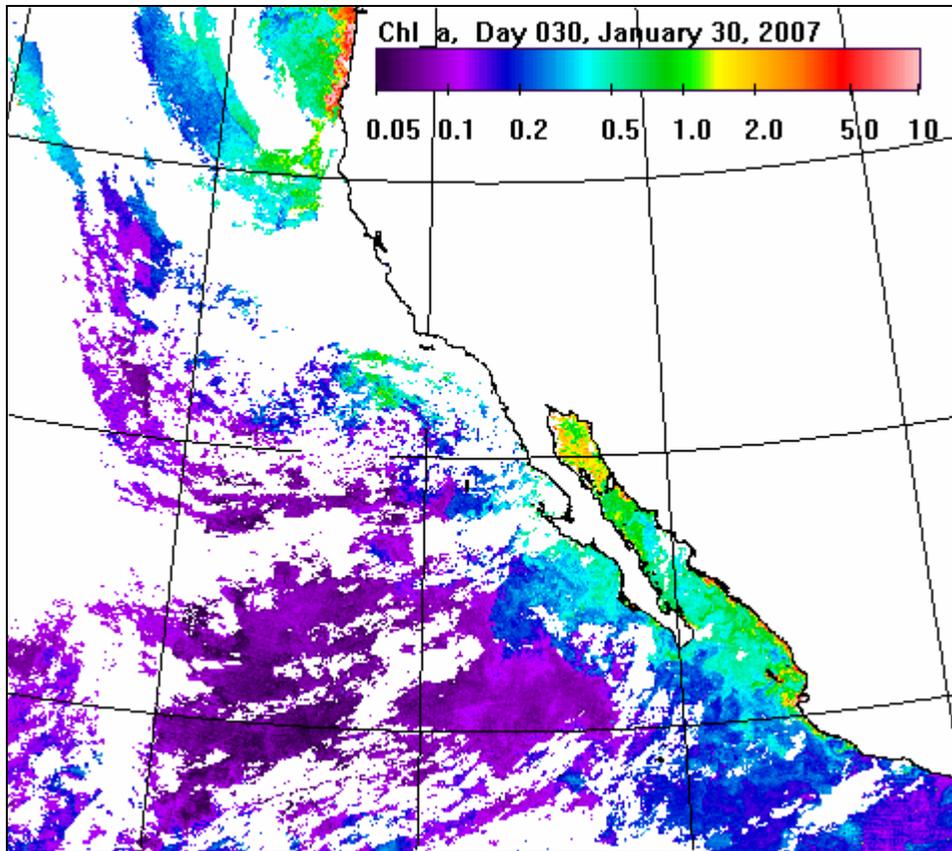


Fig. 5. Merged Aqua, Terra and SeaWiFS Chl-a for January 30, 2007. 45.4% of the ocean pixels are valid, an increase of about 22% compared to Aqua alone.

wam_composite_5days

As shown in Figs. 3-5 merging data from multiple sensors increases the coverage and decreases the number of missing pixels. However, even after merging data from 4 datasets the coverage is still usually inadequate (in our example 45% coverage and 55% of ocean pixels still cloud-covered). Therefore we will composite the multi-sensor daily datasets over time, first over a 5 day period.

- `wam_composite_5day PATTERN`
- `wam_composite_5day Pattern [OverlayFile [xPos yPos [lutFile [Min Max]]]]`

The first command above shows the basic form and composites daily mapped images into 5-day composites. The second command above uses the overlay file (the same as in previous examples) and has more options, e.g. for *OverlayFile*, a specific LUT file, positioning the annotation (*xPos*, *yPos*) and stretching the colors between *Min* and *Max*. Please see the various options by typing the command with no arguments. As output the command produces 3 types of 5-day composite files: composites (`*_comp.hdf`) and annotated composites (`*_comp_annot_hdf` and `*_comp.png`). Below is a sample 5-day composite image using the previously produced daily image as one of the components.

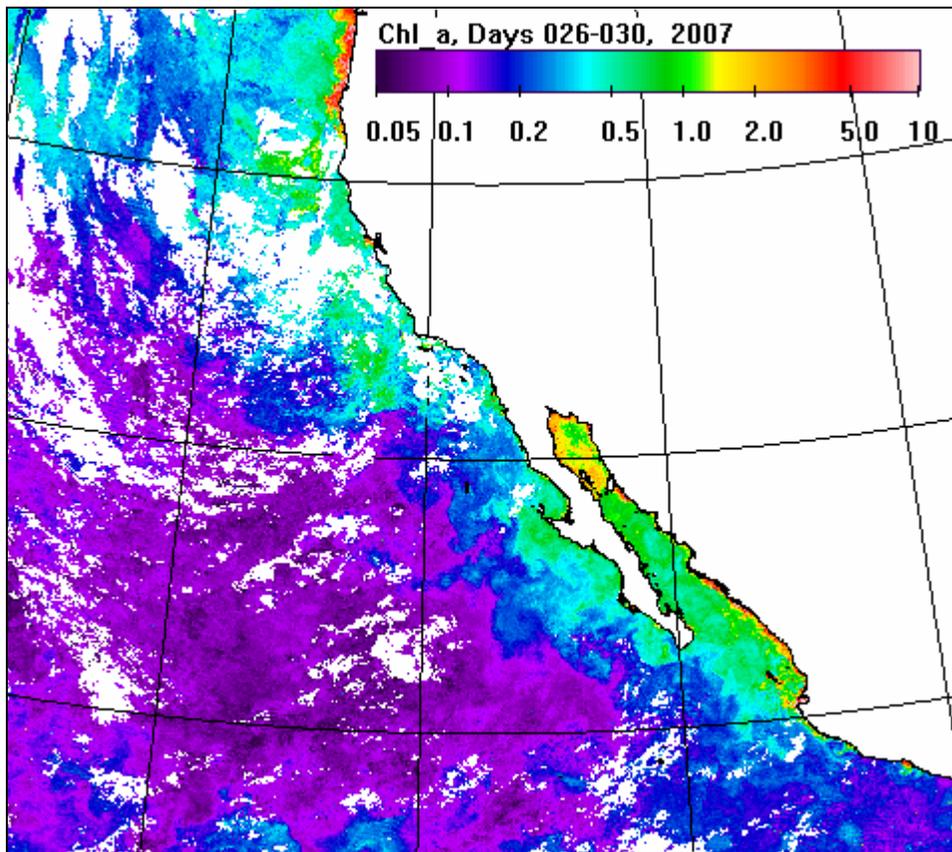


Fig. 6. A 5-day composite of the merged Chl-a for January 26-30, 2007. 80.1% of the ocean pixels are valid, an increase of about 34.7% compared to the merged single day image.

wam_composite_2x

- `wam_composite_2x PATTERN DAYS`
- `wam_composite_2x PATTERN 15 [OverlayFile [xPos yPos [lutFile [Min Max]]]]`

This command takes 5-day composites and merges those into 15-day composites. The new option here is `DAYS` that specifies the compositing range in days. The command has other options, similar to `wam_composite_5day`, e.g. for `OverlayFile`, a specific LUT file, positioning the annotation (`xPos`, `yPos`) and stretching the colors between `Min` and `Max`. Please see the options by typing the command with no arguments. The second sample command above composites images into 15 day composites. The example uses the same overlay file as in previous examples. Note that you can use any time range, e.g. 30 days or 60 days to make a composite of that length. It is statistically justified to make composites in a hierarchical way, e.g. first 5-day composites and then use these for a longer composite. Currently you cannot mix different years, e.g. you

cannot composite from December to January. Below is a sample 15-day composite image using the previous image as one of the components. Note the improved coverage.

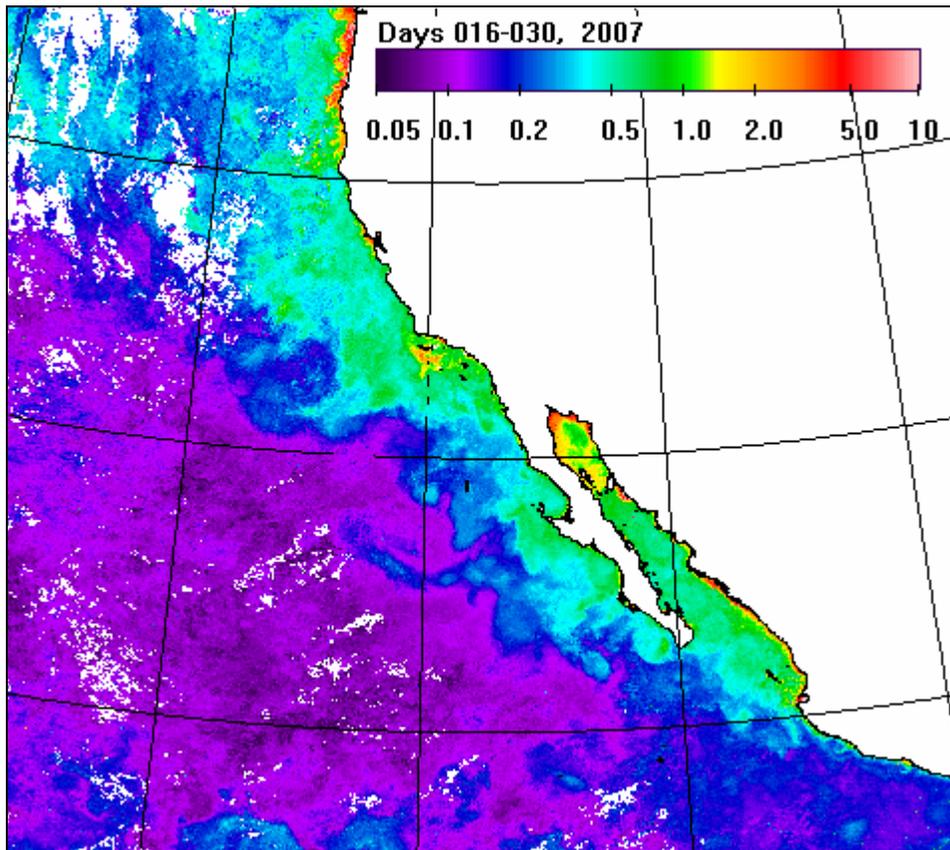


Fig. 7. A 15-day composite of the merged Chl-a for January 16-30, 2007. 93.8% of the ocean pixels are valid, an increase of about 13.7% compared to the 5-day image above.

As you can see, even the 15-day merged composite from multiple sensors has some white holes of no data. While it is not hierarchical compositing, it is common practice to make monthly composites using daily and not 5-day or 15-day composites as those do not normally match month limits.

wam_composite_month

- `wam_composite_month PATTERN`
- `wam_composite_month Pattern [OverlayFile [xPos yPos [lutFile [Min Max]]]]`

This command makes composites over calendar months. It can use both daily and longer (e.g. 5-day) composites. It is statistically justified to first make composites in a hierarchical way, e.g. first 5-day composites and then use these for a monthly composite. However, when using 5-day composite as input the final time interval is usually not

exactly a calendar month. Therefore we use daily input images. The options are similar to *wam_composite_5day*, e.g. for *OverlayFile*, a specific LUT file, positioning the annotation (*xPos*, *yPos*) and stretching the colors between *Min* and *Max*. Please see the options by typing the command with no arguments. The same overlay file as in previous examples is used.

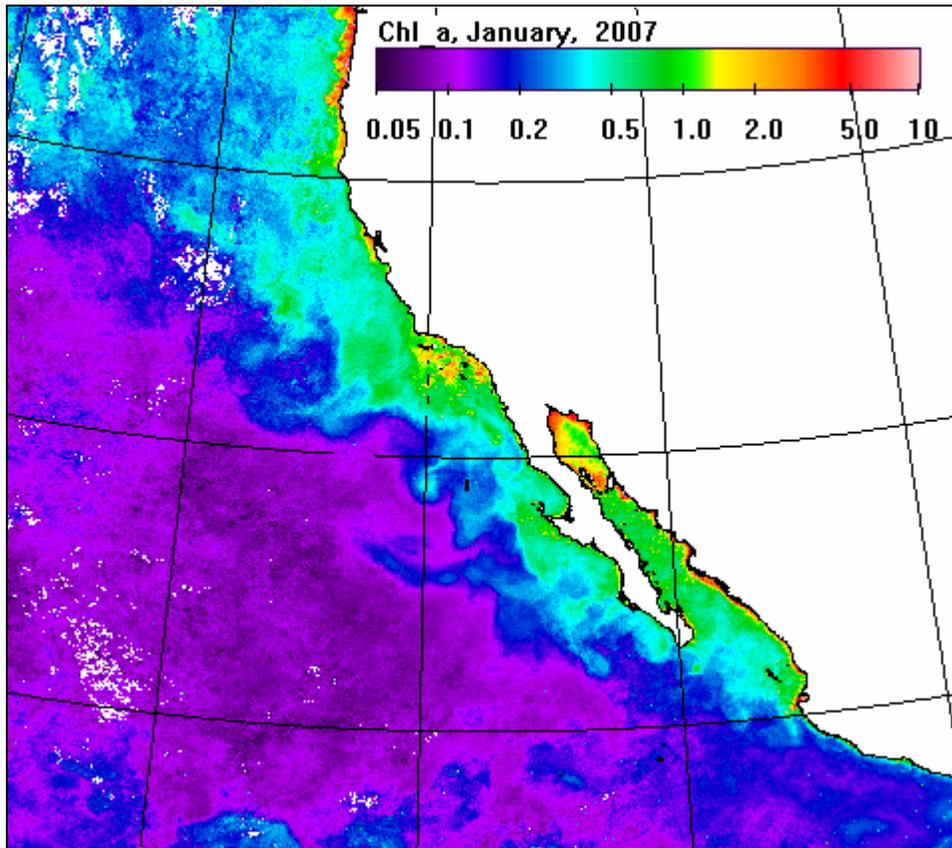


Fig. 8. A monthly composite of the merged Chl-a for January, 2007. 98% of the ocean pixels are valid, an increase of another 4.1% compared to the 15-day image above.

The above examples used the LUT file *chl1_white_end.lut* with Chl range 0.05-10. You can, of course, use a different LUT file. The example below shows SST with a different LUT file (*hsl256_black_white.lut*). It may be useful to use different LUT files for different variables. However, the SST image below reduces the visibility of gradients because of using a very smooth LUT file.

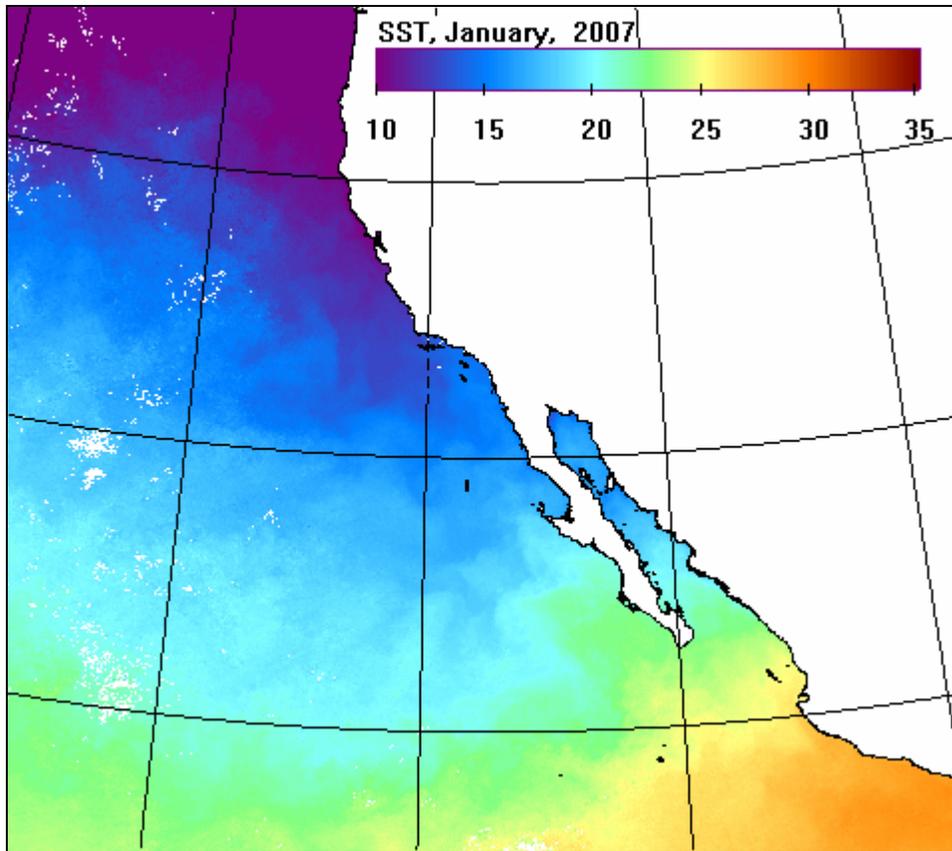


Fig. 9. A monthly composite of the merged MODIS Aqua and Terra SST for January, 2007.

Practical results using these programs are available at

[http://spg.ucsd.edu/Satellite Projects/Merged chl a time series BWZ/Merged chl a time series BWZ.htm](http://spg.ucsd.edu/Satellite%20Projects/Merged%20chl%20a%20time%20series%20BWZ/Merged%20chl%20a%20time%20series%20BWZ.htm) and at [http://spg.ucsd.edu/Satellite Projects/Full res sat time series California/Full res sat time series California.htm](http://spg.ucsd.edu/Satellite%20Projects/Full%20res%20sat%20time%20series%20California/Full%20res%20sat%20time%20series%20California.htm).

Sample commands for processing L2 data of the California Current area:

Mapping SST:

```
wam_l2_map 2007\A2007_SST\0\A200*SST.x.hdf K:\Projections\California\cal_aco_3840.hdf
K:\Projections\California\cal_aco_3840_red8_stas_sst_87_255.hdf 183 13
```

Mapping Chl:

```
wam_l2_map 2007\S2007_MLAC\0\S*x.hdf K:\Projections\California\cal_aco_3840.hdf
K:\Projections\California\cal_aco_3840_red8_stas_chl_47_200.hdf 183 13
```

Compositing SST:

wam_composite_2sensors 2007\A2007_sst_day\A*mapped.hdf
 2007\T2007_sst_day\T200*mapped.hdf
 K:\Projections\California\cal_aco_3840_red8_stas_sst_87_255.hdf 183 13
 K:\LUT\hsl256_black_white.lut 87 255

wam_composite_5day 2007\M2007_sst_day\M200*mapped.hdf
 K:\Projections\California\cal_aco_3840_red4_sst_87_255.hdf 382 19
 K:\LUT\hsl256_black_white.lut 87 255

wam_composite_2x 2007\M2007_sst_5day\M200*comp.hdf 15
 K:\Projections\California\cal_aco_3840_red4_sst_87_255.hdf 382 19
 K:\LUT\hsl256_black_white.lut 87 255

wam_composite_month 2007\M2007_sst_day\M200*mapped.hdf
 K:\Projections\California\cal_aco_3840_red4_sst_87_255.hdf 382 19
 K:\LUT\hsl256_black_white.lut 87 255

Compositing Chl:

wam_composite_2sensors 2007\S2007_chl_day_MLAC\S*mapped.hdf
 2007\S2007_chl_day_GAC\S*mapped.hdf
 K:\Projections\California\cal_aco_3840_red8_stas_chl_47_200.hdf 186 13
 K:\LUT\chl1_white_end.lut 48 200 yes

wam_composite_2sensors 2007\A2007_chl_day\A*mapped.hdf
 2007\S2007_chl_day\S*mapped.hdf
 K:\Projections\California\cal_aco_3840_red8_stas_chl_47_200.hdf 186 13
 K:\LUT\chl1_white_end.lut 48 200

wam_composite_5day 2007\C2007_chl_day\C200*mapped.hdf
 K:\Projections\California\cal_aco_3840_red8_stas_chl_47_200.hdf 186 13
 K:\LUT\chl1_white_end.lut 48 200

wam_composite_2x 2007\C2007_chl_5day\C200*comp.hdf 15
 K:\Projections\California\cal_aco_3840_red8_stas_chl_47_200.hdf 186 13
 K:\LUT\chl1_white_end.lut 48 200

wam_composite_month 2007\C2007_chl_day\C200*mapped.hdf
 K:\Projections\California\cal_aco_3840_red8_stas_chl_47_200.hdf 186 13
 K:\LUT\chl1_white_end.lut 48 200