

18. USING SEA SURFACE TEMPERATURE TO ASSESS CORAL BLEACHING RISK

By: **Yohanna W. Shaghude¹** and **Valborg Byfield²**

18.1. Introduction and relevance of application

Coral reefs are considered the oceanic equivalent of the tropical rainforest, in terms of their biodiversity, complexity and net primary production. A coral reef is an ecosystem with multiple functions: ecological, environmental and socio-economic. Ecologically, coral reefs serve as nursery for many invertebrates and fish, and as source for beach sand. Socio-economically, coral reefs support a large variety of subsistence and commercial fisheries, thereby supporting the livelihood of many coastal communities.

The reefs and the associated sand beach habitats plays a major role in the marine tourism industry in the region, which generate foreign currency and offers employment to local people, thereby providing a livelihood to coastal communities. Furthermore, coral reefs serve as physical buffers for oceanic currents and waves, thereby protecting the coast from erosion, and creating, over geologic time, a suitable environment for sea grass beds and mangroves.

Despite their many benefits to coastal communities, most of the tropical reefs are currently exposed to a variety of natural and anthropogenic threats and have been degrading at an alarming rate over recent years. A major 'natural' threat to coral health comes from high water temperatures, which, if persisting for a long period can lead to a phenomenon known as coral bleaching. This threat is likely to increase with global warming.

Coral bleaching is the whitening of corals due to stress-induced expulsion or death of their symbiotic protozoa, zooxanthellae, or due to the loss of pigmentation within the protozoa. The corals that form the structure of the great reef ecosystems of tropical seas depend upon a symbiotic relationship with unicellular flagellate protozoa, called zooxanthellae - photosynthetic organisms living within their tissues. Zooxanthellae are responsible for the colour of the reefs, with the specific color depending on the particular clade. When stressed, corals may expel their zooxanthellae and change their colour to a lighter or completely white appearance, hence the term "bleached".

Although many environmental factors may trigger coral bleaching, high sea water temperature is by far the most common cause of wide-spread bleaching events. Analysis of satellite sea surface temperature (SST) data therefore offers an opportunity for predicting location and extent of coral bleaching. For Tanzania, with its rich coral reef resources distributed widely along a coastline that is more than 1000 km long, being able to assess the location and extent of coral bleaching risk is vital for the management of the reefs. Instead of visiting all the reef sites to identify the threatened reefs, satellite SST data may provide information on the hotspots of major threats, thereby saving time and money.

¹ Institute of Marine Sciences, University of Dar es Salaam, P.O. Box 668, Zanzibar, Tanzania. Email: shaghude@ims.udsm.ac.tz

² National Oceanography Centre (NOC), Southampton, UK. Email: val.byfield@noc.ac.uk



Figure 18.1 Bleached (left) and healthy (right) coral reefs

18.2. Objective of the application

The main objective of this application is to investigate the trends in satellite derived sea surface temperature (SST) for detection of “hot spots” and assessment of the potential coral reef heat stress which could eventually cause coral bleaching along the coast of Tanzania.

18.3. Data used for the study

18.3.1. Local *in-situ* data

Seawater temperature logger deployed at Chumbe reefs Zanzibar (at 2 m depth during low tide), spanning from January 1997 – September 2010 was provided by Dr. Christopher Muhando of the Institute of Marine Sciences, University of Dar es Salaam.

18.3.2. Satellite data

The study uses 1km resolution MODIS-Aqua sea surface temperature (SST) from the DevCoCast Tanzania region, provided by Plymouth Marine Laboratory (PML) for the period January to March 2010, during the warm season when corals are known to be most at risk from heat stress.

To assess what are 'normal' temperatures to which corals are likely to be well adapted, a global monthly SST climatology was downloaded from <ftp://data.nodc.noaa.gov/pub/data.nodc/pathfinder/Version5.0/Climatologies>.

The Pathfinder data is based on a different sensor, so to allow a comparison between the climatological mean and the MODIS SST data, two further data sets were downloaded: global monthly MODIS SST from Jan-March 2006 from <http://oceancolor.gsfc.nasa.gov/cgi/13>, and monthly Pathfinder v5.0 SST for the same period, available at <ftp://data.nodc.noaa.gov/pub/data.nodc/pathfinder/Version5.0/Monthly/2006/>.

18.4. Methodology and data pre-processing

18.4.1. Methodology

The flowchart given below shows the main processing steps for this exercise. Due to reasons of data volume the import of the various data sets has already been done and a subset has been created for the coastal region of Tanzania. Some of the data import routines are described in chapter 17 of this manual.

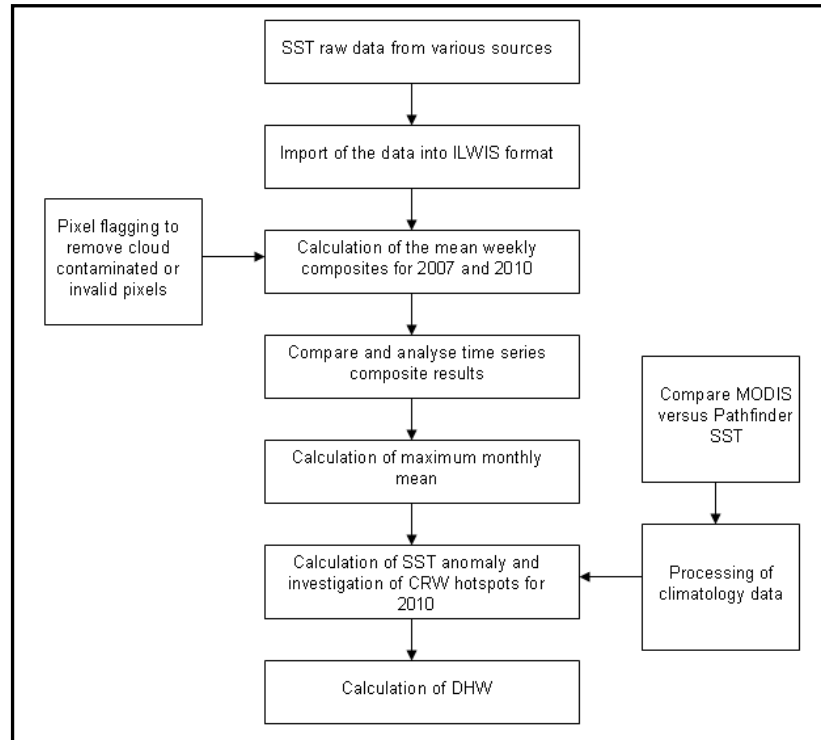


Figure 18.2 Flowchart showing the key data selection and processing steps

18.4.2. Pre-processing of the global SST data used for comparison with the 1km DevCoCast product

The global data sets containing the climatology data, and the monthly data from 2006 used to control for any difference between MODIS and Pathfinder SST products, have been pre-processed and imported into ILWIS. Only the Area of Interest (AoI) has been retained to limit the data volume. The MODIS-Aqua sea surface temperature (SST) from the DevCoCast Tanzania region, provided by Plymouth Marine Laboratory (PML) for the period January to March 2010, has also been pre-processed and time series of the two years for the AoI have been made available. The pre-processing is consisting mainly of importing the NETCDF or HDF files by selecting the relevant layers and application of the calibration coefficients. All data was re-projected to the same coordinate system and subsequently the AoI has been extracted.

For the Pathfinder mean SST-night time data, both for the 2006 and the monthly climatology datasets, the following transformation has been applied to convert the data to degree Celsius:

$$PF_SSTn_Celsius_outmap = -3.0 + clim_sst_filled_data * 0.075$$

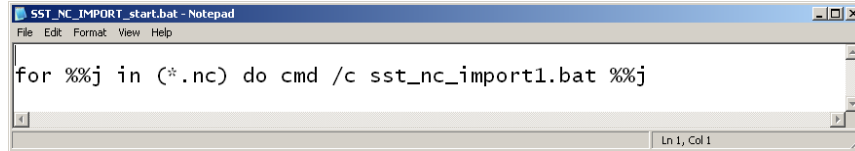
For the 2006 MODIS monthly mean night-time SST data the transformation equation used was:

$$MODIS_SSTn_Celsius_outmap = (0.000717185 * l3m_data) - 2$$

The Pathfinder monthly climatology data has also been used to derive a map containing the values of the night-time maximum mean monthly (MMM) sea surface temperature.


The MODIS-Aqua daily sea surface temperature (SST) from the DevCoCast Tanzania region only required the extraction of the AoI. Two map lists have been created containing the daily SST-night data for 2007 and 2010. There is no night SST image for 12-01-2007, the rest is complete, 89 map layers for 2007 and 90 layers for

2010, covering the period from 1st of January to the 31st of March for the two years. As will be seen later the data needs further processing to eliminate or exclude (partly) cloud contaminated and pixels with poor quality or invalid data. For import of a time series of data use is made of a batch looping procedure. All NETCDF night-time SST files are situated in a given directory and for import use is made of GDAL. Figure 18.3 is showing the batch file that is ‘starting’ the import procedure. The single line statement executes another batch file, here called ‘sst_nc_import1.bat’ that is actually conducting the import, the import continues until all files have been processed. The content of the second batch file ‘sst_nc_import1.bat’ is given in figure 18.4.



```
for %%j in (*.nc) do cmd /c sst_nc_import1.bat %%j
```

Figure 18.3 Starting the batch looping routine procedure



```
rem file name format is PML_Tanzania_MODIS_sst_refined_20070101221500.nc
set longfilename=%1
set shortfilename1=%longfilename:~31,14%
set shortfilename2=%shortfilename1:~0,8%

"D:\Ilwis372\Extensions\Geonetcast-Toolbox\GDAL\bin\gdal_translate" -of ilwis
PML_Tanzania_MODIS_sst_refined_%shortfilename1%.nc sstn_%shortfilename2%.mpr

"D:\Ilwis372\ilwis.exe" -C setgrf sstn_%shortfilename2%.mpr pml_modis_tanzania.grf

"D:\Ilwis372\ilwis.exe" -C sstn_tanz_%shortfilename2%.mpr:=MapSubMap(sstn_%
shortfilename2%,0,175,676,627)

"D:\Ilwis372\ilwis.exe" -C setgrf sstn_tanz_%shortfilename2%.mpr sst_tanzania.grf

del *.xml
```

Figure 18.4 Batch file listing showing the import syntax

The starting batch file is passing the filename, with the extension “nc” to the second batch file. Here portions of the filename are extracted, containing the timing information (year, month, day, etc) from the file name string. Subsequently 4 lines are conducting the import and pre-processing. Line 1 is calling “gdal_translate”, which imports the data and writes an ILWIS output formatted image. In line 2 a georeference is appended to the newly imported image. Line 3 creates the sub-map, retaining only the AoI and in line 4 a georeference is appended to this new map for the AoI. In this manner, import of time series of data can be efficiently done.

18.5. Satellite image processing

The main processing steps remaining for assessing potential coral reef heat stress are:

- Creating weekly composites of night-time SST data for the period of interest;
- Comparing the weekly data to the climatology to determine if current water temperatures are higher than normal, and calculating the anomalies: $\text{anomaly SST} = \text{current SST} - \text{climatology SST}$;
- Correct for any bias arising from comparing data from one sensor (MODIS) to climatology data from another (Pathfinder AVHRR);
- Calculate cumulative heat stress - degree heating weeks.

18.5.1. Creating weekly composites of night-time SST

The Coral Reef Watch (CRW) operational SST produces only night-time satellite SST observations and excludes the daytime observations to eliminate variations caused by solar heating of the sea surface during the day and also to avoid contamination from solar glare. Compared with daytime SST and day-night blended SST, night-times SST provides more conservative and stable estimate of thermal stress conducive of coral bleaching. We therefore need to extract the night-time SST observations and keep these separately from the daytime observations. Here only night-time SST images are used.

Unzip the exercise data into your working directory. Here “C:\Data\Tanzania” is used. Open ILWIS and navigate to this directory. Close ILWIS and open it again. The ILWIS catalogue should now show the content of the active working directory.

Double click on the map list icon “*sstn_tanzania_2007*”, in the next window, select from the menu the option “Open as Slide Show” and press “OK”. In the next display options window set the minimum stretch value to “0”, select a “Pseudo” Representation and press “OK” again. You now see an animated sequence of the imported night-time SST’s of 2007. You will observe that there is a need for further processing in order to eliminate clouds, invalid pixels and land areas. Also check the content of the 2010 night-time SST map list.

From the menu bar select “File” > “Create” > “Maplist”. In the Create MapList dialog window (figure 18.5) give your maplist a suitable name, for example “*sst_2007_wk1*”. There is no need for a description. Use the up and down arrows to scroll down or up to select the files containing the dates for week 1 (e.g. 0101 to 0107 for January 1 to 7), after selecting the topmost of these files, use the shift key while scrolling down to select the other files and click the arrow pointing to the right box to tell ILWIS to take the contents of your selection to the right box. Click “OK” to accept the selection of the files.

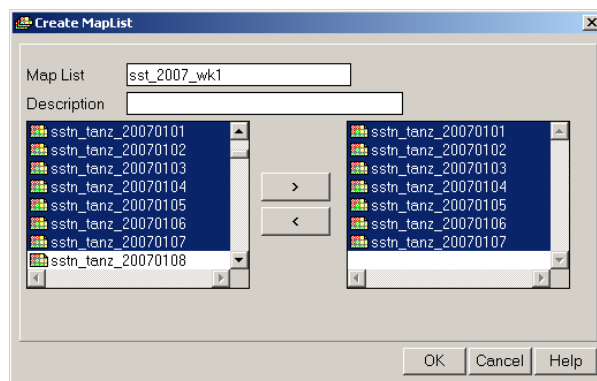


Figure 18.5 Creating a map list for week 1

Create in a similar manner the 11 other weekly map lists for the whole observation period, for details see also table 18.1. Here the name convention for the map lists created used is “*sst_2007_wk1*” up to “*sst_2007_wk12*”. Note that during the last week of the month a deviating number of maps are available as January and March have 31 days and February only 28. For the second week of January no SST image is available for the 12th of January.

Prepare yourself an identical table to create the 12 map lists needed for 2010. Use a similar map list filename convention: “*sst_2010_wk1*” up to “*sst_2010_wk12*”. Note that the number of layers contained in a map list is required for further processing later on. The only change in this respect is the number of layers for week 2 in 2010, during this week in 2010 there are 7 map layers. Upon completion of creating the map lists you should have obtained 24 weekly map lists, 12 for 2007 and 12 for 2010.

Display your results when you have created a map list. Double click on the map list icon “*sst_2007_wk1*”, in the next window, select from the menu the option “Open as Slide Show” and press “OK”. In the next display options

window set the minimum stretch value to “0”, select as Representation “*Pseudo*” and press “OK” again. You now see an animated sequence of the SST maps of the 1st week of January 2007.

January Month 01	Week1		Week2		Week3		Week4	
	Day number	No of maps	Day number	No of maps	Day number	No of maps	Day number	No of maps
	01-07	7	08-14	6	15-21	7	>21	10
February Month 02	Week5		Week6		Week7		Week8	
	Day number	No of maps	Day number	No of maps	Day number	No of maps	Day number	No of maps
	01-07	7	08-14	7	15-21	7	>21	7
March Month 03	Week9		Week10		Week11		Week12	
	Day number	No of maps	Day number	No of maps	Day number	No of maps	Day number	No of maps
	01-07	7	08-14	7	15-21	7	>21	10

Table 18.1 Details of map lists to be created for 2007

18.5.2. Masking of invalid pixels

Before calculating the mean of the valid pixels to derive the weekly composites, you need to take into consideration of the following:

- Application of a mask to exclude clouds and pixels with poor quality or invalid data;
- Application of a flag to exclude the land pixels;
- The calculation of the mean of the weekly composites only includes those pixels with acceptable data.

Cloud top temperatures are much lower than sea surface temperatures, so any pixel containing scattered cloud will have an apparent temperature that is lower than the real temperature. A quick look at the map lists show that most of the images suffer from such cloud contamination. In the absence of other methods for identifying valid data, you can use your knowledge of the study area (Tanzania) and available *in situ* data to determine a threshold temperature for excluding abnormally low temperatures. For Tanzania at this time of year, you are very unlikely to find water temperatures below 25 degrees Celsius, so this may be used as a suitable threshold. Land pixels are given the value of -163 in this data, and the fill value (no data) is -999. Hence a threshold of 25 will also exclude any land pixels and pixels with missing data.

1. To mask pixels with temperatures below 25 degrees for the entire map list type the following expression into the command line in the main ILWIS menu, and press enter to execute the operation:

```
sst_2007_wk1_flag.mpl:=maplistcalculate("iff(@1>=25,@1,0)",0,6,sst_2007_wk1.mpl)
```

Note that for this week there are 7 layers contained in this map list, which are sequentially numbered from 0 to 6! Note that the internal ILWIS map list counter starts from 0.

2. Next re-classify undefined (no data value) into a value of 0:

```
sst_2007_wk1_temp.mpl:=maplistcalculate("ifnotundef(@1,@1,0)",0,6,sst_2007_wk1_flag.mpl)
```

3. Use map list calculate to create a temporary image to hold the sum of all the valid temperatures, when the raster map definition dialog window opens just accept the defaults:

```
sst_2007_wk1_sum.mpr:=MapMaplistStatistics(sst_2007_wk1_temp.mpl,sum)
```

4. Assign 'no data' value to maps with temperature less equal 25 degrees (to avoid them being counted):

```
sst_2007_wk1_temp1.mpl:=maplistcalculate("iff(@1>=25,@1,?)",0,6, sst_2007_wk1_temp.mpl)
```

5. Count the number of valid observations:

```
sst_2007_wk1_count.mpr:=MapMaplistStatistics(sst_2007_wk1_temp1.mpl,Cnt)
```

6. Calculate the mean weekly temperature by dividing the sum by the count:

```
mean_sst_2007_wk1:=sst_2007_wk1_sum/ sst_2007_wk1_count
```

Your result should resemble the map presented in figure 18.6. For visualization of this map use is made of the "Pseudo" representation.

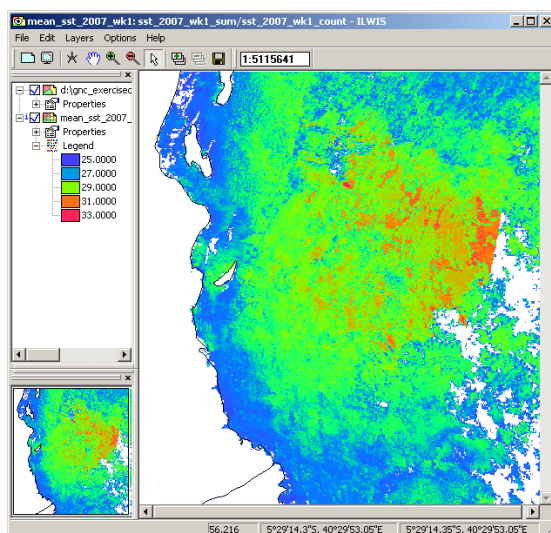


Figure 18.6 Mean weekly SST along the coast of Tanzania

Note that all the above commands were typed directly into the command line of the main ILWIS menu. These lines can also be copied from the command line history and pasted into an ILWIS script, which can be used to compute the means of other weekly composites in a more automated manner. From the catalogue double click with the mouse the script "*SST_flagging*" and note the content. You will see that there are 3 replaceable parameters, indicated by %1, %2 and %3 that need to be defined to run the script. The parameters are: %1=number of layers contained in a map list, %2=week number and %3=year. Close the script and type the following syntax into the command line of the main ILWIS menu:

```
run SST_flagging 5 2 2007
```

Note that "*run*" is used to initiate an ILWIS script, the script to be executed is "*SST_Flagging*", %1="5" (counting of layers starts from 0, so number of layers are given from 0 to 5, total of 6 layers (see also table 18.1), %2="2" , indicating the week (number) and %3="2007" is referring to the year. We do not need to

modify the script to process the other weeks or the year, one only need to change the parameter settings to calculate a weekly mean of another period. Repeat this procedure to calculate the remaining weekly means of 2007 and all weekly means of 2010. Note that upon completion of the calculations you are asked to delete the obsolete files, confirm with “Yes”, else a large number of files will appear in your catalogue. You can also delete the obsolete files created during step 1 to 5 presented above when calculating the mean SST of the 1st week.

18.5.3. Visual assessment of the weekly composites

Visual assessment of the weekly composite reveals that the threshold-method has not succeeded in masking all the cloud-contaminated pixels. The speckled appearance of the image is typical of cloud-contamination that has not been adequately masked. Despite this, it is possible to see oceanic features such as the warm eddy near the Tanzanian coast in the top left quarter of the image. In the middle of this eddy temperatures of 30 degrees or more occur.

18.5.4. Examining the image histogram

Right click with the mouse on the map “*mean_sst_2007_wk1*” and from the context sensitive menu select the option “*Statistics*” > “*Histogram*” and press “*Show*”. The histogram for the mean week1 SST (figure 18.7) shows the temperature distribution, and gives useful information about the image, such as the mean and median temperatures, and the ‘Pred’ - the number that occurs most often (the histogram peak), also known as the mode. The histogram clearly shows the cut-off threshold of 25 degrees used to mask cloud-contaminated pixels. An indication that the cut-off has been reasonably successful can be found in the fact that the median, mean and mode give very similar values. If cloudy pixels had been left in the image, the histogram would have been skewed and the mean would have been much lower than the mode. Thus the mean temperature of 27.85 degrees Celsius obtained for the weekly composite of the first week of January 2007 may therefore be considered reasonably correct.

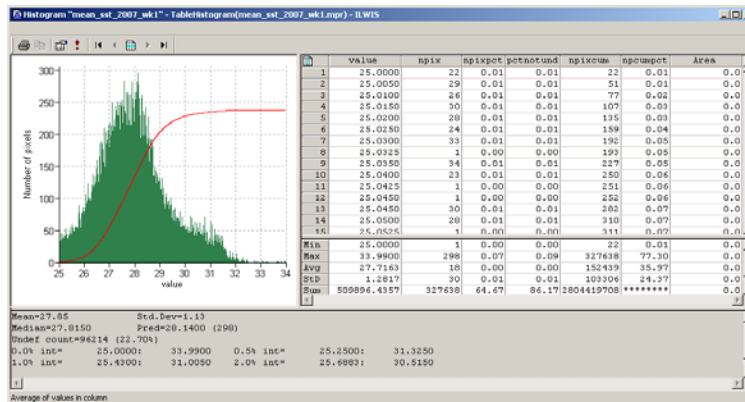


Figure 18.7 Histogram of the image for week 1

18.5.5. Changes from January to March

Compare the weekly images for the 12 weeks in each year. Now select for each weekly mean SST map the option “*Statistics*” > “*Histogram*” and press “*Show*” and note the following statistics: mean, standard deviation, median and predominant or mode, see also figure 18.8 for the histogram of week 12. Are there any obvious changes in mean temperatures from the start of January to the end of March for both years? You will note that the mean temperature in March is higher than in early January. Also consult Appendix 1, which provides the statistics for the respective weeks for the year 2007 and 2010.

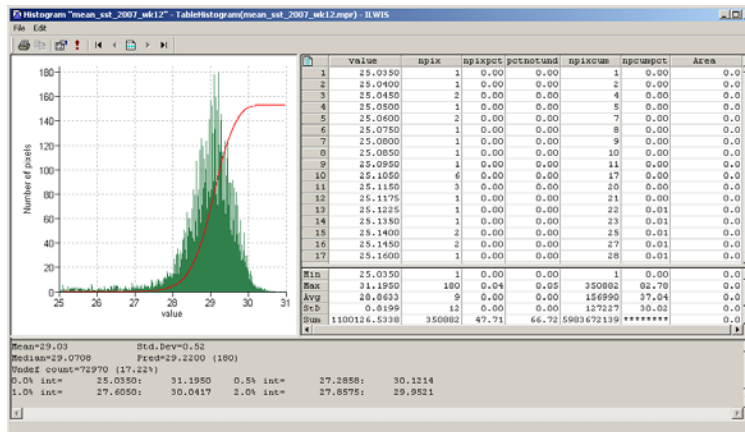


Figure 18.8 Histogram for week 12

18.5.6. Differences between 2007 and 2010

Plotting the histogram means for each week as two weekly time series is an easy first step in comparing 2007 and 2010. Are there any observable temperature differences between the two years? Check also the graphical representation of the mean weekly SST as given in appendix 1. To check where in your image these difference are occurring you can calculate the weekly SST difference. Type the following expression in the command line from the main ILWIS menu and leave all other options default and press “OK”:

```
Dif_week1:= mean_sst_2007_wk1- mean_sst_2010_wk1
```

Display the map. Most of the regions along the coast of Tanzania and around Zanzibar and Temba have negative values, indicating that the temperatures in 2010 are higher. Repeat the difference calculation for week 12 and check the results. Also compare the histogram statistics of both difference maps.

18.6. Comparison of monthly MODIS temperatures to the Pathfinder SST climatology

To determine if the warm temperatures represents a risk to coral health, it is necessary to assess the temperature over several weeks, and compare the data for 2007 to climatological data (the temperature behaviour using a larger number of years) in order to determine if the warm water is substantially warmer than normal. However, incomplete clearing of sub-pixel cloud makes such a comparison highly suspect, as the affected areas are likely to have a lowered apparent temperature. For a valid assessment, it is necessary to find a better method of masking cloud-contaminated pixels.


For this reason, the rest of the exercise describes what should be done to carry out a coral heat stress assessment, once the weekly data is of sufficient quality to give an acceptable comparison with climatology and a reliable comparison between year 2007 and year 2010.

18.6.1. Checking for MODIS v Pathfinder bias

The Pathfinder data, derived from the AVHRR sensor on the NOAA series of satellites, from January 2006 and the corresponding MODIS 4km night-time SST data are imported into ILWIS. The data is converted to degree Celsius and are re-projected to a common projection. An independent data set, covering a region over the Atlantic Ocean, over 600 lines by 600 columns (approximately 387000 pixels) has been selected for both data sets to conduct this comparison. Display, using the same stretch values (e.g. from “5” to “20”), in separate map windows the Pathfinder and the MODIS January 2006 sub-sets, “*pf_sstn_subf*” and “*modis_sstn_subf*”

respectively. Visually check the maps. It seems that the MODIS data has a slightly more irregular appearance and shows some ‘pockets’ of lower SST regions.

Close both maps and select from the main ILWIS menu the option “Operations” > “Raster Operations” > “Cross”. As 1st map select “modis_sstn_subf” and as second one the map “pf_sstn_subf”, specify as output table “cross_modis_pf” and press “Show”. Inspect the cross table created. From the main table menu select the option “Columns” > “Statistics” and as Function use “Correlation”, select the two relevant columns and check the results. You will note a high degree of correspondence (R=0.978)

Select from the Table menu the graphics icon , and from the “Create Graph” menu, select as X-axis “modis_sstn_subf” and as Y-axis “pf_sstn_subf”. Press “OK” to display the graph. You can modify the Graph properties by selecting the items in the left hand graph legend; unselect “Legend”. Proceed from the active Graph window, select from the menu “Edit”, “Add Graph” and select “Least Square Fit”. Select as X-column “modis_sstn_subf” and as Y-column “pf_sstn_subf”, use as Function “polynomial” with “2” terms (1st order polynomial function) and press “OK”. From the Graph legend, select the item: “modis_sstn_subf * pf_sstn_subf - polynomial”, change the Color to “Black” and set the Line Width to “0.2”. Also note the regression formula, which is given on the lower left hand of this menu ($Y=0.133344 + 0.990103 * X$). Press “OK”. Check the resulting graph and unselect the data display option for the item “modis_sstn_subf * pf_sstn_subf” to get a better impression of the trend line. Your results should resemble those of figure 18.9.

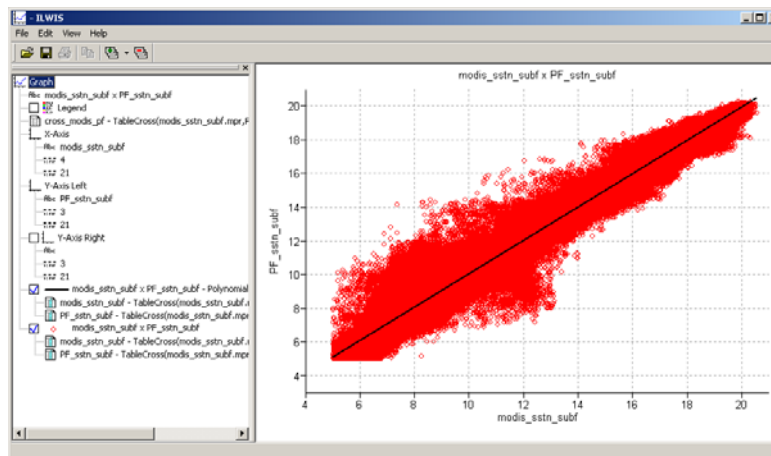


Figure 18.9 Comparing the MODIS and Pathfinder SST-night data for January 2006

The temperature range for this subset is from 5 to 20 degrees, when applying the polynomial function for e.g. 30 degree, for MODIS SST, the resulting value would be 29.85 degree for the Pathfinder SST. These deviations are relatively small and therefore given this assessment the monthly mean data from MODIS does not need to be corrected any further, even for area with higher sea surface temperatures.

One additional check is to calculate the difference between the two maps. Enter the following expression on the command line of the main ILWIS menu and accept the defaults and press “OK” to execute the operation:

```
dif_mod_pf:=modis_sstn_subf-pf_sstn_subf
```

Calculate the histogram of this difference map and check the mean, standard deviation and median values. Also here a slight positive bias can be observed but can be neglected. Note that here only January is considered, for a proper assessment also the other months have to be taken into consideration.

18.6.2. Calculation of monthly means and comparison with climatology

18.6.2.1. Calculation of monthly mean SST

You can calculate the monthly means either from the daily data, using the method described for weekly composites above, or you can do this directly using the weekly composites (4 weeks in January, 4 in February and 4 in March), using the command below (for January), using the default Raster Map definition options:

```
sst_jan_2007_mean:=(mean_sst_2007_wk1+mean_sst_2007_wk2+mean_sst_2007_wk3+mean_sst_2007_wk4)/4
```

The second option is quicker, but a little less accurate. However for a quick comparison to identify whether a particular month is warmer or colder than normal, it should be sufficiently accurate. Repeat this for the other 2 months in 2007 and for the 3 months in 2010. Check the statistics and determine for which month you have the maximum mean monthly sea surface temperature. The statistical results are also presented in appendix 1, and show that the mean SST values increase from January to March and the mean SST values are higher for 2010 compared to 2007 for all months.

18.6.2.2. Calculating monthly anomalies for March

Coral Reef Watch (CRW) hotspots are used by NOAA to predict hotspots of coral reef bleaching locations around the world where one has to investigate hotspots where the SST are higher than normal. According to Glynn and D'Croz (1990) corals start to experience threat when SST is 1°C higher than the highest maximum mean monthly (MMM) temperature.

In the previous activity, you might have noted that for the case of coastal Tanzania, the maximum mean monthly temperature occurred during the month of March. Thus to find CRW hotspots along the coast of Tanzania one would need to compare the image of the Maximum Monthly Mean for March with the global SST monthly climatological data for March. The climatology was obtained from the Pathfinder data set and the map provided is “*sstn_pf_mar_Tanzania*”. Display this map and check the values. Type the following expression in the command line of the main ILWIS menu, accept the default Raster Map definition options:

```
CRW_hotspot_March_2007:= iff(sst_mar_2007_mean -sstn_pf_mar_Tanzania>=1,1,0)
```

This calculates an anomaly map for March 2007 and the areas where the temperature difference is greater or equal to 1 is classified as 1, the other areas not meeting this threshold are assigned 0. Note that some regions may be cooler than normal but these are not of concern here. Any region with an anomaly of +1 degree C or more would be cause for concern. Display the resulting map and check your results. You will note that there are only a few pixels that have been assigned 1, check the histogram of the map if you are not convinced and eventually zoom in to inspect the map in more detail. Repeat the procedure to calculate the “*CRW_hotspot_March_2010*”. For 2010 a larger region is affected.

Use the map showing the coral reefs distribution along the coast of Tanzania with your calculated CRW_hotspot maps in order to identify any hotspot locations where high temperatures may represent a threat to coral reefs during the warmest period in each of the two years. This map is situated in the working directory and is called “*TZreefs.tif*”. You can open this map using the preview option of Windows Explorer. Visually try to identify the relevant areas.

18.7. Degree Heating Weeks (DHWs)

The prediction of coral reef bleaching is done using the concept of Degree Heating Weeks (DHW). This shows us not only where the temperatures have been higher than average for the warmest month, but also how long the high temperatures have persisted. One DHW is equivalent to 1 week of sea surface temperature at 1 degree C above the expected summertime maximum. Two DHWs can indicate either 1-week of 2 degree C OR 2 weeks of 1 degree C above the expected summertime maximum. Research carried out by Coral Reef Watch shows that significant coral bleaching may be expected when the thermal stress reaches 4 DHWs. When the thermal stress is about 8 DHWs, widespread mortality of corals may occur.

Open the map “*sst_month_max*”. This map is giving the maximum mean SST night time temperatures from the Pathfinder climatology which occurred over the warm season (January to April). This map is used as a proxy for the summertime maximum and the analysis will be done for 2010 as 2007 was hardly showing any ‘hotspots’. To derive the DHW the weekly mean night-time SST maps calculated earlier are used. First construct a new map list using the maps “*mean_sst_2010_wk1*” to “*mean_sst_2010_wk12*” and call the output map list “*mean_sst_2010*”. Type the following expression in the command line of the main ILWIS menu, press “*enter*” to execute the operation and accept the default Raster Map definition options:

```
DHW.mpl:=maplistcalculate("iff(@1-sst_month_max>1,@1-sst_month_max,0)",0,11,mean_sst_2010.mpl)
```

Check the result displaying the map list as an animated sequence. You will note that for some weeks there are “blank” areas with ‘no data’ values. These regions are set to “0” using the following expression:

```
DHW_cor.mpl:=maplistcalculate("ifundef(@1,0)",0,11,DHW.mpl)
```

Now you can aggregate the values of the 12 layers using the following expression:

```
dhw_sum.mpr:=MapMaplistStatistics(DHW_cor.mpl,Sum)
```

Finally, all areas that have remained 0, are being removed for better visualization:

```
dhw_sum_fin:=iff(dhw_sum>0,dhw_sum,?)
```

Display this map and add the country boundaries, these can be added using the “*Layers*” > “*Add Layer*” option from the active map window, browse to your ILWIS directory and select the map “*Africa_country*” from the sub-directory “*\Extensions\Geonetcast-Toolbox\util\maps*”. Compare your results with the locations of the coral reefs given by the image “*TZreefs*”, which can be opened using the Windows Explorer. Visually compare your results, looking particularly for locations where the DHW values are 4 or above. They should resemble those presented in figure 18.10, which shows the situation around Zanzibar.

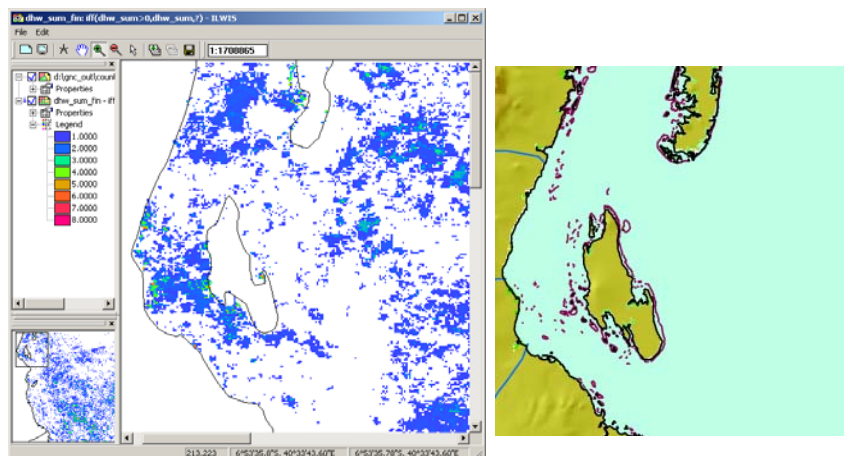


Figure 18.10 The calculated DHW for 2010 and the reef location map for the Tanzanian coastal region

To get an idea of the temporal distribution of your DHW over the 3 months of investigation, right click using the mouse the map list “DHW_cor” and select from the context sensitive menu the options “Statistics” > “Map List Graph”, use a fixed stretch, from “0” to “10”, activate the option “Continuous” and “Always on Top”, select the map “dhw_sum_fin” again and browse with the mouse over this map. Note the temporal variations of the DHW in the graphical window.

18.8. Conclusion

From this study, it is clear that the temperatures along the coast of Tanzania were rising gradually from Week 1 (January) to Week 12 (March) with highest SST towards the end of March (week 12), in both years. These results are consistent with *in situ* measurements from the temperature logger at Chumbe reefs located on the western coast of Zanzibar and the global climatological dataset. Temperatures were higher in 2010 than in 2007, and the DHW calculations revealed a few locations on the east side of Zanzibar and Pemba islands where reefs may have been at risk, whereas most locations were below the 4 DHW threshold. However, we have to be careful about drawing firm conclusions from this study alone. One reason for this is that the threshold method used for the cloud masking failed to identify all the cloud-contaminated pixels. As a result SST may have been underestimated.

Despite the shortcomings of this study, the methodology has potential capability to investigate the seasonal patterns of sea surface temperatures and identifying locations with higher than normal thermal stress to coral reefs. Once a more reliable method for masking of bad data has been found, the MODIS SST product can be used to calculate DHW and bleaching risk at 1km resolution. Such a method is explored in a follow-on lesson using the Bilko software which is being developed in EAMNet, which continues the marine component of DevCoCast (see www.bilko.org/eamnet/modis_sst_cloudclear.php). This compares the MODIS data to a lower resolution climate-quality product consistent with the Group of High Resolution Sea Surface Temperature (GRHSST) standards, and uses the results to set the cloud-masking threshold.

REFERENCES

Glynn, P. W. and L. D'Croz (1990): Experimental evidence for high temperature stress as the cause of El Niño coincident coral mortality. *Coral Reefs*, 8: 181-191.

Goreau, T. J. and R. L. Hayes (1994): Coral bleaching and ocean "hot spots." *Ambio* 23:176–180.

Strong, A. E., F. Arzayus, W. Skirving and S. F. Heron (2006): Identifying Coral Bleaching Remotely via Coral Reef Watch - Improved Integration and Implications for Changing Climate. In J.T. Phinney, et al. [Eds.], *Coral Reefs and Climate Change: Science and Management. Coastal and Estuarine Studies*, Vol. 61, American Geophysical Union, Washington, DC. 163-180 pp.

Coral Reef Watch (CRW) – Bilko module: Calculating Thermal Stress and Predicting Coral Bleaching: NOAA Coral Reef Watch Methodology. http://www.noc.soton.ac.uk/bilko/noaa_crw.php

ILWIS User Guide. Available from <http://52north.org/communities/ilwis/ilwis-userguide>

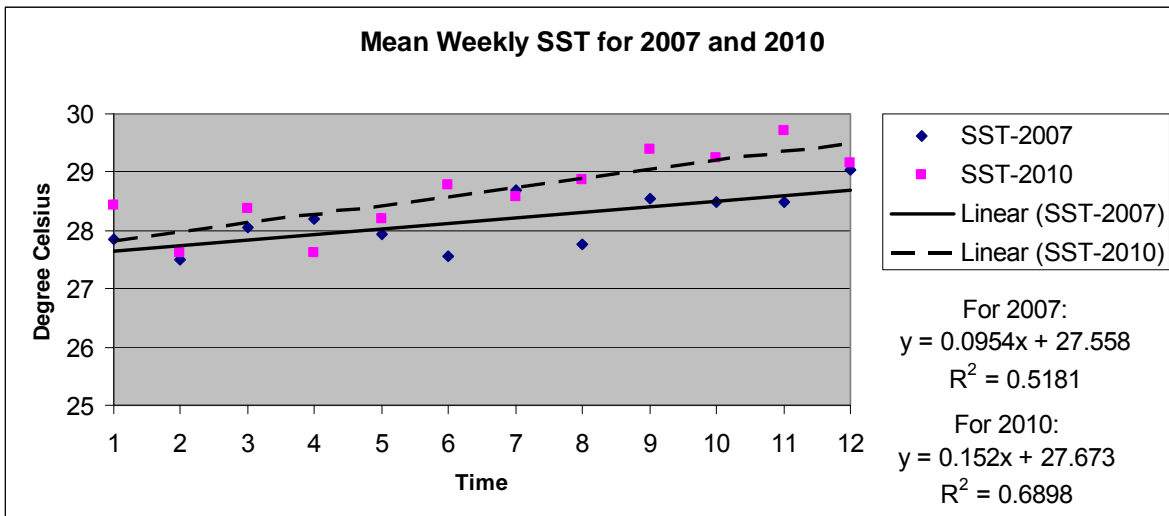
Maathuis, Ben, Chris Mannaerts, Martin Schouwenburg, Bas Retsios and Rob Lemmens (2011): Geonetcast Toolbox version 1.2 installation, configuration and user manual. Available from <http://52north.org/communities/earth-observation/geonetcast-toolbox-software>

APPENDIX 1

1. Histogram statistics for the weekly mean composites for the year 2007 and 2010

YEAR	2007				2010			
Parameter	mean	std	median	pred	mean	std	median	pred
Week1	27.85	1.13	27.82	28.14	28.43	0.90	28.52	29.14
Week2	27.51	0.66	27.57	27.77	27.62	1.09	27.73	28.13
Week3	28.04	0.84	28.07	28.27	28.38	0.67	28.47	28.68
Week4	28.21	0.80	28.30	28.52	27.61	0.67	27.65	27.69
Week5	27.95	0.77	28.01	28.85	28.19	0.75	28.25	28.64
Week6	27.56	1.07	27.58	27.60	28.77	0.86	28.90	29.35
Week7	28.69	0.85	28.72	28.72	28.59	1.20	28.75	29.27
Week8	27.76	1.11	27.83	28.56	28.86	0.98	28.95	29.31
Week9	28.56	0.65	28.64	28.69	29.38	0.73	29.45	29.97
Week10	28.48	0.75	28.55	28.85	29.23	0.83	29.26	29.10
Week11	28.50	0.79	28.52	29.02	29.71	0.87	29.80	30.27
Week12	29.03	0.52	29.07	29.22	29.16	0.77	29.21	29.30

2. Graphical representation of the mean sea surface temperatures (SST) for 2007 and 2010



3. Mean monthly SST statistics for 2007 and 2010

Month \ Year	2007	2010
January	27.89	28.00
February	28.02	28.60
March	28.65	29.37