Global Lakes Sentinel Services

GLaSS Training material, Lesson #5

Phytoplankton phenology in deep clear lakes

Does the offset of phytoplankton blooms in Lake Constance change?

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Lesson summary

Phytoplankton constitutes the base of the trophic web in freshwater environments and their biomass is coupled to all upper trophic levels. Phytoplankton biomass is sensitive to environmental change, with shifts in the seasonality of blooms, known as phenology, in response to temperature, nutrients and other environmental changes. Since phytoplankton phenology in terms of onset, peak and end or variable growth rates for has to be captured at the high frequency, satellite remote sensing is a suitable technology. This lesson covers how satellite data allow phytoplankton phenology investigations for Lake Constance, a large deep clear lake between Germany, Switzerland and Austria.

GLaSS training material outline

This lesson is part of the GLaSS training material. The complete training material outline is listed on http://data.waterinsight.nl/GLaSS/trainingmaterials/GLaSS_lesson_outline.pdf.

Note that the lessons logically follow up on each other, the later lessons might require skills that can be acquired during the earlier lessons.

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List of abbreviations

Abbreviation	Description
Chl	Chlorophyll
CHM	chlorophyll maximum concentration
CRS	Coordinate Reference System
EO	Earth observation
MERIS	Medium Resolution Imaging Spectrometer
MODIS	Moderate-resolution Imaging Spectroradiometer
MIP	Modular Inversion and Processing System
ROI	Region Of Interest
TSM	Total Suspended Matter

1 Introduction

Deep clear lakes are essential strategic resources providing multiple ecosystem services and are resources for recreation and tourism. Therefore they are typically affected by humans, leading to (often undesirable) environmental changes; moreover lake ecosystems, and especially freshwater phytoplankton, are sensitive sentinels of environmental and climate changes. In particular, the seasonality of phytoplankton biomass, known as phenology, has been demonstrated to shift in response to temperature, nutrient and other environmental changes.

Over the past decade, latest generation of ocean colour sensors such as MODIS and MERIS have provided unique information for lake monitoring. In particular, those sensors allow the phytoplankton biomass to be accurately monitored at the typical high frequency required for assessing phytoplankton phenology (Palmer et al., 2015).

This lesson relies on the 12-years long MERIS time series and aims to describe the timing (phenology) and the magnitude of phytoplankton biomass in Lake Constance, a deep clear lake between Germany, Switzerland and Austria. Although the improvement for large water treatment and restoration activities, pressures caused by high population density, climate change and the various utilizations of the lake resources (more than 4.5 million people in all the three countries depend on Lake Constance for drinking water) threaten the recent positive ecological developments.

In this lesson, the phytoplankton phenology in Lake Constance is obtained from statistical analysis of chlorophyll (Chl) concentration, used as proxy of phytoplankton biomass, obtained from MERIS data from 2003 to 2011. For each year or season, the onset as well as the frequency of occurrences of phytoplankton is computed for both the whole lake area and for few sub-basins. A variety of tools available in VISAT-BEAM are used for such purposes.

2 This lesson

2.1 Research question

Does the offset of phytoplankton blooms in Lake Constance change?

2.2 Training objectives / skills to gain in this lesson

The aim of this lesson is to investigate the phenology response of Lake Constance in terms of onset of phytoplankton bloom and spatial distribution.

- Visualisation of MERIS-derived products

- Investigation of phytoplankton abundance (in terms of Chl concentration) during the year in different sub-basins

- Definition of regions of interest (ROIs) on image data based on different tools

- Finding the timing of phytoplankton growth onset basic on statistics applied to time-series Chl data

2.3 Required software and data

Software and tools

To complete this lesson tasks, the following tools and software are required or suggested:

- BEAM/SNAP 2.0 (required, see Lesson #1).
  Figures and buttons position in this document are referred to the BEAM-VISAT interface. Some slight difference may occur in SNAP interface.

- R (see https://www.r-project.org/ for free downloading and details) incl. *xts*, *date* and *chron* packages (Ryan and Ulrich, 2014; Therneau et al., 2014; James and Hornik, 2015) are suggested to perform the analysis of phenology pattern (in Part 3) through the scripts provided, but the analysis can be performed through a spreadsheet. Packages can be installed following instructions in provided scripts.

Downloadable files

- GLaSS_Training_Lesson5.pdf
  The main document of the lesson including exercises and questions.

- GLaSS_Training_Lesson5_Answers.pdf
  A document containing answers to all questions proposed in the exercises.

- GLaSS_Training_Lesson5_DataAndTools.zip
  Supplied data and tools, described below.

The zip-file with supplied data and tools contain:

A 'Sample_data' directory containing:

- 55 MIP maps of chlorophyll concentration of Lake Constance from available dates in 2005 (GeoTIFF format).

- 'Constance.shp' and its complementary files: a shapefile containing two sample regions selected for data extraction and for the evaluation in phenology changing.

- 'Constance_timeSeries.txt': CHM statistics extracted from all available images from the same two regions contained in 'Constance.shp'.

A 'Tools' directory containing:

- 'Stats_extraction_PixEx.xml' for the extraction of pixels value from MERIS Constance products through BEAM *PixEx* operator used in batch mode.

- 'phenology_Constance.R', R script for the analysis of phenology in Lake Constance.

3 Exercise

Part 1 Long-time series generation from EO (Earth Observation) products through PixEx BEAM operator used in batch-mode

In the GLaSS project core, for the estimation of chlorophyll concentration in Lake Constance, MIP (Modular Inversion and Processing System) algorithm was used. Its algorithms are based on physical inversion schemes that derive bio-physical parameters from the measured radiance signal at the sensor (Heege et al., 2003) through the minimization of the difference between satellite measured and modelled spectra of water surface. It provides estimates of chlorophyll maximum concentration (CHM), water turbidity (linearly linked to TSM concentration at low to moderate concentrations as found in Lake Constance) and Secchi Disk values. GeoTIFF images provided contain a single band (called 'band_1'), representing CHM [mg/m^3].

Activities

The first step consists in the CHM values extraction from all available images in 2005, as a sample year, to analyse CHM trend during the year. *PixEx* operator extracts alternatively, the value recorded in a pixel or in a group of pixels, giving all values (with 'no aggregation' method), the mean, the minimum, the maximum or the median value of pixels in a square window of a given size centred in a point of given coordinates. It extracts statistics from all available products given in input.

- ➢ In the folder 'Tools' open the 'Stats_extraction_PixEx.xml' file.

  - • Complete the path for the directory in which MERIS images are stored and the file pattern (the pattern of all the products you want to include in your analysis), in this case '<sourceProductPaths>...\Sample_data*.tif</sourceProductPaths> ': *PixEx* will recursively look for all GeoTIFF products in the folder.

  - • Complete the path of the file containing Lake Constance regions centre coordinates ('<coordinatesFile>...\Sample_data\Constance_coord.txt</coordinatesFile>', coordinates should be expressed in WGS84 CRS) and the size of the window for statistics extraction: with '<windowSize>3</windowSize>' a three by three pixels window is defined.

  - • Define the output path (a directory where you want to store *PixEx* results) and the prefix you prefer for the name of results file.

  - • An expression can be used to define valid pixels: '<expression>(band_1 > 0)</expression>'. It means that the tool will skip pixels where CHM is less than zero (where CHM is not calculated, for example on the land, pixels value is equal to -9999.0 in the GeoTIFF products provided).

  - • Define the aggregation method choosing among 'no aggregation', 'min', 'max', 'mean', 'median'.

- ➢ Open BEAM *Command Line* (look for it in your browser typing 'cmd') and type 'gpt …\Tools\ Stats_extraction_PixEx.xml' (complete the directory path, do not use blank spaces in the path). *PixEx* starts collecting all available products in the selected folder.

> ➤ Two files are thus generated in the output directory,
> 'Constance_GeoTIFF_measurements.txt' and 'Constance_productIdMap.txt',
> containing, respectively, the values extracted from valid pixels for each station defined
> in the coordinates file and a list of all products used for statistics extraction.

> ➤ In 'Constance_GeoTIFF_measurements.txt' also the number of valid pixels used for
> the statistics calculation is provided. Delete all results obtained from less than 50% of
> valid pixels (i.e. less than 5 pixels), to avoid outliers.

> o *Analyse results: what's the trend of CHM during the year? It can be noticed some kind
> of seasonality or values are quite constant?*

> o *Can you recognize any CHM peak in the series? When CHM reaches its maximum in
> 2005? Is CHM similar in both regions? Where and when is it higher?*

> o *Considering CHM mean plus its standard deviation, how many times did CHM exceed
> this threshold in 2005?*

Part 2 Spatial distribution of phytoplankton bloom

As shown in Figure 1, some phytoplankton blooms occurred, but not always in both regions,
and with different magnitude. In this part, EO products are used to identify lake pixels
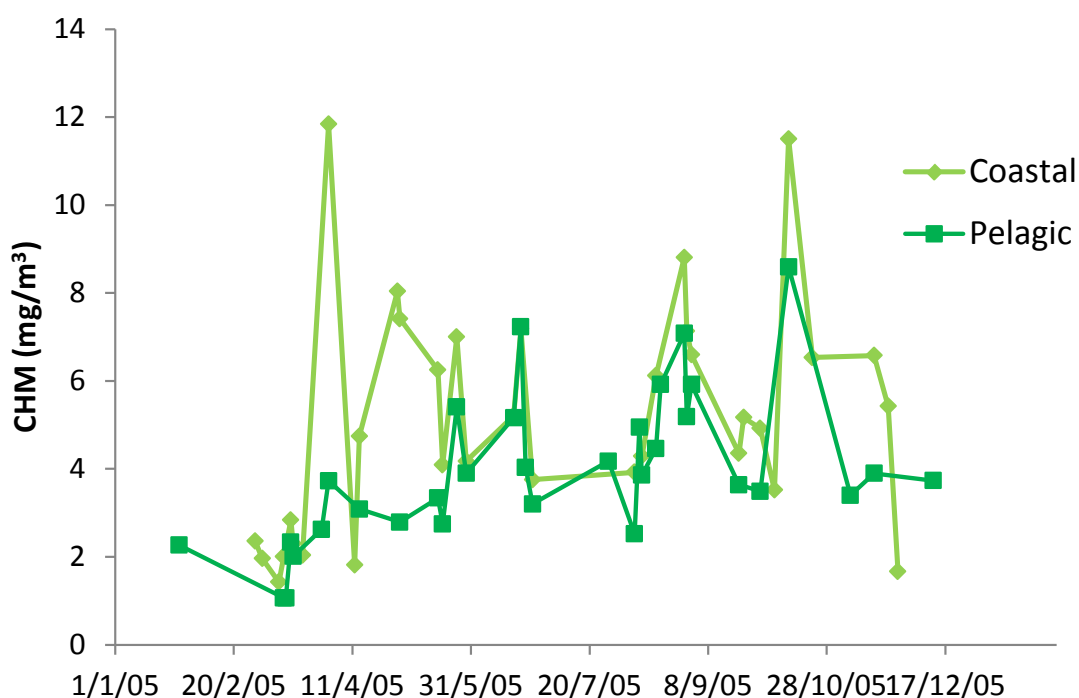affected by algal blooms and to analyse differences in algal blooms distribution.

Figure 1. CHM trend in 2005, in 'Coastal' and 'Pelagic' regions.

Activities

> ➤ Start VISAT, the BEAM interface (find it in ...\beam-5.0\bin)

> ➤ Open the MERIS image of 1/4/2005 (*File > Import Raster Data > GeoTIFF* and select
> image 'CHM_de-
> lake_constance_EOMAP_20050401_102538_MERIS_m0300_32bit.tif'). You can

read the date from the image name.

➢ Expand the product folder, expand *Bands* folder and double click on *band_1* to open a grey-scale map of CHM concentration.

➢ CHM values can be shown clicking on *Pixel info* tab and moving the pointer across the map (it shows the value for each pixel pointed).

➢ Switch to *Colour manipulation* tab: choose Editor *Basic* and the colour ramp you prefer. Change Minimum and Maximum values to be included in the scale range.
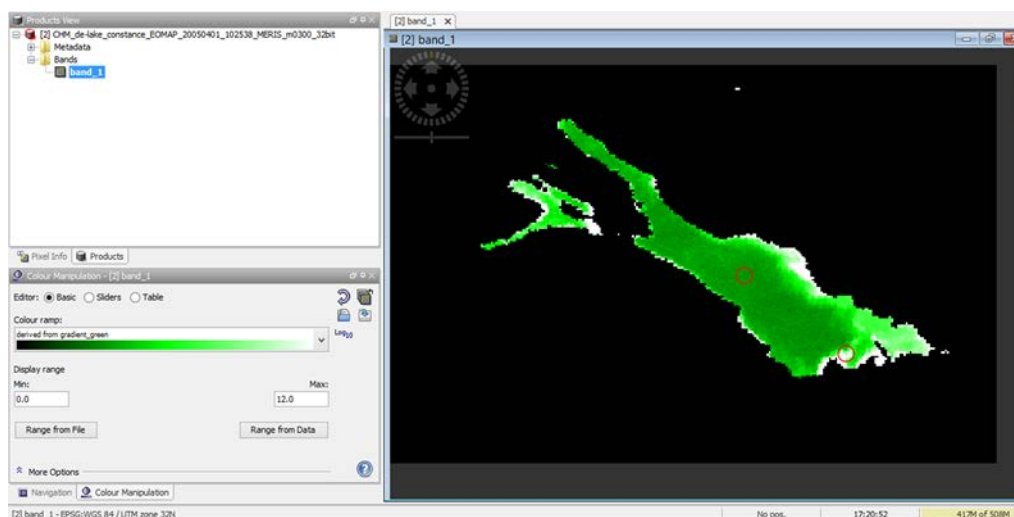

Figure 2. CHM map of Lake Constance on April 1st 2005 displayed in VISAT with Colour Manipulation tab (left side) and regions used for statistics extractions (red circles).
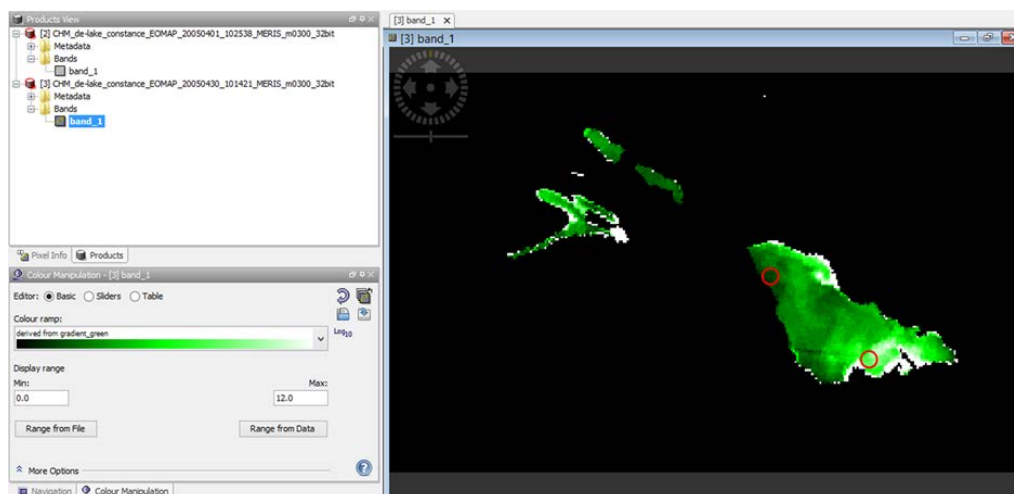

Figure 3. CHM map of Lake Constance on April 30th 2005 displayed in VISAT with Colour Manipulation tab (left side) and regions used for statistics extractions (red circles).

➢ Import the shapefile containing Constance regions polygons (*Import > Vector Data > ESRI Shapefile* and select 'Constance.shp'): two masks are automatically generated

➢ Open ⬛ and select *f(x)* to generate a mask for valid pixels only. A new window

appears, where a logical band math expression can be defined using band or predefined masks. Select all valid pixels in the maps typing 'band_1>0'. An automatic string warns you whether the expression is correct or nor.
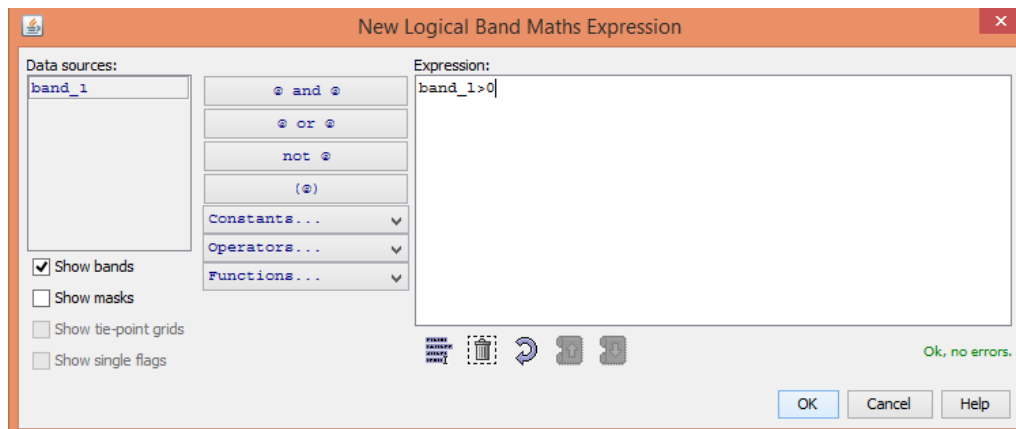

Figure 4. VISAT tool for masks definition through logical Band Maths Expression.

➤ In order to obtain a mask for each region, containing only valid pixels, open ⬛ and select one region and the mask of valid pixels previously created. Then, click on ⬛ to intersect the two elements: a new mask will be created. Edit the name typing in 'Name' column 'Pelagic_valid'. Replicate the same actions for the 'Costal' region.

➤ Open *Statistics* tool Σ and calculate statistics ⟳ using the last two masks generated ('Coastal_valid' and 'Pelagic_valid').

o *What's CHM average value in both regions on April 1st 2005?*

o *Consider the sum of CHM mean and standard deviation calculated on both region in 2005: how much of the lake surface is interested by the phytoplankton bloom on April 1st 2005?*

o *How much of the surface affected on April 30th 2005?*

Part 3 Phenology analysis

In this last part, phenology is analysed in both lake regions using long-time series generated from EO products. The date in which cumulative CHM exceeded the 25% of total CHM in each year is selected as the start date of phenology. This allows analysing differences between different regions and different years.

Activities

- Start the R console installed and open 'phenology_Constance.R'

- Complete the script defining the path and file name containing Constance CHM values (for ex. 'data <- read.table('.../Sample_data/ Constance_timeSeries.txt', header=TRUE, sep='\t')

- Start the script: after loading the data, it excludes dates with less than 50% of valid pixel in the region, and it computes phenology starting date for each year and region.

o *In what region phenology started later in 2008?*

o *In 'Pelagic' region, when phenology started earlier?*

4 More information and further reading

This lesson is based on the following report:

- GLaSS Deliverable 5.3, 2015. Global Lakes Sentinel Services, D5.3: Deep clear lakes with increasing eutrophication. CNR, WI, EOMAP, BG. Available via: http://www.glass-project.eu/downloads/

The report is suggested for further reading. It contains processed data time series analysis for several years for Lake Constance, but also for the following deep clear lakes:

- Lake Garda
- Lake Maggiore
- Lake Vättern
- Lake Michigan
- Lake Malawi
- Lake Tanganyika

For more information on GLaSS, and to download all public reports: www.glass-project.eu.

References

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Colophon

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