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D8.2: Transformation multispectral remote-sensing images in to the FU

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Abstract (for dissemination)	This report is a support to the dissemination of the multispectral remote-sensing data transformation into Forel-Ule (FU) colorimetric scale adapted to MERIS sensor. The sequence from the CoastColour data downloading, the geo-referencing, projection and Fu and Chl (derived from FU) processing to the upload in to the Citclops server are described.
Keywords	FU, Chlorophyll, remote-sensing, CoastColour, MERIS

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1 Introduction

Satellite observations take advantage from the large spatial coverage but with a medium spatial resolution. Conversely, on-ground measurements are sparse and often not regular measurements. These two datasets would benefit from each other for inter-comparison and verification.
The monitoring of the water quality can be improved with the used of the two observation modes simultaneously.
Some in-orbit instruments are dedicated to the observation of the ocean colour, and through the retrieval of specific parameters can evaluate proxies of water quality like the concentration in plankton or in suspended matter, or water optical properties.
Another semi-empirical parameter is used to give an indication on the water quality with a simple and robust method existing since more than one century: the Forel-Ule colour index. The Forel-Ule (FU) parameter is not provided in the standard satellite products and has to be processed for the Citclops project.

Based on space borne ocean colour instruments (MERIS/ENVISAT, and the future OLCI/Sentinel-3), Citclops will disseminate satellite-derived data layers through its webGIS system to the community to help the verification and interpretation of observations collected by the public over the two pilots zones: the Alfacs Bay, located in the Northwest Mediterranean sea and the Wadden Sea located in the South Eastern part of the North Sea.

2 Context

The processing described in the following is part of a wider task in which several bio-optical satellite derived parameters will be disseminate in a web GIS system that will help the comparison and evaluation of the on-ground measurements.
The first step is to build an automatic processing sequence to calculate the FU parameter from the CoastColour MERIS/ENVISAT satellite data over the two pilot zones and for the global database of CoastColour product.
In a second part, a selection of relevant parameters will be processed and will be disseminated in the GIS web system. These parameters have been selected with the Citclops partners and are given in the Citclops D8.1 document [Ref. 2].

3 MERIS Remote-sensing data

The MEdium Resolution Imaging Spectrometer (MERIS), a multichannel spectrometer onboard ENVISAT is dedicated to the ocean colour observations and has proved its efficiency on the retrieval of ocean colour parameters used in climate issues, monitoring of ocean change, fishery management, etc.
Originally, the Citclops project wanted to benefit from the near-real time dissemination service of MERIS data and link with the in-situ measurements from smartphone devices or specific instruments. The satellite is out of order since April 2012 after 10 orbiting years, consequently the near-real time service has been stopped. The Citclops partners decided to use the satellite data archive from MERIS to benefit from the temporal coverage of 10 years observations on the two application areas of the project.

The ESA-founded project CoastColour brought together specialists in water colour issues and experts in the determination of optical water properties, biology experts and

specialists in in-situ measurements. One of the objectives was to improve the MERIS originally products and to reprocess a huge database containing ocean colour products for a free dissemination in the community. Details of the CoastColour project are presented in the Citclops deliverable D8.1 [Ref. 2].
The CoastColour database is focused on 27 zones, all over the world, mainly coastal zones in which Citclops pilot areas Alfacs Bay and Wadden Sea are included.

4 Transformation of MERIS data into the FU colour index

In the Coastcolour MERIS dataset, ocean colour is grouped in several categories and cover concentration parameters like chlorophyll and total suspended matter, inherent optical properties, and chlorophyll indices like fluorescent line height and Maximum Chlorophyll Index.
Another parameter relevant for water quality monitoring is a colorimetric scale developed by Forel and Ule at the end of the 19th century (Ref. 3, Ref. 4 and Ref. 5) and described as early as 1930 by Rosen (Ref. 6). The scale is based on coloured water solutions by different mixing of dissolved chemical compounds. The methodology was then improved and adapted to multi-spectral images from MERIS sensor [Ref. 1]. The detailed methodology and algorithm is given in the Citclops deliverable D2.3 [Ref. 1].

4.1 The methodology

The formulation of the conversion from MERIS surface reflectance to FU scale has been given to NOVELTIS by NIOZ. An additional step has been to derive the chlorophyll concentration from the FU.
The details are given in the Citclops D2.3 and are briefly summarised in the annex 1.

The data generated for Citclops are the new FU and FU-derived Chl (Chl_FUdrvd) bands which are calculated on the CoastColour data in its original spatial resolution, 300m.

The FU index ranges from 1 to 21 (indigo-blue to cola-brown respectively). The colour index roughly indicates different types of natural waters; Oligotrophic, Mesotrophic, Eutrophic like the open ocean, coastal zones, tidal flats or river and lakes.

4.2 The process and management of the data

The process to obtain the FU scale is listed below and illustrated in the Figure 1:

1- Download the water leaving reflectance CoastColour (level 2 R – L2R) from the CoastColour website;
2- Management of data in the NOVELTIS server;
3- Subset the images to select the parameters and the areas of interest;
4- Reproject the data on a fixed grid and remove invalid pixels;
5- Process the FU & Chl_FUdrvd calculation from the gzip compressed data;
   ➔ Obtain the FU and Chl_FUdrvd bands in an output netCDF file;

6- Upload the processed FU and Chl_FUdrvd data to the Citclops server and manage the data in a valid tree view.

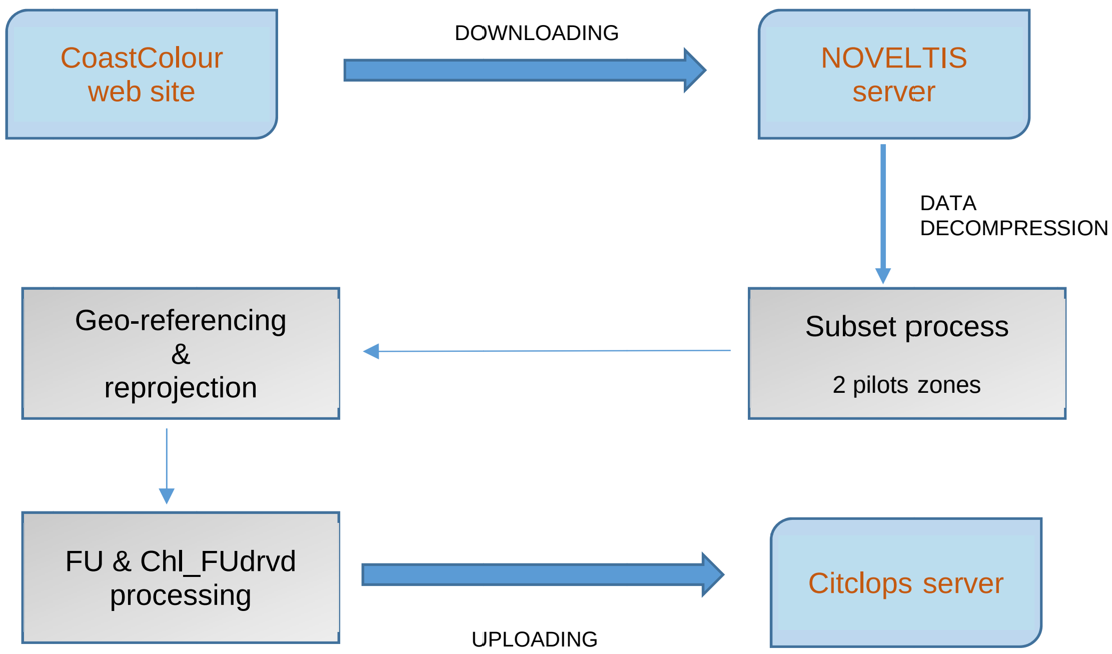

Figure 1: Diagram of the CoastColour data (MERIS images) transformation process to FU and Chl_FUdrvd to the final Citclops server upload.

The download of the MERIS data is done via the FTP of the CoastColour web site: http://www.coastcolour.org/.
These data are then stored on the NOVELTIS server and are managed in a valid tree view.

The original data are downloaded from the two CoastColour sites: Mediterranean_BlackSea and NorthSea and only the convenient tracks corresponding to the two pilot zones are extracted. These data are managed in two separate directories for the two pilot zones, Alfacs Bay and North Sea and stored for the complete database of CoastColour from 2005 to April 2012.

The total volume of data is estimated to 3.5 terabytes for the CoastColour database over the two pilot zones. At this deliverable time, the data downloaded and processed are currently for the year 2011. The download and the processing are in progress and in the future all the CoastColour database will be processed.

Simultaneously, the FU and Chl_FUdrvd are calculated. Then, the new netCDF files are managed in the same tree view and finally uploaded to the Citclops server.

4.3 Interpolation / reprojection

The input CoastColour data is georeferenced in the sense that each pixel has assigned a latitude/longitude value that was derived using an orthorectification process.

As is noted in section 6.2.1 of the CoastColour Product User Guide, the georeferencing data is however not applied to the data, instead the original MERIS grid is kept. The result is that the dimensions of the pixels do not correspond to the dimensions given by the ground coordinates, (e.g. off-nadir effects are not accounted for), meaning that the images are not directly comparable with external datasets.

For the Citclops project and in order to apply data to a Decision Support System (DSS), it is important that the CoastColour data is rapidly comparable with external datasets, and also that 2D time series data be easily extracted for arbitrary regions. For the process consuming the time series, it is important that the extracted time series data is of consistent dimensions and that pixels are directly comparable with those found directly 'underneath' or 'above' in the preceding and following time slices.

To achieve this, the initial georeferencing step was to use the lat/long coordinate values found for each pixel and to project the data into the WGS84 lat/long (EPSG: 4326) projection.

Afterwards, a second step was taken to align the resulting images to the same grid, so that every image for the same study area is exactly the same dimension, and its pixels have exactly the same coordinates. This allows us to extract a rectangular window and have a stack of time slices representing the exact same coordinates on the ground, varying only in their pixel values.

The process of georeferencing/projecting was performed simultaneously using GDAL under Python, with the idea that a single step would introduce less error. The pixel value interpolation algorithm selected was Nearest Neighbour, when applied to pixels equal or smaller to the original produces an accurate representation of the original. The pixel size chosen was representative to the one of the original MERIS pixel in the zones of the study areas. (0.00304749 degrees).

4.4 Illustration

Two derived FU maps (1st April 2011) are shown in Figures 2 and 3 (see page 8 and 9): the Baleares region and a zoomed map over Alfacs Bay.

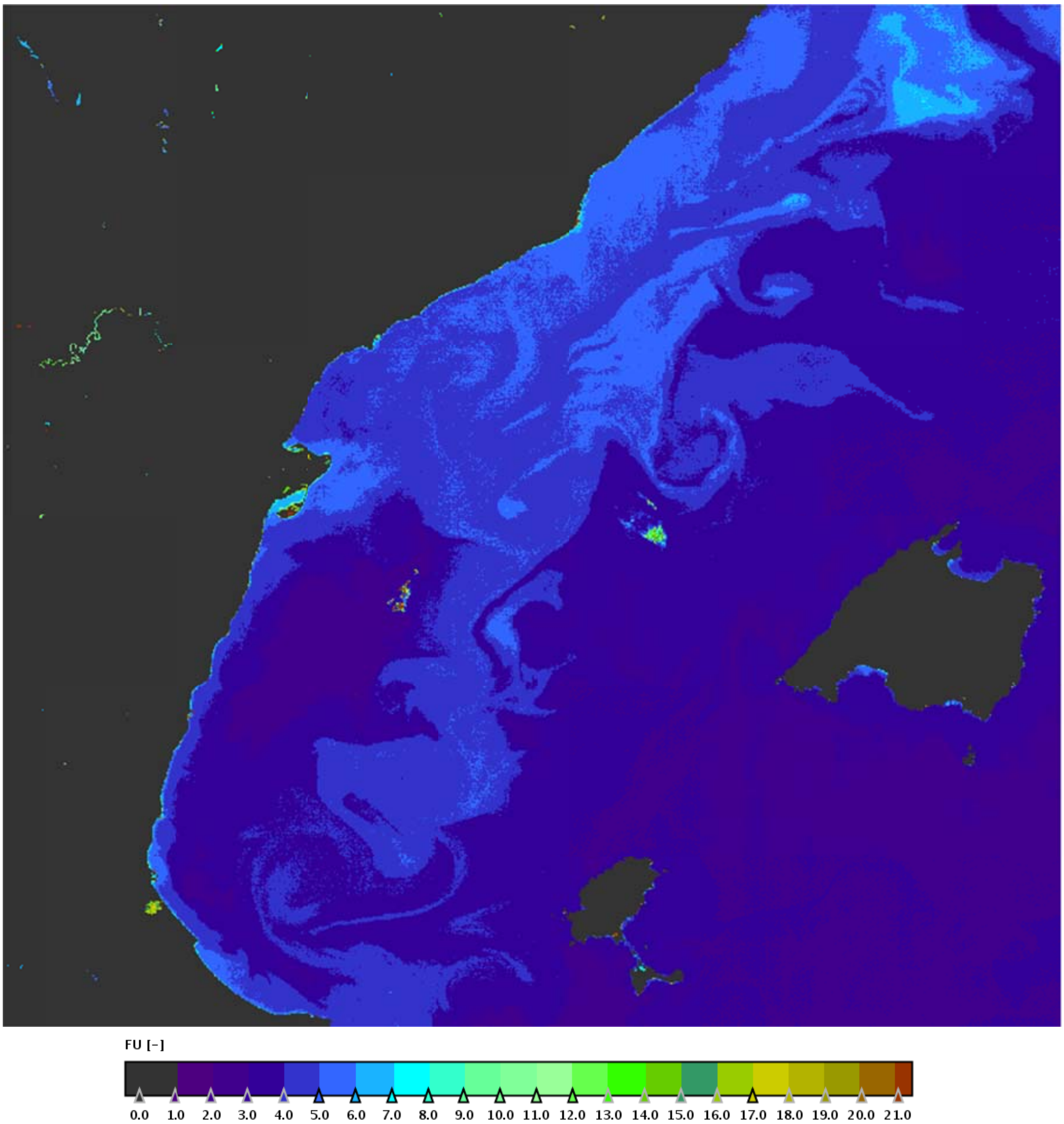

Figure 2: FU scale for the CoastColour MERIS data over the Baleares region on the 01/04/2011.

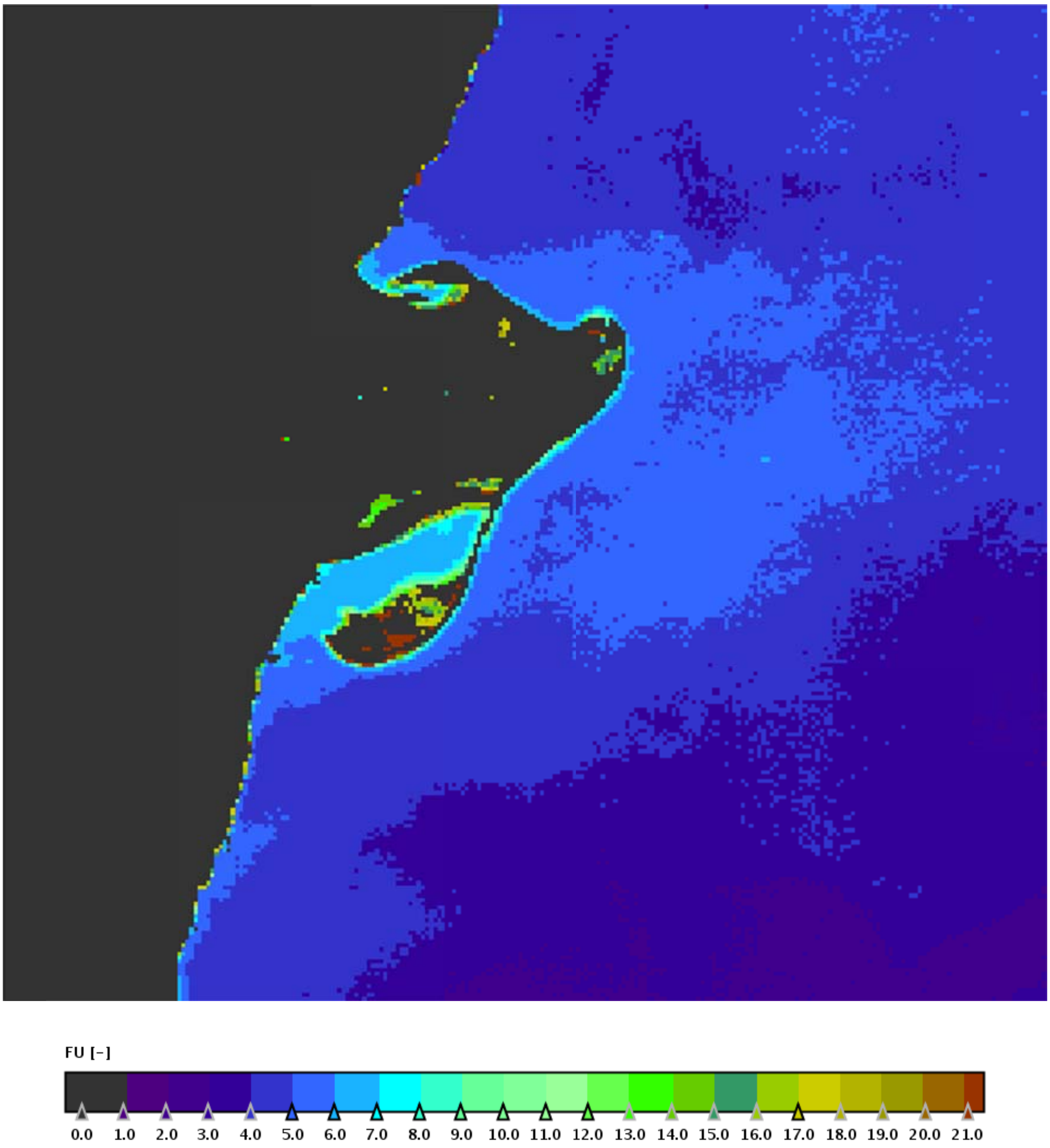

Figure 3: FU scale for the CoastColour MERIS over the Alfacs Bay on 01/04/2011.

5 Availability of the data

The data are available on the Citclops server. The IP address is available under demand; please contact the project Coordinator BDIGITAL (msanchez@bdigital.org or pmo@bdigital.org)

6 Conclusion

The process of the FU and Chl_FUdrvd from the CoastColour MERIS data products has been done for the year 2011 and is in progress for the global database (2005 to April 2012).

As each year is processed for each study zone the data will be uploaded to the CITCLOPS server, where it will eventually be exposed via the various GIS and interoperability services. As described in the D8.4 document: "*GIS systems design outlining data workflow and interfaces*" the data will be spatially indexed and represented in a relational database, allowing rapid queries of what data exists for what region and which dates.

7 References

Ref. 1 Citclops deliverable D2.3 v1.3: “Algorithms for FU index and water light extinction coefficient retrieval from images coming from smart phones and wearable underwater cameras”, 2013.

Ref. 2 Citclops deliverable D8.1 v1.1: “Transformation of MERIS multispectral remote-sensing images to GIS layers”, 2013.

Ref. 3 Forel F.A., "Couleur de L'eau" in Optique, Le Léman. Monographie Limnologique, 2, 462-487, 1895.

Ref. 4 Ule W., "Die bestimmung der Wasserfarbe in den Seen" in Kleinere Mittheilungen. Dr. A. Petermanns Mittheilungen aus Justus Perthes geographischer Anstalt, 70-71, 1892.

Ref. 5 Ule W., ”Beitrag zur Instrumentenkunde auf dem Gebiete der Seenforschung,” Dr. A. Petermanns Mittheilungen aus Justus Perthes geographischer Anstalt 40, 213–214, 1894.

Ref. 6 Rosen M.T., "Die Skala von Forel-Ule zur Bestimmung der Farbe des Wassers" in Nachrichten des Zentralbro fr Hydrometeorologie, 9, 20, 1930.

Ref. 7 Wernand, M. R., Hommersom, A., and van der Woerd, H. J., “MERIS-based ocean colour classification with the discrete Forel–Ule scale”, Ocean Sci., 9, 477-487, doi:10.5194/os-9-477-2013, 2013.

8 List of Key Words/Abbreviations

Chl	Chlorophyll
DSS	Decision Support System
ESA	European Space Agency
FLH	Fluorescence Line Height
FU	Forel-Ule
GDAL	Geospatial Data Abstraction Library
GIS	Geographic Information System
L2R	Level 2 Reflectance
MERIS	MEdium Resolution Imaging Spectrometer
MCI	Maximum Chlorophyll Index
NetCDF	Network Common Data Form
OLCI	Ocean and Land Colour Instrument
TSM	Total Suspended Matter

Annex 1

BEAM-VISAT calculation of Forel-Ule index from MERIS reflectance using CIE1931 cmf's. (Wernand – Novoa, 17 Oct. 2013)

MERIS band	nm	x-cmf	y-cmf	z-cmf
reflec_1	412.5	0.058371	0.001626	0.278693
reflec_2	442.5	0.350080	0.026284	1.772944
reflec_3	490	0.032010	0.208020	0.465180
reflec_4	510	0.009300	0.503000	0.158200
reflec_5	560	0.594500	0.995000	0.003900
reflec_6	620	0.854450	0.381000	0.000190
reflec_7	665	0.121200	0.044580	0.000000
reflec_8	681	0.043784	0.015904	0.000000
reflec_9	708	0.006627	0.002393	0.000000

Table 1. MERIS band name and wavelength with the belonging colour matching function value for x,y and z.

<u>The CIE 1931 colour matching function and MERIS</u>

1- <u>The Tristimulus values:</u>

X2

0.5*(442.5-412.5)* (reflec_2*0.35008-reflec_1*0.05837) + 0.5*(490-442.5)* (reflec_2*0.35008- reflec_3*0.032010) + 0.5*(510-490)* (reflec_3*0.032010-reflec_4*0.009300) + 0.5*(560-510)* (reflec_5*0.594500-reflec_4*0.009300) + 0.5*(665-620)* (reflec_6*0.854450-reflec_7*0.121200) + 0.5*(681-665)* (reflec_7*0.121200-reflec_8*0.043784) + 0.5*(708-681)* (reflec_8*0.043784-reflec_9*0.006627)+ (442.5-412.5)*reflec_1*0.05837 + (490-442.5)*reflec_3*0.032010 + (510-490)* reflec_4*0.009300 + (560-510)* reflec_4*0.009300 + (620-560)*reflec_6*0.854450 + (665-620)*reflec_7*0.121200 + (681-665)*reflec_8*0.043784 + (708-681)*reflec_9*0.006627

Y2

0.5*(442.5-412.5)* (reflec_2*0.026284-reflec_1*0.001626) + 0.5*(490-442.5)* (reflec_3*0.208020-reflec_2*0.026284) + 0.5*(510-490)* (reflec_4*0.503000-reflec_3*0.208020) + 0.5*(560-510)* (reflec_5*0.995000-reflec_4*0.503000) + 0.5*(620-560)*(reflec_5*0.995000- reflec_6*0.381000) + 0.5*(665-620)* (reflec_6*0.381000-reflec_7*0.044580) + 0.5*(681-665)* (reflec_7*0.044580-reflec_8*0.015904) + 0.5*(708-681)* (reflec_8*0.015904-reflec_9*0.002393) + (442.5-412.5)*reflec_1*0.001626+ (490-442.5)*reflec_2*0.026284 + (510-490)* reflec_3*0.208020 + (560-510)* reflec_4*0.503000 + (620-560)*reflec_6*0.381000 + (665-620)*reflec_7*0.044580 + (681-665)*reflec_8*0.015904 + (708-681)*reflec_9*0.002393

Z2

0.5*(442.5-412.5)* (reflec_2*1.77294-reflec_1*0.278693) + 0.5*(490-442.5)* (reflec_2*1.77294-reflec_3*0.465180) + 0.5*(510-490)* (reflec_3*0.465180-reflec_4*0.158200) + 0.5*(560-510)* (reflec_4*0.158200-reflec_5*0.003900) + 0.5*(620-560)* (reflec_5*0.003900-reflec_6*0.000190) + (442.5-412.5)*reflec_1*0.278693 +(490-442.5)*reflec_3*0.465180+(510-490)* reflec_4 * 0.158200+ (560-510) * reflec_5 * 0.003900+ (620-560) * reflec_6 * 0.000190

2- Calculation of the CHROMATICITY COORDINATES x and y

The two coordinates calculated, Chrx and Chry, represent the colour in a so-called chromaticity diagram (figure A-1). The diagram gives the colour saturation of a point with x,y coordinates between the white point and the CIE 1931 curve.

Chrx = X2 / (X2 + Y2 + Z2)

Chry = Y2 / (X2 + Y2 + Z2)

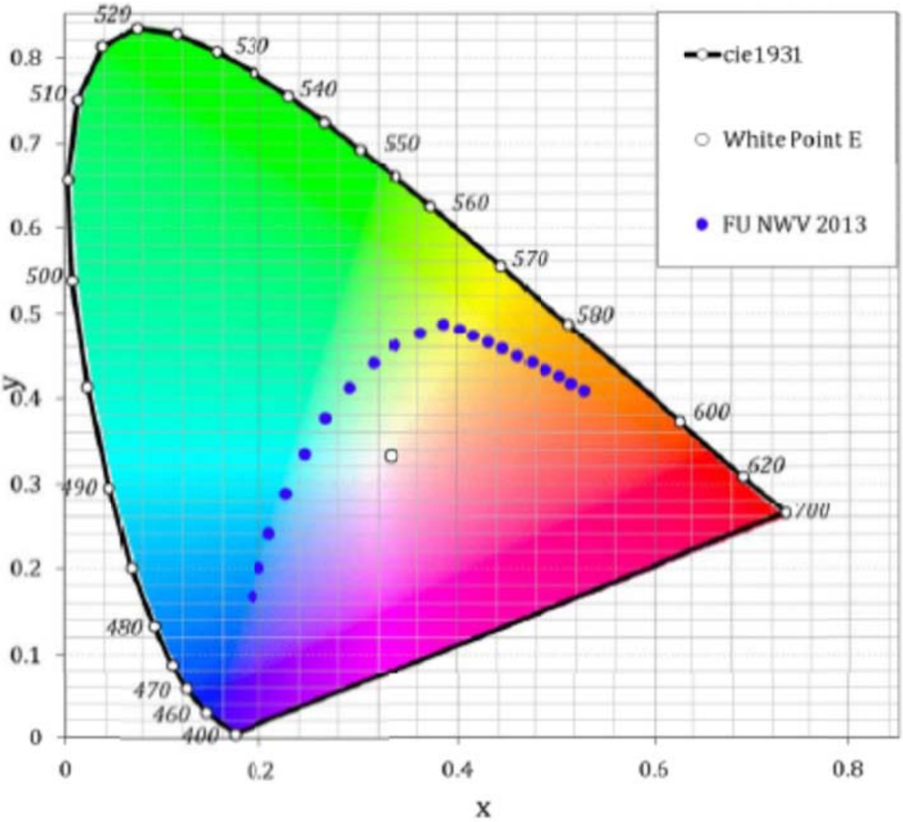

Fig A-1: Chromaticity diagram displaying the chromaticity coordinates of the FU scale (FU NWV 2013) calculated with the spectral transmission measurements of the FU solutions. The white points corresponds to an equal energy illuminant (E). (Extract from the Citclops deliverable D2.3 v1.3 final, Novoa S. and Wernand M.)

3- The FU number

The arctangent is the angle from the x-axis to a line containing the origin (0, 0), in this case the x,y of the white point (1/3, 1/3) and a point with coordinates x- xw _num, y- yw _num.

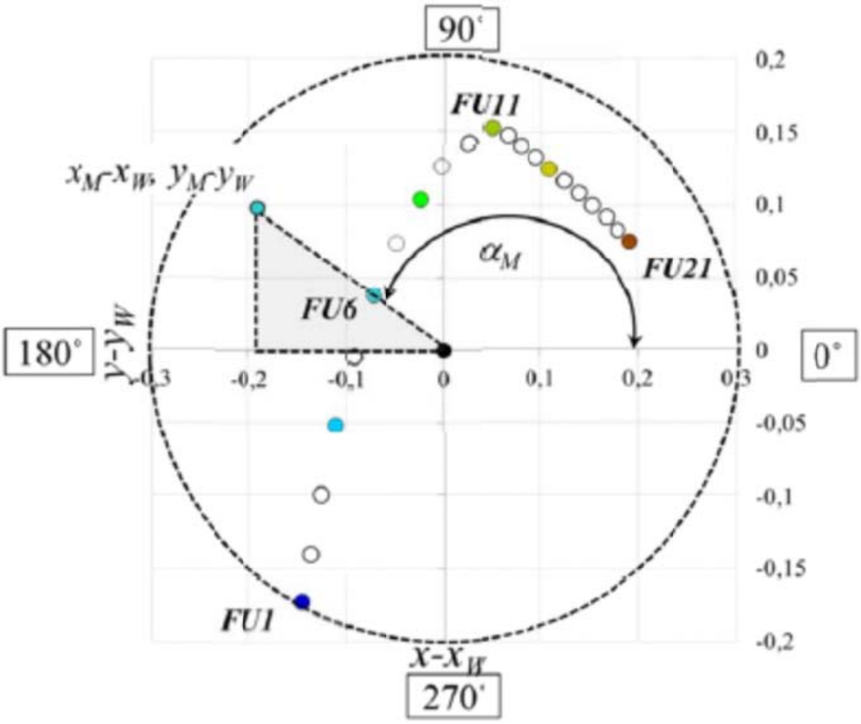

Fig A-2: Chromaticity diagram in a Cartesian system with known chromaticity coordinates relative to the white point of the scale colour FU1 to FU21 (shown in dots). An example of the chromaticity coordinates (xM – xW = -0.15, yM – yW = 0.1), again relative to the white point, derived from spectral information. This pixel can be labelled FU6. (Extract from the Citclops deliverable D2.3 v1.3 final, Novoa S. and Wernand M.)

The equation to link the chromaticity coordinates and the FU number:

$$\alpha_M = \arctan(y_i - y_W,\ x_i - x_W) \text{ modulus } 2\pi$$

where the y_W, x_W are the white points coordinates.
The FU number is assigned according the correspondence between the angles α_M and the FU number. The correspondence is given in the table A-1. The values greater than 232° and below 19° are assigned to 0.

a_{iT}	For *i=1* to *21* If $a_M > a_{iT}$ Then *FU* =	a_{iT}	For *i=1* to *21* If $a_M > a_{iT}$ Then *FU* =
232.000	0		
227.168	1	62.186	12
220.977	2	56.435	13
209.994	3	50.665	14
190.779	4	45.129	15
163.084	5	39.769	16
132.999	6	34.906	17
109.054	7	30.439	18
94.037	8	26.337	19
83.346	9	22.741	20
74.572	10	19.000	21
67.957	11		0

Table A-1: Determination of the FU-number belonging to known (x, y) chromaticity coordinates is achieved with the help of a given angle. (From the Citclops deliverable D2.3 v1.3 final, Novoa S. and Wernand M., and from Novoa et al. 2013, "The Forel-Ule scale revisited spectrally: preparation protocol, transmission measurements and chromaticity".)

4- Chlorophyll concentration

For the calculation of the chlorophyll concentration (Chl in mg/m3) derived from the FU number we use the formulation from Wernand et al. (2013).

The Chl calculation are given only for FU<11 :

$$Chl = 0.061*\exp(0.666* FU)$$

Annex 2

The colour scale of the Forel-Ule colorimetric parameter

```
#BEAM Colour Palette Definition File
#Fri Oct 18 11:44:07 CEST 2013
autoDistribute=false
color0=51,51,51
color10=128,255,153
color11=153,255,153
color12=102,255,77
color13=51,255,0
color14=102,204,0
color15=51,153,102
color16=153,204,0
color17=204,204,0
color18=179,179,0
color19=153,153,0
color1=77,0,128
color20=153,102,0
color21=153,51,0
color2=64,0,141
color3=51,0,153
color4=51,51,204
color5=51,102,255
color6=26,179,255
color7=0,255,255
color8=51,255,204
color9=102,255,153
numPoints=22
sample0=0.0
sample10=10.0
sample11=11.0
sample12=12.0
sample13=13.0
sample14=14.0
sample15=15.0
sample16=16.0
sample17=17.0
sample18=18.0
sample19=19.0
sample1=1.0
sample20=20.0
sample21=21.0
sample2=2.0
sample3=3.0
sample4=4.0
sample5=5.0
sample6=6.0
sample7=7.0
sample8=8.0
sample9=9.0
```