Haiti Matthew Hurricane damage assessment

Synthesis note

	name *function* *company*	*date* *signature*
prepared by	Serge RIAZANOFF *Engineer* VisioTerra serge.riazanoff@visioterra.fr	
	Zhour NAJOUI *Engineer* VisioTerra zhour.najoui@visioterra.fr	
	Guillaume AUREL *Engineer* VisioTerra guillaume.aurel@visioterra.fr	
checked by	Serge RIAZANOFF *Director* VisioTerra serge.riazanoff@visioterra.fr	

Document Status Sheet

Issue	Date	Comments	Author
1.0	23/12/2016	Draft 1 - Creation of the document	Z. Najoui
1.0	23/12/2016	Draft 2 - Photo-interpretation of Digital Globe data	Z. Najoui
1.0	03/01/2017	Draft 3 - NDVI processing and analysis	S. Riazanoff
1.0	09/01/2017	Draft 4 - Use of cloud masking	S. Riazanoff
1.0	08/01/2017	Draft 5 - Classification analysis	Z. Najoui
1.0	10/01/2017	First release	S. Riazanoff
2.0	22/02/2017	DELIVERY06/07 individual scenes	S. Riazanoff
3.0	03/03/2017	DELIVERY08/09 cloud masked individual scenes	S. Riazanoff
3.1	05/03/2017	DELIVERY010/12 cloud masked synthesis CC/NDI/Differences	S. Riazanoff
3.2	07/03/2017	DELIVERY013 statistical analysis of NDI differences	S. Riazanoff
3.3	18/03/2017	DELIVERY014 classes of damage severities from NDI differences	S. Riazanoff
3.4	12/04/2017	Last release of section 5.1.2. Using GPM data	S. Riazanoff

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1 Introduction

1.1 Purpose of this document

This document is the synthesis note of the project managed by UNEP for the "**Assessment of damages over Haiti after the Matthew hurricane (4th October 2016) using Earth Observation data acquired by Sentinel-2**".

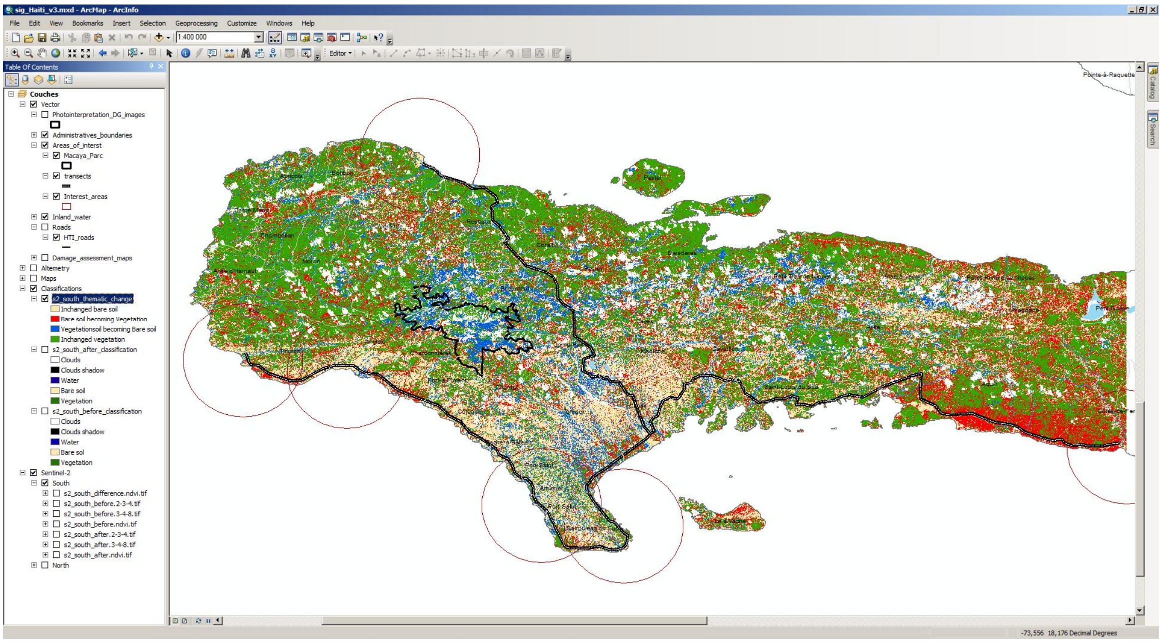


fig. 1 - Haiti project GIS showing the map of class changes from Sentinel-2 data.

1.2 Applicable documents

A-1 VT/SR/PR/279

Assessment of damages over Haiti after the Matthew hurricane (4th October 2016) using Earth Observation data acquired by Sentinel-2, Landsat-8 and THR data - Commercial offer
15th November 2016 - VisioTerra
..\..\..\propositions_commerciales\P279_UNEP_Damage_assessment_in_Haiti_after_Matthew_hurricane.pdf

1.3 Reference documents

This section describes the related documents and applied conventions to be considered within the present document.

1.3.1 Data repository

R-1 CNIGS

Haiti Data
CNIGS Haiti
http://haitidata.org

R-2 CNIGS

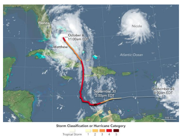
Haiti Landcover (Occupation du Sol), SPOT-CNIGS [04.1998] - polygon
CNIGS Haiti
http://haitidata.org/layers/cnigs.spatialdata:hti_biota_landcover_spot_cnigs_041998_polygon

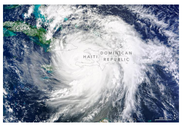
R-3 Web

Recovery Observatory
CEOS
http://dotcloud.akka.eu/drupal_dev/mapshup_page

R-4 Web NASA EO

Hurricane Matthew's Aftermath in Haiti
October 15, 2016
NASA Earth Observatory
http://earthobservatory.nasa.gov/IOTD/view.php?id=88933&eocn=image&eoci=moreiotd

R-5 Web NASA EO

Hurricane Matthew en route to Florida
October 7, 2016
NASA Earth Observatory
http://earthobservatory.nasa.gov/IOTD/view.php?id=88877&eocn=image&eoci=moreiotd

R-6 Web NASA EO

Hurricane Matthew Hits Haiti
October 5, 2016
NASA Earth Observatory
http://earthobservatory.nasa.gov/IOTD/view.php?id=88870&eocn=image&eoci=moreiotd

1.3.2 Sentinel-2

R-7
Sentinel-2 User Handbook
Issue 1, Revision 2 – 24/07/2015
SUHET
https://sentinel.esa.int/documents/247904/685211/Sentinel-2_User_Handbook
..\..\A001_VISIOTERRA_REFERENCE_DOCUMENTS\SENTINEL-2\Sentinel-2_User_Handbook.pdf

R-8 Web
SENTINEL-2
ESA
https://sentinel.esa.int/web/sentinel/missions/sentinel-2

R-9 Web
Sentinel-2 MSI Technical Guide
SEOM / ESA
https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-2-msi/

R-10 Web
Sentinel Application Platform (SNAP)
ESA
https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-2-msi/

R-11 Web
Monitoring Hurricane Matthe
Scientific Visualization Studio - NASA
https://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=4548&button=recent

1.3.3 Sentinel-3

R-12 GMES-S3OP-EOPG-TN-13-0001 *Sentinel-3 User Handbook*
Issue 1, Revision 0 – 02/09/2013
Sentinel-3 Team
https://earth.esa.int/documents/247904/685236/Sentinel-3_User_Handbook
..\..\A001_VISIOTERRA_REFERENCE_DOCUMENTS\SENTINEL-3\Sentinel-3_User_Handbook.pdf

R-13 Web *SENTINEL-3*
ESA
https://sentinel.esa.int/web/sentinel/missions/sentinel-3

R-14 Web *Sentinel-3 OLCI Technical Guide*
ESA
https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-3-olci

1.3.4 NDVI and NDII science bibliography

R-15 *Comparing the Normalized Difference Infrared Index (NDII) with root zone storage in a lumped conceptual model*
N. Sriwongsitanon & al., 23 August 2016
Hydrology and Earth System Sciences, 20, 3361–3377, 2016
Published by Copernicus Publications on behalf of the European Geosciences Union
http://www.hydrol-earth-syst-sci.net/20/3361/2016/hess-20-3361-2016.pdf
..\reference_documents\20160823_Sriwongsitanon_Comparing_the_NDII_with_root_zone_storage_in_a_lumped_conceptual_model.pdf

R-16 *Remote sensing of vegetation water content from equivalent water thickness using satellite imagery*
M. Tugrul Yilmaz & al., 22 November 2007
Remote Sensing of Environment 112 (2008) 2514–2522
http://www.sciencedirect.com/science/article/pii/S0034425707004798
..\reference_documents\20071122_Yilmaz_Remote_sensing_of_vegetation_water_content_from_equivalent_water_thickness_using_satellite_imagery.pdf - Raccourci.lnk

1.4 Abbreviations and Acronyms

This section controls the definition of all abbreviations and acronyms used within this document. Special attention has been paid to adopt abbreviations, acronyms and their definitions from international standards as ISO, ANSI or ECSS.

AOI Area Of Interest

BOA Bottom Of Atmosphere

DEM Digital Elevation Model

DG Digital Globe

EO Earth Observation

ESA European Space Agency

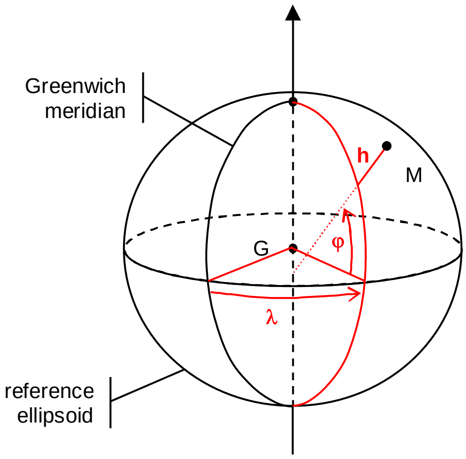
GB	Giga Bytes (=10^9 bytes)
GIS	Geographical Information System
GSD	Ground Sampling Distance
IR	Infrared
KML	Keyhole Markup Language
KMZ	Keyhole Markup Language document compressed in a ZIP file
L1C	Level 1C - L1 products in geodetic reference system (geocoded or orthorectified)
L2	Level 2 - Biophysical measurements products
MSI	Multi-Spectral Instrument (optical instrument of Sentinel-2)
NDVI	Normalised Difference Vegetation Index
OLCI	Ocean Land Colour Instrument (MR optical instrument of Sentinel-3)
S2	Sentinel-2 (series of ESA satellites for high-resolution optical imaging)
S3	Sentinel-3 (series of ESA satellites for medium-resolution optical imaging and altimetry)
SEOM	Scientific Exploitation of Operational Missions
SLSTR	Sea and Land Surface Temperature Radiometer (MR optical instrument of Sentinel-3)
SNAP	Sentinel Application Platform
SWIR	Short Wave Infrared
TOA	Top Of Atmosphere
UTM	Universal Transverse Mercator
UNEP	United Nations Environment Programme

1.5 Definitions

This section provides the definition of all common terms used within this document. Special attention has been paid to adopt definitions from international standards as ISO, ANSI or ECSS.

coordinates reference system (CRS)

geographic



geocoded

An image (or more generally any EO data) is geocoded if a simple relation exists giving the geodetic coordinates (λ,φ) or the Cartesian coordinates (X,Y) of a particular reference system from the coordinates of any point (l,p) of the image.

Generally, the geodetic position is given using a simple linear formula:

$$\begin{cases} X = X_0 + d_X \times p \\ Y = Y_0 - d_Y \times l \end{cases}$$

Where:

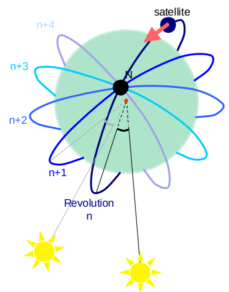
- (X_0,Y_0) are the coordinates of the upper-left pixel in the image,
- (d_X,d_Y) are the horizontal and vertical pixels spacing respectively.

Note that a geocoded image is a georeferenced image in which the localization function is the simple linear equation given here above.

heliosynchronous

A heliosynchronous orbit is an orbit which plan stands at a constant orientation with regard to the Earth-Sun direction. Such an orbit is in particular used in Earth observation to observe the Earth at a constant local time.

Landsat and SPOT are for example heliosynchronous satellites.



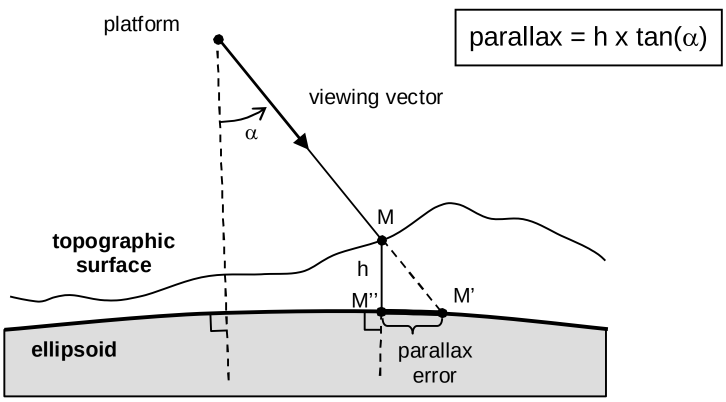
orthorectified

An image is orthorectified if its internal deformations due to the relief and the viewing geometry have been corrected. The orthorectified image does not exhibit parallax defects for the optical instrument or the foreshortening / layover defects caused by the radar instrument.

parallax

The parallax error is observed on a reference surface (generally an ellipsoid) when the viewing vector of an optical instrument is not perpendicular to this surface..

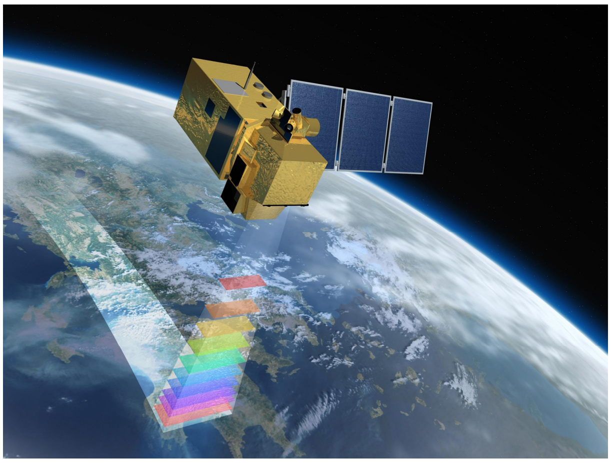
For a given viewing angle α, the parallax error (M',M'') has a magnitude growing with the elevation h of the imaged point M above the reference surface.



2 DATA USED

2.1 Sentinel-2 MSI

2.1.1 Presentation



Sentinel-2 is a mission launched by the European Science Agency (ESA) on 23 June 2015 (1st mission Sentinel-2A) acquiring data through its multispectral instrument MSI et which data are available from October 2015. A second mission Sentinel-2B shall be launched in March 2017 that will double the revisit time over whatever part of the Earth.

The Sentinel-2 MSI products are processed as Level-1C products meaning they are orthorectified (corrected from parallax defects) but are Top-Of-Atmosphere (TOA) radiance, i.e. having a backscattering signal corrupted by the atmospheric crossing.

Sentinel-2 MSI acquisitions are performed with a 280 km swath width leading to original products having a very big size (from 8 to 15 GB). For this reason, an original product is cut in a series of 100km x 100km tiles. Each tile is project in UTM with the horizontal zone number matching its location. In Haiti, tiles are project in UTM-18N. Each tile falls in standard quadrant predefined in a fixed grid; each quadrant being identified by a “nnQpl” identifier (see fig. 2).

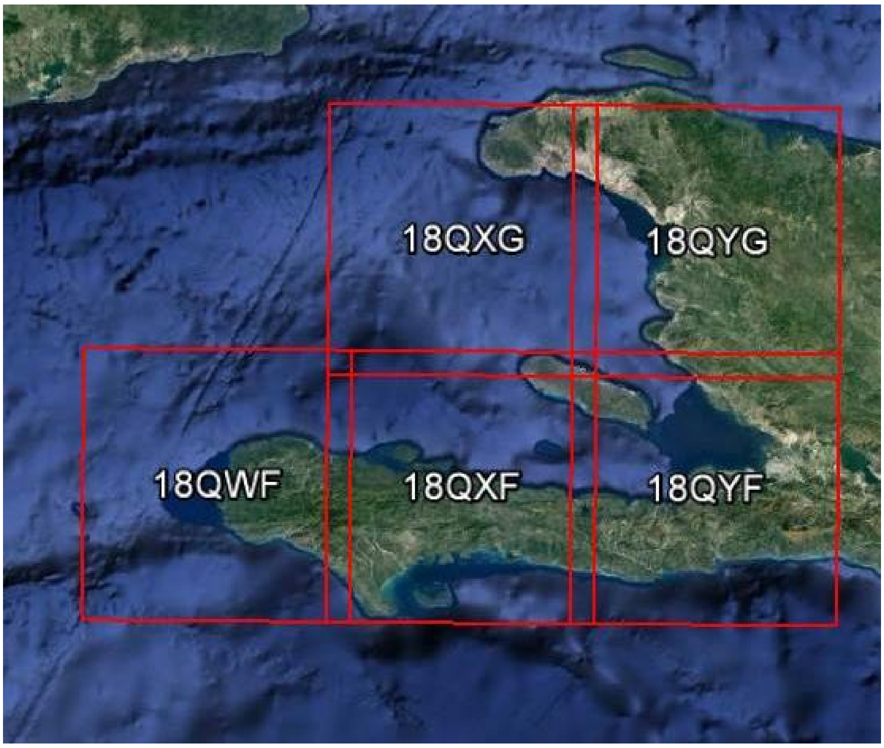


fig. 2 - Location of the standard Sentinel-2 tiles covering Haiti.

2.1.2 Selection of scenes

As shown in table 1 below, 6 products (red bold underlined in “Date” column) have been selected among the 32 collected ones, three (3) products before the event date (04.10.2016) and three (3) products after the event.

For each product, the table shows the tiles (among the five possible ones) that have been covered. Choice has been driven by -the extents of the coverage, -the cloud cover notation (illustrated by the numbers and the grey scales) and -the acquisition date.

	Cloud %	Reference						
	Date	18QWF	18QXG	18QXF	18QYG	18QYF		Mean
Post event	**08/12/2016**	**1,15**	**0,04**	**3,10**	**1,19**	**1,54**		**1,40**
	28/11/2016	**5,73**	**3,86**	**5,91**	**9,80**	**0,92**		**5,24**
	25/11/2016			100,00	43,14	21,34		54,83
	15/11/2016			100,00	52,17	73,83		75,33
	08/11/2016	32,04	26,37	23,03	40,24	19,45		28,23
	29/10/2016	98,70	70,89	97,65	88,82	87,63		88,74
	16/10/2016				74,00	55,00		64,50
	09/10/2016	46,32	98,13	54,17	98,78	58,52		71,18
Pre event	26/09/2016				3,49	5,57		4,53
	19/09/2016	11,59	7,78	15,67	5,73	10,51		10,26
	06/09/2016				9,62	12,84		11,23
	30/08/2016	36,84	85,86	82,15	99,01	89,35		78,64
	17/08/2016			62,10	4,89	32,94		33,31
	10/08/2016	8,30	0,54	16,92	5,01	14,89		9,13
	28/07/2016			0,00	0,06	0,48		0,18
	21/07/2016	11,66	3,58	10,20	7,17	4,36		7,39
	08/07/2016				20,59	16,12		18,36
	01/07/2016	8,78	3,99	10,37	5,35	8,21		7,34
	18/06/2016				1,75	4,51		3,13
	11/06/2016	**3,42**	**1,59**	**1,64**	**4,11**	**0,29**		**2,21**
	22/05/2016	1,40	10,11	1,53	15,93	3,52		6,50
	09/05/2016			100,00	63,50	98,80		87,43
	02/05/2016	5,43	1,32	6,42	9,50	16,75		7,88
	22/04/2016	97,11	96,78	90,22	100,00	94,68		95,76
	09/04/2016				18,42	18,89		18,66
	23/03/2016	21,20	0,88	16,69	0,94	15,65		11,07
	10/03/2016				18,68	7,51		13,10
	09/02/2016				4,17	5,15		4,66
	23/01/2016	96,00	37,00	45,00	1,00	1,00		36,00
	10/01/2016				0,00	6,00		3,00
	24/12/2015	**0,00**	**1,00**	**0,00**	**1,00**	**0,00**		**0,40**
	11/12/2015			1,00	72,00	80,00		51,00

table 1 - Selection of scenes.

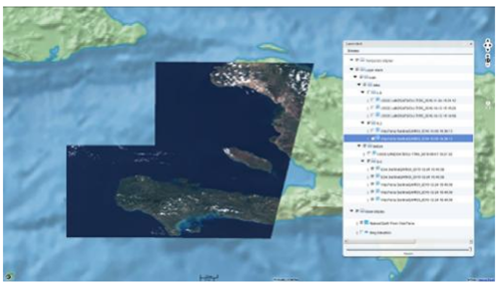


fig. 3 - Sentinel-2 (5 tiles) acquired on 24/12/2015 15:40:39 GMT.

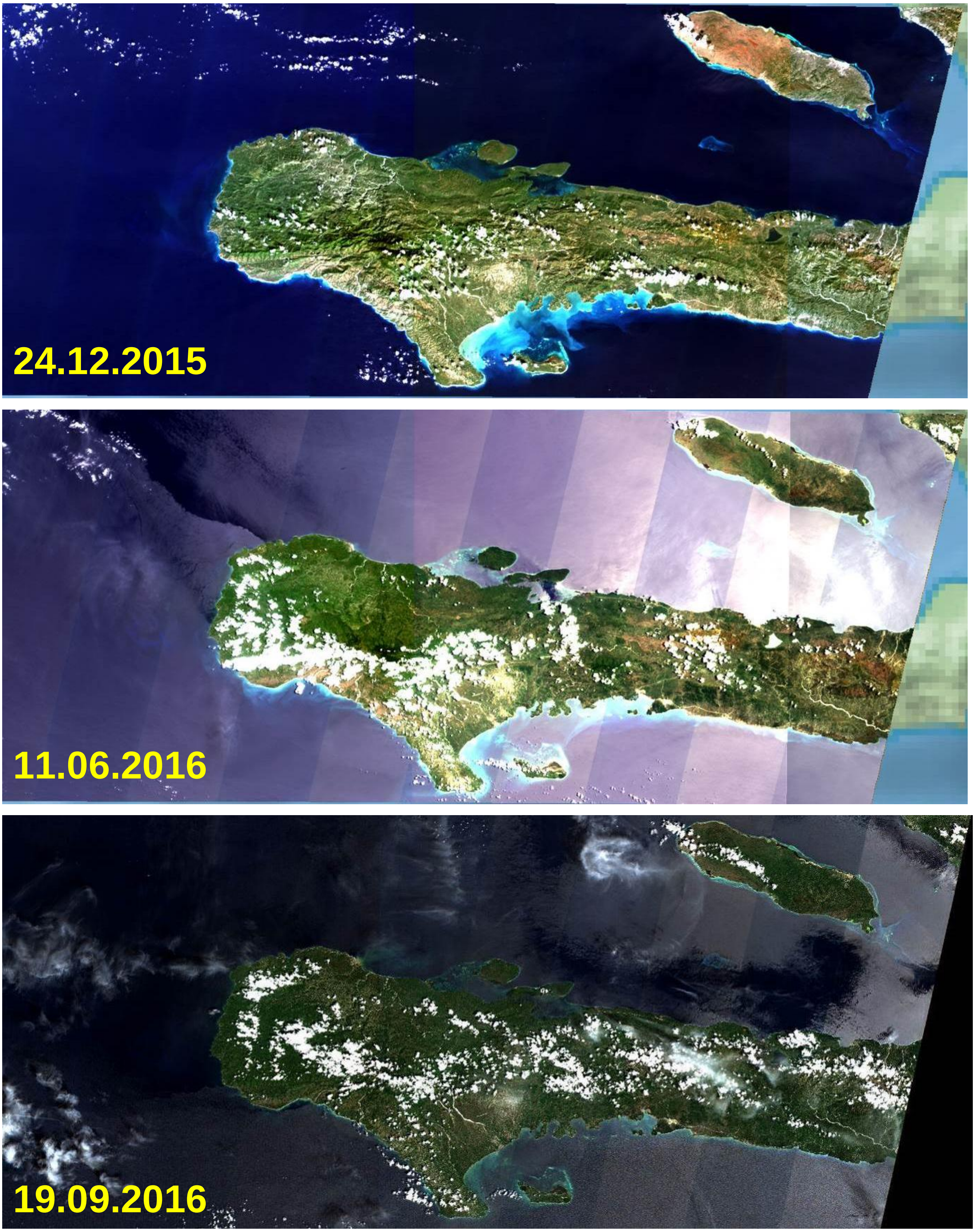


fig. 4 - Sentinel-2 pre-event.

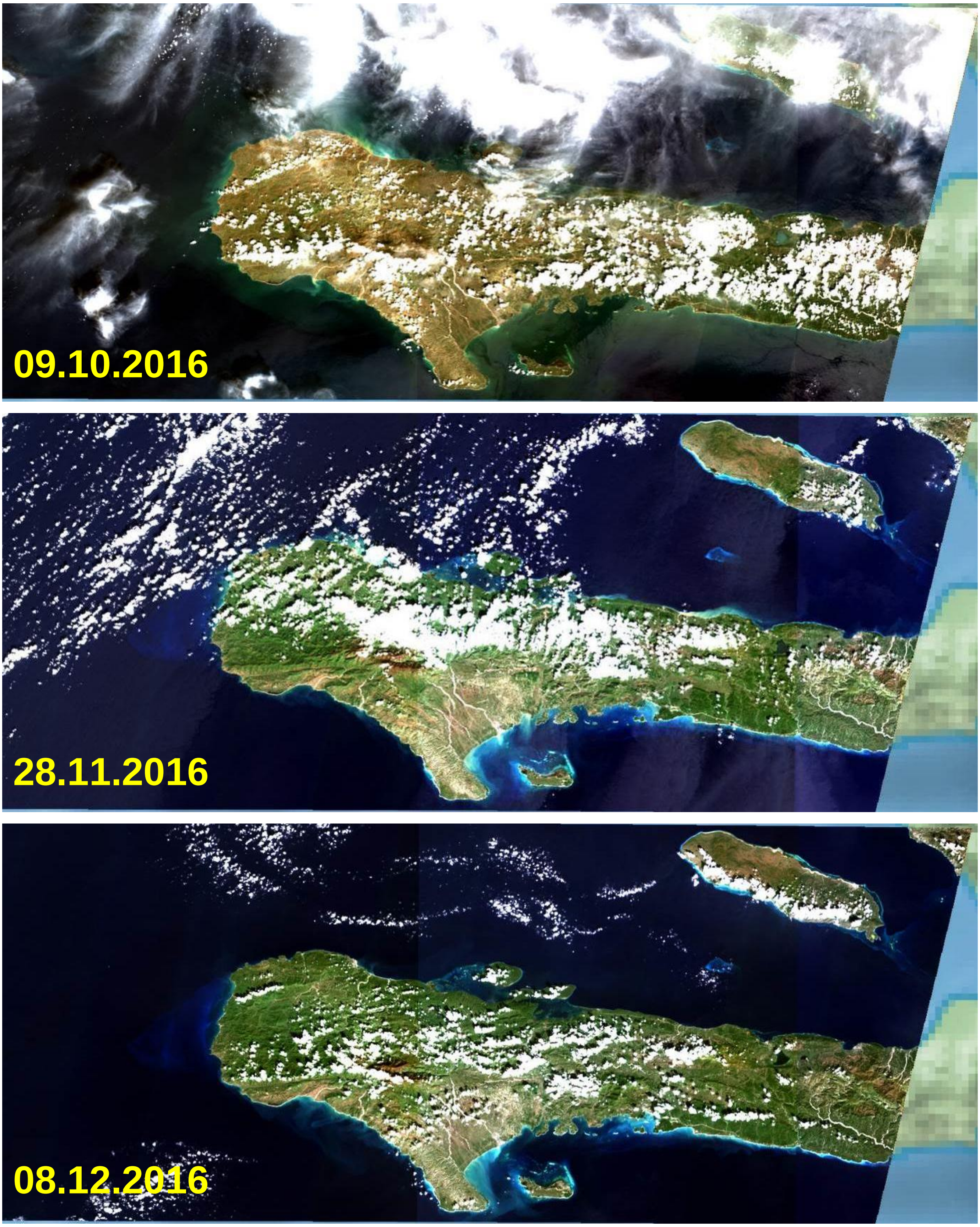


fig. 5 - Sentinel-2 post-event.

2.2 Digital Globe

Digital Globe data are freely available at the URL http://opendata.digitalglobe.com/index.html?prefix=hurricane-matthew/. All these data have been downloaded on VisioTerra disks leading to an overall data **volume of 1.271 TB** (see data hierarchy in fig. 6 below).

One may notice that the storage of the scenes acquired on 2016-10-01 in the "post-event" folder is wrong because Matthew hurricane occurred on October 4th.

Name	Size (KB)	Date	Attrib	Type	Files	F..	Percent
\\disco2\Disco2_3\DigitalGlobe\hurricane-matthew\	1 271 150 325	15/11/2016 15:06		Folder	1 211	\...	
post-event	566 313 282	15/11/2016 12:00		Folder	516	\...	
2016-10-01	32 227 857	14/11/2016 17:36		Folder	38	\...	
2016-10-07	154 000 621	14/11/2016 19:35		Folder	137	\...	
2016-10-08	104 540 568	15/11/2016 10:35		Folder	93	\...	
2016-10-09	136 015 147	15/11/2016 10:52		Folder	121	\...	
2016-10-10	69 693 712	15/11/2016 11:42		Folder	62	\...	
2016-10-11	69 835 377	15/11/2016 12:32		Folder	65	\...	
pre-event	704 837 044	15/11/2016 22:59		Folder	695	\...	
2013-01-05	84 306 909	15/11/2016 13:12		Folder	75	\...	
2013-02-27	17 989 154	15/11/2016 13:38		Folder	24	\...	
2013-06-09	70 817 804	15/11/2016 14:18		Folder	63	\...	
2013-11-13	40 475 597	15/11/2016 14:48		Folder	54	\...	
2014-01-03	35 978 308	15/11/2016 15:03		Folder	48	\...	
2014-01-12	67 445 528	15/11/2016 15:51		Folder	60	\...	
2014-11-07	26 978 211	15/11/2016 16:21		Folder	24	\...	
2014-11-13	29 232 376	15/11/2016 16:31		Folder	39	\...	
2015-07-03	98 920 107	15/11/2016 17:20		Folder	88	\...	
2015-09-24	43 839 593	15/11/2016 20:29		Folder	39	\...	
2015-10-25	43 839 593	15/11/2016 21:05		Folder	39	\...	
2016-01-31	37 095 040	15/11/2016 21:39		Folder	33	\...	
2016-03-20	43 839 593	15/11/2016 22:08		Folder	39	\...	
2016-06-12	29 232 376	15/11/2016 22:39		Folder	39	\...	
2016-06-17	34 846 856	15/11/2016 22:59		Folder	31	\...	

fig. 6 - Overall Digital Globe data dowloaded on VisioTerra infrastructure.

From a spatial point of view the **978 image files** cover Haiti and parts of the surrounding countries (see fig. 7).

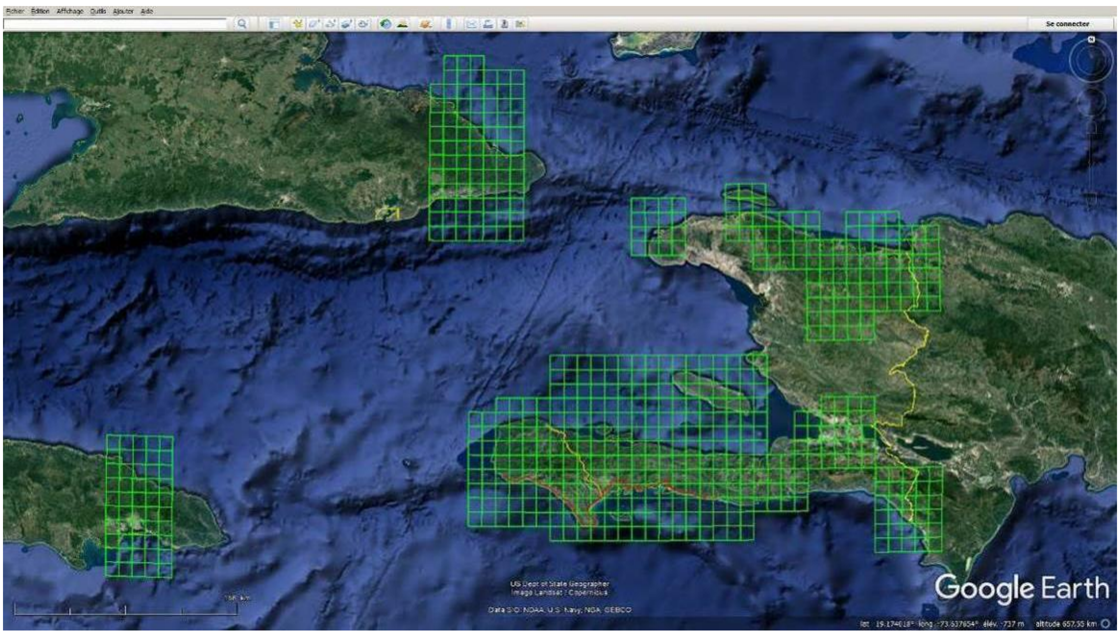


fig. 7 - Overall Digital Globe data available for the analysis of the Matthew Hurricane.

Among the 978 image files, some are acquired before the event (04/10/2016 12:00 GMT) and the other ones have been acquired post-event. Figure fig. 8 below shows the coverage of image tiles pre and post event.

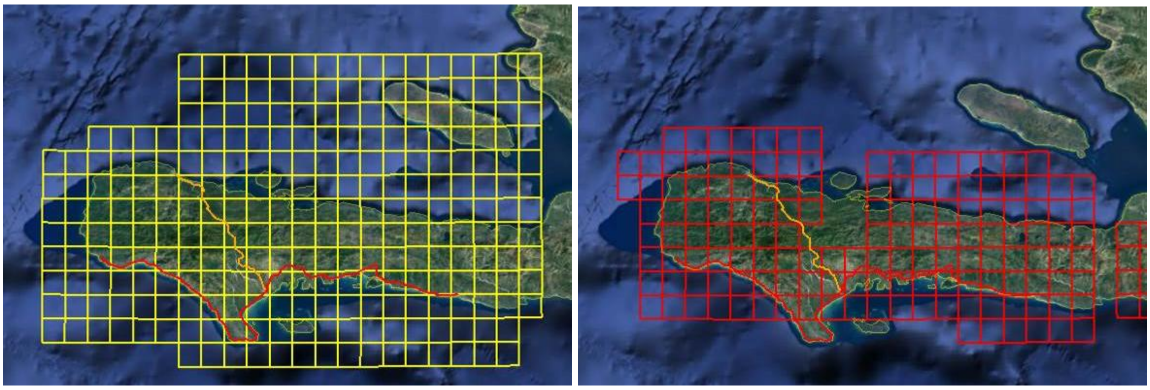


fig. 8 - Digital Globe data pre-event (left) and post-event (right).

According to the two planned transects (itineraries foreseen for the future mission), only 192 images have been imported.

3 DATA PREPROCESSING

3.1 TOA to BOA

3.1.1 Method

One major drawback of the satellite data is the impact of atmospheric conditions on the quality of the observations. In particular, the concentration of water, aerosols and other components determine the radiative transfer of the backscatter from the bottom of atmosphere (BOA) to the top of atmosphere (TOA).

The Sentinel-2 being distributed by ESA are level-1C products, i.e. orthorectified products with TOA reflectance (ratio between the received Sun light and the backscattered radiance).

A first assessment has shown that the five level-1C scenes have very different reflectance and therefore that the comparison between pre and post event dates will be biased by the difference of atmospheric conditions. To correct this bias, the first processing step is to produce level 2A products computing the TOA to BOA conversion.

This TOA to BOA atmospheric correction is performed using the Sentinel Application Platform SNAP (see R-10) that has been released by ESA. The algorithms are presented in the "Level-2A Algorithm Overview" section of the "Sentinel-2 Technical Guide" R-7.

TOA to BOA being processed by SNAP tile per tile, one shall verify the radiometric continuity of the tiles acquired on the same date (for further assembly of contiguous tiles) but also on different dates (for further loud-free synthesis). These assessments are demonstrated in the next section.

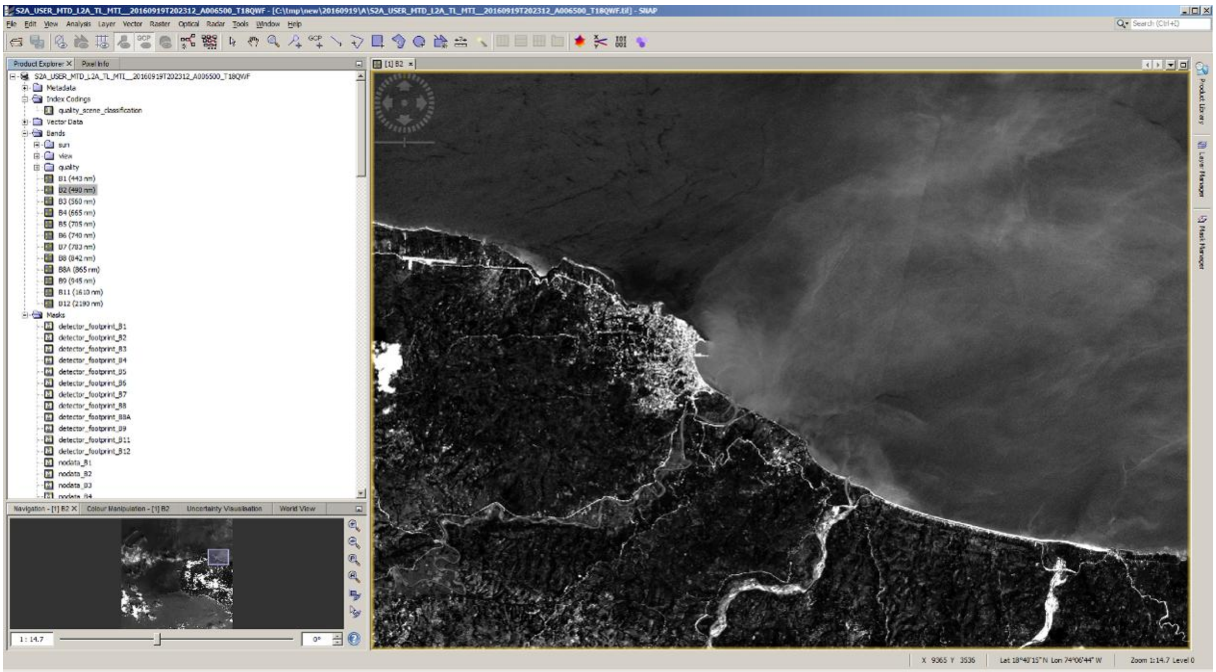


fig. 9 - View of the output product after .

3.1.2 Assessment of results

3.1.2.1 Radiometric continuity between tiles of the same date

The radiometric continuity between contiguous BOA tiles of the same date is controlled. Figures below are true-colour compositions witnessing of this continuity.

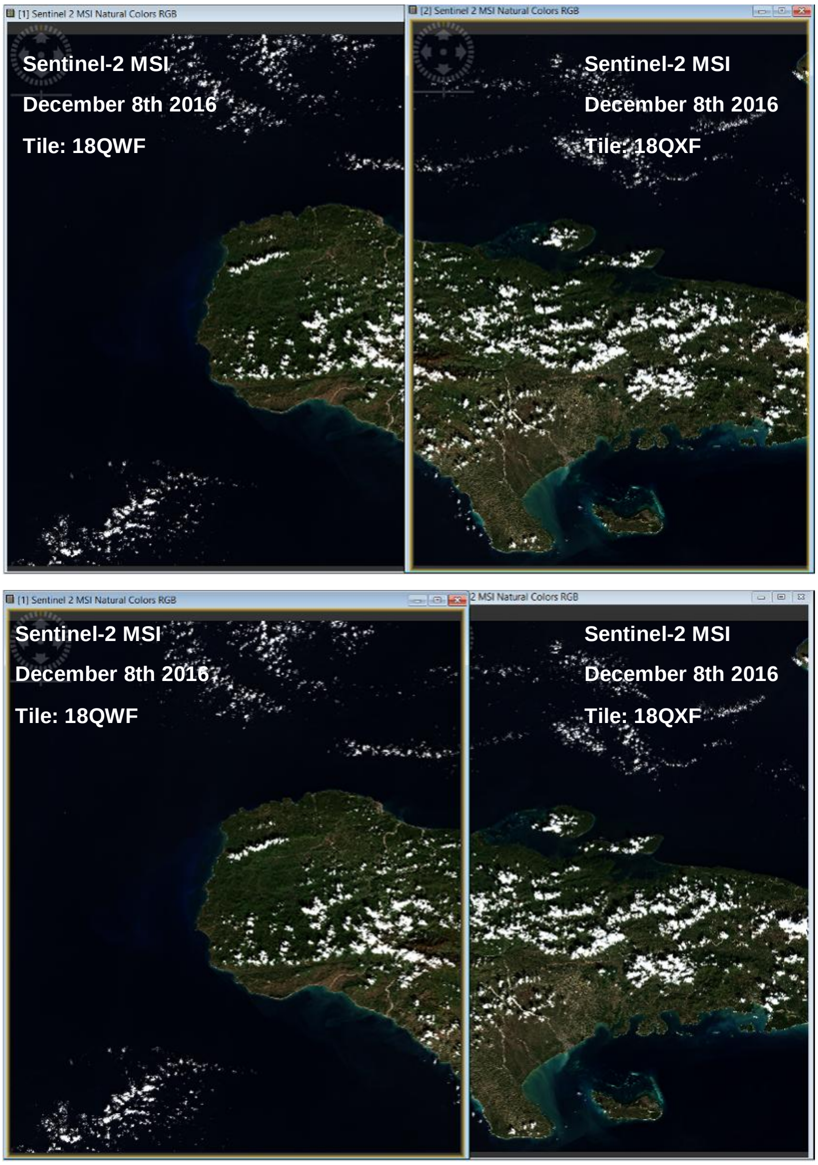


fig. 10 - Continuity between 18QWF tile (left) and 18QXF tile (right) with TOA input radiometry (top) and after BOA processing (bottom) - Full tiles.

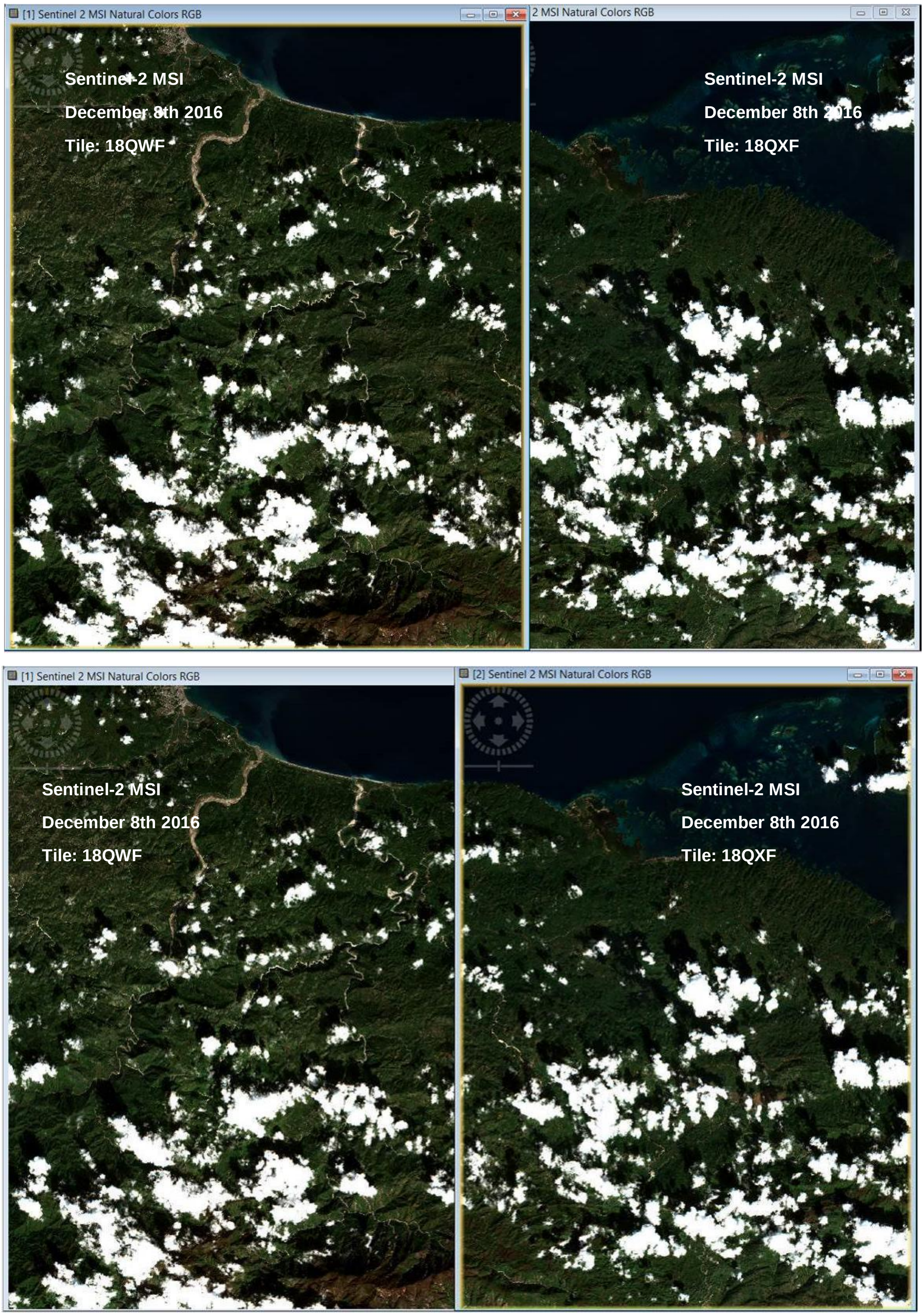


fig. 11 - Continuity between 18QWF tile (left) and 18QXF tile (right) with TOA input radiometry (top) and after BOA processing (bottom) - Zoom.

3.1.2.2 Radiometric continuity between tiles of different dates

The radiometric continuity between BOA tiles of different dates is controlled. Figures below are true-colour compositions witnessing of this continuity.

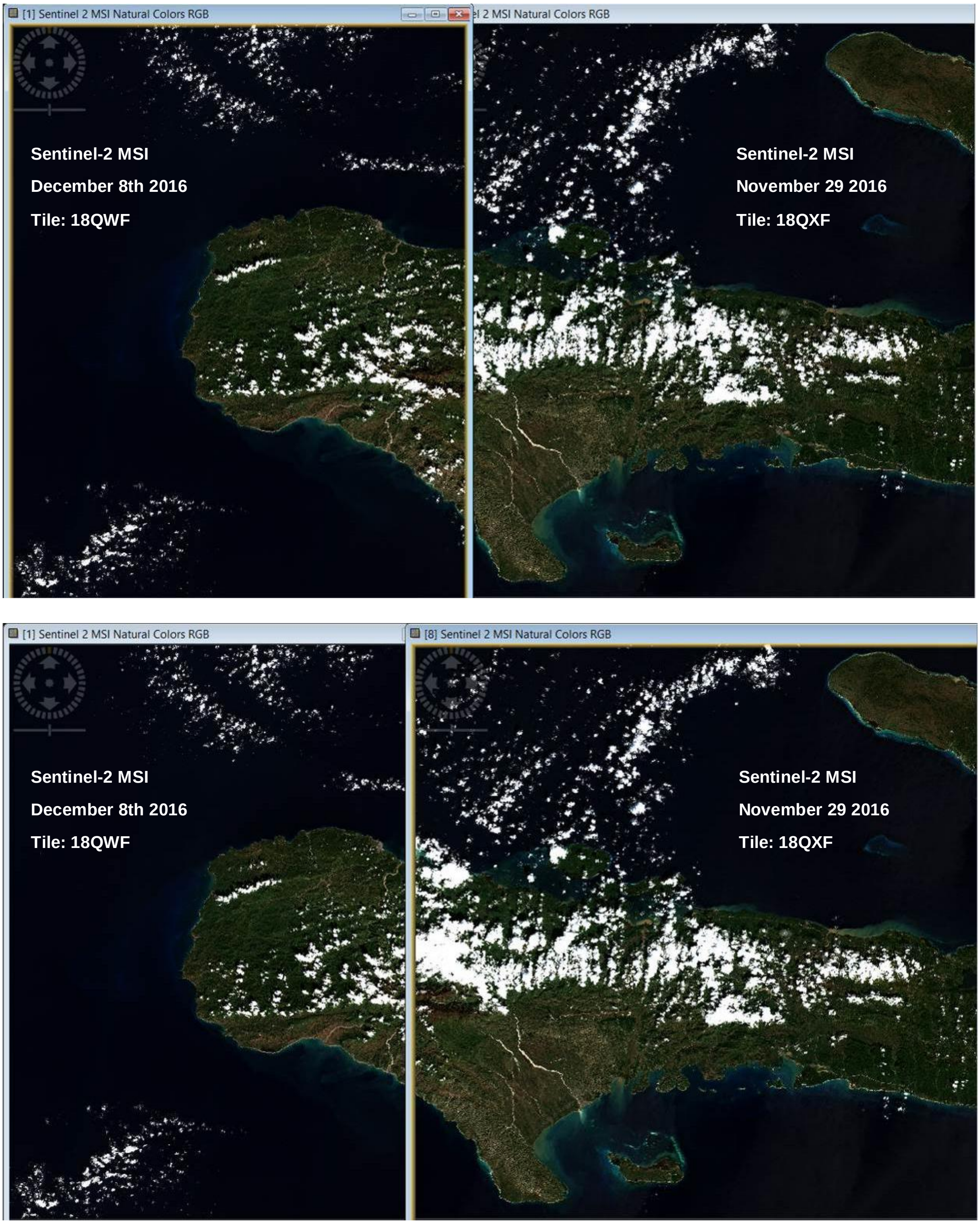


fig. 12 - Continuity between tiles acquired on 08.12.2016 (left) and 29.11.2016 (right) with TOA input radiometry (top) and after BOA processing (bottom).

3.1.3 Resampling and export

3.1.3.1 Structure of the L2 BOA product

As shown in fig. 13, the structure of the product generated by the Sen2cor module (TOA to BOA atmospheric correction) is complex.

This section explains how data shall be resampled and exported using SNAP.

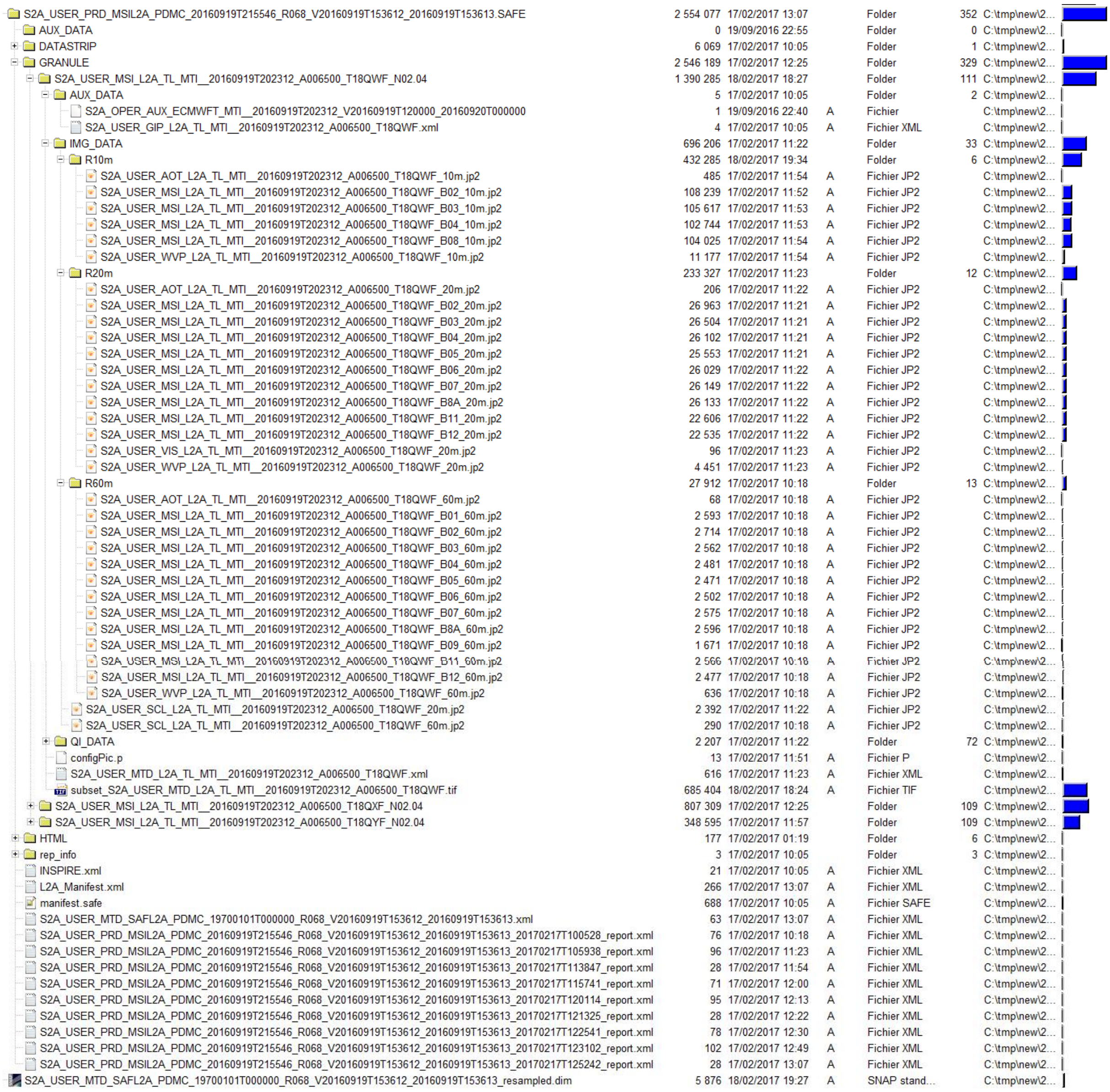


fig. 13 - Structure of the Level-2 (BOA) product.

3.1.3.2 Open product

To access to the assembly of the three (3) tiles, one shall select the first “MTD” (metadata) file just under the “SAFE” directory of the target product (see fig. 14).

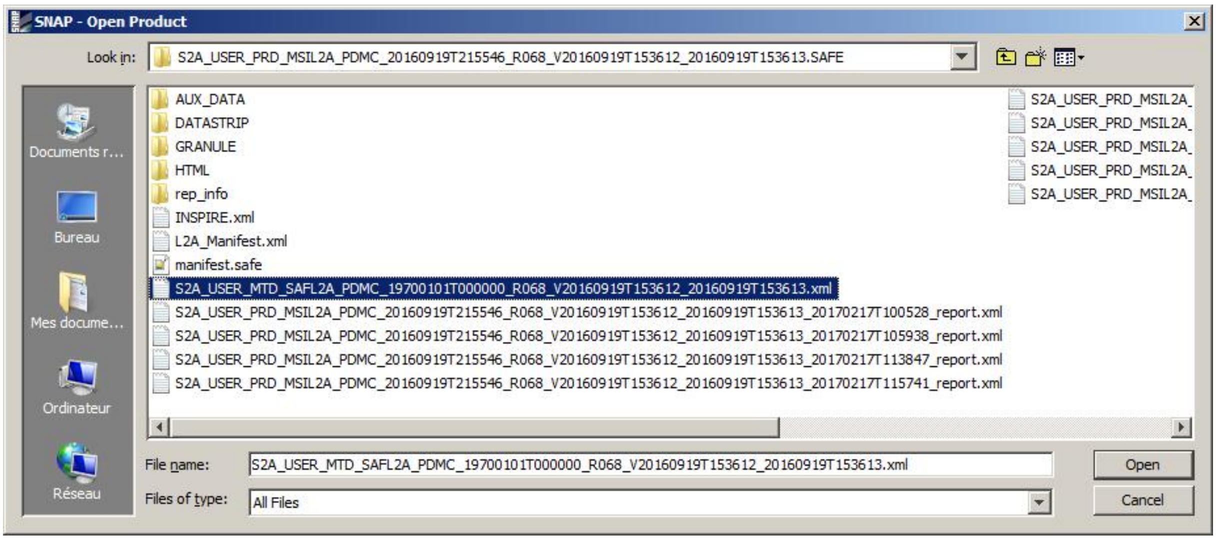
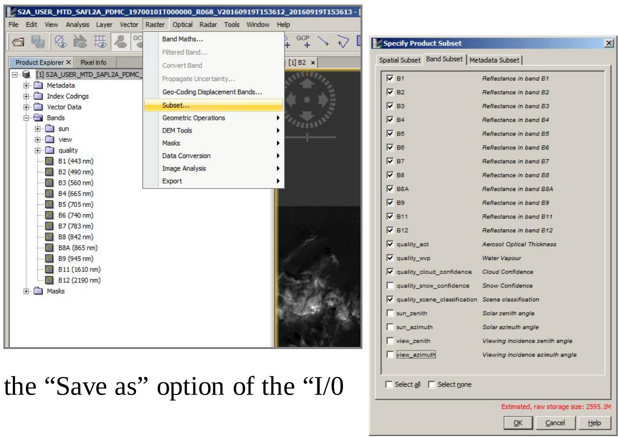


fig. 14 - SNAP - Selection of the metadat file matching the assembly of the three tiles.

3.1.3.3 Subsetting



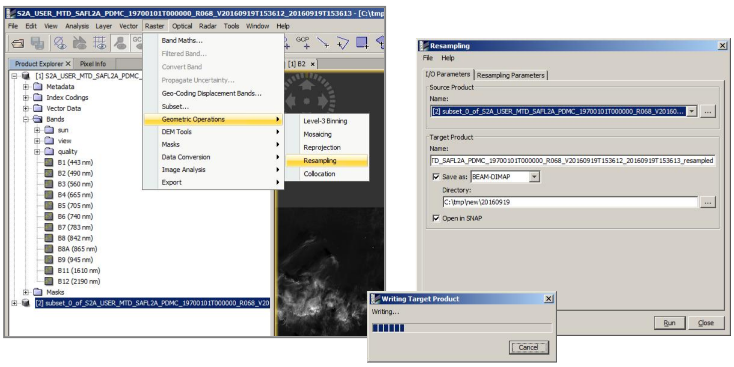
To avoid the resampling of all the useless bands, one may select only the reflectance bands and some quality planes like the “quality_scene_classification” that may be useful to build the cloud mask.

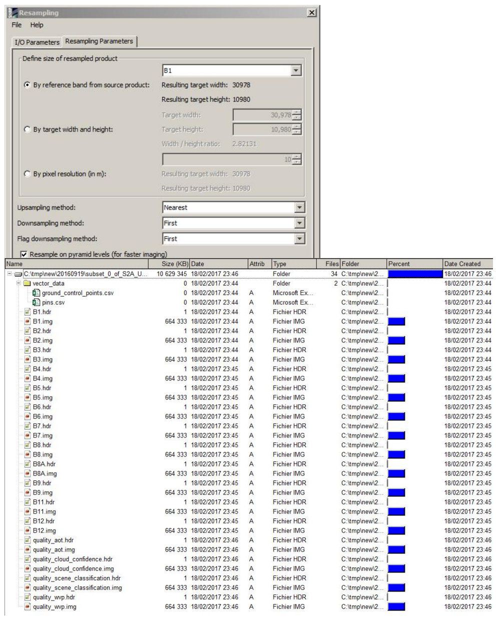
Such a selection makes decrease the total amount of resampled data from 4.1 GB to 2.6 GB.

3.1.3.4 Resampling

Data are stored on the desired location on disks by clicking the “Save as” option of the “I/0 Parameters of the “Resampling parameters” window.

Writing of big files is a long process (more than 40 minutes).





Files being produced are listed in the attached figure. Format of the “img” images is the simple dump format without header. Metadata are given in the attached “hdr” file with the same radix.

This format is simply ingested by the DMPIN process of TELIMAGO.

3.2 Clipping of “south” and “north” windows

Because of the amount of data and the required extents of the project, tiles XG, WF and XF only are processed. Because the analysis shall focus on the vegetation, two windows are extracted from these tiles (see fig. 15). These clippings have been performed after having previously reprojected all the selected tiles from UTM-18N to Geographic WGS-84 CRS.

Extraction of “south” window has required a preliminary assembly of the WF and XF tiles.

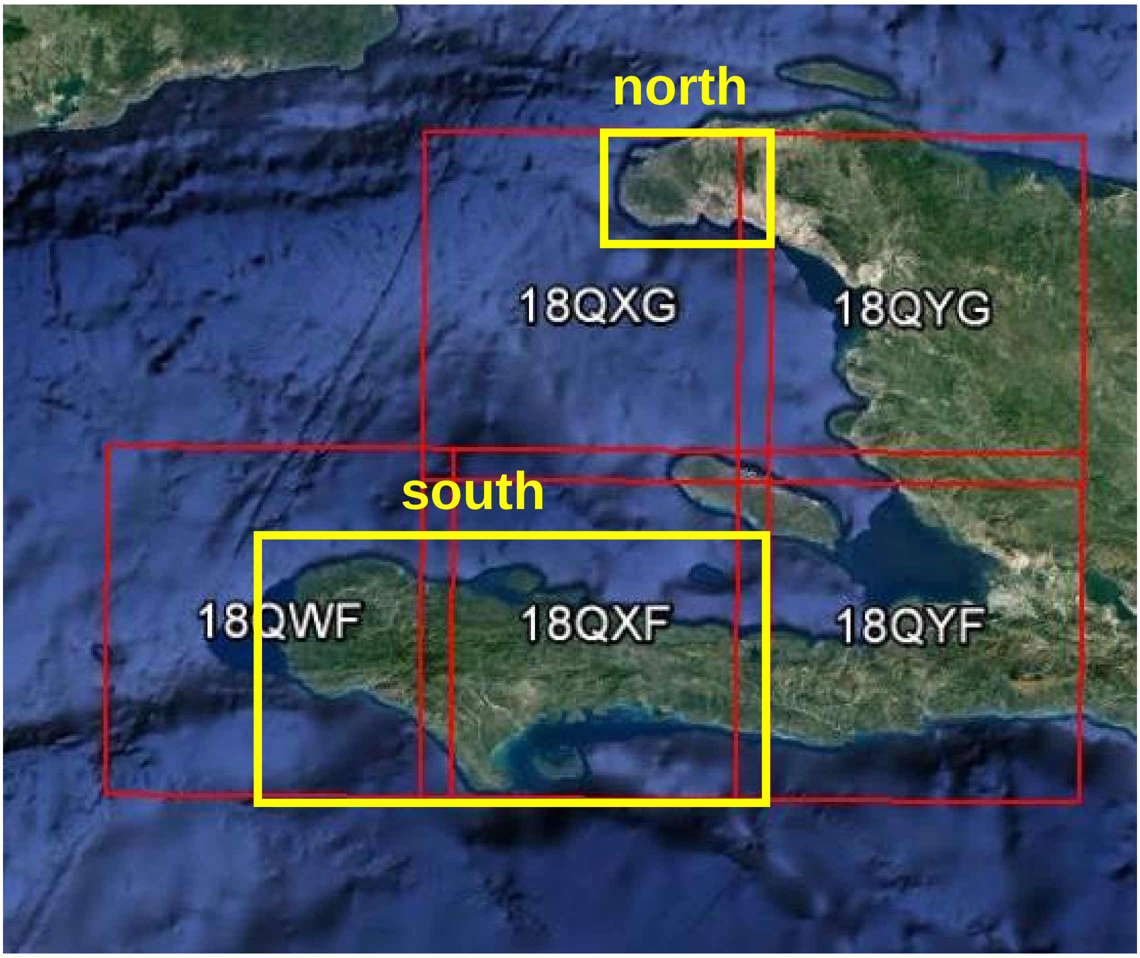


fig. 15 - Location of the standard Sentinel-2 tiles covering Haiti.

Figure fig. 16 below shows the result of clipping the before-event synthesis.

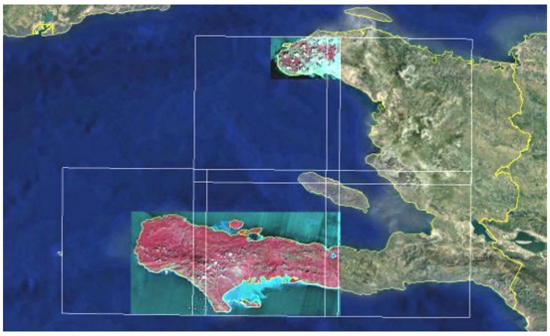


fig. 16 - Near infrared colour composition of “north” and “south” windows.

3.3 Cloud masking

3.3.1 Scope

Despite a preliminary selection (see section 2.1.2), optical images of these tropical regions often include a large amount of clouds and their inherent shadows. Scope of the “cloud-free synthesis” (see section 3.4) is to decrease and even suppress the clouds by using multi-dates.

A first edition of the “NDVI change” and “class change” maps has shown that the photo-interpretation of these maps may be hindered by the residual clouds and shadows.

An attempt has been made to mask the clouds and shadows from each Sentinel-2 tiles before their synthesis.

3.3.2 Method 1 - Use of level-2A masks

3.3.2.1 Presentation of “class products”

Label	Classification
0	NO_DATA
1	SATURATED_OR_DEFECTIVE
2	DARK_AREA_PIXELS
3	CLOUD_SHADOWS
4	VEGETATION
5	BARE_SOILS
6	WATER
7	CLOUD_LOW_PROBABILITY
8	CLOUD_MEDIUM_PROBABILITY
9	CLOUD_HIGH_PROBABILITY
10	THIN_CIRRUS
11	SNOW

One output of the TOA to BOA processing of SNAP (see section 3.1) is the production of various masks and in particular the computation of a “class” image with the attached nomenclature (see https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-2-msi/level-2a/algorithm for more details).

The “class” band in level-2A product generated by SNAP is reprojected and classes 3 (“cloud shadows”) and 9 (“cloud high probability”) are extracted to produce a “shadow mas” and a “cloud mask”.

These masks have been controlled.

3.3.2.2 Results

Figure fig. 17 describes one of the first tests performed on scene past-event acquired on 09.10.2016. Figure a shows the whole 100km x 100km and the full-resolution zoom (figure b) shows a region of the north coast near Jerémie city.

Figures c (whole tile) and d (same zoom area as b) clearly show that the said “cloud mask” (class 9) produced by SNAP also contain bare soils, flooded areas sand beaches.

Identification of flooding areas being a major issue, one cannot mask these zones like clouds.

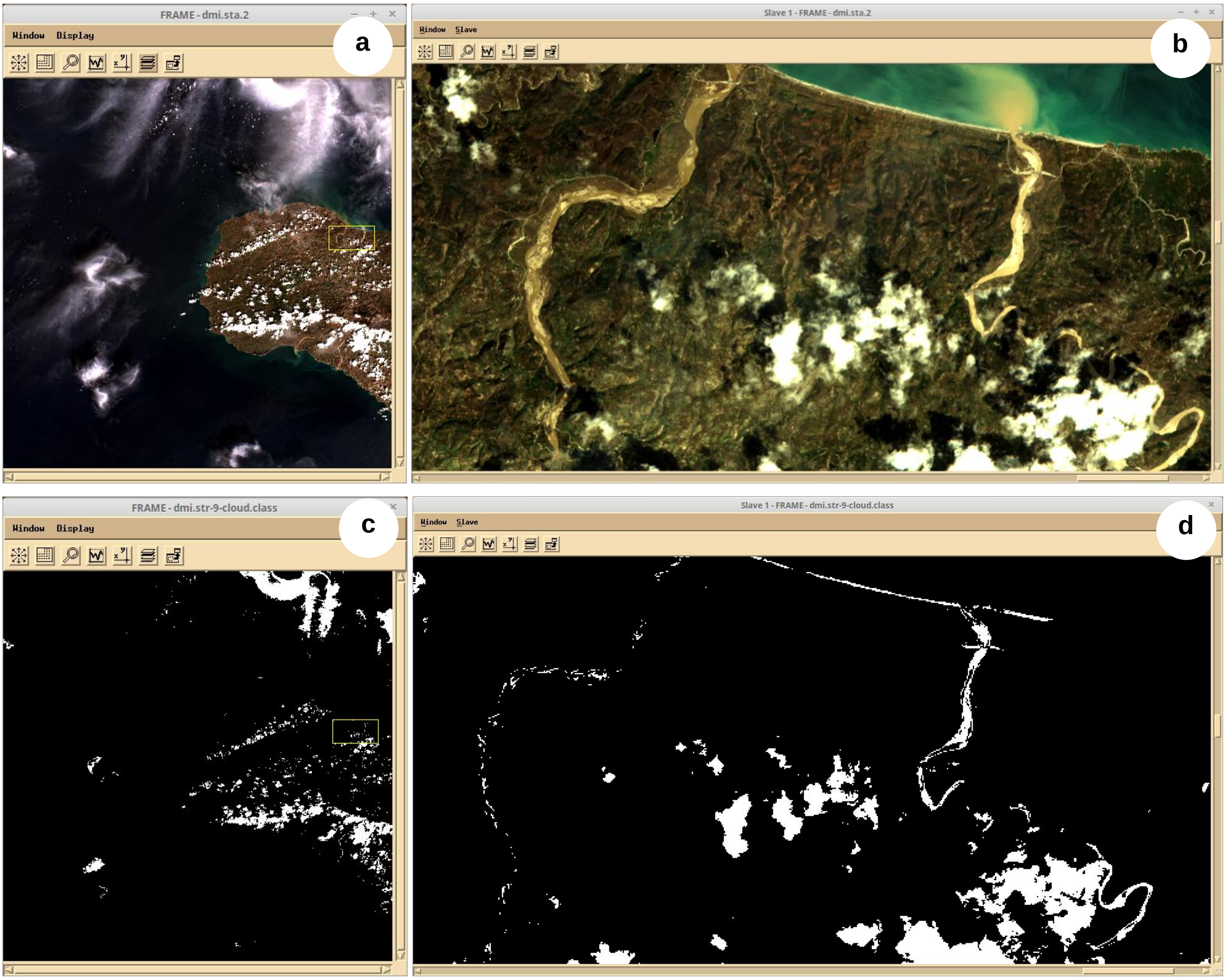


fig. 17 - Tile S2_20161009_L2A, 4-3-2 true colour composition (top) and class 9 cloud mask (bottom).

3.3.3 Method 2 - By hand thresholding

3.3.3.1 Choice of the discriminating band

One simple way to produce a “cloud mask” is to perform the best thresholding of the reflectances. Scope of this section is to select the band among the B2, B3 and B4 visible ones (see fig. 18) or the B8, B11 and B12 NIR and SWIR ones (see fig. 19) that enables the most exhaustive identification of clouds without selecting the flooded areas (see the defect of method 1 in the previous section 3.3.2).

3.3.3.2 Results

As shown in the binary images and in the histograms of fig. 18 and fig. 19, **band 8 (NIR) leads to the best segregation** because of its long high values queue. Band 12 (SWIR) may also be used for thresholding.

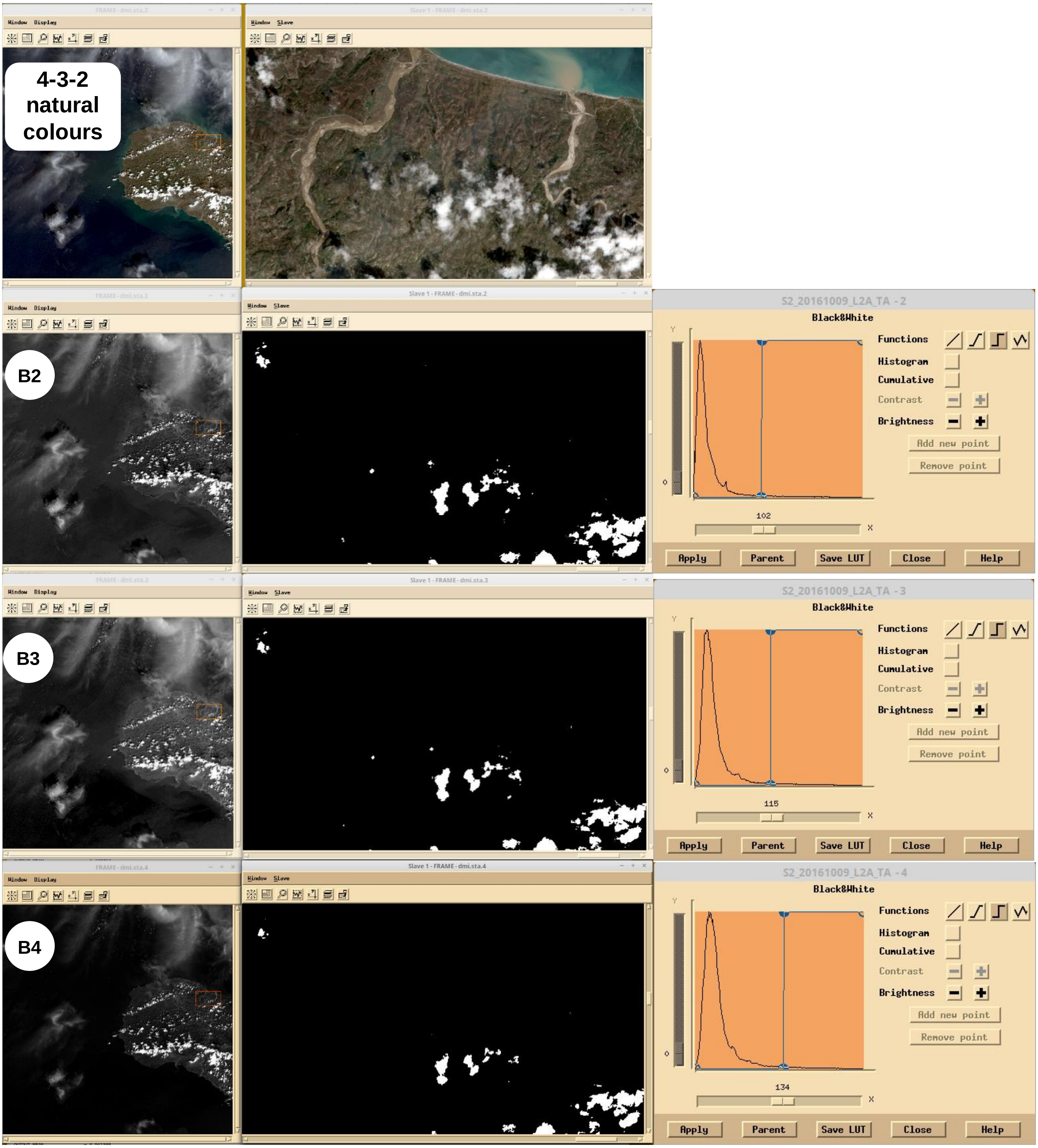


fig. 18 - Manual thresholding - B2, B3, B4 Visible bands.

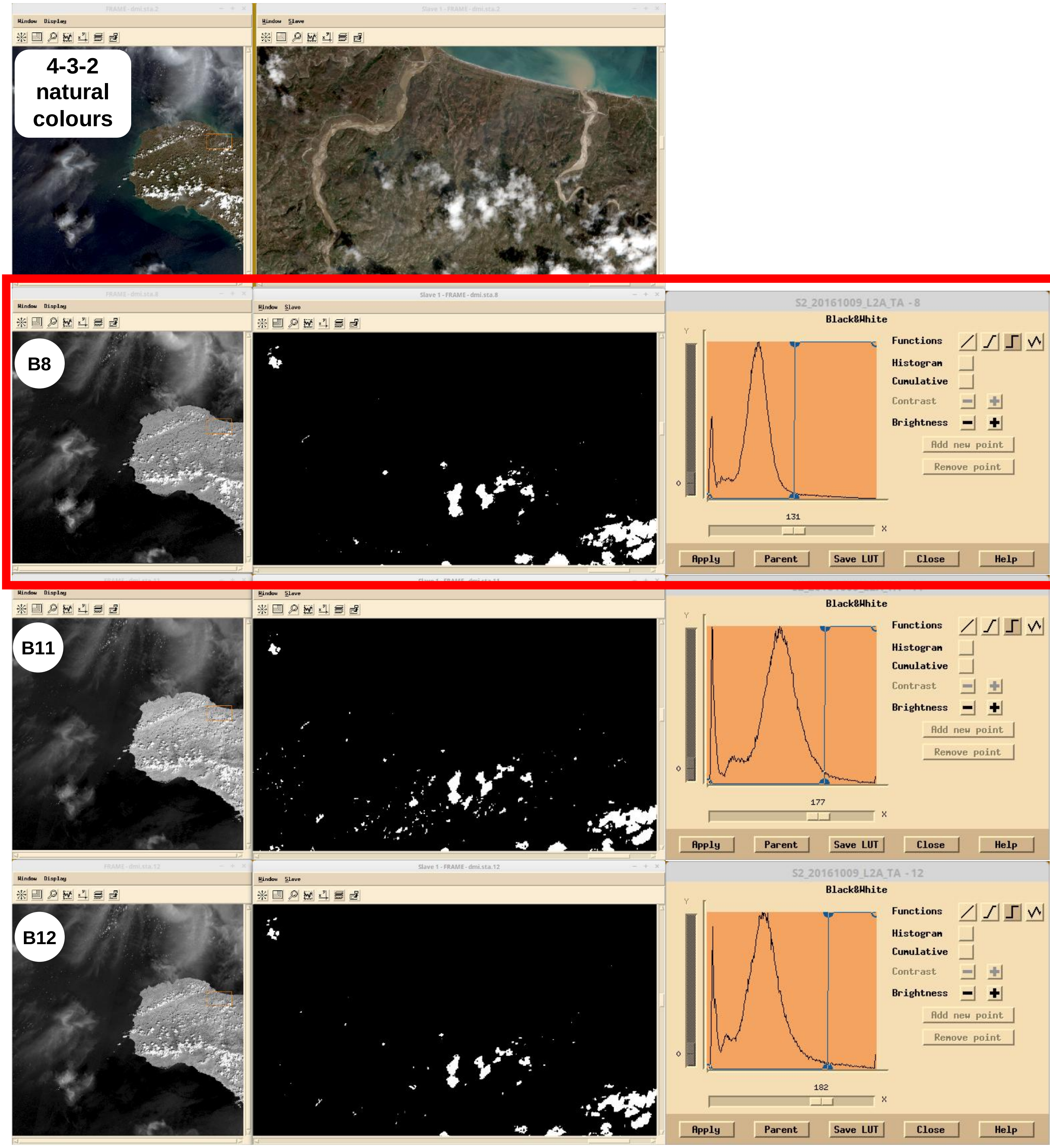


fig. 19 - Manual thresholding - B8 NIR or B11, B12 SWIR bands.

3.3.4 Processing of cloud mask

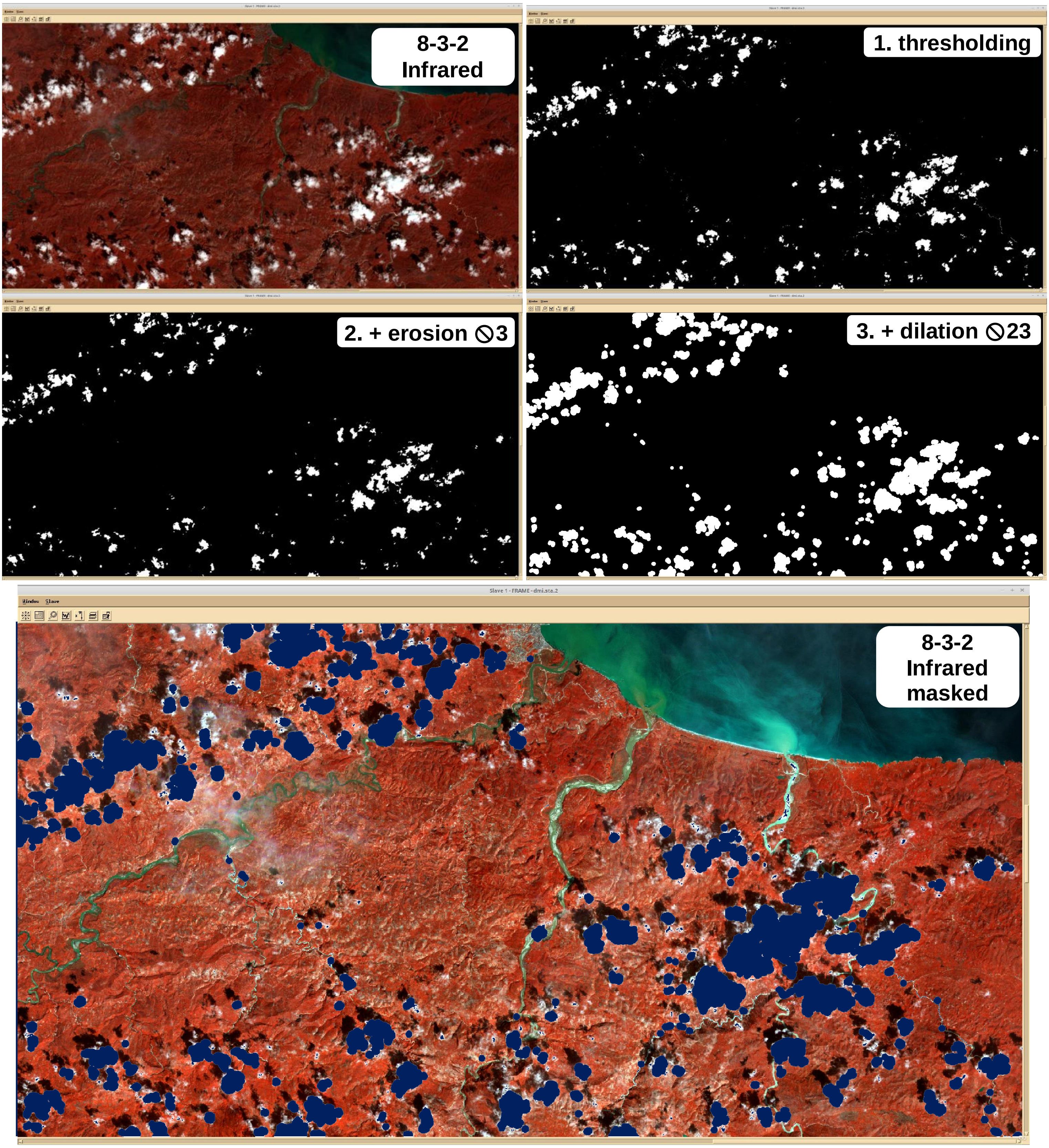


fig. 20 - Processing steps of cloud mask.

As shown in fig. 20, cloud mask of each S2 scene is performed in three steps:

- thresholding - trade-off between low values (to select the maximum extents of clouds) and high values (to avoid aggregating bare soils, sand beaches, flooded areas…),
- erosion - to remove small connex components with a diameter less than 3 pixels, this process enables to cancel elongated patterns like beaches, talwegs, rivers…
- dilation - to make grow the clouds extents up to 12 pixels (half of 25 pixels diameter) beyond the initial extents

Figures fig. 21 and fig. 22 show the results of the cloud masking applied to the two scenes pre-event and three scenes post-event respectively. Because scene acquired on 28.11.2016 shows clouds not clearly contrasted with the neighbourhood, diameter of the cloud dilation has been increased from 25 to 41 pixels.

In each one of the five figures the percentage of clouds actually forced as background is reported in white in upper-right corner.

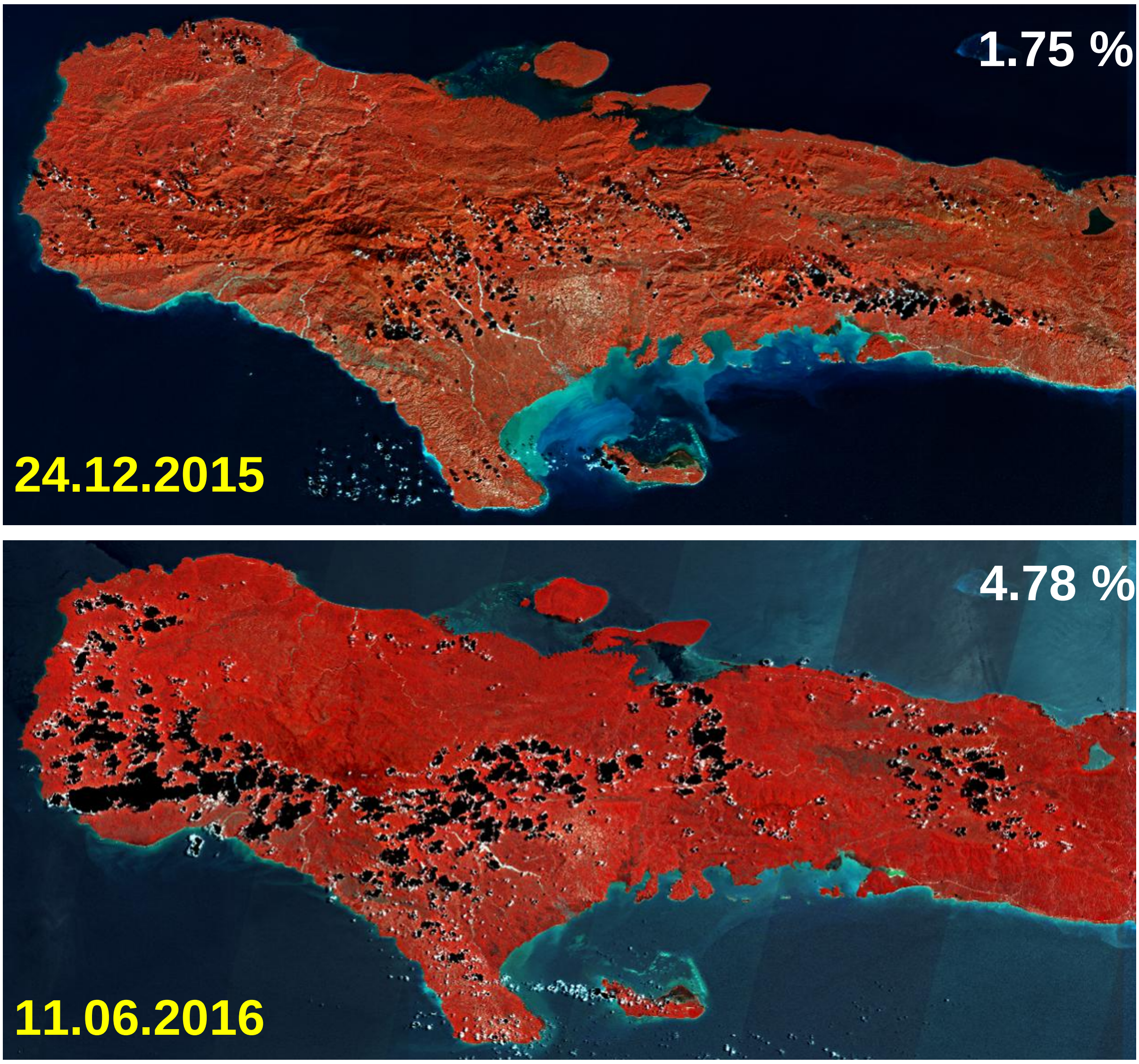


fig. 21 - Sentinel-2 cloud-masked pre-event.

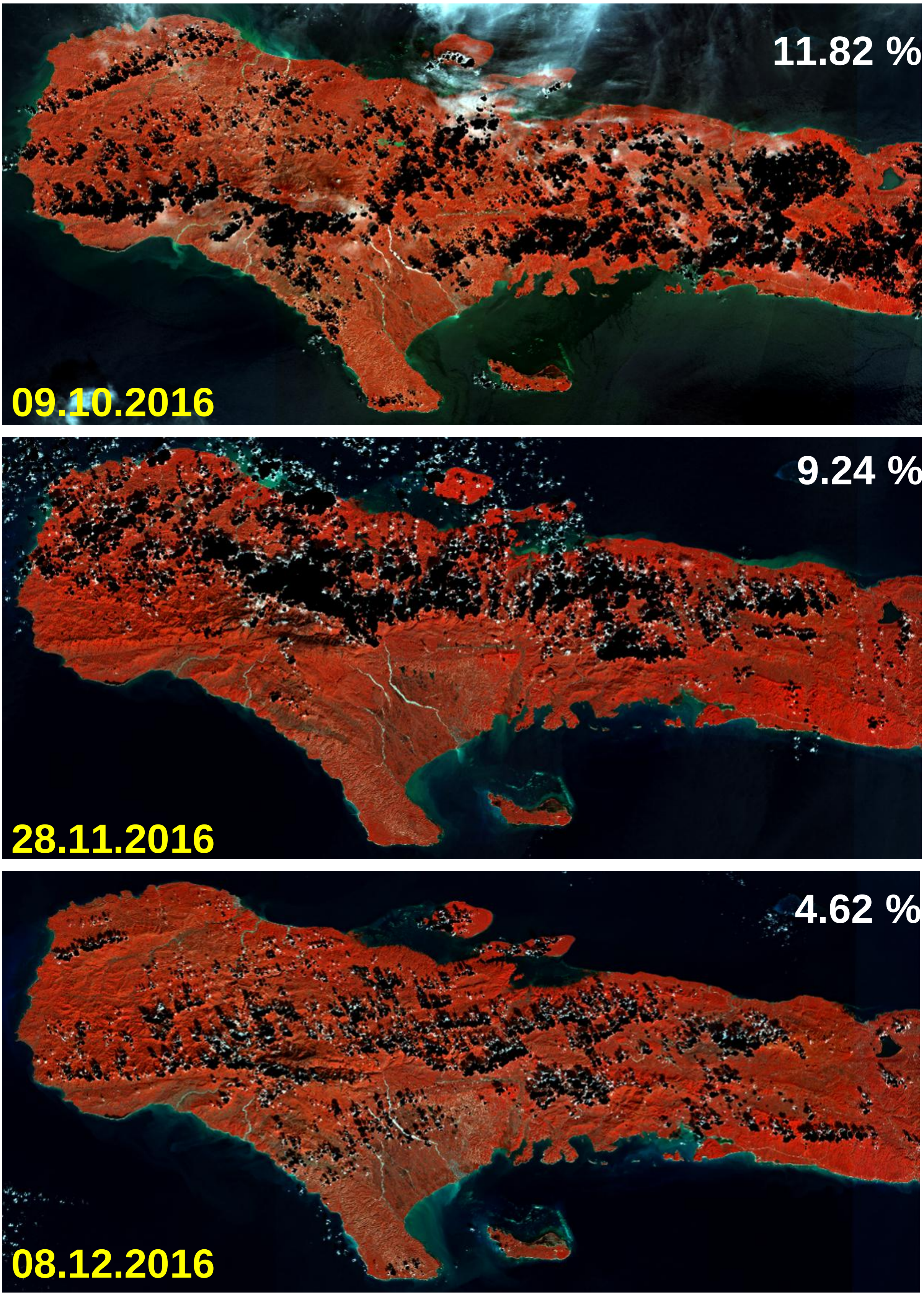


fig. 22 - Sentinel-2 cloud-masked post-event.

3.4 Cloud-free synthesis

3.4.1 Method 1 - Maximum NDVI on raw data

3.4.1.1 Presentation

As shown in fig. 23, the synthesis is performed replacing the clouds found in the first image by non-cloud pixels found at the same location in a second image. This replacement is based on the “maximum NDVI” algorithm accounting the fact that clouds have a lower NDVI than ground pixels.

fig. 23 - Cloud-free synthesis (c) of scenes acquired on 09.10.2016 (a) and 28.11.2016 (b).

3.4.1.2 Results

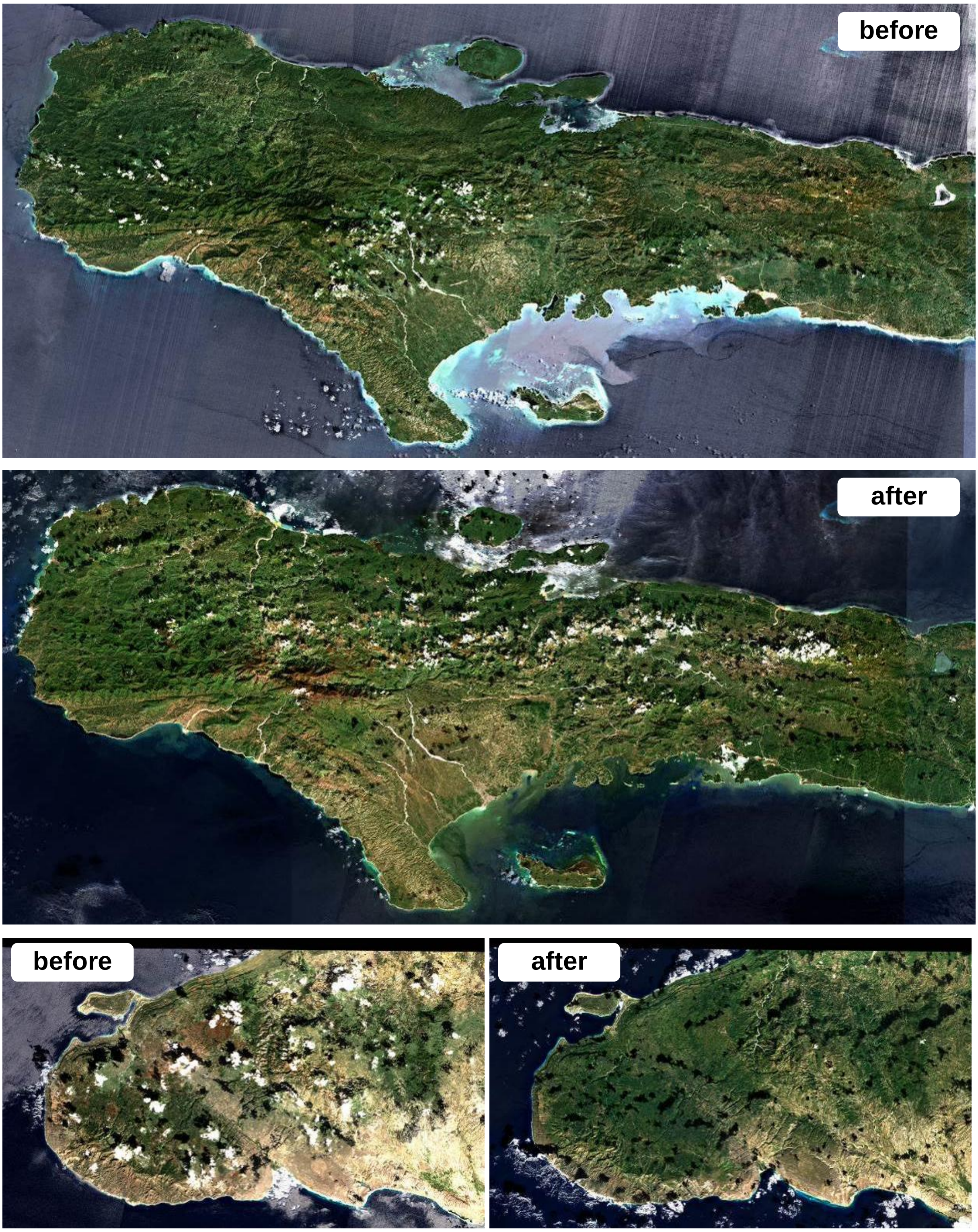


fig. 24 - Synthesis Spacemaps before and after event - Bands 4-3-2 natural colour compositions.

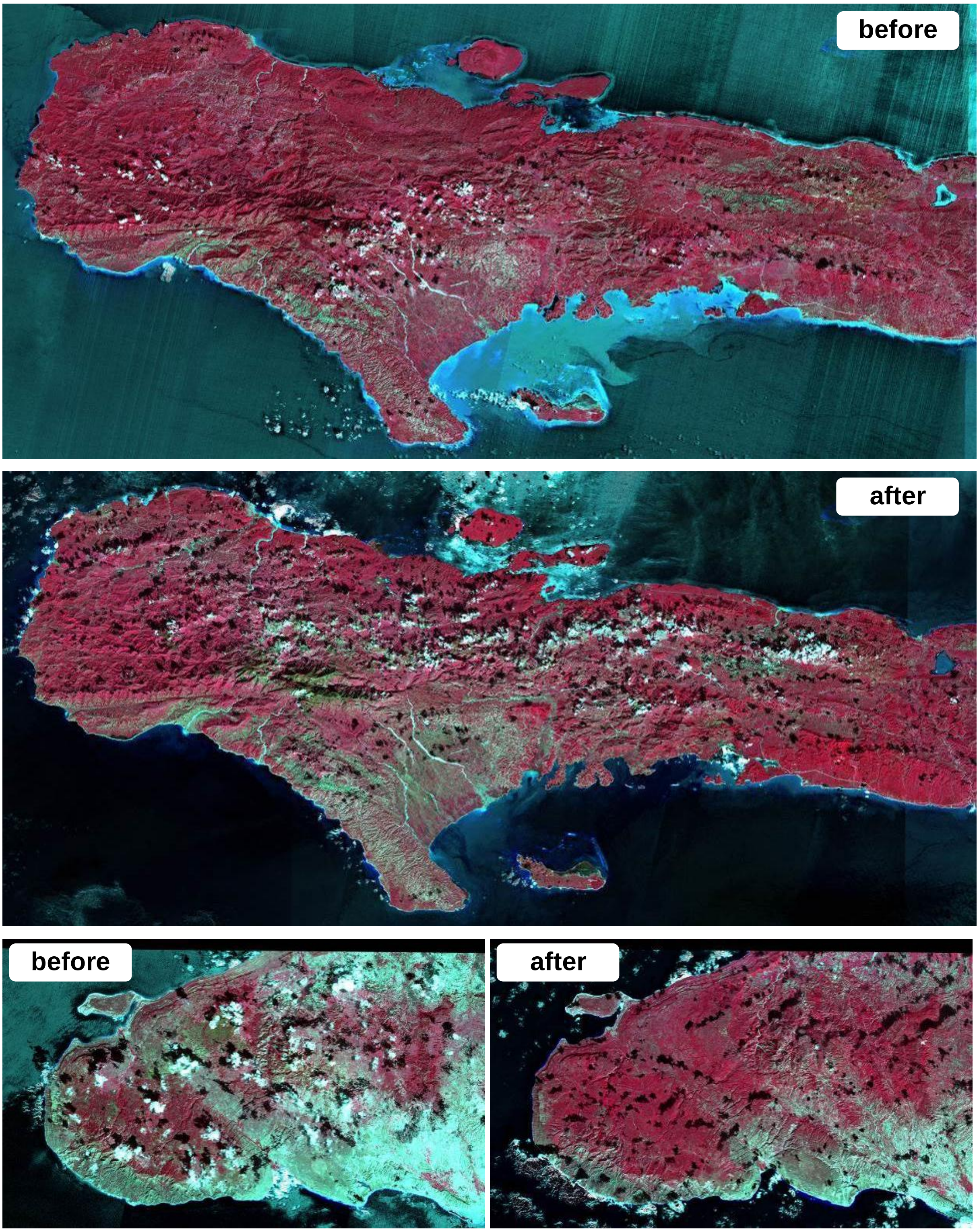


fig. 25 - Synthesis Spacemaps before and after event - Bands 8-4-3 NIR colour compositions.

3.4.2 Method 2 - Maximum NDVI on cloud-masked data

To avoid one of the drawbacks underlined by Niloufar BAYANI (see A.1) leading to "…adding a level of uncertainty…" (see the suspect traces of NDVI gains in "NDVI difference spacemap" of fig. 29), the synthesis is performed from cloud-masked images produced in section 3.3.3 (Manual thresholding).

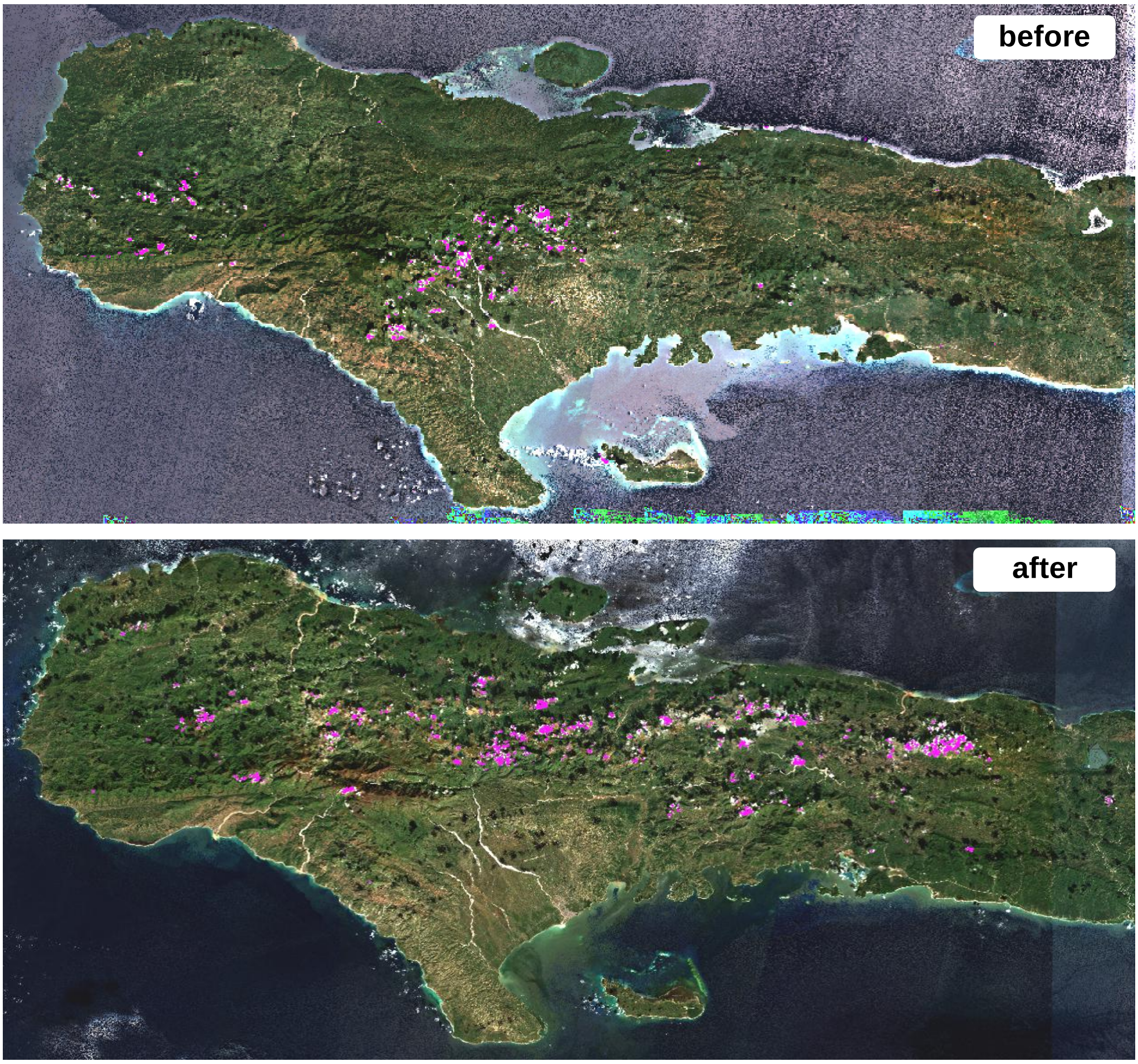


fig. 26 - Cloud-masked synthesis Spacemaps before and after event - Bands 4-3-2 natural colour compositions.

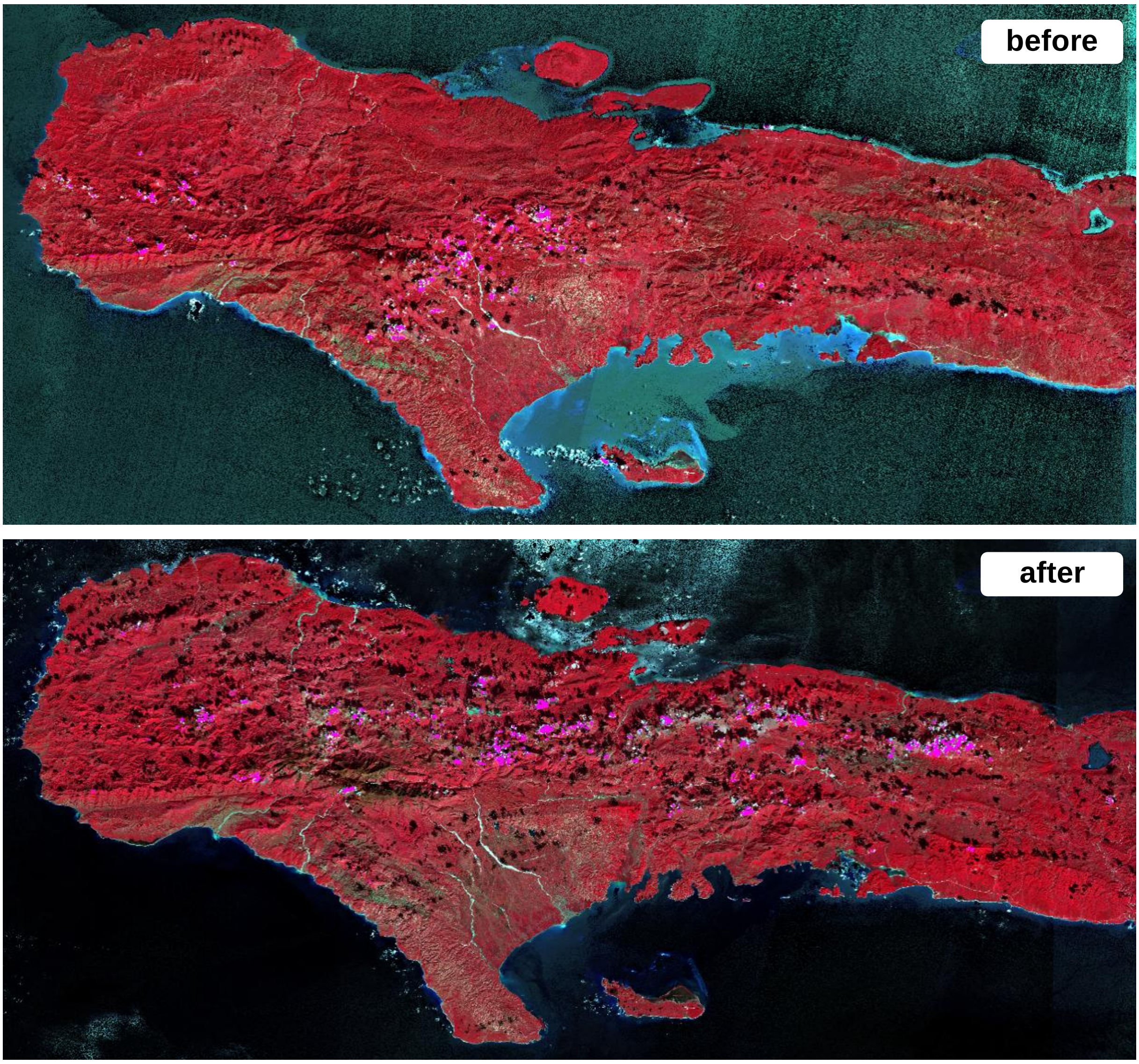


fig. 27 - Cloud-masked synthesis Spacemaps before and after event - Bands 8-4-3 NIR colour compositions.

3.5 Normalized Difference Vegetation Index (NDVI)

3.5.1 Method

As shown in fig. 28 below, the 13 spectral bands of Sentinel-2 belong to three groups of spatial resolutions: 10m, 20m and 60m. The highest resolution ones are in visible (B2, B3 and B4 for blue, green and red respectively) and the near infrared (B8).

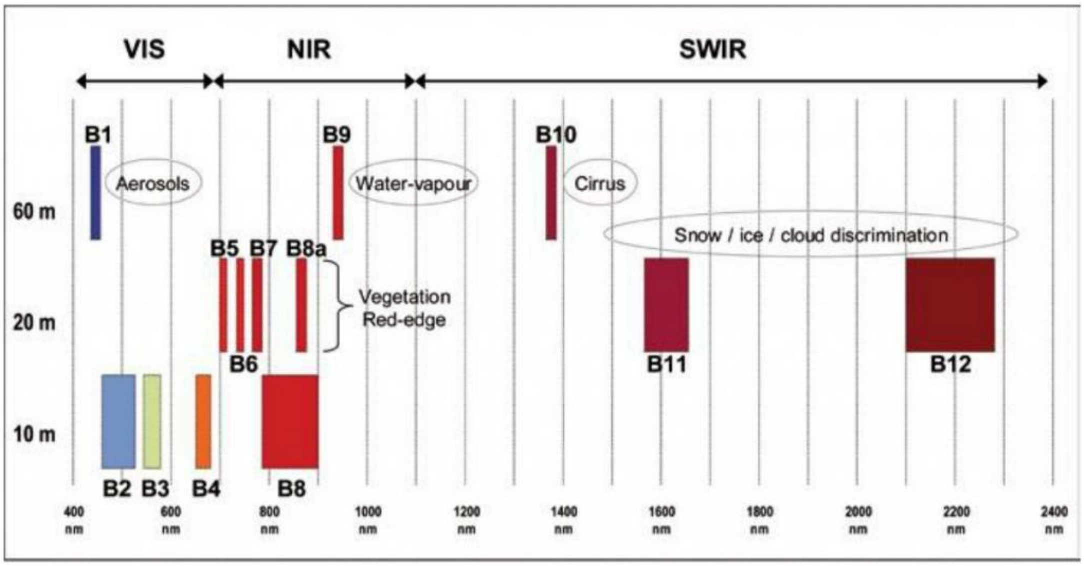


fig. 28 - Sentinel-2 spectral bands.

The normalized vegetation index of Sentinel-2 images is computed using the standard formula

$$NDVI = \frac{NIR - RED}{NIR + RED} = \frac{B8 - B4}{B8 + B4} \quad \text{(eq. 1)}$$

NDVI computation is applied to the synthesis spacemaps (see section 3.4). Output of NDVI computation is considered in the range [-1;+1]. These NDVI images are often visualised through a “rainbow” look-up table (LUT).

In each zone (“south” and “north”) the difference between the two NDVI pre-event and post-event is computed and visualised using a balance LUT with the red illustrating the gain of vegetation while the blue colour showing the decrease of vegetation index.

3.5.2 Results

One of the major spacemaps to be used is the “**NDVI difference**”. This difference has been computed from synthesis produced according to different methods (see section 3.4).

3.5.2.1 Synthesis method 1 - Maximum NDVI from raw data

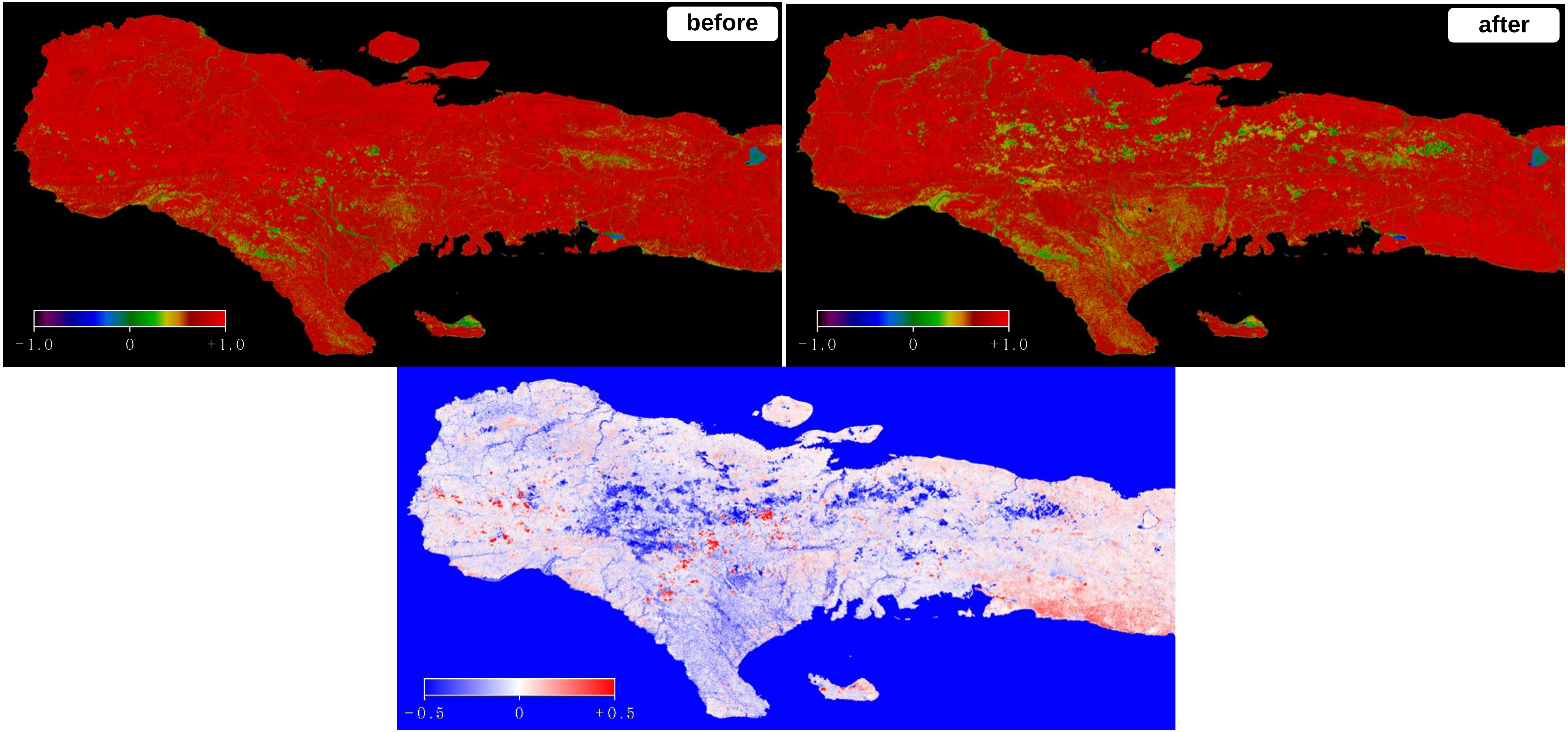


fig. 29 - Synthesis method 1 - South zone - NDVI pre-event and post-event and difference of NDVI spacemaps.

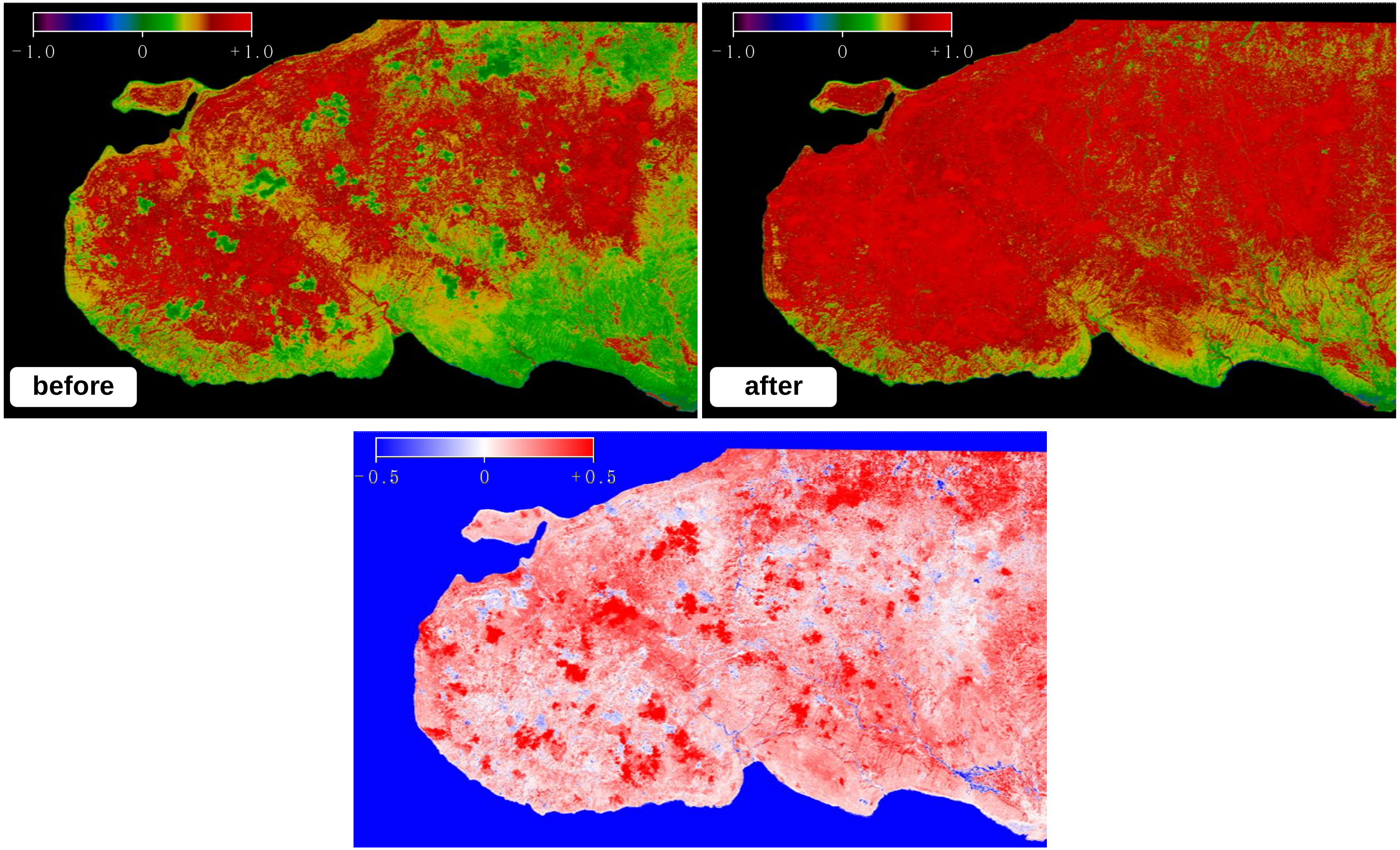


fig. 30 - Synthesis method 1 - North zone - NDVI pre-event and post-event and difference of NDVI spacemaps.

3.5.2.2 Synthesis method 2 - Maximum NDVI from cloud-masked data

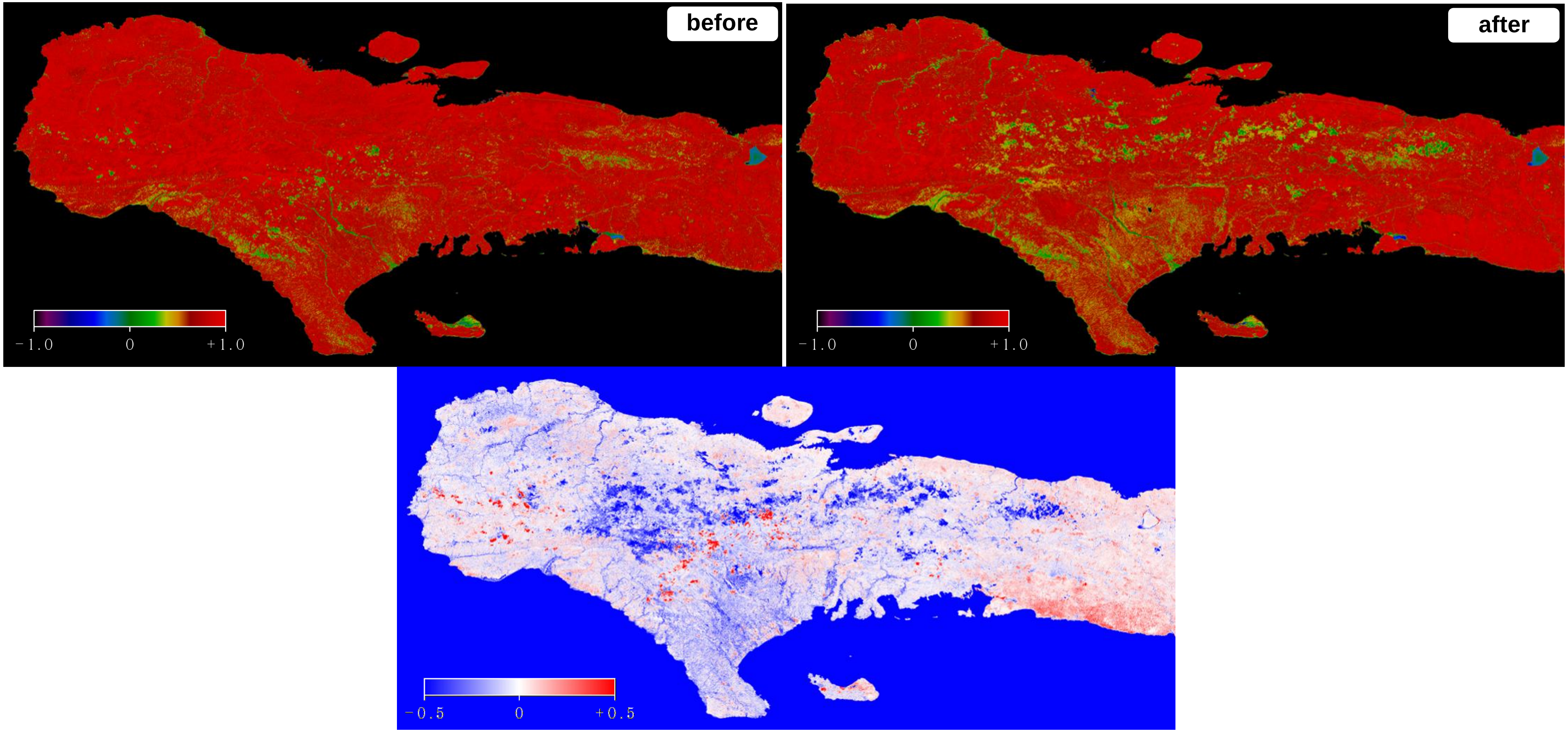


fig. 31 - Synthesis method 1 - South zone - NDVI pre-event and post-event and difference of NDVI spacemaps.

4 Photo-interpretation of Digital Globe data

4.1 Les Cayes

fig. 32 -Image Digital Globe acquired on January 05 2013 in Les Cayes and Torbeck.

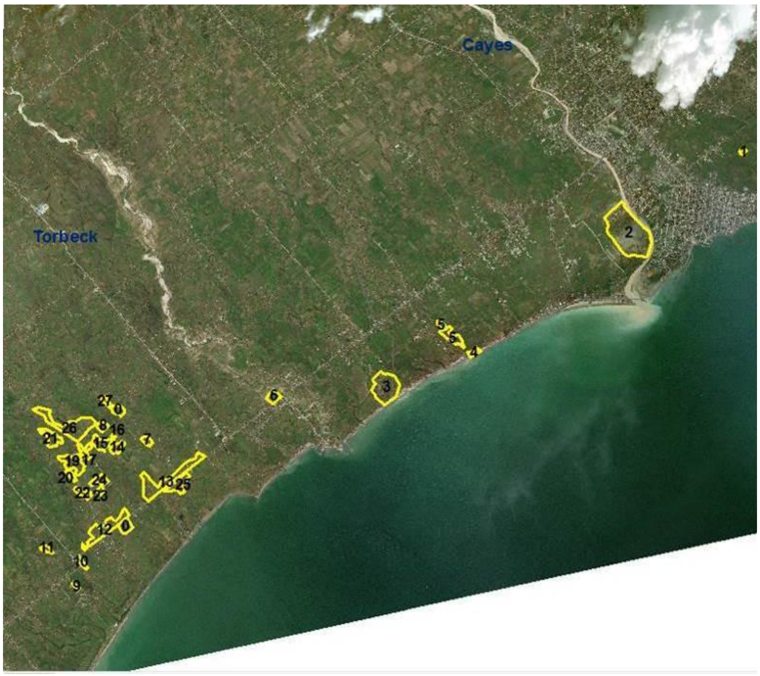


fig. 33 -Image Digital Globe acquired on October 09 2016 in Les Cayes and Torbeck.

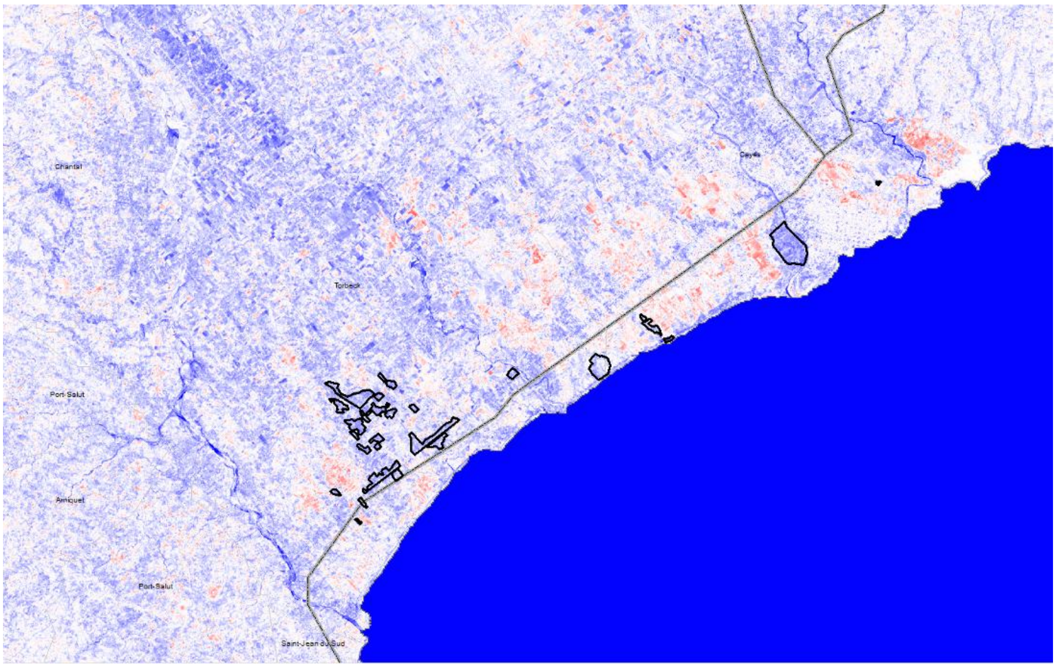
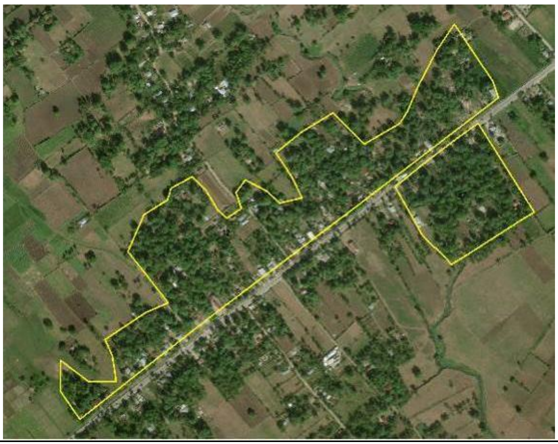


fig. 34 -Image of the NDVI difference from Sentinel-2 in Les Cayes and Torbeck.

ID	Before	After
1		
2		

3		
4		
5		
6		

7		
8		
9		

11		
12		
14		

15		

4.2 Macaya Parc

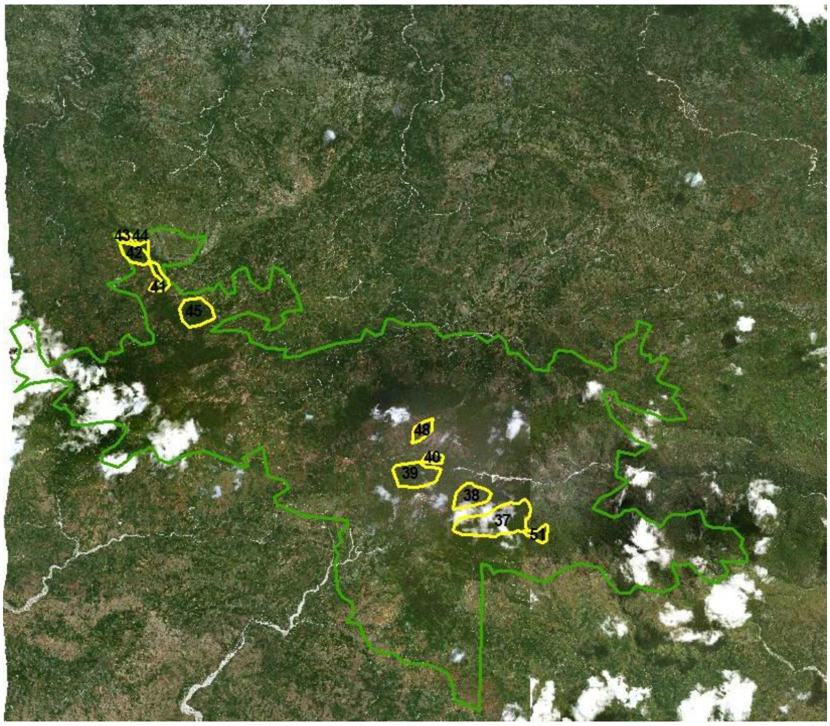


fig. 35 -Two images Digital Globe acquired on June 09 2013 and July 03 2015 in Macaya Parc.

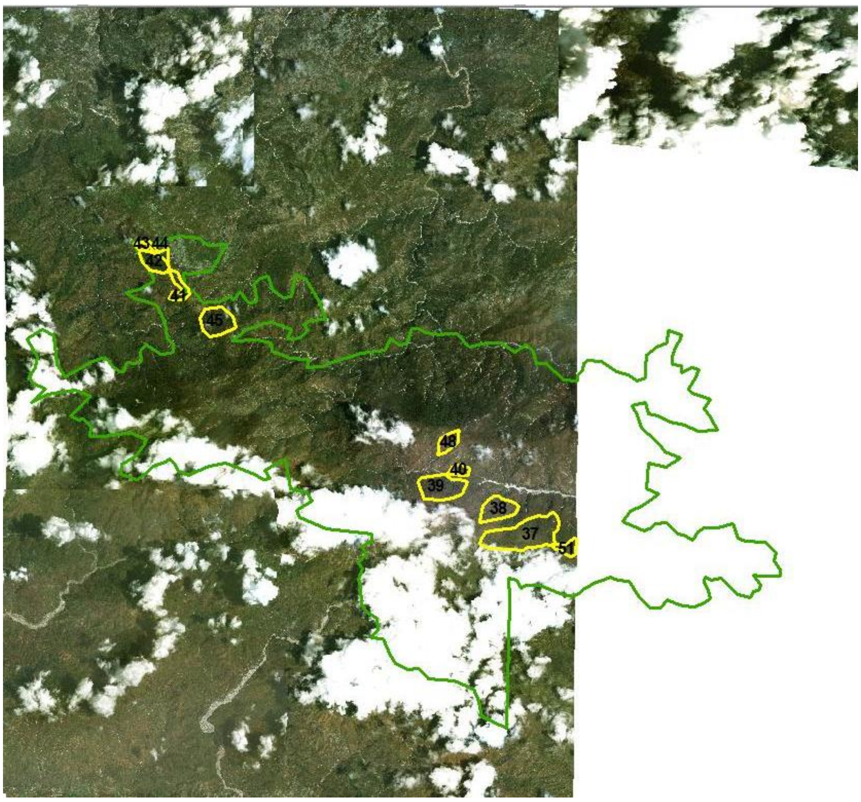


fig. 36 -Image Digital Globe acquired on October 09 2016 in Macaya Parc.

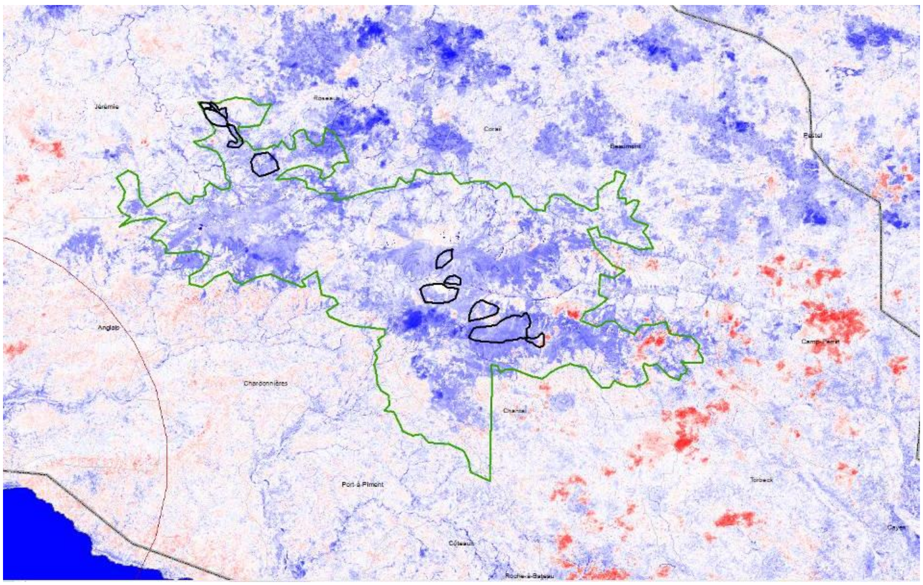
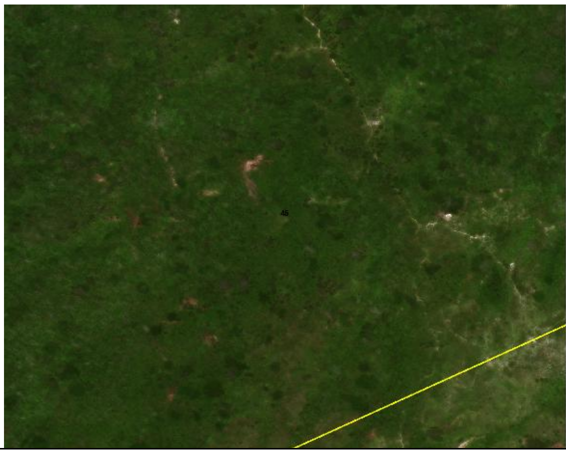
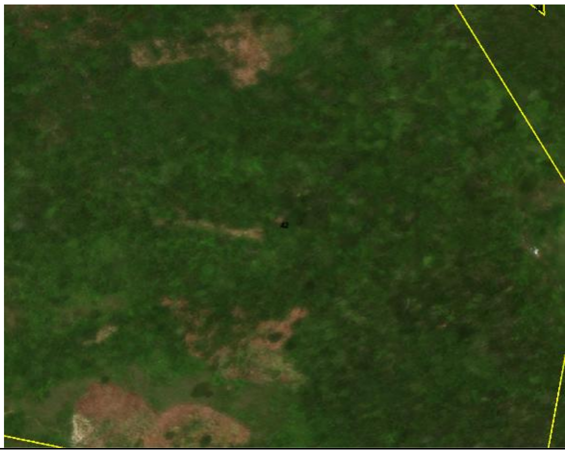
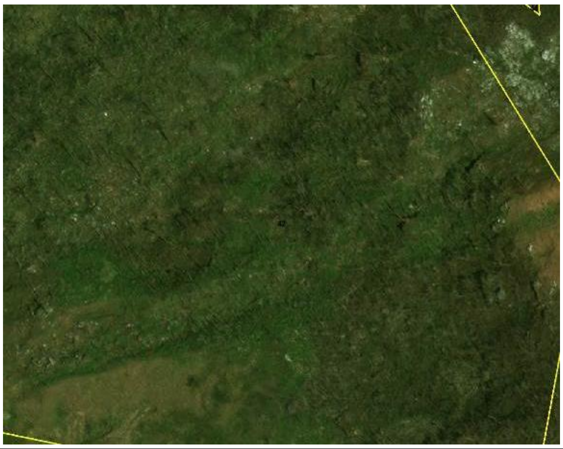
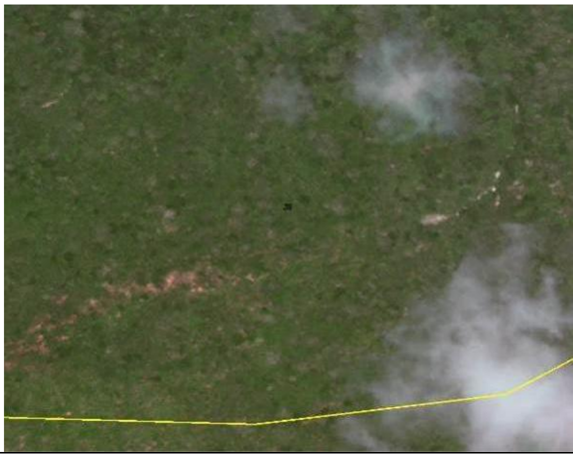


fig. 37 -Image of the NDVI difference from Sentinel-2 in Macaya Parc.

45		
42		
39		

4.3 Coteaux

fig. 38 - Image Digital Globe acquired on June 09 2013 in Coteaux.

fig. 39 -Image Digital Globe acquired on October 09 2016 in Coteaux.

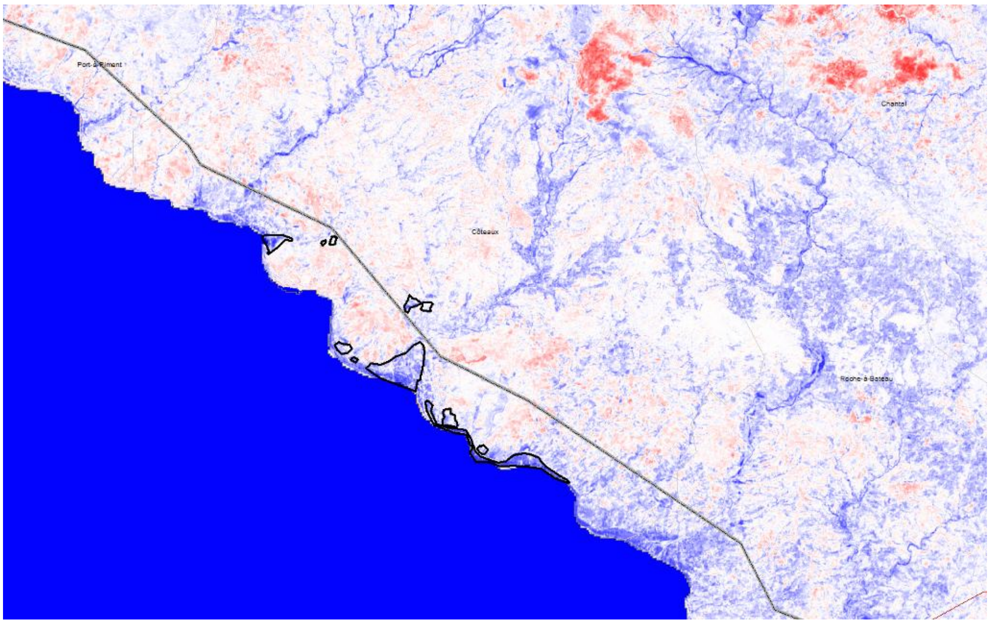


fig. 40 -Image of the NDVI difference from Sentinel-2 in Coteaux.

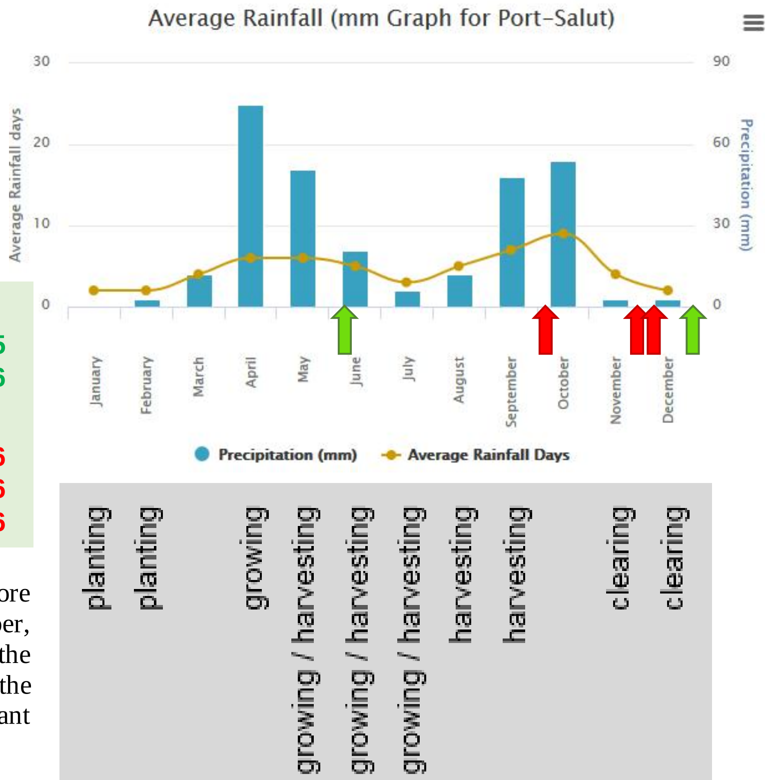
5 ANALYSIS OF NORMALISED DIFFERENCE INDICES

5.1 Influence of dates and seasons

5.1.1 Analysis of acquisition dates chosen for v1 synthesis

Jacqueline HENROT suggests to analyse the possible correlation between the precipitations (at least the averages given on the https://www.worldweatheronline.com site) and the acquisition dates. She indicates the dominant phases of agricultural activities per months: planting / growing / harvesting / clearing.

The attached figures shows the average rainfall computed on [2000;2012] period. One may observe that the values of Port-Au-Prince and Port-Salut are the same meaning that the input values have not been collected from a ground station but are certainly issued by a global model.



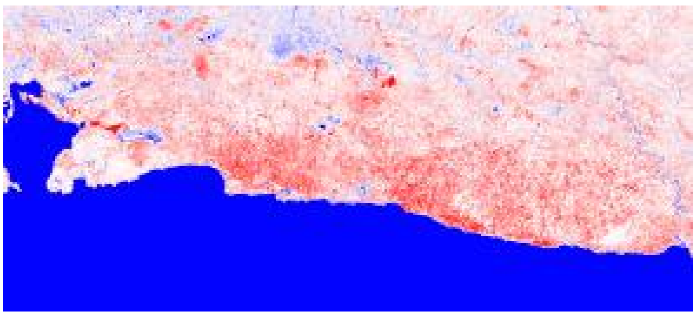
As recorded in the green box, pre-event scenes is a synthesis between two acquisitions in December and June. Considering that the synthesis process (see section 3.4) is based on the "maximum NDBI" retention, the image of June shall have been predominant.

pre-event
- **24.12.2015**
- **11.06.2016**

post-event
- **09.10.2016**
- **28.11.2016**
- **08.12.2016**

The post-event synthesis implies more contemporaneous acquisitions in October, November and December. Considering that the maximum of precipitation occurs in October, the not-cultivated vegetation should be predominant in the synthesis.

It is maybe the cause of the vegetation gain observed in the western part of the Peninsula between Côtes-de-Fer and Saint-Louis du Sud (see the attached extract of the "NDVI changes" spacemap in fig. 49).



5.1.2 Using GPM data

Data of the "Global Precipitation Measurement" (GPM) portal are recently available (less than 2 years) and in particular the "Integrated Multi-satellitE Retrievals" (IMERG) data are synthesised each 30 minutes in Near-Realtime (see https://pmm.nasa.gov/gpm/imerg-global-image) and archived from 12/03/2014 (March 12th).

5.1.2.1 Download from PMM (Precipitation Measurement Missions)

Archive data are downloadable at https://pmm.nasa.gov/data-access/downloads/gpm.

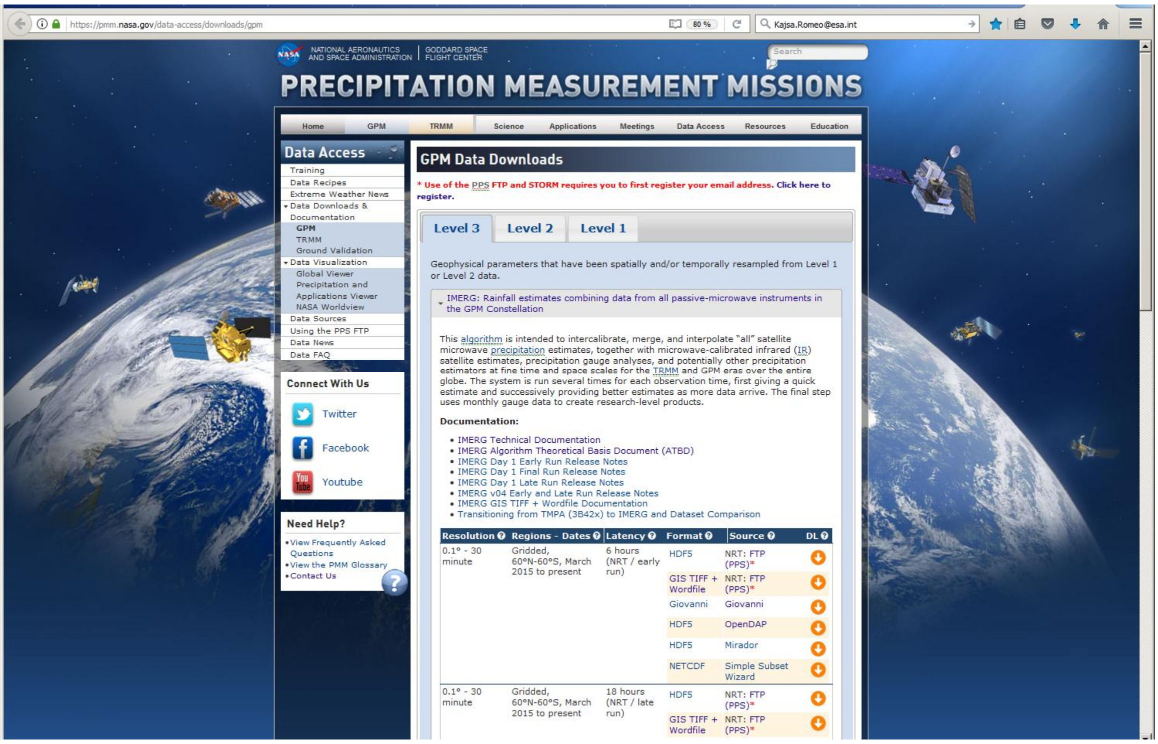


fig. 41 - Site of the Precipitation Measurement Missions (PMM).

The datasets to be selected depends on the elapsed time since the target data and the date of request. We shall first select the most consolidated data (“Final run”) and if the data have not yet been processed, the “late run” and if they are not found the “early run”. See for example the 1-Day aggregated data in the attached figure.

0.1° - 1 Day	Gridded, 60°N-60°S, April 2015 to present	6 hours (NRT / early run)	GIS TIFF + Wordfile	NRT: FTP (PPS)*	
			GIS TIFF + Wordfile	NRT: FTP (PPS)*	
			NetCDF	GES DISC	
0.1° - 1 Day	Gridded, 60°N-60°S, April 2015 to present	18 hours (NRT / late run)	GIS TIFF + Wordfile	NRT: FTP (PPS)*	
			NetCDF	GES DISC	
0.1° - 1 Day	Gridded, 60°N-60°S, April 2015 to present	4 Months (research / final run)	NETCDF	OpenDAP	
			NetCDF	GES DISC	

Data are distributed on one of the two servers given at https://pmm.nasa.gov/data-access/data-sources#register:

…

FTP Servers

The Precipitation Processing System hosts several FTP servers to access the different types of TRMM and GPM data:

- ftp://arthurhou.pps.eosdis.nasa.gov: New server for Production (PROD) TRMM and GPM data. Click here for an outline of the directory structure for production GPM data.
- ftp://jsimpson.pps.eosdis.nasa.gov: New server for Near-Realtime (NRT) TRMM and GPM data. Click here for an outline of the directory structure for realtime GPM data.

…

As indicated in an e-mail of George J. Huffman on 19.01.2017, “…your **email address** will serve as both your username AND password for logging into the FTP site…”.

retrouver le repertoire imerg !!!

The two (2) IMERG datasets being selected are daily accumulated precipitation estimates ("Final run" for 2014 and 2015 years and "Late run" for 2016 and possibly 2017). See table 2 below.

☐	Random Error for multi-satellite precipitation with climatological gauge calibration - Early Run (GPM_3IMERGHHE v03)	GPM	Half-Hourly	0.1 °	2015-04-01	2017-01-23	mm/hr
☐	Daily accumulated precipitation estimate - Early Run (GPM_3IMERGDE v03)	GPM	Daily	0.1 °	2015-04-01	2017-01-22	mm
☑	Daily accumulated precipitation estimate - Late Run (GPM_3IMERGDL v03)	GPM	Daily	0.1 °	2015-03-14	2017-01-22	mm
☑	Daily accumulated precipitation estimate - Final Run (GPM_3IMERGDF v03)	GPM	Daily	0.1 °	2014-03-12	2016-01-31	mm
☐	Merged satellite-gauge precipitation estimate - Final Run (recommended for general use) (GPM_3IMERGM v03)	GPM	Monthly	0.1 °	2014-04-01	2016-01-31	mm/hr

table 2 - IMERG precipitation datasets selected for analysis.

5.1.2.2 Aggregation and display from GIOVANNI

Data may also be viewed from the GIOVANNI portal https://giovanni.sci.gsfc.nasa.gov/giovanni/. The extraction and possible aggregation of measurements is performed in the steps of the sub-sections below.

Select measurement

In place of browsing the "Discipline" and "Measurements" trees, the target dataset may be quickly retrieved using the "**GPM Daily**" keyword. The three datasets "Early Run", "Late Run" and "Final Run" match three increasing levels of consolidation of results. The "End Date" of the available measurement depends on these levels.

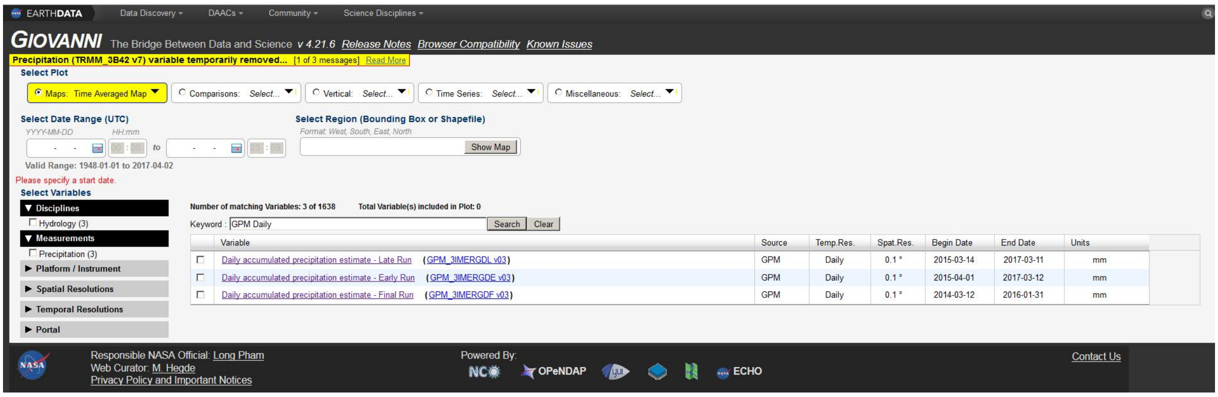


fig. 42 - Precipitations from GIOVANNI - Selection of the measurement.

Select the type of aggregation

Two major types of aggregation are available: -"Time Averaged" (left "Maps: Select…" menu) and -"Area Averaged" that has been selected.

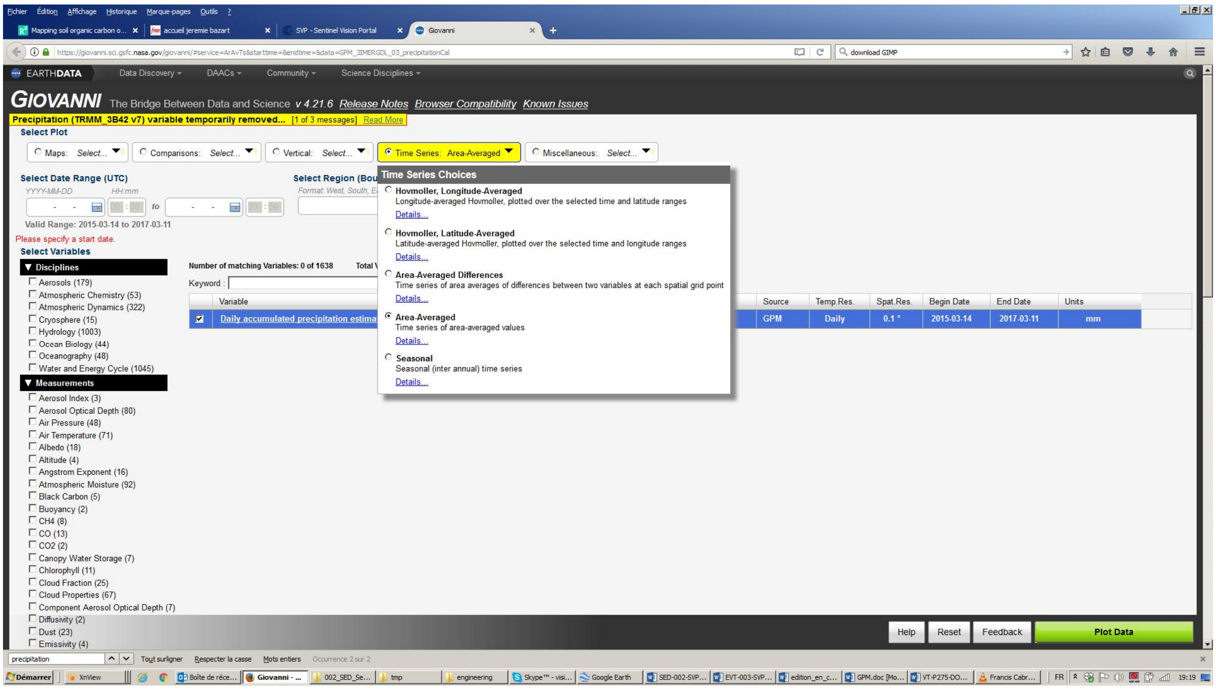


fig. 43 - Precipitations from GIOVANNI - "Area-Averaged" aggregation.

Select region

To define the region in which the "Area-Averaged" shall be computed, one should activate the "Show Map" button. The area may be interactively defined or selected across predefined shapes matching a particular country. Here "Haiti" has been selected in the pull-down menu.

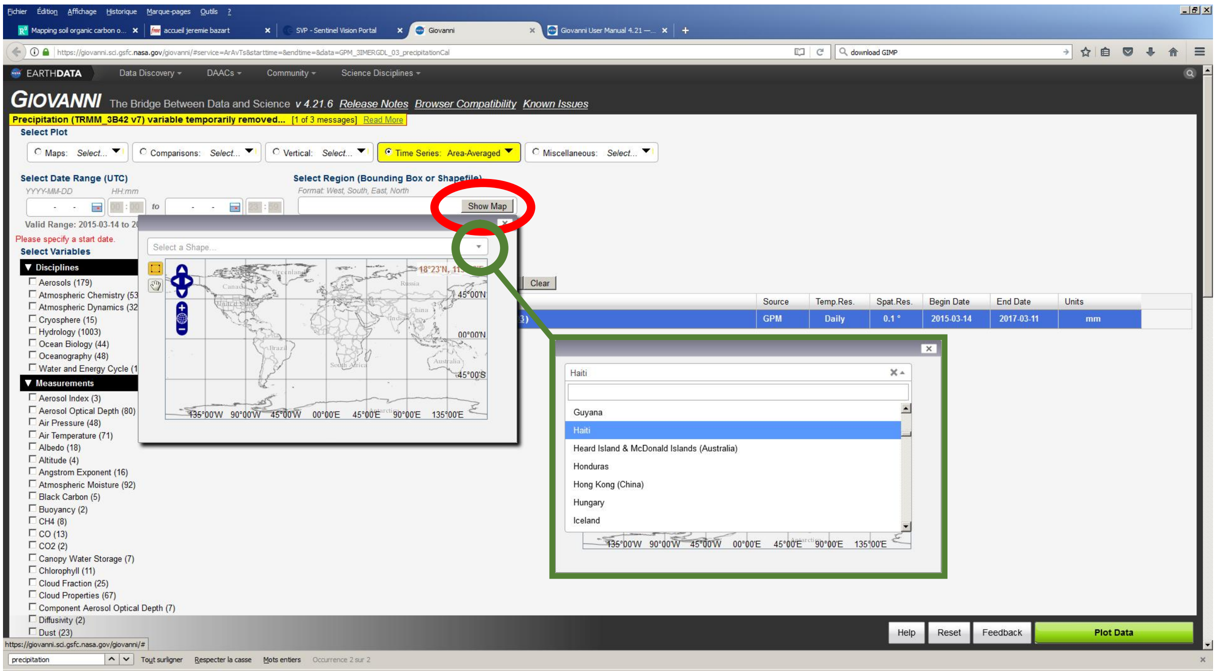


fig. 44 - Precipitations from GIOVANNI - Select region.

Plot data

After having set the date start and date stop in the valid range (see fig. 45), data computation is ordered to the GIOVANNI server using the “Plot data”.

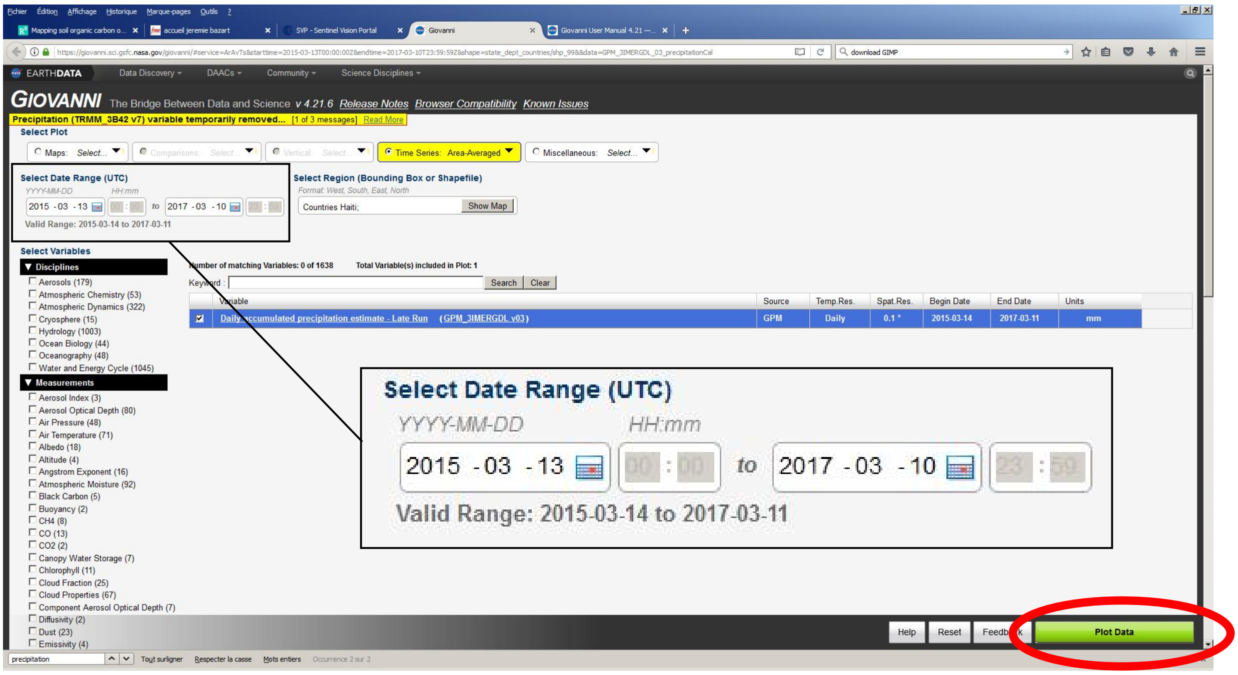


fig. 45 - Precipitations from GIOVANNI - Plot data.

Computation state is illustrated by a progress scale (see fig. 46) giving the various steps of the processing. This computation may be long (more than 5 minutes) !

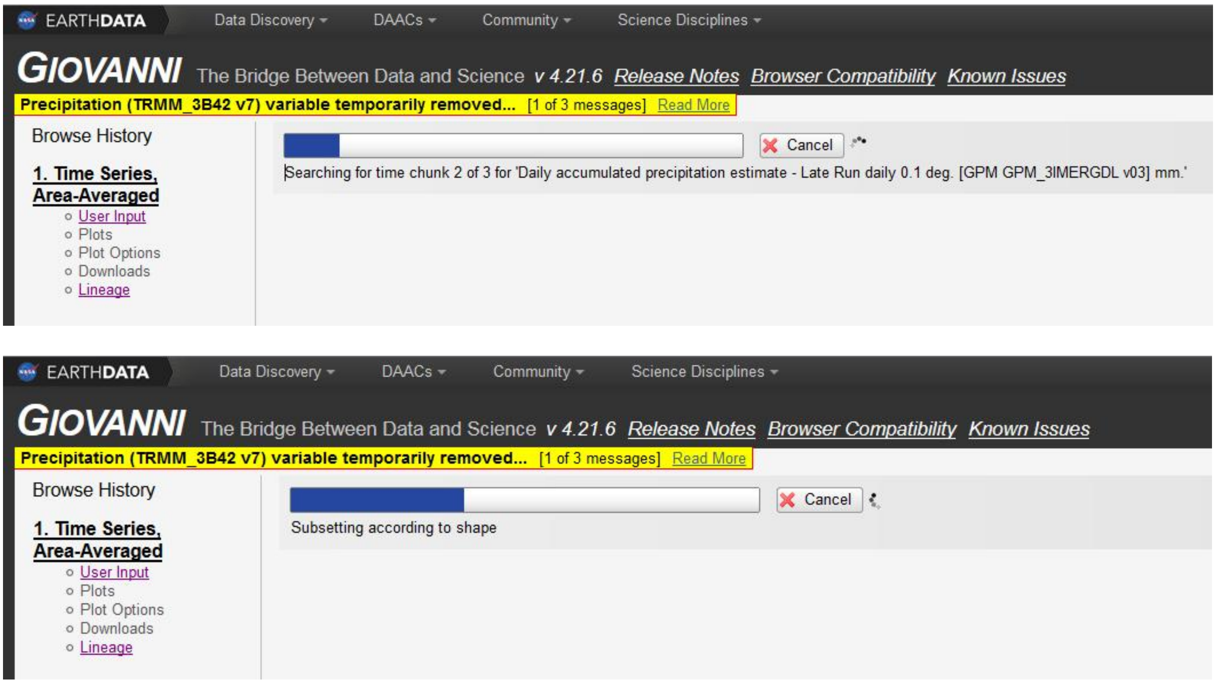


fig. 46 - Precipitations from GIOVANNI - Progress scale.

Download of precipitations values

As shown in fig. 47, numerical values may be downloaded in a ".csv" file that may be after analysed and plotted (see fig. 48) to render particular features (here for example the comparison between the three years 2015, 2016 and 2017).

fig. 47 - Precipitations from GIOVANNI - Download of daily precipitations.

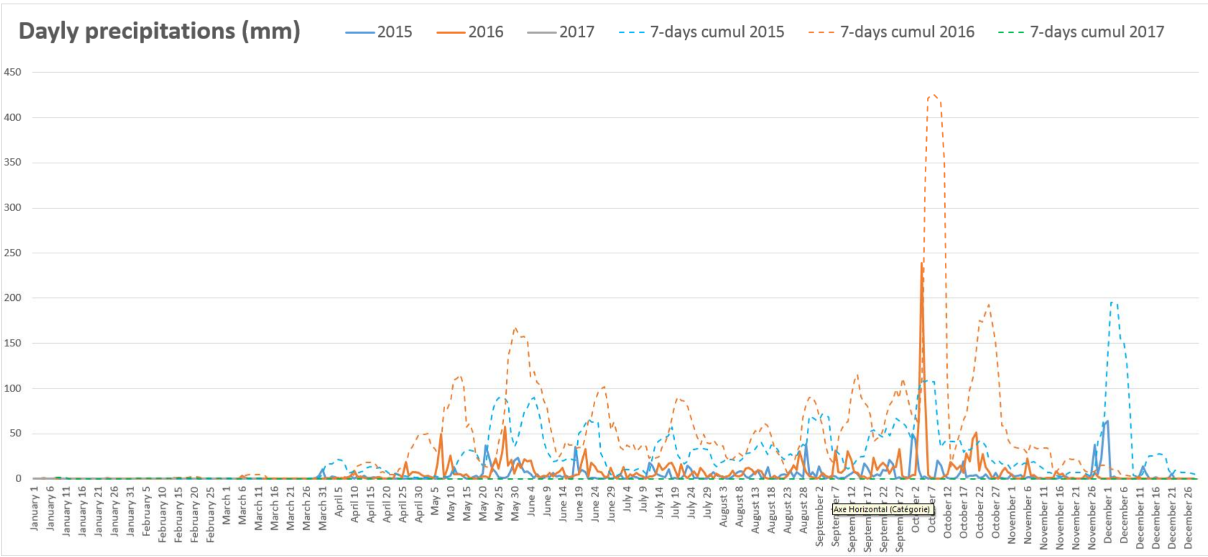


fig. 48 - Precipitations from GIOVANNI - Comparison between the 2015, 2016 and 2017 years.

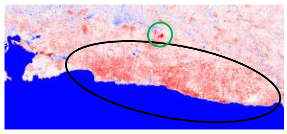
5.2 Influence of clouds and shadows

Figure below (fig. 49) shows the synthesis spacemaps before and after the event in which one has delineated by hand the groups of clouds and shadows: -violet for the synthesis before and -brown for the synthesis after. These vector delineations are copied on the "NDVI change" spacemap to analyse the correlation between possible artefacts and the presence of clouds or shadow.

5.2.1 Case of clouds in the pre-event synthesis

Most of the red zones (gain of vegetation) in the left part of the Peninsula are artefacts due to the presence of clouds in the pre-event synthesis that the "NDVI changes" computation compares with no-cloud zones which NDVI is always greater than the one of clouds whatever being the land cover (vegetation, bare soils…).

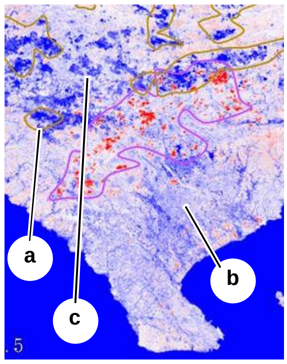
This conclusion does not apply to the red zone of vegetation gain observed along the coast in the lower-right part of the image (see the black ellipse drawn in the attached image) except for few small zones with a much higher level of contrast like the one in the green circle in the attached image. These small high-contrast vegetation gains are the artefacts depicted here above.



5.2.2 Case of shadows in the pre-event synthesis

Shadow zones in the pre-event synthesis leads to a light vegetation loss in the "NDVI changes" spacemap. This could be due to a non-linearity of the variations of red (B4) and near-infrared (B8) reflectances between shadowed pixels and not-shadowed pixels.

From a quantitative point of view, the pre-event shadows have small impacts on the "NDVI changes" results.



5.2.3 Case of clouds in the post-event synthesis

Clouds in the post-event synthesis lead to high-contrast vegetation loss (blue zones in the "NDVI changes" spacemap). These "blue patches" (a) are compact artefacts that differs from more sparse textures (b) encountered in the plains (see for example the area around Clayes) or along talweg lines.

This conclusion must be nuanced in zones like the Macaya Park in which hard vegetation losses (c) have been observed.

5.2.4 Case of shadows in the post-event synthesis

Shadows in the post-event synthesis spacemap lead to very light vegetation gain in the "NDVI changes" spacemap. This subtile effect is for example observed in the western part of the Peninsula (see the attached extract).

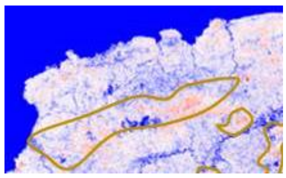


fig. 49 -South zone - Pre and post event natural colour compositions compared to the NDVI difference.

6 CLASSIFICATIONS

6.1 Method

6.1.1 Computing the classifications

A first unsupervised classification is performed on pre-event and post-event synthesis spacemaps to segment the image in homogeneous zones. This segmented image is then used to define the training parcels: -vegetation, -bare soils, -urban, -water, -clouds and their dual “shadowed” classes like “shadowed vegetation”…

6.1.2 Computing the class changes

Scope of this processing is to identify the exchanges between the two main classes “vegetation” and “bare soils”. Four classes are retained: -unchanged bare soils, -unchanged vegetation, -vegetation becoming bare soil and -bare soil becoming vegetation.

6.2 Results

Analysis has shown that the bare soils are polymorph and that urban class is also confused with the "bare soils" class. As shown in figures fig. 50 and fig. 51) final classifications have only five (5) classes: -cloud, -cloud shadow, -water, -bare soil, -vegetation.

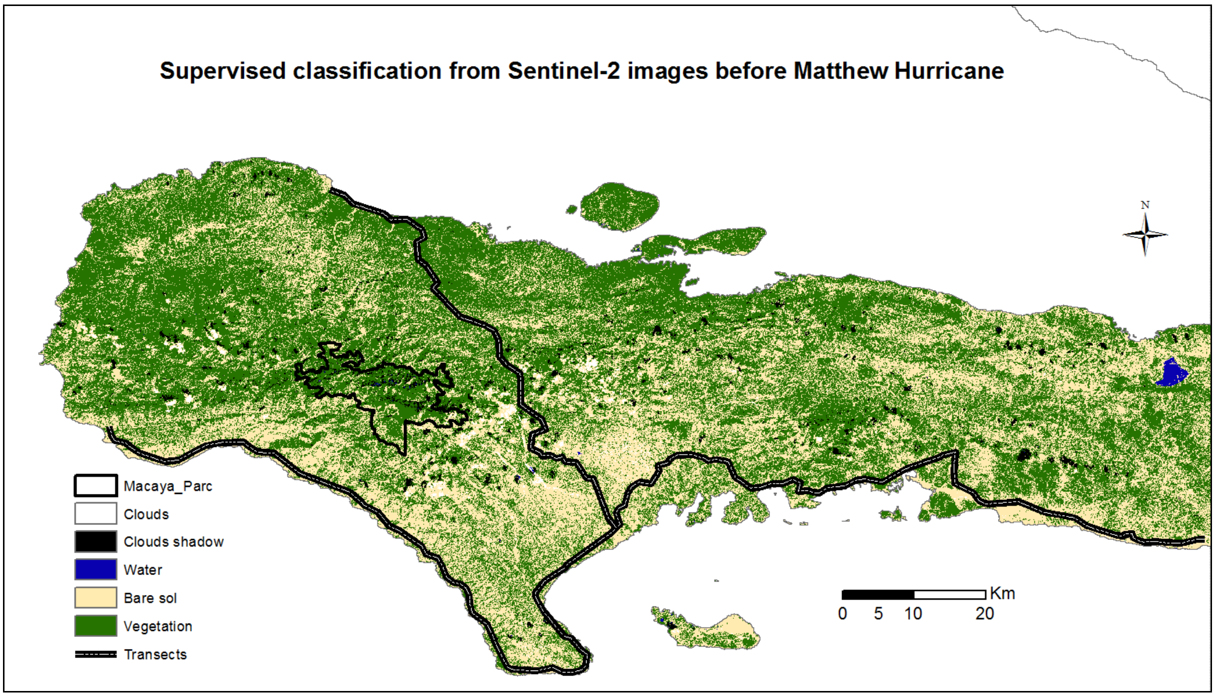


fig. 50 -Supervised classification from Sentinel-2 images before Matthew Hurricane.

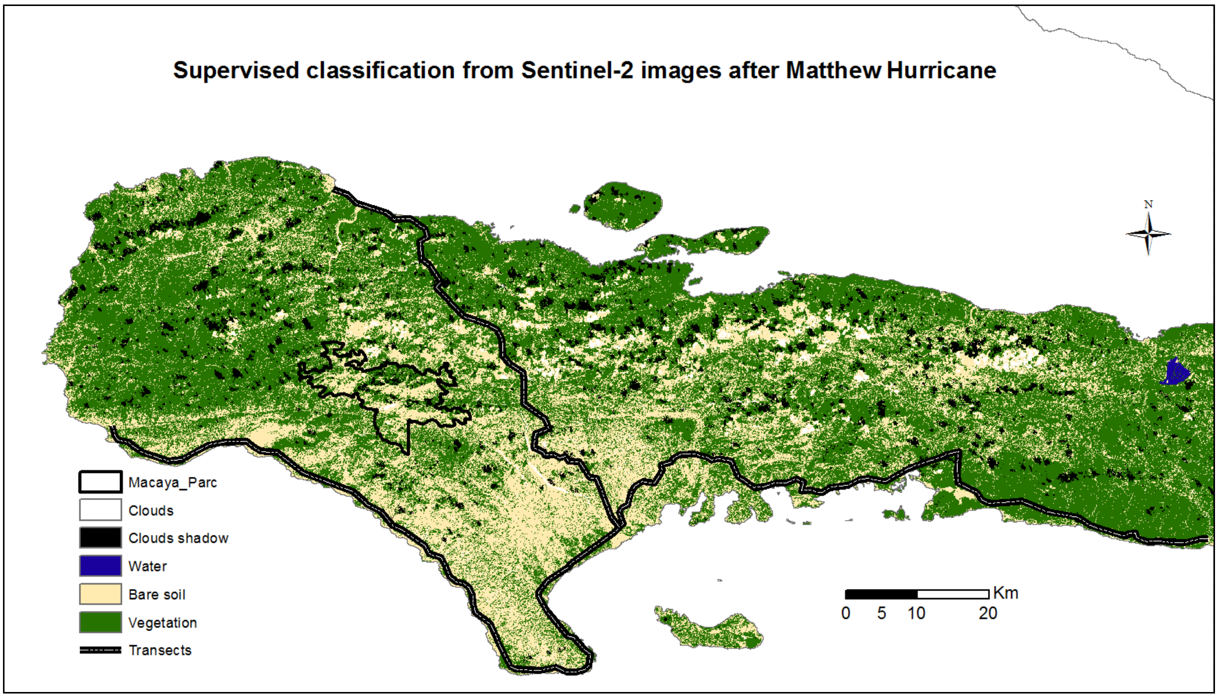


fig. 51 -Supervised classification from Sentinel-2 images after Matthew Hurricane.

As shown in fig. 52 below, one may clearly identify the "vegetation becoming bare soils" (in blue) towards "bare soils becoming vegetation" (in red). This "class changes" spacemap may be compared to the "NDVI changes" spacemap described in section 3.5 and duplicated in fig. 53 to enable the comparison.

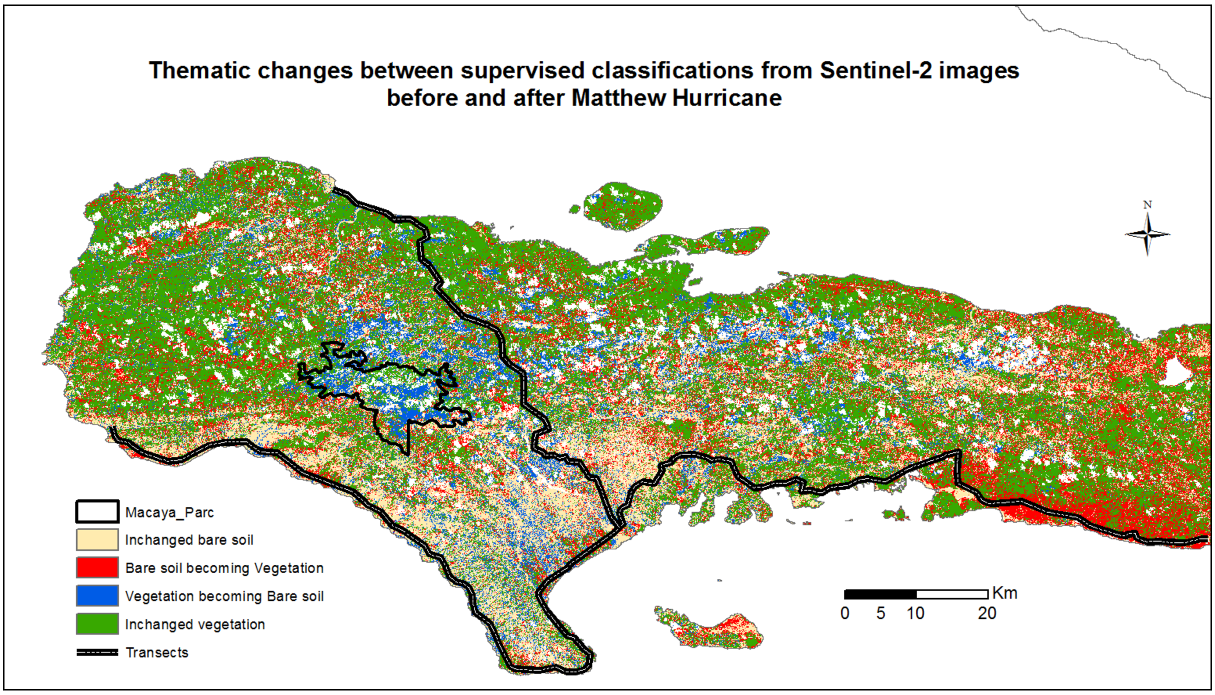


fig. 52 -Thematic changes between supervised classifications from Sentinel-2 images before and after Matthew Hurricane.

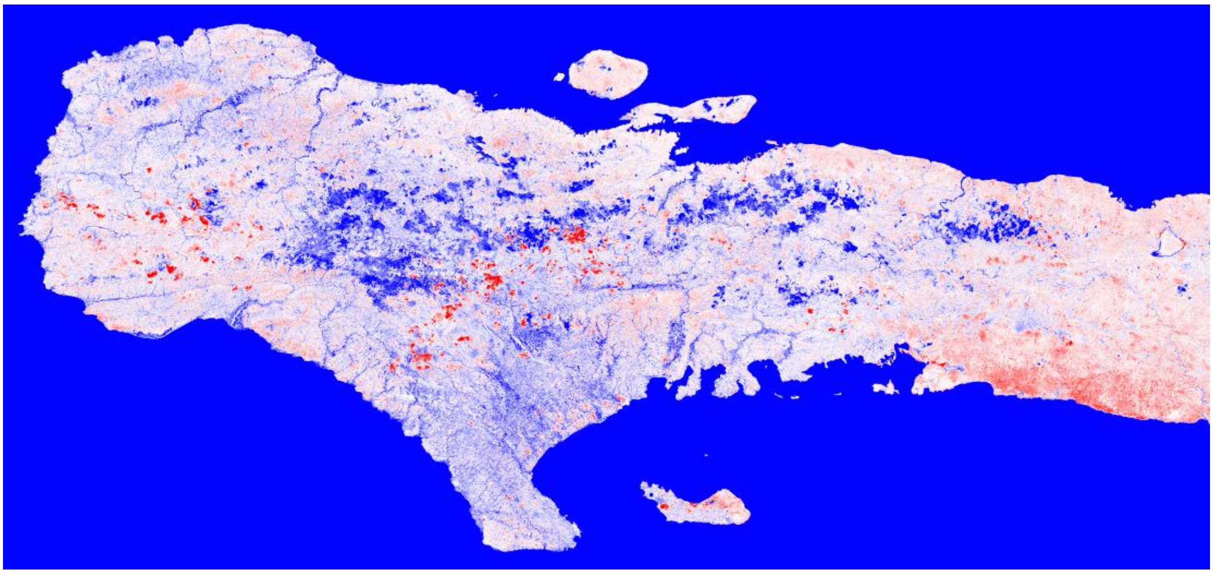


fig. 53 -Spacemap of "NDVI changes" to be compared with the "Class changes" map.

7 GROUND TRUTH

Scope of this section is to provide with cartographic material for visits during a field mission over zones for which singularities have been observed.

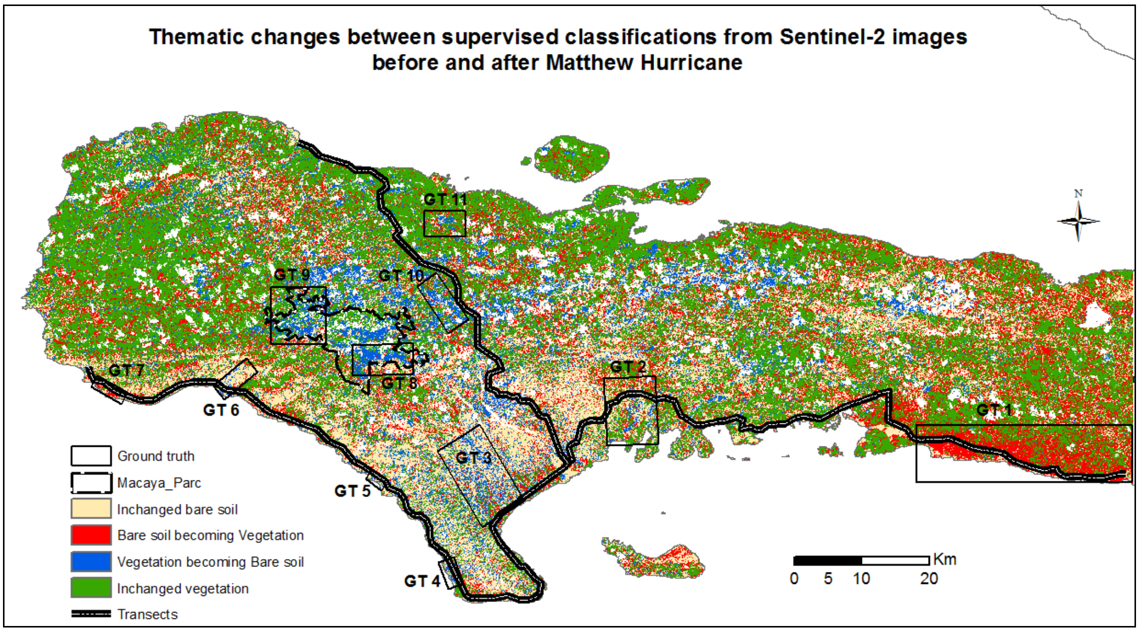


fig. 54 -Ground truth to be verified.

7.1 GT 1

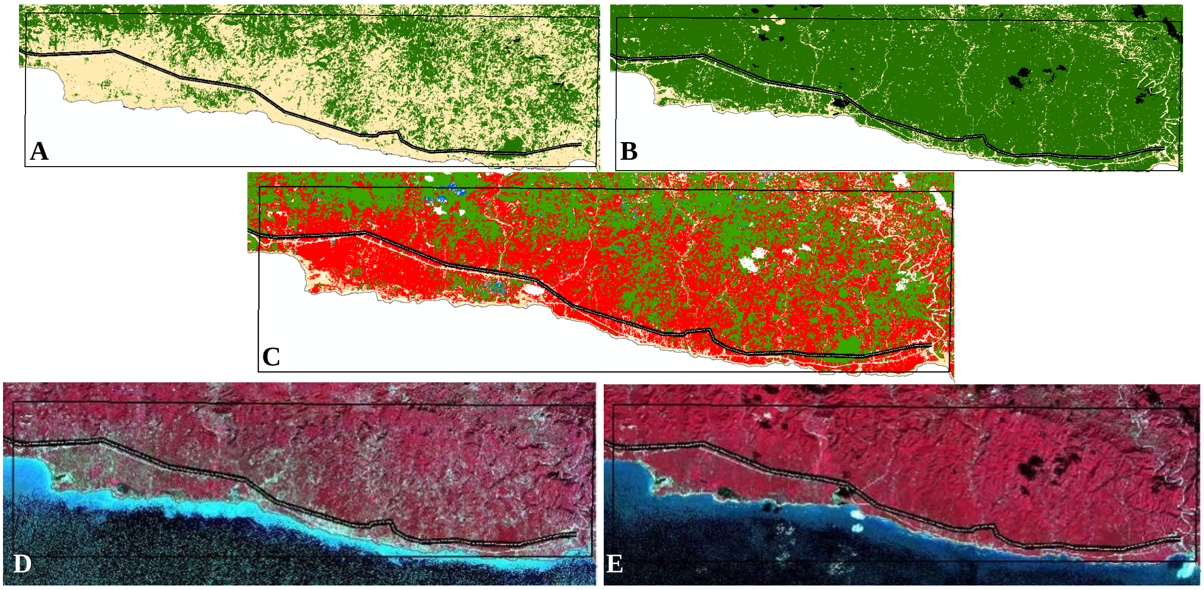


fig. 55 -Ground truth 1. A: classification pre-Matthew. B: classification post-Matthew. C: the thematic change between classifications pre and post-Matthew. D: Sentinel-2 image (colour composition 8-4-3) pre-Matthew. E: Sentinel-2 image (colour composition 8-4-3) post-Matthew. One may see that there is more vegetation after than before Matthew Hurricane (red colour in C). This area seems to not be negatively affected!

7.2 GT 2

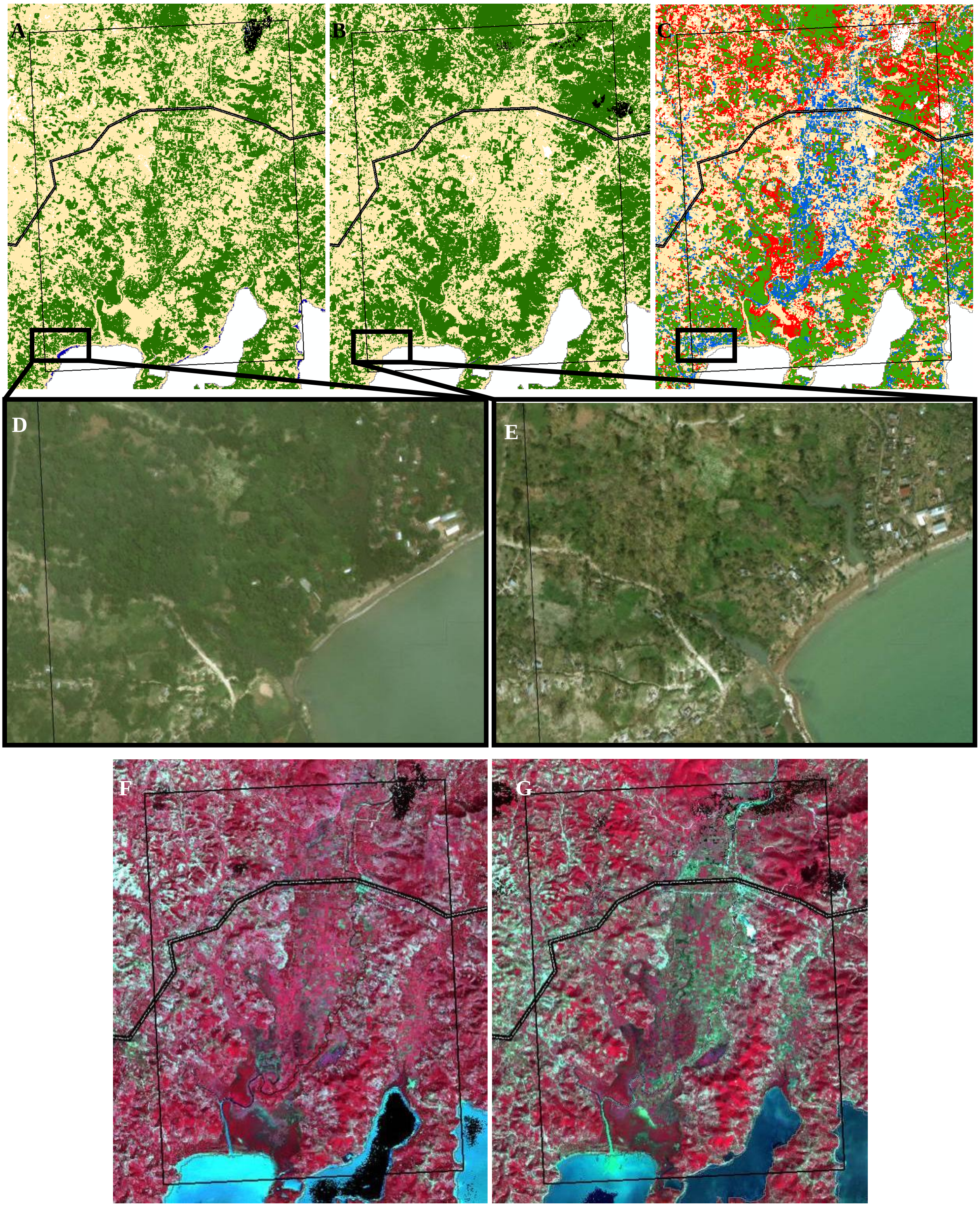


fig. 56 -Ground truth 2. A: classification pre-Matthew. B: classification post-Matthew. C: the thematic change between classifications pre and post-Matthew. D: Digital Glob image pre-Matthew. E: Digital Globe image post-Matthew. F: Sentinel-2 image (colour composition 8-4-3) pre-Matthew. G: Sentinel-2 image (colour composition 8-4-3) post-Matthew. One may see that there is less vegetation after than before Matthew Hurricane (blue colour in C). This area seems be negatively affected may be because of wind and flooding.

7.3 GT 3

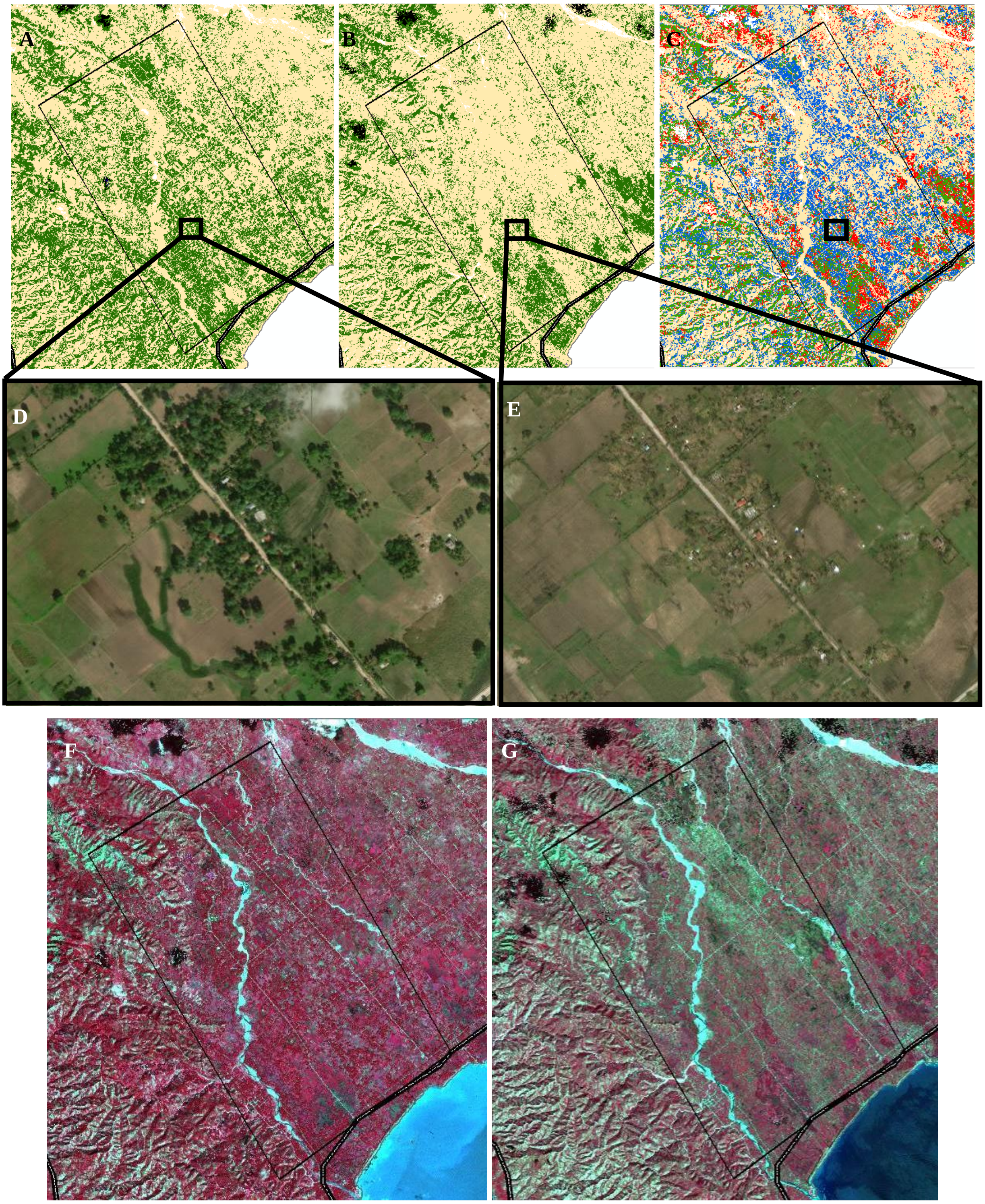


fig. 57 -Ground truth 3. A: classification pre-Matthew. B: classification post-Matthew. C: the thematic change between classifications pre and post-Matthew. D: Digital Glob image pre-Matthew. E: Digital Globe image post-Matthew. F: Sentinel-2 image (colour composition 8-4-3) pre-Matthew. G: Sentinel-2 image (colour composition 8-4-3) post-Matthew. One may see that there is less vegetation after than before Matthew Hurricane (blue colour in C). This area seems be negatively affected may be because of wind and flooding.

7.4 GT 4

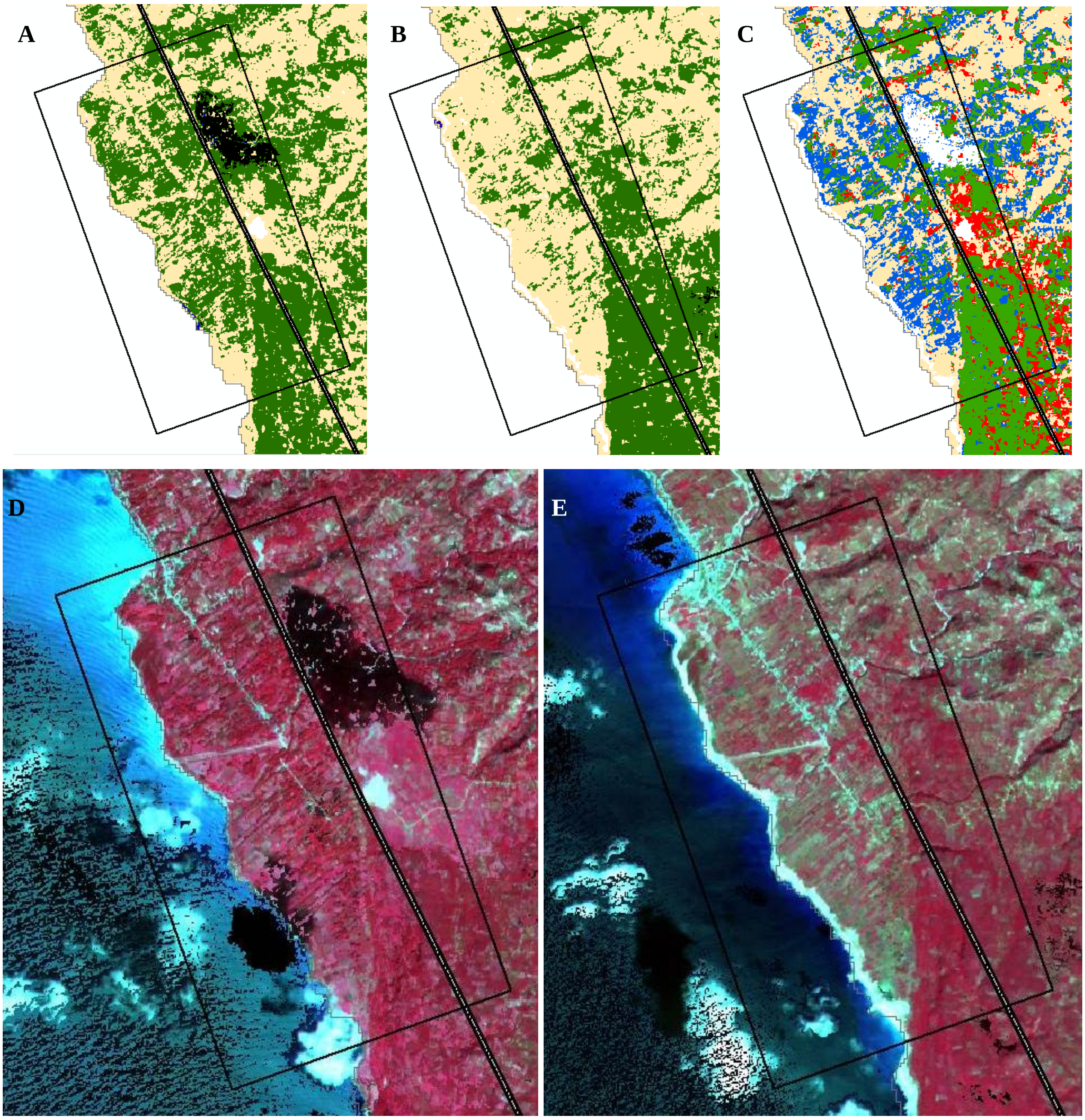


fig. 58 -Ground truth 4. A: classification pre-Matthew. B: classification post-Matthew. C: the thematic change between classifications pre and post-Matthew. D: Sentinel-2 image (colour composition 8-4-3) pre-Matthew. E: Sentinel-2 image (colour composition 8-4-3) post-Matthew. One may see that there is less vegetation after than before Matthew Hurricane (blue colour in C). This area seems be negatively affected may be because of wind and flooding.

7.5 GT 5

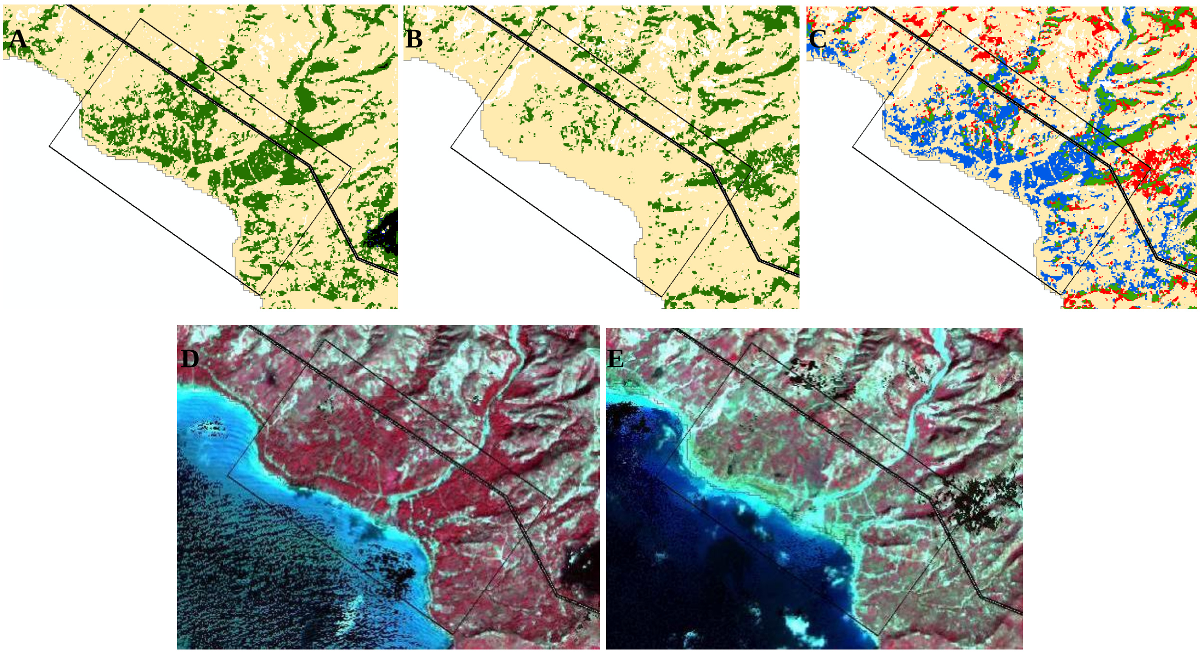


fig. 59 -Ground truth 5. A: classification pre-Matthew. B: classification post-Matthew. C: the thematic change between classifications pre and post-Matthew. D: Sentinel-2 image (colour composition 8-4-3) pre-Matthew. E: Sentinel-2 image (colour composition 8-4-3) post-Matthew. There is less vegetation after than before Matthew Hurricane (blue colour in C). This area seems be negatively affected may be because of flooding.

7.6 GT 6

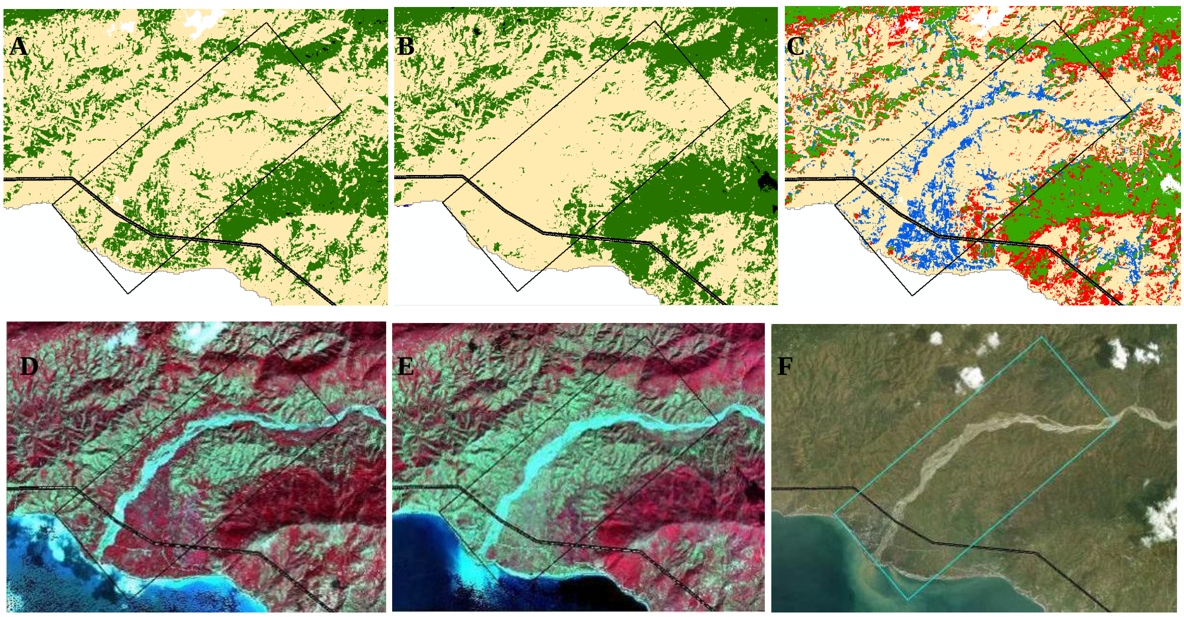


fig. 60 -Ground truth 6. A: classification pre-Matthew. B: classification post-Matthew. C: the thematic change between classifications pre and post-Matthew. D: Sentinel-2 image (colour composition 8-4-3) pre-Matthew. E: Sentinel-2 image (colour composition 8-4-3) post-Matthew. F: Digital Globe image post-Matthew. This area seems be negatively affected may be because of flooding.

7.7 GT 7

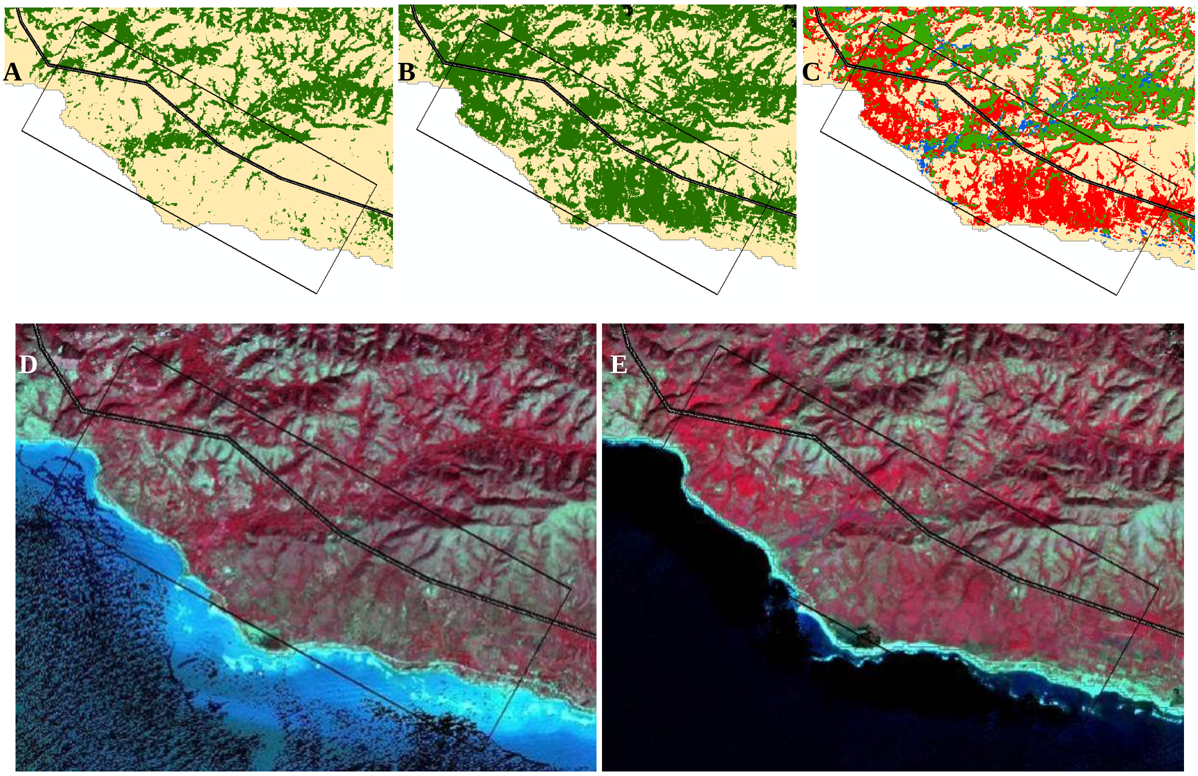


fig. 61 -Ground truth 7. A: classification pre-Matthew. B: classification post-Matthew. C: the thematic change between classifications pre and post-Matthew. D: Sentinel-2 image (colour composition 8-4-3) pre-Matthew. E: Sentinel-2 image (colour composition 8-4-3) post-Matthew. One may see that there is more vegetation after than before Matthew Hurricane (red colour in C). This area seems be positively affected.

7.8 GT 8

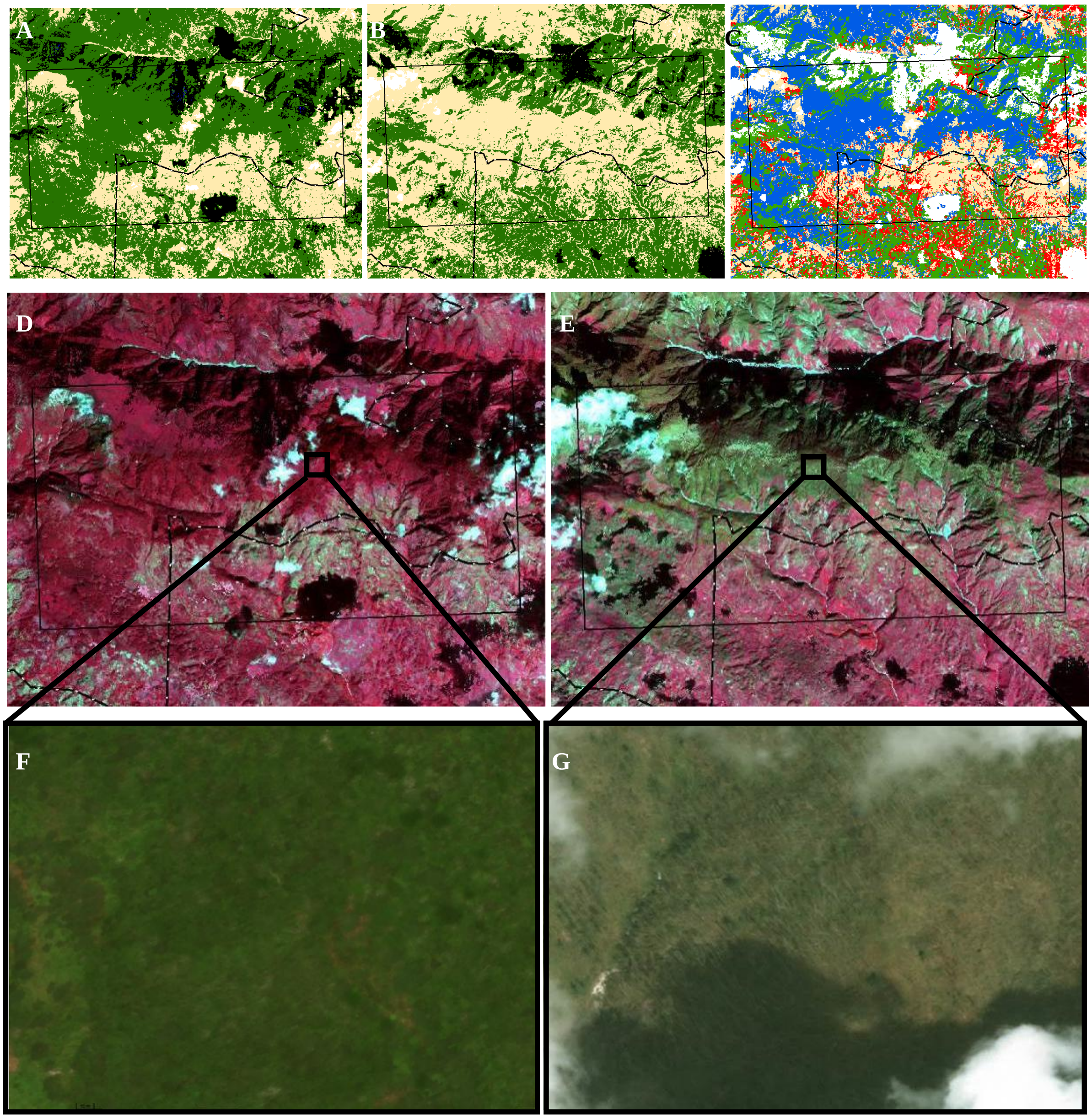


fig. 62 -Ground truth 8. A: classification pre-Matthew. B: classification post-Matthew. C: the thematic change between classifications pre and post-Matthew. D: Sentinel-2 image (colour composition 8-4-3) pre-Matthew. E: Sentinel-2 image (colour composition 8-4-3) post-Matthew. F: Digital Globe image pre-Matthew. G: Digital Globe image post-Matthew. One may see that there is less vegetation after than before Matthew Hurricane (blue colour in C). This area seems be negatively affected may be because of wind and flooding. The trees in G are completely broken.

7.9 <u>GT 9</u>

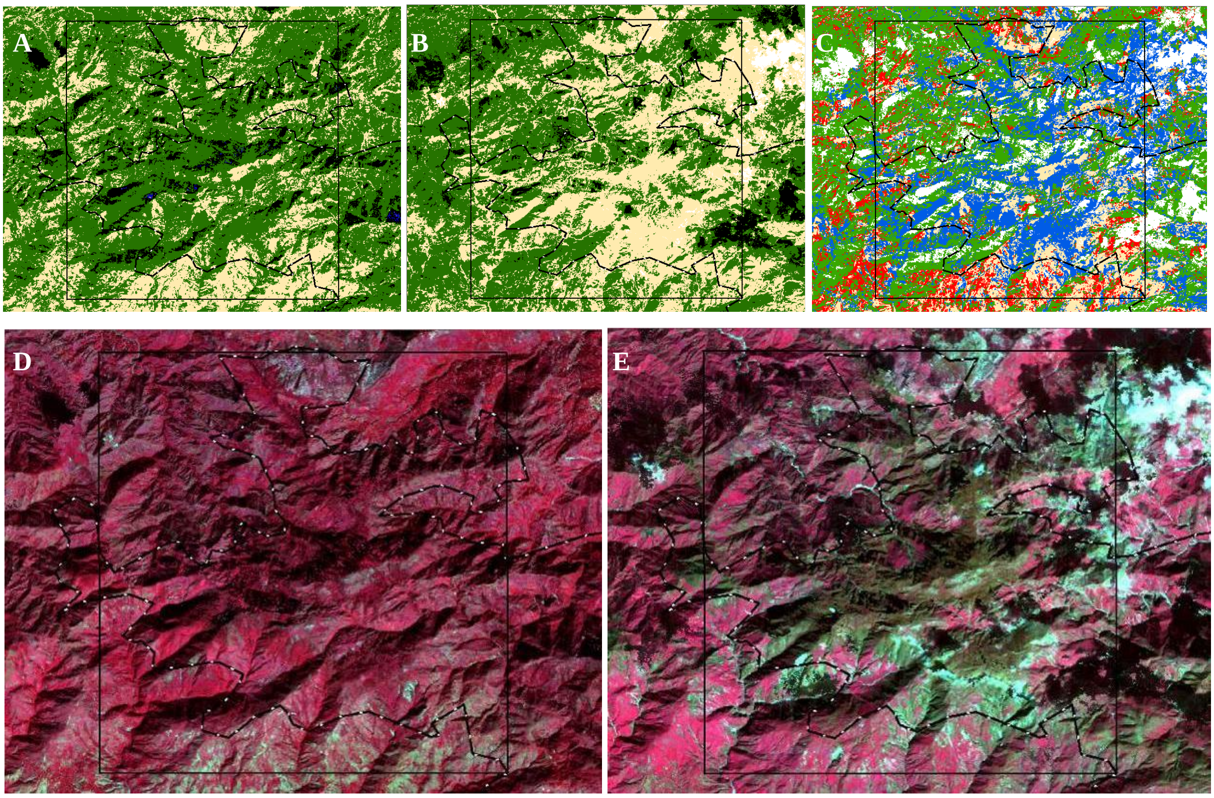


fig. 63 -Ground truth 9. A: classification pre-Matthew. B: classification post-Matthew. C: the thematic change between classifications pre and post-Matthew. D: Sentinel-2 image (colour composition 8-4-3) pre-Matthew. E: Sentinel-2 image (colour composition 8-4-3) post-Matthew. One may see that there is less vegetation after than before Matthew Hurricane (blue colour in C). This area seems be negatively affected may be because of wind.

7.10 GT 10

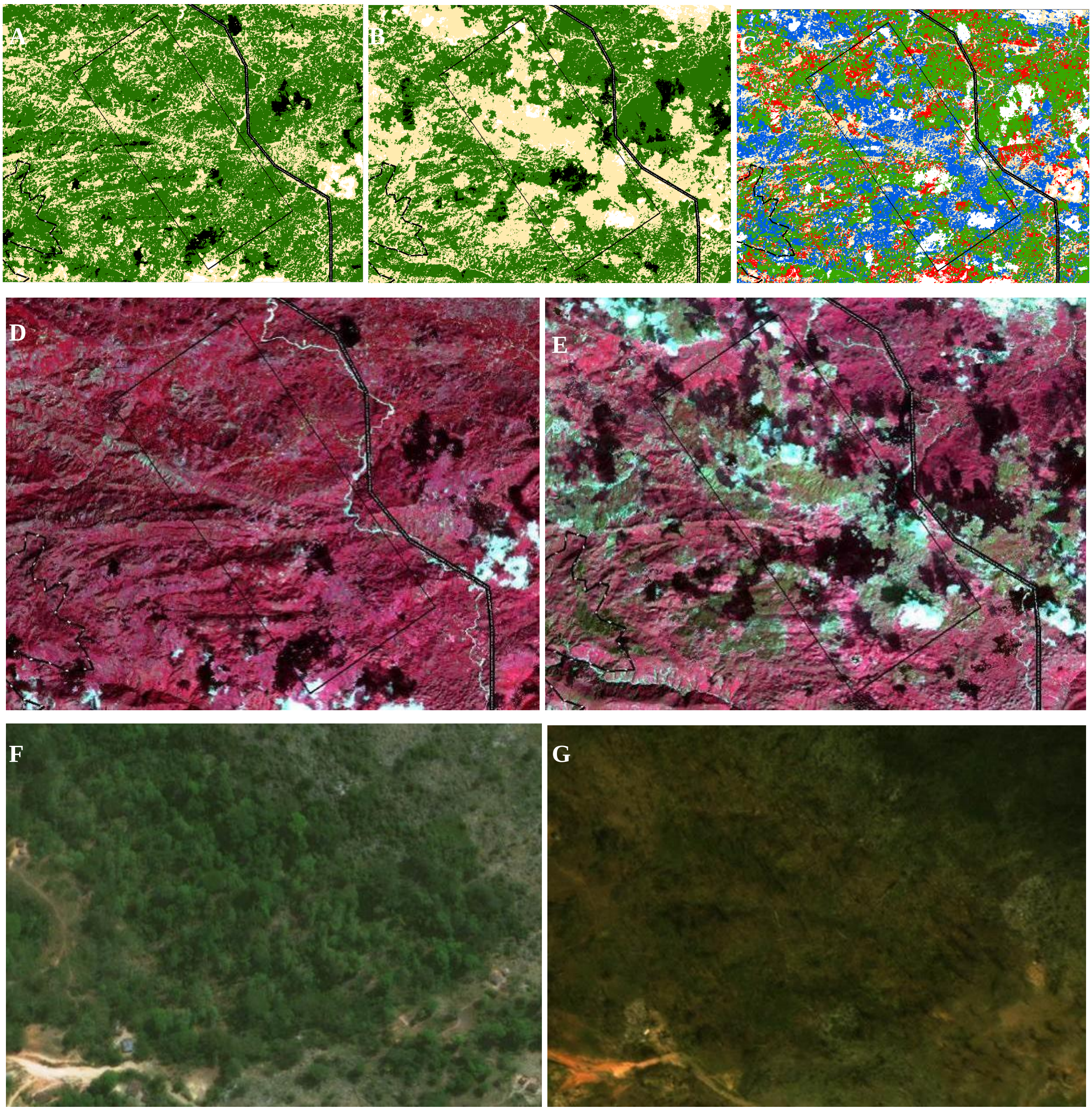


fig. 64 -Ground truth 10. A: classification pre-Matthew. B: classification post-Matthew. C: the thematic change between classifications pre and post-Matthew. D: Sentinel-2 image (colour composition 8-4-3) pre-Matthew. E: Sentinel-2 image (colour composition 8-4-3) post-Matthew. F: Digital Globe image pre-Matthew. G: Digital Globe image post-Matthew. One may see that there is less vegetation after than before Matthew Hurricane (blue colour in C). This area seems be negatively affected may be because of wind and flooding. The trees in G are completely broken.

7.11 GT 11

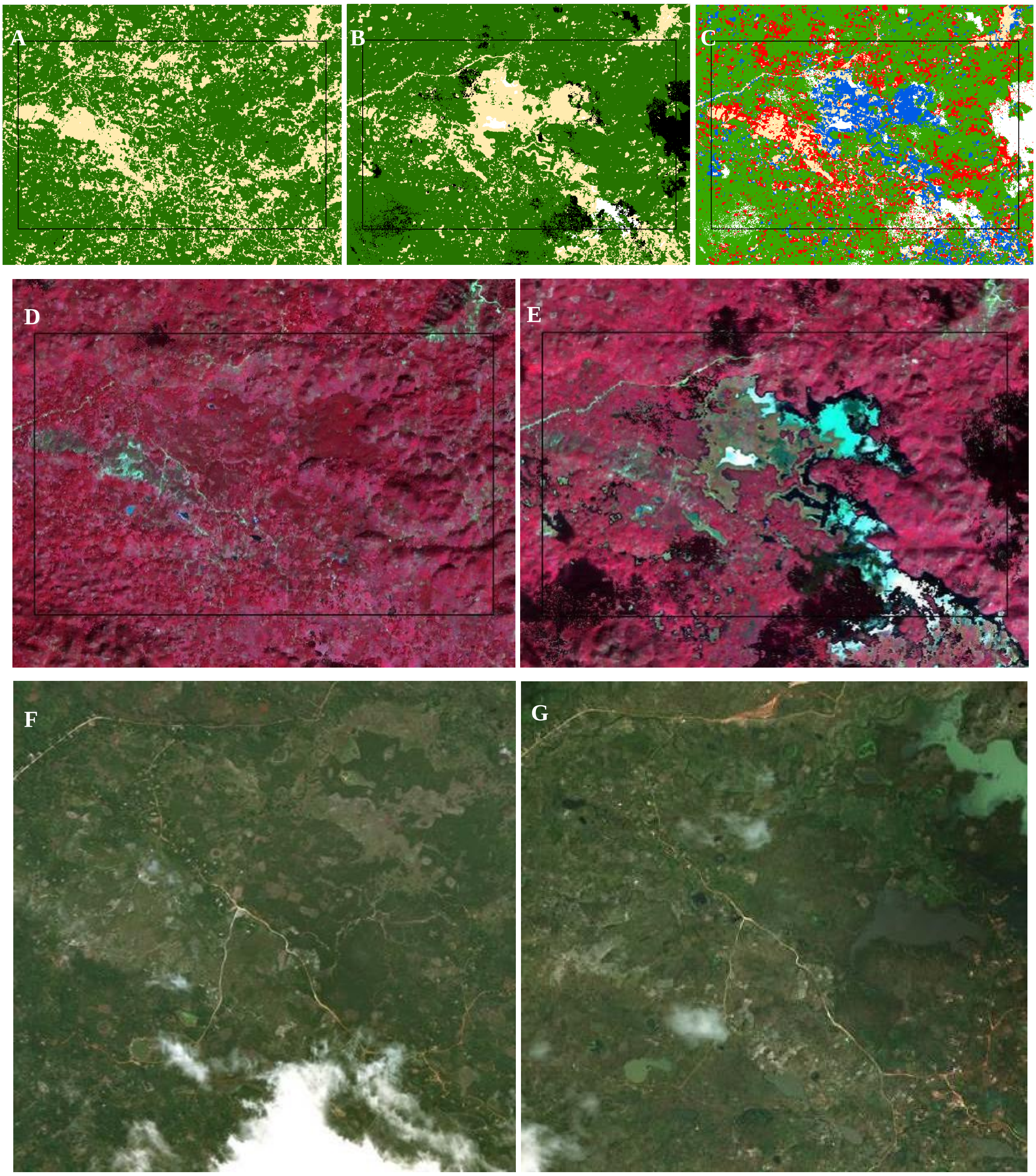


fig. 65 -Ground truth 11. A: classification pre-Matthew. B: classification post-Matthew. C: the thematic change between classifications pre and post-Matthew. D: Sentinel-2 image (colour composition 8-4-3) pre-Matthew. E: Sentinel-2 image (colour composition 8-4-3) post-Matthew. F: Digital Globe image pre-Matthew. G: Digital Globe image post-Matthew. One may see that there is less vegetation after than before Matthew Hurricane (blue colour in C). This area seems be negatively affected may be because of flooding.

8 DELIVERABLE DESCRIPTION

8.1 Delivery 1

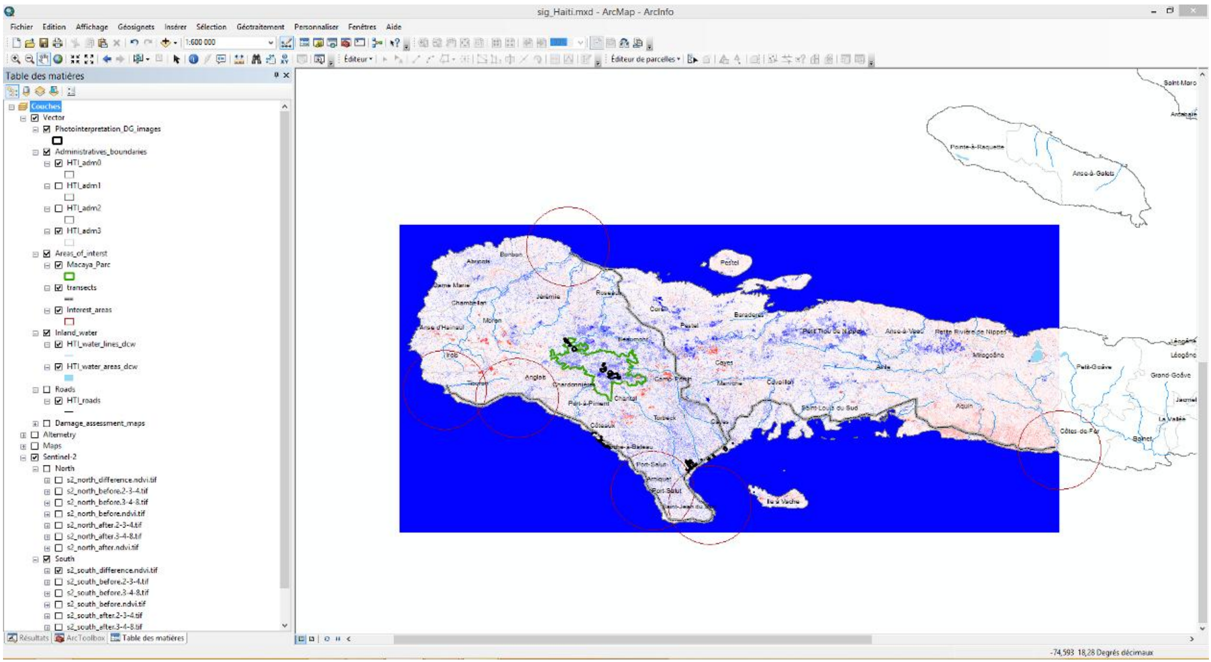


fig. 66 - View of the GIS project.

Contents of the archive "SIG_Haiti_delivery_1.zip":

Name	Size (KB)	Date	Attrib	Type	Files	Folder	Percent
D:\VisioTerra\technique\P275_UNE...	2 314 673	30/12/2016 21...		Folder	169	D:\VisioTerra\t...	
data	2 312 277	30/12/2016 22...		Folder	168	D:\VisioTerra\t...	
Damage_assessment_maps	4 566	30/12/2016 22...		Folder	24	D:\VisioTerra\t...	
HTI_administratives_boundar...	8 914	30/12/2016 22...		Folder	41	D:\VisioTerra\t...	
HTI_elevation	205	30/12/2016 21...		Folder	3	D:\VisioTerra\t...	
HTI_inland_water	235	30/12/2016 22...		Folder	8	D:\VisioTerra\t...	
HTI_roads	235	30/12/2016 22...		Folder	4	D:\VisioTerra\t...	
Interest_areas	58	30/12/2016 22...		Folder	29	D:\VisioTerra\t...	
Maps	18 074	30/12/2016 21...		Folder	8	D:\VisioTerra\t...	
Sentinel-2	2 279 964	30/12/2016 21...		Folder	42	D:\VisioTerra\t...	
Photointerpretation_DG_ima...	0	30/12/2016 20...	A	Fichier CPG		D:\VisioTerra\t...	
Photointerpretation_DG_ima...	10	30/12/2016 20...	A	Fichier DBF		D:\VisioTerra\t...	
Photointerpretation_DG_ima...	0	30/12/2016 10...	A	Fichier PRJ		D:\VisioTerra\t...	
Photointerpretation_DG_ima...	0	30/12/2016 10...	A	Fichier QPJ		D:\VisioTerra\t...	
Photointerpretation_DG_ima...	1	30/12/2016 20...	A	Fichier SBN		D:\VisioTerra\t...	
Photointerpretation_DG_ima...	0	30/12/2016 20...	A	Fichier SBX		D:\VisioTerra\t...	
Photointerpretation_DG_ima...	15	30/12/2016 20...	A	Fichier SHP		D:\VisioTerra\t...	
Photointerpretation_DG_ima...	0	30/12/2016 21...	A	Fichier LOCK		D:\VisioTerra\t...	
Photointerpretation_DG_ima...	0	30/12/2016 20...	A	Fichier SHX		D:\VisioTerra\t...	
sig_Haiti.mxd	2 396	30/12/2016 22...	A	ESRI ArcMap ...		D:\VisioTerra\t...	

8.2 DELIVERY06 - Colour compositions of individual scenes

This delivery contains colour compositions performed with always the same stretching parameters assuming that data are correctly calibrated and having performed the atmospheric correction.

First scene acquired on 24.12.2015 has been manually computed setting the stretching parameters to show:

- the most realistic natural colour composition (bands 4-3-2) and
- the maximum variations in land use / land cover (bands 8-11-2).

The five (5) other scenes have been stretched with the same parameter leading to seasonal variations of reflectances showing the lowest reflectances in winter and the highest ones in summer.

One may observe the very pronounced differences between scenes acquired on 29.09.2016 and those acquired on 09.10.2016. In 20 days elapsed time, the vegetation, in particular in the west part of Tiburon Peninsula, has been “washed” and replaced by muddy areas and bare soils.

8.2.1 File name syntax

SS_ZONE_YYYYMMDD.R-G-B[.sca-01].FFF

Examples:

- **s2_south_20151224.4-3-2.sca-01.tif -** for the “natural colours” composition of the Sentinel-2 scene observed on 24.12.2015 over the South zone (Tiburon Peninsula), resampled with a 1/10 factor (GSD, i.e. “Ground Sampling Distance”, of 100 metres) and exported in GeoTIFF format.
- **s2_south_20161208_8-11-2.kmz -** for the “healthy vegetation” colour composition of the Sentinel-2 scene observed over the South zone with its nominal spatial resolution (GSD of 10 metres) and exported in KMZ (KML zipped) format.

8.2.2 Delivery file list

Name	Size (KB)	Type	Files	Percent
\\fabio\fabio_3\P275_UNEP_HAITI\DELIVERY06_CC\	6 684 346	Folder	72	
s2_south_20151224.land.str.8-11-2.kmz	125 506	KMZ		
s2_south_20151224.land.str.8-11-2.sca-01.kmz	1 831	KMZ		
s2_south_20151224.land.str.8-11-2.sca-01.tfw	0	Fichier TFW		
s2_south_20151224.land.str.8-11-2.sca-01.tif	3 719	Fichier TIF		
s2_south_20151224.land.str.8-11-2.tfw	0	Fichier TFW		
s2_south_20151224.land.str.8-11-2.tif	371 507	Fichier TIF		
s2_south_20151224.str.4-3-2.kmz	261 093	KMZ		
s2_south_20151224.str.4-3-2.sca-01.kmz	2 621	KMZ		
s2_south_20151224.str.4-3-2.sca-01.tfw	0	Fichier TFW		
s2_south_20151224.str.4-3-2.sca-01.tif	3 719	Fichier TIF		
s2_south_20151224.str.4-3-2.tfw	0	Fichier TFW		
s2_south_20151224.str.4-3-2.tif	371 507	Fichier TIF		
s2_south_20160611.land.str.8-11-2.kmz	108 128	KMZ		
s2_south_20160611.land.str.8-11-2.sca-01.kmz	1 652	KMZ		
s2_south_20160611.land.str.8-11-2.sca-01.tfw	0	Fichier TFW		
s2_south_20160611.land.str.8-11-2.sca-01.tif	3 719	Fichier TIF		
s2_south_20160611.land.str.8-11-2.tfw	0	Fichier TFW		
s2_south_20160611.land.str.8-11-2.tif	371 507	Fichier TIF		
s2_south_20160611.str.4-3-2.kmz	254 212	KMZ		
s2_south_20160611.str.4-3-2.sca-01.kmz	2 613	KMZ		
s2_south_20160611.str.4-3-2.sca-01.tfw	0	Fichier TFW		
s2_south_20160611.str.4-3-2.sca-01.tif	3 719	Fichier TIF		
s2_south_20160611.str.4-3-2.tfw	0	Fichier TFW		
s2_south_20160611.str.4-3-2.tif	371 507	Fichier TIF		
s2_south_20160919.land.str.8-11-2.kmz	108 892	KMZ		
s2_south_20160919.land.str.8-11-2.sca-01.kmz	1 702	KMZ		
s2_south_20160919.land.str.8-11-2.sca-01.tfw	0	Fichier TFW		
s2_south_20160919.land.str.8-11-2.sca-01.tif	3 719	Fichier TIF		
s2_south_20160919.land.str.8-11-2.tfw	0	Fichier TFW		
s2_south_20160919.land.str.8-11-2.tif	371 507	Fichier TIF		
s2_south_20160919.str.4-3-2.kmz	283 207	KMZ		
s2_south_20160919.str.4-3-2.sca-01.kmz	2 914	KMZ		
s2_south_20160919.str.4-3-2.sca-01.tfw	0	Fichier TFW		
s2_south_20160919.str.4-3-2.sca-01.tif	3 719	Fichier TIF		
s2_south_20160919.str.4-3-2.tfw	0	Fichier TFW		
s2_south_20161009.land.str.8-11-2.kmz	96 286	KMZ		
s2_south_20161009.land.str.8-11-2.sca-01.kmz	1 618	KMZ		
s2_south_20161009.land.str.8-11-2.sca-01.tfw	0	Fichier TFW		
s2_south_20161009.land.str.8-11-2.sca-01.tif	3 719	Fichier TIF		
s2_south_20161009.land.str.8-11-2.tfw	0	Fichier TFW		
s2_south_20161009.land.str.8-11-2.tif	371 507	Fichier TIF		
s2_south_20161009.str.4-3-2.kmz	234 600	KMZ		
s2_south_20161009.str.4-3-2.sca-01.kmz	2 679	KMZ		
s2_south_20161009.str.4-3-2.sca-01.tfw	0	Fichier TFW		
s2_south_20161009.str.4-3-2.sca-01.tif	3 719	Fichier TIF		
s2_south_20161009.str.4-3-2.tfw	0	Fichier TFW		
s2_south_20161009.str.4-3-2.tif	371 507	Fichier TIF		
s2_south_20161128.land.str.8-11-2.kmz	105 161	KMZ		
s2_south_20161128.land.str.8-11-2.sca-01.kmz	1 708	KMZ		
s2_south_20161128.land.str.8-11-2.sca-01.tfw	0	Fichier TFW		
s2_south_20161128.land.str.8-11-2.sca-01.tif	3 719	Fichier TIF		
s2_south_20161128.land.str.8-11-2.tfw	0	Fichier TFW		
s2_south_20161128.land.str.8-11-2.tif	371 507	Fichier TIF		
s2_south_20161128.str.4-3-2.kmz	232 603	KMZ		
s2_south_20161128.str.4-3-2.sca-01.kmz	2 560	KMZ		
s2_south_20161128.str.4-3-2.sca-01.tfw	0	Fichier TFW		
s2_south_20161128.str.4-3-2.sca-01.tif	3 719	Fichier TIF		
s2_south_20161128.str.4-3-2.tfw	0	Fichier TFW		
s2_south_20161128.str.4-3-2.tif	371 507	Fichier TIF		
s2_south_20161208.land.str.8-11-2.kmz	110 865	KMZ		
s2_south_20161208.land.str.8-11-2.sca-01.kmz	1 773	KMZ		
s2_south_20161208.land.str.8-11-2.sca-01.tfw	0	Fichier TFW		
s2_south_20161208.land.str.8-11-2.sca-01.tif	3 719	Fichier TIF		
s2_south_20161208.land.str.8-11-2.tfw	0	Fichier TFW		
s2_south_20161208.land.str.8-11-2.tif	371 507	Fichier TIF		
s2_south_20161208.str.4-3-2.kmz	234 925	KMZ		
s2_south_20161208.str.4-3-2.sca-01.kmz	2 470	KMZ		
s2_south_20161208.str.4-3-2.sca-01.tfw	0	Fichier TFW		
s2_south_20161208.str.4-3-2.sca-01.tif	3 719	Fichier TIF		
s2_south_20161208.str.4-3-2.tfw	0	Fichier TFW		
s2_south_20161208.str.4-3-2.tif	371 507	Fichier TIF		

8.2.3 “Natural colours” (4-3-2) colour compositions

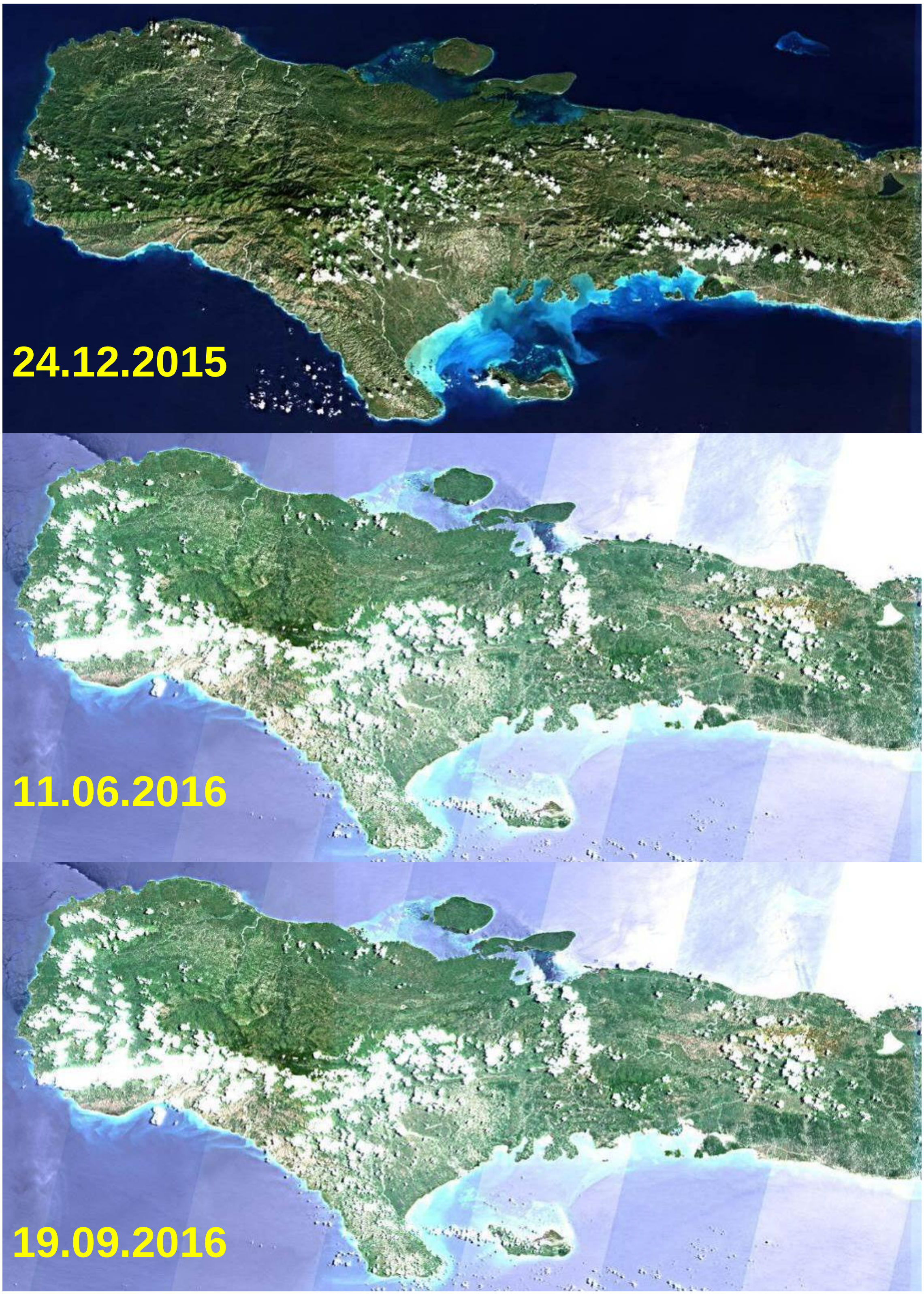


fig. 67 - Sentinel-2 “natural colour” pre-event.

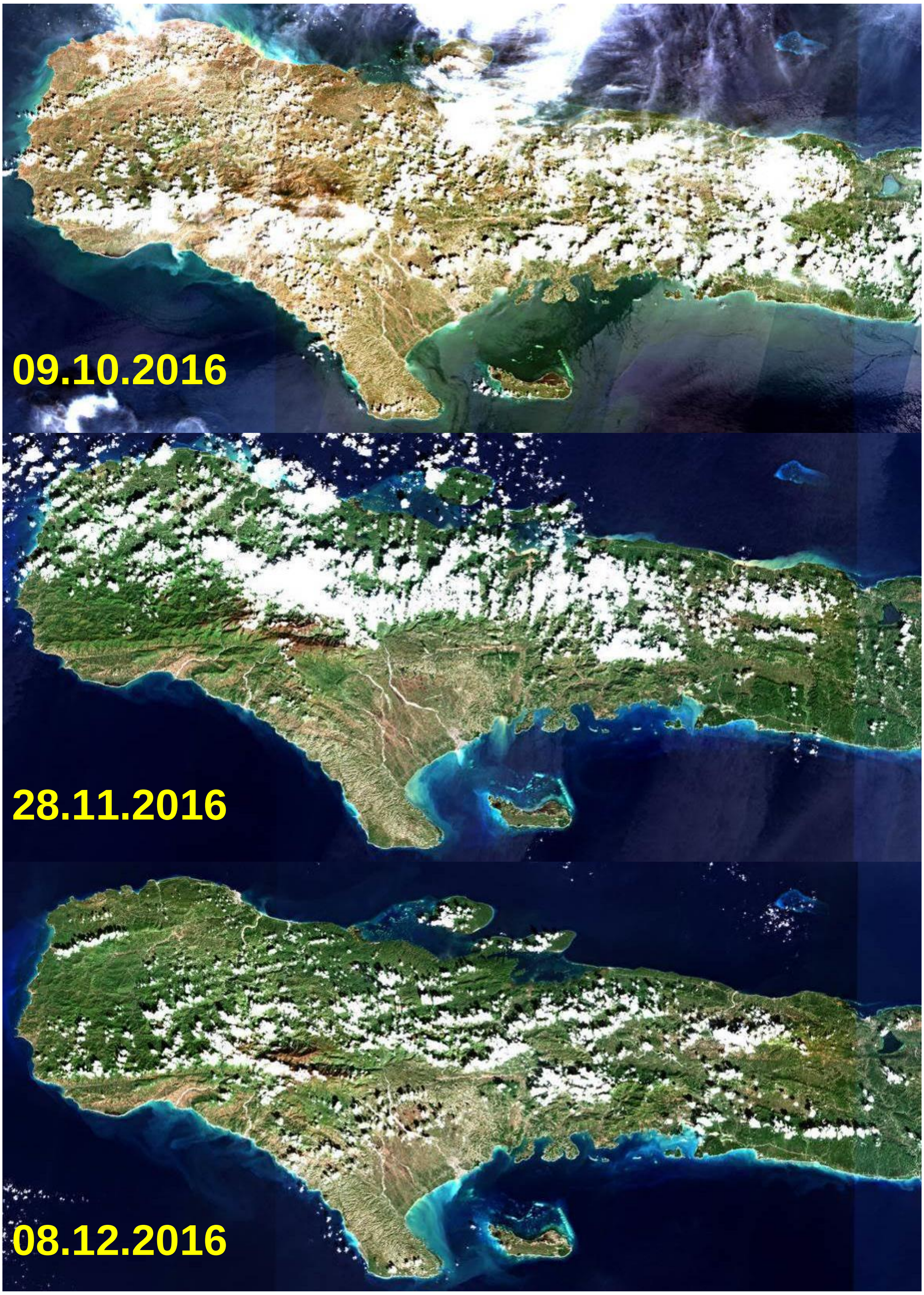


fig. 68 - Sentinel-2 “natural colours” post-event.

8.2.4 "Healthy vegetation" (8-11-2) colour composition

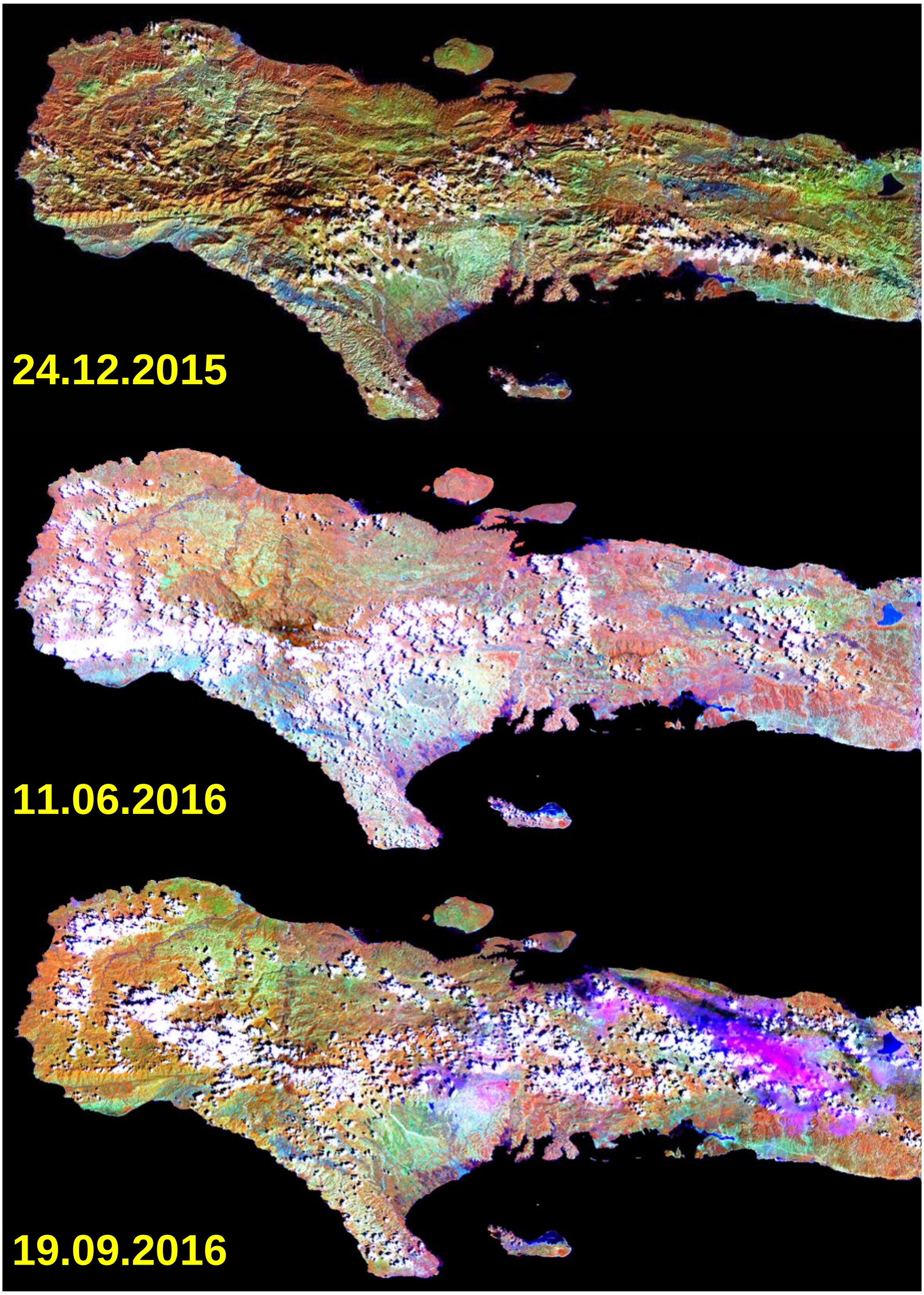


fig. 69 - Sentinel-2 "healthy vegetation" pre-event.

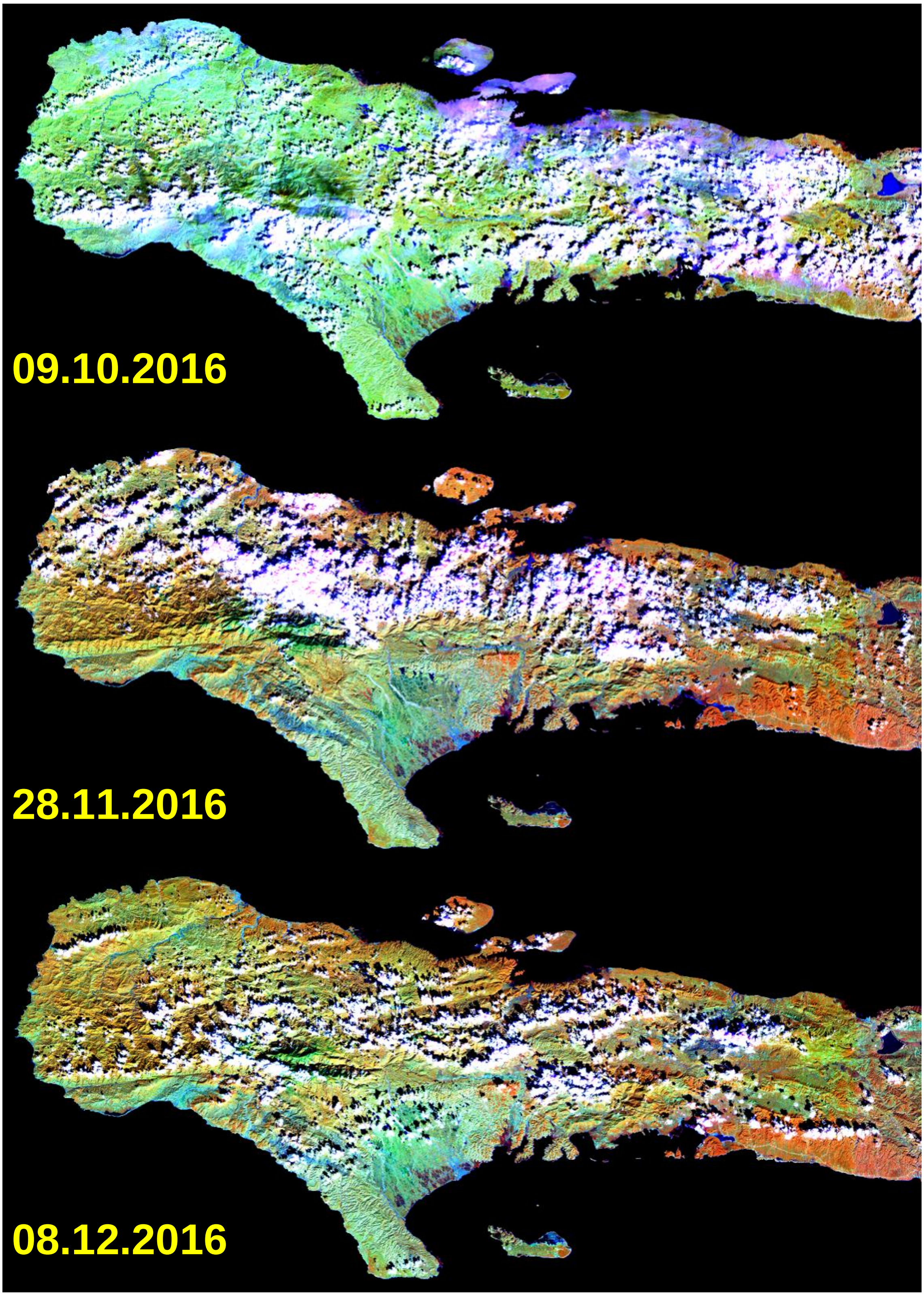


fig. 70 - Sentinel-2 "healthy vegetation" post-event.

8.3 DELIVERY07 - NDVI and NDII of individual scenes

This delivery contains:

- **NDVI -** Normalised Difference Vegetation Index images computed from the near infrared (band 8 of Sentinel-2/MSI centred on 842 nm) and the red (band 4 centred on 665 nm).
  NDVI data have been stretched in the range [0,1] and are shown with a rainbow LUT.
- **NDII -** Normalised Difference Infrared Index images computed from the near infrared (band 8 centred on 842 nm) and the short wave infrared (band 12 centred on 2190 nm).
  NDII data have been stretched in the range [0,0.75] and are shown with a rainbow LUT.

In both cases, one may observe a sharp exception on scene acquired on 09.10.2016, five days after the hurricane. May be the NDII that is NDII is widely used to monitor the equivalent water thickness (EWT) of leaves and canopy (see R-15) show more persistent damages in the post-event images.

8.3.1 File name syntax

SS_ZONE_YYYYMMDD.ndXi.[.sca-01].FFF

Examples:

- **s2_south_20151224.ndvi.sca-01.tif -** for the "normalised difference vegetation index" (NDVI) of the Sentinel-2 scene observed on 24.12.2015 over the South zone (Tiburon Peninsula), resampled with a 1/10 factor (GSD, i.e. "Ground Sampling Distance", of 100 metres) and exported in GeoTIFF format.
- **s2_south_20161208.ndii.kmz** for the "normalised difference infrared index" (NDII) of the Sentinel-2 scene observed over the South zone on 08.12.2016 with its nominal spatial resolution (GSD of 10 metres) and exported in KMZ (KML zipped) format.

8.3.2 Delivery file list

Name	Size (KB)	Type	Files	Percent
\\fabio\fabio_3\P275_UNEP_HAITI\DELIVERY07_NDVI_N...	2 154 013	Folder	72	
s2_south_20151224.ndii.kmz	56 323	KMZ		
s2_south_20151224.ndii.sca-01.kmz	561	KMZ		
s2_south_20151224.ndii.sca-01.tfw	0	Fichier TFW		
s2_south_20151224.ndii.sca-01.tif	1 246	Fichier TIF		
s2_south_20151224.ndii.tfw	0	Fichier TFW		
s2_south_20151224.ndii.tif	123 878	Fichier TIF		
s2_south_20151224.ndvi.kmz	52 086	KMZ		
s2_south_20151224.ndvi.sca-01.kmz	529	KMZ		
s2_south_20151224.ndvi.sca-01.tfw	0	Fichier TFW		
s2_south_20151224.ndvi.sca-01.tif	1 246	Fichier TIF		
s2_south_20151224.ndvi.tfw	0	Fichier TFW		
s2_south_20151224.ndvi.tif	123 878	Fichier TIF		
s2_south_20160611.ndii.kmz	55 243	KMZ		
s2_south_20160611.ndii.sca-01.kmz	559	KMZ		
s2_south_20160611.ndii.sca-01.tfw	0	Fichier TFW		
s2_south_20160611.ndii.sca-01.tif	1 246	Fichier TIF		
s2_south_20160611.ndii.tfw	0	Fichier TFW		
s2_south_20160611.ndii.tif	123 878	Fichier TIF		
s2_south_20160611.ndvi.kmz	51 944	KMZ		
s2_south_20160611.ndvi.sca-01.kmz	542	KMZ		
s2_south_20160611.ndvi.sca-01.tfw	0	Fichier TFW		
s2_south_20160611.ndvi.sca-01.tif	1 246	Fichier TIF		
s2_south_20160611.ndvi.tfw	0	Fichier TFW		
s2_south_20160611.ndvi.tif	123 878	Fichier TIF		
s2_south_20160919.ndii.kmz	56 096	KMZ		
s2_south_20160919.ndii.sca-01.kmz	572	KMZ		
s2_south_20160919.ndii.sca-01.tfw	0	Fichier TFW		
s2_south_20160919.ndii.sca-01.tif	1 246	Fichier TIF		
s2_south_20160919.ndii.tfw	0	Fichier TFW		
s2_south_20160919.ndii.tif	123 878	Fichier TIF		
s2_south_20160919.ndvi.kmz	53 268	KMZ		
s2_south_20160919.ndvi.sca-01.kmz	562	KMZ		
s2_south_20160919.ndvi.sca-01.tfw	0	Fichier TFW		
s2_south_20160919.ndvi.sca-01.tif	1 246	Fichier TIF		
s2_south_20160919.ndvi.tfw	0	Fichier TFW		
s2_south_20160919.ndvi.tif	123 878	Fichier TIF		
s2_south_20161009.ndii.kmz	52 419	KMZ		
s2_south_20161009.ndii.sca-01.kmz	547	KMZ		
s2_south_20161009.ndii.sca-01.tfw	0	Fichier TFW		
s2_south_20161009.ndii.sca-01.tif	1 246	Fichier TIF		
s2_south_20161009.ndii.tfw	0	Fichier TFW		
s2_south_20161009.ndii.tif	123 878	Fichier TIF		
s2_south_20161009.ndvi.kmz	51 344	KMZ		
s2_south_20161009.ndvi.sca-01.kmz	552	KMZ		
s2_south_20161009.ndvi.sca-01.tfw	0	Fichier TFW		
s2_south_20161009.ndvi.sca-01.tif	1 246	Fichier TIF		
s2_south_20161009.ndvi.tfw	0	Fichier TFW		
s2_south_20161009.ndvi.tif	123 878	Fichier TIF		
s2_south_20161128.ndii.kmz	55 472	KMZ		
s2_south_20161128.ndii.sca-01.kmz	574	KMZ		
s2_south_20161128.ndii.sca-01.tfw	0	Fichier TFW		
s2_south_20161128.ndii.sca-01.tif	1 246	Fichier TIF		
s2_south_20161128.ndii.tfw	0	Fichier TFW		
s2_south_20161128.ndii.tif	123 878	Fichier TIF		
s2_south_20161128.ndvi.kmz	52 121	KMZ		
s2_south_20161128.ndvi.sca-01.kmz	560	KMZ		
s2_south_20161128.ndvi.sca-01.tfw	0	Fichier TFW		
s2_south_20161128.ndvi.sca-01.tif	1 246	Fichier TIF		
s2_south_20161128.ndvi.tfw	0	Fichier TFW		
s2_south_20161128.ndvi.tif	123 878	Fichier TIF		
s2_south_20161208.ndii.kmz	56 214	KMZ		
s2_south_20161208.ndii.sca-01.kmz	578	KMZ		
s2_south_20161208.ndii.sca-01.tfw	0	Fichier TFW		
s2_south_20161208.ndii.sca-01.tif	1 246	Fichier TIF		
s2_south_20161208.ndii.tfw	0	Fichier TFW		
s2_south_20161208.ndii.tif	123 878	Fichier TIF		
s2_south_20161208.ndvi.kmz	53 307	KMZ		
s2_south_20161208.ndvi.sca-01.kmz	559	KMZ		
s2_south_20161208.ndvi.sca-01.tfw	0	Fichier TFW		
s2_south_20161208.ndvi.sca-01.tif	1 246	Fichier TIF		
s2_south_20161208.ndvi.tfw	0	Fichier TFW		
s2_south_20161208.ndvi.tif	123 878	Fichier TIF		

8.3.3 NDVI (Normalised Difference Vegetation Index)

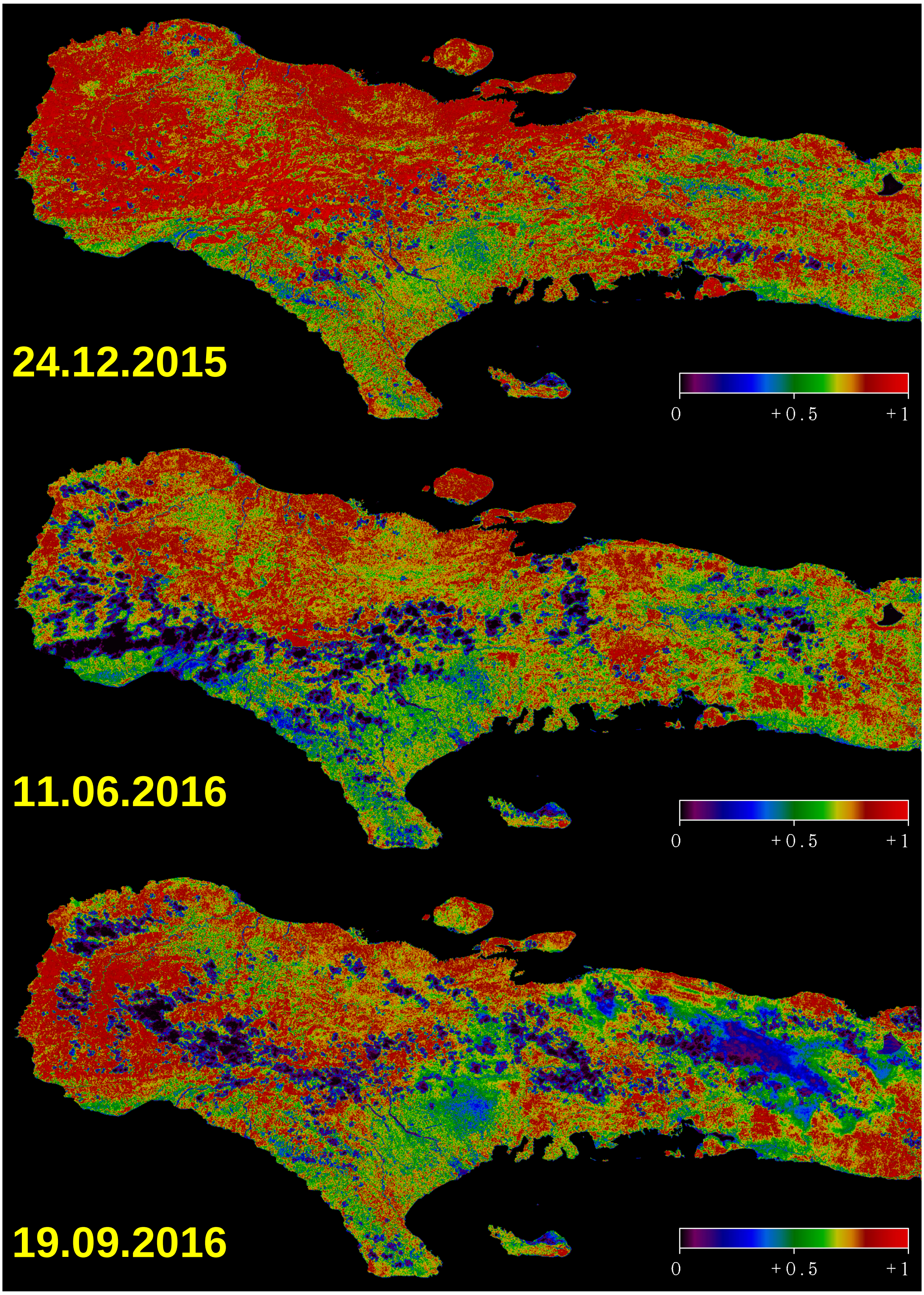


fig. 71 - Sentinel-2 NDVI pre-event.

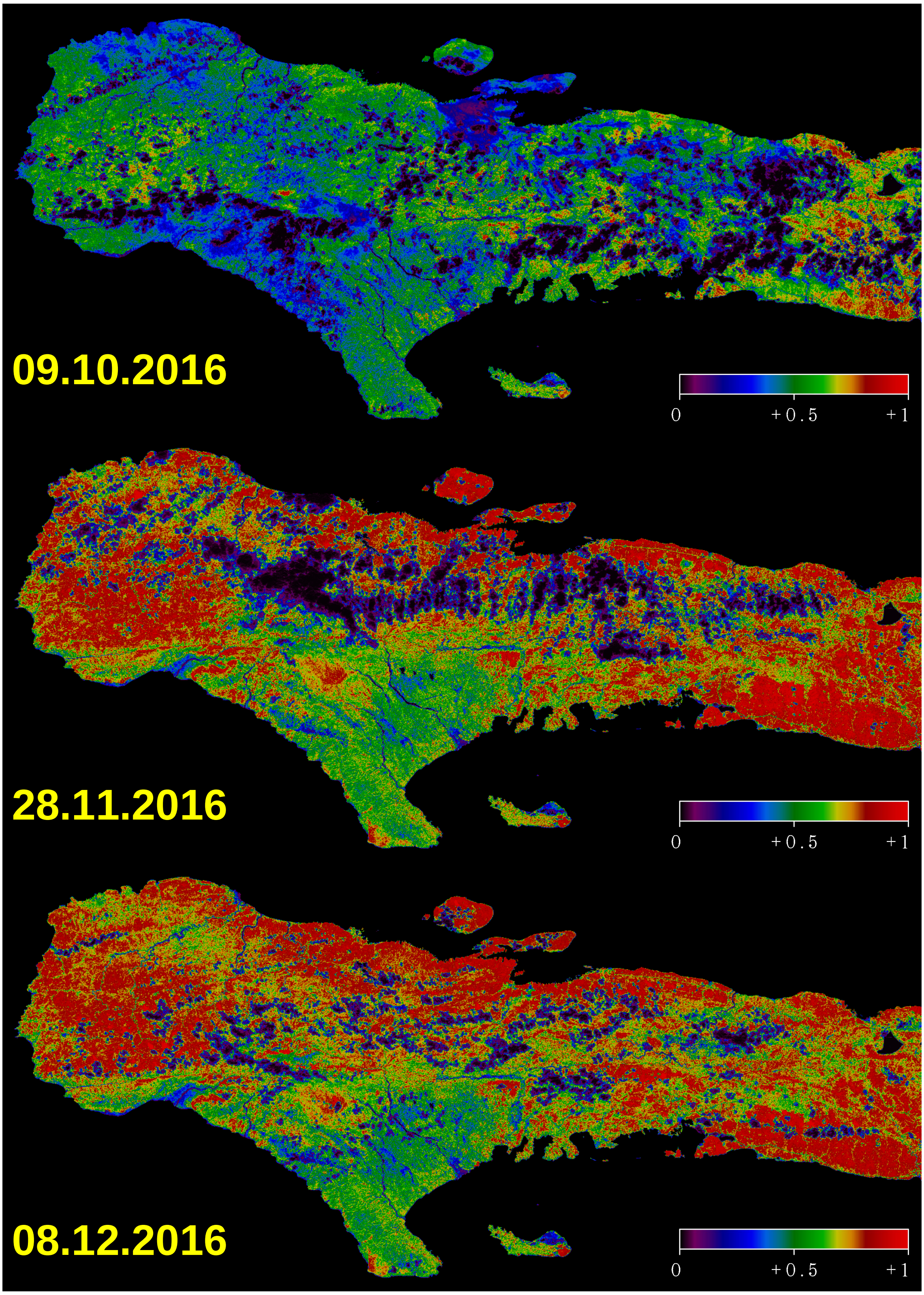


fig. 72 - Sentinel-2 NDVI post-event.

8.3.4 NDII (Normalised Difference Infrared Index)

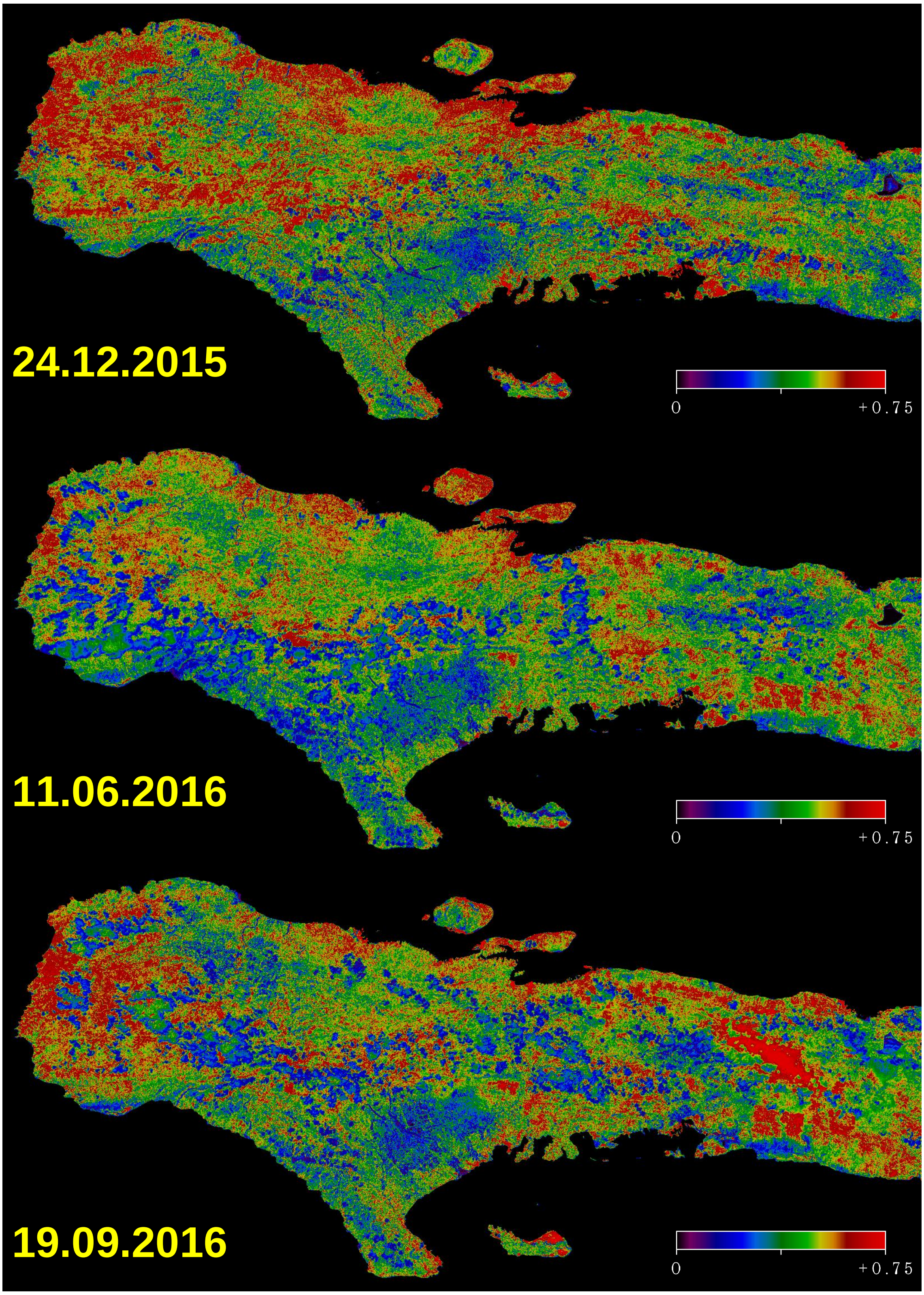


fig. 73 - Sentinel-2 NDII pre-event.

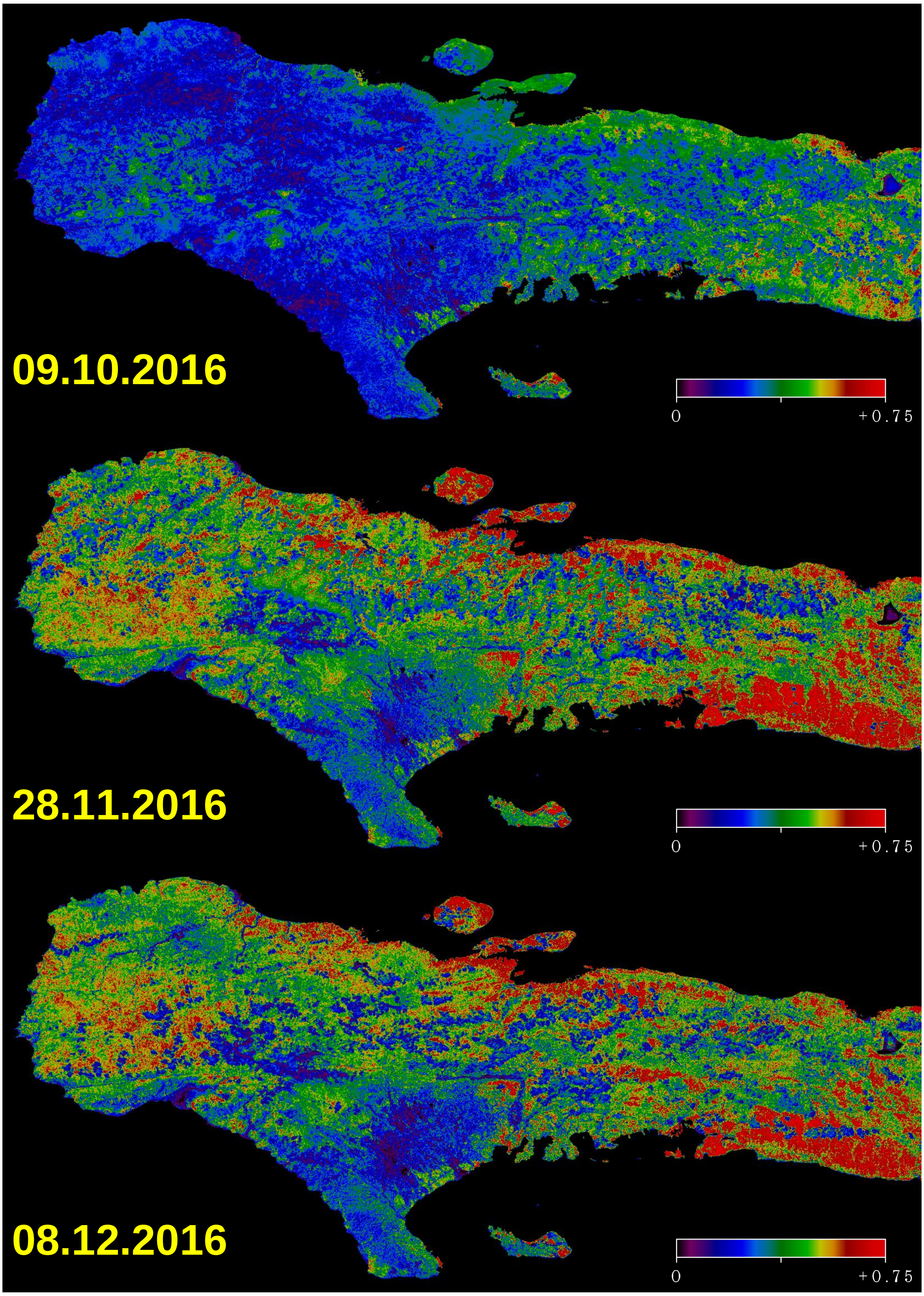


fig. 74 - Sentinel-2 NDII post-event.

8.4 DELIVERY08 - Cloud-free colour compositions of individual scenes

From this delivery, the scenes that have been processed individually or being involved in synthesis are "cloud-free" images from which a manual photo-interpretation has been performed contouring the clouds and their shadows.

Like the DELIVERY06 (see section 8.2), this delivery contains colour compositions performed with always the same stretching parameters assuming that data are correctly calibrated and having performed the atmospheric correction.

First scene acquired on 24.12.2015 has been manually computed setting the stretching parameters to show:

- the most realistic natural colour composition (bands 4-3-2) and
- the maximum variations in land use / land cover (bands 8-11-2).

The five (5) other scenes have been stretched with the same parameter leading to seasonal variations of reflectances showing the lowest reflectances in winter and the highest ones in summer.

8.4.1 File name syntax

SS_ZONE_YYYYMMDD.R-G-B.land.msk2.str.R-G-B[.sca-01].FFF

Examples:

- **s2_south_20151224.land.msk2.str.4-3-2.sca-01.tif** - for the "natural colours" composition of the Sentinel-2 scene observed on 24.12.2015 over the South zone (Tiburon Peninsula), resampled with a 1/10 factor (GSD, i.e. "Ground Sampling Distance", of 100 metres) and exported in GeoTIFF format.

- **s2_south_20161208.land.msk2.str.8-11-2.kmz** - for the "healthy vegetation" colour composition of the Sentinel-2 scene observed over the South zone with its nominal spatial resolution (GSD of 10 metres) and exported in KMZ (KML zipped) format.

8.4.2 Delivery file list

Name	Size (KB)	Type	Files	Percent
\\FABIO\fabio_3\P275_UNEP_HAITI\DELIVERY08_CLOU...	5 601 772	Folder	72	
s2_south_20151224.land.msk2.str.4-3-2.kmz	130 879	KMZ		
s2_south_20151224.land.msk2.str.4-3-2.sca-01.kmz	1 579	KMZ		
s2_south_20151224.land.msk2.str.4-3-2.sca-01.tfw	0	Fichier TFW		
s2_south_20151224.land.msk2.str.4-3-2.sca-01.tif	3 719	Fichier TIF		
s2_south_20151224.land.msk2.str.4-3-2.tfw	0	Fichier TFW		
s2_south_20151224.land.msk2.str.4-3-2.tif	371 507	Fichier TIF		
s2_south_20151224.land.msk2.str.8-11-2.kmz	114 423	KMZ		
s2_south_20151224.land.msk2.str.8-11-2.sca-01.kmz	1 660	KMZ		
s2_south_20151224.land.msk2.str.8-11-2.sca-01.tfw	0	Fichier TFW		
s2_south_20151224.land.msk2.str.8-11-2.sca-01.tif	3 719	Fichier TIF		
s2_south_20151224.land.msk2.str.8-11-2.tfw	0	Fichier TFW		
s2_south_20151224.land.msk2.str.8-11-2.tif	371 507	Fichier TIF		
s2_south_20160611.land.msk2.str.4-3-2.kmz	106 259	KMZ		
s2_south_20160611.land.msk2.str.4-3-2.sca-01.kmz	1 281	KMZ		
s2_south_20160611.land.msk2.str.4-3-2.sca-01.tfw	0	Fichier TFW		
s2_south_20160611.land.msk2.str.4-3-2.sca-01.tif	3 719	Fichier TIF		
s2_south_20160611.land.msk2.str.4-3-2.tfw	0	Fichier TFW		
s2_south_20160611.land.msk2.str.4-3-2.tif	371 507	Fichier TIF		
s2_south_20160611.land.msk2.str.8-11-2.kmz	88 086	KMZ		
s2_south_20160611.land.msk2.str.8-11-2.sca-01.kmz	1 287	KMZ		
s2_south_20160611.land.msk2.str.8-11-2.sca-01.tfw	0	Fichier TFW		
s2_south_20160611.land.msk2.str.8-11-2.sca-01.tif	3 719	Fichier TIF		
s2_south_20160611.land.msk2.str.8-11-2.tfw	0	Fichier TFW		
s2_south_20160611.land.msk2.str.8-11-2.tif	371 507	Fichier TIF		
s2_south_20160919.land.msk2.str.4-3-2.kmz	83 831	KMZ		
s2_south_20160919.land.msk2.str.4-3-2.sca-01.kmz	1 032	KMZ		
s2_south_20160919.land.msk2.str.4-3-2.sca-01.tfw	0	Fichier TFW		
s2_south_20160919.land.msk2.str.4-3-2.sca-01.tif	3 719	Fichier TIF		
s2_south_20160919.land.msk2.str.4-3-2.tfw	0	Fichier TFW		
s2_south_20160919.land.msk2.str.4-3-2.tif	371 507	Fichier TIF		
s2_south_20160919.land.msk2.str.8-11-2.kmz	72 444	KMZ		
s2_south_20160919.land.msk2.str.8-11-2.sca-01.kmz	1 063	KMZ		
s2_south_20160919.land.msk2.str.8-11-2.sca-01.tfw	0	Fichier TFW		
s2_south_20160919.land.msk2.str.8-11-2.sca-01.tif	3 719	Fichier TIF		
s2_south_20160919.land.msk2.str.8-11-2.tfw	0	Fichier TFW		
s2_south_20160919.land.msk2.str.8-11-2.tif	371 507	Fichier TIF		
s2_south_20161009.land.msk2.str.4-3-2.kmz	68 645	KMZ		
s2_south_20161009.land.msk2.str.4-3-2.sca-01.kmz	900	KMZ		
s2_south_20161009.land.msk2.str.4-3-2.sca-01.tfw	0	Fichier TFW		
s2_south_20161009.land.msk2.str.4-3-2.sca-01.tif	3 719	Fichier TIF		
s2_south_20161009.land.msk2.str.4-3-2.tfw	0	Fichier TFW		
s2_south_20161009.land.msk2.str.4-3-2.tif	371 507	Fichier TIF		
s2_south_20161009.land.msk2.str.8-11-2.kmz	57 760	KMZ		
s2_south_20161009.land.msk2.str.8-11-2.sca-01.kmz	897	KMZ		
s2_south_20161009.land.msk2.str.8-11-2.sca-01.tfw	0	Fichier TFW		
s2_south_20161009.land.msk2.str.8-11-2.sca-01.tif	3 719	Fichier TIF		
s2_south_20161009.land.msk2.str.8-11-2.tfw	0	Fichier TFW		
s2_south_20161009.land.msk2.str.8-11-2.tif	371 507	Fichier TIF		
s2_south_20161128.land.msk2.str.4-3-2.kmz	97 567	KMZ		
s2_south_20161128.land.msk2.str.4-3-2.sca-01.kmz	1 230	KMZ		
s2_south_20161128.land.msk2.str.4-3-2.sca-01.tfw	0	Fichier TFW		
s2_south_20161128.land.msk2.str.4-3-2.sca-01.tif	3 719	Fichier TIF		
s2_south_20161128.land.msk2.str.4-3-2.tfw	0	Fichier TFW		
s2_south_20161128.land.msk2.str.4-3-2.tif	371 507	Fichier TIF		
s2_south_20161128.land.msk2.str.8-11-2.kmz	83 607	KMZ		
s2_south_20161128.land.msk2.str.8-11-2.sca-01.kmz	1 279	KMZ		
s2_south_20161128.land.msk2.str.8-11-2.sca-01.tfw	0	Fichier TFW		
s2_south_20161128.land.msk2.str.8-11-2.sca-01.tif	3 719	Fichier TIF		
s2_south_20161128.land.msk2.str.8-11-2.tfw	0	Fichier TFW		
s2_south_20161128.land.msk2.str.8-11-2.tif	371 507	Fichier TIF		
s2_south_20161208.land.msk2.str.4-3-2.kmz	96 879	KMZ		
s2_south_20161208.land.msk2.str.4-3-2.sca-01.kmz	1 229	KMZ		
s2_south_20161208.land.msk2.str.4-3-2.sca-01.tfw	0	Fichier TFW		
s2_south_20161208.land.msk2.str.4-3-2.sca-01.tif	3 719	Fichier TIF		
s2_south_20161208.land.msk2.str.4-3-2.tfw	0	Fichier TFW		
s2_south_20161208.land.msk2.str.4-3-2.tif	371 507	Fichier TIF		
s2_south_20161208.land.msk2.str.8-11-2.kmz	83 948	KMZ		
s2_south_20161208.land.msk2.str.8-11-2.sca-01.kmz	1 283	KMZ		
s2_south_20161208.land.msk2.str.8-11-2.sca-01.tfw	0	Fichier TFW		
s2_south_20161208.land.msk2.str.8-11-2.sca-01.tif	3 719	Fichier TIF		
s2_south_20161208.land.msk2.str.8-11-2.tfw	0	Fichier TFW		
s2_south_20161208.land.msk2.str.8-11-2.tif	371 507	Fichier TIF		

8.4.3 “Natural colours” (4-3-2) colour compositions

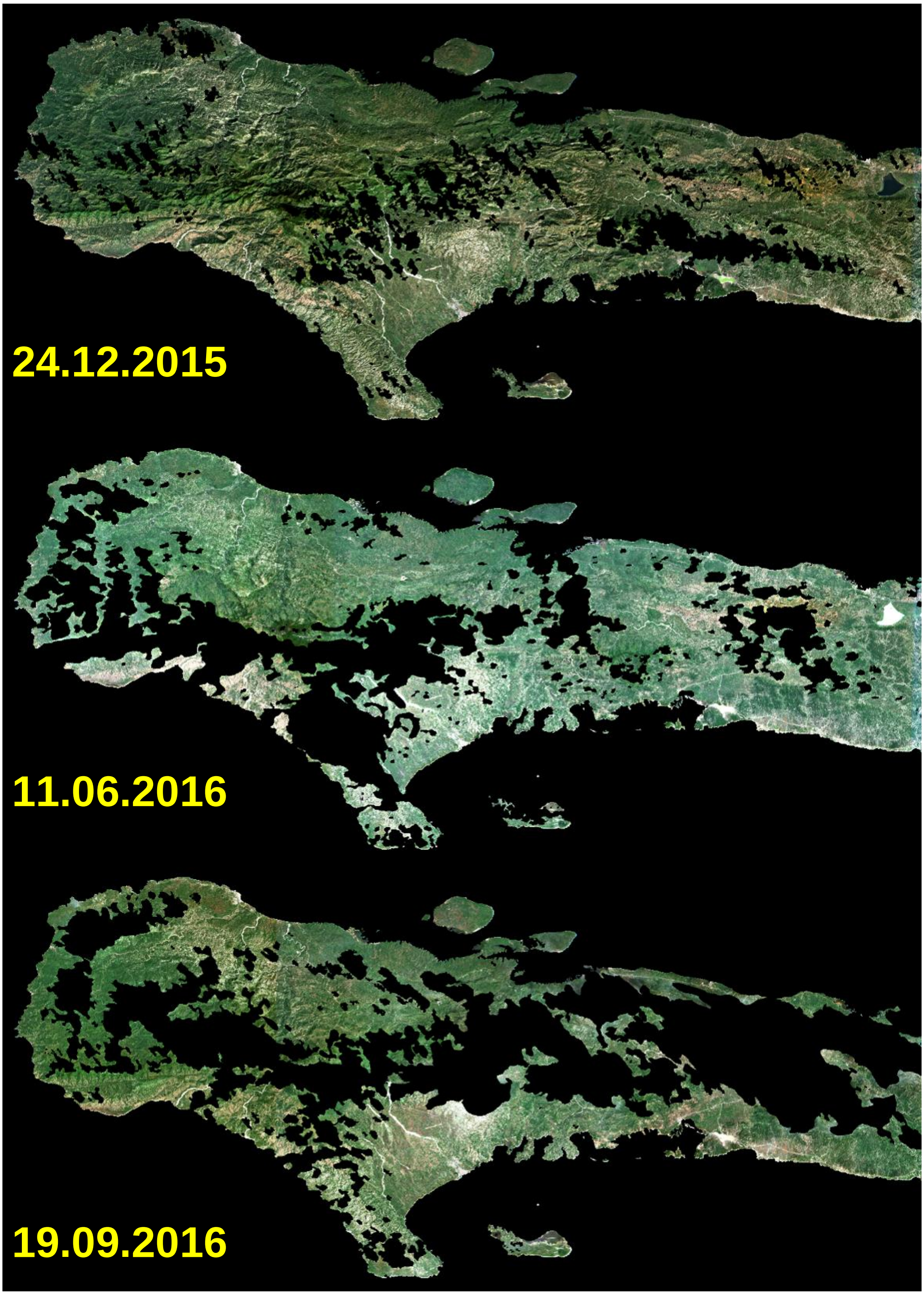


fig. 75 - Sentinel-2 “natural colour” pre-event.

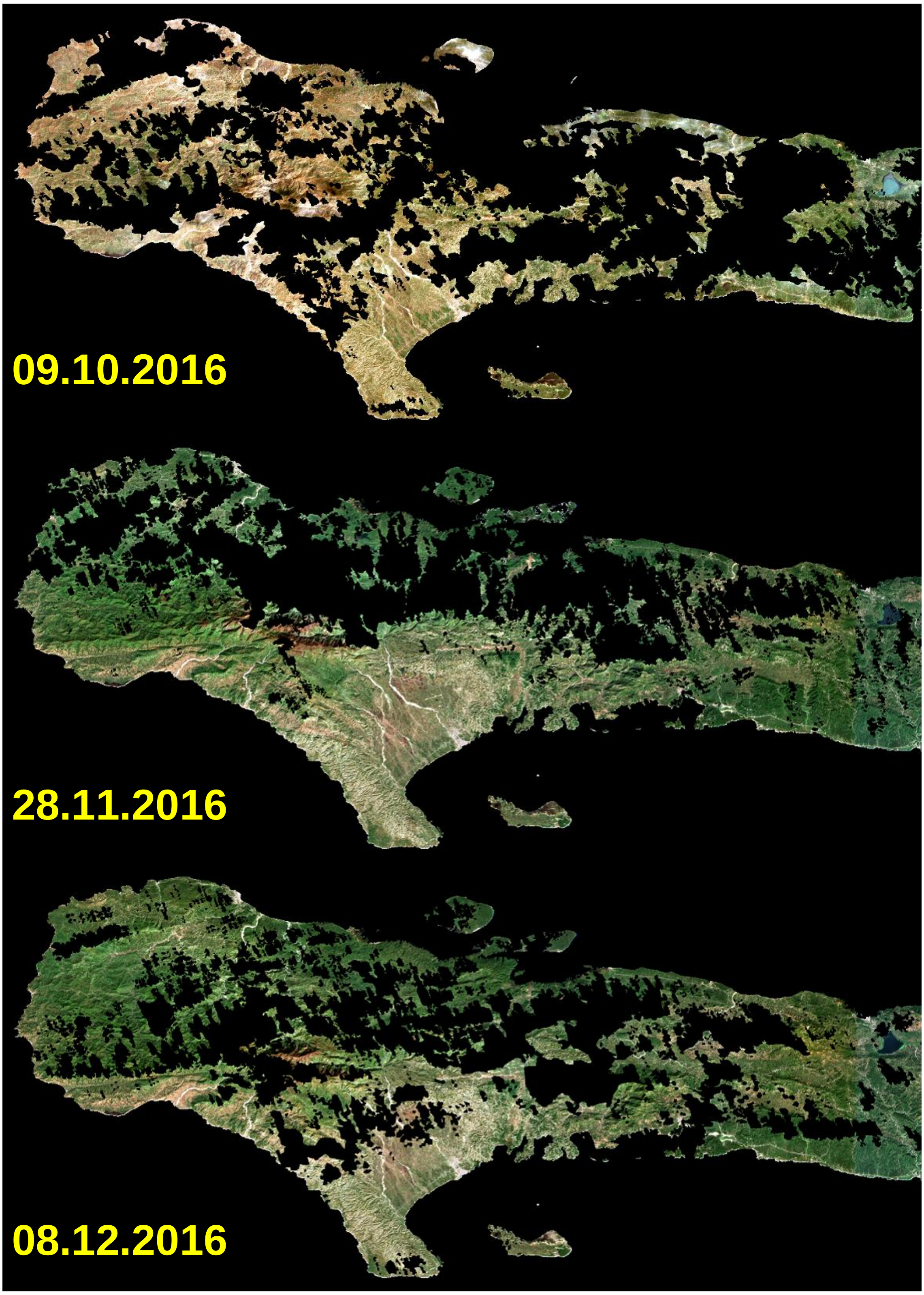


fig. 76 - Sentinel-2 “natural colours” post-event.

8.4.4 "Healthy vegetation" (8-11-2) colour composition

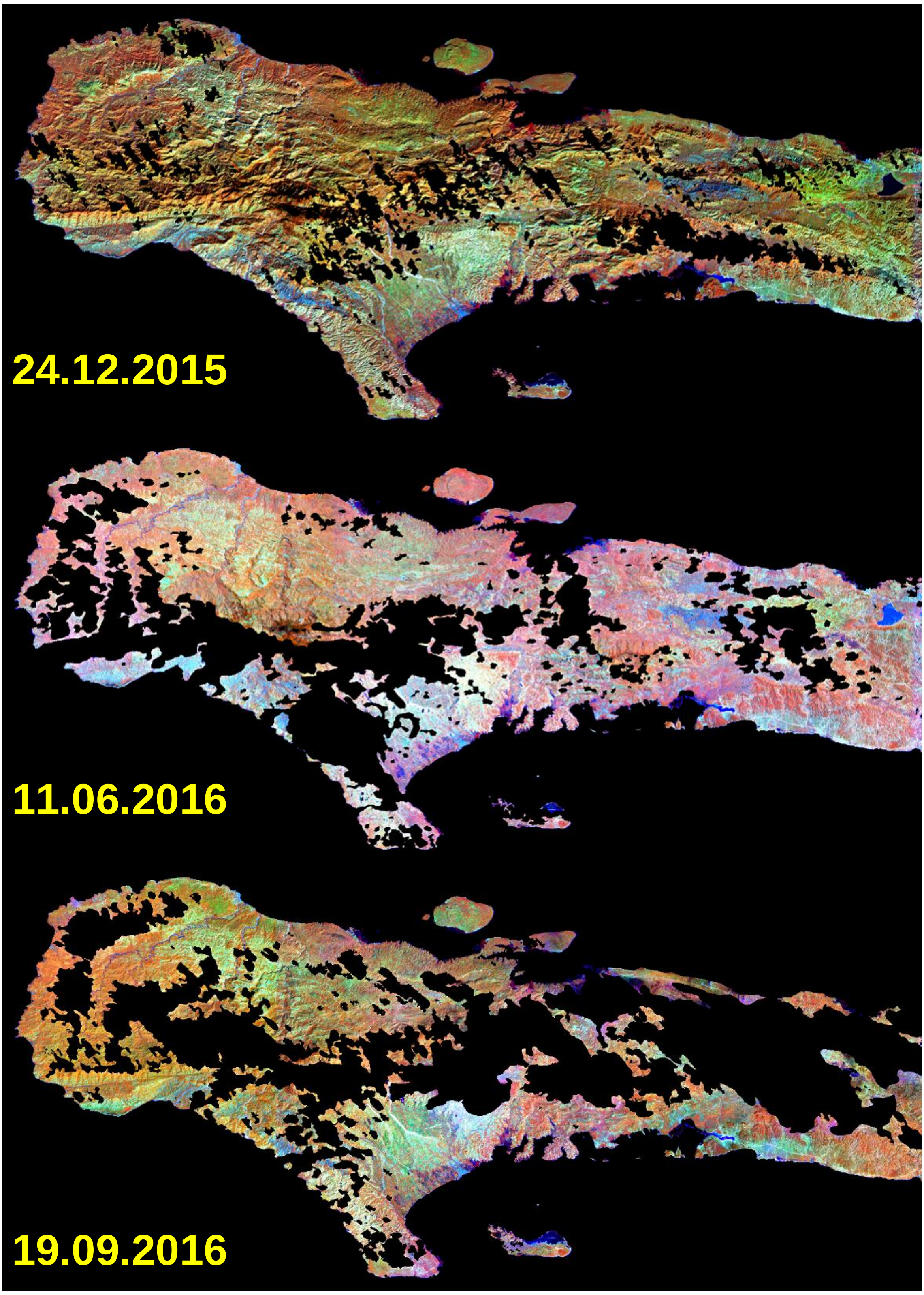


fig. 77 - Sentinel-2 "healthy vegetation" pre-event.

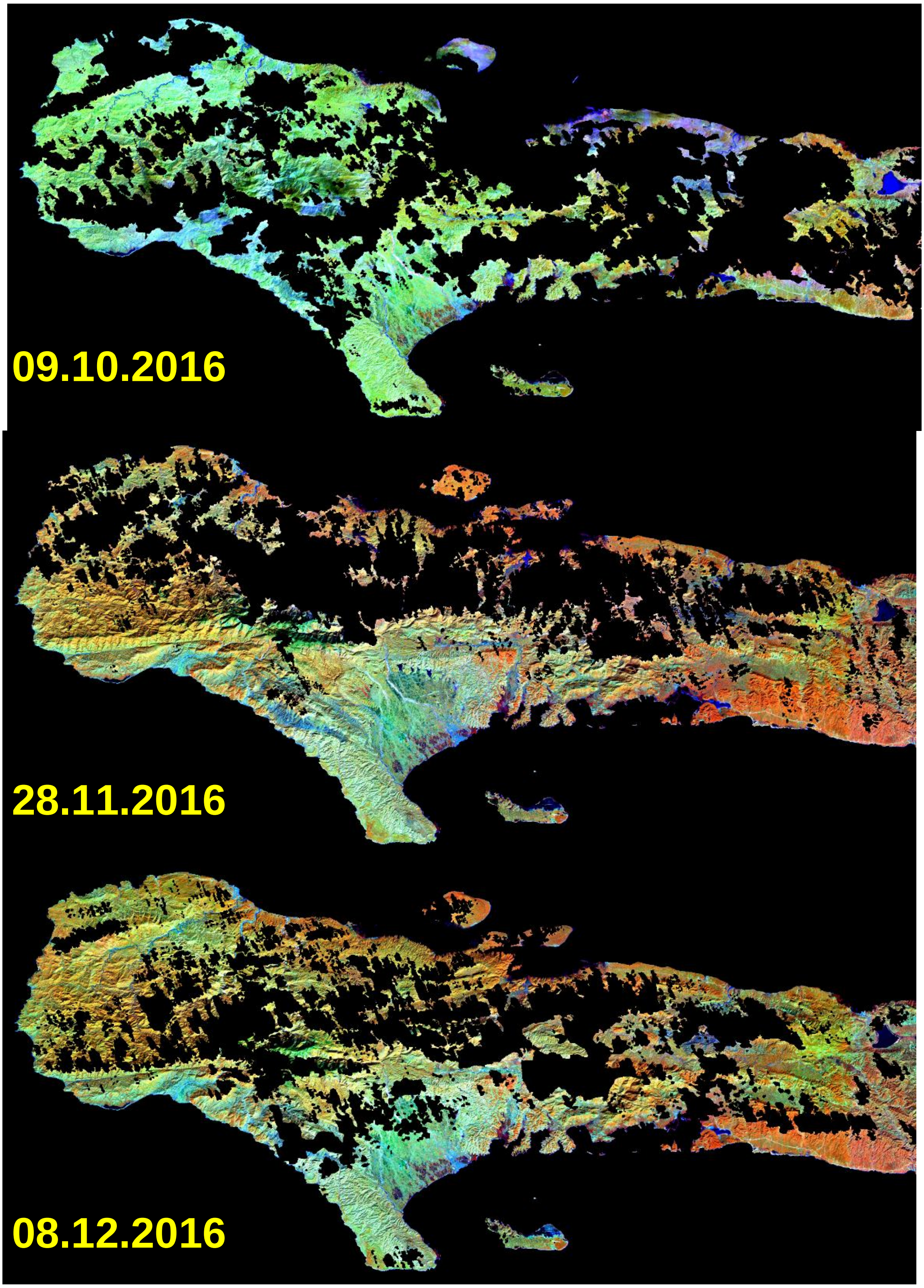


fig. 78 - Sentinel-2 "healthy vegetation" post-event.

8.5 DELIVERY09 - Cloud-free NDVI and NDII of individual scenes

These scenes that have been processed individually to remove the clouds and their shadows.

Like the DELIVERY07 (see section 8.3), this delivery contains:

- **NDVI -** Normalised Difference Vegetation Index images computed from the near infrared (band 8 of Sentinel-2/MSI centred on 842 nm) and the red (band 4 centred on 665 nm).
  NDVI data have been stretched in the range [0,1] and are shown with a rainbow LUT.
- **NDII -** Normalised Difference Infrared Index images computed from the near infrared (band 8 centred on 842 nm) and the short wave infrared (band 12 centred on 2190 nm).
  NDII data have been stretched in the range [0,0.75] and are shown with a rainbow LUT.

8.5.1 File name syntax

SS_ZONE_YYYYMMDD.msk2.ndXi[.sca-01].FFF

Examples:

- **s2_south_20151224.msk2.ndvi.sca-01.tif** - for the "normalised difference vegetation index" (NDVI) of the Sentinel-2 scene observed on 24.12.2015 over the South zone (Tiburon Peninsula), resampled with a 1/10 factor (GSD, i.e. "Ground Sampling Distance", of 100 metres) and exported in GeoTIFF format.
- **s2_south_20161208.msk2.ndii.kmz -** for the "normalised difference infrared index" (NDII) of the Sentinel-2 scene observed over the South zone on 08.12.2016 with its nominal spatial resolution (GSD of 10 metres) and exported in KMZ (KML zipped) format.

8.5.2 Delivery file list

Name	Size (KB)	Type	Files	Percent
\\FABIO\fabio_3\P275_UNEP_HAITI\DELIVERY09_CLOU...	1 921 062	Folder	72	
s2_south_20151224.msk2.ndii.kmz	48 687	KMZ		
s2_south_20151224.msk2.ndii.sca-01.kmz	500	KMZ		
s2_south_20151224.msk2.ndii.sca-01.tfw	0	Fichier TFW		
s2_south_20151224.msk2.ndii.sca-01.tif	1 246	Fichier TIF		
s2_south_20151224.msk2.ndii.tfw	0	Fichier TFW		
s2_south_20151224.msk2.ndii.tif	123 878	Fichier TIF		
s2_south_20151224.msk2.ndvi.kmz	44 690	KMZ		
s2_south_20151224.msk2.ndvi.sca-01.kmz	465	KMZ		
s2_south_20151224.msk2.ndvi.sca-01.tfw	0	Fichier TFW		
s2_south_20151224.msk2.ndvi.sca-01.tif	1 246	Fichier TIF		
s2_south_20151224.msk2.ndvi.tfw	0	Fichier TFW		
s2_south_20151224.msk2.ndvi.tif	123 878	Fichier TIF		
s2_south_20160611.msk2.ndii.kmz	38 332	KMZ		
s2_south_20160611.msk2.ndii.sca-01.kmz	401	KMZ		
s2_south_20160611.msk2.ndii.sca-01.tfw	0	Fichier TFW		
s2_south_20160611.msk2.ndii.sca-01.tif	1 246	Fichier TIF		
s2_south_20160611.msk2.ndii.tfw	0	Fichier TFW		
s2_south_20160611.msk2.ndii.tif	123 878	Fichier TIF		
s2_south_20160611.msk2.ndvi.kmz	36 228	KMZ		
s2_south_20160611.msk2.ndvi.sca-01.kmz	380	KMZ		
s2_south_20160611.msk2.ndvi.sca-01.tfw	0	Fichier TFW		
s2_south_20160611.msk2.ndvi.sca-01.tif	1 246	Fichier TIF		
s2_south_20160611.msk2.ndvi.tfw	0	Fichier TFW		
s2_south_20160611.msk2.ndvi.tif	123 878	Fichier TIF		
s2_south_20160919.msk2.ndii.kmz	30 888	KMZ		
s2_south_20160919.msk2.ndii.sca-01.kmz	330	KMZ		
s2_south_20160919.msk2.ndii.sca-01.tfw	0	Fichier TFW		
s2_south_20160919.msk2.ndii.sca-01.tif	1 246	Fichier TIF		
s2_south_20160919.msk2.ndii.tfw	0	Fichier TFW		
s2_south_20160919.msk2.ndii.tif	123 878	Fichier TIF		
s2_south_20160919.msk2.ndvi.kmz	28 877	KMZ		
s2_south_20160919.msk2.ndvi.sca-01.kmz	308	KMZ		
s2_south_20160919.msk2.ndvi.sca-01.tfw	0	Fichier TFW		
s2_south_20160919.msk2.ndvi.sca-01.tif	1 246	Fichier TIF		
s2_south_20160919.msk2.ndvi.tfw	0	Fichier TFW		
s2_south_20160919.msk2.ndvi.tif	123 878	Fichier TIF		
s2_south_20161009.msk2.ndii.kmz	24 436	KMZ		
s2_south_20161009.msk2.ndii.sca-01.kmz	280	KMZ		
s2_south_20161009.msk2.ndii.sca-01.tfw	0	Fichier TFW		
s2_south_20161009.msk2.ndii.sca-01.tif	1 246	Fichier TIF		
s2_south_20161009.msk2.ndii.tfw	0	Fichier TFW		
s2_south_20161009.msk2.ndii.tif	123 878	Fichier TIF		
s2_south_20161009.msk2.ndvi.kmz	24 339	KMZ		
s2_south_20161009.msk2.ndvi.sca-01.kmz	273	KMZ		
s2_south_20161009.msk2.ndvi.sca-01.tfw	0	Fichier TFW		
s2_south_20161009.msk2.ndvi.sca-01.tif	1 246	Fichier TIF		
s2_south_20161009.msk2.ndvi.tfw	0	Fichier TFW		
s2_south_20161009.msk2.ndvi.tif	123 878	Fichier TIF		
s2_south_20161128.msk2.ndii.kmz	35 486	KMZ		
s2_south_20161128.msk2.ndii.sca-01.kmz	391	KMZ		
s2_south_20161128.msk2.ndii.sca-01.tfw	0	Fichier TFW		
s2_south_20161128.msk2.ndii.sca-01.tif	1 246	Fichier TIF		
s2_south_20161128.msk2.ndii.tfw	0	Fichier TFW		
s2_south_20161128.msk2.ndii.tif	123 878	Fichier TIF		
s2_south_20161128.msk2.ndvi.kmz	33 760	KMZ		
s2_south_20161128.msk2.ndvi.sca-01.kmz	372	KMZ		
s2_south_20161128.msk2.ndvi.sca-01.tfw	0	Fichier TFW		
s2_south_20161128.msk2.ndvi.sca-01.tif	1 246	Fichier TIF		
s2_south_20161128.msk2.ndvi.tfw	0	Fichier TFW		
s2_south_20161128.msk2.ndvi.tif	123 878	Fichier TIF		
s2_south_20161208.msk2.ndii.kmz	35 819	KMZ		
s2_south_20161208.msk2.ndii.sca-01.kmz	395	KMZ		
s2_south_20161208.msk2.ndii.sca-01.tfw	0	Fichier TFW		
s2_south_20161208.msk2.ndii.sca-01.tif	1 246	Fichier TIF		
s2_south_20161208.msk2.ndii.tfw	0	Fichier TFW		
s2_south_20161208.msk2.ndii.tif	123 878	Fichier TIF		
s2_south_20161208.msk2.ndvi.kmz	33 571	KMZ		
s2_south_20161208.msk2.ndvi.sca-01.kmz	370	KMZ		
s2_south_20161208.msk2.ndvi.sca-01.tfw	0	Fichier TFW		
s2_south_20161208.msk2.ndvi.sca-01.tif	1 246	Fichier TIF		
s2_south_20161208.msk2.ndvi.tfw	0	Fichier TFW		
s2_south_20161208.msk2.ndvi.tif	123 878	Fichier TIF		

8.5.3 NDVI (Normalised Difference Vegetation Index)

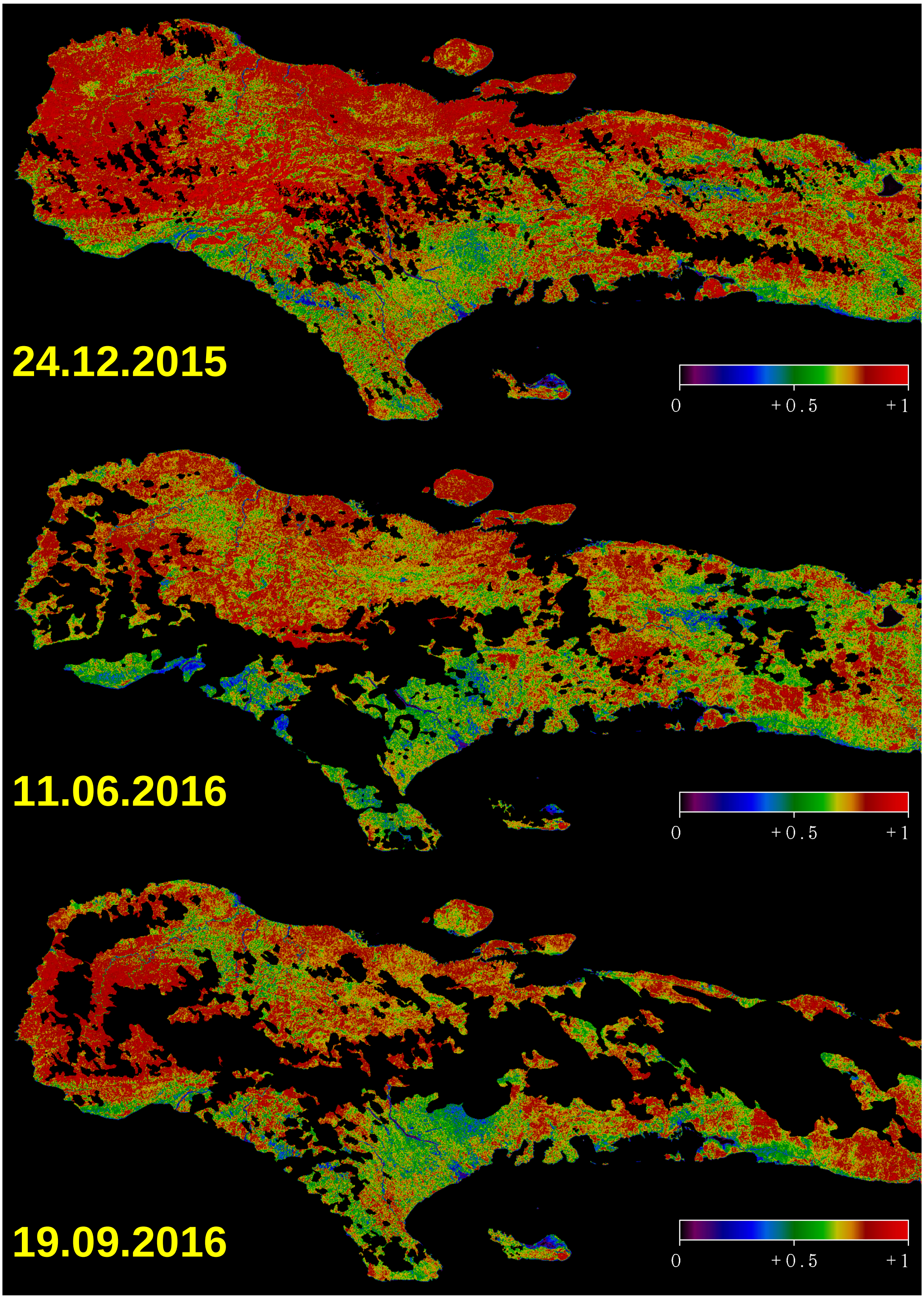


fig. 79 - Sentinel-2 NDVI pre-event.

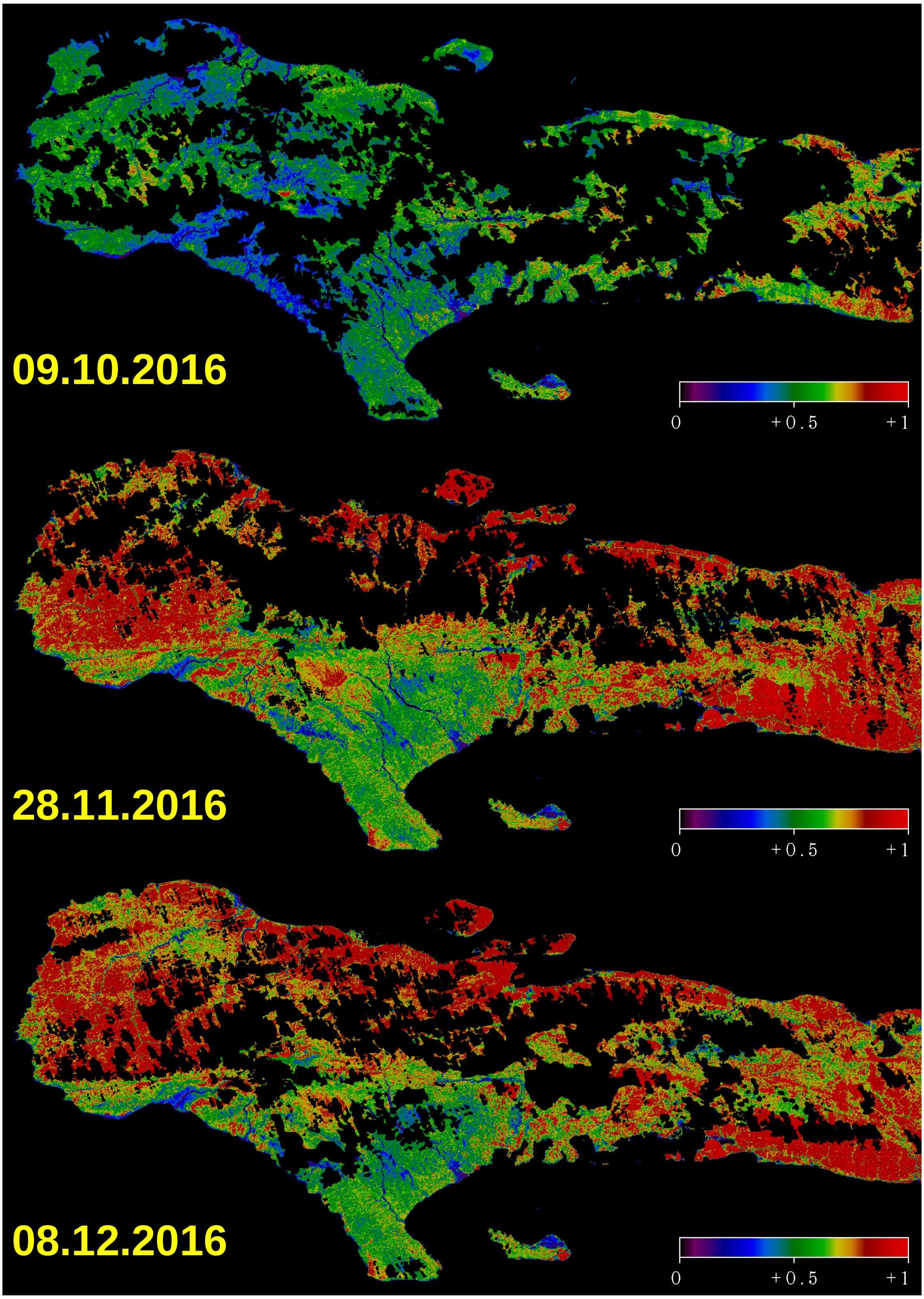


fig. 80 - Sentinel-2 NDVI post-event.

8.5.4 NDII (Normalised Difference Infrared Index)

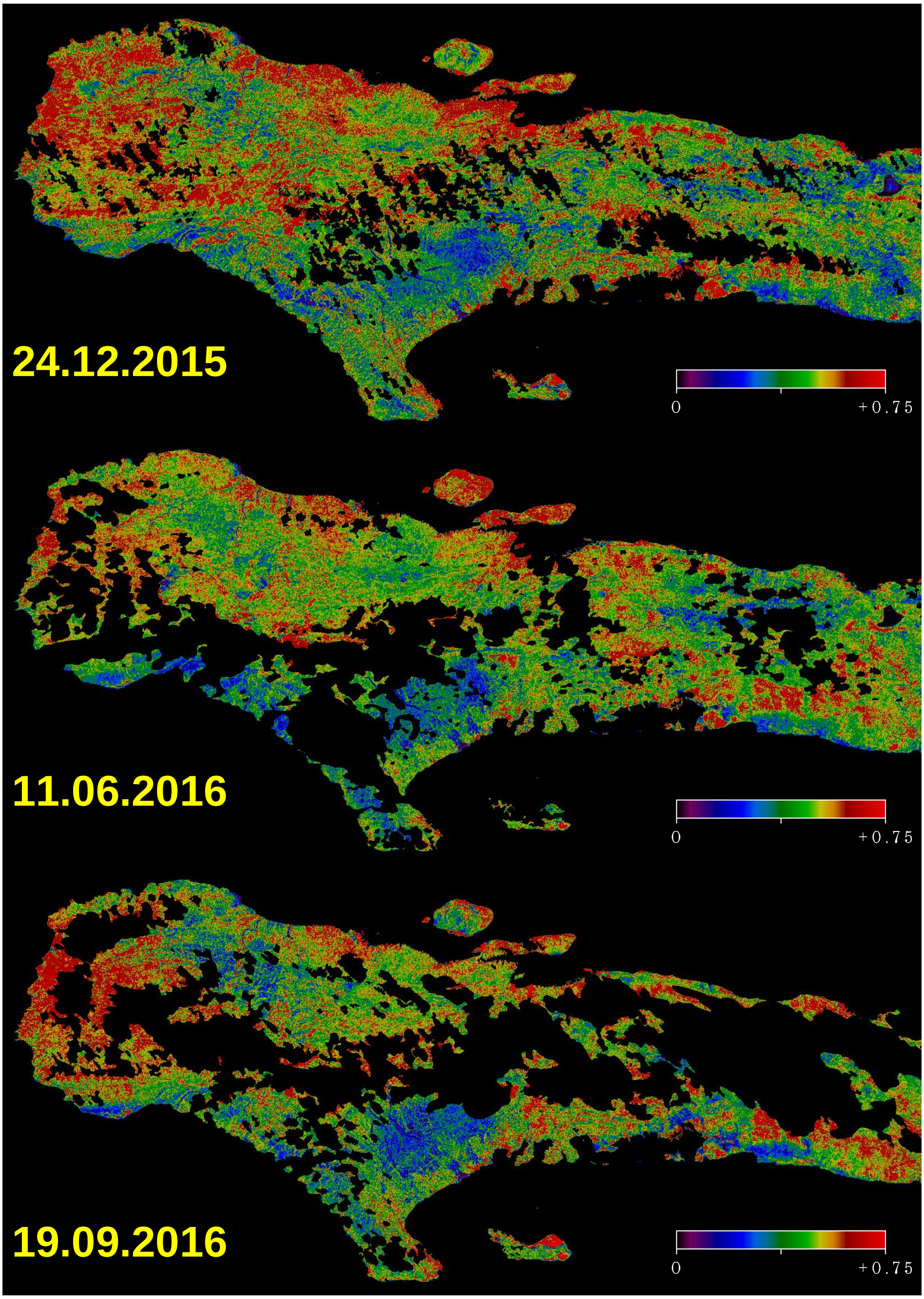


fig. 81 - Sentinel-2 NDII pre-event.

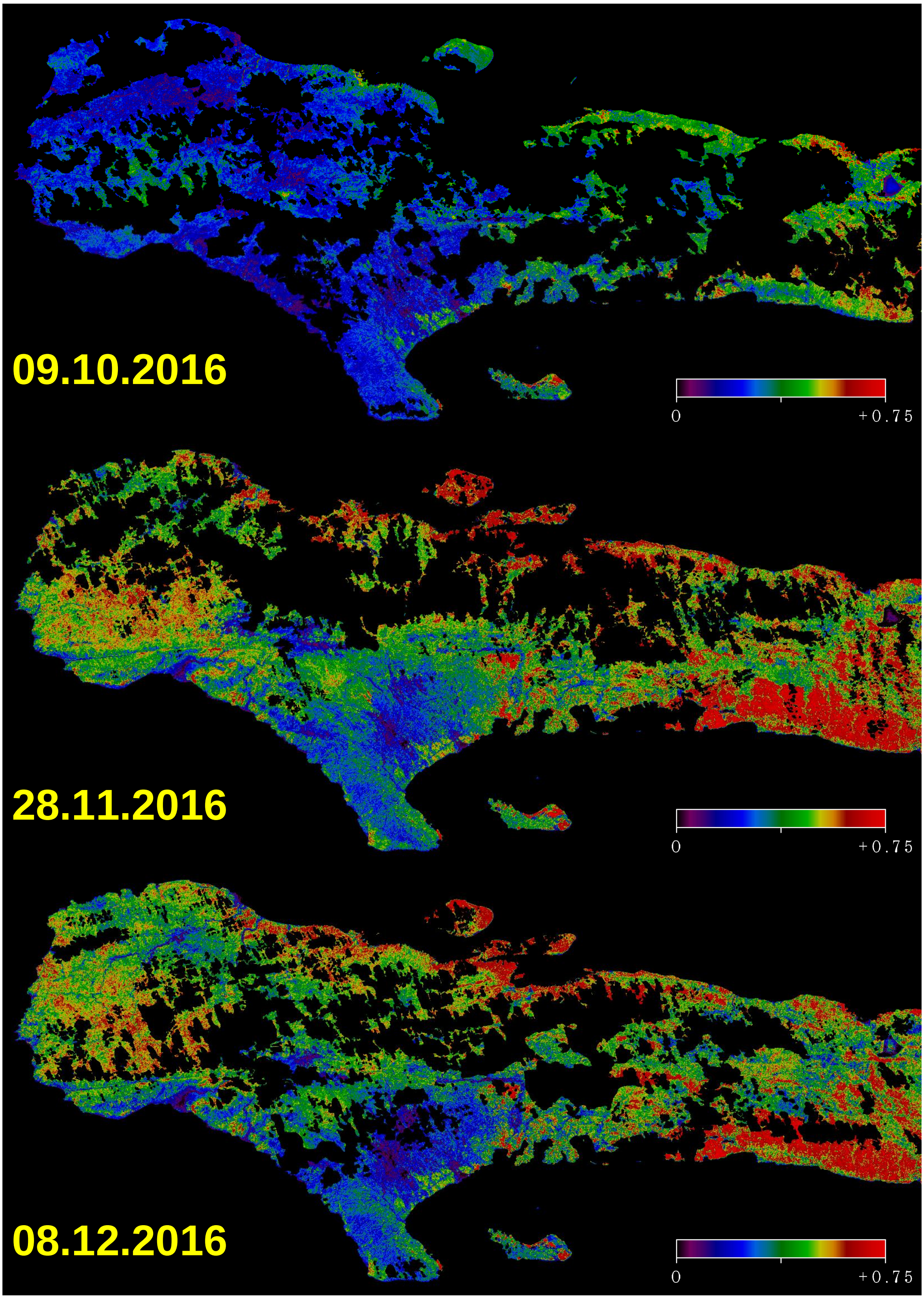


fig. 82 - Sentinel-2 NDII post-event.

8.6 DELIVERY10 - Synthesis colour compositions

After having checked a first version of the NDVI differences, UNEP experts have noticed that differences are also due to the season changes. In order to limit the impact of this difference, the post-event synthesis has been split in two groups (ef) and (def).

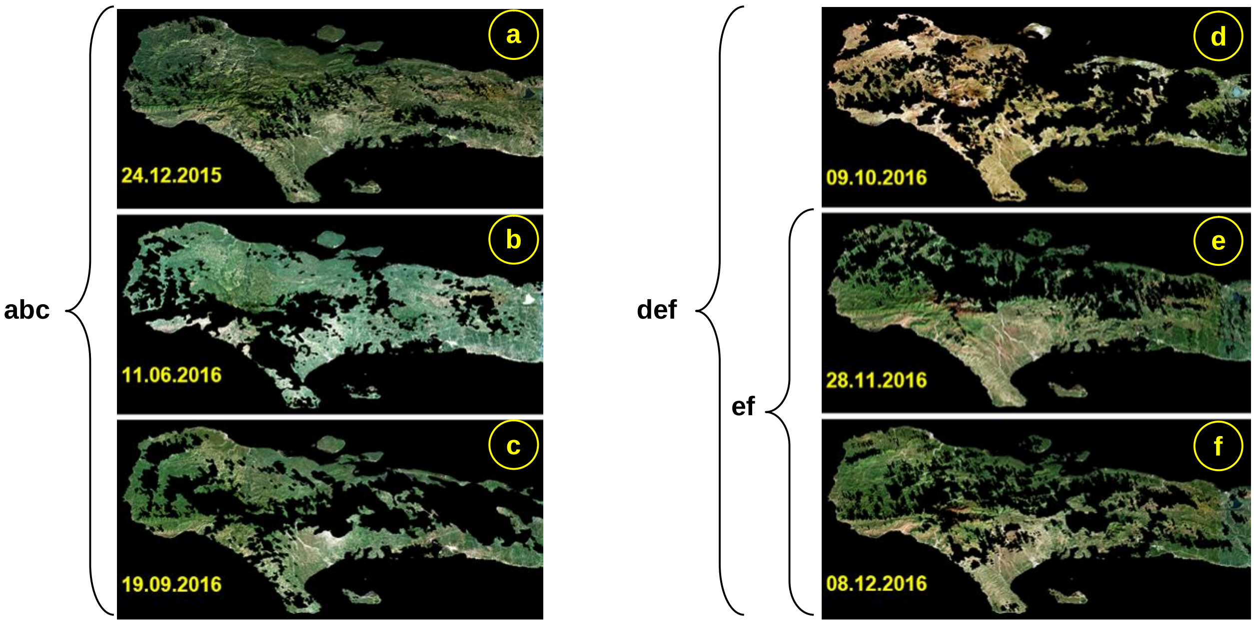


fig. 83 - Grouping scenes for synthesis.

Synthesis has been performed using the “maximum NDVI” rule; i.e. keeping the radiometry (and therefore replacing possible cloudy pixels) of the 2, 3, 4, 8, 11 and 12 bands of the date showing the best (NIR-Red)/(NIR+Red) ratio.

To avoid erroneous values, synthesis have been computed from cloud-free images (“msk2”) only.

Like the DELIVERY06 (see section 8.2) or DELIVERY08 (see section 8.4), this delivery contains colour compositions performed with always the same stretching parameters assuming that data are correctly calibrated and having performed the atmospheric correction.

First scene acquired on 24.12.2015 has been manually computed setting the stretching parameters to show:

- the most realistic natural colour composition (bands 4-3-2) and
- the maximum variations in land use / land cover (bands 8-11-2).

8.6.1 File name syntax

SS_ZONE_msk2.syn-NN[N].str.R-G-B[.sca-01].FFF

Examples:

- **s2_south.msk2.syn-abc.str.4-3-2.sca-01.tif** - for the “natural colours” composition of the Sentinel-2 scene observed before the event (synthesis “abc”) over the South zone (Tiburon Peninsula), resampled with a 1/10 factor (GSD, i.e. “Ground Sampling Distance”, of 100 metres) and exported in GeoTIFF format.
- **s2_south.msk2.syn-ef.str.8-11-2.kmz** - for the “healthy vegetation” colour composition of the Sentinel-2 scene observed in the last two scenes (synthesis “ef”) over the South zone with its nominal spatial resolution (GSD of 10 metres) and exported in KMZ (KML zipped) format.

8.6.2 Delivery file list

Name	Size (KB)	Type	Files	Percent
\\FABIO\fabio_3\P275_UNEP_HAITI\DELIVERY11_SYNT...	1 030 237	Folder	36	
s2_south.msk2.syn-abc.ndii.kmz	52 441	KMZ		
s2_south.msk2.syn-abc.ndii.sca-01.kmz	528	KMZ		
s2_south.msk2.syn-abc.ndii.sca-01.tfw	0	Fichier TFW		
s2_south.msk2.syn-abc.ndii.sca-01.tif	1 246	Fichier TIF		
s2_south.msk2.syn-abc.ndii.tfw	0	Fichier TFW		
s2_south.msk2.syn-abc.ndii.tif	123 878	Fichier TIF		
s2_south.msk2.syn-abc.ndvi.kmz	47 728	KMZ		
s2_south.msk2.syn-abc.ndvi.sca-01.kmz	489	KMZ		
s2_south.msk2.syn-abc.ndvi.sca-01.tfw	0	Fichier TFW		
s2_south.msk2.syn-abc.ndvi.sca-01.tif	1 246	Fichier TIF		
s2_south.msk2.syn-abc.ndvi.tfw	0	Fichier TFW		
s2_south.msk2.syn-abc.ndvi.tif	123 878	Fichier TIF		
s2_south.msk2.syn-def.ndii.kmz	45 566	KMZ		
s2_south.msk2.syn-def.ndii.sca-01.kmz	487	KMZ		
s2_south.msk2.syn-def.ndii.sca-01.tfw	0	Fichier TFW		
s2_south.msk2.syn-def.ndii.sca-01.tif	1 246	Fichier TIF		
s2_south.msk2.syn-def.ndii.tfw	0	Fichier TFW		
s2_south.msk2.syn-def.ndii.tif	123 878	Fichier TIF		
s2_south.msk2.syn-def.ndvi.kmz	42 645	KMZ		
s2_south.msk2.syn-def.ndvi.sca-01.kmz	456	KMZ		
s2_south.msk2.syn-def.ndvi.sca-01.tfw	0	Fichier TFW		
s2_south.msk2.syn-def.ndvi.sca-01.tif	1 246	Fichier TIF		
s2_south.msk2.syn-def.ndvi.tfw	0	Fichier TFW		
s2_south.msk2.syn-def.ndvi.tif	123 878	Fichier TIF		
s2_south.msk2.syn-ef.ndii.kmz	45 566	KMZ		
s2_south.msk2.syn-ef.ndii.sca-01.kmz	487	KMZ		
s2_south.msk2.syn-ef.ndii.sca-01.tfw	0	Fichier TFW		
s2_south.msk2.syn-ef.ndii.sca-01.tif	1 246	Fichier TIF		
s2_south.msk2.syn-ef.ndii.tfw	0	Fichier TFW		
s2_south.msk2.syn-ef.ndii.tif	123 878	Fichier TIF		
s2_south.msk2.syn-ef.ndvi.kmz	42 645	KMZ		
s2_south.msk2.syn-ef.ndvi.sca-01.kmz	456	KMZ		
s2_south.msk2.syn-ef.ndvi.sca-01.tfw	0	Fichier TFW		
s2_south.msk2.syn-ef.ndvi.sca-01.tif	1 246	Fichier TIF		
s2_south.msk2.syn-ef.ndvi.tfw	0	Fichier TFW		
s2_south.msk2.syn-ef.ndvi.tif	123 878	Fichier TIF		

8.6.1 "Natural colours" (4-3-2) colour compositions

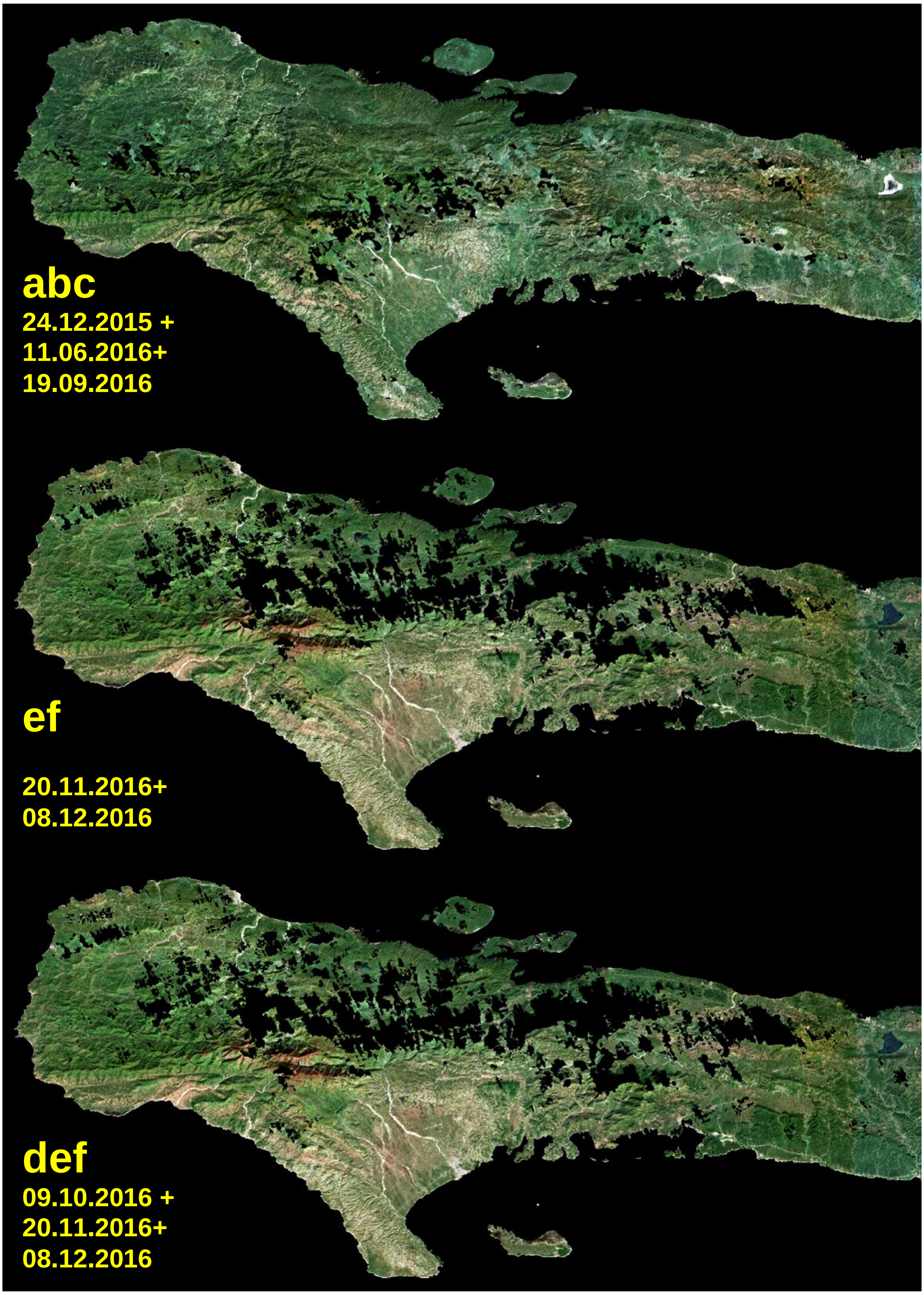


fig. 84 - Synthesis "natural colour".

8.6.2 “Healthy vegetation” (8-11-2) colour composition

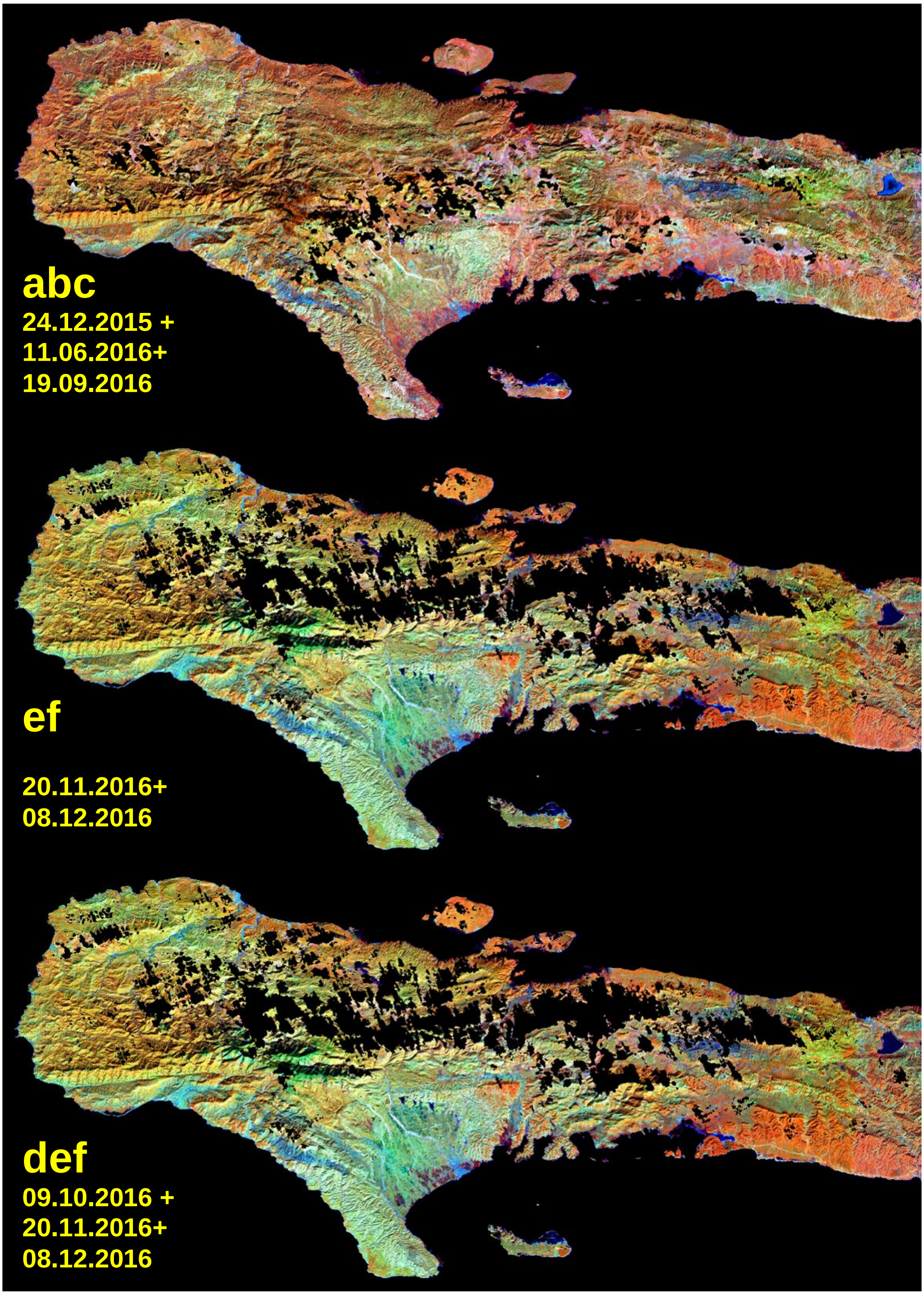


fig. 85 - Synthesis “healthy vegetation”.

8.7 DELIVERY11 - Synthesis NDVI and NDII

These synthesis have been processed from “cloud-free” input scenes.

Like the DELIVERY07 (see section 8.3) or the DELIVERY09 (see section 8.5), this delivery contains:

- **NDVI -** Normalised Difference Vegetation Index images computed from the near infrared (band 8 of Sentinel-2/MSI centred on 842 nm) and the red (band 4 centred on 665 nm).
  NDVI data have been stretched in the range [0,1] and are shown with a rainbow LUT.
- **NDII -** Normalised Difference Infrared Index images computed from the near infrared (band 8 centred on 842 nm) and the short wave infrared (band 12 centred on 2190 nm).
  NDII data have been stretched in the range [0,0.75] and are shown with a rainbow LUT.

8.7.1 File name syntax

SS_ZONE_YYYYMMDD.msk2.ndXi[.sca-01].FFF

Examples:

- **s2_south.msk2.syn-abc.ndvi.sca-01.tif -** for the “normalised difference vegetation index” (NDVI) of the Sentinel-2 pre-event synthesis (“abc”) over the South zone (Tiburon Peninsula), resampled with a 1/10 factor (GSD, i.e. “Ground Sampling Distance”, of 100 metres) and exported in GeoTIFF format.
- **s2_south.msk2.syn-ef.ndii.kmz -** for the “normalised difference infrared index” (NDII) of the Sentinel-2 scene observed in the last two dates after event (synthesis “ef”) over the South zone with its nominal spatial resolution (GSD of 10 metres) and exported in KMZ (KML zipped) format.

8.7.2 Delivery file list

Name	Size (KB)	Type	Files	Percent
\\FABIO\fabio_3\P275_UNEP_HAITI\DELIVERY11_SYNT...	1 030 237	Folder	36	
s2_south.msk2.syn-abc.ndii.kmz	52 441	KMZ		
s2_south.msk2.syn-abc.ndii.sca-01.kmz	528	KMZ		
s2_south.msk2.syn-abc.ndii.sca-01.tfw	0	Fichier TFW		
s2_south.msk2.syn-abc.ndii.sca-01.tif	1 246	Fichier TIF		
s2_south.msk2.syn-abc.ndii.tfw	0	Fichier TFW		
s2_south.msk2.syn-abc.ndii.tif	123 878	Fichier TIF		
s2_south.msk2.syn-abc.ndvi.kmz	47 728	KMZ		
s2_south.msk2.syn-abc.ndvi.sca-01.kmz	489	KMZ		
s2_south.msk2.syn-abc.ndvi.sca-01.tfw	0	Fichier TFW		
s2_south.msk2.syn-abc.ndvi.sca-01.tif	1 246	Fichier TIF		
s2_south.msk2.syn-abc.ndvi.tfw	0	Fichier TFW		
s2_south.msk2.syn-abc.ndvi.tif	123 878	Fichier TIF		
s2_south.msk2.syn-def.ndii.kmz	45 566	KMZ		
s2_south.msk2.syn-def.ndii.sca-01.kmz	487	KMZ		
s2_south.msk2.syn-def.ndii.sca-01.tfw	0	Fichier TFW		
s2_south.msk2.syn-def.ndii.sca-01.tif	1 246	Fichier TIF		
s2_south.msk2.syn-def.ndii.tfw	0	Fichier TFW		
s2_south.msk2.syn-def.ndii.tif	123 878	Fichier TIF		
s2_south.msk2.syn-def.ndvi.kmz	42 645	KMZ		
s2_south.msk2.syn-def.ndvi.sca-01.kmz	456	KMZ		
s2_south.msk2.syn-def.ndvi.sca-01.tfw	0	Fichier TFW		
s2_south.msk2.syn-def.ndvi.sca-01.tif	1 246	Fichier TIF		
s2_south.msk2.syn-def.ndvi.tfw	0	Fichier TFW		
s2_south.msk2.syn-def.ndvi.tif	123 878	Fichier TIF		
s2_south.msk2.syn-ef.ndii.kmz	45 566	KMZ		
s2_south.msk2.syn-ef.ndii.sca-01.kmz	487	KMZ		
s2_south.msk2.syn-ef.ndii.sca-01.tfw	0	Fichier TFW		
s2_south.msk2.syn-ef.ndii.sca-01.tif	1 246	Fichier TIF		
s2_south.msk2.syn-ef.ndii.tfw	0	Fichier TFW		
s2_south.msk2.syn-ef.ndii.tif	123 878	Fichier TIF		
s2_south.msk2.syn-ef.ndvi.kmz	42 645	KMZ		
s2_south.msk2.syn-ef.ndvi.sca-01.kmz	456	KMZ		
s2_south.msk2.syn-ef.ndvi.sca-01.tfw	0	Fichier TFW		
s2_south.msk2.syn-ef.ndvi.sca-01.tif	1 246	Fichier TIF		
s2_south.msk2.syn-ef.ndvi.tfw	0	Fichier TFW		
s2_south.msk2.syn-ef.ndvi.tif	123 878	Fichier TIF		

8.8 NDVI (Normalised Difference Vegetation Index)

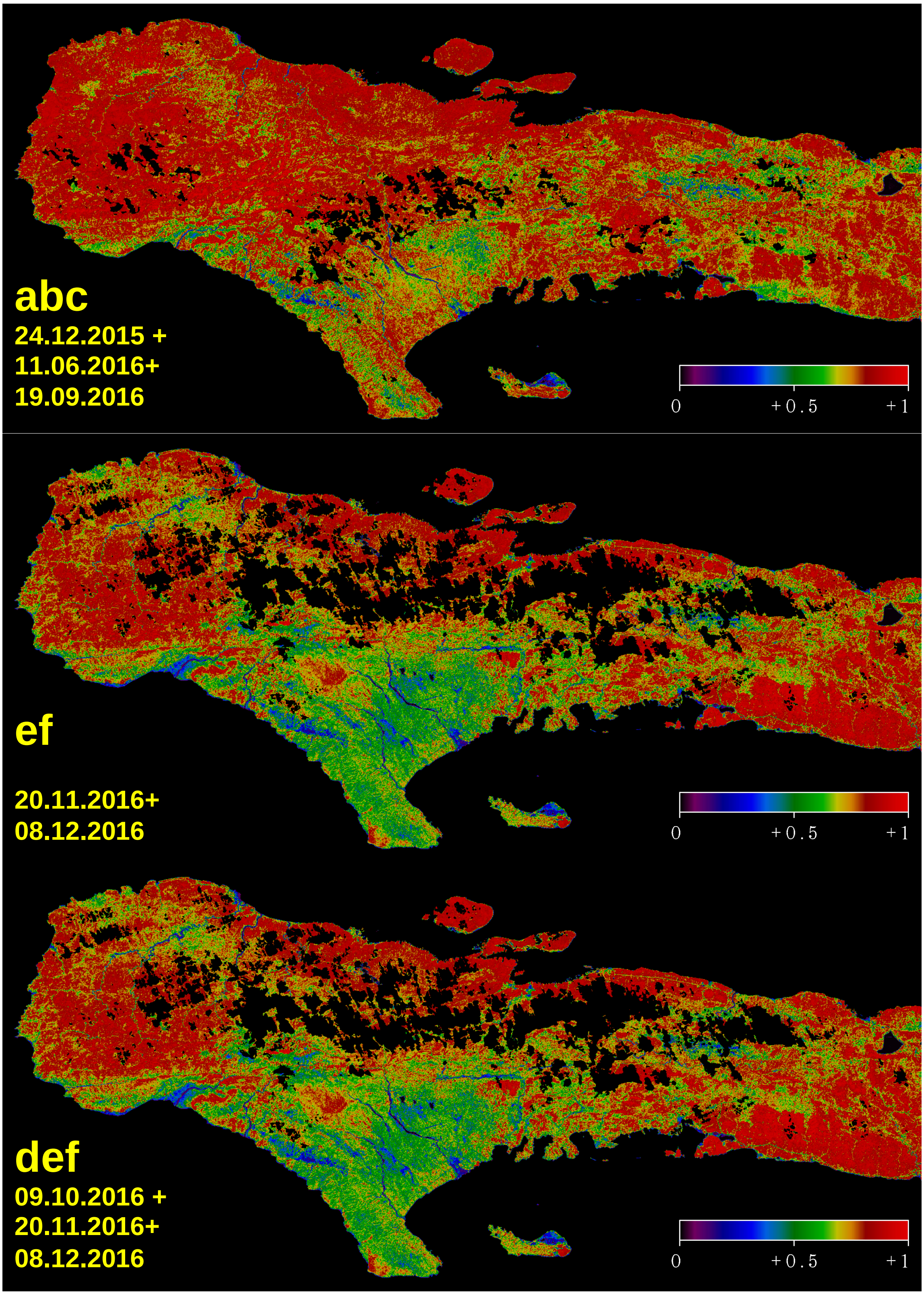


fig. 86 - Synthesis NDVI.

8.8.1 NDII (Normalised Difference Infrared Index)

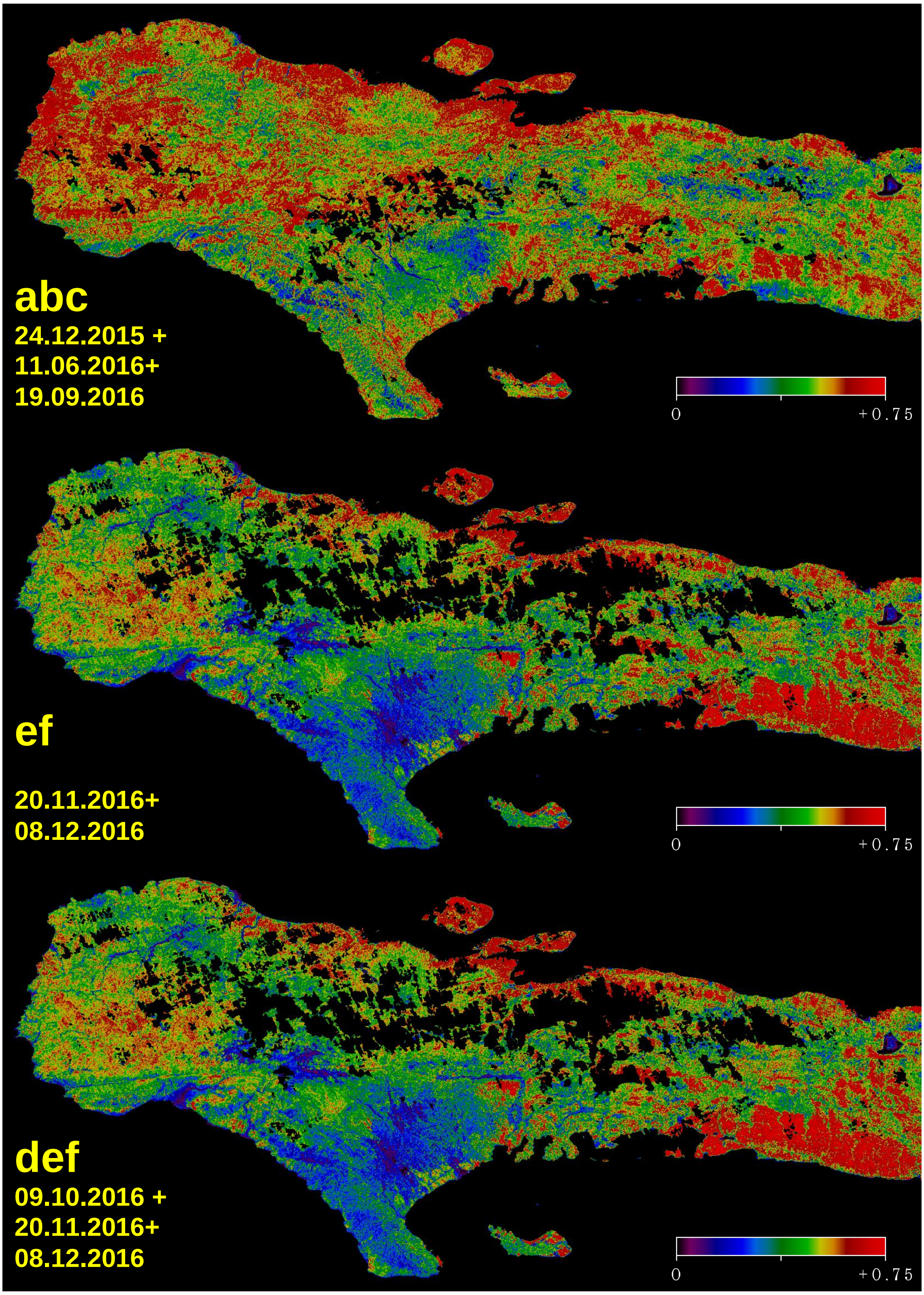


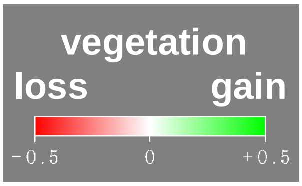
fig. 87 - Synthesis NDII.

8.9 DELIVERY12 - Difference of NDVI (or NDII) synthesis

Synthesis (see section 8.7) in input have been processed from “cloud-free” input scenes (see section 8.5) using two normalised difference indices:

- **NDVI** - Normalised Difference Vegetation Index images computed from the near infrared (band 8 of Sentinel-2/MSI centred on 842 nm) and the red (band 4 centred on 665 nm).
  NDVI data have been stretched in the range [0,1] and are shown with a rainbow LUT.
- **NDII** - Normalised Difference Infrared Index images computed from the near infrared (band 8 centred on 842 nm) and the short wave infrared (band 12 centred on 2190 nm).
  NDII data have been stretched in the range [0,0.75] and are shown with a rainbow LUT.

Next figures (fig. 88 and fig. 89) give a synaptic view of the results obtained computing the difference between the NDVI (or the NDII respectively) of the products (synthesis “abc”, “def” or “ef”) or a single scene like “d” (observation of 09.10.2016). One may note the general “**vegetation loss**” shown in red colour towards possible “**vegetation recovery**” shown in green. Note that the NDI differences are unit-less and take values in the range [-0.5,+0.5], negative values matching “vegetation gain” and positive values matching a “vegetation gain” across the time.



8.9.1 File name syntax

SS_ZONE.msk2.diff-DDD-SSS.ndXi[.sca-01].FFF

Examples:

- **s2_south.msk2.diff-d-abc.ndvi.tif** - for the difference between the single destination scene “d” (acquisition of 09.10.2016) and the pre-event synthesis “abc” of the “normalised difference vegetation index” (NDVI) of the Sentinel-2 over the South zone (Tiburon Peninsula), resampled with a 1/10 factor (GSD, i.e. “Ground Sampling Distance”, of 100 metres) and exported in GeoTIFF format.
- **s2_south.msk2.diff-ef-d.ndii.kmz** - for the difference between the synthesis “ef” of the last two the post-event acquisitions and the single scene “d” of the “normalised difference infrared index” (NDII) of the Sentinel-2 over the South zone with its nominal spatial resolution (GSD of 10 metres) and exported in KMZ (KML zipped) format.

8.9.2 Delivery file list

Name	Size (KB)	Type	Files	Percent
\\FABIO\fabio_3\P275_UNEP_HAITI\DELIVERY12_NDVI_...	1 536 531	Folder	60	
s2_south.msk2.diff-d-abc.ndii.kmz	20 739	KMZ		
s2_south.msk2.diff-d-abc.ndii.sca-01.kmz	264	KMZ		
s2_south.msk2.diff-d-abc.ndii.sca-01.tfw	0	Fichier TFW		
s2_south.msk2.diff-d-abc.ndii.sca-01.tif	1 246	Fichier TIF		
s2_south.msk2.diff-d-abc.ndii.tfw	0	Fichier TFW		
s2_south.msk2.diff-d-abc.ndii.tif	123 878	Fichier TIF		
s2_south.msk2.diff-d-abc.ndvi.kmz	22 359	KMZ		
s2_south.msk2.diff-d-abc.ndvi.sca-01.kmz	259	KMZ		
s2_south.msk2.diff-d-abc.ndvi.sca-01.tfw	0	Fichier TFW		
s2_south.msk2.diff-d-abc.ndvi.sca-01.tif	1 246	Fichier TIF		
s2_south.msk2.diff-d-abc.ndvi.tfw	0	Fichier TFW		
s2_south.msk2.diff-d-abc.ndvi.tif	123 878	Fichier TIF		
s2_south.msk2.diff-d-c.ndii.kmz	14 841	KMZ		
s2_south.msk2.diff-d-c.ndii.sca-01.kmz	187	KMZ		
s2_south.msk2.diff-d-c.ndii.sca-01.tfw	0	Fichier TFW		
s2_south.msk2.diff-d-c.ndii.sca-01.tif	1 246	Fichier TIF		
s2_south.msk2.diff-d-c.ndii.tfw	0	Fichier TFW		
s2_south.msk2.diff-d-c.ndii.tif	123 878	Fichier TIF		
s2_south.msk2.diff-d-c.ndvi.kmz	15 839	KMZ		
s2_south.msk2.diff-d-c.ndvi.sca-01.kmz	183	KMZ		
s2_south.msk2.diff-d-c.ndvi.sca-01.tfw	0	Fichier TFW		
s2_south.msk2.diff-d-c.ndvi.sca-01.tif	1 246	Fichier TIF		
s2_south.msk2.diff-d-c.ndvi.tfw	0	Fichier TFW		
s2_south.msk2.diff-d-c.ndvi.tif	123 878	Fichier TIF		
s2_south.msk2.diff-def-abc.ndii.kmz	42 642	KMZ		
s2_south.msk2.diff-def-abc.ndii.sca-01.kmz	457	KMZ		
s2_south.msk2.diff-def-abc.ndii.sca-01.tfw	0	Fichier TFW		
s2_south.msk2.diff-def-abc.ndii.sca-01.tif	1 246	Fichier TIF		
s2_south.msk2.diff-def-abc.ndii.tfw	0	Fichier TFW		
s2_south.msk2.diff-def-abc.ndii.tif	123 878	Fichier TIF		
s2_south.msk2.diff-def-abc.ndvi.kmz	40 220	KMZ		
s2_south.msk2.diff-def-abc.ndvi.sca-01.kmz	423	KMZ		
s2_south.msk2.diff-def-abc.ndvi.sca-01.tfw	0	Fichier TFW		
s2_south.msk2.diff-def-abc.ndvi.sca-01.tif	1 246	Fichier TIF		
s2_south.msk2.diff-def-abc.ndvi.tfw	0	Fichier TFW		
s2_south.msk2.diff-def-abc.ndvi.tif	123 878	Fichier TIF		
s2_south.msk2.diff-ef-abc.ndii.kmz	42 642	KMZ		
s2_south.msk2.diff-ef-abc.ndii.sca-01.kmz	457	KMZ		
s2_south.msk2.diff-ef-abc.ndii.sca-01.tfw	0	Fichier TFW		
s2_south.msk2.diff-ef-abc.ndii.sca-01.tif	1 246	Fichier TIF		
s2_south.msk2.diff-ef-abc.ndii.tfw	0	Fichier TFW		
s2_south.msk2.diff-ef-abc.ndii.tif	123 878	Fichier TIF		
s2_south.msk2.diff-ef-abc.ndvi.kmz	40 220	KMZ		
s2_south.msk2.diff-ef-abc.ndvi.sca-01.kmz	423	KMZ		
s2_south.msk2.diff-ef-abc.ndvi.sca-01.tfw	0	Fichier TFW		
s2_south.msk2.diff-ef-abc.ndvi.sca-01.tif	1 246	Fichier TIF		
s2_south.msk2.diff-ef-abc.ndvi.tfw	0	Fichier TFW		
s2_south.msk2.diff-ef-abc.ndvi.tif	123 878	Fichier TIF		
s2_south.msk2.diff-ef-d.ndii.kmz	21 526	KMZ		
s2_south.msk2.diff-ef-d.ndii.sca-01.kmz	248	KMZ		
s2_south.msk2.diff-ef-d.ndii.sca-01.tfw	0	Fichier TFW		
s2_south.msk2.diff-ef-d.ndii.sca-01.tif	1 246	Fichier TIF		
s2_south.msk2.diff-ef-d.ndii.tfw	0	Fichier TFW		
s2_south.msk2.diff-ef-d.ndii.tif	123 878	Fichier TIF		
s2_south.msk2.diff-ef-d.ndvi.kmz	21 133	KMZ		
s2_south.msk2.diff-ef-d.ndvi.sca-01.kmz	234	KMZ		
s2_south.msk2.diff-ef-d.ndvi.sca-01.tfw	0	Fichier TFW		
s2_south.msk2.diff-ef-d.ndvi.sca-01.tif	1 246	Fichier TIF		
s2_south.msk2.diff-ef-d.ndvi.tfw	0	Fichier TFW		
s2_south.msk2.diff-ef-d.ndvi.tif	123 878	Fichier TIF		

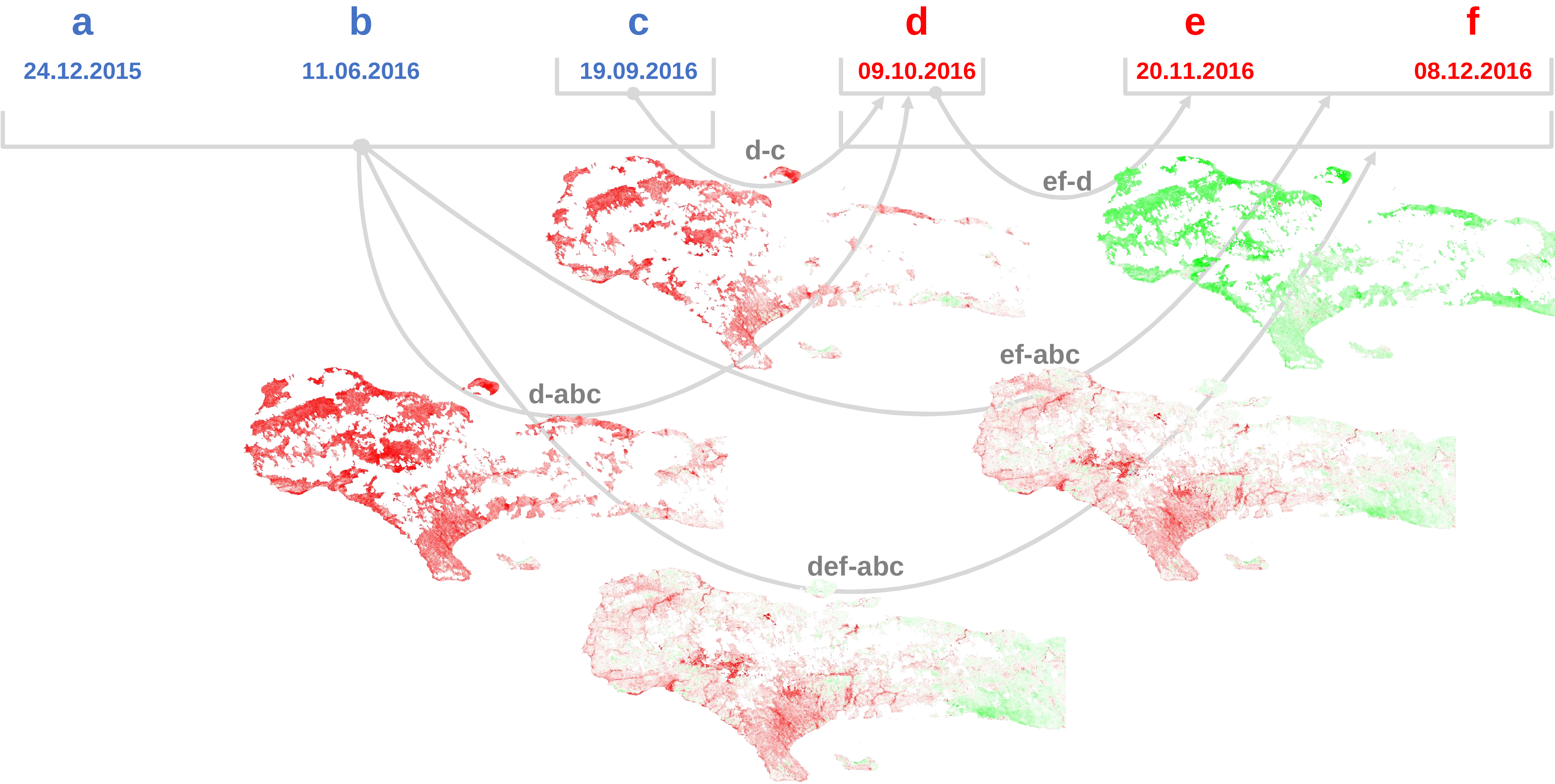


fig. 88 - Synoptic view - NDVI.

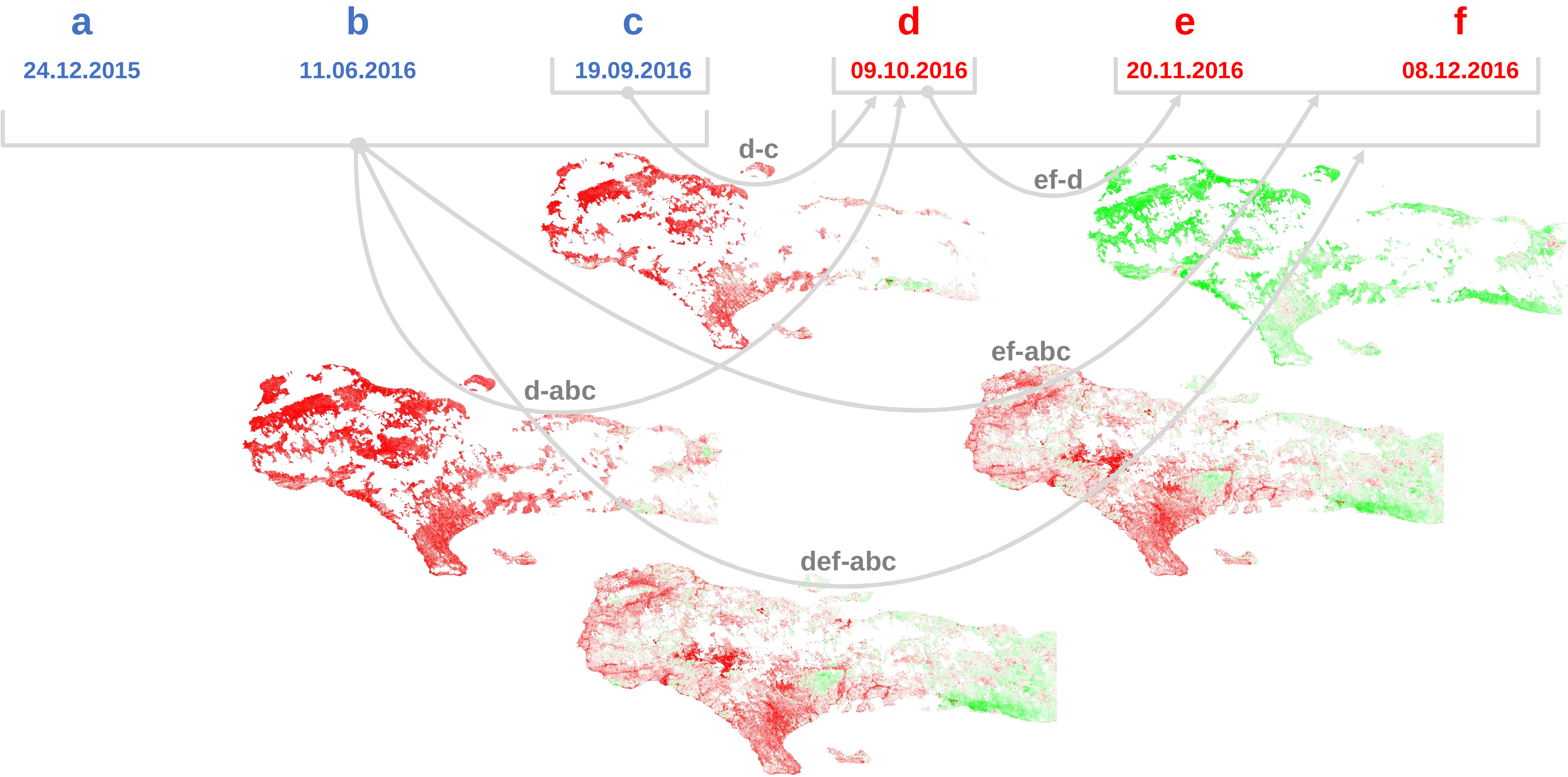


fig. 89 - Synoptic view - NDII.

8.9.3 NDVI (Normalised Difference Vegetation Index)

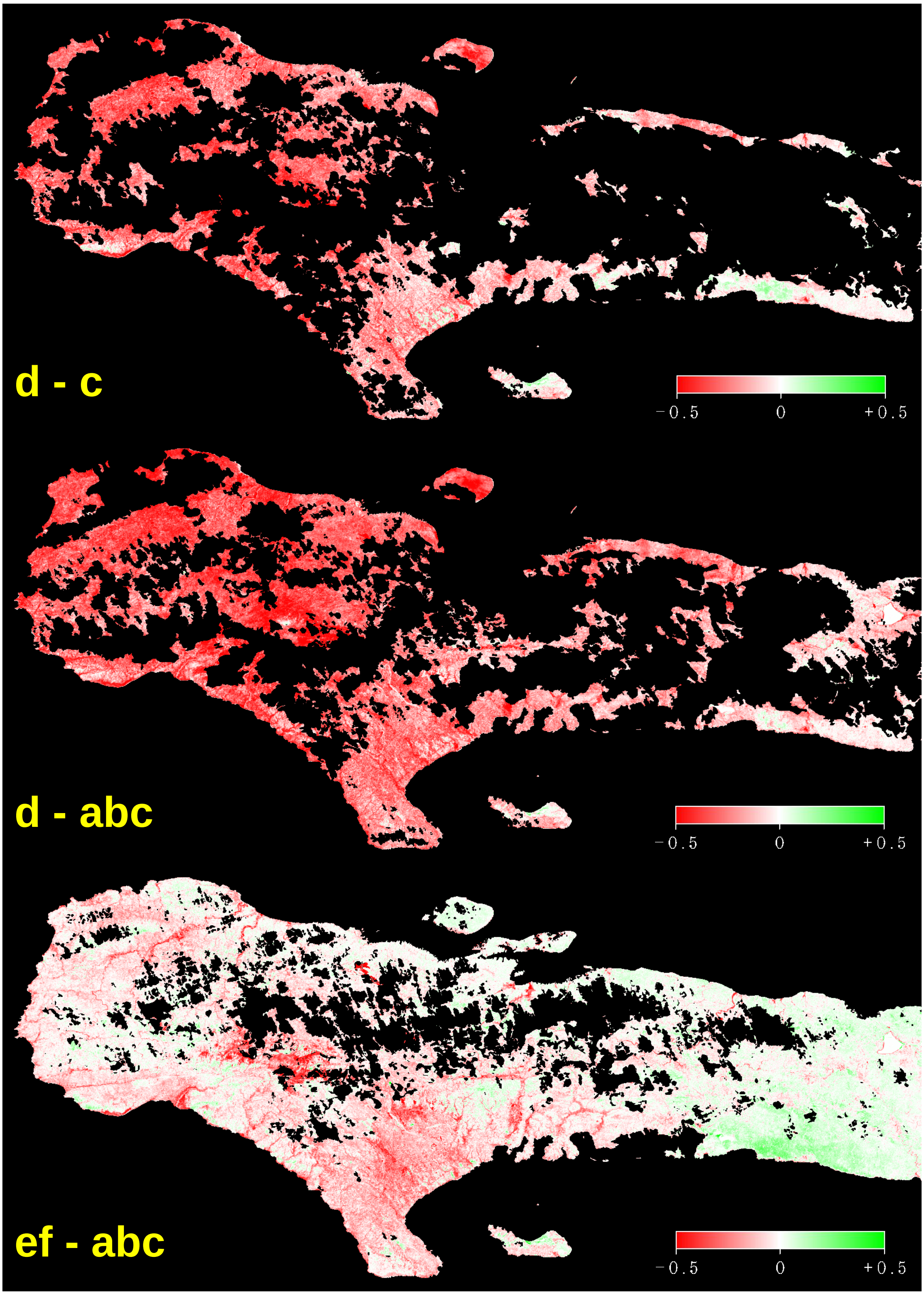


fig. 90 - Difference between NDVI of synthesis (1).

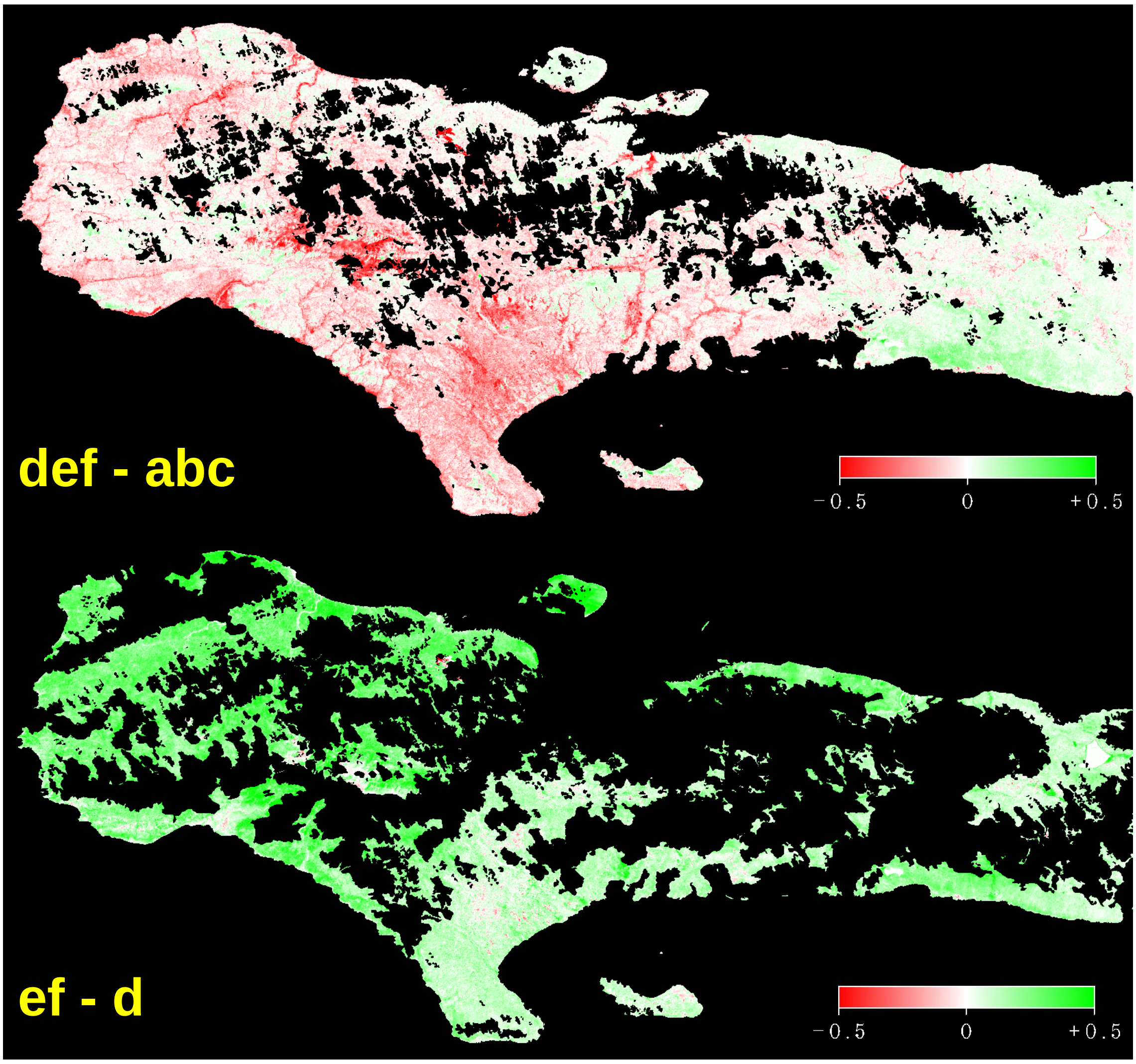


fig. 91 - Difference between NDVI of synthesis (2).

8.9.4 NDII (Normalised Difference Infrared Index)

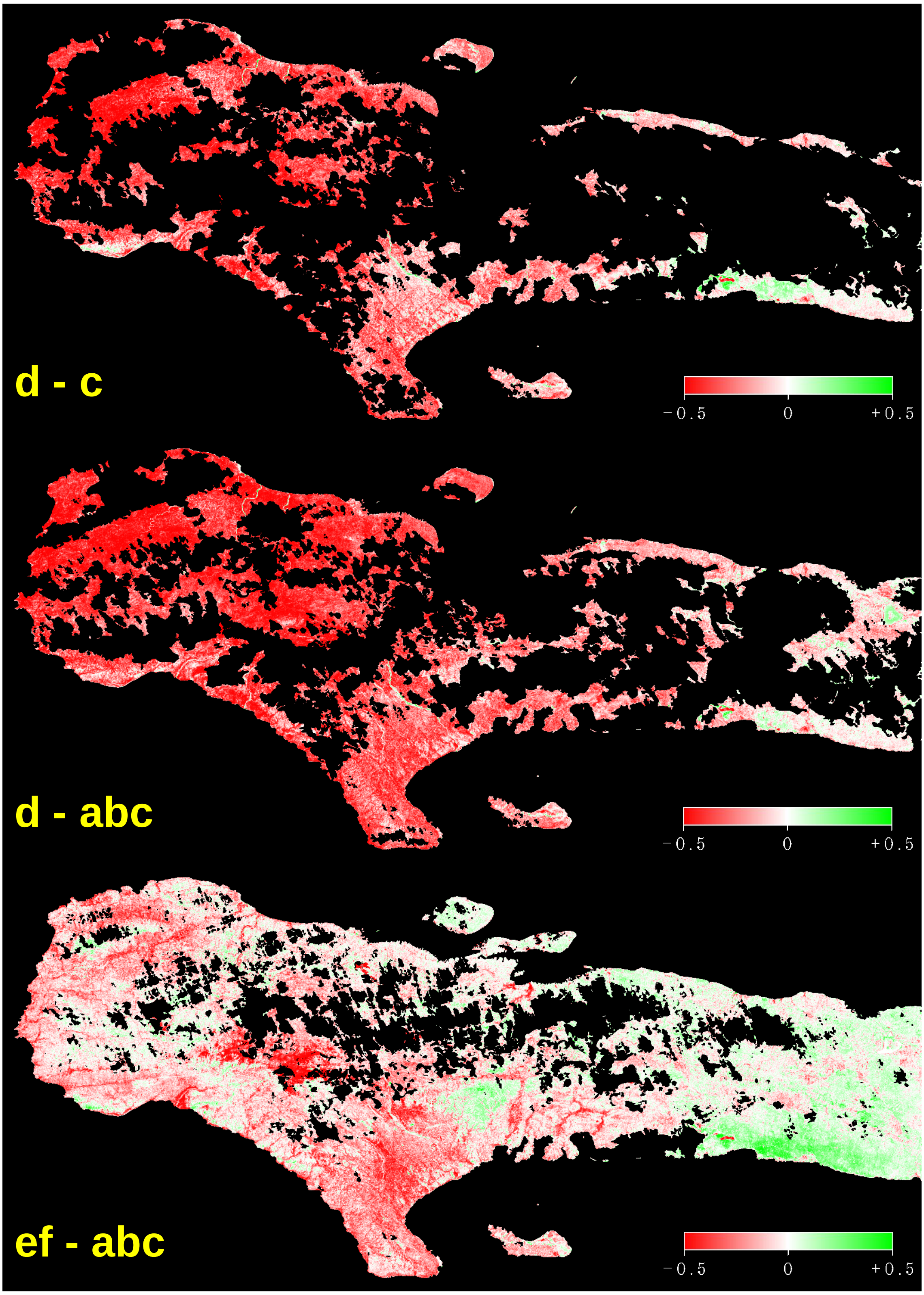


fig. 92 - Difference between NDII of synthesis (1).

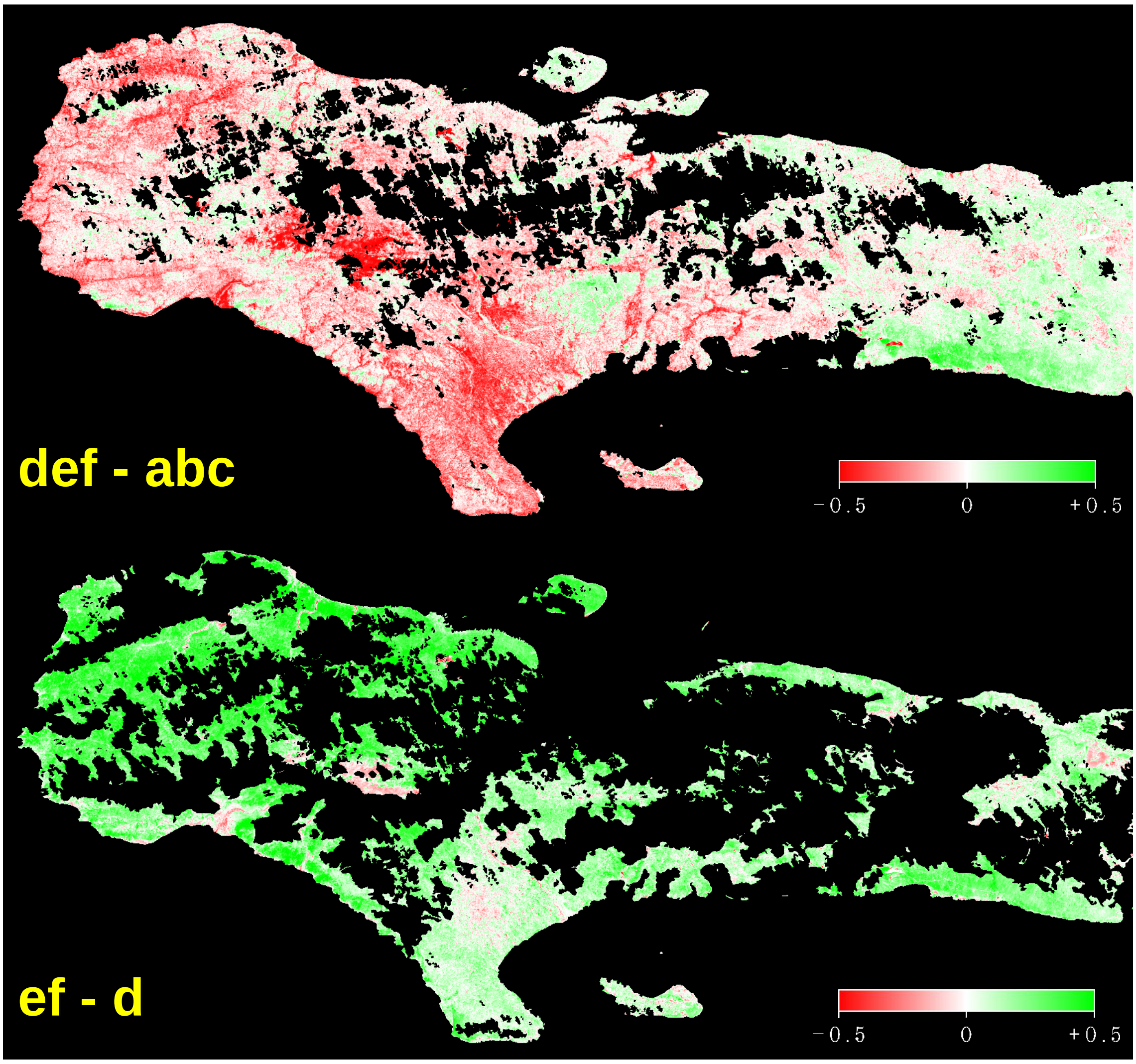


fig. 93 - Difference between NDII of synthesis (2).

8.10 DELIVERY13 - Statistical analysis of NDI differences

8.10.1 Objectives

Objectives of this delivery are manifolds:

- **Damages per classes -** to assess the loss / gain of vegetation according to the LULC (Land-Use / Land-Cover) classes.
- **Damages per zones -** to assess the loss / gain of vegetation in the 5 departments, the Macaya Park and over the whole Tiburon Peninsula.
- **NDVI v.s. NDII -** to assess the performances of the NDVI (Normalised Difference Vegetation Index) that has been computed as (B8-B4)/(B8+B4) with regard to the NDII (Normalised Difference Infrared Index) that has been computed as (B8-B12)/(B8+B12).

8.10.2 Description of zones (5 departments and Macaya Park)

As shown in fig. 94, statistics are computed for 7 zones: -the overall project area, -the 5 departments intersecting the Tiburon Peninsula and the -Macaya Park.

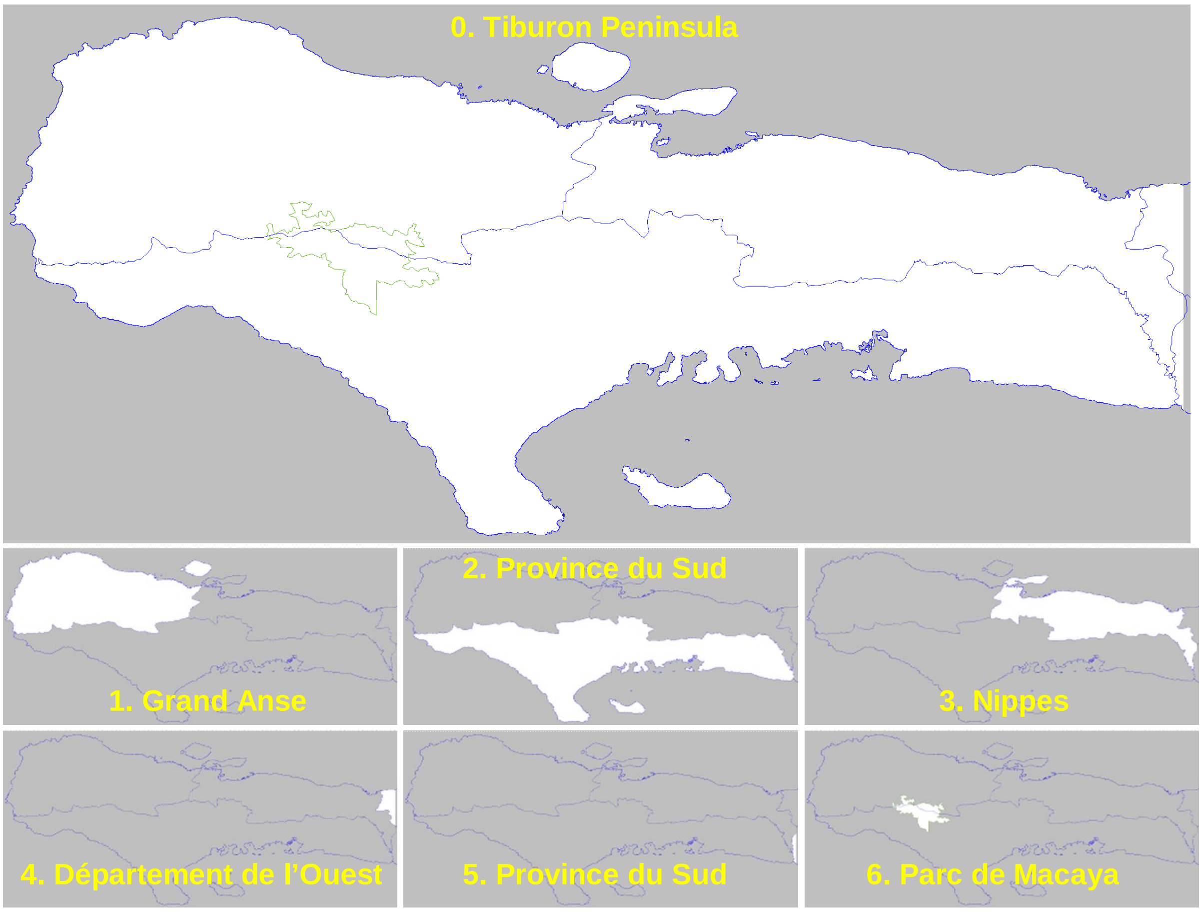


fig. 94 - Zones considered for statistics.

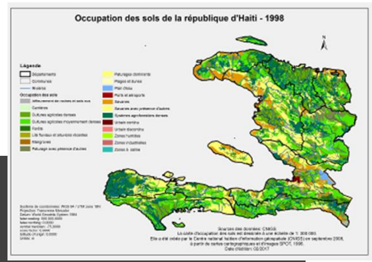
Table below gives the superficies (in pixels and hectares) of each zone. The sum of these areas matches the total area of the overall project.

Note that, because the ground sampling distance of the Sentinel-2 data is exactly 10mx10m, the area in hectares is simply given dividing the number of pixels by 100.

Z1	Grand Anse	19 505 130	195 051	32,22%
Z2	Province du Sud	27 502 599	275 026	45,42%
Z3	Nippes	12 729 375	127 294	21,02%
Z4	Département de l'Ouest	659 548	6 595	1,09%
Z5	Province du Sud-Est	148 887	1 489	0,25%
Z6	Parc de Macaya	1 390 168	13 902	2,30%
	TOTAL of the 5 departments	**60 545 539**	**605 455**	100,00%

table 3 - Zones used to compute statistics.

8.10.3 Description of classes (LU/LC 1998 and Mangroves 2015)



The only LU/LC map that has been found covering the whole project area has been produced by the CNIGS from SPOT images acquired on 1998 (R-2).

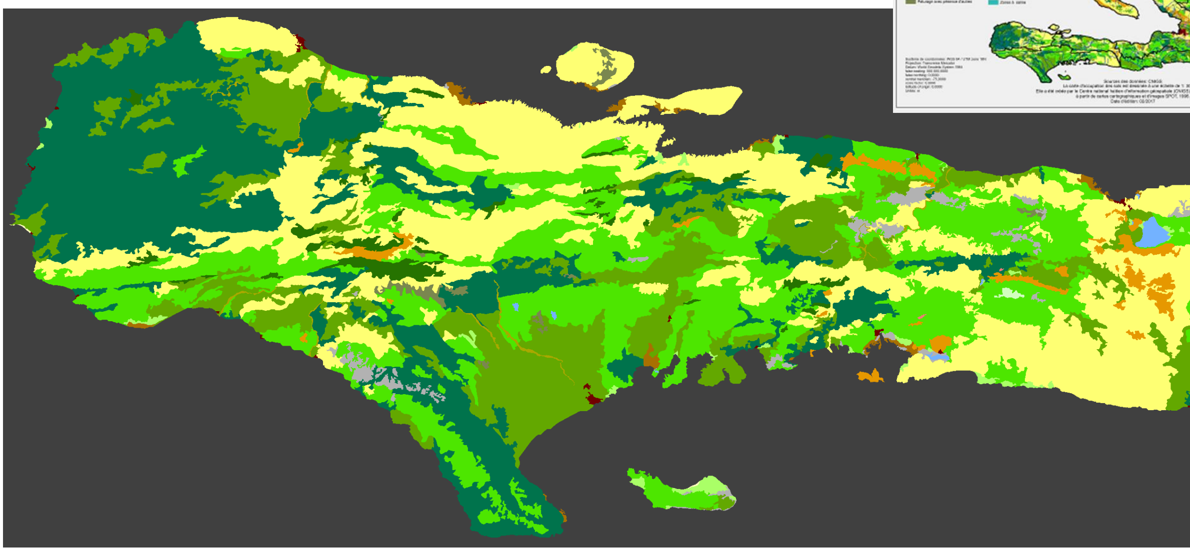


fig. 95 - LU/LC classes 1998.

UNEP has also provided with a layer of “Mangroves” produced on 2015. As shown below, this layer contains subtle details. VisioTerra has converted single path in thin corridors.

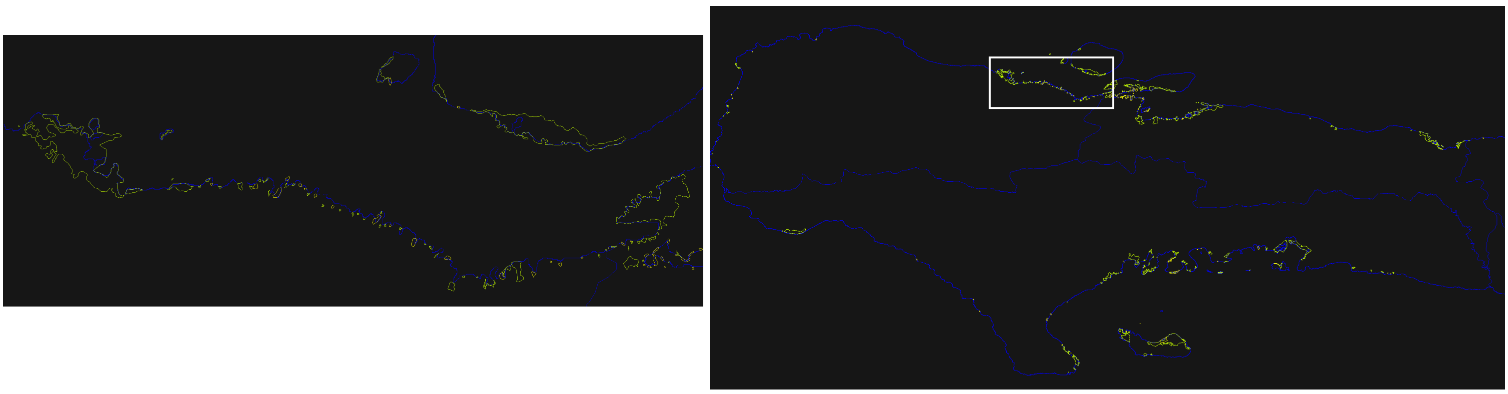


fig. 96 - “Mangroves layer produced on 2015.

ID	Class name	total in pixels	total in ha	% of TOTAL
C11	Urbain continu	86 680	867	0,14%
C12	Urbain discontinu	5 027	50	0,01%
C13	Zones industrielles	0	0	0,00%
C14	Ports et aéroports	0	0	0,00%
C21	Cultures agricoles denses	10 516 997	105 170	17,40%
C22	Systèmes agroforestiers denses	14 240 610	142 406	23,56%
C23	Cultures agricoles moyennement denses	14 525 526	145 255	24,03%
C31	Paturages dominants	41 611	416	0,07%
C32	Paturage avec présence d'autres	264 036	2 640	0,44%
C33	Savanes avec présence d'autres	16 950 507	169 505	28,04%
C41	Forêts	1 034 268	10 343	1,71%
C42	Savanes	965 129	9 651	1,60%
C43	Mangroves	281 414	2 814	0,47%
C51	Affleurement de roches et sols nus	747 503	7 475	1,24%
C52	Carrières	30 807	308	0,05%
C53	Plages et dunes	7 443	74	0,01%
C54	Zones à saline	0	0	0,00%
C55	Lits fluviaux et alluvions récentes	184 051	1 841	0,30%
C61	Plan d eau	153 655	1 537	0,25%
C62	Zones humides	412 581	4 126	0,68%
	TOTAL	**60 447 845**	**604 478**	**100,00%**
	Versus the whole image	47,68%		
Cxx	Classe "Agroforestry" (21+22+23+32+33)	56 497 676	564 977	93,47%
		pixels	area (ha)	% of total
File "Mangroves_NB.kmz" provided by Niloufar BAYANI on 23.02.2017				
C00	Mangroves in ""Mangroves_NB_SR"	560 107	5 601	0,93%

table 4 - Classes used to compute statistics.

UNEP has contemplated the possibility to build a “Agroforestry” class that would include the five classes (21+22+23+32+33) shown in the table above. Such a class would represent more than 93% of the total immerged areas and would slightly differ from the whole study area.

The statistics have been computed for each class of each zone enabling UNEP to investigate more in depth.

8.10.4 Description of the EXCEL file contents

Results are given in the MS EXCEL file “**VT-P275-TAB-001-E-01-00_Statistical_results.xls**”. This file contains the following folders:

- **Global -** showing the area of the zones (see table 3) and of the classes (see table 4).
- **Analysis -** illustrating the difference of NDVI or NDII indices according to the 5 differences, the 7 zones and the 20 classes. These figures are also arranged in a different way in the three pages below (see fig. 98 and fig. 99).

- **NDVI DDD-SSS -** providing with the numerical results of the difference of NDVI images between the destination DDD and the source SSS images. Contents of the folder is explained in table 5 below.
- **NDII DDD-SSS -** is like the “NDVI DDD-SSS” folders but for the infrared index.
- **NDVI-NDII DDD-SSS -** computes the difference between the two indices (vegetation towards infrared). These data are commented in section 8.10.5.4 here after.

Table below (table 5) is the an extract of the data located at the beginning of the “NDVI c-d” folder. The entire folder is separated in 7 sections separated by a coloured line showing the statistics for the -whole study area (no zone identifier), -the 5 departments (zones 1 to 5), and -the Macaya Park (zone 6).

The orange line matches the statistics for all the classes of the whole study area. As explained in section 8.10.5.2, the percentage (here 29.78%) is relative to the immerged surfaces of the whole study area and shows the percentage of the pixels actually processed.

Clipping the NDVI (or NDII) difference image with the mask matching the zone (whole study area, department or Macaya Park), the scalar values (unitless) of the difference are analysed computing the occurrence N, the mean (sum of pixel values divided by N) and the standard deviation (square root of the square difference to mean). Mean gives the trends while the standard deviation provides with the dispersion of pixel values.

NDVI - d-c

NDI	Difference	Zone	Class	Occurrence	Mean	St. Dev,
NDVI	**d-c**		**29,78%**	**18029593**	**-0,195**	**0,166**
NDVI	d-c		0	329465	-0,078	0,169
NDVI	d-c		11	61870	-0,127	0,159
NDVI	d-c		12			
NDVI	d-c		13			
NDVI	d-c		14			
NDVI	d-c		21	4382612	-0,186	0,166
NDVI	d-c		22	4575621	-0,259	0,148
NDVI	d-c		23	3456351	-0,166	0,167
NDVI	d-c		31	1104	-0,217	0,103
NDVI	d-c		32	75835	-0,237	0,168
NDVI	d-c		33	4273626	-0,182	0,159
NDVI	d-c		41	120616	-0,224	0,145
NDVI	d-c		42	163533	-0,158	0,179
NDVI	d-c		43	166603	-0,139	0,171
NDVI	d-c		51	181101	-0,078	0,15
NDVI	d-c		52			
NDVI	d-c		53	4626	-0,114	0,26
NDVI	d-c		55	112450	-0,173	0,178
NDVI	d-c		62	295786	-0,079	0,182
NDVI	d-c	1		7238228	-0,272	0,133
NDVI	d-c	1	0	46887	-0,131	0,142
NDVI	d-c	1	11	26772	-0,15	0,159
NDVI	d-c	1	12			
NDVI	d-c	1	13	...		

table 5 - Extract of the statistical results.

8.10.5 Photo-interpretation

8.10.5.1 "First assessment" and "Mid-term assessment"

Just after an event, one may compare the recent observation "d" with the image "c" observed just before the event or a compilation "abc" of observations before the event.

These "d-c" or "d-abc" differences are called "*first assessment*" because they may take place few days after the event.

To decrease the number of cloudy pixels but also to increase the statistical robustness, one may compute the synthesis of post-event acquisitions.

These "def-abc", "ef-abc" or "ef-d" are called "*mid-term assessment*" because they require to wait for the observation during the successive months.

Note that the "*Mid-term assessment*" but also a "*Long-term assessment*" may be required to compute the vegetation recovery between post-event scenes or synthesis.

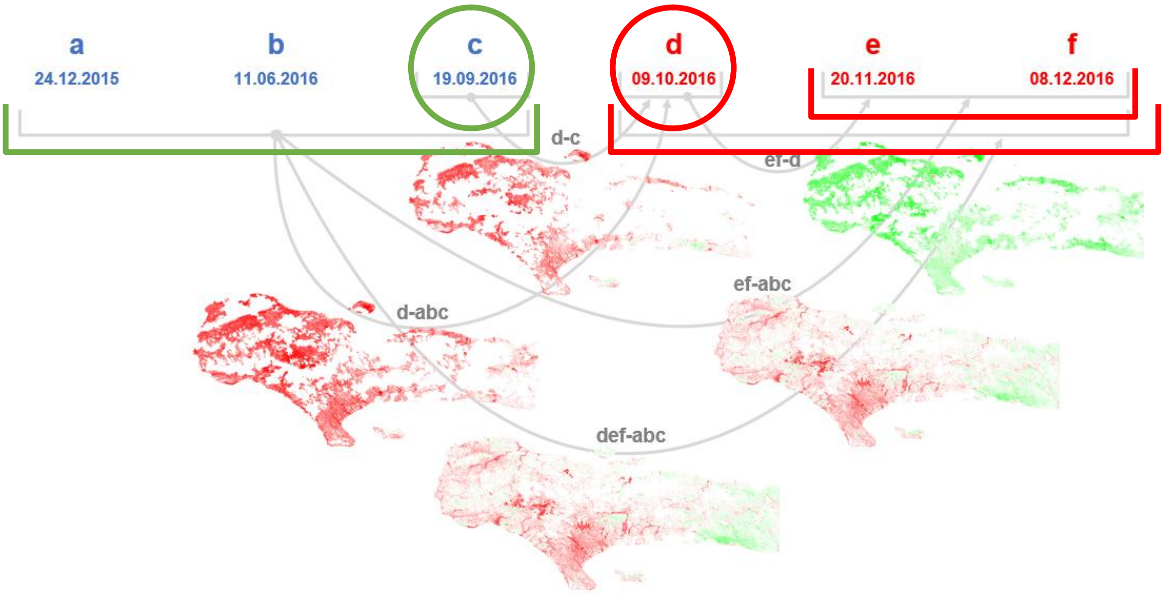


fig. 97 - "First assessment" and "Mid-term assessment".

8.10.5.2 Percentage of terrain actually analysed

The number of pixels actually processed guarantees the reliability of the statistical results. The higher is this number, the higher will be this reliability. For each image of the difference DDD-SSS between the destination image DDD and the source image SSS, this number of pixels is the intersection of cloud-free pixels in the source image and the number of cloud-free pixels in the destination image.

For each one of the 5 differences, the table below shows the number of 10mx10m pixels actually processed. The percentage of the processed area is computed towards the total number of 10mx10m pixels of the whole study area (**60 545 539 pixels** i.e. 605 455 ha).

d-c	ef-abc	ef-d	d-abc	def-abc
18 029 593	47 764 353	24 388 053	26 579 833	47 764 353
29.78%	**78.89%**	**40.28%**	**43.90%**	**78.89%**

table 6 - Percentage od pixels actually processed in each NDI difference image.

For a "*first assessment*", the immediate "c-d" difference has the lowest score while syntheses produced during a "*mid-term assessment*" show the highest score. It is effectively the scope of the multi-date synthesis to remove cloudy pixels.

8.10.5.3 Analysis of the "all classes" statistics

Global analysis

The "*first assessment*" differences ("d-c" and "d-abc") show the highest values of the mean (-0.195 and -0.248 respectively). This **19.5% vegetation index loss** is the most important result because it avoids the season impact. Indeed, the "abc" synthesis contains data observed in September, June and September. Using the "maximum NDVI" algorithm for synthesis favours the observation made in June. The difference of 5.3% (= -0.248 - -0.195) is essentially due to the seasonal variations of the vegetation coverage between June and October.

Regional analysis

NDVI															
Zone	d-c			ef-abc			ef-d			d-abc			def-abc		
whole	**18029593**	**-0,195**	**0,166**	**47764353**	**-0,046**	**0,132**	**24388053**	**0,188**	**0,145**	**26579833**	**-0,248**	**0,157**	**47764353**	**-0,046**	**0,132**
1	7238228	-0,272	0,133	14046366	-0,051	0,117	8266848	0,271	0,123	10035145	-0,323	0,123	14046366	-0,051	0,117
2	9470869	-0,148	0,169	24521893	-0,059	0,147	13114240	0,144	0,139	12884786	-0,214	0,161	24521893	-0,059	0,147
3	1282050	-0,111	0,133	8394163	-0,003	0,102	2654200	0,162	0,124	3308350	-0,166	0,137	8394163	-0,003	0,102
4	34195	-0,101	0,118	652586	0,017	0,098	342311	0,098	0,12	341098	-0,088	0,127	652586	0,017	0,098
5	3912	-0,064	0,071	148887	0	0,105	10109	0,069	0,075	10109	-0,056	0,088	148887	0	0,105
6	117034	-0,366	0,113	1052792	-0,189	0,184	585481	0,184	0,18	686914	-0,37	0,122	1052792	-0,189	0,184

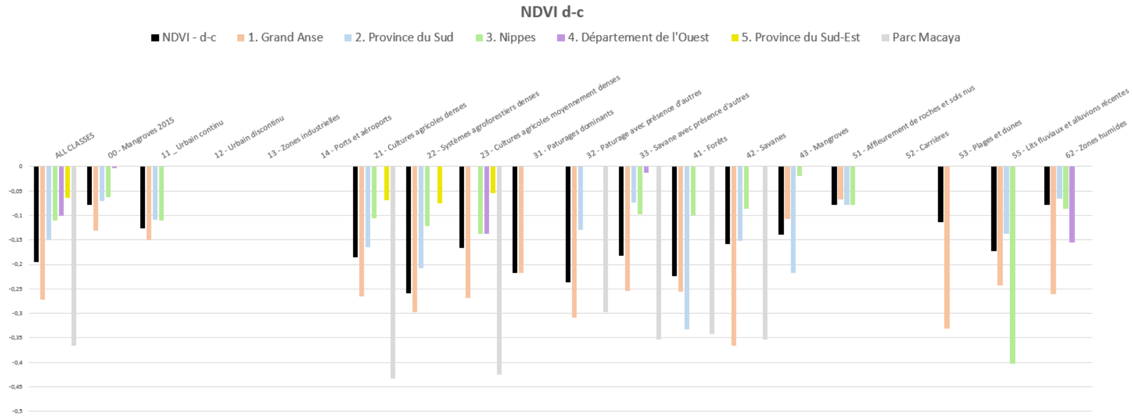
table 7 - NDVI difference "All classes" statistics per zones.

NDII															
Zone	d-c			ef-abc			ef-d			d-abc			def-abc		
whole	**18029593**	**-0,181**	**0,199**	**47764353**	**-0,052**	**0,187**	**24388053**	**0,149**	**0,183**	**26579833**	**-0,209**	**0,19**	**47764353**	**-0,052**	**0,187**
1	7238228	-0,258	0,155	14046366	-0,072	0,174	8266848	0,235	0,158	10035145	-0,289	0,134	14046366	-0,072	0,174
2	9470869	-0,137	0,2	24521893	-0,062	0,201	13114240	0,110	0,17	12884786	-0,182	0,189	24521893	-0,062	0,201
3	1282050	-0,077	0,139	8394163	0,002	0,142	2654200	0,098	0,147	3308350	-0,098	0,155	8394163	0,002	0,142
4	34195	-0,032	0,126	652586	0,017	0,143	342311	0,022	0,166	341098	-0,007	0,162	652586	0,017	0,143
5	3912	0,014	0,101	148887	0,018	0,142	10109	0,000	0,112	10109	0,026	0,111	148887	0,018	0,142
-	117034	-0,310	0,114	1052792	-0,021	0,21	585481	0,064	0,222	686914	-0,307	0,126	1052792	-0,211	0,21

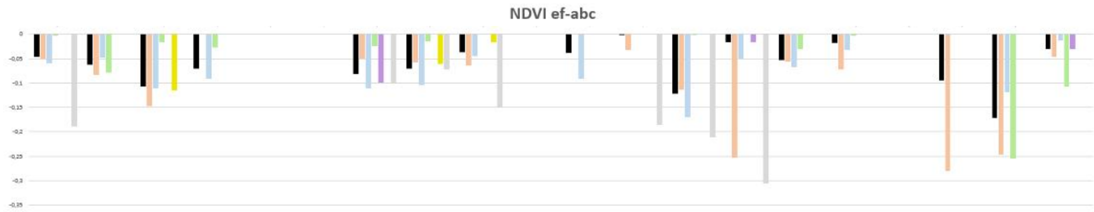
table 8 - NDII difference "All classes" statistics per zones.

8.10.5.4 Comparison between NDVI and NDII

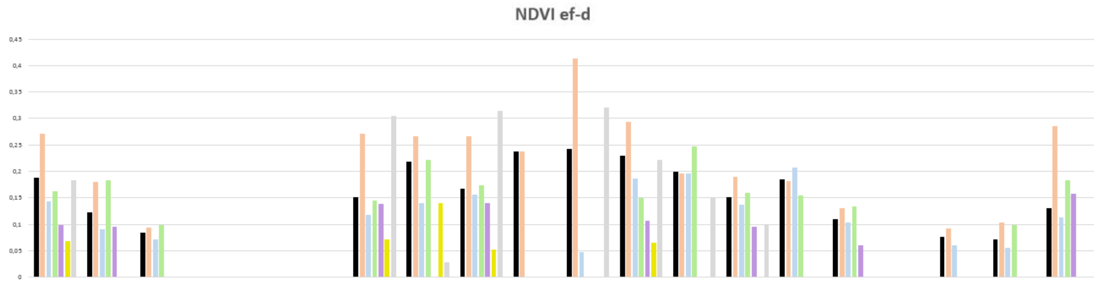
Class	Occurrence	Mean	St, Dev,
	18029593	**-0,195**	**0,166**
0	329465	-0,078	0,169
11	61870	-0,127	0,159
12			
13			
14			
21	4382612	-0,186	0,166
22	4575621	-0,259	0,148
23	3456351	-0,166	0,167
31	1104	-0,217	0,103
32	75835	-0,237	0,168
33	4273626	-0,182	0,159
41	120616	-0,224	0,145
42	163533	-0,158	0,179
43	166603	-0,139	0,171
51	181101	-0,078	0,15
52			
53	4626	-0,114	0,26
55	112450	-0,173	0,178
62	295786	-0,079	0,182



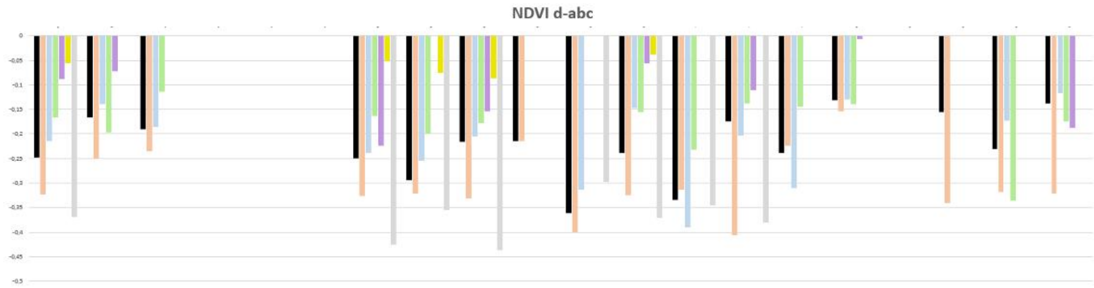
Class	Occurrence	Mean	St, Dev,
	47764353	**-0,046**	**0,132**
0	475382	-0,063	0,159
11	84723	-0,108	0,146
12	5027	-0,071	0,131
13			
14			
21	9146747	-0,082	0,144
22	11411019	-0,07	0,122
23	11316030	-0,037	0,127
31	27983	0,036	0,108
32	198610	-0,038	0,166
33	12362776	-0,002	0,114
41	592362	-0,121	0,181
42	870366	-0,017	0,139
43	257663	-0,053	0,147
51	568122	-0,018	0,114
52	30652	0,06	0,102
53	4626	-0,095	0,233
55	158027	-0,171	0,169
62	381820	-0,031	0,175



Class	Occurrence	Mean	St, Dev,
	24388053	**0,188**	**0,145**
0	336423	0,123	0,142
11	72158	0,084	0,109
12			
13			
14			
21	5340680	0,152	0,154
22	6669633	0,218	0,131
23	5034342	0,167	0,142
31	8791	0,238	0,085
32	82306	0,242	0,227
33	5117134	0,229	0,134
41	400370	0,2	0,181
42	473770	0,151	0,118
43	177240	0,185	0,138
51	277510	0,11	0,114
52			
53	4626	0,076	0,092
55	128798	0,071	0,117
62	322421	0,13	0,151



Class	Occurrence	Mean	St, Dev,
	26579833	**-0,248**	**0,157**
0	339137	-0,167	0,18
11	72158	-0,19	0,158
12			
13			
14			
21	5533348	-0,25	0,157
22	6919297	-0,294	0,137
23	5394044	-0,216	0,156
31	8802	-0,214	0,106
32	82635	-0,362	0,124
33	6390079	-0,239	0,159
41	451090	-0,335	0,135
42	483768	-0,174	0,146
43	178150	-0,239	0,162
51	318332	-0,132	0,134
52			
53	4626	-0,155	0,235
55	134962	-0,231	0,176
62	329734	-0,137	0,18



Class	Occurrence	Mean	St, Dev,
	47764353	**-0,046**	**0,132**
0	475382	-0,063	0,159
11	84723	-0,108	0,146
12	5027	-0,071	0,131
13			
14			
21	9146747	-0,082	0,144
22	11411019	-0,07	0,122
23	11316030	-0,037	0,127
31	27983	0,036	0,108
32	198610	-0,038	0,166
33	12362776	-0,002	0,114
41	592362	-0,121	0,181
42	870366	-0,017	0,139
43	257663	-0,053	0,147
51	568122	-0,018	0,114
52	30652	0,06	0,102
53	4626	-0,095	0,233
55	158027	-0,171	0,169
62	381820	-0,031	0,175

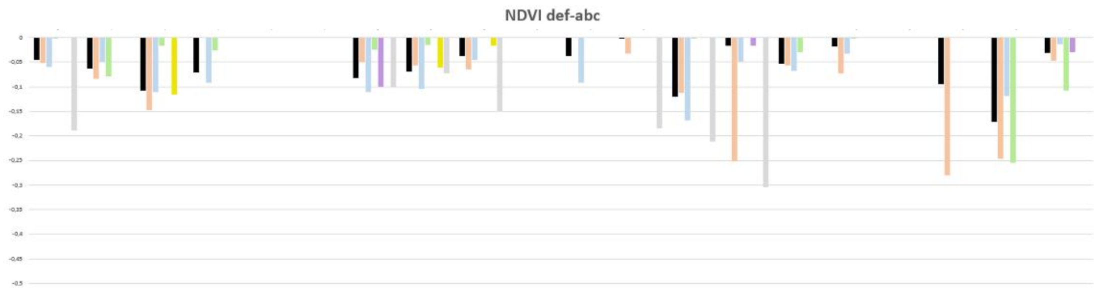
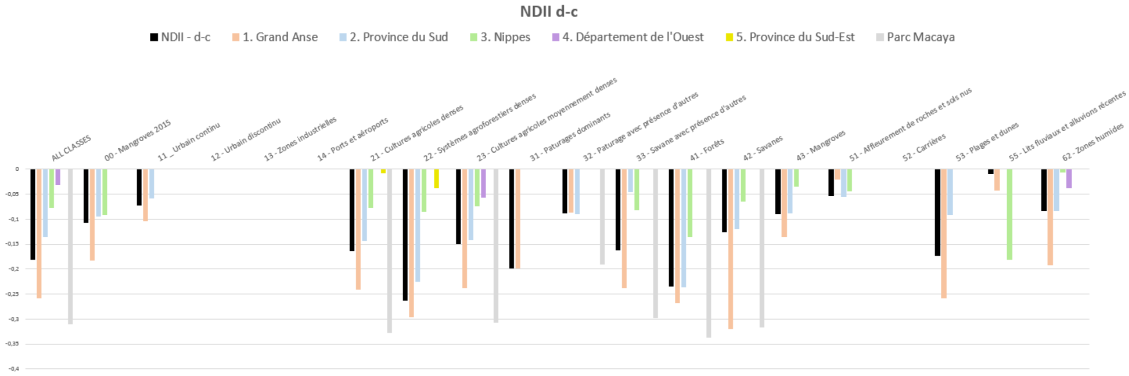
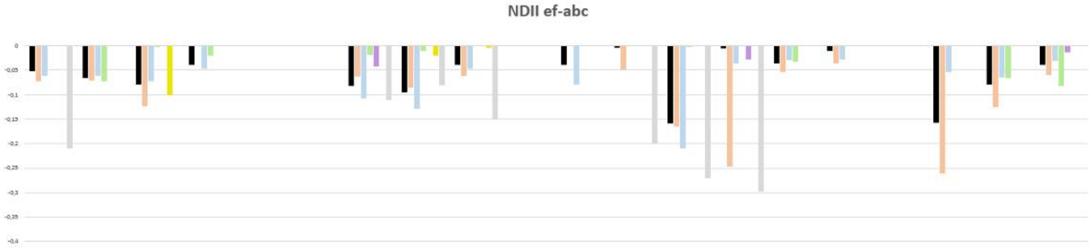


fig. 98 - NDVI synthesis differences.

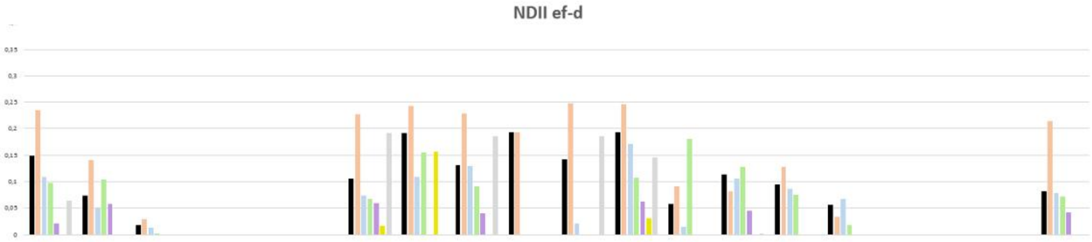
Class	Occurrence	Mean	0,75xMean	St, Dev,
	18029593	**-0,241**	**-0,18075**	**0,199**
0	329465	-0,143	-0,10725	0,175
11	61870	-0,098	-0,0735	0,176
12				
13				
14				
21	4382612	-0,218	-0,1635	0,188
22	4575621	-0,35	-0,2625	0,159
23	3456351	-0,199	-0,14925	0,193
31	1104	-0,266	-0,1995	0,149
32	75835	-0,118	-0,0885	0,179
33	4273626	-0,216	-0,162	0,199
41	120616	-0,313	-0,23475	0,148
42	163533	-0,169	-0,12675	0,228
43	166603	-0,121	-0,09075	0,181
51	181101	-0,071	-0,05325	0,203
52				
53	4626	-0,232	-0,174	0,202
55	112450	-0,012	-0,009	0,257
62	295786	-0,112	-0,084	0,208



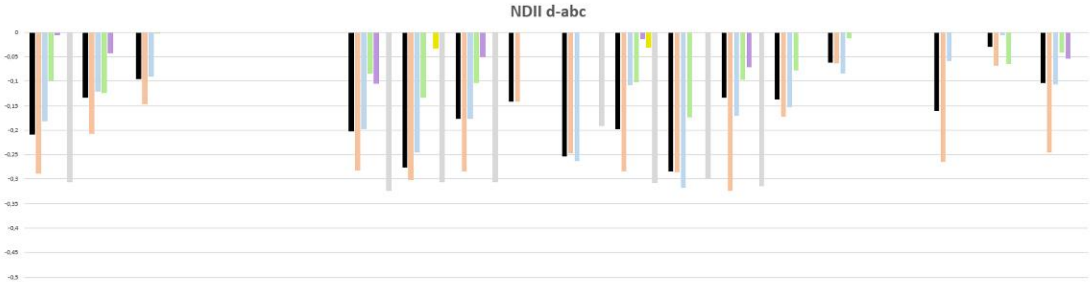
Class	Occurrence	Mean	0,75xMean	St, Dev,
	47764353	**-0,069**	**-0,05175**	**0,187**
0	475382	-0,088	-0,066	0,195
11	84723	-0,105	-0,07875	0,173
12	5027	-0,051	-0,03825	0,138
13				
14				
21	9146747	-0,109	-0,08175	0,19
22	11411019	-0,126	-0,0945	0,178
23	11316030	-0,051	-0,03825	0,174
31	27983	0,089	0,06675	0,14
32	198610	-0,051	-0,03825	0,201
33	12362776	-0,005	-0,00375	0,172
41	592362	-0,211	-0,15825	0,229
42	870366	-0,007	-0,00525	0,196
43	257663	-0,048	-0,036	0,188
51	568122	-0,013	-0,00975	0,155
52	30652	0,014	0,0105	0,125
53	4626	-0,209	-0,15675	0,246
55	158027	-0,105	-0,07875	0,217
62	381820	-0,052	-0,039	0,215



Class	Occurrence	Mean	0,75xMean	St, Dev,
	24388053	**0,199**	**0,14925**	**0,183**
0	336423	0,098	0,0735	0,178
11	72158	0,023	0,01725	0,118
12				
13				
14				
21	5340680	0,141	0,10575	0,184
22	6669633	0,255	0,19125	0,171
23	5034342	0,176	0,132	0,17
31	8791	0,259	0,19425	0,109
32	82306	0,19	0,1425	0,208
33	5117134	0,259	0,19425	0,159
41	400370	0,076	0,057	0,229
42	473770	0,151	0,11325	0,159
43	177240	0,127	0,09525	0,173
51	277510	0,075	0,05625	0,156
52				
53	4626	-0,006	-0,0045	0,12
55	128798	-0,07	-0,0525	0,197
62	322421	0,109	0,08175	0,192



Class	Occurrence	Mean	0,75xMean	St, Dev,
	26579833	**-0,279**	**-0,20925**	**0,19**
0	339137	-0,179	-0,13425	0,178
11	72158	-0,128	-0,096	0,184
12				
13				
14				
21	5533348	-0,271	-0,20325	0,182
22	6919297	-0,368	-0,276	0,147
23	5394044	-0,237	-0,17775	0,184
31	8802	-0,19	-0,1425	0,153
32	82635	-0,338	-0,2535	0,131
33	6390079	-0,263	-0,19725	0,195
41	451090	-0,378	-0,2835	0,143
42	483768	-0,178	-0,1335	0,176
43	178150	-0,182	-0,1365	0,174
51	318332	-0,083	-0,06225	0,182
52				
53	4626	-0,215	-0,16125	0,231
55	134962	-0,04	-0,03	0,26
62	329734	-0,137	-0,10275	0,208



Class	Occurrence	Mean	0,75xMean	St, Dev,
	47764353	**-0,069**	**-0,05175**	**0,187**
0	475382	-0,088	-0,066	0,195
11	84723	-0,105	-0,07875	0,173
12	5027	-0,051	-0,03825	0,138
13				
14				
21	9146747	-0,109	-0,08175	0,19
22	11411019	-0,126	-0,0945	0,178
23	11316030	-0,051	-0,03825	0,174
31	27983	0,089	0,06675	0,14
32	198610	-0,051	-0,03825	0,201
33	12362776	-0,005	-0,00375	0,172
41	592362	-0,211	-0,15825	0,229
42	870366	-0,007	-0,00525	0,196
43	257663	-0,048	-0,036	0,188
51	568122	-0,013	-0,00975	0,155
52	30652	0,014	0,0105	0,125
53	4626	-0,209	-0,15675	0,246
55	158027	-0,105	-0,07875	0,217
62	381820	-0,052	-0,039	0,215

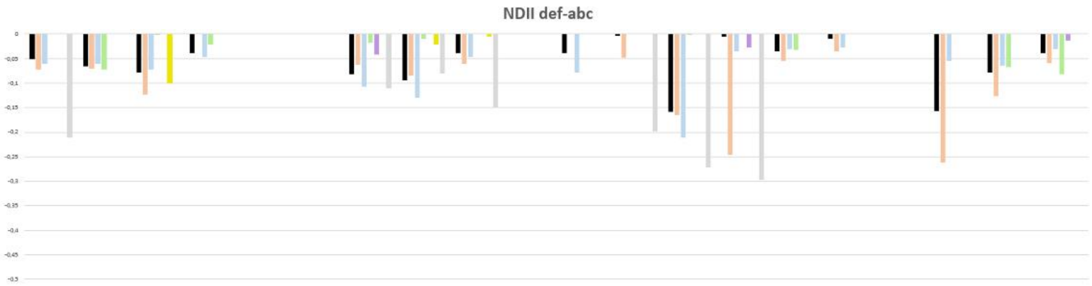


fig. 99 - NDII synthesis differences.

Class	Occurrence	NDVI mean	NDII mean	Mean diff.	relative varia
	1,8E+07	**-0,195**	**-0,1808**	**-0,0143**	**7,31%**
0	329465	-0,078	-0,10725	0,02925	37,50%
11	61870	-0,127	-0,0735	-0,0535	42,13%
12					
13					
14					
21	4382612	-0,186	-0,1635	-0,0225	12,10%
22	4575621	-0,259	-0,2625	0,0035	1,35%
23	3456351	-0,166	-0,14925	-0,01675	10,09%
31	1104	-0,217	-0,1995	-0,0175	8,06%
32	75835	-0,237	-0,0885	-0,1485	62,66%
33	4273626	-0,182	-0,162	-0,02	10,99%
41	120616	-0,224	-0,23475	0,01075	4,80%
42	163533	-0,158	-0,12675	-0,03125	19,78%
43	166603	-0,139	-0,09075	-0,04825	34,71%
51	181101	-0,078	-0,05325	-0,02475	31,73%
52					
53	4626	-0,114	-0,174	0,06	52,63%
55	112450	-0,173	-0,009	-0,164	94,80%
62	295786	-0,079	-0,084	0,005	6,33%

Class	Occurrence	NDVI mean	NDII mean	Mean diff.	relative varia
	1,8E+07	**-0,046**	**-0,0518**	**0,00575**	**12,50%**
0	329465	-0,063	-0,066	0,003	4,76%
11	61870	-0,108	-0,07875	-0,02925	27,08%
12		-0,071	-0,03825	-0,03275	46,13%
13					
14					
21	4382612	-0,082	-0,08175	-0,00025	0,30%
22	4575621	-0,07	-0,0945	0,0245	35,00%
23	3456351	-0,037	-0,03825	0,00125	3,38%
31	1104	0,036	0,06675	-0,03075	85,42%
32	75835	-0,038	-0,03825	0,00025	0,66%
33	4273626	-0,002	-0,00375	0,00175	87,50%
41	120616	-0,121	-0,15825	0,03725	30,79%
42	163533	-0,017	-0,00525	-0,01175	69,12%
43	166603	-0,053	-0,036	-0,017	32,08%
51	181101	-0,018	-0,00975	-0,00825	45,83%
52		0,06	0,0105	0,0495	82,50%
53	4626	-0,095	-0,15675	0,06175	65,00%
55	112450	-0,171	-0,07875	-0,09225	53,95%
62	295786	-0,031	-0,039	0,008	25,81%

Class	Occurrence	NDVI mean	NDII mean	Mean diff.	relative varia
	1,8E+07	**0,188**	**0,14925**	**0,03875**	**20,61%**
0	329465	0,123	0,0735	0,0495	40,24%
11	61870	0,084	0,01725	0,06675	79,46%
12					
13					
14					
21	4382612	0,152	0,10575	0,04625	30,43%
22	4575621	0,218	0,19125	0,02675	12,27%
23	3456351	0,167	0,132	0,035	20,96%
31	1104	0,238	0,19425	0,04375	18,38%
32	75835	0,242	0,1425	0,0995	41,12%
33	4273626	0,229	0,19425	0,03475	15,17%
41	120616	0,2	0,057	0,143	71,50%
42	163533	0,151	0,11325	0,03775	25,00%
43	166603	0,185	0,09525	0,08975	48,51%
51	181101	0,11	0,05625	0,05375	48,86%
52					
53	4626	0,076	-0,0045	0,0805	105,92%
55	112450	0,071	-0,0525	0,1235	173,94%
62	295786	0,13	0,08175	0,04825	37,12%

Class	Occurrence	NDVI mean	NDII mean	Mean diff.	relative varia
	1,8E+07	**-0,248**	**-0,2093**	**-0,0388**	**15,63%**
0	329465	-0,167	-0,13425	-0,03275	19,61%
11	61870	-0,19	-0,096	-0,094	49,47%
12					
13					
14					
21	4382612	-0,25	-0,20325	-0,04675	18,70%
22	4575621	-0,294	-0,276	-0,018	6,12%
23	3456351	-0,216	-0,17775	-0,03825	17,71%
31	1104	-0,214	-0,1425	-0,0715	33,41%
32	75835	-0,362	-0,2535	-0,1085	29,97%
33	4273626	-0,239	-0,19725	-0,04175	17,47%
41	120616	-0,335	-0,2835	-0,0515	15,37%
42	163533	-0,174	-0,1335	-0,0405	23,28%
43	166603	-0,239	-0,1365	-0,1025	42,89%
51	181101	-0,132	-0,06225	-0,06975	52,84%
52					
53	4626	-0,155	-0,16125	0,00625	4,03%
55	112450	-0,231	-0,03	-0,201	87,01%
62	295786	-0,137	-0,10275	-0,03425	25,00%

Class	Occurrence	NDVI mean	NDII mean	Mean diff.	relative varia
	1,8E+07	**-0,046**	**-0,0518**	**0,00575**	**12,50%**
0	329465	-0,063	-0,066	0,003	4,76%
11	61870	-0,108	-0,07875	-0,02925	27,08%
12		-0,071	-0,03825		0,00%
13					
14					
21	4382612	-0,082	-0,08175	-0,00025	0,30%
22	4575621	-0,07	-0,0945	0,0245	35,00%
23	3456351	-0,037	-0,03825	0,00125	3,38%
31	1104	0,036	0,06675	-0,03075	85,42%
32	75835	-0,038	-0,03825	0,00025	0,66%
33	4273626	-0,002	-0,00375	0,00175	87,50%
41	120616	-0,121	-0,15825	0,03725	30,79%
42	163533	-0,017	-0,00525	-0,01175	69,12%
43	166603	-0,053	-0,036	-0,017	32,08%
51	181101	-0,018	-0,00975	-0,00825	45,83%
52		0,06	0,0105		0,00%
53	4626	-0,095	-0,15675	0,06175	65,00%
55	112450	-0,171	-0,07875	-0,09225	53,95%
62	295786	-0,031	-0,039	0,008	25,81%

fig. 100 - Difference between NDVI and NDII synthesis differences.

8.10.5.1 “First assessment” and “Recovery”

Less recovery along the rivers.

A finir !

8.10.5.2 Analysis of the two “Mangroves” classes

A finir !

8.11 DELIVERY14 - Classes of damage severities from NDI differences

The present delivery post-processes the NDI differences images contained in DELIVERY12 (see section 8.9) to produce maps with the following 7 classes of severities for damages (case of vegetation loss) or recovery (case of vegetation gain):

[-1.00 ; -0.20]	severely	damaged
[-0.20 ; -0.12]	moderately	damaged
[-0.12 ; -0.04]	fairly	damaged
[-0.04 ; +0.04]	no change	
[+0.04 ; +0.12]	fairly	recovered
[+0.12 ; +0.20]	moderately	recovered
[+0.20 ; +1.00]	severely	recovered

8.11.1 File name syntax

SS_ZONE.msk2.diff-DDD-SSS.ndXi[.sca-01]. lut-02-012-004.FFF

Examples:

- **s2_south.msk2.diff-d-abc.ndvi. lut-02-012-004.tif** - for the difference between the single destination scene "d" (acquisition of 09.10.2016) and the pre-event synthesis "abc" of the "normalised difference vegetation index" (NDVI) of the Sentinel-2 over the South zone (Tiburon Peninsula), resampled with a 1/10 factor (GSD, i.e. "Ground Sampling Distance", of 100 metres) and exported in GeoTIFF format.
- **s2_south.msk2.diff-ef-d.ndii. lut-02-012-004.kmz** - for the difference between the synthesis "ef" of the last two the post-event acquisitions and the single scene "d" of the "normalised difference infrared index" (NDII) of the Sentinel-2 over the South zone with its nominal spatial resolution (GSD of 10 metres) and exported in KMZ (KML zipped) format.

8.11.2 Delivery file list

Name	Size (KB)	Type	Files	Percent
\\fabio\fabio_3\P275_UNEP_HAITI\DELIVERY14_DAMAG...	1 536 535	Folder	60	
s2_south.msk2.diff-d-abc.ndii.lut-02-012-004.kmz	20 740	KMZ		
s2_south.msk2.diff-d-abc.ndii.lut-02-012-004.tfw	0	Fichier TFW		
s2_south.msk2.diff-d-abc.ndii.lut-02-012-004.tif	123 878	Fichier TIF		
s2_south.msk2.diff-d-abc.ndii.sca-01.lut-02-012-004.kmz	264	KMZ		
s2_south.msk2.diff-d-abc.ndii.sca-01.lut-02-012-004.tfw	0	Fichier TFW		
s2_south.msk2.diff-d-abc.ndii.sca-01.lut-02-012-004.tif	1 246	Fichier TIF		
s2_south.msk2.diff-d-abc.ndvi.lut-02-012-004.kmz	22 359	KMZ		
s2_south.msk2.diff-d-abc.ndvi.lut-02-012-004.tfw	0	Fichier TFW		
s2_south.msk2.diff-d-abc.ndvi.lut-02-012-004.tif	123 878	Fichier TIF		
s2_south.msk2.diff-d-abc.ndvi.sca-01.lut-02-012-004.kmz	259	KMZ		
s2_south.msk2.diff-d-abc.ndvi.sca-01.lut-02-012-004.tfw	0	Fichier TFW		
s2_south.msk2.diff-d-abc.ndvi.sca-01.lut-02-012-004.tif	1 246	Fichier TIF		
s2_south.msk2.diff-d-c.ndii.lut-02-012-004.kmz	14 841	KMZ		
s2_south.msk2.diff-d-c.ndii.lut-02-012-004.tfw	0	Fichier TFW		
s2_south.msk2.diff-d-c.ndii.lut-02-012-004.tif	123 878	Fichier TIF		
s2_south.msk2.diff-d-c.ndii.sca-01.lut-02-012-004.kmz	187	KMZ		
s2_south.msk2.diff-d-c.ndii.sca-01.lut-02-012-004.tfw	0	Fichier TFW		
s2_south.msk2.diff-d-c.ndii.sca-01.lut-02-012-004.tif	1 246	Fichier TIF		
s2_south.msk2.diff-d-c.ndvi.lut-02-012-004.kmz	15 839	KMZ		
s2_south.msk2.diff-d-c.ndvi.lut-02-012-004.tfw	0	Fichier TFW		
s2_south.msk2.diff-d-c.ndvi.lut-02-012-004.tif	123 878	Fichier TIF		
s2_south.msk2.diff-d-c.ndvi.sca-01.lut-02-012-004.kmz	183	KMZ		
s2_south.msk2.diff-d-c.ndvi.sca-01.lut-02-012-004.tfw	0	Fichier TFW		
s2_south.msk2.diff-d-c.ndvi.sca-01.lut-02-012-004.tif	1 246	Fichier TIF		
s2_south.msk2.diff-def-abc.ndii.lut-02-012-004.kmz	42 642	KMZ		
s2_south.msk2.diff-def-abc.ndii.lut-02-012-004.tfw	0	Fichier TFW		
s2_south.msk2.diff-def-abc.ndii.lut-02-012-004.tif	123 878	Fichier TIF		
s2_south.msk2.diff-def-abc.ndii.sca-01.lut-02-012-004....	457	KMZ		
s2_south.msk2.diff-def-abc.ndii.sca-01.lut-02-012-004.tfw	0	Fichier TFW		
s2_south.msk2.diff-def-abc.ndii.sca-01.lut-02-012-004.tif	1 246	Fichier TIF		
s2_south.msk2.diff-def-abc.ndvi.lut-02-012-004.kmz	40 220	KMZ		
s2_south.msk2.diff-def-abc.ndvi.lut-02-012-004.tfw	0	Fichier TFW		
s2_south.msk2.diff-def-abc.ndvi.lut-02-012-004.tif	123 878	Fichier TIF		
s2_south.msk2.diff-def-abc.ndvi.sca-01.lut-02-012-004....	423	KMZ		
s2_south.msk2.diff-def-abc.ndvi.sca-01.lut-02-012-004....	0	Fichier TFW		
s2_south.msk2.diff-def-abc.ndvi.sca-01.lut-02-012-004.tif	1 246	Fichier TIF		
s2_south.msk2.diff-ef-abc.ndii.lut-02-012-004.kmz	42 642	KMZ		
s2_south.msk2.diff-ef-abc.ndii.lut-02-012-004.tfw	0	Fichier TFW		
s2_south.msk2.diff-ef-abc.ndii.lut-02-012-004.tif	123 878	Fichier TIF		
s2_south.msk2.diff-ef-abc.ndii.sca-01.lut-02-012-004.k...	457	KMZ		
s2_south.msk2.diff-ef-abc.ndii.sca-01.lut-02-012-004.tfw	0	Fichier TFW		
s2_south.msk2.diff-ef-abc.ndii.sca-01.lut-02-012-004.tif	1 246	Fichier TIF		
s2_south.msk2.diff-ef-abc.ndvi.lut-02-012-004.kmz	40 220	KMZ		
s2_south.msk2.diff-ef-abc.ndvi.lut-02-012-004.tfw	0	Fichier TFW		
s2_south.msk2.diff-ef-abc.ndvi.lut-02-012-004.tif	123 878	Fichier TIF		
s2_south.msk2.diff-ef-abc.ndvi.sca-01.lut-02-012-004.k...	423	KMZ		
s2_south.msk2.diff-ef-abc.ndvi.sca-01.lut-02-012-004.tfw	0	Fichier TFW		
s2_south.msk2.diff-ef-abc.ndvi.sca-01.lut-02-012-004.tif	1 246	Fichier TIF		
s2_south.msk2.diff-ef-d.ndii.lut-02-012-004.kmz	21 526	KMZ		
s2_south.msk2.diff-ef-d.ndii.lut-02-012-004.tfw	0	Fichier TFW		
s2_south.msk2.diff-ef-d.ndii.lut-02-012-004.tif	123 878	Fichier TIF		
s2_south.msk2.diff-ef-d.ndii.sca-01.lut-02-012-004.kmz	248	KMZ		
s2_south.msk2.diff-ef-d.ndii.sca-01.lut-02-012-004.tfw	0	Fichier TFW		
s2_south.msk2.diff-ef-d.ndii.sca-01.lut-02-012-004.tif	1 246	Fichier TIF		
s2_south.msk2.diff-ef-d.ndvi.lut-02-012-004.kmz	21 134	KMZ		
s2_south.msk2.diff-ef-d.ndvi.lut-02-012-004.tfw	0	Fichier TFW		
s2_south.msk2.diff-ef-d.ndvi.lut-02-012-004.tif	123 878	Fichier TIF		
s2_south.msk2.diff-ef-d.ndvi.sca-01.lut-02-012-004.kmz	234	KMZ		
s2_south.msk2.diff-ef-d.ndvi.sca-01.lut-02-012-004.tfw	0	Fichier TFW		
s2_south.msk2.diff-ef-d.ndvi.sca-01.lut-02-012-004.tif	1 246	Fichier TIF		

8.11.3 NDVI (Normalised Difference Vegetation Index)

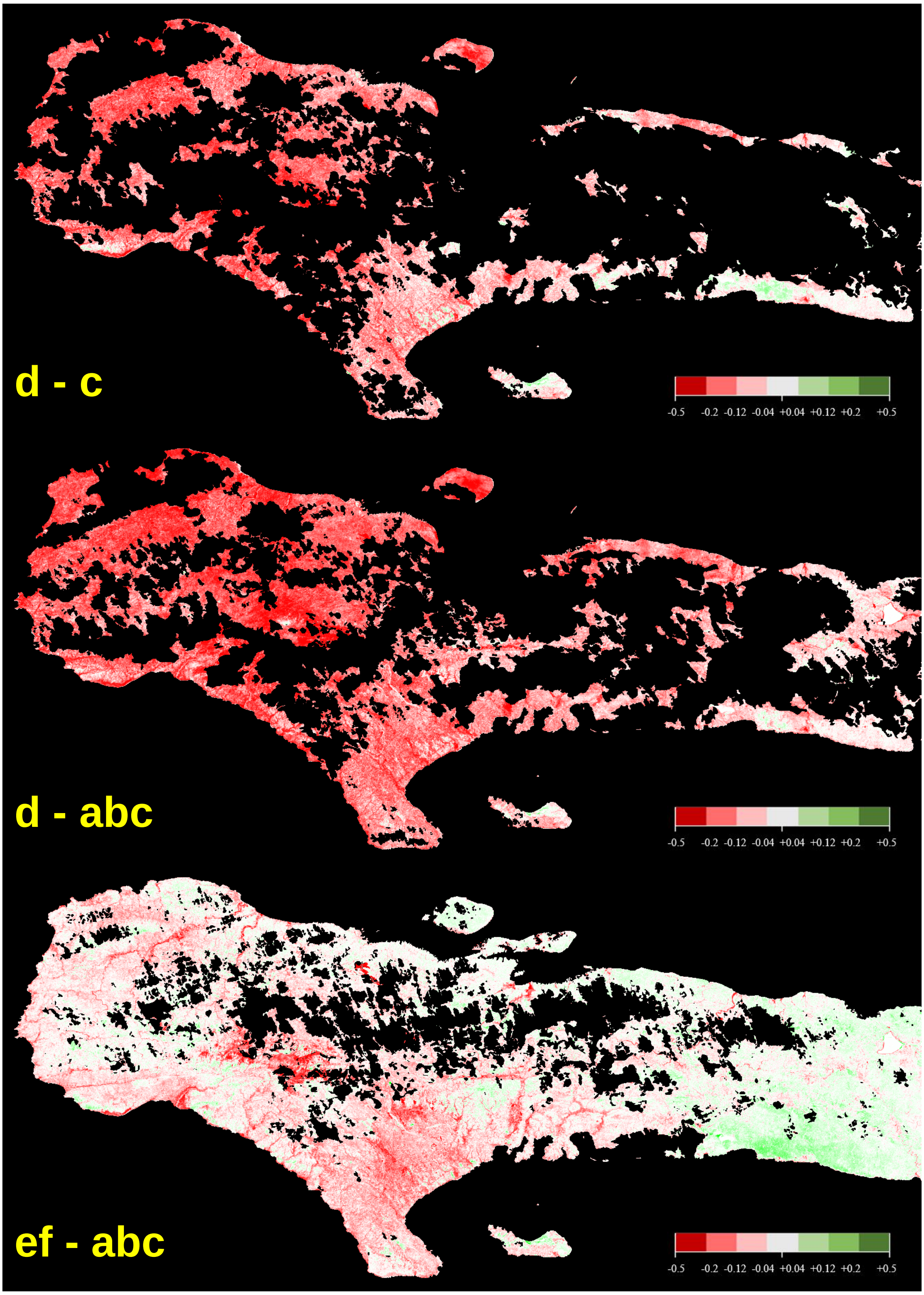


fig. 101 - Difference between NDVI of synthesis (1) by severity classes.

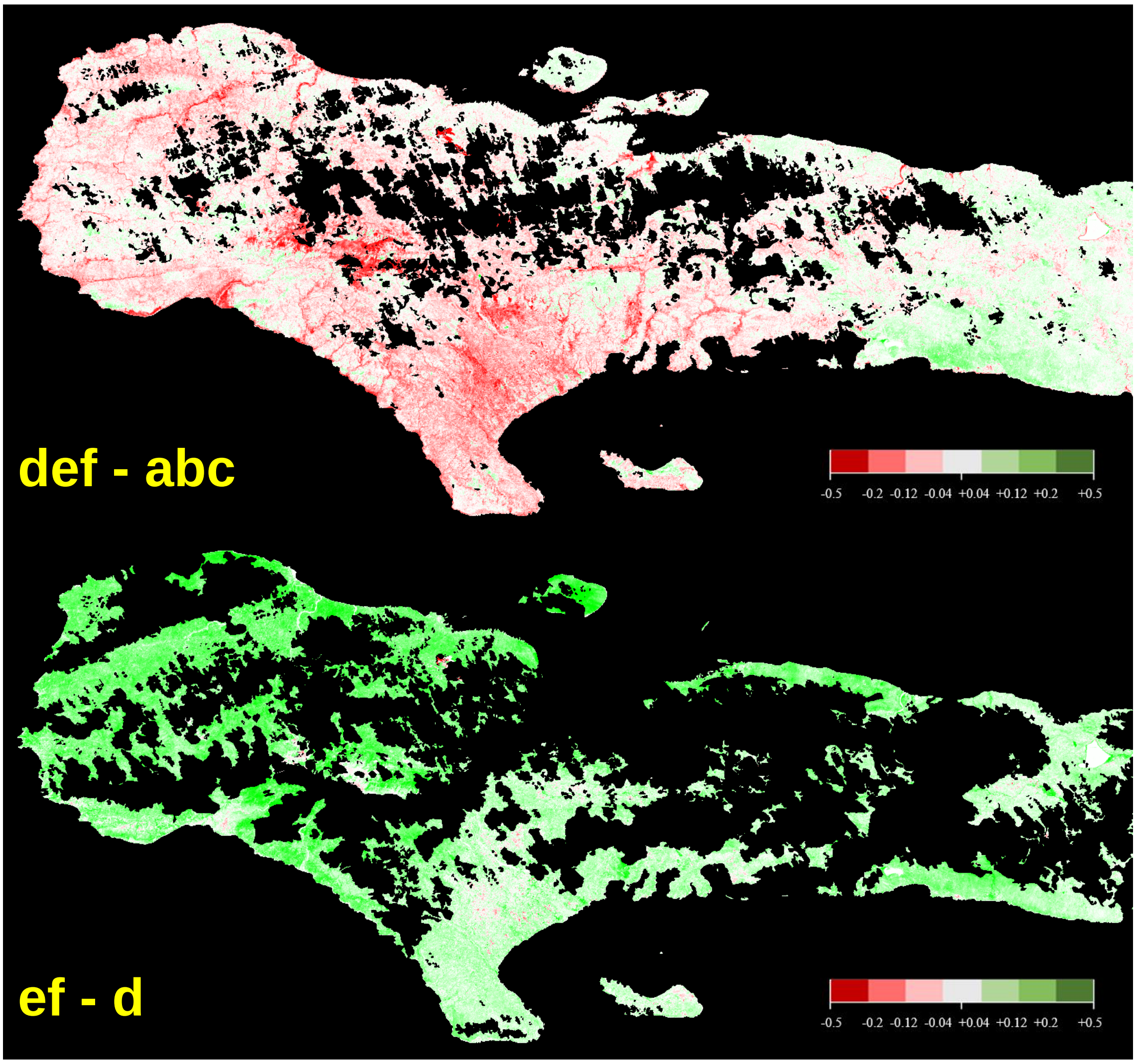


fig. 102 - Difference between NDVI of synthesis (2) by severity classes.

8.11.4 NDII (Normalised Difference Infrared Index)

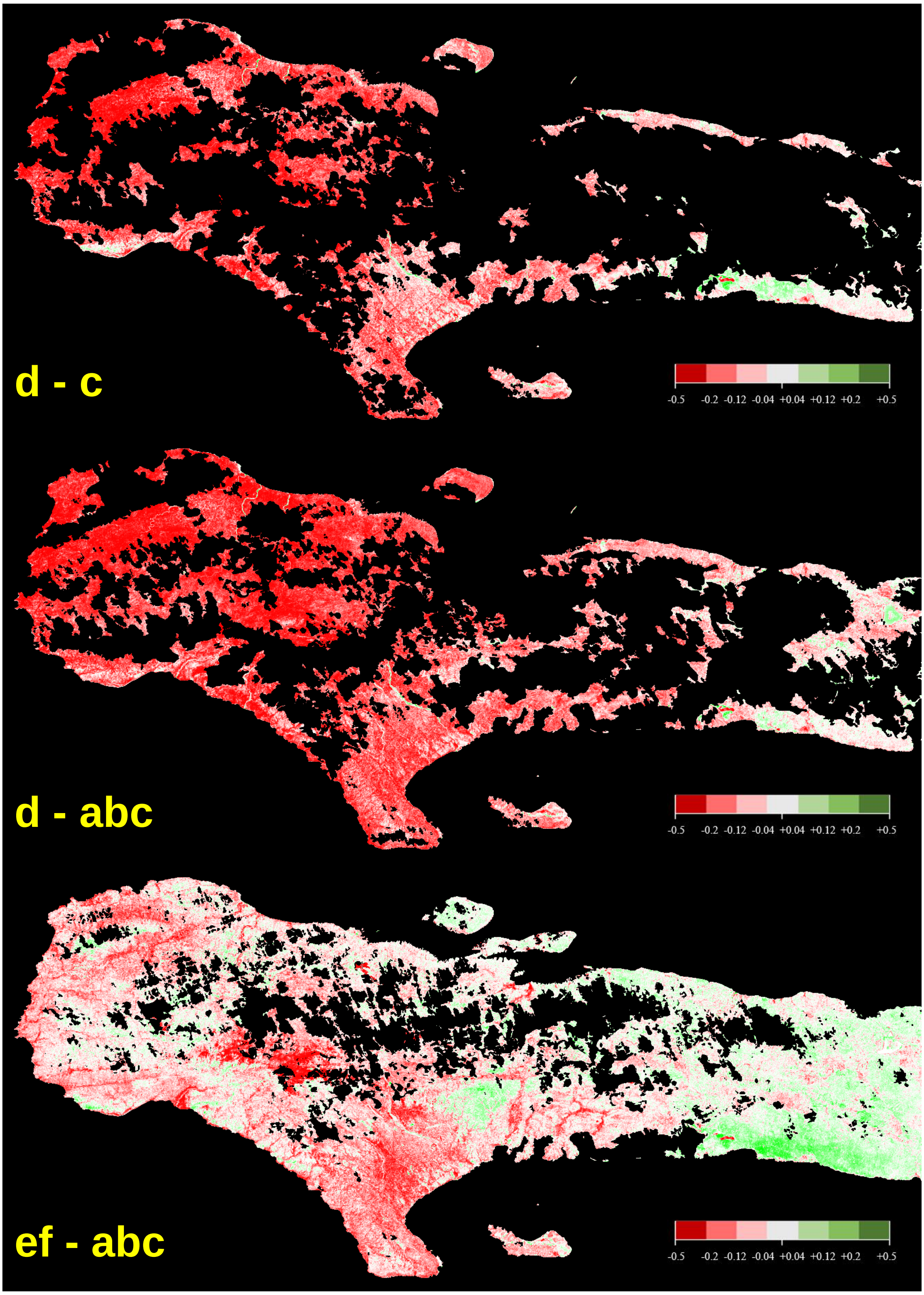


fig. 103 - Difference between NDII of synthesis (1) by severity classes.

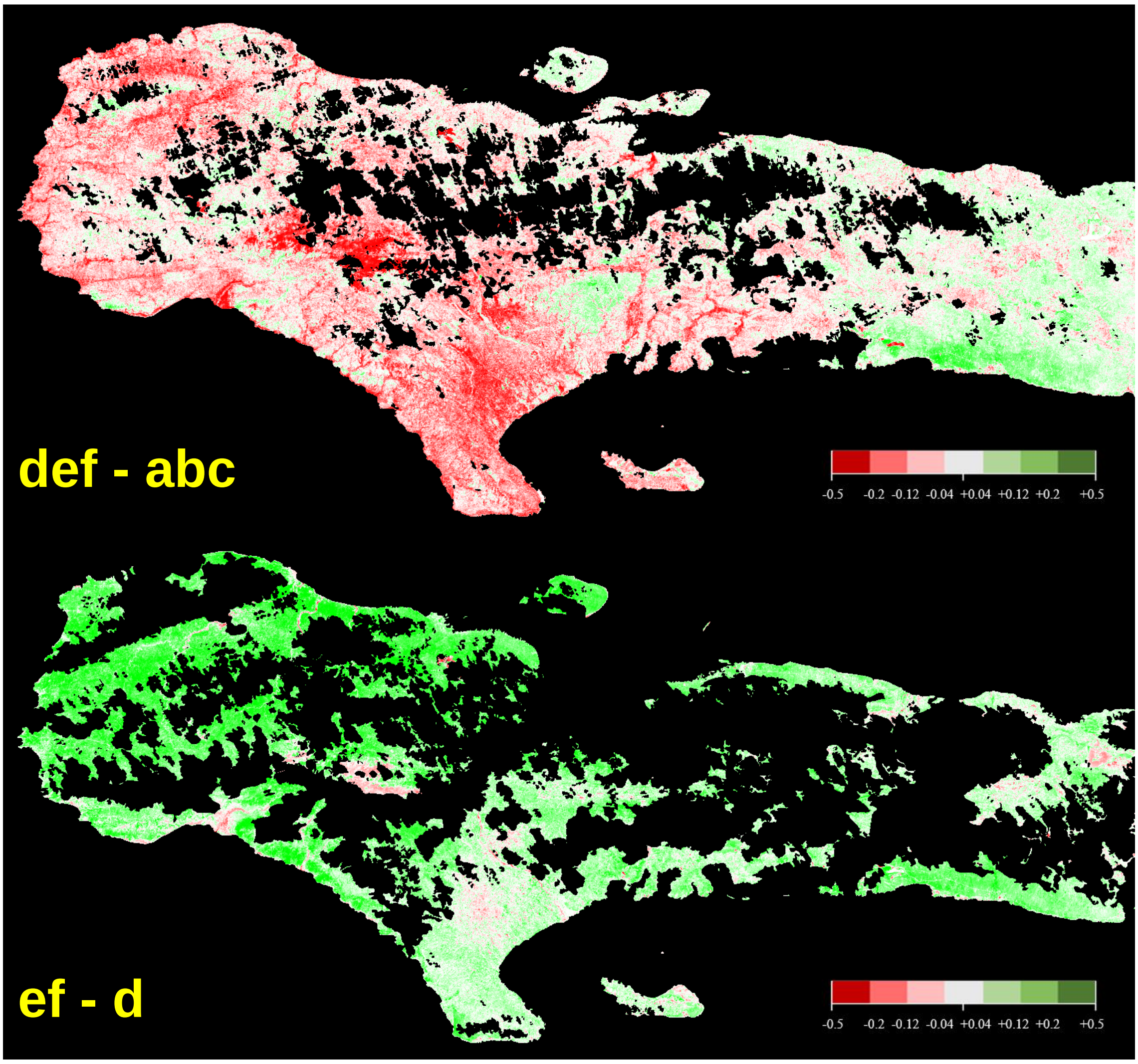


fig. 104 - Difference between NDII of synthesis (2) by severity classes.

8.12 DELIVERY15 - Coastal erosion

The present delivery post-processes the NDI differences images contained in DELIVERY12 (see section 8.9) to produce maps with the following 7 classes of severities for damages (case of vegetation loss) or recovery (case of vegetation gain):

- **Sentinel-2 / MSI** - Instrument MSI (Multi-Spectral Instrument) on-board Sentinel-2 (see R-7, R-8, and R-9) is a HR imager with GSD (Ground Sampling Distance) at 10m for the visible and near-infrared bands. As shown in section 8.12.3, damages along the coast are visible using the natural colour composition 4-3-2 in RGB respectively.

  Section 8.12.3 shows the two observations just before the event on 19.09.2016 and just after on 09.10.2016. One may in particular notice:

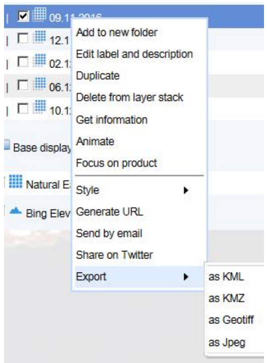
  - **Couple a, "Les Anglais" -** a full "washing" of the delta with sediments poured in sea.
  - **Couple b, "Mangrove La Cahouhane" -** showing an erased diversity.
  - **Couple c, "Tibouron" -** showing a landslide along the north coast (see yellow arrow).
  - **Couple d, "Les Irois" -** showing a kind of inundated ditch around a preserved patch.
  - **Couple d, "Jérémie" -** showing the expanded drains of rivers.

- **Sentinel-3 / OLCI** - Instrument OLCI (Ocean Land Colour Instrument) on-board Sentinel-3 (see R-12, R-13, and R-14) is dedicated to "Ocean Colour". As shown in section 8.12.4, suspended matter and in particular the sediments transported by the heavy rain are particularly visible by using the 6-5-3 RGB colour composition in which the central wavelength of the bands are -B6: 560nm, -B5: 510nm, -B3: 442.5nm.

  Sentinel-3A is a recent satellite launched on 16 February 2016 and for which the data are available from 20 October 2016 only.

  An animation is available that shows the series of 6 observed data in the hyperlook 2D_anim.

8.12.1 Access to the images



This delivery does not include static files processed and stored in a particular directory. All the images are available on-line clicking on the "hyperlook" (for example 2D_view of S3/OLCI observed on **09.11.2016**) and navigating interactively across the images that are dynamically processed on-the-fly.

Sentinel-2 data are shown before (19.09.2016) and after (09.10.2016) the hurricane. One may compare the two image using a 2D animation. See for example the landslide on north of Tiburon using the "hyperlook" 2D_anim.

As shown in the attached figure, the layer stack may be displayed by activating the button (3 horizontal segments symbol located along the rightmost side of the display area) and any layer may be exported on-demand by selecting the desired format in the "Export" function.

8.12.2 Correlation with precipitations

Precipitations data over Haiti have been gathered from the Giovanni server of NASA (see section 5.1.2.2). The 7-days accumulation of precipitations over the entire years (see fig. 105) shows that the Matthew hurricane has produced a major rainfall of more than 400 mm in one day the 4 October 2016. A second sequence of rainfall occurred few days after during about 6 days (18 to 23 October) to reach an accumulation of about 200 mm rainfall (see fig. 106).

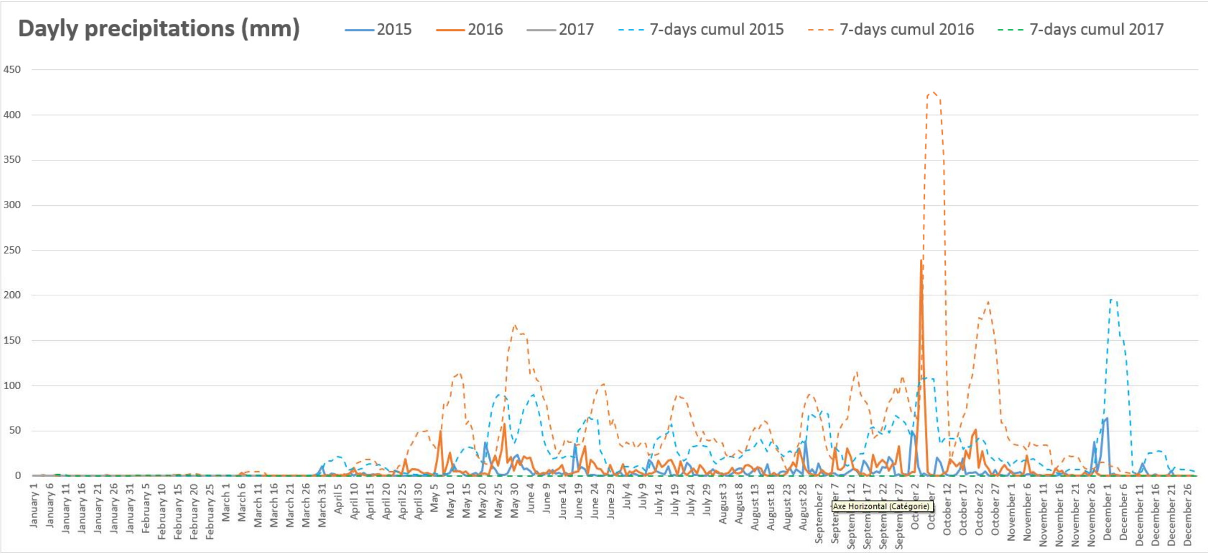


fig. 105 - Precipitations (daily and 7-days cumul) over the entire years (2015, 2016, 2017).

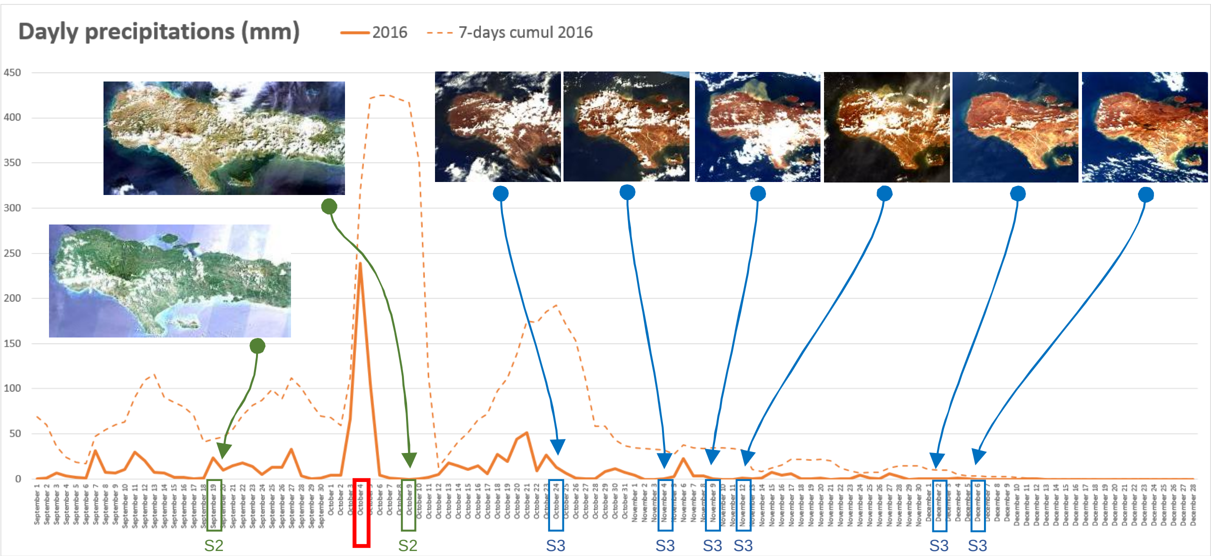


fig. 106 - Precipitations (daily and 7-days cumul) over the 4 months : September, October, November, December 2016.

8.12.3 Coastal erosion observed by Sentinel-2/MSI

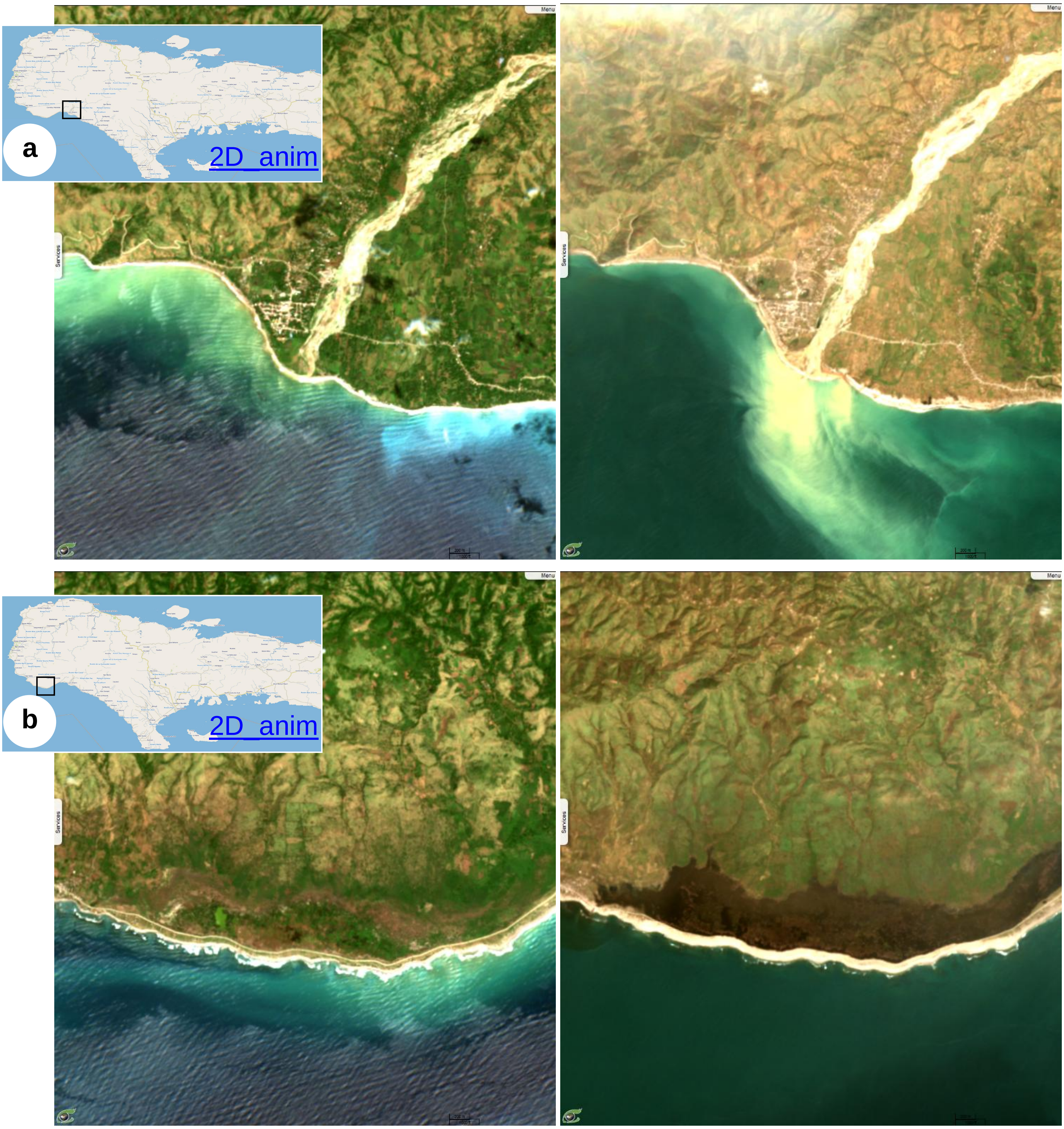


fig. 107 - Sentinel-2/MSI (10m GSD) - Comparison between 19.09.2016 (left) and 09.10.2016 (right). (1)

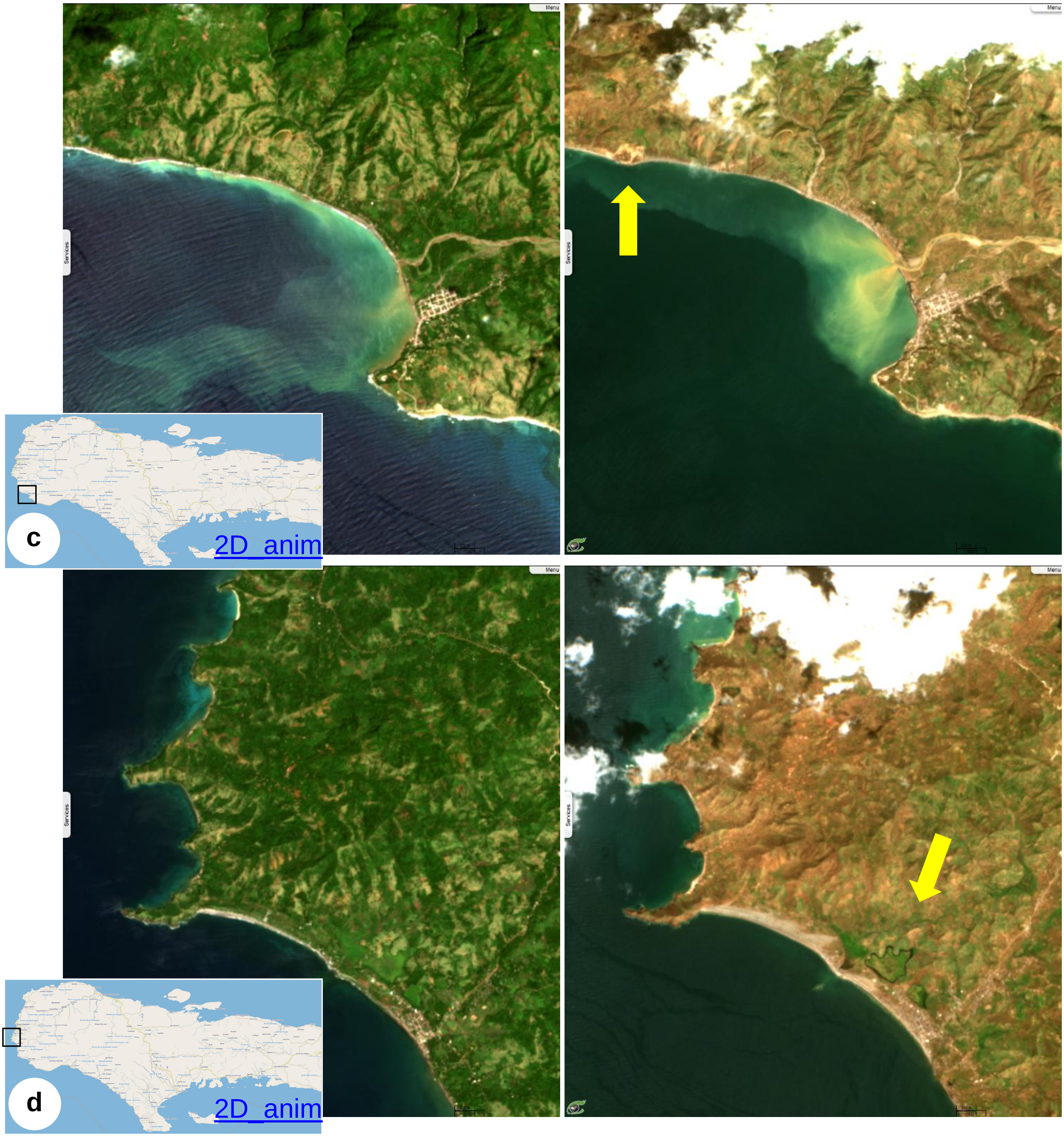


fig. 1 - Sentinel-2/MSI (10m GSD) - Comparison between 19.09.2016 (left) and 09.10.2016 (right). (2)

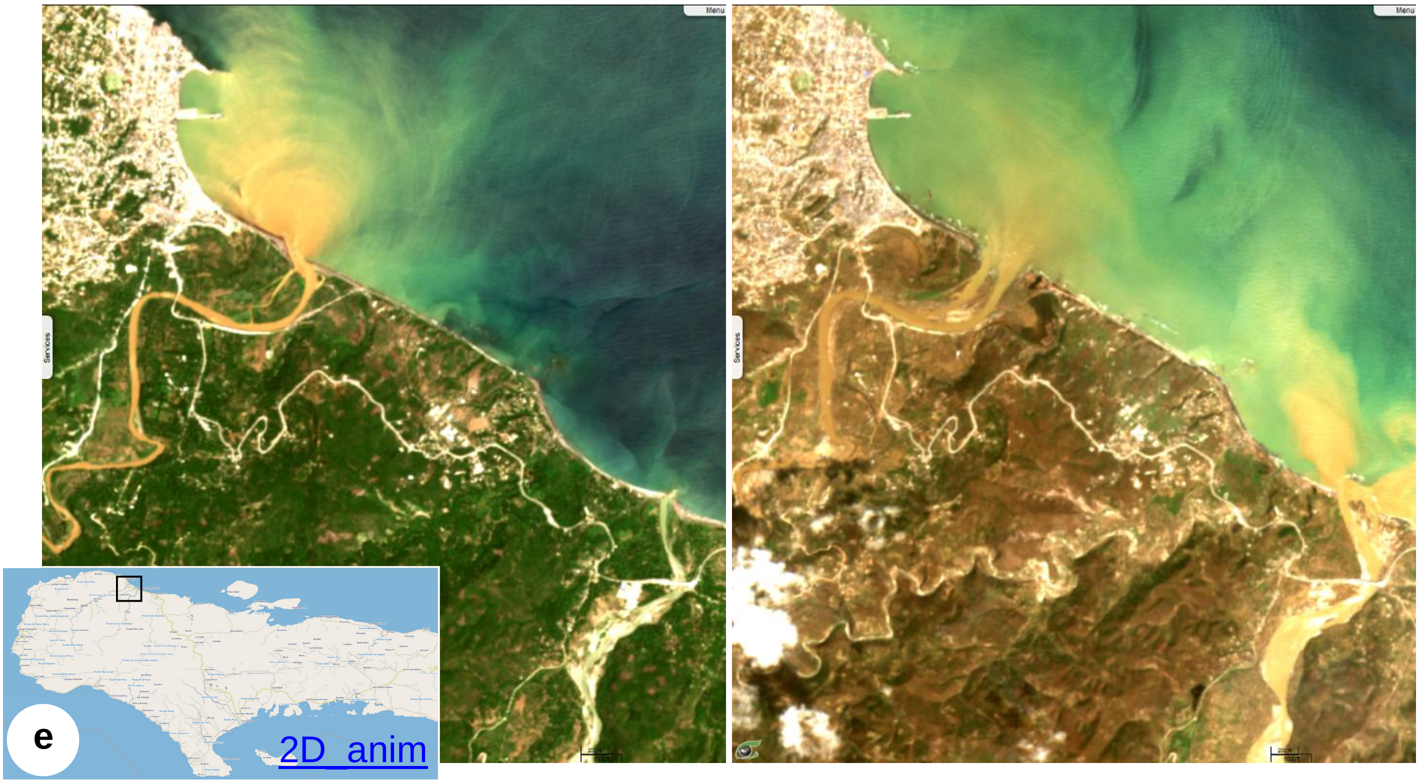


fig. 1 **-** *Sentinel-2/MSI (10m GSD)* **-** *Comparison between 19.09.2016 (left) and 09.10.2016 (right). (3)*

8.12.4 Suspended sediments observed by Sentinel-3/OLCI

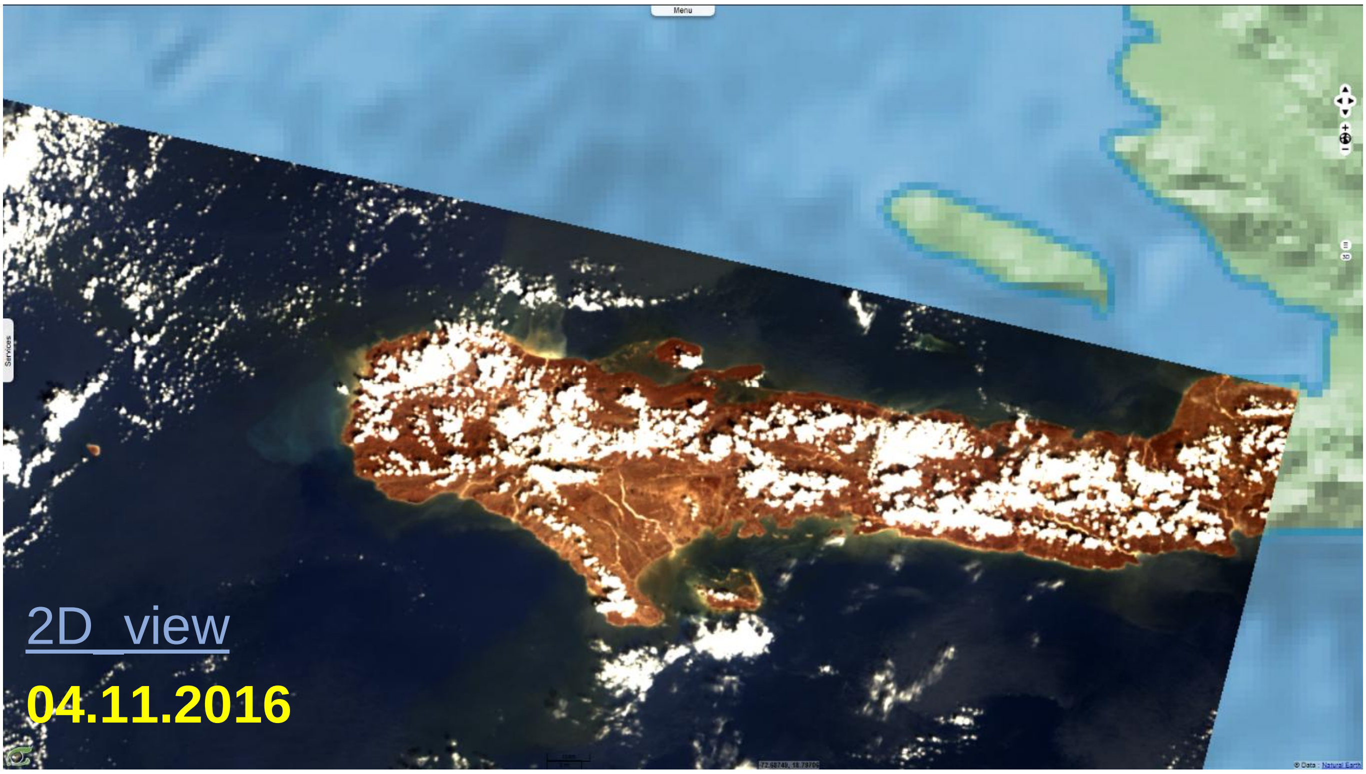


fig. 2 - Sentinel-3 / OLCI - Suspended matters seen using colour composition 6-5-3 (1).

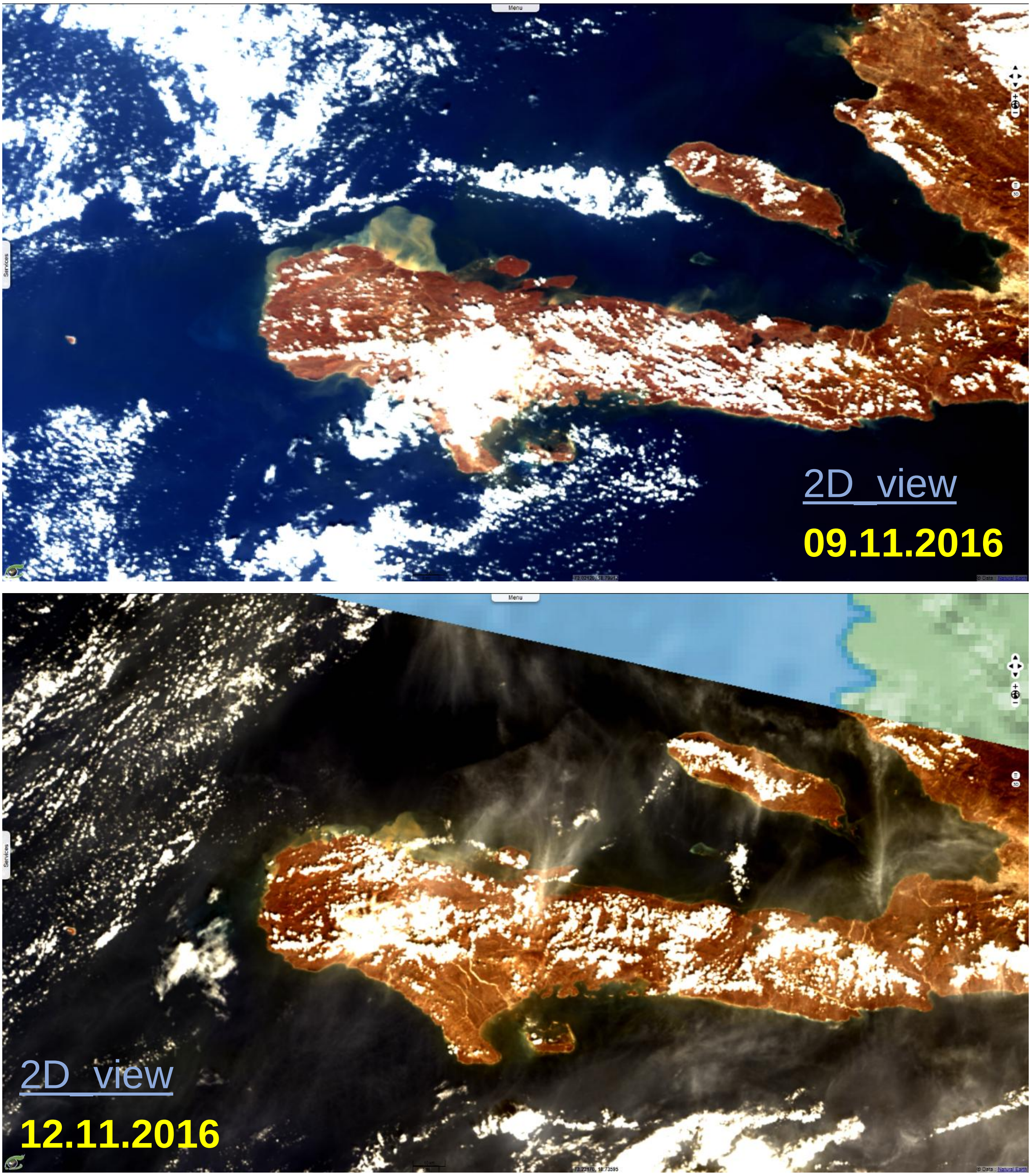


fig. 3 - Sentinel-3 / OLCI - Suspended matters seen using colour composition 6-5-3 (2).

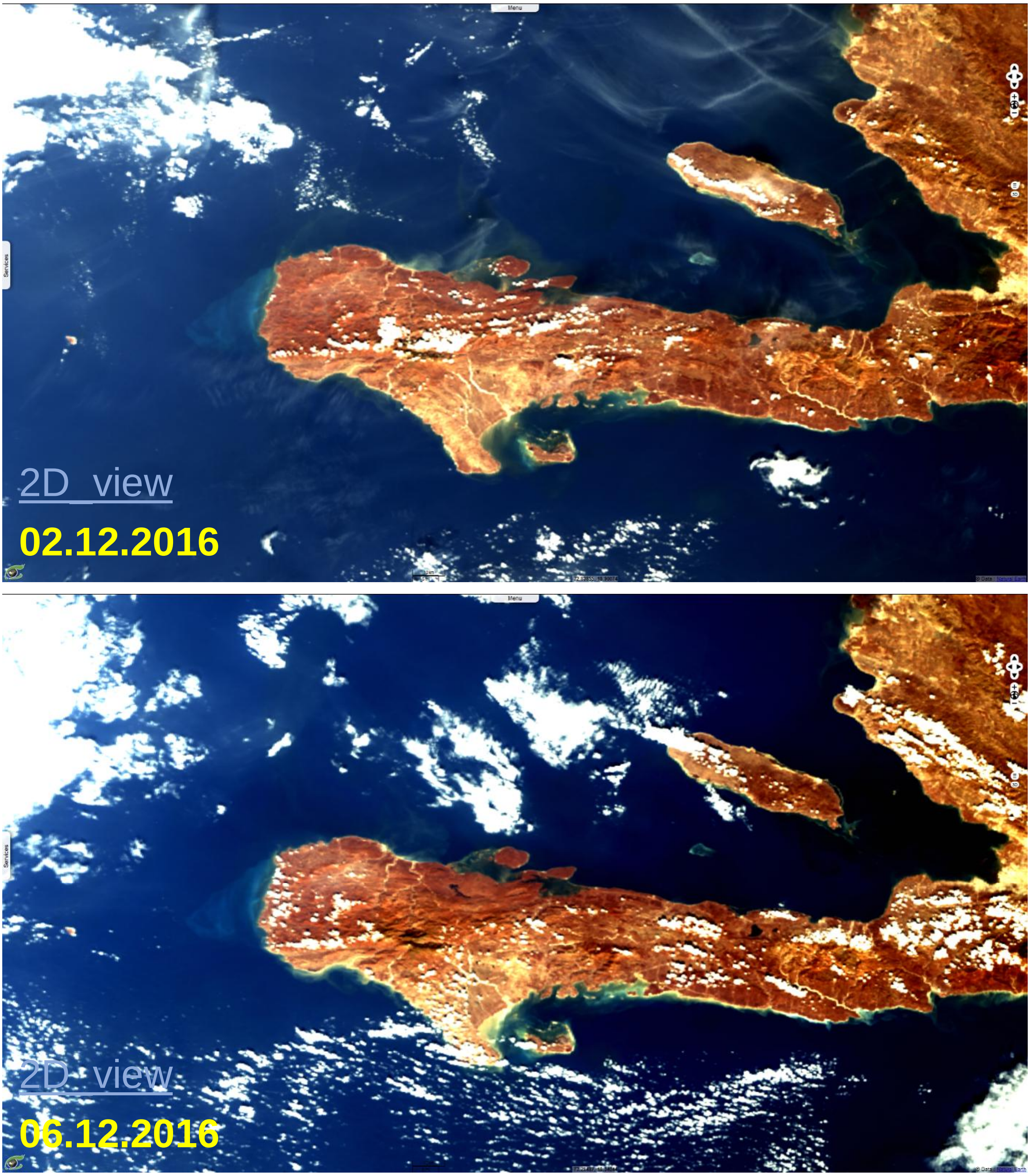


fig. 4 - Sentinel-3 / OLCI - Suspended matters seen using colour composition 6-5-3 (3).

ANNEX A – PROJECT MANAGEMENT

A.1 E-mail Niloufar BAYANI 17.01.2017 - Assessment of first delivery

De : Niloufar BAYANI [mailto:Niloufar.BAYANI@unep.org]
Envoyé : mardi 17 janvier 2017 12:03
À : Serge RIAZANOFF (VT.FR) <serge.riazanoff@visioterra.fr>
Cc : 'Jacqueline Henrot' <j.henrot@gmail.com>; 'Muralee Thummarukudy' <Muralee.THUMMARUKUDY@unep.org>; Zhour NAJOUI <zhour.najoui@visioterra.fr>
Objet : RE: - CALLING ZHOUR

Dear Serge,

Welcome back in office! I hope you had a good trip.

Thanks for working closely with Jacqueline on these maps. Overall the maps give a good picture of the extent of damage to vegetation and a stunning visual of the impact of the hurricane. However, as yourself and Jacqueline have pointed out, there are a number of issues that remain to be resolved, as is always the case in this type of work. We just need to refine the maps so they explain the reality on the ground more clearly. Please see below my comments. I would be happy to discuss these with you on the phone today, if there is anything unclear.

Image date and effect of precipitation

The main issue is that we are still seeing some anomalies, for example areas that seem to have more vegetation after the hurricane, than before. In the synthesis report you have mentioned that it was not possible to put a cloud mask and therefore we had to use the "maximum NDVI" algorithm to replace cloud covered areas with cloud-free pixels from images taken on other dates. This seems like a good alternative, but is also adding a level of uncertainty. When we compare before and after images from an area, we do not know the image date and therefore cannot control for the effect of precipitation or the season.

I think what we need to do now is compare satellite images from after the hurricane with before-hurricane images of the same month of the year (or the closest date possible) from 2014 or 2015, without using the maximum NDVI algorithm. This way we can control the effect of precipitation to some extent. If the images have too many clouds, then I suggest that we zoom into cloud-free areas as a first step.

Would you be able to prepare a few before-after comparisons of NDVI and class change this way? (i.e. with clearly identified image dates)

NDVI vs. NDII

As discussed during our visit to your office, it would be interesting to consider change in leaf water content (NDII) as an alternative to NDVI. Other studies have shown that NDII may be a better indicator of hurricane damage, particularly to mangroves, than NDVI.

Would you be able to do this analysis as well?

Quantifying impacts

This is a later step but I thought to mention it already. If we could quantify the damage to vegetation in numbers, then we would be able to give a very powerful message for awareness raising and resource mobilization in order to help the environment sector recover from hurricane damage. I'm not an expert in this so I'm not sure if it is feasible but do you think we can calculate the area (e.g. number of hectares) damaged by the hurricane? One option could be to estimate the damage based on land use type. For example XX ha of agroforestry and XX ha of natural forest were severely damaged.

We could even try to quantify the impact into damage classes. For example areas that were severely damaged, moderately damaged or fairly damaged.

If this is possible, please let us know what type of information you need from the field so we already start collecting it during field visits.

I hope my comments are clear. Please let me know if you'd like to speak on the phone today and discuss the above. If so, pls suggest a time.

Many thanks again for your excellent work.

Best,

Niloufar

UNEP
Post-Conflict and Disaster Management Branch

Niloufar Bayani
DRR - Project Advisor

United Nations Environment Programme

International Environment House
11-15 Chemin des Anémones
CH-1219 Châtelaine, Geneva
Tel: +41 22 917 83 47
niloufar.bayani@unep.org
www.unep.org/disastersandconflicts