NRT satellite detection and drift forecast of Sargassum algae in the Equatorial Atlantic

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1- Introduction

Unprecedented massive landings of sargassum floating algae have been observed since 2011 along the shorelines of a huge area encompassing the Gulf of Mexico and the Caribbean Sea. The phenomenon is highly reported in West Indies (Guadeloupe, Martinique, Barbados ...), Dominican Republic, Mexico, Costa Rica, Texas, etc. Algae arrive from the open sea as large rafts (tens of km) after having drifted over long distances, probably from Brazil or the Gulf of Guinea (see Fig. 1). This issue has tremendous negative impacts over local communities, marine environment and industry. The tourism and fishing sectors are particularly drastically affected. Pioneering work by Gower et al. (2006), and Hu (2009) has demonstrated the capacity of ocean colour satellites to detect sargassum rafts. We propose here to set up a Sargassum satellite detection and drift service in the Atlantic, Caribbean and Gulf of Mexico for the needs of scientific, institutional or private users. This service consists in (1) detecting sargassum algae using a synergy of satellite sensors (MODIS/Aqua, OLI/Landsat-8, Sentinel-3/OLCI, Sentinel-2/MSI), (2) running a drift model to estimate the sargassum trajectories and their potential landings on the coasts using environmental data coming from the Copernicus Marine Service, (3) providing dedicated bulletins to the end-users through a secured web platform to help them in their decision-making processes in all impacted sectors.

Figure 1 : An example of Sargassum rafts, as seen from an airplane

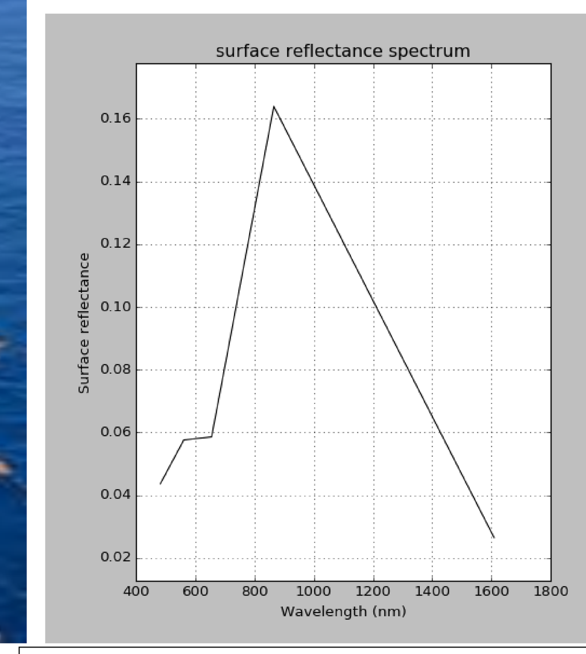

Figure 2 : Example of sargassum spectrum (Landsat-8/OLI)

2- Satellite data processing

➢ Sargassum detection

Sargassum presence is detected by the increase of the reflectance spectrum between the red and near infra-red wavelengths (see Fig. 2). Most well-known sargassum indices found in the literature, for example the Maximum Chlorophyll Index (MCI, by Gower et al., 2006), the Floating Algae Index (FAI, by Hu, 2009), the Alternative Floating Algae Index (AFAI, by Wang and Hu, 2016), follow the same mathematical statement : Index = $\rho_{NIR} - \rho'_{NIR}$

Where ρ_{NIR} denote a reflectance (or radiance) partially (or not) corrected for atmospheric effects in the near infra-red band, and ρ'_{NIR} is the equivalent NIR reflectance that would be measured at the same point in absence of sargassum. ρ'_{NIR} is approximated by a linear interpolation between the two reflectances measured at nearby wavelengths in the red and SWIR bands

The adjacent table 1 gives the wavelengths used for the three above indices

	MCI	FAI	AFAI
Red	681	645	667
NIR	709	859	748
SWIR	754	1240	869

Table 1 : Wavelengths used in the three sargassum indices

We use here a normalized version of the FAI, in which the normalization by the sum of reflectances is introduced to mitigate the variability of the FAI due to atmospheric conditions and observation geometry, as done for the NDVI over land surfaces : NFAI = $(\rho_{NIR} - \rho'_{NIR}) / (\rho_{NIR} + \rho'_{NIR})$

➢Sensors

4 sensors are processed : MODIS/Aqua, OLCI/Sentinel-3 (2 satellites), MSI/Sentinel-2 (2 satellites) and OLI/Landsat-8. Data are acquired from NASA/OBPG (MODIS), Eumetsat (OLCI), AWS (OLI) and CNES (MSI). Processing consists in applying partial atmospheric corrections on TOA reflectances to compute "surface" reflectances in the blue, green, red, NIR and SWIR bands. Table 2 gives the wavelengths used for each sensor.

	MODIS	OLCI	MSI	OLI
Blue	469	490	490	482
Green	555	560	560	561
Red	645	665	665	655
NIR	859	865	865	865
SWIR	1240	1020	1610	1609

Table 2 : Wavelengths used for each sensor

For that task, SeaDAS software distributed by NASA/OBPG is used for MODIS and OLI, and Polymer software distributed by HYGEOS (https://www.hygeos.com/polymer) is used for OLCI and MSI. As far as MODIS is concerned, the 250-m bands are used for the red and NIR bands, and the 500-m bands are used for the blue, green and SWIR bands, to use the highest attainable pixel resolution, despite the lower signal to noise ratio as compared to the 1-km ocean color bands. For OLCI, the Full resolution products (300m) are used. For MSI, reflectances are output at 20-m resolution (30-m for OLI).

➢ Land and cloud masking and data editing

Land mask as given by SeaDAS or already present in L1 products is enlarged to avoid using reflectances contaminated by nearby land. Cloud mask is computed from thresholds on the blue, green and red reflectances, as well as tests on the spectrum shape. Figure 3 shows examples of spectra flagged as cloud. However, even after cloud masking, it is necessary to remove pixels close to cloud that show the same spectral behaviour as the one given by a sargassum target. Figure 4 shows such a case for MSI. A data editing step is thus set up to remove such pixels by enlarging the clouds.

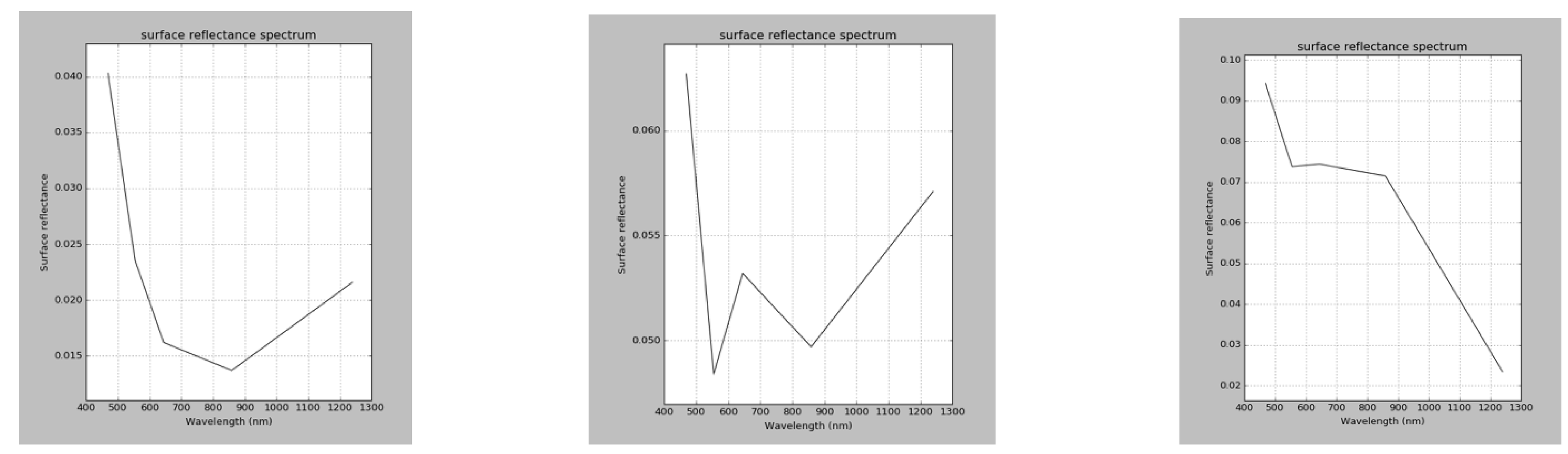

Figure 3 : An example of MODIS spectra, characterized as cloud

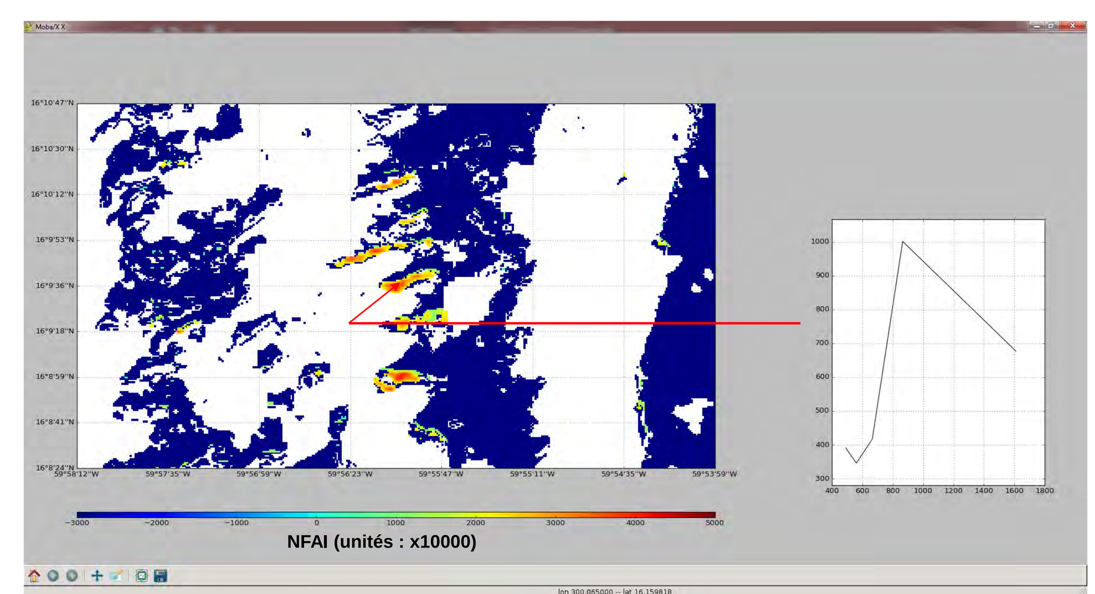

Figure 4 : MSI NFAI map, showing wrong sargassum detections close to cloud (white). Free ocean in deep blue.

➢ Special case for MSI

Due to its 10h30 UTC Equatorial crossing time and low viewing angle geometry, sunglint is a strong component of the TOA reflectance seen by MSI in our area of interest, from March to October. In comparison, OLI is less affected by sunglint due to its earlier equatorial crossing time. Moreover, the design of the MSI instrument (12 staggered detectors, the odd and even ones being shifted along-track, and, within each detector, an along-track shift of the spectral bands (ESA Sentinel-2 MSI technical guide), adds uncertainty in the spectra affected by sunglint. NFAI maps computed from MSI are thus very noisy when glint is present (see Figure 5). Consequently, an editing procedure has been set up to keep only NFAI pixels that have a sufficiently high value of NFAI in their vicinity

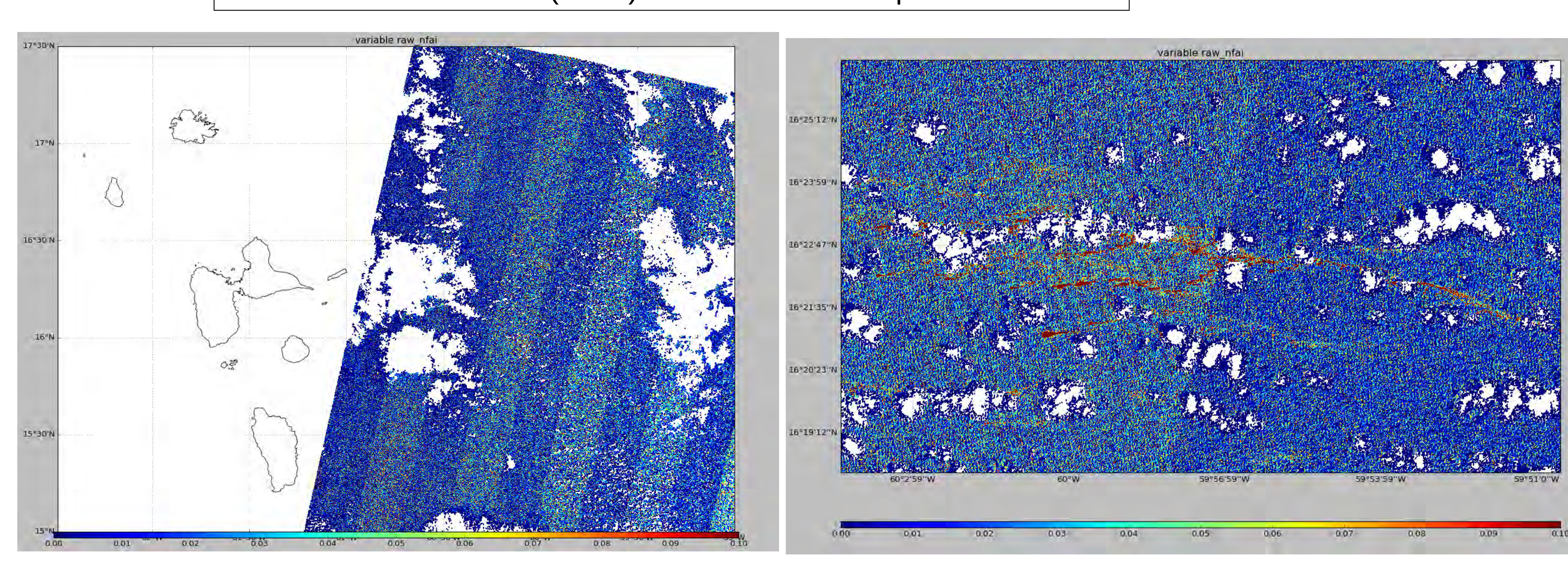

Figure 5 : MSI NFAI map, showing (left) NFAI along-track banding due to instrument design, and (zoom right), true sargassum rafts in deep red) among a lot of wrong detections

➢ Sargassum index map generation

This step is a level-3 processing that computes maps of NFAI from the individual satellite images processed as described above (level-2 products). This level-3 processing is run once a day, around 05h UTC, with the data of the day before. Maps are produced to cover the area in the Western Africa, Atlantic, Caribbean and Gulf of Mexico (5S-35N, 110W-10W), at 0.0025° resolution for MODIS and OLCI. For MSI and OLI, maps are produced at 0.00025° resolution to cover the area around the Lesser Antilles (12.5N-17.5N, 62.5W-59W).

3- Drift modeling

➢ 2D surface lagrangian model

Sargassum mats with a high risk of affecting the coastal areas are selected and contoured in automatic mode from the sargassum index maps. These contours are used to feed a 2D lagrangian drift model to estimate the sargassum trajectories and their probability of landing on the coasts (see Figure 6). Wind and ocean current forecast are used to force the drift model. Several kinds of ocean currents are extracted from the Copernicus Marine Service and tested in the drift simulation.

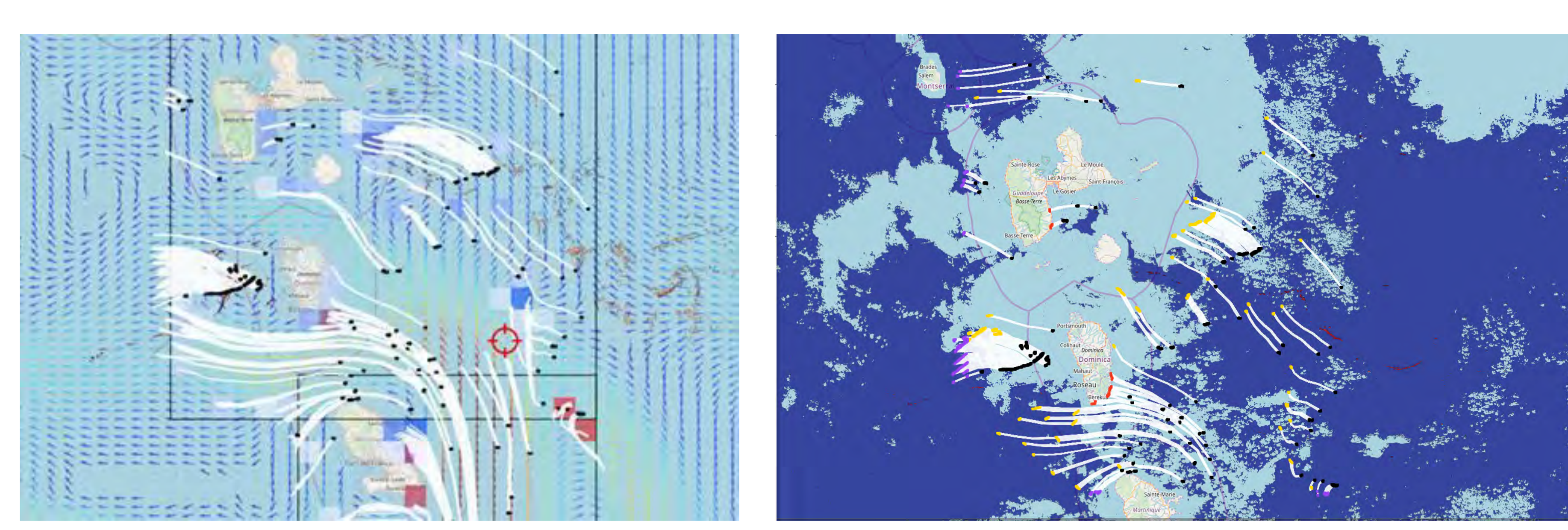

Figure 6 : Visualization of sargassum estimated trajectories overlaid on sargassum index map

4- Web interface for end-users

➢ The sargassum index map and the results of the drift simulation are provided to the end-user through a dedicated and dynamic website (see Figure 7). Analysis of the sargassum situation for a specific area is done by a local expert who produces the situation bulletin.

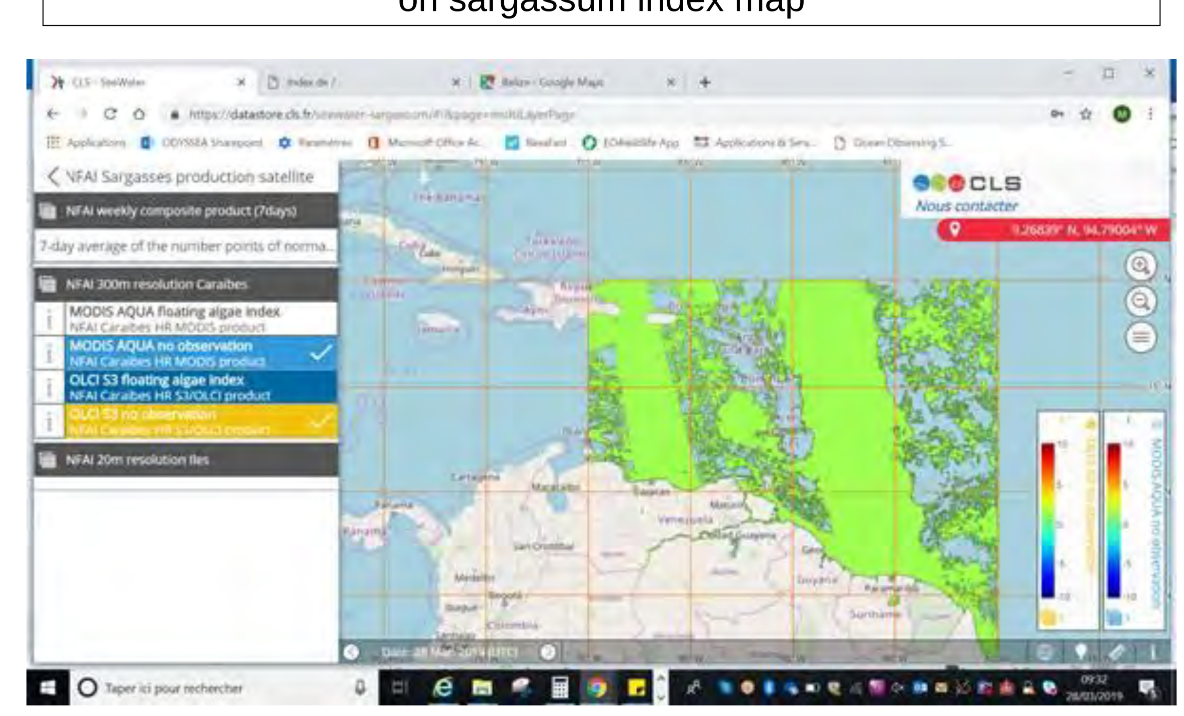

Figure 7 : An example of the Web interface for end-users

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