SUPPLEMENTARY MATERIALS: DEFINITION OF PARAMETERS, USEFULNESS OF THE SCRIPT AND ADDITIONAL EXAMPLES

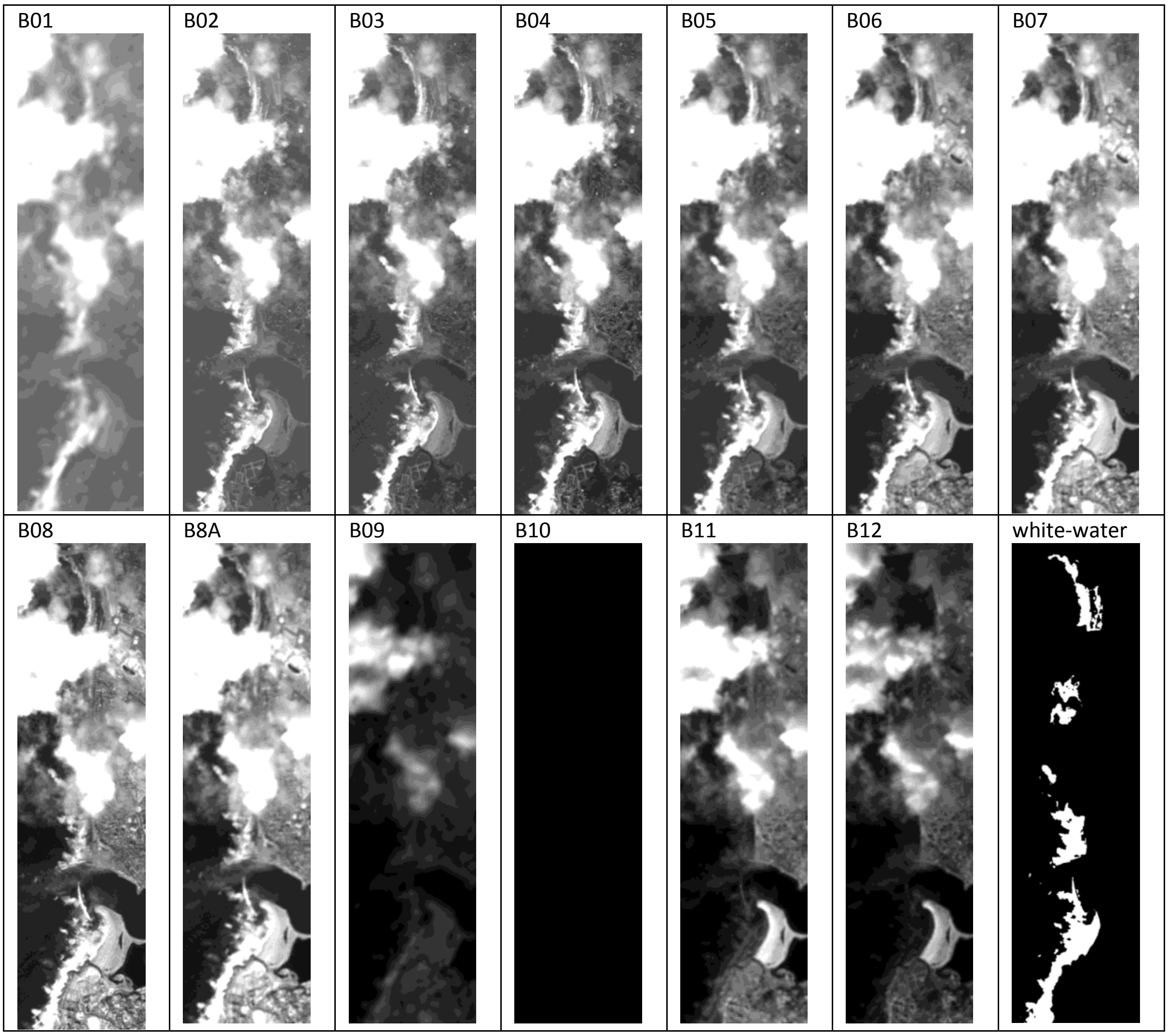
DEFINITION OF PARAMETERS FOR WHITE-WATER DETECTION

Script band and parameter values to define white-water zones were done on a basis of statistical analysis and manual calibration. Testing area for statistical analysis and manual calibration was coastline of Porto on 11.1.2016. The test area includes clouds free areas (in shadow of the clouds), clouds and white-water on coastline (in shadow of the clouds) as high waves were present at that time.

Firstly, approximate manual classification for every pixel in the test area was done with defining whether white-water is present or not. With Python, Machine Learning was tested (Decision Tree Classifier), but results were not adequate as it defined very small area of possible white-water zone.

Table 1 shows grayscale values for every band on the test area and manually identified white-water zones.

Table 1: Test area with grayscale values for every band and identified white-water zone.



Therefore, methodology to define algorithm for custom script on white-water detection is based on statistical analysis of 13 bands and different indices (NDSI, NDWI, NDVI, moisture) with manual calibration (Figure 1).

Manual classification as white-water

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B8a	ndwi	moist	ndsi	ndvi
count	13384	13384	13384	13384	13384	13384	13384	13384	13384	13384	13384	13384	13384	13384	13384	13384	13384
mean	0.796	0.810	0.791	0.833	0.820	0.773	0.792	0.742	0.166	0.004	0.221	0.125	0.760	0.040	0.543	0.560	-0.066
std	0.115	0.139	0.151	0.152	0.157	0.177	0.174	0.188	0.049	0.001	0.055	0.036	0.187	0.063	0.097	0.099	0.062
min	0.427	0.475	0.455	0.506	0.447	0.349	0.365	0.310	0.043	0.000	0.059	0.031	0.286	-0.126	0.041	0.190	-0.257
25%	0.714	0.698	0.667	0.706	0.690	0.620	0.639	0.580	0.129	0.004	0.176	0.098	0.596	-0.004	0.500	0.496	-0.106
50%	0.784	0.808	0.788	0.855	0.835	0.769	0.796	0.733	0.157	0.004	0.224	0.122	0.753	0.023	0.554	0.565	-0.059
75%	0.878	0.941	0.937	0.996	0.992	0.961	0.988	0.929	0.192	0.004	0.263	0.149	0.969	0.080	0.604	0.629	-0.008
max	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.365	0.008	0.408	0.224	1.000	0.257	0.808	0.858	0.203

Manual classification as not white-water

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B8a	ndwi	moist	ndsi	ndvi
count	162664	162664	162664	162664	162664	162664	162664	162664	162664	162664	162664	162664	162664	162664	162664	162664	162664
mean	0.615	0.556	0.500	0.491	0.500	0.541	0.565	0.540	0.221	0.005	0.416	0.309	0.565	0.003	0.228	0.189	0.019
std	0.207	0.241	0.261	0.278	0.275	0.287	0.293	0.302	0.218	0.004	0.304	0.247	0.309	0.202	0.166	0.292	0.200
min	0.380	0.271	0.184	0.122	0.133	0.122	0.122	0.094	0.020	0.000	0.027	0.020	0.086	-0.601	-0.177	-0.397	-0.394
25%	0.451	0.357	0.294	0.263	0.282	0.286	0.294	0.259	0.090	0.004	0.157	0.118	0.271	-0.118	0.105	0.000	-0.122
50%	0.533	0.459	0.396	0.384	0.400	0.502	0.545	0.514	0.157	0.004	0.373	0.259	0.561	0.000	0.204	0.088	0.000
75%	0.733	0.698	0.635	0.671	0.678	0.753	0.812	0.784	0.235	0.004	0.557	0.408	0.843	0.154	0.340	0.393	0.107
max	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.047	1.000	1.000	1.000	0.432	0.783	0.828	0.704

statistical identificator for limit of the band/index used in w hite-w ater detection

statistical identificator for limit of the band/index used in w hite-w ater detection w ith higher probabilty

Figure 1: Statistical analysis for manual classification of pixels on white-water zone (first table) and on not white-water zone (second table).

The best approach to start classification is to determine for every pixel if it is land or water. In theory, NDWI criteria should be the most appropriate one. Nevertheless, even with low limit (NDWI >= - 0.1) it overestimates water presence and with higher limit (etc. NDWI >=0) it underestimates water area. Especially white-water areas are then defined as land areas. Therefore, classification on land or water is done with NDSI (Normalised Difference Snow Index) criteria. Next, moisture index was used as white-water zones moisture above the water surface is higher. For additional identification on land or water area, NDVI index was used. In addition, later index can be used to correct any false detection of white-water on land area. For purpose of eliminating cloud in white-water detection, B10, B12 and B11 bands limits were used. Later two bands (B12, B11) and B04 band with statistical analysis comparison between manual classifications (white-water and not white-water zones) show distinct differences. In addition, tested machine learning showed B04 band as the first criteria for classification. In theory, B04 band should not (effectively) reflect from water surfaces. On contrary, reflection from white-water is high.

For identification for areas with higher probability for white-water, stricter limits on index NDSI and bands B11 and B04 were added.

USEFULNESS OF THE SCRIPT

Custom script can be used for mapping white-water zones. Primary, focus is on detection of white-water on the coastline. Secondly, it can be also used for detection of white-water on rivers.

Nevertheless, later use is limited as the best available spatial resolution for bands is 10 meters. In case of better resolution (etc. 2 meters), white-water detection on smaller rivers would be viable.

The most beneficial way to analyse white-water zones is with multi-temporal analysis. With sufficient sample size (regular data collection in significant number of years), we can identify coastline zones with certain white-water presence in different high waves conditions (swell size, direction, period, tide level, etc.).

In the coastal zone, main cause of white-water is wave breaking. Another expression for white-water zone generated by wave breaking is surf zone. The phenomena involves chemical, physical and biological processes. Very important process is wave energy dissipation. In addition, heat and gas transfer occurs between air and water. Identified phenomena's create special habitat.

White-water mapping is beneficial in different areas:

- Erosion level evaluation. By wave energy dissipation erosion of coastline and bathymetry is present. In addition, low waves breaking could result in sedimentation. Generally, wide zone of white-water perpendicular on the coastline means that higher waves are breaking on this zone and/or wave energy dissipates gradually. On the other hand, narrow zone of white-water could mean that low waves are breaking or dissipation of wave energy is abrupt, which results in higher erosion potential. Like this, we can identify dangerous erosion areas. In addition, also erosion free or low erosion areas can be identified. If main coastline is behind a (submerged) reef, zone between reef and main coastline is less exposed to erosion caused by wave breaking phenomena. Reef or submerged reef can be identified by white-water zone.
- Bathymetry slope. In connection with zone wideness, general bathymetry slope can be evaluated. Wide zone imply low slope. Narrow zone imply high slope.
- Civil engineering. Potential locations for new port could be identified as it should not be an area with abrupt energy dissipation, if possible not in surf zone and bathymetry should not be shallow. Nevertheless, identification of potential locations by Sentinel data and custom script is only approximate as highest waves usually occur with storm present on the coastline, meaning there is cloud coverage. Therefore in time of the highest waves, no Sentinel data is available on wave breaking. In addition, already described erosion level evaluation is important in civil engineering. It can identify where coast protection structures or measures are necessary.
- Maritime navigation. Similar to later potential locations for new ports, it can be identified, where anchoring in high waves situation is not recommendable. In addition, white-water zones identify dangerous routes with (submerged) reefs.
- Wave hydrodynamics. Swell direction can be evaluated on basis of comparisons of zones where white-water is present and where it is not present. Yearly comparison of white-water zones can be made. Later could identify any pattern change in predominate swell direction with high waves. For example, Portuguese coast receives highest waves from northwest swell as in that direction most intensive storms are generated in the winter. If general pattern would change (climate change), that would be very important. For an instance, all ports are mainly protected by breakwaters on northwest direction or there are the strongest breakwaters.
- Surf zone habitat. Surf zone or white-water zone is special habitat. Generally, wave climate affects diversity and abundance of inhabitants (plants, animals). Therefore multi-temporal analysis can identify surf zone habitats.

- Improvement of bathymetric mapping from multi-temporal analysis of Sentinel 2 data (https://www.adv-geosci.net/45/397/2019/adgeo-45-397-2019.pdf). For later analysis it was identified, that high sea state could cause inferior results. With the use of proposed custom script, only summer data analysis could be replaced with all year data with no or low detection of white-water (absence of white-water imply low sea state).
- Wave breaking numerical modelling. Wave breaking numerical modelling is still far from good evaluation of real wave breaking. Nevertheless, white-water zone identification with the custom script could help improve wave breaking numerical modelling in case of validating model on a real case scenario.
- Detection of new reef or island. New white-water zone in latest data can imply reduction in water depth (atolls, artificial islands) which could still be under water, but close to surface as low bathymetry causes higher waves to break.
- Wind conditions detection. High wind speed can cause wave breaking in high depths where bathymetry does not affect wave's propagation.
- Ships location. Ships with higher speed cause wake, which results in white-water, which can be detected by the proposed custom script.
- Surfing. New surfing spots could be identified by white-water zones detection. Especially A-frame and point break types of wave could be identified.

There are also 3 alternative ways to use this custom script.

It can detect white-water on rivers. Meaning it can identify abrupt slope changes in river bed and/or high water flow in the river bed. Therefore, we can predict possible river infrastructure, rapids and waterfalls locations.

In combination with tide charts, rise of the sea level or expanded reach of water inland could be identified with multi-temporal analysis. Nevertheless, this can be already done only with water surface detection in case of low sea state when no or low white-water is present.

As custom script is based on NDSI and B10 band, custom script can be also used for snow and ice detection except on high altitudes. Multi-temporal analysis can show maximum reach of snow, ice or glacier yearly or for longer period of time.

Applicability of the script:

Script is generally globally applicable on coastal zones in case of coastal white-water detection. If snow, ice and white-water are all present, script is not able to differ between them.

In case of white-water detection on rivers, script is applicable on bigger and wider rivers, where no snow and ice is present. In addition, river should not have higher amount of floating sediment.

In case of snow and ice detection, script is applicable on snowy and ice zones, except on high-altitude terrain.

Script works the best while no clouds are present. Nevertheless, higher waves and wider white-water zones could be detected with presence of clouds. In addition, white-water in the shadow of a cloud sometimes is not detected.

It is needed to stress that in case of white-water detection on coastal zone and rivers, there is a high probability that extend of white-water in multi-temporal analysis is not maximum as highest waves and highest flows usually occur in a storm; meaning clouds prevent detection of white-water.

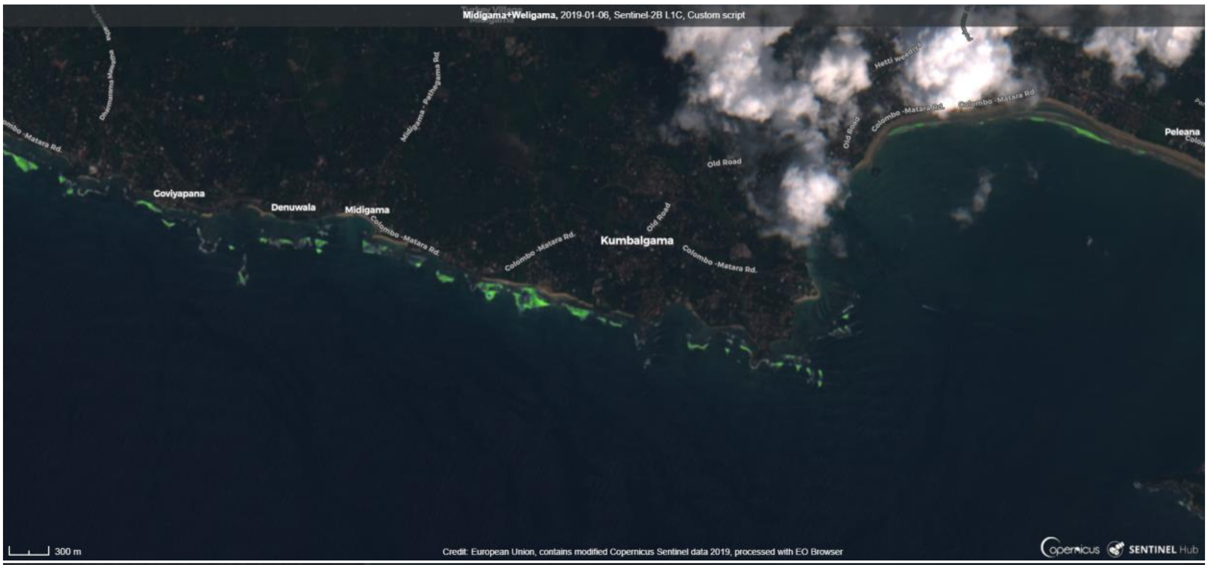
<u>False detection problems:</u>

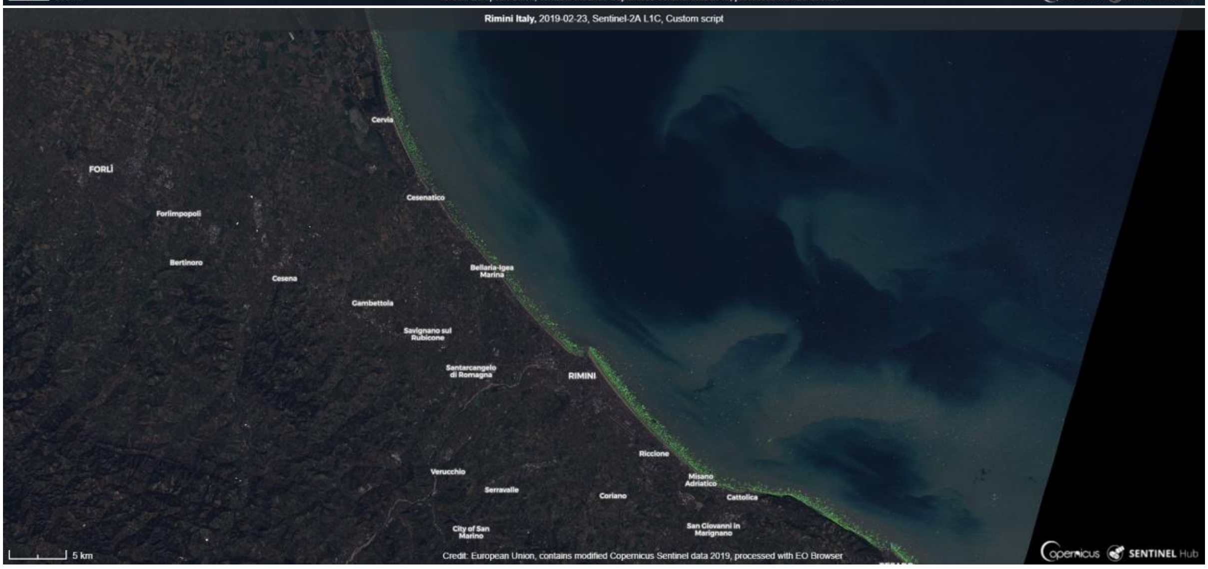
In cloudy conditions, script can falsely detect cloud as white-water. Also white-water detection on river with snow and ice coverage, everything is defined as white-water.

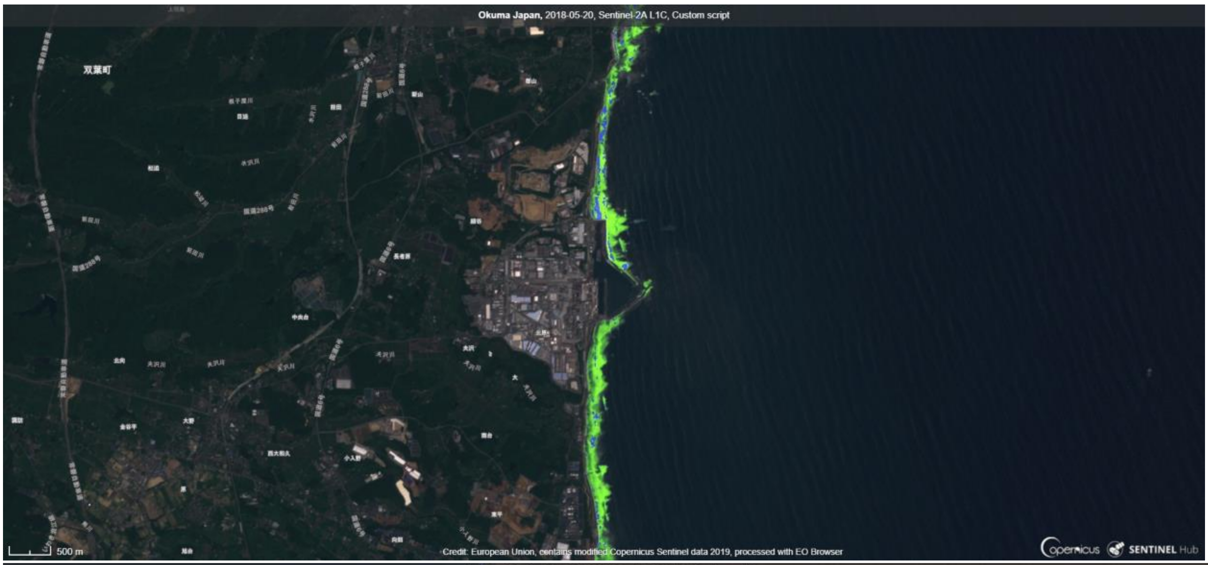
In some cases, shallow coastal waters with bright colour bed can be falsely detected as white-water.

ADDITIONAL EXAMPLES

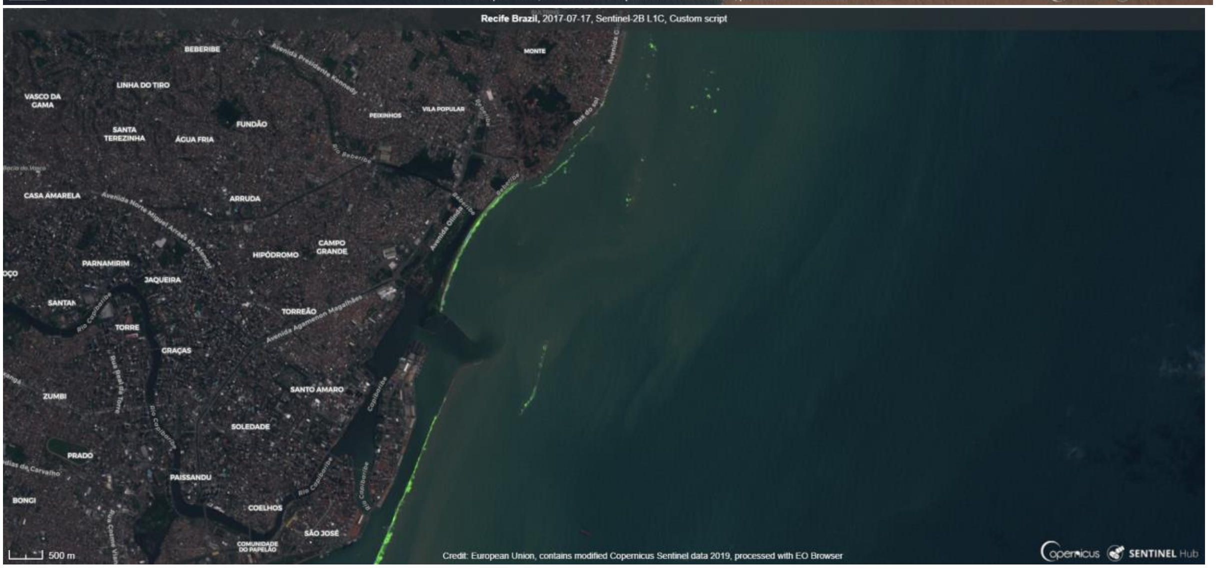
Below are other examples of custom script analysis for individual images.

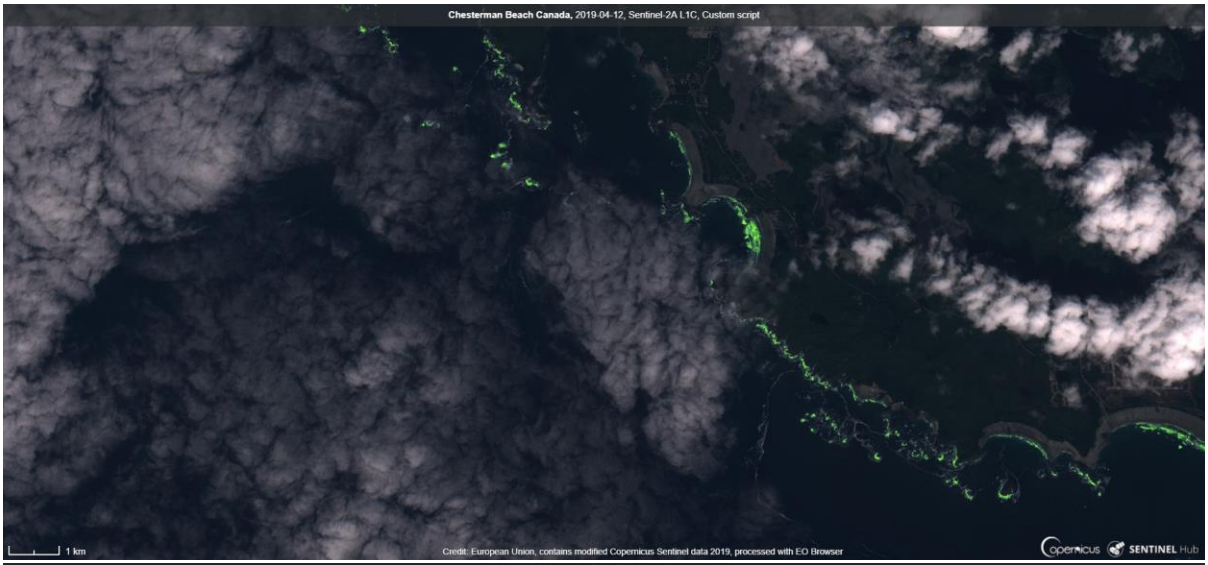


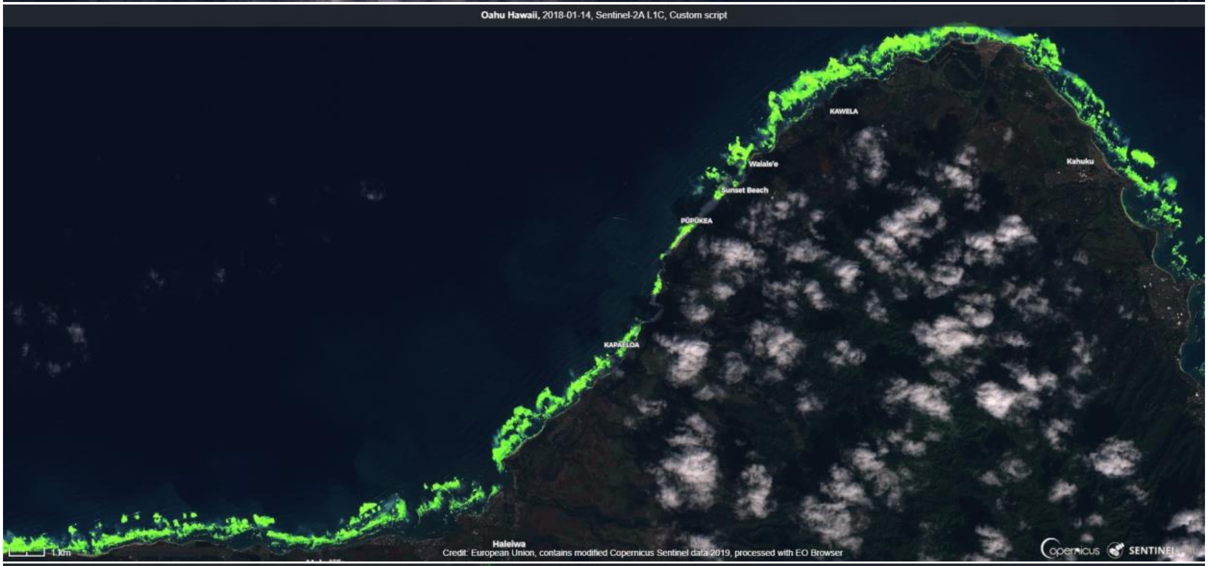


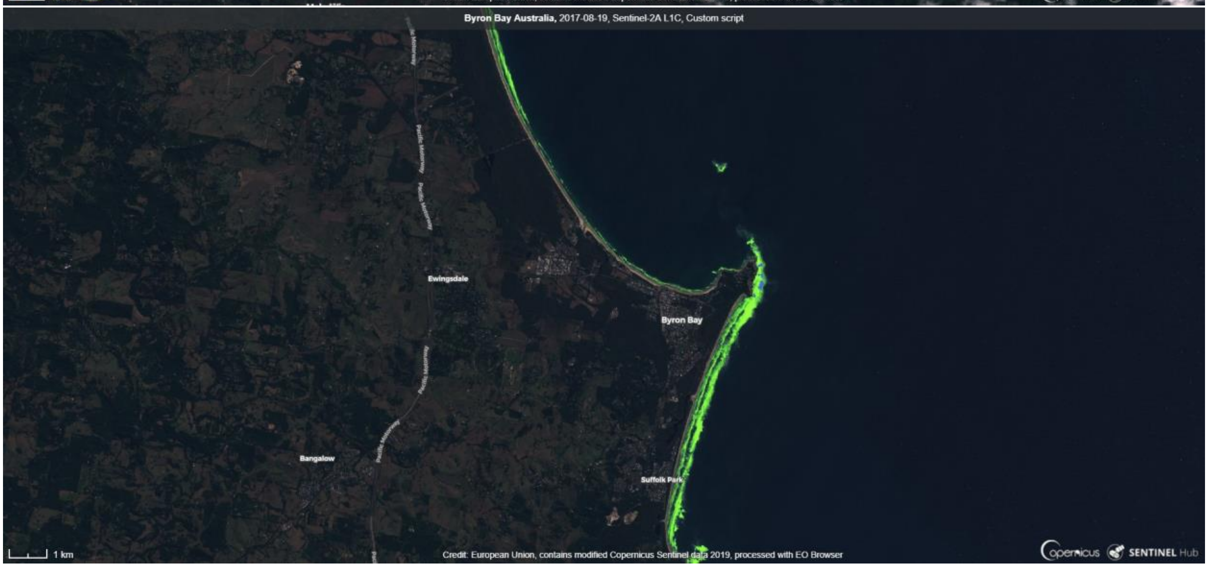

Okuma Japan, 2018-05-20, Sentinel-2A L1C, Custom script
500 m
Credit: European Union, contains modified Copernicus Sentinel data 2019, processed with EO Browser


Skeleton Bay Namibia, 2016-12-11, Sentinel-2A L1C, Custom script
1 km
Credit: European Union, contains modified Copernicus Sentinel data 2019, processed with EO Browser


Recife Brazil, 2017-07-17, Sentinel-2B L1C, Custom script
500 m
Credit: European Union, contains modified Copernicus Sentinel data 2019, processed with EO Browser


Chesterman Beach Canada, 2019-04-12, Sentinel-2A L1C, Custom script
1 km
Credit: European Union, contains modified Copernicus Sentinel data 2019, processed with EO Browser
Copernicus
SENTINEL Hub


Oahu Hawaii, 2018-01-14, Sentinel-2A L1C, Custom script
KAWELA
Waiale'e
Kahuku
Sunset Beach
PŪPŪKEA
KAPAELOA
Haleiwa
1 km
Credit: European Union, contains modified Copernicus Sentinel data 2019, processed with EO Browser
Copernicus
SENTINEL


Byron Bay Australia, 2017-08-19, Sentinel-2A L1C, Custom script
Ewingsdale
Byron Bay
Bangalow
Suffolk Park
1 km
Credit: European Union, contains modified Copernicus Sentinel data 2019, processed with EO Browser
Copernicus
SENTINEL Hub

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