UiT The Arctic University of Norway

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Investigation of ballast water conditions using remote sensing

Suspended Particulate Matter Characterization in Emden Sea Port

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Glossary

AIS	Automates Identification System
BWM	Ballast Water Management
BWMS	Ballast Water Management System
CFU	Colony-Forming Unit
CLI	Command Line Interface
DSF	Dark Spectrum Fitting
ESA	European Space Agency
EXP	Exponential Extrapolation
GUI	Graphical User Interface
IMO	International Maritime Organization
L1C	Level-1C
L2A	Level-2A
MSI	MultiSpectral Instrument
NaN	Not a Number
RBINS	Royal Belgian Institute of Natural Science
SPM	Suspended Particulate Matter
SWIR	Short Wave Infrared
UV	Ultraviolet
VNIR	Visible and Near Infrared
WHO	World Health Organization

Abstract

This thesis investigates the use of remote sensing techniques to study the conditions of ballast water in the northwestern port of Emden, Germany. Sentinel-2 data of the seaport has been collected and used in order to retrieve the suspended particulate matter (SPM), evaluating its distribution and checking for any time or spatial periodicity over the past 5 years. The aim of the study is to provide insights into the variability of ballast water conditions and identify potential areas of concern when loading the tanks of their ships, avoiding the spread of invasive aquatic species into new bioregions. Overall, this research highlights the potential of remote sensing techniques as an alternative to ground infrastructure in monitoring and managing ballast water conditions in ports and other aquatic environments.

1 Introduction

Cargo ships represent 80% of world's merchant transport. Apart from commodities, large ships carry what is known as ballast water in their tanks to improve stability. It is estimated that 3 to 5 billion tons of ballast water is transported globally each year [1]. Some studies [2], [3] have revealed that a multitude of bacterial, plant, and animal species can survive in viable states within ballast water and sediment transported by ships, even in long-distance trips lasting several weeks. Ballast water discharge appears to be a prominent factor on the formation of alien colonies of harmful species and pathogens, seriously disrupting the existing ecological balance when ballast water and sediments are released.

The potential risk for ballast water discharge has not only been recognized by the International Maritime Organization (IMO) [4], but also by the World Health Organization (WHO), who was requested by IMO to start studies on that matter, noting that ballast water is a medium for spreading epidemic disease bacteria [5]. In order to decontaminate the water used in these operations from living organisms, ballast water management (BWM) must be implemented. However, in some sea ports the seawater happens to be too heavy (dirty) to run some of the systems required to carry out BWM control before cargo ships are allowed to sail. It is crucial to address this problem as not only the security of the ship and the crew may be compromised, but the protection of coastal and ocean environment as well.

1.1 Objectives

The objective of this master's thesis is to investigate the impact of ballast water operations in the Emden Port from 2018 to 2022, specifically focusing on identifying periodic temporal and spatial patterns of water quality within the port's waterway and quays. Accordingly, the first aim is to acquire Sentinel-2 top-of-atmosphere (L1C) data encompassing the Emden port region, and determine which fields and bands from the downloaded SAFE file can be used to investigate ballast water. The second objective involves performing atmospheric correction and generating level-2 surface reflectance (L2A) data to ensure the accuracy and reliability of the information obtained. The ultimate goal is to detect and analyze the variations of the studied parameters along the waterway during the investigated timeframe. The objective of this study is to offer valuable insights that can guide future efforts in the management of ballast water.

1.2 SHIPTRACK Project

SHIPTRACK project is a joint collaboration between multiple organizations, comprising researchers from shipping-related backgrounds at NHH/SNF, experts in satellite data at The Arctic University of Norway campus of Narvik, the remote sensing start-up VAKE.ai, the shipping companies Utkilen and Western Bulk and the Bergen Shipowners' Association.

The interdisciplinary nature of the project aims to merge data from automated identification systems (AIS), optical images, and satellite data as a novel method for tracking ships automatically. By combining remote sensing technologies with new approaches for classifying commodity types and tracking stored volumes (both dry and liquid bulk), the project produces a highly effective tool that enhances visibility in commodity supply chains and bulk freight markets.

Inside this framework, they came up with another interesting matter: the water in some ports seems to be too heavy to run some of their systems, leading to time delays. Thus, insights contributing to spatial resource allocation, estimation of uncertainty in demand, transportation planning and restocking decisions are needed to guarantee safer and more efficient transportation and prevent illicit activities.

2 Background and Theory

2.1 Ballast Water

Before an empty cargo can navigate, it may need to fill its ballast tanks with water to equip the vessel with additional weight when it is transporting light or no cargo. This procedure is executed to provide the boat with extra stability, maintaining its balance in water. This water will later be discharged at the destination port. A representation of this procedure is shown in figure 1.

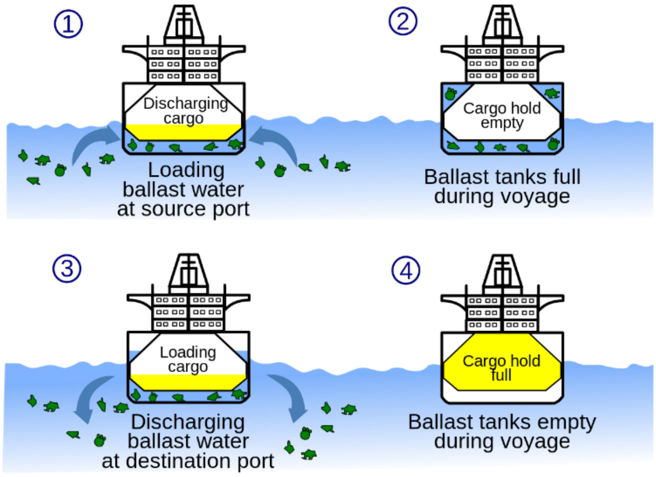

Figure 1 – Transfer of bio-species due to ballast water operation. Source: MaxxL, Water pollution by ballast water de.svg, CC BY-SA. https://commons.wikimedia.org/w/index.php?curid=33556135.

However, the water used to fill the tanks carries microorganisms like bacteria, plankton, zooplankton and other small invertebrates that are found in the original environment, but when transported to another zone can negatively affect the new bioregion, where they could become invasive species and disrupt local ecosystems. Some of these living species may die inside the tanks, others in the discharge process or once they are introduced in the new environment, while part of them may live in a viable state.

The introduction of alien species in areas in which other species are found is one of the greatest environmental and economic threats and, along with habitat destruction, a leading cause of global biodiversity loss [6].

First signs of alien species introduction were recognized after an influx of the Asian phytoplankton algae Odontella (Biddulphia sinensis) in the North Sea in 1903 [7], but it was not until the 1970s that it caught special attention to the scientific community [8], who began to evaluate in detail this issue.

It is estimated that ballast water is the responsible of carrying between 3000 and 10000 species globally in any given 24-hour period [9].

2.1.1 Ballast Water Management

As shipping is, if not the most, one of the primary international industries, legislation on this matter involves the creation of an international standard. For this purpose, the International Maritime Organization, who holds responsibility for developing global standards for ship safety and protection of maritime environments, adopted the International Convention for the Control and Management of Ships' Ballast Water and Sediments [10] in 2004. To prevent the spread of invasive species, vessels are required by the IMO to treat their ballast water before discharge. This organization currently has 175 member states and three associate members.

Starting in September 2017, the convention made it mandatory for ships that use ballast water to implement a ballast water management plan, including a ballast water record book and carrying out BWM procedures in a standardized manner. IMO issued two standards regarding this matter: the D-1 standard and the D-2 standard [11].

The D-1 exchange standard requires ships to conduct an exchange of ballast water such that at least 95% of the volume of the water is exchanged far away from the coast (i.e. at least 200 nautical miles from land and in water at least 200 meters deep).

The D-2 water performance standard specifies that ships can only discharge ballast water under the following criteria:

- Less than 10 viable organisms per cubic meter which are greater than or equal to 50 μm in minimum dimension.
- Less than 10 viable organisms per ml which are between 10 μm and 50 μm in minimum dimension.
- Less than 1 colony-forming unit (cfu) per 100 ml of Toxicogenic Vibrio cholerae.
- Less than 250 cfu per 100 ml of Escherichia coli.
- Less than 100 cfu per 100 ml of Intestinal Enterococci.

BWM involves many innovations by adopting different combinations of physical, mechanical and chemical methods. Latter ones have to go through a deeper approval process.

Ballast water can be treated when ballasting or during the process of discharging. However, IMO-approved BWMS may fail to treat seawater when ballasting in highly suspended particulate matter concentration environments due to filter clogging or insufficient generation of oxidants [12].

In some scenarios such as emergencies or due to technical issues with BWMS, the bypass mode may be used as a temporary solution. The bypass mode is what is known when no treatment of any kind is applied when discharging the water into the ocean. The BWM Convention does not allow any bypass unless there is an emergency situation for the vessel. IMO issued the circular "Contingency measures circular" (BWM.2-Circ.62) [13] as a guide on contingency measures. In any case, the ship is required to do its best to correct the malfunction of the BWMS as soon as possible, reporting a repair plan to the seaport control authorities, as stated in the circular.

2.1.2 Ballast Water Treatment

Ballast water treatment can be conducted either in ports or onboard vessels, with the latter option being relatively more convenient for implementation due to the availability of primary and secondary treatment methods [14]. The treatment process involves various techniques such as physical separation, mechanical procedures, or chemical treatments.

Treatment in port

Depending on when the water is treated there are two approaches:

Treatment before filling ballast tanks. This approach uses already cleaned water to fill the vessels tanks. Ports using cleaned water as ballast must have a treatment facility to clean seawater. This facility has to be unique to each port as each environment has its own marine species.

Treatment after discharging. If ballast tanks were filled with untreated water at the home port, then ballast water can be treated after deballasting in on-shore treatment facilities. Treated water can then be used again as ballast water for other ships, which will exchange its untreated water for the treated one.

Treatment on board

Primary treatment involves physical separation techniques such as filtration and cyclonic separation, which uses pressure of the upcoming fluid to generate a centrifugal force that separates liquid from particles with different densities. Filtration can remove more than 70% of zooplankton and phytoplankton while hydro cyclones are less effective (30% with plankton while useless against bacteria), but are used to remove sediments and solids [15].

Secondary treatment uses mechanical and chemical methods.

- Mechanical separation involves the use of ultraviolet (UV) radiation, heat treatment or electric pulses able to kill or deactivate organisms so they no longer pose a threat in new environments. Heat treatment requires a temperature of 40ºC in a short time interval (between 30 to 90 seconds) to deactivate unwanted living microorganisms [16]. Heat waste from the vessel’s engines can be used to warm up water, although additional heat sources have to be installed onboard to heat the complete volume of the tank. Microwaves and ultrasound are also used as secondary treatment.
- Chemical separation is the most effective method. Biocides like chlorine, chlorine dioxide or ozone are amongst the most used substances. The easy application of these substances and the great variety of substances make chemicals methods an attractive technique widely used, typically achieving removal rates of >95%.

Secondary treatment techniques are more effective and can achieve 100% removal of some organisms like microalgae, while achieving >90% of zooplankton, phytoplankton and bacteria removal. Primary treatment is combined with secondary treatment, typically Filtration + UV, Cyclonic separation + UV or UV + Chemical disinfectant.

2.2 Remote sensing: Sentinel-2

The Copernicus Sentinel-2 is a European Space Agency (ESA) satellite mission which comprises a constellation of two polar-orbit satellites phased at 180º to each other, with a revisit time of 5 days in the Equator [17].

Sentinel-2 satellites have one single payload, where a MultiSpectral instrument (MSI) is equipped in it. With an orbital swath of 290 km, MSI works passively, collecting sunlight scattered reflectance and providing multi band high-resolution optical images of the Earth's surface.

Sentinel-2 MSI samples 13 spectral bands with different resolutions, as shown in table 1 [18].

Table 1 - Sentinel-2 MSI bands

Band	Spatial Resolution	Central Wavelength	Description

B1	60 m	443 nm	Ultra Blue
B2	10 m	490 nm	Blue
B3	10 m	560 nm	Green
B4	10 m	665 nm	Red
B5	20 m	705 nm	Visible and Near Infrared (VNIR)
B6	20 m	740 nm	Visible and Near Infrared (VNIR)
B7	20 m	783 nm	Visible and Near Infrared (VNIR)
B8	10 m	842 nm	Visible and Near Infrared (VNIR)
B8a	20 m	865 nm	Visible and Near Infrared (VNIR)
B9	60 m	940 nm	Short Wave Infrared (SWIR)
B10	60 m	1375 nm	Short Wave Infrared (SWIR)
B11	20 m	1610 nm	Short Wave Infrared (SWIR)
B12	20 m	2190 nm	Short Wave Infrared (SWIR)

Users can freely access this data via the Copernicus Open-Access Hub.

2.3 Atmospheric correction: Acolite

Earth's atmosphere contains a range of different gases, aerosols, and water vapor that absorb, scatter and reflect the incoming solar radiation and the one emitted by the Earth's surface. These atmospheric effects can lead to errors in the satellite measurements and reduce the accuracy of the derived geophysical information.

Atmospheric correction algorithms are used to remove the atmospheric effects from the satellite data by estimating and removing the contribution of the atmosphere to the measured signal. This is typically done by using atmospheric models, satellite observation and ground measurements to simulate the atmospheric radiative transfer and estimate the atmospheric properties, such as the aerosol optical thickness, water vapor content, and atmospheric scattering properties.

While Copernicus also provides level-2 data that is atmospherically corrected, the specific focus of this project is on water bodies. Therefore, to achieve more accurate results, a specialized processor such as Acolite software [19] is required.

Acolite is a generic processor developed by the Royal Belgian Institute of Natural Sciences (RBINS) for atmospheric correction. More specifically, designed for turbid coastal and inland water applications. By default, Acolite performs the atmospheric correction using dark spectrum fitting (DSF) [20], but can be configured to use the exponential extrapolation (EXP) [21]. DSF options include aerosol correction and wind speed-based air-water interface correction used for sun glint correction.

Reflectance-derived parameters and generation of band combinations such as RGB images before and after atmospheric correction, turbidity or suspended particulate matter can be calculated by Acolite.

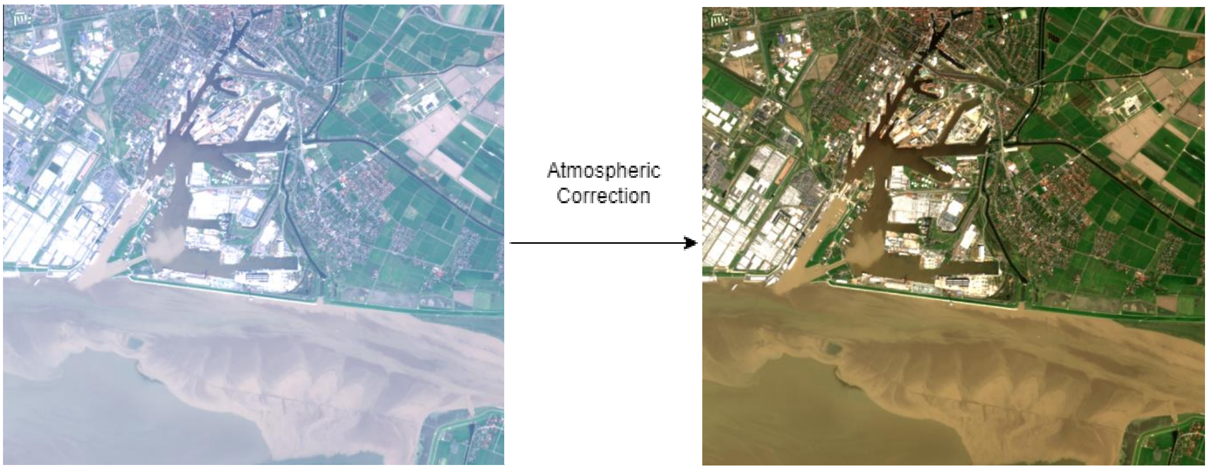

Figure 2 - Sentinel-2 data of Emden Port before (left) and after (right) atmospheric correction is applied

When processing full scenes with Acolite, very large output files will be generated. Acolite allows extraction of rectangular regions of interest (defined by bounding coordinates) inside the tile by specifying a geojson file with the coordinates defining a rectangle. Products are output as geolocated datasets in a netCDF file and can be exported as GeoTIFF and PNG images. The sensors currently supported by Acolite are Landsat (5/7/8), Sentinel-2 (A/B), Sentinel-3 (A/B), PlanetScope, Pléiades, and WorldView, amongst others.

2.3.1 Suspended particulate matter values

Excessive sedimentation can lead to the filling of waterways, impeding navigation and water transport activities. Sedimentation can make it difficult for boats to navigate through heavy water areas. This can disrupt trade, commerce, and transportation logistics. One manner to monitor sediment in water column is analyzing the suspended particulate matter found in water. Also, when ballast water is discharged into a new environment, sediment is released potentially leading to an increase in SPM concentrations in the water.

Suspended Matter Concentration (gm^{-3}) is retrieved from the reflectances caught in sensors S2A/MSI and S2B/MSI and then computed using Acolite with the algorithm of Nechad et al. (2010) [22] and recalibrated by Nechad et al. in 2016 (there is no public reference). A single band algorithm for SPM retrieval based on a reflectance model is developed and calibrated using seaborne reflectance and measurements collected in the southern North Sea area.

By default, ACOLITE will make use of the red band (i.e. 665nm) to retrieve the reflectance used for the SPM calculation. However, other wavelengths can be specified (e.g. spm_nechad2016_833 for S2B) or one of the aliases can be used for the red (spm_nechad2016_red) or NIR (spm_nechad2016_nir) bands.

The mathematical expression that relates SPM to the water reflectance is the following:

$$S = \frac{A^p(\lambda)}{1 - \rho_w(\lambda)/C^p(\lambda)} + B^p(\lambda)$$

Where $A^p(\lambda), B^p(\lambda)$ and $C^p(\lambda)$ are calibration coefficients and $\rho_w(\lambda)$ is the subsurface reflectance, which is related to the water-leaving reflectance by: $\rho_w(\lambda) = \pi R(\lambda) r_s(\lambda)$. $R(\lambda)$ represents reflection and refraction effects at the sea surface and $r_s(\lambda)$ is the subsurface remote sensing reflectance.

For the red band ($\lambda = 665\text{nm}$): $A^p = 342.10$ (gm^{-3}), $B^p = 0$ (gm^{-3}) and $C^p = 0.195630$ (dimensionless)

There is no paper reference for these re-calibrated values, but their value can be found inside Acolite folder in a txt file.

2.4 Emden Docking Infrastructure

Situated on the western bank of the Ems River, Emden port is located in the city of Emden, which is in the northwest region of Germany, about 20 kilometers upstream from the North Sea. Emden is the third-largest port [23] in Lower Saxony and an important hub for trade in the region.

Its main shipping commodity types are automotive, forest products, liquid chalk/china clay, grain/animal feed, building materials, military, aggregates, containers and wind energy components (onshore and offshore). The port is managed by Niedersachsen Ports and its subsidiary company EVAG [24] (terminals 1, 2, Nordkai, Sudkai and Außenhafen) and the private company EPAS [25] (terminals Nordkai and Südkai). Figure 3 shows the location of each terminal.

Figure 3 - Emden Port Terminal distribution. Image from EVAG Logistic Services [19]

Figure 4 shows a map with anchored (round shape) and underway (arrow shape) operating ships during regular morning.

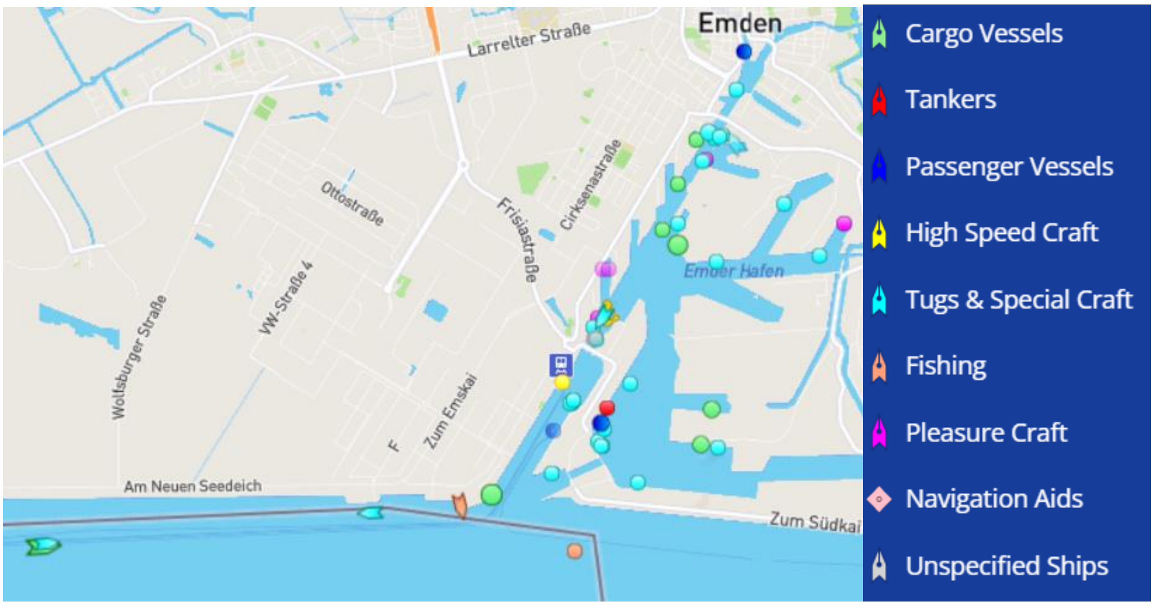

Figure 4 - Snapshot of ship movement in Emden Port on the 11/05/2023. Image extracted from MarineTraffic.

3 Methodology

A. Copernicus Data Acquisition

Level-1, top-of-atmosphere data of Emden port area during the 5-year period between 2018-2022 is obtained from the Sentinel-2 mission, acquired from Copernicus Open Access Hub. As optical bands are sensible to clouds, not all satellite passes are valid. Is for this reason that a cloud coverage requirement has been set to discard days with more than 20% of cloud coverage. This requirement filtered out images where Emden Port was hidden behind the clouds, but it led to a diminished total quantity of sample (with the constraint set, the average number of samples per year is 30) and temporal gaps without data.

B. Atmospheric correction

Atmospheric correction using dark spectrum fitting is then applied to obtain level-2, surface reflectance data. To perform atmospheric correction, Acolite version 20221114.0 has been run using a Python script via command-line interface (CLI), yet can also be run using a graphical user interface (GUI). The configuration set is:

- Target resolution set to 10 meters
- Output parameter: SPM_nechad2016 (using only the red band)
- L2w_mask = false (when true, the SPM graph showed 0 values for every coordinate in the map)
- Aerosol_correction = dark_spectrum (DSF)

C. SPM values

The SPM value for each single longitude-latitude tuple has been retrieved for each date. At this point, Not a Number (NaN) values are still considered. Then, the values for each month are grouped for every coordinate and averaged. This way, the monthly average for each point is calculated. Monthly average is done since many days have no data (due to Sentinel-2 high revisit time and cloud coverage constraint).

It is in the averaging where NaN values are excluded (if a specific point has values in some dates plus NaNs in some other days, only the values will be taken, while NaN will be skipped).

Since the interest of this study was not in the absolute values of SPM but its variation in time and space, the numeric values have been normalized to 1 with respect the maxim of all gathered samples.

$$SPM_{Normalized_i} = \frac{SPM_{value_i}}{\max(SPM_{value})}$$

Where SPM_{value_i} is the monthly averaged SPM value at point i and $\max(SPM_{value})$ is the total maximum SPM value.

<u>Results display</u>

A clear manner to display the time-space SPM variation is to plot a graph in which the x-axis represents time, y-axis is the distance and z-axis (color bar) represents the normalized amount of SPM.

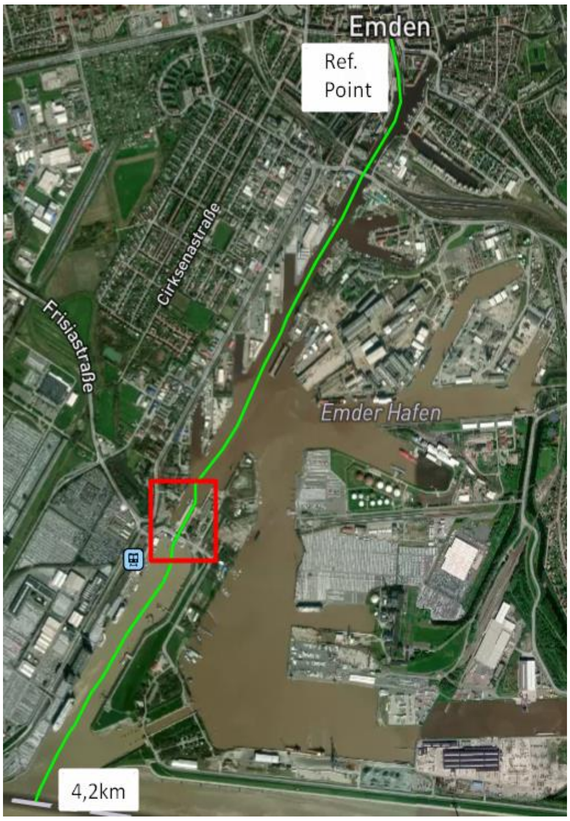

Figure 5 – Path with the tracked coordinates in Emden Port waterway (green). Lock circled in red. Image extracted from MapBox. Date: Unknown

In figure 5, the tracked path is shown with a green line. The 0 m point (the reference point) is in the upper part of the path, situated in the most inland part of the port. The lock is circled in red, situated 2.5 km far from the reference point. The path ends 4.2 km away from the reference point. Samples are taken every 20 meters.

The general block diagram for the whole process is shown in figure 6.

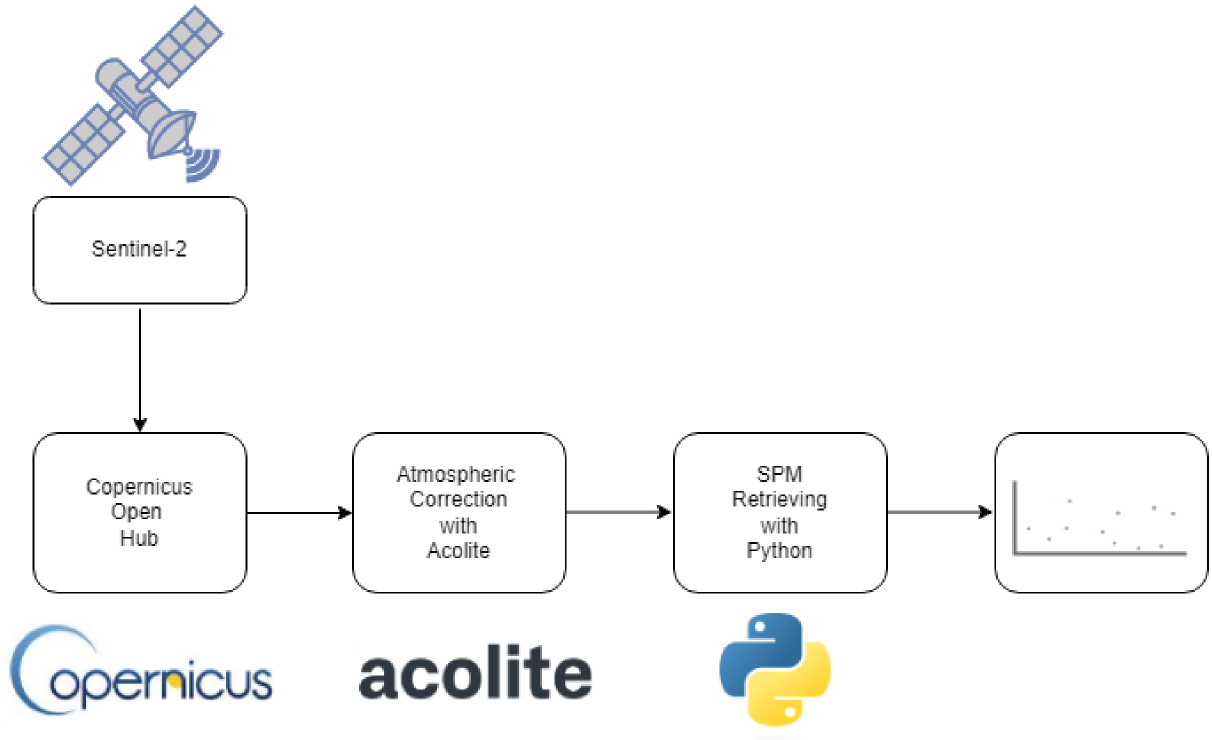

Figure 6 - Diagram Block of the performed steps from raw satellite data to SPM values

4 Results and Discussion

4.1 Time Seasonality

Localizing and understanding existing temporal patterns and factors that contribute to SPM concentration may be useful when designing management strategies in order to mitigate these impacts and improve environmental conditions.

The fluctuation of SPM values for the last five years is showed in figure 7, which displays how the suspended particulate matter varies depending on the time of the year and the distance from the reference point as explained in section 3. A value of 1 (yellow color) represents the maximum SPM concentration while 0 (dark blue) represent the minimum. Months with all values in dark blue have no data.

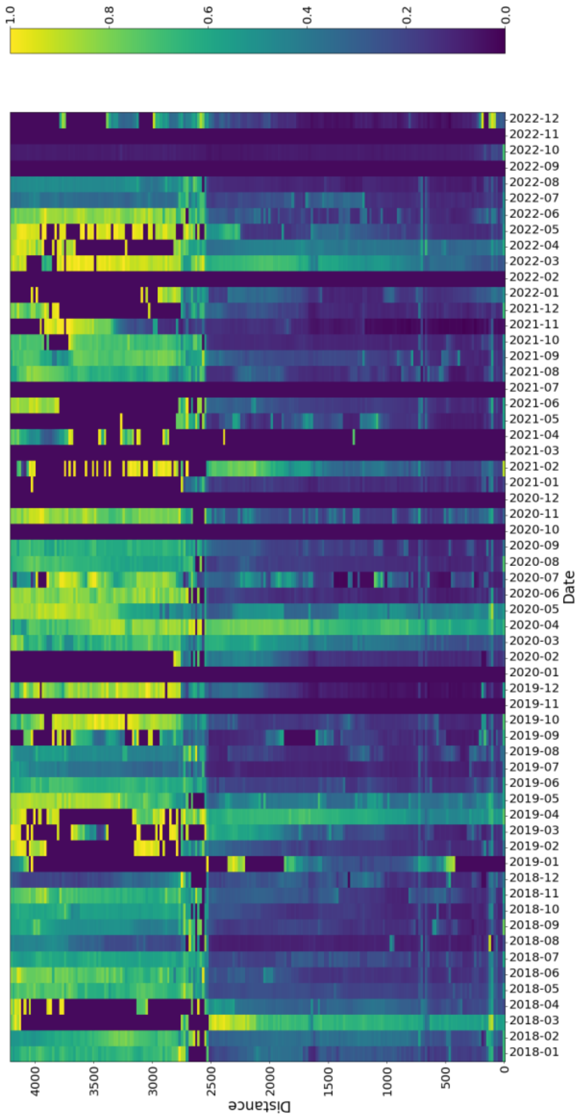

Figure 7 – Normalized SPM values along Emden seaport waterway between 2018 and 2022.

We observe how amongst each year, some months show an increased value of SPM concentration respect other months. This trend is more pronounced in the inland part of the waterway until the lock (the tidal independent zone): In 2018, February and specially March show high SPM values; in 2019 and 2020, March, April and May; in 2021, February, March and April; in 2022, March and April.

In contrast, the part outside the lock (the one nearer the sea) has a smooth transition between high and low SPM periods is smooth, yet the same periodic pattern is repeated each year; higher values are found during spring, while lower values are found during summer.

This seasonality may not be because of a single factor but several contributions:

<u>Weather and rainfall</u>: Spring is the month with more rain precipitation (see figure 8). Rain increase SPM values [26] in the port by mobilizing particulate matter from nearby land surfaces and stormwater run-off. This can result in higher SPM values in the port, especially during heavy rain and the stormwater runoff carries a significant amount of sediment delay.

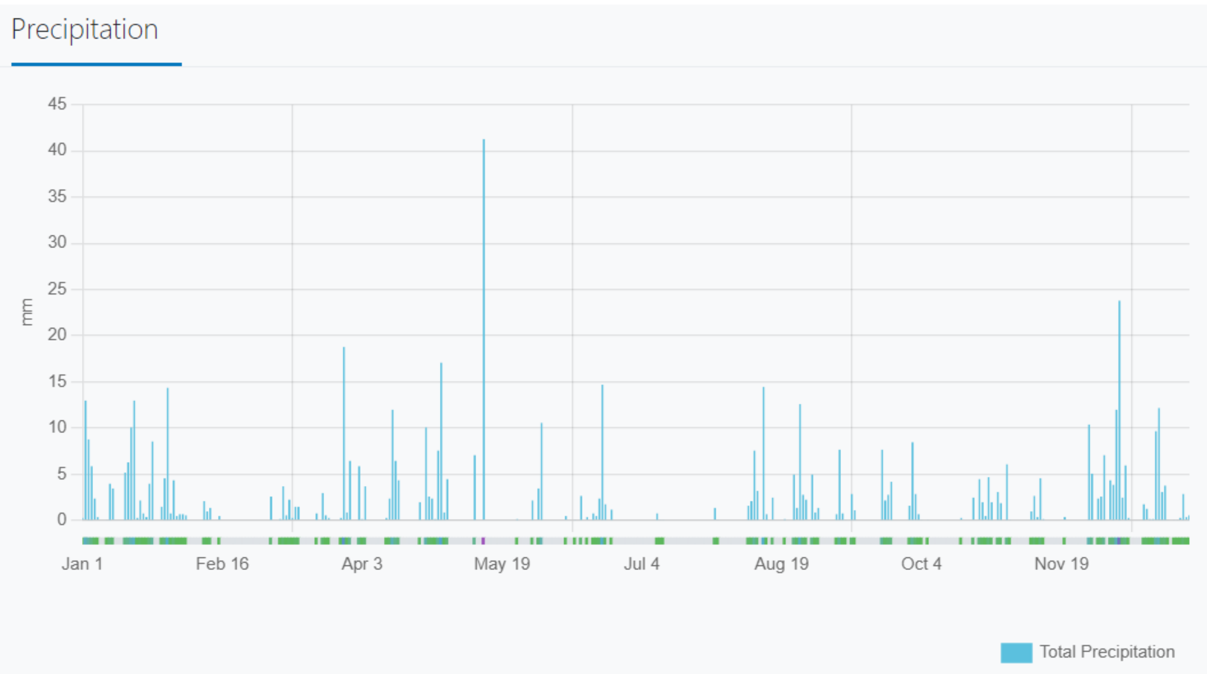

Figure 8 - Precipitation in Emden between January and December of 2018. Graphic from Meteostat

<u>Melting snow</u>: When snow melts, it carries with it sediment, organic matter, and other particulate matter from the ground and surfaces it melts from. This material can then be transported downstream by rivers and tributaries, eventually ending up in the estuary of the Ems River, which discharges in the Dollard Bay in the right part of Emden Port (see figure 9).

If the amount of particulate matter carried by the melting snow is significant, it can increase SPM concentrations in the water column of the Ems River and the port of Emden.

Human activities: The amount of industrial and agricultural activities near the river can have a significant impact on the SPM concentration. For example, during planting and harvesting seasons, there may be more run-off from fields that could contain sediments, increasing the SPM concentration.

Tidal fluctuations: The tidal cycles of the sea can influence the flow of water in the Ems River affecting the SPM concentration. During high tide, the sea water may push upstream and increase the flow of water in the river, while low tide may cause the river to slow down, allowing SPM to settle, as sedimentation is favored in slow flow.

Figure 9 - Satellite view of Emden Port, Dollard Bay and Ems River. Image extracted from MapBox

4.2 Spatial Variation

Higher concentration values are found at the final part of the waterway, outside the lock at the sea side, while lower values are found in the inland part of the channel, as seen in figure 10.

The high SPM concentration in the sea side is heavily influenced by the Ems River. It can be seen that Ems River itself has the higher concentration values.

The lower values of SPM observed in the inland part of the channel may be due to factors such as lower water flow, reduced wind and wave action and the effect of the lock, which eliminates any influence of tides and ensures a consistent water level. These may lead to less resuspension of sediment and particulate matter from the bottom of the channel.

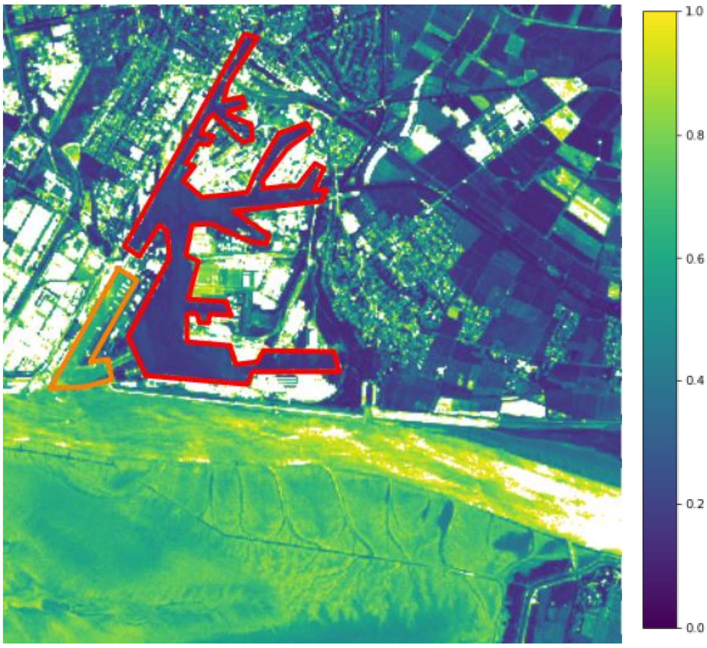

Figure 10 - High (orange) vs low (red) SPM concentration for the day: 22-07-2019

A value of 1 (yellow/white color) is the maximum while 0 (dark blue) represent the minimum SPM value.

Figure 11 shows the suspended particulate matter near the quays of each terminal (go to figure 2 to see terminal distribution of the Port of Emden).

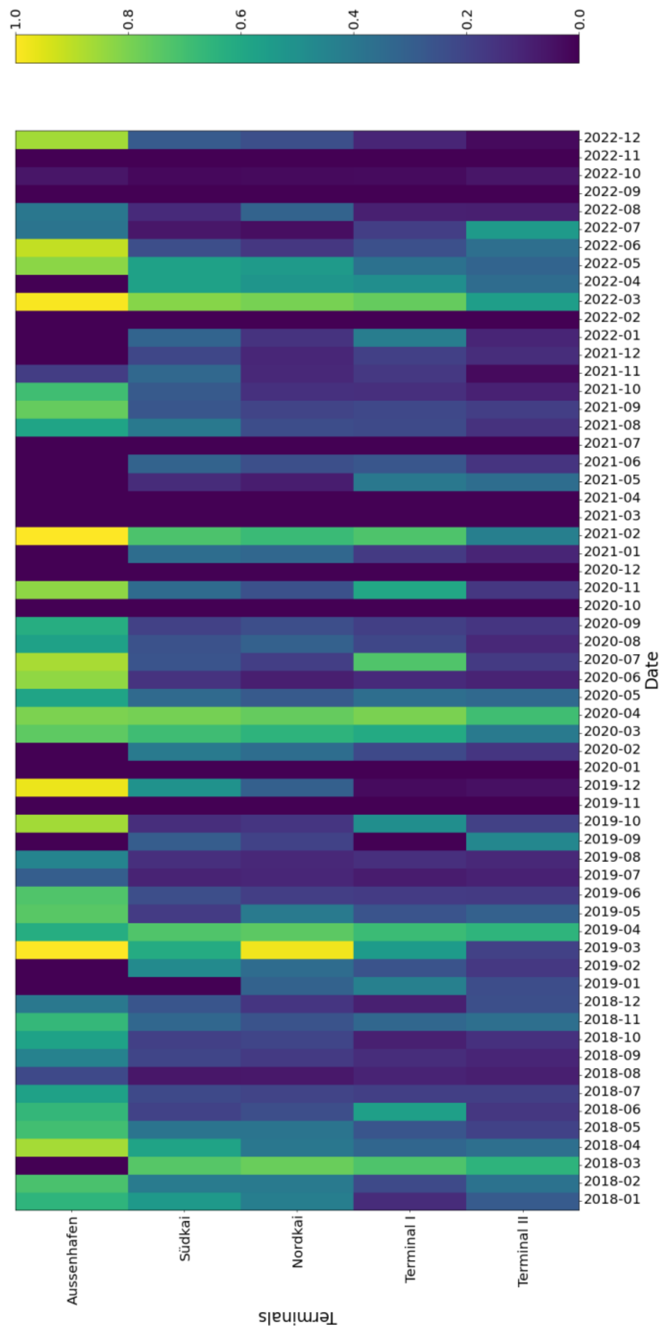

Figure 11 - Normalized SPM values for Emden terminals between 2018 and 2022

The terminals of the Emden Port located in the inside part of the harbor exhibit minimal differences between them, while Aussenhafen terminal has a greater SPM concentration.

5 Conclusion

The analysis of Sentinel-2 data has provided conclusive evidence of an annual pattern in suspended particulate matter within the Emden seaport area, consistently exhibiting elevated levels during the spring season.

While Sentinel-2 data can be utilized to observe long-term seasonal patterns and monthly trends, it is important to note that satellite imagery has limitations in terms of temporal resolution, making it unfeasible to analyze daily variations. Moreover, cloud coverage exacerbates this challenge, particularly in regions characterized by frequent cloudiness.

Regarding spatial distribution, the section within the inner part of the waterway of the port generally exhibits lower SPM concentrations when compared to the outer part of the port. This disparity is likely attributed to the independence of this area from tides, as well as its more stable and lower water flow compared to the outer part of the port. Thus, less sediments are carried or resuspended in the water columns.

This information holds significance when planning the ballasting procedure before sailing into the sea. Ships departing from quays with high SPM concentrations may need to exercise extra caution in their ballast water management planning, as their filters may become clogged due to the presence of suspended solids. On the other hand, ships sailing from low SPM concentration areas may face fewer challenges in this regard.

SPM is a good indicator when checking for sediments transportation and water treatment processes or management, and can provide helpful information for port and ballasting management. Nevertheless, it can be expected that the SPM concentration in the Emden Sea Port area is influenced by a combination of both natural and human factors. Therefore, maintaining regular monitoring of the water quality in the Emden Port is imperative in order to gain more precise insights into more accurate ballast water contribution and to identify potential environmental or human health consequences.

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Appendix

A. Workplan

Chronology of tasks and events is displayed.

I. Work packages

Table 2 - Work package with description of the tasks performed

<table>
<tr><td>Project: General research in Sentinel-2 data, ocean color and understandment of the problem</td><td colspan="2">WP ref: (WP 1)</td></tr>
<tr><td>Major constituent: Information research</td><td colspan="2">Sheet 1 of 6</td></tr>
<tr><td rowspan="2">Short description:

Get introduced to Sentinel-2 sensors and data provided inside the Copernicus mission frame.</td><td colspan="2">Planned start date: 23/01/2023

Planned end date: 10/02/2023</td></tr>
<tr><td colspan="2">Start event: 23/01/2023

End event: 10/02/2023</td></tr>
<tr><td>Internal task T1: Gather information about ballast water.

Internal task T2: Retrieve information about Sentinel products.

Internal task T3: Search for useful tools to process the obtained data.</td><td>Deliverables:</td><td>Dates:</td></tr>
</table>

<table>
<tr><td colspan="1">Project: Python IDE</td><td colspan="2">WP ref: (WP 2)</td></tr>
<tr><td>Major constituent: Set Python environment</td><td colspan="2">Sheet 2 of 6</td></tr>
<tr><td rowspan="2">Short description:

Install/update the Python console, set the environment and install all the required libraries to run Acolite software and process the obtained satellite data.</td><td colspan="2">Planned start date: 13/02/2023

Planned end date: 24/02/2023</td></tr>
<tr><td colspan="2">Start date: 13/02/2023

End date: 28/02/2023</td></tr>
<tr><td>Internal task T1: Read Acolite manual and understand each of its parameters.

Internal task T2: Download a Python console, a Python IDE and Anaconda to install the required libraries.</td><td>Deliverables:</td><td>Dates:</td></tr>
</table>

<table>
<tr><td>Project: Download Sentinel-2 data from Copernicus Open Access Hub</td><td>WP ref: (WP 3)</td></tr>
<tr><td>Major constituent: Data acquisition</td><td>Sheet 3 of 6</td></tr>
<tr><td rowspan="2">Short description:

Access to Copernicus Open Access Hub to retrieve the desired Sentinel 2, L1C data and metadata of a specific place and period of time (initially one month). Then automate the process by using the SciHub API to download the data.</td><td>Planned start date: 27/02/2023

Planned end date: 10/03/2023</td></tr>
<tr><td>Start event: 01/03/2023

End event: 27/03/2023</td></tr>
</table>

Internal task T1: Take a first look to the Copernicus Open Access Hub webpage and download data of Emden Sea port in Germany. Internal task T2: Write a script to access the Sci Hub and download the L1C data.	Deliverables:	Dates:

Project: Process the data with Acolite	**WP ref: (WP 4)**	
Major constituent: Python coding	Sheet 4 of 6	
Short description: Run Acolite atmospheric correction software through a python IDE,and read the SPM values of each day. Plot the SPM map and the SPM values for a specific boat path.	Planned start date: 27/02/2023 Planned end date: 28/04/2023 Start event: 27/02/2023 End event: 05/05/2023	
Internal task T1: Perform atmospheric correction with Acolite software. Internal task T2: Read the netCDF file for each day Internal task 3: Obtain the SPM value for each pixel and plot the result.	Deliverables:	Dates:

Project: Integration Phase	**WP ref: (WP 5)**

Major constituent: Code integration	Sheet 5 of 6	
Short description: Write a solid document with the explanation of the final master thesis, final conclusions and the steps taken to complete the analysis.	Planned start date: 03/04/2023 Planned end date: 28/04/2023	
	Start event: 03/04/2023 End event: 05/05/2023	
Internal task T1: Integrate all functions in one script which can be called in a terminal Internal task T2: Revise, complete and upload the document.	Deliverables:	Dates:

Project: Writting of the final report	**WP ref: (WP 6)**	
Major constituent: Documentation	Sheet 6 of 6	
Short description: Write a document with the explanation of the final master thesis, final conclusions and the steps taken to complete the analysis.	Planned start date: 10/04/2023 Planned end date: 14/05/2021	
	Start event: 14/04/2023 End event: 20/05/2021	
Internal task T1: Create and write the final report	Deliverables:	Dates:

Internal task T2: Revise, complete and upload the document.		

II. Milestones

Table 3 - List of tasks performmed throughout the work

WP	Task #	Short title	Milestone / deliverable	Date (week)
1	1	Ballast water information		1
	2	Sentinel products		1
	3	Processing tools		1
2	1	Read Acolite Manual		4
	2	Set python Environment		4
3	1	Use Copernicus Open Access Hub		6
	2	Download data via python script		7
4	1	Atmospheric correction		6
	2	Extract SPM values		8
	3	Analyze results		11
5	1	Integrate code		11
6	1	Creation of the final report		12
	2	Revision of the final report	FinalReport.pdf	16

Table 4 - Chronology of the work packages and tasks

Name	Duration	Start	Finish
⊟ **WP1: Information Research**	**15days**	**01/23/2023**	**02/10/2023**
Task 1: Ballast waters information	3wks	01/23/2023	02/10/2023
Task 2: Sentinel Products	3wks	01/23/2023	02/10/2023
Task 3: Processing tools	3wks	01/23/2023	02/10/2023
⊟ **WP2: Environment Set up**	**10days**	**02/13/2023**	**02/24/2023**
Task 1: Acolite Setup	1wk	02/13/2023	02/17/2023
Task 2: Set Python environment	2wks	02/13/2023	02/24/2023
⊟ **WP3 Copernicus SciHub Open Access**	**10days**	**02/27/2023**	**03/10/2023**
Task 1: Download data from Emden Port	1wk	02/27/2023	03/03/2023
Task 2: Python code to download the L1C data	1wk	03/06/2023	03/10/2023
⊟ **WP4: Process Sentinel data with Python**	**45days**	**02/27/2023**	**04/28/2023**
Task 1: Perform Atmospheric Correction	2wks	02/27/2023	03/10/2023
Task 2: Extract and read the SPM values	3wks	03/13/2023	03/31/2023
Task 3: Plot and analyze the results	1mon	04/03/2023	04/28/2023
⊟ **WP5: Integration Phase**	**20days**	**04/03/2023**	**04/28/2023**
Task 1: Integrate code	20days	04/03/2023	04/28/2023
⊟ **WP6: Final report**	**25days**	**04/10/2023**	**05/12/2023**
Task 1: Create and write report	20days	04/10/2023	05/05/2023
Task 2: Revise Documentation	5days	05/08/2023	05/12/2023
Thesis Delivery	1day	05/15/2023	05/15/2023

B. Python Code

The code performs the following main functions:

- Authenticate and download L1C from Copernicus Open Hub of the specified area and period of time in the command line (CL)
- Extract each of the downloaded zip files
- Run ACOLITE software, bound the region of interest in a geojson file and specify the desired output parameters. In thi case, SPM values map. Output is provided by ACOLITE in a netCDF file.
- Access to the L2W netCDF file for each sensed date, retrieve the SPM values for each longitude and latitude.
- Plot the SPM map
- Compute the SPM monthly average for each longitude-latitude tuple specified in a .geojson

The full code has been uploaded to GitHub here.