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Universidad
de Alcalá

FINAL **REPORT**

DETECTING PLASTIC DEBRIS FROM SPACE

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UNIVERSIDAD DE ALCALÁ

**BACKGROUND IMAGE
PROPERTY OF THE DLR**



1. Company description

The German Aerospace Center, also known as DLR, is Germany's national research center for aerospace. It was established in 1957 and initially focused on aeronautics research to support the country's aviation industry. Over time, DLR expanded its scope to include space research and technology. Today, DLR plays a crucial role in advancing aerospace sciences and technologies for both civil and defense purposes.

DLR conducts a wide range of research activities in various fields. In aeronautics, it works on developing new aircraft designs, improving safety, reducing emissions, and enhancing air traffic management systems. The center collaborates with industry partners and academic institutions to drive advancements in aviation.

In space exploration, DLR contributes to missions conducted by the European Space Agency (ESA) and other international partners. It develops and operates satellites, conducts experiments in micro-gravity environments, and explores topics such as planetary science, Earth observation, and human spaceflight.

DLR also focuses on energy research, transportation systems, digitalization, and other interdisciplinary areas that intersect with aerospace. It uses its expertise and modern facilities to foster innovation and provide scientific support.

It employs more than 10000 people, in 55 research institutes, with multiple international offices, so showing an organization chart would be a difficult task. Instead, I'll briefly present the research institutes at my facility, DLR Oberpfaffenhofen (Information inspired by the official website, [DLR Oberpfaffenhofen](#)):

1. German Remote Sensing Data Center: Provides access to satellite data, processing them into information products for diverse users and long-term preservation.
2. Earth Observation Center: Urgent societal issues related to environment, climate, mobility planning, and disaster management, utilizing satellite data from global receiving stations and providing long-term data access.
3. Flight Experiments: Assisting internal and external users in planning scientific campaigns and flight experiments, utilizing aircrafts as research platforms or as research subjects themselves.
4. Galileo Competence Center: Central task is to develop the European Galileo satellite navigation system, analyzing system performance, testing promising technologies, and preparing them for industrial use.
5. Institute of High-Frequency Technology and Radar Systems: Harnesses knowledge and experience in passive and active microwave systems to develop innovative sensors, algorithms, and applications for terrestrial, aerial, and satellite remote sensing.
6. Institute of Communication and Navigation: Carries out mission-oriented research in selected areas of communication and navigation, from theoretical foundations to real environment demonstrations.
7. Institute of Remote Sensing Methodology: My internship has been carried out in this institute. Develops advanced software and algorithms for extracting geographical information from remote sensing data, with particular focus on radar and optical imaging, atmospheric spectrometry, and AI-based data science. It also operates airborne optical sensors and contributes to the design of Earth observation systems.
8. Institute of Atmospheric Physics: Investigates the physics and chemistry of the global atmosphere from ground to middle atmosphere, addressing relevant atmospheric questions.

9. Institute of Robotics and Mechatronics: Develops robots that enhance human interaction with the environment, working autonomously in inaccessible or hazardous environments and aiding humans in work and daily life.
10. Institute of Software Technology: Supports cutting-edge research with advanced software solutions, developing open-source software.
11. Institute of System Dynamics and Control Engineering: Focuses on implementing intelligent and potent control functions in mechatronic systems, contributing to performance, energy efficiency, safety, and comfort.
12. Space Operations and Astronaut Training: A central facility for conducting space missions in Germany, responsible for satellite missions, astronaut operations, training and experiments preparation, and developing rockets for worldwide use.

2. My role at the company

My internship was assigned to the Institute of Remote Sensing Methodology, under the guidance of Dr. Daniele Cerra and Dr. Stefan Auer, both from the DLR. My primary task within the team involved enhancing and expanding the existing methodology. The main tools utilized for this task were JavaScript and Google Earth Engine.

A brief overview of the research project we have been carrying out consists of utilizing Sentinel-2 satellite and remote sensing techniques to detect and track changes in plastic clusters within inland water bodies, such as lakes, rivers or canals. It follows two primary steps. The first, "candidate search", broadly identifies potential sites of plastic clusters for further analysis in a full Sentinel-2 tile of roughly 110 x 110 km. The second step, "spectral unmixing", uses a smaller area of interest to create a detailed vectorization of the plastic clusters. This step also generates a spectral unmixing model, enhancing the detection of other plastic dumps in the area and providing an accurate estimation on the plastic surface.

3. Description of the work carried out

3.1. Internship objectives

- Prove plastic detection in river, dams and canals is possible using non-commercial satellites:

One of the main challenges we faced was the insufficient spatial resolution offered by non-commercial satellites. Taking into account temporal resolution, radiometric accuracy, and overall image size, our preferred option would be Sentinel-2. To successfully detect narrow canals, where plastic may accumulate easily, it is essential to exclusively employ the 10-meter bands. Nevertheless, this constraint limits our capacity to solely utilize the Red, Green, Blue, and Near infrared bands.

- Make use of Google Earth Engine (GEE) to access and process large time-series of Sentinel-2 data on the cloud:

When creating a tool with worldwide coverage, a large database is essential. Google Earth Engine (GEE) effectively solves this challenge by facilitating instant data retrieval, eliminating the need for extensive storage capacity. However, it is important to note that GEE is heavily constrained by memory limitations, meaning a highly streamlined script is needed.

- Estimate surface occupied by plastic debris at sub-pixel level using spectral unmixing:

The use of a vector to estimate plastic surface at the pixel level is inherently imprecise. [Cerra et al. \(2022\)](#) demonstrated that while estimating solar panel surfaces with Sentinel-2

data, there was a 100% overestimation at the pixel level, but only a 5% overestimation at the sub-pixel level. Thus, the use of spectral unmixing techniques on plastic patches becomes crucial to achieve a more precise measurement of plastic content. This approach facilitates a more comprehensive evaluation of the plastic quantity present.

- Allow users to detect plastic debris and estimate its dynamics in any region of interest / time interval with minimal supervision:

The research aims to create a user-friendly product suitable for individuals with only basic remote sensing notions. This objective is accomplished by minimizing the number of parameters while guaranteeing maximum adaptability of the script. The application's versatility is emphasized by not bounding the user by geographical location or time frames.

3.2. Methodology and tools utilized

Methodology followed

Given the spatial constraint, the number of bands available are significantly restricted. This limitation, the spectral resolution, curbs our capacity to differentiate between various materials based on their spectral signature. However, to compensate this shortcoming, we integrate multitemporal analysis, a technique that allows the identification of intensity differences over a temporal frame.

In the proposed methodology, we use a two-step approach, which, while sharing a similar pathway, incorporates distinctive actions in each phase.

In the first step, the candidate search a complete 110 x 110 km Sentinel-2 tile. Employing the Automatic Date Selection algorithm, the five less cloudy images are selected from a given time-frame. These images are then subjected to a series of preprocessing steps, aimed at preserving only the most relevant data to avoid false plastic alarms.

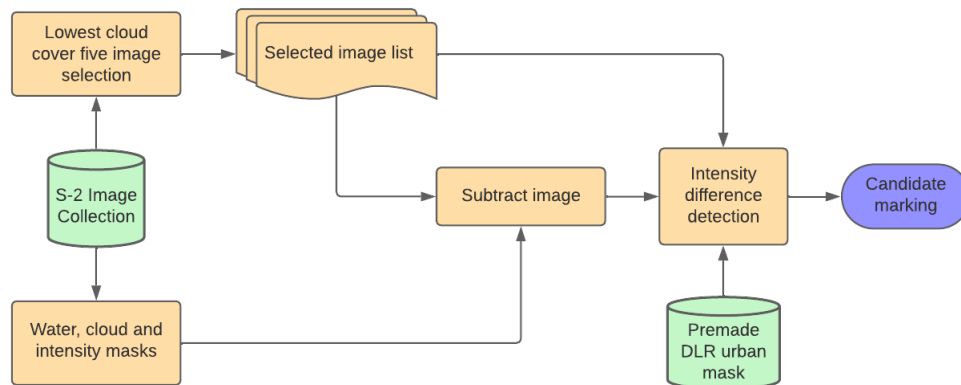


Figure 1: Flowchart for the Candidate Search

A significant portion of this cleaning process involves the use of various masks. Initially, we apply a custom-made water mask, which has been generated through a consensus of all water masks derived from the individual selected images. This allows us to focus on plastic presence within inland water bodies. The images are further refined using a cloud mask to prevent cloud formations from inducing erroneous intensity change detection, which is already included inside each of the image's metadata. The final cleaning step involves the application of a pre-existing urban mask known as the World Settlement Footprint provided by the German Aerospace Center (DLR). This mask helps to avoid any potential confusion caused by man-made structures.

Having preprocessed the images, we begin the multitemporal analysis. Here, we execute an inter-temporal comparison on the prepared images, where we subtract each consecutive image in chronological order. The goal is to observe the change in intensity values over time, which can be indicative of plastic presence.

The underlying principle of this phase is that plastic exhibits a ramp nature from blue to Near-Infrared (NIR) wavelengths, an increase in intensity. If this increase is detected in a pixel, it is categorized as an intensity jump. Either the appearance or disappearance of plastic will trigger an intensity jump.

These detected intensity jumps from all the consecutive subtractions are then compiled into a single fused product, creating a mask in those pixel where at least an intensity jump is present.

The second phase of our methodology takes a more complex route. Instead of using an entire Sentinel-2 tile, we start with a manually-drawn rectangle geometry where a candidate marking was previously identified.

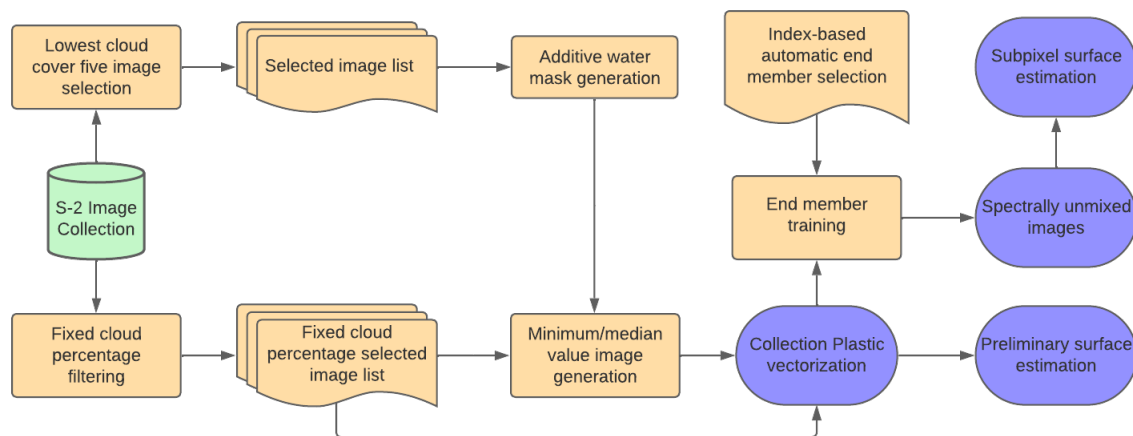


Figure 2: Flowchart for the Vectorization / Spectral unmixing

Instead of using the Automatic Date Selection algorithm, we now consider all available images within the same timeframe that fall under a specified cloud cover percentage threshold. These images undergo a similar preprocessing routine, but without the use of the cloud mask, as the reduced area of interest significantly decreases the impact of cloud interference.

The analysis of intensity change takes a slightly different approach in this phase. Rather than subtracting images in chronological order, we compare each image to a base image. This base image should ideally be free of plastic or contain the least amount possible throughout the entire timeframe. This adjustment enables us to generate a vectorization of the intensity change identified in each of the selected images in the time frame.

To create the base image for subtraction, we calculate either a minimum or median value composite. In other words, for each pixel, we select its value from the image with the lowest or median value across the entire multitemporal stack. The choice between minimum or median depends on the persistence of plastic in the area. If plastic is consistently present, the minimum value is necessary to avoid residual plastic values in the base image, which would then negate the intensity difference. Otherwise, the median is used to prevent the incorporation of potential radiometric errors or cloud shadows that could darken the image.

The vectorization provides a preliminary surface estimation from the largest plastic patch, which is then used as the training values for the subsequent phase, known as spectral unmixing. The training values, i.e., the plastic pixels, serve as the end member for plastic. Similarly, using indices or masks, we automatically extract the other end members: vegetation, water, and soil/highways. Due to the limited number of bands, the quality of our spectral unmixing might be constrained.

We now perform spectral unmixing across the whole tile for each image in the multitemporal stack. This serves two purposes. First, it allows users to locate additional plastic patches in the images. Second, it allows for a more precise surface measurement at the sub-pixel level.

As a complementary process we've also developed a simple GIF animation script. This script cycles shows all of the images in the time frame as an animated sequence. This is done only in the small rectangular area of interest stated previously, as using a larger size would cause memory problems.

Users can make more informed decisions about the process parameters, such as, the amount of cloud presence, the degree of plastic persistence, and the size of the water body. Adjusting the parameters accordingly would yield better results during the vectorization / spectral unmixing.

Tools utilized

In the execution of this project, the primary tool utilized was Google Earth Engine (GEE), a powerful platform for geospatial analysis and data visualization. GEE offers several benefits, among them being the availability of a vast repository of geospatial datasets, including real-time satellite imagery. This accessibility of data simplifies the acquisition and analysis process significantly. Its cloud-based nature eliminates the need for downloading and storing large datasets locally, enhancing the efficiency of the workflow. However, GEE also has some limitations. The most notable of these is its restricted memory capacity. As complex geospatial analyses are often memory-intensive, this limitation can pose a significant challenge. Our analysis scripts were written in JavaScript, a programming language supported by GEE.

3.3. Tasks carried out

Numerous tasks were outlined in the biweekly reports, but not all made it to the final product. Reasons include excessive memory use, methodology changes, or finding better alternatives. The tasks listed next are only those that were incorporated into the final output, in no specific order.

The original script underwent a series of changes which have not been explained in the report as these are not significant enough, due to either just being connecting sections, improvements in the processing time or small changes which are only meant to simplify the user inputs/outputs without actual changes in the methodology.

- Automatic date selection algorithm:

Both the candidate search and the spectral unmixing algorithm required manual date selection prior to data filtering. This meant that if the user wanted to move to a new area of interest, the temporal frame for each image had to be manually selected. Furthermore, the algorithm extracted a fixed cloud cover percentage for each time frame, which meant that, depending on the selected location, some data gaps could be found causing the algorithm itself to fail. Before the implementation of the automatic date selection algorithm, the only solution is to keep shifting the data ranges until the entire interval is covered.

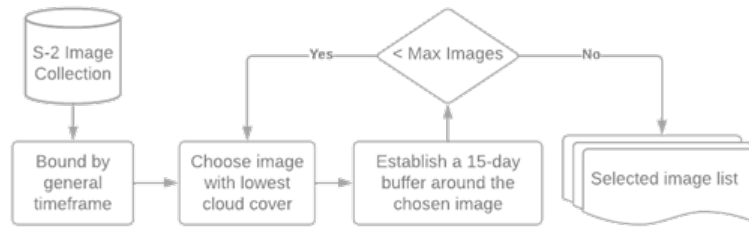


Figure 3: Automatic date selecting algorithm

The algorithm starts by filtering the S-2 image collection with the total bounding time frame, as well as by the area of interest. Those two, along with the desired amount of images are the only input required by the user. The algorithm then will sort the image collection by cloud cover, and pick the first one (least cloud cover percentage). A fifteen-day buffer will be established around the chosen date, meaning every image fifteen days after or before will be removed from the collection. This step is essential to avoid clustered dates. The value fifteen was selected based on testing various sites around the world, as it seems an adequate compromise between low cloud coverage and temporal spacing. The image is then pushed into a list, and the algorithm will keep repeating until all the desired amount of images are reached.

The algorithm has proven to work adequately, avoiding completely the possibility of image gaps. It has removed the need to manually select time frames, and modifying the amount of used images requires only changing the value of a parameter, as the algorithm is completely function based, without the use of hard-code. The implementation of the algorithm is the first step into a transition to a shareable product, where the user could seamlessly move in between different areas of interest. The most noticeable limitation of the algorithm is produced by regions with high permanent cloud coverage, where a fifteen-day buffer could remove most usable images.

- Function-based scripts:

One of the main limitations faced by the previous state of the algorithms was the lack of flexibility offered by these. Both the candidate search and the spectral unmixing scripts were completely hard-coded, which is a problem difficult to bypass when sharing a product. Also, the amount of images used could not be changed, the dates needed to be hand-picked, and moving into a different area of interest took some time.

Because of the lack of functions, the code was hard to read or modify, with multiple sections constantly repeating, or even some code that produced objects which were not used in the final product.

Both scripts were substituted with list-based functions, looping until the contents of said lists were processed. This change decreased threefold the size of the scripts, which in turn helped with the processing times.

- Base subtraction image:

In the Candidate search, images can be subtracted from one another as the final result is a combined output, which is not quantified. Therefore, there would be no problem in subtracting two images with plastic as long as one of them has more. However, in the Spectral unmixing script, the vectorization and quantifying of plastic surface require that all the images must be subtracted by one without the presence of plastic.

Using only a minimum image collection composite may include cloud shadows or other radiometric errors, which can generate false intensity increases and result in incorrect plastic detection. On the other hand, using a median image collection composite does not include these radiometric problems but only works when the area of study does not frequently accumulate plastic in most of the S-2 images. The user now has the option to select the plastic's persistence in the area of study, something that could be discerned from the Image stacker script.



Figure 4: High plastic persistence location with median (Left) and minimum (Right) composites

- End member selection. Unmixed images. Plastic quantity estimation:

Previously, there was still an unmixing process in the script, but the training areas had to be manually selected, and the outputs were much more limited. The script starts by finding the largest vectorized plastic patch, which is used as a clipping geometry for the S-2 image where the plastic patch was found. The result is a raster containing exclusively plastic pixels.

Next, the median is performed for the 10-meter band to extract a representative plastic value. A similar process is carried out using different indexes to extract representative values for water, soil, and urban areas. For all of these, the median value is extracted except for soil, where we extract the highest intensity pixels. This can sometimes lead to confusion between soil and plastic since both are highly reflective.

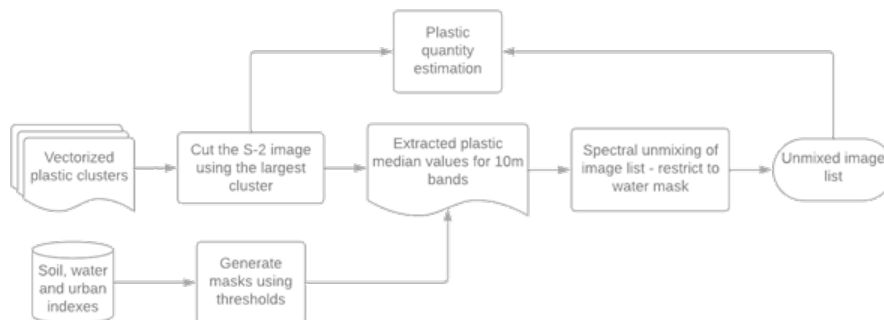


Figure 5: End member selection - unmixed images - plastic quantity estimation

The spectral unmixing is then performed on all the image list, which is then clipped by each image's respective water mask. This allows the user to find other plastic patches in the Sentinel-2 tile – differentiating these from soil, which otherwise would be hard to do using

only the base Sentinel-2 bands.

Finally we are able to estimate the amount of plastic present in the area. We do so only using the maximum amount of plastic found, as adding the quantity between all images would overestimate its presence.

We clip the unmixed image with the largest plastic patch vector. As each pixel now represents a percentage of the plastic present, and knowing that each pixel is 100 squared meters, we can then give an estimated value of the amount found. In the original script, the quantity was calculated exclusively based on area, which is not as accurate.

- GIF animation script:

This new simple addition generates an interesting output. Using the same image stack as the spectral unmixing – filtered by a fixed cloud percentage – the script generates two links, one for a GIF animation, and another showing all the frames separated, which can be useful when showing in a written report:



Figure 6: Frames from the GIF animation

After filtering the image collection, the user must input the desired frames per second, as well as the visualization bands. These may be single band or an RGB composite. Depending of the time frame and study area size, the main drawback for this output is that it required intense computational power, which may take extensive time to process. Due to this problem, this section of code may be completely separated from the spectral unmixing script.

- Graphic UI. Shareable app:

Using Google earth engine widgets, its possible to design complex user interfaces which allow interaction without the presence of code or a console. This changed let us build every process into the same script, as different widgets allow running different code segments. This means that the user can now switch between the candidate search and spectral unmixing seamlessly, making the plastic detection easier.

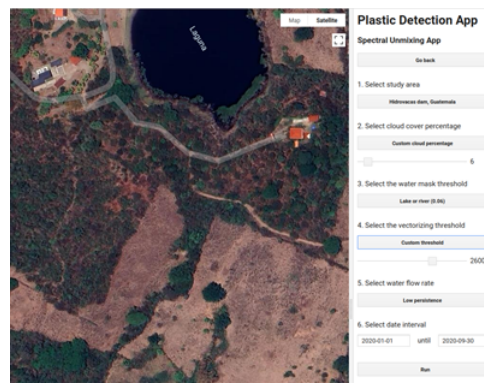


Figure 7: Section of the script's UI

This segmented code also helps to reduce computational time, as the buttons trigger individual sections, allowing the script to run smoother even with 1800+ lines of code.

Some parts of the original scripts need to be adapted for the App, but most of it remains intact. The bulk of the changes for the UI are based on the labels, text boxes and buttons, where everything, from the width, size and position to the triggers each one generate must be specified.

- User Guide:

One of the objectives of the project was to create a shareable app that could be used by individuals with only basic remote sensing notions, without requiring any programming knowledge. Developing a script that seamlessly adapts to different parts of the world without manual parameter adjustments is a difficult task. Although the number of changing factors has been minimized to the bare minimum, some are still necessary. As a result, detailed instructions have been included for each script within the app's user interface (UI).

The included guide aims to explain each concept to the user in a simple and concise manner, without diving into technical details on how the script operates.

3.4. Results obtained

The results generated from the scripts, which were not modified post-generation, can be broadly divided into three main categories, each corresponding to different stages of our methodology.

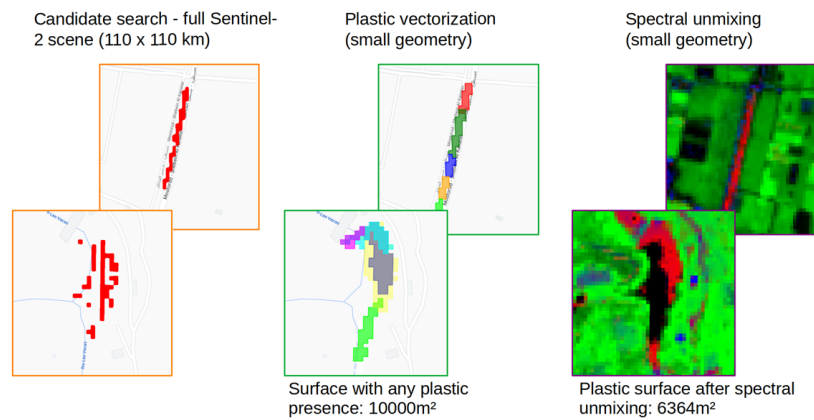


Figure 8: The three main outputs generated with our methodology. From left to right: Candidate search, vectorization, spectral unmixing.

The initial outcome from our process is a representation of combined intensity jumps derived from the selected images. The intensity jumps mark potential plastic candidates. This output is illustrated on the left side of Figure 8. The next output, in the middle of Figure 8, is obtained during the vectorization phase. In this stage, distinct plastic patches identified in different images, from different time periods, are superimposed. Each patch is represented with a unique color. Finally, the output on the right side of Figure 8, is derived from spectral unmixing. In this image, plastic is depicted in red.

Both the vectorization and spectral unmixing stages provide estimations of plastic surface. The vectorization output estimates plastic coverage at pixel level, while the spectral unmixing allows for a subpixel level estimation. The top row of images show the results from a canal in Cairo, while the bottom row showcases a dam in Guatemala (Hidrovacas).



Figure 9: Candidate search results. Showcasing nearly a full tile, without commission errors.

Diving into the candidate search, Figure 9 showcases almost a full Sentinel-2 tile with candidate search results. As depicted in the image, there are no false candidate markings present, only for a small, red marking on a small dam located at the center of the image, Hidrovacas dam. To provide a closer view of the candidate marking, the image includes a zoomed-in section on the right. After individually checking the images for that area, we were able to find that this location has almost a permanent plastic presence, which can be seen thought multiple years.

To describe the significance of a modifiable parameter for plastic persistence, we can refer to *Figure 10*. This figure demonstrates the impact of using median or minimum composites on both high and low plastic persistence areas.

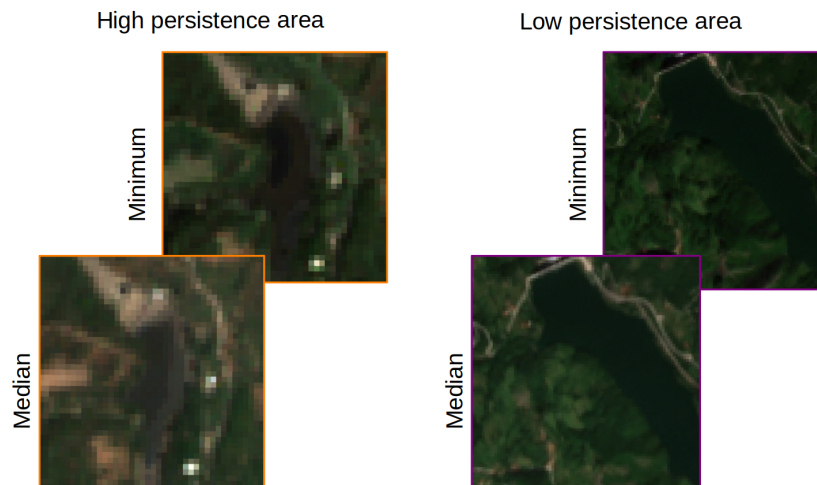


Figure 10: Base subtraction image. Differences between median and minimum composites.

As shown in *Figure 10*, using the median in a high persistence area results in a hazy base subtraction image, which in turn will generate omission errors. On the other hand, employing the minimum in an area with low persistence leads to a considerably dark image, which has the opposite effect, generating commission errors because of the intensity difference.

This one change, which appears insignificant, considerably improved the output for the vectorization and spectral unmixing, as its considered a crucial parameter for optimal results.

Lastly, analyzing the spectral unmixing results, we observed that the spectral signatures of the automatically selected end members (Plastic, vegetation, water and soil / highways) provided a correct insight on each of the cover’s usual patterns.

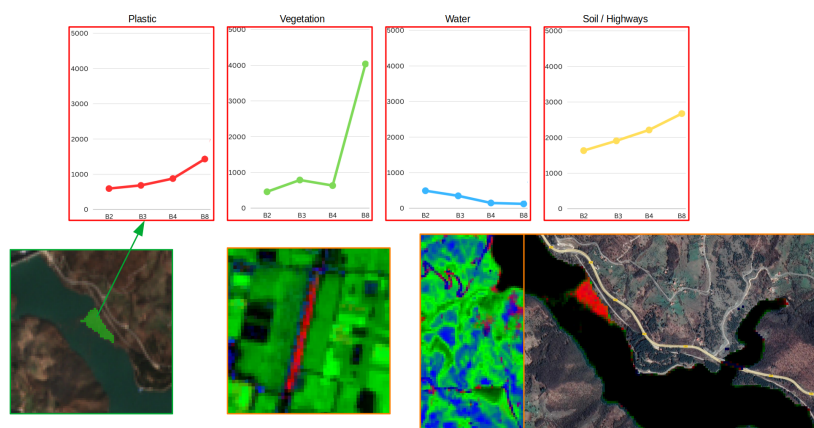


Figure 11: Spectral signatures of different end members (top). Spectral unmixing results (bottom-right).

Soil and plastic exhibit similar spectral signatures. However, soil displays a higher intensity compared to plastic, which facilitates their differentiation to some extent. Nevertheless, there is still some overlap between the two, leading to errors in the classification of inland areas. In order to

address this issue, we decided to generate a clipped version of the spectral unmixing results using the water mask.

The clipped version, depicted in the *Figure 11*, reveals a clearer unmixing, reducing the occurrence of errors caused by the similarity between soil and plastic signatures. Despite rare, it is still possible to find some soil inside the water bodies, which has been incorrectly identified as plastic.

I believe, after analysing the results, that this methodology has effectively yielded valuable results. We appreciate the efficiency of GEE, which facilitated our process and allowed us to develop a replicable approach, even if we were heavily limited by memory usage. In terms of outcomes, despite some errors in the outputs, the results exceeded our initial expectations. This positive outcome affirms the potential of satellite imagery for automatic plastic monitoring.

4. Knowledge I acquired at the company

During my internship at the DLR, I was exposed to various facets of professional working life, from technical skills to organizational insights. This experience has allowed me to significantly expand my knowledge base and skill set in numerous ways. The following bullet points highlight the key areas of knowledge and experience I gained throughout the duration of my internship:

- Acquired fundamental programming skills in JavaScript, including loops, conditional statements, and object-oriented programming.
- Gained proficiency in using Google Earth Engine for large-scale geospatial data analysis, including image processing and GIS tasks.
- Learned the basics of professional work, such as meeting deadlines, efficient communication with team members, problem-solving, and task prioritization.
- Gained understanding of cloud computing concepts, and developed knowledge about the advantages and limitations of server-based analysis versus local analysis, and understood when to use each method for optimal results.
- Acquired knowledge about the characteristics and behaviour of plastics in inland water masses.
- Gained insight into the day-to-day operations and roles of a space center.
- Learned how to effectively handle pressure and communicate our findings during a presentation to a large group of people which were not directly linked to the research.

5. Knowledge I brought from the Master's

My academic background from the Universidad de Alcalá significantly contributed to the successful execution of my internship tasks at the DLR. The competencies that I acquired during my studies were essential when navigating the complexities of the tasks assigned to me. The skills and knowledge I brought to my internship include:

- Utilized my knowledge of Python and R programming languages to structure and organize my code efficiently in JavaScript. These skills also helped me think analytically when coding.
- Applied my knowledge in GIS, and its analytical methods to execute tasks proficiently.
- Benefited from the resilience and work ethic developed during my Master's program to effectively handle tasks.
- Employed the problem-solving skills gained during my studies to troubleshoot and resolve issues.

- Benefited from my typing agility, a byproduct of extensive computer-based work during my studies.

6. Acknowledgments

I would like to thank my supervisors, Daniele Cerra and Stefan Auer, for their remarkable guidance throughout this internship. Their mentorship was essential for learning. I am also thankful to the entire DLR team, whose kindness made my experience enjoyable and rewarding. Lastly, I wish to acknowledge Universidad de Alcalá for providing me with this opportunity to grow, learn, and contribute to the field research.

7. Bibliography

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En München, Deutschlands, a 19 de Julio del 2023

Firmado por el alumno:

Visto bueno del tutor en la empresa:

A handwritten signature in black ink, consisting of several overlapping, slanted strokes that form a stylized, somewhat abstract shape.A handwritten signature in blue ink, featuring a series of connected, flowing loops and curves that form a recognizable, though stylized, name.