CleanAtlantic

Tackling Marine Litter in the Atlantic Area

Analysis of strategies for the monitoring and evaluation of accumulations of marine litter on the coast

Action 5.2: Monitoring the presence of ML in the Marine Environment

WP 5: Monitoring and Data Management

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DISCLAIMER

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ANALYSIS OF STRATEGIES FOR THE MONITORING AND EVALUATION OF ACCUMULATIONS OF MARINE LITTER ON THE COAST

1 BACKGROUND

Marine litter (ML) has been defined by the as "any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment. Marine litter consists of items that have been made or used by people and deliberately discarded into the sea or rivers or on beaches; brought indirectly to the sea with rivers, sewage, storm water or winds; accidentally lost, including material lost at sea in bad weather (fishing gear, cargo); or deliberately left by people on beaches and shores.”)

Marine litter represents a huge problem in our oceans, coasts and consequently, a serious environmental deterioration, effects on health and great economic losses of those sectors related to the marine environment.

The European Union, aware of this problem, includes in its Marine Strategy Framework Directive (MSFD) as one of the qualitative descriptors to determine good environmental status "*The properties and quantities of marine litter do not cause harm to the coastal and marine environment*". Periodic assessments of the state of the marine environment, monitoring and formulation of environmental objectives are perceived as part of the adaptive management process within THE MSFD and within the Regional Maritime Convention (CSR) Action Plans, and have become a major concern for Marine Protected Areas (MPAs).

The European CleanAtlantic project aims to protect biodiversity and ecosystem services in the Atlantic Area by improving capabilities to monitor, prevent and remove (macro) marine litter. The project will also contribute to raise awareness and change attitudes among stakeholders and to improve marine litter managing systems.

Among its specific objectives CleanAtlantic aims to provide protocols, tools, and indicators to ensure adequate monitoring of marine litter. This study focuses on the specific case of the marine coastline where there are areas that, due to their geographical position and the ocean-meteorological conditions they support, tend to accumulate floating ML on a regular basis. The evaluation of different detection strategies of these accumulation zones can be useful for managers to minimize efforts when planning the cleaning and collection of marine litter.

2 OBJECTIVE

Considering that an exhaustive inspection of the entire coastline implies a huge effort that is difficult to assume by the administrations, this study aims to analyze different strategies for the location of areas of accumulation of Marine litter that can be incorporated into monitoring, cleaning, and collection protocols.

3 METHODOLOGY

There are different reasons why a coastal area can accumulate marine litter such as its proximity to sources of litter (nearby towns, river mouths, etc.), its exposure to specific meteorological ocean conditions (exposure to winds and / or prevailing currents, etc.) or others. The mapping of these areas can be approached through different methods. In the present study, two groups of strategies have been evaluated, a strategy focused on traditional direct sampling and another strategy focused on the application of modern technologies that can be used indirectly in the detection of areas of accumulation.

In the first case, two types of direct sampling have been analyzed:

- **Monitoring using indicators**. Indicators, in conjunction with other measures and proxies, (e.g., oceanographic currents, socioeconomic data), can be used to detect the presence of ML in each habitat (exposure) and the spatial and temporal trends of accumulation (sinks) (GESAMP 2019). In this case, as will be explained later, a plastic object related to aquaculture such as the Mussel-pegs were selected as an indicator of accumulation zones. In addition, considering the advantages that the involvement of citizens can bring for the sampling of large areas, this evaluation has been carried out in collaboration with high school students.

- **Systematic characterization of areas of accumulation of ML (onwards, accumulations):** This strategy seeks to make a systematic, objective, and homogeneous classification of the accumulations found on the beaches. To this end, considering the similarities that exist between an event of accidental marine pollution (spillage of hydrocarbon or other potentially dangerous, harmful substance) and the arrival of marine litter to the coast, a methodology has been developed. This methodology, adapts the technique of evaluation of affectation of the coast (SCAT) usually used in cases of oil pollution, for the sampling of ML. In this case, the samples were carried out by personnel specifically trained to search for areas of accumulation of ML on the coast.

In the second case, two types of technologies have been analyzed for the location of accumulation zones:

- **Unmanned Aerial Vehicles (drones):** The use of drones is shown as a technology that allows the recognition of areas of difficult access, in addition, in recent years, its use for the detection of objects has also been developed in the field of marine litter. Considering the advantages that these devices can offer, a study was carried out on their effectiveness for the location not directed to specific objects, but for areas of accumulation of ML on the coast related to specific ocean weather patterns.

- **HF Radars:** The high frequency radar technology allows to know in real time the marine surface currents. The movement of floating objects, as is the case with some marine litter, is greatly influenced by such currents. To know if this technology can facilitate the knowledge of where it is more likely that ML accumulates in coastal areas, the use of surface current data, obtained by HF radars to know possible displacements of marine litter in coastal areas, was evaluated.

4 STUDY AREA

The present study was developed in Galicia has a coastline whose length is 2,555 km that are composed of 1,659 km of coastal perimeter, 432 km of islands and 464 km of marshes. Geographically, one of the peculiarities of Galicia is the presence of the rias, inlets on the coast in which the sea flooded river valleys due to a decrease in land level (relative rise in sea level). The Galician have great fishing importance, contributing to the Galician coast being one of the most important fishing and shellfish areas in the world. In addition, most of the population lives in the surroundings of the rias, where the largest urban centers and their areas of influence are located. The rias are traditionally divided into “Rías Altas” and “Rías Baixas” according to their position regarding Finisterre, the western most point of Galicia.

The study of the different methodologies presented here has focused on the Ría de Arousa which is the most extensive of the four Rías Baixas and with high socio-economic importance (**¡Error! No se encuentra el origen de la referencia.**).

Ocean-meteorological characteristics of the Ría de Arousa

The Ría de Arousa covers 33.1 km long, an area of 2.39 x 108 m^2 and an average volume of 4.8 x 109 m^3. Its orientation is EN-S. The width of the estuary ranges from 4 km in the narrowest part to 15 km in the widest part. The Ría de Arousa, is not only the largest but also the deepest, reaching more than 67 m in its central area.

Figure 1. Area view of the Arousa Ría

The climate of the Ría de Arousa is favourably influenced by the current of the Canary Islands, southern branch of the Gulf Stream, which begins precisely off the Galician coast. The climate is of a temperate rainy type with a maritime Mediterranean rainfall regime, with abundant rainfall in autumn, winter and spring and dry season in summer.

The average oscillation of sea level is around 3 m, being therefore a mesotidal estuary (between 2 and 4 m of tidal range). This tidal range goes from more than 3.5 m at spring tides to 1.5 m during neap tides. These variations in sea level height give rise to cyclical movements of water inflow and outflow, called tidal currents, which can become of great intensity.

On the other hand, if the Ría de Arousa is considered as a partially mixed estuary and averaging the currents during several tidal cycles, the residual circulation obtained is positive in two layers: a saltwater inflow bottom current from the ocean and a brackish water outward current on the surface. In the Ría de Arousa there are also several sources of stratification: the contributions of fresh water, the flow of heat through the atmosphere-estuary interface and the water exchanges that are established between the platform and the estuary. All of them give rise to longitudinal density gradients, which act as motors of the positive circulation described.

There is also a great influence of the winds in the variability of the residual circulation both in the platform and in the estuary, being able to cause three different scenarios: reinforced positive circulation when north component winds dominate, relaxation situation in transition periods with a very slow positive circulation maintained for days and reverse or negative circulation favoured by the south winds.

As summary, the Ría de Arousa behaves as an extension of the continental shelf, responding directly to the coastal wind. Its physical configuration also allows a high production of phytoplankton, with a characteristic marine flow, which makes this estuary famous for its marine wealth.

<u>Sources of marine litter in the study area</u>

The main sources of marine litter that can be assumed in the Ría de Arousa are:

- Litter coming from the Atlantic facade and that enters dragged into the flows of water from the platform.
- Population centers settled in the coastal zone. Among which stand out the most important riverside towns of the Ría de Arousa (Ribeira, Pobra do Caramiñal, Boiro and Rianxo in the north and Vilagarcía de Arousa, Vilanova de Arousa, Cambados and O Grove in the south, and the Arousa island), which add up to a population of 143,193 inhabitants (2019).
- Contribution dragged by the rivers that flow into the Ría among which it is worth highlighting in its innermost part the Ulla River, one of the largest that flow into the Rías Baixas de Galicia with an average flow of 78.8 m^{3s-1}. In addition to this river, we must consider the Umia River, which flows into the southern part of the estuary with a flow of 13.4 $m^{3s-1.}$
- Litter from activities related to the use and enjoyment of the Ría. In it takes place a great aquaculture and shellfish activity with 20 polygons that have more than 2800 rafts, mainly dedicated to the cultivation of mussels, 4 areas of cultivation parks of different bivalves, mollusk treatment plants and marine fish farms. In this sense, as mentioned below, the element used as an indicator in one of the strategies evaluated in this study comes from the cultivation of mussels (mussel-pegs) because this is the most relevant economic activity in the area. This ria is also home to an important fishing activity and numerous recreational nautical activities. Likewise, the maritime traffic that supports this area is relevant, with special importance the transit of ships related to the activity of the Port of Vilagarcía de Arousa.

5 DIRECT SAMPLING STRATEGIES

As mentioned in paragraph 2, the main objective of this study is the detection of areas of accumulation of marine litter on the coast. In this sense, the evaluation of direct sampling strategies was focused with the intention of answering the following questions.

- ✓ Where is the ML accumulating on the coast?
- ✓ Is there an area that stands out from the others?

To obtain the answers, the following criteria were defined:

a) Selection of sampling points:

To detect the areas of accumulation of marine litter on the coast of the Ría de Arousa, a sampling plan was designed in which, to be able to collect as many ocean-meteorological situations as possible along the coast, most of the sampling points were in the Illa de Arousa, which due to its insular character ensured that there was a coast exposed to all slopes (see Figure 2 A). This island is the most populated by those that are inhabited in the estuary, with a population in 2019 of 4,926 inhabitants and that has 7 km^2 of surface.

Moreover, in coordination with the awareness activities carried out in the project and taking advantage of the good availability of the staff of the "Illa de Arousa Secondary School" present on the Island, the study was framed in a citizen science initiative with secondary school students (See Annex I).

For the study on the coast of the rest of the estuary, the sampling points were chosen in coordination with the numerical modeling work carried out in the same CleanAtlantic project (Mapping and modelling ML) with the intention of being able to make a comparison between the results obtained through sampling and those obtained after numerical simulations (see Figure 2B).

All these points are located on beaches that meet the guidelines described in the monitoring program of marine litter on beaches, by the Ministry for the ecological transition and the demographic challenge of the Government of Spain, that is:

- ✓ Be composed of sand or gravel and exposed to open sea.
- ✓ Be accessible to samplers throughout the year.
- ✓ Be accessible to facilitate the removal of marine litter.
- ✓ Preferably, not be subject to other ML removal activities.

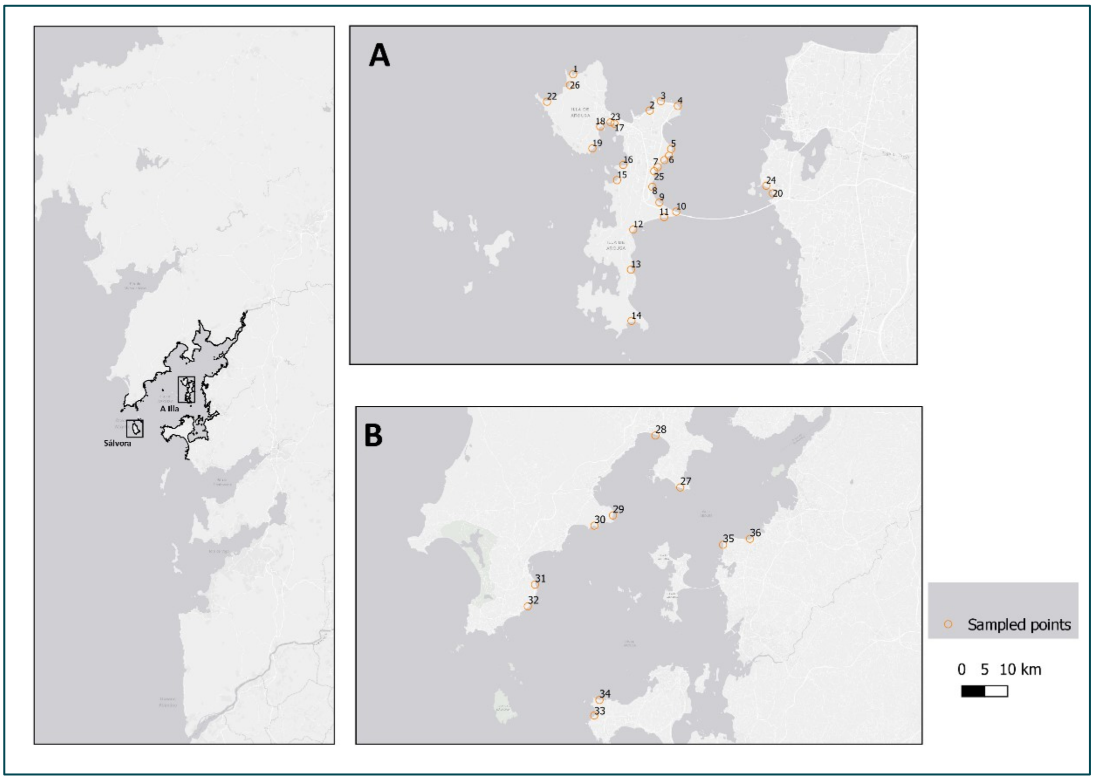


Figure 2. Sampling Points: A) Illa de Arousa, B) Ría de Arousa.

b) Sampling frequency:

A weekly sampling frequency was determined, where each beach was always sampled by the same student or professional sampler, since this helps to homogenize the data.

It was recommended that, as far as possible, sampling should always be carried out one hour after high tide to prevent samplers from being affected by the incoming tide.

During the sampling, the safety of the samplers was always overriding, therefore, these were always carried out during daylight hours and were suspended in those cases in which safety could be compromised (very adverse weather conditions, etc.). It was also emphasized that dangerous or suspected objects that could be found in the sampling area, such as munitions, chemicals, and medicines, should not be sampled, but should be reported to the responsible authorities.

c) Data collection:

Specific forms were developed for data collection (see Annex II and III). These forms were designed to collect information regarding the areas of accumulation of ML stranded on the beach. In those cases where it was possible, the data were recorded in an electronic form with the help of *Google Forms.* This form contains the same fields as paper, but the requirement for good telephone communication meant that it was not always possible to use it.

d) Data processing:

The data collected during the sampling was stored and managed through *PostGIS,* free software and compatible with the standards of the Open Geospatial Consortium (OGC), which allows to convert the *PostgreSQL* database system into a spatial database. This system allows a simple import and export of data, is fast, secure and there are a large number of desktop GIS clients and web map servers that can work with it. Therefore, it was considered to provide a good solution for the storage, management, and maintenance of spatial data.

For the visualization of the data collected in collaboration with the students of the High School, a web viewer was developed (see Figure 3), which can be consulted through the following link:
mapas.intecmar.gal/cleanatlanticarousa.
Thanks to this viewer, both the students and all the interested staff, were able to consult, throughout the study, the sampling data. This tool also made it possible to raise awareness and disseminate the CleanAtlantic project.

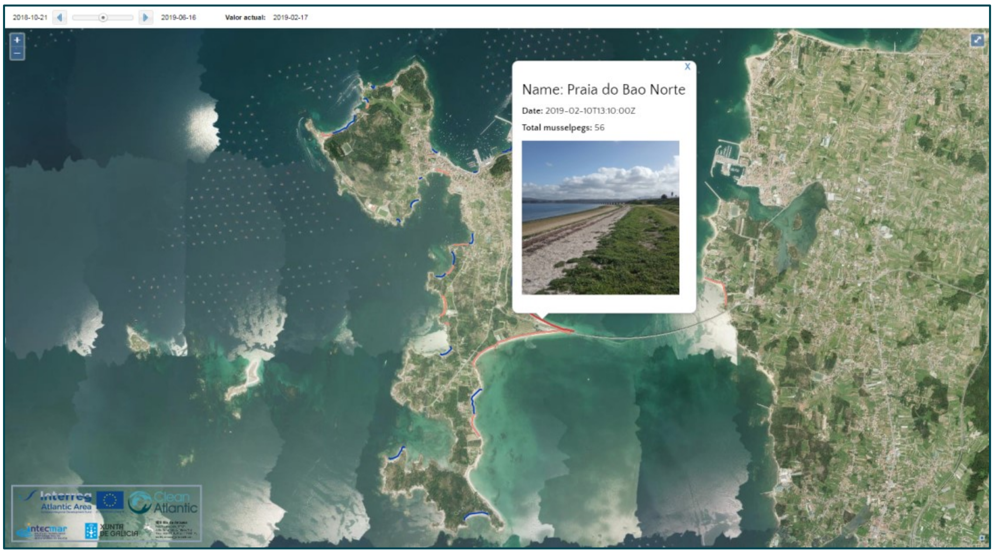


Figure 3. Viewer available in: **mapas.intecmar.gal/cleanatlanticarousa.**

5.1 Sampling of specific objects (indicators)

With the intention of obtaining a harmonized result, it was decided to carry out the sampling of objects that could be used as indicators of accumulation zones. An indicator provides a measure of the "state" of the environment, such as the abundance of plastic litter in the ocean, using data collected by tracking the coast, sea surface, seafloor, or biotic compartments.

As described before, the selection of indicators can be used to detect the presence of marine litter in each habitat (exposure) and spatial and temporal trends of accumulation (sinks), as well as to provide information on their potential sources or on their subsequent impacts on biodiversity and the benefits that nature brings to society.

An additional function of indicators is to assess the effectiveness of mitigation measures. Environmental indicators should have the following characteristics (UNEP 2016):

- ✓ Scientifically valid.
- ✓ Easy to understand by the public and managers.
- ✓ Sensitive and receptive to change.
- ✓ Economic.

In Galicia, the enormous importance of mollusc aquaculture, mainly mussels, makes this the most relevant activity of the estuary. The mussel is grown in rafts, floating platforms from which hang ropes to which the mussel is fixed, or in which sometimes baskets are placed in the breeding of other mollusks, being, therefore, suspended crops that develop in the water column. The rafts are grouped into polygons, which are production areas that are in the water sheet (see Figure 4).

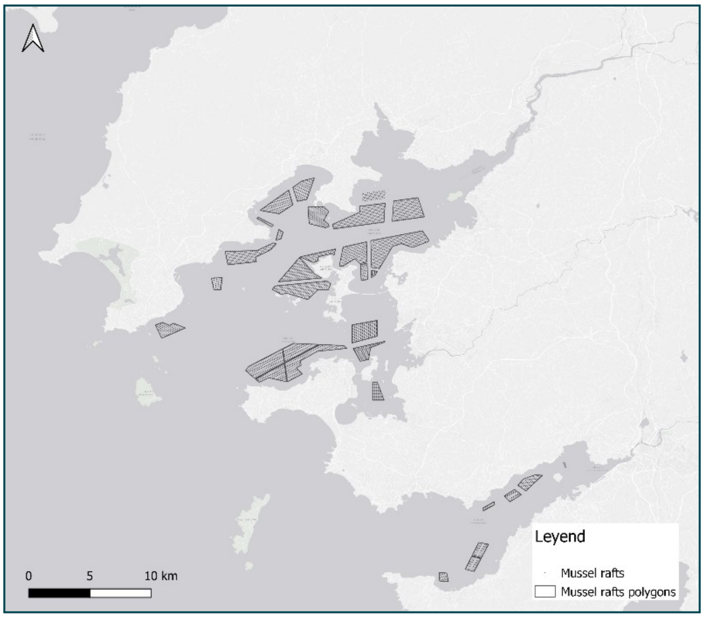


Figure 4. Location of the polygons of bateas in the Ría de Arousa.

The batea is a floating nursery consisting of a framework of eucalyptus wood, rectangular in shape, on which the mussel ropes are tied. The trough is kept suspended by a system of floats.

The mussel seed is wrapped on the rope with the help of a thin biodegradable net of rayon, giving the mussel enough time to be fixed on the rope. After a few months, due to the considerable increase in weight of the mussel, it becomes necessary to undock the ropes, that is, the manufacture of new ropes of lower density. Every 30-40 cm of rope are placed sticks of wood or plastic (more common today) between the strands of the rope to prevent groups of mussels from detaching. These plastic mussel-pegs allow a better attachment to the rope, prevents detachments, and facilitates the fixation of the mussel. They are plastic pieces 225 mm long x 30 mm wide (see Figure 5).

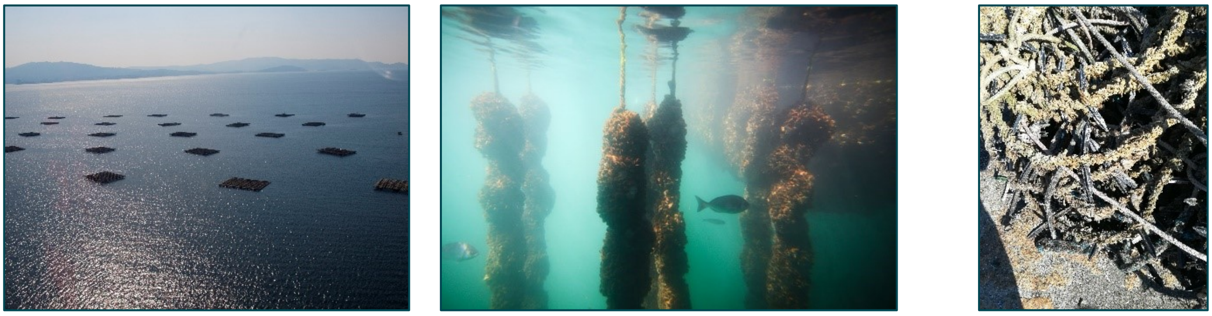


Figure 5. A) image of the rafts. B) Underwater view of the ropes. C) Detail of the chopsticks on the strings

The work of stringing, unfolding and extraction of the mussel, make the mussel-pegs of very whole, well split, are loosened and accidentally fall into the sea becoming one of the most common types of marine litter on the Galician coast.

Considering, on the one hand, the great extension of the crop, which generates a large number of these mussel-pegs poured into the water and, on the other hand, the characteristics of the same (they have known origin, are easy to characterize, can be counted and are plastic, which implies their great temporal duration) in the present study it was decided to use them as indicators of marine litter. To this end, all the mussel-pegs found were collected and counted to facilitate the study of the areas of accumulation of marine litter.

5.1.1 Sampling campaigns

The sampling carried out to evaluate this strategy was carried out in two campaigns:

Illa de Arousa: Carried out between October 2018 and May 2019, the points located in A Illa de Arousa were sampled within the framework of the citizen science project (Figure 2B, points 1-26).

Ría de Arousa: Carried out between October 2021 – April 2021, the points located on the coast of this ria were sampled (Figure2A, points 27-36). These samples were carried out by professional samplers, trained to also carry out the sampling explained in the following point.

On each day, the samplers monitoring the beach and collected data on:

- ✓ Mussel-pegs (indicators). Picking up the mussel-pegs and writing down on the card the number of mussel-pegs, both broken and unbroken, that were found.
- ✓ Distribution of ML. Drawing on the form the location of the ML, and in the case of finding areas of special accumulation, covering the information related to the composition (grouped into the following classes: Plastic, metal, wood, textile, rubber, vegetal remains, others) and size (grouped into three classes: more than 5m, between 1 and 5m, and less than 1m) of each of these accumulations.
- ✓ Photography. With the intention of having a record of the temporal evolution of each of the beaches, at the beginning of each day a photograph was taken, to be able to always be from the same point. To give visibility to the project and that it served as an awareness tool through the social network INSTAGRAM with the hashtags: #cleanatlanticwp5, #INTECMAR, #IESAILLADEAROUSA.

5.1.2 Results

In the Illa de Arousa, a total of 9205 mussel-pegs were collected, which meant the removal of 141,245 Kg of plastic from the sea (estimated from an approximate weight of 26 g for each whole mussel-peg). In the samples carried out in the Ría de Arousa the number amounted to 5428, assuming 911.28 kg.

In both cases, the total number of mussel-pegs collected is variable depending on the beach sampled (see Figure 6). In the first case it varies from 1263 mussel-pegs collected at beach 2 (facing west) to 2 collected at beach 18 (facing south). In the samples carried out in the Ría, the beach number 27 stands out, where the number of sticks removed (2125) is much higher than the rest of the beaches. In this case the beach that receives the fewest mussel-pegs, only 10, is number 29, facing east.

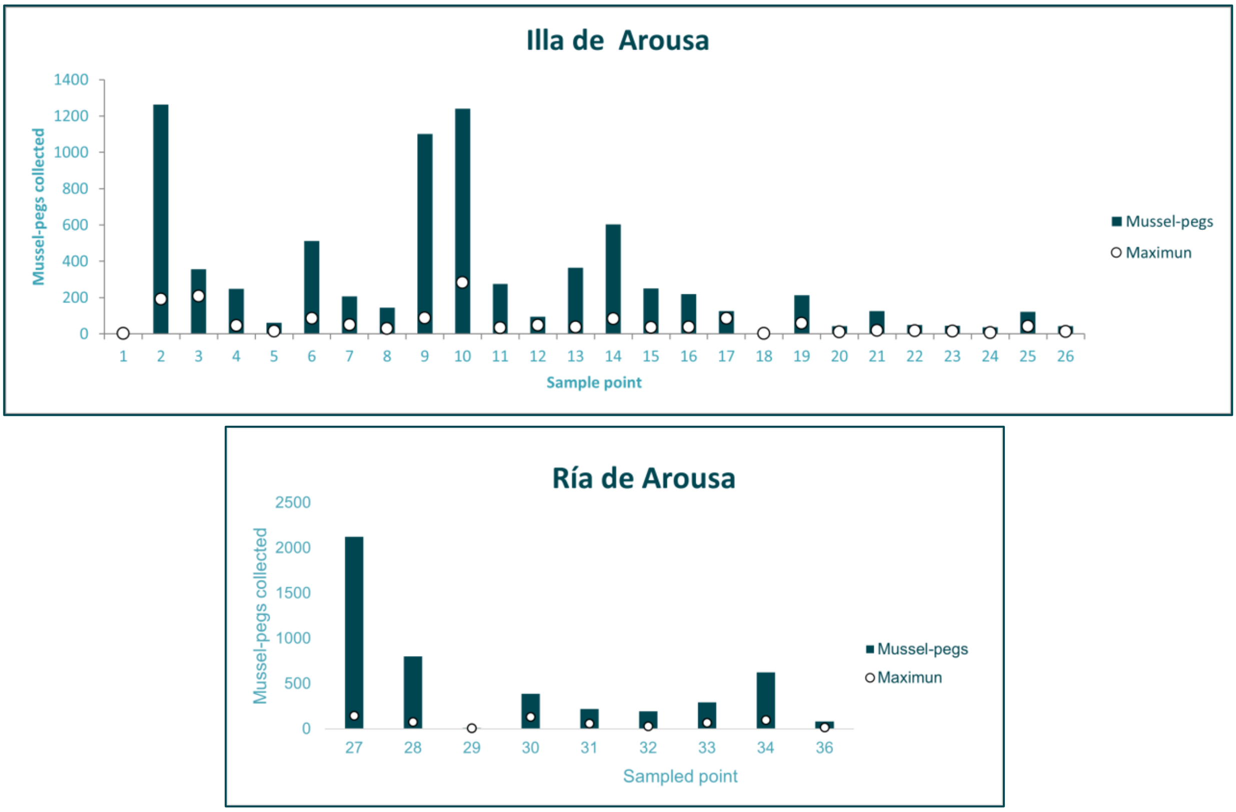


Figure 6. Mussel-pegs collected in the campaigns of A Illa de Arousa and the Ría de Arousa.

In both cases there are beaches where it is seen that practically the total of mussel-pegs collected correspond to a specific contribution in a specific week (maximum value). This happens for example on beaches number 3, 17 and 29.

These punctual maximums correspond to specific ocean-meteorological situations, to which that area is more exposed, however, this does not mean that it is an area with a clear pattern of accumulation of marine litter (see Figure 7).

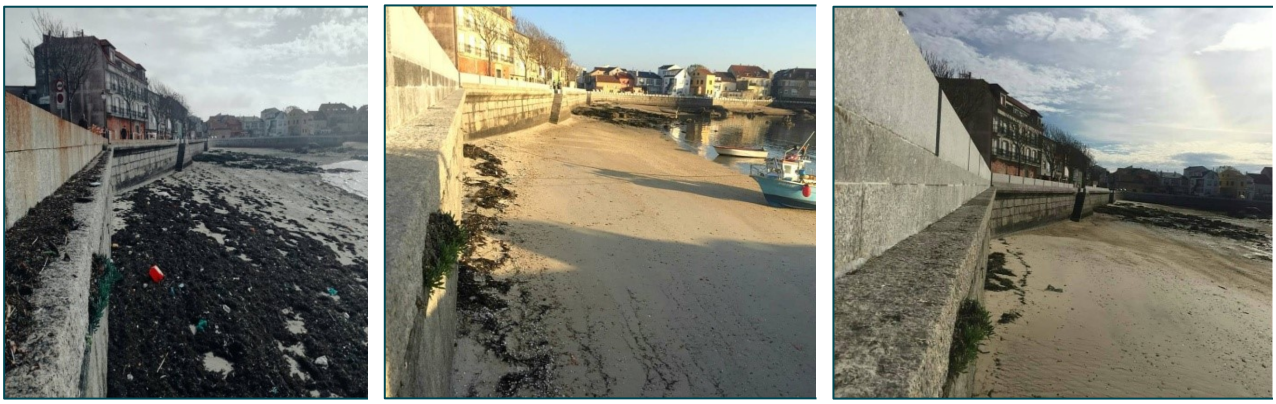


Figure 7. Photographs taken during sampling on beach number 17 in which a peak of accumulation is appreciated, which is not repeated throughout the sampling.

With the intention of revealing which are those beaches that are receiving ML continuously and not only sporadic, the calculation of an accumulation threshold was also proposed. The calculation of this threshold is done through the 80th percentile. This threshold is calculated for each of the weeks, and those beaches that exceed it, are marked as accumulation zones.

In this way, the beaches with the highest accumulation of ML in each week of sampling are selected. Analyzing how many times each beach appears repeated between the weekly maximums, it is determined if the beach is an accumulation zone or not.

The following levels were established:

Level of accumulation	% times above threshold (P80)
Very low	Less than 3%
Low	Between 3 and 10%
Intermediate	Between 10 and 16%
High	Between 16% and 45%
Very high	More than 45%

The figure 8 shows the level of accumulation that each of the beaches presents.

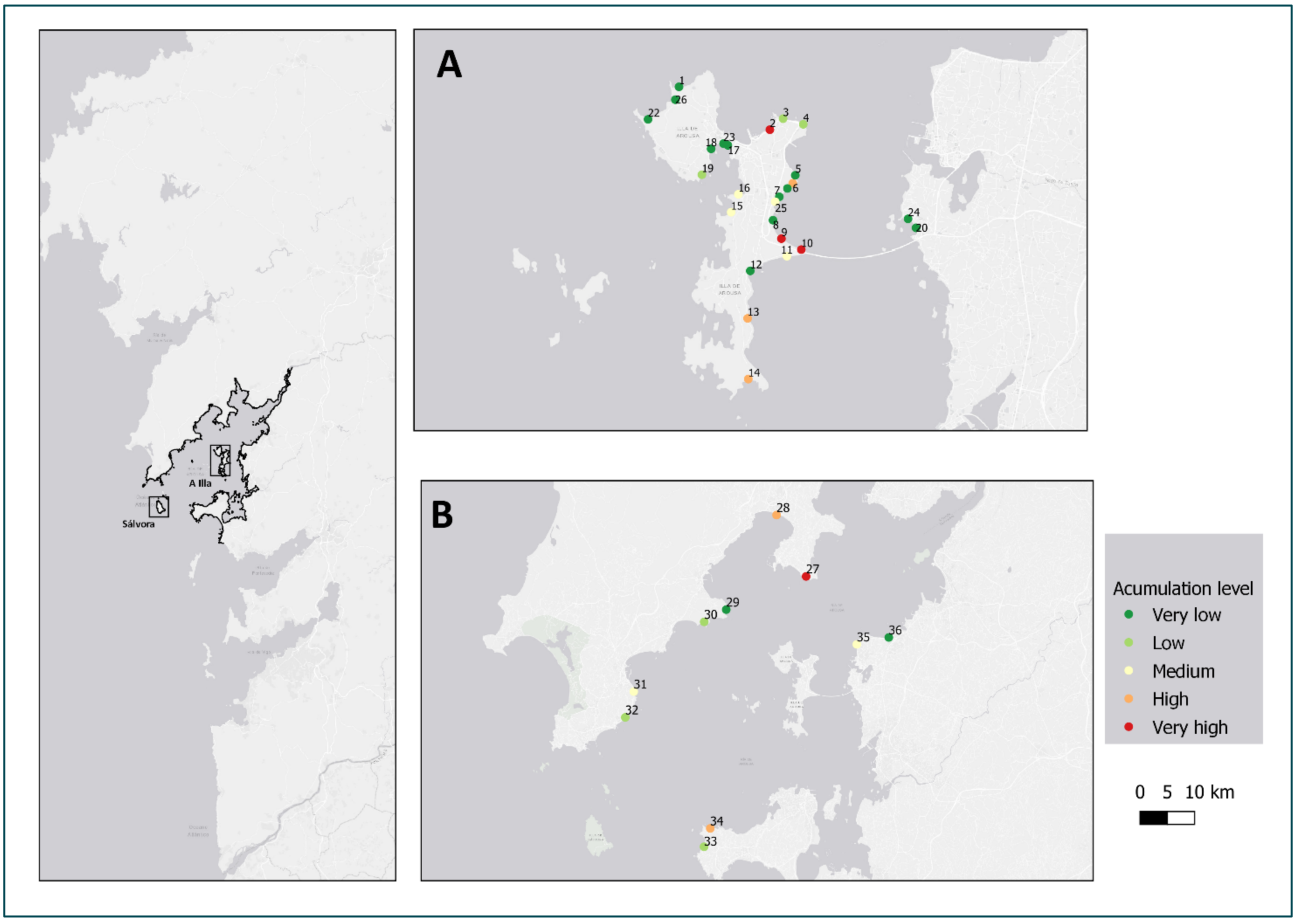


Figure 8. Level of accumulation in: A) A Illa de Arousa, B) Ría de Arousa.

In A Illa de Arousa stand out the beaches number 2, 9 and 10 with very high accumulation levels (marked in red) and the beaches number 6, 13 and 14 with high accumulation levels marked in orange.

In the case of A Ría de Arousa, beaches number 27 and 28 (both facing south) and beach number 34 (facing north) stand out at the highest levels. This beach did not stand out among those that receive the largest number of mussel-pegs, however, it does so by attending to the number of times it exceeds the accumulation threshold, this happens because the arrival of mussel-pegs to this beach occurs constantly and not at a punctual maximum.

5.1.3 Conclusions

Both in the case of A Illa de Arousa and in the case of the coast of the Ría de Arousa, several areas have been revealed where their accumulation of ML (taking as an indicator the mussel-pegs) stands out over the others, therefore, these areas could be taken into consideration when designing the cleaning strategy.

Thanks to the intensity of the sampling, many photographs have been obtained where it can be observed the temporal evolution of the different beaches. Through the photographs it can be seen how there are moments where a beach is completely clean and others where the beach has a large accumulation of both ML and algae. This, as is already known, shows that ocean-meteorological conditions are key to locating potential areas of accumulation of marine litter, so it is recommended that they be considered to define the sampling days.

The photographs also have a great value since they can serve as a basis for other studies of accumulation areas based on image analysis techniques as has been done in the case of images taken with drones.

One of the successes of this action has been, without any doubt, to be able to bring adolescents closer to the world of science while promoting the importance of taking care of marine ecosystems and the fight against pollution. On the other hand, the impact of this work in the local press has served to continue raising awareness about the importance of the care and conservation of the sea in line with other activities that have been developed within the framework of the CleanAtlantic project.

5.2 Systematic sampling of accumulation zones (accumulations)

In this case, the aim was to carry out a systematic, objective, and homogeneous classification of the accumulations found on the beaches.

For this we look at how the experts in responding to the oil or chemical substances spill carry out systematic sampling of coastal affectation, since both events (the arrival of oil and the arrival of ML) have similarities.

Following this philosophy, a methodology adapting to the sampling of ML or element washed ashore, the technique of evaluation of affectation of the coasts (Shoreline Cleanup and Assessment Technique) was developed.

This technique was developed in 1989 during the response to the Exxon Valdez oil spill when, given the large amount of coastline affected, the need arose to systematically document the different impacts of the spill along the coast.

The SCAT technique uses standardized terminology to document coastal pollution conditions. SCAT teams include people trained in the techniques, procedures and terminology of coastal assessment and field forms are used for data collection. For more information consult the shoreline Cleanup and Assessment Technique (SCAT) website | response.restoration.noaa.gov

In this case, taking as inspiration the classification carried out in the SCAT technique for the study of hydrocarbon contributions during accidental spills, a categorization of the possible accumulations of ML was carried out. This categorization is based on a triple-entry matrix that considers the width of the accumulations, their thickness, and their coverage. Thus, the accumulations are classified according to:

- ✓ Width (in direction perpendicular to the beach):
  - Width: *more than 6 m*
  - Medium: *Medium: > 3 - 6 m*
  - Strait: Strait: *> 0.5 - 3 m*
  - Very narrow: *< 0.5 m*
- ✓ Thickness:
  - Very thick: *> 10cm*
  - Thickness: *> 5 - 10cm*
  - Means: *> 1 - 5 cm*
  - Fine: *<0.5 - 1 cm*
- ✓ Coverage:
  - Continuous: *91-100%*
  - Fragmented: *51-90%*
  - Discontinuous: *11-50%*
  - Sporadic *1-10%*
  - Isolated <1%

Once each accumulation has been classified based on these three criteria, the length of the section affected by the accumulation was measured. This allows, on the one hand, to obtain an estimate of the average volume (m^3) of each of the accumulations and on the other, a description of these based on five levels: very low, low, medium, high, and very high.

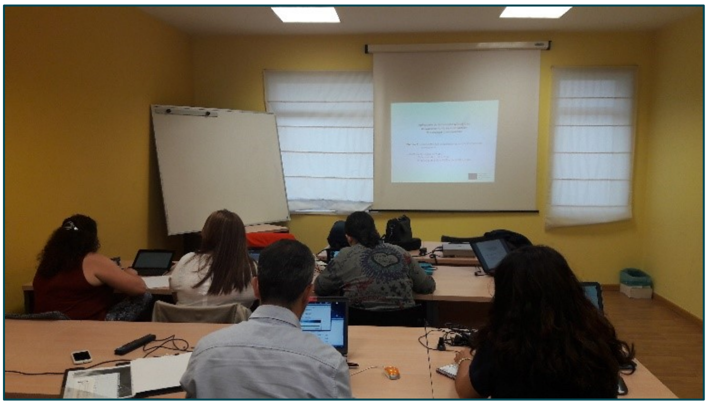
5.2.1 Sampling campaigns

The samples carried out to evaluate this strategy were carried out in a campaign where the points located on the coast of the Ría Arousa were sampled (Figure2B Points 27-36).

The sampling was carried out with the collaboration of 5 technical experts in coastal sampling who usually carry out both sampling work on the selected beaches, as well as advisory work to the shellfish sector within the framework of their daily functions.

Before starting with the sampling, within the framework of the CleanAtlantic project, a training activity was carried out (see Figure 9ª) during which the personnel were specifically trained to search for areas of accumulations of ML on the coast. With the intention on the one hand, to ensure homogeneity in the samples carried out and on the other hand, to guarantee the quality of the data generated to be able to be used for the validation of the results obtained in another of the studies carried out in the project. That is focused on the use of numerical modeling for the knowledge of the movement and accumulation of marine litter (see the results of work package nº6 of the project).

During this training activity, the photographs taken during the samples carried out by the students in the case described in point 5.1 carried out in A Illa de Arousa were very useful, since they served as a visual guide for the training of the staff.



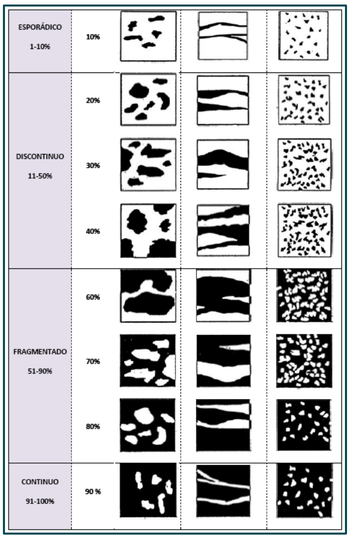


Figure 9. A) Training event with technicians B) SCAT Spreadsheet

Throughout each sampling, the following data were taken on accumulations:

- ✓ Width: Several representative measurements of the width of the accumulation were made in a perpendicular direction to the beach and the average of all was calculated. If the accumulation was not continuous, the extremes of the different groups that constitute the accumulation were taken into account.
- ✓ Thickness: The average thickness of several representative measures was considered.
- ✓ Coverage of the sediment of the beach. To help determine the coverage, a coverage sheet obtained from the SCAT technique (Figure 9B) was used.
- ✓ Length: measure of the length of the accumulation.
- ✓ Composition (Plastic, metal, wood, textile, rubber, vegetal remains, others).
- ✓ Photo: A photo is taken of each of the accumulations that can be used to resolve doubts and for future actions, both analysis, awareness and dissemination.

5.2.1 Results

With the intention of being able to make comparisons between the results obtained in this case with those obtained after the sampling of Point5.1, the results were treated in the same way. Thus, the total volume of accumulation on each beach and the maximum peak of these accumulations were calculated.

As was the case with mussel-pegs, the volume of accumulations varies significantly from one beach to another, with beach number 27, facing south, the one with the highest volume of accumulation and beach number 31 facing east being the one that receives the least (see Figure 10).

Attending to the estimated maximum in each beach, the beach number 33, facing west, stands out, where 68% of the volume of the accumulations were received in a week. The opposite happens with the beach of 36 or 27 where the maximum peak is less than 12% of the total volume.

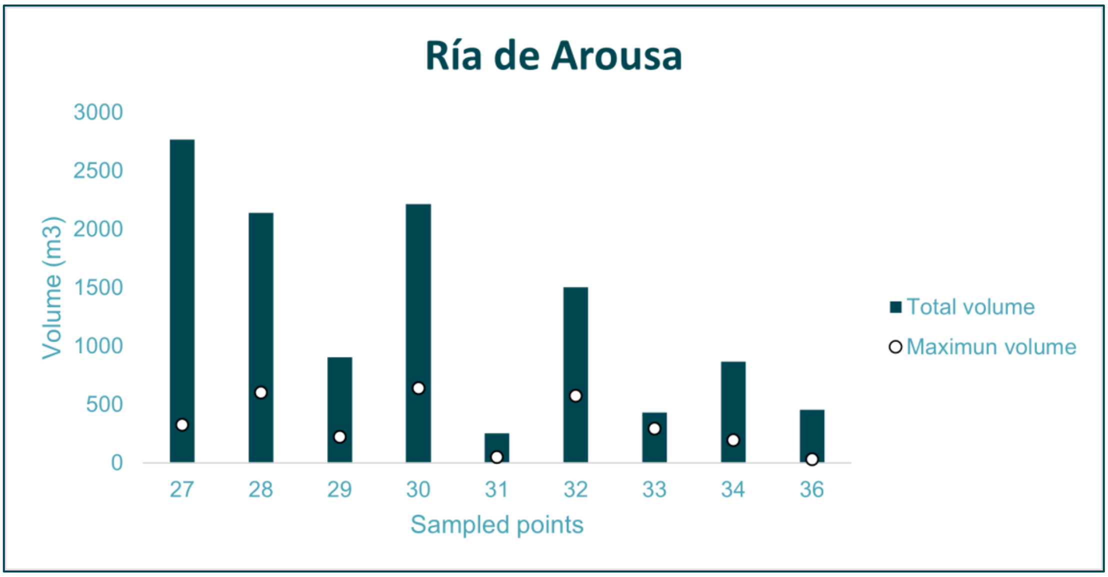


Figure 10. Volume of accumulations collected

As in the previous case, the result of the accumulation level, based on the number of times each beach exceeds the 80th percentile, is represented in the following map where beaches number 27 and 28 (both facing south) and beach number 34 (facing the north) stand out with high and very high accumulation levels. It should be noted that beach number 34, which, in the case of the total volume of accumulation, occupies position number 6, however, despite not reaching a very large volume of accumulations, it is receiving small accumulations continuously (see Figure 11).

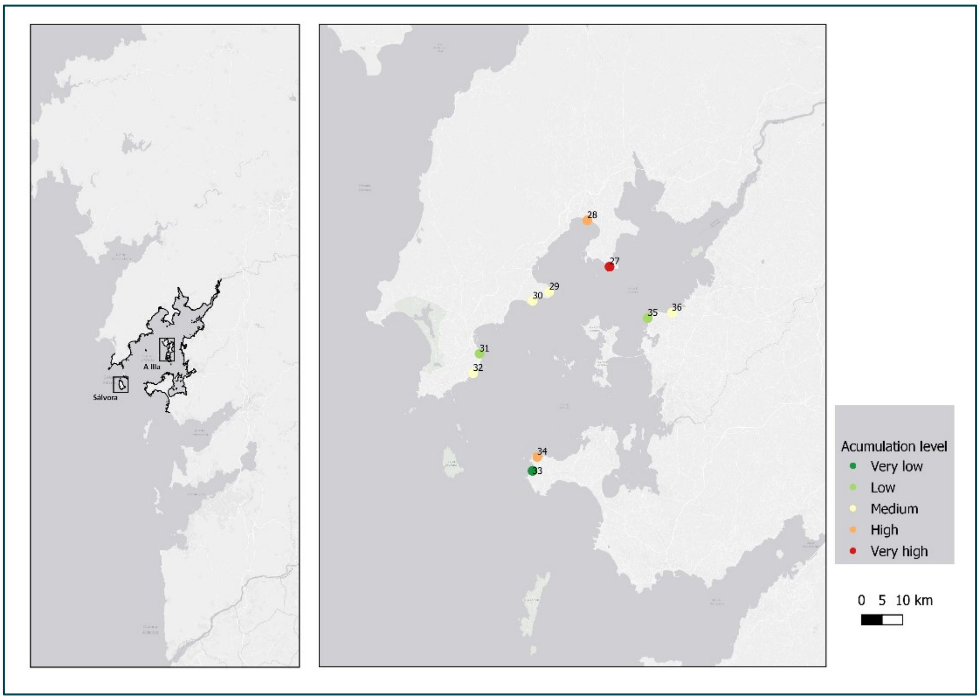


Figure 11. Level of accumulation in the Ría de Arousa

5.2.2 Conclusions

From the sampling and its subsequent analysis, it can be extracted that in both strategies (mussel-pegs and volume estimation) three beaches, numbers 27, 28 and 34 are revealed as areas whose level of accumulation is at very high and high levels, standing out from the others.

The fact that both strategies return the same result reinforces the idea that these three zones can be considered by the different managers involved in the design of the cleaning strategy.

In the rest of the beaches, the accumulation varies from very low to medium level, being also the result very similar in both strategies. Only in the case of beach number 29, the difference between both strategies is striking (medium level in volume and very low in mussel-pegs). This overestimation may be due to a sampling error in the first weeks, since the accumulations are not pulled from the beach, as is done with the mussel-pegs, being able to confuse the sampler who counts part of the accumulations twice.

The fact that both strategies return similar results suggests that both are suitable for knowing the spatial distribution of the areas of accumulation of marine litter along the coast. Although the sampling of mussel-pegs is faster than the sampling of the volume of accumulations, it is not proven that in other areas with less presence of rafts, mussel-pegs continue to be a good indicator and therefore, it may be necessary to identify an indicator that best fits the study area.

6 INDIRECT SAMPLING STRATEGIES

Direct sampling techniques are sometimes difficult to implement because they require large personnel who are not always available. The use of methodologies that do not require a large amount of labor in the collection of data or technologies that allow an indirect way to evaluate large areas, is being the subject of numerous studies in different fields. The location and tracking of floating marine litter are one of the fields in which this type of technology can be a useful tool. In this sense, the boom that drones are having in the location and aerial identification of objects, has been the starting point of this study to consider the evaluation of this technology in the identification, no longer focused on specific objects, but in a more generic way to the location of accumulation areas on the coast. For its part, taking advantage of the existence of a system of high-frequency radars in Galicia, it was decided to explore the information about surface currents generated by this system for the identification of areas to which marine litter can be dragged by these currents.

6.1 Drones

The use of unmanned aerial vehicles (drones) is shown as a technology that allows the recognition of areas of difficult access. Considering the advantages that these devices can offer, a study was carried out on their effectiveness for the location of areas of accumulation of ML on the coast, since the objective is to detect those areas of accumulation will not consider the classification of ML.

The drone model chosen to carry out this study was a DJI Mavic 2 Pro (see Figure 12A).

For the realization of the flights, the Island of Sálvora was chosen (see Figure 12B), located at the mouth of the Ría de Arousa. This Island, belonging to the Maritime-Terrestrial National Park of The Atlantic Islands of

Galicia, with 1.9 km2, is uninhabited and divides the ria into an entrance to the south, the main and deepest, with a width of 4.6 km and a depth of 50 m, and another to the north, 5 m deep, and 3.7 km wide.

The perimeter of the island of Sálvora has been divided into 13 transects, each transect is a polygon of 1000m long by 100 m wide. The number of transects was chosen in collaboration with the CleanAtlantic model group, to use the results of this study to validate the model results. In this line, the dimension of the transects has been set to ensure the best reproduction of the coastline, since a lower resolution cannot ensure the correct definition along the coast.

After the first tests, a protocol was established that allows capturing the images of the entire perimeter in a semi-automated way, generating fixed transects that are repeated in each flight session. The drone takes one direction and advances through it without going back. It is a unique one-way flight following the coastline. The target flight altitude, from take-off, was set at 40 meters above the reference sea level value (this is a value that would coincide with the average tide height, the same as used in commercial aviation).

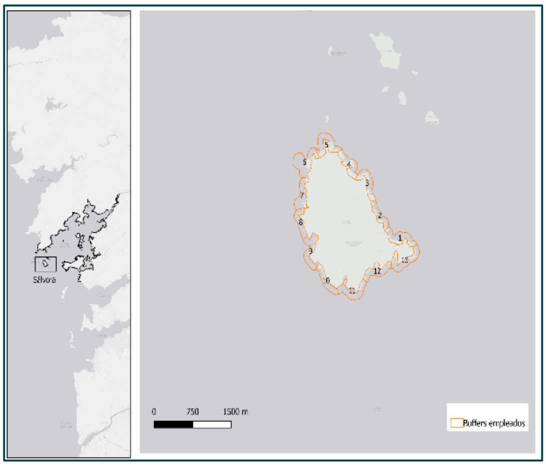


Figure 12. A) Drone DJI Mavic 2 Pro. B) Flight transects

6.1.1 Flight campaigns

It is known that ocean-meteorological conditions are key to locating possible areas of accumulation of ML. In general, each ocean-meteorological situation can be associated with a specific ML distribution pattern.

Taking this into account, the flights were made in the period between November 2018 and October 2020, planning their execution based on the meteorological predictions of Meteogalicia, (Regional meteorological service).

Galicia is clearly influenced by wide atmospheric pressure centers, annually low pressures affect 42% of the days, high pressures in 53% of cases, while in 5% of days there is a transition between them.

Low pressures are usually associated with winds of south and west component, of moderate or strong intensity while in high pressures the winds are predominantly from the east and north and usually with less intensity, even with situations of calm winds

and very local effects.

All these configurations can be grouped into 8 typical weather situations with a given occurrence frequency. Both the description of these situations and the analysis carried out for their classification can be found in Annex IV of this document.

By way of summary, the following table shows the dates of the flights and a brief description of each situation:

Number/date flight	% Of occurrence of the situation	Description
1 14/11/2018	20%	The very common situation in spring and autumn, with an anticyclone centered in Central Europe with low pressures over the Atlantic that leave a day of weak wind from the east, with punctual breezes in the early afternoon (and therefore west wind). The situation comes preceded by many days of southwest stacking water against the coast.
2 04/12/2018	13%	The very common situation in winter with a storm approaching from the Atlantic and with an anticyclone over the Peninsula that blocks its passage which causes many successive days of moderate / strong wind from the south-southwest.
3 13/02/2019	13%	The very common situation in winter and punctual in summer with an anticyclone to the north of the Peninsula, leaving intense northeast wind at the beginning of the day. The day ends with a weak south wind, after several days in the southwest.
4 13/09/2019	10%	The most typical summer situation with a blockade anticyclone in northern Galicia. East-northeast wind, with breezes at noon and turn to the west, after several anticyclonic days "drawing water" from the ria.
5 18/02/2020	5%	The most common situation in spring or at the end of winter. Northwest day, typical transition day between storms circulating in the north of Galicia and the arrival of an anticyclone from the south.
6 07/03/2020	25%	Very typical situation of the Galician winter, occurring 1 out of every 3 days in this season. Several days in a row of low pressures with westerly winds (varying between south-southwest and northwest)
7 30/10/2020	14%	Situation more typical of winter, but that can appear at any time of the year, with storms to the north of Galicia leaving winds of southern component.
8 27/05/2021	10%	Very typical situation of the end of spring and summer with the anticyclone arriving from the Azores and leaving north component wind

6.1.2 Obtaining the data

Initially, experimental drone flights, were carried out to determine the ideal speed and height above sea level of the flights. After performing static photographic tests at different altitudes ranging from 20-120 meters above sea level (ASL) with reference objects of 10 cm, it was decided to perform the flights in EVlos mode with an ASL 37-49m.

This interval is given that even if the drone flies with reference to 40 meters above sea level, there will be moments that photograph elements that are closer and further away from that distance, as well as the margin of error of the altimeter according to climatic conditions. In this 37-49 range the data are completely consistent.

In this selected range of heights, objects of length greater than 10 cm can be identified and allow to capture in a single flight the intertidal zone in which the accumulation of marine remains occurs. To use this methodology of aerial identification of marine accumulations efficiently, it is important that the analysis of accumulated debris can be done by making a single flight along the coastline.

The speed of the drone for these flights was configured so as not to exceed 9 km/h on average, always keeping a battery reserve to be able to return to a safe area at the maximum speed if necessary.

A photo was taken every 2-4 seconds, with aperture priority, a minimum exposure of 1/200 and a maximum of 1/400 with automatic ISO. The focus was manually calibrated once the drone had reached cruising altitude.

The photos were saved in JPEG format of the highest quality. After each of the scheduled flight days, the images of the drone memory were sorted into folders by flights performed V0, V6, using the DroneMapper tool to organize the stages. Metadata relating to the images of each flight was corrected (folder) using the AnalogExif program when needed.

6.1.3 Image processing

For the processing of the images made, the *Precision Mapper* Software was used, generating the orthomosaics for each of the transects that served as the basis for automatically calculating the accumulation zones. To facilitate the manipulation of the images, the original images were rescaled to 1/3 size. In this way, its subsequent processing is facilitated without losing resolution for the identification of objects larger than 10 cm.

For the selection of accumulations in orthomosaics Photoshop has been used. The right tool to facilitate the selection of accumulations is the "magic barite". In each transect analyzed were selected different accumulation samples with a sample size of 11x11 and a tolerance of 5. The areas selected as occupied by accumulations of marine origin were turned to red 255-0-0. This type of selection was repeated for each type of accumulation that differed in its original color. After automated selection based on the source color of the accumulation, a visual and manual review of the selections was carried out to validate the procedure.

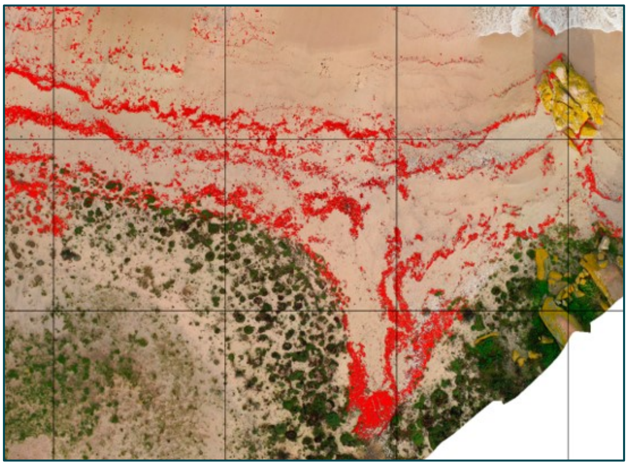


Figure 13. A) Processed image

For the accumulation count it was decided to calculate the percentage of pixels of each color 255-0-0 transect occupied versus the total pixels of the picture. To make sure the selection covered the areas where the red could suffer some antialiasing, in the selection a tolerance level 50 was used.

6.1.4 Results

The use of drones has made it possible to sample the study area, that is, 6500 meters of coastline, inaccessible in some cases to people, in a short period of time. High-resolution images (10 cm in object identification) have been obtained and used now and may be used in the future with other digital image processing techniques.

The established protocol has made it possible to capture images of the entire perimeter of the Island of Sálvora in a semi-automated way, generating fixed transects that are repeated in each flight session and that lead to a spatially consistent sampling.

After the processing of the images, explained above, the % of each transect occupied by accumulation of ML or remains of arrival is automatically obtained. Thanks to the ability to export information on % of pixels with accumulation of ML to GIS hotspots maps could be generated. These maps allow assess the accumulation rate over time in each transect.

For a greater understanding of the results the transects have been categorized into five levels (very high, high, intermediate, low and very low) using the Jenks optimization method for the percentage of pixels with accumulations they present (see Figure 14).

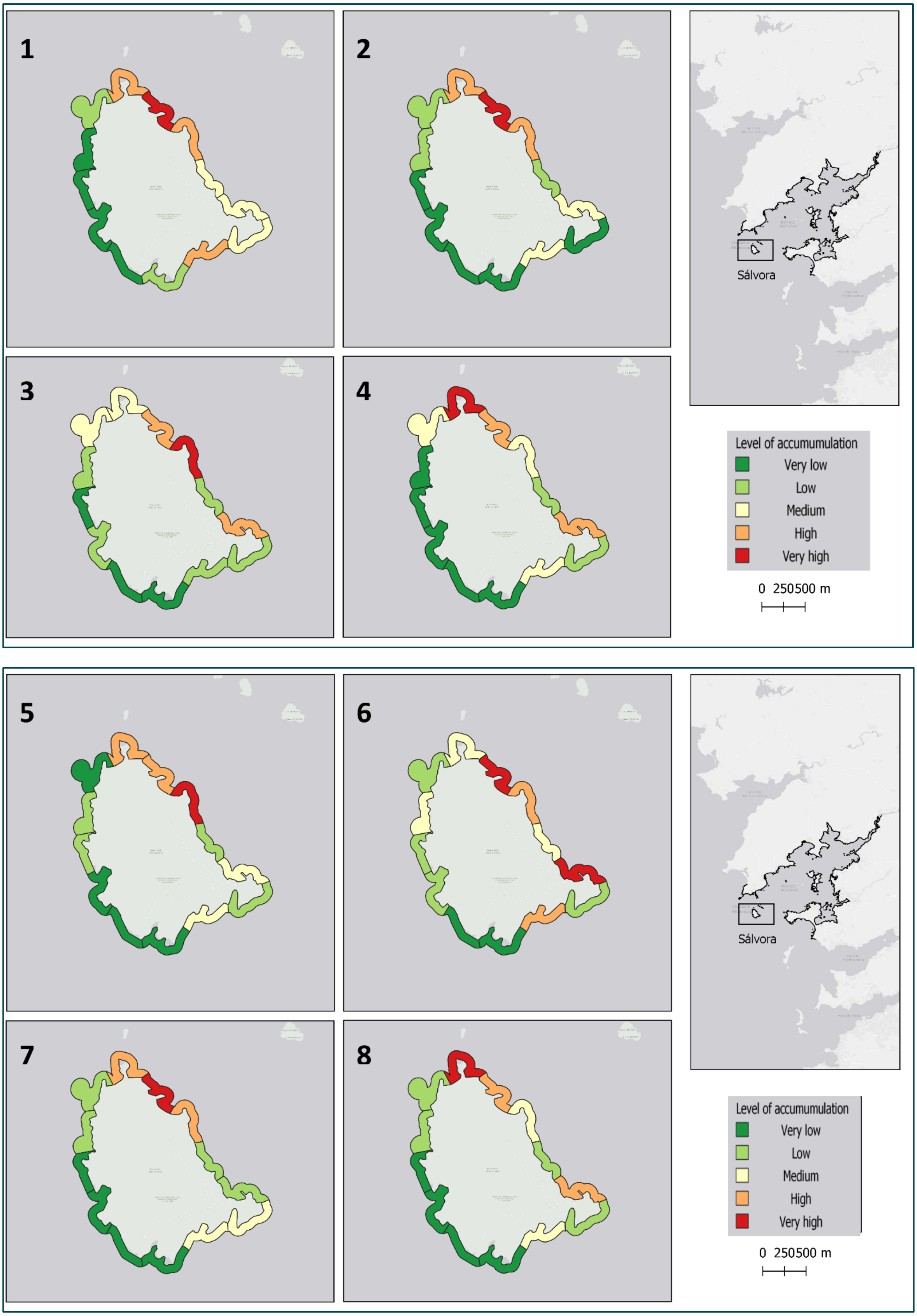


Figure 14. Level of accumulation of the Island of Sálvora in each of the flights made

The maps show that the accumulations are located on the east face of the island, highlighting in this section the northern part.

This distribution is independent of the ocean-meteorological condition in which the flight was made. This a priori may be surprising, can be explained because the coastline of the island of Sálvora is very different.

Its east side is marked by the presence of sandy beaches and small granite blocks rounded by the swings of the waves, and on its west side, rocky areas of soft relief predominate (Visit Guide Maritime-Terrestrial National Park of the Atlantic Islands of Galicia).

These rocky areas can be more selective, in the types of ML they retain, than beaches and are therefore less representative (Weideman et al).

6.1.5 Conclusions

The methodology and protocol used to implement the taking of high-resolution aerial images, allows all the necessary flights to cover the perimeter of the Island of Sálvora in a single day, obtaining images of sufficient resolution for the subsequent work of identification of accumulations from the sea.

The generation of orthomosaics of each transect is rapid and the orthomosaics can be obtained in approximately 24 hours.

The technique used to calculate the surface occupied by the accumulations in each transect can be performed by trained personnel in about 40 hours for the entire perimeter of the island. The developed protocol allows to detect objects automatically, but despite being fast, it is prone to errors when the composition of the background is not pure. For example, artifacts such as shadows or darker areas on cliffs were marked as areas of accumulation when in fact they are not.

Consequently, it is recommended to explore other image processing techniques, on the images already obtained, to successfully identify the areas of accumulation.

6.2 Radar HF

The High Frequency Radar or HF Radar technology allows remote real-time monitoring of currents and waves in an area between hundreds and thousands of square kilometers based on compact stations that are located on land. By placing two or more radar stations in front of the same area of the sea, maps of surface currents in that area can be obtained. The current date obtained are representative of the upper layer of the sea at a depth of about two meters. In addition to measuring maps of surface currents, radar technology also provides data on significant height, direction, and wave period.

In this case, the interest of HF radars lies in their use to identify critical points of coverage and track litter from the sea surface (through Lagrangian models, see results of work package 6 of the project) to define strategies for the prevention of floating marine litter before its arrival on the coast.

Figure 15. A) Transmission antenna and receiving antenna placed in the lighthouse of Cabo Vilán. B) Transmission antenna C) Receiving antenna.

6.2.1 Operation of HF radars

Like conventional radar, the one used for air traffic control, the High Frequency radar is based on the emission of electromagnetic waves and the study of their echo after lying on target to analyze, in this case the surface of the sea. Once the echo of the High Frequency signal from the sea surface has been received, by changing the frequency between the emitted and the reflected signal, the speed of the sea surface can be known, in addition to using the wave theory the velocity associated with the wave and the radial component of the velocity (see Figure 15A).

Each of the radars in the network calculates its corresponding radial velocity map and the current field map is immediately reconstructed on a central server composing them, using simple trigonometry (see Figures 15B,C, D and E).

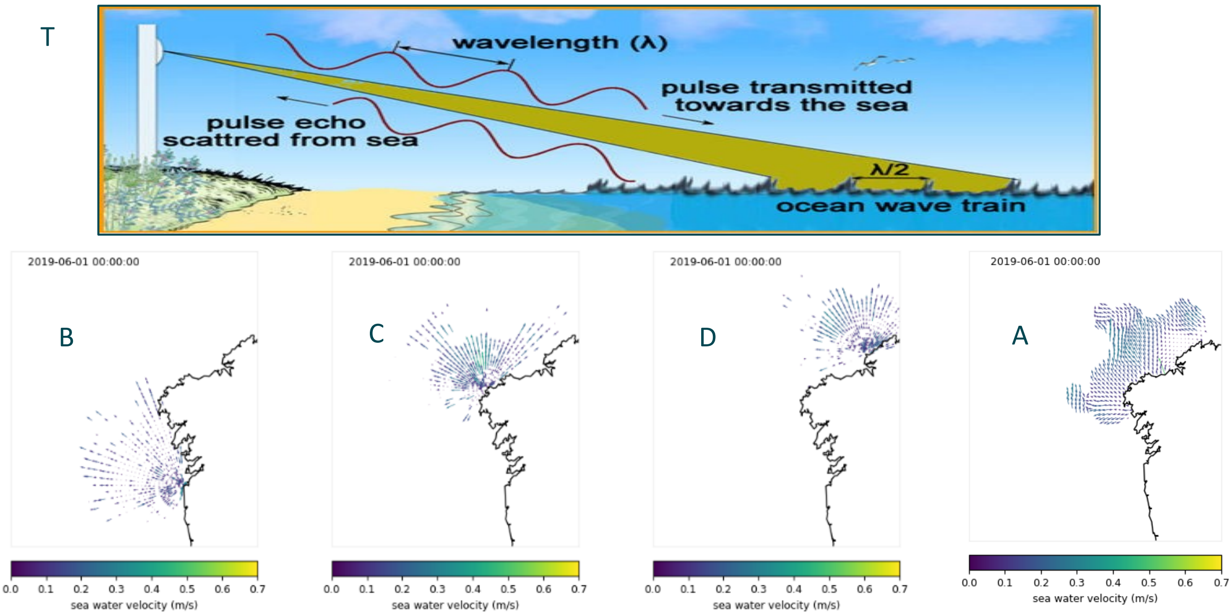


Figure 16. A) Operation of an HF radar. B-D) Maps of the radars of the Galician network E) Total composition

6.2.2 Application of HF radars in the location of marine litter

Today HF Radar data are successfully used in several applications such as coastal search and rescue, oil spill response, water quality monitoring and safe and efficient marine navigation.

What is not so widespread is the analysis of its ability to detect possible marine litter *hotspots.* After an exhaustive bibliographic review, among which the review of the applications of the HF Radars carried out by Harlan et al. al., 2010; Wyatt, 2014, it is concluded that the only way to use HF Radars to locate hotspots is through the calculation of the transport of surface current fields measured by them. These fields can then be used to force a Lagrangian model.

In this line, there is the study carried out by Basurko et al. 2015, where to reduce the time and effort of the search for floating marine litter the movement patterns of surface currents are evaluated, using HF radar date as forcing a Lagrangian model. On the other hand, Declerck et al., 2019 uses a combination of long-term HF radar results with other operational measurements and modeling data to investigate the transport of floating marine litter introduced by local river drains in the southeastern coastal zone of the Bay of Biscay.

A technique with great future projection consists of the detection of Coherent Lagrangian Structures (LCS), applying this technique not only determines the trajectories of the particles, but also defines the areas of convergence and accumulation and these may be the areas where the *hotspots* of marine litter could be located.

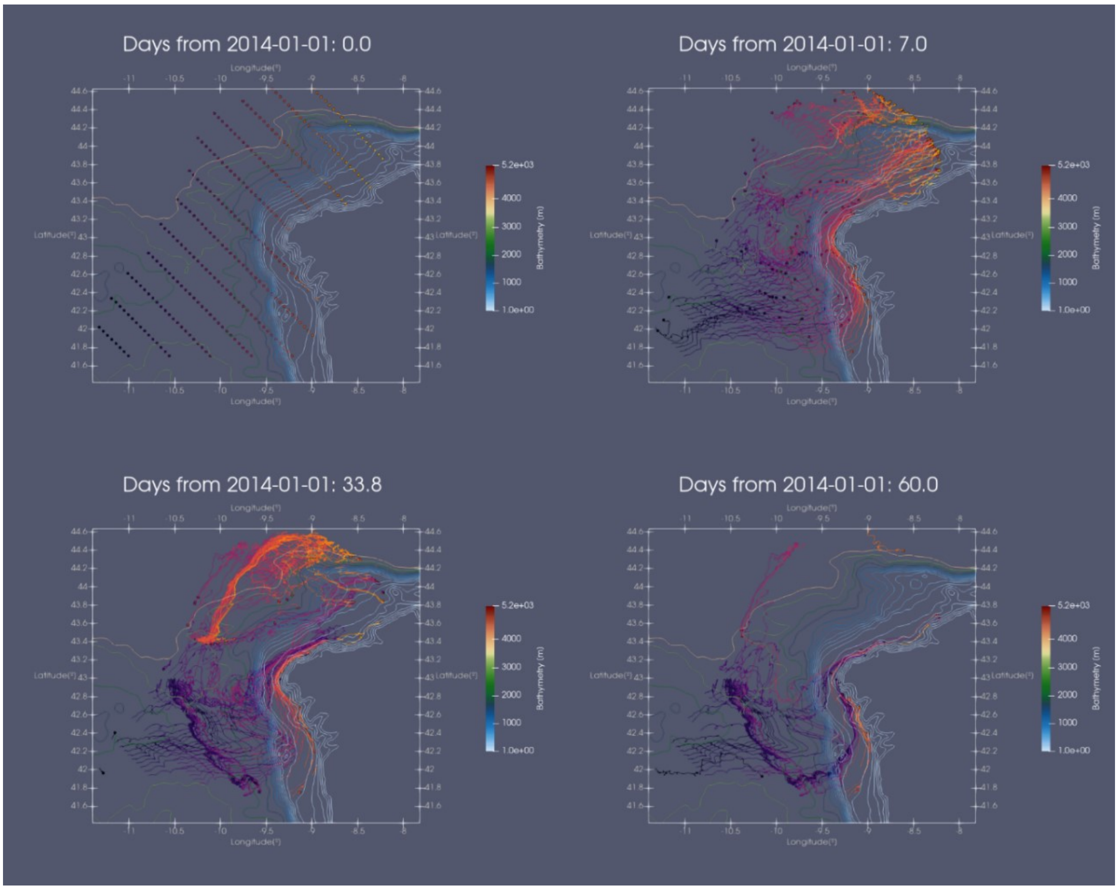


Figure 17. Results of the Lagrangian model forced by surface currents generated by the HF Radar system of Galicia. The particles simulate the overall trajectory of any possible surface debris.

The use of the information provided by the HF Radars is seen as a useful support tool to know the transport of floating ML, although more detailed studies are necessary to be able to implement its usefulness in the usual management protocols.

7 CONCLUSIONS

This study has demonstrated the possibility of using different sampling strategies to locate areas where marine litter can accumulate on the coast. Every one of the strategies evaluated is allowed for, a greater or lesser extent, mapping accumulation areas, although the complementarity between direct and indirect sampling can greatly facilitate saving resources when obtaining these maps.

The mixed use of strategies by the different administrations in their protocols for the location and removal of marine litter is proposed as the most successful option since it benefits from the advantages of each of them depending on the needs and the possibility of access to coastal areas.

It should be noted that the use of strategies framed in citizen science projects, in addition to presenting numerous advantages in the collection of information, is also a good awareness mechanism. This is so the citizen science works as speakers to send the message, about the problem that human activities generate in relation to marine litter, to the surrounding society of the participating volunteers.

To tackling Marine Litter, the strategies tested here have allowed the location of different hotspots that can be considered when planning cleaning activities. In addition, the hotspots revealed could be used as an initial point of numerical simulations in backtracking to locate possible emission points of marine litter that could be neutralized or minimized.

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9 ANNEXES

9.1 Annex I

Introduction

Within the framework of Work Package 5 (Monitoring and data management) and being aware of the long tradition of using volunteering as part of citizen science in marine litter research (Hidalgo-Ruz and Thiel 2015, Zettler et al. 2017), it was considered appropriate to start the collaboration with the students of the High School “Illa de Arousa” for the realization of specific samples in the environment of the island of Arousa.

According to the Definition of the European Commission, citizen science refers to the participation of the public in scientific research activities, in which citizens actively contribute to science, either with their intellectual effort or knowledge or with their tools and resources (European Commission, 2014).

Project preparation

When designing the collaboration between the INTECMAR team and the High School students, the recommendations described in the following table, included in GESAMP 2019, were considered.

Recommendations for Successful Citizen Science Programs

- Recruit actively
  - Presentation
  - Social Media
- Prepare simple step-by-step instructions with images and video
  - Test them for yourself
  - Ask several friends (who are not experts) to test them
  - Modify the instructions accordingly
- Make it as easy as possible for volunteers
  - Laminated and electronic versions of the instructions
  - Complete sampling kits with pre-paid shipping
  - Confirm your understanding BEFORE the sampling event
  - Easy-to-use data sheets and/or electronic data uploads
- Provide feedback to maintain motivation!
- Explanation of results
- Visual aids to show volunteers their contributions

In a first meeting, held between the STAFF of INTECMAR and the teacher in charge of the project at the High School, it was agreed to start the collaboration in October 2019, coinciding with the beginning of the school year, and the following was concretized:

- ✓ The students who participated in the activities take the subject of Technology and their age is between 14 and 15 years.
- ✓ INTECMAR selects the beaches where the sampling is carried out, considering that their distribution must guarantee the reliability of the results obtained in the validation tasks.
- ✓ INTECMAR oversees preparing the sampling material for the students and the data collection sheets.
- ✓ An information day was organized, where the project, the characteristics and needs of the sampling, etc. were explained to the students

- ✓ The distribution of the beaches among the students was done by teacher considering the preferences of each student.

Presentation and follow-up of the project with the participating students

Following the recommendations indicated above and considering the importance of training and contact with students, two training events were held at the High School facilities.

The first of these took place at the beginning of the project (October 2018) in which the students expressed their concerns about the problem of marine litter, they learned about the CleanAtlantic project, especially the tasks that are developed within it in INTECMAR, they understood the importance of their contribution to the project and received the necessary material to carry out the sampling in an efficient and safe way.

Figure 1 A) Training act with the students. B) Material distributed.

The second day took place after the first 8 samples (December 2018). During this day, the students were able to solve all the doubts that were arising and served to correct all those deficiencies that were found after the review of the first data collected.

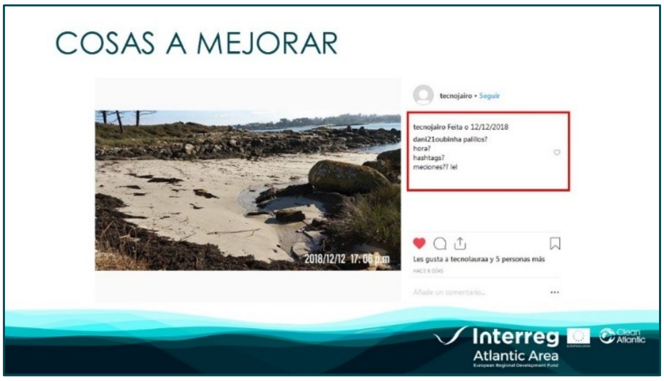


Figure 2 PowerPoint used with the students

Closure of the project

Once the sampling was completed a final event was held, during the event the students learned about the main results of their work and received a certificate accrediting their participation in the project.

One of the successes of this action has been, without any doubt, to be able to bring adolescents closer to the world of science while promoting the importance of taking care of marine ecosystems and the fight against pollution. On the other hand, the impact of this work in the local press has served to continue raising awareness about the importance of the care and conservation of the sea in line with the activities that have been developed in the WP8 of the CleanAtlantic project.

XUNTA DE GALICIA
CONSELLERÍA DO MAR

intecmar
INSTITUTO TECNOLÓXICO PARA O CONTROL DO MEDIO MARIÑO DE GALICIA

DIPLOMA DE PARTICIPACIÓN

NOMBRE APELLIDO APELLIDO

Participou como **mostreador/a no proxecto CleanAtlantic** para o INTECMAR durante o curso 2018/2019.

En Vilagarcía de Arousa, a 4 de xuño de 2019

A presidenta do INTECMAR

Dª. Rosa Quintana Carballo

Figure 3 Certificate given to students. **B) Impact on the local press**

9.2 Annex II

PRAIA BAO

Fecha:

Hora:

Mostreador:

Nº	Material							Tamaño			Observaciones
	P	Mt	Md	Tx	G	Rv	O	Pq	Md	G	

Palillos de batea	
Enteiros:	Partidos:

INSTRUCCIÓNS PARA A MOSTRAXE

1

- Achégate sempre a praia en condicións de seguridade (evita temporais e condicións adversas).
- Lembra levar todo o material que precises (metro, fichas, boli, sacos de lixo, roupa axeitada, etc.)
- **O chegar saca unha foto da praia, se é posible sempre dende o mesmo sitio**.

2

- Recorre o teu tramo de praia recollendo os palillos de batea que atopes.
- Anota na táboa cantos palillos de batea enteiros ou partidos atopas**. É moi importante para nos.**

3

- Se no teu recorrido atopas o lixo formando montóns, intenta debuxar no mapa onde están.
- Ponlle un número a cada debuxo e cubre a táboa.

4

Cubre a táboa coa información de cada montón de lixo:

En material marca cunha X os tipos de materiais que atopaches nese motón:

- Plástico (P)
- Metal (Mt)
- Madeira (Md)
- Téxtil (T)
- Goma (G)
- Restos Vexetais (Rv)
- Outro (O). Neste caso anota nas observacións que é o que atopaches.

En tamaño anota se o montón era:

- Pequeno (Pq). Mide menos de 1M
- Mediano (Md). Entre 1 e 5 M .
- Grande (G). > 5 M

5

Cando poidas sube a foto que sacaches o Instagram etiquetando o proxecto:

@cleanatlanticproject

Usa os hashtags**: #CLEANATLANTICWP5. #INTECMAR. #IESDAILLADEAROUSA**

9.3 Annex III

CleanAtlantic

Técnico/a			
Nº inspección			
Data e hora			
Praia			
Nº acúmulo			
Coordenadas			
X			
Y			
DATUM			
Lonxitude do tramo			

Materiais (tachar os presentes)

Plásticos	Metais	Madeira	Plásticos	Metais	Madeira	Plásticos	Metais	Madeira
Vidro	Goma	Vexetais	Vidro	Goma	Vexetais	Vidro	Goma	Vexetais
Visitado e sen acúmulos	Textis	Outos	Visitado e sen	Textis	Outos	Visitado e sen	Textis	Outos

Identificadores de fotos			
Categoría do acúmulo			
Nº palillos enteiros			
Nº palillos partidos			

Cometarios

9.4 Annex IV

Ocean-meteorological conditions are the main forcing used by numerical models to predict the transport and dispersal of marine litter.

In this way, we can affirm that an adequate characterization of the different ocean-meteorological situations, the frequency of appearance of these and their distribution at different times of the year, is a fundamental element to know the possible location of the areas of accumulation of marine litter.

Considering that among these forces, in a good part of the situations and for the different types of most frequent marine litter, the wind will be the greatest contribution to its movement in this work it is proposed to emphasize the classification of the situations associated with the wind on the surface over the sea in the study area. Thus, once the different wind situations and associated with them, and their frequencies of appearance, have been characterized by a set of typical days, it will be possible to carry out an adequate complete simulation of the ocean-atmospheric system associated with them.

The methodology, developed within the framework of the MARINER project (co-financed by the European Union in the framework of the Union Civil Protection Mechanism. DG-ECHO), consists of the following Steps:

A. Selection of available data: variables and study points
B. Reducing the Dimensionality of the Problem: Principal Component Analysis (PCA)
C. Climate classification: analysis "Cluster"

<u>Selection of available data</u>

The first of the tasks to be addressed within this climate classification involved assessing the adequacy of different data sources to its objectives. So, it was necessary to look for a data set with a spatial distribution (number of points) sufficiently numerous to characterize the study areas and with a set of variables capable of characterizing the wind in the area of interest.

In this sense, the following data sources were evaluated:

- Surface stations (land) and buoys (sea)
- Satellite data
- Reanalysis of global models

For the first two, the following drawbacks were found:

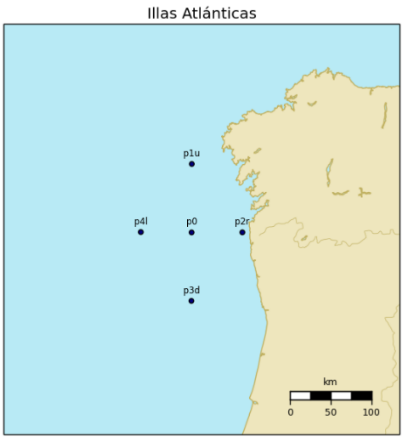
- Scarcity of surface data on the sea
- Limited representativeness of land data to characterize local wind in areas of interest
- Gaps in data time series (more pronounced in buoys and satellite data)
- Limited validity of satellite data in areas closest to the coast

So finally, due to the characteristics of the study, we chose to use the data from reanalysis of global models. The use of the reanalysis of the global GFS model (of the US NCEP) and those of the IFS model (of the European Centre for Medium-Term Prediction, the ECWMF) was evaluated. In both cases the accessibility of the data was wide, as well as the length of the series, so it was decided to opt for the data of the period 1985-2014 included in the ERA Interim analysis of the ECMWF to have a greater degree of detail.

The ERA Interim reanalysis uses data from atmospheric observations (surface stations, radio soundings, satellites, radars, etc.) to generate a representation of real weather situations compatible with the 0.75º horizontal resolution grid of the IFS numerical model of the ECMWF, considered the best global meteorological model and with the most complete data assimilation system. The ERA Interim is the most recent reanalysis product of the ECMWF, covering the period from 1985 to the present, and whose data are available under a license from the ECMWF itself that allows both its use for research and its commercial use.

Once the data source was selected, and since they were values in a regular mesh, in this case of horizontal resolution of 0.75º, it was necessary to select the specific points of study, as well as the variables to be included in it.

Regarding the spatial distribution of the points, it was decided to select a "central" point near the study area and four points around it so that they adequately covered both the area of interest and the areas in which possible marine litter could be located, as shown in Figure .



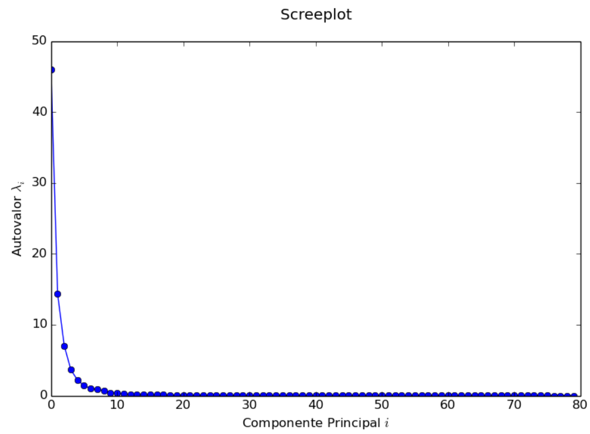
Spatial distribution of study points. Distances to center: 0.75º horizontally and 1.5º vertically

Finally, regarding the study variables, it was decided to use in each of the 5 points the surface wind (separated in its zonal components, u, and southern, v) and the geostrophic wind (also separated in both components), as a measure derived from the surface pressure gradient. To collect in the study the temporal variability of these Variables the use of the data corresponding to 00h, 12h, 24and 36 UTC was considered, with the purpose of classifying possible behaviors of ML in the next 24 hours, occurring at any time of the study day.

In this way, we have a problem with 80 dimensions. 5 points, 4 variables in 4 different moments of time.

Dimensionality reduction: PCA

As described in the previous section, we would have 80 study Variables. This is an adequate set of variables to perform the climatic characterization of the wind in the area but it is evident that the work of classifying the points located in the space defined by these 80 "coordinates" could be simplified if we managed to properly analyze the redundancies in the data, reduce the dimensionality of the same and therefore reach a new set of equally representative data.



Self-values calculated for the study area. Surrounded by a red circle are those corresponding to the main components selected by the "elbow rule"

To do this, we chose to perform an analysis of main components, a technique consisting of generating a new set of variables obtained each of them as a linear combination of the 80 variables of origin, that is:

CPi = a1i*var1 + a2i*var2 + a3i*var3 + ... + to80i*var80

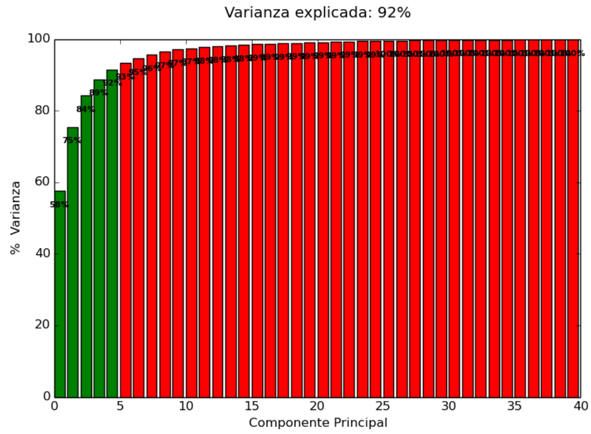
Principal component analysis (PCA) seeks to obtain these new variables (CPi) by calculating their coefficients (ai) so that the first major component explains most of the variability of the source data, the second major component would be the next to explain the variability of the source data, and so on. For this, the PCA technique diagonalizes the covariance matrix of the source variables, which formally gives rise to a new coordinate system (the main components) with as many dimensions as the original (80, in this case), and with the previous characteristics. To perform this diagonalization, the autovectors and auto values of the covariance matrix are calculated, being precisely the latter (autovectors) those that configure the matrix of change of coordinates between the original variables and the main components.

The really relevant thing about this analysis is that it allows to "concentrate" most of the variability of the source data in just a few main components, so that the others can be ignored, thus facilitating the climate classification by moving from a data set with 80 dimensions to a practically equivalent data set with only 3,4 or 5 variables, for example.

For this dimensionality reduction technique there are different criteria to choose the number of main components to stay with. Most of these criteria have a certain subjective component in the final selection of the number of major components to maintain, and virtually all of them are since each of the calculated self-values is intimately related to the variance explained by the corresponding main component.

In this work, a graphic technique was used, "the elbow rule" with the sedimentation graph ("screeplot"), together with a quantitative technique when choosing a cut value for the variance explained. The "elbow rule" requires finding the "elbow" in a graph, such as the one shown in Figure , in which the self-values are represented in descending order. To do this, the smallest values are adjusted to a line, and the main components whose self-values were above that line would be selected.

On the other hand, the relative value of each autovalue with respect to the sum of all of them gives us an estimate of the variance explained by the corresponding main component. Commonly, 75% of the variance is considered an acceptable cut-off value, although in this case, it is estimated that a variance around 90% would be desirable, as can be seen in the example in Figure .

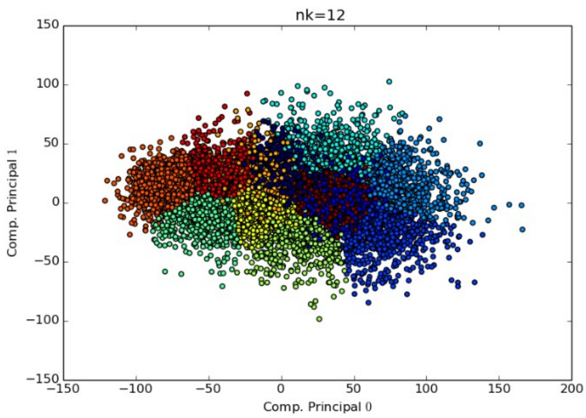


Variance explained by the different main components of the study. With the first 5 dimensions, 92% of cases are explained.

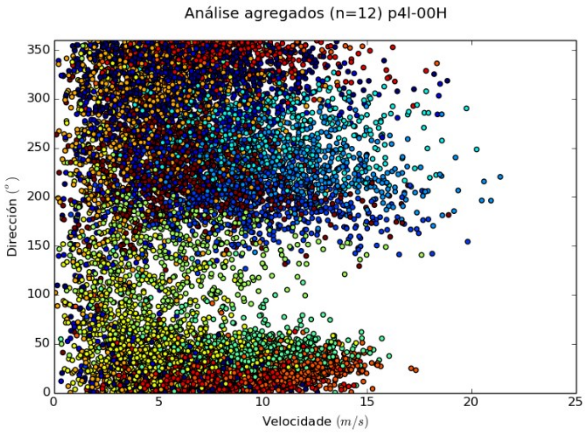
Obtaining in this way that the first 5 main components explain 92% of the total variance.

In addition, the first 2 main components already explain that 75% so a 2D representation in that coordinate base, as we see in figure , gives us a good graphic representation of these groupings.

In addition, if we represent the module and direction of every day between 2012 and 2014 we see graphically how its clustering has a logical relationship.



2D configuration of the first 2 main components



Wind speed and direction of each of the days of each cluster

Climate Classification: Analysis"Cluster"

Finally, once the dimensionality of the problem has been reduced to 5 variables, it would still be necessary to classify the different meteorological situations associated with each type of wind. To do this, a "Cluster" analysis of data projected in the first 5 main components was used.

The objective of this analysis is to find a number of different situations small enough not to load the next stages of the study related to the modelling of marine litter with calculation. But on the other hand, the number of different configurations must be high enough so that similar meteorological conditions do not appear mixed and reasonable structures are found in the wind patterns, to later have all possible conditions well reflected.

Different classifications were considered. Finally, it was decided that 8 clusters, collected all the variability in the case of the Galician west coast.

At first it was thought to use only the data with a module greater than 1.5m/s because it had a greater representativeness but seeing that the separation carried out in "Clusters" with the complete set of data separated reasonably well the calm wind situations from the rest, finally it was decided to use as definitive the "Cluster" analysis of the complete set of data.

To perform this analysis, the technique called "k-means" was used, which divides the set of starting data iteratively into n subsets, each of them formed by those points whose distance to the centroid of the subset to which they belong is less.

In this technique the number of clusters to be obtained is subjective (the algorithm is told to "generate me Nkclusters") and, in addition, it has a result that depends on the points that are used to initialize the centroid of each cluster. In an iterative way, each element (day) is assigned to its cluster, once all classified the new centroids of each cluster are calculated and start again: recalculate distances = >assignments to clusters = >new centroids, and so on. This algorithm is not very suitable for according to which classifications, because the iterative process makes the algorithm tend to group in clusters that end up containing a similar number of elements.

To avoid these "weaknesses"of the grouping with k-means, and following a procedure like that found in Articles by Martin-Vide (on synoptic classification of episodes of intense snowfall in the Irenaeus) in which PCA+kmeans are also used, the meaning of the result of the principal component analysis is used to "direct" the operation of the grouping with k-means, in the following sense:

- We look for the days that are "extreme" in each of the 80CPs and are not in the others. That its 80 clusters are initially generated, and to each cluster k belong the days for which theCP[k] has a value that moves more than 3 standard deviations away from the mean of that CP[k], but which is within that range of 3 standard deviations in each of the other 79 CPs. It is calculated among all the members of each of these initial clusters its centroid.
- The distances (in that 80-dimensional space) between each of those centroids with the others are calculated and the average of the distances of one centroid with the others is used as an indicator of how "well separated" that centroid is.
- Only the most separate centroids are chosen. To do this, again, it is taken as a "very separate" meter that the "average distance" of a centroid is higher than the average of all "average distances". With this selection and with the analyzed data set there are 8 centroids
- Once we have 8 "plausible" centroids, k-means is executed with a single iteration, that is, it is simply assigned each day to each cluster based on its distance to that centroid.
- Once we have all the days assigned to each cluster, the actual centroid of that cluster is calculated and the distance of each element to the centroid of the cluster in which it is classified is calculated.

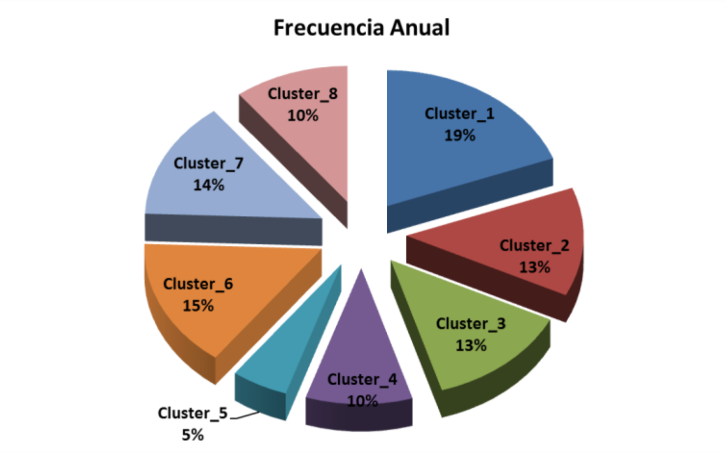
Once all the days analyzed were classified into different subsets, the frequency with which they appear in each month, each season and each year was calculated.

In this way, once the representative days of each Cluster have been chosen, for the subsequent simulations, all the results can be averaged according to these frequencies. 10 type days of each cluster were selected. All of them between 2012 and 2016 for having at that time higher resolution weather models that allow us to better define the subsequent calculation of the dispersion of pollutants.

Results

The great variability of winds and synoptic situations to which Galicia is subjected caused that there were 8 clusters necessary to collect it.

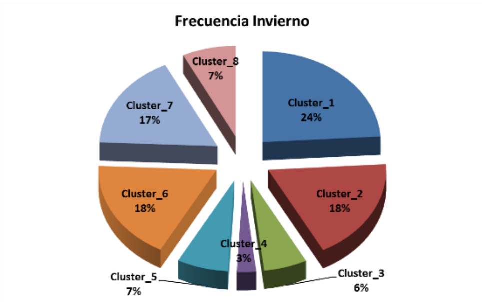
Among the 8 clusters, 3 can be considered as associated with low pressures (Cluster 2, 6, 7) and another 4 as high pressures (Cluster 1, 3, 4, and 8), along with another transition situation between low and high pressures (Cluster 5).

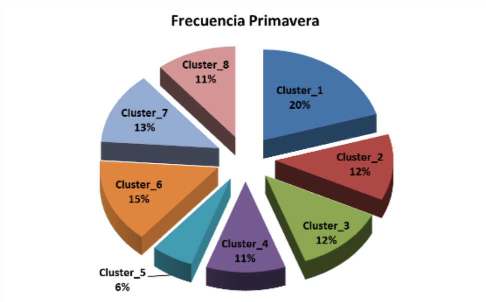


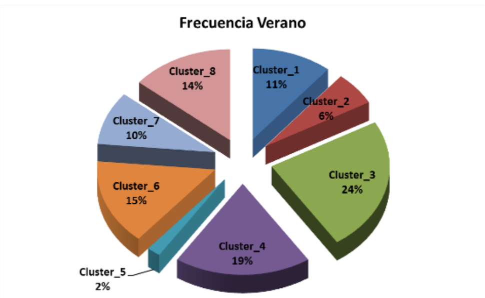
Annual distribution of each of the defined clusters.

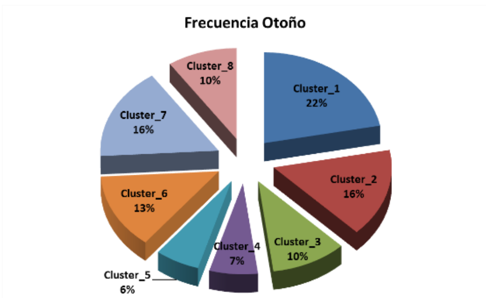
From the annual frequency of appearance of each cluster we obtain that 42% of the days are associated with low pressures, 53% at high pressures and 5% of the situations are associated with a clear transition between low and high pressures.

The monthly distribution of each of these clusters varies greatly, so, while in summer, the sum of clusters 3 and 4, for example, is repeated 43% of the days, in winter these situations only appear in 9 out of 100 days. Below is this seasonal distribution for each of the clusters.







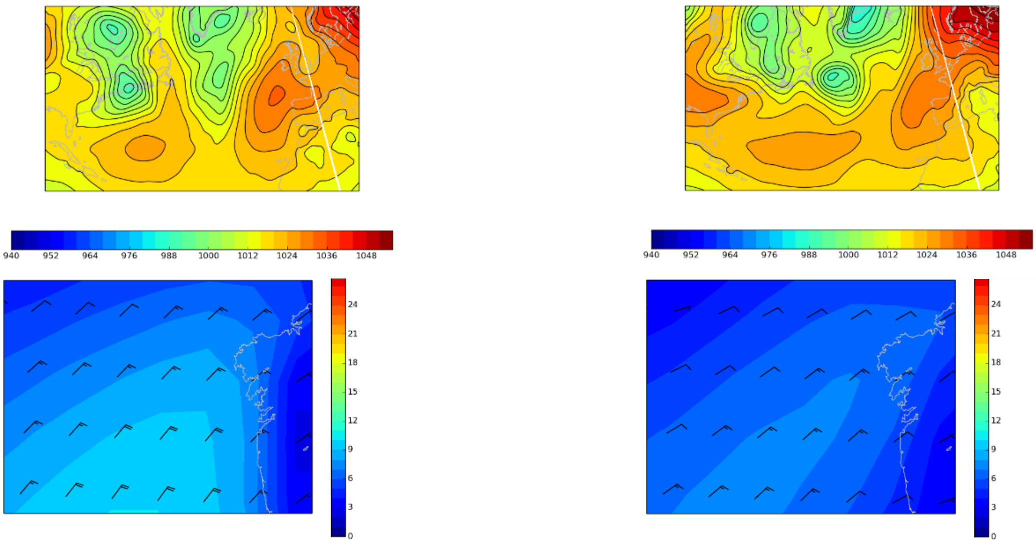


Seasonal distribution of each of the defined clusters

In the following section you can find a detailed description of each cluster.

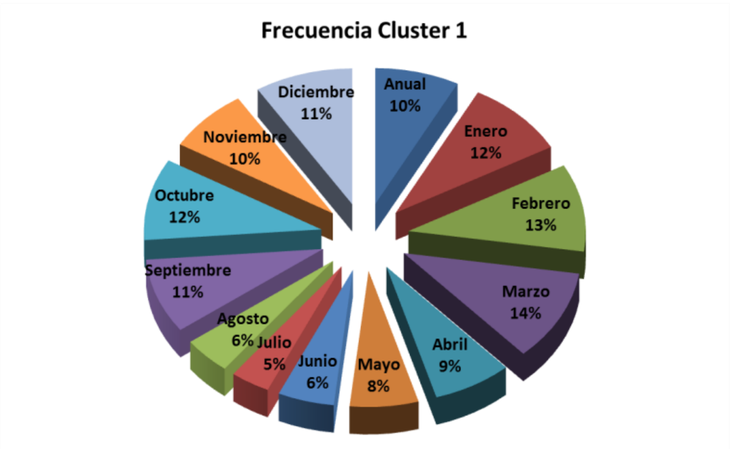
Description of each cluster

Cluster 1



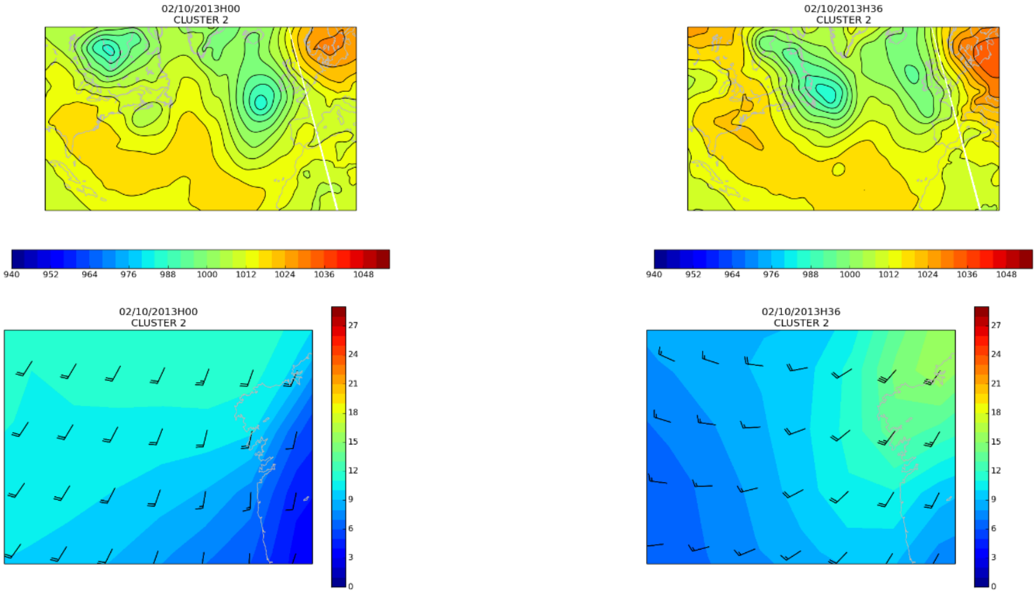
Pressure field and wind on the surface at 00h (Left.) and at 12 noon the next day (Right)

Cluster 1 unites anticyclonic situations in which the wind is from the northeast, rolling to the east due to the settlement of the anticyclone in the Cantabrian Sea. In addition, the turn to easterly winds is usually associated with a decrease in wind intensity associated with the formation of breezes, but without losing that eastern component. This situation of high pressures is more typical of spring and autumn. These are the typical sunny days of this time of year. They are not so typical in summer, since in summer the temperature difference between land and sea is usually greater than at other times and therefore the effect of the breeze would be greater and would reverse that east wind to west winds.



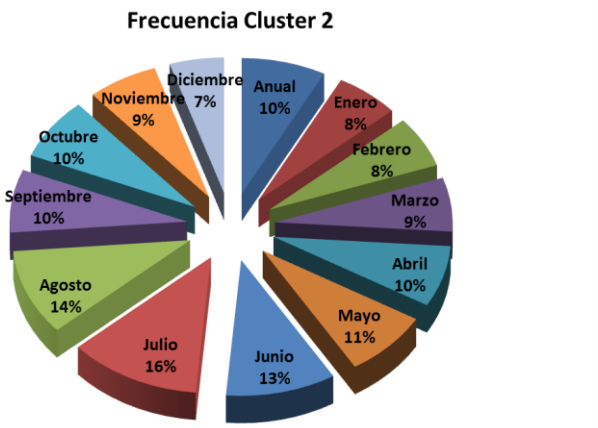
Monthly distribution of Cluster 1

Cluster 2



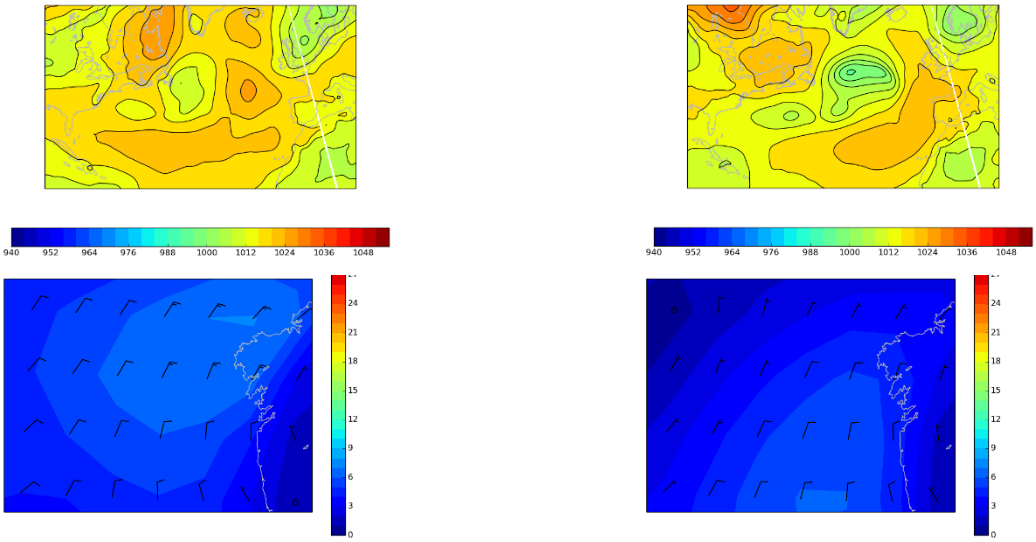
Pressure field and wind on the surface at 00h (left) and at 12h the next day (right)

Cluster 2 is characterized by the influence of a storm in the northwest of Galicia. In these situations, the wind is clearly from the southwest, and also punctually with strong gusts of wind and punctual rainfall, although locally intense. It is a situation that occurs scarcely in summer



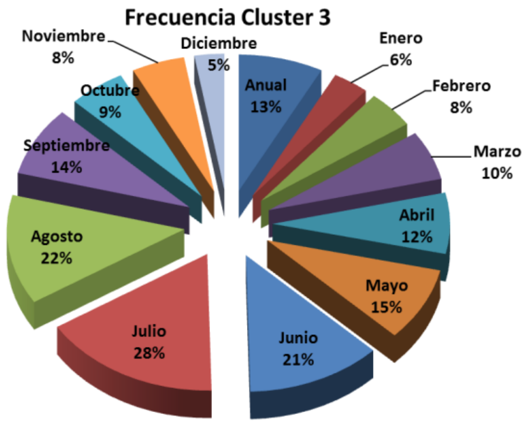
Monthly distribution of Cluster 2

Cluster 3



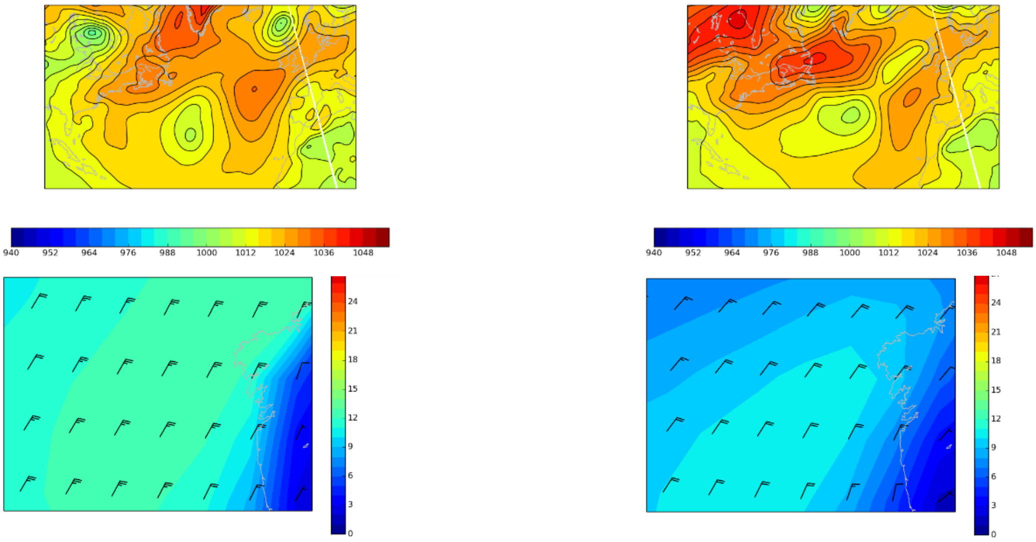
Pressure field and wind on the surface at 00h (Left.) and at 12 noon the next day (Right)

The days associated with cluster 3 are those days when the Azores anticyclone approaches Galicia, but at latitudes further north than in cluster 8. In this way the associated wind is from the north in the north of Galicia, taking a more northern component in the Rías Baixas. It is a very common configuration in summer (1 in 4 days).



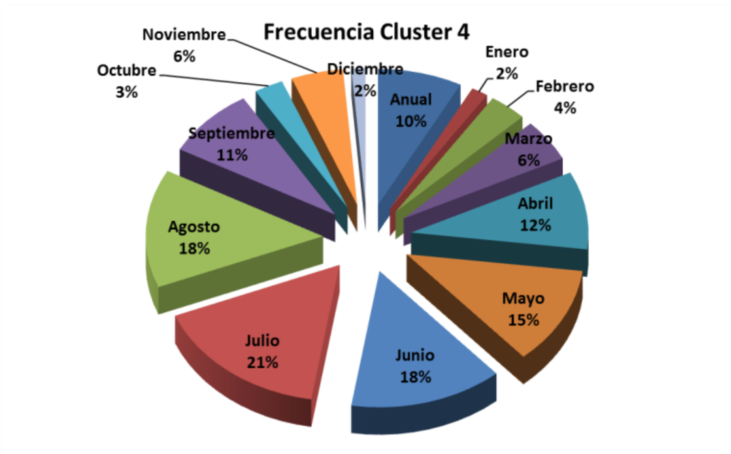
Monthly distribution of Cluster 3

Cluster 4



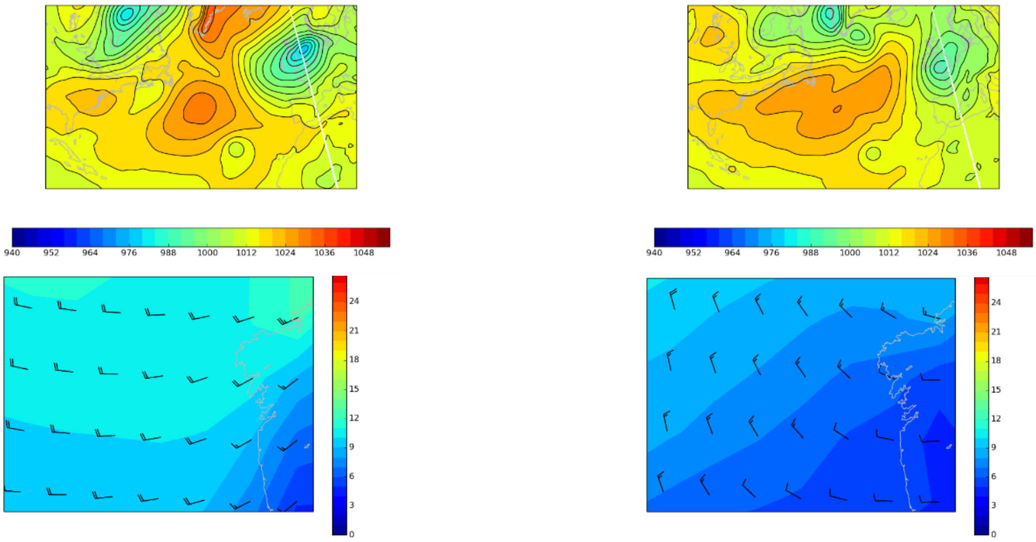
Pressure field and wind on the surface at 00h (Left.) and at 12 noon the next day (Right)

In cluster 4, the days with a strong north-north wind are grouped. They are associated with situations with a powerful anticyclone to the north or northwest of Galicia that is usually associated with the presence of a thermal low in the Peninsula or in North Africa, reinforcing the isobaric gradient near Galicia and therefore the intensity of the wind. They are much more frequent situations in summer. 1 in 5 days in the summer months belong to this classification, while only 2-3% of winter days have this configuration.



Monthly distribution of Cluster 4

Cluster 5



Pressure field and wind on the surface at 00h (Idza.) and at 12 noon the next day (Right)

Cluster 5 groups "transition" situations. That is, days in which a storm circulates through the north of Galicia, but its passage is very fast and behind it comes an area of high pressure. These days the wind rolls from the west – southwest to the north – northwest. They are situations that leave a very changing time, typical of the beginning of spring and autumn and with a very occasional appearance in summer.

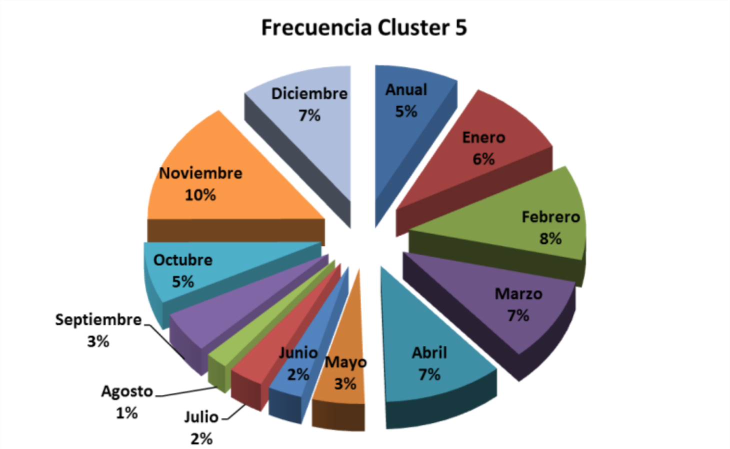
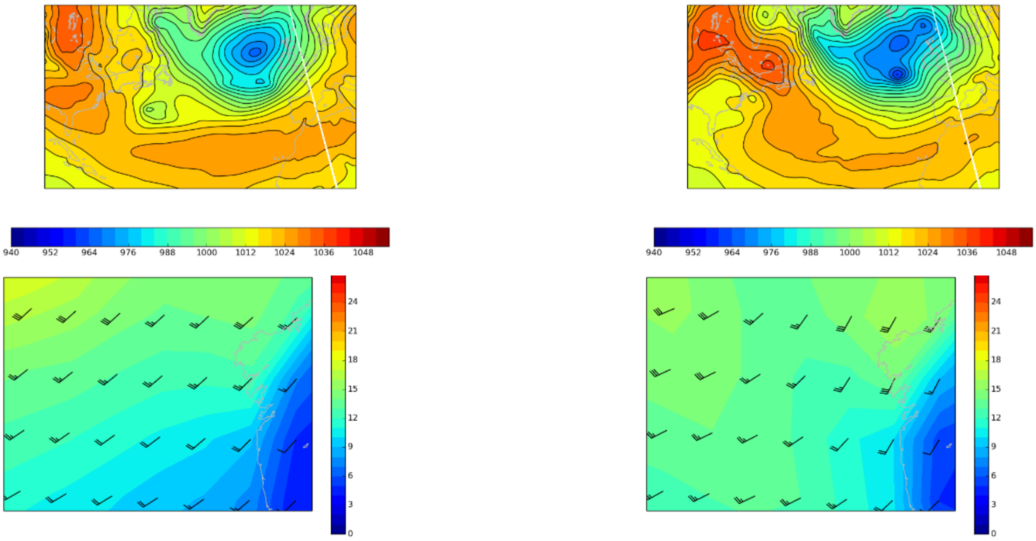


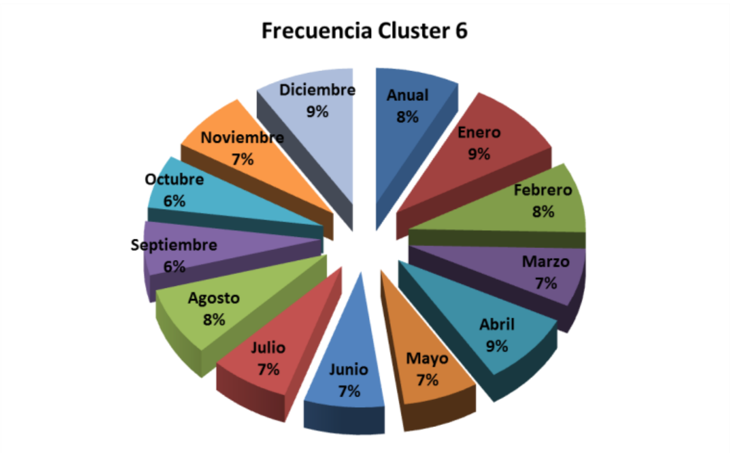
Figure A10.- Monthly distribution of Cluster 5

Cluster 6



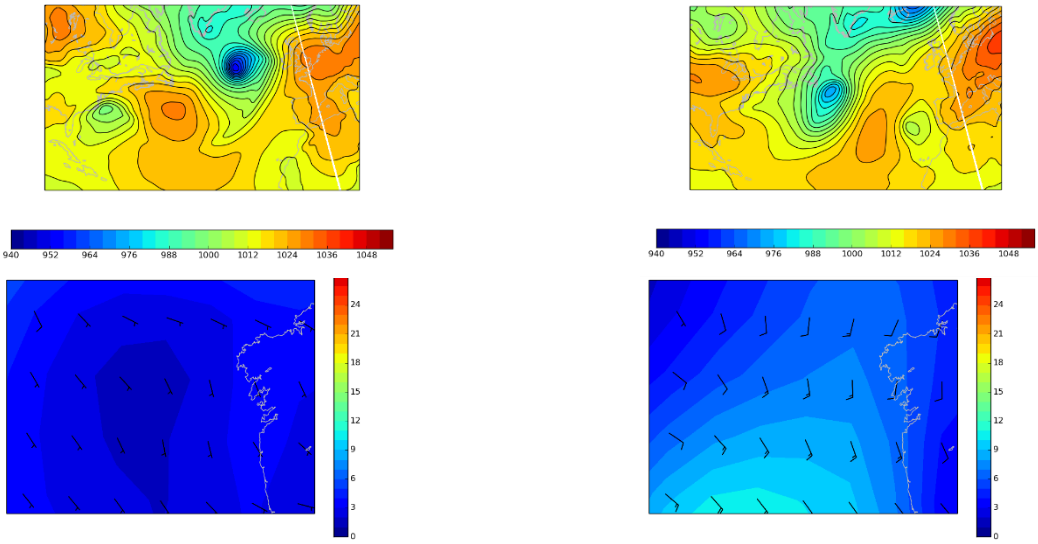
Pressure field and wind on the surface at 00h (Left) and at 12h the next day (Right)

Cluster 6 also groups together situations with southwest wind and low pressures. In this case they are situations associated with storms that occupy a large area of the North Atlantic. They leave in the Rías Baixas gusts of very strong wind, important accumulated rain, and large waves of sea in the background. They are more frequent in the winter months and are very occasional in summer.



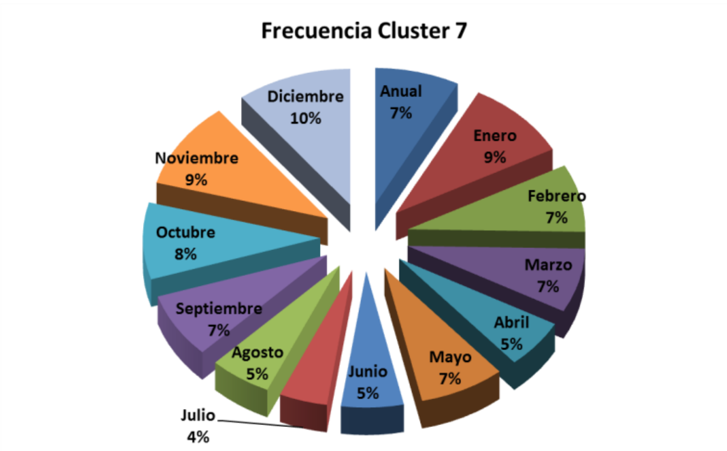
Monthly distribution of Cluster 6

Cluster 7



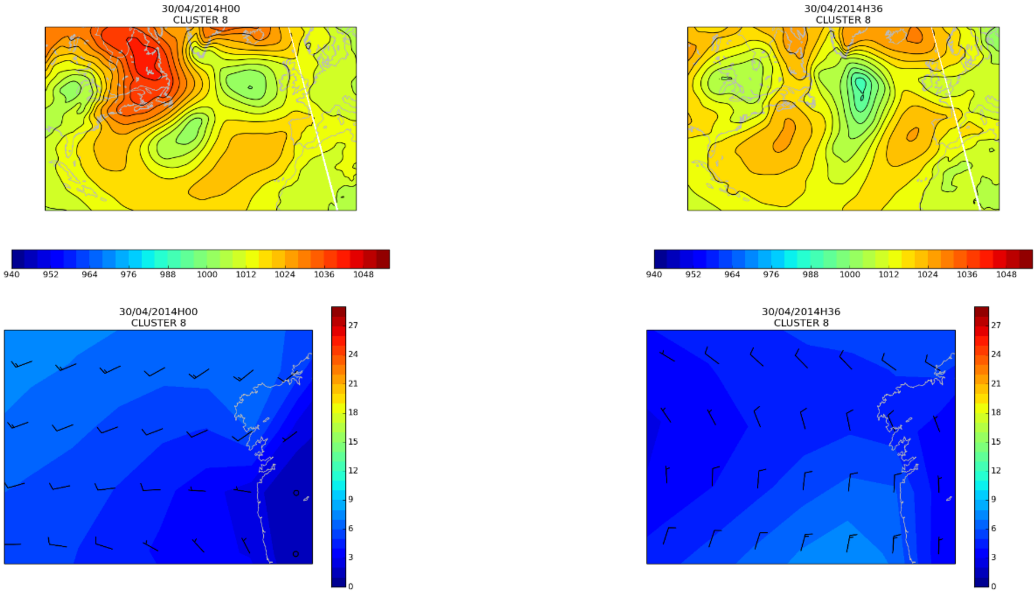
Pressure field and wind on the surface at 00h (Left.) and at 12 noon the next day (Right)

The days that are grouped in cluster 7 are marked by the wind from the south – southeast. They are characterized by the presence of a storm in the Atlantic, blocked by the presence of an anticyclone in the Mediterranean or on the Peninsula that prevents its movement towards Galicia. It usually leaves rains in the sea, in front of the Rías Baixas. They are typical autumn and winter situations and hardly occur in spring and summer.



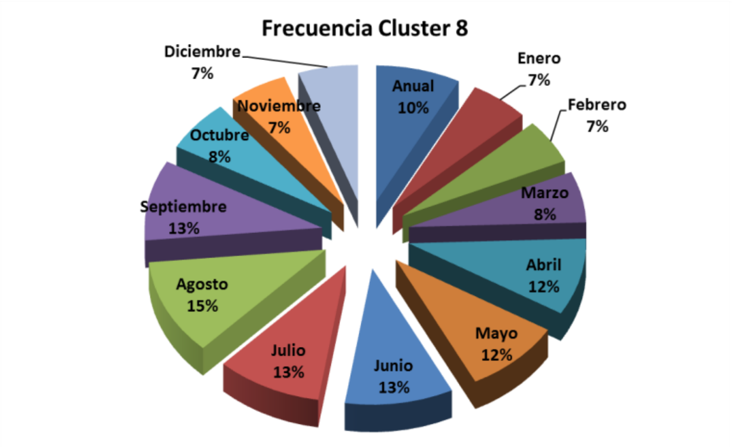
Monthly distribution of Cluster 7

Cluster 8



Pressure field and wind on the surface at 00h(Left.) and at 12 noon the next day(Right.)

Within cluster 8 are grouped days in which the Azores anticyclone extends towards Galicia leaving the southern half under its influence, but with less influence in the north. Those days usually start with winds from the west – northwest rolling to the north. They are typical days in summer with sun in Rías Baixas and more cloudy situations in the north of Galicia.



Monthly distribution of Cluster 8