Validation of ocean forecasting model data with those obtained from the first transoceanic autonomous underwater vehicles (gliders) missions in the North-East Atlantic basin.

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Trabajo Fin de Título para la obtención del título de Grado en Ciencias del Mar

Validation of ocean forecasting model data with those obtained from the first transoceanic autonomous underwater vehicles (gliders) missions in the North-East Atlantic basin.

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1. Abstract and keywords

Abstract

Autonomous Underwater Vehicles (AUVs), like gliders, can be used to cover long oceanographic missions due to their low battery consuming system. This study uses data from the Challenger Mission, between Ireland and the Canary Islands, from the 14th of May to the 8th of November 2017. It is compared to the ocean models Mercator Global Ocean Model (Mercator) and Copernicus Iberian-Biscay-Irish Regional Ocean Model (IBI), taken from the Copernicus Marine Environment Monitoring Service (CMEMS, http://marine.copernicus.eu), to validate them. The compared variables are temperature, salinity and density.

The studied area, located at the North-East Atlantic basin, is a complex dynamic region with several oceanographic processes involved, influenced by climatic phenomena and the Thermohaline Circulation (THC). The comparison between model data and glider data has been done in previous studies, but not with the models used on this study.

Salinity data has a higher variation at intermediate waters (500-1000m). Models show lower salinity than glider data on the water column, and higher on the surface. Models' temperature is generally cooler. In general, models show lower density. Overall, temperature data is more correct than salinity data. We suggest that it would be useful to do some additional studies comparing in situ high resolution glider data and ocean models in order to improve them.

Keywords

North East Atlantic. Autonomous Underwater Vehicles. Validation. Ocean Forecasting models.

2. Introduction

2.1. History and significance of Autonomous Underwater Vehicles (AUVs) and ocean models

Over the last decades, some technologies, such as subsurface floats, Remotely Operated Vehicles (ROVs) and Autonomous Underwater Vehicles (AUVs) have emerged (Bachmayer et al., 2004). AUVs are more independent than ROVs (Blidberg, 2001).

AUVs have a huge range of applications in oceanography. They have a depth range of 1000m and are being developed to travel deeper. They can cover long distance missions, from 3-4 weeks up to months, due to their low battery-consuming travelling system. (Bachmayer et al., 2006). Gliders move by changing their buoyancy and using wings to produce forward motion. They have a relatively slow speed (Rudnick et al., 2004).

Gliders provide data for oceanographic uses, by taking almost real-time measurements (Bachmayer et al., 2004). Some of the many advantages of gliders are: accessing remote ocean areas that can't be approached in a boat and cover long distance travels. While Argo floats have these same advantages, gliders also offer us the opportunity to control their path, since they don't just drift.

The glider used for this study was Silbo, in its journey from Ireland to the Canary Islands, from the 14^{th} of May to the 8^{th} of November 2017, as a part of the Challenger Mission.

Ocean models play an important role in oceanography, because they provide the opportunity to have an a priori expectation of the conditions of the ocean, helping to plan oceanographic missions. Simulations of hypothetical conditions also allow scientists to understand certain phenomena.

Ocean models already assimilate data from satellite, as well as Argo data of temperature and salinity (Dobson et al., 2013). Improving the ocean models is fundamental for making advances in oceanography.

2.2. Characteristics and water masses of the studied area

The studied area is located between 26 and 55ºN, and 19ºW and 5ºE. It's situated in the North-East Atlantic, next to the coast of Southern Europe (UK, France and Spain) and the North of Africa, until the Canary Islands latitude. It is shown in figures 1a and 1b.

The North Atlantic is a complex dynamic region with several ocean physical processes and scales involved, such as large-scale currents, tidal motions, upwelling systems and the processes occurring in the Gibraltar Strait (von Schuckmann et al., 2016, Sotillo et al., 2015).

It's influenced by both climatic phenomena, like the North Atlantic Oscillation (NAO), Atlantic Hurricane Activity, river flows or Sahel rainfall; and the water masses transported by the Thermohaline Circulation (THC) (Gulev et al., 2013, Knight et al., 2005).

Some of the most common features along the area are the Azores Front, the North Atlantic gyre, mesoscale eddies and Mediterranean Water (MW) mesoscale eddies (meddies). Meddies are formed in the Gibraltar Strait when (MW) and the Atlantic water masses interact, leaving the MW at 1000m depth and spreading into the Atlantic Ocean (Sotillo et al., 2015). There are strong upwelling conditions during summer in the western African coast (von Schuckmann et al., 2016). Figure 1a shows all these features.

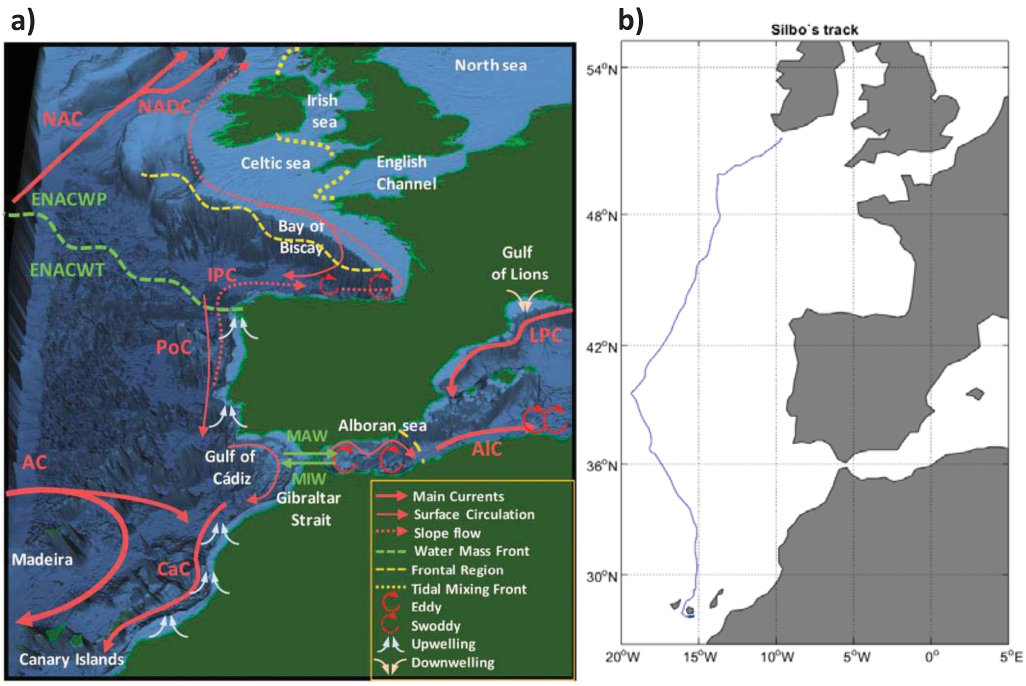

Figure 1: a) Scheme of the main oceanographic features on the studied area (Figure from Sotillo et al., 2015). b) Studied area and Silbo's track on this study. Challenger mission from Ireland to Gran Canaria, from the the 14th of March to the 8th of November 2017, travelling 4551km in 240 days.

Silbo traced a track between the South of Ireland and went to Gran Canaria (Canary Islands). It went East of the Azores and through ESTOC (European Station for Time series in the Ocean Canary Islands), and spent some time in the South of Gran Canaria, as shown in figure 1b.

As it can only go up to 1000m, it only went through surface and intermediate water masses. The main water masses in the studied area at the East North Atlantic, according to Pérez et al. (2001) and Bashmachnikov et al. (2015) are:

Surface water masses (0-500m)

- North Atlantic Central Water (NACW), described by the points H, NACWu (upper) and NACWl (lower)
- Subtropical Mode Water (StrMW)

Intermediate water masses (500-1500m)

- Antarctic Intermediate Water (AAIW) modified (named AA on this study)
- Mediterranean Water (MW)
- Subarctic Intermediate Water (SAIW)

Deep water masses (>1500m)

- Labrador Sea Water (LSW)
- North Atlantic Deep Water (NADW), described by NADWu (upper) and NADWl (lower).

Table 1 shows the main characteristics of the water masses for Bashmachnikov et al. (2015) and table 2 for Pérez et al. (2001). Figure 2 shows both TS diagrams.

Water Mass	Temperature (ºC)	Salinity (psu)
StrMW	19	36.7
NACWu	18	36.45
H	12.2	35.6
NACWl	8.8	35.15
AA	6.5	34.9
MW	13.2	37.1
SAIW	5.6	34.7
LSW	3.4	34.89
NADWu	2.5	34.94

Table 1: Water mass characteristics for the StrMW, NACW (including NACWu, H, NACWl), MW, AA, SAIW, LSW and NADW (including NADWu). Data from Bashmachnikov et al. (2015).

Water Mass	Temperature (ºC)	Salinity (psu)
NACWu	18.5	36.675
H	12.2	35.66
NACWl	8.56	35.23
AA	6.5	34.9
MW	11.74	36.5
LSW	3.4	34.89
NADWu	2.5	34.94
NADWl	1.98	34.884

Table 2: Water Mass characteristics for the NACW (including NACWu, H, NACWl), MW, AA, LSW and NADW (including NADWu and NADWl). Data from Pérez et al. (2001).

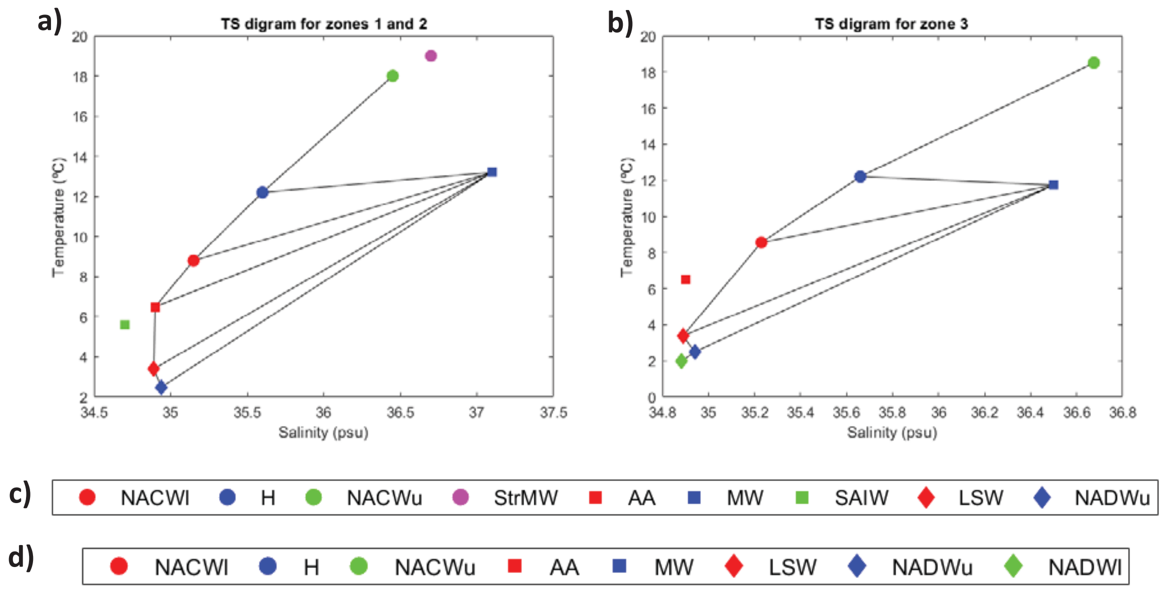

Figure 2: TS diagram showing the different water masses for a) Bashmachnikov et al. (2015) and b) Pérez et al. (2001). c) and d) show the legends for a) and b), respectively.

2.3. Previous studies

In-situ and satellite observations have been used before to validate ocean models (Le Fouest et al., 2006, Kara et al., 2006, Pohlmann, 2006, Passenko et al., 2010, Pairaud et al., 2011, Mourre and Chiggiato, 2014, Stroh et al., 2015, Zhu et al., 2016 and Chao et al., 2017). It has also been done previously with glider data (Dobson et al., 2013 and Sacatelli et al., 2014). Models have also been validated by tools like the North Atlantic Regional Validation (NARVAL) (Sotillo et al., 2015).

Dobson et al. (2013) compared the ocean models RTOFS and My Ocean using data from the gliders Silbo and RU29, regarding temperature, salinity and currents. The MyOcean model is a precursor of the CMEMS ocean models. The differences in temperature and salinity between Silbo's data and MyOcean's data were higher at the 200m level than at the 800m level. For RU29's data, at 200m MyOcean was quite accurate in temperature and salinity, and at 800m it was 1ºC too warm. Both models behaved differently.

Sacatelli et al. (2014), compared glider data with the ocean models RTOFS and MyOcean, using data from RU29 in its journey from the Ascension Islands to Sao Paulo (Brazil). They compared temperature, salinity and currents. There was a general 1ºC-2ºC difference with the MyOcean model and it didn't recognise eddy structures correctly, but there weren't notable differences. The highest variation between the models and glider data was in the first 300m of the water column. Overall, both models were mainly accurate.

Sotillo et al. (2015) analysed the results from the North Atlantic Regional Validation (NARVAL) tool, used to validate the IBI model. They divided the area in 9 sub-zones (Strait of Gibraltar (GIBST), English Channel (ECHAN), Irish Sea, (IRISH) Western Mediterranean Sea (WSMED), Gulf of Biscay (GOBIS), Gulf of Cadiz (CADIZ), Western Iberian Shelf (WIBSH), Northern Iberian Shelf (NIBSH) and Canary Islands area (ICANA)) to analyse the particularities of each area. They compared the model product to Argo data. It showed a higher concordance in deeper layers. Generally, IBI represents well oceanographic features, even in coastal regions and shelves.

2.4. Aim of this study

This study focuses on validating two ocean models regarding salinity, potential temperature and density, by comparing them to the obtained in-situ glider data. This journey belongs to the Challenger Mission. It is one of the first trans-oceanic gliders missions (Ramos et al., 2018), so the results and procedures might be quite relevant and unprecedented for the future.

These two variables are fundamental because they are key in ocean model simulations to calculate other variables, to differentiate water masses and to differentiate mesoscale phenomena. Temperature is key in the study of the heat storage. Salinity is linked to the water cycle and weather (von Schuckmann et al., 2016). Glider data can be useful for this task, since it has a fine resolution and provides data in the whole the water column.

3. Data and methods

3.1. Zones of the studied area

The area was divided in 3 main zones, as an approximation of the different conditions. Figure 3 shows them.

- Zone 1: North of 42ºN: from Ireland to the front of Azores
- Zone 2: Between 36 and 42ºN: the front of Azores
- Zone 3: South of 36ºN: from the front of Azores to the Canary Islands (Macaronesia region)

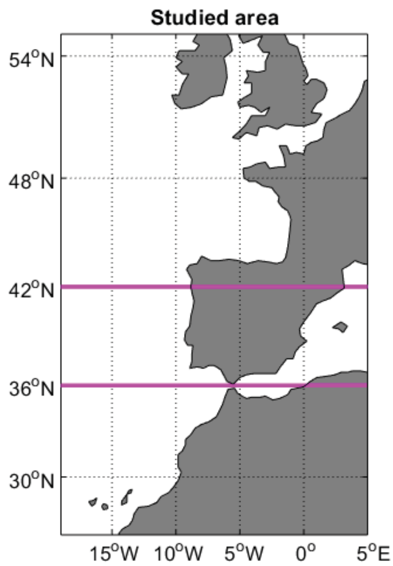

Figure 3: Studied area. The lines show the limits between the 3 selected zones.

For the first 2 zones the Bashmachnikov et al. (2015) paper was used to characterize the water masses. For the third zone, the Pérez et al. (2001) paper was used.

3.2. Ocean models

The 2 compared models are taken from the Copernicus Marine Environment Monitoring Service (CMEMS, http://marine.copernicus.eu). They are numerical forecasting models. (von Schuckmann et al., 2016). Both models were taken from the dates 14th May to 8th November 2017.

The main biases with in situ real measurements depend on the area and the depth (Sotillo et al., 2014).

3.2.1. Mercator (Mercator Global Ocean Model)

The used dataset was GLOBAL_ANALYSIS_FORECAST_PHY_001_024. It covers the whole ocean, and it was taken as the daily output. It's a numerical model.

It contains daily mean potential temperature, salinity, mixed layer depth, Sea Surface Height (SSH), currents and more variables. For this study salinity, potential temperature and mixed layer depth were the only ones chosen.

Its horizontal resolution is 1/12º (0.083º) and it has 50 vertical levels, covering from 0 to 5500m depth. The vertical levels are shown in figure 4.

The model assimilates in-situ and satellite data of sea level, temperature, salinity, Sea Surface Temperature (SST) and sea ice to adjust its initial conditions.

3.2.2. IBI (Copernicus Iberian-Biscay-Irish Regional Ocean Model)

The used dataset was the IBI_ANALYSIS_FORECAST_PHYS_005_001. It covers from 19ºW to 5ºE and 26ºN to 55ºN, and it was used as the daily output.

It contains daily mean potential temperature, salinity, mixed layer depth, SSH, currents and more variables. For this study salinity, potential temperature and mixed layer depth were the only ones chosen.

Its horizontal resolution is 1/36º (0.028º), Its grid is a subset of the global ocean model. It has the same vertical levels as the Mercator model.

It's based on a NEMO v3.4 (Nucleus for European Models of the Ocean) model. It assumes hydrostatic equilibrium and Boussinesq approximation. It's driven by atmospheric forcing fields, including wind. The boundary conditions include tidal forcing, solar penetration, temperature, salinity, velocities, sea level, atmospheric pressure and fresh water inputs from rivers (García-Garrido et al., 2016, Sotillo et al., 2015).

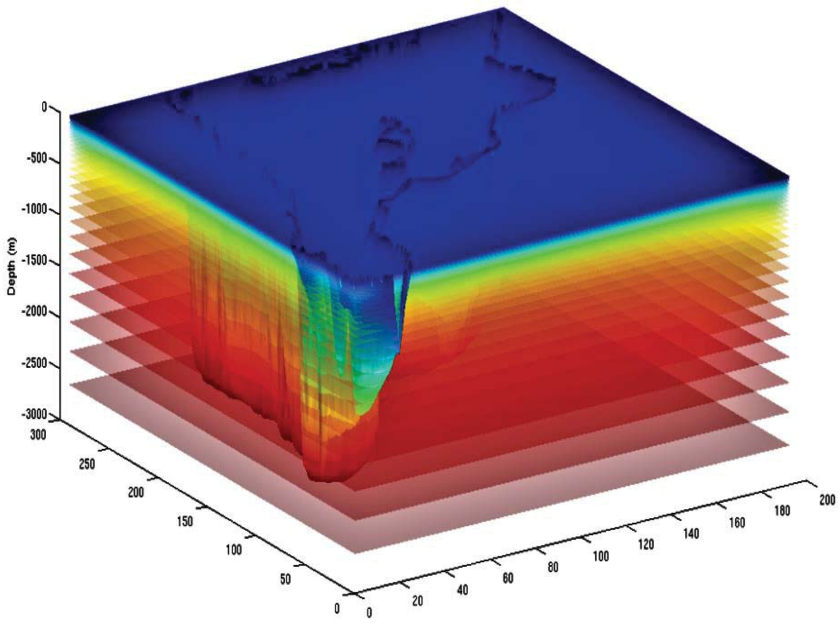

Figure 4: 3D view of the different Copernicus models' depth levels.

3.3. Glider data

For this mission, Silbo was equipped with a CTD, measuring temperature and conductivity. The used CTD was the Seabird pumped CTD. Silbo also measured pressure, and the time and location (latitude and longitude) of each measurement. For this study were used the direct and derived variables:

Direct variables:

- Temperature
- Pressure
- Time
- Latitude
- Longitude

Derived variables:

- Salinity
- Density
- Depth

Silbo made measurements every 2 seconds and 0.0013km (1.3m) average

3.4. Variables

Variable	Units glider	Units model	Final units
Latitude	decimal degrees	decimal degrees	decimal degrees
Longitude	decimal degrees	decimal degrees	decimal degrees
Time	timestamp	days	datenum
Pressure	bar	dbar	-
Depth	m	m	m
Practical salinity	psu	psu	psu
Absolute salinity	g/kg	g/kg	-
Potential temperature	ºC	ºC	ºC
In-situ temperature	ºC	ºC	-
Potential density	kg/m^3	kg/m^3	kg/m^3
Mixed layer depth	-	m	m
Track distance	km	-	-

Table 3: Variables used in this study and their units. Column 2 indicates the glider dataset units, column 3 indicates the model datasets units and column 4 indicates the finally used units. Blank means that the variable wasn't used for the results, just to calculate other variables.

3.5. Data processing

3.5.1. Glider data

- Salinity was calculated using temperature and conductivity, using the state equations (UNESCO 1981 and 1983).
- The variables latitude, longitude, time, depth, pressure, potential temperature, and practical salinity were obtained.
- As pressure was given in bar, it was transformed to dbar.
- All the non-valid data was eliminated.
    - Data that was not correctly sampled.
    - If there was missing data at any variable, the whole data point was discarded.
- Time was transformed from epoch timestamp to Matlab datenum datatype.
    - epoch2datenum, from the Slocum Power Tools toolbox (John Kerfoot, Institute of Marine & Coastal Sciences, Rutgers University).
- Absolute salinity was calculated using practical salinity, pressure, longitude and latitude.
    - gsw_SA_from_PS, from the Gibbs SeaWater (GSW) Oceanographic Toolbox of the International Thermodynamic Equation of Seawater - 2010, (TEOS-10).
- In-situ temperature was calculated using potential temperature, absolute salinity and pressure.
    - gsw_t_from_pt0, from the Gibbs SeaWater (GSW) Oceanographic Toolbox of the International Thermodynamic Equation of Seawater - 2010, (TEOS-10).
- Potential density was calculated using in-situ temperature, practical salinity and pressure.
    - sw_pden, from the Csiro Matlab SeaWater toolbox.
- This was made for each data point.

3.5.2. Model data

- Model data was obtained for each data point from the glider's dataset.
- The variables latitude, longitude, depth, mixed layer depth, practical salinity and potential temperature were obtained.
- The data corresponding to the glider data point was selected.
- The model's pressure was calculated using depth and latitude.
    - sw_pres, from the Csiro Matlab SeaWater toolbox.

- Absolute salinity was calculated using practical salinity, pressure, longitude and latitude.
    - gsw_SA_from_PS, from the Gibbs SeaWater (GSW) Oceanographic Toolbox of the International Thermodynamic Equation of Seawater - 2010, (TEOS-10).
- In-situ temperature was calculated using potential temperature, absolute salinity and pressure.
    - gsw_t_from_pt0, from the Gibbs SeaWater (GSW) Oceanographic Toolbox of the International Thermodynamic Equation of Seawater - 2010, (TEOS-10).
- Potential density was calculated using in-situ temperature, practical salinity and pressure.
    - sw_pden, from the Csiro Matlab SeaWater toolbox.

3.5.3. Results

- The differences between glider and models' data were calculated as glider minus model.
- Data was plotted in vertical sections for practical salinity, potential temperature and potential density, and the differences between glider and the models.
    - In the vertical sections for the glider data (figures 6a, 6b -11a, 11b), the mixed layer depth corresponding to the IBI model was used, since the glider data configuration didn't allow to make a reliable calculation of the mixed layer depth.
- TS diagrams were made, basing on the water masses characteristics for each zone, using the glider's practical salinity and potential temperature.
- The linear fit was made using the polyfit and polyval functions in Matlab, for practical salinity and potential temperature.
    - The surface values were removed before this calculation, considering them as the data points shallower than the mean mixed layer depth of the whole journey.
    - It was plotted with a scatterplot of the 2 compared datasets.
- The correlation between the compared datasets was made using the corrcoef function in Matlab, for the same datasets than the linear fit.
    - The surface values were removed before this calculation, considering them as the data points shallower than the mean mixed layer depth of the whole journey.

3.5.4. Interpolation

- For each data point in the glider's dataset, the closest point in time and space from the models' dataset was chosen.
- For those points that were West of 19ºW the data from the IBI model wasn't assigned, since it doesn't cover that area.
- All the processing was done using each data point instead of vertical profiles, because all the methods tried to isolate them created too many gaps in the data.

3.6. Error and uncertainty

The error was calculated considering the spatial distance between the glider data point and the nearest model data point, and the gradient of the variable between model data points. With the interpolation, it's assumed that the glider and the model data point are at the same place.

The gradient was calculated, and then, knowing the distance between the glider and the model data point, the error caused by that distance is obtained. The error for the whole datasets was calculated as the mean of all the errors for the points.

Model	Salinity error (psu)	Temperature error (ºC)
Mercator	0.0055	0.0258
IBI	0.0051	0.0217

Table 4: Uncertainty sources for the obtained results.

4. Results and discussion

4.1. Water masses

Overall, the obtained salinity range is between 35 and 37 psu, and temperature between 5 and 25 ºC, as shown in figure 5a. All the 3 zones show a similar temperature range, while zone 3 seems more saline than zone 1, as seen in figure 5a.

In zone 1 the main water masses found are NACW and MW. There is also some AA. In zone 2, the same water masses were found. The NACW is more predominant in this zone. In zone 3, the main water mass found is the NACW, and MW and LSW were also found.

The points with high temperature that don't fit into the water mass curves are surface data, more variable and frequent (surfacing of 15 minutes each 12 hours) than deeper data. Overall, water masses match the data, so it can be assumed that the measurements are correct.

All the obtained data seems correct. The data from zone 1 seems to be the less reliable for the aims of this study, and zone 3 the most reliable.

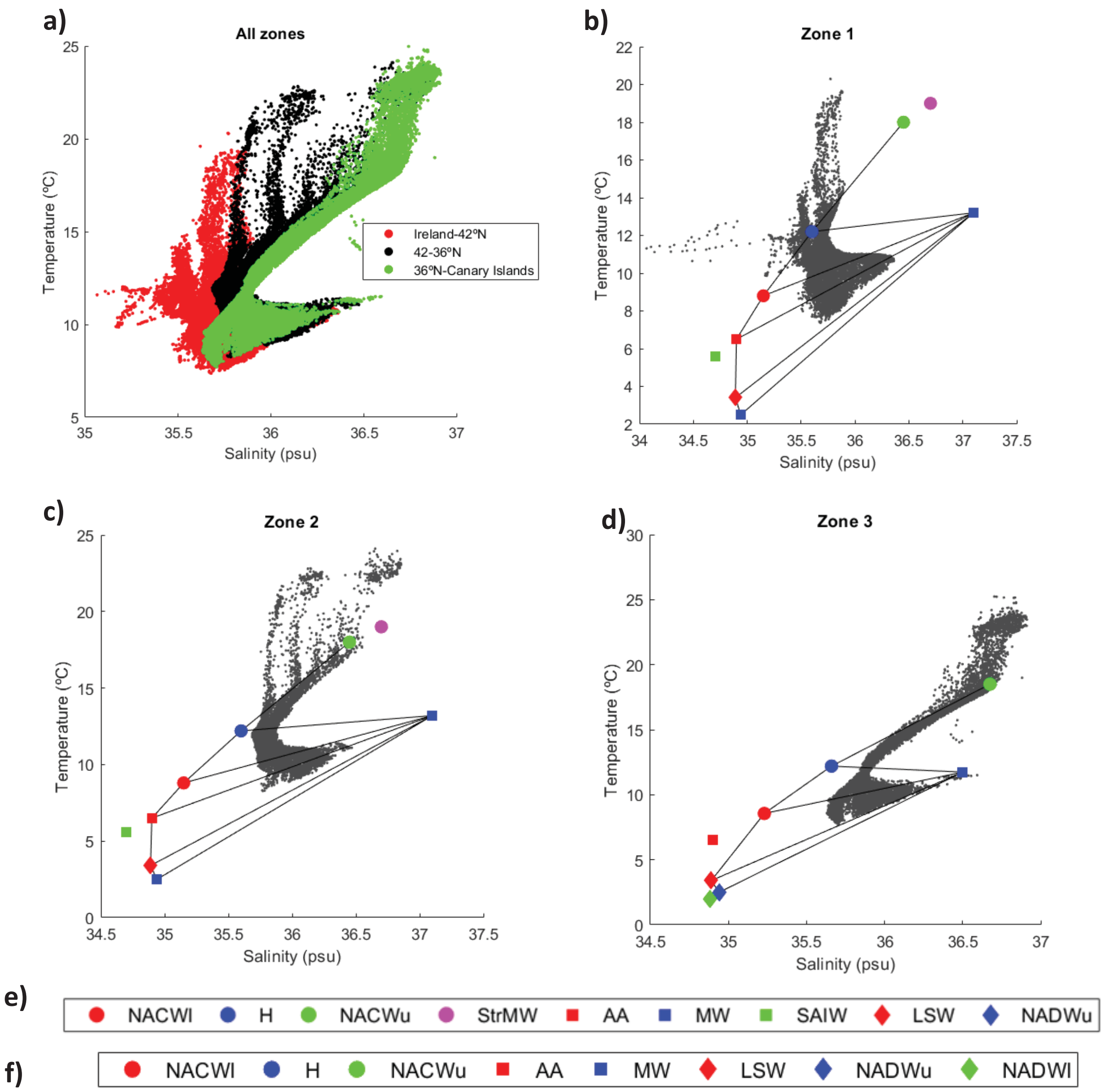

Figure 5: TS diagrams for a) All three studied zones, b) Zone 1, c) Zone 2 and d) Zone 3. b) and c) show the water masses characteristic from Bashmachnikov et al. (2015) and d) from Pérez et al. (2001). e) shows the legend for figures b) and c), and f) shows the legend for figure d). All the figures were made using Matlab.

4.2. Vertical sections

4.2.1. Salinity

Figure 6 shows the vertical sections of salinity. For all the datasets, the water is less saline at the beginning of Silbo's journey and more saline by the end of it. In general, the water has a higher salinity in surface and at intermediate waters (800-1000m).

Glider data has the highest amount of saline, intermediate depth, waters intrusions, which correspond to MW intermediate depth intrusions. It also shows the earliest apparition of saline waters in surface, at the beginning of August. At the last part of the segment, in zone 3, waters at intermediate depth seem to get less saline again, below 36 psu.

Mercator data shows slightly lower salinity than glider data. It shows the apparition of saline waters in surface by the middle of August. At the last part of the segment, intermediate waters get significantly less saline.

IBI data is similar to Mercator data. Surface saline waters appear by the end of August. Again, the last part of the segment has significantly less saline intermediate waters.

Figure 7 shows the vertical sections of the differences between glider data and both models. It is calculated as glider minus model. Overall, at the surface both models tend to estimate a higher salinity than glider data (blue-green colours), and at most of the water column, model data is less saline (orange-yellow colours).

The main differences appear in the same places as the intermediate saline water intrusions seen in figure 6. The models seem to not estimate them saline enough. The IBI model seems less accurate than the Mercator model.

Dobson et al. (2013) compared Silbo's data with the MyOcean model, and they obtained higher differences in salinity at shallower levels (200m layer) than at deeper levels (800m layer). Sacatelli et al. (2014) also found higher differences in the first 300m of the water column. Sotillo et al. (2015), who studied the IBI model, also showed a better concordance at deeper layers. This study disagrees, having found higher differences at deeper levels. The comparison between RU29's data and MyOcean model, in Dobson et al. (2013), agrees.

Overall, both models analysed on this study are quite accurate in salinity, agreeing with all previous studies. The magnitude of the uncertainties (0.0055 psu (Mercator) and 0.0051 psu (IBI)) has a smaller order than the differences obtained between the data (0.5 psu), so the results are significant.

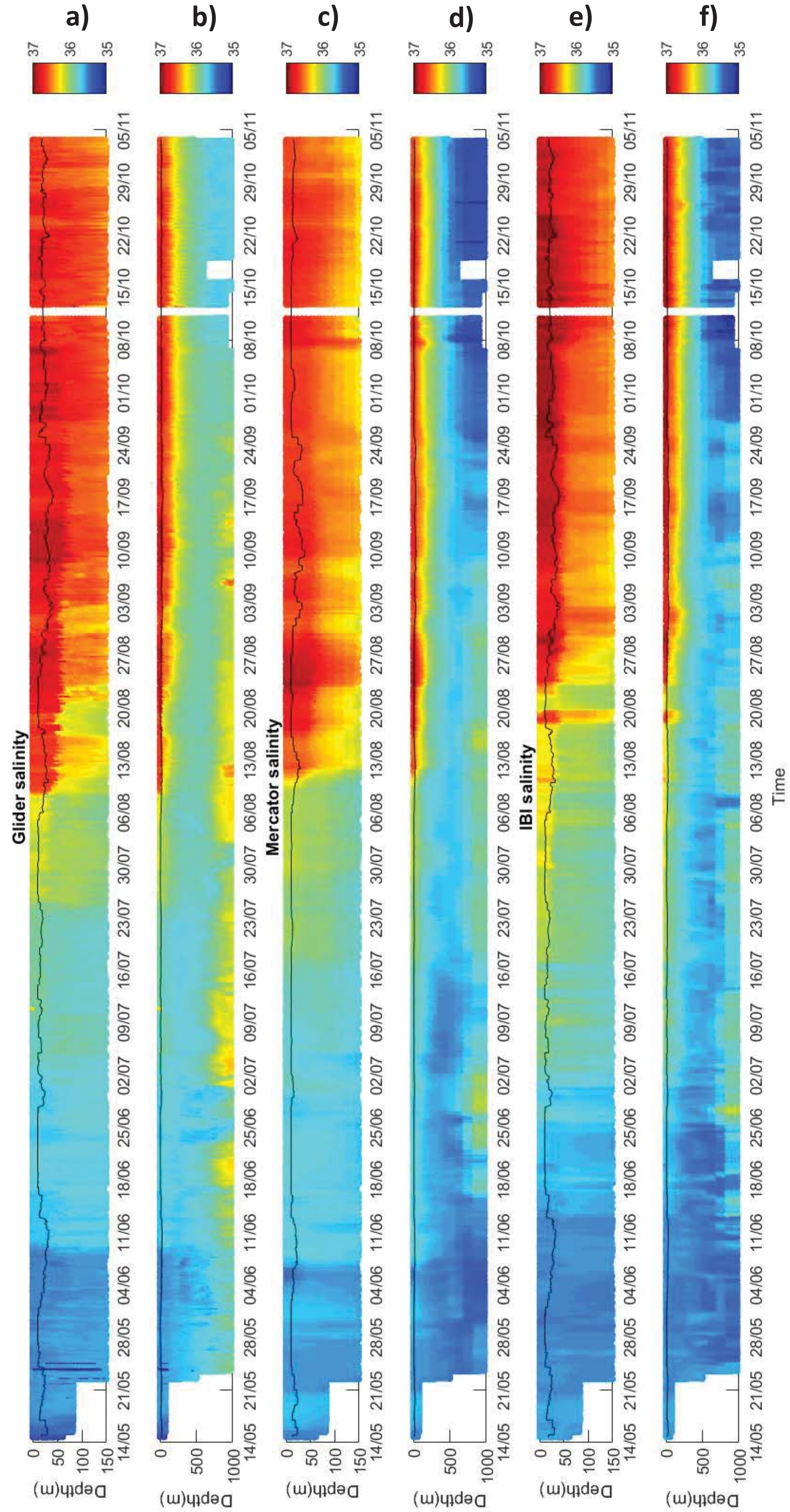

Figure 6: Vertical sections for salinity (psu). a) and b) represent the obtained glider data, c) and d) represent the data from the Mercator model, and e) and f) represent the data from the IBI model. a), c) and e) show the first 150m and b), d) and e) show the water column until 1000m. The black line represents the mixed layer depth. All the figures were made using Matlab.

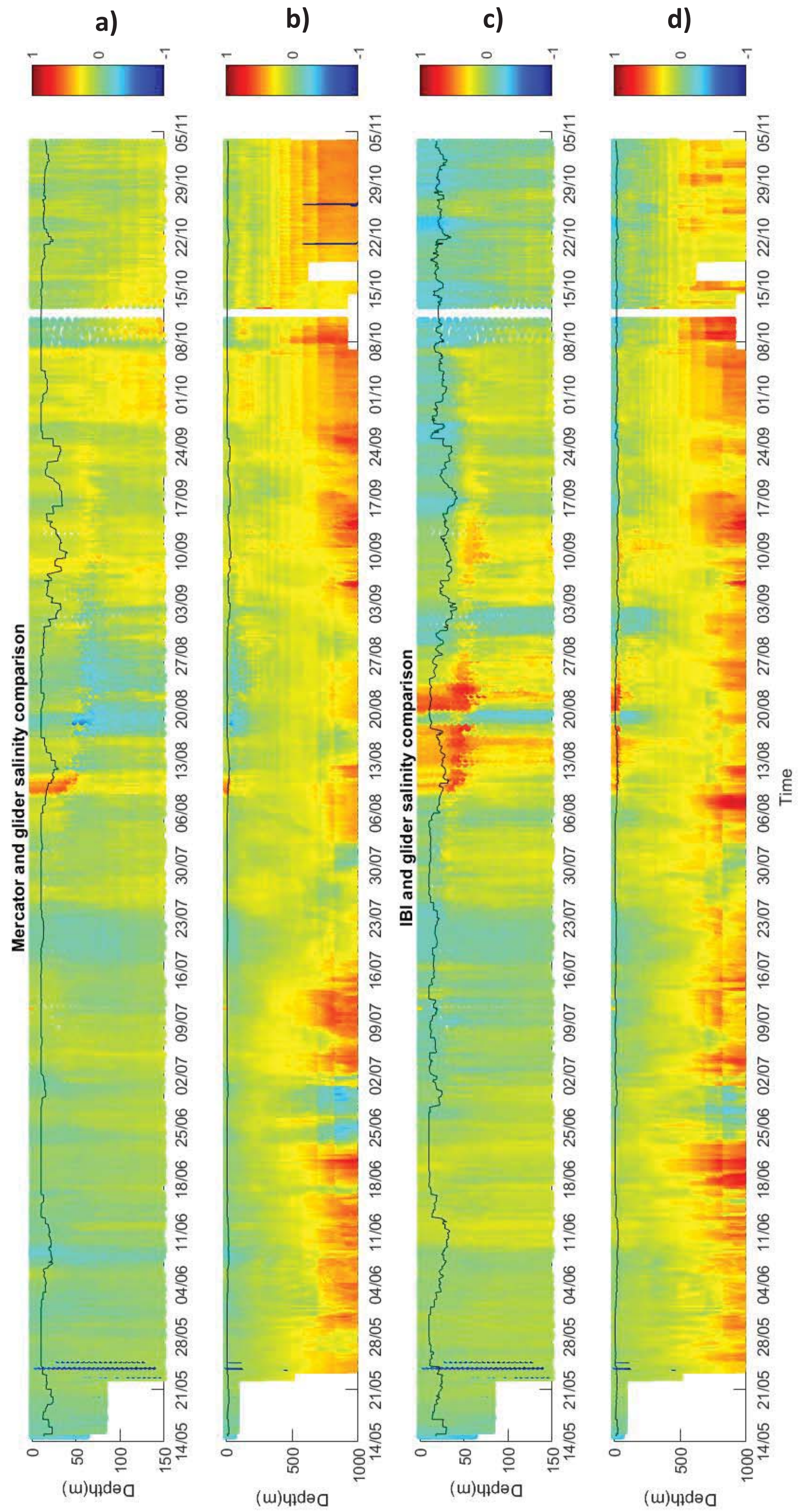

Figure 7: Vertical sections for the salinity differences (psu) between the glider data and model data. a) and b) correspond to the Mercator model, and c) and d) correspond to the IBI model. a) and c) show the first 150m and b) and d) show the water column until 1000m. It's represented as glider data – model data. The black line represents the mixed layer depth. All the figures were made using Matlab

4.2.2. Temperature

Figure 8 shows the vertical sections for potential temperature. Surface waters get warmer as Silbo travels southward. Intermediate waters (500-1000m) get colder by the end of the sections. Water gets colder as depth increases.

Glider data shows some columns of warmer water in the whole column, by the middle of June and at the beginning of July. In the middle of August, waters get generally warmer. By the beginning of October, intermediate water (800-1000m) gets colder again.

Mercator data shows the columns of warmer data at the end of June - the beginning of July. Then, water gets generally warmer at the middle of July. The colder water at the end of the segment begins to appear in the middle of September.

IBI data shows the columns of warmer waters at the beginning of July. Water in general gets warmer at the middle of July, like Mercator data. The colder water at the end of the segments begins to appear at the end of September.

Figure 9 shows the vertical sections of the differences between glider data and the models, calculated as glider minus model. As expected from the previous analysis, by the end of June and the end of July models are warmer than glider data (dark blue).

By the beginning of the segment, models seem accurate (green colours), but as it advances, the differences increase (yellow-orange and blue colours), especially at the surface. In general, the models seem to estimate cooler waters than the glider (yellow-orange). The Mercator model seems more correct in general.

Sacatelli et al. (2014), showed 1-2 ºC differences with MyOcean in general. This agrees with both models on this study. They also say that the temperature differences are higher in the first 300m. Sotillo et al. (2015) show this same result for the IBI model. This study shows these results for the IBI model, but not for the Mercator model. Dobson et al. (2013), say that the MyOcean model was 1 ºC warmer than RU29's data at 800m, and that the 200m layer is more accurate. This study disagrees with both results.

Overall, both models are quite accurate, but the Mercator model is more correct. The magnitude of the uncertainties (0.0258 ºC (Mercator) and 0.0217 ºC (IBI)) has a smaller order than the differences obtained between the data (1-2 ºC), so the results are significant.

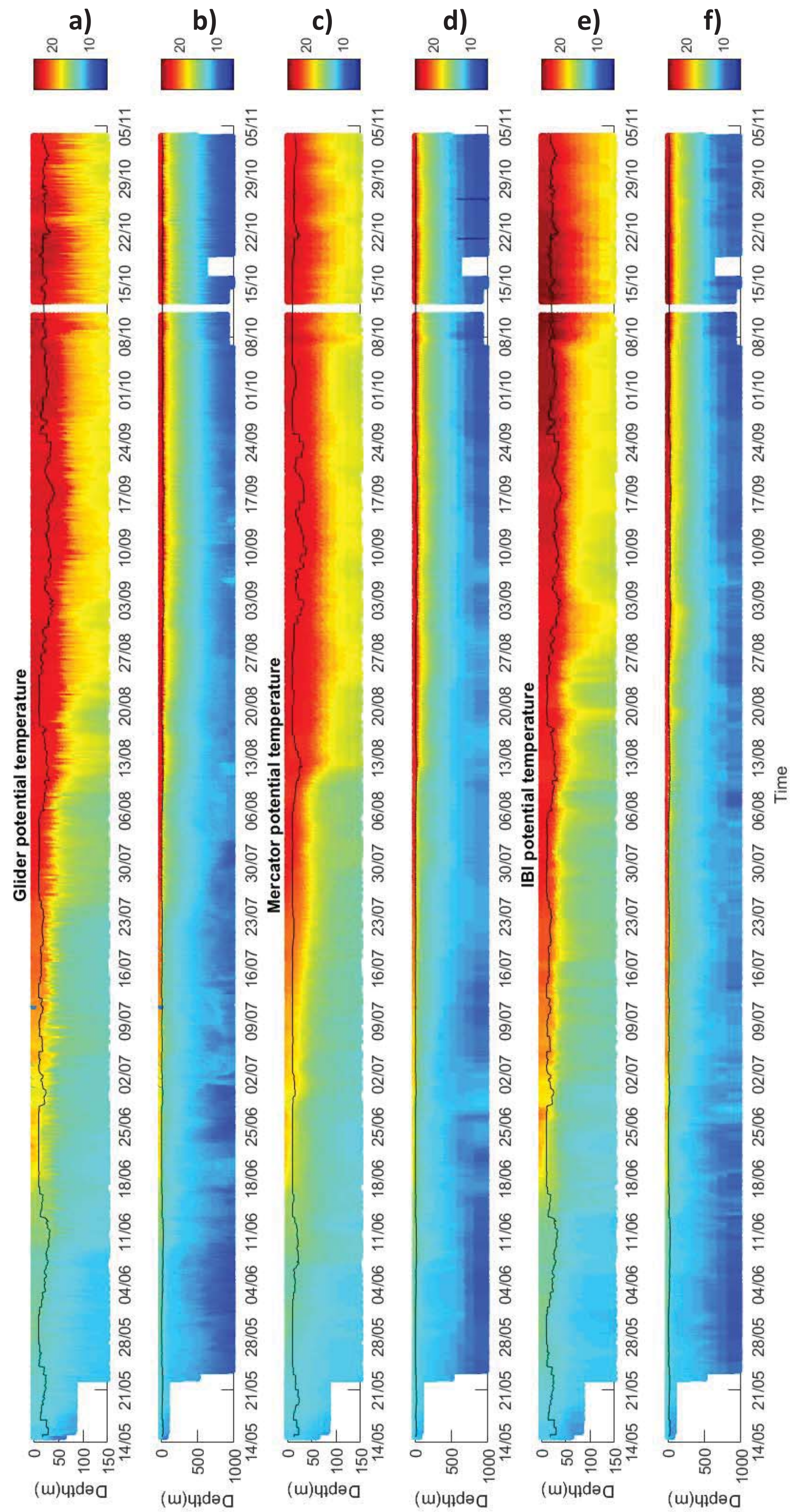

Figure 8: Vertical sections for potential temperature (ºC). a) and b) represent the obtained glider data, c) and d) represent the data from the Mercator model, and e) and f) represent the data from the IBI model. a), c) and e) show the first 150m and b), d) and e) show the water column until 1000m. The black line represents the mixed layer depth. All the figures were made using Matlab.

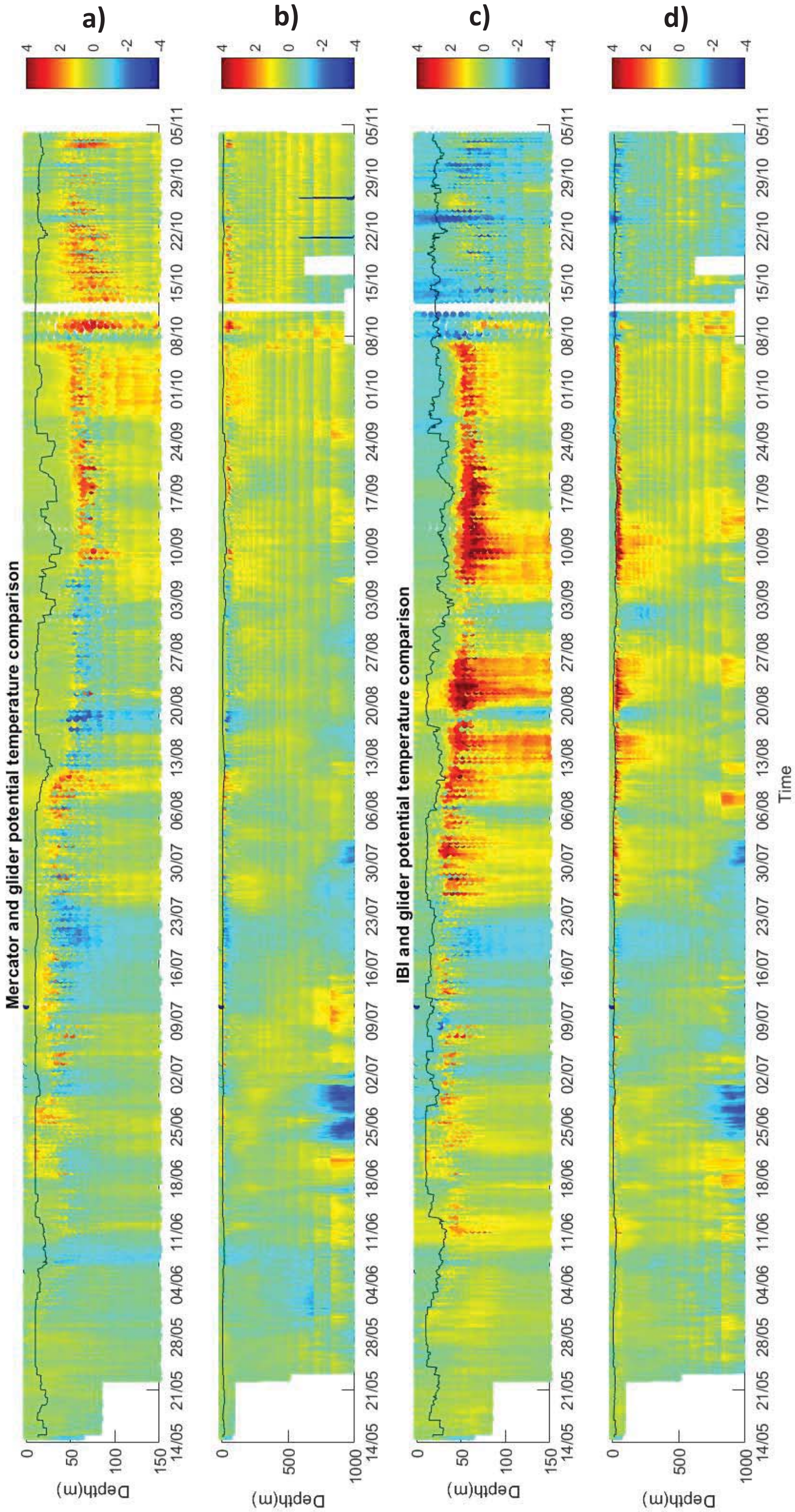

Figure 9: Vertical sections for the potential temperature differences (ºC) between the glider data and model data. a) and b) correspond to the Mercator model, and c) and d) correspond to the IBI model. a) and c) show the first 150m and b) and d) show the water column until 1000m. It's represented as glider data – model data. The black line represents the mixed layer depth. All the figures were made using Matlab.

4.2.3. Density

Figure 10 shows the vertical sections of potential density. Overall, density increases with depth. At the end of the sections, surface waters get less dense (<1025 kg/m^3).

Glider data at intermediate depths (800-1000m) gets denser than models data. Besides that, all sections are similar. A decrease of density at surface begins to appear by the middle of June.

Figure 11 shows the vertical sections of the differences between glider data and both models, calculated as glider minus model. From surface to 500-800m, the differences are small (green colours). At the deepest part of the section, model density is lower than glider density (yellow-orange colours).

Both models show some spots in surface where glider density is lower (blue colours). This is more common in the IBI model. The 2 models behave similarly related to density and are quite accurate.

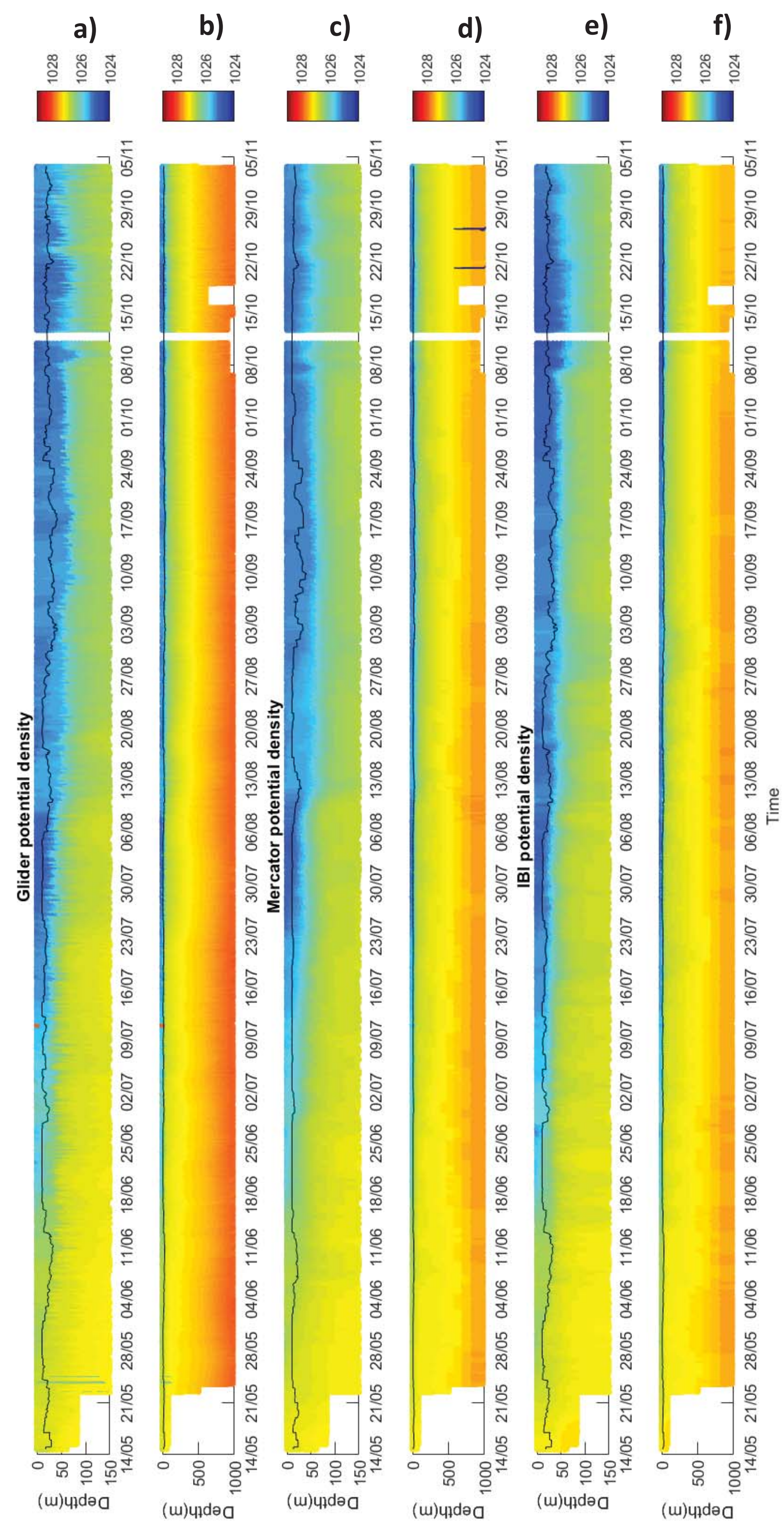

Figure 10: Vertical sections for potential density (kg/m^3). a) and b) represent the obtained glider data, c) and d) represent the data from the Mercator model, and e) and f) represent the data from the IBI model. a), c) and e) show the first 150m and b), d) and e) show the water column until 1000m. The black line represents the mixed layer depth. All the figures were made using Matlab.

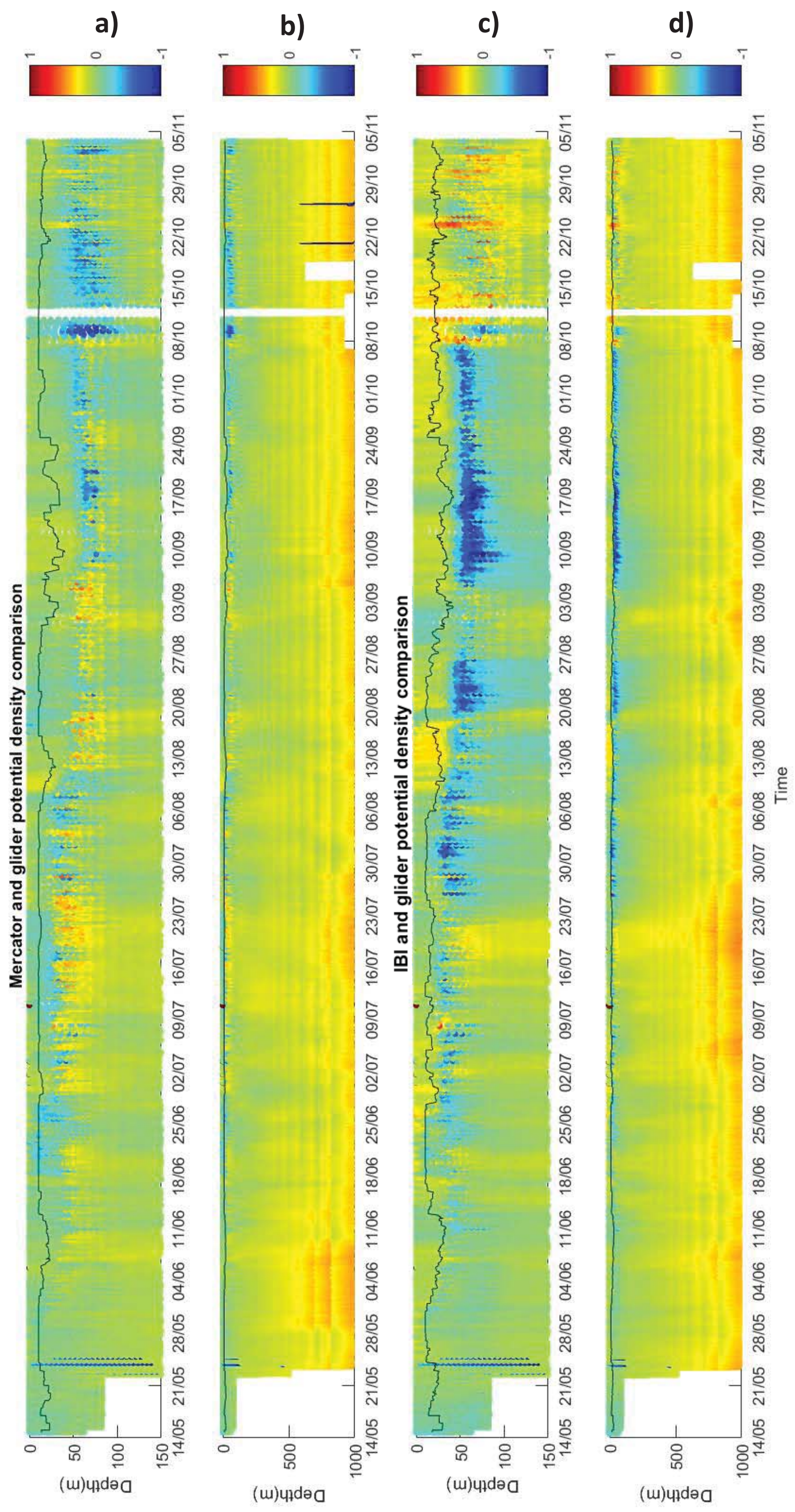

Figure 11: Vertical sections for the potential density differences (kg/m^3) between the glider data and model data. a) and b) correspond to the Mercator model, and c) and d) correspond to the IBI model. a) and c) show the first 150m and b) and d) show the water column until 1000m. It's represented as glider data – model data. The black line represents the mixed layer depth. All the figures were made using Matlab.

4.3. Model-glider comparison, correlation and linear fit

Figure 12 and table 5 show the linear fit and correlation between the datasets, regarding temperature and salinity. Overall, temperature shows a better correlation between glider and models than salinity does.

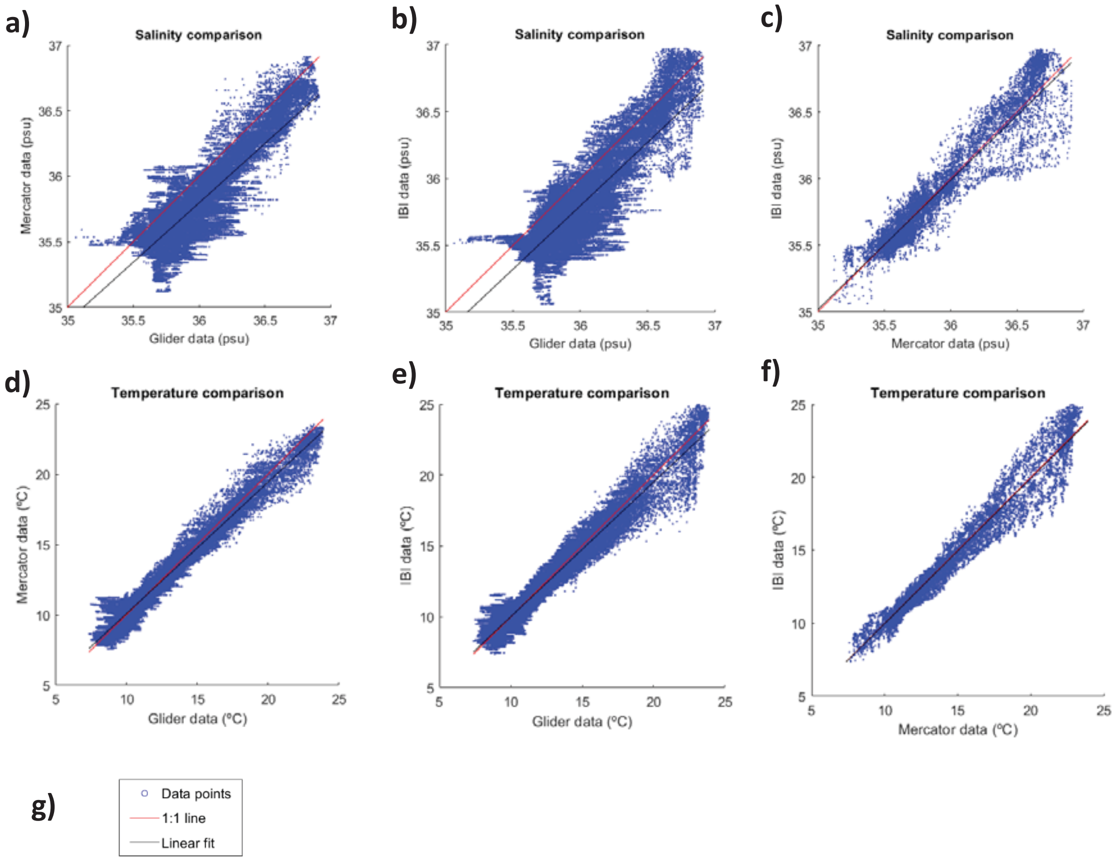

Figure 12: Scatter plot of a), b) and c) corresponding to salinity and d), e) and f) corresponding to temperature; comparing a) and d) glider data(x) and Mercator data(y), b) and e) glider data(x) and IBI data(y), and c) and f) Mercator data(x) and IBI data(y). g) is the legend

The black line represents the linear fit. The red line represents what would be the 1:1 ideal fit if both datasets were the exact same. All figures were made using Matlab.

Both models correlate between them better than they do with the glider data for salinity. The temperature correlation is better than the salinity correlation. In general, glider data correlates better with the IBI model for salinity, while it correlates better with the Mercator model for temperature.

The IBI model is slightly more saline than the Mercator model, and glider data tends to be more saline than models. The temperature range is similar for both models and glider temperature seems similar.

We can infer that temperature results are more reliable than salinity results.

Comparison	P1	P2	Correlation
Salinity glider-Mercator	0.906	3.1808	0.8464
Salinity glider-IBI	0.9502	1.5886	0.8548
Salinity Mercator-IBI	0.9698	1.0729	0.9340
Temperature glider-Mercator	0.9346	0.7313	0.9780
Temperature glider-IBI	0.9478	0.5412	0.9723
Temperature Mercator-IBI	0.9956	0.0219	0.9756

Table 5: Polynomials (P1 and P2) of the linear fitting y=p1x+p2 between the datasets; and correlation between the datasets.

5. Conclusions

The aim of this study was to analyse the performance of the ocean models Mercator Global Ocean Model (Mercator) and Copernicus Iberian-Biscay-Irish Regional Ocean Model (IBI), by comparing them to in-situ glider data. The Mercator model is more correct in general, although in some determined areas the IBI model performs better. Salinity correlates better with glider data for the IBI model, and temperature does it for the Mercator model. All the results are analysed considering the different amount of model depth levels at surface and intermediate waters.

Both ocean models estimate a too low salinity (approx. 0.5 psu) along the water column, but too high (between 0-0.5 psu) on the surface. It's important to consider that salinity data had the highest variability. The uncertainty is smaller than the differences found, so the result is conclusive.

Both models estimate generally too low temperatures (approx. 1-2 ºC). Previous papers say that, for the IBI model, deeper layers have higher concordance, which coincides with this study. The uncertainty is smaller than the differences found, so the result is conclusive.

Both models estimate not enough density (between 0-0.5 kg/m^3) at intermediate waters (800-1000m) and are more accurate at surface.

Zone 1 shows the highest variability regarding the TS diagrams. Considering future studies, the results obtained in that zone with the glider are the less reliable. On the other hand, zone 3 is the most reliable. It would be interesting to study the different areas of the North-East Atlantic basin more in detail, to observe the different accuracy of the ocean models and the oceanographic processes that cause them.

The obtained results must be used as a guidance for futures studies. It's needed to develop the techniques and do more studies to develop the models.

6. List of acronyms

- AAIW: Antarctic Intermediate Water
- AA: Modified Antarctic Intermediate Water
- AUVs: Autonomous Underwater Vehicles
- CADIZ: Gulf of Cadiz
- CMEMS: Copernicus Marine Environment Monitoring Service
- ECHAN: English Channel
- ESTOC: European Station for Time series in the Ocean Canary Islands
- GIBST: Strait of Gibraltar
- GOBIS: Gulf of Biscay
- IBI: Copernicus Iberian-Biscay-Irish Regional Ocean Model
- ICANA: Canary Islands area
- IRISH: Irish Sea
- LSW: Labrador Sea Water
- Meddies: Mediterranean Water mesoscale eddies
- Mercator: Mercator Global Ocean Model
- MW: Mediterranean Water
- NACW: North Atlantic Central Water
- NADW: North Atlantic Deep Water
- NAO: North Atlantic Oscillation
- NARVAL: North Atlantic Regional Validation
- NEMO: Nucleus for European Models of the Ocean
- NIBSH: Northern Iberian Shelf
- ROVs: Remotely Operated Vehicles
- SAIW: SubArctic Intermediate Water
- SST: Sea Surface Temperature
- StrMW: Subtropical Mode Water
- THC: Thermohaline Circulation
- UNESCO: United Nations Educational, Scientific and Cultural Organization
- WIBSH: Western Iberian Shelf
- WSMED: Western Mediterranean Sea

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8. Información adicional sobre el desarrollo de este estudio

8.1. Descripción detallada de las actividades desarrolladas durante la realización del TFG

El desarrollo del TFG ha consistido en seleccionar, obtener, procesar y analizar los datos, paralelamente a la búsqueda de bibliografía y redacción.

Selección de los datos

Los datos de los dos modelos usados (Mercator e IBI) fueron tomados de la página de Copernicus Marine Environment Monitoring Service (CMEMS, http://marine.copernicus.eu/). La zona seleccionada está entre 20ºW-5ºE y 26-55ºN. Sus códigos son GLOBAL_ANALYSIS_FORECAST_PHY_001_024 y IBI_ANALYSIS_FORECAST_PHYS_005_001. Se tomaron las variables:

- Salinidad (psu)
- Temperatura potencial (ºC)
- Latitud (grados decimales)
- Longitud (grados decimales)
- Profundidad (m)
- Profundidad de la capa de mezcla (m)

Los datos del glider se obtuvieron de los resultados de la Challenger Glider Mission (14 de Mayo - 8 de Noviembre 2017), entre Irlanda y Gran Canaria entre 0 y 1000m de profundidad. Las variables obtenidas fueron:

- Salinidad (psu)
- Temperatura potencial (ºC)
- Densidad (kg/m^3)
- Latitud (grados decimales)
- Longitud (grados decimales)
- Profundidad (m)
- Presión (bar)
- Tiempo (timestamp)
- Track distance (km)
- Un índice para indicar la validez de los datos (binario, 0-1)

Todos los datos fueron obtenidos en formato NetCDF. El tratamiento de los datos del glider hasta obtener las variables seleccionadas, se realizó con el software del grupo de investigación.

Procesado de los datos

Los datos se procesaron usando Matlab. En primer lugar, se cargaron los datos al programa. Luego, se seleccionaron los datos válidos, descartando aquellos que se considera que no tenían la calidad suficiente.

Posteriormente, dado que los modelos tienen una cobertura espacial horizontal mayor y los datos de glider tienen una cobertura espacial vertical mayor, se seleccionaron solo los datos de interés.

Una vez seleccionados se realizó la comparación entre los datos y se crearon las secciones verticales, los diagramas TS y los scatterplot con los resultados, mediante todos los cálculos necesarios.

Los parámetros comparados han sido salinidad, temperatura y densidad. La referencia para los diagramas TS fue obtenida de otros papers. Los scatterplot se acompañaron de los resultados de un ajuste lineal y correlación.

Análisis de los datos

Se realizó una representación inicial de los datos para saber qué enfoque darle al estudio, y posteriormente se fueron realizando diferentes enfoques según lo que se observaba en los resultados preliminares obtenidos.

Búsqueda de bibliografía y redacción del TFG

Mi tutor me entregó inicialmente algunos papers previos relacionados con el tema de estudio. Inicialmente realicé una búsqueda bibliográfica de otros estudios similares. Luego, a medida que me fueron haciendo falta para la redacción del TFG o me surgían dudas en algunas cuestiones. busqué más información al respecto.

8.2. Formación recibida

Se me proporcionó ayuda para realizar en Matlab todos los cálculos necesarios y aprender un poco más del programa. Por otro lado, se me formó en la obtención de datos, en este caso a través de la página web de Copernicus. Se me proporcionaron, además, los programas SeaDAS y HDFView, útiles para conocer la estructura de los datos antes de cargarlos en el Matlab. Esto facilitó en gran medida el posterior procesado, sobre el cual ya tenía experiencia previa, a lo largo de las diferentes asignaturas del grado que había cursado. He mejorado y ampliado estos conocimientos y he aprendido a trabajar de forma más eficiente en un entorno grupal.

Por otro lado, he ampliado mis conocimientos científicos oceanográficos al enfrentarme a una investigación real con datos reales inéditos. He aprendido a analizar diagramas TS y estudiar masas de agua, además de interpretar los resultados obtenidos.

He aprendido a realizar búsquedas bibliográficas más eficientes. Además, recibí un curso de la Biblioteca sobre búsqueda de información, gestión de la información y redacción del TFG.

Mi tutor y cotutor me han proporcionado y asistido en todo lo que he ido necesitando a lo largo del proceso formativo, así como otros investigadores de los departamentos de Biología y de Física.

8.3. Nivel de integración e implicación dentro del departamento y relación con el personal

El ambiente de trabajo era agradable. Me sentí integrada e implicada en el grupo y durante todo el proceso me proporcionaron toda la ayuda necesaria. En cuanto necesitaba algo, fuesen dudas técnicas o científicas, no tenía ningún impedimento para contactar al grupo y su respuesta era rápida y efectiva. He aprendido no solo de temas relacionados con mi trabajo, sino de otros temas científicos y técnicos a través de las conversaciones con ellos. Quiero agradecer, tanto a mis tutores como a los miembros de la ULPGC que me han ayudado, la atención y la ayuda recibidas.

8.4. Aspectos positivos y negativos más significativos relacionados con el desarrollo del TFG

Uno de los aspectos positivos que me llevo de las prácticas es la oportunidad de trabajar con investigadores en proyectos reales con datos reales. Esto me ha ayudado a comprender mejor cómo funciona el mundo de la ciencia y descubrir mi interés por este tipo de investigaciones.

Otro aspecto positivo es lo acogida que me he sentido desde el principio, y cómo he recibido la ayuda necesaria en todo momento, además de que los miembros del grupo de investigación se han mostrado interesados por mi progreso.

He podido adquirir nuevos conocimientos, tanto sobre el océano como sobre el tratamiento de datos. Además, me he visto en una situación en la que recae sobre mí una responsabilidad (tratamiento de datos oceanográficos inéditos reales), lo cual es una situación nueva para mí y me ha hecho ganar independencia al trabajar. He descubierto las muchas aplicaciones que tiene la oceanografía.

El único aspecto negativo que he encontrado el plazo para el desarrollo del TFG, considero que si tuviera más tiempo podría profundizar más.

8.5. Valoración personal del aprendizaje conseguido a lo largo del TFG

Considero que todo lo aprendido me resulta muy útil, ya que en el futuro me gustaría dedicarme a la investigación en la misma línea que las prácticas. Considero que lo más importante que he aprendido es a trabajar en grupo, con la responsabilidad que ello conlleva, y a enfrentarme a las complicaciones de los datos oceanográficos reales.

He podido poner en práctica todo lo aprendido durante el Grado en Ciencias del Mar y ver sus aplicaciones. Creo que seré capaz de orientar y organizar mejor el TFM el año que viene habiendo vivido esta experiencia.