

# IEOOS: the Spanish Institute of Oceanography Observing System

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## Abstract

Since its foundation, 100 years ago, the Spanish Institute of Oceanography (IEO) has been observing and measuring the ocean characteristics. Here is a summary of the initiatives of the IEO in the field of the operational oceanography. Some systems like the tide gauges network has been working for more than 70 years. The standard sections began at different moments depending on the local projects, and nowadays there are more than 180 coastal stations and deep-sea ones that are systematically sampled, obtaining physical and biochemical measurements. At this moment, the Observing System includes 6 permanent moorings equipped with currentmeters, an open-sea ocean-meteorological buoy offshore Santander and a seasurface temperature satellite image station. It also supports the Spanish contribution to the ARGO international program with 47 deployed profilers, and continuous monitoring thermosalinometers, meteorological stations and vessel mounted acoustic Doppler current profilers on the research vessel fleet. The system is completed with the contribution to the NorthWest Iberian peninsula and Gibraltar observatories, and the development of regional prediction models. All these systematic measurements allow the IEO to give responses to ocean research activities, official agencies requirements and industrial and main society demands as navigation, resource management, risks management, recreation, etc, as well as for management development pollution-related economic activities or marine ecosystems. All these networks are linked to international initiatives, framed largely in supranational programs Earth observation sponsored by the United Nations or the European Union. The synchronic observation system permits following spatio-temporal description of some events, as new deep water formation in the Mediterranean Sea and the injection of heat to intermediate waters in the Bay of Biscay after some colder northern storms in winter 2005.

## 1 Introduction

The Operational Oceanography (OO) means the activity of systematic and longterm routine measurements of the seas and oceans, their interpretation and dissemination (Parrilla, 2001) in order to fulfill upcoming needs from many different sectors: industry, service, policy making, etc., besides the scientific one. The IEO aims scientific knowledge of the oceans and the marine environment and developed based on observation and research. For more than two decades it has been investing resources, time and funds in the field of OO, to promote these results for the social development and benefit. Institutional strengthening is desirable to form the network core sampling it has managed to develop. This service is given to the interested national and international community and the IEO's Spanish representative in the European forums (International Oceanographic Data and Information Exchange (IODE), International Council for the Exploration of the Sea (ICES), ...) for appropriate action. Some data collected across this Observing System are linked to international initiatives. As an example, the IEO participates in Fixed point Open Ocean Observatory network (FixO3) european project with data from Augusto Gonzalez de Linares (AGL) buoy; and nutrients and dissolved oxygen information from water samples at different deep levels, that are collected along the hydrographic sections, are included in the European Marine Observation and Data Network (EMODNet , DG-Mare/2012) initiative in order to improve the knowledge and perform distribution maps of the variables along the European coasts.

The increase in the ocean measurements and the availability of the general information on the sea behaviour and variability have to be a fundamental chance for the rational use and exploitation of the ocean. This is one of the important lines of the blue growth and green economy. In this sense, the bigger amount of ocean data we can collect, the better responses to the social demands we could offer, such as improved weather forecasts, sea-related hazards prevention, marine safety, coastal tourism, etc.

Although all the datasets are quality controlled locally, by the same researchers that are responsible of the different programs, the IEO performs a double validation when the data

arrive to its datacenter for their permanent archive. Following the internationally agreed protocols, data are checked for spikes and position/date errors, and validated against climatological values in the different areas. To preserve the data for the future, all detected problems are flagged by a numerical code, that gives added value to the original data and facilitate further uses of them. Reformatted to internationally accepted standard formats, and metadated following the Pan European Infrastructure for Ocean and Marine Data Management (SeaDataNet) protocols and the INSPIRE directive (2007/2/EC), both, data and metadata, are incorporated to the IEO data archive structure, linked to SeaDataNet network, and made them accessible through its web portal [www.seadatanet.org](http://www.seadatanet.org).

This paper aims to give a general overview of the different programs that the IEO supports to achieve its scientific objectives as well as to serve the different demands that are imposed by the society. The different programs are been evolving as time passes, adapting the new technologies and sampling strategies to fulfill the IEO needs and the ability to manage them.

## 2 Tide gauge network

The Spanish tide gauge network (Red Operacional de Nivel del MAR, RONIMAR) is being operating since 1943. It has 12 stations, 4 of them on the islands, conforming the international requirements and contributing with the data to the Permanent Service for Mean Sea Level (PSMSL). Some stations are integrated in the Global Sea Level Observing System (GLOSS) and the long period of data registered by RONIMAR has allowed to integrate these sea level time series to global and regional datasets for studies of long term trends, as well as for decadal and interannual variability (Tel and Garcia, 2002; Tel, 2007). Nowadays the sea level is being sampled every 5 min in most of the stations and these data are also being relevant for the estimation of extreme sea levels (Garcia et al., 2012). Along the time, tide gauges network has been upgraded in line with technological advances, both in the system measurement, from the mechanical tide gauge with graphical recorder, to a radar technology; and for data transmission, from postal mailing to automatic transmission. Nowadays 4 stations (Palma de Mallorca, Vigo, Cadiz, and Puerto de la Luz) are sampled every minute,

and could be used in seiches or tsunami studies. These tide gauge data are daily made available from <http://indamar.ieo.es>.

### 3 Hydrographic monitoring sections

The IEO has been monitoring the Spanish shelf waters for the last 25 years. This is the oldest national field program for multidisciplinary marine research addressing long term variability issues at ecosystem level (Bode et al., 2014). Core observations include ship-based hydrographical, biogeochemical and plankton observations at monthly frequency in several oceanographic sections along the Iberian shelf. First series initiated in the north-western shelf (Valdes et al., 2002), and other programs extended the observations to the Mediterranean in 1992 (López-Jurado et al., 2015). This longterm monitoring allows for the knowledge of differences in the large scale off-shore oceanographic conditions along the water column (Vargas-Yáñez et al., 2012), and the description of the intermediate water seasonal formation (Vargas-Yáñez et al., 2010).

In 2003, an initiative (RadProf) to semiannual sample off-shelf waters using the same approach had been established in order to understand the mechanisms governing the internal variability of the ocean, and therefore of the climate. The Finisterre section takes a good representation of the Eastern Boundary Waters along the Iberian Basin and western Galician bank. In 2006 the deep hydrographic section around the Canary Islands began, in order to establish the scales of variability in the range decadal/subdecadal in the subtropical gyre, specifically in its eastern margin (Velez-Belchi et al., 2014). In 2009, new stations in the Gulf of Cadiz (STOCA program) has been added to the network (Monteiro et al., 2015). The results of water samples analysis at the different levels are being included in the EMODNet(chemistry) network. The whole working network can be see at Fig. 1 and table 1.

With the data collected, the IEO was able to detect the deep changes that were produced in the Bay of Biscay and Mediterranean Sea. As an example, the extremely cold and dry Winter of 2005 in the south-western Europe was detected on the different character-

istic of the water masses. In the southern Bay of Biscay, information of the IEO Shelf and Slope Sections shows that in the Bay of Biscay the episode caused a profound transformation of the upper ocean hydrographical structure, making it completely different that what it was in the previous decade (Somavilla et al., 2009). The strong local cooling and the precipitation deficit resulted in the highest density flux estimated, which triggered the mixed layer to reach unprecedented depths, affecting directly East North Atlantic Central Water (ENACW) that are usually unconnected to air sea interaction. In the Western Mediterranean the anomalous low precipitation and persistency of northerlies over the NW Mediterranean caused a large extension both in time and space of deep convection processes (Lopez-Jurado et al., 2005) and a New Western Mediterranean Deep Water (N-WMDW) was produced, slightly denser, warmer and saltier than the usual WMDW (Salat et al., 2007). Also near the continental slope, a cascading of colder and even denser water was found (Puig et al., 2013) affecting biological processes over the whole water column (p.e. Company et al., 2008; Rodríguez et al., 2013; Carbonell et al., 2014; Hidalgo et al., 2014). In the last years, linked to the improving interest to know the Mediterranean Sea health state, new variables (pH, Total Inorganic Carbon,  $\text{NO}_2$ ,  $\text{CH}_4$ ) has been added to the original sampling (Amengual et al., 2010). This multidisciplinary approach permits enhancing the management of short life cycle species such as *Octopus vulgaris* (Vargas-Yanez et al., 2009). All the RadMed oceanographic stations are included in the Mediterranean Operational Network for the Global Observing System (MonGOOS) and in the IBAMar database (Aparicio et al., 2015).

Along the Iberian Basin and NW slope, seasonality signals in the vein of Mediterranean Water have been detected in the area, with the vein constrained to the shelf break in the summer and widely distributed in winter (Prieto et al., 2013). The complete deep sections in the Cantabrian Sea have been discontinued recently while some deep stations have been included for the monthly sampling. The aim is establishing the scales of variability in the range decadal/subdecadal. Its information contributes to the knowledge of the oceanographic climatic variability and global change monitoring (Prieto et al., 2015).

The Canary Islands are immersed in the eastern margin of the North Atlantic subtropical gyre, in the coastal transition zone of the Canary Current Upwelling System. The warming of the upper 600 m continues at a rate of  $0.14^{\circ}\text{C decade}^{-1}$  in the oceanic waters and  $0.32^{\circ}\text{C decade}^{-1}$  in the waters between Lanzarote and Africa under influence of upwelling off the African coast. At intermediate levels the warming continues at rate of  $0.04^{\circ}\text{C decade}^{-1}$  in the oceanic waters and  $0.08^{\circ}\text{C decade}^{-1}$  in the waters between Lanzarote and Africa. At deeper levels, since 1997 there is not statistical significant trend. Regarding the oceanic circulation, the Canary Current presents a seasonal cycle, with the minimum transport occurring during fall, concentrated between Tenerife and Lanzarote Islands. (Vélez-Belchí et al., 2010)

#### 4 Permanent moorings

In the Atlantic Ocean, the IEOOS comprise two deep moorings in the RadProf monitoring of N/NW Iberia since 2004: Finisterre and Santander. The second stopped in September 2010 but in August 2010 a new mooring was established in Asturias ( $44^{\circ}03' \text{ N}$ ,  $005^{\circ}53' \text{ W}$ ). Mooring lines, equipped with currentmeters at the cores of main water masses, have been operative with some interruptions from 2003 at the western Iberian margin and in southern Biscay, and complete the hydrographic sections sampling. The goal is to maintain permanently at least one mooring line at each region. In the Canary Basin a permanent mooring has been placed in the Eastern Boundary Current (EBC) to quantify the water masses variability of these current as well as the Canary Current (Velez-Belchi et al., 2015).

In the Gibraltar Strait, the IEO is involved in the Gibraltar monitoring system with a mooring, that began in the framework of the national research project 'Water exchanges through the Strait of Gibraltar and their response to meteorological and climate forcing (INGRES)' in collaboration with the University of Malaga. In the Mediterranean Sea, the HYDROCHANGES program (Schroeder et al., 2013) comprises an international set of deep moorings for the long-term monitoring of the hydrological variability. The IEOOS contributes to this program with a mooring in the continental slope at the north of the Ibiza channel and

another one at the NE of the Menorca island. The moorings maintenance is planned to be every 6 to 12 months within the RadMed monitoring program (Lopez-Jurado et al., 2005).

## 5 Ocean-meteorological buoy

Deployed in 2007, at 43°50' N 3°47' W, the Augusto Gonzalez de Linares (AGL) buoy is located 22 nmi (nautical miles) north of Cape Mayor, off Santander (southern Bay of Biscay). Water depth at the buoy site is 2850 m. It is equipped with meteorological sensors for air temperature and atmospheric pressure, air humidity and wind (velocity and direction), and ocean ones for waves (height and direction), subsurface seawater temperature and salinity, chlorophyll-A concentration, dissolved oxygen. Finally, a 300 kHz Doppler current profiler monitors the first 100 m horizontal currents.

The obtained information is of great importance for the scientific, meteorological, environmental, fishery, maritime and tourist activities which have a real-time marine information source. Integration of different scales has been matter of study from hourly to monthly, and some products are freely available, together AGL buoy real time data, at [www.boya\\_agl.st.ieu.es](http://www.boya_agl.st.ieu.es). Delayed time data from 2007 to 2014 are also available through [www.seadatanet.org](http://www.seadatanet.org). As an example, figure 2 shows the 26 m height wave recorded in the Cantabrian Sea during a big storm in winter 2009, and the timeseries for salinity and water temperature. These ones are monthly validated against CTD and water bottles that are systematically taken at the Santander hydrographic section.

The Biscay AGL buoy is the IEOOS contribution to the FixO3 European project.

## 6 IEO Research vessels underway monitoring

Nowadays the IEO maintains continuously working 5 thermosalinometers (TSG), 4 meteorological stations, 4 marine data management systems and 2 vessel mounted ADCP on board the IEO R/V fleet. Collected data are routinely sent to the IEO datacenter for quality



control (mainly date, position, and range for near realtime data), dissemination and archive.

An automatic data processing system was developed to manage all the information generated in quasi-real time by this surface sampling network. The developed software applies standard systematic control subroutines and prepares the data to save them into local databases and generates preliminary graphical outputs. All network data are stored in a Thematic Realtime Environmental Distributed Data Services server (THREDDS) to facilitate its access by scientific community and its visualization by means of Open Geospatial Consortium (OGC) standard services. Nowadays an automatic data storage system based on postgres/postgis database is being developed in order to make easy the implementation of an user-friendly web service to visualize and download this kind of data.

These systematic measures had allowed some climatological products based on repeated measurements. So, from thermosalinometer data, the monthly sampling survey from Santander to Gijon, has enabled the subsurface temperature and salinity maps in Cantabrian Sea (Viloria et al., 2012; Viloria, 2012) and let us a better description of coastal conditions and their seasonal variability. In Galician Rias where the interseasonal variations have consequences as algae blooms that strongly affect to local fisheries, the weekly repeated surveys (see figure 3 showing the 4 tracks in December 2015) of R/V *Navaz* since 2008, allows us getting better descriptions of their variability patterns (Tel et al., 2014).

## 7 IEO contribution to ARGO international program

Spain participates in the international Argo program since its beginning (Roemmich et al., 2009; Freeland et al., 2010). This participation began in 2002 through the first European project where a total of 80 Argo profilers were deployed in the North Atlantic. Later, the IEO has led different special governmental actions through which Argo–Spain program is being financed. At this moment a total of 47 profilers has been deployed since 2003, and 9 are active. Additionally, 10 profilers were acquired for three Spanish research groups as part

of their observational strategy. Nowadays, the Spanish continuity on the Argo program is waiting to official pass, although various European research infrastructures demonstrated the interest of such participation.

The Spanish participation has always been subject to scientific objectives, whether to support independent objectives approved under the R+D National Plan or as a means to achieve their own goals of Argo–Spain program. These objectives are the study of the mass transport variability and the changes in temperature and salinity in the North Atlantic (24.5° N) (Vélez-Belchí et al., 2010) or the Meridional Overturning Circulation in the North Atlantic (Hernandez-Guerra et al., 2010).

## 8 Satellite SST images reception station

In July 1998 a satellite data reception station was mounted at the IEO Santander Centre. From 1998 to 2007 the station acquired and stored important information for different studies of ocean trends. Because of technical problems the station stopped working in 2007, but a new reception station has been mounted in 2010. The system receives, archives, processes and displays data from NOAA and Metop satellites. From these data, Sea Surface Temperature (SST) images are obtained for five different geographical areas and distributed in near real-time in the IEO web-page. These SST images are in jpg format with a suitable color palette applied. Nowadays, 10 daily SST images are available in the web page and shortly SST data will be available in a standard distribution format for satellite images.

The main scientific objectives are related to the identification of mesoscale features, as coastal marine ecosystems and continental margins represent the transition zone between the continents and ocean basins, and they play a crucial role in regulating the materials and energy exchanges between mainland and the deep ocean (Otero et al., 2009), being areas of intense biological productivity. In particular, these data has also been used in studies of the oceanographic conditions in the Prestige oil spill accident (Ruiz-Villarreal et al., 2006). Furthermore, assimilation of satellite data is an important tool for the validation of the hydrographical circulation models of the area and an important support tool (Garcia-

Soto, 2004) in the designing and developing of the Spanish oceanographic surveys and research.

## 9 Hydrodynamical forecasting models

The IEO runs high resolution models in the N–NW Iberian Peninsula to give response to the oceanographic water conditions, upwelling system variability (Otero et al., 2008) and harmful algal bloom prediction, among others. The main task consists of providing insight on the coastal and ocean dynamics in support to the intense IEO ecosystem and fisheries research in the area. The Regional Ocean Model System (ROMS) outputs for temperature, salinity and currents layers are freely available through a THREDDS server <http://centolo.co.ieu.es:8080/thredds/catalog/ROMS-IEO/catalog.html> and a data viewer [http://www.indicedeafloramiento.ieu.es/index1\\_en.php](http://www.indicedeafloramiento.ieu.es/index1_en.php). Using ROMS data the following derived products are generated: thermal, haline and mix layer fronts, eddies, shellfishing areas and beaches temperature.

In the last years, a high resolution ( $\sim 3$  km) configuration of ROMS physical model with atmospheric forcing, which has shown to represent the main features of the shelf and slope circulation in the area, was run coupled to a biogeochemical model (N2PZD2). Any biogeochemical model aimed at providing a reliable representation of the dynamics of a certain area should be tuned according to its characteristics. In an upwelling system, the composition of phytoplankton varies from the beginning to the end of the bloom. The spring bloom is reasonably reproduced in the NW and N coasts in time, space and intensity (Garcia-Garcia et al., 2015). Some examples of the use of the IEO models to get some insight on sardine recruitment variability (Bode et al., 2006) and harmful algal bloom prediction. In the last case, the circulation models at Rias, and data from RV *Navaz* thermosalinometer and CTD monthly profiles from Radiales program at Ria de Vigo, enable an HABs alert bulleting <http://www.asimuth.eu/en-ie/HAB-Bulletin/Pages/default.aspx> that is used by fishermen and local aquiculture enterprises in order to manage their activities.

## 10 Conclusions

The Spanish Institute of Oceanography (IEO) maintains a large and coherent ocean observing system around the Iberian Peninsula, the Canary and the Balearic Islands. The Spanish Institute of Oceanography Observing System (IEOOS) provides quality controlled data and information about Spanish surrounding waters and comprehends several subsystems. Furthermore, all the information obtained from the IEOOS is actually providing valuable information to study the biological resources and their dependence on the physic-chemical variables (Alemany et al., 2010, e.g.), and also physical effects like deep and intermediate water masses formation (Somavilla et al., 2013; Vargas-Yáñez et al., 2012, e.g.), modification and transport (Lopez-Jurado et al., 2005, e.g.), and oscillations and trends in environmental variables (Prieto et al., 2015; Vargas-Yáñez et al., 2010), while models information is being successfully used in local fisheries.

The success of the Hydrographical Sections extends beyond pure scientific knowledge, as the expertise gathered with the program has been applied to solve multiple environmental issues, from fisheries and pollution to global change. The Marine Strategy Framework Directive (MSFD), whose main objective is the achievement of good environmental status of European seas is planning of the marine environment action policy. The IEO is already conducting many of the required evaluations on the Spanish coasts. In fact, data collected in the framework of IEOOS structure has been the core of the initial assessment and the key element for the identification of environmental objectives that follow up.

The new IEO research vessels are completely equipped automatic systems that enormously increase the capacity of sampling the ocean along the ship tracks, and a collaboration with the national forecast services is expected in the near future in order to provide them data in near real-time.

In the pursuit of giving visibility to the sampling network IEO data, as well as the activities of this group, a single web portal-style is currently being developed. It would help to strengthen their position and status in the national framework and international as well as responding to demands that we are proposing recently under proposals such as Emodnet

initiatives, the EU Framework Programme for Research and Innovation: Horizon 2020, or MSFD. In this sense, the IEO is currently doing a strong effort to give visibility to all the data obtained in the framework of its OO programs, incorporating them to structures as Sea-DataNet or EmodNet, developing web-based viewers and maintaining permanent servers and services along the time. This effort will result in a better reusing of data and information obtained and benefiting of wide community of final users.

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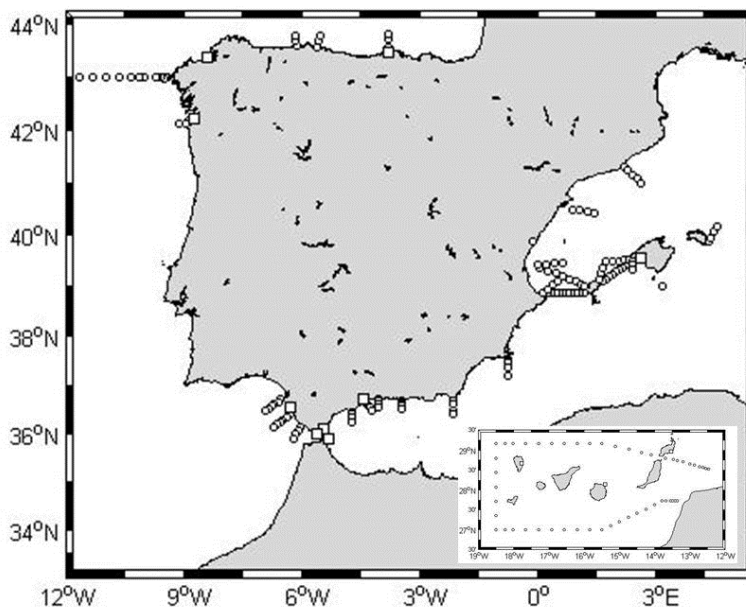
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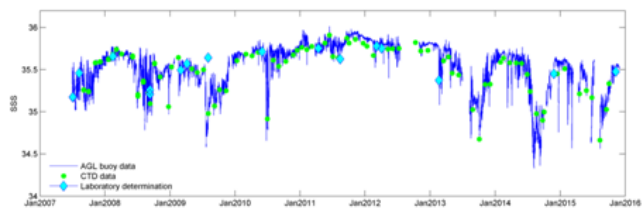
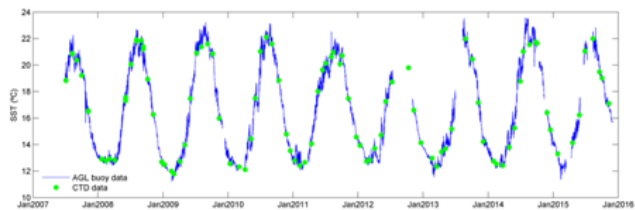
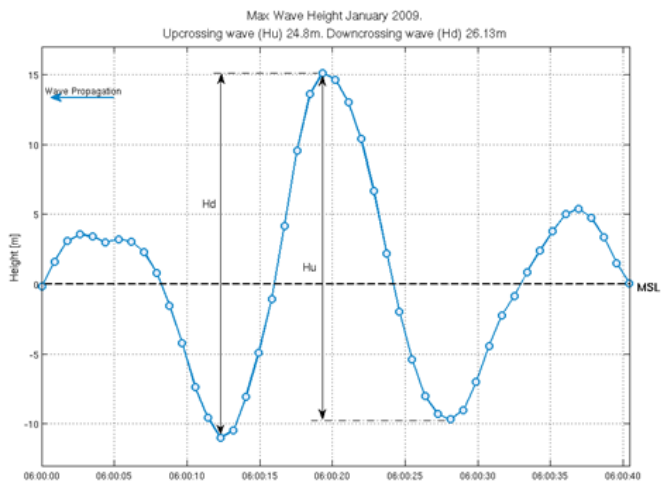
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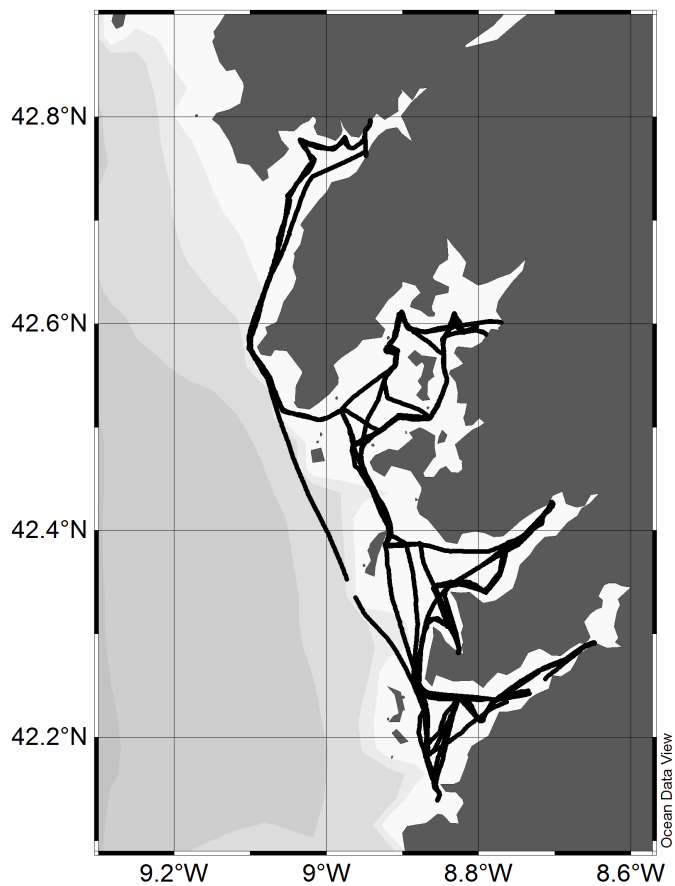
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**Figure 1.** IEO tide-gauge network (squares) and oceanographic stations (dots) from the IEO Hydrographic Monitoring Sections. AGL buoy is close to the most external station of the Santander Hydrographic Section



**Figure 2.** Big wave recorded by the AGL buoy (above) and timeseries (below) for continuous temperature and salinity recorded at buoy, and data obtained by systematic CTD and water bottle samples taken at the Santander hydrographic section.



**Figure 3.** Weekly repeated tracks of the R/V Navaz during December 2015

**Table 1.** Summary of the different hydrographical sections programmes carried out by the IEO and their contributions to international initiatives

Program	Begin	No	Geographical Area	Contributing Programs
Radiales	1990	16	Cantabrian Sea and NW Coast	EmodNet
RadMed	1992	85	Western Mediterranean, Alboran Sea, Balearic Islands	EmodNet, MonGOOS
RadProf	2003	24	NW Iberian basin, Galician Bank	EmodNet, ICES/WGOH
RaProCan	2006	50	Canarian basin	EmodNet
STOCA	2009	16	Gulf of Cadiz	EmodNet

MonGOOS: Mediterranean Operational Network for the Global Observing System is part of EuroGOOS. ICES/WGOH: ICES Working Group on Oceanic Oceanography