ICOS-SPAIN
ACTIVITY REPORT
2021 - 2022

State Meteorological Agency (AEMET)

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VICEPRESIDENCIA TERCERA DEL GOBIERNO
MINISTERIO PARA LA TRANSICIÓN ECOLÓGICA Y EL RETO DEMOGRÁFICO

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ICOS National Network Spain

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ICOS-SPAIN
ACTIVITY REPORT 2021-2022

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Executive Summary

This report summarizes the current status of the Spanish contribution within the Integrated Carbon Observation System European Research Infrastructure Consortium (ICOS-ERIC).

Spain officially joined ICOS-ERIC in 2021, after its membership application was approved by the ICOS General Assembly in November 2020. Currently, the ICOS-Spain national network is composed of the Marine Chemistry (QUIMA) group of the Institute of Oceanography and Climate Change of the University of Las Palmas de Gran Canaria (ULPGC), the National Institute for Aerospace Technology (INTA), the Oceanic Platform of the Canary Islands (PLOCAN), the Spanish Institute of Oceanography of the Spanish National Research Council (IEO-CSIC), the Mediterranean Center for Environmental Studies (CEAM) and the State Meteorological Agency (AEMET). The Ministry of Science and Innovation (MICIN), through the General Subdirectorate for the Internationalization of Science and Innovation, represents Spain in ICOS-ERIC, and through a bilateral agreement with AEMET, it assigns to this institution the technical coordination of ICOS-Spain, and the payment of the corresponding fees for Spain to have a voice and vote in the General Assemblies of ICOS-ERIC.

In the 2021-2022 period, the national node has experienced a significant increase in the number of stations from two to five locations. This expansion reinforces the capacity of ICOS-Spain to make observations and collect data on the most important greenhouse gases (GHG) in different parts of the country. In addition, the stations of the national node cover the three observation domains: atmospheric, oceanic and ecosystem, where ICOS-ERIC monitors GHGs and studies their relationship with climate change.

In December 2022, these five sites were undergoing the certification process established by ICOS-ERIC, which verifies that they meet the demanding technical requirements of the network for each domain and takes into account both the location and environment of the stations and that the instruments utilised meet the standards established by ICOS-ERIC. At the time of writing this report, the Izaña Observatory has successfully completed this certification process and has been fully integrated into ICOS-ERIC. Furthermore, the CanOA-SOOP surface ocean observing platform expects to complete this process in the coming months. The El Arenosillo atmospheric station has successfully completed the assessment of the suitability of its location and has initiated the process to certify its instrumentation and sampling system. Finally, the Majadas de Tiétar associated ecosystem station and the ESTOC oceanic platform have been admitted to ICOS-ERIC in 2022 and will start their certification process during 2023.

In parallel, ICOS-ERIC develops research projects with European funding where there is an outstanding participation of Spanish researchers and institutions. Thus, the ICOS Cities HORIZON 2020 project, in which the Autonomous University of Barcelona (UAB) participates, carries out observations on GHG emissions in urban areas, Barcelona is the only Spanish city selected with other European cities for monitoring in this project. On the other hand, the GEORGE HORIZON 2020 project (Next Generation Multiplatform Ocean Observing Technologies for Research Infrastructures) aims to improve marine observations in terms of quality, coverage and continuity through the development of novel technologies, in particular, autonomous sensors. This project involves ULPGC, PLOCAN, the Universitat Politecnica de Catalunya (UPC), the Balearic Islands Coastal Observing and Forecasting System (SOCIB), and OCEOMIC Marine Bio and Technology SLm. Finally, ICOS-ERIC coordinates the KADI project (Knowledge and Climate Services from an African Observation and Data Research Infrastructure), with the participation of 16 African and European partners, including AEMET. This project will provide new concepts for developing adapted climate services for Africa, necessary to intensify our joint action.

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1 ICOS-ERIC

The Integrated Carbon Observing System (ICOS) is a European Research Infrastructure Consortium (ERIC) on greenhouse gases (GHG) funded by the European Union and partner countries. ICOS-ERIC emerged in 2015 with the aim of increasing knowledge about the Earth-atmosphere system and its response to climate change, in order to advance in the fulfilment of the United Nations Sustainable Development Goals and the European Union Societal Challenges, especially, those related to global warming. To this end, this infrastructure provides public GHG and carbon cycle data obtained with the same technical and scientific standards from 173 measuring stations distributed throughout the European continent and adjacent oceans. The stations that are part of ICOS-ERIC are organized in national nodes, and there are currently 16 networks: Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Holland, Hungary, Ireland, Italy, Norway, Sweden, Switzerland, United Kingdom and Spain (see **Figure 1**).

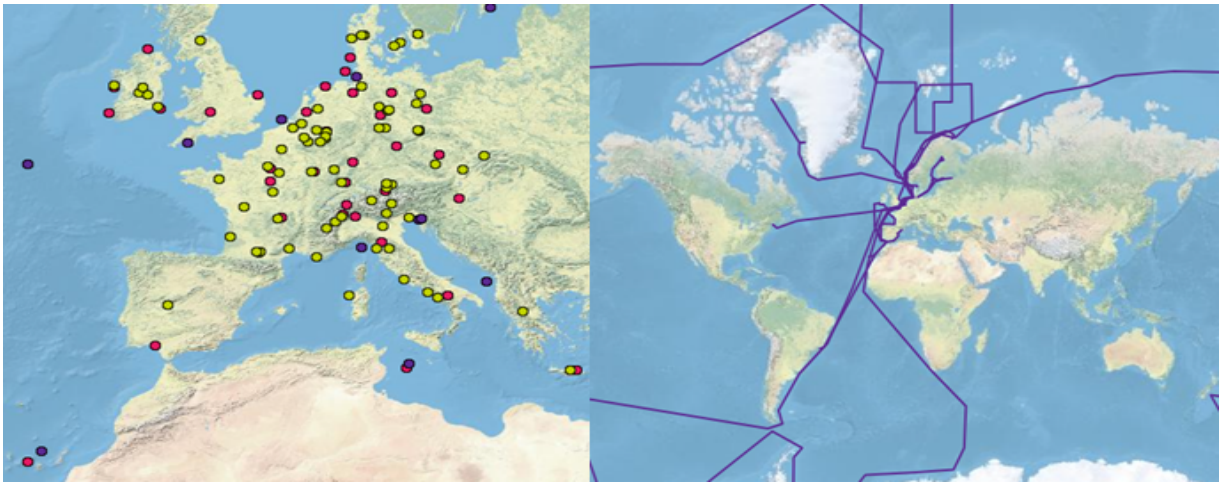

Figure 1. Map of ICOS-ERIC stations: atmospheric (magenta), ecosystems (green) and oceanic buoys and maritime lines (violet). Source: ICOS-ERIC, www.icos-cp.eu.

Structurally, ICOS-ERIC includes and identifies three working domains: atmosphere, ecosystems and oceans (see **Figure 2**). In each domain, a series of variables[1] required to be measured by the stations of the network have been established, ranging from atmospheric concentrations of different GHGs, or carbon fluxes exchanged between the atmosphere, land surface and oceans, as well as complementary information for further analysis. Atmospheric, Oceanic and ecosystem stations are classified as Class 1 or Class 2, depending on whether they monitor all or part of the established variables, respectively. However, the same quality control is applied for data in both classes. The ecosystem network is complemented by a set of associated stations, with lower requirements on the variables to be measured and sampling frequency.

The incorporation of a new station begins with the official request made by the focal point to ICOS-ERIC headquarters. Once accepted, the certification process begins, which is divided into two steps:

1. Validate that the station is located in an area of scientific interest.
2. Certify that your instrumentation meets the established accuracy requirements.

[1] Variables to be monitored depending on the station domain:
Atmospheric: https://icos-atc.lsce.ipsl.fr/documents
Ecosystem: http://www.icos-etc.eu/icos/documents/instructions
Oceanic: https://otc.icos-cp.eu/documents

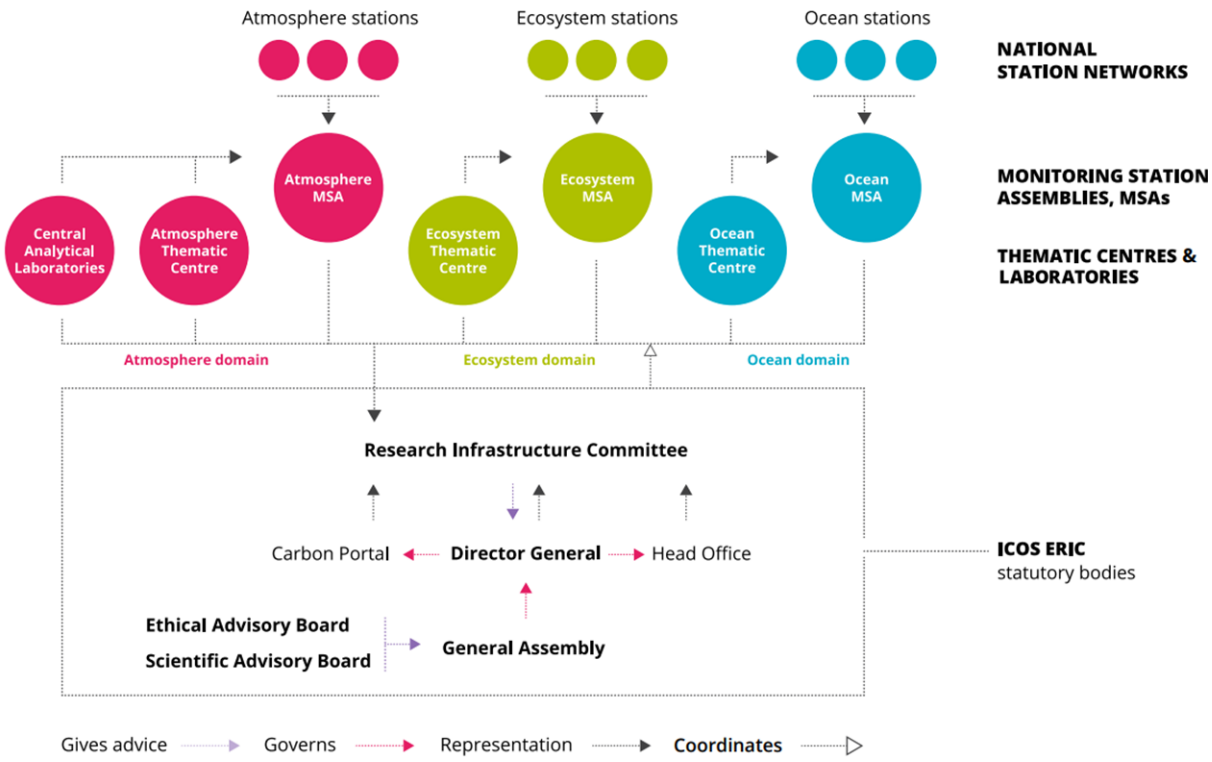

Figure 2. Organizational and research structure of ICOS-ERIC. Source: ICOS-ERIC, www.icos-cp.eu.

The above steps are verified by the respective thematic centres. In ICOS-ERIC, each domain has a thematic centre that provides technical support to the stations and their researchers during the certification process, including the technical review of their instrumentation and verifying that the researchers correctly apply quality control to their data, which will later be integrated into the publicly accessible database (Carbon-Portal).

Each thematic centre, in close collaboration with its Monitoring Station Assembly (MSA) for each domain and the Central Analytical Laboratories (CAL), coordinates the observations in each area. The Atmospheric Thematic Centre (ATC) is composed of a data centre and a metrology laboratory and is complemented by a mobile station quality control laboratory. The ATC is coordinated and managed by the *Laboratoire des Sciences du Climat et de l'Environnment* (LSCE) of France, with the support of the *Finnish Meteorological Institute* (FMI). The Ecosystems Thematic Centre (ETC) is coordinated and managed by the *EuroMediterranean Centre on Climate Change* (CMCC) in collaboration with the University of Tuscia (UNITUS) in Viterbo, Italy, the *Plants and Ecosystems* (PLECO) research group of the *University of Antwerp* in Belgium and the *National Research Institute for Agriculture, Food and Environment* (INRAE) in France. The Ocean Theme Centre (OTC) is coordinated and operated by the *Norwegian Research Centre* (NORCE) and the *University of Bergen* (UIB) in Norway, and the *University of Exeter* (UOE) and the *National Oceanography Centre* (NOC) in the United Kingdom.

The CAL is located in Germany and consists of two laboratories: The Flask and Calibration Laboratory (FCL) in Jena, which is part of the *Max Planck Institute for Biogeochemistry* (MPI-BGC), and the Central Radiocarbon Laboratory (CRL), which is part of the *Institute of Environmental Physics of the Heidelberg University* (UHEI). The FCL performs analyses of GHG concentrations and other tracers, which provide auxiliary information on the origin of air samples: stable isotopic composition of carbon dioxide (CO_2), oxygen (O_2) level, and other gases. It also develops the calibration tanks used to ensure compatibility of GHG measurements with data from other global monitoring networks and provides support on the material involved. The CRL quantifies the radiocarbon (^{14}C) content of CO_2 in air samples and develops methods to derive the contribution of fossil fuels to atmospheric CO_2 ($ffCO_2$).

The ICOS-ERIC headquarters manages the technical, operational and management structure of the infrastructure and organizes two annual General Assemblies to reach agreements with the focal points and delegates of each country on matters that affect the entire network, such as its financing, the incorporation of new countries or stations, etc.

Internationally, ICOS-ERIC participates in various initiatives such as the development of the Integrated Global Greenhouse Gas Information System (IG3IS) of the World Meteorological Organization (WMO). In addition, since 2019, ICOS-ERIC is an observer organization to the United Nations Framework Convention on Climate Change (UNFCCC) and thus contributes to the work of the Convention and its Subsidiary Body for Scientific and Technical Advice (SBSTA) and can organize its own side events in connection with the annual global climate negotiations (COP). As an observer at the Intergovernmental Panel on Climate Change (IPCC), ICOS-ERIC can actively promote the participation of its scientific community in the process of preparing the various IPCC reports. Furthermore, this infrastructure, under the umbrella of the European Commission and Copernicus, will act as validation coordinator for the *Operational Anthropogenic CO_2 Emissions Monitoring Verification Support Capacity* [1].

In addition, ICOS-ERIC has promoted synergies with other observation networks in order to disseminate the measurements and records of its network of stations. For example, carbon flux data from a large number of ecosystem stations are integrated into FLUXNET, ocean stations participate in the Surface Ocean CO_2 Atlas (SOCAT) and Global Ocean Data Analysis Project (GLODAP) and some of the atmospheric stations belong to the World Meteorological Organisation Global Atmosphere Watch Programme (GAW-WMO).

Finally, ICOS-ERIC strongly promotes the development of research activities and projects associated with the GHG and carbon cycle. Significant examples are the recent initiative ICOS Cities Project, which aims to gather and evaluate different innovative measurement approaches on GHG emissions in densely populated urban areas. This project supports the European Green Pact, aiming to develop useful tools and services for cities to support their local climate action plans. Other important examples are the GEORGE project, which focuses on developing technological improvements to optimize the entire ocean carbonate system data chain, and the KADI project for the development of climate systems on the African continent. All of these projects involve Spanish institutions and researchers.

2 ICOS-Spain

The ICOS-ERIC General Assembly approved the membership application of Spain on 17 November 2020. The national network, ICOS-Spain, is formed by the QUIMA group of the Institute of Oceanography and Climate Change belonging to the University of Las Palmas de Gran Canaria (ULPGC), the National Institute for Aerospace Technology (INTA), the Oceanic Platform of the Canary Islands (PLOCAN), the Spanish Institute of Oceanography of the Spanish National Research Council (IEO-CSIC), the Mediterranean Centre for Environmental Studies (CEAM) and the State Meteorological Agency (AEMET), which is also responsible for the technical coordination of the national network. Each partner is responsible for its station, proposing a principal investigator among its staff who will be responsible for participating in different activities organized by each thematic centre, such as the monitoring meetings during the station certification process and, subsequently, the station assemblies of each domain.

The participation of Spain has made it possible to expand the geographical coverage of the observations of this network to the northern subtropical zone of the Atlantic Ocean. At the end of 2022, ICOS-Spain consisted of only three stations covering the atmospheric domain (Izaña Observatory and El Arenosillo) and the oceanic domain (CanOA-SOOP). However, the ICOS-ERIC General Assembly approved the incorporation of two new stations as of 1 January 2023: the oceanic station, ESTOC and the associated ecosystem station, Majadas de Tiétar. The first will be operated jointly by PLOCAN, IEO-CSIC and ULPGC, while the second will be managed by CEAM (see **Figure 3**).

Figure 3. Location of ICOS-Spain stations.

In the period 2021-2022, the five stations of the ICOS-Spain network have been involved in the process of incorporation established by ICOS-ERIC described above. Researchers have been adapting their laboratories and instrumentation to the technical criteria set by this network. Moreover, in some cases, their equipment has been sent to the corresponding thematic centre or manufacturer for review. Consequently, the GHG observations made so far are not available on the data portal, because they are used by the topic centres for the monitoring of the certification process. During the preparation of this report, the Izaña Observatory has completed this process and has been fully admitted as an atmospheric station and its observations are therefore available on the ICOS-ERIC data portal. **Table 1** summarises the current status of the stations in the national network.

Table 1. ICOS-Spain stations and current status in the ICOS certification process.

Station (Institution)	Domain	Type of station	Incorporation	Certification process status[2]
Izaña (AEMET)	Atmospheric	Class 2	1/1/2021	Station validation (19/4/2021) Certification process completed (23/5/2023)
CanOA-SOOP (ULPGC)	Oceanic	Class 1	1/1/2021	Station validation (25/2/2021). Certifying its instrumentation.
El Arenosillo (INTA)	Atmospheric	Class 2	1/1/2022	Station validation (11/8/2022). Certifying its instrumentation.
Majadas de Tiétar (CEAM)	Ecosystem	Associated	1/1/2023	In 2022, it applied for membership in ICOS-ERIC. In 2023, the certification process was initiated.
ESTOC (PLOCAN, IEO-CSIC, ULPGC)	Oceanic	Class 1	1/1/2023	In 2022, it applied for membership in ICOS-ERIC. In 2023, the certification process was initiated.

2.1 ICOS-ERIC General Assembly in Madrid

The first ICOS-ERIC General Assembly based in Spain took place on 22 and 23 November 2022. This meeting, of great importance for decision-making within ICOS-ERIC, was attended by important members of ICOS-Spain and from the Ministry of Science and Innovation (MICIN), such as María Vallejo, the organizer of this assembly. The venue was the MICIN headquarters, located in Madrid (see **Figura 4**), which demonstrates the importance that this ministry attaches to Spanish participation in this European infrastructure.

During the assembly, several presentations were given to inform about different aspects of the current status of the national node. Emilio Cuevas, national focal point, summarised the progress and achievements to date. Omaira García, Melchor González, Arnaud Carrara and Gara Villalba presented the progress made at their respective ICOS stations or associated observing networks (see **Table 2**).

One of the highlights of these presentations was the presentation of the new stations that will be incorporated into the ICOS-Spain network in 2023. These stations will play a key role in monitoring and understanding carbon fluxes and ocean acidification and will allow the Spanish node to be representative in the three research domains where ICOS-ERIC operates.

[2]The certification process is described in the previous section.

Figura 4. ICOS-ERIC General Assembly, Madrid, 22 - 23 November 2022. (Left to right) Emilie Hachem - European Projects Advisor, Katri Ahlgren - Head of Communications ICOS-ERIC, Gonzalo Arévalo Nieto - Director General for Research Planning MICIN, Christian Plass-Dülmer - German Presidency of the General Assembly and Werner Kutsch - Director General ICOS-ERIC.

The presentation of these stations generated great interest among the attendees, due to the fact that they represent an important contribution to the monitoring of GHGs in the Iberian Peninsula and the Atlantic Ocean. The participation of the city of Barcelona in the ICOS Cities project was also described. Finally, the future national network COCCON-Spain was presented, coordinated by AEMET, which will monitor the concentration of the main GHGs in columns. This network will consist of 12 stations measuring CO_2, methane (CH_4), water vapour (H_2O) and carbon monoxide (CO) with Fourier transform spectrometers: six of them in background conditions in Tenerife, Huelva, Almeria, Valladolid, and in a location in the north of the Iberian Peninsula yet to be decided, and another six stations upwind and downwind of the metropolitan areas of Madrid and Barcelona, where the main urban/industrial areas with anthropogenic GHG emissions in Spain are located.

Table 2. Researchers and presentations at the ICOS-ERIC General Assembly, Madrid, 22 - 23 November 2022.

Researchers	Institution	Oral presentation
Dr Emilio Cuevas Agulló	ICOS-Spain Focal Point. Director of the Izaña Atmospheric Research Centre (IARC).	Atmosphere ICOS and non-ICOS activities
Dr Omaira E. García Rodríguez	Head of the FTIR programme. Izaña Atmospheric Research Centre (IARC).	Future COCCON Spanish network
Dr Melchor González Dávila	Head of the QUIMA Research Group. University of Las Palmas de Gran Canaria (ULPGC).	Ocean ICOS and non-ICOS activities
Dr Arnaud Carrara	Head of the Carbon Cycle Research Group. Mediterranean Center for Environmental Studies (CEAM).	Ecosystem ICOS and non-ICOS activities
Dr Gara Villalba Méndez	Departamento de Ingeniería Química, Biológica y Ambiental. Instituto de Ciencia y Tecnología Ambientales (ICTA-UAB)	GHG measurements and monitoring in the Metropolitan Area of Barcelona

3 Background and Implementation of ICOS-Spain

The initial implementation of the ICOS-Spain network is being carried out on the basis of observation stations already consolidated in the national territory. Consequently, part of the infrastructure is already implemented and, therefore, it is only necessary to adapt it to the technical requirements of ICOS-ERIC. The stations that make up the national network are described below.

3.1 Izaña - AEMET

The Izaña Observatory (28.3ºN, 16.5ºW, 2373 m.a.s.l.) is managed by the IARC, which is part of AEMET. Inaugurated in 1916, it has been carrying out meteorological and climatological observations uninterruptedly up to the present day. It is located on the mountain plateau of Izaña, above the thermal inversion associated with the top of the trade wind layer that is normally located below the station and, moreover, under the influence of the descending branch of the Hadley circulation cell. These conditions ensure clean air and clear skies for most of the year. These excellent conditions favour in situ measurements of trace gases and aerosols under free tropospheric conditions, and observations by remote sensing techniques.

In 1960, the first GHG observations were carried out at the Izaña Observatory [2,3]. Dr Reidar Nydal established a worldwide network of stations to monitor the atmospheric concentration of the 14C isotope emitted during nuclear tests up to the early 1960s in various parts of the world. The temporal distribution of this isotope was an important tool for testing models describing the flux of carbon exchanged in the Earth-atmosphere system. In 1984, the Izaña Observatory started to continuously record CO_2 and CH_4 concentrations, first as a station of BAPMoN (Background Atmospheric Pollution Monitoring Network) and, since 1987, in the framework of the current GAW-WMO Programme, where its observations are representative of the northern subtropical area of the Atlantic Ocean under free troposphere conditions. The series of CO_2 records in free-tropospheric background conditions is the second longest in existence, after the Mauna Loa Observatory (MLO, Hawaii) measurements. In 2007, the GHG observation programme was extended to include nitrous oxide (N_2O) and sulphur hexafluoride (SF_6) measurements. In addition, CO began to be monitored due to its importance in the carbon cycle [4].

The Izaña Observatory was selected to be integrated in ICOS-ERIC as a Class 2 mountain atmospheric station and, therefore, with the obligation to provide continuous in situ measurements of CO_2 and CH_4, as well as complementary measurements of CO and N_2O. Following the technical requirements of the European infrastructure, a Picarro G2401 analyzer and a Los Gatos Research (LGR) 907-0015 analyzer were expressly acquired to measure the four gases mentioned above, simultaneously and independently of the measurement instruments of the GAW-WMO Programme. In 2021, both analyzers were sent to the ATC to verify that they were within the uncertainty standards set by ICOS-ERIC. After a period of rigorous testing and instrument adjustments, the Picarro and LGR analyzers finally passed the tests on 25 November 2021 and 30 March 2022, respectively.

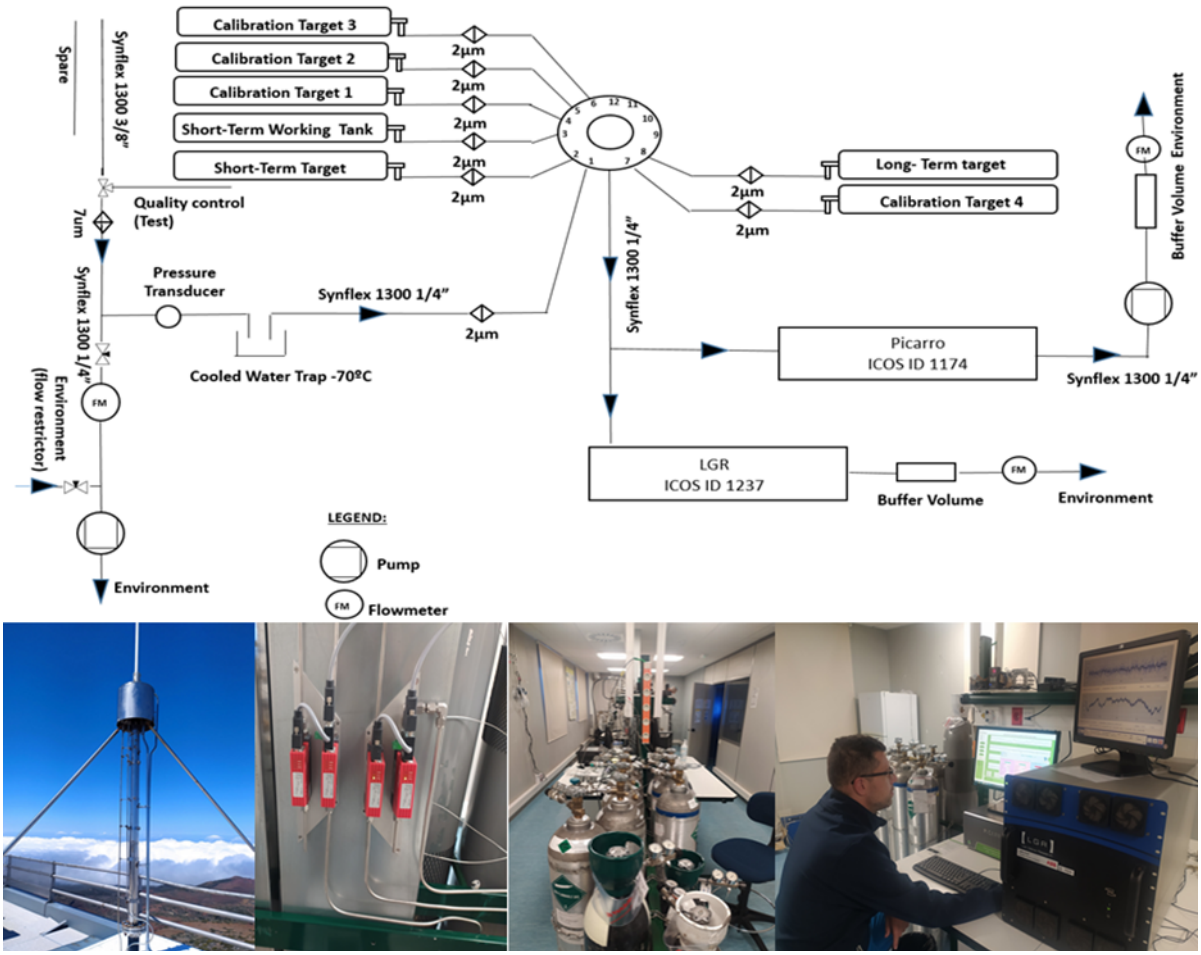

Figure 5. (Upper panel) Schematic of the ambient air pumping system and the ICOS-ERIC calibration and working standards up to the Picarro and LGR analysers implemented at the Izaña Observatory. (Lower panel) Photographs of the installation, sampling, flow meters, gas tanks and the ICOS-Spain technician (Sergio León Luis) supervising the measurement and calibration protocols of the instruments

Parallel to the acquisition and testing process of both instruments, the documentation required by the ATC to validate the location of the observatory as a mountain atmospheric station was sent, and the application was formally accepted on 19 April 2021. **Figure 5** shows the ambient air pumping system and calibration tanks (P&ID) implemented at the Izaña Observatory following the recommendations of the ATC [5]. In November 2022, periodic calibrations were started with the calibration tanks provided by CAL every 15 days. As mentioned above, the WMO-GAW and ICOS-ERIC observing programmes operate in parallel at the Izaña Observatory, which allow a continuous and real-time intercomparison of both observing networks and their traceability.

IARC also contributes to the WMO through the Global Climate Observing System (GCOS) and through the WMO-Measurement Lead Centre for Aerosols and Water Vapor Remote Sensing Instruments (MLC-Izaña). IARC, given its comprehensive atmospheric observation programme, also participates in numerous international networks and programmes such as: Aerosols, Clouds, and Trace Gases Research Infrastructure (ACTRIS), Network for Detection of Atmospheric Composition Change (NDACC), Total Carbon Column Observing Network (TCCON), Collaborative Carbon column observing network (COCCON), Baseline Surface Radiation Network (BSRN), AErosol RObotic NETwork (AERONET), Micropulse Lidar NETwork (MPLNET), EUMETNET EIG GNSS Water Vapour Programme (E-GVAP), PANDORA-PANDONIA, European Brewer Network (EUBREWNET), World Ozone and Ultraviolet Data Center (WOUDC), Neutron Monitor Database (NMDB) and Cooperative Air Sampling Network (NOAA/ESRL/GML).

More information about the Izaña Observatory can be found at: https://icos-spain.aemet.es/Izana

3.2 CanOA SOOP – ULPGC

CanOA is a surface ocean observation platform (SOOP) installed on a container ship designed and maintained by the QUIMA Group of the ULPGC. It was established in February 2019 and since January 2021 it is one of the ICOS-Spain ocean stations. The CanOA-SOOP line runs every week through the eastern region of the Canary Islands, crosses the North African region to the Strait of Gibraltar, and from there to Barcelona via the western part of the Mediterranean Sea, making the return journey the following week. The container ship calls at the island ports of Gran Canaria (Puerto de La Luz and Las Palmas), Tenerife and Lanzarote, and at the Spanish mainland ports of Sagunto (Valencia) and Barcelona. Therefore, it allows the continuous recording of data from the region with a frequency of one week. The container ship where the instrumentation is installed is the MV RENATE P of the company REEDEREI STEFAN PATJENS GmbH & Co.KG, managed in Spain by NISA MARITIMA. In November 2021, the container ship changed its name to MV JONA SOPHIE.

This oceanic station will allow observations of CO_2 content, as well as other parameters, in the Atlantic Ocean and the Mediterranean Sea. Its route covers the eastern region of the Atlantic Ocean affected by the North African upwelling and the western region of the Mediterranean Sea. In addition, the observations made in the Strait of Gibraltar, where the interaction of the two water masses with different characteristics occurs, are of particular scientific interest for this European research infrastructure.

The system installed on the container ship includes the General OceanicsTM GO8050 pCO2 measurement system with a LICOR 7000 detector and an equilibrator with spray chamber to promote gas phase equilibrium. It includes sensors for surface water temperature monitoring (Seabird 38) and inside the equilibrator, as well as for seawater salinity monitoring (Seabird 45) and a system for measuring dissolved oxygen content in seawater. The LICOR sensor is calibrated every three hours with four calibration gases in the range 0 to 850 ppm supplied by the CAL center. Every hour, the system performs a measurement of the CO_2 content in atmospheric air, which is used to subsequently estimate the atmosphere-ocean fluxes in the study region (see **Figure 6**).

In October 2021, with the transfer of the ship to dry dock for refurbishment, the measuring equipment had to be uninstalled. This period was used to send the OceanicsTM GO8050 to its manufacturer and proceed to the replacement of most of the internal sensors, piping, connections and sensor recalibration. The process was extended in time, and the equipment was shipped from the USA in July 2022. In September 2022, the equipment was reinstalled on the vessel and began recording data again.

After the first data shipment to carry out step 2 of the certification process started in September 2022, the different measurement steps were modified (three cycles for calibration gases and five for atmospheric) and a data set of 4 months of measurement was sent to the OTC to be evaluated on 4 March 2023. The calibration gases supplied by CAL were included in the measurement equipment on 11 January 2023.

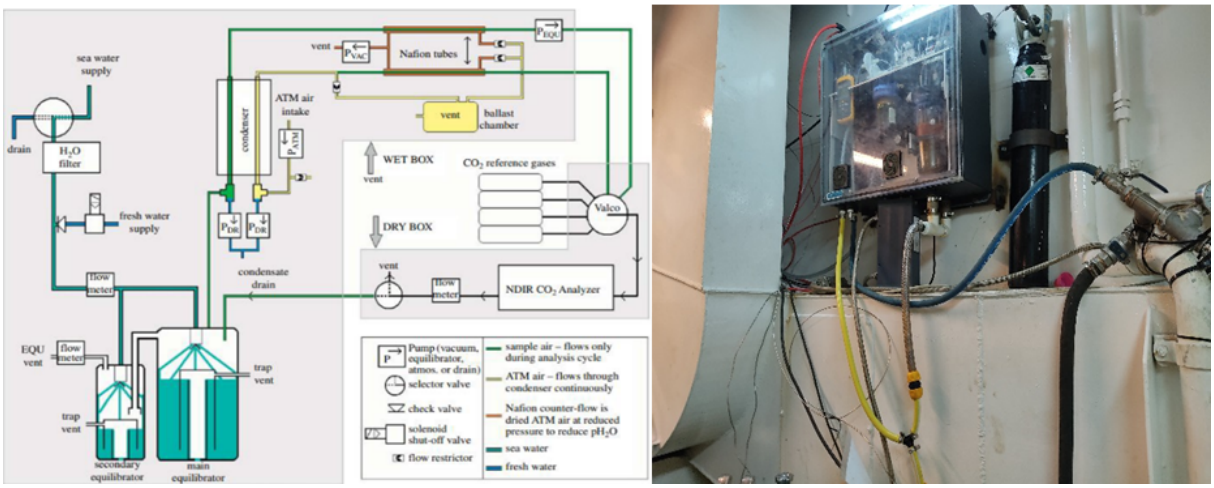

Figure 6. Diagram of the CO_2 measurement system in equilibrium with seawater and General Oceanics™ GO8050 pCO_2 installed on the vessel MV JONA SOPHIE. Photograph of the instrumentation: wet box including balancer, air cleaning and drying systems, as well as temperature and salinity sensors, dissolved oxygen and seawater flow control valves.

The CanOA-SOOP line (VOS_1) is, at the same time, part of a wider network for ocean acidification observation in the Canary Islands region, the Ocean Carbon Dioxide Observation Network in the Canary Islands (CARBOCAN) financed by the Canary Islands Government, as shown in **Figure 7**. This regional network includes a second VOS line (VOS_2) between the islands of Tenerife (Los Cristianos) and La Palma with a stop in La Gomera (Benchijigua Express ship, Fred Olsen Express Company) and a system of three surface oceanographic buoys with sensors to measure pCO2 and acidification. The buoys are located in Gando Bay, Gran Canaria (B_1), south of the islands of El Hierro (B_2) and La Graciosa (B_3).

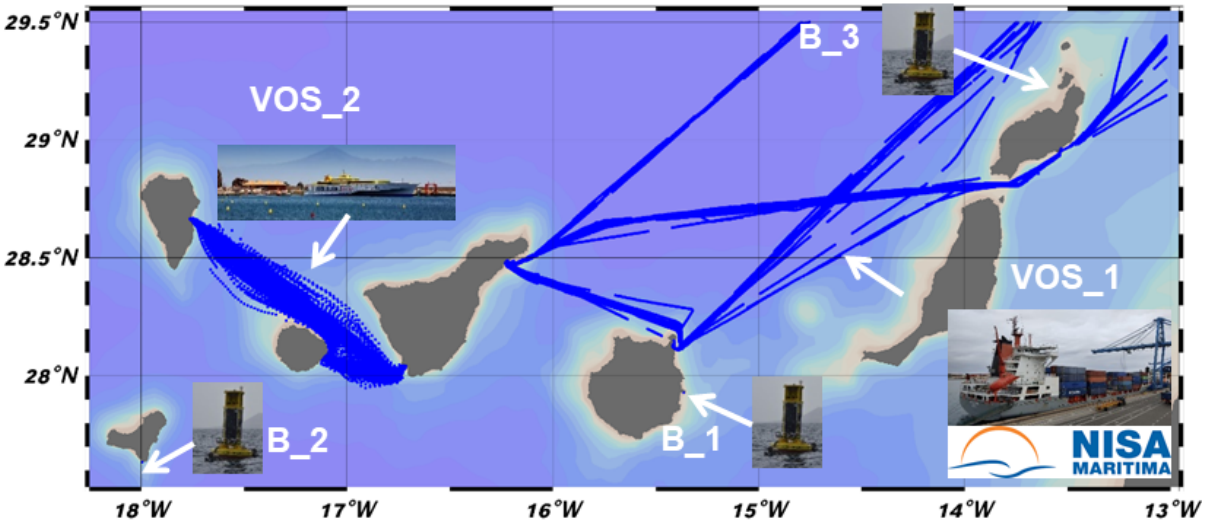

Figure 7. Maritime routes of the ships where the sampling stations (VOS_1 and VOS_2) and the location of the fixed buoys (B_1, B_2 and B_3) of the CARBOCAN network are implemented.

More information about CanOA-SOOP oceanic station can be found at: https://icos-spain.aemet.es/CanOA.

3.3 El Arenosillo – INTA

The Atmospheric Sounding Station (ESAt) of El Arenosillo (37.1 ºN, 6.7 ºW, 42 m.a.s.l.) belongs to INTA and is located in the southwest of the Iberian Peninsula, just 700 m from the Atlantic coast, in the area of the Doñana National Pre-Park. This ICOS-ERIC coastal atmospheric station has a 100 m tower (see **Figure 8**), with meteorological sensors located at the 10, 50 and 100 m levels, with continuous measurements since 2016.

Figure 8. El Arenosillo tower where GHG concentrations and meteorological parameters are measured at 10 m, 50 m and 100 m.

The main ESAt building is located approximately 1 km from the coastline and about 450 m from the aforementioned tower (see **Figure 9**). Reactive trace gases such as ozone (O_3) since 2000, nitrogen oxides (NO_x) since 2008, sulphur dioxide (SO_2) since 2015 and volatile organic compounds (benzene, toluene and xylene) since 2019 are monitored at ESAt [5–7].

Figure 9. Location of the 100 m tower and the El Arenosillo Atmospheric Sounding Station.

In addition, instrumentation is available for the measurement of different aerosol parameters (aerosol optical thickness, sub- and super-micro particle size distribution, total particle concentration, and scattering, backscattering and absorption properties), solar radiation (global, ultraviolet, direct, diffuse, etc.) and total ozone column [9,10]. Furthermore, the main surface meteorological variables have been monitored for more than three decades and a system is available for carrying out meteorological soundings and ozonesondes, and atmospheric soundings are carried out within the framework of specific campaigns.

Figura 10. Instrumentation (sampling system, pumps, filters, drying system, calibration pumps and Picarro G2401) inside the laboratory located at the base of the 100 m tower.

In September 2019, a Picarro G2401 instrument was installed at ESAt, along with the rest of the trace gas instrumentation, starting the program of surface measurements of CO_2, CH_4 and CO. After more than two years measuring on the surface, at the end of November 2021, it was moved to a laboratory located at the base of the 100 m tower. Previously, a sampling system had been installed, consisting of sampling lines located at 10, 50 and 100 m height; and inside the laboratory, the rest of the necessary elements such as pumps, calibration tanks, valves, drying system, etc. were installed (**Figura 10**). The system design and implementation was performed following the ICOS-ERIC specifications for GHG measurement in elevated towers [5]. The pump system and the rotary valve allow the entry of air from each sampling line into the Picarro, measuring the concentration of these three gases at each of the three heights for 10 minutes.

At the beginning of 2022, the El Arenosillo station started the certification process and on August 11 2022, it passed the first step of this process. After more than a year of continuous measurements on the tower (December 2021-December 2022), in the first half of January 2023, the instrument was sent to the ATC (France) to pass the instrument certification process, which is expected to be completed during 2023. Since the beginning of 2023, the first year of measurements on the tower is in the process of analysis and later publication [11].

El Arenosillo participates in other observation and research programs such as the Andalusian air quality network and the international networks WMO-GAW, AERONET, MPLNET, NOAA/FAN, ACTRIS, WOUDC and EUBREWNET. In ICOS-Spain, El Arenosillo provides measurements of great scientific interest to study the chemical composition of this transition region, where the exchange and transport of air masses from the Atlantic Ocean, the Mediterranean Sea or North Africa to the interior of the Iberian Peninsula and Europe takes place. In addition, its location next to the Doñana National Park, considered one of the largest biosphere reserves and one of the most important wetlands in Europe, will help to monitor the effects of climate change on the ecosystems of this potentially sensitive region.

More information about El Arenosillo atmospheric station can be found at: https://icos-spain.aemet.es/Arenosillo.

3.4 Majadas de Tiétar – CEAM

The associated ecosystem station of Majadas de Tiétar has been measuring H_2O and CO_2 fluxes continuously since 2003. It is located in the province of Cáceres (Extremadura), in a holm oak (*Quercus Ilex*) forest, a typical example of agrosilvopastoral system, which has a great economic and social importance in the Iberian Peninsula, both for its surface extension and for the function of supporting the rural population in its villages. The European Union recognized in 1992 (by means of the Directive 92/43/CEE of the Council), the singularity of this impressive vegetal formation, being catalogued as natural habitat. It extends over more than 3 and a half million hectares and is concentrated mainly in the southwest of the Iberian Peninsula.

The environment where the experimental station is located is a typical holm oak forest, with an open forest of holm oaks and a lower substrate of grassland composed of herbaceous plants with high biodiversity. The holm oaks are approximately 100 years old, with a 20% cover fraction and a density of 22 holm oaks per hectare. The holm oak is one of the species with the greatest dispersion in southern Europe and, without doubt, the most representative of the entire Iberian Peninsula.

The Majadas de Tiétar experimental station has an exceptional and unique infrastructure in the Iberian Peninsula. It started operating in 2003 with the installation by the CEAM Foundation of a 15 m "Eddy Covariance" flux tower in the framework of the European project CarboEurope-IP (see **Figure 11**) and contributed to several European projects (MIND, CarboExtreme, GHG-Europe, NitroEurope) and national projects (Carbored-II, CARBOREDES, BALANGEIS, BIOSPEC, FLUXPEC, GEISpain, ELEMENTA) related to the study of the carbon cycle and other biogeochemical cycles, and some specifically dedicated to improve systematic observation methods, such as the IMECC project and the ICOS-PP project, where it served as instrumental test site and ICOS-ERIC demonstration station.

Over the years, the experimental station implemented a complex long-term systematic observation program, based on CO_2, H_2O and energy flow measurement systems using the “eddy covariance” technique, complemented by hundreds of sensors of various types for monitoring meteorological variables (atmospheric pressure, air temperature and humidity, precipitation, wind speed, global, diffuse, shortwave and longwave, incident and reflected radiation), and environmental variables (soil temperature and humidity profiles, soil heat fluxes, tree temperature).

In addition to this systematic observation program, since 2014 the station has served as a research platform for several groups (MPI-BGC, CSIC-CCHS, University of Extremadura, INIA) in the framework of a research project "Monitoring Carbon and Water fluxes in Dehesa Ecosystems" coordinated by the Max Planck Institute for Biogeochemistry (MPI-BGC). Several complementary observation systems have been implemented, including 5 additional eddy covariance systems, atmospheric multispectral photometer, 3 lysimeter stations, a wireless network of sapflows sensors and automatic dendrometers, mini rhizotrons for monitoring vegetation root dynamics, systems for measuring soil CO_2 fluxes, radiometric towers with multispectral and hyperspectral sensors (Figure 11). In parallel, experimental campaigns have been carried out to monitor multiple biophysical and ecophysiological variables, and several remote sensing campaigns with UAV and hyperspectral and multispectral airborne (AHS and CASI sensors, INTA; HYPLANT, TASI and APEX sensors, ESA-FLEXSENSE).

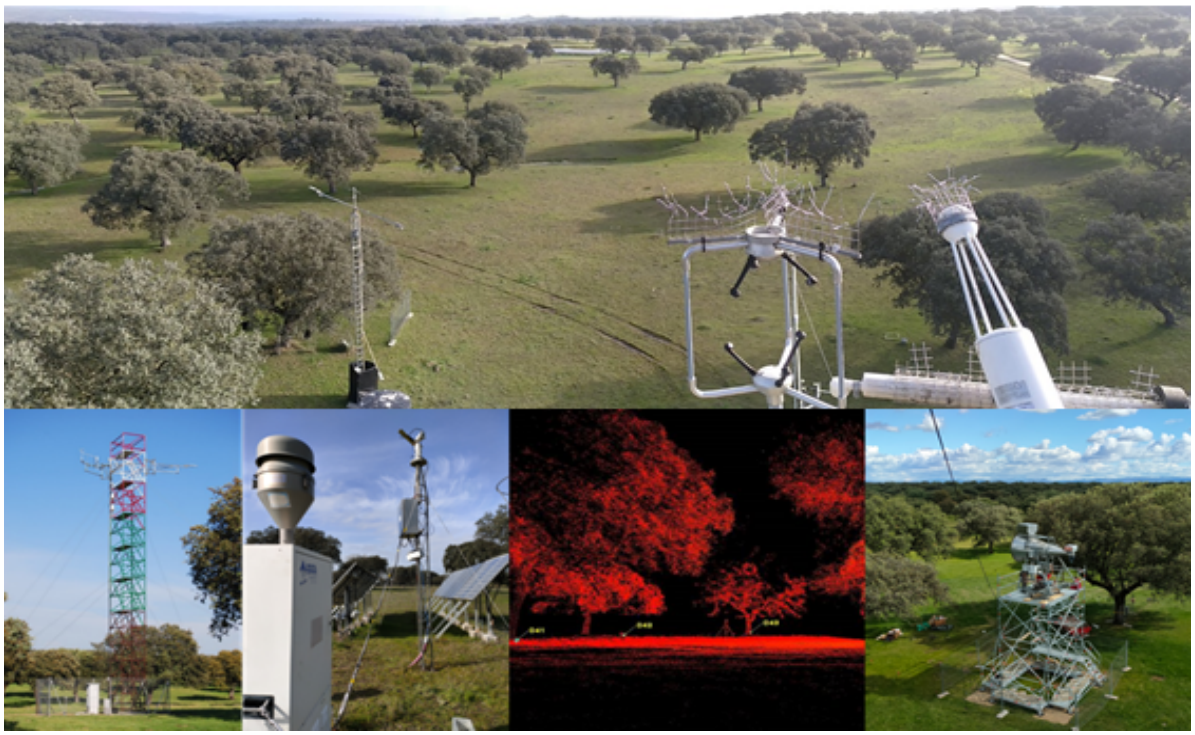

Figure 11. Photograph taken from the main flux tower. Flux tower of the nitrogen fertilized plot; sun photometer and particle collector; model obtained with LIDAR data, ELBARA system.

In addition, the Majadas de Tiétar station belongs to the Pan-European system for the Intensive and Continuous Monitoring of Forest Ecosystems (ICP-Forest, Level II Network), and has contributed since 2015 to the Phenocam global observation network dedicated to monitoring the phenology of vegetation in terrestrial ecosystems. Data from the station are integrated in international databases ("European Flux Database" at a European level and FLUXNET at a global level) to promote and facilitate their use by multiple research groups in Spain and internationally.

The data provided by the station are of particular relevance for the estimation of certain current ecosystem services, such as carbon sequestration, water use or hydrological flow regulation. Water availability being the main factor limiting the productivity of Mediterranean ecosystems, the interactions between the carbon cycle and the water cycle are crucial to study the sensitivity and vulnerability of the carbon balance of these ecosystems, and therefore of their productivity, to climate change. Their records have also been used for the calibration and validation of remote sensing products, as well as for the adjustment and validation of several models (global climate models, Soil-Vegetation-Atmosphere exchange models, complex biogeochemical and ecological models). The relevance of the studies carried out on the basis of the experimental data from the Majadas de Tiétar station is reflected in the resulting significant scientific production, with more than one hundred scientific articles published in international SCI journals, of which CEAM Foundation researchers have participated in about 50.

Majadas de Tiétar presented its application to join the ICOS-ERIC network of stations as an associated ecosystem station in 2022. This application was formally approved during the ICOS-ERIC General Assembly held in Madrid on 22 and 23 November 2022. It will be the first systematic observation station of CO_2 and H_2O fluxes at a national level to be integrated into the ICOS-ERIC ecosystem station network.

More information about Majadas de Tiétar associated ecosystem station can be found at: https://icos-spain.aemet.es/Majadas.

3.5 ESTOC-PLOCAN, IEO-CSIC and ULPGC

The Canary Islands Ocean Time Series Station (ESTOC), managed by PLOCAN, is an instrumented buoy located 60 nautical miles north of Gran Canaria. Since its inauguration in 1994, it generates and records meteorological and oceanographic time series representative of the central-eastern North Atlantic [12-14]. Its measurements have contributed to the study of climate change and its impact on the physical-chemical trends of the Atlantic Ocean [15]. Unlike the rest of the ICOS-Spain stations, this one will be co-managed by three independent institutions (PLOCAN, IEO-CSIC and ULPGC). PLOCAN is responsible for the design and maintenance of the oceanographic buoy with pCO_2 measurement with the advice of the QUIMA-ULPGC group and the physics group IEO-Canarias, the latter being also responsible for the provision of ship time to perform the monitoring of the water column profile and the mooring of the oceanographic buoy (at least twice a year).

ESTOC, located at 29º10'N, 15º30'W in the Northeast Atlantic, started as a station with monthly visits and discrete seawater sampling at 24 different depths over the 3650 m water column. In 2016, PLOCAN installed an oceanographic buoy at the ESTOC position that included in the buoy body, in addition to pCO2 and surface pH sensors, temperature and salinity sensors, fluorescence for the measurement of chlorophyll and dissolved oxygen content. The water column also included several temperature and salinity sensors at different depths, as well as a nutrient measurement system at 100 m depth. A new oceanographic buoy has been designed by PLOCAN, which includes a PROOceanus sensor with equilibrium membrane and NDIR detector, spectrophotometric pH sensor, as well as physical sensors. With each visit to the station discrete water samples will be taken to measure alkalinity and total dissolved inorganic carbon content by the QUIMA group for sensor recalibration (see **Figure 12**).

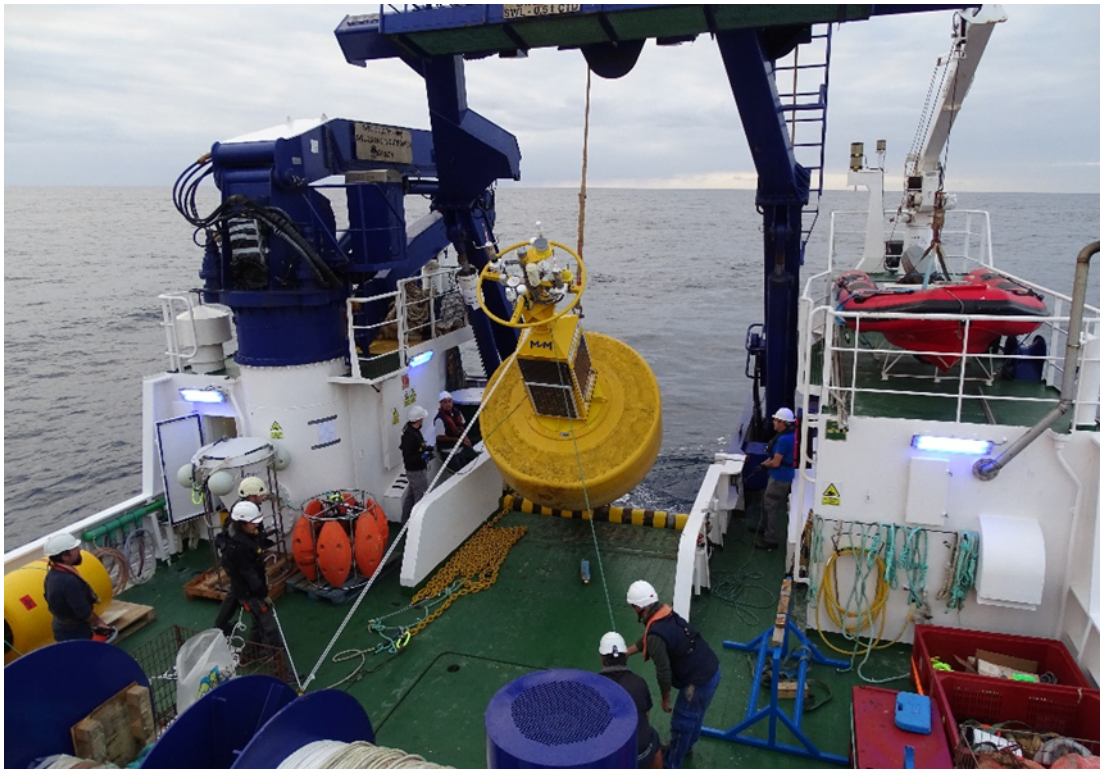

Figure 12. ESTOC maintenance tasks at sea require an adapted vessel for the removal of this infrastructure.

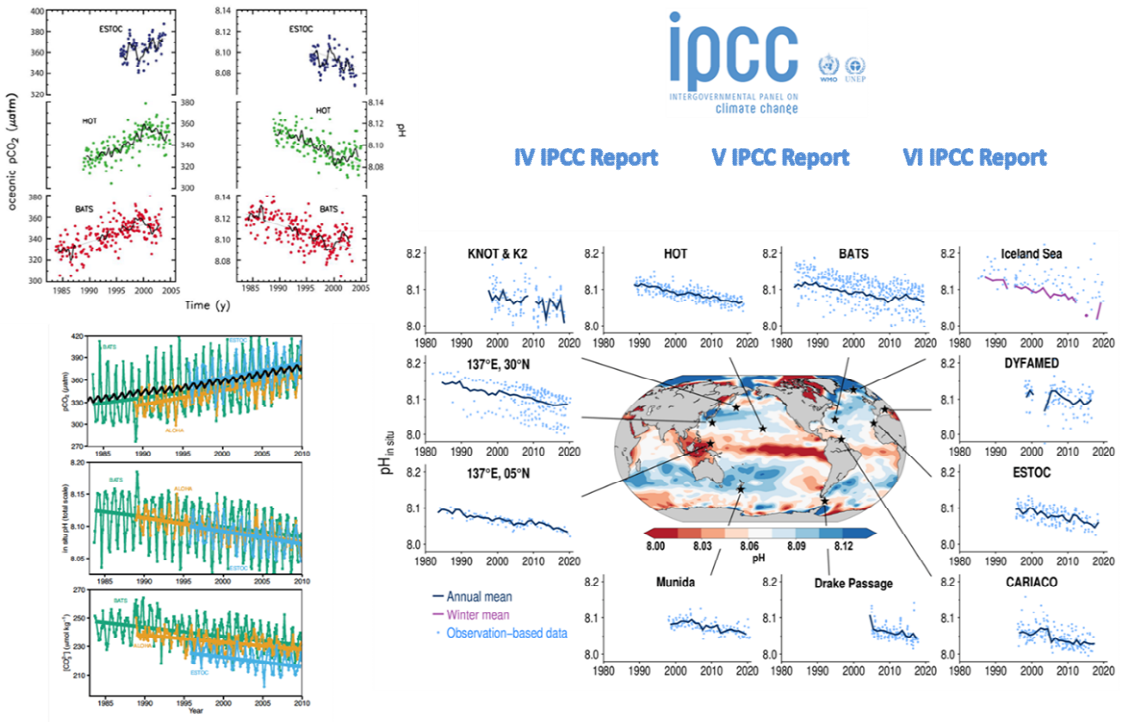

Figure 13. Data from ocean stations with series of CO_2 measurements collected in the different IPCC reports, IV, V and VI, showing ocean acidification and dissolved CO_2 content trends.

The ESTOC records have been used to study the acidification process of the subtropical Atlantic Ocean (see **Figure 13**). Together with data from other oceanic time series at the global level, the records of the evolution of both the CO_2 content of surface waters and their pH have been part of several scientific publications, which are considered as references for the spatio-temporal evolution of current trends. The ESTOC station, together with the American stations in Bermuda, BATS, and in Hawaii, HOT, have formed the basis for showing acidification trends in the IPCC reports, numbers IV, V and VI (https://www.ipcc.ch/about/).

More information about the ESTOC oceanic station can be found at: https://icos-spain.aemet.es/ESTOC.

4 Scientific-Technical Projects

4.1 ICOS-ERIC Observation Data Collection

4.1.1 European CO_2 y CH_4 Obspack

Atmospheric observational data collections (ObsPack) are an effective tool to stimulate and support carbon cycle modelling studies. The European version of GlobalView Obspack consists of a compilation of CO_2 and CH_4 time series data from European atmospheric stations, which have completed or are in the process of certification as ICOS-ERIC stations, and is complemented by some additional stations that do not belong to the research infrastructure. The data quality has been controlled by the principal investigator of each station or carried out by the ATC [16].

The CO_2 and CH_4 data collected span from 1972 and 1984, respectively, to the beginning of 2023. In this case, the complete series of records of these components at the Izaña Observatory (1984-2022) is part of this data collection.

4.1.2 Warm Winter 2020

This compilation of "Eddy Covariance" flux observation data from 73 ecosystem stations, many of them integrated within the ICOS-ERIC network, covers the period 1989-2020. The data are in the standard format used for ICOS-ERIC L2 ecosystem products, also used by other regional networks such as AmeriFlux. The processing was performed according to ONEFlux, being compatible and integrable with the FLUXNET2015 version [17]. The observations made at the Majadas ecosystem station (2014-2020) are part of this compilation.

4.2 Research Projects in the context of ICOS-ERIC.

Although the main objective of ICOS-ERIC is to establish a network of stations to monitor GHG and carbon fluxes, it also develops and participates in numerous research projects with European funding. The projects with participation of Spanish institutions are described below.

4.2.1 ICOS Cities – Barcelona

The ICOS Cities HORIZON 2020 project conducts observations on GHG emissions in densely populated urban areas because they contribute significantly to total anthropogenic GHG emissions. ICOS Cities concentrates and evaluates different approaches to record GHG emissions in these areas, aiming to develop useful tools and services for cities to support their local climate action plans.

An international scientific panel selected the cities of Paris, Munich and Zurich as pilot cities for this project, based on their climate action plans and their commitment to developing efficient and effective climate change mitigation and adaptation policies, as well as their contribution to improving existing GHG emissions inventories. However, in a second stage, this project has been expanded to 12 other European cities: Antwerp, Barcelona, Basel, Brno, Athens, Copenhagen, Heidelberg, Helsinki, Krakow, Rome, Rotterdam and Porto, which offer a greater diversity of profiles in terms of geography, population and economic activity, thus allowing to assess the feasibility of different approaches to modelling emissions in urban environments.

Specifically, for the metropolitan area of Barcelona (**Figure 14**), four continuous GHG measurement stations have been installed in four different areas of the urban conurbation of Barcelona. The stations are ICTA-UAB (41.50ºN, 2.11ºE, 123 m asl), IDAEA (41.39ºN, 2.12ºE, 80 m asl), Fabra Observatory (41.42ºN, 2.12ºE, 410 m asl), and Institute of Marine Sciences, ICM (41.39ºN, 2.20ºE, 8 m asl). These stations are intended to monitor concentrations in different characteristic areas of the urban conurbation, study the meteorological influence on concentrations and estimate the city's GHG emissions using chemical transport models.

Figure 14. Location of the continuous measurement stations. Installation of the equipment at the IDAEA station.

The stations were commissioned between January and November 2022 and all are equipped with a Picarro G2301 analyzer for continuous in-situ CO_2 and CH_4 measurements, as well as NOAA scale calibration tanks and multivalves for automatic calibration.

The URBAG group (https://urbag.eu/) of ICTA-UAB is responsible for the measurements and their quality control. We are currently working to make the updated data from the stations, already calibrated, fully accessible in open and public use. In the meantime, the characteristics of each station, the typical meteorological variables of each location, and a graph of the previous observation day can be consulted on the web site https://urbag.eu/ghg/.

4.2.2 KADI project.

The African continent is a minor contributor to total global carbon and GHG emissions. However, the African contribution to the global carbon balance is significant and is increasing due to land use change and urbanization [15]. Moreover, Africa is one of the regions of the world most vulnerable to the impacts of climate change.

The KADI project (Knowledge and Climate Services from an African Observation and Data Research Infrastructure) aims to design a pan-African climate observation system, using climate services as a guiding principle. This involves establishing an Africa-wide climate observation infrastructure to collect relevant data and provide climate services to users, as well as expanding the current information network as a basis for successful and sustainable cooperation. It aims ultimately to develop a sound strategy for the implementation and future use of the climate observing system in Africa, in close connection with potential stakeholders and users. This involves involving relevant stakeholders, such as observing systems and user communities, research organizations, governments, financial institutions and local communities, to ensure that the system is used effectively and sustainably [15].

This project, led by ICOS-ERIC, is being developed for the period 2022-2025 and involves the following institutions: University of the Witwatersrand Johannesburg, National Research Foundation (South Africa), University of Pretoria (South Africa), Helsingin Yliopisto (Finland), Centre National de la Recherche Scientifique (France), Universite Felix Houphouet Boigny (Ivory Coast), Kenya Meteorological Department (Kenya), Turun Yliopisto (Finland), Trinity College Dublin (Ireland), Norwegian Research Centre (Norway), Hellenic Centre for Marine Research (Greece), Eidgenoessisches Departement des Innern (Switzerland) y AEMET.

4.2.3 GEORGE project.

The GEORGE (Next Generation Multiplatform Ocean Observing Technologies for Research Infrastructures) project aims to provide improved technologies to enhance the data value of the ocean carbonate observing system. The marine part of the European Environmental Domain Research Infrastructures (ENVRI) has successfully implemented a world leading system of standardized ocean observations over the last 15 years, building on more than a century of experience of the marine institutes involved. This community has joined forces in the GEORGE project proposal to take them to the next technological level: long-term autonomous systematic observations.

The GEORGE project brings together 28 leading partners from academia and industry, including three research infrastructures: EMSO-ERIC, Euro-Argo-ERIC and ICOS-ERIC. Together, these three ERICs cover the full extent of European marine waters, from the coasts to the open ocean and from the seafloor to the interior and the ocean surface. The project is coordinated by ICOS-ERIC and EMSO-ERIC.

The main objective of EMSO-ERIC is to contribute, through sustained long-term observations, to the understanding of global environmental processes and to stimulate the development of new observational technologies. Euro-Argo-ERIC operates about a quarter of the international Argo program of profiling floats, which primarily measure ocean temperature and salinity from the ocean surface to 2000 m depth. ICOS-ERIC measures CO_2 levels and fluxes between the ocean surface and the atmosphere from fixed surface ocean observing platforms and ships of opportunity (SOOPs). In addition, this proposal has been connected to communities within the ENVRI framework that are developing more systematic observations of the OCEAN, specifically for coastal observations (JERICO) and glider technology (GROOM).

The primary goal of GEORGE is to provide sustained carbon observations on the spatiotemporal scales needed to constrain ocean CO_2 absorption, carbon storage and export rates, which remains a major challenge primarily due to the lack of autonomous technology for carbonate system observations and has been recognized as a top priority by the Global Ocean Observing System (GOOS). The basic philosophy behind this project is the value chain connecting ocean biogeochemical observations with science, assessment and societal impact. GEORGE will contribute to the implementation of the European Ocean Observing System (EOOS) strategy, towards an integrated European observing system, and will work closely with the International Ocean Carbon Coordination Project (IOCCP).

The QUIMA group of the ULPGC is one of the working groups of the GEORGE project. The ULPGC participants and the Canarian company OCEOMIC will advance the TRL development of autonomous samplers for SOOP and optimize them for carbonate system measurements by allowing sample preservation through bioside injection and adaptations to allow gas-tight storage and temperature/salinity monitoring at the sample inlet.

5 Dissemination of ICOS-Spain Activities

5.1 Web Page and Social Network

The ICOS-Spain website (https://icos-spain.aemet.es/) plays a fundamental role in the dissemination of the research carried out by the stations of the network (see **Figure 15**). This web portal contains a detailed description of each station and will serve to publish news on the milestones reached by each site of the national node. It also includes a list of scientific publications, congress participations and educational activities carried out by the researchers and members of each station.

In addition, each time a site completes its certification process, its observations will be shared and disseminated through this portal. In this way, the scientific community and the general public will have access to the data and results obtained, thus promoting transparency and accessibility.

In addition, ICOS-Spain has a Twitter account (@ICOS_Spain), as a complement to the dissemination efforts of the network at the national level. Through this platform, news and events related to GHG monitoring, climate change and the activities of ICOS-ERIC and ICOS-Spain will be shared.

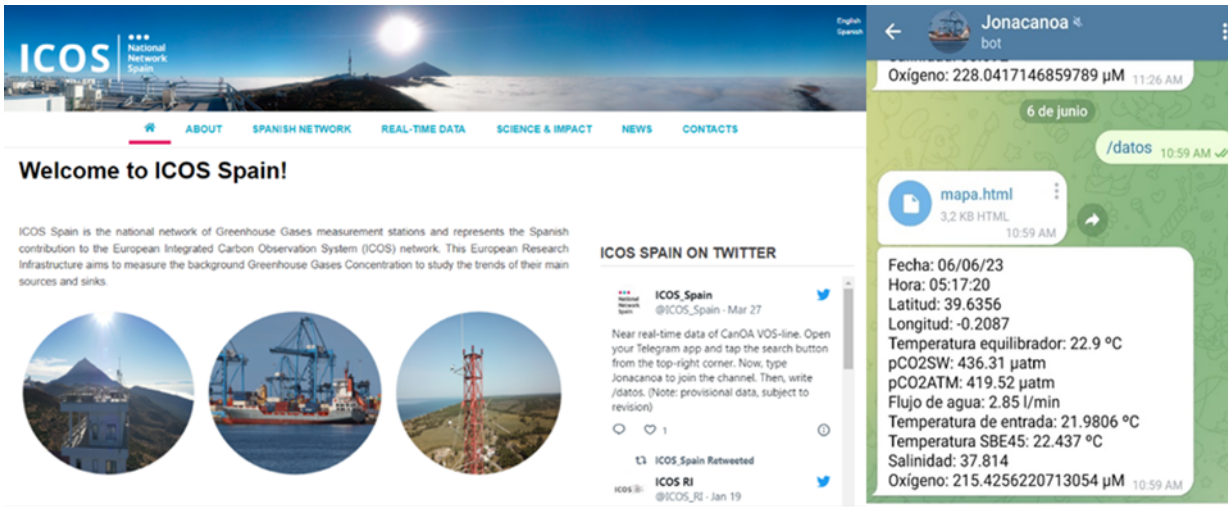

Figure 15. Home page of the ICOS-Spain web where the content of the Twitter @ICOS_Spain is incorporated. Telegram channel with the coordinates and measurements made by the oceanic station CanOA-SOOP.

Furthermore, the QUIMA research group, responsible for the CanOA-SOOP ocean station, has developed an account on Telegram that allows users to obtain real-time information on the values of the main ocean variables measured by that station. By joining the Jonacanoa bot and entering the code "/data", users can access the latest data obtained by the line when near the coast, and receive updates via text messages (SMS).

These data dissemination and access tools strengthen communication between the scientific community and the general public, thus facilitating greater understanding and awareness of the importance of GHG monitoring and climate change mitigation.

5.2 Promotion of research at ICOS-Spain Atmospheric Stations.

At the end of 2022, the Izaña Observatory and the El Arenosillo Atmospheric Sounding Station were visited by journalist Charlotta Henry and photographer Pekka Pelkonen, members of the ICOS-ERIC communications team, with the aim of collecting graphic information from both sites, as well as the impressions of their researchers.

Pedro Pablo Rivas, head of the GHG and carbon cycle program and principal investigator, Dr Omaira García, head of the Fourier Transform Infrared Spectrometry (FTIR) program and the technician Dr Sergio León were interviewed by Charlotta Henry to explain the importance of incorporating the Izaña Observatory to this European infrastructure. Regarding the El Arenosillo Atmospheric Sounding Station, José Antonio Adame, principal investigator, and Rubén Padilla, PhD student, explained the importance of carrying out GHG measurements in the environment of the Doñana National Park and close to the Strait of Gibraltar.

Both reports can be found on the main website of ICOS-ERIC:

- Izaña Observatory: https://www.icos-cp.eu/exploreicos-station-above-clouds

- El Arenosillo: https://www.icos-cp.eu/exploreicos-only-icos-tall-tower-iberian-peninsula

5.3 Publications and Conferences

ICOS-ERIC Observation Data Collection:

- Warm winter 2020 Team, & ICOS Ecosystem Thematic Centre. (2022). Warm Winter 2020 ecosystem eddy covariance flux product for 73 stations in FLUXNET-Archive format—release 2022-1 (Version 1.0). ICOS Carbon Portal. https://doi.org/10.18160/2G60-ZHAK

- ICOS RI, Bergamaschi, P., Colomb, A., De Mazière, M., Emmenegger, L., Kubistin, D., Lehner, I., Lehtinen, K., Lund Myhre, C., Marek, M., Platt, S.M., Plaß-Dülmer, C., Schmidt, M., Apadula, F., Arnold, S., Blanc, P.-E., Brunner, D., Chen, H., Chmura, L., Conil, S., Couret, C., Cristofanelli, P., Delmotte, M., Forster, G., Frumau, A., Gheusi, F., Hammer, S., Haszpra, L., Heliasz, M., Henne, S., Hoheisel, A., Kneuer, T., Laurila, T., Leskinen, A., Leuenberger, M., Levin, I., Lindauer, M., Lopez, M., Lunder, C., Mammarella, I., Manca, G., Manning, A., Marklund, P., Martin, D., Meinhardt, F., Müller-Williams, J., Necki, J., O'Doherty, S., Ottosson-Löfvenius, M., Philippon, C., Piacentino, S., Pitt, J., Ramonet, M., Rivas-Soriano, P., Scheeren, B., Schumacher, M., Sha, M.K., Spain, G., Steinbacher, M., Sørensen, L.L., Vermeulen, A., Vítková, G., Xueref-Remy, I., di Sarra, A., Conen, F., Kazan, V., Roulet, Y.-A., Biermann, T., Heltai, D., Hensen, A., Hermansen, O., Komínková, K., Laurent, O., Levula, J., Pichon, J.-M., Smith, P., Stanley, K., Trisolino, P., ICOS Carbon Portal, ICOS Atmosphere Thematic Centre, ICOS Flask And Calibration Laboratory, ICOS Central Radiocarbon Laboratory, 2023. European Obspack compilation of atmospheric carbon dioxide data from ICOS and non-ICOS European stations for the period 1972-2022; obspack_co2_466_GLOBALVIEWplus_v8.0_2023-03-08. https://doi.org/10.18160/CEC4-CAGK

- C., Ramonet, M., Apadula, F., Arnold, S., Blanc, P.-E., Brunner, D., Chen, H., Chmura, L., Conil, S., Couret, C., Cristofanelli, P., Delmotte, M., Forster, G., Frumau, A., Gheusi, F., Hammer, S., Haszpra, L., Hatakka, J., Heliasz, M., Henne, S., Hoheisel, A., Kneuer, T., Laurila, T., Leskinen, A., Leuenberger, M., Levin, I., Lindauer, M., Lunder, C., Mammarella, I., Manca, G., Manning, A., Martin, D., Meinhardt, F., Mölder, M., Müller-Williams, J., Necki, J., Ottosson-Löfvenius, M., Philippon, C., Piacentino, S., Pitt, J., Rivas-Soriano, P., Scheeren, B., Schumacher, M., Sha, M.K., Smith, P., Spain, G., Steinbacher, M., Sørensen, L.L., Vermeulen, A., Vítková, G., Xueref-Remy, I., di Sarra, A., Conen, F., Kazan, V., Roulet, Y.-A., Biermann, T., Heltai, D., Hensen, A., Hermansen, O., Komínková, K., Laurent, O., Levula, J., Lopez, M., Marklund, P., Pichon, J.-M., Schmidt, M., Stanley, K., Trisolino, P., ICOS Carbon Portal, ICOS Atmosphere Thematic Centre, ICOS Flask And Calibration Laboratory, ICOS Central Radiocarbon Laboratory, 2023. European Obspack compilation of atmospheric methane data from ICOS and non-ICOS European stations for the period 1984-2023; obspack_ch4_466_GLOBALVIEWplus_v8.0_2023-03-30. https://doi.org/10.18160/JM91-JXHK

List of independent peer-reviewed publications:

2021

- Curbelo-Hernández, D., González-Dávila, M., González-Santana, D., Santana-Casiano, J.M., 2021. CO_2 fluxes in the Northeast Atlantic Ocean based on measurements from a surface ocean observation platform. Science of the Total Environment, 775, 145804. https://doi.org/10.1016/j.scitotenv.2021.145804

- Curbelo-Hernández, D., Santana-Casiano, J.M., González-González, A. González-Dávila, M. 2021. Air-sea CO_2 exchange in the Strait of Gibraltar. Front. Mar. Sci. Marine Biogeochemistry, Volume 8 – 2021. https://doi.org/10.3389/fmars.2021.745304

2022

- Adame, J.A., Padilla, R., Gutierrez-Alvarez, I., Bogeat, J.A., Lopez, A., Yela, M. Greenhouse gases in the tall tower of El Arenosillo-ICOS station in the Southwestern Europe: first-year of measurements. Atmospheric Research (in process).

Conferences:

2021

- David Curbelo-Hernández, Melchor González-Dávila, Aridane G. González, David González-Santana, J. Magdalena Santana-Casiano. Seasonal and spatial variability of the CO2 system parameters in the Northeast Atlantic based on measurements from a surface ocean observation platform. EGU General Assembly 2021. Vienna, Austria. 19-30 April 2021.

2022

- Omaira E. García Rodríguez, Emilio Cuevas Agulló, Pedro Pablo Rivas Soriano, Sergio Fabián León Luis. Inter-comparison of CO_2, CO and CH_4 mixing ratios obtained by in-situ and remote measurements techniques in the Izaña Atmospheric Observatory. ICOS Conference 13-15 September 2022.

- José Antonio Adame, Ruben Padilla, Jose A. Bogeat, Margarita Yela. Sampling system and measurements of CO_2, CH_4 and CO in the tall tower of El Arenosillo observatory (Southwestern Europe). ICOS Conference 13-15 September 2022.

- Rubén Padilla, José Antonio Adame, Juan Pedro Bolívar, Margarita Yela. Carbon monoxide measurements at El Arenosillo Observatory. ICOS Conference 13-15 September 2022.

- Roger Curcoll, Claudia Grossi, Juan Pedro Bolivar, Isidoro Gutierrez-Alvarez, Jose Adame, Josep Anton Morguí, Arturo Vargas. Atmospheric Radon Monitor (ARMON): Overview of its applications in Spain and presentation of the new user-friendly monitor. ICOS Conference 13-15 September 2022.

- Melchor González-Dávila, David Curbelo-Hernández, David González-Santana, Adrián Castro-Álamo, J. Magdalena Santana-Casiano, Aridane G. González. High spatio-temporal resolution evaluation of oceanic CO_2 variability based on underway data collected by a VOS line within the CARBOCAN network in the Canary Islands. ICOS Conference 13-15 September 2022.

- Melchor González Dávila, Magdalena Santana-Casiano, David González-Santana, Aridane González, David Curbelo. 5th International Symposium on the Ocean in a High CO2 World CanOA, Ocean Acidification Network in the Canary Islands Region, oral presentation. 12-16 September 2022.

- David Curbelo Hernández, J.Magdalena Santana-Casiano, Melchor González Dávila, AridaneG. González. XXI Iberian Seminar of Marine Chemistry (SIQUIMAR) Spatio-temporal variability of the air-sea CO2 fluxes in the Strait of Gibraltar based on high-frequency data collected by a VOS). Oral presentation. Las Palmas de Gran Canaria 6-8 July 2022.

- Melchor González-Dávila, J. Magdalena Santana Casiano, Aridane G. González, David Curbelo Hernández, David González-Santana, Adrián Castro-Alamo, David Estupiñan-Santana. Observation network of the carbon dioxide system and ocean acidification in the Canary Islands. Oral Presentation. XXI Iberian Seminar of Marine Chemistry (SIQUIMAR). Las Palmas de Gran Canaria 6-8 July 2022.

- David Curbelo Hernández, Melchor González Dávila, David González Santana, Aridane González González, J. Magdalena Santana-Casiano. The variability of the surface CO_2 system and air-sea exchangein the Northeast Atlantic based on VOS data. VII International Symposium on Marine Sciences 2022. Oral presentation. Las Palmas de Gran Canaria 6-8 July 2022.

- David Curbelo Hernández, J. Magdalena Santana Casiano, Aridane González González, A., David González Santana, Melchor González Dávila. 2022. Variability of the air-sea CO_2 exchange in the Strait of Gibraltar based on measurements from a VOS line. EGU General Assembly 2022. https://doi.org/10.5194/egusphere-egu22-2412

  David Curbelo-Hernandez, J. Magdalena Santana-Casiano, Aridane González, Melchor González-Dávila. Spatio-temporal Variability of the Air-Sea CO_2 Exchange in the Strait of Gibraltar. In AGU Fall Meeting Abstracts (Vol. 2021, pp. GC55K-0540).

List of publications without independent peer review:

- **Informative Note ICOS-Spain Nº1:** Izaña Observatory yet again recorded a historical maximum in the concentration of carbon dioxide (CO_2) in May 2021. Covid-19 has not slowed down the increase of the greenhouse gas in the atmosphere

- **Informative Note ICOS-Spain Nº2:** Synergy between surface and column measurements at Izaña Global Atmospheric Watch station: application to the volcanic eruption on La Palma

- **Informative Note ICOS-Spain Nº3:** Atmospheric CO_2 and CH_4 concentrations measured at Izaña Observatory continue their upward trend

- **Informative Note ICOS-Spain Nº4:** Global Carbon Budget 2022

- **Informative Note ICOS-Spain Nº5:** The Mauna Loa Observatory interrupts its observations due to the volcanic eruption, but the atmospheric CO_2 monitoring at global scale goes on

- **News:** El Arenosillo Atmospheric Station passes the first: stage of the ICOS certification process

5.4 Training and Dissemination Activities in the Educational Sector

- ✓ PhD thesis on CO and CH_4 in the El Arenosillo region.

- ✓ PhD thesis on Observation and analysis of the carbonate system and CO_2 air-sea fluxes in the northeastern Atlantic and western Mediterranean.

- ✓ Master in Oceanography, University of Las Palmas de Gran Canaria: CO_2 and ocean acidification.

- ✓ Visits of high school, undergraduate and Master students, as well as other groups (public representatives and various associations) to the Izaña Atmospheric Observatory.

- ✓ Visits by high school, undergraduate and master's degree students, as well as other groups (public representatives and various associations) to the ESAt El Arenosillo, established in the CEDEA (Centro de Experimentación de El Arenosillo) visit program, eight visits in the second semester of 2022 and six visits in the first semester of 2023.

- ✓ Seminar Advancing in the Master's Degree in Environmental Technology of the University of Huelva and the International University of Andalusia, given in May 2023 by José A. Adame.

- ✓ Lecture on scientific outreach within the Aula Morán program of the Spanish Meteorological Association, given in April 2022 by Omaira García.

6 List of ICOS-Spain Members.

6.1 ICOS-ERIC General Assembly Delegates

- María Vallejo Abascal. Deputy Directorate General for the Internationalisation of Science and Innovation. Secretariat General for Research. Ministry of Science and Innovation (MICIN).
- Dr Emilio Cuevas Agulló. ICOS-Spain Focal Point. Director of the Izaña Atmospheric Research Center (IARC). State Meteorological Agency (AEMET). (Retired in August 2023).
- Dr Carlos Torres García. ICOS-Spain Focal Point. Director of the Izaña Atmospheric Research Center (IARC). State Meteorological Agency (AEMET). (From September 2023).
- Dr Melchor González Dávila. QUIMA Research Group. Institute of Oceanography and Climate Change (IOCAG). University of Las Palmas de Gran Canaria (ULPGC).

6.2 Izaña Atmospheric Station

- Pedro Pablo Rivas-Soriano. Principal Investigator. Head of the GHG and Carbon Cycle Group at the Izaña Atmospheric Research Centre (IARC). State Meteorological Agency (AEMET).
- Dr Sergio Fabián León Luis. ICOS-Spain Technician. Tragsatec.

6.3 El Arenosillo Atmospheric Station

- Dr José Antonio Adame. Principal Investigator. Instituto Nacional Técnica Aeroespacial (INTA).
- Dr Margarita Yela González. Researcher Head of the Atmospheric Research and Instrumentation Area. National Institute for Aerospace Technology (INTA).

6.4 CanOA SOOP Oceanic station

- Dr Melchor González Dávila. Principal Investigator. QUIMA Research Group. Institute of Oceanography and Climate Change (IOCAG). University of Las Palmas de Gran Canaria (ULPGC).
- Dr Aridane González González. Researcher. QUIMA Research Group. Institute of Oceanography and Climate Change (IOCAG). University of Las Palmas de Gran Canaria (ULPGC).

6.5 ESTOC Oceanic station

- Dr Eric Delory. Principal Investigator. Oceanic Platform of the Canary Islands (PLOCAN).
- Dr Pedro Vélez Belchí. Researcher. Oceanographic Centre of the Canary Islands, Spanish Institute of Oceanography-National Council for Scientific Research (IEO-CSIC).
- Dr Melchor González Dávila. Researcher. QUIMA Research Group. Institute of Oceanography and Climate Change (IOCAG). University of Las Palmas de Gran Canaria (ULPGC).

6.6 Majadas de Tiétar Associated Station Ecosystems.

- Dr Arnaud Carrara. Principal Investigator. Mediterranean Centre for Environmental Studies (CEAM).

6.7 ICOS Cities Project.

- Dr Gara Villalba Méndez. Principal Investigator. Institute of Environmental Science and Technology, Autonomous University of Barcelona (ICTA-UAB).
- Dr Roger Curcoll. Researcher. Institute of Environmental Science and Technology, Autonomous University of Barcelona (ICTA-UAB).

6.8 ICOS KADI.

- Dr África Barreto Velasco. Principal Investigator. Izaña Atmospheric Research Centre (IARC). State Meteorological Agency (AEMET).

- Dr Omaira E. García Rodríguez. Researcher. Izaña Atmospheric Research Centre (IARC). State Meteorological Agency (AEMET).

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8 List of Acronyms

ACTRIS - Aerosols, Clouds, and Trace gases research infrastructure

AERONET - AErosol RObotic NETwork

AEMET – State Meteorological Agency

ATC - Atmosphere Thematic Centre

BSRN - Baseline Surface Radiation Network

CAL - Central Analytical Laboratories

CEAM - Mediterranean Centre for Environmental Studies

CMCC - EuroMediterranean Centre on Climate Change

COCCON - Collaborative Carbon Column Observing Network

COP - Conference of the Parties

CRL - Central Radiocarbon Laboratory

E-GVAP - Water Vapour programme

ERIC - European Research Infrastructure Consortium

ESA - European Space Agency

ETC - Ecosystem Thematic Centre

EOOS - European Ocean Observing System

EUBREWNET - European Brewer Network

EURAMET - European Association of National Metrology Institutes

FCL - Flask and Calibration Laboratory

FMI - Finish Meteorological Institute

GAW - Global Atmosphere Watch

GCOS - Global Climate Observing System

GEORGE - Next Generation Multiplatform Ocean Observing Technologies for Research Infrastructures

GLODAP - Global Ocean Data Analysis Project

GOOS - Global Ocean Observing System

IARC – Izaña Atmospheric Research Center

ICOS - Integrated Carbon Observation System

IEO-CSIC - Spanish Institute of Oceanography- Spanish National Research Council

IG3IS – Integrated Global Greenhouse Gas Information System

INRAE - National Research Institute for Agriculture, Food and Environment, France.

INTA - National Institute for Aerospace Technology

IOCCP - International Ocean Carbon Coordination Project

IPCC - Intergovernmental Panel on Climate Change

KADI - Knowledge and Climate Services from an African Observation and Data Research Infrastructure

LSCE - Laboratoire des Sciences du Climat et de l'Environnment

MICIN - Ministry of Science and Innovation

MPLNET - Micropulse Lidar NETwork

NDACC - Network for Detection of Atmospheric Composition Change

NMDB - Neutron Monitor Database

NOC - National Oceanography Centre, United Kingdom

NORCE- Norwegian Research Centre

OTC - Oceanic Thematic Centre

PLOCAN - Oceanic Platform of the Canary Islands

QUIMA - Química Marina

SOCAT - Surface Ocean CO_2 Atlas

TCCON - Total Carbon Column Observing Network

UAB - Autonomous University of Barcelona

UIB - Universidad de Bergen, Noruega

UHEI - Institute of Environmental Physics of the Heidelberg University

ULPGC - Universidad de Las Palmas de Gran Canaria

UNFCCC - United Nations Framework Convention on Climate Change

UNITUS - Universidad de Tuscia, Italy

UOE - Universidad of Exeter, United Kingdom

WMO – World Meteorological Organization

WOUDC - World Ozone and Ultraviolet Data Center