Level 3 velocity products from ICATMAR High-Frequency Radar network

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Version 1.0

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Abstract

This public ICATMAR document describes the processing and characteristics of the total surface velocity product derived from High-Frequency radars provided by the ICATMAR observational system.

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Control of Versions

Date	Changes	Name
23/02/2024	Initial version and authors	LQC, GLT, CGH, JBP, JIF, EGL, JMG, CBH, JRA
04/03/2024	Description of netCDF and geoJSON data formats.	JMG, EGL
10/03/2024	Completing all the remaining sections of the report.	LQC, GLT, CGH, JBP, JIF, EGL, JMG, CBH, JRA

LQC	=	L. Quirós-Collazos	GLT	=	G. Llorach-Tó	CGH	=	C. González-Haro
JBP	=	J. Ballabrera-Poy	JIF	=	J. Isern-Fontanet	EGL	=	E. García-Ladona
JMG	=	J. Martínez González	CB	=	C. Bueno-Herrero	JRA	=	J. Ribera-Altimir

List of Acronyms

AGAUR	*Agència de Gestió d'Ajuts Universitaris i de Recerca*
CETMAR	*Centro Tecnológico del Mar*
CMEMS	*Copernicus Marine Environment Monitoring Service*
CSIC	*Consejo Superior de Investigaciones Científicas*
DGPMS	*Direcció General de Política Marítima i Pesca Sostenible*
DAC	*Departament d'Acció Climàtica, Alimentació i Agenda Rural*
EU	*European Union*
GDOP	*Geometric Dilution of Precision (unit-less coefficient which characterizes the effect that radar station geometry has on the measurement and position determination errors)*
GeoJSON	*Geospatial JavaScript Object Notation*
HF	*High Frequency*
ICATMAR	*Institut Català per a la Governança del Mar*
ICM	*Institut de Ciències del Mar*
INTERREG	*Innovation & Environment Regions of Europe Sharing Solutions*
JSON	*JavaScript Object Notation*
L2	*Level 2 data (corresponding to radial velocity provided by each individual antenna)*
L3	*Level 3 data (corresponding to 2D data of the currents velocity)*
MCINN	*Ministerio de Ciencia e Innovación*
netCDF	*Network Common Data Form*
PIE	*Proyectos Intramurales Especiales*
SMOS	*Surface Moisture and Ocean Salinity*
SOCAT	*Servei d'Oceanografia Operacional de Catalunya*
SOCIB	*Sistema d'Observació i Predicció Costaner de les Illes Balears*
JERICO	*Impact of A Changing Wave Climate on Our Coasts*

1 Introduction

The oceans cover roughly 70% of the Earth's surface, playing a pivotal role as major climate regulators and primary oxygen generators. Catalonia boasts a 692 km coastline (see figure 1), serving as a crucial resource for sustenance, energy, and the foundation for various economic endeavours including transportation, commerce, and tourism.

In light of early climate change warnings, administrations recognize the imperative to institute programs aimed at comprehending ocean dynamics and evolving phenomena. This understanding is paramount for effective management and preservation of marine resources, alongside the development of tools to navigate extreme scenarios. However, achieving these goals hinges upon access to reliable and comprehensive data.

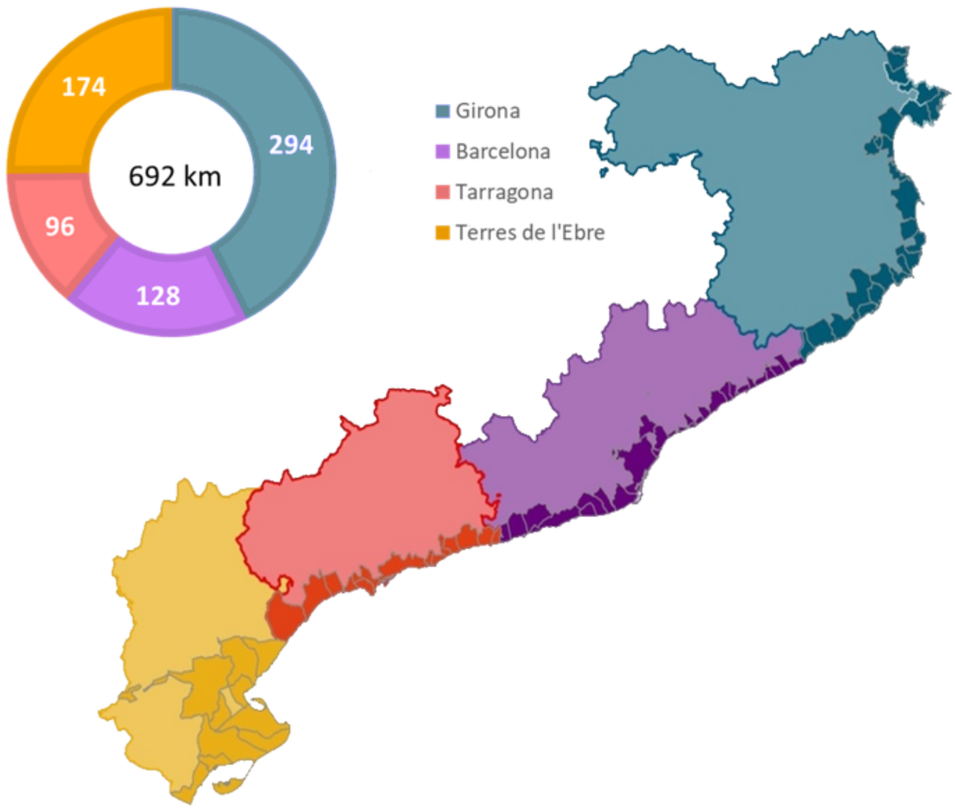

Figure 1: Distribution and length of the Catalan coastline by demarcations

Oceanography experts have long identified data acquisition as a critical challenge. The vast majority of our knowledge on Mediterranean Sea surface current dynamics stems from intricate technical procedures, often protracted and costly due to vessel and equipment availability, as well as the need for skilled personnel. Moreover, data obtained via these methods represent only a fraction of the Mediterranean Sea and lack real-time updates.

Presently, in pursuit of maintaining the measurement of coastal and oceanographic variables to establish an operational oceanography service, the adoption of high-frequency (HF) radar technology is proposed. This observation system, stationed close to the coastline, facilitates near real-time acquisition of surface data on currents intensity, direction, and waves. HF radar technology, renowned globally for its efficiency and low maintenance costs, offers promising prospects.

The escalating prominence of maritime activities along our coastline, and within the broader blue economy sectors, underscores the necessity for a real-time marine environment information gathering and analysis framework to foster efficient and secure development. In alignment with this goal, the Catalonia 2030 Maritime Strategy has delineated strategic avenues within its inaugural multi-year plan for the advancement and fortification of ICATMAR, alongside the design and implementation of a network for monitoring environmental variables in the maritime domain.

The Catalan Institute for Maritime Governance Research (ICATMAR), a collaborative initiative between the DGPMPS of the Department of Climate Action, Food and Rural Agenda (DAC), and the Institute of Marine Sciences of Barcelona (ICM-CSIC), stands committed to furnishing top-tier scientific counsel to the Government of Catalonia in the realm of oceanographic research.

Since its inception, ICATMAR has attracted scientists of esteemed reputation across diverse research disciplines encompassing marine biology and oceanography. These experts have already instituted a comprehensive advisory service catering to both professional and recreational fishing.

In a bid to broaden its scope, the DGPMPS has commenced the procurement and installation process of a HF radar network, slated to envelop the Catalan coastline, thereby fulfilling the Operational Oceanography Service needs of Catalonia.

2 High-Frequency radars

2.1 Principles of measurement

HF radar relies on a phenomenon called Bragg scattering. This occurs when the radio waves it transmits reflect off ocean waves whose wavelength is half that of the radio waves (usually between 1-100 MHz). This creates a distinct peak in the radar's received spectrum, known as the first order peak. When there are no ocean currents, the frequency of this peak experiences a Doppler shift due to the speed of the waves in the direction of the radar's antenna. The received signal spectrum typically shows two peaks, known as Bragg peaks, symmetrically positioned around the radar's transmitting frequency. One peak corresponds to waves moving towards the radar (right peak), while the other represents waves moving away from it (left peak), see Figure 2. The Bragg peaks occur near the frequencies $\pm f_b$

$$f_b = \frac{g}{\pi\lambda} \tag{1}$$

where f_b is the Doppler shift above or bellow the transmit frequency (shown at zero frequency in Figure 2), g is the acceleration of gravity, and λ is the radar wavelength.

If gravity waves travel within a current field, both peaks experience an additional Doppler shift, resulting in an asymmetric spectrum. This shift in the observed Bragg peaks is caused by the velocity of the radial component of the current (denoted as v_r), which can be estimated

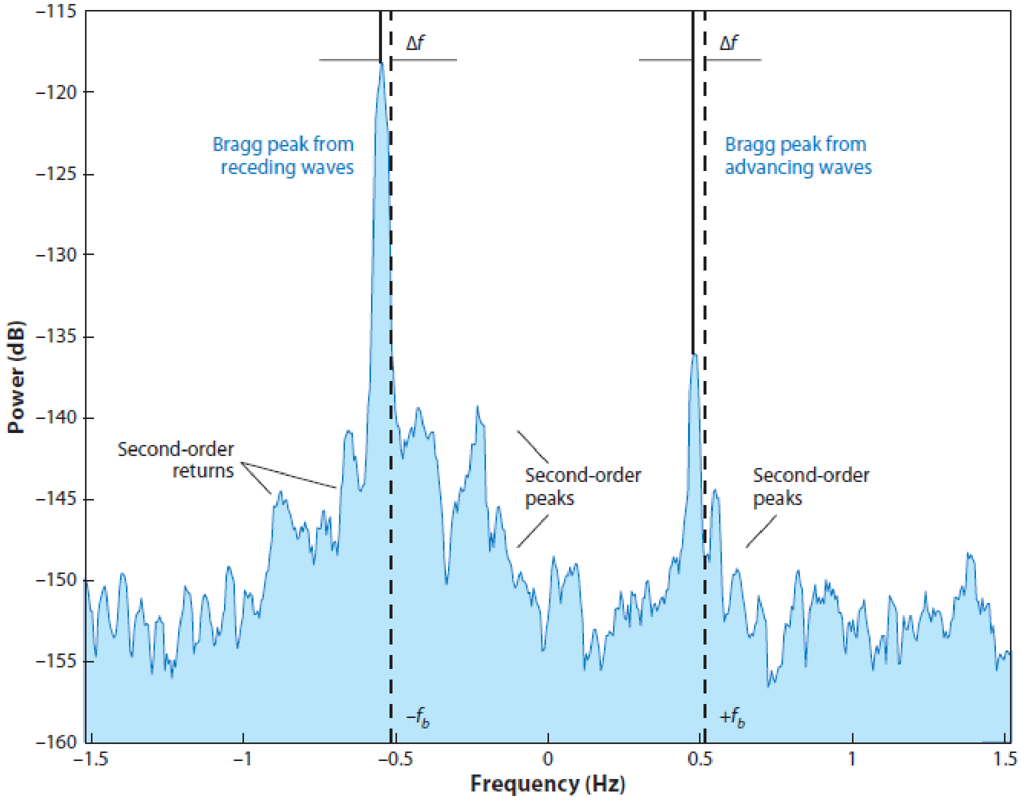

Figure 2: Sample backscatter spectrum showing the Bragg peaks, which are caused by waves moving toward and away from the receiver. Currents moving away from the receiver are causing the additional small Doppler shift Δf. Figure from Paduan and Washburn (2013) (10).

accordingly using the well-know Doppler formula (Figure 2):

$$\Delta f = 2v_r/\lambda \tag{2}$$

2.2 Network description

The infrastructure of the ICATMAR HF radar network is composed of seven HF radars located at: Cap de Creus lighthouse, Cap sa Sal (Begur), Tossa de Mar lighthouse, Port d'Arenys de Mar, Port de Barcelona, Port Ginesta and Port de Segur de Calafell (Figure 3, Table 1). All the radar stations of the ICATMAR network use the CODAR SeaSonde measurement system and operate at the same frequency of 13.5 MHz, emitting vertically polarized FMiCW (Frequency Modulated Interrupted Continuous Wave) waves with time synchronization through GPS.

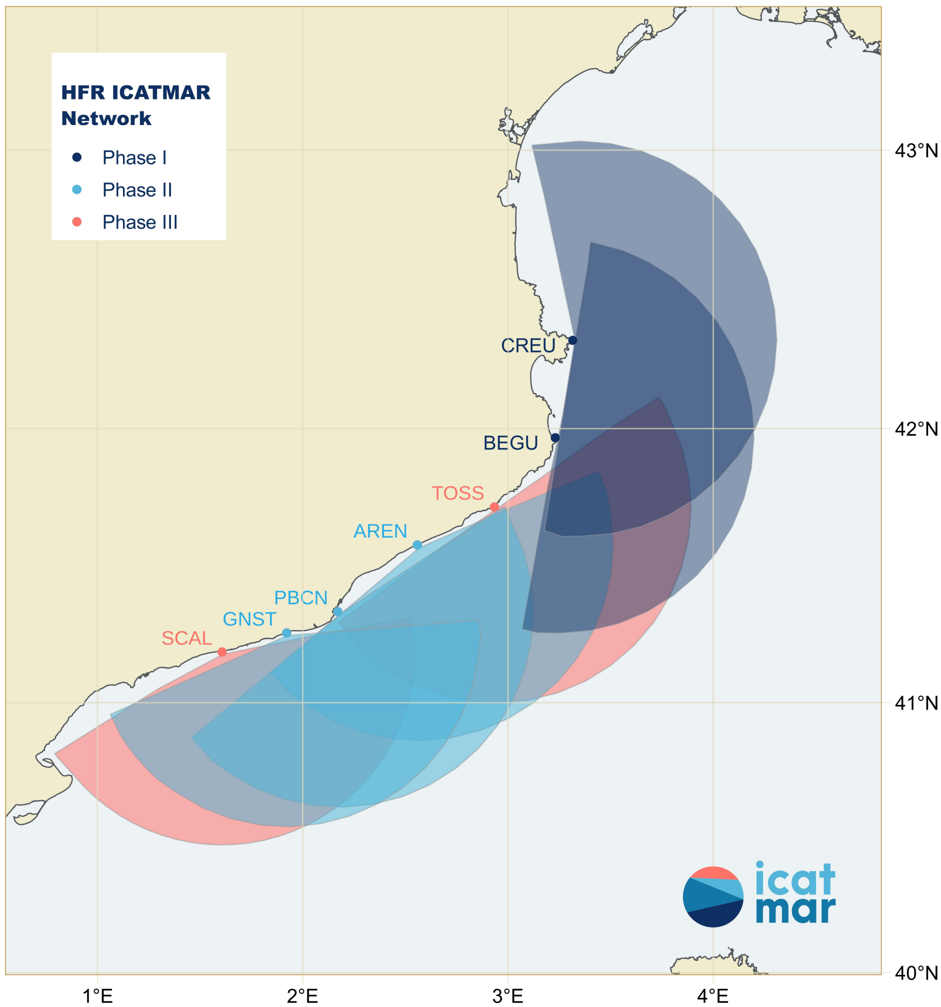

Figure 3: Distribution, theoretical coverage and deployment phases of the radar stations from ICATMAR HF radar network.

Station location	Station name	Coordinates	Deployment phase	Operating status
Cap de Creus	CREU	42.32°N 3.32°E	Phase I (Dec-2022)	Active
Cap sa Sal	BEGU	41.97°N 3.23°E	Phase I (Feb-2023)	Active
Tossa de Mar	TOSS	41.72°N 2.93°E	Phase III (Dec-2024)	Planned
Arenys de Mar	AREN	41.58°N 2.56°E	Phase II (Dec-2023)	Active
Port de Barcelona	PBCN	41.34°N 2.17°E	Phase II (Dec-2023)	Active
Port Ginesta	GNST	41.26°N 1.92°E	Phase II (Dec-2023)	Active
Segur de Calafell	SCAL	41.19°N 1.61°E	Phase III (Dec-2024)	Planned

Table 1: Location, name, deployment phase and operating status of the radar stations from ICATMAR HF radar network.

Each HF radar antenna offers radial coverage with a range between 60 and 80 km offshore. With the combination of these radial coverages, velocity and direction maps of the first meter depth of the sea surface currents are generated hourly, with a spatial resolution of 3 km^2. The infrastructure of the ICATMAR HF radar network has a total coverage of 21085 km^2.

The deployment of the seven antennas is being carried out in three phases (Figure 3, Table 1). The first covers the Cap de Creus and Begur area. The second phase covers the central area of the Catalan coast with the installation of the Port d'Arenys de Mar, Port de Barcelona and Port Ginesta radars. And the third phase includes the installation of the HF radar in Tossa de Mar, to provide continuity between the northern and the central area of the Catalan coast, and the HF radar in Segur de Calafell, with which the implementation of the infrastructure of the ICATMAR HF radar network will be completed.

3 Generation of total velocities

Each HF radar antenna allows us to estimate, over a set of cells on the sea surface, the radial component of the current velocity within each cell. With a single antenna, the perpendicular component to the radial cannot be observed. The impossibility of determining the total velocity component by a single antenna can be rephrased as follows. In polar coordinates, the total velocity is represented by two independent variables or degrees of freedom: the magnitude, U, and the angle with respect to a given coordinate origin, α_U. With only one antenna, we can observe only one independent variable, leaving the other completely undetermined. However, as shown in Figure 4, when two antennas observe the same point, two independent trigonometric relationships are established, allowing the unique determination of the magnitude and direction of the total velocity.

Three issues that must be taken into account are: i) antennas provide radial velocities in discrete cells with an area that varies depending on the distance from the antenna; ii) every measurement has a certain degree of uncertainty, which, in the case of HF radar antennas, increases with distance from the antenna and might vary according to direction; iii) the cells observed by one antenna rarely coincide with the cells observed by the other antennas. A technique used to minimize the negative effects of these problems is to invert the total velocities using all available radial measurements around the desired point (see Figure 5).

Various methods for retrieving the two-dimensional velocity field from the radial measurements within the common coverage area of two (or more) antennas have been described in the scientific literature (9; 8; 7; 1). Among them, the simplest and most robust method is called the **unweighted least squares method** or simply the **least squares method**. The least squares method looks for the values of U and α_U that better agree with all the partial observations provided by the various antennas. In other words, the values that minimize the following cost function:

$$\mathcal{J} = \sum_{i=1}^{N} \frac{w_i \left(v_i - U\cos(\alpha_U - \alpha_i)\right)^2}{(\Delta v_i)^2}, \tag{3}$$

where w_i is an optional weight applied to the i-th measurement and the quantity $(\Delta v_i)^2$ refers to the known variance of the measurement error of the radial velocity estimates. In the case

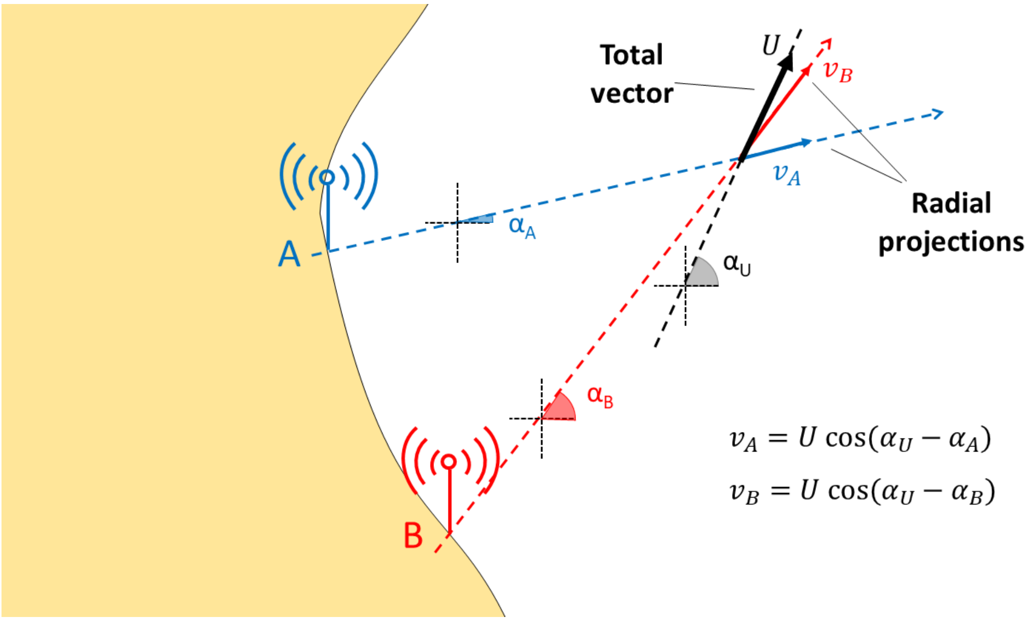

Figure 4: Projection of a 2D vector to the two radial lines defined by the relative position of two coastal antennas.

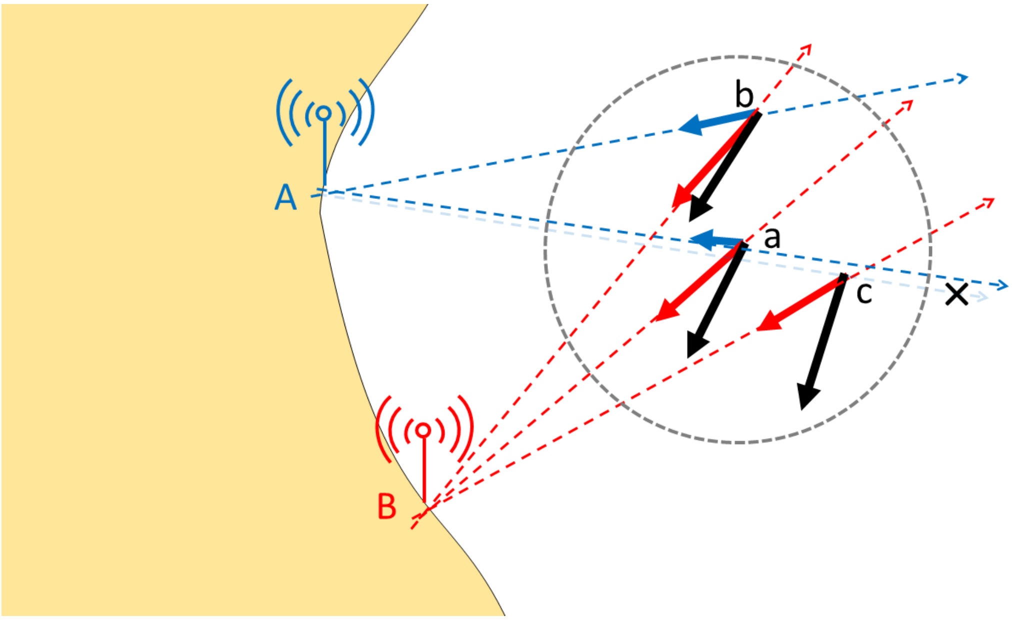

Figure 5: The two-dimensional velocity inversion uses all the available radial measurements within a pre-defined region, centered around the point of interest.

of constant values of w_i and $(\Delta v_i)^2$, the solution that minimizes the cost function is also the solution of the following linear system:

$$\begin{pmatrix} v_1 \\ v_2 \\ \vdots \\ v_N \end{pmatrix} = \begin{pmatrix} \cos(\alpha_1) & \sin(\alpha_1) \\ \cos(\alpha_2) & \sin(\alpha_2) \\ \vdots & \vdots \\ \cos(\alpha_N) & \sin(\alpha_N) \end{pmatrix} \cdot \begin{pmatrix} U_x \\ U_y \end{pmatrix} \tag{4}$$

where U_x and U_y are the zonal and meridional components of the total velocity, i.e. $U_x = U\cos(\alpha_U)$ and $U_y = U\sin(\alpha_U)$. This approximation is called **unweighted** because in the case of constant weights and error variances, the solution is independent of these values.

4 Processing levels

To obtain the sea surface current velocity fields, the signal received by the HF radar (HFR) antennas undergo different processing levels that are described in Table 2:

Processing level	Description
Level 0	Signal received by the antenna before the processing stage.
Level 1A	Spectra by antenna channel. These data is georeferenced and time-referenced and include radiometric and geometric calibration coefficients.
Level 1B	Spectra by beam direction. Level 1A data that have been processed to sensor units for next processing steps.
Level 2A	HFR radial velocity data, this is, the radial current component towards an antenna georeferenced by the distance to the antenna and the clockwise angle from the North.
Level 2B	Level 2A HFR radial velocity data that have been evaluated with a set of quality control tests in order to mark data with informative quality flags.
Level 3A	HFR total velocity data mapped on a uniform space-time grid scale.
Level 3B	HFR total velocity data. Level 3A HFR total velocity data that have been evaluated with a set of quality control tests in order to mark data with informative quality flags.

Table 2: Processing levels for HFR data.

This processing level scheme follows the model of JERICO-Next D5.14 (3). The processing levels from 0 to 2A are performed by the antennas internal software. Level 2A products are sent from each antenna to the ICATMAR servers where data are processed to obtain the level 3B product, this is, the velocity fields of surface currents.

5 Quality control and flags

In order to deliver high-quality Near Real Time (NRT) surface velocity fields, a battery of Quality Control (QC) procedures have been implemented on the data from HFR. These procedures are based on the European common QC model defined by the JERICO-Next D5.14 project (3), whose aim is to ensure efficient and automated HFR data discovery and interoperability across distributed and heterogeneous earth science data systems.

The applied QC tests are listed in Table 3 and they are the required ones for labelling the total velocity data as Level 3B (see section 4).

QC test	Variable name in L3B netCDF files	Meaning	Thresholds
Data density threshold	ddns_qc	This test labels total velocity vectors with a number of contributing radials bigger than the threshold with a “good data” flag and those with a smaller number of contributions with a “bad data” flag.	3 radial contributions
Velocity threshold	cspd_qc	This test labels total velocity vectors whose module is bigger than a maximum velocity threshold with a “bad data” flag and those whose module is smaller than the threshold with a “good data” flag.	170 cm/s
Temporal derivative	vart_qc	For each grid cell, the current hour velocity vector is compared with the previous one. If the difference is bigger than a threshold, the present vector is flagged as "bad data", otherwise it is labelled with a "good data" flag.	50 cm/s/h
GDOP threshold	gdop_qc	This test labels total velocity vectors whose GDOP is bigger than a maximum threshold with a “bad data” flag and those whose GDOP is smaller than the threshold with a “good data” flag.	2
Overall flag	qcflag	For each total velocity vector, this test evaluates the results of all the previous QC tests: it is a “good data” flag if and only if all QC tests are passed by the data	-

Table 3: Quality control tests for total velocity data. Thresholds have been chosen by following the criteria of the European HFRadar Node (https://www.hfrnode.eu/), in the case of *Data density threshold* and *GDOP threshold* QC tests, and by performing statistical analysis of model-derived regional oceanographic data provided by CMEMS and SOCIB, in the case of *Velocity threshold* and *Temporal derivative* QC tests.

Each QC test will result in a flag related to each data vector which will be inserted in the specific test variable. These variables are matrices with the same dimensions of the data variable, containing, for each cell, the flag related to the vector lying in that cell. The QC flag codes are described in Table 4; the flag coding is following the ARGO QC flag scale.

An overall QC variable, named *qcflag* in the netCDF files (see section 6.2.1), sums up the results of all the QC tests evaluated over a a total velocity vector based on the rule that it gets a "good data" flag if and only if all quality control tests have been passed by that velocity vector.

Flag code	Meaning	Description
0	no QC performed	The corresponding QC test has not been evaluated
1	good data	The corresponding QC test has been passed
2	probably good data	These data should be used with caution
3	potentially correctable bad data	These data are not to be used without scientific correction or re-calibration
4	bad data	Data have failed one or more QC tests
5	value changed	Data may be recovered after transmission error
6	value below detection	Data not used
7	nominal value	The provided value is not measured but comes from a priori knowledge (instrument design or deployment), e.g. instrument target depth
8	interpolated value	Missing data may be interpolated from neighbouring data in space or time
9	missing value	-

Table 4: Quality control flag scale. Information from columns *Flag code* and *Meaning* correspond to information in QC variables attributes *flag_values* and *flag_meanings* in the L3B netCDF files, respectively (see Listing 1).

Since a successful QC effort is highly dependent upon selection of the proper thresholds, this choice is not straightforward, and may require trial and error before final selections are made. These thresholds should not be determined arbitrarily, but based on historical knowledge or statistics derived from historical data.

6 How to access the data

The data provided by the ICATMAR HF radar network is freely distributed through our website and our FTP service (Figure 6).

6.1 Naming convention and formats

The surface currents velocity for a given date and time (level 3 or L3 files) are distributed in files whose names follow the convention `TOTL_CATS_YYYY_MM_DD_HH00`. The date and time is

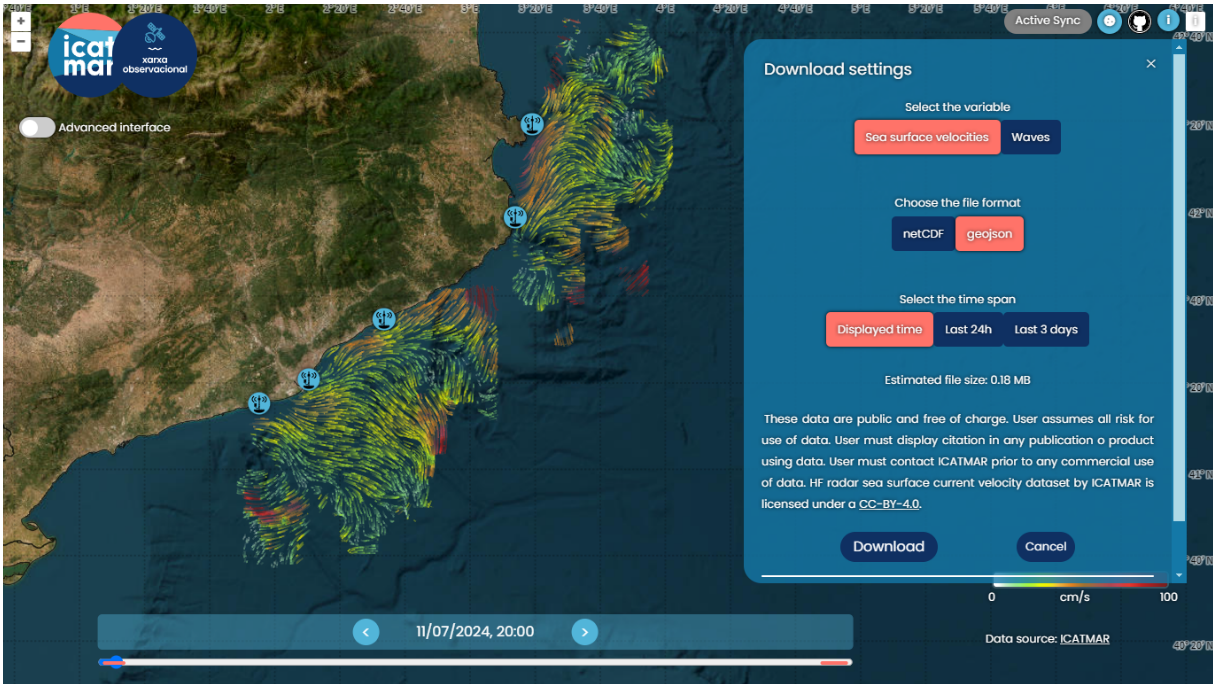

Figure 6: View of the ICATMAR web service from where data of surface velocity currents can be displayed and downloaded (`https://icatmar.cat/observacions/`).

indicated as `YYYY` (4 digits year), `MM` (2 digits month), `DD` (2 digits day), and `HH` (2 digits hour in a 24 hour format) using the Universal Time Coordinated (UTC). The antenna data used to generate these files correspond to those acquired from 35 minutes before to 40 minutes after the hour on the dot (*i.e.* every hour the data of 75 minutes of measures are used to compute L3 files).

6.2 File structure and formats

The L3 files are distributed in two formats: netCDF (Unidata) and GeoJSON (2)

6.2.1 netCDF

The netCDF format is widely used in the oceanographic and climate communities. Data in netCDF format is self-describing (contains metadata), portable (machine independent), scalable (efficient aggregation and subsets creation), sharable (concurrent access), and archivable (backward compatibility). These characteristics make netCDF an INSPIRE compliant format (6).

NetCDF is a binary file format to store multidimensional data (arrays) and metadata. There exist standard libraries to read these files in the most used programming languages (`C, Fortran, Python, Matlab...`) as well as tools to read and modify them (`NCO` `https://nco.sourceforge.net/`, `CDO` `https://code.mpimet.mpg.de/projects/cdo/wiki/Tutorial`...).

Also there are specific programs to visualize 1D and 2D netCDF data (ncview https://cirrus.ucsd.edu/ncview/, Panoply https://www.giss.nasa.gov/tools/panoply/...).

In particular, the distributed L3 netCDF files follow the standard of Climate and Forecast Metadata Conventions, version 1.10 (abbreviated as CF-1.10), which is intended for use with climate and forecast data, for atmosphere, surface and ocean. The conventions define metadata that provide a definitive description of what the data in each variable represents, and of the spatial and temporal properties of the data (4).

Data: The data depends on the time, depth, latitude, and longitude dimensions. However, the depth is fixed and it is always around 1 m (the radar signal penetration). The time is included as a record variable to facilitate the aggregation of different files.

- **u, v**: Zonal and meridional components of the velocity in m/s
- **stdu, stdv**: Standard deviation of the zonal and meridional components of the velocity in m/s
- **cov**: Covariance of the velocity field in m^2/s^2
- **gdop**: Geometrical dilution of precision

Flags: The quality of these data is indicated by means of flags. The list of flags, together with the numerical meaning of each flag is shown in Listing 1 (see section 4 for a detailed description). This Listing contains the CDL (Common Data Language) expression of the flags inside the netCDF file. CDL is a human-readable notation for netCDF (https://www.unidata.ucar.edu/software/netcdf/workshops/2011/utilities/CDL.html).

```
byte qcflag(time=1, depth=1, lat=130, lon=120);
  :_FillValue = -127B; // byte
  :standard_name = "aggregate_quality_flag";
  :long_name = "Overall quality flag";
  :units = "1";
  :valid_range = 0B, 9B; // byte
  :flag_values = 0B, 1B, 2B, 3B, 4B, 5B, 6B, 7B, 8B, 9B; // byte
  :flag_meanings = "no_qc_performed good_data probably_good_data
      potentially_correctable_bad_data bad_data value_changed value_below_detection
      nominal_value interpolated_value missing_value";
  :coordinates = "time depth latitude longitude";
  :_ChunkSizes = 1U, 1U, 130U, 120U; // uint

 byte vart_qc(time=1, depth=1, lat=130, lon=120);
  :_FillValue = -127B; // byte
  :long_name = "Variance threshold quality flag";
  :units = "1";
  :valid_range = 0B, 9B; // byte
  :flag_values = 0B, 1B, 2B, 3B, 4B, 5B, 6B, 7B, 8B, 9B; // byte
```

```
    :flag_meanings = "no_qc_performed good_data probably_good_data
        potentially_correctable_bad_data bad_data value_changed value_below_detection
        nominal_value interpolated_value missing_value";
    :coordinates = "time depth latitude longitude";
    :_ChunkSizes = 1U, 1U, 130U, 120U; // uint

  byte gdop_qc(time=1, depth=1, lat=130, lon=120);
    :_FillValue = -127B; // byte
    :long_name = "GDOP threshold quality flag";
    :units = "1";
    :valid_range = 0B, 9B; // byte
    :flag_values = 0B, 1B, 2B, 3B, 4B, 5B, 6B, 7B, 8B, 9B; // byte
    :flag_meanings = "no_qc_performed good_data probably_good_data
        potentially_correctable_bad_data bad_data value_changed value_below_detection
        nominal_value interpolated_value missing_value";
    :coordinates = "time depth latitude longitude";
    :_ChunkSizes = 1U, 1U, 130U, 120U; // uint

  byte ddns_qc(time=1, depth=1, lat=130, lon=120);
    :_FillValue = -127B; // byte
    :long_name = "Data density threshold quality flag";
    :units = "1";
    :valid_range = 0B, 9B; // byte
    :flag_values = 0B, 1B, 2B, 3B, 4B, 5B, 6B, 7B, 8B, 9B; // byte
    :flag_meanings = "no_qc_performed good_data probably_good_data
        potentially_correctable_bad_data bad_data value_changed value_below_detection
        nominal_value interpolated_value missing_value";
    :coordinates = "time depth latitude longitude";
    :_ChunkSizes = 1U, 1U, 130U, 120U; // uint

  byte cspd_qc(time=1, depth=1, lat=130, lon=120);
    :_FillValue = -127B; // byte
    :long_name = "Velocity threshold quality flag";
    :units = "1";
    :valid_range = 0B, 9B; // byte
    :flag_values = 0B, 1B, 2B, 3B, 4B, 5B, 6B, 7B, 8B, 9B; // byte
    :flag_meanings = "no_qc_performed good_data probably_good_data
        potentially_correctable_bad_data bad_data value_changed value_below_detection
        nominal_value interpolated_value missing_value";
    :coordinates = "time depth latitude longitude";
    :_ChunkSizes = 1U, 1U, 130U, 120U; // uint
```

Listing 1: Flags stored in a netCDF L3 file in CDL notation

Metadata: Listing 2 shows the global metadata, in CDL notation, contained in a netCDF L3 distributed by ICATMAR.

```
// global attributes:
:acknowledgment = "ICATMAR HF Radar Network has been established with the support of the
    European Maritime and Fisheries Fund, the European Maritime, Fisheries and Aquaculture
     Fund and the fund provided by the Government of Catalonia. The network has been
    designed, implemented and managed through the efforts of the Direcció General de Polí
    tica Marítima i Pesca Sostenible (Government of Catalonia) and the Insitut de Ciències
     del Mar (CSIC), Barcelona.";
:area = "Mediterranean Sea";
:citation = "These data were collected and made freely available by ICATMAR and the
    programs that contribute to it. Data was collected by the Government of Catalonia and
    processed by ICATMAR with the support of the European Maritime, Fisheries and
    Aquaculture Fund (EMFAF) and the Climatic Funds Program of the Government of Catalonia
    .";
:Conventions = "CF—1.10";
:date_created = "2024—02—21T11:33:02Z";
:date_modified = "2024—02—21T11:33:02Z";
:distribution_statement = "These data follow Copernicus standards; they are public and
    free of charge. User assumes all risk for use of data. User must display citation in
    any publication o product using data. User must contact ICATMAR prior to any
    commercial use of data.";
:doi = "https://doi.org/10.20350/digitalCSIC/16139";
:geospatial_lat_min = "39.5851";
:geospatial_lat_max = "43.0681";
:geospatial_lat_resolution = "0.027";
:geospatial_lat_units = "degrees_north";
:geospatial_lon_min = "0.06352";
:geospatial_lon_max = "4.26898";
:geospatial_lon_resolution = "0.03534";
:geospatial_lon_units = "degrees_east";
:geospatial_vertical_min = "0";
:geospatial_vertical_max = "0.75";
:geospatial_vertical_units = "m";
:history = "2024—02—21T11:33:01Z data collected.2024—02—21T11:33:02Z NetCDF file
    created";
:id = "HFR_ICATMAR_Total_2024—02—21T11:33:01Z";
:institution = "Catalan Institute of Research for the Governance of the Sea";
:institution_edmo_code = "5801";
:license = "HF radar sea surface current velocity dataset by ICATMAR is licensed under a
    Creative Commons Attribution 4.0 International License. You should have received a
    copy of the license along with this work. If not, see http://creativecommons.org/
    licenses/by/4.0/.";
:processing_level = "3B";
```

```
  :publisher_name = "ICATMAR";
  :publisher_email = "info@icatmar.cat";
  :publisher_url = "https://icatmar.cat";
  :source = "Surface ocean velocity field from HF—radar";
  :time_coverage_start = "2024—02—12T23:25:00Z";
  :time_coverage_end = "2024—02—13T00:40:00Z";
  :time_coverage_resolution = "PT1H";
  :title = "Near Real Time Surface Ocean Velocity";
}
```

Listing 2: Global metadata contained in the netCDF L3 files distributed by ICATMAR

6.2.2 GeoJSON

The GeoJSON specification (2) has been selected as the most suitable text based format to distribute the ICATMAR radar data. The choice has been based on a compromise between size and interoperability. With small adjustments, the integrity of the information, both data and metadata, are preserved. The GeoJSON specification follows the JSON specifications but oriented to deal with georeferenced topological objects (points, lines, polygons, . . .). As such, the GeoJSON specification allows to build a data file in a structured way, suitable for being esily ingested by GIS software (QGIS, . . .), web based map engines (OpenLayers,. . .) and by many object oriented computing languages (Python, R, JAVA, Ruby . . .).

```
{"type": "FeatureCollection",
   "features":[
      {"type":"Feature","geometry":{"type":"Point","coordinates": [2.28994, 40.6381]},
       "properties":{"var_data": [0.009, 0.006, 0.182, 0.081, 3.302, 0.014, 4, 0, 4, 1, 1]}
      },
      .........
   ],
   "metadata":{
       "doi": "to be defined",
       "geospatial_lat_min":"—90",
       "geospatial_lat_max":"90",
       "id":"HFR_ICATMAR_Total_2024—02—21T11:33:01.367292Z",
       "institution": "Catalan Institute of Research for the Governance of the Sea", "institution_edmo_code": "5801",
       .............
       "var_names": ["u", "v", ..........],
       "var_lnames": ["Surface Eastward Sea Water Velocity",..........],
       "var_units": ["m s—1", ...........................],
       "var_time": "2024—02—13T00:00:00Z"}
   }
}
```

Listing 3: Minimal schematic structure of the GeoJSON file distributed by ICATMAR

As can be appreciated in Listing 3, basically is a `FeatureCollection()` object that collects all the geographical points with measured data encoded as an array of `Point()` objects, each one with a `"properties"` structure including an array of numeric values corresponding to data and quality flags of the measurement.

Then the collection object includes a `"metadata"` structure which is not a standard GeoJSON specification but, it serves to encode all the metadata information existing in the original netCDF file, usually named as *global* and *variable attributes* according to netCDF conventions (5). This add-on does not affect the geoJSON file structure so it will not cause problems when loading the file through third party software.

In order to clarify how the radar files are structured let us summarize the most relevant aspects of the GeoJSON format for using such files.

Data values: The list of variables included in the netCDF format is given in section 6.2.1. In the geoJSON version, we only stored the data values corresponding to a subset of variables associated to each point. These are the values corresponding to the following variables:

`"u", "v", "stdu", "stdv", "gdop", "cov",`
`"qcflag", "vart_qc", "gdop_qc", "ddns_qc", "cspd_qc"`

which are collected into an array (line 4 of the Listing 3) under the property `"var_data"`:

```
  "properties":{"var_data": [0.009, 0.006, 0.182, 0.081, 3.302, 0.014, 4, 0, 4, 1, 1]}
```

The metadata information relative to the variables are provided withing the `"metadata"`.

Metadata: This is an structure of key:value pairs storing the netCDF global attributes as listed in Listing 1 and a subset of the netCDF variables attributes described in 6.2.1. These attributes are grouped into corresponding arrays matching the array of point data values mentioned before. Thus, we have retained 3 arrays, `"var_names", "var_lnames", "var_units"` (see lines 15-17 of Listing 3) containing the corresponding netCDF attributes:

`"name", "long_name" "units"`

Finally, a last but essential property `"var_time"`, is included at the end of the `"metadata"` structure (line 18 of Listing 3). The `"var_time"` property encodes the nominal time representative of the mapped data in ISO-8601 format. Note that, as mentioned at the beginning of section 6.1, a map built at a nominal time is the integration of several radar observations of 75 minutes period.

6.3 Access through the web

The latest HF radar data can be downloaded through the web application `https://icatmar.cat/observacions/`. To open the download panel, the user must click on the "Download data" button on the top-right corner of the web application. The user can download the latest 24 hours, the latest 3 days, or the current timestamp selected. There is no registration required to download data through the web application, as it is only possible to download a small part of the whole dataset. The user can select two available formats: netCDF and GeoJSON. When more than one file is requested, these are served inside a .zip folder.

The purpose of this download option is to ease the access to the data for first time users or users that only need the latest data. A link to the FTP server is provided, in case the user wants to download a bigger dataset.

6.4 Access via FTP

We serve HF radar data through a Secure FTP server (SFTP). Registration is free and data can be freely accessed by registering on our website `https://icatmar.cat/servei-ftp/`.

Registration procedure

Registration is automatic and is done in two steps:

1. Go to https://icatmar.cat/servei-ftp/ and fill in the form that appears when you click on the option *Register to the service*
2. The system will send you an e-mail containing a web link (figure 7). Access to this link to confirm your registration intention. After confirming it, you will receive a second e-mail with your password and the connection information. (see figure 8)

Reset your password

Due to security restrictions, you can not choose your password. If you forget it, or simply desire to change it, you should access the section *Reset your password*. The two steps procedure is similar to the one performed for the registration: after you fill in the form, a confirmation e-mail is sent to you and you will receive a second e-mail with your new password.

Delete your account

You can delete your FTP access account using the section *Delete your account* available at https://icatmar.cat/servei-ftp/. The two steps procedure is similar to the one performed for the registration: after you fill in the form, a confirmation e-mail is sent to you. You need to access to the link sent in this e-mail and your account will be deleted.

Configuration

The SFTP address is `corellia.cmima.csic.es:33001`. If your browser is SFTP-compatible you can browse directly from `sftp://corellia.cmima.csic.es:33001` address. In Linux systems,

icatmar ftp service registration confirmation

Confirmation mail

You or someone in your name has requested your registration in our ftp server. If you have not requested this action, simply forget this email. Otherwise, click this link to proceed with your registration or simply copy the following address in your browser:

https://icatmar.cat/servei-ftp/?opt=2&
socatftp_r=jV8aW5mb0BzZW5kZXJpc21ILnRrfDY2MTV8cGVyaWNvfvbnr3Rpbm98TWFydxwcbmV6IEdvbnrDoWxlenxwcml2YXRlfDE3MDkxMzEyMjkMTIyM

This link will be active during 24 hours.

Figure 7: E-mail of registration confirmation.

icatmar ftp service registration data

Your registration data

[redacted], your registration data at the ICATMAR ftp service is the following:

Username:[redacted]
Password:[redacted]
Email:[redacted]

You can reset password or delete your account from http://icatmar.cat/servei-ftp/ web page.

You are affiliated to an organization of the type: Private sector

Server ftp data

Protocol: sftp
Address: corellia.cmima.csic.es
Port: 33001

The used protocol is a secure ftp (sftp://corellia.cmima.csic.es). Therefore a dedicated ftp client, like Filezilla, should be used.

Figure 8: Example of the e-mail received after registration completion. This e-mail contains the username, password and connection information.

the connection can be made via the command line using the command
`sftp yourusername@corellia.cmima.csic.es:33001`

If you use a dedicated FTP client (for instance FileZilla, see figure 9), you should use the following configuration:

- Host: sftp://corellia.cmima.csic.es

- Username: your username
- Password: your password
- Port: 33001

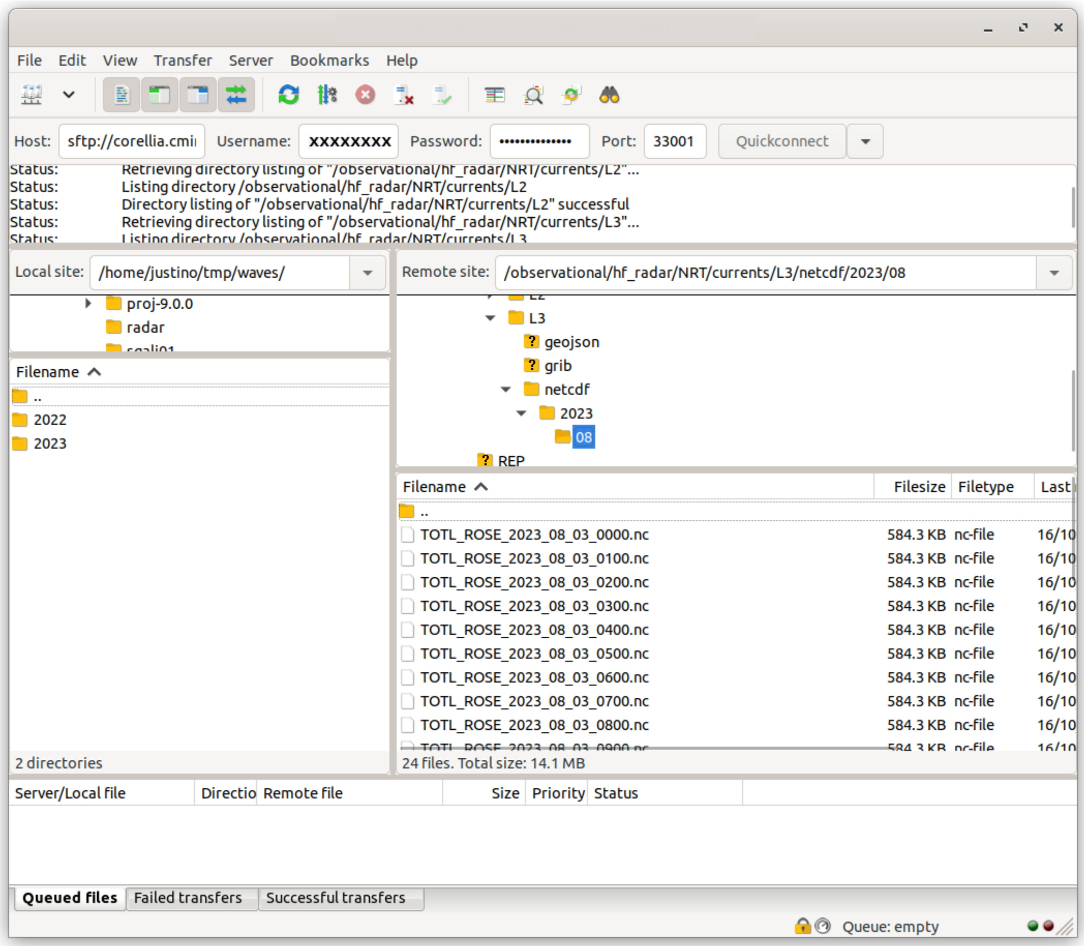

Figure 9: Example of use of FileZilla

As usual in SFTP protocol, the first time you log in from a new device you may be shown the fingerprint of our ftp server. You must accept to be able to connect to the FTP service (see figure 10).

FTP folders

The folder distribution is shown in figure 11. All the radar data are stored below the `hf_radar` folder. The data is divided into two groups: Near Real Time (below `NRT` folder) and Reprocessed data (below `REP` folder). `NRT` stores the data generated every hour. On the contrary reprocessed

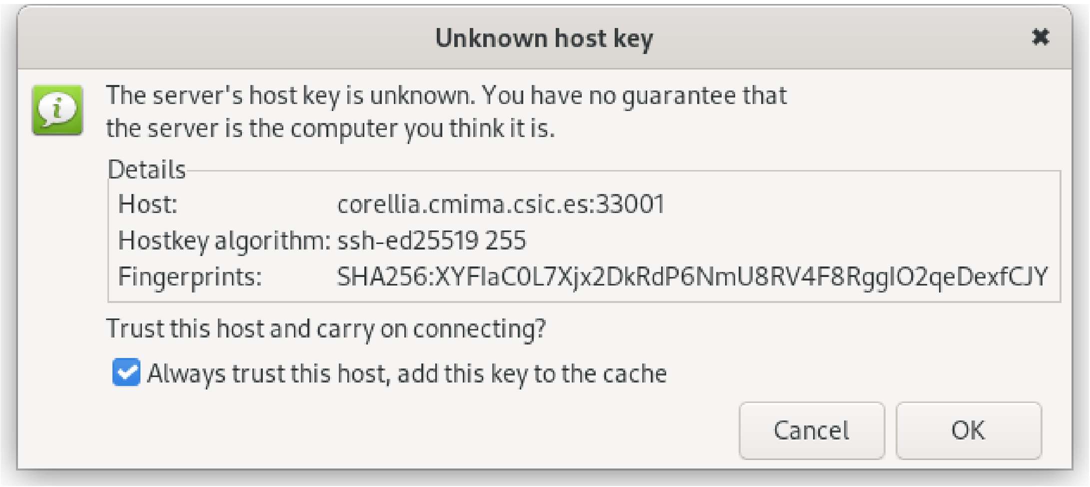

Figure 10: Example of fingerprint window shown by FileZilla

data is generated when some important change is performed in the HFR network or in the processing algorithms.

The folder `L2` contains the velocity measured by each antenna (the level 2 data). These files are constructed with the measured data for 75 minutes and deployed every hour. The data is classified according to the antenna code (aren, begu, creu, gnst and pbcn). Below each antenna folder the data is stored by year and month.

The folder `L3` contains the currents obtained by the combination of all available antenna data hourly (see section 3 to a detailed description of these files). The data is distributed in netCDF and geoJSON formats (see section 6.2) and stored by year and month.

The reprocessed data is stored in the folder `REP`. This folder contains the different reprocessing campaigns that are defined by the date of deployment in the format `YYMMDD`. The data inside each reprocessing campaign folder is distributed in a similar way as in the `NRT` folder.

```
observational
└── hf_radar
    ├── NRT
    │   ├── currents
    │   │   ├── L2
    │   │   │   ├── AREN
    │   │   │   │   ├── 2023
    │   │   │   │   │   └── 12
    │   │   │   │   ├── 2024
    │   │   │   │   │   ├── 01
    │   │   │   │   │   ├── 03
    │   │   │   │   │   └── ...
    │   │   │   │   └── ...
    │   │   │   ├── BEGU
    │   │   │   │   └── ...
    │   │   │   ├── CREU
    │   │   │   │   └── ...
    │   │   │   └── ...
    │   │   └── L3
    │   │       ├── netCDF
    │   │       │   ├── 2023
    │   │       │   │   ├── 08
    │   │       │   │   ├── 09
    │   │       │   │   └── ...
    │   │       │   ├── 2024
    │   │       │   │   └── ...
    │   │       │   └── ...
    │   │       └── geojson
    │   │           └── ...
    │   └── waves
    │       ├── AREN
    │       ├── BEGU
    │       └── ...
    └── REP
        ├── REPYYMMDD
        │   └── ...
        └── ...
```

Figure 11: Distribution of folders in the FTP server. NRT stores the Near Real Time data whereas REP stores the reprocessed data.

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