CMEMS Service Evolution 21-SE-CALL1

Report on European HF Radar systems development and roadmap for HF Radar products evolution in compliance with CMEMS needs

January 17th, 2017

FOREWORD

This document is the second and last version of the deliverable D.1.1 for INCREASE WP1. WP1 is focused on defining the basic procedures to obtain real time quality-assured, quality-controlled data in formats suitable for operational use, including gap filled velocity fields, and promoting a wider use of the HF Radar outside the scientific community. This WP1 aims to enable a step forward a unified coastal HF Radar network, in line with EuroGOOS HF Radar Task team and GEO GLOBAL HF Radar component efforts, and in compliance with CMEMS needs.

This second version has been produced after: (i) the INCREASE experts meeting (La Spezia, September 2016) and exchange with external HFR experts; and (ii) the additional discussions with the MFCs at the Service Evolution Coordination Meeting (December 2016).

Abbreviations list

ACDD: Attribute Convention for Data Discovery
ACORN: Australian Coastal Ocean Radar Network
BF: Beam Forming
CDM: Common Data Model
CMEMS: Copernicus Marine Environment Monitoring Service
CODAR: Coastal Ocean Dynamics Application Radar
DA: Data assimilation
DATAMEQ: Data Management, Exchange and Quality
DF: Direction Finding
EOF: Empirical Orthogonal Fucntions
EOOS: European Ocean Observing System
FSLE: Finite Size Lyapunov Exponents
GDOP: Geometric Dilution Of Precision
GDOSA: Geometrical Dilution Of Statistical Accuracy
GEO: Group on Earth Observations
GEOSS: Global Earth Observation System of Systems
HFR: High Frequency Radar
IBIROOS: Ireland-Biscay-Iberia Regional Operational Oceanographic System
INSTAC: In-situ Thematic Assembly Centres
IOOS: Integrated Ocean Observing System
JCOMM: Joint Technical Commission for Oceanography and Marine Meteorology
JCOMMOPS: JCOMM in situ Observations Programme Support Centre
JERICO-NEXT: Joint European Research Infrastructure network for Coastal Observatory – Novel European eXpertise for coastal observaTories
LPTM: Lagrangian Particle-Tracking Model
MARACOOS: Mid-Atlantic Regional Association Coastal Ocean Observing System
MFC: Marine Forecasting Centres
MONGOOS: Mediterranean Operational Network for the Global Ocean Observing System
MSFD: Marine Strategy Framework Directive
MUSIC: Multiple Signal Classification
NODCs: National Oceanographic Data Centres
NOOS: North West European Shelf Operational Oceanographic System
OMA: Open-boundary Modal Analysis
QA/QC: Quality Assessment/Quality Control
QARTOD: Quality Assurance/Quality Control of Real-Time Oceanographic Data
RDAC: Regional Data Assembly Centre
ROOS: Regional Ocean Observing Systems
SAR: Search and Rescue
SASEMAR: Spanish Maritime Safety Agency
SDN: SeaDataNet
SNR: Signal to Noise Ratios
STP: Short Term Prediction
TAC: Thematic Assembly Centres
TDS: THREDDS Data Server
THREDDS: Thematic Real-time Environmen-tal Distributed Data Services
WERA: WavE Radar
WP: Work Package

Index

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Their invaluable contributions were used in addition to prepare the following review paper, accepted for publication in Frontiers of Marine Science:

Rubio A, Mader J, Corgnati L, Mantovani C, Griffa A, Novellino A, Quentin C, Wyatt L, Schulz-Stellenfleth J, Horstmann J, Lorente P, Zambianchi E, Hartnett M, Fernandes C, Zervakis V, Gorringe P, Melet A and Puillat I (2017). HF Radar Activity in European Coastal Seas: Next Steps Towards a Pan-European HF Radar Network. Front. Mar. Sci. 4:8. doi: 10.3389/fmars.2017.00008

2 Introduction

The accurate monitoring of ocean surface transport, which is inherently chaotic and depends on the details of the surface velocity field at several scales, is key for the effective integrated management of coastal areas, where many human activities concentrate. This has been the main driver for the growth of coastal observatories along the global ocean coasts.

Among the different measuring systems, coastal High Frequency Radar (HFR) is the unique technology that offers the means to map ocean surface currents over wide areas (reaching distances from the coast of over 200km) with high spatial (a few kms or higher) and temporal resolution (hourly or higher). Consequently, the European HFR systems are playing an increasing role in the overall operational oceanography marine services. Their inclusion into CMEMS is crucial to ensure the improved management of several related key issues as Marine Safety, Marine Resources, Coastal & Marine Environment, Weather, Climate & Seasonal Forecast.

2.1.1 Objectives of INCREASE project

INCREASE will set the necessary developments towards the integration of the existing European HFR operational systems into the CMEMS, following **four main objectives:**

(i) Provide HFR quality controlled real-time surface currents and key derived products
(ii) Set the basis for the management of historical data and methodologies for advanced delayed mode quality-control techniques
(iii) Boost the use of HFR data for improving CMEMS numerical modelling systems and
(iv) Enable an HFR European operational node to ensure the link with operational CMEMS.

To this end, the work in **INCREASE** will be aimed to enable a homogenised integration of the existing European HFR operational systems into the CMEMS, following five main work lines: i. Define and apply common data and metadata formats and quality control methodologies to ensure the integration of high quality HFR real time data into CMEMS (TAC, MFC) ; ii. Set the methodologies for reprocessing existing data sets to obtain continuous surface coastal ocean current data sets (QUID, assimilation in reanalysis products); iii. Develop key derived products (gap-filled data, short-term prediction and derived Lagrangian products) of added-value for CMEMS users (TAC); iv. Boost the use of HFR data for improving CMEMS numerical modelling systems (MFC); v. Enable an HFR European operational node to ensure the operational availability of HFR data and data products and the link with operational CMEMS (TAC, MFC)

This will be fulfilled through 4 technical work packages (WPs) and a WP devoted to the management of the project:

WP1: Towards the integration of HFR observing technology into CMEMS
WP2: Basis for HFR data assimilation into CMEMS models
WP3: HFR Products development
WP4: HFR Node
WP5: Management, the networking and communication activities.

2.1.2 Objectives of this report

This report is the main deliverable for INCREASE WP1. WP1 is focused on defining the basic procedures to obtain real time quality-assured, quality-controlled data in formats suitable for operational use, including gap filled velocity fields, and promoting a wider use of the HFR outside the scientific community. This WP1 will enable a step forward a unified coastal HFR network, in line with EuroGOOS HFR Task team and GEO GLOBAL HF component efforts, and in compliance with CMEMS needs.

In this context WP1 will be developed through two main approaches:

-To make a diagnostic of the present development of European HFR network (existing systems, existing products, operators)

-To review and set methodologies for basic and HFR derived products with respect to CMEMS needs and towards the addition of HFR data derived services to the present CMEMS list.

In this context, the main objective of the first part of this document (sections 3, 4 and 5) is to provide a basic background on the technology, the data, their use, and an inventory of existing applications in European coastal waters as a base for defining the roadmap towards integrating HFR products into CMEMS. Then, Section 6 will be devoted to define the next steps towards the identified developments of HFR data and products.

3 Context

3.1 HF radar: a powerful component of coastal observing systems

HFR technology offers a unique insight to coastal ocean variability, by providing high resolution data at the interface between ocean and atmosphere. Recent reviews on this technology, and its applications worldwide, have been provided by Paduan and Washburn, 2013, and Liu et al., 2015. HFR data are a powerful tool for understanding the coupled ocean-atmosphere system and the different coastal circulation processes like ocean waves, mixing, momentum and heat fluxes, wind-induced currents, (sub)mesoscale variability, tidal flows, and inertial oscillations. A growing number of European studies have been developed on the use of HFR data to a better understanding of the surface ocean coastal dynamics (e.g. Shrira et al., 2001; Schaeffer et al., 2011; Sentchev et al., 2013; Shrira and Forget, 2015; Rubio et al., 2013). Moreover, since HFR data provide measurements of currents with a relatively wide spatial coverage and high spatio-temporal resolution in near real time (there are systems with lags of just 20 minutes, after generating the data), they have become invaluable tools in the field of operational oceanography. HFR systems are now an integrating technology of many European coastal observatories with proved potential for monitoring (e.g. Wyatt et al., 2006; Berta et al 2014, Molcard et al., 2009) and even providing short-term prediction of coastal currents (e.g. Orfila et al., 2015; Solabarrieta, et al., 2016), and inputs for the validation and calibration of numerical ocean forecasting models, especially near the coast (e.g. Marmain et al., 2014; Barth et al., 2008, 2011; Iermano et al., 2016; Stanev et al., 2015).

3.1.1 Principles of operation

HFR is a remote sensing measurement technique. The use of HFR for monitoring surface currents in the coastal zone, was first proposed by Stewart and Joy (1974), following the works on the link between HFR backscatter and surface wave phase speed (Crombie, 1955; Barrick, 1972). At the present, several frequency bands between 3 and 50 MHz have been allocated by the International Telecommunication Union (ITU Resolution 612 of the 2012 World Radio communication Conference) to support the use of HFRs.

Several HFR systems coexist on Europe, nevertheless two are the most extended: WERA (WavE Radar, developed in the 1990s by the University of Hamburg) and CODAR (Coastal Ocean Dynamics Application Radar, developed at NOAA's Wave Propagation Laboratory in the 1980s) (Figure 1). The main differences between WERA and CODAR radars are analysed in detail in Gurgel et al. (1999). These two systems provide basically the same outputs, while presenting some differences in hardware and data processing that may impact angular range/resolution and the capacity of accurately resolve wave-induced second-order spectral bands, i.e., for measuring surface wave spectra. Other minor differences rely on data formats and processing information available for data quality control/assessment.

a)

b)

FIGURE 1: A) EXAMPLE OF WERA SYSTEM'S ANTENNA INSTALLATION (T. HELZEL); B) *SEASONDE CODAR RECEIVER ANTENNA (DOWN RIGHT IN THE IMAGE) TRANSMIT (UP LEFT IN THE IMAGE) (L. SOLABARRIETA)*

An HFR system includes at least two radar sites, each one measuring the radial velocity in its look direction. This component of the velocity of the surface current is proportional to the Doppler shift respect to a reference frequency in the reflected signal spectrum. More in details, HFR relies on resonant backscatter resulting from coherent reflection of the transmitted wave by the ocean waves whose wavelength is ½ of that of the transmitted radio wave. The energy reflected at one wave crest is in phase with the ones coming from the other crests, thus adding coherently. This is the Bragg scattering phenomenon and it results in the 1st order peak of the received (backscattered) spectrum (Paduan and Graber, 1997).

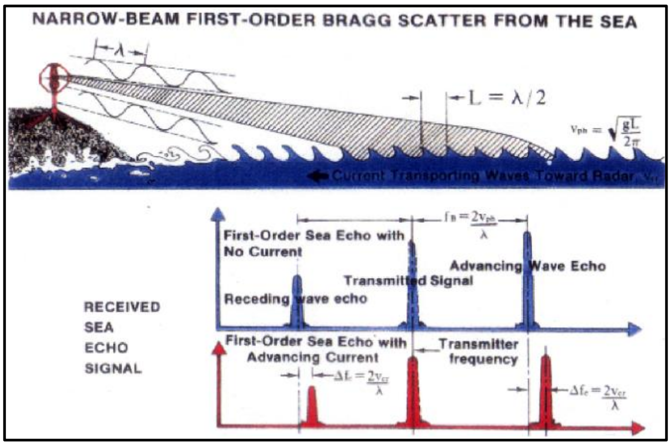

FIGURE 2: SCHEME SHOWING HOW HFRS MEASURE CURRENTS. THE ANTENNA ON THE COAST OUTPUTS A SIGNAL WITH WAVELENGTH Λ (DEPENDING ON THE FREQUENCY OF THE SYSTEM) WHICH IS REFLECTED COHERENTLY BY THE SURFACE WAVES WHOSE WAVELENGTH IS Λ / 2. (BARRICK, 1977)

In the absence of currents, the frequency of the 1st order peak has a Doppler shift caused by the phase velocity (speed) of the waves in the radial direction of the transmitting antenna.

This speed (Vg) is known since it is the wave propagation speed (for waves with ½ wavelength of the emitted wave), and is given by the dispersion relation in deep waters:

$$Vg = \sqrt{g \times \frac{L}{2\pi}} = \sqrt{\frac{g}{k}}$$

Where, L = wavelength, g = gravity and k= wave number.

Two peaks (Bragg peaks) are shown in the received signal spectrum, symmetric respect to the central transmitting frequency, and associated with the waves traveling towards (right peak) and away (left peak) from the radar, as shown in Figure 2. If gravitational waves are propagated over a current field, an additional Doppler shift affecting both peaks is produced and an asymmetric spectrum can be obtained. The difference between the theoretical speed of the waves and the velocity observed, resulting in the doppler shift in the observed Bragg peaks, is due to the velocity of the radial component of the current (the current in the same direction as the signal), that can be therefore estimated.

In order to locate the scattering area, spatial resolution has to be achieved in range and azimuth (see Gurgel et al., 1999). For the directional resolution, the most conventional design is to use a linear array of monopoles (Figure 1) and to process using the beam-forming (BF) method. This method provides a Doppler spectrum for every cell in the field of view of the radar. So, the radial current velocity deduced from the first order echo, and the wave parameters deduced from the second order, are located in the range and azimuth domain. Azimuthal resolution is dependent on the number of elements in the antenna array and its total length, and can sometimes benefit from alternative processing methods (Sentchev et al., 2013). Another alternative is to perform a procedure called direction-finding (DF) in the frequency domain to obtain azimuthal resolution. In this case, radial velocities are obtained from spectral data by using the MUSIC (MUltiple SIgnal Classification) algorithm (Schmidt, 1986). HFRs using DF technique need a periodic calibration (recommended every 1–2 years). The resulting directional antenna pattern is required for an accurate determination of the radial currents and their direction of arrival (Kalampokis et al., 2016). Main advantages of the compact direction-finding antenna are a) smaller effort needed for deploying and maintaining the system; b) field of view of 360°. Main disadvantages are a) possible failures of the direction-finding algorithm due to ambiguities; b) reduced accuracy in measuring surface wave spectra (Gurgel et al., 1999).

Once the radial components of the surface currents are calculated by two or more radars (located in different sites and looking into an overlapping area), they can be combined to provide a surface current vector map across this area (total vector map, Figure 3). Coverage area and spatial resolution depend respectively on HFR operating frequency and available bandwidth. Common values for a system of two HFRs operating at 13MHz are: coverage of 70 km x 70 km; resolution of 1,5 km. Coverage and resolution of the total map are also affected by the geometry of the radar network along the coast.

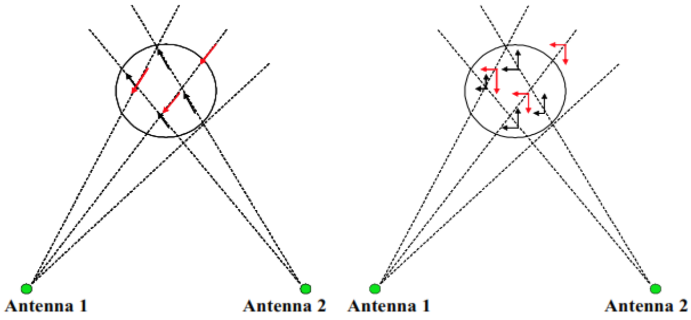

FIGURE 3: SURFACE DIRECTION GENERATING SCHEME FROM RADIAL INFORMATION (COURTESY OF QUALITAS).

Different techniques are used to combine radial data to totals (e.g. Least Square methods described in Lipa and Barrick, 1983), and including those like optimal interpolation (Kim, et. al., 2008), OMA (Kaplan and Lekien, 2007) or variational analysis (Yaremchuk and Sentchev, 2011) that allow data-gap filling. Globally, the processing from the raw data to the final products as well as the data formats is different, depending on the system configuration and/or manufacturer but also on the software used. In Figure 4 an example of an hourly field of radial velocities and the corresponding total velocity field using a least square fitting technique is provided.

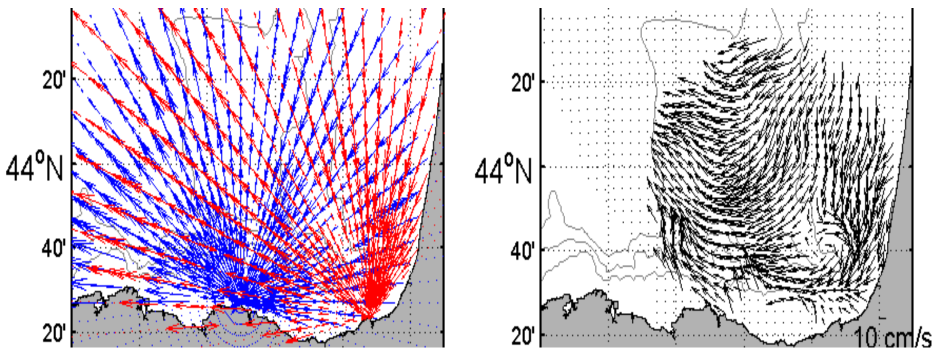

FIGURE 4: EXAMPLE OF A SURFACE CURRENT FIELD OBTAINED FROM RADIAL DATA USING AN LS ALGORITHM.

As we just explained, the processing of HFR data to obtain surface currents benefits from the fact that they are based on resonant (Bragg echo) signals, which, instrument noise permitting, enables the detection of geophysical signals while resolving high spatial and temporal variability (Forget, 2015). In addition, advanced analysis of the full spectra of the backscattered signals can provide estimation of the sea state, winds and determination of target (e.g. vessels) position and speed, in addition to, be used for tsunami detection (Lipa et al., 2006). However, extracting information other than surface currents presents a much greater challenge to systems designers since these are obtained from much weaker or partial parts of the signal, more likely to be corrupted by noise and interference (Barrick, 1977, Wyatt et al., 2006). Thus, HFR derived data other than surface currents will be out of the scope of INCREASE project. The two main reasons for this are: (i) we consider that the work needed for the integration of HFR surface currents into CMEMs is already a big challenge and a main first step, and (ii) from our point of view, major developments are still needed towards the production of these secondary data in an operational way with enough quality and reliability. So from now this document will focus exclusively on HFR current data. Additional elements on the state of the art concerning the use of other parts of the backscattered signal, its potential and limitations, are provided in Rubio et al. (2017).

3.1.2 Data flow and data formats

Generally speaking, four levels of data are produced in the operation of the CODAR and WERA HFR systems to measure ocean currents. These are summarized in the table:

TABLE 1: DATA LEVELS FROM CODAR AND WERA HFR SYSTEMS.

Data level	*CODAR*	*WERA*
Raw data	Binary files, only readable through the manufacturer's software Radial Suite	Raw files (.RAW binary Fortran) are the timeseries of complex signals (I/Q) from each channels. Not often saved.
Spectra	Binary files (*.css), again readable through manufacturer's software Radial Suite	WERA range resolved data (.SORT, binary fortran), the omnidirectional Doppler spectra along the distance for each antenna. Power spectra measured on a regular grid (.SPEC binary fortran). They are processed after beam forming by the WERA software on a linear array.
Radials	ASCII files: data + header with system configuration and processing information	Radials component on a Cartesian grid ASCII format (.cwrad) or NOAA format (.ruv). Data (lon, lat, u, v) + header
Totals	ASCII files	

As we stated previously, the processing from raw data to the final products, as well as the data formats is different, depending on the system configuration and/or manufacturer but also on the software used. Apart from the manufacturer's software (CODAR's COMBINE and WERA toolboxes) an extended tool is the HFR toolbox, developed by University of California and NPS (see https://cencalarchive.org/~cocmpmb/COCMP-wiki). HFR toolbox, developed in Matlab®, allows different methods and error quantification, starting from radial files generated by a WERA or a CODAR system. Files are converted into Matlab® binary files and all the initial information contained in radial data is kept in the Matlab® file structure.

A complete description on the radial file formats of CODAR and WERA systems can be found at the Coastal Observing Research and Development Center web page, in two documents developed by M. Otero (Scripps Institution of Oceanography):

WERA file formats:
http://cordc.ucsd.edu/projects/mapping/documents/HFRNet_WERA_LonLatUV_RDL.pdf

CODAR file formats:
http://cordc.ucsd.edu/projects/mapping/documents/radFileFormats_20050408.pdf

3.1.3 Data potential and limitations

The European Commission has recognized the need for ocean measurements with its "Marine Knowledge 2020" initiative which aims to bring together marine data from different sources at European Level. The aim is supporting industry, public authorities and researchers in finding and using marine data in a more effective way, developing new products and services. A better comprehension of coastal ocean dynamics will have an immediate impact on the planning of environmental policy and mitigation measures, and improved environmental information will also provide support to decision makers, commercial activities, and citizens.

Ocean dynamics of the coastal and shelf break zones are characterized by a large variety of processes (current instabilities, coastal jets and eddies) acting simultaneously, in response to different forcing, over a broad spectrum of scales. These processes and their combination play a key role in the dispersal/retention of pollutants, planktonic species (potentially toxic) and/or larvae, and more generally in cross shelf exchanges. HFR data series offer the opportunity to isolate and characterize these processes from tidal and near-inertial to mesoscale time scales as well as the interactions between them. A better knowledge of the physics at the coastal ocean is the best way to improve forecast tools and approaches towards coastal transport characterization. Also the availability of HFR data in real time can offer ways to operational improvements of forecasts through the direct use of the HFR data (or combinations of this with other observational information) for short-term prediction or via the validation, calibration and data assimilation into operational ocean numerical models.

The main potential of HFR resides in the fact that these systems can offer high temporal and spatial resolution current maps, matching the need for operational monitoring/forecasting of ocean transports and their applications to several Marine Strategy Framework Directive (MSFD) objectives. The progressive inclusion of HFR in coastal observatories will stimulate applied research towards increasing applications of HFR in MSFD marine safety and integrated ecosystem management as well as in Blue Growth (renewable energy) objectives. The HFR spatial resolution depends on the available bandwidth (see 3.1.1), which is limited by international and national regulations and most of the time is connected with the HFR operating frequency (table 2), ranging from 6-12 km to several hundred of meters (Gurgel et al., 1999b). The theoretical maximum range is depending more strictly on the operating frequency and can reach up to more than 200 km (at lower frequencies). No other observational technology can offer presently such a detailed insight to coastal ocean surface processes. Remote altimeter sensors can also map surface currents, however on much larger scales farther offshore and with limited temporal resolution (several days), and under the assumption that the observed flows are in geostrophic balance. HFRs, in contrast, map the total surface currents (geostrophic plus Ekman) on hourly timescales to offshore distances on the order of 100 km; the extent of alongshore mapping is limited only by the number of radar systems with overlapping coverage (Paduan and Washburn, 2013). In this sense, HFRs offer an unprecedented opportunity to give a step forward on the understanding of coastal ocean processes and transport.

The typical spatial scales resolved by the HFRs depend mainly on the resolution of the data, and thus mainly on the frequency of operation of the systems (Table 2). Several examples in the literature deal with the observation through HFR of small scale eddies. For instance, Park et al. (2009) and Archer et al. (2015) investigated O(10-20) km eddies along frontal regions of the Florida Current using a 16 MHz. Other authors have utilized very high frequency radars with a high horizontal resolution of (250 - 400m) to study O(2-3) km vortices over the shelf in different areas (e.g. Shay et al., 2000; Kim, 2010 or Kirincich, 2016).

TABLE 2- SEASONDE CODAR RADAR PERFORMANCE VS. FREQUENCY (COURTESY OF QUALITAS). [1]DEPTH AVERAGED CURRENT; [2]RANGE BASED ON 40W AVG POWER OUTPUT (SALINITY, WAVE CLIMATE AND RF NOISE MAY AFFECT THIS); [3]BASED ON BANDWIDTH APPROVAL ONLY - NO SYSTEM LIMITATIONS - HIGHER RESOLUTION WILL CAUSE SOME RANGE LOSS; [4]SIGNIFICANT WAVEHEIGHT AT WHICH 2ND ORDER SPECTRA SATURATES 1ST ORDER AND NO CURRENT MEASUREMENTS POSSIBLE .

Radar Frequency (MHz)	Radar Wavelength (m)	Ocean Wavelength (m)	Ocean Wave Period (s)	Depth of Current[1] (m)	Typical Range[2] (km)	Typical Resolution[3] (km)	Typical Bandwidth (kHz)	Upper $H_{1/3}$ Limit[4] (m)
5	60	30	4.5	2	175-220	6-12	15-30	25
12	25	12.5	2.5	1-1.5	60-75	2-5	25-100	13
25	12.5	6	2	.5-1	35-50	1-3	50-300	7
48	6	3	1.5	<.5	15-20	.25-1	150-600	3

The combination of HFR data with information on the water column dynamics from in situ moored instruments or remote sensors offer further interesting possibilities, since ecological quantities such pollutants like Floating Marine Litter (FML) and microplastics can be located deeper in the water columns and not only follow surface dynamics. An important open research line is to exploit the complementarity and synergy between HFR measurement in coastal areas and satellite remote sensing of currents on global scales (Pascual et al., 2015). Then, a step further consists of combining HFRs with numerical models, which can also be used to better understand the 4D ocean transports. A number of publications already exist showing the benefits of HFR surface currents assimilation, with a positive impact also at deeper levels (e.g. Paduan and Shulman, 2004).

Some limitations of this technology must be taken into account:

- HFRs provide data only at the surface within an integration depth ranging from tens of cms to 1-2 m, depending on the operating frequency. In fact, the effective averaging depth for surface current measurements by HFRs has been estimated as 5%–16% of the wavelength of the backscattering surface waves (Barrick, 1977; Fernandez et al., 1996; Stewart and Joy, 1974). See typical values in Table 2.

- Spatial and temporal data gaps can occur. One of the most common reasons to find spatio-temporal data gaps in radial (and total) data is the variation in the range of the measurements. This can be linked to environmental conditions as the lack of Bragg scattering ocean waves, severe ocean wave conditions (see table 2 for reference) or the occurrence of radio interference. The permanent spatial gap in the baseline, frequently located near the coastal area between the antennas, is also an issue than can be problematic for some areas.
- Data uncertainties. As described by Lipa (2013), if we assume that the radar hardware is operating correctly, we can identify the following sources of uncertainty in the radial velocities: (a) Variations of the radial current component within the radar scattering patch; (b) Variations of the current velocity field over the duration of the radar measurement; (c) Errors/simplifications in the analysis. For example incorrect antenna patterns (only for direction-finding systems) or wrong settings for the analysis, and errors in empirical first order line determination; (d) Statistical noise in the radar spectral data, which can originate from power-line disturbances, radio frequency interferences, ionosphere clutter, ship echoes, or other environmental noise (Kohut and Glenn, 2003).
- Complexity of the information provided – different scale processes (with different vertical extension) are observed simultaneously.

Related to the data uncertainties, it is worth mentioning that a number of validation exercises exist, based on comparisons of HFR currents against independent in situ measurements (ADCPs, drifters, see Chapman and Graber, 1997, Kohut and Glenn, 2003; Kaplan et al., 2005, Paduan et al., 2006; Ohlmann et al., 2007; Cosoli et al., 2010; Solabarrieta et al., 2014; Lorente et al., 2014, 2015, 2015b). These validation exercises can be limited by the fact that part of the discrepancies observed through these comparisons are due to the specificities and own inaccuracies of the different measuring systems. Indeed, the spatial and temporal scales measured with HFR are not the same that those of point-wise acoustic Doppler current profilers or drifters, so it can be expected that vertical or horizontal shear in currents contribute also to the RMSDs observed between measurements. This can explain the significant scatter found in the literature concerning point to point comparison between HFR and other in-situ measurements. When HFR data are compared with surface drifter clusters or ADCPs whose uppermost bins are not deeper than 5 m, RMSDs typical values range between 3–12 cm.s-1 (e.g. Liu et al., 2010; Ohlmann et al.; 2007, Molcard et al., 2009; Kalampokis et al., 2016).

As it will be described later on, the HFR community has started to work on the definition of the most suited QA/QC protocols for current data. The simplest QA/QC indexes are based on velocity metrics (radial and total velocities thresholds, first derivative analysis), while other indicators are based on radial and total coverage analysis, hardware status, quality of the received signal (Kirincich et al., 2012). Present efforts point towards a common definition for QA/QC protocol and reference threshold values.

3.1.4 Integration with other observing /modelling coastal systems

As already commented in the previous paragraphs, an open research line is the exploitation of the complementarity and synergy between HFR measurements with other observing systems in coastal areas. Similarly the complementarity between HFR and satellite remote sensing of currents on larger scales is under examination. Indeed, emerging studies are dedicated to the evaluation of the capabilities of altimetry, and HFRs offer useful data that can help to optimize processing methods for altimeter tracks in coastal areas (Pascual et al., 2015; Troupin et al., 2015; Roestler et al., 2013). The use of HFR data in combination with other in-situ and remote observing systems offers a unique opportunity to explore ocean processes taking into account a wide range of spatial and temporal scales.

Besides, a number of publications already exists about the assimilation of surface HFR data (Barth et al., 2008, 2011; Paduan and Shulman, 2004; Shulman and Paduan 2009; Gopalakrishnan and Blumberg 2012; Iermano et al., 2016; Stanev et al., 2015, to provide a few examples). These studies have shown the feasibility of HFR data assimilation into numerical models. Under different approaches (correcting either the model state at the surface or open boundary conditions of the model) HFR are examined as a tool for improving current forecast provided by numerical models. HFR data assimilation in models is a particular challenge which starts by obtaining accurate simulation in the study area. Thus, the careful validation of the simulation with respect to the different ocean processes and, indeed, those at HF, is a necessary starting point towards successful numerical data-assimilating model configurations. Another complex issue to address is related to the physical content of the simulations and the observations to assimilate. For instance, tides as well as processes related to surface waves may not be fully represented in models while their signature can be very intense in HFR currents (e.g. Solabarrieta et al., 2014). Finally, a detailed understanding of HFR measurements error (amplitude, time and space structure) is a non-trivial prerequisite before the data can be assimilated.

Other approaches to obtain operational forecast from HFR data have been developed using empirical models (Frolov et al., 2012, Orfila et al., 2015, Barrick et al., 2012, Solabarrieta et al., 2016, Berta et al., 2014). Results of these are promising, however, a better understanding of the HFR measurement errors, the observability of the ocean processes and their variability are the keys to improve the forecasts these methods can provide (Solabarrieta et al., 2016).

3.2 Coordination in HFR community towards improving applications

Around 400 HFR sites have been already installed worldwide, and used in a diverse range of applications (see Paduan and Washburn, 2013, and Roarty et al., 2016). In Europe, the number of HFR systems is growing with over 50 HFR sites currently deployed and a number in the planning stage. The growing number of HFRs, the optimization of HFR operation against technical hitches and the need for complex data processing and analysis, make urgent to increase the coordination in the HFR community in order to allow a: (i) extended use of HFR data through homogenized data bases and quality control procedures and a more efficient data sharing; (ii) increase in HFR applications through a more efficient data sharing and the development of HFR products adapted to the final user needs; (iii) integration of HFR data in CMEMs.

EuroGOOS has played an important role since the initial phase of Copernicus, in particular promoting co-operation, co-production and sustained observations that are mandatory to meet the requirements for all marine-related purposes, including re-search, operational oceanography, and regular assessments of the state of our seas and oceans. EuroGOOS Task Teams are linked to operational networks of observing platforms. They promote scientific synergy and technological collaboration among European observing infrastructures. Task Team members exchange open source tools, collaborate in areas of common interest, and jointly make European data available to the EuroGOOS ROOS regional data portals, which in turn are feeding data to EMODnet and CMEMS.

INCREASE project contributes to this necessary networking approach planning two workshops (HFR experts and HFR users). In the first one, HFR Experts workshop which will take place in Italy (La Spezia) on 13th-15th September 2016, a session will be dedicated to national and international networks highlighting the benefits of previous networking experience (IOOS in US, ACORN in Australia). To achieve the efficient management of a HFR European network will be based on the exchange of experience between HFR operators, the knowledge sharing about the transfer of user driven products, from the scientific community to stakeholders and blue economy.

In this context, INCREASE aims to begin the necessary developments for the integration of the existing European HFR operational systems into the CMEMS, following some key main objectives: provide HFR quality controlled real-time surface current data for direct use and through key derived products (gap-filled data, filtered data, short-term prediction and derived Lagrangian products); set the basis for the management of historical data and methodologies for reprocessing existing data sets, using advanced delayed mode quality-control techniques, to obtain the best possible continuous surface coastal ocean observations; boost the use of HFR data for improving CMEMS numerical modelling systems, through model validation, model-data blending or data assimilation; enable an HFR European operational node to ensure the operational availability of HFR data and data products and the link with operational CMEMS. INCREASE will assist CMEMS in attracting new users and address some specific developments based on users' requirements. More specifically special attention will be paid to the need for improving the link between core services and downstream services, especially dedicated to the monitoring, surveillance and management of the coastal zone.

3.3 CMEMS SE main objectives

Regarding the identified short- to mid-term objectives of the R&D key priorities described in the CMEMS Service Evolution Strategy, the development of the European HFR network and the application of the corresponding products could impact for the following aspects:

(i) R&D objectives in 4.1-Observation infrastructure and related developments, including : Adaptation of existing quality-control methods to new observing system components […]; Developments of new protocols for real-time quality checking […]; More consistent processing and assembly of data from different, heterogeneous observation platforms […]; Network studies that will provide guidance to deployments[…];

(ii) R&D objectives in 4.2-From big data streams to high-level data product, including: Specific processing and mapping of product uncertainties following world class processing and calibration/correction, for direct use and for assimilation ; Reprocessing of existing data sets with more advanced quality control methods, to facilitate the continuous ocean reanalysis activities; Production of additional physical variables from existing instruments; Preparation of composite data product[…]; Development of interfaces with the EMODnet system for long term archives of multidisciplinary data ;

(iii) R&D objectives in 4.3-Advanced assimilation for large-dimensional systems, including: Development of a capacity to assimilation new/novel observations […]; Development of community tools and diagnostics […];

(iv) R&D objectives in 4.4- Observing systems: impact studies and optimal design, including: Development of automatic observation evaluation tools […]; Impact studies of new observation data types or products for ocean analysing and forecasting (e.g. HFR, etc.) […]; Methods for explicit estimation and treatment of bias and correlated observation errors.

4 European HFR systems development

The limitations and needs for networking identified in the previous section could slow down the expansion of existing HFR systems in Europe if a proper coordination between HFR operators and users is not established. A first step towards a pan-European HFR network is to perform a diagnostic of the present status of European HFR systems. A special effort has been done to build this section to provide the needed information in order to ensure the bases of the roadmap towards the HFR integration in CMEMs are set.

4.1 Survey on European HFR systems

In Europe, the use of HFR systems is growing with over 50 HFRs currently deployed and a number in the planning stage. In order to build an up-to-date inventory of operational HFR systems and operators the INCREASE team, in close collaboration with the EuroGOOS HFR Task Team and the JERICO-Next project, launched a European survey to diagnose the present status of different HFR systems available in Europe.

The survey consisted in 46 questions oriented to provide information on four axes:

- Contact people for each network or system
- Technical information on the network, number, names, locations, working parameters of the sites (including questions on maintenance procedures and experience of interference problems)
- Technical information about the data formats, sharing protocols and policies, QA/QC and processing
- Areas of application of the data and identified users (including specific questions related to data assimilation)

The survey was launched in June 17th and was sent to the EuroGOOS HFR Task Team expert's mail-list, including JERICO-Next collaborators and other identified key actors. It was closed July 27th, gathering responses from 28 European institutions and information on more than 70 HFR systems.

The complete list of survey questions are provided in annex 1. The results of the survey have been gathered in a specific publication that will be maintained as living document to be updated each time new information concerning existing or future systems is made available (see Mader et al., 2016).

4.2 Detailed up-to-date inventory of the operational HFR systems and operators

The INCREASE European HFR survey gathered information from 28 institutions, 23 of whose are operators of ongoing or past HFR networks. A total of 72 sites (conforming 28 networks) were listed from the survey results, 51 of those sites are ongoing (20 networks). Within the remaining sites there are 9 past installations (3 past networks) and 12 future installations (5 new networks). The information provided in the following describes several aspects of the ongoing and past HFR networks (N=23) and their corresponding sites (N=60). Although we believe this survey provides a very complete view of the HFR activity in Europe we are aware of some additional past HFR installations which were not listed here, because they were very short term or experimental installations or they have been not identified by the users of the survey (e.g. two HFRs were operated close to the Rhone river mouth, NW Mediterranean, at least from June 2006 to January 2007, see Schaeffer et al., 2011).

4.2.1 General view of European HFR systems

Based on the responses provided, 92% (47) of the ongoing installations (51) are meant to be permanent. The remaining systems are temporary, with undefined dates of end of use. Figure 5 shows the location of the systems listed by the survey, with a graphical representation of the footprint areas for each antenna.

The distribution of the identified ongoing and past networks (N=23) amongst the ROOS areas (see section 4.3.2) is: 52% (12) in MONGOOS, 26% (6) in IBIROOS and 22% (5) in NOOS. In terms of number of sites MONGOOS is again the most densely populated, it contains 31 sites (52%). IBIROOS and NOOS contain 17 sites (28%) and 12 sites (20 %), respectively.

Figure 6 shows the evolution in time of the number of HFR systems in Europe, following the current inventory. The number of systems is growing with time and the plans show the increase to continue in the next year.

In addition to the general statistics presented here, a complete characterization of the existing systems has been performed, and it is presented in the corresponding tables of Annex 2. Most of the European HFR networks are (or have been) operated for several years and are built of 2 sites. The used systems range from very high frequency systems like the one in Ria de Vigo, working at frequencies of 46.5 MHz (thus providing horizontal resolution for total currents coarser than 200 m) to long range systems working at 4.5 MHz (providing horizontal resolution of 5 km) used in Spain or UK. They offer typically temporal resolution of 1 hour or less and variable spatial coverage depending on their working frequency (see Figure 5).

Only 28 % of the systems are connected to European Data System - EMODnet Physics. Some of them through other national networks like Puertos del Estado and some other are also included in other National and International Networks like: MOOSE Network: www.moose-network.fr; GEO Global High Frequency Radar Network: http://marine.rutgers.edu/~hroarty/GEO/ESRI and IBERORed: www.iberoredhf.es.

The most interesting is that the majority of the institutions whose systems are not connected express the will to do it in the future. 35 new sites are potentially being added to the list of 17 sites already connected in the next months, provided the correct tools and needed guidance are produced.

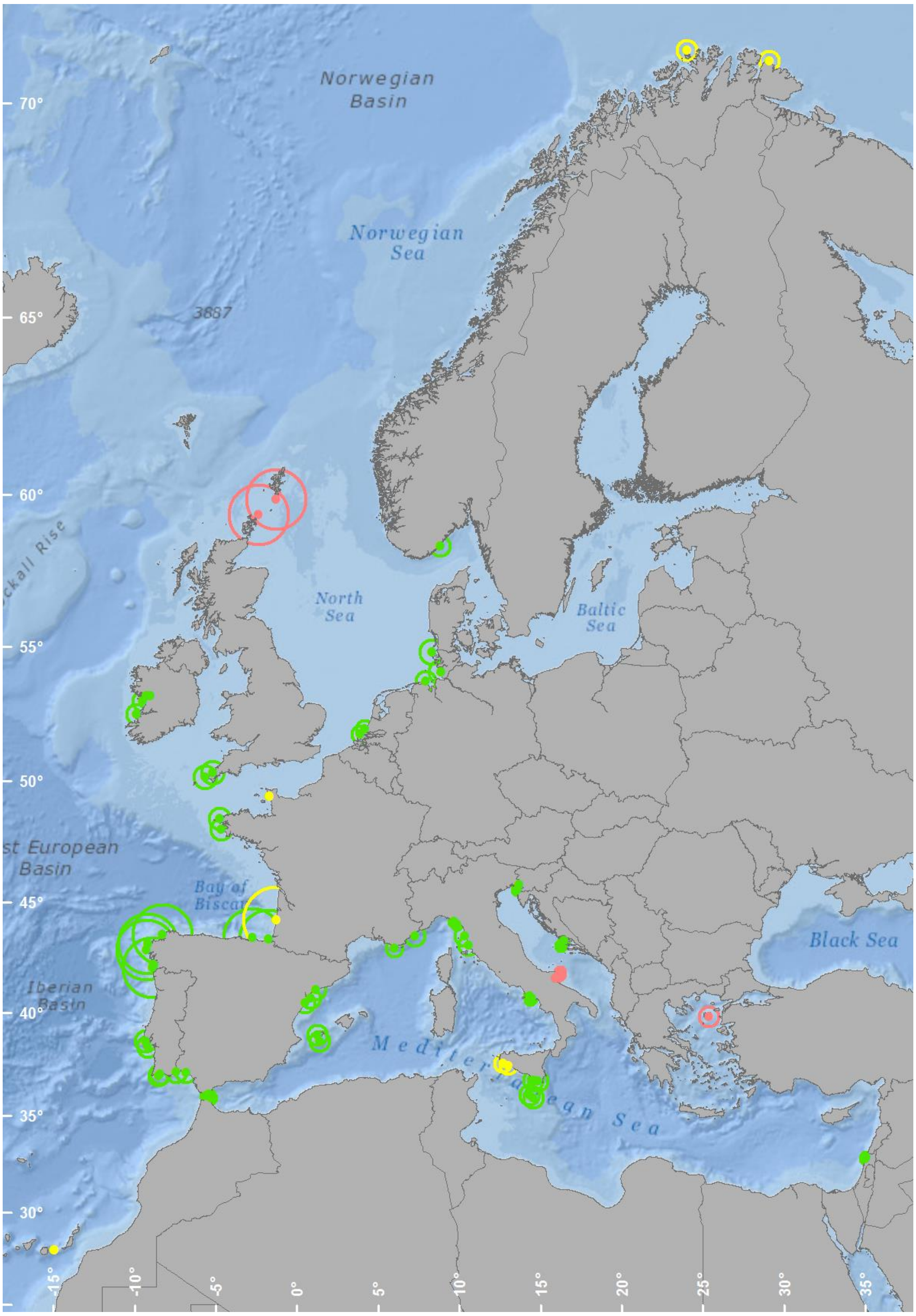

FIGURE 5: MAP WITH THE LOCATION OF THE 72 EUROPEAN HFR SITES LISTED IN THE SURVEY, AND THEIR RADIAL COVERAGE (REPRESENTED BY THE CIRCLES SCALED TO TYPICAL RADIAL RANGE ASSOCIATED TO THE FREQUENCY OF OPERATION OF EACH OF THE SYSTEMS) . GREEN: ONGOING; RED: PAST; YELLOW: FUTURE INSTALLATIONS.

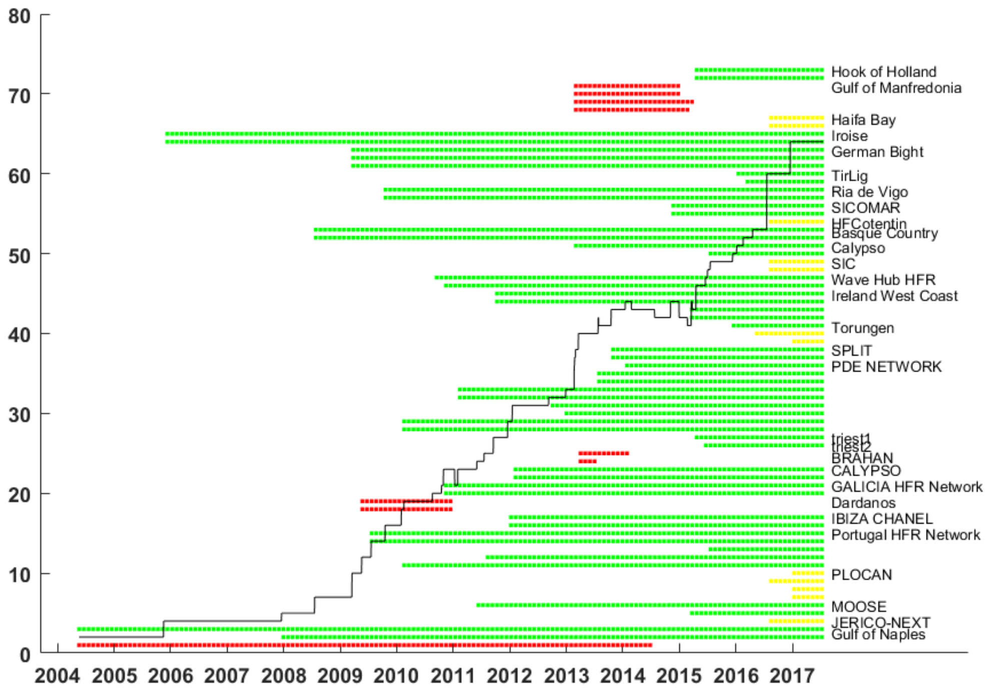

FIGURE 6: EVOLUTION OF THE NUMBER OF EUROPEAN HFR OPERATIONAL RADARS WITH TIME. THE BOLD BLACK LINE SHOWS THE NUMBER OF OPERATIONAL SYSTEMS PER YEAR (Y AXIS). THE TIMELINE OF THE EUROPEAN SYSTEMS, FOLLOWING THE INVENTORY, IS PROVIDED BY THE DISCONTINUOUS LINES. PAST SYSTEMS ARE PLOTTED IN RED, FUTURE SYSTEMS IN YELLOW AND PRESENT SYSTEMS IN GREEN. THE NAME OF THE NETWORKS AS PROVIDED IN THE SURVEY IS GIVEN BESIDE THE CORRESPONDING SITES' TIMELINES.

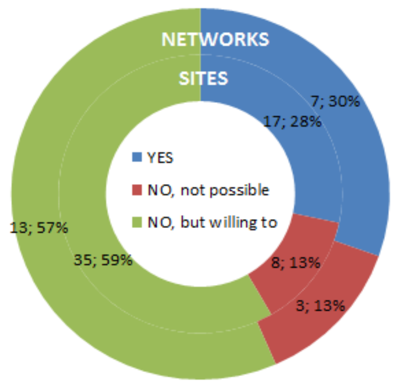

FIGURE 7: PERCENT OF NETWORKS AND SITES CONNECTED TO THE EUROPEAN DATA SYSTEM

4.2.2 HFR systems operation and maintenance

78 % of the European HFRs (N=60) are being or have been operated using DF and 20 % using BF in a phased array. One system follows in the middle of these two categories, using DF on eight receiving antenna. The two main manufacturers identified are CODAR and WERA, HELZEL Messtechnik.

The systems are operated by different kind of institutions, from Academy to technological centres and meteorological agencies to governmental organizations. The frequency of in situ technical maintenance operations is variable. Most part of the systems (74%) are controlled in situ periodically (every 3-6 months or yearly). For 20% of the systems in-situ operations are sporadic; they are performed after changes at the antennae arrays, if technical issues appear or when possible. For several of the systems additional remote check is performed in a monthly basis or even daily.

The occurrence of interferences is also variable with around 30% of the systems experiencing interferences at some level. These are observed to reduce the range of the data and/or to reduce the signal to noise ratios (SNRs). In the cases where there is continuous interference, it is observed mostly in 13.5 MHz systems, during the afternoon. These interferences are skipped in some cases by changing the system operation bandwidth. Occasional interferences seem to be related to ambient noise at different times during the day or to the ionosphere effect during the evenings (and especially in summer time).

4.2.3 Existing data formats and QA/QC protocols

Data formats and QA/QC protocols in use by the European HFR operators (N=23) are diverse (Figure 8). Most of the operators are using Manufacturer's data formats for radial data, although around a 26% of the systems are already using netcdf format for radials. In the case of total data the number of networks already using netcdf formats in addition to that of the manufacturer's is much higher (around 70%). Others include basically ASCII formats defined by the institution producing the data. NetCDF for radial data in use are those defined by RITMARE standards and proposed as standard for the European network (ongoing work in JERICO-Next project). In the case of NetCDF for total data, they follow different standards, with data files following CF-1.3, CF-1.4 and CF-1.6 conventions, ACDD, INSPIRE, Unidata Dataset Discovery v1.0 and or NOAA GNOME format compliant to NetCDF formats without compliance.

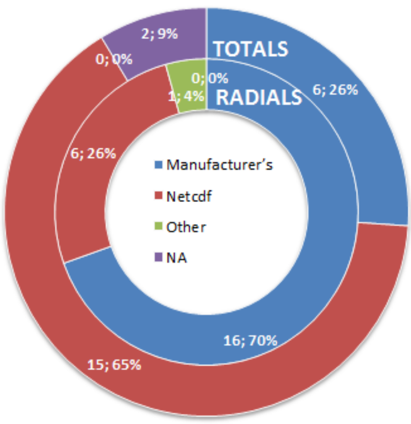

FIGURE 8: DATA FORMAT IN USE FOR RADIAL AND TOTAL DATA BY THE EUROPEAN HFR OPERATORS (N=23).

As it can be observed in TABLE 3, QA/QC procedures in use for both real time and delayed mode are, the most frequently, those of the manufacturer's.

TABLE 3: QA/QC PROCEDURES CHOSEN BY THE EUROPEAN HFR OPERATORS (N=23).

	Basic QA/QC based on manufacturer's recommendations	Advanced QA/QC based on other parameters
Real time	78% (18)	22% (5)
Delayed time	65% (15)	35 % (8)

The QA/QC advanced procedures are diverse, some examples provided for real time data are:

- At spectral level: use of SNR, 6dB peak width
- System functioning diagnostic parameters at each radial station: radial vector count, average radial bearing, difference between the average radial bearing from measured and ideal patterns
- For total velocity (vector) data: velocity and GDOP Thresholds, spatial continuity, flags on spikes, gradients and out-of-range values,
- QA/QC based in the international standards used in MARACOOS by Roarty et al., 2012.

Some examples provided for advanced QA/QC for delayed time, in addition to those for real time, are:

- Spatial and temporal continuity, distributions of first and second order derivatives of radial and vector velocities, MAD filter, deviation from a reference signal
- Validation exercises versus other in-situ or remote data as: current meters; different drifter designs (shapes and drogue); surface glider geostrophic velocities; SARAL/AltiKa altimetric velocity computation; Comparison with numerical operational models.

Following the survey responses, represented in Figure 9, QA/QC are mostly applied jointly to both total and radial data (35%), but several operators also apply QA/QC at the three levels: total, radial and spectral (19%). Other choices exist, for instance applying QA/QC only at total or radial levels or those, including AdHoc QA/QC procedures (as indicated by one of the operators).

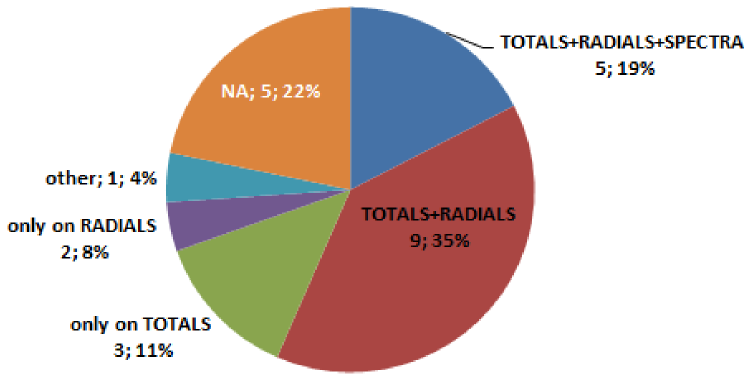

FIGURE 9: DATA LEVELS USED FOR QA/QC PROCEDURES BY THE EUROPEAN HFR OPERATORS (N=23).

Most of the operators (N valid answers= 14) use the Least Square Method (>90%) to produce totals, but other methods like OMA (Kaplan and Lekien, 2007) are also quite extended (around 30% of the responses). The most common software used for combining radials into totals is the one provided by the manufacturers (in around 68% of the cases, N valid answers= 19) although other tools like the Matlab® HFR_toolbox (26%) and specific software developed by the operators (19%) are used in other cases in addition or as alternative to manufacturer's software.

4.2.4 HFR surface ocean current data sharing protocols

The most part of the networks (70%) are applying an open data policy with no restrictions of use (Figure 10). From those, 14 operators are providing free and open data under no specific licensing. Two networks, operated by CNR-ISMAR, are offering their data under Creative Commons Attribution 4.0 International License (see http://creativecommons.org/licenses/by/4.0).

The remaining 30% of the data are not all fully restricted. For some networks there is free access to the data depending on the final user (for instance, data is open for academic use), or the resolution of the product (so only high resolution products are restricted and only available upon request). Other data are only available upon request and in one case data are restricted but near-real time visualization and validation of the current maps are available at the institution web.

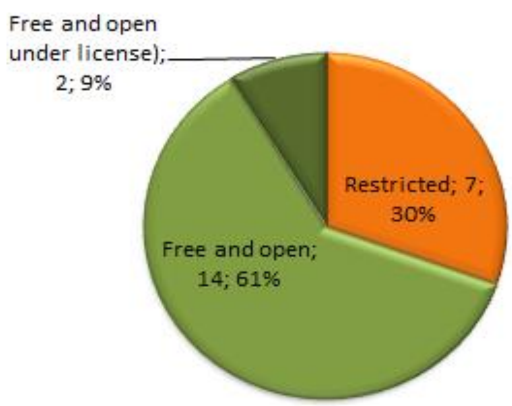

FIGURE 10: DATA POLICY (N=23)

Concerning the online availability of the data from the listed networks, while the 75% of the real time data are online, only the 51% of the historical data are (Figure 11).

The most used protocol to put the data online is the Thematic Real-time Environmen-tal Distributed Data Services (THREDDS), although other possibilities coexist (e.g. using WMS-Web Map Service through the operator webpage, or other protocols like ftp; Some data are available through the institutions' data server or portals).

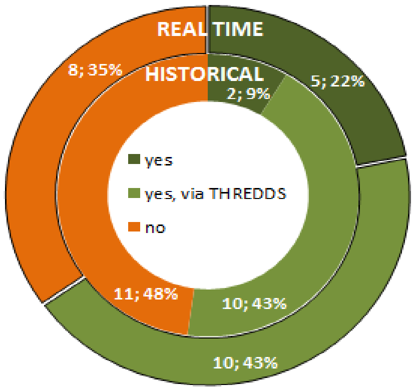

FIGURE 11: DATA AVAILABILITY AND DATA SHARING PROTOCOLS (N=23)

4.2.5 Use of the HFR for data assimilation

Only a 26% of the operators state that their data are currently being assimilated in operational model (N=23). 72 % (N=23) state that their data being currently or not assimilated in operational models have been used or are planned to be used in data assimilation (DA) exercises. Two PhD thesis have been listed where HFR data has been used for DA: Solène Jousset ("Assimilation de données de radar haute fréquence en Mer d'Iroise", 2016, University of Western Brittany) and Julien Marmain ("Coastal circulation in the North Western Mediterranean: current measurements by HFR and coupling with a numerical model", 2013 MIO/UTLN). Several examples of DA exercises or future experiments using HFR data are provided:

- ➔ UK Met-office will be evaluating value of Brahan DA into their operational circulation models. A PhD at Imperial College London in under development on this.
- ➔ IH Cantabria are working on DA using HFR data from University of Vigo
- ➔ HZG is working in the development of DA schemes as well as real time DA for current prediction (for more details: codm.hzg.de/codm)
- ➔ LaMMA Consortium has plans for performing DA in their operational regional ocean model.
- ➔ Instituto Hidrografico is working on DA on HYCOM model towards the development of a drift model, for oils spills, SAR operations and operational products for military use
- ➔ The Basque Country HFR data are being used for DA experiments at the UPV (Basque Country University)
- ➔ At the University of Palermo there are plans to assimilate the data in numerical models; they are working presently on data gap filling.
- ➔ At the National University of Ireland they have assessed 5 different DA systems and are now implementing some of them into their forecasting models
- ➔ The University of Malta HFR data will be assimilated with a coastal model of the Maltese islands
- ➔ SOCIB, with other colleagues, are working on HFR data assimilation in the framework of the project JERICO-Next: Task 3.7.3 - Optimization of HFR DA for the tracer transport. Deadline: March 2017. SOCIB is involved in DA on the Western Mediterranean OPerational model (WMOP)

To the question about what HFR data are being used or planned to be used in DA exercises 50% of the valid responses (N=15) are or plan using radials and 50% are or plan using totals. So no preferences for one level of data are shown by the operators involved in DA.

4.3 HFR networking at national, European and international levels

In the last years several groups have been working at European and international levels towards the coordinated development of the coastal HFR technology and its products, mainly based on the observation of surface ocean currents. In Europe this effort is being made in the framework of different European and international initiatives which are: EuroGOOS Ocean Observing HFR Task Team and GEO GLOBAL HFR Task, and a key ongoing European project JERICO_NEXT (Joint European Research Infrastructure network for Coastal Observatory – Novel European eXpertise for coastal observaTories, EC's H2020 2015 Programme, Contract#654410). Other existing initiatives are gathering national experts or international expert teams working in common some regions through the European coasts. This activity is described in the next subsections in order to provide a background on the European and international efforts towards an unified coastal HFR network.

4.3.1 National European HFR Networks

The Italian Coastal Radar Network.

The Italian flagship project RITMARE (www.ritmare.it) has been focusing its efforts on the integration of the existing local observing systems, toward a unified operational Italian framework and on the harmonization of data collection and data management procedures. A specific action is dedicated to the establishment of a national coastal radar network that includes both HF and X-band technologies (Corgnati et al., 2015). Furthermore, a dedicated action has been undertaken within RITMARE to foster interoperability among data providers. An IT framework is under development that aims at providing software tools for data collection and data sharing. It suggests harmonization on data format definition, QA/QC strategies, data management and dissemination policies. The coastal radar action within RITMARE project is led by CNR-ISMAR.

The Italian coastal radar network is presently composed of five sub-networks managed by the partner institutions, namely the Institute of Marine Science (ISMAR-CNR), the OGS-National Institute of Oceanography and Geophysics, the Institute for Electromagnetic Sensing of the Environment (IREA-CNR), AMRA and CoNISMA local research unit at DiST-Università degli Studi di Napoli “Parthenope”, and Institute for Coastal Marine Environment (IAMC-CNR) UOS Messina (Figure 12). The network gathers both X-band radars (7-12.5 GHz) and HFRs (3-30 MHz). In the next couple of years the national network will expand as OGS and CNR-ISMAR will be deploying two more HFRs each. Other institutions that are planning or operating HFRs nodes (LAMMA, ARPA Sicilia and Università di Palermo, Italian Navy) have been invited to join the network.

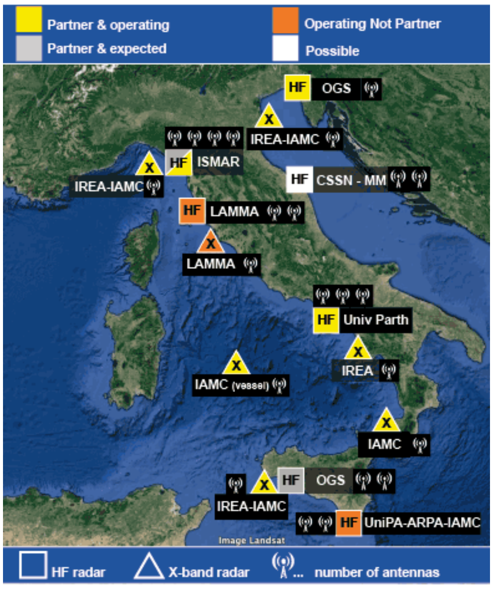

FIGURE 12: THE ITALIAN COASTAL RADAR NETWORK STRUCTURE. THE SUB-NETWORKS PRESENTLY ACTIVE IN THE NETWORK ARE DEPICTED IN YELLOW, NODES ALREADY OPERATIVE OUTSIDE THE NETWORK ARE DEPICTED IN ORANGE, SUB-NETWORKS TO BE DEPLOYED ARE DEPICTED IN GREY.

The HFR nodes of the Italian coastal network are CODAR and WERA, HELZEL Messtechnik. The three operative sub-networks are deployed in the Gulf of Trieste (managed by OGS), in the Gulf of Naples (owned by AMRA scarl and managed by the local research unit of CoNISMa at the Parthenope University of Naples) and in the Ligurian Sea (managed by CNR-ISMAR).

In the framework of the RITMARE project and jointly with the HFR Task Team coordinated by EuroGOOS and the Jerico-Next H2020 project, the design and the standardization of QA/QC strategies at Italian and European level is under development.

In order to produce data in interoperable formats, according to the standards of Open Geospatial Consortium (OGC) (Botts et al., 2008) for the access and delivery of geospatial data, the netCDF file format has been chosen, and a metadata structure has been built according to the Radiowave Operators Working Group (US ROWG) standard (Harlan et al., 2010) and compliant to the Climate and Forecast (CF) Metadata Conventions CF-1.6 (Gregory, 2003) and INSPIRE directive (Bartha et al., 2011). Each node of the network generates its hourly surface current velocity data (both radial and total velocity) in netCDF format. Some of the partners automatically upload, aggregate and attach their hourly netCDF files to a THREDDS catalogue in quasi-real time.
The catalogue provides metadata and data access and visualization (http://ritmare.artov.isac.cnr.it/thredds/ritmare/CoastalRadarOS/catalog.html). Within the end of 2017, it is expected that all the partners will implement this workflow.

IBERORED

The working group of the Iberian Peninsula (IBERORED HF, see www.iberoredhf.es) is an inter-institutional network created with the objective of improving the visibility and exploitation of data generated by HFRs on Iberian Peninsula shores. It consists of those Spanish and Portuguese institutions that meet one or more of the following requirements: (i) being HFR owners or managers; (ii) being users or developers of tools for exploitation of the data and/or (iii) being HFR technology providers. The following institutions are part of the network today: Cetmar - Centro Tecnológico del mar; Intecmar - Instituto Tecnolóxico para o control do medio mariño de Galica; Instituto Hidrográfico of Portugal; AZTI – Tecnalia; Euskalmet; IH Cantabria - Instituto de Hidráulica Ambiental;Qualitas REMOS; MeteoGalicia; Puertos del Estado; SASEMAR - Salvamento Marítimo; SOCIB; Universidad de Cádiz; Universidad de Vigo. The activities of the IBERORED HF are organized in 5 working groups: 1- Maintenance practices; 2- Quality control Procedures; 3- Data management; 4- R&D activities and 5-Applications and Downstream activities. IBERORED is maintained without dedicated funding. The community has met in three occasions in the period 2009-2015 and is working on a joint publication on the description of the activities of the five working groups, as well as future needs and working plans. The HFR systems of IBERORED network are not providing data through homogenized formats/protocols. Several of them are included in the Puertos del Estado network (see, http://portus.puertos.es/), while others systems data is available online by other means (e.g. individual data servers, directly via EMODnet).

4.3.2 The EuroGOOS Ocean Observing HFR Task Team

In the complex European coastal observing infrastructures, single institutions are usually in charge of the management of the observing systems and the first level of data processing for their own applications. However the development of Operational Oceanography involves major investments in infrastructures, including new observing systems, enhancements and coordination of the existing ones and high performance computing hardware, as well as human resources with appropriate training. Such investments are difficult to be made by a single country especially when it comes to open ocean systems either at regional or wider scale. A key point is then an active cooperation toward the development of a Global Ocean Observation System.

In order to tackle this critical issue, since 1994, EuroGOOS is coordinating the development and operation of (European) regional operational systems. Five systems are at present part of EuroGOOS: the Arctic (Arctic ROOS), the Baltic (BOOS), the North West Shelf (NOOS), the Ireland-Biscay-Iberian area (IBI-ROOS) and the Mediterranean (MONGOOS). EuroGOOS also contribute the Global Ocean System as one GRA of GOOS and in partnership with JCOMM.

These regional assemblies are the key structures in which it is possible to discuss to promote active cooperation at different levels in order to maximize the efficiency of national resources and investments in operational oceanography. This is done via specific and thematic working groups that collect and express the best expertise on specific fields. Recent EU marine data infrastructures and EU Programs are widely based on EuroGOOS and ROOSs achievements:

In 2014, the EuroGOOS Ocean Observing Task Teams, have been launched to organize and develop different ocean observation communities and foster cooperation to meet the needs of the European Ocean Observing System. In particular, the HFR Task Team was set up to promote coordinated activities in Europe around the development and use of this coastal technology.

The purpose of the HFR Task Team is to coordinate and join the technological, scientific and operational HFR communities at European level. The goal of the group is to reach the harmonization of systems requirements, systems design, data quality, improvement and proof of the readiness and standardization of HFR data access and tools.

The guidelines for the HFR Task Team are:

1. To develop the European HFR network and assist the standardization of HFR operations, data and applications, including:
    - All applications of HFR (surface current, wave, target detection…)
    - Applications in integration with other technologies (e.g. satellite, X-band, fixed platforms, gliders, numerical modelling…)
2. To contribute to the development of the European Ocean Observing System (EOOS)
3. To ensure the integration of HFR networks in the European Coastal Marine Service
4. To act as the European component in the global HFR community
5. To ensure data availability via the ROOS data portals
6. To provide recommendations (from operators to end-users) on:
    - Data structure, format and dissemination (interoperability of datasets)
    - Quality control and validation procedures
    - Technological solutions
7. To be a framework for:
    - Sharing success stories and difficulties
    - Improving administrative procedures, regulations at European level that can be adopted in member states
    - Providing and exchanging open source tools (data analysis, applications…)
    - Promoting scientific synergies for key questions
    - Filling gaps and looking for complementarity with other technologies or modelling products

The first milestone of the HFR Task Team was a side event of the past October 2014 EuroGOOS conference which established the basis for a motivated, dynamic group that is linking its activities to similar international initiatives (GEO HFR Task) to facilitate the adoption of harmonized technologies at European level and support key European end user requirements. In 2015, a pilot action coordinated by EMODnet Physics, with the support of the HFR Task Team, begun to develop a strategy of assembling HFR metadata and data products within Europe in a uniform way to make them easily accessible, and more interoperable.

4.3.3 The Copernicus Marine Environment Monitoring Service

The Copernicus Marine Environment Monitoring Service (CMEMS) has been designed to respond to issues emerging in the environmental, business and scientific sectors. Using information from both satellite and in situ observations, it provides state-of-the-art analyses and forecasts daily, which offer an unprecedented capability to observe, understand and anticipate marine environment events. The CMEMS In Situ Thematic Assembly Centre (INSTAC) was designed and developed on JCOMM and the EuroGOOS ROOSs experience and expertise, which was further developed during the MyOcean projects. MyOcean enabled to run a demonstration pre-operational service for 6 years that is now fully integrated and constituting the CMEMS INSTAC.

4.3.4 The SeaDataNet infrastructure

Another central European institution for ocean and marine data management is SeaDataNet (www.seadatanet.org). The SeaDataNet (SDN) infrastructure network involves data centres of 35 countries, active in data collection. The networking of these professional data centres, in a unique virtual data management system provide integrated data sets of standardized quality on-line historical data.

The SeaDataCloud project, launched in 2016, will contribute to the integration and long term preservation of historical time series from HFR into the SDN infrastructure. The main steps in the HFR SeaDataCloud subtask for the integration of the HFR historical data into the SeaDataNet architecture are: (i) definition of standard interoperable data and Common Data Index (CDI) derived metadata formats for historical radial and total velocity data; (ii) definition of QC standard procedures for historical radial and total velocity data, with particular focus on data versioning (iii) design and implementation of an open tool (to be run on the cloud architecture) for the conversion of native HFR data (both radial and total velocity data) into the standard data and metadata formats and for the production of related CDIs; and (iv) implementation of prototype data access services for HFR in coordination with CMEMS.

4.3.5 The European Marine Observation and Data network: EMODnet

The European Marine Observation and Data network EMODnet was first coined in 2006 in the preparations of the EC Integrated Maritime Policy as a way to provide a sustainable focus for improving systematic observations (in situ and from space), interoperability and increasing access to data, based on robust, open and generic ICT solutions. The aim has always been to increase productivity in all tasks involving marine data gathering and management, to promote innovation and to reduce uncertainty about the behaviour of the sea. EMODnet has since been promoted as a key tool to lessen the risks associated with private and public investments in the blue economy, and facilitate more effective protection of the marine environment. Since its adoption as a long-term marine data initiative, EMODnet has been developed through a stepwise approach in three major phases.

- Phase I (2009-2013) developed a prototype (so called ur-EMODnet) with coverage of a limited selection of sea-basins, parameters and data products at low resolution;
- Phase II (2013-2016) works towards an operational service with full coverage of all European sea-basins, a wider selection of parameters and medium resolution data products;
- Phase III (2015-2020) will work towards providing a seamless multi-resolution digital map of the entire seabed of European waters providing highest resolution possible in areas that have been surveyed, including topography, geology, habitats and ecosystems; accompanied by timely information on physical, chemical and biological state of the overlying water column as well as oceanographic forecasts.

Currently, EMODnet is entering in the third phase of development and provides access to marine data, metadata and data products spanning seven broad disciplinary themes: bathymetry, geology, physics, chemistry, biology, seafloor habitats and human activities. The development of EMODnet is a dynamic process so new data, products and functionality are added regularly while portals are continuously improved to make the service more fit for purpose and user friendly with the help of users and stakeholders.

Each theme is looked after by a partnership of organisations that have the necessary expertise to standardise the presentation of data and create data products. From the onset, EMODnet has been developed based on a set of core principles:

- Collect data once and use them many times;
- Develop data standards across disciplines as well as within them;
- Process and validate data at different scales: regional, basin and pan-European;
- Build on existing efforts where data communities have already organised themselves;
- Put the user first when developing priorities and taking decisions;
- Provide statements on data ownership, accuracy and precision;
- Sustainable funding at a European level to maximise benefit from the efforts of individual Member States;
- Free and unrestricted access to data and data products.

EMODnet Physics is one of the seven thematic lots, operating since 2010, and it is designed to be one stop access point to near real time and historical data on physical conditions of seas and oceans. EMODnet Physics is developed in cooperation and coordination with EuroGOOS and ROOSs and on other existing (major) European integrators infrastructure (CMEMS and SDN).

In this context, the coordination, integration and cooperation between EMODnet Physics and CMEMS – INSTAC (former MyOcean) has resulted in a better and stronger involvement of the providers, a continuous improvement of the available in situ data products (more and better data), an involvement of a wider audience (diversification) of intermediate users (easier – different data and product access).

The portal is providing a single point of access to recent and past data and products of: wave height and period; temperature and salinity of the water column; wind speed and direction; horizontal velocity of the water column; light attenuation; sea ice coverage and sea level trends. EMODnet Physics is a dynamic system, continuously enhancing the number and type of platforms in the system by unlocking and providing high quality data from a growing network of providers, e.g. the European HFR community.

In collaboration and coordination with EuroGOOS and its HFR Task Team, EMODnet Physics proactively worked on HFR data stream management, harmonization and organization and it is now connected and presenting data and data products from 26 antennas (http://www.emodnet-physics.eu/map/)

4.3.6 HFR international networks and initiatives

Integrated HFR observatories providing real-time information with unified Quality Assessment and Quality Control standards are operating in the United States as part of the US-IOOS (http://www.ioos.noaa.gov/hfradar) (Harlan et al., 2010) and in Australia within the Australian Coastal Ocean Radar Network (ACORN) (Heron et al., 2008) (http://www.ees.jcu.edu.au/acorn). These networks support agencies for SAR applications and pollution mitigation (Harlan et al., 2011). The HFR networks operating in Asia and Oceania countries were recently censused by the 1st Ocean Radar Conference for Asia (ORCA) (Fujii et al., 2013).

The Group on Earth Observations (GEO), launched in response to calls for action by the 2002 World Summit on Sustainable Development and by the G8, is coordinating international efforts to build a Global Earth Observation System of Systems (GEOSS). These high-level meetings recognized that international collaboration is essential for exploiting the growing potential of Earth observations to support decision making in a complex and environmentally stressed world. The GEO Work Plan 2012-2015 endorsed a task to plan a Global HFR Network for data sharing and delivery and to promote the proliferation of HFRs. NOAA (USA), with a small international co-chair group, has taken the lead in building this network and in promoting activities related to this task.

The Global HF Radar Network is collaborating to increase the numbers of coastal radars; ensure that HFR data is available in a single, standardized format; make/use a set of easy-to-use, standardized products; assimilate the data into ocean and ecosystem modelling; develop emerging uses of HFR.

4.4 HFR current data uses and users

In addition to many scientific works related with the study and characterization of physical ocean processes, several worldwide applications of HFR in other sectors of marine research and marine integrated management, are reviewed by Paduan and Washburn (2013). Some of the examples provided include direct applications of HFR data to search and rescue, oil-spill mitigation, and buoyant larvae advection (e.g., Frolov et al., 2012, Zelenke 2005). In addition these authors provide some examples of studies on the effect of mesoscale structures (fronts/eddies) on the dispersion/aggregation and transport of pelagic larvae and their impacts on the related species ecology (e.g. Bjorkstedt and Roughgarden, 1997; Nishimoto and Washburn, 2002) or on the enhancement of primary productivity in coastal ecosystems (Brzezinski and Washburn, 2011). Examples are also provided on the use of time series of surface HFR current maps in Lagrangian studies of particle dispersion and connectivity applied to different issues like the shoreline exposure and faecal discharge points in southern California and northern Mexico (e.g. Kim et al., 2009). Several examples of the use of HFR data for data assimilation under different approximations are provided (e.g. Breivik and Saetra 2001, Paduan and Shulman 2004).

In the case of EU, an increasing literature reflects ongoing efforts towards the applications in different sectors: oils spill management (Abascal et al., 2009; Bellomo et al., 2015), marine litter (Basurko et al., 2016), search and rescue (Orfila et al., 2015, Solabarrieta et al., 2016) and data assimilation (e.g. Marmain et al., 2014; Barth et al., 2008, 2011; Iermano et al., 2016; Stanev et al., 2015).

Following the information gathered from the HFR networks participating in the INCREASE survey, several additional applications of HFR data to different sectors in Europe are in progress and there is a number of well-established users (Figure 14). 20 of 23 operators chose at least one option between the listed users of their data among different activity sectors. The most popular identified user is the Academia, followed by European or National Maritime Safety Agencies and Weather Services. Some specific users were by Spanish operators: the Spanish Maritime Safety Agency SASEMAR and Ports Authorities through Puertos del Estado networks.

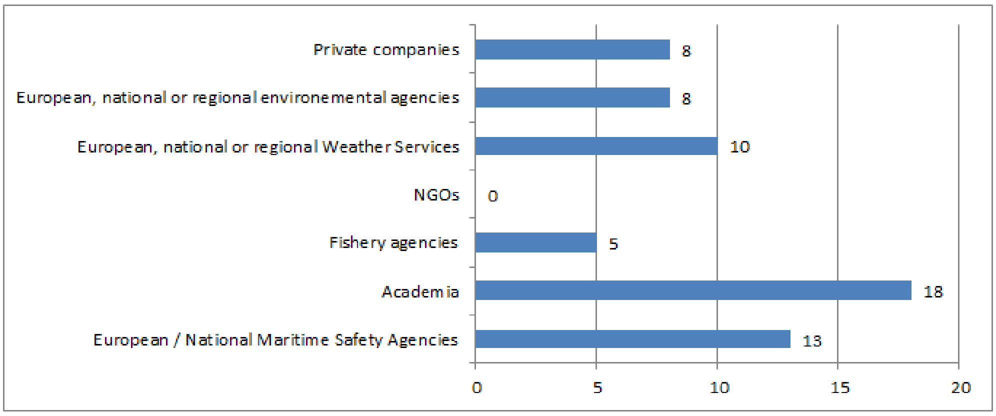

FIGURE 14: EUROPEAN HFR IDENTIFIED USERS. FROM THE 23 NETWORKS 20 CHOSE AT LEAST ONE OPTION. MULTIPLE CHOICE WAS ENABLED, SO MORE THAN ONE USER COULD BE IDENTIFIED BY THE SAME OPERATOR.

More information on current HFR applications was collected through multiple choice questions related with five activity sectors (defined by CMEMS): Marine Safety, Marine Resources, Coastal and marine environment, Weather, Climate and Seasonal Forecast and Research (Figure 15). It was asked to the survey contributors to mark only applications that were actually exploited by identified users.

The most popular sector of application of European HFR data is the Marine Safety. 14 of 23 operators identified at least one category within this sector, being the applications for oil spill response and search and rescue operations the most frequent. Among the specifications provided by the operators some applications consist of both HFR and a 3D hydrodynamic modelling (The currents measured by the HFR will be assimilated into the 3D model to provide the best forecast) but also on the indirect use of data by users (coastal guards, offshore plant and ship routing) that use both radar and model data entries, delivered in the form of reports and bulletins. In the Basque Country HFR data were used recently to update the Basque Country Contingency Plan, in the design of characteristic current scenarios. Finally the data from several of Puertos del Estado systems are directly distributed to Spanish MArine Safety agency to Search and Rescue operations SASEMAR.

Regarding Marine Resources much less applications are identified, only 7 of 23 operators identified applications in this section in the categories of Fishery research (one specific example concerning the applications of larval transport and distribution for the sustainable fishing of bluefin tuna was provided), ecosystem based approach and renewable energies.

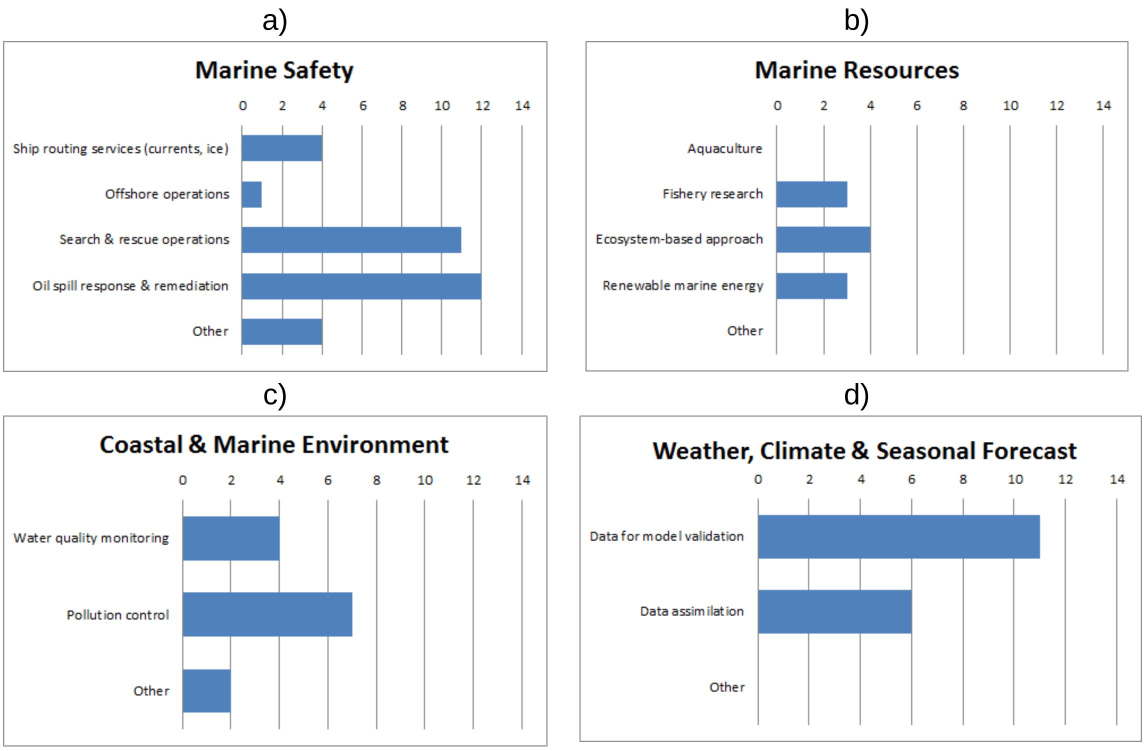

FIGURE 15: EUROPEAN HFR APPLICATIONS WITHIN FOUR ACTIVITY SECTORS: A) MARINE SAFETY, B) MARINE RESOURCES, C) COASTAL AND MARINE ENVIRONMENT AND D) WEATHER AND CLIMATE FORECAST. FROM 23 OPERATORS 14,7, 11 AND 12 CHOSE AT LEAST ONE OF THE AVAILABLE OPTIONS FOR A), B), C) AND D), RESPECTIVELY. MULTIPLE CHOICE WAS ENABLED, SO MORE THAN ONE APPLICATION WITHIN THE SAME OR DIFFERENT SECTORS COULD BE IDENTIFIED BY THE SAME OPERATOR.

In addition to water quality monitoring and pollutions control other two applications in the sector of Coastal and Marine Environment were identified: Leisure activities (sail and swimming competitions) and indirect use of data for estimating marine litter concentrations that may be accumulated by local hydrodynamic conditions (for Universities and National/Regional Environmental Agencies). 11 of 23 operators identified at least one application in this field, being the use of HFR data for pollution control the most popular.

In the field of weather forecast almost all of those operators that identified at least one application in this sector (12 of 23) were referring to the use of data for model validation and half of them to the use of the data for data assimilation.

Finally, concerning HFR related research, the most popular research lines are those related to Lagrangian approaches to surface transport and connectivity, the research on data assimilation and small scale and mesoscale ocean processes (figure 16). The most part of the categories presented are related with HFR surface current data, one user added an additional research lines related with the spatial wave measurements for research and marine renewable energy application.

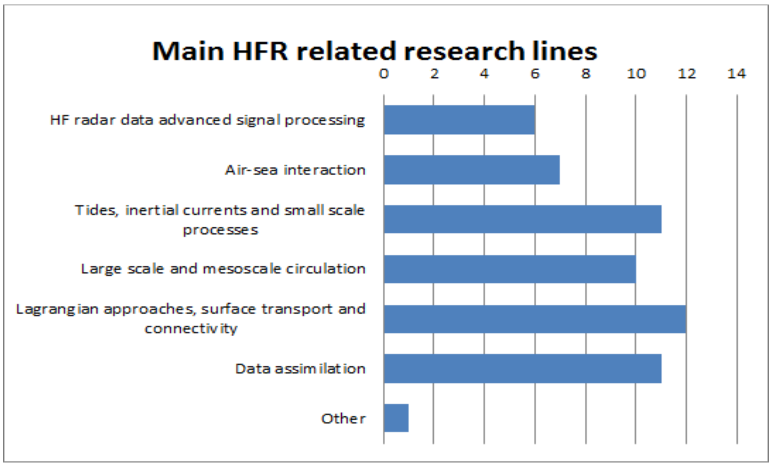

FIGURE 16: HFR RELATED RESEARCH LINES LISTED BY EUROPEAN OPERATORS CONTRIBUTING TO THE SURVEY. FROM 23 OPERATORS 15 CHOSE AT LEAST ONE OF THE AVAILABLE OPTIONS. MULTIPLE CHOICE WAS ENABLED, SO MORE THAN ONE APPLICATION WITHIN THE SAME OR DIFFERENT SECTORS COULD BE IDENTIFIED BY THE SAME OPERATOR.

5 Existing HFR products and methodology review

5.1 Review of methodologies for basic products

While all the radars share the same principles of operation, differences in signal transmission, reception and processing yield variations in metadata, quality control metrics and spatial registration. Even within the same type, HFRs may have different spatial ranges and resolutions, depending typically on the working frequency and bandwidth available. The products developed by **INCREASE** aim at putting together a common core of data and metadata structures and QA/QC protocols working for all them. The main objective of this section is to set the methodology for specific processing and mapping of product uncertainties following world class processing and calibration/correction, for operational direct use as well as to set the methodology for reprocessing of existing data sets with advanced quality control methods.

Building on the successful experience of the RITMARE project and on the EuroGOOS strategy, in the framework of the European HFR community there are many ongoing efforts aiming at the homogenization of HFR data and metadata formats and of QA/QC procedures. These efforts are done in order to design and implement standards allowing for the establishment of an effective European HFR Network. In particular, the European project JERICO-Next (http://www.jerico-ri.eu/) is focusing on the definition of recommended common metadata and data models and QC procedures for HFR data. In order to be suitable with the needs and the requirements of the European HFR community, INCREASE tasks towards the integration of HFR into CMEMs will be built on the work being done by these initiatives, which are described in the next sections.

5.1.1 Standard interoperable data and metadata structure for real-time radial and total velocity data

The main objective of JERICO-Next HFR data related tasks is to provide procedures and methodologies to enable data collected through the project to comply with the international standards regarding their quality and metadata, within the overall goal of integrating the European coastal observatories.

The activity carried out in the framework of JERICO-Next tasks devoted to the definition of HFR interoperable data and metadata formats has been mainly focused on the identification of standards facilitating the consistent and valid semantic interpretation of information and data. These standards should ensure both efficient and automated data discovery and interoperability, with tools and services across distributed and heterogeneous earth science data systems. This discussion firstly led to the choice of the data format to be adopted, then to the identification of the international conventions on metadata structures to be compliant with. Finally they were oriented the definition of a set of metadata aimed at the description of data in terms of dataset, variables and attributes.

The chosen data format is the netCDF format, since it is the international standard for common data and it is the one adopted by the US HFR network, which is the leading horizon where to aim at in the establishment of the European HFR network. This fact is also coherent with the long term goal of an international integration of the future European HFR network with the US HFR network. According to this choice, the selected reference conventions for data and metadata structures are the Unidata Dataset Discovery Convention and, consequently the Unidata Attribute Convention for Data Discovery (ACDD), the Climate Forecast Metadata Convention CF-1.6 and the INSPIRE directive. This set of regulations guarantees the adherence to the main international and European conventions for metadata architectures. On the basis of the data format and of the metadata conventions the CF-1.6 standard vocabulary (necessary to build on standard terms to be used by search services in interoperable and semantic data discovery frameworks) has been chosen. In addition, the common set of metadata for the description of datasets (i.e. information about data collection, dataset availability and licensing, etc.), variables (i.e. geophysical quantities and their related statistical accuracy indicators) and attributes (i.e. standard fields describing coverages, keywords, topics, etc.) have been defined.

Thanks to these steps, the JERICO-Next partnership are in the process to define the data and metadata architecture for HFR data (both radial and total velocity data) to be adopted as official European standard within the European HFR network. The discussion is still ongoing concerning the fine-tuning of the final set of common metadata to be adopted in cooperation with the EuroGOOS HFR Task Team, the EMODnet community and other key national partnerships like RITMARE.

It has to be noticed that the definition of the standard metadata structure also takes into account the crucial framework of QC. A specific variable has been included in the common variable list of the netCDF format describing the QC-flag for to label the data. The values to be assigned to the flags are still under discussion as they are strictly connected with the specific QC standard procedures to be identified as common regulation for the European HFR network.

In the same way, a key concept for driving the definition of the common QC procedure is the description of the processing levels to be assigned to different kind of HFR data. The identified metadata structure has a specific attribute field for the data processing level. To this extent a specific discussion has been carried out within JERICO-Next activities aimed at defining the processing levels for the identification of the different data produced during the processing workflow of a HFR device. The definition of these processing levels has been performed in order to be manufacturer-independent, i.e. the level schema is suitable to all the most common HFR devices. Table 4 shows the identified processing levels. The discussion is still ongoing concerning the fine-tuning of the sub-levels. Anyway, as said, the proposed schema is a conceptualization of the meaning of the different processing levels and it is not dependent on the specific QC procedures.

TABLE 4: PROCESSING LEVELS FOR THE DIFFERENT DATA PRODUCED BY A HFR.

Processing Level	Definition	Products
LEVEL 0	Reconstructed, unprocessed instrument/payload data at full resolution; any and all communications artefacts, e.g. synchronization frames, communications headers, duplicate data removed.	Signal received by the antenna before the processing stage. (No access to these data in Codar systems)
LEVEL 1A	Reconstructed, unprocessed instrument data at full resolution, time-referenced and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing.	Spectra
LEVEL 1B	Level 1A data that have been processed to sensor units for next processing steps. Not all instruments will have data equivalent to Level 1B.	No data at this level for the case of HFR
LEVEL 2A	Derived geophysical variables at the same resolution and locations as the Level 1 source data.	Radial velocity data
LEVEL 2B	Level 2A data that have been processed with a minimum set of QC.	Radial velocity data
LEVEL 2C	Level 2B data that have been processed with «custom» QC procedures.	Radial velocity data
LEVEL 3A	Variables mapped on uniform space-time grid scales, usually with some completeness and consistency	HFR total velocity data
LEVEL 3B	Level 3A data that have been processed with a minimum set of QC.	HFR total velocity data
LEVEL 3C	Level 3B data that have been processed with «custom» QC procedures.	HFR total velocity data
LEVEL 4	Model output or results from analyses of lower level data, e.g. variables derived from multiple measurements	Energy density maps, residence times, etc.

5.1.2 QC standard for radial and total data in real time and delayed mode

In the framework of the cooperation among European JERICO-Next project, EuroGOOS Task Team and EMODnet Physics the first integrated approach for the definition of a standard set of QA/QC procedures for HFR data is in progress. The current step of this process is the analysis of the state of the art of the QC testing procedures for HFR surface currents observations. Then, this should be followed by the discussion aimed at the identification of the set of QC tests to be adopted as standard QC procedures for real-time HFR data at European level.

The analysis of the state of the art is mostly based on the activity of the US Integrated Ocean Observing System (IOOS) that continues to establish written, authoritative procedures for the quality control (QC) of real-time data through the Quality Assurance/Quality Control of Real-Time Oceanographic Data (QARTOD) program. In particular, the manuals on the real-time QC of HFR surface currents periodically produced by the QARTOD program are used as reference for the discussion. The last draft version of this manual for HFR data documents successful QC techniques already, identifies any shortcoming of those techniques and suggest new QC tests that may be employed. (see: https://ioos.noaa.gov/wp-content/uploads/2016/06/HFR_QARTOD_Manual_05_26_16.pdf).

The focus of the manual is on the real-time QC of data collected, processed, and disseminated by the U.S. IOOS Regional Associations and it is limited to HFR surface current data. Data are evaluated using QC tests, and the results of those tests are recorded by inserting flags in the data record. The flags used by the IOOS are the UNESCO 2013 QC flags for real time data. Table 5 lists these flags and the associated descriptions.

TABLE 5: UNESCO 2013 QC FLAGS FOR REAL TIME DATA.

Flag	Description
Pass=1	Data have passed critical real-time quality control tests and are deemed adequate for use as preliminary data.
Not evaluated=2	Data have not been QC-tested, or the information on quality is not available.
Suspect or Of High Interest=3	Data are considered to be either suspect or of high interest to data providers and users. They are flagged suspect to draw further attention to them by operators.
Fail=4	Data are considered to have failed one or more critical real-time QC checks. If they are disseminated at all, it should be readily apparent that they are not of acceptable quality.
Missing data=9	Data are missing; used as a placeholder.

The QARTOD manual reviews a variety of tests that can be performed to evaluate data quality in real time. These tests presume a time-ordered series of observations and are listed in Table 6.

TABLE 6: QARTOD LIST OF QC TESTS FOR REAL-TIME HFR DATA. TESTS WITH (*) APPLY ONLY TO CODAR SEASONDE SYSTEMS AND THOSE WITH (~~) APPLY ONLY TO WERA AND LERA SYSTEMS.

Test Type	Test Name	Status	Test Control
Signal (or Spectral) Processing	Signal-to-Noise Ratio (SNR) for Each Antenna (Test 1)	Required	Embedded
	Cross-Spectra Covariance Matrix Eigenvalues (Test 2*)	Suggested	Embedded

	Single and Dual Angle Solution - Direction of Arrival (DOA) Metrics (magnitude) (Test 3*)	Suggested	Embedded
	Single and Dual Angle Solution - Direction of Arrival (DOA) Function Widths (3 dB) (Test 4*)	Suggested	Embedded
	Single and Dual Angle Solution - Direction of Arrival (DOA) Signal Amplitude Matrices (Test 5*)	Suggested	Embedded
	Signal-to-noise Ratio for Bragg Peaks (Test 6~~)	Suggested	Embedded
	Separation of 1st order Bragg Lines (Test 7~~)	Suggested	Embedded
	Broadening of Bragg Lines (3 dB) (Test 8~~)	Required	
Radial Components	Syntax (Test 9)	Required	National
	Max Threshold (Test 10)	Required	Local and National
	Over-Water (Test 11)	Required	Local and National
	Angular Section Coverage (Test 12*)	Required	Local and National
	Median Filter (Test 13*)	Suggested	Local and National
	Trend Limits (Test 14)	Suggested	
	Temporal Gradient (Test 15)	Suggested	
	Spatial Gradient (Test 16)	Suggested	
	Average Radial Bearing (Test 17)	Suggested	
	Synthetic Radial Test (Test 17.5)	Suggested	
Total Vectors	Data Density Threshold (Test 18*)	Required	Local and National
	GDOP Threshold (Test 19)	Required	Local and National
	Max Speed Threshold (Test 20)	Required	Local and National
	Trend Limits for u,v components (Test 21)	Suggested	
	Median Filter (Test 22*)	Suggested	Local and National
	Measured Minus Modelled (Test 23)	Suggested	Local and National

The QARTOD manual divides these tests into three groups (those that are required, strongly recommended, or suggested) according to the QC strategy of the IOOS. Table 6 also shows the three groups.

Sensor operators need to select the best thresholds for each test, which are determined at the operator level and may require trial and error before final selections are made. A successful QC effort is highly dependent upon selection of the proper thresholds, which should not be determined arbitrarily but can be based on historical knowledge or statistics derived from more recently acquired data. The ongoing discussion within JERICO-Next project is focused on these facts, and aims at defining a set of QC tests which could be adopted as common standard procedures in the European HFR network.

Furthermore, the most of the tests identified by the QARTOD manual are specific for Codar SeaSonde systems, due to the fact that the US HFR network is mainly using that kind of devices. The European situation is quite different, as both Codar and WERA systems are significantly present in the operating local and national networks. Thus the JERICO-Next partnership is discussing in strict collaboration with European HFR operators (both Codar and WERA users) in order to identify WERA-relevant QC parameters, tests and flags.

TABLE 6: QARTOD QC TEST HIERARCHY.

Group 1 *Required*	Test 1 Test 8 Test 9 Test 10 Test 11 Test 12 Test 18 Test 19 Test20	Signal-to-Noise Ratio Broadening of Bragg Lines (3 dB)~~ Syntax Max Threshold Over-Water (radial components) Angular Section Coverage Data Density Threshold GDOP Threshold Max Speed Threshold
Group 2 *Strongly Recommended*		None.
Group 3 *Suggested*	Test 2 Test 3 Test 4 Test 5 Test 6 Test 7 Test 13 Test 14 Test 15 Test 16 Test 17 Test 17.5 Test 21 Test 22 Test 23	Cross Spectra Covariance Matrix Eigenvalues* Single and Dual Angle Solution-DOA Metrics (magnitude)* Single and Dual Angle Solution – DOA Function Widths (3 dB)* Single and Dual Angle Solution – DOA Signal Amplitude Matrices* Signal-to-Noise Ratio for Bragg Peaks~~ Separation of 1st order Bragg Lines~~ Median Filter (radial components) Trend Limits (radial components) Temporal Gradient Spatial Gradient Average Radial Bearing Synthetic Radial Trend Limits for u,v components (total vectors) Median Filter (total vectors) Measured Minus Modelled (total vectors)

The final goal of the discussion at European level on QC procedures is thus to integrate the QARTOD list of tests with test relevant to WERA devices, and, then, to define a set of required tests to be adopted as standard QC procedures for the European HFR network. These standard sets of tests will be defined both for radial and total velocity data and they will be the required ones for labelling the data as Level 2B (for radial velocity) and Level 3B (for total velocity) data. On the basis of the test hierarchy to be defined, the HFR operators will be able to choose the further QC test they want to implement in their processing workflow. Data processed with some further QC tests aside the mandatory ones will be labelled as Level 2C (for radial velocity) and Level 3C (for total velocity) data.

5.2 Review of methodologies for advanced products

5.2.1 Gap-filled current maps and refined products in areas of higher radial resolution

In the process from radials to totals the solution is not always a gap-free map of vectors. This can be a handicap when the total data are needed to compute trajectories using a Lagrangian Particle-Tracking Model (LPTM) where spatio-temporal data gaps are difficult to handle. The gaps in the data can be produced by changes in angular or total range of the radials data due to environmental conditions. Also there is a permanent region between the antennas, the so-called baseline, where the total currents cannot be computed in an accurate way. The baseline between two HFR sites is defined as the area where the radial components from the two sites make an angle of less than 30°, so the total velocity vectors created from radial data within this data contain greater uncertainties. The solution in the baseline is normally not computed, so we observe a data gap in an area which is delimited by the rule of GDOP (see Barrick, 2002) and the limits set to this quality control parameter in the processing of the data from radials to totals.

CODAR software COMBINE has a specific option for the baseline interpolation. For this approximation, the component that is actually being measured is used, while the value of the component that cannot be solved is extrapolated using an approximations of the closest valid measurement. This increases the coverage near the baseline, although it presents two main limitations: (i) the coverage is not continuous in time, since it depends on having radial data from the two antennas. (ii) the interpolation of the non-solved component is an approach to this and it can result in total velocities fields in the baseline which present higher errors than in the rest of the domain. More information on the methodology of the COMBINE software and this method can be found in the CODAR documentation (Codar Ocean Sensors, January 2004 and June 2004).

A quite extended procedure is to use the Open Mode Analysis (OMA) to obtain total derived currents (Lekien et al., 2004, Kaplan and Lekien, 2007). OMA is a robust methodology that permits to generate gap-filled total currents from radials. The OMA modes are built by setting a minimum spatial scale, which determines which scales will be solved and thus how smooth will the final velocity fields be. The OMA analysis take also into account the kinematic constraints imposed on the velocity field by the coast, since the OMA modes are calculated taking into account the coastline of the study area by setting a zero normal flow constraint. Depending on these constraints they can be limited in representing localized small-scale features as well as flow structures near open boundaries. Besides, difficulties may arise when dealing with gappy data, especially when the horizontal size of a gap is larger than the minimal length scale resolved (Kaplan and Lekien, 2007).

Another alternative is the variational analysis, described in Yaremchuk and Sentchev (2011). The numerical algorithm is based on the minimization of a quadratic cost function in the space of all possible configurations of the velocity field. The interpolation problem is regularized by enforcing smoothness in the vorticity and divergence fields. Yaremchuk and Sentchev (2011) show the advantages over local linear interpolations of the variational method and OMA, related to their ability to reconstruct the velocity field within the gaps in data coverage, near the coastlines and in the areas covered only by one radar. Compared to OMA their method appears to be more flexible in processing gappy observations and more accurate at noise levels below 30%, with similar computational cost (which allows both methods to be applied operationally).

Finally, for some operational needs (i.e. Search and Rescue operations) higher horizontal resolution fields could be more appropriate. For the systems operating at lower frequencies, with longer range but typical horizontal resolution of several kms refined grids for total velocities can be obtained using the data closer to the antennas, where a denser coverage of radials exist. Refined products in these areas could be obtained as a product of the different methodologies described previously.

5.2.2 Short term prediction products

In addition to assimilating HFR data in numerical models, other approaches like empirical models can be used to forecast future currents based on a short time history of past observations. Some recent works have applied empirical models to HFR data to obtain Short Term Forecasts (STP) using several approaches. Barrick et al. (2012) used OMA decomposition (Lekien et al., 2004) and then a set of temporal modes was fitted to the time series of OMA coefficients over a short training period. Frolov et al. (2012) used EOF decomposition and applied a vector autoregressive model on the leading EOFs time series for prediction, incorporating wind stress forecast from a regional atmospheric model. In Orfila et al. (2014), the spatial and temporal decomposition of current variability is also performed using EOFs, then the forecast approach relies on a Genetic Algorithm (GA) (using only past observations) to identify mathematical expressions that best forecast the evolution of the amplitudes associated with statistically significant EOF modes. Recently Solabarrieta et al. (2016) applied the linear autoregressive models described in Frolov et al. (2012), using only HFR data, to perform an analysis of the model spatio-temporal performances in a multi-year experiment in the South-eastern Bay of Biscay (SE BoB). Because of the combination of the EOF pre-processing and the time-embedding in the autoregressive model with extended training periods, these forecast models are in principle able to simultaneously learn both the high-frequency signal (tidal and inertial) and the basin-wide modes of the circulation; however these studies show that the skills of the model are limited and suggest that they can be improved by using multivariable approaches and by improving the learning strategy of the models.

An alternative method to full assimilation has been recently explored in order to provide short term predictions in the Ligurian Sea. The method, called LAVA (LAgrangian

Variational Analysis; Taillandier et al., 2006, Berta et al., 2014), performs the blending of Lagrangian (drifters) and Eulerian observations (velocity fields from HFR, satellite altimetry or models) to enhance the estimate of surface transport driven by currents. Tests on trajectories' prediction show that during the first 6-10 h, the blended products reduce significantly the uncertainty on particle positions compared to using the original velocity fields to estimate trajectories. Moreover the LAVA method has been also tested in the Gulf of Mexico to reconstruct in near-real time the surface velocity field in the area covered by drifter trajectories (Berta et al., 2014b).

5.2.3 Operational Lagrangian products

HFRs are crucial in coastal areas for near real-time observation of surface currents and they find several applications in the management of the marine environment and emergencies at sea (such as search and rescue operations and oil spills mitigation). These applications require accurate prediction of Lagrangian trajectories and several studies have assessed the effectiveness of trajectory predictions using currents derived from HFR. Ullman et al. (2006) have tested Monte Carlo particle trajectory simulations using surface currents derived from HFRs using random-walk and random-flight models of the unresolved velocities. Recently, several dispersion models have been combined with weather and sea state observations to provide forecasting scenarios that can be crucial to minimize the efforts to be done to manage the emergency. Some examples of these models are: MEDSLIK (Lardner and Zodiatis, 1998; Lardner et al., 2006), GNOME (Beegle-Krause, 2001; Beegle-Krause et al., 2003; Beegle-Krause, 2008) and TESEO (Castanedo et al., 2006, Abascal et al., 2009). In particular, Abascal et al. (2009) combined the HFR currents, as well as numerical wind data to simulate trajectories using the TESEO oil spill transport model. Their study show the positive contribution of HFR currents for trajectory analysis and support the combination of HFR and dispersion models in case of oil spills or SAR. The capability to predict particle trajectories for oil spill and search and rescue using HFR data has been tested in the framework of the TOSCA project with the aim of constituting an HFR network in the Mediterranean Sea (Bellomo et al., 2015). Lagrangian dispersion studies using HFR apply also for managing fisheries and marine protected areas, such as the ongoing study about larval retention in the Gulf of Manfredonia (Adriatic Sea), within the JERICO-Next project.

5.3 Data management, existing infrastructures and HFR identified needs

For each EuroGOOS Region there is a Regional Data Assembly Centre (RDAC) operated jointly with the CMEMS INSTAC and working closely with organisations operating monitoring stations. In this federative infrastructure, the quality of the products delivered to users must be equivalent wherever the data are processed: each RDAC is responsible for assembling data provided by institutions and provides a unique data access point to bundle available data into an integrated dataset for validation and distribution (whereby validation is following common EuroGOOS

DATAMEQ –CMEMS- EMODnet harmonized procedures). Each RDAC validates the dataset consistency in their area of responsibility, typology of data and typology of parameter (Figure 17).

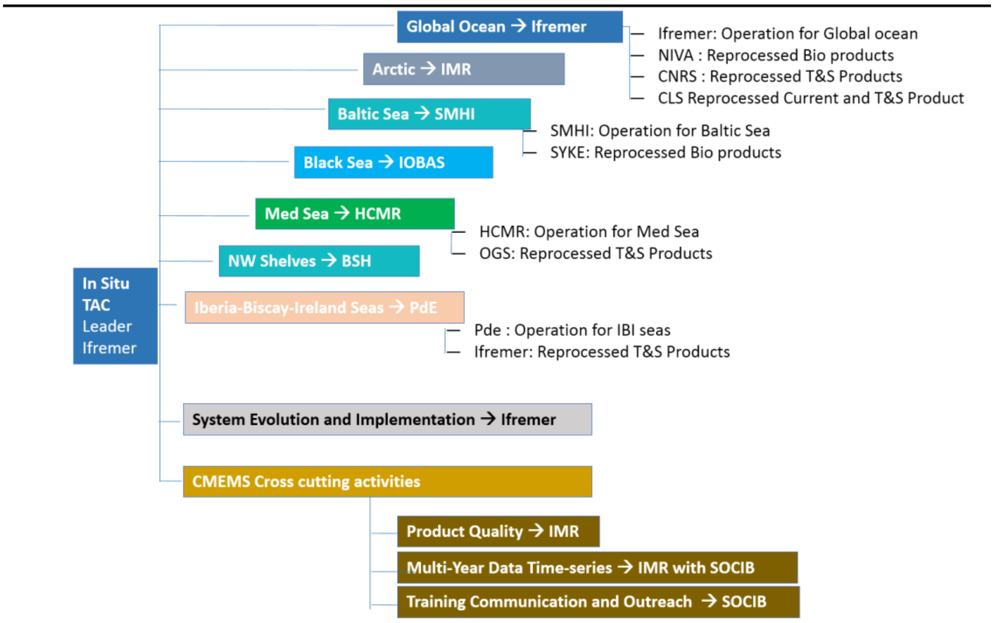

FIGURE 17.THE INSTAC HIERARCHICAL ARCHITECTURE.

Routinely (e.g.: every hour), each RDAC distributes all its new data on its regional portal. Files (i.e. NetCDF files) are organized in folders as described in Figure 18.

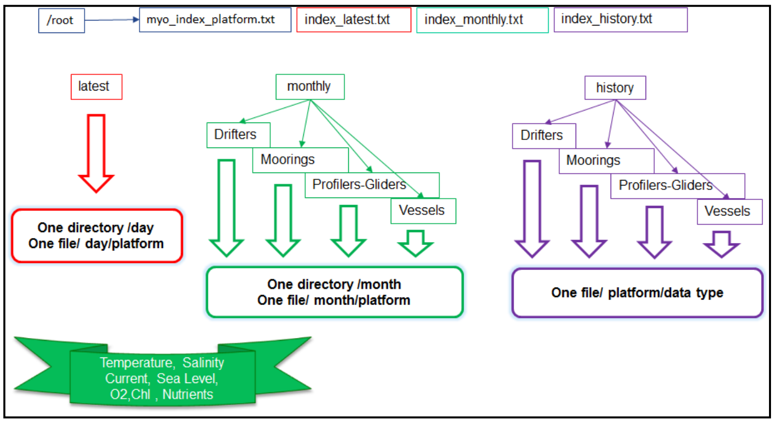

FIGURE 18 ORGANIZATION OF DATA FILES IN RDACS

During the INSTAC operational activities, quality control is performed automatically on the data that is made available in real-time and near real-time, yearly scientific assessment performed on the latest 30 years of data (60 years for T&S and Global scale).

Moreover, the SDN was designed to develop a further validation and quality control, as well as a more complete metadata description take place when the data are passed to data centres for long-term storage and stewardship. The long term preservation of the historical validated data is organised in coordination and cooperation with SDN and the network of National Oceanographic Data Centres (NODCs).

EMODnet Physics is also building on in cooperation and collaboration with the three established pillars of the European Oceanographic Community i.e. EuroGOOS, CMEMS and SDN.

EuroGOOS has contributed to EMODnet through the relevant vision paper issued in collaboration with the European Marine Board, and the Secretariat is actively participating in the EMODnet Physics. SDN community is contributing to many of the EMODnet thematic lots and are deeply involved into the development of the EMODnet Physics. EMODnet Physics and CMEMS (former MyOcean projects) have always worked together to increase the quality of the service to the oceanographic community and more in general to any potential marine data users. In August 2016 EMODnet Physics and CMEMS put in place a MoU to keep working together and further develop services to users where the user has to be at the centre of the services.

EMODnet Physics outcome is to organize the data flow of relevant data (into the EuroGOOS ROOSs, CMEMS and SDN infrastructures) and make them available in a portal to serve public and private institutions by providing operational services (e.g. atmosphere and ocean forecasts), search and rescue, ocean science. EMODnet Physics provides a combined array of services and functionalities (facility for viewing and downloading, dashboard reporting and machine-to-machine communication services) to obtain free-of-charge data, metadata and data products on the physical conditions of European sea basins and oceans. Moreover, the system provides full interoperability with third-party software through WMS services, Web Services and Web catalogues in order to exchange data and products according to the most recent standards

HFR data is in situ gridded data in time (big data) that has to be managed according its peculiarity, therefore the standard in situ data management infrastructure have to be empowered and updated to allow both TAC and MFC to assimilate and create new products including HFR data. So it will be necessary to design and develop the hardware and software infrastructures, as well as the data formats, file conventions, file dimension, file naming and labelling for both real time (i.e. the continuous data flow for latest days) and historical (i.e. the complete series) HFR data management.

Within EMODnet Physics, the EuroGOOS HFR Task Team started working to proof the basic concepts for setting up both the hardware and software infrastructure to make HFR data available in a pan European harmonized manner.

Starting from the best practices developed by AZTI and CNR it was possible to define the basic HFR data management infrastructure, metadata and data formats. The core infrastructure for managing and providing data is based on THREDDS that consists of two main building blocks: the THREDDS Data Server (TDS) and the Common Data Model (CDM) / netCDF-Java library.

The TDS is open source and runs inside the open source Tomcat Servlet container. The TDS provides catalogue, metadata, and data access services for scientific data.

Every TDS publishes THREDDS catalogues that advertise the datasets and services it makes available. THREDDS catalogues are XML documents that list datasets and the data access services available for the data-sets. Catalos may contain metadata to docu-ment details about the datasets. TDS configuration files provide the TDS with information about which datasets and data collections are available and what services are provided for the datasets. The available remote data access pro-tocols include Open DAP, OGC WCS, OGC WMS, and HTTP. It has to be noticed that the ncISO service allows THREDDS catalogues to be translated into ISO metadata records.

The CDM provides data access through the netCDF-Java API to a variety of data formats (e.g., netCDF, HDF, GRIB). Layered above the basic data access, the CDM uses the metadata contained in datasets to provide a higher-level interface to geoscience specific features of datasets, in particular, providing geolocation and data subsetting in coordinate space.

The TDS uses the CDM/netCDF-Java to read datasets in various formats. The CDM also pro-vides the foundation for all the services made available through the TDS. A pluggable framework allows other developers to add readers for their own specialized formats. The CDM also provides standard APIs for geo-referencing coordinate systems, and specialized queries for scientific feature types like Grid, Point, and Radial datasets, and so it represents the best suitable available technology to manage HFR data products.

The analysis of the existing infrastructures shows that most of the HFR data providers or their dissemination units are already adopting the same infrastructure, but there is a need for a real harmonization of metadata presentation.

TABLE 7: EMODNET PHYSICS HFR OPERATIONAL NETWORK.

Platform name	**Data format**	**Data dissem ination**	**Link**	**Data file update**
BASQUE – Cape Higer	Netcdf	AZTI	http://oceandata.azti.es:8080/thredds/catalog/data/RADAR_OO/catalog.html	Hourly
BASQUE – Cape Matxitxako	Netcdf	AZTI	http://oceandata.azti.es:8080/thredds/catalog/data/RADAR_OO/catalog.html	Hourly
CALYPSO – Tà Sopu Nadur	Netcdf	UMT.IOI.POU	http://oceania.research.um.edu.mt/thredds/ncss/grid/CALYPSO/Aggregated/CALYPSOLast10Days/ dataset.html	Daily
CALYPSO – Tà Barkat Xghajra	Netcdf	UMT.IOI.POU	http://oceania.research.um.edu.mt/thredds/ncss/grid/CALYPSO/Aggregated/CALYPSOLast10Days/ dataset.html	Daily
CALYPSO –Pozzallo	Netcdf	UMT.IOI.POU	http://oceania.research.um.edu.mt/thredds/ncss/grid/CALYPSO/Aggregated/CALYPSOLast10Days/ dataset.html	Daily
COSYNA – Radar Station Wangerooge	Netcdf	COSYNA	http://opendap.hzg.de/opendap/data/cosyna/gridded/HF-WERA/curr_portal/	Daily
COSYNA – Radar Station Büsum	Netcdf	COSYNA	http://opendap.hzg.de/opendap/data/cosyna/gridded/HF-WERA/curr_portal/	Daily

COSYNA – Radar Station Sylt	Netcdf	COSYNA	http://opendap.hzg.de/opendap/data/cosyna/gridded/HF-WERA/curr_portal/	Daily
GALICIA – Cabo Silleiro	Netcdf	Intecmar	http://opendap.intecmar.org/thredds/catalog/data/nc/RADAR_HF/Galicia/LS/last/catalog.html	Hourly
GALICIA – Cabo Fisterra	Netcdf	Intecmar	http://opendap.intecmar.org/thredds/catalog/data/nc/RADAR_HF/Galicia/LS/last/catalog.html	Hourly
GALICIA –Cabo Vilán	Netcdf	Intecmar	http://opendap.intecmar.org/thredds/catalog/data/nc/RADAR_HF/Galicia/LS/last/catalog.html	Hourly
GALICIA – Cabo Prior	Netcdf	Intecmar	http://opendap.intecmar.org/thredds/catalog/data/nc/RADAR_HF/Galicia/LS/last/catalog.html	Hourly
HAZADR – Cape Stončica, island of Vis	CSV	IZOR	faust.izor.hr/autodatapub/radar2_data_download?datausr=<user>&datapass=<password> &dayfrom=ddMMyyyy&dayto=ddMMyyyy&outtype=csv	Daily
HAZADR – Cape Ražanj, island of Brač	CSV	IZOR	faust.izor.hr/autodatapub/radar2_data_download?datausr=<user>&datapass=<password> &dayfrom=ddMMyyyy&dayto=ddMMyyyy&outtype=csv	Daily
NIB – Aurisina	JSON	NIB	http://www.nib.si/mbp/apps/wera.rest/webapi/Wera/get-headers?profileType=0&date=yyyy-MM-dd	Daily
NIB – Piran	JSON	NIB	http://www.nib.si/mbp/apps/wera.rest/webapi/Wera/get-headers?profileType=0&date=yyyy-MM-dd	Daily
Delta of Ebro - Salou	Netcdf	Puertos del Estado	http://opendap.puertos.es/thredds/catalog/RADAR_DELTAEBRO/catalog.html	Hourly
Delta of Ebro - Alfacada	Netcdf	Puertos del Estado	http://opendap.puertos.es/thredds/catalog/RADAR_DELTAEBRO/catalog.html	Hourly
Delta of Ebro - Vinaroz	Netcdf	Puertos del Estado	http://opendap.puertos.es/thredds/catalog/RADAR_DELTAEBRO/catalog.html	Hourly
Estrecho de Gibraltar – Tarifa	Netcdf	Puertos del Estado	http://opendap.puertos.es/thredds/catalog/RADAR_GIBRALTAR/catalog.html	Hourly
Estrecho de Gibraltar – Punta Carnero Lighthouse	Netcdf	Puertos del Estado	http://opendap.puertos.es/thredds/catalog/RADAR_GIBRALTAR/catalog.html	Hourly
Estrecho de Gibraltar – Port of Ceuta	Netcdf	Puertos del Estado	http://opendap.puertos.es/thredds/catalog/RADAR_GIBRALTAR/catalog.html	Hourly
Golfo de Cádiz – Sagres	Netcdf	Puertos del Estado	http://opendap.puertos.es/thredds/catalog/RADAR_HUELVA/catalog.html	Hourly
Golfo de Cádiz – Alfanzina Lighthouse	Netcdf	Puertos del Estado	http://opendap.puertos.es/thredds/catalog/RADAR_HUELVA/catalog.html	Hourly
Golfo de Cádiz – Vila Real	Netcdf	Puertos del Estado	http://opendap.puertos.es/thredds/catalog/RADAR_HUELVA/catalog.html	Hourly
Golfo de Cádiz –	Netcdf	Puertos del	http://opendap.puertos.es/thredds/catalog/RADAR_HUELVA/catalog.html	Hourly

Mazagón		Estado		
SOCIB – Puig des Galfí	Netcdf	SOCIB	http://thredds.socib.es/thredds/catalog/hf_radar/hf_radar_ibiza-scb_codarssproc001/L1/catalog.html	Monthly
SOCIB – Formentera	Netcdf	SOCIB	http://thredds.socib.es/thredds/catalog/hf_radar/hf_radar_ibiza-scb_codarssproc001/L1/catalog.html	Monthly
Ligurian Sea - MPA of Cinque Terre	Netcdf	CNR-ISMAR	http://ritmare.artov.isac.cnr.it/thredds/ritmare/CoastalRadarOS/HF_RADAR/Tyrrhenian_Ligurian_Sea/catalog.html	Hourly

In order to have an operational infrastructure it is important that each node exposes the same features and is based on the same infrastructure. If a provider is not able to set up its own infrastructure, a dissemination unit, e.g. the regional dissemination unit or a Thematic Assembly Centre, has to integrate and harmonize the data flow from the provider to upstream users.

One key element of the harmonization process is the metadata description with the following fields:

- Summary: a paragraph describing the dataset.
- Rights: describe the restrictions to data access and distribution.
- Creators: the data creator's name, URL, and email.
- Publishers: the data publisher's name, URL, and email.
- Access to original data source: link to the original data used to create the 60 days and monthly aggregations
- GeospatialCoverage: describes latitude, longitude, and vertical bounding box
- TimeCoverage describes the temporal coverage of the data as a time range.
- Variables list of variables offered by the dataset with the following information:
- variable name: the variable name in the dataset
    - long_name: a long descriptive name for the variable (not necessarily from a controlled vocabulary)
    - standard_name: a long descriptive name for the variable taken from a controlled vocabulary of variable names (CF-1.0 http://cfconventions.org/)

Based on the EMOdnet Physics proof of concept, the INCREASE WP4 is aimed at creating the European HFR Data Assembly node, which integrates data from Regional Dissemination Units that are connected to National nodes or providers directly.

In collaboration with EMODnet Physics, the INCREASE WP4 will also develop the user interface to access in situ HFR data and products and a dynamic map with all the HFR data.

6 Roadmap for the production of HFR products in compliance with CMEMS needs

An important milestone towards the definition of this roadmap has been the organization of the HFR expert workshop, which took place in Italy (La Spezia) on 13th-15th September 2016. This meeting gathered EuroGOOS HFR Task Team members, CMEMS representatives, main HFR technological providers, US and Australian communities representatives and other active European HFR actors (cf. Attendance list in Annex 3). The objective of the workshop was to involve that group of experts in:

- reviewing the diagnostic of the present development of European HFR systems
- reviewing and setting methodologies for basic and HFR derived products;
- reviewing CMEMS needs and objectives and how HFRs can fit into them;
- designing a roadmap for the establishment of a European HFR network.

The elements to build this last part of the deliverable have been extracted from the discussions that took place in three different groups with the following topics:

- GROUP1: Basic products: Data format and QA/QC
- GROUP2: Advanced products and applications
- GROUP3: Technical implementation and strategic development

The efforts that are being made for obtaining standard HFR basic products will be especially valuable within the frame of CMEMS, fully committed to inform end-users and stakeholders about the quality and reliability of the marine forecast products routinely delivered, fostering downstream services and user uptake. Incorporating HFR-derived products in CMEMS will be highly valuable for users in academia for the understanding of coastal ocean dynamics, including waves; for a homogenized operational monitoring of the coastal ocean along the European coasts; for downstream users and applications such as search and rescue operations, oil-spill mitigation, off-shore structures management, ship routing etc. HFR information can be also useful for the validation of numerical models of the ocean as well as for data assimilation purposes.

6.1 Basic products: data format and QA/QC in compliance with CMEMS needs

During the fruitful days of the HFR Experts Workshop the main issues concerning data format and QA/QC procedures have been discussed in order to meet the needs of both the HFR community and CMEMS operational services. In particular, three main points have been analysed for achieving a common consensus and set up a roadmap for the implementation activities expected within the project: data format, metadata structure, QC flagging scheme and QC tests.

In the following, the roadmap defined for the first two points will be presented. Discussion on QC flagging scheme and QC tests are still in progress and will be developed during the next quarter to fulfil D3.1. “Protocols on QA best practices and QC for radial and total data” (due date February 2017).

6.1.1 Data Format

As illustrated in Section 5.1.1, the data format chosen by the international HFR community is the netCDF format, since it is the international standard for common data and it is the one adopted by the US HFR network. The state of the art version of the netCDF format is **netCDF-4**, launched in 2008 to support per-variable compression, multiple unlimited dimensions, more complex data types, and better performance, by layering an enhanced netCDF access interface on top of the HDF5 format. At the same time, a format variant, **netCDF-4 classic model format**, was added for users who needed the performance benefits of the new format (such as compression) without the complexity of a new programming interface or enhanced data model. The HFR community agreed in the decision of producing data using **netCDF-4 classic model format**, in order to apply the state of the art version.

The CMEMS delegates present at the workshop informed that CMEMS IN-SITU TAC operates using **netCDF-3.6.1** version as standard format.

Building on the fact that both **netCDF-3** and **netCDF-4** libraries are part of a single software release and, as a consequence, if a **netCDF-4** file conforms to the classic model then there are several easy ways to convert it to a **netCDF-3** file, it has been decided to implement as standard data production of HFR operators the production of **netCDF-4** data, which will be then converted in **netCDF-3.6.1** by the central HFR node to be developed by WP4. This double data production will meet both HFR community needs and CMEMS IN-SITU TAC needs.

The CMEMS delegates also informed about the CMEMS IN-SITU TAC archiving strategy and folder structure, i.e. data files are archived as “Last data file”, “Monthly files” and “Historical files”, meaning that different temporal netCDF aggregations are needed to publish data at CMEMS. The central HFR node to be implemented in WP4 will perform the needed aggregations, regardless of the temporal frequency of data production by the HFR operators.

Finally, the naming convention that is currently used by CMEMS IN-SITU TAC has been considered. It will be adopted as the standard by the European HFR operators.

6.1.2 Metadata Structure

The CMEMS IN-SITU TAC reference conventions for the metadata attributes are CF-1.6 and OceanSITES. Thus, building on what already discussed and agreed within the HFR community, it has been decided to divide metadata attributes to be adopted for HFR data in three categories: *Mandatory Attributes*, *Recommended Attributes* and *Suggested Attributes*.

The *Mandatory Attributes* will include attributes necessary to comply with CF-1.6 and OceanSITES conventions.

The *Recommended Attributes* will include attributes necessary to comply with INSPIRE and Unidata Dataset Discovery conventions.

The *Suggested Attributes* will include attributes that can be relevant in describing the data, whether it is part of the standard or not.

The reference manual of the OceanSITES convention is available at:
http://www.oceansites.org/docs/oceansites_data_format_reference_manual.pdf

The CMEMS IN-SITU TAC reference conventions for the data variable names is the SDN P09 vocabulary, thus it has been decided to use variable names compliant with this controlled scheme. Since the gridded HFR data are not yet spread within oceanographic standards, it happens that many of the HFR related variables have no coded names in the SDN P09 vocabulary. To overcome this shortcoming, if the needed variable has no SDN P09 coded name, new 4-character-capitalized-letters names will be created and it will be requested to add these names to SDN P09 vocabulary.

The reference manual of SDN P09 (MEDATLAS Parameter Usage Vocabulary) is available at: http://vocab.nerc.ac.uk/collection/P09/current/

The Processing Level scheme was also discussed and it has been decided to remove the C sub-levels from Level 2 and Level 3. The final Processing Level scheme to be adopted as HFR standard is reported in Table 8.

TABLE 8: FINAL SCHEME OF PROCESSING LEVELS FOR HFR DATA.

Processing Level	Definition	Products
LEVEL 0	Reconstructed, unprocessed instrument/payload data at full resolution; any and all communications artefacts, e.g. synchronization frames, communications headers, duplicate data removed.	Signal received by the antenna before the processing stage. (No access to these data in Codar systems)
LEVEL 1A	Reconstructed, unprocessed instrument data at full resolution, time-referenced and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing.	Spectra by antenna channel
LEVEL 1B	Level 1A data that have been processed to sensor units for next processing steps. Not all instruments will have data equivalent to Level 1B.	Spectra by beam direction
LEVEL 2A	Derived geophysical variables at the same resolution and locations as the Level 1 source data.	Radial velocity data
LEVEL 2B	Level 2A data that have been processed with a minimum set of QC.	Radial velocity data
LEVEL 3A	Variables mapped on uniform space-time grid scales, usually with some completeness and consistency	HFR total velocity data
LEVEL 3B	Level 3A data that have been processed with a minimum set of QC.	HFR total velocity data
LEVEL 4	Model output or results from analyses of lower level data, e.g. variables derived from multiple measurements	Energy density maps, residence times, etc.

6.2 Advanced products list, applications and methodology selection

The main objectives of Discussion Group 2 during La Spezia Workshop were to review (1) the state of the art of the corresponding products (2) the interest for CMEMS (INSTAC, MFC) of each of these products (3) the level of the corresponding products (Core service? Downstream service?).

The very first step that should be granted to ensure the adoption of HFR data in CMEMs is for sure to have the HFRs operational and current data that we can trust and flag (two points that are not straightforward). Then an additional step forward, which was the main driver for the discussion, is to build a catalogue of «advanced» products that could be developed to offer an idea of the roadmap to make the way for HFR products into CMEMS.

Three main types of products/services were discussed:

1. Data gap filling and refined grid products
2. Short term prediction
3. Lagrangian products

6.2.1 Data gap filling and refined grid products

As we have seen in the previous sections, in the process from radials to totals the solution is not always a gap-free map of vectors. This can be a handicap when the total data are needed to compute trajectories using a LPTM where spatio-temporal data gaps are difficult to handle. One critical gap for most of the installations is the one at the baseline between the antennas, since it can prevent the operator from having accurate data in areas of higher interest (for instance near the coast when the two antennas are located along the coastline). Several options for gap filling are commented and discussed like: Open Mode Analysis (OMA) from radials (Lekien et al., 2004, Kaplan and Lekien, 2007) or Variational analysis (Yaremchuk and Sentchev, 2011).

The conclusion is that maybe this is one of the most necessary advanced products to allow other applications derived from HFR data. From the experience in US, the popularity of this kind of processed data depends on the user. With time different products have been set up and are offered depending on the demand, in any case these kind of advanced products have proven key to “attract” new users from different sectors. The main disadvantage is that the gap filling methods result in velocity fields that contain higher accuracies.

Since a very important aspect of any new product to be introduced in CMEMs is to have a quality assessment and homogenized processing, one of the main points will be to develop the procedures necessary to provide accuracy estimations also on the gap-filled products. The accuracy should be assessed with virtual gaps and also, the application of the gap filling methods can be constricted to avoid reconstructions when there is no enough good data. In any case, the user has to be warned about this limitation, and this product should be provided along with the total current field without data gap-filling. This implies an additional work to define new metadata elements to hold the accuracy information.

Another interesting set of products for CMEMs derived from the advanced processing of the HFR backscatter signals are the wave products and the maps of wind direction. Some new examples of these products are shown by L. Watt during the workshop, and are promising. Although, as explained in section 3.1.1, HFR derived data other than surface currents will be out of the scope of INCREASE project, an additional effort has been done to offer a review of the state of the art of these products in (Rubio et al., 2017).

As a result of the discussion held in the Workshop and the review effort made to build the previous sections of this deliverable, application of OMA method to at least two study areas: one in the SE BoB, and one in the NW Mediterranean will be one of the next steps in INCREASE project WP3. This exercise will be performed, with two main objectives: (1) to test the robustness of this methodology when applied operationally and (2) to work on the definition of procedures and standards for ensuring operational QA/QC of the resulting current fields.

6.2.2 Short term prediction

As summarized in the previous sections, simple approaches like empirical models can be used to forecast future currents based on a short time history of past observations, an alternative (or complement) to assimilating HFR data in numerical models (e.g. Barrick, et al., 2012; Frolov et al., 2012; Solabarrieta et al., 2016; Orfila et al., 2014).

There is a general agreement on that this product can be very interesting within CMEMS, with users related to the SAR and oil spill applications. Again the assessment of the skills of the method (and the radar data!) should be provided, which is not a trivial question. From the experience in US and previous works, the skills of these methods will depend on the geographical areas of application (in US, for example, STPs are working better in the east coast, which has more «predictable» patterns). As important as obtaining operational forecast is to show that STPs can offer reliable estimates, with a clear improvement with respect to persistence.

Another possibility for the short term prediction is to blend HFR data with numerical models. Additionally, it can be foreseen that in the near future the numerical modelling system for European seas implemented as part of CMEMS will, at least in some regions, provide spatial resolutions, which are comparable to HFR observations. Then, HFR data can also be used for the validation of numerical models of the ocean. An example of operational validation of CMEMS numerical models products with HFR data was showed by P. Lorente (Puertos del Estado, Spain). The assimilation of HFR data into models is not identified as short term need for CMEMs, although in the long term new dedicated products for model assimilation (for instance with similar physical contents than the models, i.e. do not offer data with tides if the model does not use tides) will certainly be of increasing interest.

As a result of the discussion held in the Workshop and the review effort made to build the previous sections of this deliverable, the application of a STP method to at least two study areas: one in the SE BoB, and one in the NW Mediterranean will be one of the nest steps in INCREASE project WP3. This exercise will be performed, with two objectives: (1) to test the robustness of the STP methodology when applied operationally and (2) to work on the definition of procedures and standards for ensuring operational QA/QC of the resulting current fields.

6.2.3 Lagrangian Products

Several studies have assessed the effectiveness of trajectory predictions using currents derived from HFR (Ullman et al., 2006; Abascal et al., 2009: Bellomo et al., 2015). So different Lagrangian products could be offered operationally like connectivity maps, Lagrangian residual currents maps, FSLE (Finite Size Lyapunov Exponents). It is also discussed the possibility of developing a LPTM suited to HFR 2D data that could be used operationally on the available fields is discussed.

The conclusion on this point is that although these products are interesting they would not be adapted to become part of CMEMs catalogue, but to be developed as User Uptake Applications or part of Downstream services. In decision from the discussion, no additional efforts would be spent in INCREASE WP3 towards this direction.

6.3 Technical implementation and strategic development

The third Discussion Group worked on defining the criteria that should be taken into account for developing the implementation of the European HFR network and data system. The technical implementation of HFR data system will be closely related to the development of the network. In the same way, the reinforcement of the HFR network will benefit from a coherent, efficient and ambitious design of the data system and products dissemination.

The technical implementation of the data system should take into account:

1. The data stream model has to be established considering the possible role of the Data Centres, CMEMS IN SITU TAC, EMODnet (Physics and Data Ingestion), SDN network of NODCs.
2. The integration and assessment of the HFR data should benefit from a centralized data system

The establishment of the HFR data stream and data flow has to be organized in the existing coordinated framework formed by the main infrastructures previously described in sect. 5.3: Data Centres, CMEMS IN SITU TAC, EMODnet, SDN network of NODCs. Given the importance of data type and the diversity with the already available data streams and quality check procedures, the implementation of the HFR data stream has to come together with the development of competence centres which role is to assess, validate, reprocess the HFR data stream in consolidate products.

The implementation of a such federative structure in situ thematic data assembly has to be coordinated at European level (Competence centre - HFR data node) and can be based on a hierarchical infrastructure to facilitate the management and integration of any potential data provider according a couple of simple and very effective rules:

- If the data provider can set up the data flow according the defined standards, the regional coordinator only has to link and include the new catalogue and data stream
- If the data provider cannot setup the data flow (because of lack of experience, technical capacity etc.), the regional coordinator has to work on harvesting the data from the provider, harmonize and format these data and make them available from the regional catalogue.

Either at regional (or central level) it will applied a second level of quality check as described in the previous sections. This will be the HFR product to be stored and saved for long term stewardship (at regional or local level - according the provider tech and infrastructure capacity).

The integration and assessment of the HFR data in a centralized data system will allow:

i. A second level quality check assessment
ii. Harmonized data products
iii. More efficient implementation of tools for downstream services

As an example, in the U.S. Integrated Ocean Observing System, the Data Management of HF-Radar Derived Surface Currents, aims to provide a scalable solution to real-time data access, distribution, processing and storage. For that, the network architecture includes:

Site – individual field HFR installation

Portal – regional site radial acquisition and distribution centre

Node – radial aggregation and processing node

Depending on the number of sites per Regional Systems, different portals or Nodes could be put in place, or centralized at European level. At least the radial processing should be kept at Site level. However, a homogeneous total processing could be possible at Node level.

The node(s) should provide different regional grids based on equidistant cylindrical projection to preserve orthogonality throughout and provide a practical dissemination format.

As already presented in sect 5.3, within EMODnet Physics, the EuroGOOS Task Team started working to proof the basic concept for setting up both the hardware and software infrastructure to make HFR data available in a pan European harmonized manner. This activity permitted to map the available capacity and identify the already available data flow and data products (Table 9).

TABLE 9: HARMONIZED DATA AVAILABLE AT EMODNET PHYSICS

Platform name	Data format	Data dissemination Unit	Data file update	Data provider catalogue	INCREASE catalogue
BASQUE	Netcdf	AZTI	Hourly	Hourly, last 5 days	Last 60 days, monthly
CALYPSO	Netcdf	UMT.IOI.POU	Hourly	Hourly (Authentication needed), last 5 days, last 10 days, last 30 days	Last 60 days, monthly
COSYNA	Netcdf	COSYNA	Hourly	Daily	Last 60 days, monthly
GALICIA	Netcdf	Intecmar	Hourly	Hourly, last 5 days	Last 60 days, monthly
HAZADR	CSV	IZOR	Daily	Daily	Last 60 days, monthly
NIB	JSON	NIB	Daily	Daily	Last 60 days, monthly
RITMARE	Netcdf	RITMARE	Hourly	Hourly, last 5 days, historical hourly, historical aggregated	Last 60 days, monthly
Delta of Ebro	Netcdf	Puertos del Estado	Hourly	Hourly, last 5 days	Last 60 days, monthly
Estrecho de Gibraltar	Netcdf	Puertos del Estado	Hourly	Hourly, last 5 days	Last 60 days, monthly
Golfo de Cádiz	Netcdf	Puertos del Estado	Hourly	Hourly, last 5 days	Last 60 days, monthly
SOCIB	Netcdf	SOCIB	Hourly	Monthly, current and previous month aggregation	Last 60 days, monthly

It was possible to define the strategy to set up a harmonized data product offering a near real time view of currents (for covered areas) and details for each platform/area. The data flow was harmonized at a central level under a common catalogue and data management infrastructure (based on THREEDS[1], see section 4 for further details) and some products based on the operational European HFR data stream are already available:

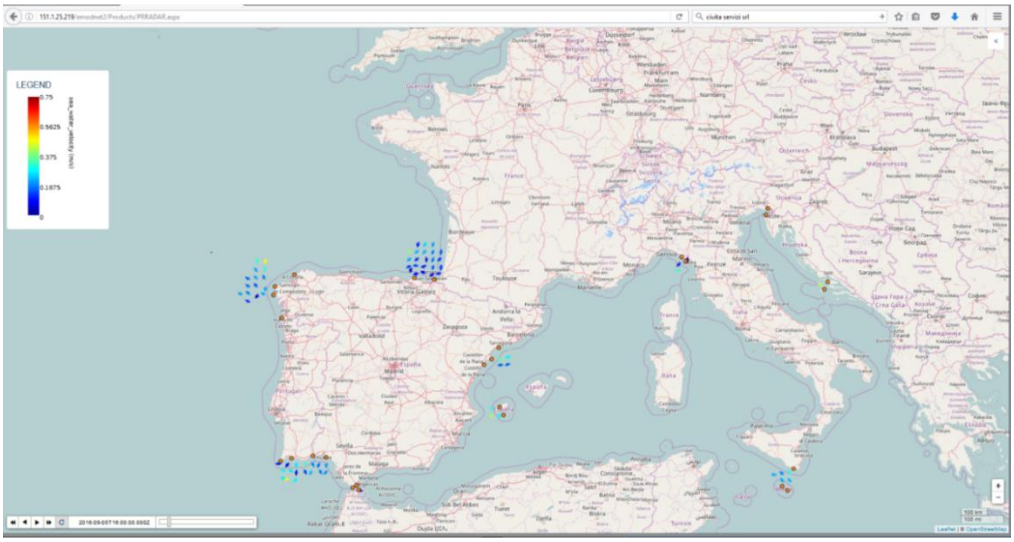

FIGURE 19. OPERATIONAL HFR IN EUROPE INCLUDED INTO THE INCREASE CATALOGUE

[1] http://thredds.emodnet-physics.eu/threddsINCREASE/catalog.html

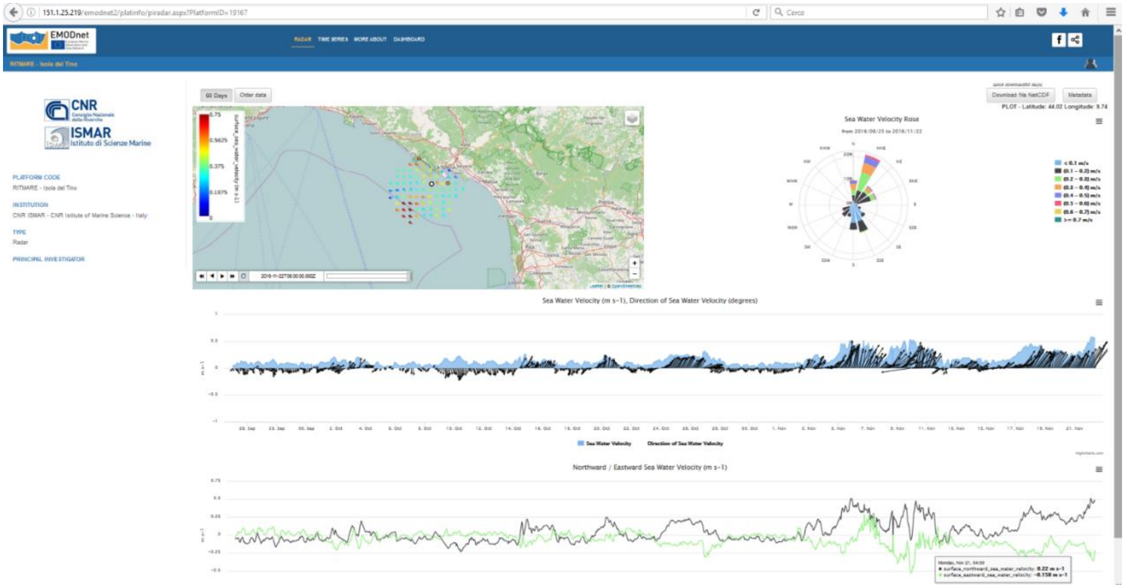

FIGURE 20. EXAMPLE OF AN IN SITU PRODUCT BASED ON THE HARMONIZED HFR DATA FLOW AND CATALOGUE

The established INCREASE catalogue is offering the EU HFR data in a harmonized way: for each platform, a NetCDF file for a sliding temporal window of past 60days and as many NetCDF file monthly aggregation files as the number of months the platform is present in the catalogue. The monthly/annual aggregation also could represent the most suitable time aggregations to be associated to a DOI

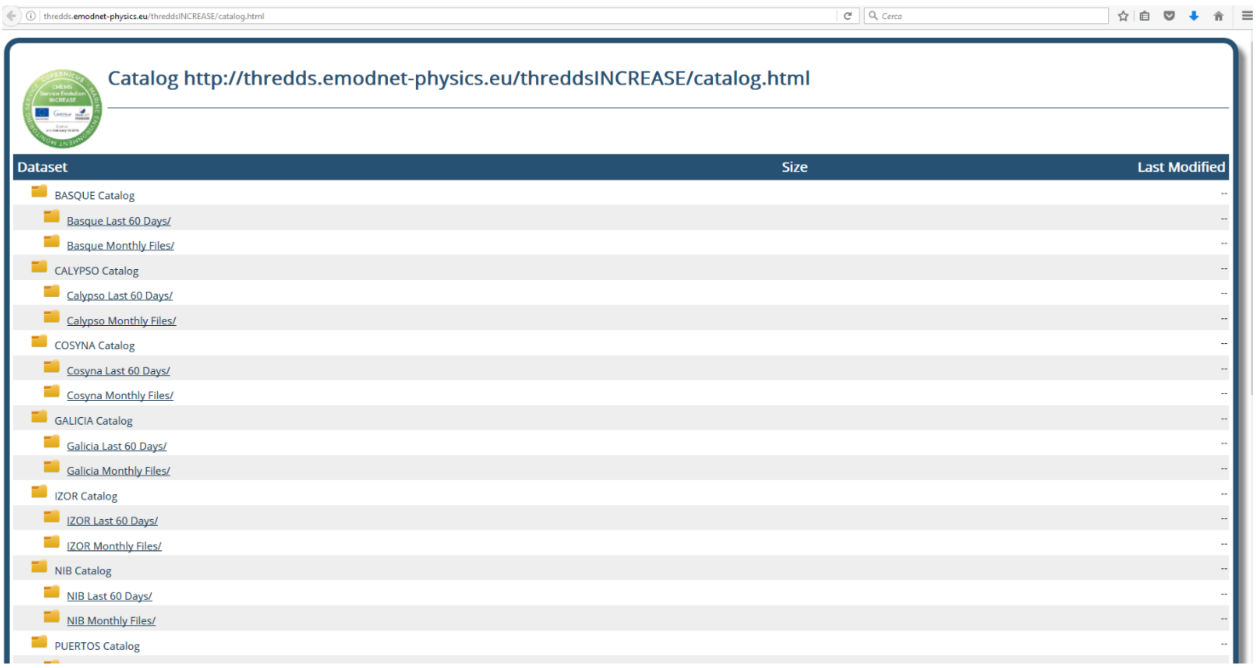

FIGURE 21. INCREASE THREDDS CATALOGUE

INCREASE TDS Installation

THREDDS Data Server

Catalog http://thredds.emodnet-physics.eu/threddsINCREASE/catalog/fmrc/BASQUElast60days/catalog.html

Dataset: Basque Last 60 Days/Basque_HFRadar

- *Data format:* FMRC
- *Data type:* GRID
- *Naming Authority:* Euskalmet, Basque Government
- *ID:* fmrc/BASQUElast60days/Basque_Last_60_Days_Basque_HFRadar

Documentation:

- **summary:** Best time series, excluding offset hours less than 0.0
- **summary:** The data set consists of maps of total velocity of the surface current in the Southeastern Bay of Biscay averaged over a time interval of 1 hour around the cardinal hour. Surface ocean velocities estimated by this HF Radar(4.65 MHz) are representative of the upper 2-3 meters of the ocean. The main objective of near real time processing is to produce the best product from available data at the time of processing. Total velocities are derived using least square fit that maps radial velocities measured from individual sites onto a cartesian grid. The final product is a map of the horizontal components of the ocean currents on a regular grid in the area of overlap of two or more radar stations.
- **rights:** Currently data, products and services are provided \"as is\", without any warranty. These data have been generated from the Basque Country in-situ Operational Oceanography observational network; Their use have to be informed at resp-meteo@ej-gv.es and appropriate acknowledgment to Euskalmet, Basque Governement, given in any publications arising therefrom.
- Access to original data source

Access:

1. **OPENDAP:** /threddsINCREASE/dodsC/fmrc/BASQUElast60days/Basque_Last_60_Days_Basque_HFRadar
2. **WMS:** /threddsINCREASE/wms/fmrc/BASQUElast60days/Basque_Last_60_Days_Basque_HFRadar
3. **NetcdfSubset:** /threddsINCREASE/ncss/fmrc/BASQUElast60days/Basque_Last_60_Days_Basque_HFRadar

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  - *http://www.euskalmet.euskadi.net/,http://www.azti.es/*

Variables:

- *Vocabulary* [CF-1.0]:
  - **GDOP (1)** = *Geometrical Dilution of precision* =
  - **cov (m2/s-2)** = *covariance of surface sea water velocity* =
  - **std_u (m/s)** = *standard deviation of surface eastward sea water velocity* = surface_eastward_sea_water_velocity standard_error
  - **std_v (m/s)** = *standard deviation of surface northward sea water velocity* = surface_northward_sea_water_velocity standard_error
  - **water_u (m/s)** = *Surface Eastward Sea Water Velocity* = surface_eastward_sea_water_velocity
  - **water_v (m/s)** = *Surface Northward Sea Water Velocity* = surface_northward_sea_water_velocity

GeospatialCoverage:

- *Longitude:* -4.0 to -1.2999999523162842 degrees_east
- *Latitude:* 43.5 to 45.400001525878906 degrees_north

TimeCoverage:

- *Start:* 2016-09-26T00:00:00Z
- *End:* 2016-11-22T16:00:00Z

Viewers:

FIGURE 22. DETAILS OF THE INCREASE THREDDS CATALOGUE FOR A GIVEN PLATFORM – LAST 60 DAYS

Catalog http://thredds.emodnet-physics.eu/threddsINCREASE/catalog/BASQUE/monthlyfiles/catalog.html

Dataset	Size	Last Modified
Basque Monthly Files		--
Basque_201611.nc	30.48 Mbytes	2016-11-22T23:19:53Z
Basque_201610.nc	44.80 Mbytes	2016-11-22T23:19:45Z
Basque_201609.nc	17.51 Mbytes	2016-10-30T08:06:16Z
Basque_201607.nc	15.24 Mbytes	2016-07-07T10:08:27Z
Basque_201606.nc	56.02 Mbytes	2016-07-07T10:08:25Z
Basque_201605.nc	68.38 Mbytes	2016-06-30T16:13:10Z

INCREASE TDS Installation at INCREASE see Info
THREDDS Data Server [Version 4.6.5 - 2016-04-04T14:13:23-0600] Documentation

FIGURE 23. DETAILS OF THE INCREASE THREDDS CATALOGUE FOR A GIVEN PLATFORM – MONTHLY AGGREGATIONS

To note that this is a preliminary implementation of the basic infrastructure that will be further extended and developed under WP4. Developments are planned at hardware level as well as at metadata description level as planned and described in sect. 6.1

In addition, the European centralization contributes to the global HFR network (see sect. 4.3.5). The current state of INCREASE development already permit to make the European HFR data stream connected to and be part of the Global network. Moreover, the available INCREASE demonstrator is already providing more advanced user oriented features and thus INCREASE is already setting up a new level of services that can represent the most suitable near future user oriented HFR data global product.

Recently the HFR was also promoted and integrated into the GOOS strategic mapping tool as an important platform to measure Essential Ocean Variables and to contribute to the GOOS mandates. In this framework, JCOMMOPS is already planning to manage the metadata catalogue for costal platforms and the INCREASE catalogue will be the source for the European HFRs.

Finally, CMEMS should be part of the strategic development of the European HFR network. It could contribute, through INCREASE, and further, on the following steps that have been discussed during the HFR Expert meeting:

1. To work on a demonstrator:
    a. Available tools are sufficient to demonstrate the capability.
    b. Radials have to be provided.
    c. Intermediate users with applied best practices should be involved.
2. To work on dissemination to public society:
    a. Why this technology and what are the benefit for key societal challenges?
    b. What do we miss if we have not the HFR network?
    c. To gather some show cases (e.g. marine safety – S&R, water pollution monitoring – long term data series in key places e.g. Naples)
    d. What are the consequences (costs) if you are missing that information and if you react wrongly?
3. To identify the plan with priorities in filling gaps and with a quantitative estimation of cost (installation and maintenance)

7 Conclusions

HFR is today recognized internationally as a cost-effective solution to provide mapping of ocean surface currents over wide areas with high spatial and temporal resolution that are needed for many applications for issues related to ocean surface drift or hydrodynamic characterization. Other R&D lines open interesting perspective for others variables like wave or surface wind data. The European HFR systems are playing an increasing role in the overall operational oceanography marine services. So, the basic and advanced products developed in INCREASE, based on the real-time 2D monitoring of shelf/slope surface circulation, will impact directly on key issues of CMEMS (Marine Safety, Marine Resources, Coastal & Marine Environment, Weather, Climate & Seasonal Forecast).

The performed inventory of the operational HFR systems in Europe (Mader et al., 2016) includes 51 sites (in 20 networks) with potential impact in CMEMS. The MFC meshes overlap so one HFR station could impact in different MFC areas. The potential impact of the currently available data is distributed as follow: MED-MFC (17 stations), IBI-MFC (9 stations), NWS-MFC (3 stations). These numbers will grow at a mid/long term scale, because countries like Portugal, France or UK are establishing plans for developing their networks.

Direct products will be potentially implemented at the end of this project in InSitu TAC. Others will be used in Sea Level TAC for data intercomparison and integration, and in different MFCs for quality assessment (QUID, real-time indicators) or through data assimilation. The covered areas by HFR allow a fundamental assessment in the buffer zone between CMEMS and downstream coastal tools. The products based on the real-time 2D monitoring of shelf/slope surface circulation will deliver key information for assessing the boundary conditions applied in the coastal models of intermediate users.

The INCREASE project will provide demonstrators of key solutions for the implementation of new products based on HFRs. Following the objective of the Service Evolution framework, these implementations could start in 2018 in the Phase two of CMEMS Operational Tasks.

Moreover, INCREASE has established the link between CMEMS and EuroGOOS HFR Task Team that is coordinating the roadmap for developing the use of this technology in Operational Oceanography in Europe. This will allow first to better take into account CMEMS needs in the design of the HFR European network and secondly to optimize the “time to service” of R&D performed in this field.

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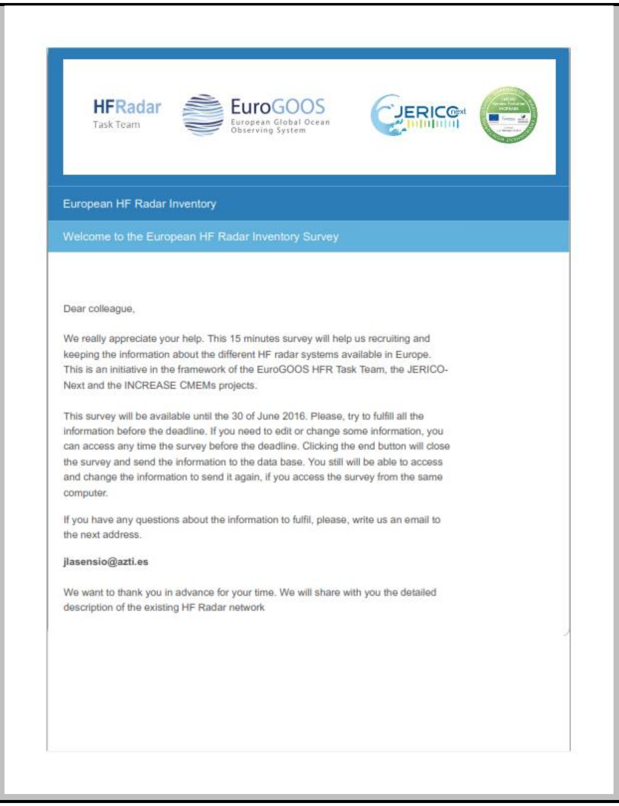
ANNEX 1 – The HFR survey

PAGE 1 - INTRODUCTION	PAGES 2-3 CONTACT INFORMATION	PAGES 4-7 HFR NETWORK SITES



Dear colleague,

We really appreciate your help. This 15 minutes survey will help us recruiting and keeping the information about the different HF radar systems available in Europe. This is an initiative in the framework of the EuroGOOS HFR Task Team, the JERICO-Next and the INCREASE CMEMs projects.

This survey will be available until the 30 of June 2016. Please, try to fulfill all the information before the deadline. If you need to edit or change some information, you can access any time the survey before the deadline. Clicking the end button will close the survey and send the information to the data base. You still will be able to access and change the information to send it again, if you access the survey from the same computer.

If you have any questions about the information to fulfil, please, write us an email to the next address.

jlasensio@azti.es

We want to thank you in advance for your time. We will share with you the detailed description of the existing HF Radar network

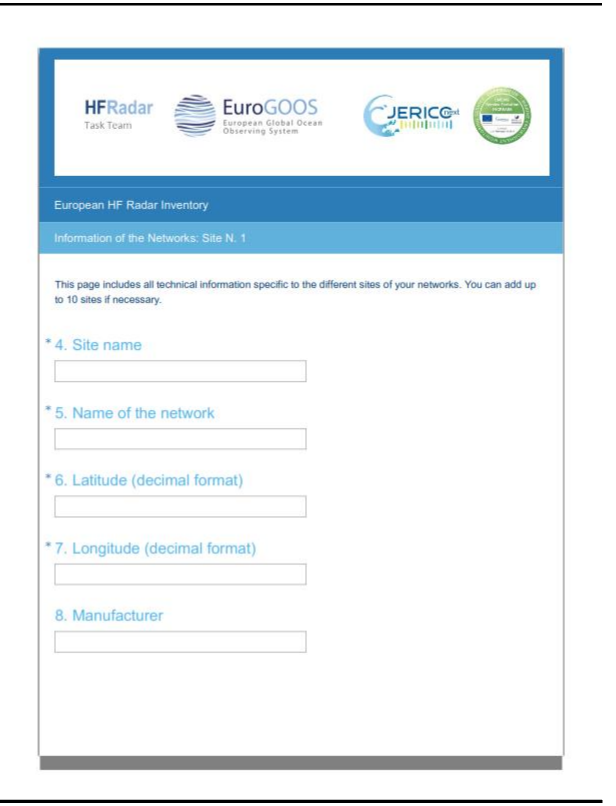
Complete the contact information relative to the Observing Network.

* 1. Contact person

Name
Institution
Address
Address 2
Country
Email Address
Phone Number

2. Owner or responsible for the network (if different from previous)

Name
Institution
Address
Address 2
Country
Email Address
Phone Number



This page includes all technical information specific to the different sites of your networks. You can add up to 10 sites if necessary.

* 4. Site name

* 5. Name of the network

* 6. Latitude (decimal format)

* 7. Longitude (decimal format)

8. Manufacturer

PAGES 4-7 HFR NETWORK SITES

* 9. System type

- Direction Finding
- Phased Array
- Other (please specify)

10. Resolution of radial data: Angular resolution (in degrees)

11. Resolution of radial data: Range cell resolution (in meters)

12. Resolution of radial data: Temporal resolution (in minutes)

13. Spatial resolution of total velocity grid (in meters)

* 14. Transmit frequency (in MHz)

* 15. Transmit Bandwidth (in KHz)

* 16. Start date of use

Date / Time DD / MM / YYYY

PAGES 4-7 HFR NETWORK SITES

* 17. End date of use or ongoing

- Ongoing
- Ended (Please enter the end date in DD/MM/YYYY format)

* 18. "Permanent" or temporary installation

- Permanent installation
- Temporary installation

* 19. Is this HF radar site subjet to regular interference?

- never
- occasionally
- periodically
- always
- Other

If you answered occasionally, periodicalle or always, specify please, in which bandwith.
If Other, should be explained here too.

20. Which is the periodicity of system maintenance?

- Bi-yearly
- Yearly
- Other (please specify)

PAGES 4-7 HFR NETWORK SITES (up to 10 sites)

21. Which is the frequency of the antenna patterns calibration (APM) campaigns?

- Bi-yearly
- Yearly
- Other (please specify)

* 22. Do you need to add another site to the network?

- YES
- NO

PAGES 8-11 DATA TECHNICAL INFORMATION	PAGES 8-11 DATA TECHNICAL INFORMATION	PAGES 8-11 DATA TECHNICAL INFORMATION

HFRadar Task Team

EuroGOOS European Global Ocean Observing System

European HF Radar Inventory

Technical information of the data

* 194. Data availability

- Free and open
- Restricted. Please, specify in the text box below.
- Licensed (e.g. Creative Commons Attribution). Please, specify in the text box below. We invite you to insert, if possible, the link to the license.

Additional information

* 195. Data formats available for radial data

- Manufacturer's
- Netcdf
- Netcdf following current HFR EuroGOOS TT – EMODnet standards
- Other (please specify)

* 196. Data formats available for total data

- Manufacturer's
- Netcdf, please specify compliances with conventions (CF conventions, INSPIRE directive...) in the text box below
- Other, please specify in the text box below.

Additional information

* 197. Real time QA/QC

- Basic QA/QC based on manufacturer's recommendations
- Advanced QA/QC based on other parameters

* 198. Delayed mode QA/QC

- Basic QA/QC based on manufacturer's recommendations
- Advanced QA/QC based on other parameters

199. At what level are QA/QC procedures applied?

- Total data
- Radial data
- Spectral data
- Other (please specify)

200. Which is the method used for total's creation?

- Least Square algorithm
- OMA
- Other (please specify)

201. Which software do you use to combine radials?

- Manufactures'
- MATLAB HFR_toolbox
- Other (please specify)

* 202. Are your real time data online?

- No
- Yes, using a thredds data server
- Yes, in other way.

* 203. Are your historical data online?

- No
- Yes, using a thredds data server
- Yes, in other way.

204. Data portal

PAGES 8-11 DATA TECHNICAL INFORMATION

* 205. Connected to European Data System

- No. Not currently possible.
- No. But open to be. Should be contacted for receiving guidance.
- Yes (please, specify)

206. Please indicate the ROOS area in which your network operates

- Mongoos
- IBIROOS
- NOOS
- BOOS

207. Please list advanced products provided in real time / delayed time (gap-filled data, short term predicttion, etc.)

* 208. Data assimilation- Are your HFR data being assimilated in operational models?

- No
- Yes, by my institute
- Yes, by other institute (please specify)

PAGES 8-12 DATA TECHNICAL INFORMATION

* 209. Previous works have been performed on DA with your data? Are there plans to use them for DA in the future ?

- No
- Yes (please, specify)

210. What data are being used for data assimilation?

- Radials
- Totals
- Other (please specify)

PAGES 13-15 APLICATIONS

HFRadar Task Team
EuroGOOS European Global Ocean Observing System
JERICO next

European HF Radar Inventory

Application area(s)

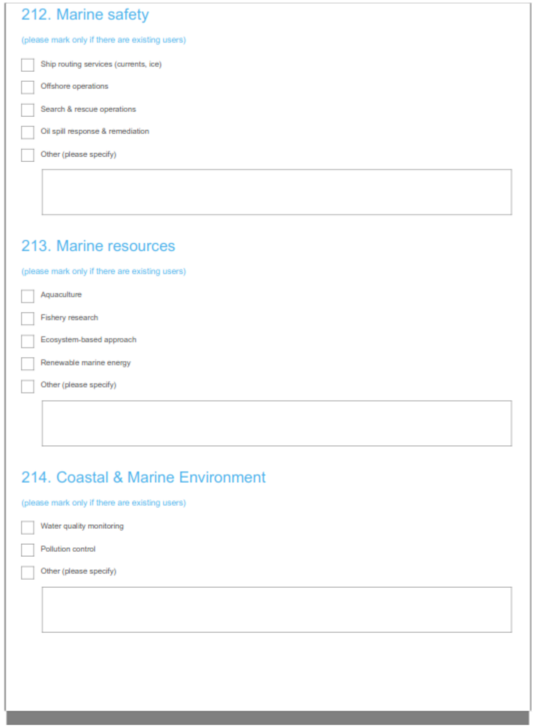
This information refers to all the observing systems previously described.

211. Identified Users (multiple choice enabled)

- European / National Maritime Safety Agencies
- Academia
- Fishery agencies
- NGOs
- European, national or regional Weather Services
- European, national or regional environemental agencies
- Private companies

You can add any relevant information here

PAGES 13-15 APLICATIONS



212. Marine safety

(please mark only if there are existing users)

- [ ] Ship routing services (currents, ice)
- [ ] Offshore operations
- [ ] Search & rescue operations
- [ ] Oil spill response & remediation
- [ ] Other (please specify)

213. Marine resources

(please mark only if there are existing users)

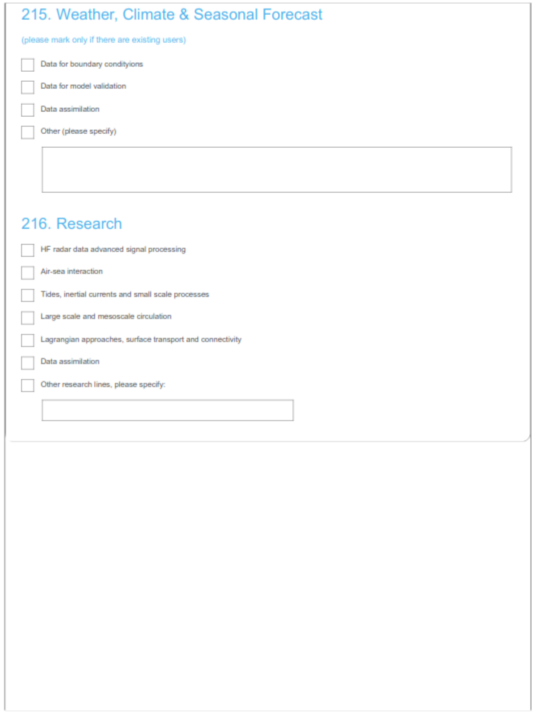
- [ ] Aquaculture
- [ ] Fishery research
- [ ] Ecosystem-based approach
- [ ] Renewable marine energy
- [ ] Other (please specify)

214. Coastal & Marine Environment

(please mark only if there are existing users)

- [ ] Water quality monitoring
- [ ] Pollution control
- [ ] Other (please specify)

PAGES 13-15 APLICATIONS



215. Weather, Climate & Seasonal Forecast

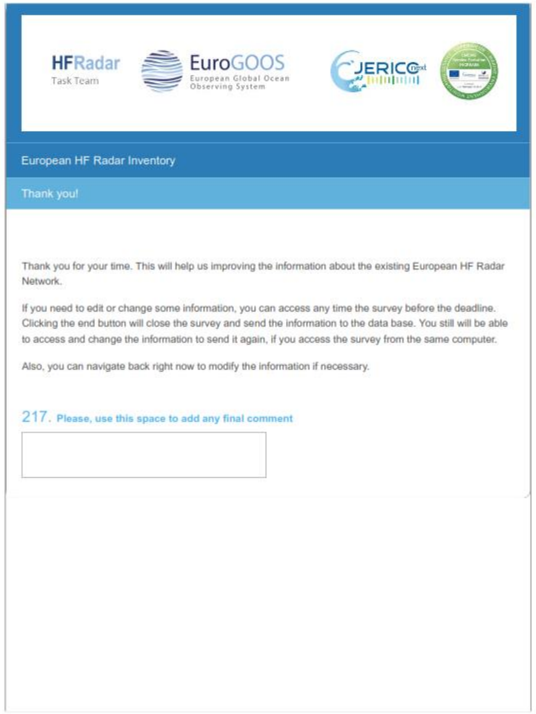
(please mark only if there are existing users)

- [ ] Data for boundary condityions
- [ ] Data for model validation
- [ ] Data assimilation
- [ ] Other (please specify)

216. Research

- [ ] HF radar data advanced signal processing
- [ ] Air-sea interaction
- [ ] Tides, inertial currents and small scale processes
- [ ] Large scale and mesoscale circulation
- [ ] Lagrangian approaches, surface transport and connectivity
- [ ] Data assimilation
- [ ] Other research lines, please specify:

PAGE 16 CLOSING INFORMATION



European HF Radar Inventory

Thank you!

Thank you for your time. This will help us improving the information about the existing European HF Radar Network.

If you need to edit or change some information, you can access any time the survey before the deadline. Clicking the end button will close the survey and send the information to the data base. You still will be able to access and change the information to send it again, if you access the survey from the same computer.

Also, you can navigate back right now to modify the information if necessary.

217. Please, use this space to add any final comment

ANNEX 2 – The European radars

TABLE A2. MAIN CHARACTERISTICS OF THE EUROPEAN HFR NETWORKS. WERA*= WERA, HELZEL MESSTECHNIK; DF= DIRECTION FINDING; PA= PHASED ARRAY.

HFR NETWORK	Hook of Holland		German Bight			Gulf of Naples			TirLig		Gulf of Manfredonia				SICOMAR		Calypso		Joe Doe	CALYPSO		SPLIT	
COUNTRY	***THE NETHERLANDS***		***GERMANY***			***ITALY***													**SLOVENIA**	**MALTA**		***CROATIA***	
OPERATOR	Rijkswaterstaat		Helmholtz-Zentrum Geesthacht			University of Naples			CNR-ISMAR						Consorzio LaMMA - CNR		University of Palermo		National Institute of Biology	University of Malta		Institute of Oceanography and Fisheries	
Numbser of SITES	2		3			3			2		4				2		2		1	2		2	
Name of sites	Ter Heijde	Ouddorp	Wangerooge	Büsum	Sylt	Portici	Castellammare di Stabia	Sorrento	MONT	TINO	VIES	PUGN	MATT	MANF	Livorno Accademia	Marina di San Vincenzo	POZZ	MRAG	Piran 1	Barkat	Sopu	Razanj	Stončica
Sites lat , lon coordinates	52,03	51,82	53,79	54,12	54,82	40,81	40,69	40,63	44,15	44,03	41,89	41,78	41,73	41,62	43,53	43,10	36,71	36,78	45,53	35,88	36,06	43,32	43,07
	4,17	3,88	7,92	8,86	8,28	14,34	14,46	14,34	9,65	9,85	16,18	16,19	16,12	15,93	10,31	10,54	14,83	14,55	13,57	14,56	14,31	16,41	16,25
Date of 1st deployment	01/10/2015		30/08/2009			01/11/2004 and 01/06/2008		11/01/2004	20/06/2016 and 01/08/2016		08/05/2013			08/08/2013	20/04/2015		14/08/2013 and 15/12/2015		01/10/2015	01/07/2012		01/04/2014	
Status	Ongoing		Ongoing			Ongoing		Ended on 06/01/2015	Ongoing		Ended on 13/06/2015		Ended on 06/09/2015	Ended on 06/08/2015	Ongoing		Ongoing		Ongoing	Ongoing		Ongoing	
Permanent installation?	yes		yes			yes			no		no				yes		yes		yes	yes		yes	
Manufacturer	WERA*		WERA*			CODAR			CODAR		CODAR				CODAR		CODAR					WERA*	
Type of radar	PA		PA			DF			DF		DF				DF		DF		PA	DF		PA	
Temporal resolution (minutes)			20			60			60		60				60		60					30	
Spatial resolution of total velocity grid (m)						1000			1500		1500				3000		3000					5000	
Tansmit Fequency (MHz)	16,1		13,5	10,8	10,8	24,6		25,2	26,275		24,53	26,275			13,5		13,5		25	13,5		26,275	
Tansmit Bandwidth (KHz)	150		100	100	100	150			150		150				100		100		150	49,6		150	

TABLE A2. MAIN CHARACTERISTICS OF THE EUROPEAN HFR NETWORKS. WERA*= WERA, HELZEL MESSTECHNIK; DF= DIRECTION FINDING; PA= PHASED ARRAY(cont.)

HFR NETWORK	IBIZA CHANEL		DELTA DEL EBRO			ESTRECHO DE GIBRALTAR			GOLFO DE CÁDIZ	GALICIA				Ria de Vigo		Basque Country		National HF Network				
COUNTRY	***SPAIN***																	***PORTUGAL***				
OPERATOR	SOCIB		Puertos del Estado									INTECMAR		University of Vigo		AZTI		Instituto Hidrografico				
Numbser of SITES	2		3			3			1	2		2		2		2		5				
Name of sites	FORM	GALF	SALOU	ALFACADA	VINAROZ	CEUTA	PUNTA CARNERO	TARIFA	MAZAGÓN	SILLEIRO	FISTERRA	Vilán	Prior	Ria de Vigo	SUBR	Matxitxako	Higer	São Julião	Espichel	Sagres	Alfanzina	Vila real de Santo
Sites lat , lon coordinates	38,67	38,95	41,06	40,67	40,46	35,90	36,08	36,00	37,13	42,10	42,88	43,16	43,57	42,20	42,25	43,45	43,38	38,67	38,41	36,99	37,08	37,18
	1,39	1,22	1,17	0,83	0,48	-5,31	-5,43	-5,61	-6,83	-8,90	-9,27	-9,21	-8,31	-8,80	-8,86	-2,75	-1,78	-9,33	-9,21	-8,55	-8,44	-7,44
Date of 1st deployment	01/06/2012		01/07/2014	07/01/2014		15/07/2011		21/02/2013	11/06/2013	15/07/2010		13/04/2011		01/04/2010		01/01/2009		01/01/2010		01/01/2016	01/01/2012	01/08/2010
Status	Ongoing		Ongoing			Ongoing			Ongoing	Ongoing		Ongoing		Ongoing		Ongoing		Ongoing				
Permanent installation?	yes		yes			yes			yes	yes		yes		yes		yes		yes				
Manufacturer	CODAR		CODAR			CODAR			CODAR	CODAR		CODAR		CODAR		CODAR		CODAR				
Type of radar	DF		DF			DF			DF	DF		DF		DF		DF		DF				
Temporal resolution (minutes)	60		60			60			60	60		60		30		60		60				
Spatial resolution of total velocity grid (m)	3000		3000			1000			1500	6000	5000	6000		187		5000		1400		1500		
Tansmit Fequency (MHz)	13,5		13,5	13,5	13,5	26,275	26,275	26,275	13,5	4,463		4,463		46,5	46,8	4,525		12,43	12,923	13,5		12,4698
Tansmit Bandwidth (KHz)	90,069		90	90	90	150	150	150	100	50		29,4	29	800,2	800	40		80,878	69,849	80,878		99,259

TABLE A2. MAIN CHARACTERISTICS OF THE EUROPEAN HFR NETWORKS. WERA*= WERA, HELZEL MESSTECHNIK; DF= DIRECTION FINDING; PA= PHASED ARRAY (cont.)

HFR NETWORK	MOOSE HF radar		Iroise		Torungen	Wave Hub HF Radar		BRAHAN		Ireland West Coast_Radars			
COUNTRY	*FRANCE*				*NORWAY*	*UK*				IRELAND			
OPERATOR	MIO, AMU-CNRS-IRD-UTLN		SHOM		Norwegian Meteorological Institute	Plymouth University		Marine Scotland Science		National University of Ireland			
Numbser of SITES	2		2		1	2		2		4			
Name of sites	ANTARES	DYFAMED	Pointe de Garchine	Pointe de Brézellec	Torungen	Pendeen	Perranporth	SUMB	NRON	Mutton Island	Spiddle	Inish Oirr	Loop Head
Sites lat , lon coordinates	42,95	43,50	48,50	48,07	58,40	50,16	50,34	59,85	59,39	53,25	53,24	53,06	52,56
	6,00	7,25	-4,78	-4,66	8,79	-5,67	-5,18	-1,28	-2,38	9,05	9,30	9,52	9,92
Date of 1st deployment	15/11/2011	01/09/2015	01/05/2006		25/05/2016	01/02/2011 and 01/04/2011		01/09/2013		01/03/2012		01/09/2015	
Status	Ongoing	Ongoing	Ongoing		Ongoing	Ongoing		Ended on 09/08/2014	Ended on 09/01/2014	Ongoing			
Permanent installation?	yes	yes	yes		yes	no		no		yes			
Manufacturer	WERA*	CODAR	WERA		CODAR	WERA*		CODAR		CODAR			
Type of radar	DF on 8 receiving antenna	DF	PA		DF	PA		DF		DF			
Temporal resolution (minutes)	60	90	10		60	60		60		60			
Spatial resolution of total velocity grid (m)	3000	0	2000			1000		5000		300		2000	
Tansmit Fequency (MHz)	16,175	13,45	12,4		13,5	12		4,5		25		13,5	
Tansmit Bandwidth (KHz)	50	50	100		75	350	375	36,8		500		49,6	

ANNEX 3 – Attendance list of the INCREASE HF Radar Experts Workshop

NAME	INSTITUTION
Simone Cosoli	ACORN (Australian COastal Radar Network)
Julien Mader	AZTI
Anna Rubio	AZTI
Jose Luis Asensio	AZTI
Angélique Melet	CMEMS / Mercator Océan
Bruno Levier	CMEMS / Mercator Océan
Loic Petit De La Villeon	CMEMS instac / IFREMER
Stéphane Tarot	CMEMS instac / IFREMER
Carlo Brandini	CNR Ibimet & LaMMA Consortium
Carlo Mantovani	CNR-ISMAR
Lorenzo Corgnati	CNR-ISMAR
Annalisa Griffa	CNR-ISMAR
Maristella Berta	CNR-ISMAR
Marcello Magaldi	CNR-ISMAR
Roberta Sciascia	CNR-ISMAR
Laura Barbieri	CNR-ISMAR
Stefano Taddei	Consorzio LaMMA - Laboratorio di Monitoraggio e Modellistica Ambientale per lo sviluppo sostenibile
Lohitzune Solabarrieta	DeustoTech
Enrico Zambianchi	DiST, Università Parthenope and CoNISMa
Pierpaolo Falco	Dpt. Science and Technology, University of Naples "Parthenope
Marco Uttieri	Dpt. Science and Technology, University of Naples "Parthenope"
Antonio Novellino	ETT
Marco Alba	ETT
Patrick Gorringe	EuroGOOS
Leif Petersen	Helzel/WERA
Johannes Schultz-stellenfleth	HZG
Jochen Horstmann	HZG
Alejandro Orfila	IMEDEA
Carlos Fernandes	Insituto Hidrografico
Maurizio Demarte	Italian Hydrographic Office
Marta Pratellesi	Italian Hydrographic Office
Cosmo Peluso	Italian Hydrographic Office
Céline Quentin	MIO
Michael Hartnett	National University of Ireland
Vlado Malacic	NIB
Branko Cermelj	NIB
Pablo Lorente	Puertos del Estado
Andrés Alonso-Martirena	Qualitas/CODAR
Jorge Sánchez	Qualitas/CODAR
Pia Andersson	SMHI
Emma Reyes	SOCIB
Adam Gauci	University of Malta (CALYPSO)
Giuseppe Ciraolo	University of Palermo (CALYPSO)
Fulvio Capodici	University of Palermo (CALYPSO)
Lucy Wyatt	University of Sheffield
Jeff Paduan	USA/IOOS, NPS
Mark Otero	USA/IOOS, Scripps