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Executive Summary and acknowledgments

The main objective of this document is to offer a comprehensive "Best Practices" document by performing a compilation of the existing references and expanding the recommendations to ensure a broader approach to optimal operation of HF-radar systems with independence from manufacturer or antenna design and setup. Several guidelines and best practice documents have been widely used as a basis for elaboration of this report, as listed in Section 1. Authors of this deliverable acknowledge the contributions of Teresa G Updyle (Center for Coastal Physical Oceanography, Old Dominion University) and MARACOOS / IOOS.

1. Introduction

HF-radar has shown to be a cost-efficient tool to monitor coastal regions at a range of up to 200 km, and therefore has become a favorable sensor to monitor coastal regions all over the world. Oceanographic HF-radars are mainly utilized to measure ocean surface current fields [Paduan and Rosenfeld, 1996; Gurgel et al., 1999] for various applications such as search and rescue [Ullman et al., 2006], oil spill monitoring [Abascal et al., 2009], marine traffic information [Breivik and Sætra, 2001] or improvement as well as data assimilation of numerical circulation models [Paduan and Schulman, 2004; Barth et al., 2008]. Further applications of the HF-radars include surface wave retrieval [Wyatt, 1990; Gurgel et al., 2006], surface wind retrieval [Heron and Rose, 1986; Shen et al., 2012], as well as Tsunami detection [Lipa et al., 2006; Gurgel et al., 2011] and ship detection [Ponsford et al., 2001; Maresca et al., 2014], of which the latter two are getting more and more popular.

HF-radar is a land based remote sensing instrument that relies on resonant backscatter resulting from coherent reflection of the transmitted wave by the ocean waves whose wavelength are half of that of the transmitted electromagnetic wave length. This is the so-called Bragg scattering phenomenon and results in the first order peak of the received (backscattered) spectrum. Two peaks (Bragg peaks) are shown in the received signal spectrum, symmetric with respect to the central transmitting frequency of the radar and associated with the waves traveling in the radial direction towards (right peak) and away (left peak) from the radar. If gravity waves propagate within a current field, an additional Doppler shift affecting both peaks is produced and leads to an asymmetric spectrum. The difference between the theoretical speed of the waves and the velocity observed, resulting from the Doppler shift of the observed Bragg peaks, is due to the velocity of the radial component of the current (with respect to the radar), which can therefore be estimated. Further in-depth analysis of the full spectra of the backscattered signals can also provide information on the sea state, winds, tsunami and determination of position and speed of targets (e.g. vessels). However, extracting information other than surface currents presents a much greater challenge since these are obtained from much weaker or partial parts of the signal, which are more likely to be corrupted by noise and interference [Barrick, 1977, Wyatt et al., 2006]. As to date the great majority of HF-radars are being utilized to retrieve ocean surface currents and therefore the focus of the best practice in this document will be related to currents if not explicitly mentioned elsewise.

Two major HF-radar developments are being utilized in oceanography: the phased array and the direction-finding concept [Gurgel et al., 1999; Barrick, 1997 and references herein]. These two types of systems differ significantly in their antenna design and setup, as well as in how the spectral information is processed in order to determine the direction of arrival of the received signal. When using a phased array of antennas, the signal is processed using the beam-forming (BF) method, which provides a Doppler spectrum for every cell in the field of view of the radar. Therefore, the information deduced from the Doppler spectrum, e.g. radial current velocity, are directly associated to the range and azimuth domain. An alternative is to perform a procedure called direction-finding (DF) in the frequency domain to obtain azimuthal resolution from the information received from a directional antenna. In this case, radial velocities are obtained from spectral data by using the Multiple Signal Classification (MUSIC) algorithm [Schmidt, 1986]. In addition, the HF-radar systems have different transmitting concepts (Table 1), which have to be considered when selecting the desired operating range and frequency as well as temporal sampling frequency.

Table 1 HF-radar systems and the utilized techniques for obtaining the range and azimuth of the sea echo.

HF-radar System	Range	Azimuth	
	Radar Waveform	Direction Finding	Beam Forming
CODAR/NOAA [Barrick et al., 1977]	Pulse	+	-
COSRAD [Heron et al., 1985]	Pulse	-	+
PISCES [Shearman and Moorhead, 1988]	FMICW	-	+
OSCR [Prandle et al., 1992]	Pulse	-	+
C-CORE [Hickey et al., 1995]	FMICW	-	+
SeaSonde [Barrick and Lipa, 1997]	FMICW	+	-
WERA [Gurgel et al., 1999]	FMCW	+	+
LERA	FMCW	+	+

To obtain surface current vectors, an HF-radar network must include at least two radar sites, where each site measures the radial velocity in its look direction. Thus, once the radial components of the surface currents are calculated, they can be combined in the overlapping area, to provide a surface current vector map (Figure 1). Coverage area, maximum range and spatial resolution depend respectively on HF-radar operating frequency, available bandwidth, water salinity, sea state and HF-radar system being utilized. The typical range resolution ranges from several hundred meters to 6-12 km, depending on frequency and utilized bandwidth of the system. The azimuthal resolution depends on the utilized HF-radar concept and varies between 8° and 18°.

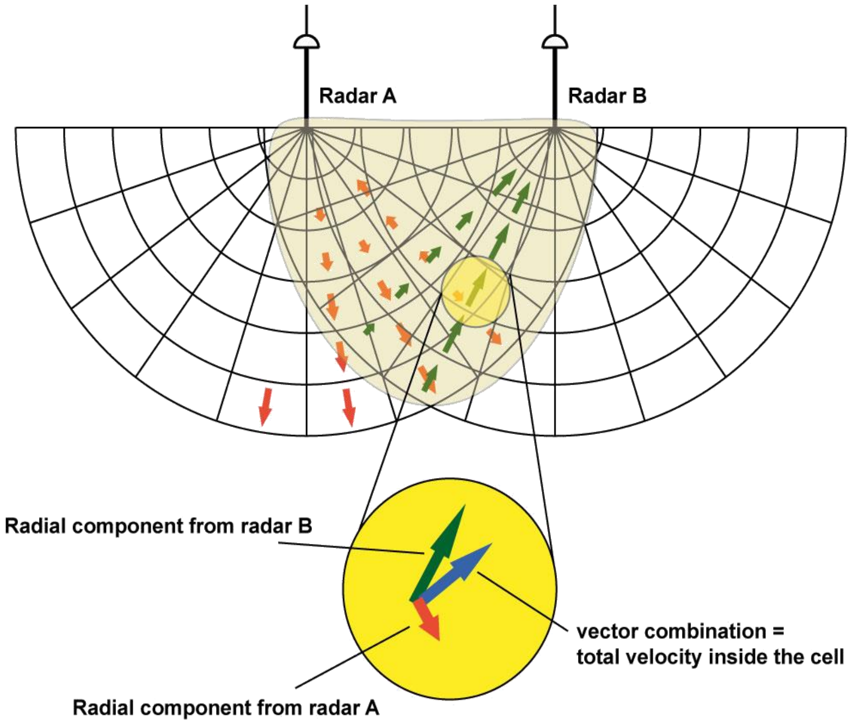

Figure 1. Concept of a HF-radar network for obtaining ocean surface current vectors. Every single site measures the radial current component, which can be combined to the surface current vector by combination of the components of at least two sites.

Around 400 HF-radars are installed worldwide and are being used in a diverse range of applications [Roarty et al., 2016, 2019]. In Europe, the number of systems is growing with over 64 HF-radars and a number in the planning stage. From the last available survey performed [Mader et al., 2017] the most extended and deployed commercial HF-radars in Europe are SeaSonde for DF and WERA systems for BF (see Table 1). Therefore, the recommendations provided here mostly refer to that kind of systems.

Nowadays, HF-radar systems are integrated in many European coastal observatories with proven potential for monitoring coastal currents and providing inputs for operational data assimilation and assessment of numerical ocean forecasting models, especially near the coast [e.g.; Barth et al. 2008, 2011; Marmain et al, 2014; Stanev et al. 2015; Iermano et al., 2016]. The growing number of HF-radars, the optimization of HF-radar performance against technical hitches (from installation to maintenance and operation) and the need for complex data processing and analysis, has driven the HF-radar community to work at European and international levels towards the coordinated development of coastal HF radar technology and its products [Rubio et al., 2018].

In response to the need for optimizing operation performance, different documents providing best practices for radar systems operation and maintenance have emerged in the past years. Most of them are either oriented to DF or BF systems, or to specific manufacturer's radar systems. In this context, the main objective of this document is to offer a comprehensive "Best Practices" document by performing a compilation of the existing references and expanding the recommendations to ensure a broader approach to optimal operation of HF-radar systems with independence from manufacturer or antenna design and setup.

A list of the guidelines and best practice documents used as a basis for elaboration of this report is given bellow:

- REF1: Cook, T., Hazard, L., Otero, M. and Zelenke, B. (eds) 2008 Deployment and Maintenance of a High-frequency Radar (HF-radar) for Ocean Surface Current Mapping: Best Practices. La Jolla, CA, University of California San Diego, Scripps Institution of Oceanography for SCCOOS, 19pp. http://hdl.handle.net/11329/368.
- REF2: U.S. Integrated Ocean Observing System (2016) Manual for Real-Time Quality Control of High Frequency Radar Surface Current Data: a Guide to Quality Control and Quality Assurance for High Frequency Radar Surface Current Observations. Version 1.0. Silver Spring, MD, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Integrated Ocean Observing System, 58pp. http://hdl.handle.net/11329/288.
- REF3: Wera Best Practices - WERA Remote Ocean Sensing. WERA Best Practice. Version 1.2 December 2018.
- REF4: Codar Ocean Sensors (COS) Technical documents and COS best practices documentation (under licence).
- REF5: SeaSonde® Remote Unit Operator's Manual SSRS-100 Product Series October 19, 2010
- REF 6: Philip, A., Oceanographic Applications of Coastal Radar (2012) Naturvårdsverket/Swedish Environmental Protection Agency, https://www.smhi.se/polopoly_fs/1.28277!/RO_41.pdf.

This document is the final deliverable (D2.4) within Task 2.3, which deals with the harmonization of different technologies, within the European project JERICO-NEXT. The first deliverable (D2.1) from this task and a first workshop (MS9) aimed to review the state of the art on HF Radars concerning existing systems in the JERICO network and their operating procedures. **This document focuses on the best practices in the planning, setup and operation of HF radars**, and results from the efforts carried out within the JERICO-NEXT project as well as of the **experience of the partners during planning, implementation and operation of 5 HF-radar networks** with a total of 14 HF-radar sites of different types (Table 2).

Table 2. HF-radar networks operated by JericoNEXT project partners. The acronyms are defined as followed: PA = phased array, DF = direction finding, Cur = surface currents, Wav = surface waves, RT-MV: real-time model-validation, DA = data assimilation, and SD = ship detection.

Operator	Country	Number & Type	Applications	Network	Location
Euskalmet – Basque Government / AZTI	Spain	2 DF	Cur	Basque Country	SE Bay of Biscay, North Atlantic
HZG	Germany	3 BF	Cur, Wav, DA, SD	COSYNA	German Bight, North Sea
ISMAR-CNR	Italy	4 DF	Cur, DA	TirLig	Ligurian Sea, Mediterranean Sea
MIO-CNRS	France	3 DF	Cur	MOOSE HF-Radar	Ligurian Sea, Mediterranean Sea
SOCIB	Spain	2 DF	Cur, RT-MV, DA	Ibiza Channel	Ibiza Channel, Western Mediterranean Sea

1.1 Contents and Structure of the Document

This document provides a comprehensive guidance for the implementation and use of HF-Radar systems, starting with planning, site selection and deployment as well as with respect to maintenance, operation and management of data flow. The document is based both on literature and the authors experience managing the two most common commercial HF-radar systems on the market.

One of the most important criteria in the planning phase of a HF-radar is the selection of the desired spatio-temporal resolution, maximum range and spatial coverage of the HF-radar together with the major parameter of interest, which in the majority of today's setups are ocean surface currents. These will determine the operating frequency, type of system to be used, number of systems and their relative location. However, other aspects may have to be considered in order to ensure the performance of the deployment, like available space (depending on the selected system), availability of infrastructure (power supply, accessibility etc.), sources of possible electromagnetic noise and interaction (e.g. power lines, industry, nearby antennas, metal fences). **Recommendations for implementation and radar setup are provided in Sections 2 and 3.**

During operation there are various factors, which either affect the radar performance directly and therefore the accuracy of the measurements or lead to an interruption of the data flow. Generally, spatial and temporal data gaps may occur at the outer edge, as well as inside the measurement domain due to different causes like: the lack of Bragg scattering ocean waves, severe ocean wave conditions, low salinity environments, the occurrence of radio interference, failures of the internet connection, power outages, to mention just a few. **Recommendations for site maintenance** to enable continuous operation are provided in **Section 4**Erreur ! Source du renvoi introuvable..

Finally, while all the HF-radars share the same principles of operation, differences in signal transmission, reception and processing yield variations in metadata, quality assessment procedures and quality control metrics. Even within the same type, HF-radars may have different spatial ranges and resolutions, depending typically on the working frequency and bandwidth available. **Recommendation for data management and the software tools available for data pre-/processing/post-processing is provided in Section 5**. In addition to data management at local level, specific guidelines are provided to ensure the flow of operation data into the European HF-radar node [Corgnati et al. 2018a]. The node is pre-operational since November 2018 and will be fully operational since April 2019 for the Copernicus Marine Service (CMEMS-INSTAC), SeaDataNet (SDN/SDC) and EMODnet Physics data delivery of the European HF-radar network data and a HF-radar task team has been organized in Europe.

Section 6 provides guidance on data quality assurance (QA) and quality control (QC) for surface current data following Corgnati et al. [2017, 2018b]. Specific guidelines apply to QA and QC procedures, to be compliant to the EU standard for data and metadata, to ensure validity and correctness of measurements and their operational ingestion in the European HF-radar node.

2. New Deployment

Due consideration needs to be given to the amount of time and money it will take to gain/purchase access to, and use of, the intended HF-radar site. Additionally, sufficient time and money must be allotted for obtaining the required permits to use the land as a HF-radar site (e.g., Coastal Development Permit) and to operate the HF-radar (e.g., Federal Communications Commission broadcast permit).

Many regulations can affect the possibility to deploy an HF-radar station, and any non-compliance with one of the required permissions may lead to a failure in getting clearance for an HF-radar installation or operation (please refer to section 2.7 for a discussion on this topic). A further important aspect in the planning phase is the location of each individual site as well as the distance of the HF-radar sites to each other, in particular when measuring surface current vectors. The optimum location and distance to each other depends on the utilized system, frequency, salinity and shape of the coastline. In case additional parameters such as sea state are to be measured, the distance between sites has to be reduced accordingly. This task becomes particularly difficult when the coastline does not offer easy access or any suitable infrastructures (e.g. buildings, roads, electrical power line). Lighthouses and coast guard offices, especially if still active, can help in such situations. Very often they offer good site requirements, being close by the shore and having clear view on the sea. However, electromagnetic compatibility with other communication or radar systems, usually existing in these places, must be verified in advance.

2.1. Site Requirements

An ideal location for a HF-radar site possesses the following general characteristics:

- minimum distance to the water but safe from waves and flooding
- enough space to accommodate antennas, electronics, and cable-runs
- free of electrically conductive objects (e.g. metallic fences, poles and containers)
- no radio interference at your selected frequency
- widest possible unobstructed field-of-view of the ocean
- onsite electricity
- onsite broadband internet connectivity or well covered by a mobile network
- secure from damage caused by animals (e.g., cows, bears) and human vandalism
- flat or gently sloping terrain that is easily traversed and free of hazards
- nearby vehicle access

Except for compact implementation of HF radar technology that allows co-located receive (Rx) and transmit (Tx) antennas, the Rx and Tx antennas should be separated by a minimum distance depending on the operating frequency and the signal processing technique. Typical setups of BF and DF are depicted in Figure 2.

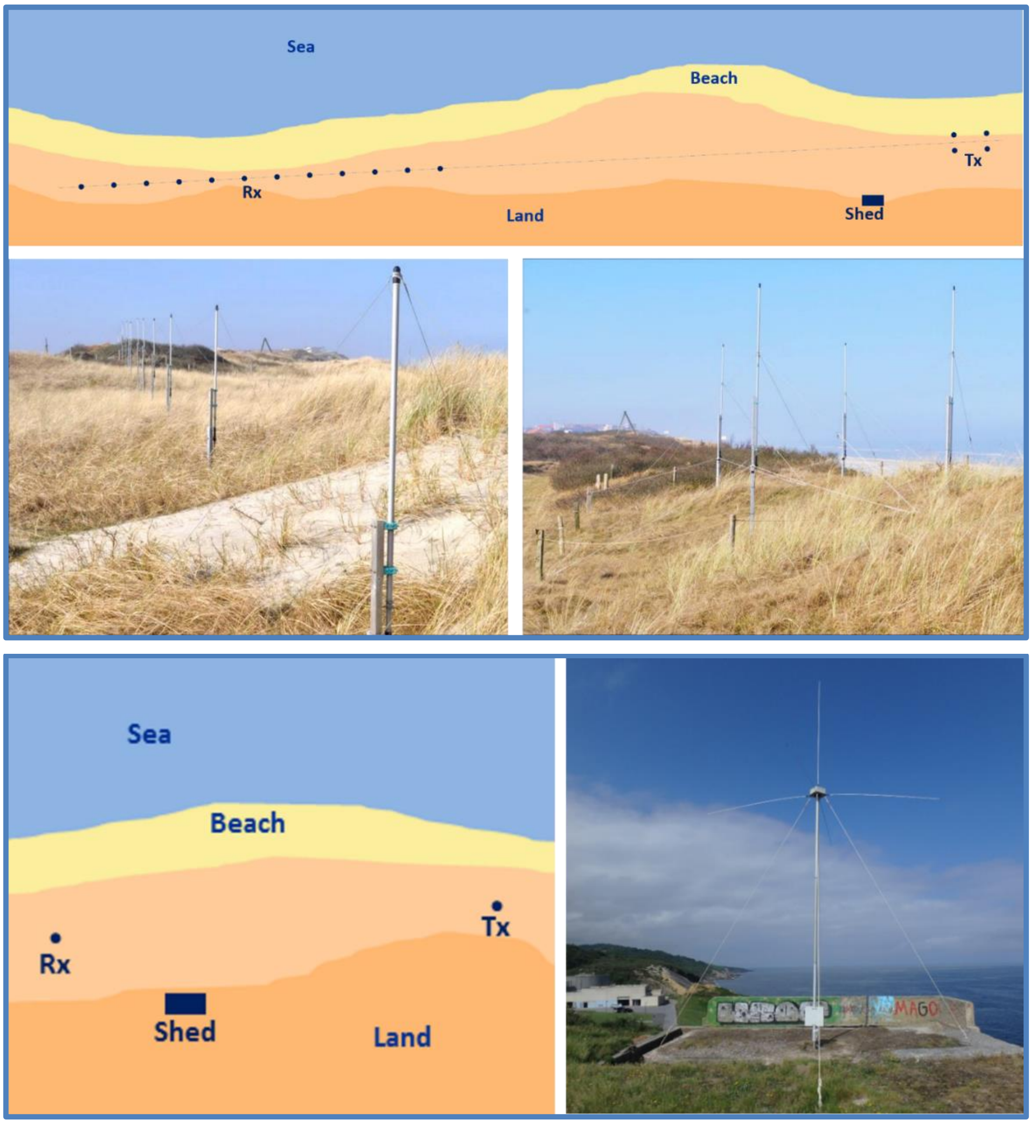

Figure 2. Upper panel shows a typical setup of a beam forming system. The photos show a beam forming setup of a WERA system on the island of Wangerooge at the German coast of the North Sea. The transmitter antenna array (Rx) is shown on the left-hand side and the receive array (Tx) on the right hand side, respectively. The bottom panel shows a typical direction finding HF radar system setup (left ha-d side). The photo (right hand side) shows a direction finding system from SeaSonde installed at Matxitxako Cape (northern coast of Spain). This system is one of the two EUSKOOS HF radars that were set up in 2009 to monitor sea surface currents within the coastal area of the Spanish Basque Country.

As an example, a SeaSonde HF-radar with separate Rx and Tx antennas, these should be separated by a minimum distance of one wavelength (λ) based on the center operating frequency, given by $\lambda = c/f$, where c is the speed of light (299792458 ms^{-1}), and f is the center frequency in Hz. In all the cases the antennas should be always placed near to the coastline within a maximum distance following Table 3, after which the attenuation of the electromagnetic signals due to propagation over land would result in a dramatic decrease of the signal to noise ratio, i.e. lower accuracy and shorter range in measurement.

Table 3. Recommended maximum distance to the water for SeaSonde and WERA Rx and Tx, based on operating frequency (according to the manufacturers of SeaSonde and WERA).

Frequency [MHz]	Maximum Distance to Water [m]		
	SeaSonde	WERA	
		Rx	TX
4-6	250	800	500
12-14	150	500	300
24-27	150	400	200
47-50	150	200	100

As already stated in REF1: *A HF-radar site needs then to have enough space to accommodate the minimum antenna separation while remaining within the specified distance from the water. Additionally, electrically conductive objects such as metal structures, trees, and power lines should be avoided, as these will distort the antenna pattern, thereby degrading data quality.*

While distortion of the antenna pattern can in some instances be compensated for with an antenna pattern measurement (refer to section 3.3), more severe distortion can invalidate all the measurements made at a HF-radar site (processed for DF methods).

Cliff faces and steeply sloped ground can also degrade the HF-radar measurements by acting as a reflector of the transmitted radio signal. Gently sloping or level ground is preferred for a HF-radar site. Many operating HF-radar sites do not meet every one of these criteria and still produce acceptable measurements. When an “ideal” site is not available, consideration should be given to mitigate existing obstructions.

For the array type antenna configurations of BF systems, no antenna pattern calibration is required. Automatic self-calibration routines correct for some irregular characteristics. Only in some extreme conditions an antenna pattern measurement can be helpful to improve the quality of the BF, in particular when being utilized for wave measurement applications.

2.1.1. Power

As already mentioned in REF1: Electrical power is required at the location of the Tx and Rx chasses. Ideally a HF-radar site should have an existing shelter available within 50 m of the HF-radar site with electrical power for the associated electronics and computer parts. In the case where electrical service from an existing utility power-grid is not already available at the HF-radar site, a concerted effort should be made to tie the HF-radar site into the power grid. In those locations where utility grid power is not available, a HF-radar site can be powered using solar panels, windmills, a generator, or even better a combination thereof. Assuming continuous operation, the cost of creating off-grid electricity to power a HF-radar site is in the tens of thousands of euros. In continuous operation, the power consumption of most commercial HF-radar systems excluding air conditioning is between 300 W and 500 W, based on technical specs and direct measurements statistics of SeaSonde and WERA systems. Other less common systems may rise to up thousands of Watts. In addition, an air conditioning unit draining between 500 W and 2.000 W of power, depending on the climate of the HF-radar site, the location of the electronics and the type of enclosure, is required in most cases. However, an intelligent power management can be used, which helps to reduce the power consumption.

Since power outages are a very common cause of HF-radar station downtime, it is strongly suggested to ensure that the work related to the power line setup is carried on by professionals.

2.2. Climate-Controlled Enclosure Specifications

2.2.1. HF-radar Enclosure and Air Conditioning

The electronics enclosure can be of different nature depending on the available space at the site, the cooling, heating and dehumidifying requirements, the number of devices to be placed inside, the need of protection against sun, water, dust, etc…

If a building is available, the enclosure can be located inside a room and a standard rack cabinet with suitable dimensions can be adopted. A standard air conditioning system can be installed in the room if needed.

If a building is not available, different options can be followed:

- Provide a weatherproof, climate-controlled shelter or trailer. This solution, although moderately expensive, allows the operator to work on a small but still comfortable environment, and provides a robust protection against natural hazards (weather, animals) and vandalisms. A trailer has also the advantage that it can be relocated easily in most cases.
- Place a sealed, insulated, air-conditioned, stainless steel enclosure with minimum size suitable for containing the electronics. Such compact solution is less protected and may require specific and tailored air conditioning systems

(e.g. thermoelectric air conditioners) but on the other hand it is very flexible, e.g. can be deployed with very little space needed and relocated with little effort.

As stated in REF1: *Use of the air conditioner is strongly suggested in most of the circumstances and is vital in case of the last option suggested above to provide heat dissipation for the HF-radar electronics and to prevent corrosion by dehumidifying the air. In a sealed enclosure the Tx and Rx chasses can overheat in less than an hour without air conditioning and will stop functioning.*

2.3. Support Equipment

2.3.1. Data Acquisition

In most commercial HF-radar systems the control of the electronics and the data acquisition are performed by x86-based systems ranging from consumer PCs to entry level servers and running Mac OS X or Linux operating systems. They are typically provided in bundle with the HF-radar system and already pre-configured with all the needed control and processing software and ready for on-site installation except for a few parameters like network settings and site-specific information (name, geographical coordinates, etc.). As the lifetime of the computer is typically much shorter than the electronic of the HF-radar system, care should be taken with respect to compatibility between the manufacturer's software's and newer operating systems.

After first deployment and some days of operation some data processing parameters need to be tuned in order to optimize both the system performance and the processing accuracy.

An external backup hard drive is recommended for archiving data acquired by the HF-radar, preferably running in RAID 1 mode (mirroring) to prevent data loss in case of one disk failure.

2.3.2. Power Line Accessories and Uninterruptible Power Supply

Once a suitable electrical power source is established, a remote HF-radar station may need additional solutions in order to minimize the need of maintenance on site due to power-related issues. They may include:

- a dedicated electrical panel and line, bypassing any pre-existing problematic panels or electrical lines.
- a dedicated grounding line for the lightning protection system or even a dedicated grounding if not already existing or if not reliable (a test is needed).
- an automatic reclosing circuit breaker that restores the power supply if the cause that triggers the breaker is temporary (e.g. overvoltage during a storm).
- a smart power stripe that can be switched on/off on schedule or by remote control if hardware power reset is needed.

An uninterruptible power supply (UPS) should be used to protect the HF-radar electronics and provide temporary battery backup in case of power failure. UPS minimum requirements for effective power backup and remote management should include:

- an adequate output rating, that in most cases can be equal to 1 KW (often UPS power rating is expressed in terms of Volt-Ampere, and these two parameters don't match in case of AC current, so please read carefully technical specs).
- an ethernet card and a website interface for remote configuration and monitoring; enough battery capacity to ensure 15 to 20 min of autonomy considering the maximum load, and the possibility to expand the battery pack if upgrade is needed.
- two or more outlet groups that can be managed separately.

An UPS acts as surge suppressor and ensures within certain limits stable sinewave (pure or simulated depending on the model) power through over-voltages and brownouts. Please remember that UPS is an emergency power backup and, with the characteristics described in the above paragraph, it's not capable in most cases to provide enough power to any air conditioning systems and therefore should not be connected to it. All other HF-radar electronics should be plugged into the UPS. Following REF1: *Most UPS systems come with software, which can be configured to shut down computers that are connected, when the battery is about to discharge totally. Results are mixed with the use of the various software products, especially with compatibility with Mac OS* or another OS*. Remote power management products may be used as a last-ditch effort to reboot computers and hardware using a phone line or IP connection. Power Stone remote power systems have been known to cause problems at several sites in US network.*

2.3.3. Lightning Electromagnetic Pulse Protection

Lightning electromagnetic pulse protection (LEMP) is also mentioned in REF1: *LEMP should be installed inline on any antenna (i.e. receiver and transmitter channels, GPS, communications) as a safety precaution for personnel and radar electronics. Lightning arrestors provide an alternate path to ground during a high voltage surge from lightning strike. There are a variety of designs, but typically the inline gas discharge types are used for RF communications, including HF radar.* At least two levels of lightning protection are recommended for any system:

- At the antenna pole, the voltage needs to be reduced to protect the cables.
- At the container/room cable inlet, the voltage needs to be reduced further to protect the radar electronics.

A third level is recommended at the input of the receiver. Furthermore, REF1 indicates: *Different devices may require different specifications for lightning arrestors, for instance the transmitter requires a lightning arrestor with a higher sparkover voltage than the receiver. Typically, common lightning arrestors (such as the Altelicon AL-NFNFB) come with gas tubes rated for 90V sparkover voltage. In this case, replacement gas tubes with 350V sparkover voltage can be purchased.*

2.4. Communication

As mentioned in REF1: *Communication with the HF-radar site via a broadband internet connection allows for near real-time data transfer and system control. While traveling to the HF-radar site to periodically download data is possible, an internet connection is functionally considered a prerequisite for a HF-radar site.* Additional benefits of an internet connection at the HF-radar site include the ability to control the radio transmission at any time (e.g. according to national authorities regulations or specific requests), remote monitoring of the site's operational status, and reduction in on-site maintenance by allowing computer and support functions to be performed remotely. Reliable internet connection and data transfer is also essential in case of near real time use of the data (e.g. for save and rescue operations).

Best results are achieved with an on-site Ethernet connection. If such a connection is not available, a mobile network data connection should be considered as second option. After 4G technology establishment and with the fast development of broadband cellular networks in terms of data rate and coverage areas (5G is upcoming, allowing data rate of the order of 1Gbps), data transfer and remote management of HF-radar stations are now easy tasks at almost no cost. If more bandwidth is needed, two or more SIM (subscriber identity module) cards from different operators can be used simultaneously with specific 4G modem-router devices, ensuring backup link and improved data rate. Industrial grade modem-router are strongly suggested as they provide wider operational range with temperature, better protection against humidity and dust, and some software features extremely useful, e.g. the continuous check of the connection status and the automatic reboot in case of network disconnection for more than a set period of time.

Where mobile network is too slow or not available, wireless outdoor bridges (e.g., 802.11 or 900 MHz) antennas can be used to link the remote site to a hardwired network connection if this is located over a distance of kilometers. Wireless outdoor bridges are implemented in several ways and in most cases, they rely on a point-to-point communication that requires free line-of-sight between two directional antennas. Additionally, wireless outdoor bridges antennas can be used to transfer the wireless internet signal around obstacles, but with each additional antenna comes the process of seeking for permissions of the landowner at the necessary location as well as the cost and complexity of additional equipment.

Satellite internet should be considered as a good alternative option, at those sites without mobile network coverage and without a wired internet connection—or where the only wired connection is a telephone modem—and where wireless relay to another network connection is impractical. Satellite internet companies should be contacted in advance to see if an intended HF-radar site falls within their coverage area. Common satellite internet plans offer enough bandwidth and data volume at reasonable costs, allowing remote management and transfer of the most important data.

A telephone modem can provide another wired connection to the internet, but this technology is considered obsolete as connection speeds are so slow as to severely inhibit remote maintenance and transfer of all but the highest-level data.

At minimum, an internet connection for the HF-radar site needs to be able to transfer approximately 300 KB hourly files of radial velocities. In case of extremely slow connection, some HF-radar systems offer the option of remote management using command line through SSH (Secure SHell) and/or control panels over HTTP (Hypertext Transfer Protocol) protocols, both requiring less bandwidth than screen sharing programs or graphical remote desktop accesses (e.g. Virtual Network Computing (VNC), Teamviewer).

Since the wired Ethernet connection could be a source of damage in case of lightning hits or surge, the use of surge protectors to protect sensitive equipment on Ethernet data lines is strongly suggested. As already mentioned above a protection should be placed also on the coaxial cable of a 3G/4G modem-router if an outdoor antenna is used.

2.4.1 Network Setup

With any kind of network connection at the HF-radar site (Ethernet, mobile, satellite etc.) as recommended above, REF1 recommends: *A router should be used to act as a gateway for the site's internet connection and to distribute connectivity to the various network-enabled components (i.e., laptop and UPS). Additional network security can be achieved by setting up a firewall allowing only the needed internet traffic and a virtual private network (VPN), which can also allow secure sharing of an existing network connection at a host facility.* The router should have some ports opened (i.e., port forwarding) depending on the running services at the HF-radar site to allow communication. Examples of protocols/applications and their standard ports are:

- 21 (file transfer protocol FTP)
- 22 (secure shell [SSH])
- 80 (hypertext transfer protocol [HTTP])

Specific services running on the HF-radar computer and other devices web interfaces may generate port conflicts and may require a careful planning of the ports they are using, with consequent router's port forwarding setup.

Incoming access to the HF-radar site will require the remote user to input an internet protocol (IP) address. Some systems require a public IP address in order to be able to locate and access the HF-radar station from remote with standard protocols. As mentioned in REF1: *Some networks and internet service providers offer a public static IP address, a numeric address visible over internet that does not periodically change. For those HF-radar sites where the internet service is provided with a public dynamic IP address, a dynamic domain name service (DDNS) can be used to frequently query the HF-radar site's IP address and map it to a static alphanumeric IP address. A static IP address is preferred, over a dynamic IP, since network access to the HF-radar site can be blocked during the window (typically less than five minutes) between when a dynamic IP changes and the DDNS service checks the dynamic IP.*

The easiest method to access a remote computer is a remote management software. This kind of software allows users to reproduce on local computer, tablet or smartphone, the desktop of the remote computer, and interact with it in a graphical way (the same way they would do in person at the HF-radar site). Several applications are available with different features, operating system support, and licenses. Most of them are commercial or free implementation of the VNC system. Known examples are Teamviewer, which comes both with commercial or free license (in case of personal use), Apple Remote Desktop (commercial) and TigerVNC, which is free.

Since they share the screen of the remote computer through internet, they require much wider bandwidth than command line remote access, however, still acceptable in almost all cases. Some HF-radar systems can also be operated over web interfaces, which use significantly less bandwidth.

2.5. Antenna Mount and Cables

HF-radar systems may have different antenna sizes, numbers, designs and setups depending on the operating frequency, implementation concept and signal processing technique (DF or BF). Antennas can be implemented with fiberglass whips, metal poles, wires or combination of these elements held by rigid structures (Figure 2). In general, two types of antenna systems are available:

- the compact but tall antennas often used for DF systems (SeaSondes)
- the small antennas used in array configurations in particular BF systems
- the very small active antenna for receive arrays from BF systems

Already stated in REF1: *Stability is maximized when the Rx and Tx antennas are mounted in level concrete pads constructed at the HF-radar site (without metal rebar to distort the antenna pattern in case of DF systems). Anchors for the Rx and Tx antenna nonconductive guy wires can be incorporated into the concrete pad as well. Cableways should be trenched from the pads to the electronics enclosure to eliminate exposed above ground wiring or placed in protective tubes. The construction permits, soil disturbance, and additional labor this mounting entails may limit its applicability to many HF-radar sites.*

HF-radar systems should be carefully planned with respect to the length and paths of the coaxial cables to the antennas. In case that extensions are needed, additional cables could be purchased on the free market, however, they should match the electrical characteristic of the original cables and should be selected with great care. In case of long paths (e.g. >100 m) from antennas to the TX and RX units, a better cable should be adopted in terms of signal attenuation at the given frequency. A continuity test should be always performed after connector installation to ensure the proper insulation between shield and central pin.

The cable and connectors role is often underestimated, while they represent a crucial component of the system and may compromise the quality of the signal. Since they have a low impact on the total cost of HF-radar stations, they should match with high quality standards and connections should be sealed with great care. Cables already used in the field should be avoided for new installations. If they are the only option, they must be carefully checked with visual inspection and specific instruments (multimeters and cable fault finders for first insight, or more advanced instruments for complete testing).

Moisture penetration inside the cables is the main reason for efficiency loss in time, and should be prevented under all circumstances by using specialized cables (some plastic sheaths are more effective than others). Furthermore, great care should be taken by protecting the connectors from direct exposure, using specific greases and self-fusing insulation tape when connecting them. In general, all cables should be handled with care, not being stressed, twisted or narrow bended.

2.6. Deployment Budget

While the total cost of the initial deployment is mostly affected by the cost of the HF-radar equipment itself, a series of non-negligible additional costs should be allocated.

The total cost of a HF-radar system and its planning and setup consist of the following items:

- cost of the initial equipment purchase (only HF-radar parts, e.g. Rx, Tx, computer, antenna, cables)
- cost of accessories as listed in 2.3 except computer (e.g. UPS, data storage)
- cost of submitting requests for authorization (design of the installation and related works)
- cost of electromagnetic impact evaluation if required by authorities
- tax for the license for radio band utilization (if required)
- cost for rental of land or building
- purchasing of the enclosure or the shed or both
- electricity contract
- internet contract
- cost of professionals for site preparation work (electrician, bricklayer…)
- training courses by the manufacturer
- cost of the third-party insurance (optional)
- cost of insurance for HF-radar station itself (e.g. damages from natural events or other causes)
- cost of personnel and travels for site survey, installation planning and execution (either if done by the purchasing subject or by the manufacturer or another company)
- cost of central computer for data processing and archiving.

After the initial deployment, some of the items listed above can be easily identified as regular operating costs.

2.7. Required Permissions

As stated at the beginning of this section a significant amount of time should be allocated to obtain the required permits for operating the HF-radar site. In particular, this implies the development of the property (antennas, cables etc.) and broadcast permits for the selected frequency with a sufficient bandwidth. Many regulations can affect the possibility to deploy an HF-radar station, and any non-compliance with one of the required permissions may lead to a failure in getting clearance for an HF-radar installation or operation. As mentioned in REF1: *It is recommended that any regulatory or governing agencies into whose purview a HF-radar installation may fall be contacted, well in advance, to determine the preferred method of application and a realistic timeframe for project approval.*

It is always required to get a radio transmission license and all users of coastal radars are operating their systems on the basis of a secondary user license. Therefore, each operator has to contact the local authorities to apply for such a license, which includes a clause that he may be forced to turn off his system as consequence of a primary radio band user request or complaint. Fortunately, in Europe some frequency bands have been recognized and assigned to HF-radar operation and usually they are not used by other subjects.

In order to prevent big delays on getting an installation approval, coordination with the neighboring countries should be undertaken well in advance. As example, an agreement between Italy, France and Spain is in effect that allows to use full bandwidth (100 kHz) in the North West Mediterranean area for all the SeaSonde or WERA type of HF-radar systems, assigning the 13 MHz band to one type and the 16 MHz band to the other. Inside each band the HF-radars synchronize and share the operating frequency without interferences thanks to their own synch capability.

Since the World Radio Communication Conference in 2011 all radar manufactures have applied to get some standard frequencies for coastal radars as primary users. However, until such an agreement is signed, all users should proceed with the secondary license as mentioned above.

In addition to the general radio transmission license, in some countries another permission is required if the power radiated by the Tx antenna exceeds a threshold. In Europe this threshold is 10 W of effective radiated power. Below this value no additional permission is required. For experimental purposes HF-radars can be operated below this level, however, with a loss in range.

In some countries specific constraints may exist in order to preserve the architectonic or landscape heritage, or to protect sensible coastal environments. Obtaining permissions often involves different governmental offices and requires professional advice in order to produce the required documentation.

Although the radiated power of an HF-radar is very low compared to other kind of radars or telecommunication stations, prolonged presence of humans in vicinity of the transmitting antenna should be avoided and the level of electromagnetic emissions should be checked to ensure to be below the limits imposed by law. Other possible limitations are due to the presence of military areas or other research facilities using nearby radio frequency bands that could be locally affected by harmonics generated by the HF-radar station.

3. Setup

The setup of the HF-radar site consists of both hardware and software installations. The site selection and placement of the HF-radar are discussed in Section 2, including hardware components required and the physical layout. With the HF-radar hardware in place as required by the manufacturer design, site specific configuration customizes the HF-radar to the environment and intended application.

3.1. Long, Medium, and Short-range Configuration

The HF-radar settings are largely governed by the allocated center frequency and bandwidth, as well as by the amount of forward and reflected power allowed for your system. For HF-radar used for operational oceanography, the International Telecommunication Union (ITU) specified in 2012 dedicated frequency bands. Europe is in Region 1 and has got the maximum number of frequency bands, which can be separated in three usage: long, medium and short range. The maximum range for surface current analysis depends on the frequency used, the emitted power, and the state of the sea state and salinity. Typical range values for surface current measurements according to the manufactures of SeaSonde and WERA systems are listed in In Table 5 the dependency of the range for surface current measurements with respect to salinity is given, were the values are estimates in % of the optimum range utilizing a propagation model, following Gurgel et al. [1999].

Table 4.

In Table 5 the dependency of the range for surface current measurements with respect to salinity is given, were the values are estimates in % of the optimum range utilizing a propagation model, following Gurgel et al. [1999].

Table 4 HF-radar optimum range performance for surface current measurements with respect to the operating frequency. For wave retrieval the optimum range reduces by approximately 30%.

	ITU Frequency	Optimum Range SeaSonde	Optimum Range WERA	Bandwidth	Range Resolution	Bragg Wavelength	Bragg Frequency Peak	Doppler Offset at 0.05 m/s
	[kHz]	[km]	[km]	[kHz]	[km]	[m]	[Hz]	[mHz]
Long Rang	4438 4488	220	500	25	12	34	0.22	1.5

	5250	175	400	25	12	28	0.23	1.8
	5275							
Medium Range	9305	80	200	25	12	16	0.31	3.1
	9355							
	13450	60	110	50	3	11	0.37	4.5
	13550							
	16100	60	90	50	3	9	0.41	5.4
	16200							
Short Range	24450	30	60	150	1	6	0.51	8.2
	24600							
	26200	30	55	150	1	6	0.52	8.8
	26350							
	39000	20	30	250	0.3	4	0.64	13.1
	39500							
	42000	15	25	325	0.25	4	0.66	14.1
	42500							

Table 5. Dependencies of the HF-radar range on salinity in percent.

Salinity	8	16	35
8 MHz	49	73	100
12 MHz	45	70	100
16 MHz	44	69	100
20 MHz	44	68	100
25 MHz	43	67	100
30 MHz	43	67	100

3.2. Antenna Tuning

The HF-radar settings are largely governed by the antenna tuning and can also be affected by the environmental conditions. For this reason, it is recommended to check each antenna after installation in the field. To increase the range of HF-radar systems, a good antenna tuning of the transmit antenna is needed. The antennae should be tuned to the intended working frequency and need to be matched to 50 ohms.

The amount of forward and reflected power is measured with a battery driven antenna analyzer without amplifier, or by using the HF-radar software itself, in case such a feature is included. In case of the Standing Wave Ratio (SWR) a value below 2 is recommended. A greater value means that reflected power is coming back to the electronic devices, which can lead to damage of the electronic equipment. Refer to the manufacturer manual respect to the tuning requirements and possibilities of the transmit antenna. If no tuning possibilities are available, an antenna tuner can be used to minimize the reflected power.

Note, that the SeaSonde transmit antenna are tuned by the manufacturer prior to delivery. However, if required an approximate and limited tuning can be performed by changing the length of the antenna whips by trimming.

WERA systems are pre-tuned by the manufacturer but can be further fine-tuned in the field. After the tuning of each antenna element of the transmit and receive array, an internal calibration of the entire systems is needed, which takes into account the antenna tuning and cable length for each element.

For adjusting the level of the power amplifier, the output power of the transmit antenna should fulfill the following requirements:

- to be below the transmit power allowed by the agreement of the local frequency agency.
- Not to saturate the receiver

For FMiCW systems, the blank delay should be used to adjust the saturation in the receiver.

Regardless of tuning method, it is important to monitor the transmitted and reflected power to diagnose transmitter health and functionality.

3.3. Antenna Pattern Measurement

The analysis of the radar signals to solve the azimuthal needs a good knowledge of the antenna specificities. For BF methods, the analytical antenna array manifold is used. It is computed by solving the electromagnetic equations for the waves propagating to the array using the precise positions (less than 0.2 m accuracy) of each antenna element. Phase and gain calibration can be performed internally. Furthermore, dedicated software for the BF systems can compensate variations of the antenna characteristic caused by environmental or technical conditions [Helzel and Kniephoff, 2010]. For WERA systems, all antenna parameter are automatically monitored, at least once per hour and a warning is automatically generated if any parameter reaches a critical value, which might cause the automatic calibration procedure to fail. In such a case a preventive maintenance should be carried out. In some BF setups antenna patterns have been measured to achieve some further improvements, in particular in regard to side lobe suppression. However, this requires a significant effort for minor improvements.

For high-resolution DF systems, the antenna pattern is crucial and needs to be carefully measured. This is in particularly important for compact design antennas, where the electromagnetic environment can affect the gains. This measurement is the so-called antenna pattern measurement (APM).

APM is a sort of calibration, which is needed for all DF systems. It is of major importance to get accurate surface current maps and is an important part of the site setup. While an assumption of an “ideal” antenna pattern allows to generate maps of radial currents. However, this does not account for distortions in the antenna patterns, which often cause inaccuracies in the measurements and therefore require an APM.

3.3.1. APM with transponder or active transmitter

To perform an APM the following items are needed: a transponder or radio wave transmitter, a GPS, a boat, and a boat’s seawater ground (electrical grounding is ensured by putting a proper conductor inside sea water). The transponder or transmitter should be placed at a distance between 1 to 3 km from the HF-radar site. The distance depends on the operating frequency of the HF-radar, with a larger distance for smaller operating frequencies. Maintaining the distance to the radar the transponder or transmitter circle around the HF-radar site (Figure 3). As APM by boat are often dependent on the weather situation as well as on the accessibility of the area around the HF-radar sites (bathymetry, restricted areas), there are several new techniques under development such as unmanned aerial vehicles (UAV), that help perform these measurements. For SeaSonde systems APM step-by-step instructions and APM forms templates are in the Appendices I, II, and III.

Figure 3. Example of a boat trajectory for an APM. The trajectory of the boats with the transponder is shown in green. The position of the HF-radar receiving antenna is indicated by the yellow mark.

3.3.2. Automated APM via Automatic Identification Systems

Antenna patterns data can also be calibrated using Doppler echoes from vessels cruising in the area, which in many cases lead to a return signal similar to that of a transponder [Emery et al., 2014]. In many cases the position of these vessels can be obtained from the information contained in the automatic identification system (AIS). In this case antenna pattern data can be collected in real time on the site and updated APMs can be generated based on the level of local vessel traffic. This technology may reduce the need for additional transponder measurements, or at least can be used to identify times when a new APM gets necessary.

3.3.3. APM obtained by Drones

For SeaSonde systems, but also applicable to other DF systems, an emerging approach for APMs employs small aerial drones [Washburn et al., 2017]. Engineers at the University of California, Santa Barbara (UCSB) have developed an APM technique using a programmable quadcopter that allows a single technician to visit an HF-radar station and measure an antenna pattern without putting a vessel in the water, saving both time and money. UCSB has developed their own lightweight signal source that is suspended below the quadcopter and flown in an arc at a distance of a few hundred meters from the antenna. This has the advantage of not requiring a boat, not being subject to sea state or bathymetric issues. However, use may be limited in areas with drone restrictions, crowded beaches, close proximity to other aircraft or licensing/insurance issues. In particular in Europe the flight permits for drones are a huge hazel.

4. Site Maintenance

As all in situ instrumentation, also HF-radar suffers from the normal deterioration, in particular - but not only - of the outdoor components. Besides that, major damages have been experienced due to severe weather events inducing storm surge or lightning, which often lead to electrical damages or antennae breakage. Another not to be underestimated source of damage results from animals (in particular to cables) or human vandalism.

Although some preventive measures have been introduced above, such as electrical grounding, lightning protection, uninterrupted power supply, mechanical protection on cable and antennae, enclosure with air conditioning, it is important to regularly check all these systems.

On the other hand, issues may arise from specific hardware or software failures without any external cause, such as data corruption due to storage failure, or software modules and applications unexpectedly freezing. For all these reasons, even if HF-radar systems can be considered fully automated acquisition platforms, a regular maintenance is necessary to ensure continuous and correct operation.

4.1. Required Maintenance

First and more frequent kind of maintenance can be performed remotely. With an internet connection as described in Section 2.4, the system status as well as its data acquisition process and data themselves can be easily diagnosed and verified by means of web tools, email alerts, screen sharing applications.

As a complement, on-site inspection is unavoidable and is recommended on a regular biannual basis, in order to confirm the good status of the equipment and prevent issues, but also to perform scheduled actions such as data backup on external disk, UPS battery replacement, etc. Additional specific on-site inspections are recommended after a severe weather event.

Results of remote and on-site checkings should be included in periodic reports, for helping the operator to keep track of maintenance history.

4.1.1. Remote Checks

Automatic real time monitoring by means of email or other kind of alerts reporting common issues is recommended on a daily basis, with the aim to reduce the response times of the operator especially in case of operational applications (like for example search & rescue operation support). Examples of checklist to be analyzed are shown in Appendices 9.2.1 and 9.8. Tools for automatic reporting and alerting are described on section 4.2.

Furthermore, the production of automatic report on a longer time window (like a monthly report as described in the Appendix 9.6 could help to:

- assess the reliability of the HF-radar data
- evaluate the HF-radar system performance and current status
- better identify suspicious data or system behavior
- compare HF-radar versus other conventional observation platforms (e.g. surface point-wise current meter) and detect potential anomalies.

In this case the active human contribution is needed to assess the performance of the system.

4.1.2. On-site Inspections

Ordinary and preventive on-site maintenance should be carried out with biannual frequency and should include a complete examination of all the components (hardware and software). An example of checklist for the recommended maintenance of the HF-radar sites to be verified during the on-site inspection is described in the Appendices 9.7 and 9.2.3.

System outages or anomalies in the remote diagnostics and data stream reported by automatic alerts or human investigation, as described in the paragraph 4.1.1, will require additional site inspections. Furthermore, an inspection of the HF-radar site is always recommended after extreme weather events (e.g., very high winds, hail, ice storms, floods, lightning).

Following REF1: *Typical regular on-site maintenance includes a check of:*

- *Rx antenna direction (compass bearing changed?) (for DF systems)*
- *Rx and Tx antenna mounting and masts (secure and level?)*
- *Signs of corrosion or salt accumulation on antennas, connectors, or electronics enclosure*
- *Condition of cable-runs (damage to conduits or cables themselves?)*
- *Tightness of guy wires (all ropes firm, secure, and free of fraying?)*
- *Condition of enclosure (clean and free of insects? gland weatherproof?)*
- *Air conditioner and filter (clean and lubricated)*
- *Electronics within the enclosure (corrosion or signs of overheating? All the cooling fans still working and rotating with low friction?)*
- *UPS (replace batteries if expired or if remote monitoring indicated they are not holding charge)*
- *On-site system status vs. remote diagnostics (the same?)*
- *Status of backup hard-drive (replace onsite if remote monitoring indicates nearing capacity)*

While this list is not exhaustive, it contains maintenance items common to most sites. The unique characteristics of each HF-radar installation will dictate the maintenance necessary for that site.

4.2. Diagnostic Reporting

HF-radar management software often provides diagnostic tools and warning messages.

The SeaSonde Radial Suite generates hardware and software diagnostics that are saved in so called DIAG files. An extension with *.hdt refers to hardware diagnostics and an extension of .rdt refers to radial diagnostics. Many of this information are reported within the radial file itself, but diagnostic files help to aggregate and show them, through DiagDisplay application, in a bigger picture. Plots of diagnostic parameters over custom time windows can be also exposed in a web page served by the RadialWebServer. Another application, the RadialSiteReporter, is able to perform a scheduled detailed check of all the software and hardware components and to produce and send to the operator detailed email alerts with highly customizable rules. These alerts are also shown by the RadialWebServer, plus are added to an alert log.

The WERA software provides hardware and software diagnostics on all levels of data acquisition or data processing. Automatic status and warning messages (.status) will automatically be send out to defined recipient groups at different intervals depending on defined priority levels. High priority messages will be sent out immediately, lower priority messages only once per day or per week. An anti-spam filter makes sure that no messages within some hours are send out more than once. In case of a detected problem, the message will contain possible solutions for the problem. Plots of time series files for different kinds of parameters, like internal voltages, temperatures, forward and reverse transmit power, hard disk usage, antenna performance, etc., can be accessed by the operator for further analysis and troubleshooting. The described status monitoring system can simply be extended by creating additional .status files in the defined data format.

For WERA systems, the software sends automatically alerts with different priorities:

- priority 1 (Immediate reaction): Messages with this priority level will be logged and sent immediately to its destination via email.
- priority 2 (Action required): Messages with this priority will be logged and appended in the outbox folder. All accumulated messages with this priority are sent to its destinations periodically (every day is recommended).
- priority 3 (Important information): Messages with this priority will be logged and appended in the outbox folder. All accumulated messages with this priority are sent to its destinations periodically (every week is recommended).
- priority 4 (Status information): Messages with this priority will only be logged, but not sent to anyone.
- any other value (e.g. priority 0): Messages with this priority will not be logged, neither sent to anyone, even when destination column has a valid value.

5. Data Management

This section provides guidance to HF-radar operators on the management of the HF radar derived surface velocity data throughout their life cycle: from acquisition to post-processing, archiving and preserving and dissemination.

HF radar data is in situ gridded data sampled at high-frequency that has to be managed according its peculiarity and complexity, which derives from the fact that it includes diverse data types (radials and totals) and with different kind of formats from the different HF radar systems.

Different steps in the data life cycle (as schematized in the Figure 4) have been defined following the processing levels specified in section 6.2.

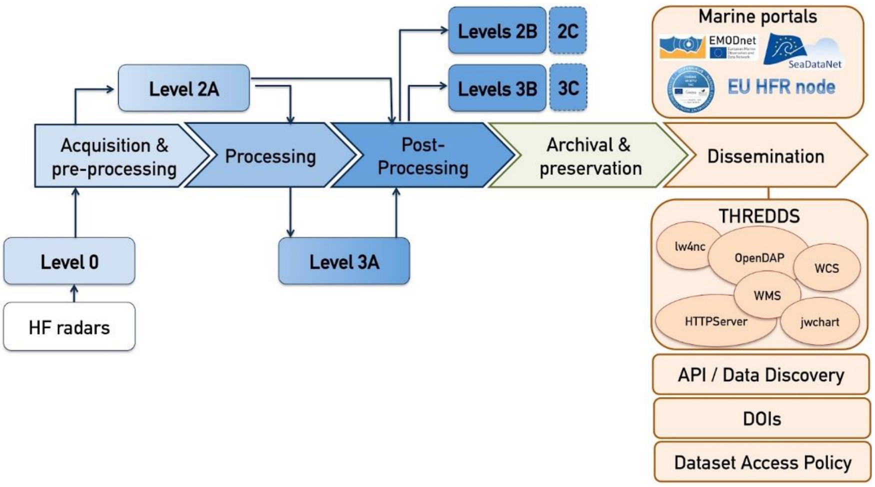

Figure 4. Data life cycle of HF-radar data from acquisition to distribution.

5.1. Data Acquisition and Preprocessing

As explained in figure 1.1, surface velocity maps are calculated by the combination of radial components measured by two or more HF-radar remote stations with overlapping coverage. This paragraph describes the data flow from the HF-radar remote stations to the central computer (so-called Central or Processing Station) where radial components of the surface current are combined into total velocity vectors. This data flow starts from the raw data acquisition and ends with radial data transfer across the network towards the Central Station. Central or processing station is a generic name for the IT infrastructure that will perform the combination, either at the data provider level or as third-party competence center (e.g. manufacturer servers, Government nodes and data centers, EU HF-radar Node as described in section 5.5.1, etc.). According to the definition of data levels given in section 6.2, this flow is summarized in the following table:

Input product	Level 0 (Signal received by the antenna before the processing stage)
Output product	Level 2A (HF-radar radial velocity data without QC defined)
Data source	HF-radar remote stations
Data target	Central or Processing Station for combination into totals

5.1.1. Software for data acquisition and pre-processing

HF-radar manufacturers provide software suites for data acquisition and radial velocities production. The suites include applications for setting up the basic information (site coordinates and name), the operating parameters (e.g. frequency and bandwidth) and the processing parameters used to obtain the radial velocities.

The two most common commercial software packages for HF Radar acquisition and pre-processing are:

- **the suite of WERA/Helze**l (available for Linux Os only, suggested distribution open SUSE), based, for the signal processing algorithms, on Klaus Werner Gurgel works [Gurgel, 1999], and supporting the two HF-radar implementations and spectral information processing methods (ref. to section 1.1) : Beam Forming processed on a regular cartesian grid (or optionally with polar coordinates), and Direction Finding by Least Mean Square developed for compact antenna system. For further information, the reader is invited to visit this link: https://helzel-messtechnik.de/de/11190-application-software
- **the Seasonde radial suite** (available for Mac Os X only) from Codar Ocean Sensors, based, for the signal processing algorithms, on the works of Lipa and Barrick (1983) and Barrick (1997). Please, visit http://www.codar.com/SeaSonde.shtml for a more detailed information.

They include also utilities for software and hardware diagnostic file production and solutions for archiving configuration and data files.
Outside the solution proposed by each manufacturer for its own HF-radar system, third party software for data acquisition and pre-processing is available under commercial license for beam forming HF-radar systems, as specified below. Authors are not aware of a comparative review between them:

- **Seaview** sensing realtime and data viewer (successfully run on Solaris-Sparc and linux-x86 systems). Seaview real-time software measures current, among other parameters, delivering metocean data in real time and supports beam forming, phased array radar systems such as WERA, Pisces or OSCR. More details can be found in the website (http://www.seaviewsensing.com/).
- **Actimar** software suite for value-added data including Hyddoa (hybrid antenna processing for large antenna receiver with direction of arrival), which increases the range of HF radar measurements and improve their spatial resolution. More details can be found in the website http://www.actimar.fr/en/our-solutions/radars/

It has to be noted that all the commercial softwares listed above are distributed under commercial license, but the operators are invited to investigate the license conditions, especially the policy for software updates, which may differ significantly, in order to allocate the correct budget for maintaining the systems.

Software for data acquisition and pre-processing			
Software/ HF radar type	**Features**	**Availability**	**Software requirements / License**

Standard WERA® Data Manager and Viewer / WERA HF radar either in Beam Forming or Direction Finding version	Data processing, real time quality flagging, data archive, plotting tools, system monitoring. Manually or automatic.	Under commercial license. Further information on applicational software packages: https://helzel-messtechnik.de/de/11190-application-software	**Linux Os only** / Commercial license - in bundle with the purchase of the WERA HF radar system
Codar SeaSonde Radial Suite / Codar SeaSonde HF radar (direction finding)	Real time processing, combination, quality flagging, data archive, plotting tools, system monitoring. Manually or automatic.	Under commercial license. Further information: http://www.codar.com/Manuals/Suite_Radial_Software.pdf	Mac Os X only/ Commercial license - in bundle with the purchase of the Codar SeaSonde HF radar system
Seaview real-time software / WERA (Beam Forming only), PISCES, OSCR	Integrated wave, current and wind measurement package, with data viewer, web access facilities, radar auto-diagnostics and environmental warning systems.	Under commercial license. Further information: http://www.seaviewsensing.com/software.html	Successfully run on Solaris-Sparc and linux-x86 systems/ Commercial license
Actimar / phase array	Doppler spectra by direction, radial velocities field, wind and waves fields	Under commercial license. Further details: http://www.actimar.fr/en/our-solutions/radars/	(information not available)

5.1.2. Acquisition and pre-processing: key considerations

- **Data transfer protocol:**

While most of the HF-radar manufactures' software suites provide tools for data transfer to the Central Station, custom solutions may be required or preferred. FTP and Rsync utilities, natively included in Unix-like operating systems, are widely used for remote files transfer. Both of them should be used over an encryption layer in order to keep the communication safer against hacker attacks.

- FTP utility relies on the File Transfer Protocol, a client-server standard network protocol for transmitting files between a client and a server on a computer network.
- Rsync utility copies files either to or from a remote host, either via remote shell or direct connection to a running rsync daemon, or locally on the current host.

We encourage the use of Rsync over SSH because rsync is the easiest and faster solution for folders synchronization because:

- It minimizes the amount of data sent over the network by sending only the differences between the source files and the existing files in the destination,
- It supports file compression,
- It preserves file attributes and
- It allows easier syntax to perform most of the equivalent FTP tasks.

The automation of the file transfer or folder synchronization from the HF-radar remote stations to the Central or Processing Station can be performed by a scheduled RSYNC job running on the source host (HF radar station's computer). For scheduling a job on Unix-like systems the utility *Cron* is normally adopted, however for Mac Os X users is preferable the use of the *Launchd* service manager. To schedule a RSYNC job with Cron:

- Generate a SSH Public Key:
    - run the generation of the Public key in console mode with the command:

```
> ssh-keygen -t rsa
```

The system will request entering the file to save the key (leave it by default) and a passphrase (leave it empty). Check if the new keys (id_rsa and id_rsa.pub) have been created in your system.

- save the public key (id_rsa.pub) in the Central or Processing Station.

- Edit the crontab file (find a Crontab reference guide in this link: https://linuxconfig.org/linux-crontab-reference-guide) in console mode:

```
> crontab -e
```

- Add the following line to automatically transfer the files from the HF-radar remote station to the Central or Processing Station, configuring the data transfer frequency based on the amount of data, the network bandwidth, the data acquisition frequency, etc. As an example, the transfer of hourly measured radials every 15 minutes is presented:

```
*/15  * * *  * * rsync -rltvz --no-o --no-g -e ssh --progress --stats $input_radials
user_name@IP_Central_Station$output_radials --log-file=$log/rsync.log
```

- $input_radials: Folder containing measured radials files at the HF-radar remote stations
- user_name: name of the user in remote server

- $output_radials: Folder storing the radial files in the Central or Processing Stations.
- $log: directory for diagnostic files (*.log)

- **Output product file naming**

In general, it is good practice to follow a file naming convention, including the data type (radial ideal or measured, total,...), the HF-radar remote station name and the date and time (UTC) of the measurement (e.g. **Radials_[STATION-NAME]_[YYYY_MM_DD_hhmm].***)

5.2. Data processing

The combination of radial velocities from two or more remote stations for obtaining total surface current velocity files is covered in this section. The radial files are collected from the folder where they are stored at the Central or Processing Station, processed, and the resulting files containing the total current velocities are transferred at the Post-processing station, a generic name indicating the IT infrastructure that will perform post-processing operations. The Central or Processing Station and the Post-processing station may coincide. According to the definition of data levels given in section 6.2, this flow is summarized in the following table:

Input product	Level 2A (HF-radar radial velocity data without QC defined)
Output product	Level 3A (HF-radar total velocity data without QC defined)
Data source	Central or Processing Station
Data target	Post-processing Station

5.2.1. Software for data processing

The most commonly adopted combination algorithm of radial vectors into total vectors is the unweighted least squares fitting (UWLS) algorithm. The UWLS approach (Lipa and Barrick, 1983; Gurgel, 1994 and Graber et al., 1997) assumes that, for each grid point, the radial velocities within the search radius are produced by a uniform velocity vector, i.e., the correlation of the current vector is assumed to be one everywhere within the search radius and zero outside.
HF-radar manufacturers provide combining suite software under commercial license often as separate product respect to the acquisition and pre-processing software described in the previous section. Besides those solutions,, the international community developed and freely distributes the Matlab tool "HFR_progs" (https://cencalarchive.org/~cocmpmb/COCMP-wiki/index.php/Main_Page:HFR_Progs_Installation_Instructions, Kaplan & Cook).

Table 6. Software for data processing

Software/ HF radar type	Features	Availability	Software requirements / License
Codar SeaSonde Combine Suite / Codar SeaSonde HF radar (direction finding)	Codar's manufacturers real-time processing applications and tools for producing total vector	Under commercial license. Further information: http://www.codar.com/Manuals/Suite_Combine_Software.pdf	Mac Os X only/ Computer and hardware requirements as specified by the manufacturer
HFR_Progs-2.1.2	Processing (total currents generation, Open boundary Modal Analysis, interpolation, filtering, tides, EOFs) of high frequency radar data	https://cencalarchive.org/%7Ecocmpmb/COCMP-wiki/upload/a/a6/HFR_Progs-2_1_2.zip	Any Mac OS X, 10.2+ / Matlab© (at least 6.5, 7.5 is not supported)
codar_processing	Rutger Center for Ocean Observing Leadership High Frequency Radar (CODAR) processing toolbox.	https://github.com/rucool/codar_processing/blob/master/README.md	Any OS X (windows, Linux, Mac OS X) / Jupyter Notebook
Standard WERA® Data Manager and Viewer / WERA HF radar either in Beam Forming or Direction Finding version	Data processing, real time quality flagging, data archive, plotting tools, system monitoring. Manually or automatic.	Under commercial license. Further information on applicational software packages: https://helzel-messtechnik.de/de/11190-application-software	**Linux Os only /** Commercial license - in bundle with the purchase of the WERA HF radar system

5.2.2. Processing: key considerations

- **Data transfer protocol:**

To copy or synchronize files and directories from the central station to the post-processing station, remotely or locally, best practices described in section 5.1.1 regarding the use of Rsync utility can be applied.

- **Output product file naming**

As mentioned in the section above, it is always a good practice to follow a file naming convention, including the data type, the HF-radar system name and the date and time (UTC) of acquisition (e.g. **Totals_[STATION-NAME]_[YYYY_MM_DD_hhmm].***)

5.3. Data post-processing

Once both radial and total files are produced, it may be convenient or required to post-process them in order to achieve a common level of Quality Control (QC), or a specific file format, or a required variable naming convention. While in general all these operations should be included in the term post-processing, we are referring here only to the application of QC tests and their description, according to the definition of data levels given in section 6.2 and to the EU common data and metadata model for surface currents defined in Jerico Next D5.14. Again, Post-processing Station represents a generic IT infrastructure that may coincide with the provider servers or with a centralized node like the EU HFR Node (as defined in section 5.5.1). Distribution centers may be dedicated portals as defined in section 5.5.2 or the Post-processing Station itself (e.g. EU HFR Node, data provider servers).

This section then comprises all the steps needed to convert the Level 2A and 3A HF-radar data files (radials and totals without QC defined, respectively) into the standard European level 2B and level 3B data files (radials and totals with a minimum set of QC, respectively) and to deliver them to the main European marine data portals. Levels 2C and 3C could also be considered in this level of post-processing. Even that, they are currently being defined and authors cannot provide best practices on this.
The flow is summarized in the following table.

Input product	Level 2A (HF-radar radial velocity data without QC defined) and Level 3A (HF-radar total velocity data without QC defined)
Output product	Level 2B (HF-radar radial velocity data with a minimum set of QC) / 2C (Reprocessed HF-radar radial velocity data with advanced QC) (currently under definition) Level 3B (HF-radar total velocity data with a minimum set of QC) / 3C (Reprocessed HF-radar total velocity data with advanced QC) (currently under definition)
Data source	Post-processing Station
Data target	Distribution centers

5.3.1. Software for data post-processing

The software tools for HF-radar Real Time data post-processing into the EU standard have been developed by the EU HFR Node and they are freely shared (provided under the license: Attribution-NonCommercial-ShareAlike 4.0 International -CC BY-NC-SA 4.0-. More information about the license in this link: http://creativecommons.org/licenses/by-nc-sa/4.0/) and kept updated on a GitHub repository. In this way, these tools can be either run at the EU HFR Node level or at the data provider level, in order to guarantee the production of data that are compliant to the required standard for distribution.

The software tools operate the real-time collection of the hourly radial data, the organization in working data structures, the QC processing, the combination of radial vectors into total vectors, the data distribution, and the data storage. They can be used then at processing and post-processing levesl, following the definition in 5.2 and 5.3 respectively. Two different bundles for these tools exist: one based on MATLAB and one based on Java. Except for a few functionalities, they work in the same manner: Before combination, radial velocities are processed for QC by applying the QC tests described in Section 6.2 After the combination, total velocities are processed for QC by applying the QC tests described in Section 6.2. QCed radials and totals are then converted into netDCF files compliant with the European common data and metadata standard for NRT HF-radar current data. All the information, metadata and QC thresholds needed for processing, quality controlling and converting the data are read by the software tools from the centralized database.

Table 7. Software for data post-processing

Tool name	**Matlab® (HFR_Combiner):**	**Java™ (JRadar)**
Tool description	The HFR_Combiner tool is a bundle of scripts developed with Matlab® to perform the tasks of transforming Codar and WERA total current into the European HFR Standard. The tool also allows for combining Codar radial current files into total ones and producing both radial and total data into the European HFR Standard.	The J(ava)Radar tool is an executable jar file already compiled and packaged ready to work.
Tool available on GitHub online	YES https://github.com/LorenzoCorgnati/HFR_Node_tools	YES https://github.com/llasensio/JRadar
Additional required software and packages (must be pre-installed by attendees)	Valid and licensed Matlab® version, later than R2016b release. Previous releases can be used, but it is recommended to have at least the R2016b version.	Java™ 8 or higher runtime environment installed with administrator permissions on the computer.
	• HFR_Progs-2.1.2 • M_Map • GSHHS • Nctoolbox-1.1.3	Unidata NetCDF package for Java™ installed: https://www.unidata.ucar.edu/software/thredds/current/netcdf-java/

	mysql-connector-java-5.1.17 JDBC driver for connecting to the MySQL database • Rdir	
Graphical user interface	NO	YES
Converts CODAR TUV files (Totals) to netCDF European HFR Standard	YES	YES
Performs radial combination	YES	NO
Performs QC	YES	YES
Can run in real time	YES	YES
Requires scripting skills	YES	NO
Allows batch processing	YES	YES

5.3.2. Post-processing: key considerations

- **Radial and total file requirements for post-processing**

When dealing with data provided by CODAR systems the CODAR LonLatUV (LLUV) file format is the recommended input format because it offers extensive metadata for radial and total data as well as hardware diagnostic data. Radial metadata can be used by quality control algorithms for total vector production. The older range-bin format of radial data is acceptable but lacks hardware diagnostic data, radial metadata is minimal and is no longer supported by CODAR. Observed variations in the range-bin file format have been documented and are available through the Radiowave Operators Working Group (ROWG) web site *(www.rowg.org)*. LLUV file format specifications are published by CODAR and available through their web site *(www.codar.com)*.

Regardless of the format, **radial files provided by CODAR systems must contain** the following information for compatibility with the European HFR standard :

- Timestamp (GMT or UTC required)
- Patterntype (‘s’ or ‘z’ for range-bin format, ‘i’ or ‘m’ for LLUV format)
- Site Location (Lat/Lon)
- FileType* (i.e. LLUV)
- LLUVSpec (i.e. version of the LLUV format specification)
- PatternDate (i.e. last Antenna Pattern Measurement date)
- RangeResolutionKMeters or RangeResolutionMeters

Regardless of the format, **total files provided by CODAR systems must contain** the following information for compatibility with the European HFR standard:

- Timestamp (GMT or UTC required)
- Contributing sites locations (Lat/Lon)
- Contributing sites codes
- FileType* (i.e. LLUV)
- LLUVSpec (i.e. version of the LLUV format specification)

It is not uncommon to see LLUV files that don’t have the timezone explicitly stated within them. This is due to multiple timezone configurations that exist in various SeaSonde software applications. It is important to make sure that Time Zone is set correctly in the Header.txt file as well within SeaSondeRadialConfig software for time zone to be correctly set within the output LLUV file.
Even if they also produce data in LLUV format, the most common radial format produced by WERA systems is the crad_ascii.

When dealing with data provided by WERA systems, and regardless of the format, the **WERA radial files must contain** the following information for compatibility with the European HFR standard:

- Site location (Lat/Lon).
- Measurement start time and duration (GMT or UTC required).
- Lon-lat coordinates of the top-left gridpoint.
- Gridcell size.
- Number of grid cells for X and Y axes.

Also, total data are produced by WERA combiner tools in LLUV format, but the most common format for total current data produced by WERA systems is the cur_asc.

Regardless of the format, **WERA total files must contain** the following information for compatibility with the European HFR standard:

- Position (Lat/Lon) and measurement start time and duration (GMT or UTC required) of contributing stations
- Lon-lat coordinates of the top-left gridpoint.
- Grid cell size.
- Number of grid cells for X and Y axes.

The geophysical variables present in radial and total files have to be at least the ones labeled as mandatory variables for complying with the EU standard, as defined in the JERICO-NEXT deliverable D5.14 “Recommendation Report 2 on improved common procedures for HFR QC analysis”.

- **Data transfer protocol**

In the case of near real time surface current fields, the European HFR Node provides the instructions and the scripts needed for the rsync-over-ssh file synchronization for surface current files.
As a term of reference, the US HFR network uses for data telemetry from remote sites the Antelope solution developed for the COCMP/National Network. The Antelope solution requires no code installation at the remote site. The only requirements are access over SSH and the presence of a single static path for recent radial files (see also section 3). Additional information on Antelope solution for data telemetry is available in ‘Data Management and Real-time Distribution in the HF-Radar National Network’, Terrill et. al., IEEE OCEANS06 (available through *www.rowg.org*).

- **Output product file naming**

The European Common data and metadata model for real-time HF-radar data is the unique model for NRT HF-radar current data distribution in Europe, thus it is mandated for data distribution on CMEMS-INSTAC, SeaDataCloud (SDC) and EMODnet Physics, along with the compliance with the European Common QC model for real-time HF-radar data. Please refer to the JERICO-NEXT deliverable D5.14 “Recommendation Report 2 on improved common procedures for HF-radar QC analysis” for the details about the European Common data, metadata and QC model for real-time HF-radar data.

5.4. Data archival and preservation

A typical HF Radar system in operation produces a variety of files that are updated at a variety of intervals. The first step for a viable data archival strategy is the identification of files to be archived, the interval at which these files are produced or altered, and the amount of space they require compared to the local computing and archiving resources. HF radar operators have a shared responsibility to ensure long-term data preservation, on their own laboratory or institutional servers.
This section includes recommendations on both on-site data archiving (in internal volumes or external HDD), mainly aiming to data discovery, and data backups (remote repository or Central Station), for disaster recovery or restoring lost or corrupted files.

5.4.1. On-site data archiving

SeaSonde software includes an archival program called Archivalist. This program can be configured to synchronize files between working directories and archive directories. It is recommended that the archive directories exist on a separate internal disk or partition. Since in the archive directory the oldest files are progressively deleted according with the settings in the Archivalist configuration file, this folder should be synchronized to a secondary folder on an additional internal or external HDD, for incremental backup.

For Codar systems, at the very least, it is advisable to save all Cross Spectra (.cs4) data files, and if space allows to save Range Series (.rs) data files. Both of these allow reprocessing radial current and wave data using different configurations, but Range Series can regenerate spectra and diagnostic information. For Codar systems, it is also necessary to save deployment- specific files contained in the */Codar/SeaSonde/Configs/RadialConfigs*, as well as the Track and Time Series files from which the Antenna Pattern can be re-calculated. supporting an APM. Moreover, it is highly recommended to preserve the file */Codar/SeaSonde/Logs/Site_XXXX.log* containing the user-provided comments on all the changes performed on the radial site, together with Alert_* and other *.log files for later debug of station behaviour in case of need.

The WERA toolbox contains a script named “BackupDataFiles.sh”, which is used to automatically create a backup copy of raw data and other data products onto an external backup hard disk. If two hard disks are used for redundancy, the script should be duplicated for optimum performance.

For WERA systems using beam forming software it is not required to save Cross Spectra files. The .URFI or .RFI files containing information about radio frequency interference during the measurement and optionally the frequency pre-scan .RAW files may be archived beside the raw data files .USORT or .SORT. The results (.CAL) of the automatic direct path test measurements will contain information about antenna health.

5.4.2. Data backup

In addition to the on-site archiving, the HF-radar remote stations should backup the most important data in real time to a remote repository through a network connection, as much as the bandwidth allows. The full backup of the data can be executed periodically (at least at biannual basis) by operators with a portable HDD that will be then synchronized with the remote repository once back at the Lab. All the copy tasks can take advantage of the Rsync utility.

For CODAR systems, the biannual backup of two HF-radar remote stations requires at minimum from 40 to 70 GB.
This amount of data corresponds to the following recommended list of directories to be back up and archived:

- Configuration files: /Codar/SeaSonde/Configs
- Hardware and radial diagnostic files: /Codar/SeaSonde/Data/Diagnostics
- Measured radials: /Codar/SeaSonde/Data/Radials/MeasPattern
- Ideal radials: /Codar/SeaSonde/Data/Radials/IdealPatttern
- Spectra data: /Codar/SeaSonde/Data/Spectra/SpectraProcessed/
- Wave data files: /Codar/SeaSonde/Data/Waves

- Critical site logs and reporting files: /Codar/SeaSonde/Logs

WERA systems will deliver more data. Depending on the setup of the system at least 1 TB of data should be assumed per year. The real data volume depends upon the number of receive channels, the measurement mode, measurement settings, cycle repetition time etc.

- Configuration files: /home/wera/etc/
- Diagnostics files: /home/wera/public_html/status/
- Log files: /home/wera/weralogs/
- Data files: /home/wera/data/

When configuring the backup of files it should be kept in mind, that the automatic housekeeping script will normally remove old data files after a while to avoid filling up the internal hard disks.

5.5. Data dissemination

This section compiles information about the different existing mechanisms that can be used to provide easy access to real-time and historical HF radar data. In addition to the dissemination of the data through the HF radar operators' portals (where HF-radar data might be presented as another element of the ensemble of operational information provided for the area covered by the coastal observatory), ensuring the availability of the data through global or European data portals will help to promote data discovery, data use and applications. The European HF-radar Node, described in section 5.5.1, is the recommended way for the channeling of HFR standard data towards European (and global) data portals. Other data marine data and information portals and channels are described in section 5.5.2 and 5.5.3.

5.5.1. EU HFR node

The European HFR Node is in charge for the NRT HFR current data collection from the HF-radar operators in Europe, for the application of the standard QC model, for the conversion of the QCed data files into the European standard data and metadata model and for pushing the converted data to CMEMS-INSTAC, SDC and EMODnet Physics infrastructures.

The architecture of the European HFR node is based on a centralized database, fed both by the operators via a webform and by the software routines running on the node, containing updated metadata of the HF-radar networks and the needed information for processing, Quality Controlling and archiving the data.
The European HFR Node architecture is based on a central database containing information about data and metadata and QC test thresholds. The software applications for data quality control and conversion work on metadata contained into data files and on general information about data and metadata contained into the database. These information (regarding the HF radar network and the HF radial stations) are loaded by

the HF-radar operators (just once) onto the database via a webform available online at http://150.145.136.36/index.php.

Thus, the radial files produced at the sites and the total files produced by the combiner tools need to contain a minimum set of information and have to be synchronized with the European HFR Node for being distributed on the European data services.

- **Data management for real-time ingestion into the EU HFR Node**

As explained in section 3.4, there are still few HF-radar systems producing exploitable operational data on waves or winds and there is no established protocol for the real-time ingestion of this type of data. This section concerns only the harmonization, quality control and the required management settings to ensure the **real-time ingestion** into the EU Node of surface current velocity files (both radial and total velocities).

The European platforms for marine data distribution operate through a decentralized architecture based on National Oceanographic Data Centers (NODC), Production Units (PUs) organized by region for the global ocean and the six European seas and a Global Distribution Unit (DU). The European HFR Node acts as the focal point for the European HF-radar data providers toward this decentralized structure, since it implements the HF-radar data stream from the data providers to the distribution platforms. The architecture of the European HFR node is based on a centralized database that is fed both by the operators via a webform and by the software routines running on the node, and contains updated metadata of the HF-radar networks and the needed information for processing/archiving the data.
A set of shared software tools uses all that information for processing native HF-radar data for QC and converting them to the standard format for distribution.

The European HFR Node is founded on a simple and very effective rule:

- if the data provider can set up the data flow according to the defined standards, the node only checks and includes the new catalogue and data stream. In this case, the data providers have to synchronize their NRT netCDF datasets (Level 2B and 3B) with the EU HFR Node Archive, in order to allow the Node to perform the file check and the dataset push toward the distribution platforms
- If the data center cannot manage the data processing, the HFR Node harvests the raw data from the provider, harmonizes, quality-controls and formats these data and makes them available. In this case, the data providers must synchronize their NRT native (Level 2A or 3A) data files with the EU HFR Node, in order to allow the Node for the data QC, conversion and distribution. The raw file synchronization can regard only the total data or the radial data. The latter is the recommended option, because it would enforce the homogenized processing and conversion of the data at European level. The synchronization of the total files must be done from the combine server (central station) storage on provider side toward the EU HFR Node. The synchronization of the radial files must be set by the provider from the HF-radar site machines toward the EU HFR Node.

In all the cases, the recommended synchronization has to be performed through rsync via ssh protocol, unless differently agreed between the data provider and the EU HFR Node. Figure 5 shows the different dataflow options from data providers toward the EU HFR Node.

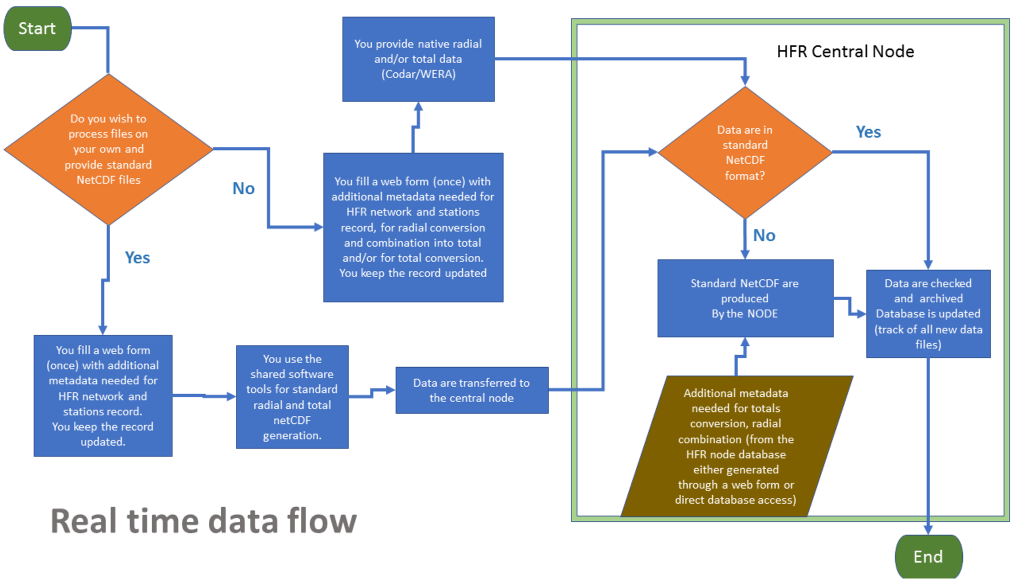

Figure 5. Data flow from HF radar data providers to the European HFR node.

In order to operationally manage the different dataflow options, the European HFR Node either operationally runs or shares software tools for HF-radar data QC (see section 5.3.2), according to the standard QC model, and for conversion into the standard data model. These tools ingest all the known file formats from all the HF-radar manufacturers (see section 5.3.1), i.e. Codar *.ruv and *.tuv files, WERA *.crad_ascii and *.cur_asc files. This strategy guarantees that, whatever the chosen workflow, the data are processed by the same software tools.

5.5.2. Marine Data and Information portals

The table below lists the existing European and Global marine data management infrastructures, which are currently distributing or will distribute in the near future near real-time and historical HF-radar data. There are many other portals that disseminate HF-radar data at institutional level or from regional or national HF-radar networks (e.g. IberoredHF, RITMARE, COSYNA, CALYPSO,....) that are out of the scope of this section.

Table 8. Data distribution portals

Distribution Portal	Description	Portal	Data

		Link	access
EMODNet-Physics	European Marine Observation and Data Network: Physics	http://www.emodnet-physics.eu/Map/	http://thredds.emodnet-physics.eu/thredds/HFRADARCatalog.html
Sea Data Net	Pan-European infrastructure for ocean & marine data management. The SeaDataNet portal offers different services: discovering, visualization, access and data downloading	http://seadatanet.maris2.nl/v_cdi_v3/search.asp	
Copernicus Marine Service INSTAC	The In Situ TAC is the component of the Copernicus Marine Service which ensures a consistent and reliable access to a range of in situ data for the purpose of service production and validation. On the In Situ TAC dashboard you can explore and donwload all the multi-source, multi-platform & heterogenous data collected in near-real-time (within 24 hours) and delivered to the Copernicus Marine Service.	http://www.marineinsitu.eu/dashboard/	ftp://nrt.cmems-du.eu/Core/INSITU_GLO_NRT_OBSERVATIONS_013_030 (radar_total dataset to be available from April 2019) ftp://nrt.cmems-du.eu/Core/INSITU_GLO_UV_NRT_OBSERVATIONS_013_048/radar_total/ (new product to be available from April 2019)
GEO Global High Frequency Radar Network	Vision for a global operational system measuring ocean surface currents to support monitoring of marine and coastal ecosystems	https://rucool.marine.rutgers.edu/geohfr/index.html	

5.5.3. Main distribution channels

There are a combined array of services and protocols that can be exploited for HF-radar data and metadata visualization, access and download in person-to-server or machine-to-machine context. The table below lists most of the conventional services and protocols that can be implemented, maintained and monitored to exchange original HF-radar data files (e.g. FTP, FTPS, HTTP, etc) or to access data and metadata for HF-radar data sets (e.g. THREDDS, MOTU). Moreover, as an integrated data server, THREDDS provides data access through different remote data access protocols (e.g. OPeNDAP, OGC WMS and WCS, etc) and data visualization using different web applications (e.g. Godiva, IDV, etc).

Distribution Channels

File transfer protocols (for file exchanges)	• File Transfer Protocol (**FTP**): for single and bulk file transfers (advantage= it is a widely used protocol without interoperability problems; drawback= it is not so strong on security). • FTP over SSL (**FTPS)**: FTP protected through SSL (advantage=retain the benefits of FTP gaining the security features of SSL, data-in-motion encryption as well as server and client authentication) • Hypertext Transfer Protocol (**HTTP**): for original file transfers (advantage=; no installation needed on the client side, users only need a web browser; drawback = inherently insecure and incapable of meeting regulatory compliance or securing data) • HTTP over SSL (**HTTPS**): secure version of HTTP (advantage: perfect choice for non-technical folks end users) • Secure Copy (**SCP**): recommended for exchanging files with a legacy SSH server. • SSH File Transfer Protocol (**SFTP**): (advantages: more firewall-friendly that FTPS, it supports data-in-motion encryption and client/server authentication), etc
Web Servers (for geo-referenced data and metadata access)	• **THREDDS** Data Server (TDS): is a web server that provides a catalogue of data and metadata access for scientific datasets. Via THREDDS you can download datasets with your web browser (e.g. HTTP Server) or use subsets without downloading the datasets (OPeNDAP) • **MOTU-Client:** the Copernicus web server for data distribution. It handles, extracts and transforms oceanographic huge volumes of data without performance collapse. Please, refer to this link (http://marine.copernicus.eu/faq/what-are-the-motu-and-python-requirements/) for download and further instructions on how to use it. • **ERDDAP**: it allows to download subsets of gridded and tabular scientific datasets in common file formats and make graphs and maps. It offers an easy-to-use way to request data via the OPeNDAP standard or via ERDDAP's Web Map Service (WMS). It retrieves data in different file formats (.html, .asc, .csv, .kml, .nc...) or either images (.png and .pdf)
Data Access protocols (major components of the web servers for	• Open-source Project for a Network Data Access Protocol **(OPeNDAP):** it is based on HTTP protocol, it supports satial, temporal and parameter subset and it retrieves data as ASCII or Binary format. • OpenGIS Consortium Web Coverage Service **(OGC WCS):** it is provided for any gridded dataset with complete coordinate

delivering data sets)	system information. It supports spatial and temporal subset. It retrieves data in GeoTIFF, GeoTIFFfloat or NetCDF. • OpenGIS Consortium Web Map Service **(OGC WMS):** it provides a simple HTTP interface for requesting geo-registered map images. It retrieves geo-registered map images (JPEG, PNG) • **Netcdf Subset Service:** it allows subsetting of scientific datasets, using earth coordinates (lat/lon) and data ranges, using a REST API. It retrieves data as netCDF, XML or ASCII format.
Web map services (for WMS access and online visualization)	• **Godiva2**: web application for WMS access and online visualization. Further info here: http://godiva.reading.ac.uk/ncWMS2/Godiva3.html • **netCDF-Java ToolsUI**: a Java interface to NetCDF files, among other types of scientific data formats. Download the tool from here: https://www.unidata.ucar.edu/software/thredds/v4.5/netcdf-java/ToolsUI.html • Integrated Data Viewer (**IDV**): a web-enabled tool for geoscientific analysis and visualization. Further info in this link: https://www.unidata.ucar.edu/software/idv/ • Lightweight for NetCDF viewer (**lw4nc2**) allows the user to browse through gridded fields by variable or date, to extract time series at chose locations, change styles, animate layers, etc. more information in this link: http://thredds.socib.es/lw4nc2/index-menu.html
Discovery API (for analysing catalogue data, enhancing data discovery)	• RESTful Application Programming Interface **(API):** to interpret the data and present the user the information they wanted in a readable way. The API filters large sets of data available in a catalogue. It retrieves the dataset in a format that is useful for machine processing (.json or .xml)

5.5.4. Dataset access policy

The sharing of open data can be incredibly beneficial to society: facilitating scientific collaboration and reproducibility, increasing government and corporate transparency, and speeding the discovery and understanding of solutions to planetary and societal needs. Most of EU HF-radar operators share unrestricted data, to make them freely available, thus facilitating access to a wider public. Some of them are using Creative

Commons licenses (https://creativecommons.org/licenses/by/4.0/) under the following terms as described in the table below:

Data Policy		
Data Type #	**Description**	**License**
Raw or NetCDF HF radar radial and totals	• **Share** — copy and redistribute the material in any medium or format. • **Adapt** — remix, transform, and build upon the material for any purpose, even commercially. The licensor cannot revoke these freedoms as long as users follow the license terms.	cc-by

Creative Commons licenses are recommended since the HF-radar operators will retain copyright while allowing others to copy, distribute, and make some uses of their data, ensuring also the operators get the credit for their data provision.

Nevertheless, HF-radar operators can still share their data considering other kind of access constraints to their data as following: academic, by negotiation, collection cost charge, commercial charge, distribution cost charge, license, moratorium, no access, organisation, SeaDataNet licence or unknown. In case the data provider decides to apply access restrictions, the user has to understand the terms under which these data are distributed and their scope of use and how to obtain permission from the data owner for the re-use of such material.
In any of the above-mentioned cases, restrictions on access to research data during and after the end of the project need to be addressed in the initial research proposal and throughout the life of the project as part of your data management plan.

5.5.5. Digital Object Identifiers (DOIs)

Assigning identifiers to research data is part of the wider research data management strategy at the main Marine Data and Information portals. Identifiers for digital objects serve several purposes, including helping to identify the object uniquely so that a reference to the object can be unambiguous. Furthermore, digital identifiers could also provide mechanisms to locate the object to facilitate access and the HF-radar data can be publish using the identifier (to be included in citations).
The Marine Data and Information portals have to work with repositories and archives to assign DOIs to datasets to help make the data discoverable, accessible and citable. Each dataset is made available with a set of mandatory and essential metadata.

In order to make sure that the data to which DOIs are assigned are trustworthy and persistent, it is mandatory the following criteria:

- the organizations must have the authority to assign DOIs to data.
- a landing page, mandatory metadata and a URL that links to the data need to be provided.
- mandatory and additional metadata must be made freely available for discovery.
- a clear and public indication to make the data available over the long-term should be stated.

5.5.6. Documentation and data management plan

The information on how the research data from an HF radar facility is managed, stored, processed and secured throughout the entire data life cycle is very valuable and it should be readily available documentation describing this. Data Management Plans (DMPs) are a key element of good data management. The DMP should describe the data management life cycle for the HF radar data and it is intended to provide descriptive details of the data, the processes, the decisions, as well as identifying roles and responsibilities. This also includes a long-term data sharing and preservation plan to ensure data are publicly accessible beyond the life of the project or funding.

As part of making research data findable, accessible, interoperable and re-usable (FAIR), a DMP should include information on:

- the handling of HF radar data
- what data will be collected, processed and/or generated
- which methodology and standards will be applied
- whether data will be shared/made open access and
- how data will be curated and preserved

There is an increasing demand of this kind of information by the main funding bodies, from which the DMP is often a requirement, and the research publishers, which strongly encourage good data management as an essential element of research best practice. For this reason, it is highly recommended to document with details all the aspects concerning the HF radar data life cycle described in section 5 and the related Quality Assurance and Quality Control as described in section 6.

Important links to be considered:

More information about FAIR data principles is available in the following links:

- https://www.force11.org/group/fairgroup/fairprinciples
- https://www.nature.com/articles/sdata201618

Best practices on How to develop a Data Management Plan are available here: https://www.iode.org/index.php?option=com_oe&task=viewDocumentRecord&docID=16859

6. HF radar Quality Assurance / Quality Control

In this section, Quality Assurance (QA) refers to the optimal configuration and operation of an HF-radar station, in terms of physical setup and maintenance, software settings, calibration, as well as vendor tests performed prior to instrument shipment.

QA covers then all the activities aimed at ensuring that the acquisition process starts in the optimal conditions, that such conditions are maintained in time by means of monitoring and recording basic operating parameters potentially affecting the acquisition (regardless the nature of the oceanographic data themselves), and that warnings are sent to the operators when such conditions no longer exist. Each HF radar system undergoes factory calibration of the electronics consisting of a receiver antenna test, transmitter chassis test, and receiver chassis test. Factory testing is required prior to receipt of a shipment. From the reception of the equipment onwards, many aspects of QA are covered by previous paragraphs in section 2 (new deployments), 3 (setup) and 4 (periodic maintenance). Once HF-radar station is deployed, its proper functioning can be assessed by the remote monitoring of its performance. In this paragraph basic considerations about HF-radar systems monitoring are explained. HF-radar systems, as discussed in previous sections in this document, can be implemented with different hardware and software design, and different signal processing techniques. For this reason, they can provide different performance indicators. However, all HF radar systems allow recording common operating parameters like temperature and voltage of subcomponents (e.g. chassis, amplifier), forward and reflected power, and indicators related to Signal to Noise ratio, and provide alert messages when measured values exceed given thresholds. This aspect must be considered carefully, thresholds must be set and software properly configured according to manufacturer's manuals, and every change in those indicators, especially if permanent, should be investigated.

As an example, any significant permanent variation of the reflected power is most likely related to a hardware failure (e.g. antennae, cables of amplifiers). Signal to Noise Ratio is usually not stable because of environmental conditions and periodically fluctuates with repeated daily pattern, but any significant permanent change in this pattern or in its variation range should be investigated.

Other parameters most related to data processing outputs are included in the Quality Control (QC) best practices discussed in 6.2

6.1. Quality Performance Metrics

UCSB has conducted a preliminary review of performance metrics on Codar SeaSonde systems titled “Evaluation of SeaSonde Hardware Diagnostic Parameters as Performance Metrics”, available at http://hfradar.msi.ucsb.edu/brian_emery/files/reports/2008_diagnostics_evaluation.pdf. The study examined a set of hardware parameters and the applicability of utilizing parameters as a diagnostic tool for measuring hardware performance. Except where noted, recommendations are based on the standard values collected during the study. Performance metrics were determined for all of the parameters specified in the study statement of work with the exception of the calculated amplitude corrections for loops 1 and 2 to the monopole (AMP1 and AMP2). The manufacturer (Codar Ocean Sensors Ltd. - COS-) recommended that these parameters be monitored for significant changes. Quality performance metrics to establish both QA and QC values is an active area of research and will be addressed in future ROW/ROWG meetings. HFR performance metric recommendations are shown in Table 6.1 and Table 6.2 for Direction Finding and Phase Array, respectively.

Table 9.- Hardware diagnostic statistics reported by the SeaSonde software (only for Direction Finding. Some values, i.e. voltages, are hardware versions dependent).

Standard SeaSonde hardware diagnostic statistics			
Parameter	*Code*	*Mean or [accepted values]*	*Standard deviation*
Receiver Chassis Temp (°C)	RTMP	<40[1] 26.2[2]	6.0[1] 5.9[2]
AWG Board Temp (°C)	MTMP	<50[1] 36.5[2]	7.0[1] 6.6[2]
MTMP-RTMP (°C)		<12[2]	
Receiver + VDC Supply	SP05	min=>4.5; max=>6 [1] 5.2[2]	0.1[2]
Receiver - VDC Supply	SN05	max=>-4.5; min=>-6 [1] -5.1[2]	0.2[2]
Receiver + 12VDC Supply	SP12	min =>10; max >=14 [1] 12.3[2]	0.1[2]
Transmitter + VDC Supply	XP05	min >= 4.5;max >= 6[1]	
Transmitter + 28 V Supply	XP28	min >= 23; max=>35 [1]	
Transmitter Front Panel Chassis Temp (°C)	XPHT	max >= 40[1]	

[1] Recommendations given by remote site monitoring scripts rs_warn.pl. This script compares the parameters of the hardware against accepted values as listed on the tables.
[2] Recommendations given by the documentation (http://hfradar.msi.ucsb.edu/brian_emery/files/reports/2008_diagnostics_evaluation.pdf)

		28.9[2]	5.2[2]
Transmitter Amplifier Temp (°C)	XAHT	max >= 50[1] 34.5[2]	5.0[2]
AWG module temperature (ºC)	AHOT	max >= 50[1]	
Receiver front panel temperature (ºC)	RHOT	max >= 40[1]	
XAHT-XPHT (°C)		>10[2]	
Transmitter Forward Power (W)	XAFW	53.0 [1]	13.0[1]
Transmitter Reflected Power (W)	XARW	5.0[1]	5.0[1]
Channel 1 signal-to-noise ratio (dB)	SSN1	min >= 20[1]	
Channel 2 signal-to-noise ratio (dB)	SSN2	min >= 20[1]	
Channel 3 signal-to-noise ratio (dB)	SSN3	min >= 20[1]	
Number of GPS satellites[3]	NSAT	min=> 4[1]	
Phase Lock Loop Loss	PLLL	0.2[2]	2.42
Run Time (hours)	RUNT	190[1] 188[2]	400[1] 402[2]
Number of radial vector -13 MHz band	RADV	520[1] 523[2]	310[1] 309[2]
Number of radial vector - 25 MHz band	RADV	280[1] 276[2]	110[1] 106[2]
Number of radial vector -40 MHz band	RADV	960[1] 960[2]	470[1] 469[2]
Average # Solns per Range Cell-13 MHz	RAPR	15[1]	5[1]
Average # Solns per Range Cell- 25 MHz	RAPR	10[1] 9[2]	5[1] 4[2]
Average # Solns per Range Cell-40 MHz	RAPR	30[1] 33[2]	15[1] 15[2]
Maximum Radial Range (km) -13 MHz band	RADR	75.7[2]	18.7[2]

[3] *Warning: the new GPS modules (MINI-JLT REV v1.0) do not provide information about the number of GPS satellites. The rs_warnm.pl must be modified to include this exception.*

Maximum Radial Range (km) -25 MHz band	RADR	29.4[2]	5.2[2]
Maximum Radial Range (km) 40 MHz band	RADR	10.6[2]	2.1[2]
Average Bearing of all Radials-13 MHz band	RABA	-88.4[2]	80.0[1] 79.0[2]
Average Bearing of all Radials-25 MHz band	RABA	-91.8[2]	80.0[1] 84.8[2]
Average Bearing of all Radials -40 MHz band	RABA	-5.7[2]	70.0[1] 72.5[2]

Table 10.- Hardware diagnostic statistics reported by the WERA software (only for Phase Array. Note that different hardware versions exist, which got different voltage limits)

Standard WERA IV hardware diagnostic parameters	
Parameter	**Nominal value / Limit**
Frequency Control Rack +3.3V	3.1 to 3.5 V
Frequency Control Rack +5V	4.9 to 5.15 V
Frequency Control Rack +12V	11.2 to 12.8 V
Frequency Control Rack -12V	-12.8 to -11.2 V
Frequency Control Rack +27V	26 to 28 V
Frequency Control Rack +5V	4.9 to 5.15 V
Frequency Control Rack +12V	11.2 to 12.8 V
Frequency Control Rack +18V	17.2 to 18.8 V
Frequency Control Rack -21V	-22 to -20 V
Frequency Control Rack temperature	Adjustable (40/45/50 degrees)
Receiver Rack 1 / 2 +20V	19 to 21 V
Receiver Rack 1 / 2 +21V	20 to 22 V
Receiver Rack 1 / 2 -21V	-22 to -20 V

Receiver Rack 1 / 2 temperature	Adjustable (40/45/50 degrees)
Power Amplifier +26.5V	25.5 to 27.5V
Power Amplifier +15V	14.2 to 15.8 V
Power Amplifier +15V	14.2 to 15.8 V
Power Amplifier forward power	(depends on power amplifier gain setting)
Power Amplifier reverse power	< 4 watts
Power Amplifier temperature	Adjustable (~70 degrees)
Power amplifier self protection (-6dB gain)	Yes / No
User PC hard disk usage	85% / 90% / 95 % (warning levels)
Receive antenna gain value	Gain factor > 10
DPT[4] - Receive channel [1…16] overdriven	>7 V RMS
DPT[4] - Receive channel [1…16] calibration value I/Q	<10
DPT[4] - Receive channel [1…16] calibration value balance	0.9<x<1.1
DPT[4] - Receive channel [1…16] I/Q balance	90 +/-3 degrees
DPT[4] - Receive channel [1…16] time series of phase value	Almost constant over time
DPT[4] - Receive channel [1…16] time series of RMS voltage values	(Similar for all receive channels)
Internal calibration measurement values	All within limits
Low level WERA hardware monitoring (Many automatic checks during boot and for each measurement.)	All basic tests OK.
Data connection	Stable
Data transfer time	<x minutes

[4] *DPT = Direct Path Test measurement*

6.2. Quality Control (QC)

In this document, QC refers to assessment of the data output for validity and correctness of measurements. Although using HF Radar to measure surface current velocity and direction has been accepted in the community, the assessment of data quality is an ongoing research area.

As described by Lipa (2013), if we assume that the radar hardware is operating correctly, we can identify different 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 (e.g. incorrect antenna patterns or 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). One of the main factors affecting the accuracy of the radial velocities is the integration time used for calculating the Doppler spectra at each time step. Recently, Forget (2015) presented a method to estimate noise properties of HF-radar measurements (again for both BF and DF processing) and to estimate the minimum timescales of variability that can be resolved given the intrinsic noise of the measurement. When dealing with total currents, as commented previously, additional geometric errors can affect the accuracy of the HF-radar data. These errors (GDOP and GDOSA) are distributed spatially and can be controlled and estimated in the processing from total to radials (Chapman et al., 1997; Barrick, 2002). Related to the data uncertainties, it is worth mentioning that a number of validation exercises exist, based on comparisons of HF-radar currents against independent in situ measurements (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; 2015a, 2015b; Kalampokis et al., 2016). 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 (Kalampokis et al., 2016, Solabarrieta et al., 2014).

Significant efforts have recently been devoted to identifying and eventually replace occasional non-realistic radar current vectors, usually detected at the outer edges of the radar domain (Wyatt, 2015). The potential elimination of accurate data, when the discriminating algorithm is based on tight thresholds, is the main disadvantage of quality-control procedures. Some fine-tuning, according to the specific local conditions of the system, is thus required to have the right trade-off between confirmed outlier identification and false alarm rate (Gómez et al., 2014). A number of previous works have focused on defining optimum threshold levels (e.g. Lorente et al., 2014, 2015a, 2015b) but there is still no worldwide consensus. Current initiatives intend to use non-velocity-based metrics related to the characteristics of the received signal (radial and total coverage analysis, hardware status, quality of the received signal) in order to implement advanced quality controls (Kirincich et al., 2012).

Concerning real-time HF-radar current data, the European common QC model described in Section 4 of the JERICO-NEXT deliverable D5.14 lists the mandatory real-time QC tests to be applied to radial and total velocity data. In particular, the mandatory tests to be performed on radial data are:

- **Syntax check**: this test will ensure the proper formatting and the existence of all the necessary fields within the radial netCDF file. This test is performed on the netCDF files and it assesses the presence and correctness of all data and attribute fields and the correct syntax throughout the file. This test is performed by the European HFR Node before pushing data to the distribution platforms.
- **Over-water test**: this test labels radial vectors that lie on land with a “bad data” flag and radial vectors that lie on water with a “good data” flag.
- **Velocity Threshold**: this test labels radial velocity vectors whose module is bigger than a maximum velocity threshold with a “bad data” flag and radial vectors whose module is smaller than the threshold with a “good data” flag.
- **Variance Threshold**: this test labels radial vectors whose temporal variance is bigger than a maximum threshold with a “bad data” flag and radial vectors whose temporal variance is smaller than the threshold with a “good data” flag. This test is applicable only to Beam Forming (BF) systems. Data files from Direction Finding (DF) systems will apply instead the “Temporal Derivative” test reporting the explanation “Test not applicable to Direction Finding systems. The Temporal Derivative test is applied.” in the comment attribute.
- **Temporal Derivative**: for each radial bin, the current hour velocity vector is compared with the previous and next hour ones. If the differences are bigger than a threshold (specific for each radial bin and evaluated on the basis of the analysis of one-year-long time series), the present vector is flagged as bad_data, otherwise it is labelled with a good_data flag. Since this method implies a one-hour delay in the data provision, the current hour file should have the related QC flag set to 0 (no QC performed) until it is updated to the proper values when the next hour file is generated.
- **Median Filter**: for each source vector, the median of all velocities within a radius of <RCLim> and whose vector bearing (angle of arrival at site) is also within an angular distance of <AngLim> degrees from the source vector's bearing is evaluated. If the difference between the vector's velocity and the median velocity is greater than a threshold, then the vector is labelled with a “bad_data” flag, otherwise it is labelled with a “good_data” flag.
- **Average Radial Bearing:** this test labels the entire datafile with a ‘good_data” flag if the average radial bearing of all the vectors contained in the data file lies within a specified margin around the expected value of normal operation. Otherwise, the data file is labelled with a “bad_data” flag. The value of normal operation has to be defined within a time interval when the proper functioning of the device is assessed. The margin has to be set according site-specific properties. This test is applicable only to DF systems. Data files from BF systems

will have this variable filled with "good_data" flags (1) and the explanation "Test not applicable to Beam Forming systems" in the comment attribute.

- **Radial Count**: test labelling radial data having a number of velocity vectors bigger than the threshold with a "good data" flag and radial data having a number of velocity vectors smaller than the threshold with a "bad data" flag.

The mandatory tests to be performed on total data are:

- **Syntax check**: this test will ensure the proper formatting and the existence of all the necessary fields within the total netCDF file. This test is performed on the netCDF files and it assesses the presence and correctness of all data and attribute fields and the correct syntax throughout the file. This test is performed by the European HFR Node before pushing data to the distribution platforms.
- **Data Density Threshold**: this test labels total velocity vectors with a number of contributing radials bigger than the threshold with a "good data" flag and total velocity vectors with a number of contributing radials smaller than the threshold with a "bad data" flag.
- **Velocity Threshold**: this test labels total velocity vectors whose module is bigger than a maximum velocity threshold with a "bad data" flag and total vectors whose module is smaller than the threshold with a "good data" flag.
- **Variance Threshold**: this test labels total vectors whose temporal variance is bigger than a maximum threshold with a "bad data" flag and total vectors whose temporal variance is smaller than the threshold with a "good data" flag. This test is applicable only to Beam Forming (BF) systems. Data files from Direction Finding (DF) systems will apply instead the "Temporal Derivative" test reporting the explanation "Test not applicable to Direction Finding systems. The Temporal Derivative test is applied." in the comment attribute.
- **Temporal Derivative**: for each total bin, the current hour velocity vector is compared with the previous and next hour ones. If the differences are bigger than a threshold (specific for each grid cell and evaluated on the basis of the analysis of one-year-long time series), the present vector is flagged as "bad_ data", otherwise it is labelled with a "good_ data" flag. Since this method implies a one-hour delay in the data provision, the current hour file should have the related QC flag set to 0 (no QC performed) until it is updated to the proper values when the next hour file is generated.
- **GDOP Threshold**: this test labels total velocity vectors whose GDOP is bigger than a maximum threshold with a "bad data" flag and the vectors whose GDOP is smaller than the threshold with a "good data" flag.

These mandatory QC tests are manufacturer-independent, i.e. they do not rely on particular variables or information provided only by a specific device.

These standard sets of tests have been defined both for radial and total velocity data and they are the required ones for labelling the data as Level 2B (for radial velocity) and Level 3B (for total velocity) data. Please refer to Appendix A of the JERICO-NEXT deliverable

D5.14 "Recommendation Report 2 on improved common procedures for HF-radar QC analysis" for the processing level definition, that is synthetically reported in the table below (Table 11).

Table 11. Processing levels for HF-radar data.

Processing Level	Definition	Products
LEVEL 0	Reconstructed, unprocessed instrument/payload data at full resolution; any and all communications artifacts, 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.	HF-radar radial velocity data
LEVEL 2B	Level 2A data that have been (re)processed with a minimum set of QC.	HF-radar radial velocity data
LEVEL 2C	Level 2A data that have been reprocessed for advanced QC.	Reprocessed HF-radar radial velocity data
LEVEL 3A	Variables mapped on uniform space-time grid scales, usually with some completeness and consistency	HF-radar total velocity data
LEVEL 3B	Level 3A data that have been (re)processed with a minimum set of QC.	HF-radar total velocity data
LEVEL 3C	Level 3A data that have been reprocessed for advanced QC.	Reprocessed HF-radar 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.

Each QC test will result in a flag related to each data vector which will be inserted in the specific test variable. These variables can be matrices with the same dimensions of the data variable, containing, for each cell, the flag related to the vector lying in that cell, in case the QC test evaluates each cell of the gridded data, or a scalar, in case the QC test assesses an overall property of the data.
An overall QC variable will report the quality flags related to the results of all the QC tests: it is a "good data" flag if and only if all QC tests are passed by the data. Please refer to Appendix B of D5.14 for the QC flagging scheme, that is synthetically reported in the table below (Table 12).

Table 12. Quality Control flag scale for HF-radar data

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

For some of these tests, HF-radar operators will need to select the best thresholds. Since a successful QC effort is highly dependent upon selection of the proper thresholds, this choice is not straightforward, and may require trial and error before final selections are made. These thresholds should not be determined arbitrarily but based on historical knowledge or statistics derived from historical data.

As stated in Section 5, the European HFR Node either operationally runs or shares software tools for HF-radar data QC, according to the standard QC model, and for conversion into the standard data model. These tools ingest all the known file formats from all the HF-radar manufacturers, i.e. Codar .ruv and .tuv files, WERA .crad_ascii and .cur_asc files. The software tools are freely available at https://github.com/LorenzoCorgnati/HFR_Node_tools. The European HFR Node architecture is based on a central database containing information about data and metadata and QC test thresholds. The software applications for data quality control and conversion work on metadata contained into data files and on general information about data and metadata contained into the database. This information is loaded by the HF-radar operators (just once) onto the database via a webform available online at http://150.145.136.36/index.php

7. Conclusions

In response to the need for optimizing the operation performance of HF-radars, different documents providing best practices for radar systems operation and maintenance have emerged in the past years. Most of them are either oriented to DF or BF systems, or to specific manufacturer's radar systems. In this document we compiled and completed existing documentation with the aim of offering a broad "Best Practices" manual for optimal operation of HF-radar systems with independence from manufacturer or antenna design/setup.

This "Best Practices" document fed with our direct experience on HF-radar systems management and on the recent literature, provides some advancement with respect to the exiting documents, in several aspects. In particular:

- We provide a more general approach to the technology, including other examples of products and suggesting best practices referring when possible only to the antenna design and setup, and to how the spectral information is processed in order to determine the direction of arrival of the received signal (direction finding / beam forming techniques).
- We take into account the latest development in the field of HF-radar set-up, maintenance and operation. Among them, communication and remote management of the HF-radar station, and new calibration (antenna pattern measurement) methods.
- We develop a section dedicated to HF-radar real time data management best practices of the HF radar derived surface velocity data throughout their life cycle: from acquisition to post-processing, archiving and preserving and dissemination, with a look on interoperability at global level.
- We highlighted the need of distributing standardized and harmonized HF-radar files and further detail the EU common data and metadata model for HF-radar surface currents and Quality Control Tests and Flags, as described in section 6.2, and as adopted by CMEMS In-Situ TAC for HF-radar data distribution.

Although this is already a quite complete document providing significant improvements and additional information to what is available in the literature, in our opinion this should be considered and scalable document which should grow with the experience of the community. Future review of this Best Practices document considering inputs from other experts external to JERICO would be considered to broader the recommendations provided to other types of HF-radars currently in use or emerging, and on aspects related to other applications of the data (like tsunami detection, winds or waves).

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9. Appendices

9.1. Appendix I: APM by boat

9.1.1. Materials checklists

The following appendix lists all materials needed for performing a SeaSonde Antenna Pattern Measurement (APM) by boat.

- ❑ Boat
- ❑ Transponder (SSTR-101)
- ❑ Correct USB cord for transponder (Type A USB to type B USB)
- ❑ Transponder charger
- ❑ Fully charged transponder battery (at 12 V 2.9 A hour SLA battery). NOTE: Light shines > battery is not full.
- ❑ Multimeter
- ❑ GPS Garmin x 2.
- ❑ Four-piece transmit whip antenna
- ❑ Whip Antenna Base
- ❑ Whip Antenna- Transponder Cable: transmit cable type N connector > 2 wires (white-top; black-back)
- ❑ Transponder Grounding Wire
- ❑ Communication Equipment
    - ❑ Walkie talkies
    - ❑ Cell phones
- ❑ Spare batteries (for walkies and GPS)
- ❑ APM instructions
- ❑ APM forms (1 for each site)
- ❑ Laptop with SS software
- ❑ Portable HDD or USB
- ❑ Site Keys
- ❑ Drifter buoys for further validation, if any

9.1.2. Step-by-step instructions

This appendix describes the procedure to perform a SeaSonde (SS, hereinafter) APM step-by-step for a system operating at 13,5 MHz:

AT THE OFFICE (some days before) **and ON BOARD** (the APM day):

1. **Check transponder battery** for charge (charge should be > 12 V)
   - ❑ Plug the transponder charger into an electrical outlet.
   - ❑ Plug transponder charger into the CHARGER socket of the printed circuit board of the transponder (switch off the transponder)
   - ❑ Look at the indicators: red and orange lights should be permanent illuminated[5]
2. **Configure the transponder: Sea Sonde Transponder**
   - ❑ Plug round black connector of the USB data cable into the USB data port on the side of the transponder
   - ❑ Plug the standard USB connector on the SS Computer.
   - ❑ Switch on the transponder[6]
   - ❑ Transponder → Select Port (SS Transponder SSRX-USB) → Open
   - ❑ Transponder → Transponder Control
   - ❑ Frequency: ____13.5____ MHz
   - ❑ Offset:________ 40.7____Hz (transponder offset frequency in Hz)[7]
   - ❑ Distance:_______1______km
   - ❑ Range: _______11______Cell
   - ❑ Doppler:_____+35_______DC
   - ❑ Send: default +click “Send” few times

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[5] *The FAST CHARGE indicator on the charger will light while the battery charges. When the FAST CHARGE indicator light turns off, the battery is charged.*

[6] *No communication with the transponder: 1) try a different cord; 2) try a different computer; 3) try the underside USB connection from the transponder board; 4) check transponder battery (> 12 V) with a multimeter (POWER SUPPLY socket on the printed ciruit board and the transponder charger)*

[7] *Offset controls where the transponder will show up in Range and Doppler in SSAcquisition cross spectra. For 13.5 MHz, an offset of 41.1 can also be used so the transponder peak will be far away from Bragg peaks, allowing a better differentiation and identification of the transponder signal.*
Target Range cell = integer value of the offset (40 Hz) divided by the receiver sweep rate (usually 4 Hz), plus the distance of the boat from the receiver (~1 km) → 11 cell (bin).
Doppler cell = fractional part of the offset (0.7 Hz) divided by the sweep rate (4 Hz)

- ❑ Click STORE to save the current settings at the power on transponder state. *You should do this after configuring the transponder.*
- ❑ Verify settings: turn the transponder off and back on.
- ❑ Click “Refresh” ⟶ query the transponder for an update (automatically every minute)
- ❑ Confirm the transponder settings are the same as those recorded above.
- ❑ Close window ⟶ close port ⟶ Switch off transponder ⟶ unplug USB data cable connector
- ❑ *DO NOT CLICK Default button: sets the transponder to its default hardware state[8].*
- ❑ Take a screenshot of the transponder configuration

TRANSPONDER ON A BOAT:

- ❑ Assemble and mount to the boat the four-piece whip antenna and feed (included with Transponder Extender Kit SSTR-EX)
- ❑ Attach the transmit signal cable to the antenna feed, the white wire to the Monopole Transponder Antenna Port (top of the transponder case) and the black wire to one of the grounding antenna ports (on the front or backside of the transponder case)
- ❑ Ground the antenna feed to the seawater with a drogue.

AT THE RADIAL SITE:

1. **Check antenna position (GPS) and verify** with SS RadialSetup

- ❑ SITE 1: indicate lon and lat of the antenna.
- ❑ SITE 2: indicate lon and lat of the antenna.

2. **Check antenna bearing** (compass clockwise from true north) and verify with Sea Sonde RadialSetup

- ❑ MagneticDeclination: convert “compass reading” (Compass Arrow Direction CW North) to antenna bearing Loop1 Bearing CW North.

[8] *You should do this before the other settings or if you are having difficulties with the transponder.*

3. **GPS synchronization with SS computer clock**: (ask date/time to boat operator; computer clock needs to be within 2 seconds from GPS time)

- ❑ Computer: System Preferences → Date & Time → Show time with seconds
- ❑ SS Controller → Receiver Controller → GPS monitor → compare time on the GPS
- ❑ GPS and SS Computer may use UTC!!

4. **Turn off other transmitters** operating on same center frequency

- ❑ Using TeamViewer (remote control application): enter to the other station(s)[9]
  - o SSController → Receiver Controller → Advance Control → Blanking OFF
  - o SSController → Receiver Controller → Advance Control → Transmit OFF
- ❑ On terminal (write the following three commands in order), accessing by ssh (ssh username@ipaddress)

> osascript -e 'tell app "SeaSondeController" to AwgCommand "xoff"' → transmit to off

> osascript -e 'tell app "SeaSondeController" to AwgCommand "boff"' → turn off blanking

> osascript -e 'tell app "SeaSondeController" to AwgCommand "prpt"' | grep "XMVF → power report confirming forward power is off (look for the line reading XMVF: 0.0W)

5. Quit the processing suit:

- ❑ Sentinel → Control → Quit Sentinel.

6. **Move and open SS Controller and SS Acquisition** to the Dock.

> open -a SeaSondeController

> open -a SeaSondeAcquisition

[9] *Update to same version number of Teamviewer to be able to connect by teamviewer between radial stations*

7. Open Teamviewer app

> open -a "Teamviewer"

8. Disable data processing: SS Acquisition

- ❑ SSAcquisition → File → Turn off "Log Cross Spectra"[10]
- ❑ SSAcquisition → Processing → Enable Loop Diagnostics

9. **Configure the receiver**: SSController

- ❑ Control → Receiver Controller → Advance Control
- ❑ Enter the following settings[11]
- ❑ SWITCH ON THE TRANSPONDER on THE BOAT

10. **Check for transponder peak:** SSAcquisition

- ❑ File → confirm Uncheck mark "Log Cross Spectra"
- ❑ Processing → confirm check "Enable Loop Diagnostics"
  - o SpectraRangeDisplay → unchecked "Use Target Info to Set Search" box
  - o Search for Peaks: Range cells [8-14]; Doppler bins [6: -6] + RECORD
- ❑ Monitors → Range Display → Range Display (confirm signal peak)[12]
- ❑ Monitors → Range Series Power Map → Range Series Power Map to better monitor the transponder peak.
- ❑ Monitors → Cross Spectra Power Map → Cross Spectra Power Map to better monitor the transponder peak.

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[10] *Disable normal data processing; turn off cross spectra to prevent SS collect and process transponder data into radials*

[11] *Reduce the "Blank" field (blanking time) to 60 microseconds to reduce the normal Bragg return, helping to keep the transponder signal from every being confused with the Bragg. Reduce the "Bdly" to reduce the delay before the receiver can listen and to make transponder respond more quickly.*
Increase the "attenuation" of the transmit signal so that the sea echo which returns from greater ranges are diminished.
Doubling the "sweep rate" pulls the first order Bragg peaks closer to DC leaving more "room" for the transponder peak to wander in the Doppler window w/o merging with the FO Bragg peaks.
Turn the Pulse shaping=OFF because at 60 microseconds blanking interval, pulse shaping will never allow the transmitter to come up to full power.

[12] *The maximum value of the peak should not be more than -50 dB (at least 20 dB above background noise). Signal too weak → lower the attenuation (14 dB) or move the transponder closer to the receiver Signal too strong (> -50 dB) → increase the attenuation (16 dB)*

- ❑ Monitors → Range Peak Info Monitor
- ❑ TEST the TRANSPONDER PEAK (at halfway-point) → SWITCH OFF-SWITCH ON

11. **Start tracks** (follow and start filling APM templates, included in Appendix III):

- ❑ First track → start point
- ❑ Start APM tracks with the boat: SSAcquisition → File → Log Time Series[13]
- ❑ Check for TimeSeries saving: /Codar/SS/Data/TimeSeries/Lvl*.ts (it updates one file every ~2 min, ~6 Mb each file). Check it on the terminal:

```
> ls -hlrt /Codar/SeaSonde/Data/TimeSeries/ | tail -1
```

- ❑ Start track logging on GPS
- ❑ Check Signal
- ❑ Check GPS track logging (verify GPS is secured and logging every 1-2 seconds; 5+ satellites is best)
- ❑ Arc at constant speed < 4 knots (radius from the antenna around 1 km; first -end points close to the coast)
- ❑ At the end of APM: SSAcquisition → File → Uncheck Log Time
- ❑ Save GPS navigator track

12. **Store APM data**: save files to disk for APM post-processing

- ❑ Create folder APM_SITE1_DDMMYYYY / APM_SITE2_DDMMYYYY
- ❑ Copy to the folder:
  - o Timeseries: /Codar/SeaSonde/Data/Timeseries/LvL*.ts
  - o Radial Site Configuration: /Codar/SeaSonde/Configs/RadialConfigs
  - o CSS files from the last 2-3 months: /Codar/SeaSonde/Data/Spectra/SpectraProcessed/*.cs
  - o Site Log Notes

[13] *Timeseries are consecutive time sweeps of received signal power over time*

   - o GPS navigator track log file:TRACK*.trk and *gpx
   - o Screenshots

13. **Set up SeaSonde for normal operation**

   - ❑ Sentinel → Control → Restart Computer
   - ❑ Check SSController settings: → Receiver Controller → Advanced (verify original settings)

     > osascript –e ‘tell app “SeaSondeController” to AwgCommand “xpuls”’ → transmit to puls

     > osascript –e ‘tell app “SeaSondeController” to AwgCommand “bpuls”’ → balnking to puls

     > osascript –e ‘tell app “SeaSondeController” to AwgCommand “prpt”’ | grep "XMVF" → power report confirming forward power is on (look for the line reading XMVF: 39.0W)[14]

   - ❑ Check SSAcquisition → File → Log Cross Spectra enabled
   - [redacted]Check if all applications (BillsScripting.app; Sentinel.app; RadialWebServer; SSController.app; SSAcquisition.app; CSPro.app; Archivalist.app) are running > ps ax | grep -i seasonde
   - ● boat: transponder off + GPS not recording → download GPS track to the computer[15]

APM POST-PROCESSING:

- ❑ Timeseries
- ❑ GPS Track (*.gpx) → GPS TrackEditor (clean GPS data)
- ❑ GPS track log → GPS Tracker → GPS Track Codar Table
- ❑ SSAcquisition → Timeseries + GS track → /Codar/SS/Data/Loops/LOOP* file
- ❑ CrossLoop Pattener: LOOP* → measpattern.txt
- ❑ MeasPattern.txt in /Codar/SS/Configs/RadialConfigs

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[14] *Look for the XMVF line and verify the normal watt reading for the site*

15 Please, be aware to export GPS time series in UTC (computer time may be in UTC) and using Datum=WGS84

LESSONS LEARNED

- ❑ Bring a computer on board of the boat with the SSTransponder app installed (just in case of checking transponder settings or transponder correct functioning)
- ❑ Bring a multimeter on board to check transponder battery before and after APM exercise
- ❑ Charge transponder battery at the end of each APM (> 12 V) and check the charge before each APM.
- ❑ Transponder should be closed when bringing on board (not connected to power supply)
- ❑ Garmin GPS:
    - o GPS should include the timezone and it will be possible to download GPX and TCX with correct UTC time[16].
    - o If you save a track before downloading, much of the data is truncated, including the time stamps (time data stripped). Download the track without saving at first and all the data should be there. Apparently, this is done as a means of reducing the size of saved files. All track log data (in the memory card) do not lose anything (they include timestamps). Using the Save function will reduce the number of points in the track log to 500 or less and remove all time data.
- ❑ In case of a parallel drifter experiment (positions defined in near-real time in terms of getting the higher residence times inside the HFR footprint area), extra-time for deployment should be considered in the workplan.
- ❑ Workplan should be sent to all participants at least 1 week in advance.
- ❑ Try to avoid tourist high season for planning APM exercises in coastal touristic areas.
- ❑ Try to avoid rush hour of marine traffic (zodiac can not exceed 4 knots during the experiment, other boats and vessels act as HF radar targets, for safety and

[16] *Track/Trip Log timestamps have been in UTC. Device and PC/Mac software convert them to the timezone set. Thus, times change with daylight-saving-time DST or local time (as does your device/PC/Mac clock) or if you change the timezone.*

security). The best time to APM exercise is early in the morning (just after sunset)

- ❏ Meeting points between SS operator and boat should be pre-defined, just in case of emergency.
- ❏ Walkie-talkie communications improve at the half-way point, at the front of the antenna (far away from initial and end point)

9.1.3. Fill-in-the-blank templates

This appendix is a template that must be fulfilled for each HFR radial site station when you perform a SS APM.

Print one template for each HFR radial site station and bring it with you.

Date:		
Site:		
Previous tests (at the boat)		
Transponder battery full charged (> 12 V)	❏	
Antenna assembled and mounted to the boat	❏	UTC:
Transmit signal cable: Type N connector → antenna White wire → monopole (top transponder case) Black wire → grounding port (back side)	❏	
Test GPS	❏	Interval[17]: 1 sec Num. satellites:
Test communications (walkie-talkies & phones)	❏	
Set up Transponder (at the boat)		

[17] GPS interval strongly recommended 1 sec.

Frequency	13,5 MHz	5	13	25	42	
Offset	40,7 Hz	20.7	40.7	40.7	80.7	
Receiver's sweep rate	4 Hz					
Range Cell	11					
Doppler Cell	+35%DC					
At HFR site						
Screenshot original settings of SSController	❑	UTC:				
Verify antenna location (GPS)	❑	Longitude: Latitude:				
Verify antenna bearing (compass)	❑	Compass Arrow Direction CW North:				
Synchronize Clock	❑	UTC:				
Turn Off Tx at Sites on Same Frequency (Transmitt OFF)	❑	UTC:				
Sentinel → Quit Sentinel	❑	UTC:				
Only SeaSondeController and SeaSondeAcquisition Running	❑					
SSController: Receiver Controller Settings						
Frequency	13,5	❑	5	13	25	42
Bandwidth	50[18]	❑	25	50	100	150
Blank	60	❑	-60			

[18] The value 49.63 could also be acceptable

Blank Delay	4,75	❑	-4,75
Attenuation	15[19]	❑	(15 boat / 30 walk)
Sweep Rate	4	❑	(2 / 4 / 4 / 8)
Blanking	Pulse	❑	
Transmit	Pulse	❑	
Pulse Shaping	Off	❑	(Off)
Screenshot of receiver settings			UTC:
SSAcquisition: Check for transponder peak			
Stop Logging Cross Spectra	❑		UTC:
Enable Loop Diagnostic	❑		UTC:
SpectraRangeDisplay	Range cell:[20]		Doppler Cell:[21]
Take screenshot	❑		UTC:
Transponder: Turn off and back on → verify peak disappears and appears back	❑ UTC (OFF):		❑ UTC (ON):
TRACKS → Start logging TimeSeries			
SSAcquisition → Start Logging Time series	❑		UTC:
Verify TimeSeries records	❑		

[19] Reduce attenuation if signal is too low (14 will be ok)
[20] The desired location in range is around range cells 8-12 (11 will be ok) and desired location in Doppler is on the right-hand side of the spectra
[21] The desired location in Doppler Cell is 6

Tell boat → begin logging with the GPS and begin the track	❑	BOAT SPEED: ~4 kn	
Confirm GPS is logging every 1 s	❑		
Start GPS 1st track – start_point	Position:	UTC:	
GPS 1st track- halfway_point	Position:	UTC:	
GPS 1st track- end_point	Position:	UTC:	
Start GPS 2nd track – start_point	Position:	UTC:	
GPS 2nd track- halfway_point	Position:	UTC:	
GPS 2nd track- end_point	Position:	UTC:	
Stop logging Time series	Position:	UTC:	
Stop recording GPS	Position:	UTC:	
Transponder OFF	Position:	UTC:	
Save Files			
Saved Files to Disk	Check:		
/Codar/SS/Configs/RadialConfigs	❑		
/Codar/SS/Data/TimeSeries	❑		
/Codar/SS/Logs	❑		
/Codar/SS/Spectra/SpectraProcessed/CSS	❑		
Screenshots	❑		
Restore receiver to normal operation			
Sentinel → Control → Relaunch Sentinel Applications	❑	UTC:	

Verify normal processing (SSController and SSAcquisition → Enable “Log Cross Spectra”)	❑	UTC:
Turn ON Tx sites on same frequency	❑	UTC:

9.2. Appendix II: Checklist of Codar SeaSonde maintenance

9.2.1. Daily remote maintenance

This appendix lists the checking points for the basic daily remote checking of the HFR radial sites. These points could be properly monitored using Codar SeaSonde radial suite software or custom scripts (e.g. *bash, *py) and reported by emails to the operators.

At daily basis it is important to control: the main parameters of the radial sites, the creation and storage of raw files, the correct transference of files to the central site and the creation and storage of total files.

HFR radial site daily checklist		
Radial Site:		
Subject:	Daily checking	
Date:		
Operator Name:		
CHECKLIST	**Acceptable values**	
Last reboot date/time		❑
HFR sites configuration files (Header.txt; MeasPattern.txt and AnalysisOptions.txt) exist and are correct[22]	OK	❑
Plot Diagnostic files ("STAT_*") to check different radial (*.rdt) and hardware (*.hdt) parameters	OK	❑
Signal to noise in the three channels[23]	OK	❑
Forward/Received power [24]	OK	❑
Chassis temperatures[25]	OK	❑
Radial files (RDLm & RDLi) are created and stored	OK (near real-time)	❑
Spectra files (CSA; CSQ; CSS) are created and stored	OK (near real-time)	❑
Diagnostic files (STAT) are created and stored	OK (near real-time)	❑

[22] If some of the configuration files are missing, the system will not produce data.
[23] Low signal < 20 dB can indicate some problem in the antenna or cable.
[24] High reflected power can indicate any problem in the cable. Zero forward means no emission. Stop transmission when reflected power > 20 W and transmitter power is > 80 W.
[25] High temperatures can seriously damage the electronics and it can indicate a problem with the air conditioning. Stop transmission when receiver chassis temperature > 40ºC

Waves files (WVLM) are created and stored	OK (near real-time)			❑
Sea Sonde Applications (Sentinel; SeaSondeController; SeaSonde Acquisition; CSPro; AnalyzeSpectra; Archivalist) are running	OK			❑
Remote desktop access (e.g. Teamviewer) is available	OK			❑
Web server is running and displaying information	OK (near real-time)			❑
Disk space	TOTAL	USE	AVAIL.	❑
System disk External HDD backup disk				
Daily alerts	OK			❑
Daily warnings	OK			❑
Sentinel Failure messages	OK			❑
Internet Connection is available	OK			❑
Critical ports (*22; *407; *8080; *8240) are open	OK			❑
Speed test (Download/Upload)				❑
Check latency ping: communication is stable	OK			❑
Number of Radial files sent to Central stations	OK			❑
Data reception and recording in the central station	OK (near real-time)			❑
Total files are created and stored	OK (near real-time)			❑
Surface currents are correctly displayed in the main portal	OK (near-real time)			❑
Validation of HF radar vs. surface point-wise current meter is available	OK (near-real time)			❑
Observations (if any):				
If any incidence is detected, it is suggested to duly noted it in the outage database using the corresponding code (Appendix VIII).				

9.2.2. Monthly on-site maintenance

This appendix lists the checking points for the monthly in-situ visit at the HF-radar radial sites.

HF-radar radial site monthly checklist		
Radial Site:		
Subject:	Monthly in-situ visit	
Date:		
Operator Name:		
CHECKLIST	**Acceptable values**	
Computer ON and working properly	OK	❑
Monitor/keyboard/mouse working properly	OK	❑
Air conditioning ON and working properly	OK	❑
Air conditioning temperature	25 ºC	❑
3G/WIMAX/ antenna, canalisations and cabling appearance	OK	❑
HF-radar Antenna external appearance, canalisations and cabling	OK	❑
GPS antenna, cabling and canalisation appearance	OK	❑
Auxiliary instrumentation external appearance (weather station)	OK	❑
Internet Connection is available	OK	❑
Internet speed (downstream/upload)	___ Mbps / ___ Mbps	❑
Data reception and recording in the computer	OK	❑
All applications are running: Sentinel; SeaSondeController; SeaSonde Acquisition; CSPro; AnalyzeSpectra; Archivalist;	OK	❑
Spectra updated in the corresponding folder and BACKUP	OK (near-real time)	❑
Setting files updated in the corresponding folder and BACKUP	OK (near-real time)	❑
Radials updated in the corresponding folder and BACKUP	OK (near-real time)	❑
Rack visual inspection (integrity of the cables, labels, connections)	OK	❑

Humidity (within the chambers, inside the cabin, ...)	NO			❑
Presence of insects, birds, rodents and other pests	NO			❑
UPS batteries visual inspection	Correct			❑
UPS battery charge	100%			❑
Inventory is updated	OK			❑
Observations (if any):				
ADDITIONAL CHECK POINTS	Model		S/N	
HF-radar Antenna				
Loop 1 (#1), 2(#2) y monopole (#3) resistance (Ohm):	#1	#2	#3	
UPS model:				❑
UPS installation date:	DD/MM/YYYY			❑

9.2.3. Biannual on-site maintenance

This appendix lists the checking points for the recommended maintenance of the HF-radar radial sites to be verified during the on site visit (once every six months at least).

It includes the checking of the operating conditions and equipment status and physical environment.

HF-radar radial site biannual checklist				
Radial Site:				
Subject:	Biannual in-situ visit			
Date:				
Operator Name:				
ANTENNA	**Acceptable values**			
Antenna bearing (measured by compass)	-			
Antenna bearing (SSController)	-			
3G/WIMAX/ antenna, canalisations and cabling appearance	OK			
GPS antenna, cabling and canalisation appearance	Status	Model	S/N	
TX/RX HF-radar Antenna (Model/Serial number)				
HF-radar antenna external appearance	OK			
Loop 1, 2 y monopole resistance (Ohm):	Loop1:	Loop2:	Monopole:	
SYSTEM VALUES	**Forwarded**		**Reflected**	
Power (Attenuation 2 dB)				
Wattmeter power				
GPS reception (satellites number)				
Internet Connection is available	OK			❑
Internet speed (downstream/upload)	___ Mbps / ___ Mbps			❑

Data reception and recording in the computer	OK	❑
Archivalist running	OK	❑
Spectra updated in the corresponding folder and BACKUP	OK (near-real time)	❑
Setting files updated in the corresponding folder and BACKUP	OK (near-real time)	❑
Radials updated in the corresponding folder and BACKUP	OK (near-real time)	❑
CABLING/CANALISATIONS	**Accepted values**	
HF-radar antenna canalisations	OK	❑
HF-radar cabling continuity and correct wiring connection	OK	❑
Junction box and caling		❑
Humidity	NO	❑
Presence of insects, birds, rodents	NO	❑
GPS antenna canalisations	OK	❑
GPS cabling continuity and wiring connection	OK	❑
Junction box and antennas's cabling	NON APPLICABLE (N/A) / DIRECT LINE	❑
Pull box of the GPS antenna	OK	❑
Communications' antenna electrical wiring	OK	❑
Communications wiring continuity	OK	❑
Communications cable splices	NON APPLICABLE (N/A) / DIRECT LINE	❑

Communications terminal and pull boxes	OK			❑
RACK/ ELECTRONICS OF THE SYSTEM	MODEL		S/N	
SeaSonde Transmitter review	SSTX-100-1300-220			❑
SeaSonde Reciver review	SSRX-100A-1325-220			❑
Visual inspection	OK			❑
Fuse holder and fuses	OK			❑
Polarization voltage (12v)	Loop1	Loop2	Monopole	
GPS antenna supply voltage(5v)				❑
UPS review	SMT1500RMI2U / AS1109121408			❑ ❑
Activation test				❑
Sound warnings operation				❑
Charging status				❑
Battery inspection				❑
Installation date	DD/MM/YYYY			❑
Lightning current arresters of coaxial lines	OK			❑
Confirm outlet grouding	OK			
Continuity, insulation measurements	-			❑
Fans in the controller rack	OK, working properly			❑

Thermostat revision	OK, programmed at 25ºC			❑
Adequate fans' noise	OK			❑
Cleaning/Replace of the particle filter				❑
Check Monitor/Keyboard/Mouse	OK			❑
Disk space	TOTAL	USAGE	AVAILABLE	
System Disk (GB)				
External backup disk (GB)				❑
RACK visual check				
Labels integrity	OK			❑
Identifications	OK			❑
Electrical protection components	OK			
Automatic mode testing	-			❑
Observations:				

9.3. Appendix III: Zabbix configuration to monitor the remote sites

This appendix describes how to configure a network monitoring solution (e.g. open source zabbix, as an example of performance monitoring tool) at the HF-radar sites to monitor the most probably incidences. Then, the operator could setup Zabbix server to send mail reports to an email address.

How to configure zabbix at your HF-radar radial site?

1. Download and install Zabbix (https://www.zabbix.com/download)
2. Copy the zabbix folder at the HF-radar sites and at the central station in your $HOME.
3. Zabbix contains 5 sub-folders: /share; /sbin/; /log; /conf; /bin and /etc
4. Set the configuration file from zabbix: $HOME/zabbix/etc/zabbix_agentd.conf
    - hostname=SITE1 / SITE2/ CENTRAL STATION
    - LogFile=$HOME/zabbix/log/zabbix_agentd.log
    - Server=server.es (specify the zabbix server)
    - ListenPort=11050
    - ServerActive=server.es:11051 (in zabbix v2.2)
5. Create a daemon to launch and control zabbix launch:

```
> $HOME/zabbix/sbin/zabbix_agend -c $HOME/zabbix/etc/zabbix_agentd.conf
```

```
> sudo launchctl load /Library/LaunchDaemons/org.zabbix.agentd.plist
```

6. If the launching does not start (launchctl), kill the process and launch it again.

```
>sudo kill -9 `ps -aef | grep zabbix_agentd | grep -v grep | awk '{print $2}'`
```

7. Check if zabbix is running in your computer

```
> ps -afucodar | grep zabbix
```

Which parameters should be monitored?

The most probably incidentes at the HF-radar radial sites are related to communications failure and power supply. Thus, the correct monitoring of the following parameters will help the operator to detect the incidence more quickly and reduce the downtime of the site:

- ❑ SITE has just been restarted
- ❑ Agent ping no data
- ❑ Processor load is too high
- ❑ SSH server is down
- ❑ UPS Battery load under 80%
- ❑ UPS Battery load under 50%
- ❑ Power Status: Not AC Power
- ❑ Hostname was changed on SITE
- ❑ Host information was changed on SITE

9.4. Appendix IV: Outages codes and useful information to report an outage

This appendix describes the procedure to manually enter outages into a database for evaluating the HF-radar site performance and status.

The use of codes allows the operator to analyze and characterize each outage by failure type to find the most common failures of your system, which may guide operations and maintenance efforts to minimize site downtime.

Database information

The database could be a excel sheet with the following columns:

- Station name
- Date start failure (time in UTC)
- Date end failure (time in UTC)
- Failure code: to identify the cause of the outage, as in the next section
- Component code: to identify the component responsible of the system malfunction, as in the next section
- Tags: to identify other factors affecting the outage, as in the next section.
- Data availability on local site: to report the main consequences of the outage in terms of loss of information/measurements (e.g. near-real-time data loss; data gaps), as in the next section
- Status: to report the incident status, as in the next section.
- Observations: brief description of the incidence as observed by the operator (e.g. power outage; connection loss; hardware outage...)
- Action required: brief description of the tasks carried out to solve the incidence.

Outages codes

The outages codes are the ones used in MARACOOS/IOOS[26]. **Each outage** is assigned one **code** that identifies the cause of the outage.

The use of codes will allow the operators to create a catalogue of the site downtime grouped by outage.

[26] as reported in the poster from Teresa Updyke presented at ROWG-2017 "A study of HF radar Outages in the Mid-Atlantic".".

FAILURE CODES	COMPONENT CODE
100 Hardware	110 Tx Chassis 120 Rx Chassis 130 Tx Antenna 140 Rx Antenna or TX/RX Combined 150 Cable 160 Enclosure/Climate Control 170 GPS Antenna or GPS Module 199 Other
200 Computer/Software	210 Computer Hardware Failure 220 Operating System Crash (frozen, no programs working) 230 Software Program/Processing Failure 240 Communication to Receiver/Transmitter Lost 250 Disk Space Full 299 Other
300 Communications	310 Service Provider Outage 320 Hardware Failure (Modem,Router,…) 330 Local Network Configuration/Transfer Scripts 340 National Network Portal or Node 399 Other
400 Site Operation and Maintenance	410 Routine/Preventative Maintenance 420 Incorrect User-Defined Operational Settings 430 Incorrect Hardware/Cable Configuration 440 Radio Frequency 499 Other 450 APM (as suggested by the Spanish Port System - HF-radar operator)
500 Power	510 Service Provider Outage 520 Hardware Failure (UPS, Power Switch,…) 530 Breaker/ground fault tripped 599 Other 999 Unknown (as suggested by the Spanish Port System - HF-radar operator)

The **tags** are used to track **additional factors** affecting the outage.

TAGS	TAGS DESCRIPTION
W	Weather/Environmental (corrosion, humidity,...)
LO	Land Owner/Property
V	Vandalism
A	Animal
LPA	Limited Personnel Availability
SLA	Limited Site Access
RMA	Radar Manufacturer RMA
RI	Radio Interference (periodical or extraordinary interferences)
MF	Multiple Failures
NA	Non available information

To report the consequences of the outage in terms of data availability:

#	DATA AVAILABILITY ON LOCAL SITE COMPUTER
0	None
1	Partial record (low range, low temporal/spatial coverage)
2	Complete record (or HF-radar radial site or entire system)

To keep track of the outage status:

STATUS	PERFORMANCE DESCRIPTION
OUTAGE	Estimated time to repair:
< 1w	< 1 week
1-2w	1-2 weeks
>2w	> 2 weeks
> 1m	> 1 month
RESOLVED	

The identification code is used to identify either the system or the HF-radar radial sites:

ID CODE	SYSTEM
EDIOS programme	Observing network
EDIOS series	HF-radar network
EDIOS platforms	HF-radar radial sites

9.5. Appendix V: Quarterly report for weekly remote site maintenance: table of contents

This appendix contains the table of contents for reporting weekly remote site maintenance tasks on quarterly periods.

1. **Project Identification**
2. **Introduction**

This report describes the work performed during the period DD/MM/YYYY to DD/MM/YYYY related to the weekly remote checkings of the HF-radar radial sites SITE1 and SITE2. It includes system status information based on spatio-temporal coverage and data availability (section 3); quality control metrics (section 4) based on the diagnostic parameters measured at the sites (power forward and reflected; temperature; voltages; signal to noise; noise floor; range and number of vectors). In section 5 the most important issues of the period are highlighted. Maintenance actions carried out during the remote checks are summarized in section 6. Finally, section 7 reflects the conclusions describing the analysis and general status of the system.

3. **Brief system performance report**

This section includes:

- ❑ figures of the HF-radar spatial coverage and total and radial data availability.
- ❑ table showing the percentage of data availability; biggest gap found in files; anomalous number of files.
- ❑ figure showing the % of spatial coverage vs. % data availability (MARACOOS 80/80 metrics, as suggested by the US Coast Guard).

4. **Extended system performance report**

This section includes temporal series of the main diagnostic parameters of the HF-radar sites (power forward and reflected; temperature; voltages; signal to noise; noise floor; range and number of vectors). Value ranges must be defined and keep constant to allow the operator check the system evolution along the different reports. Ranges to be specified: Tx/Rx power= [0 50]; Temperature=[10 50]; Voltages=[-10 30]; SNR=[0 100]; Noise Floor=[-200 -100]; Number of vectors= [0 2500]; Range=[0,100]

5. **Observations**

This section highlights the main incidents related to the system operability detected along the analyzed period, with critical consequences (radial data loss, low data quality).

6. **Maintenance actions**

This section summarizes in a table the weekly remote tasks carried out at every single HF-radar site and for the central station (or combine).

7. Conclusions

This section includes a brief summary (max. half page) of the HF-radar radial sites status, performance, changes in the configurations, principal outages and consequences.

9.6. Appendix VI: Generation of automatic monthly reports

This appendix describes the procedure to create and implement the automatic HF-radar data processing to generate automatic monthly reports.

Monthly reports include qualitative and quantitative assessment (plots and statistical metrics) of HF radar data, in order to: i) extract useful and meaningful information from the HF radar data; ii) to evaluate the HF radar system performance and system status and iii) identify temporal periods of malfunctioning.

Although the installation of a current meter inside the HF radar footprint area is highly recommended for multiplatform assessment and for performing near-real time validation, it is not mandatory. This example of monthly report includes time series showing the comparison of HF radar and current meter measurements. Nevertheless, any one of the sections included in the automatic report can be enabled or disabled, depending on the comparison or analysis available.

The documents are automatically generated based on the HF radar data available in the THREDDS Data Server (TDS) Catalog.

Reports, saved in PDF, are available to be uploaded on the Web (examples available here).

Automatic monthly reports installation

All available documentation and scripts developed are included in the git repository (https://github.com/socib/HFRadarReports). Reader is referred to the README.md for further information on how to install and usage the tool.

Qualitative and quantitative assessment

This section describes the QA/QC analysis procedures applied to the HF-radar data (radial and totals) included in the monthly reports

- ❑ Monthly Surface Current Pattern → vector map showing average monthly patterns of surface current data
- ❑ Temporal Availability → time series showing temporal availability of radial files
- ❑ Time Series of HF-radar at the nearest point of the mooring location → time-series of HF-radar eastward and northward current components, sea surface speed and direction at the nearest point on the mooring location, including the QC for each variable.

- ❑ Data Tables of HF-radar data statistics at the nearest point of the mooring → mean, minimum and maximum values for the variables available in the HF-radar dataset as well as percentage of good data.
- ❑ Comparison between HF Radar and Current Measurements → time-series, windroses and histograms showing the comparison of HF-radar surface current versus the current measurements from a surface point-wise current meter.
- ❑ Spatially Averaged Surface Current Variance → time-series of spatially averaged surface currents interpolated and different low-pass filtered data (33; 24; 12; 19 hours)
- ❑ Spatial Distribution of the Temporal Coverage → map showing the total coverage of available data at each grid point along the previous month.
- ❑ Spatial Coverage vs. Temporal Coverage → figure showing the temporal and spatial availability of all grid points containing at least one data entry. The goal of the system is to provide surface currents over 80% of the spatial region along 80% of the time (MARACOOS 80/80 metric goal, as recommended by the US Coast Guard)
- ❑ Percent of Files Larger than a given Quality Threshold → percentages showing the availability of files with a file size above the defined threshold.
- ❑ Statistics from QC Variables → tables showing the mean, standard deviation, minimum, maximum and percentage of good data with respect to their associated QC variable.
- ❑ Threshold Graphs → time-series showing the QC variables together with their acceptable ranges or thresholds.
- ❑ Histogram Radial Files per 10 Days → bar chart showing the number of available radial files per 10 days.
- ❑ Tidal Analysis → maps of tidal ellipses for the main tidal constituents.
- ❑ Energy Spectra → spectral energy values for each surface current constituent.

Tool functionalities

The tool is robust and configurable since it allows to:

- ❑ define different input sources (HF radars, but also moorings inside the HF-radar footprint area)

- define different timestamps for processing, which might be extremely useful to reprocess all months at the same time.
- specify various threshold values for the QC analysis
- specify input and output directories

9.7. Appendix VII: Maintenance checklist for WERA site

- **Site name:**____
- **Maintenance carried out by:**

Company	Name	Date	hour start	hour end

- **Begin of checklist**

  Please fill only the parts that WERA checked.

  After completion write the actual date into the filename and move this excel sheet into folder:/home/wera/Maintenance/executedMaintenance

  It will automatically be stored at a backup drive.
- **Antenna Setup**

Rx	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
vertically straight																
guidance ropes fastened																
radials attached (no tension at coils)																
no visible damage or corrosion																
coils and connectors sealed																
status / ok																

Tx	front left	front right	back right	back left
vertically straight				
guidance ropes fastened				
radials attached (no tension at coils)				
no visible damage or corrosion				
coils and connectors sealed				
status / ok				

Power splitter at Tx-array	
status / ok	

Antenna cables

Rx phase cables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
should be all not visible																
of visible: please note any damage																
conductivity test																
status / ok																

Tx phase cables	front left	front right	back right	back left
should be all not visible				
of visible: please note any damage				
conductivity test				
status / ok				

For example: Tx front right phase cable damage, in part cut -> replaced

- ❑ **Container / WERA room**

Air conditioner	status / ok
Temperature in the room	
It cools to set temperature	
Check automatic start: restart after power loss if required	
General Power	status / ok
Light is working	
WERA racks LEDs and fan are on	
No smell of smoke	
UPS is on	
UPS battery are charged	
UPS doesn't make warning sounds	
Water / Moisture	status / ok
Humidity sensor	
No visible water entry into the room or system	
Air humidity in the room seems normal	

❑ **WERA Rack /electronics part**

Systems cables	status / ok
No visible damage	
No loose connector hanging around	
All connectors are secured fixed	
WERA-rack frontside	status / ok
Clock and state machine module green LED are on	
When a measurement is running, the LED of the sweep module is on	
When a measurement is running, the LEDs of the ADC modules are on	
Power amplifier LEDs are green, no standby or red error LED is on	
WERA-rack backside	status / ok
All LED's on every rack are on	
All fans on every rack blow out air and make no strange noise	
All connectors are fixed	
Air filters of PC not blocked by dirt/dust	
Air filters of Power amplifier not blocked by dirt/dust	

❑ **WERA UserPC**

System cables	
Internet connection works	
Remote desktop access is on	
Check data link	
ssh access to CPCI is available	
disk space	

❑ **Data**

Data archive	
Archive of .raw files on external disk	
Archive of .sort files on external disk	
Other archiving	
HDD permutation	

❑ **Custom remarks / repair / problems that can't be described via this list**

Please write here

9.8. Appendix VIII: Remote monitoring for WERA site:

- ❑ **Site name:** ____
- ❑ **Maintenance carried out by:**

Company	Name	Date	hour start	hour end

- ❑ **Map of surface current (total):**

visualization website: address	status / ok
spatial coverage is nominal	

- ❑ **Remote access to each site:**

availability to remote access for each station	status / ok
station #1	
station #2	
station #3	

- ❑ **Noise level on each receive antenna:**

Station #	noise level is constant	noise level is nominal
receive antenna #1		
receive antenna #2		
receive antenna #3		
receive antenna #4		
receive antenna #5		
receive antenna #6		
receive antenna #7		
receive antenna #8		
receive antenna #9		
receive antenna #10		
receive antenna #11		
receive antenna #12		
receive antenna #13		
receive antenna #14		
receive antenna #15		
receive antenna #126		

❑ **Direct Path Test:**

File: vxwhost/~wera/status/dpt/index.html

Station #	RMS + CAL	Peak phase + I/Q balance	doppler spectra over time
receive antenna #1			
receive antenna #2			
receive antenna #3			
receive antenna #4			
receive antenna #5			
receive antenna #6			
receive antenna #7			
receive antenna #8			
receive antenna #9			
receive antenna #10			
receive antenna #11			
receive antenna #12			
receive antenna #13			
receive antenna #14			
receive antenna #15			
receive antenna #16			

❑ **Data files:**

Station #	status / ok
internal disk usage (% availability)	
external disk usage (% availability)	
.RAW files are correctly stored (number and size)	
.SORT and .RFI files are correctly stored (number and size)	
.SPEC files are correctly stored (number and size)	
.CRAD files are correctly stored (number and size)	
.WRAD files are correctly stored (number and size)	
data reception and recording to the central station	

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Approvals				
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1. Executive Summary

The JERICO network is constantly working to improve its core functionality, which is the ability to provide comprehensive observations of Europe's coastal seas and oceans. This means integrating new, promising observing technologies that can expand its spatial reach. While building the JERICO-NEXT project, cabled coastal observatories were identified as particularly attractive choices from this point of view, and a distinct task, Task 2.3 in Work Package 2 (WP2), was designed to facilitate their assimilation into the network's established observing system.

Cabled observatories offer the desirable advantage of freeing marine observing activity from the merciless restrictions of limiting power and constrained bandwidth for communication and data transfer, thereby allowing measurements to be made with a broad variety of sensors and systems even under extreme conditions (e.g., storm events, under ice, etc.). Seven such observatories are being operated by JERICO-NEXT partners, all of whom are participating in Task 2.3.

Task 2.3 of JERICO-NEXT deals specifically with the harmonization of the observing systems within the JERICO infrastructure network. The present document, constituting Part 2 of Deliverable D2.4 dealing with cabled coastal observatories of the JERICO-NEXT project, gathers and reports on the outcomes of the workshops on Cabled Observatories (MS9 and MS13) that were planned within the task.

The document provides an overview of best practices utilized during the planning and installation phases of cabled observatories, and reviews the main relevant operational aspects, applications, and data quality assessment and management issues.

It builds on a previous JERICO-NEXT deliverable, specifically, D2.1: "Report on the status of HF-radar systems and cabled coastal observatories within the JERICO network" (http://www.jerico-ri.eu/download/jerico-next-deliverables/JERICO-NEXT-Deliverable-2.1.pdf), redacted by AZTI and UPC.

Additional information concerning the Cabled Observatories events: can be found here:
http://www.jerico-ri.eu/project-information/meeting-reports/

2. Introduction

JERICO-NEXT aims to develop the infrastructural base necessary to meet Europe's present and future informational needs as regards its coastal marine systems. One of the ways it plans to do this is by strengthening pan-European cooperation to render new observing systems and the existing JERICO observing network interoperable. Cabled coastal observatories are an example. Such observatories, appropriately instrumented, will permit sustained multi-disciplinary observations, including much-needed long-term time-series of biological variables, from the sea surface to the seafloor. The assimilation of such systems into the network will greatly advance its capacity to deliver data describing: (1) the interactions between physics, chemistry, biogeochemistry and biology in Europe's coastal seas, and (2) how marine ecosystems react to anthropogenic disturbances and global environmental change.

Cabled observatories offer the attractive advantage of freeing marine observing activity from the merciless restrictions of limiting power and constrained bandwidth for communication and data transfer. These observatories can be used to conduct a wide range of long-term and innovative investigations and studies within their confines using real-time control over system elements. A broad variety of sensors and systems can be used, and measurements can be made even under extreme conditions (e.g. storm events, under ice, etc.).

EMSO (European Multidisciplinary Seafloor and water column Observatory; http://emso.eu/) is the European large-scale deep-sea observatory infrastructure for long-term monitoring of environmental processes relating to ecosystems, climate change, and geohazards. The EMSO initiative is based on developments stemming from EU projects dating back to 1990 that aimed at realizing and validating seafloor observatory and network prototypes. JERICO-NEXT is working with EMSO, seeking common solutions to technical challenges.

3. Cabled Observatories

The coastal cabled observatories involved in the JERICO-NEXT network are listed below, along with the names of the contact persons for them and their managing institutions, and their locations. An in-depth analysis of the different installations, based on their common functionalities, was presented in D2.1, "Report on the status of HF-radars systems and cabled coastal observatories within the JERICO network".

In line with the goal of this document, the following sub-sections describe best practices in the implementation and use of cabled coastal observatories, and try to provide answers to the following questions:

- What is most critical in running a coastal cabled observatory?
- What are the operational issues that need improvement most urgently?
- How to decrease access costs for coastal cabled observatories, while maximizing their availability at the same time?

Cabled coastal observatories participating in JERICO-NEXT:

- OBSEA: Joaquin del Rio Fernandez, Marc Nogueras, Universitat Politècnica de Catalunya (UPC), Spain.
- SmartBay: Alan Berry, Marine Institute (MI), Ireland.
- EMSO Nice/Molène: Nadine Lantéri, Xavier Bompais, Ifremer, France.
- Utö Atmospheric and Marine Research Station: Lauri Laakso: Finnish Meteorological Institute (FMI), Finland.
- LoVe: Henning Wehde, Institute of Marine Research (IMR), Norway.
- UNH/UNS: Philipp Fischer: Alfred Wegener Institut (AWI), Germany.
- Boknis Eck observatory: Hermann Bange, Geomar, Germany.

Best Practices Issues dealt with in this document:

A) What is most critical in running a coastal-cabled observatory?
B) What are the operational issues relating to coastal cabled observatories that need improvement most urgently?
C) How to decrease access costs for coastal cabled observatories, while maximizing availability at the same time?

Other reference documents with Best Practices information on cabled observatories:

- EU Coastal and Open Sea Observatories. Workshop on Interoperability Technologies and Best Practices in Environmental Monitoring. Brest, 10-12 October 2018.
- Project Deliverable D68 ESONET LABEL DEFINITION (http://www.esonet-noe.org/content/download/42247/file/Deliverable_D68_esonet-label-definition_1.0.pdf).
- Deliverable D3.3: FixO3 Label (http://www.fixo3.eu/download/Deliverables/D3.3%20FixO3%20Label.pdf).
- Handbook of best practices. FixO3: (http://www.fixo3.eu/download/Handbook%20of%20best%20practices.pdf).
- Report on best practice in conducting operations and maintaining D4.4 (http://www.jerico-ri.eu/download/filebase/jerico_fp7/deliverables/D4.4_Report%20on%20best%20practices%20in%20conductiong%20operations%20and%20maintaining.pdf).
- EMSOdev recommendations in terms of sensor tests and calibration.
- Sensor Web Enablement Best Practices in EMSO ERIC.

A) What is most critical in running a coastal-cabled observatory?

Cabled coastal observatories offer different types of potential benefits [1], in that they:

- provide a means to carry out fundamental research on natural and human-induced change on timescales ranging from seconds to decades, supporting advances in societally relevant areas of coastal research, such as marine biotechnology, the ocean's role in climate change, the evaluation of mineral and fishery resources, and the assessment and mitigation of natural hazards such as earthquakes, tsunamis, and harmful algal blooms.

- improve access to coastal data, enabling researchers anywhere in the world to study the oceans and earth in real-time or near real-time by providing basic observing infrastructure with a wide variety of sensors.
- help to establish permanent observation sites over the 70 percent of Earth's surface covered by oceans, permitting in-situ coverage not possible with observations limited to continental or island stations.
- assist in the development of new experimental approaches and observational strategies for studying the coast.
- contribute to the enhancement of interdisciplinary research for improving the understanding of interactions between physical, biological, and chemical processes in the oceans.
- represent observational resources as facilities, the use of and access to which can be managed through peer-reviewed proposals.
- increase public awareness of the oceans through new educational opportunities for students at all levels, using seafloor observatories as a platform for public participation in real-time experiments.
- enable the use of sensors in-situ for periods of time longer than their declared operational specifications allow for.

On the other hand, they are also subject to many potential risks [2], such as the following.

- The installation of poorly designed and unreliable observing systems (e.g., if program and project planning and risk management are inadequate, technical expertise is lacking, and/or engineering development resources are insufficient).
- Potential interference between experiments, resulting from inadequate design, coordination, and/or testing of scientific instrumentation.
- Inefficient use of resources if important technological questions are not adequately addressed before major investments in observatory infrastructure are made.
- Possible weaknesses and/or vulnerabilities in system performance if critical technologies (e.g., satellite telemetry systems and development of some sensor types) driven by market drivers outside the scientific community are not available when needed.
- The possibility that the personnel and expertise needed to run similar infrastructure will remain restricted to the very small group of institutions that have them already, with the result that many of the end-users of the observations they provide may become further removed from understanding how these are being made.
- Unreasonable constraints on the freedom of individual investigators to choose the location and timing of their experiments.
- The potential for severe impacts on observatory science funding, and funding for other kinds of research and exploratory science, if the cost of building, maintaining, and operating an observatory infrastructure is higher than initially estimated, and/or there is a catastrophic loss of observatory components.
- Underuse of observatory infrastructure if insufficient funds are budgeted for supporting observatory-related science and the development of scientific instrumentation;

- The potential inability of the present funding structure (based on peer-reviewed, 2 to 5 year long, discipline-based grants) to judge the merit of projects requiring sustained time-series observations over many years or decades, and/or projects that are highly interdisciplinary.
- The risk of producing large data sets, which are not properly quality, controlled but used anyway.

This chapter aims to provide insights on how to minimize these risks based on the experiences of JERICO-NEXT's coastal-cabled observatory community. The chapter is organized as follows:

1. **Cable and infrastructure issues;**
2. **Operational issues;**
3. **Funding and finances;**
4. **Clients, use and exploitation of data (academia, scientists, industry);**
5. **Sharing of observatory space with external users;**
6. **Discussion.**

1. Cable and infrastructure issues

The design process of JERICO-NEXT's coastal observatories differs from one observatory to another (Figure 1): The Marine Institute in Ireland contracted consultants experienced in Ocean Networks Canada's observatories to design the SmartBay observatory, while EMSO-Molène and EMSO-Nice were designed by Ifremer. Engineers from UPC designed the OBSEA observatory, and a consortium of scientists from HZG and AWI and external engineering companies designed the SVALBARD and North Sea Observatories. A common design objective was to reduce the risk of damage as much a possible, with a heavy frame used as an anchoring platform and strong side paneling to protect the sensors and connections.

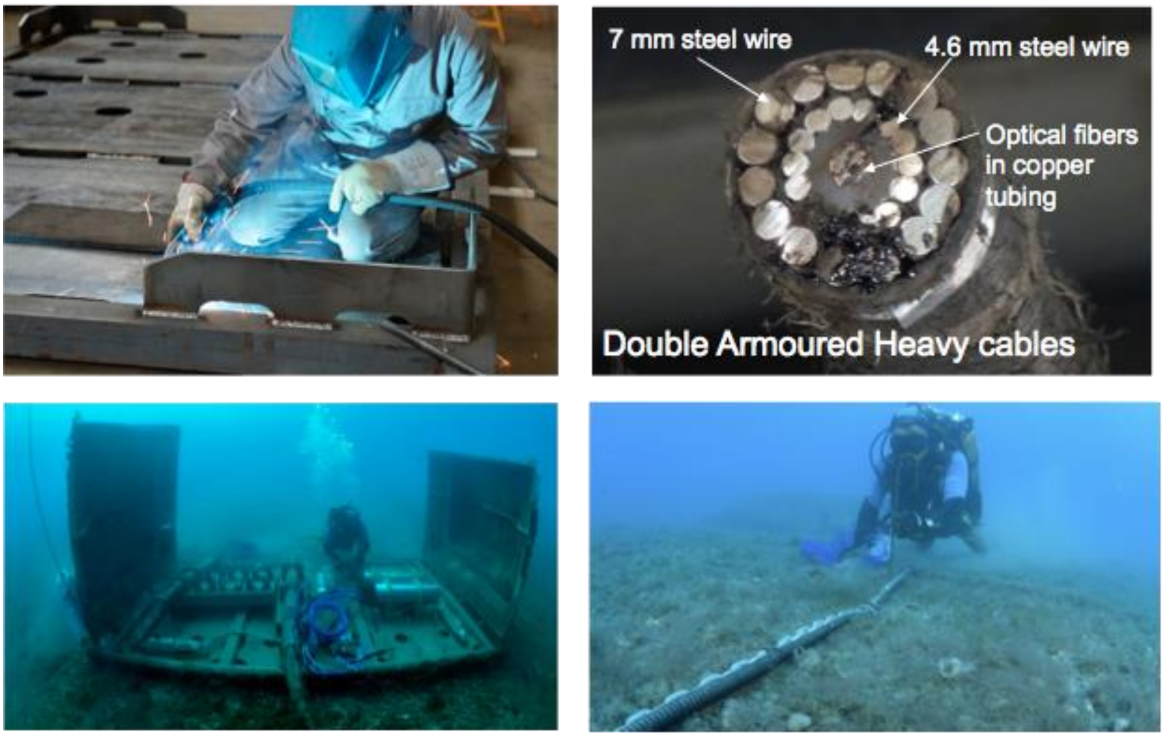


Figure 1. *Observatory with heavy frames as part of the design: weight more than 2 tons, heavy doubly - armored cables, plastic covers and corrugated flexible tubing and chains for the instrument cables.*

The land cable can be a source of big problems, arising from theft, sabotage or damage by external activities. The best approach to avoid cable theft or sabotage in the land section is to bury the cable beneath a public road or path if possible. Installations onshore are also vulnerable to adverse weather conditions. EMSO-Molène, which is installed on the coast of a small island, is especially exposed. This system encountered numerous power shutdowns, and a long power failure when a storm blew away the connection to the main power grid. OBSEA's land cable was cut by thieves looking for copper, and the optical fiber cable was severed by rodents. Thus, the shore-stations (where the shore-based cable-end equipment is installed) are highly vulnerable, and need to be inspected regularly. Another important issue for the land-end of the signal/power cables is their protection against lightning. The Utö observatory experienced damage to instruments by lightning before installing appropriate components for protection. For observatories in locations subject to heavy weather conditions, ice and wave protection on the shore are also recommended. In the case of the Utö observatory, the cables were run through a 40 m - long conduit drilled 10 m below ground in order to protect them. In the case of the AWI Svalbard Observatory, the heavily armored subsea cable was doubly protected by additional PE-tubing (wall thickness: 10 mm) to prevent damage by grounding icebergs.

A break or twist in the submarine cable is also a high risk (Figure 2). The Marine Institute has never experienced a submarine cable break in their SmartBay observatory. The inshore section of the cable is encased in protective shells from the shoreline out to a depth of about 10 m. The remainder is buried in the sediment to a minimum depth of 0.5 m. The cable was laid in an area not commonly used for mooring of vessels or bottom trawling/ dredging. On the other hand, although deployed in a marine protected area with its position notified to mariners, EMSO-Molène was severely damaged: the cable to the coast, lying on the rocky sea floor, was impaired in several places due to repetitive hooking during kelp harvesting. More recently, the seismometer connected to the EMSO-Nice observatory was displaced and damaged, most probably by a recreational fisherman. The OBSEA submarine cable (Figure 2) cover was damaged during maintenance due to the tension produced by the vessel attached to the cable at the surface. The cover was repaired to avoid a short circuit arising from contact with the water.

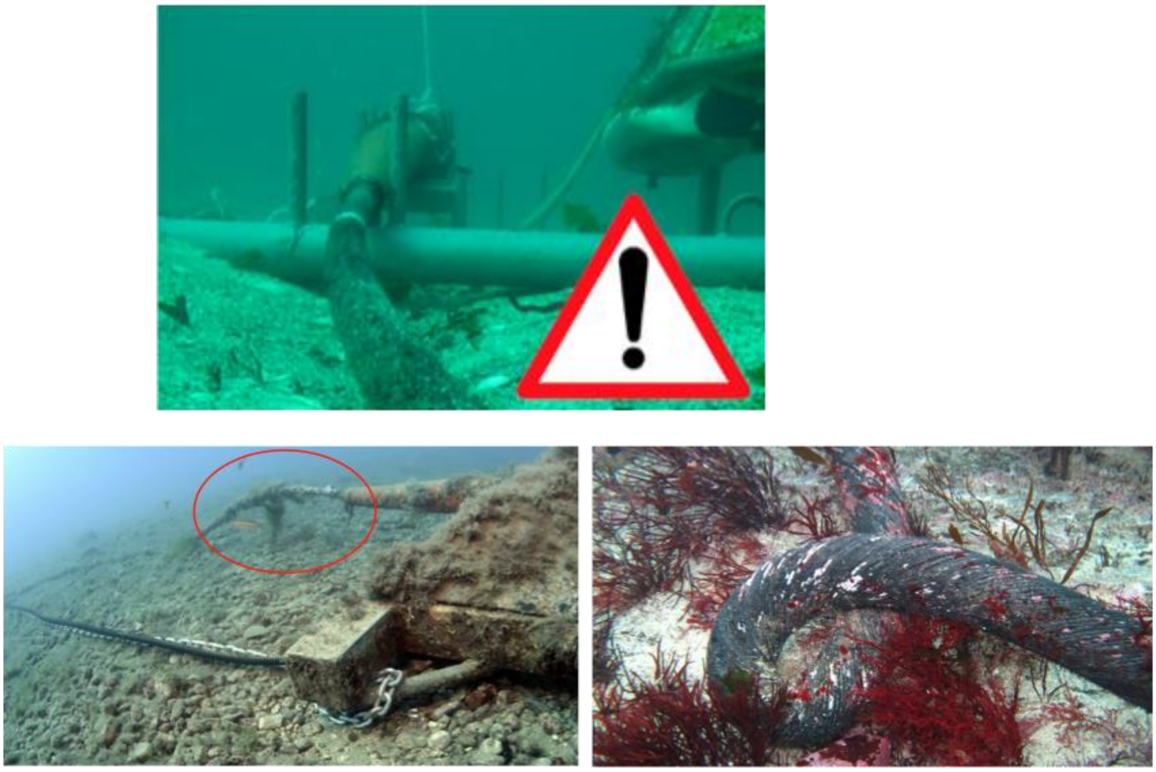


Figure 2. *Common cable laying problems: too much or too little tension and friction can generate twists in a cable; cable overlap must be avoided at all costs*.

Communication failures mainly occur as a result of an extended power outage or a power surge. For this reason, specific components have to be used to avoid problems due to voltage regulation or short circuits. For redundancy in the communications circuit, all communication lines - including the main Ethernet switch inside the junction box - should have built-in backups (2 to 3) in case one should fail. The use of industry - standard parts (if available), such as industrial power supply, network switching or network converter components, is always recommended (Figure 3) for the node hardware.

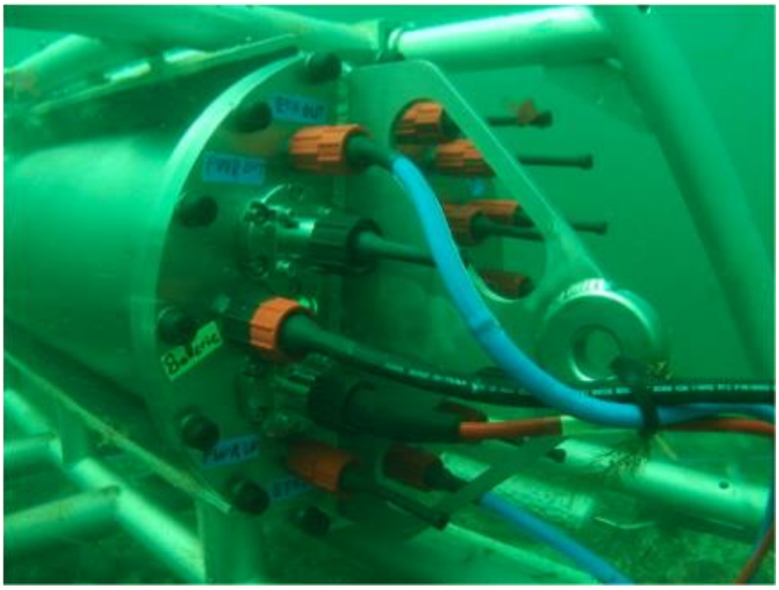
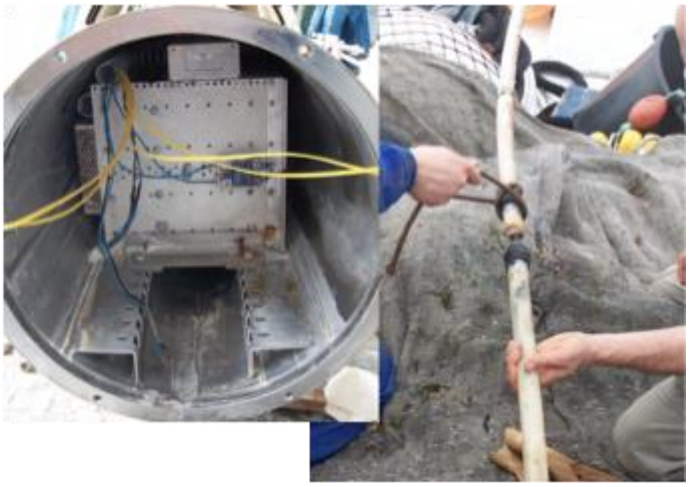


Figure 3. *Junction Box, with web-mateable connectors for attaching instruments*.

To avoid incidents and accidents to the marine infrastructure (e.g., Figure 4), a ‘no go’ zone marked out by cardinal marker buoys is recommended to limit unauthorized access such as mooring or anchoring in the vicinity of any of its elements. This is obviously the best way to protect the cables.



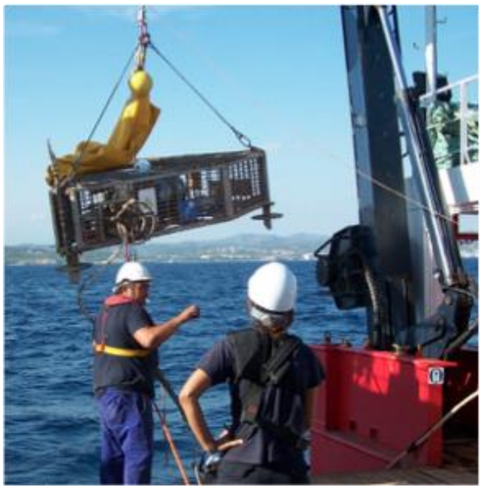


Figure 4. *On-board repair of the OBSEA submarine cable damaged during a maintenance operation of the junction box.*

The connection of surface buoys to seabed stations can be a source of cabling problems, from the perspectives of both the dynamic parts and the power delivery systems. A seabed station-to-buoy link should employ a mechanical fuse to ensure the disconnection of the cable to the surface buoy at a predetermined stress level. This protects both connected infrastructure elements, and limits any damage and the costs thereof in case of trouble. in general, surface buoy systems are more problematic when compared to subsea cables, and therefore should only be considered if the distance to land is too far to work with cables or the track being considered for the cable is difficult. Normally scaled surface buoys are usually not able to deliver sufficient power for the standard operation of subsea node systems, and therefore should not be considered as an option if it is possible to connect the node with a land station by means of a subsea cable.

When instruments are deployed away from the junction box, it is recommended that weighted lander frames be used to house the instruments. These lander frames can be moved and placed by divers using lift bags at various distances away from the main observatory frame. At the Marine Institute, all the instruments on the Observatory use at least 40 m - long cables so that instruments are recoverable at the surface by divers. For EMSO-Molene and Nice, the maximal distance for the placement of instruments is 150 m (serial link). The cables used are thin, reinforced with chains, and pinned to the seafloor at close intervals. The two seafloor stations are connected with an 800 m - long armored cable. At OBSEA, cabling of up to 100 m is used for Ethernet instruments. At the AWI observatories in Svalbard and the North Sea, 80 m - long cables are used for the Ethernet connections between the nodes and the satellite lander systems with sensors.

It is recommended that cables and connectors should be standardized across all cabled observatories. But, though the observatory-end and instrument-end connectors and bulkheads are often similar, there is a general lack of uniformity for cables and connectors among them. Cable and connector cost is generally a major factor when building observatories, and using economical cables is often a necessity.

Nevertheless, UQJ technology cables, which are easier to fix, should be the preferred choice. Finally, the phenomenon of leakage currents in seabed cables has to be taken into account as this can cause serious corrosion problems, even in the case of expensive underwater connectors manufactured specifically for underwater use (Figure 5).

Figure 5. *A Seacon hybrid (optical fiber + copper wire type) connector used at the Utö cabled observatory after nine months of deployment: the connector ring was badly damaged after a short period of use; being a hybrid connector, replacing or fixing it was not possible without sending the cable to the manufacturer*.

Although infrequent, a flooded junction box (JB) can be a source of big problems in a cabled observatory. The OBSEA JB was subjected to an inundation due to the corrosion of one of the instrument port connectors. Major parts of the electronic components inside the JB were damaged. The manufacturer fixed the instrument port connector, and a new set of electronic components was installed in the JB.

A few incidents at the AWI observatory also involved wet-pluggable cables/connectors. The principal source of trouble was the pluggable main power connector, which delivered up to 980 V to the node. The plugs used, officially rated to 1000 V, failed after only 3 months of operation even though all official handling instructions were followed. The analysis of the damaged plugs (Figure 6) revealed completely burnt (+) pins that had melted through the coating of the plug, allowing seawater to enter, causing massive short circuits.

When these failures were reported to the plug manufacturer, the response given was that they could only have been due to improper handling. Still, official tests finally revealed that the resistance between the individual pins significantly decreased when the power plugs were plugged underwater. This occurred independently of whether the plugs were greased according to the manufacturer's instructions or not. As a result, the types of plugs used in the high voltage segment of the node system were commuted to standard industrial ones.

Another development of the AWI node hardware following the plug failures and their effects on the system was a significant improvement in the housekeeping data for the underwater part. In the first node version in 2012, the only housekeeping data collected were the power supply to the ports, and the internal voltage and current during node operation. This turned out to be insufficient for troubleshooting purposes, and changes were made in order to obtain more detailed data on the system during its continuous (and mainly unsupervised) operation. Additionally, the system had no housekeeping sensors before and after the underwater connectors. As a result, failures in the node system could not be precisely located whilst underwater, leading to the need for an unscheduled recovery of all node components in order to perform repairs. Such sensors were therefore installed before and after all pluggable cables as a mitigating measure, so that it is now possible to determine the source of any error in the power supply system exactly. This has significantly reduced the downtime of the node system because emerging problems and errors in node operation can be either detected so early that an upcoming failure can be prevented or an existing problem can be solved much faster.

It is very important to remember to always add enough sacrificial anodes on all metal parts to prevent corrosion problems.

Figure 6. *A failed 1000 V-rated power plug, which was in operation carrying 800 V for 3 years in the North Sea*.

2. Operational issues

The distance to an observatory can affect operating practices. For example, the SmartBay observatory is located within the SmartBay test site, which is located approximately 17 Km west of Galway harbor. This proximity permits relatively quick access to the system by means of a rigid-hulled inflatable boat (RHIB). There are tidal slipways closer to the observatory, but these are not always useable. The OBSEA system is located just 4 Km offshore at Vilanova i la Geltrú. Reaching it by fast RHIB takes less than 15 minutes, allowing very rapid responses to on-site needs when required.

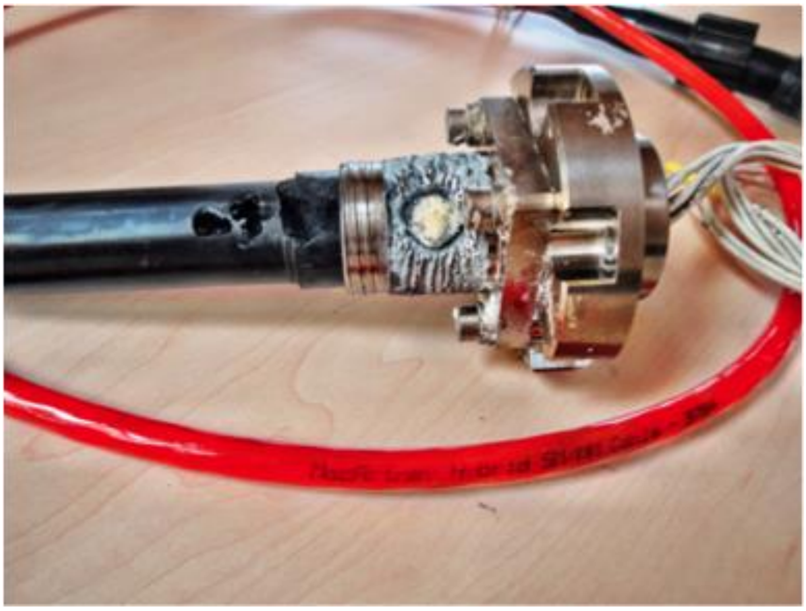


Figure 7a. *The deployment of the Utö cabled profiler in April 2018; a crane is required because of the total weight of the system (800 Kg) and its height (4 m).*

The availability of boats and divers to perform diving operations, and access to handling facilities, are also very important. All subsea maintenance work carried out at the SmartBay, OBSEA and AWI observatories involves divers. Based on the planned activities, this can include divers using both SCUBA and/or Surface Supply Breathing systems, and attention must be paid to dive times as these can be very limited depending on the depths where work has be carried out. Closeness of observatories to harbors, like in the case of SmartBay and OBSEA, often makes it easier to find small workboats and handling facilities (cranes, etc.) if these are needed.

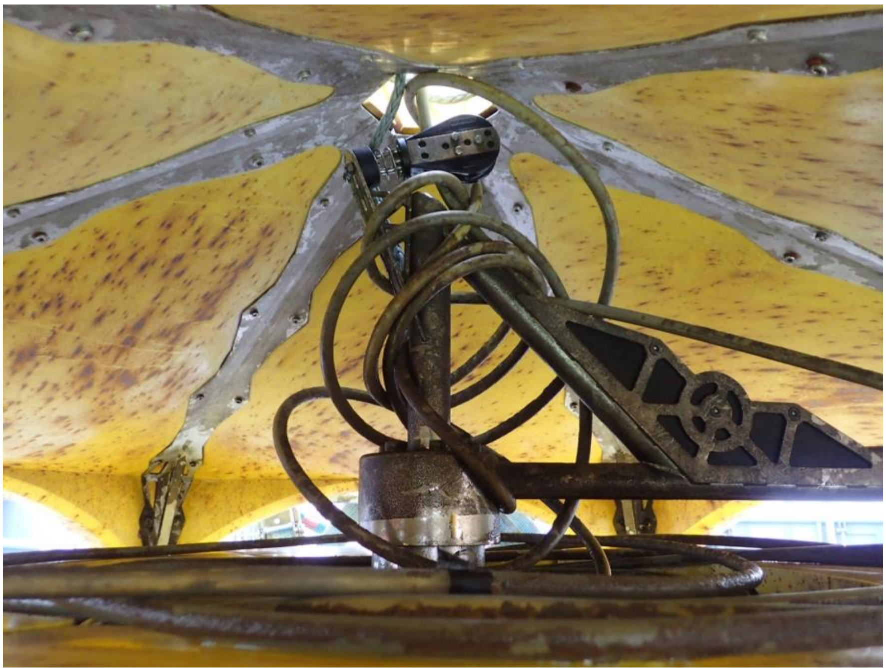


Figure 7b. *Entangled profiling system cable at Utö resulting from weather conditions which changed from calm to windy during a failed maintenance operation in August 2018; disentangling the cable required bringing it to the surface as the deployment depth of 76 m did not permit the use of divers*.

The frequency of instrument maintenance is strongly dependent on the type of sensor and also on the location of the observatory site, and the two aspects have to be dealt with separately. For example, at SmartBay, the dissolved oxygen sensor requires replacing and calibrating every 3 months or so to ensure accuracy. When planning maintenance for certain instruments, it is better to be proactive and replace/clean as many instruments as possible. At Utö, the maintenance frequency depends on two main operational issues: the weather, and the availability of a suitable vessel to reach the observatory. Figure 7a shows the deployment of the Utö cabled profiler in April 2018. After the instrument failed in August 2018 (Figure 7b), FMI, the observatory operator, attempted to get it working again twice without success, both times due to the in - situ weather conditions. Only the third attempt, in January 2019, was successful. In the period between August 2018 - January 2019, there were less than 10 days in total when the weather could have permitted instrument maintenance. During the first two attempts, FMI did not have a ship with DP (dynamic positioning) capabilities available, making it difficult to attain the accurate positioning (±10 m) that was required to restore the system. On the other hand, at OBSEA, divers usually visit the seabed station every month. This allows instruments to be cleaned or swapped for calibration more often, and with less trouble.

Figure 8. *Profiler recovery close to Utö in January 2019*.

Biofouling, sediment deposits, algae, etc. are all topics that have been addressed many times in the past, but they remain issues to be confronted. For SmartBay, biofouling is an ongoing concern, mainly with regard to potential damage and effects on data accuracy as some instruments can become clogged or impeded by organic growth. The MI, the SmartBay operator, combats biofouling on instruments through maintenance and cleaning of sensitive instruments every three months. All cable connections on the observatory and instruments prior to deployment are covered with heat shrink as standard practice as this prevents much of the biofouling which can occur. Other methods include the use of UV light in the vicinity of instruments prone to fouling, including the glass camera domes. At EMSO-Molene, and within the framework of the Jerico-Next Foulstop TNA (http://www.jerico-ri.eu/2019/01/29/fouling-protection-for-marine-optical-systems/) project at OBSEA,, the efficiency of micro-chlorination to avoid biofouling in optical sensors and video cameras was demonstrated. At the AWI observatory, biofouling is a major issue at the Helgoland site (Figures 9 and 10), especially during the short period when light returns after an arctic winter.

The maintenance of an observatory's sensors requires trained scientific divers who have experience working with the facility. At the AWI observatory in the North Sea, biofouling is a constant problem, and sensors need to be cleaned by divers every 2 - 3 weeks in winter and weekly in summer. Temperature and conductivity sensors are almost unaffected by biofouling, whilst chlorophyll, turbidity and oxygen sensors are heavily affected. If not cleaned properly, sensors can measure a diel rhythm in oxygen availability showing the production and consumption of the biofouling community rather than the oxygen content in the water. The same is true for chlorophyll (chlorophyll-*a*) sensors. In polar areas, biofouling is not a problem during the winter, but it becomes a significant one shortly afterwards when the light returns. Then, the biofouling is so strong that UV radiation, etc. have no chance to cope with growth rates, and only hard devices like wipers are effective. AWI developed wipers and other mechanical cleaning devices for several sensors, and established that these mechanical devices were by far the best option to really keep sensors free of biofouling. It, therefore, strongly recommends sensors with mechanical wipers instead of antifouling systems based on UV light.

Figure 9. *A node of the AWI observatory at Helgoland (North Sea) after 6 months in summer.*

Submersible probes and sensors are not designed for long-term exposure in shallow (productive) waters. Almost all sensors can handle short-term exposure (<1 month, and sometimes even just a few hours), not only with respect to biofouling (e.g. Figure 10) but also with respect to sensor stability and drift. Most sensors are designed for shipboard use so that the system can be calibrated daily, or at least compared to other similar sensors, between missions. However, as a rule, all sensors tend to drift with time. Furthermore, sensor manufacturers often do not supply clear performance specifications for their products, making it difficult to provide uncertainty information for measurements.

Figure 10. *A CTD probe at Helgoland (North Sea), after 6 month of exposure during summer.*

Another issue with sensors during their long-term operation in cabled observatories is the overall lack of modern communication procedures. Today, even the simplest IT equipment has fully automatic procedures and software for reconnecting automatically after a power shutdown or a connection loss. This is not yet the case for most marine sensors. Sensor developers need to innovate to smart sensor technologies - for example, by implementing self-repair mechanisms if the control software errs or fails, establishing reliable alerting functions in the event of contact failure, etc. Work done in applying the OGC PUCK standard and SWE protocols for the automation and self-identification of sensors has been demonstrated with different types of sensors and platforms in different research projects. The EMSO community is applying such standards in new developments like the EGIM (the EMSO Generic Instrument Module).

Accessing observatories is always weather-dependent, and usually difficult during winter periods, especially if the locations are covered by ice. At SmartBay and AWI, maintenance trips are scheduled on the basis of the weather as it can limit the ability to dive or reach the sites. A Datawell Waverider buoy or an ADCP in the vicinity of an observatory can provide some realtime wave and current data, which can help to determine on-site conditions. At SmartBay, there is also a CCTV system, which shows wave heights and weather conditions in-situ. At EMSO-Molène and AWI Helgoland, the stage of the tide must also be taken into account when operating with small boats near the coast. At SmartBay and at AWI, maintenance operations are quite cost-effective and responsive because a RHIB is available for quick access to observatory surface infrastructure, and a third-party dive team can be on-site within 24 hours, always depending on the weather, of course.

A summary of the operational risks for the AWI observatory nodes is given in Table 1.

Table 1. *A risk assessment matrix for the underwater nodes of the AWI observatory system in the southern North Sea and in the Arctic; the types of risks which led to complete or partial system failures in the period extending from 2012 to 2018 are shown.*

System compartment affected	**Type of failure in the underwater node system**	**Frequency of the failure**		**Duration of system shutdown in weeks**	
		North Sea	**Arctic**	**North Sea**	**Arctic**
Long distance sea cable connection (1000 V/400 V Helgoland; 400 V/240 V Spitzsbergen, and GBit fibreoptic connection)	External forces	once in 2018	multiple times until 2016	8	12
	Leakage	once in 2012	-	3	-
	Erroneous shutdown due to malfunctioning hardware or software	6-8 times from 2012 and 2013	2-3 times until 2015	<1	-
	Underwater mateable power plugs	multiple times per year	once in six years	8-12	12
Cable connection between node and sensor units (48 V and GBit copper lines)	External forces	3 times from 2012 to 2018	5 times from 2012 to 2018	1-2	8-12
	Leakage	-	-	-	-
	Erroneous shutdown due to malfunctioning hardware or software	-	-	-	-
	Underwater mateable power plugs	4-5 times from 2012 to 2018	once in 2014	2-4	12

3. Funding and finances

Sufficient technical staff with diverse skills (instruments, deployment, programming, etc.) are necessary for the operation of an underwater observatory. The people who build, maintain and run an observatory have to be highly qualified, and must have varied and extensive experience in all aspects of marine operations, ranging from marine electronics/engineering to marine geophysical surveying. This is important for smooth deployments and efficient operations.

Operating a cabled observatory requires significant funding if things go as expected, and a lot more funding if there are major problems. At Utö, the approximate annual costs for operating the cabled observatory (transport, ship time, servicing, and calibration) are on the order of 40,000 € per year. The depreciation cost of the equipment, assuming a 10-year operating time span, is approximately 40,000 € per year. Salaries amount to approximately 20,000 €, so the total annual running costs for the cabled observatory can be estimated as approximately 100,000 €, excluding the cost of scientific work related to data. However, in the case of Utö, the cabled observatory is just one system, and the total cost for the entire marine research station may be twice as much, or even three times higher if the atmospheric component is also considered. The salary costs are divided between a pool of specialists. For the cabled observatory, eight different people are needed in addition to the support from instrument manufacturers. Three of them are involved with deployment and installation operations, and one focuses on maintaining and calibrating the CTD and ADCP. Three more are responsible for the additional software and maintenance, and the coastal station and data, while one handles the maintenance and calibration of the bio-optical sensors used in the system. At AWI, the operating costs strongly depend on where the relevant observatory is located. The Helgoland observatory is close to the institute in an area where scientific divers are employed for other projects quite often. Therefore, the cleaning of the sensors or the installation of new sensors in this observatory can be combined with other jobs underwater. For the installation of new sensors, costs are estimated considering a five-day preparation phase and a two-day mounting phase. Consumables (including sensor calibration) account for about 15,000 € per year, and circa another 15,000 € are spent annually on repair and change of single parts (neglecting any related costs incurred for diving and ship time).

Obviously, estimating unexpected expenses like repairing severe damage is not a simple matter. Cable repairs can be especially long and expensive, and can cause the observatory to remain offline for many months.

Rough estimates of the operating costs of the different cabled observatories in JERICO-NEXT were presented in the JERICO-NEXT deliverable, D2.1, and can be accessed here: http://www.jerico-ri.eu/download/jerico-next-deliverables/JERICO-NEXT-Deliverable-2.1.pdf.

4. Clients, use and exploitation of data (academia, scientists, industry)

The data flow from instruments and the modes of access to acquired data are implemented differently at different observatories: at SmartBay, the MI provides observatory users with login details and virtual machines/servers, which are made available freely or privately depending on requirements. Both the node systems at AWI operate in a similar fashion to SmartBay, with servers hosting virtual machines.

Each user is provided with a virtual machine for the specific sensor/sensor unit, with full access to it and a limited amount of disk space for data storage. It is expected that the sensor owner does not use the server infrastructure as a long-term data repository, but only for temporary storage. AWI also ensures a comprehensive data flow from sensor to archive, so there is the possibility that a sensor owner can feed sensor data directly into its open-access near-real-time database, and then download the data from there (for examples, see: https://www.awi.de/en/science/biosciences/shelf-sea-system-ecology/main-research-focus/cosyna/underwater-node-spitsbergen.html or https://dashboard.awi.de/?dashboard=2847). In the case of OBSEA, a client usually has access to the raw data of an instrument, but not to the instrument itself or its port control. Data flow for the Utö system is currently being developed. However, while attaching new sensors to its profiler is not easy, the system does allow the integration of additional flow-through instruments and separate stand-alone devices.

Another lesson learnt from underwater observatory operations is that most scientists are not used to managing and verifying continuously acquired high frequency data (e.g. at 1 Hz). Currently, data management and validation procedures are still designed so that a scientist must assess the data manually, employing long and tedious visual inspections of plotted information. But, this way of operating is obviously unreasonable when a sensor or multiple sensors are online 24 hours a day, 365 days of the year. Despite recognizing the need for it, much remains to be done in the use of state-of-the-art data verification technology to automatically check data plausibility and validate data. There should be procedures for analyzing gaps and handling missing data. Integrated intelligent modeling techniques for sensor data prediction can be used to improve online data plausibility checking, and should be implemented, if possible.

Data verification and quality control are not standardized across the different observatories. SeaDataNet provides a guide for Data Quality Control procedures (https://www.seadatanet.org/Standards/Data-Quality-Control) for:

- Detecting missing mandatory information;
- Detecting errors made during transfer or reformatting;
- Detecting duplicates;
- Detecting outliers (spikes, out-of-range data, vertical instabilities. etc.);
- Attaching a quality flag to each numerical value in order to not modify the observed data.

The guide was developed reviewing a number of existing schemes (e.g. the NODC system, the WGMDM guidelines, the World Ocean Database, GTSPP, Argo, WOCE, QARTOD, ESEAS, SIMORC, etc.). At present, it contains QC methods for CTD (temperature and salinity), current meter (including ADCPs), wave and sea-level data. Activities are now underway for extending the guideline to cover surface underway data, nutrients, geophysical data, and biological data. At OBSEA, data is flagged following the SeaDataNet guidelines. At SmartBay, the data recorded by the Observatory goes through various QC processes. AWI uses the ARGO guidelines for plausibility checks, and additional procedures are applied to provide accuracy and precision information for other single parameters. Some of their data sets, such as those for chlorophyll and CO_2, are ground-truthed against information coming from the laboratory analysis of water samples collected in-situ.

5. Sharing of observatory space with external users

The choice of location will depend on the main objectives of the observatory: while some of the current observatories have a very specific scientific objective, others have a more general focus on testing. The SmartBay Observatory is located within a marine renewable energy test site which is demarcated to prevent unauthorized access, such as for anchoring or mooring, and monitored using 24 hr CCTV. This protects not only the floating/subsea infrastructure but also the public who may not be aware of the possible dangers beneath the surface. In the case of the EMSO-Nice Observatory (Ifremer), the Nice airport regulations have to be taken into account (Figure 11) because the observatory is situated offshore, adjacent to the airport. The shore station equipment and power/communications systems benefit from the airport infrastructure, but access for installation and maintenance is regulated by airport rules (use of badges, specific training requirements, supervision, etc.). The Molène Observatory (Ifremer) is mainly affected by public transit, but this freedom is an advantage, particularly when moving material for observatory operations using small boats. OBSEA is located in a Marine Protected Area signaled by 4 surface buoys delimiting the seafloor station, but it is close to the recreational and fishing harbor. This causes some problems, and once, a big collision between a boat and the surface buoy caused serious damage to the infrastructure.

Figure 11. *Access to the EMSO-Nice Observatory depends on the Nice airport regulations; Scuba divers on-site, and work being done on the land cable at the airport*.

Obviously, for a science-oriented observatory, the site will be defined by the research questions which are being addressed. However, such an observatory is sustainable only if the acquired data are shown to be scientifically important in the long-term. AWI's Spitzbergen Observatory is an example. There is a great willingness to pay for this observatory even though it is much more expensive than the other observatories run by the Institute simply because the data are deemed to be scientifically much more interesting.

Costs of third-party insurance for the sites and observatories have also to be taken into account. The SmartBay infrastructure is self-insured as the owners and operators are the MI and a state agency. In the case of OBSEA, as the owner and operator is a public university, the general insurance policy of the University also covers the specific insurance needs of the observatory.

6. Discussion

From the perspective of the technology underlying the underwater nodes of currently running cabled coastal observatories (the submerged terminal end of the sea-cable, where the sensors are installed and operated), the main operational challenges are not, contrary to common assumptions, the remote control of highly complex and partially interacting sensors. IT technology permitting the remote control of systems and devices has seen use in many applications on land for more than a decade. A common example is power management in skyscrapers, where extensive automatic systems switch lights on and off on the different floors and in different rooms, register the power consumption and activate safety procedures in case of an emergency. Compared to this, an underwater node is nothing more than a simple plug for power and network connections. The essential difference between the skyscraper and the underwater node is that the underwater node is operated in seawater. This sounds trivial considering the volume of sensor equipment commercially available for underwater use, e.g. on ship hulls, etc. One major difference between the operation of similar sensors on a ship and in a cabled observatory is that a user has no physical access to the systems for extended periods of times in the latter case. This means that it is not possible to check standard control functions (like a simple LED lamp which blinks to indicate a failure of some kind) or simply cut off power from a sensor if there is a block in communications, or perform a sensor or communications relay reset manually (e.g. by pushing a small button or switching a system off and on with a magnetic stick). Such functions are part of normal IT routines but impracticable underwater. This is an important consideration when constructing any submerged elements of a cabled observatory.

Many times, the activities carried out by the cabled observatories have to be presented and explained to regional and national stakeholders in order to strengthen the relationships between administrations and institutions (Figure 12). This is essential to align the research objectives of the infrastructures with long-term societal goals, and find science-supported solutions to key policy requirements when these are required.

Previous work on coastal observatories provides more recommendations, like the following ones from the National Science Foundation (NSF) [1].

- A comprehensive seafloor observatory program should include both cabled and moored-buoy systems. Moored-buoy systems should include both relatively high-power, high-bandwidth buoys and simpler, lower-power, limited-bandwidth buoys.
- The first step in establishing a seafloor observatory system should be the development of a detailed, comprehensive program and project implementation plan, with review by knowledgeable, independent experts.
- Program management should strive to incorporate the best features of previous and current large programs in the earth, ocean, and planetary sciences.
- A phased implementation strategy should be developed, with adequate prototyping and testing, before deployment of seafloor observatories on a large scale because of the cost, complexity, and technical challenges associated with the establishment of these systems.
- A seafloor observatory program should include funding for three essential elements: basic observatory infrastructure, development of new sensor and AUV technology, and scientific research using seafloor observatory data.
- New mechanisms should be developed for the evaluation and funding of science proposals requiring sustained time-series observations over many years or decades and for proposals that are highly interdisciplinary.
- A mechanism should be developed to transition successful instrumentation developed by an individual scientist to a community asset
- An active public outreach and education program should be a high-priority component of a seafloor observatory program, with a specified percentage of program funding dedicated to this effort.
- A seafloor observatory program should have an open data policy, and resources should be committed to support information centers for archiving observatory data, generating useable data products, and disseminating information to the general public.
- The vision of establishing a global network of seafloor observatories holds tremendous promise for advancing our understanding of Earth and its oceans.

Figure 12. *Stakeholder involvement: four members of the Finnish Parliament getting familiar with the flow-through system at the Utö Atmospheric and Marine Research Station*.

B) What are the operational issues that need improvement most urgently?

This chapter consists of discussions on the following topics:

1. Maintenance of hardware (biofouling), and maintenance protocols.
2. Power failures, interferences, and failures in communications.
3. Deployment of new instruments.
4. Data management/data quality checks.
5. Data handling and quality control.
6. Data access; Do not forget the "standard" biological scientist!
7. Use of third-party vessels and divers.
8. Observatory documentation - cabling, connectors and their standardization.

1. Maintenance of hardware (biofouling), and maintenance protocols

Each observatory applies its own maintenance protocols, depending on the characteristics of the site: in the case of SmartBay, the instruments are swapped en masse with clean and calibrated instruments. This task requires divers and a suitable vessel. The observatory frame is cleaned only when recovered (Figure 13a). Camera cleaning takes place if the camera dome shows growth present.

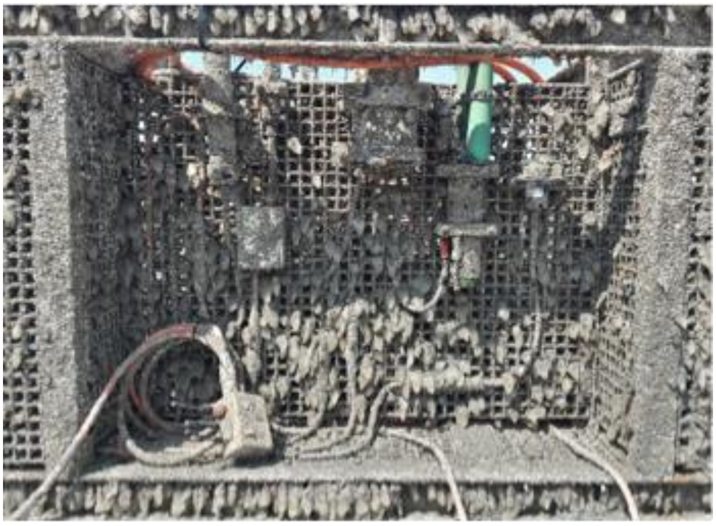


Figure 13a. *SmartBay: set of instruments covered by biofouling*.

At the Utö observatory, the main sensors are parked underwater below the biologically active layer, at around 50 m of depth, between profiles (every 3 hours). So, the amount of biofouling they are subject to is limited However, the sensors close to the sea surface, located at about 5 m, are seriously affected (Figure 13b).

Figure 13b. *An example of biofouling on an instrument deployed at a depth of 5 m at Utö; a copper wiper is necessary to keep the optical window clean*.

At OBSEA, the maintenance of instruments does not follow a strict schedule, and is performed on the basis of the results of visual inspections of the states of each specific sensor. Most of the routine cleaning of equipment like the submersible camera, optical sensors, current meter, etc. is done underwater by divers. Once or twice a year, sensors are taken to the laboratory for more intensive cleaning.

All the coastal cabled observatories considered in this document report the need for the following:

- better and more reliable mechanical cleaning devices for sensors;
- better underwater plugs;
- better housekeeping strategies for the parts of the infrastructure lying underwater.

As weather can be a limiting factor, many instrument swap-outs tend to occur during the same maintenance interval, with instruments that require more frequent swaps taking precedence. During operations, more robust instruments, which may not need immediate replacement, are often worked on first to increase efficiency. It is recommended, if possible and taking into account budget limitations, to have two sets of identical sensors available, and exchange them regularly.

Figure 13c. *The cleaning of the underwater camera dome by divers at OBSEA.*

Some specific devices like cameras require frequent cleaning (Figure 13c). This is often always done in conjunction with other operations. For flat surfaces, a new promising anti-fouling strip developed by Nitto Denko Corporation and commercialized by Nortek [2-4] was tested at OBSEA, and is giving excellent results. Figure 14 shows similar strips partially covering 3 of the 4 active transducers of an ADCP. The strips were fixed in a circular fashion along the circumferences of the transducers, which displayed no signs of biofouling in the period the instrument was deployed; also, no variations in the general performance of the ADCP were noted.

Figure 14. *New promising anti-fouling strips tested at the OBSEA Observatory, developed by Nitto Denko Corporation and commercialized by Nortek*.

For hydrophones, CTDs, ADCPs, and seismometers, a visual inspection is recommended periodically, or as often as required, due to calibration-related issues. The ADCP is the most reliable, even without regular cleaning. CTDs may need more frequent cleaning: at AWI, the CTD is cleaned every 14 days. If cleaning or maintenance cannot be performed underwater, the instrument or sensor should be swapped with a new unit.

A sacrificial galvanic anode is the main component of a galvanic cathodic protection (CP) system, used to protect buried or submerged metal structures from corrosion. Such anodes have to be installed in observatories to prevent or slow the corrosion of its metallic elements. Three metals are mainly used for galvanic anodes: magnesium, aluminum and zinc. They are all available as blocks, rods, plates or extruded ribbons. Each metal has its advantages and disadvantages.

Sacrificial anodes have to be visually inspected periodically to ensure their replacement before they are fully exhausted. At SmartBay and OBSEA, this task is carried out in conjunction with other operations. AWI substitutes the sacrificial anodes of its observatory nodes every 6 months.

Other mechanical and metallic parts of an observatory like buoy chains, anchors, etc. must also be visually inspected regularly (Figure 15). It is recommended that chains and moorings, along with their sacrificial anodes, be checked at least twice yearly for reduction in their dimensions due to corrosion.

Figure 15. *Chains require periodic visual inspections to control corrosion*.

Sensor calibration depends on the type of measurement and the device: some observatories perform calibration as required while others perform them periodically, usually once a year. Calibration is performed in-house sometimes, by specialized laboratories, or directly by the manufacturer.

Since most sensors are not designed for long-term use in shallow (productive) waters, the MI carried out some in-house modifications on instruments to enhance their durability in the SmartBay Observatory. This is still a general problem, however, and many instruments are not tested for use in long-term shallow water deployments. There is a need for innovative sensor designs, and cabled observatories are the best environments for realizing them. Some innovations are already being experimented out of necessity: new, fully automated maintenance routines for sensors such as underwater self-calibration procedures are an example. This is necessary to ensure reliable data.

A hostile operating environment means continuous maintenance, and this implies manpower and money. The development of standard operating procedures for observatories will help to rationalize and optimize the labor and the costs invested in them. This is something the cabled coastal observatory community has to work on still.

Since the cost of maintaining an operational infrastructure is very high, holes in data have to be avoided. In the case of Utö, the profiler is planned to be recovered every year or every two years, depending on the experience that will be gained in its use. The CTD can be substituted at the surface when needed, and a second CTD has been purchased for this purpose. Similarly, a second ADCP is also available to replace the one deployed, so as to avoid breaks in the continuity of current data and permit the maintenance of the recovered unit at the FMI technical facility. At AWI, the new- generation landers, which are in the process of being designed and manufactured within the next 6 months, are remote-controlled profiling units that can be brought to the surface where sensors can be cleaned or changed even by swimmers using only snorkeling equipment. All these are good techniques that help to minimize costs during maintenance.

2. **Power failures, interferences, and failures in communications**

Electrical noise due to conducted interference between instruments and/or from the main power supply can be an issue. At SmartBay, some interferences were identified over the past years, and filters were incorporated into the hydrophone systems to solve the problem. At Utö, some problems with noise on signal cables were detected, and the cable was changed to a hybrid one. However, it turned out that the connectors had corroded, and the cable was changed again to a twisted-pair type with plastic connectors. At OBSEA, some interference problems were detected when acoustic modems were used. The reception/transmission quality was affected due to power supply interferences between instruments. The use of high performance isolated voltage converters with filters can minimize such problems. At AWI, no real problems with interferences were detected.

Hydrophones used at cabled observatories can suffer from interferences, but this is often mainly caused by an improper power supply (unfiltered phantom power supply). Due to the common use of DC voltage in cabled observatories, the main sources of interference can be traced to pulsed consumption of instruments or to the use of unfiltered, switched DC/DC converters.

Power failures are always a possibility at a cabled observatory. Therefore, the design of the system must minimize the risk associated with them, and seek to mitigate any possible damage that could result if they do occur. In this context, having a backup power supply, a modular power supply or electrogen systems in place can minimize the risk of losing control. At OBSEA, the main voltage can be configured by connecting small 30VDC power supply units in series to supply up to 330VDC, and an uninterruptible power source (UPS) serves as a backup if main power is lost. No power-related problems have been noted at Utö, where a 240 VDC power supply is being used at the moment. AWI works with 1000 VDC to cover distances of up to 30 Km from land, and has never had problems with the cable itself although they have encountered significant problems with the underwater plugs.

3. **Deployment of new instruments**

To deploy new systems, well-known procedures are required to ensure problem-free connections underwater. In the case of OBSEA, instruments are connected to a replica of the observatory’s junction box in the laboratory and tested thoroughly before being taken to the real junction box underwater to make sure that power consumption, electrical interfaces, communications, and instrument control and data transfer processes are as they should be. All the instruments are also tested in a hyperbaric chamber (Figure 16) to detect possible water intrusions and mechanical problems at high pressure. At SmartBay, new instruments awaiting deployment are first tested on a test rig. In this way, full operational testing, including software interfacing, can be performed to verify system integrity prior to actual deployment. At Utö, the system does not allow the connection of new sensors to the profiler. However, it does allow the addition of flow-through instruments and deployment of separate stand-alone devices. The AWI systems can be split up underwater into separate units, which can each then be recovered by a crane with a lifting capacity of 200 Kg.

Figure 16. *OBSEA's hyperbaric chamber for testing instruments before deployment*.

4. Data management/data quality checks

At any cabled observatory, data transfer, even via the Internet, is never fully reliable under the real conditions of continuous online operation. The French cabled observatories have a data server in the shore stations where data are stored before being periodically harvested automatically. Generally speaking, not all the data can be transmitted in real time (either because the sensor is not connected or because the bandwidth is insufficient), and so there is also the recovery of data in delayed-mode to manage.

All the real-time or near-real-time data acquired by the Smartbay Observatory (http://smartbay.marine.ie) is openly accessible (http://smartbay.marine.ie/data/). In the case of OBSEA, both real-time and archived data can be accessed through the OBSEA web site or through some international repositories like EMODnet.

Almost always, the data are those coming from the instruments and sensors making the "scientific" measurements, and never those relating to sensor/instrument and/or platform management. When new instruments have to be connected or instruments have to be reconfigured or stopped, everything is still done manually at all the observatories referred to in this document. Employed data transfer routines and protocols have no self-connecting procedures, no self-repair mechanisms and no reliable alert functions in case of connection failures. There is also a strong need to implement new smart sensor techniques for marine sensors; some standards like OGC-PUCK and OGC-SWE have been successfully tested by different institutions like UPC and Ifremer among others, but they are still not widely adopted.

The SmartBay Observatory uses an in-house open-source data acquisition and alert system which signals any failures in data capture. The dashboard is a simple HTML page that displays the status of the system using Red-Amber-Green flagging. An unexpected red marker instructs the user to investigate an underlying problem. Each marker refers to a particular service (an application) or a server, and indicates the status of that service/server from the perspective of the web browser. If the browser cannot connect to the service/server for any reason, it will mark it as unavailable. When connected to the server/service, the marker will be green if the monitored server/service respects a predefined threshold (e.g. time since last update), otherwise it will show as amber or red. If a problem is signaled, there is a link which accompanies the marker that can be useful in helping to diagnose its nature.

Finally, at the present time, getting an offline sensor online again, even after only a small change in system configuration or the substitution of some of its components, remains a prevalently manual undertaking. Therefore, new technological solutions have to be developed and implemented for auto-configuring probes and data transfer protocols. Currently, each observatory is trying to do this independently. At Utö, the operation is accomplished through a server running a combination of proprietary software (from the profiler and the CTD manufacturers) and Python 3.0 scripts developed in-house by FMI. AWI has installed a sensor control system that checks the data availability every 20 seconds. If the data are older than a specified time-span, which is selectable, alerts are sent by e-mail - the first one immediately, followed by others at 6 hour intervals until the problem is solved. All the acquired data are subjected to ARGO plausibility tests, and quality checks with flagging routines.

5. Data handling and quality control

Data handling and verification procedures at cabled observatories are often not designed for unsupervised data processing. The Coriolis data service, where some of the cabled observatories feed data, provides quality-controlled in-situ data in real-time and delayed modes. The managed data sets are mainly T-S profiles and time series from profiling floats, XBTs, thermosalinographs, and drifting and moored buoys. Coriolis is progressively integrating other parameters such as sea level from European realtime tide gauges and ecosystem variables (e.g., oxygen, chlorophyll and nutrients) from ferryboxes, moorings and gliders (http://www.coriolis.eu.org/Data-Products). Data handling and verification procedures are THE top topic at almost all the cabled observatories. AWI, for example, has some procedures in place but they are not sufficient by far. Modelling and state-of-the-art smart monitoring techniques must be included to improve data quality. For example, in many observatories, there are multiple sensors for temperature or salinity but no cross-checking of any kind is performed. Drifting sensors can often be identified by similar cross-checking or modelling and forecasting procedures to calculate expected values which can then be compared to observed values. The state-of-the-art data handling procedures (flagging) need to be improved. Managing and archiving the metadata is also of major importance to ensure reusable data, and there is much to done as regards this aspect, too. Data services should work in close association with scientific teams to define procedures for data validation, quality control, formats and products. Data and metadata must be stored in a way that makes it easy for a normal user to access and work with them.

Data handling and verification procedures are still based on a manually supervised data control system model: the capabilities of online sensor technology to countercheck data against other probes and forecasting methods for online sensor control are not being exploited yet.

Providing information on the accuracy and precision for data points is really important. AWI has worked on this topic, and has developed methods for providing accuracy and precision values for each single measurement of a parameter when multiple sensors are monitoring it in a specific area. The data generated by its Svalbard observatory from 2012 to 2018 is archived in the "PANGAEA" information system, from where full datasets for the main hydrographic parameters that include accuracy and precision values can be downloaded (https://www.pangaea.de/?q=awipev+underwater+observatory+svalbard).

The complete data sets from 10 years of activity of the OBSEA Observatory can also be accessed and downloaded from PANGAEA at the following links:

- for meteorological data, https://doi.pangaea.de/10.1594/PANGAEA.903050;
- For CTD data, https://doi.pangaea.de/10.1594/PANGAEA.902215.

The data sets are assigned unique identifiers (DOIs), which facilitates their subsequent use in a way that recognizes the contribution of the data originators.

More intelligent data control and data verification procedures are needed to achieve greater data quality. Some tools like Zabbix can help to provide fast views of data. This open-source tool provides an easy way to configure and present graphical views integrating oceanographic and engineering data. It is important to be able to easily create dashboards for the real-time data gathered by observatories in order to be able to take quick looks at the data to follow their temporal trend. These dashboards must be configurable with a few clicks, and should be public so that different persons can see the data and provide feedback. In addition to open source tools like Zabbix, AWI's dashboard for the Svalbard or Helgoland observatories can be accessed here: https://www.awi.de/en/science/biosciences/shelf-sea-system-ecology/main-research-focus/cosyna.html.
The SmartBay (http://smartbay.marine.ie/) and the OBSEA (https://obsea.es/dashboard) dashboards are other examples.

AWI's experience in JERICO-NEXT is that the dashboard feature is really important when hosting sensors belonging to external users in their observatories because it allows such users to monitor how their instruments are performing in real-time.

6. Accessing data: do not forget the "standard" biological scientist!

This small section is to highlight the results of a very interesting survey that was carried out by AWI among a group of scientists who were potential users of its cabled observatories:

- 70% of the biologists were not able to use R or Matlab;
- 90% of the biologists were not prepared/trained to use NETcdf, JSON, XML, etc.;
- 90% of the scientists used Excel and standard computational programs.

These results highlight the importance of always keeping in mind how end users will be needing their data formatted!

7. Use of third-party vessels and divers

On-site operations require vessels and divers. SmartBay is in the middle of a public procurement process to engage both third-party vessels and divers to serve their needs. They also have two National Research Vessels available sometimes for deployment/maintenance/recovery operations. The divers they are looking for need to have prior experience with, and an understanding of, an observatory so as to be able to work to their full potential.

Weather is the main limiting factor from the standpoint of operations. AWI has a standing diving team trained in working on their observatories, with boats at Helgoland. The divers are all active scientists, involved in projects closely tied to the observatories themselves or specifically hired for their recognized competencies. The team is often augmented by Bachelor/Master-level students with training as scientific divers, who are then assigned small projects around the observatories. Like AWI, UPC's OBSEA engineers are also experienced scientific divers.

8. Observatory documentation - cabling, connectors and their standardization

Since the EU's FP6 ESONET (European Sea Observatory NETwork) Network of Excellence (NoE) project, many attempts have been made to standardize cabling and connector technologies in the field of marine observing, though without any great success yet. At OBSEA, the standard instrument port cable uses a GISMA series 10 - size 3 and a Seacon MCIL8F connector, but some instruments require special modifications to ensure compatibility. EMSO-Molène and EMSO-Nice offer ports with Micro 12 Contacts and MCBH12M connectors (which is the standard for the EMSO nodes). At SmartBay, the end connectors are from Teledyne (specifically, Teledyne Impulse MHDXL-12-CCR Ti UT connectors). Then, regarding the connections to the various instruments, whips are made for this purpose as required.

Serial links are hardware interfaces used by marine instruments. Ethernet or serial interfaces are the ones most commonly used for the instrument port at all the observatories mentioned in this document. The serial interfaces are converted to IP using serial to Ethernet converters in order to integrate all data traffic into the Ethernet layer. The serial interfaces are hosted on serial servers within the CEE (Control Execution Environment) to allow terminal control from shore via IP. SmartBay and OBSEA use "MOXA - Industrial RS-232/422/485 to fiber" or Ethernet converters. The SmartBay Observatory also works with HD video. The video signals are sent uncompressed over a dedicated CWDM (Coarse Wavelength Division Multiplexing) channel that reaches the Shore Station via a coaxial connector. A Lynx OH-TR-4-1570 SDI optical transceiver facilitates the conversion of the electrical SDI signal into an optical signal for transmission over fiber, and vice versa. It is used together with a Transmode MDUC04 CWDM Multiplexer/DeMultiplexer.

The CEE primary optical communications path has a backup: a secondary communications path, which is an exact replica. This replicate path provides the same connectivity as the primary one for all the services. All of the network's equipment can be remotely managed through either the primary or the secondary path. The external and internal connections in an observatory's CEE are optically isolated to minimize the effect of a short circuit in the event of a cascading system failure.

The control system usually links to a management system via an Ethernet communications network. Internal microprocessors inside the Junction Box manage electronics for switching and measurements, and perform local management. A step-down system is in place for each port to step down from high DC (1000 VDC, 400 VDC, 300 VDC) to low DC (12 VDC, 24 VDC, 48 VDC) voltages. Each port has a specific power card to control the output. All outputs are hardwired into the power cards.

C) How to decrease access costs while maximizing availability of coastal-cabled observatories?

Some considerations can be made on how to decrease the access costs to a cabled observatory while maximizing its availability. Most of them are very important to take into account during the observatory's design phase. Others are proposals to be implemented during normal operations. A list of the considerations follows.

1. Flexible platform.
2. Reuse of cables, connectors & cases.
3. Easy integration of instruments and systems.
4. Fast response to minimize time to deployment for instruments and systems.
5. Minimization of the full infrastructure cost.

6. Low-cost design and deployment plans.
7. When data flows and QA/QC processes are streamlined, collected data can be used without extra effort => support for other projects.
8. Annual, scheduled maintenance.
9. When standard operating processes are streamlined, less manpower is needed.
10. Co-funding model: applied research projects already funded or for funding.
11. Funding priority for projects with a strict open access data policy.
12. Sharing of calibration actions.
13. Sharing of cost-effective, proven developments (e.g., the Junction Box and Node).
14. Sharing of installations with other activities, not always cheaper but definitely safer (IT-dedicated area, EMR installations, JTF smart cables).
15. Central management facility.

The design of a multi-purpose, multi-use observatory is very important. The capability of an observatory to host many projects, different environmental sensors, different experiments, ocean energy devices, communications, etc. can attract different sectors and users. This can help in the implementation of a co-funding model: applied research projects already funded or for funding.

The design phase is a challenge and one of most important phases: a robust design will reduce the risk of failure. To add redundancy in critical areas like power supplies, communication links, etc. is less expensive if it is dealt with during the design phase. The cost to repair a Junction Box due to a failure in communications or power supply will be much greater than the cost incurred in implementing redundant systems for these functions inside it.

As commented previously, technical standardization among observatories and a common catalogue of spare parts for the community would also be a major step forward. Therefore, the “JERICO Label” should take into account any recommendations to promote such a step.

Finding a clever balance for the investment costs of an observatory is also important. A compromise between performance and cost is important. For example, the use of wet-mateable connectors with OF capacity is expensive. They cost about 60 K€ each, while the price of a pure electrical wet-mateable connector is on the order of 10 K€. The price of the cable is an important part of the cost of an observatory, too. Thus, it is important to consider the costs of fixing or manipulating it in future operations, should the necessity arise.

Operational activities like maintenance, calibration (in-situ, if possible), etc. have to be taken into account in the design phase to minimize costs during the operational phase. Including antifouling solutions, even expensive ones, can decrease operating costs because intervals between maintenance visits can then be safely prolonged. Tests in the laboratory have to be very well-documented to guarantee success in the field. Basic choices can be critical. For example, at Utö, using copper cables which can be fixed on-site could have been a better option instead of optical fiber systems; selecting a hybrid system was probably the wrong choice. Furthermore, the profiler system there is quite special, and it is not easy to install new sensors on it without maintenance by the manufacturer. However, the flow-through system at the site allows the addition of new sensors with minor costs. Stand-alone instrument deployments are also relatively easy, though this depends on the weight of the instrument: if it is less than 50 Kg, the cost is less than 1000 €, otherwise, a ship with a crane is needed and the costs may be ~5000 €. However, the costs are smaller if the deployment can be carried out during the annual maintenance trip when a ship with a crane is available.

For some observatories like OBSEA or SmartBay with a high yearly rotation of different sensors, reusing cables, connectors and cases is very important. A mechanical workshop with people experienced in preparing cables and connectors for interfacing instruments with the Junction Box will decrease costs by reducing the need for purchasing fresh cables or connectors for each new deployment. Doing such work in-house, when possible, is cheaper than sending cables to connector manufacturers to perform the necessary connections (cable-to-connector).

Conducting periodic intercomparison activities between observatories would be useful to help establish best practices for deployment and instrument calibration. Open documentation on hardware (connectors and cables) would also be recommendable.

Some substantial costs like those for divers, ships, spare instruments etc. are fixed and therefore difficult to reduce, though a good management plan can help to rationalize and optimize similar expenses.

4. Conclusions

The harmonization of technologies, methodologies and procedures is a vital step in ensuring efficiency and optimal returns from any kind of distributed, heterogeneous, multifaceted, coastal observing infrastructure operating on a transnational level such as the JERICO network. This is because such harmonization leads to an intelligent use of resources across the network, adds to the consistency of its services and products, and helps to provide uniformed access modes and interfaces to users.

5. References

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