ID2- RECENT TECHNICAL INNOVATIONS AROUND HF RADAR TECHNOLOGY AND STEPS TOWARDS INTEGRATED NATIONAL HF RADAR NETWORKS

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Abstract *– HF Radar is a proven technology for ocean observing that has at present more than 600 references in the world and which is since April 2016 in application on all continents for the purpose of 2D surface currents and waves monitoring. This has only been possible 44 years after its first implementation in 1972 in San Clemente Island in California, thanks to the permanent evolution of the radar technology with key achievements such as the present unique system compactness and its capability to make a very efficient use of the radio spectrum. This paper firstly presents some of the latest technical innovations around HF radar technology that are making the technology even more reliable, accurate and useful such as the new Automatic Antenna Pattern Generation solution based on AIS vessel positions and the implementation of new added value trajectory models forced by HF Radar surface currents able to accurately predict oil spill transport and movement of particles on the sea or persons adrift. Secondly, we present current plans existing in the Iberian Peninsula HF Radar network to integrate HF Radar technology as an operational component of a national tsunami early warning system. Finally, the advanced HF Radar system implemented by the Direction de la Météorologie Nationale du Royaume du Maroc is presented; one of the latest deployed systems and the first permanent system operating in Africa.*

Keywords *– Ocean observing, HF Radar, currents velocity, waves, tsunami detection*

1. INTRODUCTION

HF Radar is today one essential component in many ocean observing systems of the most advanced institutions around the globe with more than 600 stations operating in 50 countries for the remote real-time surface current mapping and wave monitoring with ranges of up to 200 km from the coast. SeaSondes are operating now continuously on all continents; this milestone was reached in April 2016 when the Moroccan Met Office has started the operation of the first HF Radars in Africa. Before that, in January 2014 SeaSonde HF Radars were installed by Rutgers University and Alaska Fairbanks University in Antarctica to investigate the impact of local coastal physical processes and the impact of climate change in a highly under-sampled area.

2. ESSENTIAL FEATURES FOR THE EXPANSION OF HF RADAR INTO OCEAN OBSERVING NETWORKS

Since Dr. Donald Barrick established the theoretical basis of HF sea scatter back in 1968 on which both current extraction as well as waves monitoring is based, HF Radar technology has experienced a continuous evolution that has made its worldwide application possible. The current uniquely compact design of the SeaSonde HF radar and the patented SeaSonde synchronizing technology that allows multiple systems to operate at exactly the same frequency without interfering each other, are two of the most important breakthrough technological achievements.

2.1. System Compactness

One of the main difficulties in selecting feasible HF Radar sites is finding places where a) continuous power supply is guaranteed, b) there is a wide coast to coast view of the sea and c) there is enough space available for deploying all radar equipment (not only the electronics but also the HF radar antennas).

At first, HF Radar systems were designed as phased arrays with tens of separated antennas operating in Beam Forming mode, which were simple in concept but occupied several hundred meters of coast when deployed. In order to feasibly operate systems in areas with complex, urban or environmentally protected coastlines for continuous long-term monitoring, a new co-located cross-loop receive antenna design was developed for the SeaSonde® and the number of antennas was brought down to two: one transmit and one receive antenna. More recently, the compact cross-loop design has been further enhanced by combining transmit and receive antennas into a single mast. This latest single-mast design is currently available for all operating frequencies higher than 10 MHz. This design reduces the antenna footprint and visual impact that, in turn, increases the number of feasible sites for deployment (Fig. 1).

Fig. 1. Compact 2 x 13.5 SeaSonde HF Radar station. Livorno, Regione ***Toscana, SICOMAR, Italia.***

2.2. Efficient Use of the Radio-Electric Spectrum

Frequency spectrum is a limited resource which needs to be shared among a wide number of applications. Thus the efficient use of it in agreement with The International Telecommunications Union recommendations is critical in order to make the implementation of wide scale HF Radar networks feasible. With this aim, CODAR invented and patented a methodology based on GPS timing along with FMCW (frequency-modulated continuous wave) gated signals to control the exact sweep time of multiple transmitters down to nanoseconds so all transmitters can occupy the exact same frequency channel without interfering each other. More precisely, each CODAR SeaSonde® system transmits a gated FMiCW (Frequency Modulated interrupted Continuous Wave) and the time difference between each system's sweep start is rigorously defined through GPS timing. This allows that, after complete demodulation, other HF Radar station signals and echoes are put in distant and unused range bins (Fig. 2).

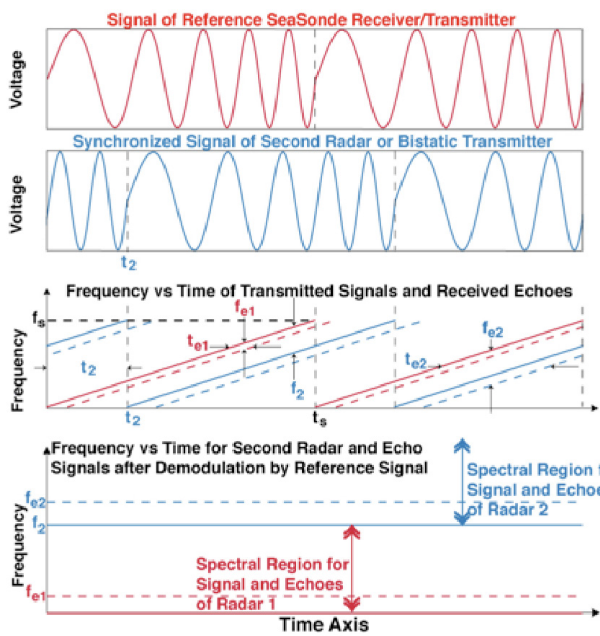

Fig. 2. Example on how GPS Modulation Multiplexing works. ***Toscana, SICOMAR, Italia.***

3. RECENT ADVANCES AROUND HF RADAR

3.1. Better QA/QC of HF Radar Data by Means of a "New

Automatic Antenna Pattern Measurement Solution" HF Radars require calibration, which is something that is independent of the system design (arrays or compact single-antenna technology). The surrounding environment to an antenna affects its properties (namely the antenna response pattern - the directional dependence of the received signals used for bearing determination), so it is necessary to take this into account when processing the received electromagnetic backscatter - (Paduan et al, 2006), (Flores-Vidal et al, 2012). In general, for the area within one electromagnetic wavelength of the receive antenna, the presence of conductive or ferromagnetic material that scale one quarter wavelength or greater will affect the antenna response pattern. University of Santa Barbara together with CODAR Ocean Sensors have developed a procedure in order to automatically measure the antenna pattern (APM) using Doppler echoes from passing vessels as a signal source and their AIS transponder data for a reference bearing.

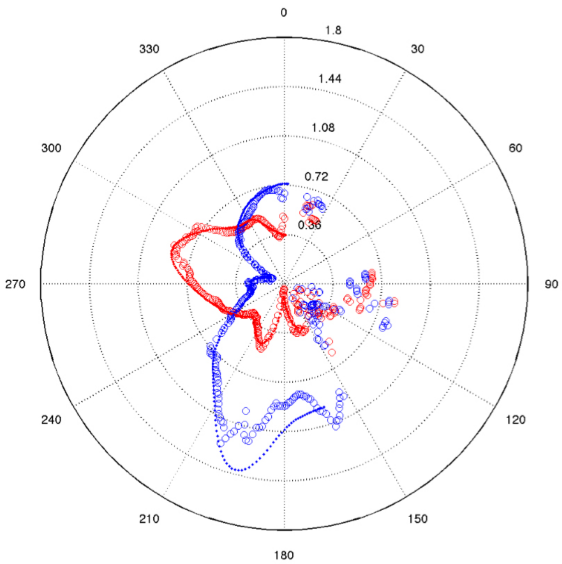

Fig. 3 - Loop patterns in the Espichel HF Radar station. Instituto Hidrografico of Portugal. Legend: red - Loop 1; blue - Loop 2; continuous line - boat pattern; circles - Auto-APM pattern. ***Toscana, SICOMAR, Italia.***

Application experience of the technology over the first two years has proven that this new Quality Assurance/Quality Control (QA/QC) enhancing technology is useful for the following purposes without increasing the cost of system operation:

a) to avoid unnecessary field antenna pattern measurements when this automatic procedure confirms the stability of the applied antenna pattern

b) to improve the overall HF Radar output quality by reducing the bearing measurement uncertainty thanks to this automatic capability to detect changes to the antenna and the antenna environment at the very early stages

3.2. Enhancement of Oil Spill and Particle Trajectory Forecasts by use of HF Radar Data

The experience acquired in the past in management of crisis like the Prestige demonstrated the importance of operational forecasting systems for oil spill response (Montero et al., 2003; Castanedo et al., 2006; González et al., 2006). The accuracy of oil spill transport simulations highly depends on the quality of the met-ocean data used to force the oil spill transport models. Traditionally, these oil spill transport systems have been forced by atmospheric and oceanographic numerical models, which have their own errors that may affect the accuracy of the transport forecasts (Edwards et al., 2006; Price et al., 2006). The uncertainty becomes more important in the ocean circulation modelling of coastal areas, where the complex pattern that characterizes the slope currents complicates the forecasting of the current fields. In order to address this problem, high-frequency (HF) coastal radar observation systems have become an alternative to provide accurate current surface maps in near-real time and therefore suitable for oceanographic practical applications as forcing for Lagrangian trajectory models in an emergency response at sea (Abascal et al., 2009b). To take advantage of these data, an oil spill forecasting and backtracking system has been developed by IHCantabria and Qualitas and validated by Marine Scotland in the Shetland-Orkney area as part of the Brahan Project to show the capabilities of HF radar systems for oil spill operations. The trajectory forecast system was operationally working during the period June 2014 - August 2014, in the framework of a project funded by the Spanish Ministry of Economy and Competitiveness (EEA Grants, IDI-20140011). The core of the system was the TESEO oil spill numerical model (Abascal et al., 2007), which was forced with ocean currents provided by the Brahan Long Range SeaSonde HF radar system and (2) wind forecast from the Global Forecast System model (NOAA) (Environmental Modeling Center, 2003). The main goal of the system was to provide short term oil spill trajectory forecasting and backtracking in the study area.

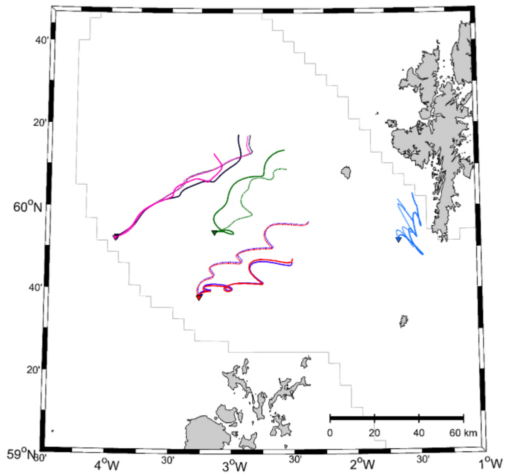

Fig. 4 Comparison between actual (continuous lines) and simulated trajectories (dashed lines). Gray line represents the HF radar system domain limit. Validation exercise carried out in October to December 2013 by Marine Scotland as part of the Brahan HF Radar project.

The oil spill transport forecast and backtracking system was calibrated by means of drifter buoys and its accuracy was successfully confirmed by comparing actual drifter trajectories and system's simulated trajectories (Oil spill trajectory modeling based on HF radar currents in the North Sea. AMOP 2015, Abascal et alter.)

3.3. Plan Towards Integration of HF Radar Into Tsunami Early Warning Systems in the Iberian Peninsula

"Today there is no full proof of tsunami detection system operational with a significant warning capability in any part of the world. Most reliable detection is claimed with the help of buoy systems which are equipped with sea level and bottom pressure sensors together with data transmitting electronics. However, their capability is limited to the local area. Therefore very large numbers of such buoys would be required to cover a large ocean area. Tide-gauge sea levels at coastal positions provide useful quantitative information for locations further downstream. The sea state monitoring HF radars have a potential for observing couple of hundreds km which is promising to use in operational manner for detecting Tsunamis." (Assessment, Strategy and Risk Reduction for Tsunamis in Europe, 2015). Dr. Donald Barrick at the NOAA/ERL/Wave Propagation Laboratory in Colorado in 1979 developed the theory supporting the capability of HF Radar to detect tsunamis. First actual offline detection of a tsunami by HF Radar happened in 2011 and in the meantime 38 further detections by SeaSonde HF Radars have been reported. In 2016 US NOAA in cooperation with Rutgers University and CODAR Ocean Sensors have started a project to leverage the national state-of-the-art observational network of SeaSonde High-Frequency (HF) radars and the SWHFR tsunami detection algorithms already developed at CODAR to develop a new tsunami detection and observation capability for the Tsunami Warning Centers (TWCs), which focus is to develop an early warning capability for meteotsunamis on the US East Coast. The Iberian Peninsula has implemented at present the widest HF Radar observing network in the EMEA region, operating a network of 22 SeaSonde HF Radar stations in a collaborative effort by 10 Spanish and Portuguese institutions (http://www.iberoredhf.es/en/radarhf). In this framework there is a plan by the Portuguese Instituto Hidrografico and the Spanish Puertos del Estado and Qualitas to validate the capability of HF radars to measure the orbital velocity of long waves using the Sagres HF Radar station as a testbed. This station would be ideally located to detect a tsunami like the one that took place in Lisbon back in 1755. After this first validation, this same plan aims to develop and calibrate the models that would allow the integration of selected Iberian HF Radar sites into a European-African "Tsunami Warning Network" for the Southwest Atlantic and Alboran Sea. These activities shall start inside 2017 and are fully aligned with similar efforts taking place in the US East Coast.

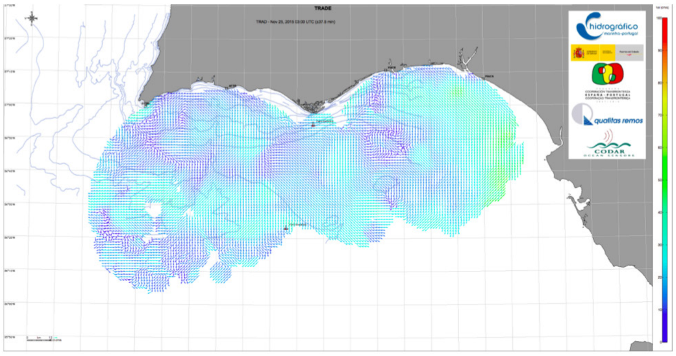

Fig. 5 Algarve and Gulf of Cadiz HF Radar network with 4 x 13.5 MHz SeaSonde stations including the Sagres site. (Operated by the Instituto Hidrografico of Portugal and Puertos del Estado of Spain, TRADE). Toscana, SICOMAR, Italia.

4. MOROCCO DIRECTION DE LA MÉTÉOROLOGIE NATIONALE STARTS THE FIRST HF RADAR SYSTEM IN AFRICA

Morocco is known for its rich cultural heritage, its natural breath-taking landscapes and also for being a reference in science and technology in Africa. In line with this idea, the Direction de la Météorologie Nationale (DMN) (http://www.marocmeteo.ma), a public service that is part of the Ministry of Energy, Mines, Water and Environment of the Kingdom of Morocco and also a permanent member of the World Meteorological Organization, has done in April 2016 a relevant step to comply with its mandate of providing accurate and continuous marine weather and climate information, more specifically 2D surface currents maps and wave data, by starting the first operational coastal HF radar ocean observing system in Africa to monitor the marine conditions with a range of up to 200 km from the coast. The installation of this system has been carried out by the Moroccan firm Qualitas (http://www.qualitasenv.com).

The first HF radar station has been implemented in Casablanca Port, on top of the Met Office building having a spectacular view of the sea and of the Grande Mosquée Hassan II, which is the tallest and the second largest Mosque in the world. The second station is installed on the premises of the Civil Protection in Temara (close to Rabat) taking advantage of the uniquely compact design of the chosen SeaSonde HF radar technology. Special consideration has been paid by the Maritime Department of the Met Office at the time of choosing and implementing the new technology to all activities that influence the long-term sustainability and short-term utility of such a project such as:

- The highest quality, easiness of use and reliability of the chosen technology
- The implementation of the most advanced global QA/QC methods and system operation software tools (figure 4) implemented into a versatile redundant IT platform with an advanced architecture (2x1TB HD software [mirroring] and 3x1TB HD data [RAID5])
- The in depth training and education of the department staff to fully assimilate all capabilities that are needed to integrate the new observational component with the other technologies and resources that are at present in application at the Met Office

5. CONCLUSIONS

HF Radar has reached the reliability and the operational readiness which makes a wide scale application of this technology possible. These systems are already delivering benefits related to the protection of the marine and coastal environment, the increased safety of navigation, efficiency in search and rescue operations, better oil spill preparedness and response, the meteorological assistance for the better planning and conduct of port operations. Application of HF radar data can also provide a better understanding of the marine physical environment supporting fisheries management and also coastal engineering in general, as well as allow further improvement of the existing circulation

Fig. 6 Compact 2 x 4.5 MHz SeaSonde HF Radar system in Morocco and principal 2D deliverables, currents mapping and waves monitoring. (HF Radar system operated by the Direction de la Météorologie Nationale).

numerical models. New ideas to take the existing HF Radar networks to the next frontier are flourishing such as the ones that intend to integrate this kind of infrastructures into early tsunami detection networks and the studies to use the HF radar data to improve the intensity prediction of tropical storms and long-term climate change studies.

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