CALYPSO
an operational network of HF radars for the Malta-Sicily Channel

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Abstract

An HF radar observing system composed of three CODAR SeaSondes is providing real-time surface current pseudo-Eulerian maps every hour in the strip of sea dividing Malta and Sicily. This initiative forms part of the CALYPSO project that principally aims to support the efficient response against marine oil spills in this busy area of maritime transportation in the Mediterranean. In combination to numerical models, an operational chain of activities provides essential data to a spectrum of applications and addresses the needs of a number of responsible entities in Malta and Sicily, targeting the better control of the trans-boundary maritime space and greater efficiency for security and safety at sea.

The usefulness of this effort is measured by the level of usage of the data provided by CALYPSO through dedicated web services with browsing, viewing, and user-defined download of data. The project comprised several validation and system performance tuning exercises through the matching of radar data with direct sea current measurements using drifters and ADCP deployments.

The spatial coverage and high temporal resolution of the HF radar data collected since September 2012 is permitting a unique and detailed characterization of the surface circulation variability in the area at sub-to-mesoscale and seasonal scales. Substantial eddy field structures are evidenced; their origin, dynamics, evolution and linkages to biological processes and the location of fisheries is the subject of ongoing research.

Keywords: observing networks, HF radars, real-time, mesoscale circulation

1. Introduction

The Malta-Sicily Channel (MSC) is a dynamically active stretch of sea within the shelf area connecting the Maltese Islands to the southern coast of Sicily. As with the rest of the Sicily Channel, this area is characterized by important dynamical processes encompassing a wide spectrum of temporal and spatial scales, with significant impacts on ecosystem characteristics as currents contribute to dispersion, transport or retention of nutrients, fish larvae and ichthyoplanktonic products of primary importance in the area (Lafuente et al., 2000).

The MSC is also under pressure due to the intense traffic of commercial vessels, shipping activities, fisheries and tourism. In particular, the maritime transport of oil crossing this region accounts for 25% of the global maritime traffic and for nearly 7% of the world oil accidents over the last 25 years. In combination with localized oil extraction plants existing in the shelf zones this situation presents a serious threat to both the open sea and coastal zone habitats, with consequent impacts on local economic activities such as tourism and fisheries, impacts on ecosystems and losses in revenue. In the case of accidental/deliberate oil spills or drifting-vessel emergency, an operative response chain must include both the detection and the trajectory prediction steps, that take advantage of the most appropriate methodologies and data availability such as: updated meteorological information, near-surface current measurements, and hydrodynamic models with oil spill weathering processes modules.

In a joint effort conducted by Maltese and Sicilian partners in the CALYPSO project (www.capemalta.net/calypso), under the partial funding of the European Union's Italia-Malta Programme – Cohesion Policy 2007 – 2013, a high-frequency (HF) radar network has been set up in 2012 to monitor sea surface currents in the Malta Channel. Radar data aim at supporting applications to optimise intervention in case of oil spill response as well as to endow tools for search and rescue, security, safer navigation, improved meteo-marine forecasts, monitoring of sea conditions in critical areas such as proximity to ports, and better management of the marine space between Malta and Sicily. HF coastal radars provide useful information to support sea safety and monitoring, as they are capable of measuring sea-surface currents with high temporal (10min – 3 hours) and spatial (500m – 6km) resolution. Designed originally for research purposes, the use of HF radars is nowadays well established worldwide and their capabilities have been extensively proven [e.g. Emery et al., 2004, Shay et al. 1998, Cosoli et al., 2013].

We present here the preliminary results of the measurements made by the CALYPSO radar system so far, the identification of near-surface circulation structures that had not yet been observed before, and preliminary results of the data validation. The radar network is introduced and described in Section 2; the data delivery services are described in Section 3, Section 4 deals with the system validation, while Section 5 discusses the main results.

2. The HF radar network

The CALYPSO network consists of three CODAR SeaSonde radars deployed in the MSC (Figure 1). During the first phase of the project, two stations were installed on the Maltese side close to Sopu Tower in Nadur on the island of Gozo and at Ta' Barkat limits of Xaghra in Malta. A third station was added on the Sicilian side at the Pozzallo Harbour. The three radar stations transmit the same frequency (13.50MHz) using a GPS-synchronization module for time synchronisation and frequency management.

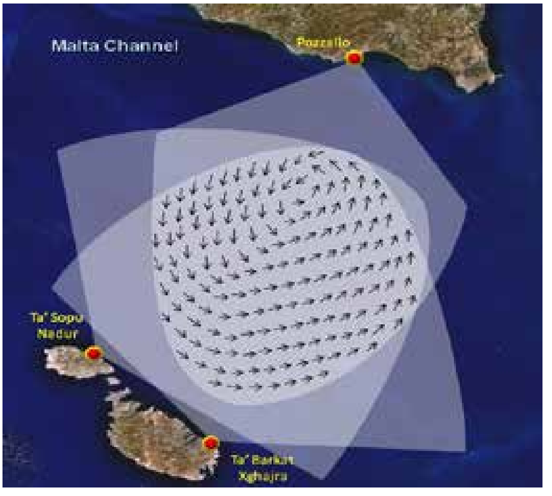

Figure 1 Radar locations on the Malta and Sicily sides

The wave peak period in this part of the Mediterranean region (3 seconds on average) determined the operating frequency in the range of 11MHz to 14MHz to guarantee a high degree of data availability. Thus the final working frequency was set to 13.5MHz according to the wave characteristics and accordingly to the International Telecommunications Union (ITU) frequency bands identified for HF radars.

Operation of the radars relies on the Bragg Scattering of electromagnetic waves by the surface gravity waves. This renders two sharp peaks in the Doppler Spectrum. Due to the underlying ocean currents, the detected peaks do not have a constant Doppler shift. Once the theoretical wave speed is computed from the dispersion relation and subtracted from the Doppler frequency shift, the radial velocity component of the surface current can be found. By installing more than one radar at different locations with an overlapping beam pattern, the same patch of water can be viewed from different angles, and the surface current radial velocity components can be summed to determine the total surface current velocity vector. Radial data from all three stations is transferred to a server at the University of Malta and combined to produce hourly maps of current vectors over a regular grid (Figure 2).

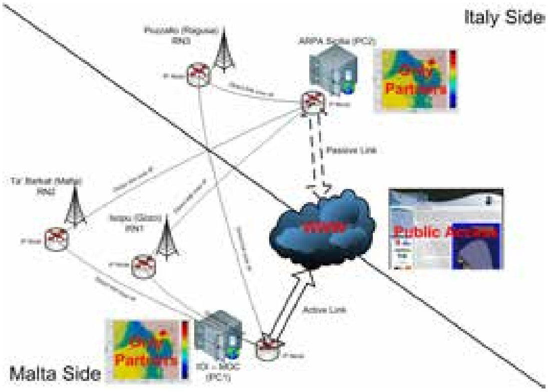

Figure 2 CALYPSO HF Radar Network Schematic

The network operates with a resolution of 1.6km and a 5° angle. Following (Stewart & Joy, 1974), in such a setup the radars are providing current measurements of the upper 1m ocean layer thus representing images of the upper layer of the water column.

A second derived measurement from each radar station is the significant wave height and the wave direction, which are extracted from the second order Doppler spectrum. When there is an increase in wave height, there is no corresponding increase in the height of the first order spectrum (Bragg peaks) since these are generally fully developed. However, there is an increase in the height of the second order peak energy which is proportional to the energy in the longer sea waves.

Due to the size of the Maltese islands, highly variable topography, competition of coastal usage and need to minimise visual and ecological impacts, the limitation of the footprint of all antenna elements was a base requirement from the Malta Environment and Planning Authority. As required by the ITU and FCC regulations, the medium radiated power from each radar is set such as to never exceed 40 watts. The HF Radar antennas have a height of about 7m to 10m. In all sites, low attenuation coaxial cables connect the radar to the electronic equipment housed in a safe location some distance away. The antennas are placed very close to the coastline and are not obstructed by any large scale structures within one wavelength (approximately 30m).

The CALYPSO HF Radar Network also makes use of new state-of-the-art technology that allows for 2D current maps to be rendered as close to the coast as possible. In particular, the radars at Ta' Barkat and Pozzallo are equipped with bistatic/multistatic modules to improve their functionality. The radar in Malta is able to process not only its own monostatic signal, but also the signals transmitted by the Gozo and Sicily stations. To this aim, all radar beams must be synchronized and all stations must share the same processing software. In regions close to the islands, a total vector made up from three or four individual vectors is constructed thus increasing the quality of the final 2D vector map. This also improves the quality of the data in the central region of the domain

The selection of the radar sites was done while keeping electricity supply and data connection in mind. Around 1.5 kW of electrical power are required to power the radar, electronics and cooling systems. At low temperatures, the cooling can be turned off and the power consumption reduces to 0.6kW. Each site is also equipped with a power stabiliser for safer and smoother electrical supply. Real-time transmission of data requires a network bandwidth in the order of 256 Kbps (upload speed). A GPS antenna is also installed on the roof of the building hosting the control unit.

3. Delivering data to the users

The value of an ocean observing system is measured by the quality of the data it delivers, the reliability of the data flow to minimize interruptions and timely publishing, the ease of access and referencing of data files, as well as the production of data dependent services that target the user needs. The CALYPSO data delivery is executed through a dedicated web interface developed within the project to give data access to users in an enhanced format that is readable and fitting to their own systems. The service further provides regular synthesis of data and value-added information to aid direct usage.

The data interface is composed of two main sections, namely: the Public Interface – targeting the public users by showing plots and statistics over nine different sub-regions in the MSC; and the Professional Interface – targeting the professional users by the presentation of quick-view plots, and allowing the download of data, and the handling of special data requests.

Apart from the nowcast sea surface currents generated by the CALYPSO HF-radar system, the data interface further makes use of forecasted sea currents data generated by the ROSARIO-6420 Malta shelf forecasting system (www.capemalta.net/MFSTEP/results0.html). The domain of data coverage has a spatial resolution of 0.03° (approx. 3Km) in the case of the observation nowcasts, and 0.0163° (approx. 1.6 Km) for the forecast fields. Data is provided with a temporal resolution of 1 hour.

The Public Data Interface (Figure 3) synthesises the hourly data fields by spatial averaging over 9 sub-regions and presents the information on sea surface currents averaged for each sub-region for a time span of 13 hours, namely: the present hour conditions; the previous 6 hours generated from HF radar observations; and the next 6 hours generated by the ROSARIO6420 forecast. The information displayed for each selected sub-region includes: the average current magnitude and direction in that sub region; the maximum and minimum current magnitude; the maximum current magnitude over the last 6 hours; and the maximum current magnitude expected in the coming 6 hours.

The Professional Data Interface (Figure 4) consists of three main components, namely: the Data QuickView section; the Data Daily Download section; and the Data Aggregated Download section.

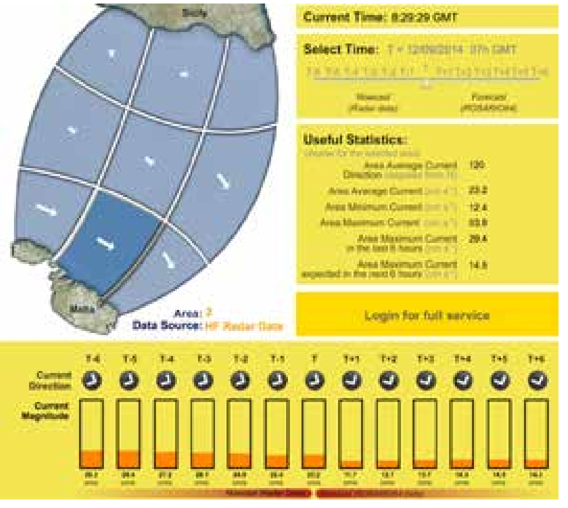

Figure 3 The CALYPSO Public Data Interface

The Data QuickView section allows the viewing and downloading of data on an hourly basis for the entire domain. The user selects the date of interest, and is presented with a set of images of the currents for the selected date and time. The user is allowed to download the data (as NetCDF or ASCII) for any specific hour. Apart from all this, the user may also view an animation of the currents for the selected day.

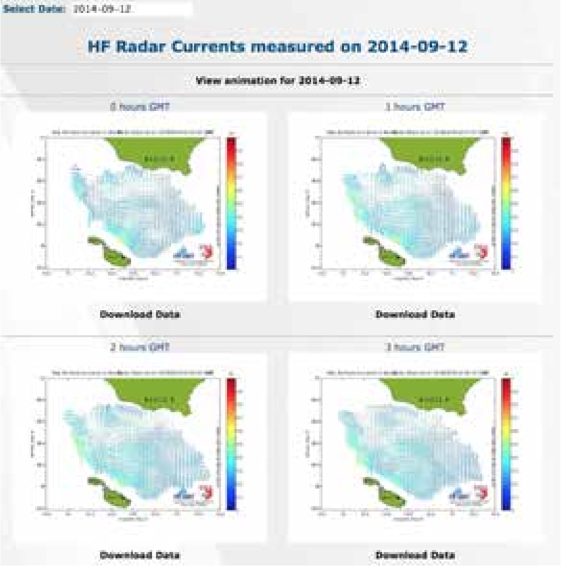

Figure 4 The CALYPSO Professional Data Interface (Data QuickView)

The Data Daily Download section presents the data for download for any month selected by the user. The data is aggregated on a daily basis. Hourly NetCDF files are concatenated together to create the daily files, whilst the ASCII files are aggregated as daily RAR archives. After the user selects the month of interest, the system shows the list of days for which there is data available.

The Data Aggregated Download section allows the aggregation and download of data over a range of user selected days. The user selects the start date and the end date of the period of interest, and the desired data format. The system performs the aggregation of data files for the selected time period up to a maximum span of 100 days. Once the aggregation is completed, the system outputs a link to the resulting aggregated file, with a summary description of the chosen dataset.

4. Performance of the system

The validation of the system was performed by comparing the HF radar observations to independent *in situ* near-surface velocity measurements, collected from Lagrangian drifters and from current profiles, acquired at selected locations within the CALYPSO radar domain. Surface Velocity Profiling (SVP) drifters were launched along a transect between the island of Gozo and Sicily in December 2012, June 2013, September 2013 and October 2013), in collaboration with the Mediterranean Surface Velocity Programme (MedSVP) of the Mediterranean Operational Oceanography Network (MOON).

They had a drogue centred at 15 m below the sea surface, with a surface buoy containing batteries, electronics, data telemetry (GPS) and a sea-surface temperature sensor. Drifter velocities were estimated as central-valued finite-differences of the interpolated positions (Hansen and Poulain, 1996; Gerin and Bussani, 2011). The SVP drifters measure quite accurately the near-surface currents, as wind-induced slip is limited (Niiler et al., 1995; Poulain et al., 2009). Hourly drifter velocity data were finally mapped on the radar grid for further analyses and comparisons. Sea current profiles were acquired by a downward looking Sontek Acoustic Doppler Current Profiler (1 MHz) attached to the side of a boat at 1 m vertical resolution.

Results of the validation of the CALYPSO radar data were consistent with those from similar installations elsewhere (Emery et al., 2004). Correlation between radar and drifter radial velocities were R = [-0.03, 0.7], and were R = [0.25, 0.79], R = [0.27, 0.89] for the U- and V-components. The comparison of ADCP measurements against the radar current vectors (Figure 5 and Figure 6) highlighted an underestimation of the velocities acquired by the radars (around 15%) whereas the agreement in terms of directions was almost perfect.

Hardware failures, software limitation or external radio-frequency interferences (RFI) determined different radial coverage between the threes radars. The latter, in particular affected the three systems after an initial period of good signal-to-noise ratio conditions radar, determining a reduction in operating range and introduction of spurious current vectors.

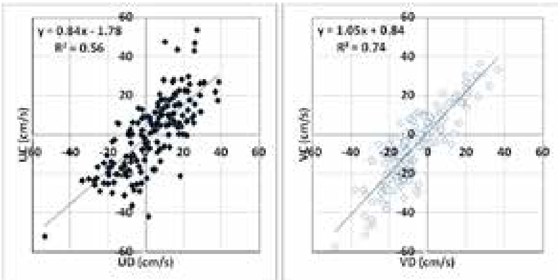

Figure 5 Comparison of drifter measured current components (UD and VD) and the corresponding values from the HF radar (Uc and Vc) (all the available drifter releases).

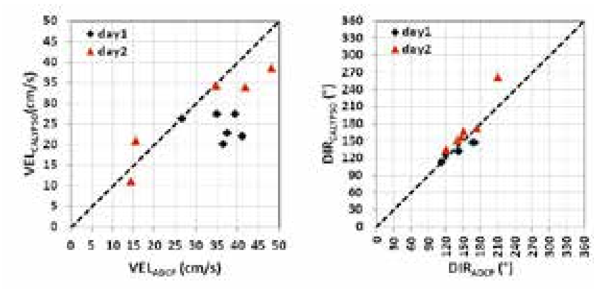

Figure 6 Comparison of magnitude (VEL) and direction (DIR) of the HF radar currents against the ADCP measurements at depth 3.5 m

5. Mesoscale circulation in the MSC

The sequence of monthly-averaged radar current maps in the MSC confirm the dominant presence of an energetic jet throughout the year, associated with the Atlantic Ionian Stream (AIS), with average currents reaching 30-40 cm/s, and directed towards SSE as it exits into the Ionian Sea. The most pertinent circulation pattern revealed by this study concerns the presence of a quasi-permanent mesoscale anticyclonic eddy in the middle of the MSC, bounded on its northern extremity by the AIS current (Drago et al., 2013). The circulation follows a seasonal pattern in which the AIS flow shifts closer to the islands of Malta during Summer and the SE flow along the northern coast of the Maltese Islands becomes particularly intense, tending to swerve against the SE tip of Malta; in Winter the AIS vein is displaced northward towards Sicily, the anticyclonic eddy formation comes into action to the extent of even tending to reverse at times the coastal mean flow along the Malta/Gozo coast to a NW direction. Similarly to the AIS, the mesoscale anticyclone follows a seasonal modulation with zonal shifts in the MSC. As evidenced by the tracks of the drifters deployed in December 2012 (Figure 7), this eddy in fact almost occupied the entire channel consequently trapping the drifters in its interior with a permanence time of 4 to 40 days depending on the point of the drifter release.

A rotary spectral decomposition of surface currents gave evidence to the main periodic oscillations in the radar currents. An example is given in Figure 8 for the grid point having the longest data return. Despite the tidal signal in the MSC is weak and mainly associated to the semidiurnal tidal components, a strong semidiurnal peak is evident at the M2 frequency with a secondary peak at the S2 frequency, which is however almost one order of magnitude smaller than the M2 signal. Near-inertial and inertial oscillations, occurring at period of approximately 15^h at 36° latitude, can be clearly seen in the rotary spectrum, as well as significant energy is observed within the diurnal frequencies. While inertial motions show a clear predominance of the anticyclonic (clockwise rotating) component over the cyclonic component, this predominance is present to a smaller extent also in the diurnal frequency band.

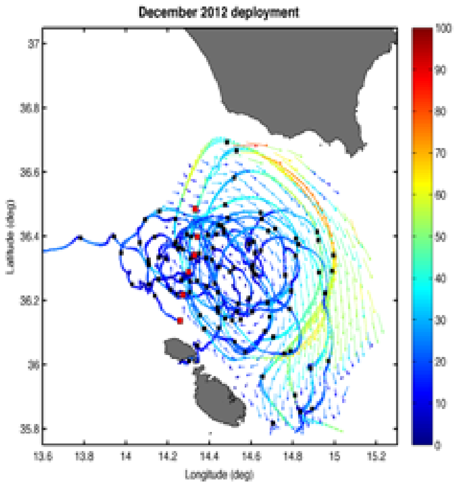

Figure 7 Time-averaged radar current pattern for the December 2012 – January 2013 drifter deployment, overlapped to the along-track instantaneous drifter velocites. Red squares show the deployment locations, black squares show the daily distance travelled by each drifter

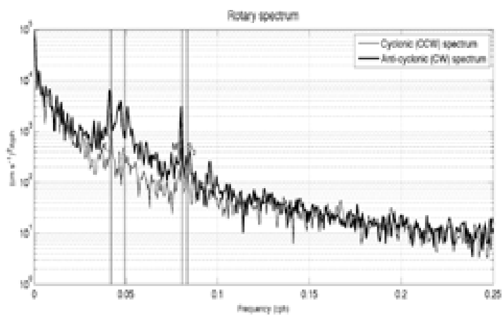

Figure 8 Rotary spectrum for radar surface currents showing current energy distribution over frequencies. Thin line represents the cyclonic (or, counter-clockwise rotating) spectrum, thick line represents the anti-cyclonic (or, clockwise rotating) spectrum. Units are (cm s-1)2 cph-1 for current variance, cycles-per-hour (cph) for frequencies

Acknowledgements

The CALYPSO project is partly financed by the EU under the Operational Programme Italia-Malta 2007-2013 and co-ordinated by Prof. Aldo Drago from the Physical Oceanography Unit of the University of Malta. Besides the authors and institutions of this paper, the project is further conducted by six other partners: Transport Malta (Capt. R. Gabriele & Galea G.), Civil Protection Department, Malta (P. Murgo & Grech S.), Armed Forces of Malta (M. Mangion & O Neill, C.), ARPA Sicilia (M. Antoci & Garretto A.), Istituto per l'Ambiente Marino Costiero uos di Capo Granitola, CNR (G. Buscaino) and Universita' degli Studi di Catania, CUTGANA (C. Grasso & Russo A.).

Special thanks to M. Menna and A. Bussani (OGS) for the drifter data processing.

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