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Downscaling hydrodynamics features to depict causes of major productivity of Sicilian-Maltese area and implications for resource management

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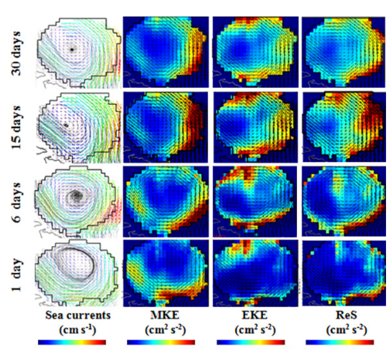
HIGHLIGHTS

- The correlation between HF currents, *CHL-a* and SST satellite data is proposed.
- High temporal HF radar data is used to resolve the main oceanographic features.
- Correlation maps allow to disentangle how sea current-driven *CHL-a* and SST affect biological and ecological processes

GRAPHICAL ABSTRACT



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ABSTRACT

Chlorophyll-*a* (*CHL-a*) and sea surface temperature (*SST*) are generally accepted as proxies for water quality. They can be easily retrieved in a quasi-near real time mode through satellite remote sensing and, as such, they provide an overview of the water quality on a synoptic scale in open waters. Their distributions evolve in space and time in response to local and remote forcing, such as winds and currents, which however have much finer temporal and spatial scales than those resolvable by satellites in spite of recent advances in satellite remote-sensing techniques. Satellite data are often characterized by a moderate temporal resolution to adequately catch the actual sub-grid physical processes. Conventional pointwise measurements can resolve high-frequency motions such as tides or high-frequency wind-driven currents, however they are inadequate to resolve their spatial variability over wide areas. We show in this paper that a combined use of near-surface currents, available through High-Frequency (HF) radars, and satellite data (*e.g.*, TERRA and AQUA/MODIS), can properly resolve the main oceanographic features in both coastal and open-sea regions, particularly at the coastal boundaries where satellite imageries fail, and are complementary tools to interpret ocean productivity and resource management in the Sicily Channel.

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1. Introduction

Understanding the abiotic processes that may generate and maintain species occurrence in a focal area is a recognized essential baseline for designing interventions to mitigate biodiversity loss, inform adaptive strategies for a sustainable use of biological resources and more simply explain biotic interaction (Mellin et al., 2016; Bauer et al., 2018). As widely reported in literature, remote sensing of environmental data provides valuable insight into the understanding of processes driving spatial and temporal changes in productivity at sea (Behrenfeld et al., 2006). These data include for instance sea surface temperature (*SST*), chlorophyll-*a* (*CHL-a*) and sea surface currents. However, there is still a poor understanding of the mechanisms that ultimately are responsible for productivity hotspots in the oceans. This knowledge become crucial in a context of multiscale interactions among anthropogenic and climate stressors and to inform future evidence-based sustainable marine resources management strategies (*e.g.*, Pikitch et al., 2004; Dietz et al., 2007; Halpern et al., 2008; Piroddi et al., 2017). The call for sustainability has become mandatory in the last decade recognizing the importance to collect and integrate abiotic and biotic data to disentangle potential resilient ecosystem functions and provision (*e.g.* seafood) to be preserved without threatening socio-economies (Westman, 1977; MA, 2005; Fisher et al., 2009). Management strategies built-up on the knowledge of the driving abiotic interactions may ensure a more tailored planning process more regionalised and spatially explicit as required in the context of the Mediterranean Sea where and when activities such as fishery, aquaculture and tourism are essentially sustained by trophic conditions generating shared productivity hotspots which driven mechanism are unknown (Sarà et al., 2011; Pranovi et al., 2013; Ramírez et al., 2017). To identify the abiotic mechanisms and drivers that generate the species occurrence patterns can be time and resources demanding given the difficulties encountered in collecting, processing, modeling and validating physical data (Mellin et al., 2016). For this reason most of the management actions in place into the Mediterranean Sea have been based on predictions of oceanographic effects on the local trophic conditions and ecological responses at local scale, often performed on mean conditions of hydrodynamic regimes (*e.g.*, monthly, annually; Levi et al., 2003; Bellido et al., 2008; Bacha et al., 2010; Agostini and Bakun, 2002; Martín et al., 2012; Basilone et al., 2013; Giannoulaki et al., 2013; Quattrocchi et al., 2016; Harrison et al., 2017).

As resulting from the gap of a more regionalized knowledge of the acting abiotic variables and the physical driving mechanisms, rules and legislation mostly designed for other environmental contexts, such as for the Northern European countries (*e.g.*, Common Fishery Policy, CFP; Frost and Andersen, 2006; Lado, 2016), were applied in the Mediterranean Sea resulting inadequate where rather the use of higher resolution data is strongly recommended when dealing with biological and ecological processes (*e.g.*, at least daily-averages or much better hourly; Montalto et al., 2014; Lado, 2016; Sarà et al., 2013). We can use a medical analogy and later translate it into the biological oceanography and ecology: the "actual patient care should be highly individualized, and patient treatment should not be based on the results of broad-scale generalizations, without considering the patient's history, risk factors and other medications" (lit.; Helmuth et al., 2014).

A broad-brush approach could be appropriate if high resolution data lack, but the present-day technology offers dramatic improvement of the temporal and spatial resolution of many types of data needed to feed more tailored regional management strategies based on high resolution environmental data layers. The Malta-Sicily Channel (hereafter referred as MSC; central Mediterranean Sea) represents a good cross-border example: the large local productivity (Fig. 1) supports one among the largest fishing fleet in the Mediterranean basin with high aggregation values of fishing pressure in proximity to productivity hotspots (Eigaard et al., 2016). This area is also under significant pressure from intense marine traffic that includes commercial vessels, tankers (La Loggia et al., 2011), oil and gas extraction plants (Mangano and Sarà, 2017) making it highly vulnerable: a tailored management of local shared resources is urgent. A number of topographic and mesoscale to sub-mesoscale oceanographic features, such as fronts, vortices and upwelling regions, both contribute in controlling the local trophic conditions and maintaining high levels of biodiversity (Lermusiaux and Robinson, 2001; Béranger et al., 2004). This region can be considered as an ecological source and sink for many pelagic and demersal species (*e.g.*, anchovy, young tunas, mackerel, red mullet *etc.*; Fiorentino et al., 2003; Levi et al., 2003; Sarà and Sarà, 2007; Falcini et al., 2015; Consoli et al., 2016) feeding primarily both Italian and Maltese local socio-economies.

This research focuses on the following points: *i*) characterizing the surface circulation in the MSC region; *ii*) characterizing the relationship among surface currents and water quality variables; and, *iii*) identifying the possible causes of the large productivity supporting local economies. For these tasks, we analyze surface current data collected through a network of High-Frequency (HF) radars deployed in the MSC area, supported by an EU Italian-Maltese Transnational Programme (Cohesion Policy 2007–2013), and satellite data products such as MODIS SST and CHL-*a* maps available from the OceanColor web portal (http://oceancolor.gsfc.nasa.gov/), managed by NASA. While the initial CALYPSO objective was to gather data for sea safety purposes, the unprecedented resolution in space and time (3 km and 1 h, respectively) of the near-surface circulation was seen as also useful to provide information to disentangle the interaction among oceanographic factors. This will also be important when building the basal information to tailor dynamically the resource exploitation management (downscaled) plans.

2. Materials and methods

2.1. Study area

Currents contribute to dispersion, transport or retention of nutrients, fish larvae and ichthyoplanktonic products of primary importance in the MSC (Lafuente et al., 2002). In first approximation, circulation in the MSC can be described as a two-layer system: *i*) the upper layer, having an approximate thickness of about 200 m, is occupied by the eastwards flow of Atlantic Water (AW); *ii*) the deep layer is occupied by the saltier Levantine Intermediate Water (LIW) (Rinaldi et al., 2014). Before entering the MSC, the AW splits into two main branches, one flowing to the Tyrrhenian Sea along the northern boundary of Sicily, and a second branch flowing into the Sicily Channel. This second branch also splits following two preferential pathways, namely the Atlantic Ionian Stream (AIS) meandering close to the Sicilian coast, and the Atlantic Tunisian Current (ATC) along the northern coast of Tunisia. AIS and ATC show a seasonal pattern in which the ATC is more pronounced in winter and the AIS is prevalent during summer periods. Additionally, the AIS is closely associated with semi-permanent mesoscale vortex features including the intermittent northward extension of the AIS (NAIS) at the Ionian shelf break, which is most likely driven by the surface density contrast between waters of the Sicilian and the Ionian basins (Béranger et al., 2004; Savini et al., 2009). A schematization of the main circulation features is provided in Fig. 1.

2.2. The CALYPSO radar network: description and validation

The radar network consists of SeaSonde HF radars, deployed in the southeastern part of the Malta-Sicily Channel. Two stations were set up initially in the Malta archipelago at the Sopu Tower (station code: SOPU) and at Ta'Barqat (site code: BARK). The area initially covered was ~4000 km^2 (~2400 km^2 of which measured at least 70% of the time). In August 2012 a third station (site code: POZZ) was added on the Sicilian side at the Pozzallo Harbor in August 2013, which significantly extended the spatial coverage in the area (Fig. 2, right panel).