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The Portuguese man-of-war: Gone with the wind

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HIGHLIGHTS

- More than 3,500 Portuguese man-of-war arrived at the Basque coast in August 2010.
- The wind drag velocity was used to estimate their region of origin and routes.
- The region of origin was probably located in the North Atlantic Subtropical Gyre.

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ABSTRACT

The Portuguese man-of-war (*Physalia physalis*) is a siphonophore that lives at the air–water interface of the sea. The wind is the main mechanism controlling its drift. In August 2010, a significant number of individuals of this species arrived at the Basque coast (southeastern Bay of Biscay), causing a great socio-economic impact. Here we investigate the most likely region of origin and routes of these individuals using the Sediment, Oil spill and Fish Tracking model (SOFT). This model was run backwards in time using only the wind drag velocity (i.e., the wind velocity multiplied by a wind drag coefficient) to estimate the drift of these Portuguese man-of-war for one year and taking into account that the final destination was the Basque coast. The wind data were obtained with the Weather Research and Forecasting model (WRF). Six different simulations were carried out with SOFT using the following wind drag coefficients: 0.02, 0.025, 0.03, 0.035, 0.04 and 0.045. The simulation period covered from the end of August 2010 to the beginning of August 2009. After the first eight months of simulation (i.e., at the beginning of January 2010), the virtual Portuguese man-of-war used in SOFT were located near or on the northwest and southwest coasts of France and England, respectively, and in the English Channel, the southern Celtic Sea and the northwestern Bay of Biscay. However, at the end of the simulation period (i.e., at the beginning of August 2009), most of these Portuguese man-of-war were located between the central part of the Bay of Biscay (∼5° W) and the open North Atlantic Ocean (∼35° W), depending on the wind drag coefficient. From these results, we conclude that the region of origin of the Portuguese man-of-war arriving at the Basque coast in August 2010 was probably located in the northern part of the North Atlantic Subtropical Gyre. This conclusion is in agreement with the general wind-driven circulation in the North Atlantic Ocean.

1. Introduction

In 2010, a large number of Portuguese man-of-war (*Physalia physalis*) arrived at the Atlantic and Mediterranean coasts of the Iberian Peninsula and the Canary Islands, threatening the tourism industry, which is a major economic sector in these coastal regions (Prieto et al., 2015). More than 3500 Portuguese man-of-war were collected in the Basque coastal area (southeastern Bay of Biscay) in August 2010. Since then, the number of Portuguese man-of-war has drastically decreased. By mid-July 2011, a few hundred individuals were also collected on some beaches of the Basque coast after several days of intense northerly winds. But in the period 2012–16, only 49 Portuguese man-of-war were recorded.

The Portuguese man-of-war is a pleustonic siphonophore that belongs to the phylum Cnidaria and consists of a complex colony of four types of individual zooids (dactylozooids, tentacles for catching prey and self-defense; gonozooids, for reproduction; gastrozooids, for digestion; and a pneumatophore, a gas-filled float), which cannot survive separately and behave as a single animal (Mapstone, 2014). The Portuguese man-of-war lives in warm tropical and subtropical waters. This species is especially

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Fig. 1. Portuguese man-of-war (*Physalia physalis*) found on the Basque coast. Photograph by Nagore Zaldua-Mendizabal.

common in the warm waters of the Florida Keys, the Gulf Stream, the Gulf of Mexico, the Caribbean Sea and the Sargasso Sea. An example of the Portuguese man-of-war found on the Basque coast is shown in Fig. 1.

Several attempts have been made to describe the physical behaviour of the Portuguese man-of-war. Iosilevskii and Weihs (2009) studied the hydrodynamics of its trailing tentacles, the interaction between these tentacles and the float, and the actual sailing performance. These authors observed that the Portuguese man-of-war sailed with its float aligned with the wind under strong wind conditions. In 2012, the Department of Security of the Basque Government established an operational protocol for the sighting and tracking of Portuguese man-of-war in the southeastern Bay of Biscay. This protocol was designed by Ferrer et al. (2015) and combines sightings of this colonial organism at sea with numerical models that simulate its drift in the ocean. The initial forecasts of this operational protocol were performed with the Sediment, Oil spill and Fish Tracking model (SOFT), using hourly surface ocean currents and winds obtained with the Regional Ocean Modeling System (ROMS) and the Weather Research and Forecasting model (WRF), respectively. After analysing the drift of eight pop-up satellite tags for fish tracking, Ferrer et al. (2015) suggested that the most straightforward way to estimate the drift of a small floating object is to use a simple empirical model based on the local wind around the moving object.

Prieto et al. (2015) carried out numerical simulations to analyse the probable drift of Portuguese man-of-war from the Atlantic Ocean into the Mediterranean Sea in 2010. They used surface ocean currents and winds obtained with ROMS and from the Advanced SCATterometer (ASCAT) observations, respectively, to estimate this drift. They assumed that each Portuguese man-of-war was transported in the wind direction at 10% of the wind speed. These authors concluded that the 2010 event was an isolated case where a combination of meteorological and oceanographic conditions led to an unusual number of Portuguese man-of-war along the Spanish coast, far from being a permanent invasion. Although some literature is available on the response of the Portuguese man-of-war to physical forcing, little information is available on its life cycle, including growth and reproduction rates, and lifespan.

Here we investigate the most likely region of origin as well as the routes of the Portuguese man-of-war arriving at the Basque coast in August 2010. Using SOFT, we test the hypothesis that the region of origin of these Portuguese man-of-war was located in the North Atlantic Subtropical Gyre (NASG). The NASG is one of the five major oceanic subtropical gyres. The currents that compose the NASG include the Gulf Stream in the west, the North Atlantic Current in the north, the Canary Current System in the east and the North Equatorial Current in the south (Laiz et al., 2012; Putman and He, 2013). The Sargasso Sea, the only sea without a land boundary, is located entirely within the NASG. This sea stretches from roughly 70° W to 40° W and from 20° N to 35° N. The general ocean surface circulation in the NASG is shown in Fig. 2(a). The results obtained from this study will increase our predictive capability for future events and will enable us to develop effective management strategies to avoid economic losses in the affected coastal areas.

2. Methods

The region of origin and routes of the Portuguese man-of-war arriving at the Basque coast in August 2010 were estimated using SOFT. This Lagrangian particle tracking model is mainly designed for marine applications. In this model, the method used for the movement of particles (i.e., sediments, oil spills, eggs and larvae, jellyfish, Portuguese man-of-war, etc.) is based on the fourth-order Runge–Kutta scheme (Benson, 1992). Ferrer et al. (2015) carried out a calibration of this model using eight trajectories from pop-up satellite tags for fish tracking. The results of this calibration showed that the wind is the main mechanism controlling the tag drift following the equation:

$$\mathbf{U}_D = C_D \cdot \mathbf{U}_{WRF} = C_D \cdot U_{WRF} + C_D \cdot V_{WRF} \qquad (1)$$

where $\mathbf{U}_D = (U_D, V_D)$ is the drift velocity, $\mathbf{U}_{WRF} = (U_{WRF}, V_{WRF})$ is the wind velocity at 10 m height obtained with WRF and C_D is the wind drag coefficient. WRF is a next-generation mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting needs. A detailed description of this model can be found in Skamarock et al. (2005). To estimate the drift of the Portuguese man-of-war, we used Eq. (1) with the hourly wind fields provided by MeteoGalicia (meteorological agency of Galicia) for 2009 and 2010. The coverage of the WRF model domain used by MeteoGalicia in its operational system is shown in Fig. 2(b). The spatial resolution of the grid is 36 km.

The C_D values used by Ferrer et al. (2015) in their numerical simulations ranged from 0.001 to 0.04. On average, the best fit between the modelled and observed trajectories was obtained when a C_D value of 0.018 was used. However, C_D must be estimated for each specific floating object. For example, a C_D value of 0.03 is commonly applied to estimate the surface drift of oil spills (Fallah and Stark, 1976; Wu, 1983). Following Ferrer et al. (2015), we used different wind drag coefficients in our simulations with SOFT to investigate the routes of the Portuguese man-of-war. In total, six values were used: 0.02, 0.025, 0.03, 0.035, 0.04 and 0.045.

Two virtual Portuguese man-of-war were released every day in August 2010 (at midday and midnight) at a distance of ~10 km from the Basque coast (see location in Fig. 2(b)). Although little information exists on the life cycle of the Portuguese man-of-war, most experts believe that the lifespan of this colonial organism is approximately one year and its reproduction takes place in autumn. For this reason, each virtual Portuguese man-of-war was moved backwards in time using SOFT for one year. Therefore, the simulation period covered from the end of August 2010 to the beginning of August 2009. The results obtained from the end of August to the beginning of January 2010 (first part of the simulation period) were plotted separately from those obtained from the end of December to the beginning of August 2009 (second part of the simulation period). The purpose of this was to identify the existence of differences between these two parts of the simulation period.