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Applicability of an empirical law to predict significant sea-wave heights from microseisms along the Western Ligurian Coast (Italy)

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ABSTRACT

The use of microseisms with appropriate predictive laws is a reliable method for estimating such sea-wave parameters as period and significant height. Through the use of opportune predictive laws calibrated with measurements obtained from wave buoys, it is possible to determine the significant height of the wave as a function of the spectral energy-content of the microseism. In this paper we will present a procedure that utilises microseisms recorded by a micro network of five seismic stations to predict the significant height of waves, and its uncertainty, along the western Ligurian coast (Italy). The calibration and validation of the procedure was performed using wave measurements obtained from a wave buoy off Capo Mele (Imperia, Italy) over a two and a half year period. The differences between the significant heights measured by the wave buoy and the empirical predictions were less than 10 cm (corresponding to 10% of the mean measured value) for 47% of the data and less than 20 cm (corresponding to 20% of the mean measured value) for 72%.

1. Introduction

The prediction and measurement of wave height is crucial for evaluating the level of security of many activities occurring in the open sea and along the coast (such as ship movement, port activity, coastal construction, etc.) because of the impact of waves on these (Niclasen et al., 2010).

Being able to have a reliable measurement of the significant sea-wave height ($H_{1/3}$) in real-time or quasi-real-time is especially important from the point of view of civil protection in those cases where meteorological conditions can produce extreme marine events such as severe sea storms. In areas where these events are frequent and evolve rapidly, as in the north-west Mediterranean and the Ligurian Sea (Fiori et al., 2014), the continual measurement of the wave height has fundamental importance. As has been noted since the 1970s (Englebreston, 1989; Reiter, 1971), the Ligurian Sea is in one of the most active cyclogenetic areas of Europe, where frequent and rapid changes in meteorological conditions (Lionello et al., 2012; Schär et al., 2003) generate storms with very high waves that are able to seriously damage or destroy coastal infrastructure. A recent example of this was the storm of 5 November 2014 with a maximum wave height of 8.7 m and a significant wave height of 4.7 m and a mean period of 10 s. That storm caused serious damage along the Ligurian coast (data from Ligurian Environmental Protection Agency, ARPAL; http://www.arpal.gov.it/contenuti_statici//pubblicazioni/rapporti_eventi/2014/REM_20141103-06_allerta1BE-allerta2ADC_vers20150429.pdf).

The prediction of wave parameters (e.g. significant height, period) is traditionally obtained from an analysis of the data on the wave height and the wind supplied by wave buoys in the area of monitoring. A lack of measurements on wave motion is often related to the high cost associated with the installation, management and maintenance of wave buoys. So, in many cases the prediction of the wave height is made through empirical or numerical models based on physical processes regulated by the wind observed at a regional scale (i.e. WAM, WaveWatch III, MIKE, SWAN) avoiding direct wave measurements (Niclasen et al., 2010). Over the years, alternative methods have been proposed, developed and applied. In some applications wave prediction has been based on the probabilistic graphical model (Bayesian Networks; Plant and Holland, 2011), or data-driven tools such as neural networks (Artificial Neural Network; Gopinath and Dwarakish, 2015; Londhe and Panchang, 2007; Makarynskyy et al., 2005). However, models using wind data have often underestimated the height in complex basins, near the coast or islands, and in areas where the fetch or the duration of the meteorological event are limited, as often occurs in the north-west Mediterranean (Ponce de León and Guedes Soares, 2008). In complex areas like the Ligurian Sea the availability of wave measurements is essential for weather forecasts.

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In this work, based on the results obtained by Ferretti et al. (2013), we propose a method for the prediction of the significant wave height in the Ligurian Sea through the analysis of microseisms. A microseism is a continuous seismic signal with a mean frequency less than 1 Hz, which is not associated with earthquakes. More in detail, the microseismic frequency band starts from about 0.05 Hz whereas, at lower frequencies, the background noise is called “hum”. Microseism is composed of P and surface waves (Gerstoft and Tanimoto, 2007; Gutenberg, 1947; Rhie and Romanowicz, 2004). The major part of the microseism energy is in the form of Rayleigh waves, as demonstrated by many authors (Haubrich et al., 1963); its spectrum is closely related to ocean wave energy coupling into the Earth's motion. The study of microseisms is important for understanding sea waves and climate change and the planning of shore-protection measures (Bromirski et al., 2005; Ferretti et al., 2013; Grevemeyer et al., 2000; Stutzmann et al., 2009; Tanimoto et al., 2006). Conventionally, the microseism is considered to be composed of two types (Barruol et al., 2006; Cessaro, 1994); a primary microseism, with a frequency between 0.05 and 0.1 Hz, is generated by the pressure variations produced by waves on a shallow seafloor and has the same frequency as sea waves (Ardhuin et al., 2015; Hasselmann, 1963). A secondary microseism has a frequency roughly double the frequency of marine waves (generally between 0.1 and 0.5 Hz) and its generation mechanism requires the interaction of ocean waves traveling in opposite directions (having nearly the same wave number), generating a pressure excitation pulse at twice the wave frequency (Bromirski et al., 2005).

In recent decades, several authors have proposed methods for estimating the parameters governing the state of the sea from seismic noise derived empirical relationships (e.g. Bromirski et al., 1999; Ardhuin et al., 2012). In Ferretti et al. (2013), the authors studied the correlation between wave motion measured close to the western Ligurian coast (i.e. significant height and period) and the characteristics of the microseism (i.e. energy, frequency content) recorded by a seismic station of the RSNI network (Regional Seismic network of North-western Italy, www.distav.unige.it/rsni), and calibrated and tested a preliminary empirical relationship for predicting the significant wave height in the Ligurian Sea from microseisms.

The aim of our work is to calibrate an empirical procedure for measuring significant wave heights in the western Ligurian Sea using microseisms recorded by a micro network consisting of five RSNI stations. This procedure, based on the empirical relationship proposed by Ferretti et al. (2013) should enable us to estimate the significant wave height and its associated uncertainty, an estimate that could be used for predicting and monitoring wave motion in the Ligurian Sea. The robustness of this procedure has been evaluated by comparing the data predicted using microseisms and those measured by a wave buoy managed by ARPAL, and analysing more than two years' worth of data. Therefore, this work presents an extended version of the method proposed in Ferretti et al. (2013) for predicting significant sea wave height in the Ligurian Sea from microseisms. In particular, the procedure here proposed has four main variations on the method proposed by Ferretti et al. (2013): (1) development of a procedure based on the use of a network of seismic stations in order to limit overestimation effects due to low-frequency disturbances that can affect one single station (as noted by Ferretti et al., 2013); (2) estimate of the uncertainty associated with each value of $H_{1/3}$ predicted when using microseisms; (3) integration with a two-step algorithm that limits underestimation effects in predicting $H_{1/3}$ values when the sea wave height is greater than 2 m; (4) statistical evaluation of the quality of the prediction procedure when analysing a significant sample of data (14,000 pieces of data).

2. Calibration of the empirical law for predicting sea-wave height

2.1. Data and processing

The microseisms recorded at the seismic stations of Imperia (IMI station), Quiliano (QLNO station), Negi (NEGI station), Grotte di Bossea (GBOS station) e Rocca Rossa (RORO station) (Fig. 1) were collected and processed according to the proposal in Ferretti et al.

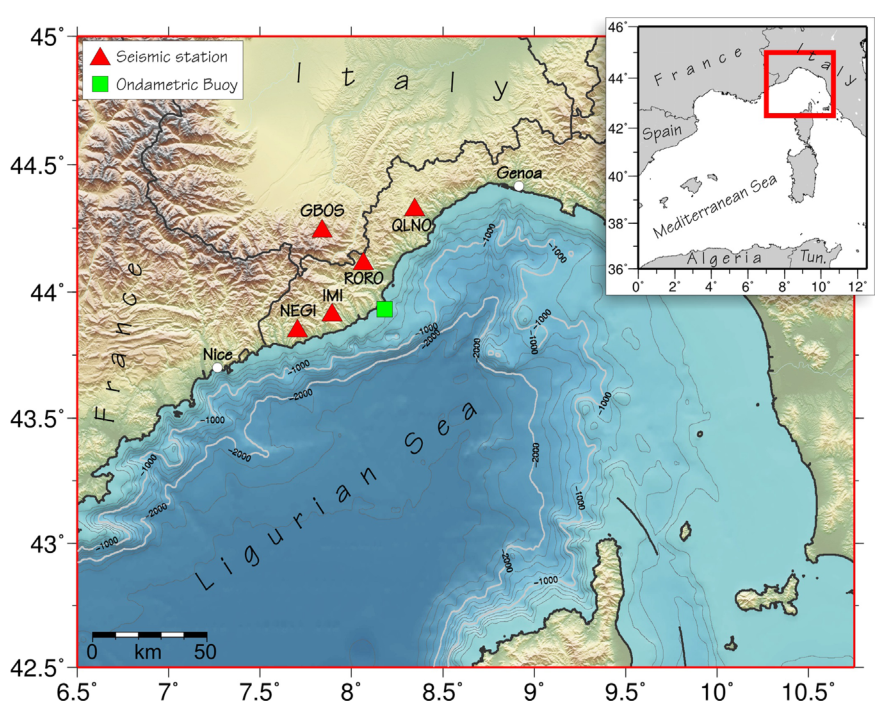

Fig. 1. Geographical position of the area studied. The positions of the Capo Mele buoy (green square) and seismic stations (red triangles) providing the data are indicated . (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)