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Modelling the impact of climate change on harbour operability: The Barcelona port case study

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ABSTRACT

Harbours are essential infrastructures for economic activity that are susceptible to impacts from climate change driven processes, like sea level rise (SLR), or alterations in wave patterns. In this paper, the impact of climate change on wave agitation in ports (oscillations due to wind waves) and, therefore, on port operability is analyzed. This is carried out through a numerical model suite, considering the RCP8.5 scenario to project changes in wave fields, and three values of SLR. The study is particularized for the port of Barcelona (NW Mediterranean), but the used methodology can be applied to other harbours. Results suggest that changes due only to waves will be minimal and with a general trend to slightly decrease wave agitation. On the contrary, the effect of SLR and the associated increase of water depth will favor the penetration of waves within the harbour, leading to a certain reduction of port operability, the magnitude of which will depend on the SLR value. However, the complexity of wave patterns within the harbours, due to multiple reflections of waves on port structures, implies that the reduction of operability strongly varies according to the position and orientation of the berthing zones inside the harbour.

1. Introduction

Climate change has become a major focus of attention because of its potential hazards and impacts on the environment, particularly in vulnerable systems like coasts (Sánchez-Arcilla et al., 2011). In coastal areas, vulnerability assessments have focused mainly on the sea level rise (SLR) and its impact on coastal communities (Nicholls et al., 2011), addressing its effects on beaches (e.g. Revell et al., 2011; Sánchez-Arcilla et al., 2011; Monioudi et al., 2016), coastal defense structures (e.g. Isobe, 2013; Lee et al., 2013; Burcharth et al., 2014), coastal ecosystems (e.g. Anon, 2012; Kane et al., 2015), or the flooding of urban areas (e.g. Hallegatte et al., 2011; Paudel et al., 2015).

In addition, SLR is not the only physical process of concern to coastal communities being affected by climate change. Potential changes in wind and atmospheric pressure distributions will modify the wave field pattern (Weisse and von Storch, 2010), which is another essential coastal driver. Indeed, changes in ocean wave climate have been reported in several studies (e.g. Lionello et al., 2008, 2016; Wang et al., 2009; Hemer et al., 2010, 2013b, 2013a; Hemer and Trenham, 2016). The potential impacts of the modification of wind wave properties due to climate change on the coast and nearshore have attracted increased attention in recent years (Zacharioudaki and Reeve, 2011; Adams et al., 2011; Barnard et al., 2014; Sierra and Casas-Prat, 2014; Casas-Prat et al., 2016).

Since seaports are located on the coast or in estuaries, they are susceptible of being affected by both SLR and wave storms. Harbour activities are strongly dependent on wave features, especially in relation with the safe entrance and exit of ships, but also for the regular port operations (Rusu and Guedes Soares, 2013). For these, the wave parameters inside the basin must not exceed certain thresholds, which depend on the type of operation (mooring, loading or unloading) and cargo involved (López et al., 2015). Moreover, as port infrastructures have often been designed for present climatic conditions, they will likely be affected by climate change (Sánchez-Arcilla et al., 2016). The increase in mean sea level or changes in the wave climate will condition essential aspects of harbour infrastructure and operations, modifying their risk levels and economic productivity. This represents one of the main climatic risks in coastal zones, since the contribution of

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ports to the economic activity in the coastal fringe and their hinterland is significant (Becker et al., 2012; PIANC, 2012; Sánchez-Arcilla et al., 2016).

SLR will increase the water depth around and inside the harbour, modifying wave propagation patterns that can in turn produce other impacts on ports, affecting processes such as wave agitation (oscillations due to wind waves within the port), siltation or structure stability (Sierra and Casas-Prat, 2014). On the other hand, changes in wave height will modify the amount of energy entering the harbours, while changes in wave period or direction will modify propagation processes such as shoaling, refraction and diffraction, thus likely inducing changes in sediment transport patterns (potentially generating siltation) or wave penetration into harbours (Sierra and Casas-Prat, 2014), and affecting port operability. All these impacts can be either positive or negative, i.e. they can improve or worsen the operability of ports.

Current port management protocols are not yet considering the effects of these potential impacts on their own operations (Becker et al., 2012), and the studies addressing the impacts of climate change on harbours (e.g. Hanson et al., 2011; Asariotis and Benamara, 2012; Messner et al., 2013; McEvoy et al., 2013; Chhetri et al., 2013; Sánchez-Arcilla et al., 2016) are few compared with the numerous assessments of such impacts on coastal areas (see previous references). Of the former, some focus on the climate change effects on a single process, such as wave agitation in ports (Casas-Prat and Sierra, 2010, 2012; Sierra et al., 2015), port breakwater overtopping (Sierra et al., 2016) or port breakwater stability (Takagi et al., 2011; Mase et al., 2013; Suh et al., 2013), while others analyze the whole vulnerability of ports to climate change and propose adaptation measures (Ng et al., 2013; Nursey-Bray et al., 2013; Becker et al., 2013, 2015; Chhetri et al., 2015).

The aim of this paper is to assess the modifications in port operability times associated to SLR and to wave pattern variations induced by climate change. The study is conducted using a series of numerical models to analyze changes in wave agitation (wind wave heights) within the Barcelona port (NW Mediterranean) produced by the aforementioned climatic drivers. The paper analyzes only inoperability due to wind waves, ignoring other factors that could affect harbour operations (wind, currents), which are out of the scope of this work. Although the study is particularized in a single port, the methodology here described is applicable to any harbour worldwide. Section 2 describes the models and data used. Section 3 presents and discusses the results of the simulations for the different scenarios considered, underlining the implications for port operability. Finally, Section 4 summarizes the main conclusions of this study.

2. Data and methods

2.1. Study area

The Port of Barcelona is located in the center of the Catalan coast (41°21′N, 2°10′E) in the northwest Mediterranean Sea, as illustrated in Fig. 1. In 2014 it was considered the third European port in terms of productivity with a throughput of 45.3 millions of tons, 1.9 million TEU and almost 3.5 million passengers (BPA, 2015). The current port land area is over 1000 ha with 22.3 km berthing length and a depth of up to 16 m. The study has considered 21 zones representing groups of docks with the same type of activity and similar features. In these zones, only commercial berths with a berthing line longer than 35 m are considered. In Table 1, this classification is presented and in Fig. 2 their position inside the port is shown.

Table 1
Berthing zones considered, with their features: length, average depth, use and threshold wave heights (Puertos del Estado, 2000) that allow operations depending on whether significant wave heights are longitudinal (**H_{sL}**) or transversal to the dock (**H_{sT}**).

Zone	Length (m)	Average depth (m)	Use	Threshold wave heights	
				H_{sT} (m)	H_{sL} (m)
1	480	16.0	General & bulk cargo	0.8	1.0
2	500	12.0	General cargo	0.8	1.0
3	1368	11.9	Cruises	0.3	0.5
4	310	8.6	Cruises & yachts	0.3	0.5
5	634	7.5	Ferries	0.3	0.5
6	160	9.5	Ferries	0.3	0.5
7	1388	9.8	Ferries	0.3	0.5
8	374	8.7	General cargo	0.8	1.0
9	850	11.2	Ferries	0.3	0.5
10	241	10.8	Bulk cargo	0.8	1.0
11	419	12.0	Bulk cargo	0.8	1.0
12	198	12.0	Bulk cargo	0.8	1.0
13	1362	14.0	Containers	0.3	0.5
14	350	12.0	Oil products	1.0	1.5
15	460	12.0	General cargo	0.8	1.0
16	348	8.0	Ro-Ro	0.3	0.5
17	1096	11.0	Containers	0.3	0.5
18	258	8.0	Ro-Ro	0.3	0.5
19	997	9.3	Ro-Ro	0.3	0.5
20	1190	12.0	LNG & LPG	0.8	1.2
21	1500	11.7	Containers	0.3	0.5

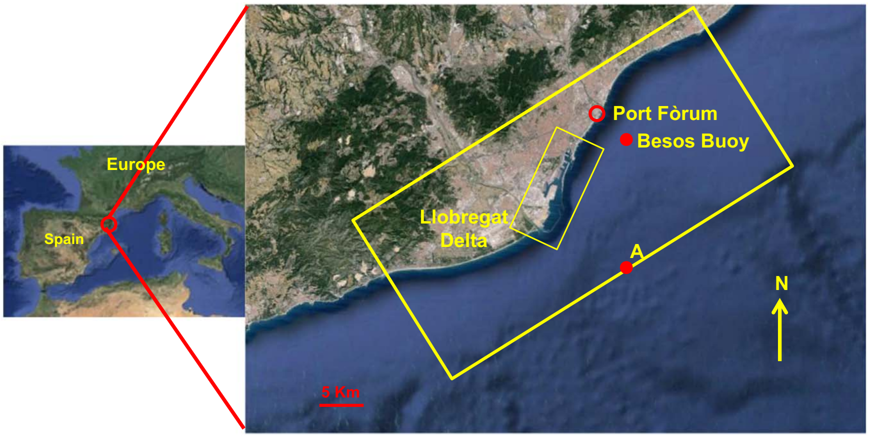

Fig. 1. Location of the port and other points of interest. The rectangles correspond to the two model grids used. "A" indicates the position of the closest grid point from the Mediterranean model.