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Multi-scale variability of storm Ophelia 2017: The importance of synchronised environmental variables in coastal impact

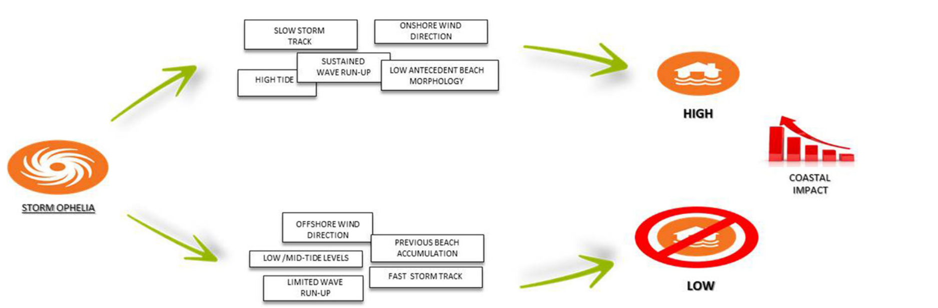
Emilia Guisado-Pintado [a,b,*], Derek W.T. Jackson [b]

[a] Department of Physical Geography and Regional Geographic Analysis, University of Seville, Seville 41004, Spain
[b] School of Geography and Environmental Sciences, Ulster University, Coleraine, BT5241SA, Northern Ireland, United Kingdom

HIGHLIGHTS

- Detailed knowledge of beach behaviour under extreme conditions for future management
- Meteorological, hydrodynamic and topographic data to understand storm Ophelia impact
- Comparison of spatial-temporal environmental parameters and actual beach response
- Lower than expected coastal impacts due to asynchronous environmental parameters
- Previous conditions and synchronicity of environmental variables drive beach response

GRAPHICAL ABSTRACT



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ABSTRACT

Low frequency, high magnitude storm events can dramatically alter coastlines, helping to relocate large volumes of sediments and changing the configuration of landforms. Increases in the number of intense cyclones occurring in the Northern Hemisphere since the 1970s is evident with more northward tracking patterns developing. This brings added potential risk to coastal environments and infrastructure in northwest Europe and therefore understanding how these high-energy storms impact sandy coasts in particular is important for future management. This study highlights the evolution of Storm (formally Hurricane) Ophelia in October 2017 as it passed up and along the western seaboard of Ireland. The largest ever recorded Hurricane to form in the eastern Atlantic, we describe, using a range of environmental measurements and wave modelling, its track and intensity over its duration whilst over Ireland. The impact on a stretch of sandy coast in NW Ireland during Storm Ophelia, when the winds were at their peak, is examined using terrestrial laser scanning surveys pre- and post-storm to describe local changes of intertidal and dune edge dynamics. During maximum wind conditions (>35 knots) waves no >2 m were recorded with an oblique to parallel orientation and coincident with medium to low tide (around 0.8 m). Therefore, we demonstrate that anticipated widespread coastal erosion and damage may not always unfold as predicted. In fact, around 6000 m^3 of net erosion occurred along the 420 m stretch of coastline with maximum differences in beach topographic changes of 0.8 m. The majority of the sediment redistribution occurred within the intertidal and lower beach zone with some limited dune trimming in the southern section (10% of the total erosion). Asynchronous high water (tide levels), localised offshore winds as well as coastline orientation relative to the storm winds and waves plays a significant role in reducing coastal erosional impact.

* Corresponding author at: Department of Physical Geography and Regional Geographic Analysis, University of Seville, Seville 41004, Spain.
E-mail addresses: eguisado@us.es (E. Guisado-Pintado), d.jackson@ulster.ac.uk (D.W.T. Jackson).

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1. Introduction

Most storms that affect the European Atlantic coastline initiate inside the mid-latitude westerly wind belt and are generically referred to as extratropical storms as they are away from the path of tropical storms (Lozano et al., 2004). The movement of cyclones follows general pathways or track corridors (Dawson et al., 2004; Dawson et al., 2002; Dolan et al., 1990; Hayden, 1981; Schmith et al., 1998) and show a general inter-annual variability in the way Atlantic coastal storms occur. Previous work by Dolan et al. (1990) examining damaging coastal storms along the western Atlantic (1942 to 1984) found no real change in the number of storms occurring annually over this period, however, they did show storm duration getting less, due in part to shifting of their tracks to a more northerly route. Increases have been found in the number of intense cyclonic events over the northern hemisphere since 1970 (Lambert, 1996; Schinke, 1993), with clear increases being evident in the number of intense cyclones occurring in the Northern Hemisphere, again possibly being forced by a more northward tracking pattern. In the last four decades of the 20th there appears to be a pattern showing a slight increase in storminess in the NE Atlantic region (Schmith et al., 1998).

Using Global Tropical and Extratropical Cyclone Climatic Atlas data (GTECCA, 1996), Lozano et al. (2004) outlined many of the attributes of storm activity (origins and history) in the NE Atlantic region, focusing on the density of extratropical winter cyclones in the Northeast Atlantic. Data from the GTECCA records demonstrate that most cyclones approach Europe from the western, the vicinity of Newfoundland, and with a majority focussing in southwest of Iceland. Lozano et al. (2004) also show that in general, cyclones move in a southwest–northeast path, parallel to the areas of overall North Atlantic maximum cyclonic activity, occurring closest to the area of highest storm energy in the region and concentrate in a narrow belt around 10^{o}W containing an average central pressure below 986 hPa.

Coastal response to storm events along sand-dominated systems around the world varies according to local conditions, where environmental setting (geological space its contained within), forcing variables such as waves and currents and the actual supply of sediment present in the system all dictate coastal response to storms (Cooper and Orford, 1998). Localised impact has been shown to vary considerably even along relatively short stretches of coastline (Carter and Stone, 1989; Splinter et al., 2018) and be dictated by relatively small-scale topographic variability along the back beach and dune system.

Ireland is not unfrequented by high energy coastal storm events and its western seaboard can be classed as a high energy coastline (Backstrom et al., 2015; Cooper et al., 2004). Impacts from storm events have been reported on its hard coasts (Anja Scheffers et al., 2009; Erdmann et al., 2017; Scheffers et al., 2010) and soft sedimentary coasts (Cooper et al., 2004; Kandrot et al., 2016) with the tail-end of a small number of Atlantic Hurricanes reaching Ireland in the past. Extraordinary events such as the “Night of the big wind” in 1839 (Shields and Fitzgerald, 1989) is believed to have been a Category 3 Hurricane and Hurricane Debbie in 1961 (Hickey and Connolly-Johnston, 2012) are two of Ireland's largest storm events in recent history. Hurricane Debbie is the only Hurricane (Category 1) ever to actually make landfall in *recorded* historical records (Hickey and Connolly-Johnston, 2012) with winds gusting over 177 km h^{-1} as it passed near Ireland's southwest coast and achieving maximum gust levels of around 182 km h^{-1} recorded at Malin Head, Co. Donegal in the NW of Ireland. Hurricane Charley (1986) was considered an extra tropical storm when it hit the south coast of Ireland but in fact it was the tail-end of the hurricane.

The contemporary coast of Ireland may therefore be said to be modally attuned to these high energy conditions, with the morphology of nearshore and shelf sediments modified by high energy forcing. Outside these extreme magnitude events it usually takes a unique combination of environmental parameters to induce significant coastal impact (Cooper and Jackson, 2003). Air photographic and map evidence of storm response obtained from a number of Irish coastal sites (e.g. Orford, 1989) show that extreme storms can invoke dramatic shoreline responses in the form of trimming and coastal retreat. Similarly, observations of storm impacts on beaches in NW Ireland demonstrate rapid erosion of foredunes. These relatively fast responses are, however, typically followed by a readjustment of the shoreline through sediment recirculation within coastal cells and then returned landward over post-storm recovery periods. Therefore, the net impact of such erosional storms in the longer term forces the coastline to fluctuate around an equilibrium position (Cooper and Jackson, 2003).

On the 16th October 2017, the extratropical storm Ophelia reached the offshore western coast of Ireland producing severe thunderstorms, flooding events, power outages and downed trees. By the time Ophelia made landfall in Ireland, it was re-classified as a “post-tropical storm” but just a few hours earlier, it was still a Category 3 hurricane (NOAA, 2017). Ophelia was described as “unusual” as it had the force and effect of a hurricane without the title but also because of its easterly location in this part of the Atlantic Ocean. It is now noted as the easternmost Category 3 Atlantic hurricane ever recorded (NOAA, 2017; UK Met Office, 2017). From 1851 to 2010, only 10 such similar magnitude storms have ever formed within 300 km of Ireland, with the last one being Hurricane Debbie in 1961 (Hickey and Connolly-Johnston, 2012). It took Ophelia <24 h to traverse the Atlantic Ocean to reach Ireland, producing sustained winds (10 min means) of >34 knots and breaking the record for the highest recorded waves at the Kinsale gas platform off the Cork coast with a Significant wave height measured at 26.1 m (Met Eireaan, 2017).

Previous research has highlighted that coastal response and post-storm behaviour present significant spatial variability, generally attributed to variations in hydrodynamic forcing (Burvingt et al., 2017; Guisado-Pintado et al., 2014) whereas on a regional scale beach morphology (Haerens et al., 2012) and geology (Jackson and Cooper, 2009; Jackson et al., 2005; Loureiro et al., 2012) drive the resulting site-specific response. Among the variables that induce morphodynamic impacts associated with high energy events, the time interval between successive storms has been widely assessed. The level of beach erosion resulting from a cluster of storms can be more significant than an individual one with a similar power index to the average storm power of the cluster but also the erosion can be enhanced when they occur at close intervals (Karunarathna et al., 2014). Further, the tidal stage (concurrence with high tidal levels) during the peak of the storm, determines the level of coastal damage (Coco et al., 2014; Masselink et al., 2016) and the impact on the dune-beach system (Dissanayake et al., 2015). The shoreline with respect to the storm track and prevailing wind conditions will also affect the incident wave angle producing sheltering effects, and influencing the beach-dune response to cross-shore and longshore transport (Castelle et al., 2015; Costas et al., 2005). In addition, morphological characteristics of the subaerial beach, and the attributes of local features such as the elevation of the dune toe, dune height, subaqueous sandbars and beach slope all determine the morphological response (Splinter et al., 2018).

In this study, we use hydrodynamic and meteorological information to examine storm Ophelia's spatial and temporal development and associated impacts as it tracked along the west coast of Ireland during the 16th to 17th October 2017. In particular, we investigate morphological changes in the intertidal and dune morphology that occurred as a result of the high energy storm Ophelia on a north western sandy beach where winds were highest. Variables such as storm direction, magnitude (in terms of significant wave height and wind speed), duration of the storm at the study site, tidal stage and water level surge relative to the storm event and the general configuration (morphology) of the intertidal topography pre- and post-storm are considered.