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Morphological impact of a storm can be predicted three days ahead

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ABSTRACT

People living behind coastal dunes depend on the strength and resilience of dunes for their safety. Forecasts of hydrodynamic conditions and morphological change on a timescale of several days can provide essential information to protect lives and property. In order for forecasts to protect they need be relevant, accurate, provide lead time, and information on confidence. Here we show how confident one can be in morphological predictions of several days ahead. The question is answered by assessing the forecast skill as a function of lead time. The study site in the town of Egmond, the Netherlands, where people depend on the dunes for their safety, is used because it is such a rich data source, with a history of forecasts, tide gauges and bathymetry measurements collected by video cameras. Even though the forecasts are on a local scale, the methods are generally applicable. It is shown that the intertidal beach volume change can be predicted up to three days ahead.

1. Introduction

Coastal areas are exposed to extreme natural conditions, such as storm surges, waves, tsunamis, and erosion. Providing warnings is one of the ways to reduce the risk to human life and to allow for property to be protected (Day et al., 1969). Although warnings are not always effective (Normile, 2012), when a disaster is imminent, people expect to be warned (Arceneaux and Stein, 2006).

The need for an improved coastal warning system arose from the disasters that impacted the United States (Katrina, Sandy) and Europe (Xynthia) (Ciavola et al., 2011b). Improving coastal warning systems has become possible due to the improved weather forecasts. Even hard to predict variables like precipitation have seen a strong improvement. The lead time has improved from 2 days ahead in 2001 to 6.5 days ahead in 2014 (European Centre for Medium-Range Weather Forecasts, 2014). The skill has improved due to higher resolution measurements and models and integration of physical and statistical models (data assimilation).

In order for a coastal warning to be helpful it needs to be relevant, accurate, provide lead time, (Baart et al., 2009) and confidence estimates. Previous studies have worked on providing relevant warnings by extending operational hydrodynamic forecast models with forecasts of morphological change (Baart et al., 2009; Plant and Stockdon, 2012; denHeijer et al., 2012; Vousdoukas et al., 2012). Adding morphodynamic processes to a coastal warning system is relevant because the failure modes of coastal dunes depend on morphological change (Sallenger, 2000; Mai et al., 2007). Most of these studies incorporate confidence (Plant and Stockdon, 2012; denHeijer et al., 2012; Baart et al., 2011) and accuracy estimates (Plant and Stockdon, 2012; Vousdoukas et al., 2012), but lack information about lead time (the time between the dissemination of a forecast and the onset of an event (Verkade and Werner, 2011)).

Here we expand on previous efforts by showing how many days of lead time a forecast of coastal change provides during a storm surge. The amount of lead time is evaluated by how much the predictive skill of forecasts improves in the days up to an imminent storm. We add information about the confidence by including confidence intervals around the forecast variables. The extensions to the warning system described in this paper are part of a collective European effort to improve the warning systems (the Morphological Impacts and COastal Risks induced by Extreme storm events (MICORE) project).

Morphological effects of a storm occur at the end of a chain of processes, which can be represented by a chain of numerical models. The last four parts of the chain, which are commonly used

Abbreviation: NCAR, National Center for Atmospheric Research; R, R Project for Statistical Computing; SS, Forecast Skill Score; AC, Anomaly correlation (Wilks, 2011); ASM, Automated Shoreline Mapper; JARKUS, Dutch Annual Coastal Measurement; ECMWF, European Centre for Medium-Range Weather Forecasts; DCSM, Dutch Continental Shelf Model; WW3, Wave Watch 3; MSE, Mean Squared Error; RMSE, Root Mean Squared Error; MCMC, Markov Chain Monte Carlo; MICORE, Morphological Impacts and COastal Risks induced by Extreme storm events; DUROS, DUne eROSion model

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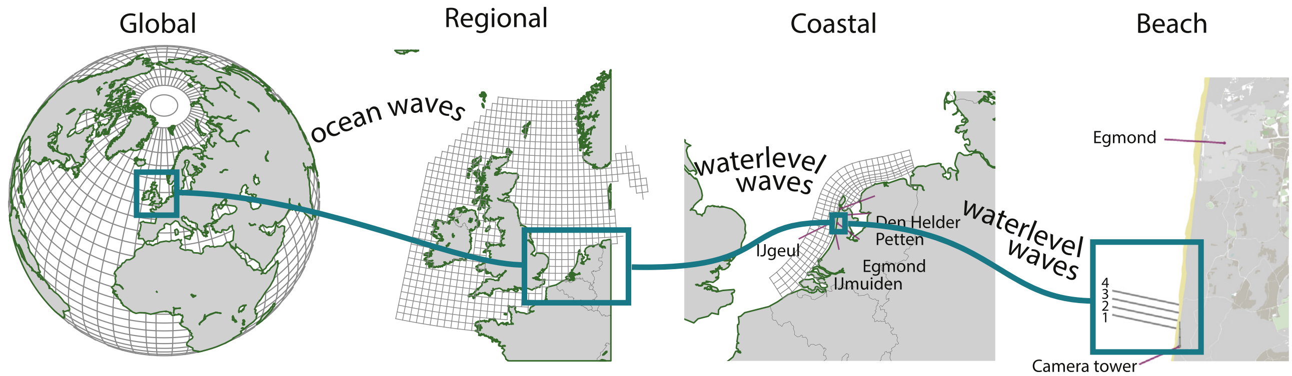

Fig. 1. Nested schematization of an operational morphological model. Applied to Egmond, the Netherlands as described by Baart et al. (2009), extensions described in Section 2.2.

to forecast the coastal morphology, are shown in Fig. 1. Each of these models is based on assumptions, schematizations and reductions of the real world (Oreskes et al., 1994) and can only explain a certain proportion of variance of the quantity for the next link.

The amount of explained variance at the end of the chain is essential in the response phase. More specifically the explained variance as a function of lead time determines the feasibility of different response actions. Given hours, one can close down a beach, but one needs a lead time of days to evacuate a city. In the case of imminent dune failure the morphological forecasts describe the relevant (Morris et al., 2008) process of dune erosion. This raises the question “How many days ahead can we still rely on local morphological forecasts during a storm?”.

For weather and ocean dynamic forecasts it is already common practice to study the forecast skill as a function of lead time (European Centre for Medium-Range Weather Forecasts, 2010). Fig. 2 shows that the forecast skill for the ocean waves are lower than the pressure fields, 60% versus 70% for the 7 days ahead forecast and 92% versus 98% for the 3 days ahead forecast. The skill for pressure fields and ocean waves eventually determines at least part of the skill for coastal morphological forecasts. Pressure anomalies generate wind and surge. During a storm, the local wind generated sea waves and the propagated ocean waves in combination with a surge and high tide can cause severe coastal erosion.

In this paper we extend Fig. 2 with information about forecasting skill for water levels and morphodynamic change. The

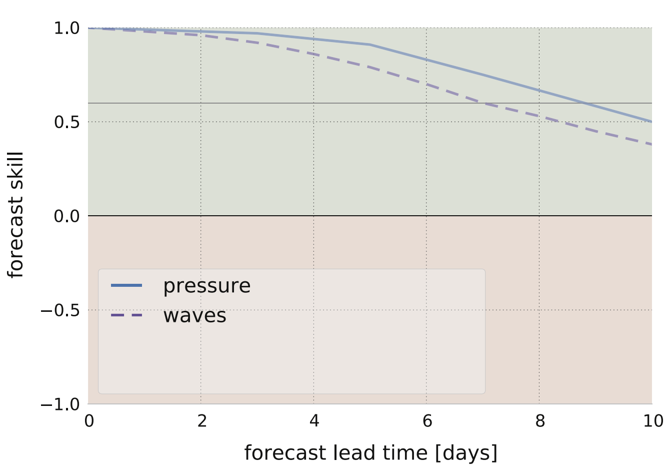

Fig. 2. Skills for pressure, waves as a function of forecast lead time. Pressures are anomaly correlation (Wilks, 2011) (AC) for the ECMWF 500 hPa forecasts (European Centre for Medium-Range Weather Forecasts, 2010), waves are AC for the ECMWF significant wave height forecasts (European Centre for Medium-Range Weather Forecasts, 2010).

coastal hydrodynamic and morphological skill as a function of lead time is most relevant under storm conditions. A local field study is appropriate as no morphological forecast or measurement system exists with a global coverage

2. Methods

2.1. Study site Egmond (the Netherlands)

The requirements of availability of dune erosion events, measurement data and existing near shore models has resulted in the selection of the Egmond study site. The Egmond study site, located on the Dutch coast (Fig. 1), has been used in numerous publications (for example Aagaard et al., 2005). The video measurement stations have generated before- and after storm bathymetry measurements over the last decade. The video system was set up in the CoastView project (Davidson et al., 2007), based on the Argus system (Holman and Stanley, 2007). The morphodynamic forecasts are relevant for the town of Egmond, as it is an area with a high risk of dune erosion (den Heijer et al., 2012a).

2.2. Model setup

The model chain used to forecast coastal change (Fig. 1) is described in detail in Baart et al. (2009). The model chain consists of a global wave model (schematisation: Wave Watch, processes: waves, model: Wave Watch 3 (WW3), with a nested regional (Dutch Continental Shelf Model (DCSM), hydrodynamic and waves, Delft3D, (Gebraad and Philippart, 1998)) and coastal model (Dutch “Kuststrook Fijn”, hydrodynamic and waves, Delft3D). For this study we replaced the water level forecasts by the setup as described by de Vries (2009) (Delft3D replaced by the similar SIMONA model engine), which provides a history of ensemble forecasts. The model chain consists of solely open source models, making the chain verifiable (Kettner and Syvitski, 2013) and reproducible. Other researchers can check and reuse the source code and model schematisations. Replacing model engines by similar components has become easier due to the combined effort of the integrated modeling community (for example Peckham et al., 2013; Voinov et al., 2010).

The last link is the beach model. Four 1D profile models describe the topography and bathymetry of the dunes at the Egmond study site. The model uses the hydrodynamics (water levels, wave energy and direction) of the previous step as input. The numerical model XBeach (Roelvink et al., 2009) is used to describe the nearshore hydrodynamics and coastal erosion. The beach model is schematised using 1D profiles instead of a 2DH bathymetry. The main reason for this is to reduce calculation time. It is believed

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