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# Approaches to evaluate the recent impacts of sea-level rise on shoreline changes

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A B S T R A C T

While global sea level has risen by 20 cm since the mid-19th century, the role of this process in present-day and past shoreline mobility is still debated. In this paper, we review previous studies that explored the relations between sea-level rise and shoreline changes over the last few decades. Existing methods can be classified into two groups: (1) approaches based on the analysis of trends and variability in shoreline change observations, which investigate whether a correlation with the temporal or spatial patterns sea level changes can be established; and (2) approaches based on the comparison of shoreline observations with a coastal model outcome, which attempt to evaluate the contribution of sea-level rise to shoreline mobility using coastal evolution modeling tools. The existing applications of these methods face two common difficulties: first, shoreline data are often lacking or insufficiently resolved temporally to capture the dynamics of coastlines; and second, relative sea level along the coast is generally only known in a limited number of areas where tide gauges are available. These two challenges can be met, owing to the increasing amount of shoreline change observations and complementary geodetic techniques. The wide range of different interpretations regarding the role of sea-level rise in recent shoreline changes highlights the necessity to conduct specific studies that rely on local observations and models applicable in the local geomorphological context.



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## 1. Introduction

Since the late 19th century, global sea level has risen by about 1.6 mm/yr (Church and White, 2011), whereas its rate did not exceed 0.6 mm/yr during the two previous millennia (Kemp et al., 2011). At timescales ranging from decades to centuries, sea level primarily varies because of anthropogenic climate change and its impacts on ice melt and the warming of the oceans (Milne et al., 2009; Church et al., 2011). As sea level is expected to rise further in the future (0.5 to 1 m by 2100 and possibly more, Church et al., 2013), there are increasing concerns about its potential future impacts on coastal zones (e.g., Hinkel and Klein, 2009; Hinkel et al., 2010; Nicholls and Cazenave, 2010; Nicholls, 2011; Hallegatte, 2012; Hinkel et al., 2012; Hallegatte et al., 2013; Mimura, 2013).

One of the expected consequences of sea-level rise is the retreat of shorelines, due to permanent passive submersion (which may affect flat and low-lying areas such as wetlands) or coastal erosion (e.g. Bird, 1996; Stive et al., 2002). The former indicates a retreat of the shoreline caused by an increase in sea level that does not necessarily cause a change in morphology, while the latter commonly refers to a range of different processes that cause morphological changes, such as: coastal sediment redistribution due to waves and currents and their interactions with human intervention (e.g., Slott et al., 2010) or biological processes (Gedan et al., 2011; Storlazzi et al., 2011) as well as other processes affecting coastal cliffs such as abrasion and hydrogeological processes (Regard et al., 2012). The term erosion is also used as a quantitative measure of different variables: the volume or mass of sediments removed from the nearshore zone, or retreat of the shoreline as measured by a wide range of indicators (Boak and Turner, 2005). Hence, passive submersion and coastal erosion can be differentiated by the movement of a volume of sediments, which may be lost from the coastal sediment budget or even redistributed (landward or seaward), but both processes may result in shoreline retreat. Sea-level rise is not a unique process causing shoreline change: instead, numerous factors and processes acting at different spatial and timescales are involved in causing shoreline changes (Bird, 1996; Stive et al., 2002; Fig. 1) and the various types of coastal systems are not expected to respond similarly to the same rates of sea-level change (e.g., Gornitz, 1991; Fletcher, 1992).

While coastal evolution at decadal to multi-decadal timescales remains difficult to predict (Woodroffe and Murray-Wallace, 2012), significant shoreline retreats are expected over the next centuries as sea-level rise will likely exceed 1 m in some locations (Schaeffer et al., 2012). Hence, many coastal sites may experience several transitional stages over the next few centuries: during the first phase, the impact of sea-level changes may remain less significant than those of other coastal processes; then, during a second phase, sea-level rise should significantly exacerbate coastal erosion; and finally, during a third phase (most likely after 2100), sea-level rise may reach several meters and many low lying area may be permanently inundated or dyked and drained. Through an analytical analysis of coastal evolution equations, Stive (2004) suggested that with current sea-level rise rates, most coastal beaches should be presently experiencing the first phase or the early stages of the second phase. The question arises as to whether this statement is confirmed by observations. This question was previously addressed by Bird (1985): by collecting shoreline change observations worldwide in the late 70s and early 80s, he noticed that most of the investigated coastal sites (in particular, 70% of beaches) were eroding. However, he could not find any clear relation between the spatial patterns of global coastline changes and those of relative sea-level rise, suggesting that global sea-level rise is not the unique cause of the global eroding crisis (Bird, 1985, 1987, 1996). Other studies suggest that even moderate rates of sea-level rise can cause significant shoreline retreat (e.g. Zhang et al., 2004), so that what remains unclear is to what extent slight changes of sea level on the order of a few mm/yr have affected shorelines over the last several decades.

This paper reviews existing studies looking at observational evidence of the recent impacts of sea-level rise on the evolution of shorelines over the last few decades. As different conclusions have been drawn from existing studies, we analyze especially the methods, which can be classified in two groups: (1) methods based on the analysis of observations of shoreline changes only (data-based approach, part 2); and (2) methods based on the comparison of

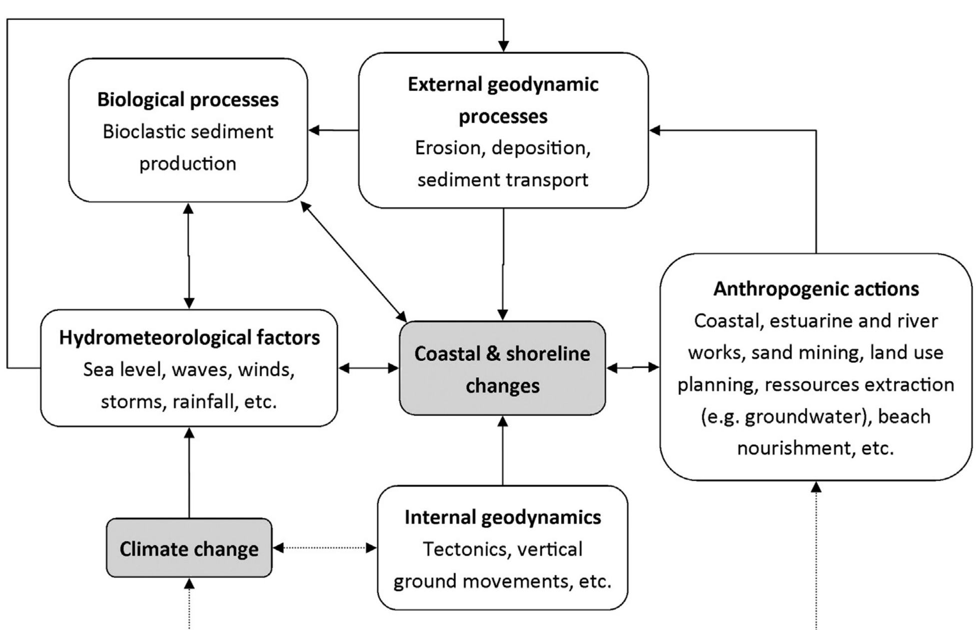


**Fig. 1.** Different categories of factors and processes involved in shoreline changes. Interactions and feedbacks between these factors are indicated by arrows. Because of the multiplicity of factors, processes, interactions and feedbacks, the attribution of shoreline change to one or several causes is complex and difficult.
After Bird (1996), Stive (2004) and Garcin et al. (2011).