

Evaluation of annual mean shoreline position deduced from Landsat imagery as a mid-term coastal evolution indicator



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ABSTRACT

The shoreline is a useful indicator of mid-term coastal evolution. Every shoreline is affected by instantaneous sea-level, the length of the run-up, and beach profile changes. In this work, annual mean shorelines are evaluated in a manner that avoids these effects by averaging the instantaneous shoreline positions registered during the same year. A set of 270 shorelines obtained from Landsat imagery between 2000 and 2014, using the method described in Pardo-Pascual et al. (2012), have been used. It has been shown that the use of annual mean shorelines enables the same rate of change to be obtained as when using all the shorelines, but that the data is simpler to manage and more useful when visualising local changes. It has also been shown that annual mean shorelines largely remove the short-term variability, and are therefore useful for analysing mid-term trend quantifications. In addition, we propose a methodology for annual mean shorelines, obtained from Landsat imagery, that minimises the effects of sea-level variation on the shoreline positions. Both shorelines – instantaneous and mean annual – appear to be about 4 or 5 m seaward from those obtained using more precise sources.

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1. Introduction

Decadal or mid-term beach changes – decades to centuries – are strongly related to variations in storm intensities, patterns of longshore migration of sand waves, as well as changes in beach and dune sediment budgets (Carter, 1988; Kraus et al., 1991; Cowell and Thom, 1994; Pardo-Pascual and Sanjaume, 2001; Davidson-Arnott, 2010). However, these changes are often difficult to quantify using changes in the shoreline because there are too many short-term variations related with water level variation, run-up dimensions, and seasonal beach profile variations (Moore, 2000; Boak and Turner, 2005). Even in microtidal coasts, the shoreline position obtained using various tools (such as aerial photographs, satellite imagery, RTK-GPS, video-monitoring, and LiDAR) is not necessarily the most representative for measuring mid-term evolution. Trend evolution during decades is often masked by considerable variability that follows a cyclical dynamic (annual, or storm/calm periods). To correctly define the mid-term trend it is necessary to obtain sufficient samples of shorelines during a sufficient number of years. This task is usually difficult because there are insufficient sets of aerial photographs or other surveys. The use of mid-resolution satellite

images with high frequency revisit times could be a good solution; however, excessively coarse pixels prevent the accurate definition of shoreline positions when quantifying beach changes (Gens, 2010). Recently, Pardo-Pascual et al. (2012) and Almonacid-Caballer (2014) proposed a methodology to extract shoreline positions from Landsat (5, 7 and 8) imagery (30 m/pixel) with RMSE values of about 5 m. This accuracy has been tested comparing 116 Landsat extracted shorelines with two shoreline segments on seawalls in the Spanish Mediterranean (a micro-tidal area). In this case, it was easy to define the shoreline position because the coastlines do not change over time.

However, on natural beaches, the wet zone can be several metres wide and thus the Landsat shoreline precision for seawalls is not necessarily the same as for beaches. Moreover, on seawall coastal segments, the water depth suddenly falls near the shoreline, whereas on natural beaches the depth drops more gradually. As a consequence of deep water near to the coast, there is a foam fringe associated with the breaker zone which is close to the coastline and narrower in seawall zones than in natural beaches. Unfortunately, no accurate surveying measurements were made when the Landsat images were registered. Thus on natural beaches, we could only check several Landsat shorelines with other nearly co-incident (in time) high precision shorelines.

Another question regards shoreline validity as a trend indicator. Shorelines – understood as waterline borders – are inaccurate indicators of coastal changes because they are strongly influenced by sea-level variations (Moore, 2000; Boak and Turner, 2005; Del Rio and

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Gracia, 2013). Some authors (Stockdon et al., 2002; Ruggiero et al., 2005; Moore et al., 2006; List et al., 2006) suggest that a good solution could be to define a datum-based shoreline, taking 3D data as a basic topographic source and using the contour line that defines the local position of mean high water as a reference. Farris and List (2007) and Psuty and Silvera (2011) used this solution to successfully monitor coastal changes. However, when using shorelines extracted from Landsat imagery it is not possible to obtain this datum-based shoreline because no 3D data coincides with the captured images. This fact means that the shoreline variation between nearby dates was sometimes very large due to small water level changes after the beach profile was flattened by storm waves (Pardo-Pascual et al., 2014). Some works (Robertson et al., 2007) demonstrate that a shoreline change (even working with datum-based shorelines) is sometimes due to small changes in the nearshore microforms rather than real sedimentary changes. Therefore, it seems clear that we cannot guarantee a correct definition of mid-term beach evolution unless we use a sufficient number of shoreline positions.

Taking all these appreciations into account, we can ask if the shorelines extracted from Landsat imagery are useful for quantifying the evolution of beaches on a mid-term scale. This could be important because, in contrast to other data sources, using Landsat data it is possible to obtain many shorelines for each year from 1984 to the present.

The availability of many shoreline positions during one year reduces the risk that the position set is unduly biased by the factors affecting the intra-annual variability. However, it is difficult to perform evolutionary analyses using many lines because it is difficult to recognise the magnitude of the changes when using the traditional techniques of map line overlays (Fig. 1). To improve the efficiency of the analytical process we propose deducing the average shoreline position for a year and so minimising the beach profile cycle changes and the sea-level variations.

Therefore, the main objective of this paper is to evaluate if the annual mean shoreline position extracted from Landsat imagery is a good indicator of beach mean position and can provide significant data to quantify the mid-term beach trend. As an initial test to estimate the precision of Landsat shorelines on natural beaches, some Landsat shorelines were compared to other shorelines registered using very high precision methods surveyed at near the same time. A comparison was then made to see if the use of annual mean shorelines enables the deduction of similar trend evolution values, as when using Landsat shorelines acquired during the period 2000 to 2014. An assessment was then made for testing whether the annual mean Landsat shorelines are sufficiently precise to define mid-term evolution. That is quite difficult because there is no 'true measure' of the mid-term evolution. In order to make a test, the annual mean Landsat shorelines were compared with the mean annual shorelines obtained using data acquired from more accurate tools, specifically several RTK-GPS and LiDAR surveys made on a segment of a beach (9 km long) that has been monitored over a period of six years (2005 to 2010). Likewise, the importance of providing information about beach slope and sea-level position at the moment when Landsat images were acquired was assessed when attempting to correctly define the mid-term coastal trend evolution.

2. Evaluation area

The test was carried out on a 9 km stretch of sandy beach at El Saler (Valencia, Spain) located on the beach barrier that closes a lagoon (the 'Albufera' of Valencia) just south of the Port of Valencia jetties (Fig. 2) (Sanjaume et al., 1996). The test area is formed of sandy beaches (average grain size of 0.21 mm) alongside a dune field (data obtained in summer 2007).

This coast is microtidal as the average astronomical tidal range is less than 20 cm, but the water level position can change more than 70 cm when affected by meteorological factors. In fact, the maximum sea-level variability recorded from 1993 to 2013 by the Port of Valencia tide-gauge was 1.32 m (REDMAR, 2014). The wave regime is

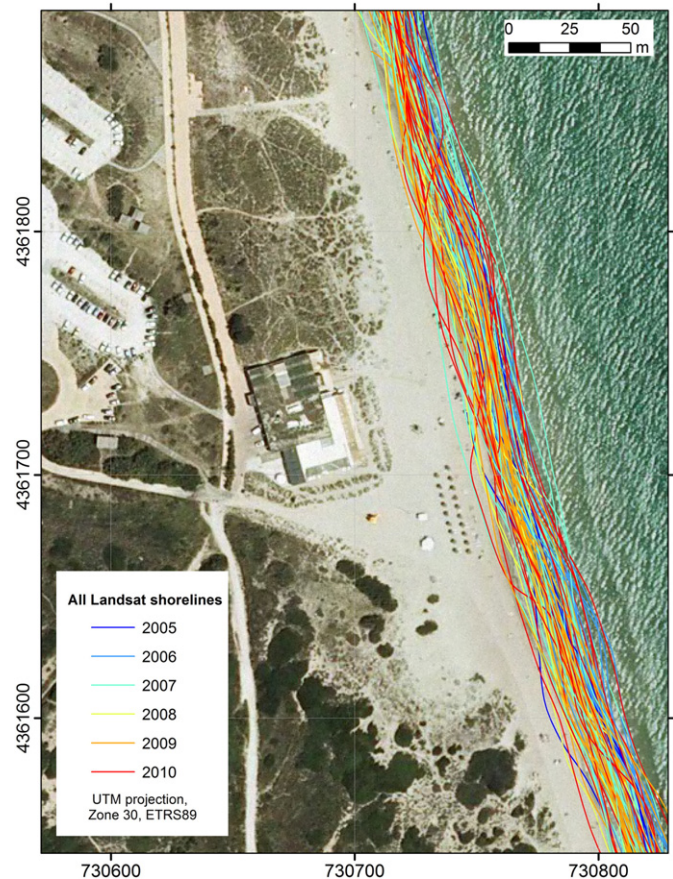


Fig. 1. On the 2008 orthophotograph from the PNOA (National Aerial Orthophotography Plan) some 118 shorelines acquired by Landsat between 2005 and 2010 have been drawn. A different colour has been assigned to each annual set of shorelines. As the maximum change recorded during these six years was about 30 m it is impossible to measure the changes over time.

characterised by low waves (average significant wave height is 0.7 m) and short periods (average peak wave period is 4.2 s). However, wave height during storms can reach 5 m and the peak period may extend to 15 s (Pardo-Pascual et al., 2014). As in many other parts of the Gulf of Valencia, Saler beach has a strong littoral drift that usually causes a significant southerly sand transport. The construction of the port of Valencia at the end of 18th century and successive extensions of its jetties caused a massive erosion south of the jetties as the port structures act as an absolute sediment trap (Sanjaume and Pardo-Pascual, 2005). The erosive impact of the port has gradually been shifting to the south and it is currently mainly affecting the central part of our study area (Pardo-Pascual et al., 2011).

3. Data

To evaluate if annual average shorelines obtained from Landsat imagery can characterise the mid-term trend evolution of a beach it is necessary to:

- Provide a sufficient number of Landsat shorelines (LS) and a sufficient number of shorelines from a more accurate source (high precision shoreline – HPS); and
- calculate the annual average shoreline.

3.1. Shoreline acquisition

A total of (i) 270 Landsat shorelines (LS) acquired between 2000 and 2014 (Fig. 3) were used; and (ii) 17 shoreline positions obtained from RTK-GPS and LiDAR surveys (HPS). In addition (iii) two shorelines

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