Exposure to coastal erosion and flooding in the northeastern Aegean islands, Greece

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Abstract

This paper presents an assessment of the exposure to erosion and flooding of the island beaches of the NE Aegean Sea under the rising relative mean sea level and extreme sea levels (ESLs) due to climate variability and change. An analytical and a dynamic model ensemble are used to predict long-term and episodic beach erosion. For the flood risk assessment two approaches were employed. First, a GIS-based method applied on a 25 m resolution DEM offered a rapid flood risk assessment for all NE Aegean island beaches, whereas the 2-D hydrodynamic model LISFLOOD-FP was used in selected beaches using a fine (2x2 m) resolution grid for detailed projections of the flood extent and depth. The findings show an increased risk of beach erosion and coastal flooding under long-term mean sea level rise and episodic ESL respectively for most island beaches studied. Based on the median estimates of ensemble predictions, it is found that by 2100 and under the RCP8.5 scenario about 30 % of all 658 beaches will disappear completely. Already in 2050, under the moderate RCP4.5 scenario, 40 % of all beaches are threatened with total retreat under the impact of the 1-100 year ESLs. Regarding the flood risk, the supervisory assessment revealed extensive parts of coastline of each island to be exposed to ESL-induced flooding mainly due their low relief. The LISFLOOD simulations for two low-lying touristic sandy beaches in Limnos and Samos under the 1-100 year extreme event showed extended inundation reaching up to 340 m and 107 m, respectively in 2050. Predictions are more severe for 2100, when substantial increases in the flooded areas are expected including for the backshore dune system in Keros beach (Limnos) and protected wetlands in the Potokaki beach (Samos) where negative impacts are also expected for the nearby port infrastructure. Comparison of the two flood assessment methods highlights the increased accuracy of hydrodynamic modelling at local scales.

Keywords: *beach erosion, Aegean Sea, coastal flooding, sea level rise, LISFLOOD*

1. Introduction

Beaches are dynamic coastal environments of high environmental importance that can also act as buffers against the flooding of backshore habitats and assets/infrastructure. At the same time, many beaches worldwide are already under erosion (Mentaschi *et al*. 2018), whether of long-term or episodic nature.

The former refers to the landward retreat of the shoreline due to mean sea level rise and/or reduced terrestrial sediment supply to the coast. In the case of beaches backed by cliffs or human infrastructure such shoreline retreats can lead to permanent beach drowning/loss. In coastal areas, long-term sea level changes are also controlled by the vertical land motions, land subsistence due to negative sediment budgets and aquifer overextraction, and extreme loading due to extensive, high-rise construction (e.g., Cao *et al*. 2021). The latter refers to the temporary beach retreat under the combined action of extreme storm waves and surges. In addition to temporary beach morphological changes such events can result in flood inundation of inland areas.

Coastal extreme sea levels (ESLs) depend on sea level rise, tides, extreme storm surges and wave set-ups. They are also controlled by seasonal climatic periodicities; offshore mesoscale eddies and changes in river flows. These hazards can negatively affect coastal populations, assets/infrastructures and activities as well as coastal habitats and biological resources and are projected to worsen considerably under climate variability and change –both in magnitude and frequency (Vousdoukas *et al.* 2018; IPCC 2019, 2023).

In the Eastern Mediterranean many coastal areas are also major tourism destinations, an economic sector accounting for a large fraction of the GDP in many coastal and island States (UNWTO 2019). The increasing erosion and/or more frequent flooding of beaches and their backshore assets will damage and reduce beach carrying capacity with adverse effects for coastal tourism and other economic activities (Garola *et al.* 2022). Coastal infrastructure, such as seaports and their inland transport connections will be also affected (see UNECE 2020). Coastal habitats, fisheries, aquaculture, as well as coastal agriculture will be also impacted to varying degrees, due to permanent and/or temporary coastal erosion and flooding, aquifer salinisation, seawater acidification, precipitation changes, droughts and wildfires. Therefore, assessments of exposure to the projected erosion and flooding at regional/island scale are needed in order to determine effective protection strategies. The present contribution focuses on climatic hazards and their potential impacts on the Greek islands of the northeastern Aegean Sea and particularly on the effects of sea level rise on coastal areas.

2. The study area

The study area comprises the seven islands that form part of the North Aegean Administrative Region: Lesvos, Chios, Limnos, Samos, Ikaria, Agios Eustratios and Psara (Fig. 1). The area is characterized by a high relief due to complex regional tectonics and comprises different geomorphological units (Poulos 2009) including the extensive N. Aegean Shelf, and the tectonic N. Aegean Trough. It is part of the Aegean Archipelago whose complex physiography results in relatively mild wind and wave climate due to the limited fetches (Monioudi *et al*. 2017) with prevailing wind and waves from the North direction (Androulidakis *et al.* 2015). The area is characterized by a microtidal regime, with tidal ranges rarely exceeding 0.2 m (Tsimplis *et al*. 1995; Marcos *et al.* 2009). Low salinity water inputs received from the Black Sea through the Dardanelles Straits are the main control factors of the complex circulation and hydrographic patterns of the region (Androulidakis and Kourafalou 2011).

The Eastern Mediterranean sea level depends on a number of processes, including sea-level changes propagating from the ocean (e.g. Calafat *et al*. 2012) and atmospheric forcing (e.g., Tsimplis and Shaw 2010). The average rate of mean sea level rise (MSLR) in the Mediterranean was calculated at around 1.7 mm yr^{-1} for the past century (Wöppelman and Marcos 2012). For the Greek Seas, during the period 1993-2021 alone, the average rate of MSLR was estimated at 3.6 mm yr^{-1}, with higher seasonal peaks in autumn and winter linked with low-pressure systems. The morphological complexity of the archipelago decreases the wind impact on storm surge formation compared to the pressure (see Androulidakis *et al.* 2023).

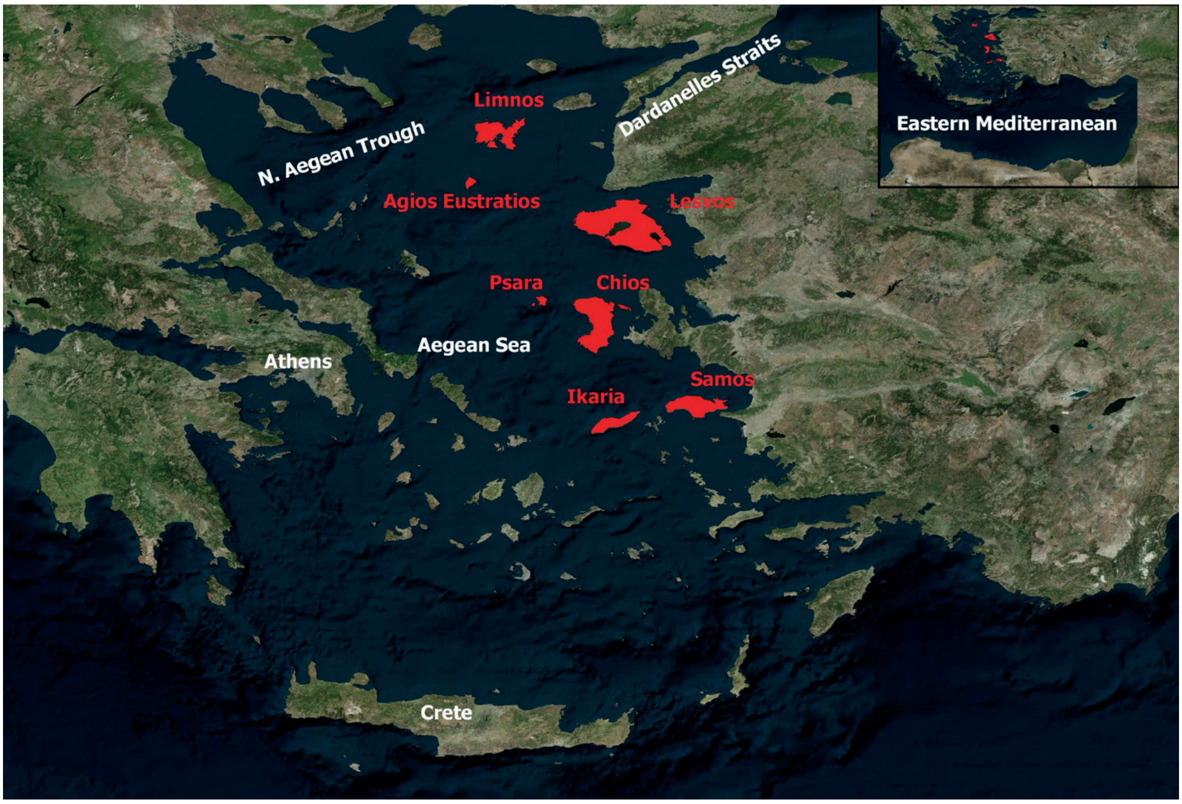

Figure 1. The Aegean archipelago and the NE Aegean islands (shown in red).

In the NE Aegean, the relative sea level rise (RSLR) in coastal waters has been projected as 0.1 and 0.2 m by 2050 under the IPCC RCP4.5 (intermediate) and RCP8.5 (high end) climatic scenarios, respectively. RSLR is projected to accelerate in the later part of the century: by 2100, the RSLR is projected as 0.5 m and 0.8 m under the RCP4.5 and RCP8.5 scenarios, respectively (Jevrejeva *et al*. 2016, Vousdoukas *et al.* 2018) with no spatial differentiations over the Aegean Sea.

Projections of the 1-100 year event ($ESLs_{100}$) for 2050 and 2100 along the Greek coastline (spatial resolution of about 25 km) are found in the global database of Vousdoukas *et al*. (2018). The baseline ESL_{100} (mean of the period 1980 - 2014) varies along the NE Aegean coastline, with the highest values in the Aegean Sea found in the north (Limnos island, up to 1.17 m above MSL). By 2050, $ESLs_{100}$ will increase by 0.12 - 0.25 m under the scenarios studied, with pronounced increases projected for some NE Aegean island coasts. By 2100, ESL_{100} increases might be substantial, reaching up to 0.75 m above the baseline values under the RCP8.5 scenario.

Further, it is noted that highly energetic events (Tropical Like Cyclones - TLCs or Medicanes) are also observed in the Mediterranean (Miglietta and Rotunno, 2019), which can induce catastrophic winds and severe coastal (and inland) flooding (Romera *et al*. 2017; Smart 2020). Projections suggest that these extreme events may become less frequent in the future, while the intensity of the most energetic events may increase.

3. Methodology

Beach exposure to erosion and flooding induced by climate variability was assessed at island scale. First, regarding the erosion risk, projections of waves, storm surge levels and RSLR along the 21st century were assigned for each beach based on the relevant projections of Vousdoukas *et al*. (2018). Second, the long-term and episodic beach erosion for the 658 identified/recorded beaches of the NE Aegean islands were estimated using morphodynamic model ensembles, and compared with present beach maximum widths (BMWs) to assess the impacts. Third, indicative volumes of material for beach nourishment were approximated for each beach. Concerning the coastal flood risk, a GIS-based method was used as a supervisory tool for risk assessment at island scale, whereas a dynamic model (LISFLOOD-FP) was applied in two beaches in order to test its capabilities to resolve the flood risk in fine detail.

3.1 Hydrodynamic forcing

The coastal morphodynamic models that were used for the prediction of beach erosion (see section 3.2) were forced by the projections of the RSLR and Extreme Sea Levels (ESLs) under the RCP4.5 and RCP8.5 which were extracted from the dataset (https://data.jrc.ec.europa.eu/dataset/jrc-liscoast-10012) of Vousdoukas *et al*. (2018). The ESL is driven by extreme weather events and combines the MSL, the astronomical tide (small in the N. Aegean Sea) and the episodic coastal water levels n_{ce} that is the combined result of the storm surge and wave set up, with the latter being generically approximated as 0.2 of the significant wave height H_s. The ESLs used in this study correspond to storm events with a return period T_r of 100 years, for two reference years (2050 and 2100).

3.2 Erosion model ensembles

The projections of the coastal response to sea level rise forcing are based on the results of two ensembles of cross shore (1-D) morphodynamic models:

a) an 'analytical' model ensemble comprising the models of Bruun (1988), Dean (1991) and Edelman (1972); and

b) a dynamic ensemble comprising the numerical models Leont'yev (1996), SBEACH (Larson and Kraus, 1989), Xbeach (Roelvink *et al*. 2009) and a model whose hydrodynamic component is based on the Boussinesq approximation (see Karambas and Koutitas 2002).

The analytical ensemble is set to estimate the long-term beach erosion due to RSLR while the dynamic ensemble is used for the prediction of episodic coastal retreat under ESLs. The approach allows for balanced projections of potential coastal retreat (ranges of minimum and maximum), which can be then compared to the recorded maximum 'dry' beach widths. Further details about the model characteristics and validation will be found in Monioudi *et al*. (2017).

The models were run in a stationary mode, using plausible ranges of beach sediment sizes and bed slopes; the regional scale of the application does not allow for more detailed inputs. The sediment texture was characterized through visual inspection of high-resolution Google Earth satellite images (and relevant photo-images), being classified into 3 classes: stones/gravel, mixed (gravel and sand) and sandy beaches. Since the beach bed slope is likely to be controlled by the beach sediment texture (Reis and Gama 2010), the bed slope range used in the models for each beach was estimated using the values of Table 1. The closure depth - a required parameter for the analytical models - was extracted from the global dataset of Athanasiou (2019).

Table 1. Sediment bed slope and sediment texture (Bujan *et al*. 2019). D_{50}, median grain-size.

Sediment Texture	D_{50} min (mm)	D_{50} max (mm)	Bed Slope (min)	Bed Slope (max)
Sand	0.2	0.5	0.034	0.05
Mixed	0.8	1	0.067	0.1
Cobbles/Pebbles	2	5	0.1	0.1

Finally, the median values of ensemble predictions of beach erosion/retreat were calculated for each beach and compared with the recorded 'dry' maximum beach widths to get an indication of the beach erosion impact, including beach carrying capacity and backshore infrastructure/assets.

The maximum 'dry' beach widths were recorded through beach polygons digitized on the available high resolution Google Earth images and are contained in the (AEGIS+) beach repository for the NE Aegean islands along with socio-economic and environmental beach variables (sdi-portal.aegean.gr/portal/apps/webappviewer/index.html?id=b71071d0730740a499a1ca41385b3802). On the basis of a multicriteria analysis (for more information about the methodology, see Andreadis *et al*. 2021) involving a subset of these variables, the beaches of all islands were graded according to a Beach Vulnerability Index (BVI) based on their erosion risk and their socio-economic significance.

In addition, the required volumes of marine aggregates (Velegrakis *et al.* 2010) for implementation of beach replenishment schemes were estimated for every beach following the approach of Equilibrium Beach Profile proposed by Dean (2002). The granulometry of the filling sediments was chosen to be the same with the native material while the beach berm height was associated with the sum of RSLR and the wave runup (approximated by the parametric relationship of Stockdon *et al.* (2006). Nourishment volumes were estimated on the basis of beach protection under extreme storm events. Therefore, the beach erosion projections of the dynamic ensemble for 2050 were considered to be remedied through beach replenishment and the desired offshore extensions of the eroded beaches.

3.3 Flood risk modeling

The flood risk was assessed using two different approaches: a static method based on GIS and a dynamic method based on hydrodynamic modeling. Under the static method the areas prone to flooding are identified as those with elevation lower than the projected ESL. This method, known as 'bathtub approach', has been widely used in previous studies on flood risk assessment (Kont *et al*, 2008; Seenath *et al,* 2016). In the present study it has been applied for a supervisory assessment of flood risk on all the beaches of NE Aegean islands using a 25 m resolution Digital Elevation Model (DEM) (https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/elevation/eu-dem).

In addition, a dynamic approach was also used to assess the flood risk in selected NE Aegean beaches, using the 2-D model LISFLOOD-FP (Bates and de Roo, 2000). The model uses a structured grid and a raster coastal DEM. Hydraulic continuity principles are applied to calculate water depth in each cell of the raster grid and water is routed across the terrain based on the difference in hydraulic head between adjacent cells. Flow rates are computed based on terrain slopes and the Manning friction coefficient. While the model was initially designed to simulate river floods, it is increasingly used in coastal flood applications as well (e.g., Le Gal *et al.* 2022).

The LISFLOOD-FP model was used for selected beaches. For the selection both the BVI ranking and suitability for the LISFLOOD-FP application were considered, so that sites that form wide areas with low bed slopes resembling floodplains were prefered. Representative examples cases are shown here, for Keros beach in Limnos and Potokaki beach in Samos. In addition to the selection criteria discussed above, both beaches, listed among NATURA 2000 sites, are of high environmental value.

The model was applied to the 1-100 year extreme event under the RCP8.5 for the two reference years 2050 and 2100. The hydrodynamic forcing involved the ESLs estimated for these beaches and set along the shoreline boundary; the storm duration of the simulation was set to 10 hours, following the analysis of Mediterranean storm events (Martzikos *et al*. 2021). A high resolution (2x2 m) DEM available from the Greek Cadastre was applied for the subaerial topography, while the Manning friction coefficient was estimated through the Land Use/Land Cover types according to Papaioannou *et al*. (2018).

4. Results

4.1. Beach erosion predictions

4.1.1 Long term erosion

Regarding the long-term beach erosion due to RSLR, the predictions of the analytical ensemble for 2050 under the RCP4.5 scenario range between 1.9 and 4.7 m. For 2100, under the RCP8.5, beach erosion ranges between 7.7 and 23 m. The projections indicate that by 2100 68.7 % of all NE Aegean island beaches will retreat/ be eroded by at least 50 % of their currently recorded maximum 'dry' beach width (BMW), whereas 29 % will retreat by a distance equal to their BMW (Fig. 2). The most severe results concern the four larger islands (Lesvos, Chios, Lemnos and Samos) where 76.5 % and 35.6 % of the beaches will retreat by 50 % and 100 % of their current BMW respectively. Given that the majority of island beaches in NE Aegean are pocket beaches backed with cliffs and/or coastal assets that do not allow landward beach migration, these beaches are threatened with permanent drowning/extinction. Clearly, the long-term beach erosion will substantially reduce the beach carrying capacity and aesthetics, with negative economic consequences on the local tourist industry.

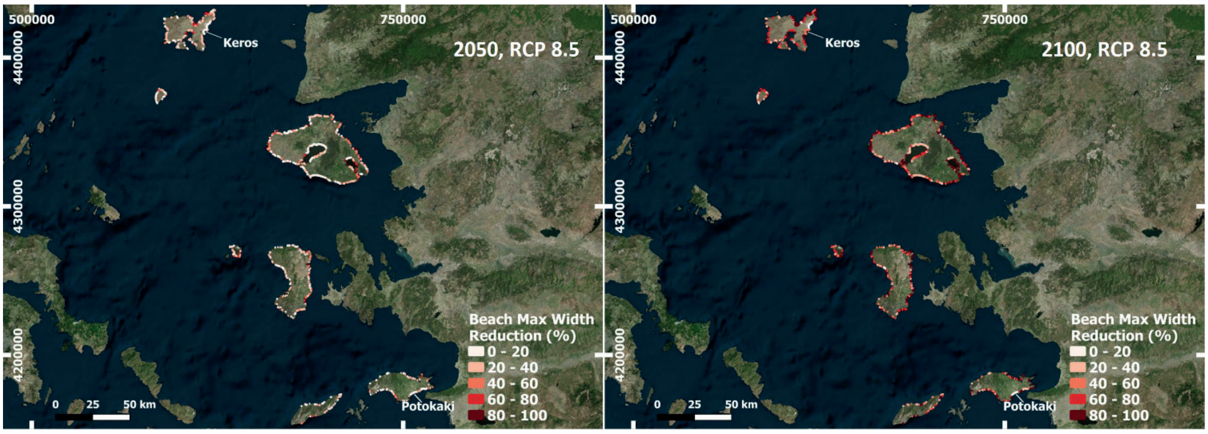

Figure 2. Median predictions of long-term erosion, expressed as percentage of the recorded beach maximum width, for the beaches of NE Aegean islands for 2050 and 2100 under RCP8.5 scenario. Red colours indicate higher reduction of beach width compared to the recorded values.

4.1.2 Episodic erosion

Regarding the episodic beach retreat, in 2050 under the intermediate scenario (RCP4.5) the median coastal erosion is estimated as high as 17.7 m (range of 9 – 29 m) while under the RCP8.5 it increases to 25 m (range of 13.5 – 41.5 m). When comparing the predictions to the recorded dry maximum beach widths it appears that in 2050, under the RCP4.5, 78.4 % of all beaches will at least temporarily retreat by 50 % of their maximum 'dry' width; 40.8 % of them are projected to temporarily retreat/be eroded by a distance equal to their BMW. Erosion predictions are even worse for the remaining cases examined, as 58.7 % of all beaches would face temporary extinction under extreme events in 2100 (RCP8.5) (Fig. 3). One notes again that beach erosion will be particularly pronounced in the four larger islands (Lesvos, Chios, Limnos, Samos), where 73.5 % of the beaches are projected to be totally eroded (at least temporarily) under the tested extreme events in 2100 (RCP8.5). The impact of erosion may be devastating for the (current) backshore assets if no protection measures are taken. Focusing on those beaches (134 out of 658) where 25 % of the length at least is backed by assets, it is projected that under an extreme event, based on the moderate RCP4.5 scenario, 48.5 % of them will be fully eroded (at least temporarily) in 2050, threatening with damages or total losses the backshore assets. Predictions are worse for the other scenarios examined, as up to 72 % of the beaches may face temporary extinction under an extreme event for the RCP8.5 scenario in 2100.

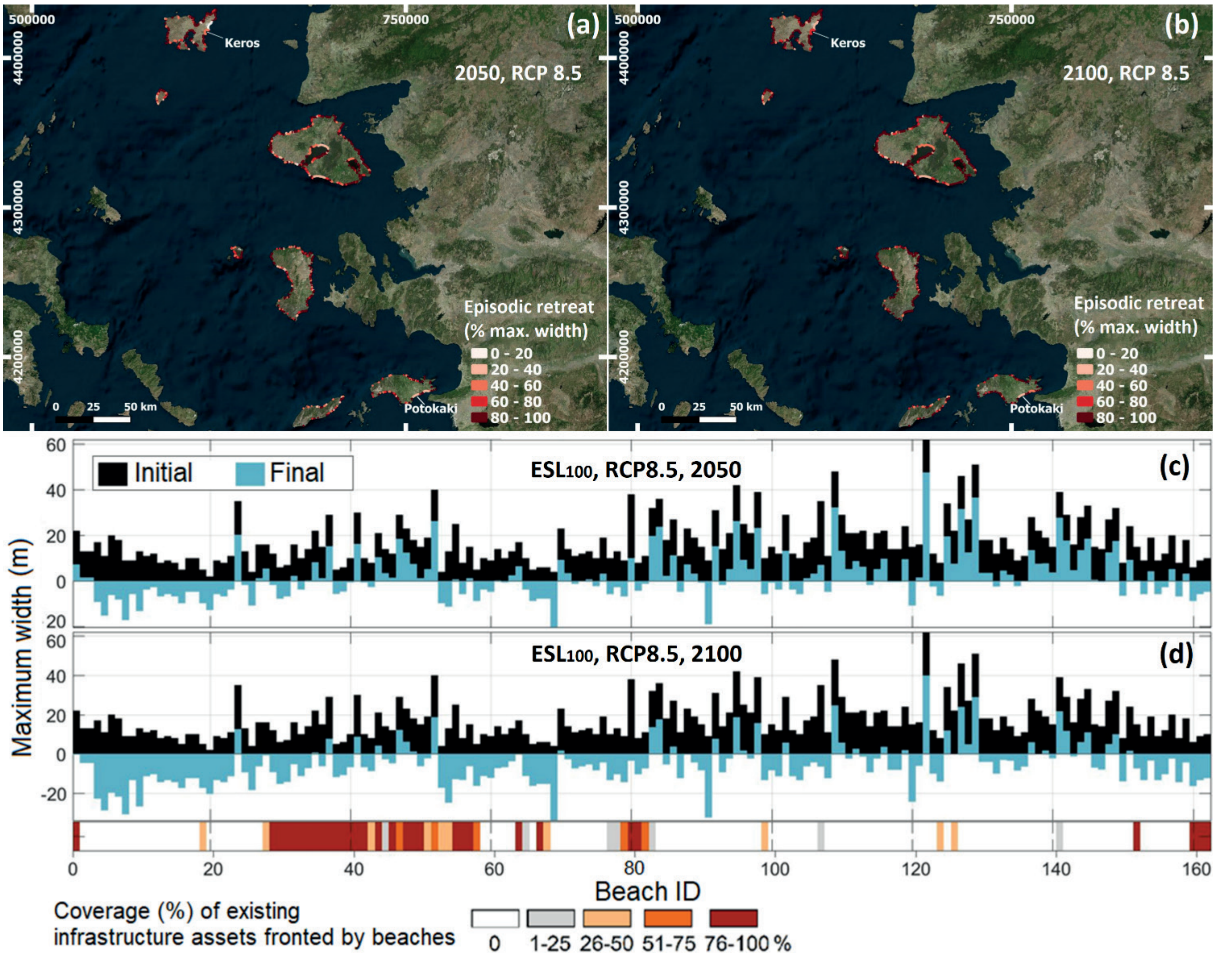

Figure 3. Median predictions of episodic erosion, expressed as percentage of the recorded beach maximum width (BMW), for the beaches of NE Aegean islands in (a) 2050 and (b) 2100 under the RCP8.5 scenario. Red colours indicate higher reduction of beach width compared to the recorded values. In the lower panels (c) and (d), the (median) projected episodic retreats are shown together with the recorded coverage of the frontline backshore assets (as a percentage of beach length); the current (initial) BMWs (black bars) are compared to those resulting from the beach retreat projections (blue bars); negative values indicate beach retreat more than the current BMW.

An estimation of the required material volumes for beach replenishment yields varying results ranging up to 2,259,640 m^3, with maximum values corresponding to beaches longer than 7 km (e.g., Kalloni beach, Lesvos). As an indication, for two long touristic beaches, Keros and Potokaki (Figs 2, 3), the required volumes have been estimated between 1,445,890 – 1,537,110 m^3 and 504,750 - 619,320 m^3.

4.2. Flood risk assessment

The outputs of the bathtub method show that most beaches of Limnos and Lesvos will be inundated under an extreme event, especially on the SW and NW sectors respectively. In Chios, flooding is projected mainly for the SW coast, while it is predicted for nearly all beaches along the northern coast in Samos. Overall, the severity of flooding increases through the different scenarios, with the maximum flood depth projected at 1.28 m under RCP4.5 for 2050 and at 1.89 m under RCP8.5 for 2100 (Fig. 4).

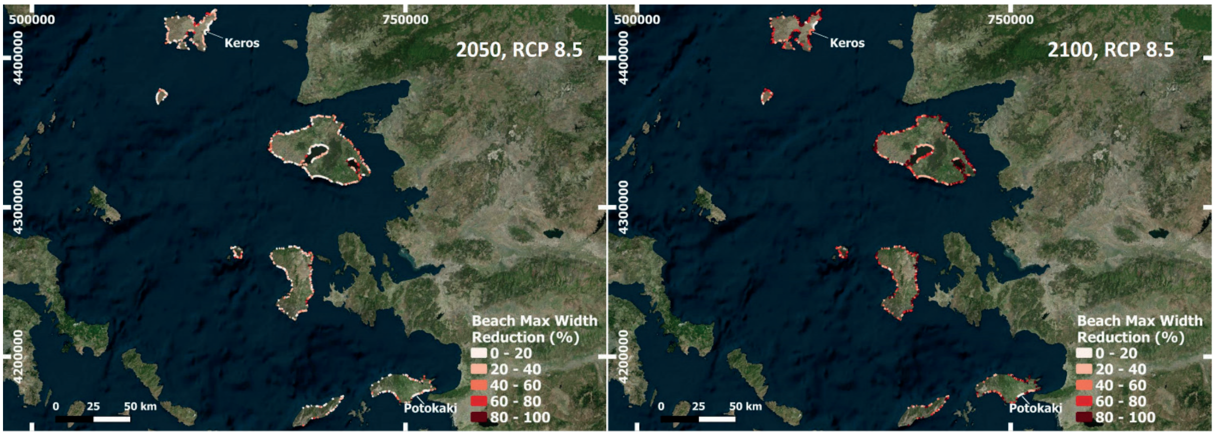

Figure 4. Predictions of flood risk for the beaches of NE Aegean islands for 2050 and 2100 under RCP8.5 scenario. The different colours stand for the estimated flood depth, with red colours indicating higher flood depths.

The following section will provide examples of the application of the dynamic method in selected beaches. Keros beach is a 5 km long, relatively narrow beach on the eastern coast of Limnos (Fig. 3). It is one of the NATURA 2000 sites. An extensive dune system with low vegetation forms its inland boundary which extends further inland along the central and northern part of its backshore. Further inland the protected Asprolimni and Chortarolimni bird habitats are also found. Projections (see Fig. 5) show that a large part of the area will be flooded with a maximum flood extent of 340 m for both reference years, with a 100 % flooding of the beach. By 2050 already, the coastal flood may inundate a substantial part of the backshore, especially in its northern and southern sections.

In 2100, the inundation extent appears much higher as most sand dunes will be overwashed and the flood will propagate further inland (as far as 70 m) in the central section of the beach, inundating up to 50 % of the backshore dune system. Furthermore, in the southern section between the beach and Chortarolimni, more than 1700 acres of land are projected to be flooded. Taking into account that LISFLOOD does not incorporate morphodynamic processes such as dune breaching, these projections may be conservative.

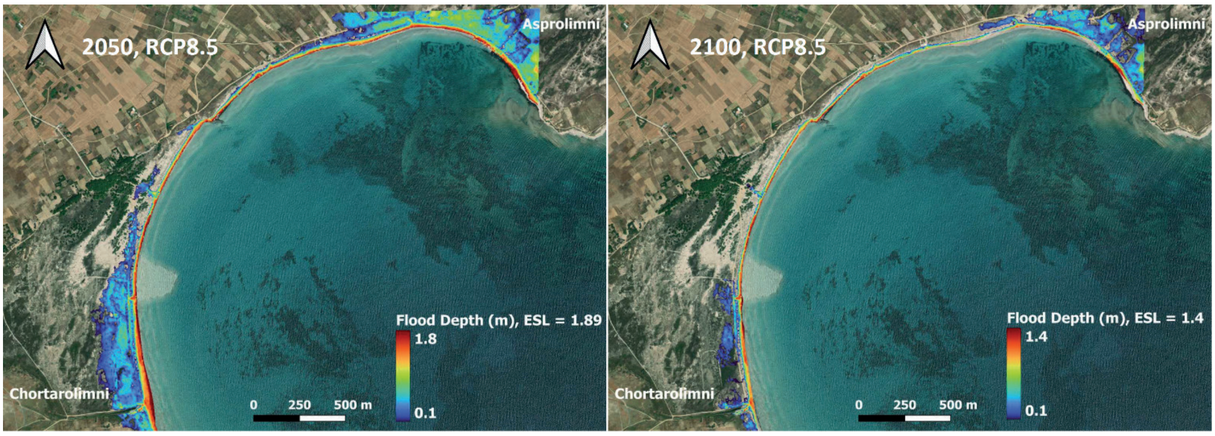

Figure 5. Flood extent on Keros beach for 2050 and 2100. The different colours stand for the estimated flood depth. On the SW edge of the site is the Chortarolimni habitat and on the BE edge the Asprolimni habitat.

Potokaki beach (Samos) is a 4.6 km long and narrow (20 m) low lying beach (Fig.3). At its backshore, the eastern end of the Samos airport runway is located, whereas there is also significant coastal development settlement and a wetland protected habitat. The city of Pythagorio and its port are located to the northeast of the beach. The LISFLOOD simulations project flooding for large areas (Fig. 6), with a maximum flood extent of 107 m in 2050 and 220 m in 2100; corresponding flood coverage of the beach are 87 % and 100 % respectively. By 2050 already flood is shown to inundate large parts of the backshore coastal development as well as the coastal road and parts of the wetland protected habitat. In addition, the main dock at the port of Pythagorio will be fully inundated, as well as the other port infrastructure.

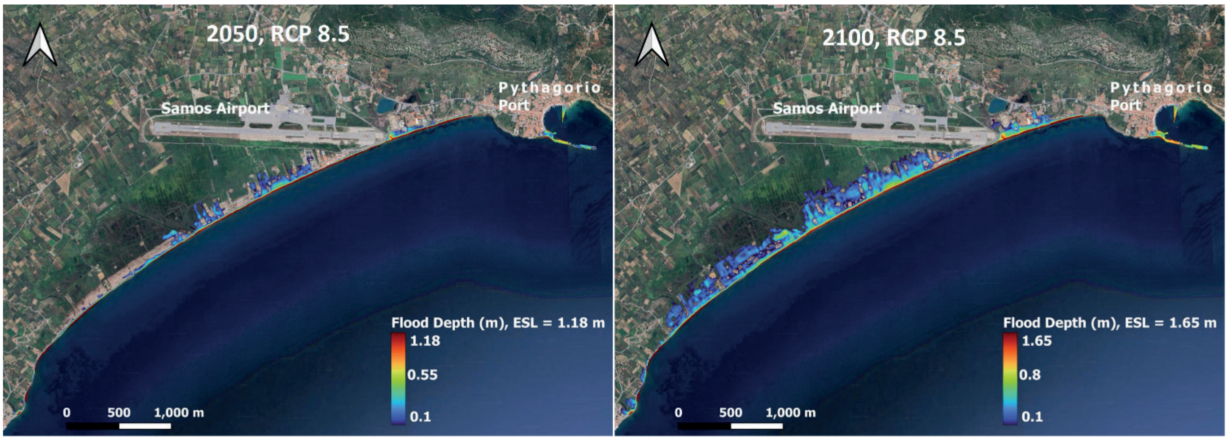

Figure 6. Flood extent on Potokaki for 2050 and 2100. The different colours stand for the estimated flood depth. On the east side the city and port of Pythagorio are shown.

Predictions are worse for 2100 when more than 50 % of the backshore assets/infrastructure are projected to be inundated, with flood depths reaching up to 0.5 m. Flood extent in some locations reaches the road between the airport runway and the beach, whereas 28 acres of the wetland are also flooded. In the port dock severe flooding is projected, with flood depth up to 0.8 m.

5. Discussion and conclusions

Our findings show an increased risk of beach erosion and flooding for most island beaches in the NE Aegean Sea. Compared to the current maximum beach dry width, it appears that 29 % of the beaches will permanently retreat by a distance equal to their current maximum width by 2100 due to the slow-onset RSLR. Moreover, severe erosion is predicted under an -100 year extreme event. Between 40.8 % (RCP4.5, 2050) and 58.7 % (RCP8.5, 2100) of all beaches are projected to be entirely eroded, at least temporarily. These estimates fall within the ranges found in a previous beach erosion study in the Aegean Archipelago (Monioudi *et al*, 2017), in which the hydrodynamic forcing included slightly different RSLR values (Hinkel *et al*, 2014) and the ESLs were based on storm level predictions without considering changes in the return period (Tsimplis and Shaw, 2010). Based on the minimum and maximum estimates of model ensembles instead of the median value, it is found that by 2100 between 12.4 - 68 % and 39.1 - 91 % of all beaches will face total permanent and temporary erosion, respectively. In an erosion assessment of the Cyprus beaches (Monioudi *et al*, 2023) which are also characterized by narrow widths and limited terrestrial sediment supply similar to the NE Aegean islands, the median estimates of the model ensemble project similar rates of erosion, indicating increasing pressure on the Mediterranean islands.

Our findings further suggest that by the end of the century the exposure to episodic erosion will increase mostly due to RSLR, as storm surges and waves in the Aegean Sea are not projected to change substantially over time (Androulidakis *et al*. 2015). Therefore, our results correlate well with those of the global analysis on future erosion of sandy beaches (Vousdoukas *et al*. 2020), which showed an increasing erosive trend driven mainly by RSLR, which may result in the extinction of about half of world's beaches. The relative importance of storm driven erosion due to the 1-100 year event was found to decrease with time; however, the authors underlined the increased vulnerability of backshores to coastal flooding under storm events, due to the predicted long-term erosion.

Regarding the calculation of flood risk two distinct approaches were used. First, a supervisory flood index was estimated for all beaches with the bathtub approach applied on a 25 m resolution DEM, which was considered sufficient for island scale applications. Exposure to flood risk was studied in more detail in selected beaches, using the LISFLOOD hydrodynamic model on a fine (2x2 m) grid with increased elevation accuracy compared to the 25 m DEM. Results of the two methods were compared for the Potokaki beach in order to highlight the advantages of the numerical simulation over the GIS based method (Fig. 7). Although outlier points that were not hydraulically connected with the rest of the predictions were manually removed, inundation is still highly overpredicted by the bathtub approach with maximum values extending more than 500 m inland compared to LISFLOOD maximum extent. The predicted flooded area in the wetland is estimated ten times higher than with the numerical model (374 vs 38 acres). The main reason behind these discrepancies is that bed friction effects on the water flow dynamics are simply ignored by the GIS method (Seenath *et al*, 2016). In addition, overestimation is introduced by the elevation inaccuracies on the 25 m DEM; in the wetland elevations are found to be systematically 1 m lower compared to the Greek Cadastre fine DEM. These differences seem to substantially mislead the GIS analysis when comparing with an ESL of 1.18 m. Overall, together with Seenath *et al*. (2016) we find the bathtub approach appropriate for rapid flood risk assessment on large scales, where numerical modeling on fine grids is not applicable due to the computational cost. In addition, LISFLOOD-FP provides outputs of flood evolution at defined timesteps, which can be crucial on the coastal management and preparedness to flood risk.

Figure 7. Comparison of flood inundation extent as predicted by the bathtub method (red line) and the LISFLOOD simulation (yellow) for the Potokaki beach (RCP8.5, 2050).

Collated information on the beach natural and socioeconomic characteristics (not shown in detail in the present article) can be highly beneficial when assessing the exposure to erosion and flood risk on island/archipelago scale. Recording of the recent beach maximum widths is crucial in order to identify those most exposed to erosion. Furthermore, recording of backshore assets allows identifying sites where erosion/flooding will potentially have the greater negative consequences on human assets and activities.

The severe predictions for the majority of NE Aegean island beaches imply that immediate action should be taken for the design of coastal protection and mitigation. Art. 8.2 of ICZM Protocol to the Barcelona Convention (ICZM 2008), which refers to the allocation of 'set-back' zones where further development and construction shall not be allowed, could be beneficial for the beaches in the region, where asset density is relatively low. Greece, however, has not yet ratified the ICZM Protocol and it currently defines set-back zones with a maximum width of 50 m. To gauge the perceptions and policy prioritization by local decision makers, a structured process is required through which priorities could be identified in terms of wider policy objectives (e.g. Kontopyrakis *et al.* 2024). This prioritization can affect the distribution of the available human and financial resources for efficient management responses. Local decision makers in coastal planning, and a crucial control of the coastal climatic exposure. Clearly Existing ICZM policies and legislation should properly take into consideration the local perceptions and environmental and socio-economic particularities.

In addition, hard engineering solutions such as offshore breakwaters, appear inadequate to protect beaches against RSLR (Dean and Houston 2016) and are more expensive (Narayan *et al.* 2016) than nourishment projects which through beach widening simultaneously protect backshore assets, increase beach carrying capacity for leisure activities and do not disturb beach aesthetics (Cantasano *et al*. 2023).

Finally, it must be noted that EU Member States must comply with the Flood Directive – FD (2007/60/EC) which establishes a framework for flood risk management, including in coastal zones, and requires coastal flood risk assessments, mapping of flood extent, of assets and humans at risk, plus adequate and coordinated measures to manage the risk. The results of this study provide a first approximation of the required information, as well as indications on the needed approach for the accurate mapping of flood extent and quantification of its potential impacts.

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