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ASSESSING FUTURE LOCAL SEA LEVEL RISE IN THE ISLANDS OF THE OUTERMOST REGIONS OF THE EUROPEAN UNION

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Abstract:

The aim of this paper is to develop a methodology to calculate the sea level rise (SLR) caused by global warming in the Outermost Regions (ORs) of the European Union, mostly represented by islands. ORs are especially vulnerable to SLR since their economies are based mostly on coastal activities. There is a lack of studies at local scale about this phenomenon, mainly caused by the data requirements of the statistical methods used to predict future SLR. Long-term series of tide gauges located on ORs often do not meet the needs of these methods. Therefore, in this paper we proposed a methodology based on the comparison between observed local (from tide gauges of ORs) and global SLR time series. It allows to estimate SLR from short or incomplete time series for future scenarios in ORs SLR. In general, the results show that most of the ORs will suffer from a significant SLR. The differences between the predicted SLR and the expected sea level rise according to future scenarios are not minor.

Keywords: *sea level rise, ORs, trends, projections, climate change scenarios, EU*

1. INTRODUCTION

The concern about the effects of sea level rise (SLR) as a result of climate change has grown since the last decade, leading to strong efforts in reviewing the records of tide gauges and satellite data (e.g., Cazenave and Llovel 2010; Church and White. 2011; Meyssignac at al. 2011, Meyssignc and Cazenave, 2012) and in assessing SLR impacts in several coastal settings worldwide (National Research Council, NRC 2010; IPCC, 2013, Horton et al., 2014).

Since the first tide gauges were installed by the 19th century, global sea level has been steadily rising at a rate of +1.7 mm/year during the period 1901-2010 (IPCC 2013) and up to +2.0 mm/year since 1971 to 2010. If we focus on the period 1993-2010, the results are even higher, with values of +3.1 mm/year (IPCC, 2013). The changes in the trends of the sea level were recorded by tide gauge registers -the only source of information until 1992- and altimetry satellites, which measure the height of the sea surface in ocean waters since 1992.

The scientific consensus about the occurrence of SLR is nearly absolute although the extent and magnitude remain uncertain. This is due to two reasons: a) the lack of awareness about which future scenarios involving the emission of greenhouse gasses might take place and b) the uncertainties about the models of SLR, especially in the last 10 years, after the works of Pfeffer et al. (2008), Rahmstorf (2007) or Mitrovica et al.

(2011), which have remarked the differences between the expectations according to IPCC models and the records of tide gauges and satellites during the last 20 years. IPCC report of 2013 did not determine which of the two main approaches about future SLR is right.

While a number of recent studies focus on the global SLR and its causes for the past few decades, less attention has been given to the local expectations of SLR. Further the discussion about SLR scenarios, many researchers have carried out local studies to estimate future impacts (e.g. inundations, flooding processes). In order to determine the local impacts of SLR it is necessary to consider not only the water rise but also the vertical movements of the land, which have been widely reported as even higher than the vertical movements of water (Tosi et al., 2007; Gilman et al. 2007; Woodworth et al., 2009). Three different approaches have been developed to estimate future impacts of SLR in local areas:

i) A simplistic approach, using global SLR scenarios to estimate future local inundation, without taking into account local tide gauges data (Titus and Richman, 2001; Yin et al. 2009).
ii) An intermediate approach, adding the local calculated trends to the projections of global sea level rise. This approach might lead to double counting (Titus and Narayanan, 1998) whatever is the portion of the historic local trend caused by eustatic movements (Lambeck et al., 2011).
iii) A detailed approach, in which it is assumed that any detected SLR in a particular location contains contributions both from global changes in ocean level and from vertical movements of the ocean or the land upon which the gauges are situated (Woodworth et al. 1999), leads to remove the globally detected value of SLR during historic times (varying from 12cm to 18cm in the 20th century) from any calculation of future SLR.

In the past, when most of the research was focused on the implications in the interval 1-2 m SLR, there were hardly any differences between the implications of the three approaches (Titus and Narayanan, 1998). In the last two decades, this topic became much more important when most of the SLR projections made by different authors and institutions were below 1 m, and the accuracy of any prediction became smaller.

Titus and Narayanan (1998), proposed to remove the local trends in tide gauges time series analysis. Thus, the future projections in the local trends estimated from a global model of SLR were changed by the data measured in the long-term time series (more than 100 years). According to these authors, the time series had to be continuous, with no missing years. Although this methodology has been widely cited by several authors (Nicholls et al. 2011, Little et al. 2013, Moss 2001, Emrich and Cutter, 2011, Fraile-Jurado et al. 2017), most of the citations refer to its probabilistic concept of SLR, but not to the method of removing the effects of observed local SLR.

During 21st century, other approaches have been used, especially those based on empirical orthogonal functions (EOF) (Meyssignac at al. 2012). Nevertheless, the requirements of these methodologies are the same as the previous one: the availability of continuous time series data provided from different tide gauges. The improvement of requirements to carry out this analysis would mean an important advance in areas with incomplete records or short time series. The development of future SLR expectations based on the existence of long time series or neighbour time series is not suitable for the ORs of the European Union (EU) since most of their tide gauges have measured SLR only for a few decades, or the neighboring tide gauges are located thousands kilometers away.

ORs, specifically islands, are vulnerable areas to SLR and climate change (IPCC, 2013). Hence, most of the research about islands and SLR has been focused on the risk of disappearance (completely or partially) of islands, mostly located in the Pacific and Indian Ocean (Jayaprakash et al. 2016). Nevertheless, there are no studies about SLR expectations specifically in islands. This is even more relevant when considering that islands are especially vulnerable territories to SLR. Their economies are highly dependent on their harbors, tourism beaches, infrastructures, or natural protected areas, often dealing with a high ecological importance (Ellison and Stodart, 1991; Woodroffe et al., 2016, Peña-Alonso et al., 2017). In recent years, the assessments about sustainable coastal tourism have become a common topic (Mínguez, 2012; Barman et al. 2015; Safarabadi et al., 2016), although it is poorly considered by the media (Gómez-Martín et al. 2014).

Establishing a threshold that defines flooded territories in the future is essential for planning and developing natural hazard assessments. However, SLR is not included in most of the urban and territorial planning (Barrera Fernández and Hernández Escampa, 2017). Nevertheless, some countries are establishing thresholds in urban planning regulations. The United States (Karl et al., 2009, Titus and Anderson, 2009) applies the possible future SLR as a threshold to delimit the areas in which building is allowed or forbidden (Schubert et al., 2006). Still, most islands do not include this topic on their legal framework. Among other reasons, an additional difficulty is the lack of knowledge about future scenarios of local SLR. Therefore the accurate knowledge about the future scenarios of local SLR will be a key issue in order to develop an appropriate management of coastal wetlands (Valjavec and Polajnar Horvat, 2014).

The aim of this paper is to develop a methodology to calculate future local SLR. We use both data from long term time series of global sea level rise scenarios and local sea level rise measured by tide gauges located in ORs of the EU.

2. STUDY AREA

The study area comprises the Outermost Regions (ORs) of the European Union (EU): Canary Islands (Spain), Madeira and Azores (Portugal), Mayotte, French Guiana, and Reunion (France). Moreover, other overseas territories (OT) of the EU were included in the analysis such as French Polynesia, Faeroe Islands, Bermudas, Falkland, Cayman, and British Virgin Islands. These territories have an special administrative status with the EU (Figure 1).

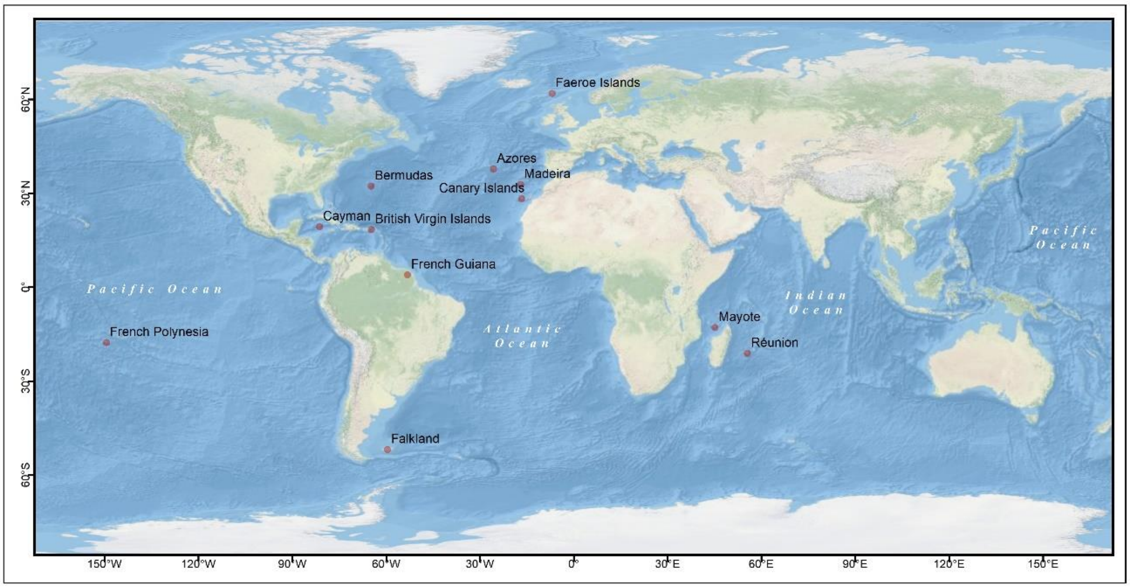

Figure 1. Location of study area.

The criteria for selecting the ORs were based on the availability of long term time series datasets, discarding territories with time series below 15 years. Some of these territories are highly populated, like Canary Islands (2.1 million inhabitants) (table 1), summarizing a total amount of 4.3 million inhabitants. However, the lack of studies about future scenarios of SLR is quite relevant, considering their great geostrategic importance (e.g.: Canary and Falkland Islands) or their high economic dependence on coastal use areas (tourism, infrastructures, transport or shipping) that might be inundated. Moreover, the European Environmental Agency (EAA) encouraged studies about climate change, sea level rise and insularity through its own research and legislation (e.g. Copernicus Regulation No 377/2014 from 3 April 2014).

Table 1. Study area: Basic facts.

Study Areas	**EU**	**Country**	**Population (2016)**
Mayotte	OR	France	217,091
French Guiana	OR	France	259,109
Reunion	OR	France	145,022
Canary Islands	OR	Spain	2,144,684
French Polynesia	OT	France	274,217
Madeira	OR	Portugal	267,785
Azores	OR	Portugal	246,746
Faeroe Islands	Not member	Denmark	48,351
Bermudas	OT	UK	67,837
Falkland	OT	UK	2,931
Cayman	OT	UK	59,967
British Virgin Islands	OT	UK	25,098

3. DATA

The data were recorded in tide gauges belonging to different local national authorities from ORs of EU. Seventeen annual time series of Mean Sea Level (MSL) were used to carry out this work. All of them were obtained at the Permanent Service for Mean Sea Level (PSMSL) main website. The data were available in monthly and annual time series. The annual time series represent the mean values of sea level for local data, measured in tide gauge benchmarks (TGBM) or local network of benchmarks (Revised Local Reference, RLR) (Woodworth, 1999).

These series can be used to analyze secular trends, since they provide a full benchmark datum history (Woodworth, 1999). Only time series lasting more than 15 years within the period 1900-2011 were chosen. The data of 47 tide gauges were acquired, although only 30 of them were used due to this temporal constraint.

Finally, the global sea level dataset calculated by Church and White (2012) was provided by the Commonwealth Scientific and Industrial Research Organization (CSIRO). From the beginning of the 20th century, CSIRO produces an annual weighted average of sea level from tide gauges around the globe (figure 2).

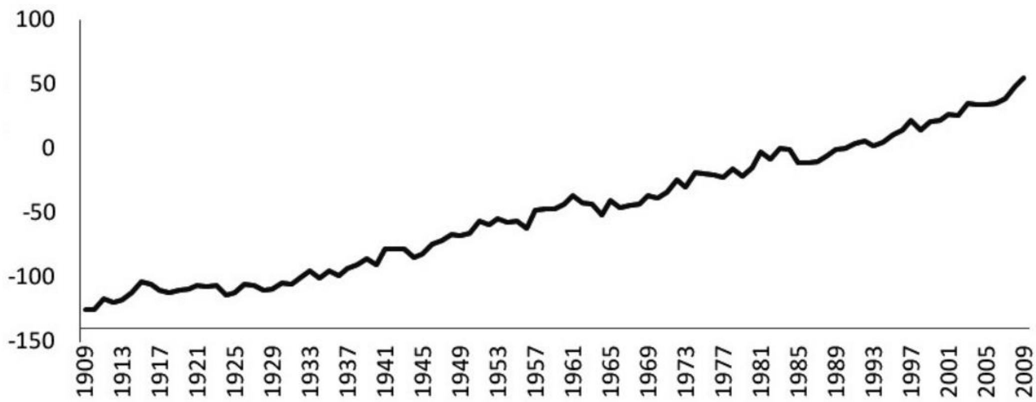

Figure 2. Time series of global sea level (mm) during 1909-2011 (modified from Church and White, 2012).

The time period of the analysis ends in 2011, since it is the final year of the global sea level record of CSIRO and, according to the proposed methodology, an overlapping of both types of data (local and global) was required.

4. METHODS

The methodology presented in this paper is designed to calculate future mean sea levels by combining the present mean sea level trends (SLT) with the expected SLR predicted by models of SLR in the 21st century.

The SLT were calculated from time series recorded by local tide gauges and from global sea level records provided by CSIRO. Therefore, it was necessary to adjust the global records from CSIRO dataset to each tide gauge time series. The missing years found in the tide gauges time series were inserted as gaps into the CSIRO dataset, thus a new CSIRO dataset was collected as a global reference for each one of the tide gauges time series.

Future sea level rise (FSLR) at any location is considered as the addition of two terms:

$$FSLR = G + L \qquad \text{(eq. 1)}$$

Where,
G = Global SLR from 1986-2005 to 2080 -2100, according to the IPCC (2013)
L = Local component of SLR in 21st century.

Term G is provided by a global sea level rise scenario. Obtaining term L implies estimating the weight of the local variables without counting in the global SLR. In order to do so, the local component involved in any past SLR trend was isolated. According to Titus and Narayanan (1998), it can be assumed that once the global influence has been eliminated from the local time series, the remaining trends will remain constants in the next centuries (e.g., due to local tectonics).

Linear regression analysis were made to estimate the equation of the best-fit line in which the slope means the rate of change in sea-level for each tide gauge (Penland and Ramsey, 1990). Two lineal trends per tide gauge were gained: a single trend from each tide gauge record and another for each adjusted CSIRO dataset. Thus, local and global trends for a same period length were calculated.

The difference between both trends was considered as the local trend (Zormpas et al., 2017). Therefore, there was no requirement to obtain homogeneous time series in order to compare this term between different tide gauges time series. The local trend was multiplied by the reference time period (100 years) so as to obtain the term L as a metric value.

Pearson correlation coefficients were calculated between each time series and the global series, in order to evaluate the reliability of the results. Finally, FLSR was obtained for the IPCC (2013) scenarios RCP2.6, RCP4.5, RCP6.0 and RCP8.5 by applying equation 1.

The standard errors of FSLR corresponding to the limits of the interval of confidence of 0.05 and 0.95 provided by IPCC for their SLR scenarios (2013) and the 0.05 and 0.95 p values estimated from a linear regression analysis between local tide gauges time series and the CSIRO dataset were added. This step implies the assumption that the homoscedasticity of the relationship between both variables will remain stable in the future.

5. RESULTS AND DISCUSSION

The results are summarized in tables 2, 3 and 4. In table 2 local observed trends for each tide gauge time series and the differences with the global time series are presented. Only five tide gauge time series showed a correlation coefficient (R) higher than 0.7 (R^2 >0.5) in the relationship between local and global (CSIRO dataset) time series. Other five tide gauges have R coefficients between 0.5 and 0.7.

The highest difference between local and global time series was estimated in Las Palmas (Canary Islands), with a value of 1.26 mm/year. In fact, there are no other tide gauges with high Pearson coefficients showing values over 1 mm/year in the difference between global and local tide gauge trends. These differences are much lower than those found in other studies in regional contexts (Thieler et al., 1999; Sallenger et al., 2012, Fraile and Ojeda, 2013). These low differences can be explained by the fact that the geological stability in some of the ORs (Ponta Delgada, Santa Cruz de Tenerife, Las Palmas, Funchal, Arrecife) has been reported as lower or inexistent (Carracedo, 2006) since they are volcanic areas. Thus, local sea levels could have increased due to global warming, without the influence of the vertical movements of the studied ORs.

Table 2. Results of local and global observed SLR trends, and the obtained Pearson correlation coefficient between the two time series. In bold, the tide gauges with statistical significance at 0.9 (*) and 0.95 (**).

TIDE GAUGE LOCATION	PSMSL CODE	TOTAL YEARS	LOCAL OBSERVED TREND (mm/year)	GLOBAL TREND (mm/year)	DIFFERENCE (mm/year)	R
Las Palmas	565	**17**	**3.81**	**2,55**	**1.26**	**0.88****
Santa Cruz de Tenerife	303	**56**	**1.64**	**1,76**	**-0.12**	**0.76****
Ponta Delgada	258	**14**	**2.65**	**2,01**	**0.64**	**0.76***
Torshav	839	**32**	**1.77**	**1,71**	**0.06**	**0.75****
St. Georges	368	**61**	**2.09**	**1,83**	**0.26**	**0.73****
Funchal	1030	**16**	**2.71**	**2,19**	**0.52**	**0.73***
St Marys	**1855**	**13**	**2.87**	**2,51**	**0.36**	**0.62***
Papeete	**1397**	**32**	**2.46**	**2,07**	**0.39**	**0.59***
North Sound	**1422**	**18**	**1.36**	**1,6**	**-0.24**	**0.58***
Stanley	**1796**	**14**	**1.90**	**2,87**	**-0.97**	**0.58***
St. Helier	**1795**	**16**	**1.93**	**2,77**	**-0.84**	**0.54***
South	1426	**17**	**2.31**	**1,42**	**0.89**	**0.50***
Rikitea	1253	24	1.43	**1,68**	-0.25	0.39
Arrecife	593	43	0.25	**1,76**	-1.51	0.16
Lerwick	830	44	-0.23	**1,83**	-2.06	-0.02
Noumeachaleix	852	17	-2.94	**1,66**	-4.60	-0.40

The standard errors from the regression model are shown in table 3. The values of homoscedasticity remained stable between local and global variables. Hence, the homocedasticity of the relationship permits to add the values derived from the statistical models

Table 3. Standards errors from linear regression analysis

Location	0.05/0.95 ERROR (m)
Las Palmas	**+/- 0.08**
Santa Cruz de Tenerife	**+/-0.15**
Torshav	**+/-0.18**
South	**+/-0.24**
St. Georges	**+/-0.25**
Funchal	**+/-0.28**
Ponta Delgada	**+/- 0.30**
St Marys	**+/-0.30**
Papeete	**+/-0.32**
North Sound	**+/-0.34**
Stanley	**+/-0.36**
St. Helier	**+/-0.38**

Table 4 shows the future SLR expectations for the twelve tide gauges in which Pearson coefficient is higher than 0.5. The differences between local and global time series did not reach high values and the results were very homogeneous, what means that the results are not too far from the global IPCC expectations. According to RCP2.6 scenario of IPCC (2013), mean sea level might rise 0.52 m in Las Palmas, while the lowest result was found in Stanley, with a future expected SLR of 0.30 m. All the rest of tide gauges are fluctuating between these values.

RCP4.5 and RCP6.0 showed values between 0.60 m (Las Palmas) and 0.37 (Stanley), respectively. Both scenarios are similar in their results for the late 21st century. In the case of RCP8.5, the maximum value of SLR (Las Palmas) was 0.76 m, while the lowest value (Stanley) was 0.53m. The comparison between these results and other works which used a different approach and data from altimetry satellites (Fraile et al., 2014) showed similar results in Canary Islands.

All the expected SLR were within the limits of the possible ranges published by IPCC for each scenario, revealing the homogeneity of the differences between local and global trends and the low SLR trends for the selected tide gauges. This is coherent with the works reporting local SLR trends higher than 7 mm/year (Wooldrofe, 2005) or even 10 mm/year (Dean et al., 1990).

The highest Pearson coefficients (table 2) were observed in the Atlantic tides gauges (Ponta Delgada, Tenerife, St Georges, Las Palmas, Torshav and Funchal), providing a high confidence in the results shown in table 4 for them. The results for the rest of the locations shown in Table 4, with lower Pearson coefficients, should be interpreted with caution, although the relationship between the local and the CSIRO records was significant.

Table 4. Obtained results for a 0.05, average and 0.95 p-values in the studied tide gauges.

Location	95%	RCP2.6	5%	95%	RCP4.5	5%	95%	RCP6.0	5%	95%	RCP8.5	5%
Las Palmas	0.44	0.53	0.61	0.51	0.60	0.68	0.52	0.61	0.69	0.67	0.76	0.84
South	0.25	0.49	0.73	0.32	0.56	0.80	0.33	0.57	0.81	0.48	0.72	0.96
Ponta Delgada	0.16	0.46	0.76	0.23	0.53	0.83	0.24	0.54	0.84	0.39	0.69	0.99
Funchal	0.17	0.45	0.73	0.24	0.52	0.80	0.25	0.53	0.81	0.40	0.68	0.96
Papeete	0.12	0.44	0.76	0.19	0.51	0.83	0.20	0.52	0.84	0.35	0.67	0.99
St Marys	0.14	0.44	0.74	0.21	0.51	0.81	0.22	0.52	0.82	0.37	0.67	0.97
St. Georges	0.18	0.43	0.67	0.25	0.50	0.74	0.26	0.51	0.75	0.41	0.66	0.90
Torshav	0.23	0.41	0.58	0.30	0.48	0.65	0.31	0.49	0.66	0.46	0.64	0.81
S.C. de Tenerife	0.24	0.39	0.54	0.31	0.46	0.61	0.32	0.47	0.62	0.47	0.62	0.77
North Sound	0.04	0.38	0.72	0.11	0.45	0.79	0.12	0.46	0.80	0.27	0.61	0.95
St. Helier	-0.06	0.32	0.70	0.01	0.39	0.77	0.02	0.40	0.78	0.17	0.55	0.93
Stanley	-0.06	0.30	0.66	0.01	0.37	0.73	0.02	0.38	0.74	0.17	0.53	0.89

The methodology combines several good features from other published methods, such as the fact of being based on the integration of a local trend into a global SLR model (Titus and Narayan, 1998, Fraile and Fernández, 2016). Nevertheless, none of the consulted references had calculated the differences between local and global observations during this period according to local time series.

6. CONCLUSIONS

The analysis of tide gauge time series, independently of their length, allowed the estimation of future SLR.

The results evidence that mean sea level will rise in all Outermost Regions of the European Union. Most of the tide gauges considered in the study showed trends of increasing sea levels in agreement with the global projections. This research represents an advantage from the coastal management and urban planning point of view, since most of the research about this topic and its impact assumes simple scenarios. However, in some locations, such as Las Palmas, South or St Mary's, a higher SLR is expected and therefore special measures will be required in order to adapt and mitigate the effects of SLR.

The EU should focus some of its efforts on mitigation of SLR and adaptation to its impacts in the ORs. Therefore, future research should focus on estimating the impact of SLR in such areas in order to assess their vulnerability (economy, population migration…).

REFERENCES

Barman, N. K., Goutam, B., and Pradhan, M. K. 2015. Assessing sustainability in coastal tourism sectors of Odisha coast, India. *European Journal of Geography*, *6*(4), 35-50.

Cazenave, A., and Llovel, W. 2010. Contemporary sea level rise. *Annual review of marine science*, *2*, 145-173.

Change, I. C. 2013. The Physical Science Basis: Working Group I. Contribution to the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). New York: Cambridge University Press, 1, 535-1.

Church, J. A., and White, N. J. 2011. Sea-level rise from the late 19th to the early 21st century. *Surveys in Geophysics*, *32*(4-5), 585-602.

Ellison, J. C., and Stoddart, D. R. 1991. Mangrove ecosystem collapse during predicted sea-level rise: Holocene analogues and implications. *Journal of Coastal research*, 151-165.

Emrich, C. T., and Cutter, S. L. 2011. Social vulnerability to climate-sensitive hazards in the southern United States. *Weather, Climate, and Society*, *3*(3), 193-208.

Fernández, D. B., and Escampa, M. H. 2017. Spatial analysis of tourist activities and services in the historic city: the cases of Malaga and Plymouth. *European Journal of Geography*, *7*(5), 139-160.

Fraile-Jurado, P., Álvarez-Francoso, J. I., Guisado-Pintado, E., Sánchez-Carnero, N., Ojeda-Zújar, J., and Leatherman, S. P. 2017. Mapping inundation probability due to increasing sea level rise along El Puerto de Santa María (SW Spain). *Natural Hazards*, 87(2) 581-598.

Fraile Jurado. P, and Fernández Díaz, M. 2016. Escenarios de subida del nivel medio del mar en los mareógrafos de las costas peninsulares de España en el año 2100. *Estudios Geográficos*, *77*280), 57-79.

Fraile-Jurado, P., and Ojeda-Zújar, J. 2013. The importance of the vertical accuracy of digital elevation models in gauging inundation by sea level rise along the Valdelagrana beach and marshes (Bay of Cádiz, SW Spain). *Geo-Marine Letters*, *33*(2-3), 225-230.

Fraile Jurado, P., Sánchez Carnero, N., and Ojeda Zújar, J. 2014. Sensibilidad del cálculo de los niveles medios del mar al método y período de las series temporales de los mareógrafos en los procesos de inundación: Valdegrana (Cádiz). *Boletín de la Asociación de Geógrafos Españoles*, (65), 59-70.

Fraile-Jurado, P., Sánchez-Rodríguez, E., Fernández-Díaz, M., Pita-López, M. F., and López-Torres, J. M. 2015. Estimación del comportamiento futuro del nivel del mar en las Islas Canarias a partir del análisis de registros recientes. *Geographicalia*, (66), 79-98.

Gilman, E., Ellison, J., Sauni, I., and Tuaumu, S. 2007. Trends in surface elevations of American Samoa mangroves. *Wetlands Ecology and Management*, *15*(5), 391-404.

Gómez Martín, M. B., Armesto López, X. A., Martí, C. I., and Muñoz-Negrete, J. 2014. Communicating the effects of climate change on tourism. The Spanish written press as a case study. *European Journal of Geography*, *5*(3), 73-84.

Horton, B. P., Rahmstorf, S., Engelhart, S. E., and Kemp, A. C. 2014. Expert assessment of sea-level rise by AD 2100 and AD 2300. *Quaternary Science Reviews*, *84*, 1-6.

Lambeck, K., and Chappell, J. 2001. Sea level change through the last glacial cycle. *Science*, *292*(5517), 679-686.

Little, C. M., Urban, N. M., and Oppenheimer, M. 2013. Probabilistic framework for assessing the ice sheet contribution to sea level change. *Proceedings of the National Academy of Sciences*, *110*(9), 3264-3269.

Meyssignac, B., and Cazenave, A. 2012. Sea level: a review of present-day and recent-past changes and variability. *Journal of Geodynamics*, *58*, 96-109.

Meyssignac, B., Calafat, F. M., Somot, S., Rupolo, V., Stocchi, P., Llovel, W., and Cazenave, A. 2011. Two-dimensional reconstruction of the Mediterranean sea level over 1970–2006 from tide gage data and regional ocean circulation model outputs. *Global and Planetary Change*, *77*(1), 49-61.

Mínguez, C. (2012). The management of cultural resources in the creation of Spanish tourist destinations. *European Journal of Geography*, *3*(1), 68-82.

Mitrovica, J. X., Tamisiea, M. E., Davis, J. L., and Milne, G. A. 2001. Recent mass balance of polar ice sheets inferred from patterns of global sea-level change. *Nature*, *409*(6823), 1026-1029.

Mokaram, M., and Sathyamoorthy, D. 2015. Morphometric analysis of hydrological behavior of North Fars watershed, Iran. *European Journal of Geography*, *6*(4), 88-106.

Moss, R. H. 2011. Reducing doubt about uncertainty: Guidance for IPCC's third assessment. *Climatic change*, *108*(4), 641-658.

Nicholls, R. J., Hanson, S. E., Lowe, J. A., Warrick, R. A., Lu, X., Long, A. J., and Carter, T. R. 2011. Constructing sea-level scenarios for impact and adaptation assessment of coastal areas: A guidance document. *Intergovernmental Panel on Climate Change Task Group on Data and Scenario Support for Impacts and Climate Analysis (TGICA)*, 1-47.

Peña-Alonso, C., Fraile-Jurado, P., Hernández-Calvento, L., Pérez-Chacón, E., and Ariza, E. 2017. Measuring geomorphological vulnerability on beaches using a set of indicators (GVI): A tool for management. *Journal of Environmental Management*, *204*, 230-245.

Pfeffer, W. T., Harper, J. T., and O'Neel, S. 2008. Kinematic constraints on glacier contributions to 21st-century sea-level rise. *Science*, *321*(5894), 1340-1343.

RAHMANI, V. A., ZABIHI, H., and IZAD, E. (2016). The role of tourism in the development of coastal villages. A case study in Noor Town, Iran. *European Journal of Geography 7*(4), 67-79.

Rahmstorf, S. 2007. A semi-empirical approach to projecting future sea-level rise. *Science*, *315*(5810), 368-370.

Safarabadi, A., Moayedfar, S., and Varesi, H. 2015. Urban sustainable development with emphasis on the empowerment of informal settlements in urban areas: the case of Yazd, Iran. *European Journal of Geography*, *6*, 83-97.

Sallenger Jr, A. H., Doran, K. S., and Howd, P. A. 2012. Hotspot of accelerated sea-level rise on the Atlantic coast of North America. *Nature Climate Change*, *2*(12), 884-888.

Thieler, E. R., and Hammar-Klose, E. S. 1999. *National assessment of coastal vulnerability to sea-level rise; US Atlantic Coast* (No. 99-593).

Titus, J. G., and Narayanan, V. 1996. The risk of sea level rise. *Climatic Change*, (2*33*2), 151-212.

Titus, J. G., and Richman, C. 2001. Maps of lands vulnerable to sea level rise: modeled elevations along the US Atlantic and Gulf coasts. *Climate Research*, *18*(3), 205-228.

Tosi, L., Teatini, P., Carbognin, L., and Frankenfield, J. 2007. A new project to monitor land subsidence in the northern Venice coastland (Italy). *Environmental Geology*, *52*(5), 889-898.

Valjavec, M. B., and Horvat, K. P. 2014. Catchment approach in managing of coastal wetlands, Slovenia. *European Journal of Geography*, *5*(3), 85-95.

Woodroffe, C. D., Rogers, K., McKee, K. L., Lovelock, C. E., Mendelssohn, I. A., and Saintilan, N. 2016. Mangrove sedimentation and response to relative sea-level rise. *Annual Review of Marine Science*, *8*, 243-266.

Woodworth, P. L., Teferle, F. N., Bingley, R. M., Shennan, I., and Williams, S. D. P. 2009. Trends in UK mean sea level revisited. *Geophysical Journal International*, *176*(1), 19-30.

Yin, J., Schlesinger, M. E., and Stouffer, R. J. 2009. Model projections of rapid sea-level rise on the northeast coast of the United States. *Nature Geoscience*, *2*(4), 262-266.

Zormpas, K., Vasilakos, C., Athanasis, N., Soulakellis, N., and Kalabokidis, K. (2017). Dead fuel moisture content estimation using remote sensing. *European Journal of Geography*, 8(5), 17-32.