Sea Level Rise Future Predictions: A Case Study in Crete

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Abstract: This work presents an estimation approach for coastal data with regard to climate change. Specifically, future sea level rise (SLR) values are predicted on the basis of initial corresponding values, which are identical to the values for the year 2025 that are provided by the Mediterranean Coastal Database (MCD). The proposed estimator is named Coastal Data Estimator (CDE) and is used for predictions in the Crete island, Greece. During the years from 2030 to 2100, the CDE estimation performance is evaluated against the MCD regarding the representative concentration pathways 2.6 (RCP26), 4.5 (RCP45) and 8.5 (RCP85) as well as the medium and high ice-sheet melting scenarios. Concerning the high ice-sheet melting scenario in RCP26, the CDE deviates less than 10% for the years 2030-2065 and 2080-2100. In the case of RCP45, the CDE estimator achieves predictions with deviations less than 10% from the year 2030 to the year 2080 and 2075 for medium and high scenario, correspondingly. Future work includes the CDE testing in other Mediterranean sites. Additionally, the CDE equation could become multibranch as well as estimations should be automized, excluding the per year constants.

1 INTRODUCTION

Coastal erosion to be managed during climate change needs valid projections of shoreline change across large time scales i.e. decades and hundreds of years. Nevertheless, coastal erosion modelling presents important challenges like that the long-term evolution of the shoreline entails interacting and coupled short-to-long term coastal processes, also influenced by the climate change. Besides, future estimates of shoreline change are affected by multi-source uncertainties (Toimil et al., 2020).

Several works on coastal erosion estimations have appeared in the literature. A collection of numerical models is used to assess coastal erosion and the performance of various recommended solutions, along a section of coast in southern Rhode Island, US, in (Hayward et al., 2018). The study in (Cham et al., 2020) proposes a novel method, of utilizing multitemporal remote sensing images during 1965-2018 and digital evaluation model with tidal correction, to analyse the changes in shoreline and estimate the rate of erosion and accretion in the Cua Dai estuary, Vietnam. In the work of (Scardino et al., 2020) a new predictive model of submersion is developed to support coastal management in sea level rise (SLR) conditions over the next decades up to 2100 for the Gulf of Taranto in southern Italy.The paper in (Toimil et al., 2020) reviews the contemporary techniques which are used to model climate change-induced coastal erosion.

Robust estimations penalizing outliers (Panagiotopoulou, 2012; Panagiotopoulou, 2013; Tukey, 1983) could prove useful for the prediction of coastal data values. Actually, individual coastal adaptation practitioners may have different preferences and acceptable degrees of risk. The particular uncertainty should be passed onto end users and get incorporated into decision analysis (Hinkel et al., 2019).

In the present work a novel estimation approach for SLR is presented. Specifically, SLR values get predicted for the future based on corresponding present time values. The starting point of estimation, thus present values, is equivalent to the Mediterranean Coastal Database (MCD) provided values for the year 2025. The proposed estimator is called Coastal Data Estimator (CDE) and serves for predictions in the Crete island, Greece. SLR values that are provided by the MCD are utilized for the

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evaluation of the CDE estimation performance throughout the years from 2030 to 2100.

2 THE SEA LEVEL RISE EFFECT GLOBALLY

Enhanced greenhouse effects on earth environment have brought the global climate change. Thermal expansion of sea water, resulting from temperature increment of the ocean upper layer, is defined as the main source of SLR (Woodworth, 2017; Shannon et al., 2019). SLR is anticipated to have a tremendous impact on human activity near coastal regions. In fact, inundation of low-lying coastal areas is a direct outcome of SLR and constitutes a long-term problem having been under consideration in a variety of fields (Pickering et al., 2017; IPCC, 2021).

The ocean thermal expansion and the melting of glaciers, ice-sheets cause SLR that demonstrates a timescale of 100–200 years, which is related to the continuance of CO2 in the atmosphere and therefore the radiative forcing time span. In accordance with the model of (Jevrejeva et al., 2012), SLR of 0.57–1.10 m by 2100 has been predicted. In effect, simulation indicates that sea level will keep at rising for many centuries after stabilization of radiative forcing, finally outstretching between 1.84 and 5.48 m above sea level by 2500 concerning all scenarios, apart from the RCP3PD low emission scenario. The work (Hinkel et al., 2014) evaluates on a global scale the coastal flood damage and adaptation costs under 21st century SLR. Devoid of adaptation, it is expected that 0.2–4.6% of the world's population will be flooded annually by 2100 within 25–123 cm of a global mean SLR. Moreover, concerning coastal sea level changes and the associated risks of flooding and erosion, wind waves are a key factor. The work (Melet et al., 2020) is based on empirical formulations, different estimates of beach slopes and an ensemble of global wave models, to propose a first-order estimate of the correlation significance of the input of atmospheric climate directed wave setup changes to 20-year mean projected coastal sea level changes at global scale.

Thereafter, the challenge for coastal regions globally is the projection of SLR and its effects into the future. The Intergovernmental Panel on Climate Change (IPCC) is seriously concerned with the latter, but also governments individually are simultaneously trying to estimate future SLR projections for their own regions. Future climate projections are attainable through global climate models. In these models, uncertainties and assumptions regarding future greenhouse gas emissions (i.e., Representative Concentration Pathways-RCPs) are contained whilst the factors that will influence global climate, including ice melt and consequently SLR, are modeled (Griggs and Reguero, 2021). Nowadays, all predictions for the next few decades, generally agree, but projections in concern with the end-of-century vary between models. In fact, RCPs play a substantial role, with growingly broader uncertainties and ranges in estimations by 2100. By the newest estimates, the values for the end-of-century (2100) range from a low of ~50 cm to as high as ~310 cm, independence of greenhouse gas emission scenarios and various probabilities, mainly regarding the extent of Greenland and Antarctica ice melt (De Conto et al, 2016).

Virtually definitely, global mean sea level (GMSL) will keep up rising over the 21st century coming after the continued warming of the climate system (IPCC, 2021). The SLR will carry on with over the centuries and millennia following emissions stopping, which is related to continuing ocean heat growth and the slow adjustment of the ice sheets. By 2100, GMSL is projected to increase per 0.28–0.55 m under SSP1-1.9 and per 0.63–1.02 m under SSP5-8.5 relative to the 1995–2014 average (IPCC, 2021), where SSP represents a shared socio-economic pathway. Concerning the scenarios of higher CO2 emissions, sea level projections for 2100 and beyond are strongly debatable, which is linked with the ice-sheet responses to warming. In the case of a low probability, hard plot and a high CO2 emissions scenario, ice-sheet processes, that are characterized by deep unpredictability, could bring GMSL rise up to about 5 m by 2150.

Considering the long-term commitment, uncertainty in relation to the timetable of outstretching different GMSL rise levels is an important contemplation for adaptation planning. Regional sea level changes differ from global estimates. This happens due to alterations in ocean density and circulation, in atmospheric pressure as well as in Earth Gravity, in Earth Rotation and in viscoelastic solid-Earth deformation with regards to mass redistributions such as ice melting and groundwater extractions (Gregory et al., 2019; Toilim et al., 2020). In fact, SLR tends to increase at lower latitudes and decrease at higher latitudes.

Due to the great uncertainty issues and the complex factors that have to be considered in simulation models, future climate projections and in specific SLR projections, would need an alternative way of estimating. Here lies the usability of the CDE estimator which is proposed in the current work. The

CDE estimator constitutes a novel mathematical model for future SLR predictions. The proposed estimator could prove useful for predicting how much the sea level will rise, without the need for gathering the various data of global patterns in the ocean and atmosphere, that climate models get as input.

3 SEA LEVEL RISE PROVIDED BY THE MEDITERRANEAN COASTAL DATABASE

The area of interest in the present study is Crete island in Greece. Six geographical locations in Crete, whose the latitude and longitude coordinates are given in Table 1, are considered. For this region, coastal data are available through the MCD (Argus et al., 2014; Peltier et al., 2015; Wolf et al., 2018).

Table 1: Geographical Point Coordinates in Crete island.

Location Number	Latitude	Longitude
1	35.5296	23.9249
2	35.5145	23.9790
3	35.5162	24.0269
4	35.5296	24.0488
5	35.5193	23.8993
6	35.5357	24.0480

In particular, there are regionalized SLR scenarios, which take into account the effects of regional gravity and rotation due to changes in ice mass distribution and steric changes i..e. changes caused by ocean temperature and salinity variations. Particularly, mean SLR relative to 1985-2005 in meters for RCP values equal to 2.6, 4.5 and 8.5 for a high ice-sheet melting scenario as well as for a medium ice-sheet melting scenario are given (Hinkel et al., 2014). The latter study provides results of equal range as those of national studies (Molinari et al., 2019) but a couple of uncertainties inherent to the nature of the global socioeconomic coastal analysis endure. Also, the study in (Hinkel et al., 2014) mistreats the issue of groundwater depletion for human use, which was projected to contribute up to about 8 cm to global SLR by the end of the century (Wada et al., 2012). Along with SLR, potential storminess changes and possible rise in cyclone intensity could modify flood damage (Jevrejeva et al., 2012) but are not regarded here. An additional primary element of uncertainty is human-induced subsidence resulting from the withdrawal of ground fluids, particularly within densely populated deltas, which may lead to rates of local relative SLR that are one order of magnitude higher than current rates of climate-induced global-mean SLR (Syvitski et al., 2009).

In Tables 2-3 the MCD values for the mean SLR in meters are presented. The six geographical points in Crete island which are described in Table 1 are attributed approximately the same mean SLR (Wolf et al., 2018). The SLR shows an increasing trend throughout the years from 2025 to 2100. Also, the high ice-sheet melting scenario values supersede those of the medium scenario (Hinkel et al., 2014). The aforementioned facts hold true for all three RCP values.

Table 2: Mean Sea Level Rise in meters for representative concentration pathways 2.6 and 4.5 (Hinkel et al., 2014).

Year	RCP26		RCP45	
	M[1]	H[2]	M	H
2025	0.079	0.110	0.080	0.111
2030	0.101	0.145	0.100	0.140
2035	0.121	0.174	0.119	0.168
2040	0.138	0.200	0.141	0.202
2045	0.156	0.228	0.164	0.236
2050	0.178	0.260	0.190	0.275
2055	0.197	0.288	0.218	0.317
2060	0.215	0.318	0.246	0.361
2065	0.232	0.345	0.276	0.410
2070	0.250	0.374	0.306	0.461
2075	0.267	0.402	0.337	0.510
2080	0.284	0.429	0.368	0.557
2085	0.302	0.458	0.397	0.604
2090	0.320	0.486	0.428	0.651
2095	0.338	0.513	0.457	0.698
2100	0.356	0.542	0.487	0.746

[1]Medium scenario, [2]High scenario

Table 3: Mean Sea Level Rise in meters for representative concentration pathway 8.5 (Hinkel et al., 2014).

Year	RCP85	
	M[1]	H[2]
2025	0.086	0.124
2030	0.108	0.154
2035	0.134	0.190
2040	0.156	0.227
2045	0.188	0.268
2050	0.221	0.317
2055	0.255	0.371
2060	0.295	0.434
2065	0.336	0.450
2070	0.381	0.568
2075	0.426	0.639
2080	0.475	0.718
2085	0.528	0.803
2090	0.583	0.893
2095	0.638	0.988
2100	0.696	1.090

[1]Medium scenario, [2]High scenario

4 THE COASTAL DATA ESTIMATOR

In this section the proposed estimator, called CDE, is presented. The values of mean SLR for the years 2030 to 2100 are estimated, where as starting point or present value is taken the mean SLR value for the year 2025 that is provided by the MCD.

The CDE mathematical formula is given in equation (1):

$$SLR_{y+5} = SLR_y \times 100 \times \sigma - \frac{SLR_y}{2.4/c} \qquad (1)$$

where SLR_y stands for the mean SLR in year y and σ denotes the standard deviation of the set of mean SLR values in the year y.

As far as c in equation (1) is concerned, it is a constant relating to the year as described in Table 4. Mean SLR values for medium and high scenario as well as for all three RCP values are included in the aforementioned set. For the year 2030 predictions, the CDE utilizes the SLR values of 2025 as given by the MCD. Regarding all other years, the CDE estimates SLR values by taking into consideration its own predictions five years behind.

Table 4: Constant c values in relation to the year of prediction.

Year	c
2030	1
2035	2.4
2040	3.8
2045	4.4
2050	5.6
2055	7.1
2060	8.6
2065	9.8
2070	11.2
2075	13.2
2080	15.1
2085	15.1
2090	15.1
2095	16.4
2100	17.6

The CDE estimations as resulting from equation (1) are given in Tables 5-6. The % deviation between the MCD and CDE estimations is presented in Tables 7 and 8, where the MCD values are considered as the groundtruth ones. With regard to RCP26 and medium scenario, the CDE deviations are smaller than 10% for the years 2030-2060 and 2085. Concerning the high scenario in RCP26, the CDE deviates less than 10% for the years 2030-2065 and 2080-2100. In the case of RCP45, the CDE estimator achieves predictions with deviations less than 10% from the year 2030 to the year 2080 and 2075 for medium and high scenario, respectively. As far as RCP85 is concerned, for both medium and high scenarios, during the years 2030-2050 the CDE deviations are smaller than 10%. This holds true additionally for the year 2065 in the high scenario.

Table 5: Mean Sea Level Rise in meters for representative concentration pathways 2.6 and 4.5 by the Coastal Data Estimator.

Year	RCP26		RCP45	
	M[1]	H[2]	M	H
2030	0.101	0.141	0.103	0.142
2035	0.121	0.169	0.124	0.170
2040	0.135	0.189	0.138	0.190
2045	0.157	0.220	0.161	0.222
2050	0.183	0.257	0.188	0.259
2055	0.209	0.293	0.215	0.296
2060	0.233	0.327	0.240	0.331
2065	0.260	0.365	0.268	0.370
2070	0.295	0.414	0.304	0.419
2075	0.324	0.455	0.334	0.461
2080	0.327	0.459	0.337	0.465
2085	0.330	0.463	0.340	0.469
2090	0.377	0.513	0.377	0.520
2095	0.402	0.547	0.402	0.555
2100	0.429	0.583	0.429	0.592

[1]Medium scenario, [2]High scenario

Table 6: Mean Sea Level Rise in meters for representative concentration pathway 8.5 by the Coastal Data Estimator.

Year	RCP85	
	M[1]	H[2]
2030	0.110	0.159
2035	0.132	0.191
2040	0.147	0.213
2045	0.171	0.248
2050	0.199	0.289
2055	0.227	0.330
2060	0.253	0.368
2065	0.283	0.411
2070	0.321	0.466
2075	0.353	0.513
2080	0.356	0.517
2085	0.359	0.521
2090	0.398	0.577
2095	0.425	0.615
2100	0.453	0.656

[1]Medium scenario, [2]High scenario

With regard to all considered RCPs and the two ice-sheet melting scenarios, the time spans of CDE estimation deviations smaller than 10% are clearly presented in Table 9. Also, Figure 1 plots the mean SLR predictions of MCD and CDE that are presented in Tables 2-3 and 5-6. The prediction accuracy of CDE is smallest in the case of RCP85.

Table 7: Percentage deviation (%) regarding the comparison of mean sea level rise estimations, for representative concentration pathways 2.6 and 4.5, by the Coastal Data Estimator to the Mediterranean Coastal Database values. The minus symbol denotes underestimation.

Year	RCP26		RCP45	
	M[1]	H[2]	M	H
2030	0	-2.8	3.0	1.4
2035	0	-2.9	4.2	1.2
2040	-2.2	-5.5	-2.1	-5.9
2045	0.6	-3.5	-1.8	-5.9
2050	2.8	-1.2	-1.1	-5.8
2055	6.1	1.7	-1.4	-6.6
2060	8.4	2.8	-2.4	-8.3
2065	12.1	5.8	-2.9	-9.8
2070	18.0	10.7	-0.7	-9.1
2075	21.3	13.2	-0.9	-9.6
2080	15.1	7.0	-8.4	-16.5
2085	9.3	1.1	-14.4	-22.3
2090	17.8	5.5	-11.9	-20.1
2095	18.9	6.6	-12.0	-20.5
2100	27.2	7.6	-11.9	-20.6

[1]Medium scenario, [2]High scenario

Table 8: Percentage deviation (%) regarding the comparison of mean sea level rise estimations, for representative concentration pathway 8.5, by the Coastal Data Estimator to the Mediterranean Coastal Database values. The minus symbol denotes underestimation.

Year	RCP85	
	M[1]	H[2]
2030	1.9	3.2
2035	-1.5	0.5
2040	-5.8	-6.2
2045	-9.0	-7.5
2050	-9.9	-8.8
2055	-11.0	-11.0
2060	-14.2	-15.2
2065	-15.8	-8.7
2070	-15.7	-18.0
2075	-17.1	-19.7
2080	-25.0	-28.0
2085	-32.0	-35.1
2090	-31.7	-35.4
2095	-33.4	-37.7
2100	-34.9	-39.8

[1]Medium scenario, [2]High scenario

Table 9: Time spans where the percentage deviation (%), regarding the comparison of mean sea level rise estimations by the Coastal Data Estimator to the Mediterranean Coastal Database values, is smaller than 10%. The three representative concentration pathways and both ice-sheet melting scenarios are shown.

Scenario	RCP26	RCP45	RCP85
Medium	2030-2060, 2085	2030-2080	2030-2050
High	2030-2065, 2080-2100	2030-2075	2030-2050, 2065

5 CONCLUSIONS

Managing coastal erosion in the process of climate change needs valid projections of shoreline change across very large time scales. However, coastal erosion modelling presents significant challenges while future estimates of shoreline change get affected by uncertainties arising from multiple sources. Robust estimations could prove useful for the prediction of coastal data values, where the prediction uncertainty may be evaluated by individual coastal adaptation practitioners and be passed on to end users as well as to decision analysis.

In the present work a new estimation approach for sea level rise is proposed. The starting point of estimation is equivalent to the Mediterranean Coastal Database provided values for the year 2025. The proposed estimator is named Coastal Data Estimator and is used for predictions in the Crete island, Greece throughout the years from 2030 to 2100. There is calculated the % deviation between the MCD and CDE estimations, where the MCD values are considered as the groundtruth ones. Concerning the high ice-sheet melting scenario in RCP26, the CDE deviates less than 10% for the years 2030-2065 and 2080-2100. In the case of RCP45, the CDE estimator achieves predictions with deviations less than 10% from the year 2030 to the year 2080 and 2075 for medium and high scenario, correspondingly.

The current study presents certain limitations which need to be addressed in future work. In specific, future work includes the CDE application and testing in other Mediterranean sites. Also, the CDE mathematical formula could become multi-branch to better adapt to medium and high ice-sheet melting scenarios and/or RCP values. Additionally, the CDE formula automation, excluding the per year constants, should be worked out.

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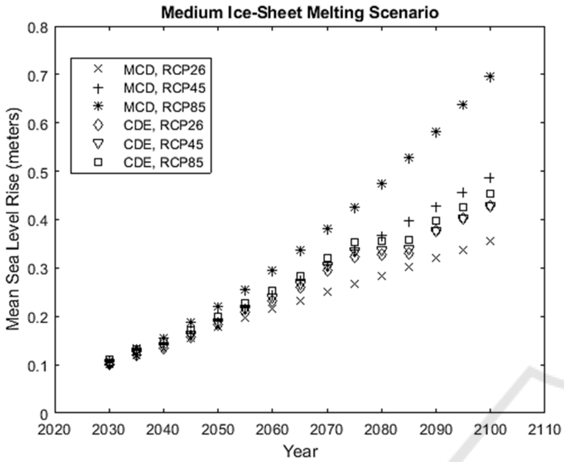
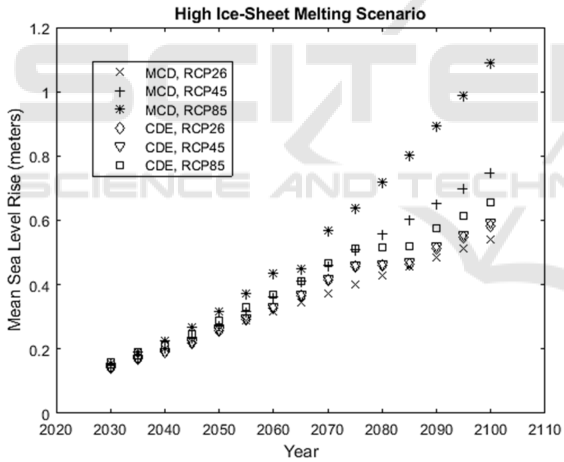


(a)



(b)

Figure 1: The Mediterranean Coastal Database and the Coastal Data Estimator predictions for mean sea level rise throughout the years up to 2100, per representative concentration pathway (a) Medium ice-sheet melting scenario (b) High ice-sheet melting scenario.

REFERENCES

Argus, D. F., Peltier, W. R., Drummond, R., Moore, A. W. (2014). The Antarctica component of postglacial rebound model ICE-6G_C (VM5a) based on GPS positioning, exposure age dating of ice thicknesses, and relative sea level histories. In*Geophysical Journal International*, vol. 198, pp. 537–563, https://doi.org/10.1093/gji/ggu140.

Cham, D. D., Son, N. T., Minh, N. Q., Thanh, N. T., Dung, T. T. (2020). An analysis of shoreline changes using combined multitemporal remote sensing and digital evaluation model, In *Civil Engineering Journal*, vol. 6, no. 1. http://dx.doi.org/10.28991/cej-2020-03091448

DeConto, R. M. and Pollard, D. (2020). Contribution of Antarctica to past and future sea-level rise, In *Nature*, vol. 531, pp. 591–597, https://doi.org/10.1038/nature17145

Gregory J. M. et al. (2019). Concepts and terminology for sea level: mean, variability and change, both local and global, In *Surveys in Geophysics*, pp. 1-39, https://doi.org/10.1007/s10712-019-09525-z

Griggs G. and Reguero B.G. (2021). Coastal adaptation to climate change and sea-level rise, Water, vol. 13, no. 2151, https://doi.org/10.3390/w13162151

Hayward, S. et al. (2018). Numerical simulation of coastal erosion and its mitigation by living shoreline methods: A case study in Southern Rhode Island, In *Shore & Beach*, vol. 86, no. 4, pp. 13-25.

Hinkel, J. et al. (2014). Coastal flood damage and adaptation costs under 21st century sea-level rise. In *Proceedings of the National Academy of Sciences, U.S.A*, vol. 111, pp. 3292–3297, https://doi.org/10.1073/pnas.1222469111.

Hinkel, J. et al. (2019). Meeting user needs for sealevel rise information: a decision analysis perspective. In *Earth’s Future 7*, https://doi.org/10.1029/2018EF001071

Masson-Delmotte, V. P.et al., (In Cambridge University Press). IPCC, 2021: Summary for Policymakers, In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*.

Jevrejeva S, Moore J, Grinsted A. (2012). Sea level projections to ad2500 with a new generation of climate change scenarios.In *Global Planet Change,*vol.80–81, pp. 14–20.

Melet A. et al., (2020). Contribution of wave setup to projected coastal sea level changes, In *Journal of Geophysical Research: Oceans*, https://doi.org/10.1029/2020JC016078

Molinari, D. et al., (2019). Validation of flood risk models: current practice and possible improvements, In *International Journal of Disaster Risk Reduction,* vol. 33, pp. 441-448. https://doi.org/10.1016/j.ijdrr.2018.10.022

Panagiotopoulou, A. (2012). Multi-frame super-resolution image reconstruction employing the novel estimator L1inv-norm. In *Proceedings of International Conference on Systems, Signals and Image Processing, (IWSSIP),* pp. 562-565.

Panagiotopoulou, A. (2013). Iterative multi-frame super-resolution image reconstruction via variance-based fidelity to the data. In *International Journal of Remote Sensing Applications*, vol. 3, pp. 203-214.

Peltier, W. R., Argus, D. F., Drummond, R. (2015). Space geodesy constrains ice age terminal deglaciation: The global ICE-6G_C(VM5a) model. In *Journal of Geophysical Research: Solid Earth*, vol. 120, pp. 450–487, https://doi.org/10.1002/2014jb011176.
Pickering M. D. et al., (2017). The impact of future sea-level rise on the global tides, In *Continental Shelf Research*, vol. 142, pp. 50-68, http://dx.doi.org/10.1016/j.csr.2017.02.004
Scardino, G. et al., (2020). Sea-level rise and shoreline schanges along an open sandy coast: case study of gulf of Taranto, Italy, In *Water*, vol. 12, no. 1414, doi:10.3390/w12051414
Shannon S. et al., (2019). Global glacier volume projections under high-end climate change scenarios, In *The Cryosphere*, vol. 13, pp. 325-350, https://doi.org/10.5194/tc-13-325-2019
Syvitski, J.P.M. et al. (2009). Sinking deltas due to human activities. In *Nature Geoscience*, vol. 2, pp. 681-686.
Toimil, A. et al. (2020). Climate change-driven coastal erosion modelling in temperature sandy beaches: Methods and uncertainty treatment. In *Earth-Science Reviews*, vol. 202. https://doi.org/10.1016/j.earscirev.2020.103110
Tukey, J.(1983).*Understanding Robust and Exploratory DataAnalysis.* John Wiley and Sons. New York, USA.
Wada, Y. et al. (2012). Past and future contribution of global groundwater depletion to sea-level rise.In *Geophyical Research Letters,*vol. 39, no . 16.
Wolf, C. et al. (2018). Data Descriptor: A Mediterranean costal database for assessing the impacts of sea-level rise and associated hazards. In *Scientific Data*. DOI: 10.1038/sdata.2018.44.
Woodworth, P.L. (2017). Differences between mean tide level and mean sea level, In *Journal of Geodesy*, vol. 91, pp. 69-90, https://doi.org/10.1007/s00190-016-0938-1