Revista Brasileira de Cartografia
ISSN 1808-0936 | https://doi.org/10.14393/revbrascartogr
Brazilian Society of Cartography, Geodesy, Photogrammetry and Remote Sensing

The Sea Level Rise and its Relationships with Non-oceanic Variables: a Bibliometric Analysis

O Avanço do Nível do Mar e suas Relações com Variáveis não Oceânicas: uma Análise Bibliométrica

Nilton de Souza Ribas Junior [1] and Aloísio Machado da Silva Filho [2]

1 Universidade Estadual de Feira de Santana, Postgraduate Program in Modeling in Earth and Environmental Sciences, Feira de Santana, Brazil. niltonribasjr@gmail.com.
ORCID: https://orcid.org/0000-0003-2170-136X
2 Universidade Estadual de Feira de Santana, Postgraduate Program in Modeling in Earth and Environmental Sciences, Feira de Santana, Brazil. aloisioestatistico@uefs.br.
ORCID: https://orcid.org/0000-0001-8250-1527

Received: 05.2022 | Accepted: 10.2022

Abstract: Approximately 70% of our planet is occupied by water, which for the most part, forms our oceans. In addition to enchanting us with its beauty, the sea, with its strictly regular vertical movement driven by gravitational forces, has been suffering increasingly intense disturbances, causing its elevation due to several factors, mainly environmental and climatic. An integral part of one of the sustainable development objectives (ODS 13 - Action against Global Climate Change), a global agenda adopted during the United Nations Summit, consisting of 17 goals and 169 targets to be achieved by 2030, the mean sea level rise has been a concern for governments, non-governmental and researchers for some time, especially when the future scenarios are not encouraging at all. These risks are even more accentuated when we refer to coastal regions, as the consequences are felt in a much more direct and accentuated way, such as erosion of beaches, coastal flooding, and loss of ecosystems, among others. Creating negative impacts both from a socioeconomic and environmental point of view. To contribute to research related to the topic, through bibliometric techniques, the referring study analyzed 35 articles between the years 2009 and 2021 extracted from the Scopus database with the application of mathematical and statistical methods as a way of quantitatively evaluating these researches, among them: historical and geographic trends, main journals and institutions, keyword characteristics and citation network analysis. The objective is to have an overview of how the theme "mean sea level" has been studied over time and its relationship with its disturbing factors, such as land subsidence and climatic factors, which techniques are being used and which are the main discoveries.
Keywords: Mean Sea Level. GNSS. Time Series.

Resumo: Aproximadamente 70% do nosso planeta é ocupado por águas, que em sua grande maioria formam os nossos oceanos. Além de nos encantar com sua beleza, o mar com seu movimento vertical rigorosamente regular, impulsionado pelas forças gravitacionais, vem sofrendo perturbações cada vez mais intensas, ocasionando sua elevação em virtude de diversos fatores, principalmente ambientais e climáticos. Parte integrante de um dos objetivos de desenvolvimento sustentável (ODS 13 – Ação Contra a Mudança Global do Clima), agenda mundial adotada durante a Cúpula das Nações Unidas, composta por 17 objetivos e 169 metas a serem atingidas até 2030, o aumento do nível médio do mar vem preocupando autoridades governamentais, não governamentais e pesquisadores há algum tempo, principalmente quando os cenários futuros não são nem um pouco animadores. Esses riscos são ainda mais acentuados quando nos referimos as regiões costeiras, pois as consequências são sentidas de uma forma muito mais direta e acentuada, tais como: erosão das praias, inundações costeiras, perda de ecossistemas, entre outras, impactando tanto do ponto de vista socioeconômico quanto ambiental. Com o intuito de contribuir com pesquisas relacionadas ao tema, por meio de técnicas bibliométricas, o referente estudo analisou 35 artigos entre os anos de 2009 e 2021 extraídos da base de dados *Scopus* com a aplicação de métodos matemáticos e estatísticos como forma de avaliar quantitativamente essas pesquisas, entre elas: tendências históricas e geográficas, principais periódicos e instituições, características de palavras-chave e análise de rede de citações. O objetivo é ter um panorama geral de como o tema "nível médio do mar" vem sendo estudado ao longo do tempo e suas relações com seus fatores perturbadores, tais como a subsidência da terra e fatores climáticos, que técnicas estão sendo utilizadas e quais os principais achados.
Palavras-chave: Nível Médio do Mar. GNSS. Séries Temporais.

1 INTRODUCTION

The strictly regular vertical movement of the sea level is driven by the forces of gravitational attraction between the Earth, the Sun, and the Moon, although all this rigor has been disturbed in an increasingly intense way, causing its elevation due to several factors, but mainly, by the emission of gases that upon reaching the atmosphere, raises the temperature of the planet and, consequently, the volume of the oceans.

This concern is not new on the part of governmental and non-governmental authorities and researchers around the world. A September 2013 publication by the National Geographics magazine (FOLGER, 2013), based on the OECD report (2008) on the 136 largest port cities in the world, states that with the warmer planet, the rise in sea levels is accentuated, and estimates that by 2070 150 million people in these cities would be at risk and a wealth valued at 35 trillion dollars would be threatened. This rise in the mean sea level would be mainly due to the consumption of fossil fuels by society, which, by releasing carbon dioxide and other greenhouse gases into the atmosphere, warmed the Earth by more than half a degree Celsius over the last century.

The fifth report presented by the IPCC (Intergovernmental Panel on Climate Change) shows that the thermal expansion of the oceans and the melting of glaciers have been the dominant contributors to the global mean sea level rise of the 20th century. Observations since 1971 indicate that this global mean sea level rise will continue beyond 2100 (IPCC, 2013).

Understanding the mechanisms of mean sea level change is one of the major concerns of geosciences in the era of climate change, with implicit consequences for coastal ecosystems and human societies (SIMAV et al., 2012). For Fenoglio-Marc et al. (2012), the rise in mean sea level has important implications, such as beach erosion, land flooding, increased salinization of coastal aquifers, damage caused by storms, and loss of coastal ecosystem. Tsimplis et al. (2011) consider these processes an excellent indicator related to climate change.

Since the beginning of 1993, sea level variations have been measured by satellite altimetry (FENOGLIO-MARC, 2012). While these methods to measure sea level managed to have a much larger coverage area, global mean sea level changes are derived from modeling and do not correspond to actual sea level measurements *in loco*. Compilations of individual tide gauges that have a certain quality control in obtaining the data and sufficient historical series length provide much more reliable and secure information for monitoring mean sea level (PARKER; OLLIER, 2015), although they only guarantee this condition at the measured location. On the other hand, it is worth remembering that these tide stations are affected both by the absolute variation of the sea level and by the vertical crustal movements (BUBLE; BENNETT; HREINSDÓTTIR, 2010, 2010). Additionally, Moghadam (2017) used the rules governing an artificial neural network to identify a set of large-scale meteorological variables that significantly affect sea level variability.

Therefore, analyzing other components of altimetric variation combined with meteorological series, such as temperature and precipitation, for example, can help to better understand the results obtained in the historical analysis of such tide gauge series. To do so, this study reviewed 35 articles between the years 2009 and 2021 taken from the Scopus database. Through bibliometrics, the objective is to map the literature on mean sea level and its relationship with satellite altimetry and/or meteorological factors while organizing and identifying the main lines of thought and evaluating the impact of a country's scientific production on the theme and the scientific production resulting from research investments by funding agencies, among others.

The article is structured in sections that intend to clarify the methods used and their selection criteria, in addition to the main results found and their consequent discussions that elucidate such results.

2 MATERIALS AND METHODS

2.1 Materials

Among the various databases available (Web of Science, Scopus , Google Scholar, etc.), it was decided to use the Scopus database as it is the largest database of abstracts and citations of peer-reviewed literature, offering a comprehensive view of the world's research output in various fields of knowledge, as well as smart

tools to track, analyze and visualize research (more details at: https://service.elsevier.com/app/home/supporthub/scopus/).

To help synthesize the data and generate graphs and/or tables, the "Bibliometrix" tool (ARIA; CUCCURULLO, 2017) was also used, a package developed in R language that provides routines for bibliometric analysis and construction of co-citation, coupling networks, scientific collaboration, and keyword analysis, among others (more details at: https://www.bibliometrix.org/index.html).

2.2 Methods

For the development of the research, bibliometric analysis techniques were used. These are defined as a set of methods to quantitatively analyze academic publications through statistical techniques, with the potential to trace research trends and popular issues at a global level (SHI et al., 2020). Araújo (2006) defines it as a quantitative and statistical technique to measure indexes of production and dissemination of scientific knowledge.

Making a brief report, the term "statistical bibliography," today defined as "Bibliometrics," was used for the first time in 1922 by Hulme, before the date on which the formation of the Information Science field is attributed, with the connotation of clarifying scientific and technological processes by counting documents. Later, the term was used by Gosnell in 1944 and Raisig in 1962, although there was a consensus that the term was not entirely satisfactory (GUEDES; BORSCHIVER, 2005). Thus, the term Bibliometrics is suggested to name the field in question (PRITCHARD, 1969).

Other review methods could have been used, each one with its advantages and limitations, but the simplicity of the systematized search, the identification of trends, and the creation of indicators favored the choice of bibliometrics. Bibliometric approaches, through which science can be portrayed through the results obtained, are based on the notion that the essence of scientific research is the constituent manifestation of this knowledge (OKUBO, 1997).

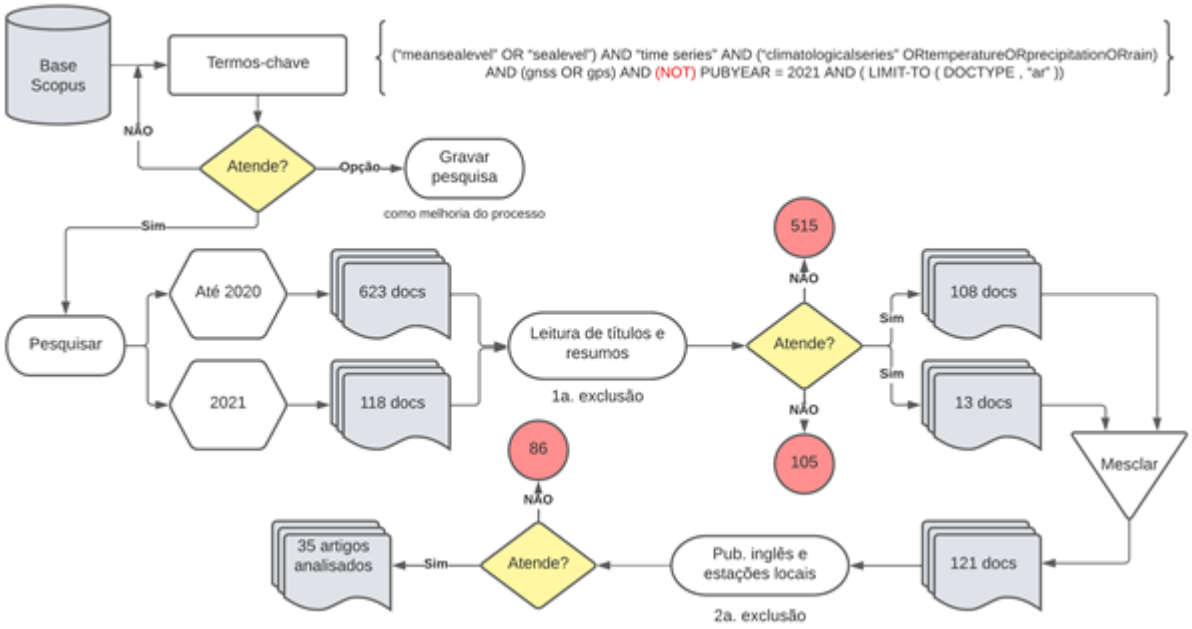
2.3 Selection Criteria

The choice of key terms, that is, the terms defined as search criteria for articles of interest, is given as a fundamental step in the review process because it will have a direct influence on the results of the analysis. At this point, as these are very specific topics, being too rigid in choosing terms could restrict the query too much, making the review unfeasible.

As this review focused on the assessment of mean sea level and its relationship with altimetric and meteorological variables, the terms "mean sea level" or simply "sea level" were used, in addition to "climatological series" or "temperature" or "precipitation" or "rain," in addition to the term "gnss" or "gps." The first two terms refer to the assessment of mean sea level, the following four refer to meteorological variables, and the last two refer to the altimetry component extracted from GNSS (Global Navigation Satellite System) systems. The first consultation was carried out in October 2021 and was limited only to publications from previous years and of the article type, resulting in 623 publications. In 2022, the same terms previously researched were used, adding publications of the year 2021, resulting in 118 more articles.

As shown in the flowchart in Figure 1, the first exclusion criterion was based on reading the titles and, in many cases, their abstracts, resulting in 121 documents. In these exclusions, in addition to the uncorrelated publications that always contaminate the selection process, most of these articles referred to satellite altimetry missions, like the Jason 1, Jason 2, and Topex/Poseidon missions. These were not considered since only those studies based on the analysis of the altimetric component of GNSS systems were of interest.

Figure 1 - Flowchart of the selection process of articles related to the sea level theme, 2009 – 2021.



Source: Lucidchart (2022) and Adapted by the authors (2022).

More carefully, another 86 documents were eliminated in a second exclusion criterion. At that time, only publications in the English language and those that analyzed the fluctuations of the mean sea level through local tide gauge stations were of interest since these tide gauge stations bring the real situation of the place, unlike altimetric missions.

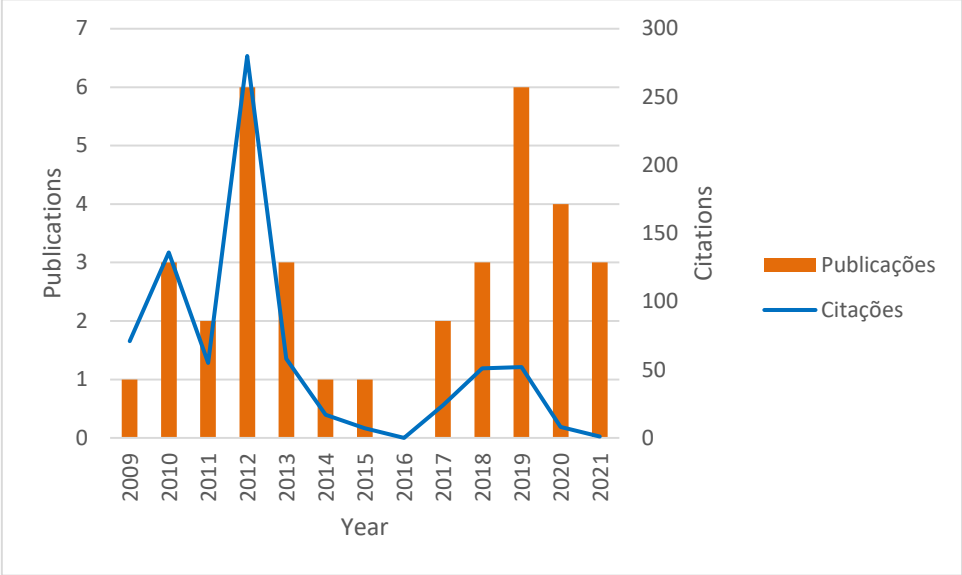
Finally, after the inclusion and exclusion criteria, 35 total publications between the years 2009 and 2021 were analyzed in this review. A positive point to highlight is that no selection percentages were made for the result. The articles were analyzed one by one, considerably reducing or even eliminating possible biases in the erroneous analysis of the study.

3 RESULTS AND DISCUSSIONS

3.1 Overview

In this research, 35 documents were selected between the years 2009 and 2021; all of them were scientific article types, according to the selection criteria. With these numbers, an average of 2.7 publications and 58.5 citations were obtained annually, with 21.7 being the average of citations per document. According to Figure 2, the number of publications over the years is presented, as well as the number of citations related to the respective publications, which does not mean that the citation occurred in the same year of its publication.

Figure 2 - Number of annual publications and respective citations related to sea level, 2009 – 2021.



Source: The authors (2022).

Still concerning Figure 2, it is clear to see the high variability of publications and citations (68% and 131% of variation around the average, respectively), making any attempt to identify a trend an unfeasible task. Regarding the publications, an atypical behavior is perceived, reaching zero in 2016 and two peaks in 2012 and 2019. Finding an answer to such a scenario is not an easy task, but the fact that IPCC reports exist in later years can help to understand such a scenario.

Another question is why publications only started in 2009, given that satellite coordinate retrieval originated as early as the 1950s. The first answer is that the first continuous GPS (Global Position System) stations started to operate close to tide gauges only from 1994 onwards (SCHÖNE et al., 2009), and only then did they reach an adequate level of maturity for the comparison of high precision vertical velocity fields (FADIL et al., 2011); the second is that the selection was very specific, relating tide gauge data with GNSS data and meteorological data.

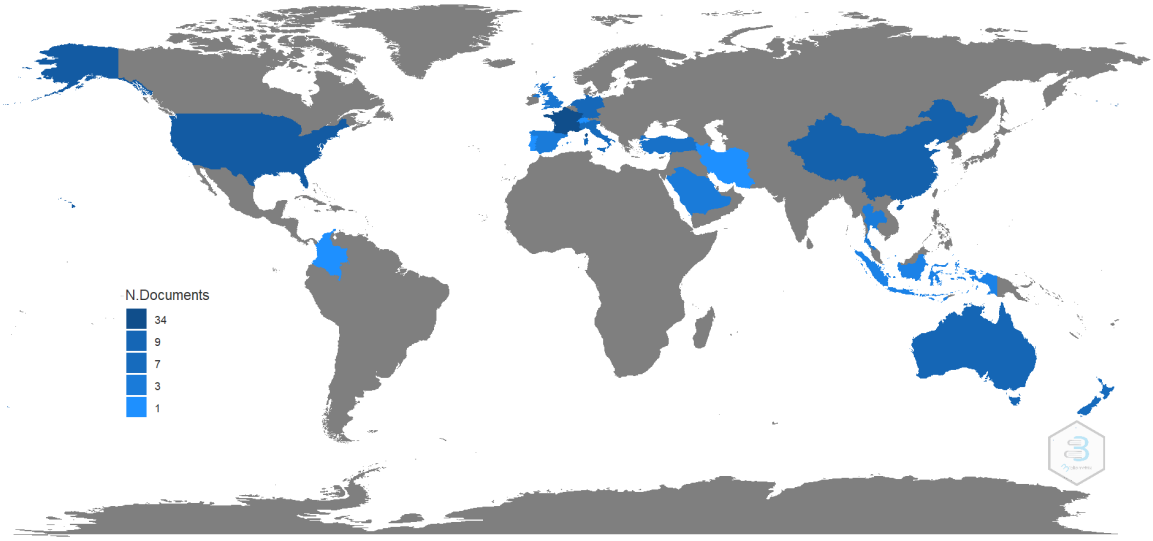
Regarding the citations, a large amount can be seen in 2012, in which 2/3 of them refer to only 2 of the 6 publications of the year in question (SANTAMARÍA-GÓMEZ et al., 2012; WÖPPELMANN; MARCOS, 2012). As expected, from 2012 onwards, the number of citations will decrease (decreasing trend) since fewer people read recent publications.

Additionally, 397 keywords were used by 113 authors. Of these, 4 (3.5%) were of single authorship, and another 109 (96.5%) were shared.

3.2 Main Countries

Although the main countries were highlighted, the data actually refers to the nationality of its main authors. Figure 3 shows France, the United States, and China as the most influential countries, followed by Australia, Germany, the Netherlands, Italy, New Zealand, Colombia, and the United Kingdom rounding out the "top 10" group; together, they represent almost 88% of total publications. Almost half of the data is concentrated on 3 countries: France at 27.2%, the United States at 12.8%, and China at 9.6, totaling 49.6%.

Figure 3 – Publications by country of origin related to the sea level theme (2009 – 2021).



Source: Biblioshiny (2022) and Adapted by the authors (2022).

Regarding citations, France remains in the lead with 331 (44.9%), followed by Germany with 128 citations (17.4%), both accounting for almost 2/3 of the total number of citations. Next, we have the United States with 12.9%, the United Kingdom with 8.6%, the Netherlands with 5.7%, Australia with 5%, New Zealand with 2.7%, and Thailand with 1.9%, which together add up to more than 99 % of all citations.

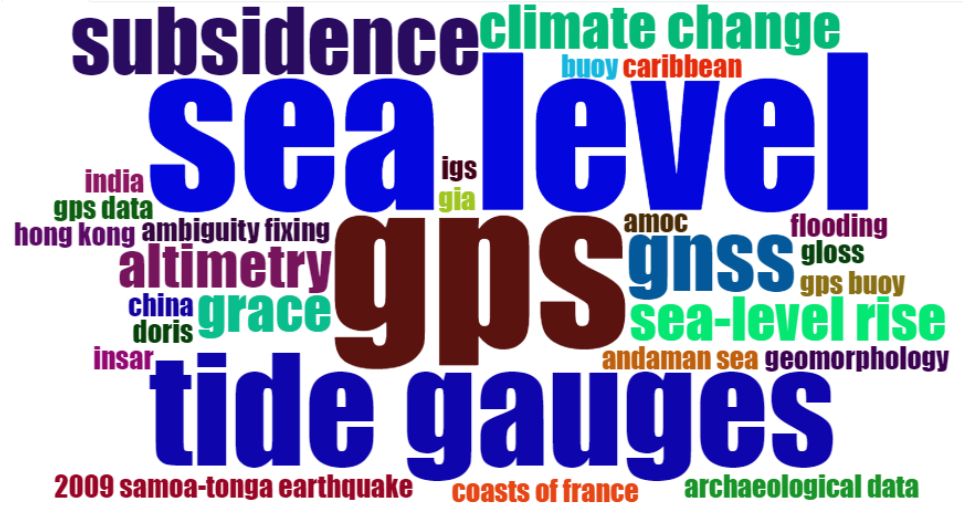
As previously reported, sea level rise is a global concern, with the thermal expansion of oceans and melting glaciers as major contributors (IPCC, 2013). It was noticed in this analysis that a large number of authors use tidal data provided mainly by the Permanent Service for the Mean Sea Level (PSMSL) to analyze the behavior of sea levels on global scales (SCHÖNE et al., 2009; RAY; BECKLEY; LEMOINE, 2010; SANTAMARÍA-GÓMEZ et al., 2012; KLEINHERENBRINK; RIVA; FREDERIKSE, 2018), but some focus on more punctual analyzes (BUBLE; BENNETT; HREINSDÓTTIR, 2010; TSIMPLIS et al., 2011; SARAMUL; EZER, 2014; PARKER, 2018; DODET et al., 2019; BORETTI, 2021), mainly concerned with the coastal regions of countries that can be more impacted by conditions such as beach erosion, flooding of land, increased salinization of coastal aquifers, that can cause direct impacts on the people who live there, both from a social and economic point of view (FENOGLIO-MARC et al., 2012).

3.3 Keywords

As previously mentioned, 397 keywords were used by 113 authors. Of this total, the 12 most relevant words were in many occurrences: "sea level change" (25), "tide gauge" (24), "sea level" (23), "satellite altimetry" (18), "tide gages" (16), "gps" (15), "subsidence" (13), "tide gauges" (10), "mediterranean sea" (8) and "global positioning system" (7), "sea level rise" (7) and "Atlantic ocean" (6). It is easy to observe that there are some synonyms in this group of terms; these words are automatically extracted from the publications and translate the reality that each author wants to express at the moment, and the simple fact that these terms can be expressed in singular or plural form can discriminate them for example. Some programs allow the use of a database of words to group words with similar meanings, also known as "thesaurus," but we were not able to use this tool when using bibliometrix. If we could use this tool, the 12 most used words could be just 7, such as: "sea level" ("sea level change," "sea level," and "sea level rise"), "tide gauge" ("tide gauge," "tide gages" and "tide gauges"), "satellite altimetry," "gps" ("gps" and "global positioning system"), "subsidence," "mediterranean sea" and "Atlantic Ocean," accounting for 55 occurrences (31 .98%), 50 (29.07%), 18 (10.47%), 22 (12.79%), 13 (7.56%), 8 (4.65%) and 6 (3.49%) %), respectively.

The word cloud in figure 4 highlights the aforementioned keywords.

Figure 4 – Cloud of keywords related to the sea level theme. 2009 – 2021.

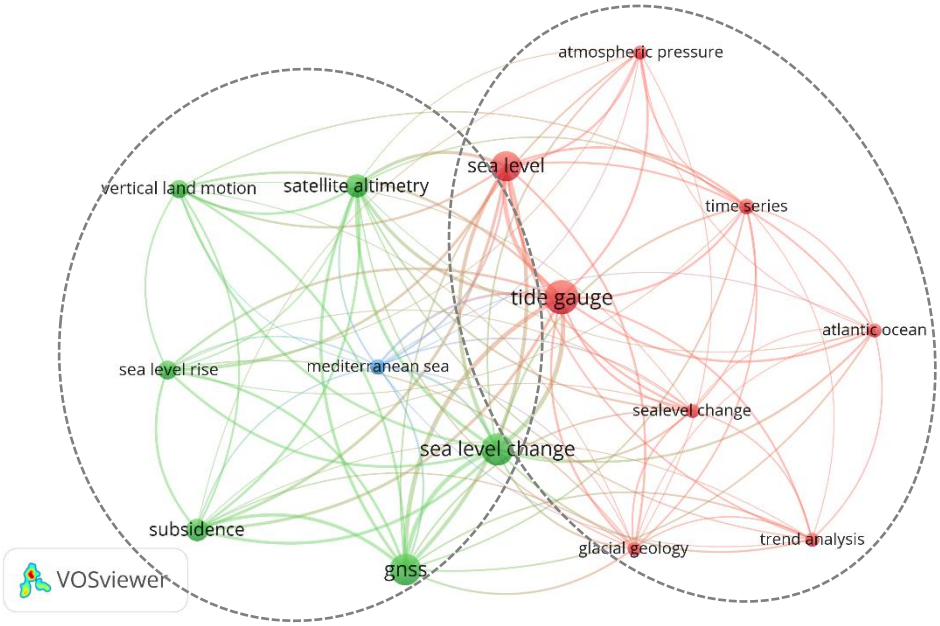


Source: Biblioshiny (2022) and Adapted by the authors (2022).

Interestingly, the following 8 most relevant words do not bring this grouping characteristic seen in the first 12, namely: "atmospheric pressure" (6), "time series" (6), "uncertainty analysis" (6), "climate change" (5), "glacial geology" (5), "trend analysis" (5), "China" (4), except for "sea level change" and another 5 occurrences that join the group "sea level."

Keywords are also related, and this is called co-occurrence, that is, the frequency with which two words are used together in articles. For each word, its co-occurrence with another word is analyzed, along with its frequency (OKUBO, 1997). Also, according to the author, the underlying assumption of the method is that co-words can be used to identify and represent specific networks of a particular type of research.

Figure 5 - Keyword co-occurrence network.



Source: Vosviewer (2022) and Adapted by the authors (2022).

This reality was perceived in Figure 5, created using Vosviewer, a software used as a tool for building and visualizing bibliometric networks. The set of words can be divided into two clusters represented by the dotted circles, which show us on one side (red) the sea level, tide stations, and the time series basically, and on the other side (green) that highlight the study of the variation of the Earth's surface and its sensors and satellites that can measure such variation. In other words, the cluster of absolute movements. In Figure 5, the keywords are represented by nodes, and the arcs are their links with other nodes or other keywords. The sizes of each node indicate the importance of each keyword. It can be seen, therefore, that the tide gauge stations

are related to the sea level, which they are responsible for monitoring, and that this data is correlated with series from satellite altimetry and GNSS series to correct or eliminate vertical movement of the Earth, this correlation is seen in almost all research articles.

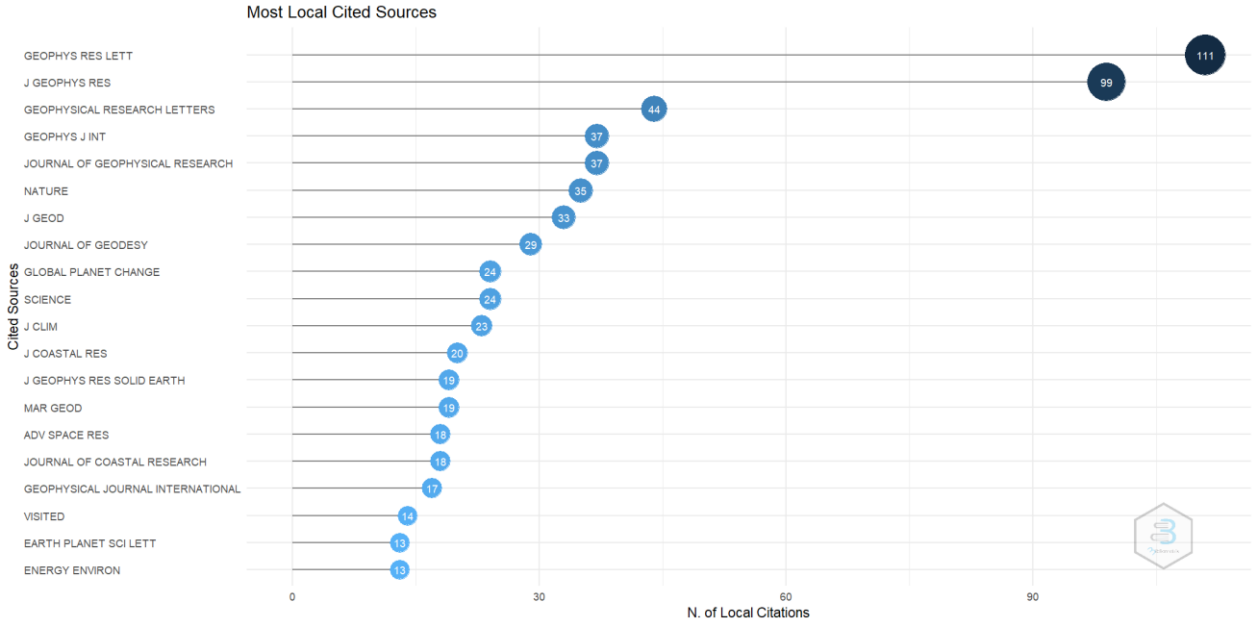
3.4 Most relevant journals

To disseminate research related to the theme of sea level advance and its relationships with non-oceanic variables, 20 journals were used between the years 2009 to 2021. Of these, the 7 most relevant with two or more publications are the following: *Journal of Geophysical Research: Oceans*, *Advances in Space Research*, *Global and Planetary Change*, *Journal of Geophysical Research: Solid Earth*, *Journal of Coastal Research*, *Nonlinear Engineering* and *Ocean and Coastal Management*. The first three are responsible for 16 of the 35 articles, which corresponds to almost half of all publications (45.71%).

According to Mathankar (2018), the number of articles is an indicator that reflects scientific production, measured by the number of*"papers,"* while the number of citations can be considered a measure of the impact of cited articles, as well as their relevance and usefulness. It is assumed that an article must have a certain quality to have an impact on the scientific community (MATHANKAR, 2018).

Producing a lot of scientific studies does not mean they will necessarily be the most cited. An example of this is the *Journal of Geophysical Research: Oceans*, which has the largest number of publications, five in total. However, in terms of citations, the aforementioned journal only appears in fifth place with 37 citations, the same number of citations as the *Geophysical Journal International* and surpassed by the *Geophysical Research Letters* with 44, *Journal of Geophysical Research* with 99, and *Geophysical Research Letters* with 111 citations, as it can be observed in figure 6.

Figure 6 – Most cited journals related to sea level. 2009 – 2021.



Source: Biblioshiny (2022) and Adapted by the authors (2022).

Still concerning journals, Samuel Bradford formulated in 1934 the law of dispersion to describe the distribution of articles on a given subject in different journals, concluding that these could be categorized into 3 separate groups, namely (MATHANKAR, 2018):

a) Those who produce more than four references in the year (Zone 1);
b) Those who produce between two to four references per year (Zone 2);
c) Those with one or fewer references in a year (Zone 3).

According to Bradford's Law, Table 1 classifies journals and their respective zones.

Table 1: Classification of journals according to Bradford's Law.

JOURNAL	RANK	FREQ	FREQ ACC	ZONE
Journal of Geophysical Research: Oceans	1	5	5	Zone 1
Advances in Space Research	2	4	9	Zone 1
Global and Planetary Change	3	4	13	Zone 1
Journal of Geophysical Research: Solid Earth	4	3	16	Zone 2
Journal of Coastal Research	5	2	18	Zone 2
Nonlinear Engineering	6	2	20	Zone 2
Ocean and Coastal Management	7	2	22	Zone 2
Acta Oceanologica Sinica	8	1	23	Zone 2
Arabian Journal of Geosciences	9	1	24	Zone 2
Comptes Rendus - Geoscience	10	1	25	Zone 3
Geophysical Journal International	11	1	26	Zone 3
Geophysical Research Letters	12	1	27	Zone 3
Ieee Journal of Selected Topics in Applied Earth Observations and Remote Sensing	13	1	28	Zone 3
Journal of Geodesy	14	1	29	Zone 3
Journal of Hydrologic Engineering	15	1	30	Zone 3
Marine Geodesy	16	1	31	Zone 3
Ocean Science	17	1	32	Zone 3
Physics and Chemistry of The Earth	18	1	33	Zone 3
Studia Geophysica Et Geodaetica	19	1	34	Zone 3
Water (Switzerland)	20	1	35	Zone 3

Source: The authors (2022).

3.5 Outstanding institutions – country of origin

It is worth mentioning that the success of a country in research is directly linked to the publication capacity of its institutional contributors. An example of this is France, which leads the ranking at the expense of its institutions or affiliations, which appeared 6 times as those that publish the most. Using the same reasoning, China appears with two major centers of weight, the *National Ocean Technology Center* and the *Institute of Earthquake Forecasting*. On the other hand, the Netherlands, which appears as the fifth country that publishes the most, is in this position because of the *Delft University of Technology*, which leads the ranking of the affiliations that published the most, with 8 in total. It is understandable that the Netherlands has a lot of research on this issue, given that part of its territory is below sea level and that it suffered a lot in the 50s when hundreds of people died and thousands of homes were destroyed by floods.

In addition to the *Delft University of Technology*, the other 4 institutions or affiliations that have published the most are as follows: the *French University of La* Rochelle/CNRS with 7, *the Chinese National Ocean Technology Center*, the *German Technical University Darmstadt* with 5 and the *Chinese Institute of Earthquake Forecasting* with 4.

3.6 Authors

Perhaps this is the most important topic of the study. After all, all articles analyzed have one or more authors, which will later be reflected in their affiliations and countries of origin.

Following the same structure that has been presented in the previous topics, the authors who published the most among the 35 articles being studied were: *Wöppelmann* with 5 publications; *Boretti and Testut*, both with 3 publications and with 2 publications each; *Becker, Fenoglio-Marc, Frederikse, Gravelle, Marcos, Parker, and Riva.*

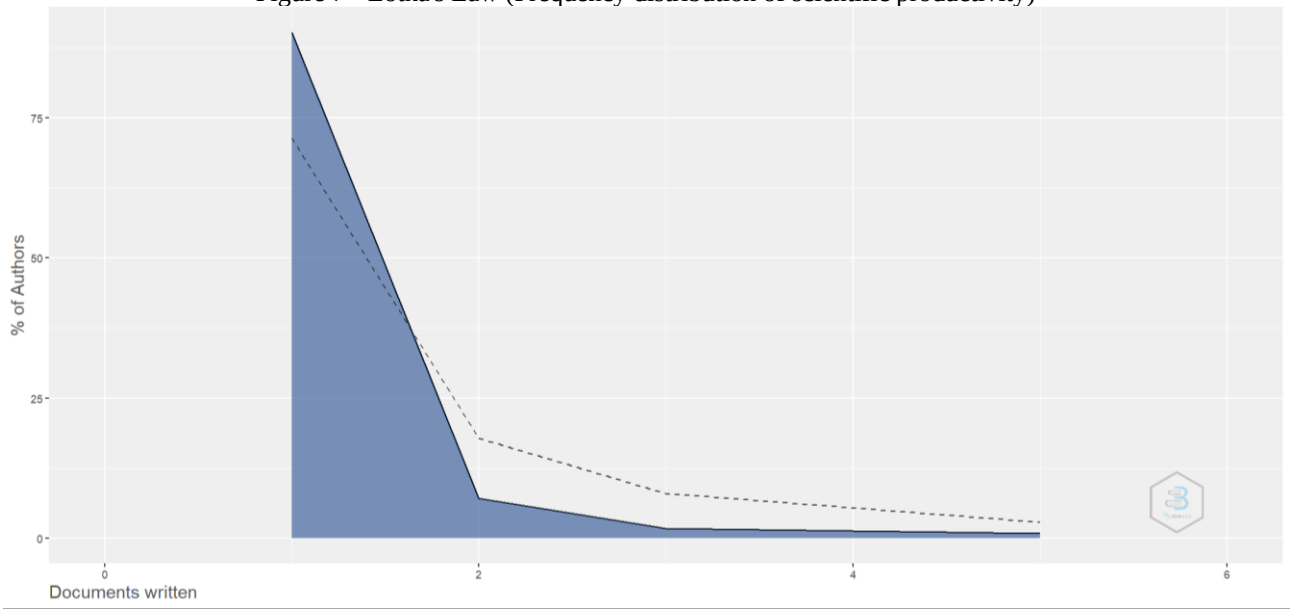
This publication metric made Lotka, in 1926, propose an inverse square law of science productivity

(MATHANKAR, 2018). He was one of the first to link the notion of productivity to counting, noting that the number of published articles was not evenly distributed and that productivity tended to be concentrated in a limited number of researchers (OKUBO, 1997). In other words, Lotka found that the productivity of scientists followed the inverse square law whereby for every 100 authors that contribute with one article, 25 will contribute with two articles, 11 will contribute with three, 6 will contribute with four, and 4 will contribute with five articles (MATHANKAR, 2018). Figure 7 shows the frequency distribution of scientific productivity proposed by Lotka.

In this case, this means that 90% of the authors will produce only 1 article, 7% will produce 2 articles, less than 2% will produce 3 articles, just over 1% will produce 4 articles, and less than 1% will produce 5 articles or more.

In terms of citations, *Wöppelmann* also leads the way with 11 citations in all. According to Okubo (1997), the citations of a scientific article are an indication of the importance that the community attaches to the research. Thus, citations can be considered a criterion for selecting the most reputable scientific journals based on the articles they contain (OKUBO, 1997). Following in the number of citations is *Marcos* with 6 citations and *Collilieux, Gravelle, Guichard, Míguez, Santamaría-Gómez, and Tiphaneau* with 5 citations each. Figure 8 below shows the authors' production over the period studied. The line corresponds to the author's active period, the size of the circles indicates the number of publications, and their intensity indicates the number of annual citations. With this, the figure also helps to understand who were the authors that appeared in the first half of the studied period (Marcos, Schöne, Barriot, Beckley, and Bennett) and those who appeared later (Frederikse, Parker, Riva, Bouchette, among others). In addition, it is possible to see who showed more constancy, such as *Gravelle*, *Becker*, *Testut* and mainly *Wöppelmann*, which justifies why he was active for so long and has the highest number of citations among the authors.

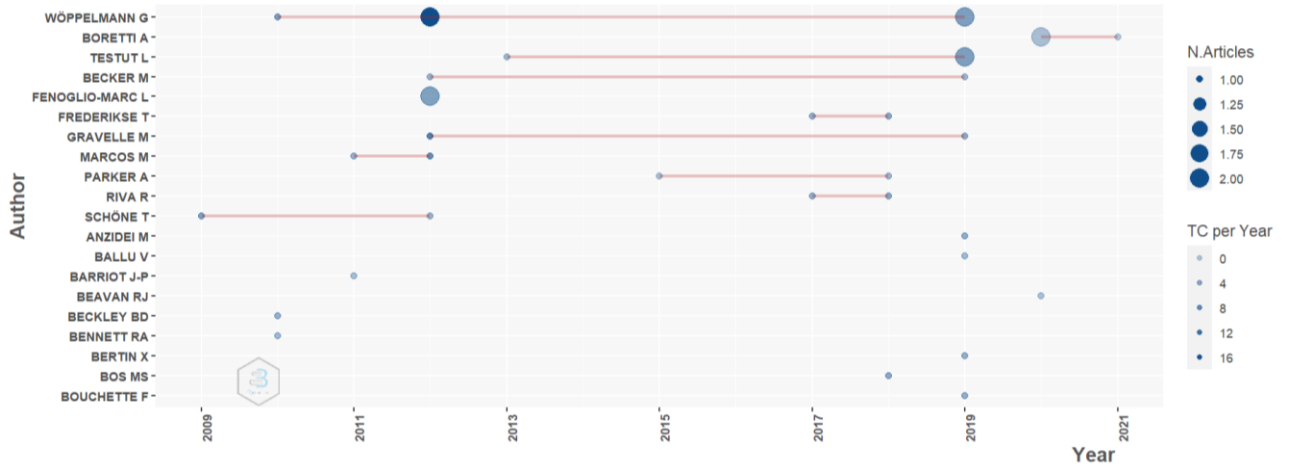
Figure 7 - Lotka's Law (Frequency distribution of scientific productivity)



Source: Biblioshiny (2022) and Adapted by the authors (2022).

On the other hand, citations can also have a negative connotation, that is, when the author may be cited for research of a controversial nature or methodology error (OKUBO, 1997). This can be seen in the article that studied sea level variability from tide gauges with more than 100 years of observation in the Pearl River Delta region of China. Its objective was to discuss the sea level acceleration in the area, showing that the levels are not accelerating but only rising at the same rate, thus contradicting several studies, including the IPCC (PARKER, 2018).

Figure 8 - Authors' production over time.

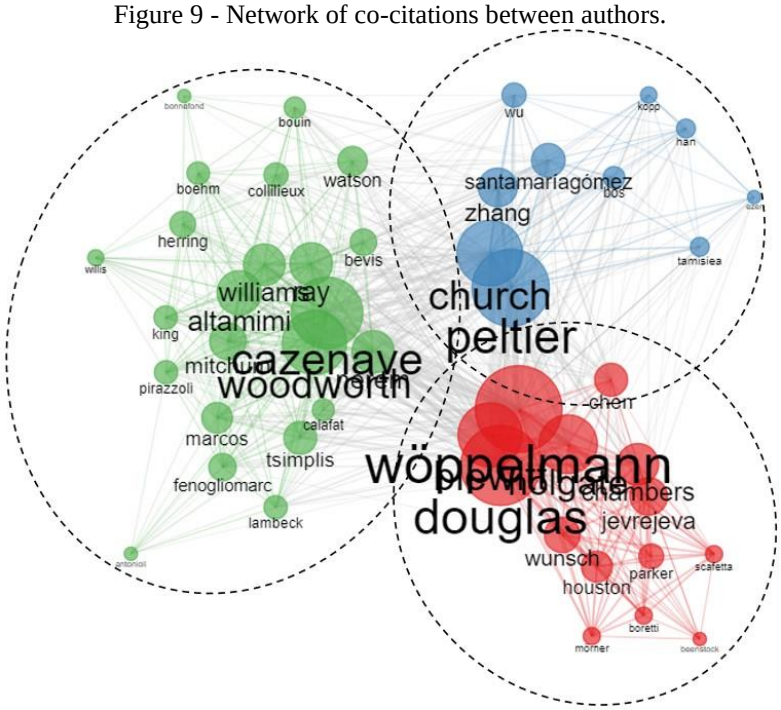


Source: Biblioshiny (2022) and Adapted by the authors (2022).

It is possible for two articles to be cited simultaneously in the same article, which we call co-citation. This indicator illustrates thematic networks and the influence and impact of the authors, representing partially the reactions of the scientific community to the research results (OKUBO, 1997). On the other hand, the author also emphasizes that the method is limited to describing only a part of the knowledge assembly process, as it provides a highly selective analysis of science, which refers much more to scientific literature than to technological literature. Figure 9 shows the co-citation network for the study in question.

As in the co-occurrence of words, the formation of clusters occurs not only because they are discussing the same object of study, obviously, but also because they share the same line of thought, with strong influences being *Wöppelmann, Douglas*, and *Blewitt*, as well as *Peltier*, *Church*, *Woodworth* and *Cazenave* in their respective groups.

Figure 9 - Network of co-citations between authors.



Source: Biblioshiny (2022) and Adapted by the authors (2022).

4 RELATIONS BETWEEN ARTICLES

Assessing sea level behavior is a complex task, as it involves several independent forcing factors, that is, variables that interfere in the determination of mean sea level, each one producing signals that can only be separated based on frequencies and time and spatial scales (TSIMPLIS et al., 2011). This causes the sea level

variation to stop being homogeneous and to behave differently from one place to another. Perhaps because of this, some authors prefer to leave the global analysis aside and start to analyze local cases in isolation, with examples being studies of the Adriatic Sea (BUBLE; BENNETT; HREINSDÓTTIR, 2010), the Mediterranean Sea (TSIMPLIS et al., 2011), Thailand (SARAMUL; EZER, 2014), China (PARKER, 2018), France (DODET et al., 2019) and Oceania (BORETTI, 2020).

It is worth mentioning that the way of monitoring sea level behavior has not changed throughout history, except for the incorporation of new technologies that have helped or made analysis even more complex as a whole, which is the case for GPS receivers that started to operate close to tide gauge stations in 1994 (SCHÖNE; SCHÖN; THALLER , 2009) and later became multi-satellite (GNSS). Added to this technological set are satellite altimetry missions, such as Jason and Topex/Poseidon.

Regardless of the scope of the study, the results found are never the same, although many use the same statistical devices to calculate their findings, such as the simple differences between sensors and linear regression models (BOUIN; WÖPPELMANN, 2010; FENOGLIO-MARC et al., 2012; TORRES; TSIMPLIS, 2013). In fact, the linear regression model is in part even contested as being an inadequate model for sea level estimation as it does not provide any instructions regarding time acceleration s given the inherent assumptions of constant velocity and zero acceleration (WATSON, 2019).

Some researchers have proposed using more robust statistical models, such as the model proposed by Sjoberg, which uses differences in tide gauges to infer relative rates of elevation of secular lands (BUBLE; BENNETT; HREINSDÓTTIR, 2010). In another study, advanced techniques were used to compare tide gauge data with satellite altimetry, replacing the lack of tide gauge stations with coupled GPS (WÖPPELMANN; MARCOS, 2012). Some studies used maximum and minimum values in addition to average values (BORETTI, 2020). In other studies, medians of GNSS trends were used in better alignment with the trends of the differentiated altimetry meter (KLEINHERENBRINK; RIVA; FREDERIKSE, 2018) and even the use of neural networks to identify a set of meteorological variables that affect anomalies (zonal and meridional wind speed, precipitation, relative humidity, and air temperature); this study found that more than half of the predicted variability was manifested by zonal wind patterns (MOGHADAM). , 2017).

The climate issue was one of the search criteria of this research and is present in other articles. For the Arctic Ocean, for example, it was observed that steric effects (ocean temperature and salinity variations) and atmospheric pressure contributed to 35% to 30% of the sea level rise, respectively (HENRY et al., 2012).). In the same sense, climate issues were also evaluated in the Caribbean Sea (TORRES; TSIMPLIS, 2013), in Hawaii (YANG; FRANCIS, 2019), and in the Hong Kong region (ZOU et al., 2021).

By taking advantage of new technologies and increasingly consolidated GNSS systems, new ideas are emerging, such as the use of buoys attached to GNSS receivers to monitor the absolute movement of sea level (FUND et al., 2013; DODET et al., 2019; ZHAI et al., 2020), but this method that uses differential observations still needs to advance a lot in terms of precision.

5 FINAL CONSIDERATIONS

Sea level change has significant environmental, social and economic impacts and can be used for diagnosis as an indicator of processes related to climate change (TSIMPLIS et al., 2011).

However, researching the various processes that contribute to the relative sea level change at a given location is a challenging task involving the scientific examination of several independent forcing factors, each producing signals that can only be separated based on frequencies, temporal and spatial scales (TSIMPLIS et al., 2011). These factors range from astronomical (tidal), atmospheric (atypical events and sea winds), and oceanic processes (waves and currents) to solid terrestrial processes (land movements) (DODET et al., 2019; WATSON, 2019), which turns the job of determining the level of the sea into a complex task.

Simav et al. (2012) already stated that understanding the mechanisms of sea level change is one of the greatest concerns of geosciences in the era of climate change, with implicit consequences for coastal ecosystems and human society.

In this study, through bibliometrics, statistical techniques were used as methods to quantitatively

analyze the main academic publications on the subject between the years 2009 and 2021. A strong variability in the number of publications and citations was identified, and France, the United States, and China were identified as being the most influential countries on this subject; this occurs due to their contributing institutions or affiliations and, mainly due to, their authors. The latter stands out for *Wöppelmann*, both from a publication's and a citation's point of view.

As well as the keywords in their co-occurrence networks, the authors also relate to each other regarding the importance that the community attaches to their research, and this can be considered a criterion for selecting the most reputable scientific journals. Some of these authors contribute with global analyses, others with more regional analyses, but all are concerned with the impacts that sea level rise can bring to society as a whole.

In the previous item, it was seen that the methodology for monitoring sea level presented little change historically speaking, except for the increase in new technologies such as GNSS and satellite altimetry. The problem lies in the strong dependence on global models that are not even able to take into account phenomena that occur locally. An example is the GIA (Global Isostatic Adjustment Model), which only provides wider scale resolution, not detecting local processes associated with tectonic activity, volcanism, sediment compaction, subsidence by water extraction, etc. (WATSON, 2019; BORETTI, 2021). Denys et al. (2020) further state that this model is very well accepted for high-latitude regions, but outside of them, GIA vertical rates are a small fraction of the vertical earth movement measured by GNSS stations.

It is no exaggeration to say that statistics is not only important in this bibliometric analysis, but it is also fundamental and indispensable in the very understanding of the behavior of sea level and forcing factors. A good part of studies uses elementary statistics to calculate averages, medians, and trends, and a small portion goes a little further when using more robust statistical methods.

Acknowledgments

The authors thank the Postgraduate Program in Modeling in Earth and Environmental Sciences (PPGM-UEFS) and CAPES for their support.

Authors' Contribution

This article was developed from research carried out in the academic doctorate of the author N. S. R. J., with the contribution of each of the authors as follows: N. S. R. J. – research, conceptualization, writing, review, and final editing; A. M. S. F. – guidance and review.

Conflicts of interest

The authors declare that there is no conflict of interest.

References

ARAÚJO, C. A. Bibliometria: evolução histórica e questões atuais. **Em questão**, v. 12, n. 1, p. 11–32, 2006.

ARIA, M.; CUCCURULLO, C. bibliometrix : An R-tool for comprehensive science mapping analysis. **Journal of Informetrics**, v. 11, n. 4, p. 959–975, 2017. DOI. 10.1016/j.joi.2017.08.007.

BORETTI, A. Relative sea-level rise and land subsidence in Oceania from tide gauge and satellite GPS. **Nonlinear Engineering**, v. 9, n. 1, p. 175–193, 2020. DOI. 10.1515/nleng-2020-0007.

BORETTI, A. Nonlinear absolute sea-level patterns in the long-term-trend tide gauges of the East Coast of North America. **Nonlinear Engineering**, v. 10, n. 1, p. 1–15, 2021. DOI. 10.1515/nleng-2021-0001.

BOUIN, M. N.; WÖPPELMANN, G. Land motion estimates from GPS at tide gauges: A geophysical evaluation. **Geophysical Journal International**, v. 180, n. 1, p. 193–209, 2010. DOI. 10.1111/j.1365-246X.2009.04411.x.

BUBLE, G.; BENNETT, R. A.; HREINSDÓTTIR, S. Tide gauge and GPS measurements of crustal motion and sea level rise along the eastern margin of Adria. **Journal of Geophysical Research: Solid Earth**, v. 115, n. 2, 2010. DOI. 10.1029/2008JB006155. Acesso em: 15 ago. 2021.

DENYS, P. H.; BEAVAN, R. J.; HANNAH, J.; PEARSON, C. F.; PALMER, N.; DENHAM, M.; HREINSDÓTTIR, S. Sea Level Rise in New Zealand: The Effect of Vertical Land Motion on Century-Long Tide Gauge Records in a Tectonically Active Region. **Journal of Geophysical Research: Solid Earth**, v. 125, n. 1, 2020. DOI. 10.1029/2019JB018055. Acesso em: 15 ago. 2021.

DODET, G.; BERTIN, X.; BOUCHETTE, F.; GRAVELLE, M.; TESTUT, L.; WÖPPELMANN, G. Characterization of Sea-level Variations Along the Metropolitan Coasts of France: Waves, Tides, Storm Surges and Long-term Changes. **Journal of Coastal Research**, v. 88, n. sp1, p. 10–24, 2019. Coastal Education Research Foundation Inc. DOI. 10.2112/SI88-003.1.

FADIL, A.; SICHOIX, L.; BARRIOT, J.-P.; ORTÉGA, P.; WILLIS, P. Evidence for a slow subsidence of the Tahiti Island from GPS, DORIS, and combined satellite altimetry and tide gauge sea level records. **Comptes Rendus - Geoscience**, v. 343, n. 5, p. 331–341, 2011. DOI. 10.1016/j.crte.2011.02.002.

FENOGLIO-MARC, L.; BRAITENBERG, C.; TUNINI, L. Sea level variability and trends in the Adriatic Sea in 1993-2008 from tide gauges and satellite altimetry. **Physics and Chemistry of the Earth**, v. 40–41, p. 47–58, 2012.

FENOGLIO-MARC, L.; SCHÖNE, T.; ILLIGNER, J.; BECKER, M.; MANURUNG, P.; KHAFID. Sea Level Change and Vertical Motion from Satellite Altimetry, Tide Gauges and GPS in the Indonesian Region. **Marine Geodesy**, v. 35, n. SUPPL. 1, p. 137–150, 2012. DOI. 10.1016/j.pce.2011.05.014.

FOLGER, T. Rising seas. **National geographic**, v. 224, n. 3, p. 30–59, 2013.

FUND, F.; PEROSANZ, F.; TESTUT, L.; LOYER, S. An Integer Precise Point Positioning technique for sea surface observations using a GPS buoy. **Advances in Space Research**, v. 51, n. 8, p. 1311–1322, 2013. DOI. 10.1016/j.asr.2012.09.028.

GUEDES, V. L.; BORSCHIVER, S. Bibliometria: uma ferramenta estatística para a gestão da informação e do conhecimento, em sistemas de informação, de comunicação e de avaliação científica e tecnológica. **Encontro Nacional de Ciência da Informação**, v. 6, n. 1, p. 18, 2005.

HENRY, O.; PRANDI, P.; LLOVEL, W.; CAZENAVE, A.; JEVREJEVA, S. Tide gauge-based sea level variations since 1950 along the Norwegian and Russian coasts of the Arctic Ocean: Contribution of the steric and mass components. **Journal of Geophysical Research: Oceans**, v. 117, n. 6, 2012. DOI. 10.1029/2011JC007706. Acesso em: 15 ago. 2021.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC). **Climate Change 2013:** The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [STOCKER, T.F., D. QIN, G.-K. PLATTNER, M. TIGNOR, S.K. ALLEN, J. BOSCHUNG, A. NAUELS, Y. XIA, V. BEX AND P.M. MIDGLEY (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

KLEINHERENBRINK, M.; RIVA, R.; FREDERIKSE, T. A comparison of methods to estimate vertical land motion trends from GNSS and altimetry at tide gauge stations. **Ocean Science**, v. 14, n. 2, p. 187–204, 2018. Copernicus GmbH. DOI. 10.5194/os-14-187-2018.

MATHANKAR, A. R. Bibliometrics: An overview. **International Journal of Library & Information Science (IJLIS)**, v. 7, n. 3, 2018.

MOGHADAM, F. M. Neural network-based approach for identification of meteorological factors affecting regional sea-level anomalies. **Journal of Hydrologic Engineering**, v. 22, n. 3, 2017. American Society of Civil Engineers (ASCE). DOI. 10.1061/(ASCE)HE.1943-5584.0001472. Acesso em: 15 ago. 2021.

NICHOLLS, R., HANSON, S.; HERWEIJER, C.; PATMORE, N.; HALLEGATTE, S.; CORFEE-MORLOT, J.; CHÂTEAU, J.; MUIR-WOOD, R. Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates, **OECD Environment Working Papers**, No. 1, OECD Publishing, Paris, 2008. DOI. 10.1787/011766488208.

OKUBO, Y. **Bibliometric Indicators and Analysis of Research Systems: Methods and Examples**. OECD Science, Technology and Industry Working Papers, 1997. DOI. 10.1787/208277770603.

PARKER, A. Sea level oscillations in Japan and China since the start of the 20th century and consequences for coastal management - Part 2: China pearl river delta region. **Ocean and Coastal Management**, v. 163, p. 456–465, 2018. DOI. 10.1016/j.ocecoaman.2018.08.004.

PARKER, A.; OLLIER, C. D. Sea level rise for India since the start of tide gauge records. **Arabian Journal of Geosciences**, v. 8, n. 9, p. 6483–6495, 2015. Springer Verlag. DOI. 10.1007/s12517-014-1739-6.

PRITCHARD, A. Statistical bibliography or bibliometrics. **Journal of documentation**, v. 25, n. 4, p. 348–349, 1969.

RAY, R. D.; BECKLEY, B. D.; LEMOINE, F. G. Vertical crustal motion derived from satellite altimetry and tide gauges, and comparisons with DORIS measurements. **Advances in Space Research**, v. 45, n. 12, p. 1510–1522, 2010. DOI. 10.1016/j.asr.2010.02.020.

SANTAMARÍA-GÓMEZ, A.; GRAVELLE, M.; COLLILIEUX, X.; GUICHARD, M.; MÍGUEZ, B. M.; TIPHANEAU, P.; WÖPPELMANN, G. Mitigating the effects of vertical land motion in tide gauge records using a state-of-the-art GPS velocity field. **Global and Planetary Change**, v. 98–99, p. 6–17, 2012. DOI. 10.1016/j.gloplacha.2012.07.007.

SARAMUL, S.; EZER, T. Spatial variations of sea level along the coast of Thailand: Impacts of extreme land subsidence, earthquakes and the seasonal monsoon. **Global and Planetary Change**, v. 122, p. 70–81, 2014. Elsevier. DOI. 10.1016/j.gloplacha.2014.08.012.

SCHÖNE, T.; SCHÖN, N.; THALLER, D. IGS Tide Gauge Benchmark Monitoring Pilot Project (TIGA): Scientific benefits. **Journal of Geodesy**, v. 83, n. 3–4, p. 249–261, 2009. DOI. 10.1007/s00190-008-0269-y.

SHI, Y.; BLAINEY, S.; SUN, C.; JING, P. A literature review on accessibility using bibliometric analysis techniques. **Journal of transport geography**, v. 87, p. 102810, 2020. Elsevier. DOI. 10.1016/j.jtrangeo.2020.102810.

SIMAV, M.; YILDIZ, H.; TÜRKEZER, A.; LENK, O.; ÖZSOY, E. Sea level variability at Antalya and Menteş tide gauges in Turkey: Atmospheric, steric and land motion contributions. **Studia Geophysica et Geodaetica**, v. 56, n. 1, p. 215–230, 2012. DOI. 10.1007/s11200-010-0067-x.

TORRES, R. R.; TSIMPLIS, M. N. Sea-level trends and interannual variability in the Caribbean Sea. **Journal of Geophysical Research: Oceans**, v. 118, n. 6, p. 2934–2947, 2013. DOI. 10.1002/jgrc.20229.

TSIMPLIS, M.; SPADA, G.; MARCOS, M.; FLEMMING, N. Multi-decadal sea level trends and land movements in the Mediterranean Sea with estimates of factors perturbing tide gauge data and cumulative uncertainties. **Global and Planetary Change**, v. 76, n. 1–2, p. 63–76, 2011. DOI. 10.1016/j.gloplacha.2010.12.002.

WATSON, P. J. Updated mean sea-level analysis: South Korea. **Journal of Coastal Research**, v. 35, n. 2, p. 241–250, 2019. Coastal Education Research Foundation Inc. DOI. 10.2112/JCOASTRES-D-18-00138.1.

WÖPPELMANN, G.; MARCOS, M. Coastal sea level rise in southern Europe and the nonclimate contribution of vertical land motion. **Journal of Geophysical Research: Oceans**, v. 117, n. 1, 2012. DOI. 10.1029/2011JC007469. Acesso em: 15 ago. 2021.

YANG, L.; FRANCIS, O. P. Sea-level rise and vertical land motion on the Islands of Oahu and Hawaii, Hawaii. **Advances in Space Research**, v. 64, n. 11, p. 2221–2232, 2019. DOI. 10.1016/j.asr.2019.08.028.

ZHAI, W.; ZHU, J.; MA, C.; et al. Measurement of the sea surface using a GPS towing-body in Wanshan area. **Acta Oceanologica Sinica**, v. 39, n. 5, p. 123–132, 2020. DOI. 10.1007/s13131-020-1599-8.

ZOU, F.; TENZER, R.; FOK, H. S.; MENG, G.; ZHAO, Q. The Sea-Level Changes in Hong Kong from Tide-Gauge Records and Remote Sensing Observations over the Last Seven Decades. **IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing**, v. 14, p. 6777–6791, 2021. DOI. 10.1109/JSTARS.2021.3087263.

Main author biography

Nilton de Souza Ribas Júnior was born in Recife/PE in 1975. He holds a degree in Cartographic Engineering from the Federal University of Pernambuco (1999), a master's degree in Environmental Sciences from the Universidade Estadual de Feira de Santana (2019), and a Ph.D. candidate in Environmental Sciences from the same institution. A Federal Public Servant since 2002, he has performed several engineering works at local, regional, and national levels. Currently, he manages the Geodesy and Cartography Sector of the IBGE in the State of Bahia.