

OCEAN MODELLING IN BRAZIL, A QUICK OVERVIEW

Modelagem oceânica no Brasil, uma visão geral rápida

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ABSTRACT

Hydrodynamic numerical modelling studies, at least partially focused on the Brazilian oceanography, were identified using the Scopus database. Ocean modelling in Brazil started in 1994 and has been increasing especially since 2007. In recent years, however, the rate of the increase is slowing. The main ocean models used are ROMS, POM and HYCOM, and the main institutions publishing in ocean modelling in Brazil are located in the states of São Paulo and Rio de Janeiro, resulting in the Southeast as the most studied region. Men dominate the ocean modelling in Brazil, with only three women in the top twenty scientists. Oil industry is a great sponsor of oceanography in Brazil. The interest in renewable energy offshore is, on the other hand, very low, with only two publications assessing the potential for renewable energy extraction from the ocean.

Keywords: ocean modelling, Brazil, models, regions, authors.

RESUMO

Este trabalho identificou na base de dados Scopus estudos de modelagem hidrodinâmica com foco, pelo menos em parte, na oceanografia brasileira. A modelagem oceânica no Brasil começou em 1994 e vem crescendo, em especial, desde 2007. Nos últimos anos, no entanto, a taxa de crescimento tem diminuído. Os principais modelos utilizados são o ROMS, o POM e o HYCOM, e as principais instituições com publicações em modelagem oceânica no Brasil estão localizadas nos estados de São Paulo e Rio de Janeiro, resultando na região Sudeste como a mais estudada. A modelagem no Brasil é dominada pelos homens, existindo apenas 3 mulheres nos primeiros 20 cientistas. A indústria do petróleo é o grande patrocinador da oceanografia brasileira. O interesse pelas energias renováveis oceânicas é, por outro lado, muito baixo, existindo apenas duas publicações de avaliação do potencial de extração de energias renováveis do oceano.

Palavras-chave: modelagem oceânica, Brasil, modelos, regiões, autores.

INTRODUCTION

The earth has two main external forcings, the universal gravitation and the electromagnetic radiation. While both forcings are periodic (mostly associated with the Sun and Moon), the complexity of the geophysical continuous systems and their interaction, generate subsystems with a large variety of time and space scales. Among the earth continuous are the atmosphere and the ocean. The atmosphere has been observed and studied for long time, especially because of its incredible power to create and to destroy. The advent of navigations raised the interest in the physics of the ocean. For the first time, humans were not only subjected to the wishes of the gods of the atmosphere and coastal waters, but also to unknown conditions in regions away from land, leading to the knowledge of the oceanic and atmospheric mesoscale. Without the ability to understand the Volta do Mar and the main oceanic boundary currents, the navigation without propulsion around the world would not be possible more than 500 years ago. The navigations also led to a better understanding of coastal oceanography and the development of other fields like mathematics and astronomy.

Nowadays, the interest in ocean sciences is general around the world. Nevertheless, very different national efforts are assigned to the subject. While some countries observe and study every km of coast, many coastal countries don't have, or have a very small, budget for ocean sciences. A large percentage of world population live in coastal regions which are at the front line of the initiating first strike of climate change (IPCC, 2019, 2021). Humankind had settle at coasts near the mouth of rivers and nowadays a large proportion of the world economy orbits around coastal regions. Activities like commerce and navigation, tourism, fishing, energy extraction and other industries are very or fully dependent on oceanic and coastal waters. Increasing the understanding of marine systems is thus not a luxury but a requirement to increase quality of life in communion with the nature, which present us with dangers but also with opportunities.

The first approach to study earth systems consists on observations, as science can only study known existences. The time and space limitations of the observational facilities, together with the evolution of the computational skills in recent decades, resulted in the development of numerical models of the earth system, in particular the modelling in physical oceanography. Modelling complements the observations by filling the observational gaps and providing a full time and space description of the physical systems. In addition, and very important, modelling can be used to predict future conditions. For instance it can be used to hindcast the nursing region of some marine species, to forecast the fate of some pollution spill in the ocean, or to assess the impact of changing the Amazon river discharge in the large scale circulation years from now.

Brazil has one the world longest coastlines, around 7500 km, and a very high percentage of population living in coastal and estuarine regions. The country covers most part of the west side of the South Atlantic and includes the world largest riverine discharge, mainly due to the Amazon river. The recent decades saw an increase in oceanography studies in the country and an increase in international collaborations, in both observational and numerical oceanography. This manuscript provides an overview of the evolution of numerical modelling in the Brazilian oceanography, including oceanic, coastal and estuarine modelling.

METHODS

This study is based on published articles indexed by Scopus (<https://www.scopus.com>), disregarding conferences. The journal articles or book chapters considered were those describing the conception or utilization of an original ocean, coastal or estuarine numerical ocean physics configuration, with partial or total focus on Brazilian marine systems. Non-hydrodynamic modelling was not considered, like waves modelling or particle tracking, as well as analysis from freely available large scale or global modelling solutions. For instance an article describing the Brazilian Current based on results of a global model, not developed in the framework of a study related with the Brazilian oceanography, were not considered. On the other hand, articles including the exploration of numerical results from a Brazilian configuration already described in other publication, were considered as ocean modelling articles. The Scopus search used the words ocean/coastal/estuarine modelling and Brazil, including variants like oceanic model or estuary modelling. The search was done in the title, abstract and keywords on September 15, 2021. After the first search, additional sensitivity tests were done including the main model names (identified in the first search). A few more publications were found this way and included in the present study.

RESULTS

The first article found on ocean modelling including the term Brazil dates back from 1988 describing a global ocean circulation model (Semtner & Chervin, 1988). That article was however not, at least partially, focused in Brazilian oceanography and was thus not considered in this study. Six years later England and Garçon (1994) was the first publication in some extent dedicated to the Brazilian ocean circulation. And four years later was published the first article on Brazilian ocean modelling produced by a Brazilian institution (Franchito *et al.*, 1998). Between England and Garçon (1994) and nowadays, Scopus identifies 92 publications on ocean modelling in Brazil (journals of all the quartiles and book chapters), including 71 articles in journals of quartiles 1 and 2, typically higher quality publications. The evolution of these publications along the time is shown in Figure 1. While all publications started increasing by 2003 (Figure 1a), the higher quality articles stronger increment initiated in 2007 (Figure 1b). In addition, high quality publications seem to continue nowadays increasing at a faster rate than all publications, indicating that lower quality manuscripts are losing importance. Nevertheless, the rate of publications increase appears to be slowing in recent years.

Regarding the numerical model used in Brazilian studies, these are illustrated in Figure 2. The main model used in high quality articles is ROMS, associated with 44% of the publications. The second model is POM (19%) and the third one is HYCOM, used about four times less than ROMS (10%). These are followed by MICON (6%) and NEMO (4%). Other models, each one used in less than three publications, are used in 16% of the articles. In terms of the time evolution of the usage of the main models (ROMS, POM and HYCOM), it can be observed in Figure 2c that while POM is in use since the nineties, ROMS and HYCOM are much more recent. ROMS in particular has been increasingly used in publications since 2009 and reached the peak of seven publications in 2019.

Figure 1 - Evolution of the Brazilian ocean modelling publications. a) all publications; b) high quality publications (journals of quartiles 1 and 2). The red lines represents the logistic functions that best fits to the data, excluding the year 2021 (the last data point)

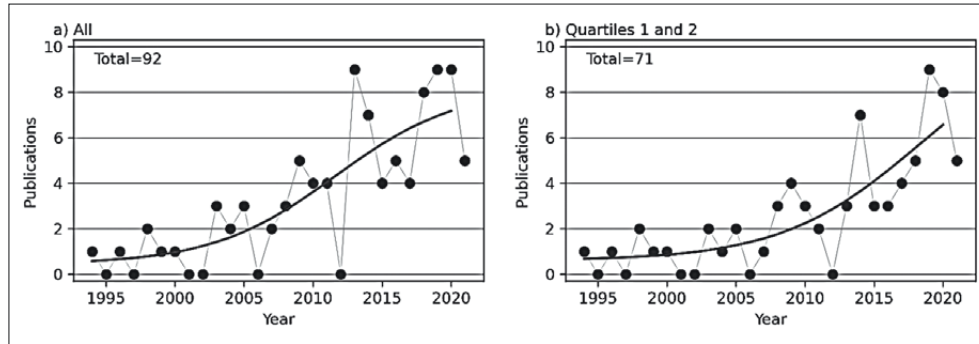
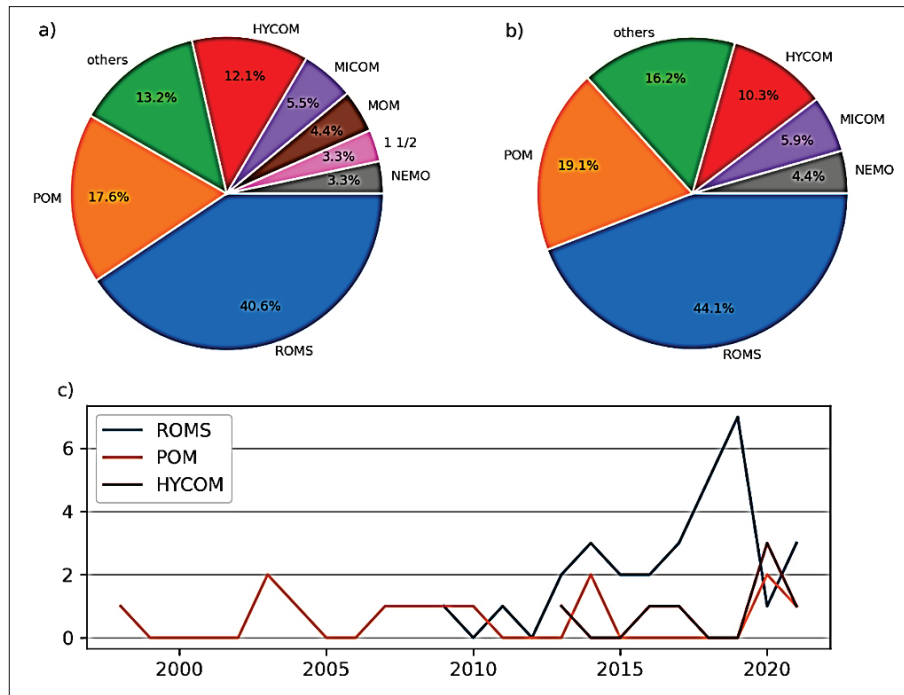


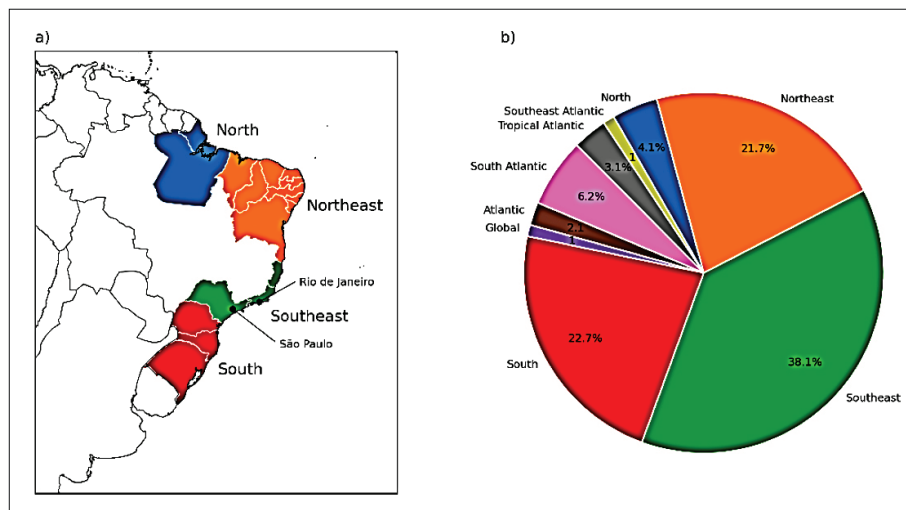
Figure 2 - Hydrodynamic models used in Brazilian studies. a) all publications; b) high quality publications (journals of quartiles 1 and 2); c) evolution of the usage of the three main models (ROMS, POM and HYCOM)



The model domains used in Brazilian ocean modelling studies are very diverse. While high resolution regional domains are coastal, other studies used basin scale or even global domains (Figure 3). The Southeast region is by far the most studied Brazilian region (38% of the publications), followed by South and Northeast, with 23% and 22% of the publications, respectively. The North region is much less studied, with only 4% of the regional domains focused on the North. This region includes the discharge of Amazon river and has been studied with wider domains covering the Tropical Atlantic or even larger domains. Even so, the North region has been very disregarded in terms of ocean modelling studies, despite of the possible importance of the Amazon discharge on the climate change at several time and space scales (Marengo & Espinoza, 2015; Jahfer; Vinayachandran & Nanjundiah, 2017). In addition, the region is known for its great potential for renewable energy production. The

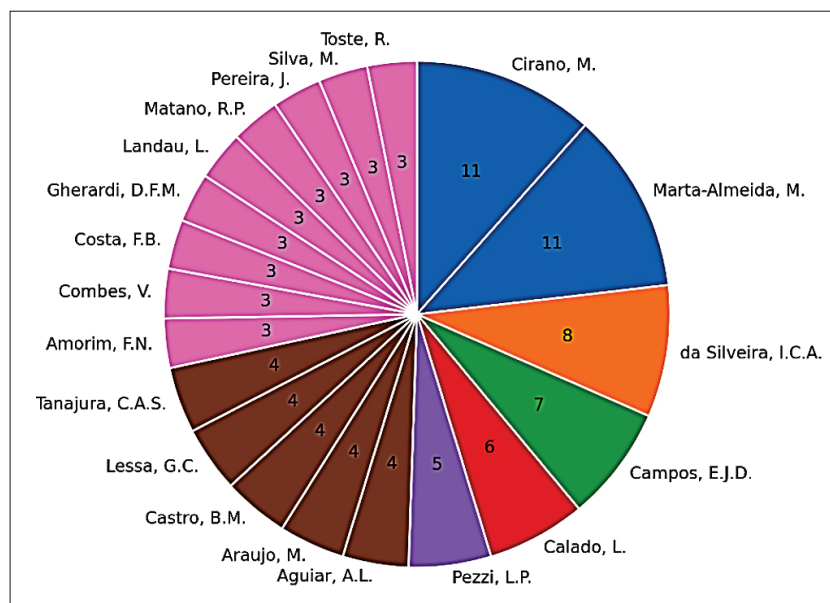
justification for the higher concentration of studies in Southeast region is associated with the location of the main ocean research facilities of Brazil, namely the University of São Paulo (USP), the Federal University of Rio de Janeiro (UFRJ) and the National Institute for Space Research (Inpe). Also in Figure 3, part of studies considered in the Northeast region actually include only the southernmost part of it, namely the Abrolhos Bank, with a considerable part of the domains hosting the Southeast.

Figure 3 – Region covered by hydrodynamic models used in Brazilian ocean modelling publications (journals of quartiles 1 and 2). The coastal states and corresponding regions are shown in a)



The main authors publishing in ocean modelling applied to Brazilian regions are shown in Figure 4 (no distinction is made between first author and co-authors). The authors with more publications are M. Cirano and M. Marta-Almeida, with eleven articles. These two authors have been associated with the Federal University of Bahia for many years but are

Figure 4 – Main authors of Brazilian hydrodynamic modelling studies and their respective number of publications in journals of quartiles 1 and 2



now at the UFRJ and the Spanish Institute of Oceanography (Spain), respectively. The next authors are I. C. A. da Silveira (USP, eight publications), E. J. D. Campos (USP, seven publications), L. Calado (Brazilian Navy, six publications) and L. P. Pezzi (Inpe, 5 publications). While the main research institutes of Southeast Brazil have in general a higher number of publications, it should be highlighted the effort of authors from the regions North and Northeast, typically with less financing opportunities, especially in recent years.

CONCLUSION

This work used the Scopus database to identify the publications on ocean modelling at least partially focused on Brazilian regions. Only hydrodynamic modelling studies were considered (conception and usage of modelling configurations). Studies using or analysing large scale or global modelling solutions were disregarded. Some publications may have been left out in the Scopus search but the results presented here most probably include the large majority of the published articles, since search sensitivity tests were done and the new results included.

The ocean modelling studies in Brazil have been increasing since 2007. The rate of the increase seems, however, to be slowing in recent years. This increasing modelling efforts may have many reasons, mainly: i) lack of resources for observational studies; ii) higher budget for the science in general and; iii) higher concern with climate change, which requires numerical forecasting. On the other hand, the decrease can only be due to lower investment in science, leading to less national projects and brain drain, which is already occurring in the country for some years.

The numerical modelling of the ocean is highly controlled by institutions of only two Brazilian states, São Paulo and Rio de Janeiro. The result is almost 40% of the studies focused on the Southeast region, while the highly sensitive equatorial margin has 10 times less attention. Among the 20 researchers with the highest number of high quality publications identified in this study (Figure 4), the first ones working in a Brazilian institution outside the states of São Paulo and Rio de Janeiro appear in the sixth position in terms of number of publications, and are from the states of Bahia and Pernambuco. Besides ocean modelling scientists, the distribution of computational resources also appear to be highly concentrated in few institutions of the two mentioned states. Figure 4 has another interesting information which is the almost total dominance of men in ocean modelling in Brazil. Only three women are present among the 20 scientists listed, and one is currently working outside Brazil.

The main source of financing in oceanography (not shown) has been public and from CNPq (National Council for Scientific and Technological Development), Fapesp (São Paulo Research Foundation) and Petrobras/ANP (Brazilian Petroleum Corporation/Brazilian National Agency of Petroleum, Natural Gas and Biofuels). The oil industry interests have been the main sponsor of scientific development in the country in several fields, including oceanography. And this is bad news since it makes science too dependent on politics and the stock market. It also may force certain scientific directions at the expense of others eventually more needed for the overall social development, like climate change and renewable energies.

While the world is placing the bets on renewable energy, associated with the development of electric vehicles, with the circular economy and with the mitigation of climate change, in Brazil there are so far only two ocean renewable energy numerical

assessment studies (Marta-Almeida *et al.*, 2017; Czizeweski; Pimenta & Saavedra, 2020). But the awareness of society on the need for a more environmental friendly way of life is also increasing fast and surely ocean modelling and forecasting will have a place in the first row of the approaching new era.

A national policy should be conceived to decrease regional discrepancies, to attract women to ocean/climate studies and to increase science budget, in order to avoid the brain drain and to attract new talent. Especially regarding climate studies, a wider participation in international projects and the appreciation of the role of the most capable new scientists, could put the country on the world stage of sustainability with a modest monetary effort.

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