CURNet

The Caribbean Upwelling Research Network

Working Group proposal submitted to SCOR

April 2018

Summary/Abstract

The Caribbean Upwelling system (CUS) is likely the least known coastal upwelling system in the world. Its biological and fishing productivity is lower than the Eastern Boundary Upwelling Systems (EBUS). Total EBUS catch small pelagic in ~ 12 million tons, while the total small pelagic acoustic biomass in CUS has been estimated ~ 1.5 million tons. Despite that, some studies suggest this system could support most of the productivity observed in the Caribbean basin, besides its variability could have an important effect in the climate of the northern South America. The CUS shares some characteristics with its EBUS counterparts, but there is still a lack of information related to its functioning, long-term variability, the origin and nature of its upwelling waters and its real productive potential. Academic, governmental and research institutions in the Caribbean countries currently have limited capacity to develop research initiatives that fill up these information gaps. The Caribbean Upwelling Research Network (CURNet) is proposed as a collaborative strategy to focus research efforts in the CUS, promoting the exchange with recognized research groups from 3 EBUS; the Chile-Peru, California and the Canary systems. The CURNet initiative seeks stimulated the academic exchange, increase the number of indexed publications, and strength the observational and modeling capabilities of the system. The CURNet products could have an important impact on the technological and socioeconomic development of most of the coastal communities of the region, most of which are economically depressed and exploit artisanally the fishery resources as sustenance and source of protein.

1. Scientific Background and Rationale

The southern Caribbean coast off Colombia, Venezuela and Trinidad (61-74 °W and 10-13 °N) experience an intense coastal upwelling mainly during January to May (Andrade and Barton, 2005; Rueda-Roa and Muller-Karger, 2013). This Caribbean Upwelling System (CUS) generates a significant increase in the phytoplankton productivity (Muller-Karger *et al*., 1989), stimulates the growth and determines the ecological structure of coral reefs, grasslands and macroalgae communities (Diaz-Pulido and Garzon-Ferreira, 2002; Eidens *et al*., 2014), supports ~ 95% of the small pelagic biomass (Rueda-Roa and Muller-Karger, 2013), and affects the hurricanes frequency in the Caribbean (Jury, 2017). The CUS is forced by the trade winds, which flow east-west and get intense in the center of the Caribbean basin, forming the Caribbean Low Level Wind Jet (CLLJ; Wang, 2007). The CLLJ determine more intense upwelling favorable winds in the Western sector of the CUS (74-70ºW), which force an intense seasonal upwelling with high offshore transport of upwelled waters (Andrade and Barton 2005). The Eastern

Sector (65-61ºW), outside the CLLJ influence, has less intense winds but upwelling-favorables throughout the year, which produce a lower offshore transport but a deeper pumping than in Western sector (Rueda-Roa and Muller-Karger, 2013). These two sectors also shown differences in biological and fishing productivity. The Eastern sector have the highest chlorophyll concentrations and the major pelagic biomass (~ 78%). This major productivity has been related to a longer retention times and less turbulence, which can favor a major local use of upwelling nutrients by phytoplankton and major recruitment of clupeids (Rueda-Roa and Muller-Karger, 2013). The Western sector shows the formation of extense upwelling filaments which interact with mesoscale eddies transported by the Caribbean Current (Andrade and Barton, 2005). This filament-eddy interaction seems export nutrients and planktonic biomass towards Caribbean open waters and islands, generating impacts still unknown on the biological productivity of the entire basin. The biological production of both CUS sectors is significantly lower than that observed in the major EBUS (Chavez and Messie, 2009). Despite that, some preliminary observations suggest that CUS is probably the largest source of nutrients for the biological productivity of the Caribbean Sea. Even the nutrient enrichment of the upper ocean layer originated in the CUS could have productivity implications in the Gulf of Mexico, which is dynamically connected with the Caribbean through the Caribbean Current, the Yucatan Current and the Loop Current. Preliminary observations in the upper layer (first 400 m) of the Gulf of Mexico (Camacho-Ibar pers. Pers.) indicate a nutrient enrichment with respect to the northwest Atlantic (the origin of Gulf waters), which apparently occurs during the transit of surface waters through the Caribbean and its modification in the CUS.

As the CUS is a tropical upwelling system forced zonally by the trade winds on the southern edge of the Caribbean basin, is not in the strict sense an EBUS. However, some typical EBUS characteristics are similar to those observed in the CUS. Most of CUS variability depends on the variability of the CLLJ (Ordoñez *et al*., In prep.), which have similar structure of the coastal low level wind jets of the main EBUS. The CUS presents 2 well-defined sectors or biomes (Rueda-Roa and Muller-Karger, 2013) and, in general, the EBUS presents between 3 and 4 (Chávez and Messie, 2009). Intense mesoscale eddies are generated in the coastal transitional zones of EBUS (Chaigneau *et al*., 2009), structures that travel hundreds of kilometers (Hormazabal *et al*., 2013, Combes *et al*., 2017), interacting in their path with seamounts and oceanic islands, and producing significant chlorophyll increases associated with the generation of submeso-scale eddies (Andrade *et al*., 2014). Altimetry data have allowed to observe how CUS frontal zones interact with mesoscale long-lived eddies from the Caribbean current (Murcia *et al*., In prep.), structures that are intensified in the CUS and travel toward the west of the Caribbean (Jouanno *et al*., 2012), likely transporting properties to Caribbean island (eg San Andrés archipelago) and the Gulf of Mexico. Some evidences indicate

the presence of a subsurface countercurrent in the CUS (Andrade *et al*., 2003) that possibly transports waters and nutrients that are eventually pumped by the upwelling (Correa-Ramirez *et al*., In prep), in a similar way the subsurface countercurrents do in the EBUS (Chávez and Messie, 2009). The EBUS presents an interannual to decadal variability associated to low frequency variability of the Pacific and the Atlantic (Di Lorenzo *et al*., 2008), which is transmitted to these systems through atmospheric and oceanic remote connections (eg, Kelvin waves / Rossby) (Thomas *et al*., 2009). In CUS strong low frequency variability has been observed, whose origin and transmission form to the system is not yet clear (Ordoñez *et al*., In prep), considering that the Caribbean does not have a direct connection with the Pacific and Atlantic oceans. It has been observed a long term trend of upwelling intensification in the CUS (Santos *et al*., 2016) which has also observed in the other EBUS (Bakun, 1990) and has been related to early effects of the global warming due to anthropogenic greenhouse gases (Garreaud and Falvey, 2009).

Despite these similarities, there are many aspects still unknown in the CUS in comparison to its EBUS counterparts, which make CUS the least known coastal upwelling system in the world. Still unknown aspects such as: what is the potential of productive of CUS? What are the main limitations of the biological productivity? Which are the mixing processes in the upwelling waters? What is the role of the mesoscale eddies in the connectivity of the CUS with the rest of the Caribbean? How is the contribution of the CUS to the physical and biological variability of the Caribbean? Which is the origin of the nutrients from the upwelling waters? What is the relationship of the CUS with the oxygen minimum zone and the anoxic events that generate important fishing losses in the region? What is the structure and energy transfer in the tropical food chain of the CUS? What is the long-term variability of the system? How could the CUS respond to future scenarios of atmospheric / ocean warming associated with climate change? This low level of knowledge in the system is reflected in a low number of indexed publications (~ 15), most of which have been cited in the present background. The CARIACO project (Carbon Retention in a Colored Ocean), is possibly the initiative that has developed a greater amount of studies on the biogeochemistry of the Cariaco basin and the CO_2 exchange between the atmosphere and the ocean, in the CUS eastern sector. In addition to the CARIACO series, there are no other initiatives promoting a regional analysis, due in part to technical and budget limitations of the academic and research centers in the region.

Most of the Caribbean coastal communities in Colombia and Venezuela have low economic conditions, as a result of political instability, the marginalization of governmental development programs, the historical processes of violence and forced displacement. Much of the current economic livelihood and source of protein dependent

on artisanal fisheries associated with CUS. Despite, has been observed a decrease trend of fishing resources (García *et al*., 2007) whose causes are still unknown, but could be associated with aspects of the CUS variability. The socio-economic importance of the CUS, supports the need to advance in collaborative strategies that allow to concentrate efforts to rapidly increase the current level of knowledge about the CUS, facilitating the exchange / transfer of experiences and technology with other research groups of recognized trajectory in upwelling systems, as proposed in the CURNet initiative.

2. Terms of Reference

ToR 1. Promote research efforts **in the tropical coastal upwelling system** off the Southern Caribbean coast. Facilitate the academic exchange between the institutions conforming CURNet. Increase the number of these works and indexed manuscripts in identified scientific topics of the System.

ToR 2. Advance in the **development of** appropriates **numerical models of the Caribbean Upwelling System**. Conform a working line to build and validate coupled physical-biological models required to understand the dynamic functioning of the system and its long term trends in the future climate change scenarios. Provide information useful to economic and operational activities.

ToR 3. Strengthen the technological exchange to increase the observation capabilities and the social appropriation of relevant information of the system. Improve the built capacity of local instrumental laboratories, promoting the design of low-cost oceanographic instruments to monitor the Caribbean Upwelling variability. Contribute to the development of operational - oceanographic web applications to serve information to artisanal fisheries and economic activities in the region.

3. Working plan

In **year 1**, CURNet will focus on organizing the WG and designing the strategy to reach the proposed terms of reference (ToR). A first meeting of the WG will be held at the main headquarters of INVEMAR (Santa Marta), where it is expected: Act. (Activity) _1 Identify the main research topics required to increase the knowledge of the upwelling system (ToR 1); Act._2 Identify the requirements in terms of training and technology

transfer needed to achieve the proposed development and research topics (ToR 1, 2 and 3); Act._3 Prepare a review manuscript that synthesizes current advances in the knowledge of the CUS (Deliverable 1). Part of the strategies for the development of these activities includes the promotion of academic exchanges, topic courses and lectures in the following years. For this purpose, it is expected to identify alternative sources of funding for research internships and student mobility.

During Years 2 and 3 (2020-2021), the efforts of the WG will be focused on the design / implementation / assimilation of physical / biological coupled models (Act._4), that reproduce the Caribbean upwelling system (ToR 2). This activity is expected to be developed through the creation of a work line in numerical modeling, in order to analyze the internal dynamics of the upwelling system and its long-term trend. As a result of this activity, a validated regional model for the Caribbean Sea (Deliverable 2) will be obtained.

Additionally, during the year 2 (2020), the second meeting of the WG will be held at the main headquarters of INVEMAR (Santa Marta). In the 3 days following the meeting, the First cycle of Short Courses in Advanced Topics of Upwelling Systems will be held (Act._5), on some of the key topics that will be identified in Act._1 and Act._2, oriented to the scientific and academic community. Most of these courses which will be dictated by the full members, based on their expertise. This is a strategy of social appropriation of knowledge about the environmental and economic importance of upwelling systems. With this activity it is expected to train a greater number of young researchers and motivate them to develop their undergraduate and postgraduate researches on relevant issues of the upwelling system. This academic activity will be carried out biannually. It is expected that this activity will be recognized as an important periodic event for the regional scientific community, which will leverage resources for its realization in future years, with the option that it can be carried out in other countries of the region.

In the years 3 (2021) and 4 (2022) will be addressed the technological exchange activities related to both, the oceanographic instrumentation and Web platform development, according to the ToR 3. The products obtained in previous years will be reviewed to the identify of information gaps and propose improving alternatives for the observation systems of the CUS, thus creating a research line to propose low-cost devices to monitor the main environmental variables associated with the CUS (Deliverable 3). During these years, efforts will also be directed to design and implement Web modules that complement the already existing Observatory of the tropical seas of the Americas – ObserMar on issues related to biological productivity and variability of the water column in the upwelling system (deliverable 4).

Finally, in year 4 (2022) the third meeting of the WG will be held at the main headquarters of INVEMAR (Santa Marta). This meeting will end with a Socialization Seminar (Act ._7), open to general public, where the WG products will be presented. In the days after the meeting, the full members of the WG will dictate the Second Cycle of Short Courses in Advanced Topics of Upwelling Systems (Act._8).

4. Deliverables

1. Year 1-2) **A review manuscript** in an indexed journal, with peer review by referees and in Open Access mode, in which the current state of knowledge of the Southern Caribbean Upwelling System will be synthesized. This manuscript will also compare the known characteristics of this system with those of the Eastern Boundary Upwelling Systems of Pacific (Peru-Chile, California) and the Atlantic (Benguela, Canary Islands), in order to identify common dynamic patterns and point out lack of information where it is necessary a greater research effort
2. (Year 2-3) **A regional model for the Caribbean Sea**, which reproduces the main dynamic characteristics of the upwelling system. The model will be validated by comparison with the main historical data bases available. The model will provide information for research and operational purposes.
3. (Year 3-4) **Design of a low-cost oceanographic measurement device** to strengthen the observation / monitoring capacity in the Caribbean Upwelling System.
4. (Year 3-4) Implementation of **two (2) new modules in the ObserMar oceanographic web platform** (obsermar.invemar.org.co): Variability in Depth and the Biological Productivity module.

5. Capacity Building

Establish a research network of the Caribbean Upwelling System (CUS) will allow us to understand this important system of ocean-atmosphere coupling in the Caribbean, and to elucidate its influence on biological, geochemical and climatic aspects, among others. To develop long-term capacity in this area, it is expected that the strengths of each member of the research group will be used, and offered as a tutoring opportunity to further develop understanding of the subject.

Knowledge transfer will be facilitated through workshops and different advanced level courses for undergraduate and postgraduate students to consolidate a new community of ocean scientists. the INVEMAR as a center of the Ocean Teacher Global Academy (OTGA) of UNESCO, could take advantage of this capacity to obtain additional funds to establish a course on the topics of this proposal

in terms of capacity building, Victor Camacho-Ibar has a fully operational laboratory for inorganic nutrient analyses which has recently participated in an international intercalibration exercise led by the SCOR-WG #147. The generation of high quality nutrient data which are comparable among laboratories is not trivial, thus the UABC group can collaborate in capacity building via training, workshop organization and intercalibration exercises for nutrient analyses among laboratories participating in the project. He has performed research on the biogeochemical interaction between the California Current upwelling system and adjacent coastal lagoons in Mexico, and is currently leading research on nutrient biogeochemistry in deep waters of the Mexican region of the Gulf of Mexico. Thus, his group can share his experience in the biogeochemical interpretation of nutrient data. In turn, his group will benefit from the experience of other members in mesoscale processes observations and modeling.

Overall, these activities will maximize the building of long lasting global capacity within this important topic.

6. Working Group composition

Full Members (no more than 10, please identify chair(s))

CURnet has 10 Full and 3 Associate members that bring together state-of-the-art skills in upwelling systems, modelling and the development of monitoring systems (device and web platform). The Full Members are responsible for the delivery of our objectives, while the Associate Members. provide important input from the complimentary fields. Our Full members represent 5 different nations. Moreover, we include early career researchers as Full members, which will aid their career development

Name	**Gender**	**Place of work**	**Expertise relevant to proposal**
Emanuele Di Lorenzo (United States of America)	Male	Professor of Ocean & Climate Dynamics Director, Program in Ocean Science &	Ocean and Climate Dynamic, Regional and Coastal Oceanography, Low

		Engineering (OSE) School of Earth & Atmospheric Sciences Georgia Institute of Technology Atlanta, GEO, USA	Frequency Ocean Variability, Ocean & and Inverse Modeling, Coupled Ocean & Atmosphere Variability
Angel Rodriguez Santana (Spain) **Co-Chair**	Male	Professor at Universidad de Las Palmas de Gran Canaria - UPLC Grupo I+D Observación y Modelización de Fenómenos Geofísicos y Marinos (OFYGA) Gran Canaria, Spain	Turbulence, mixing processes, nutrient transfer and frontal zones in upwelling systems.
Constanza Ricaurte Villota (Colombia) **Co-Chair**	Female	Coordinator of Geoscieces program, at the Coastal and Marine Research Institute – INVEMAR Santa Marta, Colombia	Past and present Ocean and Climate Dynamic, Regional and Coastal Oceanography.
Samuel Hormazabal Fritz (Chile) **Co-Chair**	Male	Professor at Pontificia Universidad Católica de Valparaiso - PUCV Valparaiso, Chile	Coastal dynamics, upwelling, coastal trapped waves, Rossby waves, El Niño and the Southern Oscillation, Eastern boundaries currents, mesoscale eddies, physical-biological coupling
Marco Correa Ramirez (Colombia)	Male	Researcher at Coastal and Marine Research Institute - INVEMAR Santa Marta, Colombia	Physical-biological coupling in the ocean, upwelling systems, satellite oceanography and mesoscale processes.
Antonio Juan González Ramos (Spain)	Male	Investigador en Robótica y Oceanografía Computacional Instituto Universitario de Sistemas Inteligentes y	Operational oceanography, marine robotics and observational systems of the ocean.

		Aplicaciones Numéricas en Ingeniería - UPLC Gran Canaria, ESP	
Joaqim Bento (Chile)	Male	Assistant Professor at Marine Science School, Pontificia Universidad Católica de Valparaiso - PUCV Valparaiso, Chile	Operational oceanography
Victor Camacho Ibar (Mexico)	Male	Researcher at Instituto de Investigaciones Oceanológicas, UABC Ensenada, México	Nutrient biogeochemistry in upwelling influenced coastal lagoons and in deep waters of the Gulf of Mexico
José Martín Hernández Ayón (Mexico)		Researcher at Instituto de Investigaciones Oceanológicas, UABC Ensenada, México	Chemical Oceanography, coastal and upwelling carbonate system

Associate Member (no more than 10)

Name	**Gender**	**Place of work**	**Expertise relevant to proposal**
Vincent Combes (United States of America)	Male	Research Associate – Physical Oceanography OREGON STATE UNIVERSITY – College of Ocean and Atmospheric Sciences COAS Corvallis, OR USA	Low frequency ocean variability, Coastal upwelling, Eddy dynamics, Cross-shelf transport.
Martha Bastidas (Colombia)	Female	Instituto de Investigaciones Marinas y Costeras “Jose Benito Vives de Andreis” Invemar	Remote sensing and dynamic oceanography
Silvio Andres Ordoñez (Colombia)	Male	Instituto de Investigaciones Marinas y Costeras “Jose	Frequency-Domain Analysis, Statistical

		Benito Vives de Andreis" Invemar	approach to system analysis, Programming and development, Satellite Image processing

7. Working Group contributions

Emanuele Di Lorenzo is a modeller of Coupled Ocean & Atmosphere Systems, will be the leader of the development of the regional model of the Caribbean Sea

Angel Rodriguez Santana as expert in mixing processes and frontal zones in upwelling systems, will help to understand these issues in the CUS and will share their knowledge with the group.

Constanza Ricaurte-Villota is the head of the program of Marine and Coastal Geosciences of INVEMAR, and the leader of the new research group of the CUS. She will share her expertise in Past and present Ocean and Climate Dynamic. Also she will coordinate the actions of the group using their great experience in managment of projects and research groups.

Samuel Hormazabal Fritz as expert in coastal dynamics, upwelling, mesoscale eddies and physical-biological coupling, will lead studies in the CUS on these topics.

Marco Correa-Ramirez is an associated researcher at INVEMAR, expert in satellite oceanography and data analysis. He has carried out some studies in the CUS and currently he is leading an agency project on the interconnectivity of this system with the Caribbean basin.

Antonio Juan González Ramos as expert in observational systems of the ocean will lead the development of oceanographic measurement device

Joaqim Bento is an expert in Operational oceanography, who has participated in the development of the POMEO web platform in Chile, and will help the development of the new ObserMar modules.

Victor Camacho-Ibar will share his expertise in nutrient analyses and the biogeochemical interpretation of nutrient data.

Martín Hernandez-Ayon is a Chemical Oceanographer, will lead the subject of the carbonate system in the CUS.

8. Relationship to other international programs and SCOR Working groups

9. Key References

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Appendix

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